NASA's Long-term Debris Environment and Active Debris Removal Modeling Activities

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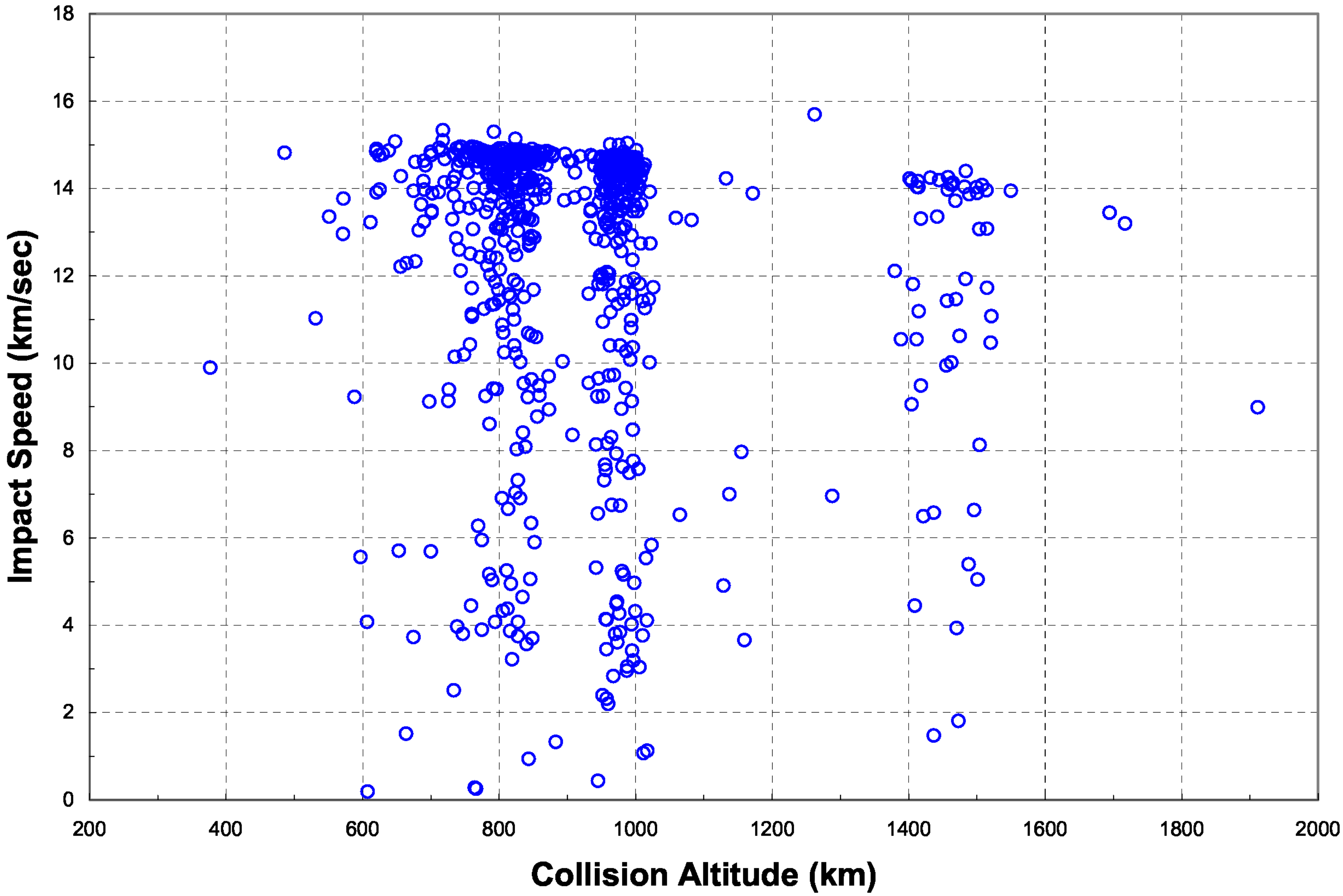
Outline

- **Review of the long-term debris environment modeling activities at the NASA Orbital Debris Program Office since 2004**
- **Updated assessments of the environment**
- **Necessity to model the effectiveness of debris removal technologies**

