National Aeronautics and Space Administration

The Top 10 Questions for Active Debris Removal

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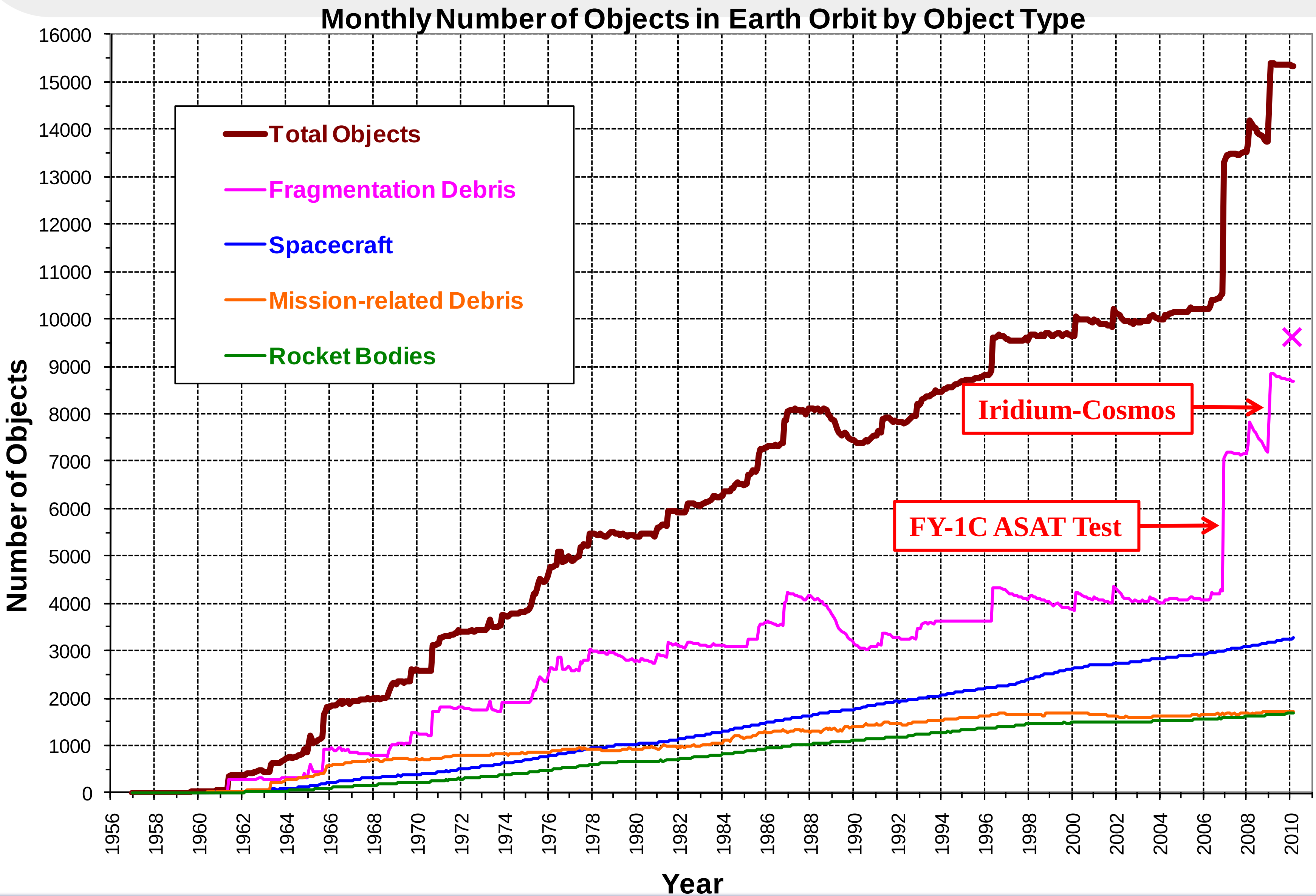
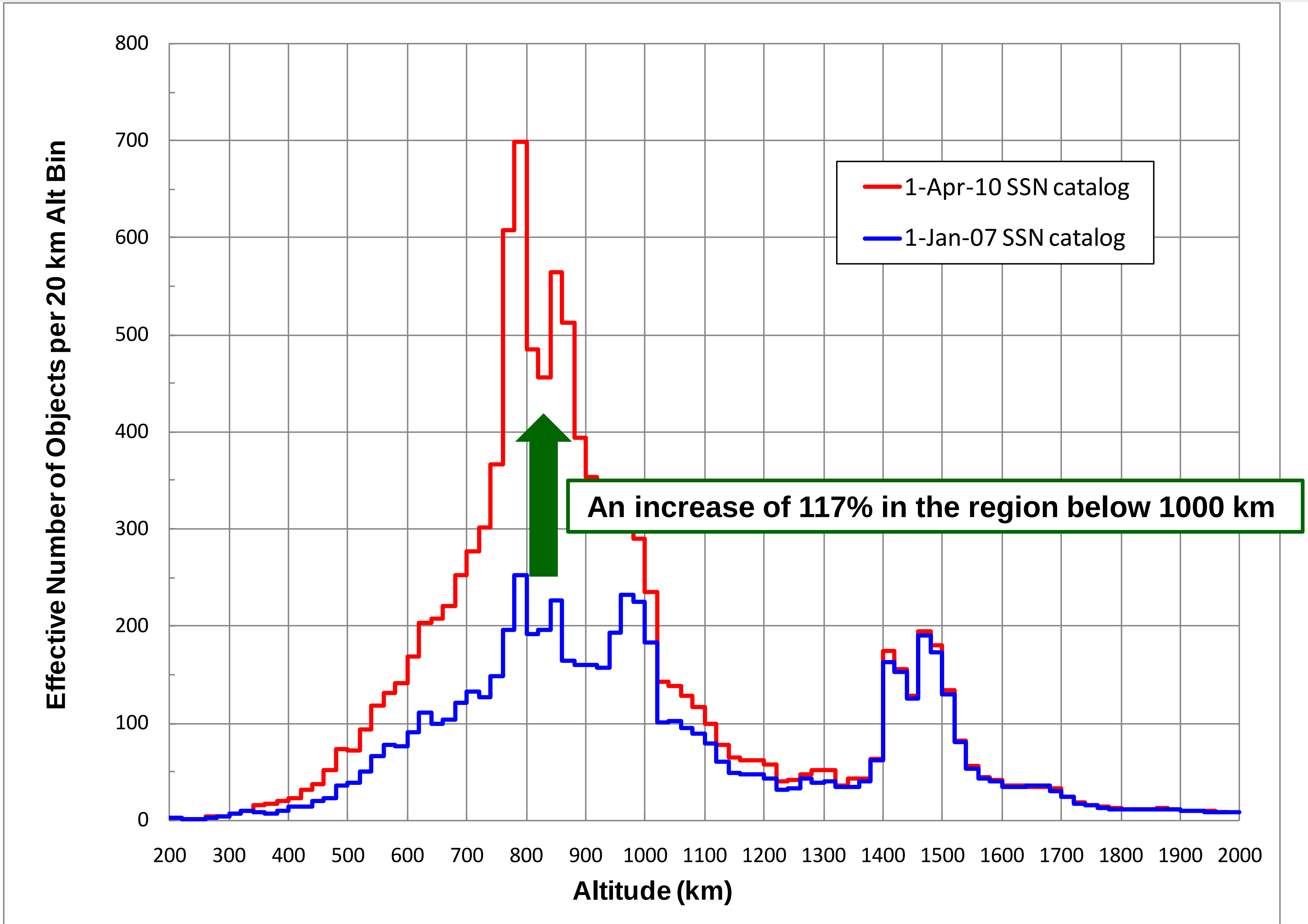
Outline

- **Historical and current orbital debris environment**
- **The top 10 topics for active debris removal (ADR)**
  - Focus the discussion on ≥10 cm objects
  - Limit the future projection to 200 years
  - Use the NASA orbital debris evolutionary model, LEGEND (an LEO-to-GEO Environment Debris model), for simulations
  - Address environment remediation only (will not discuss cost, technology, ownership, legal, liability, and policy issues)
- **Recent and future active debris removal activities**
  - ADR conference, workshops, studies, opportunities, etc.

