NASA Orbital Debris Program Office and MACS HTV-X3 Technology Demonstration Mission

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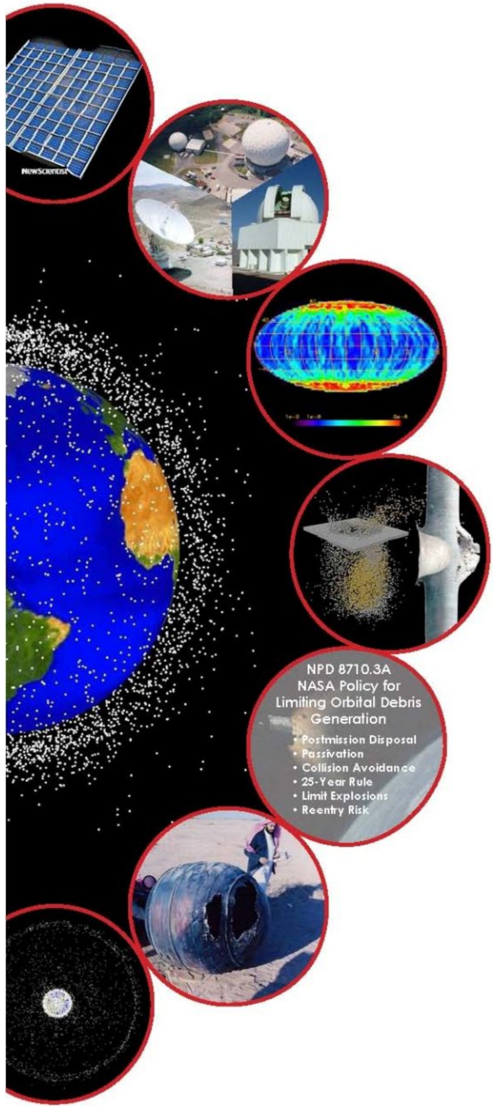
Outlines

- **Overview of the NASA Orbital Debris Program Office**
  - Measurements, modeling, mitigation
- **Risk from small, millimeter-sized orbital debris**
  - Technology and data gap
  - Mandate to address the risk
- **Multi-layer Acoustic & Conductive-grid Sensor (MACS) HTV-X3 technology demonstration mission**
  - *In situ* sensor technology development
  - From DRAGONS to MACS
  - HTV-X3 Mission preparation status

NASA Orbital Debris Program Office

NASA Orbital Debris Program Office (ODPO)



- **ODPO is the only organization in the U.S. government (USG) conducting a full range of research on orbital debris**
  - ODPO is a Delegated Program in the NASA HQ Office of Safety and Mission Assurance (OSMA)
  - This unique NASA capability was established by pioneers led by Don Kessler, Joe Loftus, and others at NASA JSC in 1979
- **ODPO provides technical and policy support to NASA HQ, NASA missions, the USG, and commercial organizations**
- **ODPO represents the USG in international forums (United Nations, IADC, ISO, *etc.*)**
- **ODPO is recognized as a pioneer and leader on orbital debris environment definition, modeling, and mitigation policy development**

IADC = Inter-Agency Space Debris Coordination Committee

ODPO's Roles and Responsibilities (1/2)

2.1.2.a. Collects measurement data to characterize the orbital debris populations and the ever-changing orbital debris environment.

b. Maintains and leads the advancement of orbital debris models, assessment tools, and mitigation standards.

c. Provides technical evaluations of the Orbital Debris Assessment Reports (ODAR) and End of Mission Plans (EOMP).

d. Tracks the compliance with orbital debris mitigation measures by NASA programs and projects.

e. Assists U.S. Government departments and agencies on matters related to the characterization of the orbital debris environment and the application of orbital debris mitigation measures and policies.

f. Contributes to the determination, adoption, and use of international orbital debris mitigation guidelines through international fora such as the United Nations Committee on the Peaceful Uses of Outer Space, the IADC, and ISO.

(NASA Procedural Requirement 8715.6E, 18 April 2024)

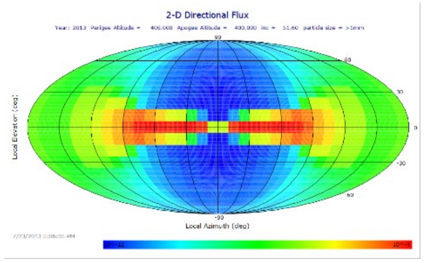
ODPO's Roles and Responsibilities (2/2)

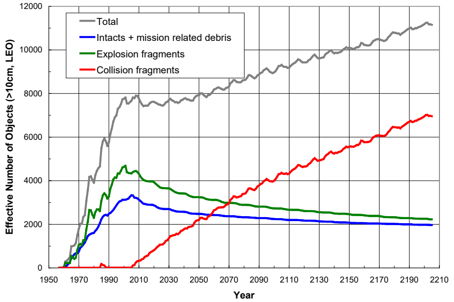
3.6.1. The ODPO, based on information provided by the U.S. Space Force, tracks and provides notifications of upcoming reentries of large NASA-related spaceflight systems to relevant NASA Offices and Mission Directorates.

