National Aeronautics and Space Administration

Introduction to the Orbital Debris Environment and Mitigation Requirements

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Overview

- **An Overview of the Orbital Debris Environment**
  - Historical and current environment
  - Mitigation and remediation

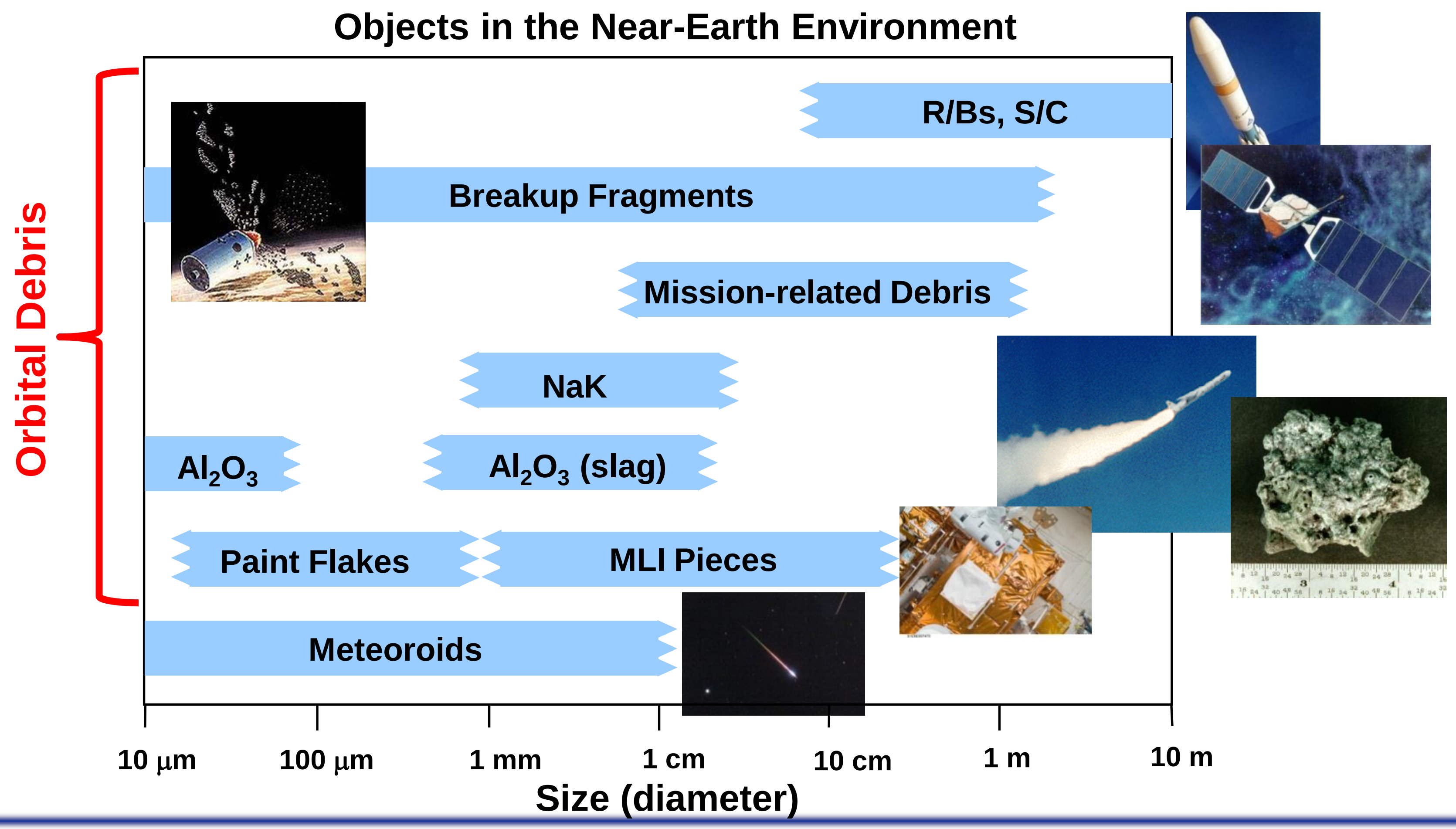
- **The NASA Orbital Debris Program Office and Highlights of Its Recent Activities**
  - Roles and responsibilities
  - Recent activities

- **Orbital Debris Mitigation Policies and Guidelines**
  - NASA
  - United States
  - International Community

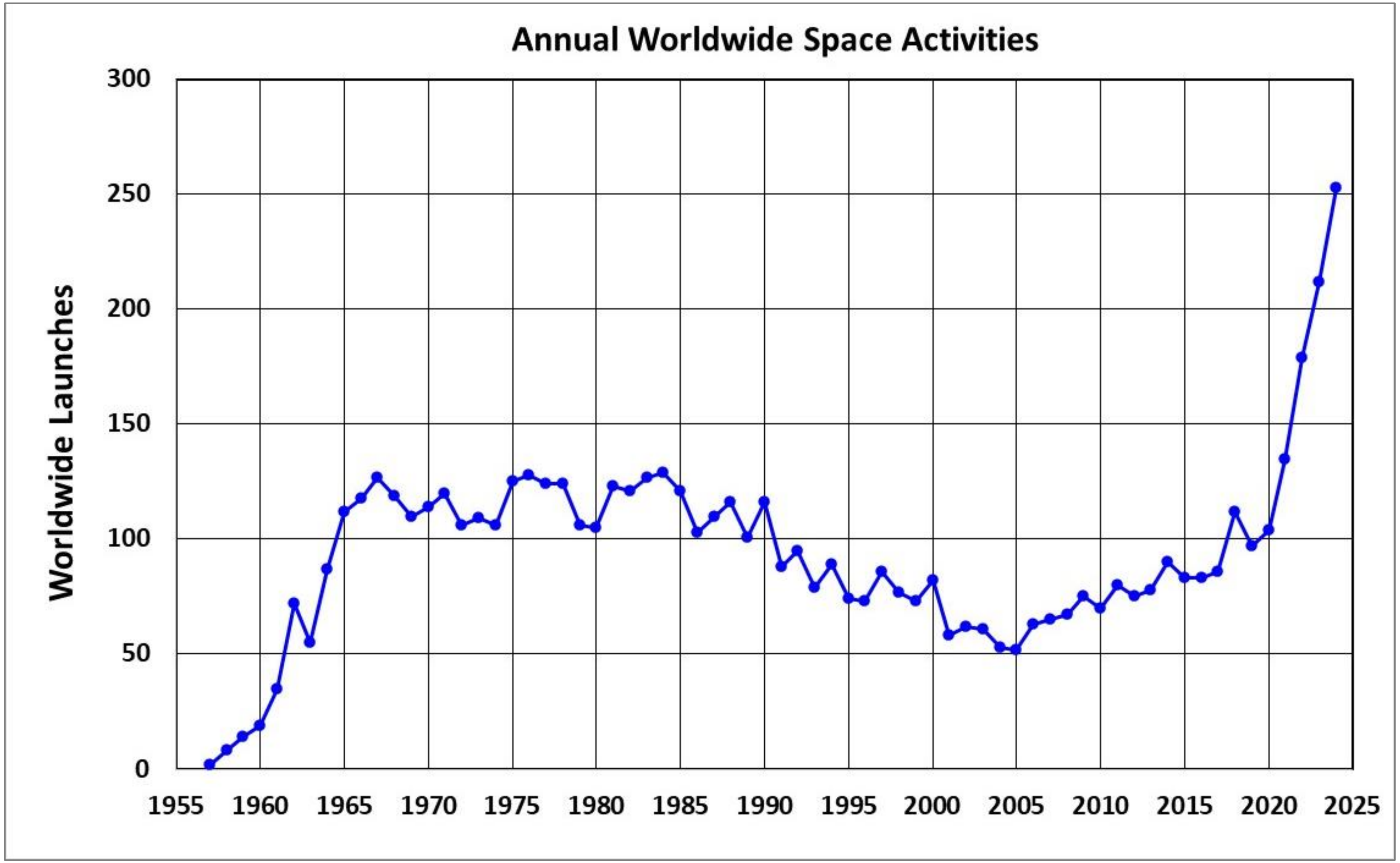
- **Challenges for the Small Satellite Community**
  - Proliferation of CubeSats
  - Large Constellations

What is Orbital Debris?

