

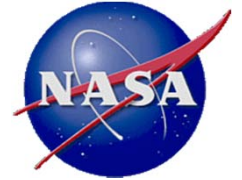
## **The Near-Earth Orbital Debris Problem and the Challenges for Environment Remediation**

J.-C. Liou, PhD

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The near-Earth space environment has been gradually polluted with orbital debris (OD) since the beginning of space activities 55 years ago. Although this problem has been known to the research community for decades, the public was, in general, unaware of the issue until the anti-satellite test conducted by China in 2007 and the collision between Cosmos 2251 and the operational Iridium 33 in 2009. The latter also underlined the potential of an ongoing collision cascade effect (the “Kessler Syndrome”) in the low Earth orbit (LEO, the region below 2000 km altitude). Recent modeling results have indicated that mitigation measures commonly adopted by the international space community will be insufficient to stabilize the LEO debris population. To better limit the OD population increase, more aggressive actions must be considered.

There are three options for OD environment remediation – removal of large/massive intact objects to address the root cause of the OD population growth problem, removal of ~5-mm-to-1 cm debris to mitigate the main mission-ending threats for the majority of operational spacecraft, and prevention of major debris-generating collisions as a temporary means to slow down the OD population increase. The technology, engineering, and cost challenges to carry out any of these three options are monumental. It will require innovative ideas, game-changing technologies, and major collaborations at the international level to address the OD problem and preserve the near-Earth environment for future generations.



# **The Near-Earth Orbital Debris Problem and the Challenges for Environment Remediation**

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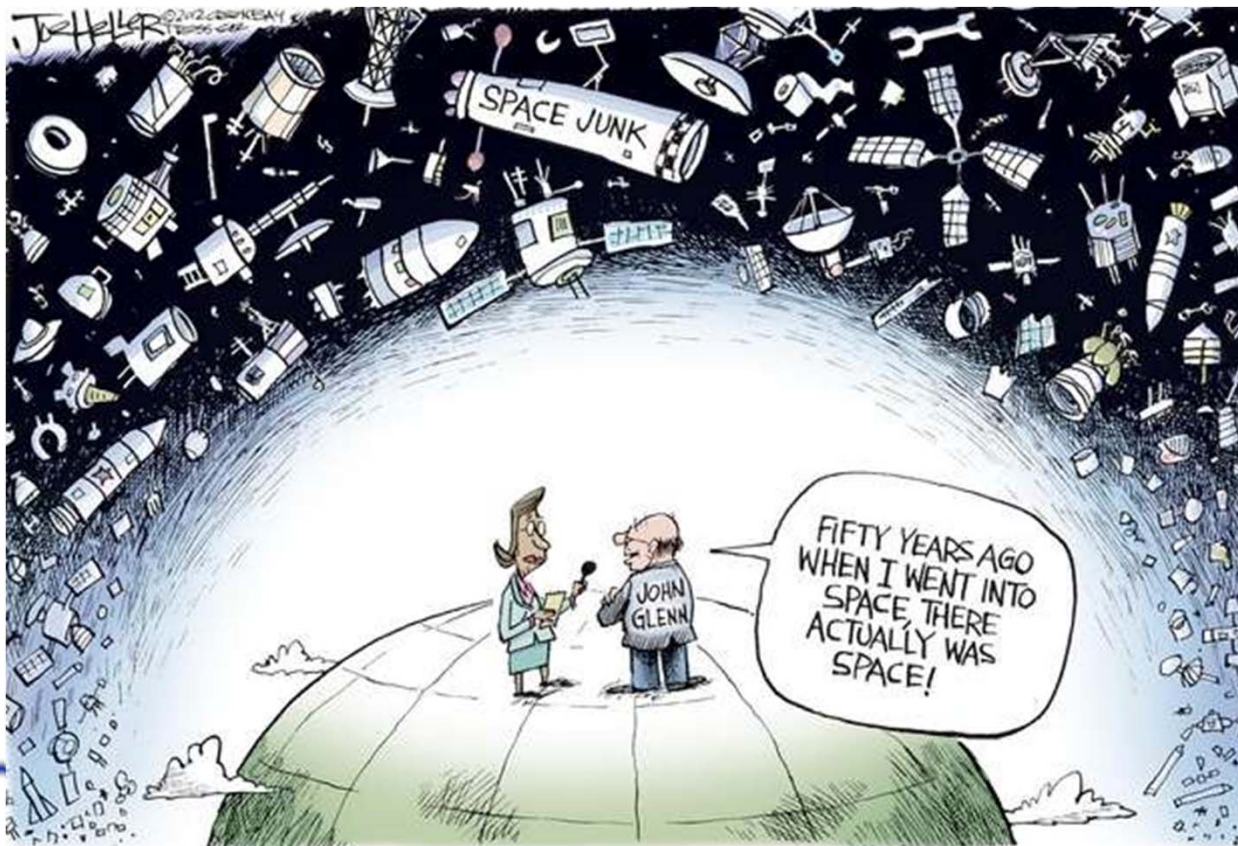
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**The 3<sup>rd</sup> International Space World Conference  
Frankfurt, Germany, 6-8 November 2012**



