



The Multi-layer Acoustic & Conductive-grid Sensor (MACS) Technology Demonstration on HTV-X3

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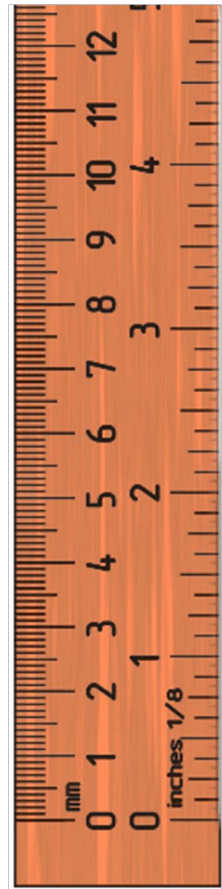


Outlines

- **Risk from small, millimeter-sized orbital debris**
 - Technology and data gap at these sizes
 - Mandate to address this risk
- **Multi-layer Acoustic & Conductive-grid Sensor (MACS)**
 - Technology development
 - Component and system testing
- **MACS HTV-X3 Technology Demonstration Mission**
 - Mission preparation



Current Orbital Debris Population



Baseball size or larger (≥ 10 cm): ~28,000 (tracked/cataloged by the 18 SDS and the 19 SDS of the USSF)



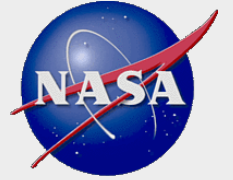
Marble size or larger (≥ 1 cm): ~500,000



Dot or larger (≥ 1 mm): >100,000,000 (a grain of salt)

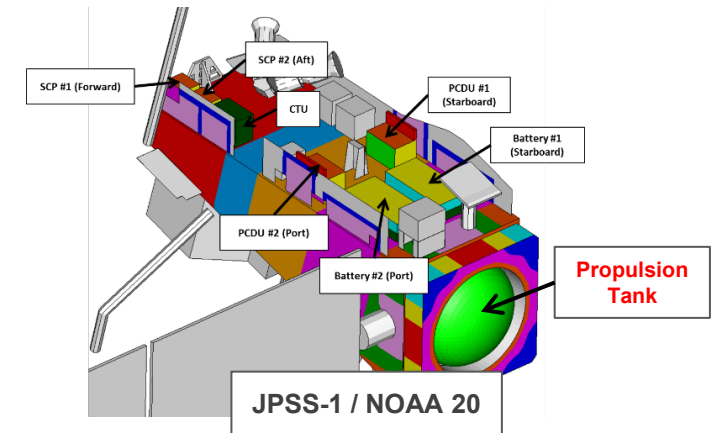


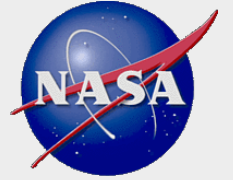
- Due to high impact speed in space (~10 km/sec in LEO), even sub-millimeter debris poses a realistic threat to human spaceflight and robotic missions
 - 10 km/sec ~22,000 MPH
 - Speed of a bullet ~1,500 MPH
- Mission-ending threat is dominated by **small (millimeter-sized)** debris impacts



