# FRAGMENTATION EVENT MODEL AND ASSESSMENT TOOL (FREMAT) SUPPORTING ON-ORBIT FRAGMENTATION ANALYSIS

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## *FREMAT*

- The Fragmentation Event Model and Assessment Tool (FREMAT) project for ESA was carried out with the objectives of:
  - simulating on-orbit fragmentations
  - assessing their impact on the space population
  - evaluating the capability of identification of fragmentation events from existing surveillance networks.
- In the frame of the FREMAT activity, the implementation of several algorithms related to on-orbit fragmentation events was carried out.
- FREMAT encompasses three individual tools:
  - Fragmentation Event Generator (FREG)
  - Impact of Fragmentation Events on Spatial density Tool (IFEST)
  - Simulation of On-Orbit Fragmentation Tool (SOFT)

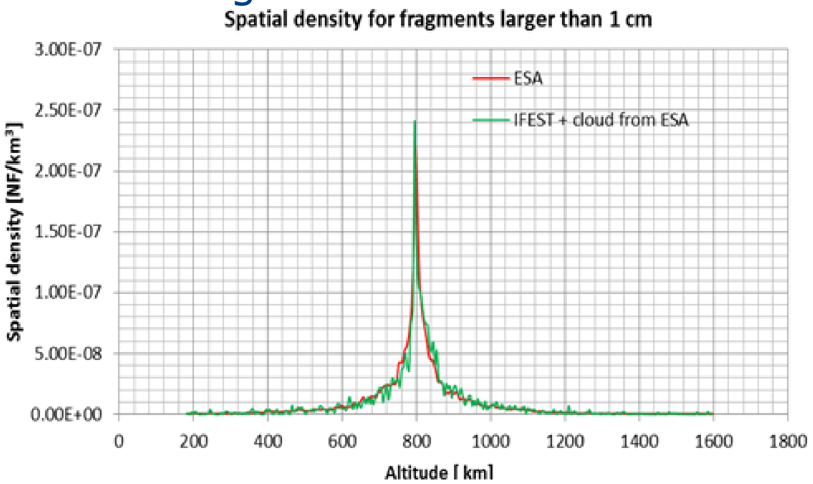
# 2. DESCRIPTION OF THE TOOLS

## *2.1 Fragmentation Event Generator (FREG)*

- FREG has been conceived to simulate fragmentation events (explosion and collisions)
- MASTER 2009 NASA Breakup Model was employed as the baseline model for this tool
- The baseline model was enhanced in order to ensure the consistency of mass and momentum in the created fragment clouds.
- The user must specify the following inputs for the tool:
  - Type of event (explosion/collision)
  - Type of object (spacecraft/ rocket body)
  - Mass of the parent(s) object(s)
  - State vector(s) of the parent object(s) at event epoch
  - Scaling factor (for explosion)
  - FREG also requires a discretization as input for the computation of representative fragments
- Its output is one or two clouds of fragments (original or representative) that can later be fed into IFEST or SOFT, or to any other propagator.

## 2.2 *Impact of Fragmentation Events on Spatial density Tool (IFEST)*

- IFEST (Impact of Fragmentation Events on Spatial density Tool) allows the evaluation of the impact of on-orbit fragmentations in the space debris population.
- It employs a fast semianalytic propagator (DSST from Orekit library) for computing the long-term evolution of the clouds of fragments (up to hundreds of years) obtained from FREG
- Computes the 3D spatial density of the fragments (as a function of altitude and/or longitude and time)
- Allows defining discretizations for altitude and longitude
- Computes the percent increase in the background spatial density obtained from MASTER
- The computation of the spatial density within this tool is validated against results provided by ESA's POEM tool.