A Key Orbital Debris Evolutionary Model

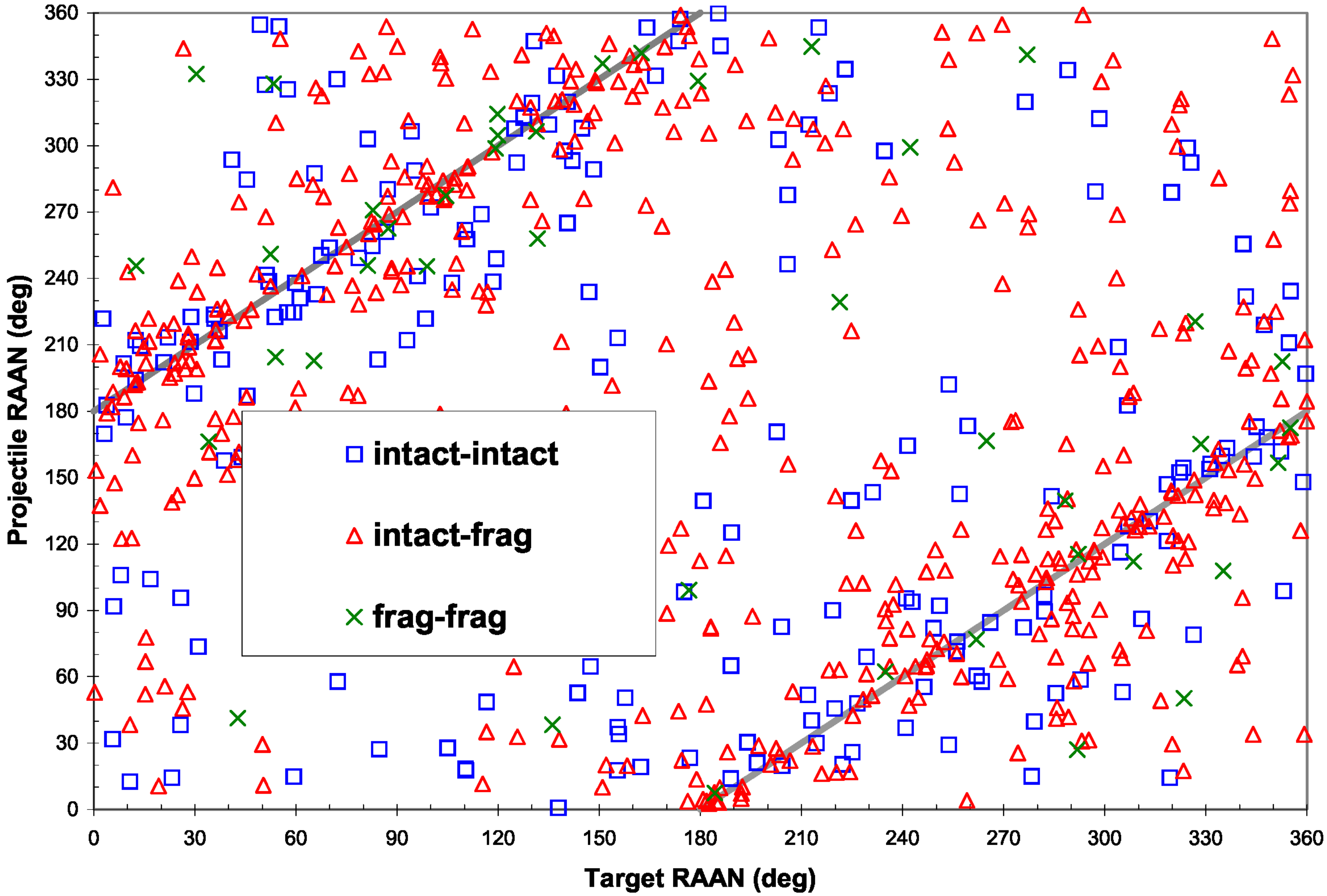
- **LEGEND, a LEO-to-GEO Environment Debris model, was developed between 2002 and 2004**
  - Is a high fidelity three-dimensional numerical simulation model with the capability to treat objects individually
  - Uses a deterministic approach to mimic the historical debris environment based on recorded launches and breakups
  - Uses a Monte Carlo approach and a reliable collision probability evaluation algorithm to simulate the future breakups and the growth of the debris populations
  - Future debris environment is analyzed based on specified launch traffic cycle, postmission disposal, and active debris removal options

LEGEND Simulated LEO Collisions (V_{imp})



