National Aeronautics and Space Administration

NASA's Orbital Debris Program Office

Briefing to the NASA Advisory Council

Gene Stansbery
Orbital Debris Program Office

Introduction

- **Introduction**
- **Current Environment**
- **Mitigation**
- **The Case for Remediation**
- **Major Recent & Near-Term Initiatives**
- **Orbital Debris Success Story**

Program Overview & Objectives

- **NASA's Orbital Debris Program Office Goals;**
  - Preserve the space environment, in the area of orbital debris, for the continued safe operation of both robotic and human crewed spacecraft;
  - Raise global awareness of orbital debris issues and effective mitigation strategies, standards, and requirements; and
    - Ensure that US space industry has "level playing field."
- **Orbital Debris Program Office Objectives;**
  - Orbital Debris environmental definition, measuring, monitoring, and projection;
  - Space vehicle risk assessments;
  - Development of operational and design mitigation measures;
  - Support of US and International policies and policy-making activities in close coordination with other US Government agencies, especially the Department of Defense (DoD), the Department of State, the Department of Transportation (DOT), NOAA, and the FCC;
  - Research and Development to support NASA OD safety standards and mitigation activities; and
  - Assistance to all NASA space programs and projects, as well as other space users, both US and International, on OD questions and concerns.

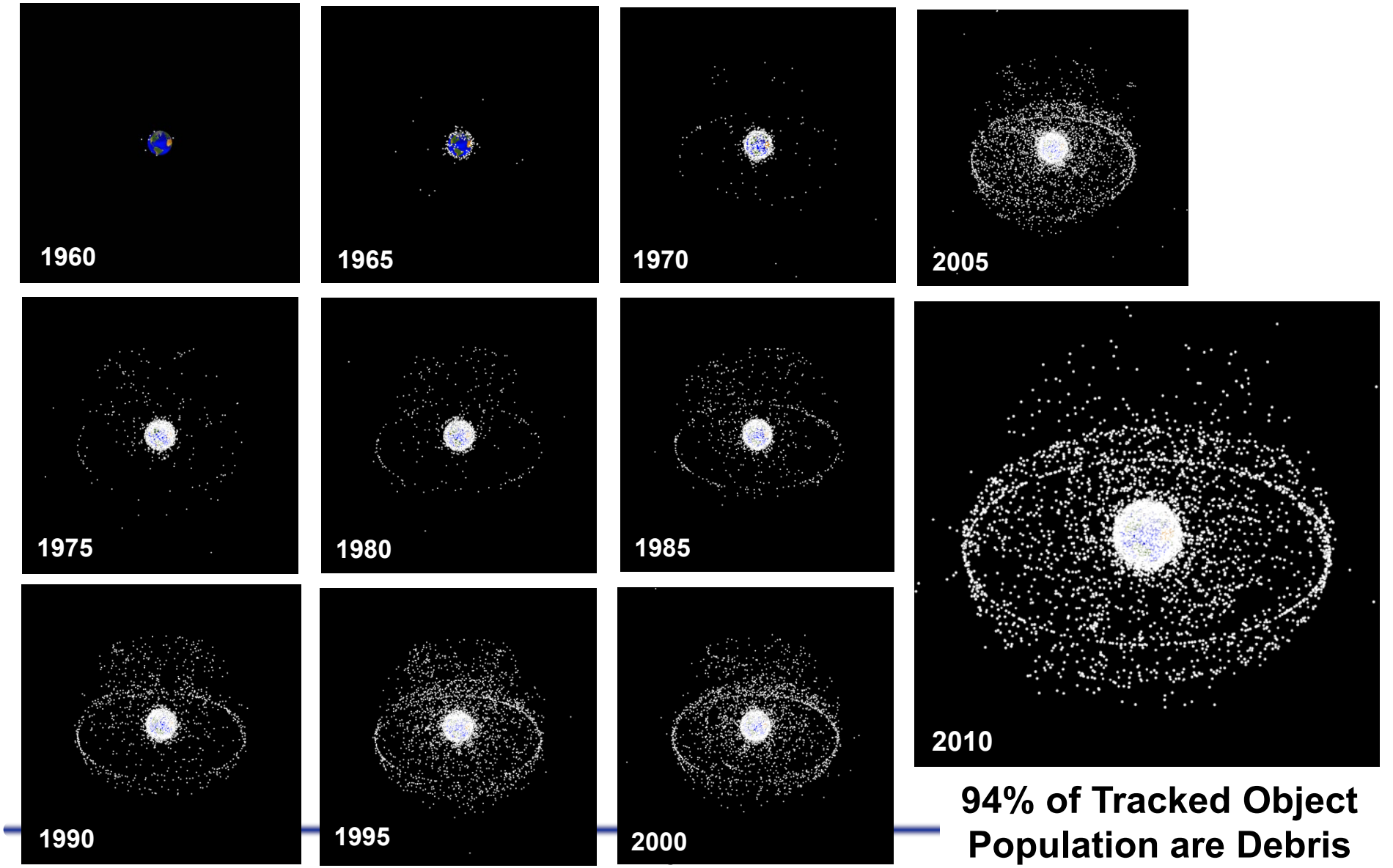
Orbital Debris Related Tasks Performed by Other NASA Groups

- **Collision Avoidance;**
  - Collision Avoidance for human crewed spacecraft is performed by JSC's Mission Operations Directorate (MOD); and
  - Collision Avoidance for robotic spacecraft is performed by GSFC's Conjunction Assessment Risk Analysis (CARA) group.

- **Spacecraft Shielding and Hypervelocity Testing;**
  - Performed by the Hypervelocity Impact Technology Group (HVIT); and
  - HVIT also performs detailed risk assessments using BUMPER.

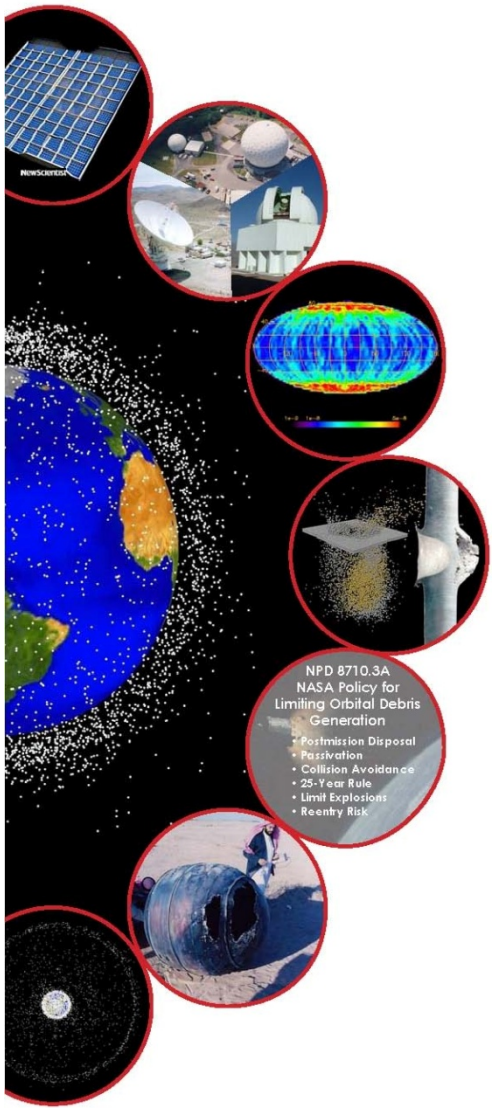
- **Environment Remediation (Active Debris Removal);**
  - Recent NASA policy assigns Remediation related technology development to the Space Technology Mission Directorate and the Office of Chief Technologist; and is
  - Currently limited to TLR levels 1-4.

Growth of the Satellite Population



94% of Tracked Object Population are Debris

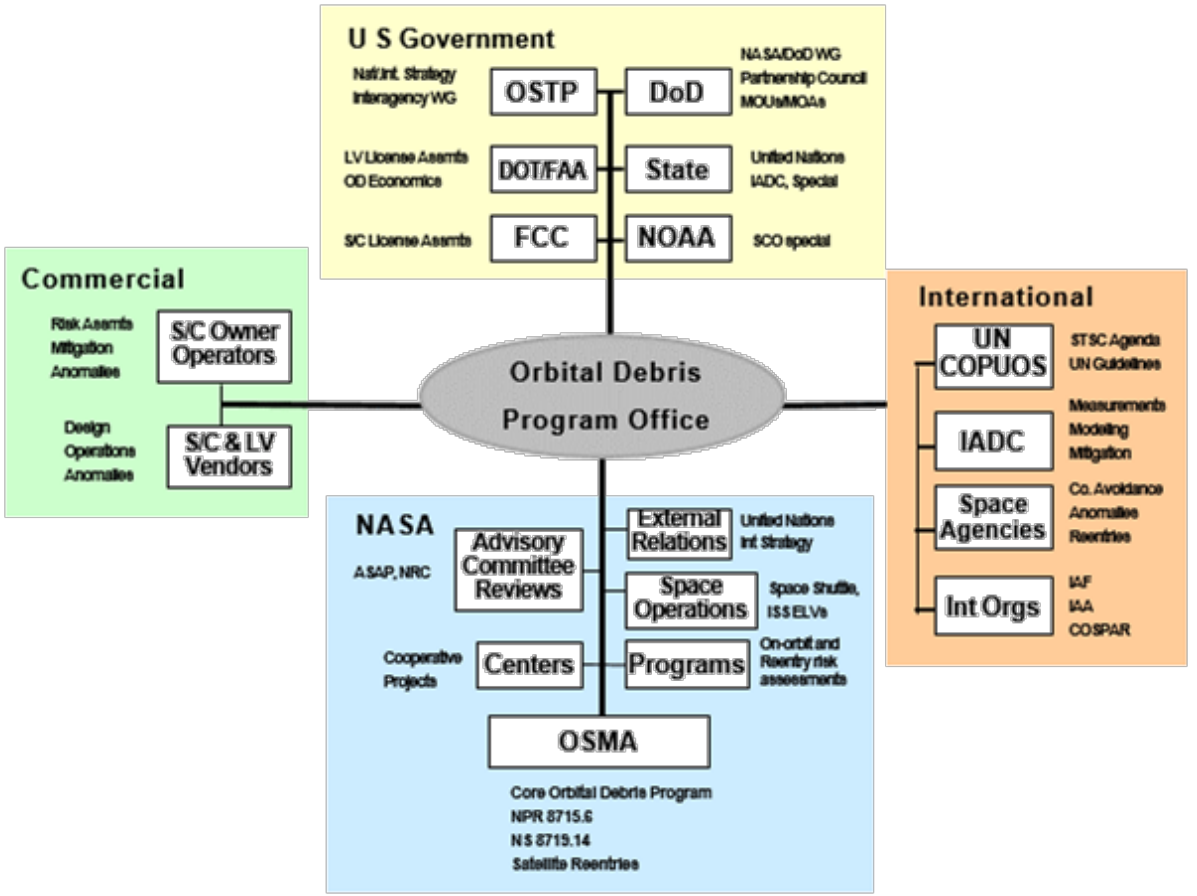
NASA's Orbital Debris Research Program



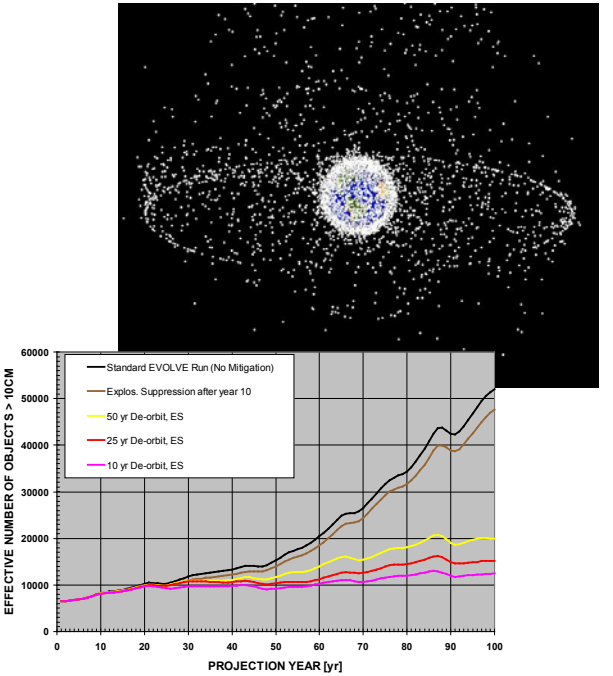
- **The Orbital Debris Program Office (ODPO) is the only organization in the US Government conducting a full range of research on orbital debris;**
  - Established at JSC in 1979;
  - ODPO roles and responsibilities defined in NPD8700.1 and NPR 8715.6A; and
  - Currently funded through HQ/OSMA.
- **Characterize the orbital debris environment to support risk assessments for all NASA projects and programs;**
- **Provide technical and policy level support to NASA HQ, OSTP, other US Government agencies and the commercial sector;**
- **ODPO represents the US Government in international fora, including the United Nations and the Inter-Agency Space Debris Coordination Committee (IADC); and**
- **Evaluate risk of human casualties from satellite reentries.**

Orbital Debris Program Office Interfaces

- **NASA produced the first OD mitigation guidelines in the year 1995;**
  - Effective without being unduly restrictive;
- **ODPO led effort to develop US Orbital Debris Mitigation Standard Practices;**
  - Applies to all sectors of government;
- **NASA OD Guidelines and US Standard Practices provided the foundation for IADC and UN OD guidelines;**
  - Level playing field for US space industry; and
- **Close cooperation with other USG agencies;**
  - DOD – measurements;
  - OSTP, State – policy; and
  - FAA, FCC, NOAA - regulatory



ODPO End-to-End Research & Services



Debris Assessment Software

- Normal Operations
- Accidental Explosions
- Intenational Breakups
- On-Orbit Collisions
- Postmission Disposal
- Reentry Survival

Satellite Breakup Risk Assessment Model

Measurements

Ground-based and in-situ measurements of debris smaller than 10-centimeter diameter

Modeling

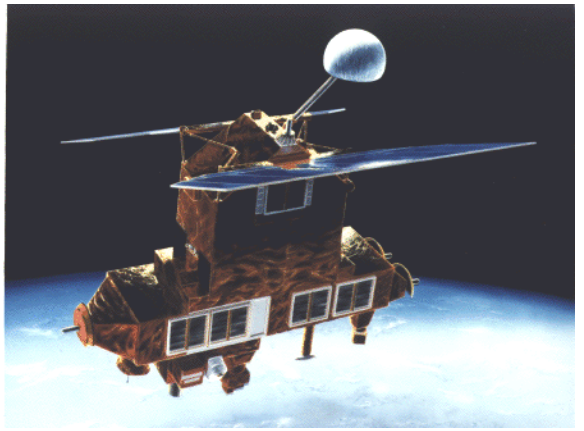
Near-term engineering, long-term evolutionary, and special purpose models

Risk Assessment

Software tools for risk assessments for all NASA space projects: human space flight and robotic

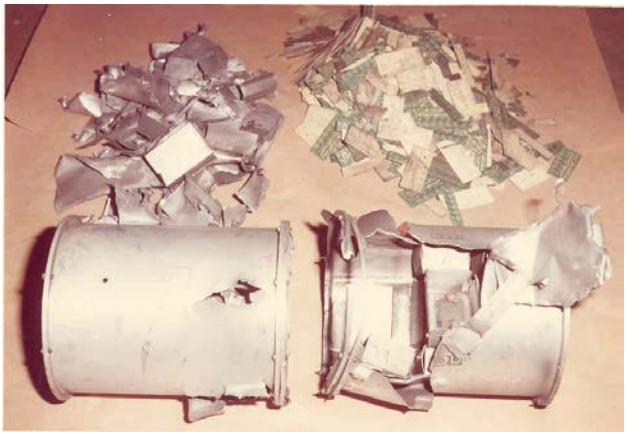
What is Orbital Debris?

