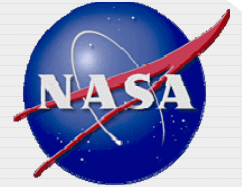


Risks from Orbital Debris and Space Situational Awareness

J.-C. Liou, PhD

**Chief Scientist for Orbital Debris
National Aeronautics and Space Administration**

**2nd IAA Conference on Space Situational Awareness
Washington DC, January 14-16, 2020**

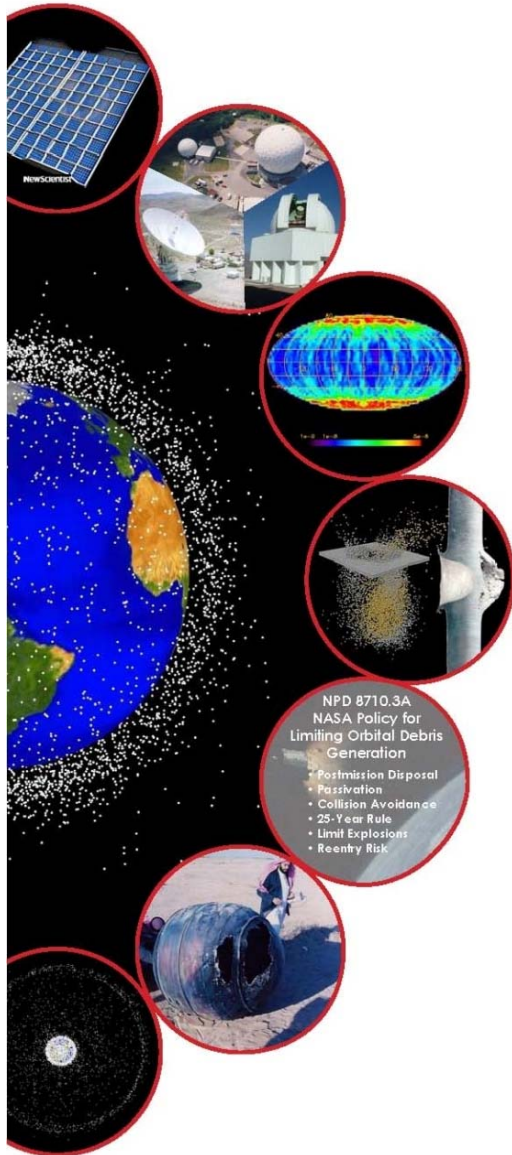
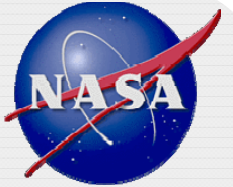


Outline

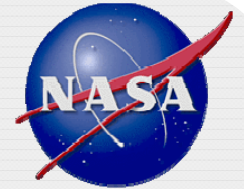
- **The NASA Orbital Debris Program Office (ODPO)**
- **The orbital debris (OD) problem**
 - The environment
 - Long-term population growth
 - Risks to space missions
- **Space situational awareness (SSA) and risks from small debris**

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

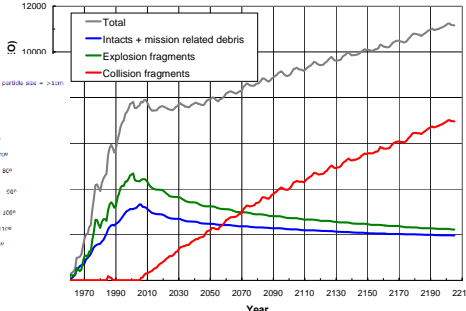
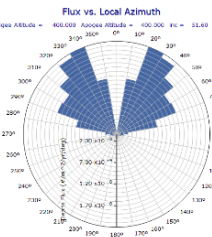
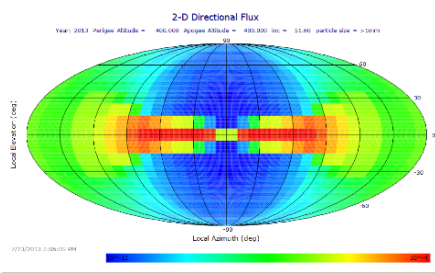
NASA Orbital Debris Program Office (ODPO)



- **The ODPO is the only organization in the U.S. government (USG) 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 NASA Procedural Requirements NPR 8715.6B
- **ODPO provides technical and policy level support to NASA HQ, OSTP, NSpC, and other USG and commercial organizations**
- **ODPO represents the USG in international fora (IADC, ISO, United Nations, *etc.*)**
- **ODPO is recognized as a pioneer and 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

