

Space Debris Characterization Through Multiband Photometry

Alfredo Biagini (presenter)

INAF- Osservatorio Astronomico di Palermo (OAPA)

G. Micela (OAPA),

M. Guarcello (OAPA),

A. Petralia (OAPA),

Alessandro Nastasi (Fondazione GAL Hassin)

Space capacity allocation for the sustainability of space
activities Workshop Politecnico di Milano, 3-5 June 2026

◆ INAF

ISTITUTO NAZIONALE
DI ASTROFISICA
NATIONAL INSTITUTE
FOR ASTROPHYSICS



Our Scientific Goal:

Characterization of a sample of artificial objects through optical observations using observation campaigns with the GAL Hassin telescopes in the Madonie Mountains (Sicily):

- Multi-band observations and lightcurves**
- Diversification of the sample's physical parameters**
- Repeated observations of a selected subsample of targets.**

GAL Hassin Observatory



Attività svolte fra
Luglio 2023 a Giugno 2026



INSTRUMENTS

GRT telescope:

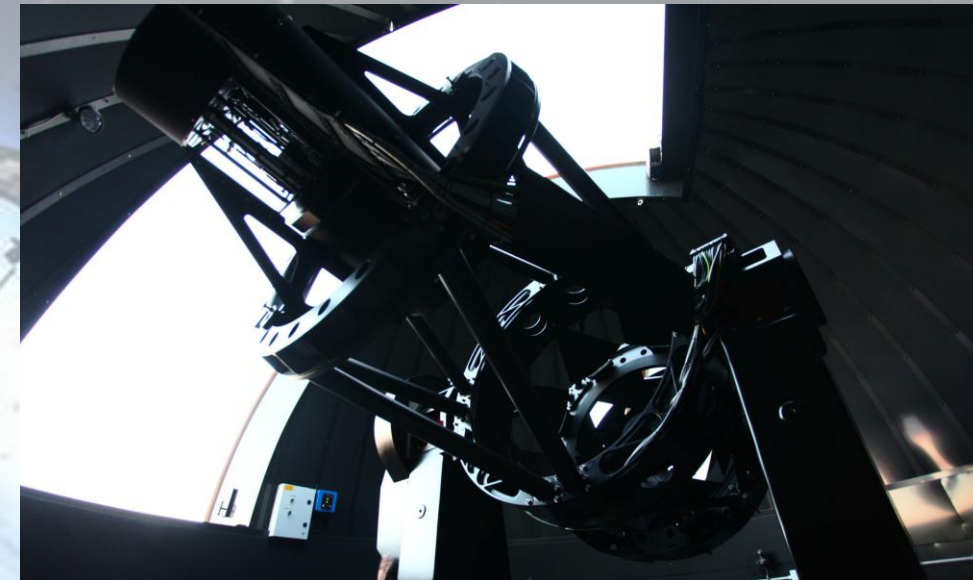
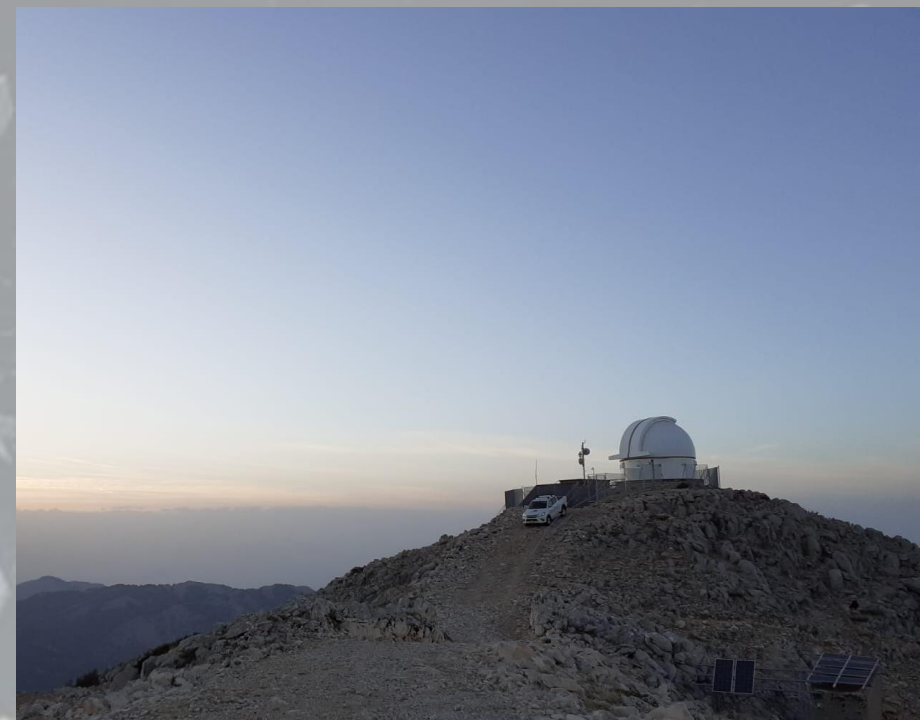
- diameter: 40 cm
- f/3.8
- location: GAL Hassin (Isnello-PA)
- FoV 80' x 80'
- Sloan Filters u, g, r, i, z_s2



INSTRUMENTS

WMT telescope:

- Diameter: 1 m
- f/2.1
- location: Monte Mufara (1865 m)
- FoV 150' x 150' corrected
- Sloan & Johnson Filters + Clear