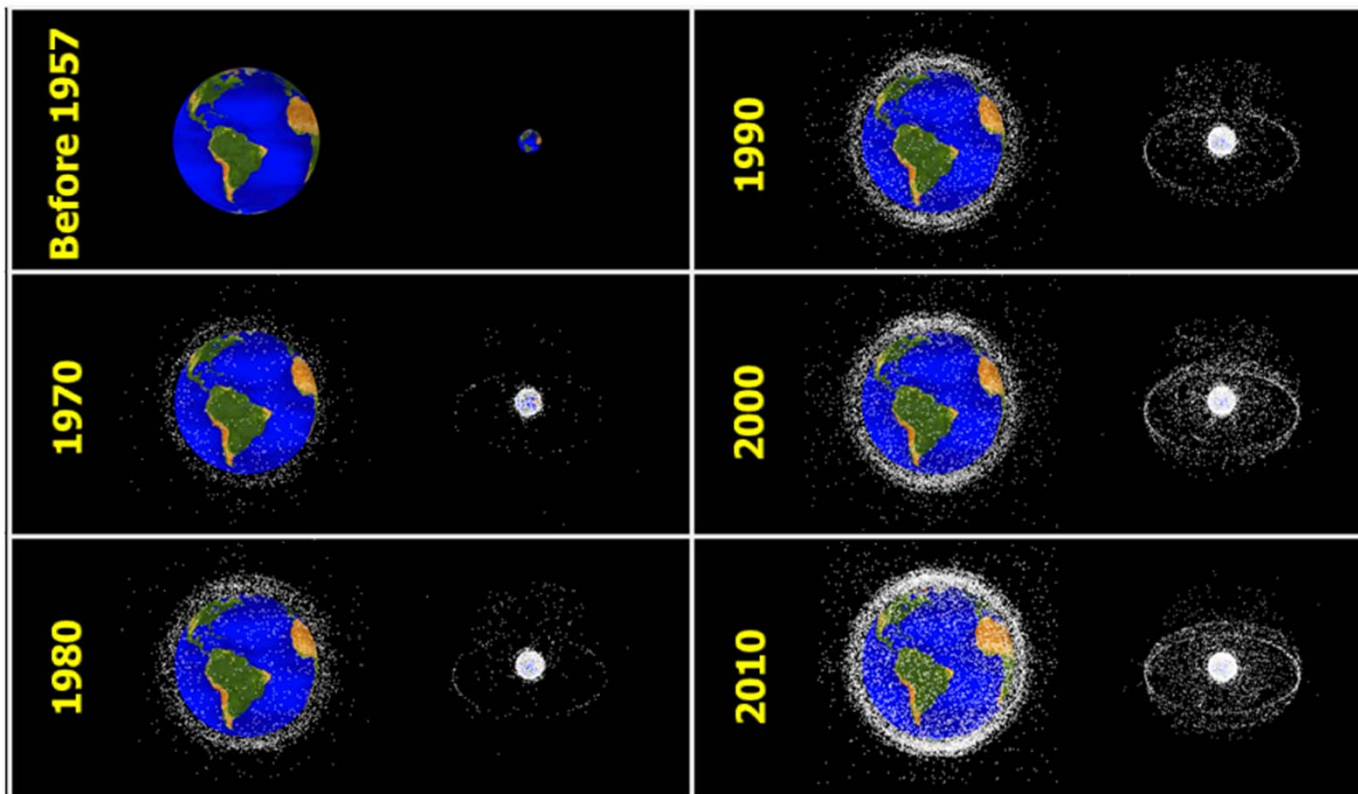
## Outline

- **Buildup of the Orbital Debris (OD) Population**
- **Assessments of the Problem**
- **Options for Environment Remediation**
- **Challenges Ahead**





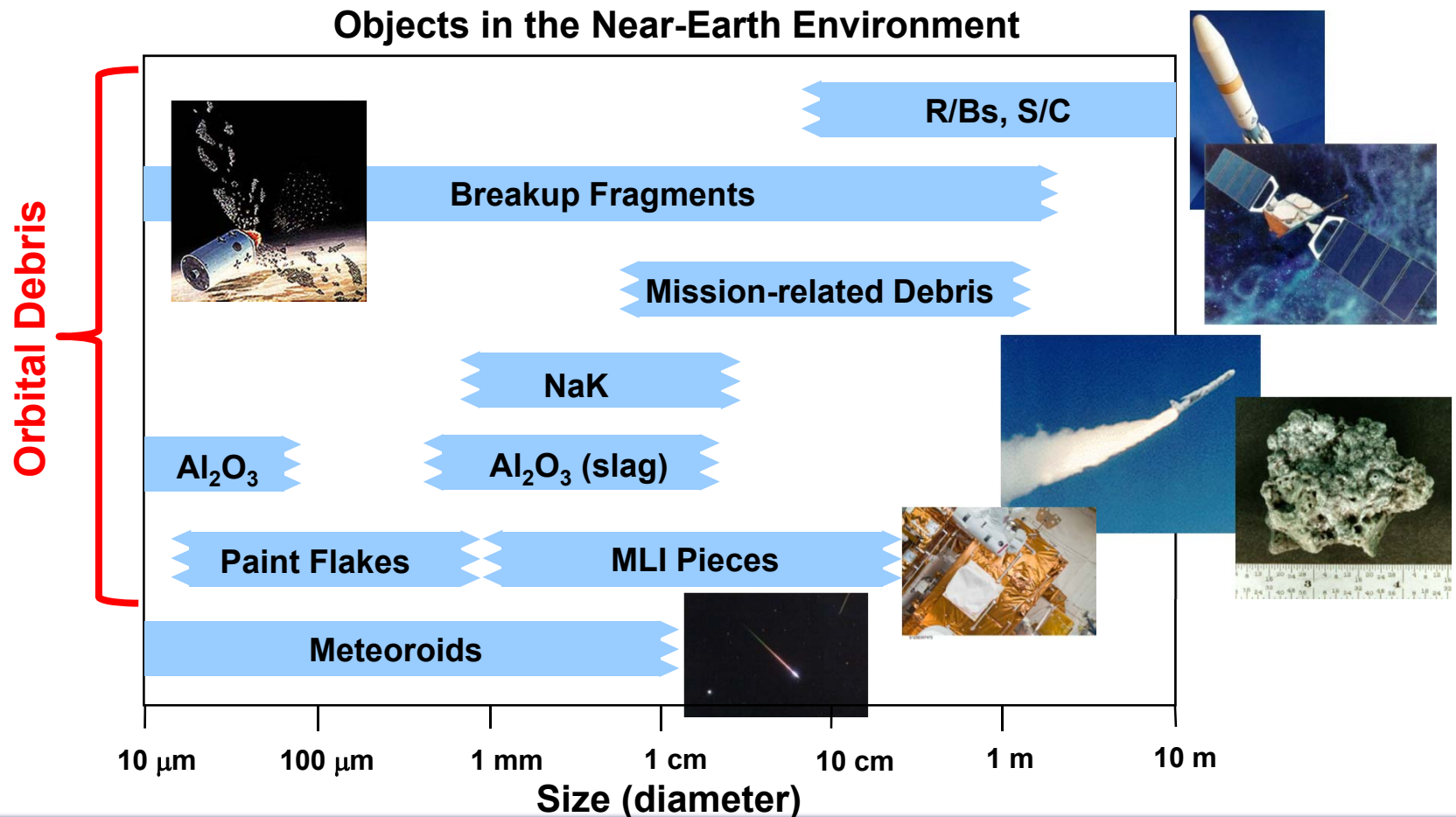
# Buildup of the Orbital Debris Population

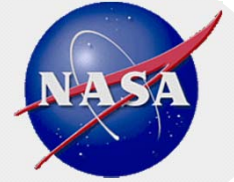




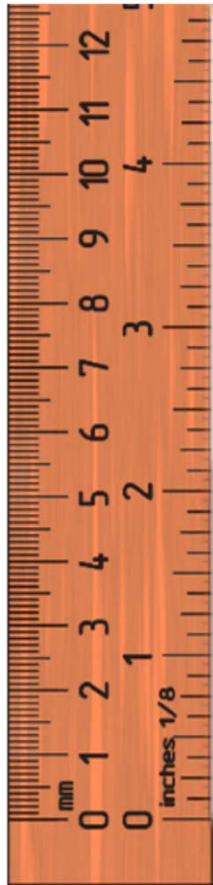
# What Are Orbital Debris?

