Risk from Orbital Debris

J.-C. Liou, PhD

Chief Scientist for Orbital Debris
National Aeronautics and Space Administration

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Outline

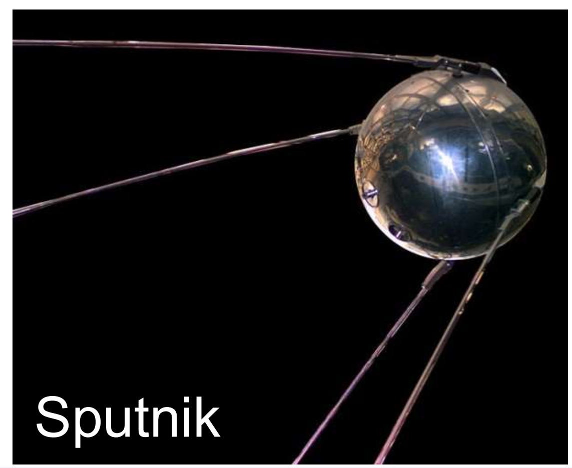
- **The orbital debris (OD) problem**
  - The environment
  - Long-term population growth
  - Risk to space missions
- **OD mitigation, space situational awareness (SSA), and space traffic management (STM)**

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

The Orbital Debris Problem

The Space Age

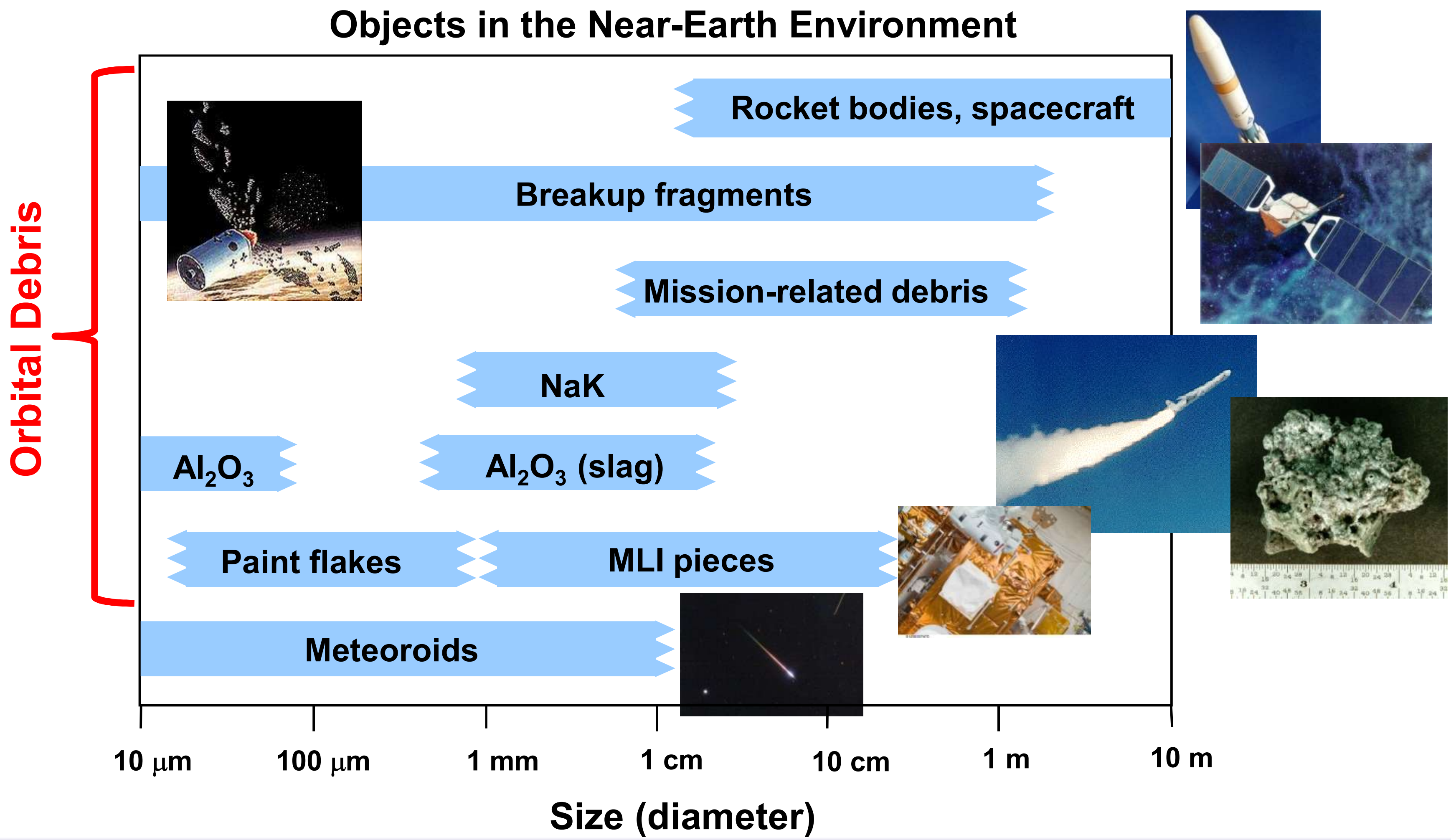
- **The first human-made satellite, Sputnik, was launched by the Soviet Union on October 4, 1957 to study the atmosphere**
- **Since then, more than 5000 launches have been conducted worldwide**
- **Benefits of space activities**
  - Communications
  - Environment monitoring
  - Explorations
  - Technology advancements
  - Many others
- **But…**