3.6.5. The ODPO, based on breakup notifications provided by the Department of Defense, assesses risks from new major on-orbit fragmentation events to the International Space Station and to the environment. The ODPO also provides notifications, including results of the assessments, to OSMA and relevant NASA Offices

(NASA Procedural Requirement 8715.6E, 18 April 2024)

End-to-End Orbital Debris Activities at ODPO





MACS
MULTILAYER ACOUSTIC CONDUCTIVE GRID SENSOR

Mission Support

Compliance assessments
Risk assessments
(ISS, Orion, robotic missions, *etc.*)
Reentry assessments

Measurements

Radar
Optical
In situ
Laboratory

→

Modeling

Breakup
Engineering
Evolutionary
Reentry

→

Environment Management

Mitigation
Remediation
Mission Requirements
Policy

Coordination

USG, IADC, ISO
United Nations

Credit: NASA JPL

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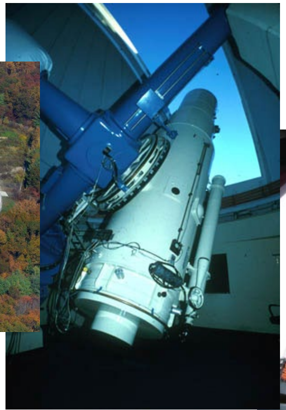
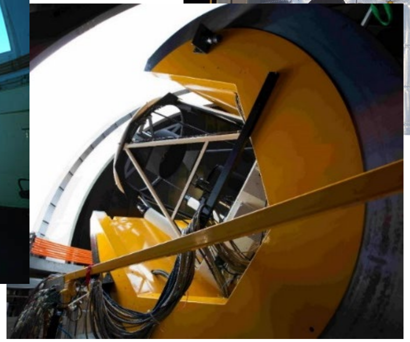
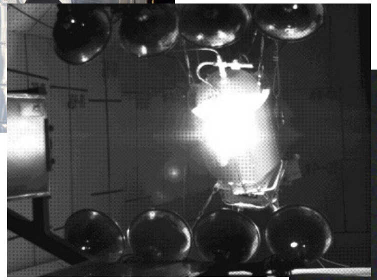


Credit: Patrick Seitzer, University of Michigan

Credit: Ben Hanna

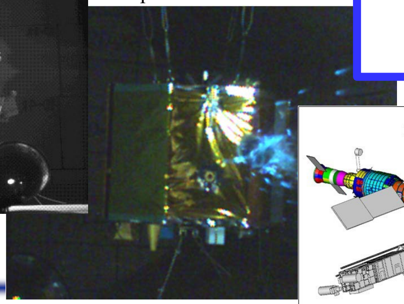


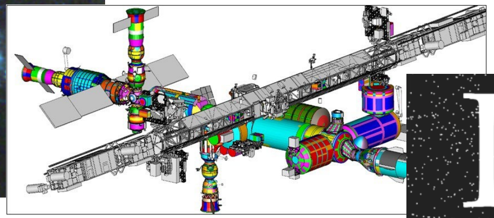
Credit: NASA

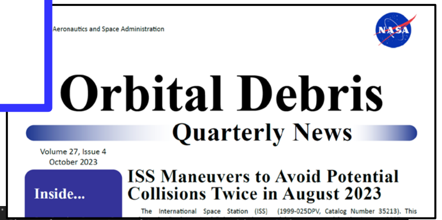


Credit: The Aerospace Corporation

Credit: Arnold Engineering Development Complex/Air Force

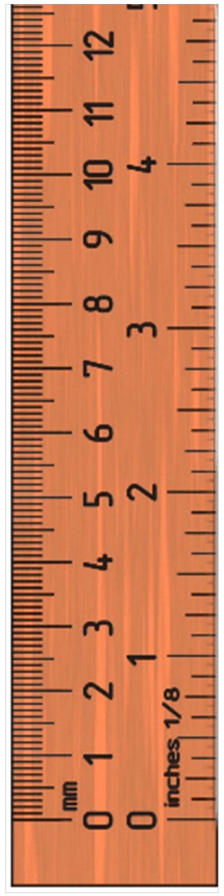






Risk from Small, Millimeter-sized Orbital Debris

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)

