Modeling the Large and Small Orbital Debris Populations for Environment Remediation

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3rd European Workshop on Space Debris Modeling and Environment Remediation

CNES HQ, Paris, France, 16-18 June 2014

Outline

- **Options for Environment Remediation in LEO**
- **Knowledge of the Environment**
- **Modeling the Future Large and Small Orbital Debris Population Growth**

Options for Environment Remediation in LEO

Stability of the LEO Debris Environment

- **The Inter-Agency Space Debris Coordination Committee (IADC) investigated the stability of the orbital debris population in LEO several years ago**
  - Six Agencies (ASI, ESA, ISRO, JAXA, NASA, UKSA) used six different models for the study
  - A final study report was prepared and placed at the IADC website (http://www.iadc-online.org) in January 2013
  - A study summary was presented to the UN Committee on the Peaceful Uses of Outer Space (COPUOS) Scientific and Technical Subcommittee (STSC) in February 2013

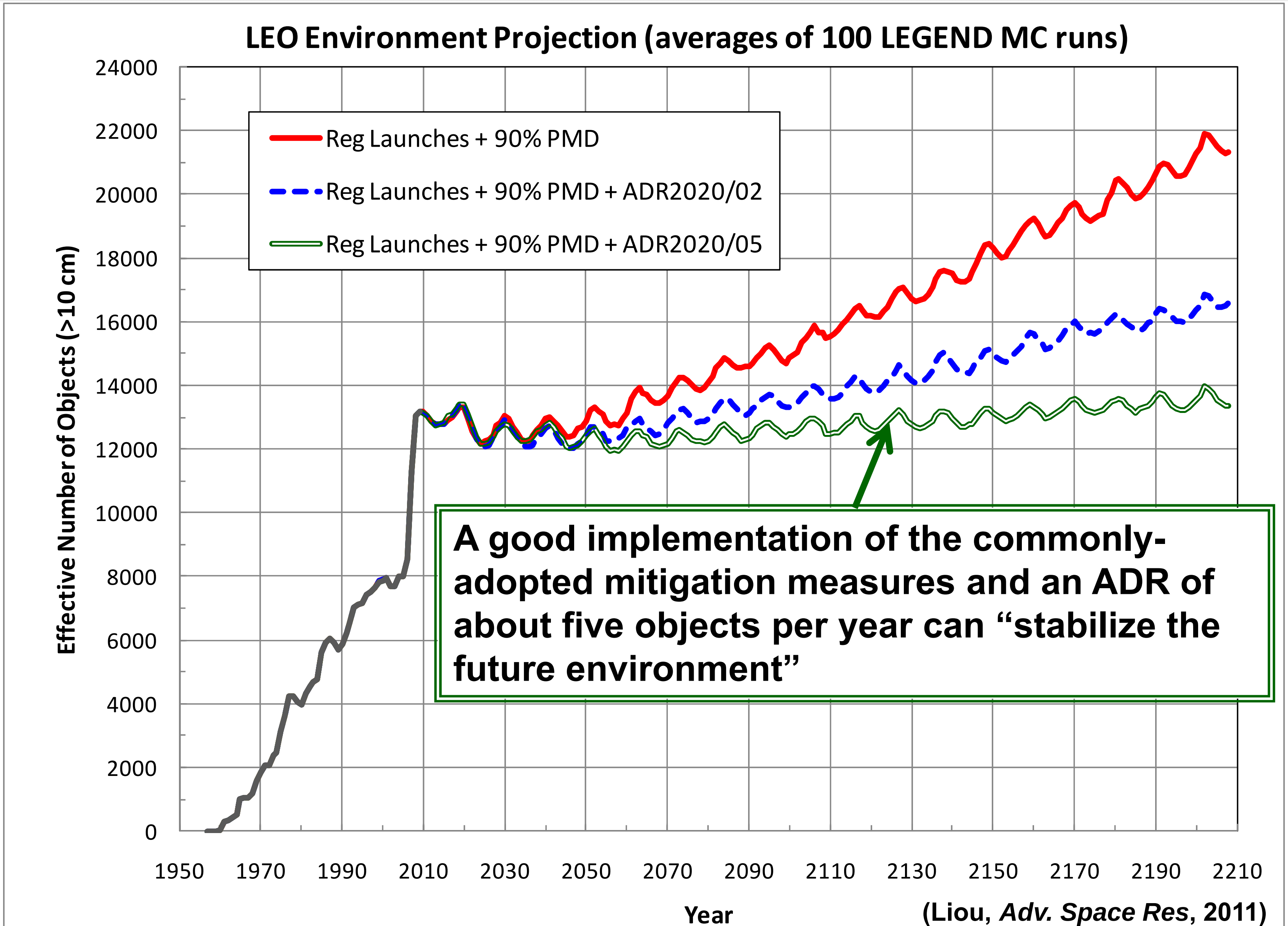
Conclusions of the IADC Study

- **Even with a 90% compliance of the 25-year rule and no future explosions, the LEO debris population is expected to increase in the next 200 years**
  - Monte Carlo (MC) statistics: 644/725 MC runs, 89% probability
  - Population growth is primarily driven by collisions between 700 and 1000 km altitudes
  - Catastrophic collisions are likely to occur every 5 to 9 years
- **To better limit the growth of the future debris population and to reduce collision activities in LEO, new mitigation measures, such as active debris removal, should be considered**

