

**The Scintillation Prediction Observations Research Task (SPORT):  
An International Science Mission using a CubeSat**

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### ABSTRACT

The Scintillation Prediction Observations Research Task (SPORT) is a 6U CubeSat mission to address the compelling but difficult problem of understanding the preconditions leading to equatorial plasma bubbles. The scientific literature describes the preconditions in both the plasma drifts and the density profiles related to bubble formations that occur several hours later in the evening. Most of the scientific discovery has resulted from observations at a single site, within a single longitude sector, from Jicamarca, Peru. SPORT will provide a systematic study of the state of the pre-bubble conditions at all longitudes sectors to enhance understanding between geography and magnetic geometry.

SPORT is an international partnership between National Aeronautics and Space Administration (NASA), the Brazilian National Institute for Space Research (INPE), and the Technical Aeronautics Institute under the Brazilian Air Force Command Department (DCTA/ITA), and encouraged by U.S. Southern Command.

This talk will present an overview of the SPORT mission, observation strategy, and science objectives to improve predictions of ionospheric disturbances that affect radio propagation of telecommunication signals. The science goals will be accomplished by a unique combination of satellite observations from a nearly circular middle inclination orbit and the extensive operation of ground based observations from South America near the magnetic equator.

### 1. Introduction

Much has been learned about the conditions, or state, of the ionosphere that typically precede equatorial plasma bubbles. Signatures in both the density profiles and the plasma drifts are related with some confidence to the resulting formation of plasma bubbles several hours later in the evening. A significant amount of this scientific discovery has come from the Jicamarca Radio Observatory, a single site in Peru, within a single longitude sector. What is needed now is a systematic study of the state of the pre-bubble conditions at all longitude sectors. We have developed a science focused CubeSat mission, the Scintillation Prediction Observations Research Task (SPORT), to do just that. SPORT addresses key science questions using both in situ and radio occultation sensors augmented by ground instruments in the Brazilian sector. A satellite in a mid-

inclination orbit using both of these types of observations can probe the ionospheric state in a given longitude sector and then examine that same sector later in the evening for the development of plasma bubbles and scintillations. Ground-based observations of both the state of the ionosphere and scintillations of RF signals will complete the dataset required for this study.

SPORT is an international partnership between NASA, the Brazilian National Institute for Space Research (INPE), and the Technical Aeronautics Institute under the Brazilian Air Force Command Department (DCTA/ITA). It has been encouraged by U.S. Southern Command (SOUTHCOM) to foster increased cooperation and ties between academics, civilian space programs and the militaries. SPORT has proven leadership in key positions, clarity in roles and responsibilities, and clean simple interfaces between

institutions. NASA is overseeing the flight instruments and the launch to orbit; U.S. partner institutions are providing flight-proven instruments; and the Brazilian partners are contributing the spacecraft, observatory integration and test, ground observation networks, and mission operations and data management. The science data will be distributed from and archived at the INPE Brazilian Monitoring and Study of Space Weather (EMBRACE) regional space-weather forecasting center, and mirrored at the NASA Goddard Space Flight Center (GSFC) Space Physics Data Facility (SPDF).

## 2. Mission Objectives and Methodology

Low latitude ionospheric structures including equatorial plasma bubbles have been observed for decades. They are the primary source of radar reflections in the equatorial F-region ionosphere and cause strong scintillations on radio signals passing through them. The relationships between background ionospheric conditions and the irregularity regions, which may influence their growth to high altitudes are still poorly understood. SPORT will address two specific questions about these phenomena: (1) What is the state of the ionosphere that gives rise to the growth of plasma bubbles that extend into and above the F-peak at different longitudes? (2) How are plasma irregularities at satellite altitudes related to the radio scintillations observed passing through these regions?

The SPORT mission will answer these science questions by (1) developing and launching a CubeSat observatory to measure key phenomena, (2) leveraging data from existing Brazilian ground observation networks, (3) collecting, analyzing, and distributing resultant geophysical data and

analysis tools, and (4) integrating relevant data analysis into scientific presentations and publications addressing the posed science questions.

