The Low-Latitude Ionosphere/Thermosphere Enhancements in Density (LLITED)

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The Aerospace Corporation’s Low-Latitude Ionosphere/Thermosphere Enhancements in Density (LLITED) selected for funding by NASA’s Heliophysics Science Division’s 2016 HTIDs program

Team Members:
- Rebecca Bishop, PI, (CTECS-A Lead)
- James Clemmons, Co-I, (MIGSI Lead)
- Aroh Barjatya, Co-I, (PIP Lead)
- Richard Walterscheid, Co-I

Mission consists of two 1.5 U CubeSats, 1-year lifetime, three sensors

CubeSats separated by \( \frac{1}{4} \) to \( \frac{1}{2} \) orbit

Purpose: Characterize and improve our understanding of the Equatorial Temperature Wind Anomaly (ETWA), provide insight into the coupling physics between the ETWA and the Equatorial Ionization Anomaly (EIA), and increase our knowledge of the dusk-side dynamics that may influence space weather.
Science Background

- EIA, ETWA are two prominent features in the mid-, low-latitude nighttime ionosphere/thermosphere
- Occur between ± 40 geographic latitude
- ETWA noted by enhancements in neutral temperature and densities
- EIA consists of regions of enhanced plasma density on either side of the magnetic equator
  - 1st discovered in 1939
- ETWA occurs at latitudes slightly poleward from the EIA
- Using data from CHAMP and COSMIC data, able to look at EIA and ETWA simultaneously
  - ETWA crests are not always reflected in the EIA
  - EIA shows wave-4 structure

CHAMP/COSMIC observations. From Figures 1, 3, 6 of Lei et al. [2010].
Science Background

ETWA Observations

• ETWA difficult to observe in-situ
• Most observations from ground sensors and modelling studies
• STREAK satellite mission hosted an Ionization Gauge Sensor (IGS)
• STREAK satellite in polar orbit for 10 months (2005-2006)
• IGS made pressure measurements at altitudes below 350 km.
  – Polar orbit meant IGS sensitive to cross-track winds
• Figure shows single orbit of IGS data (black) along with MSIS00 model results (blue) for reference
• Large-scale structure primarily due to oblateness of earth
  – Lower s/c altitude at equator and higher observed pressure
• Wave-like structures visible

From Clemmons et al. [2013].
Science Background

ETWA and EIA

• Top plot shows 20-days of IGS data (~320 orbits) near December solstice 2005.
  – Multiple crests/troughs observed on either side of magnetic equator

• Bottom panel shows observations for 14 October 2005 from GUVI (green) and IGS (red/blue)
  – GUVI shows 135.6 nm emission primarily from radiant recombination between O⁺ and e⁻
  – O⁺ emission shows crests/troughs indicative of EIA
  – O⁺ emission crest coincide with neutral pressure trough near magnetic equator

From Clemmons et al. [2013].
LLITED Science Questions

1. What is the mesoscale variability of the ETWA as a function of season, and longitude/latitude as well as its relationship to EIA heating?
2. What is the relationship between neutral wind (i.e. tides) and the EIA zonal structure?
3. Are the small-scale wave fluctuation in neutral atmosphere quantities, such as those observed by earlier missions exhibited in the ionospheric density?

• Required measurements: Neutral pressure/density, Neutral winds, In-situ electron density
• Spatially separated observations provide structure and temporal information
**LLITED Spacecraft**

- Consists of two 1.5 U CubeSats
  - *Identical bus and payloads*
- Bus similar to AeroCube 7 except for four-deployed solar panels instead of two.
- Hosts three science payloads:
  - *Miniature Ionization Gauge Space Instruments (MIGSI)*
  - *Planar Ion Probe (PIP)*
  - *Compact Total Electron Content Sensor – Aerospace (CTECS)*
LLITED – Sub-systems

Electronics Architecture:
• Uses Aerospace distributed processing architecture
  – Simplifies integration
  – Each subsystem is managed by dedicated processor
  – Master satellite processor is the flight computer
    • Manages satellite radio, scheduler, issues commands, manages SOH data