• **Average Vimp~12 km/s; ~50% collisions have Vimp > 14 km/s**

LEGEND Simulated LEO Collisions (RAAN)



- Collisions are more likely to occur when the two objects' right ascensions of the ascending node (RAAN) are 180° apart

An Assessment of the LEO Environment

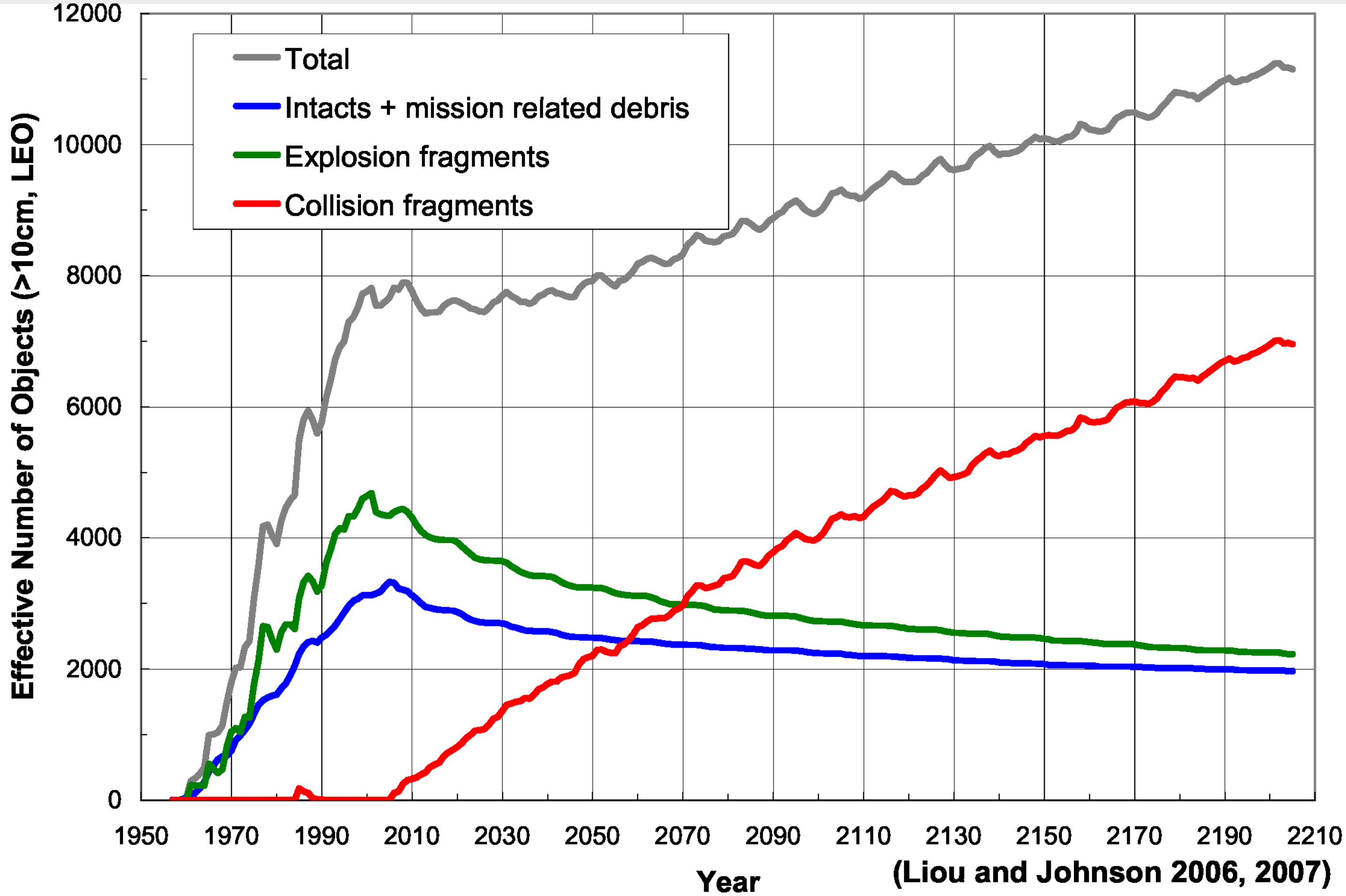
- **A major LEGEND study on the debris environment was conducted in 2005**
  - "The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future."
  - "Only remediation of the 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***, 20 January 2006

