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

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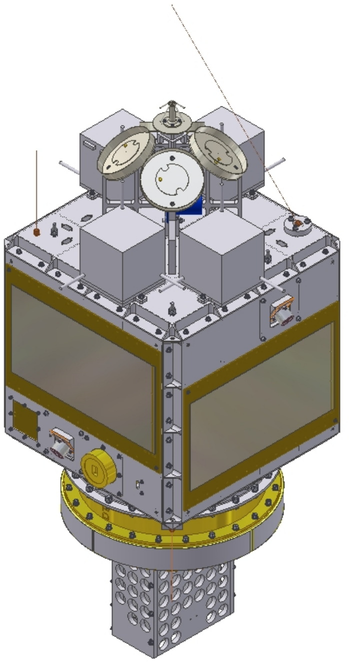
FalconSat-3—Space Physics on a small satellite

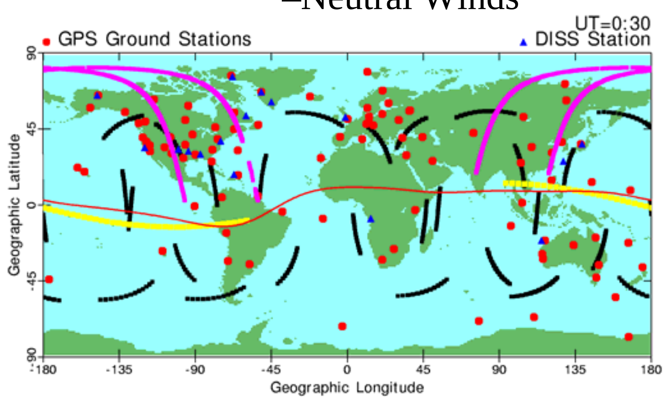
- Built 2005-2006
- Launched 8 March 2007
- Two plasma sensors
  - Plasma Local Anomalous Noise Experiment (PLANE)
  - Flat Plasma Spectrometer (FLAPS)



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

Space Weather	Terrestrial Weather
Basic measurements required to drive models	
–Plasma Temperature	Neutral Temperature
–Plasma Density	Neutral Pressure
–Neutral Winds	Neutral Winds



Space Weather is under-sampled!

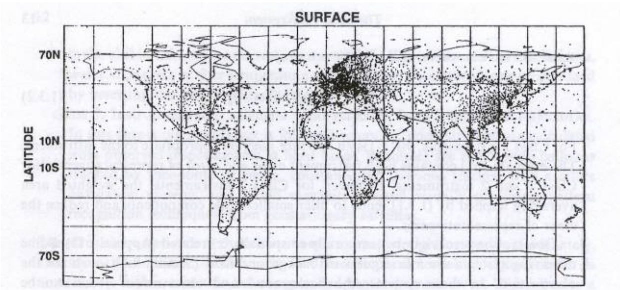


Fig 1.5 Daley
In-situ

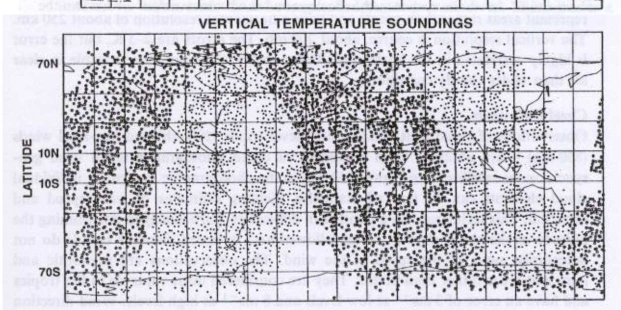
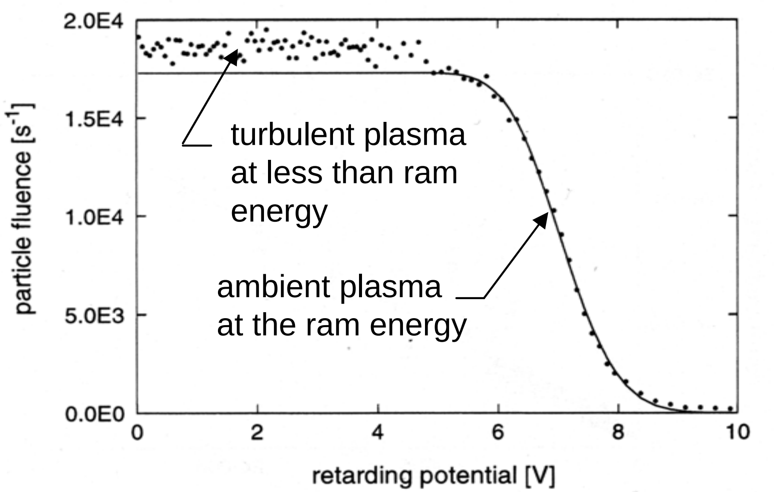