- **Orbital debris is any object in Earth orbit which no longer serves a useful function.**



Non-operational Spacecraft

Derelict Launch Vehicle Stages



Fragmentation Debris

Mission-related Debris

Non-Fragmentation Debris

Current Environment

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How Much Debris Is There?

Marble or larger (greater than 1 centimeter): about 500,000

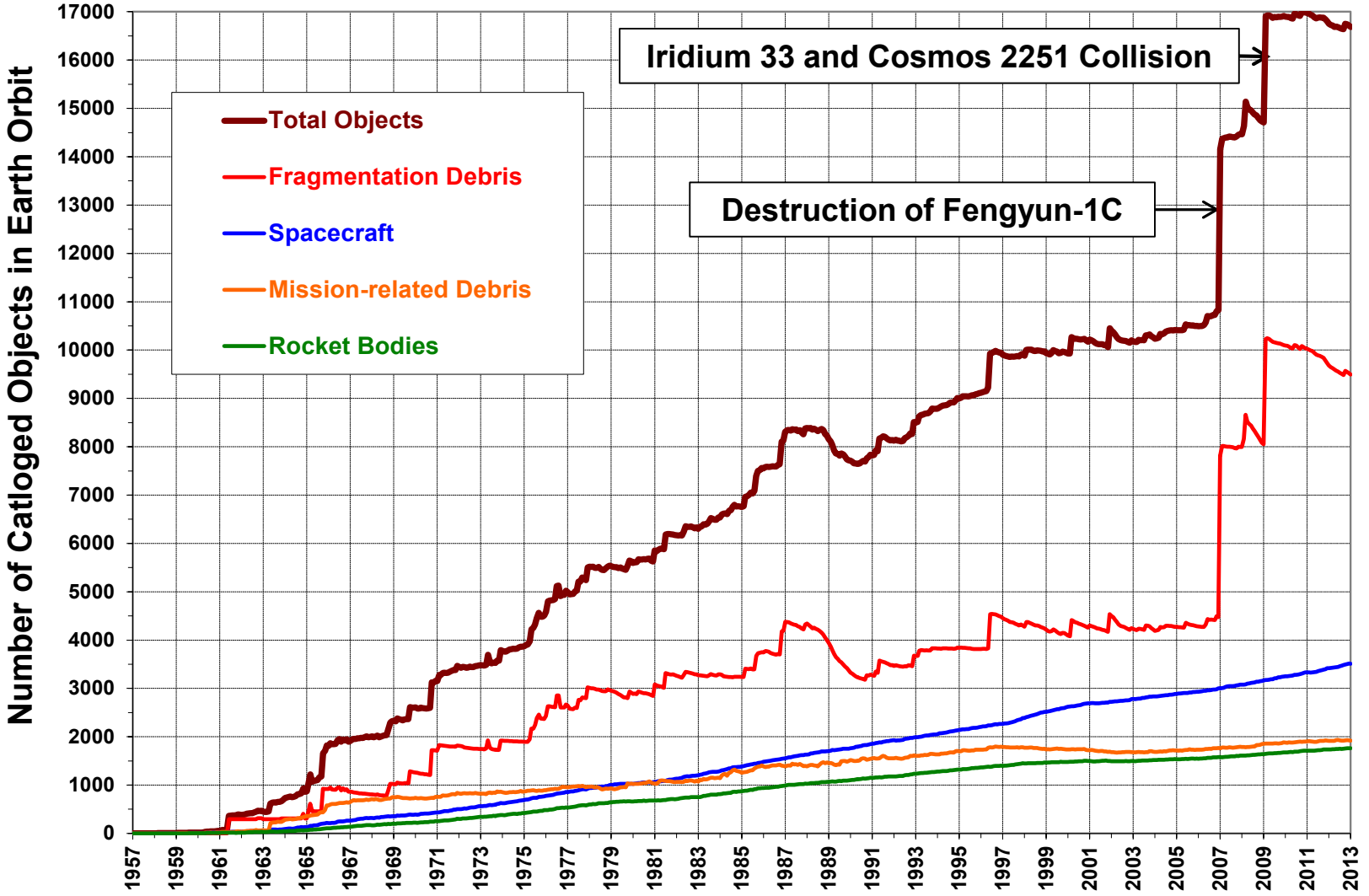
Dot or larger (greater than 1 millimeter): about 135,000,000 (1/4 the size of a BB)

Softball or larger (greater than 10 centimeters): 20,000+

Orbital Debris Detection Responsibilities and Capabilities

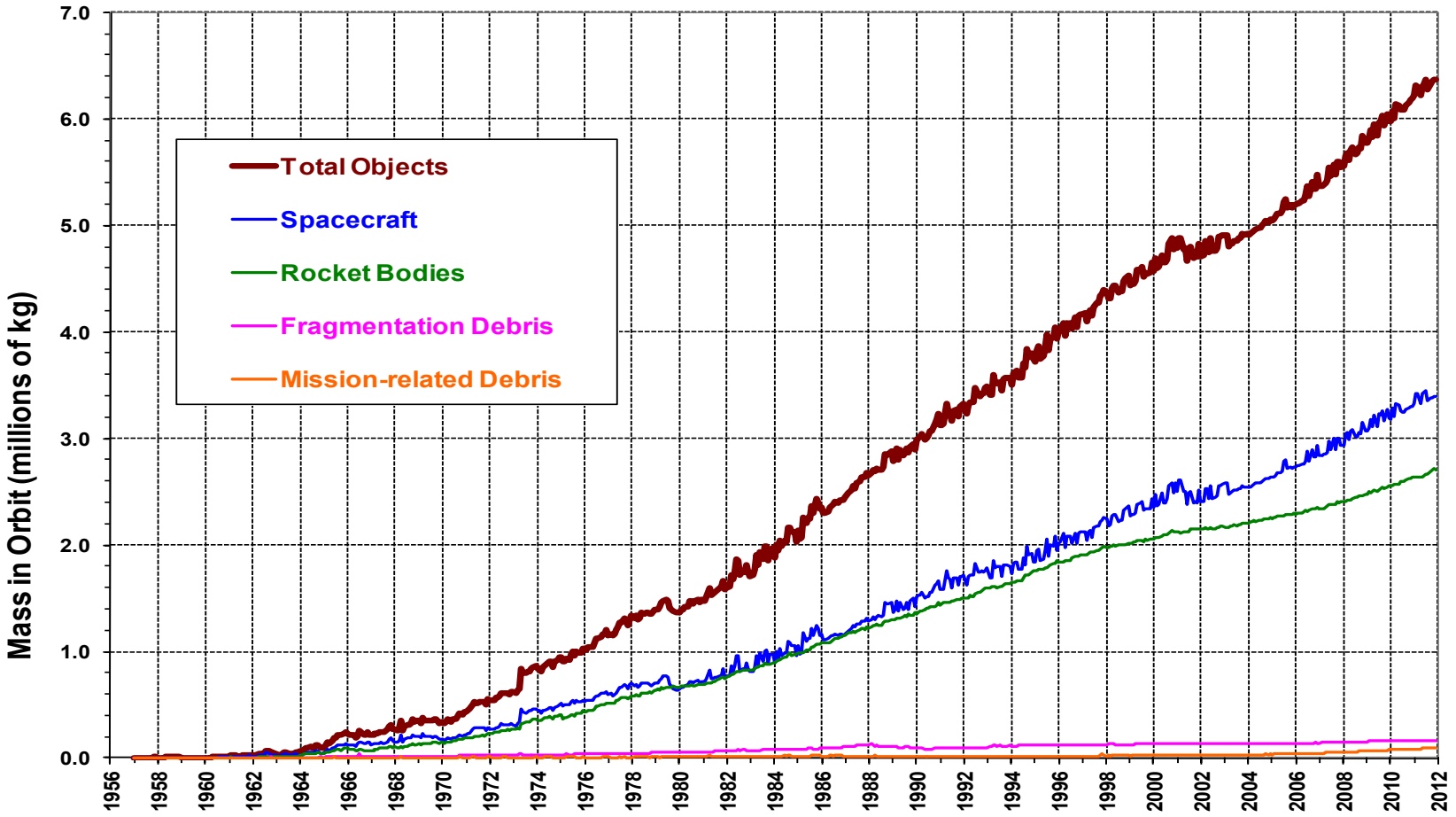
- **NASA and the Department of Defense share responsibility for determining the Earth satellite population at various sizes and altitudes;**
  - The Department of Defense is the lead for objects equal to or greater than 10 centimeters in LEO and equal to or greater than 1 meter in GEO; and
  - NASA is the lead for objects less than 10 centimeters in LEO and less than 1 meter in GEO.
- **Department of Defense assessments are deterministic, while NASA assessments are primarily statistical;**
- **A wide variety of radars and electro-optical sensors are employed;**
- **Department of Defense databases are also used for conjunction assessments and collision avoidance, while NASA models support probabilistic risk assessments for the small debris population; and**
- **NASA also has the lead for predicting the future Earth satellite population.**

Growth of the Cataloged Satellite Population in Earth Orbit: Numbers of Objects



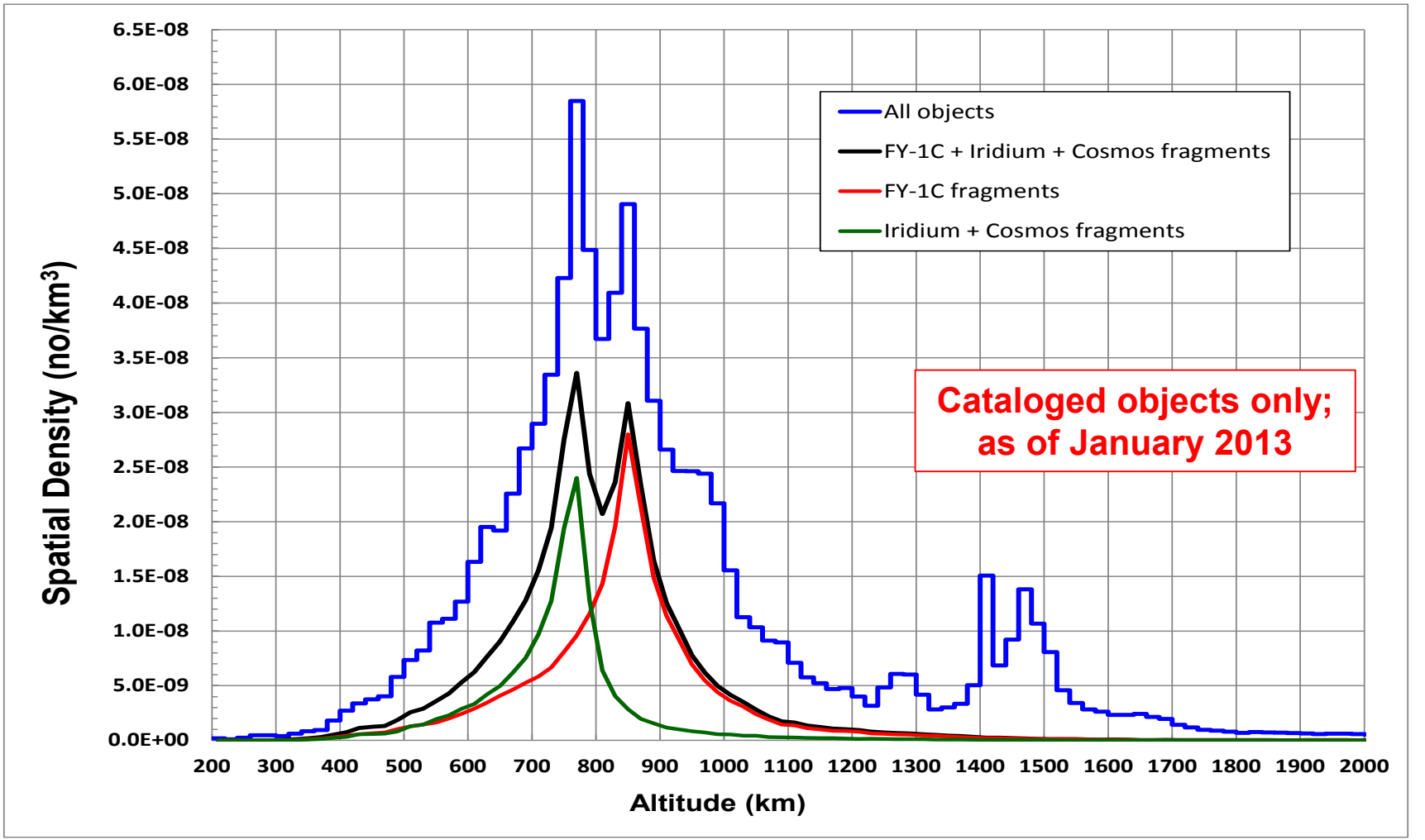
Growth of the Cataloged Satellite Population: Mass of Objects

- **Recently, the rate of mass growth in low Earth orbit has averaged nearly 200 metric tons per year. Only approximately 40 percent of the mass is in LEO.**