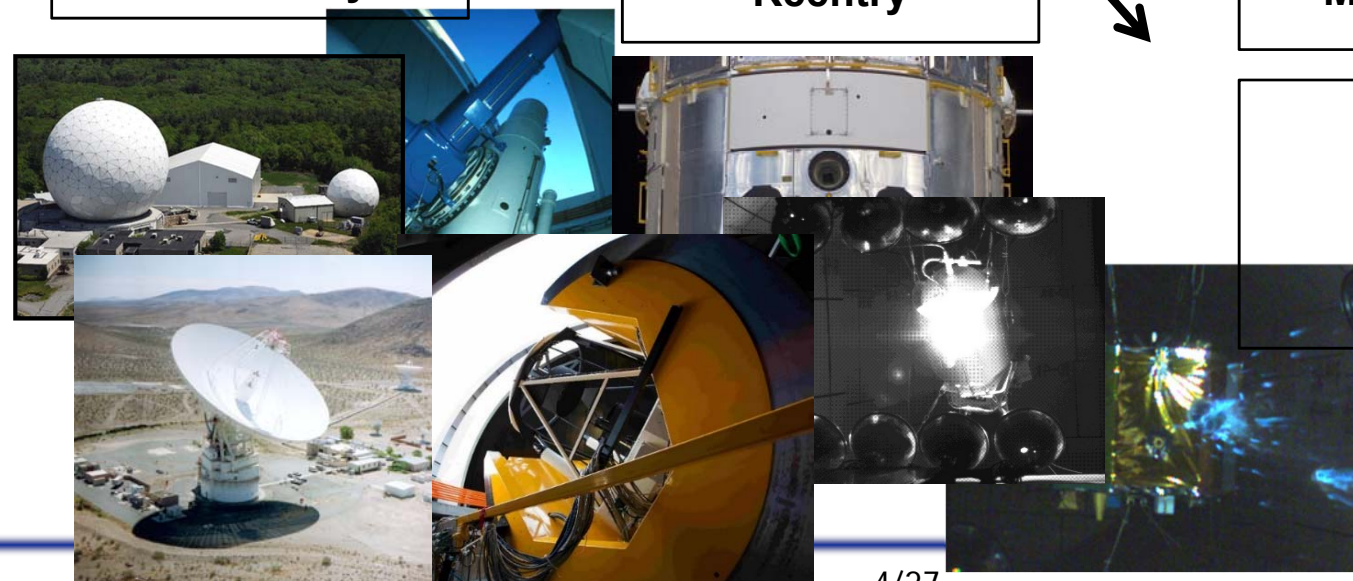
**Breakup
Engineering
Evolutionary
Reentry**

Environment Management

**Mitigation
Remediation
Policy
Mission Requirements**

Coordination

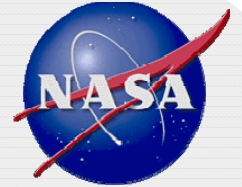
**U.S. government
IADC, ISO
United Nations**





