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A Very Low Altitude Satellite for Equatorial Ionosphere Measurements

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ABSTRACT

The Satellite Research Centre at Nanyang Technological University is currently developing the Atmospheric Coupling and Dynamics Explorer (ARCADE) Mission, which is flying a hall effect thruster to progressively lower the altitude from an initial 500 km to 250 km. ARCADE is also the fourth satellite in the INSPIRE (International Satellite Program in Research and Education) satellite series with joint development from IIST, India and NCU, Taiwan. ARCADE is a 27U spacecraft carrying an ionospheric plasma payload which will make ion temperature, velocity, density and electron temperature measurements. The satellite will be launched along with six other Singaporean satellites on a Singapore dedicated PSLV in 2020 into a near equatorial orbit. Since the final altitude is expected to be 250 km, the ARCADE/INSPIRESat-4 mission provides an excellent opportunity to study the equatorial ionosphere at low altitudes where the ion and electron density are much higher. The mission is expected to provide new information on plasma irregularities along the magnetic equator. The mission is also a technology demonstration of a hall effect thruster developed by French Startup 'Thrust Me'. Another addition to the mission is a Spatial Heterodyne Interferometer Infra-Red Imager for imaging the Mesosphere and Lower thermosphere region between 60-120 km. The SHI instrument will provide temperature information and help for understanding the dynamics of the equatorial MLT region. The presentation will cover the teams approaches to dealing with Very Low Earth Orbit (VLEO) and the challenges it poses in terms of thermal and atomic oxygen effects.

INTRODUCTION

The Atmospheric Coupling and Dynamics Explorer is a 27U micro-satellite currently being developed at the Satellite Research Centre at Nanyang Technological University for flight in 2020. ARCADE is being built in collaboration with other universities in the International Satellite Program for Research and Education (INSPIRE)[1]. ARCADE is the fourth mission in the INSPIRE series of satellites. The science objectives of the ARCADE mission are to understand the dynamics of the equatorial ionosphere and explore the temperature structure of the Earth's Mesosphere and Lower Thermosphere (MLT).

ARCADE carries an ion propulsion thruster to lower its orbit to less than 300 km to make in-situ ionospheric measurements. The thruster is expected to enable the mission to survive under 300 km for a duration of 6 months or more. The mission objectives of the ARCADE mission are as follows:

(1) In-situ measurement of plasma irregularities along the magnetic equator. Characterize the formation and evolution of ionospheric anomalies like plasma bubbles and its effects on GPS signal scintillation.

(2) Perform in-situ measurements of ionospheric plasma below 300 km in altitude.

(3) Quantify the role of wave dynamics in the upward and downward coupling of the MLT region and its influence on the dynamics and variability of the MLT region.

(4) Image the equatorial region at a high resolution.

PAYLOADS

The ARCADE mission carries the following payloads.

1. Compact Ionosphere Probe (CIP)

The Compact Ionosphere Probe (CIP), developed by Space Payload Laboratory at NCU, is a successor to the Advanced Ionospheric Probe[2] aboard the FORMOSAT-5 satellite. CIP is an all-in-one plasma sensor that uses a single instrument to perform multiple sensor functions in a time-sharing mechanism. The CIP instrument needs to be pointed in the RAM direction to make the measurements.

The CIP performs in-situ measurements of the ionospheric plasma compositions, ion concentrations, velocities, and temperatures to explore the terrestrial ionosphere. The CIP instrument is being flown in a mid-latitude orbit in the INSPIRESat-1 mission and in a polar sun-synchronous orbit on the INSPIRESat-2 mission. Together with INSPIRESat-4 in an equatorial orbit, a constellation of such instruments is expected to be operational by Q4 of 2020 providing ionospheric measurements at a range of altitudes and local times.

The data collected by the CIP will give insight to ionospheric phenomena like plasma bubbles and mid-night temperature maxima. The plasma bubbles can cause scintillation in the GPS signals. The ion density will identify the plasma bubbles since the satellite will pass through these bubbles at some angle which will be indicated by the sudden drop in the ion density measurement of the CIP. Figure 1 shows the mechanical structure of CIP.

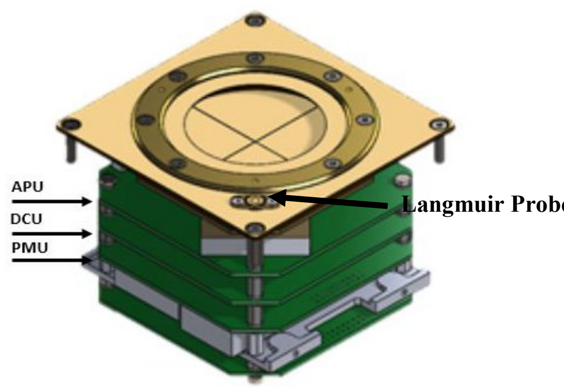

Figure 1: CIP mechanical structure

The CIP contains three circuit boards:

1. Analog Preprocessing Unit (APU): It transduces currents from sensor into digital signals.
2. Digital Control Unit (DCU): It controls digital to analog/analog to digital converters (DA/ADs) on APU board, monitors PCBs' temperature, and receives commands/sends science data from/to C&DH.
3. Power Management Unit (PMU): It supplies and regulates necessary powers for CIP.

