

Space Debris Characterization Through Multiband Photometry

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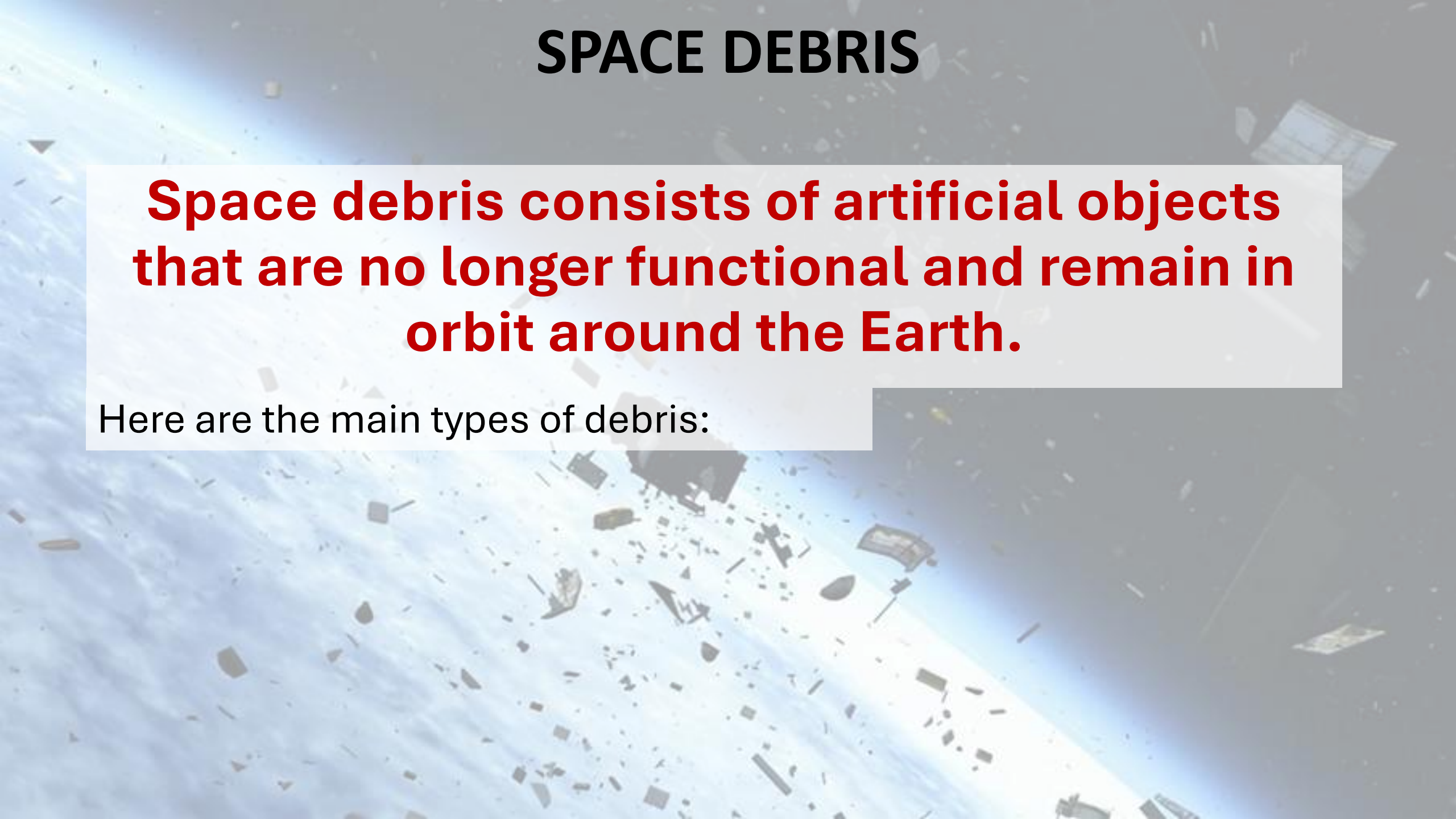


SPACE DEBRIS

The background of the slide is a high-resolution image of space debris. It shows a vast number of objects of various sizes, from tiny specks to larger, more complex structures, scattered across the dark void of space. At the bottom of the frame, the bright, curved horizon of the Earth is visible, providing a sense of scale and location. The debris appears to be in motion, with some objects showing motion blur, suggesting a high-speed environment.

Space debris consists of artificial objects that are no longer functional and remain in orbit around the Earth.

SPACE DEBRIS

The background of the slide is a composite image showing a dense field of space debris in orbit around the Earth. The debris includes various shapes and sizes, from small fragments to larger satellite components. The Earth's surface is visible at the bottom, showing a blue and white horizon. The overall scene is set against a dark, starry space background.

Space debris consists of artificial objects that are no longer functional and remain in orbit around the Earth.

Here are the main types of debris:

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- Defunct satellites



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- Metal fragments or various post-fragmentation materials



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Here are the main types of debris:

- Defunct satellites
- Metal fragments or various post-fragmentation materials
- Rocket stages



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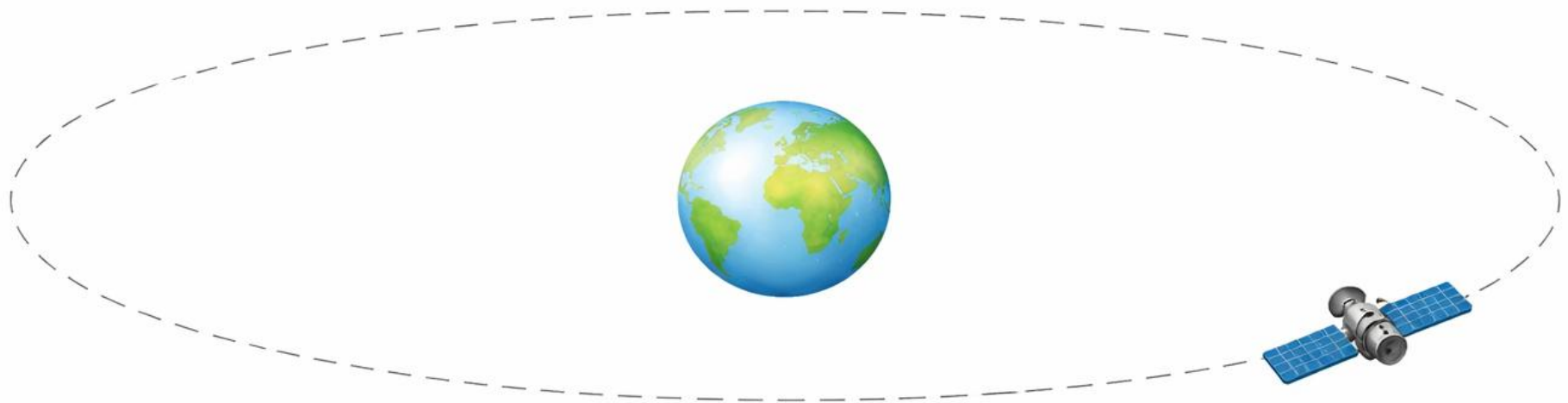
Here are the main types of debris:

- Defunct satellites
- Metal fragments or various post-fragmentation materials
- Rocket stages
- Fuel