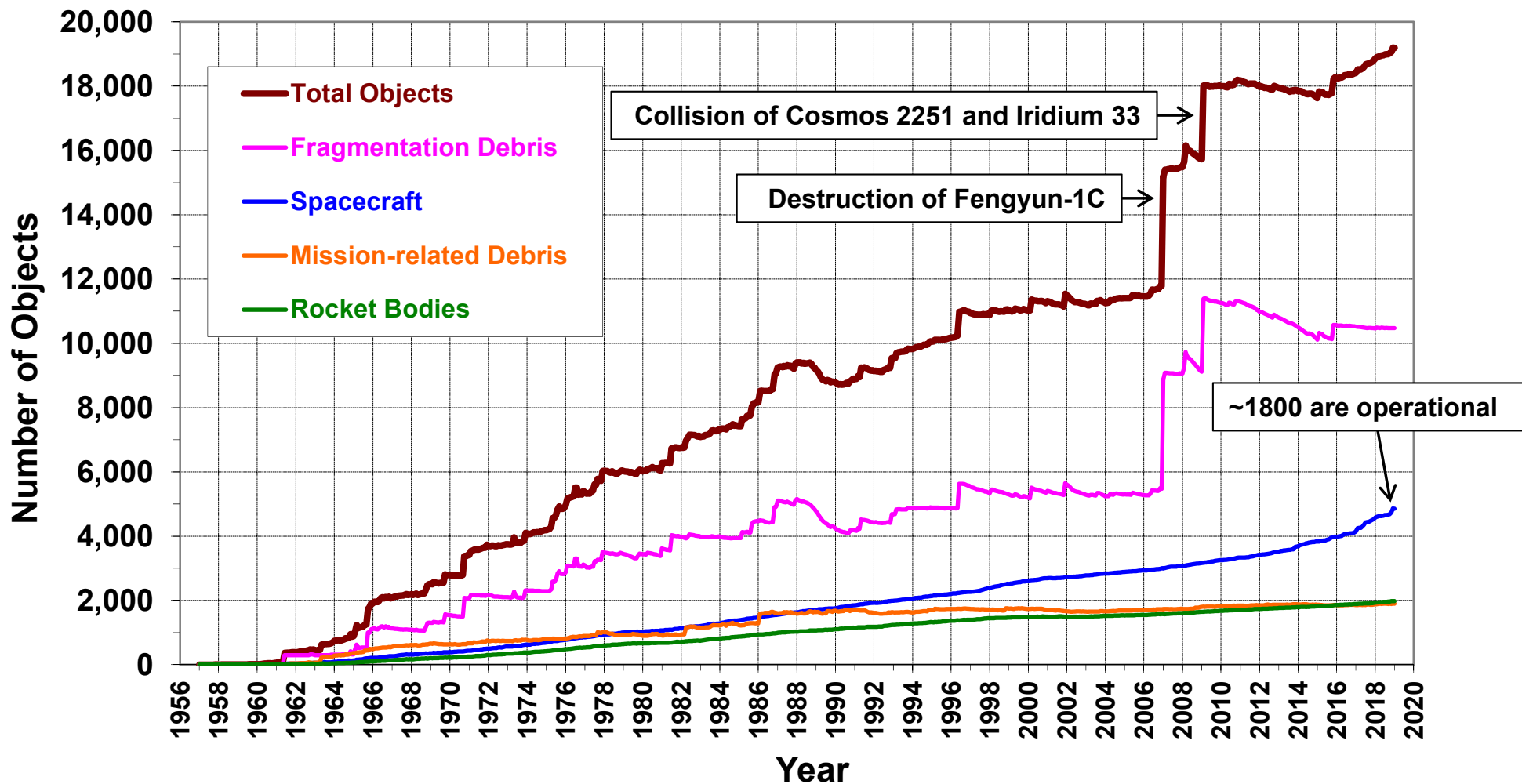
The Orbital Debris Problem

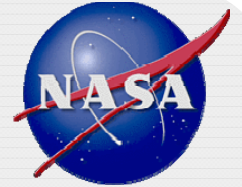




Growth of the Cataloged Populations

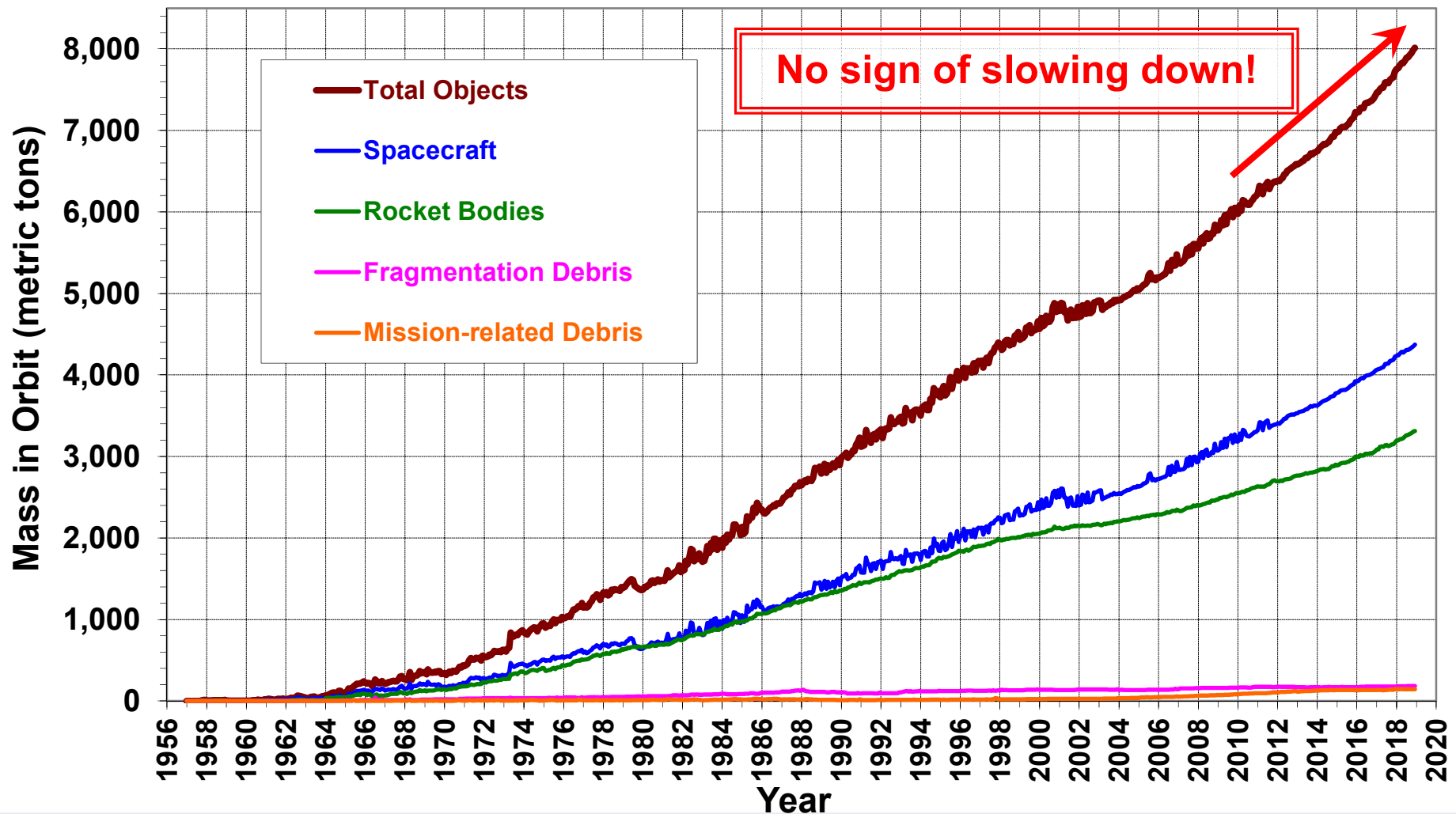
- The U.S. Combined Space Operations Center (CSpOC) tracks ~23,000 large objects and catalogs most of their orbits

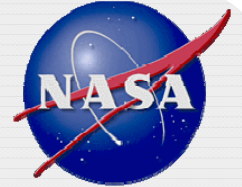




Mass in Orbit Continues to Increase

- The material mass in Earth orbit continues to increase and has exceeded 8000 metric tons





How Much Orbital Debris is Up There?

