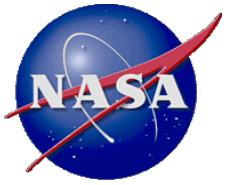
National Aeronautics and Space Administration



Orbital Debris Mitigation and Challenges to the Space Community

J.-C. Liou, PhD

Chief Scientist for Orbital Debris
National Aeronautics and Space Administration

Keynote at the Space Disposal and Debris Mitigation Conference

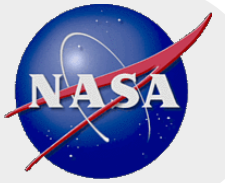
10 March 2021

Outline



- **Introduction**
  - The NASA Orbital Debris Program Office (ODPO)
  - Current orbital debris environment
- **Orbital debris (OD) mitigation in the U.S. and at NASA**
- **The OD problems and challenges**
  - Long-term population growth
  - Risks to space missions
  - Forward challenges

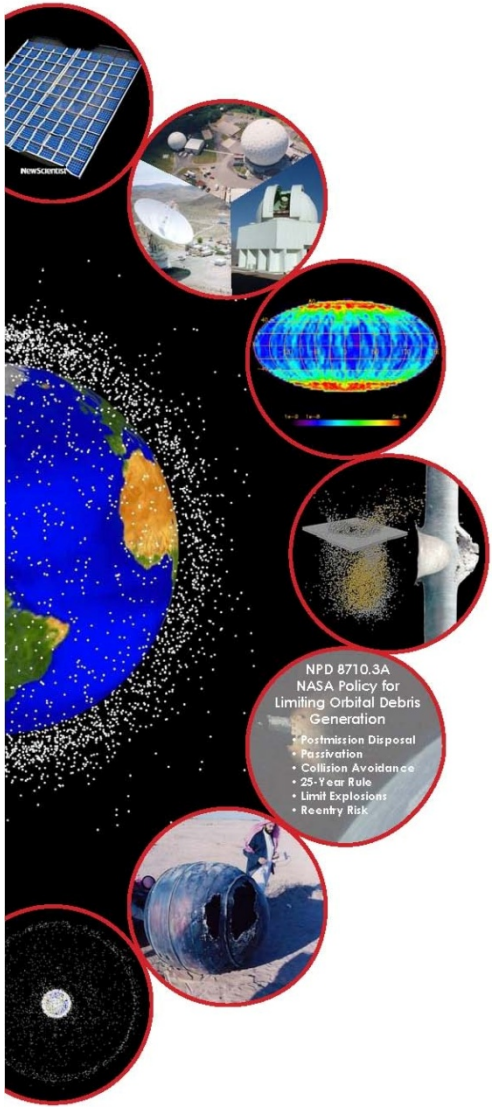
Orbital debris = human-made debris in Earth orbit
Space debris = micrometeoroids and orbital debris (MMOD)



Introduction

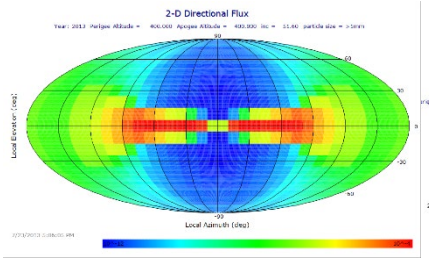
- ODPO and the Current Debris Environment

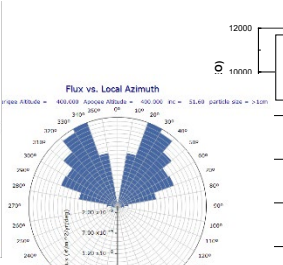
NASA Orbital Debris Program Office (ODPO)

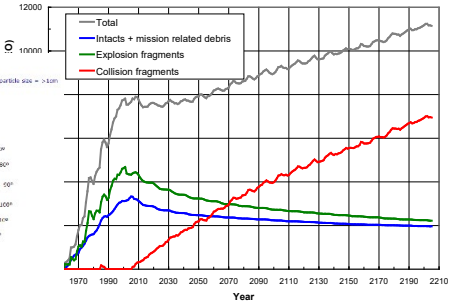


- **The ODPO is the only organization in the U.S. government (USG) conducting a full range of research on orbital debris**
  - This unique NASA capability was established at JSC in 1979 (D. Kessler, J. Loftus, B. Cour-Palais, *etc.*)
  - ODPO's roles and responsibilities are defined in NASA Procedural Requirements NPR 8715.6B
- **ODPO provides technical and policy level support to NASA HQ, OMB, 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

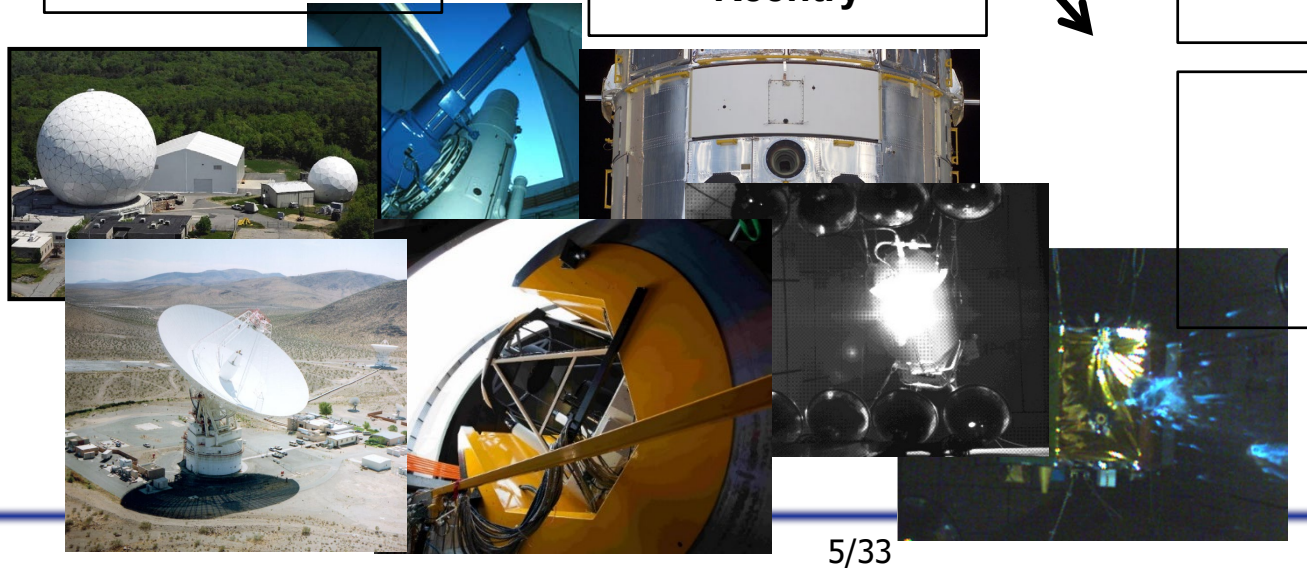
Breakup
Engineering
Evolutionary
Reentry

