KYUSHU UNIVERSITY 2011
100th Anniversary

IUGONET研究集会

宇宙活動の長期的持続可能性に影響するスペースデブリと地球温暖化

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令和6年9月17日

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Introduction

This paper investigates the impact of space debris and global warming on the long-term sustainability of outer space activities.

- The thermosphere is becoming increasingly cold due to global warming. As the temperature of the thermosphere decreases, the atmospheric density of the thermosphere also decreases.
- This paper assumes that the rate of decrease in atmospheric density is 2% and 5% per decade since 1971.
- The baseline scenario uses the initial population as of 1st January 2021 and assumes “Reg Launches” and “90%PMD” with no decrease in atmospheric density.
- Comparisons include population growth over 100 years, spatial density after 100 years as a function of altitude, and collision activities over 100 years as a function of altitude.

Current Situation

Current situation in LEO is unstable.

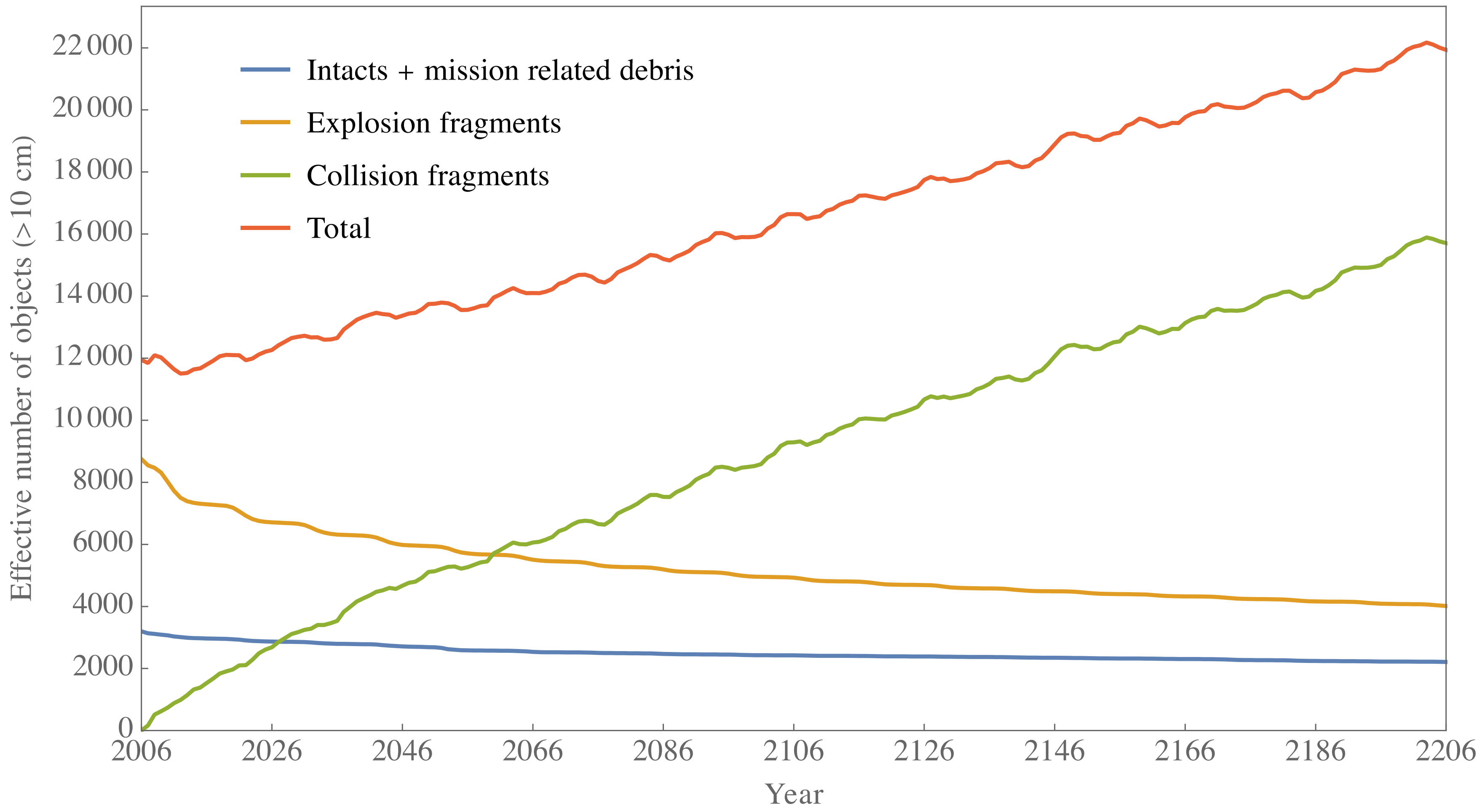
- This unstable situation in LEO is sometimes called “Chain Reaction” or “Kessler Syndrome.”
- “Chain Reaction” or “Kessler Syndrome” is a scenario in which the density of objects in LEO is high enough that collisions between objects could cause a cascade.
- One implication is that the distribution of debris in orbit could render space activities and the use of satellites in specific orbital ranges unfeasible for many generations.