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



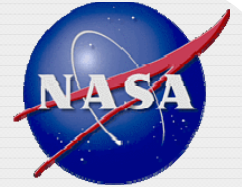
Marble size or larger (≥ 1 cm): ~500,000



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

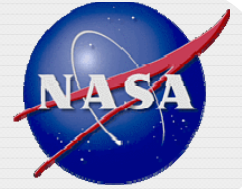


- Due to high impact speed in space (~10 km/sec in LEO), even **sub-millimeter** debris pose a realistic threat to human spaceflight and robotic missions
 - 10 km/sec = 22,000 miles per hour (the speed of a bullet ~1,500 miles per hour)
- **Mission-ending threat is dominated by small (mm-to-cm sized) debris impacts**
- Total mass: >8000 tons LEO-to-GEO (~3000 tons in LEO)

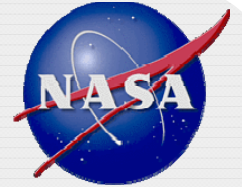


The Orbital Debris Problems

- The long-term problem: The OD population continues to increase over time despite decades of efforts to **limit the generation of new debris**
- The near-term problem: **Mission-end risk** for most operational spacecraft is driven by **small, millimeter-sized debris**



The Long-term Orbital Debris Problem



The Long-term OD Problem

- **The long-term problem: The OD population continues to increase over time **despite decades of efforts to limit the generation of new debris*****
 - U.S.: NASA OD Mitigation Guidelines (1995), U.S. Government OD Mitigation Standard Practices (2001, 2019), *etc.*
 - International: IADC Space Debris Mitigation Guidelines (2002), UN COPUOS Space Debris Mitigation Guidelines (2007), *etc.*

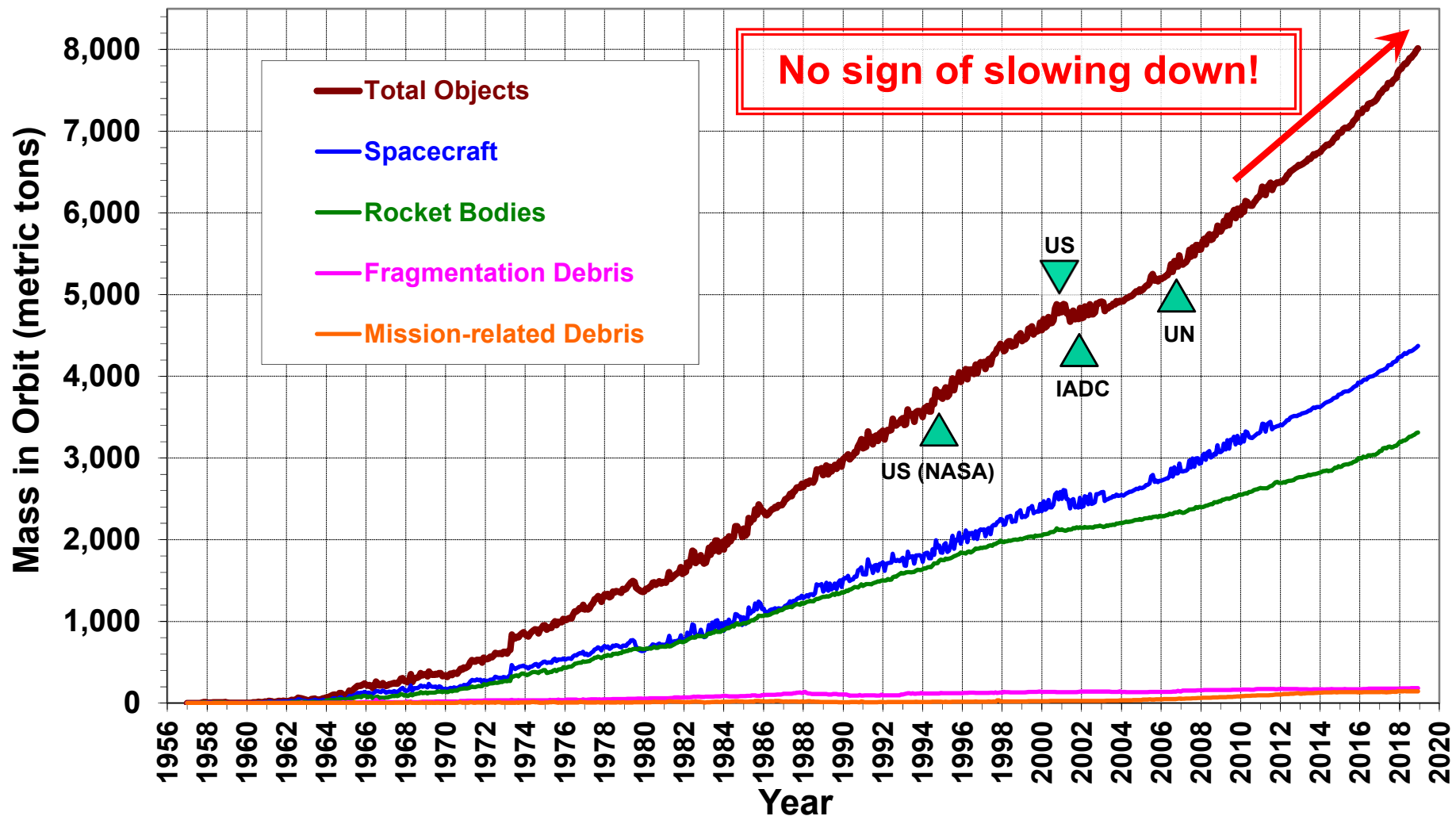
***Four guiding principles of OD mitigation to limit the generation of new debris**

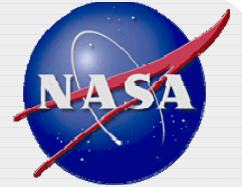
- **Limit mission-related debris (adapter rings, payload covers, *etc.*)**
- **Minimize accidental explosions**
- **Avoid accidental collisions**
- **Follow post-mission disposal (the 25-year rule, *etc.*)**