Environment Management

Mitigation
Remediation
Policy
Mission Requirements

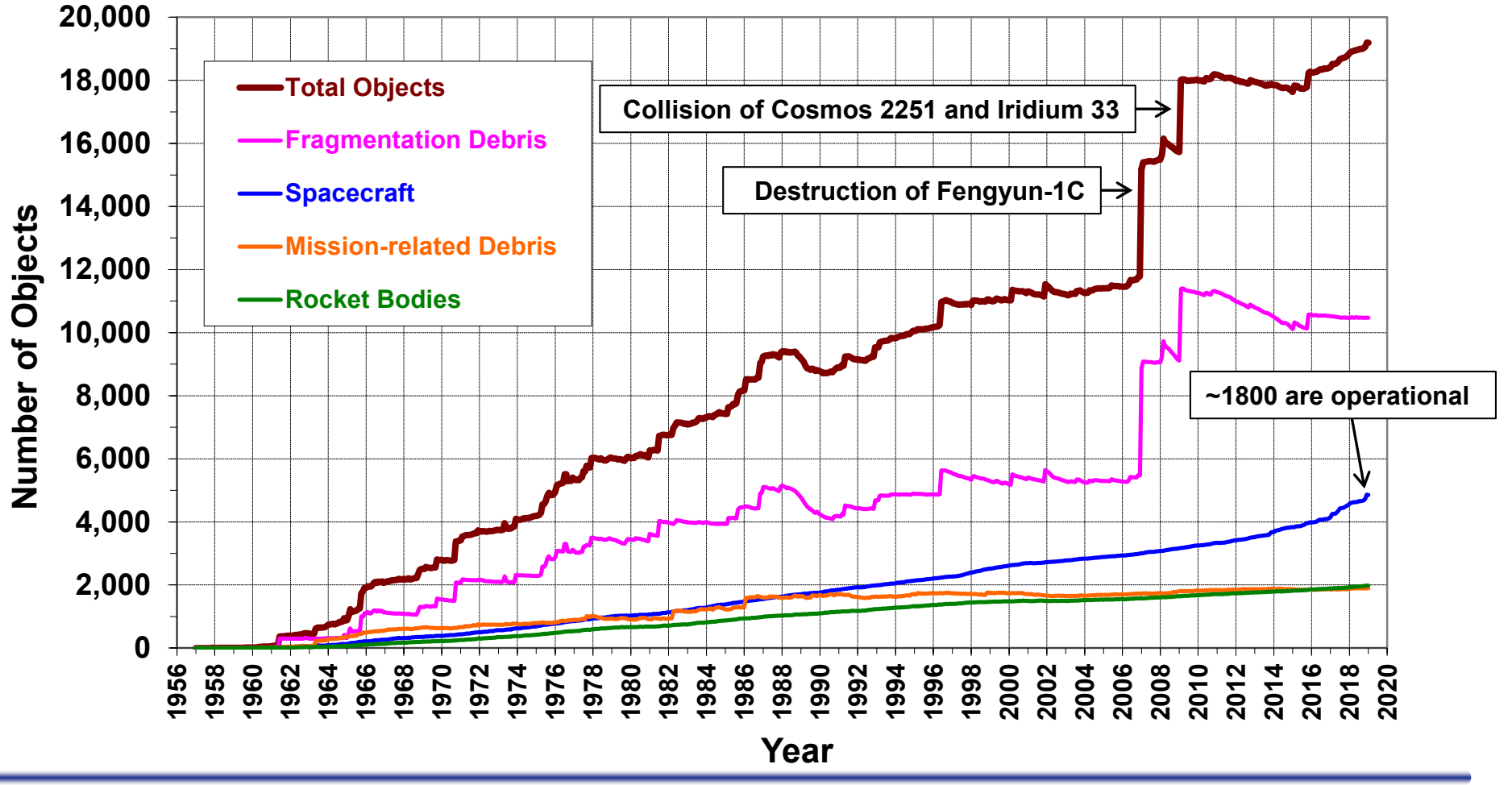
Coordination

U.S. Government
IADC, ISO
United Nations



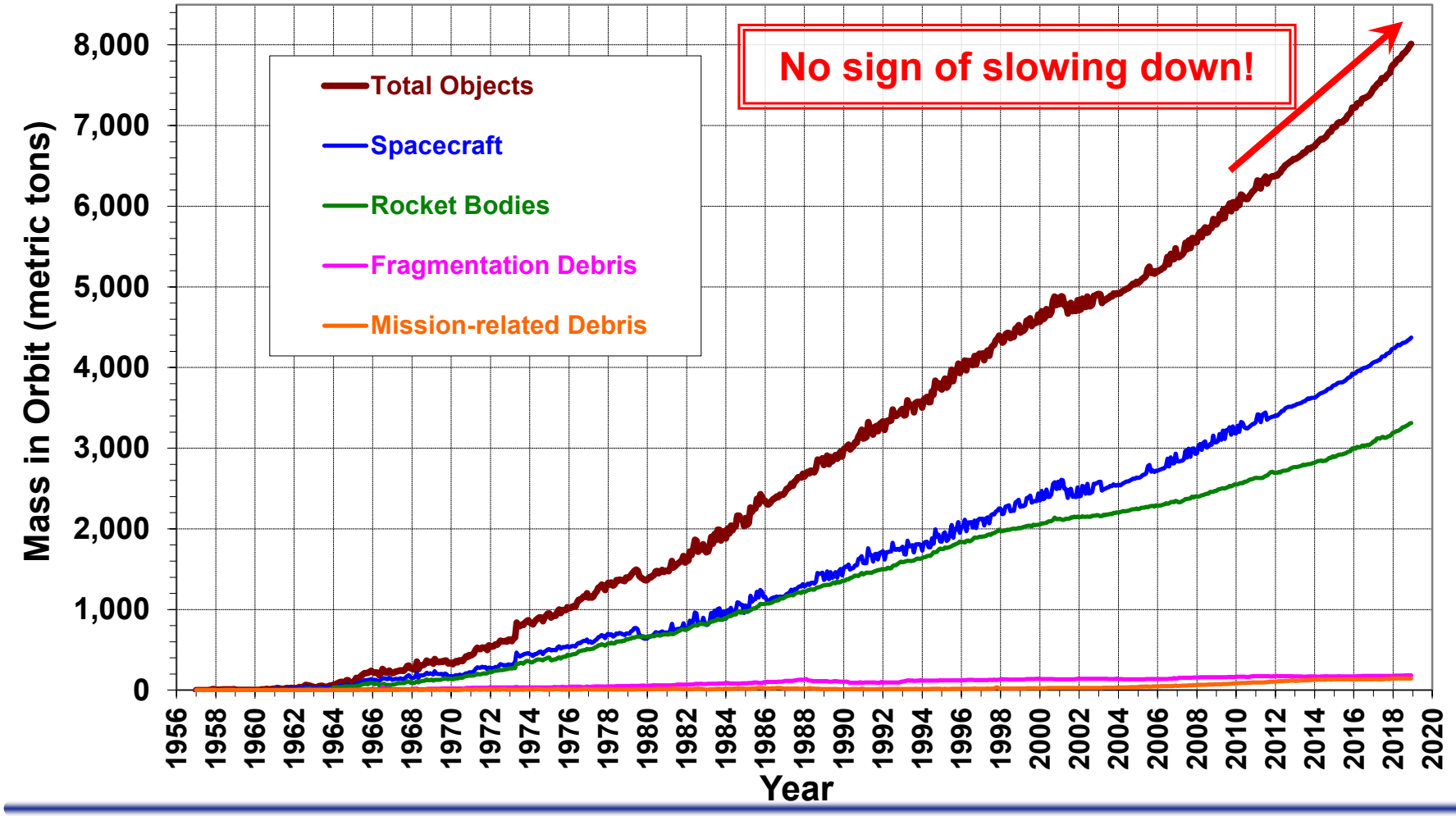
Growth of the Cataloged Populations

- **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 OD is Up There?



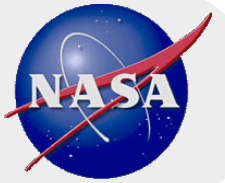
Softball size or larger (≥10 cm): ~23,000
(tracked by U.S. Combined Space Operations Center, CSpOC)



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

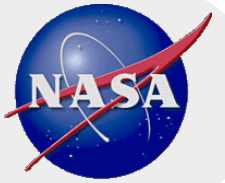
Dot or larger (≥1 mm): >100,000,000
(a grain of salt)

- **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: >8100 tons LEO-to-GEO (~3000 tons in LEO)**



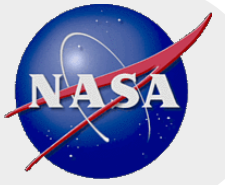
OD Mitigation in the United States and at NASA

OD Mitigation vs. Remediation



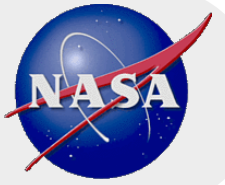
- **OD Mitigation = Prevention**
  - Limiting the generation of new debris
- **OD Remediation = Cure**
  - Dealing with objects that already exist in the environment (*i.e.*, active debris removal)

OD Mitigation in the United States (1/2)



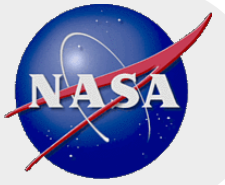
- **OD mitigation has been included in every U.S. National Space Policy since 1988 (1988, 1989, 1996, 2006, 2010, 2020)**
  - **1988**: "*The directive further states that all space sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness.*"
  - **2010**: "*For the purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall…Continue to follow the United States Government Orbital Debris Mitigation Standard Practices, consistent with mission requirements and cost effectiveness, in the procurement and operation of spacecraft, launch services, and the conduct of tests and experiments in space;*"

OD Mitigation in the United States (2/2)



- **OD mitigation has been included in every U.S. National Space Policy since 1988 (1988, 1989, 1996, 2006, 2010, 2020)**
  - **2020**: "*To preserve the space environment for responsible, peaceful, and safe use, and with a focus on minimizing space debris the United States shall…Limit the creation of new debris, consistent with mission requirements and cost effectiveness, during the procurement and operation of spacecraft, launch services, and conduct of tests and experiments in space by following and periodically updating the United States Government Orbital Debris Mitigation Standard Practices…*"