Falcon 9 R/B

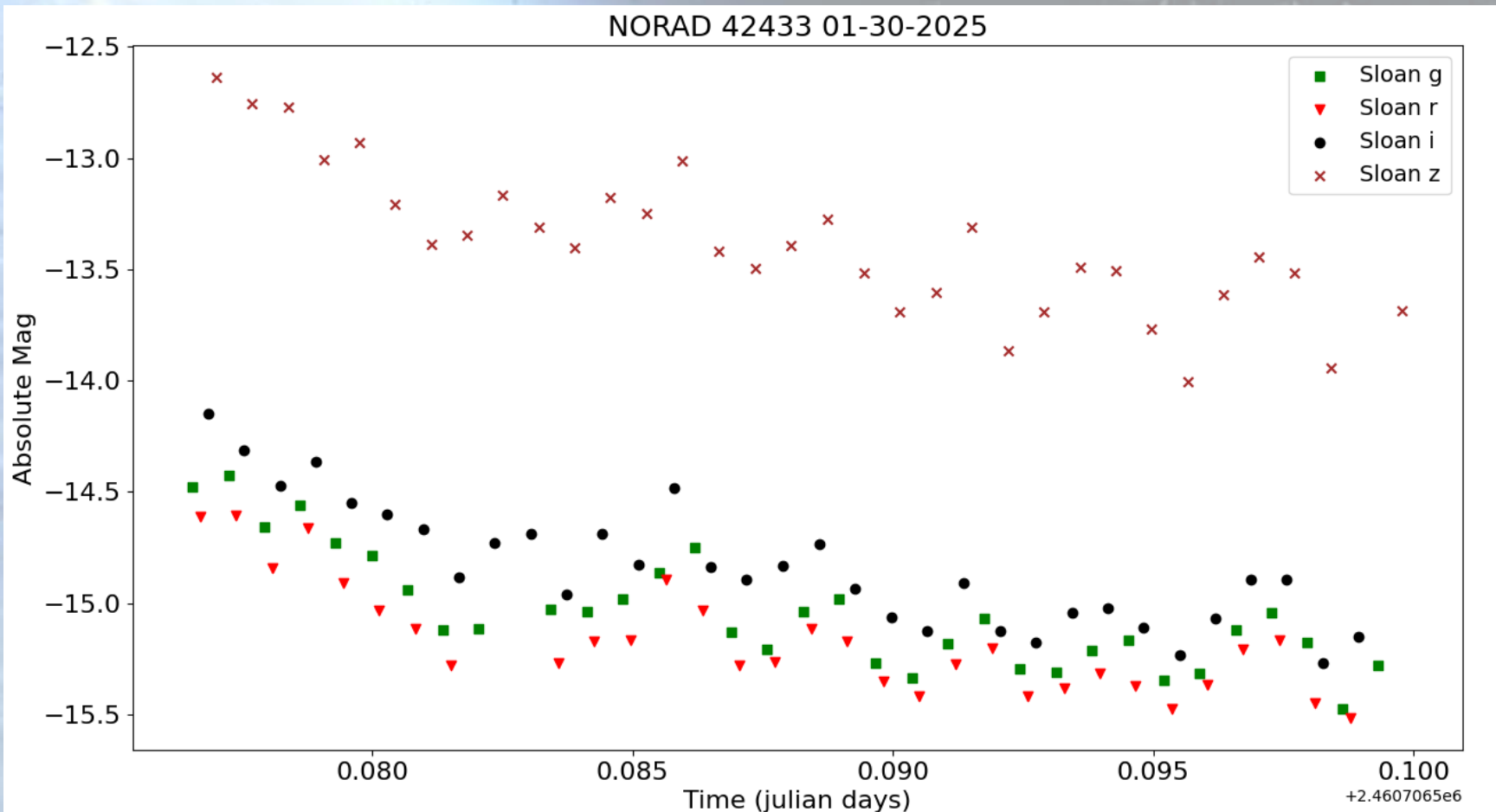
We conducted multiband observations of a selected list of Falcon 9 R/B as test observations.

Analysis and interpretation are ongoing.

GOAL: Modelling of known objects (materials and surfaces) to test the pipeline



Falcon 9 R/B



Examples of Falcon 9 multiband photometry: Multiband photometry of Falcon 9 R/B 42433, as observed on January 30, 2025 – GRT.

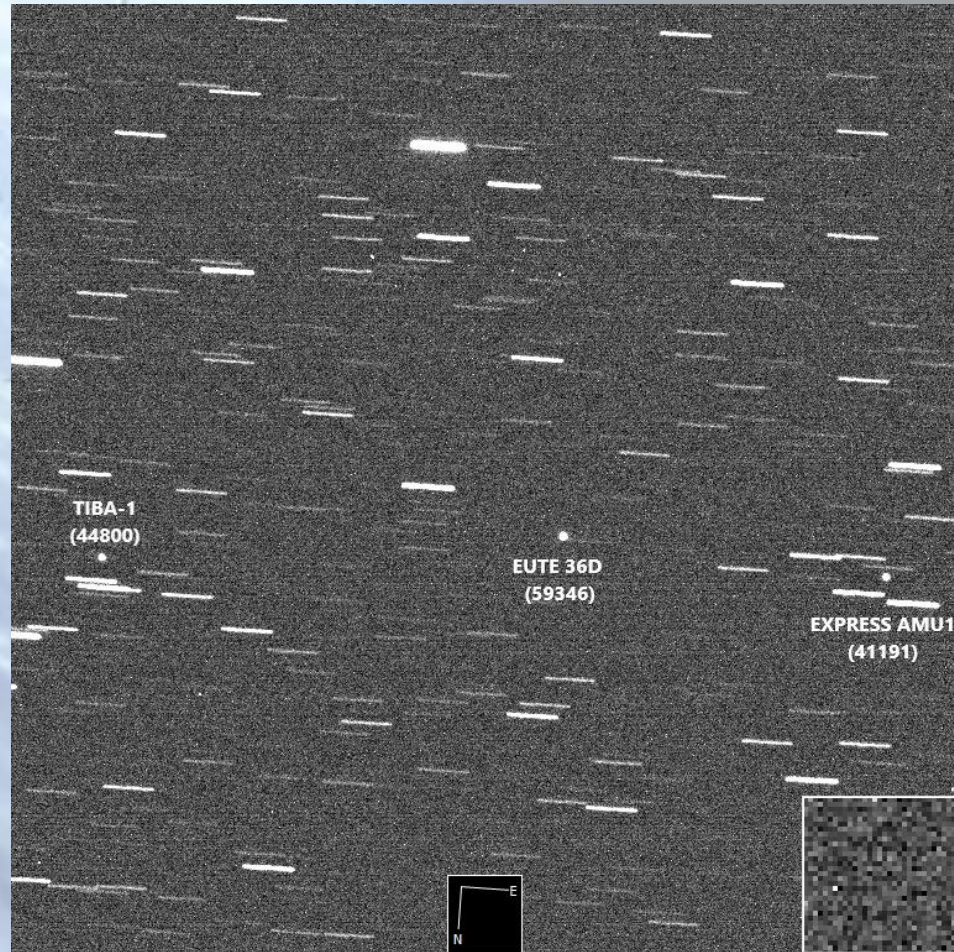
Signal modulation due to the rotation of the object.