OD Mitigation and Population Increase

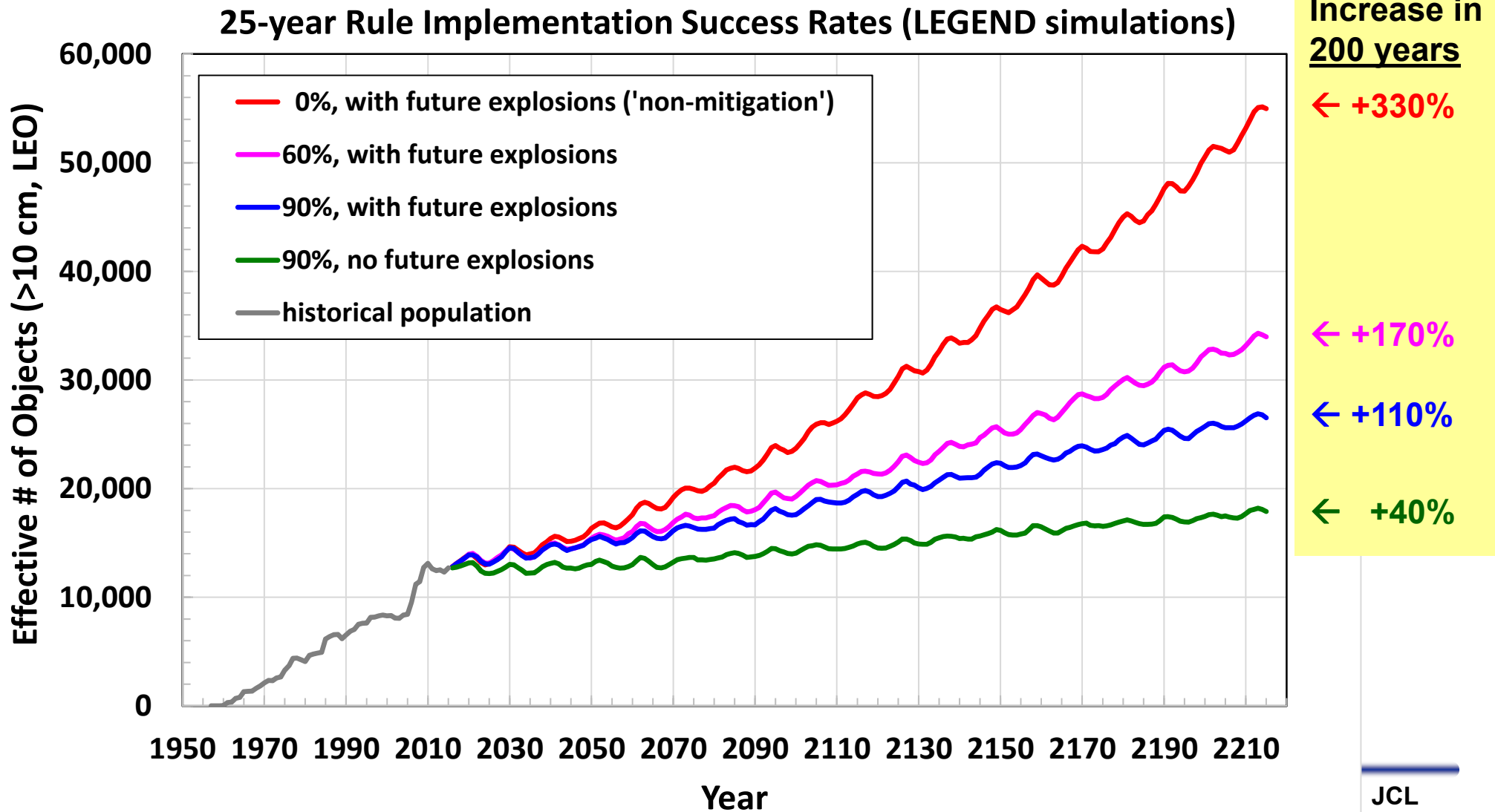
- Green triangles indicate when key OD mitigation requirements, standard practices, and guidelines were first established

