Scanning Imaging Photometer System (SIPS)
Ionospheric Space Weather Sensor

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• Atmospheric & Space Technology Research Associates LLC
• Small business (Boulder, CO)
• Specializing in Solar-Terrestrial research/applications/products
• Current/recent customers:
  • AFRL
  • AFOSR
  • ONR
  • NRL
  • NASA
  • NSF
  • JHU-APL
  • Aerospace Corp.
  • Los Alamos National Laboratory
  • Various universities

❖ Science
❖ Technology
❖ Applications
Bringing It All Together
ASTRA: Space Weather Focus

**Modeling**
- Physics-Based Modeling (TIMEGCM)
- Real-Time Specification of Ionosphere/Thermosphere

**Data Assimilation**
- High-latitude Electrodynamics
- Global Ionosphere
- Thermospheric Neutral Density

**Data Services**
- Space Based Data
- Ground Based Data
- Forensic Space Weather Analysis
- Spaceweather Phone Apps

**Ground-based Instrument Development**
- GPS-based Space Weather Monitor
- E-fields and Magnetometers
- Low Power Ionospheric Sounder
- HF TID Mapper

**Space Systems**
- CubeSat Missions
  - NSF: DICE & LAICE
  - AF: DIME, SIPS & TSS
  - NASA: SORTIE & MiRaTa

**Plug-N-Play Avionics**
- CubeSat Instruments
  - Scanning UV Photometer
  - E-field Double Probe
  - RF Waves & Sounder
  - Wind Profiler
  - GPS-based Space Weather Monitor
  - Magnetometer & Langmuir Probe

**Hosted Payloads**
Importance of Space Weather

- **Space Systems Operations**
  - Predict Behavior of the Geospace Environment
  - Understand Nature of Solar-Induced Perturbations
  - Minimize Risk of Comm/Navigation System Failure

- **Space Situational Awareness**
  - Protect Assets in Orbit
System performance limited by ionospheric variability.
Models of the ionosphere can reproduce the largest-scale average features

Small scale structure is more difficult

Small scale structure tends to affect systems
Ionospheric irregularities remain one of the most important yet least understood phenomena in ionospheric science.

Ionospheric space weather includes gradients and irregularities that affect trans-ionospheric radio wave propagation.
E-fields
Electron Density
Magnetic Field
Topside Sounder Instrument

Uses HF Radio signals
Measures ionospheric electron density profile
SIPS – UV Scanning Photometer

OUTPUT

INSTRUMENT CONCEPT

DETECTOR

IONOSPHERE

SATELLITE GROUND TRACK

Scan Mirror CTIP SENSOR SIPS INSTRUMENT
Small-Sat Constellations

ASSP Rocket

DIMESat

Constellation
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<th>Ground-based Instrument Development</th>
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<td>Satellite Drag &amp; Ballistic Coefficients</td>
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<td>HF TID Mapper</td>
<td>NASA: SORTIE &amp; MiRaTa</td>
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<td>Magnetometer &amp; Langmuir Probe</td>
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Once Upon a Time …..

Development of CubeSat Infrastructure: PnP Discipline

Demonstrations and tests
SP-A-U radiation test board [Lyke et al., 2005].

Spacecraft Avionics Experiments

AFRL “Smart Deck”
SPA-U PnP Rate Sensor
AeroAstro SPA-U Sun Sensor
MSI PnP IPDR Avionics

SPA-U PnP Reaction Wheel Electronics

Launch on TacSat-3 in Dec 2007
Dimensions: 9” x 9” x 5.75”
Mass: 8 kg
Orbital Average Power: 10W

CubeFlow PnP Bench Kits

[Lyke, 2008]
Once Upon a Time …..

Development of CubeSat Infrastructure: PnP Discipline

Demonstrations and tests

SPA-U radiation test board [Lyke et al., 2005].