Previous Studies

- **Increasing debris population may lead to collision cascade (Kessler and Cour-Palais 1978; Eichler and Rex 1989)**
- **The "critical density" concept was pioneered by Kessler (1991) to describe the threshold of the instability**
- **Various analytical, semi-analytical, and numerical studies, based on different model assumptions and different future traffic rates (constant, increased, with or without postmission disposal, *etc*.) have been performed**
  - Su (1993); Rossi *et al*. (1994); Anselmo *et al*. (1997); Kessler (2000); Kessler and Anz-Meador (2001); Krisko *et al*. (2001)
- **These study results indicate that, as the space activities continue, the LEO debris populations at some altitudes are unstable and population growth may be inevitable**

Instability of the Current LEO Environment
(no new launches beyond 1/1/2006)



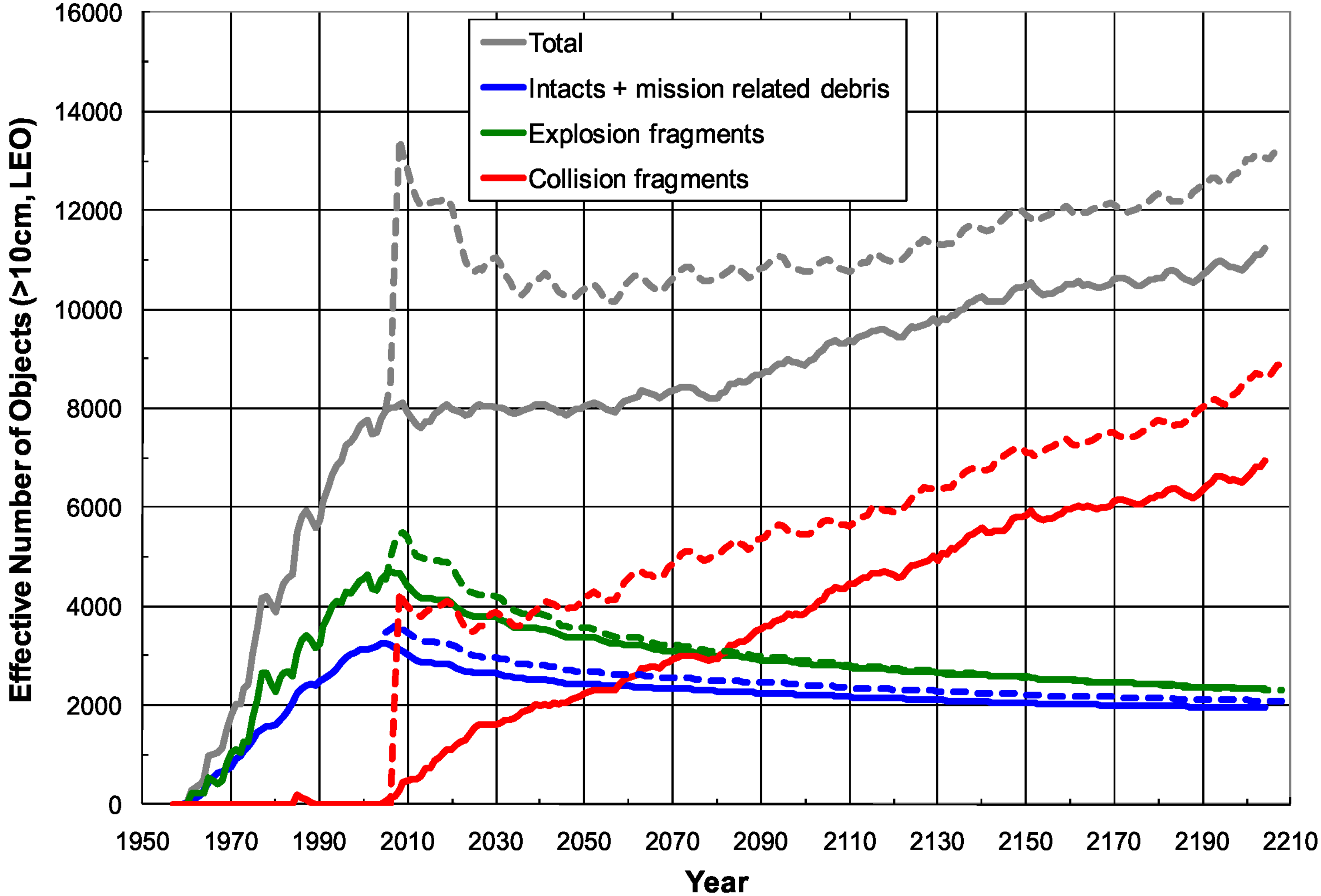
(Liou and Johnson 2006, 2007)