Sputnik

What is Orbital Debris?

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



How Much Orbital Debris is Up There?

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

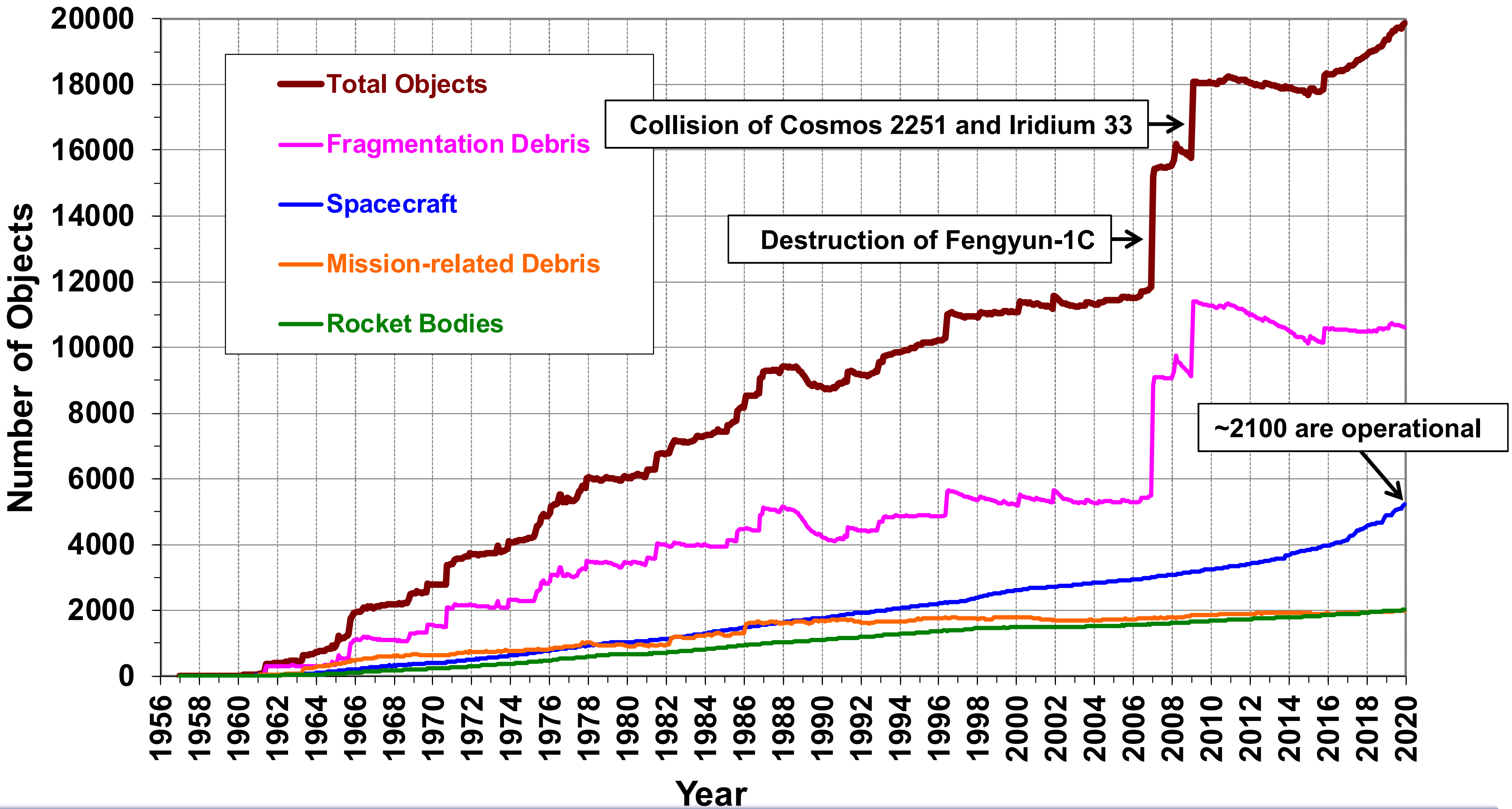
Marble size or larger (≥1 cm): ~500,000

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

- **Due to high impact speed in space (~10 km/sec in low Earth orbit, 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 (~3100 tons in LEO)**