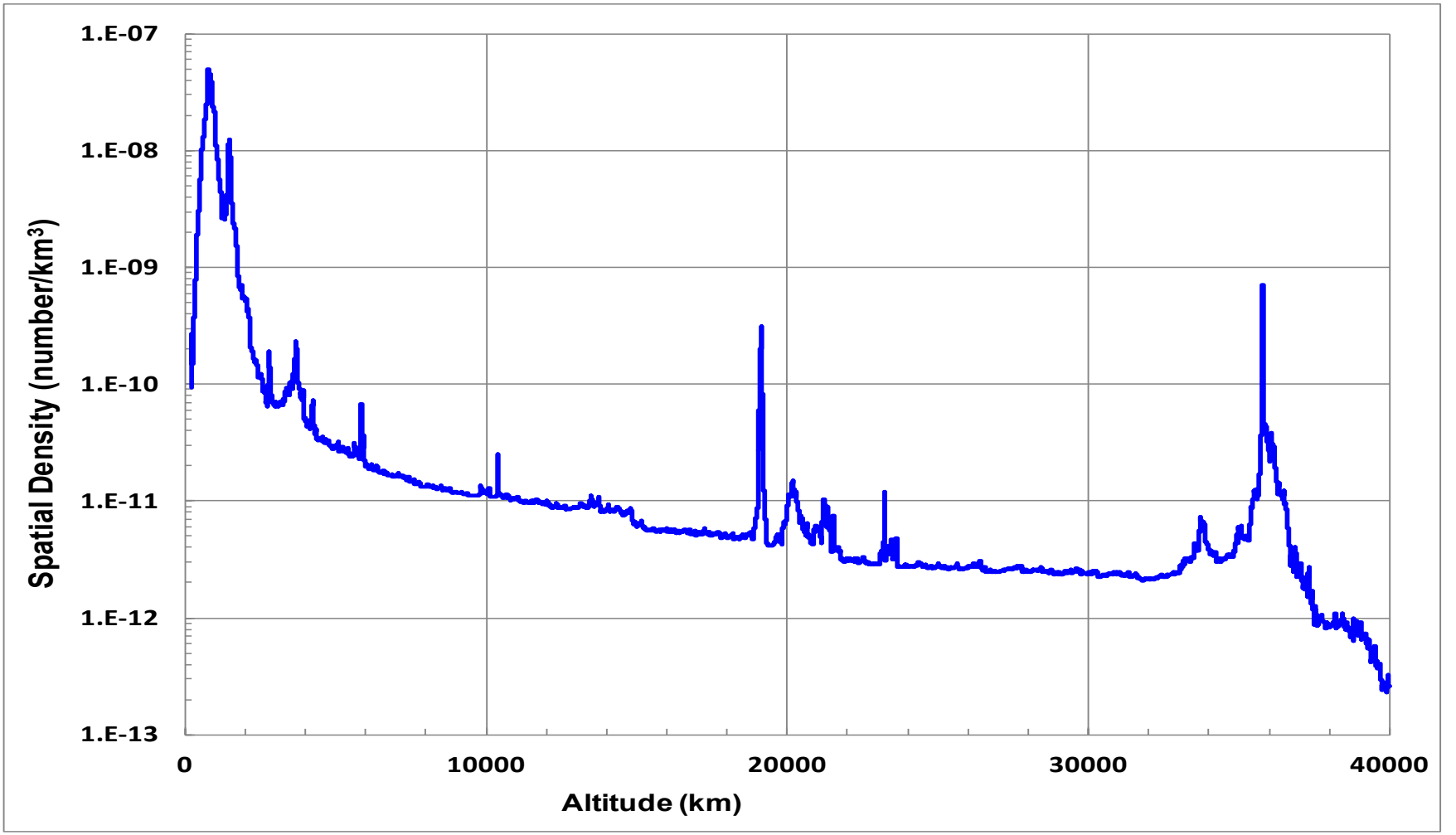
More Current LEO Spatial Density

- **The collision of the Iridium 33 and Cosmos 2251 satellites significantly altered the amount and distribution of orbital debris in LEO.**

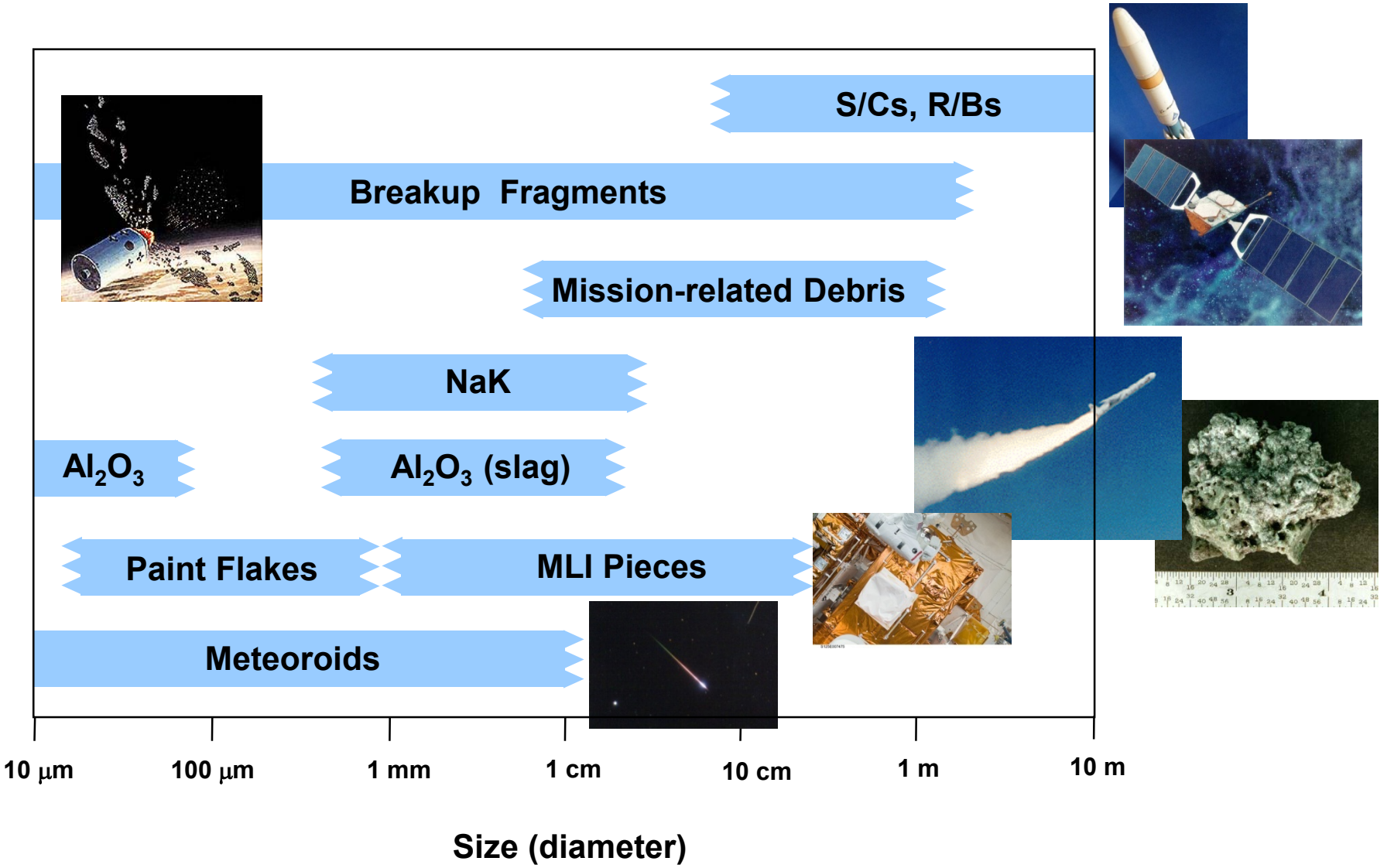


Spatial Densities Through GEO

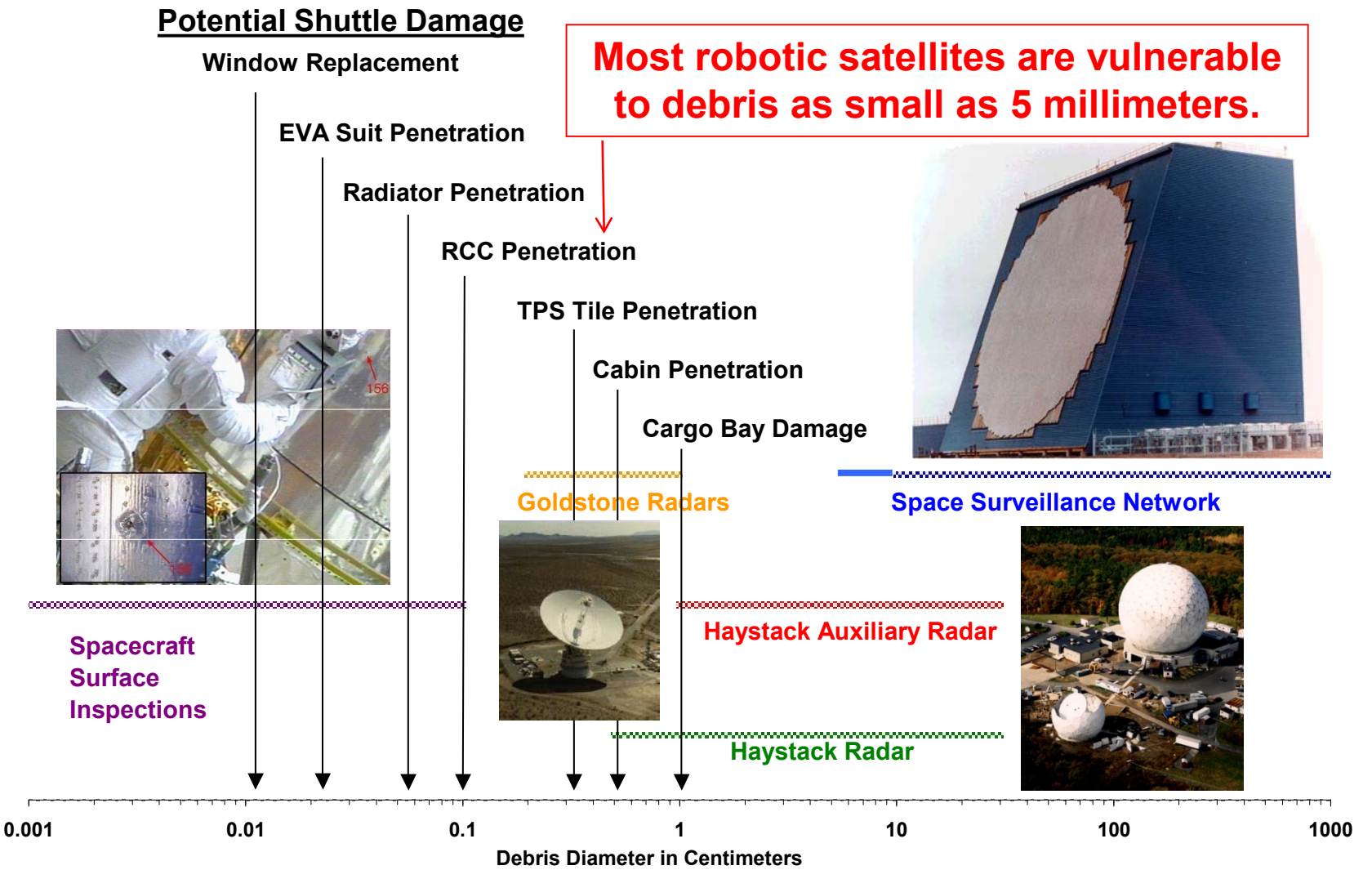
- **Spatial densities in general decrease above LEO with higher concentrations near semi-synchronous and geosynchronous altitudes.**



Summary


S/Cs, R/Bs
Breakup Fragments
Mission-related Debris
NaK
Al_2O_3
Al_2O_3 (slag)
Paint Flakes
MLI Pieces
Meteoroids
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
Size (diameter)

Orbital Debris Detectors and Damage Potential



Mitigation

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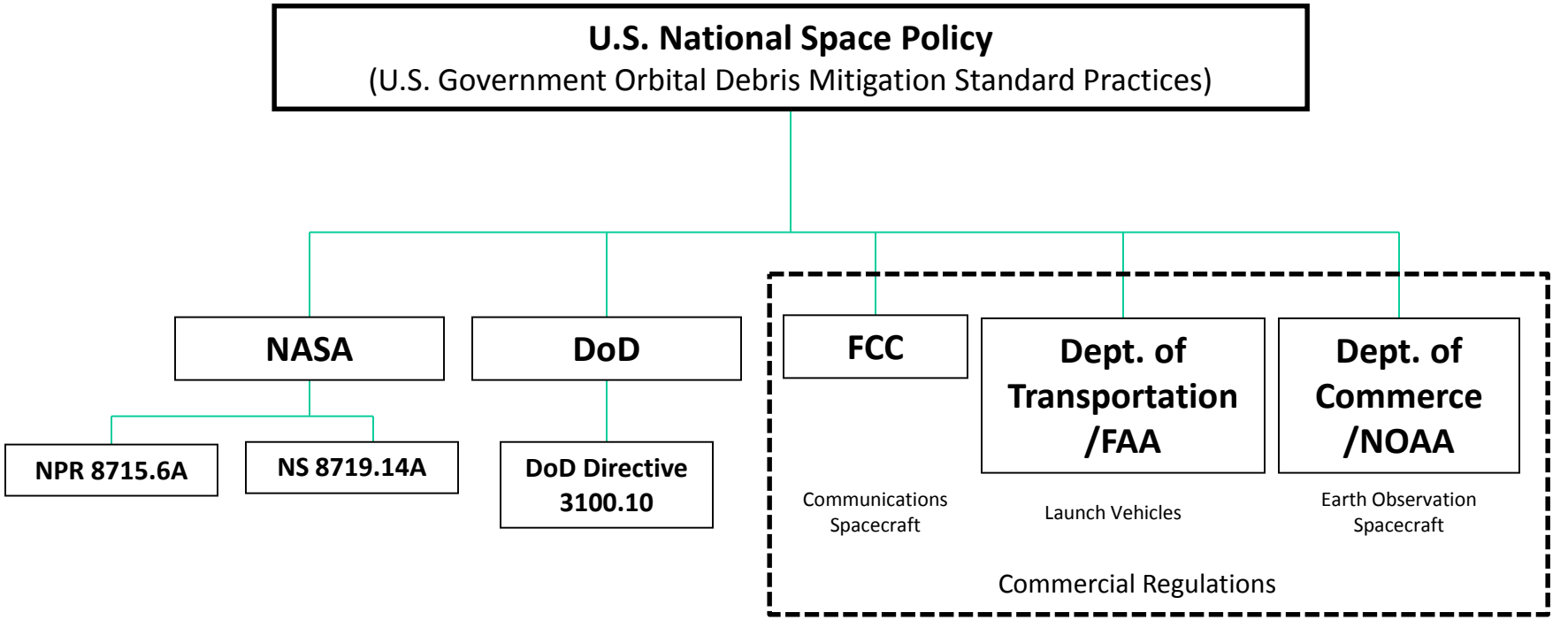
Overview of U.S. Orbital Debris Mitigation Policies

- **All U.S. government requirements and commercial regulations for orbital debris mitigation are derived from the U.S. Government Orbital Debris Mitigation Standard Practices which are cited in U.S. National Space Policy.**



USG Orbital Debris Mitigation Standard Practices Highlights

- **Standard Practice 1;**
  - Eliminate or minimize mission-related debris; and
  - Limit orbital lifetime of LEO debris to 25 years.

