RESEARCH AREAS IN SPACE

RESPOND&AI

CAPACITY BUILDING & PUBLIC OUTREACH (CBPO)

Indian Space Research Organisation
Bengaluru

May 2023

RESEARCH
AREAS IN SPACE

A Document for
Preparing
Research Project Proposals

RESPOND & AI

Capacity Building & Public Outreach (CBPO)
ISRO-HQ, Bengaluru

May 2023

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Message

The Indian Space Research Organisation (ISRO), Department of Space, is the country's key organisation for developing research capabilities in the space domain in order to adapt the sector's expanding technical advances. The best way to tackle the issues is to collaborate with both industry and academia to realise the possibilities. In light of this, ISRO publishes broad themes of space research in order to solicit research proposals from academia via the existing ecosystem. In this regard, I'm quite pleased to share the document "Research Areas in Space-2023" with you.

The document lists several main research areas that will be critical to the future of space exploration and utilisation. These include developments in high-throughput satellite technology, technological advancements in launch vehicles, materials science, remote sensing, communication systems, navigation, space situational awareness, space weather, and planetary science, among other things.

In this context, the ISRO's **Capacity Building and Public Outreach office (CBPO)** has assumed the lead role in preparing the "Research Area in Space-2023" document, which consolidates inputs from most of the ISRO/DOS centres regarding the upcoming R & D requirements, wherein academia can play a crucial role. This document will assist researchers from prospective Space Technology Cells (STC), Regional Academic Centre for Space (RAC-S), Space Technology Incubation Centres (STIC), and other ISRO-engaged institutes in developing targeted research projects that contribute to ISRO's strategic goals.

This publication will undoubtedly be a useful information for scholars, researchers, startups, academia and other space community stakeholders. In order to empower the technological growth of our nation, let's keep pushing the limits of space exploration and scientific quest.

सोमनाथ

May 01, 2023

(Somanath S)

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N Sudheer Kumar
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PREFACE

The Indian Space Research Organisation (ISRO) began collaborating on scientific research in the space sector with the country's major academic institutions in 1970. Since then, efforts have been continually increased to connect with numerous institutions across the country. As part of this, ISRO publishes a document outlining the cutting-edge fields being researched immediately. For the benefit of the scientific research community that aspires to engage with ISRO, a document titled "Research Area in Space Document 2023" was published by ISRO. This is yet another initiative to support space-related research and innovation.

"Research Areas in Space" is a biennial publication produced by RESPOND and Academic Interface, Capacity Building and Public Outreach programme office at ISRO headquarters. This document will assist enthusiastic researchers at Space Technology Cells (STC), Regional Academic Centre for Space (RAC-S), and Space Technology Incubation Centres (STIC) in selecting relevant research themes and submitting project proposals, as well as provide numerous opportunities for collaborating with ISRO and sharing their expertise and experience for the benefit of the Indian Space Programme.

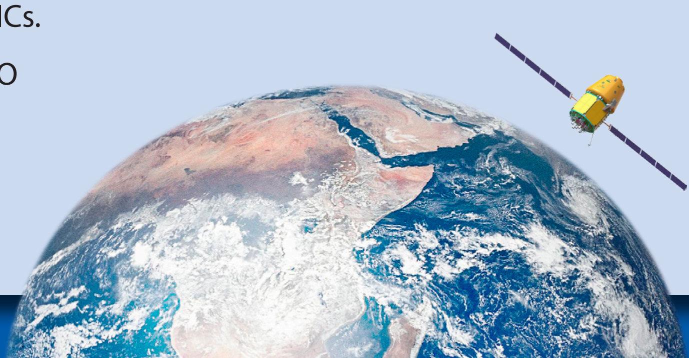
In line with the technological developments taking place in the space industry, the Research Area in Space document covers a broad variety of themes of interest to ISRO, including artificial intelligence, the human space programme, robotics, machine learning, quantum technologies, etc. Through this, ISRO also gains knowledge that contributes to the development, evolution, and advancement of space technology.

I am optimistic that ISRO's initiatives will continue to motivate faculty and other researchers to do qualitative research and help society gain a deeper knowledge of space science and technology.

(N Sudheer Kumar)

General Instructions

1. ***"Research Areas in Space"*** is a comprehensive document highlighting ISRO's major programmes, current and upcoming R&D requirements of ISRO. This document will exclusively cater to the advanced research requirements of ISRO wherein Space Technology Cells (STCs), Regional Academic Centre for Space (RAC-S) and Space Technology Incubation Centres (S-TICs) established at various IITs/NITs and premier institutes across the country can select and generate R&D proposals. The faculty of these institutes are encouraged to submit their project proposals in these diverse research areas.
2. To enable the faculty to prepare suitable proposals of relevance to space programme, a detailed list of R & D areas /sub areas/topics and a brief write up about the topic have been given in this document.
3. The concerned ISRO/DOS centre interested in the research topic is given in brackets after the areas/sub areas/problems.
4. The faculty of these STCs, RAC-S and S-TICs may submit the proposals to the convener of their respective STCs/ RAC-S/ S-TICs. Further, the submitted proposals will be subjected to critical evaluation by ISRO/DOS Centres. The proposal will be evaluated on the basis of novelty, methodology, approach, deliverables, experience of the PI in the subject area, duration of the project, budget etc.
5. The evaluation reports of the proposals received from the ISRO/DOS centres will be further reviewed by the Joint Policy Committee (JPC) of STC , Joint Policy Management Council (JPMC) of RAC-S and Joint Management Committee (JMC) of S-TICs before its recommendation for funding support.
6. The age limit for the Principal Investigator is below 65 years (sixty-five) including the project period.
7. One hard copy and a soft copy of the proposal shall be submitted to the respective STCs/ RAC-S/ S-TICs.
8. "Application for Grant of Funds including the project proposal" and "Form-C" shall be submitted in the prescribed formats only. Formats are given in the Annexure -1 & 2.
9. Conveners of STC/RAC-S/S-TICs shall submit a hard copy and a soft copy of the proposal to the respective ISRO/DOS centre. The addresses and e-mail ids of Respond Coordinators of respective ISRO/DOS centres are given in Annexure -3.
10. The proposals may be submitted by the faculty of STC, RAC-S and S-TICs institutions based on the call for proposals by the respective institutes.
11. The Projects having envisaged outcome as a product or process of business/commercial potential shall be submitted through S-TICs.
12. For any other information kindly visit ISRO https://www.isro.gov.in/academia.html



CONTENTS

LAUNCH VEHICLE

A	Area	Aerospace Engineering (VSSC)
A1	Sub Area	Development of Tools (VSSC)
A1.1		**Adjoint / Feature Based Grid Adaptation for Unstructured Grids (VSSC)** Mesh generation is one of the most significant steps in CFD workflows. Currently it is highly interactive and user dependent. Creating good quality meshes need high expertise and may not always be optimal to the problem at hand. Mesh adaptation comes handy in this situation. The solution-adaptive mesh refinement feature allows the user to refine and/or coarsen grid based on geometric and numerical solution data. The main issue in the design of the refinement algorithm is to minimize the reduction in grid quality of the adapted mesh, since high quality meshes are often desired for numerical reasons. Additionally, the boundary layer transition prediction methods require well resolved boundary layer profiles including accurate higher order derivatives and inflection points. The properties of the boundary layer are not known before the solution is computed. This makes grid adaptation uniquely suited to ensuring that the first cell height and the outer portions of the boundary layer are properly resolved. Using a rigorous mathematical approach to automate the grid resolution required within the boundary layer would have a dramatic impact on complex design and analysis applications. Mesh adaptation for mixed element unstructured meshes is still a developing field. Adaptation can be based on flow solution or adjoint. There are techniques for metric field based adaptation using flow solution and adjoint solution. But these are not well developed for mixed element types. The basic idea of the adjoint-based adaptation method is to construct an adaptive sensor from a more robust and accurate error estimation. It is seen that the adjoint solutions provide a very powerful approach to compute output error estimation as well as to systematically adapt grids to reduce spatial discretization errors. The adjoint can be based on the output quantity of interest. The focus of the work should be towards a feature/adjoint based grid refinement algorithm which can operate in all types of flow regime (subsonic, transonic till hypersonic flows) and mixed element types (Hex / Tet / Quad / Pyramid). The algorithm should resolve the flow features like shocks, wakes and vortices with relative ease and should be automated with minimal human intervention.
A1.2		**Higher Order Solver for LeS of Compressible Flows (VSSC)** With the advent of higher computing power, fidelity of numerical simulations is also increasing. Second order RANS simulations are routinely carried out for aerodynamic design and characterization. Improved fidelity can be achieved by carrying out Large Eddy Simulations with higher order of accuracy. Towards this, a higher order solver is essential which can be based on Discontinuous-Galerkin or the

	Flux-Reconstruction framework which has shown promise in the recent past. As the configurations on which the solver will be used are not amenable for structured grid, the solver has to be based on 3D unstructured grid topology with mixed elements such as tetrahedrons, hexahedrons, triangular prisms and pyramids. Additionally, most of the flows over launch vehicles and re-entry bodies are high Mach number flows. Hence the solver should be designed for compressible flows with shocks.	
A1.3	**Jet Noise Field for a Supersonic Jets (VSSC)** Jet noise is one of the primary factors that induces dynamic load on vehicle structures during lift-off of launch vehicle. Noise from the rocket nozzle typically is dominated by broadband spectrum from shock associated and mixing noise. Computational estimation of the jet noise is carried out with Large Eddy Simulations with low dissipation and dispersion schemes. Further, the simulation domain for LES is only restricted closer to the jet and are solved along with NRBC and sponge layers. Hence, noise field with LES is only tractable in the near jet region. For farfield noise computation, propagation of acoustic sources (resolved from LES) is carried out using a separate solver. The acoustic sources can be time series information of the acoustic sources or synthetic noise sources from RANS simulations. Hence, a propagation solver with user defined acoustic sources is required for farfield noise computation.	
A1.4	**Transient Moving Body Simulation CFD Capabilities with Overset Mesh in Unstructured Grid Frame-work (VSSC)** It is essential to enhance capabilities of a CFD code to transient moving body simulations. This is required in order to carry out accurate assessment through dynamic analysis in various critical scenarios, where significant effect of relative motion, acceleration is present on the vehicle aerodynamics. As an example, such a situation arises in case of CES abort scenario, where CES moves very fast with respect to parent vehicle, leading to significant drag differences in comparison to steady state simulations. There are several other situations, where such simulation capabilities are essential. This research proposal is invited for the development of accurate and robust overset mesh solver capabilities to carry out dynamic (moving body) simulations in our unstructured (mixed element) grid framework, suitable for compressible/incompressible flow problems. This will require efficient cutting/blanking algorithm (that can handle multiple bodies), accurate interpolation algorithms for overlapping cells, time accurate solution algorithm implementation (implicit dual time stepping), 6 DOF solver and appropriate grid partitioning method for large number of CPU cores for large size problems.	
A2	**Sub Area**	**Experimental Aerodynamics (VSSC)**
A2.1	**Wake Flow Field, Effect of Free Stream Turbulence And Reynold's Number on Aero Coefficients of Crew Module at Subsonic Speeds (VSSC)** Crew Module (CM) is a bluff body whose aerodynamic characteristics are highly	

	dominated by its Reynolds number. During the mission, the CM experiences high angles of attack. The wake characteristics need to be understand properly. This proposal seeks the explanation of flow features over CM under different model attitudes for different Reynold's numbers. Wake flow characterization at subsonic speeds of the CM configuration at different model attitudes using hot wire, use of water tunnel for wake flow field and laser sheet flow visualization apart from conventional force measurements at different Reynolds numbers. The effect of free stream turbulence on the aerodynamic coefficients and flow field may also be attempted.	
A3	**Sub Area**	**Launch Vehicle Mission (VSSC)**
A3.1	**Advanced Rigid Body Dynamics Software (VSSC)** Separation dynamics analysis is a critical design step in any launch vehicle mission design. Recently, there is gap observed in the current simulation capability and the increasing complexity of design problems. In order to bridge this gap commercial software like ADAMS is being used. In this regard, an indigenous in-house Rigid Body Dynamics Software is essential which can cater for requirements like – Contact, Joint and friction modelling with a fast Integration scheme. It can be used for applications like estimating the contact force between two colliding bodies, the effect of delayed separation of a joint, slung body dynamics. Currently, codes have been developed for basic rigid body analysis with external forces and moments, the above-mentioned features will act as an augmentation. The visual interfacing for the code is also developed so as to improve the user interface. The development of this code will allow customizability for unique ISRO applications.	
B	**Area**	**Avionics (VSSC)**
B1	**Sub Area**	**Instrumentation and Telemetry (VSSC)**
B1.1	**RF-based Sensors and Sensing Systems (VSSC)** Advanced high performance sensors and sensing systems using RF medium is an evolving area of research for industrial and biomedical applications. They are especially useful for new generation technologies like IoT and Health Monitoring. THz and mmWave based sensing systems are typical examples of research areas which are being pursued by academic institutions as well as industry and space research organizations like NASA. This project aims to study, design and develop such sensors for aerospace applications relevant in ISRO's context. Sensor prototypes will be realized and characterized for performance.	

<table>
<tr><th>B2</th><th>Sub Area</th><th>Data Acquisition and Telemetry (VSSC)</th></tr>
<tr><td>B2.1</td><td colspan="2">Advanced ADCs and Hardware Architectures for Miniaturized High-performance Data Acquisition Systems (DAS) (VSSC)
The hardware architecture and circuit configuration suitable for compact realization of high-performance Data Acquisition Systems is an active area of research in Circuits and Systems field. ADC architectures like Continuous Time Sigma-Delta, Discrete Time Sigma-Delta with Multiplexed inputs and High Resolution Software Programmable Successive Approximation are being researched extensively in Mixed-signal VLSI area. Further, the hardware configuration at board-level to derive best performance from these while maintaining low size, weight and power is also to be investigated. This project aims to study the suitability of state-of-the-art device architectures and hardware configuration towards realization of DAS for aerospace telemetry applications in ISRO's context. VLSI device prototypes will be realized and DAS prototypes developed using them characterized for functionality and performance.</td></tr>
<tr><th>B3</th><th>Sub Area</th><th>Wireless Instrumentation for Scientific Payloads in Launch Vehicle and Spacecraft (VSSC)</th></tr>
<tr><td>B3.1</td><td colspan="2">Networked Wireless Sensor Interfacing and Smart Sensors (VSSC)
This proposal is for developing a wireless network of sensors for scientific payloads. For scientific payloads putting long wires for sensors kept far away from controller is not a good approach due to signal interference. Putting controllers near each sensor will lead to multiple controller scheme for a single payload. Hence, optimum approach is to use wireless sensors which will transmit the data in digital form directly to common onboard controller. Smart Sensors with or without wireless interface can be utilized for the sensor networking for the above.</td></tr>
<tr><th>B4</th><th>Sub Area</th><th>Wide band Radio Sounding system development for Spacecraft for Ionospheric studies (VSSC)</th></tr>
<tr><td>B4.1</td><td colspan="2">Wideband Transmitting and Receiving Antenna For RF, Highly Efficient RF Transmitting and Receiving Systems, Onboard RF Data Processing (VSSC)
The Scientific Objective of this proposal for Radio Sounder is to investigate the temporal variations of the lunar or planetary ionosphere in the vicinity of Moon/Planet surface under varying solar conditions. In the case of Moon, its atmosphere is characterized by the absence of a unified magnetic field. This allows the direct interaction of solar wind with lunar surface and atmosphere, which will in turn leads to the formation of a lunar 'ionosphere'. Such a lunar ionosphere would be an ideal plasma laboratory to understand the behavior of plasma in the absence of a unified magnetic field. Hence the plasma distribution both spatial and temporal would depend on the magnetic field conditions unique to the Moon. Similar observations can be conducted in planet atmosphere in planetary missions.</td></tr>
</table>

B5	Sub Area	Sensor Design &characterization (VSSC)
B5.1	**Simulation and Experimental Studies on Cryogenic Temperature Measurement using Optical Fiber Sensors (VSSC)** Fibre Bragg Grating (FBG) principle is used to realize fibre optic sensors. Immunity to electromagnetic interference, significant cable weight saving, reliability, safety, Good corrosion resistance and very low magnetic field interactions, reduced turn over time and cost advantages are the major advantages. Multiple sensors can be realized on a single fibre, which can be signal processed by one set of electronics. Taking into consideration these advantages, using them to measure cryogenic temperatures in LVM3 & GSLV are being explored in this research proposal. The FBG sensor has Small-to-negligible thermal expansion coefficient at low temperatures. Integration of a coating around an optical fiber / Fiber Bragg grating (the coating having a TEC that is greater than that of the fiber alone) can allow the induction of additional thermal strain in the fiber. Theoretical Verification using finite element analysis software (COMSOL Multi physics, Rsoft, ANSYS) for temperature test simulation. Optimization of the thickness of the coating, the composition and/or the geometry of the sensing fiber etc. are aimed at. Once realized, the sensor will be calibrated for different cryo temperatures and efforts will be made to improve sensitivity, response time and recovery time.	
B6	**Sub Area**	**Actuators (VSSC)**
B6.1	**Design and Analysis (Static & Dynamic) of a Planetary Roller Screw (VSSC)** Planetary roller screws having double nut configuration are used in high power electromechanical actuators for converting the rotary motion to linear. The scope includes: • Mechanical design of the roller screw based on input requirement which includes detailed specification and outer dimensions of Roller screw • Generation of 3D CAD model • Kinematic analysis and estimation of slip • Static analysis (Finite Element Analysis), stiffness and efficiency • Dynamic analysis (Using solvers like ADAMS) • Fabrication drawing of all components	
B6.2	**Design and Analysis of Harmonic Drive (VSSC)** Harmonic drive replaces the conventional gear train of the rotary actuator. The scope includes: • Mechanical design of the harmonic drive for the input requirements • Modelling and quasi-static analysis using finite element analysis for the tooth mesh conditions [for stress, strain and stiffness]	

	• Kinematic and kinetic analyses using ADAMS like software • Tooth profile optimization for maximizing performance • Generation of fabrication drawings • Procurement of components (like elliptical bearings, circlip, etc, needed for the assembly) • Realisation, assembly and testing
B6.3	**Mathematical Modelling of 5000psi Based Axial Piston Pump for Control Actuation Systems (VSSC)** Use of higher pressure in hydraulic power systems will enable development of state of the art technology & considerable reduction in size & mass of electro-hydraulic actuation systems (EHAs) used in launch vehicles. Currently the de-facto standard operating pressure in many aerospace systems is 3000 psi. In an effort to change over from existing 3000 psi to 5000 psi based pressure system & to harness the claimed advantages, all associated systems like actuators, valves, pumps, tubing, sealing system etc with sufficient pressure rating and aerospace quality have to be developed. A critical subsystem towards the development of 5000 psi based EHAs is a high pressure hydraulic 'power source'. The high pressure hydraulic source conventionally used for aerospace electro-hydraulic system is a type of positive displacement pumps with a primary choice as variable displacement axial piston pump of pressure compensated type. It is usually chosen on account of its higher pressure capabilities, good efficiency and its effect on the total system efficiency. Positive displacement pumps are prone to pressure ripple and noise which are unwelcome characteristics of such pumps. Due to relatively large number of moving parts, generation of a mathematical model amenable to dynamic simulation and which can bring out the transient response with good fidelity is an involved task. On account of its critical output requirements which are expected from the pump and in order to predict the transient behavior, an independent and detailed mathematical model to capture the dynamics involved is envisaged. Although the overall pump requirements are specified in terms of overall flow, efficiency, pressure ripple etc, a true–to-the-physical article mathematical model requires incorporation of finer design features like inertia of various parts, pressure cut-off loop gains, related fluid inertias, bulk modulus, etc. in order to predict transient responses. A coupled CFD analysis also may be required to predict the leakages, effect of hydrostatically held pistons on the swash plate etc. A coupled structural analysis is also envisaged to analyze the fluid-structure interaction effects of the pressure compensation loop brought about by the bulk modulus of fluid.

	Thus a detailed mathematical model incorporating the fluid-structure model capable of prediction of transient responses is required. Also it should be able to incorporate parametric study of ripple reducing grooves of various geometries in addition to the prediction of efficiency, response time, torque ripple etc.	
B7	**Sub Area**	**IoT /MEMS / VLSI (VSSC)**
B7.1	**Body Area Network (VSSC)** An Energy Harvesting Wireless Sensor Network (EHWSN) architecture designed for use within an astronaut's space suit. Body Area Networks (BAN) offer new ways for technology to interact with our physical world. The building blocks for BAN are nodes that possess sensing capabilities to measure/detect physical quantities (e.g., movement, chemicals, and body temperature) and associated low power radio technologies to transmit that data. The physical and mental health of astronauts on deep space missions will be challenged by the harsh operating environment. Various devices have been developed to track and predict an astronaut's health status in order to both maximize their working efficiency and ensure their safety. Wirelessly networking these devices to create a body area network will offer the capability to track the health of the astronaut in real time.	
B8	**Sub Area**	**VLSI (VSSC)**
B8.1	**Direct RF Sampling Receivers (VSSC)** The research focuses on the development of Direct RF sampling receiver chain where the RF data from antenna is directly converted to digital format for further processing and the development of a high-speed serial data transfer protocol for communication between the ICs in the chain. The current infrastructure is not adequate to support the expected growth in wireless data. Direct RF sampling captures the desired signal without the need for an analog RF front end. As a result, all processing can be handled digitally and reprogrammed for a multitude of communication tasks. The non-linearities associated with the analog RF front end and the extraneous spurious signals, issues related to image signals, frequency-dependent components, and dc offsets can be overcome via direct digitization in the RF domain.	
B8.2	**EM-Wave Biosensors (VSSC)** The research focuses on the development of a MEMS based EM-wave bio-sensor to detect abnormalities in a human body. EM-wave biosensors will be greatly beneficial as they will pave way for non-invasive sensing and facilitate continuous monitoring applications. A biosensor is a detection device which converts a biological response into a measurable signal. Treating biological tissue as a dielectric substance, having a unique dielectric signature, it can be characterized by frequency dependent parameters such as	

	permittivity and conductivity. Through measuring the changes in permittivity, concentration of medically relevant biomolecules such as glucose, neurotransmitters, vitamins and proteins, ailments and abnormalities can be detected. By observing the unique permittivity spectrum, cancerous cells can be distinguished from healthy ones. In case of RF microwave/mm-wave biosensors, capacitive sensing is most commonly employed where changes in permittivity are reflected as changes in capacitance, through components like inter digitated electrodes, resonators and microstrip structures.	
B9	**Sub Area**	**Testing (VSSC)**
B9.1	**Miniaturised Raspberry pi Based Acquisition and Data Processing Station (MiniRAPS) (VSSC)** Aviation industry uses both analog and digital data acquisition systems which are housed inside a chassis of 3U size along with other add on cards housed in the said rack doing different test station functionalities. Such systems are bulky, require special cooling requirements and not conducive to movement across a distributed testing environment having multiple test beds and sites. Furthermore, these systems are often imported, proprietary products with only API (Application Programmer Interface) for application development which leads to very high system costs with huge AMC cost requirements as part of future maintenance. Hence, there is an urgent need of miniature, reconfigurable and reprogrammable test station which can be interfaced with a single PC and will be able to acquire all test data's associated with a test article using reconfigurable, Raspberry pi based architecture. **Problem Statement:** To design, simulate and test a Raspberry pi based open source hardware and software data acquisition system capable of replacing bulky and large checkout test stations. The system should be able to acquire MIL-1553B telemetry, analog telemetry, digital input data, RS485 telemetry. As there are no available on board transceivers for 1553B data conversion, the system must be designed to do the same using external MIL-1553B grade transceiver ICs. The system should support a sampling rate of at least 10k samples/sec per channel and include signal processing algorithms to ensure data acquisition without any data miss. The designed system should reduce acquisition noise by employing noise cancellation techniques. Techniques include integration wherein each input channel is averaged over a programmable period of time to produce 1 measured value to reduce high frequency noise, usage of digital filters with a programmable cut off frequency which can be used to reduce noise above the specified cut off frequency and use of active noise cancelling techniques which consist of adaptive filters based on LMS(Least Mean Square) which use the filtered signal as a feedback to change filter coefficients to reduce noise. It should have a small form factor, be able to interface with a host PC running the acquisition GUI using USB or Ethernet interface to transmit telemetry data. The system itself should also be capable of running	

	a real time display on screen attached to Raspberry PI. The system should be reconfigurable to the number of data channels to be acquired and voltage levels to be acquired. **Methodology:** The methodology shall first consist of selection and procurement of trainer Raspberry pi boards for both space and ground application with special emphasis on flexibility of data acquisition, fast acquisition rates, ability to implement complex algorithms, real time acquisition and display. Based on test requirement the **hardware architecture finalization** shall be carried out by selection of ICs such as ADCs, 1553 Transceivers, LDOs, Crystal Oscillators, I/O pads etc. This will be followed by **architecture finalization for application software**. This also includes finalization of integration algorithm and adaptive filter based active noise cancellation algorithms. **MiniRAPS PCB design** shall be carried out next followed by **rigorous testing** of the designed card with the controller. **Expected Results:** Data acquired by **MiniRAPS** should have noise values within the 1 bit error range with provision to acquire different voltage levels. It should also be able to display data in real time both on attached host PC as well as screen attached to Raspberry pi.	
B10	**Sub Area**	**Antenna (VSSC)**
B10.1	**Development of Heat Sink Integrated Antenna configurations for Phased Array Applications (VSSC)** High Power active phased arrays are used in various satellite payloads and also for ground based applications. In active arrays each antenna element is equipped with a power amplifier module and these distributed amplifiers produce large amount of heat. This would lead to thermal run away in amplifier modules and affect the performance of both transmitter and receiver modules. A possible solution is to add heat sinks on the microwave circuit side of the PCB, at the cost of increased real estate and possible EMI problems while encapsulating the entire system. In normal sense the electromagnetic radiation from heat sinks is typically undesirable and should be minimized to reduce electromagnetic interference (EMI). However, it can be advantageous to maximize the radiation from a heat sink by using the antenna as a heat sink. In microstrip antennas the radiation structure can be modified as heat sinks by providing proper heat routing strategies. The introduction of heat sinks should not affect the radiation and reflection characteristics of the antenna. The proposals are invited to develop a heat sink integrated microstrip antenna configurations suitable for S band phased arrays. Antenna should operate in 2GHz-2.1GHz and 2.2GHz-2.3GHz band with dual circular polarization. The expected deliverables are heatsink integrated antenna having dual circular polarizations, wide bandwidth and	

	good impedance matching in the presence of heat sinks. Simulation and measurement results need to be provided. Finally, a working prototype having RF amplifier module integrated with a novel heat sink integrated antenna must be demonstrated.	
B11	**Sub Area**	**Power System (VSSC)**
B11.1	**Wireless Power Transfer (VSSC)** The project aims at the design and development of wireless power transfer technique to transfer power from battery to various subsystems for aerospace applications. The project aims at the study of existing technologies of wireless power transmission and to arrive at a suitable technique to transfer power in the following cases; 1) Low power at a distance of few centimetres (charging of batteries etc) 2) Medium power at a distance of few meters. The proposed scheme has to be verified by hardware implementation.	
B11.2	**Integrated on Chip Multi-output DC-DC Converter with Soft Switching Topology (VSSC)** The scope of the project includes the modelling, analysis, design and development of miniaturised multiple output isolated DC-DC converter with soft switching topology for aerospace applications. These converters should have efficiency greater than 85%. The scope of the project includes the design of on chip PWM controller for the proposed control algorithm. The proposed scheme shall be verified by simulation and hardware implementation.	
C	**Area**	**Robotics (VSSC)**
C1	**Modeling, Simulation, Analysis and Design of a Controller for a Robotic Manipulator having Five Degree of Freedom for Lunar Mission (VSSC)** Robotic manipulator having five degree of freedom forms part of a lunar exploration rover. The scope includes: • Generation of a mathematical model and its analysis which includes forward and inverse kinematics, work space analysis, trajectory planning, static and dynamic analysis • Design of a controller and simulation of certain predefined tasks • Hardware realization of the controller (control electronics to drive the manipulator) • Experimental demonstration of the predefined tasks (Robotic manipulator will be provided for this purpose	
C2	**Design, Analysis and Experimental Verification of a Force and Slip Controller for the Object Grasp by an under Actuated Three Fingered robotic hand (VSSC)** • Design of force and slip controller (including selection and procurement of appropriate sensor / sensors)	

	• Simulation of grasp (Spherical, Cylindrical & Planar) with objects of various sizes and shapes • Experimental demonstration of grasp (Spherical, Cylindrical & Planar) with objects of various sizes and shapes (Under actuated robotic hand will be provided for this purpose)	
C3	**Conceptual Design of Redundant Robotic Arm for Executing Reactionless Motion Paths on Free-Flying Spacecraft (VSSC)** Robotic systems such as robotic arms have effectively been used to replace humans in dangerous or repetitive tasks in potentially hazardous environments. Thus they are best suited for space exploration missions, space debris deorbiting missions, space infrastructure development and satellite maintenance missions etc. The most well-known space manipulation systems are: Canadarm or the Shuttle Remote Manipulator System (SRMS), Canadarm2 or Space Station Remote Manipulator System (SSRMS). In a free-flying spacecraft-manipulator system obeying the momentum conservation law, space manipulators in motion create reaction forces and reaction moments which are transferred to the base spacecraft and cause translation of its centre of mass and rotation about the centre of mass. Such disturbances impact the pose accuracy of the manipulator's end-effector, preventing it from following the pre-programmed path accurately. Proper manipulator path planning techniques can be employed to achieve reactionless manipulator motion. A specialised control scheme for joint control of the robotic arm can be employed to utilise the redundancy available in the joints to build motion paths that do not impart reactions to the base spacecraft. Thus the scope of the project involves the following aspects: • Mathematical formulation of reactionless null-space control technique • Conceptual design of robotic arm capable of executing reactionless paths on a floating base spacecraft	
D	**Area**	**Artificial Intelligence & Machine Learning (VSSC)**
D1	**AI Based PCB Design (VSSC)** During PCB Layout design, placement & routing takes about 70% of layout design time. One solution is to use automated tools for placement & routing. Present day auto placement tools are ineffective for the current designs. Auto routers are betted placed. The first version of Auto routers (X-Y grid routers) for PCB were developed by UNIX in 80's. Those were very inefficient in utilizing floor plan. In 2000's Shape based/Blood hound routers appeared in EDA tools. Most of the PCB designers are manually routing and designing their boards, a time consuming and tedious process. AI can bring much more automation in placement and routing.	

	Artificial intelligence has been available in most EDA tools including PCB layouts which automates the component placement and routing. Designers will use auto routers and auto placement tools trained using Artificial Intelligence. The routing engine learn from the well-designed layouts, designs & styles and try to replicate the same style to different designs. In-case of ICs, an efficient auto placement can be achieved by learning through the datasheets. The system will take feedback from user interactions with the software, learn from changes that user does and remember those to come up with a design plan to meet the user expectations. Expected Deliverables are: • Library - Library of components & Sub circuits • Language – Higher Level Language • Schematic compiler – Compiles HDL into schematics • Schematic Linker – Makes Aesthetically pleasing schematic • Reconciliation – Mapping generics part to specific Network & User instructions as input (if required) • Placement & Layout – Placement & Routing • Static Analysis – To find out impossible things • Simulation & analysis – SI, Power, EMI/EMC analysis • Packaging – DFM & Gerber for Industries	
D2	**AI Based Smart Inspection of Components & Wired PCBs for Defect Detection (VSSC)** Incoming Inspection of EEE components & QC Inspection of PCB assemblies of Avionics packages for all launch vehicles are done manually using microscopes and skilled manpower. With the automation of electronics fabrication with SMT soldering, manual inspection is the most time consuming and tedious process. Deep Learning methods used in Artificial Intelligence platforms can be employed for the inspection process by training the models/algorithms with sufficient database on the surface defects involved in EEE components and the solder joint defects in case of PCB assemblies to reduce time and to improve accuracy with respect to the inspection of solder joints, identification of defects and their classification to various categories. The goal is to develop an intelligent vision system that can guide inspectors in visual inspection of EEE components & avionic packages, thus reducing the overall cycle time in Avionics package fabrication.	
E	**Area**	**Composites/Launch Vehicle Structures (VSSC)**
E1	**Sub Area**	**Modelling (VSSC)**
E1.1	**Modelling of Film Boiling CVI (FB-CVI) Process (VSSC)** Carbon-Carbon Composites are realized by densification of carbon preform with carbon matrix, either derived from an organic liquid precursor like phenolic resin or pitch, or by	

	pyrolysis of hydrocarbon through CVI process. Out of the different variants Film Boiling CVI is considered to be one of the fastest method considering high densification rate of the order of 3-10 mm/hr. In FB-CVI process, the preform is densified by means of resistive or inductive heating technique. Inside the preform, a heater of desired shape is built preferably with a material which can produce the heat flux when heated to carry out the process. The resistor allows to reach high temperatures in the centre of the preform (~1300K). The precursor inside the preform is then vaporized and a film-boiling zone is formed inside the hot zone. During FB-CVI process various physical and chemical phenomena are involved in the preform densification like (a) electro kinetics, which accounts for resistive/inductive heating (b) heat transfer from the heater to the surrounding fluid (c) boiling, which includes fluid transport and phase change, and (d) densification, which is the result of gas species transport within the preform and homogeneous and heterogeneous chemical reactions leading to pyrocarbon deposition. A numerical modelling of the electro kinetics, thermal, diffusive and reactive phenomena is required in order to study the densification phenomenon with respect to the heat transfer from the heater/susceptor, the deposition chemistry and the resulting densification behaviour for various preform architectures like 2D, 3D, 4D and non-oven based preforms.	
F	**Area**	**Propulsion (VSSC/SDSC SHAR/LPSC)**
F1	**Sub Area**	**Solid Propellant Plant (SDSC SHAR)**
F1.1	**Simulation of Ammonium Perchlorate Cleavage by Inter-particle and Surface Impacts in Hammer Mill under Different Operating Conditions (SDSC SHAR)** Ammonium Perchlorate (AP) is used as oxidizer in Solid Propellant processing with wide particle size distribution. Coarse AP of ~300 microns average size is ground into fine of 50 micron average particle size. The microscopic properties of the material define fine tuning of end product properties. Simulation of Particle breakdown during grinding in hammer mill due to impact with particle to particle, and housing surfaces under different operating conditions like rotor speed, air velocity, feed rate, number of particles is required. This can be used to optimize the process conditions for wide particle size distribution, surface area control, packing density etc. and thus better tuning of final product towards our requirement.	
F1.2	**Method to get Uniform Particle Size by Innovative Size Reduction Method for AP at Lab Scale (SDSC SHAR)** Ammonium Perchlorate is currently being ground by Hammer mill.This gives a wide distribution of partcle size. AP fine product control is achieved with great difficulty due	

	to various factors like residency of the grinder usage, selection of RPMs and screens. It is difficult to get the desired PSD in the range of less than ±1 weight percentage,even with great care. With the requirement of control burn rate between paired motors, the variation in PSD upto the extent of ±1 weight percentage may not be meeting our requirement. Hence, it is proposed to explore for alternative methods to achieve the required specifications.	
F2	**Sub Area**	**Liquid Propulsion (LPSC)**
F2.1	**Evaluation of Passive Devices for Control of Combustion Instability in Liquid Engines (LPSC)** Combustion instability is a phenomenon that sometimes occurs in liquid rocket engines and can lead to damage/destruction of the hardware. It can be controlled by passive techniques such as slots, baffles, resonators etc. It is necessary to model the combustion instability in the presence of these dampeners and evaluate their effectiveness under different operating conditions. The effect of variation of geometric parameters is to be quantified. Combustion instability model for liquid rocket engine with passive dampeners.	
F2.2	**Experimental Evaluation of Coking Characteristics of Rocket Grade Kerosene (Isrosene) in the Regenerative Coolant Channels of Semi Cryogenic Engine Combustion Chamber (LPSC)** In the regenerative coolant channels of semi cryogenic engine combustion chamber, Isrosene comes into contact with the chamber wall at high temperature. This induces a possibility of hydrocarbon decomposition resulting in coking in the cooling channels. This coke can clog the injector element holes, which are very small in size (~0.8 mm). Also, it can change the heat transfer characteristics of the coolant channel. Hence the coking characteristics of Isrosene is to be studied thoroughly for different conditions of the thrust chamber coolant channels including flow velocity in the range of 10m/s to 65 m/s and for different materials. Expected outcome may be covering the following aspects; • Literature review regarding coking of Kerosene • Details of experimental setup with measurement scheme. • Results of the experiments in terms of the following aspects. • Effect of surface and fluid bulk temperature on coking. • Effect of variation of flow velocity from 10m/s to 65 m/s • Effect of the channel material (Copper and stainless steel) and surface condition (coating/without coating) • Effect of surface irregularities on coking.	

F2.3	**Mathematical Modeling of Liquid Migration under Zero 'G' Condition and Propellant Evaporation Caused by Heat Transfer in LH2 Tank of Cryogenic Propulsion Stage (LPSC)** In cryogenic propulsion stages, residual liquid migration in Liquid Hydrogen propellant tank is generally observed after cryo engine shutdown. This causes higher tank pressure due to mixing of liquid Hydrogen with warm pressurant gas and heat transfer with warm tank wall. Hence, it is required to model liquid migration at zero 'g' condition coupled with heat transfer (conjugate heat transfer) in tank usage volume and validate the model with the flight data provided by LPSC. Source code in MATLAB/ Python with necessary documentation, numerical model, solution methodology, model results and validation with flight data provided by LPSC.
F2.4	**Modeling of Mono Propellant Hydrazine Thruster used in Spacecraft (LPSC)** The monopropellant thrusters are generally used in reaction control systems of Earth observation spacecraft's. The monopropellant Hydrazine thrusters use principle of dissociation of Hydrazine using catalyst to produce the exhaust gases. These exhaust gases are expanded through the nozzle to produce thrust. The complete hydrazine dissociation model for the monopropellant thruster is required for thruster design and optimization. This involves capturing multi-physical phenomena such as two-phase flow, adsorption, heterogeneous reaction, desorption, porous media flow etc. which would help in designing the catalyst bed required to catalytically decompose the monopropellant. The model developed has to be validated with the hot test data provided by LPSC. Expected Deliverables are: 1. Numerical model with source code, numerical model, solution methodology, model results and validation with thruster hot firing test data supplied by LPSC.
F2.5	**Two Phase Flow Modeling in Cryogenic Propellant Feed Lines (LPSC)** Cryogenic engines make use of propellants such as liquid Hydrogen and liquid Oxygen at sub-cooled temperatures. The propellant is fed to the engine from the storage tank via. feed lines that are typically of 70-400mm diamater. The feed lines are either super-insulated or foam insulated and are initially at ambient temperature (≈298K). The feed lines are required to be chilled to respective cryogenic temperatures of the fluid (≈20K for Hydrogen feed line and ≈80K for oxygen feedline) prior to the start of engine operation to avoid undesirable flow oscillation. The chill down process is complex in nature

	due to varying two phase flow boiling regimes and heat-in-leak conditions. In this regard, a validated conjugate numerical model is to be developed to simulate the following: • Feedline chill down from ambient temperature to the respective propellant temperature. The model must include heat transfer correlations which will be invoked based on wall temperatures and fluid quality • The model has to capture the effect of pipe orientations viz. horizontal, vertical and inclined on the chill down characteristics • In case of large diameter feed lines, stratified flow predominates and thermal bowing of feedline may occur. The model should be able to capture this flow regime and the associated thermal gradients The time varying temperature evolution of the feedline in axial and circumferential direction and the time taken for feedline chilling completion are some of the important parameters to be compared. The flow regime transition at different points in the feedline.
F2.6	**Conjugate Heat Transfer Analysis in Liquid Rocket Engine Systems (LPSC)** Liquid fuel rocket engines employ several cooling techniques to maintain material temperatures within acceptable limits. The Vikas engine, for example, uses a combination of an ablative throat (Silica Phenolic) and film cooling. During the ablation process, the Silica Phenolic sacrifices itself by burning to char. Furthermore, pyrolyzed gases from within the ablative material generate a film cooling layer. A numerical tool that can estimate heat flux into the walls of rocket engines and simultaneously simulate such a cooling methodology as ablation, along with radiation, will go a long way in the design optimization of existing engines. The development of a validated conjugate heat transfer code to simulate the following is thus proposed: • Conjugate heat transfer analysis of combusted gas flow through rocket nozzles, and predict the accompanying heat flux into nozzle walls • Ablative cooling in thrust chambers of liquid rocket engine with material recession, along with the associated film cooling by the pyrolyzed gases. Expected Deliverables are: Validated parallelized numerical tool that can simultaneously estimate the heating of chamber walls of liquid rocket engines and simulate the performance of ablative cooling methodology with radiation.

F2.7	**Spray Interaction Effects in a Multi-Element Injector Head of a LOX-Kerosene/ LOX-Methane Engine (LPSC)** Multi-element coaxial injectors are used in high thrust LOX-Kerosene and LOX-Methane engines. The injector elements are arranged in a specific pattern based on the thrust per injector element of the rocket engine. The conical sprays from an injector element interact with each other and with the sprays formed in its neighboring elements. The performance and stability of these engines are influenced by both intra-element and inter-element spray interactions. Spray interaction in a multi-element injector head depends on both the intra-element spray characteristics as well as combustion chamber operating conditions. For simulating the spray interaction in a multi-element coaxial injector head, analysis needs to be carried out for different sprays at various operating conditions. Expected Deliverables are: Numerical model for the spray characteristics of multi-element swirl coaxial injectors.
F2.8	**Development of Mathematical Model for Predicting Pressure Evolution in LH2 Tank During Flight (LPSC)** Complex thermodynamic processes occur in the ullage volume of LH2 tank which causes tank pressure variation during flight. Tank pressure variation is primarily caused by vaporization of LH2, cooling of ullage gas due to slosh induced heat transfer in tank wall and liquid-vapour interface, condensation of Hydrogen vapour etc.. till engine start in flight. Subsequently, warm pressurant gas is supplied to tank ullage for pressure maintenance during LH2 outflow from tank. During tank pressurisation with warm pressurant gas, heat and mass transfer occur in tank ullage volume. The above heat and mass transfer aspects are to be mathematically modelled and the results are to be validated with ground test/flight data. Expected Deliverables are: Source code in MatLab/ Python/C/C++ to be given to LPSC with necessary documentation
F2.9	**Development of Void Fraction Meter for Cryogenic Two-Phase Flows (LPSC)** Cryogenic two-phase flows are encountered during chill down of cryogenic stage feed line, mixing of hot vapor with cryogenic liquid in the exit line of Semi-cryogenic engine booster pump, etc.. Information of vapor void fraction along with the distribution of vapor and liquid phases is required for estimating the system performance and its optimum design. Experimental data of the vapor and liquid phase distribution is also required to validate the two-phase flow models. In this regard, a void fraction meter is required that may be developed in a phased manner for Nitrogen.

	Phase 1: A void fraction meter that can provide an average value of vapor volume fraction at a cross-section / volume of the feedline with Nitrogen flow. **Phase 2:** In the second phase of the development, the capability of the void fraction meter developed in phase-1 has to be extended to provide spatial distribution of the vapor and liquid phases at a cross-section or volume of the feedline having Nitrogen flow. The pipe diameter can be considered in the range of 70-300mm. Expected Deliverables are: A cryogenic void fraction meter capable of providing distribution of vapor and liquid phases at a section / Volume of the pipe. The design methodology, calibration details of the equipment, results of the flow tests and the algorithms have to be provided along with the void fraction meter.
F2.10	**Study, Design & Optimization of Clearance Seals used in High Speed Turbo-Machinery Operating in Cryogenic Fluids and Vacuum Conditions (LPSC)** Dynamic seals are used in cryogenic turbo pumps which work in liquid and gaseous phases of Hydrogen and Oxygen during operation of the cryogenic rocket engine. These seals have to work in vacuum up to 5 mbar and rubbing speeds up to 55 m/s. Minimum wear & heat generation and maximum life are the desirable properties of seals used in turbo pumps. Detailed study in this area is required to optimize the existing seal designs/ configurations and material selection. Expected deliverable are: Optimized design of the seal/runner and its material selection for use in cryogenic turbo pumps.
F2.11	**Development of Damper Seals for Turbo Pumps (LPSC)** The proposed research is for the development of damper seals for cryogenic turbo pumps of the rocket engine. The damper seals, in addition to leak control are required for dampening and controlling the excess rotor response. These seals should have high direct damping and low cross coupled damping. We need to develop a seal of this category, experimentally demonstrate its performance and optimize its geometry for use in high speed cryogenic turbo pumps. Expected deliverables are: • Optimized damper seal design which works in cryogenic fluids (Liquid Oxygen & Liquid Hydrogen) • Mathematical model for evaluating the seal parameters like damping coefficients, stiffness etc. Experimental setup for evaluating the performance of damper seals is also preferred.

F2.12	**Development of Chemical Kinetic Mechanism for Combustion Modelling of Hypergolic Propellants (LPSC)** A combination of hypergolic propellants (generally derivatives of Hydrazine and Nitrogen tetra-oxide) is used for satellite/lunar lander propulsion applications of ISRO. Combustion modelling of such thrusters is imperative to understand combustion performance (film cooling effectiveness) and stability during nominal and off-nominal operating conditions. A chemical kinetic mechanism which can represent the MMH-NTO or UDMH-NTO chemistry accurately is required. The mechanism should reproduce accurate chemistry at low to high temperature and pressure conditions. The developed kinetic mechanism should be elaborate, but can be utilized for CFD based combustion modelling effectively. The kinetic mechanism should be a multi-step with necessary gas phase and liquid phase reactions. The developed kinetic mechanism should be validated with a benchmark problem / LPSC thruster data for major observable test parameters. The validated mechanism will be directly utilized for combustion and design studies for existing and upcoming hypergolic thrusters. Expected deliverables are: • Detailed validated chemical kinetic mechanism and associatedthermodynamic-transport data file, which can be utilized for combustion modelling of LPSC thrusters • Kinetic mechanism preferably in Chemkin format for compatibility with in-house CFD packages • Mechanism, reduction procedures and other necessary details on kinetic mechanism development
F2.13	**Property Characterisation of Chemical Propellants to Determine the Greenness Index (LPSC)** The greenness of the propellant is required to be quantified in order to appreciate the difference between the conventional and green propellants. The study requires evaluation of various parameters associated with propellants to determine greenness. The parameters like Exposure Limits (dependent on properties like TLV, vapour pressure), Toxicity (LD50, LC50), Fuming capability (dependent on vapour pressure), Radiative Forcing caused by exhausts and Ozone Depletion Substances (ODS). Eventually, the greenness index based on these parameters will be evaluated. The determination of greenness of the propellant based on the above mentioned parameters is not required to be done in this scope of project. This will be done in house. Currently two propellants will be supplied which are blends Isrosene and Ethanol respectively. The properties for these propellants are required to be evaluated. Expected Deliverables are: The parameters like Exposure Limits, Toxicity, Fuming capability, Radiative Forcing caused by exhausts and Ozone Depletion Substances (ODS) will be evaluated for the propellants of interest.

F2.14	**Development of Physics Based Model to Predict the Soot Formation in the Combustion Chambers of Methane - Oxygen and Isrosene - Oxygen Engines (LPSC)** Development of a physics based combustion model to predict soot formation as a function of liquid engine operating parameters such as chamber pressure and mixture ratio. The chemical kinetics, reaction mechanism, species and their desired properties required for combustion modelling have to be formulated through standard published literature for both methane-oxygen and Isrosene-oxygen propellant combinations. The developed model has to be validated with the test data provided by LPSC or with the relevant data available in the open literature. Expected Deliverables are: Quantification of soot formation during methane-oxygen and Isrosene-oxygen combustion in liquid rocket engines. A combustion model to predict the effect of mixture ratio and other operating parameters of the engine on the degree of soot formation.
F2.15	**Development of a Miniaturised Laser Unit for Liquid Rocket Engine Ignitor Application (LPSC)** Methodology to develop a miniaturised laser. Development of the prototype. Demonstration of laser based ignition of the LOX-Hydrogen mixture and LOX-Methane mixture at rocket engine operating conditions. Expected Deliverables are: Weight of the laser system <1000 g, It should be accommodated within a cube of volume 150x150x150 mm. The energy of the system should be at least 100 mJ/pulse with pulse rate of 20 pulses per second. The input power supply of the laser is a DC source of 28V to 32 V.
F2.16	**Regenerator Studies on Free Piston Stirling Engine (Fpse) (LPSC)** The work aims at optimising the regenerator using the available FPSE with LPSC to achieve highest possible thermal efficiency. The heat transfer in the regenerator is studied simulating the oscillatory nature of the flow. The objective of this is to experimentally measure the friction factors and Nusselt numbers in oscillating flow of regenerator matrices that will be used in Stirling engines that are planned for space power generation. The experimental data will be analyzed and usable correlations of the friction factor and Nusselt number will be provided. The aim of the study is to optimise the regenerator to enhance the efficiency of the LPSC FPSE from the existing 18-20% (theoretical) by at least 25% using the regenerator. Expected Deliverables are: • Optimised regenerator design for the FPSE designed by LPSC.

F3	Sub Area	Green propellants (VSSC)
F3.1	**Combustion Diagnostic Studies of Green Hypergolic Bipropellants (VSSC)** • Development of green hypergolic bipropellants are envisaged for various missions of ISRO in order to replace the toxic hydrazine derivatives • Different fuel systems based on isrosene, ethanol and energetic ionic liquids (EILs) based on azoles are being developed in ISRO which are having hypergolic properties in combination with 90% H2O2 as green oxidiser • Screening of the compounds are undertaken by molecular modelling techniques and theoretical performance analysis using NASA-CEA code. The promising systems are further screened by drop tests. Functional level evaluation of the optimised systems is being undertaken for thruster level evaluation • Further, a detailed characterisation of the fuels systems being developed is required to study the stability, combustion characteristics and decomposition mechanism of the propellant systems • Spectral characterisation techniques such as fast rate pyrolysis, T-jump FTIR, rapid scan FTIR, Diffused reflectance spectroscopy etc are proposed for studing the decomposition mechanism • Flame characterisation, experimental ignition delay measurements, molecular level interactions and a detailed chemical kinetics of the propellant system are to be studied for understanding the molecular level interaction and kinetics	
F4	**Sub Area**	**Electric Propulsion (VSSC/LPSC)**
F4.1	**Modeling of Hall Effect Thruster Physics (VSSC)** Hall Effect thrusters are widely used for satellite station keeping, operational life of the satellite is dependent on thruster. By developing a numerical model for simulating the flow physics with adequate validation studies, thruster life can be enhanced. With the help of the numerical models a detailed parametric studies can be carried out so that the; 1) Damaging flow interactions/collisions can be steered to the least damaging locations or spread across larger areas to minimize the damage to the thruster walls 2) Improving the efficiency of the thruster by minimizing different kinds of losses.	
F4.2	**Modelling of Plasma and its Dynamics Inside Hollow Cathode in Hall Thruster (LPSC)** Hollow cathode is one of the most important component of Hall thrusters which is an electron source for plasma discharge and beam neutralization. The life and performance of hollow cathode directly resembles thruster's life and performance. The hollow cathode can be divided into orifice region, insert region and plume region. Plasma density and temperature inside the hollow cathode decides the discharge current that can be extracted from the cathode. The emitter temperature of the cathode	

	is provided by orifice heating, ion heating and electron heating in heater less operation mode. Hence models that quantitatively describe the trends of plasma parameters with varying operating conditions and to simulate discharge parameters (discharge voltage and cathode temperature) is needed. The following are the expected deliverables: • Thermal model of Hollow cathode using orifice heating, ion heating and electron heating phenomena • Quantitative description of trends of plasma parameters with varying operating conditions and simulate discharge parameters (discharge voltage and cathode temperature)	
F4.3	**Multi-Plume Interaction Studies of Clustered Hall Thrusters (LPSC)** The performance of a thruster in a cluster may be different from a standalone situation. One interest is to investigate the plume interactions, especially in the complex and important near field locations. To accurately simulate the plasma plumes from a cluster of Hall thrusters requires an accurate modelling of the complex physical plume mechanism. Traditionally, the computational simulation of plasma plume flows into vacuum is performed with a hybrid particle-fluid approach. The Direct Simulation Monte Carlo (DSMC) method models the collisions of the heavy particles (ions and atoms) while the Particle In Cell (PIC) method models the transport of the ions in electric fields. This study is intended to simulate the detailed three-dimensional plume structures and plume interactions. Expected deliverables are: • Simulation of Electron temperature, plasma density and plasma potential profile downstream of single SPT thruster (plume) • Effect of clustering of three SPTs on above plasma parameters • Prediction of overall thrust, efficiency and specific impulse of clustered system	
F5	**Sub Area**	**Catalytic Decomposition (VSSC)**
F5.1	**Modelling of Catalytic Decomposition (VSSC)** Performance of mono propellant thrusters mainly depends on the catalytic decomposition of propellant in a suitable catalytic bed. Sizing of bed, pressure drop across the bed and the decomposition temperature plays crucial role in the thruster performance estimation. A model for the same can help in reducing several tests to be carried out with different bed loadings, bed sizing etc which increases the cost and time for development of new thrusters with green/ high performance propellants under development. The model attempts to predict an optimum design for the catalytic bed and thruster which is planned to be developed.	

F6	Sub Area	Hybrid Rocket Motor (VSSC)
F6.1	**Modelling of Hybrid Rocket Motor Internal Flow Field (VSSC)** Burn rate of solid fuel in Hybrid Motors depend on convective heat-flux from the flame. Empirical relations for calculating fuel pyrolysis and burn rate as a power law function of oxidizer flow rate are not accurate enough to be clubbed with high fidelity reactive flow simulations. A conjugate heat-transfer based model to predict the pyrolysis rate of HTPB fuel based on heat-flux at the fuel surface needs to be developed and implemented in existing CFD packages to supplement the existing reactive simulation capabilities.	
F7	Sub Area	Liquid Propellant Storage and Service (SDSC SHAR)
F7.1	**Enhancing the Existing Method UH-25, MMH, N_2O_4 & MON3 Effluent Treatment (SDSC SHAR)** Currently the effluent treatment of the propellant effluents is being carried out in batch process mode using reaction tank. Instead of batch process, continuous method of treatment with improved chemical method is being looked for.	
F7.2	**Alternative Method of Scrubbing / Neutralizing UH25 & N_2O_4 Vapour (SDSC SHAR)** Currently UH25 & N_2O_4 (hazardous, toxic & hypergolic liquids) are scrubbed by using tower packing column of ceramic balls. Alternative method for neutralizing these vapours is to be studied.	
G	Area	Polymers and Chemicals (VSSC)
G1	Sub Area	Polymer (VSSC)
G1.1	**Electrochromic Polymer Films for Spacecraft Temperature Control (VSSC)** Aims at development of multi-layer polymer films that change their thermo-optical properties in response to an applied voltage. Mainly consists of three layers- transparent conductive layer (indium tin oxide), a polymer gel electrolyte and a coating with reversible oxidation state, preferably with reversible dark colour. These films exhibit variable infra-red emissivity in the range of 0.35-0.75, and find applications as smart surfaces, providing thermal control of spacecraft in changing orbital conditions.	
G1.2	**Biomimetic Self-healing Foams (VSSC)** Human skin is a self-healing mechano-sensory system that detects various mechanical contact forces efficiently through three-dimensional innervations. Here, we propose a biomimetic artificially innervated foam by embedding three-dimensional electrodes within a new low-modulus self-healing foam material. The foam material is synthesized from a one-step self-foaming process. By tuning the concentration of conductive metal particles in the foam at near-percolation, we demonstrate that it can operate as a piezo-impedance sensor in both piezoresistive and piezocapacitive sensing modes without the need for an encapsulation layer.	

	The sensor is sensitive to an object's contact force directions as well as to human proximity. Moreover, the foam material self-heals autonomously with immediate function restoration despite mechanical damage. It further recovers from mechanical bifurcations with gentle heating (70 °C). This material will be useful as damage robust human-machine interfaces.	
G1.3	**Development of CFD Enabled Modelling for Extruded Rubber Products (VSSC)** PED has been developing and realising various elastomeric products for all the stages of launch vehicles. Some critical components like lengthy rubber products, sheets, profiled gaskets, extrudates for huge sized o-rings/seals are realised through extrusion method. During the shaping stage of extrusion, uncured rubber that flows through the narrow die is exposed to compression, shear, and heat build-up, which leads to the elongation of polymer chains. Rubber compounds being highly viscoelastic, exhibit die swell, which may lead to changes in the extrudate cross section compared to the die. Moreover, apart from the choice of base rubber and additives, mixing methodology also adds to the complexity in designing the die for rubber products. Trial and error method involved in finalising the design of metallic die is time consuming and involves material loss. Visualising flow of uncured rubber compound is essential to optimise the design of extrudate die, which calls for studies on the swelling behaviour of rubber compounds using computation methods. The expected outcome of the proposed studies are as follows: • Modelling based die design to be proved with practical cases using die shapes for 3 different given profiles of silicone and EPDM rubber compounds • Studying the effect of different mixing methodologies on the rheological properties of rubber compounds • Compute the extrudate die swell of silicone and EPDM compounds with different fillers, for different types of rubber profile using computational fluid dynamics	
G2	**Sub Area**	**Chemical systems (VSSC)**
G2.1	**Development of Stabilized α-Alane (Aluminium Hydride) as an Energetic Fuel in Solid Propellants and as Hydrogen Source for Fuel Cells (VSSC)** Aluminum hydride (AlH_3) which is well known as alane, is a promising hydrogen source for fuel cell applications as well as an energetic fuel for solid propellant formulations. It is considered as one of the most promising additives in space propulsion because of its capability of releasing hydrogen during decomposition and / or combustion. Alane exists in seven different polymorphic crystal structures (α, α',β, γ,δ,ε crystalline phases and solvated solid ξ phase). Among them, α – AlH_3 is reported as the most stable phase.	

	The following deliverables are expected as a research outcome: • To develop a lab scale process for synthesis of stable α-alane • Analytical characterization • Scale-up the process to a batch size of 1 kg • Evaluation of the developed material at VSSC (lab / scale-up)	
G3	**Sub Area**	**Catalysis (VSSC)**
G3.1	**Development of Effective Catalysts and Reaction Kinetic Models for Carbon Dioxide Reduction Reaction (VSSC)** The Sabatier reaction, also referred to as carbon dioxide methanation, involves reacting carbon dioxide and hydrogen in presence of a catalyst producing water and methane. Number of catalysts have been reported in the literature for the reaction. Development of highly efficient catalyst with high methane selectivity, lower on set temperature and minimum pressure drop is solicited. Towards this objective, bimetallic or tri-metallic catalysts on suitable supports are required to be designed. Either wash-coating on monoliths or support on metal based mesh for enhanced heat transfer properties may be attempted for realization of the catalyst system with the desired efficiency. Further, reaction kinetic studies for the developed catalyst (s) are required to be undertaken based on which kinetic models should be developed / formulated. These kinetic models shall form the basis for designing of the reactor for undertaking carbon dioxide methanation reaction.	
G4	**Sub Area**	**Energy Systems (VSSC)**
G4.1	**Development of Platinum Alloy Catalyst for LT PEM Fuel Cell (VSSC)** Platinum alloy catalyst are considered to achieve high durability in the PEM fuel cells. In this regard platinum alloy preferably with nickel, Iron cobalt, etc. are widely reported combinations. The catalyst mass activity of > 0.3 A/mg-Pt @ 900 mViR-free and 30, 000 durability cycles as per DOE criteria is essential to achieve development target.	
G4.2	**Development of Air Electrode for LT PEM Fuel Cell (VSSC)** Cathode catalyst accounts for major share of performance and durability issues associated with PEM fuel cells. The proposed work shall be focus on development of high performance cathode with power density of greater than 1200 mW/cm^2 at 0.6 V for hydrogen and air operation at fuel cell MEA level. The targeted platinum loading level shall be within 0.4 mg/cm^2 maximum on the cathode. The catalyst chosen may be platinum or its alloy preferably with nickel, Iron, cobalt, etc. for elevated catalytic activity and durable ORR performance in PEM fuel cell condition.	
G4.3	**Development of Electrodes for Aqueous Lithium ion Batteries (ARLIBs) (VSSC)** Current Lithium ion batteries rely on organic-based electrolytes which use highly toxic and flammable solvents which can cause safety hazards if not used properly. Furthermore, non-aqueous electrolytes generally have ionic conductivities about two orders of	

	magnitude lower than those of aqueous electrolytes, and the also the processing costs of organic electrolytes are high. These drawbacks limit their application in large-scale batteries. The most promising approach is to use aqueous electrolytes instead of the flammable organic electrolyte. Water is cheaper than the organic solvents and inexpensive water soluble salts are available. The material cost and processing cost are also greatly reduced in the case of aqueous electrolyte. In addition, the ionic conductivity of aqueous electrolytes is generally significantly greater than that of organic electrolytes, allowing higher rates and lower voltage drops. However, the chemical/electrochemical processes of lithium intercalation compound electrodes in aqueous solutions are much more complicated than those in the organic electrolytes. Many side reactions are involved, such as the dissolution of electrode materials in water, electrode materials reacting with water or O_2, proton co-intercalation into the electrode materials parallel to the intercalation of lithium ions, and H_2/O_2 evolution reactions. So, electrode materials (cathode and anode) which are stable in aqueous electrolytes are required.
G4.4	**Development of Porous Air Cathode and Oxygen Selective Membranes for Li-Air (O_2) Batteries (VSSC)** Lithium-air (Li-air) batteries, with higher theoretical energy density than conventional lithium batteries and other metal air batteries, are being developed for various applications. The lithium–oxygen battery comprises a lithium-metal anode, lithium conducting electrolyte and a porous oxygen electrode. The operation of Li-O2 batteries incorporates elements of a fuel cell (e.g., reduction of gaseous O_2 from the environment during discharge) with that of a battery (storage of electrons and Li+ in the oxygen electrode). Porous air cathode and oxygen selective membranes are two important requirements for Li-Air batteries. **Porous Air cathode** An air cathode for Li-air cell should possess the following desired properties. • Should be porous enough for the diffusion of oxygen • Stable enough to act as a support for the discharge product • Should be stable in the oxidative environment **Oxygen selective membranes** Water vapour from air must be prevented from corroding the lithium metal negative electrode during discharge under ambient conditions. One method of protecting the Li metal from corrosion is to use an oxygen selective membrane (OSM) that allows oxygen into the cell while stopping or slowing the ingress of water vapour. An OSM for Li-air cells should possess the following desired properties.

	• High O_2 permeability • No water vapor permeability • No electrolyte solvent permeability • No carbon dioxide (CO_2) permeability
G4.5	**Development and Testing of 3D Printed Polymer Derived Ceramic Electrodes for Energy Systems (VSSC)** For energy storage devices, a hierarchical electrode porosity in three dimensions provides several advantages. For example, the electrochemical performance of the electrode material would be influenced not only by submicron scale porosity via parameters such as pore size, pore distribution, and pore morphology, but also by macro scale porosity that forms the electrode structure. The manufacture of 3D-structured electrodes at micro scales has been challenging because of the fact that most micro fabrication methods have been largely planar. Recent advances in 3D printing (i.e., additive manufacturing), however, have opened new pathways to realize geometrically optimized electrode architectures. The scope of the project includes numerical modelling, design and realization of 3D printed electrodes using polymer derived ceramics. The work shall include an exhaustive study of the effect of 3-dimensional (3D) electrode architectures on the electrochemical performance of batteries and used the gained knowledge to determine optimized electrode structures (anodes and cathodes) for maximum areal and specific capacity.
G4.6	**Development of Efficient OER Catalyst for LT PEM Water Electrolysers (VSSC)** OER catalyst forms the key in achieving energy efficient water electrolysis. The work is about establishing a synthesis route for high durable catalyst and realizing OER catalyst layer with the same and demonstrate electrode level performance of 1 A/cm^2 or greater within 1.70 V for Low temperature.
G4.7	**Development of Catalyst for Electrochemical Reduction of Carbon Dioxide Gas to Methane in Proton Exchange Membrane (PeM) Cells (VSSC)** Energy efficient conversion of CO_2 gas to methane is highly relevant in manned space missions as well as mars missions. It also assumes significance in terms of carbon sequestration and recycle. PEM cell based electrolytic conversion of CO_2 gas selectively to methane using water and electricity forms a potentially attractive solution in this regard. It is envisaged to develop efficient electro-catalyst for selective reduction CO_2 to methane in PEM electrolytic cells.The deliverables shall include optimal catalyst chemistry based on studies using theoretical simulations or performance data and sample material (~10g), with electrode processing conditions, for evaluation at VSSC.

G5	Sub Area	Polymer derived Ceramics (VSSC)
G5.1	**Development of Flexible Ceramics using Preceramic Route (VSSC)** Ceramics are known to be stiff, high-strength but brittle materials. If this brittleness could be overcome, it should be possible to expand the use of ceramic materials to a lot of current applications which require withstanding high strain levels before rupture. In opposition to classical brittle ceramics these materials are called flexible ceramics. They will be highly useful, for example as anti-vibration materials and as refractory materials to resist to thermal shocks and to failure induced by thermal cycling. Literature reports the preparation of flexible ceramics via electrospinning; solution blow spinning; tape casting; 3D printing etc. The scope of the project includes the development; characterisation and end use evaluation of flexible non-woven fibrous ceramics or a flexible ceramic tape.	
G5.2	**Development of Microwave Chemical Vapor Infiltration Technique for Fabrication of Ceramic Matrix Composites (VSSC)** Ceramic Matrix Composites (CMC) have found use as high temperature materials in aerospace, nuclear and defence applications. For the fabrication of a CMC an infiltration process is needed for depositing matrix on the reinforced fiber (which is generally Carbon fiber). This infiltration is best done using Chemical Vapor Infiltration. Microwave CVI is an emerging technique. The idea behind the technique is microwave heating for carrying out the infiltration process. This infiltration method gives fast and uniform densification of matrix. Further, the densification can be done at lower temperatures owing to direct impact of heat on the fiber preforms. The development scope of the work includes: • Numerical modelling of the entire MWCVI process. This includes the transport, reaction and electromagnetic modelling • To study the roles played by fibre and matrix on exposure to microwaves • To design, develop and demonstrate the microwave CVI process lab-scale • To characterise the final CMCs produced from MWCVI using mechanical and microstructural methods	
G5.3	**Polymer-Derived Ceramic Precursor Technology in High-Entropy Ceramics & UHTCs (VSSC)** Polymer-Derived Ceramics (PDCs) technology has enabled the application of ceramics to fibers, composites, coatings, and films, mainly due to the excellent design, process, and low-temperature ceramic properties. Polymer-derived ceramics technology in recent years has been extended to the field of development of high-entropy ceramics & UHTCs. Disorder enhances desired properties, as well as creating new avenues for synthesizing materials. For instance, hardness and yield stress are improved by solid-solution strengthening, a result of distortions and atomic size mismatches.	

	Thermo-chemical stability is increased by the preference of chemically disordered mixtures for high-symmetry super-lattices. Vibrational thermal conductivity is decreased by force-constant disorder without sacrificing mechanical strength and stiffness. Thus, high-entropy ceramics propel a wide range of applications: from wear resistant coatings and thermal and environmental barriers to catalysts, batteries, thermoelectric and nuclear energy management. The development of polymer-derived ceramic precursors for High-Entropy Ceramics & UHTCs has broad research prospects. This will greatly improve the understanding and design of high-entropy ceramics and Ultra High temperature ceramics, which cab accelerate their application in the space field.	
H	**Area**	**Materials & Metallurgy (VSSC/LPSC)**
H1	**Sub Area**	**Additive Manufacturing (VSSC)**
H1.1	**Residual Stress Reduction in L-PBF & L-DED Products of Nickel Based Superalloys (VSSC)** Quantify the residual stress evolution in nickel-based superalloy components fabricated using Laser Additive Manufacturing (LDED and LPBF) processes. Optimize L-DED process parameters for fabrication of sound deposits with minimal residual stress using computational modeling in conjunction with selective experimentation Optimize LPBF process parameters for fabrication of sound deposits with minimal residual stress using computational modeling in conjunction with selective experimentation. Investigate the influence of low plasticity burnishing parameters on residual stress of as-deposited LDED and LPBF coupons. Produce demo parts in nickel based superalloy using both LDED and LPBF techniques.	
H1.2	**Development of Al-50wt.%Si Alloy through Additive Manufacturing (VSSC)** The low CTE materials such as Al-50wt.% Si is used in electronic systems in space. Present proposal is to develop 3D printing technology of Al-50wt.% Si alloy through Powder Bed Fusion technique. Samples of size 10 x 10 x 10 mm has been successfully attempted and samples with density >99.5% could be realized. However, during printing of samples of larger size (>20 mm), profuse cracking was observed. This proposal is looking for a solution to this problem of cracking in Al-Si alloys (30-70% Si). Cracking problem can be addressed through optimization of process parameters or modification of powder composition for prints of size >20mm through Powder Bed Fusion technique. Modification in composition should not increase the CTE of the material. Thorough analysis is to be done on the effect of process parameters on the cracks in the samples. Effect of scanning strategy should also be studied.	

H1.3	**Integrated Machine Learning, Multiscale Modelling and Physical Simulation Approach to Build Defect-free Additively Manufactured Parts (VSSC)** Additive manufacturing (AM) of high-temperature materials like Ni-based superalloys is getting wider attention due to its high temperature capability and requirements for complex geometries. Although AM is promising technology for aerospace applications still, challenges are faced while making defect-free parts (defect such as micro cracks, lack of fusion and porosities), phase transformation during the additive process, etc. Experimental parameter optimization is time-consuming and requires numerous resources. Recently the application of machine learning accelerated the design and processing of materials. Also, the application of multi-scale simulation is already found usage in AM process. The proposed work shall aim to integrate machine learning, multiscale modelling and physical simulation from the process parameter optimization to the product stage. The ML shall predict the conditions for defect/defect-free process parameters. These parameters shall be utilised for multiscale simulation (FEM + microstructure simulation). Using FEM, thermal field shall be obtained, for given additive manufacturing parameters and its output shall be used for microstructure simulation and physical simulation (by Gleeble). This framework shall bring out the optimum processing conditions for additive manufacturing of Ni-based superalloys with fewer resources.	
H2	**Sub Area**	**Anodising (VSSC)**
H2.1	**Conversion Coatings for Aerospace Application (VSSC)** Anodsing by Chromic acid process is being widely used for the protection of aluminum alloy h/w of our Launch Vehicles, owing to its excellent properties like corrosion resistance and base for painting and adhesive bonding. However, the electrolyte used is hexavalent chromium based compound, which is harmful to the environment and humans. This technology is getting replaced with green alternatives in many industries. The proposal is to identify, evaluate and qualify a suitable alternate to Chromic acid anodising, which can meet all our requirements in various service conditions of the Launch Vehicles.	
H3	**Sub Area**	**Materials Processing (VSSC)**
H3.1	**Generation Damage Models for Prediction of Defects during Metal Forming (VSSC)** The research area focuses on generation of damage models for prediction of defects during metal forming and integration with the commercial FEM packages like FORGE, ANSYS and ABAQUS. The materials of interest include Ti6Al4V, Inconel 718, Ti5Al2.5Sn ELI, CP-Ti and Monel K500. The work includes determining critical damage parameters for different damage models which can be used for prediction of defects and their validation. The range of strain rate to be considered is 1 to 200 s^{-1} which covers the velocity experienced by Hydraulic press, Mechanical press and Hammer. The output of the research will be validated damage models with critical values which be integrated with commercial FEM packages to predict the defects.	

H4	Sub Area	Welding and Joining (VSSC/IPRC)
H4.1	**Brazing of Alumina to Metals using Reactive Brazing Foils (VSSC)** Generally, a layer of Mo-Mn and Ni coatings are provided on the ceramic (Al2O3) substrate to enhance the wettability. Alternatively, active braze alloys (ABAs) can be used for metal-ceramic brazing easily by eliminating complicated metallization process. These ABAs contain reactive elements such as titanium, which activates or reacts with the surface of the ceramic base material facilitating good wetting. Metals to be joined with alumina are Kovar, copper, and molybdenum. Study involves selection and development of suitable ABAs and optimization of brazing process. Scope also includes development of new active braze alloy, vacuum brazing and extensive mechanical (as per AWS guidelines) and microstructure characterization of brazed joints. VSSC can extend vacuum brazing support.	
H4.2	**Physical and Mechanistic Modelling of Self-Reacting Friction Stir Welding Process (IPRC)** • Friction stir welding is an innovative solid-state welding process in which high quality welds joints are made using a rotating tool than plasticises the materials through friction and joins them through high forge force. A variation of friction stir welding called self-reacting friction stir welding process (SRFSW) window and tools have been developed by IPRC for AA2219 aluminium alloy at the coupon level. Self-reacting friction stir welding incorporates two opposing shoulders on the crown and root sides of the weld joint. This eliminates the need for a stout tooling structure to react the high weld forge force required in the typical friction stir weld process. Therefore, the self-reacting feature reduces tooling requirements and, therefore, process implementation costs. This makes the process attractive for aluminium alloy circumferential weld applications • To develop SR-FSW process and tools for aluminium circumferential welding • Development of a methodology for characterizing the tool/part interface in SR-FSW for improvement of predictive modeling in aluminum alloys	
H4.3	**High Entropy Alloys as High Temperature Oxidation Resistance Coating for Semi-Cryo Engines (IPRC)** The primary objective of this particular topic is to coat RHEA on the Semi-cryo engine component using APS technique to improve the overall efficiency, capability, high temperature oxidation resistance and service life of the system. To investigate the following types of high temperature oxidation resistant HEAs using CALPHAD (NiCoYHfSix, NiCoZrTaAlx, NiCoCeWAlx, NiCoNbBAlx, NiCoMoVAlx) to choose the suitable RHEA forcoating on Superalloy X750 or 718 substrates using APS technique.	

	To investigate the improvement in high temperature oxidation resistance at 540 m/s high velocity hot gas and thermal barrier capacity of HEA coatings. And Characterize the changes in phase, microstructure, mechanical properties, and temperature resistance of the deposited coating. To check the percentage of improvement in temperature and oxidation resistance of the substrates to counter failure.
H4.4	**Demonstration of GTA Welding in Martian Atmosphere (IPRC)** For expanding the capability of humans in outer space, researching and understanding the effects of different space environment on humans, structures and manufacturing process is mandatory. Mars colonization being the near futuristic goal, Titanium and Aluminium can be found and mined on Mars and can be used for building structures. This necessitates exploring the welding capabilities in Martian atmosphere. Arc welding being the cornerstone of manufacturing throughout the present century, portability and versatility of Gas Tungsten Arc welding (GTAW) will be necessary for repair and manufacturing components on Mars. **Phase 1:** Analysing the Martian and terrestrial gas effects without consideration for atmospheric pressure and gravitation effects. (i.e. at std. Temperature and pressure of Earth). **Phase 2:** Temperature and pressure of Martian atmosphere will be inducted in this phase. Variables and Parameters accounted for study • Materials considered for welding: AA2219-T87 and Ti-6Al-4V • Process variables considered: i. Phase 1: Flow rates of torch shielding gas (Argon) is varied (15lpm, 10lpm, 5lpm), CO_2 and terrestrial environments. ii. Phase 2: Flow rates of torch shielding gas (Argon) is varied (15lpm, 10lpm, 5lpm), CO_2 and terrestrial environments, Temperature (-63^0 C) and pressure (6.518 mbar) • Process constants considered: i. Phase I & II: Welding current ii. Welding position: 1G iii. Weld length: 150mm (min.) • Testing: i. D/W ratio measurement ii. 100% NDT (X Ray, UT, DPT) iii. Tensile test at room temperature and 77K iv. Micro hardness, Macro and micro structural analysis

H5	Sub Area	Materials Characterisation (VSSC)
H5.1	**Secondary Electron Measurement of Bn/Silica Composite for Electric Propulsion Application (VSSC)** Secondary electron emission characteristics of the discharge chamber wall material have a significant role in determining the plume characteristics and hence the thruster efficiency of stationary plasma thruster for electric propulsion. Measurements to quantify the secondary electron emission from BN/silica are very important to select the wall material. At present BN/silica composite is being used as wall material for ISRO's electric propulsion system. Understating the variation of secondary electron emission with varying the silica content of the composite will help to select the appropriate composition of the composite material as discharge chamber wall.	
H6	**Sub Area**	**Foundry Technology (VSSC)**
H6.1	**Design of Alloys for Powder Base Additive Manufacturing Processes (VSSC)** Powder base additive manufacturing processes involves high solidification rates. It can lead to design of new alloys which cannot be processed through conventional processes but can be processed through SLM/LENS process into a component. It can lead to development of component in alloys with exotic properties and significant weight saving. Under this project, few alloys can be selected for light weight, high strength, stiffness for light weight and high temperature capability.	
H6.2	**Solidification Behavior and Grain Refinement of Cast Superalloys (VSSC)** Superalloys are used for making many cast components used at turbine side of the turbo-pumps. Investment casting is the process used for making these components. Grain coarsening happens due to inherent slow cooling involved in the process. Suitable grain refinement techniques are needed to control the grain size for better fatigue and strength properties and weld ability. Detailed study is envisaged to understand the solidification behavior, homogenization parameters and ageing characteristics for the Ni-base and Ni-Fe base superalloys. The project deliverables would be optimized process parameters for grain refinement.	
H7	**Sub Area**	**Material development (LPSC)**
H7.1	**Development and Characterization of new Thermionic Material for Hollow Cathode of Electric Thruster which cannot easily get Poisoned (LPSC)** Hollow thermionic material is a critical element in the development of cathode for Electric Propulsion (EP). Cathodes are electron source for plasma generation and neutralization in EP thrusters. Thermionic material made of inorganic refractory material. i.e. Lanthanum hexa-Boride (LaB6) with work function of about 2.6eV emit electron as bulk material without any chemical reaction. Further, it is less sensitive to impurities and air exposure. LaB6 cathode has long life in thruster application because of low evaporation rate. At present this material is imported. evaluation.	

	Hence, indigenous development & characterisation of thermionic material for hollow cathode is required with well understanding of surface properties, emission characteristics, temperature profile etc. to operate the cathode for various thruster discharge currents. • Detailed material processing methodology • Data on material characterization such as work function, surface properties, mechanical properties etc. • Sufficient quantity (specified by LPSC) of developed thermionic material for evaluation	
H7.2	**Development of new Thermal Barrier Coating to reduce Heat Flux in Semi Cryogenic Engine Thrust Chamber (LPSC)** Thermal barrier coating (TBC) for Semi-cryogenic thrust chamber is mandatory requirement to bring down the coolant channel temperature below the coking limit of the coolant (fuel). Heat flux to thrust chamber material (copper alloy) can be minimized by TBC .TBC can be any material which has got conductivity less than chamber material (copper alloy). The base material for trials will be provided by LPSC. Expected Deliverables: TBC technology on copper alloy substrate to control the temperature to below 1100 ^{o} C.	
H7.3	**Development of Coating Materials used in High Temperature Environment (LPSC)** New materials are being studied for their suitability to replace expensive Niobium alloy (C103) for satellite thrusters. The potential material includes Tantalum and Molybdenum based alloys. This proposal envisages the development of oxidation protection coating which is needed for refractory alloys operating at 1500 oC. The base material and thruster for trials will be provided by LPSC. Expected Deliverables: Coating technology and demonstration on satellite thruster.	
H7.4	**Physical Property Measurement at Low Temperature up to 20K (LPSC)** Physical properties like thermal conductivity, coefficient of thermal expansion/ contraction measurement are mandatory requirement for all cryogenic engine and stage materials used up to minus 253 C. The materials include AISI 321, AISI 202, ASIS 316L, 12-10PH, 15-5 WPH, AA2219, AA2195, CuCrZrTi, Inconel 625 and Inconel 718. Expected Deliverables: Database on physical properties of above materials from RT to minus 253˚C.	
I	**Area**	**Transducers and Sensors (LPSC)**
I1	**Design and Development of Piezo Electric Sensing Element for High Temperature Dynamic Pressure Measurement (LPSC)** Presently, imported Piezoelectric based dynamic pressure sensor is used for the measurement of fast varying pressures of non-aggressive liquids & gaseous media in terms of electrical signal for liquid propulsion engine performance analysis. The aim	

	of the project is to develop dynamic pressure sensor based on Piezo electric material for sensing the fast varying sensing media pressure. This sensing element shall have a sensitivity of approximately 10millivolt/bar with a frequency response of minimum 5KHz & temperature stability in the range of 20oC to 500oC. The proposal envisages the following: • Selection and fabrication of high sensitivity piezo electric material for pressure sensing for dynamic range of 5 KHz or better • Deposition/bonding of the developed piezoelectric material to mechanical sensing element/diaphragm & providing lead wires from the sensor for electrical contact • Demonstration of functionality of the sensing element in high temperature environment Expected Deliverables are: 10nos. of sensing elements with characterization test results.
12	**Development of a Quantity Sensing System and Cryo Compatible Electrical Heater for a Cryogenic Super Critical Storage Vessel (Hydrogen & Oxygen) in Space Environment (LPSC)** A quantity sensing system and cryo compatible electrical heater for a super critical storage system for Hydrogen and Oxygen is to be developed. The container will be spherical in shape with approximately 1m inside diameter. The storage pressure will be higher than 1.3 MPa for LH2 & 5.1MPa for LOX. Pressure inside the container shall be maintained above critical pressure using electrical heaters. A cryo compatible electrical heater and an accurate quantity sensing system for cryogenic fluids have to be developed. The sensor system should be able to give dependable results in the following scenario. At ground in the loading condition with the liquid in saturated condition. During operation in space environment with the fluid in super critical phase in varying temperature conditions. The tank pressure will be above critical values. Based on the feasibility, independent proposals can be submitted for quantity sensing system and electrical heater. A capacitance or RF based system is preferred over temperature and pressure-based measurements considering both the operating regimes and preferably single system for different regime. Expected Deliverables are: 1. Detailed design, documentation and test results of the sensor / heater system. 2. Working prototype (non-flight) including sensor / Heater

J	Area	Launch Vehicle Tracking System, Range Operation and Safety Engineering (SDSC SHAR)
J1	Sub Area	Ground Safety (SDSC SHAR)
J1.1	**Study on Radiant Heat Flux from Propellant Fires and its Effects (SDSC SHAR)** Estimation of Heat flux around the propellant burning areas through experimental setup can be used for validating our theoretical estimation, thereby it provides input for ensuring the adequacy of protection to working personnel and systems.	
J1.2	**Design of Fire Alarm and Detection System for High Bays based on Smoke Modelling (SDSC SHAR)** To design optimal and effective Fire Alarm detection systems for High rise and high bay based on smoke modelling. Also to optimize the location of the sensors and detection mechanisms for a faster detection.	
J1.3	**Risk Analysis for Liquid Propellant Storage Facilities (SDSC SHAR)** The Siting of Liquid propellant storage facilities are based on the quantity distance criteria, fire ball diameter calculations etc., considering the worst-case scenario. Risk analysis studies can be used for estimating the risk levels of the liquid propellant storage and handling in bulk as well as the adequacy of safety system and its protection levels.	
J1.4	**Smoke Extractor System for Solid Motors Exhaust Gas during Testing (SDSC SHAR)** As a part of qualification trials for the solid motor testing of Agni motors have increased manifolds. Solid motors exhaust gases contain traces of toxic Products like HCl gas, Al2O3 and CO. In order to protect the environment and working personnel from these exposures, it is proposed to have a smoke extractor system for safe collection of exhaust gases for disposal.	
J1.5	**Experimental Studies on Dispersion of Solid Rocket Motor Exhaust Gases (SDSC SHAR)** The Exhaust gases dispersion studies can be used for understanding the behavior of gas dispersion. Based on which static testing of solid motors safety criteria's can be evolved with aim to prevent the dispersion of exhaust gases towards land mass. Also to protect the public /operational personnel from toxic gases as well as to protect the flora and fauna at Sriharikota.	
J1.6	**Experimental Studies on Oxygen Deficiency Environments due to Accidental Spillage or Release of Toxic Gases (SDSC SHAR)** The Box model sub-scale gases dispersion studies can be used for understanding the behavior of toxic gas dispersion. This can be used for estimating the concentration levels at various elevations and distances etc. Also to optimize the location of the sensors and detection mechanisms for a faster detection.	

J1.7	**Experimental Studies on Liquid Propellant Dispersion due to Accidental Release or Spillages (SDSC SHAR)** The Exhaust gases dispersion studies can be used for understanding the behaviour of gas dispersion. Based on which safety criteria's can be evolved with aim to estimate the toxic corridors and pollution levels form the source of leak. Also to optimize the location of the sensors for a faster response and for initiating the safing actions at a faster detection.	
J2	**Sub Area**	**Solid Motor Performance & Environmental Test Facility (SDSC SHAR)**
J2.1	**Developing a Jet Noise Source Localisation Technique using a Microphone Array with Appropriate Beam Forming Algorithms (SDSC SHAR)** Locating the jet noise sources in the lift-off scenario of a launch vehicle will benefit highly in the suppression of the noise sources. Present method proposes to use an array of microphones and employ suitable algorithm and develop a code to locate the noise sources.	
J2.2	**Modelling and Evaluation of Damping in Threaded Joints of Load Cells and its Impact on Measuring Dynamic Force Components (SDSC SHAR)** During static test, the thrust load transfer is through threaded joints. The thread damping is important with respect to the dynamic thrust measurement. The objective is to model and experimentally evaluate the threaded joint damping for unsteady load transfer.	
K	**Area**	**Aerospace Manufacturing (LPSC)**
K1	**Sub Area**	**Non Destructive Evaluation (LPSC)**
K1.1	**LASER Ultrasonics for Titanium Alloy Electron Beam (EB) Weld Evaluation (LPSC)** Spacecraft propellant tanks are made of Titanium alloy (Ti6Al4V) through Electron Beam Welding route. The Electron beam welds of thickness 3-4mm are to be evaluated for porosity, cracks and Lack of Fusion (LOF). The present technique of conventional PAUT (Phased Array Ultrasonic Testing) is proposed to be replaced by LASER based ultrasound generation. The research shall be carried out on generation of ultrasound, optimizing the parameters in terms of power, pulse width etc. in order to achieve detectability of LOF of a/2c=0.1, a=0.5 & better and porosities of 0.3 mm or smaller. The technique shall be in-situ inside the EB chamber with or without vacuum and the set-up shall be portable to be able to move across EB machines. The change in properties of the test article in the ablation regime for ultrasound generation (if considered) shall also be studied. The deliverables at the end of research and study shall be (i) detailed technology and process in laser ultrasonics for Ti alloy EB weld evaluation (ii) LASER source, suitable interferometer and the processing systems.	

K2	Sub Area	Non Destructive Testing (NDT) (LPSC)
K2.1	**Detection and Quantification of De-bonds in the Dissimilar Metallic Interfaces of Explosive Bonded Plates orDiffusion Bonded Rings using Non-linear Ultrasonics (NLU) (LPSC)** Aluminium Alloy Stainless Steel Bi-Metallic Adapters (BMAs) are used for the joining between AA2219 propellant tanks to SS pipes & valves in launch vehicle stages. BMAs are realized through one of the following routes followed by machining, Explosive bonding of AA2219 T87 and ICSS-1218-321 with a sandwiched pure Aluminium interlayer in the butt configuration Diffusion bonding of AA2219 T87 and ICSS-1218-321 rings in lap configuration As the bond integrity of the dissimilar metal interface decides the quality of the final BMA, detection of de-bond/ discontinuity, if any, at the intermetallic interfaces is of paramount importance. The aim is to develop a Non-destructive Evaluation procedure using Non-linear Ultrasonics (NLU) for reliable detection of de-bonds in the dissimilar metallic interfaces in the butt and lap joints of the BMAs (i.e. SS to pure Al and AA2219 to pure Al composite butt joints in explosion bonded plates and; SS to AA2219 lap joints in diffusion bonded rings) with minimum area of 3.14mm2 (equivalent to 2mm Flat Bottom Hole) or lesser.	
K2.2	**Studies on Weldability of Additively Manufactured (AM) Inconel Alloys (IN718 and IN625) i.e. AM-AM & AM-Wrought Welding (LPSC)** Additive manufacturing (AM) has emerged as an effective manufacturing process for the production of complex shaped components in low volume. The research proposal is for the generation of data related to welding of AM-AM components and AM-wrought product, especially for high pressure and temperature application (650 oC). Data shall be generated with respect to TIG & EB welding of AM products with different heat treatment conditions. The effect of soundness and defects such as porosity on properties shall also be studied through microstructural evaluation. Expected Deliverables are: TIG & EB welding process parameters for welding AM-AM and AM-wrought of the following material • Inconel 718 • Inconel 625	
K2.3	**Strength, Fatigue/Fracture Properties and Micro Structural Characterization of Additively Manufactured (AM) AlSi10Mg (LPSC)** Additive manufacturing (AM) has emerged as an effective manufacturing process for the production of complex shaped components in low volume. The proposed research envisages evaluation of strength, fatigue and fracture properties of AlSi10Mg components realized through AM with different post processing conditions at room and cryo temperature especially for Semicryogenic, LOX-Methane turbo pump components	

	subjected to high pressure & dynamic loading. Detailed fatigue and fracture testing shall be carried out with microstructure and fractographic studies of the tested specimens. The effect of defects such as porosity on properties shall also be studied through microstructural evaluation. Expected Deliverables are: • The data base on Strength, fatigue and fracture properties characteristic of AlSi10Mg realized through AM at room and cryo temperatures
K2.4	**Development of Technology for Joining Dissimilar Metals through Additive Manufacturing (LPSC)** Additive manufacturing (AM) has emerged as an effective manufacturing process for the production of complex shaped components in low volume. The proposed research envisages development of technology for dissimilar metal joints like Titanium (Ti5Al2.5Sn) to Stainless steel(SS321), Titanium (Ti5Al2.5Sn) to Aluminium (AA2219), Aluminium (AA2219) to Stainless Steel (SS321)through additive manufacturing like DED, Cold spray, etc. The strength and leak tightness of the joints shall be evaluated. Expected Deliverables are: • Technology development for joining dissimilar metal
K2.5	**Fatigue and Fracture Properties of Additively Manufactured (AM) Inconel 718 and Ti-6Al-4V (LPSC)** The scope of proposed research is evaluation of fatigue (HCF) & fracture properties of Inconel 718 superalloy and Ti-6Al-4V Titanium alloy manufactured through AM route. Additively manufactured components display wide variations in mechanical properties with build direction & this aspect has special significance with respect to fatigue and fracture properties, especially for turbo pump components subjected to high pressure & dynamic loading. The scope of project shall cover the following aspects: • Evaluation of fatigue & fracture properties of Inconel 718 in i. 3D printed + ST ii. 3D printed + HIP + ST iii. 3D printed + STA iv. 3D printed + HIP + STA • Evaluation of fatigue & fracture properties of Inconel Ti-6Al-4V in i. 3D printed + Annealed ii. 3D printed + HIP + Annealed iii. 3D printed + STA iv. 3D printed + HIP + STA • Manufacture of AM blanks & specimens (as per relevant ASTM/AMS standards) and carrying out all necessary tests

	• All tests shall be carried out in build direction, perpendicular to build direction & inclined direction • Minimum 10 sets of data shall be generated for each combination of direction & material condition • A comparative study of AM & wrought products shall be made w.r.t fatigue & fracture properties Expected Deliverables are: A data base on fatigue & fracture properties of Inconel 718 superalloy and Ti-6Al-4V Titanium alloy manufactured through AM route. This database would aid designers in design & analysis of components manufactured through AM, especially those experiencing dynamic loads & high pressures.
K2.6	**Formability Studies on Friction Stir Welded (FSW) Blanks of C103 Nb Alloy (LPSC)** Niobium alloy C-103 (Nb-10Hf-1Ti) is one of the structural refractory alloys widely used for high temperature aerospace propulsion applications, owing to its high melting point (2350°C), creep resistance and lowest density among refractory alloy family. The major applications include realization of divergent portion of upper stage liquid engine of launch vehicle and satellite thrusters used in Attitude Orbiter Control Systems (AOCS). The divergent portion of liquid engines are realised through flow forming process from larger sheet of C-103 Sheet. However, realizations of larger size sheet have strategic challenges and increased cost. The objective of present proposal is to explore the possibility of carrying out forming/spinning of welded (FSW) blanks of C-103 Sheet. • Optimization of Friction Stir Welding (FSW) parameters for welding of C-103 sheets • Microstructural and Mechanical Characterization of FS welded C-103 material • Effect of post weld annealing on microstructural and mechanical property • Evaluation of Formability parameters of FSW C-103 blanks • Demonstration of formability/ spinning on FS welded C-103 blanks towards realization of subscale nozzle divergent Expected Deliverables are: • Optimised FSW parameter for the welding of C-103 sheet to achieve more than 95 % weld efficiency • Estimation of forming/spinning capability of FS welded C-103 sheet towards realisation of subscale nozzle divergent
K2.7	**Forming Limiting Diagram (FLD) Generation and Optimization of Cold forming of KC20WN Cobalt Based Super Alloy for Rocket Nozzle Divergent (LPSC)** Presently developmental PS4 divergent with KC20WN material is realised through spinning and welding route in two half and joined together. The present proposal is study the spinning/flow forming of KC20WN to optimise the processing parameters and heat treatments towards realisation of divergent without cir-seam weld configuration.