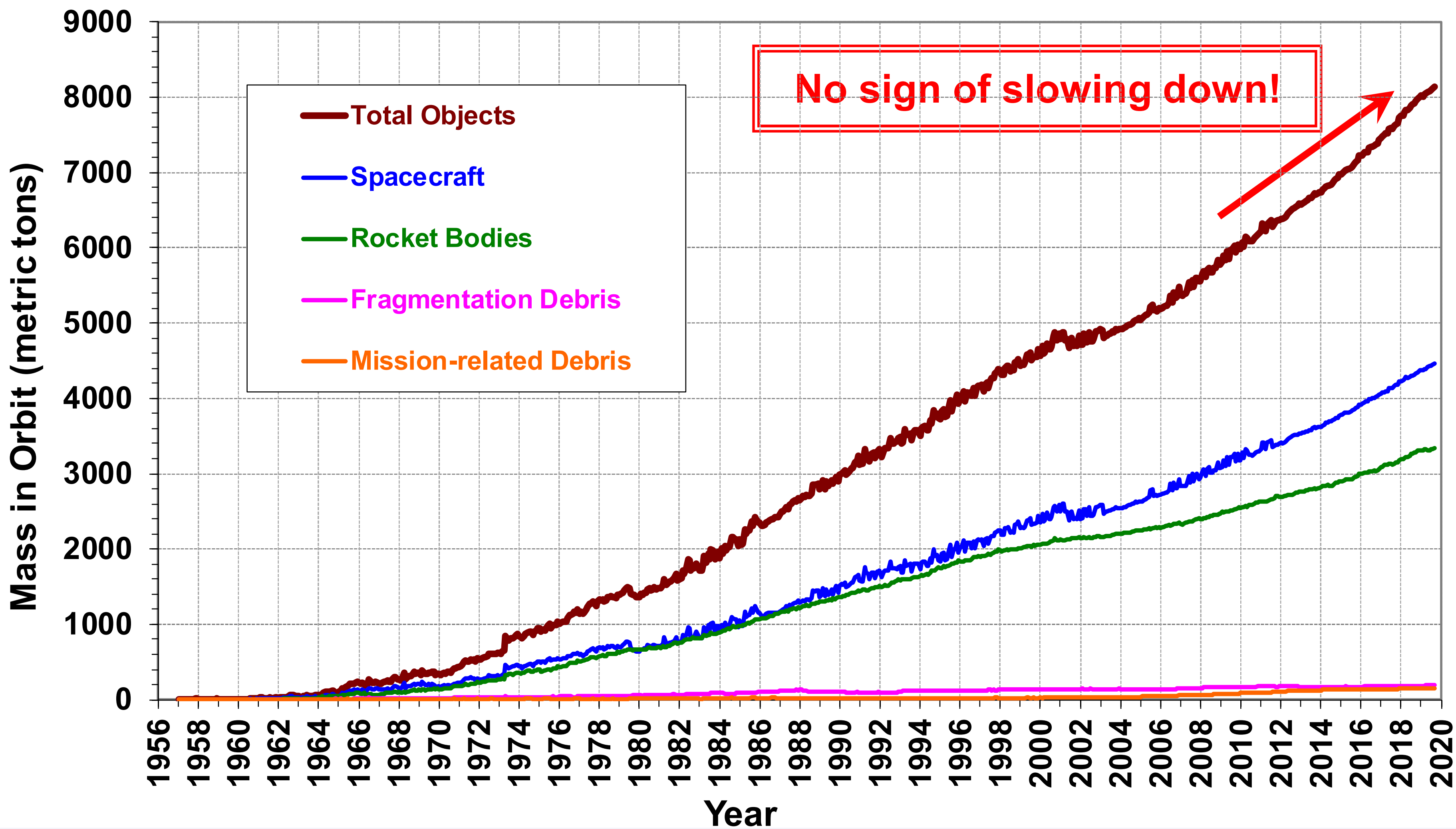
Growth of the Cataloged Populations

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



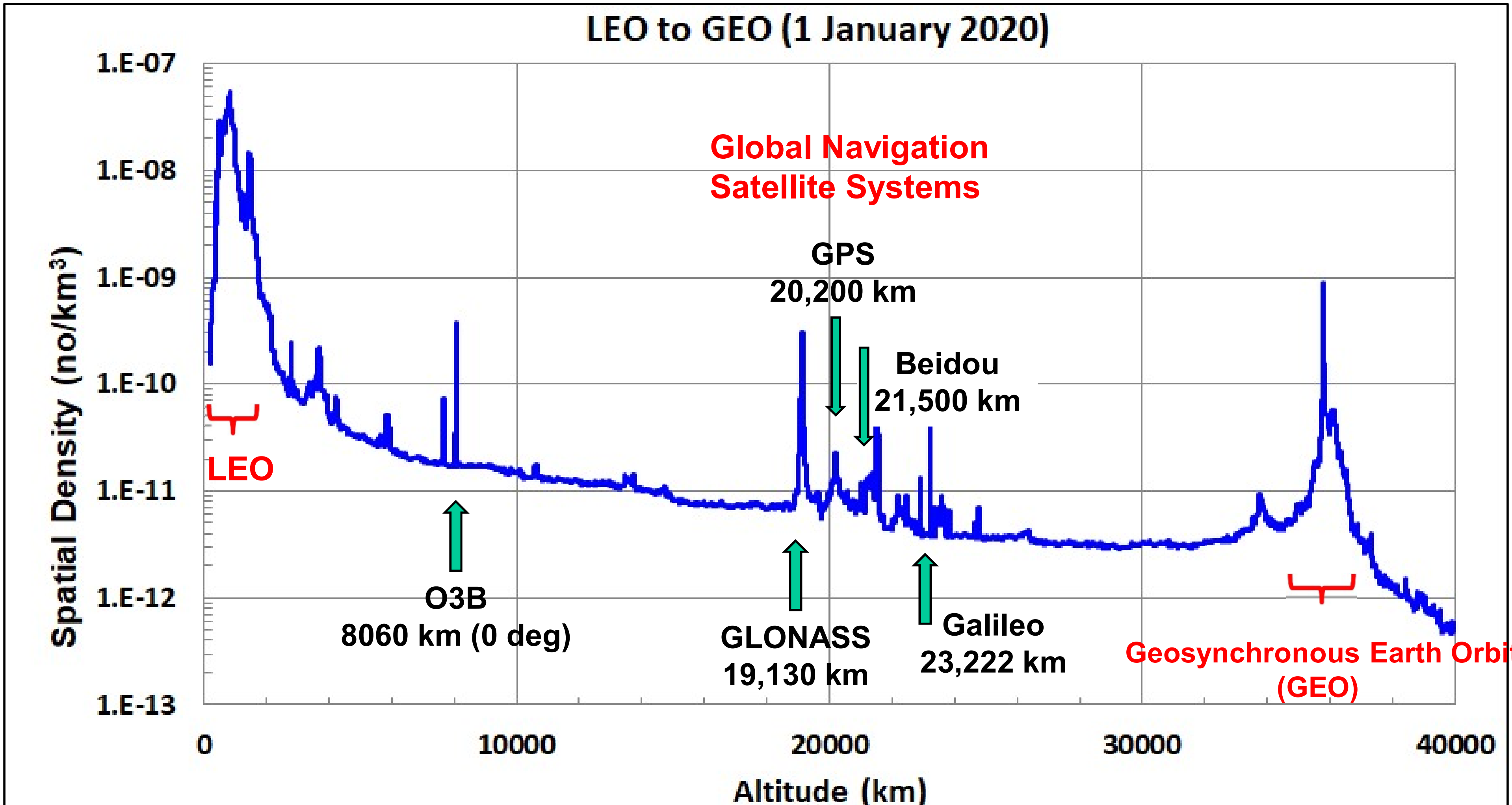
Mass in Orbit Continues to Increase

- **The material mass in Earth orbit continues to increase and has exceeded 8100 metric tons**



Distribution of the Cataloged Objects

- **LEO (the region below 2000 km altitude) has the highest concentration of cataloged objects**