Top Orbital Debris Risks to Robotic Missions in LEO

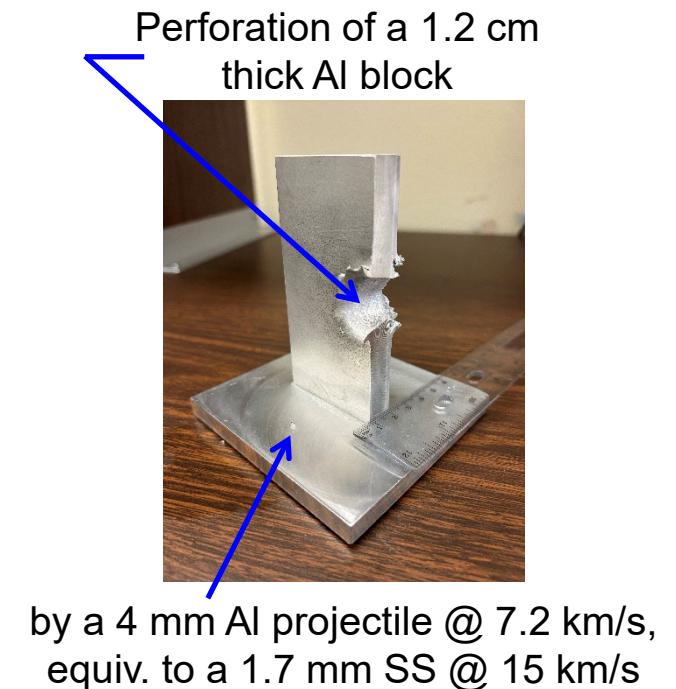
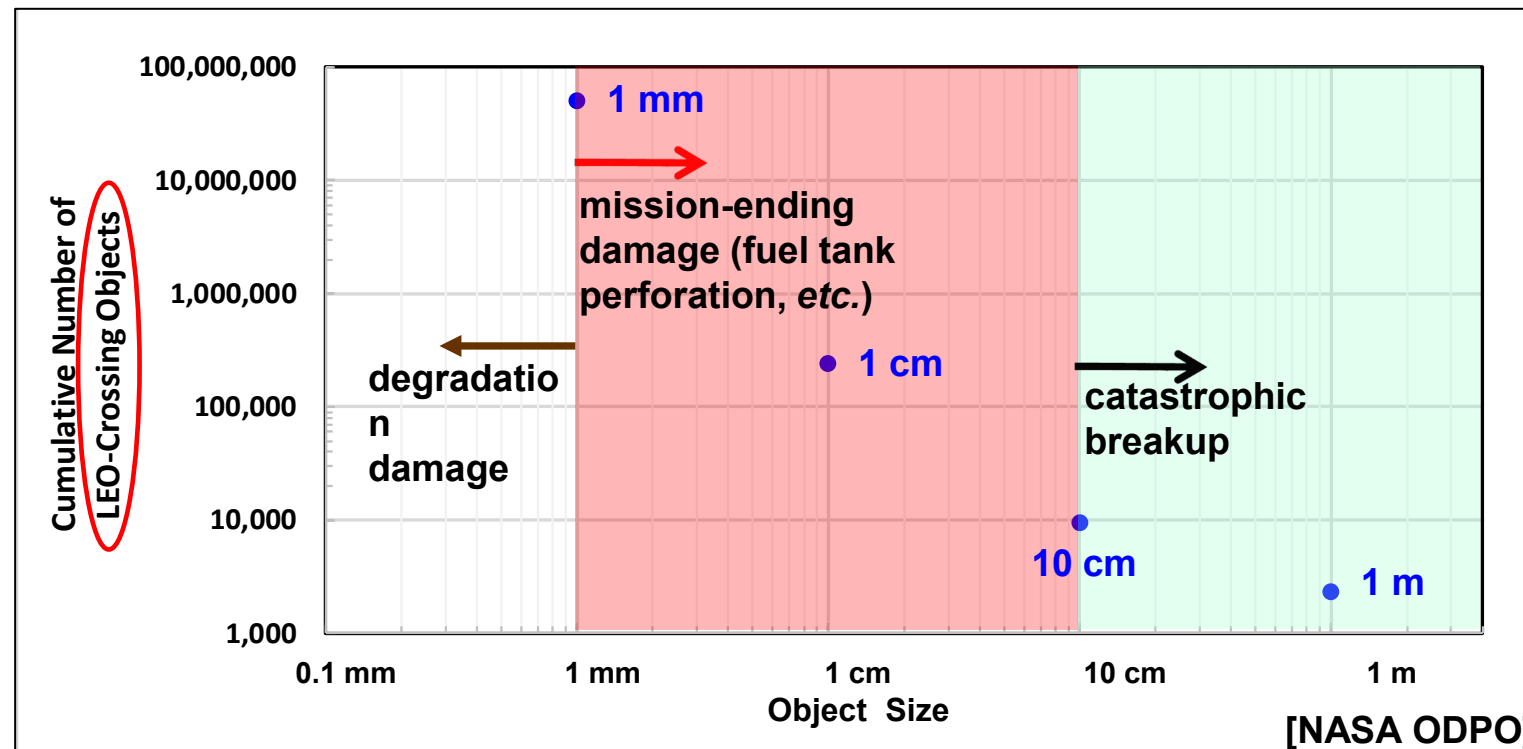
- **Millimeter-sized orbital debris** represents the highest penetration risk to most operational spacecraft in LEO
 - As concluded by a NASA Engineering and Safety Center panel study (NASA/TM 2015-218780)
- **Currently, more than 400 missions operate at 600–1000 km altitudes**
 - Including 18 NASA missions (A-Train@705km, NOAA@825km, IXPE@600km, *etc.*)
- **There is a lack of measurement data for millimeter-sized orbital debris above 600 km altitude**
 - Direct measurement data for such small debris is needed to support the development and implementation of cost-effective, protective measures for the safe operation of future missions