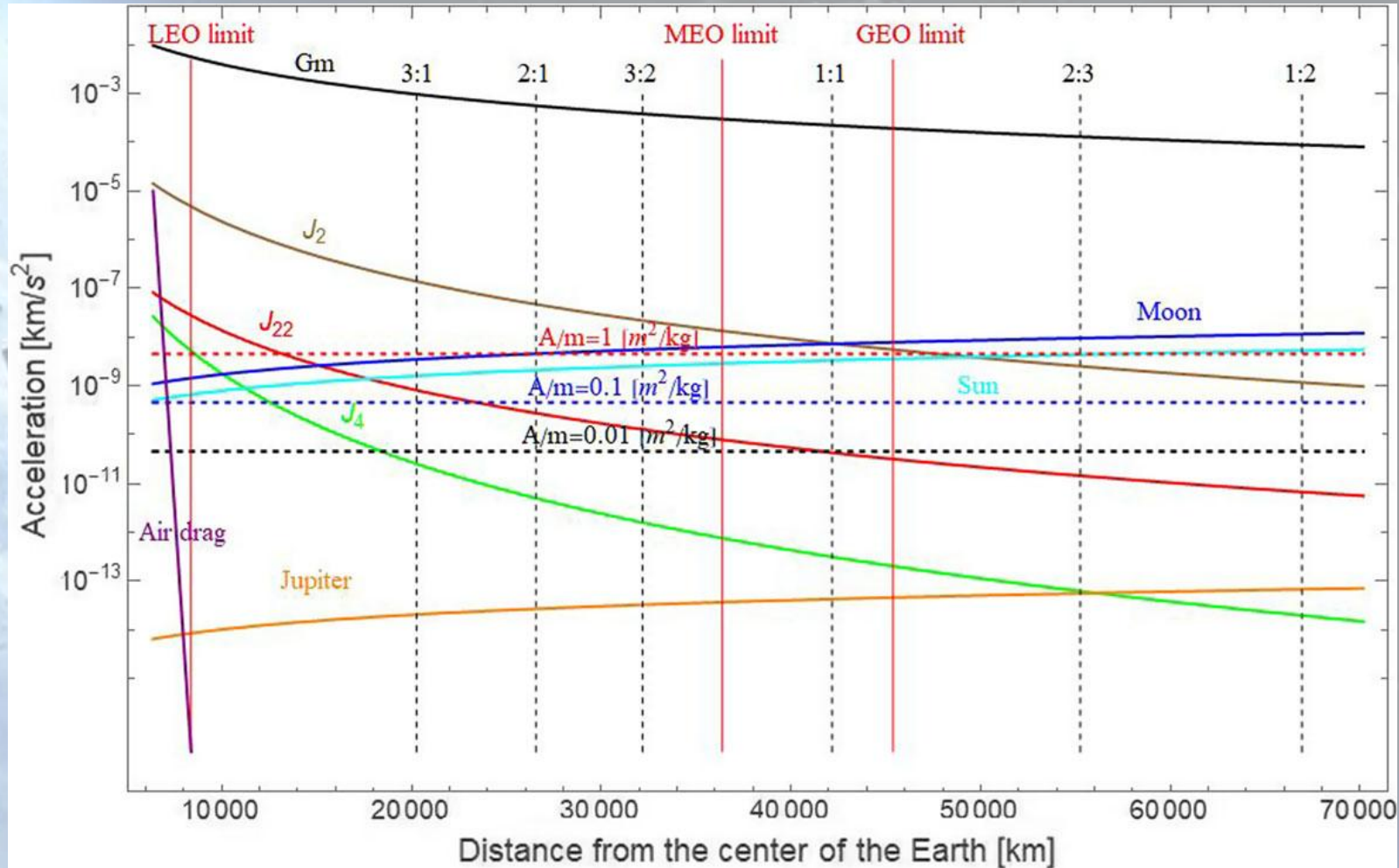


ORBITS

- **LEO**: 200 - 2000 Km
- **MEO**: 2000 Km - 30 000 Km
- **GEO**: > 30 000 Km



ORBITS PERTURBATIONS



Acceleration acting on a body, produced by various perturbing effects on the orbits (from Marius Apetrii & Alessandra Celletti et al., 2024)

ORBITS PERTURBATIONS

- **LEO**: atmospheric drag, non-sphericity of Earth
- **MEO and GEO**: gravity of the Moon and Sun, radiation pressure

NEED FOR ORBITAL CORRECTIONS

NOT possible for SPACE DEBRIS

SPACE DEBRIS ORIGINS

- **COLLISIONS** with/between **FAULTY** or non-steerable satellites.
- **COLLISIONS** with micrometeorites
- **IMPACTS** with small, high-velocity debris
- Destruction of satellites due to **MILITARY MANOEUVRES**
- **EXPLOSIONS** due to **technical failure**
- **Fuel exhaustion**
- **General malfunction**

MALFUNCTIONS

The background of the slide is a detailed illustration of a space debris field. It shows a vast number of objects of various sizes, shapes, and colors (including metallic grey, brown, and white) floating in a blue-grey space. A bright, glowing white and blue diagonal streak, representing the Earth's horizon or a light source, cuts across the lower half of the image, creating a sense of depth and scale.

CAUSES:

MALFUNCTIONS

CAUSES:

- **AGING**



Vanguard 1 (US), the oldest artificial object in orbit.

MALFUNCTIONS

CAUSES:

- AGING
- **IMPACTS/MICRO-IMPACTS**
(speed of about 10-30 km/s)



Effect of a microimpact on a robotic arm of the ISS.

MALFUNCTIONS

CAUSES:

