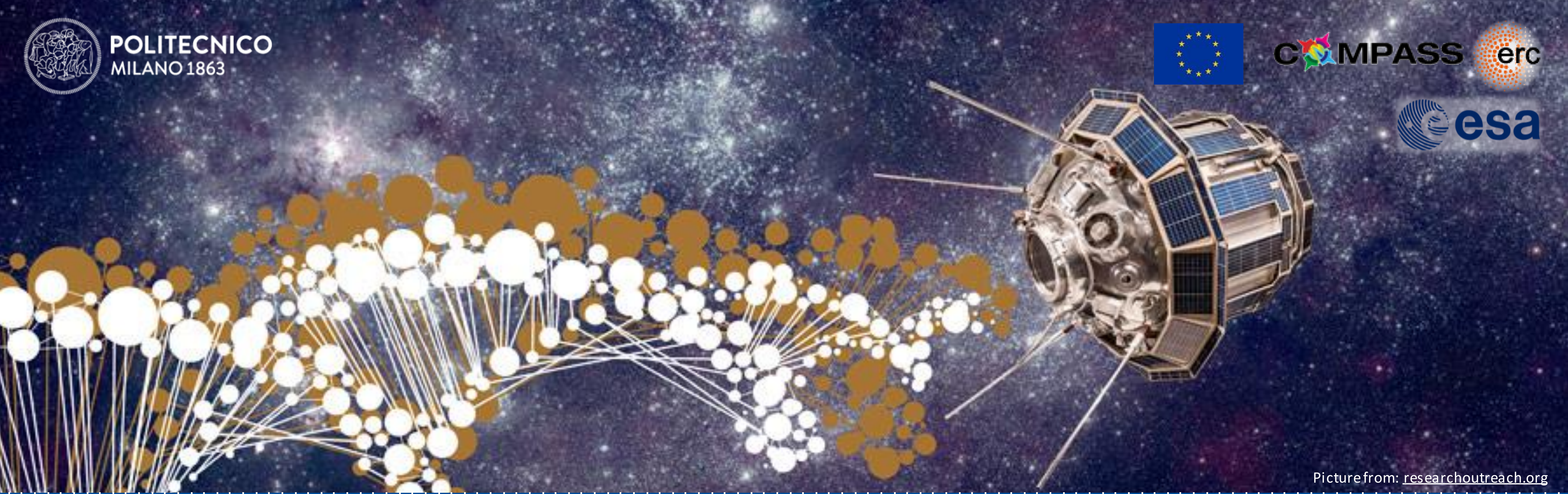

Picture from: researchoutreach.org

Technical and programmatical challenges in planetary protection and planetary defence

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Politecnico di Milano

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Introduction

Interplanetary mission challenges: JUICE

Movie from: JUICE (esa.int)

Picture from: Cosmos (esa.int)

What about disposal objects with all these flybys?

