



POLITECNICO
MILANO 1863



Detection and effects of fragmentations in low Earth orbit

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PUZZLE

- Initially developed for ASI for support to SST services
- Later improved with additional functionalities
- Dual goal
 - **Detection** of past fragmentations
 - **Characterisation** of masses and energy
- Approach
 - **Short-term** (days)
 - No assumption of breakup
 - Using **comparison metrics** and **convergence analysis**
 - **Osculating** orbital elements



STARLING 2.0

- Developed within an ESA project
- Dual goal
 - **Characterisation** and **Propagation** of fragments clouds through a continuum approach
 - Estimation of the **probability of impacts** with defined targets
- Approach
 - **Dynamics** agnostic model
 - Up to **6D phase space** of slow varying Keplerian elements and A/M
 - Kinetic gas theory analogy

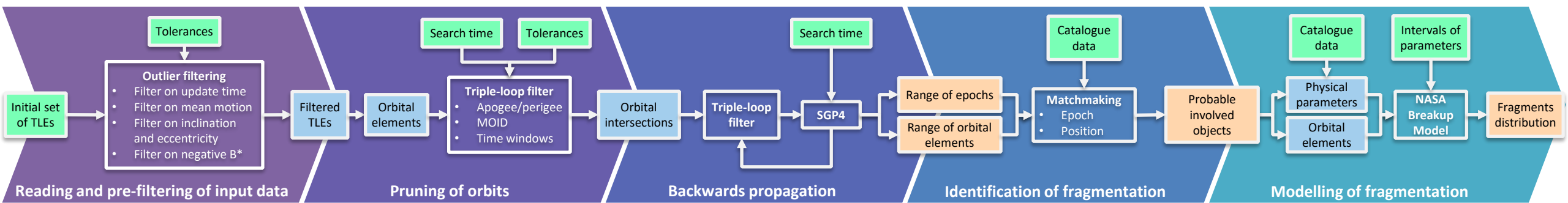
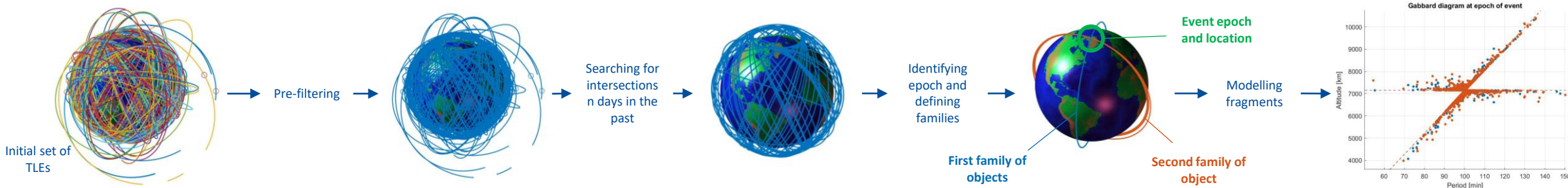
Input and output

INPUT

- Set of TLEs from catalogues
- Search parameters:
 - Time interval
 - Distance margin
- Additional parameters

OUTPUT

- Event characteristics:
 - Estimated epoch and location of the event
 - Objects involved (in terms of parent(s) and fragments)



- Hoots, F. R., Crawford, L. L., and Roehrich, R. L. (1984). An analytic method to determine future close approaches between satellites. *Celestial Mechanics*, 33:143–158.
- Johnson, N., Krisko, P., Liou, J.-C., and Anz-Meador, P. (2001). Nasa’s new breakup model of evolve 4.0. *Advances in Space Research*, 28:1377–1384.
- Kelso, T., Hoots, F., and Roehrich, R. (1988). Spacetrack report no. 3-models for propagation of norad element sets. NASA, Tech. Rep.
- Lidtke, A., Gondelach, D., and Armellin, R. (2019). Optimising filtering of two-line element sets to increase re-entry prediction accuracy for gto objects. *Advances in Space Research*, 63:1289–1317.
- Zappala, V., Cellino, A., Farinella, P., and Knezevic, Z. (1990). Asteroid families. i. identification by hierarchical clustering and reliability assessment. *The Astronomical Journal*, 100:2030–2046.

