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Abstract

The Space and Atmospheric Instrumentation Laboratory at Embry-Riddle Aeronautical University launched a mid-latitude sounding rocket named SpEED Demon from Wallops Flight Facility in August 2022. SpEED Demon was a NASA technology demonstration mission that also had a comprehensive suite of instruments for electrodynamic and neutral dynamics measurements. The main payload consisted of a Sweeping Langmuir Probe for measuring plasma density and electron temperature, a pair of multi-Needle Langmuir Probes for 5KHz electron density, Positive Ion Probe for relative ion density, ionization gauges and sensitive accelerometers for background neutral density, a suite of sensitive magnetometers and a pair of electric field measurements on 6m tip-to-tip stacer booms. The main payload also ejected four sub-payloads, each carrying a Positive Ion Probe, a sensitive magnetometer, and an accelerometer capable of performing 'falling sphere' analogous neutral density measurements. The in-situ measurements are supported by ground-based remote measurements, from VIPIR radar and the MIT Haystack Observatory, to provide larger scale context for the localized measurements. We present the salient features of all instrument as well as preliminary data and performance characteristics.

Plasma Density (Langmuir Probe Suite)

≤ 0.3 m resolution
10³-10⁷ /cm³ range
50 /cm³ resolution

Electron Temperature (Langmuir Probe Suite)

400 - 5000K
~100 K resolution

Payload Potential and Electric Field (Floating Potential Probes)

≤ 0.1 mV/m resolution
≥ DC to 2000 Hz bandwidth

Magnetic Field (Fluxgate and Magneto-inductive magnetometers)

< 0.1 nT sensitivity ;
≤ 1 m resolution

Neutral Density (Ionization Gauge and Accelerometer)

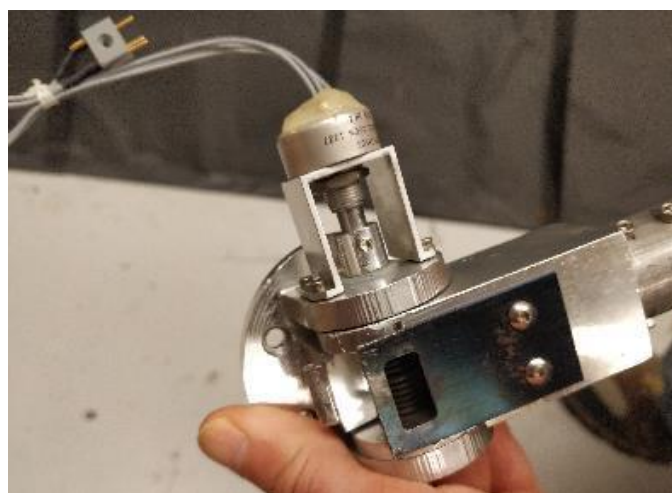
Ionization Gauge: ~10⁻⁶ kg/m³ resolution
Accelerometer: 10⁻⁷ kg/m³ resolution

Deployable Booms

Spring deployed, locking booms hinges.

Testing fixed length and telescoping designs for future use.

Identical hinge and sensor mount designs allows for ease of manufacture and design.