- Orbital debris are all human-made objects in orbit about the Earth which no longer serve any useful purpose





# How Much Junk Is Currently Up There?



**Softball size or larger ( $\geq 10$  cm): ~22,000**  
**(most of them are tracked by the US Space Surveillance Network)**



**Marble size or larger ( $\geq 1$  cm): ~500,000**



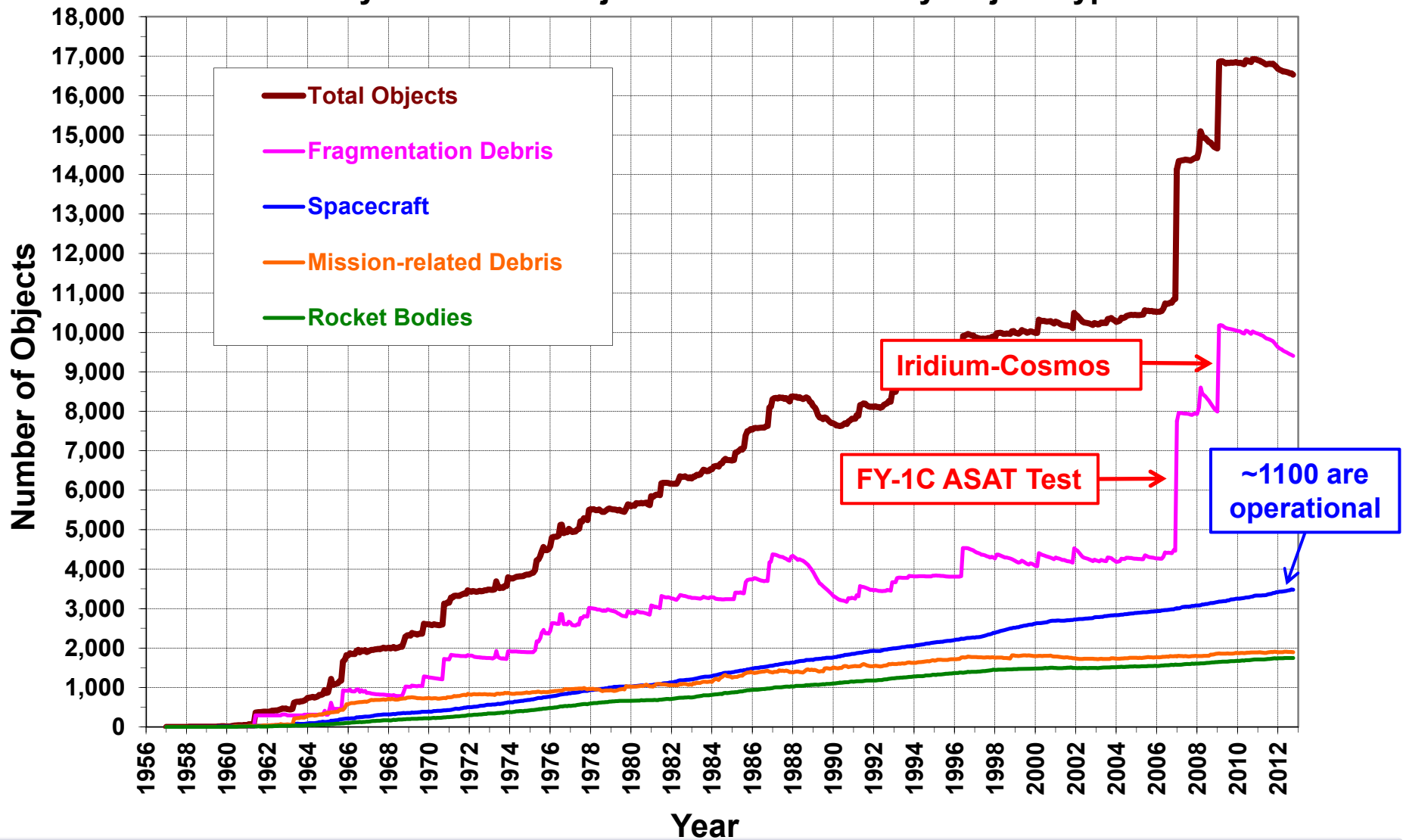
**Dot or larger ( $\geq 1$  mm): >100,000,000**  
**(a grain of salt)**

- **Total mass: ~6300 tons LEO-to-GEO (~2700 tons in LEO)**
- **Due to high impact speed in space (~10 km/s in LEO), even sub-mm debris pose a realistic threat to human spaceflight and robotic missions**