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

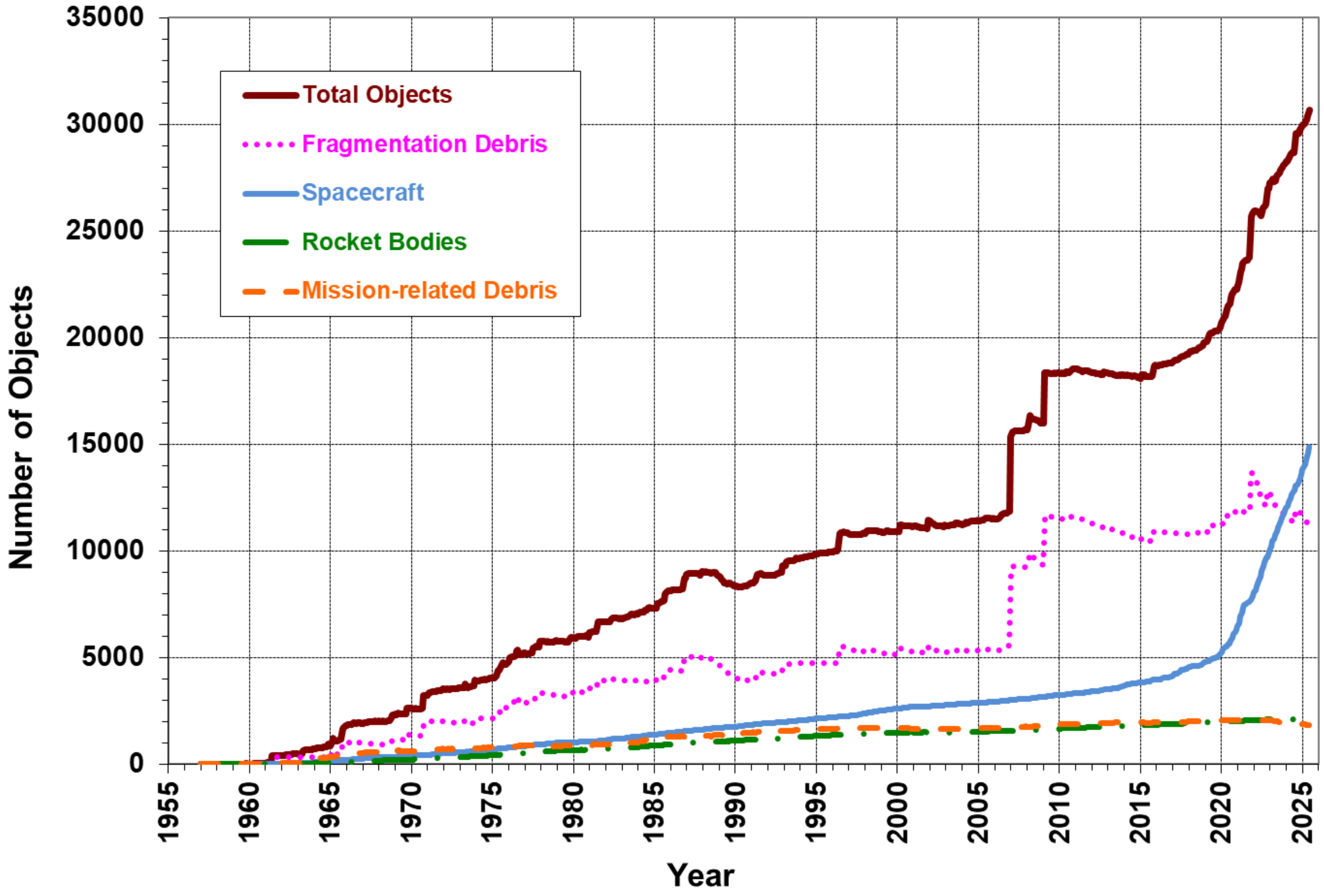


Worldwide Space Activity in 2024



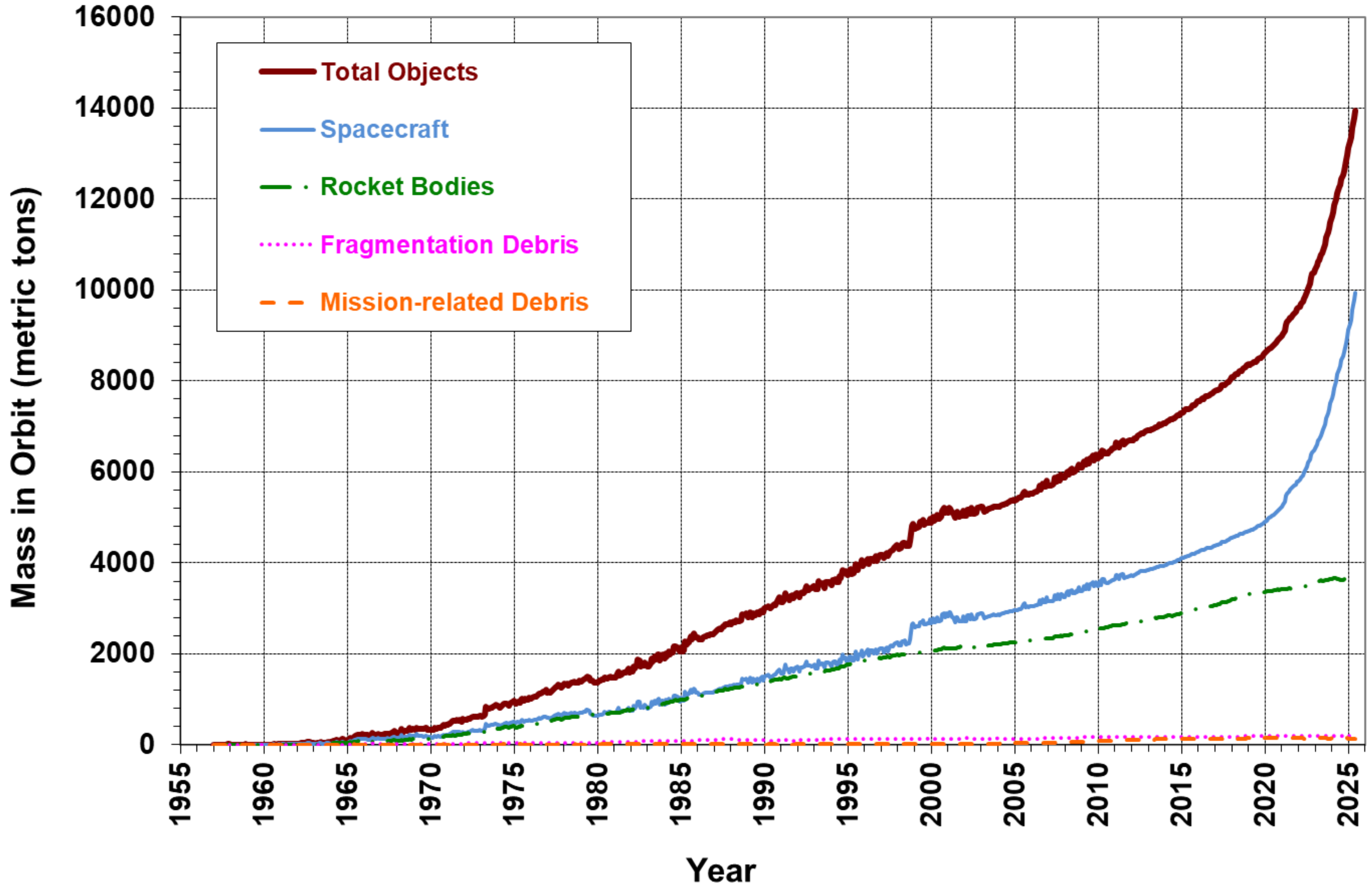
- **The year 2024 set another record of global space activities with more than 250 launches**
  - Close to 2500 spacecraft were deployed to the near-Earth space environment, from low Earth orbit (LEO) to Geosynchronous orbit (GEO)

Growth of the Cataloged Population



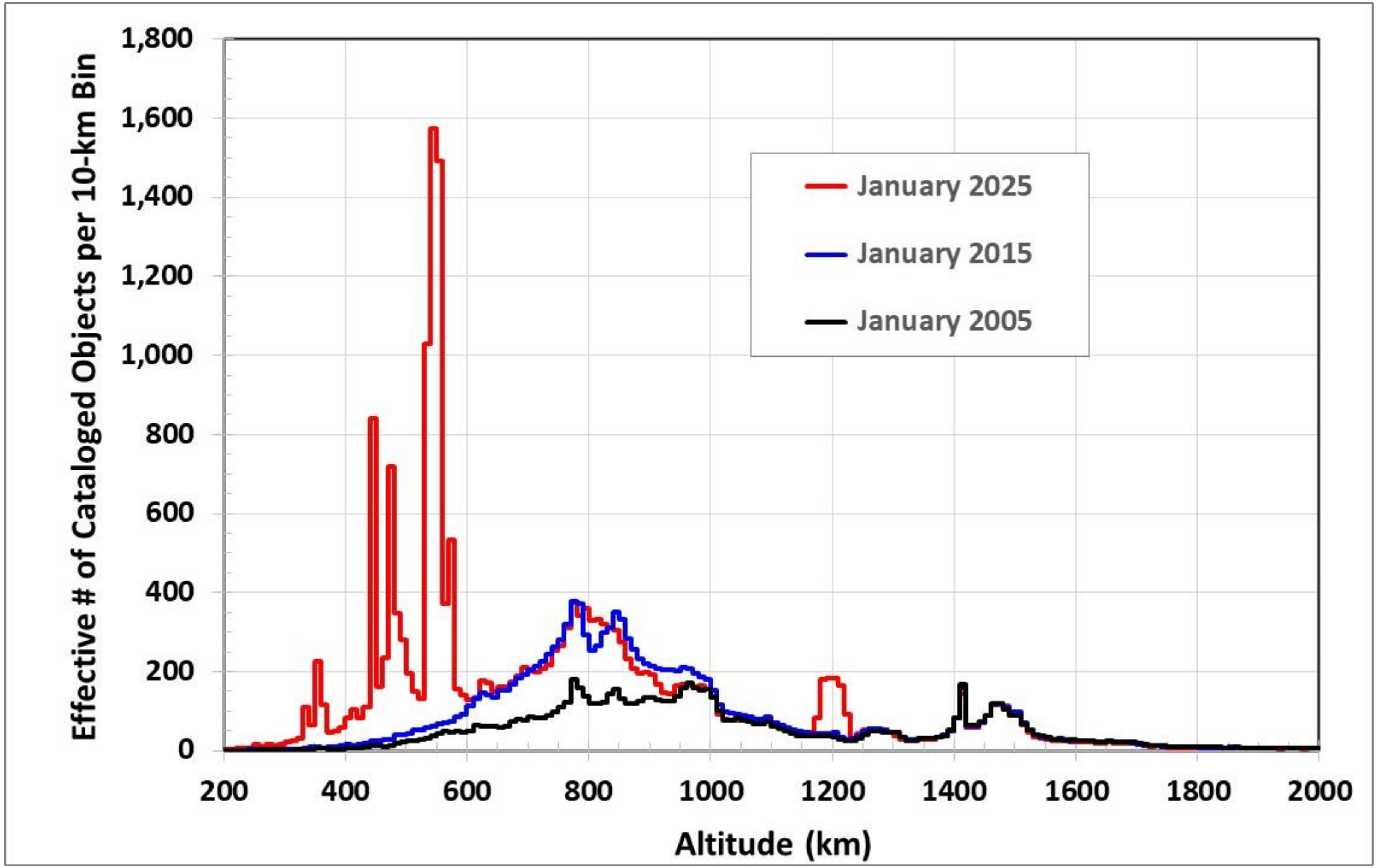
- **The cataloged objects continued to increase**
  - Spacecraft, including ~12,400 active and 2,500 defunct, have significantly surpassed fragmentation debris.
  - The rapid increase in spacecraft is due to CubeSats and large constellations.
  - Many more debris too small to be cataloged exist in the environment. Mission-ending risk is driven by such small debris.

