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

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4 August 2019

Approved for Public Release. OTR 2019-00978
Introduction

• The Low-Latitude Ionosphere/Thermosphere Enhancements in Density (LLITED) mission consists of two identical 1.5U spacecraft with three distinct payloads:
  – Miniature Ionization Gauge Space Instrument (MIGSI)
  – Planar Ion Probe (PIP)
  – Compact Total Electron Content Sensor – Aerospace (CTECS-A)

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.

• Team Members:
  – Rebecca Bishop, PI, (CTECS-A Lead)
  – James Clemmons, Co-I, (MIGSI Lead)
  – Aroh Barjatya, Co-I, (PIP Lead)
  – Richard Walterscheid, Co-I
  – William Chavez PM (Aerospace)
  – Darren Rowen SE (Aerospace)
Science Background

ETWA and EIA

- EIA, ETWA are two prominent features in the mid-, low-latitude nighttime ionosphere/thermosphere
  - Occurs between ± 40° geographic latitude
  - ETWA noted by enhancements in neutral temperature and densities

- EIA, discovered in 1939, consists of regions of enhanced plasma density on either side of the magnetic equator

- LLITED is a Low Earth Orbit (LEO) mission with orbit altitude between 400-500 km, inclination 70°-110°, and LTAN 1800-2400 or 0600-1200.
  - Potential launch identified in late 2020

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

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?

LLITED will perform the first *simultaneous* measurements of the EIA/ETWA in time space.

GUVI 135.6 emission (green) and IGS (red/blue) observations for 10/14/05. From *Clemmons et al.* [2013].
LLITED Development Strategy

• Leverage extensive heritage of the Aerospace CubeSat program
• Majority of bus subsystem boards have flight heritage
  – No or minimal re-design required
• Non-traditional schedule with development of payloads and identified high risk items beginning immediately following kickoff meeting.
  – Payload development leads bus development
    • Bus development activities minimal until payload engineering models completed.
    • Finalized payload interface requirements preventing bus development iterations
  – Cost saving and resource management
• High risk (low TRL) bus items:
  – Bi-Fold wing and deployment mechanism
  – Payload interface board
  – High-voltage board
  – Mechanical design
**LLITED Reviews and Testing Activities**

- In place of large team reviews, PDR and/or peer reviews of individual payloads and specific subsystems employed
- Peer reviews consist of the team and independent review.
  - *Peer reviews are a gate to continuing activities*

<table>
<thead>
<tr>
<th>Peer Reviews</th>
<th>Milestone Reviews</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. PIP Peer Review – Oct 2018</td>
<td></td>
<td>Random Vibration Testing</td>
</tr>
<tr>
<td>9. BUS Mechanical – Oct 2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. BUS/Payload Interface – Nov 2018</td>
<td></td>
<td></td>
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<tr>
<td>11. Initial Thermal Analysis Review – Jan 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Thermal Analysis Review #2 – Jan 2019</td>
<td></td>
<td></td>
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<tr>
<td>13. Thermal Analysis Update Review – Apr 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. EPS Mechanical – Apr 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. EPS HVD Layout – May 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. BUS Pre-Fabrication – Jun 2019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PIP Status

Liam Gunter, Dr. Aroh Barjatya
Embry-Riddle Aeronautical University
Space and Atmospheric Instrumentation Lab
**Planar Ion Probe**

Planar Ion Probe is a flat plate sensor that is kept at a negative voltage w.r.t. plasma. The measured collection current is directly proportional to ambient ion density, collection area and spacecraft velocity, and is largely independent of applied voltage. This makes the measurement tolerant towards spacecraft charging events of few volts.
PIP Status (1 of 2)

• Engineering model testing
  - Component Level testing
  - High precision, low temperature drift resistor block testing
  - Comprehensive Functional Test

• Flight model testing
  - Thermal data collection over full temperature range and dynamic range of input current to construct temperature calibration -35C to +50C in environment chamber
  - Data collection in vacuum/plasma environment to validate ion collection in ERAU space plasma chamber
  - Vibrational shake testing performed at Aerospace facilities, to be followed by a checkout test to ensure functionality
    - Numerical vibrational analysis on assembly has not yet been tested, but will be prior to integration
  - Fully integrated functional test
    - Commanding from C&DH board
**PIP Status (2 of 2)**

- **PIP Flight Instruments Delivered!**
  - 4 flight versions of PIP assembly (sensor + PCB).
    - Two for actual flight and one backup for each.
  - 2 engineering boards.
    - Travelers for all boards.
  - Variety of parts and supplies if any chip breaks and needs to be replaced.
  - Programming dongle, in case PIP needs to be reprogrammed.