- **Standard Practice 2;**
  - Use design and procedures to avoid breakups during mission operations and after disposal.

- **Standard Practice 3;**
  - Protect against collisions with small debris and avoid collisions with large debris.

- **Standard Practice 4;**
  - LEO: Limit post-mission orbital lifetime to 25 years limit human casualty reentry risk to 1 in 10,000; and
  - GEO: Maneuver to a disposal orbit approximately 300 kilometers above GEO.

International Mitigation Efforts

- **Inter-Agency Space Debris Coordination Committee (IADC);**
  - Organization of Space Agencies;
  - Twelve members include all the leading space agencies in the world from Canada, China, France, Germany, India, Italy, Japan, Russia, Ukraine, United Kingdom, and the United States, as well as ESA; and
  - Developed first consensus international orbital debris mitigation guidelines in October 2002 (slightly revised in 2007).
- **United Nations;**
  - STSC Member States adopted space debris mitigation guidelines in Feb 2007, followed by adoption of the full COPUOS in June 2007 and by the full General Assembly in late 2007.
- **National Policies;**
  - Japan: Space Debris Mitigation Standard (NASDA-STD-18A), March 1996;
  - France: CNES Space Debris – Safety Requirements (MPM-50-00-12), April 1999; new national space law in December 2010;
  - Russia: General Requirements for Mitigation of Space Debris Population (Branch Standard), July 2000;
  - China: Requirements for Space Debris Mitigation (QJ 3221 – 2005), July 2005; and
  - ESA: European Code of Conduct for Space Debris Mitigation, 2006.

The Case for Remediation

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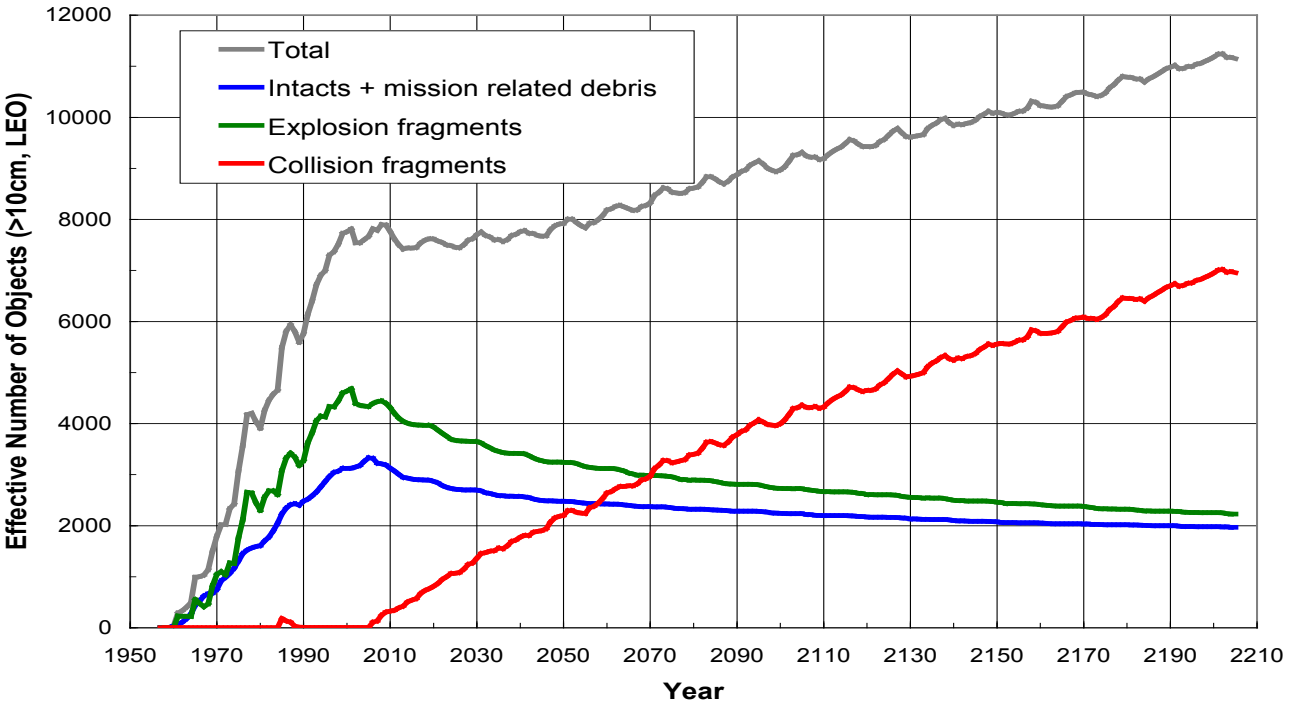
National Space Policy (NSP) and Active Debris Removal

- **Orbital Debris is mentioned in every NSP since 1988;**
- **New NSP adds: "Pursue research and development of technologies and techniques, … to mitigate and remove on-orbit debris, …";**
- **Although the "Kessler Syndrome" is occurring, it is a slow process**

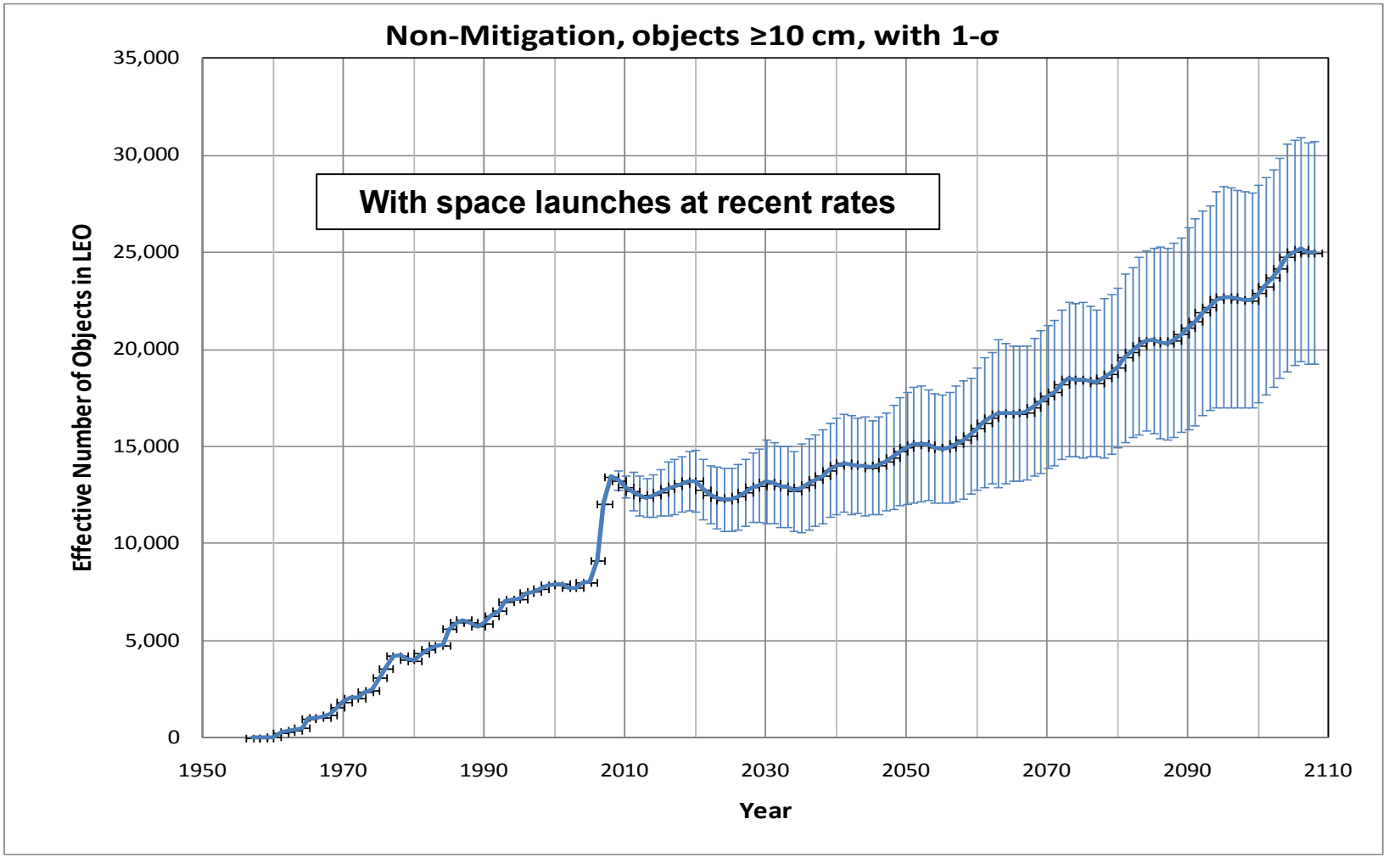


"The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future"

– Liou and Johnson, ***Science***, 20 January 2006

Revised Projection in 2009

- **The effects of the Chinese ASAT test in 2007 and the collision of Iridium 33 and Cosmos 2251 in early 2009 made matters much worse.**



Major Recent and Near-Term Initiatives

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Major Recent and Near-Term Initiatives

- **ORDEM 3.0 Released** – Updated Environment Model;
  - Uncertainties;
  - Material density categories; and
  - Model extended to GEO.
- **Meter Class Autonomous Telescope (MCAT);**
  - Collaboration with Air Force Research Laboratory (AFRL) and AF Forty-fifth Space Wing;
  - 1.3 meter telescope to be located near equator at Ascension Island, and
  - Improve survey measurements at GEO and low inclinations.
- **DebriSat;**
  - Collaboration with AF Space and Missiles Center (SMC), Aerospace, Univ. of Florida;
  - Ground hypervelocity impact of a high-fidelity satellite mockup using modern materials and construction; and
  - Improve breakup models.
- **Debris Resistive/Acoustic Grid Orbital Navy Sensor (DRAGONS);**
  - Collaboration with U.S. Naval Academy (USNA), U.S. Naval Research Laboratory (NRL), the University of Kent, and Virginia Tech (VT); and
  - *In-situ* measurements of debris smaller than 1 millimeter.

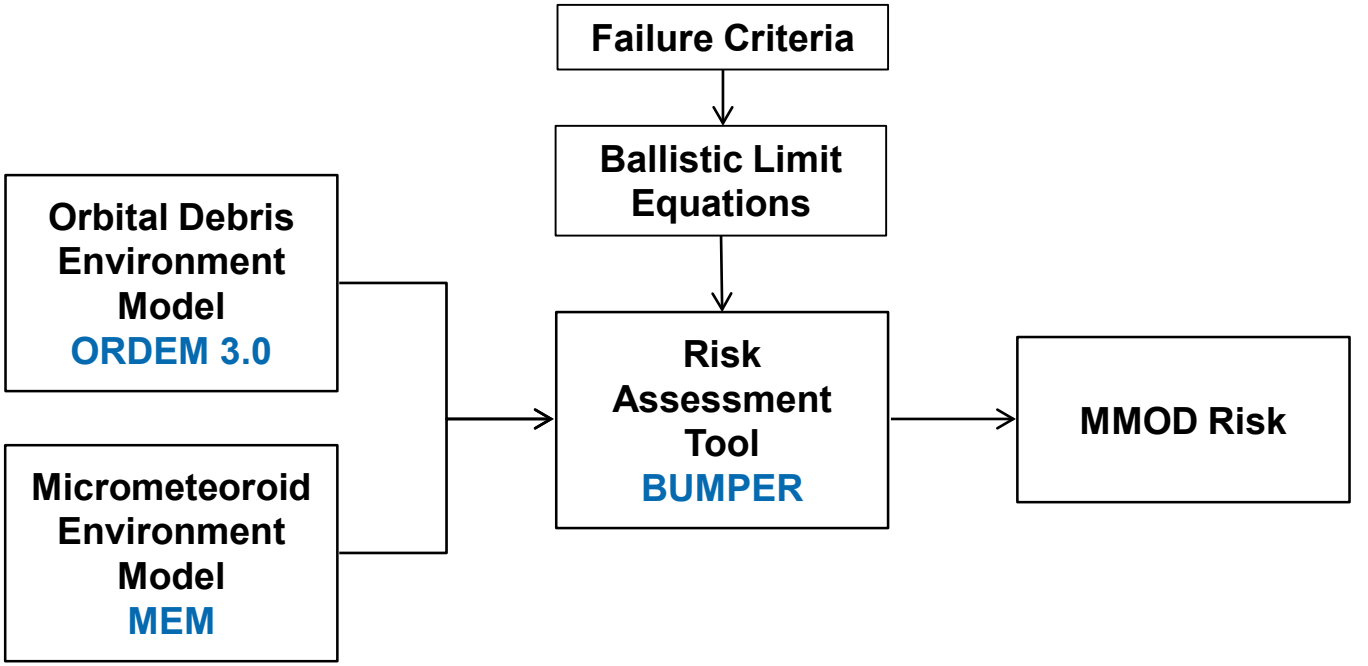
ORDEM 3.0

- **ORDEM 3.0 represents our best estimate of the current and near future orbital debris environment;**
  - The Orbital Debris Environment is dynamic and must be updated periodically.

- **ORDEM 3.0 has significant new capabilities;**
  - Uncertainties;
  - Material density categories;
  - Model extended to GEO; and
  - Can easily calculate flux for satellites in highly elliptical orbit.

