In orbit fragmentation reconstruction and collision risk estimation.

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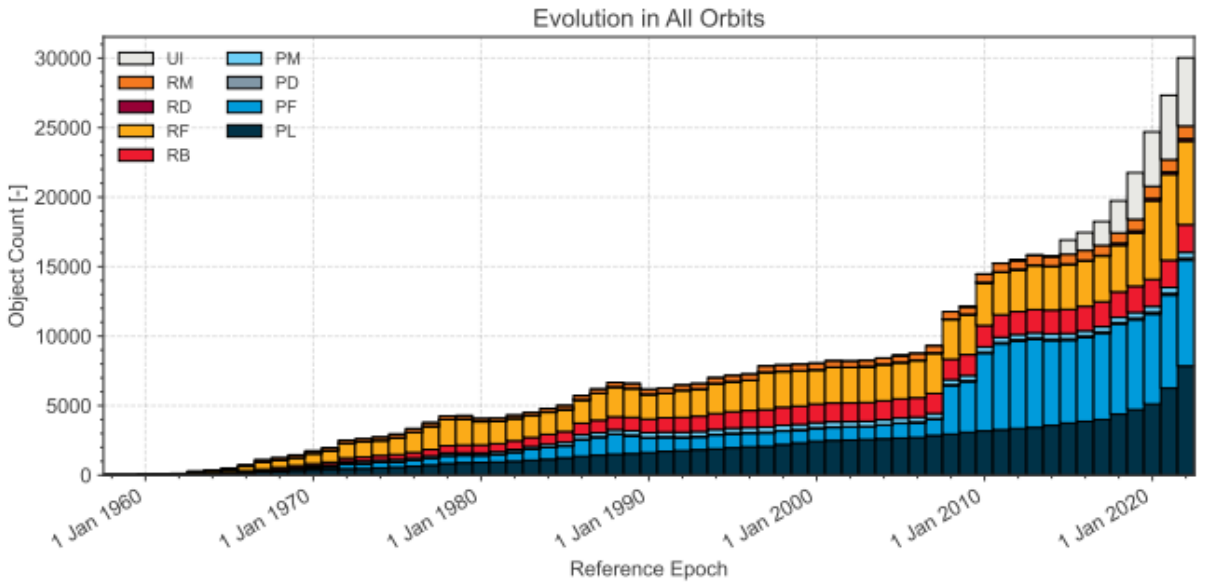
6 September 2022

Background

- Increasing number of objects around the Earth
  - Several new launches
  - Several breakup events every year
  - New fragments detected by SST
- Needs to
  - Properly track the objects
  - Investigate the origin of newfound fragments
  - Perform collision risk estimations



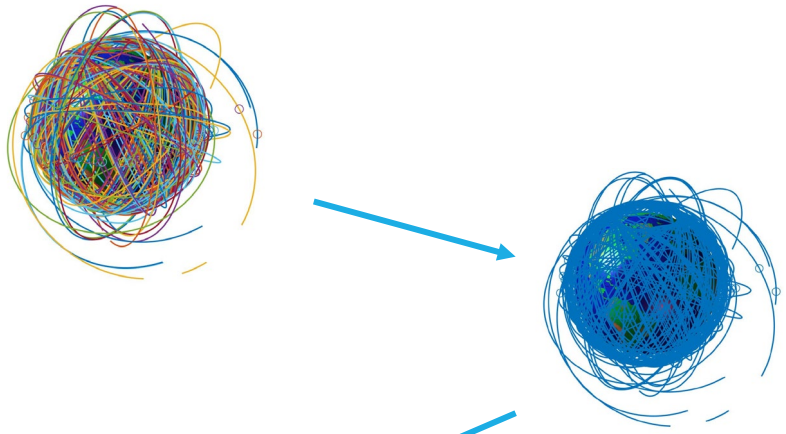
Evolution of the number of objects

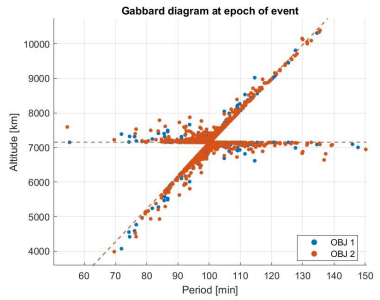
➢ **ESA, "ESA'S ANNUAL SPACE ENVIRONMENT REPORT", 2022**

Fragmentation detection

PUZZLE

- Initially developed for ASI to support SST services
- Objectives:
  - **Detection** of fragmentations
  - **Characterisation** of masses and energy
- Main features:
  - No assumption of breakup
  - Using **comparison metrics** and **convergence analysis**
  - **Osculating** or **mean** orbital elements
- Functionalities:
  - **Short-term** (days) investigation
    - **Uncertainty** propagation (using a GMM approach)
  - **long-term** (months up to years) investigation