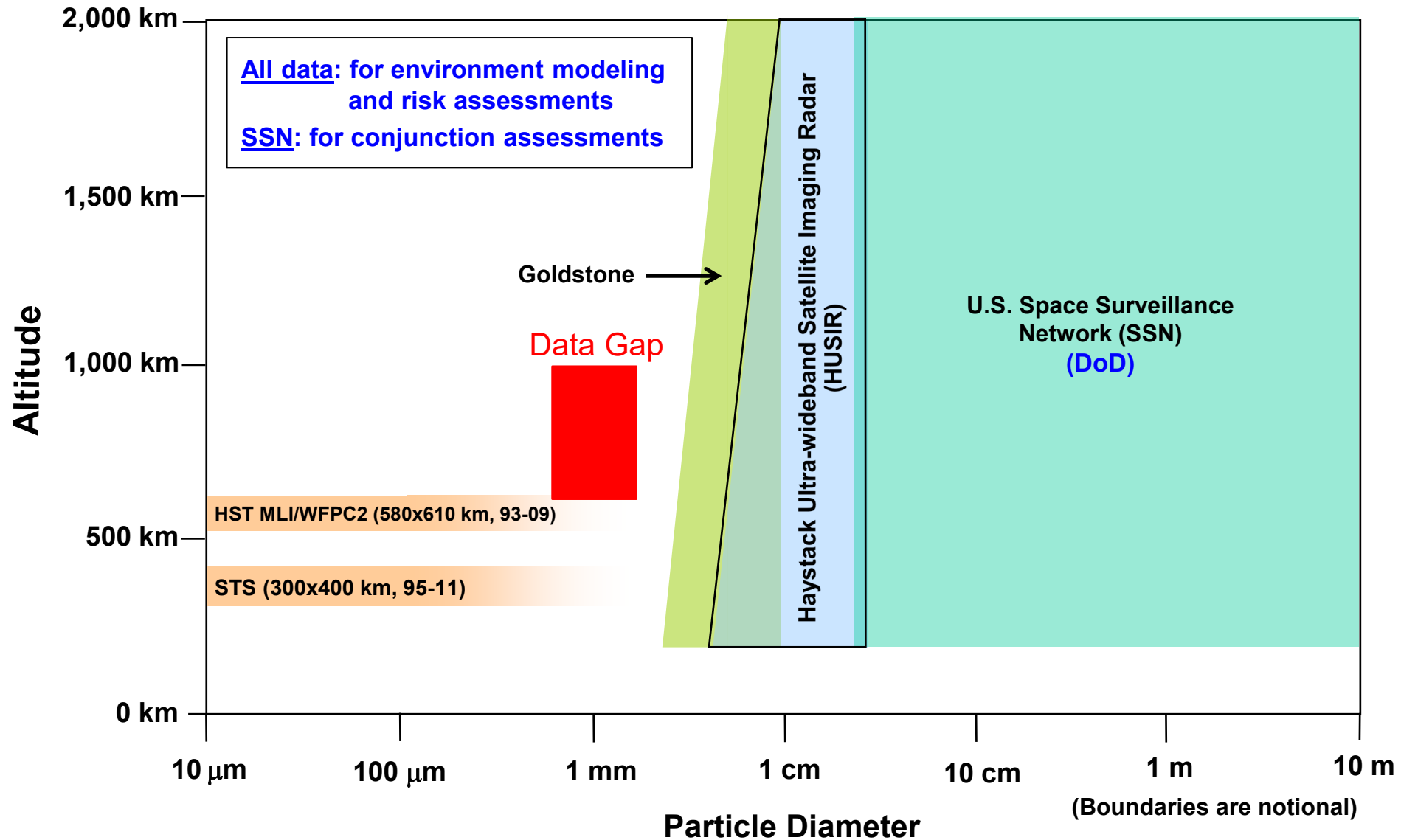
Mission-ending Risk from Orbital Debris

- **There is far more small debris than large debris**
 - Mission-ending risk is driven by **millimeter-sized orbital debris in LEO**, but there is a lack of direct measurement data on such small debris
 - Conjunction assessments and collision avoidance maneuvers against the large (≥ 10 cm) tracked objects only address **<1% of the mission-ending** impact risk from orbital debris





Orbital Debris Measurement Coverage in LEO





Mandate to Address Risk from Small Debris (1/2)

- **U.S. Space Policy Directive 3, the National Space Traffic Management Policy (2018)**
 - Section 4, Goals (a) Advance SSA and STM Science and Technology