Attitude Control System:
• Identical to AC7 a, b, c and ISARA.
  – Sun/earth sensors, MEMS IMU, magnetometer sensors, Star Trackers
• Demonstrated 3-axis stabilized performance is better than 1° without Star Trackers
• Inclusion of start trackers improves accuracy and knowledge to 0.1°

Power System:
• 10 solar cells distributed on four-long sides of bus prior to wing deployment
  – Provides 1W orbit average as it tumbles in safe mode (operation requires only 0.4 W)
• Deployed panels result in 12 solar cells for 4 W orbit average power in LVLH
• Additional 5-body mounted solar cells increase power to 5.1W orbit average
LLITED – Sub-systems

Thermal Control:
• Passive Thermal Coating used to maintain avionics and battery within a safe range in all power and ACS modes

SWAP Budgets:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LLITED</th>
<th>Available</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (bus + payloads)</td>
<td>1.8 kg</td>
<td>2 kg</td>
<td>10%</td>
</tr>
<tr>
<td>Size</td>
<td>1.5U</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Safe mode power (payloads off; ACS off; s/c tumbling)</td>
<td>0.4W</td>
<td>1W</td>
<td>150%</td>
</tr>
<tr>
<td>ACS mode power (ACS on – orientation controlled; payloads off)</td>
<td>3.5W</td>
<td>6.5 W</td>
<td>85%</td>
</tr>
<tr>
<td>Mission mode power (ACS on – LVLH; payloads on)</td>
<td>6.5 W</td>
<td>6.5 W</td>
<td>Duty cycle</td>
</tr>
<tr>
<td>Power Collection mode power (payloads off; ACS on – sun-pointing)</td>
<td>3.5 W</td>
<td>6.5 W</td>
<td>85%</td>
</tr>
<tr>
<td>Telemetry Download (daily)</td>
<td>13.5 MB</td>
<td>20 MB (Note 4)</td>
<td>50%</td>
</tr>
<tr>
<td>Orbit lifetime</td>
<td>&lt;19 years (500km)</td>
<td>1 year funded</td>
<td>18 years</td>
</tr>
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</table>

• Payloads duty cycled to fit available power
• Assumes the use of four ground stations
• Expect to comply with CubeSat Design Specification (CDS)
**LLITED – Payloads**

*Ionization Gauge (MIGSI)*

- MIGSI is a modified design of STREAK IGS
- Consists of three components:
  - Bayard-Alpert sensor
  - Accommodation chamber
  - Controller board
- Controller board redesigned for NSF’s LAICE CubeSat (PI: Virginia Tech)
- Requirements:
  - Aperture located on the ram face of s/c
  - 3-axis stabilized
  - Aperture aligned within 1 of velocity vector
- Amount of neutral gas entering sensor is dependent on s/c velocity, s/c orientation, and ambient gas parameters
LLITED – Payloads

Planar Ion Probe (PIP)

- Fixed bias Langmuir probe
  - Selected to reduce possibility of s/c charging
  - Bias fixed at -7V relative to CubeSat bus
  - Operates in the ion saturation region
- 4 x 6 cm rectangle with 1cm wide guard
  - 1 mm gap between probe and guard
- Requirements:
  - Gold-plated to better withstand atomic oxygen environment
  - Located on s/c ram facing surface
- Heritage:
  - Electronics flown as part of NASA MTeX rockets, and similar to NSF DICE CubeSat
- Measurement Range: 2x10⁹ to 2x10¹³ m⁻³
- Resolution: 2x10⁸ m⁻³
- Sampling rate selectable, demonstrated on MTeX rocket to 5 kHz
LLITED – Payloads

GPS Radio Occultation (CTECS-A)

• Consists of custom antenna, Aerospace designed receiver and front-end RF electronics
• Provides Total Electron Content, scintillation observations
• Measures GPS L1/L2 frequencies (1.575/1.228 GHz)
  – Pseudorange, phase, SNR
• Unlike previous CTECS, CTECS-A is integrated as part of the navigation receiver
  – Expanding Aerospace single frequency receiver to include L2 frequency and output low-level data
• Heritage:
  – Antenna flown on PSSCT-2, SENSE
  – Antenna to be flown on SPORT, AeroCube X
  – Receiver to be flown on AeroCube X

Antenna flown on SENSE mission
# Science Traceability

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<tr>
<th>LLITED Mission</th>
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<td>General Observational Approach</td>
<td>Science Measurement Requirements</td>
<td>Limiting Space Systems Requirements</td>
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## 1. Determine the mesoscale variability of the ETWA as a function of season and lat/lon as well as its relationship to EIA heating?