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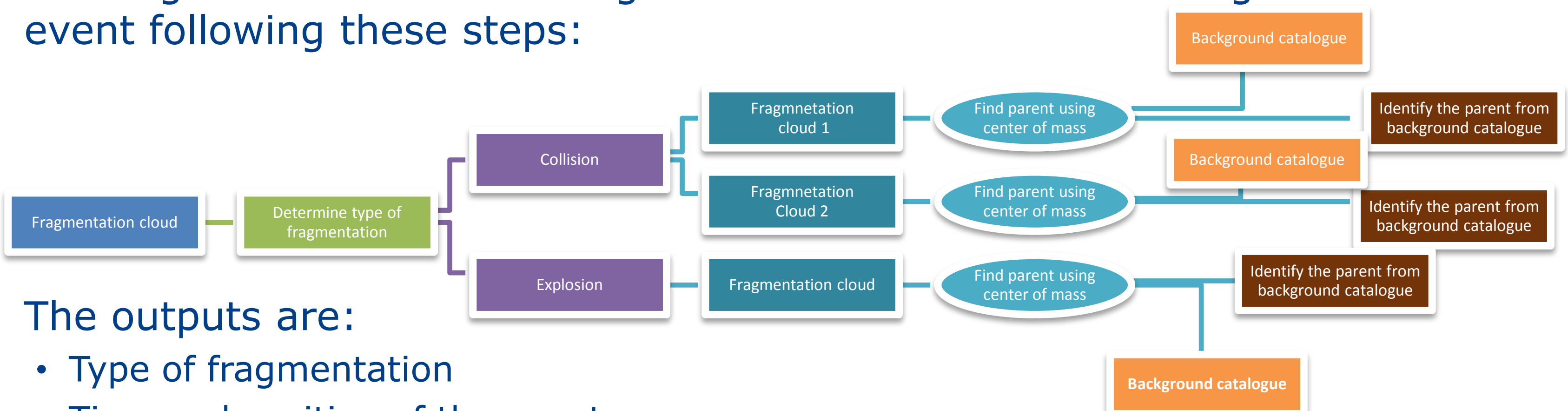
## *2.3 Simulation of On-Orbit Fragmentation Tool (SOFT)*

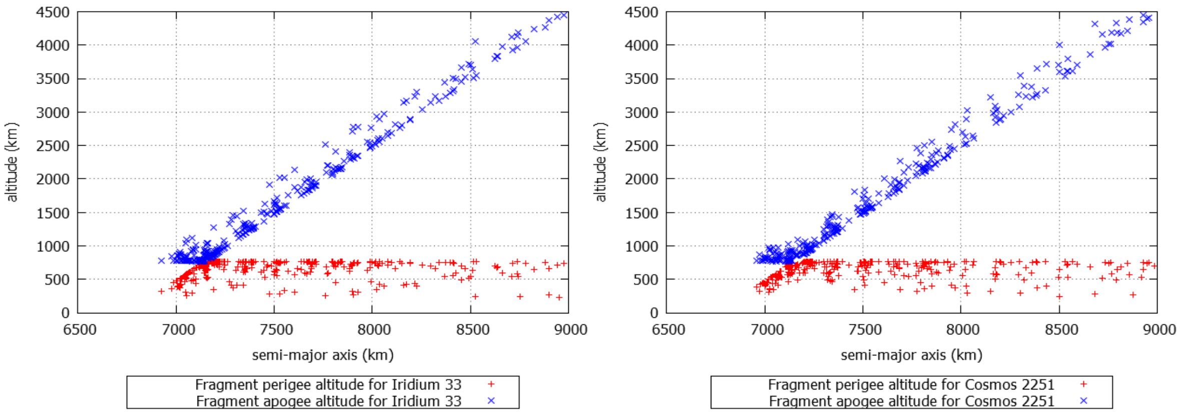
- SOFT simulates the identification of a fragmentation event when a space surveillance network detects a number of unexpected new objects and a fragmentation event is considered a possible cause.
- Uncertainties in the knowledge of the orbits of the fragments and the presence of foreign objects is also considered.
- Starting from a cloud with fragments the tool identifies a fragmentation event following these steps:



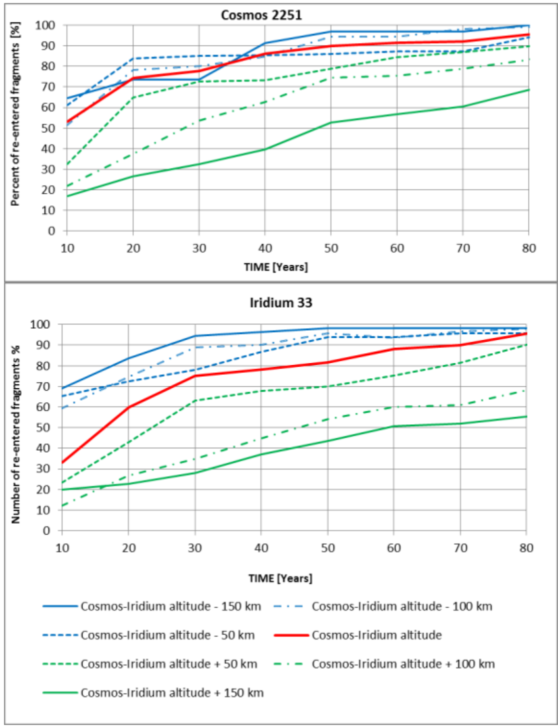

- The outputs are:
  - Type of fragmentation
  - Time and position of the event
  - Objects involved in the event, selected from a background catalogue

## 3.1 Collision Cosmos 2251-Iridum 33

**Gabbard diagrams from FREG for collision at the event epoch, left plot corresponds to the Iridium 33 fragments, whereas right plot is associated to the Cosmos 2251 pieces**




**Percentage of re-entered objects for different altitudes of collision:**



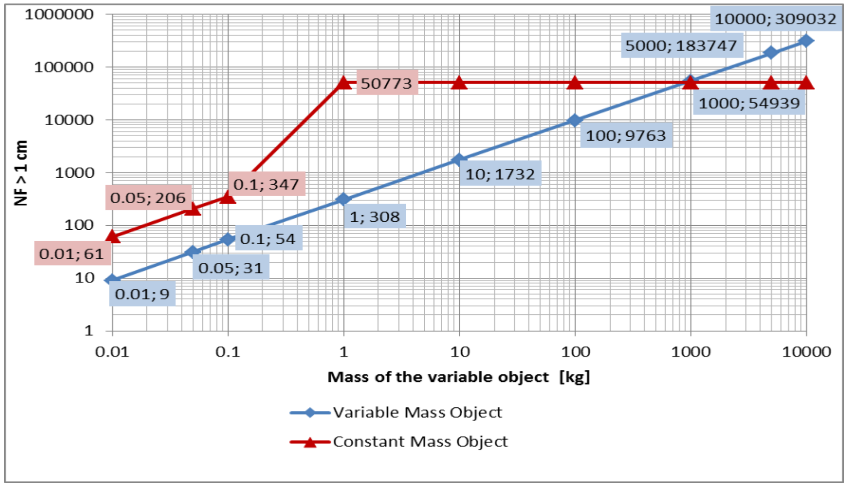

**Summary results from FREG:**

| Type of event | Num. of fragments > 1 cm | Num. of fragments > 10 cm | Num. of representative fragments |
|---|---|---|---|
| Iridium 33 | 35378 | 608 | 484 (>1cm) |
| Cosmos 2251 | 50773 | 876 | 876 (>1cm) |