- **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

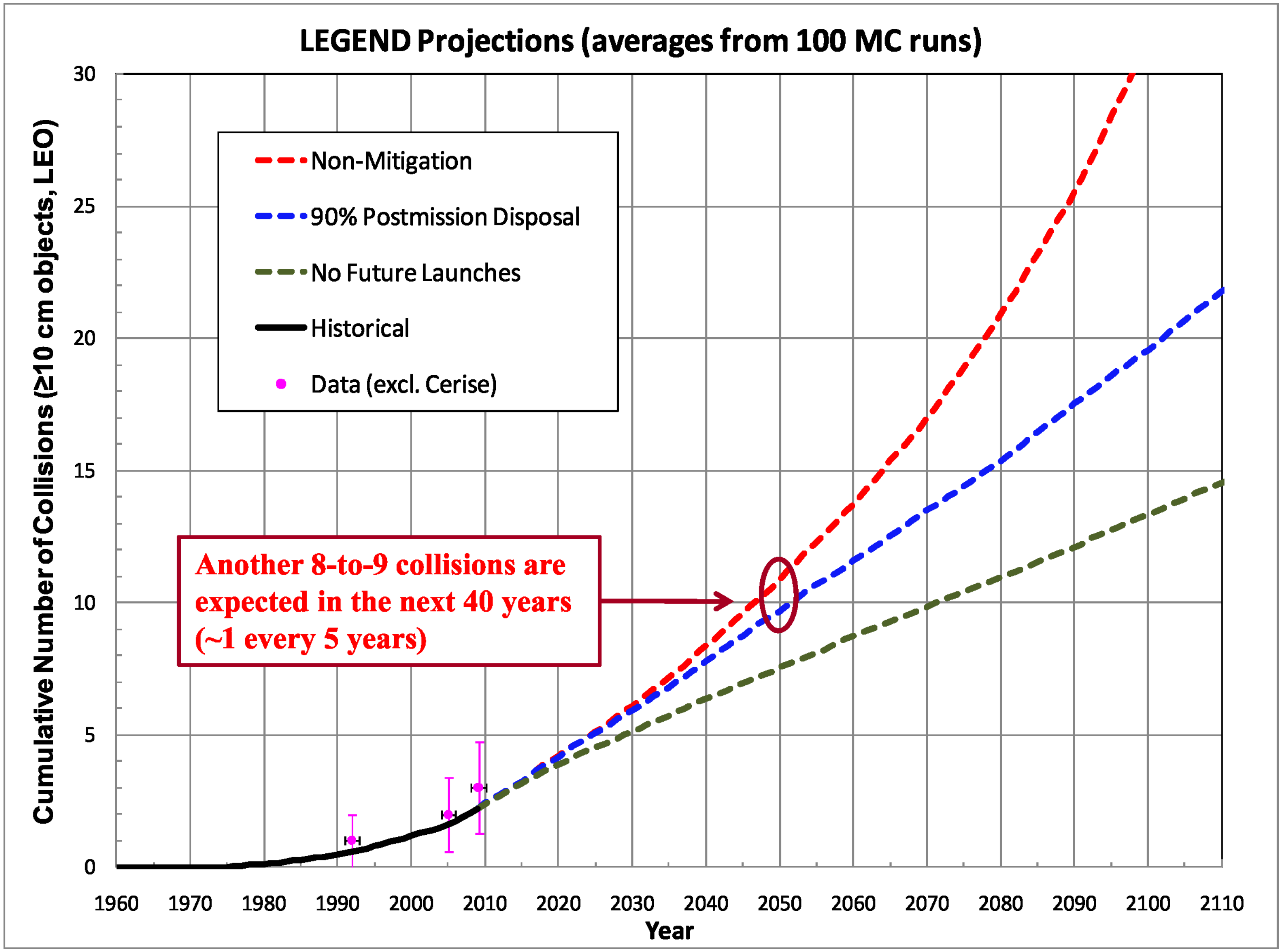
- **In reality, the situation will be worse than the "no new launches" scenario as**
  - satellites launches will continue
  - major breakups may continue to occur (*e.g.*, Fengyun-1C, Briz-M, Iridium 33/Cosmos 2251)
- **Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient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