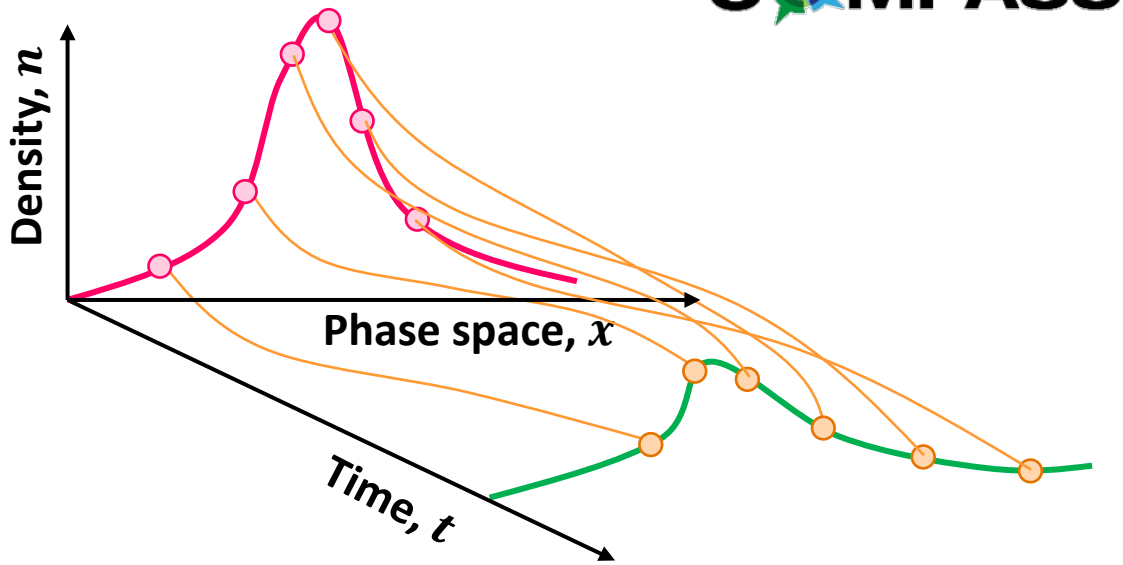
- European Commission Framework Pro-gramme H2020 "SST Space Surveillance and Tracking" con-tracts N. 785257 (2-3SST2016).

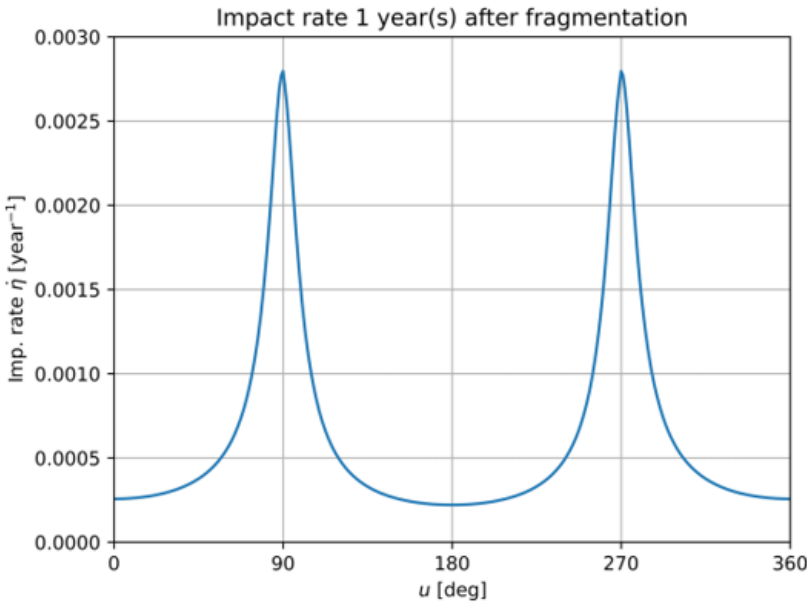
- A. Muciaccia, M. Romano, C. Colombo, "Detection and characterisation of in-orbit fragmentations over short and long periods of time", 72nd IAC, Dubai, United Arab Emirates, 25-29 October 2021

Collision risk

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





- European Space Agency contract 4000133981/21/D/KS
- L. Giudici, M. Trisolini and C. Colombo, "Phase space description of the debris' cloud dynamics through continuum approach," in 73rd International Astronautical Congress, Paris, France, 2022.