	The scope of works includes. • Optimisation of spinning/flow forming parameter for KC20WN material towards realisation of nozzle divergent • Detailed Microstructural and Mechanical characterisation of spun /flow formed KC20WN • Optimisation of associated Heat treatment process
K2.8	**Thermodynamic Modelling of Phases present in Non-standard Materials (Stainless Steel, Copper and Nickel Based Superalloys) used in Liquid Rocket Engine Materials (LPSC)** A quantitative understanding of phase equilibrium of a material, with respect to temperature and composition, is a pre-requisite for the development of structure-property correlations & optimizing manufacturing & heat treatment operations. This information represented graphically in phase diagrams, are available for most of the standard alloys. However, majority of the alloys used for cryogenic & semi-cryogenic programmes are non-standard ones of Russian origin and phase diagrams are not available in open literature. Hence there exists a serious need for generation of phase related data with respect to temperature and composition (within specification limits). The scope of present work is generation of phase related data with respect to temperature and composition employing THERMOCALC software Validation of the phases predicted by THERMOCALC software though experimental verification on material employing advanced characterisation techniques such as SEM/EDS, XRD, TEM and APT. The generated data would be able to accurately predict the phases present in a material at a particular temperature & chemical composition. Expected Deliverables are: A data base on phases present in non-standard alloys (stainless steels, Copper alloys and Ni base super alloys, totally-15 grades) used in liquid engine applications at a particular temperature & chemical composition. This would definitely aid in the development of structure-property correlations & optimising manufacturing & heat treatment operations.
K2.9	**Effect of Manufacturing Operations on the Microstructure and Mechanical Properties of Non-standard Liquid Engine Materials under Simulated Conditions (LPSC)** The proposed research envisages evaluation of changes in microstructure & properties of the 03X12H10MTP PH stainless steel, 06X15H6MBФБ-w stainless steel, Cu-Cr-Zr-Ti copper alloys materials due to manufacturing operations through simulative tests. The simulative test parameters shall be chosen to accurately simulate the thermal & mechanical loads due to sequence of manufacturing operations for various sub-systems.

	Expected Deliverables are: A data base on structure-property correlations and its variations due to various manufacturing operations. This data would definitely aid in optimizing manufacturing sequence, heat treatment operations and would aid designers in analysis of sub-systems and assembly.	
L	**Area**	**Mechanical Design & Analysis (LPSC)**
L1	**Sub Area**	**Fracture studies of aerospace materials (LPSC)**
L1.1	**Crack Growth Studies in Propellant Tanks through Experiments & Theoretical Modeling (LPSC)** This study plans to address the fracture behavior of Aluminum and Titanium alloys materials used in propellant tanks of liquid rocket stages. The behavior of these materials containing part through cracks under tensile stresses is to be explored at ambient and cryo temperatures through tests and simulations.	
L1.2	**Machine Learning Based Approach for Accelerating the Structural Assessment of Propellant Tank in the presence of Non-conformances (LPSC)** Propellant tanks in launch vehicles are fabricated by joining different parts through welding. Commonly observed weld defects are pores, GBPM (grind below parent metal), weld collapse, mismatch etc. Presently dedicated finite element models are made to assess the structural integrity of tanks in the presence of non-conformances or snags. However, creating FEA models with actual snag modelled, usually take long computing times. It is envisaged to develop a Machine learning based approach for accelerating the structural assessment of propellant tanks without having to model the snag explicitly. This work is proposed for second stage earth storable propellant tank of PSLV. Configuration of propellant tank is cylindrical shell with tori-spherical end domes at both ends. LPSC will provide details of the usual non-conformances observed in propellant tanks, elasto plastic material properties, methodology used to model and assess the snag from finite element results. The deliverables shall include a software which can take the dimensions, location of the non-conformances, external loads etc as an input and then predict the elasto-plastic stress and strain field in and around the defect location across the thickness (with less than 3% error) and conclude on the acceptability of the snag. Usages of simple statistical models are not entertained, multiple deep learning algorithms shall be used and the algorithm with minimum error shall be chosen. Once developed and validated, the code will bring down the computational time and enable the designers to provide prompt feedback to the fabricator. This code will be used as a tool for checking flight worthiness of propellant tanks. Expected Deliverables are: The deliverables shall include software which can take the dimensions, location of the non-conformances, external loads etc as an input and then predict the elasto-plastic stress and strain field in and around the defect location and conclude on the acceptability of the snag.	

M	Area	Advanced Inertial Systems (IISU)
M1	**Sub Area**	**Launch Vehicle Inertial System (IISU)**
M1.1		**Neuromorphic Sensing and Computing System (IISU)** Neuromorphic Sensing and Computing System comes under the class of Brain Inspired Artificial Intelligence (BI-AI) which has excellent advantages compared to conventional sensors and existing AI/ML computing systems with respect to Size, Power, Speed of Operation, Robustness, Tolerance to extreme environments etc. For Ex: a Dynamic Vision Sensor (DVS) which is a Neuromorphic image sensor can deliver a frame rate equivalent of 10,000 FPS with a typical data speed of 1 Mbps at a latency of 1us and power of 50mW. The Neuromorphic computing system also has high processing capability at power in the range of few milliwatts (eg. IBM TrueNorth, Intel Loihietc). Moreover, the Neuromorphic computers are typically realized using non-CMOS process which are inherently radiation and high temperature tolerant which makes them ideal for space applications. Sensor Development: Currently very few manufacturers around the world manufacture DVS but none specifically for space applications in challenging environments like temperature and radiation. It is the primary objective of the proposal to; • Evaluate an off the shelf state of the art event sensor and ruggedize it for space applications • Design and realize an indigenous DVS targeting space radiation (100KRad, 60 MeV-cm^2/mg) and temperature (-40degC to +125degC) constraints • Identify the space qualified optics and mounts required for the specific applications Dataset generation: • Required space application relevant datasets corresponding to DVS sensors shall be generated Software development: • Design and develop algorithms/software for DVS processing like Spiking Neural Networks (SNN) etc. Neuromorphic Computing Framework: • Design and development of Spiking processor or Neuromorphic processor Design of software tools including compilers and other development environments targeting Neuromorphic processor.
M1.2		**3D Ranging-System on Chip (3DR-SoC) (IISU)** 3D Ranging Information is required in relative navigation applications for 3D geometry reconstruction, DEM generation and collision detection. Commercially available sensor modules are large in volume, size and power. This advanced R&D aims to explore and realize a System on Chip solution for critical technologies of 3D Ranging sensor in a power efficient configuration. On chip laser beam

	steering, Silicon detector design and ToF electronics as single chip (MCM) solution. MCM along with Laser pulse conditioning electronics, Timing Control electronics and Point Cloud Generation electronics with thermal conditioning as single footprint system. To develop Multichip module (MCM); • SPAD detector-based pixel • On-chip Beam steering as photonic IC • Time-of-Flight (ToF) processing as Silicon IC To develop electronics with; • Laser Drive module with pulse conditioning circuits • Timing control to synchronize beam steering angle, Laser pulse generation and output generation • Point Cloud generation from ToF output, and System interface
M1.3	**Development of Ultrasonic Motors for Special Applications (IISU)** Design and Development of Linear Ultrasonic motor (LUSM) for Path Length control of ISRO LASER GYRO. USM has advantage of better electromagnetic compatibility, quick response, Low noise, high torque density at low speed, direct drive without speed reduction gears. This LUSM can be used as Path Length control of ISRO LASER GYRO. The USM consumes less power, with this overall ILG sensor power can be reduced by 60%.
M1.4	**Fiber Optic Sensors for LV Applications (IISU)** Fiber Bragg Grating sensor array and its readout electronics development for different physical measurements like tactile, strain, temperature and displacement. To design and realized arrayed FBG sensor with interrogator electronics for tactile measurement.
M1.5	**Videometer BASED NS for Autonomous Rendezvous and Docking (IISU)** The Scope involves development of a fully autonomous vision navigation system for doing relative navigation. A set of retro reflectors mounted on the target at specified coordinates form a three dimensional target pattern which will be imaged using camera kept at the chaser vehicle. The camera detects the reflected signal. The onboard processor in the chaser process the detector output and the image processing algorithms resident in the processor analyzes the imagery to identify the corner reflectors and to derive the current state vector. The relative navigation and attitude state variables are estimated using a state observer and suitable filtering algorithms. • Develop relative navigation concept for use in future missions like landing missions, in final docking phase (<500m range) of autonomous rendezvous docking process, in stage recovery experiment, etc. • Identify the technologies involved and define suitable configuration of sensors, reflector pattern, camera and various elements of the system • Design of image processing algorithms, state observer and filter algorithms to estimate the relative state vectors (position, velocity, attitude and angular rates)

	• Development and realization of the system elements and integration of the system • Develop the test methodology and test system required to demonstrate performance • Performance demonstration & qualification of the developed system
M1.6	**Advanced NavIC Receiver with Anti Spoofing and Anti-jamming Capabilities (IISU)** • GNSS receivers operate at very low received signal power levels, buried inside the ambient thermal noise • Such signals can be jammed either by an intentional noise source or unintentionally by harmonics of different radiating sources (Jamming). A clever RF source can mimic the GNSS signals and can make the conventional receiver to generate wrong navigation solution also (Spoofing) • The proposed anti jamming/anti spoofing system makes the GNSS receiver system immune to such interference signals and ensures solution availability even in the presence of intentional / unintentional signal jammers • To design, develop and realize Advanced NavIC Receiver with anti-jamming and anti-spoofing capabilities.
M1.7	**Maglev LVAD Controller and Motor Drive (IISU)** It is aimed to develop a motor, levitation hardware, system controller & miniature motor drive for IIIrd generation magnetically levitated LVAD (Left Ventricular Assist Device). It involves development of; • Development of electro mechanical hardware • Control electronics for two axis actively controlled magnetic bearing for LVAD Storage, transfer and real time monitoring of health parameters • Spin Off of space Technology for societal use
M1.8	**Micro Mount Vibration Isolators (IISU)** Vibration levels for small spacecrafts and small launch vehicle are observed to be higher than bigger ones, due to its lesser mass. Also the use of COTS or Equivalent components in PC cards makes it venerable to vibration environments. Isolators are being used in all sensor package of Launch Vehicle and Spacecraft packages. However they are bulky and cannot be used with PC cards without changing the configuration of existing designs. Thus a micromount isolator is planned with standards interfaces so that all PC cards can be effectively vibration isolated. One foreign source available manufactures only in select capacities, which at most times Warrants the selection of a higher capacity isolator than the one needed and changing the existing designs interface to a non- standards one, resulting in a less efficient design. The development and realization of micromount isolators of typical capacities and quality required for PC cards used in IISU systems in different configurations lending better adaptability, flexibility and efficiency in designs.

HUMAN SPACE PROGRAMME

A	Area	Human Engineering Systems in Space Flight (HSFC)
A1	Sub Area	Musculoskeletal Modelling (HSFC)
A1.1	**Strength Assessment with Human Musculoskeletal Modelling (HSFC)** Musculoskeletal modelling of crew and strength assessment to perform tasks in space needs to be done by optimizing the position of various packages and restraints inside the Crew Module to reduce the muscle stress while performing an activity during various mission phases. Joint forces and range of motion of joints of subjects with or without the crew flight suit (Pressurized and Unpressurised) conditions needs to be assessed. Long term studies to include counter measures and exercises to be performed in space to overcome muscle strength loss needs to be carried out. Injury assessment during impact loading for crew attenuation system design needs to be done through generation of human injury criteria for dynamic loads.	
A2	Sub Area	Artificial Intelligence and Neural Networks (HSFC)
A2.1	**Remaining Useful Life (RUL) Prediction of Dynamic Systems using Time Series Analysis (HSFC)** The objective is to predict the remaining operation cycles available to deploy maintenance operations for a dynamic system subjected to stress . The methodology can be extended to ISRO Launch vehicle engines, ground systems and manufacturing plants for predictive maintenance. The accuracy of the model in real life scenarios depends on the fidelity of the simulation data provided for training. NASA has released a dataset of 16 sensor data comprising run-to-failure simulations for the turbo engine RUL prediction problem that is taken as baseline. The implementation of (Long Short-Term-Memory) networks is a novel development in this problem. Extensive knowledge in the domain of Machine Learning, Deep Learning and Recurrent Neural Networks are required.	
A2.2	**Design and Development of Bot–A Digital Companion for Manned Missions for Crew Assistance, Support and Onboard Operations (HSFC)** The work involves hardware design of autonomous bot with facial expression, cameras, speaker and other sophisticated hardware for crew assistance. Deep learning-based speech recognition system, emotion processing system and facial recognition needs to be developed. Provision shall be there for communication with the Crew during the mission, provide support, log crew information as well as other on-board data. Addition of reinforcement learning algorithm for bot to continuously learn from mistakes onboard needs to be implemented. A decision algorithm to provide autonomy to bot for experiment on-board and a software	

	module which can be integrated into a high-performance hardware needs to be developed. Hardware shall be developed on a DSP processor-based system. A Wireless communication system shall also be developed for intra-spacecraft communication internal to crew module for high mobility and reduction in unnecessary harness.	
A3	**Sub Area**	**Crew Health Monitoring System (HSFC)**
A3.1	**Development of Integrated Crew Health Monitoring System (HSFC)** A Crew health monitoring system with required sensors and measurements shall be developed for the assessment of Crew health as well as cognitive load during the mission. A Machine Learning based pattern recognition algorithm to predict anomalies in crew health (using ECG, Heart Rate, Respiratory Rate, SpO2 and skin temperature parameters) shall be devised and optimised for implementation in the on-board system. The work involves Identification of sensors for health monitoring, qualification and characterization of sensors and development of Interface electronics with on-board avionics and telemetry systems. Medical domain experts shall be involved in validation of the proposed algorithm.	
B	**Area**	**Human Spaceflight - Mission Aspects (HSFC)**
B1	**Sub Area**	**Micro Meteoroid and Orbital Debris Shield (HSFC)**
B1.1	**Development of MMOD Shields for Human Spaceflight Modules (HSFC)** Characteristic Ballistic Limit Equation (BLE) data base for all material and composition of structural elements in ISRO human spaceflight modules needs to be generated. Co-efficient for constitutive model and equation of state used in Hydrocode analysis for composite materials shall be derived. Design and Fabrication of shielding samples meeting facility constraints for testing in Hyper Velocity Impact facility and data assessment shall be done and a suitable metric for Probability of No penetration for different critical elements of the space craft shall be arrived.	
B1.2	**Development of MMOD Impact Detection Sensor (HSFC)** The Impact Detection Sensor shall detect in-situ MMOD impacts (while in orbit) and the same data shall be transmitted back to ground data recorders. The Sensor should be capable of detecting impact instance and keeping a count, determining the location, size, velocity and angle of the impact. The work involved includes identifying and developing different impact detection sensors based on resistive grid or acoustic sensors or a combination of both, developing a flexible PCB (included in the design of Resistive Grid Detector) to cover various surface profiles of spacecraft, developing impact detector capable of handling all of the possible environmental loads (both launch and on-orbit loads), realising a setup to appropriately measure the instance, location, size, velocity and angle of impact for an on-ground HVI test case (for performance evaluation) and developing a logic for high bit-rate data collection, interpretation and storage.	

B2	Sub Area	Crew Recovery- Rescue Beacons (HSFC)
B2.1	**Development of a Novel Crew Rescue & Locating Aid (CRLA) (HSFC)** The safe and timely recovery of crew is one of the most important aspect of a human space flight mission. One of the most critical aspect of recovery is to locate the Crew module/crew. Major Technology Elements to be developed include systems for Tracking and ranging, GPS beacon, Sea marker dye and Personal locating beacon. For sea recovery ships are deployed at a safe distance of nominal impact location. Once the GPS coordinates are obtained the ship sails towards the general direction of impact coordinates. Aircrafts/helicopters are used for locating the Crew module, as they have advantage of "birds' eye" view. To overcome the short comings of conventional practice, it is proposed to use "Rescue balloons" as locating aid for Crew and crew module. Development of an Inflatable "Rescue balloon with UHF Transmitter and LED blinker" as a locating aid for Crew Module and Crew is to be done.	
B3	Sub Area	Human Rated Software (HSFC)
B3.1	**Formal Methods' Enabled Software Development for Safety Critical Systems in Manned Missions (HSFC)** Formal methods and supporting tools are being increasingly used in commercial applications where safety-critical systems are being delivered. The formal method solution becomes feasible when each of the development phase can be accurately modelled. Defining formal specifications is the crucial step for successful realisation. For arriving at a formal specification, study needs to be initiated across similar systems realised for a mission/project and derive a superset of system specifications. Specifications is not limited to requirements, but includes the design as well. This is an area to be explored in the domain of human space missions, as more and more safety-critical softwares are to be delivered on-board. Modelling the design specifications shall be a challenge as technological changes need to be accounted for. Thus, it is envisioned that formal method approach shall be a continuous exercise aimed towards delivering reliable safety critical software. Efforts are to be directed to achieve this accurate modelling of the software requirements and design targeted towards a defined platform, from the project/mission requirements as the input. The modelling should consider aspects like: type of schedulers, timing margins, real time requirements, autonomy and automation requirements to name a few.	
C	Area	Environmental Control and Life Support System (HSFC)
C1	Sub Area	Cabin Pressure Control System (HSFC)
C1.1	**Development of Gas Sensor (HSFC)** For monitoring and control of crew cabin conditions, development and qualification of flight grade sensors needs to be carried out. Characterization of the sensor with materials to study the sensitivity of material to specific gases shall be done as part of the project.	

C2	Sub Area	Human Metabolic Simulator (HSFC)
C2.1	**Human Metabolic Simulator for Simulating Human Metabolism in Unmanned Missions (HSFC)** A simulator for simulating Human Metabolic Activity during unmanned mission, programmable for 1/2/3 crew at different metabolic rates to simulate exercise, sleep, etc in closed loop shall be developed. This system shall contain CO2 gas bottle, Humidifier, water bladder tank and oxygen concentrator. The system shall also have actuators and sensors for its functionality and a control unit. It shall have FPGA based drive system that controls the system operation based on its algorithm and should be capable of Humidity addition and oxygen removal in microgravity. It shall also have Carbon dioxide heater to prevent liquefaction as well as Compressor motor and drive electronics. The project involves Algorithm development for controlling various actuators with Digital PID based control in FPGA, DC/DC converters and power electronics designing.	
C3	Sub Area	Crew Hygiene Management System (HSFC)
C3.1	**Crew Hygiene Management System (HSFC)** A compact system shall be developed to collect and store human feces, urine and vomit in a short duration space flight. It involves development of waste collection systems for operations in microgravity, compact and efficient air blowers, Moisture absorption foam and Waste stabilization agents.	
D	Area	Crew Auxiliary Systems (HSFC)
D1	Sub Area	Crew Seat (HSFC)
D1.1	**Design, Development and Characterization of Efficient Energy Absorption System for Crew Seat Assembly (HSFC)** Design and development of high efficiency (higher stroke length) energy absorber (EA) technology for impact attenuation system of Crew seat assembly needs to be done. It involves Development of bi-directional Energy Absorber (EA) technology to attenuate impact loads during adverse landing and realisation, testing and qualification of different energy absorption systems designed. As part of the project, Analytical / FEA based assessment of attenuation loads and its validation through quasi static / dynamic testing and Configuration design of EA system to maximize the stroke efficiency shall be carried out.	
D1.2	**Design, Development & Characterization of Crew Seat for Human Spaceflight Mission (HSFC)** The project involves design of modular and ergonomic indigenous crew seat to provide adequate support to the crew during dynamic phases of the human spaceflight program, restraint system to provide appropriate support to the crew and Realization, testing and qualification of the developed crew seat. The work involves defining crew posture based	

	on crew anthropometry, ergonomics, and safety, Design of crew seat bucket to provide adequate support to crew, Design of strain hardening foam liner which does not undergo any dynamic amplification during impact landing, Design of 5-point support restraint harness which has single point locking/ unlocking provision, Development of the process for shaping the foam liner customized to crew's body contour and Development of a comprehensive qualification plan to qualify the developed crew seat.	
D1.3	**Design and Development of Indigenous Viewport (HSFC)** The project involves identifying the potential optical materials for Viewport panes, identifying and development of interfacing elements in Viewport, Qualification and testing of all the components of Viewport and Functional demonstration of Viewport as a system. It involves development of Optical Glass, Thermal Seal which can sustain high temperature upholding structural integrity and maintain compatibility with glass and Interfaces within Viewport and between Viewport and Crew Module.	
E	**Area**	**Human Spaceflight and Advanced Technology Area (SAC)**
E1	**Development of measurement systems and sensors for gas concentration (SAC)** Human Spaceflight requires continuous measurement of concentration of major air constituents (O_2, CO_2, CH_4, NH_3 & CO) and more than 200 trace gases including trace volatile organic compounds (VOC) at ppm to ppb levels, which are relevant to astronaut's health. These are by-products of metabolism/combustion/chemical reactions in the cabin. Measurement of these gases can be achieved by discrete sensors for each gas or by holistic techniques like spectrometry. Both approaches have their own advantages. Handheld measurement systems can use discrete sensors to build compact, light-weight and battery powered systems. Other techniques can be used to measure array of gases from the same sample. Indigenous development of compact and lightweight sensors and other systems using laser, chromatography, Fourier transform techniques etc have good potential for present and future applications in HSP.	
E2	**Development of mitigation techniques for Communication blackout during re-entry (SAC)** A spacecraft entering the Earth's atmosphere is enveloped by a plasma sheath which results in complete loss or a severe decrease in the strength of RF signals between the re-entry vehicle and the ground. This is referred as Communication Blackout. It results in loss of voice communications and data telemetry during the re-entry of manned space vehicles. The black-out duration can be up to 10-15 minutes and it occurs during the most crucial part of the vehicle's flight. It coincides with the maneuver phase and eliminates ground support during this vital portion of the re-entry phase. In case of an accident during re-entry, this phase is important for post accidental analysis. Due to its criticality, it is important to develop techniques to mitigate this problem. The theoretical	

	study and the analysis should be validated through the practical experiments. Practical experiments may be conducted in the suitable plasma environment to validate the following: • Dependence of EM wave attenuation on plasma profile • Dependence of EM wave attenuation on operating frequency w.r.t. plasma frequency In principle, the most obvious way in which the reentry communication blackout problem can be alleviated is by designing the communications system with a system margin greater than the plasma signal attenuation encountered during reentry. Typical plasma attenuation may exceed 100 dB, thus the required system margin is unrealistically large and cannot be achieved in practice. Hence, other alleviation techniques should be investigated which can be used in conjunction with the system margin. Worldwide many experiments have been done using following techniques to overcome communication blackout: • By avoiding attenuation region in plasma sheath: Higher Frequency method • By reducing concentration of electrons in plasma sheath: Aerodynamic shaping, Injection of coolants • By altering the properties of plasma to minimize its interaction with the electromagnetic waves: Magnetic Field Method Development of techniques to enable communication during this phase or to mitigate complete communication black-out can help existing and future missions of HSP. Experiments and finding that can aid to the understanding of phenomenon also can be seen as value addition.
E3	**Development of wireless communication systems (SAC)** Introduction of wireless networking enhances communication in the vicinity of a spacecraft and also facilitates many aspects of communication within a spacecraft including mobile crew monitoring and communication, environmental monitoring and control, structural monitoring, and situational awareness.Wireless system designs should also consider conditions of operational space environment. It is required to develop wireless systems that demonstrate reliable data transfer across avionics components, subsystems, and interfaces to simplify system integration, reconfiguration, and testing. Solutions that enable new avionic architectures and provide capabilities that expand mission performance while decreasing the Size, Weight, and Power consumption and cost of the resulting spacecraft are highly desirable. Applications include sensors communication within habitat volume, communication during Extra Vehicular Activities, video capturing of separation events etc.

E4	**Study of In-flight identification and quantification of species in water for long term space missions (SAC)** Long Duration Human Spaceflight requires continuous monitoring of water quality to ensure crew health and safety. Water monitoring equipment like colorimetric water quality monitoring kit (CWQMK) are already a part of the ISS. For our future space station and interplanetary travel requirements, it is important to initiate the developments of these systems. These instruments would have immense applications in future space station, interplanetary travel and other long duration space missions. Development of apparatus, test setups for experiments related to above subject, evaluation of data received from such experiments and development of mitigation techniques for observed ill effects can help in current and future missions of HSP.
E5	**Assessment of flame spread of large scale microgravity fire (SAC)** Materials with high flammability must be assessed for the flame spread rate using HEAT AND SMOKE RELEASE RATE TEST. Understanding nature of flame, process of combustion, rate of spread, mass consumption, quantity and rate of heat release etc can be taken up as study. Additionally, apparatus, test setups and identification of methodology, both on ground as well as in micro gravity also is needed to further the understanding of the subject.
E6	**Microbial monitoring in microgravity environment i.e Non- culture based in flight monitoring with species identification and quantification (SAC)** Microgravity can affect the growth and survival of microbes. The research on this topic is essential to achieve safe and healthy long duration space habitation. Non-culture based in-flight monitoring with identification and quantification of microbial species is targeted for the development. This research would help in understanding the relationship between humans and microbes, which may be affected hugely in microgravity. It will enable the understanding of how and where microbes proliferate in confined environment in space. Test setups and instrumentation required for remote observations can be developed to achieve the above mentioned purpose followed by findings and conclusions that may become input or directive for future missions.
E7	**Disinfection technique and technologies for microbial control of water systems and environment in microgravity (SAC)** Disinfection and de-contamination are highly essential to achieve safe and healthy long duration space habitation. ISS has a decontamination system which was designed with crew members' safety in mind by using high-power, ultraviolet, light-emitting diodes (UV LEDs) to sanitize surfaces. This cleaning process takes only a matter of minutes before and after the crew conducts the experiments. The sanitation process also removes

	airborne contaminants -- such as biological and chemical impurities -- and cleans up spills inside the glovebox, providing optimal accommodations for cell science and life science research. It also has an exchangeable glove system that was redesigned to be better suited for these types of studies. These disinfection systems based various technologies like the Ultraviolet Germicidal Irradiation (UVGI) method etc. are essential for long duration space missions/Space Stations for disinfection/removal of microorganisms. Other alternate techniques also can be developed which are safer and more efficient.
E8	**Application of AI and ML in Crewed Missions (SAC)** Currently, System controls are based on ground based command or crew inputs through button/switch controls which require specific user action. Warning systems are based on predefined criteria and thresholds. AI and ML are relatively in nascent phase as far as space systems are concerned. However, the potential of technique and its application in future cannot be ignored. Hence, exploring possibilities of AI and ML in HSP is encouraged with all potential applications. Some are listed below. • Voice based system commanding mechanism without restricting/requiring use of any limb action • An early warning system which learns from previous data to warn on possible occurrence of a hazard
E9	**Compact fire suppression systems for crewed missions for micro gravity applications (SAC)** On board fire in HSP is one of the most serious on-board hazards. Every HSP mission carries fire suppression system. FSS should be safe for humans, should be quick and efficient in dousing fire, should be clean and its application should be safe for onboard electronics. Fine water mist based FSS is in use onboard ISS now. Indigenous development of compact, portable, easy to use and safe FSS is needed for current and future HSP missions.
E10	**Next Generation Fire Detection Systems (SAC)** Fire is one of the most critical on-board hazard for any HSP mission. Detection fire is of paramount importance. Sensors must have very high sensitivity to variety of fire, flame and electric spark. At the same time, it should offer high immunity to false detection. Most mission experiences have reported early detection by humans through smell, rather than on-board sensors. Development of "Electronic Nose" which can detect very low concentrations of combustion products can help in early detection of fire. Fire is detected by measurement of concentration of specific gases, heat, temperature, flame etc. Novel approaches n detection, new parameters that can aid to detection of fire also is needed to enhance the fire detection scenario.

E11	**Display and other Situational Awareness Technologies (SAC)** Visual information (for situational awareness) is made available to the crew either through print pages or displays. A more effective method should allow crew to quickly access context based information. Development can be focused on fixed and portable display devices with higher efficiency (lower size, mass and power) and better human centric aspects, taking advantage of advancement in display panel technology like flexible films displays etc. Augmented reality based devices can be used to provide context based information to the crew for information such as visual alert, holographic communication and object information. AI and ML can be included in such systems to make them more efficient and effective.
E12	**Personalized Instrumentation for Astronauts (SAC)** Personalized instruments like wearable health monitors etc. are essential for all human spaceflight missions. Variety of sensors are flown with astronauts for monitoring of crew health parameters like Blood Pressure, Oxygen Saturation, Pulse Rate, Exhaled Breath Analysis etc. Wearable medical devices need to be developed for continuous monitoring and transmission of these parameters to ground. This is essential for both long term and short term missions. Apart from its on-board application, they are equally useful during training and simulation studies. These instruments would have immense applications in all kinds of human spaceflight missions for safe, reliable and continuous health monitoring of all crew.
E13	**Instrumentation for Docking (SAC)** Docking of spacecraft with space station or other manned modules for human or cargo transfer is an autonomous activity in most contemporary HSP missions. ISRO envisages development of these technologies to support automated or assisted docking while in orbit. Laser based or other types of ranging systems, camera based video systems, RF based systems are required for beacons, altimetry or distometry, velocimetry, optical flow techniques, close range photogrammetry and other parameters of situational awareness either in assist mode or in close loop mode for automated docking. Development of sensors, integrated systems and demonstration models can help in future docking missions of HSP.
E14	**Space Suit Related Instrumentation (SAC)** Space suit is an integral element of any HSP mission. Variety of sensors including health parameter monitoring systems are part of an integrated spacesuit. Personal communication systems, integrated display systems, tools for articulations during EVA (Extra Vehicular Activity) and other accessories helpful to accomplish routine and specific tasks of astronauts are needed to be developed for all HSP missions.

SATELLITE COMMUNICATIONS

<table>
<tr><th>A</th><th>Area</th><th>Controls & Digital Systems Area (URSC)</th></tr>
<tr><td>A1</td><td colspan="2">Predictive Maintenance for Remaining useful life (RUL) of S/C elements (URSC)

It estimates the optimum time to do maintenance by predicting time to failure of a Spacecraft elements. For complex system like satellites, we can't really risk running it to failure, as it will be extremely costly to repair highly damaged parts. But, more importantly, it's a safety issue. That's why to prevent failure before it occurs by performing regular checks on their equipment. One big challenge with preventive maintenance is determining when to do maintenance. Since we don't know when failure will occur, we have to be conservative in our planning, especially if you're operating safety-critical equipment. But by scheduling maintenance very early, we're wasting machine life that is still usable, and this adds to our costs. However, if you can predict when machine (part like actuators /sensors) failure will occur, we can schedule maintenance right before it. Predictive maintenance can estimate time to failure. It also pinpoints problems and helps us to identify what parts need to be fixed. This way, we can minimize downtime and maximize equipment lifetime.

Remaining useful life (RUL) (i.e. the length of time a machine is likely to operate before it requires repair or replacement.) By taking RUL, we can schedule maintenance, optimize operating efficiency, and avoid unplanned downtime.

The method used to calculate RUL depends on the kind of data available:
• Lifetime data indicating how long it took for similar machines to reach failure.
• Run-to-failure histories of machines similar to the one you want to diagnose.
• A known threshold value of a condition indicator that detects failure.</td></tr>
<tr><td>A2</td><td colspan="2">Development of the software Tool for Designing Rotor Blade of a Quadrotor Capable of Flying in Martian Atmospheric Regime Under Given Constraints of Atmospheric Flow Conditions, Size, Mass and Power (URSC)

• Develop full-fledged computer programme for solving the aerodynamics flow physics for a given airfoil section and subsequently 3-D wing for the rotor blade of a rotating wing air vehicle which can achieve the atmospheric powered flight in Mars.
• The software should be capable of providing the pressure profile and finally the Lift and Drag coefficients of given airfoil section. Incorporate an optimization strategy to modify a baseline airfoil shape profile and hence, results in a best optimal airfoil section given the constraints of flow conditions, size, mass and power.
• A comprehensive test plan should be provided which incorporates appropriate static and dynamics test cases needed to validate the airfoil and blade performance under the aforementioned conditions.</td></tr>
</table>

A3	**Reinforcement Learning for Spacecraft Control (URSC)** To develop a spacecraft attitude control system based on Reinforcement learning for linear as well as non-linear actuation. The agent should be trained using RL method to obtain an attitude control for a spacecraft with varying parameters in real-time. The software should be capable of performing the following tasks: • Real time estimation of physical parameters through RL method. • Based on the estimated parameter, policy formulation to achieve the best attitude control law.
A4	**Neural Network for System Identification Using Offline Data (URSC)** To develop an artificial Neural Network (ANN) for identification of non-linear dynamic systems. This can be used to establish high fidelity models of sensors and actuators based on enormous onboard data available.
A5	**Safe Controller Synthesis and Motion Planning of Autonomous Multi-agent System for Planetary Exploration in a Sample Collection-and-Return Mission (URSC)** Future planetary missions will consist of sample collection and return objective. For that purpose, multi-agent system can be deployed to explore a wide terrain of scientific interest. At first, the agents need to map the terrain in a distributed fashion for identifying the exact interest points and obstacles. After collecting the sample, they should plan individual trajectories to reach the source point by leveraging their collective knowledge about the terrain. During return, each agent utilizes a safe control architecture which follows the generated reference trajectory within an error bound and ensures the reach avoid specification i.e. avoid both obstacles (learned during exploration time) as well as other agents of the group. Moreover, the agents should be capable of planning and reconfiguring their individual trajectories in real-time under failure of any member of the swarm. The scope of this research work consists of development of algorithm for terrain mapping, motion planning as well as safe control law synthesis. This work should extend to planetary exploration using both terrestrial as well as aerial swarms. The final milestone of this work is to demonstrate the performance of the complete algorithm on an experimental test bed.
A6	**Realisation of Quadrupled Robots Along with its Guidance & Control, for an Interplanetary Mission (URSC)** The proposal is to materialise a Quadrupled robot, which will be used for exploration of rough terrains on interplanetary mission. Also, the problem statement is to come up with a feasible control strategy for motion control of a Quadrupled robot, which will be used for exploration of rough terrains on interplanetary mission. The guidance would suffice the requirement of motion planning of the quadruple

	from the initial location to the given final location. The design of the hardware should be designed under constraints of certain requirements like payload mass capability and max speed of the robot The scope of the project is to deliver a Quadrupled robot with appropriate control actuators. Also, an appropriate control and guidance strategy for motion control and motion planning of quadruple has to be delivered. Guidance will be responsible to provide the path to be taken by the robot, with prior knowledge about the obstacles (their location, size & shape). And the control is responsible to balance the robot, and decide the walking gait of the robot (on the basis of velocity requirement). The actuator constraints like max torque and max angular rates would be applied on the control and guidance scheme, to bring out the algorithm that can be implemented on the hardware.
A7	**Realisation of Highly Dexterous Pair of 7DOF Robotic Manipulator, Which Can be Controlled Remotely, and Function as a Humanoid Hand for Dexterous Operation in Space (URSC)** The proposal is to materialise a pair of highly dexterous humanoid hands that will placed on upper torso like structure, to mimic the dexterous operation that can be done by humans, in extreme conditions like space. The control of these arms would be done remotely for safety of the operator. The movement of the operator's hands should be translated to the movement of the humanoid hands in order to fulfil the operational goals. The hardware deliverable would be 2 dexterous robotic arms that are placed on a structure that mimics the human's torso and hand. Along with the realisation mechanical structure and appropriate actuators with certain torque capabilities, there would be another motion detection hardware at the operator end. It can be either vision-based, tactile-based, or certain wearable based hardware that will detect the motion of operator's hand and understand the kinematics. These motion data of operator's hand would be translated into motion of the humanoid hands. Then the control strategy would be responsible for carrying out the motion as commanded by the operator.
A8	**Development of Real Time Operating System (RTOS) Software (URSC)** Development of BSP and RTOS to support multi core systems based on RISC – V instruction set architecture. The RTOS software shall contain kernel, support for any application development. Some of the features of the RTOS software are: • Task/ CPU scheduling • interrupt handler • Exception handler

A9	• Inter process communication • Multicore task scheduling for effective time utilization. • Application Programming Interface (API) • Memory management • IO interfaces A standard BSP (Board Support Package) interface is required to be provided between all it's hardware (MilStd 1553B, UART, Space wire, CAN, I2C) and RTOS. CCSDS standard support. **Miniaturize ASIC Die Packaging Techniques to Handle Power Dissipation (Thermal Issues) at Temperatures as High as 150 deg C in Miniaturized Driver Devices (URSC)** MOSFET drivers to drive 1A at 42V dissipate power of the order of 1.6W due to RDS. It is required to package atleast 4 switches in one device. Advanced IC packaging for Spacecraft electronics are required to efficiently transfer heat of the order of 6W from ASIC wafer to package. This includes techniques for packaging the die, attaching the package to the PCB for efficient heat transfer with minimal additional mass, size and cost. Explore various packaging techniques to miniaturize driver circuits, metallic die attach materials, lead types to ensure integrity of the package at high temperatures, severe shock and vibration as encountered in Space Electronics. The packages have to be hermetically sealed.
A10	**Design and Development of Miniaturized HV Drivers, H-bridge, Switches Based on SiC/ GaN with Low Power Dissipation (URSC)** A large number of MOSFET drivers are used in spacecraft electronics to drive various coils, actuators etc. These provide HV (28-42/70/100V) drive @1-2A. Using components from HV ASIC libraries, the die size for the drivers can be minimized. However, Power dissipation for continuous operation of the devices is a concern with MOSFET drivers due to Rds. Alternate designs have to be realized to miniaturize the drivers.
A11	**Fault Tolerant Bio-Inspired Hardware Architecture (URSC)** The fault tolerant hardware architecture is to be proposed for control system design. The biology inspired architecture with self-repair is to be adopted for intra-planetary missions. In Micro Satellite, this architecture will replace the system level redundancy and TMR within FPGA, presently used in control system hardware design.
A12	**Study of AI Enable Reconfigurable Embedded Systems (URSC)** The reconfigurable embedded system design through AI-Evolutionary Computation (EC) technique. The Evolutionary Algorithm (EA)-based hardware reconfiguration is to be proposed. The circuit optimization and fault tolerance are the major objectives to be achieved by AI-EC.

A13	**Development of Cryptographic Techniques to Work Against Very High Computing Speeds (Thousands of Terraflop) (URSC)** Present advanced algorithms are considered to be quantum safe because the time considered for breaking the system with present computing speed (say tens of terraflop) is reasonably high, but with advancement in computing speed due to high end processors and Multicore processors/quantum computing, present algorithms cannot be quantum safe. Hence there is a requirement for corresponding advancement in cryptography also which can be quantum safe against hundreds of computers parallel working with thousands of terraflops of computing speed.
A14	**Development of Codes for CDMA Systems when Number of Users are in Thousands (URSC)** Present codes used in CDMA can support to up tens of users using the same frequency simultaneously depending on the length and type code. Since the Frequency crunch is exponentially increasing which in turn increases the number of users of using the same frequency simultaneously, there is a need for development of new codes (proprietary) to support simultaneous users beyond thousand in number.
A15	**Channel Coding for Megabit TC link (URSC)** When there is need to send huge data from ground to spacecraft in specific satellites say navigation satellites, Present channel coding schemes put a limit on uplink rate based on uplink power available. If you need to send Megabits bits of TC data (versus kilobits of present rate) with limited power available either from ground to satellite or through ISL, new channel coding techniques need to be evolved to enable the same.
A16	**Contact dynamics Mathematical Modelling for Robot Systems for Docking Demonstration Application (URSC)** The objective this proposal is to develop high fidelity dynamics mathematical modelling and simulation with high fidelity simulation system to enable docking behaviour under physical contact using force torque measurement. When a physical contact happens the contact force and moment generated by the docking hardware will be feedback to the satellite simulator to enable the motion equivalent to on-orbit satellites being simulated. In this respect, two ground robots are used to simulate satellite relative motion and shall respond to the HILS control command fast response based on contact. When reacting a physical contact during docking operation the robots at their tip shall dynamically behave like the on-orbit satellite being simulated. Space docking contact dynamics simulation and verification soft docking under various non-nominal conditions. Expected Outcome: Mathematical model for contact dynamics, contact force and torque measurement equipment. simulation software and hardware. Demonstration on robotic platform.

A17	**Vision Based Pose Estimation using AI/ML (URSC)** Estimation of Relative Position, Relative velocity, Relative attitude and Relative Attitude Rate and tumbling targets for non-cooperative targets. AI/ML techniques can be applied to estimate states and re-enforcement learning capability to be incorporated on real-time data. High accurate(2 mm in position, 0.3 mm/sec in velocity , 0.05 deg attitude, 0.01 deg/sec in rate) and with minimum computation time (< 500 ms) prime objective as there are limited resources on-board. Real time Pose estimation can be demonstrated with Mono/Stereo Camera/ LIDAR sensors capable from 30 m to 2m, Processor, AI algorithms and Navigation algorithm should be appropriately selected based on accuracy and speed of real time application. Expected Outcome: Vision based AI navigation algorithms, Mathematical models for relative dynamics and estimation.
A18	**Parachute Modelling and Strategies for Landing application (URSC)** High fidelity aerodynamic mathematical modelling and simulation for landing applications. The modelling should cover Stretching, reefing, disreefing dynamics. Strategies to be incorporated and interaction between pilot and main parachute. Demonstration of modelling aspects on experimental set up to be carried out.
A19	**High Speed Accelerators: Development for Software In Loop Simulation (SILS) (URSC)** The software simulator is a platform uses for carryout simulation which include mathematical models, estimators, NGC algorithms and logical and functional blocks on workstations. The verification and validation of NGC spacecraft advaned R&D Projects demands thousands of digital simulations (Monte Carlo simulations). Hence, it is required to have faster execution time which can be carried out with software accelerators and hardware accelerators for Software in loop simulation (SILS) platforms. This can be invoked through various techniques RHEL Linux based platforms, parallel processing and containers etc. However, in-order to accelerate further execution time improvement in single Work Station advanced techniques can be used, like linking emulator operation with ground software with GPU based accelerators. Essentially, this research work aims towards running the emulator (grmon based Leon emulator software) and other C++ applications on GPU systems to speed up the simulation operations. The objective of this project is high speed accelerators development for SILS for NGC applications targeting to carried out thousands of MC simulations quickly (less than a half day).
A20	**Real Time Anomaly Detection using AI/ML for Spacecraft NGC applications (URSC)** The research work aims at real time anomaly identification and its root cause using AI/ML techniques. For spacecraft, this is essential for detecting off-nominal situations and responding accordingly. The software should able to classify the parameters to identify

	the anomaly in real time. A distinction is made between point anomalies, contextual anomalies and collective anomalies. For autonomous systems and anomaly detection, however, a consistent storage of all mission data is essential to have a broad database for state estimation, pattern recognition and decision-making. Anomaly detection is performed on time-series data like temperature readings over time for detecting off-nominal situations and states, but also on multi-dimensional like images, mostly to detect science opportunities or filter the amount of data selected for downlink. Support Vector Machines (SVMs) present an other exploitable approach to anomaly detection. SVMs are a mathematical procedure for classification and regression that transforms its input data to higher dimensions under the assumption that the data becomes linearly separable by a hyperplane. The anomaly can be software or hardware, autonomous operations and recovery for NGC algorithms. The anomaly detection on vision navigation, RF navigation, and laser navigation main important applications. The Guidance and control anomalies and automation operation smooth activities.
A21	**Autonomous path planning Rover using AI/ML (URSC)** There is a need to have planetary exploration rover due to hazardous environment and risk element involved in sending human beings to any planet. The present rovers are having a semi-autonomous to conduct scientific experiments on the planetary surface. Future Rovers are typically used for exploring unknown and partially known terrains autonomously. Nowadays, with the constant evolution of Artificial Intelligence and Robotics, autonomy has become more perceptive than ever. This allows for the robots to perform tasks with a high degree of autonomy in varying circumstances. As the main purpose of autonomous rover is to traverse through perilous operating environments which are unknown or not fully known, an intelligent path generation, hazard detection, avoidance and safe reaching target under constraints. Conventional rover mission planning activities utilize simplified path planning and execution approaches tailored for localized operations to individual targets. Target paths are hand-selected on ground and executed by the rover's local obstacle detection and avoidance software. The path planning and execution tasks can be made more generic, resource-efficient and adaptable to dynamic environments by the aid of Artificial Intelligence (AI) techniques. The problem statement is to develop path planner for autonomously navigating an unknown or partially known terrain. The objective can be stated as the "building of AI techniques which will be used for the optimal path planning of a rover in an unknown terrain by identifying the hazards around it (boulders, obstacles), and, generating steering commands to move from its present location to a prescribed target location." Simultaneous localization and mapping (SLAM) can be employed for autonomously learning the map to aid the path planning.

<table>
<tr><td></td><td colspan="2">The autonomous NGC module for Rover will carry out path planning from source to destination with Digital Elevation Maps provided by on-board cameras for given destination coordinates provided by mission. Autonomous path panning should handle the constraints autonomously generated for same set of source/destination and each path will be characterized based on the following parameters 1) mobility type 2) solar panel string status 3) rover attitude 4) minimum distance from hazard points.

Various aspects of rover NGC for autonomous rover as follows. Path planning based on AI algorithm, taking into account different types of constraints like maximum roll, pitch angle. Added additional feature of path planning generating a path with ‘safe corridor’. This ensures even if there is dispersion from path due to slip, rover will be safe. Autonomous Rover mobility operation Generating wheel speed commands for rover mobility from source to destination. Autonomously study the Wheel –soil to estimate the slippage and appropriately configure the rover NGC. The inverse kinematic model are usedto study each joint angle variation, wheel velocity and wheel-terrain contact point trace variation during the rover traversing on an uneven terrain. The forward kinematic of rover are used to enabling movements in the directions, as well as yaw, roll and pitch rotations.</td></tr>
<tr><td>B</td><td>Area</td><td>Thermal Systems (URSC)</td></tr>
<tr><td>B1</td><td colspan="2">Thermal/ Plasma Spray Based Functional Coatings (URSC)

As thermal/ plasma spray coatings has the ability to coat high temperature ceramics as well as composites materials and the deposition yield is very high, this this technique can be utilized to develop several functional coatings (such as high emittance with high temperature resistant surface, high solar absorptance, corrosion resistance, erosion resistance, etc).Development Requirements:

• Development of Alumina-titanium ceramics, carbide, boride, super alloy, composites, etc., based coatings on flat and contour shaped metals and alloys such as Al6061/ 2024, SS304, Ti6Al4V, etc.
• To establish and develop the process development parameters.</td></tr>
<tr><td>B2</td><td colspan="2">Studies on Degradation of Thermo-Optical Properties by High Energy Particles, Atomic Oxygen And Uv Radiation on the Thermal Elements Used in Spacecraft (URSC)

The thermal materials used in spacecraft thermal control application is prone for degradation with respect to the thermo-optical properties due to harsh also exposure to UV. Also there is potential impact of atomic erosion and reaction with the exposed materials in low earth orbit satellites.</td></tr>
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	Development requirements: • To develop and establish suitable equipment/ system to measure and characterize coatings and materials for ATOX resistance, stability against UV radiation and particle radiation.
B3	**Development of Micro Heat Pipes for Space Application (URSC)** Micro heat pipes are potential devices for removal of hot spots from electronic chips with high heat flux densities and achieve better iso-thermalization. Microchannel etched on silicon wafers act as the fluid carrier and provide necessary capillary action. These devices are very much essential for thermal management of high flux electronic chips/ devices in future spacecraft. Development requirements: • Design, fabrication, charging, sealing and development of micro heat pipe for chip level electronics cooling. • Testing and thermal performance demonstration.
B4	**Thermal Properties of Solid Materials at High Temperatures and Extreme Environmental Conditions (URSC)** Thermal properties at high temperatures and in extreme environmental conditions are important input for the design and development of thermal control systems for missions (such as Venus, etc). To predict the thermal properties of solid materials at high temperatures and extreme environmental conditions, a combination o f computational framework based on nanoscale phonon and electron transport phenomena and experiments are envisaged. Development requirements: • Development of computational framework that can accurately estimate the properties of various solid materials at high temperatures and extreme environmental conditions. • Validation of the computational framework with experimental data.
B5	**Thermal Louvers for spacecraft Thermal Control (URSC)** Thermal louvers are active thermal control devices that have been used in various forms on numerous spacecraft. These louvers can reject heat as a function of temperature, thereby providing effective temperature control and minimizing heater power requirement for maintaining radiator temperature. A thermal louver generally has a framework with shutters, which islocated on the front of thermal radiator. These shutters can be mechanically actuated to provide a variable exposed area to the thermal radiator, depending on the temperature requirement.

	Mechanical actuation can be provided either by using a space grade BLDC motor or by using temperature dependent smart material. Development requirements: • The technology and the proof-of-concept hardware, for demonstrating the working principle of a mechanical actuation-based louver by using either a motor or smart material are to be developed. • The required test and characterization facilities are to be established.
B6	**Heat Switches for Spacecraft Temperature Control (URSC)** Heat switches (or thermal switches) are devices that switch between roles as good thermal conductors and good thermal insulators as and when required. Heat switches achieve their action by changing the thermal resistance between the source and the sink. This can be achieved by changing either the thermal resistance at interfaces or material thermal resistance of the heat switch itself. The main advantages include efficient thermal management of spacecraft packages with cyclic operation and reduction in parasitic heat load on payload detectors from redundant cooling systems. Development requirements: • The technology and the necessary hardware, for demonstrating the working principle of a heat switch are to be developed. • The required test and characterization facilities are to be established.
B7	**Thermal Conductivity Measurement Using Transient Methods for Paste/ Gel/ Powder (URSC)** A knowledge of thermal conductivity is essential for characterizing materials such as paste, powder and gel (thermal conductivity is less than about 25 W/mK). For such materials, thermal conductivity could be measured using single/ double sided transient plane source methods with a small sample size. Development Requirements: • Design, development and validation of computational and experimental framework for transient measurement methodology to determine thermal conductivity for grease, powders and gels (typically less than 25 W/mK) with a small sample size. • Method should give good measurement accuracy and repeatability.
B8	**Low Mass Pulse Tube Cryocooler (~3 Kg) Using Moving Magnet Compressor (URSC)** PTCs have been developed (~4.5 kg) at TSG using moving coil compressors and flight proven on GSAT-29 mission for a life of ~3 years of operation. To achieve improvement in performance and save on footprint and hence mass, cryocoolers utilising moving magnet compressors are envisaged for future applications. Development requirements: • The target specification is 0.7 to 1 W @ 70K with an input less than 50 W to the device. • The expander can be of in-line, U-tube or coaxial type.

B9	**Composite Regenerative Heat Exchanger for Pulse Tube Cryocooler (PTC) (URSC)** The performance of PTCs especially at cryogenic temperatures below 50K is largely dependent on the effectiveness of the heat exchangers used in the expander assembly. Homogenous heat exchangers utilising SS or Ph-Br screens are observed to have a drop in their heat capacity below 50K necessitating the use of composite heat exchangers utilising rare earth materials which exhibit non-homogenous high heat capacity characteristics especially at lower temperatures. Development requirements: • Design and development of composite heat exchanger using rare earth materials for the PTC at cryogenic temperatures below 50K.
B10	**Compact recuperative Heat Exchanger for J-T Cycle Cryocoolers (URSC)** J-T cryocoolers have been successfully developed to meet target specification of 1000 mW @ 100K wherein the heat exchanger used were of tube-in-tube type in multi-start pattern. To achieve reduction in mass there is the need of developing compact heat exchanger using 3D printed techniques with no loss in performance characteristics. Development requirements: • Design and development of compact recuperative type heat exchanger with reduced mass using 3D printed techniques for J-T cycle cryoccolers. • Design and development of composite heat exchanger using rare earth materials for the PTC at cryogenic temperatures below 50K.
B11	**Development of an Advanced Solver for Coupled Fluid Flow and Heat Transfer with Conduction, Radiation (Participative and Non-Participative) and Convection (URSC)** Spacecraft use various optical devices that consist of mirrors, lenses, prism, etc. New devices under design are often exposed to high intensity irradiation viz., mirrors in Coronagraph payload, corner-cube in spacecraft, Earth sensor, payloads in inter-planetary mission(during transfer orbit), etc. Development requirements: • Solver development to accurately estimate the temperature of various optical elements under harsh radiative and convective environment. • Radiative energy transport in participating medium needs to be established.
B12	**Development of Light Weight Engines for Spacecraft Application to Generate Power Using Waste Heat (URSC)** Development of high efficiency engines for space power generation using waste heat of nuclear sources is essential for inter-planetary missions beyond Mars, where sun intensity is very low to generate required power. Development requirements: • Study of suitable thermodynamic cycles such as Stirling, Brayton, Rankine, etc. for the system.

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<tr><td></td><td colspan="2">

- Thermo- fluid modelling of these systems
- Development and characterization of working fluids.
- System design, fabrication of proto-model, space qualification and performance demonstration.

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<tr><td>B13</td><td colspan="2">

Development of Liquid Droplet/ Sheet Radiator (URSC)

Liquid Droplet Radiator (LDR) utilizes electric or magnetic fields to control droplet trajectories of fluids such as silicone oils (FC75/DC705) for heat removal from electronics. Heat is absorbed from the heat source by the working fluid. The hot liquid then enters into a droplet generator that generates fine liquid droplets (size: 200-300 pm). These droplets reject heat to space and the cooled droplets are collected by a droplet collector. The collected liquid is circulated back using a pump. The concept of Liquid Sheet Radiator (LSR) is same as that of LDR, except that LSR uses thin liquid sheet (~100 pm) as radiating surface (through narrow slits). These can handle heat load sink.

Development requirements:

- Design and development of LDR/ LSR for space application
- Fabrication and testing of proto model of LDR/ LSR
- Space qualification and performance demonstration.

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<tr><td>C</td><td>Area</td><td>Structures (URSC/IISU)</td></tr>
<tr><td>C1</td><td colspan="2">

Studies of Sandwich Panel for Impact Loading (URSC)

Structural behaviour of sandwich panels under low velocity and hypervelocity impact is of interest in this work. In space applications, aluminum honeycomb cores are being generally used for developing sandwich panels. Honeycomb core's influence to resist external impact is negligible, mainly because of its open cell form. Of late, closed cell aluminum foams are also available. It is necessary to understand the capability of these cores in resisting impacts, especially for micro debris or meteoroid impacts. Different, modelling / simulation, development, characterization and tests are required to understand the behaviour.

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<tr><td>C2</td><td colspan="2">

Multi-scale Modelling of Structural Components (URSC)

Multi-scale modelling is a methodology in which multiple models at different scales are used simultaneously to describe a system. Conventional structural analysis considered homogenized material properties. However to account for heterogeneity, it is essential to develop analytical models to a scale lower than the conventional material characteristics estimation. Objective of the work is to develop analytical model for capturing heterogeneity and anisotropy in microscale. Conversion of micro scale to macro scale for incorporating as localized homogeneity. Algorithm to convert micro to macro material models. Software to map / transfer the localized property to conventional FE model. Finally, macro level results to be translated to micro level by means of localisation technique.

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C3	**Design and Development of Lattice Structures for Space Applications (URSC)** The lattice structure consists of helical and hoop ribs intersecting each other in a regular pattern. The ribs provide both membrane and bending stiffness of the structure. It is important that the ribs are made by continuous filament winding and have a unidirectional structure demonstrating high specific strength and stiffness. These advantages mostly relate to the unidirectional nature of the grids in a lattice and the one-step manufacturing process that allows for the integration of all the structural features in a single process, saving cost and time. Design and development of Tertiary and Secondary structural members will be carried out to gain confidence. Successful progress may lead to develop an efficient Primary Structure.
C4	**Development of Self-healing Composites (URSC)** Micro cracks, de-bonds, de-lamination in composites due to changes in environmental conditions or due to external forces like debris can be life limiting problem in space. Self-healing or autonomic healing is a way to address this problem which can effectively extend the life of structure with better structural integrity. A suitable self-healing method involving development of suitable materials and manufacturing techniques to be developed and demonstrated for satellite structural applications.
C5	**Development of Cnt Based Multifunctional Nano-Composite Laminates for Structural, Thermal And Electrical Applications (URSC)** To develop multifunctional nano-composite material for spacecraft structural applications. CNT based nano-composite improve thermal and electrical conductivity of composite material along with higher stiffness and strength. At present this is still a challenge to be realized for practical applications. The objective is to realize space grade composite prepregs with low density CNTs paving way for light weight prepregs with enhanced structural and thermal properties.
C6	**Structural Health Monitoring (SHM) of Spacecraft Structural Members (URSC)** To develop damage detection and quantification methods for typical damages in spacecraft structural members made of composite and or honeycomb sandwich. This includes damage to material and failure of sandwich embedment / structural joints, theoretical and experimental studies on damage detection using guided wave using PZT sensors / Fiber optic sensors and experimental demonstration of implementation of above methods on Spacecraft structural members with sensors, actuators and necessary acquisition, data processing and instrumentation.
C7	**Analytical Modeling Direct Field Acoustic Testing (DFAT) to estimate Acoustic and Structural Responses (URSC)** Spacecraft has a few sub-systems that are critical for acoustic loads and the design is primarily to withstand the loads. Those sub-systems needs to be qualified for the expected acoustic loads. The qualification can be performed in diffused acoustic field in a reverberation chamber or in direct acoustic field. The Direct Field Acoustic Testing is emerging technique in aerospace industries. This technique is handy, as the test setup

	is portable and there is a scope for response limiting for critical components. However achieving the required Sound Pressure Level (SPL) in direct field is a challenging task. The achievable SPL depends on the test setup like characteristics of Speakers, Sub-woofers & Horn, its position and arrangements and also the test specimen (spacecraft/sub-system) dimensions. Considering the test setup details, expected SPL at multiple locations for the initial test setup around the specimen needs to be estimated. The structural responses on the specimen for the test frequency range needs to be estimated and the results needs to be test correlated. Objective of the analytical model development is to predict the sound pressure levels around the test specimen and predict the structural responses at the test specimen/spacecraft sub-systems during DFAT.
C8	**SMART Materials Like Piezoelastic, Electrostrictive and Magnetostrictive Materials (URSC)** There are several applications in which the vibrations to be reduced. Development of active isolator is one of the aims. In some applications large actuating force needs to be applied. There are cases where the shape control need to be achieved. These can be achieved by employing the above materials in suitable manner. The collaboration is in working with such materials.
C9	**Inflated Structure for Space Application (URSC)** Recent Technological advantages have presented a new possibility to the space community with ultra light Inflatable structures. These can be used for solar sails, balloons, for large light weight antenna, space habitats etc. The term inflatable structure indicates that a compact configuration will be launched into space and then deployed by pressurization using a gas or other means to its full intended form. For some of the applications, rigidization of an inflatable structure is necessary whereby; following deployment via inflation, the structure is physically rigidized to the point where it will maintain its intended shape without reliance on continued pressurization and will be capable of taking load.
C10	**Development Theoretical Models for Prediction of Response to Acoustic Excitation (BEM, SEA) (URSC)** Estimation of responses to acoustic excitation at low frequencies are carried out using Boundary Element Method (BEM). For estimating the responses at higher order modes, Statistical energy Analysis (SEA) is used. Significant amount of work in this direction is already carried out. But there are still some differences between such predicted responses and the experimentally seen responses. Need to fill this gap.
C11	**Image Processing Techniques (Ultrasonics, Thermography, Speckle Interferometry) (URSC)** Composite and honeycomb sandwich panels are widely used in spacecraft. The quality is assessed through NDT techniques such as ultrasonics, thermography, and speckle

	interferometry. They are image based techniques. Some of the images need further processing to reveal the defects. The work is to develop image processing techniques / algorithms such that the defects are revealed.
C12	**Estimation of Micro-vibration and its Mitigation Techniques (URSC)** Micro-vibrations are generated in the spacecraft while in orbit. Estimation of these disturbances is essential. Development of mathematical models to realistically estimate these disturbances are being investigated. Techniques other than finite element based are looked up on. Once the models are reliable ways to mitigate, passive or active, also need to be addressed.
C13	**Development of Theoretical Models for Prediction of Response to High Frequency Shock (Spectral Element, Wave Propagation Techniques, Statistical Energy Analysis) (URSC)** The high frequency shock responses can be estimated using spectral elements / wave propagation techniques / Statistical Energy Analysis. Some amount of work in this direction is already carried out. Several spectral elements including for honeycomb sandwich construction are developed. Responses are determined using wave propagation techniques. But still there are unresolved issues. Looking for collaboration in these works.
C14	**Unconventional Manufacturing Technique for Composites (URSC)** Autoclave processing is normally done and it needs large autoclaves and is costly. VARTM is also being used for specific applications. New processing techniques are being evolved which are of out of Autoclave. Looking for other techniques for specific applications that will benefit compared to autoclave processing.
C15	**Curing Induced Deformation and Stress in Composites (URSC)** Curing process used for the manufacturing of composite structures results in built-in stresses. This results in shape deformations. The work involves understanding of curing stresses, their mathematical modelling, experimental verification and ways to reduce them. Some amount of work is already carried out, some specific development is looked up on.
C16	**Configurable Scan Mechanisms for Spacecrafts (IISU)** • The scan mechanisms currently being used for meteorological applications are configured as single-axis or dual-axis scan types, depending upon the scanning modes and the nature of the orbit in which such payloads are to be launched. • The design of such mechanisms, however, is specific to a particular project, depending upon the size and inertia of the scan mirror, the speed of rotation, the pointing accuracy etc. and hence calls for changes in the configuration from one project to another.

	• This advanced R&D envisages to employ a robotic system / manipulator having significantly high stiffness and high load bearing capability and capable of accommodating scan mirror of any shape and size with considerably good pointing accuracy. • Parallel manipulators are envisaged to employ judiciously in order to avoid singularity in the working range so that it can meet the various scanning requirements. The design of the mechanism essentially envisages to use a platform which can be oriented about a chosen point spatially. Optimisation for the number of actuators and the type of actuators required to orient the platform will be done to make the platform compact in size and mass. • Configuration design of platform and manipulator • Mathematical modelling, simulation and Motion Planning Algorithm; Optimisation of actuators and design of encoders • Design of characterisation scheme • Realisation of Engineering Model and Technology demonstration Qualification for enveloped spacecraft levels
C17	**Reaction Sphere for future satellites (IISU)** Development of Reaction Sphere actuator that can provide angular momentum in all three axes. In spacecraft attitude control, reaction spheres are promising alternatives to conventional momentum exchange devices for the benefits brought by their 4π rotation.
C18	**Non-Contact Power transfer (IISU)** Electrical connections between static and rotor parts of different systems are realized by means of sliding contacts, usually slip rings. Contactless rotary joints significantly increase the overall system reliability and life. Rotary transformers use strong magnetic coupling to achieve high efficiency and relatively high power ratings. High efficiency rotary transformer can be used for contactless power transfer in different applications like SADA, CMG, etc. The objective of the Advanced R&D is to indigenously design and develop a contactless power system using high efficiency rotary transformer and the GaN MOSFET based power electronics circuit for enabling the high efficiency power transfer of up to 1 Kilo Watt. • To design & develop Rotary Power Transformer. • To Develop Power processing electronics.

D	Area	Systems Integration (URSC)
D1	**Conformal, Transparent and Lightweight Absorbers for Ground and Space Applications (URSC)** An optically transparent, broadband, polarization insensitive microwave absorber having return loss more than 20 dB over the frequency range of 2 to 40 GHz. The structure should have power handling capability of 2 kW/m2 and should work in temperature range of -1000C to +1000C. Total thickness will be in a range of 3 to 4 cm. The proposed absorber should be fire retardant and should not emit any harmful toxic odour. **Scope of research:** Developed absorber should pass thermal cycling, thermal soak, and vacuum test, out gassing, fire retardant tests to qualify for space applications. Development of suitable technology to make large area Microwave absorbers (e.g. 100cm x 100cm). Final Report will consist of : a. Mathematical formulation, Modeling and simulation procedure and results b. All the Tests Procedures and their results, performed during design, development, ruggedization, optimization and qualification. Identification and qualification of an Industry which can mass produce the developed microwave absorbers	
D2	**Design and Realization of Micro-Vibration Isolation System for Optical Payload On-board Satellite for Blur Free Imaging (URSC)** Satellites and its payloads during orbit manoeuvres are subjected to micro-vibrations caused due to the presence of moving/rotating mass such as momentum or reaction wheels, flexible manipulator systems, cryo-coolers, solar array drive mechanism and other specialized devices. The micro vibration are of very low-level vibration compared with the dynamic environment during launch and typically occurs at a frequency from less than 1 Hz up to 1 kHz. The presence of microvibration affects the sensitive payloads such as laser communication devices, on-board camera, astronomical telescopes and micro-gravity experimental instruments. With the rapid development of space remote sensing technology, the high-quality and high-resolution imaging of spacecraft systems have been paid much attention by countries around the world. The presence of low levels induced disturbances degrade the performance of the sensitive payloads. In order to achieve stability and pointing accuracy of the optical payloads, the disturbances due to micro-vibrations has to be suppressed. Micro-vibration of the spacecraft can be suppressed using 3 techniques such as disturbance source suppression, payload isolation and transfer path suppression. Payload isolation is one of the most effective techniques where disturbances can be attenuated by using a passive or active isolation. **Scope of research:** The proposed research work is to develop a vibration isolation system which will be mounted between the precision payload and the disturbance base. The system will provide greater isolation at higher frequencies, transmissibility at low frequencies and	

	minimal amplification at all frequencies. To develop the isolation system, the research will focus on development of mathematical models using measured vibration data, FEM, vibration analysis and control system techniques etc. The mathematical modelling will be validated using appropriate test setups. The research will fulfil the stringent pointing accuracy and image quality requirements of the sensitive optical payload.
D3	**Configuration, Design, Development and Testing of Electromagnetic Docking System (URSC)** Docking of small satellites in space is quite challenging and also it involves lot of risks in operations due to many uncertainties. Relative position and orientation of spacecraft are very important during docking. Lack of mature docking technologies is also a major concern. This is particularly true for missions that involve multiple docking and undocking procedures like swarm-based construction and reconfiguration. Also assembling of smaller pieces in space and creating a larger satellite is one of the key area where lot of ground related handling costs and launch costs can be reduced. The same concept can also be used for reconfiguring spacecraft to different shapes. Electromagnetic docking system can be a major game changer to mitigate these risks through robust, ultra-soft, propellant-free docking. Scope of research: The proposed docking system should also contain the gripping mechanism which is able to dock at a variety of relative orientations, and tolerant of small misalignments. The work should also focus on developing the simplified electromagnetic force/torque model and coupled orbit-attitude dynamics modelling for spacecraft electromagnetic docking. The magnetic field distributions around spacecraft for different configurations to be worked out. Optimized electromagnetic configuration to produce the required force with minimum spacecraft power is challenging task. In this regard, the complete configuration, design of electromagnets for each chaser and target spacecrafts to be carried out. The work should also focus on test setups required for testing the docking systems
D4	**3D Metrology assisted AR/VR/XR Based Virtual simulation of 6DOF of Two free falling/flying/Docking Objects (URSC)** ISRO's advanced R&D projects are aimed at spacecraft docking, interplanetary travel and landings, Gaganyaan missions, deployment of large structures and segmented antenna/ mirror assembly. Virtual ground based simulation of on- orbit operations is needed to validate the configuration design and functionality of different elements of given spacecraft from end-to-end. Development Requirements: The goal of this research is to integrate 3D metrology and AR based virtual simulation systems, which will help the user to study the 6DOF of two free flying objects virtually and accurately.

D5	**Hypervelocity impact simulation modelling for Al Foam sandwich panel (URSC)** Open cell metallic foam core sandwich panel strictures are of interest for application in spacecraft micrometeoroid and orbital debris shields due to their novel form and advantageous structural and thermal performance. Repeated shocking as a result of secondary impacts upon individual foam ligaments during the penetration process acts to raise the thermal state of impacting projectiles ; resulting in fragmentation, melting, and vaporization at lower velocities than with traditional shielding configurations (e.g. Whipple shield). **Scope of research:** The objectives of the research are as follows: • To numerically simulate the phenomenon of hypervelocity impact on Al foam sandwich panel by Aluminum projectiles using nonlinear finite element method. The formation of debris cloud and its impact with the plates will also be attempted. • To develop constitutive models for mechanical behavior of Al foam panels deforming at very high strain rates and to implement them within the finite element framework • To compare the simulation results with available experimental data in terms of penetration depth and spall behavior/damage. • To develop ballistic limit equations (BLE) for Al foam sandwich panels based on the computational simulations. • Development of Thermal material/Empirical models for Al foam sandwich panels.	
E	**Area**	**NavIC Ground Segment Related Research Works (ISTRAC)**
E1	**Sub Area**	**Atomic Clock-Navigation Related Technology (ISTRAC)**
E1.1	**State Selection Magnet Development for Active Hydrogen Maser (ISTRAC)** An atomic clock uses an electron transition frequency in the microwave, optical, or ultraviolet region of the electromagnetic spectrum of atoms as a frequency standard for its timekeeping element. Atomic clocks are the most accurate and stable time and frequency standards known and are used as primary standards for international time distribution services, Deep space communication and in navigation satellite systems such as GPS, GLONASS, NavIC, etc. In the development of an Active Hydrogen Maser, state selection magnet plays a crucial role in the selection of the required atomic states of hydrogen atoms. The State-selection magnet can be of four-pole or six-pole. This selection of the states is carried out by a state-selection magnet made up of ferromagnetic alloy material. There are essentially two different types of state-selecting magnets: focusing and non-focusing. The atoms from the collimator do not enter the field precisely along the same trajectory, if the field gradient and the force they experience is not the same at all points in the field. The beam "profile," that is, the distribution of atoms over a cross-section of the beam gets affected. The main objective of a state-selection magnet design is to produce	

	a field gradient over the cross-section of an atomic beam that distorts the profile in a beneficial way, in order to reduce natural divergence.	
E1.2	**Frequency Synthesizer for Active Hydrogen Maser (ISTRAC)** In the development of Hydrogen MASER the Frequency synthesizer circuit plays a main role in handling the weak signal output from the MASER cavity. The power output from the Hydrogen MASER is very low, typically about -100 dBm. Therefore, to obtain a useful signal, the MASER output is phase-locked to a synthesized frequency derived from a high-quality 5 MHz quartz crystal oscillator. The challenge is to do this without significantly affecting the free oscillation of the MASER. The detailed design of the receiver and synthesizer necessary to phase-lock a 5 MHz quartz oscillator to the MASER output in order to obtain useful standard signals can, of course, vary widely.	
E1.3	**Low Noise Electronics for Active Hydrogen Maser (ISTRAC)** The Active Hydrogen MASER for time keeping must have excellent performance with long-term frequency stability, low frequency drift and high reliability for long term functioning. Based on the study and hands-on experience it has been realized that the key technical improvements for time keeping Active Hydrogen MASERS are the improvements in the electronics package. The electronics improvements include: • The analysis on the principle of the cavity auto-tuning technique • Improving the modulation system • The development of phase-lock receiver For making the technical breakthrough it is required to satisfy the needs for atomic time keeping, the project aims to improve the existing methodologies to improve long-term characteristics and reliability. This proposal is for developing low noise electronics for active hydrogen maser which will eventually enhance the reliability and performance characteristics.	
E2	**Sub Area**	**Antenna and RF Systems (ISTRAC)**
E2.1	**Stacked Microstrip Patch Antenna for four frequency bands (L1, L2, L5 & S bands) (ISTRAC)** The NavIC satellites provide will downlink the navigation signals in four frequency bands namely the L5 (1176.45 MHz), L2 (1227.6 MHz), L1 (1575.42 MHz) and S band (2492.028 MHz) and in two services namely the Standard Positioning Service (SPS) and the Restricted Service (RS) in near future.The NavIC ground segment shall operate in four frequency bands. Therefore, a need arises for developing an antenna solution that resonates in all the above mentioned bands. The proposed antenna design is a stacked microstrip patch antenna which can be used in the NavIC ground segment application.	
E2.2	**Choke ring Ground plane Antenna for Multipath Mitigation in four frequency bands (L1, L2, L5 & S bands) (ISTRAC)** The NavIC ground segment consists of various subsystems, among which the Integrity Monitoring Stations are one the major systems. The Integrity Monitoring Station's heart	

	is a Reference Receiver system. This Reference Receiver system consists of two parts, one is the Reference Receiver subsystem and the other is the Antenna Subsystem. The Antenna subsystem is usually placed on the rooftop for the reception of NavIC signals, where there are multiple sources of ground reflections or multipath signals from the nearby structures. Therefore, a requirement for the development of a choke ring ground plane antenna arises. The design for the choke ring ground plane can be proposed as a ground plane that enhances the cross-pol gain by reducing the LHCP profile. This design of an canter antenna element with a choke ring ground plane can be provided as a solution for upcoming NavIC satellites ground segment support.
E2.3	**C band Antenna Feed with efficiency >85% for cassegrain geometry for ground station (ISTRAC)** Design of antenna fed with better efficiency will always allow good reception sensitivity and allow for better tracking and less power uplink from the ground station. The NavIC Ground stations required better feed systems for cassegrain geometry antennas.
E2.4	**Dual band filter Waveguide based filter for C band (ISTRAC)** NavIC two way CDMA based ranging station requires to acquire and track the NavIC satellite CDMA signals in the RF environment which is challenged by 5G Interferes. These calls for dual band waveguide based C band filter with can allow two frequencies namely 3400-3425 MHz Ranging frequency and 4180-4200 tracking frequencies. This filter shall have sharp cutoff and low insertion loss.
E2.5	**Sharp cutoff S band filter for NavIC ground stations (ISTRAC)** NavIC signals operate in S band 2492.028MHz with a bandwidth of 16.5 MHz. For the One way ranging station it is required to have a sharp cutoff filter in the antenna front end which shall provide low insertion loss.
E2.6	**Power Amplifier 100W for ground stations (ISTRAC)** Ground Station for NavIC two way ranging requires power amplifiers with capability of 100-200 Watts in extended C band to perform ranging to NavIC satellites. A reliable 24x7 operational and efficient power amplifier is required at such stations.
E2.7	**Anti-spoof and Anti jam system for NavIC ground segment (ISTRAC)** NavIC ground segment is a critical ground infrastructure which needs to be protected from unintended attempts. Spoofing and Jamming may cause non favorable results which may lead to the non-availability of ground segment. It is required to device methods for PTA i.e Protect, Toughen and Augmentation of the ground infrastructure to overcome the Spoofing and Interference threats from adversaries.

E3	**Sub Area**	**Navigation Signal (ISTRAC)**
E3.1	**Ground terminal setup for NavIC SQM (ISTRAC)** It is necessary to observe navigation signals onboard to access any onboard anomalies which may cause integrity problems for end users. Navigation fraternity employs large dish antennas to receive, decode and process signals using vector signal analyzers. This provides the ability to understand error modes and to perform rapid diagnosis of signal anomalies. This is particularly of importance for navigation signals used in high Integrity applications.	
E3.2	**Interference Hunter up to C band frequency (ISTRAC)** Unintentional or Intentional jamming in overly crowded RF spectrum has become a challenge to detect and isolate the jammer in Navigation signal applications, as the Navigation signals are very weak in nature they are readily vulnerable. Location of Interferers, their directions and distances from the ground station will effectively help in mitigating the sources.	
E4	**Sub Area**	**Software Defined applications for NavIC Ground Segment (ISTRAC)**
E4.1	**Software defined Ground Station for Ranging to NavIC Satellites (ISTRAC)** NavIC ground station for Satellite two way CDMA based precise ranging consists of uplink in Ext C band and downlink in lower end of C band. Such multiple ground terminals form a network of stations to provide precise timestamp based Range measurements (accuracy of <1 nanoseconds) to enable NavIC orbit determination. These ground stations shall be built on software defined radio concept.	
F	**Area**	**Spacecraft Operations (ISTRAC)**
F1	**Sub Area**	**Spacecraft operations (ISTRAC)**
F1.1	**Autonomous spacecraft health monitoring and commanding to the satellites (ISTRAC)** Integrated end-to end process monitors for all ground segment activities/events of spacecraft mission operations involving multiple ISRO centres/units. Automatic alert through suitable messaging system to the concerned in case of anomaly/contingency. Enhancing intelligence to aid analysis and generate various reports/graphs and outputs to reduce man hours involved in this activity. Research in developing AI/ML based software packages for automation process to detect anomalies and trend analysis. Robust and reliable spacecraft simulators for mission analysis, planning and verification. Virtual satellite control center in future with data monitoring and commanding feasible from the experts systems connected in the secure public network which will reduce the burden of ever expanding real estate requirements for control center facilities. Spacecraft information management system with data base of past and current satellite data using data warehousing and mining techniques.	

F2	**Sub Area**	**Flight Dynamics (ISTRAC)**
F2.1	Precise Orbit determination for Deep Space Missions with DDOR measurements along with traditional Range & Doppler for ISRO future missions. Orbit determination & Prediction for Asteroid along with estimation of gravity of irregular shape. Interplanetary Trajectory Design for ISRO missions. Controlled Re-entry trajectory design over Earth & other solar system Planets. Instantaneous location estimation for distress beacon using MEOSAR System	
F3	**Sub Area**	**Spacecraft Scheduling (ISTRAC)**
F3.1	Advanced algorithms for spacecraft TTC & Payload scheduling to cater to all future requirements based on Spacecraft New Automation, IDRSS, Inter-satellite Communication... etc. 24X7 On Line Real Time Scheduling requirements to be met in automated way. Single Window System to auto Generate, Validate & Verify the Scheduling requirements.	
G	**Area**	**Satellite Ground Systems (MCF)**
G1	**Sub Area**	**Ground Segment (MCF)**
G1.1	**Realization of Phased Array Antenna for GEO/GSO spacecraft TTC applications (MCF)** A Phased Array Antenna with Electronic Beam Steering Capability shall be realized towards GEO Spacecraft Telemetry & Command applications in C-Band / Ku-Band. The proposed PAA shall be capable of simultaneous TTC Operations of collocated spacecrafts at particular longitude or multiple spacecrafts spread across different longitudes. The Phased Array Antenna beam shall be steered electronically thereby pointing to be achieved without any mechanical movement of the Antenna System. • Feasibility Study to propose suitable architecture towards realization of Multi-frequency, multi-beam Phased Array Antenna with electronic beam steering capability for GEO/GSO Spacecraft TTC Applications. • Producing conceptual design with appropriate topology, identification of hardware and software required. • Design of Phase Shifter (active, passive or hybrid) towards achieving electronic steering of the Antenna beams. • Defining milestones (achievable goals) with time schedule • Demonstration of proto-type Phased Array Antenna of 4x4 elements with electronic beam steering in Transmit & Receive mode. • Fabrication of complete phased array antenna with required gain and beam steering capability for GEO/GSO Spacecraft TTC Applications meeting major specifications.	

	Desirable Specification

S/No.	Parameter	Specification Value	
		C-Band	Ku-Band
1.	Transmit Freq. Band (GHz)	5.85 – 6.45	12.75 – 13.25
2.	Receive Freq. (GHz)	3.7 – 4.2	10.70 – 11.70
3.	Max. EIRP (dBw)	≥ 75	≥ 75
4.	G/T (dB/K)	≥ 26	≥ 30
5.	Polarization	LP	LP
6.	XPD (dB)	≥ 20	≥ 20
7.	Beam Steerability (Degree)	± 60	± 60

G2	**Sub Area**	**Ground Segment (MCF)**

G2.1

Realization of Interference (Satcom Signal) Geolocation System (MCF)

Interference or Sat-com Geolocation System needs to work on principle of Triangulation. Interference Signals are received from affected (primary) satellite and mirror (secondary) satellite meeting certain criterion like similar uplink frequency plan, polarization and overlapped ground coverage. Secondary or mirror satellite can be at the separation ranging from 1 to 10-15 deg. These signals need to be digitally processed to find out Time Difference of Arrival (TDOA) and Frequency Difference of Arrival (FDOA) between two signals. Then by knowing the precise locations of primary, secondary satellites and receiving station, TOOA and FDOA information can be processed to find out location of Interference Signal.

To improve accuracy of Geo-location errors contributed due to on-board Local-oscillators, Ground Systems a reference signal from precisely known locations needs to be processed parallelly. Additional enhancements like support various Geo-location scenarios, Carrier cancellation to reduce processing gain requirements, ephemeris correction, estimation of error ellipse, estimate best time of day to improve accuracy etc. Requirements would be development of Hardware and Software

1. **Realization of Hardware:** Four Channel Digitizer, Signal Conditioning Unit, Down Converter Chains, Signal Synchronising circuitry, Signal Processing Units or computers etc
2. **Realization of Software/Algorithms:** Digitizer Data Acquisition, Digital Signal Processing (eg. CAF- Cross Ambiguity Function) to find out TDOA, FDOA involving Coarse and Fine Correlation for processing large data to achieve required processing gain. Spacecraft Orbital Data and Ground Location co-ordinate processing to derive transmitter locations etc

G3	**Sub Area**	**Ground Segment (MCF)**

G3.1

Realization of Signal Interception System (MCF)

Signal interception System needs to carry following functions:

- Scan the selected Spectrum
- List all the carriers
- Carrier Type Identification

	• RF characterization of carriers (Center Frequency, Bandwidth etc) • Modulation Characterization (Type, Symbol Rate, Code Rate, Eb/N0 etc) • Protocol Identification • Content Analysis (Video, Audio, Data, Messages, Pictures etc) **1. Realization of Hardware:** Suitable Intermediate Frequency Digitizer, Signal Conditioning Unit and Signal Processing Units or computers etc **2. Realization of Software/Algorithms:** Carrier Detection, Carrier Classification, Modulation Classification, Protocol Classification and Content classification and Display **Desirable Specifications**

S. No.	Parameter	Specification
1.	Frequency Band support	It will work on IF so that signals in any band can be supported by down-conversion. (S, C, Ku Ka etc)
2.	Carrier Type Detection (of all Open Standard and non- standard)	Bursting, Continuous, Forward/Return, SCPC, PCMA, CnC, TDMA, DVB-S, DVB-S2, DVB-SX
3.	Modems Support	All commercial Modems
4.	Processing scan Bandwidth	50MHz or 120 MHz
5.	Scan Bandwidth	1.2 GHz
6.	Modulation Types	All commercially used types e.g BPSK, QPSK, 8PSK, 8QAM, 16QAM, 16APSK, 32APSK etc
7.	FEC Type	Convolutional, RS, BCH/LDPC, TPC, LDPC, Versa FEC etc
8.	Content Analysis	All Standard Contents and Provision to add new protocols/types

H	**Area**	**Satcom & Navigation Payload (SAC)**
H1	**Sub Area**	**Digital Systems in Advance Satellite Technology Research (SAC)**
H1.1	The current success of satellites is primarily in the fixed satellite services, broadcast satellite services and broadband/internet-related satellite services. In the satellite communication business, the trend for ever-increasing capacity, flexibility and availability of service, as well as increasingly more affordable, more compact, lighter, and even more stylish and ergonomic ground and personal terminals, has become need of the present. It is also believed that satellites in future still play a key role in providing mobile services despite the setbacks that came with early market failures. Onboard digital signal processing has potential for offering innovative satellite services. Availability of space-qualified high-capacity high-speed Field Programmable Gate Array (FPGAs), availability of high-speed Analog to Digital Converters (ADCs) / Data Assimilation Converters DACs and development of specialized-function Application Specific Integrated Circuits (ASICs) have made advanced services a reality. Managing mass, power, complexity, functionality and reliability for such payload is of paramount importance for offering services at acceptable cost. The emphasis worldwide is on:	

<table>
<tr><td></td><td colspan="2">Increasing the performance (i.e. service availability)
Quality of experience (i.e. less delay)
Reducing cost/bit of information Efficient use of spectrum
Network integration with terrestrial system
Flexibility (i.e. reconfigurable payloads)
Integration with navigation and observational satellite systems
Security of communication
Resistance to interference and jamming
The accomplishment of above tasks would require developing techniques for:
Innovative and efficient spectrum processing and sensing algorithms
Innovative techniques, protocols and architecture
Innovative business models</td></tr>
<tr><th>H2</th><th>Sub Area</th><th>Communication Satellite Related Technology (SAC)</th></tr>
<tr><td>H2.1</td><td colspan="2">Advanced Coding and Modulation for Satellite Communication (SAC)
Most of the communication satellite in ISRO like Indian National Satellite (INSAT) and Geosynchronous Satellite System (GSAT) class of series satellites used mostly Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) modulation system. The reason of using these modulation systems, because of their simplicity and better performance compare to other modulation systems in satellite communication scenario. They are still the popular choice, even in worldwide satellite communication scenario. There are two major approaches for modulator design heterodyne and homodyne. Heterodyne approach basically involves two level of up conversion i.e. the first modulation at Instruction Fetch (IF) label and then up conversion to desire Radio Frequency (RF) frequency. In homodyne approach involves direct conversion from zero IF to desired RF frequency. Till now mostly all major modulator design is based upon heterodyne based approach. But now current state of art design is based upon homodyne approach. Following figures shows direct S and Ka band modulator design for Gaganyaan project. The challenges are left in these modulation are to handle high data rate, where the hardware or component used earlier design will not be useful. The other challenges are reduction of size and power consumption of such system. So, high data rate system using our current modulation scheme with reduces size and power is the current challenges.</td></tr>
<tr><td>H2.2</td><td colspan="2">Channel coding for satellite communication (SAC)
Currently most of the satellite made by ISRO used convolutional code with different code rate 1/2, 3/4, 7/8 in concatenation with Reed-Solomon (RS) code in some of the satellite. This type of channel codec works well since last 20 years in satellite communication world. However due to increasing in demand of quality of service and several upcoming deep space explorations, it is now essential that change channel codec for future mission. The Consultative Committee for Space Data Systems has suggested few of the channel code for future satellites and deep space explorations. The current state of the art channel codec is</td></tr>
</table>

- Turbo convolutional codes (TCC)
- Turbo product code (TPC)
- Low density Parity check code (LDPC)

New channel coding Scheme

For our satellites and deep space mission Turbo convolutional code and LDPC code are the two main area of thrust for future mission.

- **Turbo Convolution Code**

Parallel-Concatenated Convolutional Codes (PCCC), known as turbo codes, allows structure through concatenation and randomness through interleaving. The Consultative Committee for Space Data Systems (CCSDS) Telemetry Channel Coding Recommendation establishes a common framework and provides a standardized basis for the coding schemes used by CCSDS Agencies for space telemetry data communications. This standard traditionally provides the benchmark for new and emerging coding technologies Turbo codes have an astonishing performance of bit error rate (BER) at relatively low Eb/No. The reason was the significant improvement in terms of power efficiency assured by turbo codes over the old codes of the standard. In Chandrayan-1 mission of ISRO, we have used Turbo convolutional code as per CCSDS standard 131.0-B-1 for low data rate telemetry application. We have also planning to use this turbo code for human space program.