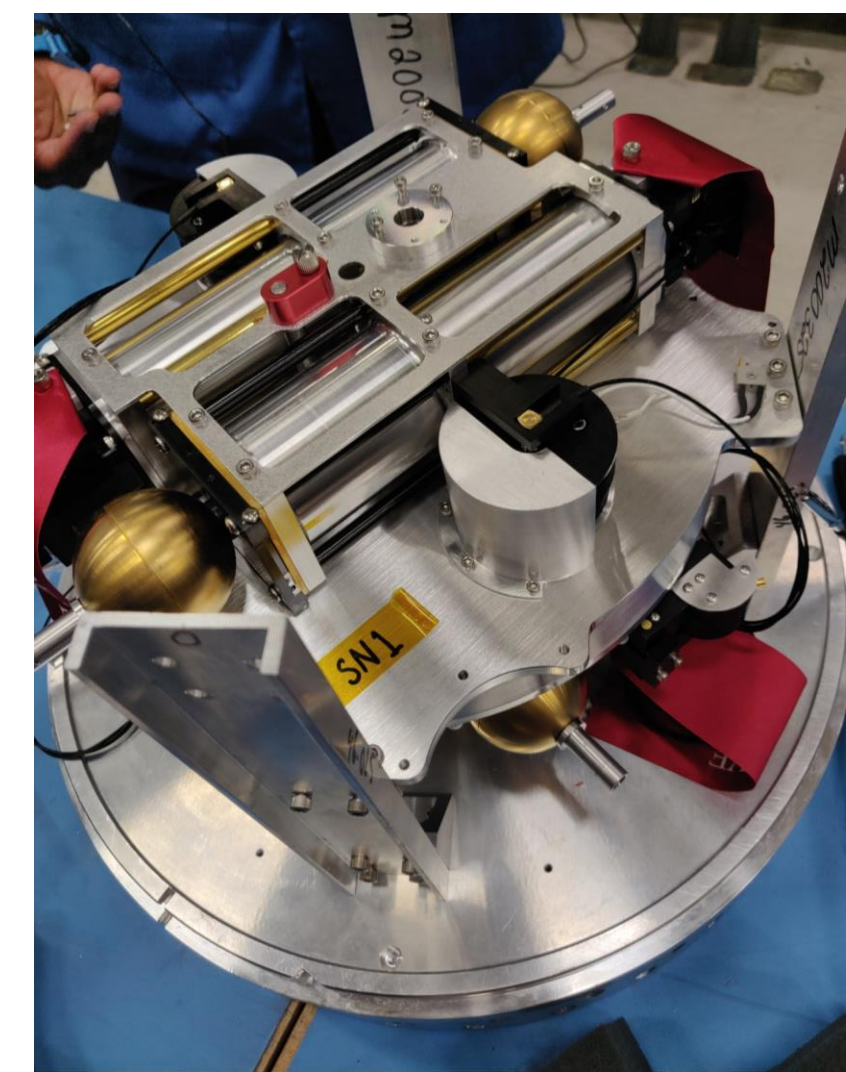
Floating Potential Probes

Main Payload Instruments

Floating Potential Probes x 4

Heliospace Deployable Quad Stacer booms³
Gold coated 2" diameter sensor spheres

4 independent Floating Potential Measurements: 50μV resolution
2 pairs of differential Electric field measurement: 0.1 mV/m
6 m tip-to-tip distance fully deployed
5kHz measurement frequency



Magnetometers

Main Payload Instruments

Billingsley Triaxial Fluxgate TFM65VQS²

Aft axially mounted
Accuracy: ± 0.75% of full scale (± 100 μT)
Linearity: ± 0.015% of full scale
Sensitivity: 100 μV/nT
5kHz measurement frequency

PNI-RM3100⁴ x 2

Located on a fore deployable boom
1.5 nT 3-axis sensitivity
15 Hz measurement frequency

Both magnetometers are meticulously calibrated in a Zero Gauss Chamber and Helmholtz cage

See poster [SH32D-1787](#) for more information and in-situ instrument data from the magnetometers onboard SpEED Demon flight.

Ionization Gauge

Cold Cathode Ionization Gauge⁵

PKR360 x 2

Mounted 45° from axial fore end
Measurement range: 7.5e-10 to 750 torr
5kHz measurement frequency

See poster [SH32D-1789](#) for more information and in-situ instrument data from SpEED Demon flight.



Accelerometers

ADXL 355⁷

±2g measurement range
~30 μg resolution
2.5 kHz measurement frequency

Kionix KXR94-2283⁶

±2g measurement range
Offset Error: 4 mg ± 1.25% of measurement
0.1% non-linearity
5kHz measurement frequency

Kionix previously flown on MTeX mission.⁹
Experiment measures drag on payload sensitively enough to compute neutral density up to ~110km.