Risk Assessment

- **ORDEM 3.0 is only one part of the risk assessment process**

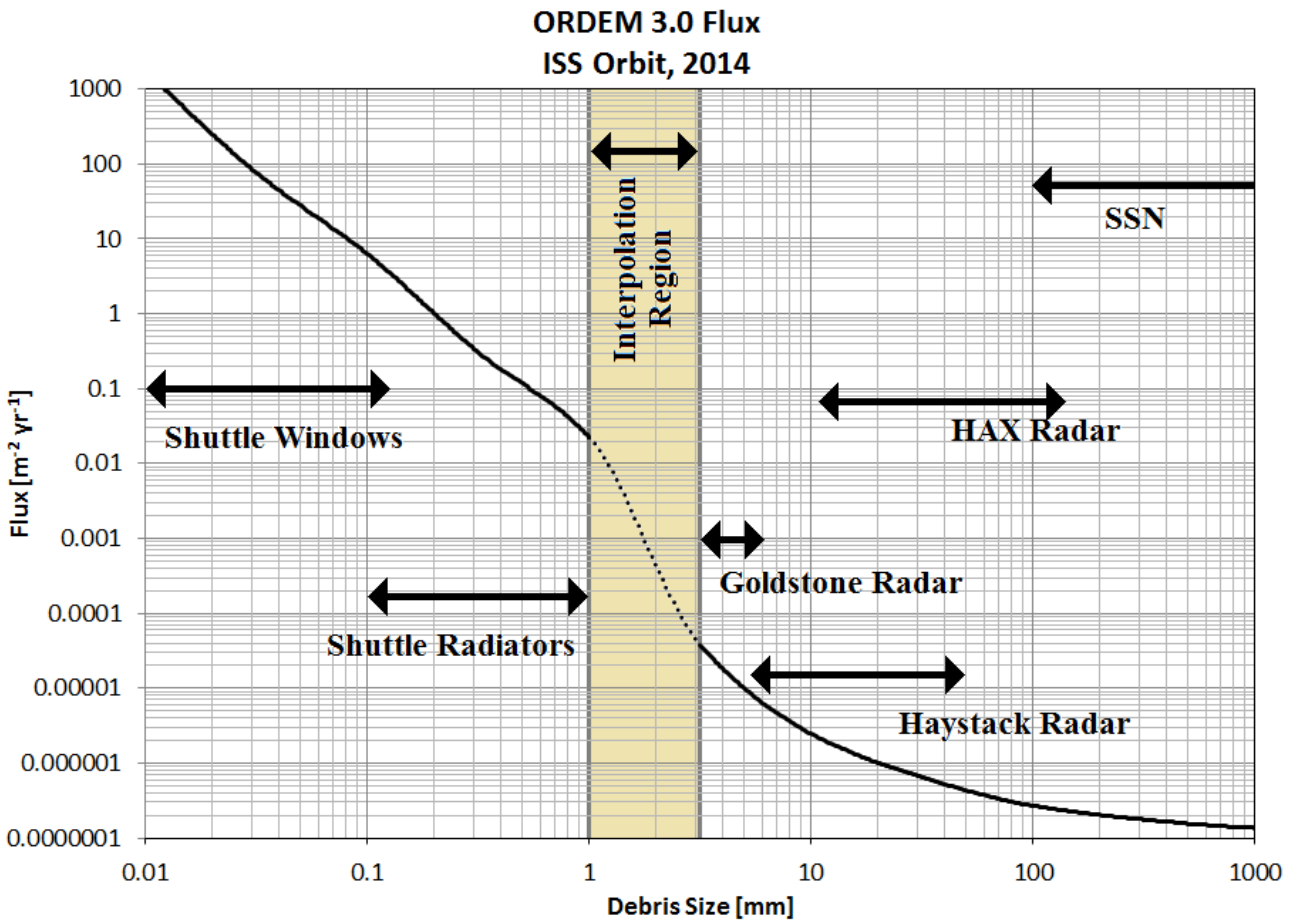


- ORDEM 3.0 managed by ODPO (based at JSC in KX).
- MEM managed by Meteoroid Environment Office (based at MSFC)
- BUMPER & Ballistic Limit Equations are managed by HVIT (based at JSC in KX)

ORDEM Flow

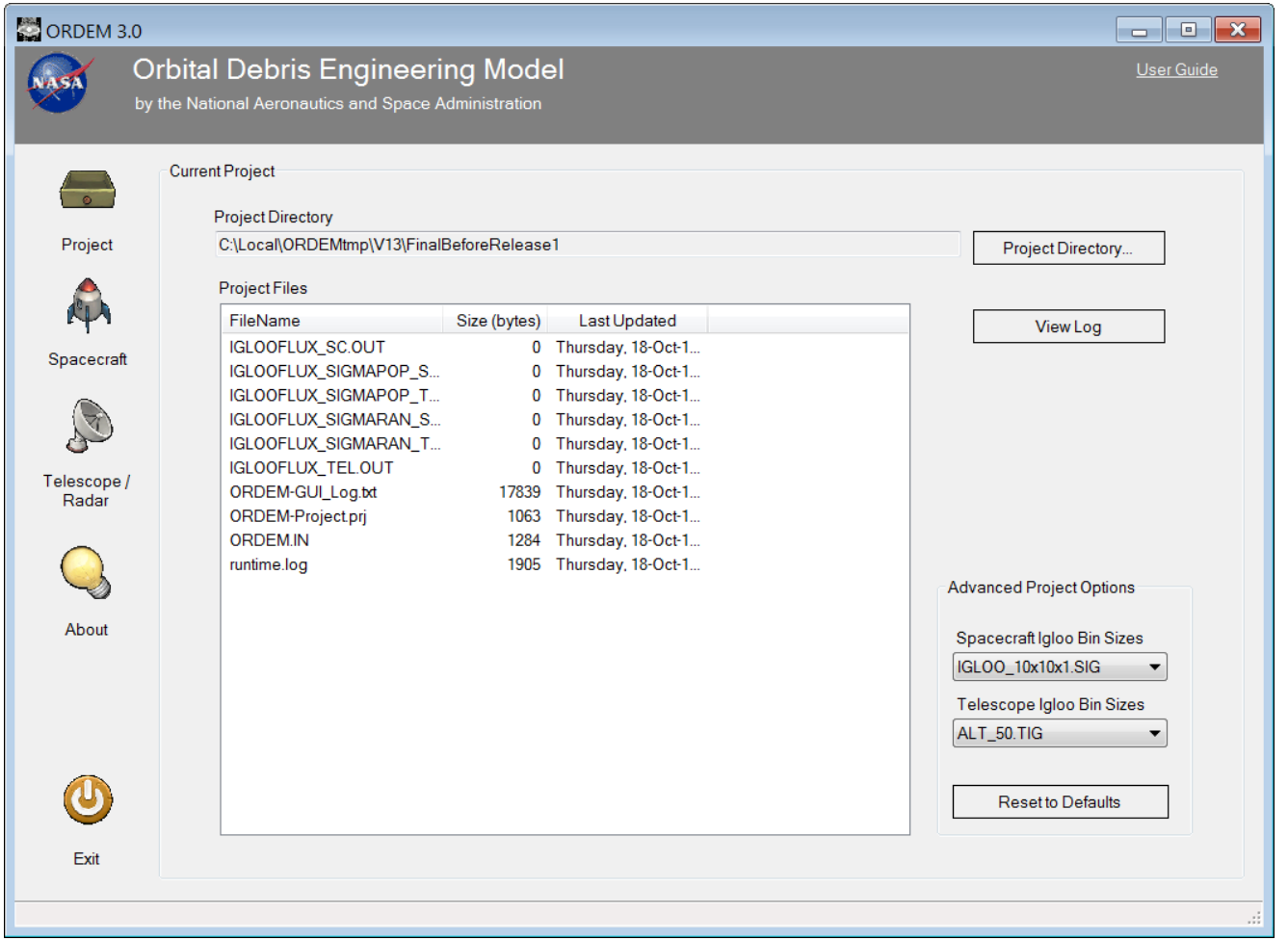
- Initial environment created using database of known space activity and tools such as the NASA Standard Breakup Model & PROP3D;
- Initial environment fit to measurement data using Maximum Likelihood Estimator to create final "Current" debris environment;
- LEGEND used to propagate the "Current" environment into the future;
- When LEGEND creates new future debris (such as through collision or explosion) the same weighting values that were used to fit historical size distributions are applied to debris production in the future;
- Launch rate, solar activity, and explosion rate are independent inputs into the model;
- One hundred and twenty Monte Carlo future environments are created; and
- Reported future environment is the average of the 120 possible future environments

Data and Size Regimes



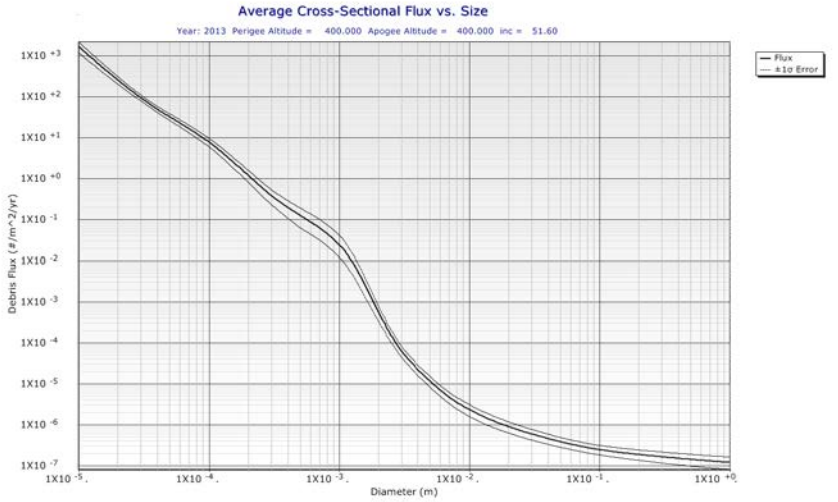
- **Small particle populations are fit separately from large particle populations**

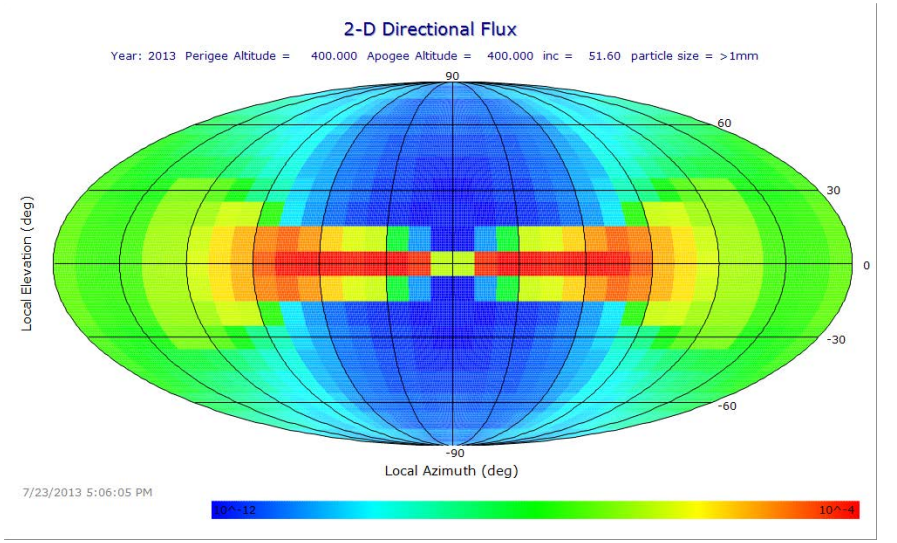
ORDEM 3.0 Graphical User Interface (GUI)

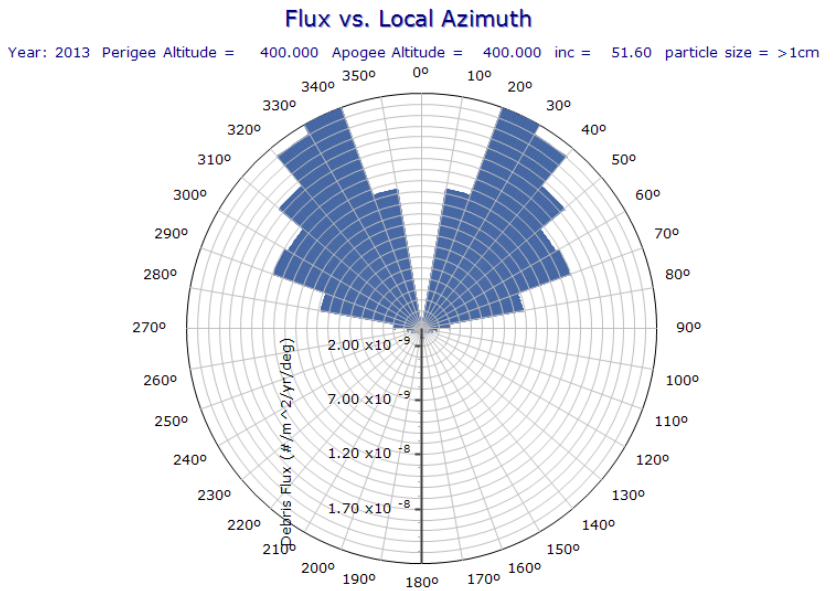


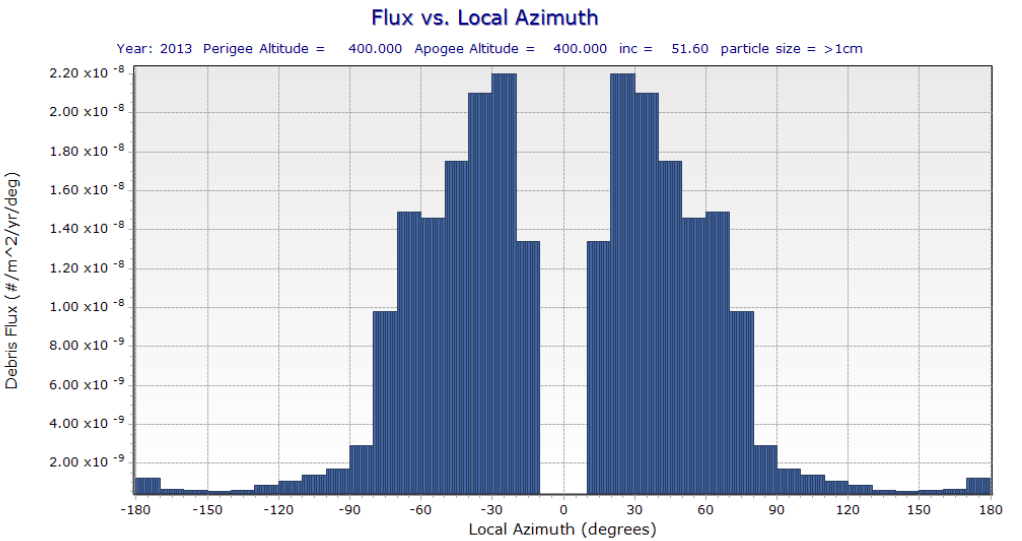
- **Stand alone version uses a Graphical User Interface (GUI); and**
- **Can be run in either "Spacecraft" or "Telescope/Radar" modes**

