The Long-Term Stability of the LEO Debris Population and the Challenges for Environment Remediation

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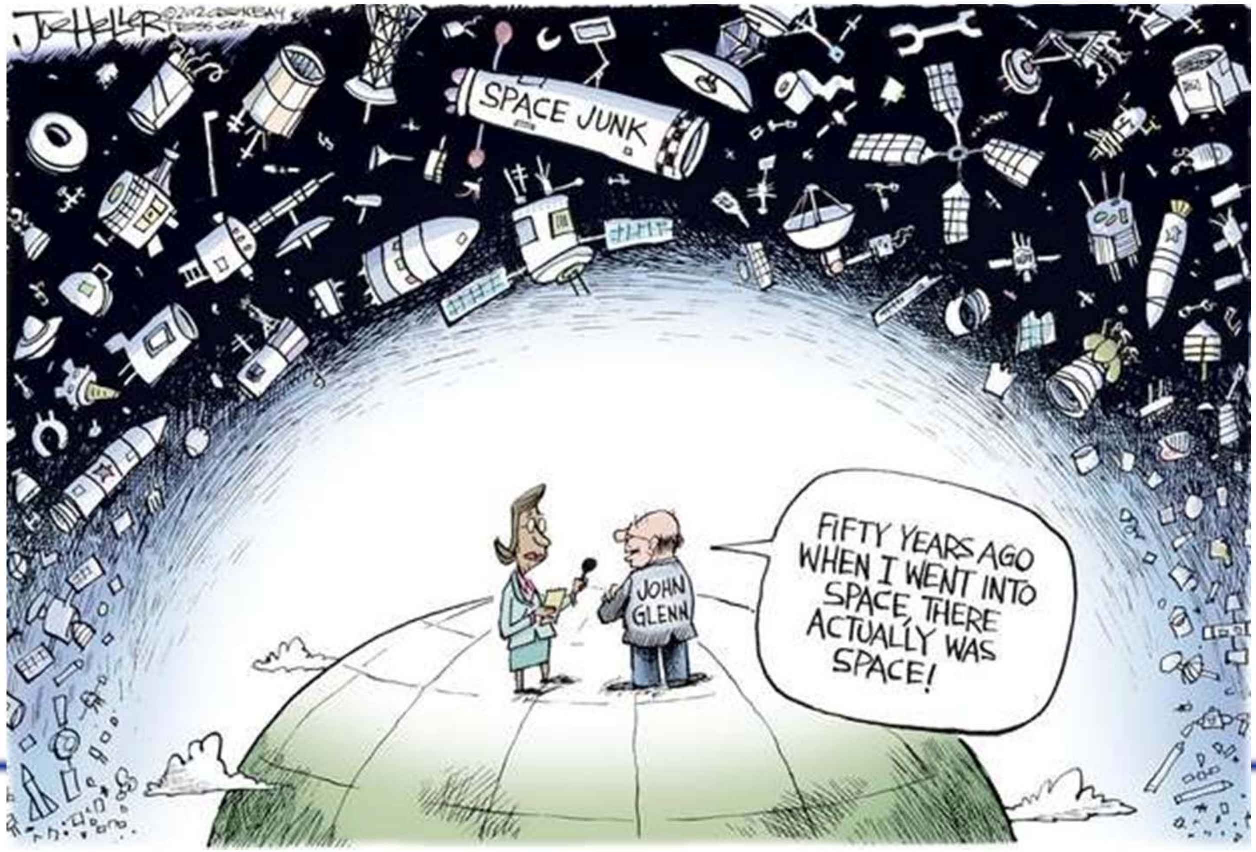
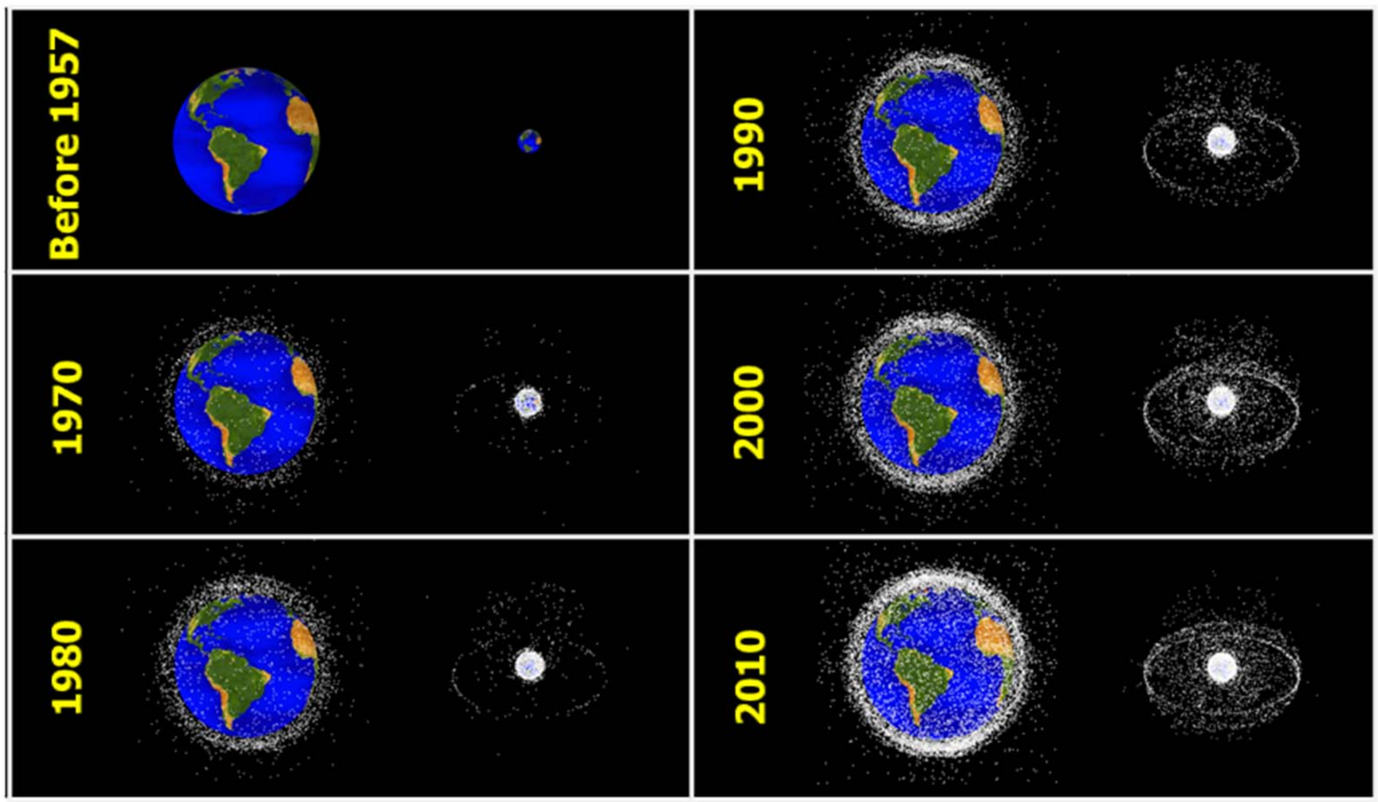
Outline