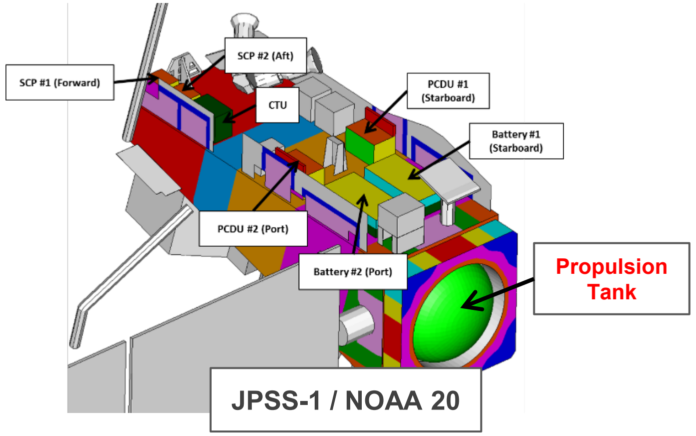
Marble size or larger (≥1 cm): ~500,000

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**

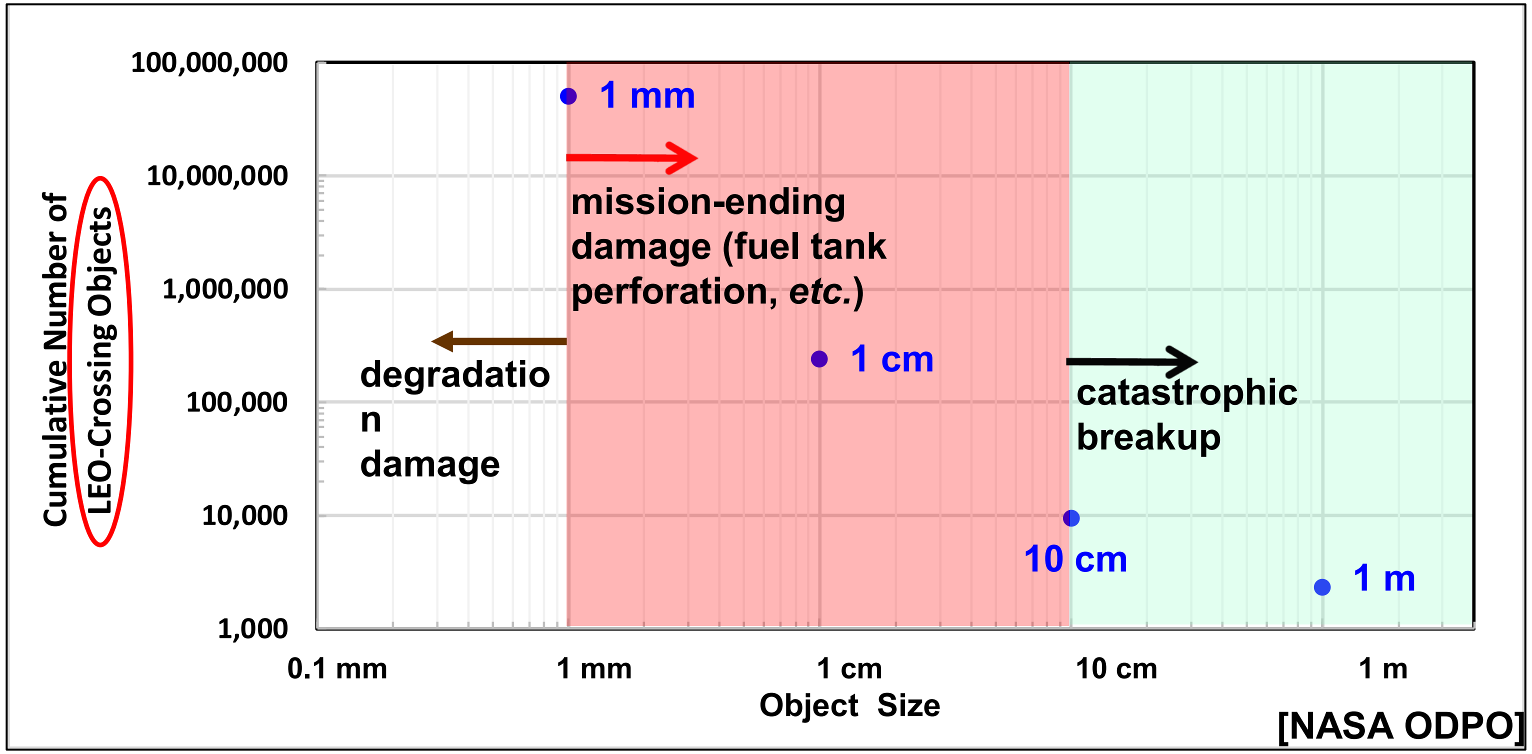
Top Orbital Debris Risks to Robotic Missions in LEO