1st flyby of Earth
2nd flyby of Earth
3rd flyby of Earth

Flyby of Venus

Flyby of Mars

Introduction

Planetary protection starts at the disposal of the launcher's upper stage

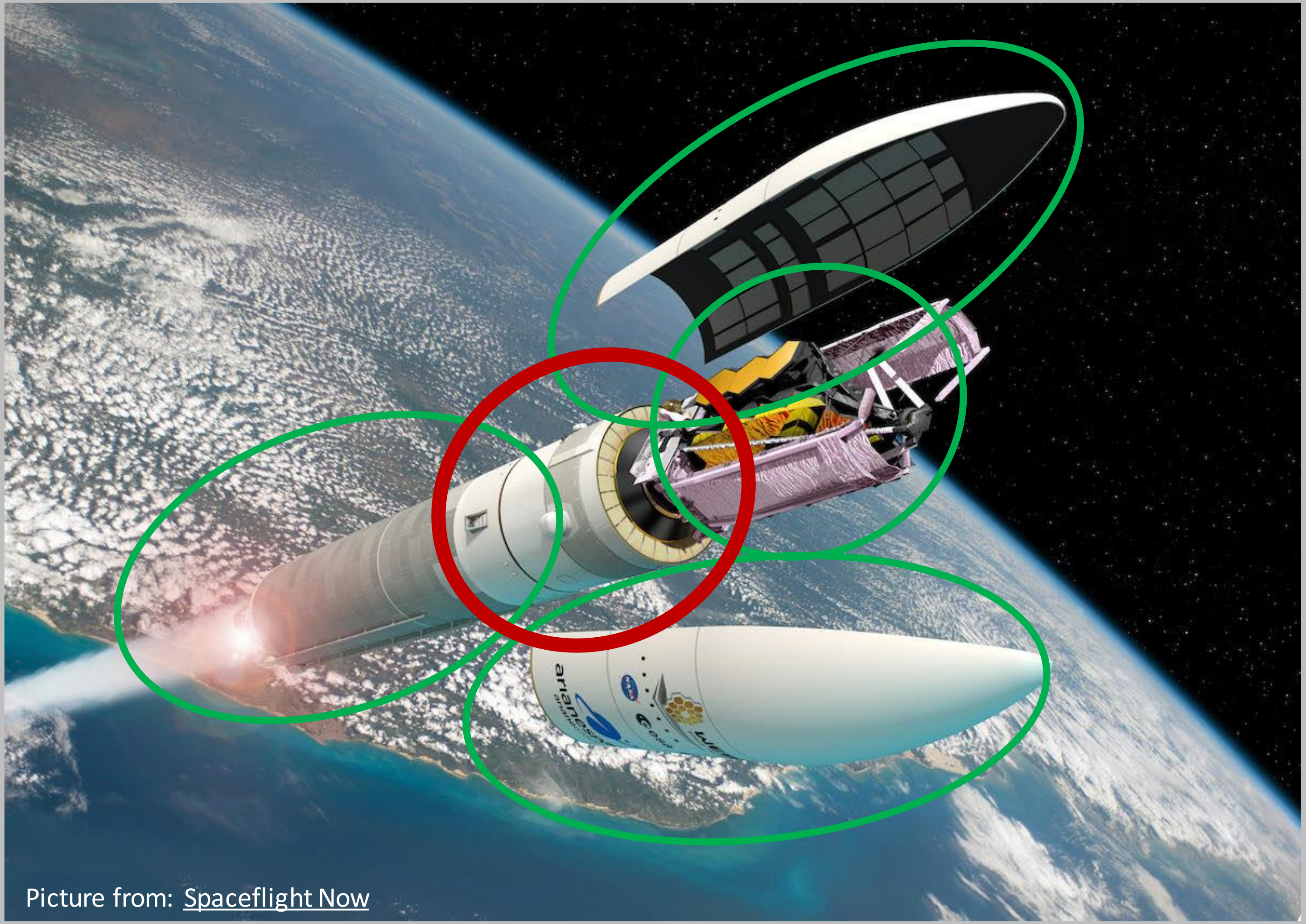
Recall: Ariane 5 injects JUICE in an orbit pointing to a flyby of Earth… We don't want to have an impact!

More insight

Payload:	sterilised
Lower stage:	stays in atmosphere
Boosters:	stay in atmosphere
Fairings:	burn up in atmosphere
Upper stage:	injected in uncontrolled interplanetary orbit

A first planetary protection/defence task: design JUICE's mission so that Ariane 5's upper stage impact probability with Earth is lower than 0.01%

Note: not all parts can be sterilised!