GEO SATELLITES

We conducted multiband observations of a sample of GEO satellites for their photometric characterization under different angles of incidence of sunlight, to characterize various materials and reflective surfaces.

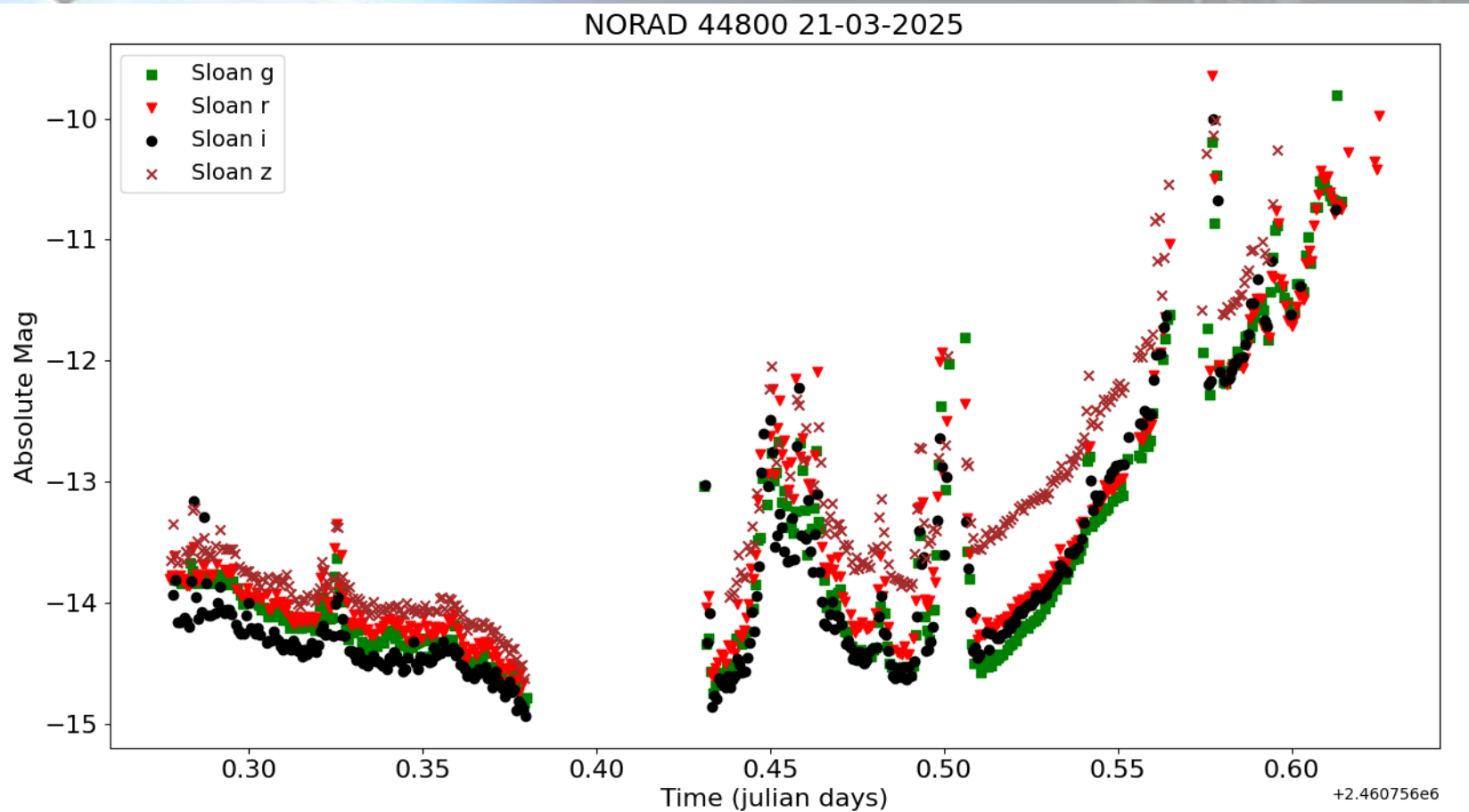
The observations took place in November 2024 and in January and March 2025 through the GRT.