- **Compatibility Testing with BUS Interface**
  - Functional Testing
  - Ground SW development

- **ICD complete**
  - Includes all relevant hardware/software technical details

- **Spacecraft Level Testing**
  - EMI testing
  - Functional Testing

- **Data Analysis Software development**
  - Data Visualization
MIGSI Status

Dr. James Clemmons
MIGSI PI
University of New Hampshire
Sensor Board provides filament power and grid bias; Interface board digitizes collector and emission currents, housekeeping monitors, and interfaces to bus.
MIGSI Mechanical Design

EM Assembly

- MIGSI Interface PCB
- EMI Shield/Spacer
- Sensor PCB
- Mounting Brackets
- Ion Gauge Adapter
- Ion Gauge Chamber
MIGSI Status
Engineering Model electronics

• Electronics bench test completed
  ✓ Simulated filament load (2.5 ohm)
  ✓ Grid bias at 187 volts
  ✓ Filament relay
  ✓ Commands and telemetry data
  ✓ Current digitizer ranges

• Power consumption
  – 5V, 120mA
  – 12V, 287mA (with simulated filament)

• Next steps
  – Functional test with test ion gauge
  – Tune emission current regulation
  – Calibrate housekeeping monitors
  – Calibrate current digitizer chips
    • UNH to perform testing and chip selection
    • Ready to ship the parts and needed support hardware to UNH
  – Update GSE software
**MIGSI Next Steps**

*Engineering (EM) and Flight Model (FM)*

- Procure second MIGSI chamber
- Bus compatibility testing
  - *PIC SW, Ground SW*
- MIGSI Calibration
  - *Full calibration will be performed on the EM and FM*
  - *Bracket fixture provides interface between the PCB stack-up, ion gauge, and test chamber*
  - *Calibrations will be performed by UNH personnel in Aerospace*
    - Pressure and gas composition runs in cal stand
    - Winds runs in winds chamber
    - Two GSEs would be helpful to parallelize testing
    - Data will be reduced by UNH
- Data analysis software development
Compact Total Electron Sensor - Aerospace (CTECS-A) Status

Dr. Rebecca Bishop
CTECS PI
CTECS-A

Heritage

- Part of the FGA (flight computer/GPS/Attitude control) board.
  - Bus Subsystem not an independent payload
  - Provides position/navigation to flight computer and ACS
- Red items do not meet requirements

<table>
<thead>
<tr>
<th>Board Version</th>
<th>C</th>
<th>D.2</th>
<th>D.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Provide Intermittent PNT (few times per orbit)</td>
<td>Provide improved time accuracy and intermittent PNT (few times per orbit)</td>
<td>Observe occulted L1/L2 signals for ionosphere measurements. Provide Intermittent PNT (few times per orbit)</td>
</tr>
<tr>
<td>Heritage</td>
<td>Pre- ACX</td>
<td>ACX (AC14, DALI)</td>
<td>LLITED</td>
</tr>
<tr>
<td>Tracked Signals</td>
<td>L1 C/A</td>
<td>L1 C/A, L2C</td>
<td>L1 C/A, L2C, L2 P(Y) (semi-codeless)</td>
</tr>
<tr>
<td>Power</td>
<td>1.6 W</td>
<td>1.3 W</td>
<td></td>
</tr>
<tr>
<td>Channel Number</td>
<td>10</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>L2 Bandwidth</td>
<td>N/A</td>
<td>16 MHz</td>
<td>24.3 MHz</td>
</tr>
<tr>
<td>RF Front end</td>
<td>Maxim 2769 chip; RF mixer</td>
<td>Maxim 2771 chip; No RF mixer (fewer components)</td>
<td></td>
</tr>
</tbody>
</table>

*Only Board D.3 is capable of meeting science measurement requirements!*
CTECS-A

Current Status – Board D3

• Schematic completed
• Breadboard assembled to test RF front-end
  – Large spur observed with in L2 wide-band
    • Will compromise L2 P(Y) measurements unless corrected
    • Inherent in the Maxim Chip design – Confirmed by manufacturer
    • Mitigation: Increase electrical gain (i.e. noise floor) to swamp spur signal.
      – May limit occultation range
      – Testing determined it is correctable.
• Aerospace CTECS custom antenna version 2 selected for LLITED
  – Peak Gain: L1: 5 dB-Hz, L2: 6 dB-Hz
  – Currently have 3 flight antennas from previous SENSE mission
  – Working to transfer to LLITED program
  – LNA circuit will not be utilized
• FGA software status
  – L1, L2C tracking
  – Output of low-level products
  – 24 channels
  – Outstanding: L2 P(Y) tracking
CTECS-A
Tasks and Decision Points

Tasks
1. Maxim spur mitigation activities ✓
2. Finalize link budget
3. Schematic peer review
4. GPS section of FGA layout
5. Peer Review
6. Board procurement
   - Includes board population
7. Acceptance Testing:
   - Test procedure development
   - Measurement of final RF front end noise values
8. FPGA programming of L2 P(Y) tracking
9. Functional testing
   - GPS orbital simulator testing (not occultation)

Decision Points
1. Raise noise floor vs narrow band-width – Resolved: Spur can be removed.