Mass in Orbit



- **The mass in orbit also continued to increase**
  - The total mass in orbit is approaching 14,000 metric tons
  - The mass was dominated by spacecraft (~71% of the total) and rocket bodies (~26% of the total)
  - More than half of the mass was concentrated in LEO

Changes in LEO Environment: 2005 to 2025



- **The landscape of the LEO environment has dramatically changed over the past two decades**
- **Changes below 1000 km altitude were driven by**
  - 2005 to 2015: two major breakup events (FY-1C, I33-K2251)
  - 2015 to 2025: proliferation of CubeSats and the deployments of large constellations

How Much Junk is Currently up There?

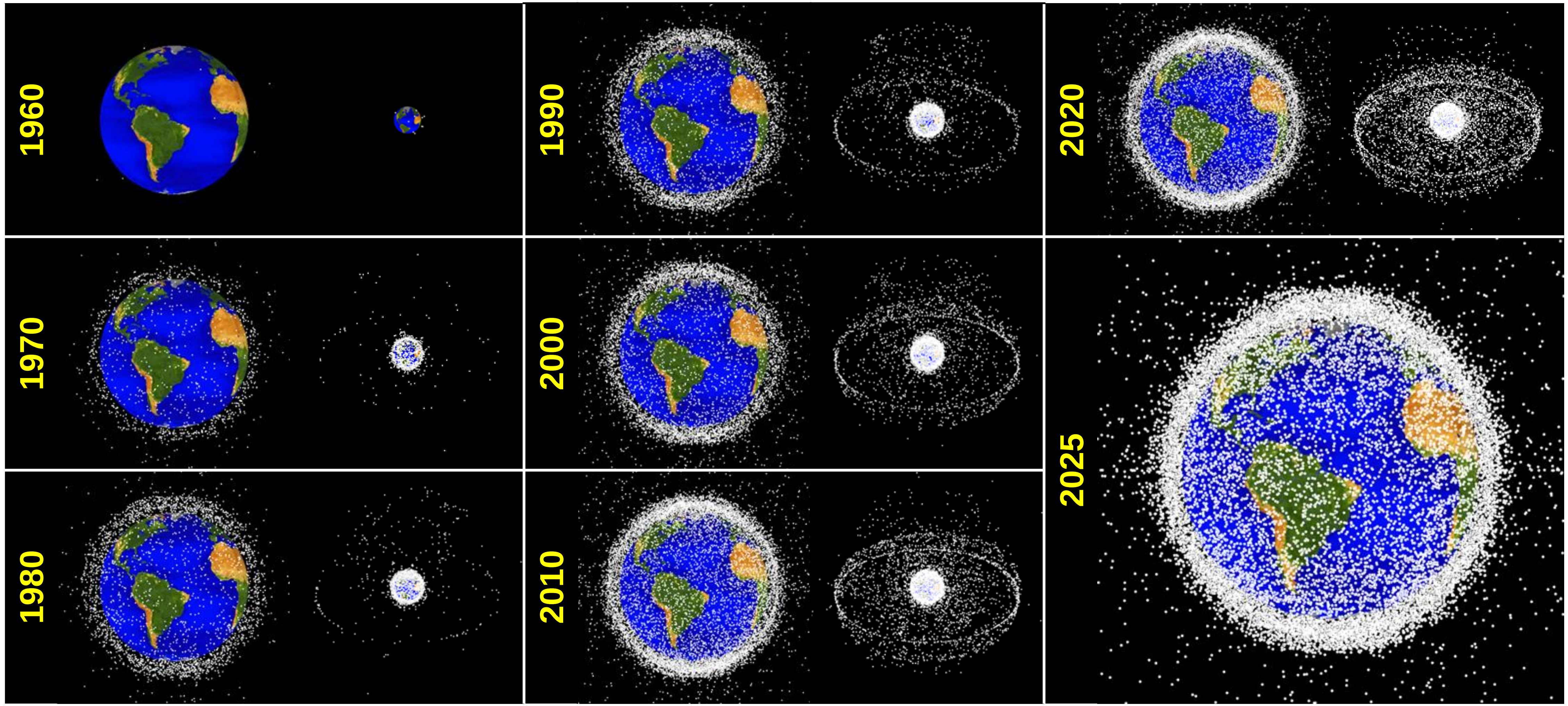
Softball size or larger (≥10 cm): >30,000
(tracked by the U.S. Space Surveillance Network, SSN)

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

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

- **Due to high impact speeds in space (~10 km/s in LEO), even sub-millimeter debris pose a realistic threat to human spaceflight and robotic missions**
  - **7 km/sec = 25,200 km/hr; 10 km/sec = 36,000 km/hr**
  - **1-cm Al sphere @ 10 km/s = 200 kg safe @ 90 mph**
  - **5-mm Al sphere @ 7 km/sec could penetrate a 2.54 cm thick Al wall**
- **Total mass: ~11,500 tons LEO-to-GEO (~6000 tons in LEO)**

The Near-Earth Environment



- **Only objects in the U.S. satellite catalog (~10 cm and larger) are shown**
- **Sizes of the dots are not to scale**

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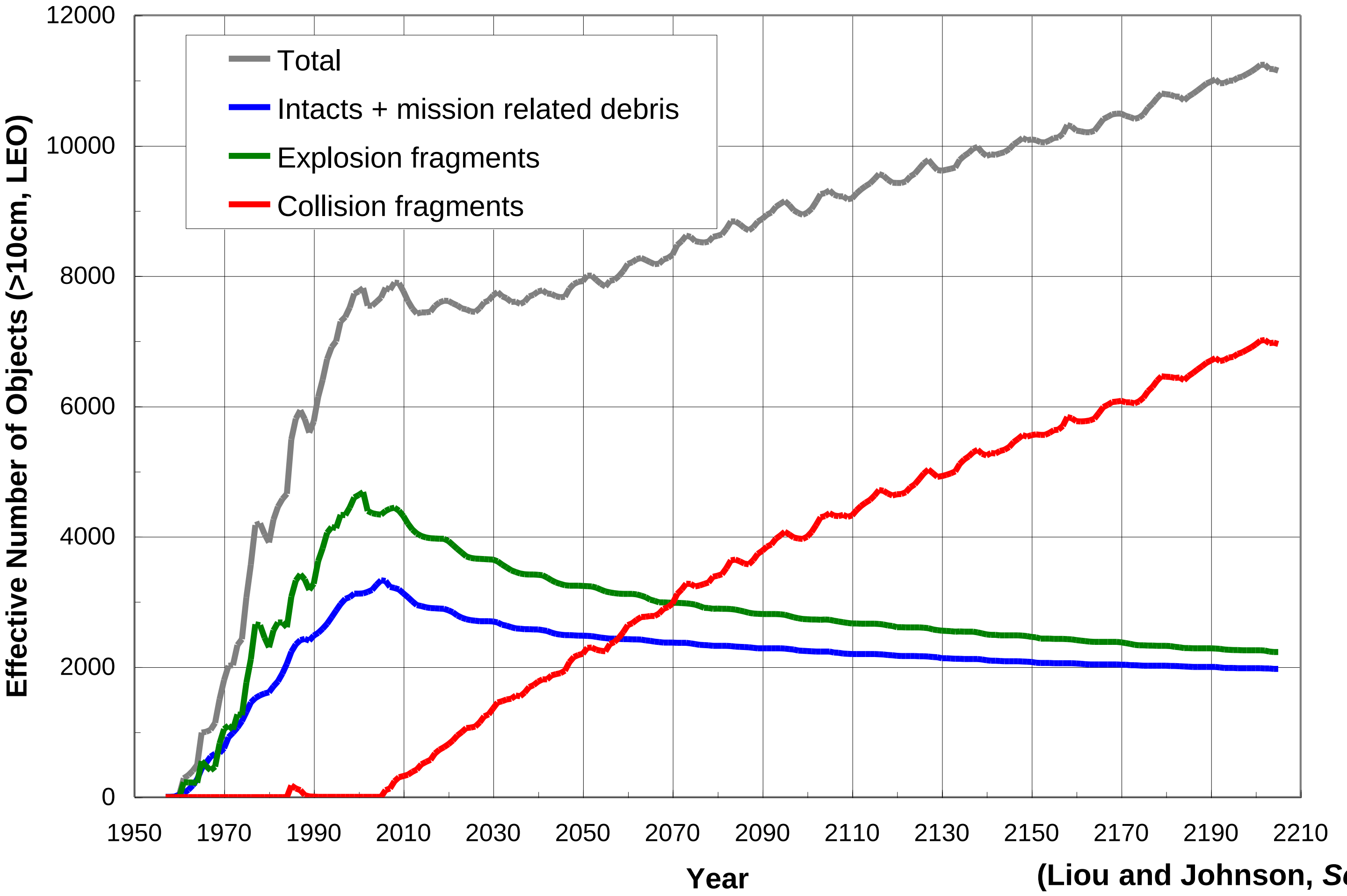
LEO Env Projection – the Best-Case Scenario

(No New Launches Beyond 1/1/2006)



