Langmuir probes and accelerometers for MMOD Observations

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A few means to observe MMOD (<= 10 cm)

- MMOD (several mm to several cm) observations by solitons
  - Coherent Density fluctuations
  - Magnetic field fluctuations
  - Electric field fluctuations
- MMOD (< several mm) observations by impact on spacecraft
  - plasma discharges
  - Impact vibrations/sudden change in spacecraft velocity

Solitons and Wakes [MMOD (< several cm)]

- (Solitons – upstream) and (Wakes – downstream)
- At High LEO altitudes (>700 km)…

	Wakes*	Solitons**
Wave amplitude in Density	~+/-2x (1e3/CC) Turbulent structure	~+/-2x (1e3/CC) Coherent structure
Scale size	Multiple tens of cms	Tens of cms
Electric field	???	mV/cm (?)
Magnetic field	???	Few nT (?)

- Langmuir probes requirements
  - Measure fluctuations at 1e2/CC scale (bit better than needed!)
  - For spacecrafts moving at 8 km/sec, sample at ~80 KHz
  - Deploy probe(s) outside the self-wake to detect the soliton
  - Multiple deployed probes (may) help determine direction
  - Measure spacecraft charging to better than 1 mV

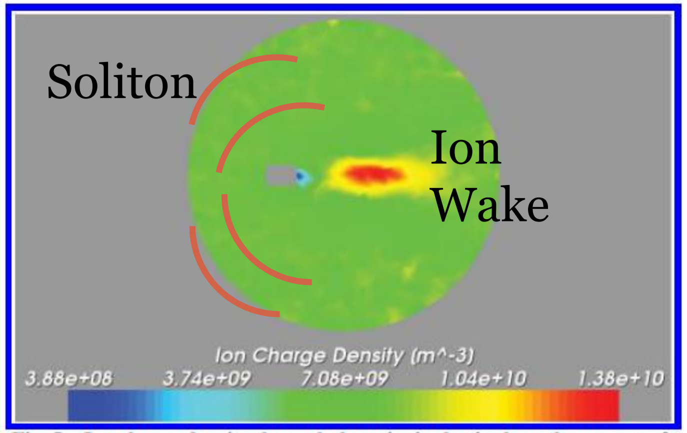


Fig. 5 Ion charge density through the principal axis along the spacecraft velocity vector.