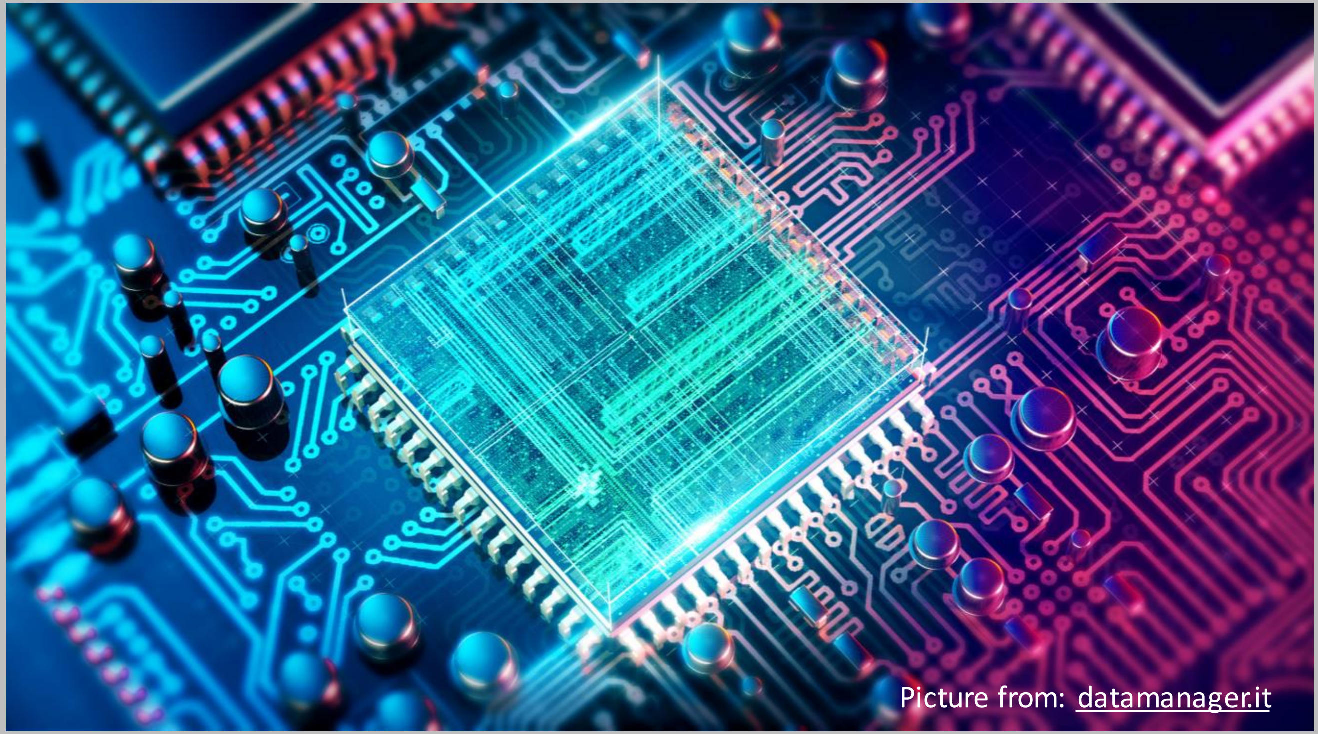


Picture from: Spaceflight Now

Planetary protection challenges

Computationally intensive task

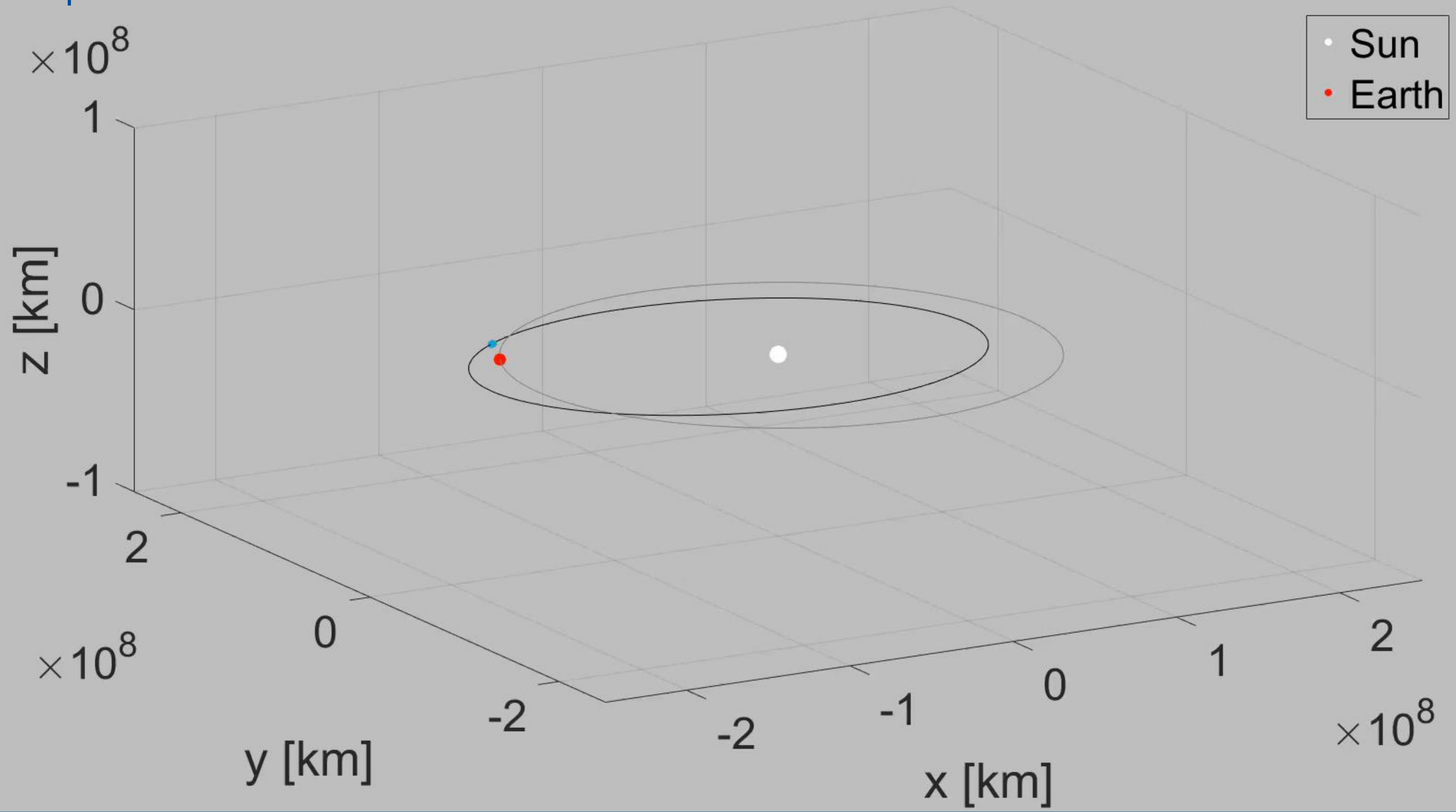
- Planetary defence-like problem: protect Earth (and all our satellites)
  - Impact probability below 0.01%, for the next 100 years: minimum Monte Carlo size is 50-60k simulations!
  - The fastest software performs one simulation in 1-2 seconds. Computational burden increases to test multiple scenarios…
- Planetary protection of Enceladus and Europa:
  - Impact probability below 0.01%, for the next 1000 years… Getting even more intensive!
- Emerging computing technologies come to play
  - Scientific computing on graphics card
  - High performance computing facilities


