Title: Smallsat Ionosphere Exploration at Several Times and Altitudes (SIESTA)

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Need

Plasma bubbles in the Earth's ionosphere can cause scintillation in GPS or radio signals as they pass through these density anomalies causing communication disruptions on the ground. These bubbles are transient features of the atmosphere and are difficult to measure in 3-dimensional space. A constellation of satellites, like the one proposed here, measuring properties of the Earth's ionosphere at different altitudes and inclinations can provide deeper insights to the structure and occurrence characteristics of these bubbles. A secondary goal is to better understand the midnight temperature maximum whose causal nature is not well understood. These goals are uniquely addressed by small satellite due to their rapid production rate and lower orbital altitude requirements. This program also introduces academic curriculum which is inclusive and open to all allowing anyone to participate in meaningful aerospace projects.

Mission Objectives

1. Characterize the temporal and spatial distribution of plasma bubbles
    a. Plasma bubbles occur primarily around sunset and midnight at low latitudes but their distribution across longitudes, latitudes, and time remains an important area of study
2. Characterize the three-dimensional structure of plasma bubbles
    a. Several in-situ instruments taking coordinated measurements with proximity in time and space allow the possibility that some plasma bubbles will be sampled at three different altitudes and through 3 different line of sight profiles. With this information, the bubbles size and growth pattern may be better understood.
3. Characterize the spatial and temporal distribution of the Midnight Temperature Maximum
    a. The MTM is a neutral temperature bulge around midnight local time at low latitudes in an otherwise cooling ionosphere. This transient feature of the ionosphere is not well understood and is only captured in very few atmospheric models. High density measurements like those provided by this constellation allow greater insight into the occurrence characteristics of the MTM.

Concept of Operations

INSPIRESat-1 and IDEASSat

The International Satellite Program in Research and Education's first satellite (INSPIRESat-1) and the Ionospheric Dynamics Explorer and Attitude Subsystem Satellite (IDEASSat/INSPIRESat-2) are both carrying the same compact ionosphere probe (CIP) payload and will operate with the same concept of operations shifted in time to accommodate different launch dates. The INSPIRESat-1 is slated for launch in November of 2019 while the IDEASSat is targeted for the middle of 2020. Both satellites are expected to complete a 6-month primary mission with plans to continue operations beyond that until the satellite re-enters the Earth's atmosphere about a year after launch. The CIP must be pointed in the ram direction during science operations and thus the space segment of the mission is relatively simple.

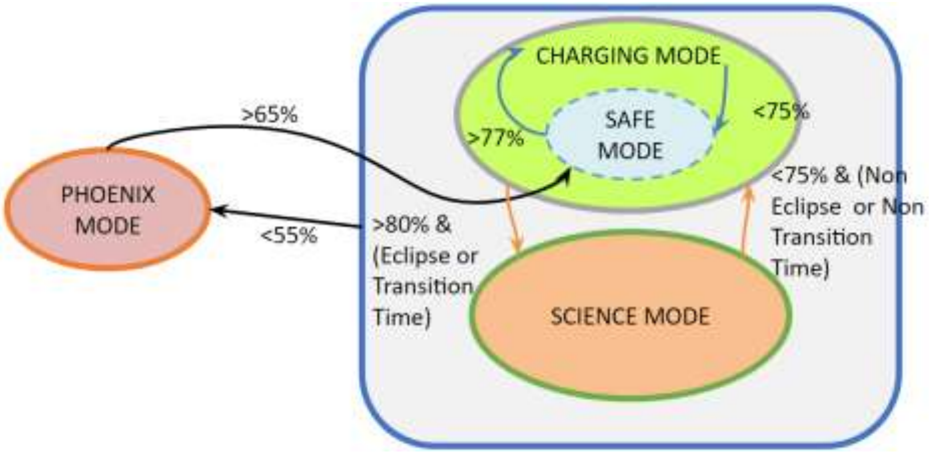
Nominal operations switch between charging and science modes in sun or eclipse respectively. There are two emergency modes as well and switching between all modes is either controlled by the depth of discharge of the battery, an anomaly, or manual switching of modes on the ground (see Figure 1). In charging mode, the spacecraft aligns the solar panels to the sun while keeping the S-band antenna as close to nadir pointed as possible and keeping the field of view keep out zones of the star tracker clear. In science mode, the spacecraft points the CIP in the ram direction while maintain the same requirements of charging mode for the star tracker and s-band patch antenna. These modes of operation have been set based on power requirements and the science objective of the mission.

