

Risk from Orbital Debris

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**RAS Specialist Discussion Meeting on Space Dust and Debris in the Vicinity of the Earth
London, UK, 9 November 2018**



Outline

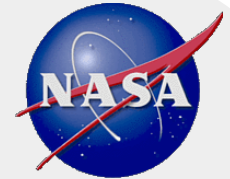
- **Overview of the orbital debris (OD) problem**
- **NASA Orbital Debris Program Office (ODPO)**
- **Characterization of the OD risk to space missions**

Orbital debris = human-made debris in Earth orbit
Space debris = micrometeoroids and orbital debris (MMOD)



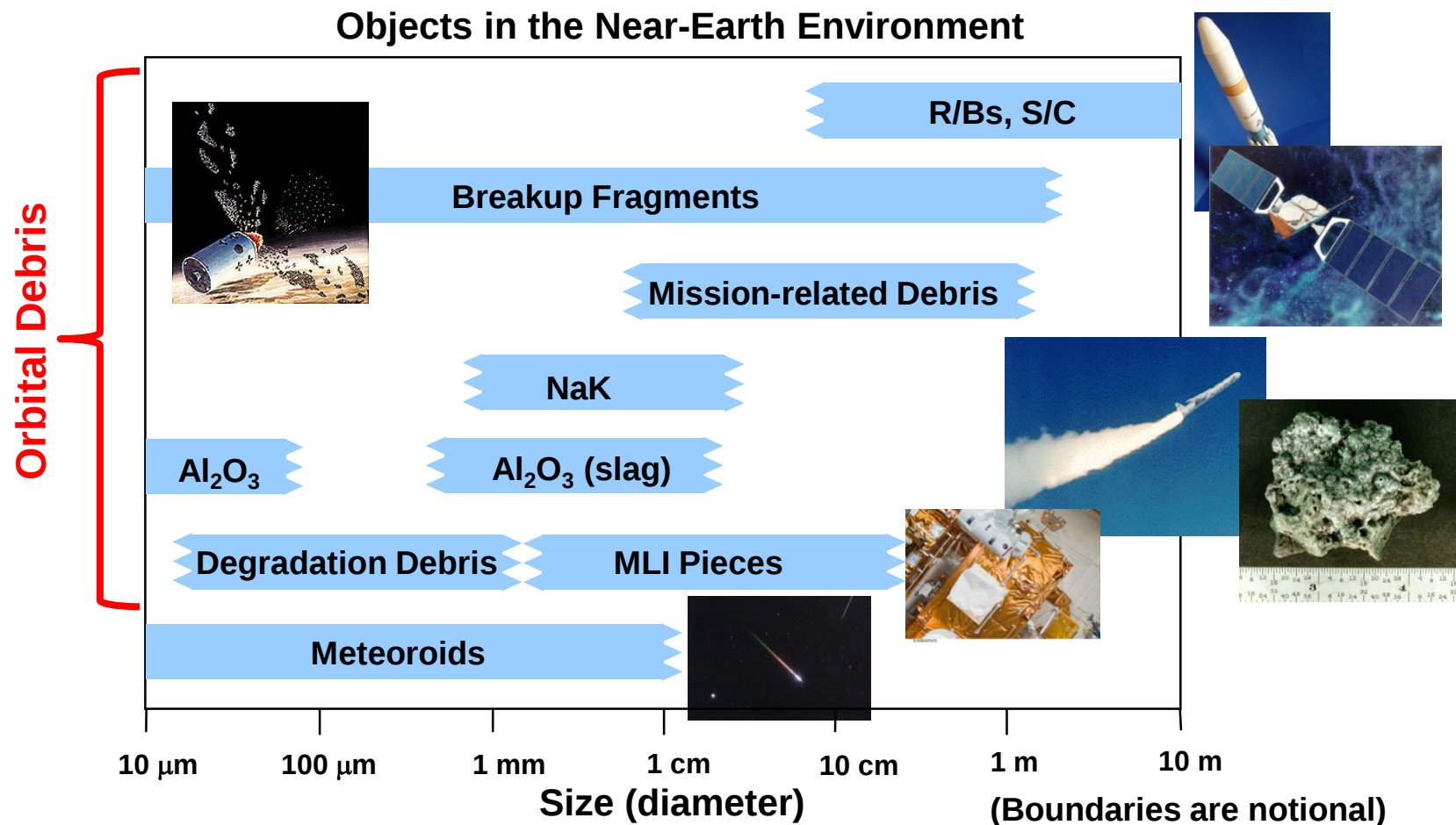
Overview of the Orbital Debris Problem





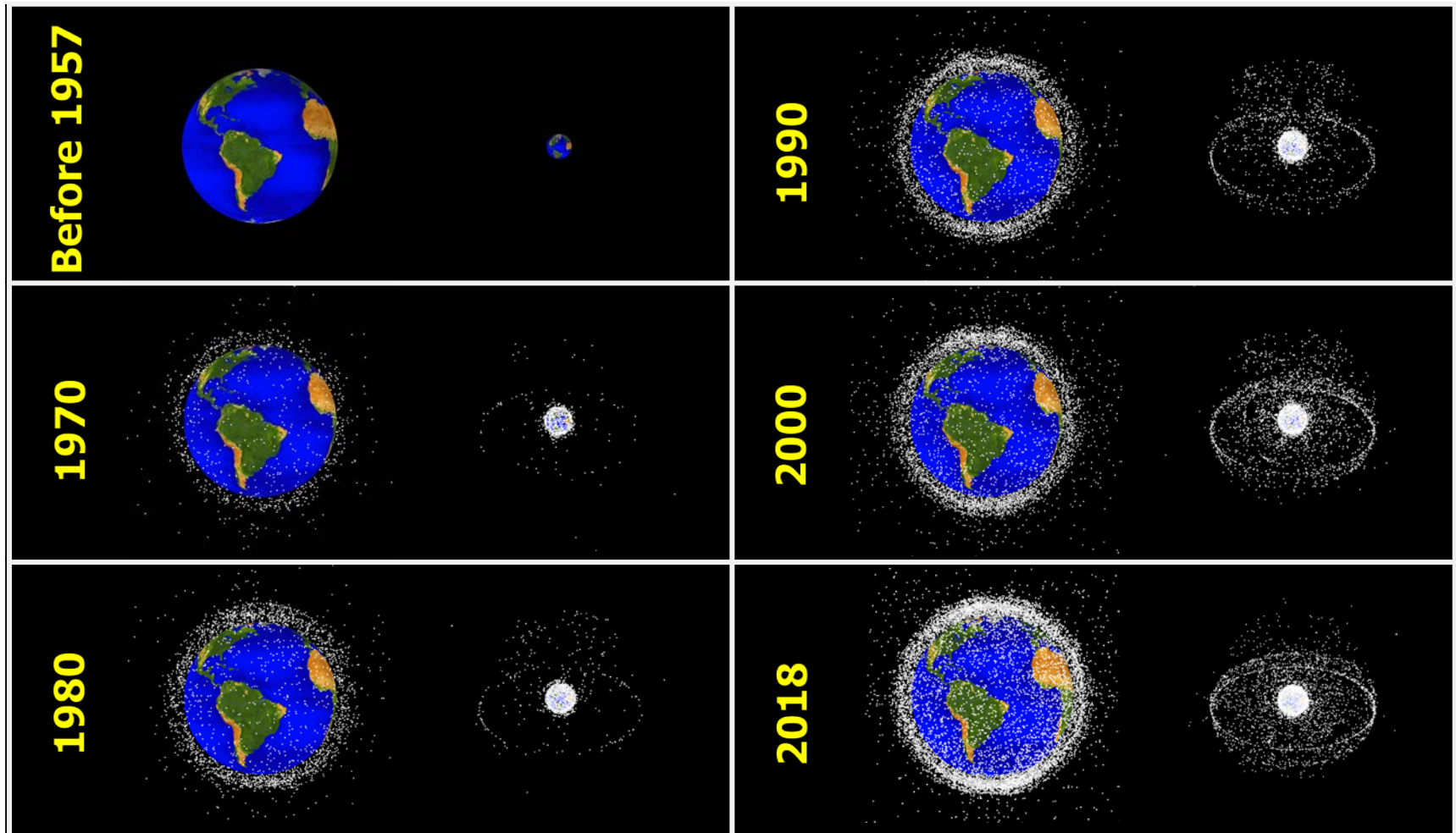
What Is Orbital Debris?