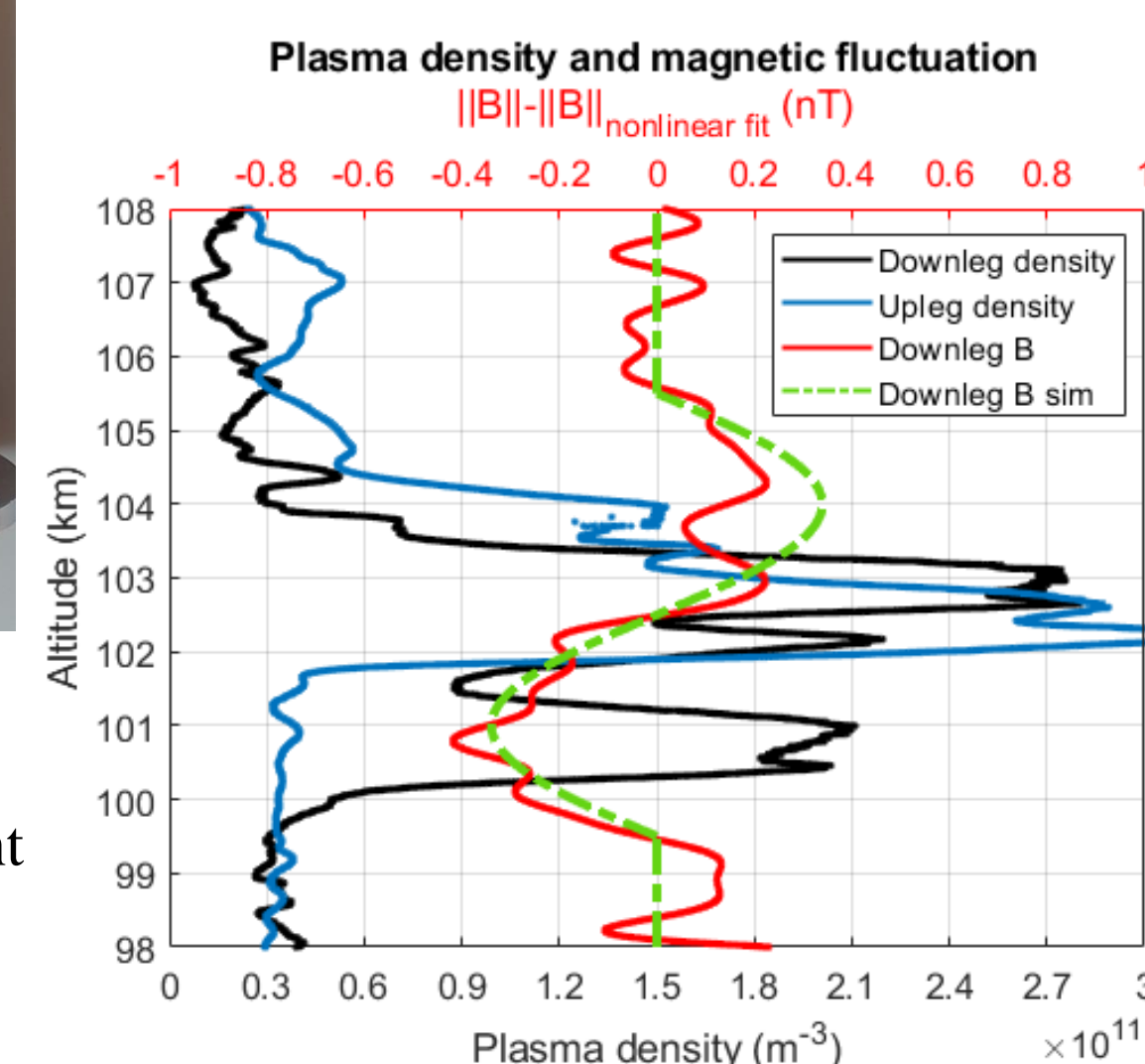
Both Accelerometers mounted together in the center of the main payload.

See poster [SH32D-1789](#) for more information and in-situ instrument data from SpEED Demon flight.

Floating Potential Probes

Billingsley Magnetometer

Below: Billingsley magnetometer measurements during Sporadic-E layer crossing on the downleg portion of the trajectory. The measured magnetic field fluctuation (red line) coincides with the Es layer (black and blue lines) and is equivalent to simulated field generated by a ~0.1 uA/m² current density Field Aligned Current.