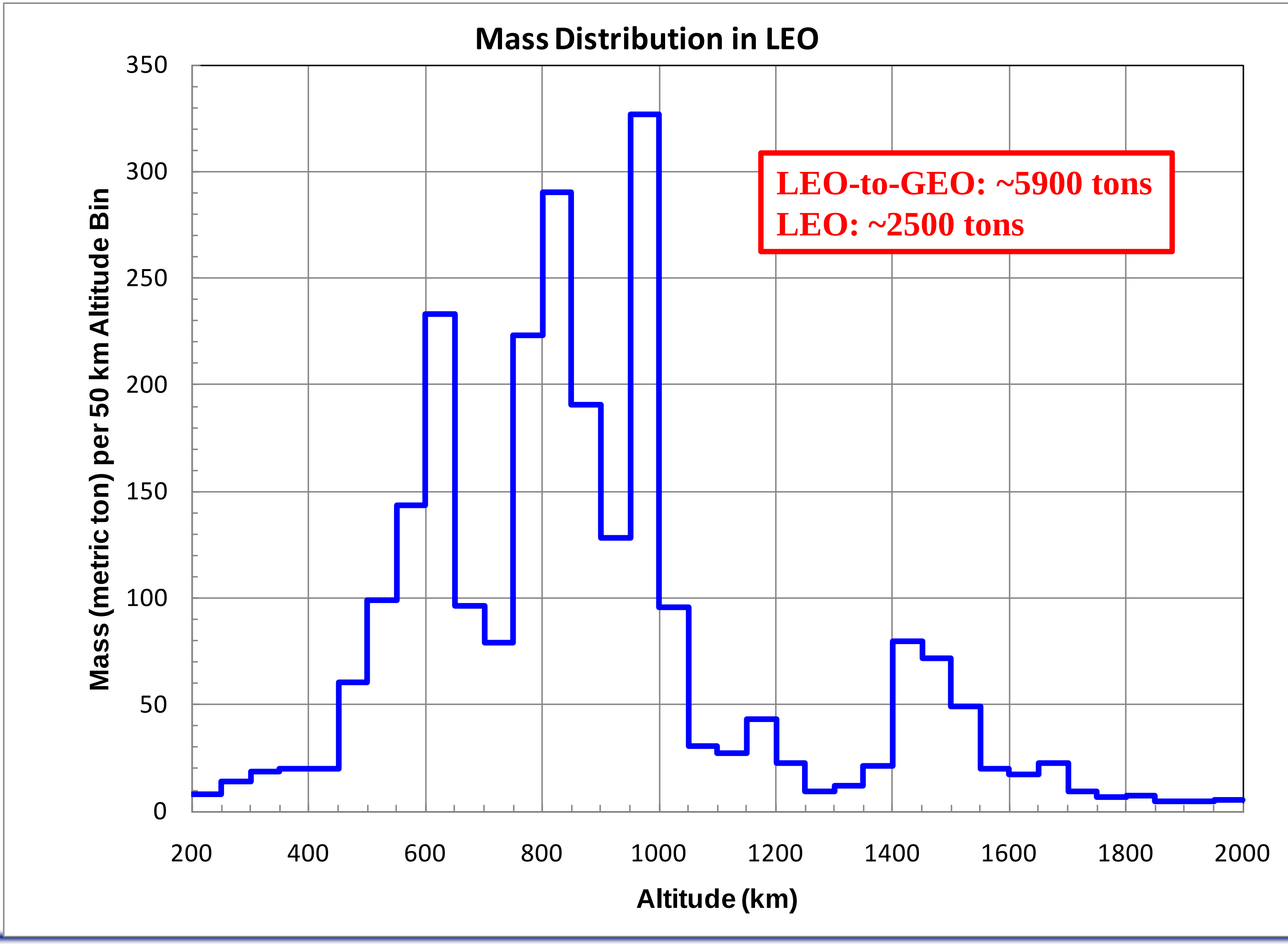
Growth of the Historical Debris Populations



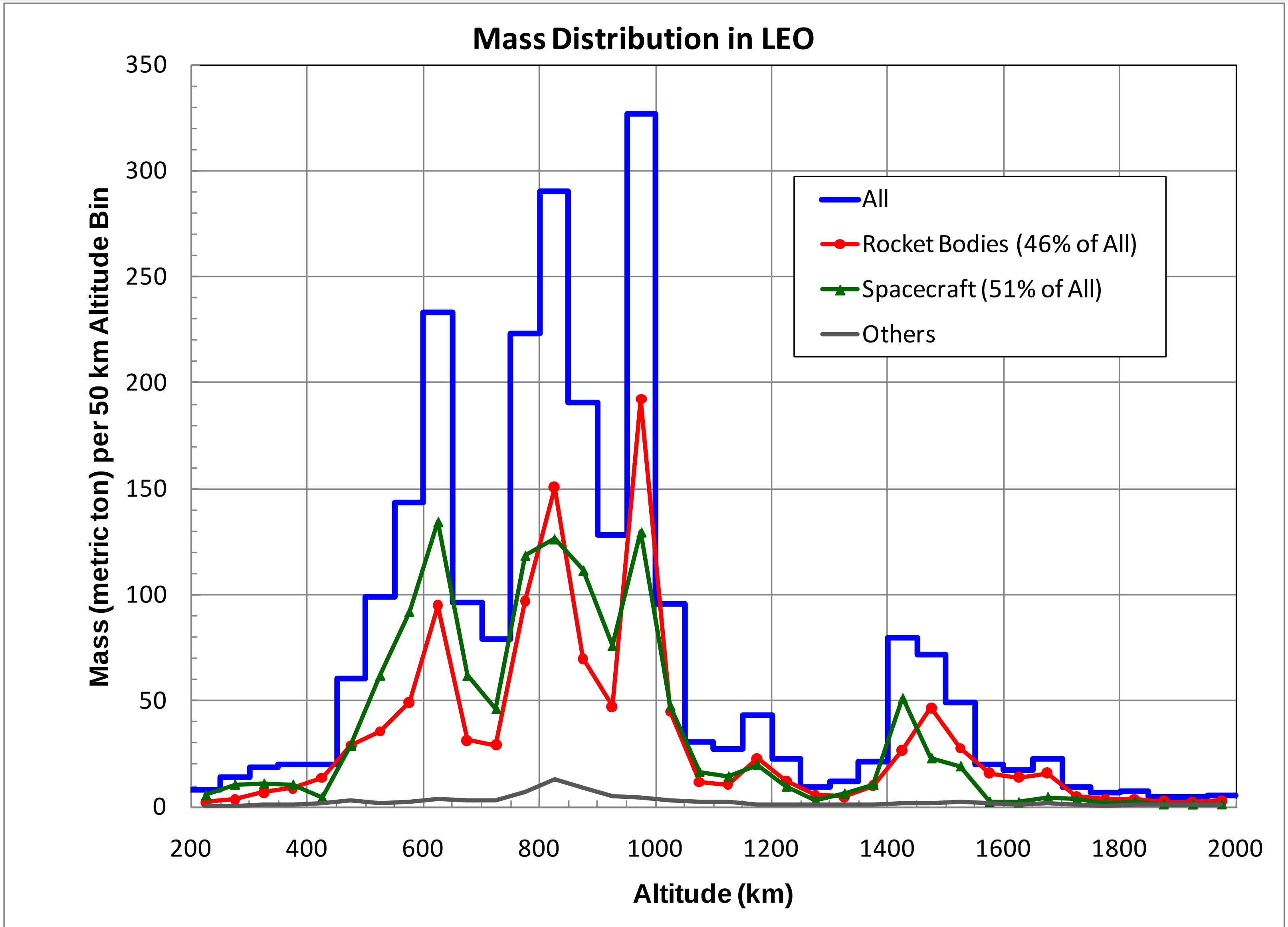
Consequences of the Two Major Breakups



Mass in Orbit (1/2)



Mass in Orbit (2/2)