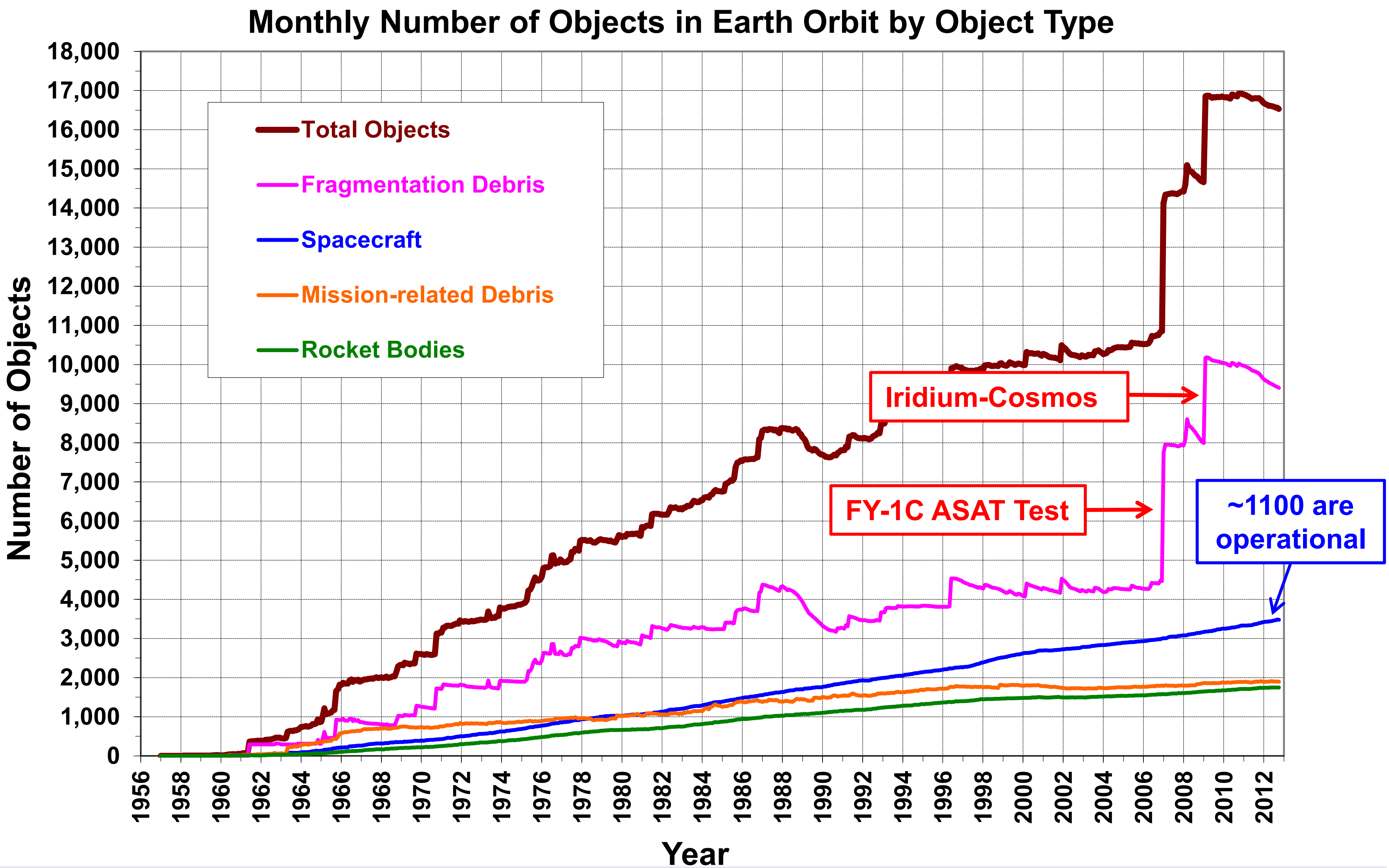
- Buildup of the Orbital Debris (OD) Population
- Projected Growth of the OD Population
- Options for Environment Remediation
- Challenges Ahead