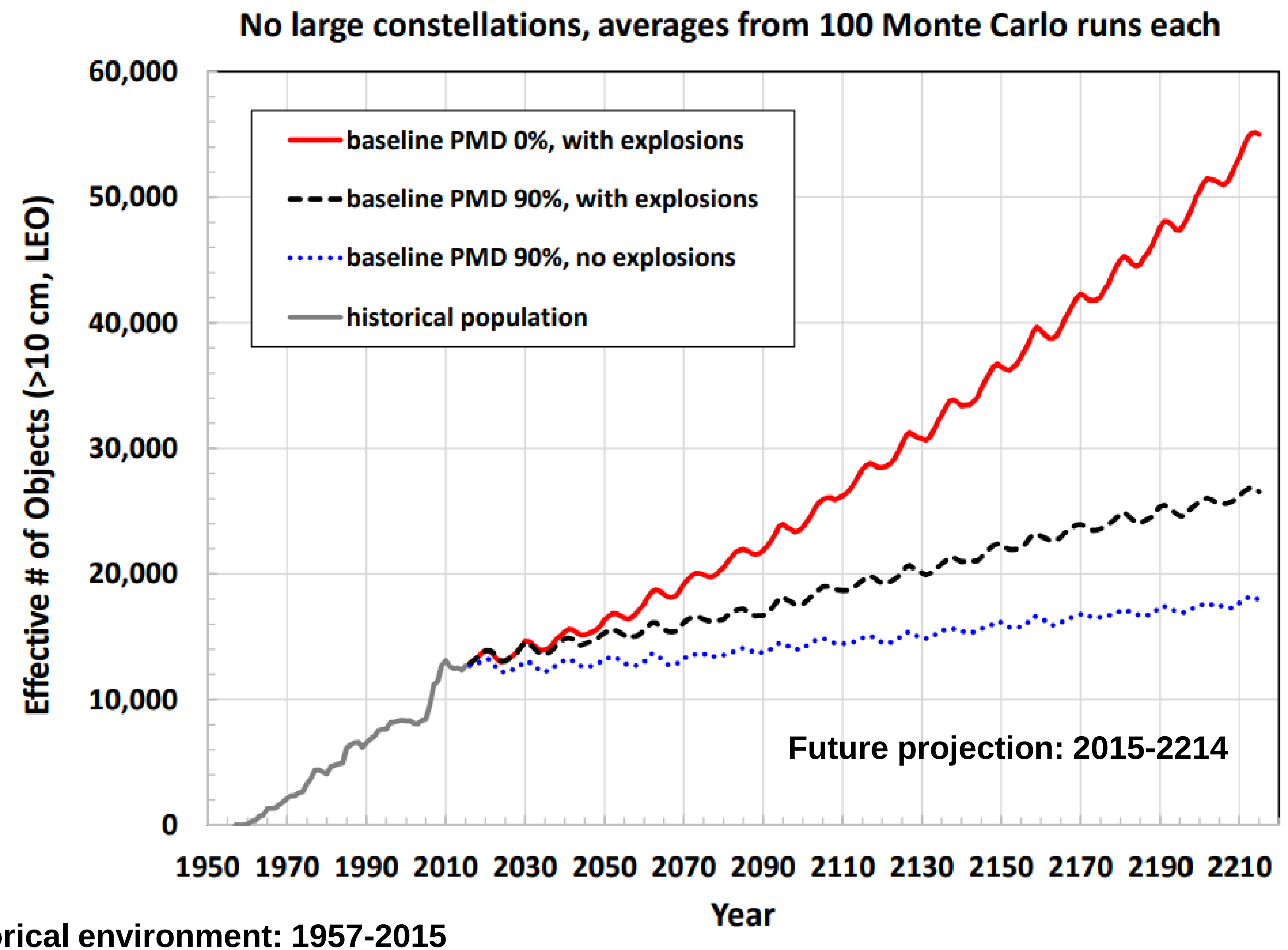
(Liou and Johnson, *Science*, 2006)

- **Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant**
- **Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions**

A Realistic Assessment of LEO Environment

- **In reality, the situation will be worse than the "no new launches" scenario because global space activities will continue.**
- **Post-mission disposal (such as a 25-year decay rule) will help but will be insufficient to prevent the self-generating phenomenon from happening.**
- **To preserve the near-Earth space for future generations, remediation measures, such as Active Debris Removal (ADR), must be considered.**

Projected LEO Population Growth



Historical environment: 1957-2015

Orbital Debris Environment Management

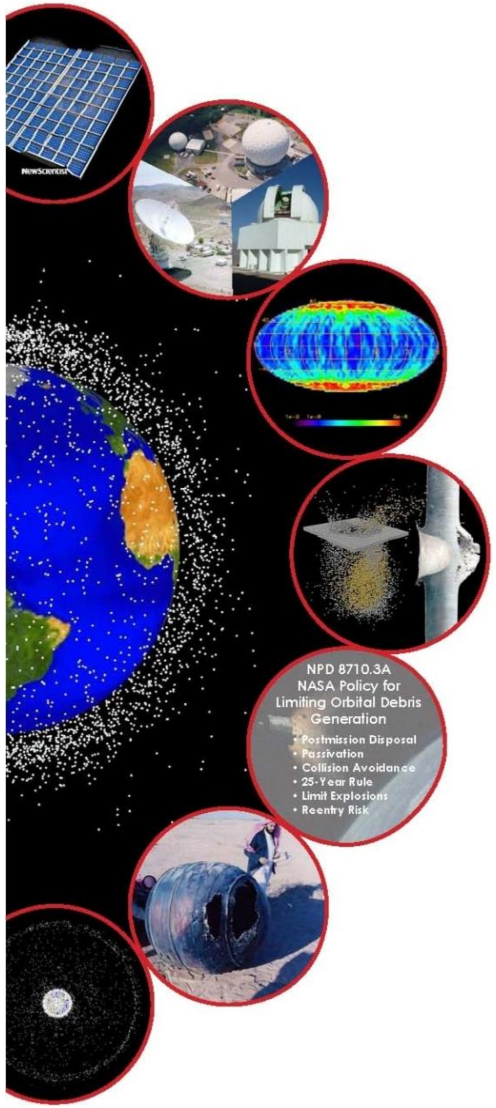
- **“Prevention is better than cure”**
  - (*Prov*.) It is better to try to keep a bad thing from happening than it is to fix the bad thing once it has happened
- **“An ounce of prevention is worth a pound of cure”**
  - (*Prov*.) It is better/cheaper to stop something bad happening than it is to deal with it after it has happened

- **Orbital Debris Mitigation = Prevention**
- **Orbital Debris Remediation = Cure**

- **The global space community must comply with existing mitigation guidelines/requirements and develop long-term remediation strategies to preserve the near-Earth space environment for future generations**

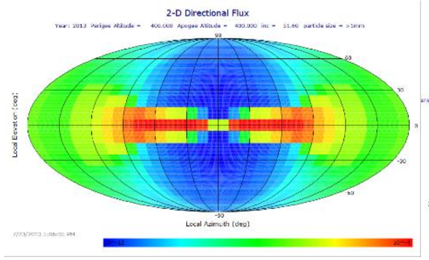
The NASA Orbital Debris Program Office

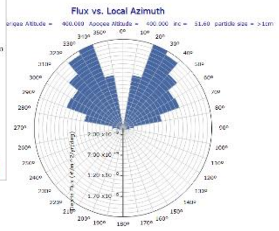
NASA's Orbital Debris Research Program

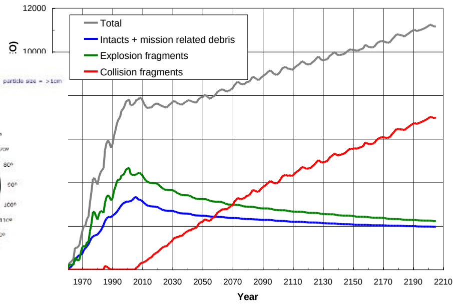


- **The NASA Orbital Debris Program Office (ODPO) is the only organization in the US Government conducting a full range of research on orbital debris**
  - This unique NASA capability was established at JSC in 1979 (D. Kessler, B. Cour-Palais, H. Zook, etc.)
  - ODPO's roles and responsibilities are defined in NPD8700.1 and NPR 8715.6B
  - ODPO is currently funded through HQ/Office of Safety and Mission Assurance (OSMA)
- **Provide technical and policy level support to NASA HQ, Office of Science and Technology Policy (OSTP), other U.S. Government agencies and the commercial sector**
- **ODPO represents the U.S. Government in international fora, including the United Nations and the Inter-Agency Space Debris Coordination Committee (IADC)**
- **Recognized as world leader in environment definition and modeling and in mitigation policy development**

End-to-End Orbital Debris Activities at ODPO







Measurements
Radar
Optical
In situ
Laboratory

→

Modeling
Breakup
Engineering
Evolutionary
Reentry

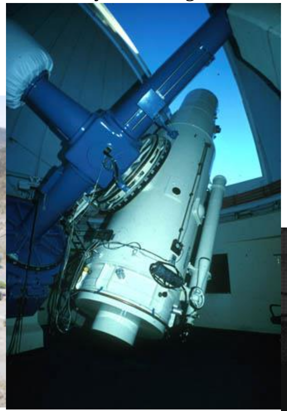
→

Environment Management
Mitigation
Remediation
Policy
Mission Compliance

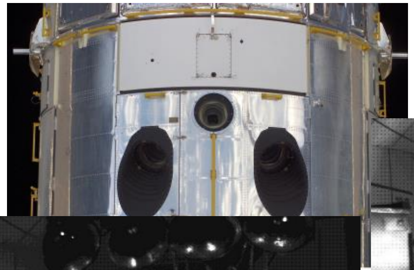
Coordination
U.S. Government
IADC
United Nations