- **Low density parity checks code (LDPC)**

The another important error correcting code, whose performance close to Shannon limit know as low density parity check code. The LDPC code is also a close contender of turbo code. LDPC codes have a remarkable performance with iterative decoding that is very close to the Shannon limit. When compared to the decoding algorithm of convolution code, LDPC decoding algorithm has more parallelization, low implementation complexity, low decoding latency, as well as no error-floors at high Signal-to-Noise Ratio (SNR) as turbo code. The next generation satellite communication systems e.g. digital video broadcast satellite/terrestrial (DVB-S2/T2) have readily adopted LDPC code for Forward Error Correction (FEC), mostly due to its near Shannon performance at very low signal to noise ratio. However, the channel code performance also depends upon the modulation scheme, figures shows the performance of LDPC codec and convolutional code with respect to BPSK and 16 Quadrature Amplitude Modulation (QAM) modulations. The use of advanced channel coding techniques (e.g. TC and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcasting services to fixed terminals in the Ku/Ka frequency bands into two-ways (i.e. Digital Video Broadcasting – Second Generation (DVB-S2) in the forward link and

	Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS) in the return link, respectively), in which the Additive white Gaussian noise (AWGN) channel is usually assumed. In particular, DVB-S2 considers irregular LDPC codes of either 16200 or 64800 bit code words and 11 coding rates (i.e. ranging from 1/4 to 9/10). With respect to DVB-RCS, double-binary turbo codes are assumed with 12 frame sizes (i.e. ranging from 48 to 752 bit couples) and 7 coding rates (i.e. ranging from 1/3 to 6/7).
H2.3	**Sync word less Concatenated RS and convolutional code encoder and decoder development (SAC)** The recommended concatenated coding system in satellite communication consists of a Reed-Solomon outer code and a convolutional inner code (which is Viterbi decoded). In typical scenario there is requirement of sync word for synchronization for RS decoder, which lead to reduce the overall efficiency of data transmission and also the overall throughput. The proposed activity will remove the requirement of sync word in each data packet which will improve the overall data efficiency. The proposed activity will be useful for future payload like Gaganyaan etc.
H2.4	**Digital Processors for High Throughput Satellites (SAC)** Conventional high throughput satellites employ limited, RF based processing due to unavailability of wideband signal processing hardware. For future high throughput satellites, it will be necessary to employ processing techniques to distribute the on-board resources in an optimal fashion and extract the maximum possible throughput. The relevant research areas would be: • Development of integrated wideband, direct sampling data converters and RF transceivers. • Development of on-board partially or fully reconfigurable, failure tolerant, ultra-scale FPGA based signal processing system • Development of multi-channel wideband signal processing system for digital beamforming and channelization in broadband multibeam communication payloads.
H2.5	**Precoding for V/High Throughput Satellites (SAC)** Precoding is to counteract the multibeam interface when high/full frequency reuse is employed in V/HTS so that noncomplex UTs can maintain a high Signal to Interference plus Noise Ratio (SINR), even the same carrier frequency is used by adjacent beam. To achieve this precoding employs the channel state information (CSI) toward each UT to mitigate the interference. Signal processing for optimization of precoding matrix and implementation of Precoding function in next generation V/HTS. Some research areas are calculation of Precoding Matrix, and Efficient Implementation of Precoding Matrix in satellite.

H3	Sub Area	Navigation Satellite Related Technology (SAC)
H3.1	**Modulators for Navigation Satellites (SAC)** This Satellite Navigation has revolutionized the navigation world, opening new opportunities in an increasing number of sectors that require high precision. ISRO has taken up the project for the implementation of an independent regional navigation system currently known as Navigation with Indian Constellation (NavIC). The project Indian Regional Navigation Satellite System (IRNSS) envisages establishment of regional navigation system using a combination of Geostationary Orbit (GEO) and Geosynchronous Orbit (GSO) spacecraft's. NavIC is already providing two types of services restricted and unrestricted services or public domain services in L5 and S Band. Binary offset carrier (BOC) and Binary phase shift keying (BPSK) is use for these services. In NavIC, we are using different method for combining these two modulation scheme in order to get constant modulation envelope i.e., the total transmitted power does not vary over time. So that the transmitted information is not contained in the signal amplitude and the transmitted signal amplitude becomes less critical. However, in future NavIC satellite we are going to transmit L1 band signal also for better interoperability and compatibility. In L1 band, we need comply the power spectral density of Multiplexed binary offset carrier (MBOC) modulation. There are other navigation players, who are transmitting their own custom modulation scheme in L1 band. These are mention below. **CBOC:** The Composite BOC is the solution adopted by Galileo for the Open Service in E1/L1. **TMBOC:** The Time-Multiplexed BOC is the solution adopted by GPS for L1C. **Quadrature Multiplexed BOC:** Adopted by compass. A suitable modulation scheme, which comply MBOC power spectral density may design and develop to complete the future requirement.	
H3.2	**Coding Scheme (SAC)** Like other wireless communication signals, navigation signals are subject to noise, multipath and shadowing effects which may induce errors in the received data. Modern navigation signals employ some techniques to detect and correct these errors. Galileo, modernized GPS as well as space-based augmentation systems (SBAS) (e.g. Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS)) messages make use of FEC. In the following the various error protection techniques used by these systems are described and some details are given for the encoding and decoding processes. The fundamental principle of channel coding is to add redundancy to the navigation message, which is used by a receiver to detect or correct possible errors in the received symbols. The redundant bits added by the encoder are a function of the original information. The original bits may or may not be directly visible in the encoded message. In the first case the encoding is called systematic while in the second case it is called non-systematic.	

	Channel coding techniques can be further divided into block codes and convolutional codes. Block codes operate on fixed sized blocks of data, each of which are encoded separately, while convolution codes operate on a continuous stream of input data.
H3.3	**Optical Interconnects for High Speed Signal and LO distribution (SAC)** There is a need for High bandwidth (BW) serial data transmissions. Optical Interconnects are required to minimize power consumption, mass and volume. They are practically lossless propagation in an optical fiber within a Digital sub-systems module. The other significant advantages are Immunity to Electromagnetic Interference (EMI) and Electro Magnetic Compatibility(EMC), are mechanically flexible and galvanic ally isolated and provides low phase noise degradation.
H3.4	**High-Performance DSP for Software Defined Payloads (SAC)** To meet the requirement of high speed and reconfigure software defined payloads, a high performance Digital Signal Processors (DSP) processor which can meet space electronics quality guidelines are required. Their performance should be benchmarked for following applications • DVB-S2 modem: 2 Gb/s transmit, 1 Gb/s receive • Fast Fourier Transform FFT (complex 16 bit fixed-point): 150 GOPS (Giga Operations per Second)
H3.5	**Digital Cancellation Scheme for High-Order Passive Intermodulation Interference (SAC)** Passive intermodulation (PIM) is a phenomenon that additional signals at new frequencies (not only the harmonic frequencies) are generated when signals containing two or more different frequencies are processed at the passive devices, such as duplexes, cable connectors, waveguides and antennas. PIM would worsen the antenna gain-to-noise-temperature (G/ T) value, thereby further disrupting the whole system. A full-digital PIM canceling adaptive scheme can be explored based on Least Mean Square LMS algorithm.
H3.6	**Onboard Clock Ensemble for clock anomaly handling (SAC)** To improve the clock accuracy in future navigation payloads it is required to generate the output frequency signal based on an ensemble of input clocks with optimized performance and improved robustness by clock anomalies handling. Following three algorithms can be developed: Measurement Filtering (MF), based on a cascade of low-pass recursive filters with exponential window functions. Clock Fault Detection and Correction (CFDC), with associated logic based on MF outputs, onboard Clock Ensemble (ONCLE), based on weighted averaging according to filtered frequency information covering clock anomaly handling.

H3.7	**On-board Autonomous Orbit Determination of Navigation Satellites using inter-satellite ranging (SAC)** Autonomous orbit determination of a navigation constellation is the process by which the orbit parameters of navigation satellites are autonomously calibrated onboard the satellites without the need for external aids. It commonly uses a satellite onboard data processing unit and a filtering method to process the measurements of inter-satellite ranges. The onboard data processing unit is the main module of autonomous navigation systems.	
H3.8	**FPGA/ASIC Design Methodology (SAC)** Following areas for research in FPGA/ASIC Design for onboard signal processing: • 65 nm, 28 nm Fully Depleted Silicon On Insulator (FD SOI) to be evaluate for low power Application-Specific Integrated Circuit (ASIC) development for future high speed Digital Subsystems • Formal Verification to Verify Single Event Upset (SEU) Mitigation Techniques for increasing design reliability • High Level Design Methodology for faster design rollout	
H4	**Sub Area**	**Development of Ferrite Material for Space Use (SAC)**
H4.1	Microwave circulators and isolators are used in communication payloads to improve impedance matching and to avoid multiple reflections. Ferrite material is used in the waveguide junctions because of its non-reciprocal properties, resulting in circulation when magnetized. Understanding the structure of the ferrite material requires knowledge of chemistry, theory of magnetism in ferrites, the non-reciprocal characteristic of ferrite junction at microwave frequencies due to gyromagnetic effect, which involves physics and advanced mathematics. The important properties of a ferrite are: **Saturation Magnetization, Ms:** This property is related to the spontaneous alignment of electron spins parallel to the applied magnetic field. **Gyromagnetic Line width, ΔH:** It is a measure of ferrite magnetic losses in the vicinity of ferromagnetic resonance. **Effective line width, ΔHeff:** It is a measure of ferrite magnetic losses for off-resonance operating points (below and above resonance) **Spin wave line width, ΔHk:** It is a measure of attenuation factor of spin waves excited above a power level. **Magnetization temperature coefficient, α:** It is a measure of relative change in magnetization with respect to temperature.	

	Research undertaken/to be taken up in Ferrite Devices at SAC • Low power and High power Wideband Coaxial circulator • High power waveguide circulator at Q-V band and millimeter wave • Ferrite Phase shifter • High power and low power Ferrite switches	
H5	**Sub Area**	**Amplifier Technology (SAC)**
H5.1	**The Scope of Research in Amplifier technology as follows** • Wideband, high power SSPA & Channel amplifiers in UHF, L, S, C, Ku, Ka and Q/V-band. • GaN based high power compact SSPAs at UHF, L and S-Band. • High power amplifier GaAs and GaN MMIC designs. • State-of-the-art technology for design & development of compact SSPA at Q/V-band with waveguide RF interfaces. • Spatial power combining techniques at millimeter wave frequencies. • High efficiency Continuous Waves (CW) SSPAs with associated thermal & power management. • Implementing Efficiency enhancement techniques in S, C, Ku-band Power amplifier. • Thermal modelling & thermal simulations of MMIC power amplifiers. • Modelling & simulation of entire amplifier module consisting of MMICs for the effects of bondwires, package cavity etc. on RF performance at Ku-band & beyond. • Design & development of ASIC for the tele-command interface control circuit for channel amplifier & SSPAs. • Design & development of high isolation switches and voltage variable attenuators at Ku & Ka-band.	
H6	**Sub Area**	**Reconfigurable Filters for Satellite Communication (SAC)**
H6.1	**Mechanically Tunable waveguide cavity filters (SAC)** **Bellow-Mounted Tunable Filters:** Waveguide cavity filters have been widely used in satellites, due to the high-Q and high-power handling capability. In addition, cross-coupled circular-waveguide dual-mode filters, typically operating in TE113 mode, offer mass and size reduction and excellent RF performance. Mechanically tunable waveguide cavity filter maintains both High-Q and high-power-handling capabilities. A mechanically tunable waveguide filter can be implemented using bellows. The bellows is a flexible electroformed	

	copper structure which acts as a tuning element. It is a thin-walled (nominally 0.002-in thick) metallic closed-end piston with a designed profile and specific number of convolutions. The bellows-mounted tunable filter offers a very low loss performance over a wide tuning range. A very stable transmission response over a very wide tuning range is also a distinctive feature of this technique. However, there is a tradeoff between RF and mechanical performance when designing a bellows profile. Mechanical operating characteristics are maximized by increasing the number and amplitude of convolutions, whereas RF performance relies on bellows with fewer convolutions.
H6.2	**Fully Tunable TE011 Cavity Filters (SAC)** A fully tunable filter for a completely flexible transponder requires tunability of both the bandwidth and center frequency of the filter. RF performance of the filter should be maintained over wide tuning range. In cylindrical cavity filter operating in TE011 mode, electric field strength and current distribution approach zero at the edge of the cavity end walls making it possible to use tuning discs without Q degradation, which in turn leads to the potential for incorporating small and low power consumption motors due to the contactless tuning feature. A movable plunger with diameter smaller than or equal to that of the cavity is used for filter tuning. The A contactless plunger is used to provide a reactive short-circuit condition at the back of the metal disc ensuring good electrical contact, creating a near shortcircuit condition. This type of plungers consists of quarter-wavelength transformers. The three-section plunger incorporates two low-impedance sections and one high-impedance section. Providing an RF enclosure to the resonator prevents unwanted modes from interfering and degrading the operating TE011 mode. The achieved Q of approximately 10,000 for a Ku band filter is reported in the literature. This design, however, has narrow spurious free window due to presence of low-Q TM111 mode.
H6.3	**Coaxial Tunable Filters (SAC)** Coaxial resonators offer moderate-Q and have been implemented for satellite channel-filtering applications. Coaxial technology is suitable for tunable filter applications because of the ease of tuning, which is a well-known characteristic of coaxial resonators. A design of a manually tunable coaxial filter is shown in following figure. In this design, Tuning is achieved by rotating a shaped cam above the resonator post which in turn changes the capacitive loading of the resonator. Variation in capacitive loading required for tuning resonant frequency of coaxial resonator can also be achieved by varying the height of tuning disk used at the top of the resonator.

H7	Sub Area	Synthesis and Analysis of Microwave Filters Based on Available Computational Methods (SAC)
H7.1	**Reflectionless Microwave filter (SAC)** Reflectionless Bronchopleural Fistula (BPF) devices developed mostly in planar realizations. However, to much lesser extent they are also have been demonstrated in other technologies. **MMIC and low-frequency technologies:** Reflectionless BPFs in MMIC technologies are demanded for modern, energy-efficient, compact RF front-end chains .A theoretically perfectly matched symmetrical BPF network with even- and odd-mode subcircuit compensation, an integrated, passive, two-port absorptive BPF is developed. This prototype exhibits a quasi-elliptic-type bandpass filtering response centered at 2.5 GHz with return loss levels above 15 dB from dc to 10 GHz for a chip area of 1 mm2. It should be noted that commercial counterparts of this solution are already available showing promise for deployment in future RF transceiver modules. On the other hand, although, thus far, they are used only in low-pass filtering components (which can be easily extended to BPF ones after appropriate lowpass-to-bandpass frequency transformations), the novel classes of reflectionless filters for very low-frequency applications. The future need is to demonstrate and extend this concept for Ku and Ka-band. **Acoustic wave technology:** BPFs in acoustic wave realizations are leading frequency-selective devices in mobile communications systems, due to their high quality factor (Q) and compact footprint However, most show some major limitations in terms of their very narrow operational bandwidth and frequency-static filtering transfer function being mostly of the reflective type and because of their spurious mode creation. By efficiently combining the acoustic-wave lumped, element resonator (AWLR) concept presented in for enhanced-bandwidth, quasi-elliptic-type BPF realization with the complementary diplexer approach. AWLR-based BPFs with reconfigurable out-of-band TZs. **Multilayer technology:** The exploitation of microstrip-to-microstrip vertical transitions with slot line resonators in multilayer schemes has proven its potential in the development of ultra-wideband BPFs aimed at broadband and RF receivers. Using this concept and the lossy-stub-loading philosophy for reflectionless BPF design, new ultrawideband BPFs that simultaneously exhibit a very broad, symmetrical, reflectionless behaviour can be developed.	

<table>
<tr><td>H7.2</td><td colspan="2">Ceramic filters (SAC)
As the name implies, RF & IF ceramic bandpass filters are manufactured from ceramics that exhibit the piezo-electric effect. One of the most common ceramics used is known as Lead Zirconate Titanate (PZT), lead zirconium titanate. The ceramic element uses its very high Q mechanical resonances to provide the resonant feature. They have bandwidths that are typically measured between 0.05 and 20% of the operating frequency. Often the Q levels range between around 500 up to 10 000

Ceramic filters are electronic components that are widely used in IF and RF bandpass filter applications for RF circuit design in radio receivers and transmitters and the like. They may also be used as resonant elements in a variety of electronic circuit designs</td></tr>
<tr><td>H8</td><td>Sub Area</td><td>Channelized Power Output Configuration Design and Analysis of Electronic Power Conditioner (EPC) for Synthesizers (SAC)</td></tr>
<tr><td>H8.1</td><td colspan="2">These advanced requirements certainly require dedicated research and analysis on following areas:
• End-to-end simulation of power converter with detailed close loop stability analysis.
• Power loss optimization techniques for high current outputs.
• Isolated feedback network design with minimal stability implications.
• Low noise cascaded filter designs for attenuation of switching ripples.
• Reverse voltage protected high power switch design, with load current sense and fold back protection circuits.
• ASIC/ Hybrid Microcircuits (HMC) based solutions for single high power output DC-DC converter.</td></tr>
<tr><td>H9</td><td>Sub Area</td><td>Theoretical Analysis & Realization of Singular Electronic Power Conditioner (EPC) Approach for Integrated Payloads in Communication Satellites (SAC)</td></tr>
<tr><td>H9.1</td><td colspan="2">• Complete theoretical analysis of EPC including modelling and simulation with suitable topology selected
• Incorporation of advanced techniques to miniaturize the size and increase the efficiency of the EPC like soft switching etc.
• Designing of efficient Printed Circuit Board (PCB) layout maintaining signal integrity and minimum noise in sensitive low voltage high current lines like those of an FPGA
• Design and implementation of turn-on and turn-off delay circuits between various output voltage lines which are within a subsystem like FPGA and between two or more subsystems
• Design and implementation of separate telecommand circuit to enable switching of transmission supply of EPC on-board
• Realization and delivery of EPC with compliance of electrical specifications of all of the subsystems</td></tr>
</table>

H10	**Sub Area**	**Integrated EPC for Multiple Subsystem Stacks: Individual Control of Commanding, Over Current Protection and Other Protection Mechanisms for EPC and Intended Subsystems (SAC)**
H10.1	Theoretical study and analysis of advanced EPCs, which can supply power to multiple subsystem stacks, which involve several challenges viz. • Electrical circuit modelling and simulation of circuit. • Supplying power to multiple subsystems and meeting output voltage sequencing requirement of each individual. • Dynamic switching load with fast transient response and converter stability. • Selectable RF load at spacecraft through Telecommand. • Protection of EPC in case of single/ multiple subsystem failures such that there is no impact on remaining subsystems if one or multiple subsystems fail to which EPC is supplying power. • Thermal effects of subsystem failures on EPC.	
H11	**Sub Area**	**Switching GaN based EPC for High Power SSPA (SAC)**
H11.1	Recent advancement in radiation hardened Switching GaN devices paved the way for highly efficient and miniaturized converter realization. High Figure Of Merit of GaN switching devices in contrast Si switching devices help in achieving high switching frequencies without much trade off in the efficiency. This device technology significantly improves size and mass of the next generation high power converter and helps in high density payloads realization for SSPA. Scope of research proposal are as follows • Study of Gate drive circuit of GaN High-Electron-Mobility Transistor (HEMT) devices • Spice based modeling and simulation of GaN HEMT driver circuit. • Power circuit topology for efficient use of GaN HEMT devices. • High output power EPC of 300-500W working at high Switching frequency. • Use of Hybrid planer magnetics for miniaturization. • Thick film hybrid HMC for realization of control circuit for further miniaturization of package.	
H12	**Sub Area**	**Receiver & Frequency Sources Technologies (SAC)**
H12.1	Compact, low power consumption and small volume are the system requirements of all times. In this direction a major emphasis and thrust has been provided over the years for development of miniature Low-Noise Amplifier LNAs, Receivers and Frequency converters over frequencies ranging from UHF to Q/V band. MMIC technologies combined with advance packaging techniques are being utilized for various communication and navigation payloads. Higher operating bandwidths and gain requirements combined	

<table>
<tr><td></td><td colspan="2">with stringent spurious performance poses a challenge for development of compact systems as stringent filters are also to be incorporated.

Scope of research proposal are as follows
• Beam Forming Receiver
• Receiver Design for Doppler Shift
• Flexible Receivers in terms of frequency and bandwidth
• Design and development of RF switches, Variable Valve Actuation (VVA) and Video Graphics Array (VGA) upto Q/V band
• Fully integrated Receiver (RF, Local Oscillator (LO) & DC/DC in single package)
• Medium Power Beacon Sources
• Design of Synthesizer Integrated Circuit (IC)s</td></tr>
<tr><td>H13</td><td>Sub Area</td><td>System Engineering (SAC)</td></tr>
<tr><td>H13.1</td><td colspan="2">LEO Constellation for Regional Coverage (SAC)
• Development of algorithm for inter-satellite link dynamic routing/handover for data downlink/uplink to/from gateways
• System studies on integration of LEO broadband constellation & future terrestrial 6G technologies
• Development of on-board resource management algorithm based on user demand
• System study and algorithm development for LEO-GEO & LEO- Medium Earth Orbit (MEO)-GEO multilayer constellation routing
• Development of single aperture multi-beam , compact and light weight antenna integrated with compact lightweight trans-receiver module
• Development of compact ISL terminals for LEO-LEO and LEO-GEO communication
• Compact ISL terminals for LEO-LEO, LEO-GEO communication: compact optics, pointing and tracking system, optical modulators etc.
• Development of translucent/transparent on-board processing digital system based on commercial processor/FPGA technology</td></tr>
<tr><td>H13.2</td><td colspan="2">Software Defined radio based Satellite architectures for Future Satcom systems (SAC)

In present scenario, low cost small satellites (Micro or Nano Satellites) are being launched or planned for launch on LEO orbit to provide communication services over the Globe. Small satellites provide an efficient and cost effective solution to different communication services as compared to bigger satellite platforms targeted for GEO orbit. Due to their low mass, power and volume envelope, the payload also has to be</td></tr>
</table>

	designed considering these constraints. Software defined radio (SDR) based payload architectures can provide solution for compact/miniaturized design which requires low mass, low DC power consumption & less volume. Present SDR systems can receive/transmit signals directly at RF level up to C-band. This will eliminate the requirements of the complex frontend hardware which in turn provides savings in mass, volume and DC power consumption. SDR based communication payload architecture is well suitable for Indian Nano Satellite Bus (INS) and Indian Micro Satellite Bus (IMS). SDRs will also be useful for future communication payloads for GEO/LEO satellite. • Common RF transceiver (single chip/module) having RF front end and Digital subsystems (direct sampling based ADC and DAC modules) to operate from UHF to Ku band frequencies. • Studies and implementation of different signal processing algorithms for regenerative processing and flexibility in terms of channelization and bandwidth. • Development of integrated wideband RF front end with LNA, Bandpass Filters & Precautionary and Liquidity Line (PLL) on RF Transceiver module • Development of Direct Sampling based ADC and DAC modules which can be integrated with wide band RF front end.
H13.3	**Hybrid Satellite/Terrestrial networks and their compatibility with 5G cellular system (SAC)** As the spectrum resources are becoming limited and trend is towards delivering high speed data rates in both satellite and terrestrial mobile communication. Hybrid network of terrestrial and satellite systems complementing each other shall be developed for ubiquitous coverage, seamless connectivity and high data rates. Research areas in this direction are: • Studies on Satellite – Terrestrial system architecture compatible with 5G Networks • Channel modelling considering both land-mobile and earth-to-space channels • Investigation of Multiple-Input Multiple-Output (MIMO), precoding and other signal processing techniques for enhancing capacity of mobile satellite systems and ensuring coexistence of terrestrial and satellite systems. • Protocol level integration of satellite and terrestrial system and development of satellite-5G testbed. • Investigations on satellite platforms and terminal architectures complementing terrestrial 5G networks.
H13.4	**Development of signal processing and resource allocation algorithms for multi gigahertz on-board processors (SAC)** With the advancement in signal processing capabilities, the trend is towards channelization and processing of wideband signals covering gigahertz bandwidth.

	Similarly, the necessity to dynamically and efficiently allocate a communication payload's on-board resources such as power and bandwidth over the desired coverage requires the development of algorithms for beamforming-precoding, beam-hopping etc. Research areas in this direction are: • Development of signal analysis algorithms for wideband signals (multi-gigahertz bandwidth). Sparse signal analysis/compressed sensing based algorithms can be targeted. • Development of translucent processing algorithms which bridge transparent and regenerative payloads through partially decoding packets on satellite. • Development of algorithms for beam-hopping, digital beamforming, and precoding for efficient spatial allocation of on-board resources. • Satellite system design and architecture for multi-gigahertz signal processing payload.
H13.5	**Studies on Advanced Navigation systems (SAC)** • Use of IRNSS signals for navigation with "signals of opportunity" of terrestrial networks. • Systems studies for autonomous satellite navigation for MEO constellation. • Development of simulation tools for situation awareness for navigation end users supporting their mission planning. Such tools will consider the complete navigation systems and provide the information about the system accuracy, availability, integrity and reliability for any operational situation. • System studies on provision of standalone Positioning, Navigation and Timing (PNT) services for the missions on extra-terrestrial bodies like Moon/Mars. • End-to-end performance analysis of IRNSS signals in LMS channels using software/ hardware simulation platform. • Research on security features of navigation signals such as anti-spoof and message authentication. • Studies on navigation signal generation, multi-level signal/sub-carrier design and multiplexing using multicarrier constant envelope modulation schemes. • Studies of various signal modulation schemes like Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying (GMSK), Orthogonal Frequency-Division Multiplexing (OFDM), etc. as potential candidates for the future navigation signals. Studies should also include overall receiver performance analysis for such signals. • Studies of interference mitigation techniques like wavelet based de-noising or other compressive sensing methods on receiver performance. • Research in utilizing space service volume capability of GNSS signals. • Clock ensemble algorithm development for improvement of on-board timing system performance.

<table>
<tr><td>H13.6</td><td colspan="2">Space based Automatic Dependent Surveillance-Broadcast (ADS-B) and Automatic Identification System (AIS) (SAC)

AIS and ADS-B both rely on message transmitted by users regarding their navigation status/location. Space based AIS and ADS-B augment the surveillance capability beyond the terrestrial system range with global coverage (remote, polar and oceanic areas), unrestricted by location. AIS & ADS-B payloads, hosted on low earth orbit (LEO) platforms receive AIS/ADS-B messages, process them and relay them back to ground for usage by service provider to end user.

Satellite receives the message from multiple AIS and ADS-B terminal at a same time which causes on-board message collision or messages may get garbled. Since, this is an upcoming area, there are several challenges:

• Development of On-board algorithm for detect, de-collision and decode of AIS and ADS-B message in low SNR (<9 dB).
• Development of low-size, weight and power (SWaP) digital processor.
• Development of low noise sensitivity (<-105 dBm) AIS and ADS-B RF front end.</td></tr>
<tr><td>H14</td><td>Sub Area</td><td>RF characterization of communication and navigation payloads (SAC)</td></tr>
<tr><td>H14.1</td><td colspan="2">Payload testing also requires design and development of various ground components (low power and high power) such as Switching & Interconnect Network, switch matrix, waveguide/coaxial adaptors, couplers, dividers, high power waveguide terminations etc. to enable realization of ground test setup for communication and navigation payloads. Future research scope exists in ongoing activities:

• Development of web based Miniaturized ATS to characterize payloads from UHF to Q/V band and above, having very narrow to very wide bandwidths (5 KHz to 500MHz), using DSP techniques.
• Development of fast phase array antenna (PAA) measurement technique (in near/far field conditions) for LEO payloads
• Design of PAA test setup as well as qualification in thermovac & compact antenna test range (CATR) chamber.
• Characterization of multiple transponders in parallel using DSP techniques.
• Mismatch Fault isolation analysis using time domain techniques.
• Design and development of very high power waveguide terminations (> 2KW) at Ku and Ka band
• Design and development of high power pressure windows at S, C, Ku and Ka bands (quartz or alumina based).
• Design and validation of stimulus for various scenarios for communication, navigation, ADS-B, AIS, Radar, spectrum processing.</td></tr>
</table>

	• Development of efficient technique for ground setup RF calibration setup for wideband multibeam/communication payloads. • Feasibility analysis of Artificial Intelligence and Machine Learning (AI/ML) concepts application in analysis of payload test data generated during multiple phases of testing • Query based trend analysis on centrally stored payload test data, generated at different geographical locations.	
I	**Area**	**Satcom and SATNAV Applications & Associated Technologies (SAC)**
I1	**Sub Area**	**SATCOM Applications and Technology Development (SAC)**
I1.1	**Non Orthogonal Multiple Access (NOMA) based Multi-beam High Throughput Satellite /Ultra High Throughput Satellite System (SAC)** Recent research contributions have shown the way to use NOMA in SATCOM systems. Researchers are encouraged to submit their proposal for NOMA-based multi-beam satellite systems including mathematical analysis and the applicability of integrating NOMA to satellite systems from a system-level point of view. The researchers are requested to provide general approaches for cooperating NOMA with pre-coding techniques and their implementation plan. NOMA technique is also claimed to work under low C/I conditions in multi-beam HTS networks. Researchers are encouraged to submit their NOMA based receiver algorithm design, simulation, performance analysis and implementation plan for multi-beam SATCOM ground network. Additionally, NOMA breaks the orthogonality in conventional orthogonal multiple access (OMA) such that multiple terminals can access the same time-frequency resource simultaneously, which improves the efficiency of spectrum utilization. The resulted co-channel interference can be alleviated by performing multi-user detection and successive interference cancellation (SIC) at the receiver side. Researchers are encouraged to submit their research proposals on how to improve spectral utilization in SATCOM networks using NOMA technologies for different application scenarios.	
I1.2	**Algorithm and Implementation of real-time Wideband Spectrum Sensing (WSS) and Automatic Modulation Recognition (AMR) system for Blind Signal Detection (SAC)** Blind Signal Detection needs highly efficient algorithms for wideband spectrum sensing and automatic modulation recognition system to facilitate its real-time implementation. These systems are also enabled to make identification of communication streams and their demodulations that uses advance technologies like carrier-in-carrier (CIC) or Professional Convention Management Association (PCMA). Researchers are encouraged to submit their proposal for efficient spectrum sensing coupled with automatic modulation recognition system. The proposal should or may also include interference	

	monitoring system, signal demodulation plan together with its implementation. Another problem of interest includes blind scrambler identification and channel coding technique identification.
I1.3	**Advance Baseband Technologies for Mobile Satellite Service (SAC)** GEO-Mobile Radio Interface, better known as Grandhi Mallikarjuna Rao (GMR), is an European Telecommunications Standards Institute (ETSI) standard for satellite phones. GMR standard derived from the 3rd Generation Partnership Project (3GPP)-family terrestrial digital cellular standards and supports access to Global System for Mobile Communication (GSM)/Universal Mobile Telecommunications System (UMTS) core networks. Adaptive Communication Environment (ACeS), Initial Coin OfferingICO, Inmarsat, SkyTerra, TerreStar and Thuraya for high-speed internet as well as audio and video services use it. ISRO is coming up with its next generation of MSS satellite with 6/9/12m antenna in space. Researchers are encouraged to look at the protocol stack development opportunity (GMR like) for seamless voice communication between terrestrial (Logistics Task Force (LTE)/4G) and ISRO's MSSnetworks. It is expected from researchers to analyse the different channel models and "propose, develop & implement" efficient protocol stack for voice communication between terrestrial and MSS network. Researchers may look at opportunity to propose technologies to use upcoming 5G technologies and ISRO MSS network for IoT and Machine to Machine (M2M) communication applications.
I1.4	**Baseband Technology for Search And Rescue (SAR) systems of ISRO (SAC)** ISRO operates INSAT satellite(s) equipped with a 402-MHz Search and Rescue payload as well as 406 MHz Data Relay Transponders that are being used for SAR operations using different types of distress beacons of maritime, aviation and land users. • Researchers are encouraged to submit their proposal for development of MEO-SAR emergency locator transmitters with requisite Letter of Undertaking (LUT) processing algorithm. • Data Relay Transponders are usually of 200 to 350 kHz bandwidth and being non-regulated band suffer from interference from users.The nature of interference being non-time dependent and sweeping nature causes the communication loss. Researchers are encouraged to submit development proposal in interference resistant waveform for sensor data reporting in burst mode of transmission that can offer better quality of service. • Proposal on development of Mixed signal ASICs for SAR user terminals are encouraged.
I1.5	**MSS/DRT Network for data collection from Oceanic Platform (SAC)** ISRO has already established a network with multiple GSAT satellites carrying MSS transponders & INSAT satellites carrying Data Relay Transponders (DRT) transponders. Also morenext generation satellites with advanced MSS/DRT transponders & larger

	antenna will be coming up in future. This network can be potentially utilized for data collection & relaying applications from oceanic platforms. This network can facilitate the data collected by different oceanic sensors deployed at different locations to be communicated to control centre in near real-time. The network can have hybrid reconfigurable terminals which can communicate in both MSS & DRT bands & provide unified interface with sensors. Researchers are encouraged to innovate and propose design of ASICs, low-profile planar antenna system with beam-forming capability and suitable waveform for robust communication and leading to low power miniaturized system realization. A very low bit-rate (25-300 bps), fast acquisition, spectrally efficient spread spectrum burst demodulator design will add value to the proposal.
I1.6	**Baseband Sub-systems of Ground Network with multi-homing capabilities for Gaganyaan (SAC)** ISRO has been working on the Gaganyaan Project, which will also include development of audio/video processing system for ground segment. All ground stations are connected to Master Control Centre (MCC) through multiple ground links to achieve failsafe transmission reliability and service quality. For real-time multiplexed streams comprising audio, video and data, the reliability requirement is different for each type of data stream. So there is a need of an efficient transmission technique for such multiplexed streams with different reliability parameter settings for each stream over a multi-homed networking environment. It is also required to have a suitable handoff mechanism in case of link failover with minimum handoff latency. Researchers are encouraged to propose a custom protocol stack for seamless multimedia communication over multi-homing network.
I1.7	**Design and Simulation of digital beam-forming / electronic beam steering-techniques for high frequency COTM/SOTM (Communication on the Move / Satcom on the Move) applications (SAC)** ISRO has been allocated S-band for Mobile Satellite Service and Ku/Ka band is being used to offer aeromobile broadband services. In order to make the terminal efficient andsupport COTM/SOTM, electron beam steering technology is needed. Research proposals are invited on design anddevelopment of efficient electronic beam steering system with interference protection features for S/Ku/Ka band of operations. Researchers are also encouraged to submit their proposal for mechanically steerable antenna system of small size as well as hybrid system for aeromobile applications.
I1.8	**Design and Development of Header Compression andQoS Mechanism for IP data communication services over satellite network (SAC)** Header compression is a mechanism that compresses the IP header in a packet before the packet is transmitted. Header compression reduces network overhead and speeds

	up the transmission of either Real-Time Transport Protocol (RTP) or Transmission Control Protocol (TCP) packets. The RTP Header Compression over Satellite Links feature allows to use RTP header compression over an asymmetric link (such as a satellite link), where the uplink and downlink connections are on separate interfaces. This feature provides improved system performance by reducing network overhead and speeding up transmission of RTP packets. Quality of Service (QoS) is the collective effect of service performance, which impacts the degree of satisfaction of a user of the service. QoS is to the ability of a network element (e.g. an application, host or router) to have some level of assurance that its traffic and service requirements can be satisfied. To enable QoS requires the cooperation of all protocol layers from top-to-bottom, as well as every network element from end-to-end. Proposals are solicited for various techniques to enhance QoS and an enriched user experience.
I1.9	**Development of baseband signal processing elements for aero-mobile terminals (SAC)** Broadband connectivity 'at 35,000 feet' i.e. in-flight is growing in several dimensions. More aircraft are installing on-board broadband systems, more data is being consumed while in-flight, and the expectation for service network performance is increasing.The service is offered using high-throughput Ka-band satellites and ISRO's common ground equipment comprised of multiple satellite gateways and user terminals. The network is a multi-beam network and offering efficient broadband services with high throughput using low cost terminal is a challenge. Researchers are encouraged to offer their innovative design of UHTS class of Modem Technology (wide and faster acquisition with capability to support large drifts) supporting state of the art access schemes, Mobility management techniques for aero-mobile broadband and other signal processing techniques for low cost terminal realization.
I1.10	**Design & Simulation of physical-layer waveform for high mobility wireless channel (high Doppler-delay channel) (SAC)** Providing reliable wireless communications for high mobility terminals remains one of the main challenges faced by satellite high-mobility communication systems. because the high Doppler frequency offset, Doppler rate & delay caused by the high-mobility nature of the mobile terminal, and low signal-to-noise ratio (SNR) circumstances caused by limited satellites' link budgets degrade the system performance seriously. This is a very challenging aspect in LEO broadband communication. Most of algorithms mainly focused on the estimation and compensation of Doppler frequency rate and Doppler frequency offset, rather than reducing the influence of Doppler effect in the communication system. To solve such a problem in high-mobility satellite communications advance physical layer waveform may be proposed which is insensitive to Doppler & delay.

	Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.
I1.11	**Design & Simulation of baseband technologies for LEO Broadband communication (SAC)** The LEO Broadband Communication Network consist of Ka/Ku band user terminal, Space segment & Ka-band Satellite Gateway. Satellite Orbit propagation & Scheduling, automatic antenna pointing/beam steering, beam acquisition/ switching, Space resource management, Satellite handover & security are the major technology challenges. Researchers are encouraged to propose innovative efficient solutions/algorithms for above challenges. Researchers may also propose detailed hardware & software architectures of various baseband systems in User Terminals & satellite gateways.
I1.12	**Design & Simulation of waveforms for Extremly Low SNR Satellite communication (SAC)** Recently, the satellite communication sector is witnessing rapidly increasing demand in the field of mobile broadband & IoT applications. Such applications require development of miniaturized, low-cost & low power user terminals which can operate at extremely low SNR (<-30dB) with minimal compromise on bandwidth efficiency. Researchers are encouraged to propose innovative efficient waveforms along with advanced signal processing algorithms for robust acquisition, synchronization & reliable operation of receiver under dynamic channel conditions (extremely low SNR & high Doppler). Additionally, researchers are encouraged to propose efficient multiple access schemes & signal processing technologies for achieving maximum capacity in the satcom networks employing proposed waveforms.
I1.13	**Enhanced Spread Spectrum Aloha Technology Development (SAC)** Enhanced Spread Spectrum Aloha (E-SSA) is an asynchronous access protocol especially conceived to provide messaging services over the satellite return link. Protocol is slightly modified version of the robust 3GPP Wideband Code Division Multiple Access (W-CDMA) random access waveform (asynchronous burst transmission). The absence of synchronization mechanisms simplifies deployment and activation of the terminals. A wide range of applications based on burst transmissions not significantly capacity-demanding have been envisaged, such as telemetry, environment and traffic monitoring, emergency alerts, fleet management, highway tolling, forecast predictions. Researchers are encouraged to submit their proposal for ESSA system simulation and Receiver design and implementation plan.
I1.14	**IoT enabled terminal development (SAC)** Implementation of IoT/M2M via satellite deals with mainly two issues: First, the physical layer level: terminal related constraints (limited in power, energy, and antenna size), channel (potentially with masking and multipath) and the space segment to ensure proper link budget allowing the communication. On the other

	hand, the need to provide access to the resource to a large number of terminals. The access layer should also be able to interface with larger networks architectures. There are two possible ways of realizing IoT/M2M via satellite. The first scenario involves the use of a satellite relay terminal that interfaces with terrestrial access technology sensors (backhaul communication link). The second scenario is based on direct communication with sensors / objects via satellite constellation. Research proposals are invited for implementation of low power, low cost terminals, waveforms and other sub-system technology to support IoT over Satellite & Terrestrial networks.	
I2	**Sub Area**	**Ground Segment Network and Hardware Technology Development (SAC)**
I2.1	**Indigenous VSAT sub-systems technology development (SAC)** In current scenario, there is another requirement of indigenization of various baseband subsystems of VSAT terminals. VSAT remote terminals have stringent power/size & operational requirements which results in miniaturization of RF & baseband subsystems. Researchers are encouraged to innovate and submit proposal for indigenous design and development of following sub-system of VSAT technology: • Mass-manufactural, efficient low cost design solutions of RF Sub-systems (Battery Disconnect Unit (BDC), Block upconverter (BUC), Supplier Security and Privacy Assurance SSPA etc.) • Rapid Deployable VSATs: Rapidly deployable VSAT terminals is another important technology for quick emergency disaster communication. These design of such terminals involves advanced antenna & RF technology including supported by state-of-the-art baseband technology for quick antenna pointing & establishing reliable communication link from a mobile platform having limited power/space availability. These terminals should also extend interface to terrestrial devices for providing backhaul connectivity through satellite. • Development of Low Profile Ku/Ka band terminal for Mobile Satellite Service • ISRO is aiming at realizing the mobile satellite service in Ka-band. Researchers are encouraged to submit their proposal for Ka-band Mobile Satellite Service system solutions with their feasibility and recommendations; Proposals for terminal design, Proposal for protocol stack development for seamless overlay with existing MSS services, in case needed. Innovative ideas are encouraged from researchers towards providing reliable MSS services in Ka-band along with sub-system design proposals.	
I2.2	**Development of Low Profile Ku/Ka band terminal for Mobile Satellite Service (SAC)** ISRO is aiming at realizing the mobile satellite service in Ka-band. Researchers are encouraged to submit their proposal for Ka-band Mobile Satellite Service system	

	solutions with their feasibility and recommendations; Proposals for terminal design, Proposal for protocol stack development for seamless overlay with existing MSS services, in case needed. Innovative ideas are encouraged from researchers towards providing reliable MSS services in Ka-band along with sub-system design proposals.
I2.3	**Portable HUB baseband system development (ESIM) (SAC)** Earth stations in motion (ESIM) address a complex challenge – how to provide reliable and high-bandwidth Internet services to what are – literally – moving targets. They provide broadband communications, including Internet connectivity, on platforms in motion. There are currently three types of ESIM: ESIM on aircraft (aeronautical ESIM), ESIM on ships (maritime ESIM) and ESIM on land vehicles (land ESIM). Earth Stations in Motion (ESIMs) are the result of the most modern satellite technological developments and are designed to be used on aircraft, ships and land vehicles. They are small size terminals, with high-precision tracking capabilities, associated with state-of-the-art Ka-band satellites providing high-power multiple spot beam coverage, allowing transmission rates in the order of 10-50 Mbits/s. Recognizing that there is a need for global broadband mobile-satellite communications and that part of this need could be met by allowing ESIMs to communicate with fixed-satellite services (FSS). The advances in satellite and earth station technology make ESIMs the best solution for users on the move and bring the benefits of high performance FSS networks to communities that have yet to benefit from true broadband offerings. Researchers are encouraged to submit their proposal for design, development and implementation of different ESIMs.
I2.4	**Internet Protocol for Satellite Network (SAC)** In recent years, many routing algorithms have been proposed for LEO satellite networks. Routing Internet traffic over satellites can be addressed using two alternative approaches. We can simply consider each satellite as a node in the Internet and use a traditional protocol stack. However due to the long round trip time (RTT) delay between the satellites and the terrestrial infrastructure, problems such as routing instability and slow convergence will be even worse than only using the terrestrial Internet. On the other hand, we can consider the satellite network a separate autonomous system (AS), with its own protocols. In this case, an IP packet will be encapsulated in a suitable way when entering the constellation, and rebuilt when inserted back in the terrestrial network at destination. The routing problem is divided into two sub problems: Up-and-Downlink (UDL) routing and Inter satellite link (ISL) routing. Again, to ensure quality of services, research in this field is growing and there are various open issues and research areas in the field of Satellite Networks like – • Reducing the routing overhead of a dynamic QoS routing in a different traffic is a challenge

	• GEO satellites have advantage of technological maturity and good coverage but due to high delay and attenuation limits, transmitting real time information becomes a problem. A single layer LEO satellite network has poor performance on transmitting long distance. How to combine advantage of both the satellite to improve network performance • Multicasting datagram in the satellite networks to achieve larger coverage area on the terrestrial infrastructure is also a potential research area.
I2.5	**Adaptive protocol (SAC)** To cope with the highly dynamic behaviour associated with the wireless environment and mobility, it is widely recognized that protocols should be able to adapt to a wide variety of situations. While protocols in the wired network also adapt to different conditions in a very limited way, usually at connection-setup time. Once a connection in a wired network is established, the underlying conditions will remain relatively stable, other than occasional congestion. This is often not so in wireless mobile networks. The wireless link experiences a range of conditions e.g., fading, transient service outage, high error rates, burst error patterns, and highly unpredictable traffic on shared links. Furthermore, mobility exacerbates the situation by introducing handovers, motion-induced effects, rerouting actions, and limited battery life. Adaptive protocols provide productive ground for advanced protocol research. As nearly all protocol research has been done on relatively static protocol architectures, there is much to learn about how to select a different protocol on the fly when the original one no longer provides the required level of service. Protocol adaptation may be realized in several ways. Active networking, in which packets may contain executable instructions (in addition to headers and data), provides one approach to implementation. The efficient implementation of adaptive protocols in both hardware and software present interesting research problems. Some of the challenges are listed below: • End-to-end protocol design that dynamically switches from one interface to the other, transparently to the application and its user • Protocol stack development to support adaptiveness • Development of principles to allow on-the-fly protocol selection in wireless mobile networks. Identify techniques for deciding when to select a new protocol, for switching protocols, and for efficiently implementing this feature in software and hardware.
I2.6	**SATCOM in Non-Terrestrial Network (NTN) of 5G (SAC)** With the advent of 5G terrestrial network, Satellites are being proposed as an integral NTN component. ISRO is keen on extending its reach to be a part of next generation 5G communication, especially in the light of new satcom policy of the Govt of India. Researchers are encouraged to submit their research proposal for system and sub-system design for facilitating NTN component in 5G using SATCOM.

I2.7	**Q/V Band Propagation Study (SAC)** Presently Alphasat is the only satellite operating in Q/V band for European region available for such studies. Recently with GSAT-29, ISRO had established a limited capacity communication system for experimental purpose between Ahmedabad & Delhi. Due to congestion in higher band and bandwidth availability & demand, a very strong push for Q/V band is expected in future. Very high signal impairments and no availability of validated models for the Indian Region indicate a need to investigate this hereunto neglected area. These will serve as vital input for future satellite designs and deciding QoS and availability figures. Modelling and associated mathematical studies, development or realization of RF subsystems, beacon from satellite, pan-India study; Academia & Foreign Collaboration may be explored.	
I3	**Sub Area**	**ASIC Technology Development (SAC)**
I3.1	**Design and Development of miniaturized, multiband S, L, UHF band) / S-bandLow Power Wideband Transceiver Mixed Signal ASIC for SATCOM terminal (SAC)** • The mixed signal ASIC will comprise of comprise of front-end LNA, filter, transceiver with built-in LO for full duplex operations, gain& filter blocks, ADC-DAC etc. The selected architecture should have all imbalance measurement and compensation techniques built into it. The device calibration feature will be an added advantage. • The research proposal should address the development of low power, low cost custom RF wideband transceiver ASIC inS/L/UHF-band to support communication using miniaturized handheld and battery operated SATCOM terminals. The proposal should include all specifications of each sub-block, the reconfiguration parameters etc.	
I3.2	**Design and Development of RF-ASIC to support implementation of low-power, cost-effective electronic beam steering capabilities for aero- mobile communication in Ka/Ku band (SAC)** Aero-Mobile terminal in Ku-Band/Ka-Band with beam steering capability could be miniaturized using RF-ASIC. Researchers of this domain are encouraged to submit their proposal for design and implementation of RFIC for miniaturized, power and cost efficient terminal implementation.	
I3.3	**Development of low cost terminal with Commercial-off-the-shelf (COTS) ASICs for RF front-end (MMIC and LTCC based RF Frontend for miniaturization) (SAC)** There are a few techniques to reduce size & weight of the RF section. One of the most-utilized techniques is MMIC design in place of discrete microwave circuits where discrete active and passive components are integrated using either transmission lines on different substrates chosen according to frequencies. Monolithic Microwave Integrated Circuits (MMICs) contain active, passive, and interconnect components all on single wafer and	

	can operate at frequencies from hundreds of MHz to hundreds of GHz. The size advantage obtained is very drastic as MMIC are of size of um to mm whereas theMicrophone MIC circuits are in range of cm. Most of today's MMICs are fabricated on III-V compound substrates such as GaAs, InP, and GaN. This new technique enables us to make the circuits like LNA, Mixer, Power amplifier etc on a single Silicon doped chip, which are instead made using discrete components. Another miniaturizing technique lies in a type of packaging technology named Low Temperate Co-fired Ceramics (LTCC) where the technology is used for robust assembly and packaging of electronic components. It also offers may features like embedded components like capacitors resistors and inductors, as the passive components are available they can be utilized to make filters. The technology also allows us to make Substrate Integrated Waveguide filters. Further as the MMICs are bare dies, they need packaging, and interconnection LTCC proves to be the best option, which results in an integrated on a single RF module, which is very space efficient, and light weight. Furthermore, Antennas can also be made in order to make a more integrated space efficient and lightweight RF module which contains everything from Antenna to the IF signal. • Modem ASIC development for Ultra High Data Rate System (100 Mbps- 2 Gbps) • Mixed Signal ASIC development with built-in low cost SATCOM transceiver for various low-power IoT applications.
I3.4	**Power Saving technique (Backend ASIC design) of ultra-low power Software Defined Modem(SDM) ASIC (SAC)** Satcom baseband modem ASIC is being developed for various Satcom ground applications. Typical application of Modem ASIC, which are battery, operated & demands low power consumption. The Modem ASIC supports multiple mod-code & wide range of data rate. Based on application ASIC is configured by Serial Peripheral Interface (SPI)/Universal Asynchronous Receiver-Transmitter (UART) interface. Currently even when a simple configuration is running, the power of entire core is ON and the clock is active. Idea is to implement various power saving technique in frontend/backend ASIC design to suspend functionality of partial design or full design based on applications. Following power saving modes can be thought of considering nature of applications: • **Fully sleep mode:** This mode is very useful in case of burst transmission & reception. Device will consume minimal power when not active. In this case, only configuration core is always active. Modem core is enabled whenever required & kept shut for rest of the time. Typical applications: Reporting Terminal,

	• **Partial sleep mode:** This will be useful in almost all applications. This mode will disable the non-functional block for a particular configuration. In only Viterbi is used is active then other decoder should be shutdown. Entire receiver chain can be turn off in case of transmit only terminal & vice-versa. Typical applications: Two way MSS Vessel tracking terminal Sleep mode can be implemented using following methods i. Clock gating ii. Power gating iii. Multi-Voltage level	
I4	**Sub Area**	**Applications and Tools Development (SAC)**
I4.1	**Development of Hybrid Network for Real-time Person or Asset Tracking using Machine to Machine Communication Technology and Indian Navigation System. (SAC)** The network will consist of terminals having the ability to communicate their location and other significant information with the hub via satellite and terrestrial networks. The terminal will be equipped with NavIC receiver to detect its location. It should have the intelligence to detect the availability each of this network and switch between them as and when required. As an extension of this functionality, the terminal should be intelligent enough to detect the presence of similar neighbours (terminals) around it. This may be achieved via point-to-point communication using Bluetooth/Wi-Fi. The Hub can also assist in finding neighbours. The terminal can find its neighbours and can directly contact them in emergency. A smartphone may interface with the terminal for visual representation of location and other information. Mobility management and interface for interaction between terminals also needs to be developed. • Development of Spectrum and Waveform Analysis tool using low cost SDR platforms • Hub No Man's Sky (NMS), Network Control Program (NCP) and Web-based tools for effective Decision Support System • Propagation studies, Advance Fecal Microbiota Transplantation (FMT) development and inclusion for improved QoS • SATCOM System definition, Unified protocol stack and Test Bed development of 5G with Non-Terrestrial Networks (NTN) element • NTN standardization efforts and Capacity Development Activities • Development of mobility management algorithm and Hub Network Management System for different application	

I4.2	**Satellite Communication On The Move (SOTM) (SAC)** Satellite communications-On-The-Move (SOTM) is a communication capability used for high speed satellite connectivity in moving vehicle. SOTM terminal with vehicle mounted automatic tracking antenna will provide two-way, high-speed communications on the move under various operational conditions using HTS (High Throughput Satellite). Using SOTM terminal, it is possible to provide high speed satcom connectivity for aero-mobile, land or marine applications. ISRO has developed prototype Ku band SOTM receive terminal with 0.6m antenna using 2 axis (Az and El) stabilized servo based system and demonstrated it for live DTH reception in moving vehicle. Expected Outcome • Mechanism and Control system design for 3 axis/4 axis automatic antenna steering and tracking of targeted satellite within +/- 0.1 degree accuracy for Ku band transmission. • Solutions for estimating highly accurate heading information by INS (Inertial Navigation System)/ Sensor in dynamic magnetic environment. Magnetometer is not providing proper heading under dynamic magnetic field condition. • Technology for Low cost INS with GNSS without compromising performance • Compact and light weight Ku/Ka band flat panel/planner array antenna/ Carbon Fiber Reinforced Polymer (CFRP) reflector for mechanically steered transmit-receive SOTM system • Design and development of efficient electronic beam steering system for Ku/Ka band operations as well as hybrid scanning system (electronic + mechanical) • Design and development of system to test pointing accuracy of SOTM in lab environment and algorithms to find out misalignment.
I4.3	**Satellite Network Simulator (SNS) (SAC)** The project's main objective is to develop a Satellite Network Simulator, which is used to generate and collect data-driven insights into the satellite network-level planning and design activities. The simulator will allow an estimation of bandwidth and power requirements to attain a target system-level capacity. The simulator will model the Variable Coding and Modulation (VCM), Adaptive Coding and Modulation (ACM), and Uplink Power Control (ULPC) systems that will be executed in an operational satellite network. Using the simulator, the system engineer will determine the attainable data rates attained in the clear sky and the rainy conditions and gather insights into the potential avenues of removing or reducing the bottlenecks so that the overall system capacity is improved. SNS is being developed in Python language with features viz. to carry out the forward and return link budget calculations, rain fade modelling, capability of providing

	DR site suitability recommendation, ULPC/ACM simulations, selectable DVB-S2 and S2X modcods in both forward and return link and evaluation of system availability. It will be useful for System engineering, network planning, throughput evaluation at different fading levels of existing & future High throughput satellites in higher frequency bands.	
I5	**Sub Area**	**New Frontiers in SATCOM (SAC)**
I5.1	**Development of High Data Rate (HDR)/ Ultra High Data Rate (UHDR) modems for Home broadband service (SAC)** SATCOM based Home broadband service is one of the emerging field. Ultra High Data Rate Modems will be essential component of this technology. These modems should be capable of supporting upto 1Gbps receptions capability for offering broadband services equivalent to terrestrial broadband, to remote users. The major design challenges for such UHDR modems include reconfigurable hardware platform & high-speed data processing subsystems including demodulation loops, high throughput advanced FEC Encoder/Decoders & multi-core baseband data processing engines.	
I5.2	**Indigenization of Future HTS Gateways (SAC)** ISRO is inclined towards providing Direct to Home Broadway connectivity using HTS Satellites. This will require Gateways & antenna system in large quantities. Aim is to bring down the overall cost with indigenization efforts. Today, across the globe three major market players are operating and have maximum market share. The trend is to implement gateways in frequency band of Ka or higher band. Researchers and Industry partners are encouraged to innovate and propose efficient design of 9/11m antenna system, RF-sub-systems, NavIC based TFGU, Hub Monitoring and Control System, Antenna Tracking System etc. which can reduce design and production lead time, be cost effective and mass producible design.	
I6	**Sub Area**	**Satellite-Based Navigation (SATNAV) Technology & Applications (SAC)**
I6.1	**Interference/Jamming Detection & Mitigation (SAC)** • Pulse Blanking • Adaptive Notch Filtering • Control Radiation Pattern Antenna (CRPA) • Spectral filtering using FFT/ Inverse Fast Fourier Transform (IFFT) • Short time Fourier Transform • Wavelet Transform • Robust Statics	

I6.2	**Spoofing Detection/Mitigation (SAC)** Spoofing of GNSS signals has drawn a lot of attention due to increased risk among GNSS users especially by defense and strategic users. Spoofing is the intentional transmission of fake GNSS signals to divert users from their true position. This may fool a receiver to output wrong position. This may prove hazardous, even fatal in a strategic scenario. Following are the activities which may be taken up for development: • Automatic Gain Control AGC gain monitoring • Spoofing Detection usingReceiver Autonomous Integrity Monitor(RAIM) with/ without INS coupling • Angle of Arrival Discrimination • Signal Spatial Correlation • Correlation of Propagation-Dependent observables • Polarization Discrimination or Dual Polarization Antenna (DPA) • Sum of Squares (SOS) Detector • Cross-checks between code & carrier-phase measurements from different frequency bands
I6.3	**GNSS-INS Integration (SAC)** GNSS signals are highly vulnerable to jamming but provide very accurate position. However, INS cannot be jammed but position accuracy degrades after some time, primarily due to drift. Therefore, GNSS-INS integration is one of the most robust solutions to be offered to navigation users. Such kind of receivers are very useful where GNSS signals are obstructed such as inside long tunnels, indoors, under foliage, hilly terrain, urban canyon scenario, etc. Following are the techniques which could be addressed: • Loosely-coupled GNSS and INS integration • Tightly-coupled GNSS and INS integration • Deep-Coupled integration
I6.4	**GNSS Weak Signal Acquisition & Tracking (SAC)** • High Sensitivity Receiver The sensitivity of a baseband signal processing (acquisition & tracking), is critical for a GNSS receiver to function in weak signal environments. Typical Line of Sight (LOS) GNSS signals power is around -130 dBm. Attenuation due to foliage, tall buildings results in signal power level upto -160 dBm or lower. Very efficient FPGA hardware implementation is required. High Sensitivity Navigation Receiver for Commercial Applications. GNSS Receiver Algorithms for Space Service volume/Lunar mission type applications. • Open Loop Navigation Signal Processing

I6.5	**Development of CMOS /BiCMOS RFIC (SAC)** SAC is involved for design and development of NavIC based receiver for broad range of applications, like Civil, Military and Space applications. It is required to develop Complementary Metal-Oxide Semiconductor (CMOS)/BiCMOSBipolar Complementary Metal-Oxide Semiconductor,Radio Frequency Integrated Circuit(RFIC) to have multi-chip module solution along-with indigenous baseband ASIC and to have miniaturized NavIC Rx. for various applications. Commercial and space grade RFIC is required with the following blocks: • Tri band integer PLL/ Fractional PLL. • Triband / wideband LNA • Image reject Mixer Narrow band and wideband • Variable gain amplifier • Low drop out regulator • Complex filter for IF range • SPI interface to control the overall receiver block • Multibit ADC: Multibit low power ADC is required to meet high Anti-jamming capability. ADC specifications: i. aBit resolution: 16 bit ii. SFDR: 86dB iii. Sampling clock: 50MHz iv. ENOB: >14 bits • MEMs based Temperature Compensated Crystal Oscillator (TCXO): Satellite application of space-grade NavIC receiver required high acceleration sensitive TCXO. MEMs based TCXO can meet the 0.5 ppb/g acceleration sensitivity. MEMs based capacitive resonator is suitable choice for space application and piezo resistive resonator can meet ground application.
I6.6	**Construction and selection of balanced and near balanced Pseudorandom Sequences with lower correlation values and large linear complexity (SAC)** Spreading PRN codes are utilized in satellite navigation for ranging, spectrum spreading and satellite identification in Code Division Multiple Access (CDMA) based GNSS systems. Considering future navigation signals, there is an increasing demand of spreading codes families of various Length, family size, and correlation properties PRN sequences to be used in communication and satellite navigation should have certain statistical and correlation properties. While designing a sequence for satellite navigation, it is desirable for sequence to be balanced, have low value of out of phase auto-correlation and

	cross-correlation, have well behaved distribution of one and zeros and should be easily implementable in hardware. Since the sequences in sequences in the field of satellite navigation are also modulated by data or overlay codes thus, it is also desirable the sequences have low values of out-of-phase odd auto-correlation and odd cross-correlation as well. Sequences with longer length or time-period greater than few milliseconds are often partially cross-correlated in a navigation receiver. Large linear complexity sequences are a potential candidate for signals with anti-spoofing capability. This work involves designing of a PRN code family where each PRN sequence of the code family should have the properties of randomness. The code family set should have sufficient number of codes to satisfy a global constellation of satellites and enough for supporting the augmentation system, if any. It also involves selection criteria determination and to compare the performance of a set of codes against the performance parameter matrix to find optimum codes. Performance parameters for code selection include sequence balance; run length, orthogonality, auto- and cross-correlation histograms at various Doppler offsets, excess line weight and values for the low auto-correlation functions.
I6.7	**Design and Development of True Random Number Generators (SAC)** Random numbers are of paramount importance in field such as cryptography, Monte Carlo simulations, randomized algorithms etc.In contrast to Pseudo Random Number Generator, physical (true, hardware) random number generators extract randomness form physical processes that behave in a fundamentally nondeterministic way, which makes them better candidates for true random number generation. TRNG are useful for key generation in field of encryption and authentication of satellite navigation signals. This work objective is to develop a true random number generator, which produces random numbers that passes through the criteria of randomness, which is given by a series of statistical tests of National Institute of Standards and TechnologyNIST Test suit, Diehard battery of randomness tests etc. In general, TRNG suffers with unequal probability of occurrences of one and zero which is known as bias. Thus, the developed TRNG should also include the post processing mechanism of bias removal. Some of the RNG constructions are as follows- • Noise-based RNGs • Free running oscillator RNGs • Chaos RNGs • Quantum RNGs • The resources utilized by TRNG, its throughput and frequency of operation are some of the design criteria which needs to be considered while choosing an architecture. The generated random numbers should pass through randomness property measured using statistical tests.

16.8	**Multi constellation and multi frequency GNSS positioning algorithms (SAC)** Owing to the complementary nature of the various GNSS signals / services, there is a worldwide trend for deriving position solutions of more than one GNSS signal. Known as multi-GNSS, this has the potential of providing an accuracy superior than any of the GNSS signals when used singly; complementing the number of satellites in case of lower availability and / or blockage and extension to the space service volume (SSV). Employing more than one frequency (multi-frequency) to obtain the positioning solution offers the advantages of enhanced accuracy, resolution of ionospheric effects, etc. Potential research areas in these two domains may be satellite selection, triple-frequency for ambiguity resolution, inter-system/signal/frequency bias estimation, etc.
16.9	**GNSS Security, Vulnerability, Encryption, Authentication (SAC)** • Key exchange Algorithms: IRNSS RS service for authorized users involves encryption and to improve security, encryption keys are changed regularly to avoid brute force attack and cryptanalysis from unauthorized users. IRNSS RS receivers deployed in field will have to be communicated with changed keys. • Key Distribution/Key management for GNSS strategic applications • RAIM, Advanced RAIM and TRAIM Algorithms • Spreading Code Encryption for very long code using stream/block ciphers • Block-chain technology for authentication/security of GNSS services • Geo-encryption • Message Authentication Techniques for NavIC
16.10	**Precise Satellite Relative Location Estimation System for Tandem Satellites operation (SAC)** Design & development of "precise Baseline/Orbit determination system" for Tandem Satellites operation. Following are important research area in this topic: • High-precision GNSS receiver • Precise orbit & Baseline determination • Implementation Dynamic Force Models • High-precision orbit propagation
16.11	**Navigation Simulators (SAC)** The design and development cycle of GNSS Receivers is highly dependent on the signals provided by GNSS Simulators right from conceptualization to product development cycle. Following are important research areas in Navigation Signal Simulation: • Low-cost NavIC Simulator • Handheld GNSS Simulator • Interference Simulator for GNSS bands

	• Low-cost Navigation Educational Kit • Seamless indoor/outdoor navigation with NavIC and other Signals of Opportunity/ Technologies • LEO GNSS and NavIC + LEO GNSS Simulators
I6.12	**Software Defined Radio (SDR) based NavIC system Development (SAC)** SDR is a popular trend that allows the configuration of generic receivers that may be customized based on specific user requirements. Potential domains for research proposals in this area may be: • NavIC-GNSS receiver • NavIC-GNSS simulator • SDR for RTK and PPP • SDR for Pseudolite-based navigation System. • SDR for GNSS + Pseudolite System
I6.13	**Pseudolite-NavIC-GNSS receiver algorithm Development (SAC)** Pseudolite System is ground-based navigation system which may provide very accurate position within a localized area. These are low-cost systems and can be easily integrated with other GNSS systems. Following topics may be taken for development of new algorithms: • Successive Interference Cancellation to mitigate near-far problem in Pseudolite • Pseudolite-NavIC-GNSS hybrid user position algorithm/Extended Kalman Filter (EKF)/Unscented Kalman Filter (UKF) based algorithms • Time synchronization algorithms with GNSS • Signal acquisition & tracking in pulse-CDMA mode • Pseudolite indoor-positioning algorithms • Multipath mitigation algorithm • Algorithms for bi-directional Pseudolite based system for interplanetary scenario like Mars, Moon etc. • Pseudolites for landing application at Indian airports
I6.14	**LEO GNSS (SAC)** Position, Navigation and Time (PNT) services can be provided by mega-constellations in LEO orbits, which are otherwise primarily meant for providing communication and broadband internet services across the globe. Following are the research areas in this domain: • System engineering aspects • Doppler Positioning and Velocity Algorithms • New navigation processing algorithms for acquisition and tracking • GNSS+LEO constellation designs and algorithms

I6.15	**Differential Positioning & RTK Receiver Algorithm Development for NavIC (SAC)** Differential positioning is a technique which provide cm-level accurate position and transmits corrections from a base or reference receiver at accurately known location to a rover receiver through UHF/VHF link. This technique assumes that both base and rover receivers are observing common set of satellites. Differential positioning is performed using both pseudo-range and carrier-range measurements. Following algorithms may be developed: • Integer Ambiguity (AI) resolution in carrier-phase measurements • Carrier Phase-Based Positioning • Low-cost single frequency RTK receiver algorithms • RTK correction generation & dissemination module in RTCM format • GNSS Corrections: RTK, RTK-PPP, PPP • Network RTK for India • NTRIP based interface for NavIC • High-accuracy Post-processed RTK positioning algorithms
I6.16	**Precise Point Positioning (PPP) Receiver Algorithms (SAC)** Precise point positioning (PPP) is a technique using Global Navigation Satellite System (GNSS) satellites to achieve decimetre level or better position accuracy using a single receiver. This technique relies on the availability of highly precise ephemeris and clock products from a network of reference receivers without using a base station. PPP also requires a dual-frequency receiver with precise carrier range measurements. However, nowadays single frequency-PPP is also being attempted by researchers. Precision usually in this case means a horizontal position accuracy of 10 cm or better. • Precise ephemeris & clock product generation & dissemination • EKF-based PPP algorithms • Low-cost single-frequency PPP algorithms • Multi-constellation PPP • PPP-AR (Ambiguity Resolution) algorithms • High accuracy Post-processed PPP algorithms • PPP-INS positioning algorithms • PPP-RTK positioning algorithms • PPP with Pseudolite or GNSS + Pseudolite system

<table>
<tr><td>I6.17</td><td colspan="2">Atmospheric Studies (SAC)
NavIC L5 and S Band signals along with other GNSS signals can be used for estimation of better ionospheric TEC and relevant model development. These signals are useful for ionospheric scintillation studies and also for tropospheric model development.
• Ionospheric studies over the Indian Region
i. Real-time ionosphericTotal Electron Content(TEC)& scintillation map generation
ii. Ionospheric tomography model development
• Tropospheric Studies
i. Tropospheric model development for Indian region
ii. Tropospheric mapping function development
• Weather Monitoring and forecast through NavIC S-Band
i. Thunderstorm detection using Machine Learning/Deep Learning Techniques
ii. Multipath and Soil Moisture model development using AI/ML/DL</td></tr>
<tr><td>I7</td><td>Sub Area</td><td>GNSS Applications (SAC)</td></tr>
<tr><td>I7.1</td><td colspan="2">Precision Agriculture (SAC)
India is an agricultural country. Produce of agricultural products can be optimized using GNSS techniques such as RTK and PPP. This entails significant savings of equipment usage, fuel consumption, potential for manual error, etc. and can significantly enhance productivity. Following algorithms/solutions may be developed:
• RTK-based precision agriculture solutions
• PPP-based precision agriculture solutions
• Low-cost or community-based solutions (e.g. village-level)</td></tr>
<tr><td>I7.2</td><td colspan="2">Mobile Application Development (SAC)
• The availability of NavIC-enabled mobile phones will provide improved accuracy and availability as these mobile phones use all-in-view (multi-constellation) based processing. Besides GNSS, other sensors in the mobile phones can aid in improving accuracy as well as availability of position solution in the places with weak or blocked GNSS signals. Mobile applications can be developed for fusion of GNSS and sensor data for location-based services.
• NavIC-GNSS mobile App for location based services using GIS map
• Mobile-based train tracking App for Railways including paperless ticketing
• NavIC/GNSS based Navigation App for blind/physically impaired person
• Android Studio based positioning using raw NavIC/GNSS observables
• NavIC/GNSS anomaly reporting</td></tr>
</table>

I7.3	**Scientific Applications (SAC)** The following research activities may be suggested for scientific applications of GNSS. One may extend this work in future for finding the cloud dynamics and even for hydrology. This, however, is possible when the measured data is highly dense in nature. With more precision in measured data, it may also be utilized for finding the cyclonic condition and movements. Especially, NavIC S-band signals may be very useful for weather studies. Also, networked GNSS data may be utilized for earthquake research and hazard mitigation. Data from available network over India, may be collated, in one hand to find the crustal movements, while the post-earthquake signatures on ionosphere may be studied, on the other hand, to identify and index the strength of the earthquake and its extent. • Modelling Equatorial TEC perturbation • Forecasting of ionospheric scintillation • Integrated Water Vapour (IWV) estimation using GNSS • Cyclone tracking & Precipitation prediction • Seismic studies using TEC	
J	**Area**	**Antenna Systems (SAC)**
J1	**Sub Area**	**Antenna (SAC)**
J1.1	**Parallel Plate Waveguide Slotted Array (SAC)** Recent global trend of constellation of Small SAR satellites for remote sensing provides the opportunity for development of lightweight SAR antenna. One of the options for this can be parallel plate waveguide slotted array, which has inherent advantage of being lightweight, planar and suitable for easier deployment. The requirement is to develop a small sub-array tile and a deployable feeding network, to develop a large array antenna for lightweight SAR application.	
J1.2	**GRIN Lens based Beam Steering Antenna (SAC)** Lens based beam-forming antennas offer a low-power, low cost alternative to hybrid beamforming antenna arrays. Graded refractive index (GRIN) lens are the metastructures with a continuously spatially graded index of refraction which allows for some control of the EM radiation passing through the structure. The major advantage of use of graded index type lens (GRIN) is their capability to enhance the field of view using beam steering. Once the lens is designed with base radiator, it can be mechanically rotated to conically steer the beam. Such technology offers low profile and light weight beam steerable antenna best suited for various Ku and Ka band ground terminals being developed at SAC.	
J1.3	**Ultrawideband Dual Polarized Vivaldi Antenna Arrays for High Resolution SAR (SAC)** High-resolution SAR systems usually requires wide signal bandwidth, to achieve the fine resolution in elevation direction. Such system requires high gain Ultra wideband (UWB)	

	type array antenna to cater such need, for both polarizations. Vivaldi array antenna inherently offers wide bandwidth performance and one of the most suitable candidate for such SAR system. Vivaldi array antennas made with PCB technology allows reducing the height and overall mass of the array as well as improved feed network losses. Vivaldi antenna being the end-fire radiator, poses the main challenge in making it dual polarized and developing it using PCB technology. The preferred operating frequency range for the required UWB array antenna is 9-10GHz with ~33dBi gain.
J1.4	**High gain beam scanning antenna using near-field rotatable phase correcting plates (SAC)** Beam-scanning high-gain antennas are widely anticipated for future satellite based communication system and spaceborne synthetic aperture radar (SAR). The requirement of agile, slim and lightweight beam steering antenna is always preferable for the said systems. The use of nearfield rotatable phased correcting plates to conically steer the beam is one of the state-of-art technologies, being explored world wide in different forms. Such antenna system requires the base radiator, with nearly symmetric aperture field distribution. The two phasing disc offering progressive phase shifts in the two orthogonal directions are placed in the nearfield to offer the resultant progressive phase shift to the radiating field. Such beam steering concept is based on Risley prisms in optics. Such beam steerable antenna has major advantage in term of profile and mass. SAC has requirement to develop such antenna at Ka-band.
J1.5	**Mechanical Beam-Steering multi panel Array Antenna (SAC)** Low cost moderate gain beam steerable antenna are in urgent demand for MSS type ground terminals at S-band. Such antenna is to be designed with simple, stable, robust structure offering low production cost in commercial markets. Mechanical Beam-Steering Array Antenna (MBSA) is one of the technologies falling the similar category. Here, the phase shift is achieved by physically displacing the antenna element using motors on backside. The major advantage of MBSA is high aperture efficiency (>90%) as compared to the available competitive beam steering technologies.
J1.6	**Design & development of High Power Ferrite Phase shifters for RF beamforming Antennas (SAC)** The proposed research work will be catering to development of high power re-configurable beam antenna systems. Design and development of Ferrite based phase shifter involves selection of different types of phase shift mechanisms. Ferrite material selection. Ferrite biasing mechanism selection. Characterization of ferrite for a given bias and computing the hysteresis loop. The design can be of analog or digital type phase shifter. High power handling design and multipaction margins to be-analyzed. Size and compactness also play a vital role as these phase shifters will be accommodated between a cluster of feeds.

J1.7	**Plasma antenna (SAC)** The plasma antenna is an emerging technology that partially or fully utilizes ionized gas as the conducting medium instead of metal to create an antenna. The key advantages of plasma antennae are that they are highly reconfigurable and can be turned on and off, which is good for stealth and resistance to electronic warfare and cyber attacks. The plasma can be freely moved to the desired geometry of the reflector by plasma diode which enables the beam to be steered quickly without the need for mechanical motion. When the gas is not ionized, it allows other antennas to transmit and receive without any interference which is a very useful feature.
J1.8	**Design & Development of Terahertz Planar Array Antennas (SAC)** The proposed research work will be catering THz communications and imaging systems. Developing antenna systems at terahertz frequencies will investigate many problems related to antenna realization, integration and characterization Design and development of terahertz array antennas will involve selection of suitable radiating elements (Horn, slots, patch etc.) and design of appropriate feeding mechanism (waveguide, Substrate-Integrated Waveguide (SIW), Gap WG etc.). Emphasis should be on the antenna realization technology (silicon micro machining, metallization, Computer Numerical Control (CNC) fabrication etc.). The RF design should take care of all the limitations arising out of realization methods. The design should also address the scalability of antenna architecture to achieve higher antenna Gain. Suitability of material selection for space missions to be addressed.
J1.9	**Reconfigurable reflector antenna for Flexible payload (SAC)** In the life span of a satellite it might be required to change the service area and for that beam reconfigurability is the prime requirement. Reflector antennas are of paramount importance for satellite communication. While unshaped parabolic reflectors are useful for generating circular pencil beams, shaped surface are useful for generating contoured beams. Conventional reflector antennas are generally made of rigid materials and beams cannot be reconfigured while in orbit. Reflectors with phased array antenna as feed with a large number of active elements can be reconfigured in orbit, but they have a number of disadvantages in terms of complexity, mass, high power requirements and cost. Hence, it is required to develop reconfigurable reflector antenna made of some flexible material (electrically conductive) like membrane or mesh. The surface shape of the reflector to be modified using a matrix of linear actuators. Expected deliverables are complete research report with guide lines for development of reconfigurable reflectors, Realization of Reconfigurable reflector antenna operating at Ku Tx & Rx band – preferably dual reflector system with Gregorian optics and Performance demonstration at SAC CATF.

K	Area	Electro-Optical Sensor Technology (SAC)
K1	Sub Area	EO Sensor System Design, Simulation and Characterization (SAC)
K1.1		**Development of physics-based models for simulation of Electro-Optical Sensors (SAC)** Design and development of EO sensors is a very complex process and requires a thorough understanding of the system behaviour and assessment of its possible outcomes before one embarks on the development of physical system. A physics-based model of EO sensors can significantly help in understanding and visualizing performance aspects and also extensive trade-off studies. The model shall capture the functional/behavioural characteristics of various subsystems such as optics, detectors, electronics and also shall account for various instrument effects arising due to their complex interplay at highest abstraction level. The model shall help in simulating final data/images for a proposed EO sensor configuration to enable visualization and quantitative assessment of instrument sensitivity to the design parameters/system, environment/on-board processing/ viewing geometry, etc. Based on the model a software tool needs to be developed that should interface with COTS design software systems in Optical/Mechanical/Electrical domain and available RT models for atmospheric effect simulations. In other words, an end-to-end model shall be developed starting from simulation of ground targets, illumination conditions, observation geometry, intervening medium/atmosphere, at-sensor radiance, sensor characteristics, boundary conditions (under which the sensor is performing) leading to digital counts. The input scene to the sensor model can be typical laboratory targets, actual ground 3D targets or images acquired from the other sensors. This is an exciting research field and will help in the development of a comprehensive model and simulation tool for upcoming ISRO missions.
K1.2		**Design and development of on-board calibration system for absolute calibration of EO sensors (SAC)** Extensive pre-flight absolute calibration of EO sensors are carried out in laboratory for establishing the transfer function of the EO sensors. However, due to launch loads, in-orbit operating environment, and natural aging process of its components, the sensor characteristics tend to change. This has significant impact on accuracy of Digital Number (DN) to radiance conversion process, which in turn affects the remote sensing parameter retrieval accuracies. Hence, it is important to design and develop appropriate on-board calibration system(s) for periodic calibration and updation of the sensor response function to ensure desired accuracy in DN to radiance conversion. The calibration system should ensure both radiometric and spectral calibration from visible to Infrared Radiation (IR) spectral region. These sources can be passive or active. Research is invited in the areas of design and development of on-board calibration sources e.g. Blackbody for IR calibration

	(high emissive nano-particle coating), diffuser plate for Visible/Near-Infrared (VIS/NIR) calibration, doped diffusers or active sources for spectral calibration. These systems are required to be compact and stable over long period of time. This can significantly help in improving the accuracy of payload data.
K1.3	**Design and development of a proto-type LIDAR system (SAC)** Light Detection and ranging (LIDAR) measures distance or characteristics of the target by illuminating that target with a laser light. A narrow laser-beam can map physical features with very high resolutions. Typically, light is reflected via backscattering. LIDAR can be used for ranging, surface profiling and atmospheric studies (clouds, aerosol and wind). Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by identifying wavelength dependent changes in the intensity of the returned signal.
K1.4	**Image Simulators and Algorithms for Characterization of Imaging Sensors (SAC)** EO sensors undergo extensive pre-flight testing and performance characterization to ascertain sensor behaviour and demonstrate performance compliance against specifications. Currently, static targets such as bar targets, slits, and flat field targets are used as input scenes for the EO sensor testing and characterization. However, this limits test capability in terms of temporal, spatial, and spectral variations in the scenes that an EO sensor sees in the actual remote sensing scenes. Research opportunity exists for design and development of synthetic scene simulators to generate dynamic scenes for EO sensor testing and characterization. Digital Mirror Device and Digital Light Processing can be potentially used for generating Multi-spectral and Hyper spectral scenes. The research in this field involves design and development of hardware and software system for generating suitable synthetic scenes having required dynamic variations, development of methods/algorithms for EO sensor performance estimation using the sensor output and evaluation in terms of image quality metrics, etc.
K1.5	**System configuration and simulation studies for Sparse Aperture telescope (SAC)** The angular resolution of a traditional telescope is diffraction-limited and is given by $1.22\lambda/D$, where λ is the wavelength and D is the size of the optical system aperture. However, the optical system aperture is limited by the current glass-making technology and the cost involved. In order to overcome this limit, the technique of optical synthetic aperture have been reported in the literature. The optical synthetic aperture consists of several telescopes (as shown in figure below) with smaller apertures, phased in a manner to generate an equivalent large aperture.
K1.6	**System design, simulation studies and control system development for Segmented mirrors based EO sensor (SAC)** A segmented mirror is an array of smaller mirrors designed to act as segments of a single large curved mirror. The segments can be either spherical or asymmetric. They are used

	as objectives for large reflecting telescopes. To function, all the mirror segments have to be polished to a precise shape and actively aligned by an active optics system using actuators built into the mirror support cell. In this research field opportunity exist to study feasible system configuration, develop simulation model, design and develop metering, actuation and control systems to maintain the segments in required shape and orientation to get the desired performance. This research aims to develop a small-scale prototype for demonstration and validation of the involved technology elements, and processing techniques.
K1.7	**Extending Super Resolution concept to Spectral Domain (SAC)** Extraction of finer spectral resolution information from Hyper-spectral Imagery, given a large number of relatively coarser resolution images with overlapping spectrums. Similar to super-resolution imagery, if data is collected with a given spectral bandwidth, but with finer spectral sampling compared to the bandwidth, then it should be possible to generate images having narrower spectral bandwidth. The scope of the work includes development of models and simulation studies to demonstrate the concept and also develop a proto-type system to study hardware implementation aspects.
K1.8	**Design and development of Active cavity radiometers (SAC)** Active cavity radiometers (ACRs) is one type of pyrheliometer used for measurement of direct beam solar irradiance. It is an electrically self-calibrating, cavity pyrheliometer used to measure total and spectral solar irradiance. They can be suitably tuned for measuring radiation from UV to IR spectral region. These radiometers remain stable over long duration and thus can be used as a calibration standard for relative calibration of uniform illumination sources or spectro-radiometers. Various research opportunities in the field includes studying active cavity radiometers, define feasible system configuration, perform extensive simulation studies and develop a proto-type model for demonstration.
K1.9	**Long range 3D imaging using flash LIDARs (SAC)** 3D Flash LIDARs have emerged as a potential imaging sensors for real time terrain mapping, 3-D measurements, guidance and navigation to support in rendezvous and soft landing missions, etc. A 3D flash LIDAR provides depth information of objects in the scene in addition to their 2D spatial distribution. The technological elements in 3D flash LIDARs involve Laser head, receiver optics, focal plane unit and electronics system with embedded image processing techniques for 3D measurements etc. This research envisages design and development of a proto-type 3D flash LIDAR imaging systems that involves system configuration studies, simulation studies, realization of small scale proto-type with COTS components, development of electronics system with embedded processing capabilities, performance characterization and field studies.

K1.10	**Design and development of high-resolution imaging system with active optics correction elements (SAC)** High resolution imaging system generally employ large aperture optical systems and are generally affected by launch loads and orbital environmental conditions, which induces large amount of aberrations effects leading to loss of MTF in the acquired images. Active optics correction systems enable corrections of these deformations using an actively controlled optical surface in the telescope chain. The proposed study aims to design and develop an active optics correction based EO sensors for future missions.	
K2	**Sub Area**	**Focal Plane Detection Systems (SAC)**
K2.1	**CCD and CMOS sensor fabrication process modelling and simulation studies (SAC)** CCD and CMOS image sensors are mainstay sensor technology employed in spaceborne imaging systems. State-of-the-art imaging systems require custom development of these sensors. Sensor fabrication process and device modelling and simulation studies are very important milestone in the development of these sensors. SEDA has developed a dedicated modelling and simulation lab for design of these sensors as it allows more leverage to meet custom requirements. The lab is equipped with various simulation tool kits such as Technology Computer-Aided Design (TCAD) and MATLAB etc. The research opportunities include modelling of CMOS and CCD based optical image sensor fabrication process to estimate key performance parameters such as quantum efficiency, cross talk, sensitivity, dynamic range, charge handling capacity, etc.	
K2.2	**Modelling and simulation studies on Superlattice structure-based SWIR and MWIR sensors (SAC)** Infrared imaging detectors are increasingly being used in the focal plane of spaceborne imaging systems as it offers unique opportunities for variety of remote sensing applications. SEDA has taken up modelling and simulation activities for design of exotic sensors operating in Short-Wave IR (SWIR), Medium-Wave IR (MWIR) and Low-Wave IR (LWIR) spectral range. Research opportunities in this field includes TCAD and MATLAB modelling of Type-II superlattice structure for sensitivity in IR ranges, development of methodologies for higher temperature operation by suitably modifying stack to reduce dark current and development of techniques for enhancement of Quantum efficiency beyond 50%.	
K2.3	**Design and development of high power NIR and SWIR LASER modules (SAC)** Spaceborne LIDAR systems are gaining attention of the remote sensing community as it offers variety of applications in surveying, geodesy, geomatics, geomorphology, seismology, forestry, atmospheric physics, laser guidance, and laser altimetry etc. One of the important elements in the LIDAR system is high power Light Amplification by Stimulated Emission of Radiation (LASER) system. Currently SEDA is exploring design and development of the of high-power NIR & SWIR laser modules. The research opportunities include design and development of laser head, amplifier circuits, pump sources, drivers, diffractive optical elements, cooling system etc for long distance 3D measurement and flash LIDAR applications.	

K2.4	**Thermal Background modelling for integrated IR detector cooler assembly (IDDCA) (SAC)** Thermal background is one of the major sources of noise and offset in the IR detector system. Hence, it is important to estimate thermal background flux in the IDDCA to implement effective thermal control system. The research opportunities include development of physics-based model for estimation of thermal background in a given IDDCA configuration using various software tools such ray-tracing tool, thermal analysis tool, result visualization and quantitative estimation in Labview/Matlab etc. These modelling efforts will help in understanding the source of thermal background and enable improved design of IDDCA and the imaging system.
K2.5	**Design and development of drive circuits for CCD sensors (SAC)** The research opportunity exists in design and development of CCD based image sensor drive circuitry for minimization of noise floor and clock induced charges. The design shall adopt different circuit design techniques for shaping CCD clocks (-10V to +15V, drive capacitance: 500pF, frequency: 10MHz) for maximization of stable video and reference sampling zones.
K2.6	**Design and development of Photonics Integrated circuits (PIC) based system on chip (SAC)** System-on-chip significantly helps in integrating various image sensor circuit function in a very small footprint, thereby saving resources on payload/spacecraft. The research focuses on design and development of integrated circuits for clock and data multiplexing / demultiplexing, modulation/ demodulation, laser driver, laser and photodetector, packaging of imaging detector with PIC based chipset to miniaturize focal plane detector proximity electronics.
K2.7	**Design and development of High speed Event detector (SAC)** The research focuses on design and development of CMOS image sensor pixels for automatic thresholding, target detection and tracking applications. Fast occurring events could be observed by identifying them within the pixel at analog level by using programmable thresholding circuitry. The pixel level circuitry initiates readout by raising appropriate flag. Such flags help row – column circuitry to readout events of interest at high frame rate, up to 50kHz. Once of the possible application could be automatic detection and radiometry of lighting events.
K2.8	**Development of process flow for CMOS chip debug (SAC)** The research opportunities exist in the de-processing, micro-surgery, hot electron imaging active micro-probing, and IR microscopy, etc for debugging of CMOS chips. After we fabricate any chip, it is quite challenging to debug possible problems areas (design, fabrication, assembly, integration, packaging and testing) if it does not meet the desired performance. We have to develop some of the chip debug tools to be able to debug

	complex chips. These sort of tools and technologies would also help to identify possible reasons for yield reduction.
K2.9	**CMOS pixel process development at 180nm (SAC)** The research opportunities exist in Pinned photodiode-based pixel (7 to 50micron pitch) development to meet charge handling requirement from 30ke to 3Me. This research will lead to development of pixel process for TDI CMOS focal plane arrays.
K2.10	**Packaging of Infrared detector arrays for multispectral application (SAC)** This research focuses on development of techniques using industry for butting of smaller arrays to form large arrays, integration of filter / cold shield / lens, assembly of detector onto cold table mounted with flexible thermal link for cooling down to 50K and minimization of thermal load by utilizing new interconnect materials.
K2.11	**Design and development of Ultraviolet detectors based on wideband gap semiconductors (SAC)** Photon detectors based on wide band gap semiconductors have recently garnered considerable attention due to its suitability in development of highly sensitive ultraviolet detectors. The scope of research includes comprehensive review of literature in the field, understand the mechanism of these sensors, inherent advantages and disadvantages of those detectors, explore suitable materials for producing these detectors, etc.
K2.12	**Development of curved sensors (SAC)** Curved image sensors have emerged as novel technology that can decouple the traditional constraints between field-of-view (FOV), resolution and image quality. Usage of curved sensors relaxes the stringent imaging performance requirements on the optical systems at extreme fields. Many research groups are working on the device fabrication technologies. The scope of the research in this field is to explore various fabrication process technologies, carry out design and simulation studies for pixel architecture for curved sensors, address issues/challenges in the field and attempt to develop proto-type curved sensor for characterization studies. This research will lead to adaption of such curved sensors in the future spaceborne missions.
K2.13	**Metamaterial based absorber surfaces for image sensors applications (SAC)** Metamaterial structures have attracted substantial attention due to their ability to obtain desired effective permittivity and permeability by carefully designing its structure. It has resulted in the discovery of exotic phenomena such as negative refraction, cloaking, perfect absorption etc., which are not possible with ordinary materials. Broadband metamaterial absorber shows a promising prospect in applications such as controlled reflectors, solar cell, infrared detection. Junyu Li, Haoran Zhou et al have developed deep subwavelength plasmonic metamaterial absorbers for infrared detection (Conference on Laser and Electro-Optics (CLEO) 2019 © OSA 2019). In this study, a metal-insulator-metal based infrared plasmonic metamaterial absorber consisting of deep subwavelength

	meander line nano-antennas(MLAs) based array was fabricated and experimentally demonstrated the absorption from 11 µm to 14 µm with a pixel pitch of 1.47 µm. Plasmonic metamaterial absorbers (PMAs) are arrays of subwavelength-spaced metallic nano-objects (also termed as optical antennas) whose primary function is to concentrate the propagating light into regions much smaller than the wavelength and efficiently dissipate the optical energy into heat via localized surface plasmon resonances (LSPRs). The proposed research aims to explore CMOS compatible metamaterial absorber structure, simulation of absorption characteristics of these materials, explore fabrication feasibility, etc.
K2.14	**Dilute Magnetic Semiconductor (DMS) material synthesis for spintronics applications (SAC)** A new class of materials known as dilute magnetic semiconductor (DMS) are semiconductor materials that exhibit both ferromagnetism (and a similar response) and useful semiconductor properties. If implemented in devices, these materials could provide a new type of control of conduction. Whereas traditional electronics are based on control of charge carriers (n- or p-type), but magnetic semiconductors would also allow control of quantum spin state (up or down). DMS have been a major focus of magnetic semiconductor research. These are based on traditional semiconductors, but are doped with transition metals instead of, or in addition to, electronically active elements. Due to their novel properties of change and spin control, they have generated huge interest among the scientific community as a strong candidate for the fabrication of spin transistors and spin-polarized light-emitting diodes.
K2.15	**Optical Beam Steering Photonic Chip for Lidar (SAC)** In a Lidar, a laser beam is formed to concentrate the optical power within single pixel instead of the whole scene, which makes it a point-wise measurement system. To form an image, the beam is scanned through the FOV Namely, a beam scanner. Scanning LiDAR achieves higher signal-to-noise ratio (SNR) at the cost of lower points per second (i.e. point throughput) and slower frame rate, and more importantly, at the cost of having a beam scanner. Beam scanner is often realized through mechanical actuation of either the source itself or the discrete optics around the source. While mechanical optical beam scanner design is already an established domain of engineering, there is a fundamental challenge associated with achieving good control precision and reliability goals for automotive vehicles using a low-cost mechanical system. To reduce the unit cost of a scanner module and make it feasible for consumer electronics, various solid-state beam scanning solutions are the preferred option. There are many approaches to realize a photonic chip for Optical beam steering like MEMS Switch based array of grating coupler, Optical phased array, true time delay based beam steering, etc. The beam steering chip shall define the beam width of less than 0.2 degree and shall steer the beam within 20 degrees in both axes.