*“The United States should...improving the fundamental knowledge of the space environment, such as the **characterization of small debris**...”*
- **U.S. National Orbital Debris Research and Development Plan (OSTP, 2021)**
 - Section 2.1, Characterize Orbital Debris and the Space Environment

*“...Efforts to characterize debris populations **should focus in particular on millimeter-scale debris**, since this drives mission-ending risk to most operational spacecraft, and measurement data on them are lacking...”*

OSTP = White House Office of Science and Technology Policy
SSA = Space Situational Awareness
STM = Space traffic management



Mandate to Address Risk from Small Debris (2/2)

- **U.S. National Orbital Debris Implementation Plan (OSTP, 2022)**

- Section 2.3.1, Improve Characterization of Debris Less than 1 cm in LEO

*"Investigate technology development and mission opportunities for in-situ measurement sensors to identify, develop, and mature in-situ measurement technologies; leverage researched technologies; and encourage the development of novel concepts capable of collecting similar types of data, including **size, mass, material density, speed, and direction, on the millimeter-sized orbital debris**. Identify mission opportunities to deploy sensors to collect statistically meaningful data on the millimeter-sized orbital debris between 600 km and 1000 km altitudes." (Lead: NASA)*

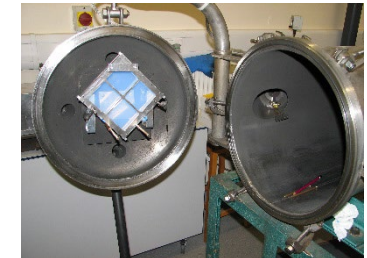
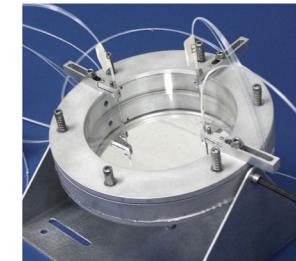


MACS and HTV-X3 Technology Demonstration



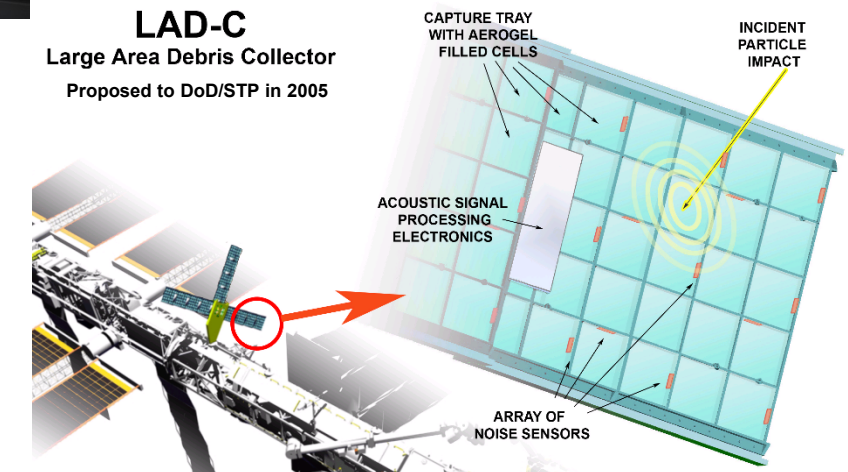
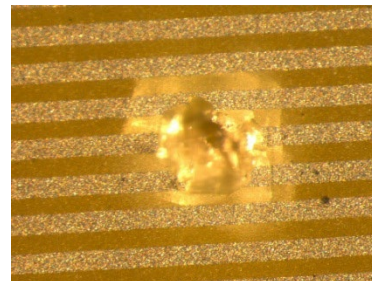
ODPO's *In situ* Measurement Technology Development

- The ODPO, in collaboration with NRL, USNA, VT, UKent, and JAXA, has explored/developed various innovative *in situ* orbital debris detection technologies since 2002*
 - Polyvinylidene fluoride (PVDF) acoustic impact sensors
 - Impact ionization sensors
 - Fiber optic displacement sensors
 - Aerogel
 - Resistive grids
 - Dual-layer thin films
 - Dual-layer laser curtains
 - DRAGONS
 - MACS