Test case

Definition

Fragmentation detection

- General:
  - Collision: Iridium 33 – Cosmos 2251
  - Date of the event: 10 February 2009
  - Size of initial set: 1500 TLEs (including parent(s) and generated fragments - 22 objects)
  - Reference date of initial TLE set: 18 February 2009
- Objective:
  - Identification of the event (epoch, involved objects, etc.)

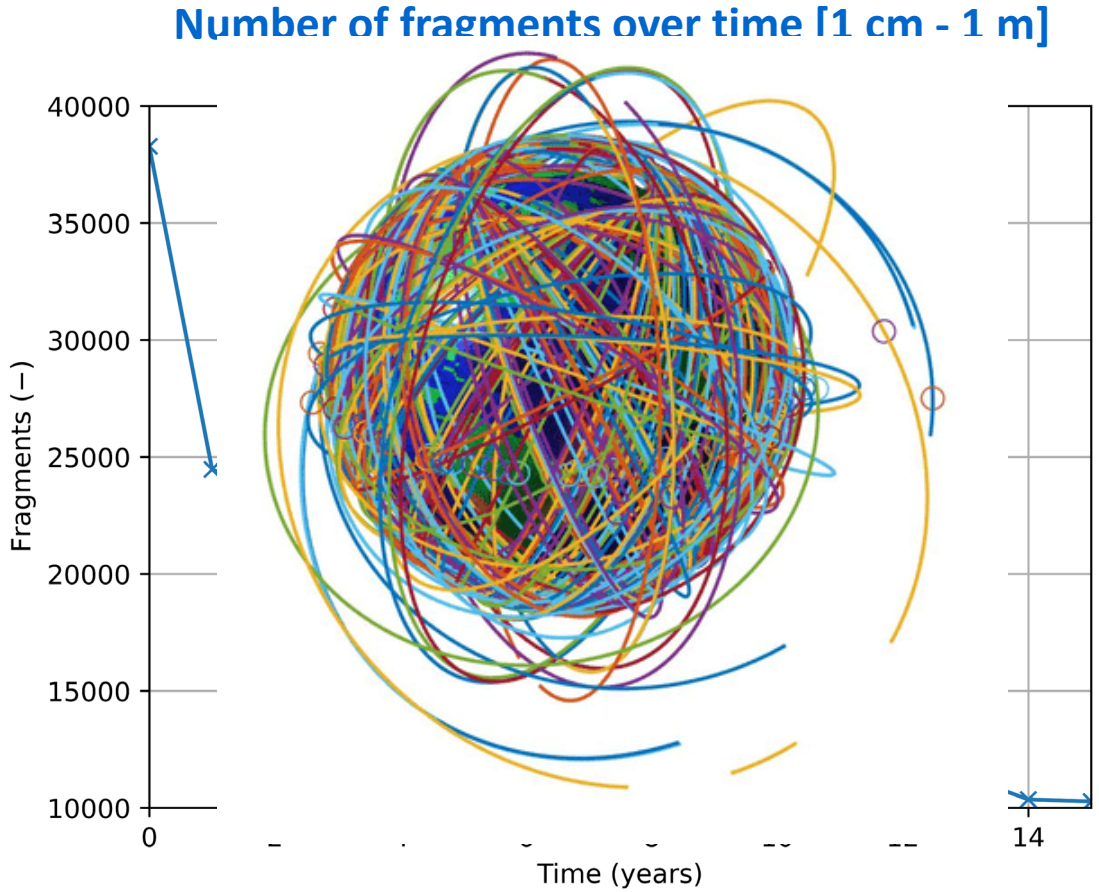
Collision risk analysis

- General:
  - Event characteristics (e.g., location): from PUZZLE
  - Timespan of the analysis: 15 years
  - Targets: 175 active objects (2009)
- Objective:
  - Collision risk analysis on targets

Test case

Fragmentation detection

- Event epoch (**minimum distance** between the objects set at **5 km**):
  - Estimate: 10 February 2009, 16:55:40
  - Margin: ± 0.417 min
- Families of objects in the estimated interval:
  - 2 orbital families (Collision)
- Objects associated to the event:
  - 22 objects
  - Parent ID: 22675 (Cosmos 2251), 24946 (Iridium 33)
- Computational time*: ~ 9 min