A ground network of several UHF and S-band capable ground stations is employed. Primary data downlink will be completed over S-band at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado. Command and control of the spacecraft will be completed over UHF at LASP or the National Central University in Taiwan. The INSPIRESat-1 will launch onboard a Polar Satellite Launch Vehicle with the Indian Space Research Organization and IDEASSat will launch as a secondary payload onboard another rocket provider.

FORMOSat-5

The FORMOSat-5 was launched on August 24, 2017 and is being operated by the National Space Organization of Taiwan. As a result, the FORMOSat-5 is a passive element of this constellation mission. No control over the space, ground, or general operations is possible by our team. However, we have acquired early ion density data from the Advanced Ionosphere Probe (AIP, larger version of CIP) which looks good and bodes well for the miniaturized versions onboard the microsats.

Figure 1: Modes of Operation for the INSPIRESat-1 and IDEASSat



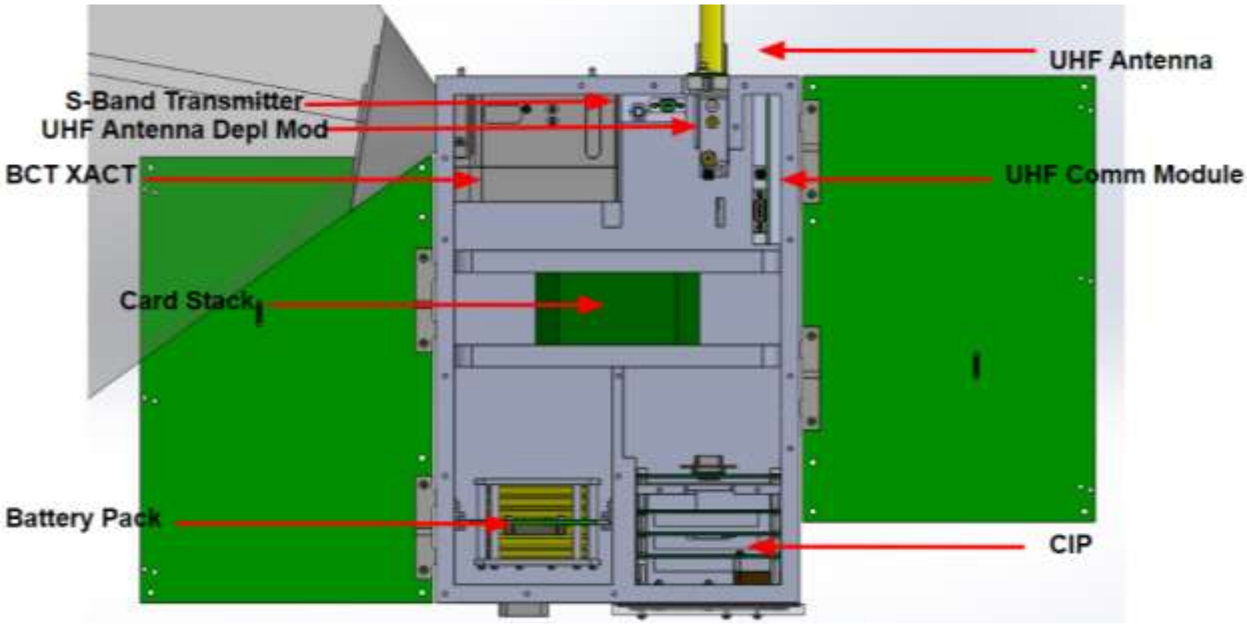
Key Performance Parameters

1. The spacecraft shall be able to measure the in-situ plasma density (Ni) at a range between 10^3 to 10^6 cm^{-3} at a sensitivity of 1% and accuracy of 10%.
2. The spacecraft shall be able to measure the ion velocities cross track and ram direction at a range ±2.5 kms^{-1} and ±7.5kms^{-1} (ram) at a sensitivity of ±10 ms^{-1} and ±100 ms^{-1} (ram) and accuracy of ±50 ms^{-1} and ±200 ms^{-1} (ram)