The Top 10 Topics for Active Debris Removal

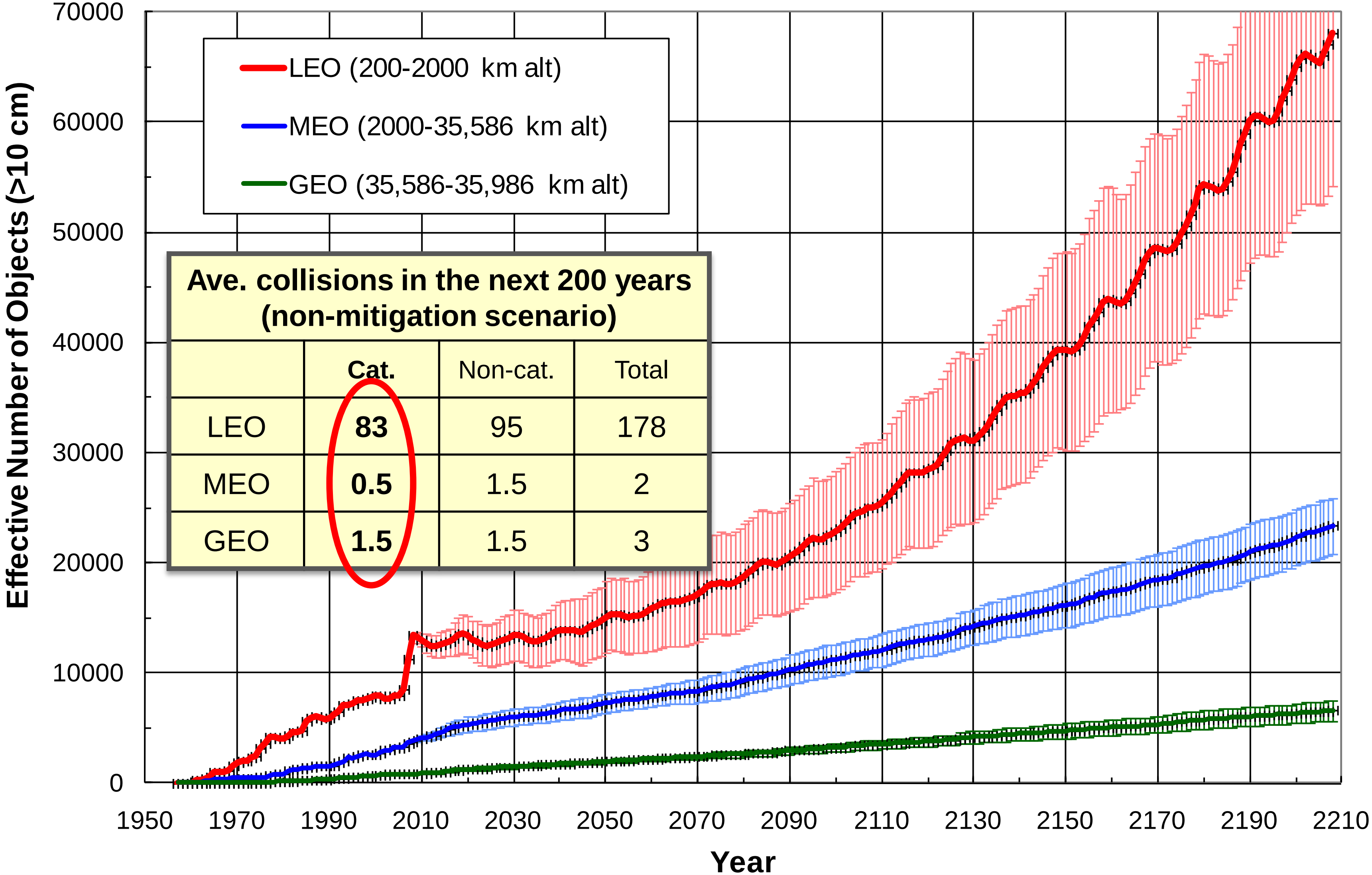
The Top-10 List

1. Which region (LEO/MEO/GEO) has the fastest projected growth rate and the highest collision activities?
2. Can the commonly-adopted mitigation measures stabilize the future environment?
3. What are the objectives of ADR?
4. How can effective ADR target selection criteria to stabilize the future LEO environment be defined?
5. What are the keys to remediate the future LEO environment?
6. What is the timeframe for ADR implementation?
7. What is the effect of practical/operational constraints?
8. What are the collision probabilities and masses of the current objects?
9. What are the benefits of collision avoidance maneuvers?
10. What is the next step?

1. Which region (LEO/MEO/GEO) has the fastest projected growth rate and the highest collision activities?

Projected Growth of the Future Debris Populations

Non-Mitigation Projection (averages and 1-σ from 100 MC runs)



Ave. collisions in the next 200 years (non-mitigation scenario)

	Cat.	Non-cat.	Total
LEO	**83**	95	178
MEO	**0.5**	1.5	2
GEO	**1.5**	1.5	3

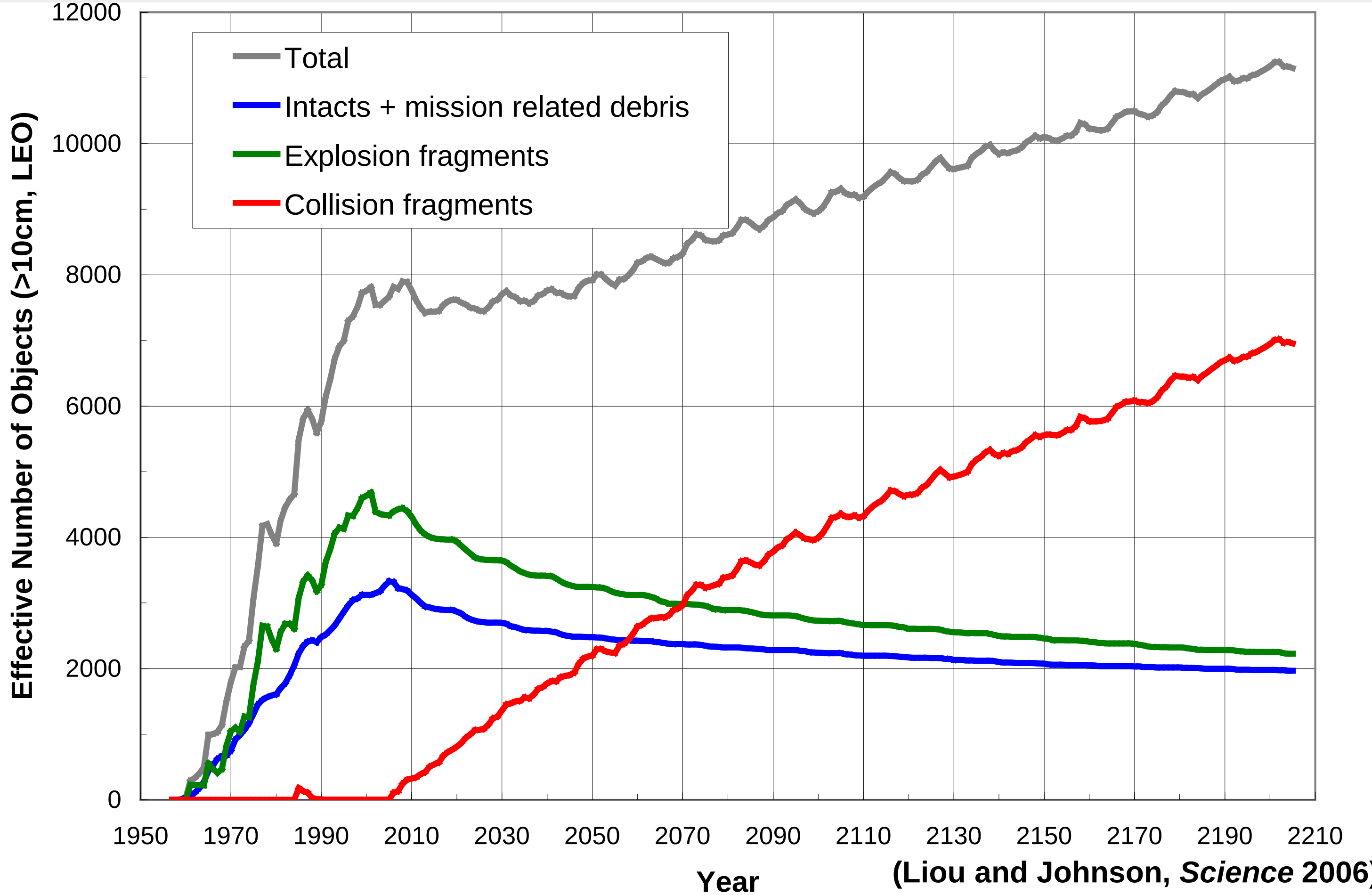
Assessments of the Non-Mitigation Projection

- **LEO: the non-mitigation scenario predicts the debris population (≥10 cm objects) will have a rapid non-linear increase in the next 200 years**
  - This is a well-known trend that was the motivation for developing the currently-adopted mitigation measures more than 10 years ago

- **MEO and GEO: the non-mitigation scenario predicts a moderate population growth**
  - Only a few accidental collisions between ≥10 cm objects are predicted in the next 200 years
  - The currently-adopted mitigation measures will further limit the population growth in key regions
  - Active debris removal is not a priority

2. Will the commonly-adopted mitigation measures stabilize the future LEO environment?

2005 LEGEND Study – the Best Case Scenario
(No New Launches Beyond 1/1/2006)



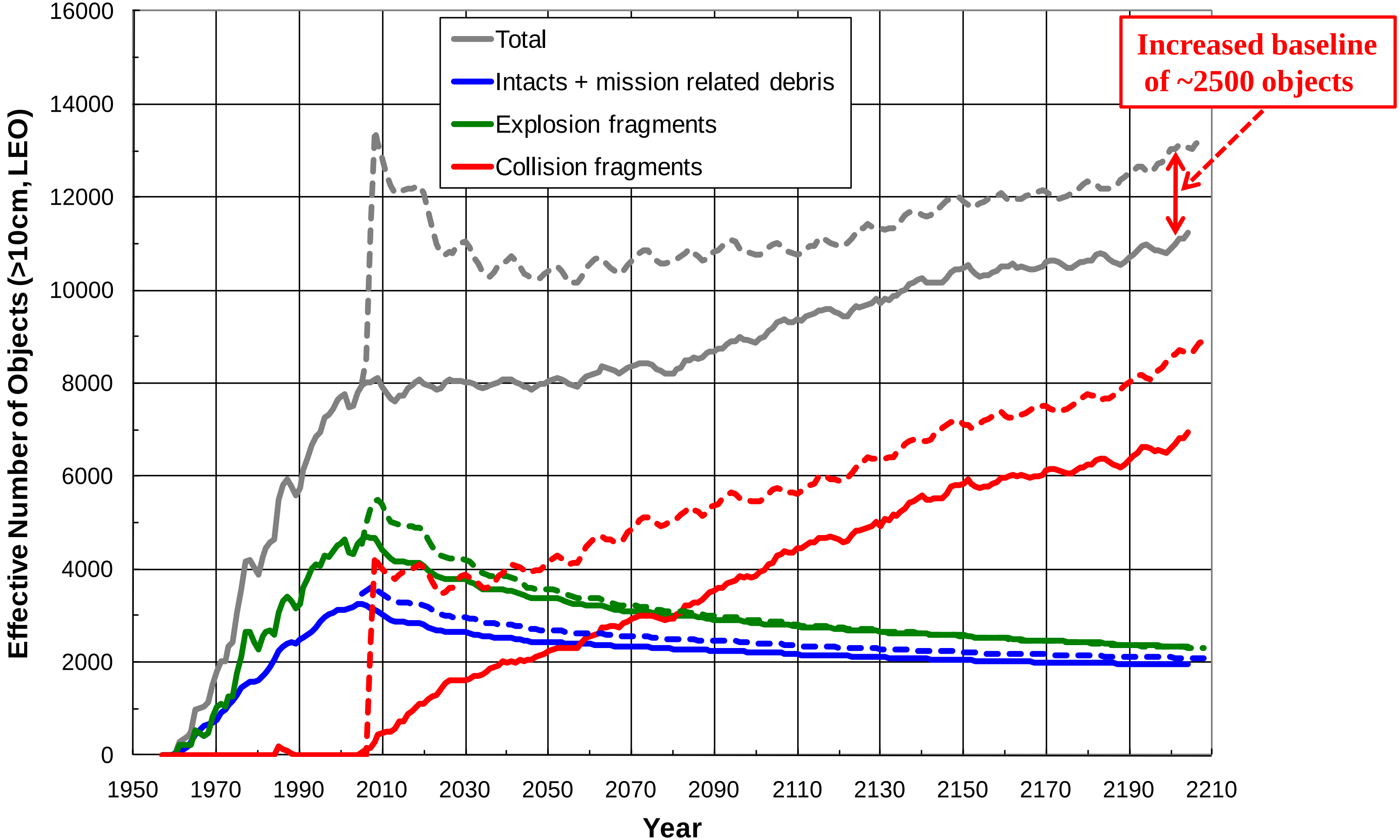
(Liou and Johnson, *Science* 2006)