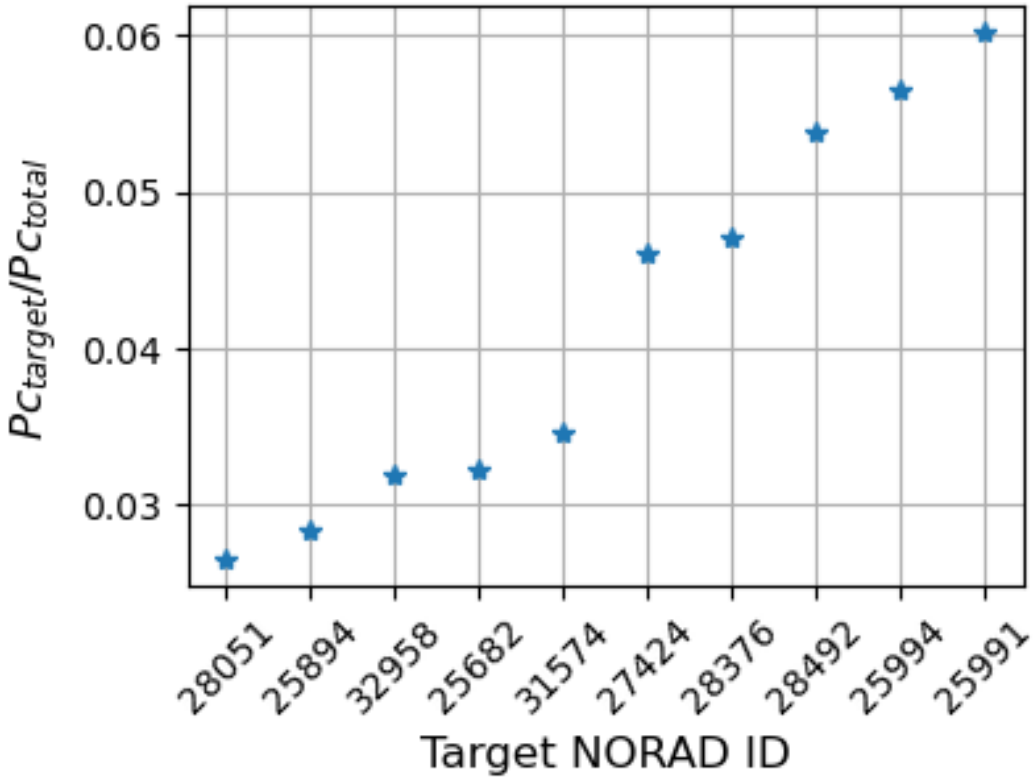
➢ SpaceTrack

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

Test case

Collision risk analysis

- Fragments cloud generation and propagation
- Estimation of the cumulative collision probability between the fragments generated by the breakup and the targets
- Selection of the 10 most at-risk objects