Input and output

INPUT

- Event initial states (from PUZZLE)
- Event type
- Type of objects involved
- Targets
- Additional parameters

OUTPUT

- Debris density distribution over time
- Impact rate and collision probability with targets

- Test cases:
 - Iridium 33 – Cosmos 2251 collision
 - Cosmos 1408 breakup

- Objectives:
 - Identification of the event (epoch, involved objects, etc.)
 - Collision risk analysis on targets

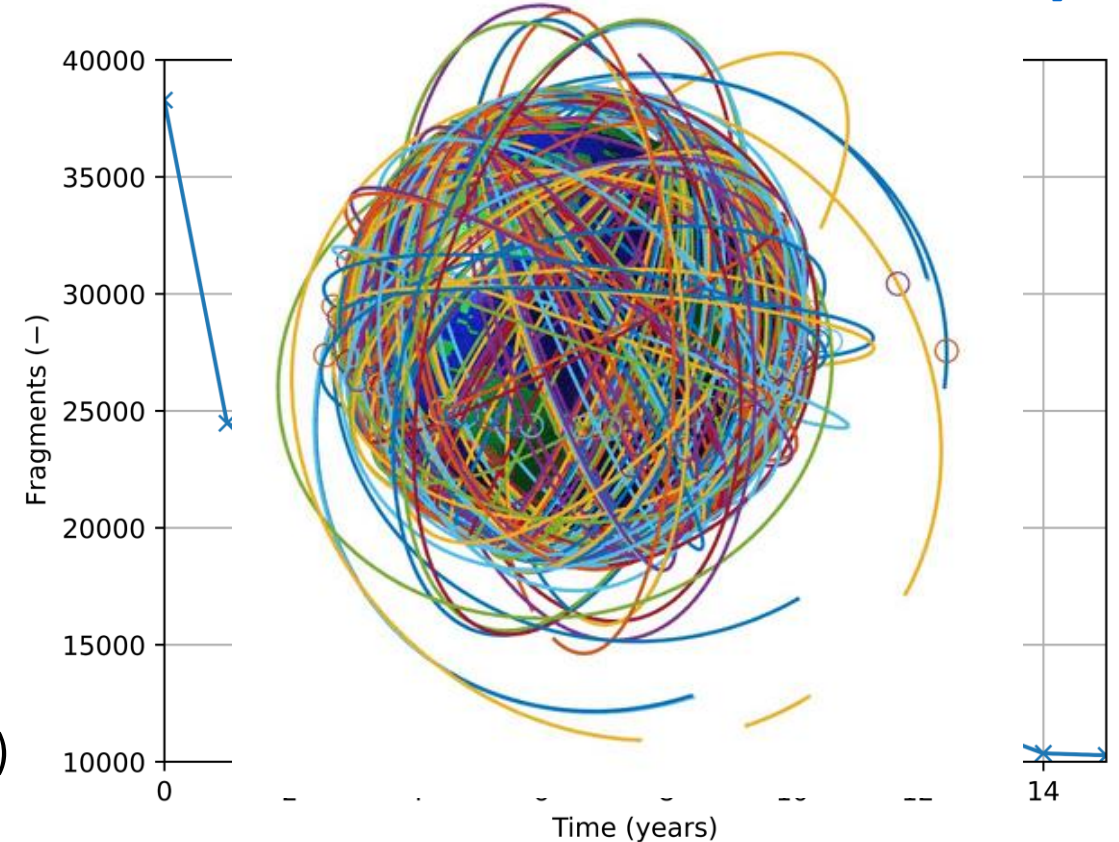
Cosmos 2251 – Iridium 33

- Size of initial set: 1500 (including parent(s) and generated fragments)
- Reference date of initial TLE set: 18 February 2009
- Identification of event epoch (**minimum distance** between the objects set at **5 km**)
 - Estimate: 10 February 2009, 16:55:40
 - Margin: ± 0.417 min
- Identified 2 orbital families in the estimated interval (Collision)
- Identification of involved objects
 - 22 objects
 - Parent ID: 22675 (Cosmos 2251), 24946 (Iridium 33)