- 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

A Realistic Assessment

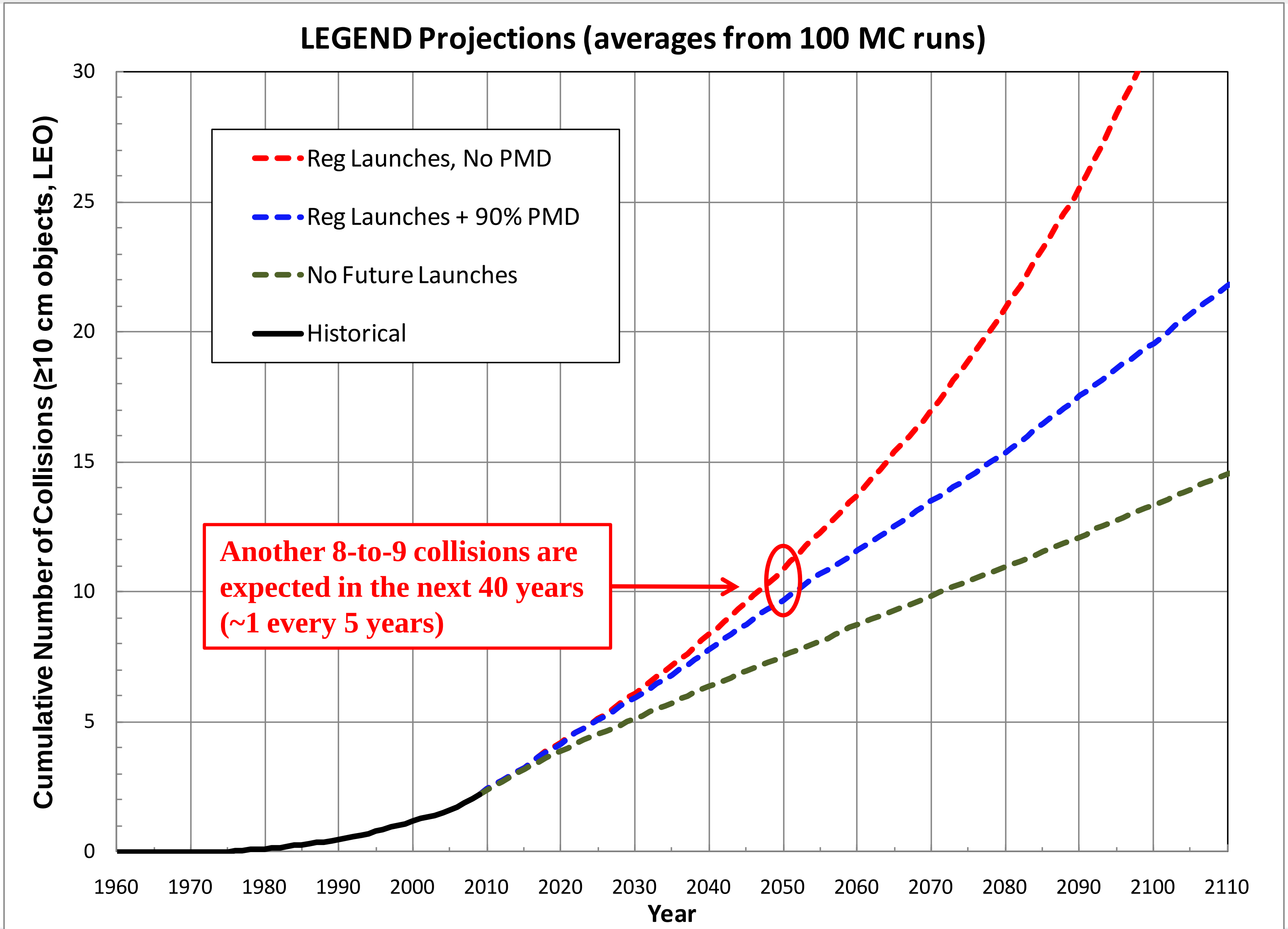
- **In reality, the situation will be worse than the "no new launches" scenario as**
  - Satellites launches will continue
  - Major breakups may continue to occur (e.g., Fengyun-1C, Briz-M, Iridium 33/Cosmos 2251)
- **Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient to prevent the self-generating phenomenon from happening**
- **To preserve the near-Earth space for future generations, ADR must be <u>considered</u>**

LEO Environment After FY-1C and Iridium/Cosmos Breakups



- **Solid lines: 1957-to-2006, no new launches beyond 2006**
- **Dashed lines: 1957-to-2009, no new launches beyond 2009**

Collisions in LEO



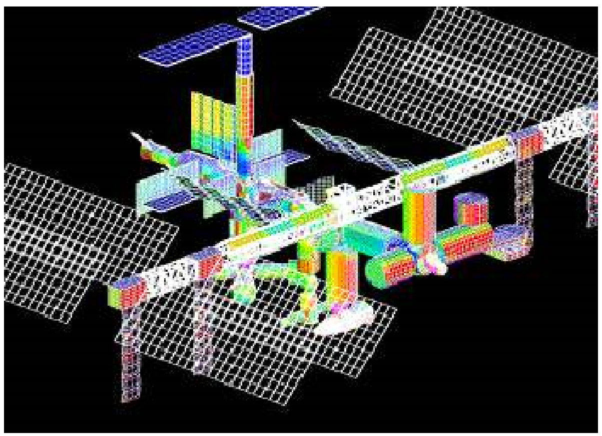
3. What are the objectives of ADR?
(How to define mission success?)

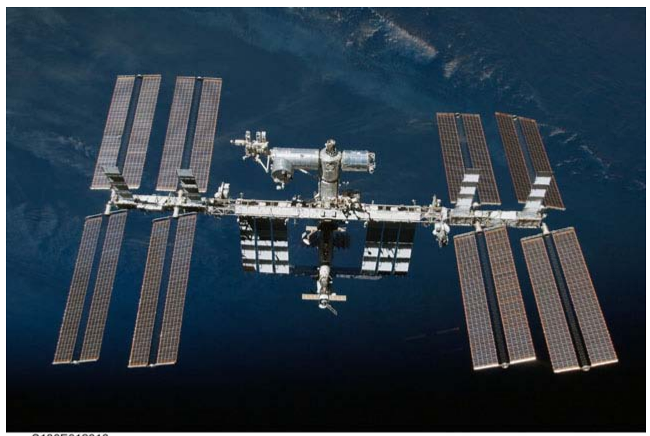
How to Define Mission Success?

- **The mission objectives guide the removal target selection criteria and the execution of ADR**
- **Specific objectives**
  - Control population growth (≥10 cm or others)
  - Limit collision activities
  - Mitigate short-/long-term risks (damage, not necessarily catastrophic destruction) to selected payloads
  - Mitigate risks to human space activities
  - And so on
- **Common objectives**
  - Follow practical/mission constraints (in altitude, inclination, class, size, etc.)
  - Maximize benefit-to-cost ratio

One Example: Risks From Small Debris

- **The U.S. segments of the ISS are protected against orbital debris about 1.4 cm and smaller**
  - "Currently", the number of objects between 1.5 cm and 10 cm, with orbits crossing that of the ISS, is approximately 1200
    - **~800 of them are between 1.5 cm and 3 cm**
  - To reduce 50% of the ISS-crossing orbital debris in this size range (1.5 cm to 3 cm) will require, for example, a collector with an area-time product of ~1000 km^2 year





4. How can effective ADR target selection criteria to stabilize the future LEO environment be defined?

A Simple Physical Argument

- **Future LEO environment is likely to be dominated by fragments generated via accidental collisions**

- **The effort to reduce <u>future accidental collision fragments</u> should focus on**
  – Objects with the highest collision probabilities
  – Objects with the potential of generating the greatest amount of fragments after collisions

