Title: PARIDHI – 6U Nanosatellite constellation mission for observation and study of the Van Allen Belt

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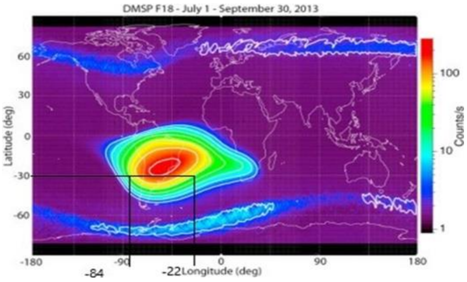
Need:

Studying the Van Allen Belt is important due to the potential hazards it poses and the intriguing presence of antimatter within its confines. The need to comprehensively investigate this radiation-rich region, characterized by high-energy particles, arises from the importance of protecting human space exploration and unraveling the mysteries surrounding antimatter's abundance in such an environment.

The Van Allen Belt presents a formidable challenge for space exploration due to its intense radiation levels. Energetic particles, including electrons and protons, can damage critical spacecraft systems, disrupt communication, and pose health risks to astronauts. A thorough understanding of the belt's formation, dynamics, and radiation characteristics is crucial for developing effective shielding strategies, spacecraft design modifications, and radiation mitigation techniques to ensure the safety and success of future missions.



Mission Objective:

The primary objective of the mission is to conduct an in-depth study of the Van Allen Belt, considering its unique characteristics of limited antimatter confinement and high radiation levels. The satellite will be specifically designed to navigate through the ***South Atlantic Anomaly (SAA)***, a region within the belt where the radiation levels are particularly intense.

1. **Radiation Environment Analysis:** The mission aims to analyze the Van Allen Belt's radiation environment using advanced instruments. By measuring radiation levels, energy spectra, and particle fluxes, it will provide crucial data for assessing hazards to spacecraft and future human missions. This will enable the development of effective shielding strategies and radiation mitigation techniques.
2. **Antimatter Confinement Investigation:** The mission's focus is to study antimatter confinement in the Van Allen Belt. Using specialized detectors and spectrometers, it aims to determine the presence, abundance, and distribution of antimatter particles in this region. Insights gained from understanding antimatter's interactions with the belt's radiation and magnetic fields will shed light on the underlying processes and conditions required for antimatter generation and stability.
3. **Correlation between Radiation and Antimatter:** The mission investigates the correlation between high radiation levels in the Van Allen Belt and antimatter presence. By analyzing data, it aims to understand interactions and dynamics in the belt, shedding light on radiation effects on antimatter confinement.
4. **Space Exploration and Technological Implications:** The mission's findings have significant implications for space exploration and technology. By understanding the radiation environment and antimatter confinement in the Van Allen Belt, the objective is to improve spacecraft design, radiation shielding, and advanced materials. These insights will also advance research in particle physics, astrophysics, and the potential use of antimatter for energy production and propulsion systems.

Concept of Operations:

Ground Segment: The IIST ground station will be utilized for satellite communication due to the specific orbit trajectory that ensures regular coverage over the Indian subcontinent.

Space segment [Detail description in the next section]:

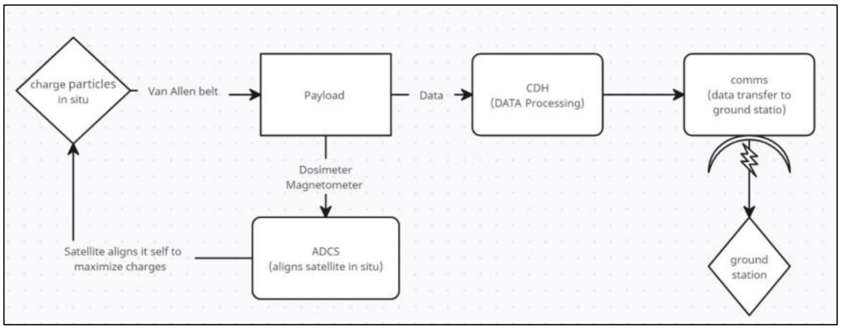


Fig.1: Flowchart showing the data collection and transmission process to the ground stations.