Spacecraft Avionics Experiments

ASTRA space environment sensors

CubeFlow PnP Bench Kits

[Lyke, 2008]
Ultra-Violet Remote Sensing of Ionosphere

Hyperspectral Imagers (e.g. DMSP-SSUSI, NASA-GUVI)
Ultra-Violet Remote Sensing of Ionosphere

Hyperspectral Imagers (e.g. DMSP-SSUSI, NASA-GUVI)

Photometers (e.g. TIPS, CTIP)
Ultra-Violet Remote Sensing of Ionosphere
Hyperspectral Imagers (e.g. DMSP-SSUSI, NASA-GUVI)

DMSP-SSUSI
17” x 12” x 12”
25 Kg
25 W
$10 Million
UV Photometer Development
NRL-TIPS, SRI-CTIP

CTIP Optical Elements
### Requirements of the CTIP and TIPS Instruments

<table>
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<tr>
<th>Parameter</th>
<th>CTIP</th>
<th>TIPS</th>
</tr>
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<tbody>
<tr>
<td><strong>Responsivity</strong></td>
<td>&gt; 300 counts/R-s</td>
<td>&gt; 300 counts/R-s</td>
</tr>
<tr>
<td><strong>Field of View</strong></td>
<td>3.8°</td>
<td>3.8°</td>
</tr>
<tr>
<td><strong>Average Power</strong></td>
<td>2 W</td>
<td>7.6 W</td>
</tr>
<tr>
<td><strong>Shutter In-rush</strong></td>
<td>2.6 W X 0.1 s</td>
<td>&lt;2.4 W</td>
</tr>
<tr>
<td><strong>HV In-rush</strong></td>
<td>6.4 W X 0.3 s</td>
<td>&lt;2.4 W</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>1500 cm³ (1.5 U)</td>
<td>3000 cm³</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>&lt;800 g</td>
<td>2300 g</td>
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</table>
Single Pixel Photometer Provides Under-Sampled View of the Ionosphere

TIPS 135.6-nm
2100 LT at equator
14 Sep 2006

Slide Courtesy of Clayton Coker, NRL

Model Prediction
Single Pixel Photometer Provides Under-Sampled View of the Ionosphere

TIPS 135.6-nm
2100 LT at equator
14 Sep 2006

Counts $= 20$ Rayleighs

Model Prediction

Slide Courtesy of Clayton Coker, NRL
C/NOFS Satellite In-situ measurements of irregularities
C/NOFS Satellite In-situ measurements of irregularities
GUVI/SSUSI Used a Scan Mirror

Proposed Instrument Evolution

TIP  ➔  CTIP  ➔  SIPS
Scanning Imaging Photometer System (SIPS)

Scan-enabled CTIP Sensor

- Scan geometry for SIPS. The viewing geometry for SIPS is similar to that used for SSUSI.
- The scan mirror sweeps the FOV of the CTIP sensor side-to-side perpendicular to the satellite motion building up a raster scanned image of the 135.6 nm airglow from the ionosphere.

Utilizes Scan Mechanism..... ..... to produce images
CTIP

- Detects photons at **135.6-nm**
- Current plan is to use EDU from the SENSE mission (GFE)
- Power supply needs to be replaced on this EDU unit to meet responsivity requirement for potential test flight
Alignment of SMA to CTIP

- Two bearings and hollow shaft maintain optical axis perpendicular to rotation axis
- Tip tilt adjustment when mounting motor assembly to optical bench
Scan Mirror Overview

- Carbon fiber mirror mount
- Piezoelectric Motor
- PIC controller
- Optical Encoder
- 400 position control resolution
- Custom bearing assembly
- Optical bench made out of single piece of carbon fiber material for stability

- SMA Mass: 200g
- Power Consumption: 2W
- MOI of moving parts is <1% that of a 6U spacecraft