GEO SATELLITES



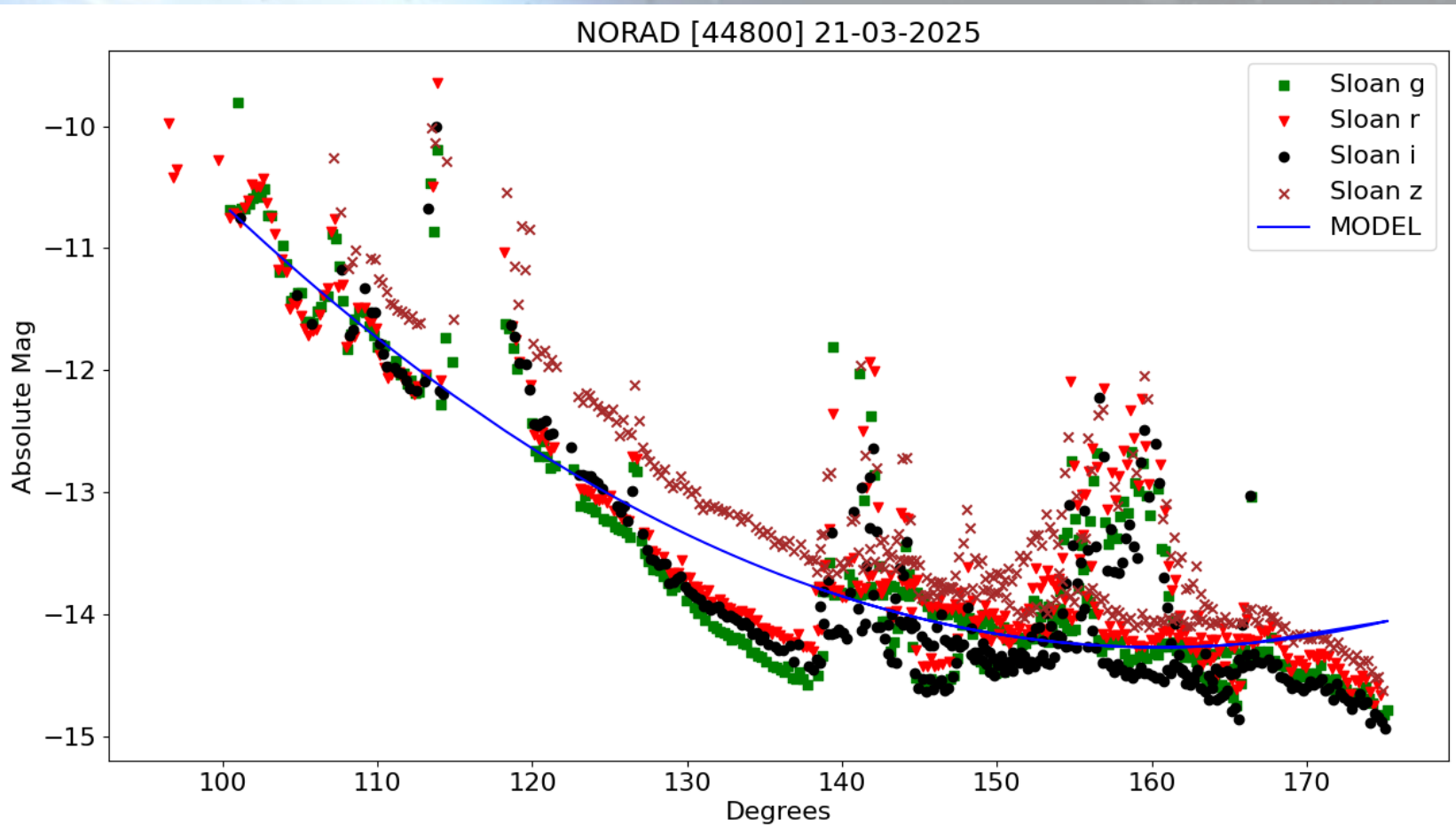
***GEO satellites observed in 03/19/2025
(GRT)***

GEO SATELLITES



*Multiband photometry of the
NORAD 44800 satellite
observed on 03/21/2025 in the
Sloan g-r-i-z band (GRT).*

GEO SATELLITES



Relationship between the angle of incidence of sunlight and the multiband magnitude of NORAD 44800 satellite observed on March 21, 2025, in the Sloan g-r-i-z band (GRT).

The parabolic model that best fits the data is shown in blue.

INTELSAT 33 E

INTELSAT 33 E was a communications satellite in geostationary orbit.

It fragmented on October 19, 2024, due to unknown causes.

