EXPLORESCIENCE

National Aeronautics and Space Administration

Space Debris/Space Situational Awareness: Heliophysics Responsibilities and Research Plans

Reinhard Friedel, OD-SSA Program Officer

Alex Fletcher, Deputy OD-SSA Program Officer

NASA Headquarters

Science Mission Directorate

Heliophysics Division

Committee on Solar and Space Physics

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Overview

- Broader National and NASA Context, role of Heliophysics Division
- The Problem
  - *Tracked Object Growth*
  - *Sample OD size distribution*
  - *OD Measurement Needs*
- Object Signatures
- Orbital Debris Driving New Science
- Current Heliophysics Division Activities
  - *Instrument flight programs*
  - *HTIDS-SWE projects*
  - *Other Concepts*
- Mission Design Lab Study

US National Context, NASA Risks

- US Office of Science and Technology Policy National Orbital Debris Implementation Plan (July 2022):
  - Debris Mitigation
  - Tracking and Characterization of Debris
  - Remediation of Debris

- NASA has identified the small orbital debris problem as an agency risk, which has been split into three individual risks:
  - Space Sustainability: Orbital Debris Risk
  - Space Sustainability: Interference to NASA Operations Risk
  - Space Sustainability: Space Traffic Management Risk

- NASA's Science Mission Directorate (SMD) directed the Heliophysics Division (HPD) to:
  - Develop and deploy the space-based instruments and other investigations to better constrain the micro-debris environment in the 500 to 1000 km altitude range;
  - Develop and deploy space-based instruments and other investigations to allow for better prediction of the natural processes that lead to the losses of orbital debris in the Earth atmosphere; and
  - Work to integrate these measurements into the Orbital Debris activities conducted by NASA, and especially the Orbital Debris program office at NASA Johnson, as well as to improve Space Weather forecasts.

NASA Orbital Debris, Heliophysics Role

The Heliophysics Division (HPD) has partnered with NASA's Orbital Debris Program Office (ODPO) to help address the insufficient state of knowledge of the small (<3 cm) orbital debris population:

> ***One cannot fully understand OD without understanding the environment (SSA), and you cannot fully understand the operational environment (SSA) without characterizing the debris population and its effects. All of this is best done by leveraging the relevant expertise of HPD.***
>
> ***Small natural and man-made space objects (Orbital Debris [OD], micrometeorites, dust) are to be considered alongside traditional Space Weather in making up the Space Working Environment (SWE) and are part of HPD's Space Weather Program.***

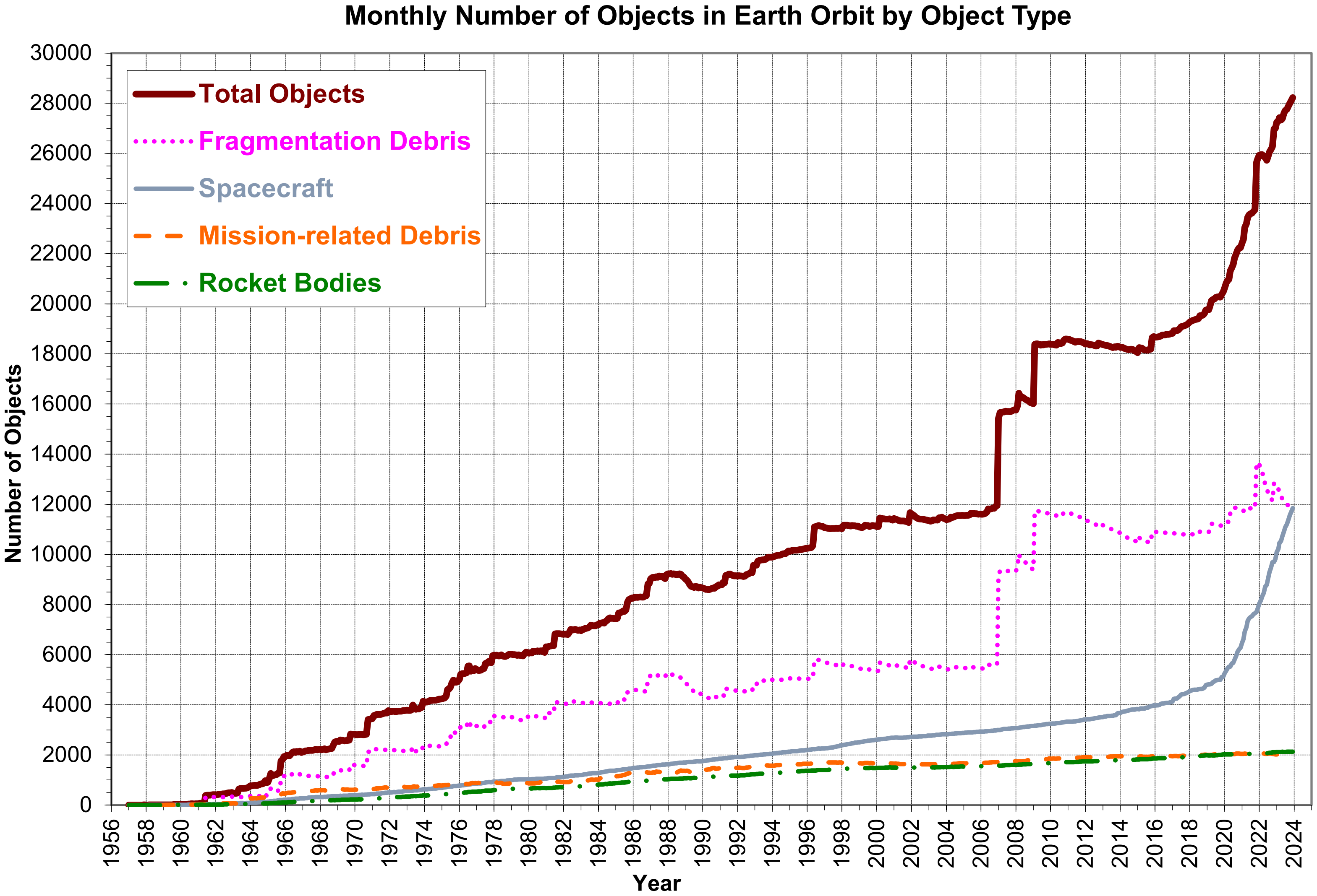
SMD/HPD:

- Provide the basic science elements around the detection of small space objects
- Explore the scientific utility that can be derived from small space objects
- Understand the space environment (space weather) that affect small space objects
- Investigate the signatures of small space objects interacting with the natural environment

ODPO:

- Provision of state-of-the-art models for OD environment, evolution, and assessment primary for NASA risk assessment, but also to the broader community
- Development of measurement requirements and techniques to address the lack of information of the small OD environment.