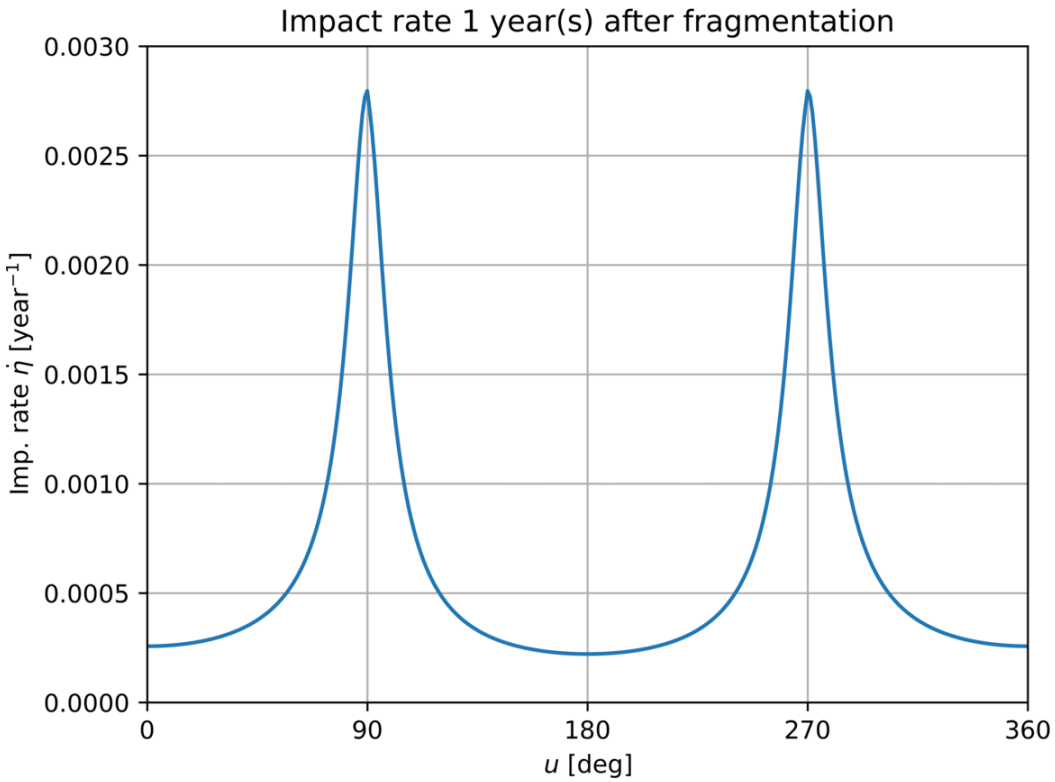


Pc_{target} = *cumulative collision probability associated to a single target*
Pc_{total} = *cumulative collision probability associated to the entire set of targets*

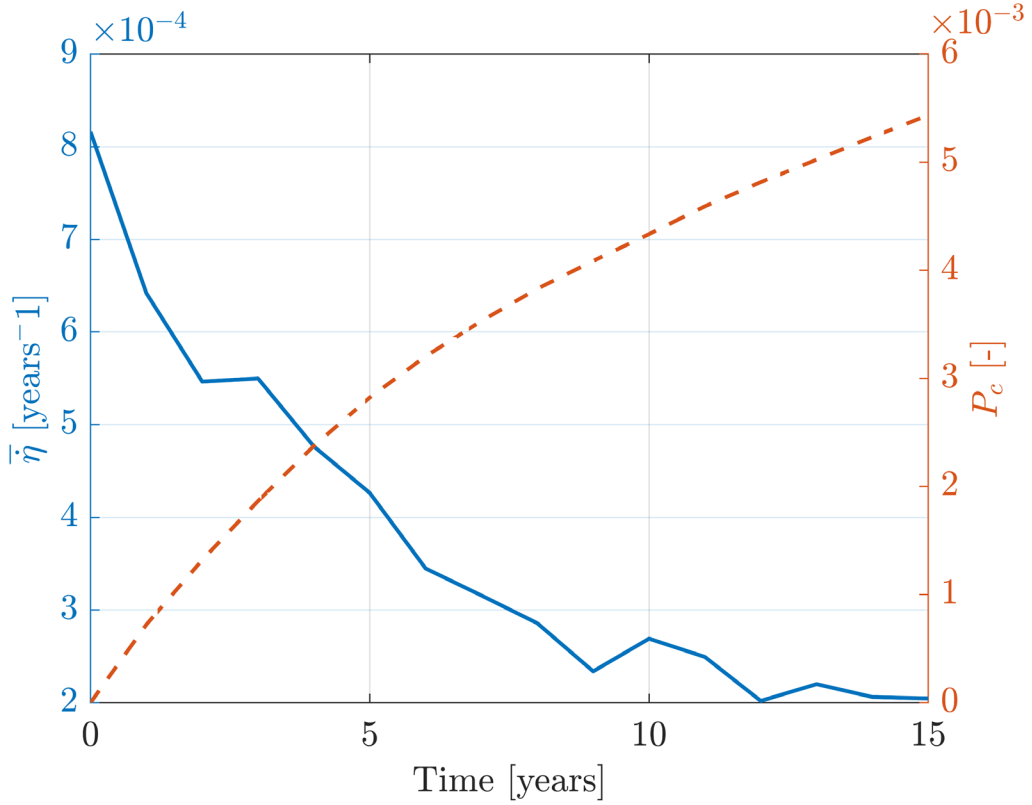
Test case

Collision risk analysis

Target: DMSP 5D-3 F-15 (cross section: 28.16 m^2)



Impact rate over time between the generated fragments and the target



Mean impact rate and cumulative collision probability over time

Conclusions

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

The research activities described in this presentation were performed within European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 679086 – COMPASS).

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