- **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

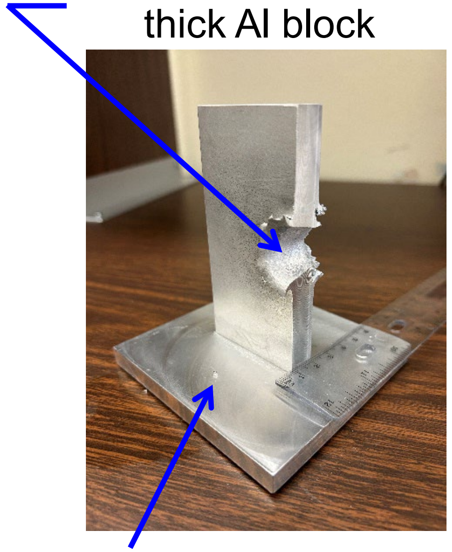


Mission-ending Risk from Orbital Debris

- **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

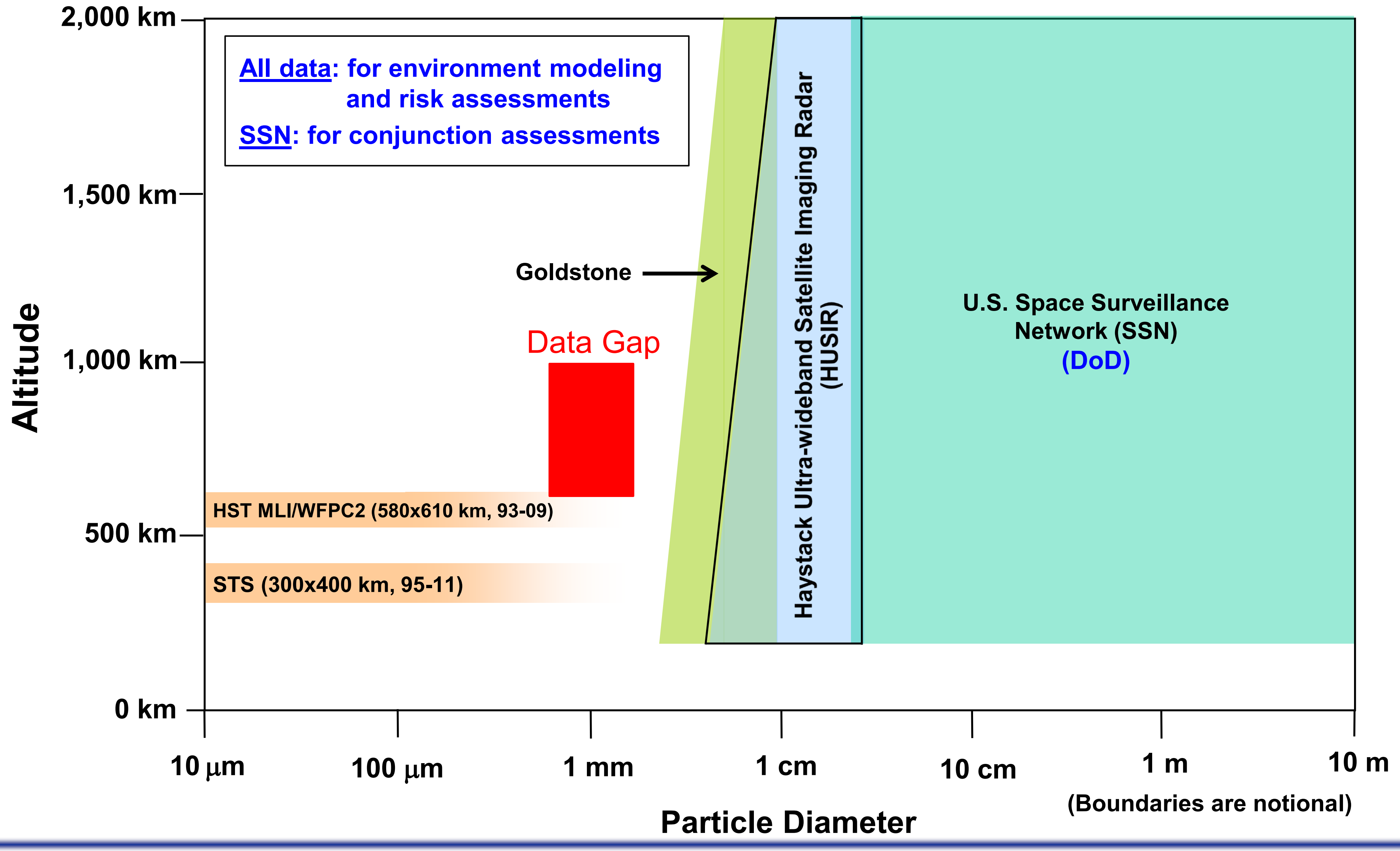


Perforation of a 1.2 cm thick Al block



by a 4 mm Al projectile @ 7.2 km/s, equiv. to a 1.7 mm SS @ 15 km/s

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)

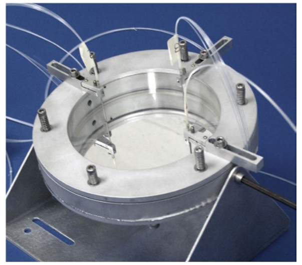
- **U.S. National Orbital Debris Implementation Plan (OSTP, 2022)**
  - Section 2.3.1, Improve Characterization of Debris Less than 1 cm in LEO

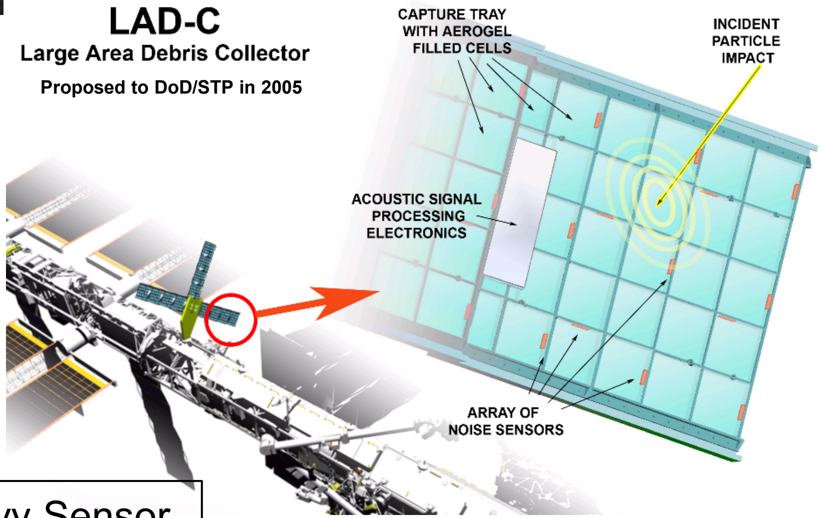
    "*Investigate technology development and mission opportunities for in-situ measurement sensors to identify, develop, and mature in-situ measurement technologies; leverage researched technologies; and encourage the development of novel concepts capable of collecting similar types of data, including size, 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

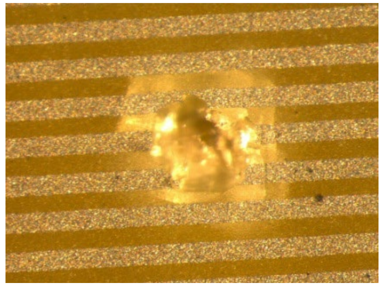
ODPO's *In situ* Measurement Technology Development