Table 1: CIP specifications

Parameters	Value
Mass	0.5 Kg (< 1 Kg)
Dimension	0.7 U
Voltage	12 V
Power	3.45 W
Interface	UART, 115200 bps (RS422)
Connector	9-pin D-sub female.

The specifications of the CIP is present in table 1. The data is transferred to the C&DH using UART with RS422 encoding.

Modes of Operation

CIP has the following operation modes:

1. Planar Langmuir Probe (PLP): Measures electron temperature (T_e).
2. Ion Drift Meter (IDM)/Ion Trap (IT): Provides arrival angles (θ_v and θ_H) of ion velocity (V_i) and ion density (N_i).
3. Retarding Potential Analyzer (RPA): Measures ion temperature (T_i), ion composition (C_i), ion density (N_i) and ion ram velocity (U_r).

2. *ATMOLITE*

AtmoLITE is a highly miniaturized limb sounder utilizing a monolithic spatial heterodyne interferometer for day and nighttime atmospheric temperature sounding. Atmospheric temperature profiles are obtained by limb-sounding O2 A-Band emissions at a wavelength of 762 nm from a low Earth orbit[3]. It is a complete remote sensing instrument with optics, detector, electronics, structure, and a radiator. Figure 2 gives an overview of the AtmoLITE design.

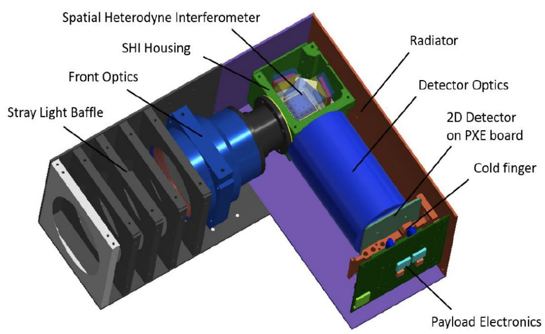

Figure 2: AtmoLite mechanical structure

Light enters the instrument through the baffle and a band pass filter. The front optics focuses the atmospheric scene onto the gratings of the spatial heterodyne interferometer (SHI). The light is dispersed at the gratings and forms a fringe pattern at the exit of the interferometer. The detector optics images this fringe pattern onto the 2-dimensional Limb Sounding Detector (LSD) in CMOS technology. The detector image provides spectral and spatial information simultaneously. In the direction perpendicular to the grating grooves the interferogram is encoded. The dimension parallel to the grating grooves contains the spatial information which shall be the vertical profile of the atmospheric scene. Therefore, it is essential that the attitude of the detector optics is horizontal with respect to the horizon and the Line-of-Sight (LOS) is pointed to ~90 km.

The two-dimensional limb sounding detector is operated by a proximity electronics (PXE), which sends the data to the front-end electronics (FEE), which handles the communication with the satellite, provides house-keeping data, etc. The field of view (FOV) of the limb sounder is ~2 deg, which corresponds to an altitude range of approximate 60 km at the limb. The region of interest is in the Mesosphere and Lower Thermosphere (MLT) between 60 km and 120 km.

ARCADE/INSPIRESAT-4 SPACECRAFT

The ARCADE/INSPIRESat-4 spacecraft has heritage from the INSPIRESat-1 & 2 missions with a common architecture for the Command and Data handling and Power systems. Figure 3. Shows the electrical block diagram of the spacecraft.

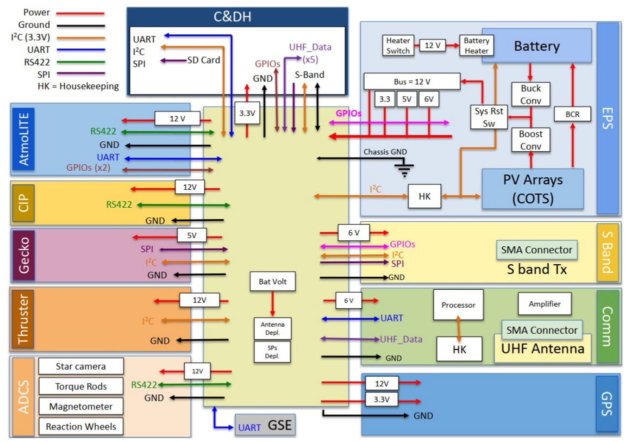

Figure 3: Electrical Block Diagram

Figure 4 shows the spacecraft in the deployed configuration with the internal components. The spacecraft has a mass of 26 kg and dimensions of 30x30x30 cm. The spacecraft has three deployable panels each with a 30x30 cm size and a body mounted panel of the same size accommodating 21 AzureSpace solar cells each. The solar panels can produce 85W of power BOL. The spacecraft has two battery packs with one primarily used for spacecraft operations and having 48 Whr capacity and the second battery pack with 125 Whr capacity being used primarily for the electric propulsion thruster operations.