LAD-C
Large Area Debris Collector
Proposed to DoD/STP in 2005

Credit: NASA



*2003-2005: SMD PIDD award

*2009-2012: SMD/ESMD LASER award

DRAGONS = Debris Resistive/Acoustic Grid Orbital NASA-Navy Sensor



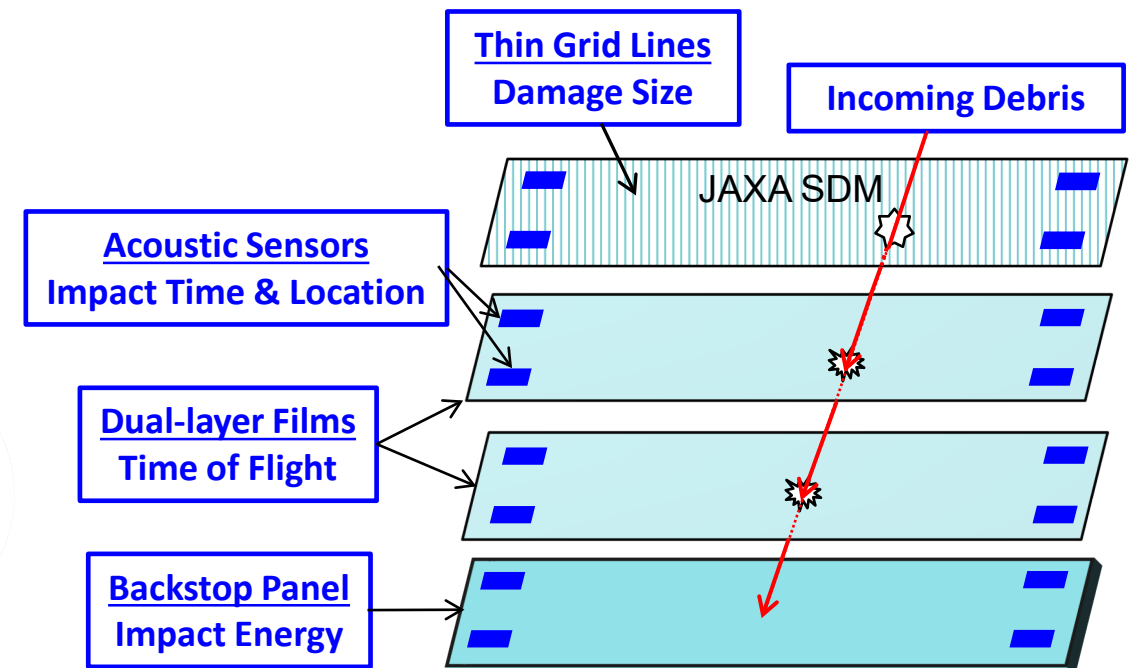
NASA Science Mission Directorate (SMD) DRAGONS Study

- **SMD funded the ODPO for a 3-month feasibility study in 2015**
 - Engineering mission assessment
 - Benefits of the data to environment modeling
 - Analyses of alternative instruments
- **Conclusions of the study**
 - DRAGONS is the best available sensor to collect data on the millimeter-sized orbital debris at 600 to 1000 km altitudes for meaningful model improvements
 - A hosted payload option for a 1 m² detection area DRAGONS is quite feasible
 - **DRAGONS is a 3-layer system consisting of a thin resistive-grid layer, a thin Kapton® film, and a backstop panel**
 - Data from a 3-year mission can reduce the flux uncertainty to approximately a factor of 2
- **CapSat-DRAGONS**



MACS Detection Principles

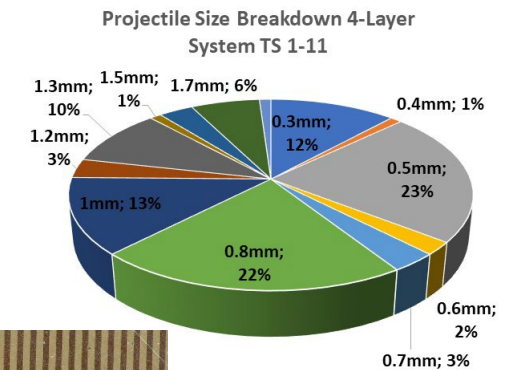
- **MACS is an improvement to DRAGONS, designed to detect and measure orbital debris in the millimeter-sized regime**
 - MACS combines several impact detection technologies, including Japan's IHI-patented, JAXA funded, and flight demonstrated (HTV-5, 2015) conductive grid film ("Space Debris Monitor," SDM), to maximize information that can be extracted from the detected impact events
 - **Impact time**
 - **Impact location**
 - **Particle size**
 - **Impact speed/direction**
 - **Impact energy/ Particle density**