Space Debris Evolutionary Model

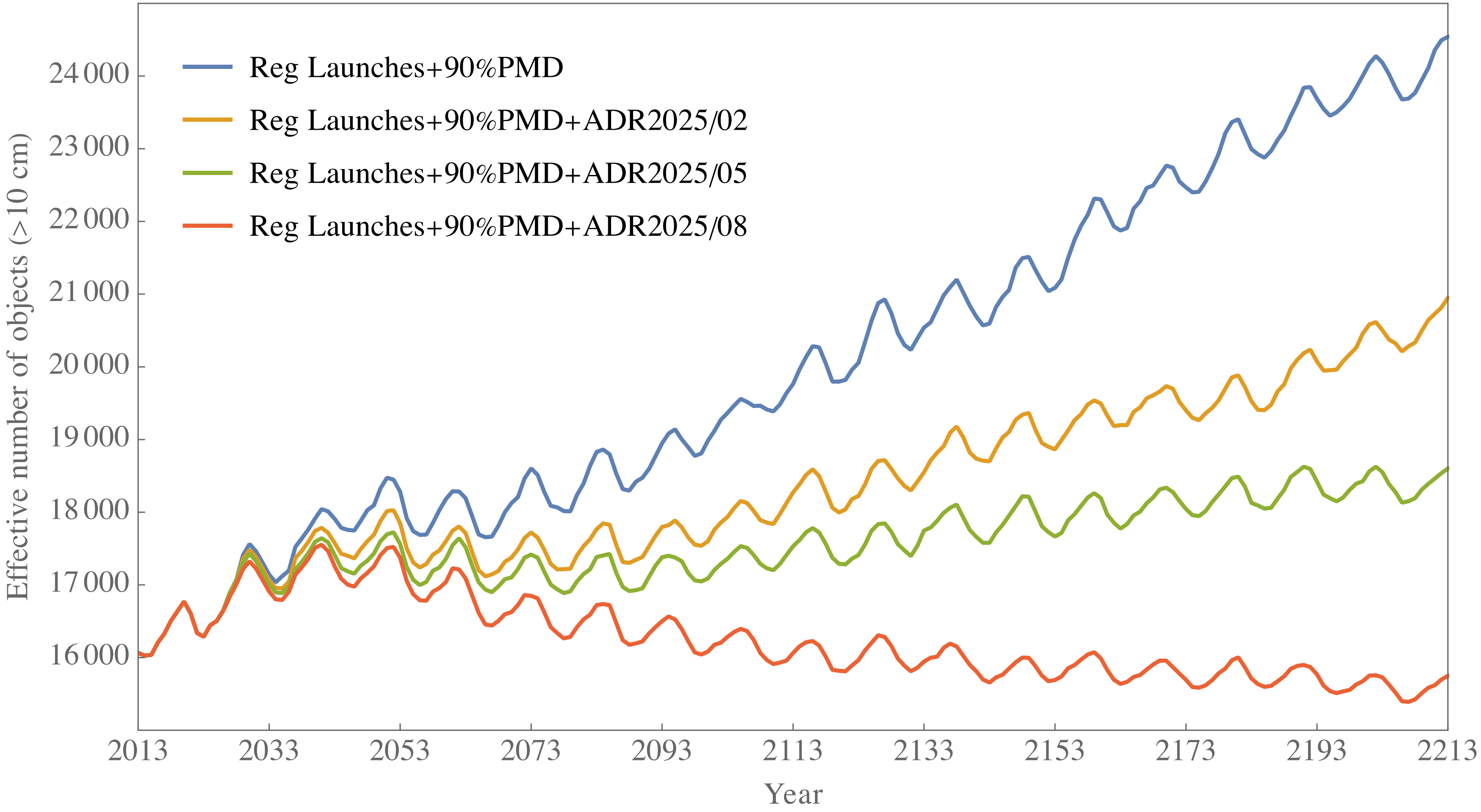
Computational models are required to evaluate the effectiveness of space debris mitigation and environmental remediation.