- Orbital debris is any human-made object in orbit about the Earth that no longer serves any useful function





Historical Orbital Debris Environment



- Only objects in the U.S. Space Surveillance Network (SSN) catalog are shown
- Sizes of the dots are not to scale



How Much Junk Is Currently Up There?

Softball size or larger (≥ 10 cm): ~23,000
(tracked by U.S. Combined Space Operations Center, CSpOC)

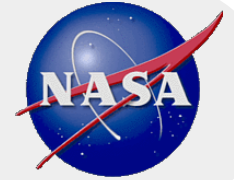


Marble size or larger (≥ 1 cm): ~500,000



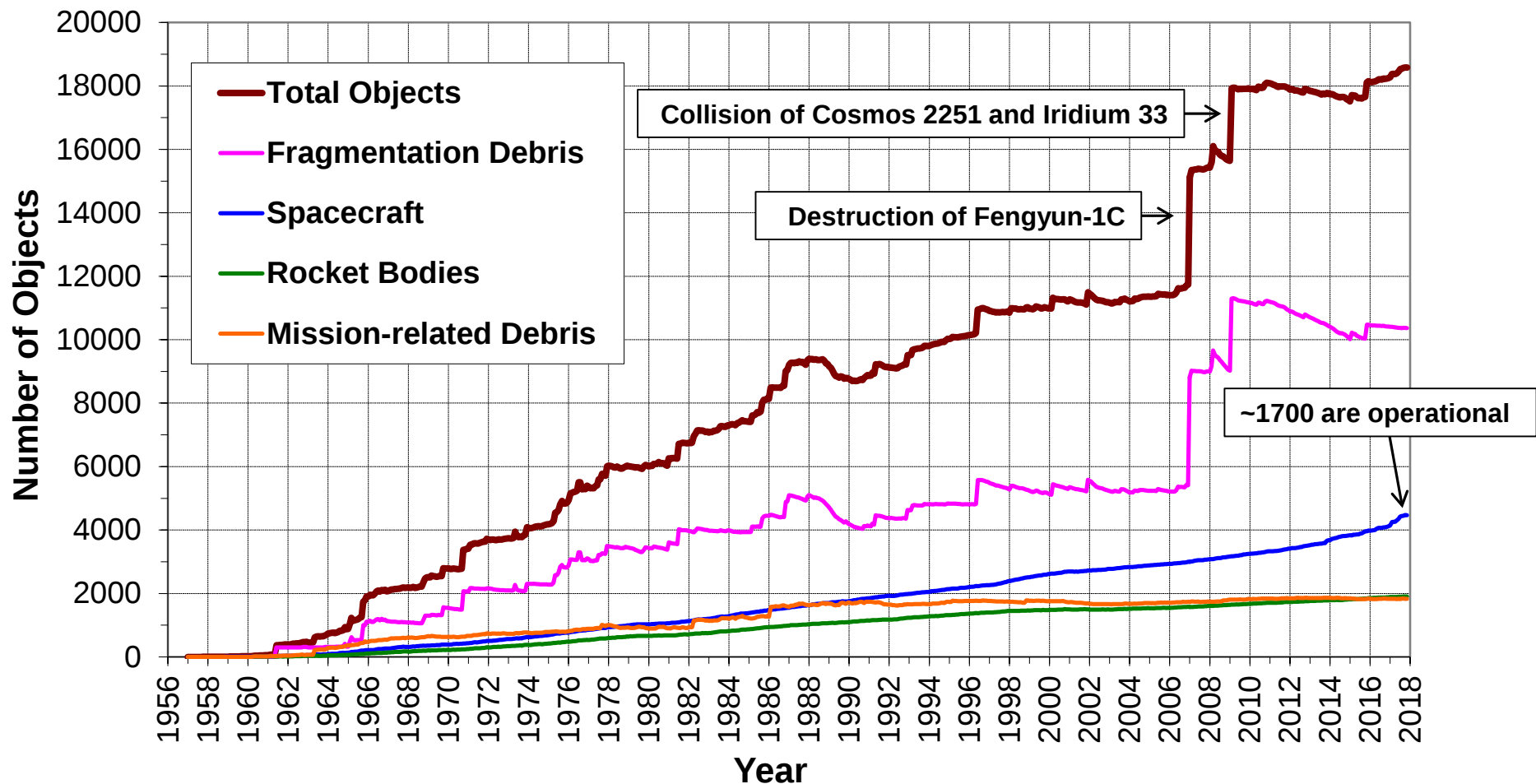
Dot or larger (≥ 1 mm): >100,000,000
(a grain of salt)

- Due to high impact speed in space (~10 km/sec in LEO), even **sub-millimeter** debris pose a realistic threat to human spaceflight and robotic missions
 - 10 km/sec = 22,000 miles per hour (the speed of a bullet ~1,500 miles per hour)
- **Mission-ending threat is dominated by small (mm-to-cm sized) debris impacts**
- Total mass: >7600 tons LEO-to-GEO (~3000 tons in LEO)