3. The satellite shall be able to point in the RAM direction with ±0.5° (3-sigma) pointing accuracy

Space Segment Description

The INSPIRESat-1 is a custom microsat (~9U) and the IDEASSat is a 3U cubesat. The INSPIRESat-1 is using an ISRO developed IWL 150 ring separation system and thus does not conform to the cubesat standard. Both the INSPIRESat-1 and IDEASSat will use the same internal components and thus for simplicity we focus on details of the INSPIRESat-1. Below in Figure 2, is a CAD drawing with explanatory text of the satellite bus and components. The satellite is 8.6 kg and has a maximum power consumption of 11.6 W and a worst-case power generation of 13.8 W. The spacecraft is more than capable of downlinking all science and housekeeping data to the ground with a single S-band pass per day.

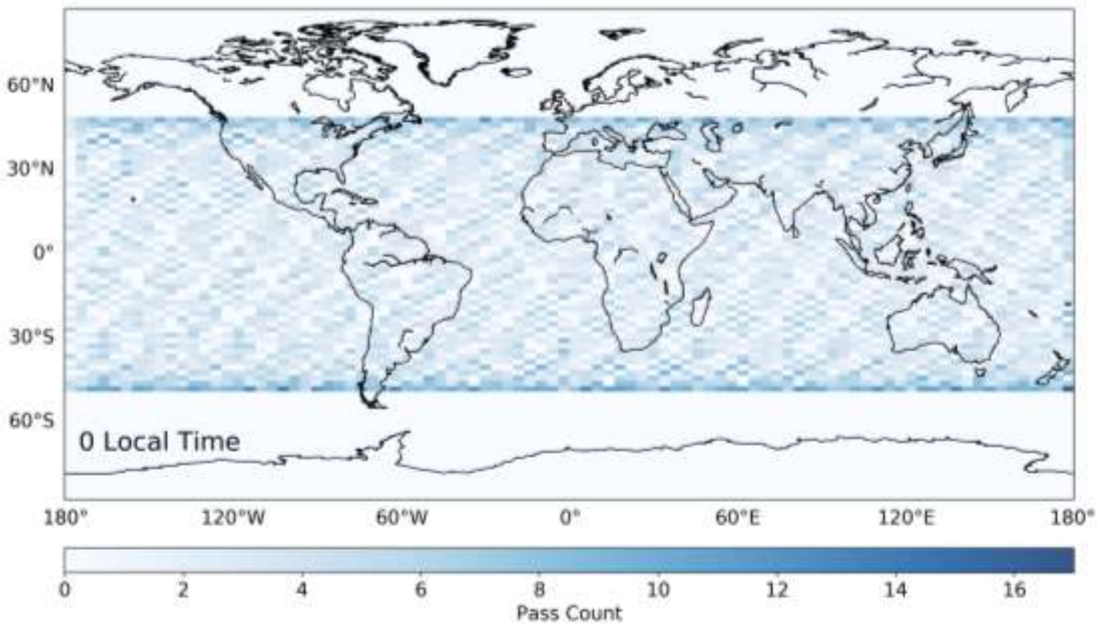
Figure 2: INSPIRESat-1 Bus



Orbit/Constellation Description

The INSPIRESat-1 will be placed in an orbit at 500 km altitude with a 50° inclination and the IDEASSat will placed in a polar orbit at the same altitude filling in the higher latitude gaps that the former mission misses. This combination of orbits ensures global coverage with high revisit rates at lower latitudes. Figure 3 shows the data coverage for just the INSPIRESat-1 over 7-months at zero local time in each gird cell. The FORMOSat-5 is currently orbiting at 720 km with an inclination of 98°.