K2.16	**On-chip nano wire grid fabrication for polarization sensing (SAC)** Traditional imaging systems have focused on capturing and replicating the imaged environment in terms of colour and intensity. One important property of light, which the human eye is blind to and it is ignored by traditional imaging systems, is polarization. Polarization of light caused by reflection from materials contains information about the surface roughness, geometry and other properties of the imaged environment. Polarization-contrast imaging has proven to be very useful in gaining additional visual information in optically scattering environments, such as target contrast enhancement in hazy/foggy conditions, depth map of the scene in underwater imaging, presence of ice in clouds or non-spherically shaped dust particles and in normal environmental conditions, such as classifications of chemical isomers, classifications of pollutants in the atmosphere, and non-contact fingerprint detection among others. In addition, polarization of light has found a niche in many biomedical applications, such as imaging for early skin cancer detection, cell classification and retinal surgery. Wire grid polarizer is compatible with complementary metal-oxide-semiconductor (CMOS) technology, and it can be fabricated monolithically by using metal layers for wiring. Using deep-submicron CMOS technologies, which allow the design of metal patterns finer than 100 nm. The angle (0, 45, 90 and 135 degree) of the polarizer on each pixel can be designed.	
K3	**Sub Area**	**Design and Development of Optical Systems (SAC)**
K3.1	**Optical systems using freeform surfaces (SAC)** Freeform optics offers more degrees of freedom to optical design that can benefit from a compact package size and a large field of view for imaging systems. The introduction of freefrom optical surfaces in a space instrument offers the possibility to improve its performance, its volume and weight or a combination of both. Motivated by the advances in modern optical fabrication and metrology, freeform optics has found place in many applications. The freeform mirrors are manufactured by diamond turning based on a feedback modification strategy. Freeform optics involve optical designs with at least one freeform surface which, according to the International Organization for Standardization (ISO) standard 17450-1:2011, has no translational or rotational symmetry about axes normal to the mean plane. Integration of freeform optics and surfaces into imaging systems remains a major challenge. However, the new degrees of freedom introduced by freeform optics designs are the driver to overcoming these challenges. These additional degrees of freedom enable many potential advantages, including system miniaturization, reduced component count and even entirely new optical functionality that will have a profound effect on the optics industry.	

K3.2	**Chalcogenide optics in dual-band IR Applications (SAC)** Chalcogenide glasses consist of mixtures of the Group 16 elements selenium (Se), sulphur (S), and tellurium (Te), and various Group 14 and 15 elements such as arsenic (As), germanium (Ge), tin (Sn), and others. These glasses are well suited for imaging in the IR regime because of their high transmission, low dispersion, and low refractive-index change with temperature. By changing concentration ratios, glass properties can be tailored for index of refraction, dispersion, glass transition temperature, and other properties. This gives the optical designer or the lens manufacturer more freedom than traditional IR materials. As traditional IR materials such as Ge and zinc selenide (ZnSe) rise in cost, the use of chalcogenide glasses is becoming more widespread. Chalcogenide materials offer substantial savings today in both the raw material cost and in fabrication methods such as molding technology. They also provide numerous benefits to systems with stringent specifications. There are many sources for chalcogenide glasses, including Vitron GmbH (Jena, Germany), SCHOTT North America (Duryea, PA), and IRradiance Glass (Orlando, FL), which produces a number of glass types along with custom melts. The scope of the Research: • Study of feasibility for use of chalcogenide glasses for spaceborne remote sensing application. • Design of dual band IR common optics using chalcogenide glasses that will image both MWIR and LWIR on the same or different imaging sensors. • Collaboration with indigenous industry and universities for realization of Chalcogenide optics via. Fabrication, assembly and testing for achieving the desired performance goals.
K3.3	**Adaptive test techniques for Aspherics and Freeform surfaces (SAC)** During the manufacturing of optics, the in-process (i.e., not-yet-completed) optical surface must be accurately measured to correctly guide the iterative fabrication process. The customized null element makes the process time taking and costly. Also, for interferometric surface form measurement of final freeform surfaces the measurement is limited by the Nyquist criteria, which is often encountered due to large slope of freeform surfaces. To overcome this, one of the current techniques is Adaptive interferometric null testing method. The adaptable null component may be a Spatial Light Modulator or Deformable Mirror.
K3.4	**Test set up using Spatial Light Modulator (SAC)** The DM-based null test is adaptive and economical compared to CGH; however, DM has limited range of stroke of actuators and can only compensate mild free form departures. A high-definition (i.e., >1080 pixels, <5 μm pitch) spatial light modulator (SLM) circumvents the limitation of the DM. The phase conjugation algorithm is additionally utilized for turning resolvable fringes into null ones. Finally, local severe surface figure error is extracted from the SLM phase and the null test result by reverse optimization based on ray trace model.

K3.5	**Tilted Wave Interferometer (SAC)** The use of aspheric and freeform surfaces becomes more and more important in the design of modern optical systems. These surfaces offer additional degrees of freedom to the optical design, allowing to improve the optical imaging as well as to reduce the number of surfaces needed for an optical design. However, testing of such surfaces is still a difficult task. This issue can be addressed using the technique of Tilted Wave interferometer. TWI is non-null, full-field interferometric measuring technique for aspheric and free-form surfaces with a new degree of flexibility. The interferometer uses a set of tilted wave fronts to locally compensate the deviation of the surface under test from its spherical form. Also since its non-null technique, hence the costly optics is not required for testing. The main difference of this approach to the scanning type interferometers is that the acquisition of the data is highly parallelized, since all test wavefronts are applied to the surface in only four steps. Further, the surface under test (SUT) does not have to be moved during the measurement process. Both these advantages lead to a very short measurement time of far under a minute.
K3.6	**Optical Design of telescope for space observatory for study of Exoplanets (SAC)** Planets that orbit around other stars are known as Exoplanets. Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit. Therefore, indirect methods such as radial velocity, transit photometry/spectroscopy and timing variation methods are used to detect exoplanets. In some cases, direct imaging method is also used to find exoplanets. The telescope to study exoplanets can consist of a single instrument (eg. Characterising ExOPlanets Satellite (CHEOPS) ofEuropean Space Agency(ESA)) or a cluster of instuments (eg. Habitable Exoplanet (HabEx) of National Aeronautics and Space Administration (NASA)). The design options include Ritchey-Chritien (RC) or a three mirror anastigmat (TMA) design followed by science instruments. The spectral range of these telescopes generally include ultraviolet (UV), visible and near-infrared (near-IR), shortwave infrared (SWIR) and sometimes midwave infrared (MWIR) regions. The telescopes include both imaging and spectroscopic capabilities. Stray light suppression using effective baffling is very important as the faint light from exoplanets should not be suppressed by any other light coming from earth or stars. Research in this field is invited for the development of optical systems for upcoming exoplanet missions.
K3.7	**Design and development of Volume Holographic Grating (VHG) (SAC)** VHGs are widely used in ground based astronomical spectrometers with moderate to large diameter telescopes ranging anywhere between 8 meters to 10 meters. These have also been extensively used in gas sensors where spectral peaks with very narrow bandwidths are required to match with gas absorption spectra. They are suitable for both ground and spaceborne applications. Considering the major advantage of higher number

	of grooves/mm and consequently finer spectral bandwidth of few picometer, the VHG have been used in multiple global space missions like Sentinel 3A and Rosetta etc. This research proposes design, fabrication and characterization of a plane/curved VHG for spaceborne imaging spectrometers for astronomical observations and environmental monitoring. The fabrication of VHG basically involves writing of a typical pattern by optical interference between two coherent laser beams (reference and object beams) superposing in a photosensitive material making fringes in the material by means of a periodical variation of the refractive index (i.e. a sinusoidal profile) throughout the volume of the photosensitive material. The technique enables writing 600 to 6000 grooves/mm on a substrate diameter upto 850 mm. The Scope of the research as follows • Modelling of the grating with peak efficiency at required wavelength mainly catering to VNIR and SWIR, fabrication and characterization. • Indigenous/ in-house development of the holographic exposure system to record fringe pattern of desired frequency and orientation using photo-polymer coated plane/curved glass substrate. • Indigenous / in-house development of photo-polymer or gelatin like films. • Development of a suitable processing technique so that modulation pattern is accurately reproduced after a wet-dry processing cycle. • Exploring feasibility for space usage and carrying out related testing.
K3.8	**Computer Generated Holograms (CGH) (SAC)** Aspheric and freeform optical surfaces are frequently used in spaceborne/airborne sensing instruments as they help in reducing the number of optical components in the system, thereby reducing the size and weight of the sensing instruments. Aspheric surfaces are usually tested using null interferometric testing methods: either refractive (null lens) or diffractive (Computer generated Holograms). A Computer Generated Hologram (CGH) is produced via computer synthesis, where the object does not exist physically but it is expressed in mathematical terms. CGH's can generate any shape of wavefront including freeform. Two types of CGH's are used: Amplitude CGH (chrome pattern on glass) and Phase CGH (Pattern etched on glass). High precision and high resolution CGH's can be fabricated using microlithography technologies like electron beam lithography and laser beam lithography. These microlithographic techniques are common in semiconductor industry for integrated circuits (IC) fabrication. The Scope of the research as follows • Resist (e-beam or photo resist) coating • Electron beam / Direct Write Laser (DWL) Lithography for resist patterning • Resist development, Metallization (E-Beam evaporation) • Lift-off or Wet Chemical Etching for Amplitude CGH and Glass dry etching for Phase CGH

K3.9	**Design and development of Strip Filters in VNIR spectral range. (SAC)** Strip filters are interference filters. The strip filter assembly can be developed using butcher block technique. In this the filter strips catering to different spectral bands are glued together to form an array. Using the coating facility (SYRUSpro1110) at thin film lab SEDA, the required band pass filter (B1-B4) coatings will be developed. These filters are then diced into strips of required widths using the dicing facility in the lab. Four filter strips belonging to different bands (B1-B4) will then be glued together to form the filter arrays. These activities can be carried out at SAC. In order to use it on board, one needs to block the stray radiations at the junction of the strips, for which masking coating needs to be applied, which also defines precisely the clear aperture of each filter strip. For this purpose, we need to use lithography followed by masking coating deposition followed by dry etching. At present these facilities are not available in the lab, hence the facilities available at other institutions can be utilized for this purpose.
K3.10	**Development of band pass filters with controlled thickness variation across the filter length (SAC)** The interference band pass filters are sensitive to angle of incidence. Not only the central wavelength shifts due to angle but also the shape and transmission changes at higher incidence angles. This becomes more significant in case of narrow band pass filters. In optical payloads with large field of view, it becomes almost mandatory to design the tele centric optics in order to minimize this effect. This in turn makes the design very complicated and may require aspheric components, which are difficult to fabricate. In order to reduce spectral shifts due to large angles, a band pass filter can be design to compensate for this shift by introducing controlled variability in the filter thickness. The variability can be introduced by designing the appropriate masks, which will be filter specific. By replacing conventional filters by these variable filters, the optical design can be made very simple. The design of these filters will be done in house. Development of the controlled thickness variation of the coating across the filter will be taken up in collaboration with Academic institutions.
K3.11	**Development of IR filters (SAC)** For payloads, involving IR imaging we need filters catering to the spectral range from 3 – 15 microns. The proposal is to design the filters in house and get it coated with the help of institutions within India. At present, the thin film lab does not have the facilities to develop the coatings in the IR spectral range. These activities can be taken up with the help of other institutions within India.
K3.12	**Development of Rugate Notch Filters (SAC)** Notch filters are optical filters that selectively rejects a portion of the spectrum, while transmitting all the other wavelengths. Notch filters based on the principle of optical interference can be fabricated using Rugate dielectric stack, which provides high reflection in a narrow wavelength region and high transmission outside.

K3.13	**AI enabled design of next generation optics/optical systems (SAC)** The traditional design method for imaging optics is to first find a starting point, and then perform optimization. However, for freeform system design, proper starting points with similar system specifications and special nonsymmetrical configurations are very rare, which greatly increases the possibility of using extensive human effort. Use of Deep learning algorithms (Artificial Neural Network (ANN) in particular) can significantly aid in finding optimized starting points for imaging system design. This research work envisages development of an intelligent framework where the entire design process need not be repeated again and will result in faster development of EO payloads.	
K4	**Sub Area**	**Electronics System Design and Development (SAC)**
K4.1	**Development of Integrated Circuits for Harsh Environment Operation (SAC)** Harsh Environments are defined as environments, which are characterized by high/low temperatures, extreme vibration loads, harsh chemical environment, high radiation etc. The electronics or systems required to operate under such harsh/extreme conditions have application such as in aircraft engines, automotive, oil-well drilling and space exploration like near to Sun and planets like Venus where the surface temperature is appx. >400^{o}C. Hence there is a requirement of development of electronics and sub-systems (both commercial and space) which can operate under extreme environments. Present technology used in development of integrated circuits are mostly Silicon which is suitable for reliable operation when the temperature is <150^{o}C. The other technology Silicon-On-Insulator (SOI) can operate upto temperatures <300^{o}C. Hence, these ICs are susceptible to damage in high temperature and radiation environment and hence require additional distancing and shielding, thereby putting restrictions to where these circuits can be placed. Recent developments have shown use of wide bandgap (WBG) semi-conductors like Silicon Carbide (SiC), Gallium Nitride (GaN), diamond etc. These materials have shown tremendous resistance to harsh temperature and radiation. Development of an integrated (like SiC-CMOS) circuit technology enables development of integrated circuits which are stable in harsh environments. The benefits are improved reliability, reduction in size / weight and power for cooling systems (which are typically required when conventional electronics (Si or SOI) is used) and possibility of direct sensing and control systems in harsh environment.	
K4.2	**System Modelling and Controller Development for IR Payloads (SAC)** Various control systems are used in IR payload for controlling the temperature of various Opto-mechanical elements. IR detector requires temperature control of IDDCA cold tip, detector window, Blackbody and other elements within few mK accuracy and stability. There is a need to develop an executable model of the system including the plant using first principle methods or other methods (using experimental data). MATLAB or other modelling tools can be used for developing the executable model.	

	Methodology: • In first principle method, equations governing the working principle of the plant are developed. Consideration to material properties and interfaces are given to develop accurate relationships between controlling variable and controlled variable. If information related to operation of some blocks are not available, field data (experimental data) can be used to model these blocks. • Above models are simulated and Controller is tuned and optimized for best performance in terms of overshoot, rise time, settling error and stability. • Additional logic e.g. safety logic can be included for protection against over current / voltage. • Controller architecture algorithm should be selectable / programmable. • This PID controller is to be implemented in Micro-controller/FPGA. To achieve this translation from the system level model to HDL or C language is required. This can be achieved using C Code or HDL coder toolboxes or similar tools/ methods. • Generated HDL/C Code are simulated and compared against the results from system level model. • Final validation is done by doing Hardware in loop tests with the actual FPGA/Micro-controller.
K4.3	**ASIC: Design, Simulation, Fabrication and Modelling (SAC)** The scope the activity covers Analog, Digital and Mixed signal ASIC design, simulation, verification, layout, tape-out and fabrication. The main motivation is miniaturization and indigenization of electronics in the form of low power ASICs and Readout Integrated Circuits (ROICs) with objective of integrating multiple functionality in a single device. The ultimate goal is to integrate individual blocks to realize "System on Chip (SOC)". Some of the ASICs, but not limited to, are multi-channel Analog Front end device for detector signal processing, High data rate Serializer-deserializer, High precision low noise multi-output voltage reference, programmable bias generator and regulators (negative and positive), Bipolar high speed high capacitive CCD clock drivers, IR detector ROICs, multi-channel temperature controller, switches etc. Design and development of radiation hardened library covering standard cells and devices is also covered under the scope. ASIC modelling either software or based on implementation in FPGA/microcontroller of various ASICs to be part of various system level simulations and optimizations is also envisaged.
K4.4	**Modelling of Special Components, Interfaces, Hardware (SAC)** Modelling of various state of the art mixed signal devices, detectors, interfaces etc is envisaged. Font-End design (detector proximity electronics) of an electro-optical payload faces lot of constraints w.r.t system requirements, detector used, real estate availability, harness routing, mechanical design, optical ray diagram, thermal requirements, grounding scheme, hardware in the vicinity etc. Also almost all electro-optical payloads

	are unique for each mission w.r.t above constraints and it becomes impractical and non-optimal to use a common standardized design for front end electronics. Hence development of various models of components, detectors, interfaces taking into account mechanical constraints, layout, routing, signal integrity, thermal issues, pcb size, circuit topology, grounding scheme, hardware in the vicinity etc needs to be developed. The development of this kind of integrated model will help in better understanding of the system performance at early stage and faster realization of the hardware.
K4.5	**Generic Multi-Channel Front-End and Digital Proportional-Integral-Derivative (PID) Controller with actuator interface ASIC for Temperature Control (SAC)** Electro-optical payload cameras have many elements like detector, calibration source, optical elements etc. which need stabilized temperature for proper functioning. Range of temperature depends on system engineering, physics involved in device working and overall mission performance specification. Passive cooling is popular and simpler method for temperature control. Cooled object (achieved through deep space radiative coupling) is heated using close loop system to maintain defined temperature. In this scheme, Thermistor or Platinum Resistance Thermometer (PRT) are used as temperature sensor. Foil heater of required capacity are used as actuator. Control is either based on On/Off method or PID method. Other type of temperature control uses active cooling where very low temperature (<200K, cryo-temperature) is to be achieved. In general, any digital domain based temperature controller has (a) Temperature Sensor (b) Signal conditioner (c) Digitizer (d) PID or On/Off control logic (e) Interface control signals for actuator driver (f) Driver for actuator excitation. ASIC proposed for blocks (b), (c), (d) and (e) is multi-channel (typically eight) independent temperature signal conditioning channel ASIC, with versatile and generic design, planned to support multiple application of temperature control. Offset and gain control in signal conditioner blocks is required to allow temperature control using PRT and Thermistors. 3 PRT, 3 Thermistor and 2 Transistor based channels are planned. Digital interface (Low Voltage Complementary Metal Oxide Semiconductor (LVCMOS)/ Low-Voltage Differ-ential Signaling (LVDS)) is planned for actuator driver control. 2 On/Off actuators control, 4 PID actuator control and 2 motor actuator control are planned. Digital PID controller should be programmable using CAN or any other interface for adaptability to multiple applications.
K4.6	**ASIC development of Generic N-channel MOSFET drivers and PWM generator with integrated Current and Hall Effect sensing mechanism and sigma delta ADC (SAC)** The main objective of development of this ASIC is complete indigenization of space grade motor drive electronics. Generic design of Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) driver is aimed for half bridge control. The ASIC envisaged also has integrated current sense amplifier, hall effect sensing, Pulse-width modulation (PWM) generator and ADC. N-channel MOSFET drivers are mainly used in N-channel Metal-

Oxide Semiconductor (NMOS) based drive circuits of stepper motors, BLDC motors, Cryo-coolers etc. A MOSFET driver is a type of power amplifier that accepts PWM signals and produces a high current (>1A) / high voltage (>10V) drive input for the gate of a high-power transistor (such as power MOSFET) with fast switching frequencies (>100KHz) and dead time (~500ns).

Current sensor amplifies a small differential input voltage developed by the current flowing in a sense resistor at the load side. The processing circuit processes the electrical signal generated by Hall Effect sensor or resolver output. Modern Sigma-delta converters offer high resolution, high integration, low power consumption, and low cost, making them a good ADC choice. Multi-channel delta sigma ADC is required for processing control parameters e.g. Load current, voltage etc. The Independent PWM Generator (switching frequency > 100KHz) block is required to generate pulses for carrier-based pulse width modulation converters. The block can be used to fire the MOSFETs of single-phase, two-phase, three-phase bridges. PWM resolution of >10 bit is preferred. PWM generator shall provide internal or external reference input for modulation and shall have a bypass option for providing input from external FPGA/uC. An uncommitted (low bandwidth, precision) op-amp is required, so they can be tuned based on the application. The gain resistor of op-amps should be external to allow the buffer and filtering of required signals. Typical specifications and block diagram of the ASIC is as below.

Typical Specifications:

- 4 High and 4 Low side outputs
- >1A drive per output
- High side voltage/bootstrap voltage > 50V
- Programmable dead time up-to 500ns
- 3 Current sensors
- 4/8 channel sigma delta ADC, >12 bits, >100ksps
- 6 bi-level inputs for Hall sensors
- Resolver interface (optional)
- Optional Buffered PWM inputs (3.3V or 5V)
- In-built PWM Generator with bypass option
- PWM resolution: better than 10 bits
- PWM frequency > 100KHz
- Duty cycle range: 5% to 95%
- Un-committed Op-amp (BW- 1MHz, typical)
- Serial programming

K4.7	**Reconfigurable System-On-Chip based solution for satellite on-board computing (SAC)** The SoC on-board computer (SoC-OBC) consists of mainly soft IP cores, programmable gate arrays including the LEON/ Advanced RISC Machine (ARM) processor and multiple peripheral devices. A purpose-built Direct Memory Access (DMA) controller handles the data transfers between the peripheral cores and the main memory. The AMBA AHB and AXi buses is for interfacing of high-performance system modules. The Advanced Microcontroller Bus Architecture (AMBA)Aadhaar Payment Bridge (APB) bus supports peripheral functions with minimal power consumption and reduced interface complexity. The CAN, High-level Data Link Control (HDLC), SpaceWire and space fibre network interface controllers and the EDAC block are typical components and interfaces for use in space. Designing On-board Computer consisting of programmable system on chip hardware is really challenging and this will provide the common miniaturized hardware platform for multiple missions along with providing seamless solutions and flexibility of programming, controller, data processing and standard interfaces. The Scope of the research as follows • Design and development of On-board computer hardware encompassing mainly Programmable System on chip(PSOC), Rad hard FPGA, high end memories and all standard interface CAN/Spacefibre/Serdes/LVDS interfaces along with SI and PI analysis with industry collaboration. • Soft cores IP design for standard interfaces and Logic • Standard Memory DDR2/3, ONFI controller designs. • External peripheral interfaces design &development. • Embedded processsor/LEON/ARM processor interface with FPGA. • Onboard partial n selective configuration. • Space fibre codec n network design and development.
K4.8	**Real time image processing in on-board Space systems (SAC)** Target detection and tracking has gained significant importance in many applications, including optical communication, inter-satellite communication, motion detection, reconnaissance and surveillance in which the major is to reveal trajectories of the targets. Considering the recent developments, many electro-optical systems are in need of full automation for achieving this task. Therefore, many multi-tracking algorithms include two fundamental stages as the automatic, time independent detection of targets; and association of the detections in the temporal space. Problems remains to be challenging mainly due to unknown and changing number of targets; noisy and missing observations; interaction of multiple targets. Moreover, all these challenges are needed to be solved in a time efficient manner for real-time applications in space systems.

	The Scope of the research as follows • Study and implementation of object detection algorithm for low SNR targets and its real time implementation in on-board FPGA hardware • Tracking algorithm development: Kalman for tracking and trajectory prediction. • Study/development of Optical Flow algorithm for planetary landing. • DSP based real /near real time data processing for signal analysis and image processing. • Real Time decision making for Landing System. • Machine learning techniques along with computer vision techniques need to be studied and implemented for the targets required for obstacle detection, landing site and surveillance. • Real Time Operating System (RTOS) optimisation for on board
K4.9	**Power supply systems for Space missions (SAC)** Payloads for Remote sensing and planetary exploration missions require state of art Power Supply electronics to cater to various requirements of Camera Electronics sub systems. These Power Supply Electronics requires to meet several stringent requirements such as multi-output voltage lines in range 3.8V to 24V, very low noise (≤20mV), high efficiency (>70%), EMI 461E complaint, inbuilt input power protection and output short circuit protection. The following technologies are of particular interest in future Power Supply electronics development • Very Low noise (≤5mV), Low power (<10W), highly efficient (>80%) complying with EMI 461E standard, space grade isolated power supply /module. • Multi-output (3 to 4 voltage lines in range 3.8V to 24V), high efficiency (>80%), Medium Power (25W – 100W), Low noise (≤15mV) complying with EMI 461E standard isolated space grade power supply • Development of Hybrid Micro Circuit (HMC) based miniaturised dual output (+3.8V and +5.6 V) DC-DC converters with high efficiency (>75%), medium power (> 30 W), inbuilt EMI filter and having EMI/EMC compliance to MIL-STD-461E. • Development of housekeeping and protection circuitry in the form of HMC to monitor and protect power supply electronics from various fault conditions such as Overvoltage and under-voltage protection, Over temperature protection, Overcurrent protection and Output Short circuit protection • Development of Rad-hard non-isolated synchronous buck converters for wide input voltage (10-30VDC), adjustable output voltage (from 3V to 80% of Vin) and high output current (>10A).

K4.10	**Optical data transmission system for Nano/micro payloads (SAC)** High resolution wide swath imaging typically requires payloads and satellites of large dimensions & weight. Huge amount of data requires to be transmitted to ground requiring multiple transmitters further increasing the mass and size. Cost of such satellites is too high. Development time is large and penalty associated with any component under performing/ malfunctioning is large. Alternative approach is to develop a constellation of Nano satellites to cater to above requirements. However traditional Nano satellites suffer from low data transmission capability and poor pointing accuracy. To overcome this problem it is proposed to develop a Nano satellite utilizing optical data transmission. However incorporating a traditional Optical Communication Terminal (OCT) is not feasible in the mass and power constraints of a Nano platform. It is therefore proposed to develop & demonstrate a miniaturized Optical data transmission system to enhance the capabilities of ISRO's small satellites.
K4.11	**Single Board Controller based Payload & Mainframe Electronics for High Resolution Nano Satellites (SAC)** Traditional ISRO Nano satellites (~10Kg) are capable of providing ~20m resolution from LEO orbits. However higher resolution & lower mass is desirable for future Nano missions. A Nano Satellites consists of following subsystems: • Payload sub-systems (Sensor, Electronics, Optics, Mechanical) • Mainframe subsystems (Attitude Control system ,OBC, RF system) • Electrical Harness • Mechanical Frame/Housing for Payload and Mainframe • DC-DC for payload • DC-DC for Mainframe Present approach has dedicated electronics for various functions of the payload and satellite mainframe e.g. • Sensor Bias, Sensor Control, Sensor data processing, Compression , Data Formatting, Data Transmission is managed via 2-3 Boards. • Payload DC-DC Electronics Board • Satellite mainframe OBC Board, ADCS Board, RF Board. • Mainframe DC-DC Electronics Board For reducing the overall satellite mass (<5kg) while improving payload performance (resolution, swath, SNR), miniaturization & integration of various Electronics is proposed. A Single Board High Performance Controller along with a bus structure shall be developed carrying out functions of Sensor Bias, Sensor Control, Sensor data processing, Compression, Data Formatting, Satellite mainframe OBC, ADCS, RF Data Transmission.

K4.12	**Space qualified flexible EMI Shielding and Radiation resistant coatings and enclosures for Onboard Electronics (SAC)** High speed electronics systems, miniaturization of PCBs, Electronics packages, small payloads and other such advanced capabilities, electronic sub systems requires highly populated PCBs / Packages / harnesses to support their functionality and performance requirements. Such compact/dense packaging causes EMI effects. Traditional metal EMI shields take too much space thereby reducing the overall competitive functionality of electronic devices and increases the size as well. Therefore, more recently, the research focus is on flexible coatings and enclosures developed from nanocomposites. Therefore, we feel the requirement of the development of MIL-STD-461E compliant flexible EMI shielding and radiation tolerant enclosure, which can be easily applied and adapted onto a PCB design and very sensitive signal lines. The required composites should suite the needs of ISRO especially like space-qualified material, high thermal stability, flame retardant and durable for mission life of more than 10 years. These composites can be explored for designing materials that can shield radiation and protect PCBs and harnesses without much overheads. The qualification of these composites, but not limited to, should include Thickness measurement test, thermal shock test, thermos vacuum test, humidity test, coating peel test, outgassing test etc. The design of enclosures should be in a way that they don't need to be electrically grounded to the PCB, thus simplifying or eliminating masking. This should also be able to address EMI issues on the PCB, in between tightly packed semiconductor devices and can be tuned to absorb EMI at specific required frequencies. The design must also take care that they could be applied at the end of a product design cycle. These enclosures should not affect the electrical performances and sub system functionality at ground and at onboard. The shielding performance also need to be brought out for frequency range up to 1GHz with respect to the material thickness.	
K5	**Sub Area**	**EO sensor System AIT and Performance Characterization (SAC)**
K5.1	**Design and development of smart test setups (SAC)** Test setups help in simulating spacecraft mainframe interfaces, control and command of the sensor, and data acquisition for performance evaluation. Currently, test setups are custom developed for each EO sensor considering its interface, functional and operational requirements. However, in view of the upcoming demand for variety of EO sensors, there is a potential scope of research and development for smart test setups for EO sensor testing. The smart setups are easily reconfigurable to cater to variety of sensors, they have fault tolerant designs, and are self-calibrating to enable faster turnaround time and ensure precision measurements of EO sensor performance parameters.	

K5.2	**EMI analysis and mitigation techniques (SAC)** During AIT, various electronics subsystems, test setups and associated harness assemblies exhibit complex interplay and results in a complex EMI environment. This causes various random and fixed pattern noises in the EO sensor data, which can significantly impact radiometric quality of the imaging sensor. Hence, it is very important to identify the potential noise sources and develop suitable mitigation techniques. This offers a research opportunity for design and development of EMI analysis tool, which accounts for various noise sources in the sensor chain including electronics component level noise, crosstalk, signal coupling effects, ground noise coupling, engineering noise coupling, etc. and helps to analyse complex EMI scenario, identify the noise sources and help in developing suitable mitigation techniques. Available COTS software modules can be suitably used in the proposed analysis tool.
K5.3	**Development of new methods for EO sensor performance evaluation (SAC)** SNR and MTF are two key performance parameters that are used as performance markers for comparative studies. Many methods exist for performance evaluation in terms of MTF and SNR, however, considering the stringent requirements of EO sensor performance in upcoming future missions, many new methods are required to be developed. This offers significant research opportunity in this field. We need to develop efficient, simple and robust methods for SNR and MTF measurements. Also, study shall identify new performance markers and develop suitable methods for its implementations.
K5.4	**Thermal analysis model of harness assemblies (SAC)** Thermal analysis of EO sensors and spacecraft systems are carried out to evolve suitable thermal design and implementation approaches. Generally, thermal analysis of all electronics subsystems are carried out to evolve suitable thermal implementation scheme. However, thermal modelling and analysis of harness assemblies are generally ignored, although they are passive dissipating element in every spacecraft system. Thermal modelling of harness assemblies is very critical as it helps derive rerating specifications, avoid potential arching conditions, helps in improving performance of thermal control system.
K5.5	**Design and development of machine/deep learning methods for payload test data analysis (SAC)** Large amount of data is acquired during ground testing of EO sensors. These data sets help in analysing EO sensor performance under various operating and environmental conditions. However, analysing huge data sets to bring out minute but potential performance degradations is very difficult with traditional approaches. There is an opportunity to develop machine learning techniques to analyse large amount of data acquired for various EO sensors.

K5.6	**Machine Learning Techniques for Fault Diagnosis using TM data (SAC)** Complex EO sensors employ large number of interconnected subsystems to perform imaging task. The performance of all subsystems are monitored through the large number of telemetry (TM) channels such as voltage, current, temperature, timing information, configuration details etc. TM data is acquired during ground testing and also during in-orbit phases resulting in huge amount of TM data. These TM parameters allow designers to monitor the health of the sensor. Machine learning techniques can be developed to analyse the large amount of TM data to observe even subtle performance deviations that can help in diagnosing the faults in the operations of EO sensors.
K5.7	**Development of harness embedded panels for plug and play AIT (SAC)** Interconnection harness constitute an integral and important part of the EO sensor and satellite system. Various electro-mechanical constraints in implementing the harness interconnection calls for significant efforts in the design and development of EO sensors. Literature survey shows innovative concept of harness embedded panels, which significantly helps in saving precious volume on resource constrained satellite systems. We envisage to develop such harness embedded panels for Indian remote sensing sensors. In this arrangement harness is run within the panel thickness and connectors are available on top and bottom surface of the panel as end points for package interconnection. The proposed research work involves exploring innovative design of harness embedded panels, structural analysis, usage of smart materials and proto-type development, etc.
K5.8	**Development of efficient algorithm for image reconstruction for compressive imaging sensor (SAC)** Compressive imaging (Optical domain compression) is an emerging field that allows design and development of single pixel camera systems for imaging. Significant efforts have been reported in the literature for development of single pixel camera systems as an alternative to current commercial cameras. However, not much study has been carried out in exploring the feasibility of developing a spaceborne imaging system architecture based on optical domain compression. Currently, we are working on a single pixel camera architecture for spaceborne applications. The research opportunities exist in development of efficient algorithm for image reconstruction using the images acquired by a compressive imaging sensor and carry out extensive bench marking against available methods.
K5.9	**Development of robust image quality metric and suitable methods for its estimation using in-orbit images (SAC)** In-orbit image quality evaluation of EO sensors is a continuous evolving research field. This research work envisages development of a robust image quality metrics and suitable methods for its estimation from in-orbit images.

K5.10	**Development of methods for accurate estimation of SNR and MTF from in-orbit images (SAC)** EO sensors undergo extensive ground testing during development phase. However, post launch performance deviations are generally observed due to various instrument effects due to launch loads and orbital environmental conditions. On-board and vicarious calibration methods are employed to assess the in-orbit SNR and MTF performance of EO sensors. However, the achieved accuracies in deriving performance parameters always suffer from limitations either from measurements or the methods itself. The proposed research work will first study the available methods and suggest new approaches for accurate estimation of these performance parameters.	
K5.11	**Development of techniques for quantitative estimation of MTF contributions from various elements in the EO imaging sensor chain (SAC)** In-orbit images generally suffer from MTF degradations due to instrument behaviour in the orbital conditions, platform vibrations and jitter, and atmospheric conditions. Extensive characterization is carried out in laboratory using standard targets and also in-orbit using stellar and various calibration targets. It is important to quantitatively ascertain MTF contribution from each elements of the imaging instrument to understand anomalous behaviour (if any) of one or more elements using the laboratory data and in-orbit images. This research work envisages development of methods/techniques to quantitatively measure/derive MTF contribution from each element in the EO sensor chain. Also, extensive validation studies to be performed using available EO sensor data.	
K5.12	**Design, development and characterization of Spacefiber interface-based data transmission board (SAC)** Spacefiber interface is an emerging technology for transferring huge amount of data running up to 40 Gbps and can have multiple channels for increasing the data Tx rates. The interface protocol is based on Spacewire. The Spacefiber protocol has wires or fibres as physical layer for data transmission. This research work envisages comprehensive study of Spacefiber interface, design and development of a bread-board functional model and extensive characterization of the developed data transmission board.	
K6	**Sub Area**	**Ground Checkout Systems for EO Payload Testing (SAC)**
K6.1	**Computer based Multichannel High Speed Digital Data Acquisition System (SAC)** High Resolution EO cameras generate high speed data (of the order few Gbps). Evaluation of these cameras during various phases of testing, calls for design & development of High Speed Digital Data Acquisition System. Data Acquisition System receives incoming digital data from payload and transfers it to the computer. Data Acquisition System comprises of Data Formatter, Data Acquisition Modules installed in the computer and Data Acquisition Application. Data Formatter receives the digital data from payload over multiple chains with required electrical interface (LVDS, serializer/deserializer (SERDES)), formats it and transfers packed data to Data Acquisition Modules. Acquisition application acquires data from Data Acquisition Modules.	

	Out of different options for transferring the high speed data to computer, Camera link interface based transfer is one suitable option. Camera link interface supports high data transmission rates (2.04 Gbps for BASE mode, 5.44 Gbps for FULL mode & even higher for extended FULL mode configuration) & can be used to transfer very high speed data from Data Formatter to computer. Camera link's transmission method requires fewer conductors to transfer data. Hence it reduces the hardware components, interconnecting cables and simplify the Data Acquisition System configuration. Design & development of High Speed Data Acquisition System which involves Data formatter (Data Input – Multi channel, SerDes interface) along with the Data Acquisition Application can be taken up for data transfer rate upto 4.0 Gbps using camera link i/f in-house which will be very useful during the testing of High Resolution EO cameras.
K6.2	**Comprehensive Automation of Test Benches (SAC)** Automation of Spectral Response Measurement (SRM) test bench using a Bentham mono-chromator has been very successful and because of the same, the spectral characterization for all payloads works smoothly and effortlessly. Complexity of the payloads have increased which demands more and more testing and that too repeatedly in different conditions. The 1553 bus based TC and TM systems simplify the tasks and have been implemented and are successfully working. Integrated testing becomes a laborious process when carried out by the test engineers and has chances of errors. A scheme is proposed which has a generic architecture to combine instrumentation, data acquisition, parametric evaluation and a final output generation. The 1553 bus based instrumentation provides both the TC and TM functions. Tele-commands issued can be verified thru the telemetry for the confirmation. Synchronized data acquisition request can be made, followed by data processing to compute a set of parameters. This process is repeated for all modes of operations of the payload under a given test condition. At the end of execution of all operations, post-processing can be carried out over the data-set. Such instructions can be combined as a macro and executed as and when required. For Microsat-2A (LWIR and MIR) payload calibration, there was a requirement to acquire and record the data of all seven exposures for different temperature settings ranging from 180K to 340K. To cater to this requirement, automation feature was developed for payload commanding to change the exposure, acquire and record the data and generate the results simultaneously. With the automation, the task could be completed with about a factor of three improvements in timings as compared to manual task. This shall be an in-house development with the participation of focal persons from integration team, software and instrumentation developer for one test case project.

K6.3	**Knowledgebase Creation and Information Extraction (SAC)** A huge database of information is available for all E/O payloads developed so far by SEDA. This information contains automatically archived test results, TM data, raw data, logs and manually uploaded documents. The information is structured at sub-system level and project level under categories such as Results, Issues, Discussions and Solutions. This will provide contents for to create a knowledge base for future generation projects. An interface on top of this, using Natural Language Processing (NLP) techniques can be developed. This interface shall accept the queries in human-understandable natural language and provide answers by processing the information. Academia has subjects related to Information Retrieval, Data Mining and alike under broad topic of Artificial Intelligence. Students from academia can be involved in the projects.	
K6.4	**Development of learning algorithm for fault identification and recovery of EO payload by analyzing the video data, telemetry and commanding sequences (SAC)** Electro Optical camera/payload consists of multiple subsystems i.e. Detector, Optics, Camera electronics and mechanical subsystems. To meet the performance specifications, it is required that all these subsystems operate to their best potential. During the course of integration and calibration of subsystems, lot of payload calibration data and payload telemetry is generated in response to the commanding sequences given to the payload. During this phase of payload integration, problems are observed which can be due to multiple reasons like faulty commanding sequence, improper cabling or faulty behavior of any subsystem. To diagnose these problems at the earliest, a learning algorithm needs to be developed which can continuously analyze the video data, telemetry and commanding sequences given to the payload and build a model of the payload over time. This algorithm will not only help during the payload integration phase but also during satellite integration and in-orbit operations of payload.	
L	**Area**	**Microwave Sensor Technology (SAC)**
L1	**Sub Area**	**Microwave Transmitter & Receiver Technology (SAC)**
L1.1	**High Power RF Subsystems (SAC)** For the development of Transmitters for various Microwave remote sensing payloads, many state of the art RF design and development activities, have been carried out in recent years, which have been successfully utilized in many of the delivered and ongoing payloads. To mention a few, major successfully completed in-house developments are: • GaN based Dual-Pol Pulsed Transmitters for Chandrayaan-2 SAR. • GaAs High power MMIC power amplifier development at C and X-Band with an output power of more than 12W required for C-Band and X-Band SAR payloads. • Ferrite based circulators and switches for various payloads. • X-Band 8x8 Butler Matrix. • X-Band 250W GaN Solid State Power Amplifiers.	

L1.2	**RFCMOS Based Frequency Synthesizer (SAC)** Design of RFCMOS based Frequency Synthesizers is very much essential to cater to the requirement of mini satellites program of ISRO as these satellites demand very small payloads in turn single chip based RF sub-systems. These Synthesizers are based on mixed signal technology in which Low Frequency PLL and high frequency RF circuits viz. Amplifiers, Mixers etc are integrated in a single chip as single RFIC. Broadband Space Borne chips at L, S, C, X, Ku and Ka-band can be taken up for the development.
L1.3	**FMCW PLL Based Frequency Synthesizer (SAC)** Sub-Sampling Phase Locked Loop Synthesizers with wideband Frequency Modulation are required for Frequency Modulated Continuous Wave (FMCW) RADAR applications. Linear Frequency Modulated Output can be generated directly from a single PLL chip using this approach with integrated DAC upto 1GHz bandwidth. Sawtooth / Triangular Baseband Chirp waveforms will be generated using DACs and this baseband chirp is fed to fractional PLL synthesizers as reference signal for generating the up-converted output directly from PLL synthesizer. Broadband Space Borne chips at X-band can be taken up for the design and development.
L1.4	**Stepped Frequency Continuous Wave Frequency Synthesizer chip (SAC)** Stepped Frequency Output from 0.5GHz to 2 GHz in steps of 5MHz/2MHz over the sweep time of 7.5ms to 30ms is to be generated for Ground Penetrating RADAR applications. Dwell time for each step is programmable from 25us to 200us. PLL with broadband Voltage Controlled Oscillator (VCO) is to be used for the development.
L1.5	**Broadband Voltage Controlled Oscillators (SAC)** The bandwidth of any Phase Locked Loop synthesizers is limited by the bandwidth of the VCO's that are being used. Broadband Voltage Controlled Oscillators are being realized with wide tuning range by using bank of varactor diodes and the required band is selectable by external command. Broadband (around 20-25% Bandwidth) Space Borne chips at L, S, C, X, Ku and Ka-band can be taken up for the development.
L1.6	**Wide band Analog Multipliers (SAC)** When high output chirp bandwidth is required with limited bandwidth of base band chirp, we need to multiply the bandwidth using Frequency Multipliers. For high resolution SAR applications, requirement of output chirp bandwidth is very high. Hence Wideband Analog Multipliers are very much needed for high resolution SAR applications. Broadband (around 20-25% Bandwidth) Space Borne chips at L, S, C, X, Ku and Ka-band can be taken up for the development.
L1.7	**High Power Broadband MMIC Power Amplifier (SAC)** Design using GaAs/GaN MMIC Processes: Collaborative work with academia for design of state of art broadband MMIC based high power amplifier using both GaAs and GaN MMIC processes.

	• Target Output Power: better than 10W (for GaAs process) & better than 40W (for GaN process) • Target operating Bandwidth: 10% - 15% • Target Frequency Band: L / S / C / X / Ku
L1.8	**Broadband High Power Front-end Duplexer using Ferrite devices (SAC)** Design of state of art broadband & high power ferrite based duplexers in radar bands • Target Products: Broadband High Power Circulator & Switches at X/Ku-band and Circulator-Isolator-Limiter assembly at S/C-Band • Target bandwidth: better than 20% • Power Handling: 250W peak with 10% Duty cycle (S/C-Band); 2KW peak with 25% Duty cycle (X-band); 150W peak with 30% Duty cycle (Ku-Band)
L1.9	**Development of discrete GaN devices for High Power Amplifiers (SAC)** Collaborative work with indigenous organizations and academia for the development of discrete GaN devices for High Power Amplifiers development could be extremely useful. Development work involves the following: • Development of discrete GaN high power devices up to Ku-Band. • Development of non-linear models of these devices required for power amplifier design.
L1.10	**X-Band and Ka-Band Receiver RFICs (SAC)** This activity is to design and develop Receiver Core-chips using commercial RF CMOS technology at X and Ka-Band. Receiver core chip consists of low noise amplification, Manual/AGC and down conversion to IF/IQ signal of received input signal with the aid of LO as per the requirements. The tentative noise figure and gain of the X and Ka band receiver should be less than 3 dB and 5 dB respectively and better than 75 dB respectively with 30 dB dynamic range using the available commercial RFCMOS process. Core chip must also include all the necessary drivers, decoders, regulated power supply and LO amplification blocks as per the detailed specifications.
L1.11	**Design, modelling and technology development of wafer level packaged MMICs (SAC)** The proposal is for Design, modelling and development of suitable wafer level packaging technique for RF MMICs. Presently MMICs are packaged in LTCC and metal ceramic packages consuming more area, thus increasing the size and weight of the subsystems. This new proposal shall enable compact 0-level wafer level packaging.
L1.12	**RF Absorber sheets for use in RF discrete, LTCC and MMIC packages (SAC)** • Design and development of absorber sheets with specified rejection over broadband frequency range. • Design and development of multiple absorber sheets with specified strong rejection over narrowband frequency ranges.

L1.13	**C-type and Pi-Type line filters/Feedthroughs for use in RF packages (SAC)** This research area can be taken up to reduce dependence on foreign sources.	
L1.14	**High power Waveguide Terminations at various frequency bands to provide matched termination for high RF power at termination ports of various subsystems (SAC)**	
L2	**Sub Area**	**Millimeter, Submillmeter& Terahertz Sensors Technology (SAC)**
L2.1	**Design and development of Schottky Barrier Diode-based Sub-Harmonic Mixers up to 750GHz (SAC)** At mm/sub-mm-wave frequencies, mixer is used as front-end element of receivers due to non-availability of LNAs at these frequencies, making it the most critical element to achieve high sensitivity receivers. At mm/sub-mm wave frequencies, sub-harmonic mixer topology is preferred owing to difficulties in generation of high power LO signals at fundamental frequencies. This work involves design and development of sub-harmonic mixers from 350GHz to 750GHz using Schottky barrier diode as non-linear element. The mixers shall be designed to offer minimum conversion loss and noise equivalent temperatures.	
L2.2	**Design and development of SIS-tunnel junction based mixers up to 1.2THz (SAC)** The superconductor–insulator–superconductor tunnel junction (SIS) is an electronic device consisting of two superconductors separated by a very thin layer of insulating material. SIS-based receivers, operating at ~ 4K temperature, can achieve state-of-the-art noise performance of the order of 2-5 times the quantum limit. The SIS based mixers are fundamental mixers, utilizing SIS junction as non-linear element for mixing operation. This research work involves design and development of cryogenically cooled (operating at ~ 4K) SIS based mixers operating up to 1.2THz.	
L2.3	**Design and development of Schottky Barrier Diode-based frequency multipliers up to 1.2THz (SAC)** At mm/sub-mm-wave/terahertz frequencies, GaAs Schottky diode based frequency multipliers are used for LO signal generation. This project deals with design and development of mm/sub-mm wave frequency multipliers till 1.2THz with operation at cryogenic temperatures of ~80K. The frequency multipliers should offer optimum efficiency and output power required for generating the required LO drive for Schottky diode/SIS junction based mixers.	
L2.4	**Design and development of Electronically Tunable frequency synthesizers (SAC)** Local oscillator sources use microwave oscillators followed by amplification and frequency multiplication stages with appropriate filtering to generate LO signals, required for down-conversion in heterodyne receivers. This project aims at design and development of electronically tunable frequency synthesizer with YIG-tuned oscillator (YTO) locked to a highly stable reference as the fundamental source to allow for electronic tunability.	

L2.5	**Design and development of Gunn-diode oscillator based frequency synthesizers (SAC)** Gunn diode oscillators based frequency synthesizers are widely used at mm-wave frequencies as they provide highly repeatable frequency tuning characteristics along with high output power. Gallium Arsenide (GaAs) and Gallium Nitride (GaN) are the most common diode materials for realizing Gunn diode based oscillators at mm-wave frequencies. This project deals with design and development of Gunn diode based oscillators at W-Band for generation of mm-wave LO signals.
L2.6	**Design and development of InP-HEMT based LNA MMICs at mm/sub-mm wave frequencies using MMIC foundry services (SAC)** Traditional LNA designed using GaAs process offers high noise figures at mm/sub-mm wave frequencies. LNA using InP HEMT MMIC technology offers superior noise figures at mm/sub-mm wave frequencies compared to other semiconductors. This project work targets design and development of InP-HEMT based LNA MMICs spanning from few GHz up to 750GHz using suitable MMIC foundry services.
L2.7	**Design and development of High-speed Digital board for high-end Spectrometers to be used for earth observation and astronomy (SAC)** High-speed digital PCBs with wideband ADCs (6Gsps sampling requirement), FPGAs (Xilinx ultra-scale series or equivalent) and associated circuitry are required for design and development of digital FFT based spectrometer for heterodyne spectroscopy based systems. This research work involves design and development of a modular, scalable, multichannel spectrometer board with wideband high speed ADCs catering to 3GHz analog input bandwidth with an FPGA for spectrum generation.
L2.8	**Design of mm/sub-mm wave temperature and humidity sounder on CubeSat platform (SAC)** The mm/sub-mm wave sounder from a CubeSat platform focuses on improved rapid-update capabilities provided by a low-earth-orbit satellite constellation for atmospheric observations. mm/sub-mm wave atmospheric sounder is a radiometer configured in noise injection mode of operation with a highly-integrated electronics to accommodate over a 6U CubeSat platform. The principle challenge of developing a radiometer payload for CubeSat platform is the high level of integration necessary to meet size, weight, and power (SWaP) requirements. The major technological elements in this research work are miniaturized receiver front-ends and associated LOs, hyper-spectral IF back-end system, antenna with its scan mechanism and radiometer calibration.
L2.9	**System configuration design of mm/Sub-mm wave Hyperspectral Atmospheric Sounder for earth's and other planetary atmospheres (SAC)** Sub-mm wave atmospheric sounders are passive radiometers making measurements of absorption lines of different molecules in sub-mm wave band like oxygen, water vapor, ozone, etc. which provides useful information regarding atmospheric conditions of the

	earth. Hyper-spectral mm/sub-mm wave Atmospheric Sounders is a new concept of achieving very high vertical resolution using a large no of channels in mm-wave bands. This project deals with system configuration design addressing detailed specifications for sub-systems; weighting functions for these molecules in different atmospheric conditions; Vertical resolution; channel placement on absorption profiles; Required bandwidth for each channel.	
L3	**Sub Area**	**Digital Controls, Data Acquisition, Processing (SAC)**
L3.1	**On board control Sub-systems of microwave remote sensing payloads (SAC)** Payload Controller (PLC) is the central controller subsystem for a microwave remote sensing payload. PLC is responsible for control, coordination and status monitoring of all sub-systems of the payload. PLC has Mil-Std-1553 Interface with spacecraft On Board Computer, through which it accepts all tele-commands and provides telemetry. PLC generates timing signals and control signals for all other digital and RF sub-systems of the payload. PLC is implemented using On board Controller (OBC) ASIC and FPGA. Microwave payloads with active phased array configuration (e.g. RISAT-1/1A, RISAT-2A, etc.) have three level hierarchy of distributed control sub-systems. Control sub-system hierarchy for RISAT-1/1A is as shown in following figure. PLC is the central beam controller. It controls 12 Tile Control Units (TCU) which is at 2nd level. Each TCU further controls 24 Transmit/Receive Controller (TRC) which is at 3rd level. Thus, the phased array active antenna has total 288 (12x24) TRCs. Communication among distributed controllers is done through RS-422/485 serial link. PLC sends beam selection data to TCU, which further transmits beam characterization data to TRC through serial commands.	
L3.2	**Rad-Hard by Design (RHBD) Memories IP development (SAC)** RHBD memories are used in various On Board Controller (OBC) ASICs for digital control sub-systems of radar payload. OBC ASICs contains on chip volatile memories like Single Port RAM (SPRAM)&Dual Port RAM (DPRAM), while external non-volatile memory Electrically Erasable Programmable Read Only Memory (EEPROM) is used in RISAT-1A and similar payloads. Following RHBD memory IPs for 180nm CMOS process are required for future ASICs: • Design & Characterization of Radiation Hardening by Design(RHBD) volatile memories like Single Port SRAM, Dual port SRAM with size of 32KB to 1MB. • Design & Characterization of RHBD non-volatile memories like EEPROM/Flash and OTP with size of 16KB to 256KB. Area & Timing efficient memory cells should be signed, simulated and GDS-II layout should be generated. SAC will facilitate test chip fabrication and radiation testing for characterization of SEE & TID performance.	

L3.3	**Real Time Operating System (RTOS) optimization for on board Payload Controller (PLC) (SAC)** PLCis central control sub-system for control and status monitoring of whole microwave remote sensing payload. This proposal is to customize standard RTOS for PLC applications. Open-source RTOS may be customized in terms of optimization for resources (like memory, power, etc.) & performance (timing, accuracy, etc.) so that it fits in existing PLC hardware. Fault Tolerant (FT) features to be incorporated in design to enhance reliability for space borne applications
L3.4	**System on Chip for distributed controller (SAC)** This proposal is to design System on Chip (SoC) with embedded processor, floating point coprocessor, differential I/Os, ADC, Oscillator, SRAM and Non-volatile memory, etc. This SoC should have fault tolerant features like EDAC, Watchdog timer, Lock-step processor so that it is usable in space environment. 180nm CMOS process or other suitable process technology may be chosen for design. This SoC is targeted for single chip implementation of T/R module controller for phased array SAR. Integration of digital SoC with RF chip for further miniaturization should be explored.
L3.5	**Multicore Digital Processing & Control SoC (SAC)** Multicore processor based SoC with various peripheral module is planned to be developed for future microwave remote sensing payloads. This SoC will have dual/quad core of 32 bit RISC-V processors and various peripheral modules such as Mil-Std-1553, Space-wire, Timing Signal Generator, UART, SPI, etc. which will be connected through AMBA AXI bus. A dedicated Co-Processor/Accelerator for FFT/IFFT and signal processing for vision based navigation will also be available in it. This SoC will be useful for miniaturized implementation of Radar Altimeter with Hazard Detection and Avoidance functionality. The targeted SoC may be realized on 28 nm CMOS process with adequate radiation hardening by design (RHBD) features for usage in Space-borne applications.
L3.6	**On board Wireless data transfer tranceivers (SAC)** This proposal is for design & development of wireless data transfer transceivers for space applications. Wireless transceivers should operate in Industrial, Scientific and Medical (ISM) (2.4GHz) band or other open frequency bands for data rate of 1Mbps with range of 10m. Applications of such transceiver is in intra-satellite data transfer between rotating to stationary sub-systems or Tile control sub-systems. The design should be done with target of fault tolerance so that it is suitable for space applications.
L3.7	**EDAC IP for FPGA of Solid State Recorder (SAC)** This IP will be useful for design and development of a Solid State Recorder (SSR) based on Not AND (NAND) Flash memories for onboard usage. Flash memories are prone to random bit failures, error correction and detection algorithms needs to be employed to maintain data integrity and reliable operation of these solid state recorders. The main aim of the research would be to develop an efficient error detection/ correction algorithm.

	for NAND flash based Solid State Recorders. Also the research must focus on real time optimal implementation of the ONFI (Open NAND Flash Interface), EDAC algorithm and efficient low overhead file system amenable for implementation on FPGA/ASIC.
L3.8	**Advanced Synchronization techniques for distributed sub-systems (SAC)** There is a need of clock and timing signal synchronization techniques for distributed sub-systems within a single satellite or across satellites. Both cases of single platform distributed system with wired connection and different platform distributed sub-systems without any connection should be addressed. GNSS disciplined oscillator based clock & timing signal synchronization techniques for space borne application is to be explored under this research area.
L3.9	**Onboard SAR processor (OBSP) (SAC)** In order to leverage the benefits of onboard processing for SAR missions, the first and foremost requirement is the ability to generate precise SAR images onboard the spacecraft. One of the primary benefits of onboard SAR image generation apart from various onboard applications (like target detection, flood inundation map generation for Disaster management) is that, it substantially reduces the SAR sensor data rates for medium and low resolution modes. This capability is particularly essential for various planetary missions wherein downlink rates and earth visibility time are at a premium. Also, the Lossy BAQ compression is bypassed resulting in better image quality. The potential research areas: • Processing Element and Hardware Configuration: • FPGA configuration and architecture amenable for Real Time SAR processor implementation • Design of various SAR processing IP cores with radiation-tolerant features • Design of fault tolerant SDRAM/DDR2/DDR3/DRR4/FLASH memory controllers for space use • Design and development of full ASIC based SAR processor • Configuration, Architecture, interfaces and data distribution scheme for multi-processor based system • Onboard Signal Processor Algorithm: • Efficient SAR processing algorithms amenable for onboard implementation catering to various SAR operating modes (Stripmap, ScanSAR, Mosaic etc.). • Low latency SAR image generation algorithm for spotlight & sliding spotlight modes with limited bit precision • Design of robust processing algorithms (with low precision arithmetic) for image generation in the absence of accurate spacecraft attitude/pointing/ velocity estimates • Use of High Level Synthesis (HLS) tools for onboard SAR processor implementation on FPGA. • Raw SAR Data simulator with the ability to simulate SAR data with motion and attitude errors.

L3.10	**Integrated RADAR Digital Receiver and Signal processor (SAC)** Typical functional requirements for any baseband digital subsystems of a RADAR payload include high bandwidth linear frequency modulated signal generation, high speed multi-channel digitization, real time signal processing and high speed data transmission. These functionalities are currently realized using multiple discrete devices/subsystems. The requirements for signal synthesis and acquisition are as follows: • ADC Sampling Frequency: 750 MHz • ADC Resolution: 8 bits or higher (Better than 7-bits Effective Number of Bits (ENOB)) • Number of ADC Channels: 2/4 • DAC Reconstruction Clock: 1 GHz • DAC Resolution: 10 bits or higher • Number of DAC Channels: 2 • Processing Functionality: Data Compression using BAQ (Block Adaptive Quantization) / Matched Filtering Data Acquisition and Signal Processor developed at MRSA/SAC
L3.11	**Design & Development of miniaturized digital system for Airborne/UAV and LEO SAR missions (SAC)** High resolution SAR system for aUnmanned Aerial Vehicle (UAV) platform/Cube-SAT pose severe SWaP constraints on the RADAR hardware. This calls for direct RF sampling/ synthesis systems (eliminating RF down/ up conversion chains) integrated on a single chip. This research area involves design of digital systems based on RFSoC or similar devices for realization of miniaturized SAR systems capable of direct signal acquisition, synthesis and processing in L/S/ C- or X-band.
L3.12	**Multi-Channel Digital Beam Forming & Autonomous Controller (mDBF-AC) (SAC)** The following research areas are proposed towards realization of mDBF-AC system: • FPGA based Digital Hardware design comprising of multiple-channel high-speed data acquisition, digital signal processor & data formatter, Radar wide band transmit waveform generation and Autonomous Payload control operations in single board • Multi-Channel Data acquisition scheme @ IF/RF with very fine synchronization and channel alignment techniques • High speed interfacing techniques between FPGA and data converters • IP Core development for Efficient Phase synchronization & Digital Beam Forming techniques • IP core development for fault tolerant Double Data Rate 3(DDR3)/DDR4 memory controller • Wide band transmit waveform generation with inverse sync compensation followed by signal up conversion at IF or Radar RF frequency • Enhancement in current payload controller operations including Autonomous control and onboard computation of programmable parameters • On-the-fly software reprogramming techniques • Scrubbing techniques for SEU mitigation

L3.13	**Onboard Signal Processor for GNSS Reflectometry (SAC)** GNSS Reflectometry (GNSS-R) payload is a passive sensor used for sensing reflected Navigation signals over Earth's surface to measure key ocean and land parameters. The reflected signals after passing through amplification are digitized and processed for Delay Doppler Map (DDM) generation. This research area involves • Design & development of a highly compact low power digital hardware consisting of quad channel medium speed ADC's, high density / high through put FPGA, digital control processor and volatile memory for intermediate data storage. • Design of Onboard Signal Processor algorithm for Precise Orbit Determination, Specular point calculation and DDM generation using direct and reflected signals • Development of Hardware simulator which caters to modeling and generation/ synthesis of the direct navigation signal and the corresponding reflected signal, received at LEO satellite in the operational scenario of a GNSS Remote Sensing spacecraft to be used for testing GNSS-R Signal Processor.
L3.14	**Signal Processing algorithms for RADAR Altimeter (SAC)** MRSA/SAC has developed a RADAR altimeter based on FMCW technique. Presently design and development of Pulsed based Radar Altimeter is under progress in MRSA/ SAC. These systems will be used in precise altitude and velocity measurements. Following are research areas • Algorithms and schemes for precise velocity measurement techniques. • Real time unambiguous velocity estimation from a FMCW RADAR Altimeter
L3.15	**Signal Processing Platform for Navigation and Hazard Detection and Avoidance (HDA) applications (SAC)** Future generation of landing craft will autonomously map the surface, using vision, microwave and/or laser based sensors, during the terminal phase of powered descent and then, in real-time, choose and divert to a safe landing site in order to avoid hazards using Hazard Detection and Avoidance techniques. This will also require accurate position and velocity data during descent phase in order to ensure safe soft landing at the pre-designated sites. Following are the research areas • Processing algorithms (for HDA, Position estimation, velocity estimation, image generation etc.) for real time microwave/optical based imaging sensors • Development of suitable digital hardware platform having signal acquisition, control (for controlling sensors), processing (for sensor data processing s) and storage (for storing pre-known features of the landing sites) capabilities to cater to interplanetary landing missions
L3.16	**Audio Video Processing Unit (AVPU) (SAC)** Targeted for Gaganyaan mission, Audio-Video Processing Unit provides two-way Audio and Video communication between crew members and ground segment, comprehensive information display and situational awareness to the crew about the status of all aspects of the spacecraft and mission. Following areas provide opportunities for research:

	• Hardware Configuration: i. Selection of heterogeneous radiation/fault tolerant hardware platform enabling Size, Weight and Power (SWaP) optimized configuration ii. Suitable for advanced high performance Multimedia applications like H.264/H.265 compression and decompression, high-speed data transfer over Display Port interface etc. iii. Support for high performance, low latency user applications with provision for interfacing with various peripheral subsystems. • Software Architecture: i. Development of application software for safety critical system ii. Hypervisor for heterogeneous processor configuration iii. Inbuilt fault tolerance, fault identification, isolation and recovery	
M	**Area**	**Power Electronics (SAC)**
M1	Miniaturized circuit protection module for DC-DC converters for Aerospace applications. The protection circuit comprises of Resettable eFuse, Input pug-in inrush current limiter and Under Voltage Lock-out (UVLO) (SAC)	
M2	Work involves design, simulation and optimization of Generic front-end protection circuit for DC-DC converters. The final circuit may be implemented on a power ASIC or HMC (SAC)	
M3	Development of software tool for design, modelling and analysis of planar power transformer and power inductor. Digitally controlled energy efficient multi-output DC-DC converter with fast transient response. The work involves design, simulation and proto-type development of highly efficient multi-output EPC for high speed digital circuits with FPGAs. The EPC should have programmable output ON/OFF sequencing with fast transient response (SAC)	
M4	Study of design topologies and packaging aspects of GaN MOSFET based high voltage EPC for pulsed TWTA. The work involves study, simulation and comparison of various design topologies/configurations for high voltage EPC for multi collector pulsed TWT with Beam focus electrode for pulsed operation. The work also involves study and comparison of space grade high voltage potting materials and packaging aspects (SAC)	
N	**Area**	**Quantum Technology (SAC)**
N1	**Sub Area**	**Optical Communication (SAC)**
N1.1	**DWDM based 200 Gbps Floating Storage and Offloading Unit (FSO) link demonstration for future Terabit optical communication (SAC)** Terabits of data rate will be required for future high-speed links for LEO satellites and Intersatellite links for LEO constellations. Also high throughput satellites require 100s of	

	Gbps data to be transmitted through multiple gateways. RF bands are facing saturation and limited to strict frequency regulation, leading to a requirement of large number ground stations for feeder links. Increasing frequency demand from terrestrial wireless communications also puts restriction RF frequencies and on feeder locations due to signal isolation requirement and practical operational issues. Multiple feeder stations call for multiple terrestrial links involving multiple operators and puts signal security at stake. Technologies developed will be utilized for high data rate links for satellite-based links (LEO –ISL, LEO GEO, GEO-Ground) as well as for optical feeder links for high throughput satellites. A single optical feeder Station can cover vast geographical areas without number of RF feeder stations and their terrestrial links, which requires vast amount of ground infrastructure. These technologies can be extended to Terabits links for future Optical communication and HTS links.
N1.2	**Multi wavelength Fiber Laser Generation Technique (SAC)** Multi-wavelength laser generation from a single source of laser has attracted considerable attention among researchers over the last few decades. The Multiwavelength Fiber Laser Sources have potential Applications in dense wavelength-division-multiplexed (WDM) in High Throughput Satellite in optical communication, optical instrument testing and characterization. Such light sources are particularly in-demand because they provide an efficient and economical solution to increase the flexibility of WDM system. It has various advantage such as low cost and low insertion loss. The requirements for such optical sources are a high number of channels over large wavelength span, moderate output powers with good optical signal to noise ratio (OSNR) and spectral flatness, single longitudinal mode operation of each laser line, tunability and accurate positioning on the International Telecommunication Union (ITU) frequency grid. Technologies developed in this research will be utilized for optical feeder link for high throughput satellite The scope of the work shall include to explore the several techniques used for multi wavelength generation namely comb filter, cascaded modulation, Brillouin scattering technique, and arrayed waveguide grating.
N1.3	**Compact Optical Terminal Development for Optical Inter-Satellite Link (SAC)** The upcoming data rate requirement need a paradigm shift from conventional RF satellite link to free space optical link. RF link has some advantage over free space optical (FSO) link where atmosphere is involved. But for inter-satellite link, FSO link is the only viable solution in terms of size, weight and power. The added advantage of FSO link is high data rate, narrow beam width, low EMI/EMC etc. ISRO has initiated the development for FSO inter-satellite link. The base band data will be modulated using optical carrier which has frequency in THz. Using a compact terminal consisting of optical telescope, optical communication subsystems and pointing acquisition and tracking (PAT) mechanism, ISL can be realized. This will also effective reduce the number of ground segment and will add space diversity.

N1.4	**Microwave Photonics for next generation broadband payload (SAC)** Broadband Satellite Communication in coming future shall have the capability of providing very high throughput (vHTS) 'Terabits/sec' with multi-beam coverage and with data rate >10Gsps on-board switching. It will be capable of providing flexible power, bandwidth and coverage depending on varying demand over the multi-beam coverage. Microwave Photonic-based on-board processing will be a feasible solution to meet the high-speed processing demand of next-generation broadband satellite system with added advantage of lower mass, lower volume, less power consumption and better EMI performance. The research areas in MWP are Microwave Photonic Filter, Photonic switching and Beam forming. PIC based approach for the above areas are also initiated.
N1.5	**High Power Er Doped Fiber Amplifier (SAC)** High power optical amplifier (EDFA) is inevitable for the realization of free space optical communication link. This is the device, which amplify the 1550 nm optical signal directly without the need of any electrical conversion. Er - doped fiber is popularly used as the gain medium for optical amplifier. The Pump laser will provide the required population inversion in Er fiber. Different pumping topologies e.g. forward pumping (co- propagation), Backward pumping (Counter propagation) and Bi-directional pumping (Co+ Counter propagation) is explored in the development to maximize the Gain, Saturated power and minimize the noise figure. Fiber fusion and thermal management of fiber plays the crucial role on the operation life EDFA. For any type of optical communication payload, EDFA serves the purpose of power house to sustain the communication link. Though many commercial EDFAs are available, those are meant for ground applications. For space based EDFA, there are lots of design challenges in thermal design, optical fiber assembly, high power electronics aspects. SAC have initiated the in-house development of EDFA in different phases with mid and high power output targets. This development is being carried out in phases. At present 5W output at ambient has been realized.
N1.6	**Higher order optical switch for low latency applications (SAC)** The increasing user demands required high throughput microwave and optical payloads where onboard signal processing in photonics domain is the most viable option to meet the latency requirements of reconfigurable networks. In photonic switching there are several techniques such as optical MEMS, Semiconductor optical amplifier, waveguide and thermal. In this technology, selection and hardware realization of the switch will be explored which has capability of high switching order (16*16 or higher), switching latency (few nano sec.) in optical C-band. The Cross talk (-40 dBc or better), polarization independent, transparent to data rate up to 10 Gbps with suitable tele command and telemetry provision are the key features of the hardware.

N1.7	**Digital Signal Processing for Optical Coherent Receiver in BPSK, QPSK or advanced modulation format (SAC)** For advanced optical communication formats e.g. BPSK, QPSK, 8-PSK etc., the post processing of electrical signal is inevitable after detection through coherent receiver with single polarization (X channel) or dual polarization (X and Y channel) multiplexing. Several impairments cause the optical signal distortion and those effects need to counter through algorithm. Main algorithm stage conventionally consists of Bessel filtering, Resampling, Quadrature imbalance, non-linearity and Chromatic dispersion compensation etc. The data rate is typically more than 10 Gbps. In such high data rate, the DSP using FPGA is very challenging. There is a scope of code development for FPGA to mitigate the effects.	
N2	**Sub Area**	**Quantum Key Distribution on a Moving Platform (SAC)**
N2.1	**FPGA IP development (SAC)** The real time key generation in QKD system requires processing and synchronization of the generated raw data between transmitter and receiver terminal in very short time. The development of all needed functional elements in one NavIC synchronized FPGA-IP for protocols BB84, BBM92 and Decoy state has already been successfully completed and demonstrated. Current IP for BB84 and BBM92 has been tested for up to 33MHz of repetition rate. Same IP is also capable of performing BBM92 protocol with a coincidence window of 20ns. Further, there is need of high-performance IPs for rate up to 200MHz pulse repetition rate and sub-nanosecond co-incidence window both for fiber and free space based QKD. This next generation IP is under development. Further, IPs for supporting new protocols are also being explored which can support fiber and free space QKD. New precision timing synchronization system using optical methods are also being explored to meet future high performance QKD links.	
N2.2	**Quantum Network (SAC)** SAC is working towards development of quantum network technology for last mile connectivity to users to communicate with unconditional security. A hybrid quantum network test bed is under development which includes both fiber and free space links within SAC for end user applications. A key management system is needed for routing and efficient distribution of keys between multiple nodes. Study and countermeasures of all possible eavesdropping attack on such network is also to be studied.	
N2.3	**Single photon detector development (SAC)** Single photon detectors are used for quantum communication based applications include characterization of single & entangled photon sources, photon detection at QKD receivers etc. Various technologies like Single photon avalanche diodes (SPAD), Photo-gated phototransistors and Nanowire SNSPD are being used for the detection of photons with different photon detection efficiency and dark count rates and are being operated at room temperature or cryogenic temperatures. SAC has initiated the development	

	of 1550 nm single photon detectors which can be operated at room temperature with Photon detection efficiency > 50%, Dark count rate <500 Hz, Dead time <10 microsecond which will give self-reliance to SAC in this technology. In this regard, SAC has initiated in-house & collaborative work with academia to develop the bare SPD chip and setup for its characterization and packaging.	
N2.4	**Photonic Integrated circuit development (PIC) (SAC)** Photonic Integrated circuit is the State of Art technology which brings all the bulk and discrete photonic components into a single miniaturized chip and thereby reduces the size & weight of bulky optical/photonic systems. PIC based chips requires less power and capable of providing much higher data rates in Tx-Rx based systems. SAC, has initiated PIC based design and development of Quantum Transmitter for Quantum key distribution. Various protocols are being explored in Indium Phosphide and silicon photonics platforms for the design implementations. Initiated design & simulations work for the implementation of BB84 based QKD Tx PIC. Various foundries are being explored for fabrication of in-house designed PICs. PIC based Quantum Random number generators, Entangled photon source and Single photon detectors are also being explored for future developments.	
N3	**Sub Area**	**Quantum Systems and Technologies (SAC)**
N3.1	**Software toolkit for simulation and analysis of polarization sensitive beam propagation system for Satellite based Quantum Communication (SAC)** A user-friendly GUI based software toolkit is required for modelling the evolution of Gaussian beam of light and its polarization properties in near field and far field for any given optical system scenario including multiple components like lenses, mirrors, dichroic, beam—splitters etc. with the option of custom rotation/tilts. The software should support any input polarization state & DOP while having provision for defining the polarization properties of each surface through Muller formulism or input of birefringent material properties/measured data. It should further be able to simulate and analyse the transformation of beam profile and the polarization state of light for given orbital parameters (satellite trajectory, orientation etc.) and layout of on-board/ground optical system. Accordingly, it should generate required inverse transformation using any suitable birefringent optics system (like waveplates, liquid retarders etc.) for performing dynamic polarization compensation at the ground.	
N3.2	**Development of High speed Polarization Modulator for Quantum transmitter (SAC)** Several Quantum communications related protocols are developed on the basis polarization states / phase / time bin encoding of light. For polarization based protocols, Quantum Transmitter sends random polarized light sequences, with which secret shared key is created between Transmitter and Receiver. A typical setup for such communication consists of four laser transmitter units corresponding to four polarization states. However,	

	a single laser transmitter unit with polarization modulator controlled through electrical bias can generate required polarization states, thus greatly reduce the setup size making it more appropriate for the satellite applications. Literature survey shows design of such polarization modulator can be done using a phase modulator. It is imperative that polarization controller should generate different polarization states at rate in few GHz range (20 MHz - 2 GHz) with desirable operating wavelength of 785 nm and 1550 nm.
N3.3	**Development of system engineering tool kit for simulation of Quantum Key Distribution (QKD) protocols for fiber based systems (SAC)** A suitable software tool kit is required for extensive simulation and performance analysis of various QKD protocols. This toolkit can be used for end-to-end modelling, simulation and analysis of various fiber based QKD architecture to aid in system engineering. The software toolkit should support detailed modelling architecture for analysis of a full system including link budget analysis, QBER, secure key rate etc. for fiber based prepare and measure as well as entanglement based QKD protocols like Decoy state BB84, BBM92, E91, DPS, COW, CV-QKD etc. This toolkit will consist provision of non-ideal/ practical systems or components for realistic estimation of QKD system performance in various scenarios. It will also help to perform comparative analysis of various QKD protocols in a similar operating and environmental conditions.
N3.4	**Development of frequency up conversion based Single photon detector (SAC)** Single photon event detection is done either by an avalanche photodiode (SPAD) or by super conducting nanowires (SNSPD) maintained in a cryo-cooled environment, operating in Geiger mode supported by output pulse shaping and avalanche quenching circuits. Visible-NIR (700-850nm) photon detectors have Si based technology while for optical telecom IR (1530-1575nm) it is InGaAs/InP. An alternative and effective method for single photon detection for IR wavelengths is through up conversion to the efficient Si detector technology. The development of such an up-conversion detector design requires sum frequency generation of IR single photon signal and a pump signal to generate an up converted single photon signal in visible domain (780-850nm) using non-linear crystals/waveguide. Research advancement in this technology will be a good development towards enabling QKD systems for both 800nm and 1500nm wavelength domains.
N3.5	**Design of single/entangled photonic source with high rate/dimensionality (SAC)** The demand for faster key generation rates and better link margins in QKD systems is pushing photon source technology towards high generation rates (>100MHz typically). While attenuated pulsed lasers are simple solution to this, true-single/entangled photon sources are still considered a better option for making QKD systems truly secure against some of the eavesdropping attacks. It is desirable to have high rates, high dimension photon sources for increasing quantum channel efficiency (more bits per photon transmission). Hence, faster weak coherent pulsed sources and high fidelity-high rate

	single/ entangled photon source development in visible and IR operating wavelength domain is an ongoing research at SAC.	
N3.6	**Study and analysis of suitable Optical ground station (OGS) locations across Indian mainland for free-space optical/quantum communication links (SAC)** Optical ground stations (OGS) are required for carrying out satellite-to-ground (STG) and ground-to-satellite (GTS) based optical and quantum communication related experiments. This proposal deals with detailed study, analysis and identification of suitable OGS locations over Indian mainland considering various system engineering, atmospheric and orbital parameters in both STG and GTS scenarios. The research work must include comprehensive analysis of possible losses/ distortion due to optical beam propagation through turbulent atmosphere single (weak coherent pulse) as well as entanglement based protocols in satellite based quantum communication scenarios at both 800 and 1550nm wavelength band. The operating conditions w.r.t sun light considering night time as well as day time operations with satellite in LEO/MEO/GEO orbit are to be considered. Multiple locations of ground stations should be identified along with their preference corresponding to five different zones of Indian mainland: north zone, east zone, west zone, south zone and central zone clearly highlighting over the year atmospheric loss profile, turbulence, cloud mapping, polarization/phase/entanglement perturbations, ambient noise, solar irradiance etc. Comparative study should also be done on downlink and uplink configuration of optical/quantum communication. Suitable experiments, like radiosonde to characterize the atmospheric turbulence and atmospheric chemistry measurements should also be carried out for validation of the study & analysis. Development of a numerical model (software) to simulate end-to-end laser beam propagation through lossy and turbulent atmosphere.	
N4	**Sub Area**	**Atomic Clock-Navigation Related Technology (SAC)**
N4.1	**Rubidium atomic clock modelling and theoretical studies on fundamental limitations in detection schemes and stabilities of atomic frequency standards (SAC)** A detailed analytical modelling of rubidium atomic clock is to be performed. This should include the modelling of atomic signal and its features and the locking of crystal oscillator using the atomic signal. The signal-to-noise ratio in an atomic clock depends on the detection noise present in the system. Low noise detectors and low noise electronics have to be employed in order to reach better clock stabilities. Thorough studies on the best possible detection schemes is needed to employ the efficient methodology in compact space clocks.	

<table>
<tr><td rowspan="1">N4.2</td><td colspan="2">Coherent Population Trapping based schemes for atomic clocks (SAC)
In the Coherent Population Trapping scheme, the use of microwave cavities can be avoided to build atomic clocks. This can, in principle, bring down the size to a considerable extent. The recent advances in chip-scale atomic clocks has been possible due to CPT methods. Initial theoretical and experimental studies on this can be helpful for us to take it forward towards the space based atomic clocks.
Studies on light-shift effects in atomic clocks and analyses of onboard clock jumps.
Rubidium atomic clocks are the widely used clocks in GNSS for space based navigation. These Rb clocks are prone to onboard frequency jumps, which results in the error on the navigation signals. It is of utmost importance to understand the source of the jumps in the Rb clocks. The primafacie understanding has brought to notice that light-shift effect is the main cause of these jumps. However, a detailed study is needed to quantitatively understand the physics behind these jumps. Moreover, in this study the other potential parameters such as the radiation effect, magnetic effects etc need to be addressed which may result in giving rise to clock frequency jumps.</td></tr>
<tr><td>N4.3</td><td colspan="2">Trapped mercury-ion atomic clock (SAC)
The trapped mercury-ion atomic clocks can reach stabilities and drifts, which are 1 and 2 orders (respectively) better than the rubidium lamp based RF clocks. These are strong potential candidates for the future deep space navigation missions alongside the current NavIC missions. The area of research include study, design and demonstrate the trapped mercury-ion-clock physics package meeting state of the art specifications.</td></tr>
<tr><td>N5</td><td>Sub Area</td><td>Travelling Wave Tube Amplifier (TWTA) (SAC)</td></tr>
<tr><td>N5.1</td><td colspan="2">The Scope of Research Development in TWTA
• Development of large signal simulation tools,
• Study & development of special UHV grade materials & special coating techniques on UHV material suitable for high temperature brazing,
• Characterization of Secondary Electron Emission (SEE) & work function of various metallic & non-metallic surfaces & methods for improving SEE characteristics
• Development of methods for coating and texturing on copper surface for reducing SEE,
• Techniques for measurement of high temperature stress & strain in complex shapes,
• Design & development of long life high reliable space cathode.
• very high peak power Pulse TWTAs for radar applications,
• Q/V band CW TWTAs,
• folded waveguide TWTA and Coupled cavity TWTAs for higher frequency band power amplification,
• brazed Helix technology useful for higher CW power,</td></tr>
</table>

<table>
<tr><td></td><td colspan="2">• Microwave Power Modules – combination of Solid state amplifier and TWT with advantages of both the technologies,
• Flexible TWTAs for dynamic allocation of frequency, BW & power,
• Filtered Helix TWT with improved harmonic suppression,
• Cold cathodes,
• Mini TWT that can be placed right at the back of phased-array antenna,
• High power source that can be beamed to Microwave rockets.</td></tr>
<tr><td>O</td><td>Area</td><td>Signal & Image Processing and Data Product (SAC)</td></tr>
<tr><td>O1</td><td>Sub Area</td><td>Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL) (SAC)</td></tr>
<tr><td>O1.1</td><td colspan="2">Mutlispectral-to-Hyperspectral Reconstruction using Deep Learning (SAC)
A wide variety of high resolution Mutlispectral images are acquired by satellites every day. However, the availability of high resolution hyper-spectral data is still limited due to hardware constraints. Deep learning and other AI methods have the potential to address this limitation by synthesizing hyperspectral images from the available mutlispectral images with minimal compromise in the spectral characteristics. Though such mapping is an ill-posed problem, setting proper prior knowledge in the model can help solve this problem. Recent works in AI such as diffusion models and Neural transformers have shown promising results in tackling such problems. The motivation of this research is to generate qualitative hyperspectral images from multispectral images for scientific utility.</td></tr>
<tr><td>O1.2</td><td colspan="2">Infrastructure mapping and monitoring using AI/ML techniques from Synthetic Aperture Radar (SAR) Data (SAC)
Synthetic Aperture Radar (SAR) is an active microwave sensor that can take images of targets during day as well as night and can also penetrate cloud cover. The high resolution images acquired by SAR can be used to map and monitor various infra structure such as highways, airports, railway, bridges, buildings, vegetation etc. With availability of large amount of images from past, current and future SAR missions, a software for classification and temporal monitoring of government and non-government assets can be very useful for administrative purposes. The prime focus of this research is design and development of AI/ML based technique for classification of infrastructure in the readily available SAR image datasets. The infrastructures thus identified can be added to a library which can be referred for their temporal monitoring.</td></tr>
<tr><td>O1.3</td><td colspan="2">Artificial Intelligence (AI) Powered Rover Navigation (SAC)
Low power (<5W) and less weight (<1kg) vision system for planetary rover navigation is the future demanding technology for exploring the permanently shadowed regions and deep craters. Additionally, Rover has to have intelligence build-in to navigate in hazardous terrain and should be able to plan its navigation path dynamically based on the self-health and environmental conditions. It is proposed to build on-board vision compute element as an integrated solution of having vision sensors and processing hardware with terrain generation capability</td></tr>
</table>

O2	Sub Area	Image Processing (SAC)
O2.1	**Digital Elevation Model (DEM) generation from Multispectral bands (SAC)** Digital Elevation Model (DEM) generation from satellite imagery or other data sources constitutes an essential tool for a wide area of applications and disciplines, ranging from 3D flight planning and simulation, rectification of aerial photography or satellite imagery, creation of relief maps, 3D visualization, autonomous driving and satellite navigation, to modeling water flow, precision farming and forestry. The research element in this field is to develop and demonstrate a DEM generation algorithm for multispectral images with a very narrow baseline. In the traditional approach for DEM generation, one of the most important part is the development of a highly accurate sub-pixel matching algorithm for estimation of image shifts with an accuracy of the order of ~1/100-pixel. On the other hand, Artificial Intelligence and Machine Learning/ Deep Learning algorithms have experienced unprecedented growth in recent years as they can extrapolate rules in a data-driven manner and retrieve convoluted, nonlinear one-to-one mappings, such as an approximate mapping from satellite imagery to DEM's. Both conventional as well as Deep Learning-based methods need focused research in order to construct the mapping for DEM generation given a single RGB satellite image acquired from multispectral sensor. Also a technique needs to be developed to derive accurate absolute height values from the relative disparity map to generate DEM. This research will also help the generation of DEMs from relatively inexpensive platforms.	
O2.2	**Multi-Modal Satellite Image Registration (SAC)** Multi-modal remotely sensed satellite images generate a better representation of the target features and useful for diverse earth observation applications that includes resource assessment, vegetation profile mapping, snow/glacier studies and environment monitoring. Image registration is the crucial step in multi-modal image analysis that should align multi-temporal images acquired by different sensors. The different modalities of imaging acquisitions such as optical and microwave remote sensing images considered to be a challenging pair for remote sensing image registration. It plays an important role in remote sensing image processing domain and applied in wide variety of tasks such as image fusion and change detection. The SAR/Optical image fusion results in generation of science quality data product only when multi-modal data are corrected or modelled for relative geometric error at sub-pixel level. Even Thermal Infrared and visible images acquired by different satellites and sensors provides useful complementary information. The multi-modal image pair need to be registered for any kind of next level of data analytics and image interpretation. The research should be focus on literature survey, data preparation, model design and development of multi-modal satellite image registration software using novel image processing techniques that can have amalgamation of recent machine learning techniques as well as powerful deep learning models. Even the research area can also focus on improving the already	

	established feature and intensity based methods to achieve the spatial alignment of multi-modal remote sensing images. The experiments need to be evaluated with openly available remote sensing datasets in diverse landscape and showcase the results both qualitatively and quantitatively. The scope of the proposed research cover survey, design and implementation of recent trends in computer vision, image processing, machine learning and deep learning models in remote sensing data processing domain.
O2.3	**Remote Sensing Data Change Detection Framework (SAC)** Time-lapse remote sensing images provide vital information to study surface feature changes that happened gradually over decades. Monitoring gradual land cover change using earth observation satellites is required to identify urban sprawl, deforestation zones, new infrastructure's location, change in agricultural land areas, wetland distribution over inland water bodies and for various other space borne applications to make the planet earth habitable. The change information becomes a crucial input for land/ urban planning and helps to take correct policy level decision for a large geographic area. The research work should focus on end-to-end remote sensing change detection framework design and implementation using latest machine learning techniques and deep learning models. The literature survey should be comprehensive and exhaustive enough before selection of change detection methodology adopted for the research work. Change detection software developed should be generic enough and not only focused on Earth but also possible to detect changes for planets of our solar system due to availability of large remote sensing image archives. Among them, Mars is a dynamic and active planet in our solar system, which attracts humans due to different geological events continuously reshaping its surface. The experimental results should showcase the visual assessment of the changes identified among bi-temporal remote sensing images in the form of change intensity detection map and colour composite image at different feature targets. The quantitative assessment of the change detection result should also be computed and compared with the state-of-the-art remote sensing change detection techniques. The scope of the proposed research cover survey, design and implementation of recent trends in computer vision, image processing, machine learning and deep learning models in remote sensing data processing domain.
O2.4	**Aerosol Optical Depth Estimation from High Resolution Images (SAC)** Atmospheric compensation or correction is an essential pre-processing step in scientific data analysis or interpretation of any satellite imagery and most importantly in applications that involve temporal studies. For this compensation or correction, a precise atmospheric model is very important which is quite sophisticated due to various inputs like aerosols, humidity, temperature, gaseous environment, surface properties, sun-target-sensor geometry etc. In atmospheric modeling, aerosols plays most important role and correct

	information about type and distribution is required to model the atmosphere. Therefore correction is ideal when scene-specific (in-situ) atmospheric data (aerosol content, water vapour, ozone, gaseous environment etc.) are available, which is rare and not possible in operational scenarios. The most important parameter, Aerosol Optical Depth (AOD), can be accessed from various sources like Aeronet, Indian National Satellite System (INSAT), Moderate Resolution Imaging Spectrometer (MODIS) and Climatology (modeled using several years of data of a particular location). However it is not possible to get AOD for the date and time (except In-situ) for which the atmospheric correction has to be done but it can be derived from the multi-spectral (MX) bands, essentially having blue or near blue band. We are trying to estimate AOD using signature like water, vegetation and man-made constructions (e.g. tar and cemented structures) by considering them as standard reflecting targets and using spectral library as reference. Also in another approach, we are trying to use top of the atmosphere reflectance (TOAR) from above targets to estimate AOD by modeling TOAR vs AOD for a sensor of a particular satellite.	
O3	**Sub Area**	**Computer Vision (SAC)**
O3.1	**Flash LiDAR based Terrain Relative Navigation (SAC)** Landing on unknown territory is always a challenging task and navigating Lander to a safe location often require absolution sensor update. The active area of research in Terrain Relative Navigation is to use Flash LiDAR data as input for determining the absolute position and also for navigation relative to hazards. It is proposed to build on-board system of processing algorithms and hardware for Flash LiDAR based Navigation. This includes matching LiDAR intensity image with DEM or optical images on space qualified FPGA platform at a minimum update rate of 1fps. It should be able to provide hazard identification and absolute position (latitude and longitude) with an accuracy of <10m.	
O3.2	**Lunar Surface Image Generation for Testing Image processing algorithms in closed loop (SAC)** This research focuses on design and development of algorithms and software for generation of Lunar Surface Image using sensor geometry, sun geometry, platform attitude, local terrain data and surface properties. The surface image thus generated will be validated using actual planetary images. The methodology for Lunar surface Image generation can be used in closed loop for testing Lunar data Image processing algorithms.	
O3.3	**Illumination, Scale, Translation and Rotation invariant image matching (SAC)** For Interplanetary, Comets and Asteroid Landing Missions with precise position requirements, on-board Algorithm has to be developed for illumination, scale, translation and rotation invariant image matching on space qualified FPGA platform. This image matching should operate at a minimum update rate of 1fps and should be able to provide absolute position (latitude and longitude) with an accuracy <10m.	