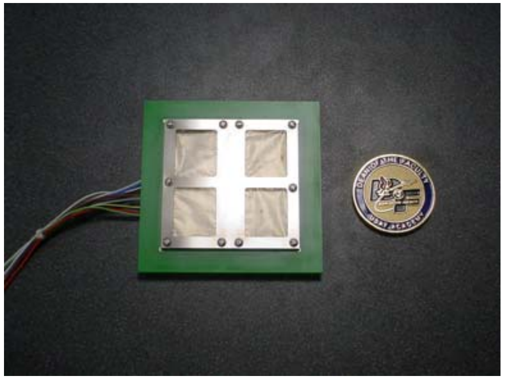
Fig 1.6 Daley
Remote

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



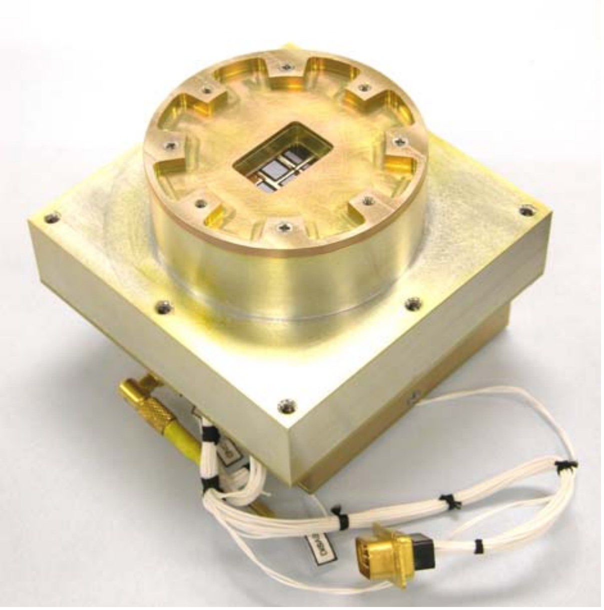
Data obtained during CHAWS experiment provided motivation for PLANE

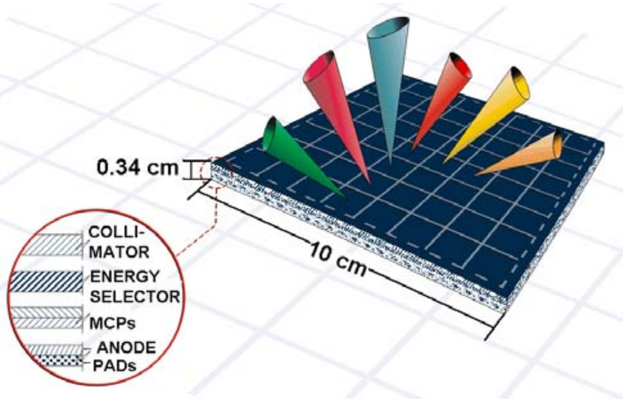


PLANE prototype

Flat Plasma Spectrometer (FLAPS)