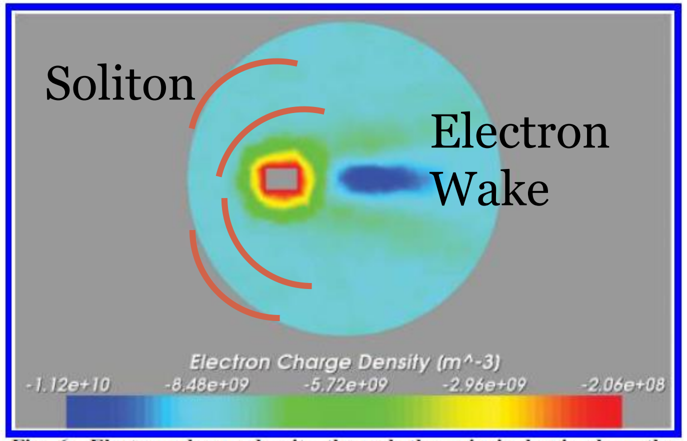
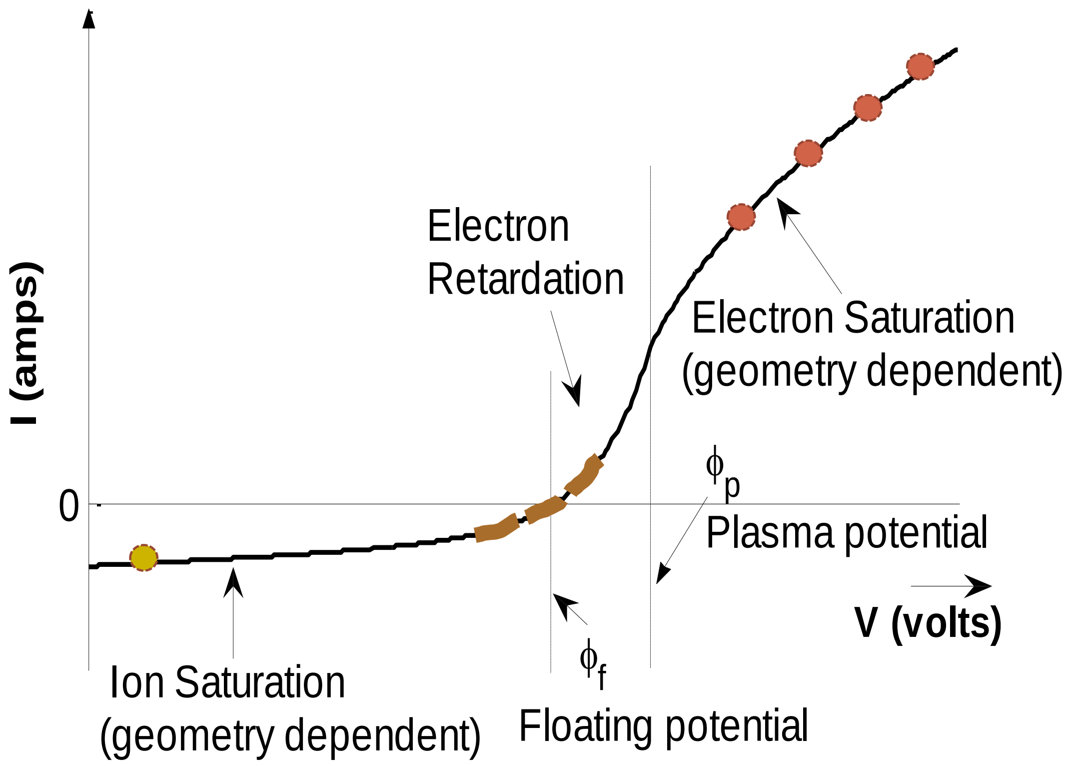


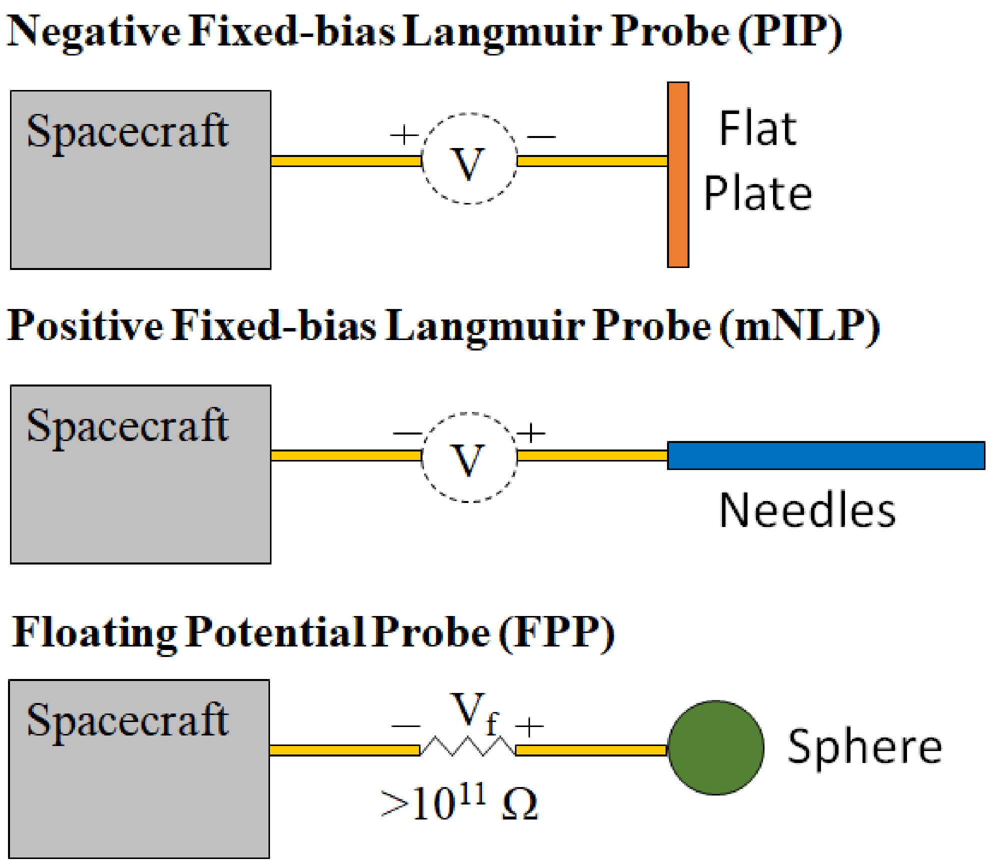
Fig. 6 Electron charge density through the principal axis along the spacecraft velocity vector.