Growth of the Cataloged Populations

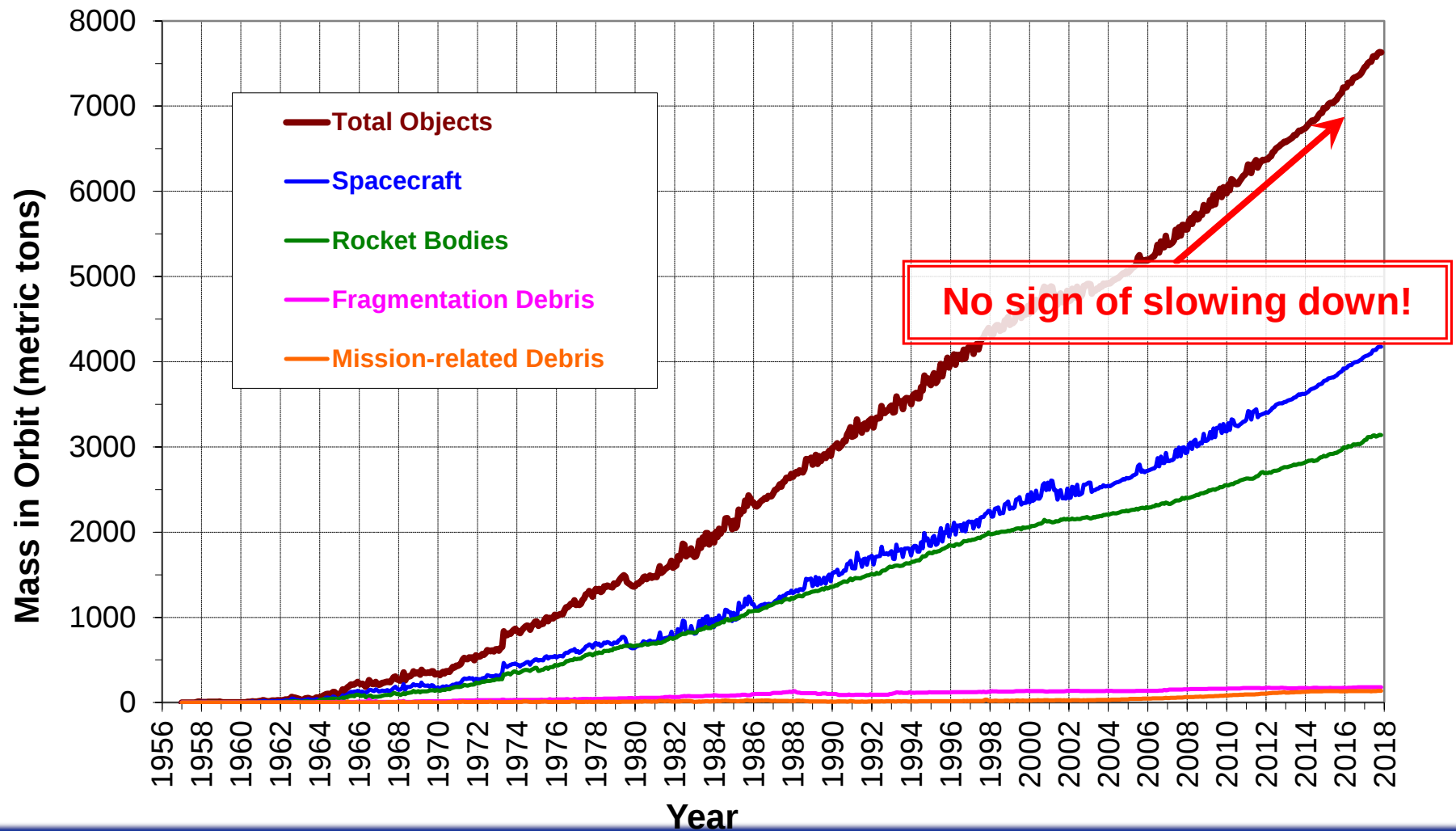
- The CSpOC is tracking ~23,000 large objects and maintains most of their orbits in the U.S. Satellite Catalog





Mass in Orbit Continues to Increase

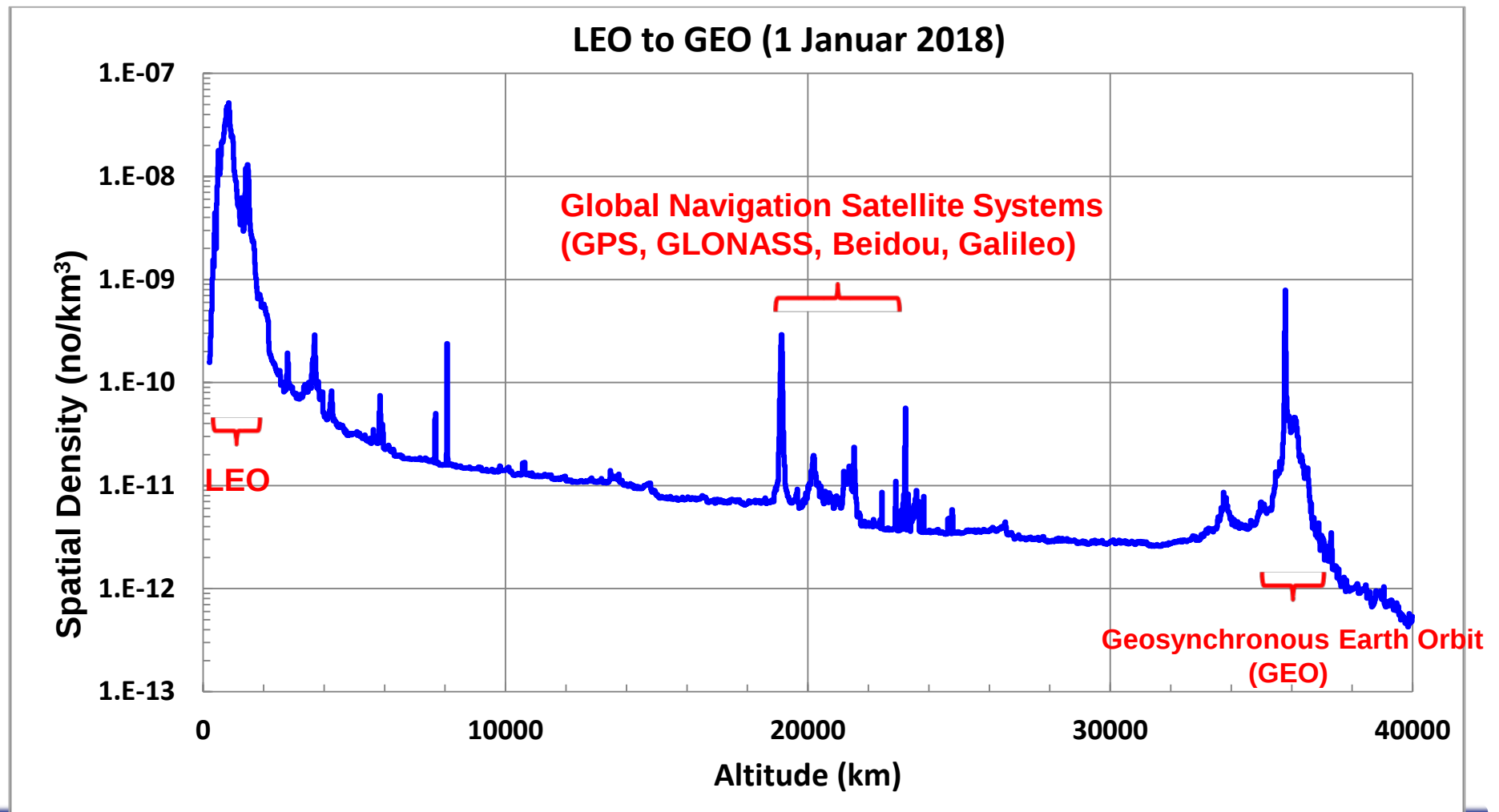
- The material mass in Earth orbit continues to increase and has exceeded 7600 metric tons