Dimensions: (7.8 x 3.6 x 3.2) meters

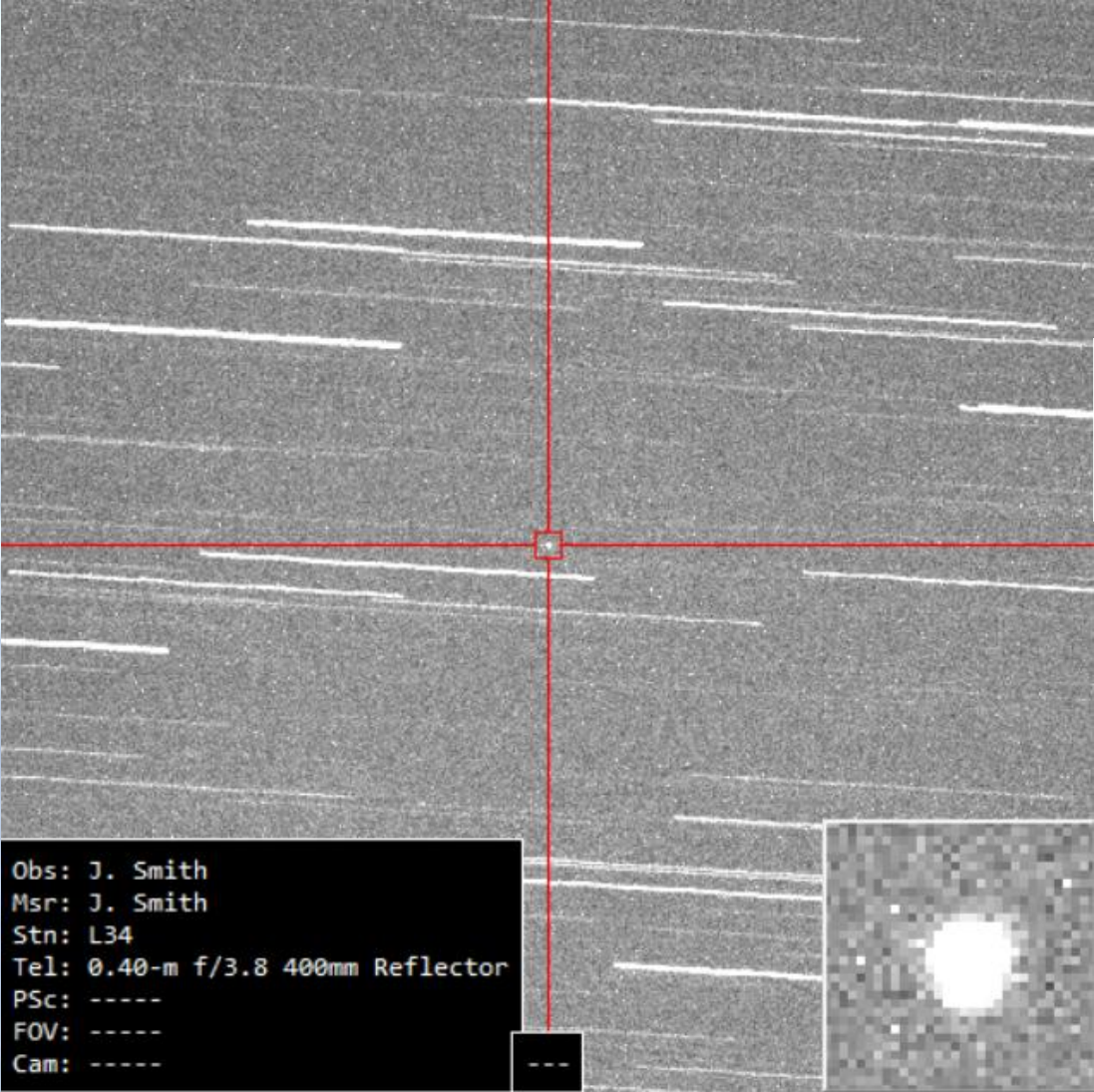


Intelsat 33 E Again

- Multiband photometric data analysis (main body and secondary debris).
- Debris identification was performed in two ways: plate solving and image binning over timescales of approximately 300 s.
- Determination of both the rotation period and the phase angle illumination (ongoing).

Final goal: characterization of debris surfaces, and measure of their velocities and rotation periods to reconstruct the physical parameters related to the fragmentation of the original satellite.

Intelsat 33 E Again



Intelsat33E debris observed by tracking the object in a luminance filter (GRT).

Analysis of fragments of INTELSAT 33 E

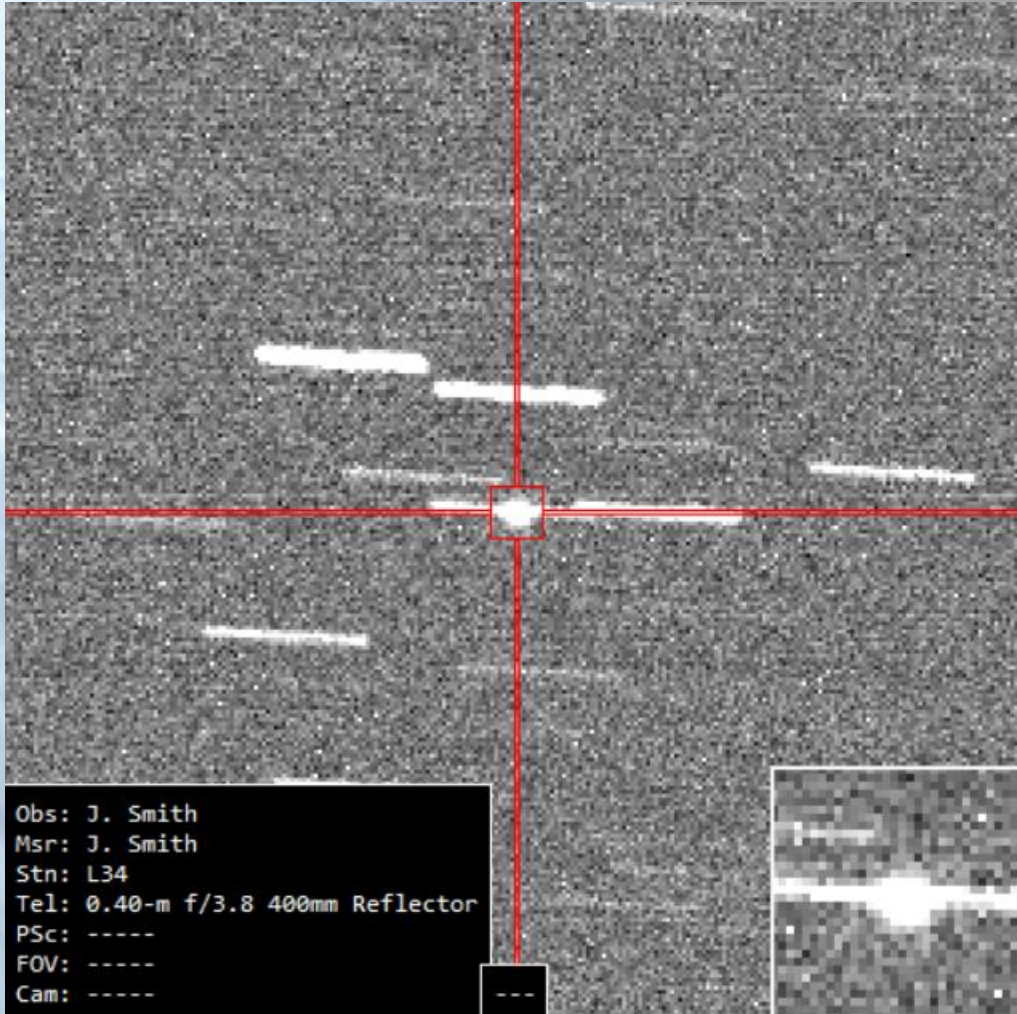
- Ongoing collaboration with the University of Padua to provide observations of the Intelsat 33 E debris.
- Comparison of our data analysis with fragmentation simulations developed by the team led by Dr. Lorenzo Olivieri and Nicolò Trabachin (CISAS-UNIPD) and presented at IAC 2025 in Sydney.
- Paper under review
- Another contribution to the article is to provide estimates of the debris size, its rotation period, and its brightness as a function of phase angle.