- Computational models are called **space debris evolutionary model**s.
- **Evolutionary model**s conduct future projections of space debris population over a long period (>100 years).
- **Evolutionary model**s assume the rate of future explosion based on past events to explode objects and estimates the probability of accidental collision between objects to collide objects. Then, the resulting fragmentation debris is added to the space debris population in place of the objects that exploded or collided.

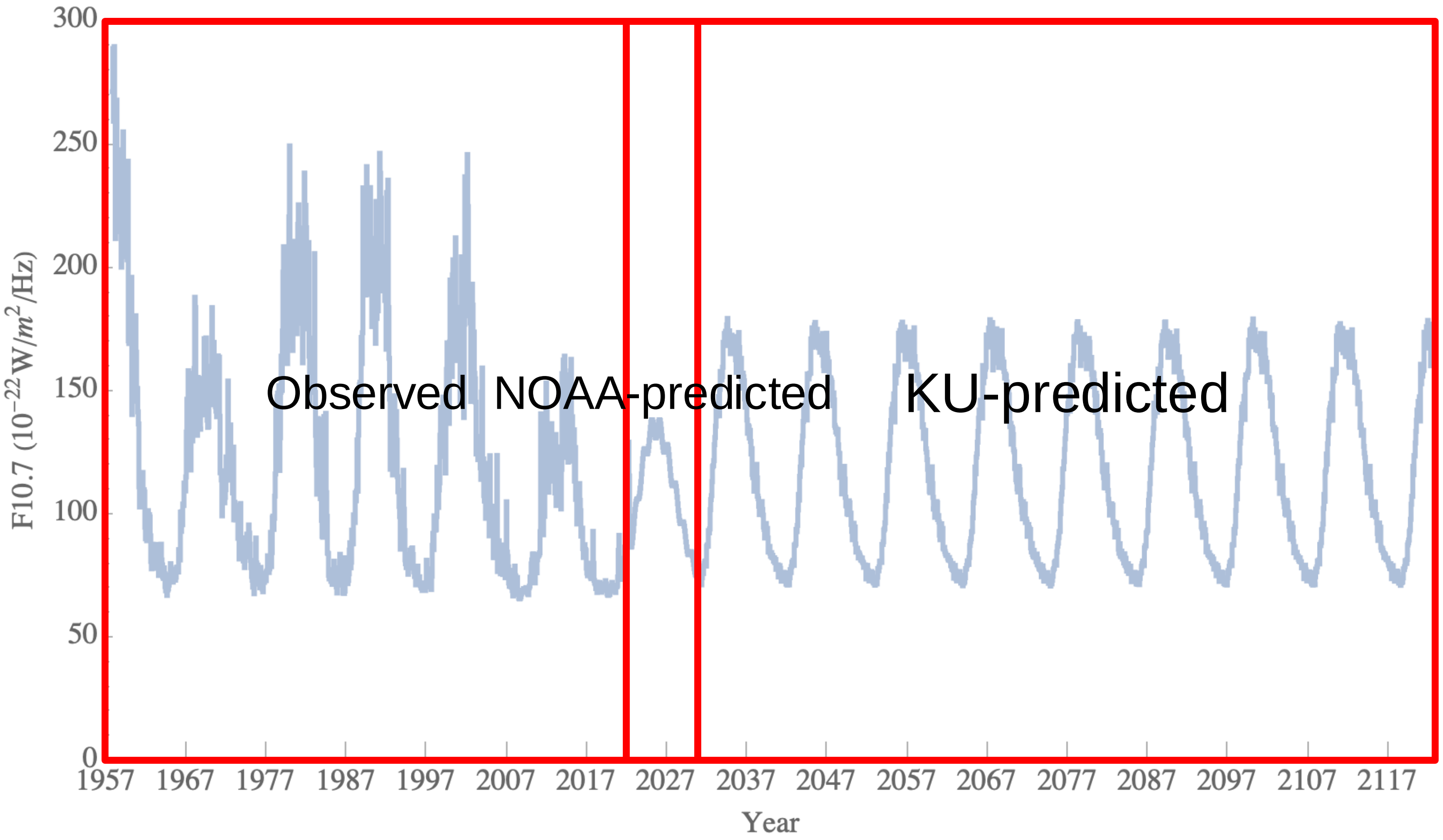
Instability of Debris Population in LEO



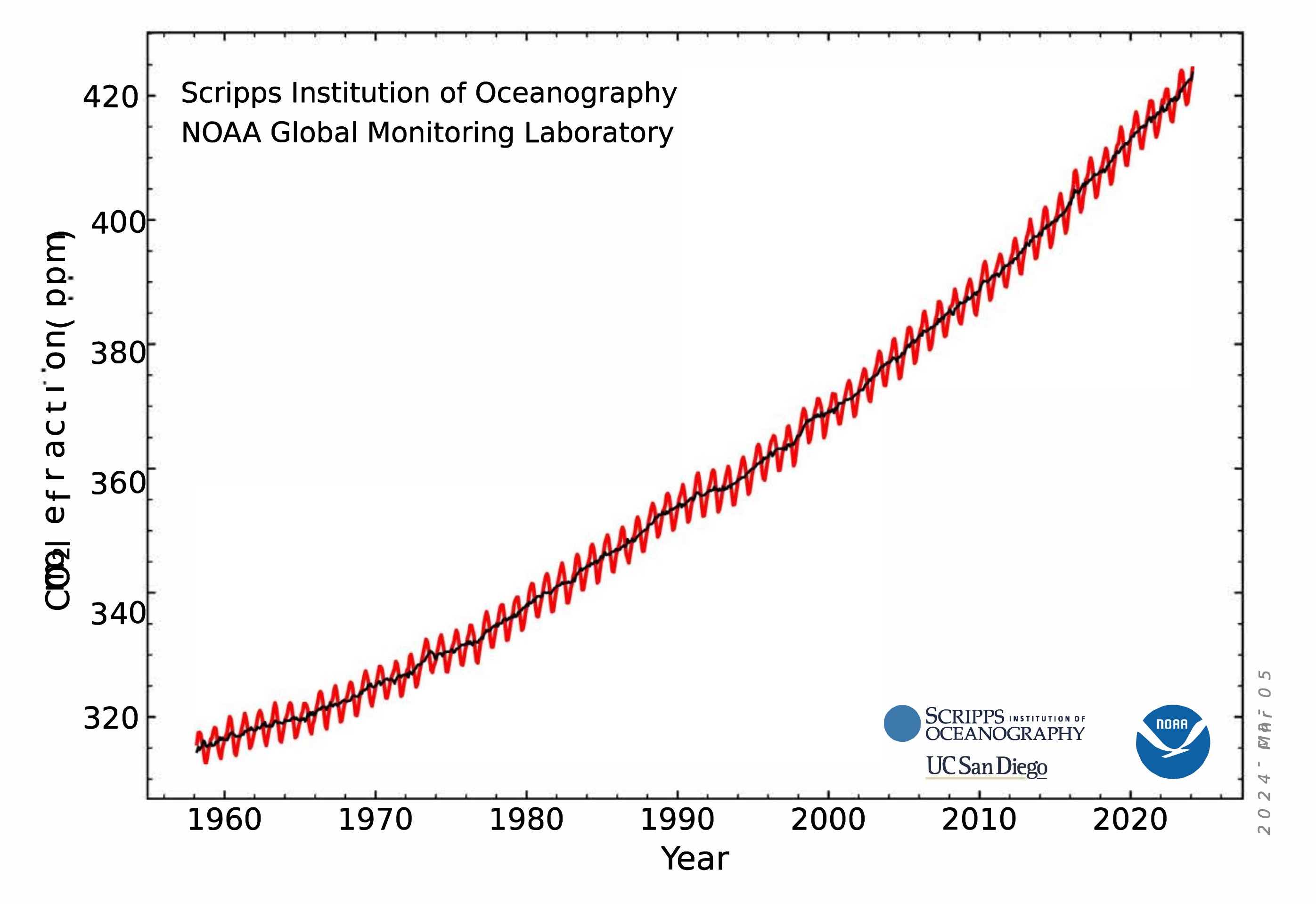
Effectiveness of Environmental Remediation in LEO