In situ and radio occultation sensors on a CubeSat will be augmented by ground instruments in the Brazilian sector. SPORT will be launched into a mid-inclination nearly circular orbit.

Superimposed on airglow images in Figure 1 in black is the ground trace of the satellite orbit. Plasma drifts and density will be observed in situ and each satellite pass will give a latitude profile of the plasma density across the anomaly peaks in a longitude range of  $<30^\circ$ . A global position satellite (GPS) radio occultation receiver will be used to observe both plasma density profiles and scintillation occurrences remote from the spacecraft. The tangent point distance for these GPS occultations often occurs over previous or upcoming ground traces of this spacecraft's orbit. This geometry allows SPORT to characterize the ionospheric state (drifts, density, etc.) of a longitude sector and then observe the same region one orbit later to determine if bubbles or irregularities have formed and/or evolved. Ground-based observations of both the state of the ionosphere and scintillations of RF signals will complete the dataset required for this study. When SPORT is over the Brazilian sector, satellite techniques currently being developed will be correlated against ground-based observations. We will compare the ground-based observations of scintillation on RF signals with satellite-based measurements of density structures to address the parts of our scientific study focused on scintillation mechanisms.

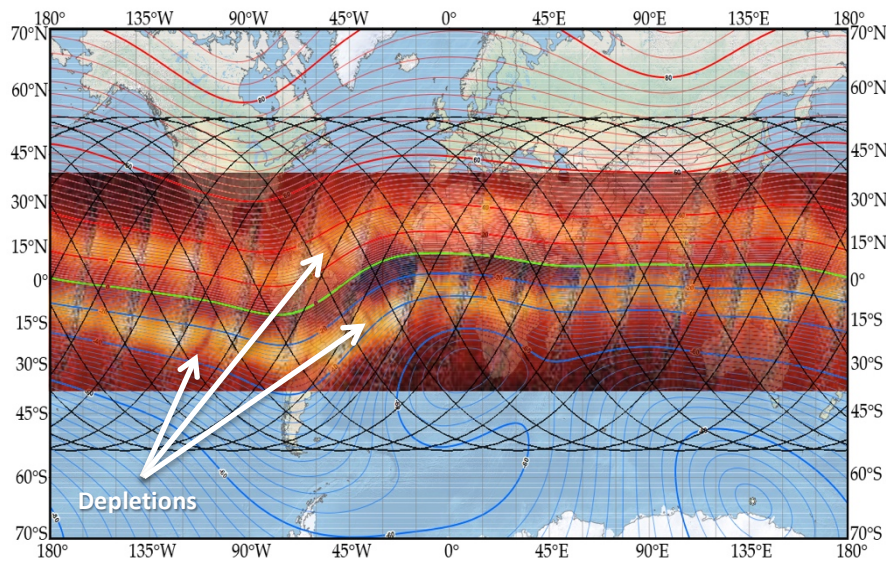


Figure 1. UV Airglow images from TIMED GUVI clearly showing the equatorial anomaly with embedded depletions that have penetrated through the F peak. Green, Red and Blue traces show the magnetic equator and positive and negative dip angles. SPORT 52° inclination ground tracks are superimposed as black traces.

### 3. Scientific Objectives and Requirements

The science objectives of SPORT are consistent with the strategic goals of the NASA Heliophysics Division and the National Science Foundation (NSF) Geospace Section of the Atmospheric and Geospace Division. It is fully consistent with the conclusions and recommendations of the National Academy report "Achieving Science with CubeSats" [National Academy, 2016]. SPORT addresses outstanding questions on the triggers, predictability, and effects of irregularities in the equatorial ionosphere. SPORT provides balance to NASA's Heliophysics Division's current and future mission portfolio with its focus on the Earth's ionosphere and is synergistic with two upcoming Explorer class missions: Global-scale Observations of the Limb and Disk (GOLD); and Ionospheric Connection Explorer (ICON). GOLD can provide global context to the SPORT observations and ICON can provide regional context on the formation of the equatorial anomalies where irregularities occur. Together SPORT, GOLD and ICON form a powerful probe of the ionosphere.