Analysis of fragments of INTELSAT 33 E

Table 5 Dimension rearranged estimates for the different observed NORAD objects at two albedo assumptions.

NORAD ID	Albedo 0.1 (m)	Albedo 1.0 (m)
41748	3.139 ± 0.010	1.729 ± 0.007
61991	0.196 ± 0.004	0.062 ± 0.001
61992	0.868 ± 0.195	0.253 ± 0.067
61993	0.192 ± 0.011	0.059 ± 0.003
61995	0.500 ± 0.100	0.160 ± 0.050
61996	1.048 ± 0.018	0.337 ± 0.004
61999	0.070 ± 0.020	0.021 ± 0.007
62000	0.070 ± 0.020	0.021 ± 0.007
62005	0.168 ± 0.016	0.055 ± 0.004

Automatic Stellar Contamination Removal



Enlargement of a typical debris/satellite image contaminated by the streaked image of a star. The image was correctly recognized and automatically discarded by our code.

Size Estimation

We have begun developing a code to estimate the size and (as a first approximation) the mass of the observed debris from multiband photometric data.

The code uses the instrumental magnitude measured on the camera, the object's position in the sky, its airmass, and its height above the ground to derive the energy reflected by the target and then, with realistic albedo assumptions, estimates its size.

Mass Estimation

Determining the dimensions

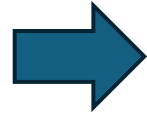
The next step will be to attempt to determine the object's mass from its dimensions, using realistic assumptions about geometry and materials, and then its kinetic energy, including rotational energy estimated based on its rotation period.

Tests are underway with known objects (Falcon 9).

Outlook:

Determination of debris properties

- Estimating the size, mass, orbit, and rotation period of the debris



Lower limit to the kinetic energy generated by fragmentation (Intelsat 33 E)

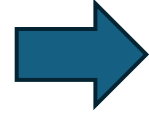


Comparison with the possible fragmentation scenarios hypothesized so far.

Outlook:

Determination of debris properties

- Estimating the size, mass, orbit, and rotation period of the debris

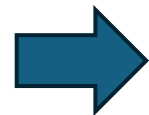


Lower limit to the kinetic energy generated by fragmentation (Intelsat 33 E)



Comparison with the possible fragmentation scenarios hypothesized so far.

- Same size for all observed bands



Albedo estimate in the various bands

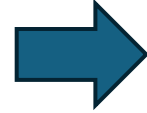


Materials recognition

Outlook:

Determination of debris properties

- Estimating the size, mass, orbit, and rotation period of the debris



Lower limit to the kinetic energy generated by fragmentation (Intelsat 33 E)



Comparison with the possible fragmentation scenarios hypothesized so far.

- Same size for all observed bands

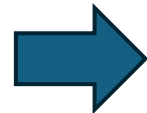


Albedo estimate in the various bands



Materials recognition

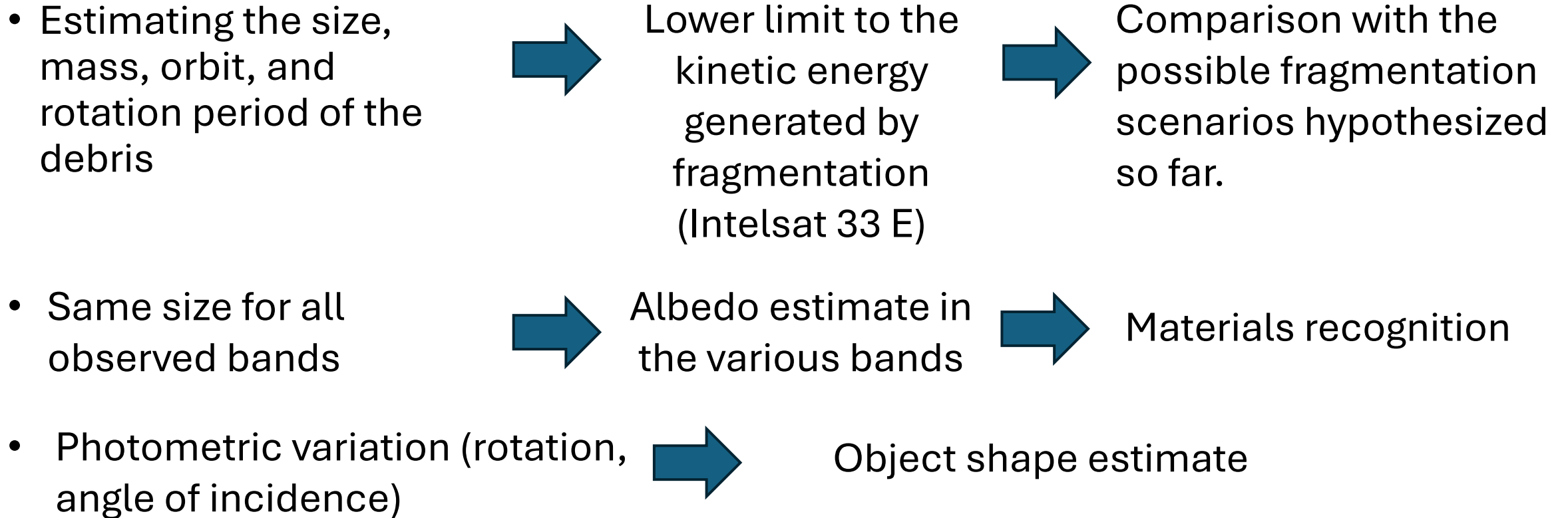
- Photometric variation (rotation, angle of incidence)