Graphical Output Options for Spacecraft Mode



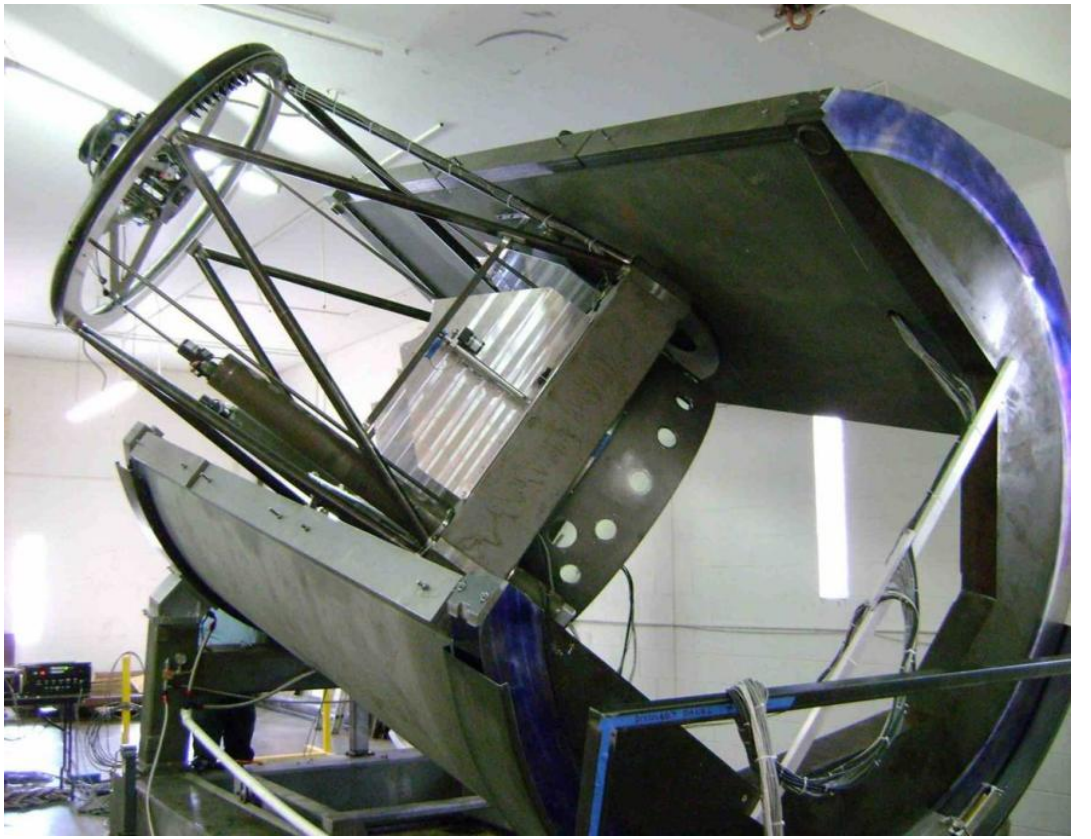






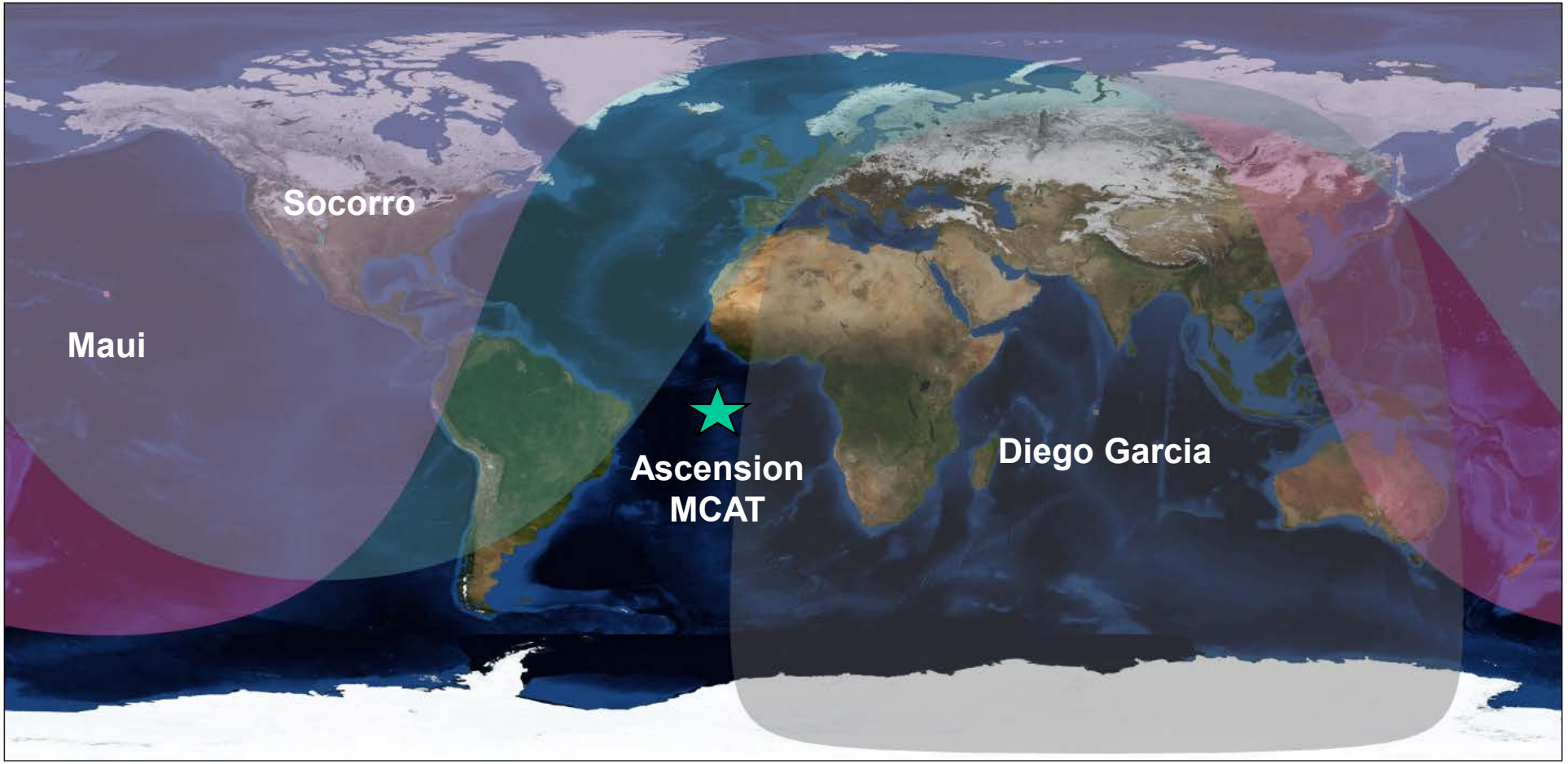
Meter-Class Autonomous Telescope (MCAT)

- **NASA is currently working with the Air Force and AFRL to deploy a new 1.3-meter telescope on Ascension Island;**
- **The low latitude of the site will permit observations of low inclination debris at all altitudes;**
  - **Debris as small as 10 centimeters in GEO should be detectable.**
- **The telescope will be operated remotely from JSC; and**
- **Operations will start in 2015.**



The MCAT telescope and mount will be non-traditional.

GEODSS Network Coverage

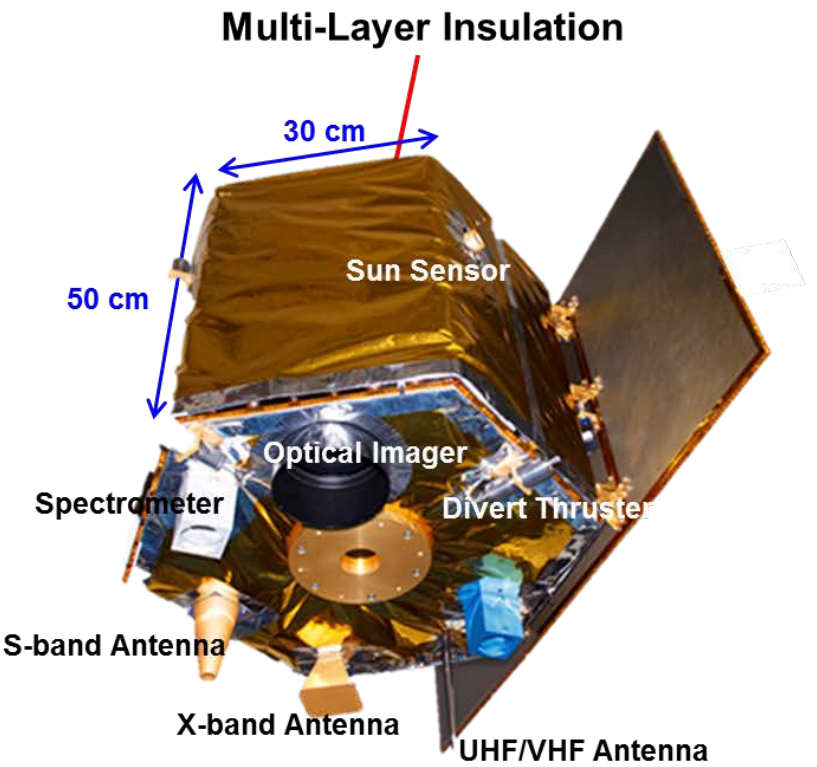


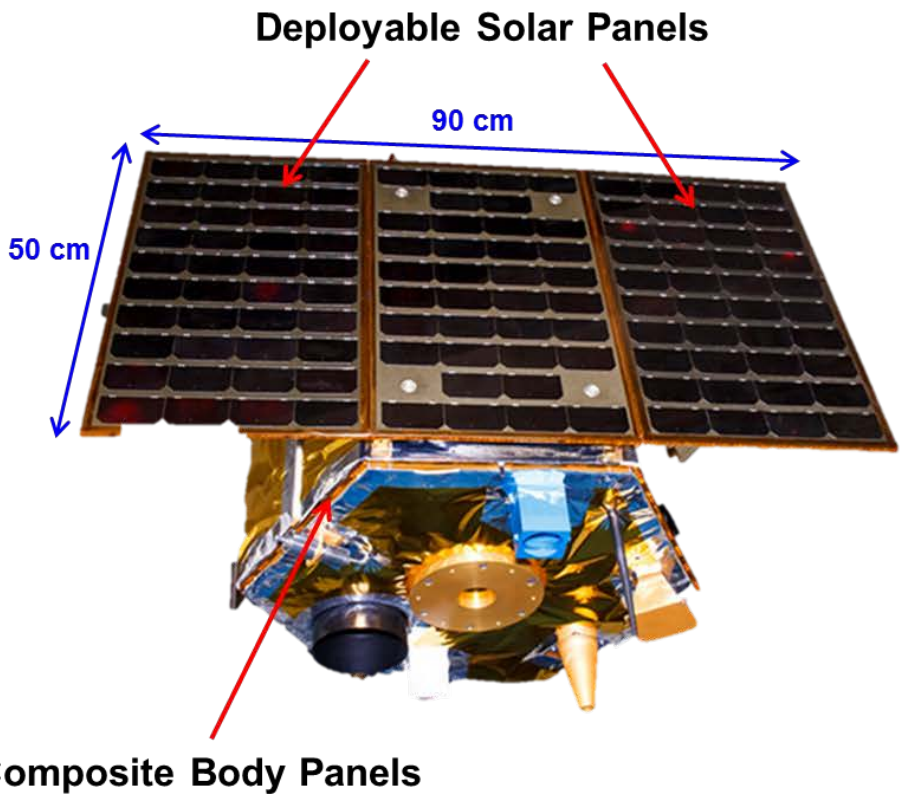
DebriSat

- **NASA Standard Breakup Model;**
  - Based on ground based hypervelocity impact tests and on-orbit fragmentations, explosion and collision;
  - Ground based tests were on performed on 1960's Transit satellite and simulated spacecraft & rocket bodies;
    - No multilayer insulation (MLI) or solar panels; and
  - Iridium/Cosmos collision in 2009 showed differences between "new" and "old" construction.

- **DebriSat;**
  - Design and fabricate a 60-centimeter/50-kilogram class satellite, including MLI and solar panels, to be representative of modern payloads in LEO; and
  - Carry out a hypervelocity impact test with sufficient kinetic energy to completely breakup DebriSat.