The SPORT mission is focused on the very compelling but difficult problem of understanding preconditions leading to equatorial plasma irregularities also known as Spread-F or plasma bubbles. The growth and evolution of plasma density structures in the equatorial ionosphere have been studied for many years and information about their general appearance and climatological variations is available. Much of the information is obtained from detailed ground-based observations from the South American continent [Woodman, 2009] and from a distributed network of radio scintillation receivers [Aarons, 1993].

Our scientific objectives place requirements for observing plasma drifts, density and the presence of scintillations in specific regions and ways. The objectives flow down to specific instrumentation, sensitivities, and sampling rates. Most important is the observational strategy we have developed to address our science questions.

In Figure 1, UV Airglow images from the TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) mission clearly show the equatorial anomaly with embedded depletions that have penetrated the F peak. Green, red, and blue traces show the magnetic equator, and positive and negative dip angles. SPORT ground tracks are superimposed in black.

The equatorial anomaly is due to the so-called fountain effect associated with upward plasma drifts [Hanson and Moffett, 1966]. The TIMED satellite shows the equatorial plasma density anomaly as observed by bright bands in 135.6 nm emissions on both sides of the magnetic equator. Superimposed on Figure 1 are the magnetic equator in green, the dip angle in red and blue illustrating

the uniqueness of the magnetic geometry in the Brazilian sector. These observations were obtained at the same local times, several hours after local midnight, for each longitude sector. They record bubble formation over the course of a single evening. Large plasma depletions viewed from above can appear as broad backward C-shaped structures across both peaks of the anomaly that are conspicuous due to the absence of ultraviolet emission from electron and O<sup>+</sup> recombination [Kil et al., 2004]. SPORT will make progress on addressing questions of the state of the ionosphere that preceded plasma bubble formation and ultimately help in explaining why bubbles develop and rise to various altitudes at different times in different regions and latitude.

#### 3.1 Science Methodologies and Closure on Science Objectives

We will address our first science question with several methodology and observational scenarios. In the first, the state of the ionosphere at a specific longitude and local time is first sampled using the in-situ instruments. On the next orbit, the Earth's rotation subsequently moves that same longitude sector away from the satellite to be sampled remotely using GPS occultation at a local time that is 1 hour and 40 minutes later than previously sampled. In this manner, a description of the plasma density profile and line of sight scintillations at different latitudes in the target longitude region may be compared with the latitude profile of the plasma density, drift and structures observed earlier in time by the satellite.

The second scenario reverses the role of the in-situ and remote occultation measurements. Here a description of the plasma density profile at different latitudes in the target longitude region from radio occultation may be compared with the latitude profile of the plasma density, drift and structures observed later in time by the satellite's in-situ instruments. Again, during the daytime the coupling between plasma dynamics and the plasma density distribution will be examined and across sunset and in the evening hours, the conditions that promote the growth of plasma structures will be revealed.

In the third scenario, the target longitude is located in the South American continent where extensive ground based observational capability is in place. In this case, the time development of the ionosphere will be well documented. It will then be directly compared with the in-situ latitudinal profiles obtained from the satellite. Further, the appearance of plasma structures will be well documented, whether or not they penetrate to the satellite altitude.

An occultation will provide both a vertical profile of line-of-site total electron content (TEC) and a vertical profile of the S4 index indicating the presence of scintillations. The line-of-site TEC will be used to compute the height

of the F-peak and a plasma density profile. Key to achieving the observational strategy is the number of GPS occultations with tangent points at adjacent orbits tracks. Simulations show that over a one-year mission period, at least 39 appropriate occultation events occur in each of 18 longitude sectors for each two-hour local time window. This provides a sufficient number of events to statistically address the first science question in the time period from sunset to midnight.