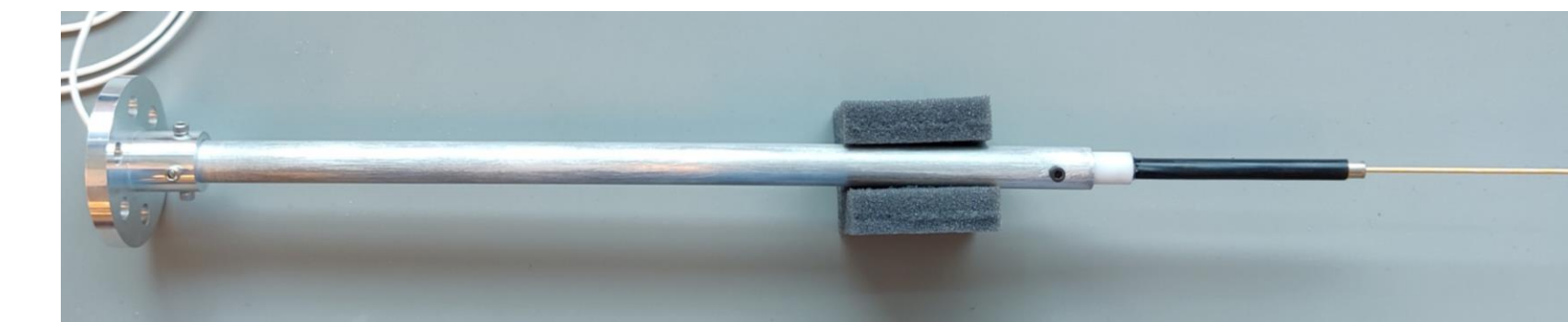


Sweeping Langmuir Probe

Langmuir Probe Suite

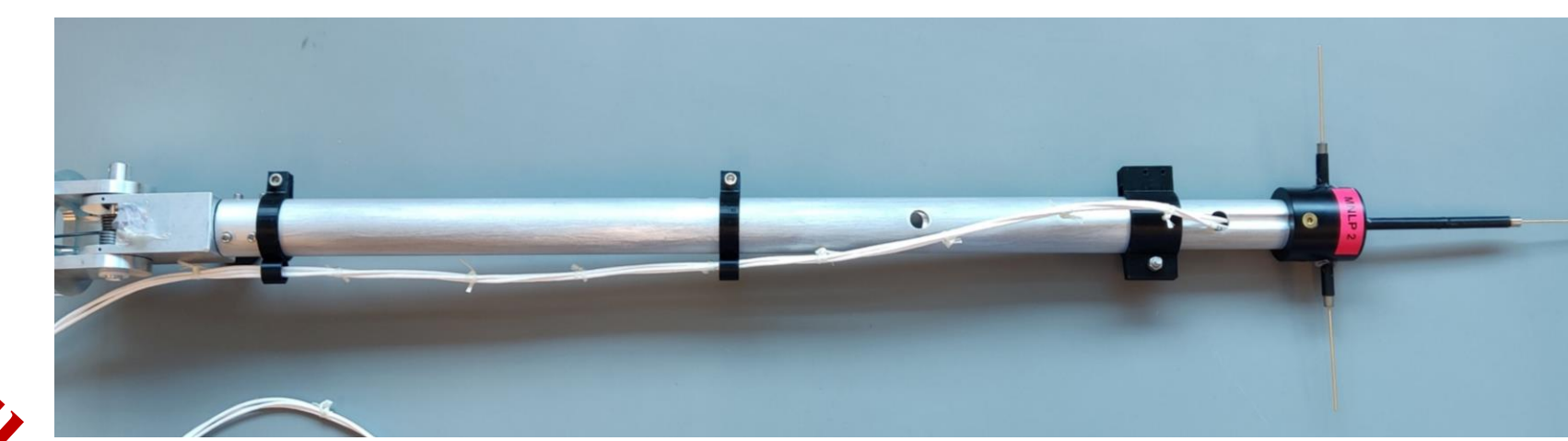
Sweeping Langmuir Probe (SLP)

Flown recently also on ENDURANCE mission⁸
Capable of fixed bias and sweeping measurements
46.8 kHz measurement frequency
~20 Hz sweep frequency (configurable)
-3 to +4 measurement voltage range (configurable)
See session [SH36A-05](#) for in-situ data