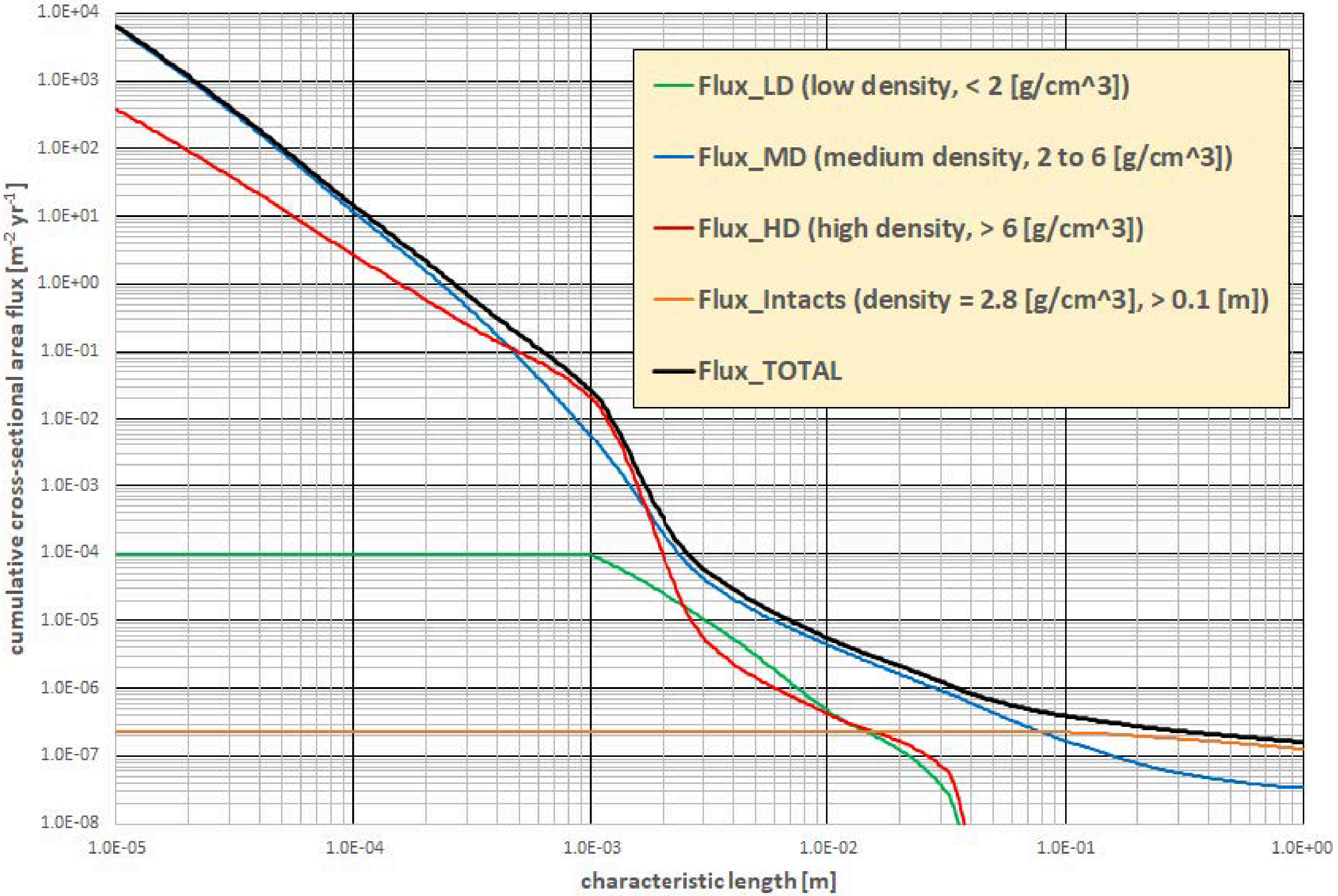
The Problem - *Tracked Object Growth*



For Space Catalog 2024 Objects greater than 10 cm

Credit: NASA Orbital Debris Program Office (ODPO)