*Albarran and Barjatya, 2016
** Truitt and Hartzell, 2020

SAIL Langmuir Probes

- Sweeping probes, fixed bias probes, floating probes and all geometries





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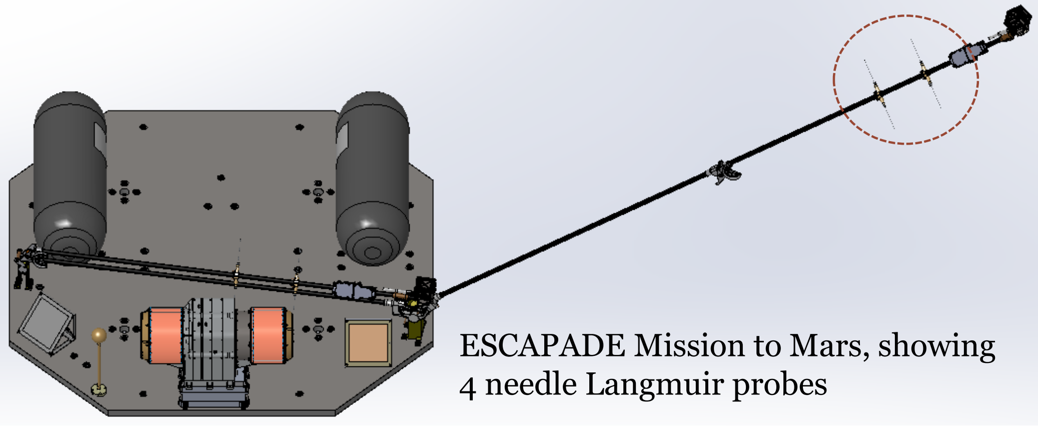
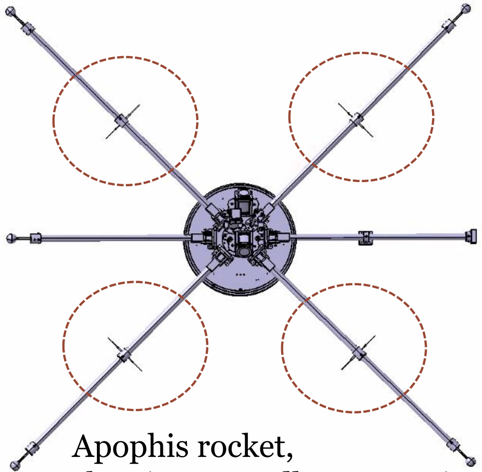
SAIL Langmuir Probes … performance

- Density : 1e2/CC to 1e7/CC
- Sampling frequency: Current max ~90 KHz
- Needle dimensions: 1 mm diameter – 5 cm length
- Deployable on long booms
- Multiple probes can give directional information!
- 1.6m separation between two-needles takes 0.1 msec to travel at 16 km/s. Resolvable at 80 Khz sampling