7. No re-spin. White wire work only. Worst case revert to D2 boards if D3 inoperable. (Science return would be significantly reduced.)
Bus Subsystems Status

Mechanical
Bi-Fold Solar Panel
Payload Interface Board
LLITED Satellite Exploded View

- Four sub-assemblies
  1. Frame Assembly, -X-Y
  2. Frame Assembly, +X+Y
  3. End Plate Assembly, +Z
  4. End Plate Assembly, -Z
  5. SDR Antenna
  6. RMA Cover
-X-Y Frame Assembly

- Major Sub-Assemblies
  1. Avionics Stack
  2. MIGSI
  3. Sensor Bracket Assembly
  4. Bi-Fold Solar Panel Assembly
  5. Reaction Wheel Interface PCB
  6. Reaction Wheel Assembly
Avionics Assembly

• Design Based on AeroCube
  10
• Major Sub-Assemblies
  1. Power Supply Assembly
  2. Avionics PCBA’s
  3. Top Plate Assembly
  4. Payload Interface PCBA
  5. Harnesses
Bi-Fold Solar Panel Assembly

- Hinge machined onto the frame
- Stainless steel washer bar
- Torsion Spring (Body to Panel) Open 135deg
  - Reaction Wheel Stall torque 0.0115 in. lb → 12 times higher torque
- Delrin Slider
- Curved Disc washer as kick off spring
- Testing started (Based on GSFC STD-7000A)

Qualification Test Campaign

- Cyclic Deployment Test ✔
- Random Vibration Test ✔
- Hot Deployment Test
- Cold Deployment Test

Test completed
Test to be completed
Bi-Fold Solar Panel Test
Interface Board and Payloads Block Diagram
Payload Interface Board

• Board design and prototype completed

• **PIP Payload Testing Status:** Successfully Completed Functional Test on PIP Engineering Unit.
  – *Tested analog response using various single resistors. Connected PIP analog circuitry to 500kΩ, 1MΩ, 56MΩ, and 100MΩ, verifying high and low gain responses to within 10%. Each resistor analog tests were done using VB GUI as well as using interface board event scheduler to send the "Measurement" commands at a polling rate of 100Hz.*

<table>
<thead>
<tr>
<th>Resistor Values</th>
<th>High Gain Counts</th>
<th>Low Gain Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>500kΩ</td>
<td>~65,535</td>
<td>~45,700</td>
</tr>
<tr>
<td>1MΩ</td>
<td>~65,535</td>
<td>~22,800</td>
</tr>
<tr>
<td>56MΩ</td>
<td>~40,400</td>
<td>~410</td>
</tr>
<tr>
<td>100MΩ</td>
<td>~22,600</td>
<td>~270</td>
</tr>
</tbody>
</table>

• **MIGSI Payload Testing Status:** MIGSI payload testing currently has not started.
  – *Software is developed*
ConOps and Ground System
**CONOPS**

- On-orbit lifetime (funding based) is 1-year
  - *S/C maintain a ¼ to ½ orbit separation for science mission (uses differential drag)*
  - *Minimize the time it takes to obtain separation To maintain spacing use*
- CONOPS driven by power budget and science requirements
  - *Payloads will require duty cycle*
  - *Power generation is the priority outside of science region*

- Total of 5 operating modes.
  - “CTECS-A Payload” mode is CTECS-A on \(\pm 15°\) outside science region
- Minimum of 2 consecutive orbit for science operations

<table>
<thead>
<tr>
<th>Mode #</th>
<th>Mode Name</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Safe</td>
<td>No ACS/payloads</td>
</tr>
<tr>
<td>1</td>
<td>Sun</td>
<td>Panels Toward Sun / No Comm</td>
</tr>
<tr>
<td>2</td>
<td>LVLH</td>
<td>ACS On / Payloads Off / No Comm</td>
</tr>
<tr>
<td>3</td>
<td>RF Comm</td>
<td>ACS On / Payloads Off / SDR On</td>
</tr>
<tr>
<td>4</td>
<td>CTECS-A Payload</td>
<td>ACS ON / CTECS-A On / No Comm</td>
</tr>
<tr>
<td>5</td>
<td>Nominal Payload</td>
<td>ACS &amp; Payloads On / No Comm</td>
</tr>
</tbody>
</table>
The Aerospace Ground Station Network

- **Aerospace Ground Network**
  - 5 dishes remotely operated dishes
  - Currently download 5 MB/day
  - Automated capability to reduce costs

- 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.
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*
- Instruments leading bus design
  - *Eliminates iteration on bus design/requirements*
- Current Status:
  - *MIGSI and PIP design and engineering (or flight) model completed*
  - *Bus subsystem activities commencing post Design Review*
  - *Completion and delivery March 2020*
- Potential launch identified late 2020
References