The Problem - *Sample OD Size Distribution*

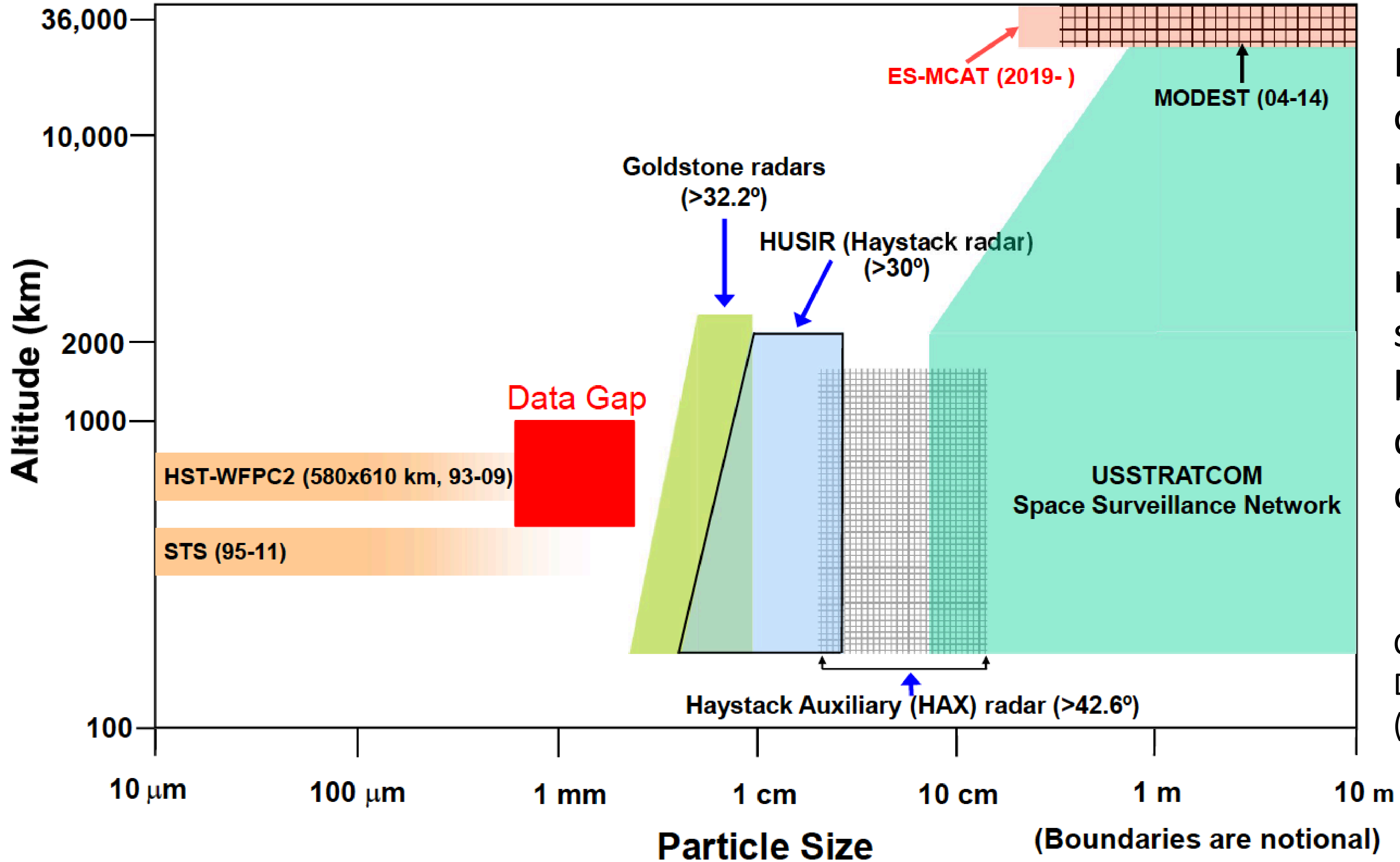


Size (cm)	Increase*
1	1.8×10^{1}
0.1	7.5×10^{2}
0.01	2.6×10^{5}
0.001	1.5×10^{10}

*Relative to 10 cm flux at ISS altitude

Credit: NASA Orbital Debris Program Office (ODPO)

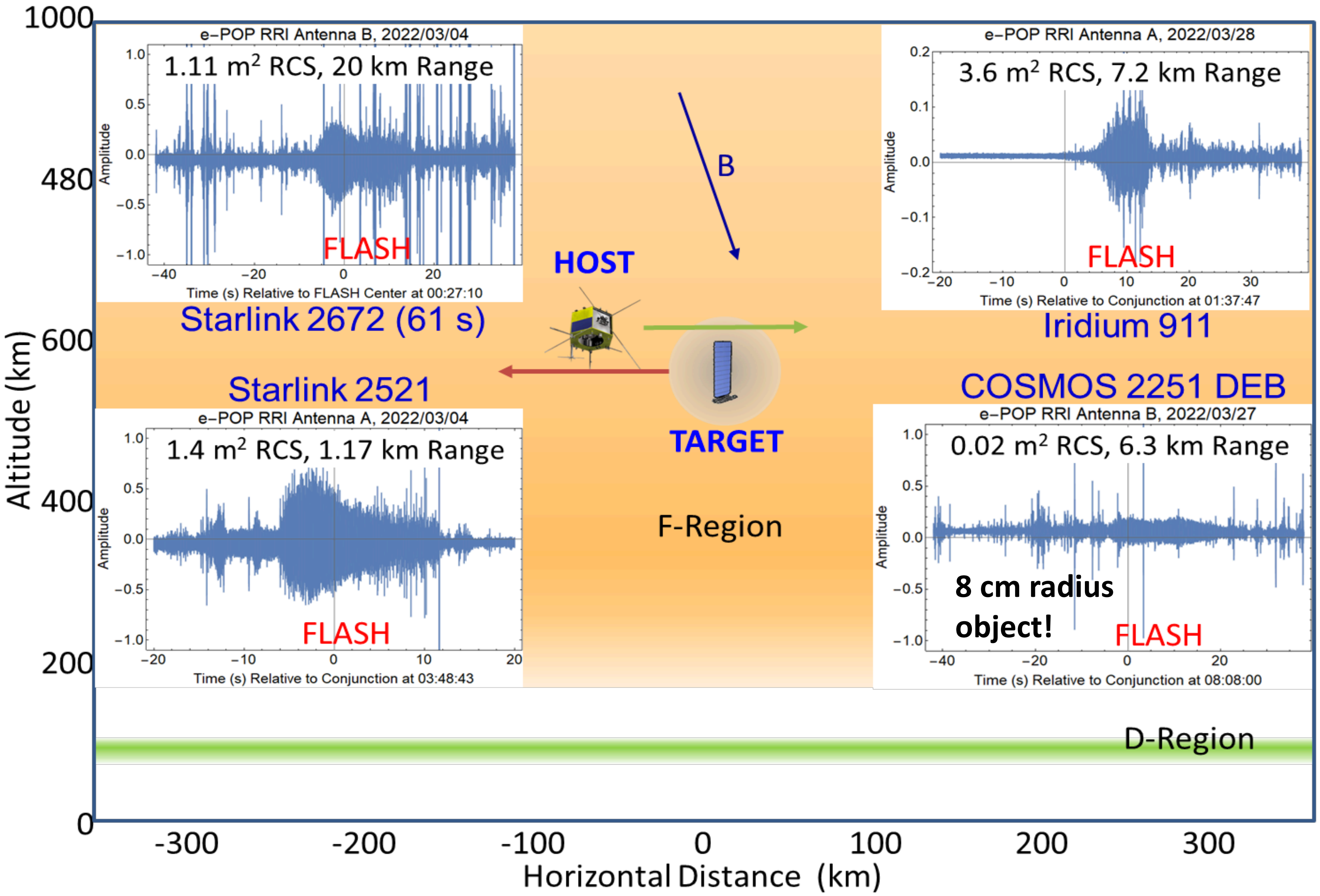
The Problem - *OD Measurement Needs*



Millimeter-sized orbital debris represents the highest penetration risk to most robotic spacecraft in LEO, but there is a lack of data on such small debris