These data will be augmented with a nearly complete description of the ionospheric state obtained from ground-based measurements in Brazil. Of most significance to SPORT is an array of GPS receivers that provide a description of the equatorial TEC distribution localized in South American longitudes. The EMBRACE center provides TEC maps every 10 minutes.

The second science question will be addressed through measurements of the plasma density and vertical plasma drift with high spatial resolution, allowing characterization of the spatial structures with scale sizes down to 200 m. While the full resolution data will be retained for analysis, for the purposes of ionospheric specification we will characterize the irregularities in terms of the power spectral density and spectral slope in the range from 200 km to 2 km and from 2 km to 200 m.

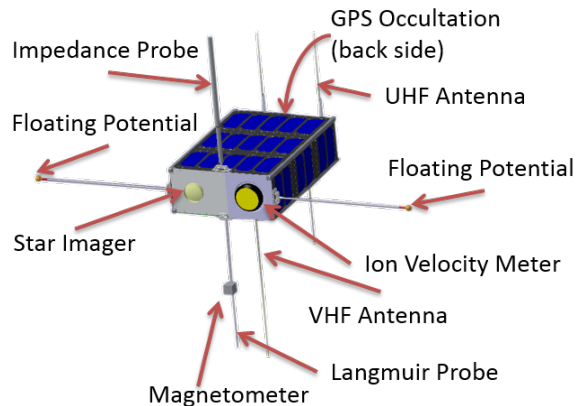
Work by Stoneback et al. [2013] has shown that plasma density irregularities observed at the satellite can be used in conjunction with information on the spectral content of the structure to infer equivalent scintillation intensity for given frequencies. Comparisons with ground-based observations using this technique suggest that such a methodology can be used globally and verified at specific locations. Once verified using available data in the Brazilian sector, the same procedures can be applied at other longitudes to produce a global description of scintillation at different frequencies.

Another prediction approach we are exploring uses the line-of-site S4 observations from a GPS occultation that fall along or near the satellite track. This will allow a comparison between the spectral content of the in situ density observations with the line-of-site observations of TEC, which has not been reported in the literature.

#### 4. Technical Approach and Methodology

The SPORT 6U CubeSat is illustrated in Figure 2. Booms deploy to place sensors in undisturbed plasma and to remove them from various noise sources present at the spacecraft bus. The ridged booms lie along the spacecraft bus and are spring hinged, locking into place once deployed. One set of 30-cm booms is deployed horizontally as a set of probes for the Electric

Field Probe (EFP) that observes waves and the spacecraft floating potential. A 30-cm probe is deployed in the anti-nadir direction for use by the impedance probe and a second boom is deployed nadir with both a Langmuir probe sensor tip and a magnetometer. The GPS patch antenna is mounted on the wake surface of the satellite and a set of turnstile antennas are used for communications with the spacecraft bus. An X-band antenna is located on the nadir face for offloading data at high rates.



**Figure 2. SPORT CubeSat configuration illustrating the location of science instruments and spacecraft orientation on orbit.**

The scientific objectives in Table 1 can be achieved with, for example, a launch from the ISS that meets the altitude and inclination requirements and for which launch opportunities are frequent. The spacecraft will be pointed on orbit such that the spacecraft presents a minimum cross-section to minimize drag. The spacecraft will have ballast mass added to extend the life of the spacecraft. An ISS launch provides ~2.5 mission years with the spacecraft starting at 400 km and ending at 350 km during the proposed mission period. The Nanoracks standard ISS deployment allows for 6U spacecraft up to a mass of 16.9 kg, which gives a mission life of more than 5 years. Because of this, there is significant margin to meet the one-year mission requirement of SPORT.