Distribution of the Cataloged Objects, LEO-to-GEO

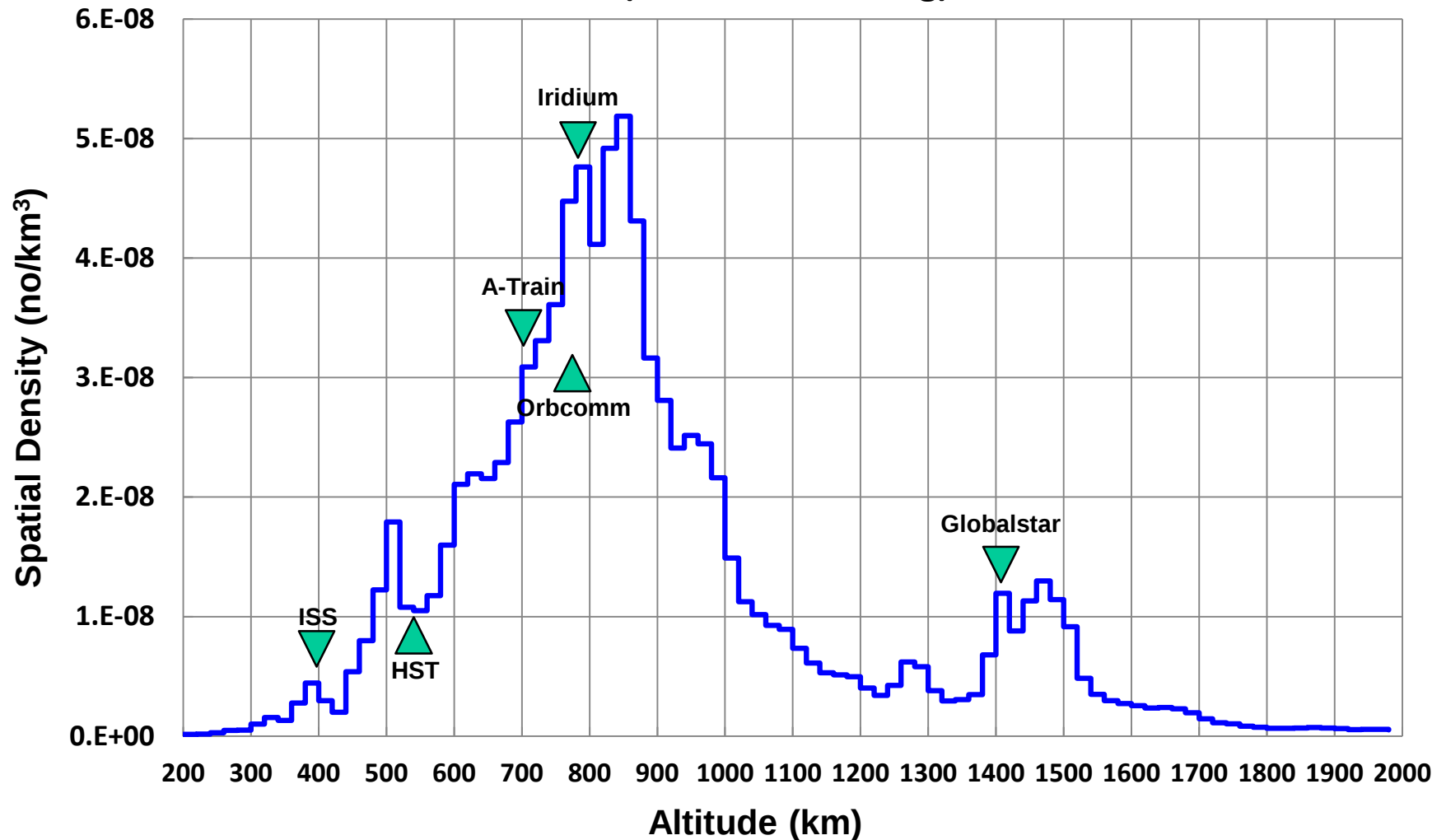
- The low Earth orbit (LEO, the region below 2000 km altitude) has the highest concentration of the cataloged objects, followed by GEO.





Distribution of the Cataloged Objects in LEO

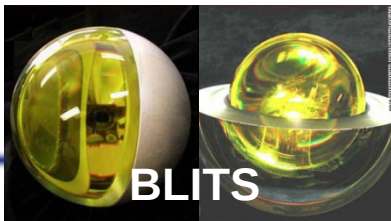
LEO (1 Jan 2018 Catalog)





Threat from Orbital Debris - Examples

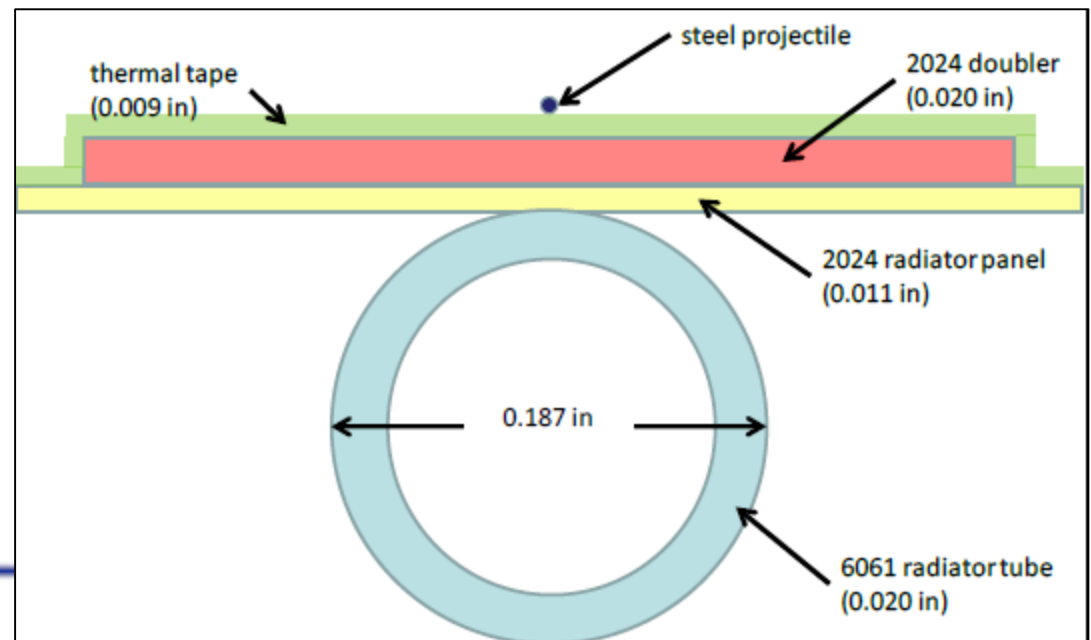
- The gravity-gradient boom of an operational French satellite (CERISE) was cut in half by a tracked debris fragment in 1996
- The fully operational Iridium 33 was destroyed by the retired Russian Cosmos 2251 in 2009
- Near the end of the Space Shuttle Program, the Loss of Crew and Vehicle risks from MMOD impact damage were in the range of 1 in 250 to 1 in 300 per mission (OD to MM ~2:1 at ISS altitude)
- Impacts by small, untracked debris could be responsible for many satellite anomalies
 - A 17-cm Russian retro reflector, BLITS, was damaged and shed a piece of trackable debris in January 2013
 - The European Space Agency's Sentinel-1 was hit by a small debris, leading to some power loss and 6 trackable debris in August 2016





Orbital Debris Success Story (1/2)