Picture from: datamanager.it

Addressing these requirements must happen for any proposed mission scenario. Assessing the planetary protection compliance of trajectories (not even all mission systems yet!) is already a bottleneck for the mission development

Planetary protection challenges

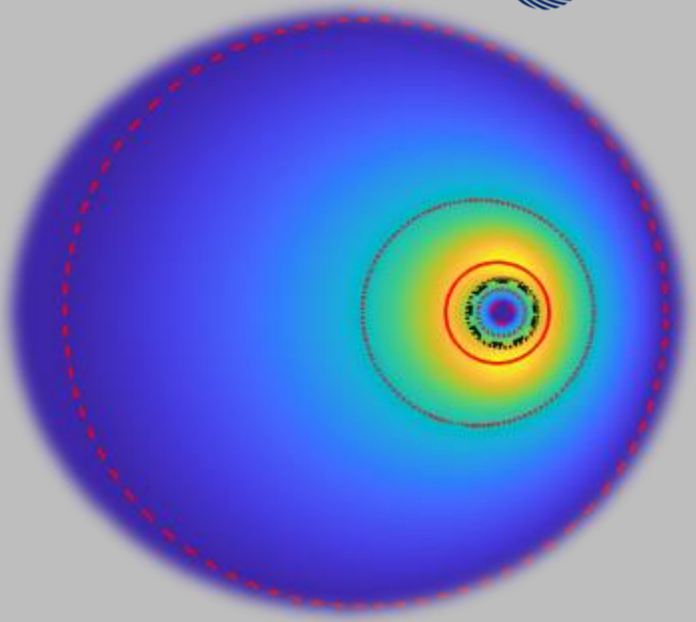
Flyby dispersion



Planetary protection challenges

Wide range of close encounter conditions

- Long-range interactions become relevant
  - Small orbit variations make the difference between a near miss and impacts
  - Recall the flyby dispersion problem: different flyby depths result in *both* distant and close interactions to be studied
  - One (small) initial uncertainty, one common initial flyby, wide range of diverging trajectories