# Growth of the Cataloged Populations

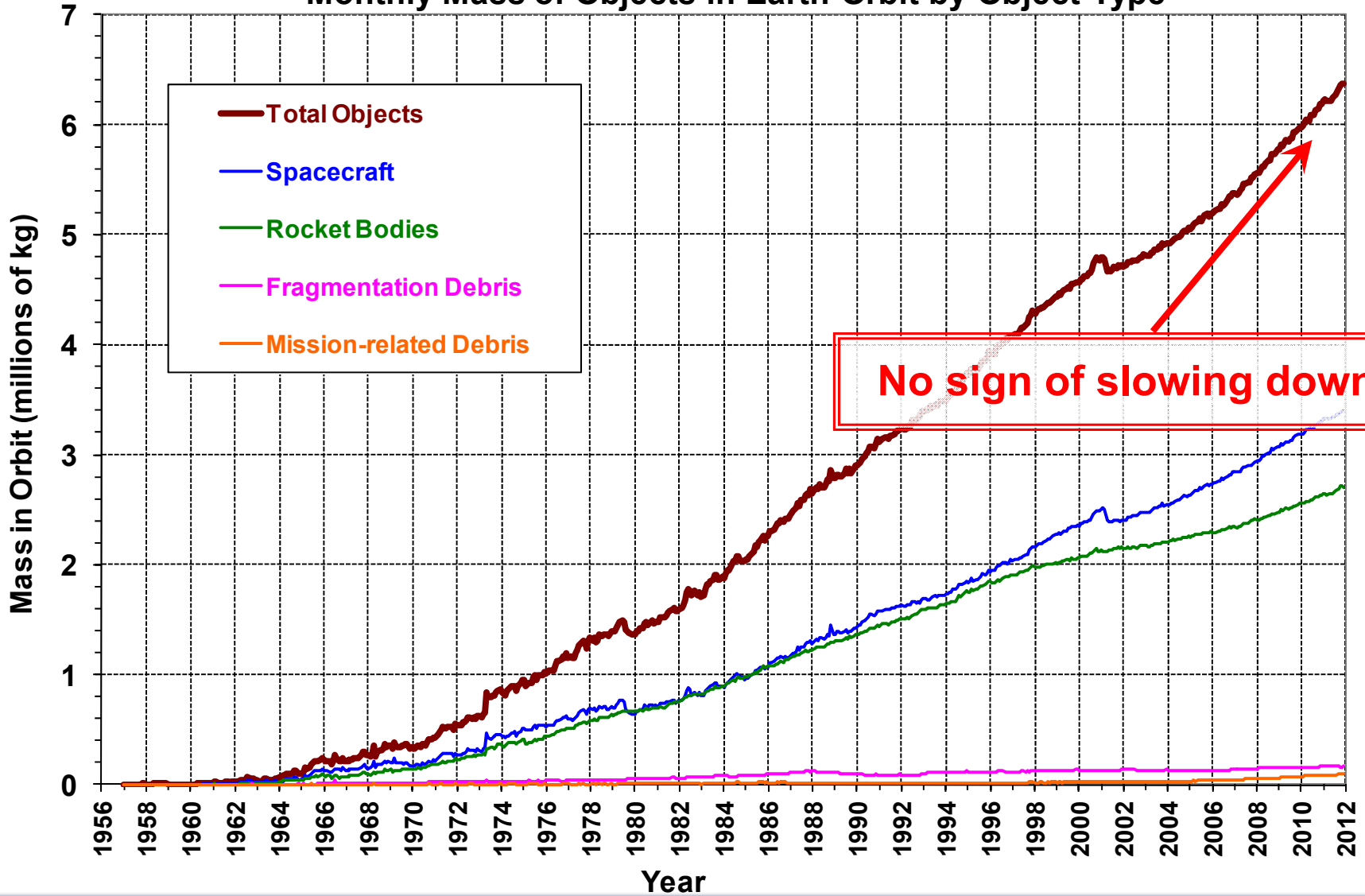
## Monthly Number of Objects in Earth Orbit by Object Type





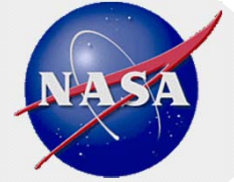
# Mass in Orbit

## Monthly Mass of Objects in Earth Orbit by Object Type



No sign of slowing down!





## The Big Sky Is Getting Crowded

- **Four accidental collisions between cataloged objects have been identified**
  - The collision between Cosmos 2251 and the operational Iridium 33 in 2009 underlined the potential of the Kessler Syndrome
- **The US Joint Space Operations Center (JSpOC) is currently providing conjunction assessments for all operational S/C**
  - JSpOC issues ~10 to 30 conjunction warnings on a daily basis, and more than 100 collision avoidance maneuvers were carried out by satellite operators in 2010
- **The International Space Station (ISS) has conducted 15 debris avoidance maneuvers since 1999**
  - 4 times since April 2011



# Threat from Orbital Debris – One Example

## Potential Shuttle Damage

Window Replacement

EVA Suit Penetration

Radiator Penetration

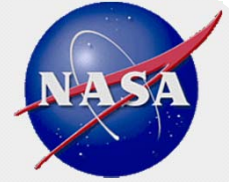


- Shuttle Loss of Crew and Vehicle (LOCV) risks from MMOD impact damage were in the range of **1 in 250** to **1 in 300** per mission
  - The risks vary with altitude, mission duration, and attitude
  - OD to MM is about 2:1 at ISS altitude