ESCAPADE Mission to Mars, showing 4 needle Langmuir probes



Apophis rocket, showing 8 needle Langmuir probes

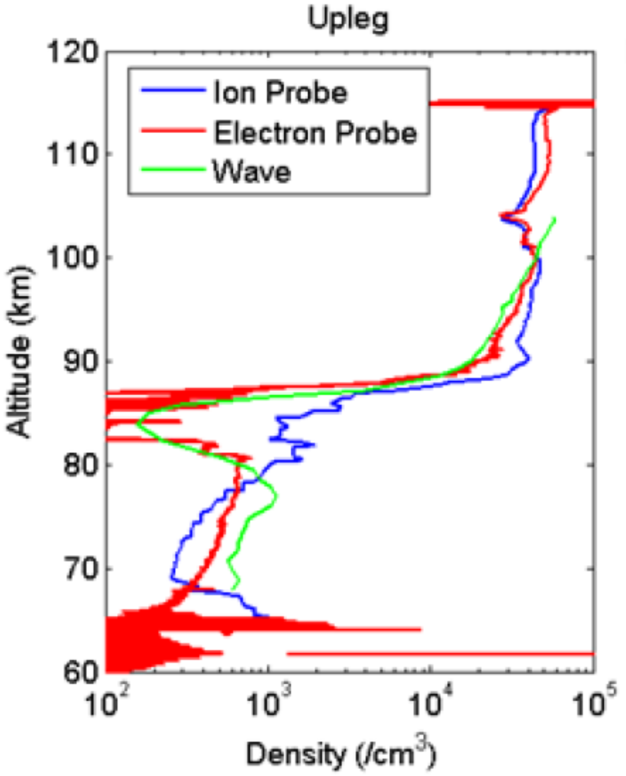


Fig.12 WADIS 1 data showing an electron bite-out, that the Ion probe is immune to.

Magnetic Field

- ~1 nT B Fields have been found associated with solitons in Ulysses spacecraft data.
- It is in solar wind, so not clear if that impacts HLEO solitons
- In any case, SAIL miniature magnetometer meticulously calibrated to give 1 nT resolution at 1 Hz… and 3-5 nT at 10 Hz.