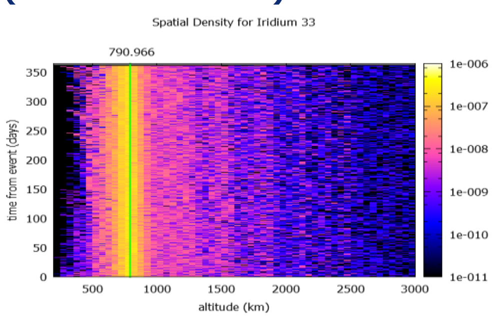
# 3. SIMULATION CASES

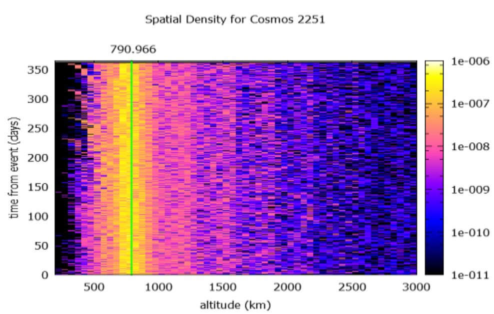
## 3.1 Collision Cosmos 2251-Iridum 33

**Number of objects obtained for each colliding object as a function of the mass of one of the parent objects:**



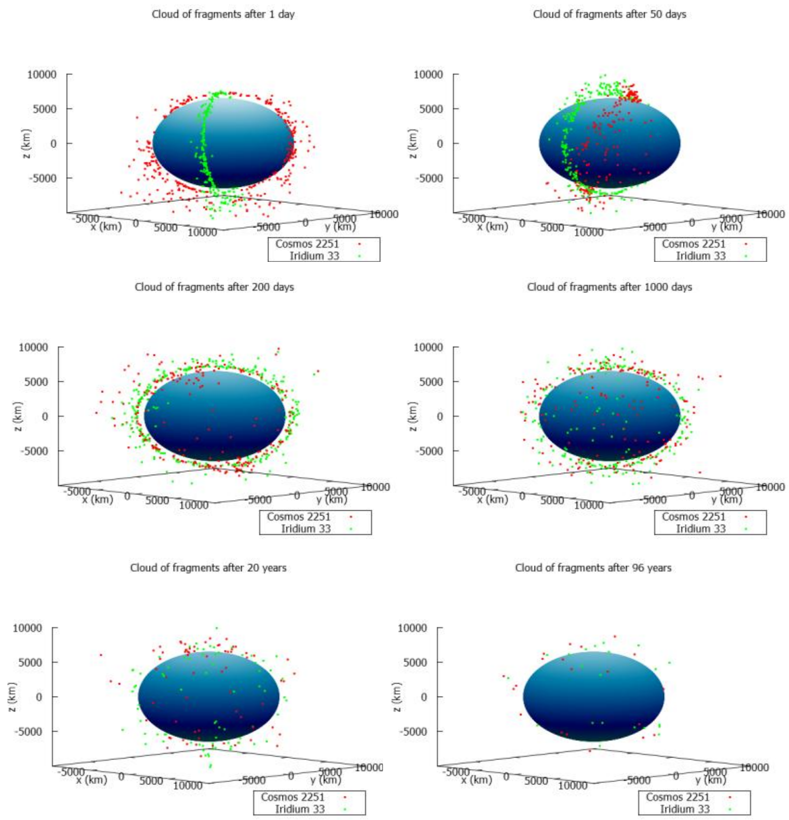

**Spatial density as a function of altitude over 1 year (Cosmos-Iridium):**




**Evolution of the fragmentation clouds from Cosmos 2251-Iridium 33 collision. From left to right and from top to bottom, the :**

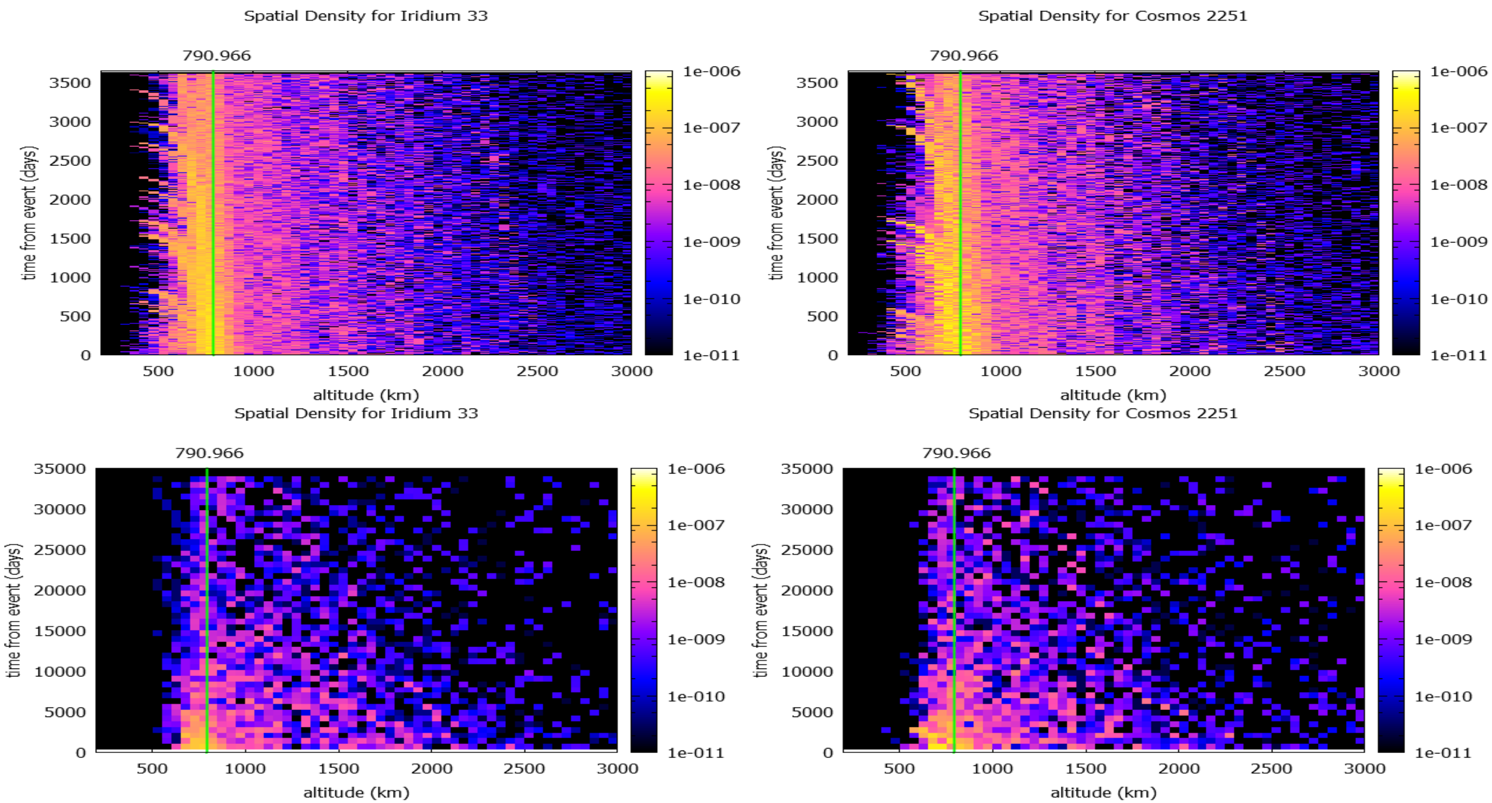
**1 day, 50 days, 200 days, 1000 days, 20 years and 96 years.**