#### 4.1 Instruments

The instrument suite is summarized in Table 2 including the scientific parameters to be sensed and the expected measurement performance of the instruments. This table, together with Table 1, presents our science traceability matrix for SPORT. This table also presents an overview of the requirements for the sensors including pointing, mass, volume and telemetry requirements on the spacecraft bus.



Table 1. Science Objectives to Measurement Requirements Traceability

The Scintillation Prediction Observation Research Task (SPORT)		Instrumentation	Spacecraft
Observational Approach	Science Measurement Requirements	Instrument Approach	Space Systems Requirements
<b>1) What is the state of the ionosphere that gives rise to the growth of plasma bubbles that extend into and above the F-peak at different altitudes?</b>			
Observations in the 1700 to 0100 LT sector over -30° to 30° latitude  Height profiles of the plasma density to specify the magnitude and height of the F peak density in the EA  Vertical ion drifts at or below the F peak in the EA	<b>Plasma Density Profile</b> 1) 140 to 450 km alt 2) 10 <sup>4</sup> to 10 <sup>7</sup> p/cm <sup>3</sup> range 3) 20% p/cm <sup>3</sup> accuracy 4) 1000 km along track sampling  <b>Ion Drifts (Earth Reference Frame)</b> 1) ±800 m/s Range 2) 20 m/s precision & accuracy 3) 10 km along track sampling	<b>GPS Occultation</b> Observe GPS satellite occultation along and to the sides of the orbit plane to obtain line of site TEC  <b>Ion Velocity Meter</b> Observe vertical ion drifts by angle of arrival of heavy ions at detector	<b>Satellite Orbit</b> 1) ≥1 year mission life 2) 40° to 55° inclination 3) 350 to 450 km altitude 4) ±10 km eccentricity  <b>Spacecraft</b> 1) ±15° Ram Pointing 1σ 2) ≤1 km position knowledge 3) ≤10 ms timing
<b>2) How are plasma irregularities at satellite altitudes related to the radio scintillations observed passing through these regions?</b>			
Observations in the 2200 to 0200 LT sector over -30° to 30° latitude  Observations of irregularities in electron density and E-field power spectral density in slope from 200 km to 200 m	<b>E-Field (Earth Reference Frame)</b> 1) ±45 mV/m range 2) 1.1 mV/m precision & accuracy 3) 1 km along track sampling 4) 10 km - 200 m along track waves  <b>Plasma Density</b> 1) 10 <sup>3</sup> to 10 <sup>7</sup> p/cm <sup>3</sup> range 2) 10 <sup>3</sup> p/cm <sup>3</sup> precision & accuracy 3) 1 km along track sampling 4) 10 km - 200 m along track waves  <b>B-field</b> 1) ± 56,000 nT range 2) ±100 nT precision and accuracy 3) 1 km along track sampling	<b>E-Field Double Probe</b> Observe probe floating potential for AC E-fields from irregularity  <b>GPS Occultation</b> S4 scintillation index  <b>Langmuir/Impedance</b> Observe DC and AC probe response for relative and absolute electron density and observe irregularities  <b>Three Axis Magnetometer</b> Support VxB computation for ion velocity and E-Field measurements	<b>Spacecraft Mechanisms</b> 1) ≥0.6 m tip-to-tip booms  <b>Attitude (Post Flight Knowledge)</b> 1) ≤ 0.02° 1σ-uncertainty

**Ion Velocity Meter (cs-IVM).** The CubeSat Ion Velocity Meter (cs-IVM), provided by the University of Texas at Dallas (UTD) uses a technique with extensive heritage in space to measure the velocity of the ion component of ionospheric plasma at the sensor location (Figure 2). The IVM is mounted on the spacecraft to view along the velocity vector in the ram direction, and acts as two traditional instruments, a planar retarding potential analyzer (RPA), and a planar ion drift meter (IDM), which measures arrival angle of the thermal plasma with respect to the look direction in two mutually perpendicular planes.