Options for Environment Remediation

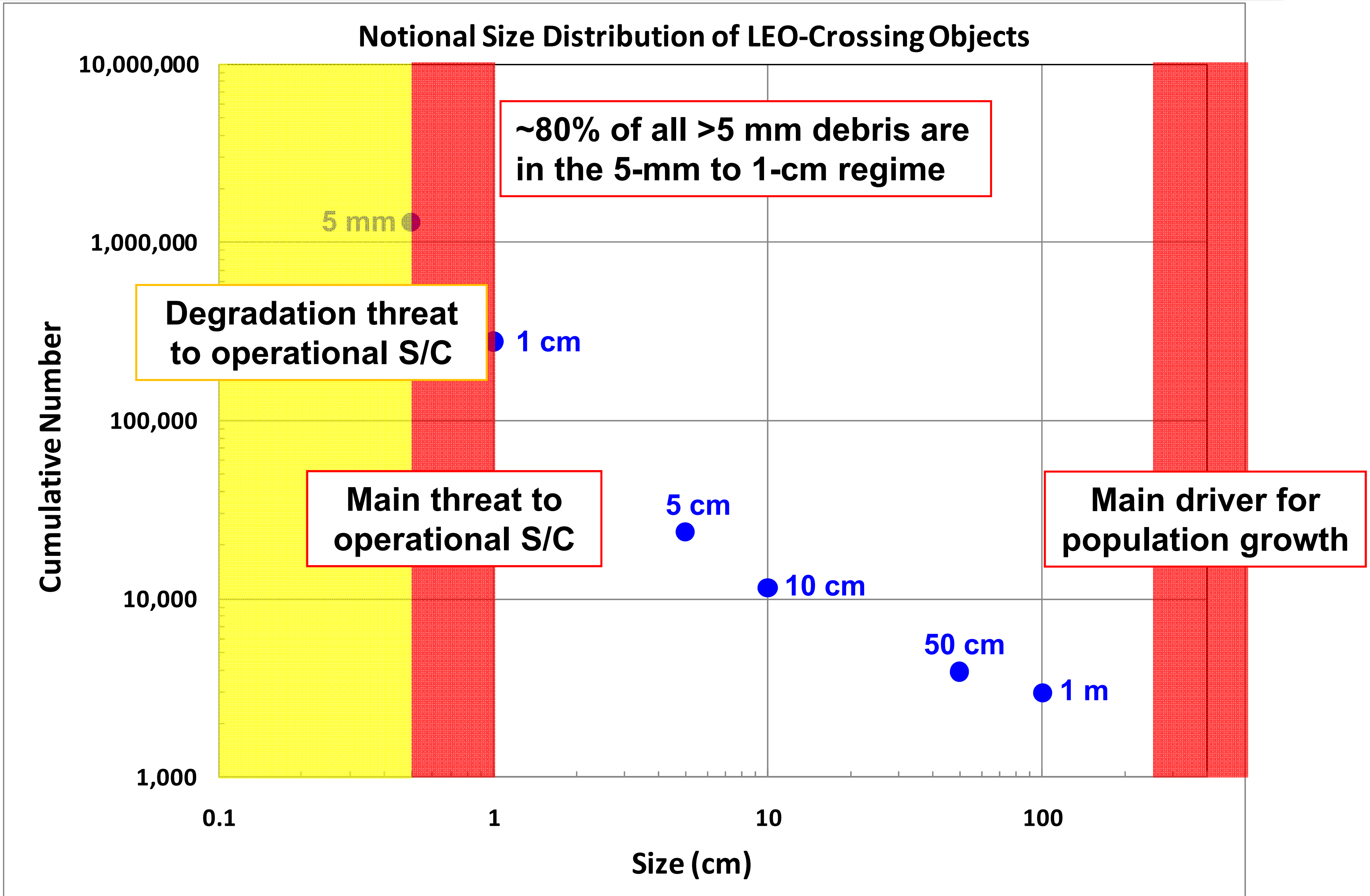
- **Removal of massive intact objects, with high collision probabilities, to address the root cause of the future debris population growth problem**
- **Removal of ~5-mm to 1-cm debris to mitigate the main threat for operational spacecraft**
- **Prevention of major debris-generating collisions involving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