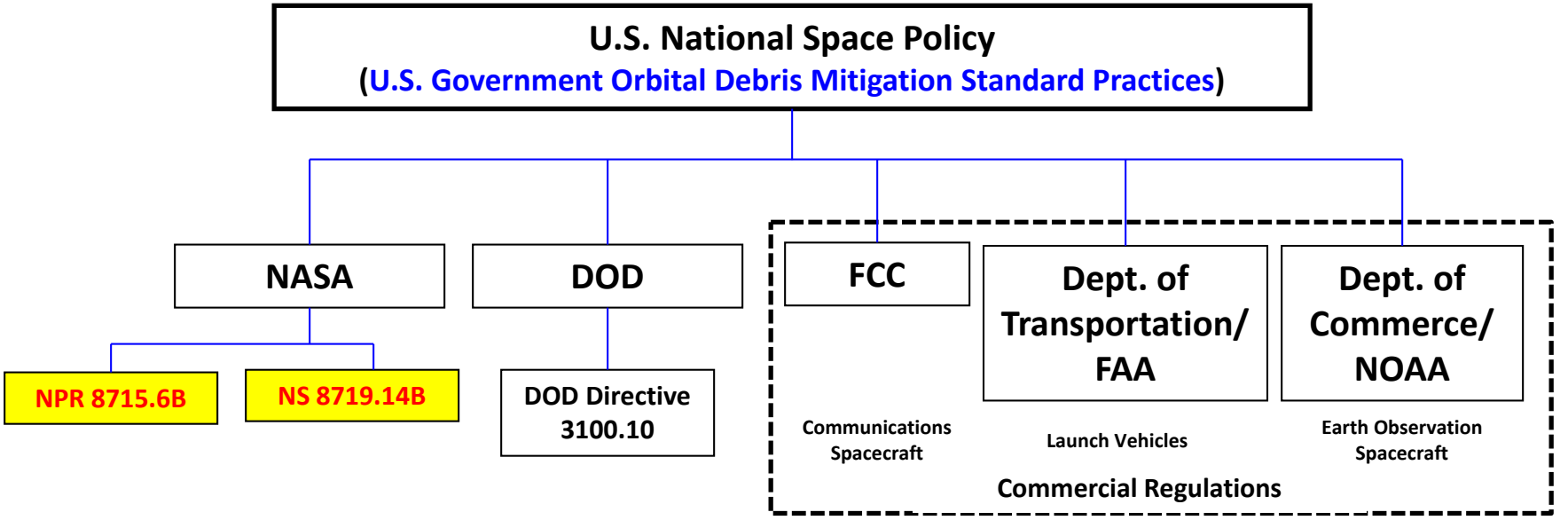
OD Mitigation at NASA



- **NASA was the first organization in the world to develop specific OD mitigation requirements for near-Earth space missions**
  - 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
    - **The 25-year rule for LEO-crossing upper stages and spacecraft**
    - **The 8 m^2 debris casualty area limit (derived from the 1:10,000 human casualty risk threshold) for random reentry events**
    - ***Etc.***

USG OD Mitigation Standard Practices (ODMSP)

- **NASA and the Department of Defense (DOD) led the effort to establish the original USG ODMSP in 2001. The ODMSP was updated in 2019.**
- **The U.S. National Space Policy (2006, 2010, 2020) directs USG departments and agencies to follow the ODMSP**

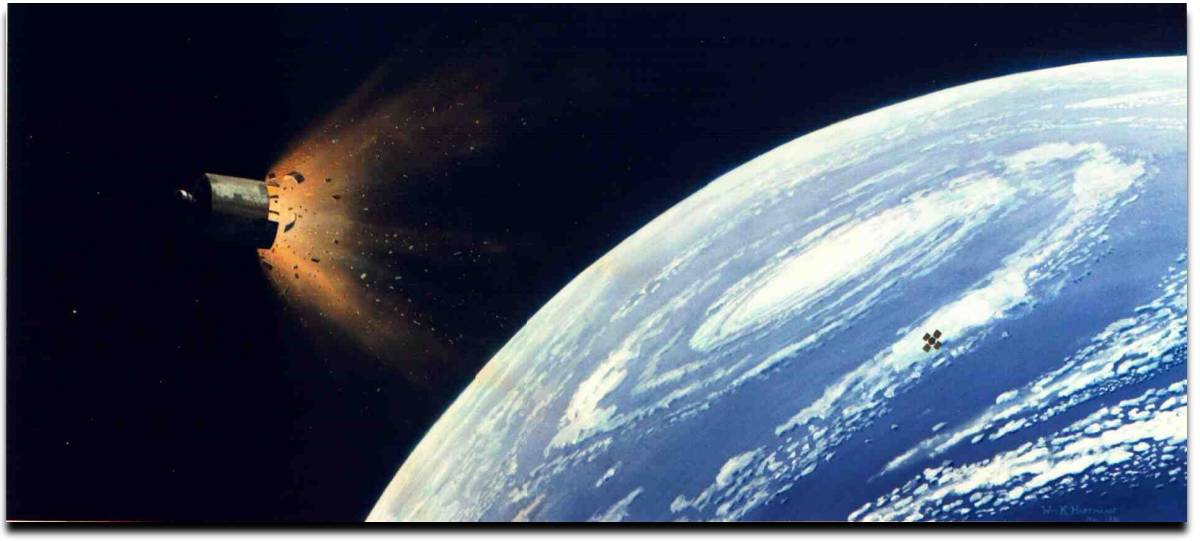


International OD Mitigation

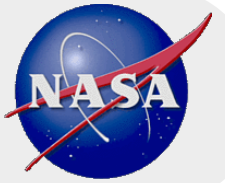
- **Inter-Agency Space Debris Coordination Committee (IADC)**
  - NASA, as the founding member of the IADC, was a major contributor to the development of the IADC Space Debris Mitigation Guidelines in 2002 and all the updates since that time
- **United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS)**
  - NASA, as a member of the U.S. delegation to the UN COPUOS, also supported the development of the COPUOS Space Debris Mitigation Guidelines (2007) and the Guidelines for the Long-term Sustainability of Outer Space Activities (2019)

Inter-Agency Space Debris Coordination Committee

The OD Problems

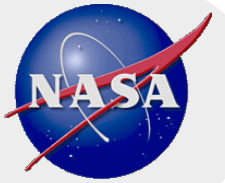


The OD Problems



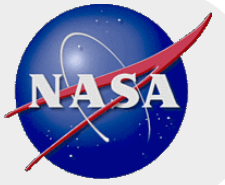
- **The long-term problem:** The OD population continues to increase over time despite decades of efforts to limit the generation of new debris