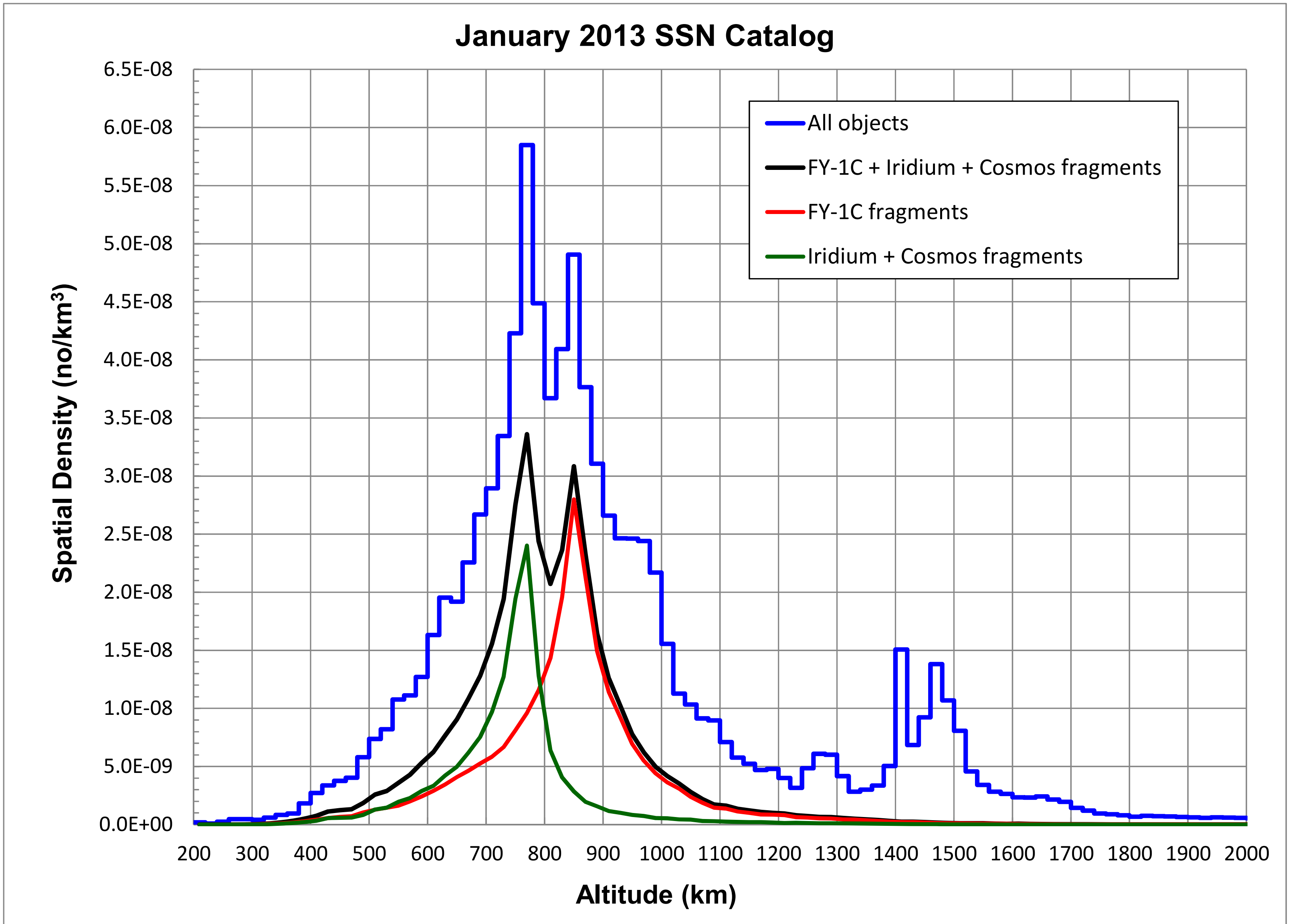
Buildup of the Orbital Debris Population