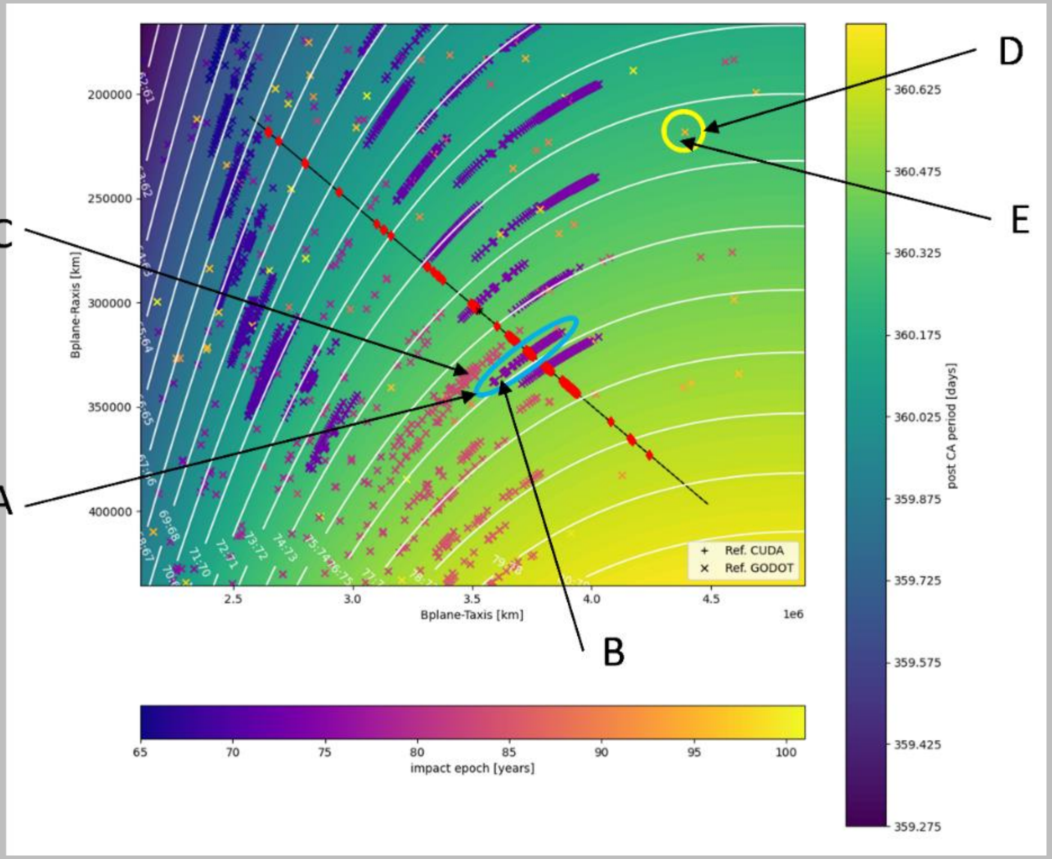


- Open questions:
  - How to account for all relevant interactions?
  - What makes an interaction relevant?
  - How can we simplify the problem without accuracy loss?