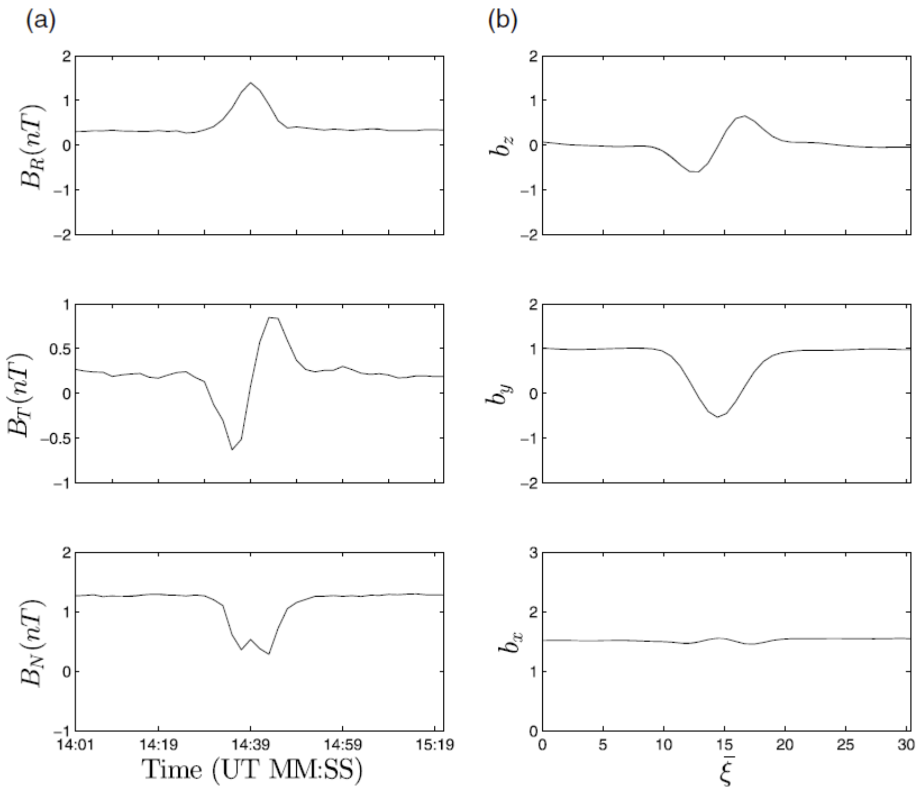


Figure 1. Ulysses magnetometer data from 17 July 2002, around 08:15 UT. (a) Field components as a function of time expressed in RTN coordinates. (b) Field components as a function of ξ, the scaled and rotated x, after the following transformations have been applied: (i) rotation using the minimum variance transformation, (ii) scaling to the asympotic value of B_x, and (iii) rotation about the new x direction to eliminate the asymptotic value of b_z. The eigenvalues that resulted from the minimum variance analysis [*Sonnerup and Scheible*, 2000] were 33.88, 15.75, and 1, scaled to the minimum eigenvalue. The minimum variance direction, x, makes an angle of $\theta \approx 32.8°$ with respect to the background magnetic field.

Wheeler, H. R., IV, M. A. Reynolds, and R. L. Hamilton (2015), J. Geophys. Res. Space Physics, doi:10.1002/2014JA020770.