Credit: NASA Orbital Debris Program Office (ODPO)

Object Signatures



Plasma wave electric fields from the Radio Receiver Instrument (RRI) on the Canadian Swarm-E satellite for conjunctions with satellites and space debris. The wave frequency spectra indicate that compressional Alfven waves are generated by charged space objects moving across the ambient magnetic fields in the ionosphere. Lightning excited whistlers and VLF hiss contribute to the detection noise background.

Credit: Paul Bernhardt, University of Alaska, The Physics of Plasma 2022, submitted.

Orbital Debris Driving New Science

Note: The small OD population is NOT measurable from the ground

Understanding of all OD signatures in the natural environment

Measurement requirements and techniques for characterizing OD

In situ OD measurements

Other Existing Instrument Concepts

New technology and missions

ODPO Benefit

Specification of small OD environment

Reduction of OD environment model uncertainties (x10)

Better NASA risk assessment, space survivability, cost models

Basic plasma science of objects moving through a magnetized plasma

Explore plasma physics inaccessible in the laboratory

SMD/HPD Science Benefit

OD as probe of global space weather processes

SSA Space Weather: Improved drag models

Current Heliophysics Division Activities

Instrument development and flight programs to characterize small OD:

- Laser-sheet Anomaly Resolution and Debris Observation (LARADO) instrument– STP-Sat7 launch late 2025
- Multi-layer Acoustics & Conductive-grid Sensor (MACS) – JAXA HTV-X3 launch ~2027
- Multi-Needle fast Langmuir Probe - ESA VISDOMS mission launch ~2028

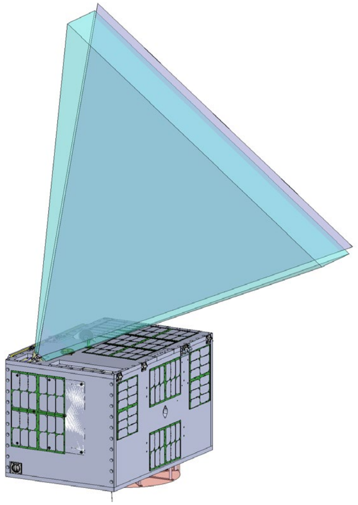
NASA Research Opportunities in Space and Earth Science (ROSES) Programs:

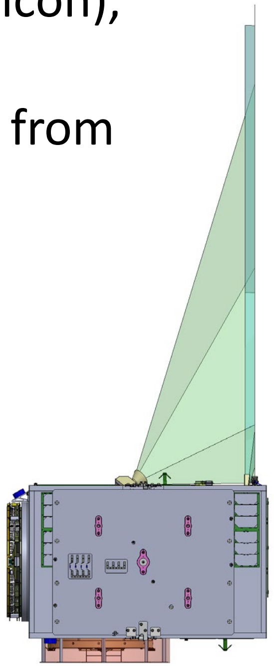
- Heliophysics Instrument Development for Science (HTIDS) program - Instrument development call for characterizing small OD (HTIDS-SWE).
- Heliophysics Supporting Research (HSR) - Special Topic in HSR on “Signatures of objects moving through a space plasma”.
- Solicited Proposal proposal on identifying indications of minor debris strikes in spacecraft telemetry (reaction wheels).
- Anticipated pipeline instrument development program for OD-SSA mission instruments.

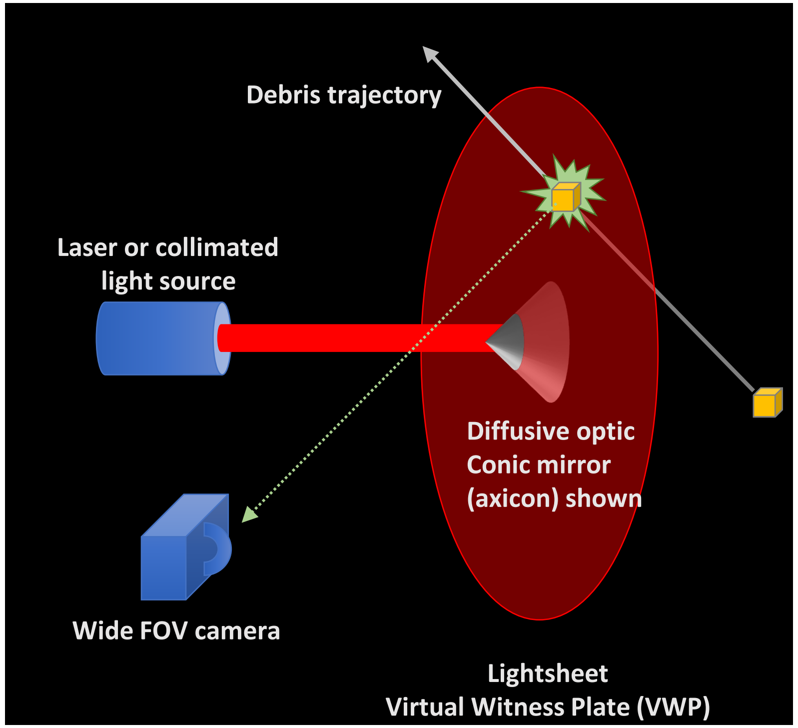
Laser-sheet Anomaly Resolution and Debris Observation (LARADO)

<u>Objective:</u> Demonstrate an innovative concept to perform real time, on-orbit, local object detection to provide damage attribution and Space Situational Awareness.