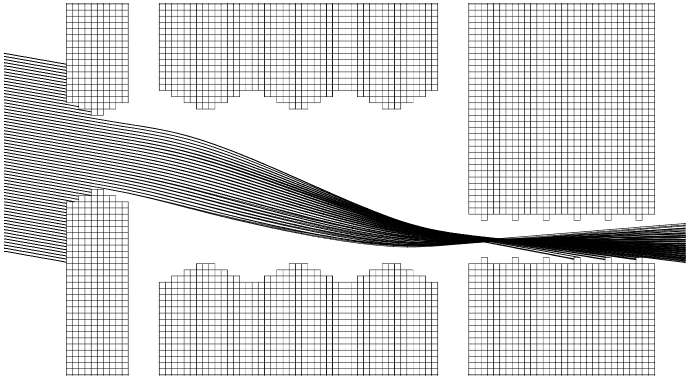
- Flat Plasma Spectrometer missions
  - SSA—Monitor plasma environment
  - DCS—Detect plasma turbulence
- FLAPS—smart skin MEMS sensor $\frac{\Delta E}{E} \approx 0.05$
  - 200 cm^3
  - 0.35 watts
  - 400 grams
  - Embedded ASCIS, high voltage power supply, micro-channel plate
  - Designed by Dr. Fred 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



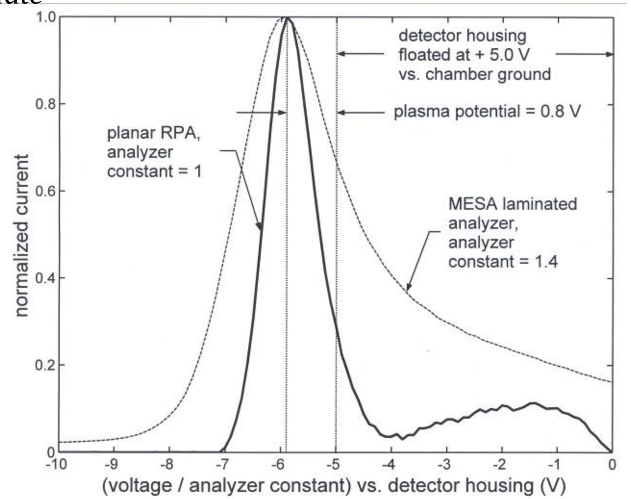


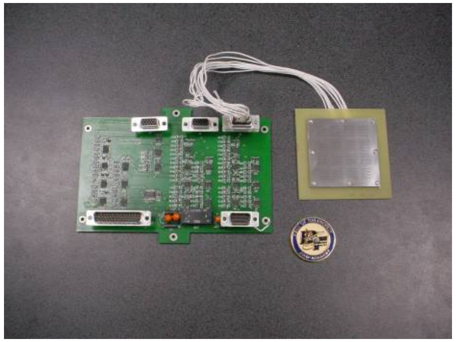
Miniaturized Electrostatic Analyzer (MESA)—A Smart skin sensor

- 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



Cross-section of MESA; steeres particles from the entrance aperture to the exit aperture by electrically-biased central plate