- AGING
- IMPACTS/MICRO-IMPACTS
- **SOLAR WIND**

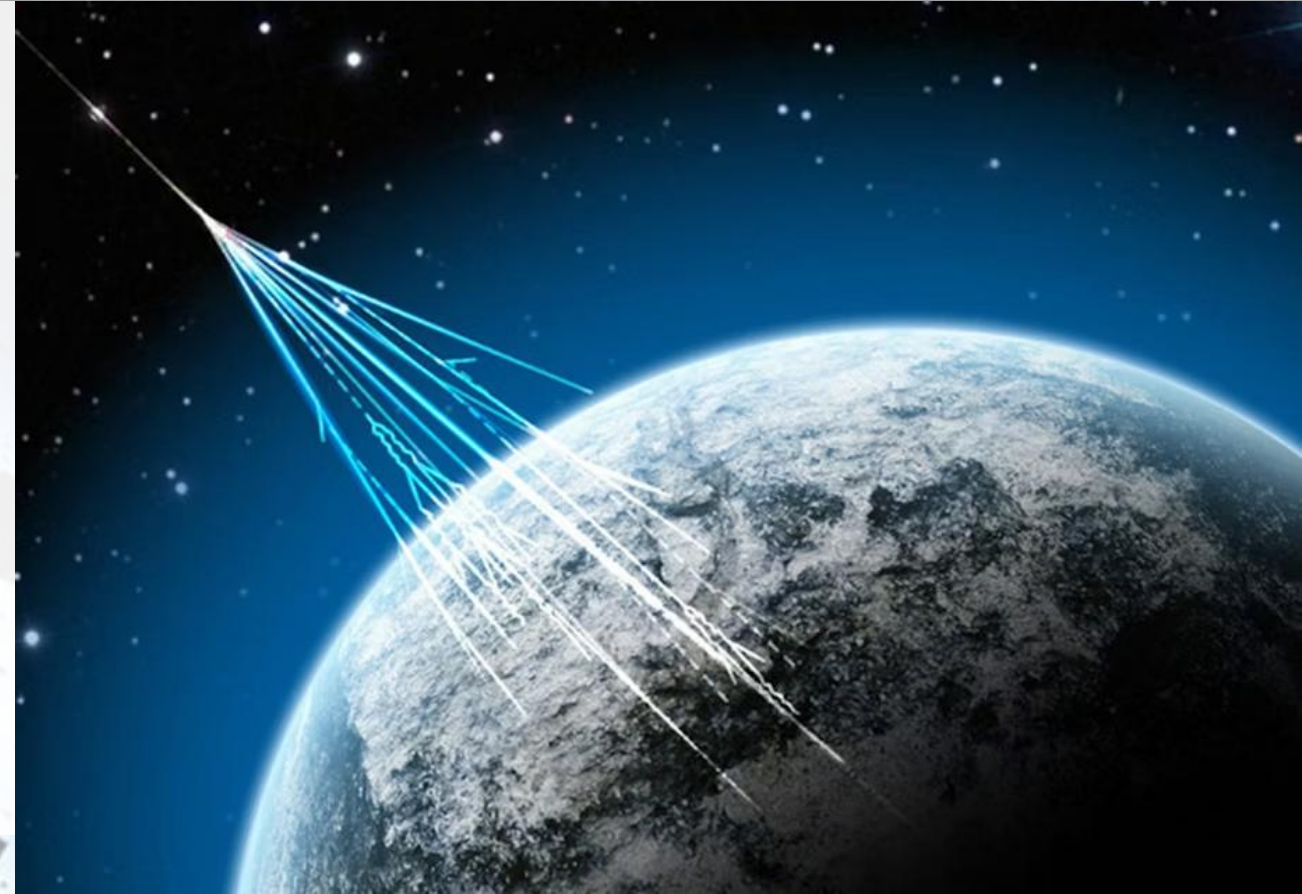


Composite image of a solar storm. (MEDIA-INAF)

MALFUNCTIONS

CAUSES:

- AGING
- IMPACTS/MICRO-IMPACTS
- SOLAR WIND
- **COSMIC RAYS**



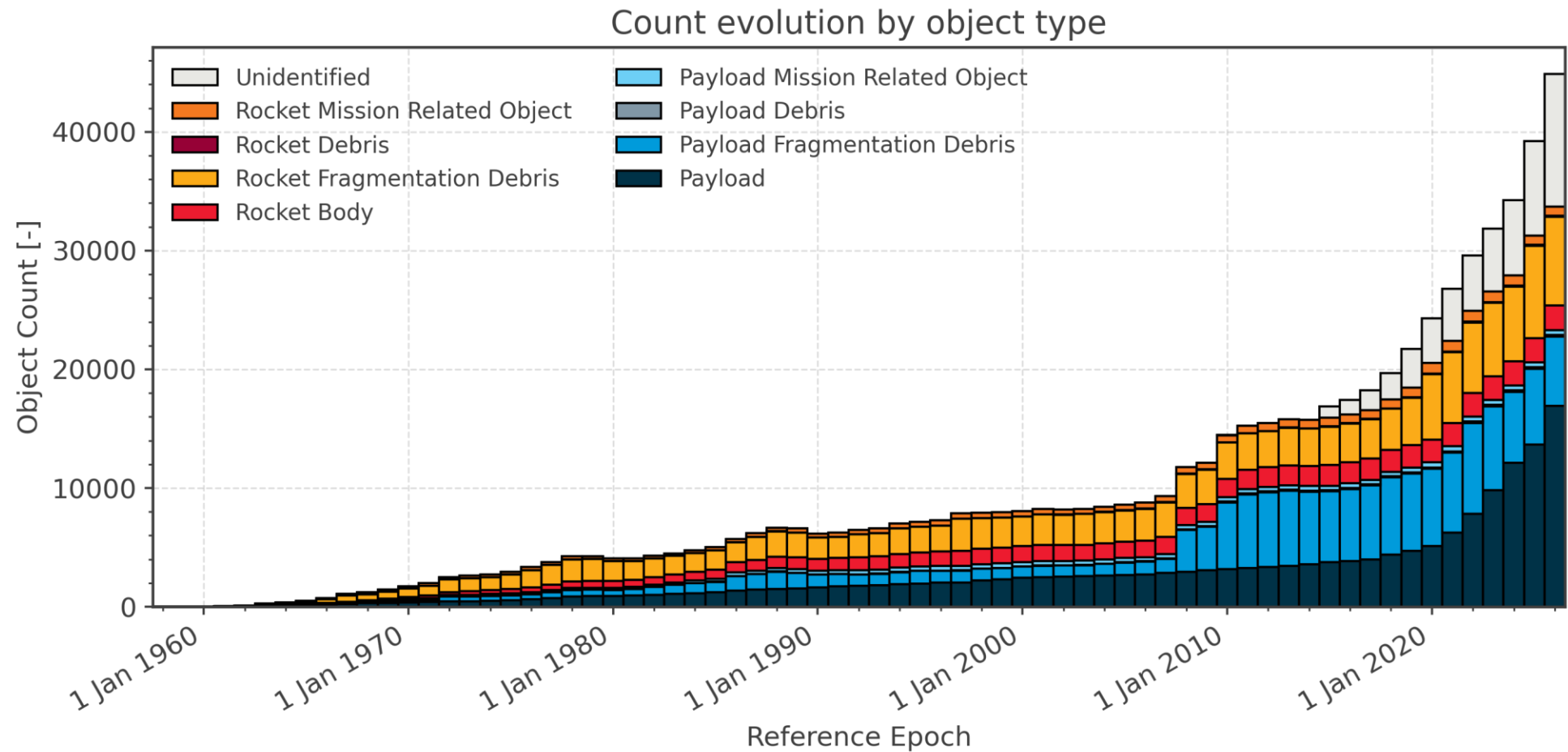
EFFECTS:

- Possible impacts on the ground or aircraft (very unlikely, but possible) → Potential political consequences
- Air and water pollution with heavy metals and toxic compounds
- Debris-satellites impacts → Risk of a cascade effect (KESSLER SYNDROME)
- Danger for astronauts

SITUATION PER ORBIT TYPE

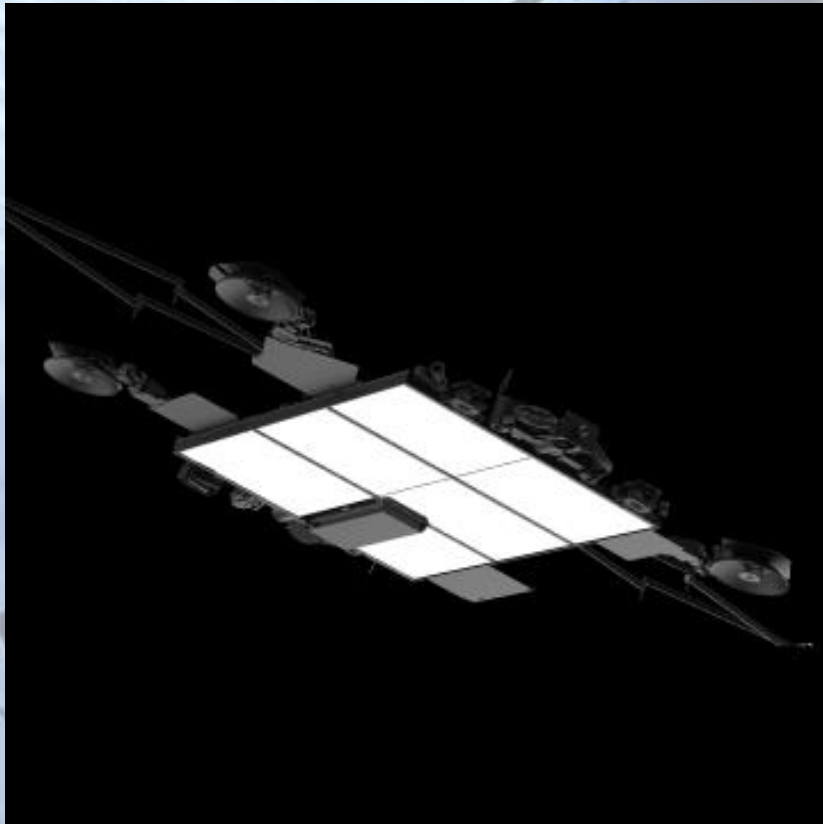
ORBIT	PROS	CONS
LEO	Atmosphere clears orbits in a few years or decades	Risk of saturation (KESSLER SYNDROME). Total blockage of access to space
MEO/GEO	Low collision risk	Almost eternal debris