- ➢A light sheet is formed using a collimated light source (e.g. a laser) and a conic mirror (axicon), Powell lens or diffuser.
- ➢A camera is used to detect scattered light from objects penetrating the laser sheet.

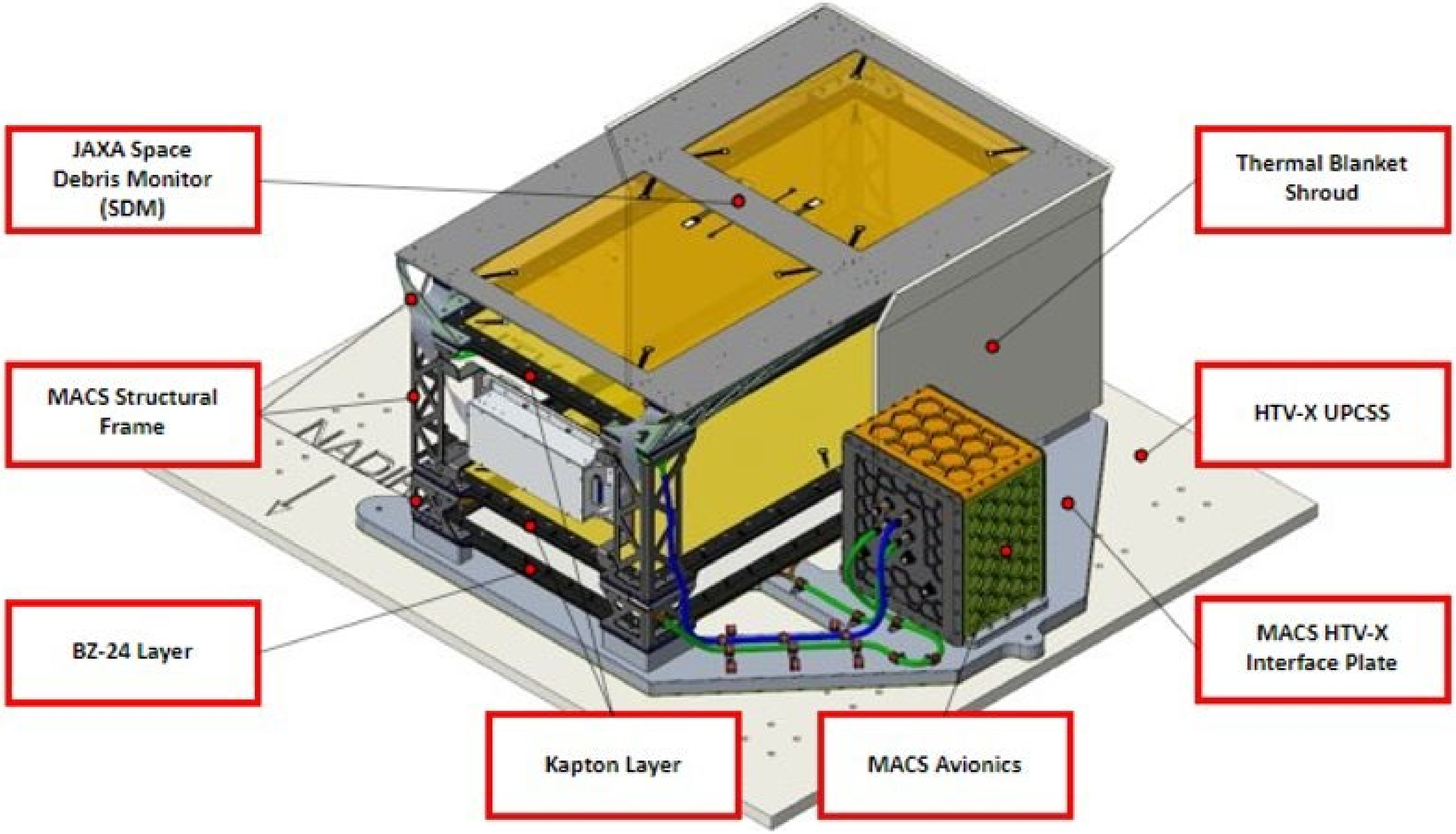






Courtesy Naval Research Laboratory, Andrew Nicholas

Multi-layer Acoustics & Conductive-grid Sensor (MACS)



Courtesy NASA Orbital Debris Program Office, Johnson Space Flight Center

Multi-Needle Langmuir Probe

HTIDS-SWE 23, PI: Aroh Barjatya (Embry-Riddle Aeronautical University)

Idea

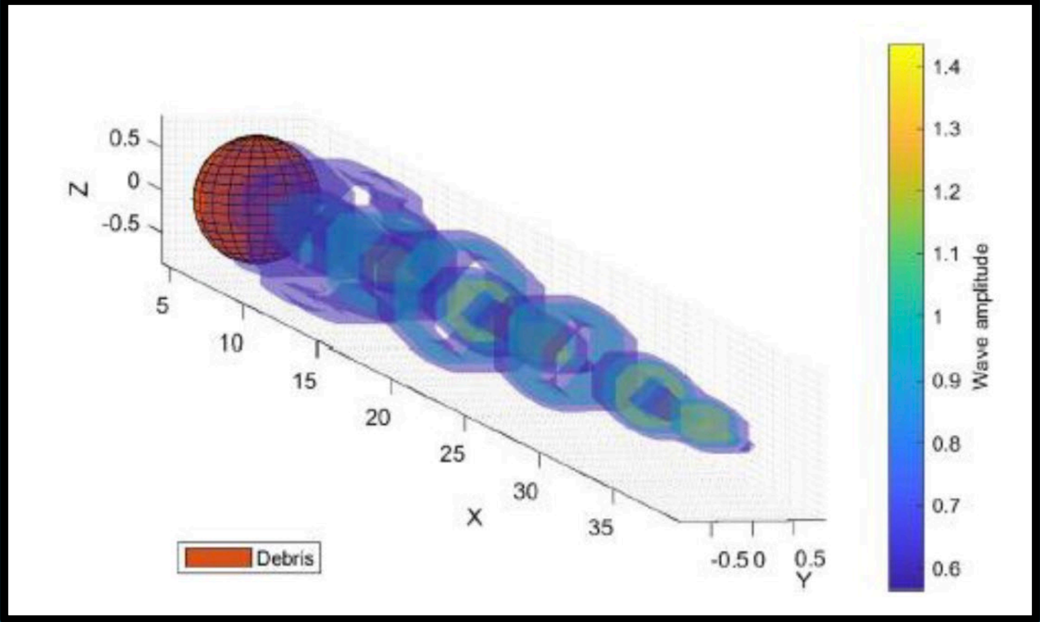
High-cadence multi needle Langmuir probe detects plasma density perturbations (waves, solitons, shocks, wake) from charged debris