Risk Assessment
Space assets
(ISS, Orion, etc)
Reentry

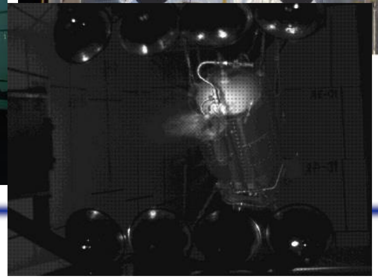
Credit: NASA JPL

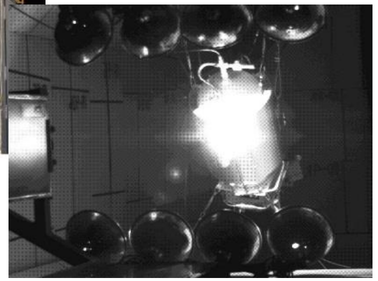


Credit: Patrick Seitzer, University of Michigan



Credit: NASA





Credit: The Aerospace Corporation

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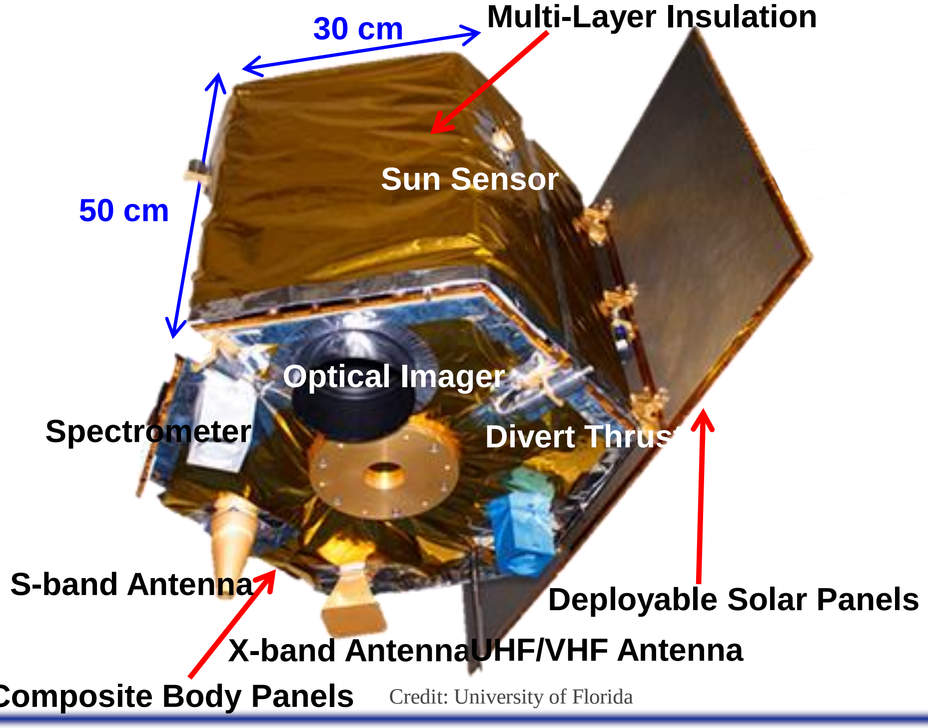
NASA Mission Requirements on Orbital Debris

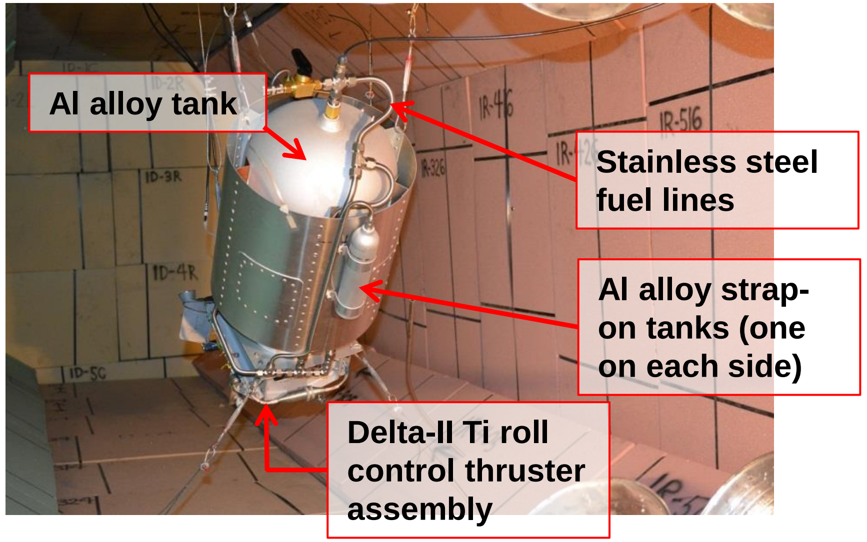
- **NASA was the first organization to lead the development of orbital debris mitigation measures in the 1990s.**
- **NASA and DoD led the effort to establish the 2001 U.S. Government Orbital Debris Mitigation Standard Practices and update them in 2019.**
  - The U.S. National Space Policies of 2006, 2010, and 2020 direct agencies and departments to implement the Standard Practices.
- **U.S. has endorsed the United Nations' Orbital Debris Mitigation Guidelines.**
- **In compliance with the above, NASA has established NPR 8715.6E, *NASA Procedural Requirements for Limiting Orbital Debris*, and NS 8719.14C, *Process for Limiting Orbital Debris* for NASA missions.**
  - Formal Orbital Debris Assessment Reports (ODARs) are due to NASA HQ in conjunction with the PDR and CDR milestones.

Lab-based Satellite Impact Experiments

- The "DebriSat" project is a collaboration among NASA, the U.S. Air Force, The Aerospace Corporation, and the University of Florida for laboratory-based hypervelocity impact experiments on a representative, modern LEO satellite and an upper stage mockup.
- The objective is to characterize the physical properties of impact fragments to improve satellite breakup models and space situational awareness.



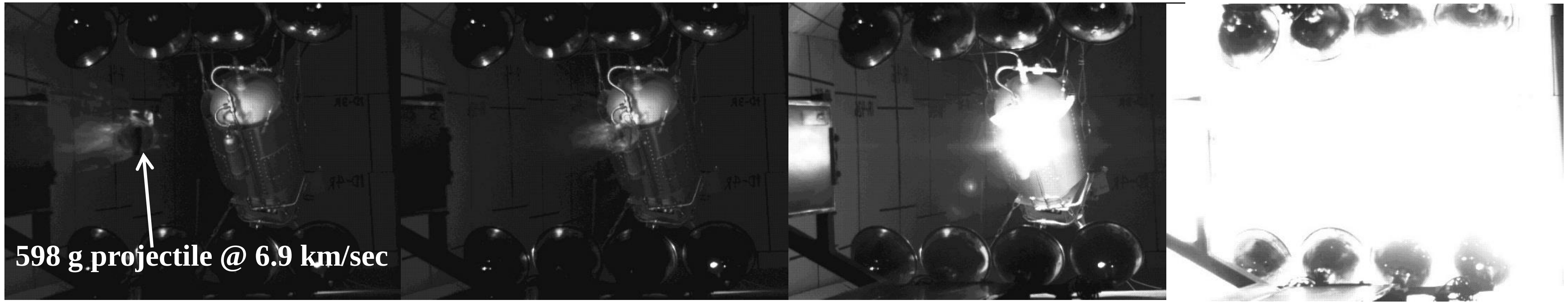
Credit: University of Florida



Credit: Aerospace Corporation

Hypervelocity Impact Sequences

- **Hypervelocity impacts of the two targets were successfully carried out at the Arnold Engineering Development Complex in April 2014.**
- **Fragment processing and measurements are currently underway.**

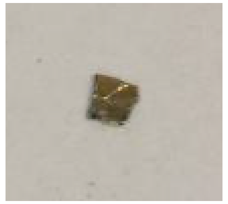


Credit: Arnold Engineering Development Complex/Air Force.

Credit: Arnold Engineering Development Complex/Air Force.

DebriSat Counts

- We ***expected*** ~85,000 fragments >= 2mm
- We have ***collected*** >324,000 fragments
- We have actually ***characterized/measured*** ~67,000
- We now ***estimate*** >400,000 fragments (>500%)
- We’re still counting and measuring



- DebrisLV (the simulated launch vehicle) is expected to have produced only ~35K fragments since its construction lacked carbon fiber and much wiring

HUSIR Overview

- **Monostatic radar**
- **OD data collection uses pulsed continuous wave (CW) signal at X-band**
- **Historical sensitivity ~5.5 mm at 1000 km**
- **Provides majority of small OD data in LEO**
  - 400-500 hours of data each FY
  - Collect ~2/3 of data at 75° elevation, 90° azimuth (75E), ~1/3 of data split between 20° and 10° elevation, 180° azimuth (20S, 10S)

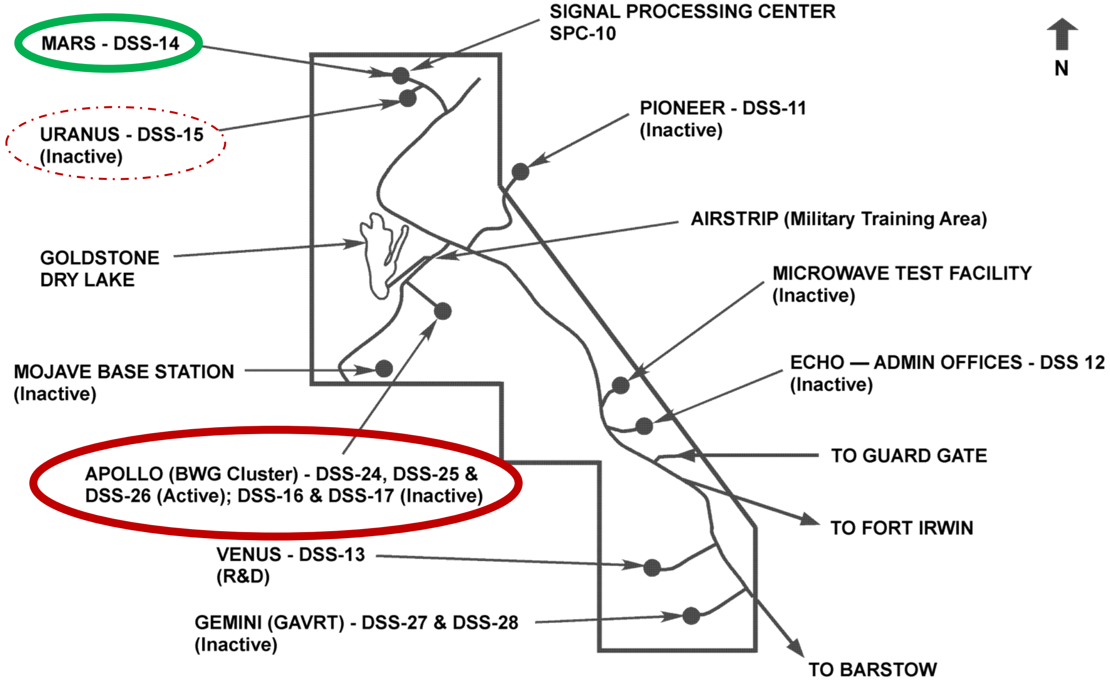
Credit: Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts

Operating Parameter	Nominal Value
Peak Transmit Power	250 kW
Transmit Frequency	10.1 GHz
Wavelength	3.0 cm
Antenna Diameter	36.6 m
Beamwidth	0.058°
Sensitivity*	59.2 dB

***Defined as the single pulse SNR for a 1 m^2 object (RCS) at 1000 km**

Goldstone Overview

Credit: NASA/JPL-Caltech



Operating Parameter	Nominal Value
Peak Transmit Power	440 kW
Transmit Frequency	8.56 GHz
Wavelength	3.5 cm
Antenna Diameter	70 m (transmitter) 34 m (receiver)
Beamwidth	0.03° (transmitter) 0.06° (receiver)

- **Bistatic radar**
- **Linear frequency modulated (LFM) waveform or chirp**
  - New sawtooth waveform in development to improve sensitivity
- **6 pointings to cover altitudes of interest from 430-975 km altitude**
  - Provides coverage down to <2 mm at lowest altitudes
- **As of FY 2023, ~290 hours of data each year**

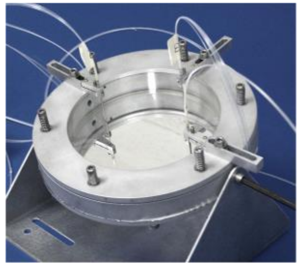
ES-MCAT Overview

- **Eugene Stansbery Meter Class Autonomous Telescope (ES-MCAT)**
  - Located on the U.S. Space Force base on Ascension Island (Space Launch Delta 45, Detachment 2 near the Ascension Auxiliary Air Field)
    - 7° 58’ S, 14° 24’ W, 350’ El
  - 1.3-m, f/4, DFM Engineering fast-tracking optical telescope paired with an Observa-Dome fast-tracking dome
    - Accommodates tracking debris at all orbital altitudes
  - 4096 by 4096-pixel CCD camera
  - Field of View: 0.68° x 0.68°, 0.96° diagonal
  - Fully autonomous operations
  - Coverage down to ~30 cm objects in GEO
- **Mission milestones:**
  - First light in 2015
  - Full operational capability in 2021
  - GEO surveys completed 2020-2022 and 2023-2025

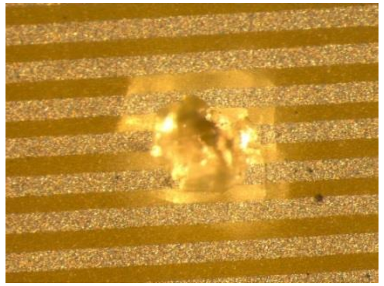
Credit: Ben Hanna

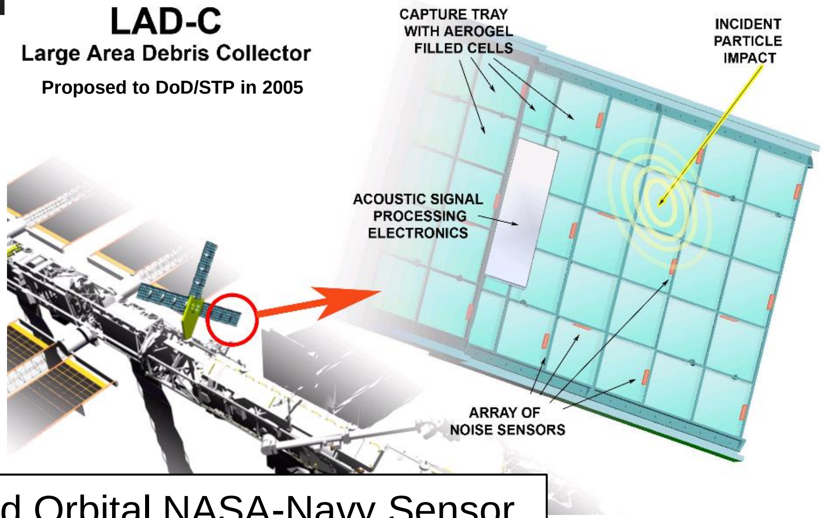
ODPO's *In situ* Measurement Technology Development

- **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





***2003-2005: SMD PIDD award**
***2009-2012: SMD/ESMD LASER award**

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

MACS = Multilayer Acoustic & Conductive Grid Sensor

Questions?

Objective of Orbital Debris Mitigation

- **Objective of Orbital Debris Mitigation:**

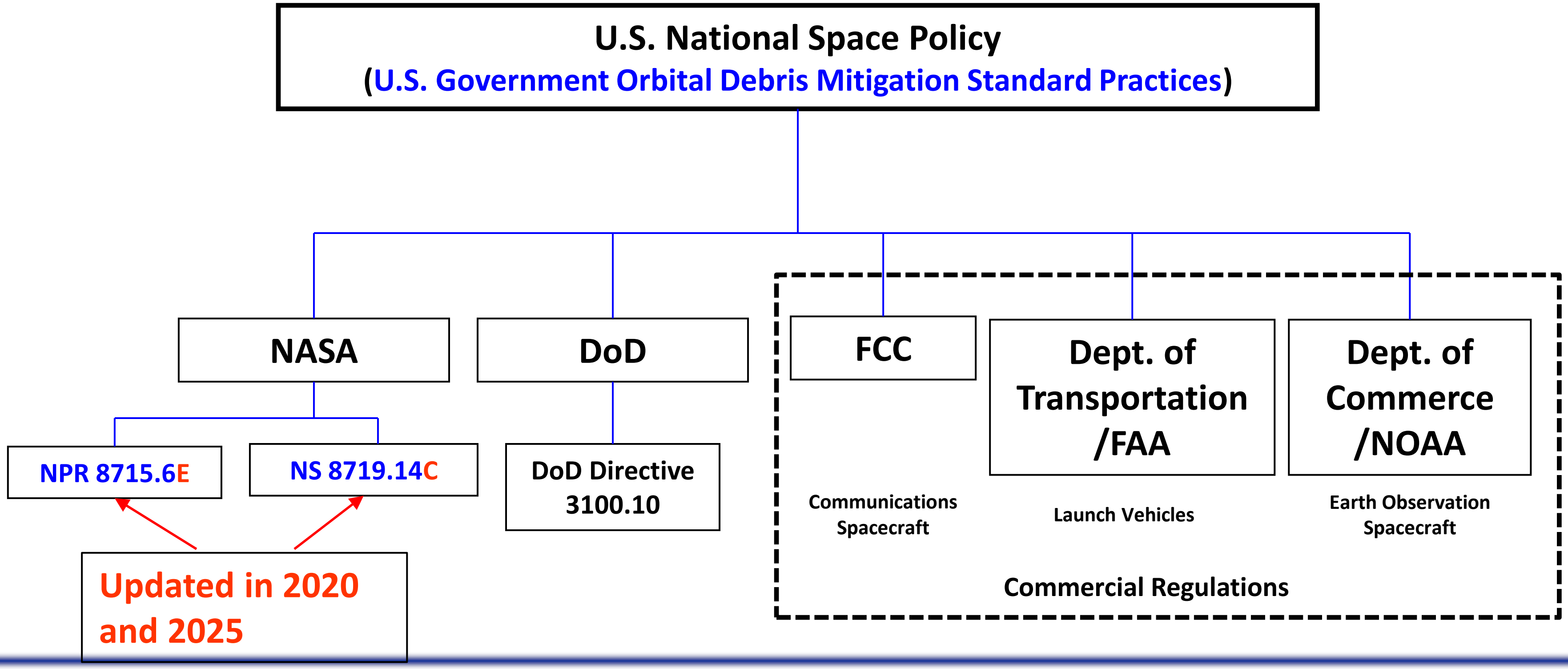
→ **To prevent the generation of new and long-lived orbital debris in the environment**

NASA and USG Orbital Debris Mitigation

- **NASA was the first organization to develop orbital debris mitigation policy and guidelines in the 1990s.**
  - NASA Management Instruction (NMI) 1700.8 "*Policy for Limiting Orbital Debris Generation*" was established in 1993.
  - NASA Safety Standard (NSS) 1740.14 "*Guidelines and Assessment Procedures for Limiting Orbital Debris*" established the first detailed set of mitigation guidelines for NASA missions in 1995.
- **NASA and DoD led the effort to establish the U.S. Government Orbital Debris Mitigation Standard Practices (approved in 2001) and update them in 2019.**
- **The U.S. National Space Policy of 2006, 2010, and 2020 direct agencies and departments to implement the U.S. Government Orbital Debris Mitigation Standard Practices.**

U.S. Orbital Debris Mitigation Policies

- All current U.S. government requirements and commercial regulations for orbital debris mitigation are derived from the 2001 U.S. Government Orbital Debris Mitigation Standard Practices and the 2019 update, which are cited in U.S. National Space Policy in 2006, 2010, and 2020.



USG OD Mitigation Standard Practices, Objective 1

- **Eliminate or minimize mission-related debris**
- **Limit the orbital lifetime of such debris to 25 years**

OBJECTIVE

1. CONTROL OF DEBRIS RELEASED DURING NORMAL OPERATIONS

Programs and projects will assess and limit the amount of debris released in a planned manner during normal operations. Objects with planned functions after release should follow standard practices set forth in Objectives 2 through 5.

MITIGATION STANDARD PRACTICES

1-1. ***In all operational orbit regimes***: Spacecraft and upper stages should be designed to eliminate or minimize debris released during normal operations. Each instance of planned release of debris larger than 5 mm in any dimension that remains on orbit for more than 25 years should be evaluated and justified. For all planned released debris larger than 5 mm in any dimension, the total debris object-time product in low Earth orbit (LEO) should be less than 100 object-years per upper stage or per spacecraft. The total object-time product in LEO is the sum, over all planned released objects, of the orbit dwell time in LEO.