- **The near-term problem:** Mission-ending risk for most operational spacecraft is driven by small, millimeter-sized debris



The Long-term OD Problem

The Long-term OD Problem



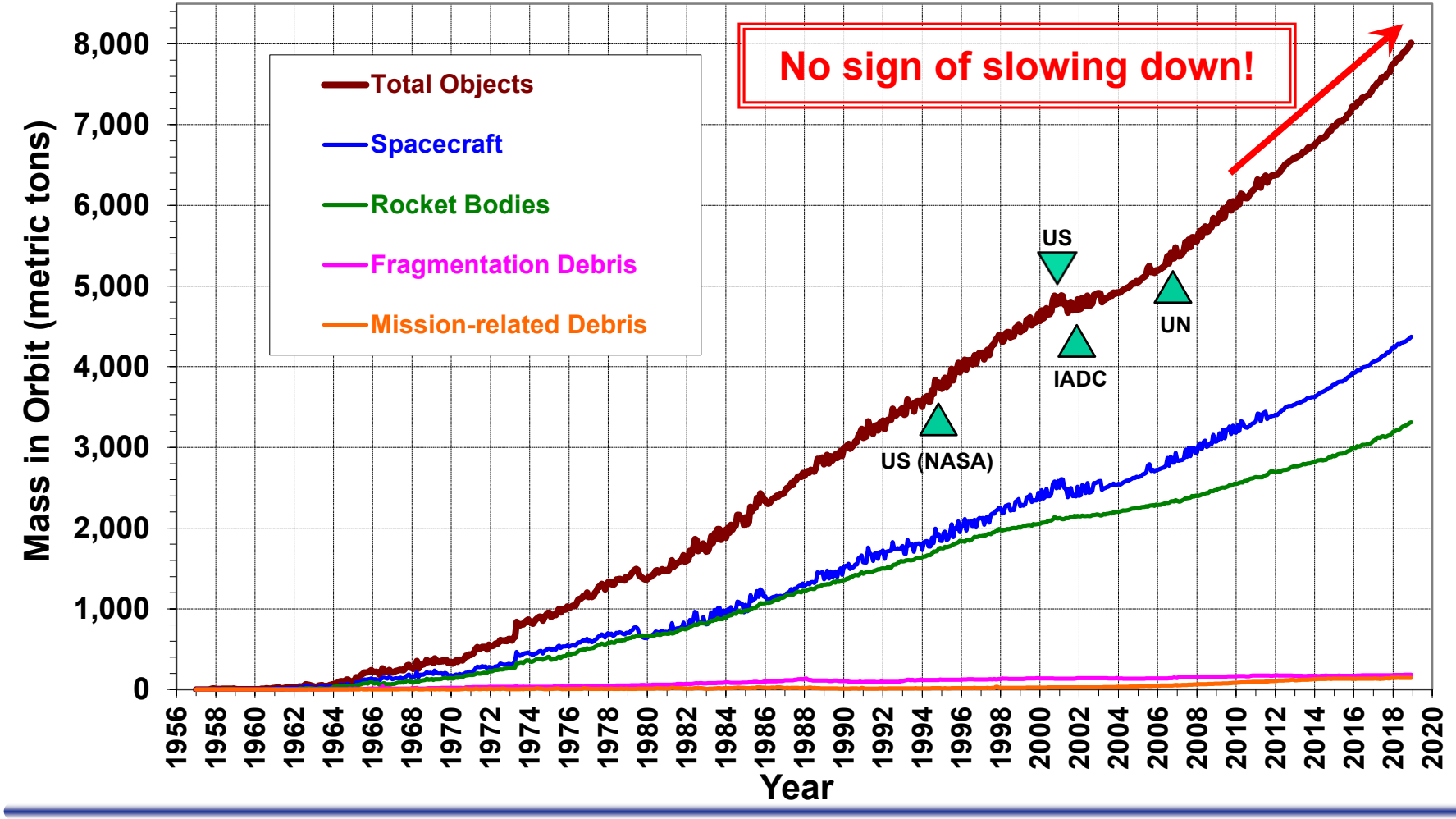
- **The long-term problem: The OD population continues to increase over time despite decades of efforts to limit the generation of new debris***
  - U.S.: NASA OD Mitigation Guidelines (1995), U.S. Government OD Mitigation Standard Practices (2001, 2019), *etc*.
  - International: IADC Space Debris Mitigation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