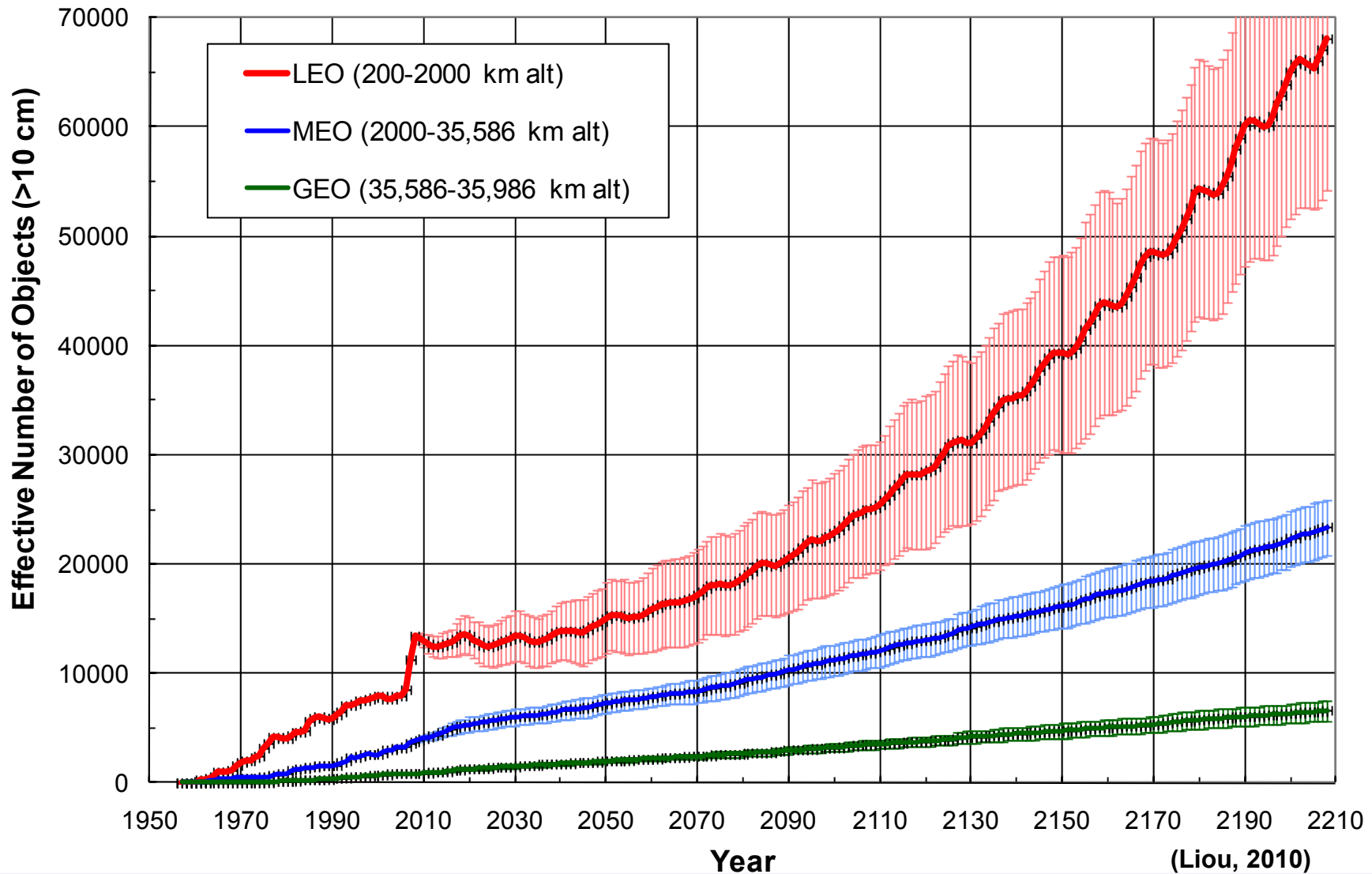


# Projected Growth of the Debris Population



# Future Projection – The **Worst Case Scenario** (Regular Satellite Launches, but **No Mitigation Measures**)

**Non-Mitigation** Projection (averages and 1- $\sigma$  from 100 MC runs)





## Assessments of the Non-Mitigation Projection

- **LEO: the non-mitigation scenario predicts the debris population ( $\geq 10$  cm objects) will have a rapid non-linear increase in the next 200 years**
  - This is a well-known trend (the “Kessler Syndrome”) that was the motivation for developing the currently-adopted mitigation measures (e.g., passivation, the 25-yr rule) in the last 15 years
- **MEO and GEO: the non-mitigation scenario predicts a moderate population growth**
  - Only a few accidental collisions between  $\geq 10$  cm objects are predicted in the next 200 years
  - The currently-adopted mitigation measures (including EOL maneuvers in GEO) will further limit the population growth
  - **Environment remediation is not urgent in MEO and GEO**

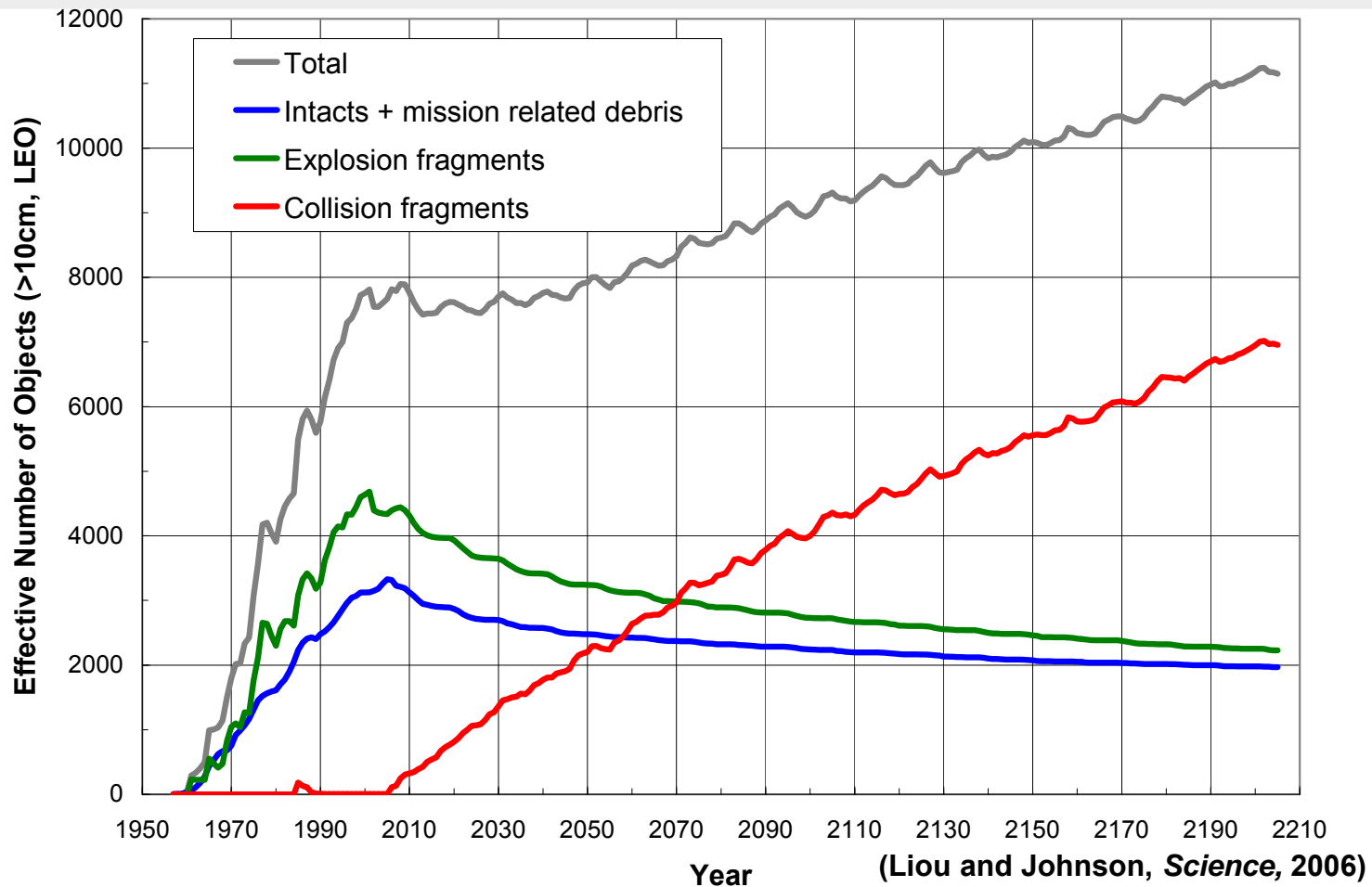


# Will the Commonly-Adopted Mitigation\* Measures Stabilize the Future LEO Environment?

**\*Mitigation = Limit the generation of new/long-lived debris (NPR 8715.6A, NASA-STD-8719.14, USG OD Mitigation Standard Practices, UN Debris Mitigation Guidelines, *etc.*)**