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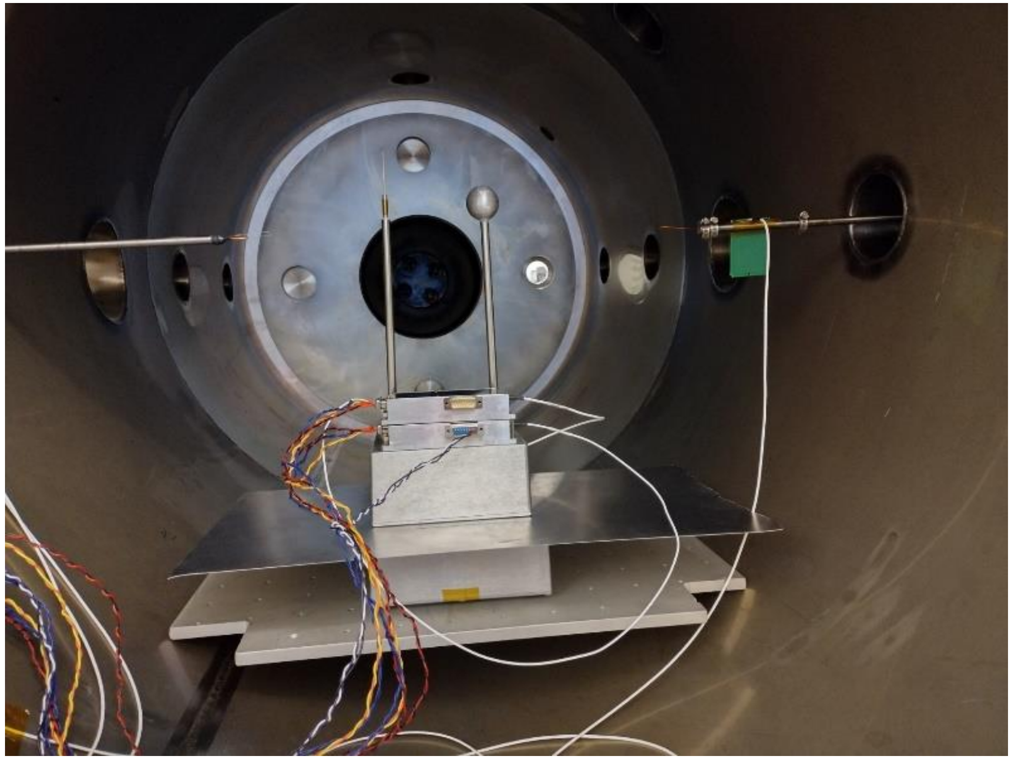
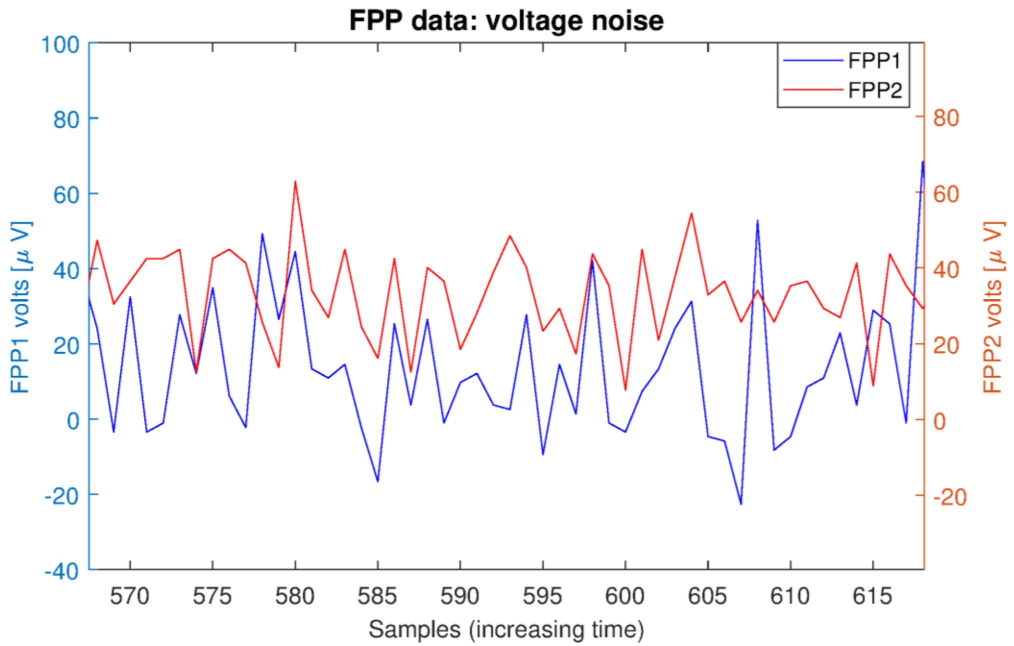
Electric Field