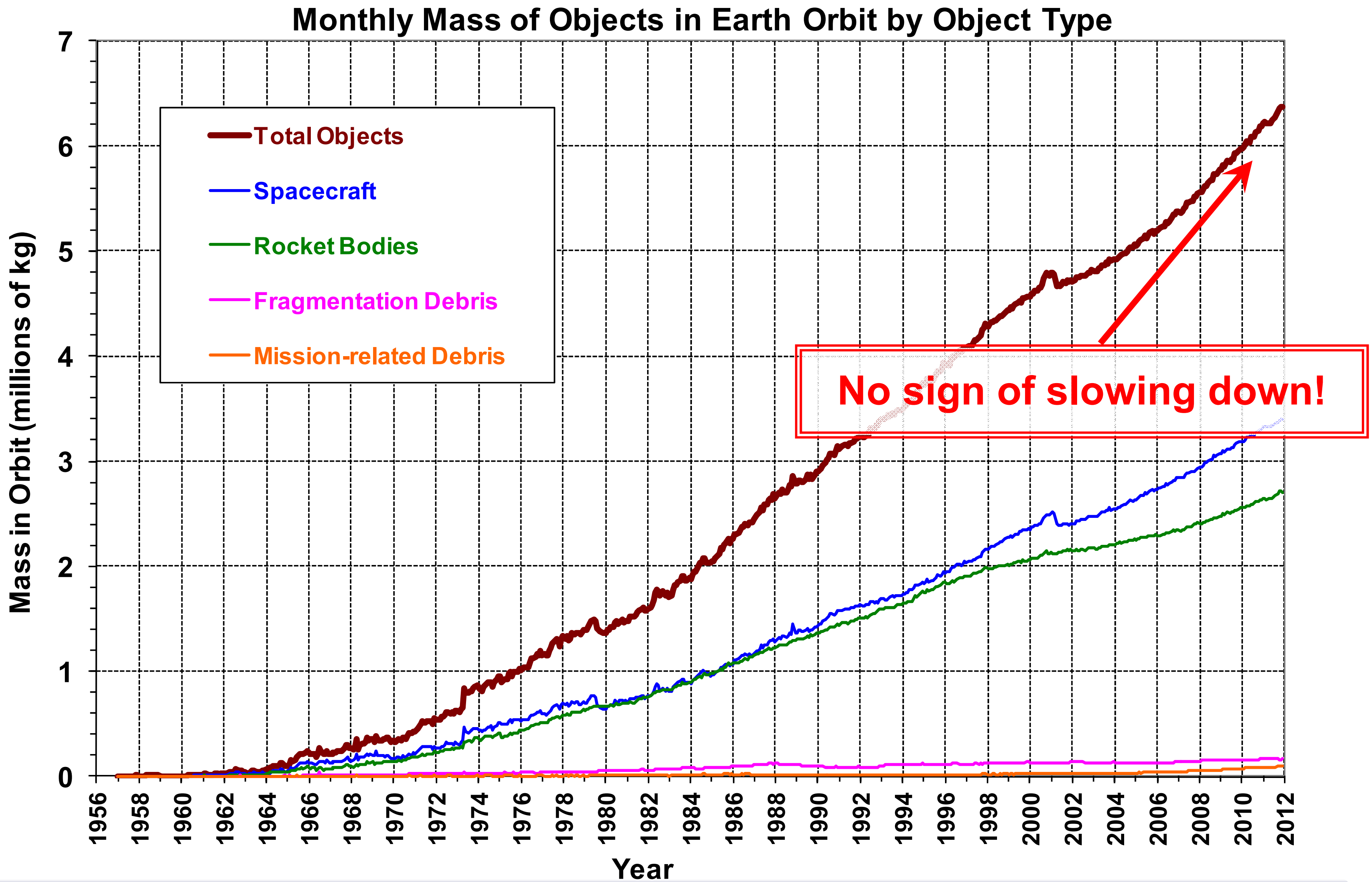
Growth of the Cataloged Populations



The LEO Environment



Mass in Orbit

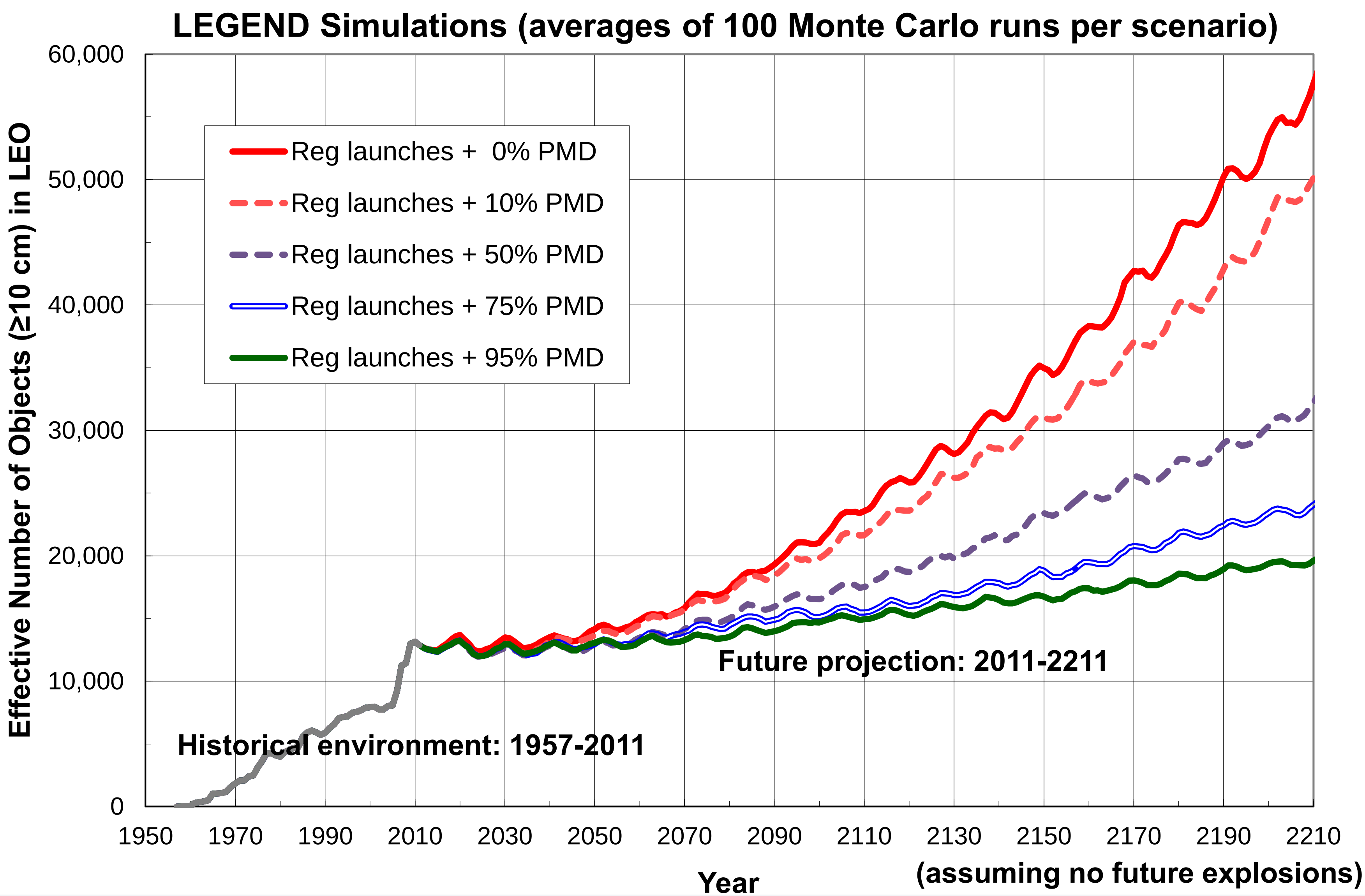


The Big Sky Is Getting Crowded