# Future Projection – The **Best Case Scenario** (**No New Launches Beyond 1/1/2006**)



- **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**

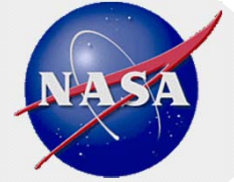
# Assessments of the Best Case (No New Launches) Scenario



- **In reality, the situation will be worse than the “no new launches” scenario as**
  - Satellite launches will continue
  - Major unexpected breakups may continue to occur
- **Postmission 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, more aggressive measures, such as active debris removal (ADR\*), must be considered**

\*ADR = Removing debris beyond guidelines of current mitigation measures





## Conclusions of the 2006 NASA Study

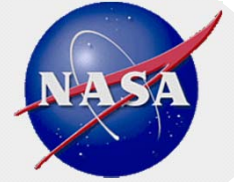
- **“The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future.”**
- **“Only remediation of the near-Earth environment – the removal of existing large objects from orbit – can prevent future problems for research in and commercialization of space.”**

- Liou and Johnson, *Science*, January 2006



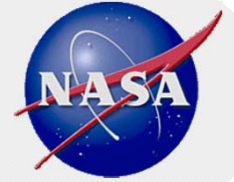
# Options for Environment Remediation\*

**\*Remediation = Removal of pollution or contaminants (*i.e.*, old and new debris) to protect the environment**



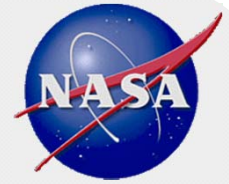
## Key Questions for Environment Remediation

- **Where is the most critical region?**
  - **What are the mission objectives?**
  - **What objects should be targeted first?**
    - The debris environment is very dynamic. Breakups of large intacts generate small debris, small debris decay over time,...
  - **What are the benefits to the environment?**
  - **How to do it?**
- **The answers will drive the top-level requirements, the necessary technology development, and the implementation of the operations**

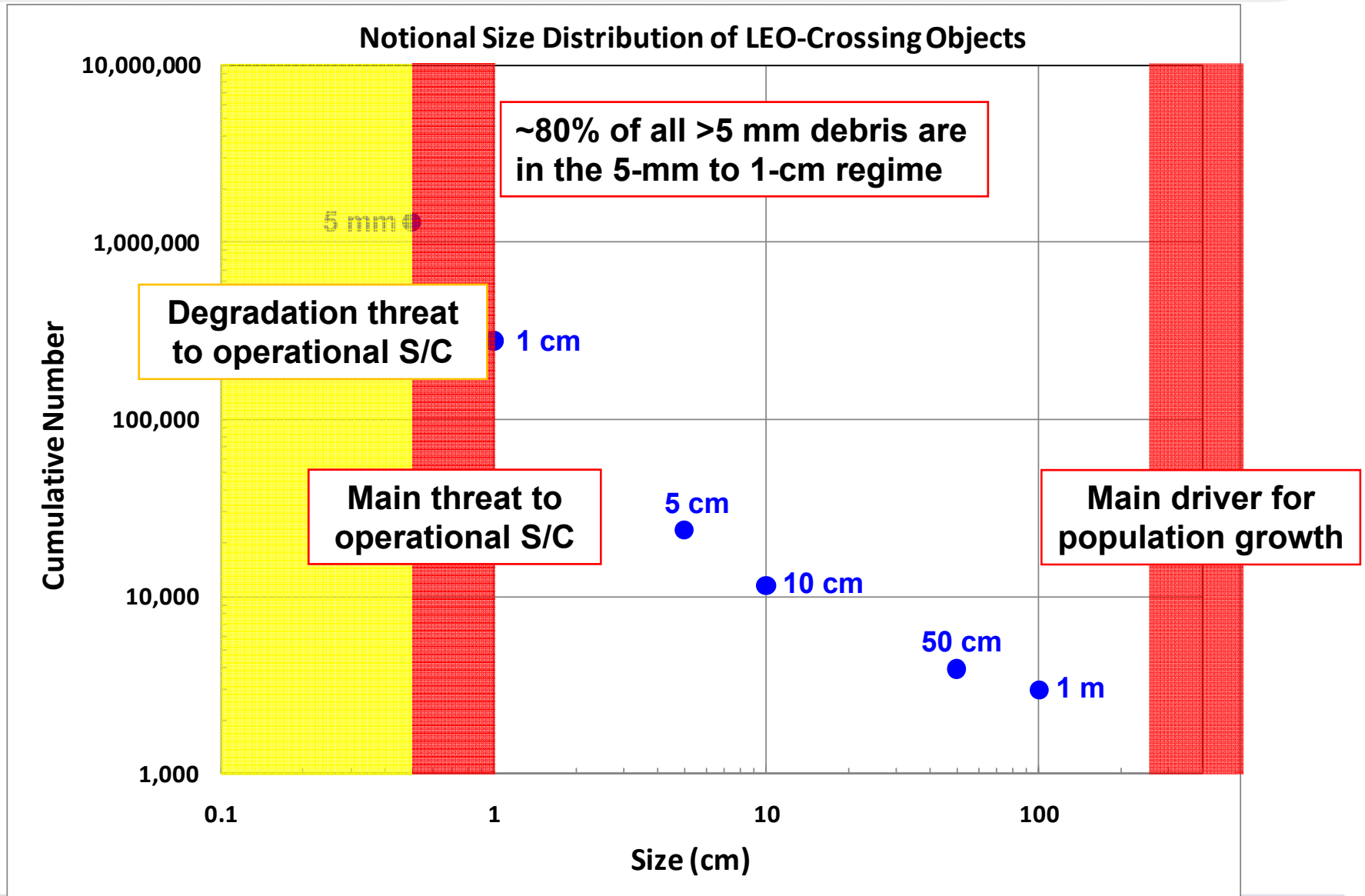


## Target Selection

- **The problem: LEO debris population will continue to increase even with a good implementation of the commonly-adopted mitigation measures**
  - The root-cause of the increase is catastrophic collisions involving large/massive intact objects (R/Bs and S/C)
  - The major mission-ending risks for most operational S/C, however, come from impacts with debris just above the threshold of the protection shields (~5-mm to 1-cm)
- **A solution-driven approach is to seek**
  - Concepts for removal of massive intacts with high  $P_{\text{collision}}$
  - Concepts capable of preventing collisions involving intacts
  - Concepts for removal of 5-mm to 1-cm debris