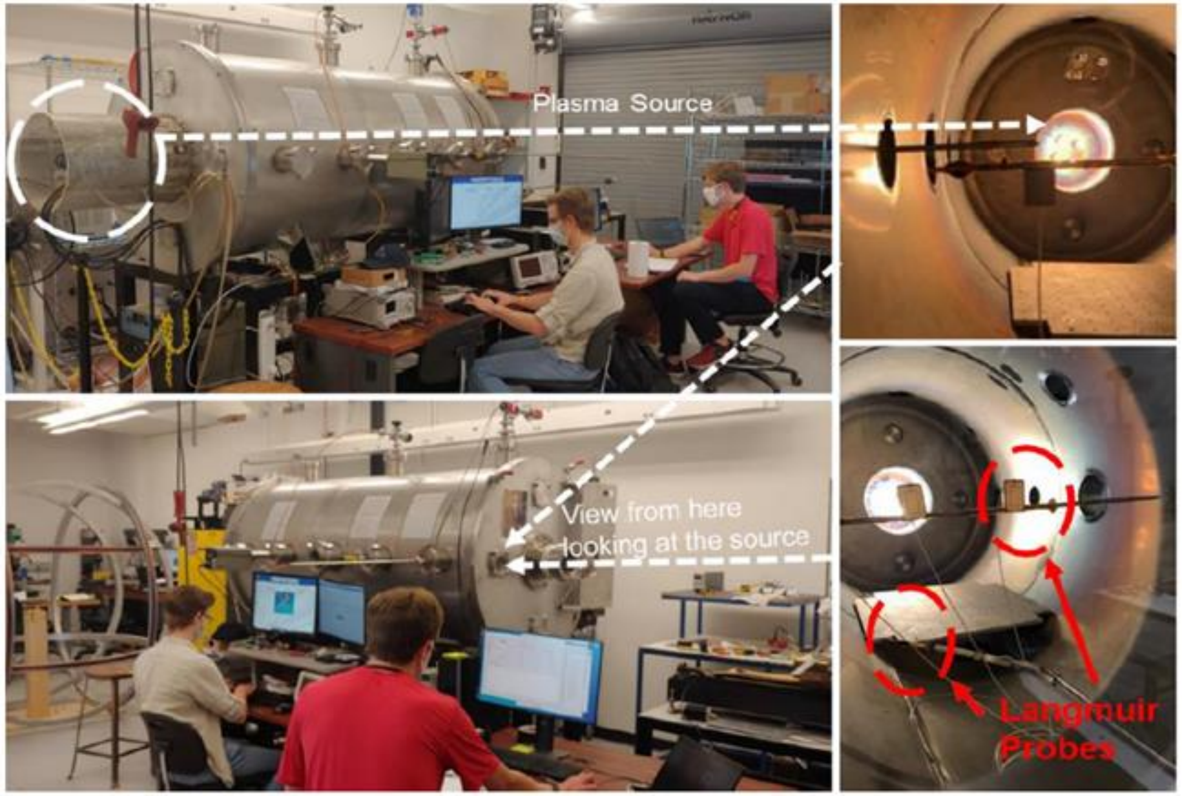
- SAIL Floating probes have 10s of uV noise floor… <0.1mV/m resolution
- Tested in Plasma Chamber and multiple upcoming rocket flights





Testing in a plasma Chamber !?!

- Concerns with solitons:
  - Strong geometrical attenuation in 3D, as opposed to 1D or 2D
  - Effect on solitons due to density gradients?
  - Effect on particles due to energy lost by the waves *?
- With a LEO plasma source that generates flowing plasma we can test solitons in a plasma chamber with many possibilities
  - Multiple geometries and arrival angles
  - Multiple debris sizes and flow velocities



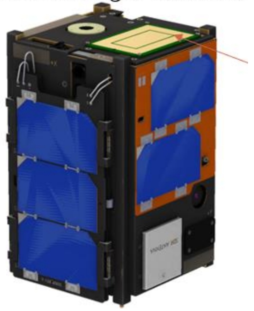
Plasma Chamber setup at ERAU.

