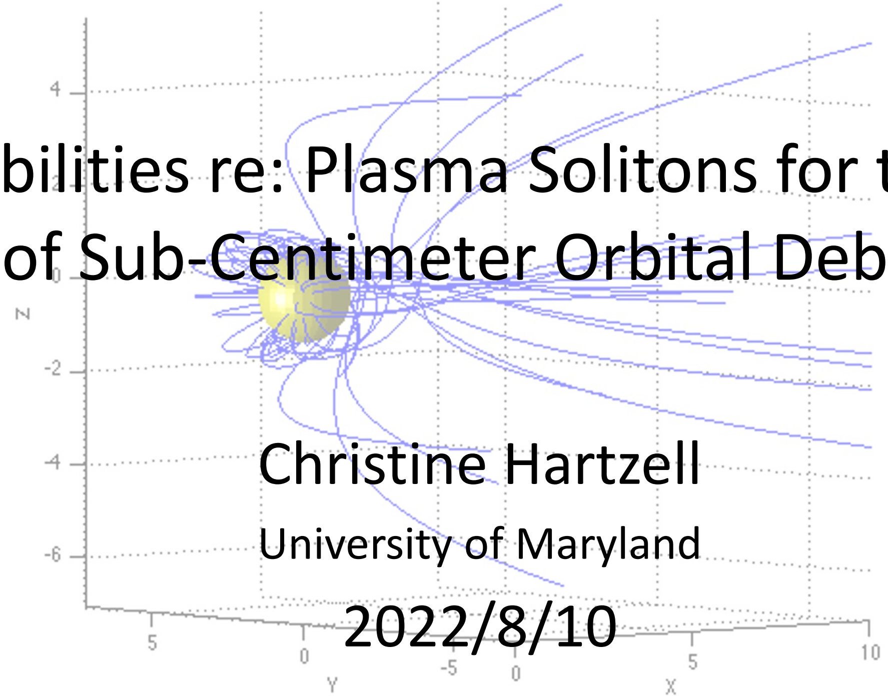
UMD Capabilities re: Plasma Solitons for the Detection of Sub-Centimeter Orbital Debris



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Capabilities: Overview

Goal: Detect small (sub 10cm) debris via plasma signature

- Simulate (1D-3D) precursor and pinned electrostatic solitons produced by orbital debris
  - including damping effects and dissipation due to variation in the plasma environment
- Autonomously identify solitons in noisy data using inverse scattering transform
- Experimental facilities:
  - 2 dusty microTorr vacuum chambers, emissive filament, 4K fps high speed camera (in vacuum chamber)
- Astrodynamics

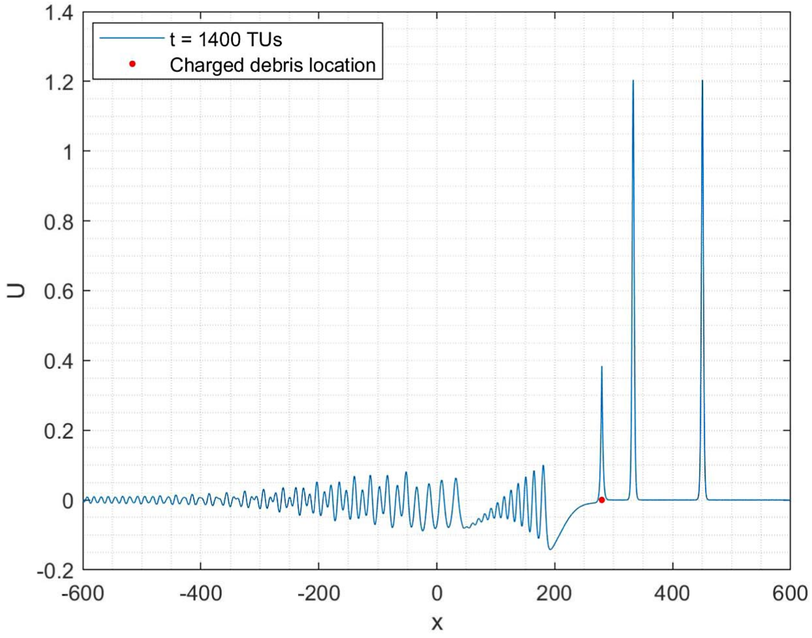
Figure Source: Nature, Vol 376, 1995.

Soliton Simulation Capabilities

- A. Truitt and C. Hartzell, *"Simulating Plasma Solitons from Orbital Debris using the Forced Korteweg-de Vries Equation"*, Journal of Spacecraft and Rockets. 2020. Vol 57 (5), 876-897. https://doi.org/10.2514/1.A34652

- A. Truitt and C. Hartzell, *"Simulating Damped Ion Acoustic Solitary Waves from Orbital Debris"*, Journal of Spacecraft and Rockets. 2020. Vol 57 (5) 975-984. https://doi.org/10.2514/1.A34674

- A. Truitt and C. Hartzell, *"3D Kadomtsev-Petviashvili Damped Forced Ion Acoustic Solitary Waves from Orbital Debris"*, J. of Spacecraft and Rockets, 2021, Vol. 58, No. 3, pp. 848-855 https://doi.org/10.2514/1.A34805.