O4	Sub Area	Processing and Analysis Frameworks (SAC)
O4.1	**Block Chain enabled system for Geospatial data sharing (SAC)** Blockchain is a revolutionary disruptive technology which has brought ripples in multiple fields ranging from finance to medical sciences. Originally designed to solve the double spending problem in a distributed ledger, several innovative applications have emerged and new ones are being discovered every day. At the heart of Blockchain, lies an immutable distributed ledger which contains a record of all transactions performed on the blockchain. The ledger is immutable in that once records are added into it, they cannot be edited or manipulated thus facilitating tamper-resistance. In a typical blockchain-based system, trust and management responsibilities are distributed among the operators. Unlike traditional systems, blockchain based systems require nodes to perform consensus operations to be able to verify and validate incoming transactions and add the blocks to the blockchain. Many revolutionary full-fledged applications, concepts as well prototype solutions have been developed in different fields such as Finance, Gaming, Banking, Supply chain management, etc. have been developed and working. Concepts such as DeFi, Smart contracts, DApps, as well Distributed Autonomous Organizations (DAOs) are currently being used to transform the way traditional organizations work. We believe that space applications can also benefit immensely from the power of this technology. Research in this field is currently focusing on building a decentralized and secure Geospatial data sharing system which can support a wide variety of users autonomously. The system will enable seamless sharing of Geospatial data availability records over a public or permissioned blockchain and will enable better synchronization amongst users in the emerging scenario of the Geospatial landscape in the country. Towards this, research needs to be done to develop algorithms which can autonomously validate the data being shared on the network through efficient consensus mechanisms. Also, techniques for scalable and efficient wide-spread usage need to be developed so that it can be adopted in real scenarios.	
O4.2	**Data Cube Infrastructure for Optical and Microwave IRS data (SAC)** Number of Earth observation(EO) data users and developers are growing and a number of challenges need to be solved to fill the gap of acquisition and use of ever-increasing satellite data acquired by ISRO. The majority of EO data still remain underutilized mainly because of their complexity, increasing volume and lack of efficient processing capabilities. However, the full information potential of EO data can be utilized by directly providing Analysis-Ready-Data(ARD) to the user community. The ARD has all pre-applied corrections for radiometry and geometry. EO Data Cube (DC) is a new paradigm aiming to realize full potential of satellite data by lowering barriers caused by these Big data challenges and providing access to large spatio-temporal data in a user and developer friendly form thereby fulfilling both visualization and analysis needs. Systematic and regular availability of Analysis Ready Data for Optical and Microwave IRS missions, will	

	significantly reduce the post processing burden on ISRO's IRS data users The aim of this research is to enable rapid data access and pre-processing to generate ARD using interoperable services chains	
O4.3	**Clifford Algebra (also known as Geometric algebra) based processing and analysis framework for multispectral and Hyperspectral Images (high dimensional data manifold) (SAC)** Geometric algebra (GA) provide a unified and concise homogeneous algebra framework based on advanced geometric invariants, projection geometry, affine geometry, etc. It can efficiently solve the geospatial data processing problems due to its advanced geometrical vector-based data processing. GA is important in image processing and computer vision due to its application in handling color/channel by using vector and its ability to solve AI classification problems. Feature extraction of a given image is a key step in many computer vision and image analysis tasks, such as satellite image denoising, remote sensing image object identification, image fusion, super-resolution reconstruction, and target recognition. At present, there are many solutions, but due to mathematical limitations, these methods mostly deal with grayscale images, and the matching of color images is rarely studied. The common method used for color image matching is to convert the images into a grayscale images and then use the gray image method to match them. Converting a color image into a grayscale image leads to the vector attributes of the color and some important color information being lost, however, which can cause matching failures. GA can provide a solution for this via its sub-algebra quaternions.	
O5	**Sub Area**	**Synthetic Aperture Radar Data (SAR) Processing (SAC)**
O5.1	**Baseline refinement and Phase Noise reduction in SAR Interferograms (SAC)** SAR Interferometry has a wide range of areas for usage. In SAR Interferometry, two observations of the same region either in a single pass or repeat pass are required. Phase difference of the two SAR images for same feature is a combination of phase differences from sources like orbital position of two sensors, atmospheric delay, target elevation and target deformation over time. For analysis related to target elevation and deformation, phase difference induced due to different orbital positions must be cancelled. Thus, it becomes utmost important to have precise knowledge of orbital positions of sensors. Imprecise knowledge of sensor positions results in inaccurate baseline (distance between two sensor positions) which is used for compensating phase difference due to different orbital positions. Also, depending upon the duration between two passes, decorrelation between targets occurs. Larger the time duration between the two observations, more is the phase noise and hence it directly affects the quality of unwrapped phase. Research in this area focuses on development of techniques for improving the Interferogram quality & there by improving accuracies in various interferometric applications.	

O5.2	**Moving Targets identification and their parameter estimation from SAR Image (SAC)** During Synthetic Aperture Radar (SAR) imaging, the sensor is flown in an Aircraft/ spacecraft, pulses are sent and the return echo's are recorded. While processing, the range and the relative motion between sensor and target (earth) is utilised to generate images. In SAR, the background region, called clutter, is the region of interest and it is assumed to be stationary and SAR image focusing is done. Moving targets likes cars, Trains, etc in the images are defocussed and/or displaced and may appear as artifact in the image. Getting information of moving targets for SAR image will provide valuable information in utilisation of SAR images in strategic applications. Additionally, the work will help in designing the state of the art SAR systems for moving target indication. In the scope of this research, software implementation of various methods of Moving Target detection using SAR raw data, single/multiple SAR image has to be done.Parameters for moving target like position and velocity must be estimated. Refocusing of moving targets in SAR image should be attempted.	
O6	**Sub Area**	**Image Geometric quality improvements (SAC)**
O6.1	**Image Geometric quality and Satellite Platform performance assessment (SAC)** Level-1 products are the basic products without geometric correction and any other-processing, therefore are of prime importance for any feedback on platform performance and stability. Location errors in Level-1 products can be traced back to the errors in attitude or residual-attitude, orbit, drift and micro-vibrations of the platform. The main aim of this research is to analyze the Level1-products over different orbits and time to understand the behaviour of residuals in attitude, orbit and drift. Once these parameters are properly modelled, the eventual location errors on the ground should not significantly vary. Under this research, a simulation using the physical sensor model will also be required to generate the bias-compensated Level-1 product and will be used for accuracy assessment. It is expected under systematic coverage conditions, location errors on the ground should remain stable. Also, consistency of the parameters under different imaging conditions (different roll, pitch, yaw, for instance) can be analyzed.	
O6.2	**IRS satellites Orbit accuracy estimation from Ephemeris parameters (SAC)** The aim of this research is to estimate the orbit accuracy using orbital parameters in conjunction with satellite broadcast ephemeris. The error in orbit essentially contributes to various system level errors in data products, namely location error, targeting error etc. and the effect of orbit errors on the accuracy of the data products cannot be neglected. The broadcast ephemeris typically contains the time-tagged GPS coordinates of the satellite. Precise orbit determination and state vector generation require actual GPS based position vectors of the satellite in ECI (Earth Centred Inertial) frame. First, the	

	preliminary or approximate orbit is determined using established techniques (ref: P.R. Escobal, "Methods of orbit determination"). Then the refined orbit is obtained by using batch least square process and differential correction procedure. A full force model is required for orbit propagation and the predicted positions can be validated against the GPS data. This study mainly requires an accurate full force model development, which accounts for gravitational forces due to Sun and Moon, solar radiation pressure, etc., for the orbit propagation. Further, modelling errors and orbit drift with time can also be investigated.	
P	**Area**	**Electronics and Microelectronics Design, Fabrication and Testing Technologies (SAC)**
P1	**Sub Area**	**Passive Device and Component Technologies (SAC)**
P1.1	**Simulators for SAW filter design (SAC)** Surface Acoustic Wave (SAW) filters provide efficient RF filtering in a compact footprint, in the frequency range of 10 MHz to 3 GHz. In spite of the prevalence of these devices in modern communication equipment, general purpose design tools for the simulation of these filters are non-existent. The scope of the proposed research work, hence, shall be to develop accurate simulation tools for the prediction of SAW filter performance. Target specifications and fabrication support shall be provided by SAC. The accuracy of the developed tools shall be checked against the measured performance of fabricated filters.	
P1.2	**Development of Silicon micromachined THz interconnects (SAC)** High transmission losses associated with planar transmission lines obviates their use at mm and sub-mm wavelengths. Metal waveguides realized through fine CNC milling techniques have hence become the preferred medium for signal transmission at THz frequencies. However, they need accurate hand alignment and are non-compatible to planar integration with THz active and passive devices. Since the last few years, Deep Reactive Ion Etching (DRIE) based Silicon micromachining has shown immense promise for the realization of THz interconnects and hence are being actively pursued in research. Proposals are invited for development of DRIE based Silicon micromachining processes for realizing THz interconnects. The scope of the proposed work shall include (a) development of Si micromachining processes for THz interconnects suitable up to 500 GHz and (b) demonstration of performance through fabrication and testing of interconnects. The process recipes developed and the hardware realized shall serve as the deliverables of the project.	
P1.3	**TCAD based modeling of GaN HEMTs (SAC)** Gallium Nitride High Electron Mobility Transistor (GaN HEMT) has become the device technology of choice for the realization of high frequency-high power amplifiers. However, GaN HEMT being a comparatively nascent technology, many of the effects that manifest at the device level are still in the domain of research. Models are required to be	

	developed for these devices for their use in circuit design. Measurement based empirical models can be fast but not very accurate. Physics based compact models are fast and offer better accuracy. However, these models themselves need some validation at different stages of their development, where some of the real device effects are ignored while others are considered. This validation is carried out through a comparison with the predications of TCAD simulators, where the number of real device effects, physical parameter values etc. can be independently chosen. Proposals are invited for TCAD based 3-D modelling of GaN HEMTs. The scope of the proposed work shall include (a) development of Silvaco TCAD 3-D models based on device geometrical and physical parameters provided by SAC and (b) validation of DC, RF, noise and non-linear behaviour predictions of the developed models with measurement data to be provided by SAC. Models developed and the simulation flow shall serve as the deliverables of the project.	
P2	**Sub Area**	**Micro And Diffractive Optical Component Technologies (SAC)**
P2.1	**Development of 45° Bending Mirror for out-of-plane coupling in Polymer Optical Waveguides for Optical Interconnects (SAC)** Bending Mirror is one of the simple solutions for out-of-plane coupling of light between optical waveguides and optoelectronic devices fabrication. In this type of coupling, light is reflected due to either a metal coating or total internal reflection at the end of a polymer waveguide. A PCB compatible 45° bending micro mirror is to be fabricated on polymer optical waveguides using tilted beam photolithography. After successful fabrication, the mirror needs to be characterized for coupling efficiency. The activity shall include the following: • Survey and selection of required materials and process as per detailed SAC requirements. • Development of fabrication process.	
P2.2	**Development of Precision Slits / Apertures / Bar Targets (SAC)** Precision slits, apertures and bar targets are one of the essential components for realization / calibration of optical imaging cameras. These components when fabricated with high precision provide a well-defined desired image without problems like beam scattering etc. The precision slits / apertures / bar targets may be fabricated in Si (with appropriate optical coatings) or in metal foils (of appropriate metal) so that it works with the visible and IR spectrums. The coated Si substrate / metal foil shall work as an opaque material with the gaps in them allowing the light to pass through as per the design of the pattern. The activity shall include the following: • Survey and selection of required materials as per detailed SAC requirements.	

	• Development of fabrication process, typically Si through etch / Lithographie, Galvanoformung, Abformung(LIGA) based processes. • Process, component demonstration and qualification.
P2.3	**Development of Deformable Mirror (SAC)** Deformable mirror is an integral part of a variety of modern adaptive optics system, which are used to correct the optical aberration of the wave front. It is carried out by deforming the shape of a membrane (mirror) in response to an applied control signal. A Polysilicon Multi-Users MEMS (PolyMUMPS) type or similar process is to be developed for Fabrication and Packaging of the deformable mirror array device. It is desirable that fabrication and packaging be followed by relevant characterization steps to validate the performance of the device. The activity shall include the following: • Survey and selection of required materials and process as per detailed SAC requirements. • Development of the fabrication process. • Process, component demonstration and qualification.
P2.4	**Development of Reflective Optical Coating over PMMA Resist (SAC)** Optical coating is an important process in several micro/diffractive optical devices in order to alter the way light interacts with them. To achieve required reflectance in the desired wavelength range appropriate reflective optical coatings are used. This application requires reflective optical coating on 2D/3D shapes fabricated over Poly Methyl Methacrylate (PMMA), a polymer. This work requires the development of optical coating over 950K PMMA Electron Beam Sensitive Resist. The structure shall have either binary or greyscale resist pattern over planar or non- planar substrates of irregular sizes. The coating shall have excellent adhesion with resist (PMMA) and shall preferably be abrasion free. The activity shall include the following: • Survey and selection of required materials as per detailed SAC requirements. • Development of optical coating process over Patterned PMMA Resist Structures. • Process, coating performance demonstration and qualification.
P3	**Sub Area** — **Microfabrication Process Technologies (SAC)**
P3.1	**Development of Electron Beam Sensitive and Dry Etch Compatible High Resolution Resist (SAC)** Electron beam lithography has been an attractive technology to delineate nano-structures. These patterned structures can further be transferred on underlying metals (such as Aluminium in this case) using Dry Etching technique. This process requires the resist to be electron beam sensitive as well as dry etching compatible. Scope of Work: A Dry etching compatible electron beam sensitive resist with its developer is to be prepared.

	The activity shall include the following: • Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements. • Process, material demonstration and qualification - Process with Aluminium Deposition, Electron Beam Lithography, Aluminium Dry Etching over an area of 15mm x 15mm with 70nm half pitch (preferable 40nm) Binary Grating structures
P3.2	**Development of Electron Beam / Photo Lithography and Dry Etch Compatible Resist with High Stability at Elevated Temperatures (SAC)** In certain applications, e.g. for MESA isolation, it is required to perform multiple processes such as Etching, Deposition and further lift off in a single lithography step. This demands the resist to be not only dry etching compatible, withstand subsequent high process temperature during deposition process but also support lift off afterwards. Scope of Work: Resists with suitable developer (as per detailed SAC requirements) are needed to be synthesized that should be dry etch compatible, withstand high temperature deposition process without getting deformed and then support lift off process in a single lithography step. The activity shall include the following: • Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements. • Process, material demonstration and qualification.
P3.3	**Development of Dry Film Resist for Thin Film Integration on LTCC (SAC)** Low temperature co-fired ceramic is a useful technology for RF applications. Integration of multilayer structure in LTCC is based on thick film processing. Development of dry film resist (DFR) is required for thin film integration on LTCC. This is needed for the fabrication of certain circuit elements having smaller (<100μm) features. Scope of Work: A Dry Film Resist is to be developed and using it process needs to be demonstrated meeting SAC requirements. The LTCC contains slots (cavities) and may have process-induced warpage, bow etc. The activity shall include the following: • Survey, selection and development of required materials, resists, developer, plating chemistries, suitable equipment etc. • Development of fabrication process, which includes seed-layer deposition, DFR lamination, lithography, electroplating, seed layer etching etc. • Process demonstration and qualification.

P3.4	**Electrically controlled tunable integrated devices using Magneto-electric (ME) composites (Thin film/Bulk & Thin film/thin film) for microwave integrated circuit applications (SAC)** The emerging research area of Magneto-electric devices where the magnetic characteristics are controlled by an electric field and/or the electric characteristics are controlled by a magnetic field, the magnetoelectric (ME) effect, is a very attractive subject for novel microwave circuit applications. The composite systems usually include Ferrite-Ferroelectric/Piezoelectric combinations. In such bilayer system, the ferrite, when driven to Ferromagnetic Resonance (FMR) and an electrical signal is applied; the FMR frequency can be shift thereby facilitating tunable characteristic. It is proposed to develop suitable composite material system with at least one component in thin film form and demonstrate dual-tunable integrated microwave components like tunable inductor, phase-shifter, attenuators, filters etc. using the developed material system.
P3.5	**Studies on energy dependent Secondary Electron Yield of Carbon Nanotube (CNT) coatings on OFHC Copper for high frequency (Ka band) TWT (SAC)** One of the prime objectives of very high frequency (e.g. Ka band) TWT especially for Space use, is to reduce the secondary electron emission (SEE) from Multistage Depressed Collectors (MDC) so as to improve the TWT efficiency. Variety of techniques have been investigated and being deployed for the intended objective. One of the recent research areas is developing CNT coating on conducting surface of collector which is expected to reduce secondary electron yield by a factor compare to other materials like Graphite. The activity aims to develop suitable method for CNT synthesis, deposition of CNT coating on OFHC cupper collector surface and characterizing the SEE.
P3.6	**Development of Nanostructured Magnetostrictive thin films for Surface Acoustic Wave Applications (SAC)** Surface Acoustic Wave (SAW) devices are widely used in communications such as filters, delay line etc. Conventional SAW devices consist of metallic IDT on top of piezoelectric film or substrates. Research involves the development of high quality thin films of giant magnetostrictive materials (e.g. Fe-Si) which exhibit high magnetostriction coefficient suitable for low insertion loss SAW devices.
P3.7	**Brazing/Attachment media for Ceramic /Quartz substrates for high reliable micro assembly (SAC)** This work shall include selection of reliable micro assembly Candidate material based on thermomechanical modelling and experimentations for the following applications: Void free low temperature (~ 300 degC) attachment media and process of large ceramic substrate (1”x1 “to 3”x5”) attach over metallic carrier plates suitable to withstand -55 to +125 degC temperature cycle regime. Configuration study and recommendations on metallic carrier mechanical properties are also to be devised for reliable assembly for a given substrate configuration/design. Simulation & experimental study of attachment void v/s over RF performance up to Ka Band Amplifier circuit made with discrete elements and alumina substrates.

P4	Sub Area	Electronic Circuit Simulation (SAC)
P4.1	**Functional Verification of Digital circuit and Model development for Equivalence checking at Gate level with Resistor Transistor Logics (RTL) logics (SAC)** Electronic circuit simulation uses mathematical models to replicate the behavior of an actual electronic device or circuit. Some electronics simulators integrate a schematic editor, a simulation engine, and on-screen waveform display, allowing designers to rapidly modify a simulated circuit and see what effect the changes have on the output. They also contain extensive model and device libraries. These models typically include IC specific transistor models like Pspice, Verilog A and Hardware Description Language (VHDL)- Additional Member System (AMS) etc. Printed Circuit Board (PCB) design requires specific models such as transmission lines for the traces, I/O Buffer information Specification (IBIS) models for driving and receiving electronics.	
P4.2	**Design and Simulation of Embedded passive technology (EPT) based PCB (SAC)** Embedded Passive Technology (EPT) is the process of building passive components such as resistors, capacitors and inductors inside Printed Wiring Boards (PWBs) during board fabrication. The need for embedded passives technology is driven by multiple factors such enhanced electrical performance (SI & PI) higher packaging density and potential cost saving.	
P5	**Sub Area**	**Electronic Calibration (SAC)**
P5.1	**Calibration of Test & Measuring Equipment used in the field of Optical Communication (SAC)** SAC is involved in development of optical communication devices like optical amplifier, photonics Analog to Digital convertor, optical switches, O-E & E-O convertors which are used in high speed optical links etc. For Testing of these devices Test & Measurement Equipments are used like Tuneable Laser Sources, Optical Power Meter, Optical Attenuator and Optical Spectrum Analyzers. So seeing increase in optical payload activity; SAC calibration facility is working for upgradation in the field of optical communication. For this Calibration lab is trying to establish the traceability for optical parameter especially in the band of 1550±20 nm and trying to find out the ways for calibration/validation of test & measuring equipment in optical communication field.	
P6	**Sub Area**	**Surface Treatment Process Technologies (SAC)**
P6.1	**Process Development to realize Electroforming Process for Aluminium Component (SAC)** Electroforming is a technique used in fabrication of complex contoured components with high dimensional tolerances which are difficult to fabricate using conventional machining methodology. At present, electroforming process of copper components on Aluminium mandrels has been successfully realized at SAC. Copper has disadvantage of high density of 8.9 grams/cc.	

	Hence, efforts are invited to carry out in depth feasibility study to realize electroforming process of Aluminium components and develop detailed process & setup for the same. This process can be used for mm-wave components.	
P6.2	**Non-cyanide based Electroless Silver Plating Process Development (SAC)** Silver plated components are widely used in RF systems of satellites. With miniaturization of mechanical assemblies and usage of higher frequency bands like K-band & Ka-band, dimensions have decreased to around 4 mm & lower. Also long waveguides of the length of 1.2 meters are being used with twists and turns in various planes, making it extremely difficult to silver plate inside surface of the cavity using the conventional electrolytic silver plating methodology. Hence, efforts are invited in the area of non-cyanide based Electroless silver plating chemistry for plating aluminium 6061T6 alloy components with plating thickness of >=2 microns of silver inside complex multi planar wave guides.	
P6.3	**Development of Electroless Gold Plating Process (SAC)** Gold plating on aluminium 6061T6 boxes and Kovar carrier plates is being carried out for EMI/EMC requirements, corrosion protection, solder ability etc. Hence, efforts are invited in the area of Electro less gold plating process using either cyanide based or non-cyanide based chemistry for plating aluminium 6061T6 alloy components/Kovar substrates with plating thickness of >=2 microns of gold. Once developed, this process will be used for all ISRO projects as per requirements.	
P7	**Sub Area**	**Space Environment Simulation and Testing Technologies (SAC)**
P7.1	**Super Insulated Cryogenic Transfer Lines (SAC)** Vacuum jacketed Cryogenic transfer lines are an integral part of a thermal vacuum system, as they offer compact size footprint, extremely low heat inleak, aesthetic layouts, ease of installation and lower long-term maintenance costs.	
P7.2	**Pulse-Tube Cryo Cooler (SAC)** Pulse tube cryo-coolers have been evolved in recent years and matured as a promising technology for meeting the challenging cooling requirements of space industry. They provide significant advantages in terms of overall size, extremely lower vibration levels, and higher reliability. These coolers have been used in ground segment testing of space hardware as well as for onboard applications. The scope of this work shall entail development of compact, low cost single stage/ double stage Pulse Tube cryo-coolers to facilitate testing tiny devices at low temperature as well as for low cooling requirement for IR/CCD detectors. Expected cold tip temperature for this development activity is 80K with ~10-watt cooling capacity @80K, which can be verified in existing facilities at SAC with appropriate set-up.	

P7.3	**ThermoAcoustic Cooler (SAC)** Thermoacoustic coolers can provide a very compact, simple & reliable way for producing the desired refrigeration effect. This cooler also has an advantage of using inert gases and produces very low environmental impact. The scope of this work will involve development of acoustic coolers for small detector cooling application and handling heat from the heat sinks etc.
P7.4	**Mixed Gas Refrigeration System (SAC)** The recent advancements in the development of mixed gas refrigeration systems has generated considerable interests in potential application of such systems, which were earlier out of reach for mechanical refrigeration systems particularly for cryogenic temperatures. The scope of this work shall involve development of mixed gas refrigeration based thermal system for compact climate test chambers and thermal vacuum chambers. The researchers shall be responsible for design, simulation, analysis, optimization & realization and testing of thermoelectric coolers. The expected lowest temperature for mixed gas refrigeration system is -150degC in cascade mode. The performance of the realized system will be tested and verified against the target specifications.
P7.5	**Liquid nitrogen consumption and optimization study (SAC)** Liquid nitrogen is a fluid of choice for majority of thermal vacuum chambers due to its characteristics like low temperature of liquefaction, very wide temperature range in single phase, large latent heat of evaporation and lower cost. As LN2 is utilized across the facilities in majority of thermal vacuum chambers, its overall usage and optimization is equally important. The present proposal will involve Study and analysis of Liquid Nitrogen consumption in Thermo-vacuum test facility with respect to different type of tests being carried out in different LN2 based thermo-vacuum chambers. Study and analyze transfer, static and flash losses taking place in various system elements during thermo-vacuum tests and carry out detailed process study as well as make recommendations in this regard for implementation.
P7.6	**InfraRed imaging system for temperature monitoring (SAC)** Real time temperature monitoring of different critical components and surfaces during a thermal vacuum testing necessitates availability and utilization of an accurate & fast response-based temperature measurement system. Temperature sensor mounting at the required locations on a subsystem is an essential but laborious and time intensive activity, and an IR based imaging system can provide a non-contact type real time temperature monitoring inside a thermal vacuum chamber.

	The present scope of work involves a development of IR mapper-based temperature measurement system for monitoring the package temperature inside a thermal vacuum chamber, thereby eliminating the need of physically temperature sensor mounting. The required temperature range for the measurements is, from -40degC to +85degC.	
P7.7	**Design and realization of XHV system (SAC)** Achieving Extreme High vacuum has been a holy grail of vacuum science. Simulation of interstellar space, processing of some advanced semiconductor devices, surface science experiments and measurements are few important applications for XHV level. The present scope of work will involve development of a small experimental cavity/ volume XHV system for achieving better than 1e-12 mbar vacuum.	
P7.8	**Zero-Boil-Off System (SAC)** Zero-Boil-Off (ZBO) systems can provide considerable savings for mission critical cryogens particularly for interplanetary missions. These systems become more critical for human space missions needing long duration in space. ZBO-Zero Boil Off Cryogenic system will demonstrate long term storage & saving of cryogen (Experimental system) with minimal cryogen losses from the storage tanks due to natural boil-off. The proposed prototype may also be utilized as a platform for future interplanetary type missions which will certainly have this requirement.	
Q	**Area**	**Mechanical Engineering Systems (SAC)**
Q1	**Sub Area**	**Thermal Engineering (SAC)**
Q1.1	**Efficient Heat Transfer/Transport devices/Energy Storage Systems (SAC)** • Loop Heat Pipe • Pulsating heat pipe (PHP) and its characterization in zero/micro gravity environment • Micro heat pipes for device level thermal management • Cryogenic heat pipes • Heat Pipes with Self-Rewetting Fluids for Space Applications • Diode Heat Pipes • Metal-based submillimetre-thick flexible flat heat pipe with innovative wick structures • Cooling/Pumped Loops • Phase Change Materials • Honeycomb panel with heat pipes and PCM • Any other innovate concept for efficient heat transfer	
Q1.2	**Variable Emissivity Coated (VEC) Micro-electromechanical System (MEMS) radiators (SAC)** Technologies/process related to development of VEC/MEMS based radiators for optimizing radiator size for deep space missions need to be developed. Collaboration is envisaged in any experimental/numerical aspect of the same.	

Q1.3	**Deployable Radiators (SAC)** Technologies associated with deployable radiators to optimize heater power need to be developed.	
Q1.4	**Cryo Coolers (SAC)** Following types of cryo-coolers and its associated technologies (experimental and numerical aspects) need to be developed for cooling of various kinds detectors/systems in various temperature ranges upto 4.2K: • Stirling Cryo-cooler • Pulse tube Cryo-cooler • J-T Cooler • Peltier effect Coolers	
Q2	**Sub Area**	**Various Cooling Technologies For Low And Ultra-Low Temperature Range Cooling (SAC)**
Q2.1	**Adiabatic demagnetization refrigerator (ADR) (SAC)** Collaboration is envisaged in development of various subsystems and critical technologies related to ADR like salt pill, Magneto Resistive Heat Switches, Superconducting Magnets, etc. Development of numerical code for modelling of magneto calorific effect (MCE) and system level modelling of ADR also need to be taken up in joint academic collaboration	
Q2.2	**Dilution Refrigeration (SAC)** Dilution refrigerators are a common technique for reaching temperatures below 1K, particularly where continuous cooling at these temperatures is required. Helium exists in two stable isotopes: 4He and 3He. Naturally occurring 3He is extremely rare, constituting less than 1 part per million of helium gas. However, 3He can be manufactured, as it is a radioactive decay product of tritium (3H), an isotope of hydrogen. Almost all 3He used today is artificially produced. A dilution refrigerator uses a mixture of liquid 3He and liquid 4He and takes advantage of physical attributes of these mixtures. In its simplest form, then, a dilution refrigerator can be created by creating a bath (referred to as the mixing chamber) containing a mixture of 3He and 4He below 0.8K and then pumping on the 4He rich zone. This will preferentially remove 3He atoms. In order to maintain equilibrium, 3He atoms will move from the 3He rich zone to the 4He rich zone, causing the mixture and whatever is thermally attached to it to cool. Without any additional heat load, dilution refrigerators can reach a temperature of less than 10mK. More typically, dilution refrigerators remove 200 – 400 µW at 100mK.	
Q2.3	**Optical Cooling (SAC)** Optical refers to a number of techniques in which atomic and molecular samples are cooled down to near absolute zero. Laser cooling techniques rely on the fact that when an object (usually an atom) absorbs and re-emits a photon (a particle of light) its momentum changes. For an ensemble of particles, their temperature is proportional to the variance	

	in their velocity. That is, more homogeneous velocities among particles corresponds to a lower temperature. Laser cooling techniques combine atomic spectroscopy with the aforementioned mechanical effect of light to compress the velocity distribution of an ensemble of particles, thereby cooling the particles.	
Q3	**Sub Area**	**Composites and Advanced Materials Applications (SAC)**
Q3.1	**Development and characterization of High Strain Tolerant Infusion Grade Resin System for realizing elastic foldable structures for space applications (SAC)** Resin System are the essential elements for the Development of the Composites materials and components. The resin systems are primarily responsible for the load transferring between the reinforcement materials and protecting it for the environmental effects. The composites material exhibits linear behavior against the applied load near to its fracture. Large strain tolerant resin system will lead this for the foldable structure to minimize the space requirements by folding it in the launch vehicle envelope. The development of the large strain tolerant (>20 %) resin system will pave the way for minimizing the space about 50% in the stowed conditions.	
Q3.2	**Design &Finite Element FE simulation of non-linear behaviour of bendy and foldable composite booms (SAC)** In recent years, satellite size is increasing or multiple satellites have been launched in one go but it is constrained by payload fairing size of the launch vehicle. Therefore, it is necessary to make compact and lightweight components in the payload of the spacecraft. Self-deployable composite booms would be very useful candidate to fulfil this requirement. Design of bendy and foldable composite boom involves geometric non-linearity behaviour because of large deformation, bending and folding. FE simulation is must to predict the bending feasibility, strain energy, stresses, elasticity and establish design margins. Post deployment stabilization timing of the boom is also an important parameter. Shock waves generated by the deployment action are also to be evaluated.	
Q3.3	**Development of High Strain Tolerant Infusion Grade Resin System for the Space Applications (SAC)** Resin systems are the essential elements for the Development of the Composites materials and components. The resin systems are primarily responsible for the load transferring between the reinforcement materials and protecting it for the environmental effects. The composites material exhibits linear behaviour against the applied load near to its fracture. Large strain tolerant resin system will lead this for the foldable structure to minimize the space requirements by folding it in the launch vehicle envelope. The development of the large strain tolerant (>20 %) resin system will pave the way for minimizing the space about 50% in the stowed conditions.	

Q3.4	**Design, FE Simulation and Development of Elastic Foldable Reflector for Large Aperture Antenna (SAC)** Antenna Reflector are the main element for the satellite communication. Due to requirement of the large shape antenna for the future space missions and limitations for the space in the launch vehicle for the accommodation, elastic foldable antenna reflectors are the prime candidate for the future satellite based communications and navigations.
Q3.5	**Development of shape configurable/deformable parabolic reflector using shape memory alloy (SMA) or equivalent actuation (SAC)** Development of large flexible antennas is becoming critical today; such antennas can be realized with shape memory alloy actuated mechanism. It can be reconfigured in space for variable antenna footprint, and hence can be utilized for signal transmission to different geographical locations. Requirement of changing the shape is quasi-static and hence SMA based actuators and very much suitable for this application.
Q3.6	**Metallization of composites for enhancing electrical and thermal conductivity for development of RF components (SAC)** Light weight & high modulus composite structures are the need of the current Space scenario. These composite structures provides excellent load carrying member as well as maintaining dimensional stability in harsh space environment. The use of composites are limited to only structural parts. To utilize in realizing RF parts, there is need of improvement of electrical and thermal conductivity of the composites. Metallisation on a composite part itself calls for the various qualification and always leaves uncertainty in terms of quality. The biggest challenge is survival of the metallization in extreme space environment in the orbit. There are various methods, which may be tried for metallization. • Conductive surface coating or metallization of CFRP. Surface activation & Electro plating or Electro-less plating. • Development of Electrical Conductive Prepregs /Resin system (lamination) for Space grade composite systems. • Development of carbon-carbon composites with excellent electrical and thermal conductivity for realization of RF components. • Metallization of CFRP may also be done by inclusion of graphene/CNT at layup stage.
Q3.7	**Development of techniques for tri-axial in-plane weaving of carbon fibres for realization of spring-back antenna reflectors (SAC)** Future communication space programme require larger and highly accurate/precise space borne reflector antennas, while earth observation and scientific missions require even higher frequency operation. To realize such reflectors, flexible thin fabric membranes are to be developed and qualified. These type of reflectors are mainly known as spring-back reflectors and can be developed using tri-axially woven carbon fabric.

Q4	Sub Area	Microwave Payloads Mechanical (SAC)
Q4.1	**Prediction of metal component behaviour beyond linear elastic range (SAC)** Behaviour of metal components beyond linear elastic range has remained a gray area in the field of space payload component development. Understanding behaviour of material post plastic deformation will enable accurate life estimation and mass optimization in payload components. For comparison one can take example of an L-angle realized using matching and the other realized by bending a sheet of same material and cross section. The structural behaviour of both the components will be in a way that machined component will be more rigid than the formed component.	
Q4.2	**Implementation of Active cooling methods for Microwave packages of space payloads (SAC)** With increase in heat dissipation densities due to increase in power of RF devices and miniaturization of subsystems, current passive cooling techniques have a limitation, which can be overcome by design of compact Active cooling for such devices, which enables utilizing the device capabilities to the fullest. The proposed cooling methods may include Phase change materials, Thermo-electric coolers, micro heat pipes etc.	
Q4.3	**Reduction of structural dynamic response in Multi-level Stacked package assemblies (SAC)** Payload subsystems are stacked one over the other in order to reduce footprint of electronics subsystems on spacecraft deck. With each level increase in package stacking, the structural dynamic response of the stack on the top increases, which forms limiting factor for the packages/ devices planned to be stacked on the top. A methodology to reduce structural dynamics responses on the stack-up top, without compromising thermal coupling between packages, will enable further reduction in footprint by accommodating more packages on stack-up top	
Q4.4	**Effect of Annealing (Heat Treatment) on Surface roughness of Pure metals such as Copper and Aluminium (SAC)** Objective of this study is to examine effect of annealing on surface roughness and its effect on thermal contact resistance. This study is to be done for annealed samples as well as for non-annealed samples to quantify the variations. All experiments are to be done in temperature range of 4-10K, 20-40K & 80-100 K. This exercise is to be done using OFHC Copper and various metal joint combinations such as 1) Oxygen free High Conductivity (OFHC) Copper to OFHC Copper. 2) Aluminum to OFHC Copper 4) OFHC Copper to Tellurium Copper (TeCu) etc. Effect of bulk material conductivity and thermal contact resistance is to be also studied after machining annealed samples to achieve better surface roughness. All the results are to be consolidated and guideline based on the experiments is to be made.	

Q4.5	**Finite element simulation of behaviour of Wire rope isolators under vibration environment (SAC)** Wire rope isolators have been widely used in transportation industry ranging from Rail, road, sea, air to Space transportation. The isolation products made of wire ropes cater to both vibration isolation as well as shock suppression and provide a robust solution to the transportation industry. The products are robust, durable & reliable. However, the behaviour of such product is less understood in FE environment. Through, the characterisation details of each type of isolator are widely available, if a capability of 'simulating wire rope isolator behaviour' in FE environment is developed, it will enable us to explore many more geometries/ topologies/ arrangements and various loading conditions along with the behaviour of suspended system.
Q4.6	**Measurement of structural & thermal material properties of adhesives for a temperature range of 4K to 500K (SAC)** Objective of this research is to carry out measurement of structural material properties of adhesives such as Elastic modulus, Poisson's Ratio, yield strength, ultimate strength, shear strength, surface hardness, thermal expansion co-efficient and thermal properties such as thermal conductivity, specific heat capacity. Epoxy based structural, thermal and Room Temperature Vulcanizing (RTV) adhesives, which are used for Aerospace applications, can be considered for the purpose of evaluation of the above mentioned properties for a temperature range of 4K to 500K. This results obtained from this research should be compiled in a report for use of structural and thermal designers.
Q4.7	**Micromachining of metal components for space use (SAC)** Future microwave payloads are to be developed in Terahertz frequencies starting from 235 GHz and beyond. Looking to the stringent micro sized geometrical features required for millimetre wave / terahertz payload components, there is a requirement to establish new facility/augment the existing facilities for manufacturing and metrology in SAC and to explore such state of the art facilities within the country with either Indian industry or academia. To realize such components, methodology for machining of metals such as Al Alloy 6061-T6, OFHC Copper, Copper Tellurium (CuTe) etc., are to be developed and qualified. For said purpose, micromachining process simulation to fine tune the process parameters needs to be done to achieve proper geometrical tolerances and surface finish which is essential to meet the final RF performance parameters. Following table shows some of the feature sizes and tolerances are to be achieved on micro machined components.

R	Area	Systems Reliability (SAC)
R1	**Reliability and life estimation of Mechanical Systems and Parts (SAC)** Mechanical subsystems used in the satellites have to operate continuously and are "mission critical" (i.e. Rotary Joint). Reliability of these subsystems are very important, as they cannot be repaired in case of any failure. Reliability estimation of electronics parts are being done, assumptions are made for mechanical parts and certain relevant factors such as process performance, physics of failure etc. related to design are not considered. • Define the most suitable methods to analyse and assess the reliability and life of mechanical parts. • Provide methods and procedures for reliability and life verification by testing (Accelerated testing). • Provides inputs for development of a handbook on reliability and life assessment of mechanical systems and parts, which can be used for future missions also. Anticipated Benefits: • Analytical modelling of operating environment and test severity and their impact on life consumed and life remaining of mechanical hardware supports key decision making process.	
R2	**Development of flexible waveguide for space applications (SAC)** Waveguide plays crucial role in satellite functionality and transmission of Microwave signals within the satellite. In the confined space of the satellite, or in the large satellite with long waveguide lengths; integration of these interconnecting elements needs critical alignment. Mismatches in waveguide flange joint results in large stresses at various interfaces. Additionally, thermal excursion results in large stresses in the assembly. • Development of flexible waveguide in Ku and Ka band through detailed study of materials and processes suitable for low losses in RF signal and operating in space environment for long life. • Performance demonstration under defined environmental conditions. Anticipated Benefits: • Flexible waveguides aids in perfect RF alignment with stress free transponder assembly	
R3	**Non-contact method for estimation of Preload in Bolts in the assembled Condition (SAC)** Assembly of large number of electronics subsystems with the satellite panels is done through bolts. In addition to the subsystems, waveguides, RF cables etc. also form the part of payload. To ensure long and reliable life of each junction; the applied torque is to be verified for each and every fastener / bolt. After integration, there is limited accessibility for verification of the applied torque; and any novel technique to verify torqued stress would overcome this problem, and be very useful to quickly assess integrity in cases of suspected loosening of bolts.	

	Scope: • Development of a non-contact method for estimation of the stress/ load/ looseness in the bolts in the assembled condition. Anticipated Benefits: • This method enables to estimate the applied torque on a remote inaccessible fastener in a space payload
R4	**Automated Assembly Inspection using Artificial Intelligence in Image Correlation (SAC)** A typical space hardware consists of multiple parts in a functional arrangement through various types of joints and processes. All the parts and processes used needs to be evaluated through inspection. In cases of large number of identical subsystems, automation in inspection offers a suitable solution in saving time and achieving consistency in inspection standard. It is proposed to develop a concept of using Artificial Intelligence in the automation of inspection process of space hardware. Scope: • Preparation of setup including Algorithm, Code and related hardware including camera and respective data acquisition hardware etc. Anticipated Benefits: • Automated inspection system with associated hardware and software supporting rapid and consistent inspection process
R5	**Development of low-weight Passive damping and isolation solution for critical Electronics and Optical components and subsystems aimed at reduction of vibration response (SAC)** In Space hardware it is necessary to qualify components/subsystems. Conflicting requirements in terms of weight volume and functionality are often encountered, in such cases solutions are needed to ensure that responses are limited so that failures can be avoided during the flight and testing also. The role of passive damping/isolation solution is critical to avoid high responses at critical components/subsystems. Scope: • Understanding and literature survey of tailor made damping and isolation solutions for Space subsystems. • Optimization and customization of damping and isolation specific to our needs. • Demonstration of effectiveness of solution on STM and QM of targeted subsystems. Anticipated Benefits: • Passive damping and isolation solutions will help in reduction of responses at critical interfaces.

R6	**Study & Evaluation of Coefficient of friction between different types of materials, interfaces & surface conditions (SAC)** Evaluation of Coefficient of friction between different material is of prime importance in space industry to determine the slippage margin, possibility of screw loosening during dynamic vibration testing. Incorrect coefficient of friction increases uncertainties, which can lead to failures during testing, it can be avoided, if accurate values are taken at the time of design and structural analysis. Scope: • Literature survey of International standards and compilation of standard coefficient of friction between the material interfaces encountered in space hardware and method of determination of coefficient of friction. • Creating an indigenous database of coefficient of friction values for various material interfaces for usage at the time of design. Anticipated Benefits: • Study and tabulation of Coefficient of friction values will decrease failures/anomalies observed post dynamic testing and improve the design review process.	
R7	**Sub Area**	**Material and Process Development (SAC)**
R7.1	**Development of Nano material based components for Space Applications (SAC)** Satellite payloads require a large range of mechanical elements. Some are having structural requirements with critical CTE (brackets, spider etc) others require resilience to thermal excursions (feeds, Filters and cavities etc) or high thermal conductivity with zero CTE (for mounting of heat sinks / pipes for detectors and other high power devices) and many are serving as enclosures for electronics. Nanomaterials such as CNT, Fullerenes, Graphene, Quantum Dots are used as reinforcement in composites such as metal matrix, ceramic matrix and polymer matrix to achieve required bulk properties. Further, surface properties can be tailored using nano materials like Titanium dioxide, Gold & Silver nano particles, Zinc oxide as surface treatment for future aerospace components. Scope: • Theoretical study, optimization and testing of nanomaterial reinforced composite structures for space applications. • Demonstration of these material for typical payload structures in terms of customisation of desired properties coupled with miniaturization. Anticipated Benefits: • Mass reduction combined with high thermal & electrical conductivity low CTE culminating into a miniaturised functional product	

R7.2	**Failure Modes & Strength characterization of Composite Sandwich constructions for Space Applications (SAC)** Currently Space hardware developed from Composite sandwich constructions using aluminium alloy core with aluminium skin and CFRP skin. Qualification tests evaluates the Mechanical Properties and strength for different types of loading for characterization. The strength Properties are useful to simulate the design of Space Hardware to determine the margins and failure modes. Further, Process & Product Qualification carried out as per American Society for Testing and Materials ASTM Standard, determines the criteria for Process repeatability evaluation on witness coupons. Scope: • Understanding and interpretation of failure modes vis-à-vis types of loading through analysis and experimental validation. • Optimization of CFRP laminate pattern and vis-à-vis core thickness. • Defect Characterization through Modal Impact Hammer Test via comparison of Mode shape and amplification. Anticipated Benefits: • Study results in understanding and rationalisation of correlation between sandwich laminate thickness and core finally leading to anticipation of failure modes
R7.3	**Metallisation of CFRP for Space Hardware (SAC)** CFRP (Carbon Fibre Reinforcement Plastic) materials are used for fabrication of space hardware such as Feed horn, Waveguide, Antenna reflectors etc. due to light weight and high strength to weight ratio. Since, CFRP is electrically nonconductive, metallization is necessary to improve RF performance through electrical conductivity and in some cases, to enable its soldering of electronic parts to such CFRP elements. Scope: • Development and qualification of Metallisation (Copper/ Nickel / Silver) process on CFRP laminates. • Demonstration of RF performance including adhesion on a standard component. Anticipated Benefits: • Electrically and thermally conductive CFRP Based sandwich construction finds many applications in space hardware.
R7.4	**Development of new smart materials for space applications (SAC)** Smart materials possess adaptive capabilities to external stimuli, such as loads, force or environment, with inherent intelligence. Smart materials which possess the ability to change their physical properties in a specific manner in response to specific stimulus input. The stimuli could be pressure, temperature, electric and magnetic fields, chemicals, hydrostatic pressure or nuclear radiation. The associated changeable physical properties

	could be shape, stiffness, viscosity or damping. Smartness describes self-adaptability, self-sensing, memory and multiple functionalities of the materials or structures. Probable Applications: Spacecraft & Antenna deployment, shape control, flexible structure vibration control, jitter isolation, precision pointing, etc. Smart materials, regardless of technology field, can be broken down into the following categories: Sensing - System Identification - Health Monitoring Quasi Static - Deployment - Positioning - Shape Correction Vibration Control - Structural - Acoustic Scope: • Development of new material processes • Testing & qualification methodology Anticipated Benefits: • Smart Materials finds applications in harsh environments of space and where on-board actuations are necessitated	
R8	**Sub Area**	**Software Engineering (SAC)**
R8.1	**Development of Automated GUI testing Environment for Desktop, Mobile and Flash based applications (SAC)** • Establishment of GUI testing techniques for automated regression testing of desktop, mobile and flash based applications. • Establishing an integrated functional, performance and security software testing techniques with provision of automated testing of web-based applications also. • Development of Generic software framework for parallel test execution environment. Anticipated Benefits: • Automation of GUI applications will aid in testing the continuously evolving multiple versions of applications and improve overall project release turn-around time.	

R8.2	**Automating Scenario Based Testing with Unified Modeling Language (UML) and Aspect Oriented Programming (AOP) (SAC)** Scope: • The main goal of this project work will be to develop approaches and tools for the automatic generation of executable tests from UML behavioural models (particularly interaction diagrams), taking advantage of existing unit testing frameworks and aspect oriented programming techniques for test execution. These approaches and tools should enable a new generation of "model-based test- driven development (TDD)", that is, a TDD approach in which test are specified in UML. • Intercept run-time behaviour and check conformance with the UML specification, using Aspect Oriented Programming (AOP) techniques • User interaction testing in distributed and concurrent systems • Support for complex features in UML interaction diagrams and the generation of executable tests in different platforms using Model-Driven Architecture (MDA) concepts. Anticipated Benefits: • New techniques will be established to automate the executable tests from models and improve the overall programming modularity	
R9	**Sub Area**	**Optical Metrology and Inspection Systems (SAC)**
R9.1	**Development of measurement technique for rubidium atoms in Rb-bulb and Rb-cells (SAC)** Rb-bulbs and cells are used in rubidium atom frequency standards (RAFS). Amount of rubidium in the bulb is an important parameter for a stable RAFS and it has to be monitored during different phases of screening and qualification of the Rb-bulbs and cells. Highly accurate and precise quantification of amount of Rb within the bulb are required for selecting a reliable Rb-bulb for use in the RAFS. Hence, efforts are invited to develop accurate and precise measurement technique for Rb-atom in the bulbs and cells.	
R9.2	**Development of automated scratch and dig inspection system for optical components (SAC)** Coated optical components are frequently used in imaging systems. Coating imperfections such as scratch and dig are to be quantified for screening and qualification of the optical components. Manual scratch and dig inspection method is very exhaustive and cumbersome. For automated scratch/dig inspection system an imaging system of very high dynamic range to be developed which can acquire image of anti-reflecting surface and light scattered from the scratch simultaneously. This acquired image has to be processed further for quantification of scratch/dig and finally generate an inspection report.	

	The scope of this work shall involve to develop imaging system with pixel level dynamic range control and image processing for image stitching & quantification of the scratch/dig parameters.	
R9.3	**Development of high efficiency coupler for single mode (SM) fibre to SM silicon waveguide (SAC)** Ultra-compact photonic integrated circuit is an emerging field in photonics. The dimension of the SM silicon waveguide is in sub-micron range. To characterise SM silicon waveguide, light has to be coupled to the waveguide from SM fiber and from silicon waveguide to the SM fiber. Coupling of light from fiber to the waveguide and vice versa is very critical for characterization of the waveguides. Hence, efforts are invited to develop robust coupler for coupling light from the SM fiber to the silicon waveguide and from silicon waveguide to the SM fiber with high efficiency	
R10	**Sub Area**	**Space Radiation effects and mitigation (SAC)**
R10.1	**Development of nano-particle based polymer composites flexible material (SAC)** One of the possible technique to protect the electronic component from Total ionisation is providing shielding. The conventional techniques employ usage of high density metals to attenuate the radiation. However, this causes mass penalty and also the secondary radiation which may have adverse effect on the semi-conductor. Nano-particle impregnated polymer material is one of the possible solution providing shielding with advantage of lower mass as well as flexible material which can be shaped as per the component package.	
R10.2	**Development of resin based Radiation shielding material (SAC)** Study involves development of resin based shielding material having combination of thermally conductive materials like Bismuth and Boron to replace existing tantalum/ Lead based radiation shielding materials which is heavy and not flexible. Scope: • Activity involves identification of suitable materials, finalization of their chemical composition, process optimization, attachment compatibility with package, material fabrication and characterization. • The developed material will be used to improve shielding effectiveness of the electronic hardware. Thus, the material should have good thermal conductivity and also provide high attenuation/ absorption to space radiations. Possibility for usage of Nano-composites shall be explored. • Material should be 3D printable and cure at normal ambient temperature Anticipated Benefits: • Developed material can be used to provide shielding against space radiation for all the semiconductor devices of all payloads.	

	• Easy to Use over all-electronic components located anywhere on PCB. • Weight reduction over conventional materials used for shielding	
R10.3	**Failure Mechanism in Composite Semi-conductors (SAC)** State of the art semi-conductor technologies offer edge on performance with advantage of miniaturisation. However, usage of these technologies calls for qualification of components and thorough understanding failure mechanism. There are wide variety of EEE components realised in composite semi-conductors like GaN, InGaP, InGaAs with different technologies. Scope of the work involves study of possible failure mechanism for the semi-conductor material and fabrication technology and generating models for the same.	
R10.4	**Reliability Prediction (SAC)** Design analysis is an important aspect in satellite payload reliability assurance. Reliability analysis, failure rate estimation is one of analysis carried out to assess compliance to mission goal. This needs the failure rate numbers, models to calculate the failure rates. For VLSI technologies, ASICs and state of the art technologies, the empirical numbers are conservative. For such applications models and failure rate numbers are to be derived based on the design and application conditions. Scope: Studies on failure mechanism, its model generation and Reliability prediction of following technologies is targeted. • FPGAs (with ≤ 65nm feature size process) considering different failure mechanisms and actual HDL/RTL design • Rubidium Lamp for use in Atomic Frequency Standard for navigation applications. Targeted outcome : • Modelling of failure mechanisms as per literature and field data (commercial applications) to arrive at the failure rate (in FITs) under actual operating environment • Consideration of technology and packaging attributes on reliability • Contribution of design and environment on the reliability	
S	**Area**	**Management (SAC)**
S1	**Knowledge Management in Collaborative and Research Partnerships (SAC)** Knowledge management is a process of capturing, developing, sharing and effectively using knowledge The importance of Knowledge Management is well recognized in all forms of organizations. Knowledge Management is all the more important in research and innovation led organizations, since most of the assets in these organizations are intangible in nature. To be productive and efficient in a competitive and dynamic environment, effective knowledge management is of critical importance and need R&D in an innovation led organization like ISRO.	

	The Knowledge generated can be broadly classified into two categories: explicit and implicit. Explicit knowledge includes research papers, documents, software, algorithms, and so on. Implicit or tacit knowledge involves observations, experience and so on that are not often documented and exists in the consciousness of the participants. The importance of tacit knowledge is equally important as explicit knowledge. While explicit knowledge exists in organizations, the implicit knowledge exists in people. Effective management information systems in research and development enable innovation and help organisations avoid redundancy. Technology can also help the organisations capture tacit knowledge which is otherwise lost in passive communication among the research group. There is significant scope for developing an integrated solution for knowledge management and tacit knowledge capture. The objective of this research is to create a framework for a knowledge management system which is capable of both managing explicit information and boosting tacit information capture. The web based applications and new tools can be developed to capture tacit knowledge which is otherwise lost in passive communication among the research group. An integrated framework and management system for capturing tacit and explicit knowledge with enhanced knowledge management can be generated with academia support. Tools like Machine Learning (ML), Artificial Intelligence (AI) and in particular Natural Language Processing (NLP) can be used for information discovery, extraction, topic classification, fuzzy and semantic search which could be integrated in to the Knowledge Management system for better engagement. In addition, Review and SWOT analysis on the existing processes of Knowledge Management Systems at other R&D organisations is also required. Establishing Key Performance Indicators (KPIs) and Metrics for analysing the quality and quantity of knowledge captured based upon number of contributions, interactions, avg. response time, Daily & Monthly Active Users (DAU & MAU), Search activities, number of backlinks or number of times an article is shared, number of upvotes, number of views / reads, Avg. reading time duration etc. can ne included. The Knowledge Management system framework will be very useful to capture tacit and explicit knowledge generated through execution and implementation of sponsored research projects in ISRO's current and future missions and programmes.
S2	**Fostering Innovation through Research in Science and Technology (FIRST) (SAC)** A scientific invention is a new idea or concept generated by research and development. The scientific convention when transformed and applied as a socially useable product becomes an innovation. An intrapreneur is a visionary inventor who pursues the idea into a profitable reality. Developing innovation and intraprenurship culture in Govt. R&D Organizations may be a thoughtful approach for skill development and improving the research quality with growing organisational needs and future challenges. Fostering a creative and intrapreneurial environment is the requirement of the current times. The implementation strategy may include translational research domains relating to both enabling science and technology as well as government's citizen centric priorities in

	various fields viz. agriculture, environment, natural resources management, disaster preparedness and management etc.
S3	**Crowdsourcing, an emergent tool for Knowledge Management in a R&D organisation (SAC)** Crowdsourcing principles when applied in R&D may result to technological innovations, which can enhance the knowledge management. 'Collective wisdom' through crowdsourcing gradually evolve into focussed problem solving. Crowdsourced R&D inputs may offer hitherto undiscovered potentialities for solving societal problems; in particular using space technology. Due to the increasing complexity of our world and the way change occurs "faster" than we can evaluate the changes, let alone respond to them, the process of crowdsourcing may yield timely capabilities and policies to support the systems in a R&D organisation
S4	**Research Productivity Assessment and Evaluation of Research at Govt. R&D organisation (SAC)** As it may be noted that more than 45% share of India's gross expenditure on R&D comes from the Central Government, it becomes imperative to explore the quantum of research contribution by these institutes. The main objective of research is to produce new knowledge. A research activity is a process with human intellect, tangible (scientific instruments, materials etc.) and intangible (accumulated knowledge, social networks etc.) resources used as inputs. The output in form of 'new knowledge' has a complex character of both tangible nature (publication, patent, database, paper presentations etc.) and intangible nature (tacit knowledge, experience gained etc.). Thus, research is a multi-input and multi-output process. Currently, following Project Evalution approach is being carried out to carry out tehcno-managerial evaluation of completed Sponsored Research projects at SAC. Academia can put forward their expertise and submit research proposals which may address: • Study of standard tools for gauging institutional research contribution and feasibility of their application in present setup. • Design and development of tools and matrices for institutional research productivity assessment.
S5	**Human Resources Development (SAC)** Engaged employees demonstrates organization citizenship behavior (OCB) and hence, employee engagement has significant influence on organizational performance. Understanding the employee engagement in Indian R&D context helps in designing effective HR practices in engaging millennials effectively. HR analytics is less explored area in R&D organization, particularly using big data generated at the user end. The research may include identifying potential use of social media analytics for HRM. The potential

	use of AI and ML might result in generating action-oriented HR practices in Organisation. Personality and performance are correlated and psychometric tool development is another possible area of research in the domain of HR
S6	**Work flow design/ management (SAC)** Under this researcher should study work flow of the various electronics & Mechanical Fabrication and suggest the improvements. Also designing of the web-based tracking mechanism for the effective management.
S7	**Monitoring & Evaluating Projects: Contemporary Methods (SAC)** Projects Management and Monitoring: Measuring Performance: Earned Value Analysis Methods and other methods like trend analysis etc.
S8	**Library Information Science: Knowledge Management Practices in Research and Development (SAC)** Libraries represent an indispensable link in the scientific system chain, an important link in the knowledge innovation. Knowledge management (KM) has rapidly moved beyond the stage of a trend and has established itself as a key part of many libraries' knowledge strategy. Knowledge and information has become a key resource and is very vital for the survival of the organization in the future. Due to increasingly dynamic environment, organizations are beginning to realize that there is a vast and largely untapped asset floating around the organization.Major functions of Knowledge Management includes development of- processes and applications for transforming research data into scientific information; tools for creation, validation, standardization and dissemination or sharing of knowledge; the acquisition, contextualizing, and management processes; and assessment and applications tools using information and knowledge. The core of the process is how to make implicit or tacit knowledge, explicit. It involves a multi-disciplinary approach to achieve organisational objectives by making the best use of the explicit and tacit knowledge of researchers. The suggested research topics are: Exploring various Knowledge Management Systems (KMS) programs in different R&D organisations. Investigating missing interactions in present knowledge management system. Designing suitable framework for effective Knowledge Management System. • Development and designing of processes and applications for access management; resource management, validation, contextualizing, and standardization. • Development and designing of processes and applications for effective information retrieval and dissemination tools, integrated search and other applications for meaningful utilization of knowledge pool. • Delivery of organized knowledge resources through innovative information services. • Preservation of Institutional Intellectual output.

S9	**Research Data Management (SAC)** Research is crucial for society's scientific advancement and prosperity and research data is indeed the primary component that conveys the research findings and implications. Organisations are also initiating research data management services to manage and preserve data for future reuse and transparency in research. Open Science has become a new paradigm for research and Research Data Management (RDM) supports open science through a standardized organisation of research data for access, reuse and long term preservation. To meet challenge of big datasets resulting from research RDM will play a vital role in an organisation.
S10	**Cyber Services and Information Security (SAC)** The digital world is a reality today in all aspects of our lives. Digital infrastructure is the backbone of prosperous economies, vigorous research communities, strong state defense, transparent governments and free societies. As never before, Information and Communication Technology (ICT) is fostering transnational dialogue and facilitating the global flow of information, goods and services. The reach of networked technology is pervasive and global. For all organizations, the underlying digital infrastructure and information has become a critical asset. For SAC, the information could be strategic (Project documents), personal (Employee data etc.), legal (Indents related activities), financial (Budget documents, PO copies), procedural documents (Design documents) etc. With the advent of technology and need for ease of access, SAC had also taken initiatives in the direction of digitalization. Digitization increases the productivity and efficiency that facilitates SAC users to focus on innovation and R&D. It also has other advantage like immutable backup of data for a longer duration of time, flexible and optimal archival policies based on user profiles etc. However, Digitization comes with its own set of challenges. Threats to information of critical organization like ISRO are increasingly organized and targeted, helping criminals, state actors and hacktivists to reap immense benefits out of information compromise, theft or espionage. Cybercriminals can carry out identity theft and financial fraud; steal critical information such as intellectual property; conduct espionage to steal ISRO's state related secrets; and disrupt critical infrastructures by exploiting the vulnerabilities in any system connected to the Internet. The cybercriminals could be located anywhere in the world and they can target a particular user, system or a particular service in ISRO IT assets. Worse still, the cybercriminals can cover their tracks so that they cannot be traced. Thus, there is a need to protect the critical IT assets of SAC without compromising the flexibility of SAC users in the internet connected modern era. Though the domain of research in cyber security field is immense and diversified, certain research areas like indigenous hardware-based VPN, cryptography and cryptoanalysis, side channel attacks, security of air-gap networks, zero day vulnerability detection of SAC IT assets, secured data flow between different trust networks, breach detection and response solutions, Zero Trust Network access, Network Admission Control, Botnet Detection & DNS Security, indigenous design and development of perimeter and endpoint security solution could be of major interest for SAC

S11	**Design / Deployment plan of one space infrastructure on new technology platform (SAC)** Zero-foot print compute set up, office space & lab space: No overhead on client or user and only charge or audit on actual use (green computing). Use of active screen (wearable / non-wearable with embedded processor, ports and memory) similar to mobile with wi-fi network. Work at anytime, anywhere through high speed network, secure compute-data warehouse infrastructure similar to cloud on earth now (next in space). AI & ML adoption in demand & supply (similar to learning, fault prediction and solution): Actual thing start before and synchronize with thinking level from human brain from the present model and problem analysis, situation understanding, meeting and solution in best fit approach. Unified Platform for researcher, student, developer of any domain to try, adopt, implement, distribute the product. Plug and play (add, modify, model, visualize, analysis, discussion, meet, decision for engineering, medical and societal use).
S12	**Economic survey and predication of Global and Indian Space Industry (ISRO-HQ/ SAC)** In last one decade, the growth in space sector has been observed across the globe due to entry of many established companies and new startups, innovations in technological and commercial application front of space. A study by M/s. Bryce Space Technology has been estimated global space economy of 344.5 Billion USD in 2016 out of which majority of portion 260.5 Billion USD is estimated from satellite and associated services. After announcement of space sector reforms by Government of India in 2020, many new startups have also turned up in space applications, satellite and Launch vehicle design and manufacturing in addition to conventional industries, which are functioning as external fabricators / suppliers for ISRO. It is important to carry out economic survey and predication in present time to fine tune the strategy and priorities the potential sector for growth of space sector in India. In the above context, the present project is proposed to carry out the India and global survey of space economy from primary and secondary sources and predication for next decade. It shall also bring out sub sector-vise viz. space applications, satellites, Launch vehicle services estimation and predication at India and global level. The studies shall also bring out initial impact of space sector reforms on Indian Space Economy and also recommendations for increasing the share of Indian Space Economy in global space economy.

S13	**Survey of Space startups ecosystem across the globe (ISRO-HQ/SAC)** Startups in space sector have unique problems like difficulties viz. complex technology, long gestation period, non visibility of immediate returns, lack of investors etc.. However, government and industry bodies have created friendly policies, access to incubation support, seed funds at many countries. Startups can bring innovative solutions and bring out various low cost solutions to solve the problem of environment, agriculture, and society in general by harnessing space science and technology. Hence, it is important to have robust startups ecosystem in the country and need to improve it by understanding the best practices followed else ware. In above context, present project proposed the survey of the best startup eco systems in space sector followed at various countries with respect to policies, seed funding, incubator – accelerator support and their impact on survival and growth of space startups revenues in quantitative terms. The project shall also bring out some of the recommendations to improve the existing space startup eco-system in the country.
S14	**Studies on analysis of Capacity Building & Public Outreach activities using social media analytics (ISRO-HQ/SAC)** ISRO conducts many of capacity building and public outreach programme throughout the year across the country. Often feedbakcs are received and recorded through various means for improvements of the programme. Many of the lecture series, like Space Vaarta are also being conducted through online / phygital mode. In recent times, it has been observed that Social media has emerged a better platform to get feedbacks and suggestions for improvements. Hence, this project is proposed to carry out analysis of Capacity Building & Public Outreach, ISRO activities using social media analytics. The outcome of the project shall be overall feedbacks obtained through social media platform on CBPO activities in quantative terms like which are the post / courses most liked / not liked by general public for last 5 years and also the recommendations for improvements in programme based on feedback obtained in social media platform.
S15	**Development of edutech tool & games for explaining the concept related to Space Science & Technology (ISRO-HQ/SAC)** In conventional way, the concept of Space Science and Technology are often explained through mathematical formulations and jargons. Often, students at early and later stage find this as difficult to understand and distracting at first instance. In this context, with advancement of edutech technology, it is proposed to developed some of the concept through games, where student not only can understand the concepts in "learn with fun" way but also able to appreciate the impact of changing various parameters. The following concept shall be attempted to explain through games

	• Working and design of Liquid Rocket Engines : The game shall be interactive to explain the working of liquid rocket engine for various power cycle from start to shutdown. Game shall also provide option like selection of propellants, selection of power cycle, selection of pumps and turbine parameters, injector patterns and shall be able to predict the rocket engine in final shape, whether it can be a practical, stable rocket engine or not. If not , then what are the parameters need to be changed to make it a functional, stable rocket engine etc. • Life cycle of a Star : The game shall be able to explain the birth of star in a particular context, category of star, life and cycle of star and end of star, whether it will become a white dwarf or supernova etc.. through interactive games. The proposed project envisaged to develop interactive games with a target user group of high school students to explain such concept in easier and interesting way.

EARTH OBSERVATIONS

A	Area	Cryospheric Sciences (IIRS/SAC)
A1	Sub-Area	Glaciers, Glacial Lakes and Permafrost Studies (IIRS)
A1.1		**Glacier and Glacial Lake Changes Under Changing Climate (IIRS)** Most of the Himalayan glaciers are retreating in response to on-going climate hange. The melting of glaciers also instigating formation and expansion of glacial lakes. The warming is also responsible for permafrost thawing. The expansion of glacial lakes and permafrost thawing are major concern for glacial lake outburst flood and slope destabilization. Optical, microwave and thermal datasets can be used to monitor changes in glacier response and monitoring glacial lakes for possible lake hazards.
A1.2		**Himalayan Snow (SAC)** SAC has been generating sub-basin wise snow cover products database using Advanced Wide Field Sensor (AWiFS) data since 2004 in the Himalayan region. These products are the best available time series snow cover products having fine spatial and temporal resolution so far in the world. INSAT-3D/R provides daily snow cover products at India Meteorological Department (IMD) from geostationary platform. Snow products have been used in snow melt runoff estimations, in understanding of accumulation and ablation pattern of snow in different climatic zones of HKH region, and in assessing the snow cover trends to ever-changing climate. However, there are important challenging areas where research is needed to address cryosphere studies. These are estimation of annual seasonal snow mass using photogrammetric/interferometric and scattering mechanism using PolSAR data. Snow parameter retrieval using SAR/Hyperspectrl data, Radiative transfer modelling and role of snow parameters in climate model will be helpful to understand the impact of climate on Himalayan mountains. Disaster applications such as Avalanche, GLOF etc. are other crucial areas of research. Development of snow-melt runoff at high altitude area, suitable site selection for micro hydroelectric projects using geospatial modelling and real time assessment of discharge for Indian rivers using satellite data are important in the field of surface hydrology.
A1.3		**Himalayan Glaciers (SAC)** Inventory and monitoring of Himalayan glaciers within periphery of IGB basins has been a foremost requirement of our nation to know the stock of glacier stored water, and variations in dimensions of glaciers as an impact of climatic variations. SAC has carried out extensive work in this direction using data from Indian sensors such as AWiFS, LISS III and LISS IV of Resourcesat series satellite. The glacier inventory in IGB basins is available at VEDAS portal of SAC for visualization. However, automatization of glacier feature extraction and change detection from space platform in Himalayan region are the research areas to be addressed. Glacier mass balance is important to assess the status of their current response to climate change, and requires improvement in estimates to minimize the uncertainty. Major research domain in mountain glacier region includes geodetic mass balance

	estimation with field validation at sub-basin scale using Carto-1 images, improvement in Accumulation Area Ratio (AAR) and Mass Balance relationship in HKH region, retrieval of ice velocity and facies using SAR/PolSAR data, understanding the glacier dynamics, Regional Climate model and impact assessment on cryospheric elements in different scenarios.
A1.4	**Himalayan Permafrost (SAC)** The permafrost is very important element of Cryosphere studies. The distribution and changes occurring at permafrost in the mountainous HKH region as a result of climatic variations needs to be known in view its importance to ecology and land cover changes. Exploration of Permafrost might give new insights to high altitude environmental changes through optical, thermal and active microwave data. Estimation of permafrost zonation, geomorphological signatures, degradation, and interaction with SAR/PolSAR data are essential to understand the dynamics of permafrost in high altitudes of HKH region to assess the impact of climate change.
A1.5	**Polar Ice Sheets (SAC)** One of the most challenging research area in polar ice sheets is estimation of ice sheet mass balance and resulting sea level rise. State of art techniques, development of algorithms utilizing SARAL/AltiKa data and analysis of results have been demonstrated at SAC through various studies. It needs to be expanded further by using globally available LASER/RADAR altimetry datasets. Another important research area is to investigate the dynamics of polar ice sheets using optical, SAR data along with incorporating numerical Ice sheet modelling. Development of techniques to automatize monitoring of ice shelves margin and calving events, to access the impact of various surface melt processes on the polar ice dynamics and exchange of surface energy fluxes are another important activities in polar ice sheet studies.
A1.6	**Polar Sea Ice (SAC)** One of the major contribution of SAC in polar ice studies is extraction of sea ice area from ISRO's Scaterrometers data and understanding its spatial-temporal variability. Technique development has been demonstrated to measure sea ice thickness using data from SARAL/AltiKa. It needs to be a continuing activity by using other globally available LASER/RADAR altimetry datasets to enrich and analyse long-term trend in sea ice thickness. More research is required to address sea ice drift estimation, sea ice albedo & energy exchange processes and understanding the oceanic and atmospheric driving factors for global sea ice variability. Automatic techniques using multi-sensor approach along with iceberg detection and tracking are needed for improving sea ice advisories required for safer ship navigation during Indian Scientific Expedition to Antarctica.

A2	Sub-Area	Planetary Geology and Applications (IIRS)
A2.1	**Advanced Data Analysis in Geosciences (IIRS)** Classification of satellite image into various categories can be done using segmentation algorithms to delineate specific features of interest in both terrestrial and planetary cases for numerous applications in the domain of geosciences. Microwave and optical data for lunar test sites from both Indian and foreign payloads can be utilized to aid and/or uncover aspects of lunar surface unseen in visual imagery and also to compare and contrast surface features seen in microwave and optical data.	
A2.2	**Microwave Techniques Development (SAC)** • Development of techniques to simulate Geostationary Search And Rescue (GeoSAR) data and its processing algorithms, to study geophysical parameters retrieval accuracies • Development of object/feature detection techniques using GPR and Wall-Penetration radars, and their performance evaluation • Development of processing methodologies for Rail-mounted Interferometric SAR system for landsubsidence monitoring; system development, demonstration of processing methodology and its performance evaluation • Full-wave numerical Maxwell Model 3D simulations for microwave scattering from forests including detailed 3D modeling of forest canopy structure • Signal processing techniques for forest mapping using 3D-SAR Tomography and Higher dimensional SAR Tomography; applications of SAR tomography for forest mapping in plains and hill slopes • Tree height and structure mapping and species diversity mapping from LIDAR and fine resolution optical data • Classification and discrimination of vegetation types from time series vegetation profiles; Vegetation phenology mapping for assessing the vegetation characteristics for studying impact of climate • Long time series monitoring of crop sowing shifts and impact on the potential yield of crops • Detection of vegetation disturbance and generation of alert system; Dryland agriculture and yield gap analysis • Data Driven Techniques development for Daily Real Time Soil Moisture Estimates and Forecast using Deep Learning • Development of techniques for root-zone soil moisture estimation • Development of Polarimetric SAR models for Permafrost characterization in Himalayan regions • PS- and DS-InSAR based algorithms for land-deformation estimation; Algorithms for Landslides damage assessment from SAR data; development of regular monitoring system with alert generation capability	

B	Area	Geological Hazards (IIRS/NESAC/SAC/NRSC)
B1	Sub-Area	Landslide Hazard, Seismic Hazard (IIRS)
B1.1	**Risk assessment, Simulation/ Modelling and Characterization of Geotechnical Properties of Vulnerable Slopes and Landslides in Parts of the Uttarakhand and Himachal Himalaya (IIRS)** Landslide hazard/ susceptibility mapping aided by EO based techniques and analysis of geo-engineering aspects has led to damage assessment till date. Hence there is a high requirement of advanced space/ air-borne technologies to be employed for better mapping, characterization and monitoring of landslides. A complete analysis of landslides in terms of mapping and monitoring, geotechnical characterization, simulation major landslides/debris flow events by numerical methods, and integration rain fall thresholding to support early warning mechanism for major landslides in parts of Garhwal-Kumaun and Himachal Himalaya can grout this knowledge gap. Such studies lead to derivation of the important outputs as mentioned above taking cues from Earth Observation techniques to understand the root cause of the devastation, which is essential for effective mitigation measures. Main outputs include hazard zonation maps at suitable scale, predictive and post-facto calculation of modelled height, momentum and velocity of debris flow as it poses danger of blockade in river and thereby causing diversion of the river and resulting inundation. Geophysical investigations can help to determine the slip surface and other sub-surface details, alternatively which can only be obtained by expensive and time-consuming drilling with complimentary numerical simulation. These emerging technologies caters to high resolution terrain attributes essential for landslide modelling, designing remedial measures, to evacuate people and also help to simulate and understand the actual cause, process and mechanism of landslides.
B1.2	**The Assessment of Seismic Hazard in the Himalayan Region Through the Identification of Earthquake Precursor, Subsurface Features and Estimating the Enduring Strain Build-Up Rate by the Integrated Study of SAR, GNSS and Geophysical Methods (IIRS)** The Himalayan terrain is an epitome of geodetic deformation, which requires a detailed strain accumulation and prevailing convergence measure for future seismic assessment. Geophysical methods can detect the presence of an active tectonic zone (characterized by an active fault or any past fault activity). Although earthquakes cannot be predicted but effective planning and basic knowledge of seismic precursors may reduce the substantial risk of the aftermath. SAR and GNSS data measurements can be used to estimate the stress/strain, strain modelling, subsurface features identification (whose records are hard to find in some geological studies), monitoring crustal deformation and analysis of the earthquake precursor to perceive a profound idea on Himalayan future seismicity.

B1.3	**Earthquake Precursor Analysis for Moderate to High Magnitude Earthquakes in India for Understanding the Spatio-temporal Likelihood of Earthquakes (SCA / NRSC /IIRS/ NESAC)**	
B1.4	**Early warning of landslides (SAC/IIRS/NRSC/NESAC)**	
B1.5	**2D Flood Inundation Modelling - Simulation of flood Inundated Areas for a Given Discharge using DEM and other Inputs from Satellite Data (NRSC/ NESAC)** To explore the applicability of hydro-dynamic equations in various conditions of overland flood wave propagation on different floodplain topographies. Inter comparison of different DEM products for 2 dimensional hydraulic simulations.	
B1.6	**Flood Early Warning System (FLEWS) (NESAC)** Calibration and validations of all distributed river/tributary models in Brahmaputra and Barak river valleys with available hydro-logical and river geometry datasets. Sensitivity analysis of various model parameters to understand the hydrologic response of various types of river catchments in the said study area.	
B1.7	**Flood Hazard Zonation and Risk Assessment in Major Riverine and urban Flood Prone Catchments (NESAC)** Applicability of various approaches of flood hazard zonation such as flood frequency based hydraulic simulations, inundation occurrence based FHZ and NESAC developed multi-criteria analysis in both riverine and urban flooding conditions.	
B1.8	**Integration of Satellite Based Inputs Along with DEM for Forecasting a Flood Discharge and to Provide Early Warning (NESAC)**	
B1.9	**Thunderstorm Now-casting Modelling (NESAC)** Developing AI & ML based Thunderstorm now-casting model.	
C	**Area**	**Hyperspectral Remote Sensing in Geosciences (IIRS/SAC)**
C1	**Sub-Area**	**Mineral Exploration Studies (IIRS)**
C1.1	**Application of Hyperspectral Remote Sensing and Reflectance Spectroscopy for Mineral Exploration in Parts of Mineral Rich Belt in Pats of Selected Precambrian Cratons in India (IIRS)** Fundamental aspects of field and space-based spectroscopy of minerals and rock and satellite derived/airborne hyperspectral products can contribute in mineral exploration and MoM directives as per ISRO`s mandate to contribute in mineral exploration and MoM directives. Remote sensing data (especially hyperspectral) can help in deciphering the geological structures & density of lineaments and geomorphic & spectral anomalies for narrowing down prospective areas. The research outputs can be used for as updates/enriches for Spectral Library (reflectance and emittance) of ore, host rock and path finder samples (with XRD/ICP MS validation) in standard format and that can be	

	used as a reference from repository at IIRS and zeroing on locations for further finding signatures of mineralization zone. Further, it has scope to fulfil the technological gaps in mineral exploration particularly with respect to hyperspectral remote sensing. Identification of new potential ore mineralized zones using mineral abundance mapping, classification techniques etc. from the multispectral and hyperspectral datasets like ASTER, Hyperion and recent Prisma aids the remote sensing derived data product for mineral exploration can add substantial knowledge in the field of hyperspectral remote sensing (such as identification of surface indicator viz. altered mineral species, structural and geomorphological proxies for better characterization of mineralized zones and understanding of metallogenesis often in the light of by analysis of high resolution airborne data, if available.	
C2	**Sub Area**	**Hyperspectral Techniques Development (SAC)**
C2.1	**Machine Learning Models for Hx Classification (SAC)** The application of deep learning with hyperspectral images is less straightforward as compared to other optical datasets since hyperspectral datasets are represented by high dimensionality with high spectral resolution. Supervised classification faces challenges like the imbalance between high dimensionality and limited availability of training samples which often limits the depth of deep CNN networks. Another relevant aspect is to incorporate both spatial and contextual information in the classification process so as to take advantage from both the sources of information. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging. Following challenges are needed to be taken up; • To explore Residual-3D-CNN, standard computer vision models such as LeNet-5, AlexNet, VGG, Darknet, Squeezenet to Hx classification with different learnable filters such as using 1D, 2D and 3D to see their effectiveness for remote sensing data classification. • Another relevant challenge is to integrate spatial-contextual information in spectral-based classifiers for hyperspectral data to take advantage of the complementarities. For Example: 3D deep convolutional neural networks (CNN). • The Challenge in Vegetation (multi-crop, forest species) classification now is learning temporal information from time series hyperspectral data. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging.	

	• Current research on simultaneous contextual information extraction and temporal information extraction can also be further explored by combining the concept of Convolutional and Recurrent neural Network (RNN) such as Convolutional Long Short-Term Memory (LSTM) or Convolutional Gated Recurrent Unit (GRU) to the temporal image data. This can be very effective for time series data classification. • Physics inspired Deep-Learning based Inversion models for geophysical parameter retrieval.
C2.2	**Challenges in Hyperspectral-Multispectral Data Fusion (SAC)** There is a trade-off between Spatial Resolution and Spectral Resolution as can be seen in the case of Hyperspectral data and Multispectral data. In order to fully utilize the advantage from both the sensors like having data with both high spatial resolution and high spectral resolution data fusion is required. Another challenge is the introduction of noise in the dataset during the fusion process. Current methods often fail to address the issue of registration errors and are widely ignored thereby in the future comprehensive modelling and compensation of realistic noise and registration error can also be addressed. • To explore hypersharpening based methods for denosing which are based on component substitution (CS) and multiresolution analysis (MRA). • The unmixing based strategies such as Hyperspectral Image Superresolution via Subspace-Based Regularization (HySure) and CNMF (Coupled Non Negative Matrix Factorization) have great potential even when Spectral Response Function (SRF) has limited overlap. • A possible future for further performance improvement lies in developing hybrid approaches that combine the advantages of different classes of methods such as MRA and Unmixing. Current Unmixing approaches rely mostly on the assumption of Linear Unmixing Model which can be further extended to Bi-linear or Non-Linear based models. • VNIR-Hx and thermal-Hx data Fusion and Hyperspectral, LIDAR and SAR data fusion for precision agriculture, soil characteristics, forest biomass etc. studies.
C2.3	**Spectral Nonlinear Unmixing (SAC)** Spectral unmixing is the most important and challenging in hyperspectral imaging. It is known as blind source separation problem. The spectral unmixing problem includes two major tasks a) Identifying the pure pixels (materials) called endmembers b) Estimates their corresponding fractional quantities (abundance) presented in the mixed pixel. There is need to develop robust models for non-linear spectral unmixing where light typically interacts with more than one component as it is multiple scattered such as the case of minerals, soil grains etc. A complete physics based approach to nonlinear unmixing would involve the inversion of the Radiative Transfer Theory (RTT), which is an extremely complex ill-posed problem. Therefore we need to take up following challenges;

	• To develop physics-inspired and sparse based non-linear un-mixing models • Real-Time robust spectral unmixing algorithm and tools (Which can be used in airborne or drone based sensor) • Development of high performance / parallel computing model for spectral unmixing (Sparse unmixing models depend on spectral library which takes too much time) • Dictionary Learning based Estimation and data recovery for sub-pixel classification of Hx data. For eg. soil property estimation from mixed pixels	
C2.4	**Aerosol retrievals, atmospheric corrections and air quality (SAC)** Aerosol and atmospheric corrections involves following challenges; • Aerosol and dust characterization • Atmospheric corrections of VNIR sensors is a challenge in absence of SWIR channels. In this direction, there is need to develop methods for AOD and surface reflectance retrieval for VNIR sensors such as AWiFS, Linear Imaging Self Scanning (LISS-III), Cartosat-2 etc. • Mapping and analysing the patterns of ground level particulate matter (an important factor to determine the ground level Air-Quality) using satellite data and modelling. Development of models to estimate particulate matter using satellite data specifically for Indian atmosphere. The quantification of factors leading to harmfully high levels of particulate matter Scope of Research: • Requirement of hyperspectral CubeSat-constellation for high-temporal hyperspectral data • Development of on-board Parallel/FPGA algorithm for real-time application of hyperspectral data • Simulation of synthetic hyperspectral data using Radiative Transfer and Ray tracing models	
D	**Area**	**Earth, Weather and Climate Sciences (IIRS/NRSC/SAC/PRL/NESAC)**
D1	**Sub-Area**	**Atmosphere and Climate Sciences (IIRS/SAC/NRSC/NESAC)**
D1.1	**Regional air Quality Monitoring and Measurement using Satellite Data (IIRS)** Indian region is one of the global hotspot of absorbing and elevated aerosol loading and is increasing. Atmospheric processes occurring in this region affects the atmospheric composition, chemistry and dynamics over regional as well as global scale. The changes in meteorology and atmospheric dynamics besides the elevated emission source strengths and upwind biomass-burning, highly complicate the detailed understanding of aerosol behavior. Hence, it is necessary to monitor & measure air quality parameters on a continuous basis, to identify emissions sources, pollution hotspots and understand the air quality dynamics and their associated health impacts at urban city to regional	

	level. The spatial and seasonal variations trends, vertical distribution of aerosols, optical properties and long range transport using satellite remote sensing, re-analysis and ground data helps to examine the air quality predictions over the region.
D1.2	**Distribution of Air Pollutants over the Indian Subcontinent: Analysis of Satellite / in-situ Observations and Chemistry Transport Modelin (IIRS)** Tropospheric ozone is recognized to be a severe threat to human health and have a detrimental effect on crop production. It is an important greenhouse gas having climatic implications. Its major precursors like CO, Non-methane hydrocarbons and NOx are also very harmful air pollutants which are mostly emitted into the atmosphere due to various anthropogenic and natural processes. Their complex chemistry changes from one location to other significantly. During last few decades, rapid growth of population has enhanced vehicular activities, industrial sectors and energy consumption over the Indian subcontinent, increasing emission of these gases to the atmosphere. The World Health Organization (WHO) estimates that 14 out of the world's 20 most polluted cities are located in India. Deteriorating air quality in India is currently affecting lifetime of about 660 million people. Poor air quality also damage crops enough to feed approximately 94 million people every year. Thus, it is important to study the spatio-temporal distribution of air pollutants, their emission hotspots, effect of various events (crop residue, forest fire, dust storm etc.), long range transport, chemical and dynamical processes responsible for levels and variabilities of gaseous air pollutants and their long term trend over this region using satellite data, in-situ observations and chemistry transport modeling.
D1.3	**Satellite Data and Numerical Simulations Based Studies of Intra-seasonal Variability of Indian Summer Monsoon (IIRS)** Rainfall during the summer monsoon season is one of the most important factors in deciding the fate of the economy in tropical region. Livelihood of people specifically in Indian subcontinent region largely depends on agriculture yield, which is considerable modulated by amount of rainfall within a monsoon season. Prediction of the seasonal total rainfall have notably been improved in recent years based on the present set of global circulation models (GCMs), however still there is a substantial scope to improve our present understanding of intra-seasonal variability of the Indian summer monsoon. Intra-seasonal variability is observed across various elements of the monsoon system e.g. pressure of monsoon trough, cross-equatorial flow, monsoon clouds and rainfall etc. which consist of periodicities at similar temporal scales and propagation. Such periodicities are connected with the active and break periods during the principal rainy season and are found to be largely affected by the land-atmosphere feedback mechanism (local and regional) as well as the large-scale forcing. In a country like India where major agriculture practices are based on rain fed agriculture, the development of suitable methods and analysis for improved understanding of the mechanism of active and break spells formation are of utmost importance. Satellite based data sets have been proved to be useful in delineating the active and break rainfall spells in several previous

	studies (Hoyos et al., 2007; Singh et al., 2016; Singh et al, 2017; Singh and Dasgupta, 2017). It is proposed to study the intra-seasonal variability of Indian summer monsoon system parameters based on satellite, reanalysis data sets and numerical simulations which will be helpful in developing the understanding of physical mechanism behind this variability. Such a study would be a value addition to the ongoing studies in this context and may prove to be helpful in developing a method for identification of active and break rain spells and their spatial-temporal characteristics.
D1.4	**Predication of Tropical Cyclogenesis (IIRS)** The tropical cyclogenesis is a process in which some pre-existing, synoptic-scale or mesoscale weather feature in the tropics develops so as to take on the characteristics of a tropical cyclone. The following six environmental conditions are important for TC formation: warm sea surface temperatures, high relative humidity near the mid-troposphere, conditional instability, high low-level relative vorticity, weak vertical shear, and sufficient Coriolis force to sustain low pressure system (e.g., beyond 5° from equator in latitude). The tropical cyclone genesis statistics at long time scales are closely related to these conditions. Numerical modeling has been a very powerful way to hypothesize and test the physical mechanisms associated with tropical cyclone formation and intensification. As numerical models have shown the potential to improve tropical cyclone track and intensity forecasts, their ability to depict the processes that contribute to the formation of tropical cyclone can be examined. Due to limitation of the in-situ observations over the oceanic region, satellite observations play major role in numerical models during the early and transient stages related to tropical cyclone formation.
D1.5	**Predication of Track and Intensity of Tropical Cyclones (IIRS)** The tropical cyclones forecasting involves the prediction of several associated parameters, such as the cyclogenesis, track, intensity, landfall induced storm surges and rainfall. Among all these associated parameters, it is most important to know about the intensity, direction of a cyclone movement and landfall position so that the inhabitants of potentially affected areas can be warned well ahead of time and minimize the damage potential. Recently, numerical models have shown significant improvement in tropical cyclone forecasting due to high resolution, improved data assimilation techniques and more number of satellite data. The intensity forecast from numerical models is still challenging task. Satellite measurements are an important source of regional and global observations in support of numerical weather prediction models. Data assimilation uses both observations and short-term forecasts to estimate the initial conditions. In the modern numerical models, both traditional observations and satellite observations can be assimilated in the system, and provide useful atmospheric initial condition information for improving the forecasts. The use of high spatial and temporal resolution satellite observations in numerical weather models through advance data assimilation techniques can improve the track, intensity and landfall position of tropical cyclones.

D1.6	**Studies of Fog using Space and Ground Based Observations over Indian Region (IIRS)** Fog is one of the meteorological or environmental phenomena, which has a significant socio-economic impact in the Indo-Gangetic Plains (IGP) of Northern India every winter. The reduced visibility during fog obstructs air, land and sea traffic. Also, fog is one of the most critical weather situations. Fog albedo delays the thermal dissipation of the corresponding temperature inversion due to which air pollutants can be trapped in the stable boundary layer. Moreover, long term changes in fog frequency, optical (albedo, optical depth) and microphysical (liquid water, effective radius) properties can significantly affect the radiation balance. Therefore, reliable fog information with higher spatial and temporal resolution can be of great help. The information provided by weather stations about the fog episodes is based on point observation, which is discontinuous and dispersed, therefore, does not satisfy this requirement. At night time, these observation stations have further limited capabilities. Hence, satellite data having the advantage of continuous spatial coverage can be used to generate fog products. Therefore, fog retrieval from satellite data is very crucial. However, fog retrieval from the satellite is a challenge as satellite sensors are able to view only the top of the fog. The available satellite fog products are there during day and night time only which doesn't include dawn and dust. Moreover, there are many limitations in the present fog retrieval methods and we understand that the major problem is the lack of spectral information in presence of fog. The fog and clouds spectral signature in various channels varies significantly with fog/cloud optical depths, water vapour content, fog/cloud droplet size etc. Once we have a rigorous study on the spectral nature of fog, we may have a good fog retrieval method from satellite data. An additional attempt is required to develop an algorithm for fog retrieval working throughout the day. Moreover, most of the fog products from satellites are the combination of fog and low stratus clouds i.e. the distinction between fog and low stratus clouds is not made. Therefore, further modifications in the algorithm is required so that it is able to remove low stratus giving a better fog product.
D1.7	**Seasonal Prediction of Indian Summer Monsoon Rainfall (ISMR) using Climate Model (SAC)** The Indian summer monsoon (ISM) occurring every year from June through September, is one of the most dominant features of the global hydrological cycle. It causes more than 75% of annual rainfall over the country during this period. Although, the onset of the monsoon over Kerala in India takes place at the start of June with the seasonal reversal of wind over the Arabian Sea with a consistent manner from year after year, the seasonal prediction of ISMR during the recent times become more and more challenging. It is mainly due to several external factors both natural and manmade viz. the fast changing climate, the manmade changes in land-use-land-cover, The fast growing infrastructure development activities in large scale over a landmass that significantly modify the respective land surface properties, heat and water budget, composition of atmospheric gases, aerosols etc. One of the biggest challenge is to model these changes and incorporate the impact of them in medium to long-term model prediction.