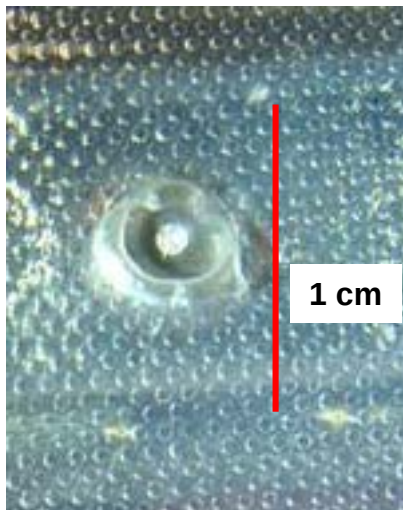
- **Based on debris modeling and impact testing efforts to better protect the Space Shuttle, key modifications were approved in 1997 to “harden” the Orbiter from the increased OD impact risk**
 - An extra layer of 0.5-mm thick aluminum (aluminum doubler) bonded to the radiator face sheet directly over the cooling tubes
 - Automatic isolation valves added to each coolant loop to isolate a leak in a radiator panel from the rest of the Freon system



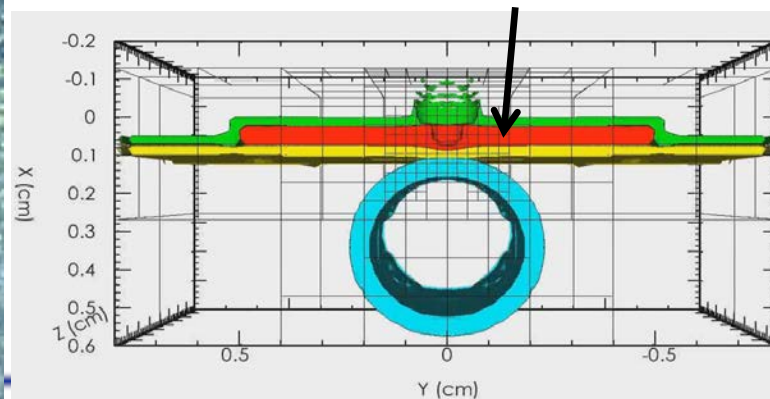


Orbital Debris Success Story (2/2)

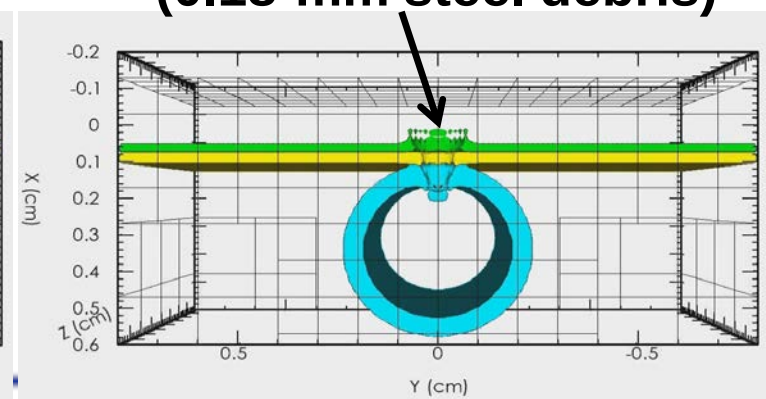
- **An impact on the aluminum doubler directly above the Freon tube was identified during the 2009 STS-128 (Discovery) postmission inspection**
 - Simulations show that had the doubler not been in place, the Freon tube would have been breached
 - Without the second modification isolating the leak to the radiator panels, all of the Freon (which is under pressure) would have leaked from the system, requiring the Shuttle to terminate its mission and land within 24 hours, and with reduced avionics (due to depletion of coolant)



aluminum doubler

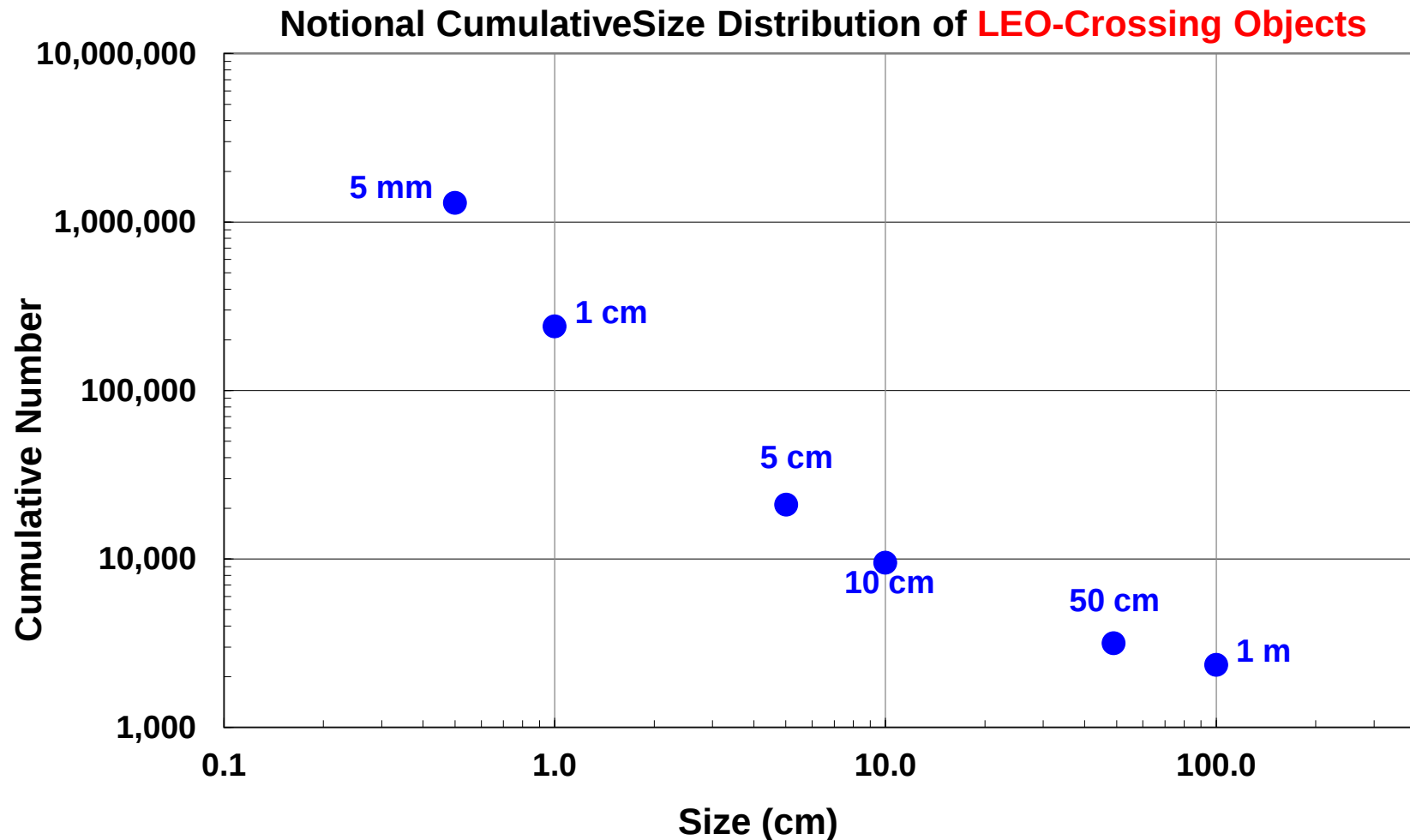


**simulated impact
(0.18-mm steel debris)**





Orbital Debris Size Distribution



Mission-ending threat is dominated by small debris impacts



Top Risk for NASA Missions in LEO (1/2)