In a single revolution, our satellite payloads generate an estimated ***data volume*** of approximately ***180 megabytes.*** To facilitate payload telemetry, we utilize the ***S band***, which operates at a data rate of ***500 kilobits per second (kbps).*** This band enables us to efficiently transmit telemetry data related to the satellite's payload.

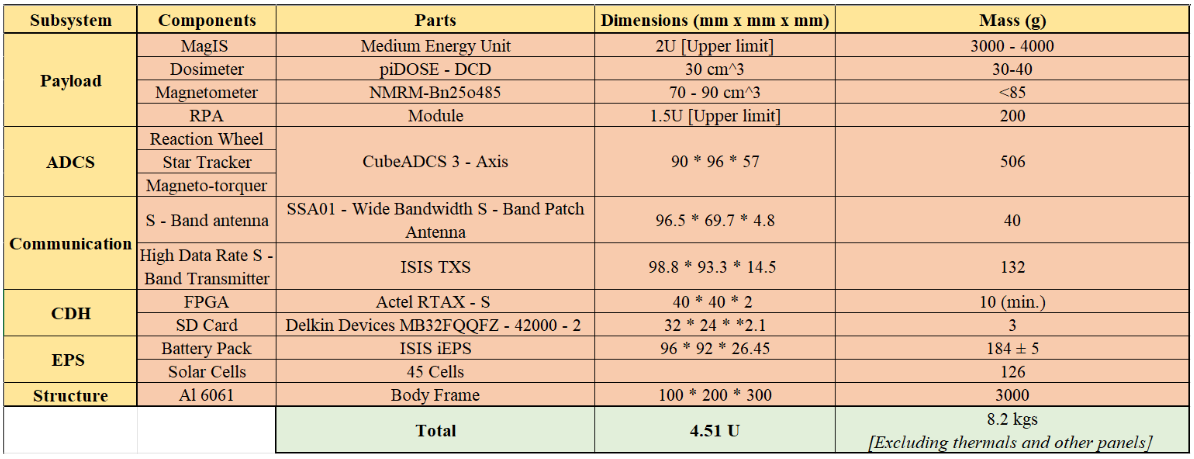
For telemetry tracking and communication purposes, we leverage the ***UHF band***. This band allows us to establish effective communication links and track the satellite's movement and operational status. Our satellite experiences a peak power consumption of approximately ***20 Watts***. To ensure operational efficiency, we have a ***margin of about 55%,*** which translates to an available power of ***31 Watts.***

The satellite's power management system dynamically ***adjusts its orientation*** based on sunlight conditions. During periods of sunlight, the satellite aligns its solar panels to face the sun, maximizing energy absorption. Additionally, to enhance communication capabilities, the satellite keeps its ***antenna pointed towards the nadir*** direction. This alignment optimizes signal reception and transmission for better communication performance.

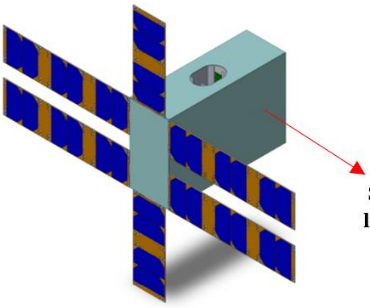
Key Performance Parameters:

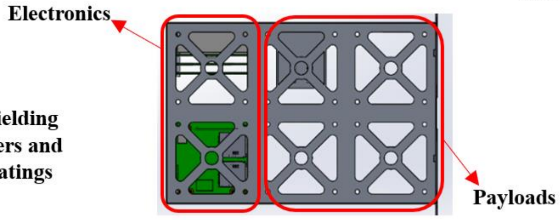
1. The payloads have been engineered to ***operate exclusively during their passage*** through the South Atlantic Anomaly (SAA) and the Van Allen Belt. They will remain deactivated during other phases of the mission.
2. To guarantee that tests are carried out effectively [precise positioning of the spacecraft], it is necessary to achieve a ***pointing accuracy of ± 5 degrees***. The spacecraft's ***magnetometer and dosimeter payloads*** are essential to obtaining this accuracy.
3. Protecting the equipment and onboard electronics is crucial due to the high-energy environment in which the CubeSat is operating. Numerous actions have been taken to secure their protection in order to address this issue. These include the application of ***proper thermal coatings, charge dissipation coatings, and radiation shielding*** using carefully selected materials and the appropriate thickness. These safety precautions reduce the dangers of potential charge accumulation, temperature changes, and radiation exposure, guaranteeing the instrument and electronics' integrity and performance during the flight.