	Therefore, there is a recognized need to demonstrate the state-of-art seasonal prediction of ISMR describing both the spatial and temporal variability of rainfall in conjunction with the satellite and in-situ observations. A seasonal prediction system has been setup at Space Applications Centre (SAC) Ahmedabad in research and operational mode. The experimental prediction of ISMR has been generated through 50-member ensemble CAM model simulation during April every year and updated monthly till September. Each ensemble member has been started with different initial conditions and sea-surface boundary conditions. End of season (EOS) validation has been conducted every year to measure the model prediction skill and to identify the shortcomings and lacuna of the prediction system. It is a continuous evolving process of the prediction system to improve its skill of prediction year after year.
D1.8	**Impact of Atmospheric Chemistry on Weather Prediction (SAC)** Atmospheric aerosols have a large influence on air quality and, also in the well-being of human and ecosystem. Aerosols affect the earth-atmosphere radiation budget directly by scattering and absorbing the incoming solar radiation and indirectly by influencing the processes of formation of clouds and precipitation. Assimilation of satellite derived aerosols and other chemical constituents in NWP along with the chemical transport modelling have been planned (Figure). The impact of chemical data assimilation on mesoscale weather prediction will be also studied.
D1.9	**Assimilation of Satellite Data in Numerical Weather Prediction Models (SAC)** Accurate prediction of high-impact weather events and the area of the greatest threat represent a major challenge for planners to minimize the loss of lives and damage to property. Advance research is being planned to carry out non-linear data assimilation of satellite measurements in the numerical weather prediction (NWP) models. ISRO is aiming at improving short-range weather forecasting using satellite observations. For this activity various satellite observations are ingested in the NWP model using advance data assimilation techniques. In addition, research is also focused to improve NWP prediction using combination of Data Assimilation and Machine Learning methods
D1.10	**Satellite and Radar Based Weather Nowcasting (SAC)** Satellite and radar data is being used for development of algorithms for nowcasting and tracking of cloud and precipitating systems. INSAT-3D/3DR data is extensively used for monitoring cloud growth and also for predicting the flow fields associated with precipitating systems. The research outputs feeds into the operational nowcasting application hosted on the MOSDAC web portal for societal benefit. In conjunction, Doppler weather radar (DWR) data is also used for developing algorithms to track and predict the movement of convective systems. Polarimeteric radar has also been used to develop Hydrometeor classification algorithm for more potential lightning prediction. Furthermore advanced AI/ML are been experimented on, for better accuracy and longer lead time. In near future blending of data / model outputs from different sources is future.

D1.11	**Satellite Based Cloud Microphysical Applications (SAC)** Data from multitude of satellite sensors are used to derive information about cloud microphysical parameters. The study of cloud processes in microscale is also carried out to improve our understanding of many meteorological phenomena like monsoonal active and break phases, tropical cyclone development, intrusion of dust into thunderstorm and its impacts. In addition, we are also experimenting on different schemes to generate a merged cloud microphysical product from optical sensors onboard different satellites.
D1.12	**Cyclone Track and Intensity Prediction Using Satellite Data and Numerical Models (SAC)** Advance and accurate prediction of tropical cyclones is highly important for issuing the warnings and saving the lives. Real-time winds obtained from scatterometer (SCATSAT-1) are used for tropical cyclogenesis predictions of all the low-pressure systems formed in the North Indian Ocean. The cyclone track and intensity prediction is being done using numerical models and satellite data that involves empirical and dynamic modelling and assimilation techniques. The cyclone centric satellite products are generated, which are very useful for cyclone positioning and its structure and intensity estimation.
D1.13	**Regional Monitoring of Trace and Green House Gases (NRSC/NESAC)** Trace and green house gases in earth atmosphere are important as they affect both air quality and radiation balance of the earth atmosphere system. Anthropogenic activities influence abundance of many of these gases in the atmosphere. In view of this, it is necessary to have continuous monitoring of these gases and changes in their concentrations over different regions to understand anthropogenic impacts on global climate change.
D1.14	**Transport of Chemical Constituents of Atmosphere using WRF chemical Transfer modelling (NRSC/NESAC)** Atmospheric dynamics lead to dispersion and transport of chemical constituents in atmosphere from their source regions to distant locations. In order to understand effects of chemical constituents in earth atmosphere, their transport from source regions to other locations has to be examined. Transport of chemical constituents in atmosphere can be investigated in detail using models such as WRF.
D1.15	**Aerosol Characterization and its Impact on Solar Radiation (NRSC/ NESAC)** Atmospheric aerosols, one of the major climate forcing agents, affect earth atmosphere radiation balance through aerosol radiation interactions and aerosol cloud interactions. Despite the efforts being carried out for past few decades, atmospheric aerosol remains one of the major sources of uncertainty in climate forcing estimates. Better understanding of aerosol impacts on weather and climate demands adequate incorporation of aerosol parameters in climate models, which needs accurate measurements of aerosol characteristics.

D1.16	**Impact of Aerosol on Agricultural Productivity (NRSC/ NESAC)** Atmospheric aerosols alter energy balance of the earth atmosphere system through scattering and absorption of radiation and also by modifying cloud properties. Through scattering and absorption, atmospheric aerosols reduce surface reaching solar radiation, which in turn affect agricultural production. In addition aerosols affect large scale circulation systems such as Indian summer monsoon and associated rainfall. Changes in rainfall will have significant effect on agricultural production.
D1.17	**Retrieving vertical Profile of Temperature and Humidity using Radio Occultation (RO) Data (NRSC/ NESAC)** Vertical profiles of atmospheric temperature and humidity are important parameters in atmospheric research, especially for weather forecast and climate change studies. Radio Occultation technique is an effective method to retrieve these profiles by receiving radio signals from GPS navigation satellites. The method makes use of the fact that degree of refraction of radio waves while passing through the atmosphere depends on gradients in air density which in turn depends on temperature and humidity.
D1.18	**Surface Energy Budgeting using Remote Sensing (NRSC/NESAC)** Surface energy budgeting assumes importance as the surface energy balance is one of the major factors affecting hydrostatic stability and mixing of atmospheric constituents such as pollutants in lower atmosphere. Remote sensing can be used for surface energy budgeting over large spatial extends to understand changes in surface energy balance and related effects in earth atmospheric boundary layer characteristics and associated processes Atmospheric Transport (role in determining the distributions of chemical species in the atmosphere, understanding process, circulation, vertical transport, atmospheric stability, turbulence etc) (NESAC) Trace gases measurement and monitoring (understanding trace gases, evolution, transportation, processes, measurements analysis and modelling) (IIRS/ NESAC)
D1.19	**Regional Monitoring of Atmospheric Lightning Occurrences (NRSC)** Atmospheric lightning is an intriguing but least characterized phenomenon in the climate sciences. The array of ground based lightning detection sensors in combination with satellite data is important tool to monitor the lightning occurrences in regional scale. Growing consensus in the climate science community is that the lightning occurrences show increasing trend with the rising tropospheric temperatures. The changing patterns of ENSO are making the territorial patterns of lightning to change. To understand these changes, it is important to monitor the lightning occurrences from macro to the micro scales. A database mining of the lightning occurrences pertaining to the spatial characterization and diurnal variation from climate perspectives is required. Key objectives are as follows; • Seasonal and diurnal characterization of lightning occurrences • Identification of multiple frequency of oscillations in the lightning occurrences

	• Linkage between ENSO and lightning occurrences • How the tropospheric temperatures impact the lightning occurrences	
D2	**Sub Area**	**Investigating the precursors to the atmospheric lightning occurrences (NRSC)**
D2.1	**Atmospheric Lightning Occurrences (NRSC)** For the atmospheric lightning to occur, a conducive ambient is required. The appropriate combination of temperature gradient, upward winds, and humidity are essential parameters. These parameters, together with the land use land cover makes the lightning occurrence to occur at one place while the nearby place lightning may not occur under the same ambient conditions. It is therefore needed to identify the appropriate combination of precursors from Indian context. The Scope of the research: • Identification of land use land cover influence on the lightning occurrences • Pre-conditioning scenario of ambient atmosphere before the lightning strikes • Role of aerosol and pollution on the preferential lightning sequences	
D2.2	**Vegetation and Climate Relationships (NRSC)** The core questions like how climate conditions can affect vegetation and how vegetation changes can regulate climate conditions; help to understand the interaction between vegetation and climate in the context of climate change. The topics of interest are: climate change in vegetation regions; vegetation changes under the background of climate change; advances in vegetation and climate research; responses of vegetation to climate change; feedbacks of vegetation on climate change; relationships between climate change and vegetation, etc.	
D2.3	**Emerging Extreme Events in Changing World (NRSC)** Understanding the spatiotemporal patterns and interactions among the climate variable is essential for better prediction and forecasting of extreme events. Further with the existing challenges of global-warming-induced climate change, these patterns and interactions become further unusual, unexpected, and unpredictable. Globally, it is recognized that the climatic and other geophysical processes are intrinsically nonlinear and carry multi-scale features with influences that are in general of time-varying nature. With these challenging realities, this topic is prompted with an implied aspiration to develop a collection of advanced studies addressing aforementioned issues. This is expected to advance our understanding of the emerging new patterns, interaction and its variability and impact to climate extremes (such as drought, flooding, heat waves, and so on)in a changing world for more accurate prediction or projection of their changes especially on different spatial–time scales.	

D2.4	**Development of Indices for Assessing the Impacts of Climate Change (NRSC)** In general, indices have proven fundamental in the discovery and understanding of global patterns. The new variables (cloud mixing ratio, buoyancy, etc.) can be utilized to define new Indexes. The new fields, e.g., thunderstorm, cloud physics, hydrology, aerosol science, ice melt, and biosphere, have a great impact on climate change. Appropriate Indexes can be put together to access and analyze the climate change and global warning issue. New insights based on new Indexes, themselves in turn based on new advances and variables, can provide new dimensions to the climate change science. Multidisciplinary disciplines may join to access climate change using Indexes from their filed.
D2.5	**Efficient Formulation and Implementation of Data Assimilation Methods (NRSC)** In recent years (in operational data assimilation), the scientific community has centered its efforts on providing assimilation schemes wherein, information brought by ensemble members and optimization features of variational methods are exploited in order to reduce the impact of sampling errors over innovations and to provide efficient and practical implementations of robust data assimilation methods. The demonstration of this new approach to assimilate remote sensing retrievals into numerical models for an improved forecast and/or near-real time operations is solicited.
D2.6	**Coastal Change Monitoring (NRSC)** In general, coastal areas are naturally dynamic, and climate change is considered responsible for many impacts over the long term, a number of other factors, such as human interventions, sediment supply from fluvial systems, etc., also contribute significantly. Coastal change is not limited to erosion in the form of coastal retreat and/or subsidence, but it also integrates transformation of the vegetation, changes in management, protection, and occupation ways, as well as effectiveness and rapidness of the coastal resilience in the face of weather–climate imbalances in the very short (storm, cyclone, etc.) or longer term (sea level rise). To complement the contribution of in-situ measurements and facilitate systematic surveying, various strategies have recently emerged using innovative technologies in remote sensing (RS). The future studies should aim at using high-frequency Remote Sensing monitoring of morphological indicators of the coastline, the bathymetry changes, or the evolution of coastal vegetation, the expert community applies itself to respond to many questions on these complex interfaces at the junction of terrestrial, marine, and meteorological mechanisms and other natural constraints.
D2.7	**Network of Volatile Organic Compounds (VOCs) Measurements in India: Biosphere-Atmosphere Exchange (PRL)** Volatile organic compounds (VOCs) play an important role in the photochemistry of the atmosphere by influencing ozone, hydroxyl radical (OH) concentrations and the conversion rates of nitrogen oxides (NOx). Measurements of VOCs are valuable

	to understand the emission and atmospheric processes impacting the climate in South Asia. Ambient air VOC composition data represents a complex mixture of numerous species emitted from various anthropogenic and natural and sources. Network of comprehensive measurements of different types of VOCs will provide the quantitative estimation of the contributions from anthropogenic and biogenic sources. The main objectives of the measurements of C2-C12 VOCs at network stations are outlined here. • Biogenic Emissions: Emission fluxes of biogenic volatile organic compounds (BVOCs), such as isoprene, monoterpenes, toluene emitted from forest/plant/ocean will be characterized, particularly the impacts of monsoon circulations in the tropical regions • Photochemistry: The data from a network of stations will provide quantitative estimates of VOC mediated photochemistry in the formation of ozone and precursors of organic aerosols. Contributions of various VOCs in diurnal and seasonal variations of ozone and organic aerosols in different regions of India will be estimated. The data will serve as key input in box model simulations • Transformation: Chemical evolution of air VOCs at remote locations will be investigated as several pairs of VOCs can be used to get the information of origin and photochemical age • Model: The data will be useful to validate the fluxes estimated using different models used to generate global emission dataset of biogenic volatile organic compounds BVOC. The global scale chemistry and climate models lack proper representation (of both inventory and photochemical mechanism) of VOCs. The measured BVOCs data will be useful to improve the model simulations of ozone and organic aerosols in the troposphere
D2.8	**Anthropogenic and Biogenic Sources of Volatile Organic Compounds (VOCs) in Urban Regions of India (PRL)** The lack of representative local and regional parameterization of VOC emissions is one of the largest sources of uncertainty in the chemistry-climate model. Emission and photochemical processes of VOCs over the South Asia region are not well understood mainly due to the lack of comprehensive measurements. The dependence of both emission and atmospheric processes of VOCs on the key meteorological/environmental parameters is poorly understood over India and surrounding oceanic regions. Emissions of VOCs from primary the anthropogenic, secondary and biogenic sources are important to estimate in urban regions of India. The research objectives of PRL involve measurements of various VOCs using state of the art instruments such as the Proton Transfer Reaction- Time of Flight-Mass Spectrometer (PTR-TOF-MS) and Thermal desorption-gas chromatography-flame ionization detector (TD-GC-FID) in urban regions of India.

D3	**Sub Area**	**Information Extraction from Multi-Source / Multi-Sensordata for geospatial analysis & modelling (IIRS)**
D3.1	**Surface Parameter Extraction of Vegetative, Urban/Rural and Water Surfaces Such as 2D/3D Parameter Extraction and Modelling of Urban/Rural Objects/ Trees/ Plantations, Water (IIRS)** Exploring advanced techniques of information extraction, their performance evaluation for automated mapping, analyzing objects (buildings, trees, etc.) and other resources, their quantification and parametrization, and proper inventorization, building accurate databases and 3D models of man-made and natural resources is the ultimate goal of this research. Advanced routines for object based image analysis, spatial spectral segmentation and semantic segmentation, AI and ML methods are required to be explored for fully automating the information extraction from images for developing 2d/3d geo database of study area for further analysis and modelling of geographic phenomena to assist location based services. Specific sub topic addressing any application requirement under this umbrella is required for deep and focused study to target specific algorithm/ routine/ module development.	
D4	**Sub Area**	**Analysis, Modelling & Dissemination of Geospatial phenomena (IIRS)**
D4.1	**Investigating Methods for Mapping, Modelling of Spatial Phenomena (IIRS)** For analysis & modelling of Geospatial phenomena such as pollution dispersion, disease spread, spatial networks of utilities, population distribution, land-use growth and change, exploring, developing and evaluating advanced methods of geospatial modelling (such as advanced methods of spatial modelling, geo-statistical modelling, multi-dimensional modelling (surface modeling, time-series analysis and modelling), network modelling, etc.) is the need of time for utilizing huge information being derived from available repositories of satellite data. Proposals addressing investigation of models for modeling of such phenomena will enable appropriate and efficient use of the available space based, aerial and ground based data repositories. Development of advanced techniques and methods, for analysis, modeling and dissemination of big data, portal developments for geo web services in open platforms, efficient geo visualization methods of huge spatio temporal data are required. Specific sub topic addressing any geospatial phenomena or application under this umbrella is required for deep and focused study to target specific algorithm/ routine/ module development.	
E	**Area**	**Microwave Remote Sensing Applications in Agriculture, Soil Moisture, Forestry & Wetland Ecosystem (IIRS)**
E1	**Sub Area**	**Monitoring of Crop Growth, Retrieval of Crop Biophysical Parameters, Crop Yield Estimation, Soil Moisture Retrieval (IIRS)**
E1.1	**Crop Growth Monitoring & Crop Biophysical Parameters Retrieval (IIRS)** All weather capability of SAR data which ensures uninterrupted data supply, when coupled with unique sensitivity of SAR data towards physical, geometrical and di-electrical properties	

	of various crops along with penetration capability of SAR make it a perfect choice for cropgrowth monitoring and crop biophysical parameters retrieval for various crops. Use of multi-parametric SAR and advance SAR techniques like SAR Interferometry (InSAR), SAR Polarimetry (PolSAR) & PolInSAR allow to retrieve various crop biophysical parameters like LAI, Crop height, Crop volume, Crop water content, Crop fresh biomass, crop density etc. Use of various Machine Learning Techniques can further improve the retrieval accuracy.	
E1.2	**Crop Yield Estimation (IIRS)** Unique sensitivity of SAR data towards physical, geometrical and dielectrical properties of crop along with all-weather & penetration capabilities of SAR can successfully be used for crop yield estimation by incorporating various agro-climatic parameters in crop yield models.	
E1.3	**Soil Moisture Retrieval (IIRS)** Large difference between dielectric constant of water and dry soil & penetration capability of Radar signal are the key factors behind the fact that microwave remote sensing is the best tool for large area soil moisture retrieval / mapping. However, along with dielectric constant/water content of soil, SAR is also sensitive towards many other target properties like surface roughness, vegetation cover and soil texture. These parameters act as noise while retrieving soil moisture using microwave remote sensing data. Therefore, it is necessary and also challenging to retrieve soil moisture with high accuracy by incorporating the effects of noise parameters in the soil moisture retrieval model. Use of multi-parametric SAR along with advance SAR techniques like Interferometric coherence, Hybrid polarimetry, fully polarimetry, PolInSAR can successfully retrieve soil moisture under variety of agricultural heterogeneities. Use of advance Machine Learning Techniques are expected to further improve the soil moisture retrieval accuracy. Passive microwave remote sensing data can also be used for very large area soil moisture estimation but due to very poor spatial resolution, soil moisture retrieval accuracy is relatively lower than SAR data and it's also difficult to apply it on farmers'fields. However,advantage of fine temporal resolution of passive microwave RS data and advantage of fine spatial resolution of SAR RS data can be combined to generate daily soil moisture maps at relatively finer spatial resolution.	
E2	**Sub Area**	**Forest Biophysical Parameters Retrieval & Forest Type Discrimination (IIRS)**
E2.1	**Forest Species Discrimination & Forest Biophysical Parameters Retrieval (IIRS)** Penetration and all-weather capability of SAR along with sensitivity of SAR data towards physical, geometrical and di-electrical properties of forest trees and plantations of various shapes, sizes and structures along with all-weather & penetration capabilitiesof SAR can successfully be used to retrieve various biophysical parameters of forestlike forest above ground biomass, tree height etc. Availability of multi-parametric SAR along with advance SAR techniques like SAR Interferometry, Hybrid polarimetry, fully	

	polarimetry, PolInSAR, SAR tomography etc. can be used successfully for various other forestry applications along with detailed forest type discrimination in mixed forest type scenario.	
E3	**Sub Area**	**Wetland Ecosystem (IIRS)**
E3.1	**Assessment, Monitoring and Management of Wetland Ecosystem using Radar Remote Sensing (IIRS)** Wetlands play an important role in ground water recharge and also provide unique habitats for wide range of flora & fauna. Therefore, wetlands have significant biodiversity resources. However, the recognition of biodiversity conservation values of the wetlands has been neglected for a long time. As a result of this, there is an alarming loss of wetlands. The alarming loss of wetlands all over the globe had initiated an inter-governmental treaty which provides the framework for National action and International cooperation for the conservation and wise use of wetlands and their resources. This treaty was signed in Ramsar, Iran, in 1971 and is known as 'Ramsar Convention'. In order to monitor wetlands, on local, regional and national levels, there is an urgent need to develop user friendly and cost effective tools. Remote sensing can play an important role for assessment, monitoring and management of wetland ecosystem. Lot of work has already been done in the field of wetland studies using data from conventional remote sensing sensors operating in optical and infrared region of the electromagnetic spectrum. However, for studies of wetland, optical remote sensing data exhibit a few limitations. In contrast to radar remote sensing, the major limitation with optical data is uncertainty of getting cloud free data during monsoon (rainy) season. The analysis during monsoon season is of prime importance as it is the main source of water that controls the ecosystem of most of the inland wetlands. Moreover, sensitivity of optical data for physical, geometrical, dielectrical and textural variation of vegetation (both terrestrial and aquatic) is also limited as compared with Radar data operating in the microwave region of the electromagnetic spectrum, which is highly sensitive for these properties of various components of a wetland ecosystem. Capability of microwave signals transmitted from the Synthetic Aperture Radar (SAR) sensor to penetrate vegetation cover and to sense the moisture content of the earth materials, allows microwaves to monitor the wetland ecosystem more accurately as compared to optical remote sensing tools.	
F	**Area**	**Geospatial Areas (IIRS/SAC)**
F1	**Sub Area**	**Geoinformatics & Information Extraction (IIRS)**
F1.1	**Automating Information Extraction for GIS (IIRS)** Extraction of important information from a satellite image or a set of satellite images is important for various purposes such as inventorisation, planning, management and decision making at various levels. Availability of multi & hyper spectral (optical/ microwave), multiresolution/sensor, multi multitemporal from multiple platforms (space based aerial/ ground based/ UAV/ LiDAR) coupled with appropriate automated methods	

	could fulfil the requirement of information extraction from satellite images. Several potential methods such as neural networks & deep learning, natural intelligence based methods, object based methods considering spatial spectral classification analysis, contextual methods, appropriate fusion (at pixel/ feature level) of multi-source data, need to be explored for effective utilization of the huge amount of multi-source data available from remote sensing satellites.
F1.2	**Modelling of Geodata Data (IIRS)** Efficient modelling of geospatial data is still a research field. To complement legacy geospatial systems, loose coupling of new algorithms and technologies is the current demand in the geospatial landscape. Advances in the fields of machine learning and artificial intelligence are rapidly finding its applications in the geospatial domain. There is urgent need to adopt these techniques for better understanding of Earth processes. The geospatial practice has traditionally gained a lot from techniques such as knowledge data discovery and information mining. However, its potential has yet to be fully utilized in modern scenario of cloud based, distributed databases for elastic scale and real-time analytics. Big data poses another set of opportunities as well as difficulties in geodata analysis and modelling. The Big Geospatial Data architectural landscape is evolving rapidly. In the deluge of information, several technologies are being experimented with for deriving insights and inferences such as in-memory distributed processing (Spark), ultra-latency (Ignite), HDFS based data handling & storage (HBase, Hive). Computer science and geospatial technology need to collaborate to provide relevant, timely and reliable geospatial solutions.
F1.3	**Geostatistics (IIRS)** Geostatistics, which associates spatial coordinates of data with analyses is the core and indispensable component of any geospatial system is in its strong mathematical foundation. Advances in geostatistics need to be tested and validated in real world situations. This will yield new tools and methods for the collection, storage and processing of geospatial data and pioneer new applications of geospatial data to societal problems.
F1.4	**Geospatial Visualisation (IIRS)** The final consumption of geospatial technology is through demand-driven reporting. Traditional methods (Maps, Reports, and Dashboards) are now giving way to newer interaction methods (Bots, API, Alerts). Out of the box ways of conveying geospatial information is where human computer interaction and information exchange should be focussing on.
F1.5	**Dissemination of Geoinformation on Web (IIRS)** Dissemination of Geospatial information is one important theme which needs to grow further. The ecosystem of web technologies is exploding, and the geospatial component is yet to catch up. There are limited instances where latest frameworks such as Angular and Vue are being employed to develop web interfaces. Also processing on the web / on-the-fly is being looked at with great eagerness. State of the art research with special emphasis

	on solving real world problems is the need of the hour. There has been spectacular growth and adoption of open source GIS primarily fuelled by secure & scalable on commodity hardware and easy to learn high level programming languages such as Python. Capacity building, documentation, means of delivery and their quality assurance and stability are areas where more work is required. From the systems approach view-point, much research needs to be carried out to improve user experience and participation.	
F1.6	**Location Based Services (IIRS)** Several new types of location based data is being actively used in geospatial domain (UAV, sensor & equipment logging, video, IoT, and social media) apart from the conventional ones (satellite, aerial, GNSS, and weather). These require different types of ingestion: batch wise, streaming or event driven and can be of several formats (compressible/non-compressible, regular/sparse). Current research in this area deals with how best of make use of this location based data for its intended end use (real-time, in-memory, cache, and graph query based databases).	
F2	**Sub Area**	**Geospatial Data and Information Science (SAC)**
F2.1	**Advanced Data and Computing Architecture (SAC)** • Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatiotemporal analysis. • Techniques for forecasting and in-painting in Data Cubes • High Performance Computing of satellite images on Cloud	
F2.2	**Data Visualisation and Web Processing (SAC)** • Advanced data rendering and fast visualization techniques of 2D and 3D satellite data • Fast Tiling and caching techniques for visualization of satellite Images • Development of techniques for automatic on-demand web mashup generation • Cloud and Semantic enabling of Web Processing Services	
F2.3	**Data Mining and Web Analytics (SAC)** • Real time analytics for Big Earth Data • Pattern recognition based techniques for Event detection • Geospatial feature extraction using deep learning techniques • Automated event tracking (Cyclone, dust storm, etc.) using machine learning techniques • Region growing algorithms for identification and tracking of meteorological and oceanographic events (Fog, bloom, convective initiation, etc.)	
F2.4	**Data and Information Lifecycle Management (SAC)** • Automated algorithms for value evaluation of data and information • Techniques for automatic Quality checking of data • Techniques for Persistent identifier management	

	• Techniques for generation of Linked data • Faceted search and Browsing of satellite images • Semantic annotation and labelling of satellite images	
F2.5	**Data Security and Information Dissemination (SAC)** • Data encryption and compression techniques for multicasting of satellite data • Customization and optimization of multi-cast protocol using critical distance of client nodes to cater to requirements of real-time data dissemination. • Content based data multicasting • Information and Data security models for small devices • Location aware satellite data dissemination for mobile devices	
F2.6	**IoT and Sensor Network (SAC)** • IoT enabled sensor network for acquisition of weather data • Smart weather data acquisition systems • RTOS based Data acquisition system • Virtual Sensors for Weather data acquisition • Optimal data capture and processing in Sensor Network	
F2.7	**Virtualization and Cloud Computing (SAC)** • High Performance Cloud for Satellite Image Processing • Network Virtualization and Software Defined Network • Software Defined Storage	
F3	**Sub Area**	**Geophysical Parameter Retrievals (SAC)**
F3.1	**Retrieval of Geophysical Parameters from Satellite Data (SAC)** ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. Presently it has INSAT-3D/3DR satellites in the orbit. In near future, it has plan to launch many satellites in Geostationary and polar orbits for the same such as Oceansat-3 and INSAT-3DS. This also includes many advanced sensors such as Microwave Temperature Sounding Unit (TSU) and Humidity Sounding Unit (HSU) in future missions. There is also possibility of inclusion of an advanced microwave radiometer similar to GPM Microwave Imager (GMI) in future missions. Future generation of INSAT satellite may also have advanced imager, lightning imager and hyperspectral sounder on-board. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling, Geophysical Model Function development and the Inverse modeling techniques.	
F3.2	**IRNSS/GNSS Applications (SAC)** IRNSS/GNSS offers unique opportunity to retrieve atmospheric geophysical parameters such as TPW. ISRO may also develop satellite-borne receivers for IRNSS/GNSS reflectometry, which has potential to provide various surface parameters including sea surface height,	

	intense sea surface wind speed and direction under severe weather conditions, soil moisture, ice and snow thickness, etc. Theoretical modelling and simulations of the reflectometry observations is desired for the retrieval of the parameters. Until IRNSS receivers are not available, International missions such as TDS-1 and Cyclone Global Navigation Satellite System (CYGNSS) can be used to validate the simulation studies and retrieval algorithms.
F3.3	**Merged Data Products (SAC)** Develop data fusion methods to derive most optimized products using a synergy of observations. The examples are (a) Optimized temperature/humidity profiles using IR and microwave sounders (b) Optimized SST and rainfall products from IR and Microwave imagers.
F3.4	**Advanced System Studies for New Sensor Definition (SAC)** For measurements of atmospheric and Oceanic parameters, new advance sensors have to be defined for future satellites. System studies are being done with the help of Radiative transfer models to define the appropriate frequency, NEDT/SNR and bandwidth of new sensors. Sensitivity analysis is also being carried out to understand the error budget and appropriate resolutions (both spatial and temporal) required for the retrieval of geophysical parameter.
F3.5	**Development of Procedures for Long Term Records of Essential Climate Variables (SAC)** Long term records of essential climate variables such as SST, wind, radiation budget, water vapour, clouds, ozone, precipitation, sea surface salinity, sea level, sea state, etc., which are defined by Global Climate Observing System (GCOS), are necessary for characterising the trends in earth's climatic variations. Measurements from different satellite instruments suffer from different accuracies and biases due to evolution/performance of the instruments and/or retrieval algorithms. Thus there is need to intercalibrate the instruments/parameters to reduce the measurement biases among them.
F3.6	**Research Areas Related to Parameter Retrieval (SAC)** • Cloud/Rain type classification using INSAT/Kalpana observations. • Study of cloud micro physics using 157 GHz of MADRAS and INSAT data • Combination of INSAT-3D Imager and Sounder products to improve the quality of a few critical atmospheric products, such as atmospheric stability, total WV contents, SST etc. • Improved tracer selection, tracking and height assignment methods for Atmospheric Motion Vectors (AMV) retrieval from VIS, MIR, WV, TIR1 channels • Retrieval of high-resolution winds is a challenging research area that may be attempted with Geo imagine Satellite (GISAT) satellite

F4	Sub Area	Geosciences (SAC)
F4.1	**Geo Hazards (SAC)** It is required to develop techniques for early warning of geo-hazards using space technology and geoinformatics. In this context, one of the most challenging research area is to understand mechanism of earthquake triggering geodynamic processes. Study of geodynamic processes using advanced space based techniques is required to understand regional seismic hazard vulnerability in regions like the Himalayas and active seismic zones in peninsular India. Research related to quantification of the active tectonic deformation, modelling inter-seismic slip and strain rate and estimating moment-build up rate from geodetic, seismological and paleo-seismic data is required. Inter-seismic deformation measurement from space geodesy, their analysis and advanced modelling techniques are required to be developed. Study of land subsidence due to over exploitation of ground water, coal, hydrocarbons and crustal deformation associated with volcanos and slow-moving landslides using geodetic measurements for hazard assessment is another potential research area.	
F4.2	**Marine Geosciences (SAC)** Offshore exploration using satellite altimetry is a major research area. Altimeter derived geoid undulation and free-air gravity anomalies over Indian Ocean needs to be utilised to understand plate tectonic processes relating to oceanic ridges, subduction zones, formation of marine sedimentary basins and the evolution of continental margins. There is a need to improve the marine geoid and gravity data by including high precision altimeter data in geodetic mode for detailed work. The structural frame work of the Indian Ocean is quite complex with numerous fracture zones, abandoned spreading centers, aseismic ridges, seamounts and subduction zone. The Indian Ocean lithosphere is constantly under stress due to spreading activity south of it, resulting in fractures and intense deformation in this region. The thick sediment deposits in the Bay of Bengal mask the underlying crust and pose severe restrictions in constructing the geodynamical history of the basin. Splitting the geoid data into different wavelengths and correlating them with geology/tectonics and also their modeling may help to better understand structure and dynamics of the Indian Ocean lithosphere and may also help in offshore hydrocarbon exploration.	
F4.3	**Coastal Geosciences (SAC)** Coastal zones are the interface between land and ocean and are dynamic fragile ecosystem, where interaction among complex natural coastal processes, coastal hazards, vital habitats and human activities occur and integrated studies for sustainable coastal zone management are required for protecting life, property and environment. Some of the major coastal geoscience research area includes coastal sediment transport modelling using satellite retrieved parameters, understanding coastal processes and causes of coastal erosion, dynamics of various coastal processes and its impact on evolution of	

	coastal geomorphology, modeling coastal erosion and developing methods to predict shoreline changes, use of advanced automated methods to delineate shoreline (high Threshold Logic (HTL)/ Less than Truckload(LTL)) from satellite data, understanding impact of coastal processes on critical/vital habitats, understanding impact of predicted sea level rise on coastal zone, understanding coastal hazards and vulnerability/risk assessment, developing techniques for automated coastal landforms/wetlands/land use/ land cover mapping, detecting and monitoring coastal pollution, understanding impact on coastal ecosystem and developing models for integrated coastal zone management.
F4.4	**Mineral Exploration (SAC)** Although large part of the country has been conventionally surveyed and location of most of the economic mineral deposits have been investigated in detail, still new mineral deposits needs to be explored to meet ever-increasing demand of the industries. Mineral exploration using conventional techniques involve geological mapping followed by geophysical and geochemical investigations, pitting, trenching, exploratory drilling, estimating reserves etc. Remote sensing based methods have been so far limited to updating the existing geological/structural maps and in identifying hydrothermal alteration zones as a useful guide. Alteration halo is much more widespread of rocks surrounding a mineral deposit that are caused by solutions that formed the deposit. Research is required to explore integrated use of multispectral, hyperspectral, thermal and radar data along with high resolution DEM (space-borne as well aerial), geochemical and geophysical data sets in diverse geological and environmental settings to identify and map new mineral prognostic zones. Methods for automated mapping of minerals associated with alteration zones, development of spectral-geochemical relationship using spectral and geochemical datasets need to be developed.
F4.5	**Geo-Archaeology (SAC)** Space based geo-archaeological exploration along with geo-spatial tools is one of the most fascinating geoscience application. It involves interpretation of multi-sensor satellite data to explore new archaeological sites, understand development, preservation and destruction of archaeological sites in context of regional scale environmental changes, evolution of physical landscape and impact of human groups by applying concepts and methods of geosciences (especially geology, geomorphology, hydrology, sedimentology, pedology and exploration geophysics). Research is required to develop methods/ approach to explore archaeological sites using multi-sensor satellite data (Radar and high resolution multispectral data in particular) in conjunction with geospatial database of known archaeological sites. It is required to understand impact of neo-tectonic activities and palaeo-climatic changes on evolution of ancient civilisations.
F4.6	**Environmental Geosciences (SAC)** Desertification and land degradation constitutes one of the most alarming geo-environmental global problem affecting two third countries of the world on which one billion people live (one sixth of world's population). Land degradation is reduction or

	loss of productive land due to natural processes, climate change and human activities. Desertification is land degradation in arid, semi-arid and dry sub-humid areas (also known as Drylands). The processes of desertification and land degradation are observed to have accelerated during recent years globally. There is a need to stop and reverse the process of desertification and land degradation. It is required to develop advanced digital classification techniques using object based approaches, machine learning/ artificial neural network for automated land degradation mapping using multi-temporal and multi-sensor satellite data, vulnerability and risk assessment and developing action plans to combat land degradation
F4.7	**Imaging Spectroscopic Study for Moon (NRSC)** Imaging Infrared spectrometer (IIRS) sensor onboard Chandryana-02 satellite has collected latest hyperspectral images for different parts of Moon. This sensor provides continuity of imaging spectroscopic data of Moon after previous imaging spectrometer, Moon Mineralogical mapper (M3) onboard Chandrayaan-01 derived updated mineralogical maps of Moon from its hyperspectral images. However, it is essential to develop vicarious and hybrid calibration methods for deriving IIRS data-based reflectance products for accurate mineralogical mapping and establish the accuracy of the derived reflectance products. Further to above, research should also be taken up for conjugated utilization of Low energy X Ray, High energy X Ray and M3, Imaging infrared spectrometer (IIRS) datasets for delineating imprints of magmatic process in different parts of the Moon with special focus areas around KREEP, South pole Aitkin basin and Lunar Dome areas.
F4.8	**Imaging Spectroscopy for Mineral Exploration (NRSC)** Imaging spectroscopic data provide surface proxies of mineralization (i.e. identification of alteration zones, residual capping etc.). These proxies are often integrated with other geo-scientific evidence layers for deriving prospecting models for exploration. It is important to identify geo-botanical anomalies that are associated other surface proxies of mineralized province. In this regard, identification of spectroscopic indicators of geo-botanic anomalies are essential. These anomalies combined with other evidence layers, proxy maps of mineralized belt would provide improved prospect models for mineral prospecting. Further, research attempts are also required to implement machine learning based prospect models over knowledge-based prospect models for targeting new mineral deposits for which genetic models of ore deposit formation is poorly defined.
F4.9	**Himalayan Cryosphere (NESAC)** • Improvements and development of snow melt run-off models • Applications of snow melt run off for irrigation and hydro-power requirements. (NESAC) • Improvements and development of glacier mass balance models • Understanding glacier dynamics • Modeling snow and glacier depth

	• Development of algorithms for auto extraction of glacier features from multi-sensor satellite data with particular reference to Hyperspectral and thermal data • Microwave remote sensing for snow & glaciers including interferometry techniques • Comparative study of Himalayan glaciers with other mountain glaciers • Impact of climate change on Himalayan snow & glaciers (NESAC)	
F4.10	**Vulnerability Profiling of Capital Cities of NER (NESAC)** Urban areas are susceptible to disasters (man-made or natural). It is the need of the hour to make a rapid vulnerability assessment of urban areas in order to understand what is required for building disaster resilience community. The potential impact of different parameters on urban services arising from the geographical setting of a city; the nature, size and density of its settlements; and the existing coping capacity of its society and governance system can be studied to create vulnerable profile of urban areas.	
F5	**Sub Area**	**Biogeochemistry (PRL)**
F5.1	**Biological N_2 Fixation in Oxygen Minimum Zones (OMZs) of the Indian Ocean (PRL)** Nitrogen and oxygen are important elements for life and their cycling in ocean is interconnected. The distribution of oxygen in the ocean interior is controlled by an intimate interplay of physics and biology. Oxygen is transported by circulation and mixing processes into the ocean interior from near-surface waters, where it is produced by photosynthesis and exchanged with the atmosphere. Oxygen consumption by bacterial respiration of organic matter occurs throughout the ocean but most intense in oxygen minimum zones (OMZs). Recent observations suggest that the biological N_2 fixation (major source of bioavailable nitrogen in open ocean) occurs in such OMZs. Both the supply and consumption of oxygen and bioavailable nitrogen are sensitive to physical parameters in ways that are not fully understood. Research carried out at PRL has led to substantial improvement in our understanding of the various transport and biogeochemical processes responsible for regulating N_2 fixation in the Indian Ocean.	
F5.2	**Carbon: Nitrogen: Phosphorous stoichiometry in the Indian Ocean (PRL)** Availability of nitrogen (N) and phosphorus (P) determine the strength of the ocean's carbon (C) uptake, and variation in the N:P ratio in inorganic nutrients is key to phytoplankton growth. A similarity between C:N:P ratios in the plankton and deep-water inorganic nutrients was established in the last century. However, recent studies have suggested a variation in nutrients N:P ratio as well as cell species dependent phytoplankton C:N:P ratio. At present, our understanding of the (environmental) factors governing C:N:P stoichiometry remains poor. The northern Indian ocean due to its geographic setting and monsoonal wind forcing provides a natural biogeochemical laboratory to explore the effect of environmental and physical factors on C:N:P stoichiometry. Research carried out at PRL under the ISRO-GBP program has improved our understanding to some extent on the C:N:P ratio in bulk organic matter pools and nutrients. However, knowledge at the cellular level is still fragmentary, yet critical to identify the variation in the ratio.	

F5.3	**Trace Element Biogeochemistry in Ocean (PRL)** PRL played a lead role and initiated studies on trace elements and their isotopes for the Indian Ocean region under the aegis of International GEOTRCAES programme. As part of the Indian GEOTRACES and related programs, high-resolution sampling was performed in the Arabian Sea, the Bay of Bengal, and the Indian Ocean along with some major estuaries and rivers of India to understand biogeochemical cycling and distribution of trace elements. Trace elements in ocean are essential micronutrients and their abundances influence overall productivity of the ecosystem. Distribution of trace elements and their isotopes in oceans also provide information on physical and chemical processes such as water mass movement, redox condition, and sources and sinks of these elements. PRL intends to continue these studies in the northern Indian Ocean as this region is not well constrained vis-à-vis their geochemical cycling.
F5.4	**Nitrogen and Carbon Cycling in a Tropical Estuary and Adjacent Coastal Region (PRL)** Estuaries and adjacent coastal regions are vulnerable ecosystems due to increased nutrient loading from anthropogenic activities. Excess nutrients enter the system as organic and inorganic N and P compounds through rivers and the atmosphere, and threaten coastal ecosystems. Anthropogenic inputs cause many estuarine-coastal systems to shift drastically from N limitation to an N surplus leading to eutrophication, a major threat to most of the estuaries and coastal waters around the world. At present, our knowledge of N and C cycling, particularly N uptake dynamics and its dependence on N and P distribution in tropical estuaries and the adjacent coastal waters remains rudimentary. Information about the rates of transformation of N and C in such systems is needed to develop mitigation strategies to restore and save the estuarine-coastal coupled systems from eutrophication. The research carried out in PRL in recent years at different estuarine-coastal coupled systems of India has added significantly to this knowledge.
F5.5	**Carbon and Nitrogen Fluxes in River Systems of India (PRL)** Human activities are drastically altering water and material flows in river systems across India. These anthropogenic perturbations have rarely been linked to the carbon (C) fluxes of Indian rivers that may account for considerable percentage of the global fluxes. In this regard, a conceptual framework for assessing human impacts on Indian river C and N fluxes is needed. Lower reaches and tributaries of rivers, such as the Ganges, which drains highly populated urban centers, tend to exhibit higher levels of organic C and the partial pressure of CO_2 (pCO_2) than less impacted upstream reaches. Also, proper quantification of impacts of river impoundment on CO_2 outgassing from the rivers of India is still lacking. Within this context, PRL has initiated a program to study C and N cycling in rivers of India, where movement of these important elements throughout the river continuum will be studied.

F5.6	**Nitrogen and Carbon Cycling in a Terrestrial Ecosystems of India (PRL)** In past few decades, human activities have altered many terrestrial ecosystems by increasing human derived N inputs which has caused shift in natural cycling of elements. This has eventually affected C fluxes and its storage capacity of soils, providing positive feedbacks to climate change. As N acts as an important growth limiting nutrient for plants and the biogeochemical cycles of N and C are coupled, it is important to understand N cycling in forest ecosystems in order to develop proper forest management practices. Production of NH4+ in soils can be studied by determining either net rates which shows the amount of nutrient remaining after consumption; or gross rates which allows quantification of total mineralized N. So far, many studies have been conducted on net rates of mineralization as it is considered to be the principal step which determines plant productivity but few studies exists. vis-à-vis gross mineralization rates worldwide. For the first time in the southeastern Asian region, research carried at PRL using isotope dilution technqiue to quantify rates of gross mineralization and nitrification in the Himalayas, Western Ghats, Rann of Kutch, and Kerala has added significantly to our knowledge regarding natural pathways of nutrient production and consumption in different ecosystems of India.	
F6	**Sub Area**	**Paleoclimate (PRL)**
F6.1	**Coral as a Proxy for Sea Surface Properties (PRL)** Coral are organisms growing in shallow marine conditions and are sensitive to sea surface temperature (SST). They form annual bands and record properties of sea surface conditions at very high-resolution and could prove to be a good calibration for paleoclimatic studies. Based on corals from the Andaman region, reservoir age correction was provided as applicable to radiocarbon dates of marine samples. Paired measurements of Sr/Ca and stable isotopes in corals from Andaman region have shown that these can be effectively used for calibration of SST and show signatures of Indian summer monsoon. Coral radiocarbon measurements for the period 1949-2013 have yielded air-sea exchange rates of CO_2 for the Indian Ocean and shows relation with wind speed and alkalinity.	
F6.2	**Paleoclimatic Reconstructions from Marine Sediments of the Indian Ocean (PRL)** PRL has been at the forefront of research in paleoclimate reconstruction. Towards this, several marine cores from the northern Indian Ocean have been investigated. Based on studies of a sediment core from the western Arabian Sea, it was observed that variations in the Somali upwelling has relationship with southwest monsoon rainfall. Evidence of poor bottom water ventilation during LGM in the equatorial Indian Ocean was found from studies in the equatorial Indian Ocean. Recently, signatures of global climatic events and forcing factors for the last two millennia from the active mudflats of Saurashtra has been found. Similarly, cores from other regions of the Indian Ocean are under investigation.	

F6.3	**Past climate using Speleothems (PRL)** Past monsoon conditions can be assessed from variations in oxygen isotope ratios and trace element compositions in cave carbonate deposits (stalagmites). Exploring new caves covering different geographical sites and monitoring variability in isotopic and geochemical compositions of modern cave seepage water can add to a very limited data set available on past monsoon from terrestrial records. Also, trapped water in the carbonate matrix represents the past water. Its isotopic composition can be utilized to interpret past hydrological conditions. Work is being carried out on the development of vacuum technique to extract trapped water from the carbonate matrix along with dating technique utilizing U-Th decay series, which is presently unavailable in India. Overall, PRL has contributed significantly to paleomonsoon reconstruction using speleothems.
F6.4	**Paleoglaciation Records from the Central and Western Himalaya (PRL)** The mountain glaciers are active geomorphic agents to shape the landforms and are responsible for producing some of the most spectacular landscapes on the surface of the earth. Timing and amplitude of paleoglaciations represent important cornerstones of terrestrial paleoclimatic research as glaciers are arguably the most sensitive recorde rs of climate changes as they respond to the combined effect of snow fall and temperature. To reconstruct the history of glaciations, large scale field mapping of glacial deposits (moraines) along with geochronology using different techniques like optical chronology and cosmogenic radionuclides dating is being carried out at PRL.
F6.5	**Application of Non-traditional Stable Isotopes to Study Earth System Processes (PRL)** It is important to understand the origin and temporal evolution of the Earth and its various systems. Recently, non-traditional stable isotopes have been used as a new tool to study various earth system processes. Some of the important aspects that can be explored using non-traditional stable isotopic systems are redox evolution of Earth's oceans and atmosphere (Fe, Mo and U isotopes), reconstruction of silicate weathering history and understanding the weathering regime (Li isotopes), reconstruction of seawater paleo-pH (B isotopes), paleo-volcanism (Hg isotopes), biomineralization of foraminiferal tests (Ca isotopes). The initial step to study these problems in Earth Sciences by suitable non-traditional isotopic proxies involve intensive field work for collection of appropriate samples (e.g., recent marine sediments and black shales for understanding recent and past ocean redox using Mo isotopes, river water and suspended sediments to understand weathering regime using Li isotopes) followed by sample preparation in laboratory for extraction and purification of element(s) of interest, their mass spectrometric analyses, and modelling of data. PRL has been involved in such studies and wishes to continue using emerging techniques as they are indispensable for understanding the Earth as a system.

F6.6	**Catastrophic Events across the Indian Geological Records (PRL)** At PRL, we aim to understand 'catastrophic events' such as mass extinction events across major boundaries (Permian-Triassic -250 Million Years ago, Cretaceous-Palaeocene – 65 Million year etc.) from the Indian geological records. Also, works on impact craters (Lonar, Dhala, and Ramgarh etc.) are underway, where the major objectives are to understand the processes responsible for such global events using the geochemical anomalies and chronological information along with proxies to pin point the factors responsible for such type of events.	
F6.7	**Present and Past Extreme Events (PRL)** The extreme precipitation events, like of June 2013 in Uttarakhand, create flash floods in monsoon dominated Central Himalayan valleys. The fluvial deposits in the associated river basins are being studied at PRL to understand the past processes from the central to western Himalayas during the late Quaternary period. Generally, sediment bulking in the monsoon dominated Himalayan rivers is caused due to (i) landslide dammed lake out bursting, (ii) the glacial lake out bursting, and (iii) recession of valley glacier deglaciation. In this program, we intend to quantify the spatial and temporal changes in the sediment provenance in order to ascertain the role of climate and tectonics in valley-fill deposits.	
F6.8	**Accelerator Mass Spectrometer: Application of Cosmogenic Radionuclides in Geosciences (PRL)** The Accelerator Mass Spectrometer Facility at PRL has been installed to measure ^{14}C, ^{10}Be and ^{26}Al. Radiocarbon (^{14}C) has been extensively used in application of earth, ocean, planetary and atmospheric sciences. Several samples from archaeological sites have been dated using ^{14}C. Radiocarbon has been used as a tracer to understand various ocean processes. One of the major oceanic climatic process which governs the Earth's climate is ocean circulation. Based on radiocarbon dates of planktonic and benthic foraminifera in marine sediments, ventilation rates of the Indian Ocean have been established for the last 50 kyr. Radiocarbon dates of groundwater provide estimate of climatic conditions at the time of recharge. Meteoric 10Be has been used as chronological tool for dating marine sediments up to 10 million years. In-situ 10Be is being used for deriving the exposure age of glacier and gives understanding of glacier retreat or advance rates.	
F7	**Sub Area**	**Atmospheric Chemistry (PRL)**
F7.1	**Non-conventional Stable Isotopes in Atmospheric Carbon Cycle Research (PRL)** Precise quantifications of the sources and sinks of CO_2 in the atmosphere are very important for modelling future climate. The existing studies, mainly based on the conventional stable isotope ratios and CO_2 concentration are not enough to precisely quantify the CO_2 budget because of their complex interactions with various reservoirs and contribution from multiple components with overlapping range of isotopic ratios. Clumped and triple oxygen isotopes in CO_2 are two recently developed isotopic proxies and are found to be applicable to address many of the carbon cycle issues. Clumped isotopes in CO_2 are molecules in which more than one isotopes are replaced by their rare	

	counterparts and are mostly used as a proxy of CO_2 formation/exchange temperature. The triple oxygen isotopes or 17O excess in CO_2 is the excess abundance of 17O compared to that expected from mass dependent fractionation processes and is mostly acquired from the interaction of CO_2 with ozone in the stratosphere. These two isotope proxies basically measure anomalies and are free from many terrestrial complex processes. With modern mass spectrometry techniques, very precise measurements of these isotope ratios are possible and hence can be used to estimate the contribution of CO_2 from different sources and estimate the gross primary productivity, the total CO_2 assimilated by plants. Geosciences division of PRL recently started developing techniques for measuring these nonconventional isotope ratios, along with the existing conventional isotope measurement facilities to precisely constrain the atmospheric carbon budget in India.	
F7.2	**Research on Aerosol Chemistry and Characteristics (PRL)** Aerosols are known to affect the Earth's climate (radiation budget, hydrological cycle), aquatic ecosystem (biogeochemistry of oceans and lakes), and air quality (visibility and human health). After emission and/or formation, aerosols react with other species during atmospheric transport that further lead to transformations in their chemical and physical properties. These processes not only affect their optical and hygroscopic properties but also the bioavailability of nutrients present in aerosols. However, the characteristics and composition of aerosols remains poorly understood. Aerosol research at PRL focusses on understanding the physicochemical characteristics of ambient aerosols over different regions of India, and how they relate to atmospheric chemistry, clouds, climate, ecosystem, air quality, and human health. Chemical and isotopic compositions of aerosols as well as their characteristics using state-of-the-art online and offline measurements techniques over different parts of India and surrounding oceans are being studied. In addition, focus is specifically on studying emerging research areas such as secondary organic aerosols, brown carbon aerosols, and oxidative potential of aerosols. Such studies are not only important in understanding and assessing the effects of aerosols on air quality and climate, but also in validating/modifying regional and global climate models.	
F8	**Sub Area**	**Earth Surface Landforms and Processes (PRL)**
F8.1	**Fluvial Depositional Environment and Facies (PRL)** Rivers are one of the dominant agents of landscape modification as the flowing waters are continually eroding, transporting, and depositing sediments (Fluvial Processes) in the course of time. Fluvial geomorphology deals with the form and function of streams and the interaction between streams and the landscape around them. It depends on fluvial dynamics, sediment load, slope / slope stability, vegetation, surface runoff, climate, tectonics, etc. An architectural element may be a component of a depositional system, characterized by a distinctive facies assemblage, internal geometry, external form etc. Stream morphology is dynamic and constantly changing in both space and time. River	

	based flooding is among one of the most frequent and widespread natural hazards of our country. Apart from studying palaeo-climates, studying fluvial deposits are important in economic aspects as they are characterized by good porosity and permeability, thus constitute excellent aquifers, placer deposits, coal, oil and gas reservoirs are hosted in fluvial units. The understanding of system dynamics will help us for planning for climate change. Thus, proposal is invited to understand fluvial processes and palaeoclimate changes.	
F8.2	**Coastal Configuration Changes and Interaction with Sea Level and Tectonics (PRL)** The long coastline of India makes it a suitable area to study the past surface, internal and climatic processes that shaped the present day coastline. Understanding the past response to various forcing are important to understand and model the present coastal dynamics in the view of ongoing threat of global warming, climate, sea-level changing scenarios. In view of this, it is important to understand the process taking place along the coast in past and present. The study of such processes will enable us to design the strategies for probable future issues and provide us the parameters which should be monitored via ground or satellite based observations. Sedimentary archives along the coast provide excellent proxies to study such processes in past. Such archives are need to be studied in order to develop understanding of coastal sedimentary processes. The proposals are thus invited for coastal sediment studies.	
G	**Area**	**Earth, Ocean, Atmosphere, Planetary Sciences and Applications (NRSC/SAC/NESAC)**
G1	**Sub Area**	**Study of Lightning using Space Based and Ground Based Sensors (NRSC)**
G1.1	**The atmospheric Lightning can be Monitored using the Optical and RF Sensors. (NRSC)** The space based sensors often rely on the optical glow for the lighting detections. The most of the information on the lightning occurrences are based on the lightning imaging sensor onboard the tropical rainfall monitoring mission. A similar sensor has been installed at International space station. However, since the advent of ground based RF detection methods relying on VHF and VLF range, it has been shown that detection capabilities of optical and RF sensors has large differences. The assessment of limitation of each method becomes imperative for the cautious utilization of these data sets. Systematic investigations on the detection methods are required for a statistical and quantitative assessment which is lacking over the Indian sector. Key objectives are as follows. Characterization of space based information on lightning monitoring Inter-comparison of ground based and space borne observations and efficiency estimation. Understanding the limitation of ground based RF, Optical, and space based microwave, and optical sensors.	

G2	Sub Area	Forest and Environmental Science (NRSC)
G2.1	**Remote Sensing-based Assessment of Forest Vulnerability (Dynamic) to Fire (NRSC)** Earth observation data has proven to be one of the most important tool to further our understanding of forest fires because of ability of observe on systematic basis and monitor changes over time in domains beyond human capacity. In India Active fire alerts based on thermal bands are operationally being sent to concerned forests official of the region. Fire vulnerability assessment (static) of Forests based on past fire occurrences have been done. But today's climate is much more dynamic in nature and is contributing a lot of change in fire occurrence pattern. Real time machine learning based model with latest Meteorological data (Precipitation, Temperature, Wind Speed etc.), Satellite based Vegetation Index, forest density and type, Land Surface Temperature, Fuel Moisture Content, Terrain, Elevation, Aspect and LULC trained with past scenarios of the same based on burnt area records mapped using appropriate multi spectral data will better help us to manage our forests from previously unpredicted fires.	
G2.2	**Earth Observation Suite for Monitoring Stubble Burning in Northern India (NRSC)** Stubble-burning in northern India is an important source of atmospheric particulate matter (PM) and trace gases, which significantly impact local and regional climate, in addition to causing severe health risks. Scientific research on assessing the impact of these burnings on the air quality over Delhi is still relatively sparse. Most of the researches done in this field rely almost entirely on MODIS or SUOMI-NPP derived active fire counts, which is not a good estimate of extent of damage done by the fire in both in terms of area and severity. Medium resolution multi-spectral was earlier not encouraged because of lower temporal resolution. But with availability of multiple satellites from the same series (LANDSAT, Sentinel-2 and IRS series) the temporal resolution of availability of multi spectral data from space is down to 2-3 days can be much more effectively used to monitor the extent and severity of the fire event. More over concentration of atmospheric pollutants and gases can be monitored using Sentinel 5, and MODIS/SOUMI-NPP satellites. All of this combined with ground data in Delhi will be used to effectively estimate the contribution of stubble burning in Air Quality Index(AQI) of Delhi. Hence a with proper Earth Observation Suite to monitor stubble burning in Northern India we can help in management of Air quality of Delhi-NCR region.	
G2.3	**Urbanization-induced Effects on Agricultural Land and its Productivity Using Geospatial Technology (NRSC)** India has the world's second largest population; thus, food demand and security is a widely concerned topic. There are remarkable changes in landscape caused by rapid urbanization during the past decades. The increasing demand for urban development is considered as the main cause of loss in agricultural land, which has been observed in several Indian cities. The protection of agricultural land is the primary task to ensure the food supply. Therefore, monitoring the agricultural land dynamics and modelling	

of its future distribution is critical for local administration to develop suitable strategies for development. The investigation of urbanization induced effects on agricultural land has now become one of the important subjects in yield estimation. Accurate and updated information on the extent of urban areas and changes in agricultural land are vital for prioritization of areas for policy intervention, urban sustainability, natural resource management, and environmental impact assessment. Mapping of urban agricultural land, including fragmented irrigated areas, is a challenging task due to its dependency on the diverse range of irrigated plot sizes, crops, and water sources. The existing methods are not able to capture the changes in agricultural land use adequately in rapidly growing urban areas. So, it is needed to develop an effective technique for mapping net sown area and yield estimation of major cultivated crops. However, only modelling the land cover dynamics according to the past trend is not sufficient to predict the precise future scenario, because recently released policies can easily change the local developing patterns. There is, alternatively, slight understanding of how urbanization and crop land consolidation may interact to influence agricultural land use and food production in future. There is a paradoxical competition between land use for residence and agricultural for food. Consequently, some of the regions are suffering the effects of this land-use conflict as a risk both to the environment and food security. The understanding of interaction between urban growth and loss in agricultural land and yield can provide significant insights for implementing policies to promote food production along with the negative impacts of urban development. This research includes a novel modelling application to produce spatially explicit forecasting of urbanization and changes in land cover by considering several criteria at the same time including socio-economic, ecological, and landscape planning variables. Such modelling approach imitates the possible impacts of a specific policy-oriented scenario on future landscape transformations. The overall objective of this research is to investigate the urbanization trends, the resulting effects on the natural environment and agricultural land for sustainable urban development and food security.

The major objectives of this research are:

- Assessing the drivers of landscape changes based on integrated analysis of multi-temporal remote sensing images and socioeconomic data
- Geospatial scenario-based simulation and prediction of urban growth dynamics
- Geospatial modeling of the cropland changes under rapid urbanization

G3	**SubArea**	**Soil Resource Characterization, Land Use Planning and Watershed Management (IIRS/ NESAC)**
G3.1	**Terrain Characterization in Hydrological Properties of Soils (IIRS/NESAC)** Developing/improving models for terrain characteristics of soil (Texture, Structure, Saturated hydraulic conductivity (Ksat), Consistence, Bulk density, Available water capacity (AWC))with respect to hydrological properties.	

G3.2	**Soil Nutrient Management for Precision Agriculture using Hyper Spectral Data (IIRS/NESAC)** To study develop model/algorithm using hyperspectral imaging for precision farming.	
G3.3	**Soil Carbon Sequestration (IIRS/NESAC)** Developing methodology/model to estimate soil carbon sequestration status using different resolution satellite data.	
G4	**Sub Area**	**Agriculture and Agro-ecosystem (NESAC/SAC/NRSC/IIRS)**
G4.1	**Green House Gases Estimation (NESAC)** One of the recent trends in remote sensing understands the climate change trough space measurements. Atmospheric Green house gases concentration and measurements of flux are important research Area. Currently available sensor system includes GOSAT, ENVISAT-SCIAMACHY, MOPITT etc. India has plans to launch such mission (ENVSAT Series) in future with other countries (OCO of USA, GOSAT-2 of Japan). There is need to develop radiative transfer scheme to model and retrieve the gases concentration. There is need to in situ measurement of CO_2, CH_4, N_2O etc fluxes for validation of satellite products.	
G4.2	**Forest Meteorology and Ecosystem Modeling (NESAC)** Forest plays an important role in governing the energy and mass exchange over a region. Quantification of energy fluxes helps in modeling regional climate. SAC is involved in development of 24 Micrometeorological station network in India which are taking continuous measurements in agriculture and natural vegetation system. There is need to develop land surface process models to quantify the fluxes with reference to surface and atmospheric forcing. Most of the biogeochemical modeling depends on phenological understanding of different vegetation types. There is need to carry out ground experimentation as well as satellite modeling to estimate the phenological matrices of different vegetation types. Such efforts would lead to develop the forest growth simulation models. Modeling NPP using satellite measurements such as INSAT-CCD is an important future thrust area. There is need to develop process based model to quantify the net primary productivity and ecosystem level productivity. Network of annual biomass measurements are needed to validate the NPP products. It is known that biomass modeling is limited with optical measurements due to saturation of optical light in denser canopy. Radar based approaches provide improved assessment. It is proposed to develop LIDAR based modeling to account the height of the forest in the estimation of forest biomass. Detection of forest fire and development of fire alarm system based on bioclimatic indices is an important research area which will be carried out using INSAT-3D satellite data.	

G4.3	**Retrieval of Green House Gases using Satellite Data (NRSC/ NESAC)**
G4.4	**Aerosol Optical Thickness and Atmospheric Correction over Land (IIRS/ NESAC)** Calibration and radiometric normalization is the key issue in future remote sensing activities related with biophysical parameter retrieval and climate change. Atmospheric correction of the satellite data is a challenge. Most important input for atmospheric correction involved estimation of Aerosol optical thickness (AOT) either from network of ground observations or satellite data. Retrieval of AOT sensors like Resourcesat series is a challenge. There is need to develop simplified correction approach including AOR inputs using dark dense vegetation approach. There is further need to develop instrumentation with capability of polarized measurements and LIDAR sensing.
G4.5	**Aerosol Optical Thickness and Atmospheric Correction over Land (SAC/IIRS/ NESAC)** Calibration and radiometric normalization is the key issue in future remote sensing activities related with biophysical parameter retrieval and climate change. Atmospheric correction of the satellite data is a challenge. Most important input for atmospheric correction involved estimation of Aerosol optical thickness (AOT) either from network of ground observations or satellite data. Retrieval of AOT sensors like Resourcesat series is a challenge. There is need to develop simplified correction approach including AOR inputs using dark dense vegetation approach. There is further need to develop instrumentation with capability of polarized measurements and LIDAR sensing.
G4.6	**Climate Change Impact assessment (NRSC/ NESAC)** Anticipated/Ensuing climate change is expected to alter the water resources availability, demand and use patterns. Many uncertainties remain about the extent of these climatic changes, as well as about their societal implications. Assessment of vulnerability and resulting risk to water resources due to climate-change impacts is necessary to work out appropriate adaptation and mitigation strategies.
G4.7	**Wetland Ecosystem (NESAC)** Wetlands mapping has been carried out by SAC at 1:50,000 scale for India. There need to develop scheme to map the wetlands using improved and integrated approach involving microwave and optical data. Wetland eutrophication needs to be studied using temporal high resolution optical sensors. Efforts on modeling Methane Emission from Wetlands is an important future thrust area.
G4.8	**Development of GHG Models for Agro-Ecosystems under Different Conditions (SAC/NESAC)**
G4.9	**Understanding Shifting Cultivation as a Driver of LULC Change (NESAC)** Identifying space based indicators to link shifting cultivation as a driver for LULC changes and its impact.

G4.10	**Crop Health Assessment using Multispectral / Hyper Spectral UAV Data and Artificial Intelligence (NRSC)** As a consequence of rapid ongoing technological developments and increasing integration into agricultural mechanization and agricultural intelligence, UAVs are gradually starting to play an increasingly important role in field crop management and monitoring. UAVs can be used for agricultural activities such as field surveillance, plant counting, weed mapping, yield prediction, irrigation management, plant disease detection, plant health monitoring, and crop spraying. Indian government also emphasizing use of drones and UAVs in Indian farming practices. High resolution Multispectral / Hyper spectral data collected from UAV platform along with GPS/DGPS data can play a vital role in crop health assessment. UAV based multispectral and hyper spectral data can effectively be used for mapping and quantitative monitoring and assessment of crop damage. Machine learning (ML) / Deep Learning (DL) based classification algorithms can easily capture complex class signatures and are not affected by the distribution of data, i.e., it is non-parametric. Data of high spatial resolution can help in identifying crops at a smaller scale and help in crop management, crop insurance in face of calamity, yield forecasts, etc. Main objectives of this research are: • Crop health assessment using Multispectral / Hyper spectral UAV data using Artificial intelligence • Field level crop classification and yield estimation • Field level crop damage assessment due to Natural Hazards for crop insurance	
G5	**Sub Area**	**Agriculture, Terrestrial Biosphere and Environment (SAC)**
G5.1	**Crop Production, Yield and Price Forecasting (SAC)** • Monthly forecast of major crops & long-lead forecast • Automated crop yield estimation thorough process-based model • Prediction of market arrival & price through statistical and AI/ML approaches • Acreage of rabi pulse types, Kharif onion through Opti-SAR observations • Fodder type-wise area, yield & production • Site suitability of medicinal plants	
G5.2	**Agro Advisories and crop Loss Assessment (SAC)** • New Drought product from Satellite and its use in crop loss • Prototype demonstration of Digital agro-climatic atlas • Horticulture-specific weather-based insurance product using satellite data • Local-scale / high-resolution weather forecast using AI/ML • Modelling macro/micro climate & animal disease prediction	

G5.3	**Precision Agriculture (SAC)** • Resource-use efficiency (Crop Water Productivity, Nutrient Use Efficiency), Soil carbon dynamics • Fodder nutrient, Active medical ingradient & pesticide residue investigation (UAV, satellite hyperspectral, thermal, Imaging microscopy – Experiments, analysis, data fusion) • Investigations on Solar-Induced Fluorescence (SIF) & hyperspectral related to photosynthesis & early disease detection
G5.4	**Forest Ecosystem Studies (SAC)** • Quantification of Essential Ecosystem Services for assessments and monitoring of ecosystem service supply, demand and benefit • Essential biodiversity variables (distributions, abundances, morphology, physiology, phenology) for modelling & monitoring in space-time for species distribution monitoring • Forest Physiognomic Studies using LiDAR remote sensing • Forest Phenological Studies and PhenoMet model developments • Mapping Invasive Species using AI/ML • Forest Fire Mapping, Biomass Burning Emission & Forest Fire Risk Zonation
G5.5	**Atmospheric Trace Gases, Aerosols and Air Quality Research (SAC)** Atmospheric trace gases include greenhouse gases (CO_2, CH_4, etc.) and air pollutants (O_3, NO_2, CO, SO_2, etc.) which play momentous role in climate change, atmospheric chemistry and air quality. Development of retrieval techniques for retrieving methane and carbon dioxide from space is a gap area in the context of Indian Remote Sensing Program. • Development of Retrieval Technique for Atmospheric Methane and Carbon Dioxide through Differential Optical Absorption Spectroscopy (DOAS) based technique • Modelling the Vertical Particulate Extinction and Backscatter Profiles from satellite and ground LIDAR observations
G5.6	**Heliophysics, Space Weather and THz Astronomy (SAC)** • Understanding temporal evolution of elemental abundances in solar flares X-ray observations through theoretical modeling and satellite observations • Ionospheric properties of Earth with modeling and satellite observations for understanding the space weather • Sub-mm astronomy can answer some of the most profound questions related to the cold components of the Universe on scales of galaxies, molecular clouds, star and planets. Precursor studies using multi-wavelength studies using observations from global sub-mm telescopes

G6	Sub Area	Physical Oceanography (SAC)
G6.1	**Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE) (SAC)** Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE) Advance research is being carried out for assimilation of satellite derived parameters salinity, temperature, sea level, wave height, ocean color and wave spectrum) in ocean prediction models. This involves development of various assimilation techniques for improving the initial condition in the models. Apart from satellite data, lot of in situ measurements (glider, HF Radar, wave rider buoys etc.) are also being taken in the present. The outputs from these models are routinely available on the mosdac.gov.in through the "Ocean Eye" and disseminated on request through an automatized email based system. In order to identify gap areas in the current space based observing systems, observing system simulation experiments are performed for defining future sensor missions. This require intensive modelling and optimization techniques to ascertain the importance of satellite-based and in situ-based observations and to suggest optimum sensor characteristic. Model tuning by parameter estimation using data driven techniques (like AI/ML) can be an important step in improving the model simulations.	
G6.2	**High Resolution Oceanography (SAC)** In the view of high resolution (temporal and spatial) satellite observations from synthetic aperture radar, forthcoming Oceansat-3, Strengths, Weakness, Opportunities and Threats (SWOT) mission, and optical imageries, high resolution oceanography is fast becoming a reality. Synergistic use of these information will be key to understanding many unresolved processes at sub-mesoscale level, which can help in better ocean estimation. Interaction of mesoscale scale dynamics (eddies) with sub-mesoscale is another interesting area of research for energy cascading. Region specific high resolution models with relocatable grids are being utilized for this purpose.	
G6.3	**Ocean Reanalysis and Air Sea Interaction Studies (SAC)** One of the future goals is to develop a methodology to generate high quality three dimensional ocean reanalysis product for last 30 years based on satellite observations and numerical ocean model. This will be utilized not only for various oceanic process studies but also to initialize seasonal prediction coupled models. Some of the reanalysis fields that are currently being generated are of sea level, currents and chlorophyll. Research is also being carried out in generating merged products (like for e.g. SST) by combining observations from various Indian and International missions in order to provide continuous and gridded space-time observations for various applications and process studies. Efforts are also being carried out to generate high resolution salinity field from low resolution satellite observations using Lagrangian based techniques. These fields will be useful for fine scale process studies.	

G6.4	**Study on Coastal Dynamics Using Satellite and High Resolution Numerical Models (SAC)** Coastal dynamics are extremely important to understand as it has significant implications on coastal population. Currently following research topics are being envisaged in SAC: Storm surge and coastal inundation: In this component, numerical models and satellite data are used to simulate and forecast the storm surge and inundation along the Indian coasts during the event of cyclone. Impact of satellite derived winds is also studied. This activity will be further extended to generate vulnerability maps for Indian coasts due to storm surge inundation in the climate change scenario. Oil spill trajectory forecasting is extremely important for planning the mitigation steps in order to minimize the damage to the marine ecosystem due to an event of oil spill. Advection based models have been developed in house in order to identify the source of tar balls found on the beaches of various Indian coasts. Further research with high resolution satellite currents (from combination of SWOT and Oceansat-3) and introducing complexities in the trajectory models is being carried out. Finite time Lyapunov exponent (FTLE) fields derived from satellite currents are available on MOSDAC that help to forecast pathways of oil spill.	
G6.5	**Seasonal Ocean Prediction with Coupled Atmosphere-Ocean Models (SAC)** Forecast of anomalous oceanic conditions (Dipole/El Nino) at least one season in advance is of high importance as it has direct influence on the Indian Summer Monsoon. These seasonal to long term forecasts are required to be done by making synergistic use of satellite observations and couple Ocean Atmosphere models. Effect of satellite data assimilation on the skills of these forecasts are also required to be assessed. Regional Sea level rise is analyzed from the 36 years of altimeter observations and the mechanisms responsible for difference in Service-level Agreement (SLA) rise rates in different basins (Arabian Sea and Bay of Bengal) are being studied. One of the major challenges is the coastal sea level rise, for which the only source of observations are the tide gauge stations because of the non-availability of altimeter data near to the coast. Hence it is required to develop AI/ML based/dynamical techniques for interpolating/ downscaling sea level observations from altimeter to the coastal regions by making use of numerical models and tide gauge stations. This is an important activity which will further help in identification of vulnerable zones in the climate change scenario.	
G7	**Sub Area**	**Visualization of Earth Data & Archival System (VEDAS)**
G7.1	**Algorithms / Procedures for Time Series Visualization (SAC)** VEDAS is responsible for archival and dissemination of thematic data and data products available within SAC. Large amount of spatial time series data is collected over time and visualization of available spatiotemporal data is essential for exploring and understanding structures and patterns, and to identify unusual observations or hidden	

	patterns. However, the volume of data available and number of concurrent users that may be accessing the data challenges current time series map visualisation. The start and end time of episodic events or span of intensive observations may also be dynamic. So algorithms are required to be developed and modern techniques are required to be used for visualization of large spatio-temporal (ST) datasets ordered in time for animated mapping. This will be further used for exploring or monitoring unusual observations in large datasets like NDVI, snow, temperature, solar insolation etc.
G7.2	**Data Analytics and Knowledge Discovery (SAC)** To understand and appreciate a natural phenomenon and attach cause and effects to an evolution, there is a growing demand of rendering "on the fly" multi-layer information. There may be concurrent users accessing same set of data. So there is motivation to parallelize computation to improve turn around time of a service. The research initiatives will be useful steps towards achieving this goal. Design & Development of parallelizable algorithms for interactive geospatial data analysis with high temporal resolution. Design & Development of parallel execution frameworks and/or distributed computing libraries for geospatial data processing operations. Design and Development of scalable general purpose systems/algorithms for removing noise from spatiotemporal datasets. Design and Development of scalable general purpose systems/algorithms for predictive analytics from spatiotemporal datasets. Design and Development of data-mining algorithms for spatial-temporal datasets. Design and Development of scalable techniques for semantic segmentation of orthoimagery.
G7.3	**Super Resolution Image Generation (SAC)** Super Resolution is an Image Processing technique which is used to enhance the image resolution of scene from a number of lower resolution images of same area by reducing effects of noise in the reconstructed image. In case of satellite images, this can be seen as a powerful tool of getting high resolution multispectral images (spatial) from low resolution panchromatic images. This will facilitate improved (in spatial scale) Land cover for better natural resource management.
G7.4	**Web Enabled Sensor System for Efficient Resource Management (SAC)** There is need to develop a prototype and demonstrate the applicability of wealth of information that can be gathered by set of remotely located instruments. Instruments can measure the meteorological conditions as well as ambient conditions and transmit the data to a central hub. Air quality monitoring of a region is a one such example where measurements of PM2.5 and PM10, concentrations of target gases (NOx and SOx – for example), their dispersal (based on wind direction and speed), temperature and humidity are all required by administrators and managers to issue advisory and / or take pro-active preventive measures.

G8	Sub Area	Urban Studies (SAC)
G8.1	**Urban Feature Extraction (Road Network Delineation) (SAC)** Transportation networks such as roads and railway lines are important for several urban applications including disaster management, urban planning, impervious surface extraction, urban growth modelling etc. The automatic methods such as template matching, object-based classifiers and machine learning methods such as neural networks, support vector machines, deep learning etc. can be used to efficiently extract road network from very high-resolution optical and SAR images acquired by Indian Remote Sensing satellites.	
G8.2	**Urban Feature Extraction (Impervious Surface / Urban Area Mapping) (SAC)** The mapping of urban land cover remains a challenging task owing to the high spectral and spatial heterogeneity of urban environment. The accuracy of urban area extraction can be improved by combining multi-temporal, multiresolution and multi-sensor optical and SAR earth observation data.	
G8.3	**Urban Feature Extraction (3D Building Reconstruction) (SAC)** The 2D and 3D information of buildings and other urban structures are needed not only for impressive visualisation of urban areas, but also as an input in several urban applications like population estimation, roof-top solar energy potential assessment, visibility studies etc. Building extraction from high-resolution satellite images in urban areas is an intricate problem. Techniques are to be developed for automatic extraction of buildings from Very High Resolution optical data. The availability of very high-resolution imagery from Cartosat series data necessitates development of techniques and algorithms for 3D building reconstruction.	
G8.4	**Urban Heat Island (SAC)** Spatial and Temporal Distribution of Urban Heat Islands on Land Surface and Near Surface Atmosphere Development of models for deriving day-time and night-time air temperature from satellite-derived land surface temperature and vegetation indices can assist in identification and analysis of spatial and temporal distribution of urban heat islands. Impact of Land Cover Types on Urban Heat Islands The changes in land use-land cover pattern and declining vegetation cover in cities are predominant factors influencing the growth of urban heat islands in the cities. Satellite data derived land use land cover information can be compared with the temperature profiles to assess the impact of land cover on urban heat islands.	
G9	**Sub Area**	**Calibration and Validation (SAC)**
G9.1	**Optical Sensor Calibration (SAC)** • The optical sensor calibration exercise is performed by vicarious (absolute), relative and inter-sensor calibration methods. The absolute calibration is performed through simulation of top-ofAtmosphere radiance for calibration gain and offset calculation.	

	• For this purpose we developed ocean site at Kavaratti and land site at Little Rann of Kutch (partially campaign). In each aspect of operational methods are based on R&D carried out here • The relative sensor calibration exercise for radiometric performance monitoring is performed through land, ocean, snow and deep convective cloud targets • The sensor performance is also cross verified with contemporary sensors using synchronous nadir pass and its measurements. These exercises is performed by normalizing the central wavelength and out off band contribution in case of optical sensors • Radiative modeling of satellite sensor measured radiance though ground truth measurements • Periodic monitoring and updating of radiometric performance of optical sensor through terrestrial surface radiance measurement and model simulation • Radiometric performance monitoring using moon, deep convective clouds, desert and ocean sites for optical sensors (both high and coarser resolution)
G9.2	**Microwave Sensor Calibration (SAC)** • Synthetic Aperture Radar (SAR) radiometric calibration is one of the important aspects to characterize and maintain image quality throughout the mission and to provide stable, quantifiable image products to the users • Radiometric parameters of SAR sensors like sigma0, speckle index and radiometric resolution are monitored over invariant, distributed calibration targets like Amazon rainforest, Boreal forest, Antarctica for the data sets with same instrumental parameters (beam, polarization). This exercise is used to estimate noise equivalent sigma0 to ensure the data quality • Corner reflector based calibration is done to compute the impulse response parameters. A regular and systematic analysis helps to estimate the radiometric accuracy and stability using corner reflector based data • Monitoring of SAR instrument subsystem components is used to study gain variations or linearity • Generic software for estimation of calibration parameters using SAR images and orbital parameters over synchronized satellite pass with various Corner reflectors • A novel approach for Data quality evaluation of Scatterometer (OceanScat or upcoming mission ScatSat-1) is being worked out where one can relate the parameters available at different levels of product to geophysical parameters • Scatterometer calibration includes the monitoring of on-board calibration data to keep a check on transmitted power. Invariant sites like Amazon rainforest, Sahara Desert, Antarctic snow are required to be monitored regularly and time series of backscattered or brightness temperature can be generated to check the system behaviour

<table>
<tr><td>G9.3</td><td colspan="2">Geo-Physical Products Validation (SAC)
The most important exercise of validating sensor derived geo-physical products are done using community vetted matchup methodology and qualifying various data sets (in-situ, contemporary missions, climate data sets, data from various collaborative agencies, etc.)
Protocol development on measurements, instrument operation, quality control, and calibration standards
Inter-comparison of rainfall estimates measurements made by various ground based instruments like Micro Rain Radar, Disdrometer and rain-gauges over a validation site
Optimization of disdrometer/ rain-gauges distribution and number for addressing beam filling problem in validation of satellite derived rainfall estimates
Satellite derived geo-physical products plays an important role in making effective use of satellite data by various user community. These activities are achieved through partnership of collaborative agencies, autonomous measurement systems (land, ocean) and also through special measurement campaigns</td></tr>
<tr><td>H</td><td>Area</td><td>Remote Sensing Applications in Agriculture & Land Use / Land Cover (NRSC)</td></tr>
<tr><td>H1</td><td>Sub Area</td><td>Agriculture, Horticulture, Agro-ecosystem and Land Usestudies (NRSC)</td></tr>
<tr><td>H1.1</td><td colspan="2">Automation of Operational Land Use-Land Cover Mapping (NRSC)
Land use / land cover is being mapped at various levels using appropriate satellite data. Hybrid models comprising digital / visual interpretation were employed in the mapping process. LU/LC is mapped at various scales starting from 1:250000 to 1:4000, specifically addressing the requirements of strategic, tactical and operational level planning. Traditionally LU/LC is mapped using in-season ground truth by employing multi-temporal data to distinguish between land cover features and addressing seasonal variations. As scale map of mapping is dependent on the GSD of the sensor, appropriate data has to be used at respective scales. All the available data sets (multi-temporal, multi-sensor, multi-resolution) could be utilized for better accuracies. As filed data collection is labour intensive, ground-truth libraries / spectral libraries could be prepared, which intern could be provided as services. Many classes LU/LC like built-up, water, vegetation, snow / ice etc. could be derived using compatible multi-spectral / hyperspectral indices. Data from other sources like forest boundary etc. could be used to avoid misclassifications.

Automation of the digital models, incorporating traditional approaches as well as latest AI / ML techniques is required for faster and timely generation of this vital natural resource's information. As geo-referenced cadastral maps are available for vast parts of the country, training / testing / validation data could be prepared at cadastral level that can be used for producing LU/LC information at cadastral level. Vast amount of training data can be prepared by custom made mobile apps for collecting field data, which will go as input into the ML/DL models</td></tr>
</table>

H1.2	**Automation Operational Crop Mapping (NRSC)** Over the decades ISRO has developed methodologies and tools for of mapping cropped areas and institutionalized copped area mapping. Some of the notable achievements in this regard are Crop Acreage and Production Estimation (CAPE) based on sample segment approach and Forecasting Agricultural Areas using Space Agrometeorology and Land based observations (FASAL) based on complete enumeration. Even though both methodologies have fair bit of automation for mapping crops, their main focus has been on area estimates. There is great need for automation of mapping of various crops and operational products and services addressing the needs of decision makers. Development of techniques for automation of the crop mapping is essential to reduce the turn-around-time for processing and analysis satellite data to derive the crop map at regional / national level. Improved accuracies of crop map could be achieved with incorporation of data from multiple sources (satellite, aerial, UAV, field data) in the automation process. Several steps in the entire process chain in crop mapping could be automated for achieving partial / complete automation to achieve reasonable accuracy for crop land mapping. These steps include ingestion and corrections of remote sensing data; generation of training samples using field data; generation of spectral libraries/ vegetation indices using long term data; evaluation of different data analytic techniques like conventional per pixel, hierarchical, hybrid, AI /ML approaches; development of customized tools for automatic mapping of crop lands and accuracy assessment and continuous refinement / updating process of crop maps for different seasons. Both optical and SAR data can be considered for cropland mapping. Use of spectral profiles / libraries along with different vegetation indices in relation to crop phenology can be attempted for improved crop land mapping towards automation. Software modules/ tools can be developed to address each of the processing and analysis steps.
H1.3	**Surveillance of Pest and Diseases in Citrus Horticulture (NRSC)** Geospatial techniques comprising of remote sensing, GIS and GPS can play a vital role in management of citrus orchards in India. Citrus cultivation is plagued with various problems due to limiting growing conditions, limiting water resources and high occurrence of pests and diseases. Pest surveillance programs such as field scoutings are often expensive, time consuming, laborious and prone to error. As remote sensing gives a synoptic view of the area in a non-destructive and non-invasive way, this technology could be effective and provide timely information on occurrence and spatial variability of pest damage over a large area. Remote sensing (RS) of biotic stress is based on the assumption that stress interferes with photosynthesis and physical structure of the plant at tissue and canopy level, and thus affects the absorption of light energy and alters the reflectance spectrum. Citrus are susceptible to a number of destructive pest and diseases that are continuously emerging and which can severely limit production of a country.

	The use of multispectral and hyper spectral data along with spectro-radiometer data will help in surveillance of pest, diseases of citrus through geospatial analysis including AI/ML techniques in India. Thus, remote sensing can guide scouting efforts and crop protection advisory in a more precise and effective manner. With the recent advancements in the communication, aviation and space technology, there is a lot of potential for application of remote sensing technology in the field of pests and diseases management of citrus orchards.
H1.4	**Development of Yield Models for Citrus Horticulture (NRSC)** The successful prediction of crop yield was largely based on the ability of sensors or imagers to detect various canopy variables such as leaf area index (LAI), leaf chlorophyll content, or leaf nitrogen content, which each are significantly associated with crop yield. Previous studies on the application of remote sensing for yield estimation and mapping were mainly performed on field crops. Few studies on the usefulness of remote sensing of orchard crops have been reported. Yield modelling of citrus is one important aspect of citrus orchard management. Perennial crops exhibit greater variability in canopy structure and fruit yield than annual crops, and this is attributed to the internal mechanism of alternate bearing in individual plants. Field observations of citrus trees have shown that there is a wide variability in the numbers of new leaves and floral buds during the earlier growing seasons, as well as wide variability in fruit yield. The differences in canopy structure among trees during particular seasons may provide information related to their fruit production level. If particular spectral features of canopy structure detected by airborne hyperspectral imagery are found to be correlated with fruit yield, these canopy spectral features can be used to develop a programme of tree-specific application to improve horticultural profitability and minimize the impact on the environment. Presently, yield of citrus is declined in terms of quality and quantity due to biotic, abiotic, edaphic as well as various management factors in India. To improve the fruit quality by alternate bearing though pruning and thinning of fruit of selected tree and development of citrus yield modelling is essentially required using geospatial techniques. The use of multispectral, hyper spectral and UAV data will help in the development of yield modelling of citrus through geospatial analysis including AI/ML techniques in India.
H1.5	**Crop Health Assessment using Multispectral / Hyper Spectral UAV Data and Artificial Intelligence (NRSC)** Geospatial technologies plays a vital role in crop health assessment due to damage caused by pests and diseases as well as other natural hazards like floods, drought etc. Both Satellites (multispectral, hyperspectral and SAR data) and UAV based data can be effectively used for mapping as well as monitoring and assessment of crop damage. High resolution Multispectral / Hyperspectral data collected from space borne and UAV platforms along with GPS/DGPS data can play a vital role in crop health assessment. Machine learning (ML) / Deep Learning (DL) based classification algorithms can easily

	capture complex class signatures and are not affected by the distribution of data. Data of high spatial resolution can help in identifying crops at a smaller scale and helps in crop management, crop insurance in face of calamity, yield forecasts, etc. The agricultural food production is affected by incidences pests and diseases. The crop protection aims at reducing pests and diseases to at acceptable level with minimum environmental impact and health hazards. Hence, dissemination of near real time crop pests and disease information at early stage is very critical for the farmers to take an informed decision to take control / preventive measures. In this context, development of an integrated crop disease information system plays an important role in improved management of Agriculture. With the availability of high spatial, spectral and temporal resolution satellite / UAV images, weather data and IoT sensors along with advanced data analytics and cloud/edge techniques, it is possible to synergistically analyze multi-source information to generate near real-time spatial information on pests and disease. Main objectives of this research are: • Crop health assessment using multispectral / hyperspectral Satellite& UAV data using Artificial intelligence • Field level crop classification, crop damage assessment and yield estimation for crop insurance • Retrieval of relevant canopy parameters using multispectral/hyperspectral data and development of AI based disease prediction model • Designing and development of an AI enabled mobile and Web GIS application
H1.6	**Soil nutrient modelling for assessing the soil health and sustenance of soil fertility (NRSC)** Soil is an important natural resource for the future of Indian agriculture. The large-scale soil degradation in India is not getting public attention like floods, droughts, pest & diseases etc. However, in order to protect our degrading soils, regular monitoring of soils and fertility status is very critical. For understanding the role of different process, a budgetary approach offers good tool through analyzing the turnover of nutrients in the soil-plant system at different spatial scales. Nutrient balances / audits can provide an early indication of potential problems arising from a nutrient surplus leading to accumulation of nutrients or a deficit and depletion of soil nutrient reserves. It is very important to identifying the root cause as well as assessment of nutrient dynamics at field level, farm level and regional level. A holistic approach using nutrient budgeting model like NUTMON for analyzing the nutrient dynamics is required to monitor the status of soils and the strategies needed to sustain the fertility to explore the possibilities of increasing the crop productivity in environmentally sustainable way. The scope of the research includes a) development of Decision Support System for assessing the soil nutrient balance by considering nutrient dynamics from the agro ecosystem for regular assessment nutrient status at farm / regional level to evolve strategic decision on policy interventions and to provide agro-advisory services to the farming community

H1.7	**Climate Smart Agriculture Through Crop Simulation (NRSC)** Due to rapid population increase and accelerated rate of urbanization in developing countries, it becomes the most important challenge to ensure the food security of the world population in future. As per the future projection, by 2050 the world population will be around 10 billion with around 50% more demand for agricultural products. The challenge posed by the changing climate has further complicated the scenario. The input-intensive cultivation practices during last few decades lead to deforestation, depletion of ground water level, loss of soil fertility and emission of green-house gases etc. Hence, sustainable and climate adaptive agriculture towards increased crop production and productivity by conserving the natural resources, like forests, soil, water etc. should be the major focus. Climate smart agriculture (CSA) has evolved as the major paradigm for achieving the sustainable development goals in the agricultural system considering the impact of changing climate. The three major Objectives of CSA are: (i) Sustainable and equitable increases in agricultural productivity and incomes, (ii) Greater resilience of food systems and farming livelihoods, and (iii) Reduction or removal of Green-house gas (GHG) emissions associated with agriculture, where possible The CSA approach is in its early stage and implementations of the technologies or/and policies demand detailed understanding of trade-offs and synergies among them. Due to its limited assets and resources in developing countries, the selection of the technologies should be done judiciously to meet the multiple goals. The scope of the research includes (i) analyse the probable impacts of climate change on target crop using crop simulation models (CSM) under different climate scenarios, and (ii) evaluate the sustainable developmental plans by choosing the potential solutions towards climate smart agriculture (CSA) system.	
I	**Area**	**Water Resources (NRSC/NESAC/SAC)**
I1	**Sub Area**	**Hydrology (NRSC/SAC/NESAC)**
I1.1	**Rapid Flood Mapper (RFM) for Near Real Time Flood Mapping (NRSC)** Rapid dissemination of accurate information related to the extent of flood water, vulnerability and risk is essential for emergency response activities carried out by disaster management personnel. In recent years, cloud platforms like the Google Earth Engine (GEE) is widely used in numerous remote sensing applications. Proposal can be submitted for Development of a Cloud Based Rapid Flood Mapper (RFM), a Google Earth Engine based app that allows users to generate the flood maps quickly without any technical complexities. The app should perform various Machine Learning (ML) algorithms and statistical analysis for automatic detection of flood regions with generation of flood inundation maps, flood duration maps and damage reports.	