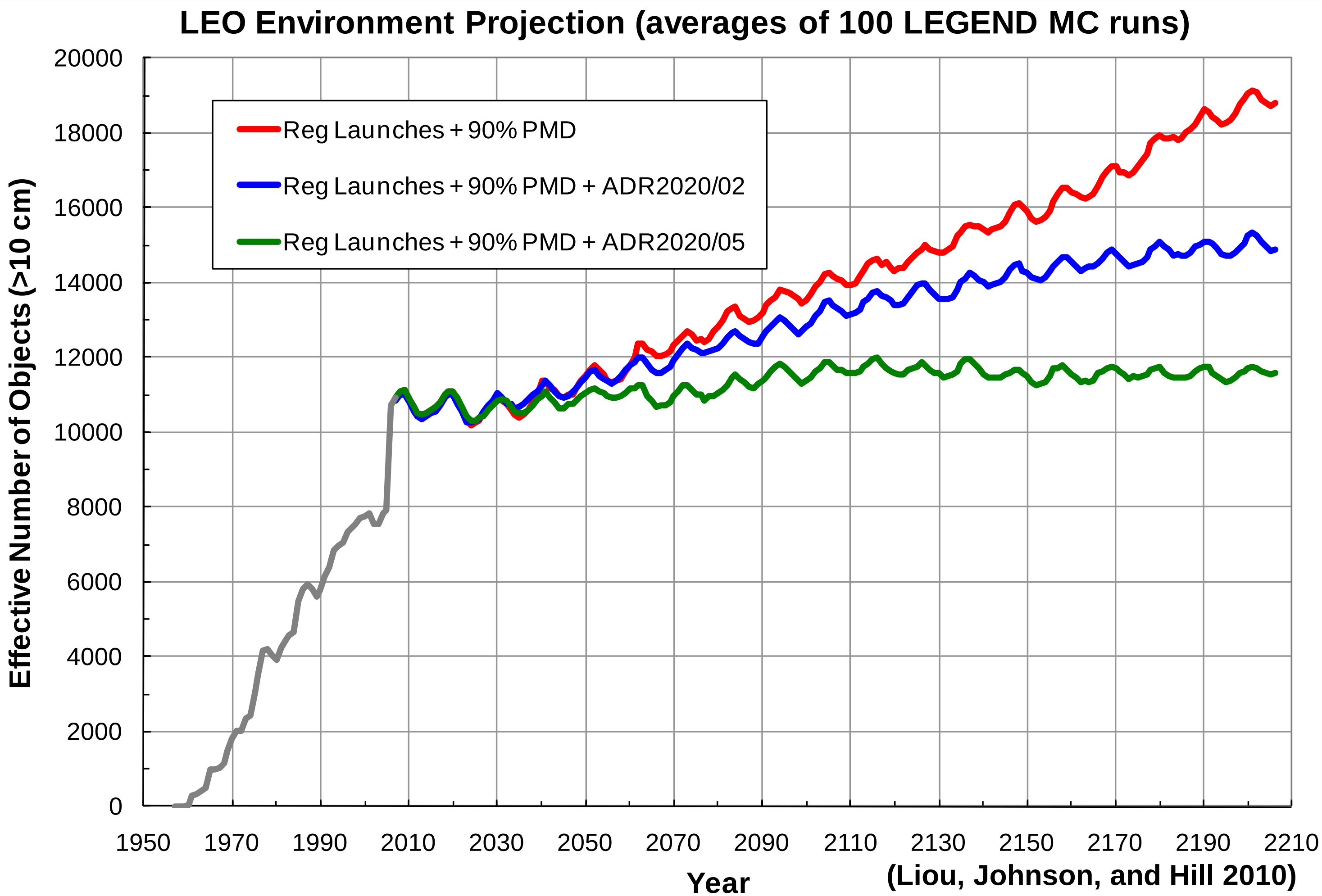
- **An effective ADR target selection criterion can be defined as**
  – Objects with the highest [M × Pc]; M: mass, Pc: collision probability

5. What are the keys to remediate the future LEO environment?

Active Debris Removal Modeling

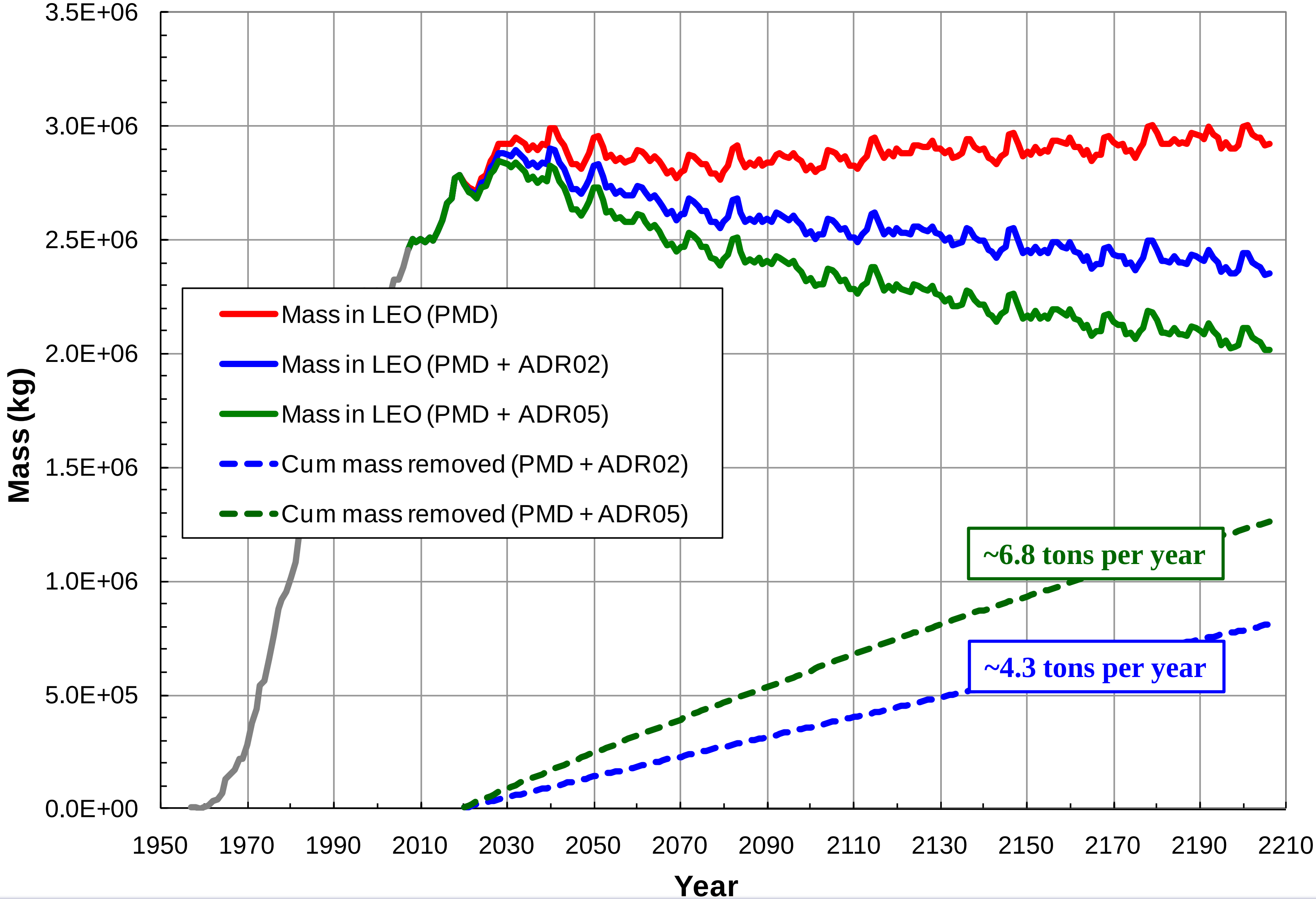
- **A 2008-2009 LEGEND study shows that the two key elements to stabilize the future LEO environment (in the next 200 years) are**
  - A good implementation of the commonly-adopted mitigation measures (passivation, 25-year rule, avoid intentional destruction, etc.)
  - An active debris removal of about five objects per year
    - **Select objects with the highest [M × Pc]**
    - **Is based on two assumptions: (1) future launches can be represented by the traffic cycle from the last 8 years, and (2) implementation of ADR start in 2020**
    - **Does not include Iridium 33/Cosmos 2251 fragments**
  - Future LEO environment can become better than what it is today if more than five objects per year are removed