Strengths

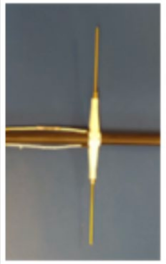
- Extremely high cadences allows the detection of spatial structures ~10 cm and below
- Low SWaP allows deployment on small sats
- Could be used to measure kinetic scale structures, instabilities, turbulence for other applications

Status

- 80 kHz sampling instrument created
- Similar (but slower) Langmuir probes on SpEED Demon sounding rocket and Escapade
- Possible flight demonstration on ESA VISDOMS



ESCAPADE Needle Langmuir Probe Pair



LARADO-N | Lightsheet Anomaly Resolution And Debris Detection - Neuromorphic

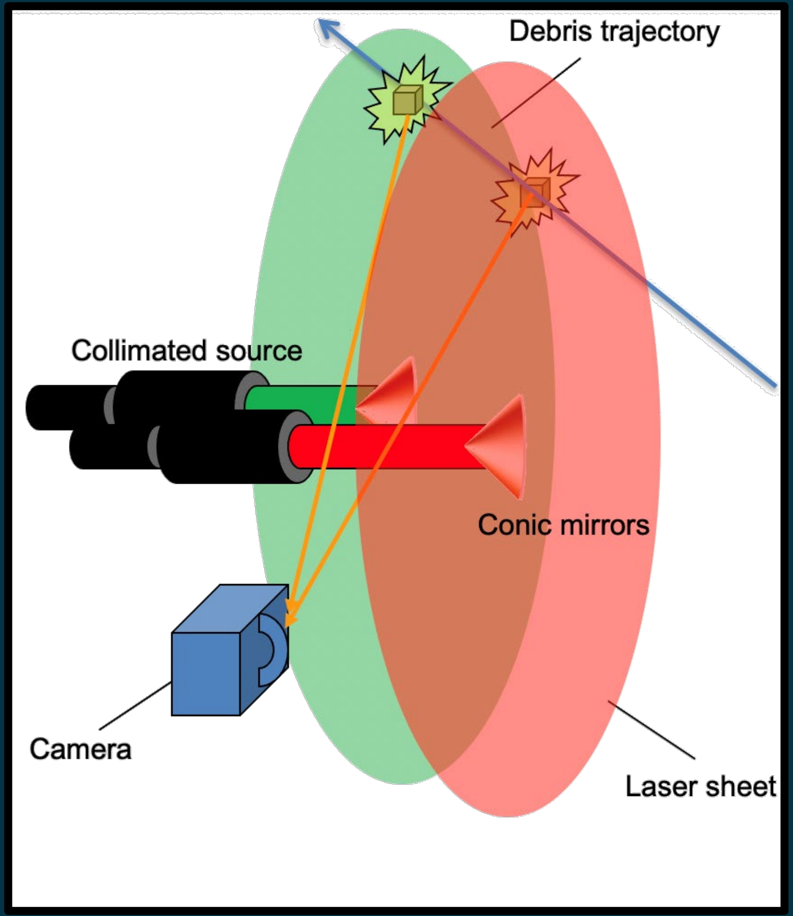
HTIDS-SWE 22, PI: Andrew Nicholas (Naval Research Laboratory)

Idea

Create a sheet of light in space and observe scattered photons from objects passing through.

Strengths

- Larger collection area from not needing to intercept an object
- Two lightsheets provide velocity vector
- Object material from scattering by multiple wavelengths
- Neuromorphic camera gives high speed output, large dynamic range, and reduced data bandwidth



Status

- Tested with airsoft projectiles in lab; fall experiments at NASA Ames Vertical Gun Range
- Multiple potential flight opportunities identified
- Predecessor (LARADO) integrated and tested on Space Test Program Satellite 7, launching next year

DENTS | Debris and meteoroid ENvironment Sensor

HTIDS-SWE 22, PI: David Malaspina (University of Colorado)

Idea

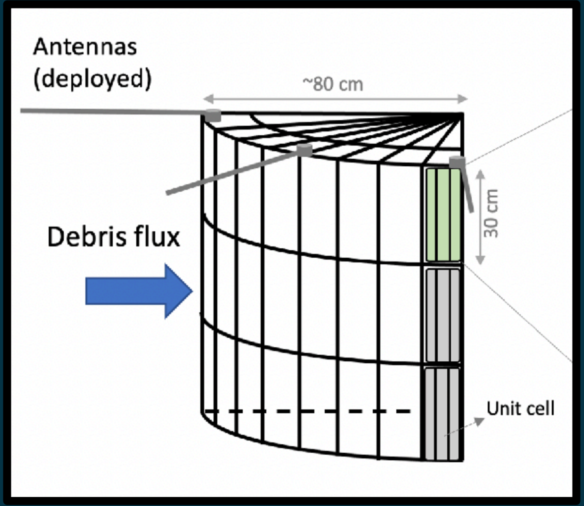
Impactor passes through PVDF foil and strikes a plate. A grid electrode detects ions from impact. Electric field antennas detect electric potential spike near impact.