- **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





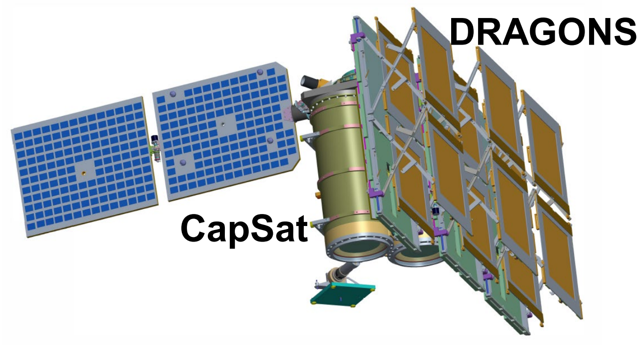
Credit: NASA



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

NASA Science Mission Directorate (SMD) DRAGONS Study

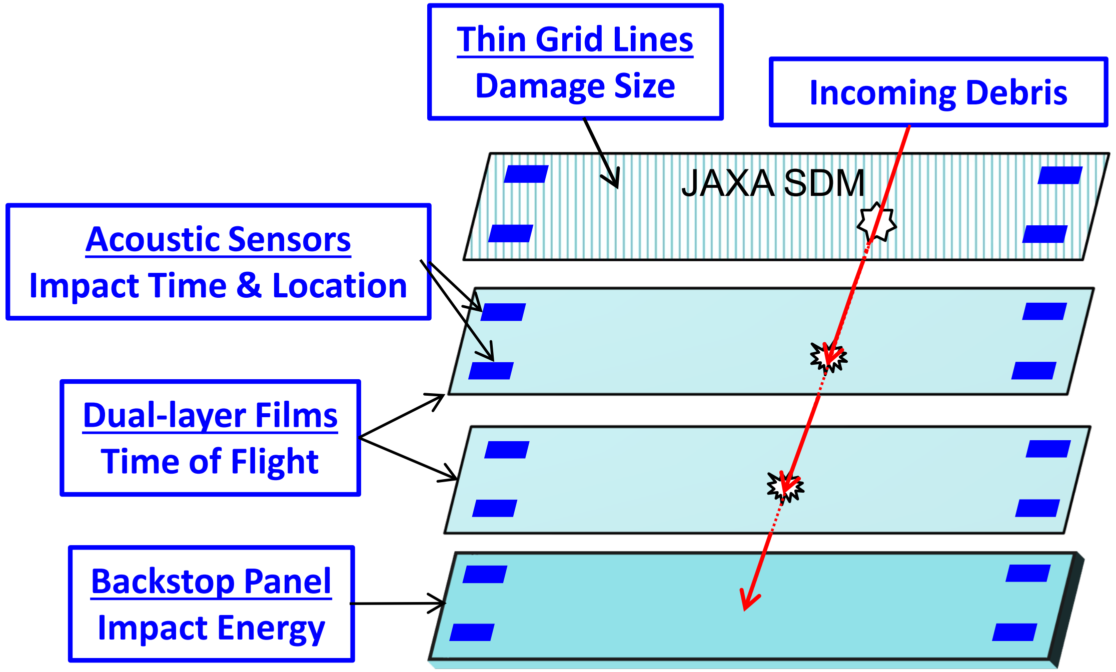
- **SMD funded the ODPO for a 3-month feasibility study in 2015**
  - Engineering mission assessment
  - Benefits of the data to environment modeling
  - Analyses of alternative instruments



- **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 m^2 detection area DRAGONS is quite feasible
    - **DRAGNS 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

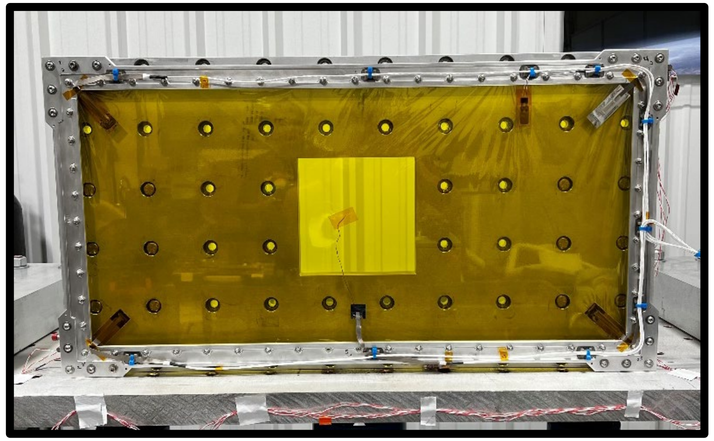
- **MACS is an improvement to DRAGONS, designed to detect and measure orbital debris in the millimeter-sized regime**
  - MACS combines several impact detection technologies, including Japan's IHI-patented, JAXA funded, and flight demonstrated (HTV-5, 2015) conductive grid film ("Space Debris Monitor," 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**