Controlling Debris Growth with ADR



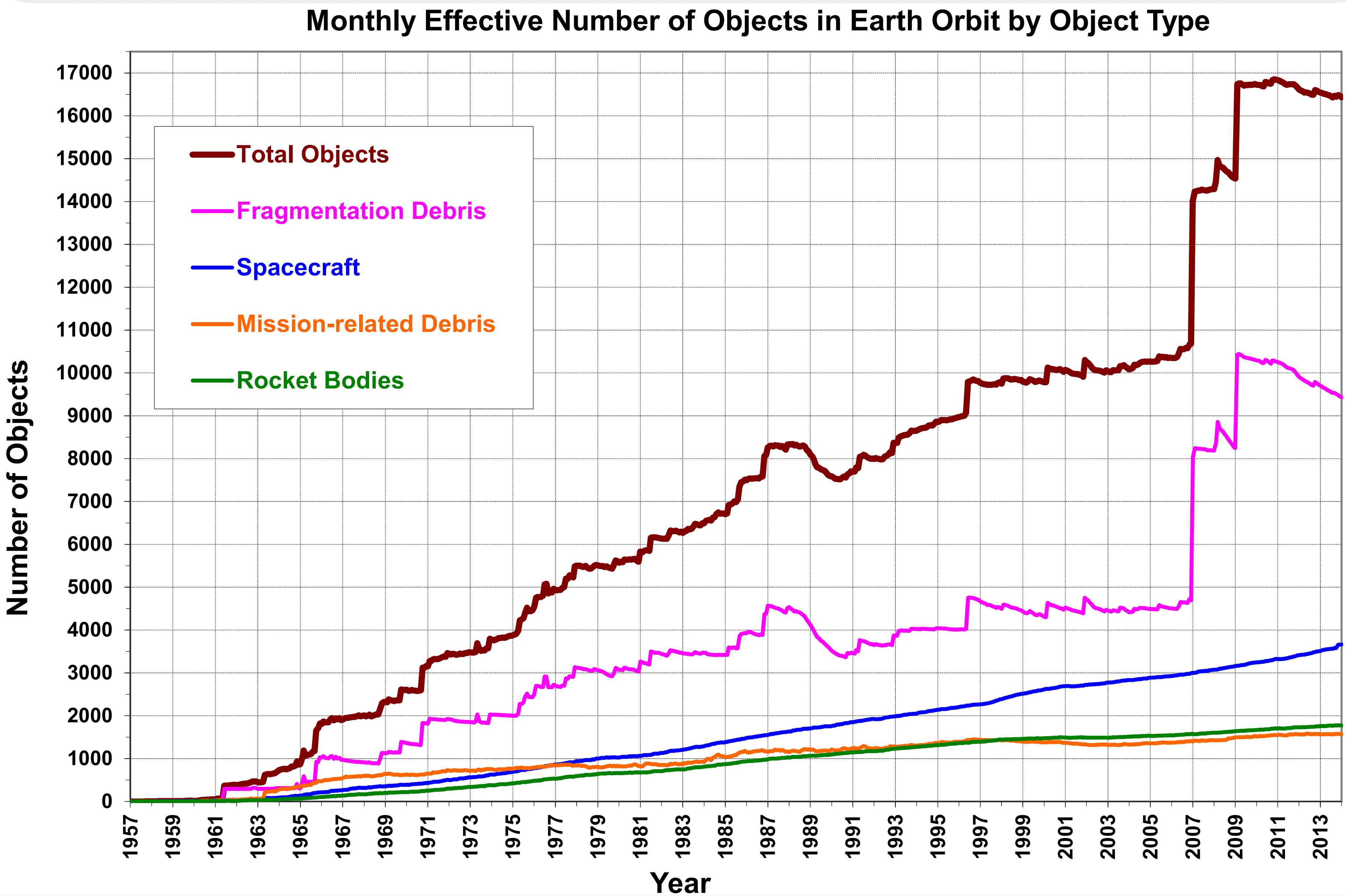
(Liou, *Adv. Space Res*, 2011)