# 3. SIMULATION CASES

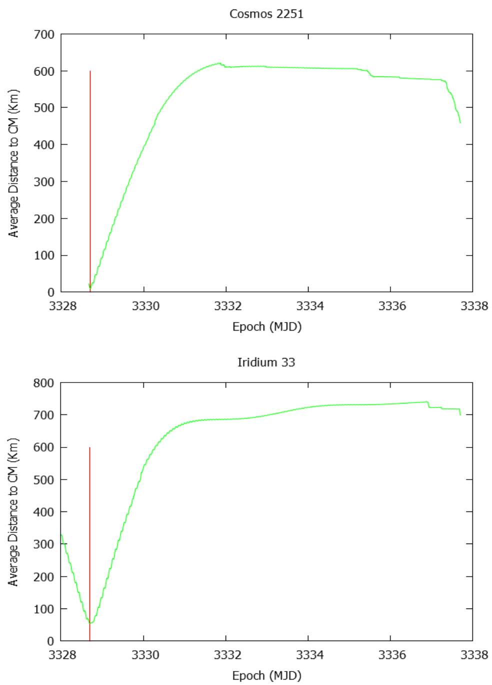
## *3.1 Collision Cosmos 2251-Iridum 33*

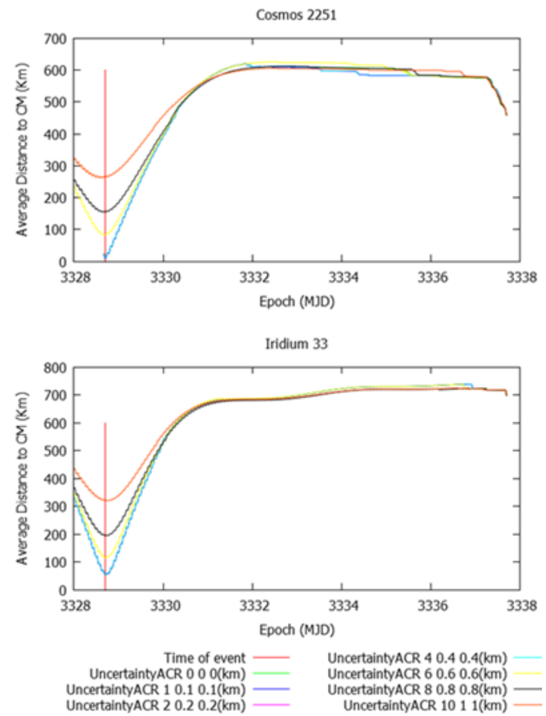
**Spatial density for Cosmos-Iridium as a function of altitude over 10 years (top) and over 100 years (bottom):**