- **SIGNIFICANT IN-ORBIT MATERIAL INCREASE**



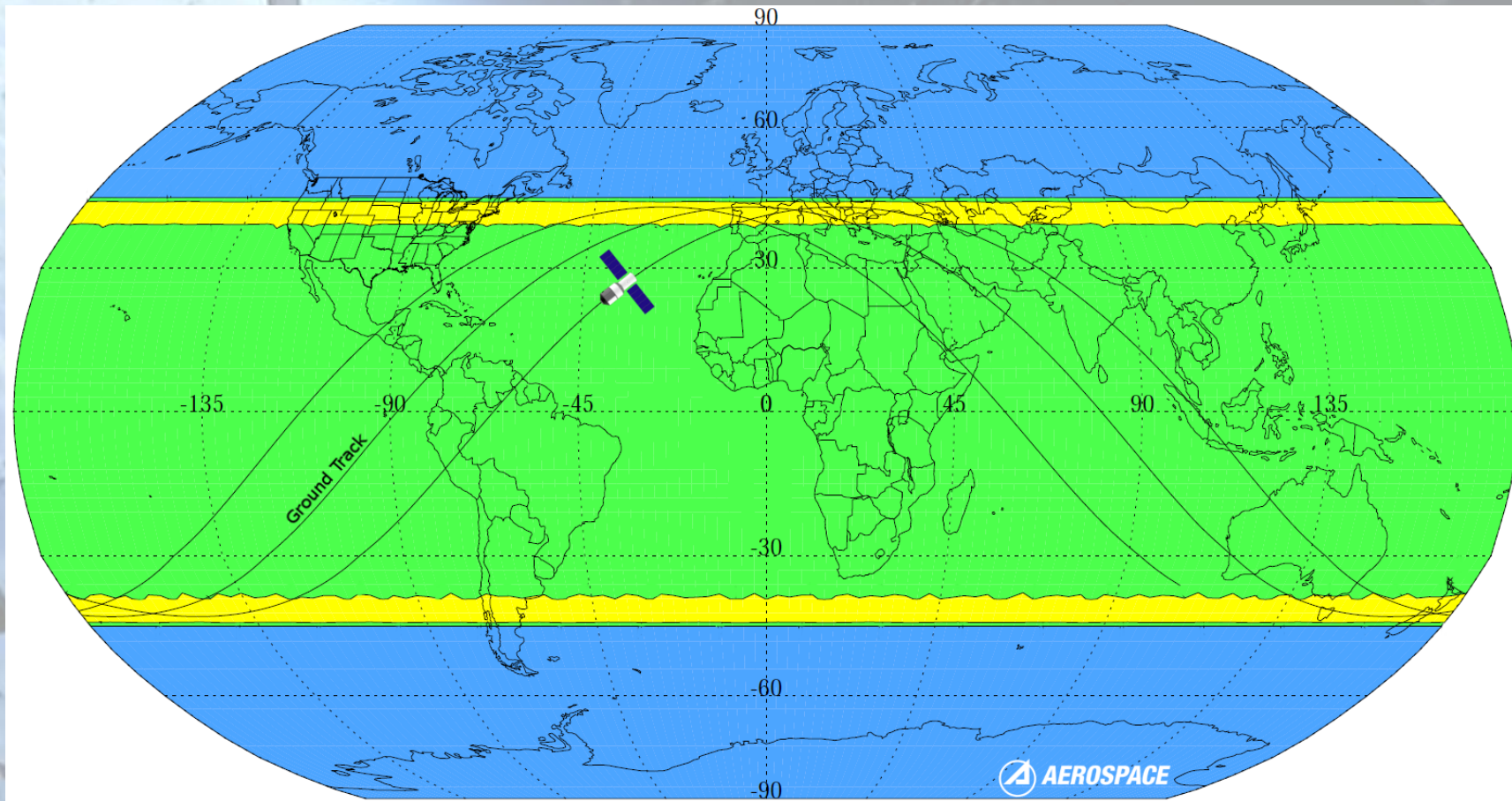
CURRENT SITUATION

- **STARLINK:** Tens of thousands of satellites in low orbit, with plans to further increase