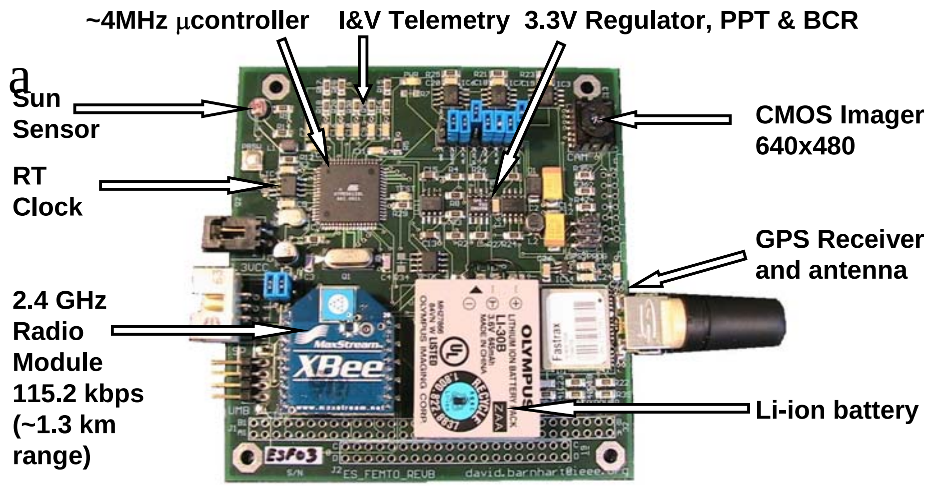


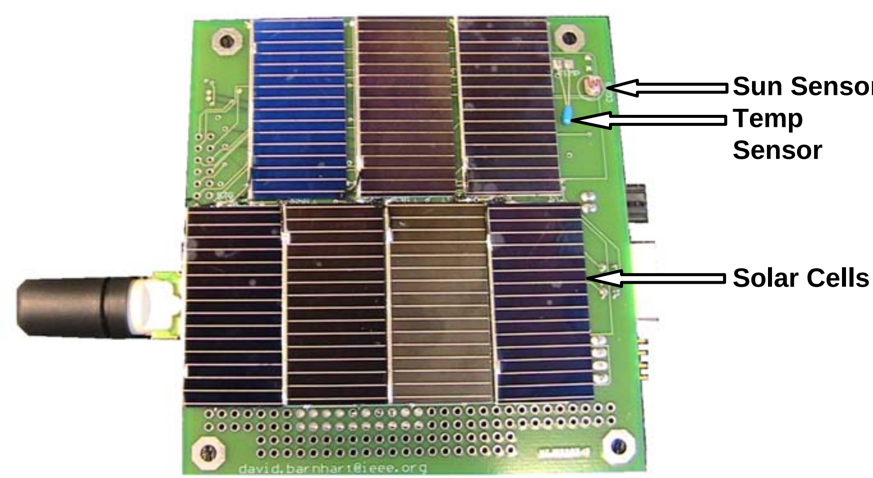
Proto-type MESA designed for FalconSat-2

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

Future ideas

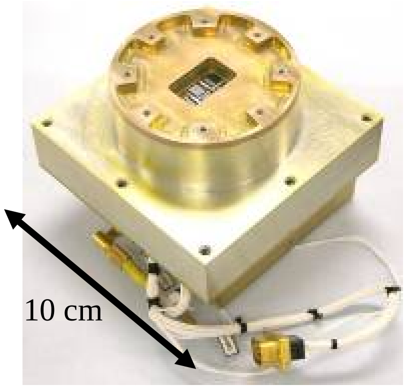
- What can you do with an iMESA in a cubesat size?
- PCBsat—satellite on a board
  - 3.2 in sq. x 1 in thick
  - 200 gm, $500 cost for board
  - Contains a cell phone camera
  - 3V, 500 mW power system
- PCBSat ➡ PUBSat
  - 50 PUBSats in an orbit
  - Simultaneous plasma and optical measurements of the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



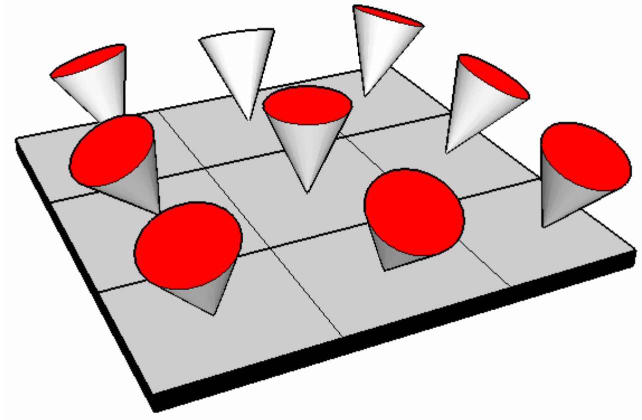


MEMS—aggressive miniaturization for plasma sensors

- 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



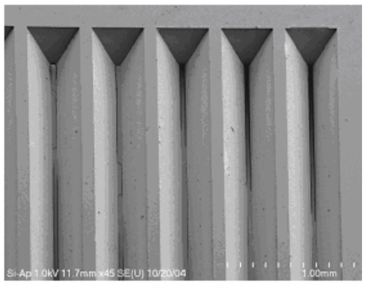
FLAPS qualification model: left showing close up of 5 detectors, right showing entire assembly