## 3.1 Collision Cosmos 2251-Iridum 33

The identification of the fragmentation event was simulated with SOFT using as input a catalogue with fragments from TLE data of 19 February 2009. According to SOFT the fragmentation happened on 2009-02-10 at 16:55:40.038 and the parents were correctly identified from the background catalogue.



# 3. SIMULATION CASES

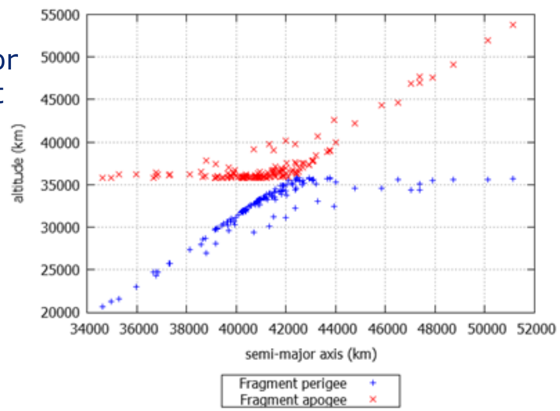
## 3.2 Explosion of Breeze-M R/B

On 20 January 2016, at approximately 1900 UTC, the JSpOC (Joint Space Operations Center) identified a possible breakup of a Breeze-M R/B (NORAD id 41122) in GEO.

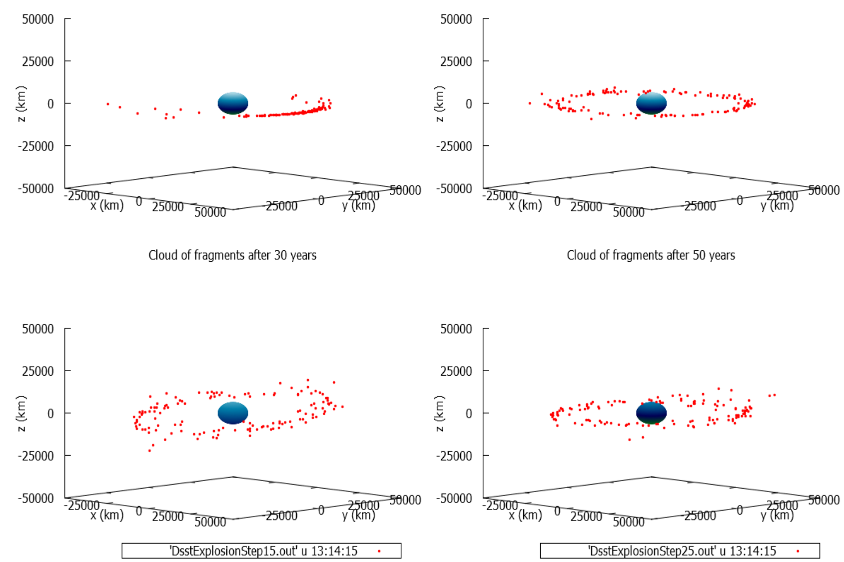
- ❑ Summary results from FREG:

| Type of event | Num. of fragments > 1 cm | Num. of fragments > 10 cm | Num. of representative fragments |
|---|---|---|---|
| Breeze-M R/B | 11056 | 248 | 136 (> 10 cm) and 595 (>1 cm) |

- ❑ Gabbard diagrams for collision at the event epoch

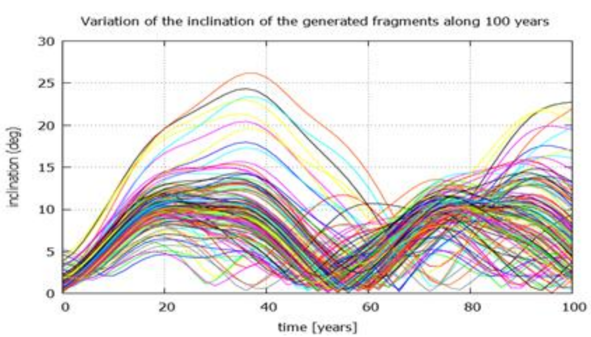



Evolution of the fragmentation clouds from Breeze-M R/B explosion. From left to right and from top to bottom, after : 1 day, 10 days, 30 years, 50 years.