CURRENT SITUATION

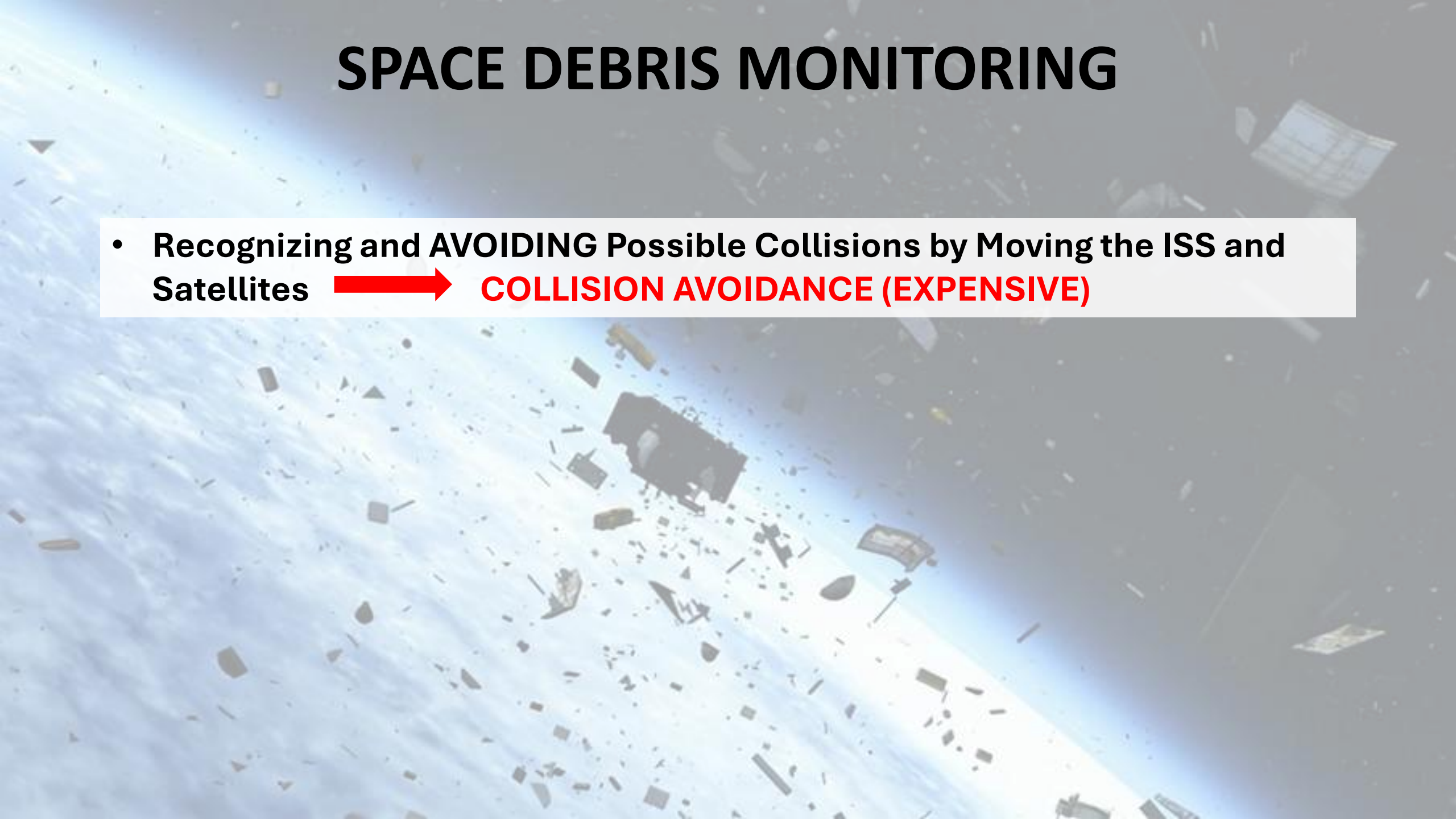
- CHINESE SPACE PROGRAM



POSSIBLE SOLUTIONS

- **INNOVATION** (REUSABLE ROCKETS)
- **SPACE DEBRIS MONITORING**
- **NEW REGULATIONS** for the **SPACE ECONOMY** and **SPACE EXPLORATION**
- **DE-ORBITING** (experimental)
- **IN-ORBIT RESTORE INTERVENTIONS** (experimental)

SPACE DEBRIS MONITORING

The background of the slide is a composite image showing a dense field of space debris in orbit around Earth. The debris consists of numerous small, irregular fragments of varying sizes and shapes, some appearing as bright streaks against the dark background of space. The Earth's horizon is visible at the bottom, showing a bright blue and white glow from the atmosphere and sunlight.

- Recognizing and AVOIDING Possible Collisions by Moving the ISS and Satellites  **COLLISION AVOIDANCE (EXPENSIVE)**

SPACE DEBRIS MONITORING

- Recognizing and AVOIDING Possible Collisions by Moving the ISS and Satellites  COLLISION AVOIDANCE (EXPENSIVE)
- Studying how debris returns to the atmosphere and its DYNAMICS

SPACE DEBRIS MONITORING

- Recognizing and AVOIDING Possible Collisions by Moving the ISS and Satellites → **COLLISION AVOIDANCE (EXPENSIVE)**
- Studying how debris returns to the atmosphere and its **DYNAMICS**
- Understanding the **CAUSES** of fragmentation (We're working on it)

NEW REGULATIONS

Every mission must have a decommissioning plan:

- Materials disintegrating in the atmosphere (**PLANNED DE-ORBITING**)
- **GRAVEYARD ORBITS**

PROS: Possible solution

NEW REGULATIONS

PROS: Possible solution

CONS:

- **low probability of an international agreement**
- **difficult surveillance**
- **limitation of the SPACE ECONOMY**

GAL Hassin Observatory



INSTRUMENTS

GRT telescope:

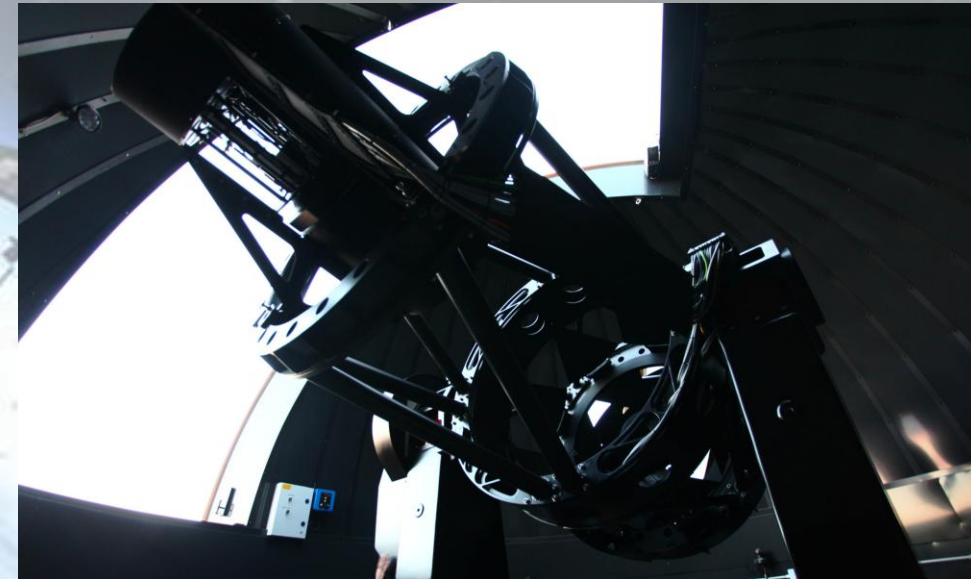
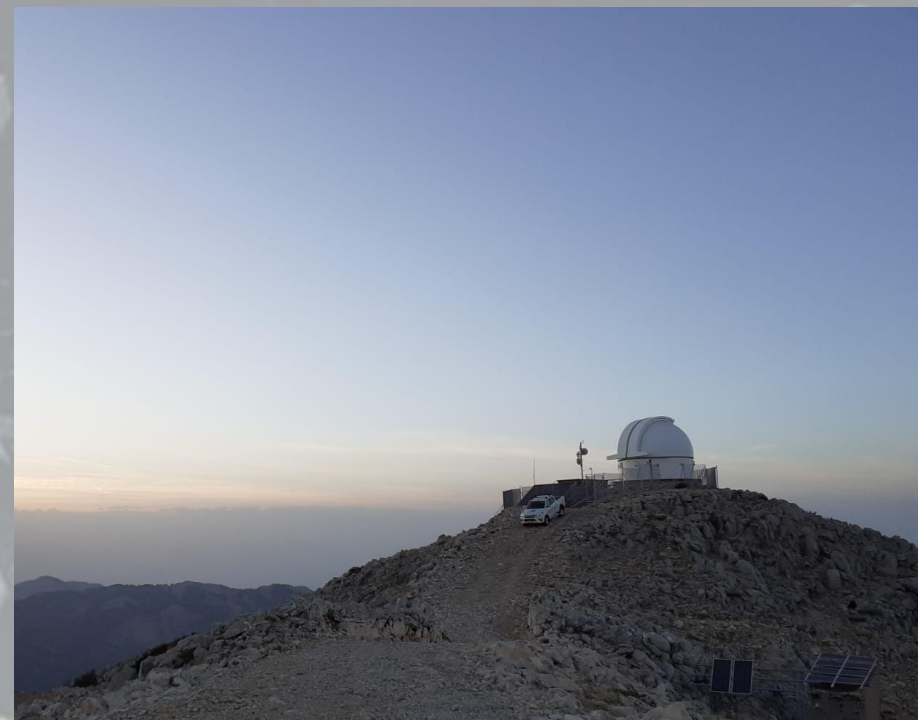
- diameter: 40 cm
- f/3.8
- location: GAL Hassin (Isnello-PA)
- FoV 80' x 80'
- Differential tracking
- Sloan Filters u, g, r, i, z_s2



INSTRUMENTS

WMT telescope:

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



ACTIVITIES

The background of the slide is a dynamic, blue-toned image depicting a dense field of space debris. Numerous fragments of varying sizes, including what appear to be satellite components, solar panels, and smaller particles, are scattered across the frame. A bright, glowing blue streak or light source is visible on the left side, creating a sense of motion and depth. The overall aesthetic is futuristic and technological.