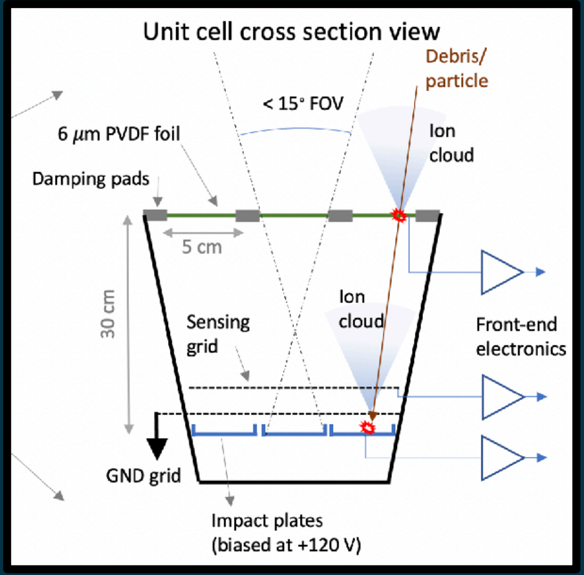
Strengths

- Modular design allows deployment on many platforms
- Characterizing impact electric potential spikes could help interpret similar measurements from prior missions
- Directional information from fan of cells
- Also detects micrometeoroids that are much faster and smaller than debris

Status

- Prototype 3-cell tested in Van de Graaff dust accelerator at CU
- Possible flight demonstration on ISS, cubesat at ~800 km, or with HFORT in combination with a Heliophysics SBIR project





In-situ LIDAR Sensor

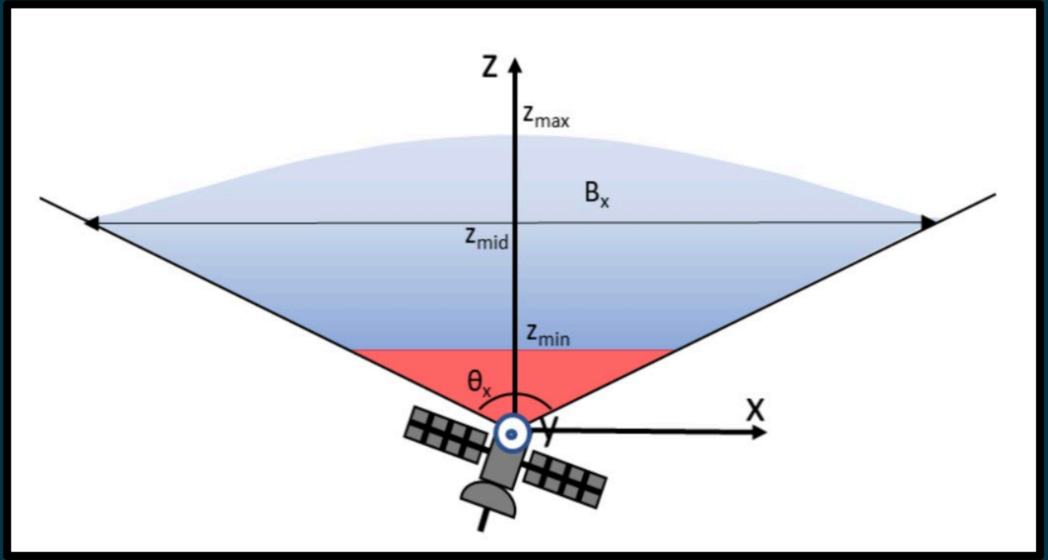
HTIDS-SWE 22, PI: John McVey (Aerospace Corporation)

Idea

A pulsed LIDAR-based sensor system generates a short-range optical fan shaped beam; uses the time-resolved return reflection signal to identify debris.

Strengths

- LIDAR can reach beyond the spacecraft volume, driven by the amount of laser power on board
- Low enough SWaP to be on a CubeSat or as a hosted payload on a larger mission
- Multiple scatterings provide velocity vector information



Status

- Static laser tests in lab have characterized millimeter scale objects

Other Concepts in development

- Solar panel as a sensor – acoustic sensor equipped panels to detect impacts – potentially huge aperture (with GSFC).

- Passive glint observations in star-trackers (multiple partners).

- Spacecraft as a sensor – use of reaction wheel data to detect impacts (Study with Northrop Grumman) – extend to all NASA spacecraft.

Mission Design Lab Study

A HPD-led satellite mission that addresses the outstanding NASA Agency risk on the small OD environment. This aims to provide a home/platform for a range of interconnected activities and research needs related to OD, SSA, and associated impacts on spacecraft. We bring together four distinct but related communities that cover the following topical areas (**TAs**):

- **Orbital Debris Measurements -** Addressing a measurement gap in the OD size range (0.1–10 mm) that has been identified as an Agency risk.
- **Space Situational Awareness Science -** Addressing scientific questions related to the spacecraft drag environment and how it impacts SSA capabilities and OD dynamics.
- **Space Situational Awareness Research to Operations (R2O) Development** Addressing the basic research needed to combine simple low-latency data with models to provide up-to-date estimates of the relevant environments.
- **Dust / Impact Science / Satellite Effects -** Addressing spacecraft effects from natural and small anthropogenic particles (<0.1 mm).