- Computational time*: ~ 9 min

➤ SpaceTrack
*Intel(R) Core(TM) i7/7700 CPU @ 3.60GHz

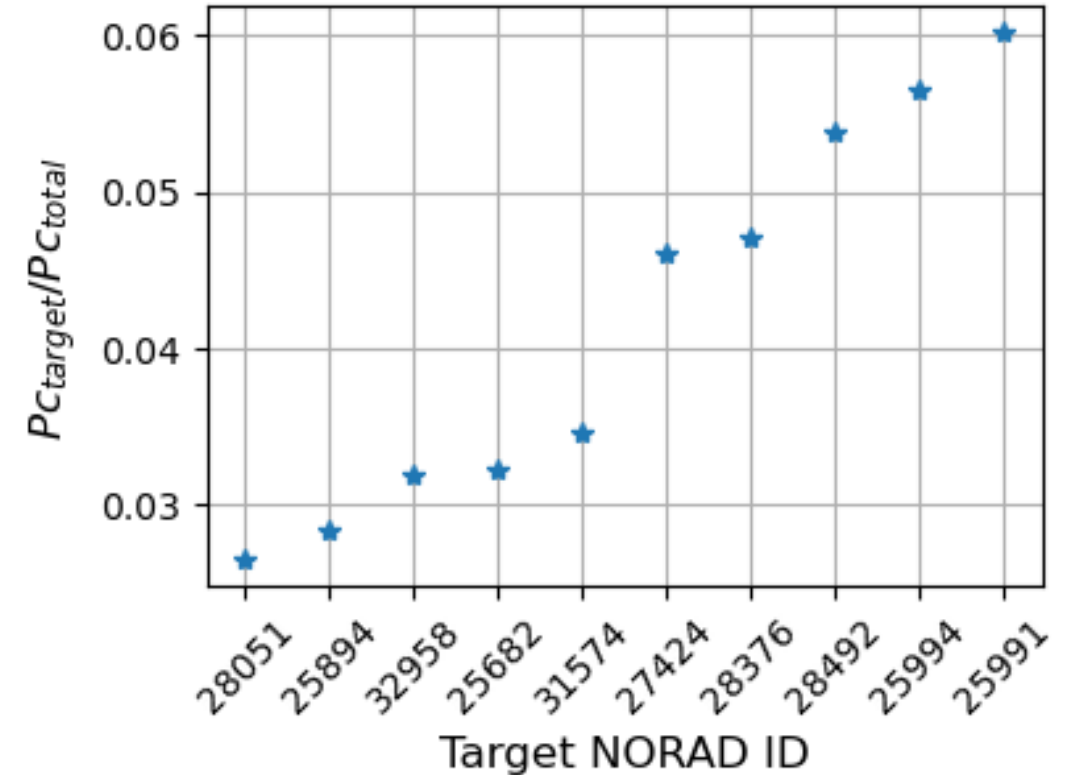
Number of fragments over time [1 cm - 1 m]



Application

Cosmos 2251 – Iridium 33

- Set of active objects in 2009 (175 objects)
- Timespan of 15 years
- Estimation of the cumulative collision probability between the targets and the fragments generated by the breakup
- Selection of the ten most at-risk targets



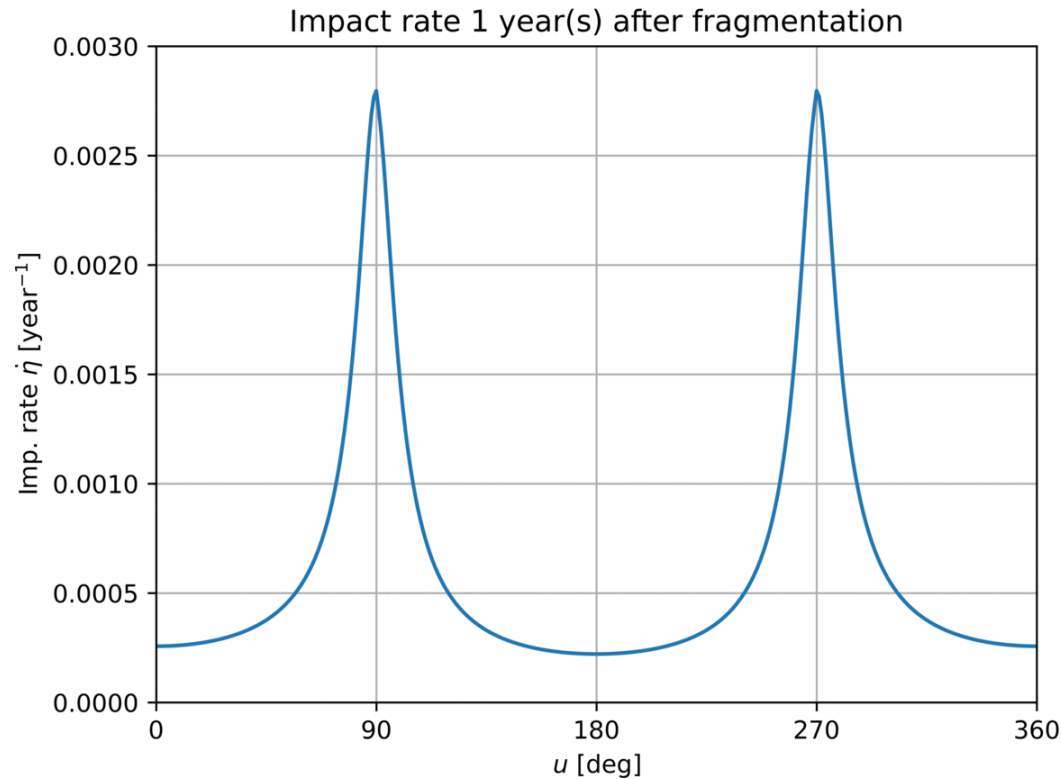
$P_{C_{target}}$ = cumulative collision probability associated to a single target
 $P_{C_{total}}$ = cumulative collision probability associated to the entire set of targets