# Targets for Environment Remediation



# Options for LEO Environment Remediation



- **Removal of massive intact objects with high collision probabilities to address the root cause of the future debris population growth problem**
- **Removal of 5-mm to 1-cm debris to mitigate the main threat for operational spacecraft**
- **Prevention of major debris-generating collisions involving massive intact objects as a potential short-term solution**



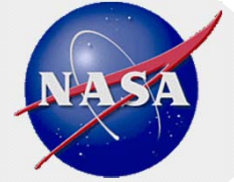
# Challenges for Environment Remediation



# Challenges for Small Debris Removal

- **Targets are small**
  - Approximately 5-mm to 1-cm
- **Targets are numerous (>500,000)**
  - For any meaningful risk reduction, removal of a significant number of targets is needed
- **Targets are not tracked by SSN**
- **Targets are highly dynamic**
  - Long-term operations are needed
- **Concepts proposed by various groups: large-area collectors, laser removal, tungsten dust, etc.**





## Challenges for Collision Prevention

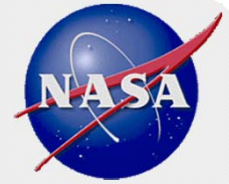
- **To allow for actionable collision prevention operations**
  - JSpOC must expand its conjunction assessments to include R/Bs and retired S/C
  - Dramatic improvements to debris tracking and conjunction assessment accuracy are needed
- **To be effective, collision prevention operations must be applied to all conjunction warnings**
- **Targets are limited in number, but many are massive R/Bs or S/C (up to 9 metric tons dry mass)**
- **Concepts proposed by various groups: ballistic intercept, frozen mist, laser-nudging, etc.**



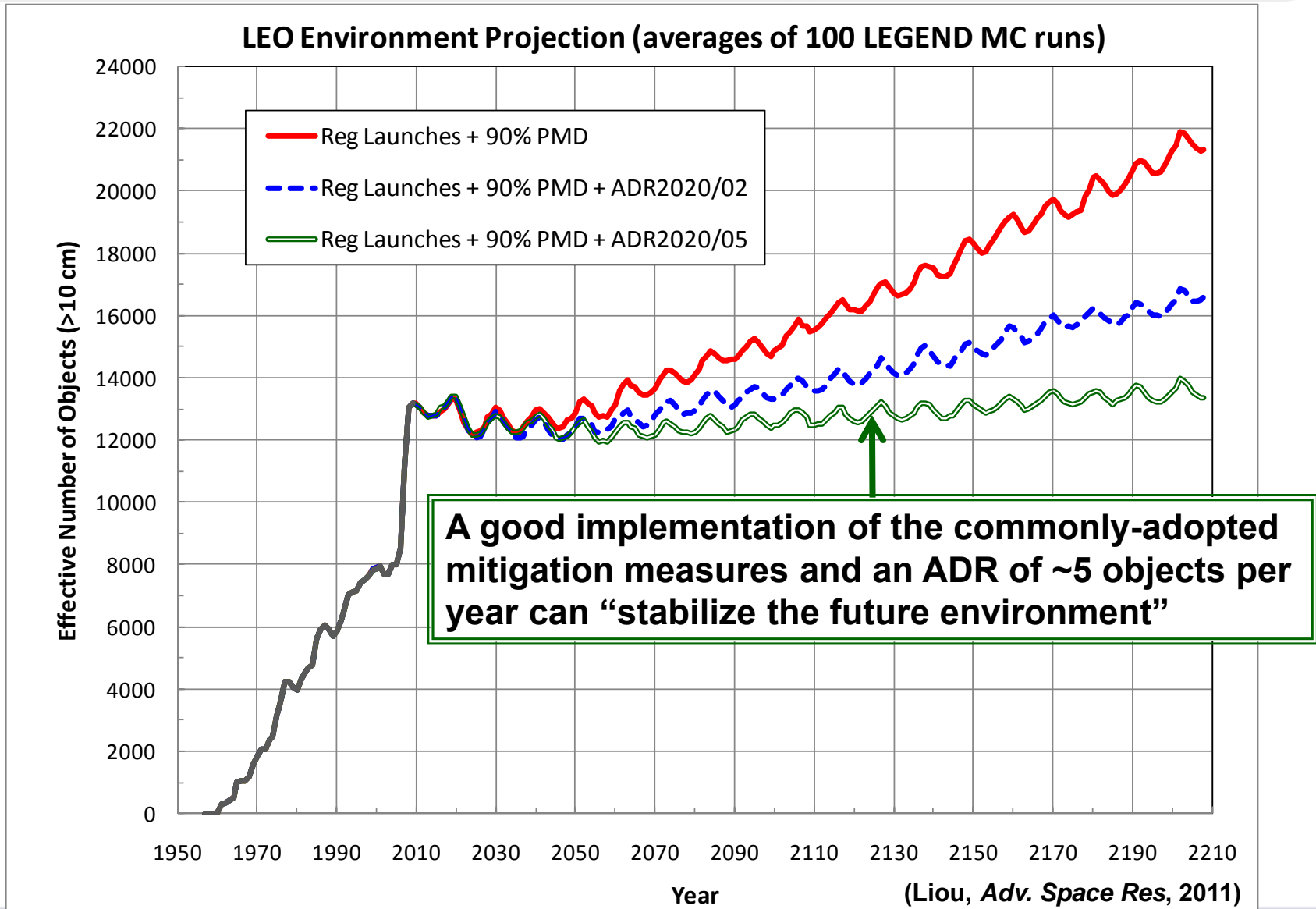
## Targeting the Root Cause of the Problem