Planetary protection challenges

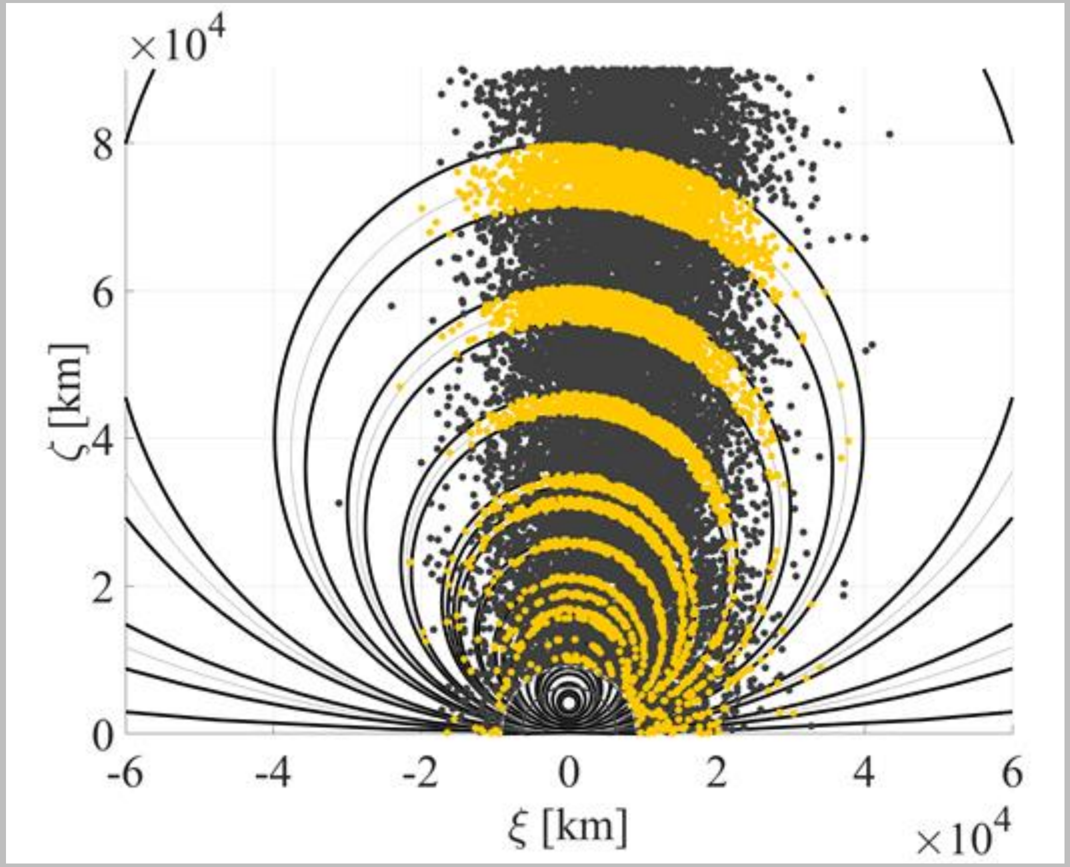
Disposal manoeuvre design: avoid impacts (today) and resonances (tomorrow)

JUICE b-plane disposal optimisation



Picture from: A. Boutonnet and A. Rocchi

Solar Orbiter Monte Carlo resonances in the b-plane

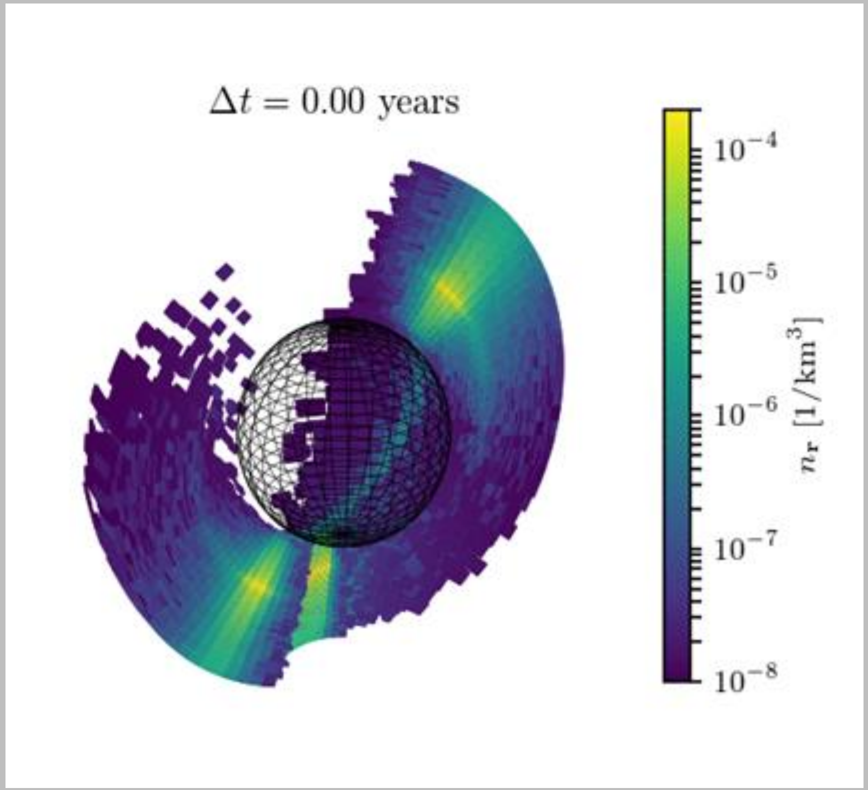


Planetary protection challenges

Ongoing works

Addressing the planetary protection compliance of space missions is an interdisciplinary problem