DebriSat Components

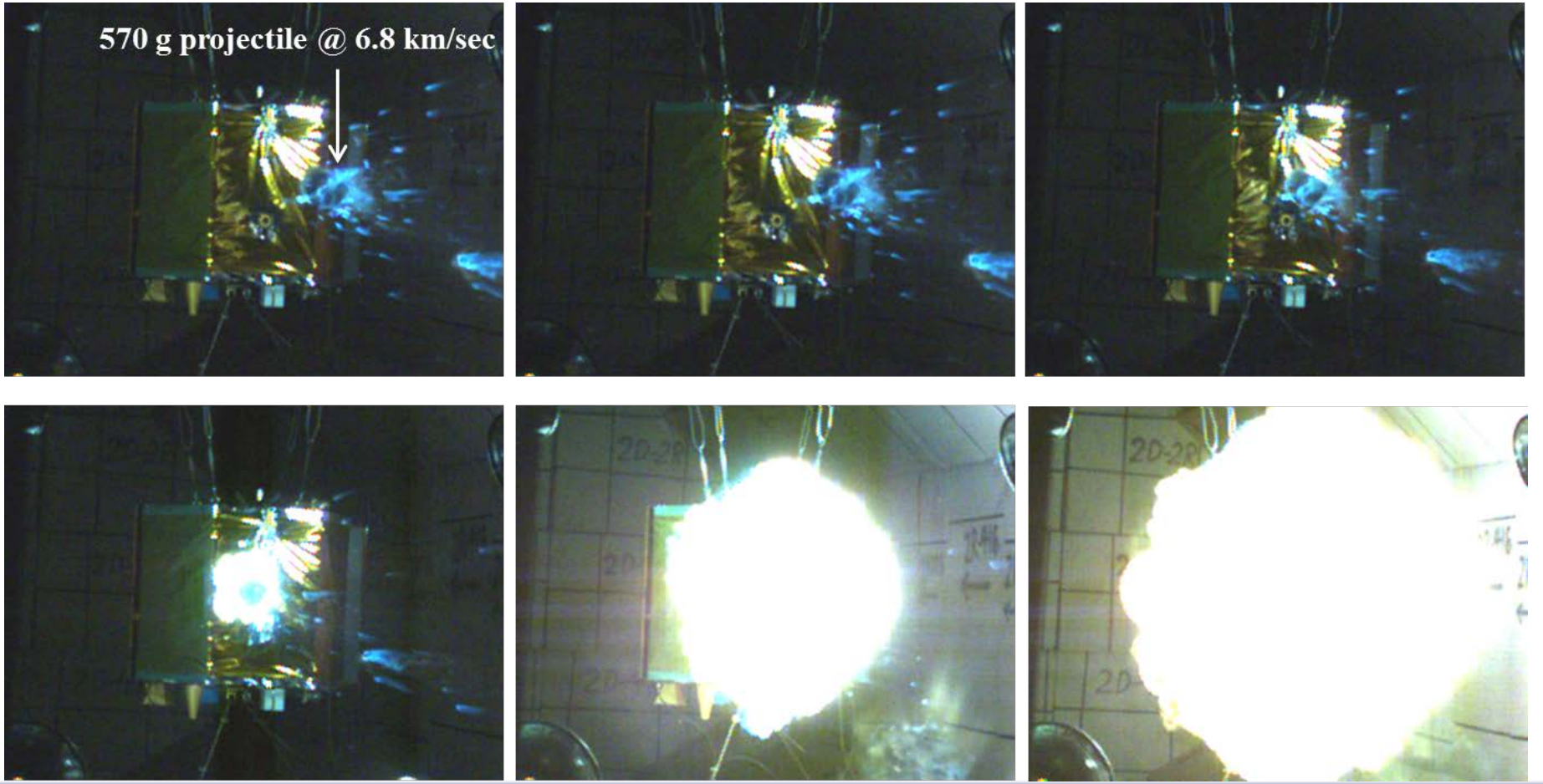




8.6 cm × 9 cm, 570 g
6.8 km/sec

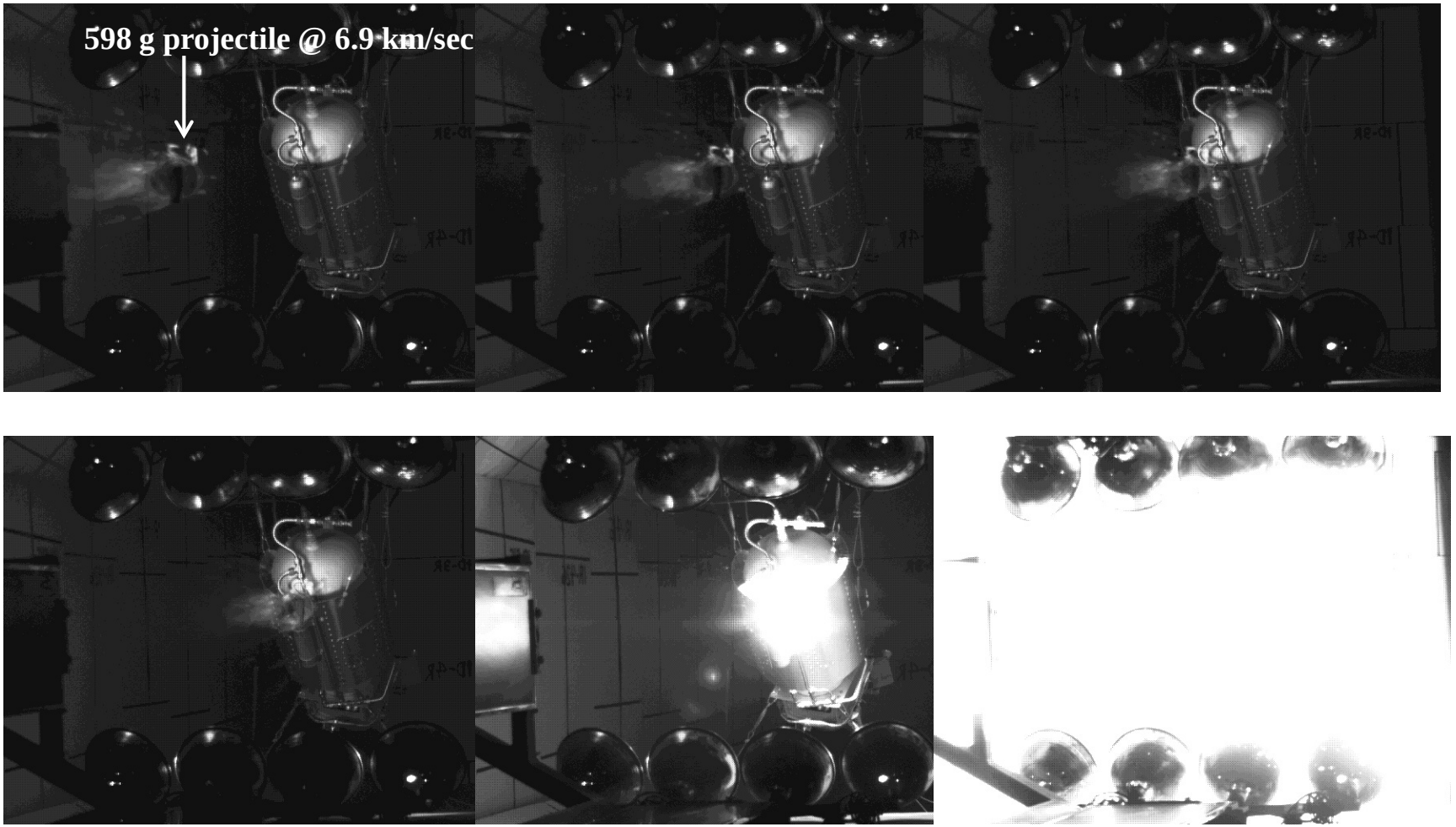
DebriSat Test Shot

- **DebriSat shot was successfully conducted on April 15th at Arnold Engineering Development Center (AEDC)**
  - Projectile impacted DebriSat at 6.8 kilometers per second and completely fragmented the target



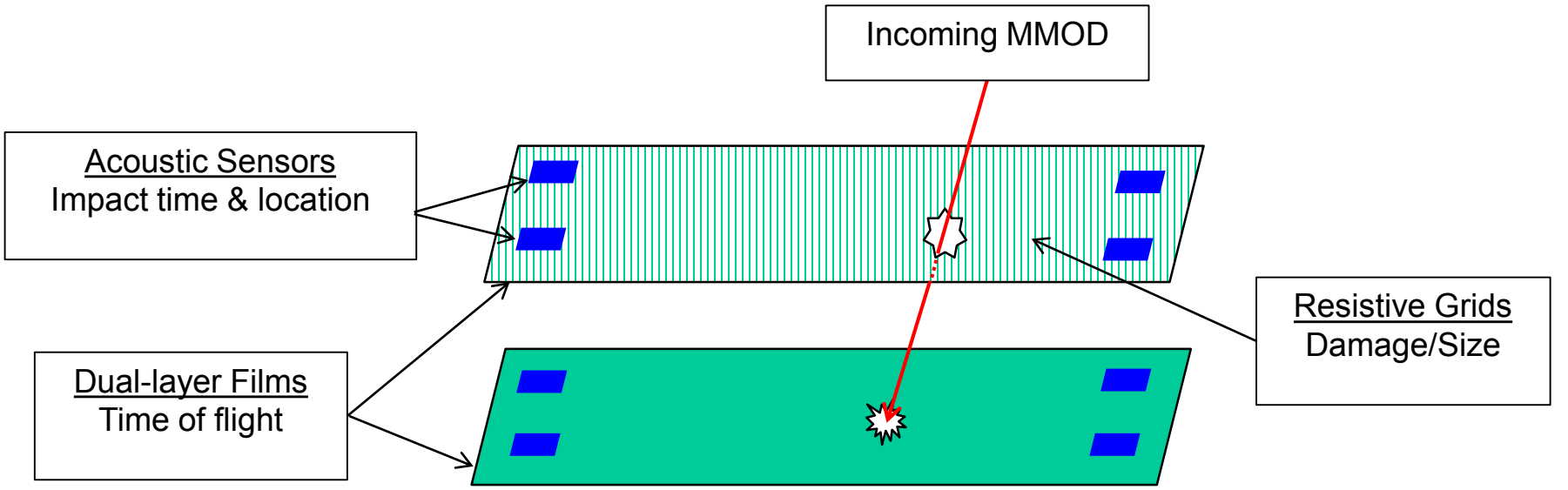
DebriSat Pre-Test Shot

- **AEDC always conducts a test shot prior to the main event**
  - Opportunity to test emulated upper stage



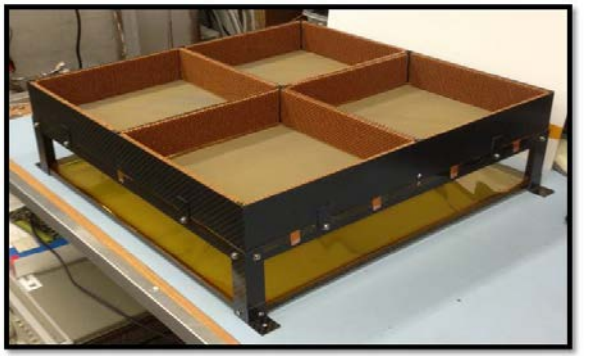
Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor (DRAGONS)

- **Purpose is to provide data on debris smaller than 1 mm**
- **DRAGONS combines dual-layer thin films and an acoustic sensor system with the resistive grid sensor system to create a COTS-based instrument that provides excellent semi-real-time impact detection and recording capability**
  - Impact data includes: **Impact time, impact flux, particle size, impact speed, impact direction, and impact energy**

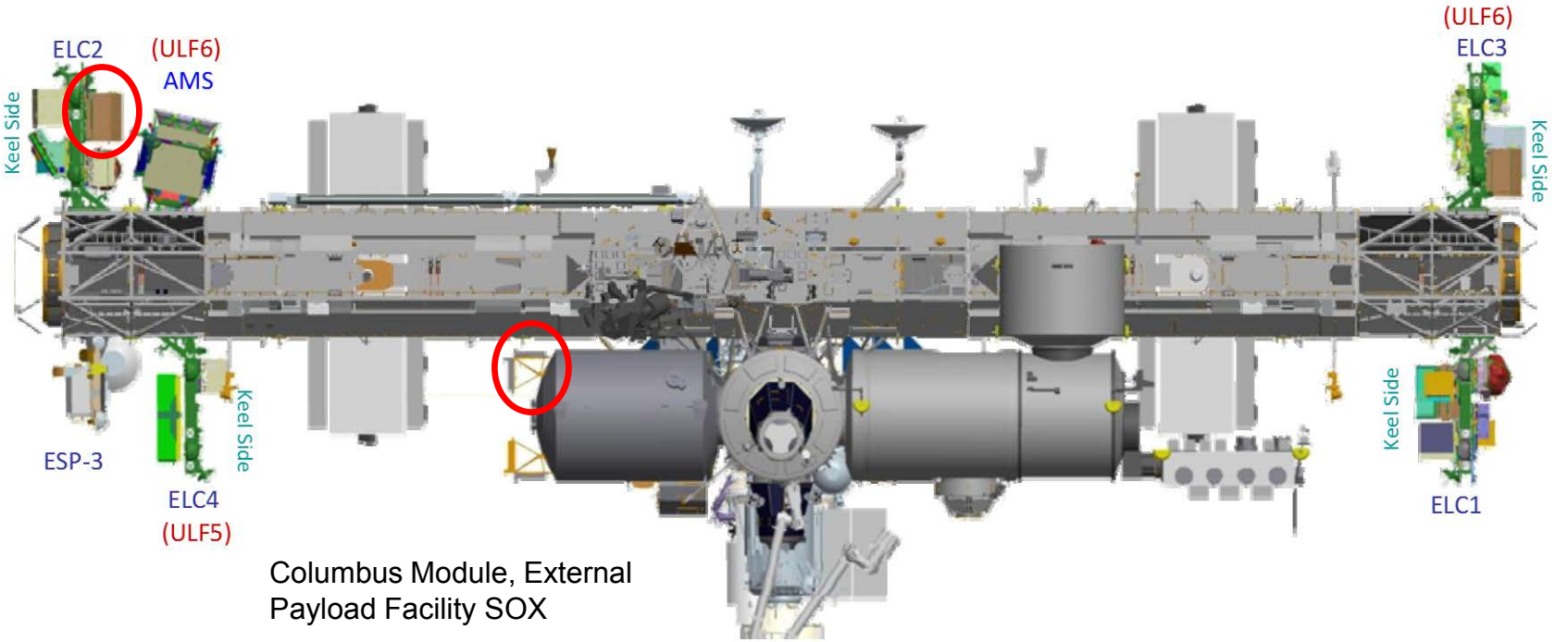


DRAGONS

- **Two potential flight opportunities**
  - ISS Technology Demonstration Office
  - DOD Space Test Program – higher altitude



DRAGONS Prototype



Columbus Module, External Payload Facility SOX

Orbital Debris Success Story

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Orbital Debris Success Story
A Decade in the Making

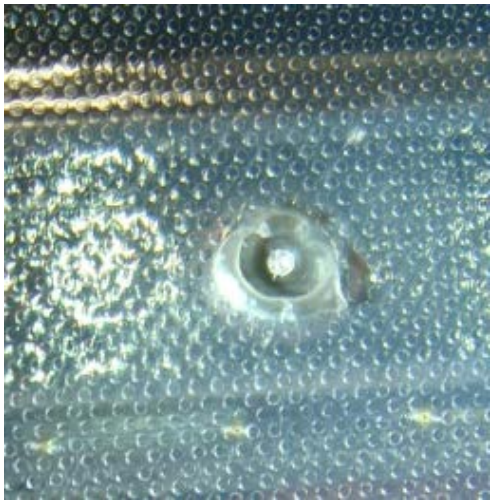
- **STS-128 post flight inspection found numerous small impact features including one on the payload bay radiators located directly above one of the Freon cooling loops;**

- **Basedonorbitaldebrismodelsandhypervelocityimpacttestsand evaluations,modificationstohardentheShuttlefromorbitaldebris impacts were approved in 1997 and implemented shortly after, including;**
  - **Adding aluminum "doubler" directly above the Freon cooling pipes; and**
  - **Installing automatic isolation valves.**