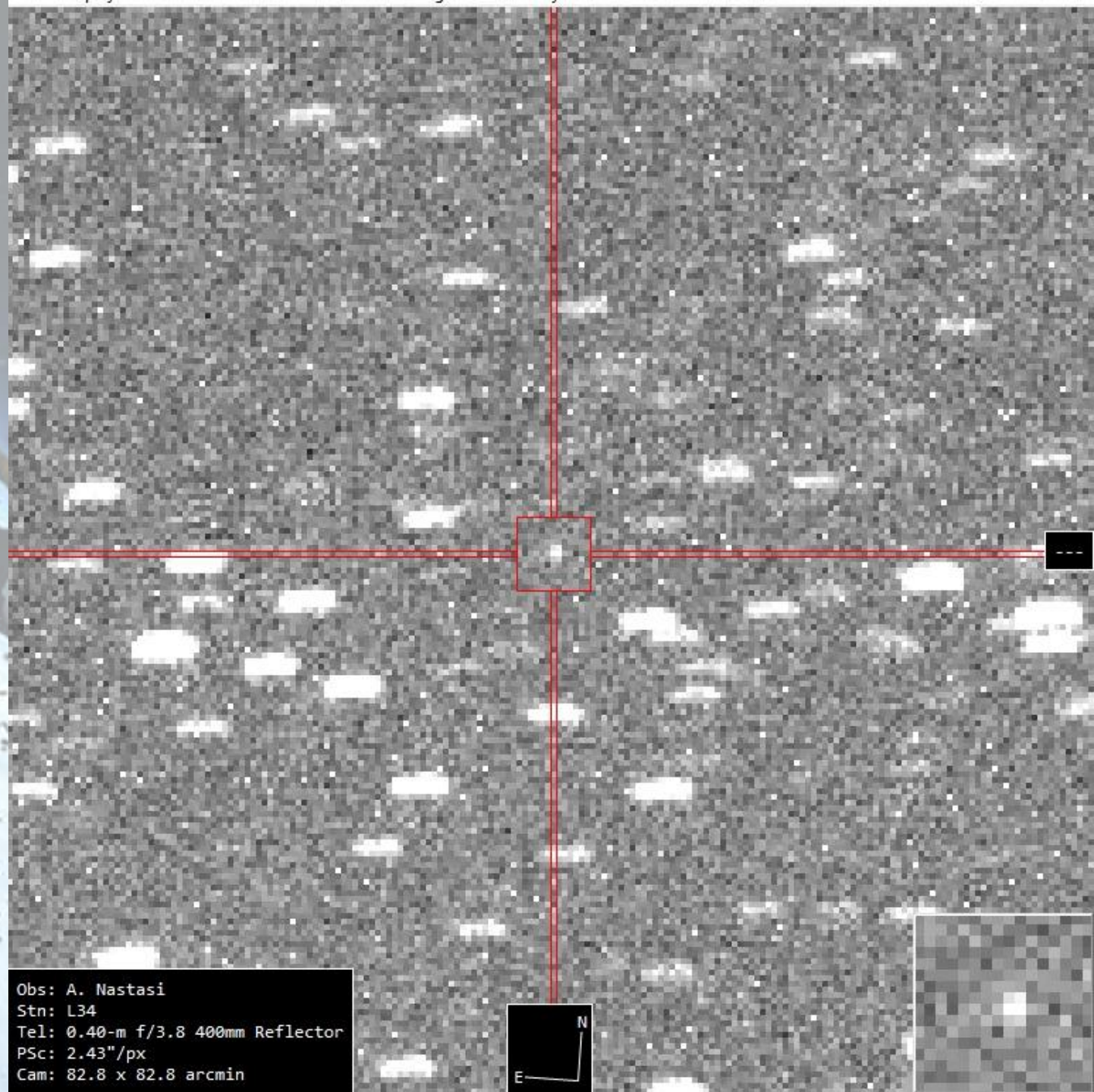
Debris survey

**Survey-style observations using a luminance filter
to track the new space debris.**

Great time precision required

Satellites Atmospheric re-entry monitoring

*Image of the Salsa satellite
(Cluster 2/FM6) acquired by the
GRT with a 30-second exposure
tracking the object, using the Lum
filter, on September 6, 2024.*



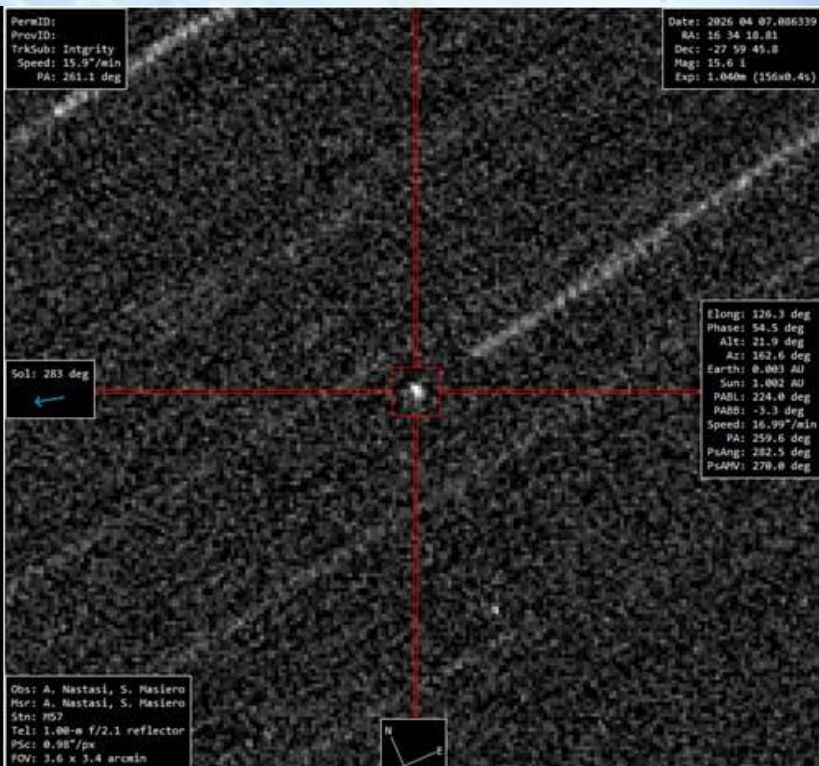
Obs: A. Nastasi
Stn: L34
Tel: 0.40-m f/3.8 400mm Reflector
PSc: 2.43"/px
Cam: 82.8 x 82.8 arcmin

CIRCUMLUNAR OBJECTS

As part of the Italian IADC activities, the GAL-Hassin observed several circumlunar artificial objects:

- 34714-ATLAS 5 Centaur R/B, 23716-ARIANE 44P+3 R/B, the Artemis 2 Integrity capsule, and 25867-CXO.

Observations through GRT, with the exception of **Artemis 2** (image), which was observed with the WMT and is the furthest artificial object ever observed from GAL-Hassin observatory.