**GPS Occultation (CTECS).** SPORT will make use of Aerospace Corporation’s Compact Total Electron Content Sensor (CTECS) to obtain electron density profiles at low latitudes and to detect the presence of scintillation. CTECS is a GPS occultation sensor consisting of a commercial NovAtel receiver, the OEM628, with modified software and a custom-designed antenna. CTECS has flown on the PicoSatellite Solar Cell

Testbed 2 (PSSCT-2) mission in 2011 and on the two-CubeSat Space Environment NanoSat Experiment (SENSE) mission in 2013 [Bishop et al., 2012]. CTECS can be commanded to sense slant TEC, scintillations (S4 mode), or both.

**Electric Field Probe (EFP).** The electric field probe (EFP), provided by Utah State University (USU), is used to measure only one component of both DC and AC electric fields for identifying disturbed regions of the ionosphere. It is an implementation of the double-probe class of in-situ electric field instruments that has been used for decades to observe electric fields in the space environment [Fahleson, 1967]. The EFP has most recently flown as part of the Auroral Spatial Structures Probe (ASSP) in January 2015, and the Dynamic Ionosphere CubeSat Experiment (DICE) mission [Fish, 2014].

**Table 2. SPORT instrument suite with the scientific parameters to be sensed and the expected measurement performance of the instruments**

Table 2. Expected Instrument Performance and Requirements							
Parameter	Ion Velocity Meter	GPS Occultation	Electric Field Probe	Langmuir Probe	Impedance Probe	Magnetometer	
Requirement	$V_i$ : $\pm 800$ m/s, 20 m/s $\Delta N_i$ : $10^3$ to $10^7$ cm <sup>-3</sup> $\Delta N_e$ : $10^3$ to $10^7$ cm <sup>-3</sup>	$N_e$ -Profile: $10^4$ to $10^7$ cm <sup>-3</sup> S4: 0.2 to 1.2	$0.1$ to $\pm 45$ mV/m	$\Delta N_i$ : $10^3$ to $10^7$ cm <sup>-3</sup> $\Delta N_e$ : $10^3$ to $10^7$ cm <sup>-3</sup>	$N_e$ : $10^3$ to $10^7$ cm <sup>-3</sup>	$\pm 56,000$ nT, 100 Abt	
Instrument Performance	$V_i$ : $\pm 2000$ m/s, 20 m/s $\Delta N_i$ : $10^2$ to $10^7$ cm <sup>-3</sup> , 5% $T_e$ : 250 to 5000 K $C_i$ : 0-100%, 1-40 amu DC to 2 Hz	Scintillation (S4) Slant TEC: 3 to 200 units $N_e$ -Profile: $10^3$ to $10^7$ cm <sup>-3</sup> S4 0.1 to 1.5 $\sigma$ : 0.1 to 20 rads 50 Hz	$V_i$ (derived): 20 m/s DC-40 Hz 16 spectrometer ch. 20 Hz to 15 kHz	$\Delta N_i$ : $10^2$ to $10^7$ cm <sup>-3</sup> , 5% $\Delta N_e$ : $10^3$ to $10^9$ cm <sup>-3</sup> , 5% $T_e$ : 200 to 5000 K $V_f$ : $\pm 10$ mV to $\pm 12$ V $V_p$ : $\pm 10$ mV to $\pm 12$ V DC-40 Hz, 25 s/sweep 16 spectrometer ch. 20 Hz to 15 kHz	DC-40 Hz, 25 s/sweep	DC-40 Hz	
boom	Mechanism	8 cm aperture	7.6 x 7.6 x 0.5 cm patch antenna	Two 30 cm booms	0.3 x 30 cm boom	30 cm boom	25 cm boom
pointing	Attitude Control	15° pointing control	15° pointing control	15° pointing control	15° pointing control	15° pointing control	NA
field of view	Attitude knowledge post processed req.	0.02°	2°	0.02°	10°	10°	2° pointing
power	Field of View	30°	160°	180°	180°	180°	180°
volume	Peak Power	0.3 W	1.5 W	0.15 W	0.15 W	0.4 W	0.45 W
size	Volume	1.0U Cube 9 x 9 cm	~0.15U Cube 1.5 x 9 x 9 cm	~0.1U Cube (Shared with LP) 0.75 x 9 x 9 cm	~0.1U Cube (Shared with LP) 0.75 x 9 x 9 cm	~0.1U Cube 0.75 x 9 x 9 cm	~0.5U Cube 5 x 9 cm
weight	Mass	< 1000 g	< 200 g	< 80 g (shared)	< 80 g (shared)	< 160 g	< 1000 g
data rate	Data Rate	2.0 kbps	1.0 kbps Day; 15 kbps Night	1.4 kbps	2.0 kbps	1 kbps	2 kbps
cell size	Horizontal Cell Size	10 km	100 km	200 m; 20 m spectrometer	200 m; 20 m spectrometer	190 km	10 km
vertical cell size	Vertical Cell Size	NA	30 km	NA	NA	NA	NA