- **NASA currently operates more than 20 missions in LEO**
 - Thirteen missions at 600-1000 km altitude: Aqua, Aura, CALIPSO, CloudSat, OCO-2, QuikSCAT, Terra, SORCE, TIMED, NuSTAR, IRIS, O/OREOS, SMAP
 - Seven missions for NOAA and USGS at 600-1000 km altitude: NOAA-15, -18, -19, Suomi NPP, JPSS-1, Landsat 7, Landsat 8
 - Seven missions below 600 km alt: ISS, HST, GPM, Fermi, AIM, Swift, CYGNSS (8 spacecraft)
- **Millimeter-sized orbital debris represents the highest penetration risk to most operational (robotic) spacecraft in LEO**



Top Risk for NASA Missions in LEO (2/2)

- **The 2015 NESC JPSS MMOD assessment report includes the following findings and recommendation**

*F10. In spite of the identified uncertainties, **ORDEM 3.0 possesses several advantages** over ORDEM2000, MASTER-2009 and the current version of ADEPT.*

*F-4. The models disagree significantly **for particles <3 mm, which is also the size that poses the highest penetration risk to most spacecraft.***

*F-2. For the flux for particles < 3 mm, orbital debris model validation **for altitudes above 600 km is most effective using in situ data.***

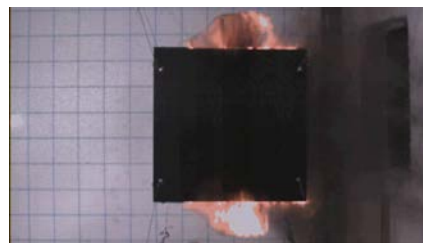
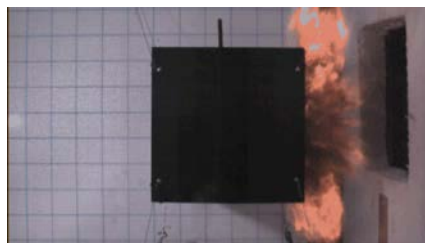
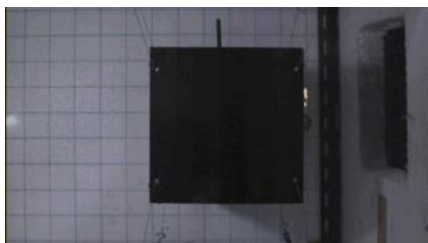
*R-19. Increase efforts to directly characterize the debris environment, especially **at altitudes above 600 km for which there is currently no in situ data.***

NESC = NASA Engineering and Safety Center

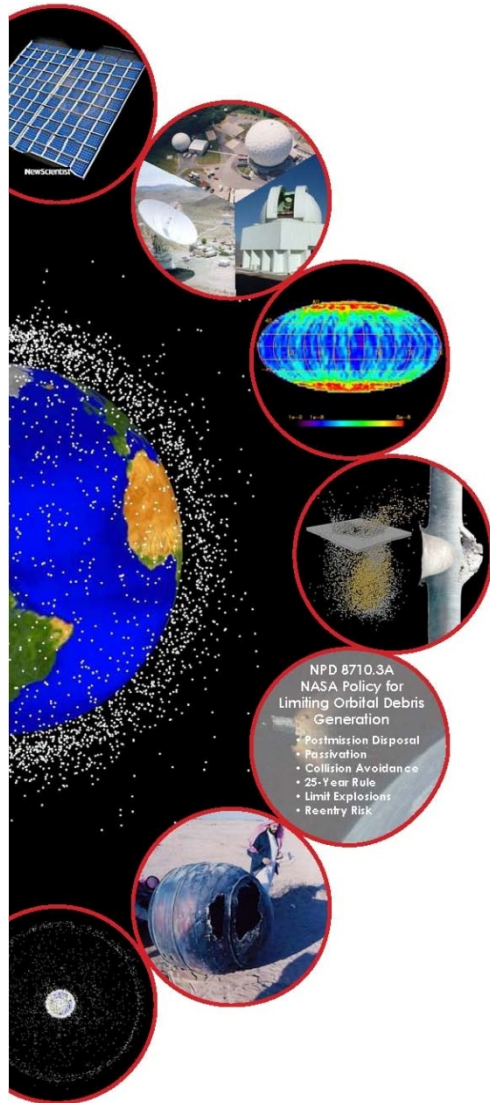
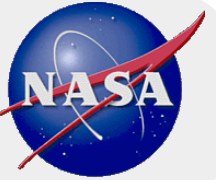
JPSS = Joint Polar Satellite System



The NASA Orbital Debris Program Office



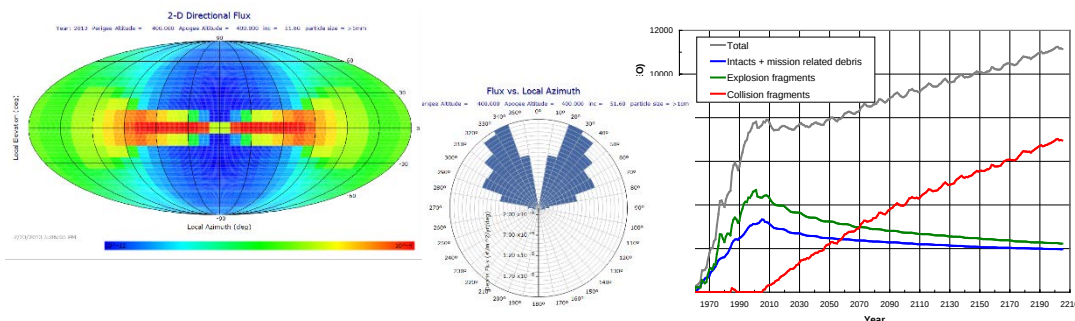
NASA Orbital Debris Program Office (ODPO)



- **The ODPO is the only organization in the U.S. Government conducting a full range of research on orbital debris**
 - This unique NASA capability was established at JSC in 1979 (D. Kessler, J. Loftus, B. Cour-Palais, *etc.*)
 - ODPO's roles and responsibilities are defined in NPR 8715.6B
 - ODPO is currently funded through HQ/OSMA
- **ODPO provides technical and policy level support to NASA Centers, NASA HQ, OSTP, other U.S. Government agencies and the commercial sector**
- **ODPO represents the U.S. Government in international fora, including the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations**
- **ODPO is recognized as the world leader in environment definition and modeling, and in mitigation policy development**