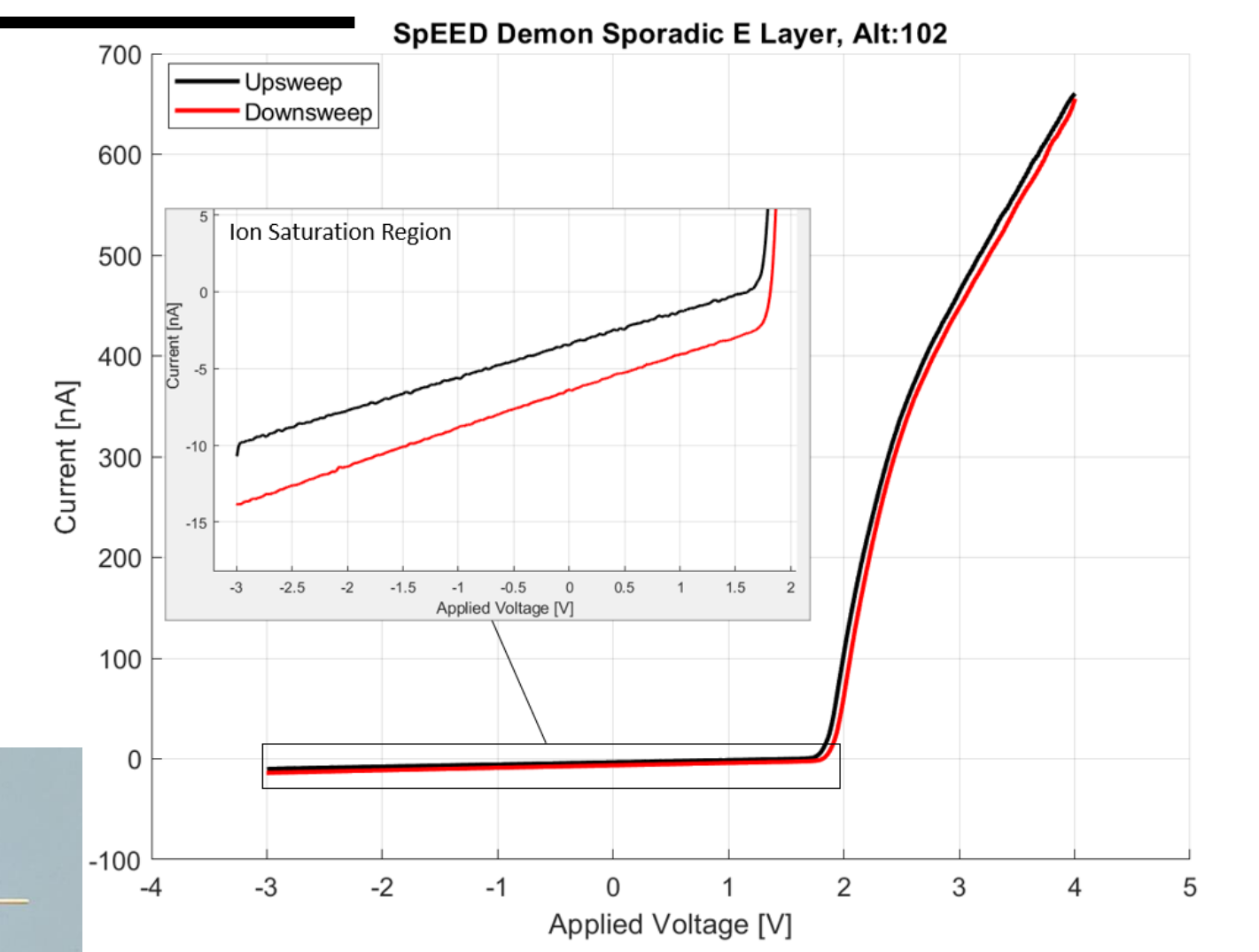
Multi-Needle Langmuir Probe x 2 (mNLP)

3 gold coated needles per boom,
electron saturation region at +4,5,6,7,8,9 V
telescopic hinged boom design (right)
5kHz measurement frequency