Targets for Removal

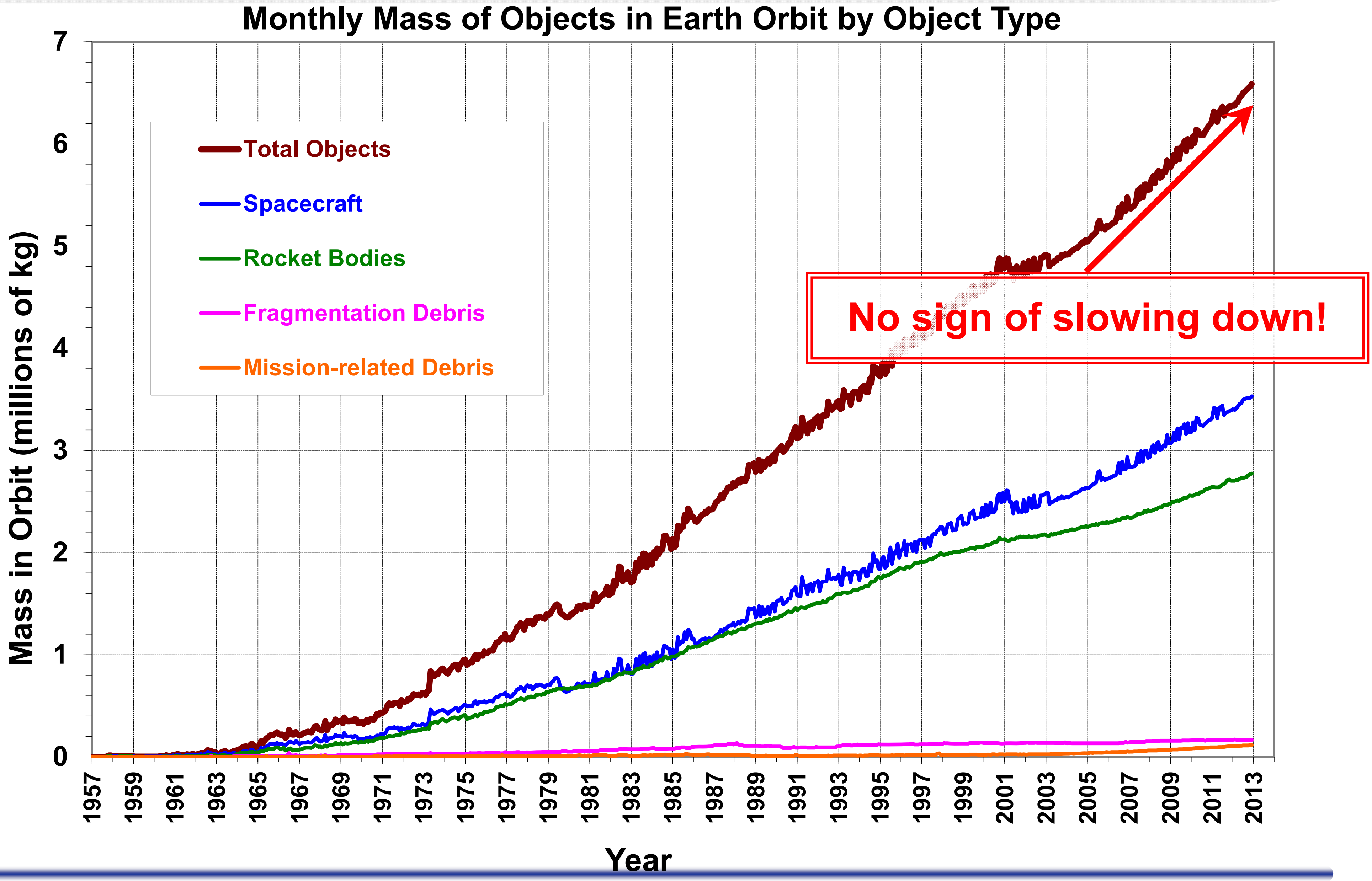


Knowledge of the Orbital Debris Environment

Growth of the Cataloged Populations



Mass in Space



Key Messages

- **Both number and mass distributions are important parameters for environment assessments**
  - Health of the environment
  - Effectiveness of mitigation and remediation measures

- **Other factors, such as threat to critical space assets need to be considered as well**

How Much Junk Is Currently Up There?

Softball size or larger (≥10 cm): ~20,000 to 22,000 (tracked by the U.S. Space Surveillance Network, SSN)

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/s in LEO), even sub-millimeter debris pose a realistic threat to human spaceflight and robotic missions**
  - **1-cm Al sphere @ 10 km/s = 400 lb safe @ 60 mph**
  - **5-mm Al sphere @ 7 km/sec could penetrate a 2.54 cm thick Al wall**
- **Total mass: ~6300 tons LEO-to-GEO (~2700 tons in LEO)**

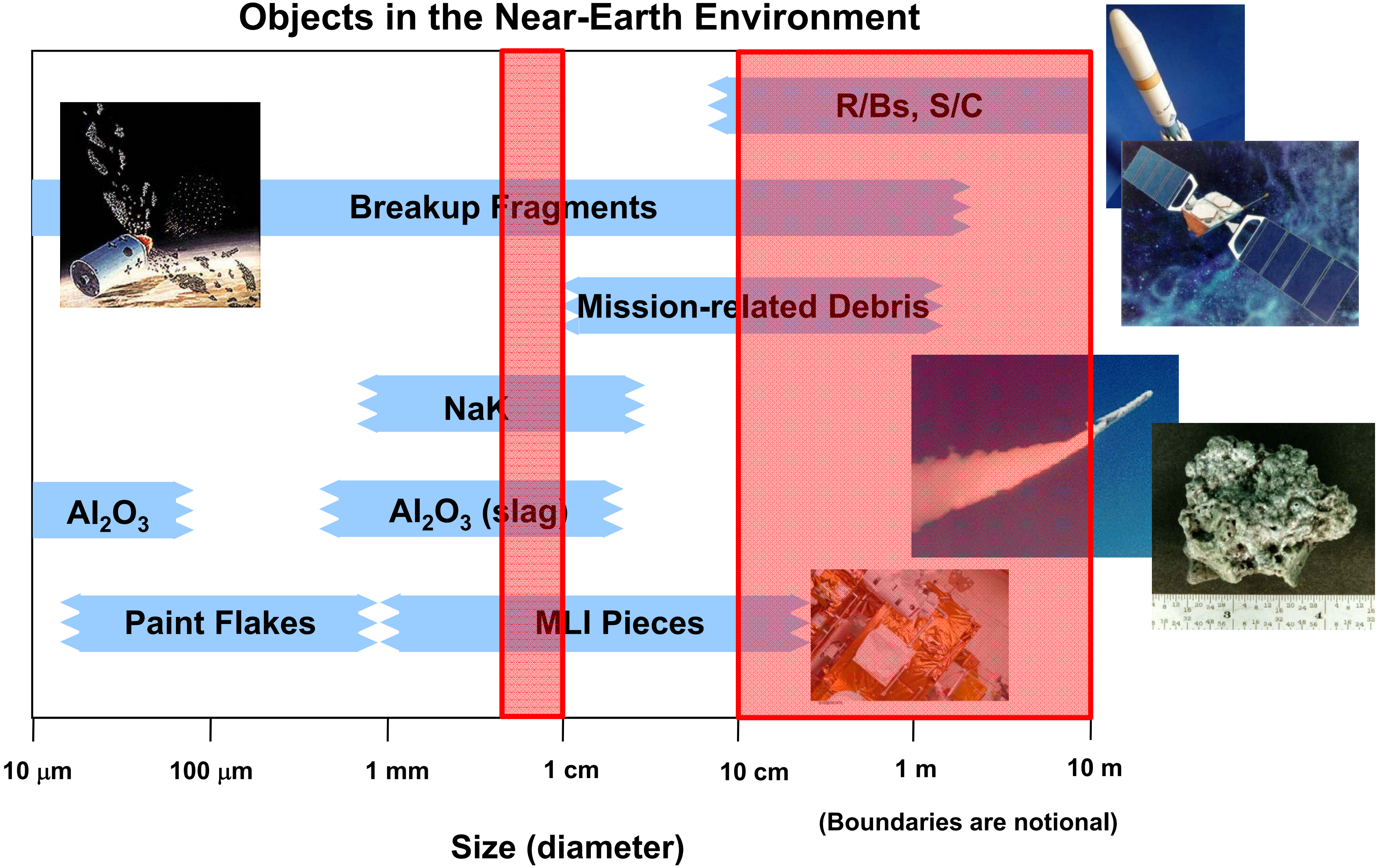
Knowledge of the Historical and Current Environment