na potential;  $N_e$ -phase index,  $V_i$  – ion drift velocities;  $\Delta N_i$  – relative ion density;  $\Delta N_e$  – relative electron density;  $T_e$  – electron temperature;  $T_i$  – ion temperature;  $V_f$  – floating potential;  $V_p$  – plasma electron density; B- Magnetic Field; TEC – total electron content;  $C_i$  – Ion composition; DC – 1D DC Electric Field; S4 – RF signal amplitude index,  $\sigma$  – RF signal

**Langmuir Probe.** The Langmuir probe is also provided by USU to measure plasma density,  $N_e$  and  $N_i$ , as well as temperature,  $T_e$ , the floating potential,  $V_f$ , and the space potential,  $V_s$ . The measurements are based on the current-voltage (I-V) response characteristics of a conductor immersed in plasma at a Debye length or greater from surrounding structures [Mott-Smith and Langmuir, 1926].

**Impedance Probe.** The Swept Impedance Probe (SIP) will be used to determine the absolute electron density, irrespective of the payload charging, by monitoring the changing impedance of a short cylindrical probe excited over a radio frequency (RF) range. This data will be used to compute  $N_e$ , which will be used to understand the state of ionosphere and nature of the density structures observed. Impedance probe techniques have been used for over 30 years to probe electron density in the ionosphere [Barjatya et al., 2009]. Three of these probes most recently flew on the NASA ASSP and Mesosphere-Lower Thermosphere Turbulence Experiment (MTeX)

missions in January 2015 in auroral conditions.

**Magnetometer.** A GSFC produced miniature vector fluxgate magnetometer system will provide high-resolution measurements of the ambient magnetic field with sufficient sensitivity to potentially observe perturbations due to pressure gradients, diamagnetic cavities, or Alfvénic waves. The fluxgate magnetometer is deployed on a relatively short boom (~20 cm) to remove it from the majority of the magnetic noise of the spacecraft bus. Two additional magnetometers, a USU magneto-resistive magnetometer located at the base of the boom and a Brazilian Hall current magnetometer in the spacecraft avionics near the wake side of the spacecraft, provide independent observations of the spacecraft magnetic noise, e.g., Ness et al., [1971]. The GSFC Fluxgate is an in-house research and design effort based on the Space Technology 5 (ST-5) mission magnetometer [Slavin et al., 2008]. It is being deployed on the DELLINGR 6U CubeSat currently being built at GSFC.