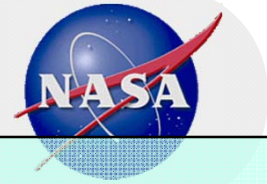
- **A 2008-2009 NASA study shows that the two key elements to stabilize the future LEO environment (in the next 200 years) are**
  - A good implementation of the commonly-adopted mitigation measures (passivation, 25-year rule, avoid intentional destruction, *etc.*)

- An active debris removal of about five objects per year
  - These are objects with the highest [  $M \times P_{\text{coll}}$  ]
  - Many (but not all) of the potential targets in the current environment are spent Russian SL upper stages
    - **Masses:** 1.4 to 8.9 tons
    - **Dimensions:** 2 to 4 m in diameter, 6 to 12 m in length
    - **Altitudes:** ~600 to ~1000 km regions
    - **Inclinations:** ~7 well-defined bands



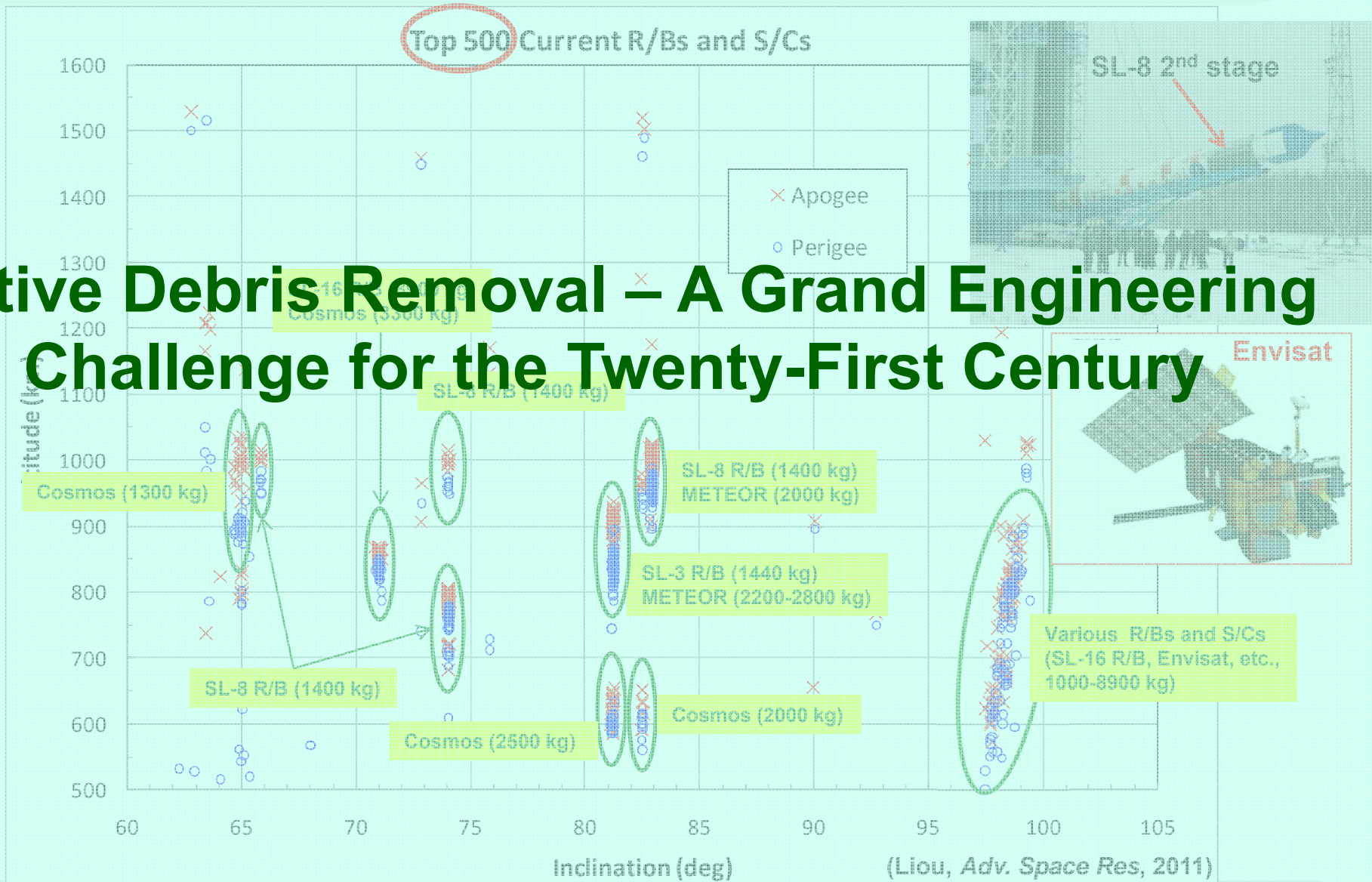
# Controlling Debris Growth with ADR



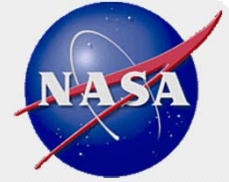


# Potential Active Debris Removal Targets

## Active Debris Removal – A Grand Engineering Challenge for the Twenty-First Century



# Challenges for Large Debris ADR Operations



Operations	Technology Challenges
Launch	Single-object removal per launch may not be feasible from cost perspective
Propulsion	Solid, liquid, tether, plasma, laser, drag-enhancement devices, others?
Precision Tracking	Ground or space-based
GN&C and Rendezvous	Autonomous, non-cooperative targets
Stabilization (of the tumbling targets)	Contact or non-contact (how)
Capture or Attachment	Physical (where, how) or non-physical (how), do no harm
Deorbit or Graveyard Orbit	When, where, reentry ground risks

- **Other requirements:**

- Affordable cost
- Repeatability of the removal system (in space)?
- Target R/Bs first?



## Forward Path

- **There is a need for a top-level, long-term strategic plan for environment remediation**
  - Define “what is the acceptable threat level”
  - Define the mission objectives
  - Establish a roadmap/timeframe to move forward
- **The community must commit the necessary resources to support the development of innovative, low-cost, and viable removal technologies**
  - Encourage multi-purpose technologies
- **Address non-technical issues, such as policy, coordination, ownership, legal, and liability at the national and international levels**



# Preserving the Environment for Future Generations

- **Innovative concepts and technologies are key to solve the ADR challenges**
- **International consensus, cooperation, collaboration, and contributions are needed for environment remediation**