- **For the ≥10 cm population**
  - The sources and components (including the large and massive rocket bodies and spacecraft) are well understood
    - **Good historical launch records**
    - **The U.S. Space Surveillance Network tracks and maintains the orbits of the objects in the U.S. satellite catalogs**

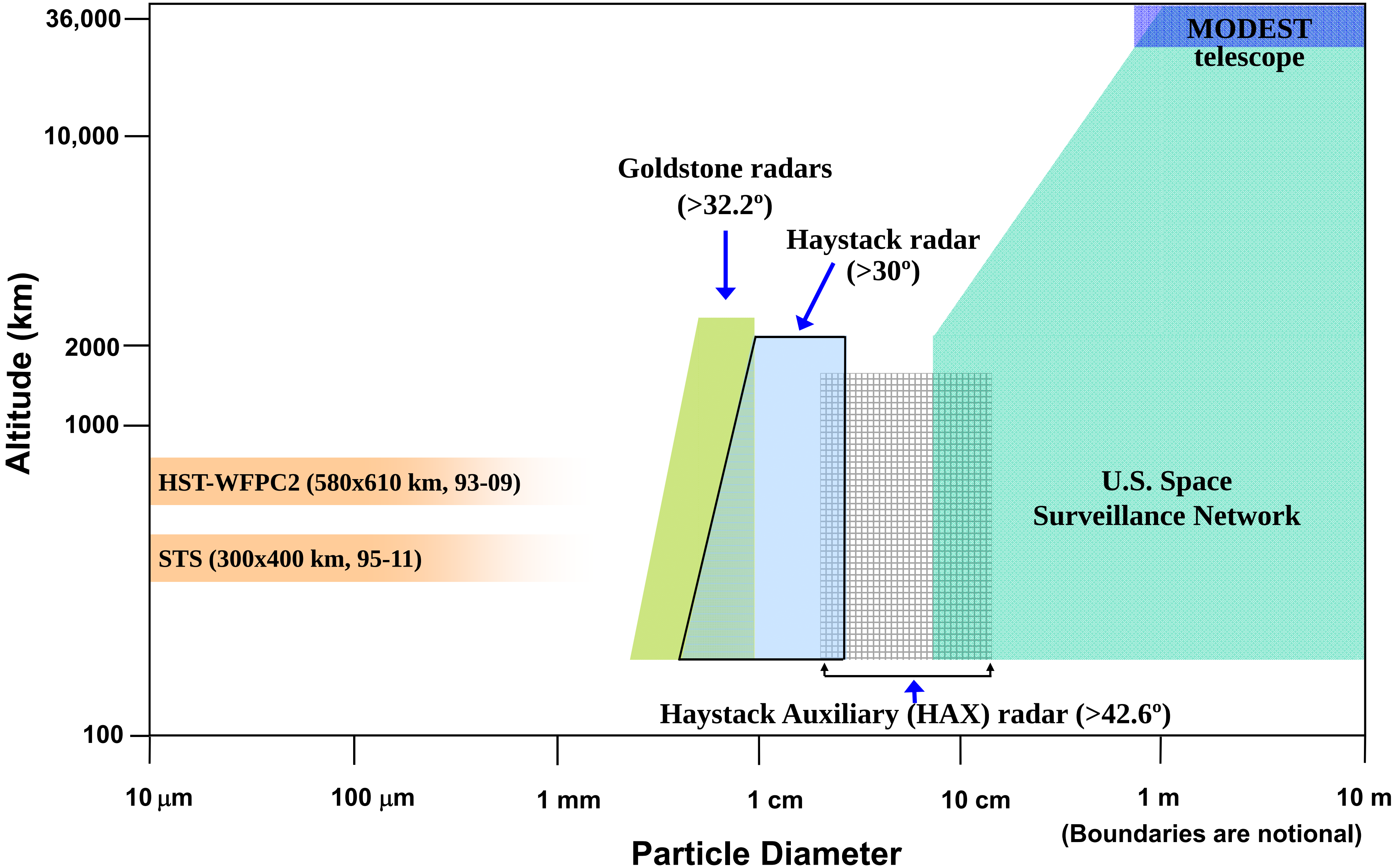
- **For the ~5-mm to 1-cm population**
  - The sources and components are NOT well characterized
    - **Only limited data are available based on statistical sampling of a small fraction of the environment**