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



Active Debris Removal Modeling

- **The NASA Orbital Debris Program Office initiated the LEGEND ADR modeling study in late 2006**
  - Develop simple, reliable, and objective ADR selection criteria
  - Quantify the effectiveness of different ADR scenarios
  - Explore various ADR strategies to stabilize the future debris environment

- **The results indicate that the key to stabilize the future LEO environment in the next 200 years**
  - A good implementation of the commonly adopted mitigation measures (passivation, 25-year rule, *etc*.)
  - An active debris removal of about five objects per year
    - **Select RSOs with the highest [M × Pc]**

LEGEND Benchmark Scenario

- **LEGEND baseline scenario (PMD25):**
  1. Include (1957 to 31 Dec 2006) + FY-1C fragments + 200 years
  2. Repeat (1999-to-2006) launch traffic
  3. Allow no explosions for R/Bs and S/Cs launched after 2006
  4. Include objects 10 cm and larger in collision consideration
  5. Move R/Bs to 25-year decay orbits after launch
  6. Move S/Cs to 25-year decay orbits or LEO collection orbits (depending on ΔV) after 8 years of mission lifetime
  7. Set postmission disposal success rate to 90%
  8. Complete 100 Monte Carlo runs
  9. Focus on the 10 cm and larger populations

ADR Scenarios

- **LEGEND ADR scenarios (PMD + ADR):**

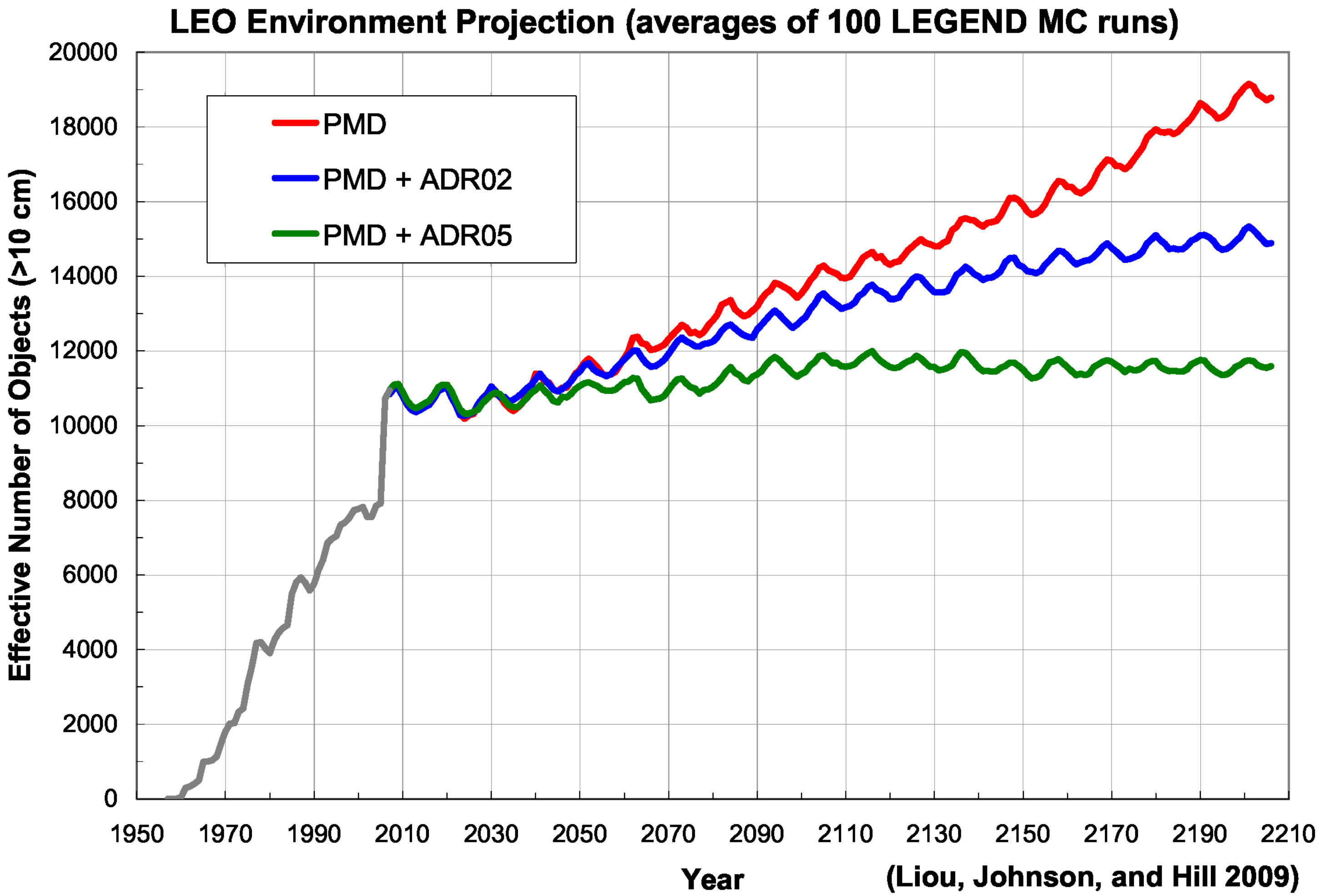
1. through 9. are identical to those in the baseline scenario