USG OD Mitigation Standard Practices, Objective 2

- **Use design and procedures to avoid accidental explosions during mission operations and after disposal (passivation)**

OBJECTIVE

2. MINIMIZING DEBRIS GENERATED BY ACCIDENTAL EXPLOSIONS

Programs and projects will assess and limit the probability of accidental explosion during and after completion of mission operations.

MITIGATION STANDARD PRACTICES

2-1. ***Limiting the risk to other space systems from accidental explosions and associated orbital debris during mission operations***: In developing the design of a spacecraft or upper stage, each program should demonstrate, via commonly accepted engineering and probability assessment methods, that the integrated probability of debris-generating explosions for all credible failure modes of each spacecraft and upper stage (excluding small particle impacts) is less than 0.001 (1 in 1,000) during deployment and mission operations.

2-2. ***Limiting the risk to other space systems from accidental explosions and associated orbital debris after completion of mission operations***: All on-board sources of stored energy of a spacecraft or upper stage should be depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as such an operation does not pose an unacceptable risk to the payload. […]

USG OD Mitigation Standard Practices, Objective 3

- **Avoid collisions with large debris and protect against collisions with small debris**

OBJECTIVE

3. SELECTION OF SAFE FLIGHT PROFILE AND OPERATIONAL CONFIGURATION

Programs and projects will assess and limit the probability of operating space systems becoming a source of debris by collisions with human-made objects or meteoroids.

MITIGATION STANDARD PRACTICES

3-1. ***Collision with large objects during orbital lifetime***: In developing the design and mission profile for a spacecraft or upper stage, a program will estimate and limit the probability of collision with objects 10 cm and larger during orbital lifetime to less than 0.001 (1 in 1,000). For the purpose of this assessment, 100 years is used as the maximum orbital lifetime.

3-2. ***Collision with small debris during mission operations***: Spacecraft design will consider and limit the probability to less than 0.01 (1 in 100) that collisions with micrometeoroids and orbital debris smaller than 1 cm will cause damage that prevents planned postmission disposal.

USG OD Mitigation Standard Practices, Objective 4

- **Remove structures from orbit or from traffic areas**

OBJECTIVE

4. POSTMISSION DISPOSAL OF SPACE STRUCTURES

Programs and projects will plan for disposal procedures for a structure (i.e., launch vehicle components, upper stages, spacecraft, and other payloads) at the end of mission life to minimize impact on future space operations.

MITIGATION STANDARD PRACTICES

4-1. ***Disposal for final mission orbits***: A spacecraft or upper stage may be disposed of by one of the following methods:

a. Direct reentry or heliocentric, Earth-escape…
b. Atmospheric reentry…
c. Storage between LEO and GEO…
d. Storage above GEO…
e. Long-term reentry for structures in MEO, Tundra orbits, highly inclined GEO, and other orbits…
f. Direct retrieval…

4-2. ***Reliability of disposal***: The probability of successful postmission disposal should be no less than 0.9 with a goal of 0.99 or better.

USG OD Mitigation Standard Practices, Objective 5

- **Applicability to all missions and special cases**

OBJECTIVE

5. CLARIFICATION AND ADDITIONAL STANDARD PRACTICES FOR CERTAIN CLASSES OF SPACE OPERATIONS

These classes of space operations and structures should follow Objectives 1 through 4 plus the additional standard practices for orbital debris mitigation set forth in this section.

MITIGATION STANDARD PRACTICES

5-1. ***Large Constellations***…
5-2. ***Small satellites, including CubeSats***, should follow the standard practices set forth in Objectives 1 through 4.
5-3. ***Rendezvous, proximity operations, and satellite servicing***: In developing the mission profile for a structure, the program should limit the risk of debris generation as an outcome of the operations. […]
5-4. ***Safety of Active debris removal operations***: In developing the mission profile for an active debris removal operation on a debris structure, the program should limit the risk of debris generation as an outcome of the operation. […]
5-5. ***Tether systems*** will be uniquely analyzed for both intact and severed conditions […]

The 25-year Rule and the Reentry Risks

- **NASA Safety Standard 1740.14 (1995) first established the guideline for all LEO spacecraft and upper stages to remain in orbit for no more than 25 years after end-of-mission to protect the space environment.**
  - This guideline is now accepted by the U.S. Government and many foreign space agencies and international bodies.
- **However, such uncontrolled reentries shift on-orbit satellite collision risks to human casualty risks on Earth.**
  - If a random reentry results in a human casualty risk greater than 1 in 10,000, then a controlled reentry must be conducted to ensure the risk is below the acceptable threshold.

Inter-Agency Space Debris Coordination Committee (IADC)

- **The IADC is an international forum of national and multi-national space agencies for the coordination of activities related to space debris.**
  - IADC members: ASI, CNES, CNSA, CSA, DLR, ESA, ISRO, JAXA, KARI, NASA, ROSCOSMOS, SSAU, and UKSA.
- **More than 100 orbital debris specialists meet annually to exchange information and to work on specified Action Items.**
- **IADC developed first consensus on international orbital debris mitigation guidelines in October 2002; subsequently submitted to the United Nations.**

Orbital Debris Mitigation for Small Satellites

- **Small satellites are subject to current orbital debris mitigation policy, guidelines, and requirements.**
  - The NASA Procedural Requirements for Limiting Orbital Debris, the FCC debris mitigation regulations, the U.S. Government Orbital Debris Mitigation Standard Practices, the IADC Space Debris Mitigation Guidelines, and the UN Space Debris Mitigation Guidelines have no automatic exclusions for any satellite due to its size or mass limit.
  - Key requirements include: limit accidental explosions, limit accidental collisions with large objects, follow post-mission disposal, and limit reentry casualty risk.
  - NASA's Debris Assessment Software (DAS) is freely available and provides validation of a spacecraft's design and mission plan against all US Government Mitigation Guidelines and NASA Requirements.
    - Entry survivability safety, if showing excessive ground risk in DAS, can be assessed in the higher-fidelity Object Reentry Survival Analysis Tool (ORSAT)
      - via reimbursable Space Act Agreement with ODPO
      - Not expected for most smallsats

Introduction to DAS

- **The NASA Debris Assessment Software (DAS) is a set of custom tools designed to assist space programs and projects in preparing orbital debris assessment reports.**
  - Assessment requirements are described in NSS 8719.14C, "Process for Limiting Orbital Debris"
  - DAS addresses most requirements point-by-point
  - Referenced in FCC Regulations as method to assess compliance
  - Widely used by satellite designers around the world as a method to assess compliance with general orbital debris mitigation guidelines

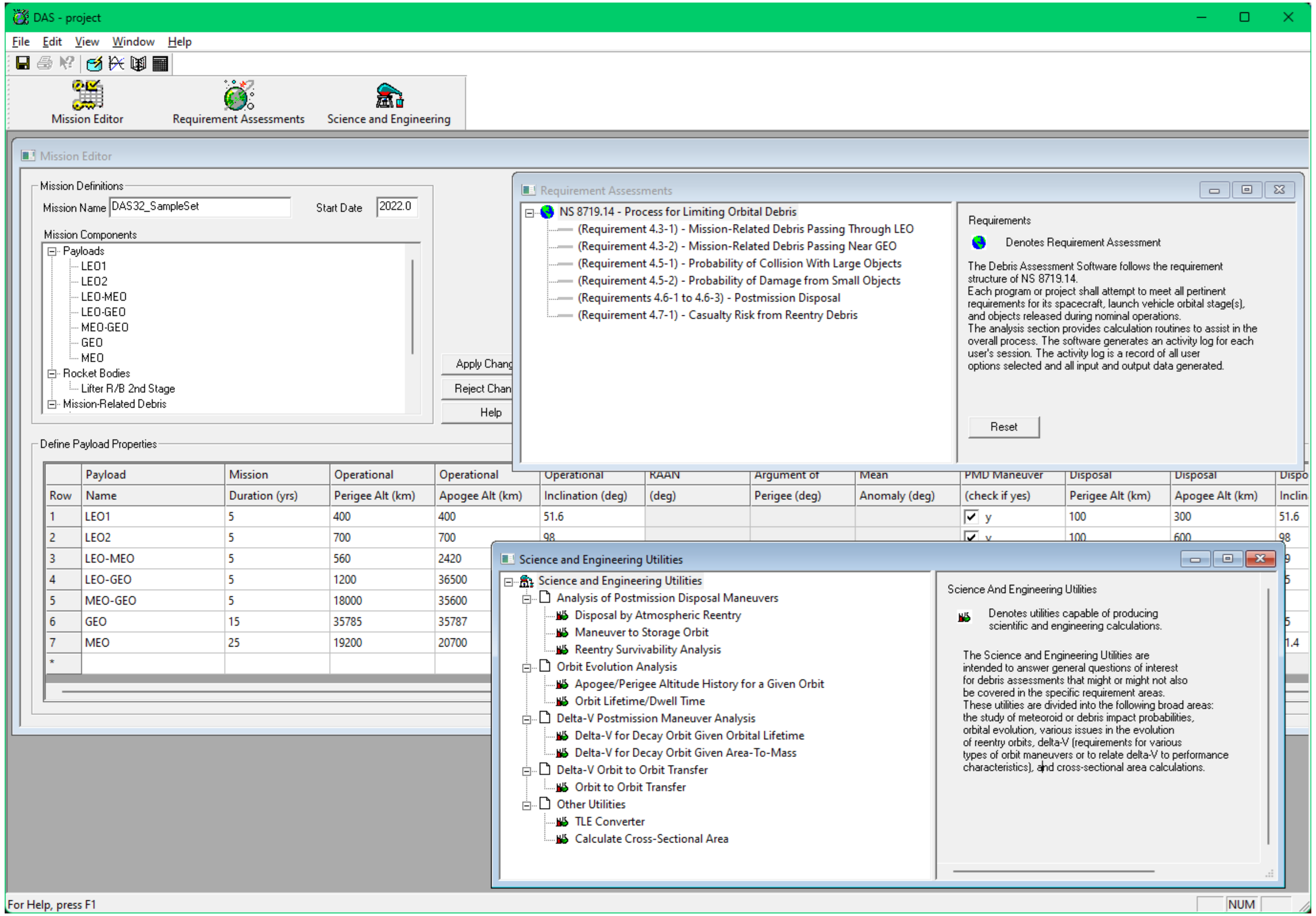
- Request software (with User Agreement) and download reference materials at:

https://www.orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html

https://software.nasa.gov/software/MSC-26690-1

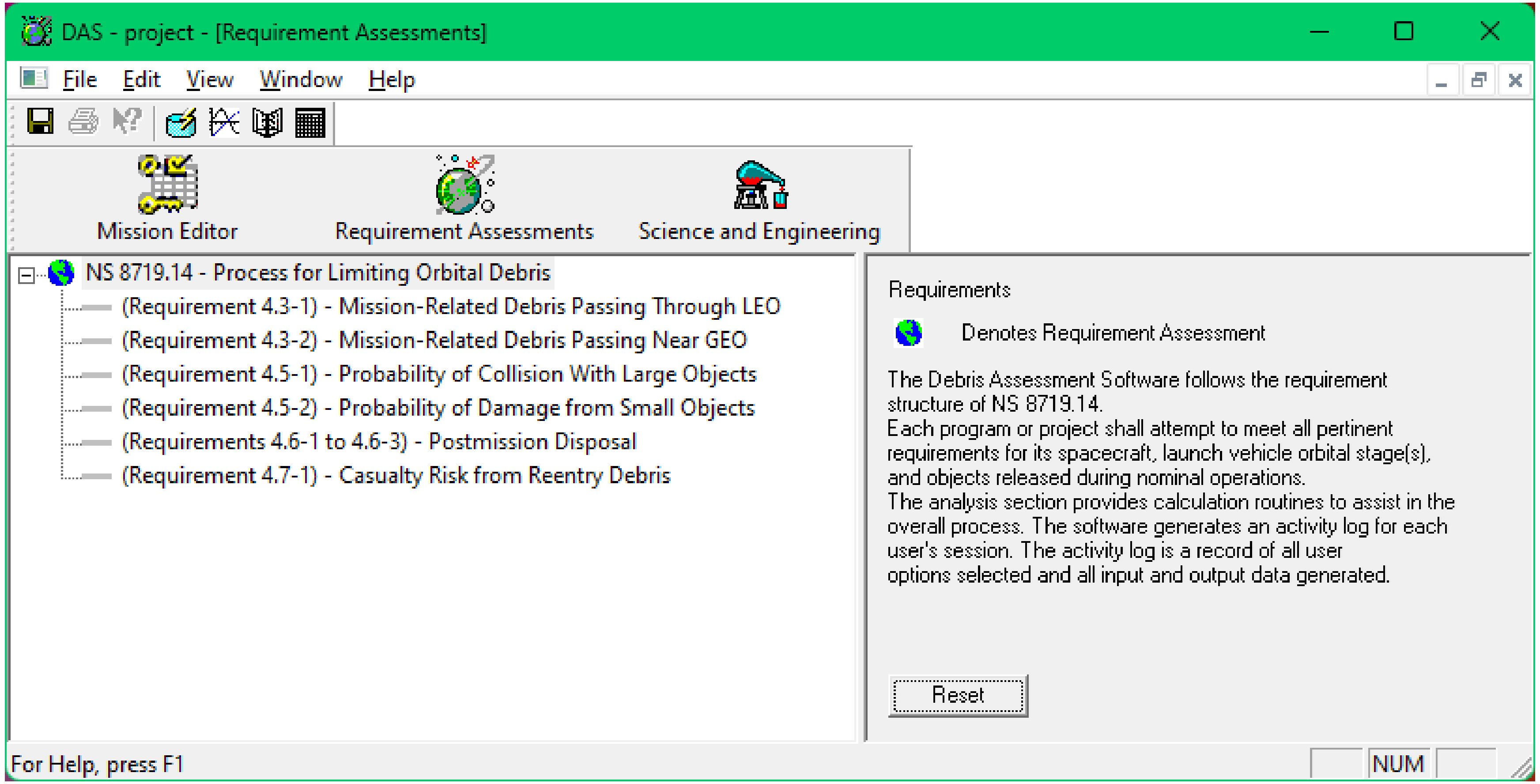
DAS User Interface

The DAS top-level window, and three main dialog windows



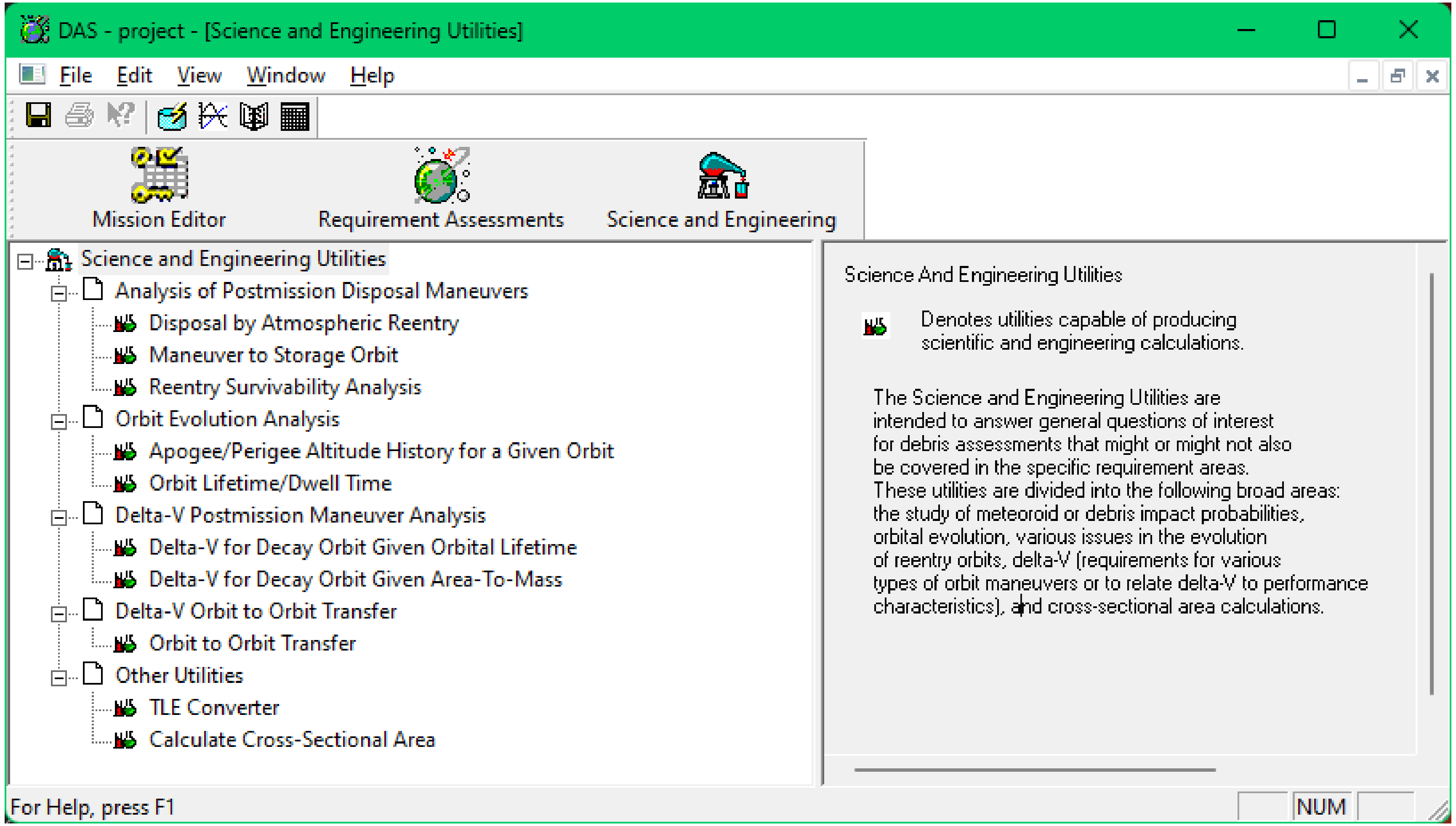
GUI: Requirement Assessments

The user may assess the mission's compliance with each requirement



GUI: Science and Engineering Utilities

These utilities allow the user to explore options in mission design and to perform other supporting calculations



Summary

- **DAS is the standard method of assessing compliance with NASA's space debris mitigation requirements (NS 8719.14).**
  - DAS provides point-by-point assessment of a mission's compliance with NASA's requirements.
  - Results from DAS may be included in reports to NASA as well as other regulating agencies
  - DAS provides additional tools for mission-planning and input conversion.
  - Inconclusive DAS Reentry results (>1:10000 risk) necessitate ORSAT analysis by ODPO
- **The modular internal structure of the software allows for easy updates (such as to the debris environment model or the human population density) in the future. Solar activity forecasts are updated quarterly.**
- **Software and documentation are available on the NASA Orbital Debris Program Office's internet site:**

https://www.orbitaldebris.jsc.nasa.gov/mitigation/das.html

New and Unique Challenges for Small Satellites

- **The ongoing deployment of large constellations and continued increased launch rate of small satellites present several new and unique challenges to the space environment and to other operational spacecraft.**
  - Increased collision risks to other operational spacecraft if the small satellites, especially CubeSats and smaller, cannot be tracked and cannot maneuver.
  - Increased collision risks to further debris population growth.
    - Adding many more smallsats to the environment on a regular basis will increase collision probability in the environment.
  - Collective reentry human casualty risks.
  - Increased debris-generating chain reaction potential at the large-constellation mission altitude.

Solutions

- **Compliance with existing OD mitigation guidelines and requirements**
- **Trackability**
  - Follow CSpOC's Recommendations…
- **Reliability**
  - Ensure high mission reliability (spacecraft and formation maintenance) for large constellations.
- **Careful post-mission planning for large constellations**
  - Conduct direct reentry or post-mission disposal in phases.

Questions?

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