The Orbital Debris Family

Objects in the Near-Earth Environment



Current NASA Orbital Debris Database



Modeling the Future Orbital Debris Population Growth

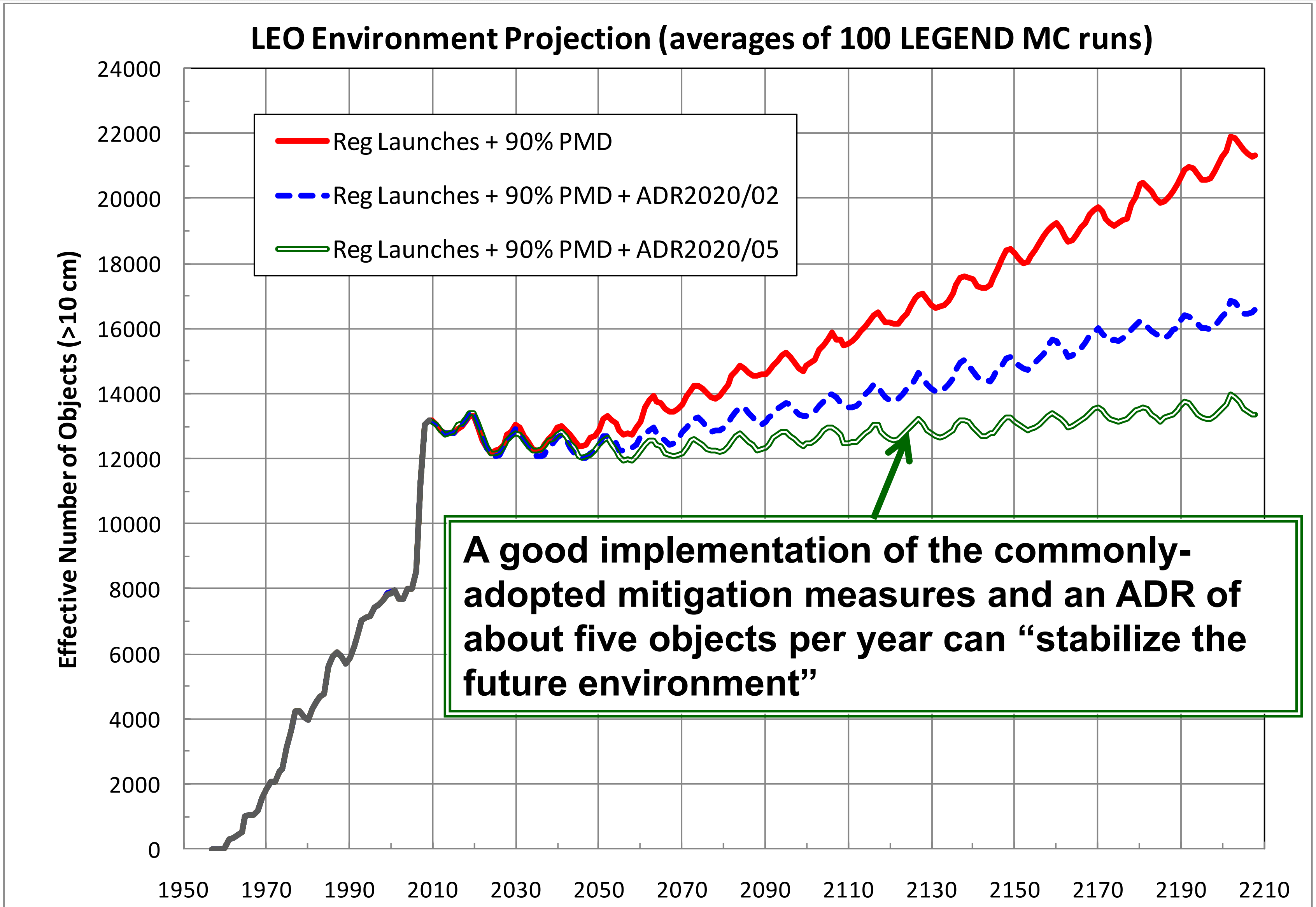
Predicting the Future

- **Key uncertainties in environment projection**
  - Initial population
  - Future sources
    - **Rocket bodies and spacecraft (launch frequency, orbits, masses, dimensions, materials, mission lifetimes, etc)**
    - **Fragmentation debris (breakup frequency and outcome)**
    - **Non-fragmentation debris**
  - Solar activity
  - Post-mission disposal compliance
  - Monte Carlo approach

Two general approaches for future projection:

- Examine extreme cases to bound the problem
- Analyze nominal cases based on reasonable assumptions

Controlling Debris Growth with ADR



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

About the "Five Objects Per Year"

- **The "removing five objects per year can stabilize the LEO environment" conclusion is somewhat notional. It is intended to serve as a benchmark for ADR planning.**
- **Assumptions in the LEGEND ADR simulations**
  - Nominal launches during the projection period
  - A 90% compliance of the 25-year rule and no future explosions
  - ADR operations start in 2020
  - Target selection is based on each object's mass and P_{coll}
  - No operational constraints on target selection
  - Immediate removal of objects from the environment
  - Average solar activity cycle