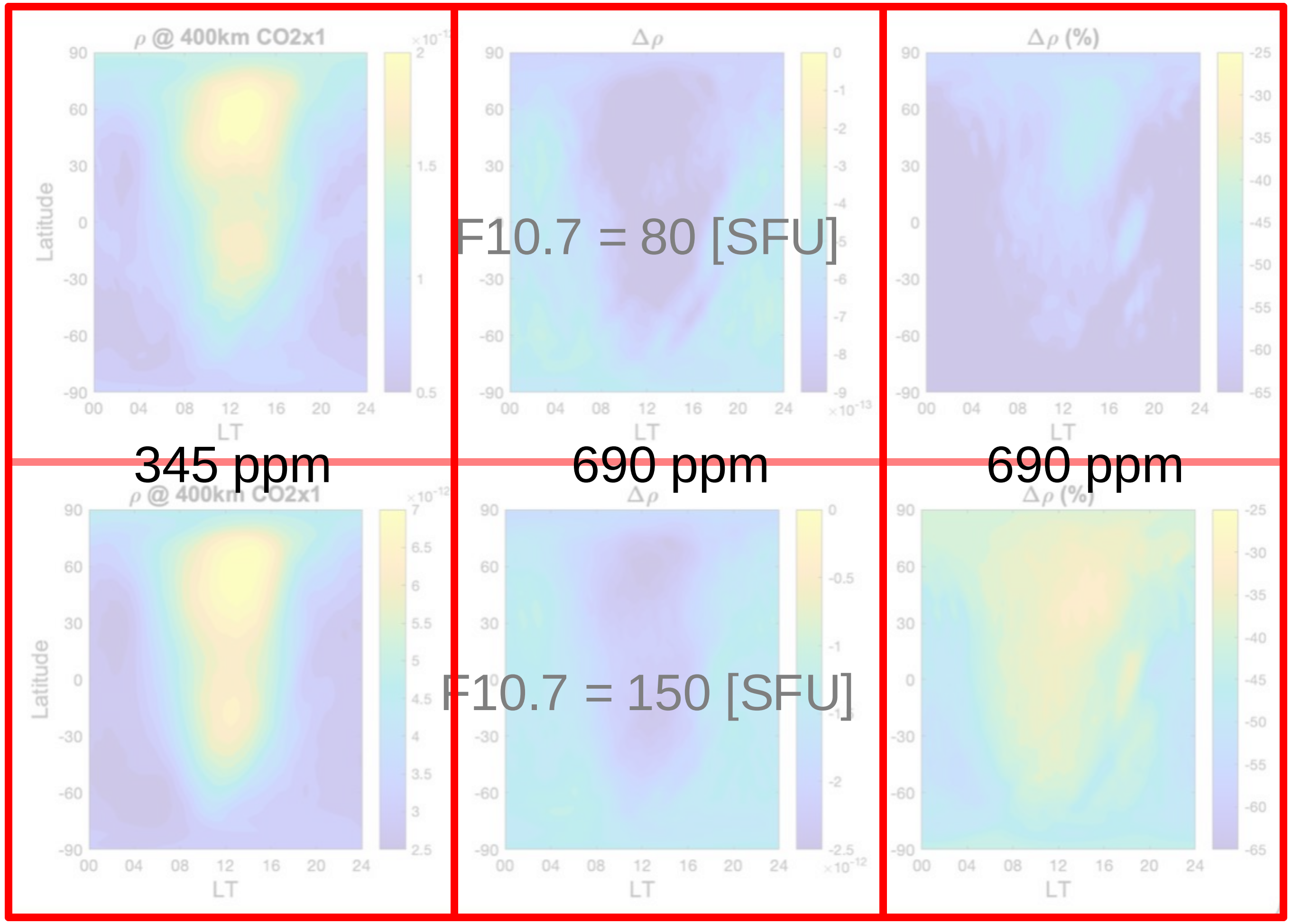
Observed and Predicted Values for F10.7 since 1957-10-04



Trend in Atmospheric CO_2 at Mauna Loa Observatory



Thermosphere Density Response at 400 km Alt. When CO_2 Increases from 345 to 690 ppm



Future Projection Scenarios

Future projections begin with the initial population as of 1st January 2021, including all 10 cm and larger objects in or crossing LEO.

Future explosion is set to 0.

“Reg Launches” are allowed beyond 1st January 2021, repeating the insertion history of the past eight years from 1st January 2013 to 31st December 2020.

“PMD” is incorporated with a success rate of 90%.