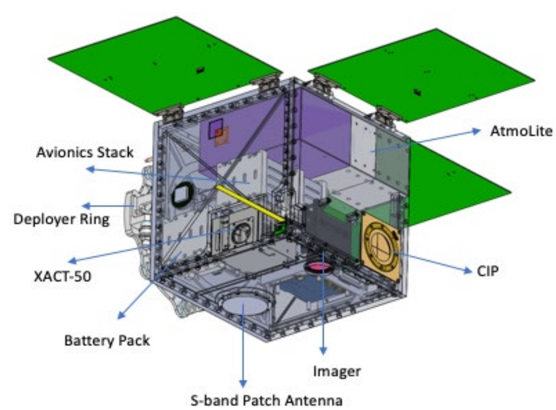

Figure 4: ARCADE Internal structure in deployed configuration with CIP pointed RAM.

Table 2: ARCADE Subsystems and TRL

Subsystem	Short Description	TRL
Payload	Compact Ionosphere Payload (CIP)	8
	AtmoLite	9
C&DH	INSPIRE CDH (self-developed)	7
Power	INSPIRE EPS (self-developed)	7
Structure and Thermals	Self - developed	7
ADCS	XACT, Blue Canyon Technology	9
Communication	UHF - Endurosat STX - Clyde Space/CPUT	9
Propulsion	Thurstme NPT-30	7
Imager	SAS Gecko Imager	9

ARCADE spacecraft details are presented in-depth by Srivastava et al[4].

Spacecraft Concept of Operations

The ARCADE spacecraft is designed for one year of operation with the first six months dedicated to collecting science data and the next six months for active deorbiting of the spacecraft to a Very Low Earth Orbit (VLEO). The launch vehicle is expected to put the spacecraft into a 540 x 450 km altitude (6918 x 6828 km), 5 degree inclined orbit.

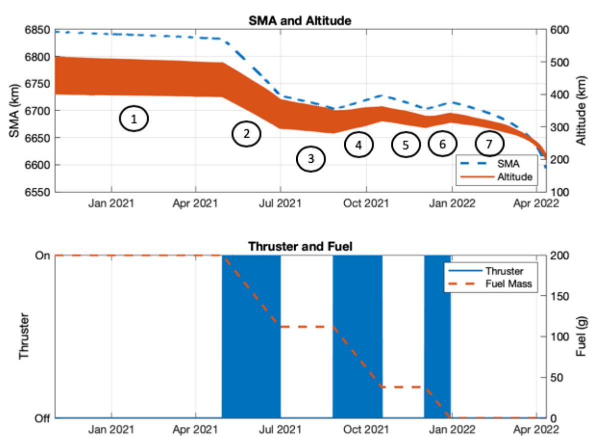

Figure 5: ARCADE orbit during the mission life (top) and thruster fuel consumption (bottom).

Figure 5 shows the planned phases of the mission. During phases 1,3,5 and 7, the thruster is switched off and the spacecraft deorbits due to atmospheric drag. In phase 1 for the first 6 months after launch the spacecraft is collecting science data and deorbits about 20 km due to atmospheric drag during this phase. The thruster is turned on during phase 2 to actively bring the orbit altitude to ~ 325 km in two months. The NPT30-thruster from ThurstMe nominally produces 600 mN of thrust at about 60W of power. During phase 3, the satellite deorbits rapidly due to increased drag at the VLEO. The thrusters are fired during phase 4 to increase the altitude back to 350 km. This is repeated during phase 5 and 6 before the satellite orbit decays during phase 7 and deorbits once the thruster is out of fuel.

During thruster firing, the payloads are switched off and once thruster firing is completed during one orbit, the next two orbits are used for battery charging. The different modes of operation of the spacecraft and the sub-systems that are operational during each phase are shown in figure 6.

Subsystem	Emergency Modes		Nominal Modes			
	Phoenix	Safe	Science	Thruster		
				Charge	Eclipse	Operation
C&DH	ON	ON	ON	ON	ON	ON
EPS	ON	ON	ON	ON	ON	ON
ADCS	OFF	Coarse Sun	ON	ON	ON	ON
CIP-Payload	OFF	OFF	ON	OFF	ON	OFF
AtmoLITE	OFF	OFF	ON	OFF	ON	OFF
GECKO	OFF	OFF	ON	OFF	ON	OFF
UHF Rx	ON	ON	ON	ON	ON	ON
UHF Tx	Beacon	Beacon	ON	ON	ON	ON
S-band Tx	OFF	OFF	ON	OFF	ON	OFF
Thruster	OFF	OFF	OFF	OFF	OFF	ON
Battery Heater	As Required	As Required	As Required	As Required	As Required	As Required

CONCLUSION

ARCADE/INSPIRESat-4 is a Singapore led mission being developed via an international collaboration. The mission is expected to obtain in-situ measurements of equatorial ionospheric plasma between 250 km -350 km for a duration of 6 months. This would be an unprecedented dataset for such measurements from a small satellite platform. This will lead to better understanding and prediction of ionosphere plasma anomalies and possibly scintillation effects on GPS in the equatorial region. Additionally, the MLT temperature measurements are expected to give insight into gravity wave effects on MLT temperature and their effects on upward and downward coupling of the upper atmosphere.

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