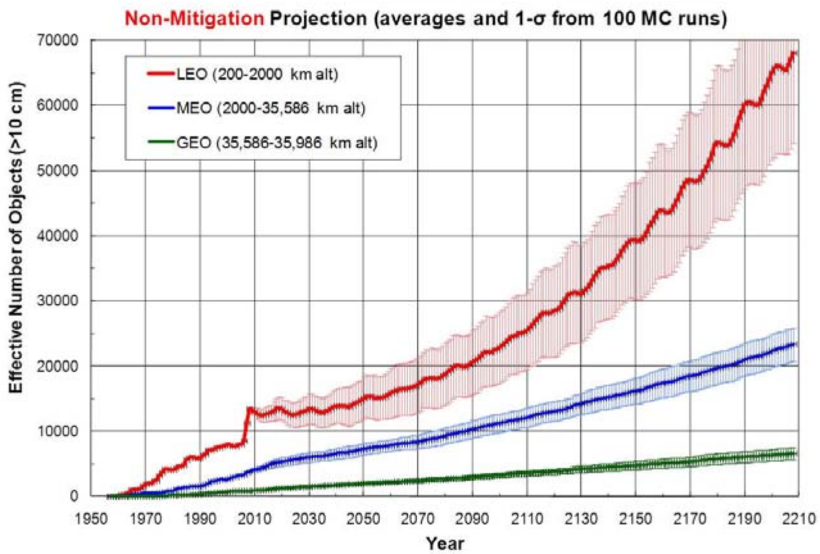
Approach Adopted for the IADC Studies

- **Reasonable assumptions**
  - Future launches can be represented by a recent eight-year traffic cycle, average spacecraft mission lifetime is 8 years, explosions can be minimized, good compliance of the 25-year rule, etc.
- **Best available tools from each participating agency**
  - Each participating member agency uses its official/best models for the solar flux prediction, orbit propagation, collision probability calculation, and satellite breakups
- **Nominal cases**
  - Monte Carlo results are analyzed
  - Study conclusions are drawn from the nominal/average results

Analyzing the Monte Carlo Results

- **Options to present Monte Carlo simulation results**
  - Averages
  - Averages with σ's
  - Tabular format
  - Scatter plots
  - Distributions
  - Averages and extremes
  - Individual projections
  - Others

Examples



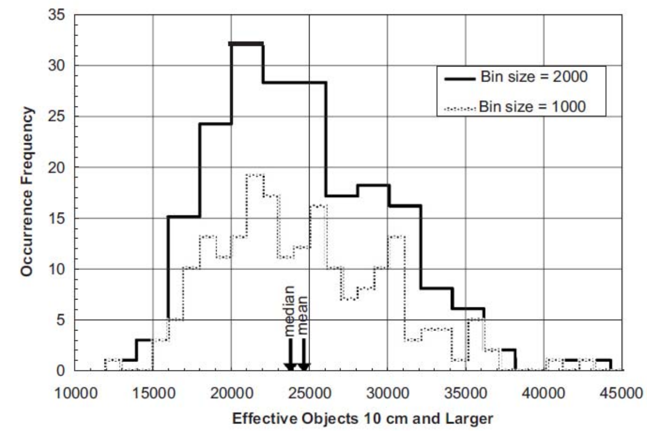
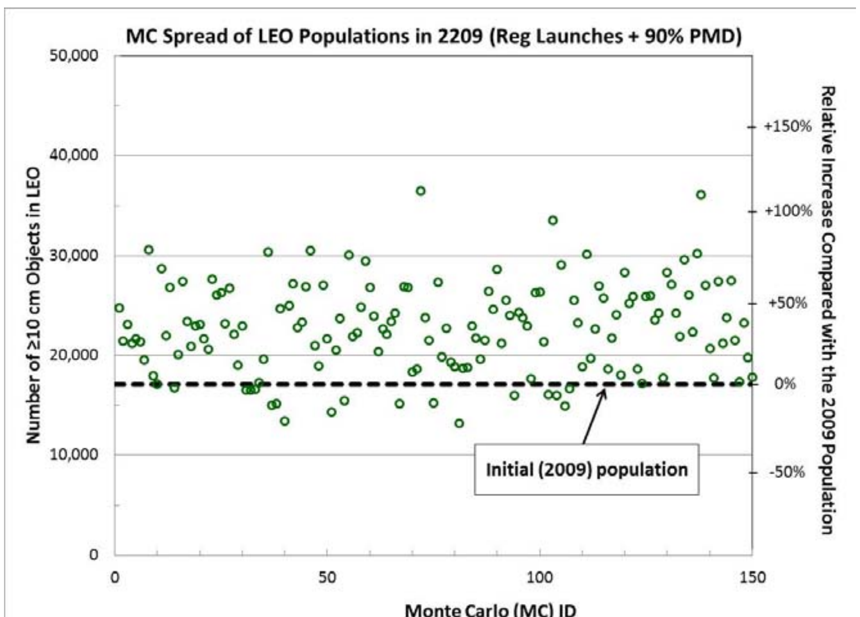


Fig. 3. Distribution of the projected LEO debris populations (⩾10 cm) in 2104 from 200 MC simulations. Two different bin sizes are used to make the two histograms. Neither one resembles a Gaussian distribution. The mean and median of the 200 samples are indicated by the two down arrows. The bootstrap estimated 90% confidence interval of the mean is between 23,900 and 25,100.