- **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 16 debris avoidance maneuvers since 1999**
  - 5 times since April 2011

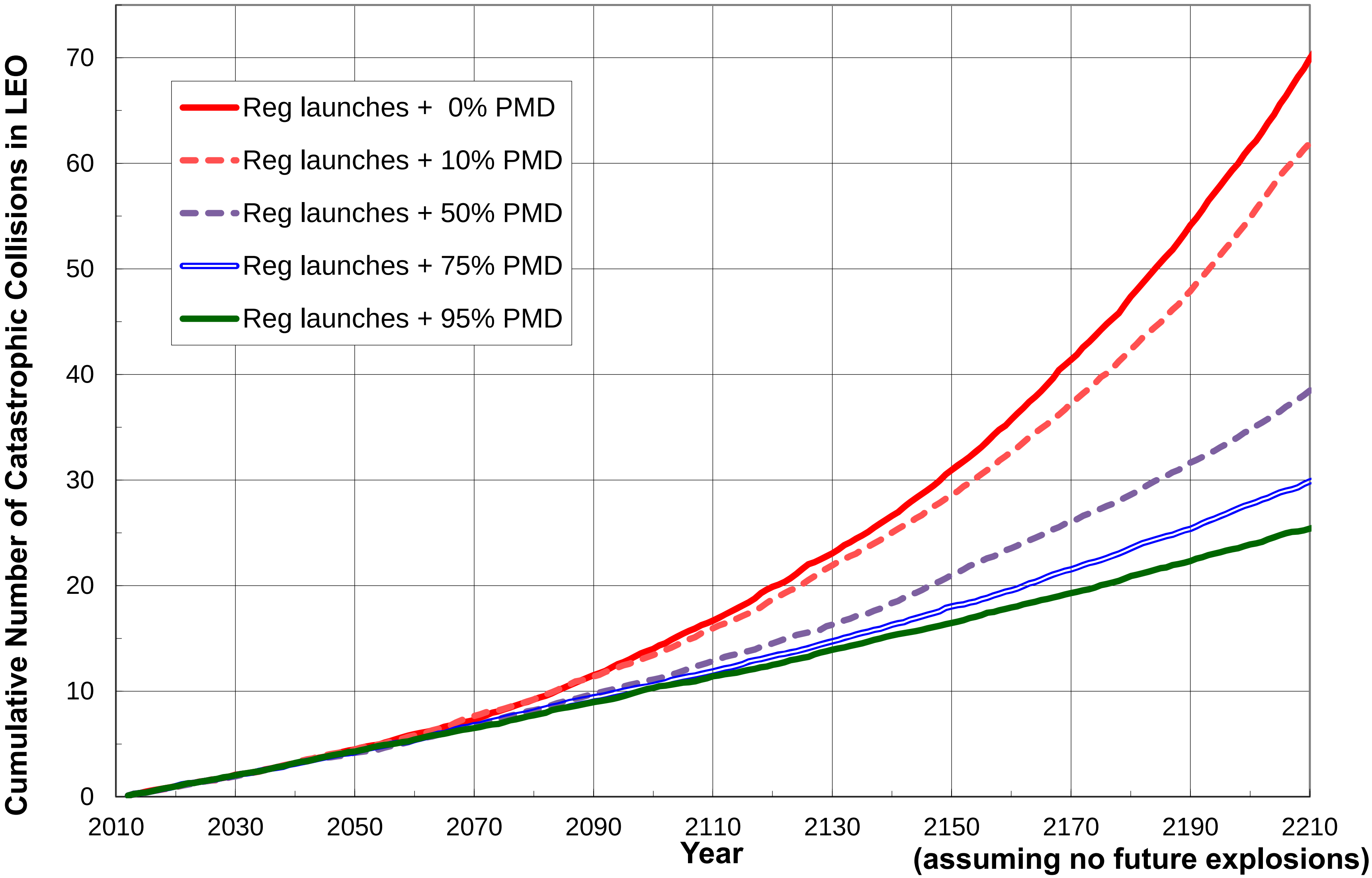
Projected Growth of the Debris Population