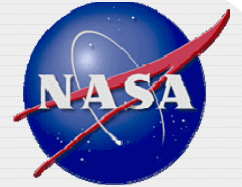




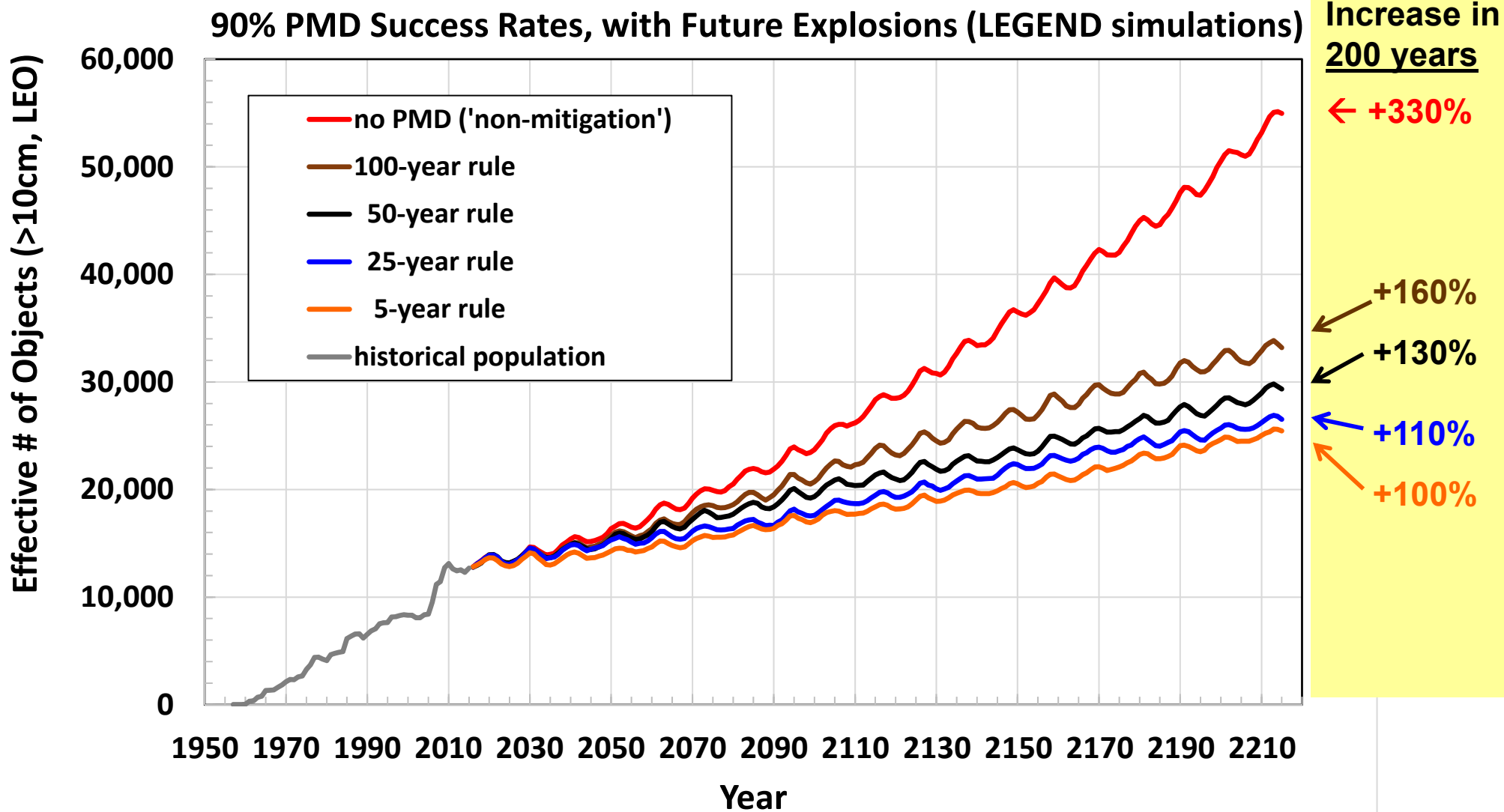
Projected Future OD Population Increase

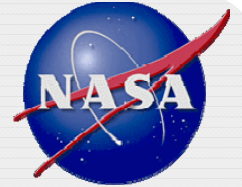
- A good implementation of the **existing** OD mitigation measures can significantly limit the future OD population increase





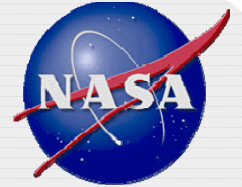
Effectiveness of the 25-year Rule





Managing the Long-term OD Problem

- **“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 from happening than it is to deal with it after it has happened.
- **Orbital Debris Mitigation = Prevention**
- **Orbital Debris Remediation = Cure**



Mitigation and Remediation

- **The Space Policy Directive-3 (SPD-3)**
 - SPD-3, the National Space Traffic Management Policy, contains key references and guidelines specific to orbital debris

SPD-3: Sec. 4. Goals

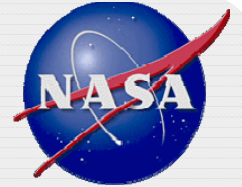
*“It is in the interest of all to minimize new debris and mitigate effects of existing debris. This fact, along with increasing numbers of active satellites, highlights **the need to update existing orbital debris mitigation guidelines and practices to enable more efficient and effective compliance, and establish standards that can be adopted internationally.**”*

SPD-3: Sec. 5. Guidelines

*“**The United States should pursue active debris removal as a necessary long-term approach to ensure the safety of flight operations in key orbital regimes. This effort should not detract from continuing to advance international protocols for debris mitigation associated with current programs.**”*