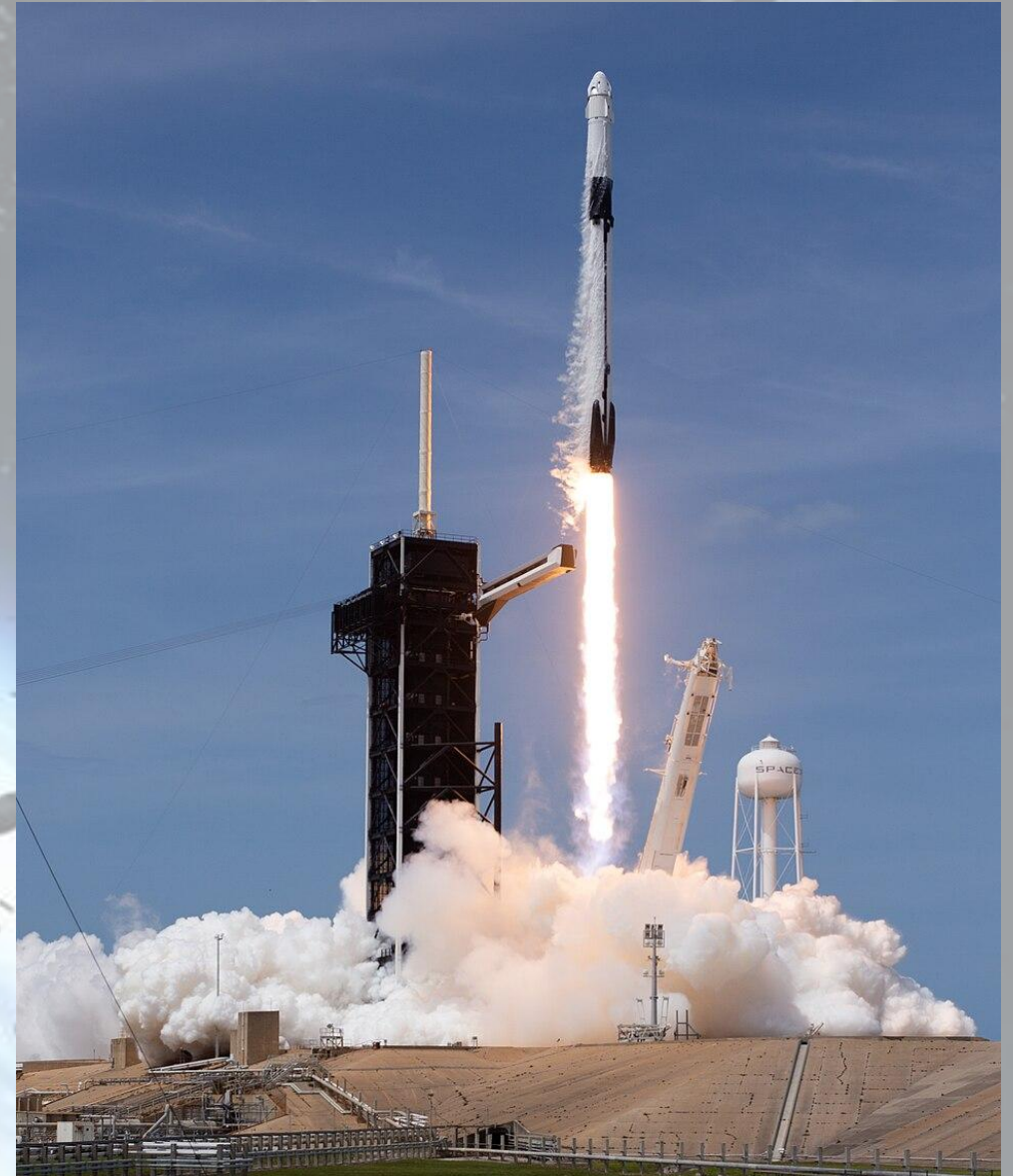


Falcon 9 R/B

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

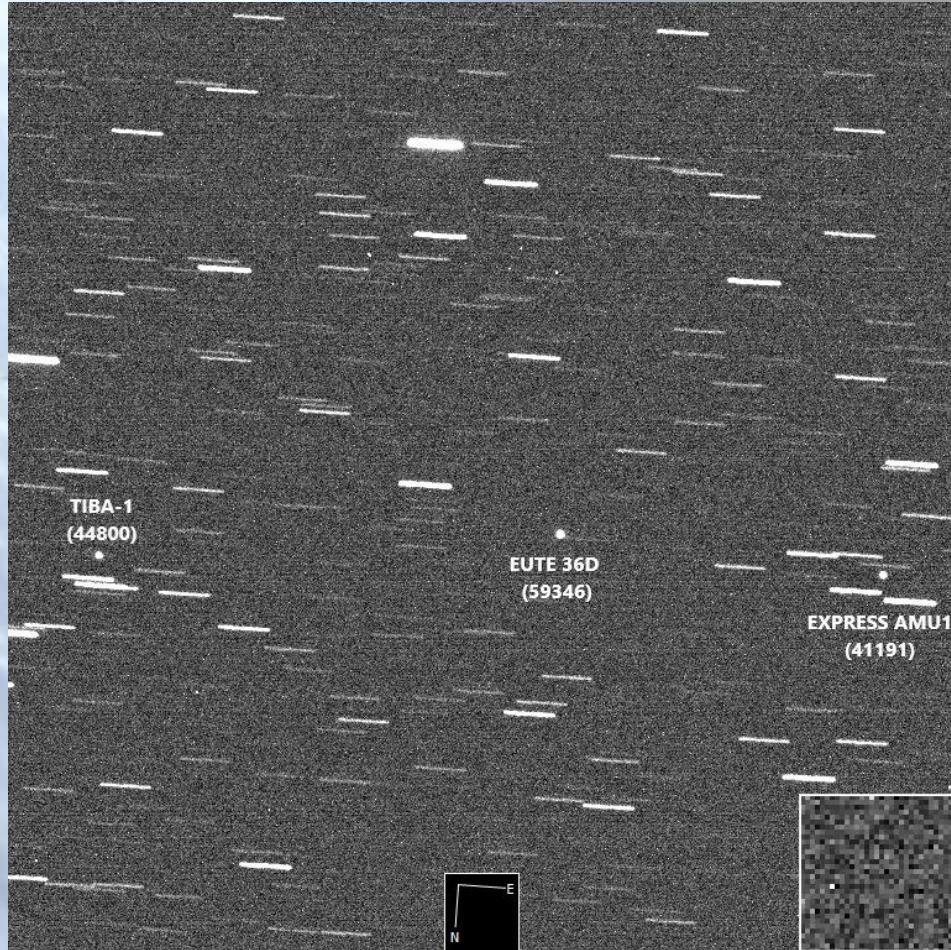


GEO SATELLITES

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.