Effectiveness of Postmission Disposal (PMD)



Projected Catastrophic Collisions in LEO

LEGEND Simulations (averages of 100 Monte Carlo runs per scenario)



Assessments of the Future Projections

- Postmission disposal (PMD), including passivation and the 25-year decay rule, can significantly limit the future population growth, but PMD will be insufficient to stabilize the LEO environment
- 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

Options for Environment Remediation*

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

Key Questions for Environment Remediation

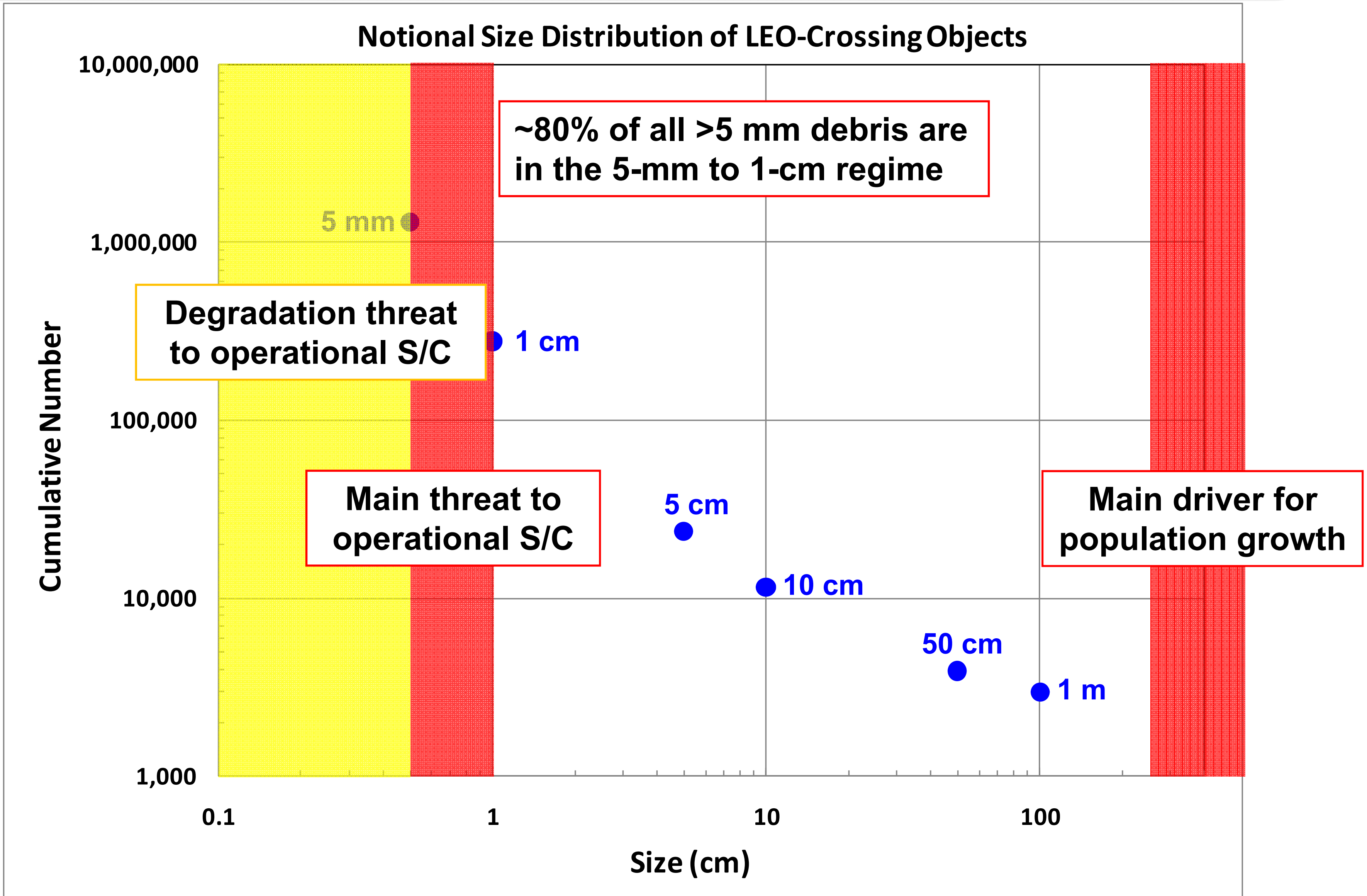
- **Where is the most critical region?**
- **What are the mission objectives?**
- **What objects should be targeted first?**
  - The debris environment is very dynamic. Breakups of large intacts generate small debris, small debris decay over time,…
- **What are the benefits to the environment?**
- **How 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 <u>solution-driven</u> approach is to seek**
  - Concepts for removal of massive intacts with high $P_{collision}$
  - 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 <u>short-term</u> 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.***