LEO Population Control



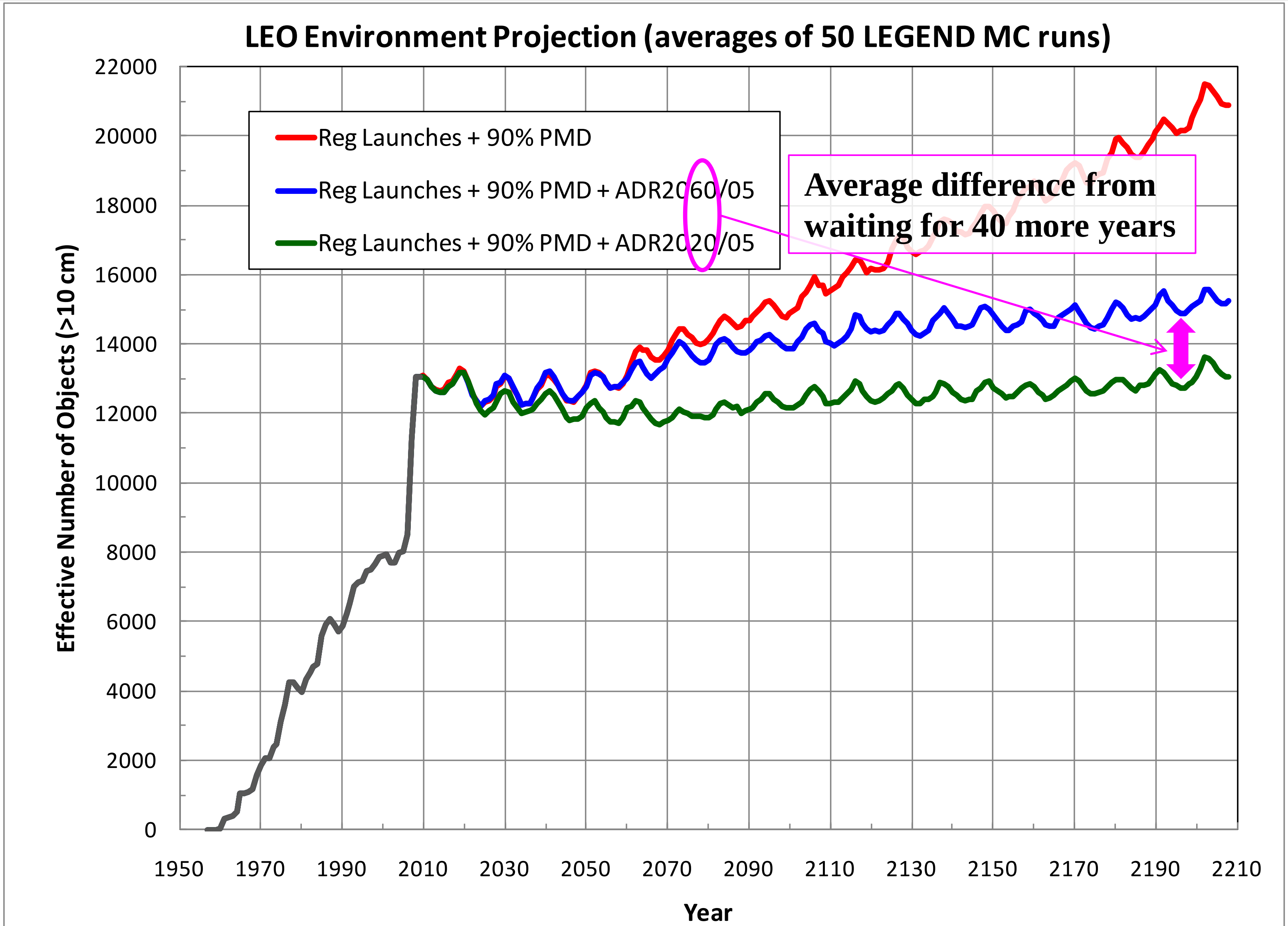
- **PMD scenario predicts the LEO populations would increase by ~75% in 200 years**
- **The population growth could be reduced by half with a removal rate of 2 obj/year**
- **LEO environment could be stabilized with PMD and a removal rate of 5 obj/year**

Mass in Orbit and Mass Removed



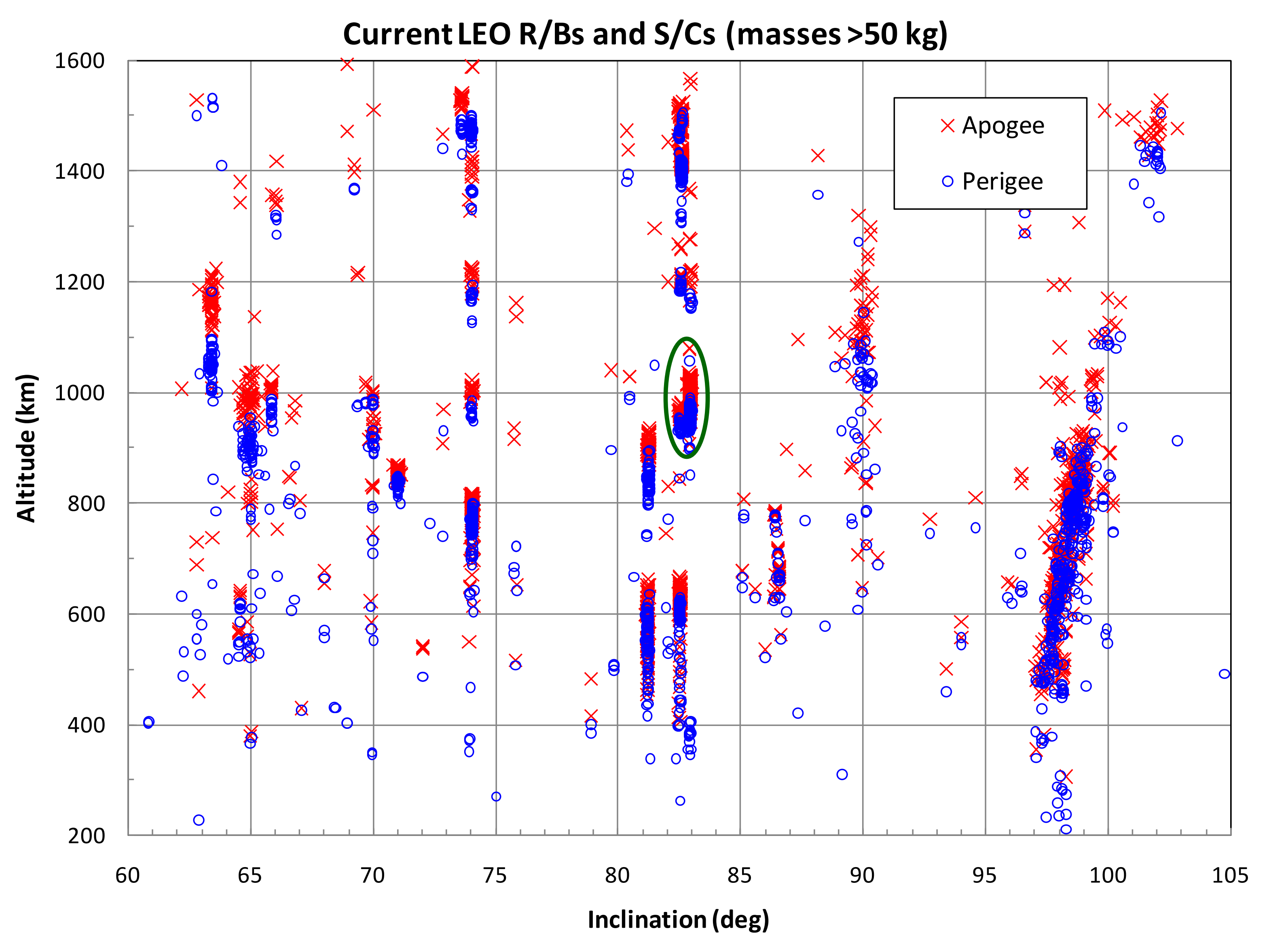
6. What is the timeframe for ADR implementation?

Sooner or Later?