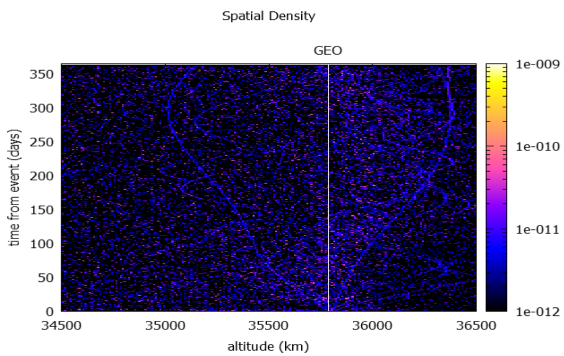

- ❑ Variation of inclination for the fragments obtained from the explosion :

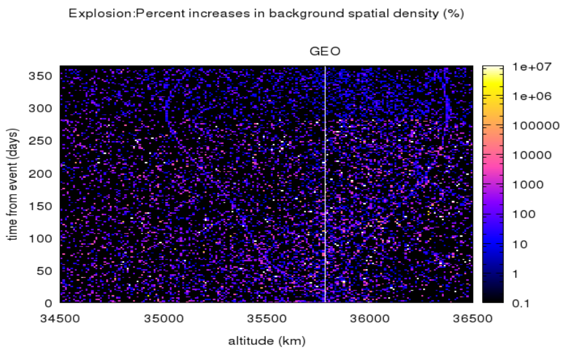
- typical secular trend is produced by third-body perturbations: variation of inclination up to ±15 with a period of dozens of years.



## 3.2 Explosion of Breeze-M R/B

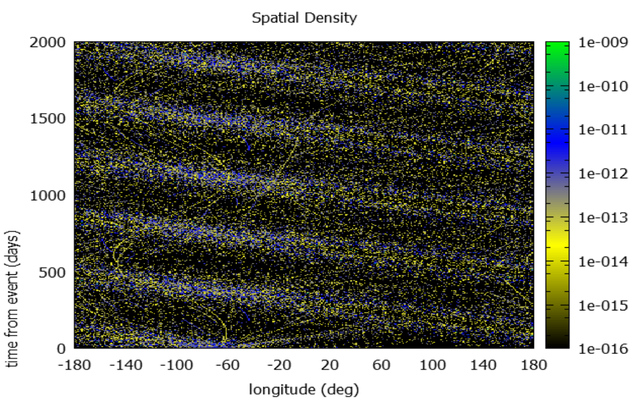
Spatial density and percent increases in background spatial density in the proximity of GEO altitude for Breeze-M R/B:



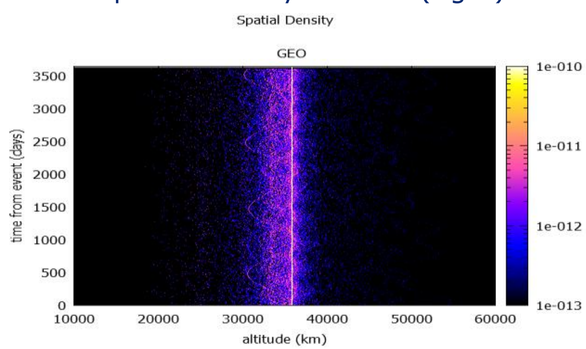



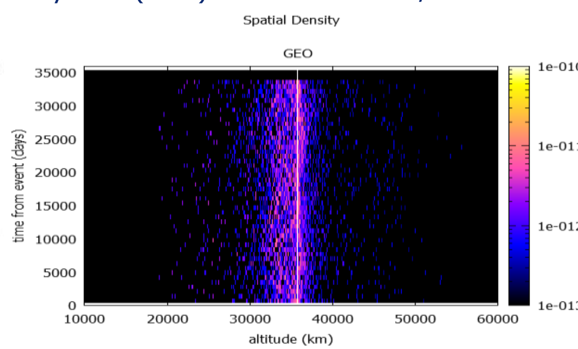

Spatial density as a function of longitude over 2000 days

- libration effect visible: part of the fragments that are oscillating around the stable point located at -105° .