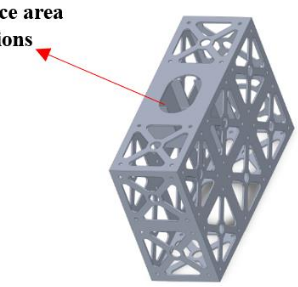
Space Segment Description:



Subsystem	Components	Parts	Dimensions (mm x mm x mm)	Mass (g)
Payload	MagIS	Medium Energy Unit	2U [Upper limit]	3000 - 4000
	Dosimeter	piDOSE - DCD	30 cm^3	30-40
	Magnetometer	NMRM-Bn25o485	70 - 90 cm^3	<85
	RPA	Module	1.5U [Upper limit]	200
ADCS	Reaction Wheel	CubeADCS 3 - Axis	90 * 96 * 57	506
	Star Tracker			
	Magneto-torquer			
Communication	S - Band antenna	SSA01 - Wide Bandwidth S - Band Patch Antenna	96.5 * 69.7 * 4.8	40
	High Data Rate S - Band Transmitter	ISIS TXS	98.8 * 93.3 * 14.5	132
CDH	FPGA	Actel RTAX - S	40 * 40 * 2	10 (min.)
	SD Card	Delkin Devices MB32FQQFZ - 42000 - 2	32 * 24 * *2.1	3
EPS	Battery Pack	ISIS iEPS	96 * 92 * 26.45	184 ± 5
	Solar Cells	45 Cells		126
Structure	Al 6061	Body Frame	100 * 200 * 300	3000
		Total	**4.51 U**	8.2 kgs *[Excluding thermals and other panels]*







Payloads:

The payload for this mission consists of a magnetic ***ion mass spectrometer, retarding potential analyser, Geiger counters, and a magnetometer***. Together, they provide us with information on the main parameters to understand the space weather along the orbit, especially the SAA (South Atlantic Anomaly) region.

The ***spectrometer*** will be used to measure the ***energy and momentum of the charged particles*** in the region using an artificially created uniform magnetic field in a lead-lined chamber. The ***potential analyser*** gives information on the ***arrival direction and energy distribution*** of both ions and electrons up to 100 eV. The ***Geiger counter and magnetometer*** are used to measure the ***extent of radiation*** and the ***directional vector of the magnetic field*** present in the region respectively, which will also serve in directing the orientation of the satellite to allow for better collection of data.

Orbit/ Constellation Description:

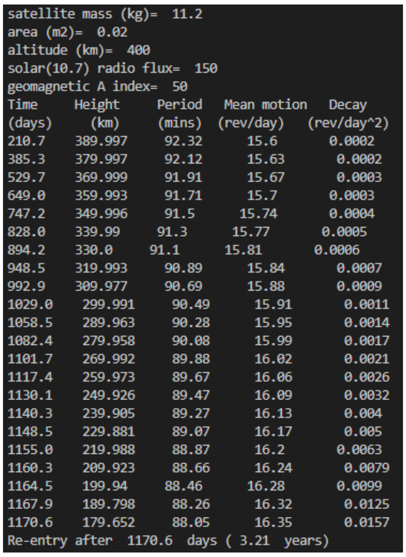
400km alt and 31 degrees inclination

400km alt and 25 degrees inclination for narrowness

In our planned constellation, we have designed ***four satellites*** to work in tandem, each playing a specific role.

Two of these satellites will be positioned in a ***400 km orbit***, with a ***pointing angle of 31 degrees and 25 degrees*** respectively. These satellites will operate in close proximity to each other, allowing for efficient ***data exchange and coordinated functions***. The other two satellites will be placed in a ***600 km orbit***, with ***pointing angles of 25 degrees and 31 degrees*** respectively. This orbital distribution ensures optimal coverage across the target area, particularly within the Van Allen Belt region.