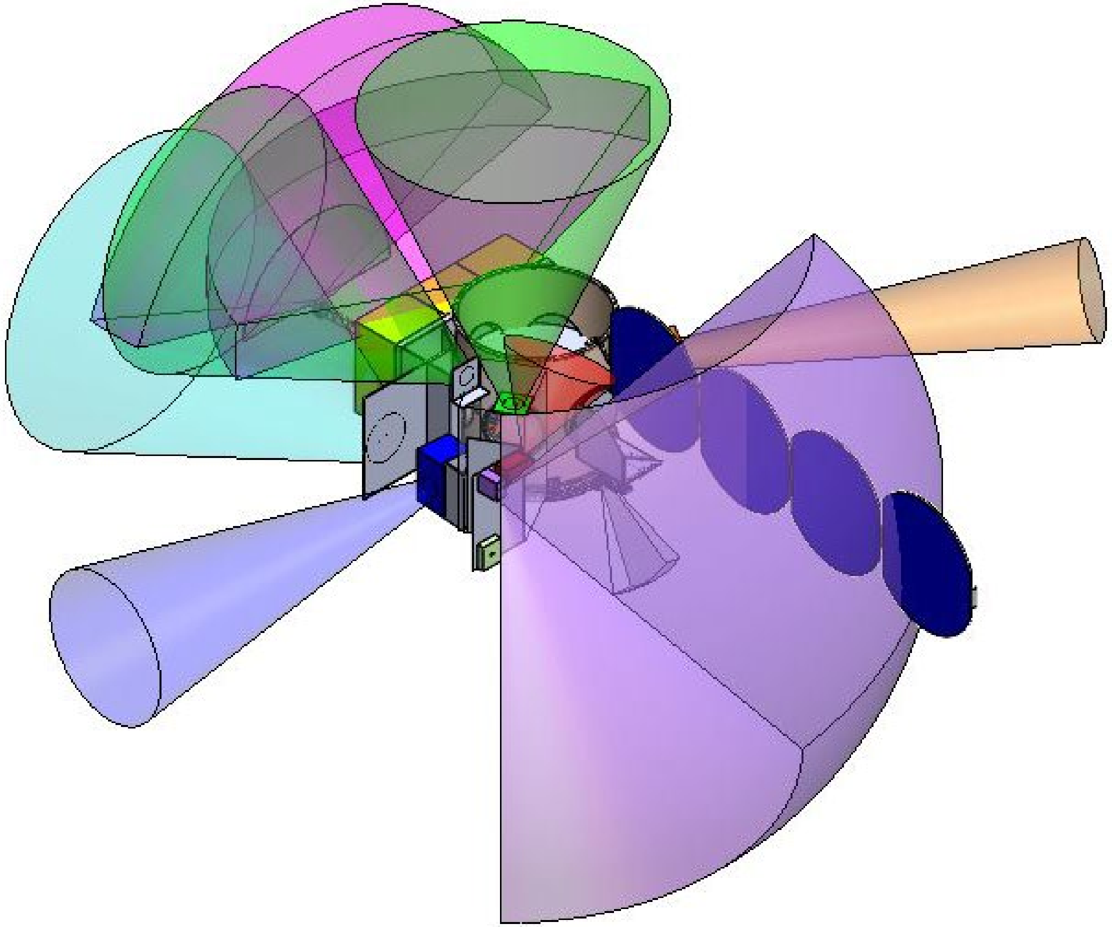
Tiger Teams were conducted in each topical area to identify measurement priorities.

Top Level Mission Summary

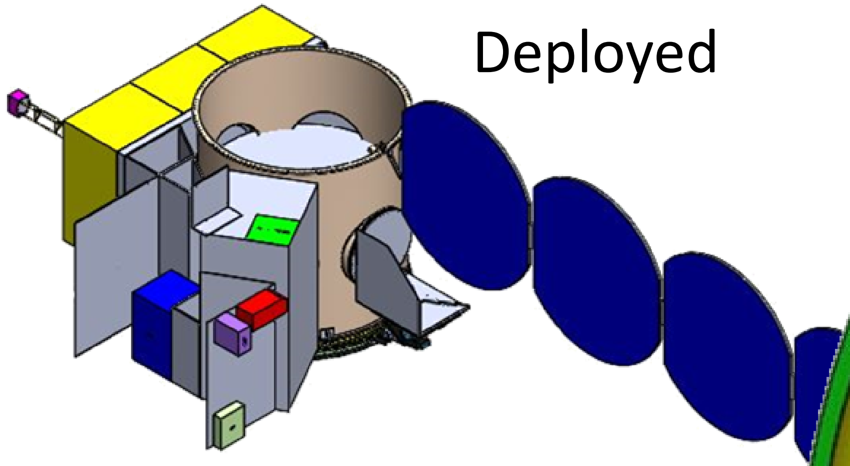
The table below provides a top-level summary of the relationship of the proposed measurements to the Topical Areas, SMD Science, and other key areas.

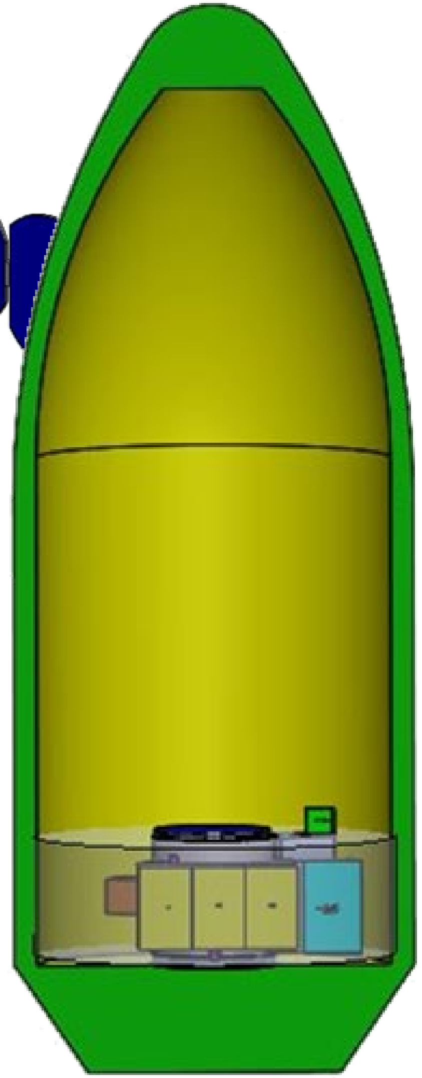
Measurement	**TA-1 OD**	**TA-2 SSA Science**	**TA-3 SSA R2O**	**TA-4 Dust-Impact**	**Space Traffic Management**	**Science Area**	**SC Risk reduction**
Optical laser based OD						HPD, AD, ESD	All SMD
Large Impact OD						HPD	All SMD
Dust Impact OD						HPD, PSD	
ESA passive Optical						HPD, AD, ESD	All SMD
Imaging Spectrograph						HPD	
EUV						HPD	
Energetic Particle						HPD	
Dust Impacts with Electric Field Signals						HPD, PSD	

ESPA Tug Concept



Deployed





Instrument pipeline activities through a ROSES research call to prepare for an OD-SSA mission expected to start in 2025.

An OD-SSA mission is not yet a funded part of NASA planning.

Mission would be implementable with a SMEX sized budget.

Questions?