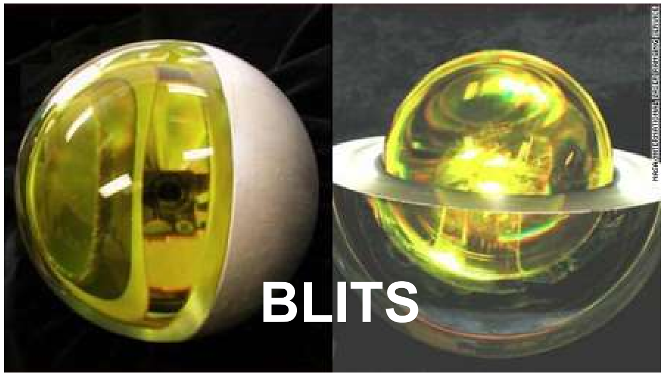


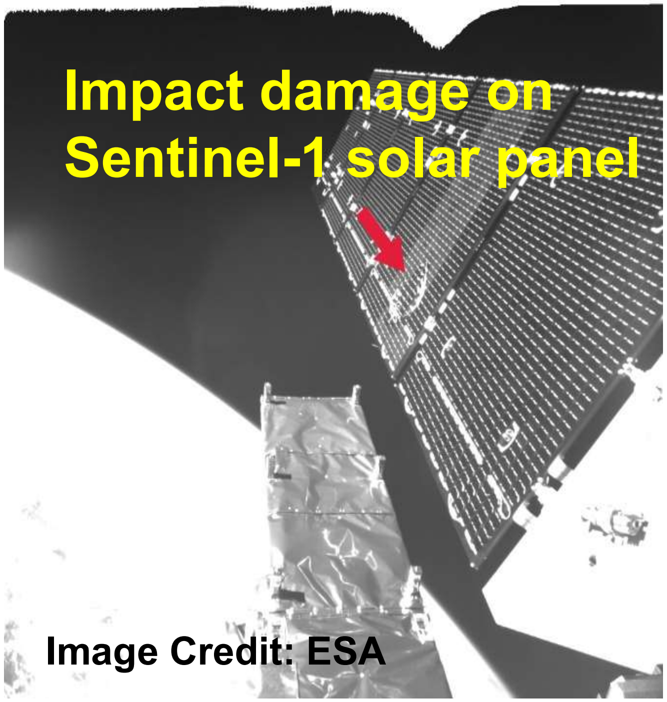
Threat from Orbital Debris – Examples (1/2)

- The gravity-gradient boom of an operational French satellite (CERISE) was cut in half by a tracked debris fragment in 1996
- The fully operational Iridium 33 was destroyed by the retired Russian Cosmos 2251 in 2009
- Near the end of the Space Shuttle program, the Loss of Crew and Vehicle risks from MMOD impact damage were in the range of 1 in 250 to 1 in 300 per mission (OD to MM ~2:1 at ISS altitude)
- The current probability of International Space Station crew evacuation due to MMOD impact damage is approximately 13.7% over a 10-year period

Threat from Orbital Debris – Examples (2/2)

- **Impacts by small, untracked debris could be responsible for many satellite anomalies**
  - A 17-cm Russian retro reflector, BLITS, was damaged and shed a piece of trackable debris in January 2013
  - The European Space Agency's Sentinel-1 was hit by a small debris piece, leading to some power loss and six trackable debris in August 2016





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 short-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

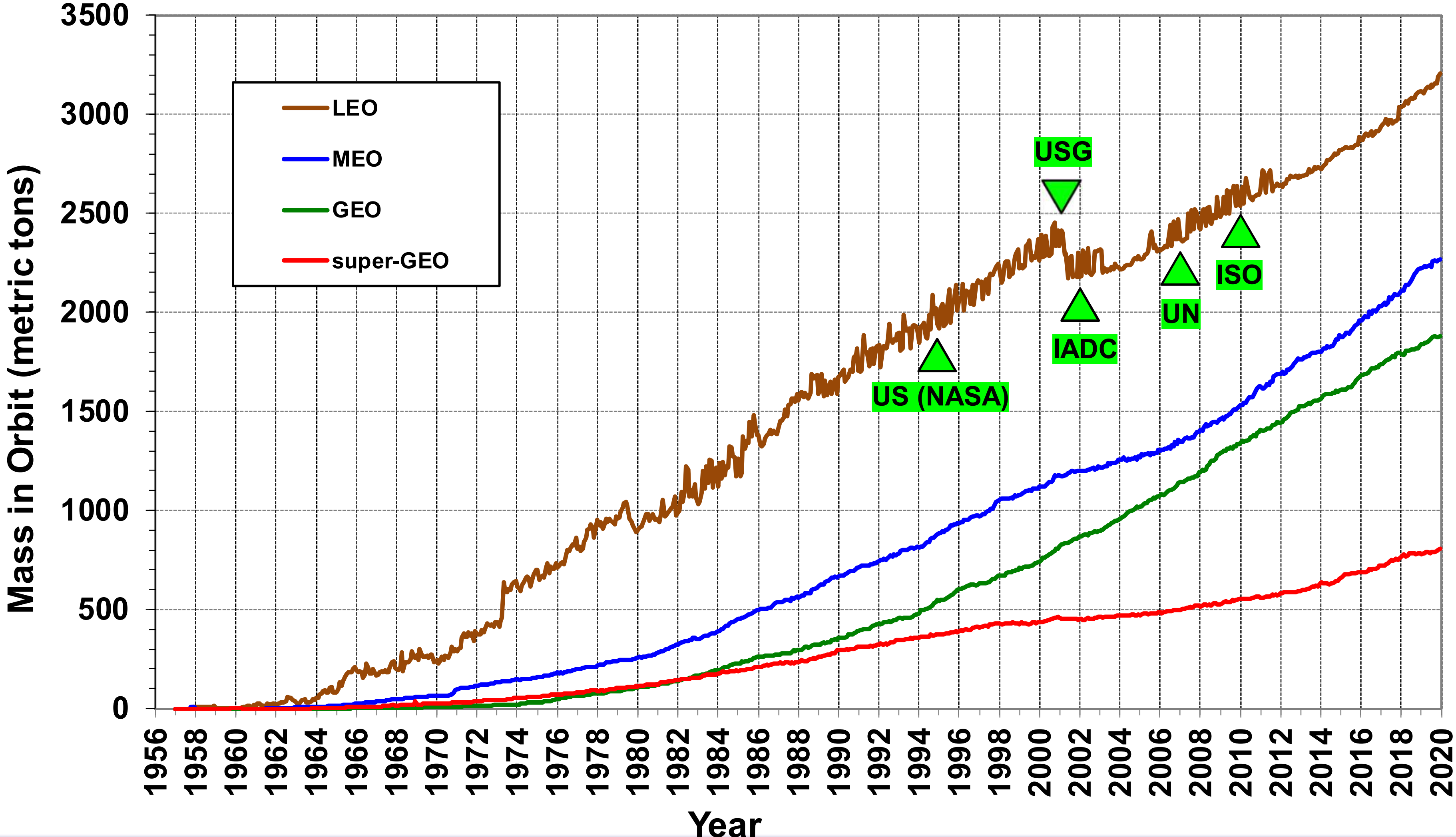
- **The long-term problem: The OD population continues to increase over time despite decades of efforts to limit the generation of new debris***
  - U.S.: NASA OD Mitigation Guidelines (1995), U.S. Government OD Mitigation Standard Practices (2001, 2019), *etc*.
  - International: IADC Space Debris Mitigation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