I1.2	**Automatic Detection of Wetlands for National Wetland Inventory and Assessment (SAC)** Regular Wetland inventory at national scale is important activity required by Ministry of Forest Environment and Climate Change. This involve development of automatic algorithm to delineate wetland and its type based on advanced techniques such as Deep learning/ machine learning etc.
I1.3	**Groundwater Assessment (SAC)** Assessment of ground water potential zone and its dynamics is important to regional water resource planning. There is need to develop hydrological model incorporating aquifer properties to simulate the infiltration and ground water variations in different hydrological regime. It is required to develop tools to relate the groundwater fluctuations with GRACE water equivalent height information, existing surface water components and groundwater recharge and abstraction scenario.
I1.4	**Flood Inundation Modeling and Forecast (SAC)** Extreme events are increasing due to global warming and it results in frequent floods in many rivers and urban areas. Satellite data helps in delineation of flood prone region but due to limitations of revisit period there are some gaps in observations. There is need to develop flood inundation modeling system using meteorological data, high resolution DEM and historical records of flood conditions for major flood region of India. Efforts are required to have weather forecasting coupled hydrological system (WRF HYDRO) for forecasting river discharge and water inundation of India.
I1.5	**Water Level and Discharge Modeling (SAC)** Monitoring Water level from space platform is important to augment existing ground network in remote and inaccessible regions including Trans-boundary rivers. There is need to develop advanced approach to estimate water level from Nadir Microwave as well as LIDAR based altimeters. Estimation of water velocity and discharge is challenge from remote sensing. Methods need to be developed to address Swath altimetry which consists of nadir altimeter as well as two SAR system working in interferometric mode (SWOT) to assess water height and inundation volumes simultaneously.
I1.6	**Water Quality Assessment (SAC)** Hyperspectral remote sensing is known to have potential to estimate some of the water quality parameters of river and reservoirs. It involves development of radiative transfer modeling and simulations. There is need to develop method and carryout model simulations to assess the water quality issues of important rivers like Ganga and Yamuna.
I1.7	**Isotope Hydrology (SAC)** Partitioning Evaporation and Transpiration in terrestrial vegetation is a concern. Hyperfine spectroscopy provides information on isotopic composition of water molecules. There is need to develop methods to estimate the evaporation and transpiration components of major forest ecosystem as such measurements help in more accurate assessment of water cycle and Land surface processes.

I1.8	**Submarine Ground Water Discharge (SGD) (SAC)** Quantification of water flow into ocean through sub marine ground water discharge is a challenge for Indian coast. Thermal remote sensing data provide initial signals of SGD in coastal region. There is need to explore the regions of SGD in Indian coast and model the discharge of water into the ocean.
I1.9	**Integrated Quantitative Understanding of the Change in Water Cycle due to Anthropogenic Activities (SAC)** How surface and ground water availability is changing in space and time along with science of changing water cycle which is accelerating/decelerating will be studied.
I1.10	**Hyperfine Hydrological Modelling to Address the Social Hydrology Involving Local Drivers of Change (SAC)** Hydrological modelling at high spatial resolution by ingesting detailed local information as well as climate projection to fulfill the societal needs.
I1.11	**Application of Oxygen and Hydrogen Isotopes to Understand Hydrological Processes (PRL)** There are complex hydrological processes which cannot be discerned by measuring volumes and fluxes of water across hydrological boundaries. Such processes are, for example, variation in vapour source for rainfall, evaporation from falling raindrop, continental recycling of water, surface water - groundwater interaction and exchange. These processes can be discerned by monitoring oxygen and hydrogen isotopic composition of water in different hydrological reservoirs such as groundwater, river water, rainwater, oceanwater and atmospheric water vapour. Spatio-temporal variation in isotopic composition of water in these hydrological reservoirs in conjunction with various geohydrological and hydrometeorological parameters can provide new insights in the hydrological processes. A Stable Isotope Ratio Mass Spectrometer laboratory set up under the National Programme on Isotope Fingerprinting of Waters of India (IWIN National Programme) is leading this long-term programme of isotopically characterizing water sources of India with a view to obtain new insights into hydrological processes. Some of the important scientific results from this research pertains to interaction between rain and vapour, relative contribution of vapour from the Arabian Sea and the Bay of Bengal, extent of evaporation from falling raindrops, identification of regions in which groundwaters do not seem to be recharged by freshwater during an annual cycle of groundwater hydrology.
I1.12	**Hydrological Modeling using Artificial Neural Network (NRSC)** Establishing the relationship between rainfall and runoff for a watershed is one of the most challenging problems faced by engineers. The relationship is found to be highly nonlinear and complex in nature. Artificial neural networks (ANN) can be an effective way of modeling the runoff process. An ANN is a flexible mathematical structure that is

	capable of identifying complex nonlinear relationships between input and output data sets. Proposal can be submitted for hydrograph modelling using ANN. The advantage of ANN technique is that it does not require the detailed knowledge of catchment characteristics; being a universal approximator establishes an empirical relationship between the input (rainfall) and output (runoff) on the basis of learning through the process of training of the neural network. In developing the ANN model, various combinations of causal meteorological parameters like precipitation, air temperatures, and potential evapotranspiration values can be used as inputs, and stream flow values can be obtained. The Study would be highly useful in Water Resource Management and Disaster Management
I1.13	**Dynamic Downscaling of General Circulation Model Outputs to Finer Spatial Resolution (NRSC)** The General Circulation Models (GCMs) provides projections of climate variables under different emission and socio-economic scenarios. They are designed to evaluate the behavior of the global climate system and are relatively effective at simulating climate characteristics like global temperature and broad circulation patterns. The coarse resolution GCMs severely limit the direct application of GCM output in regional and sub-regional analysis and decision-making. This limitation is particularly challenging in areas with diverse topography, land cover and drainage patterns, such as mountainous regions or by large lakes. At present, roughly 20 GCMs provide climate data for variables such as precipitation, temperature, relative humidity, down welling shortwave and long wave radiation, etc at 1-degree spatial resolution. Only few GCMs provide climate data projections at spatial resolution of <50 km. Over India, IITM, Pune provides high resolution climate simulations at ~35 km spatial resolution and products from COordinated Regional Downscaling EXperiment (CORDEX) are available at 0.22 degree and 0.44 degree (25 - 50 km) spatial resolution. The coarse resolution of these products severely limits the assessment of climate change impacts over small watersheds and administrative units (districts/ taluks/ blocks) in India. Dynamic Downscaling uses a Regional Climate Model (RCM) nested within a General Circulation Model to simulate patterns of climate at regional/ local scale. RCM is a finer resolution climate model that can simulate the effect of topography and land cover features at scales which is ignored or poorly represented in General Circulation Models. However, setting up RCM model representing local climate and its parameterization is a challenging task. Most of RCMs are limited to 25-50 km grid resolution which may not be optimum for small watersheds and relatively smaller administrative units such as districts/ blocks. There is a need to develop a downscaled climate variable database for India that would support climate change impact assessment studies at block/district level.

I1.14	**Early Season/In-season Crop Mapping for Irrigated Command Area using satellite Data with Single (one) Time Ground Truth (NRSC)** Land cover classification in remote sensing is often faced with the challenge of limited ground truth labels. Incorporating historical ground information has the potential to significantly lower the expensive cost associated with collecting ground truth and, more importantly, enable early and in-season crop mapping that is helpful to many pre-harvest decisions. To map crop types in the target year that has little or even no ground truth, several methods have been proposed to transfer historical knowledge by first training a classifier using historical labels and then applying it to the target year. These methods are known as "decision boundary-based approaches" because they attempted to transfer decision boundaries built from historical years to the target year. The underlying assumption for transferring decision boundaries is stable and consistent spectral features over time. However, this assumption is often violated, particularly for land cover types with rapid seasonal changes under cross-year scenarios because spectral features have both intra-annual variability and inter-annual variability due to changes in weather and crop progress. Therefore, transferring decision boundaries over time may lead to greater errors, especially to another year with different weather and management practices. This is true even with incorporating phenological features that are believed to reduce the impacts of intra- or inter-annual variability, thus existing methods often don't perform well in early- and in-season mappings. A time invariant pattern should be recognized for the classification of the crops. The topology (e.g. relative position) of the crop cluster in the feature space is observed to be time invariant by studies. Hence research is required to generate the crop clusters in feature space and identify the topology from historic ground truth and transfer it to target year.
I1.15	**Impact of Climate Change on Crop Water Requirement and Yield (NRSC)** Ball berry model relates concentration of CO_2, relative humidity and assimilation rate to stomata conductance. The model states that CO_2 is inversely proportional to stomata conductance whereas relative humidity and assimilation rate are directly proportional to stomata conductance. Hence it is expected that higher concentration of CO_2 in climate change scenarios leads to lower stomata conductance, hence lesser transpiration. This implies that with lesser water transpired, more yields can be expected as the concentration of CO_2 increases. Studies also states that with increase in temperature, crop water requirement will increase and hence leads to higher irrigation demand in the context of climate change. This calls for an in-depth analysis in the effect of increase in temperature and CO_2 on crop water requirement and irrigation water requirement in different climate change scenarios, which can be used in planning and management of irrigation systems.

I1.16	**Generation of Harmonized Water Layers Dataset using Data from Multiple Satellite Missions (NRSC)** Water is an essential component of the Earth and a vital resource in human life and production. The spatial and temporal distribution of water bodies has been changing due to climate change and human activities, and the global shortage of water resources is becoming increasingly severe. As a result, monitoring of water bodies is critical. Remote sensing, which has the advantages of real-time, comprehensive coverage, and rich information, has emerged as a reliable means of obtaining water-spread information quickly. The primary data sources for this application include optical and SAR sensors. A wide variety of techniques were developed for different types of sensors and platforms which can effectively delineate the water. Each of these techniques has its own advantages and disadvantages, with the accuracy of water delineation depending on many other factors (cloud/haze, floating vegetation, etc.). As this information is essential for the management of water resources, a reliable dataset is required to be generated which is comparable across the spatial and temporal domains irrespective of the source (sensor/platform) of the input data. This dataset can be generated at a monthly time step at a resolution of 30 m from 1990-2022. Machine learning and deep learning techniques are to be developed and trained to learn the patterns in the temporal variability in water spread information. These techniques may be used to generate/synthesize water layers in the absence of input data (Optical/SAR) with the help of temporal information already available and other ancillary information (precipitation, routed runoff, etc.) so that the gaps in the data can be minimized. Research is required to develop these algorithms.	
I1.17	**Precipitation Estimation (IIRS/ NESAC)** Better understanding of the spatial and temporal distribution of precipitation which is critical to climatic, hydrologic, and ecological applications.	
I2	**Sub Area**	**Marine Biology, Ecosystem & Related Activities (NESAC)**
I2.1	**Atmospheric Aerosol Research (SAC/ NESAC)** Algorithms for atmospheric aerosols using satellite over plain & hilly land and oceans, Aerosol transportation and climate studies.	
I2.2	**Bio-Optical Characterization of Estuaries, Brackish Water Lagoons and Coastal Wetlands (SAC)** Estuaries, lagoons and wetlands are important components of marine ecosystem, heavily influenced by anthropogenic activities and susceptible to climate change. These are categorized as optically complex waters (OCW). Challenging areas of research are • Accurate estimation of optically active components such as chlorophyll concentration, coloured dissolved organic matter (CDOM) absorption, total particulate matter and total suspended sediments in optically complex waters	

	• Development of atmospheric correction models for accurate estimation of remote sensing reflectances in OCW • Hyperspectral characterization of optical constituents in VIS-NIR region • AI –ML based techniques for retrieval of optical constituents in OCW
I2.3	**Biogeochemical Dynamics in Coastal–Estuarine Ecosystems (SAC)** Biogeochemical transformation and pathways of aquatic carbon in coastal, estuaries, lagoons and wetlands is an important area of research and use of ocean colour data along with in-situ observations in biogeochemical models are important for climate change studies. Some of the challenging areas are • Quantifying various components of the aquatic carbon in diverse marine ecosystems using ocean colour (Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), Dissolved Inorganic Carbon (DIC), Particulate Organic Carbon (POC), Phytoplankton C, Detritus C) • Quantifying nitrogen components of the aquatic system using remote sensing • Evaluating nutrient dynamics in estuarine- coastal regions using remote sensing • Modeling primary, new and export production from remote sensing
I2.4	**Marine Living Resource Management (SAC)** Climate change is profoundly effecting habitat, breeding and population dynamics of marine living resources. Some of the challenging areas of research in this field are • Habitat identification of endangered marine organism using geospatial information • Site suitability for mariculture using remotely derived parameters and in-situ observations in GIS based models • Ocean colour remote sensing in zooplankton, secondary production and tertiary production studies • Ocean colour remote sensing for microbial ecosystems • Habitats of large pelagics using remotely sensed parameters and fishery data
I2.5	**Biodiversity and Ecosystem Studies (SAC)** Climate change and global warming is rapidly effecting species biodiversity with native population replaced by few fast growing species and loss in biodiversity. Major areas of research are • Ocean colour remote sensing in biodiversity studies of micro and macroalgae of Indian marine waters • Optical and biological studies of harmful and beneficial algal blooms using remote sensing • Optical and biological characteristics of benthic ecosystems (Sea grass, Seaweeds, benthic microalgae)

	• Phytoplankton fluorescence and physiological studies • Impact of ocean acidification on biodiversity • Climate change studies on phytoplankton functional groups, size classes and ecosystem structure

J	Area	Aerial Remote Sensing UAV (NESAC)
J1	**Segmentation of Aerial / Satellite Data** Segmentation becomes more important with increasing spatial resolution of imagery. Texture in high-resolution aerial and high resolution satellite images requires substantial amendment in the conventional segmentation algorithms. The potential applications of this segmentation process are (1) Automatic 3D model generation (2) automatic DEM generation from DSM (3) Automation in Quality Checking of vector maps and many more.	
J2	**Design & Assembly of UAV Components-Payloads, Communication Components etc., UAV Data Acquisition, Processing, 3D Feature Capturing, Construction of 3D Surface Model/DEM, Automatic Object or Pattern Recognition (NESAC)**	
J3	**Development of Long Range Communication System for UAVs (NESAC)** Most of the commercial UAVs available today come with a communication range of 5-10 kms in clear line of sight. However for some applications like medicine delivery in remote/ disaster areas, river mapping/monitoring applications require long communication range 40-50 kms for real time transfer of telemetry and data. A low cost, low weight and range communication system will improve the capabilities of existing UAV systems.	
J4	**Development of Data Processing Software for High Volume UAV Data Processing (NESAC)** Processing of UAV data is a unique challenge due to its large volume. Few of the commercial softwares used for generation of complete data products such as DEM/DTM, 3D point cloud, contour maps etc are very costly and require high end systems. There is a need for developing in house data processing software using open source tools with end to end data processing capabilities which do not require very end computers.	
J5	**Real time UAV Data Processing for Disaster Monitoring Applications (NESAC)** Data acquired from UAV surveys is downloaded after the survey and processed in the lab. Due to the high volume of data, the processing takes lot of time and real time quantitative analysis from the data cannot be made. A real time data processing technique where data is downloaded to ground station in real time as the flight progresses and put into software where maps/models are generated simultaneously and automatically will be helpful for quick disaster response and assessment.	
J6	**Improvements in Battery Capacity used in UAVs (NESAC)** Lithium Polymer batteries are being used as source of electric power in the present UAV systems which gives a maximum flight endurance up to 1 hr with different combinations. It is required to develop low weight high capacity batteries to further improve upon the flight endurance of UAVs using different materials and techniques.	

J7	**Automatic Detection of tree Height, Leaf Area Index, Canopy etc. for Biomass Estimation (NESAC)** Developing models for UAV data processing for automatic detection of tree height, canopy etc.	
J8	**Tree Species Detection from LiDAR Waveform Data (NESAC)**	
K	**Area**	**Data Processing (NRSC)**
K1	**Sub Area**	**Advanced Image& Signal Processing using Remote sensing Satellite Data (NRSC)**
K1.1	**Advanced Sensor Models for Optical & Microwave Data Geo-referencing (NRSC)** Georeferencing is the process of assigning spatial location to each pixel of an image using sensor model or GCPs. Precise georeferencing is a major issue especially in high resolution optical and microwave imagery. Presently, rigorous sensor models and rational function models are widely used in optical imagery geo referencing. For microwave sensors the range Doppler method is generally employed for assigning precise geo-location. This method corrects the imagery for foreshortening and layover effects by utilizing the topology, orbit and velocity measurements from satellite and assigns a geolocation to each pixel. We welcome proposals that defines new methods/models and implementation of any of the above algorithms both for optical and microwave imagery	
K1.2	**Advanced Models for Satellite Data Pre-processing (NRSC)** The availability of remote sensing big data and cloud computing services provides new opportunities for the preprocessing, analysis, and visualization of satellite images. The preprocessing of data is a crucial step in the remote sensing analytical workflow and is often the most time consuming. This research shall focus on innovative high resolution image processing algorithms like image restoration, noise elimination, blur reduction and other quality improvements including advanced geometric correction models for satellite imagery.	
K1.3	**Automatic Image Registration (NRSC)** Image registration is an important image processing technique in remote sensing applications. It has been widely used in change detection, image fusion and other related areas. In order to integrate different kinds of sensor data and different temporal data, image registration is an indispensable preprocessing tool in integrating multi-source and multi-temporal images. In change detection process, the image registration accuracy directly influences the accuracy of change detection result. This research should cater to multi-temporal, multi-resolution and multi-spectral imagery registration with a specified accuracy for each category with a sub-pixel accuracy, similarly for co-registration of multi-data and multi-frequency SAR data for time-series analysis.	

K1.4	**Bundle Block Adjustment of Aerial/Satellite Imagery (NRSC)** A technique development for operational bundle adjustment of large number of satelliteimagery. This should cater to the multi-resolution, multi-temporaland multi view angle satellite imagery and should make use of a distributed processing environment including the state-of-the-artcomputing architecture.
K1.5	**Techniques for Multi-Date, Multi-View Angle Data Mosaics Generation with Radiometry Normalization (NRSC)** Generation of district level, state level, country level mosaics require usage of multi-data, multi-view angle HR sensors data. Hence, to meet the requirements of radiometrically and geometrically seamless mosaic, good registration and radiometric normalization techniques are to be developed for handling the high-resolution data. Solutions are invited to address the radiometry harmonization for generating seamless radiometry country level mosaic using sub-meter data.
K1.6	**New Advanced Techniques for High Resolution Imagery Processing (NRSC)** High-resolution satellites with stereo and tri-stereo capabilities have been implemented to satisfy the increasing need for higher accuracy and larger area coverage for digital model production. These recent advances in sensor technology and algorithm development enable the use of HR remote sensing imagery for development of various products such as DTM/DEM and DSM, orthophoto and orthophotomosaics, three-dimensional photogrammetric models. The application fields are increasingly developing from landslide and landfill monitoring to archaeological applications, monitoring an active volcanic area, morphological studies and so on. Independent of application, each product must be validated in order to define the metric level of precision and accuracy. In fact, high and very-high resolution images are affected by deformation mainly due to camera distortions and acquisition geometry, then they must undergo a geometric rectification process in order to be used for metrical purposes. Development of algorithms for DSM/DEM/DTM extraction from High resolution satellite stereo imagery and their validation. Development of New open-source based advanced solutions for multi high resolution imagery automated geometric processing using bundle adjustment. • Development of cutting edge multi resolution, multi temporal Multi spectral and hyper spectral data harmonization techniques, advanced image processing algorithms for restoration and de-noising • Development of algorithm for DSM/DEM/DTM extraction from high resolution satellite stereo imagery and their validation • Development of new open-source based advanced solution for multi high resolution imagery automated geometric processing using bundle adjustment • Deep neutral network for Remote sensing Application

K1.7	**Signal and Image Processing Solutions for Remote Sensing Images (NRSC)** Remote Sensing data can be multidimensional signals, multispectral, hyperspectral images radar data, Time series and video sequence. Efficient data analytic in these signals is crucial in order to exploit all historical archives as well as the newly acquired observations in near real-time. The applications are vast including numerous Environmental monitoring tasks, agriculture, safety, security, Engineering, etc. fields. Using Signal and Image Processing for Remote Sensing, development of the cutting edge multi-resolution, multi-temporal multispectral and hyperspectral data harmonization techniques, advanced image processing algorithms for restoration and de-noising. Signal processing for SAR interferometric pair for generation of coherence, change detection and analysis, Generation of Digital Elevation models.
K1.8	**Atmospheric Correction Procedures Implementation for Visible, NIR & HySi (NRSC)** Atmospheric correction is a key image processing step to retrieve surface reflectance values from spectra recorded by remote sensing space borne sensors. This further helps in standardizing physical variables, thus facilitating comparisons across time series of such variables. Presently, Atmospheric correction of all bands of Resourcesat-2 AWIFS and LISS III sensors is being carried out utilizing water vapor, ozone data products from MODIS, Aerosol optical depth from INSAT satellites using 6S RTF algorithm. The atmospheric correction has improved our estimation of normalized difference vegetation index by a factor of 50% with respect to TOA. There are possibilities of improving these estimations further by modelling the Bidirectional reflectance distribution functions, using reflectance references from Drones or physics-based models. We invite proposals in any of these areas that aim to minimize the influence of atmospheric effects in estimation of physical variables.
K1.9	**Development of Techniques of Hyper Spectral Analysis for EO and Planetary Applications (NRSC)** Hyperspectral sensing is a method of extracting information about an object or scene in narrow spectral band using imaging spectroscopy. Since the object or scene is imaged in narrow bands of wavelengths the neighboring pixel values are highly correlated. Further the imaging condition plays a vital role in extracting the end members for specific application such as crop clarification, mineral mapping and urban scene analysis, A range of hyper spectral sensors are flown by ISRO namely, Hyper spectral imaging camera of ISRO (HySi-ISRO) is flown on IMS-1 and Chandrayan-1 having spectral range from 0.4 to 0.9 micro meters at 10nm spectral resolution Chandrayan-2 mission Imaging Infra-Red Spectrometer for studying mineral mapping on moon. The present challenges facing the hyperspectral imagery processing and analysis being(i) data fusion, (ii) spectral unmixing, (iii)Data Reduction, (iv) fast computing and (v) data mining.

K1.10	**DEM Generation by Processing Cartosat-1 Forward and Reverse Pitch Mode Acquired Quadruplet Data (NRSC)** Cartosat-1 satellite has collected the data over entire India in all the possible modes, i.e., forward pitch, Reverse pitch and wide swath mono modes. The forward and reverse pitch stereo viewing offers stereo pairs with +/-5 deg, +/-26 deg viewing angles. CartoDEM has been generated by processing stereo data. This proposal invites solutions for generation of the DEM by processing the quadruplet data to improve the elevation accuracy. Also development of techniques for generation of DTM from the DSM obtained.	
K2	**Sub Area**	**Time Series Data and Image Analysis (NRSC)**
K2.1	**Algorithms for Time Series Analysis of Satellite Data (NRSC)** National Remote Sensing Centre has been archiving all remote sensing data right fromIRS-1A mission of ISRO till date. The datasets have all the characteristics that may constitute a time series and hence is a good resource for long term studies related to climate change and change detection etc. One of the possible applications of a time series data is to build models for forecasting. Statistical Methods such as ARIMA and GARCH are popular in predicting time series but they are far from satisfactory in terms of precision. Recent developments in machine learning algorithms and its use in regression and classification problems have paved a way of their use in forecasting time series. We invite proposals that incorporate the state-of-the-art algorithms for remote sensing applications, characterization of sensors and reconstruction of data.	
K2.2	**Generation of Time Series Data Stack from Medium Multi Resolution IRS and non-IRS Sensors (NRSC)** An accurate Inter sensor harmonization techniques are required using hybrid approaches and ML techniques for surface reflectance from IRS to achieve interoperability with foreign sensors. There does not exist any model for operational output for Indian region. Calibrated backscatter SAR data will be put in the stack to overcome the limitations of Optical sensor. This research shall focus to generate a time series surface reflectance stack of fixed resolution for land use Land cover monitoring for India and surroundings. This study will open up huge number of Artificial intelligence and deep learning application for land and Ocean applications. For Many thematic applications, it is the need of the hour, especially for agriculture, horticulture, Ocean applications. All the Resourcesat series data, Oceansat series data and RISAT series data will be used and On-Demand Data services can be built on NRSC Bhoonidhi portal. SAR Analysis Ready Data (ARD) data cubes for multi-frequency, multi-polarization theme specific data for Ecosystem, solid earth, Cryosphere, soil moisture, Coastal and ocean applications.	
K2.3	**Hyper Spectral Image Analysis (NRSC)** Modern hyperspectral imaging systems produce huge datasets potentially conveying a great abundance of information; such a resource, however, poses many challenges in the analysis and interpretation of these data. This research intends to development of techniques of hyper spectral analysis for EO and planetary applications.	

K3	Sub Area	Hardware Acceleration of Data Processing Algorithms (NRSC)
K3.1	**Reed Solomon Decoding Software Development for Satellite Data (NRSC)** Satellite communication channels are subject to channel noise, and thus errors may be introduced during transmission from the source to a receiver. Error detection techniques allow detecting such errors, while error correction enables reconstruction of the original data. Reed Solomon decoding algorithm is one of the error correcting algorithms to correct the received data with errors. Different formats of RS decoding standard algorithms are available like (247.253), (223,255) These things work in two modes one in CCSDS format and the other in traditional standard mode. Because of huge volume of satellite data and large mathematical computation it is time consuming to decode the data by using the traditional methods of Reed Solomon decoding algorithm. Hence there is a need for the high-speed implementation of the same. The requirement is the parallelism of a reed Solomon algorithm in General purpose graphic processing unit (GPGPU) and by parallel approach in Central processing Unit (CPU).	
K3.2	**Development of High Speed CCSDS Image Compression/Decompression Technique (NRSC)** The CCSDS has established a recommended standard for a data compression/ decompression algorithm applied to two-dimensional digital spatial image data from payload instruments and to specify how this compressed data shall be formatted into segments to enable decompression at the receiving end. The steps followed can be briefed as: performing an image de-correlating operation (DWT) and then encoding the coefficients in various stages in order to obtain the compressed image. The compressed image had to be decoded with the knowledge of segment header. Rate regulation needs to be done in order to adjust the compression rate. The decoded coefficient are correlated back (inverse DWT) to get the reconstructed satellite image. All the future Cartosat missions follow the CCSDS image compression/decompression technique and there is a need for the high-speed implementation of the same. The requirement is the implementation of all the compression and decompression steps using General purpose graphics processing unit (GPGP) and CUDA software.	
K3.3	**Firmware Development for Higher Level Satellite Data Processing (NRSC)** Study of multi-spectral data fusion techniques, suitability of technique, based on type of data inputs and implementation in FPGA hardware for near real time data processing for value added product generation. To develop identified image fusion algorithm and enhancement in hardware descriptive language (Verilog) simulation and verifying the result, in FPGA using Altera Quartus software. This will facilitate the reduction in Tum around Time (TAT) for value Added Product generation along with the automation in processing.	

K4	Sub Area	Distributed Workflow Management (NRSC)
K4.1	**Autonomous Multi Agent Job Scheduling Algorithms for Distributed Systems (NRSC)** Large scale processing and knowledge extraction from data requires execution of complex workflow in distributed environment. A generic workflow needed to be evolved for collaborative computing among the resources to obtain maximum throughputs from the systems. Development of (i) Multi agent system architecture for processing date in a distributed network environment (ii) Models of multi agent communications (iii) schemes for automatic configuration of agents based on the dynamics of real time jobs scheduling and (iv) Resource optimization algorithms to improve the processing timelines	
K5	**Sub Area**	**Web GIS, Payload Programming & Data Dissemination (NRSC)**
K5.1	**Data Dissemination & Web GIS (NRSC)** With an ever-increasing wealth of earth science data produced from various sources and platforms including earth observation, modelling and forecasts, the opportunities to exploit such vast amounts of data to produce valuable information products are challenging and exciting. These data are widely used for monitoring, simulation and analysis of measurements that are associated with physical, chemical and biological phenomena across the ocean, atmosphere and land. The capabilities to share geospatial data and information products to meet the need of varying levels of users is accomplished through Web GIS, which is an architectural approach, for implementing a modern GIS. It is powered by web services that deliver data and capabilities as well as connect components. It can be implemented in the cloud,on-premises, or more typically as a hybrid combination of the two, leveraging the best of both worlds. The following research areas facilitates to provide solutions for user community. • Augmented Reality • Indoor Mapping with WiFI/Bluetooth • Passive GIS sync and social media • Sensor wed with uniform Resource identifier • Open-source data centre computing • Geo intelligence (Quality score, categorization) for crowd sourced information • Trend Analysis on time series thematic Data	
K5.2	**Tools development in payload programming for the effective utilization of satellites (NRSC)** Development of tools to address the following parameters: • Auto cloud cover Estimation • Multi mission pay load proposal generator	

	• Weather integration for all future satellites while planning This research shall address to automatically assess the cloud cover for the optical high-resolution satellites. The module will be run along with the level-0 operations so that automatically the cloud cover is updated and stored. This will reduce the load on browsing and also help in future planning. Methodology will be developed to assess the cloud cover for high resolution sensors. At present we have implemented successfully for Resrourcesat-2& Resourcesat-2A kind of satellites. Development of methodology and implementation in the payload planning system, so that the weather information will be made useful while planning future collects. Software for Weather information integration in Pass programming for all future satellites while planning. This will be useful in optimal utilization of satellites during emergencies, when the user needs data from any satellite that is possible.	
K6	**Sub Area**	**Calibration and Validation (NRSC)**
K6.1	**Establishment of Automatic Ground Truth Collection for Vicarious Calibration of Optical Sensors (NRSC)** Currently, NRSC established IN-HOUSE CAL SITE, which caters Optical/Microwave calibration with a good scope. The vicarious calibration using this site is being carried out by manually collecting the Ground truth by Spectroradiometer, Microtops AOD, Ozone and Water Vapour. The site w.r.t optical targets is well characterized geometrically and for its spatial invariance. To meet the global standard and Joint ventures, automation of Ground Truth is very critical. Hence in this agenda, we are proposing to deploy permanent instruments in the site and monitoring remotely from Lab for further utilization in the analysis and computation of Radiometric Calibration coefficients. This enables to make the site with global standards in joining with the international group of sites.	
K6.2	**Development of Thermal Data Calibration and Validation (NRSC)** With the experience of optical data calibration where 6S RT code is well used, we would propose to develop Thermal data calibration (8-14 MICRO) using MODTRAN RT code. Currently 6S RT is supporting up to 2.5 microns atmospheric modelling. THERMAL DATA CALIBRATION is aimed for both UAV and Space based systems in this proposal using MODTRAN.ATMOSPHERIC Transmittance, upwelling and down welling radiance will be modelled for the 8-14 micro wavelength range using synchronous ground measurements. Identification of natural targets or developing artificial targets based on the resolutions under study, which are suitable for calibration is also a critical task.	

K7	Sub Area	Software Engineering (NRSC)
K7.1	**Software Reliability Modelling and Metrics (NRSC)** There is a need to develop automated tools to extract different metrics from various software packages developed by ISRO to estimate their reliability and predict, if possible, the failure rates from the version history. Time, near real time, post processing, work flow software and distributed software. Develop customized metrics for different types of software packages including real time, near real time, post processing, workflow software and distributed software. Develop algorithms for estimating the software reliability numbers and predictive models for forecasting the failure conditions.	
K8	**Sub Area**	**Machine Learning and Deep Learning usage for Remote Sensing Data (NRSC)**
K8.1	**Deep Neural Network for Remote Sensing data (NRSC)** In recent years, several types of remotely sensed data, e.g., optical multi-spectral and hyper spectral image, Synthetic Aperture Rader (SAR) and in many cases with extensive time series are increasingly available. All these remotely sensed data is motivating the development of large repositories and, most importantly, the development of advanced methods and algorithms for data analysis and processing. On the other hand, Deep Neural Network (DNN), Commonly called Deep Learning (DL) models are showing very high potential in recognition of spatial and temporal patterns in a wide range of remotely sensed application (e.g in scene classification, object detection, spectral un-mixing, Spatial super-resolution, pixel classification, dimensionality reduction etc.) providing a great variety of algorithms, procedures and models under different learning strategies(supervised, un-supervised, semi supervised). In particular convolutional Neural Network (CNNs) a type of DNNs currently constitutes the state-of-the-art in image classification objects detection and instance segmentation. Generative adversarial networks (GAN) are showing promising results in the mapping of terrestrial surface and in super resolution problems. Recurrent Neural Networks (RNNS) are also showing good results in identifying patterns in time series and in forecasting meteorological events. However, due to the huge number of parameters that need to be learned by DL models, The complex nature of DL models, The complexity of Remotely sensed data itself (e.g high Dimensionality) and the lack of labeled data sets, these approaches must deal with important problems, which can lead to inadequate generalization and loss of accuracy. Analyzing multi-band images acquired from diverse sensors using one or a combination of several Deep Learning models, solution to be implemented for Remote sensing Image classification for Land use/ Land cover mapping image construction/ Image restoration by Image Learning. By using SAR polarimetric data, suitable Deep learning techniques for training polarimetric SAR data for realizing SAR based Land and Ocean applications.	

K8.2	**Automatic Feature Extraction from High Resolution Data using Deep Learning Techniques (NRSC)** The objective of the study is to automatic feature extraction from high resolution data using deep learning techniques. The objective is to train deep learning models using transfer (Unet - Segnet) to identify features like buildings roads and trees in an image, based on their spatial and spectral properties. The scope of the work is to develop algorithms to extract automatically features from high resolution remote sensing data. Automatic feature extraction for different classes of land use/landcover from high resolution data for change detection and in real time for disaster applications. Automatic feature extraction from High resolution SAR data for different thematic classes for Land use/Land cover, ship, ship wakes, oil slicks etc., using deep learning techniques.	
K8.3	**A Unified Time Series-Based Cloud Database Using Cloud Identification Using Deep Learning Method on Satellite Imagery for Cloud Tracking, Satellite Data Planning and weather Application (NRSC)** Accurate Inter sensor harmonization techniques are required using hybrid approaches and ML techniques for surface reflectance from IRS to achieve interoperability with foreign sensors. There does not exist any model for operational output for Indian region. Calibrated backscatter SAR data will be put in the stack to overcome the limitations of Optical sensor This research is intended to generate cloud data from various satellites and store it in a unified geospatial database for satellite data planning, cloud tracking and weather applications.	
K8.4	**Learning Based Data Ingest for Faster Accessing from Tape Library (NRSC)** NRSC has a huge volume of satellite data in the order of petabytes archived over the years. All this data is stored in a Hierarchical Management Solution comprising disk and tape-based storage solutions. The data is spanned across disk and tape storage as per the policies defined. User requests correspond to data products of different sensors comprising various resolutions and types, and different acquisition times. Data ingest to the data processing chain happens immediately for the data available on disk storage, whereas for the data available on tape storage there is an inherent latency directly linked with the drive availability at that point in time. An algorithm is required to be designed to understand the patterns of user requests in detail, predict and pre-fetch the data from archives in order to make it available for ready ingest even in the case of very old legacy data. The algorithm should analyze the user requests based on the knowledge gathered over a period of time w.r.t. sensor, resolution, type, and acquisition times.	
K9	**Sub Area**	**Cloud Computing and Big Data (NRSC/IIRS)**
K9.1	**Cloud Computing (NRSC)** NRSC is having huge data archive amounting to petabytes acquired over the year's right from 1988. Moreover, with operational satellites of RISAT series, upcoming satellites like	

	GISAT that will be down linking data 24*7 of the tune of 5-6 TB per day, data and metadata storage, cataloguing and search becomes a daunting challenge. Processing Online on cloud computing infrastructure for quick archival and retrieval of remote sensing data utilizing lossless data compression techniques. Generation of super resolution image with multi temporal low resolution in high resolution images.	
K9.2	**Algorithms for knowledge extraction from big data (NRSC)** Large volumes of data that cannot be stored in normal relational databases are being generated every day from the remote sensing satellites. Many software elements extract information from the raw data generating information in unstructured form suchas images, log files, user orders in pdf, word etc. There is a need for developing efficient data mining algorithms to tag the data sets for facilitating efficient buildup of archival and retrieval. In general data mining algorithms work on data sets that are of reasonable size and cannot handle BIG data. • Develop parallel algorithms for mining the classification rules to facilitate data archival in an optical manner • Develop mining algorithms that are Incremental and can learn and unlearn from the continuous satellite data acquisitions • Develop algorithms for extracting meaningful trends in the customer ordering, build customer satisfaction index, predict the future sales or potential sensors or popular products etc.	
L	**Area**	**Bhuvan (NRSC)**
L1	**Digital Twin Infrastructure (NRSC)** With increasing number of foreign cities developing their own digital twin for analysing mobilization (infrastructure) and urban growth, localized weather data (temp., wind, radiance, rainfall) and any relevant local IOT data. This aims to create a framework for creating such digital twin models for Indian cities with secure data sharing mechanism across collaborators.	
L2	**Drone Data Standards and Analytics (NRSC)** As a result of several government policies in the geospatial sector and programmes like SVAMITVA, there is an increase in the availability of drone data across the country. However, there is a need to have a standard on how this data is collected, maintained and processed for several national applications. Thus, we need to improve the research of standards and applications in the following areas: • Development of data ingestion and data processing of drone over cloud • Change detection using drone data	

	• Drone data processing for web application and spatial analysis • Extraction of 3D foot prints from LIDAR/Stereo data
L3	**POI Language Translation (NRSC)** Conversation of POI/vector data to respective regional languages using NLP or any other conversion standards. Language detection from images and text extraction/Translation.
L4	**Development of Social Indices from Geospatial Inputs (https://www.opportunityatlas.org/) (NRSC)** Social indicators are set of indicators that measure progress towards the policy objectives designed for promoting employment, combating poverty, improving living and working conditions, combating exclusion, developing human resources, etc.Location is a key factor that affects these social indicators. Factors determining these different policy objectives need to be spatially mapped to compare and objectively measure the developments in different regions of the country. These indicators and their factors can be further analysed to determine the challenges to improve the quality of life.
L5	**Geospatial Network Analysis Platform (NRSC)** Network Analysis plays an important part in city planning, resource optimisation and disaster management. There is a need to develop an integrated tool to analyse different spatial networks and interactions between different spatial layers. The following tools can be developed • Point-to-point analysis • Coverage Analysis • FleetOptimizing Analysis • Optimal Site Selection • Multiple Origin-Destination – (OD) Cost Matrix Analysis
L6	**Geo-intelligence to Collect Crowd Sourced Information (NRSC)** Crowd sourcing refers to enlisting the help of a large group of people for data collection. People may submit text message-based questionnaires or report incidents within a specific app. For example, people with grievances about water quality can report visible pollution by submitting photos online or on an app.
L7	**Radiometric Normalization for Generating Very High Resolution Satellite Country Mosaic (NRSC)** The very high resolution satellite data country mosaic is essential for various earth observation web portal, which will be used as base layer, feature digitization, feature extraction and to get the view synaptic view of terrain. The challenge in generating these country mosaic includes planimetric accuracy, maintaining feature continuity across the region and also radiometrically balanced image. The latter has great complexity as it involves generating mosaic using images which are acquired during various seasons and varied years.

	Radiometric normalization among images is considered necessary for remote sensing applications. Radiometric normalization generally refers to reducing the differences between images in time series or mosaics and is required to remove radiometric distortions and to make the images comparable. Radiometric consistency is hard to maintain between separate adjacent images since the images used are generally acquired at different times and with different methods, atmospheric conditions, variations in the solar illumination angles, and sensor calibration trends. Radiometric normalization of multi-temporal satellite image is very important for change detection or generating image mosaics. In the literature there are various radiometric normalization methods include histogram normalization, matching and IHS based normalization method. Also, there are methods like 'bundle' radiometric normalization methods are available in literature and COTS packages. However, these methods are inadequate while generating very high resolution satellite country mosaic. Hence, there is requirement to make robust radiometric normalization methods.	
L8	**On the Fly Contrast Enhancement on Earth Observation Portals (NRSC)** The goal of contrast enhancement is to improve interpretability of image. The Earth observation portals provides satellite data for visualization and feature extraction. Traditionally most of web portal pre-enhances the images and provides the enhanced images for visualization, which reduces the load (processing time) on the client. Contrast enhancement methods like localized contrast methods are well suited for web portal requirement. However, as these images are pre-enhanced and these not suitable for further improvement by users. Alternatively there are mechanism where enhancements was carried out client side. There many methods in literature to do contrast enhancement. The challenging is reduce the processing time on the client to improve the rendering. Hence, there requirement to develop new contrast enhancement methods with improves processing time at client.	
M	**Area**	**Satellite Data Reception & Ingest Systems Area (SDRISA) (NRSC)**
M1	**3D Modelling, Structural Analysis & Design of X-Y Tracking Pedestal (NRSC)** 3D Modelling, Structural analysis & design of X-Y tracking pedestal suitable for 7.5M diameter parabolic reflector with Cassegrain feed arrangement (for both aluminium and Carbon fibre material) with full hemispherical coverage. The antenna has to track LEO satellites from 300 KM orbit onwards to receive data in X band from 8.0 to 8.4 GHz frequency with an operating wind conditions up to 60 KMPH and wind gust up to 80 KMPH.	

M2

Design of Low Noise Amplifiers for Satellite Data Reception Ground Stations (NRSC)

In satellite ground station applications, the Low-Noise Amplifier (LNA) is an important RF component for good figure of merit of antenna system. Low noise figure of amplifier improves the effective C/No of the weak RF signals. In the receive chain, the first amplifier after the antenna contributes the most to the system noise figure. RF low-noise amplifiers (RF LNAs) are designed to increase the desired RF signal amplitude without adding distortion or noise. The target Noise temperature and gain parameters to be achieved are as below:

Specifications	**X-band**	**Ka-band**
Frequency range	7950MHz to 8550MHz	25500 MHz to 27000 MHz
Gain	50 dB over the band	40-50 dB over the band
Noise temperature	50°K @ room temperature	150°K @ room temperature
Input port	Waveguide WR112	Waveguide WR34
Output port	Coaxial SMA	Coaxial 2.92 or Waveguide WR34
Power Supply	+15V DC	+15V DC

M3

Design of HMIC/MMIC Based Coaxial Digital Phase Shifters (NRSC)

Phase shifter is a two-port device, whose basic function is to provide a change in the phase of the signal with practically negligible attenuation. Phase shifters are broadly classified according to their medium and mechanism of phase control i.e., Ferrite and PIN diode-based phase shifters, analog and digital phase shifters. A Digital phase shifter generally consists of cascade of several phase bits with phase shifts incremented in binary steps. For example: In a 'n' bit 360° phase shifter, the entire range of 0° to 360° is covered by 2^n steps. The size of the smallest phase bit is $(360°/2^n)$ degrees and that of the largest phase bit is 180°. Our required target specification is design of DIGITAL Phase shifter with 6 to 8 bit control and negligible loss (Gain if possible) for S-band (2.2 to 2.3GHz), X-band (7.8 to 8.5 GHz) and Ka band (25.5 to 27 GHz)

M4

Design of RF Components: Isolators, Mixers, Coaxial Switches, RF Amplifiers, Power Dividers, etc. (NRSC)

These active and passive RF components are utilized for development of RF systems (viz. Up-converters, down-converters, translators, etc.) in ground station for data reception. The target frequency range is for S-band (2.0 to 2.3 GHz), X-band (7.8 to 8.5GHz) and Ka band (25.5 to 27 GHz) within good insertion loss and return loss characteristics.

M5

Design of Modular / Compact Down-converter for S and X-band (NRSC)

The requirement is for the design of compact down-converters with good phase noise synthesizers using MMIC based surface mount components. They can be digitally tuned for different frequencies required. The target specification for S-band down-converter input frequency range is 2.2 to 2.3GHz and output is 70MHz. Similarly for X-band down-converter input frequency range is 7.8 to 8.5GHz and output is 720 +/- 320 MHz.

M6	**Design of Modular Frequency Synthesizers (NRSC)** Frequency Synthesizers shall be designed to provide Local Oscillator signal for up/down conversion of received RF signals in S,X and Ka band. These synthesizers shall be developed with good phase noise, and output power with the provision for tuning to any frequency in the specified range.
M7	**IF Matrix using SMD Technology (NRSC)** Solid State switches realized with MEM technology and good isolation greater than 60 dB , programmable gain in the path of the " Non – Blocking" IF Matrix can be designed and developed for ground station applications.
M8	**Development of Coding & Decoding Algorithms (NRSC)** Different channel coding schemes like LDPC 7/8, Convolution decoding, 4D-TCM employed in Remote sensing Satellites shall be considered for development of IP core and portability in FPGS based hardware.
M9	**FPGS based Hardware (NRSC)** FPGA Hardware catering to the need of Algorithm Realization for multiple requirements viz., Carrier Recovery, Clock Recovery, Coding Schemes etc. of different Modulation/Demodulation Schemes of M-PSK with necessary interfaces shall be designed and developed.
M10	**Design & Development of NAVIC based Ground Receiver for Ground Station Timing Systems (NRSC)** Currently Ground Data Reception systems are employed with GPS based Timing systems. As NavIC has now become fully functional, it's time to move from GPS based GNSS to NavIC prime GNSS for the Ground station Timing systems. The development of a dual-band (L5 and S) NavIC receiver for precise timing applications includes the design of a RF front end circuit and an AGC which carries out the signal conditioning and down conversion of the NavIC RF signals to IF. The baseband circuit, based on FPGAs, carries out the demodulation of the navigation data. Timing information extraction circuitry from the NavIC signal needs to be implemented for IRIG- G/B/A output formats, 1PPS Input/output and 10MHz clock input/output.
M11	**Study of suitable Materials / Design Approach and Innovative Manufacturing Methodology for large CFRP Reflectors for Future Tri axis-Tri band Ground Station Antenna Systems (NRSC)** When the ground station antenna is to be designed for data reception in higher frequencies. The selection of materials for reflectors plays a major role. The material must be such that the surface profile is not affected under any weather conditions while in operation, as any change in surface profile accuracy affects the overall gain of the antenna system. The surface profile accuracy is affected by thermal gradient in conventional aluminium reflectors. As an alternative to this it is proposed to use composite material such as CFRP for making the antenna reflectors that offer high Specific strength, high specific weight and low coefficient of thermal expansion without any compromise on RF properties.

N	Area	Remote Sensing Applications in Forestry, Biodiversity and Environment (NRSC/NESAC)
N1	Sub Area	Forestry and Ecology (NRSC)
N1.1		**Terrestrial Biodiversity and Wildlife Management (NRSC)** Terrestrial wildlife species viability is dependent upon maintaining a mix of vegetation quantity, quality, and distribution (habitat). Vegetation change, both natural and human-caused, and human use of the land are the major influences on terrestrial wildlife. Spatial characteristics of landscapes—such as fragmentation, patch size distribution, and connectivity—are largely determined by management actions and their interactions with natural disturbances such as fire, insects and disease. The landscapes of the Ecogroup represent diverse, highly complex systems that have been affected by many factors, including the interaction of soils, aspect, elevation, climate, and disturbance. The geospatial techniques have been effectively used in the field of ecology, biodiversity, conservation and wildlife management. Western Ghats is considered a global biodiversity hotspot, harboring rich flora and fauna including luxuriant vegetation compositions under major forest types. Natural ecosystems of Western Ghats are subject to a number of threats that vary widely in the nature and intensity of their impacts on biodiversity. Human-wildlife conflict, corridors for wildlife movement, loss of wildlife habitat ranges, poaching, forest fires, invasive plant species along with monoculture of commercial plantations, and climate change are among the major ecological concerns for this region. Remotely sensed imageries can help to identify both suitable habitat for individual species, and environmental and terrain conditions that foster species richness. The scope of the research includes a) Spatio-temporal analysis of protected areas using multi-source information and data analytics b) Identification and mapping of grassland /pastures for assessment of food and fodder availability for wildlife c) Comparative assessment of protected areas within Biosphere reserves of Western Ghats using Dynamic Habitat Indices (d) Evaluation of wildlife habitat ranges / territories and their carrying capacity
N1.2		**Biophysical Parameter Retrieval and Species Identification using High Resolution and Hyperspectral Data sets in Different Forest Ecosystems in India (NRSC)** Remote sensing has demonstrated wide applicability in the area of estimating and mapping forest physical and structural features as well as species identification. Focus in recent years has been directed towards measuring the biophysical/physiological character of forest ecosystems in order to estimate and predict forest ecosystem health, composition and sustainability. Multispectral data has long been used for vegetation type classification however hyperspectral data with narrow bands has provided with opportunities to attempt for species level mapping, improved forest type maps and also the vegetation biophysical parameter retrieval. High spectral resolution remote sensing data has the potential to measure vegetation red-edge parameters, deriving leaf area index and identifying forest species and stand parameters which are crucial for sustainable forest management plans and biodiversity conservations. Hyperspectral

	data at medium resolution are subjected to mixed pixel effects due to mixing of the species at this resolution and subpixel level analysis remains a challenging task for species level classification. The proposed topics focus on hyperspectral data application for Biophysical parameter retrieval and forest vegetation species detection towards biodiversity characterization using Hyperspectral Remote Sensing. The proposed study will attempt the derivation of biophysical and species level identification in two different ecosystems in India i.e. mangrove, evergreen and deciduous ecosystems. Mangrove forests are considered as critical coastal ecosystems and these continue to be threatened by both natural and anthropogenic factors. Since the forests are often unreachable for field data collection, remote sensing becomes an important tool for characterizing the mangroves, their structure and quantifying the benefits that these provide in terms of carbon sequestration. Application of different machine learning approaches for the estimation of different biophysical properties of three different forest ecosystems i.e. mangroves, deciduous and evergreen forests using high resolution and hyperspectral satellite data. Monitoring of the forest species composition using the outperforming algorithm(s).	
O	**Area**	**Remote Sensing, Signal and Image Processing and Software Development (NRSC/NESAC)**
O1	**Sub Area**	**Virtual Reality, Machine Learning (NRSC)**
O1.1	**Virtual Reality Applications in Geospatial Domain (NRSC)** Virtual Reality (VR) technology has come of age in the past few years and holds a lot of potential when used in conjugation with Geospatial data. The VR devices currently available offer unprecedented realism due to the 6 degrees-of-freedom that they offer along with high resolution Head Mounted Displays (HMDs) and hand-held controllers. While this technology is actively being used in entertainment and gaming sectors, it could be a game changer in the way Geospatial data is visualized and interpreted. A generalized Virtual Reality platform can be developed to explore 3D data from multifarious sources ranging from Lidar scans and CAD to photogrammetric models created using data from UAVs and terrestrial photographs. The technology can also be used for accurate measurements and simulations in the virtual world and when compounded with the latest concepts like Digital Twins, it is perfectly poised to become a very useful tool of the future. There is a lot of scope to research and implement the use of Virtual Reality in GeoSpatial domain for data visualization, measurements and simulation as well as training for endeavors such as Human Space Flight.	
O2	**Sub Area**	**Image Processing (SAC/ IIRS/ NESAC)**
O2.1	**Automatic Extraction of 3D City Models using LIDAR/ Satellite/UAV data (IIRS/ NESAC)** Algorithm for automatic classification of point cloud from Lidar dat to create 3D CITY model	

O2.2	**3D surface Modelling and Features Capturing of UAV/UAS data (NESAC)** Development of efficient model for extraction of 3D surface from UAV/UAS data	
O3	**Sub Area**	**Development of Image Processing Algorithms**
O3.1	**Hyper Spectral Image Analysis (NESAC)** Development of techniques of hyper spectral analysis for EO and planetary applications	
O3.2	**Techniques for Multi-date data Registration and Mosaicing (SAC/NRSC/ IIRS/ NESAC)** To develop a model for automatic detection of tie points for registration and mosaicking multi date satellite images considering the difficult terrain like NER	
O3.3	**Techniques for Geospatial Data Analysis (SAC/ NRSC/ IIRS/ NESAC)**	
O3.4	**Atmospheric Correction Procedures Implementation for Visible & NIR & HySI (SAC/ NRSC/ IIRS/ NESAC)** Develop new model for atmospheric correction of satellite data in regional/local scalez	
O3.5	**PolInSAR based Semi-empirical Modelling for Forest Aboveground Biomass Estimation (IIRS/ NESAC)** Improving above biomass estimation empirical models of PolInSAR data for undulating terrain.	
O3.6	**Semi-empirical Modelling for Forest Biophysical Characterization using PolSAR Data (IIRS / NESAC)** Developing model for very high-density forest in NER. Developing robust model of parameter retrieval in highly undulating terrain condition	
O3.7	**SAR Calibration and Attenuation Measurement using Triangular Trihedral Corner Reflectors for RISAT-1 Data (IIRS)**	
O3.8	**Characterization of Opencast Mining Areas using Various Polarimetric Decomposition Techniques (IIRS / NESAC)** Developing classification keys/feature classes and characterization of opencast mining prevailing in NER using different polarimetric decomposition techniques.	
O3.9	**Urban Feature/Metallic extraction using Fully Polarimetric Data (IIRS/ NESAC)** Exploring usability of high resolution polarimetric data for Urban feature identification/ extraction.	
O4	**SubArea**	**DataMining (NRSC/IIRS/SAC)**
O4.1	**Algorithms for Knowledge Extraction from Big Data (NRSC/SAC/NESAC)** Large volumes of data that cannot be stored in normal relational databases are being generated every day from the remote sensing satellites. Many software elements extract information from the raw data generating information in unstructured form such as images, log files, user orders in pdf, word etc. There is a need for developing efficient data mining algorithms to tag the data sets for facilitating efficient build up of archival and retrieval. • In general data mining algorithms work on data sets that are of reasonable size and cannot handle BIG data	

	• Develop Parallel Algorithms for mining the classification rules to facilitate data archival in an optimal manner • Develop mining algorithms that are Incremental and can learn and unlearn from the continuous satellite data acquisitions Develop algorithms for extracting meaningful trends in the customer ordering, build customer satisfaction index, predict the future sales or potential sensors or popular products etc.,	
P	**Area**	**Disaster Management (ISTRAC/NRSC/SAC)**
P1	**Sub Area**	**Generation of Lightning Vulnerability Maps (NRSC)**
P1.1	Atmospheric Lightning is a natural disaster having the highest mortality rate world-wide among all the natural disasters. When the lightning struck to an establishment, lot of property damage also occur which is not well documented over India. For disaster management and mitigation, it is important to identify the vulnerable zones. The vulnerable area needs further check with the help of ground reality. A reliable time-unbiased mapping of cloud to ground lightning flashes is important from this perspective. Using the NRSC-LDS network, the vulnerability maps can be generated which can be utilized for the disaster management and public awareness. The objectives of this research are as follows: • Generation of vulnerability maps state-wise and district-wise • Ground-truth data collection for checking the vulnerability maps • Preparation of public awareness program by suggesting the precautionary steps	
P1.2	**Forecasting the Cloud to Ground Lightning Occurrences (NRSC)** Cloud to ground lightning is a major natural disaster which is expected to double with every two degree warming of earth. It is there understood that forecasting the cloud to ground lightning would become an essential aspect of disaster mitigation. The data assimilation and forecasting may be based on numerical weather prediction, machine learning methods or precursor prediction. The key objectives of this research are as follows. • Identify the best schemes possible for the lightning forecasting • Use of machine learning methods for now casting of the lightning • Identification of the precursors for lightning and forecasting the precursors	
P2	**Sub Area**	**Precipitation Now casting & Forecasting (ISTRAC)**
P2.1	**Weather Radar Now Casting Model for Indian Region using Multi Sensor Data (ISTRAC)** A variety of radar-based precipitation now casting techniques can be developed based on assumptions we make regarding precipitation field characteristics. In recent years, the massive amount of existing data has aroused research interest in data driven machine	

	learning techniques for now casting. By taking advantage of available historical data, data-driven based approaches have shown better performance than classical ones in many forecasting tasks. Furthermore, while classical machine learning techniques rely on handcrafted features and domain knowledge, deep learning techniques automatize the extraction of those features. The weather radar network in India is extensive. These data when combined with satellite as well as ground truth sensors like LPM/rain gauge can provide a robust real time now casting of precipitation. The aim of this proposal is to build a robust and accurate Now casting model that is best suited for Indian terrain, by leveraging multi sensor data available.	
P2.2	**Prediction of Extreme Precipitation Events Over Indian Region using Doppler Weather Radar Data Assimilation (ISTRAC)** In recent times Indian subcontinent is experiencing increased frequency of extreme precipitation events. This severe weather condition causes heavy damage to both life and property. For skillful forecasting and giving warnings at the right time, development of regional Numerical Weather Prediction model (NWP) is needed. Difficulty in obtaining accurate observations may results in improper forecast modeling, which in turn gives false predictions. Assimilation of weather radar data has exciting potential for improving forecasts from operational NWP models. This study aims to investigate the effect of assimilation of Doppler weather radar data in Weather Research Forecasting (WRF) numerical model for the prediction of heavy rain events in Indian region.	
P3	**Sub Area**	**Flash Flood Prediction Model Development (ISTRAC)**
P3.1	**Flash Flood Prediction using Multi Sensor Data Fusion (ISTRAC)** The primary goal of the Flash Flood Prediction project is to improve the accuracy, timing, and specificity of flash flood warnings in India, thus saving lives and protecting infrastructure. Flash floods tend to be associated with many types of storms, all capable of producing excessive rainfall amounts over a particular area, so detection remains a challenge. Sometimes a flash flood threat is overshadowed by other severe weather events happening at the same time. The main tools used to detect heavy rainfall associated with flash floods are satellite, lightning observing systems, radar, and rain gauges. Radar can show the location of the intense rainfall cores, and estimate the duration of rainfall. Radar can also track the evolution of storm systems over time. Forecasters are able to watch existing storm cells intensify, and see when new cells begin to develop. Rain gauges provide the most accurate method of measuring rainfall at a single geographic point. Estimates of rainfall from satellite data are less direct and less accurate than either gauges or radar, but have the advantage of high resolution and complete coverage over oceans, mountainous regions, and sparsely populated areas where other sources of rainfall data are not available. Since flash flood events often originate with heavy rainfall in sparsely instrumented areas that can go undetected, satellite-derived rainfall can be a critical tool for identifying hazards from smaller-scale rainfall and flood events. The aim is to develop a flash flood prediction model that provides high resolution and accurate flood forecasting for Indian & Regional terrain by ingesting data from our existing weather sensors network situated all over India.	

P3.2	**Automated RFI Interference Detection Algorithm and its Mitigation in Weather Radar Network (ISTRAC)** Weather radar data are commonly compromised by interference from external sources mostly at C-Band frequency. Similar is the situation in C-Band weather radars in India also. An algorithm development for RFI classification with respect to the severity and duration of RFIs is still a long way as far as Indian radars are concerned. The efficient and objective detection and removal of external radio frequency (RF) transmitters that disturb radar data is an on-going and time consuming challenge. The removal of an RFI source is essential, because the raw meteorological information gets masked by an external interference and cannot be properly recovered. This is especially true for quantitative products derived by fully automatic algorithms. Up to date there is no algorithm available which can separate the meteorological signal from a superimposed RFI signal in the raw radar data (IQ data) on the radar signal processor. On the other hand, algorithms to identify RFI signatures in the derived radar moments do exists and are in most cases somewhat able to increase data quality by applying strict filter methods. The current work will focus on to generate an automated way of detection of RFI interference and its mitigation for improved data output.	
P3.3	**Weather Radar Data and Distributed Hydrological Modeling: An Application for South Indian Region (ISTRAC)** The frequent occurrence of exceptionally very heavy rainfall in South India during the summer causes flash floods in many areas and major economic losses. A key element to mitigate the flash flood hazards is the implementation of an early warning system with the ability to process the necessary information in the shortest possible time, in order to increase structural and non-structural resilience in flood prone regions. The real-time estimation of rainfall is essential for the implementation of such systems and the use of remote sensing instruments that feed the operational rainfall-runoff hydrological models is becoming of increasing importance worldwide. However, in some countries such as India, the application of such technology for operational purposes is still in its infancy. The main goal is to examine the feasibility of the use of remote sensing instruments and establish a methodology to predict the runoff in real time in urban river basins with complex topography, to increase the resilience of the areas affected by annual floods.	
P4	**Sub Area**	**Optimizing Radar-Based Rainfall Estimation Using Machine Learning Models (ISTRAC)**
P4.1	Weather radar research has produced numerous radar-based rainfall estimators based on climate, rainfall intensity, a variety of ground-truthing instruments and sensors (e.g., rain gauges,disdrometers), and techniques. Although each research direction gives improvement, their collective application in an operational sense still yields uncertainty	

	in rainfall estimation at times. This study aims to explore the concept of implementing Machine Learning (ML) models in optimizing the radar-based rainfall estimations at the bin level from a group of estimator. In this study, benefit of Machine Learning (ML) to optimize the radar-based rainfall estimation from a group of estimators at the radar bin level will be developed.	
P4.2	**Algorithms for Advanced Aviation Products from Weather Radar (ISTRAC)** Aviation safety is one of the main applications where weather radars play an important role. The pilots should have advance information of Hail and lightning, Turbulence and wind shear. The study aims at developing advanced algorithms for aviation meteorology using weather radar data.	
P4.3	**Classification of Rain Types using Machine Learning based on Disdrometer and Cloud Observations (ISTRAC)** Rain microstructures parameters assessed by disdrometers ar commonly used to classify rain into convective and stratiform. Current study will aim to combine disdrometer observations combined with cloud observation to construct a set of clear convective ad stratiform intervals. ML based classification method provide a concrete and flexible procedure that will be regardless of the geographical location or the device.	
P5	**Sub Area**	**Digital Beam Forming Algorithm Development (ISTRAC)**
P5.1	**MIMO based RADAR Beam Forming (ISTRAC)** MIMO technique is based on transmitting different orthogonal signals from different antenna elements, where the signals can be separated on receiver with matched filters and processed independently. Continuous illumination of the whole area - transmit beam covers the whole area of interest at once where field of view (FOV) is equal to field of regard (FOR). Study and simulation of MIMO based adaptive beam forming for collocated coherent MIMO RADAR and MIMO Virtual Array simulation to improve SNR and angular resolution. Simulation and design of optimum orthogonal Waveforms and Transmit beam forming. Computation complexity analysis and optimization of signal processing algorithms shall be proposed.	
P5.2	**Development of FPGA based Real Time Adaptive Beam Former (ISTRAC)** The adaptive beam forming algorithms like Bartlett, SLL suppression, Maximum likelihood, MVDR, MPDR, MUSIC, RDBS and MMSE for SIMO and MIMO should be implemented in FPGA for real time applications. Real time DOA estimation and angle tracking. Real-time Adaptive weight computation and updating. True-time delay Beam forming and wide band beam forming. Simultaneous orthogonal waveform Generation and Tx Beam forming System. Matrix inversion using QR Decomposition and back substitution to be implemented in FPGA.	

<table>
<tr><td rowspan="1">P5.3</td><td colspan="2">
Development of Massive MIMO Digital Beam Forming Techniques with Quantum Computing (ISTRAC)

Beam forming provides provisions for adaptively altering amplitude and phase to contribute to power variation and beam steering or null steering in the intended directions. To be more specific, the digital beam forming processor has the potential to produce multiple independent beams that are capable of being directed in any given direction.

Using the same number of RF chains is necessary for large MIMO hardware implementation. The required number of radio frequency (RF) chains for a feasible 100x100 planar array arrangement that uses dipole antennas is impossible.

Any classical computing algorithm or circuit can be converted into Quantum Computing Circuit by simply replacing every NAND gate with a Toffler gate (CCNOT gate) of Quantum logic.

Physical development of Quantum Processing Unit (QPU) also exhibited promising results. Aim is to develop suitable 100x100 digital beam forming arrays based on classical or sparse signal processing techniques and shall transfer the same into a Quantum Computing Processing algorithm.

This project will also investigate the potential for the developed Quantum Beam forming Algorithm and attempt the architecture to be realized in physical hardware for an array of 8x8 structures.
</td></tr>
<tr><td>P6</td><td>Sub Area</td><td>GaN based SSPA with MMIC Technology (ISTRAC)</td></tr>
<tr><td>P6.1</td><td colspan="2">
GaN based SSPA with MMIC Technology (ISTRAC)

GaAs and GaN based Monolithic Microwave Integrated Circuits (MMICs) technologies and discrete devices are being utilized for the design & realization of amplifier circuits. At the lower end of frequency spectrum, at UHF to C-band, availability of GaN technology is offering newer breakthrough in realizing the power amplifiers.

In the future, solid-state technology could allow engineers to overcome common drawbacks of traditional GaAs IC amplifier with GaN for higher efficiency and power output.

Till date all weather radar transmitters were developed with high power amplifier tubes and commissioned and recent trends are phased array weather radar where active antennas are designed with high power low weight with reduced size to accommodate all as a Line replaceable unit.

Weather Radars are working in UHF,VHF, L , C,X, Ka band. ISTRAC is looking for GaN based power amplifier design in CAD tool and analysis for ready for fabrication ready model on a certain fabrication process technology with MMIC technology based GaN power amplifier with the following.
</td></tr>
</table>

	• High-power and high-efficiency designs typically utilize a reactive matching network to obtain a large-signal impedance match of the high-electron-mobility transistors (HEMTs) employed in the circuit • When designing a matching network in a large and densely routed HPA MMIC, extensive coupling of neighboring structures as well as other distributed effects can dominate the RF-response of the network • Interstate matching networks (ISMN), where complex impedance is matched to another complex impedance	
P7	**Sub Area**	**Polarimetric Phased Array Weather Radar (ISTRAC)**
P7.1	**Development of Polarimetric Calibration Process and Optimized Scanning strategy for Phased Array Weather Radar (ISTRAC)** Phased array radar (PAR) technology is being considered as one of the candidates for the next generation of weather-surveillance radars. The unique capabilities of this technology can potentially enable enhanced weather-surveillance strategies that could increase the quality and timeliness of weather radar products, ultimately improving severe-weather warnings and forecasts. Phased-array system employing electronic beam steering exhibit different co-polar and cross-polar antenna radiation patterns for each steering angle, and require a different set of calibration parameters for each. Demonstration of various calibration procedure and optimized scan strategy for weather surveillance to meet goals of Phased Array Weather Radar is needed. It shall include required Polarimetric weather radar data generation, simulation and test results.	
P8	**Sub Area**	**Neural Network Based Now casting Model Development (ISTRAC)**
P8.1	**Edge Inference and Validation of Neural Network Based Now casting models using FPGA (ISTRAC)** The exploration of deep learning techniques in radar-based now casting has begun, and the potential to overcome the limitations of standard tracking and extrapolation techniques has become apparent. Some of the existing NN Based Now casting models include Rain-Net, Deep mind Now casting, SmaAT –Net, MSDM model. After the implementation of NN models using the frame works available, these needs are to be implemented using FPGAs. The main approach of this work is to find an existing framework that takes as input a high level description of a trained neural network and generates a synthesizable accelerator which can be run on an FPGA (Xilinx Versal AI Engine).The end goal is near real time inference of now casting model from real time weather data.	
P9	**Sub Area**	**Precipitation Monitoring and Validation of Doppler Weather Radar (DWR) Data (ISTRAC)**
P9.1	**Development of Quality Control Algorithm for data of Optical Disdrometer in High Wind Speed and Gusting Condition (ISTRAC)** Optical laser disdrometers constitute a very important tool for measuring surface precipitation properties. It is capable to estimate not only the rainfall amount and intensity, but also the number, size and velocity of the falling drops. However, these	

	observations are affected by various sources of error being some of them related to environmental conditions like high wind, gusting etc. This work will focus on making the disdrometer observation free from all these errors. Radar Development Area (RDA) of ISTRAC has already deployed 15 laser disdrometer in various parts of the country. The quality output from these in-situ measurements is a must as it will be utilized for validation of Doppler Weather Radar (DWR) Data.	
P10	**Sub Area**	**High Power Transmitter (ISTRAC)**
P10.1	**Computational Modeling for Ground Potential Rise (ISTRAC)** High voltage or high current subsystems are part of any high power transmitting radar. Earthing is essential for a safe and reliable power system. Methods to improve radar subsystem grounding with supporting measurements of earth resistance, and computational models to simulate the possible Ground Potential Rise (GPR) due to injected current surges are of particular interest. The main objective of the project work is to develop a reliable computational model for the impedance of insulation earthing mats and the distribution of the surface potential that occurs when a power frequency fault current is injected into the earthing system. The initial effort is to verify its performance. Computational model can be tested with experimental results and also Earthling Standards and standard literature formulas available. Extensive work can be carried out to study the effect of the surface potentials in and around the earthing system when comparing with the computer software computations. Secondary effort can be on study of the potential distribution due to the insertion of a local high resistivity barrier can be carried out. The purpose of using local high resistivity is to skew the potential contours, so the earth potential rise immediately beyond the barrier can be reduced. As the power frequency current can penetrate very deep into the ground, the effectiveness of the high resistivity barrier needs to be examined. Effects of barrier geometry under various system conditions can be analyzed. Both solid barrier and barrier made of plates with various spacing's of gaps can be tested and modeled in the computational software.	
P10.2	**Sustainable Materials for HV Applications (ISTRAC)** Electrical generation and distribution equipment employs both liquid and solid materials within subsystems. New materials to replace those currently used, which are less detrimental to the environment both in service and at the point of disposal. The project can be divided in two parts, dealing with liquids and solids. The first part of the project deals with liquid insulation systems. Liquids are used both as an insulator and a coolant in many items of high voltage plant including cables, transformers and switchgear. However, the current oil employed in almost all of these applications is mineral oil which is toxic to the environment and comes from a non-renewable source (crude oil). They have been thermally aged under different atmospheres (ranging from	

	air to nitrogen) to simulate equipment conditions, and their ageing behavior has been characterized by a variety of optical and electrical techniques. The various available oils have been successfully ranked in terms of their ability to withstand ageing and suitable biodegradable oils for use in existing plant have been recommended. Proposed work concerns optimizing and improving, through the use of additives and blending, their ageing resistance for 70 KV applications. The second part of the project deals with solid insulation systems. Currently, the majority of solid power cables employ cross-linked polyethylene (XLPE) which has excellent thermal, mechanical and electrical properties but is not easily recycled and hence its use poses serious disposal problems. To replace XLPE, both ethylene and propylene based alternatives have been proposed which have the advantage of being recyclable after use. Proposed work is to focus on alternative on optimizing the mechanical, thermal and electrical properties through suitable choice of material and processing conditions for at 70 KV applications..	
P11	**Sub Area**	**METASURFACE (ISTRAC)**
P11.1	Met surface apertures have been developed as a type of holographic antenna, using met material elements to form a hologram excited by a feed wave acting as a reference. The overall radiation pattern of the aperture is then the superposition of the radiation from each element. Externally tunable components, such as liquid crystal or diodes, can change the response of each element independently by shifting the resonance. Tuning each element allows the overall aperture's response to be dynamically reconfigured, enabling the rapid creation of arbitrary radiation patterns, including steerable, directive beams. High efficiency, low side lobe, dual polarized with low cross-polarization met surface antenna array design in large scale is proposed for wide scan angle with minimum steering loss for radar application.	
P12	**Sub Area**	**Conformal Array (ISTRAC)**
P12.1	Conformal Array will be used for multi-satellite tracking & telemetry, conformal array digital beam forming & adaptive array signal processing to be carried out for receiving telemetry data from multiple satellite. To improve SINR various array signal processing techniques like MVDR, MPDR, MUSIC & RDBS to be performed on conformal array	
P13	**Sub Area**	**Wind Profiler (ISTRAC)**
P13.1	**Atmospheric Turbulence through Boundary Layer Wind Profiler Measurements (ISTRAC)** The boundary layer is defined as that part of the atmosphere that directly feels the effect of the earth's surface. Its depth can range from just a few meters to several kilometers depending on the local meteorology. Turbulence is generated in the boundary layer as the wind blows over the earth's surface and by thermals, such as those rising from land as it is heated by the sun, but also thermals associated with clouds. All this turbulence redistributes heat, moisture and the drag on the wind within the boundary layer, as well	

	as pollutants and other constituents of the atmosphere. In so doing it plays a crucial role in modulating the weather (temperature, humidity, wind strength, air quality, etc.) as we experience it, living on the surface. The strength of turbulent mixing is extremely variable and understanding that variability is a key aspect of boundary layer research. Much of this is modulated through interactions with the surface and so close links are maintained with those working on Surface and sub-surface processes. Much of our research shall involve the use of very high resolution numerical modeling of the boundary layer like Large Eddy Model which allows us to explore sensitivities and so improve understanding.
P13.2	**Boundary Layer Characterization (ISTRAC)** The boundary layer is defined by the presence of mixing that couples the air to the underlying surface on a time scale of less than a few hours. improving the understanding and representation of the earth surface and boundary layer interactions in both weather and Climate models, and dispersion models especially as it relates to water, air chemistry, greenhouse gas processes and predictions. Air quality predictions and alerts, plume dispersion forecasts -smoke, fire weather, dusts, and volcanic eruptions. Plume Dispersion Research and Development - Hysplit predictions are sensitive to boundary layer parameters such as the vertical profiles turbulence as well as the local atmospheric stability. Air Quality Forecasts, especially urban areas - Air quality predictions are not only sensitive to boundary layer parameters such as the vertical profiles turbulence but to profiles of humidity, temperature and radiation levels. Long Term Climate Observations - Long-term and sustained climate observations such as surface air temperature and precipitation are key signatures of atmospheric process and interactions in the boundary layer, including max/min air temperature, precipitation rates, and soil moisture/temperature. Regional Mesonets and Applications - A coupling of modeling and measurements provide a platform to increase understanding of PBL dynamics, with attention to particular aspects of atmospheric fluid flow that impact the transport and dispersion of pollutants. Urban Mesonet - The urban boundary layer is the part of the atmosphere in which most people live, and yet is one of the most complex and least understood microclimates, especially when it comes to modeling.
P13.3	**Surface-Atmosphere Exchange and Feedback (ISTRAC)** The Boundary Layer is the most dynamic in Earth's atmosphere as a result of constant exchange and interactions with the land/water surface. This interface, where the exchanges of energy, momentum, moisture, gases, and aerosols take place, is where weather and climate begin. The exchanges of heat and water vapor between the land and atmosphere are largely driven by the surface radiation budget, a combination of incoming and outgoing short and long wave radiation. Understanding the processes and environmental variables that control surface-atmosphere exchanges, and translating this understanding into more accurate model parameterizations, is a vital research activity that will lead to improved weather, climate and air quality predictions. In particular,

	surface-atmosphere exchange rates of reactive nitrogen (nitrogen oxides and ammonia) are highly uncertain and difficult to model, even though these species serve important roles in the formation of air pollution, and their removal back to the Earth's surface can have harmful environmental consequences.	
Q	**Area**	**Satellite Data Reception and Ground Station (ISTRAC)**
Q1	**Sub Area**	**Design and Development of Antenna Mechanical System (ISTRAC)**
Q1.1	**Development of Carbon Fiber Composite Parabolic Reflector for Large Antennas (ISTRAC)** In general, TTC support antennas have parabolic reflector made of aluminum alloy panels. These panels, which are stretch formed aluminum sheets, are aligned to match with its theoretical profile. Adjustment during assembly demands skill and high end instruments like LASER tracker and consumes lot of time. New generation reflectors made of Carbon Fiber Re-Enforced Polymer (CFRP) will be lighter in weight and stiffer against external loads in comparison with aluminum reflectors. Due to their higher interface tolerances, it takes lesser time for assembly, lighter counterweights for its balancing. Its higher specific stiffness and specific strength improves the surface accuracy and pointing accuracy of antenna. Scope of development involves design and analysis of CFRP parabolic reflector incorporating the ribbed/isogrid/honeycomb sandwich panels for large sized antennas (≥ 11m diameter of reflector).	
Q1.2	**Graphene Based Antenna Reflectors for Higher Frequency Bands (ISTRAC)** Graphene, a Two-Dimensional allotrope of Carbon, exhibits high mechanical strength (strongest known material) and high electrical conductivity. Carbon fiber reinforced Polymer(CFRP) can be coated with graphene in order to increase not only its strength but also its surface accuracy and reflectivity. Reflectors for higher frequency band antennas (Ka and above) demand stringent surface accuracy and pointing accuracy which is largely affected by stiffness of reflector. Graphene coating has been proven to increase strength of CFRP and can be employed on antenna reflectors too. Scope of development involves design and analysis of Graphene based reflector for high frequency band antenna system, establishing best suited graphene coating/re-enforcement methodology on CFRP reflectors.	
Q1.3	**Indigenous Development of Dewar System for Cryo Cooled LNAs (ISTRAC)** Cryogenic Dewar is used in Deep Space Network for cooling of low nose amplifiers and some of the feed components. Presently IDSN 32 meter system is equipped with a imported Dewar assembly for cooling S and X band Dependency of foreign vendor during maintenance /repair has very long lead time. The development involves design of vacuum Dewar assembly which houses RF components. Important design objectives are:	

	• Cryo temperature of 10K or better for S Band and 15K or better for X Band is met • Degree of vacuum achieved • Refrigeration selection, choice of material for vacuum chamber walls, internal components, fabrication techniques etc. • Minimum MTTR for Cryo cooled LNA's assembly and ease of maintenance for Dewar
Q1.4	**Solid Deployable Reflector for Transportable Terminal Antenna System (ISTRAC)** Transportable terminal antenna is deployed at remote locations on land/sea for launch vehicle/satellite tracking. The total antenna system has to be made operational in least time with limited manpower. The reflector diameter ranges from 4.6m to 5.4m, making it difficult to transport antenna with assembled reflector inside standard ISO containers which necessitates reflector petals removal during transportation. Assembly/disassembly of reflector petals during deployment needs human intervention and consumes considerable amount of time. A mechanized solid deployable reflector will reduce the integration time and human effort. The objective of development involves • Design of light weight composite mechanized reflector meeting the required deployed stiffness • Mathematical modeling and FE analysis for compact folding mechanism • Scaled prototype development and testing before realizing the actual reflector

SPACE SCIENCES

A	Area	Space and Atmospheric Sciences (PRL)
A1	Sub Area	Investigations on Near-Earth Environment (PRL)
A1.1		**Solar Wind and Interplanetary Processes (PRL)** The variability of alpha-proton ratio in the solar wind at 1 AU in small time scale (e.g. a few days during the passage of transient disturbance like ICME) as well as in large time scale (solar activity cycle) is investigated. This theme gets special importance in the context of the Aditya-L1 mission of ISRO. In addition, the generation, thermal anisotropy and acceleration of solar wind particles are of special importance that have been taken up. The generation of solar energetic particles and its association with the ICME and solar flares are also being looked into.
A1.2		**Wave Particle Interaction at the Radiation Belt (PRL)** The wave particle interaction at the terrestrial radiation belt, acceleration of radiation belt electrons and the role of solar wind shocks are investigated.
A1.3		**Equatorial, Middle and High-Latitude Upper Atmospheric Phenomena (PRL)** The equatorial, middle and high-latitude processes are replete with unique atmospheric processes of their own. This is essentially due to the configuration of magnetic field lines which are different at different latitudes and thereby affect the neutral plasma motion in different ways at different latitudes. The horizontal nature of magnetic field orientation over geomagnetic equatorial, and low-latitude regions generates dynamo effect which gives rise to equatorial electric fields and several associated processes such as the equatorial electrojet, plasma fountain effect/equatorial ionization anomaly, neutral anomaly, equatorial temperature and wind anomaly, and convective ionospheric irregularities, among others. Particle precipitation at high-latitudes during geomagnetic storms/space weather events present additional source of energy and momentum to the earth's upper atmospheric regions which contribute to the generation of neutral and plasma waves and setting up of winds and creation of plasma irregularities. Several state-of-the-art radio propagation techniques, magnetic measurements, and in-house built optical techniques are used to answer highly pertinent questions of global importance and global scales.
A1.4		**Daytime Upper Atmospheric Neutral Wave Dynamics (PRL)** The solar ionizing radiation incident in the daytime upper atmospheric regions gives rise to several phenomena due to availability of additional energy and differential heating that sets up driving forces in several directions. While radio measurements are available for the investigation of the ionized part of the upper atmosphere, the neutral part of the atmosphere can be studied by the naturally occurring optical airglow emissions. New in-house built techniques and approaches have

	been evolved at to enable the measurement of these airglow emissions in the daytime against the strong solar scattered background contribution. A new field of daytime optical aeronomy has emerged, wherein investigations of neutral gravity wave activity that exists in the daytime, is now possible. Several new insightful results have been obtained and there exists a great potential in this nascent area of research.
A1.5	**Space Weather Effects at High- and Mid-Latitude Ionosphere Thermosphere System (PRL)** The high- and middle-latitude ionosphere-thermosphere regions are especially affected by the particle precipitation at high latitude and ensuing electric fields and currents that are formed in the auroral oval wherein convective cells are formed. The local time dependence and simultaneous role of substorms, shocks, disturbance dynamo etc. in generating the extreme electric field disturbances in the ionosphere are investigated. Daytime polar cusp aurora, polar cap patches, stable auroral red arcs, stable auroral polarization streams, storm enhanced density plumes, and associated affects are of research interest in the characterization of space weather effects on the terrestrial ionosphere thermosphere system.
A1.6	**Impact of Mid-Latitude Ionospheric Processes and Irregularities on Low Latitudes (PRL)** The impact of Medium Scale Travelling Ionospheric Disturbances (MSTID) on low latitude ionospheric electrodynamics is investigated. Further, the characterization of mid latitude irregularities at the transition region of low-mid latitude boundary is also being carried out in recent times.
A1.7	**Vertical Coupling of Atmospheric Regions (PRL)** Earth's atmospheric regions are organized with respect to its temperature structure. Different regions are governed by different convective and dynamic processes and so have been conventionally considered to be behaving independent of one another. Due to multipronged daytime, nighttime, optical, radio, magnetic, re-analysis, and other global datasets it has been shown that efficiency in vertical (upward) coupling of atmospheric regions is solar activity dependent over long timescale with greater efficiency during low-solar activity epoch. On smaller timescales tropospheric convective storms (few hours) and stratospheric sudden warming events (several days) give rise to vertical coupling of atmospheric regions. Several ensuing processes, mechanisms, and consequences of such vertical coupling is a topic of research that's being pursued in PRL.
A1.8	**Investigations of Mesosphere Lower Thermosphere (MLT) Region (PRL)** MLT region is dominated by the effect of waves (planetary, tides, gravity waves) that originate in the lower atmosphere and propagate upwards which consequently gain large amplitudes that leads to wave breaking and momentum deposition. Multi-wavelength airglow observations using optical techniques, measurements

	of mesospheric rotational temperatures using OH Meinel and O_2 atmospheric bands (both ground and satellite based), and modelling studies are required for a comprehensive understanding of the processes in the MLT region. The topics of interest are: Couplings (vertical, latitudinal, longitudinal) of the atmospheres under varying geophysical conditions, atmospheric waves in the MLT region, long-term changes in the MLT region, effects of Sudden Stratospheric Warming (SSW) from high-latitude on global MLT dynamics, Mesospheric Temperature Inversion (MTI) and it's possible causative mechanism, high frequency waves in the MLT region.
A1.9	**Wave Dynamical Coupling in Lower and Middle Atmosphere (PRL)** Atmospheric waves (gravity waves, tides, planetary waves) are most important coupling agents in the lower and upper atmospheric processes. They are generated in the lower atmosphere due to various disturbances and propagate upwards. Their interaction with background wind and other waves leads exchange of their energy with the surroundings at different altitudes. Additionally, the low latitude regions are substantially influenced by a number of unique wave activities due to maximum solar incident radiation and resulting large scale convection activities compared to the mid and high latitudes. Therefore, investigation of equatorial dynamics draws an additional importance to address global scale atmospheric dynamics.
A1.10	**Variability of Upper Atmospheric Wind and Temperature (PRL)** As the upper atmosphere is affected by the forcings from both top and bottom, the dynamical state of it varies significantly over various scales. The variability can be found effectively in the dynamical parameters, e.g. wind, temperature etc. Therefore, by investigating the variability of these parameters one can delineate the dominant processes occurring therein.
A1.11	**Upper Atmospheric Modelling Over the Equatorial and Low Latitudes using Advanced Techniques (PRL)** A broad range of user applications are crucially reliant or affected by the state of the ionosphere. As such, modeling and correction of these impacts is subsequently highly sensitive to the choice of ionospheric representation. The equatorial and low latitude ionosphere exhibits high degree of variability due to the presence of electrodynamic processes such as the Equatorial Electrojet (EEJ), Equatorial Ionization Anomaly (EIA), etc. Consequently, the height distribution of ionospheric electron density significantly vary with time, season, latitude, longitude and solar activity. Quantitative representation of the short and long term variations of different ionospheric parameters is a major requisite to develop accurate ionospheric models over the low latitude sectors. Developing new methodologies and formulations by employing Artificial Intelligence and Machine Learning (AI/ML) tools will bring new avenues to characterize low latitude ionospheric variabilities towards achieving improved accuracy in model development.

A2	Sub Area	Atmospheric Aerosols and Trace Gases (PRL)
A2.1	**Radiative and Climate Impacts: Observations and Modelling (PRL)** To characterize different aerosol types and gaseous pollutants, their spatial and temporal variations, understand their linkages with physical, chemical and dynamical processes, and study their impact on environment, radiation budget and climate. • Atmospheric Aerosols: Characterization, Radiative and Climate Impacts • Biomass burning and Aerosols • Trace Gases: Chemistry, Transport and Effects	
A3	Sub Area	Cloud Research (PRL)
A3.1	**Investigations of Atmospheric Clouds and Boundary Layer Characteristics (PRL)** To characterize different types clouds their structures, Cloud Base Heights, Wave-cloud interactions, Microphysics of clouds, Cloud dynamical features. Dynamics of atmospheric Boundary layer.	
A3.2	**Development of Indian Lidar Network (ILIN) (PRL)** To investigate Atmospheric Cloud characteristics, Boundary layer dynamics, Vertical distribution of atmospheric water vapor and other atmospheric constituents over different regions of India; we are establishing a network of Lidar laboratories (ILIN) in the different parts of India covering different regions (North, South, North East, West and Central India).	
B	Area	Planetary Sciences (PRL)
B1	Sub Area	Dust Devils (PRL)
B1.1	Convective vortices(dust devils) inject dust into the atmosphere, which is then transported by global winds and strongly moderates the Martian climate system directly through the radiative impact of local and global dust storms, and indirectly by affecting the complex ion photochemistry. We are studying the characteristics of such dust devils on Mars through modeling and remote sending observations.	
B1.2	**Lunar Surface Sciences (SAC)** Planetary Sciences division is mainly involved in analyzing the data from the contemporary Indian and international planetary missions, formulating the objectives of future science missions and carrying out Planetary Analogue studies for developing customized spectral library.	
B2	Sub Area	Photochemistry Coupled GCM of Mars and Venus (PRL)
B2.1	The current climate of Mars and Venus is controlled by interactions between chemical tracers (such as ozone), water vapour and dust aerosols, coupled through dynamics and radiative processes. Scientists at PRL are studying these interactions with varying levels of complexity. The latest efforts are to understand the couplings through a	

	photochemistry coupled general circulation model (GCM). The current focus is also to understand boundary layer processes (through which the surface forcings influence the free atmosphere) through mesoscale modeling.	
B3	**Sub Area**	**Planetary Lightning (PRL)**
B3.1	The electric fields due to dust charging could be an important source of lightning on Mars. Similarly, charging of sulfuric acid aerosols may play an important role to generate lightning on Venus. The lightning is of particular interest, as electrical discharges from lightning could help form new exotic species or even molecules needed to jumpstart life. Not much is know about these phenomena for which instrumentation and modeling are being developed. Microphysical modeling of the cloud layers of Venus will be used to study charging of the cloud layer, generation of possible lightning, and its effect on the photochemistry. This study is very important for India's future mission to Venus.	
B4	**Sub Area**	**Planetary Remote Sensing (PRL/SAC/IIRS)**
B4.1	Remote sensing data from Moon, Mars along with other planetary bodies are useful to understand the evolution of these planetary bodies. They are used to understand surface and geological processes such as impact cratering, glaciation and volcanic activities using surface and subsurface analysis.	
B5	**Sub Area**	**Understanding Planetary Processes through Meteorites and Planetary Samples (PRL)**
B5.1	Isotopic and noble gas studies of meteorites and planetary samples can help us understand the origin and formation process of planetary bodies. It also gives us time line of materials evolution in the proto solar system and time scale information in the early solar system. Analysis of organic matter from various meteorites can provide the constraints on thermal and aqueous alteration taking place at the Asteroidal region. Carbon isotopic studies in carbonaceous Chondrites can help understand the origin, identification of C bearing reservoir and migration of volatiles in early solar system.	
B6	**Sub Area**	**Planetary Environmental Simulations and Analogue Studies (PRL)**
B6.1	Laboratory measurements of planetary analogous materials under simulated environments provide key support to the definition of science and measurement objectives of ground-based, orbital, and lander observations; instrument design and calibration; mission planning; and analysis and interpretation of retrieved data. The main aspect of such a work would be to design and develop environmental chambers/ facility of different scales and capabilities that can simulate astrophysical and planetary environments and conduct experiments using analogous samples under these environments. Study of analogues found on Earth can reveal processes we might expect on planetary bodies. For example, identification of new impact structures in Indian Subcontinent and meteorite expedition in hot and cold deserts in India could be useful areas of investigation.	