The Near-term Orbital Debris Problem



The Near-term OD Problem

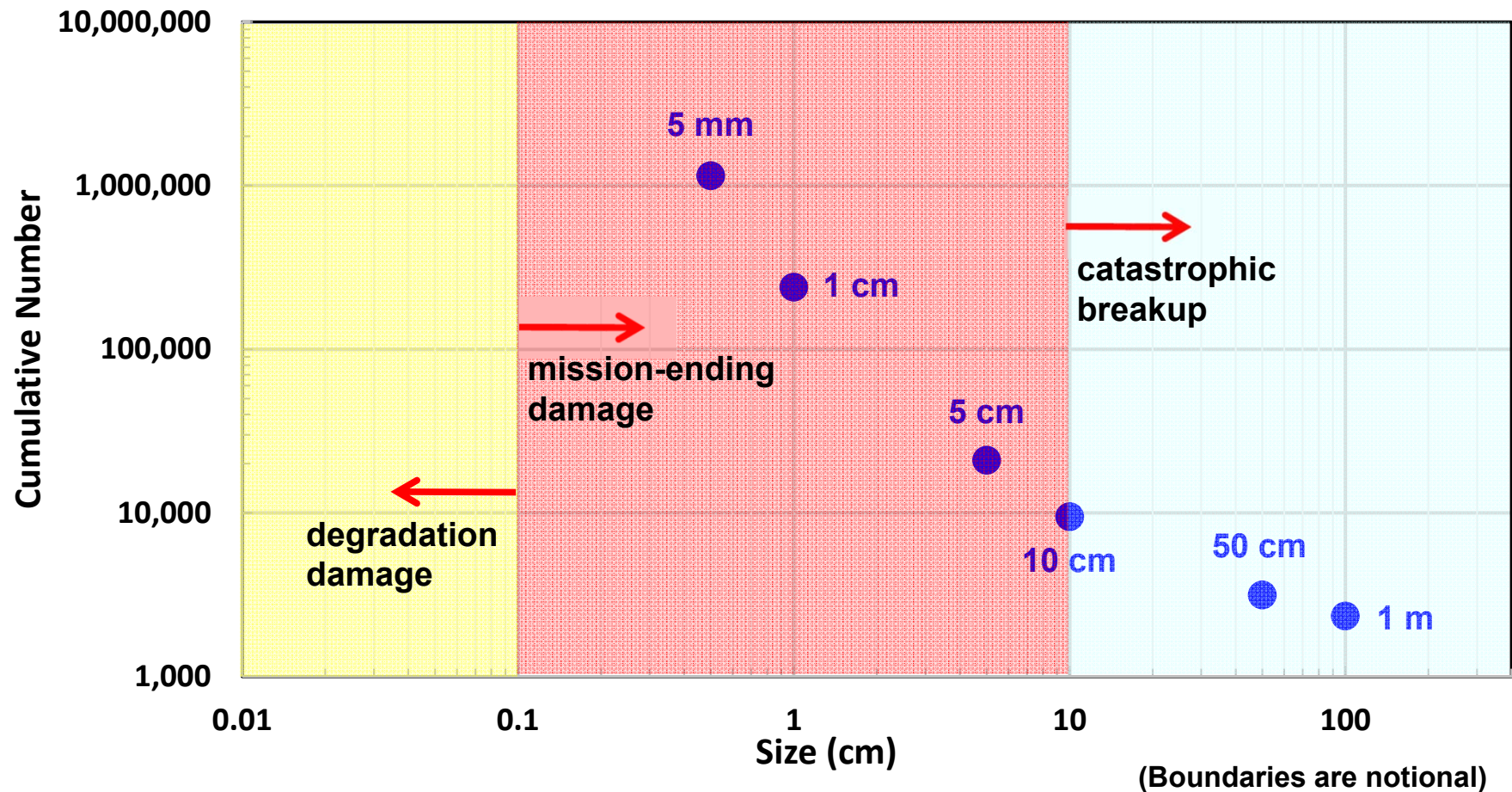
- **The near-term problem: Mission-end risk for most operational spacecraft is driven by small, millimeter-sized debris**
 - The orbital debris population follows a power-law size distribution. This means there is significantly more small debris than large debris. Therefore, **mission-ending risk is always dominated by small debris impacts.**
 - **Conjunction assessments** and potential collision avoidance maneuvers against the tracked objects (which are typically 10 cm and larger) **only address a small fraction (<1%) of the orbital debris impact risk.**



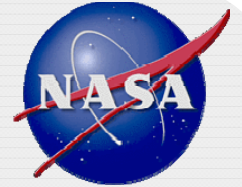
Orbital Debris Size Distribution



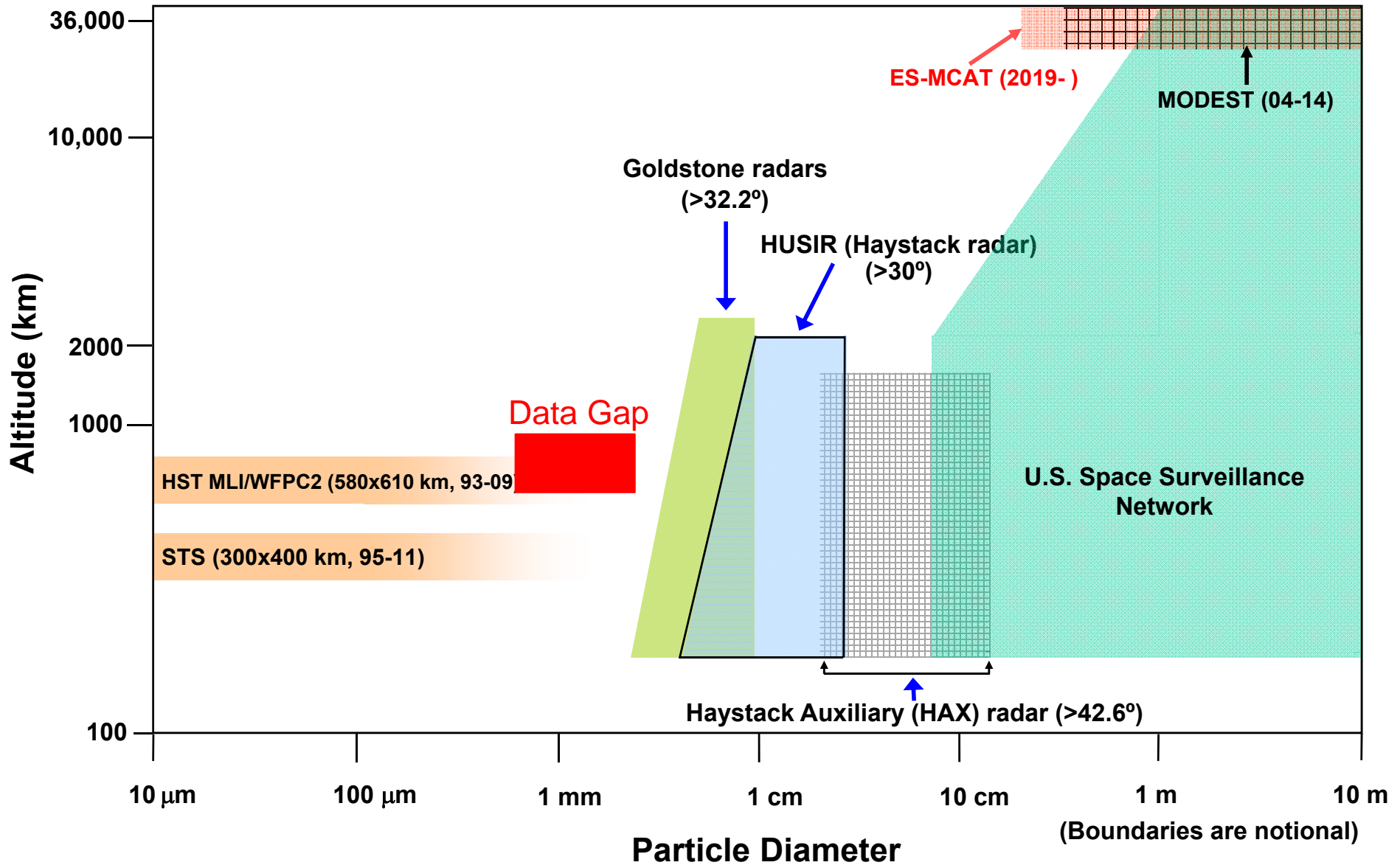
Notional Cumulative Size Distribution of Current LEO-Crossing Objects