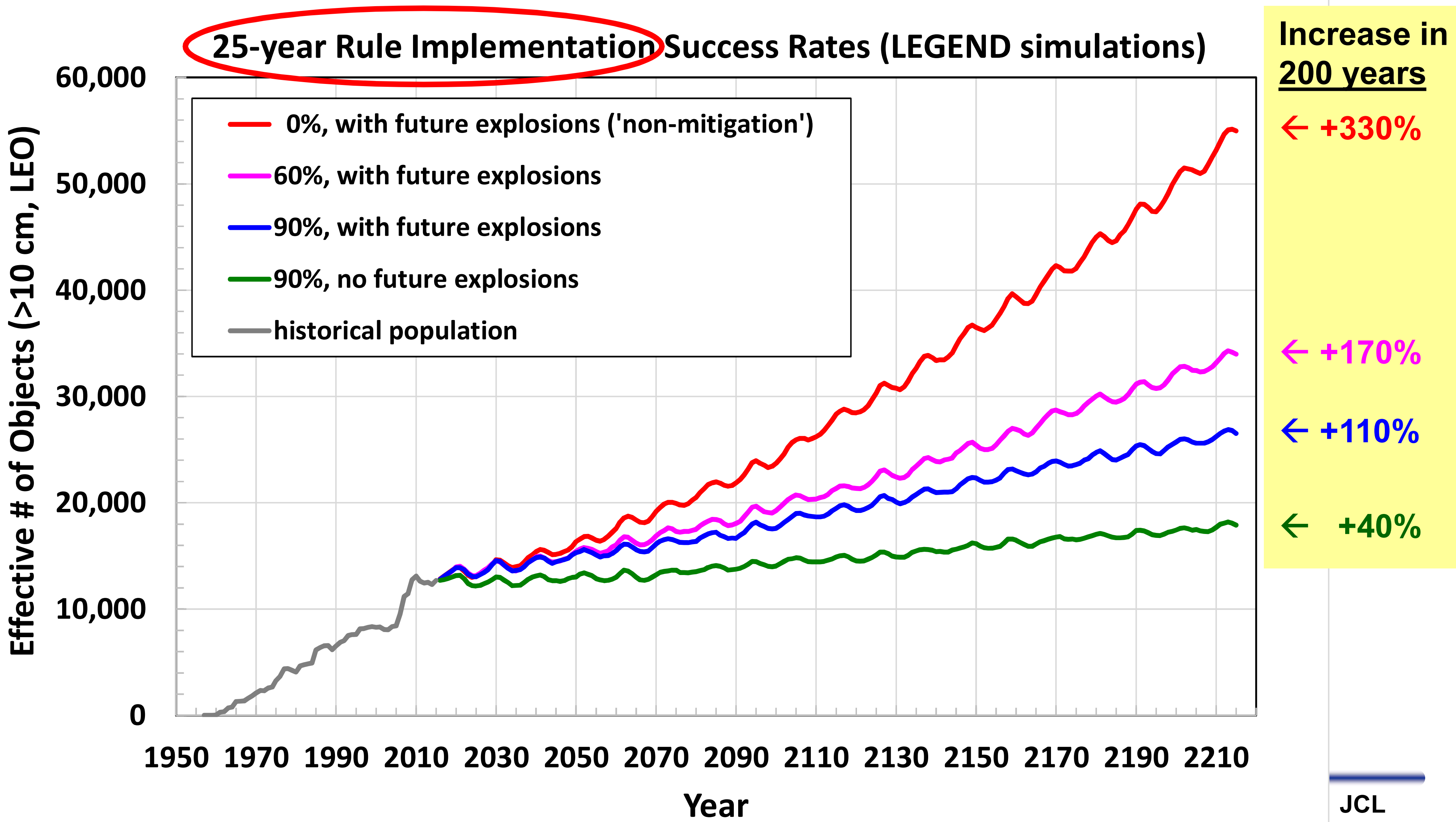
OD Mitigation and Population Increase

- **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**



Managing the Long-Term OD Problem

- **"Prevention is better than cure"**
  - 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"**
  - 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 Short-Term Orbital Debris Problem