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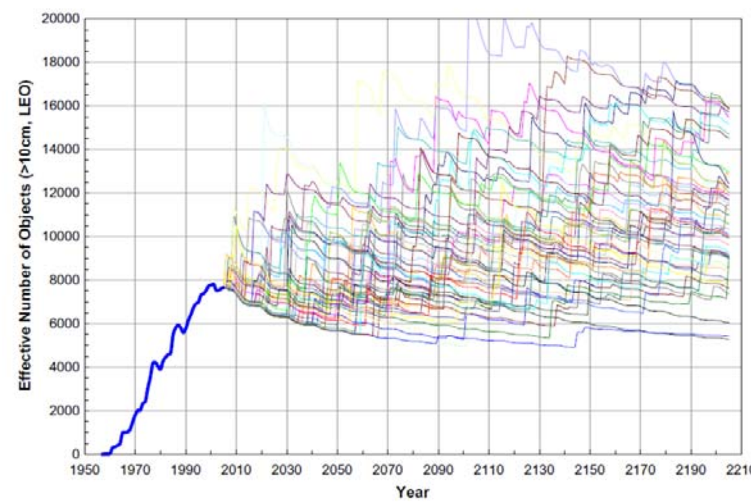
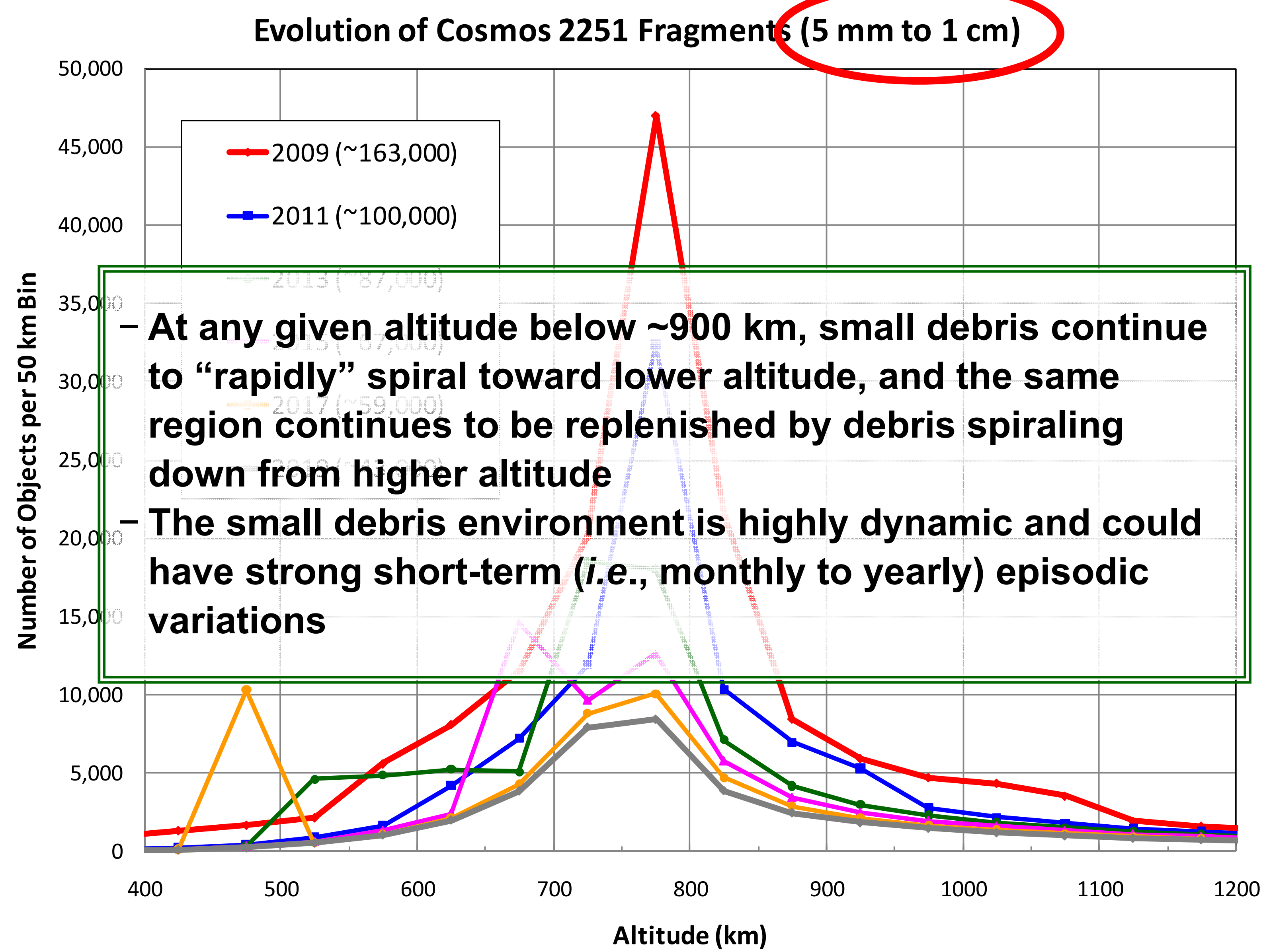


Fig. 3. Individual population growths (effective number of LEO objects 10 cm and larger) from the first 50 MC simulations. The sudden upward jumps are caused by breakups associated with each individual simulation.

Additional Difficulty for Modeling Small Debris Population



- At any given altitude below ~900 km, small debris continue to “rapidly” spiral toward lower altitude, and the same region continues to be replenished by debris spiraling down from higher altitude
- The small debris environment is highly dynamic and could have strong short-term (*i.e.*, monthly to yearly) episodic variations

Concluding Remarks

- Future environment projection is a difficulty task
- There exist different approaches to provide insights into the future to guide the development of mitigation and remediation measures
- Any study results must be clearly presented with the assumptions and the Monte Carlo nature of the outcome
- In reality, the assessments of the environment and the need for remediation efforts must be evaluated on a regular basis