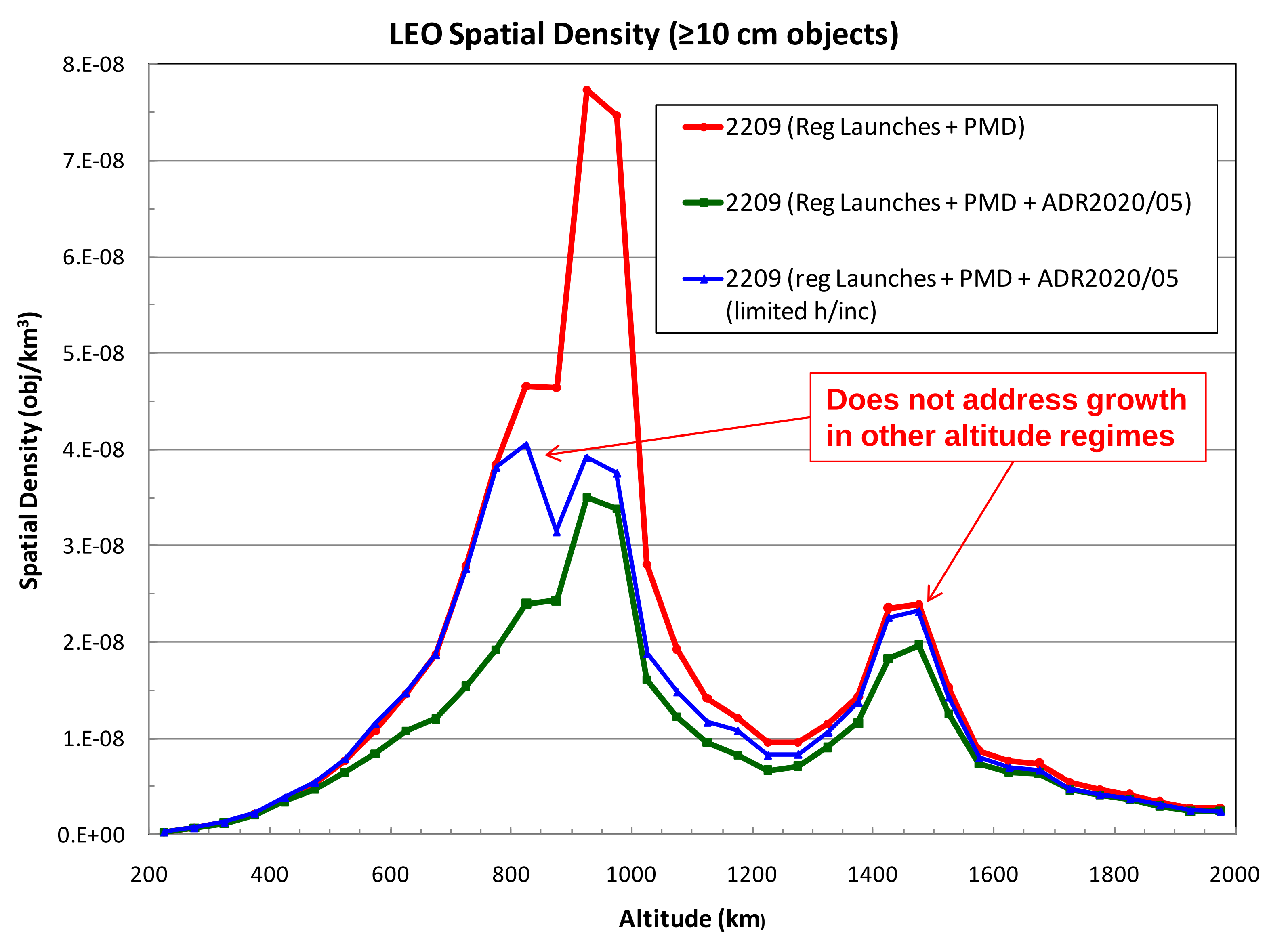


7. What is the effect of practical/operational constraints?

Distributions of R/Bs and S/Cs in LEO

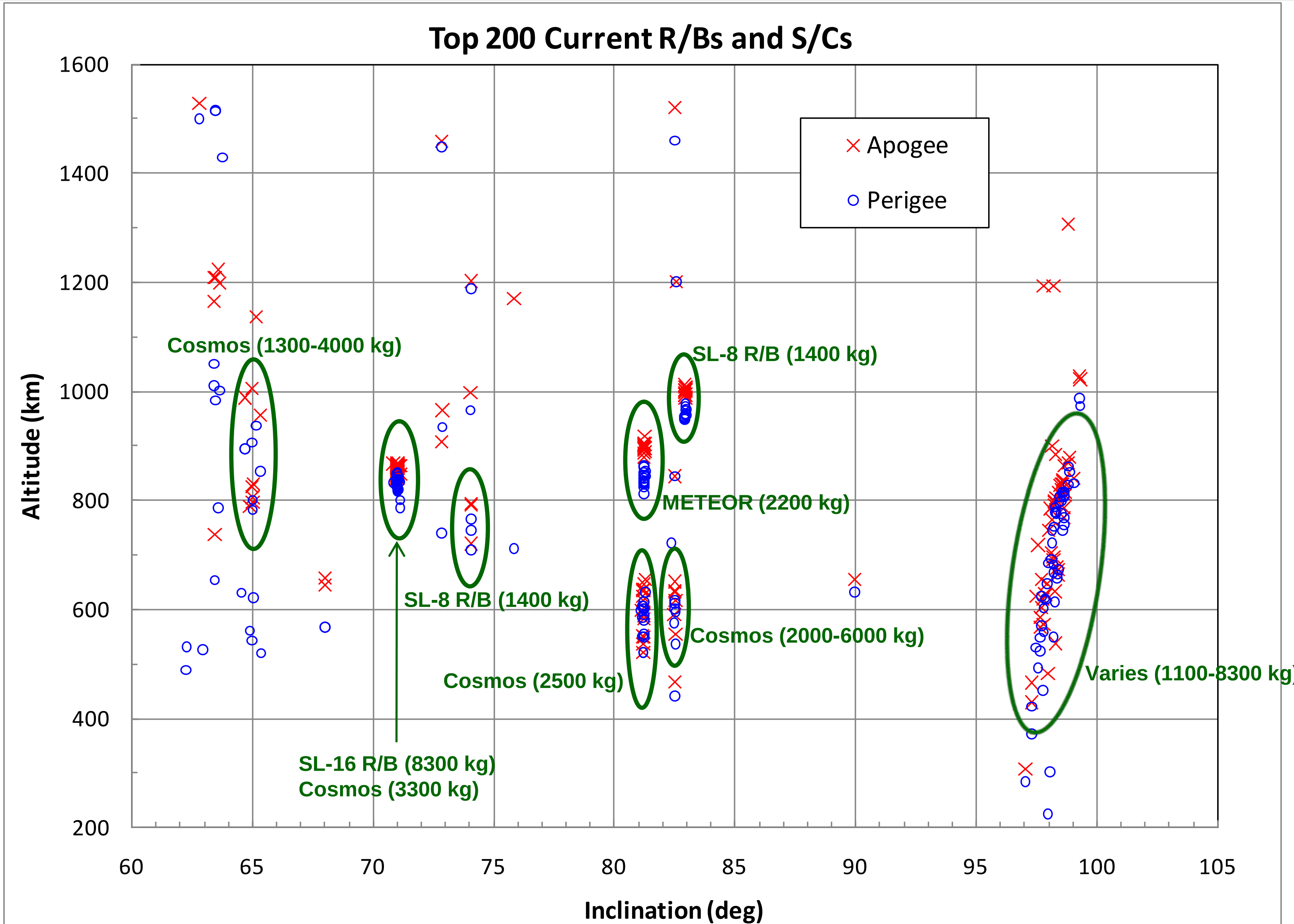


One Example
(Limiting ADR Targets to 900-1050 km alt and 82.5°-83.5°)