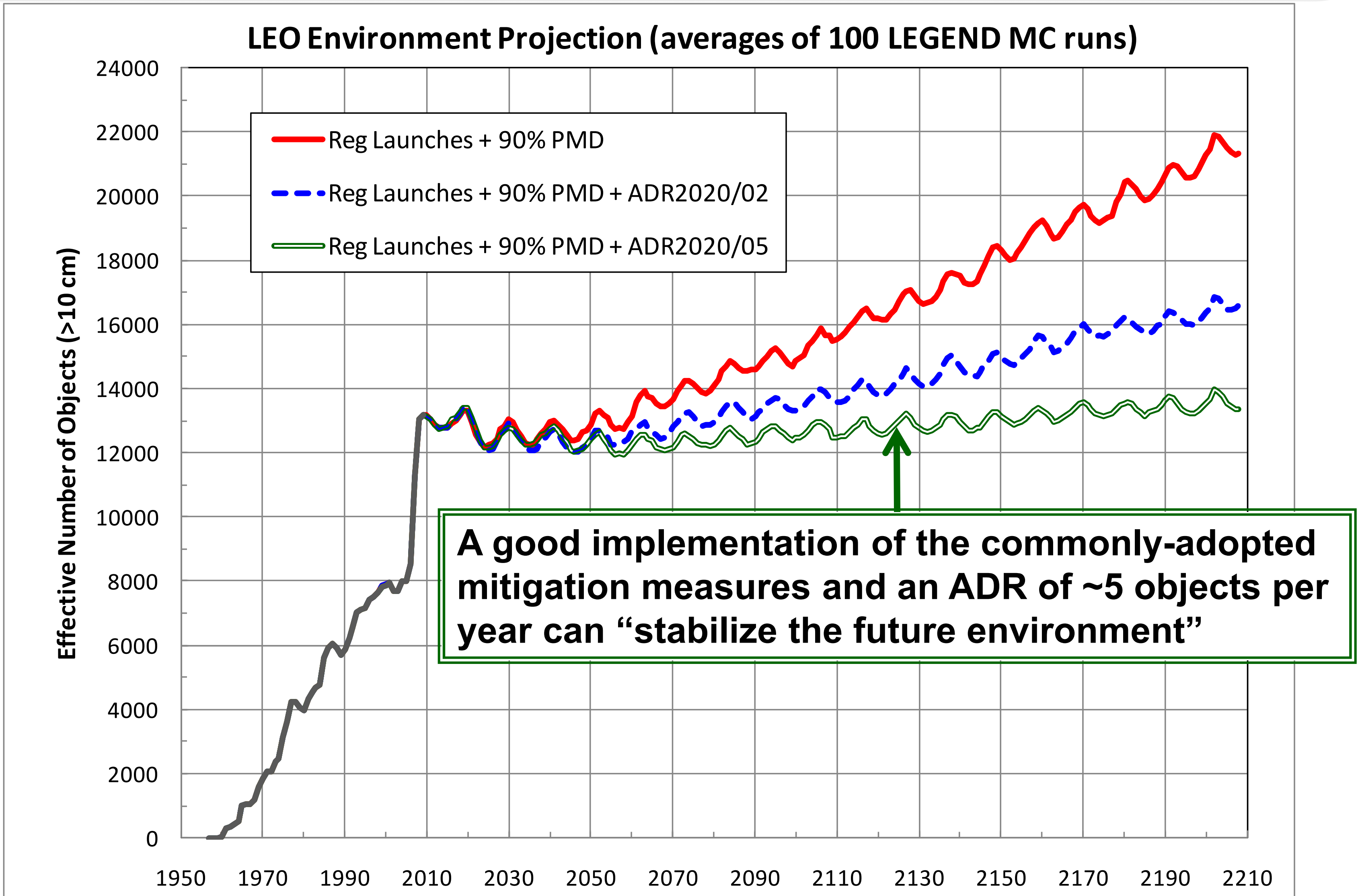
Challenges for Collision Prevention

- **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

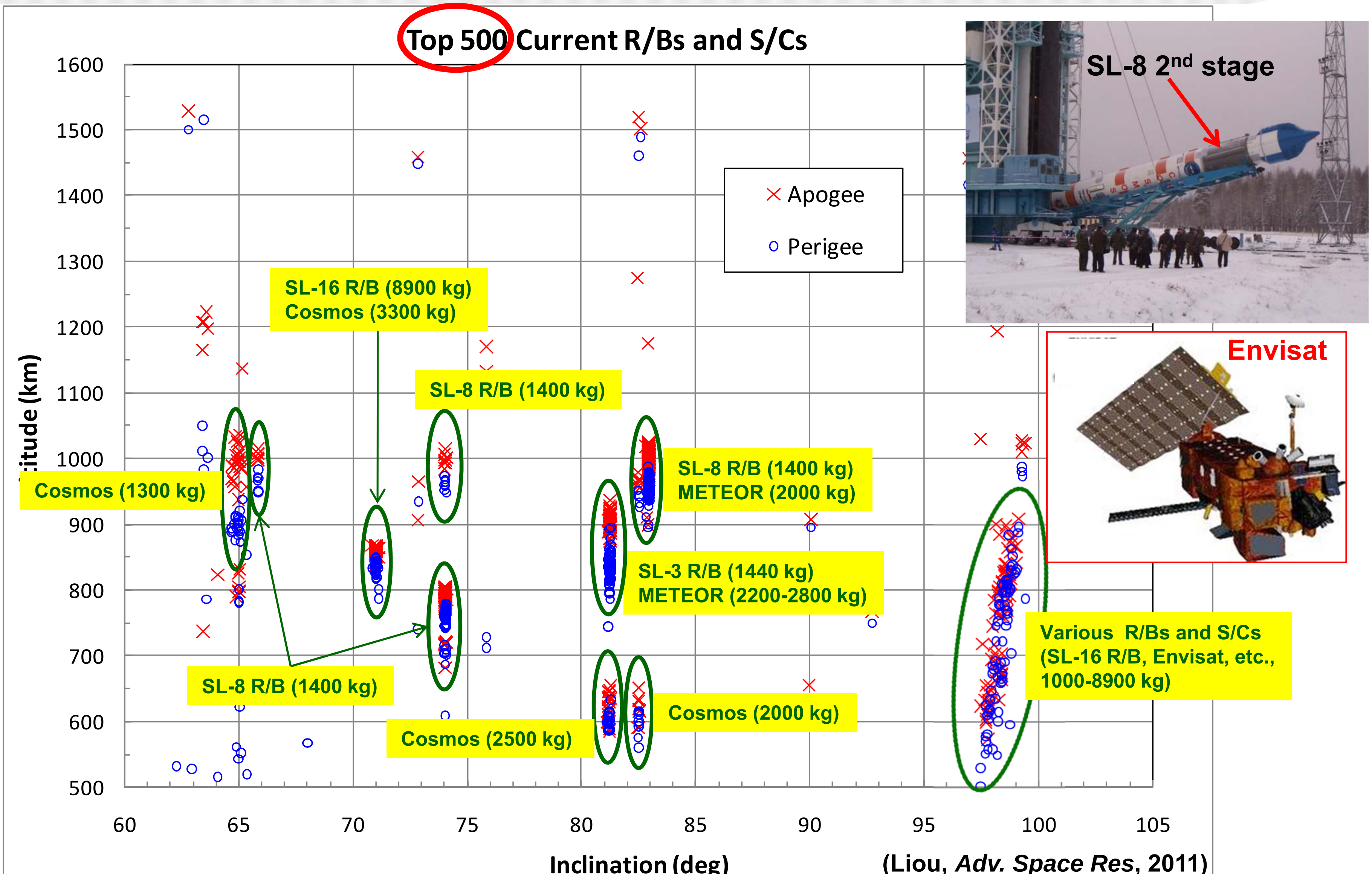
- **A 2008-2009 NASA study shows that the two key elements to stabilize the future LEO environment (in the next 200 years) are**
  - A good implementation of the commonly-adopted mitigation measures (passivation, 25-year rule, avoid intentional destruction, *etc.)*
  - An active debris removal of about five objects per year
    - **These are objects with the highest [M × P_{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



(Liou, *Adv. Space Res*, 2011)