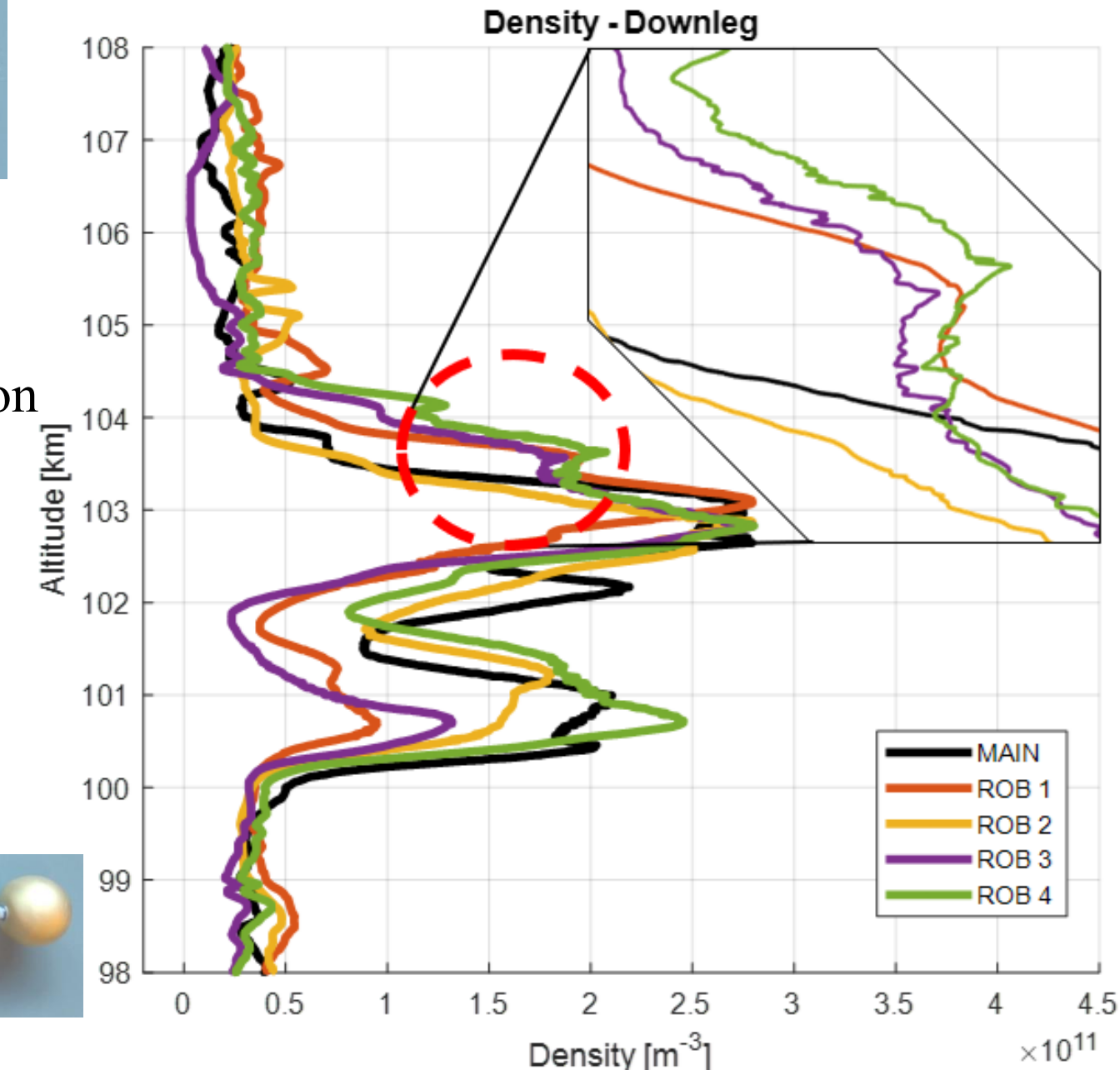


Positive Ion Probe (PIP)

1.5" diameter gold coated sphere, ion saturation region
Biased -6V w.r.t. rocket chassis ground
5kHz measurement frequency
See poster [SH32D-1793](#) for more information and in-situ instrument data from SpEED Demon flight.



Above: Sweeping Probe I-V curve during Sporadic-E crossing on the downleg. See session [SH36A-05](#) for in-situ data analysis of the Electron and Ion saturation regions, hysteresis, and floating / plasma potential measurements during the SpEED Demon Launch.



Above: Multi-point in-situ ion density measurements from the main SpEED Demon payload and 4 deployable subpayloads during the downleg Sporadic-E layer crossing.

See poster [SH32D-1793](#) for more information and in-situ instrument data analysis from the SpEED Demon flight.

Accelerometers @ CG

Swarm Subpayloads

Swarm Subpayload Instrumentation

~3 m/s deployment speeds relative to payload
Deploy parallel to ground in pairs,
Each pair deployed 180° from each other
GPS positioning pre and post ejection from main payload

5 point (main payload + 4 ejectable) multi-point in-situ measurements of:

Planar Langmuir Probe

Gold coated axially symmetric cylindrical flexible PCB sensor
Ion measurement analogous to main payload PIP sensor
~2.9 kHz measurement frequency