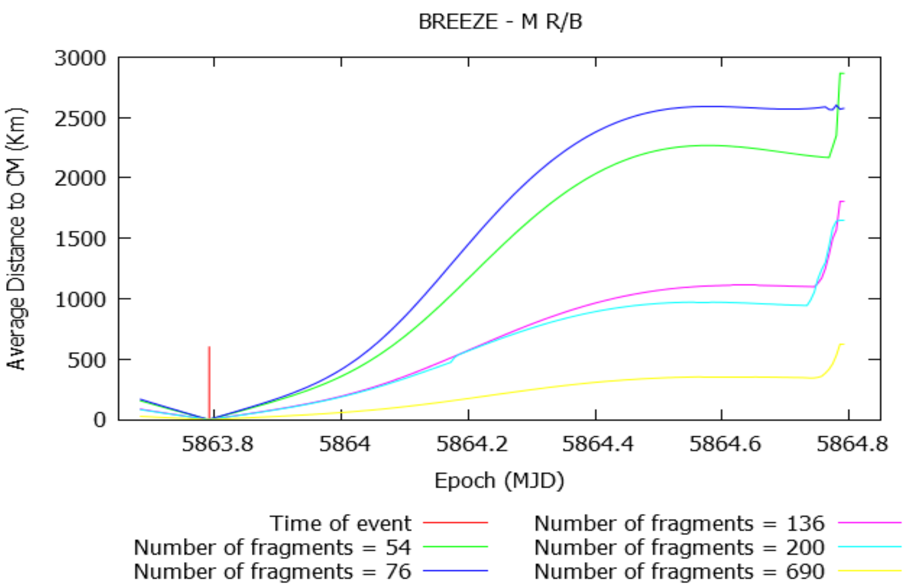

Spatial Density over 10 (right) and 100 years ( left) for Breeze-M R/B:

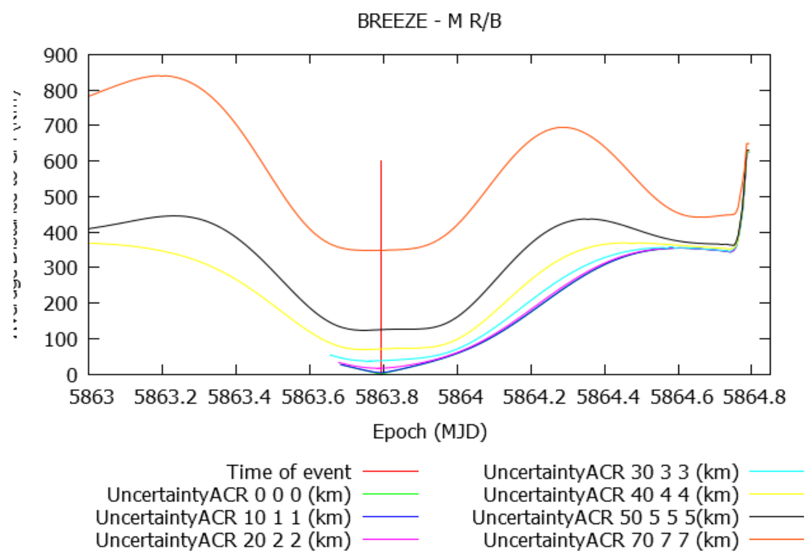


## 3.2 Explosion of Breeze-M R/B

The situations when the fragmentation clouds are incomplete (not all objects created in an event are detected) and inaccurate (the orbits of the fragments are known with a certain error) lead to considerable errors in the identification of the fragmentation event.



# 3. CONCLUSIONS

- The tools presented support the study of fragmentation events, either by simulating them or by using real orbital data obtained from a sensors network and also from TLE information.
- It is possible to study the long term effect of these events by means of the resulting spatial density, allowing comparison with the ESA MASTER tool.
- It is also possible to attempt to locate the position and orbit of the object(s) involved in the event in spite of having not complete clouds and poor accuracy.
- These tools can be used independently (in order to support studies such as the examples presented in this paper), or as part of a longer processing toolchain

# Thank you

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