- Build faster software
  - More precise models
  - Implement faster algorithms
  - Get faster computers
  - Exploit graphics card
- Learn from other space experiences!
  - Any solution/tool from the Space Debris-problem that be borrowed?
- Explore the dynamics of the problem
  - Any way of filtering the outgoing trajectories to study only the case that contribute to future impacts?

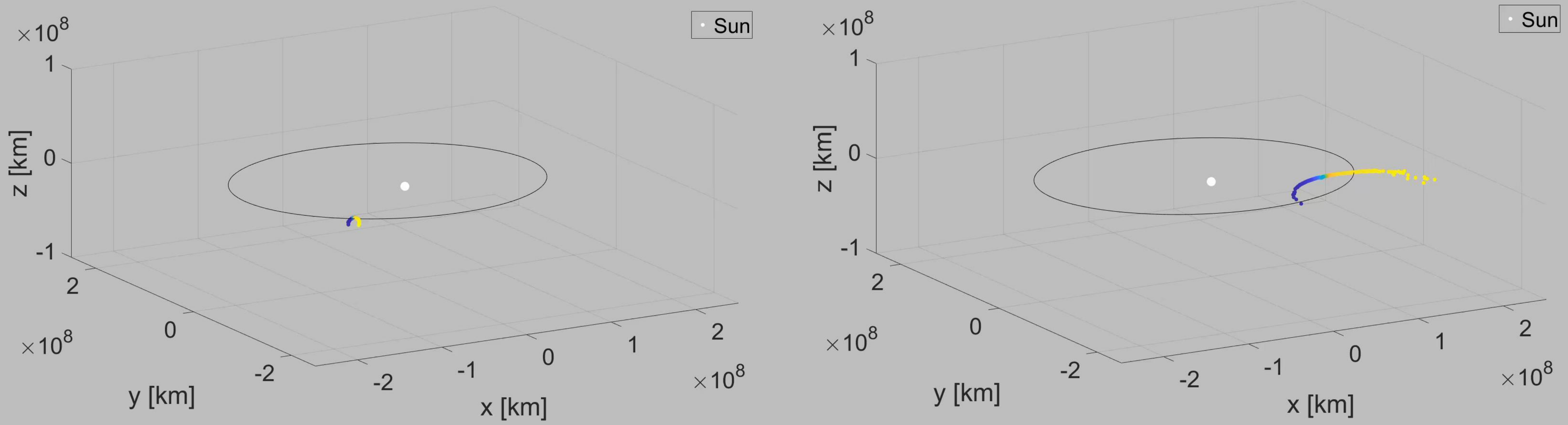


Picture from: Frey S., Evolution and hazard analysis of orbital fragmentation continua, Doctoral thesis, Politecnico di Milano, 2020, Supervisors: Colombo, C., Lemmens, S. and Krag., H.

Planetary protection challenges

Ongoing works

Alternative mathematical models may highlight physical features that are (apparently) hidden by chaos!



Conclusion

- Planetary protection introduces complex technical challenges, already at the trajectory planning level
  - Properly dispose launcher upper stages. Protect Earth, protect Mars!
  - End of life of spacecrafts (e.g., JUICE)
  - Work with diverging and expanding uncertainties
  - Multidisciplinary context: statistics, orbital dynamics, biology, computing, mathematical modelling,…
- The complexity certainly increases for backward planetary protection applications
  - How many new challenges are introduced by Mars Sample Return?
- Biological aspect yet to be taken into account: even more points to be covered!
  - Can we make our trajectories even more robust, in case of unexpected events or system failures?
  - Analogously, can our increasingly improved understanding of the space environment (e.g. sterilising radiation) contribute to relax the requirements and ease the design of space missions?

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Thank you for your attention!

Any questions?

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Picture from: researchoutreach.org

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