Future Projection Scenarios, cont’d

Atmospheric density would decrease by 2% and 5% per decade.

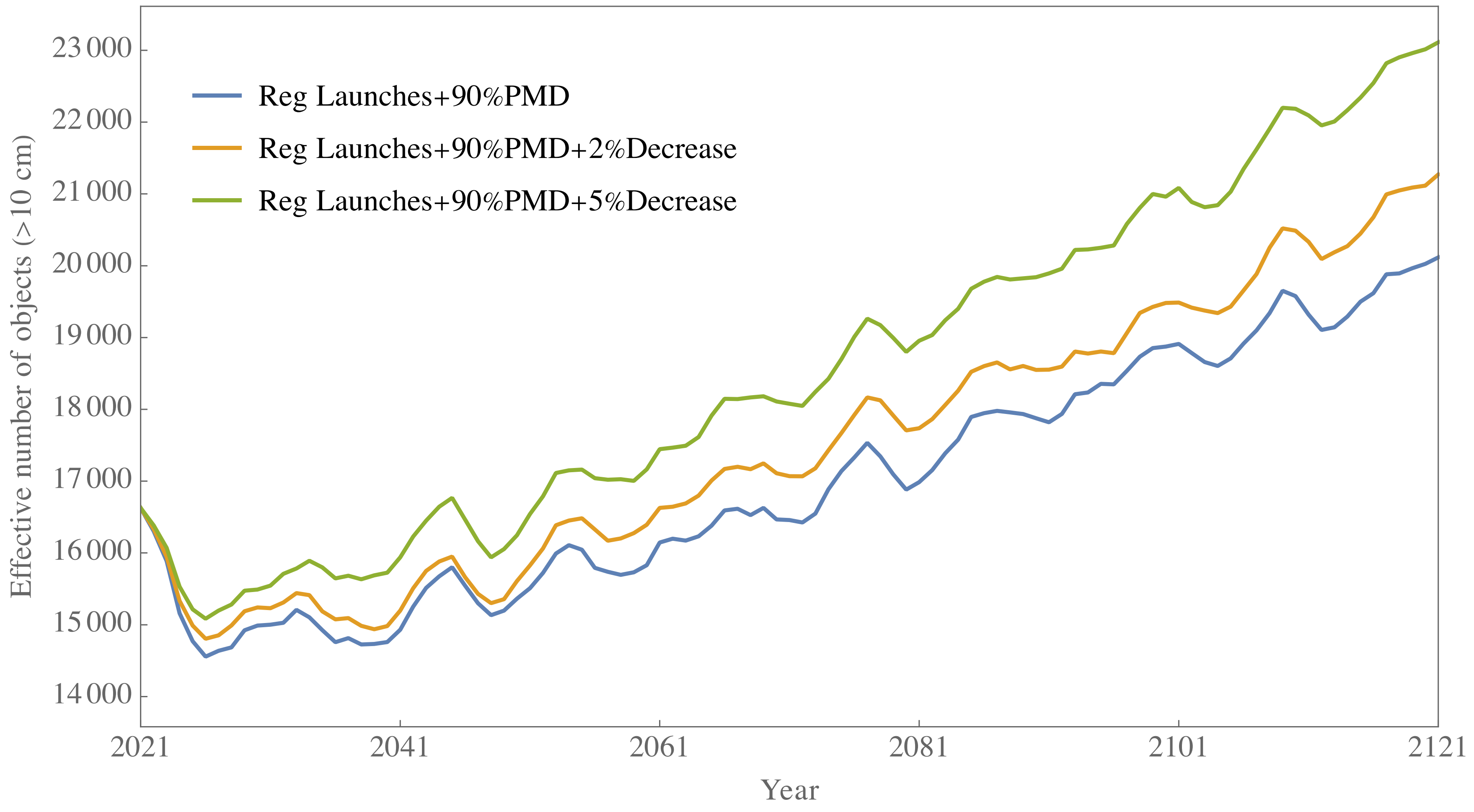
Jacchia-Roberts 1971 atmosphere is used as the model atmosphere.