Application

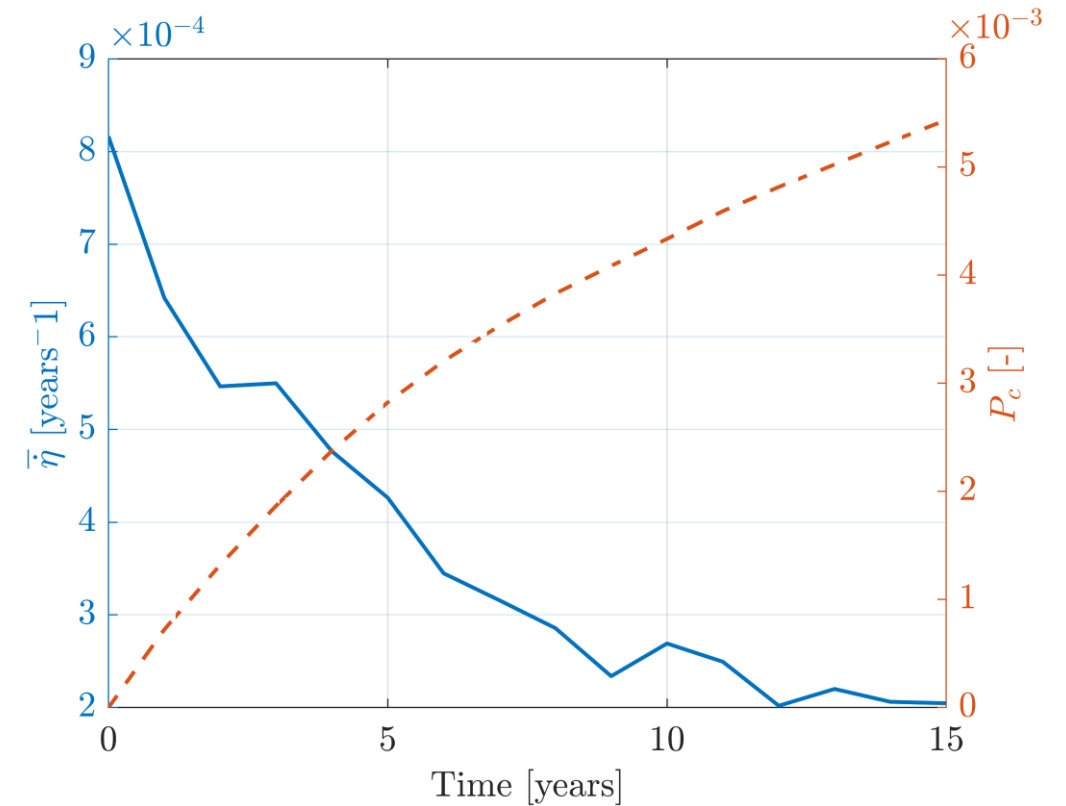
Cosmos 2251 – Iridium 33

Target:

- DMSP 5D-3 F-15
- Cross section: 28.16 m^2
- Time interval: 15 years



Mean impact rate and cumulative collision probability over time

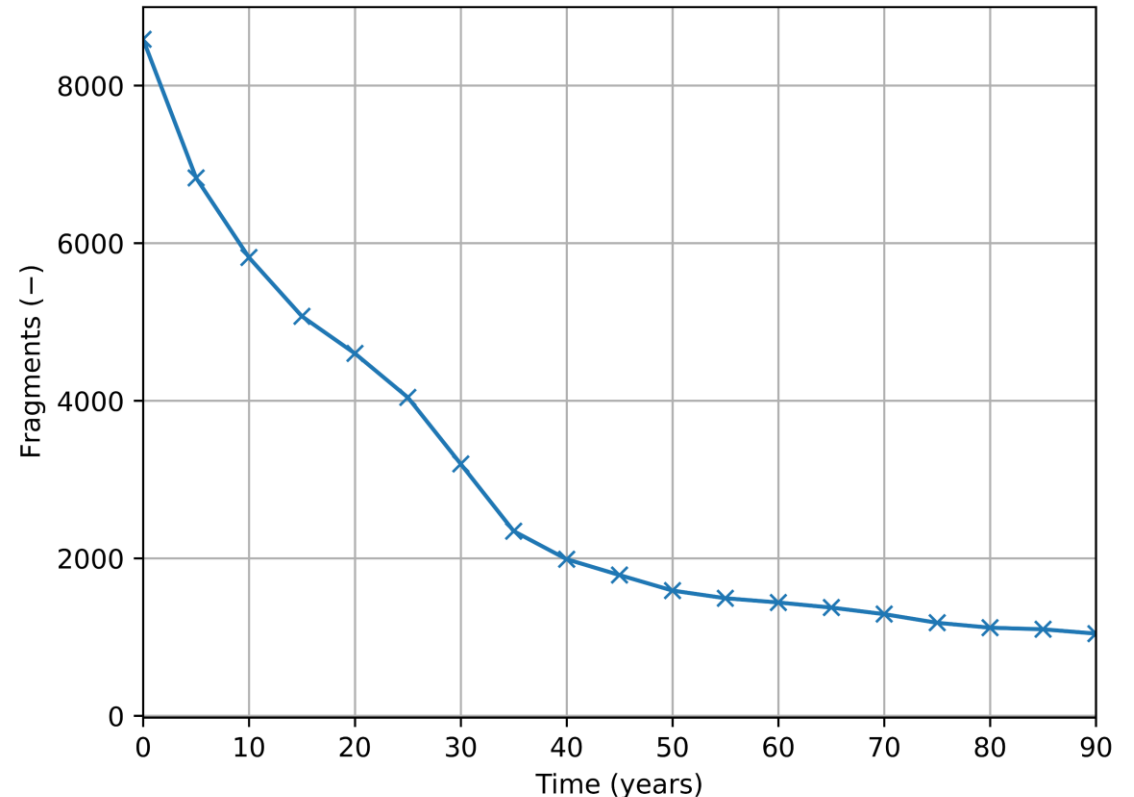


Cosmos 1408

- Size of initial set: 1588 (including parent and generated fragments)
- Reference date of initial TLE set: 1 December 2021
- Identification of event epoch (**minimum distance** between the objects set at **25 km**)
 - Estimate: 15 November 2021, 02:47:59
 - Margin: ± 0.417 min
- Identified 1 orbital family in the estimated interval (Explosion)
- Identification of involved objects
 - 24 objects
 - Parent ID: 13552 (Cosmos 1408)

- Computational time*: ~ 8.4 min

Number of fragments over time [1 cm - 1 m]



➤ SpaceTrack, www.space-track.org

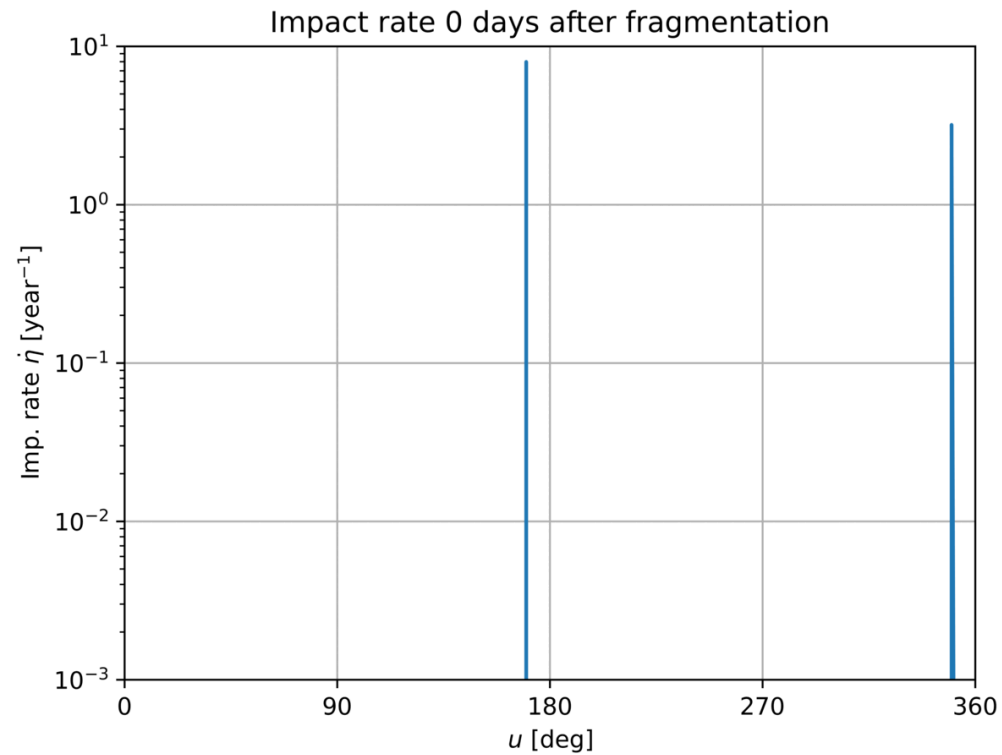
*Intel(R) Core(TM) i7/7700 CPU @ 3.60GHz