*Pereira and Morales, 1981

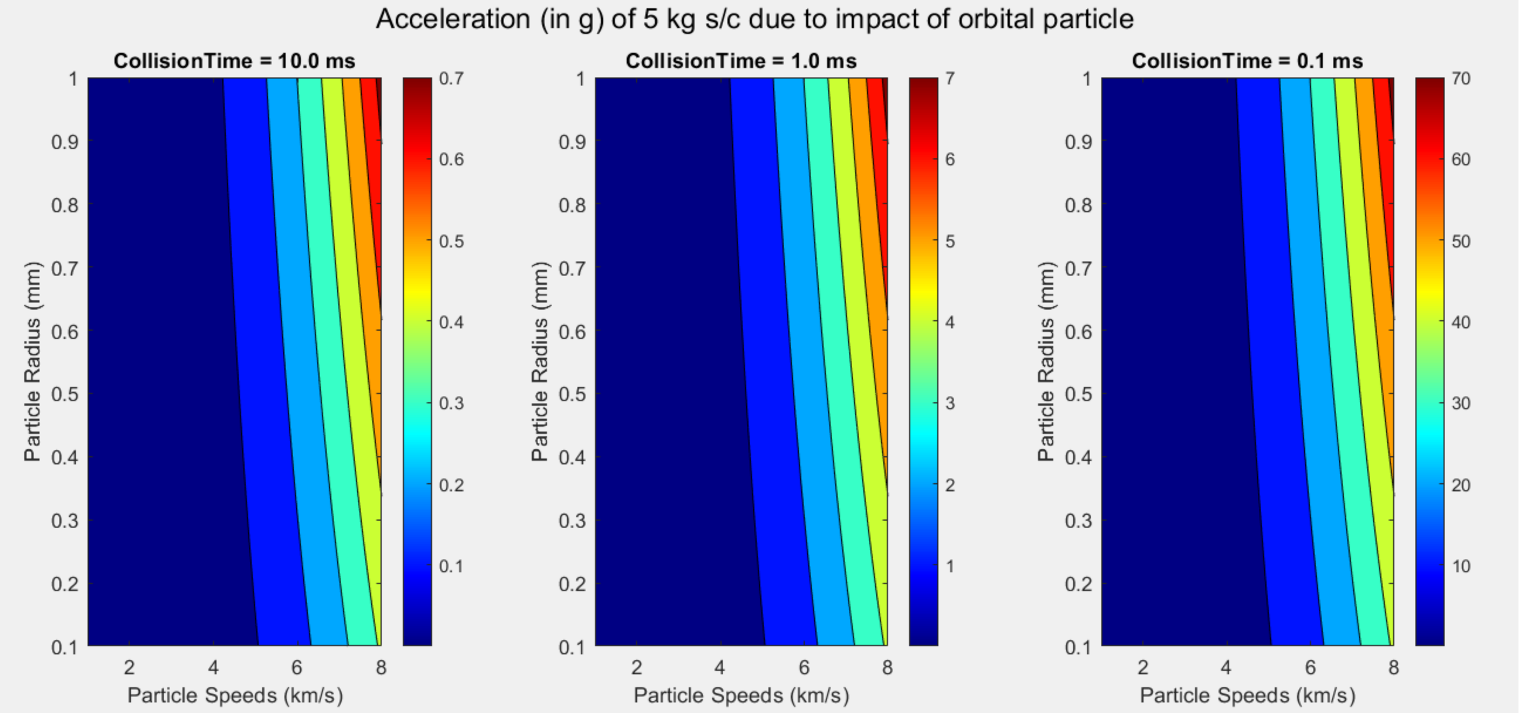
MMOD < 1mm : Observations by impact on spacecraft

- Oscillations in potential will be seen by Floating Potential Probe
- Changes in local plasma density will be seen by patch Langmuir probes. To right is an image of a 1.5U CubeSat that has a gold patch.
- Accelerations seen by sensitive high sample rate accelerometers

LLITED 1.5U CubeSat



- Plot to the right shows particles coming in varying relative speeds (x-axis), and particle size (y-axis) assuming aluminum spheres. CubeSat mass assumed is 5kg (3U).
- Depending on how long it takes for the particle to come to rest, the acceleration experienced by the CubeSat is shown in 3 columns.
- Takeaway: we need accelerometers sampling at several KHz to catch the impact



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Summary

- SAIL Langmuir probes are low SWaP.
  - They can conform to any reasonable Length x Width PCB dependent on small satellite bus constraints.
  - Their performance characteristics make them suitable for high cadence density measurements allowing observations of solitons.
  - Deployment of multiple sensors on same spacecraft with optimal distances could potentially enable directional information
  - Plasma chambers with flowing LEO source could be the best first step towards determining instrumentation for soliton detection.
- SAIL has additional small accelerometers that may be suitable for detecting extremely small debris hits (<1 mm). Multiple of these accelerometers could be deployed on large surface area satellite.
- We also meticulously calibrate a COTS magnetometer enabling ~1nT accuracy and precision measurements at 1 Hz. Lower precision at higher sampling rates.