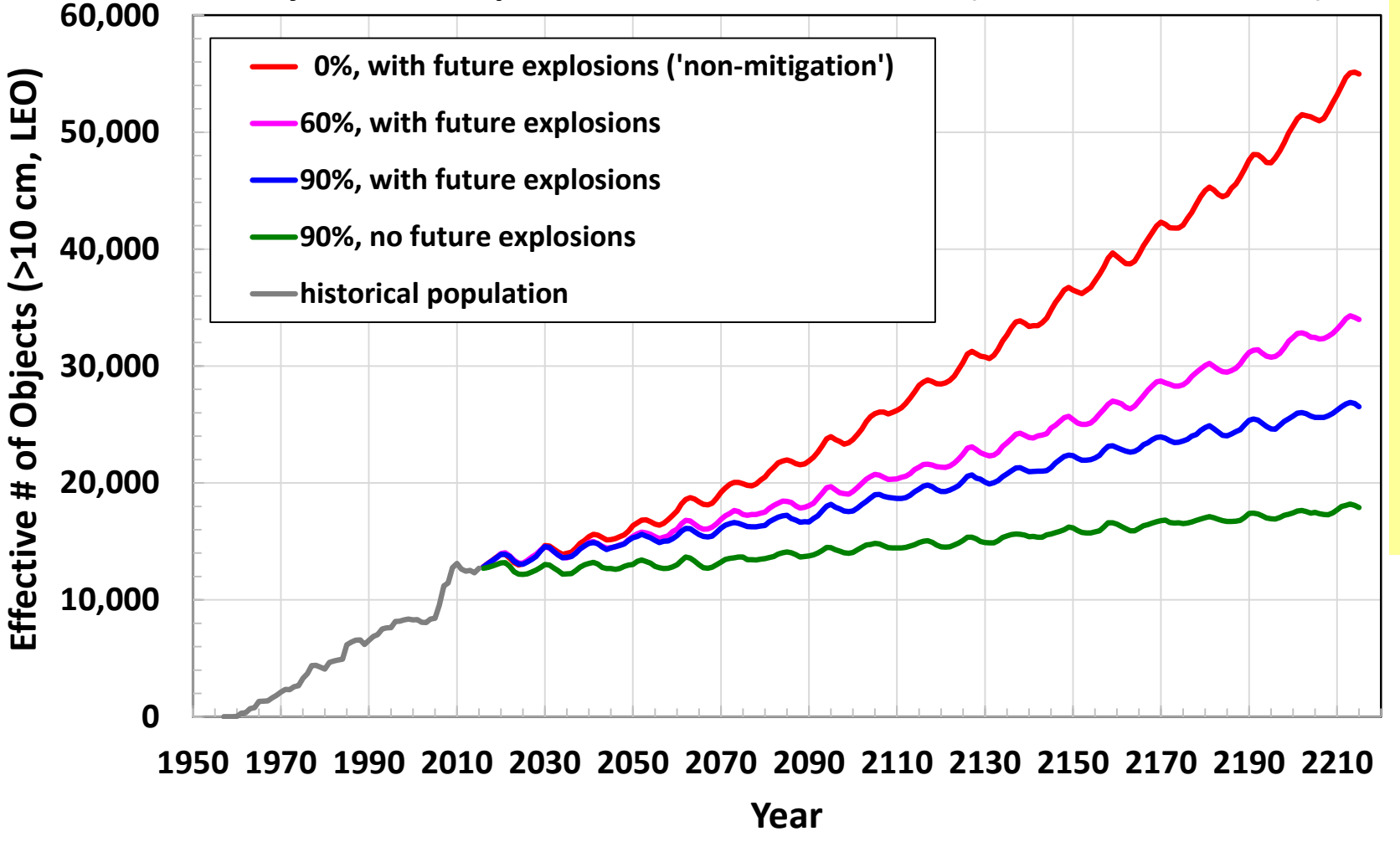
OD Mitigation and Population Increase

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

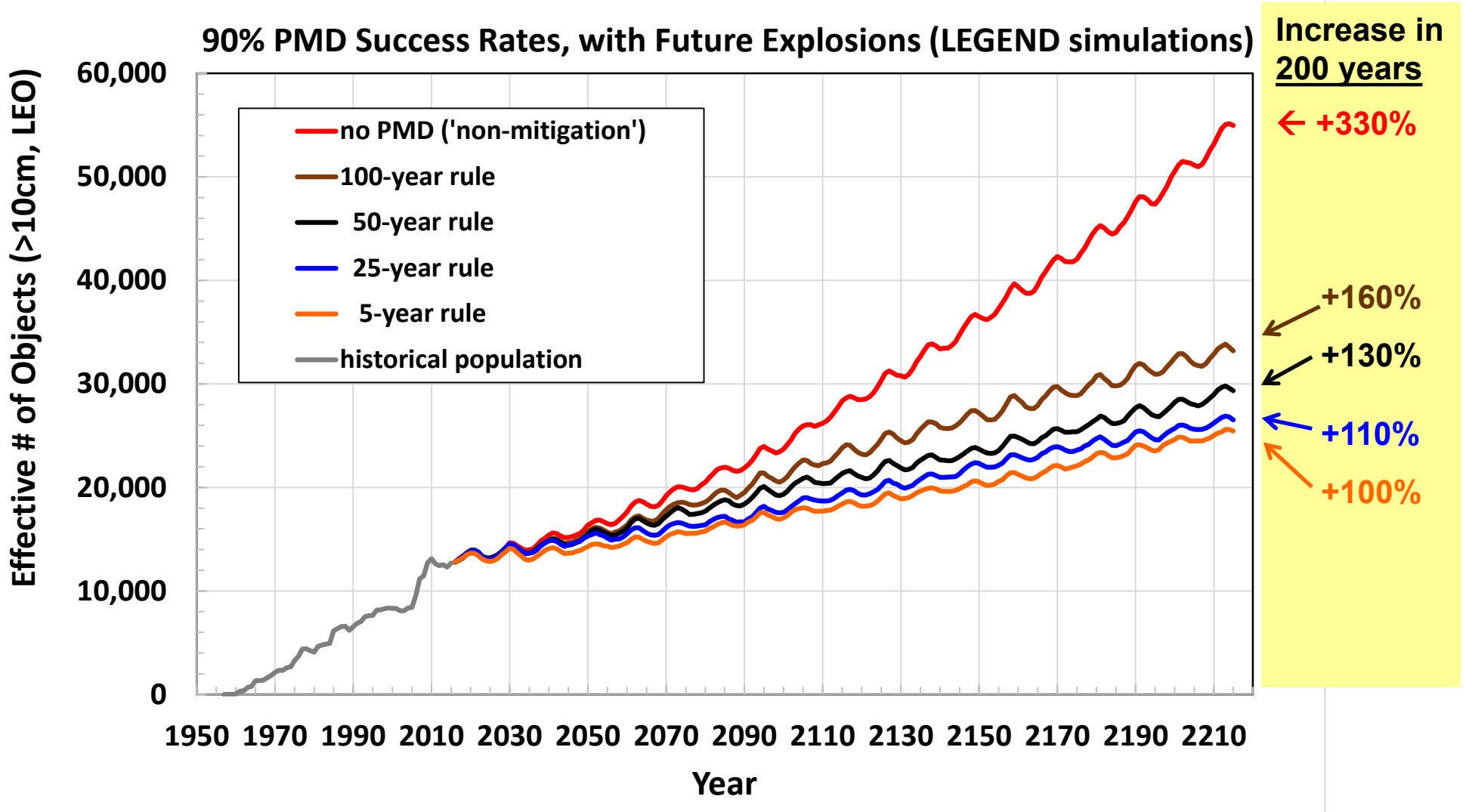


Projected Future OD Population Increase

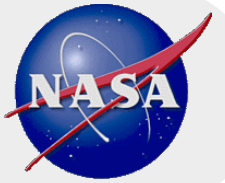
- **A good implementation of the existing OD mitigation measures can significantly limit the future OD population increase**