PNI-RM3100 Magnetometer⁴

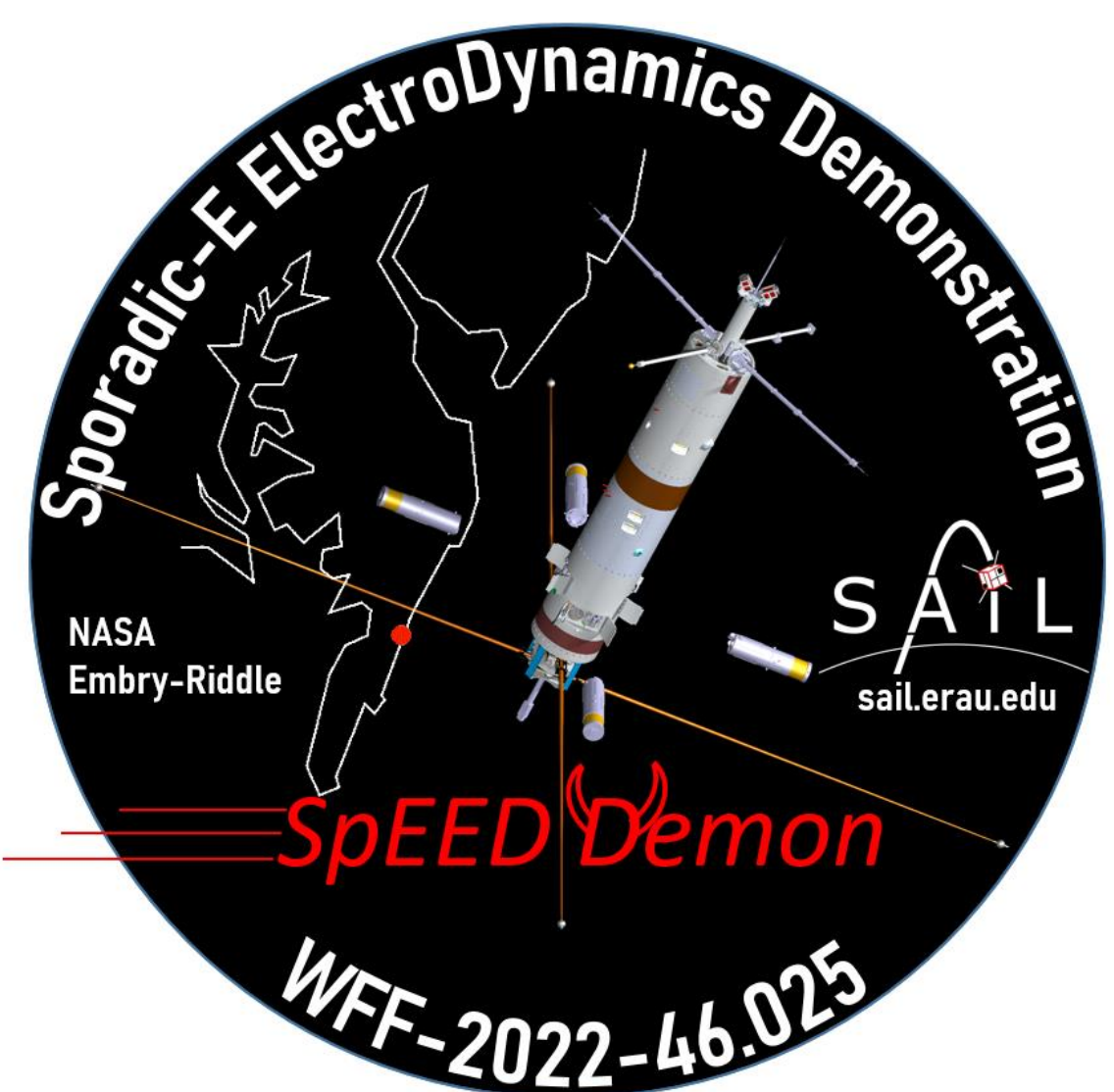
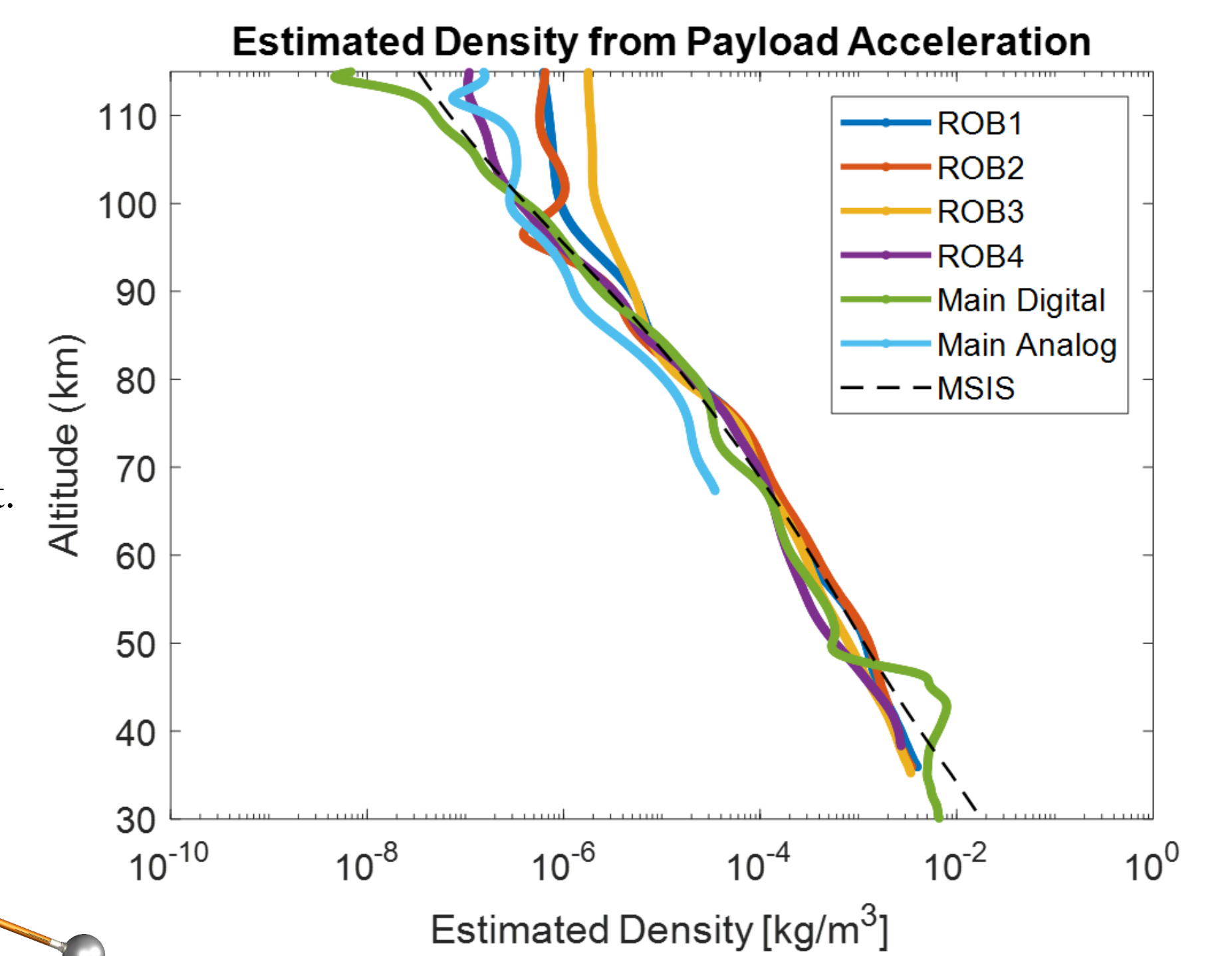
Identical to main payload PNI magnetometers
15 Hz measurement frequency
1.5 nT 3-axis sensitivity