Since the decrease in atmospheric density had already begun before 1971, this study decided to modify it as written in

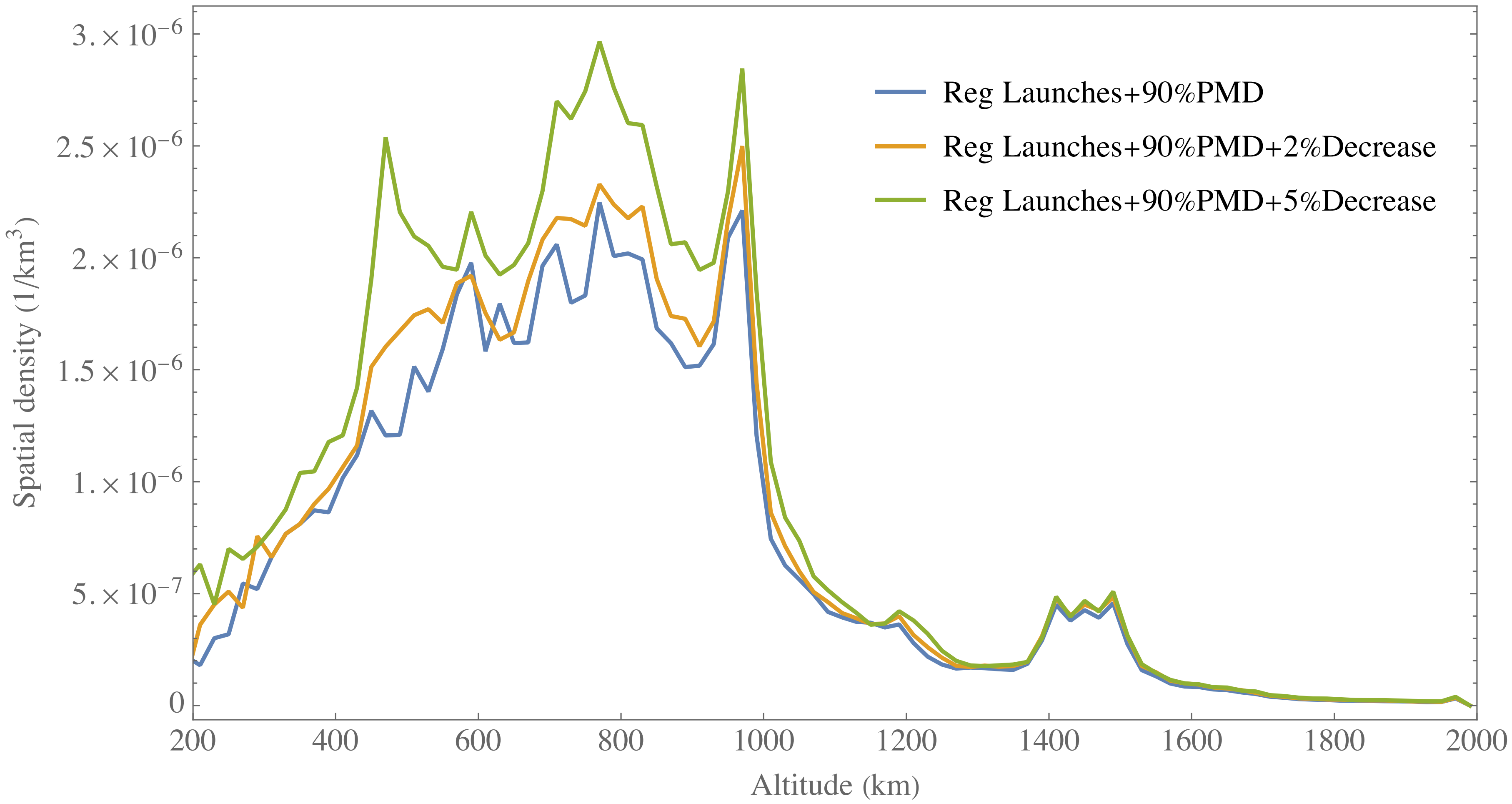
$$\rho' = \rho e^{-\lambda(JD - JD_{1971.1.1})}$$

where ρ is the atmospheric density calculated by the Jacchia-Roberts 1971 atmosphere, λ is the rate of decrease in atmospheric density, and JD is the Julian day number plus the fraction of a day since the preceding noon in Universal Time.