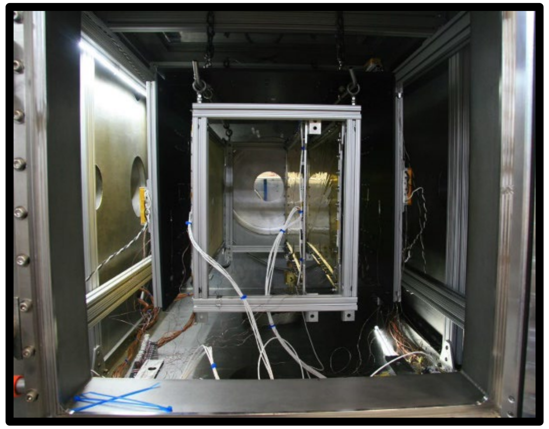
MACS Technology Development

- **Several JAXA-NASA agreements have been established to integrate JAXA's SDM into ODPO's multi-layer sensor system since 2017**
- **Component-level environmental testing and hypervelocity impact testing have been conducted to characterize the system response, improve design, and mature MACS sensor technology**
  - Some environmental tests were funded by SMD/HPD

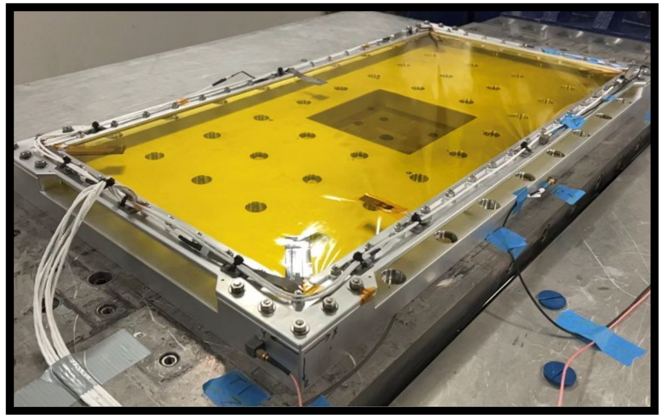
Credit: NASA



ITO Kapton® Y-Axis Shock Testing



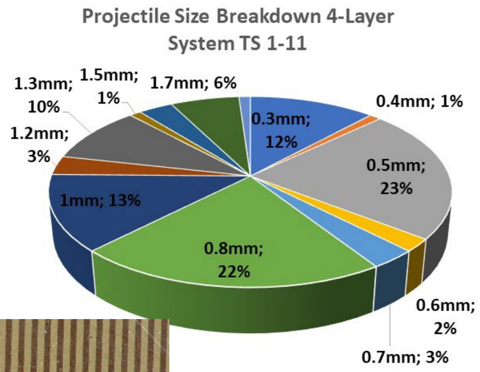
MACS 3-Layer Thermal-Vacuum Wing

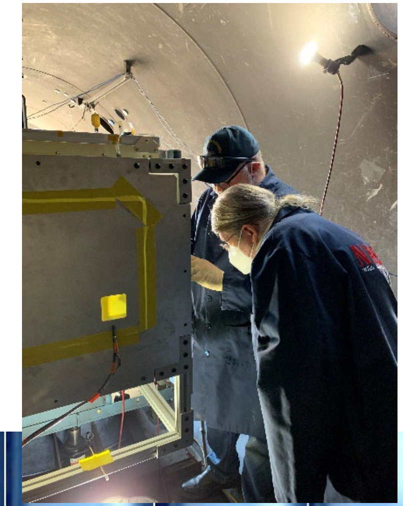


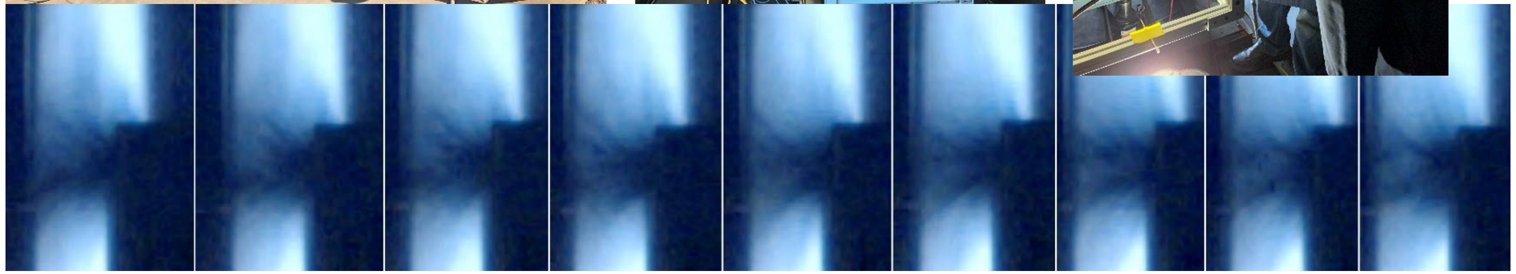
ITO Kapton® X-Axis Random Vibration

MACS Hypervelocity Impact Testing

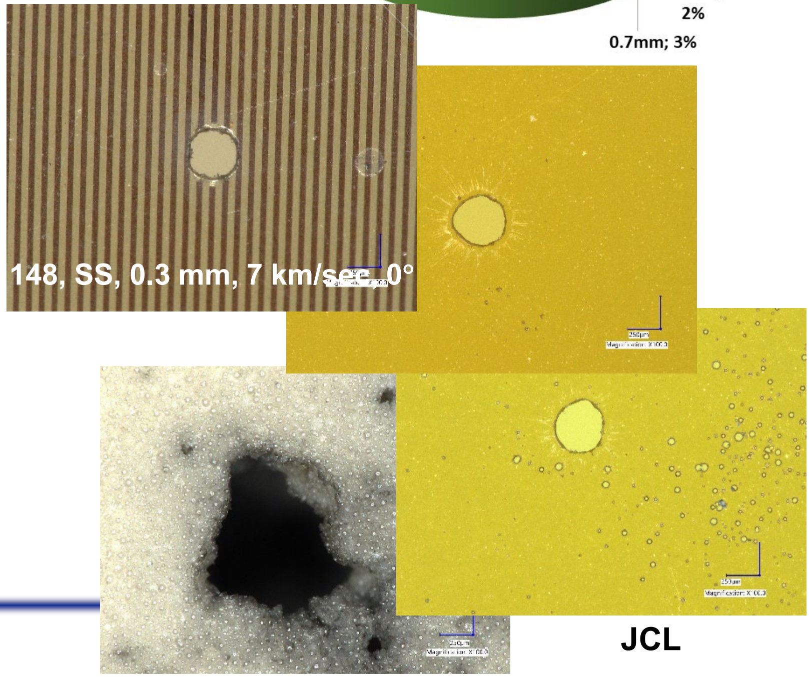
- **A total of 14 week-long hypervelocity impact test series on the MACS prototype unit have been carried out at NASA White Sands Test Facility**
  - Projectiles: different sizes, materials, impact speeds, and impact angles
  - System: different configurations and impact locations