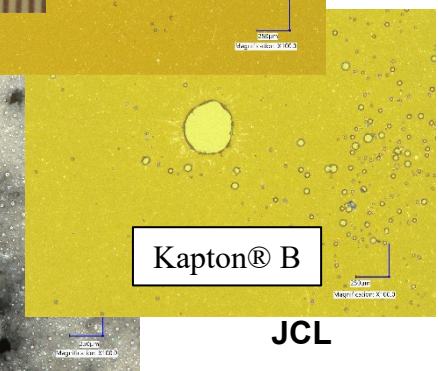
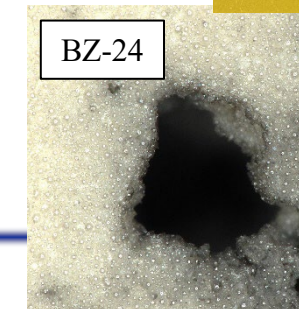
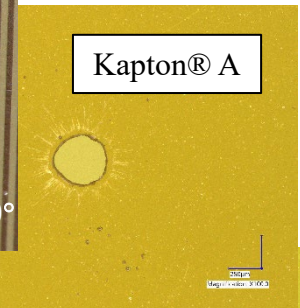
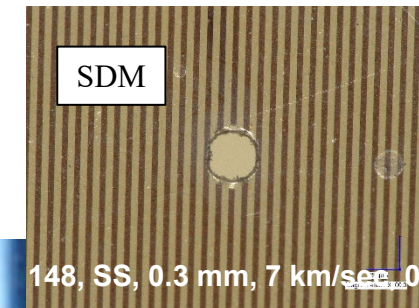


MACS Hypervelocity Impact Testing

- **A total of 14 week-long hypervelocity impact test series on the MACS prototype unit have been completed at NASA White Sands Test Facility**
 - Projectiles: different sizes, materials, impact speeds, and impact angles
 - System: different configurations and impact locations



Credit: NASA



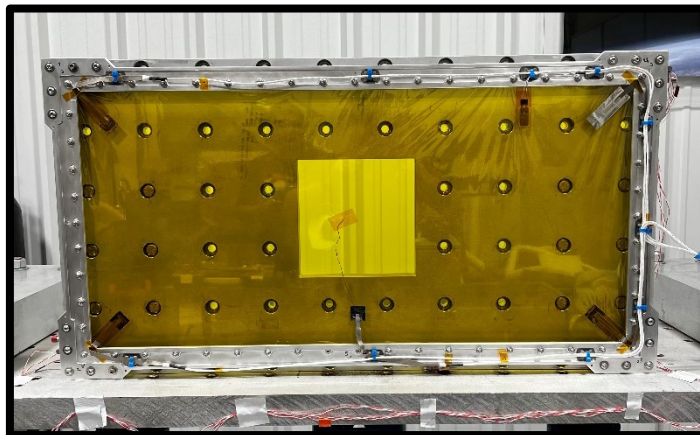
JCL



MACS Environmental Testing

- **Several component-level environmental tests have been conducted to further advance the technology readiness level of MACS**
 - Random vibration
 - Thermal vacuum
 - Shock
 - Atomic oxygen
 - Some environmental tests were funded by SMD/HPD