Figure 3: Pass Count for the INSPIRESat-1 over a 7-Month Period at 0 Local Time



Implementation Plan

The INSPIRE program is an international collaboration between institutions and universities all over the world which leverages the expertise of individual participants to enable satellite development and capacity building. The INSPIRESat-1 and 2 are collaborations between the University of Colorado Boulder in the United States, the National Central University in Taiwan, and the Indian Institute of Space Science and Technology in India. Each institution has some responsibility over the program and employs students to provide the bulk of the research and engineering work (see Figure 4). Each satellite will cost approximately 1 million US dollars. All satellite integration, testing, and assembly will be conducted at LASP with final flight model delivery to ISRO in India. The program schedule can be seen in Figure 5 with delivery to ISRO in September 2019. The top five project risks are as follows:

1. Mesh grid of the CIP becoming deformed during handling
2. Reaction wheel/ torque rod failure
3. Abnormally high initial angular rates after ejection from PSLV
4. Failure to deploy antenna or solar panels
5. Single event latch-ups/burnouts in FPGA of on-board computer

Figure 4: Project Organization and Responsibility Breakdown

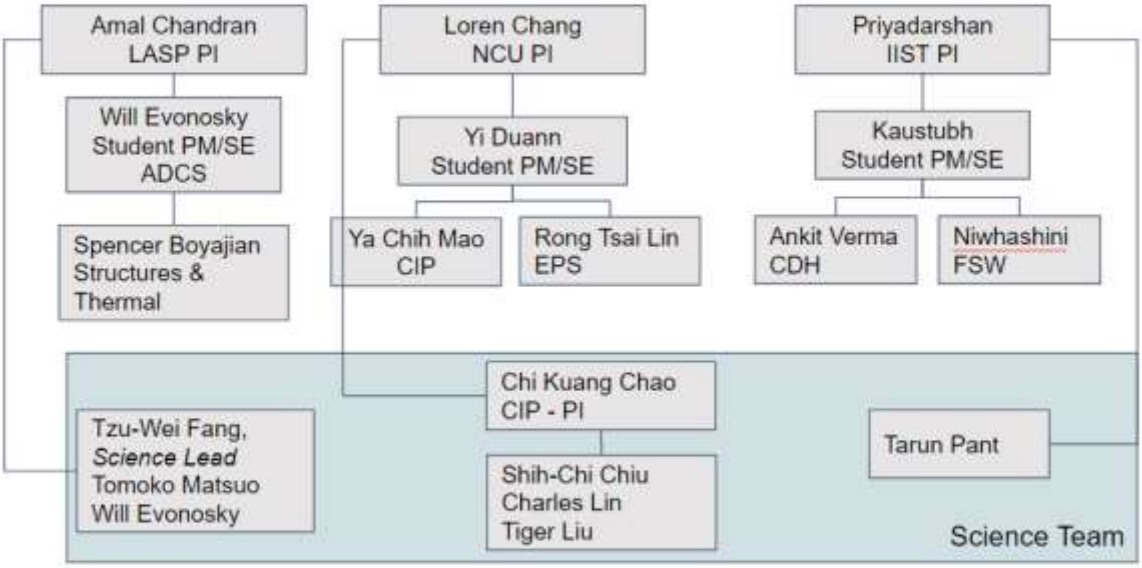


Figure 5: Project Schedule for the INSPIRESat-1