Effectiveness of the 25-year Rule



Managing the Long-term OD Problem



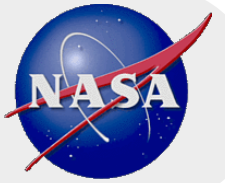
- **"Prevention is better than cure"**
  - (*Prov.*) It is better to try to keep a bad thing from happening than it is to fix the bad thing once it has happened.
- **"An ounce of prevention is worth a pound of cure"**
  - (*Prov.*) It is better/cheaper to stop something bad from happening than it is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

- **OD Mitigation = Prevention**
- **OD Remediation = Cure**

OD Remediation in the United States

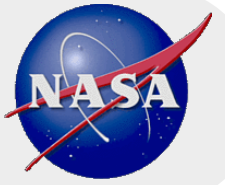


- **The 2010 National Space Policy**
  - "*Pursue research and development of technologies and techniques, through the Administrator of the National Aeronautics and Space Administration (NASA) and the Secretary of Defense, to mitigate and remove on-orbit debris, reduce hazards, and increase understanding of the current and future debris environment.*"
- **The 2018 Space Policy Directive-3**
  - "*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 2020 National Space Policy**
  - "*Evaluate and pursue, in coordination with allies and partners, active debris removal as a potential long-term approach to ensure the safety of flight in key orbital regimes.*"