The constellation of four satellites will collectively enhance the coverage area of the Van Allen Belt, enabling comprehensive data collection and analysis of the space environment within this region. In terms of data transmission, the ***two satellites*** in the 600 km orbit will serve as ***data relays.*** They will ***transfer their collected data*** to the two satellites in the 400 km orbit. These two closer satellites will act as intermediaries and further relay the received data to the ground station using the ***S-band frequency***. This setup ensures efficient and reliable data transfer from the higher orbit to the ground station.



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satellite mass (kg)=  11.2
area (m2)=  0.02
altitude (km)=  400
solar(10.7) radio flux=  150
geomagnetic A index=  50
Time      Height     Period    Mean motion    Decay
(days)     (km)      (mins)   (rev/day)   (rev/day^2)
210.7    389.997     92.32      15.6        0.0002
385.3    379.997     92.12      15.63       0.0002
529.7    369.999     91.91      15.67       0.0003
649.0    359.993     91.71      15.7        0.0003
747.2    349.996     91.5       15.74       0.0004
828.0    339.99     91.3       15.77       0.0005
894.2    330.0     91.1       15.81       0.0006
948.5    319.993     90.89      15.84       0.0007
992.9    309.977     90.69      15.88       0.0009
1029.0    299.991     90.49      15.91       0.0011
1058.5    289.963     90.28      15.95       0.0014
1082.4    279.958     90.08      15.99       0.0017
1101.7    269.992     89.88      16.02       0.0021
1117.4    259.973     89.67      16.06       0.0026
1130.1    249.926     89.47      16.09       0.0032
1140.3    239.905     89.27      16.13       0.004
1148.5    229.881     89.07      16.17       0.005
1155.0    219.988     88.87      16.2        0.0063
1160.3    209.923     88.66      16.24       0.0079
1164.5    199.94     88.46      16.28       0.0099
1167.9    189.798     88.26      16.32       0.0125
1170.6    179.652     88.05      16.35       0.0157
Re-entry after  1170.6  days ( 3.21  years)
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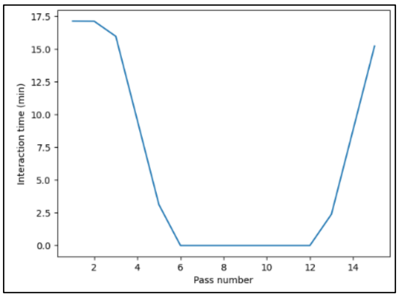
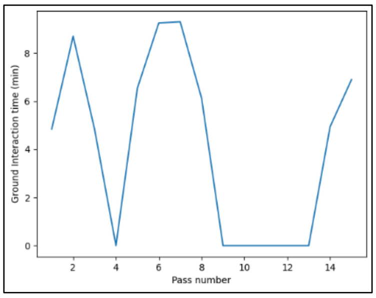
According to simulations, the ***satellite's life*** *(before re-entry)* is approximately ***3.21 years*** (as seen in the image).

The satellite can perform ***15 orbits in a single day*** with a ***time period of 1.56 hrs***. These two graphs give us a decent idea of how long the payloads interact with the environment per orbit and how long the interactions with the ground stations last.





ADCS:

The first key sensor employed in the ADCS is the ***Sun sensor***. By monitoring the position and intensity of the Sun relative to the satellite, the Sun sensor provides crucial information for attitude determination and navigation. This data is essential for establishing a reference frame and maintaining the satellite's orientation in space, ensuring accurate measurements and data collection during the mission.

The second sensor utilized is the ***Nadir sensor***. This sensor observes the Earth's surface directly below the satellite and aids in determining the satellite's attitude relative to the Earth. By continuously monitoring the nadir point, the Nadir sensor provides valuable feedback for attitude control, ensuring that the satellite remains aligned with the desired observation targets and orbits.