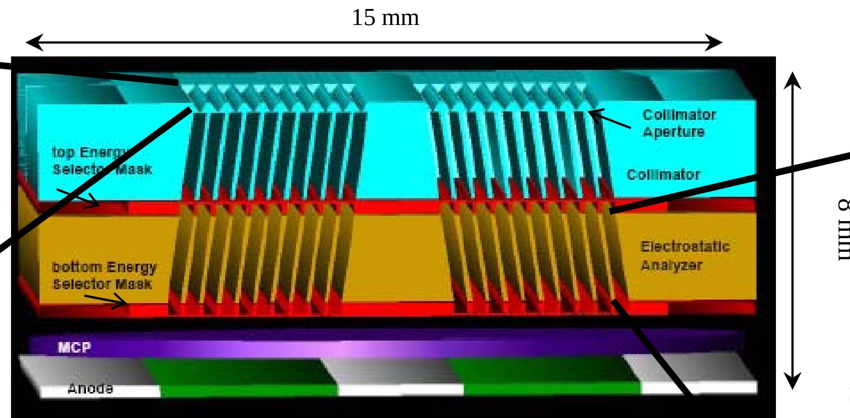
Notional top-view of WISPERS instrument showing 9 sensors and 15°x15° FOV.

FLAPS/WISPERS Technology

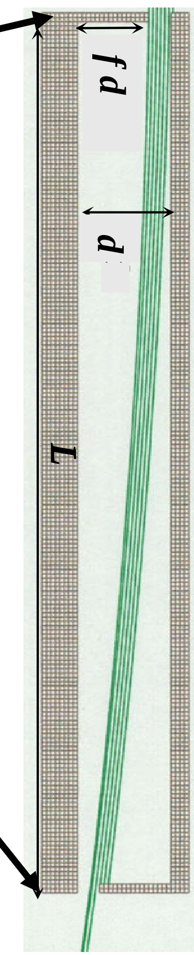
USAFA Space Systems Research Center



Scanning electron micrograph of the collimator aperture



Schematic of WISPERS cross section



Schematic of a single energy analyzer slit and SIMION simulation of an ion beam

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

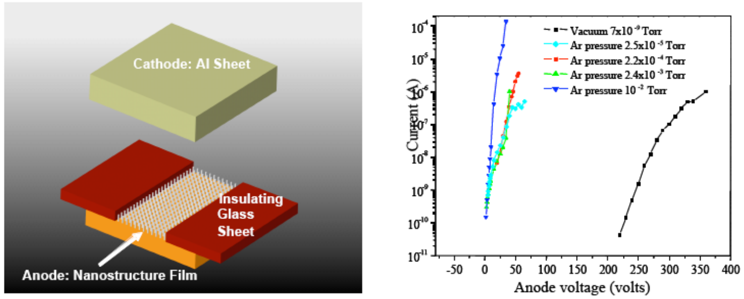
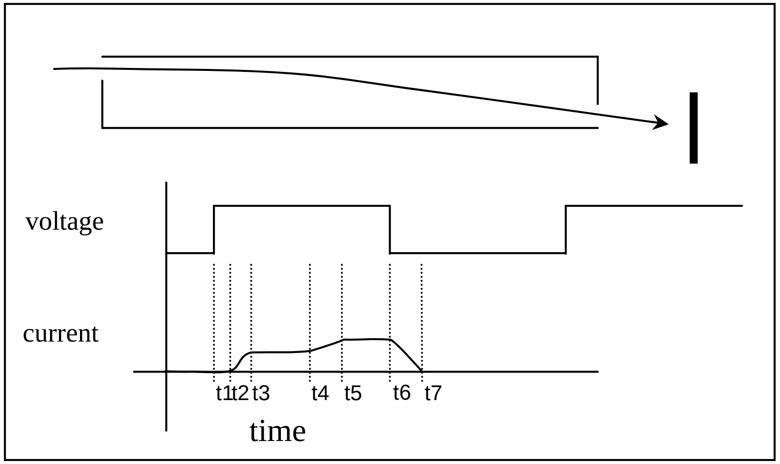


Figure 1: (Left) schematic of the nanoscale gas ionization device. (Right) typical results showing stable ionization discharge for argon at extremely low operating voltages (3-4 Volts).

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!