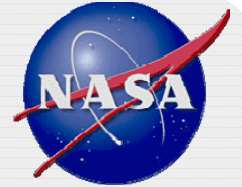


There is more small debris than large debris to cause mission-ending damage



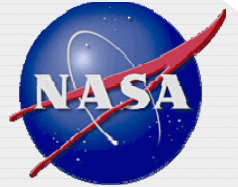
Current NASA Orbital Debris Database





Top OD Risk to Space Missions in LEO (1/2)

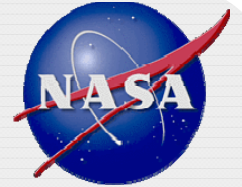
- **Millimeter-sized orbital debris represents the highest penetration risk to most operational (robotic) spacecraft in low Earth orbit (LEO)**
 - As concluded by a recent NASA Engineering and Safety Center (NESC) panel study (NASA/TM 2015-218780)
- **Currently, more than 400 missions operate between 600 and 1000 km altitudes**
- **There is a lack of data on such small debris above 600 km altitude**
 - Direct measurement data on such small debris is needed to support the development and implementation of **cost-effective protective measures** for the safe operations of future missions



Top OD Risk to Space Missions in LEO (2/2)

- **The 2015 NESC study 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.***



Space Situational Awareness (SSA)

- **SPD-3: Sec. 2. Definitions**

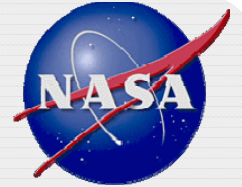
“(a) *Space Situational Awareness* shall mean the knowledge and characterization of space objects and their operational environment to support *safe, stable, and sustainable* space activities.”



SSA on Small Debris

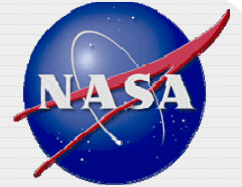
- **SPD-3: Sec. 4. Goals**

“(a) Advance SSA and STM Science and Technology. The United States should continue to engage in and enable S&T research and development to support the practical applications of SSA and STM. These activities include **improving fundamental knowledge of the space environment, such as the characterization of small debris...**”



Large and Small Debris Risk Mitigation

	Large/trackable debris	Debris too small and/or too numerous to be tracked
Observe	Collect measurement data (radars, telescopes, <i>etc.</i>)	Collect measurement data (radar, telescopes, in-situ, <i>etc.</i>)
Assess	Calculate the <u>probability</u> of conjunction (collision)	Calculate the <u>probability</u> of mission-ending impact damage
Mitigate	<ol style="list-style-type: none"> 1. Accept the risk or 2. Conduct avoidance maneuver to mitigate the risk 	<ol style="list-style-type: none"> 1. Accept the risk or 2. Implement cost-effective impact protective shielding to mitigate the risk
Time of Actions	During mission operations	During mission design and development

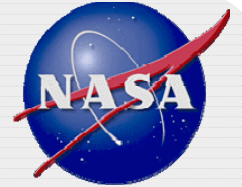


STM, SSA, and Risks from Small Debris

- **SPD-3: Sec. 2. Definitions**

“(b) *Space Traffic Management* shall mean the planning, coordination, and on-orbit synchronization of activities to enhance the *safety, stability, and sustainability* of operations in the space environment.”

- **If safety is a priority, orbital debris is a priority**
- **If safety is a priority, SSA on small, millimeter-sized orbital debris is a priority**



Forward Challenges

- **There are two priorities to enhance the safety, stability, and sustainability of operations in the future space environment**
 - **Improve SSA on small debris**, especially the millimeter-sized orbital debris in LEO, to better protect future space missions
 - Improve existing OD mitigation best practices and **promote better global compliance** to slow down the debris population growth for the long-term sustainability of near-Earth space activities