# Game Theoretic Analysis of the Space Debris Dilemma

## Executive Summary

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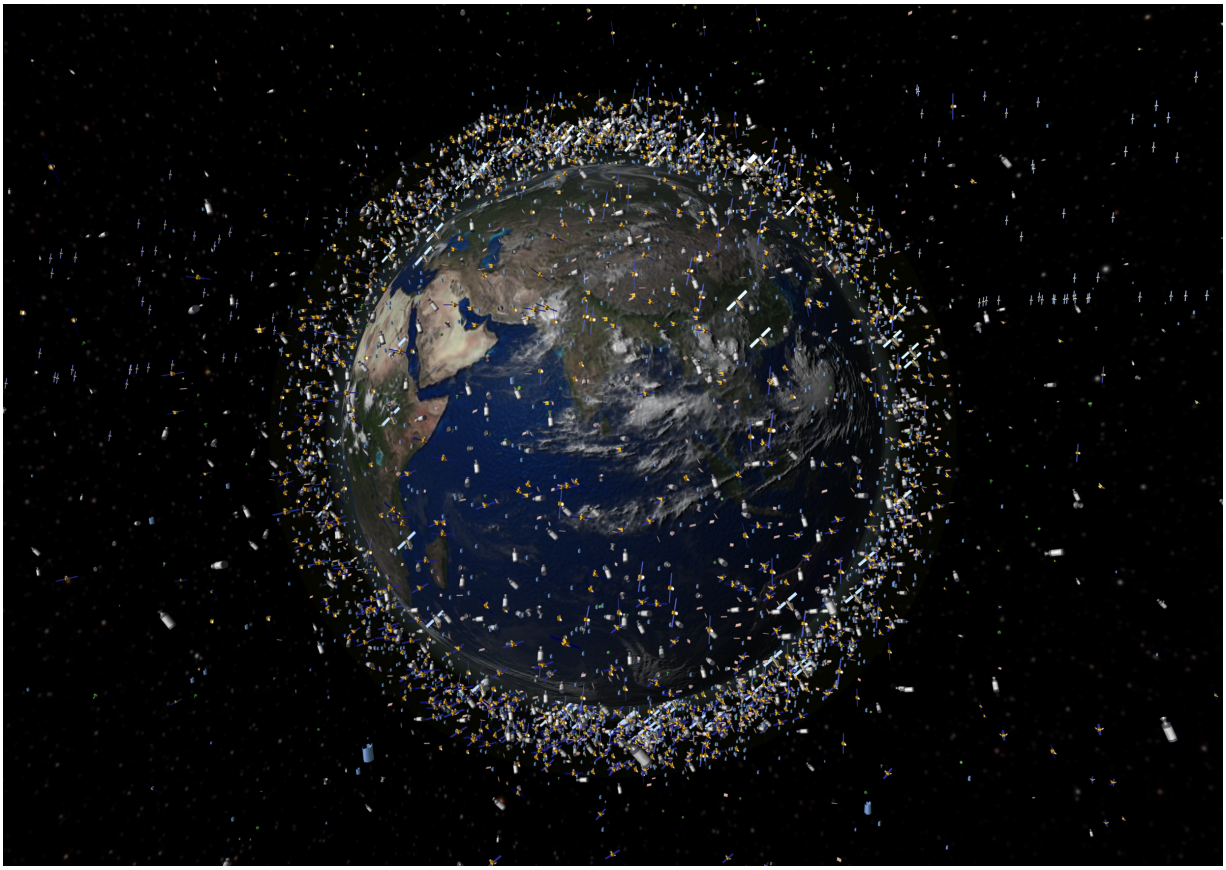
**Picture:**



**Motivation:**

We use empirical game theoretic methods combined with the PyKEP simulator to model and study the space debris removal dilemma as a strategic game, and analyse the resulting (Nash) equilibrium strategies and evolutionary dynamics.

**Methodology:**

The increase of space debris means that active space debris removal becomes relevant. An active debris removal mission has a positive effect (or risk reduction) for all satellites in the same orbital band. This leads to a dilemma: each agency has an incentive to delay its actions and wait for others to respond.

We model this scenario as a non-cooperative game between self-interested agents in which the agents are space agencies. Using a high-fidelity simulator we estimate payoffs to agents for different combinations of actions taken, and analyse the resulting game in terms of best-response dynamics and (Nash) equilibria. Contrary to

the urgency of the space debris dilemma there has not been much attention to this problem in scientific circles. To the best of our knowledge we are the first to consider this dilemma in the context of multi-agent strategic decision making using empirical game theoretic techniques.

**Results:**

This study has resulted in the following main contributions. We have

1) shown that the active debris removal (ADR) dilemma can be modelled as a multi-player strategic game;
2) introduced a debris removal game, and demonstrated how this game can be used for the computation and approximation of equilibria, basins of attraction, and stability properties of the different equilibria or solutions of the game;
3) gained insight in the evolutionary dynamics of, and determine potential optimal strategies in, the debris removal game by means of heuristic payoff tables; and
4) shown by means of the strategic substitutes property the types of equilibria we can expect in this game in general.

**Publications:**

Accepted at ECAI:

- R. Klima, D. Bloembergen, R. Savani, K. Tuyls, D. Hennes, and D. Izzo, “Space Debris Removal: A Game Theoretic Analysis,” in *Proceedings of the 23rd European Conference on Artificial Intelligence (ECAI)*, 2016.

An extended version of this work has been submitted to the special issue “Real world applications of game theory” in the journal “Games”, conditionally accepted:

- R. Klima, D. Bloembergen, R. Savani, K. Tuyls, D. Hennes, and D. Izzo, “Space Debris Removal: A Game Theoretic Analysis,” conditionally accepted in Games, special issue on Real World Applications of Game Theory.

**Highlights:**

The results of this study help agencies to better understand the debris removal problem and its short and long term consequences, in order to prepare for mitigation strategies. For instance, we show that removing just one high risk debris object every two years can already substantially decrease the risk of collision for active satellites. Additionally, removal of indirect collision risks is beneficial as well as it reduces the number of potential future on-orbit collisions.