8. What are the collision probabilities and masses of the current objects?

Objects with the Highest [M x Pc] Values

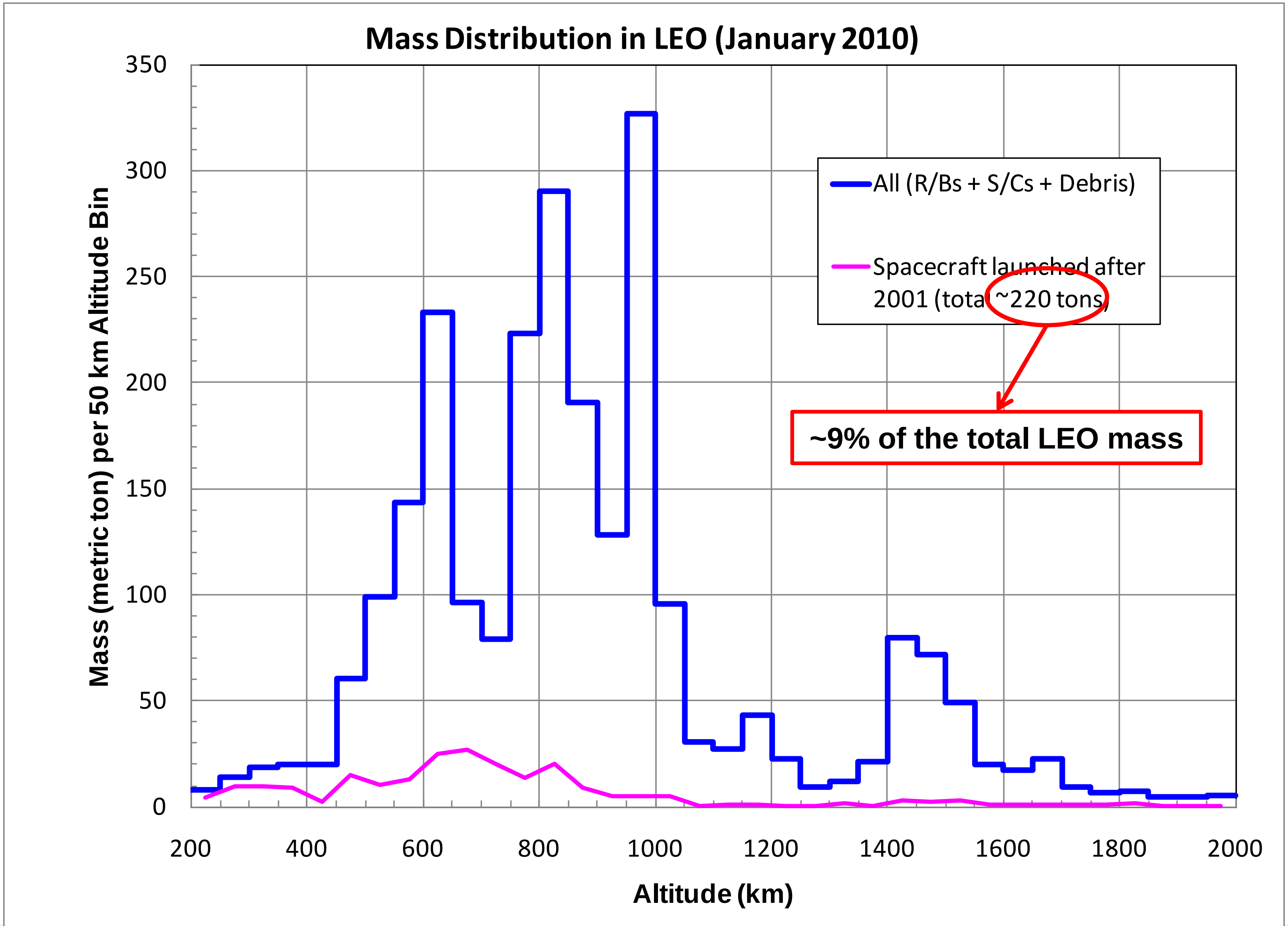


9. What are the benefits of collision avoidance maneuvers?

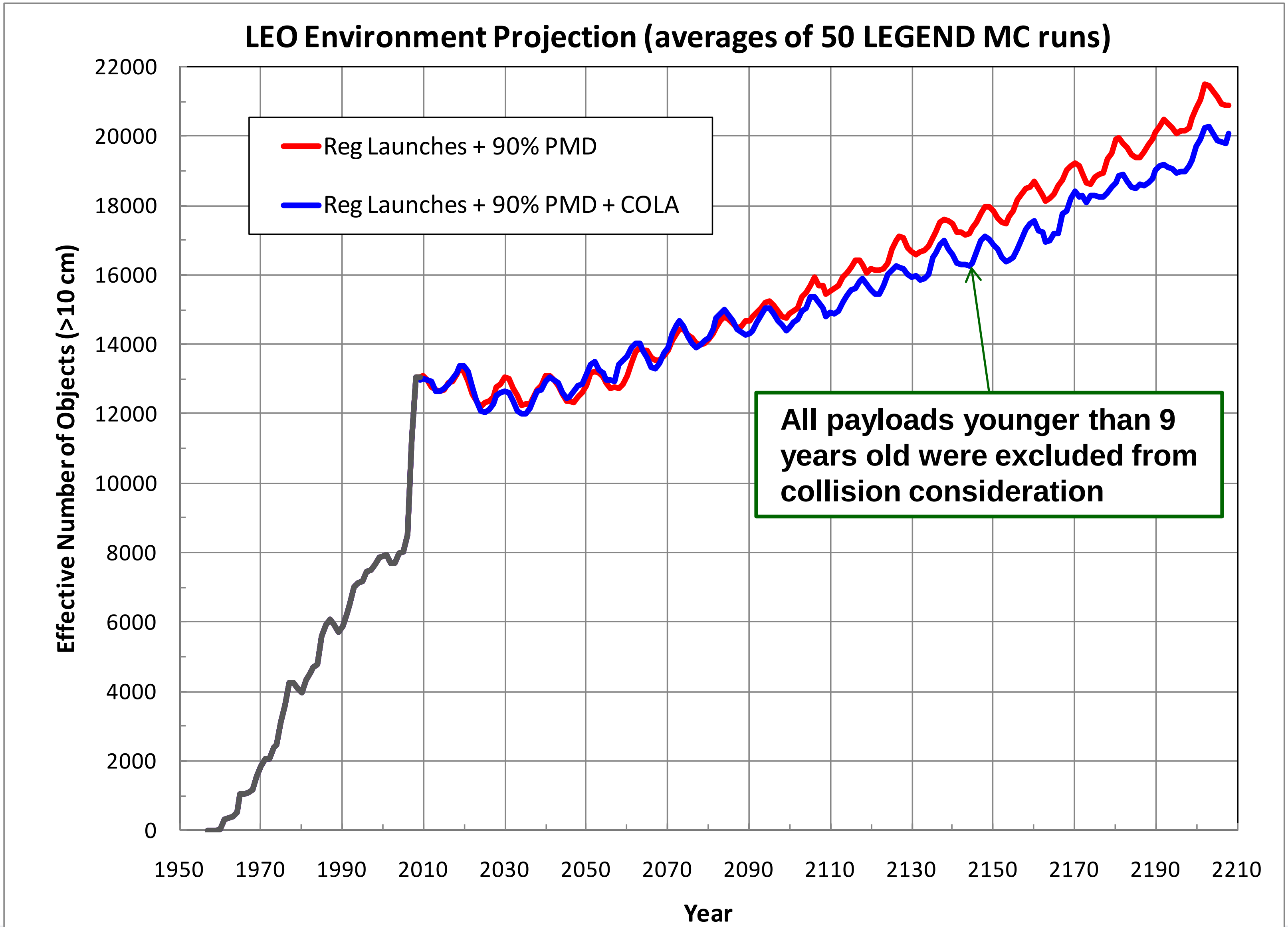
Effects of Collision Avoidance Maneuvers

- **Collision avoidance (COLA) maneuvers**
  - Can prevent spacecraft from colliding with objects in the U.S. Space Surveillance Network (SSN) catalog
    - **~80% of the ~300 currently active payloads in LEO have the maneuvering capability**
  - Do not protect spacecraft from non-catalog objects
    - **Objects smaller than 10 cm are still lethal to payloads**
    - **The LEO population growth is a concern to every satellite operator/owner**
  - Do not significantly reduce the long-term LEO debris population growth

Mass Distribution of “Young” Spacecraft



Benefits of COLA Maneuvers



10. What is the next step?

The Challenges Ahead – a Personal Perspective

- **Reach a consensus on the instability problem of the LEO debris environment**
- **Determine if there is a need to use ADR for environment remediation**
  - Define "what is acceptable"
  - Establish a timeframe to move forward
- **Commit the necessary resources to support the development of low-cost and viable removal technologies**
- **Address the policy, coordination, ownership, legal, liability, and other issues at the national and international levels**

Recent and Future Activities Related to Active Debris Removal

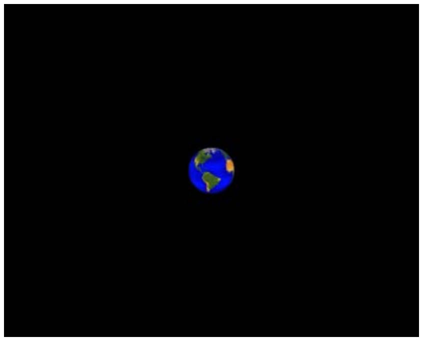
The International Conference on Orbital Debris Removal (Dec. 2009)

- **The 2.5-day conference included 10 sessions**
  - Understanding the Problem; Solution Framework; Legal & Economic ; Operational Concepts; Using Environmental Forces; Capturing Objects; Orbital Transfer; Technical Requirements; In Situ vs. Remote Solutions; Laser Systems.
  - Had 275 participants from 10 countries; 52 presentations plus 4 keynote speeches
- **The conference reflected a growing concern for the future debris environment**
- **It represented the first joint effort for different communities to explore the issues and challenges of active debris removal**

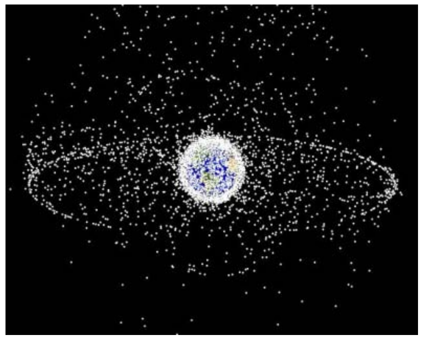
Maintaining a Good Momentum to Move Forward

- **ISTC Space Debris Mitigation Workshop (April 2010)**
- **European Workshop on Active Debris Removal**
- **IAA study on removal technologies, IADC study on the LEO environment, debris removal papers at upcoming COSPAR, IAC, etc.**
- **NASA RFI for small satellite demonstration missions**
  - orbital debris removal, autonomous/collaborative/close proximity operations, etc.
- **Potential collaboration on ADR demonstration missions**

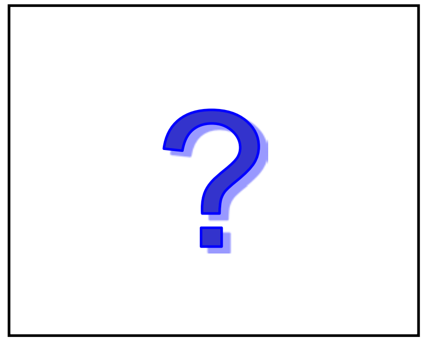
The Future is in Our Hands



Pre 1957



2010



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Backup Charts

Journal Publications
(LEGEND and LEGEND Applications)

- **LEGEND – A three-dimensional LEO-to-GEO debris evolutionary model, *Adv. Space Res.* 34, 5, 981-986, 2004.**
- **A LEO Satellite postmission disposal study using LEGEND, *Acta Astronautica* 57, 324-329, 2005.**
- **Risks in space from orbiting debris, *Science* 311, 340-341, 2006.**
- **Collision activities in the future orbital debris environment, *Adv. Space Res*. 38, 9, 2102-2106, 2006.**
- **A statistic analysis of the future debris environment, *Acta Astronautica* 62, 264-271, 2008.**
- **Instability of the present LEO satellite population, *Adv. Space Res*. 41, 1046-1053, 2008.**
- **Characterization of the cataloged Fengyun-1C fragments and their long-term effect on the LEO environment, *Adv. Space Res*. 43, 1407-1415, 2009.**
- **A sensitivity study of the effectiveness of active debris removal in LEO, *Acta Astronautica* 64, 236-243, 2009.**
- **Controlling the growth of future LEO debris populations with active debris removal, *Acta Astronautica* 66, 648-653, 2010.**