<table>
<tr><td>B7</td><td>Sub Area</td><td>In-situ Technologies for Planetary Surface and Sub-surface Science (PRL)</td></tr>
<tr><td>B7.1</td><td colspan="2">We are at the verge of a new epoch of robotic exploration of solar system bodies. The next generation of scientific missions to planetary bodies of our Solar System requires development of advanced robotic technologies for in-situ surface and sub-surface science (for examples core drilling and sample collection techniques). These missions have also motivated initiation of the design and development of highly capable and miniaturized science instruments for carrying out in-situ surface and sub-surface science.</td></tr>
<tr><td>B8</td><td>Sub Area</td><td>Outer Solar System Studies with Emphasis on Icy Bodies/Satellites (PRL)</td></tr>
<tr><td>B8.1</td><td colspan="2">Comets are among the least altered objects in our solar system. They can preserve the chemical and physical signatures of the protoplanetary disk that formed the solar system. In addition, the discovery of the first interstellar comet 2I/Borisov opens the doorway to studying comets in exo-planetary systems. In our group, we study the hydrodynamical conditions and the formation of simple through complex molecules in the cometary atmosphere and the cometary nucleus.</td></tr>
<tr><td>C</td><td>Area</td><td>Planetary Geology (SAC)</td></tr>
<tr><td>C1</td><td>Sub Area</td><td>Moon (PRL/SAC/IIRS)</td></tr>
<tr><td>C1.1</td><td colspan="2">Moon (SAC)
• Characterizing the mineralogical diversity of the lunar crust and understanding the nature of lunar water cycle:
i. Constraining lunar crustal composition through high-resolution hyperspectral data of the Moon obtained from recent, ongoing and upcoming lunar missions.
ii. Comparative compositional studies of lunar near and far side mare and their implications in thermal and chemical evolution of the Moon.
iii. Unambiguous detection of lunar hydration features (molecular water /hydroxyl ions) and characterizing their nature using hyperspectral data.
• Investigation of lunar volatiles at polar regions: Development of new techniques and radar-based models for detection and quantitative estimation of water-ice deposits inside the permanently shadowed regions at lunar poles.
• Lunar morphological studies:
i. Detailed investigation of global lunar geological and morphological features and preparation of seleno-morphological maps.
ii. Morphometric and rheological study of lunar domes.
iii. Analysis of spatial and statistical distribution of boulders from high-resolution optical datasets.</td></tr>
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- Characterization of physical properties of lunar regolith:
  - i. Inversion of global regolith thickness and physical properties of the lunar near surface using multi-wavelength radar studies.
  - ii. Development of physical models for dielectric constant and surface roughness estimation over lunar surface.
  - iii. Development of empirical and semi-empirical radio-wave scattering models to address scattering from surface and subsurface heterogeneities.
- Lunar crustal shortening studies: Understanding the lunar crustal shortening through morpho- structural analysis of wrinkle ridges distributed at different regions of the Moon.
- Retrieval of Photometric parameters from optical remote sensing data: Development of algorithms and simulation of physics-based models to retrieve topographically corrected photometric parameters and comparison with lab-based BRDF measurements collected over Apollo samples.
- VNIR and thermal remote sensing simulation Studies:

i. Visible-Near Infrared (VNIR) reflectance calculation using physics-based models and studying the effects of optical properties, viewing geometry, grain size, etc.
ii. Estimation of thermal radiation from lunar regolith.
iii. Development of physical retrieval algorithms for lunar surface temperature and spectral emissivity in 3-5 µm range.

- Lunar Emissivity & Temperature: (a) Developing algorithms and models for simultaneous retrieval of Lunar temperature and emissivity using infrared thermal data sets

</td></tr>
<tr><td>C1.2</td><td>

Chemical, mineralogical and morphological studies (PRL)

We tend to use various proxies like chemical, mineralogical, morphological, chronological etc. studies, typically in combination, to understand the processes involved in shaping (physical and chemical differentiation of) the terrestrial planets throughout geologic time. Various approaches, e.g., orbital, in-situ experiments and sample (including meteorite) studies in labs, should be considered comprehensively to work on the fundamental science problems (or part of them) for any planetary missions.

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<tr><td>C1.3</td><td>

Lunar surface sciences (SAC)

The main research themes for research includes Lunar Surface composition, Lunar morphology, Hyperspectral data analysis for Lunar Surface, Thermal Remote Sensing of the Moon, Spectral characterization of Lunar analogues, Lunar surface dating and lunar volcanism. Multi-frequency microwave SAR studies for H_2O / Ice detection on Lunar surface.

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</table>

C1.4	**Lunar surface science (Impact Cratering, Volcanism, Space weathering) (PRL)** The main research themes includes Lunar Morphology, Surface composition via Hyperspectral data analysis, Thermal Remote Sensing of the Moon, Lunar surface dating using crater chronology, Spectral characterization of Lunar analogues, and Multi-frequency microwave SAR studies for H_2O / Ice detection.
C1.5	**Estimation of water abundance on the Moon (PRL)** A combined approach of study using remote sensing observations from Chandrayaan missions and modelling is required to investigate variations and abundances of hydration on the lunar surface. Such an approach of looking at global scale variations using the multiwavelength data of Chandrayaan missions will help to understand associated transport processes and their origin.
C1.6	**To Understand Surface Properties and Aqueous Processes on Mars (PRL)** Radar signatures are key in exploring the surface and surface properties of the planetary bodies – SHARAD and MARSIS are currently active orbital radars operating at different capacities with different scientific objectives. The discovery of icy layers on poles and subsurface ice are prominent features and leap in the planetary exploration. The instrument operates on the concept of detecting the dielectric discontinuities through electromagnetic wave reflections. It could be promising to investigate the surface and subsurface properties of the global or local region of interest for a planetary mission. Based on abundances of secondary mineral assemblages, recent orbital and in-situ findings suggest a diverse aqueous environment for Noachian terrain (>3.7 Ga) of Mars. The nakhla meteorite also holds the record of aqueous alteration due to the presence of abundant secondary minerals. Thus, a focused scientific approach could help to identify future potential areas for past habitable zones and can provide clues to identify sites for hydrothermally induced microbial life on Mars. Geochemical, Spectroscopic, X-ray & astro-biological studies of the terrestrial analogues of Moon and Mars.
C1.7	**Geological Characterization of Lunar and Martian Surface Features (IIRS)** Availability of High-resolution optical, multispectral, hyperspectral sensors and elevation data from various lunar and Martian missions can be utilized to characterize geological features like impact basins, craters and volcanoes and related landforms by analysing them for mineralogy, lithology, morphological, topographical and structural interpretation. These data with utility for identification, spectral-compositional analysis, geomorphic evolution and chronological study can be integrated with ground based Spectral-compositional study of various igneous exposures in conjunction with geochemical study to understand and correlate their mineralogy, composition, formation conditions, and environment in similar setup at the Moon and Mars.

C2	Sub Area	Mars (PRL/SAC)
C2.1	**Mars (SAC)** • Simulation of Martian subsurface for characterizing water ice layers: Shallow buried Ice detection using multi-frequency microwave radiometer and Brightness Temperature estimations. • Global albedo mapping of Mars: Using data from optical and Shortwave Infrared (SWIR) observations. • Martian geological studies: Mineralogical and morphological studies of volcanic provinces, and monitoring of Polar Ice caps on Mars using optical and hyperspectral remote sensing data.	
C2.2	**Morphology, mineralogy, chronology and topography studies (PRL)** This topic research aims to analyze the morphology of glacial and fluvial landforms on Mars to infer the potential role of water and ice in their formation, examine the role of topography to infer the consequences of topographic control on the emplacement of the landforms, infer the presence of primary and secondary minerals in the deposits to examine role of aqueous processes, and to establish chronological history of landforms to deduce their period of formation in the past geological history of Mars. Morphological studies from major geological processes will provide major pathways to explore these rocky planetary bodies.	
C2.3	**Studies on Martian analogue (PRL)** To study the potential planetary analogues sites on the Earth to understand the intricacies of planetary processes such as the connection between impact-fluvial processes on Earth and Mars, impact fragmentation on Earth and Moon, gully formation on Earth and Mars, debris covered glaciation on Earth and Mars. The reflectance spectroscopy measurement from the laboratory based instruments will provide more insights in understanding the mineralogical composition. Boulder falls on the Earth, Moon and Mars provide an opportunity to do comparable planetology. The basaltic crusts comprising the surfaces of the Mars often resemble the terrestrial basalts and many volcanic and sedimentological features appear similar to be existed on Mars. Therefore, planetary analogues studies are essential to understand the geologic context and validate the orbiter data for ongoing and future space missions to Mars.	
C3	**Sub Area**	**Venus/Asteroids/Mercury (PRL/SAC)**
C3.1	**Venus (SAC)** • Venus geological studies using microwave remote sensing data: i. Scattering properties of Venusian geologic features, i.e., volcanic landforms and highland regions using ground-based and orbital-based radar data and development of radar scattering models.	

	ii. Characterization of large-scale Venusian volcano-tectonic structures by integrating observations from Magellan SAR, Radiometer and Altimeter observations. • Limb darkening studies of Venus using thermal remote sensing observations.
C3.2	**Asteroids (SAC)** • Constraining the origins of Asteroids: Investigation of Visible and Near Infrared spectra of Main Belt and Near-Earth Asteroids obtained from spacecraft-based observations and link with those obtained from meteorites to understand their origins. • Polarimetric radar studies of Near-Earth Asteroids to characterize their near-surface physical properties.
C3.3	**Mercury (SAC)** Ground-based polarimetric radar studies of Mercury Poles to constrain the potential distribution and purity of water ice deposits associated with permanently shadowed regions.
C3.4	**Planetary Atmospheres (SAC)** • Radio Occultation Techniques for Atmospheric Profiling of Venus and Mars: Development of end-to-end retrieval algorithms for deriving atmospheric profiles of temperature, pressure and sulfuric acid concentration for planetary atmospheres such as Venus and Mars using Radio Occultation (RO) techniques. In addition, research towards error propagation analyses in RO experiments for characterization of system noises feeding towards system definition for realization of future indigenous RO missions. • Understanding the atmospheric circulation dynamics of the Venusian atmosphere: Retrieval of atmospheric winds from UV channels and dynamical modelling of the Venusian Atmosphere to understand the atmospheric circulation dynamics. • Understanding the diverse wave characteristics and induced angular momentum forcing in the Venusian atmosphere: Study of atmospheric waves and oscillations of winds at different altitudes in Venusianatmosphere using retrieve winds and dynamical model to understand the diurnal, seasonal and annual periodicity. • Investigating the elusive nature of Venusian lightning using synergistic observations. Synergistic measurements from instruments aboard upcoming Venus mission of ISRO are targeted to probe unambiguous detection of Venus lightning in a more decisive manner. • Measurements of Venus cloud top brightness temperature statistics at different locations, emission angles, and times, and generation of cloud top temperature maps. • Retrieval of Venus surface emissivity and near-surface atmospheric parameters. • Investigations of dust storms and dust devils on Mars. • Estimation of atmospheric optical depth (AOD) as a function of altitude and scale height of aerosols on Mars.

<table>
<tr><td>C3.5</td><td colspan="2">Planetary Analogues (SAC)
• Terrestrial hot springs and their Astrobiological implications: Field studies, sample collection, and characterization of mineral assemblages in the spectral range of 0.4-25 μm found in the vicinity of different hot springs located along various faults of North Western Himalayan region.
• Lunar and Martian Water Ice Analogues: Permafrost deposits present in the North-western Arid Himalayan regions are analogous to the water ice deposits thought to be present on Mars and the Moon. These frozen grounds are studied using longer wavelength Synthetic Aperture Radar (SAR) observations combined with in situ Ground Penetrating Radar (GPR) observations.</td></tr>
<tr><td>D</td><td>Area</td><td>Solar Physics (PRL)</td></tr>
<tr><td>D1</td><td>Sub Area</td><td>Helioseismology (PRL)</td></tr>
<tr><td>D1.1</td><td colspan="2">Helioseismology is based on precise measurements of solar acoustic oscillations. The study of the solar global oscillations during major flares have shown that such energetic transients taking place in the solar environment can generate pressure impulses in the Sun. The knowledge gleaned from these solar results could be useful in identifying the asteroseismic signatures of such transients in solar-like pulsating stars. The study of these acoustic oscillations in the sunspots during major flares have shown that abrupt changes in solar magnetic fields can lead to impulsive changes in Lorentz force acting on the sunspots, which results into inducing acoustic emission in the sunspots. These acoustic emissions could be helpful in better understanding of physical dynamics beneath the sunspots. Additionally, such magnetically driven acoustic emissions can travel upward into the solar atmosphere as magnetoacoustic waves and thereby can heat the active region atmospheres. It is also believed that acoustic waves intermittently interact with the background solar magnetic fields. Application of wavelet technique to the velocity signals shows leakage of photospheric oscillations into the chromosphere. Gravity waves in the solar atmosphere are now increasingly recognised as an important contributor to the dynamics and energetics of the lower solar atmosphere. The study of two-height velocity-velocity cross-spectra and phase and coherence signals in the wavenumber-frequency dispersion diagrams and their association with background magnetic fields would be quite useful in understanding the propagation characteristics of these gravity waves.</td></tr>
<tr><td>D1.2</td><td colspan="2">Flux emergence and the Coupling of the Solar Atmosphere (PRL)
The emergence of magnetic fields on the solar photosphere occurs on a wide range of spatial and temporal scales. Investigating the processes of flux emergence is essential for understanding how the magnetic field couples the solar atmosphere and in determining
i) the heating of the transition region and corona,
ii) the production of small-scale transients, and
iii) the instabilities driving mass ejections from the Sun.</td></tr>
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	This field of solar physics requires multi-wavelength and multi-resolution observations which will provide an unprecedented view of the Sun and its magnetic field with the next-generation ground-based telescopes and space missions becoming operational within 2-3 years.
D1.3	**Magnetic Field and Velocity Mapping for Prediction of Solar Eruptions (PRL)** Solar surface magnetic field is measured to monitor magnetic energy storage and evolution of the stresses leading up to these eruptions combined with the velocity measurements on the surface. Above the surface, physical parameters of the chromospheric and coronal phenomena are being used to predict the geoeffectiveness of these eruptions.
D1.4	**Solar Cycle Variation, Prediction of Activity Cycle (PRL)** The 11-year activity cycle is a dominant characteristic of the Sun and also the solar dynamo that generates the solar magnetic field. The discovery of solar magnetic fields introduced a 22-year periodicity, as the magnetic polarities of the polar regions change sign every 11 years. Correlations have been identified and quantified among all the measured parameters, but in most cases such correlations remain empirical rather than grounded in physical processes. For a better physical understanding of solar physics a systematic reassessment of solar activity indices and their usefulness in describing and predicting the solar activity cycle is required.
D1.5	**Study of Solar Rotation (PRL)** The differential rotation of the Sun plays a key role in the formation of sunspots and thereby governs the solar activity cycle. Recently it is shown that the solar corona also shows differential rotation with increasing height (or, temperature). Furthermore, the study of North-South asymmetry in the rotation of the Sun has indicated that this asymmetry leads the solar activity cycle. The study of chromospheric rotation with height and its variation over the solar activity cycle can improve our understanding about the differential nature of the solar rotation.
D1.6	**The Heating of Solar Corona and Transition Region (PRL)** The tenuous outer atmosphere of the Sun commonly known as 'corona', is orders of magnitude hotter (> 1 MK) than the solar surface (< 6000 K). It is now widely accepted that magnetic field plays an important role in the heating of solar corona. Magnetohydrodynamic (MHD) waves and small-scale transients (e.g., microflare, nano-flare, spicules) are proposed to provide sufficient energy to maintain the hot corona and transition region. Although there exist ample observations of wave propagation and small-scale transients in the solar atmosphere, the exact physical processes/mechanisms behind their dissipation and contribution to the heating of coronal plasmas are still unclear and not fully quantified. Therefore, a thorough assessment of the role of each of these proposed mechanisms is required.

D1.7	**Transient Phenomena: Flares, Eruptive Filaments/Prominences, Coronal Mass Ejections (PRL)** CMEs inject large amounts of mass and magnetic fields into the heliosphere, causing major geomagnetic storms and interplanetary shocks, which are a key source of solar energetic particles. CMEs are often associated with erupting prominences and flares but our physical understanding of how and why CMEs are initiated is poor. It is important to carry out long term and high resolution studies of source regions of CMEs and also monitor their manifestations in the solar wind. Further, study of halo-like CMEs, which suggest the launch of a geoeffective disturbance toward Earth is also very important for space weather forecasting purpose. The fast and wide CMEs produce coronal and interplanetary shocks which are observed as type II radio bursts in meter and Decameter-hectometer (DH) wavelengths. The investigation of solar radio bursts in metric and DH wavelengths is also extremely important in view of probing the origin and propagation of CMEs.
D1.8	**Multi-wavelength Studies of the Sun (PRL)** Our understanding of the solar interior, the visible outer layers, and the "invisible" corona are not complete. New developments in the observational techniques from ground and space in optical, X-ray, ultra-violet and radio regimes of the electromagnetic spectrum are expected to continuously extend the frontiers of knowledge of the Sun in particular the eruptive phenomena such as flares and CMEs. Further, the HXR spectroscopy of solar flares is of particular importance to explore the basic physics of particle acceleration and explosive energy release in solar flares. Combination of imaging and spectroscopic observations in X-ray regime would reveal the location and strength of accelerated electrons and ions besides that of the hottest plasma.
D1.9	**Numerical Simulation for Solar Atmosphere (PRL)** The solar corona is intriguing because of its million degree Kelvin temperature and hosting eruptive processes which releases energy and mass which influence the space weather. In absence of any reliable measurement of the coronal magnetic field, it becomes important to numerically construct it using photospheric observations from ground and space based observatories. Additionally, state-of-the-art computer simulations are employed to explore the coronal dynamics.
D1.10	**Heliospheric Evolution of CMEs and their Space Weather Impact (PRL)** When coronal mass ejections or CMEs are launched from the Sun, they arrive at Earth within 1-4 days depending upon their initial speeds and their level of interaction with the ambient solar wind through which they travel. Research is being carried out for a better understanding of the expansion and propagation of CMEs in the inner heliosphere, thereby improving the forecasting of CME arrival and their impact on the Earth's atmosphere. Such knowledge is crucial, as energetic and high speed CMEs are known to be the major cause of severe disturbances of the Earth's space weather.

D1.11	**Solar Wind Turbulence (PRL)** Even after 60 years since its discovery, the physics of solar wind remains elusive. Multiple spacecrafts continuously sample various solar wind parameters at different heliospheric distances. These data reveal that the magnetic plasma of the solar wind is turbulent in nature. However, the generation and dissipation mechanisms of this turbulence remains an unsolved problem. In-situ data further reveal that the collisionless nature of the magnetic plasma gives rise to several waves and instabilities in the heliosphere, which in turn interact with the solar wind plasma. Elemental abundances of the solar wind also change in a non-trivial way. Many of these problems are thought to be interlinked. They are also supposed to be connected to the lower corona. A thorough understanding of turbulence, wave-particle interaction, and elemental abundances of the heliosphere may unfold many important questions about it. Such can be done either through sophisticated numerical simulations or through existing spacecraft data analysis. Data analysis from the Parker Solar Probe (PSP), the Advanced Composition Explorer (ACE), WIND, STEREO, etc., gives a detailed understanding of the heliosphere. Through such analyses, one also gains experience in tackling data from the upcoming in-situ instruments (e.g., ASPEX, PAPA, Magnetometer) onboard Aditya-L1.	
E	**Area**	**Astronomy & Astrophysics (PRL)**
E1	**Sub Area**	**Minor Bodies of the Solar System (PRL)**
E1.1	**Comets and Asteroids (PRL)** Comets and asteroids form the major part of the population of small bodies of the Solar System. These objects were scattered into different directions during the proto-solar nebula phase as the planets formed. This has given rise to many reservoirs of comets and asteroids. As they come closer to the Sun, the material constituting the comet starts to sublimate and is thrown out. The ejected material develops into a coma and tail. The characteristics of the dust in the coma can be studied by measuring the polarization induced by scattering of solar light by the dust. The dust properties and the chemical composition of the coma allow to infer the basic building blocks of the Solar system. We have a long running program to study the dust properties and the composition of the comets and asteroids. For this we make use of optical polarimetry, imaging as well as spectroscopy with the observing facilities operated by PRL at Mt Abu.	
E1.2	**Near Earth Objects (NEOs) (PRL)** Near Earth Objects and Potentially Hazardous Objects Most of the asteroid population in the Solar system is confined to a belt between Mars and Jupiter. However, some of the asteroids do have orbits that bring them closer into the inner Solar system. Asteroids that have perihelion distances less than the 1 AU are known as Near Earth Objects (NEO). During some part of their orbit, they may approach close to the Earth. Asteroids are typically quite faint objects (mag fainter than 17) but when they come close to the Earth,	

<table>
<tr><td></td><td colspan="2">they can brighten up substantially allowing for detailed observations with even smaller telescopes. A small fraction of the NEOs with the minimum orbit intersection distance with Earth of less than 0.05 AU are called Potentially Hazardous Objects. Close approach by the Near-Earth-Objects (NEOs) provides a unique opportunity to study these very numerous, but normally very faint population of minor bodies in the solar system.</td></tr>
<tr><td>E1.3</td><td colspan="2">Extra-solar Planets (PRL)
A new program for detection and characterization of exoplanets using optical fiber-fed stabilized high-resolution spectroscopy was initiated at the Mt. Abu Gurushikar Observatory of PRL. The project is called PRL Advanced Radial-velocity Abu-sky Search (PARAS). PARAS have the capability to a level of sub-2m/s precision on bright stars (< 6.5 mag) and 5 to 10m/s on fainter stars up to 10th mag. PARAS was involved in the first detection of an exoplanet from the Country (India) which has a mass of a 27 Earth mass.
In the near future we will have 2.5m telescope and PARAS-2 for sub-1m/s precision, which will able to detect super Earths in close orbits around G and K dwarfs. We also have a 43cm wide field telescope for doing exoplanet transit observations. Apart from Exoplanet detections, research work on exoplanet atmospheres are also conducted through global collaborations and modelling of exoplanet atmospheres.</td></tr>
<tr><td>E2</td><td>Sub Area</td><td>Galactic Astronomy (PRL)</td></tr>
<tr><td>E2.1</td><td colspan="2">Star Formation (PRL)
To explain the origin of massive stars (> 8 Msun) and young stellar clusters, a cloud-cloud collision process has been proposed in recent years as an interesting alternative against the existing competing theories of massive star formation. Multi-wavelength studies are being done from Radio to optical wavelengths to model and understand the physical processes inside the star forming molecular clouds.</td></tr>
<tr><td>E2.2</td><td colspan="2">Studies on Asymptotic Giant Branch (AGB) Stars (PRL)
Post-Asymptotic Giant Branch (PAGB) stars are rapidly evolving low and intermediate-mass stars (1-8 Solar mass) in the transition phase from the mass-losing AGB stars to the Planetary Nebulae (PNe) and are enshrouded by optically thick circumstellar matter that generally consists of molecular gas and dust. There exist a number of unresolved issues as to the physical processes that govern the evolution at these late stages. The chemistry of the circumstellar environment of these stars is highly dynamical due to the enrichment of the surface layers by the convective dredge-up process; initially oxygen-rich envelopes turning to carbon-rich.</td></tr>
<tr><td>E2.3</td><td colspan="2">Novae and Super Novae (PRL)
Cataclysmic events in the sky called Novae where a white dwarf accretes mass from a Giant star in a binary system and when the total mass of the white dwarf exceeds the Chandrashekar limit of 1.4 Solar Mass, hydrogen fusion flash happens on the surface of the white dwarf. Such astrophysical are extensively observed from Mount Abu facility</td></tr>
</table>

	using the PRL Near-IR camera and spectrograph and are studied in detail. Several interesting results were derived from these studies like detections of Dust, evolution of atomic and molecular species to understand the evolution and time scale of such astrophysical systems. NIR study of supernovae were initiated from early 2014 from Mt. Abu in the near infrared wavelengths with the outburst of Supernova 2014J which was the brightest and closest supernova Type 1a in the last four decades. Three bright supernovae namely SN2014J, SN2016adj and SN2017eaw are extensively observed from Mt. Abu facility both spectroscopically and photometrically and studied in detail.
E2.4	**X-ray Binaries and Pulsars (PRL)** Galactic X-ray binaries are among the brightest X-ray sources in the sky and are known to be variable over time scales ranging from milliseconds to years. However, over the intermediate time scale of few minutes to hours these sources, particularly the black hole binaries, are not known to vary significantly. We employed an innovative method of phased resolved spectroscopy with constrained system parameters which showed that, it is the high mass accretion rate that is responsible for the observed 'heartbeat' type variability. For this space-based X-ray telescopes are used like RXTE and XMM-Newton. Astrosat was used to measure the first polarization measurements in the CRAB pulsar in the X-ray wavelengths. The Crab pulsar is a typical example of a young, rapidly spinning, strongly magnetized neutron star that generates broadband electromagnetic radiation by accelerating charged particles to near light speeds in its magnetosphere. Despite of the spectroscopic and timing observations over decades, the mechanism of the emission in pulsars remains poorly understood. Polarization analysis only within the off-pulse region of the pulse profile showed that the emission has slightly higher polarization with fraction of polarization 39.0 +/-10%. The high significance of polarization detection enables to examine the dependence of polarization characteristics with pulse phase.
E2.5	**Structure of the Milky Way Galaxy (PRL)** We know that the Milky Way is a spiral Galaxy. However, the detailed structure of the Milky Way is not yet clear since we are in the disk of the Galaxy. Dust in the Galactic plane prevents a clear view of the distant regions of the Galaxy in the optical wavelengths. One can probe the structure of the Milky Way in a relatively better way by observing in the infrared domain where the effects of the dust are much reduced. We make use of large scale archival data from various optical and near infrared surveys to understand the details of the structure of the Milky Way. We make use of various tracers such as the Red Clump stars, the open clusters, Variable stars etc to study the structure of the distant regions of the Milky Way Galaxy. We have also initiated a program using PRL telescopes to study the polarization properties in different lines of sight towards distant regions of the Milky Way. This allows to understand the properties of the dust distribution in various directions and also to understand the large scale material distribution in various components of the Milky Way.

E3	Sub Area	Extra-Galactic Astronomy (PRL)
E3.1	**Active Galactic Nuclei (PRL)** In a long-term program, active galactic nuclei (AGN) have been studied to understand their structure and energy processes which lead to huge energy output from a very compact region. Blazars, a subclass of AGN, are used as tool in this study. Optical brightness and polarization variability studies enables us to make studies on the size of the inner region from where the central engine that is the black hole is located and indirectly infer the mass of the black hole.	
E3.2	**Studies of High-redshift Radio Galaxies (PRL)** Deep radio surveys combined with auxiliary multi-wavelength surveys have helped the discovery of a new population of distant and dusty galaxies. These galaxies termed as Infrared-Faint Radio Sources (IFRSs) are detected at radio wavelengths but they are very faint or undetected in the optical, IR wavelengths. Notably, the surface density of IFRSs is found to be higher than that of radio galaxies. It was found that the IFRSs are high-redshift radio-loud active galactic nuclei at the redshifts $z = 1.7 - 4.3$, and a limit of $z \geq 2.0$ is placed on the IFRSs with no or faint optical counterparts. The discovery of this new population of galaxies is crucial to understand the galaxy evolution in the early Universe. Such observations are being carried out using the national facility of GMRT in the radio wavelengths, and then look for their optical counterparts. They also help us to understand the Universe at an epoch time of redshift of $z > 2.0$.	
E3.3	**Astrochemistry, Astrobiology (PRL)** Conditions commensurate to the ISM and Solar System icy bodies can be recreated in the laboratory in order to understand the physico-chemical nature of molecules that are largely frozen on to the cold ISM dust grains. A combination of closed cycle helium cryostat and UltraHigh Vacuum (UHV) condition is used to bring temperatures down to 4 K and pressures of the order of 10-10 mbar. An optical window, mimics the dust grain in these experiments. The nature of the optical windows depends on the wavelength that is used to probe the molecular ices, for example, Zinc Selenide (ZnSe) and Lithium Fluoride (LiF) is used for infraRed (IR) and Vacuum UltraViolet (VUV) probing / Spectroscopy, respectively. To simulate shock processing either shock in the ISM or impact induced shock, an 8-meter-long, high intensity shock tube is used. Samples processed in our shock tube can reach temperatures up to ~ 10000 K. Various facilities are used in order to mimic the condition experienced by astrochemical ices and astromaterials; (i) electron from a commercial electron gun, (ii) for ion irradiation we use the ECR facilities, (iii) for the precious VUV photons from Synchrotron beamlines and (iv) the shock processing from a gas gun driven shock tube.	

	Thus, the astrochemical icy conditions are recreated and the physico-chemical nature of astrochemical ices are probed by spectroscopy. Proposals are invited in order to use these unique facilities mimicking (i) ISM cold dust and solar system icy surface conditions and (ii) shock processing of dust in the ISM and impact induced shock on planetary bodies. These facilities can be used to understand the survivability of biomolecules (and even microbes) under the extreme conditions that can be recreated in the laboratory, so proposal related to astrobiology are also invited.	
F	**Area**	**Space Instrumentation (PRL)**
F1	**Sub Area**	**Upper Atmosphere (Ionosphere/Thermosphere) (PRL)**
F1.1	**Optical Techniques (PRL)** • MISE (Multiwavelength Imaging Spectrograph using Echelle Grating): MISE is a high spectral resolution, large field-of-view (FOV; 140 degrees) instrument that is capable of retrieving faint dayglow emissions at multiwavelengths (OI 557.7, 630.0, and 777.4 nm) that are buried in the strong solar scattered background continuum • NIRIS (Near Infrared Imaging Spectrograph): NIRIS is a large FOV (80 degrees) grating spectrograph that yields spectra in the 823 - 894 nm region. NIRIS is used for deriving nighttime Mesospheric OH and O2 emission intensities and their corresponding temperatures • HiTIES (High Throughput Imaging Echelle Spectrograph: HiTIES yields nighttime spectra at multiple wavelengths of thermospheric interest are OI 557.7nm and OI 630.0nm • CMAP (CCD-based Multi-wavelength Airglow Photometer): CMAP is a narrow field of view photometer that provides nightglow emission intensities at multiple wavelengths spanning mesosphere to thermosphere. The emissions being Na 589.0nm, OI 557.7 nm, OI 630.0nm, OI 777.4 nm • CPMT (CCD-based Photometer for Mesospheric Temperature): CCD-based photometer for Mesospheric Temperatures (CPMT) is a 5-filter photometer for focussed study of mesospheric temperatures corresponding to OH and O_2 emissions • PAIRS (PRL Airglow InfraRed Spectrograph): PAIRS yields nighttime spectra at multiple wavelengths • ADIC (Automated Digital Imaging Cameras) have been developed to carry out simultaneous photography from 4 locations of rocket vapour cloud released from Thumba, India • UVIS (Ultraviolet Imaging Spectrograph): UVIS was designed to obtain emission intensities at MgII 280.0 nm and OI 297.2 nm wavelength which originate in the height range of 85-110 km. It has a FOV of 80 deg with spectral resolution 0.2 nm at 297.2 nm	

	• Narrow Spectral Band, Narrow Field-of-view airglow photometer: This instrument is capable of enhancing the signal to noise ratio (SNR) of nighttime airglow emissions in the wavelengths of OI 630.0 nm and 777.4 nm by limiting the spectral bandwidth and brings out the small variations in the airglow intensity buried in the background by limiting the field of view. This philosophy is now being adopted for space-borne measurements on-board Indian satellites	
F1.2	**Radio Techniques (PRL)** • DPS (Digisonde Portable Sounder): For ionospheric studies we use a digisonde wherein radio waves of different frequencies (0.5 - 20 MHz) are sent upwards and their return echo is monitored which yields information on the height of the ionosphere and the plasma densities therein • GPS/GNSS/IRNSS receiver based Total Electron Content (TEC) measurements: Three receivers measure TEC over this region using GPS, GNSS and IRNSS satellite transmissions at multiple frequencies (L1, L5, S band etc.) and are operational in the lab round-the-clock • Langmuir Probe: The lab is also engaged in the design and fabrication of Langmuir probes for space plasma measurements on-board rocket and satellites. The speciality of this class Langmuir Probe is its capability to capture small changes in the electron density perturbations enabling the group to address various plasma irregularity processes in the ionosphere	
F2	**Sub Area**	**Earth's Lower/Middle Atmosphere (PRL)**
F2.1	• Aerosol Chemical Speciation Monitor (ACSM) • Ceilometer • Disdrometer • Dual wavelength dual Polarization LIDAR • Flame Ionization Detector (FID) • Gas Chromatographs • Greenhouse Gas Analysers • Hygroscopic Tandem Differential Mobility Analyzer (HTDMA) • LIDAR • Multiwavelength Radiometer • Single Particle Soot Photometer (SP-2) • Surface Trace Gas Analysers • Dual wavelength dual polarization Lidar • Multi wavelength sun photometer • Pyranometer • Pyrgeometer • Pyrheliometer	

	• **Proton Transfer Reaction- Time of Flight- Mass Spectrometry (PTR-TOF-MS)-** The PTR-TOF-MS technique is used for the measurements of different VOC compounds present in atmosphere. The time of flight (TOF) mass spectrometer separates the ions according to their mass to charge ratio (m/z). The PTR-TOF-MS provides the mass spectra of many VOCs in a short time (<1 s). PTR-TOF is used for measurements of trace gases (ppt-ppb levels) in air and provides a high time resolution data. This is India's first Proton Transfer Reaction Time of Flight Mass Spectrometer (PTR-TOF-MS) system • **Thermal Desorption-Gas Chromatography-Flame Ionization Detector/Mass Spectrometer Detector (TD-GC-FID/MSD)-** The GC-FID/MSD system which is coupled with a Thermal Desorption-gas is used for the analysis of a class of VOCs known as non-methane hydrocarbons (NMHCs) for which PTR-TOF-MS based measurement is not possible • **VOC Analyzers-** The VOC analyzer provides online gas chromatograph for the analysis and monitoring of trace amounts of C2-C12 hydrocarbons. VOC analyzers are portable and have been used in field experiments at remote places. This setup has been operated during ship-borne campaigns to study the remote atmosphere	
F2.2	**Laboratory Instrumentations (PRL)** • Development of electron and ion imaging spectrometer (PRL) • Coincidence momentum imaging spectrometer, reaction microscope (PRL) • Development of ions source/Ion gun (PRL) • Laser produced plasma: Plume dynamics and plasma spectroscopy (PRL) • Laser Induced Breakdown Spectroscopy: Fundamentals and applications (PRL) • Development of Magnetic Bottle electron Spectrometer (PRL) • Large area Position sensitive detectors for charged particles imaging (PRL) • Development of Piezo pulse valve (0 to 1 KHz rep rate) and plunger-based pulse valve (0 to 1KHz rep rate) for supersonic atomic/molecular beam generation(PRL)	
F3	**Sub Area**	**Planetary Exploration (PRL)**
F3.1	**Atmosphere Experiments (PRL)** • Charge particle measurements • Ion and Neutral Composition (Mass Spectrometer) • Vertical distribution of Electron Density • Vertical distribution of Species • Planetary Lightning experiment: To understand lightning on other planets like Venus and Mars. Research work can involve modelling, data analysis and instrumentation related to cloud charging, EM wave propagation in ionosphere, plasma waves, ground based experiment • Radio Occultation Experiment to observe profiles of atmospheric parameters like temperature, density etc.	

F4	Sub Area	Planetary Atmosphere (PRL)
F4.1	**Surface Measurements (Elemental Composition) Experiments (PRL)** • X ray Spectrometer • Laser induced breakdown spectroscopy • Surface & Subsurface Thermophysical properties of planets • Dust and surface charging The objective is to study lunar surface charging, dusty plasma, laboratory experiments, dust levitation, dust impact, escape study, instrumentation • Microwave probing of surface and subsurface • Planetary Geophysical Studies – Experiments and Numerical Modeling (PRL)	
F5	**Sub Area**	**Astronomy (PRL)**
F5.1	**Instrumentation for Ground-based and Space-based Facilities (PRL)** • Visible and IR imaging with precision photometry, polarimetry, low resolution spectroscopy in IR and optical wavelength and high resolution optical fibre based spectroscopy for ground based 1.2 m and upcoming 2.5 m telescope • X-ray instrumentation for space-based facilities (Imaging and Spectra and Polarization) • Gamma Ray Spectrometer for space-borne platforms • Active optics for upcoming 2.5 m telescope • Detector arrays for Visible, IR and X-ray regions	
F6	**Sub Area**	**Solar Studies (PRL)**
F6.1	**Solar Wind Instrumentation (PRL)** Aditya-L1 mission is India's first dedicated science mission for the study of the Sun. Aditya-L1 will be placed at the first Lagrangian point (L1) of the Sun-Earth System. ASPEX payload on-board Aditya-L1 will be dedicated for the investigation of the characteristics of solar wind ions (H+, He++ and few other ions) from low to high energies with directional information. Not only that, the arrival of interplanetary transient events (e.g. ICME) at the L1 point will be flagged by the enhancements in ion counts in 3 channels beyond a pre-defined threshold and thus three distinct flags will be available as soon as telemetry allows. Therefore, ASPEX holds not only scientific promise but also the potential as a useful payload as far as space weather forecasting is concerned.	
F6.2	**Optical instrumentation for Solar Observations (PRL)** A 50 cm telescope for solar observations. Specialised back-end instruments, namely a Narrow–band Imager to record simultaneous images of the photosphere and chromosphere, a Polarimeter to measure the magnetic fields in sunspots and an Adaptive Optics system for image stabilisation and to achieve diffraction-limited performance.	

F6.3	**Active and Adaptive Optics for Diffraction Limited Imaging (PRL)** To achieve high-resolution observations with ground-based telescopes, Udaipur solar observatory (USO) is engaged in the research and development of active and adaptive optics systems for compensation of atmospheric turbulence in real-time. A low-order adaptive optics system is already developed; to achieve the maximum possible resolution with existing telescopes at USO, the development of a high-order AO system is in progress. In this regard, different mechanisms/techniques are being explored for wavefront sensing and wavefront reconstruction. Besides, off-line image restoration techniques such as blind-deconvolution and speckle masking techniques are being explored.	
G	**Area**	**Laboratory Study of Astromaterials (PRL)**
G1	**Sub Area**	**Meteorites from Asteroids (PRL)**
G1.1	**Early solar system processes and time scales (PRL)** Solar system formation scenarios have been debated for a long time now. Various processes that took place 4.56Byrs ago are recorded in some of the early forming solids preserved in few of the primitive meteorites/asteroids. Study of these important meteorites and samples from sample return mission provide clues into origin and evolution of the Solar system.	
G2	**Sub Area**	**Moon and Mars Meteorites (PRL)**
G2.1	**Composition, evolution and chronology (PRL)** Planetary bodies formed at different locations of the protoplanetary disk and are a tell-tale of the original composition of the protoplanetary disk along with information on how & when the bodies formed. Stable and radioactive isotopes from the various bodies (mars, moon, asteroids, comets) provide the compositional as well as chronological information of the different phases of planetary evolution.	
H	**Area**	**Payloads for Upcoming Planetary Missions (PRL)**
H1	**Experiments Based on EM Radiation, Particle Irradiation and Nuclear Reactions can be Devised to Understand Surface and Subsurface Composition and the Equipment can be Realized in a Miniaturized Space Qualified Form (PRL)** It involves development of X-ray fluorescence spectrometers for surface elemental composition measurement. Gamma ray and Neutron spectrometers will help in identifying the sub-surface elemental composition studies. This includes realization of radiation detectors which can work at extreme temperature conditions based on the planetary applications.	
H2	**Radio Occultation Experiment (PRL)** This is to observe profiles of neutral density, temperature, ion densities in the atmospheres of Mars and Venus for future ISRO missions.	

H3	**Development of In-situ technologies for planetary surface and sub-surface science (PRL)**	
H4	**Experiments related to Hypervelocity Dust Impact, Micro-meteorite Detection, Modelling and Data Analysis, Study of Space Debris. Payloads are being Developed to Dust Interplanetary Dust Particles (PRL)** The Interplanetary Dust Particles (IDPs) or micrometeorites or space debris are originated from asteroid belt and other sources. The IDPs have velocity greater than 1 km/s (i.e., hypervelocity) and may enter a planet. They are sometimes trapped between two planets and create a resonance dust ring. The properties of the dust at a planet may be understood using a hypervelocity dust, impact experiment using an instrument on future planetary missions/modelling. The project can cover such aspects related to the interplanetary/planetary dust detection/modelling.	
H5	**Langmuir Probe (PRL)** The knowledge of the local plasma environment and its variability with time and space is essential in determining the plasma dynamics and transport properties within the Martian ionosphere. In this context, the Langmuir probe is probably the simplest technique to measure the plasma configuration in terms of particle density, temperature, electric potential, and particle distribution within a plasma environment–moreover, tweaking with an additional probe to the instrument could also measure the local electric fields. The instrument primarily works on the principle of measuring currents under varying applied voltages and subsequent variations in V-I characteristics.	
H6	**Miniaturised Neutral Ion Mass Spectrometer (PRL)** To observe ions in the exosphere of Mars and Venus in ISRO's future missions.	
H7	**Energetic Ion Spectrometer (PRL)** Energetic Ion spectrometer (EIS) is the instrument aimed at measuring the energetic particles in the energy range of 100 keV to 100 MeV in the space/planetary environment.	
H8	**Lightning Experiment (PRL)** Payload to detect and study lightning on Venus is being developed for future ISRO mission.	
I	**Area**	**Atomic, Molecular and Optical Physics (PRL)**
I1	**Sub Area**	**Spectroscopy (PRL)**
I1.1	**Ultrafast Science and Technology (PRL)** The electron dynamics in atomic and molecular system is in attosecond (10-18 s) and the nuclear dynamics is ranging from picosecond (10-12 s) to femtosecond (10-15 s) time scale. Science at this time scale is named as ultrafast time. At atomic level, most of dynamical processes are in this time scale. Modern experimental techniques are needed to understand the ultrafast science.	

	• Femtosecond stimulated Raman spectroscopy (PRL) • Femtosecond transient absorption spectroscopy (PRL) • Femtosecond-Laser Induced Breakdown Spectroscopy (PRL): nanosecond-LIBS, Nanoparticles Enhanced LIBS, Femtosecond-LIBS • Femtosecond micromachining (PRL)	
I1.2	**Development of XUV/EUV Light Source using Femtosecond Laser (PRL)** • Development of XUV/EUV source based on Higher Harmonic Generation method (PRL) • Higher Harmonic Generation from gas, solid, liquid and plasma (PRL) • XUV-IR pump probe experiment (PRL) • Photoionization of atoms and molecules using XUV/X-ray (PRL) • Photoelectron Spectroscopy (PRL) • Intense TW femtolaser light interaction with matter: Extreme photonics (PRL)	
I1.3	**Attosecond Science and Technology (PRL)** • Attosecond Streaking (PRL) • Attosecond transient absorption spectroscopy (PRL) • Attosecond physics phenomena at nanometric tips	
I1.4	**Atomic Collisions (PRL)** • Electron and ion impact processes in molecules (PRL) • Study of atomic and molecular clusters (PRL)	
I1.5	**Laboratory Instrumentations (PRL)** • Development of electron and ion imaging spectrometer (PRL) • Coincidence momentum imaging spectrometer, reaction microscope (PRL) • Development of ions source/Ion gun (PRL) • Laser produced plasma: Plume dynamics and plasma spectroscopy (PRL) • Laser Induced Breakdown Spectroscopy: Fundamentals and applications (PRL) • Development of Magnetic Bottle electron Spectrometer (PRL) • Large area Position sensitive detectors for charged particles imaging (PRL) Development of Piezo pulse valve (0 to 1 KHz rep rate) and plunger-based pulse valve (0 to 1KHz rep rate) for supersonic atomic/molecular beam generation (PRL)	
I2	**Sub Area**	**Theoretical Atomic Physics (PRL)**
I2.1	**High-Precision Spectroscopy (PRL)** Accurate spectroscopic properties of atomic systems are immensely useful in analyzing data from laboratory, astrophysics and space research-based measurements. Relativistic many-body methods are developed to carry out high-precision spectroscopic properties of isolated and plasma embedded atomic and molecular systems.	

	• Oscillator strengths, transition probabilities, lifetimes • Fine structure splitting, hyperfine interactions • Electric moments, magnetic moments, polarizabilities • Isotope shifts • Relativistic many-body methods	
I2.2	**Atomic Clocks (PRL)** By performing high-precision calculations of properties sensitive to stray electromagnetic fields, suitable atomic candidates for space-based and laboratory-based microwave and optical clocks are identified. Atomic clock properties sensitive to variation of fine-structure constant and interactions with dark matters are determined. • Systematic estimations of microwave and optical atomic clocks • Magic wavelengths for optical clocks • Fundamental physics probe using atomic clocks	
I2.3	**Physics Beyond the Standard Model of Particle Physics (PRL)** By combining precise atomic calculations with the measurements, physics beyond the standard model of particle physics is probed to complement the findings of accelerator method based particle physics. • Atomic parity violation • CP and T-symmetry violations • Lorenz symmetry violation • New physics using non-linear isotope shift effects	
I3	**Sub Area**	**Photonics and Nonlinear Optics (PRL)**
I3.1	**Quantum Communication and Quantum Key Distribution (QKD) (PRL)** Quantum mechanics provides ultimate security to the data by encrypting it with the key, which is distributed using principles of physics inbuilt into the quantum mechanics. This cannot be matched with the security provided by the present encryption techniques which are based on computational hardness of the problem and will be redundant with the advent of quantum computers utilizing enormous computing power along with intelligent quantum algorithms. The key distribution based on photonic qubit could be done through the fibre as well as through the free space. However, to generate these keys one needs to make sources of single photons and entangled photons which are distributed using different communication protocols. At PRL, we are working on all aspects of quantum communication and QKD.	
I3.2	**Quantum Sensing and Metrology (PRL)** The measurement of quantum states interacting with a system can provide very precise knowledge about the system. One can use it for sensitive measurements of displacement, rotation, time intervals, magnetic fields as well as high-resolution imaging.	

	All this requires creating quantum states such as superposition states and entangled states of photons or electron spins and their measurements. This is another theme, PRL is involved with under quantum science and technology.	
I4	**Sub Area**	**Luminescence Physics (PRL)**
I4.1	**Development of a Compact Online Radiation Dosimetry System for Personal Monitoring (PRL)** There are several instances like in case of nuclear accident or space missions where it is difficult but important to predict the radiation level and its effect on humans. In such cases, the use of the passive dosimeter may not be possible and even if it's possible, it will provide delayed results as samples need to be brought to laboratory to measure the dose. In such cases, the idea of making a compact system equipped with on spot radiation measurement mechanism can be very useful. The development of compact online dosimeter will be useful for the space program as an on-board tool to keep a check on the radiation dose, which will enable monitoring the radiation safety of crew. Further, the development of technology will be useful for persons working the other areas, associated with radiation hazard situations. Such a system will mainly require three components a) Heat and light stimulation system with associated electronics b) Dosimeter c) Detection system with dose analysis program and associated electronics. There are several dosimeters, like Al2O3:C, LiF etc. which are currently being used as a personal dosimeter due to their good radiation response and dosimetry linearity. Our group expertise in the dose estimation procedures and have some experience in development of ground based systems for measurements and analysis. In this regard, proposals are invited for designing a system, which is compact in size and can be useful for personal dosimetry for manned missions.	
I4.2	**Nanodosimeters for Space Missions (PRL)** Radiation dosimetry is the technique that quantitatively measures the ionizing radiation absorbed by matter or tissue. Though, there are many active devices like electronic personal dosimeters and area monitors that are often used within a facility, however, usually passive systems like thermoluminescent (TL)/ optically stimulated luminescence (OSL) dosimeters and film badges are preferred for the purpose of personnel dosimetry because of their easy usage, tissue equivalence and minimal maintenance requirement. Because of its successful applications, themoluminescence has been recognized for many decades as a method for radiation dosimetry of ionizing radiation. In the recent developments where ISRO is planning to send humans for outer space missions, development of new TL/OSL dosimeters will be helpful to meet future requirements. We thus want to develop and collaborate for development of new radiation dosimeters suitable for passive and active dosimetry during space missions. From the techno-economic point-of-view, the final product of the proposal (new nano dosimeters) can be used by several scientific agencies especially dealing with radiation sources. ISRO has already issued a *"Humans in Space policy for India 2021"* guidelines in this regard.	

I4.3	**Development of Up-conversion and Down-conversion Phosphors (PRL)** Luminescent phosphors are nowadays widely used to tune the wavelengths of the incoming light in order to meet the desired results. The luminescent phosphors have capability to modify the spectrum of incoming radiations and enhance the output in desired wavelength range. One of the upcoming field in these phosphors is development of up-conversion and down-conversion phosphors. In up-conversion two or more low energy photons are combined to give a high energy photon and in down conversion high energy light photons are converted to low energy photons. This has significant application in increasing efficiency of solar cells and will be especially useful in situation where light availability is less. Solar cells respond to visible region (400-700 nm) with maximum response in 600-700 nm. As a result, a significant part of solar spectrum is not used in conversion of energy. In some carefully designed materials the response can be further extended in near infrared region but leads to escalation of the cost. One of the easier approach for enhancing the efficiency of solar cells (conventional or improved materials) is by tuning the energy of unused part of solar spectrum viz. infrared and UV to visible region. A thin coating of phosphor layers on solar cells can suitably tune the solar spectrum for increasing the efficiency. Thus this project seeks development of such up-conversion and down-conversion phosphors which can be used for enhancing the efficiency of solar cells and will be useful for future space missions.	
I5	**Sub Area**	**Ultrafast Laser Application (PRL)**
I5.1	**Femtosecond Laser Precision Engineering (PRL)** • Micro and nano structure development using femtosecond laser • Diamond, silicon, ceramic, etc. cutting using ultrafast laser • Micromilling using ultrafast laser • High Harmonic generation based EUV lithography	
I5.2	**Optical Fiber and Application (PRL)** • Fabrication of optical fiber • Development of Hollow Core Fiber for femtosecond pulse compression • Fibre optics-based tools development for medical, defence, aerospace, etc.	
I5.3	**Ultrafast Science and Technology (PRL)** • Attosecond physics phenomena at nanometric tips • Femtosecond filamentation and plasma chemistry	
I5.4	**Technology Development in Laser and Photonics (PRL)** • Development of Femtosecond oscillator, Femtosecond amplifier, Femto-optics (grating, mirrors, polarizer, etc.) • Development of XUV/EUV optical components.	

	• Development of Nd: YAG laser, Fiber laser, LIDAR, etc. • Development of Ion gun, electron gun, Time-of-flight mass spectrometer. • Development of photon/electron detector, power meter, etc.	
I5.5	**Quantum Control, Quantum Sensing, Quantum Computation and Quantum Information Processing: with Atoms, Molecules, and Photons (PRL)** • Construction of quantum networks for quantum communication using atom-cavity systems, quantum Internet • Quantum information processing, Quantum measurement, and Quantum information dynamics • Study of Quantum Entanglement, Quantum Teleportation, Quantum logic gates using molecular transitions • Development of single photon source, entangle photon source, quantum homodyne detection and quantum Interferometer • Generation, Transmission and Application of Orbital Angular Momentum	
J	**Area**	**Emerging Areas In Theoretical Physics (PRL)**
J1	**Sub Area**	**Ameliorating the Theoretical Frameworks of Fundamental Physics (PRL)**
J1.1	**Scrutinising the Validity of the Standard Models of Particle Physics and Cosmology and their Extensions by Computing Various Observables and Comparing them with the Experimental Data (PRL)** Some of the experimental evidence in the areas of particle physics and cosmology indicate that the known and established theoretical frameworks in these areas are not complete and adequate. Quantifying these inadequacies, modifying theoretical frameworks and testing their viabilities constitute a core of the theoretical physics programme emerging in the next couple of decades.	
J1.2	**Probing Physics Beyond Standard Model in Neutrino Experiments (PRL)** Exploring signatures of physics beyond the Standard Model of particle physics in experiments to detect neutrinos from Astrophysical and laboratory sources constitutes a very important current research area presenting many new opportunities. Next generation neutrino experiments offer particular advantages over existing experiments, including large volumes and high intensity beams. These detectors also open up the possibilities of detecting low mass dark matter candidates, new neutrino interactions etc.	
J1.3	**Probing Nature of Neutrinos in Rare Processes (PRL)** Neutrinos being particles with zero charge can be their own antiparticles i.e can have Majorana nature. This violates lepton number and allows the rare process of neutrino less double beta decay. There are many experiments which are searching for these	

	processes. Neutrino less double beta decay can help in probing the neutrino mass along with beta decay experiments and cosmological constraints. One can also look for predictions of physics beyond the Standard Model in such processes. In addition an analogous lepton number violating process can take place in colliders and complementarity of these with neutrinoless double beta decay experiments can constrain the parameters of the beyond Standard Model physics.
J1.4	**Charge-Parity (CP) Violation in the Neutrino Sector and Origin of Matter-antimatter Asymmetry (PRL)** Several neutrino oscillation experiments are in the process of determining the amount of CP violation in the lepton sector and it is expected to be measured within the next 10 years. Whether the observed amount is enough to explain dominance of matter seen in our universe is a question of fundamental interest.
J1.5	**Testing Grand Unification through Proton Decay (PRL)** Hypothetical theories which unify the fundamental interactions predict unstable protons. Several ongoing experiments are searching for the proton decay and they are expected to give decisive results on some of the simplest frameworks of unification. Activities in this area are therefore going to increase in the coming years.
J1.6	**Precision Physics at the LHC (PRL)** Due to the tremendous improvement of the Large Hadron Collider (LHC) experimental results, theoretical predictions of the Standard Model and beyond the Standard model processes need to be extremely accurate. This necessitates inclusion of higher order terms in the perturbative calculations and that, in practice, invokes non-trivial complexity due to the increasing number of loops and legs. To compute such theoretical estimations and to build machinery in order to attain such precise results are of utmost importance, as the present and future success of the LHC crucially depends on these theoretical inputs.
J1.7	**Search for the Theory of Unconventional Superconductivity (PRL)** Several superconducting materials have been discovered in the last couple of years which do not follow the known theory of superconductivity. It is one of the active areas where a radically new theoretical framework might be needed to describe the observations.
J1.8	**Quantum Materials, Superconducting Junctions, and their Functionalities (PRL)** Superconducting interfaces in combination with non-superconducting quantum materials have been found as excellent platforms to host emergent phases which are not possible to find in bulk superconductors. Exploring new quantum materials with topological properties, forming their interfaces with superconductors to find new functionalities are challenging and extremely needed for the possible future applications.

J2	Sub Area	Fundamental Physics using Space-borne Experiments (PRL)
J2.1	**Searching for Dark Matter through Balloon/Satellite/Space-station based Detectors (PRL)** The existence of a non-luminous and non-baryonic form of matter, popularly known as dark matter (DM), is already well established and measured at different length scales of the Universe by the observations like galaxy rotation curves, gravitational lensing, bullet cluster etc. Besides that, the current relic density of DM has been measured quite precisely in satellite-borne experiments like Planck and WMAP. A dominant part of the matter in the present Universe is in the form of DM. However, the nature and production mechanism of the same remains a mystery and an open question to date. This proposed research wishes to look into the properties and interactions of possible candidates of DM, be it weakly or feebly interacting fundamental particles originated through particle interactions in the early Universe. It is essential to look into such models and study the possible signature of such new physics in the present and upcoming experiments that comprises direct, indirect and collider searches of dark matter. It will add to our understanding in perspective to the broad area of Astrophysics, Cosmology and High energy physics. Through different ground-based and space-borne experiments, direct and indirect searches of Dark Matter can reveal useful information.	
J3	**Sub Area**	**Data Science and Machine Learning (PRL)**
J3.1	**Developing Algorithms to Train Machines for Efficient Processing of Big Data (PRL)** The true power of deep learning comes from "learning from data," more often than not, a deep neural network's performance improves as we feed in more data from a more extensive statistical sampling. For example, deep learning in the domain of high-energy phenomenology needs to generate data with the correct physical distribution first and then use it in our analysis. Due to the complex nature of the phase space simulations and the different scales of physics involved (from the sub-nuclear range to the length scale of the detector (which is at the order of tens of meters), the data we use have a large memory footprint.	
J3.2	**Applying Machine Learning Techniques in the Areas of Fundamental and Space Physics (PRL)** Different Machine Learning applications give the unique opportunity to explore complex phenomena in nature, and it is now widely used in different streams of research. In this project, we test and develop machine learning applications to improve the detection of new physics searches, especially in the context of theoretical particle physics, and try to develop physics-intuitive neural networks which follow specific requirements. Our group at PRL has been actively working in this field for the last few years.	

<table>
<tr><th>K</th><th>Area</th><th>Space Situational Awareness (ISTRAC)</th></tr>
<tr><td>K1</td><td>Sub Area</td><td>Space Surveillance (ISTRAC)</td></tr>
<tr><td>K1.1</td><td colspan="2">Space Debris Detection and Characterization in Optical Images (ISTRAC)
Reflected sunlight from Earth-bound resident space objects (RSOs) creates trails in the digital images obtained via ground as well as space based optical/NIR/IR telescope sensors. Instantaneous image noise reduction, calibration, RSO streak detection, identification and cataloguing is essential for the orbital determination process. This research proposal will be dedicated to the development of a software application as a solution for image reduction as well as calibration and Artificial Intelligence based RSO streak detection and identification on the fly.</td></tr>
<tr><td>K1.2</td><td colspan="2">Space Object Characterization using Remote Sensing Data Mining (ISTRAC)
Remote Sensing satellites collect data of Earth from orbit that includes any space object passing through the Field-of-View (FOV). This information is usually filtered out for remote sensing applications. The research is towards understanding and developing an automated software to ingest the remote sensing (RS) satellite images and process the image to identify for presence of any space object. The objective is to extract the dimensions and shape of the space object through existing RS images. The shape data of space objects thus captured might be crucial for space object catalogue maintenance and other SSA applications. Initially, the study may be focused towards RS optical image processing and later may be extended to other frequency domain observations.</td></tr>
<tr><td>K1.3</td><td colspan="2">Day time Observation of Space Object using Telescope (ISTRAC)
Observation of space objects through optical telescope gives the data of space object from which information of its position can be derived. The main hindrance for optical observations are climatic conditions and restriction of observations to night time. The research is to study and propose a conceptual design for day time passive observation of space objects. The objective is to compare various methods available for day-time observation of space debris and finalize a method along with required details for realization.</td></tr>
<tr><td>K2</td><td>Sub Area</td><td>Planetary Defense(ISTRAC)</td></tr>
<tr><td>K2.1</td><td colspan="2">Space-based Sensors for NEO Threat Mitigation (ISTRAC)
Planetary defense addresses the risk estimation and mitigation of Near-Earth asteroid impact with the Earth, which are known to have had catastrophic effects in the past, including mass extinction of several species. Almost all space-faring agencies have their own planetary defense programs and in light of the growing interest in this area, it is necessary to develop awareness and build technical capabilities in this area through suitable research. Detection, monitoring and characterization are the essential</td></tr>
</table>

	prerequisite of planetary defense. Near Earth Objects (NEOs) coming from day sky having a diameter 10 m or more is difficult to be detected by any ground based or near-Earth space-based observational facilities. But at the same time, they can be hazardous as was the case for Chelyabinsk event in 15 February 2013. The proposed research aims to conceptualize realizable space-based sensors for NEO detection and monitoring to avoid missing detection during close fly-by. The sensor needs to be located at an optimal place in deep space for timely detection of the asteroid to enable determination of the orbit, approach velocity, mass etc. and predict the highest possible accurate atmospheric entry point.	
K2.2	**End-to-end Automated Telescope System Design for NEO Detection and Monitoring (ISTRAC)** India's geographic location belongs to the void region where the International Asteroid Warning Network (IAWN) lacks ground-based sensors for asteroid monitoring. Ground based asteroid detection system in India, scanning the ecliptic plane with large field-of-view and high sensitivity will be advantageous for high cadence NEO detection and possible discoveries. This planetary defense driven project of setting up ground-based sensor will be coupled to a dedicated and integrated software application for automated detection of asteroids, measuring their astrometry, photometry and finally, accurately report to MPC. The software should facilitate a minimum human interaction by optimized and automatic task completion algorithms. The observations will not only be limited monitoring and discoveries of NEO but also their characterization in terms of rotation period, sizes, shapes and properties of their surfaces.	
K2.3	**Binary Asteroid System Characterization (ISTRAC)** Scientific understanding of binary asteroids is important in the context of planetary defense to identify the impact threat and define the mitigation strategy. It is estimated that 15% of asteroids are double (or triple) body systems. The proposed research is aimed to detect and characterize spin-orbit interaction of binary systems through modeling the data obtained from optical observations as well as archived survey data and derive binary nature of the asteroid system such as the orbital period of the primary and secondary bodies, spin state, spin-orbit coupling, their size ratio and accurate orbital parameters. The existing binary system catalogue will be augmented and strengthened not only by the discoveries of new binaries but also by follow up observation of the known ones.	
K3	**Sub Area**	**Space Debris (ISTRAC)**
K3.1	**Sparse Array for Space Surveillance & Tracking (ISTRAC)** Space Surveillance & Tracking System permit to build the space picture by maintaining the catalogue of low- earth orbit (LEO objects). Sparse array need fewer sensor element to realize a given aperture another advantage of sparse array is that they are less affected	

	by mutual coupling compared. While Minimum redundancy array and minimum hole array existed for more then five decades other sparse array such as nested array, co-prime array &super nested array have been designed with past decade. The use of sparse array in SSA System is promising as they operate with little or no degradation in performance compared to URA.	
K3.2	**Radar Resource Management Technique for Space Surveillance Radar (ISTRAC)** Radar Time Resource Allocation is generally called scheduling the effective scheduling of task competing for the radar time resources without significant delay is an important research area. The scheduling is crucial for both time allocation and sustainable operation of the radar subsystem. A simulation environment can be built which contain adoptive update rate, dynamic task prioritization, tracking & task interleaving feature. Different scheduling algorithms include multi type adaptive time balance scheduler & knapsack scheduler.	
K3.3	**Very High Resolution Imaging of Satellites and Objects (ISTRAC)** in Space, Space debris nowadays is one of the main threats for satellite systems especially in low earth orbit (LEO). The effects of an impact often are not identifiable directly from ground. High-resolution radar images are helpful in analyzing a possible damage. Furthermore investigations on unknown space objects or satellites can be performed. High-resolution radar images are obtained by using Inverse Synthetic Aperture Radar (ISAR) techniques. Different signal techniques shall be designed for determining the high resolution images like Compressive Sensing (CS) method (given the sparse nature of space debris images), randomly stepped frequency method, orthogonal coding signals with different delays and a modified Smoothed L0-norm (SL0) algorithm, single-range matching filtering (SRMF).	
K4	**Sub Area**	**Array signal processing (ISTRAC)**
K4.1	**Array Signal Processing with Model Errors (ISTRAC)** Phased array sensors are gaining wide range of applications due to its beam agility. DOA estimation and beam forming are the wide explored areas in the field of array signal processing. Current research focuses on array signal processing with ideal assumptions such as far-field sources, narrow-band signals, perfect waveforms, well-calibrated sensors, and white Gaussian noise. However model error always occurs in practical scenarios which could significantly degrade the performance of the existing algorithms. Typical non-ideal scenarios include sensor mutual coupling, gain-phase error, broken sensor, coherent sources, and non-Gaussian noise. Therefore it is extremely important to analyse the model imperfections and develop methods to improve the robustness of the array. Potential topics include the development of array signal processing algorithms with mixed coherent and non-coherent sources, mixed wide-band and narrow-band signals. Another interesting area could be the development of algorithms in the presence of mutual coupling, in the presence of gain-phase error and with partial sensor failure which are common practical problems.	

K5	Sub Area	Adaptive Debris Detection Algorithm Development (ISTRAC)
K5.1	**The Scope of this Project is to Develop Detection Algorithms for Debris Radar (ISTRAC)** capable of detecting 10 cm RCS objects at a range of 2000 km .The project aims to develop algorithms, simulation scenario as well as test and validate the algorithms. Some of the detection algorithms in the literature includes NP detector, Bayesian Detector, GLRT detectors, CFAR detectors. Adaptive/Knowledge based detections can better model the detection algorithms when the Noise Covariance Matrix is unknown. An efficient detection algorithm should be able to adaptively modify the detection threshold keeping a constant Pfa while, maximizing the Pd. An extensive literature survey of the detection algorithms is expected as part of the proposal. The final outcome would be an efficient Adaptive Detection algorithm that can detect the debris targets within the field of view so that they can be efficiently tracked.	
K5.2	**Multi–Object Tracking Algorithm for Debris Tracking Radar (ISTRAC)** The scope of this research is to develop data association and tracking algorithms for multi-object debris tracking and find which algorithm will be suitable best for tracking debris scenario. The project aims to develop the tracking algorithms with high accuracy. Some of the data association algorithms explored in literature are global nearest neighbor, joint probabilistic data association, multiple-hypothesis testing and PHD filter and tracking filters algorithms like Extended kalman filter, Unscented Kalman filter, cubature kalman filter, particle filter and Interactive Multiple model filter. The final outcome would be an efficient tracking algorithm that will be able to keep tracks of multi-debris and track them with less error.	
L	**Area**	**Radar System for Orbital Debris Detection (ISTRAC)**
L1	Sub Area	Cryo-cooled MMIC Design (ISTRAC)
L1.1	**Design of Cryo-cooled MMIC (ISTRAC)** Extremely low noise Front end Receivers are the key component to improve the system sensitivity requiring state-of-the-art performance, such as Space debris tracking, deep space missions and radio astronomy. Low noise figure with high gain MMIC Receiver chip Design, simulation and performance Evaluation for cryo temperature and room temperature at L,C,S,X and Ka band frequencies. Designed MMIC chip shall be capable to operating at temperature 4K ,15 K , 77K and 300K.	
L2	Sub Area	MEMS Design (ISTRAC)
L2.1	**MEMS based Cryo-Cooler (ISTRAC)** MEMS based J–T Cryocooler that can provide relatively high cooling power (100–1000 mW / more) with modest input gas pressure (1–2 MPa). Phased array RF front end applications that require a moderate cold-end temperature ranges from 300K-4K	

	by using Multi Stage/single Cooling. Design , modeling, CFD simulation and theoretical calculation has to be developed. System level design and simulation of compressor, micro cooler(heat exchanger, evaporator ,high pressure inlet and low pressure outlet, throttling), getter filters, mass flow meter, vacuum chamber for micro cryo cooler, sensors(pressure, catylitc heater and temperature), pressure regulator splitter, vacuum pump, reservoir.	
L3	**Sub Area**	**Radar Signal Processing (ISTRAC)**
L3.1	**Development of Real time Detection, Tracking, Range Migration, Coherent Integration & Data Association Algorithm for Multiple Object Tracking Algorithms (ISTRAC)** • Development and realization of Real time Detection algorithms for Space debris surveillance & tracking radar. The algorithms include Bayesian detector, Neyman Pearson detector & Maximum likelihood detector • Development and realization of Real time tracking algorithms include extended kalman filter, Unscented kalman filter, Cubature kalman filter, Particle filter, Gaussian sum filter & Interactive Multiple Model • Development and realization of Data Association algorithms include Global Nearest Neighbor (GNN), Joint probabilistic data association (JPDA), Multiple-hypothesis tracking (MHT), Non assignment based tracker for MTT, Probability Hypothesis Density filter (PHD) • Development and realization of Range Migration and Coherent Integration Algorithms include Keystone Transform, Second-order keystone transform (SoKT), Doppler keystone transform (DKT), Keystone-Lv's distribution (KT-LVD), Scaled inverse Fourier transform (SCIFT), Frequency-domain deramp-keystone transform (FDDKT), Modified location rotation transform (MLRT), Three-dimensional scaled transform (TDST), Radon Fourier transform (RFT), Generalized Radon Fourier	
L3.2	**Cognitive RADAR for Multiple Object Tracking (ISTRAC)** A cognitive radar system embodies three fundamental ingredients: (1) learning from the environment through experience (2) adjustment of the transmitted signal in an intelligent manner (3) feedback from the receiver to the transmitter to make this adjustment possible. A cognitive approach that learns over time may well provide a solution for the application which involves several tasks and the tasks have to be prioritized. A surveillance radar system builds up its knowledge of the environment from one scan to the next and makes decisions of interest on possible targets at unknown locations in the environment; the locations are not known before the radar is switched on, but they become determined by the radar receiver once the targets under surveillance are declared. A state-space model of the environment is adopted and recursively updating the state vector representing an estimate of certain parameters pertaining	

	to the environment. The requirement to update estimation of the environmental state is necessitated by the fact that the radar environment is non-stationary. The radar has to learn from experience on how to deal with different targets, large and small, and at widely varying ranges, all in an effective and robust manner.	
M	**Area**	**Space Physics (VSSC)**
M1	**Sub Area**	**Atmospheric Studies (VSSC)**
M1.1	**Development of State-of-the-art Inversion Techniques for the Retrieval of Aerosol Parameters over the Ocean and Land Areas from the Satellite-measured Radiance (VSSC)** Retrieval of aerosol parameters from polarization and angular measurements observed at multiple wavelength bands, incorporating multiple scattering, surface reflectance and absorption and scattering by aerosols and molecules is a challenging problem. The study can have two parts: • theoretical formulation, algorithm and software development, simulations and sensitivity analysis, • inversion of the satellite data based on the above algorithm to derive aerosol properties and its validation based on comparison with other observations	
M1.2	**Development of State-of-the-art Inversion Techniques for the Retrieval of Trace Gases over Ocean and Land from the Spectral Radiances in the UV, Visible, and IR Wavelength Bands (VSSC)** Development of state-of-the-art inversion techniques for the retrieval of trace gases over ocean and land from the spectral radiances in the UV, visible, and IR wavelength bands • Development of appropriate mathematical inversion schemes for satellite based measurements of columnar concentration and vertical profile of trace gases • Theoretical formulation and development of algorithms and software for the retrieval of trace gases, from satellite measured spectral radiances in UV, visible, and IR • Simulations using line-by-line radiative transfer codes and sensitivity analysis • Implementation of developed algorithms for the retrieval of trace gas concentration • Validation of retrieved trace gas concentrations, by comparison with other observations	
M1.3	**Numerical Modelling of the Impact of Aerosols and Trace Gases on Regional Climate over the Indian Region incorporating Space-based Observations (VSSC)** Atmospheric aerosols and greenhouse gases play a crucial role in modifying the climate, including changes in the atmospheric and surface temperatures, cloud development and precipitation pattern. Quantification of this aspect is a major challenge in the present scenario.	

	Numerical modelling of the impact of aerosols and trace gases on regional climate (including atmospheric and surface temperature, rainfall, extreme weather events) over the Indian region incorporating space-based observations is very important. This also includes the potential impact on monsoon circulation and associated rainfall changes.
M1.4	**Modelling of the Atmospheric Boundary Layer Parameters and Processes based on Improved Parameterization Schemes for Tropical Regions (VSSC)** Dynamics and time evolution of Atmospheric Boundary Layer (ABL) plays a crucial role in the transfer of mass, momentum and energy from the surface to the atmosphere, mixing of aerosols, water vapour and pollutants (including trace species), exchange with free troposphere, and development of convection and clouds. The boundary layer parameters and processes are parameterized in numerical models. Often, the ABL characteristics represented in models do not agree with those observed and is a major source of error in the numerical models, especially over the tropics. This requires the modification of the parameterization schemes for ABL parameters in numerical models. Modelling of the atmospheric boundary layer parameters and processes based on improved parameterization schemes suitable for tropical regions that reproduce the observed boundary layer fluxes and mixing height is a major problem that needs to be addressed.
M1.5	**Modelling of the Propagation of Atmospheric Gravity Waves and Planetary Waves, their Dissipation and Role in Regulating the Mean Winds and Temperatures in the Middle and Upper Atmosphere (VSSC)** Atmospheric waves of various scales and sources generated in the lower atmosphere propagate through the middle atmosphere, carrying the momentum and energy to the middle and upper atmosphere. This is one of the most importance mechanisms of coupling between different atmospheric layers. Dissipation of these waves in the middle atmosphere is a major source for regulating the thermodynamics and circulation of the middle atmosphere and a major cause for the ionospheric variabilities. Modelling of the propagation of atmospheric gravity waves and planetary waves, their dissipation and role in regulating the mean winds and temperatures in the middle and upper atmosphere is a challenging problem.
M1.6	**Modelling the Space Weather impacts over the Equatorial and Low Latitude Regions (VSSC)** Earth's ionosphere plays a pivotal role in the propagation of radio waves and has applications in GPS navigation. This requires a detailed understanding and modelling of the ionospheric processes and characteristics. There are several important aspects to be investigated in this direction. This include • the modelling of development and decay of different layers and phenomena (e.g., Spread-F, Counter Electrojet, Ionospheric ledges),

	• spatio-temporal evolution of total electron content (TEC) over the low latitude and equatorial region, • effect of dynamical forcing from the lower atmosphere, • geomagnetic effects and space weather • lateral and vertical coupling
M1.7	**Development of Three-Dimensional Physics based Ionospheric Model for the Indian Region (VSSC)** The horizontal nature of the geomagnetic field, in association with many factors such as lower atmospheric forcing, coupling of low latitude with high latitude, and the indirect impacts of geomagnetic storms make the equatorial and low-latitude ionosphere, which encompasses the Indian region, much more complex. A theoretical model is much essential to understand the day-to-day variability of the ionosphere and also for understanding the distribution of plasma over the Indian region. The study will focus on the expansion of the quasi-two-dimensional model to three dimensions by adding various components such as (a) diffusion of plasma along the magnetic field lines (b) vertical drift of plasma over the geomagnetic equator and (c) effect of neutral winds on the plasma dynamics.
M1.8	**Solar Wind Interaction with the Plasma Environments of Planets (VSSC)** The Solar activity at various timescales is manifested in the radiation levels, solar wind and magnetic fields in the heliosphere, and in transient events such as flares, Coronal Mass Ejections (CMEs) and Co-rotating Interacting Regions (CIRs). The planetary plasma environment and the interplanetary space respond to these transient changes in the Sun, which is known as space weather. Estimating the impacts of space weather is crucial to understand the state of the upper atmospheres of planets. Understanding and predicting space weather is also important in the context of protecting of the space assets from potential hazards.
M1.9	**Transportable Gravimeter (IISU)** Precision measurements are inevitable in navigation systems and cold atom based sensors is the epitome of navigation due to its potential for very high accuracy absolute measurements (acceleration: ~ 10-10g, Rate: ~ 10-7deg/hr). Researchers, world over are working towards this and demonstrated in airborne platforms and defined missions for space deployment. Proof of the concept demo for cloud formation and initial results are obtained in the laboratory model as well as transportable model. IISU is in the forefront of demonstrating such technologies in lab level and now the same have to be proved as a standalone and compact system, for deployment at testing locations. This TDP ultimately aims at developing compact quantum technology-based Accelerometer and Gyroscope using cold atom interferometry. This is the state-of-the-art development initiated by IISU as Advanced TDP on Precision Inertial Navigation Systems.

	Technologies mastered, and proved proof mass generation and atom manipulation using lasers. Initial steps of atom interferometry are demonstrated and are in the final phase to capture the gravimeter measurements.
M1.10	**Electrostatically Levitated Accelerometer Development (IISU)** Development of an Ultra-Sensitive tri-axis accelerometer based on electrostatic levitation. A parallelepiped proof-mass is enclosed in a three-parts cage made out of highly thermally stable and electrically insulating material and the mass is electrostatically levitated and maintained at equilibrium (reference) position along three orthogonal axes. The proof mass response under external forces is capacitively measured and forced to re-balance its position by control electronics. The accelerometer is capable of measuring low-frequency (1 to 10-4 Hz) forces, simultaneously along three orthogonal axes. The ultra-sensitive accelerometers are essential in measuring non-gravitational effects on spacecraft particularly in low orbit applications. This development aims to realize low-frequency; ultra-sensitive accelerometers for LEO as well as interplanetary mission spacecraft applications with suitably low drift. A multi-target sputter coater is used to deposit a electrically conductive layer over the proof-mass and the electrode surfaces realized in cage parts. The suitable thickness and type of materials need to be established from the several experiments and designer level characterization; hence a dedicated thin-film deposition tool is required with appropriate fixtures to enable uniform thickness over proof-mass covering normal surfaces. The ultra-sensitive accelerometers stability/drift parameters are majorly contributed by environmental variables such as temperature, humidity and vacuum levels. Hence a ultra high vacuum pumping station with in-situ temperature and humidity controller is essential for designer level characterization. • Mathematical modeling and analysis of the design • Design of sensors and fixtures, generating drawings • Establishing fabrication line and process parameters • Realization of fixtures, assembly and integration of the mechanical elements of accelerometer • Design and optimization of read-out and control parameters • Realization and integration of sensor electronics • Demonstration of performance and evaluation • Sensor level qualification

N	Area	Meteorology - Weather and Climate (PRL)
N1	**Sub Area**	**Radiation, Aerosols, and Trace Gases (NARL/IIRS/NRSC/PRL)**
N1.1	**Modelling of Atmospheric Chemistry and Dynamics (PRL)** Atmospheric chemistry and dynamics play key roles in impacting the air quality and climate. In this regard, modelling over varying scales (local, regional, and global) and complexities (box, chemical transport, general circulation) are being performed at PRL supported by Vikram HPC. In particular, the focus is on the modelling of atmospheric trace gases and aerosols over the South Asian region. A variety of natural and man-made emissions, together with improved representation of complex topography and detailed chemistry are included in complex earth system models. The simulations assist in interpreting observations and in predicting effects of possible scenarios. Feedbacks between atmospheric chemistry and regional climate, also through biogenic processes, are to be studied.	

Application for Grant of Funds

1.	Title of the Research Proposal	
2.	Name of the Principal Investigator (Address/Phone/E-mail)	
3.	Name(s) of other investigator(s) with the name(s) of their Institution	
4.	Name of the Institution with Full Address	
5.	Whether the Institution/University is a Government Institution or Non-Government Institution?	
6.	Is the Institution/University/Society managed by an NGO/Trust/Society If yes, provide the details	
7.	If the Institution/society is Non-Government: NGO Darpan Unique ID of the Institution* : PAN Number* : *(It is mandatory for all institutions/ professional societies other than Central/ State Govt. Institutions /Departments)	
8.	Proposed duration of Research Project	
9.	Amount of grant requested (in Rs.) 1st Year, 2nd Year, 3rd Year & Total	
	Manpower	
	Equipment	
	Satellite Data/Data	
	Consumables & Supplies	
	Internal Travel	
	Contingency (3% of the Total Project Cost)	
	Others	
	Overheads	
	Total	

10.	a) Bio-data of all the Investigators (Format-A). b) Brief description of the Research Proposal with details of budget (Format-B). c) Declaration (Format-C).
11.	I/We have carefully read the terms and conditions for ISRO Research Grants and agree to abide by them. It is certified that if the research proposal is approved for financial support by ISRO, all basic facilities including administrative support available at our Institution and needed to execute the project will be extended to the Principal Investigator and other Investigators.

Name	**Institution**	**Designation**
Principal Investigator		
Co-Investigator(s)		
Head of the Department/Area		
Head of the Institution		

Form A

Bio-data of the Investigator(s)

(Bio-data for **all the investigators** should be given, each on a separate sheet)

1.	Name	
2.	Date of Birth (dd/mm/yyyy)	
3.	Designation	
4.	Degrees conferred (begin with Bachelor's degree)	

Degree	Institution conferring the degree	Field(s)	Year

5.	Research/training experience (in chronological order)

Duration	Institution	Name of work done

6.	Major scientific fields of Interest	
7.	List of publications (Only the journal papers to be listed)	
8.	Email id and Telephone number of PI with STD Code	
9.	Email id of the Head of the academic institution	

Form B

1.	Title of the research proposal	
2.	**Summary of the proposed research** A Simple concise statement about the investigation, its conduct and the anticipated results in no more than 200 words	
3.	**Objectives** A brief definition of the objectives and their scientific, technical and techno-economic importance.	
4.	**Major Scientific fields of Interest** A brief history and basis for the proposal and a demonstration of the need for such an investigation preferably with reference to the possible application of the results to ISRO's activities. A reference should also be made to the latest work being carried out in the field and the present state-of-art of the subject	
5.	**Linkages to Space Programme and Deliverables to ISRO on successful completion of the project**	
6.	**Approach** A clear description of the concepts to be used in the investigation should be given. Details of the method and procedures for carrying out the investigation with necessary instrumentation and expected time schedules should be included. All supporting studies necessary for the investigation should be identified. The necessary information of any collaborative arrangement, if existing with other investigators for such studies, should be furnished. The principal Investigator is expected to have worked out his collaborative arrangement himself. For the development of balloon, rocket and satellite-borne payloads it will be necessary to provide relevant details of their design. ISRO should also be informed whether the Institution has adequate facilities for such payload development or will be dependent on ISRO or some other Institution for this purpose.	
7.	**Data base and analysis** A brief description of the data base and analysis plan should be included. If any assistance is required from ISRO for data analysis purposes, it should be indicated clearly.	
8.	**Available Institutional facilities** Facilities such as equipments, etc, available at the parent Institution for the proposed investigation should be listed.	

9.	**Fund Requirement** Detailed year wise break-up for the Project budget should be given as follows:

Fellowships*	**1st Yr**	**2nd Yr**	**3rd Yr**	**Total**
Research Scientist				
Research Associate				
Research Fellows				
Total				
*Note: please specify the designation, qualification and rate of salary per month for each				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Equipment**				
Total				
Please specify the various individual items of equipment and indicate foreign exchange requirement, if any				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Satellite data/data				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Consumables & Supplies				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Internal Travel				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
	Total			
Contingencies				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
	Total			
Others				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
	Total			
Overheads(Overhead Expenses of 20% of Total Project Cost not exceeding `3.00 lakhs)				
Total				

10.	Whether the same or similar proposal has been submitted to other funding agencies of Government of India. If Yes please provide details of the institution & status of the proposal.	Yes/No

**Justify each equipment. If computer is proposed, only desktop has to be purchased but not laptop.

Annexure-2

Form –C

Terms and Conditions of ISRO Research Grants

1. The approved funds should be utilized solely for the purpose for which they have been granted unless ISRO agrees otherwise. A Certification that the funds have been so used should be produced by the grantee Institution after the end of each year of the support.

2. Due acknowledgement to ISRO should be made in all reports and publications arising out of the part of the work supported by ISRO. The grantee will take prior permission of ISRO before publishing any work based on the ISRO supported project.

3. Two copies of all the publications resulting from the research conducted with the aid of the grant should be submitted to ISRO.

4. Any intellectual property rights or such information/knowledge being able to sustain or create or any such right arising out of the projects sponsored by ISRO will be held jointly by the Academic Institution/R & D institution and ISRO as per RESPOND norms. Academic Institute/R & D institution and ISRO shall inform each other before filing for any protection of any Intellectual Property Rights resulting from any of the project sponsored by ISRO. Academic institute/R & D institution and ISRO will ensure appropriate protection of Intellectual Property Rights generated from cooperation, consistent with laws, rules and regulations of India. The expenses for filling the Patent protection in India and abroad shall be borne equally between Institute and ISRO. Any/all financial accruals due to any commercial exploitation, of this patent shall be shared equally between them, on 50:50 basis. However any of the parties is free to utilize the IPR for their own use on non commercial basis.

5. The principal Investigator is required to submit two copies of yearly reports indicating the progress of the work accomplished. He is also required to submit two copies of a detailed technical report on the results of the research/development after the completion of the project. The reports will become the property of ISRO.

6. In addition, ISRO may designate Scientists/specialists to visit the Institution periodically for reviewing the progress of the work.

7. An inventory of items purchased from ISRO funds should be sent to ISRO, giving the description of equipment, cost in rupees, date of purchase and name of the supplier along with a purchase certificate from the Administration of the Institution. All items of equipments and unconsumable items costing more than Rs. 5,000/- shall remain the property of ISRO and ISRO reserves the right to transfer them or dispose of them on the termination of the project as ISRO may deem fit.

8. The accounts of the expenses incurred out of ISRO funds should be properly maintained and should be authenticated by an approved auditor. The final accounts statement in duplicate duly audit should be sent to the pay & Accounts Officer, DOS/Senior Accounts Officer, ISRO Headquarters, as the case may be, at the end of each financial year of support.

9. If the total amount sanctioned is not spent during the period of support, the remainder amount should be surrendered to the Pay & Accounts Officer, ISRO Headquarters, as the case may be, within

one month after the completion of the project.

10. The assets acquired wholly or substantially out of the ISRO grant should not, without its prior sanction, be disposed off, encumbered or utilized for purposes other than that for which the grant is sanctioned.

11. A register of assets permanent and semi-permanent should be maintained by the grantee Institution, which should be available for scrutiny by Audit.

12. The grantee institution should not divert the grants-in-aid for utilization of the same for similar objects of another institution if it is not in a position to execute or complete the assignment. The entire amount of the grant should then be immediately refunded to ISRO by the institution.

13. The terms and condition of ISRO research grants are subject to change from time to time, but the funding of any project will be governed by the terms and conditions existing on the date of starting of the project with ISRO funds.

Declaration

I / We have clearly read the above terms and conditions and hereby agree to abide by the rules and regulations of ISRO research grants and accept to be governed by all the terms and conditions laid down for this purpose.

I / We certify that I / We have not received any grant-in-aid for the same purpose from any other Department of the Central Government / State Government / Public Sector Enterprise during the period to which the grant relates.

	Signature & Name	**Designation**
Principal Investigator		
Head of the Department / Area		

Annexure-3

One hard copy and a soft copy of the proposal shall be sent to the respective ISRO/DOS Centre to the addresses given below with a copy to Respond Office, ISRO HQs by the convener of the STC/RAC-S/STICs.

RESPOND COORDINATORS OF ISRO/DOS CENTRES

Sl. No	ISRO/ DOS Centre	Name & Designation	Contact details
1.	SAC	Dr. Abha Chabra Scientist/Engineer RESPOND and Research Coordination Division Planning and Projects Group Space Applications Centre (SAC), ISRO Ahmedabad- 380015, Gujarat	Tel Phone No: 079- 26913306/3334 Email: abha@sac.isro.gov.in
2.	VSSC	Shri Santhosh Kumar S, Scientist/Engineer RESPOND Coordinator Programme Planning & Evaluation Group Vikram Sarabhai Space Centre (VSSC) ISRO PO Thiruvananthapuram : 695 022	Tel Phone No: 0471-2564620 Email: s_santhoshkumar@vssc.gov.in
3.	LPSC	Shri TV Sreejith Scientist/Engineer RESPOND Coordinator PPEG, MSA Entity Liquid Propulsion Systems Centre (LPSC) Valiamala PO Thiruvananthapuram: 695 547	Tel Phone No: 0471-2567562 Email: tvshreejith@lpsc.gov.in, respond@lpsc.gov.in
4.	PRL	Dr. Nandita Srivastava Professor and Deputy Head (Admin), Udaipur Solar Observatory Physical Research Laboratory (PRL) Badi Road, Dewali Udaipur-313001, Rajasthan	Tel Phone No: 0294-2457211 (office) Email: nandita@prl.res.in; respond@prl.res.in
5.	URSC	Dr. J Krishna Kishore Scientist/Engineer GD, ATDG U R Rao Satellite Centre (URSC) HAL Airport Road Vimanapura PO Bangalore: 560 017	Tel Phone No: 080-25084480/81 080-25084391 Email: jkk@ursc.gov.in
6.	NRSC	Shri P Krishnaiah Scientist/Engineer Head, TMD RESPOND Coordinator National Remote Sensing Centre (NRSC) Balanagar, Hyderabad: 500 037	Tel Phone No: 040-23884051 Email: krishnaiah_p@nrsc.gov.in

7.	NARL	Dr. S. Sridharan Scientist/Engineer National Atmospheric Research Laboratory (NARL) Gadanki-517 112, Pakala Mandal Chittoor, Andhra Pradesh	Tel Phone No: +91-8585-272124 Email: susridharan@narl.gov.in
8.	SDSC-SHAR	Shri Bala Narayanan N R, Scientist/Engineer PPEG / MSA Sriharikota - SDSC-SHAR Andhra Pradesh: 524 124	Tel Phone No: 08623 22 6382 Email: nrbala@shar.gov.in
9.	IPRC	Shri Nagarajan C Scientist/Engineer Manager, HRD IPRC Mahendragiri: 627 133	Tel Phone No: 04637 281776 Email: nagarajan.c@iprc.gov.in
10.	IIRS	Dr. Ashutosh Bhardwaj Scientist/Engineer RESPOND Coordinator & Head, RPMD Programme Planning and Evaluation Group (PPEG), Indian Institute of Remote Sensing (IIRS), Indian Space Research Organization (ISRO), 4 Kalidas Road, Dehradun – 248001	Tel Phone No: 0135-2524350, 4351 (Off.) Email: respond@iirs.gov.in; ashutosh@iirs.gov.in
11.	NESAC	Dr. K K Sharma RESPOND Committee Chairman Scientist/Engineer North Eastern Space Applications Centre, (NESAC) ISRO, Umiam, Meghalaya : 793 103	Tel Phone No: 0364 2570138 Email : sarmakk@gmail.com
12.	IISU	Shri K S Nandhakumar Scientist/Engineer Head-PPEG, PPED ISRO Inertial Systems Unit (IISU) Vattiyoorkavu PO Thiruvananthapuram: 695 013 Kerala	Tel Phone No : 0471 2569340 Email:ks_nandhakumar@vssc.gov.in
13.	ISTRAC	Shri Pradeep Kumar C, Scientist/Engineer Group Head, Signal Processing & Software Development Group, Radar Development Area, ISTRAC/ISRO, Plot No 12 & 13, 3rd Main, Phase II, Peenya Industrial Area, Bangalore-560058	Tel Phone No :+91-80-28094489 Email: pradeepkc@istrac.gov.in

14.	MCF	Shri S.N. Jaggannatha, Scientist/Engineer Master Control Facility, Hassan-573201 Karnataka	Tel Phone No : 08172-273112 Email: jagannath@mcf.gov.in
15.	HSFC	Smt. Ramya V Scientist/Engineer RESPOND Coordinator MSA, Human Space Flight Centre (HSFC), ISRO HQ, Bangalore 560094	Tel Phone No : 080-22172643 Email: ramya-hsfc@isro.gov.in

RESPOND&AI

CAPACITY BUILDING & PUBLIC OUTREACH (CBPO)

Indian Space Research Organisation

Headquarters, Bengaluru