Object shape estimate

Outlook:

Determination of debris properties



FALCON 9 TESTS (KNOWN OBJECTS)

SHAPE RETRIEVAL:

MACHINE LEARNING

Hardware:

CPU (64 core), 512GB RAM, 2 GPU NVIDIA A30 24GB

Software:

- BLENDER for space debris modeling

Supervised machine learning trained on ~ 8 millions of lightcurves

BLENDER

BLENDER is a community project for 3D rendering and animation.

It can simulate the following features:

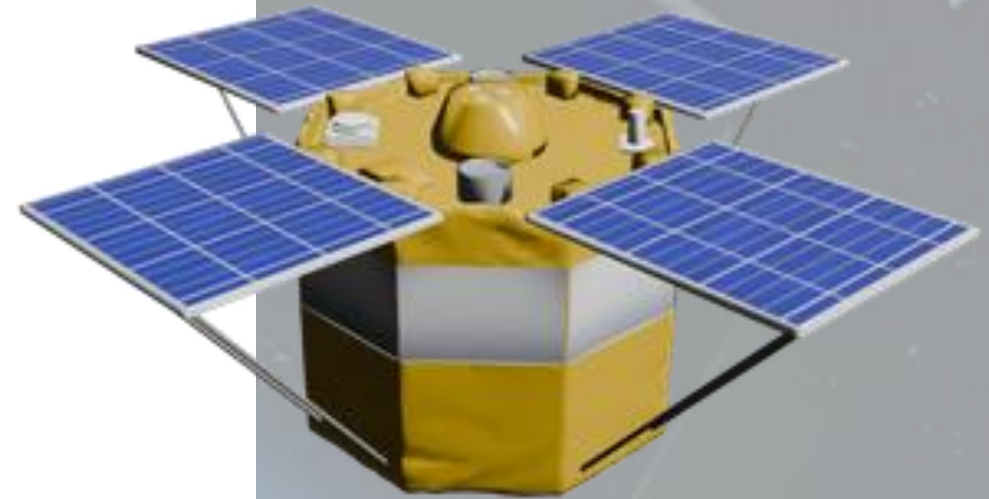
- object shape (both simple and complex)
- materials reflectivities in different bands
- the light reflection of complex objects at different angles of illuminations



BLENDER

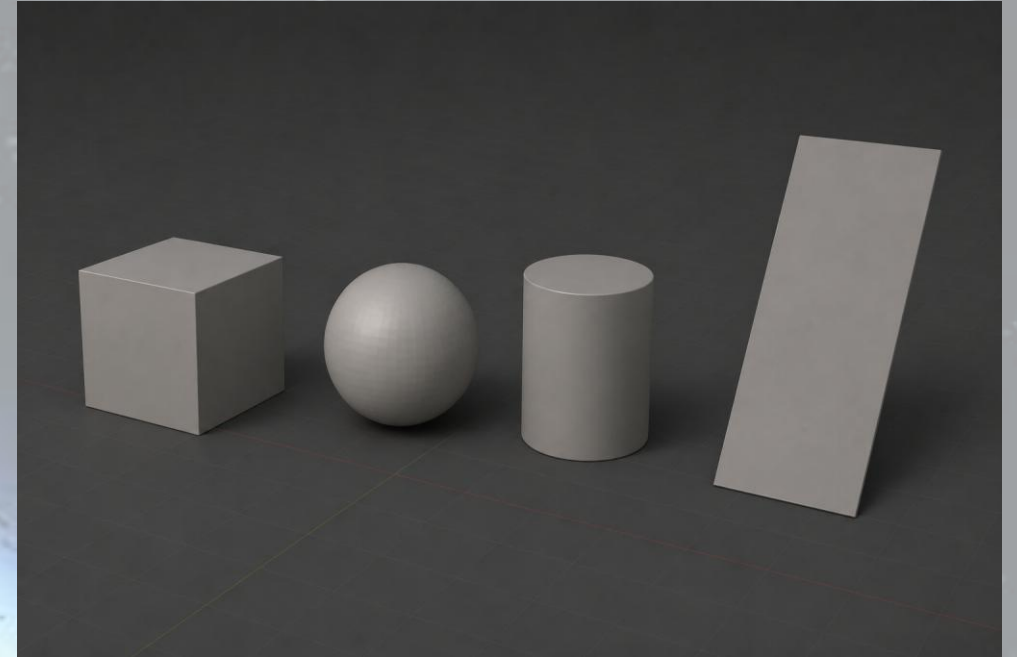
BLENDER is a community project for 3D rendering and animation.