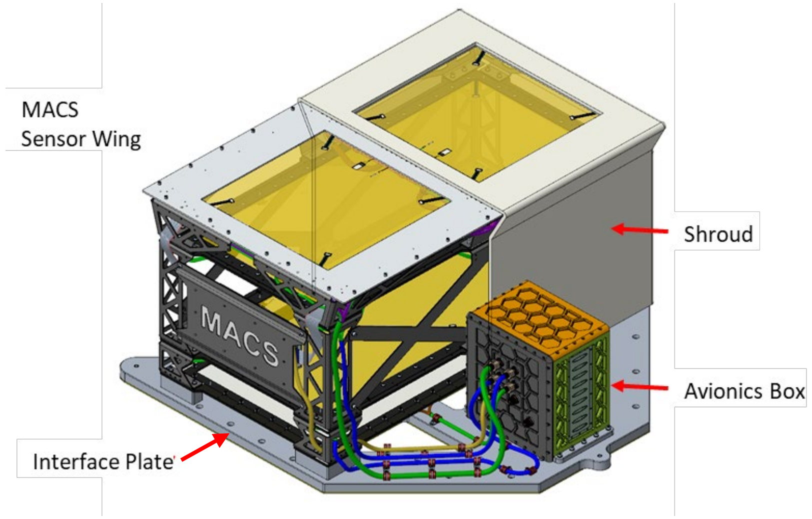
Credit: NASA

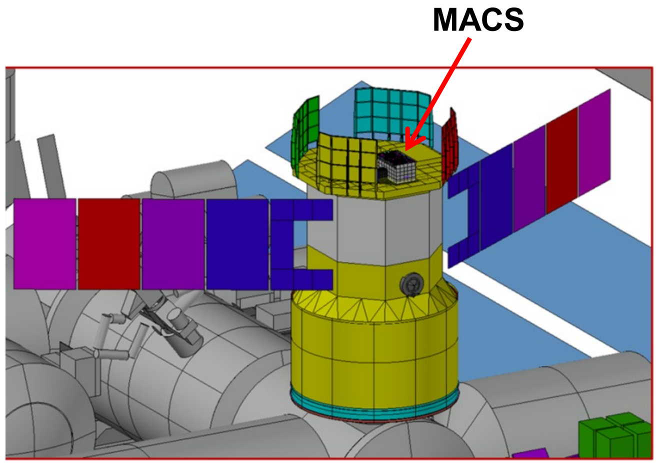


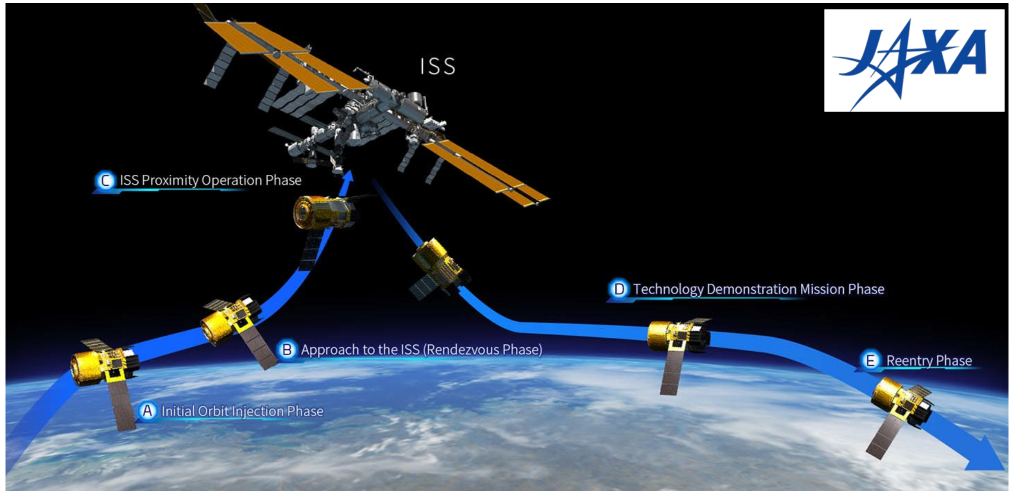
JCL

MACS HTV-X3 Technology Demonstration Mission

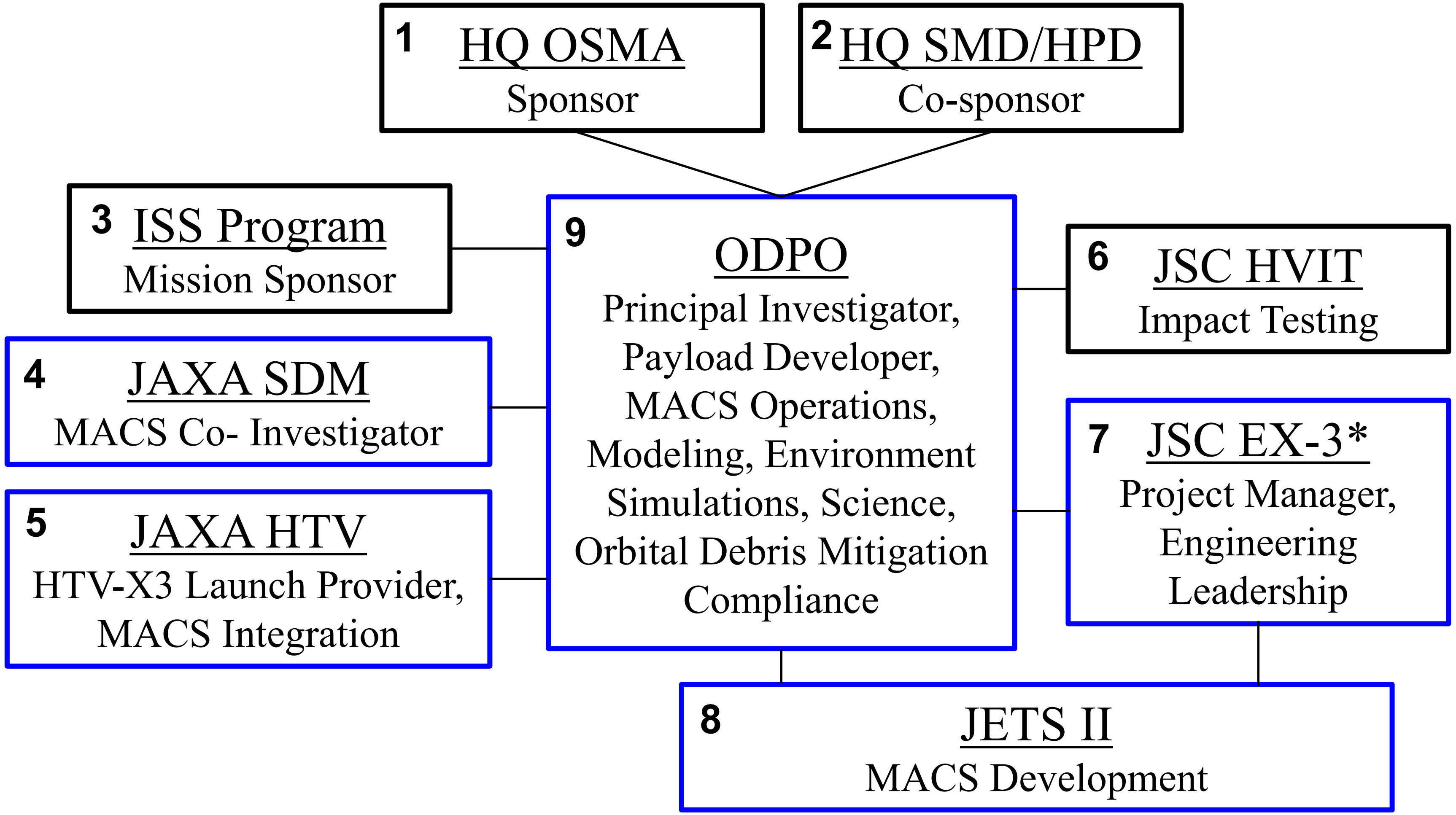
- **ODPO, in collaboration with JAXA, with co-sponsorship from SMD/HPD and the ISS Program, has secured a technology demonstration mission opportunity to deploy a single-wing MACS on HTV-X3 in late 2026**
  - A single MACS wing will be mounted to HTV-X3's unpressurized cargo base (UPCSS)
  - HTV-X3 will 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 NASA and JAXA Teams

NASA Leads

J.-C. Liou (PI)
Robert Corsaro (Co-I)
Megan Ortiz (PM)
Heather Cowardin (in-situ lead)
Mario Garcia (PM)
Jorge Rivera (electrical lead)
Mack Sanjak (software lead)
Ryan Hall (mechanical lead)
Rob Rowland (SE&I lead)
Jonah Smith (thermal lead)
Phillip Anz-Meador (in-situ lead)
John Opiela (safety lead)
Mark Matney (modeling lead)

JAXA SDM Leads

Satomi Kawamoto (Co-I)
Teppei Okumura
Daiki Nakanishi
Haruhisa Matsumoto
Ryuusuke Harada
Yu Takeuchi
Joh Nagata
Hiroyuki Kishindo

JAXA HTV-X Leads

Tomoya Suehiro
Kei Saito
Koji Yamada
Ayano Iida

MACS HTV-X3 Mission Preparation Status

- Approval to Proceed: February 2023
- System Requirements Review: November 2023
- Preliminary Design Review: May 2024
- **Critical Design Review: May 2025**
- **Hardware Delivery: July 2026**
- **Launch: Late 2026 (tentative)**