Application

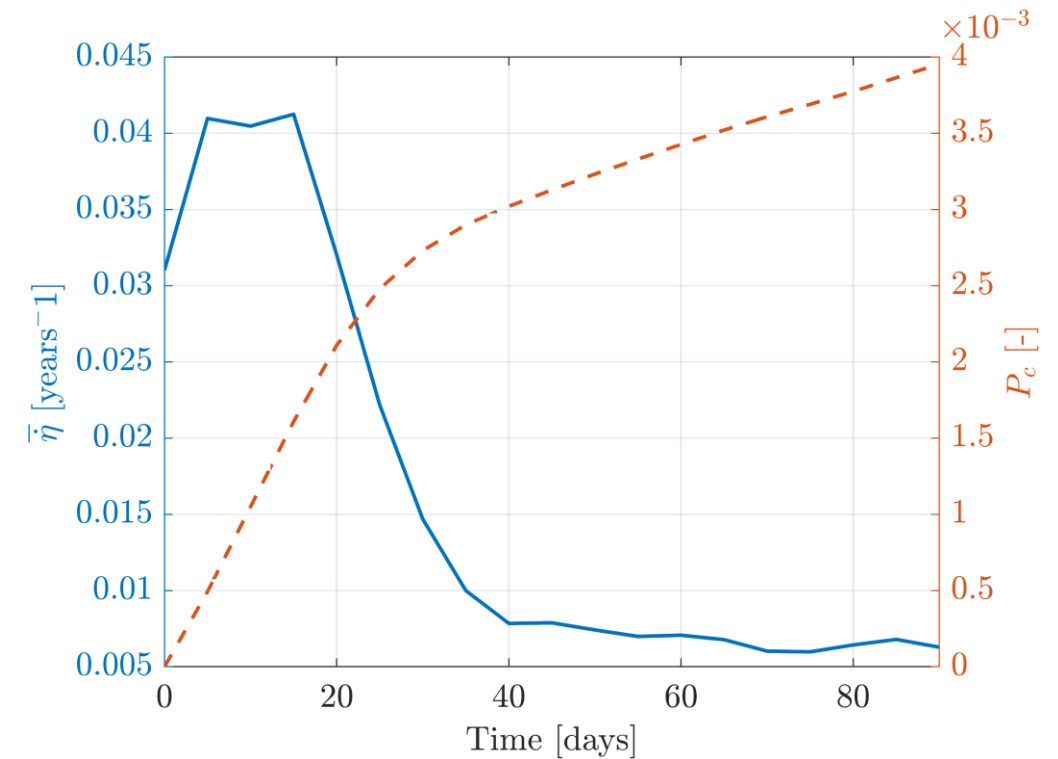
Cosmos 1408

Target:

- International Space Station
- Cross section: 5762.4 m^2
- Time interval: 3 months



Mean impact rate and cumulative collision probability over time



- Identification fragmentation as early as possible
- Modelling the fragmentation event detected
- Performs analysis of effects on orbiting objects

- Future works
 - Including uncertainties in the PUZZLE simulations
 - Improve connection between PUZZLE and Starling
 - Add feedback effect (trigger new fragmentations according to Pc)
 - Further analysis on different targets



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