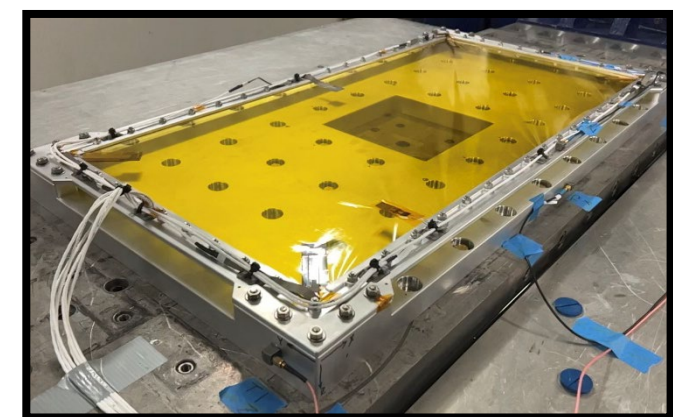
Credit: NASA



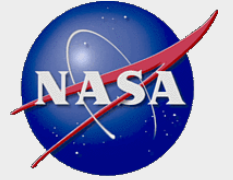
ITO Kapton® Y-Axis Shock Testing



MACS 3-Layer Thermal-Vacuum Wing

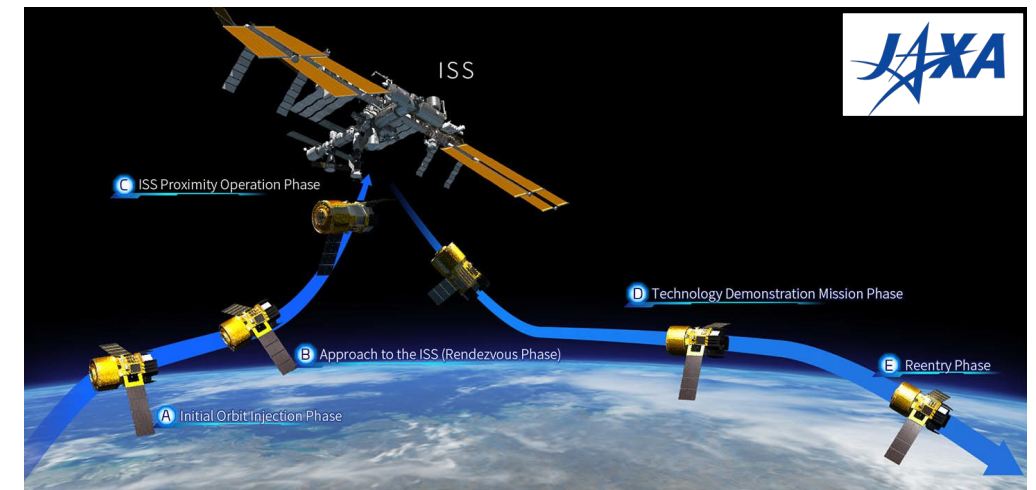
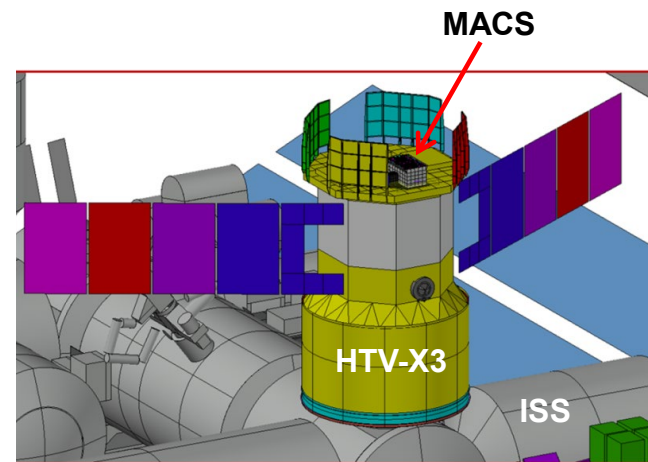
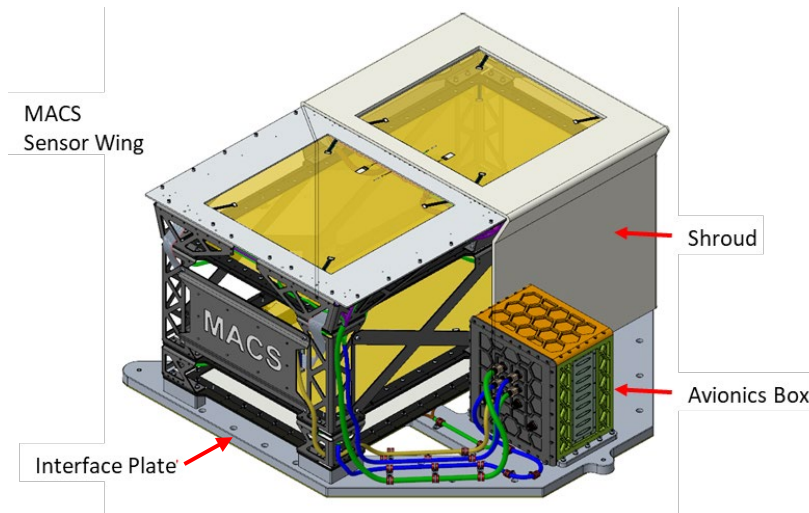