NASA uses Blender to create 3D models of missions and satellites



PROJECT

- 12 different shapes (4 fundamentals and their combinations)
- Few real satellites shapes
- Different angles of incidence
- Rotations around different axes
- Different materials
- 3 observed bands

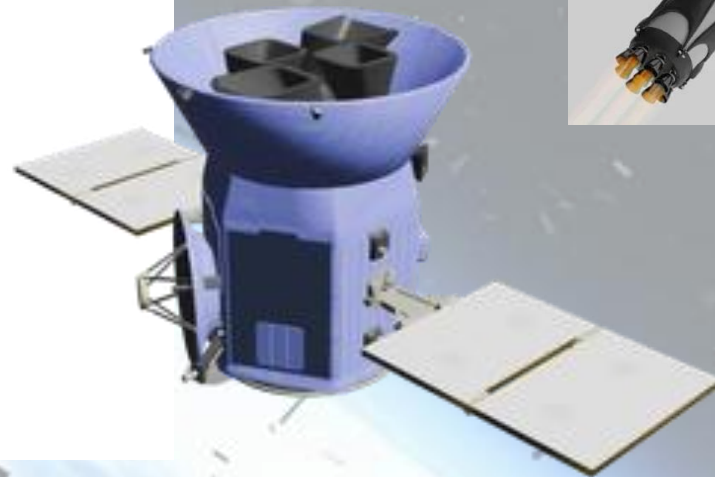


Fundamental shapes

PROJECT

- 12 different shapes (4 fundamentals and their combinations)
- Few real satellites shapes
- Different angles of incidence
- Rotations around different axes
- Different materials
- 3 observed bands

➔ ~ 8 millions of lightcurves



PROJECT

GOALS:

- Approximate shape and size retrieval and material recognition.

PROJECT

GOALS:

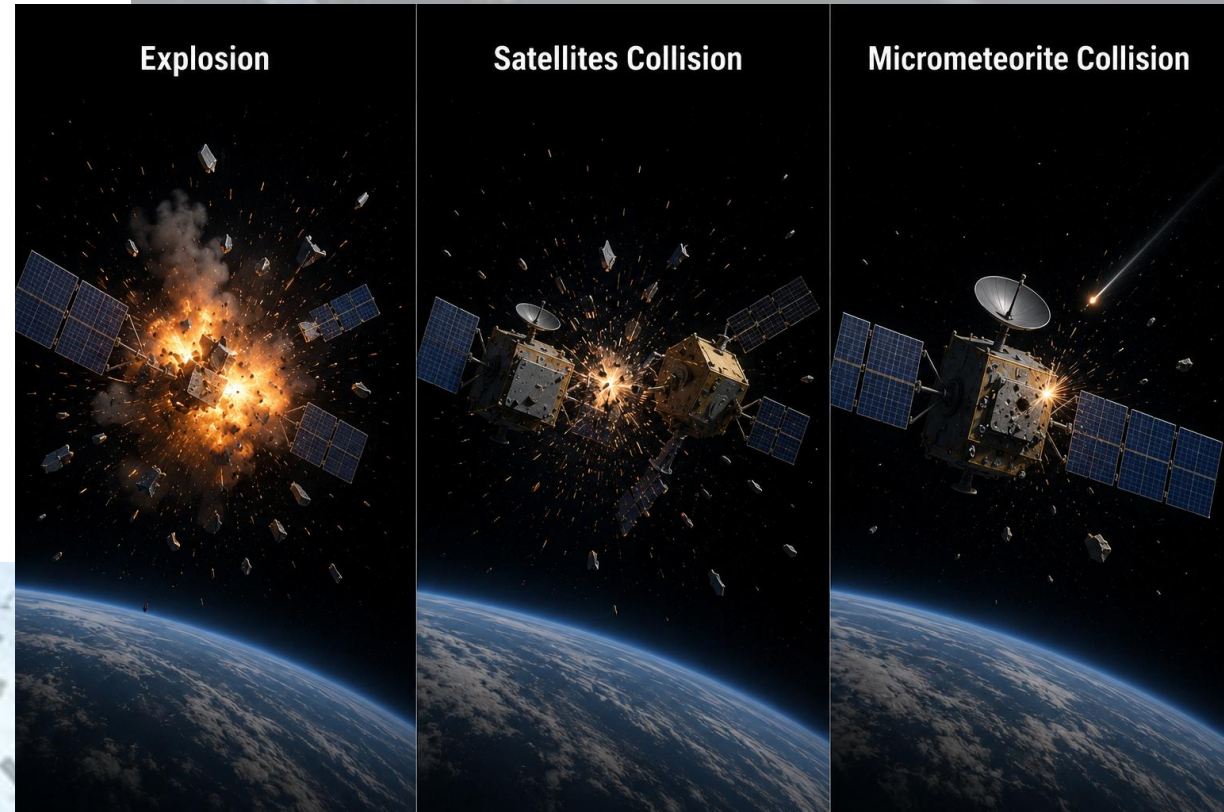
- Approximate shape and size retrieval and material recognition.
- Original body components recognition



PROJECT

GOALS:

- Approximate shape and size retrieval and material recognition.
- Satellite components recognition
- Possible analysis of different fragmentation scenarios



PROJECT

GOALS:

- Approximate shape and size retrieval and material recognition.
- Satellite components recognition
- Possible analysis of different fragmentation scenarios
- Better analysis of atmospheric drag for major debris → better re-entry predictions

#EUSpace



#EUSpace



CONCLUSIONS

Space debris represents one of the greatest obstacles to space exploration. It is the result of years of underestimation of the problem and the enormous expansion of the space sector.

We believe it is time to move from population studies to specific targets analysis:

- **Accurate assessment of in-orbit risk**
- **Better predictions of debris reentry into the atmosphere**
- **Analysis of the causes of fragmentation**



THANK YOU!!