End-to-End Orbital Debris Activities at ODPO



Mission Risk Assessments

NASA space assets
(ISS, Orion, robotic missions, etc.)
Reentry

Measurements

Radar
Optical
In-situ
Laboratory

Modeling

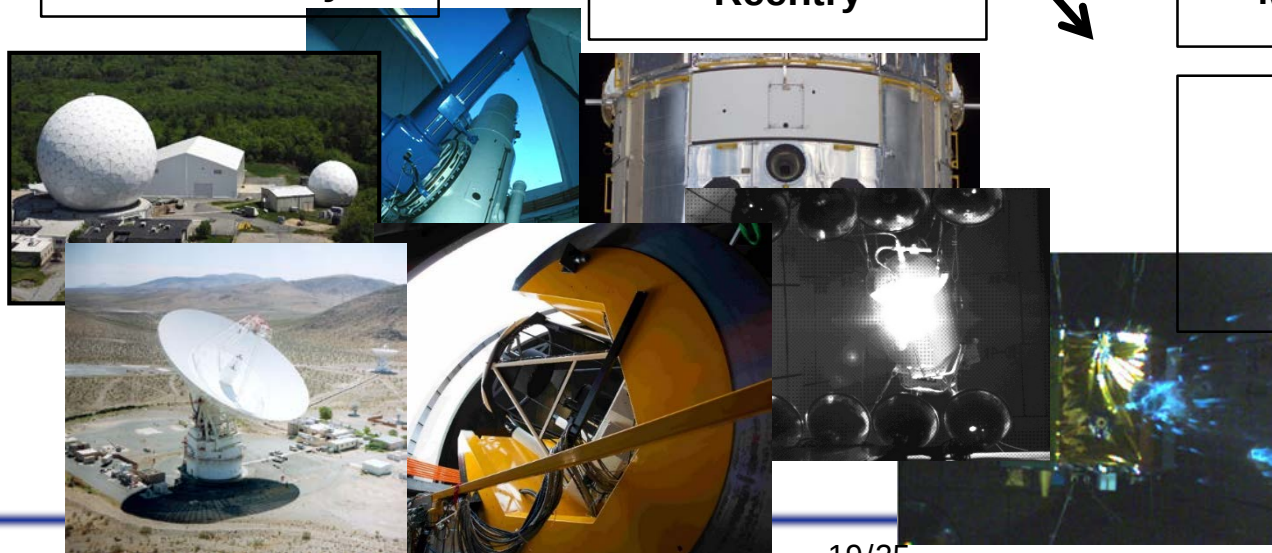
Breakup
Engineering
Evolutionary
Reentry

Environment Management

Mitigation
Remediation
Policy
Mission Requirements

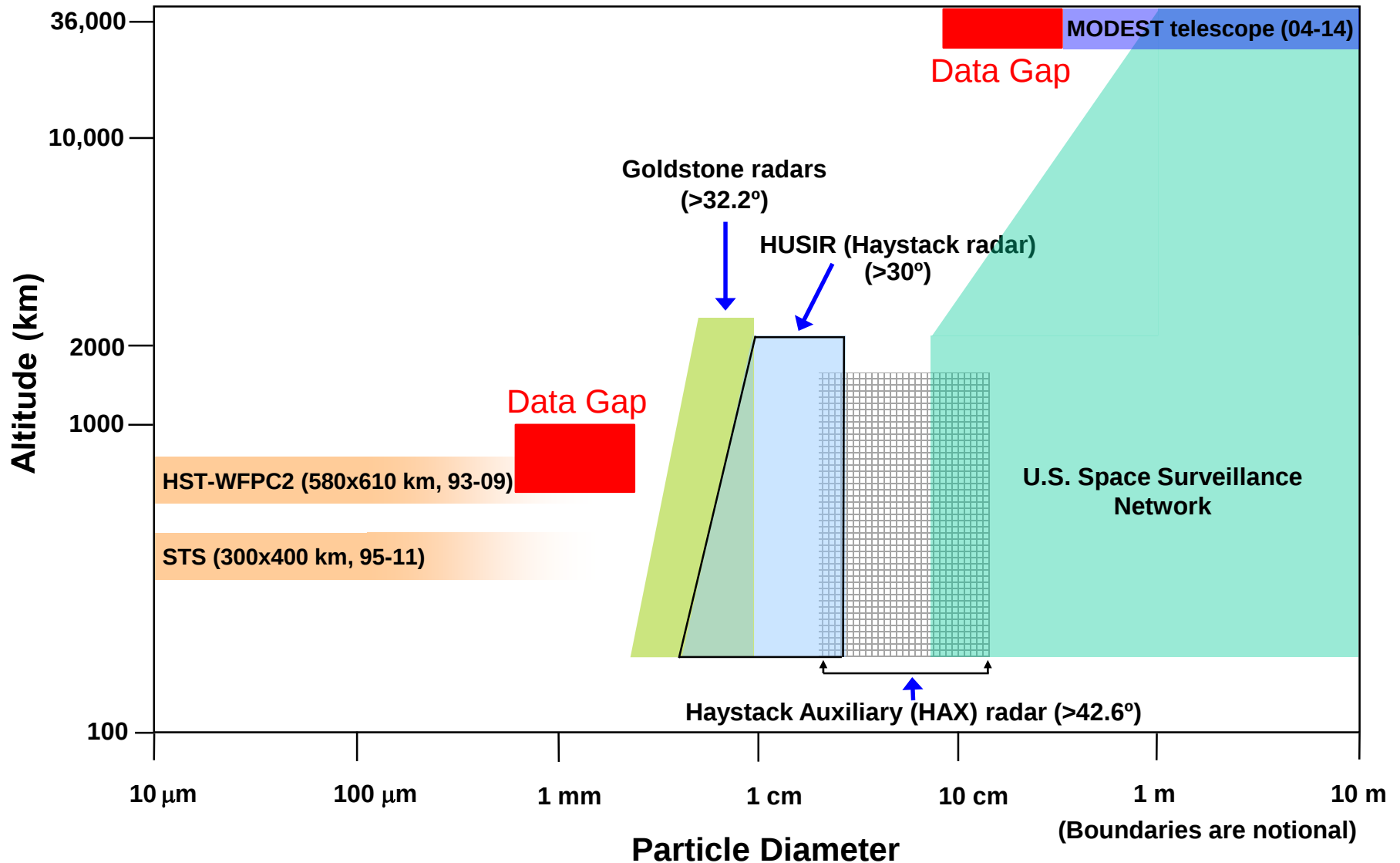
Coordination

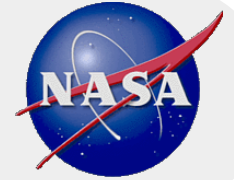
U.S. Government
IADC, ISO
United Nations