Accelerometer: ADXL355⁷

Identical to main payload ADXL accelerometer
±2g measurement range
~30 μg resolution
250 Hz measurement frequency

Right: Derived multi-point density calculations from onboard accelerometer and Ion gauge measurements.

See poster [SH32D-1789](#) for more information on in-situ drag calculation and instrument data from SpEED Demon flight.



References

- ¹Space and Atmospheric Instrumentation Lab, <http://sail.erau.edu/>
- ²Billingsley Aerospace & Defense, <https://magnetometer.com/>
- ³Heliospace Corporation, <https://helio.space/>
- ⁴Positioning Navigation Intelligence, <https://www.pnicorp.com/>
- ⁵Pfeiffer Vacuum, <https://www.pfeiffer-vacuum.com/en/>
- ⁶Kionix, <https://www.kionix.com/>
- ⁷Analog Devices, <https://www.analog.com/en/products/adxl355.html>
- ⁸Collinson, G., Glocer, A., Pfaff, R. et al. The Endurance Rocket Mission. *Space Sci Rev* **218**, 39 (2022). <https://doi.org/10.1007/s11214-022-00908-0>
- ⁹Lehmacher, G., et al., On the Short-term Variability of Turbulence and Temperature in the Winter Mesosphere. *Annales Geophysicae* **36**, 4 (2018). DOI: 10.5194/angeo-36-1099-2018