Precursor, 2.5mm debris, 1200km circular orbit

Soliton Simulation Capabilities

- Modeled using forced KdV equations (1D), KP equations (2D,3D)
- Focused primarily on wave in plasma density, but from density, can derive electric field
- Questions we have answered:
  - what size debris produce precursors? at what altitude, latitude, longitude?
  - what are the characteristics of the precursors: amplitude, width, generation frequency, time to first generation, distance traveled prior to dissipation?
  - could be extended for pinned solitons

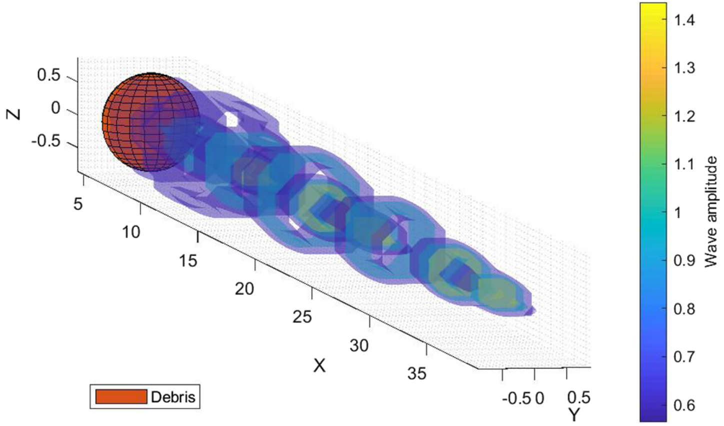


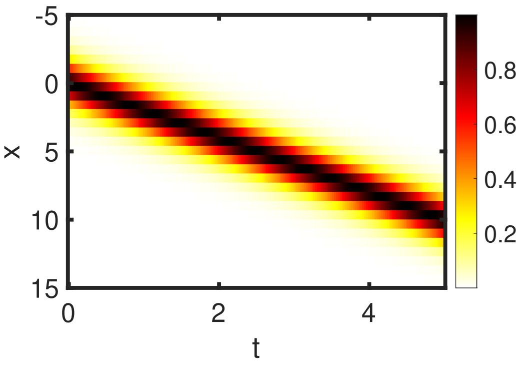
Fig. 8 Three-dimensional simulation results in the equal axis scale for precursor solitons $G = 0.75$, $V_{\mathrm{rel}} = 0.1375$, at $t = 79.8$ TU.

Example 3D precursor soliton

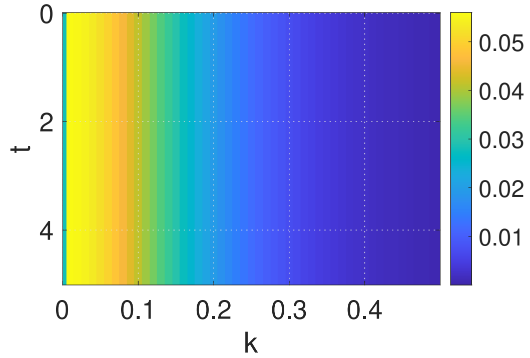
Source: Truitt and Hartzell, 2021, JSR

On-Going Work: Signal Inversion

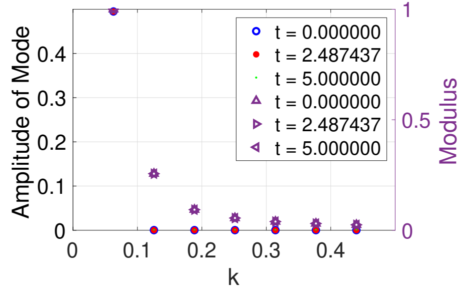
- Agnostic to sensor, given a measurement of the plasma density, how can we detect the presence of a soliton?
  - inverse scattering transform works with forced, noisy signal
  - Publication soon to be submitted to Physics of Plasmas
- Given a detected soliton, what can we infer about the debris?



(a) Single soliton translating.



(b) Fast Fourier transform in space of soliton signal. No clearly identifiable mode.

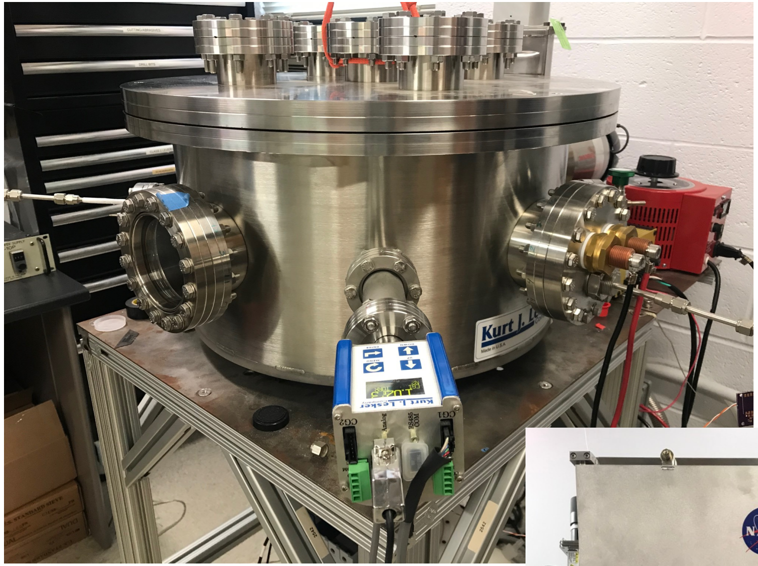


(c) PIST transform of soliton signal at $t = 0$, 2.48, and 5. Modulus of each mode is on the right y axis and marked with the differently oriented triangles. The amplitudes use the circular markers.

FIG. 2: Spectrum of $u(x) = sech^2\left(\frac{\sqrt{2}}{2}(x - 2t)\right)$ using the FFT and PIST.

Lab Facilities

- Two ‘dusty’ vacuum chambers capable of microTorr levels
  - 22.75” diameter, 11” deep collar-type vacuum than can be mated to 18”x22” bell jar
  - 24”x24”x30” chamber
- 4K fps high speed camera that can be used in the larger vacuum chamber (PCO Dimax CS3)
- emissive filament plasma source
- 44 core lab server
- access to UMD’s supercomputers



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