Current NASA Orbital Debris Database





Radar Measurements

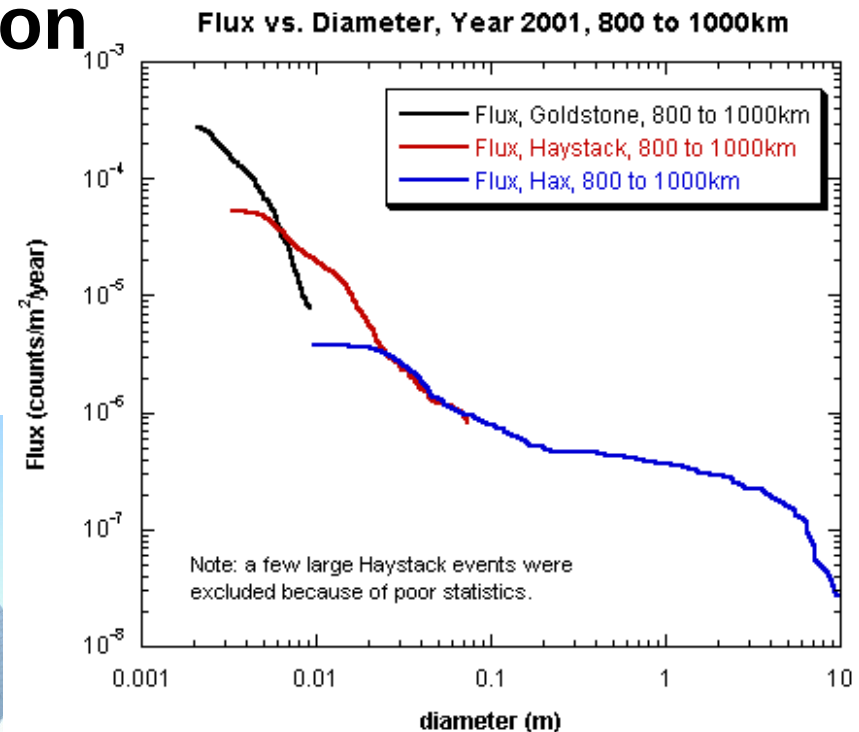
- Data processing
- Object detection/correlation
- Debris size estimation
- Orbit assessment
- Environment definition



HUSIR and HAX (MIT/LL)



Goldstone
(NASA/JPL)

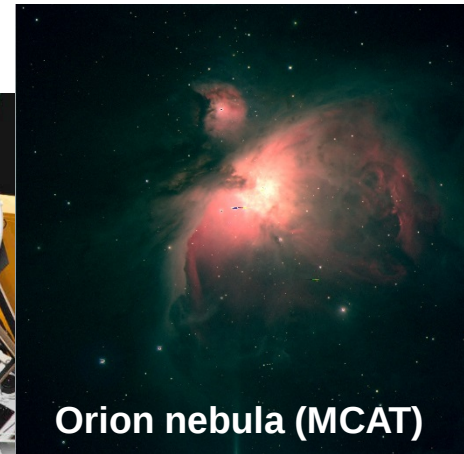
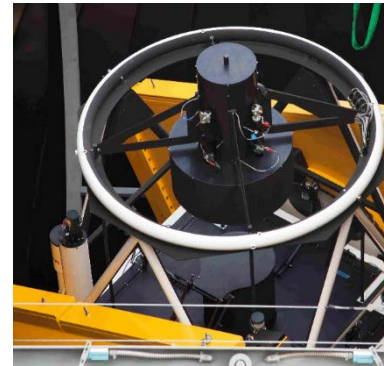


HUSIR = Haystack Ultra-wideband
Satellite Imaging Radar
HAX = Haystack Auxiliary Radar

Eugene Stansbery Meter Class Autonomous Telescope (ES-MCAT)



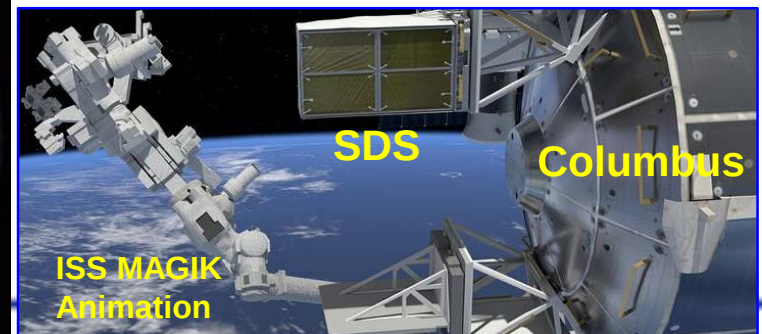
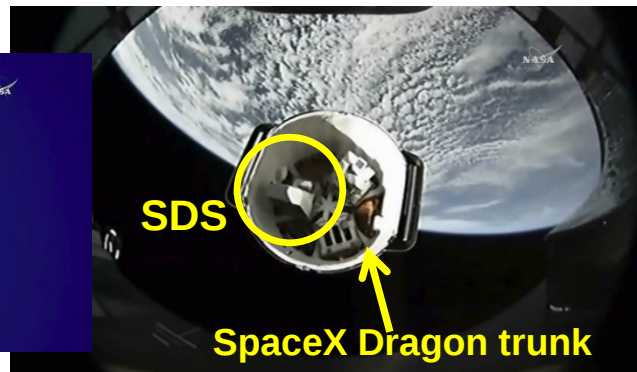
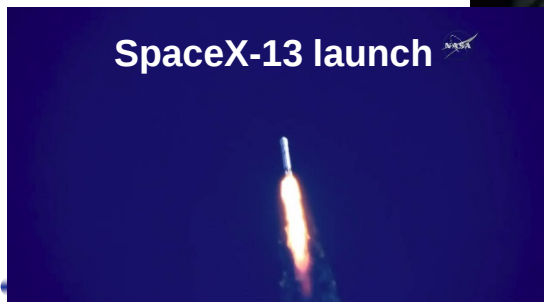
- A NASA, U.S. Air Force, and Air Force Research Laboratory joint project
- The facility is located on Ascension Island (7° 58' S, 14° 24' W)
- The two instruments are a 1.3-m telescope (MCAT) and a 0.4-m Mini-CAT telescope
 - MCAT: a double horse-shoe DFM telescope with a field-of-view of 41' × 41'
 - Mini-CAT: an Officina Stellare telescope with a field-of-view of 44' × 44'
- Objectives for operations
 - Conduct GEO and LEO statistical surveys
 - Detect debris as small as ~20 cm in GEO
 - Characterize low inclination objects in LEO
 - Provide rapid break-up response
 - Support space situational awareness coverage





In-Situ Measurements of Small Debris

- **NASA, the Naval Academy, the Naval Research Lab, Virginia Tech, and the University of Kent (Canterbury, UK) have developed new technologies for in-situ measurements of small debris from space**
 - The Space Debris Sensor (SDS) / Debris Resistive/Acoustic Grid Orbital NASA-Navy Sensor (DRAGONS) combines several particle impact detection principles to measure time, location, speed, direction, energy, and the size of each impacting particle
 - SDS was launched as a technology demonstration mission and installed on the ISS on 1 January 2018
 - The sensor collected good test and calibration data for more than 3 weeks, but also experienced two serious computer-related anomalies and ceased to function on Jan 26th
 - The DRAGONS team continues to pursue new mission opportunities





Laboratory-Based Satellite Impact Experiments

- **To better understand the outcome of an on-orbit collision, NASA, the Air Force Space and Missile Systems Center, the Aerospace Corporation, and the University of Florida are collaborating on a project called DebrisSat**
 - Conduct laboratory-based hypervelocity impact experiments on a representative, modern LEO satellite and an upper stage mockup
 - Collect, process, and measure fragments down to a few millimeters in size
 - Use the data to improve satellite breakup models for better protection of the operational spacecraft and to improve space situational awareness of the orbital debris environment





Forward Challenges

- **Conduct space-based in-situ measurements on millimeter-sized OD populations in LEO to address the top risk for missions in low Earth orbit**
- **Improve mission compliance with the existing OD mitigation requirements**
- **Develop near- and long-term cost-effective OD mitigation and remediation strategies to preserve the near Earth space environment for future generations**