10. Start active debris removal in 2020

11. Follow RSO selection criteria
    - **Exclude operational S/Cs (assuming mission lifetime of 8 years)**
    - **Exclude objects with perigee altitude above 2000 km**
    - **Exclude objects with eccentricity greater than 0.5**
    - **Exclude fragments**
    - **Select objects with the highest [mass × P_c], where P_c is the instantaneous collision probability at the beginning of the year**

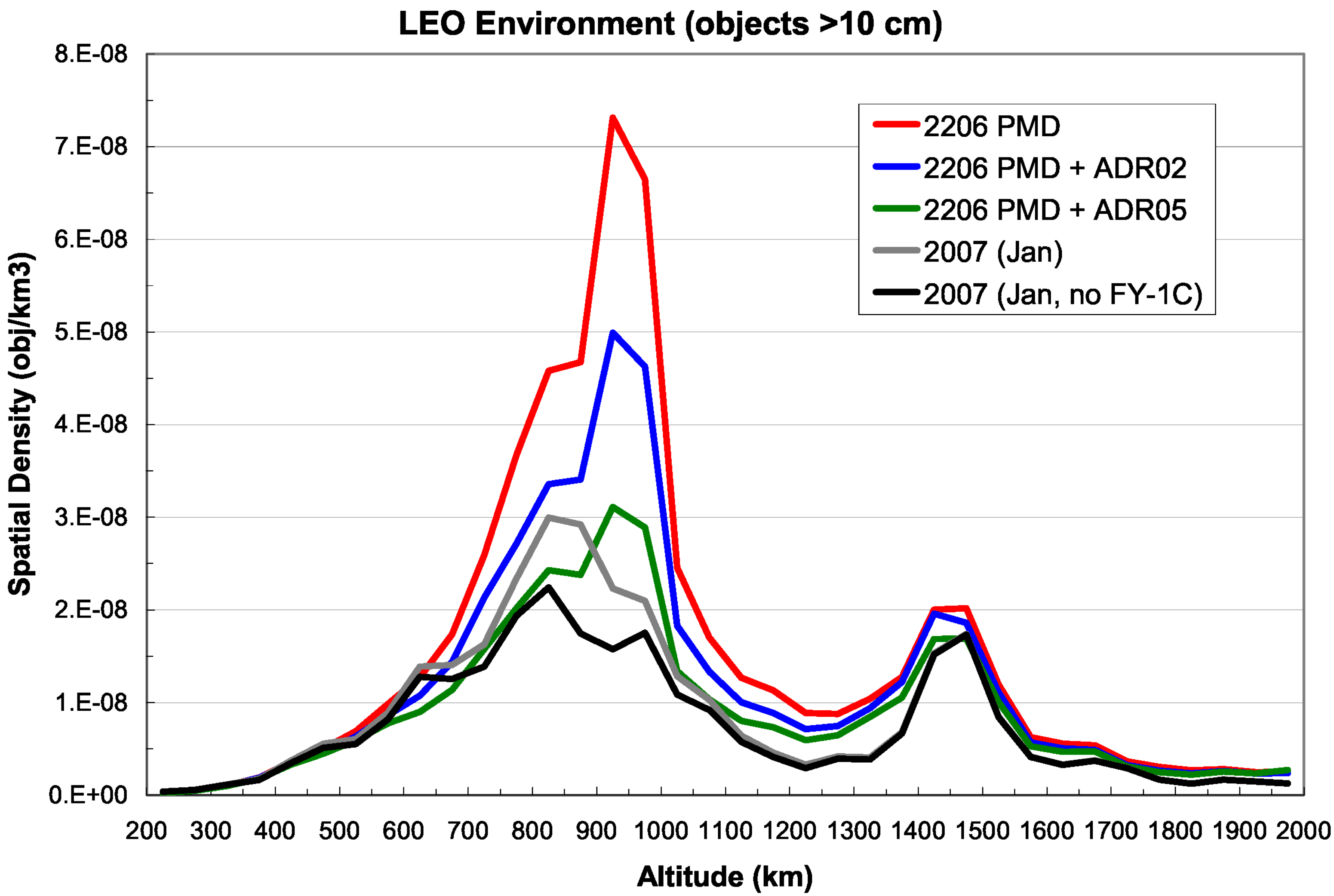
12. Test two removal rates. After objects are selected (at the beginning of each year), remove them from the simulated environment immediately
    - **2 objects per year (ADR02)**
    - **5 objects per year (ADR05)**