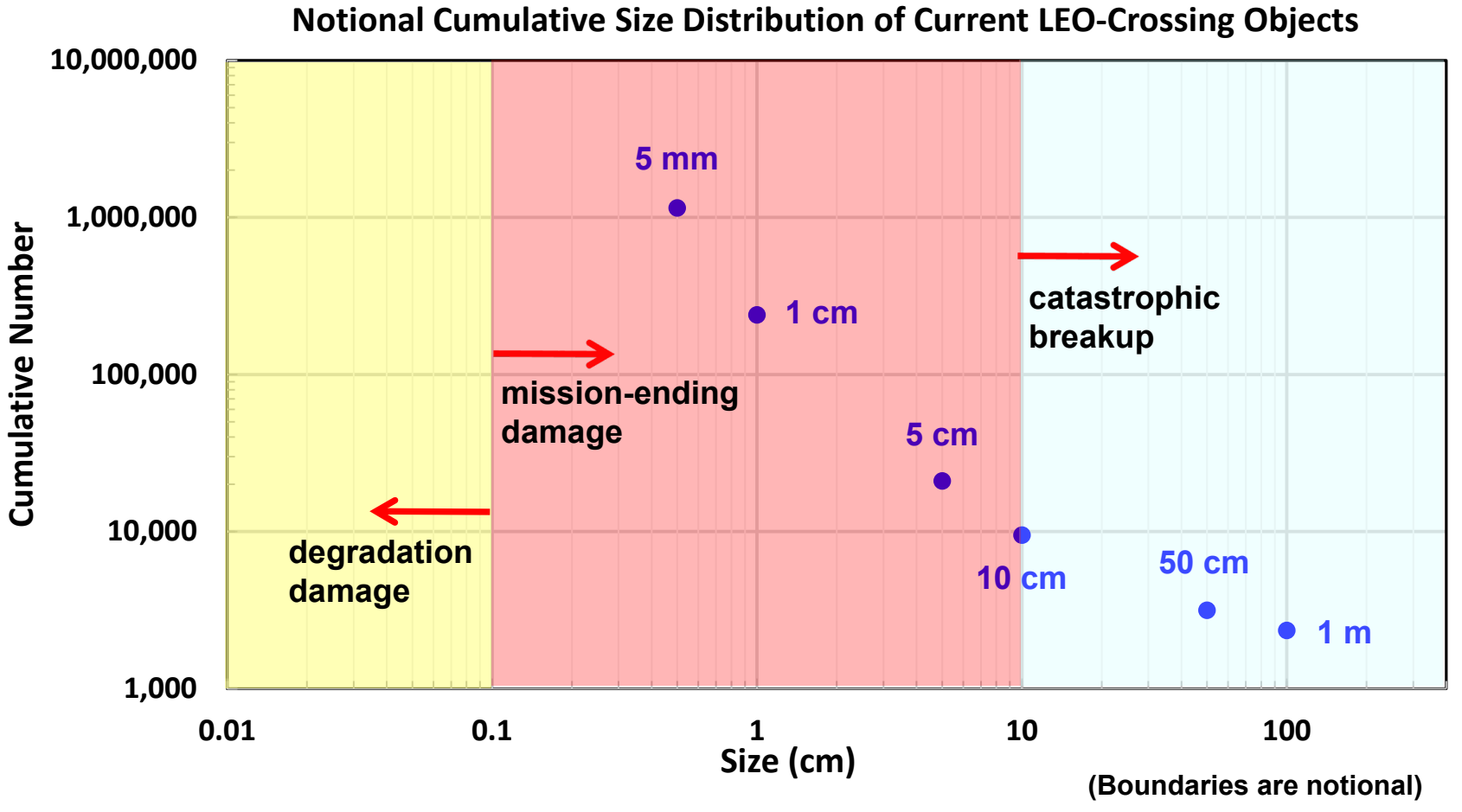
The Near-term OD Problem

The Near-term OD Problem



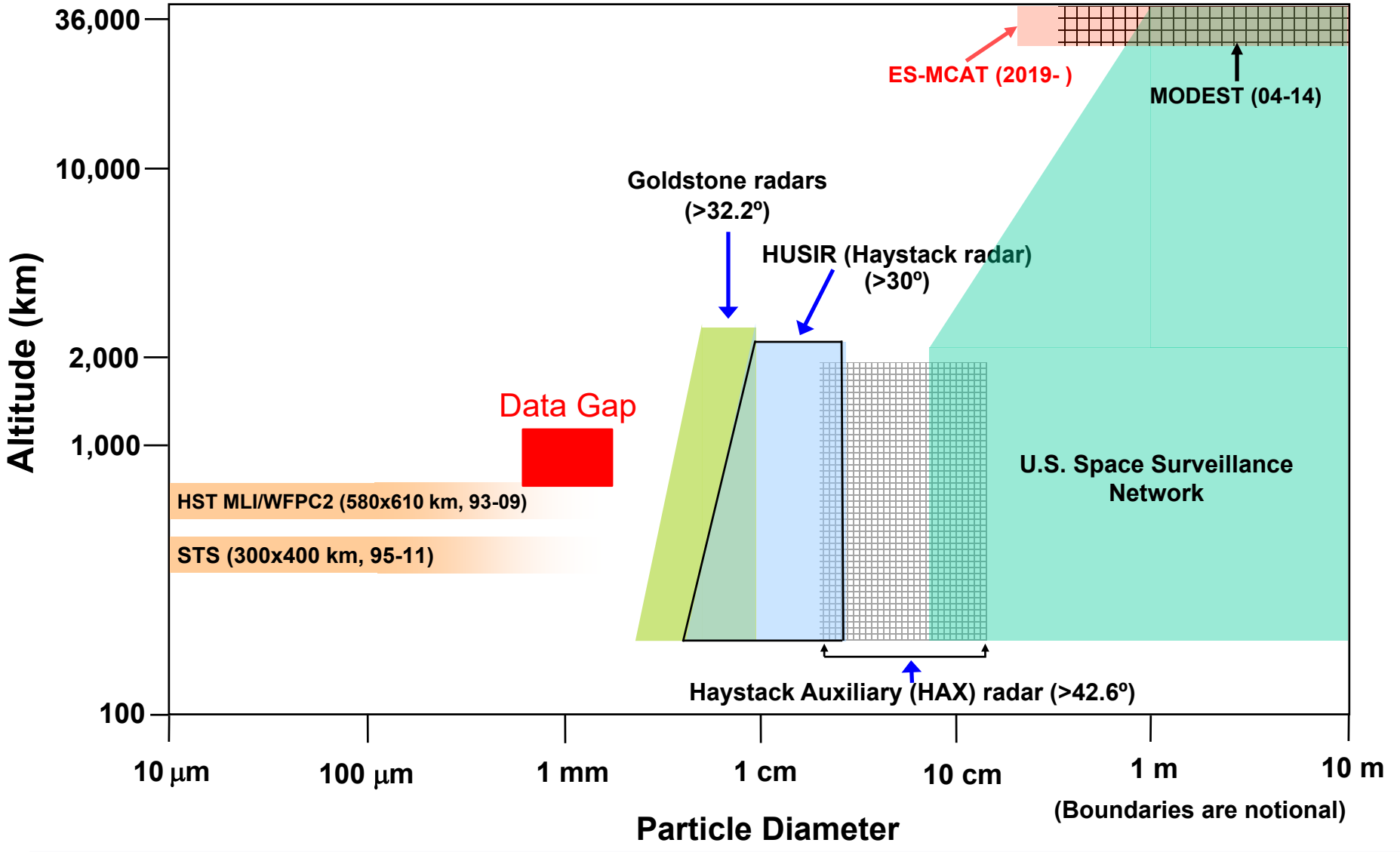
- **The near-term problem: Mission-ending risk for most operational spacecraft is driven by small, millimeter-sized debris**
  - The OD population follows a power-law size distribution. This means there is significantly more small debris than large debris. Therefore, mission-ending risk is always dominated 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.

OD Size Distribution



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

Current NASA OD Measurement Database



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



- **Millimeter-sized OD 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 km 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.

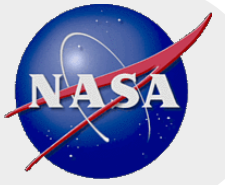
F-4. The models disagree significantly for particles <3 mm, which is also the size that poses the highest penetration risk to most spacecraft.

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.

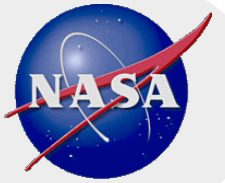
Actionable OD Impact Risk Mitigation

- Against Large and Small Debris



	Large/trackable debris (<1% mission-ending risk)		**Millimeter-sized debris** (drives the mission-ending risk)	
Observe	Collect measurement data (radars, telescopes, *etc.*)	✓	Collect measurement data (radar, telescopes, in-situ, *etc.*)	✗
Assess	Calculate the probability of conjunction (collision)	✓	Calculate the probability of mission-ending impact collision	✓
Mitigate	1. Accept the risk or 2. Conduct an avoidance maneuver to mitigate the risk	✓	1. Accept the risk or 2. Implement cost-effective impact protective shields to mitigate the risk	✓
Time of Actions	During mission operations	✓	During mission design and development	✓

STM, SSA, and Risks from Small Debris



- **The 2018 U.S. Space Policy Directive-3**

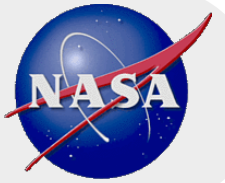
"Section 2. Definitions.

(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.

(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, OD is a priority**
- **If safety is a priority, SSA on small, millimeter-sized OD is a priority**

Forward Challenges



- **Key OD priorities to enhance the safety, stability, and sustainability of operations in the future space environment**
  - Improve space situational awareness on small debris, especially the millimeter-sized debris in LEO, to better protect future space missions
  - Promote better global compliance with existing mitigation best practices to slow down the debris population growth
  - Establish long-term goals, combining mitigation and remediation, to preserve the near-Earth space environment