Potential Active Debris Removal Targets



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

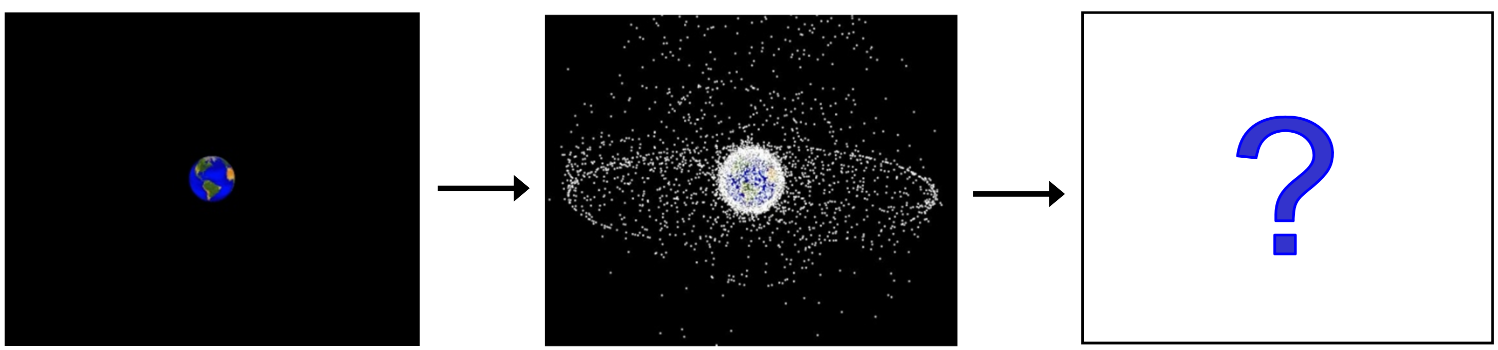
- **Other requirements:**
  - Affordable cost
  - Repeatability of the removal system (in space)?
  - Target R/Bs first?

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 <u>innovative</u>, <u>low-cost</u>, and viable removal technologies**
  - Encourage multi-purpose technologies
- **Address non-technical issues, such as policy, coordination, ownership, legal, and liability at the <u>national and international</u> 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**



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