- Shake& Bake August 2015
Optical Bench

- 3-D printed using WindformXT 2.0 carbon fiber
- Mates with both CTIP and motor
- Largest CTE along rotation axis
- Rigid structure
- Monolithic construction (one piece)
  - Best practice at SSI
  - Reduces alignment uncertainties
- Conductivity can be tailored by manufacturer
- Static cantilever deflection of WindformXT with mirror assembly mounted is $<10^{-2}\text{mm}$
# SIPS Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SSUSI/GUVI</th>
<th>SIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength range/Bandpass</td>
<td>115 nm to 180 nm</td>
<td>135.6 ± 3.0 nm</td>
</tr>
<tr>
<td>Wavelength resolution</td>
<td>better than 2 nm across full range, 160 resolution elements</td>
<td>Equal to BandPass</td>
</tr>
<tr>
<td>Field of view</td>
<td>11.8 deg x 0.8 deg, line of 16 resolution elements</td>
<td>3.8 deg cone</td>
</tr>
<tr>
<td>Angular pixel dimension</td>
<td>0.74 deg x 0.8 deg instantaneous single element field – three slits are available as well as a closed position (0.8, 0.4, and 0.2 deg width)</td>
<td>3.8 deg instantaneous</td>
</tr>
<tr>
<td>Mirror scanning</td>
<td>140 degree full angle cross-track in 0.4 degree steps</td>
<td>120 degree full angle cross-track in 3.8 degree steps</td>
</tr>
<tr>
<td>Field of Regard (FOR)</td>
<td>140 x 11.84 deg</td>
<td>120 x 3.8 degree</td>
</tr>
<tr>
<td>Spectral channels (binning)</td>
<td>HI 121.6 nm, OI 130.4 nm, OI 135.6 nm, N₂ LBH&lt;sub&gt;short&lt;/sub&gt; 140 – 150 nm, N₂ LBH&lt;sub&gt;long&lt;/sub&gt; 165 – 180 nm</td>
<td>OI 135.6 nm</td>
</tr>
<tr>
<td>Aperture</td>
<td>2.5 cm x 2 cm; 5 cm²</td>
<td>5.08 cm dia</td>
</tr>
<tr>
<td>Integrating time</td>
<td>0.11 seconds</td>
<td>0.11 seconds</td>
</tr>
<tr>
<td>Quantum Efficiency</td>
<td>&gt;10 % at 130 nm</td>
<td>0.27 at 135.6 nm</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>&gt;200,000 counts/second maximum</td>
<td>&gt;200,000 counts/second maximum</td>
</tr>
<tr>
<td>Physical dimensions</td>
<td>73 cm x 33 cm footprint; 30 cm height</td>
<td>150 cm² footprint, height 10 cm CTIP without scan mirror</td>
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</tbody>
</table>
Left panel is the GUVI image from combining two nightside passes on Day 86, 2003. Right panel is the corresponding count per sample for the SIPS instrument at an altitude of 850 km. Two ionospheric bubbles are evident in both images as depletions in the brightness that extend across the magnetic equator.
• Detector (TRL-9)
• Scan Mirror (TRL-4)

• SRI built the detector for SENSE mission
• Expecting CTIP detector as GFE from SMC

• SIPS is a technology demonstration and risk reduction mission for future constellation flights
• SIPS will prove the technology by imaging bubble formation regions to aid in specification and forecast of ionospheric irregularities and their effects
• Data from a future SIPS constellation would be complementary to data from ASTRA’s DIME and Topside efforts supported by AFRL:
  • all three would provide a robust and low-cost constellation
  • Each meets critical IORD requirements and augments current DMSP observations

<table>
<thead>
<tr>
<th>Measures</th>
<th>Images ultraviolet emissions from nightside ionosphere and aurora; estimates of TEC and aurora; identifies presence, location, size, drift, evolution of plasma bubbles and aurora</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>Present-time topology and evolution of ionospheric structures, including bubbles and aurora. Reduces SWaP and cost by factor of 10 vs DMSP</td>
</tr>
<tr>
<td>IORD-II</td>
<td>TEC, scintillation</td>
</tr>
</tbody>
</table>

Disaggregated Space Weather Network of Complementary “Sensor Sats”
• Robust to various conditions
• 100% effective and subject to graceful degradation
FUV Spectral Region Exhibits the Signatures of Space Weather in the Upper Atmosphere

- FUV spectral features were identified and interpreted during 30 years of rocket and spacecraft missions.

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<th>4</th>
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<tr>
<td><strong>Dayside</strong></td>
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<tr>
<td><strong>Limb</strong></td>
<td>HI (121.6 nm)</td>
<td>OI (130.4 nm)</td>
<td>OI (135.6 nm)</td>
<td>N₂ (LBHs)</td>
<td>N₂ (LBHI)</td>
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<td><strong>Disk</strong></td>
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<tr>
<td>HI (121.6 nm)</td>
<td><strong>H profiles and escape rate</strong></td>
<td>Amount of O₂ absorption</td>
<td>O altitude profile</td>
<td>Amount of O₂ as seen in absorption</td>
<td>N₂, Temperature</td>
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<td><strong>Column H</strong></td>
<td><strong>Solar EUV</strong></td>
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<td><strong>Used with LBHs to form O/N₂</strong></td>
<td><strong>Solar EUV</strong></td>
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<td>EDP</td>
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