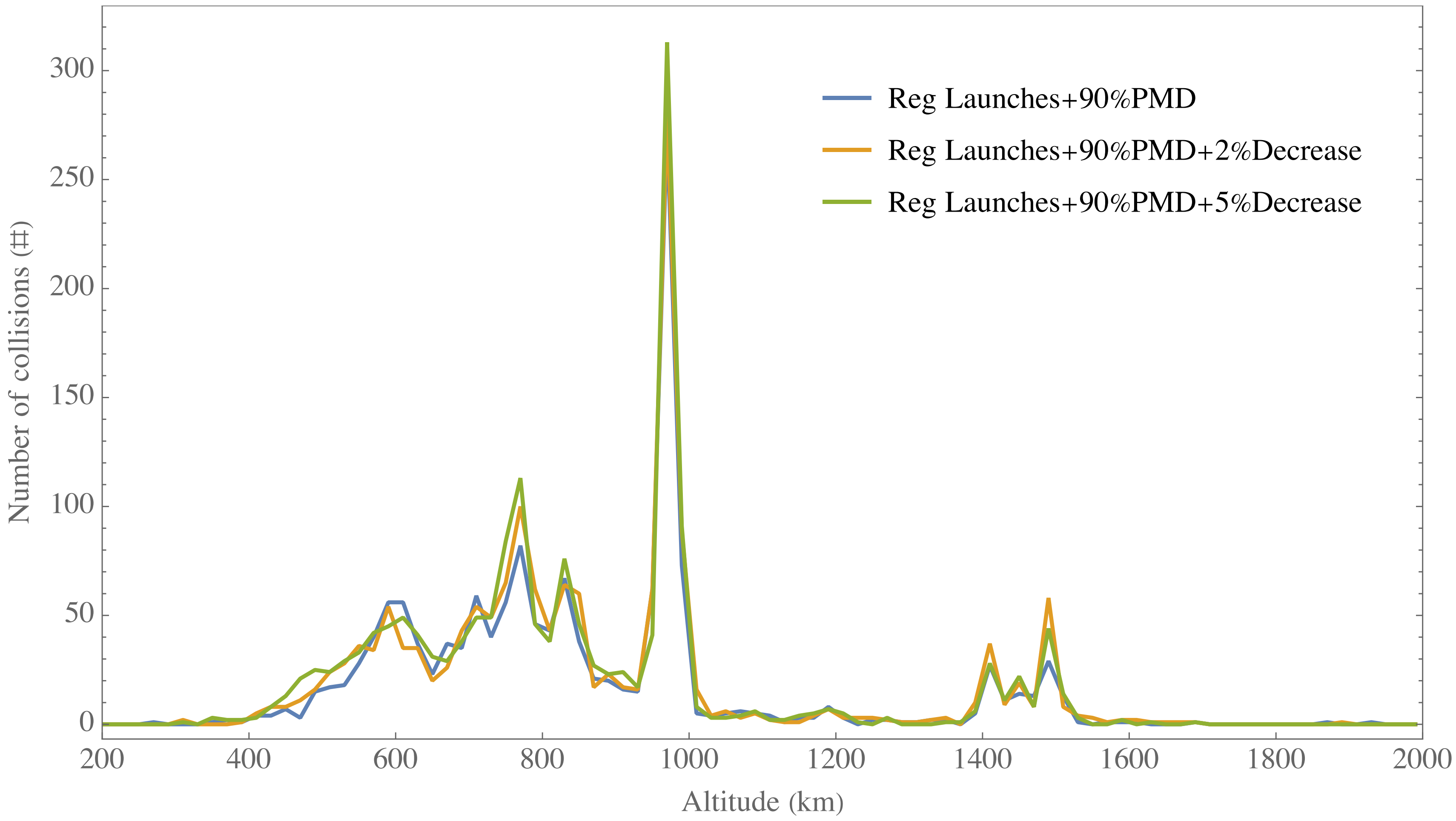
Impact of Thermosphere Cooling in Terms of Effective Number of Objects in LEO



Impact of Thermosphere Cooling in Terms of Spatial Density in LEO



Impact of Thermosphere Cooling in Terms of Collision Activities in LEO



Summary

Space debris and global warming have become a major problem that also affects the long-term sustainability of outer space activities.

- It is necessary to consider the decrease in atmospheric density when calculating the lifetime of orbits that are expected to decay into the atmosphere within 25 years.
- The orbit calculated by considering the decrease in atmospheric density will be an orbit with a lower altitude, therefore the amount of fuel required to move to that orbit will increase. This may also affect the operation and design of the spacecraft.
- The decrease in atmospheric density affects not only the instability of the space debris population but also the effectiveness of space debris mitigation and environmental remediation.