Miniaturized In-Situ Plasma Sensors—Applications for NSF Small Satellite program

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FalconSat-3—Space Physics on a small satellite

- Built 2005-2006
- Launched 8 March 2007
- Two plasma sensors
  - Plasma Local Anomalous Noise Experiment (PLANE)
  - Flat Plasma Spectrometer (FLAPS)
Space Weather (Ionosphere)—Comparison to Terrestrial Weather

- Any weather forecast requires
  - Remote measurements to give world wide coverage
  - In-Situ measurements to give error bars for the remote measurements

<table>
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<th>Space Weather</th>
<th>Terrestrial Weather</th>
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<td>Basic measurements required to drive models</td>
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<tr>
<td>- Plasma Temperature</td>
<td>Neutral Temperature</td>
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<tr>
<td>- Plasma Density</td>
<td>Neutral Pressure</td>
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<tr>
<td>- Neutral Winds</td>
<td>Neutral Winds</td>
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Space Weather is under-sampled!

Fig 1.5 Daley
In-situ

Fig 1.6 Daley
Remote
Plasma Local Anomalous Noise Experiment—PLANE

**Principle of operation**

- PLANE uses two retarding potential analyzers (RPA)
- Separate the signal from the turbulent lower energy from the higher ram energy ions
- Output from both instruments differenced and monitored at high frequency
- Monitors turbulence to 10 cm scale size, a **factor of 100 improvement over current techniques**

**Status:**

- On-orbit initial checkout

Data obtained during CHAWS experiment provided motivation for PLANE

PLANE prototype
Flat Plasma Spectrometer (FLAPS)

- Flat Plasma Spectrometer missions
  - SSA—Monitor plasma environment
  - DCS—Detect plasma turbulence
- FLAPS—smart skin MEMS sensor
  - $\frac{\Delta E}{E} \approx 0.05$
  - 200 cm$^3$
  - 0.35 watts
  - 400 grams
  - Embedded ASCIS, high voltage power supply, micro-channel plate
  - Designed by Dr. Fred Herrero of NASA Goddard
  - Built by Applied Physics Lab
- Capabilities:
  - Full ion energy spectra
  - Detect non-thermal ion properties associated with plasma bubbles
- Status:
  - On-orbit initial checkout
Miniaturized Electrostatic Analyzer (MESA)—A Smart skin sensor

- **MESA design philosophy**
  - Begin with the end in mind
  - “Good enough” quality instrument
  - Thermal plasma density and temp.

- **Laminated electrostatic analyzer allows thousands of apertures**
  - Large aperture area/sensor volume ratio
  - Band-pass energy analyzer
  - No charge multiplication—relies on LEO densities
  - Manifested on 3 different satellites

**Proto-type MESA designed for FalconSat-2**

**Cross-section of MESA:** steers particles from the entrance aperture to the exit aperture by electrically-biased central plate

**MESA has performed as expected in chamber tests against a planar RPA.**
Future ideas

• What can you do with an iMESA in a cubesat size?
• PCBsat—satellite on a board
  – 3.2 in sq. x 1 in thick
  – 200 gm, $500 cost for board
  – Contains a cell phone camera
  – 3V, 500 mW power system
• PCBSat → PUBSat
  – 50 PUBSats in an orbit
  – Simultaneous plasma and optical measurements of the earth
  – Kit up 60 PUBSats, distribute to multiple universities—pick 50 that work
MEMS—aggressive miniaturization for plasma sensors

- **WISPERS**—Follow-on to (FLAPS)
  - 9 sensor heads covering 15°x15° FOV (FLAPS: 5 heads and 8°x1° FOV)
  - Detect up to 500 eV particles
  - Funded by NRL Operational Responsive Space (ORS) program
  - Payload on FS-5, manifested 4Q 2009

FLAPS qualification model: left showing close up of 5 detectors, right showing entire assembly

Notional top-view of WISPERS instrument showing 9 sensors and 15°x15° FOV.
WISPERS design

- Uses proven electrostatic energy filtering
- Smaller $d(1-f)$ means smaller aperture and better energy resolution
- Larger $L/d$ means capability to detect higher energy thruster particles
- Charge multiplication will allow MEO and GEO operation
  - Current design not radiation hardened—will need to be radiation hardened for MEO or GEO operation
MEMS future concepts

- Detection of neutrals
  - Low power MEMS ionizer provides ions for WISPERS
  - Improved pointing knowledge allows neutral wind measurements

- Mass spectrometry
  - Chop ESA allowing time of flight measurement

Figure 1: (Left) Schematic of the nanoscale gas ionization device. (Right) Typical results showing stable ionization discharge for argon at extremely low operating voltages (3-4 Volts).

Koratkar et al. 2005
Final Thoughts

- Building instruments for small satellites is not hard
  - Miniaturization makes size and power not an issue
- Matching sensors with missions is an issue
  - Keep the number of instruments on S/C small
    - 2 to 3 at most
    - Match the instruments and S/C cost/mission
- Keep the missions simple—but launch more of them!