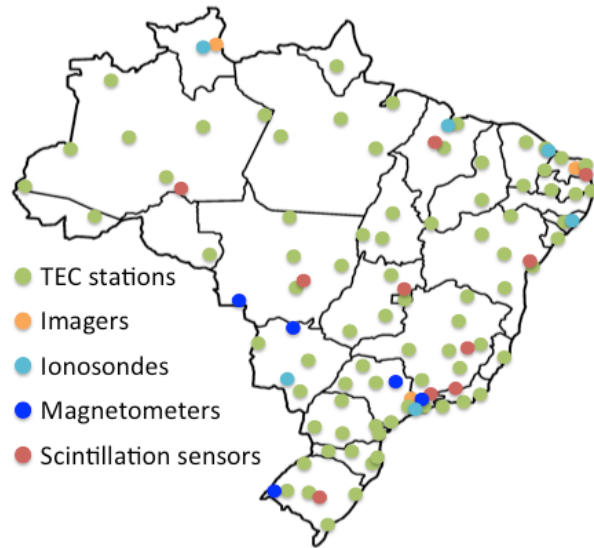
## 4.2 Ground Segment

SPORT will use ground segment elements and operational procedures that already exist in the INPE ground facilities located at Cuiabá (center west), São José dos Campos (southeast), and Santa Maria (south). For scientific data downlink (ERD), we will use two X-Band antennas located at Cuiabá. For mission command and monitoring, two telemetry, tracking and command (TT&C) ground stations will be available in São José dos Campos and Santa Maria under control of Satellite Control Center (CCS), also located in São José dos Campos. The CCS at INPE headquarters in São José dos Campos will remotely operate very high frequency / ultra-high frequency (VHF/UHF) ground stations using SATellite Control System (SATCS) software system and communication private links Consultative Committee for Space Data Systems (CCSDS) combined.

**4.3 Data Management.** The data center at EMBRACE will receive the CCS Level 0 data and distribute decommutated instrument and engineering data to the instrument teams for data reduction. The reduced instrument data will be sent back to EMBRACE from each instrument team, where it will be processed, archived, and ingested into space weather analysis models and tools. SPORT has a fully open data policy consistent with NASA data policies. The scientific data reduction, dissemination, and storage of SPORT data will be managed at EMBRACE. EMBRACE will be the SPORT mission data distribution center for the science and user communities. The data will be mirrored and also archived in the GSFC SPDF. The science results will be published and presented at relevant conferences.

## 4.4 Ground-Based Science Instruments

SPORT will use a distributed ground network to compliment its space-based observations. Figure 3 shows the geographical coverage and type of instrumentation that will be used. Of primary significance is a ground-based GPS receiver network that maps the ionosphere TEC over Brazil and provides near-real time data to EMBRACE. The spatial resolution is 50–500 km depending on receiver density. EMBRACE provides real-time TEC maps every 10 minutes. This network describes the evolution of irregularities and scintillation signals at a specific longitude in the South American sector regardless of the altitude at which irregularities appear. Other ground-based assets such as incoherent scatter radars and all-sky cameras will provide secondary science opportunities. A review paper by Denardini, et al. [2016] provides a complete description of ground networks in the South American sector, including the network that SPORT will use.



**Figure 3. Distribution of the Brazilian SPORT ground network related to the neutral and ionized atmosphere and the Earth's magnetic field.**

## 5. Concluding Remarks

In summary, the relationships between background ionospheric conditions and the irregularity regions themselves, which may influence their growth to large apex heights, are poorly understood. We therefore seek to advance our understanding by addressing fundamental and compelling questions in ionospheric physics concerning the genesis and evolution of equatorial ionospheric plasma bubbles. We attack these science questions by combining radio occultation profiles of ionospheric density with density and bulk plasma drift measurements in the topside equatorial ionosphere during the key period – just before local sunset until just after local midnight – when irregularities have fully formed. Both space and ground based scintillation of RF beacons and GPS satellites will be compared with measurements of density structuring during coincident periods.

## Acknowledgements

The work of U.S. partners is supported by the NASA Science Mission Directorate Heliophysics Division's H-TIDS program SPORT Project. International partners work under the auspices of the Brazilian National Institute for Space Research (INPE) and the Technical Aeronautics Institute of the Brazilian Air Force Command Department (DCTA/ITA).

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