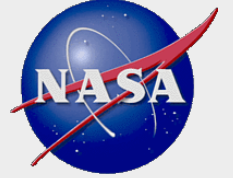
ITO Kapton® X-Axis Random Vibration



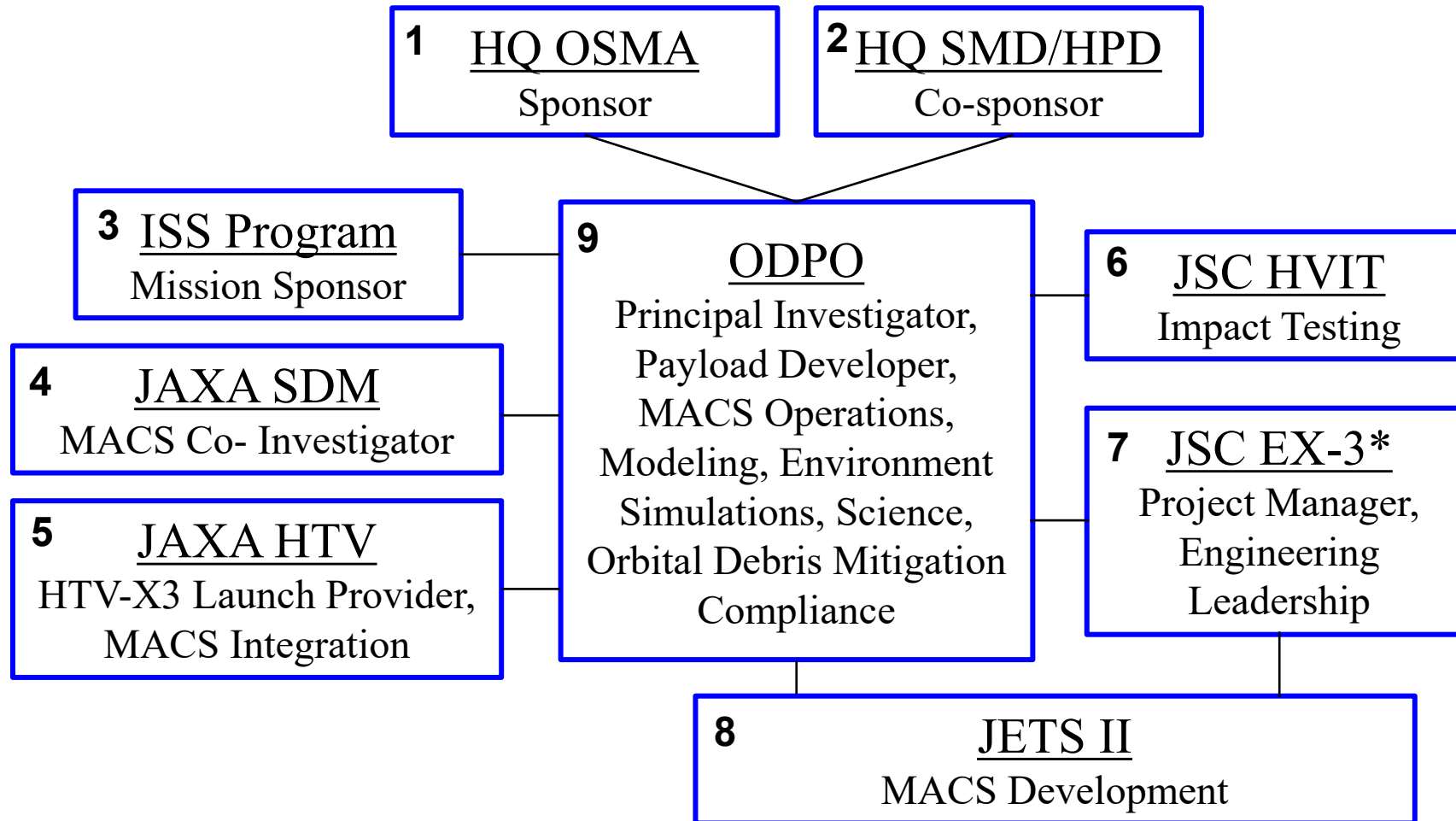
MACS HTV-X3 Technology Demonstration Mission

- **ODPO, in collaboration with JAXA, with co-sponsorship from SMD/HPD and the ISS Program, has secured a technology demonstration mission opportunity to deploy a single-wing MACS on HTV-X3 in early 2027**
 - A single MACS wing will be mounted to HTV-X3's unpressurized cargo support system (UPCSS) base
 - HTV-X3 will be docked to the ISS for up to 6 months
 - After leaving the ISS, HTV-X3 will start its technology demonstration phase





MACS HTV-X3 Project Organization Chart



*EX3: JSC Engineering Directorate /
Project Management & Systems Engineering
Division / Project Management Branch



MACS HTV-X3 Mission Preparation Status

- Approval to Proceed: February 2023
- System Requirements Review: November 2023
- Preliminary Design Review: May 2024
- **Critical Design Review: November 2025**
- **MACS Delivery to JAXA HTV-X3: September 2026**
- **MACS System Acceptance Review: November 2026**
- **HTV-X3 launch: Early 2027 (tentative)**