- **Observations in the 17:00 to 00:00 LT (dusk) sector and over -40° to 55° latitude**

  **LLITED Products:**
  - In-situ neutral pressure
  - Measurements altitude range: 350–450 km

- **In-situ neutral pressure**
  - 200 km resolution
  - $2 \times 10^{-7}$ to $1 \times 10^{-6}$ torr

- **MIGSI: Ionization Gauge**
  - 1 Hz sampling (8 km)
  - $2 \times 10^{-8}$ to $1 \times 10^{-2}$ torr

- **Orbit:**
  - Polar, Circular
  - 350-450 km, preferably 400 km

- **Attitude:**
  - 3-axis stabilized
  - Control: 1°
  - Knowledge: 0.1°

- **On-board Data Storage:**
  - >8 MB for MIGSI

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2. What is the relationship between neutral winds (i.e., tides) and the EIA structure?

Observations in the 15:00 to 01:00 LT (dusk) sector and over -40° to 55° latitude

**LLITED Product:** Background ionosphere density measurements

**LLITED Product:** Coincident neutral pressure/plasma density measurements

Measurements altitude range: 350–450 km

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<td>200 km resolution</td>
<td>1 Hz sampling (8 km)</td>
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<td>2 x 10^{-7} to 1 x 10^{-6} torr</td>
<td>2 x 10^{-8} to 1 x 10^{-2} torr</td>
<td>Control: 1°</td>
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<tr>
<td>Plasma Density Profiles: TEC from 100-400 km</td>
<td>CTECS-A: GPS RO TEC from 100 km to orbit altitude.</td>
<td>Knowledge: 0.1°</td>
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<td>Plasma Density in-track: 200 km resolution</td>
<td>PIP: Impedance Probe: 1 Hz (~8 km res.)</td>
<td>On-board Data Storage: &gt;128 MB for 3 sensors</td>
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<tr>
<td>10^{12} to 6x10^{12} m^{-3}</td>
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#### 3. Are the small-scale wave fluctuations in neutral atmosphere quantities, such as those observed by earlier missions exhibited in the ionospheric density?

Observations in the 15:00 to 01:00 LT (dusk) sector and over -40° to 55° latitude

**LLITED Product:** Coincident neutral pressure/plasma density

**Measurements altitude range:** 350–450 km

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**On-board Data Storage:** >16 MB for 2 sensors
Ground System

- Four remotely operated ground sites:
  Texas A&M, University of Florida, Hawaii, Vandenberg, AFB.
- Control center located at The Aerospace Corporation in El Segundo, CA
- 2-meter parabolic dishes operating at 915 MHz with 115.2kbps downlink rate
- Nominal data download ~20 MB per day assuming two contact per day with a minimum three-minute duration.
- Plan to move into traditional S-band later this year.
CONOPS

• Request circular orbit 350-450 km altitude
• Polar orbit (inclination >70°)
• Within 6 hours of deployment, s/c will fly over one of the ground stations
  – Contact made and SOH downloaded
• If initial SOH nominal, next contact deploys wings of 1-s/c
• At end of early orbit checkout (~4-weeks) 2\textsuperscript{nd} s/c wings deployed
  – S/c will be 180° in phase
• Between ±45° latitude, payloads powered and s/c in LVLH
• Outside of ±45° latitude, s/c sun-pointed for power generation
Summary

• LLITED is a 12 month mission consisting of two 1.5U CubeSats in polar orbit, separated by \( \frac{1}{4} \) to \( \frac{1}{2} \) orbit
• The LLITED Mission will investigate the EIA and ETWA
  – First coincident ETWA and EIA observations from single s/c
  – Provide neutral density, cross-track wind, and plasma density
  – Explore the spatial structure and their relationship to one another
• CubeSats delivered in 20 months from start date
References