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 a removal rate of 5 obj/year

Spatial Density of Objects 10 cm and Larger



- **The ADR selection criterion, mass × P_c, successfully removes objects from high collision activity regions and reduces the overall population growth.**

Optimize ADR Target Selection

- **Different parameters can be defined to quantify the effectiveness of the ADR target selection criteria**
  - Population growth (≥10 cm or others)
  - Collision activities
  - Mass, spatial density, risks (conjunctions, damage) to selected payloads, risks to human space activities, *etc.*

Effective Reduction Factor (ERF), ADR05	
Number of objects removed via ADR through 2206 (A)	935
Reduction in LEO ≥10 cm objects by 2206 (B)	7,196
ERF by 2206 = (B) / (A)	7.7

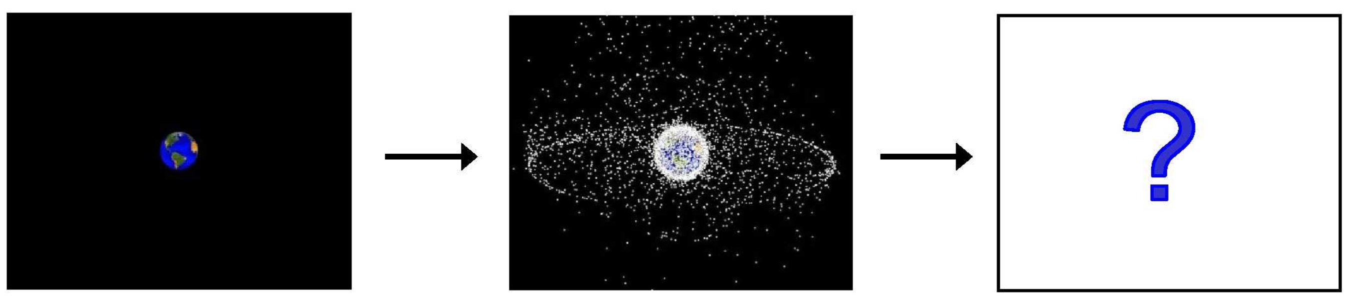
Collision Reduction, ADR05	
Number of objects removed via ADR through 2206 (A)	935
Reduction in cumulative collisions by 2206 (C)	17.9
(A) / (C)	52

Concluding Remarks (1/2)

- **Key to stabilize the future LEO environment**
  - A good implementation of the commonly adopted mitigation measures (passivation, 25-year rule, *etc*.)
  - An active debris removal of about five objects per year starting in the near future (~2020)
    - **Select RSOs with the highest [M × Pc]**
  - The environment can be better than what it is today if more than 5 objects per year are removed
- **GEO and MEO**
  - The population growth is moderate in the next 200 years

Concluding Remarks (2/2)

- **The challenges ahead**
  - Community consensus, recognition, and commitment
  - Technology
  - Cost
  - Ownership, legal, liability, policy, *etc*.
- **Alternative target selection criteria (in size, altitude, inclination, class, *etc*.) may be more practical, but will need to be carefully evaluated to maximize the benefit-cost ratio of active debris removal**



Pre 1957 **2009** **2209+**