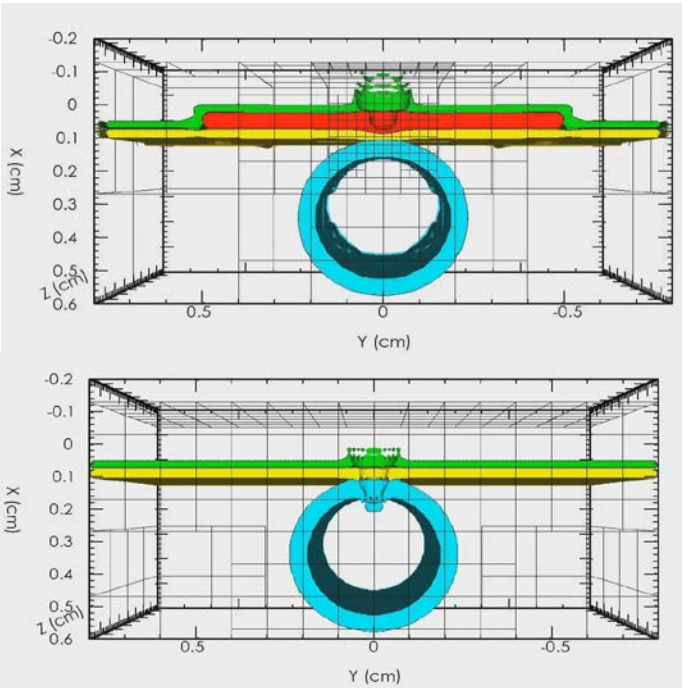
- **Without these modifications, the STS-128 impact would have potentially resulted in loss of half the cooling capacity of the Shuttle resulting in the Shuttle requirement to land within 24 hours with reduced avionics.**

STS-128 Radiator Impact

- **An impact occurred directly center on doubler, which protect the radiator flow tubes from MMOD**
  - **Impact crater penetrated through the thermal tape, completely through the 0.02 inch thick doubler, and damaged the facesheet below the doubler**
  - **Analysis indicates the same impact would have penetrated the flow tube if the doublers were not present**
  - **Doublers added in 1997-1999 time period, to provide additional protection for ISS missions**
  - **Conclusion: Doublers performed as designed/expected preventing a radiator tube puncture**



MMOD impact into Radiator LH1 doubler protecting flow-tubes
Crater diameter = 0.8 millimeters
Crater depth = 0.58 millimeters
Doubler thickness = 0.51 millimeters



Simulation of impact after two micro-seconds <u>with doubler</u>: crater through thermal tape (green) and penetration nearly through doubler (red)…i.e., similar to actual damage.

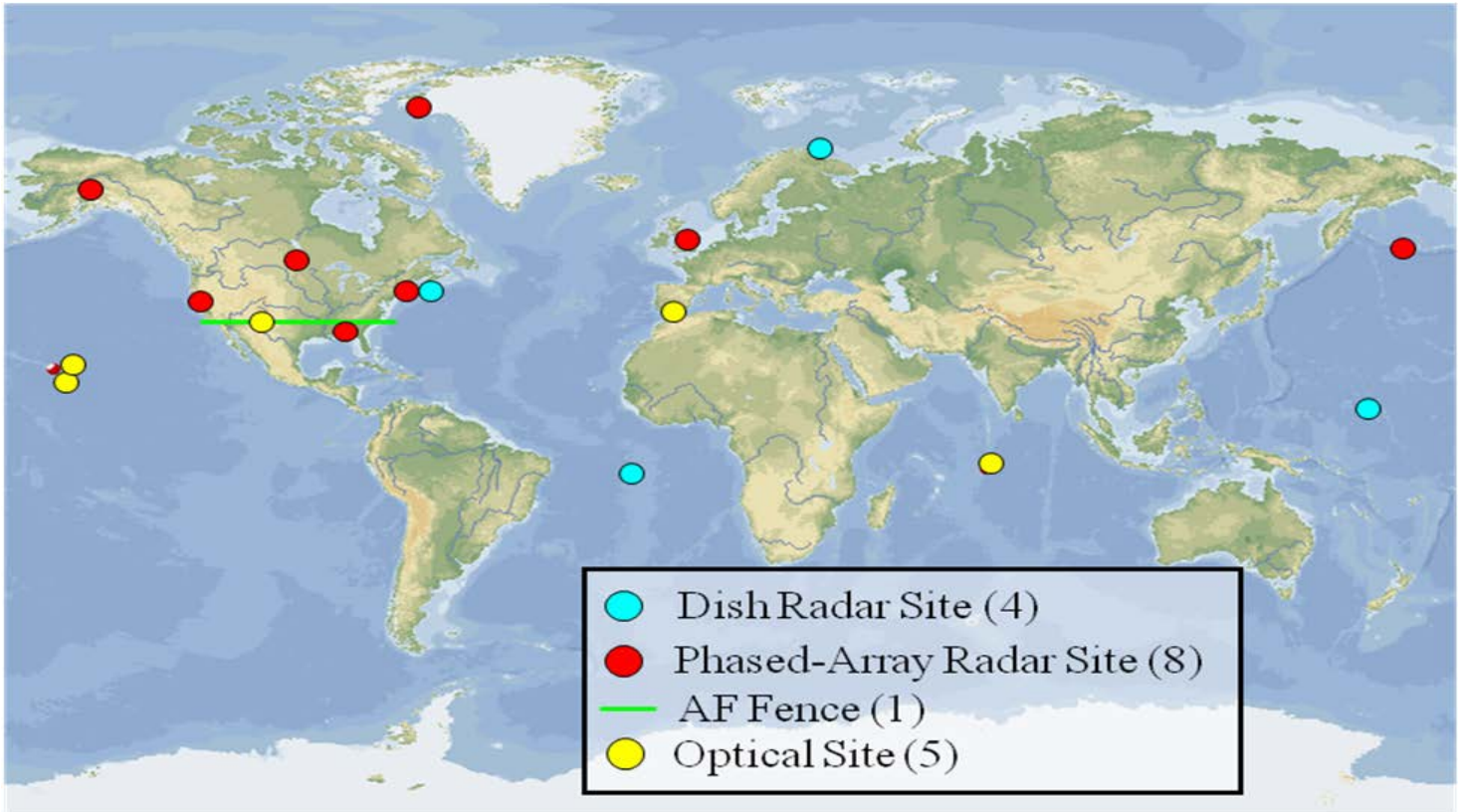
Simulation of same impact after two micro-seconds <u>without doubler</u>: crater through thermal tape (green), through facesheet (yellow) and through flow tube wall (blue)…i.e., leak would have occurred without doubler.

For more information – see our website at http://orbitaldebris.jsc.nasa.gov/

Backup Slides

U.S. Space Surveillance Network

- **The Department of Defense operates the U.S. Space Surveillance Network, which is comprised of radars and electro-optical sensors around the world, and maintains the official U.S. Satellite Catalog.**
  - Objects as small as 5-10 centimeters in low Earth orbit
  - Objects as small as approximately 1 meter in geosynchronous orbit



U.S. Space Surveillance Network (2)

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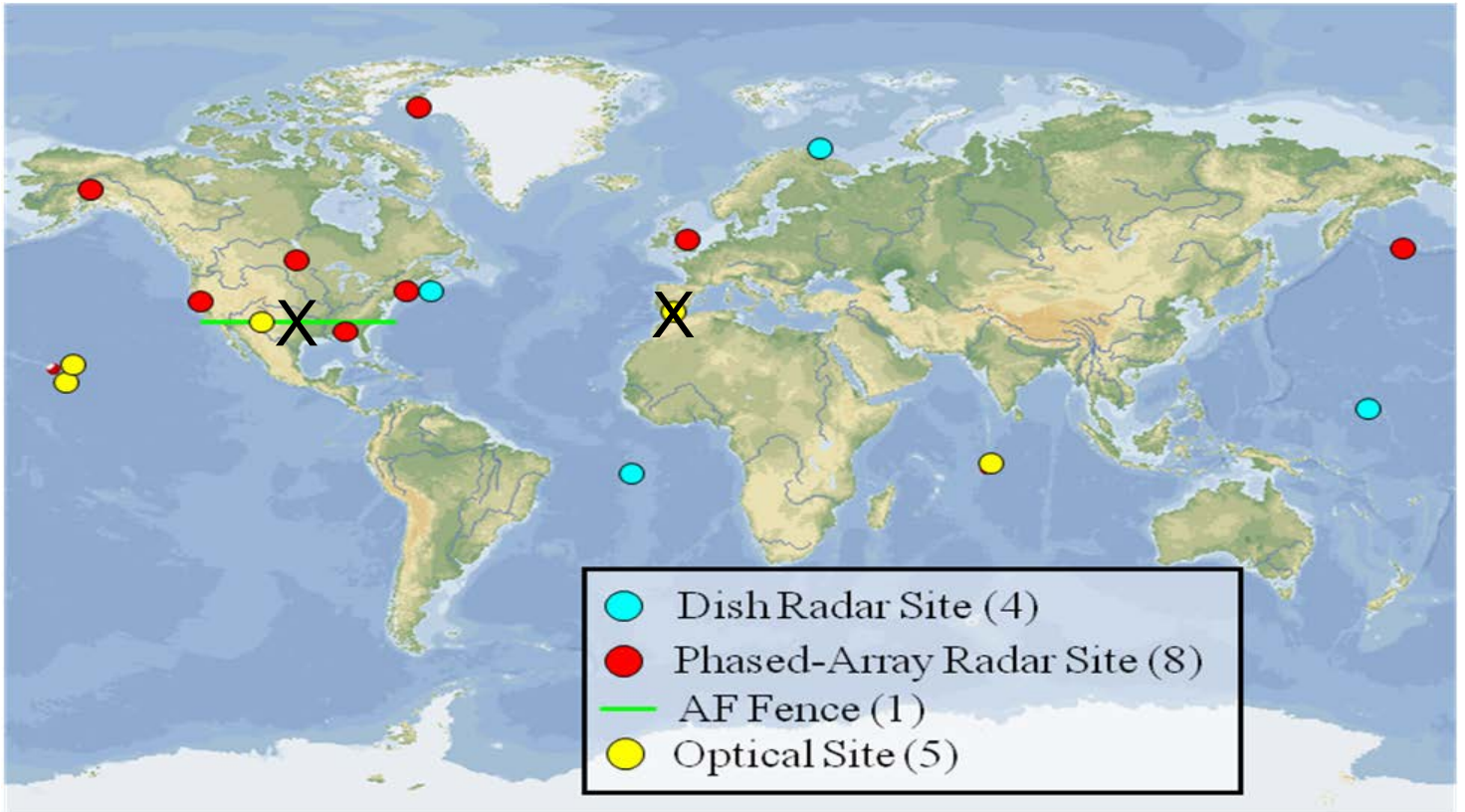


United Nations COPUOS STSC Space Debris Mitigation Guidelines

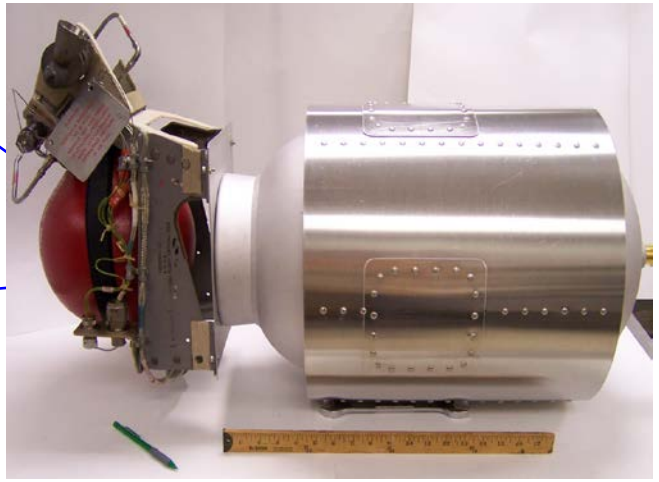
- **The 2007 U.N. COPUOS Scientific and Technical Subcommittee's Space Debris Mitigation Guidelines contains seven numbered guidelines**
  - Guideline 1: Limit debris released during normal operations;
  - Guideline 2: Minimize the potential for break-ups during operational phases;
  - Guideline 3: Limit the probability of accidental collision in orbit;
  - Guideline 4: Avoid intentional destruction and other harmful activities;
  - Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy;
  - Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission; and
  - Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with geosynchronous Earth orbit (GEO) region after the end of their mission

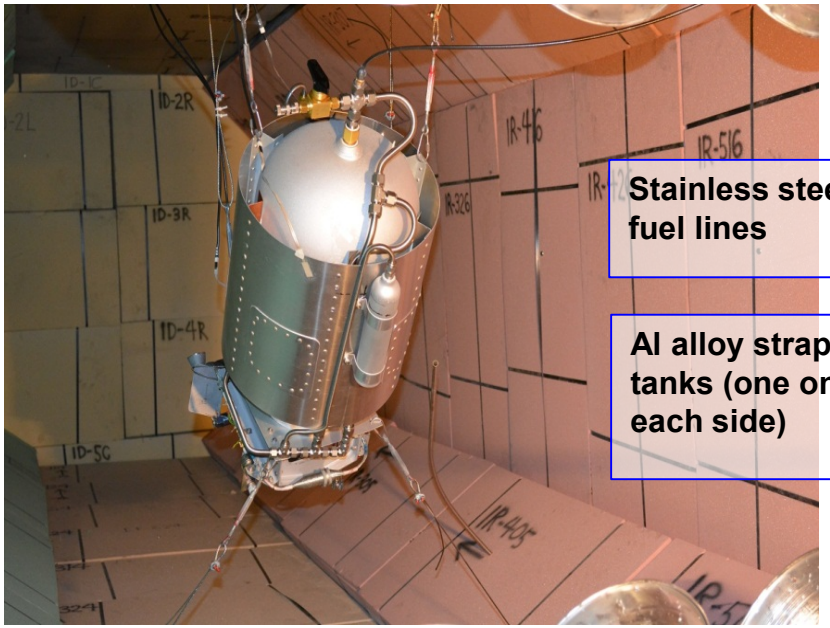
Debris LV Pre-Test Shot

- **To further increase the benefits of the project, Aerospace built a target resembling a launch vehicle upper stage ("Debris LV") for the pre-test shot**
  - Debris LV: 17.1 kilograms, body dimensions ~ 88 centimeters (length) by 35 centimeters (diameter)
  - Pre-test shot was successfully conducted on April 1st
  - Projectile impacted Debris LV at 6.9 kilometers per second and completly fragmented Debris LV

Delta-II Ti roll control thruster assembly

Al alloy tank (xenon 15 psia) and Al alloy skin





Stainless steel fuel lines

Al alloy strap-on tanks (one on each side)