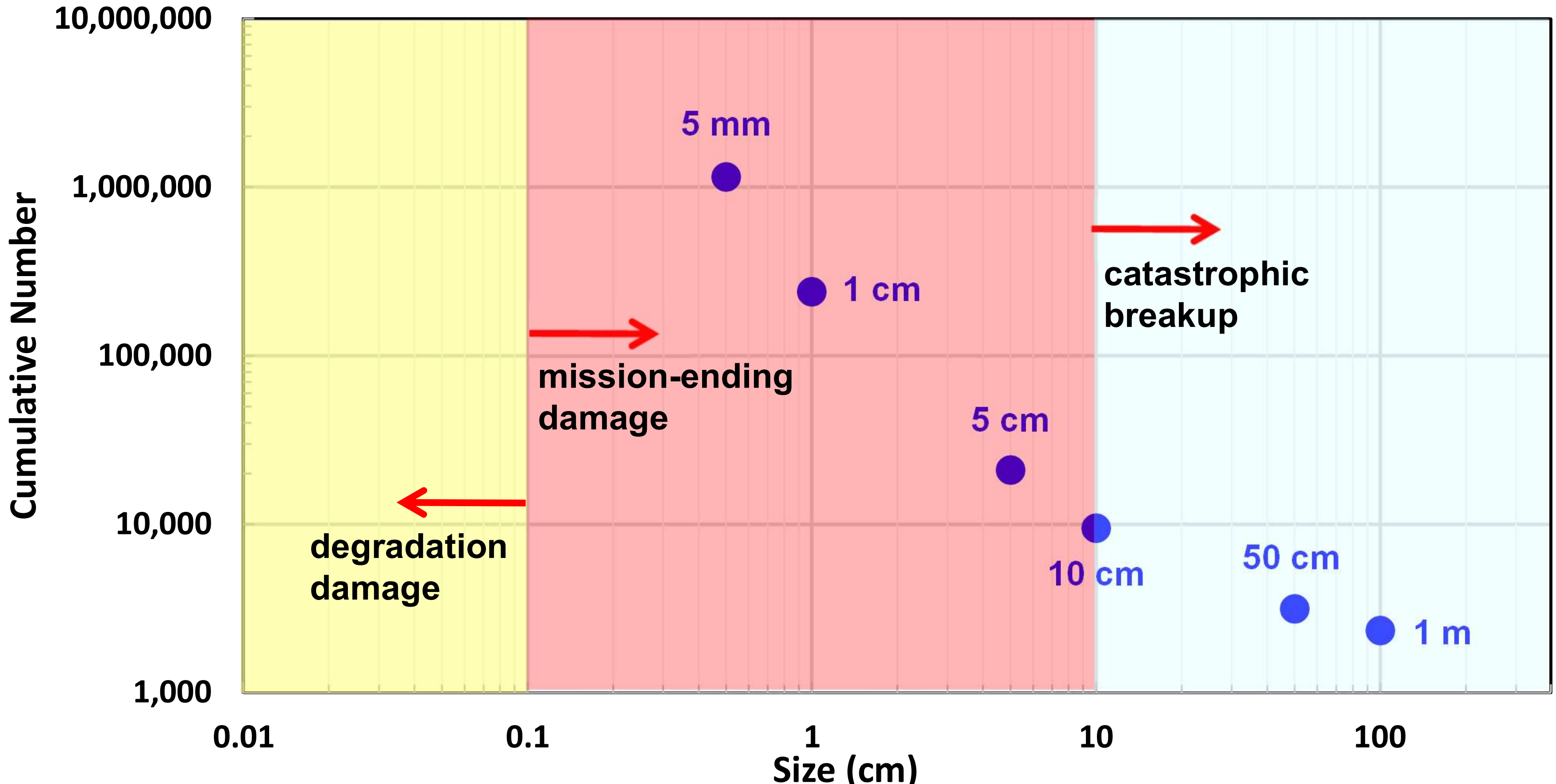
The Short-Term OD Problem

- **The short-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

1 mm

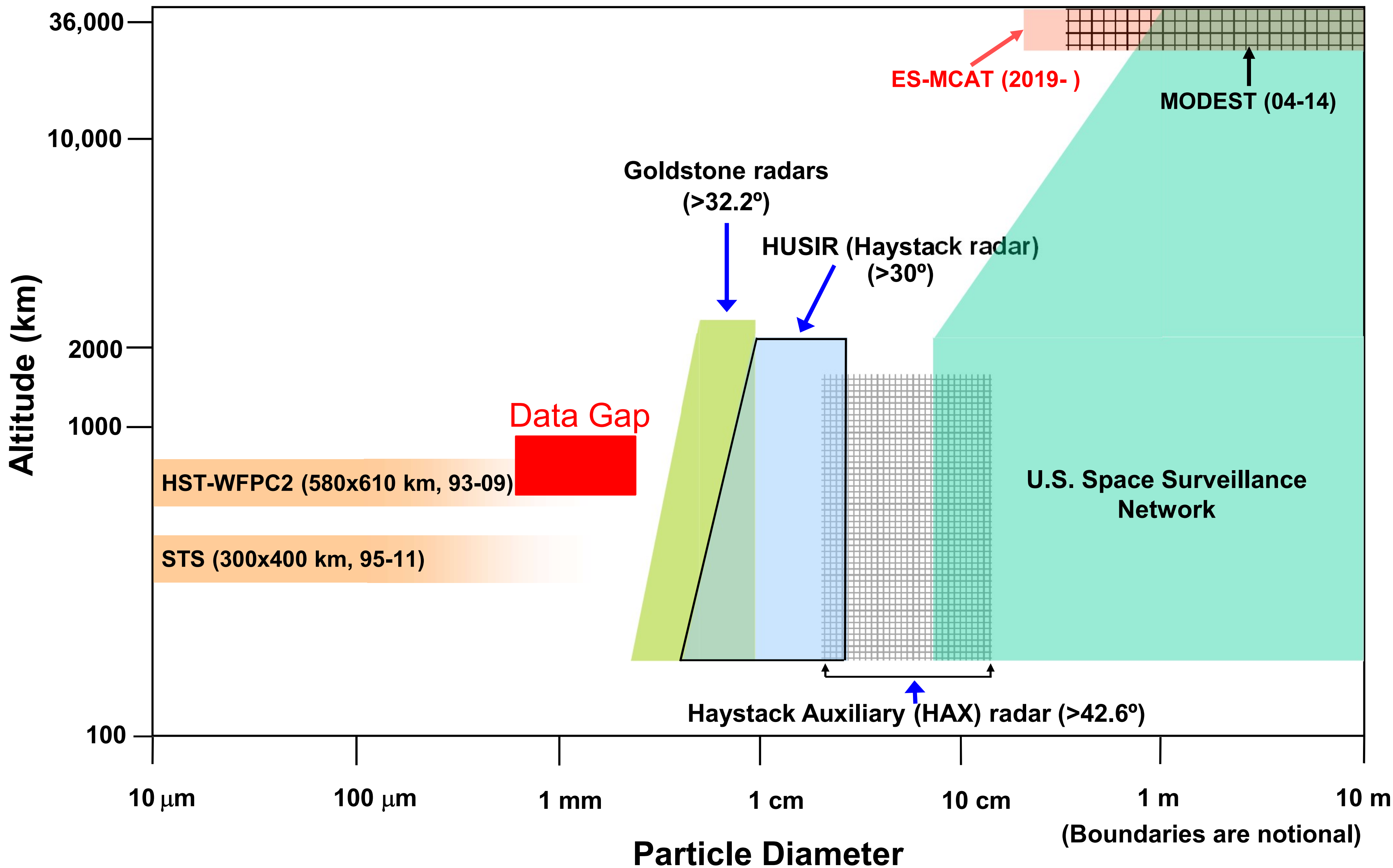
Notional Cumulative Size Distribution of Current LEO-Crossing Objects



(Boundaries are notional)

There is more small debris than large debris that causes mission-ending damage

Current NASA Orbital Debris Database



Top OD Risk to Space Missions in LEO

- **Millimeter-sized orbital debris represents the highest penetration risk to most operational spacecraft in LEO**
  - As concluded by a recent NASA Engineering and Safety Center 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 altitudes**
  - 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

Space Situational Awareness on Small Debris

- **The need to improve the SSA on small debris is highlighted in the SPD-3**

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..."

Managing Risks from Orbital Debris

- "*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.*" (SPD-3)

- **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 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