Additionally, a ***magnetometer is integrated*** into the ADCS to measure the Earth's magnetic field. This sensor helps determine the ***satellite's orientation relative to the Earth's magnetic field***, which is particularly important for studying the Van Allen Belt and the SAA. The magnetometer data allows for the accurate mapping of magnetic field variations, aiding in understanding the complex interactions between the Earth's magnetic field and the radiation particles present in the SAA.

Power requirements:

Components	**Communications**	**ADCS**	**CDH**	**Payload**			
				MagIS	**Magnetometer**	**Dosimeter**	**RPA**
Power (W)	6	5	3	~ 4.5	≤ 0.75	~ 0.07	~ 0.12

Command and Data Handling (CDH):

- Data volume: ***200 MB/rev***.
- ***RAD750 Microprocessor:*** A ***radiation-hardened*** and high-performance processor used in space applications' On-Board Computer (OBC) boards.
- ***Actel RTAX FPGA***: A powerful Field-Programmable Gate Array (FPGA) used in Satellite On-Board Computer (OBC) board development.
- ***Delkin Devices MB32FQQFZ-42000-2 SD Card***: An essential component for satellite On-Board Computer (OBC) board development.
- The ***ADCS*** utilizes an ***RS-485 interface***, ensuring efficient data exchange for precise attitude control. The ***EPS (Electrical Power System)*** communicates through an ***I2C interface*** for ***power management*** and a ***UART*** interface for ***telemetry and control***. ***External storage*** is facilitated by an ***SPI interface***. ***Communication*** interfaces include ***RS-232 and UART***. the payload subsystem consists of multiple components such as MagEIS (interface: ***100BASE-TX***), Magnetometer (interface: ***100BASE-TX***), Geiger Counter (interface: ***USB***), and RPA (interface: ***100BASE-TX***)

Implementation Plan:

- **Pre-Launch Preparations:**

- The design of structures and payload will be done in ***IIST in collaboration with SSPACE*** (Small-spacecraft Systems and Payload Centre) and ***ISRO***.
- The manufacturing and assembly will be done in IIST with help from national or international collaborators for specific subsystems.

- The payload sensors and electronics (with shielding) will be ***tested in a vacuum chamber*** (***ISRO or EPDL lab in IIST***) and their behaviour will be studied and simulated under similar charged and high radiation and magnetic environments as present in the Van Allen belt.
- Vibration and thermal testing will also be performed to ensure the satellite's robustness.
- Establish ground stations in strategic locations with international collaborators.

- **Launch Phase:**
- Integrate nanosatellites onto the ***PSLV rocket*** and choose a launch window to achieve the desired orbit.
- Conduct thorough testing and simulations to validate the satellite's behaviour under the high acceleration phase of launch.

- **In-Orbit Operations**:
- Continuously monitor solar panel performance and degradation, utilizing algorithms to optimize power generation.
- Utilize established ground stations, for continuous communication and tracking, implementing redundancy and error-correction coding to enhance reliability.

The major risks in order of criticality are as follows:

1. Not reaching the desired orbit due to launch or ejection failures.
2. Communication failure during initial power up or due to the highly charged environment and debye sheath formation around the antenna in the Van Allen belt.
3. Failure to deploy solar panels (reasons include compromised mechanism due to high inertial forces during launch).
4. Reaction wheel/ torque rod failure (will cause the satellite to tumble out of control and leave directional payloads inoperable).
5. Single event upsets (due to cosmic rays or shielding failure; can be handled with error correction codes or restarting the satellite).

Risk Mitigation:

- Implement radiation-hardened components, shielding, and redundancy in satellite design to mitigate radiation damage.
- Conduct extensive testing and simulations to verify the reliability of solar panel deployment mechanisms in radiation-prone environments.
- Develop robust communication protocols and backup plans to ensure reliable communication in the presence of radiation-induced interference.

Contingency and Recovery:

Develop contingency plans and procedures to address potential failures, such as satellite loss, communication disruptions, ADCS failure, or solar panel degradation.

References:

1. Kirby, Karen, et al. "Successes and challenges of operating the Van Allen probes mission in the radiation belts." *2015 IEEE Aerospace Conference*. IEEE, 2015.
2. Gilmore, David G., ed. *Spacecraft thermal control handbook: Fundamental technologies* Vol. 1. AIAA, 2002.