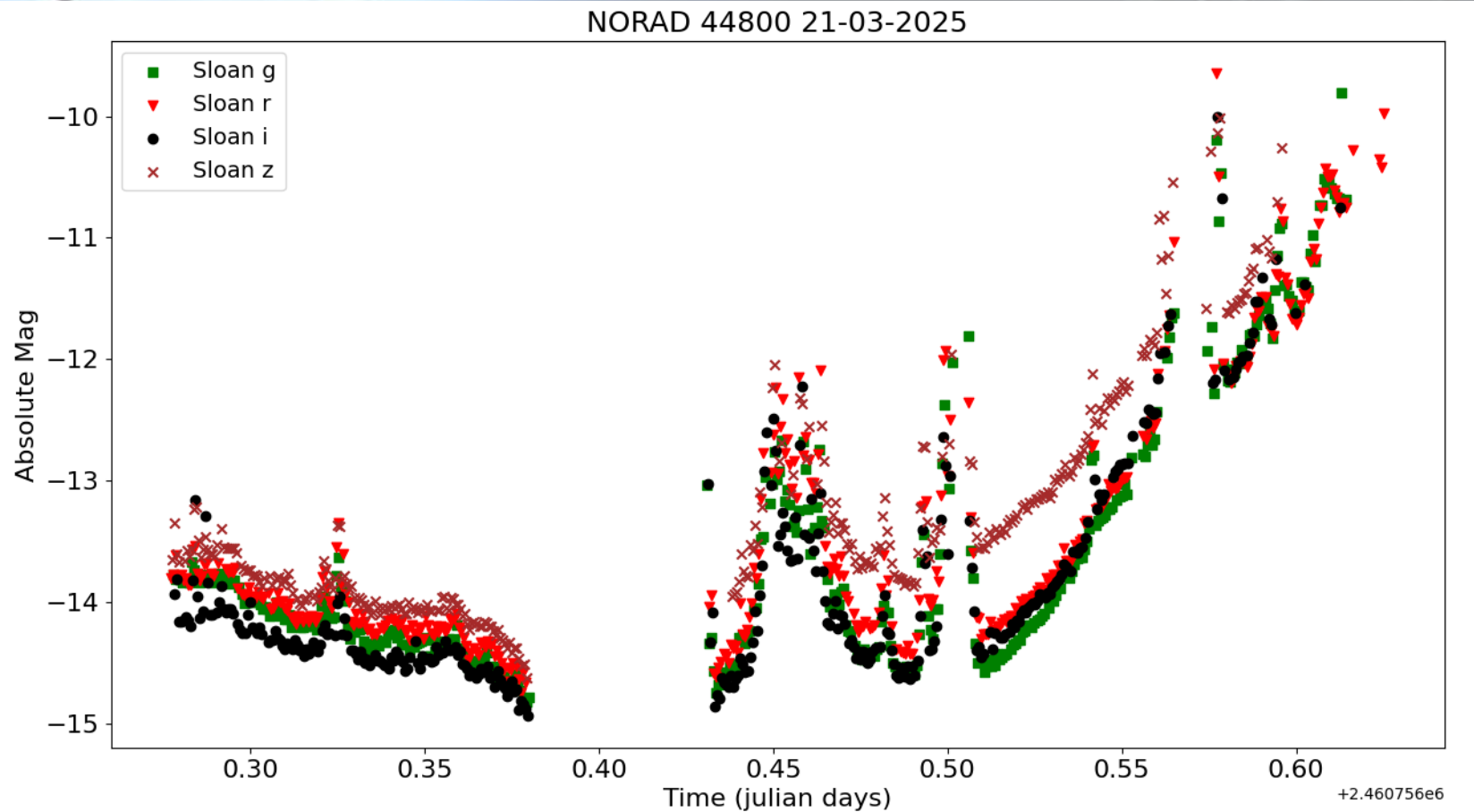
The observations took place in November 2024 and in January and March 2025 through the GRT.

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).*

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

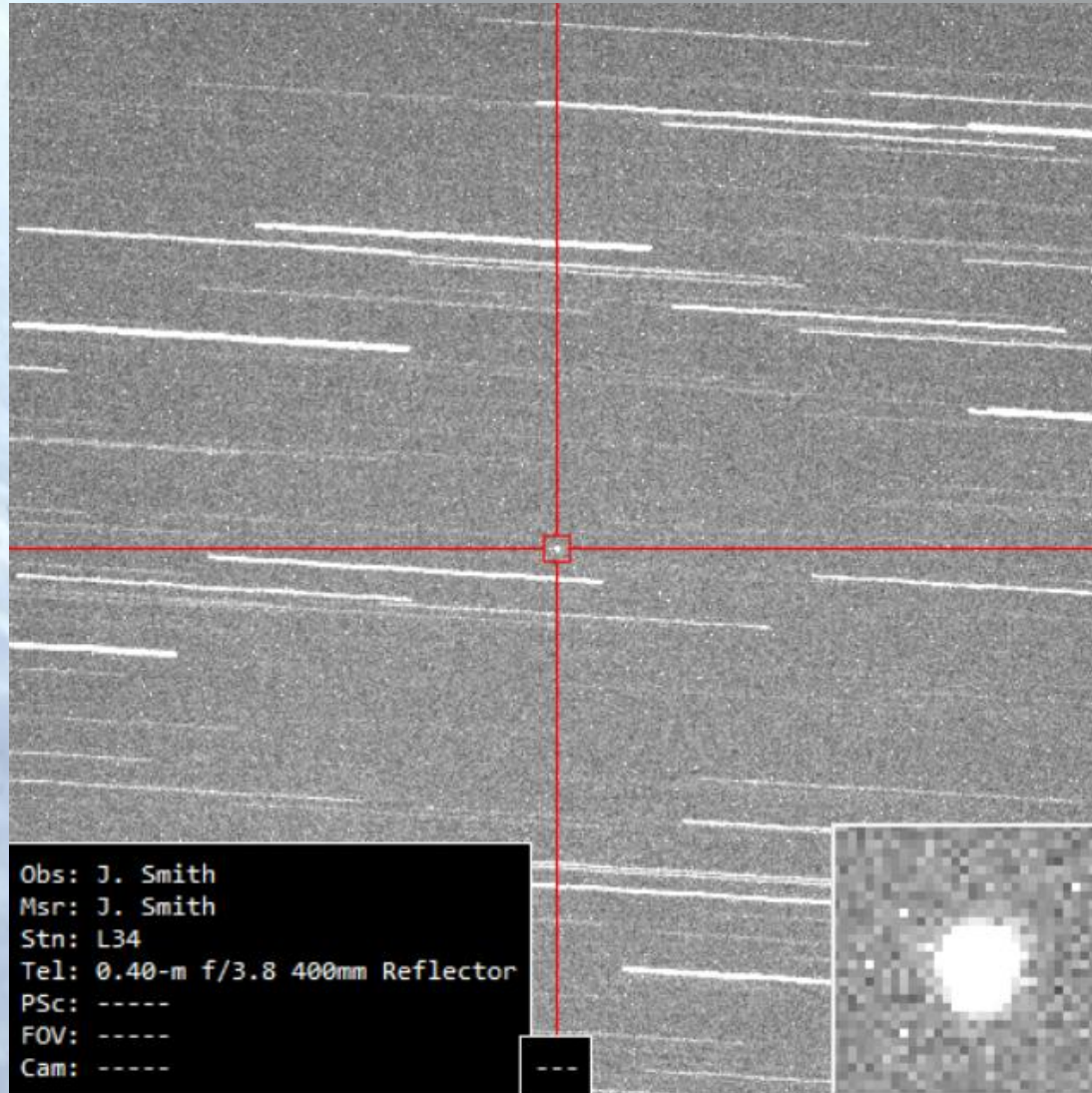


Intelsat 33 E Observations

- Multiband photometric observations (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).

SATELLITES DEGRADATION STUDY

INSTRUMENT:

REM telescope in Chile: a 60-cm aperture telescope capable of simultaneous observation in both optical and infrared bands thanks to a beam splitter and two instruments observing in parallel: ROSS2 (g', r', i', and z') and REMIR (z', J, H and K).

Project:

- Sample of satellites in GEO, some still active, others deactivated
- Observation through multiband photometry (optical and near IR)
- Goal: evaluation of the degradation of the satellite materials.
- Ongoing observations.



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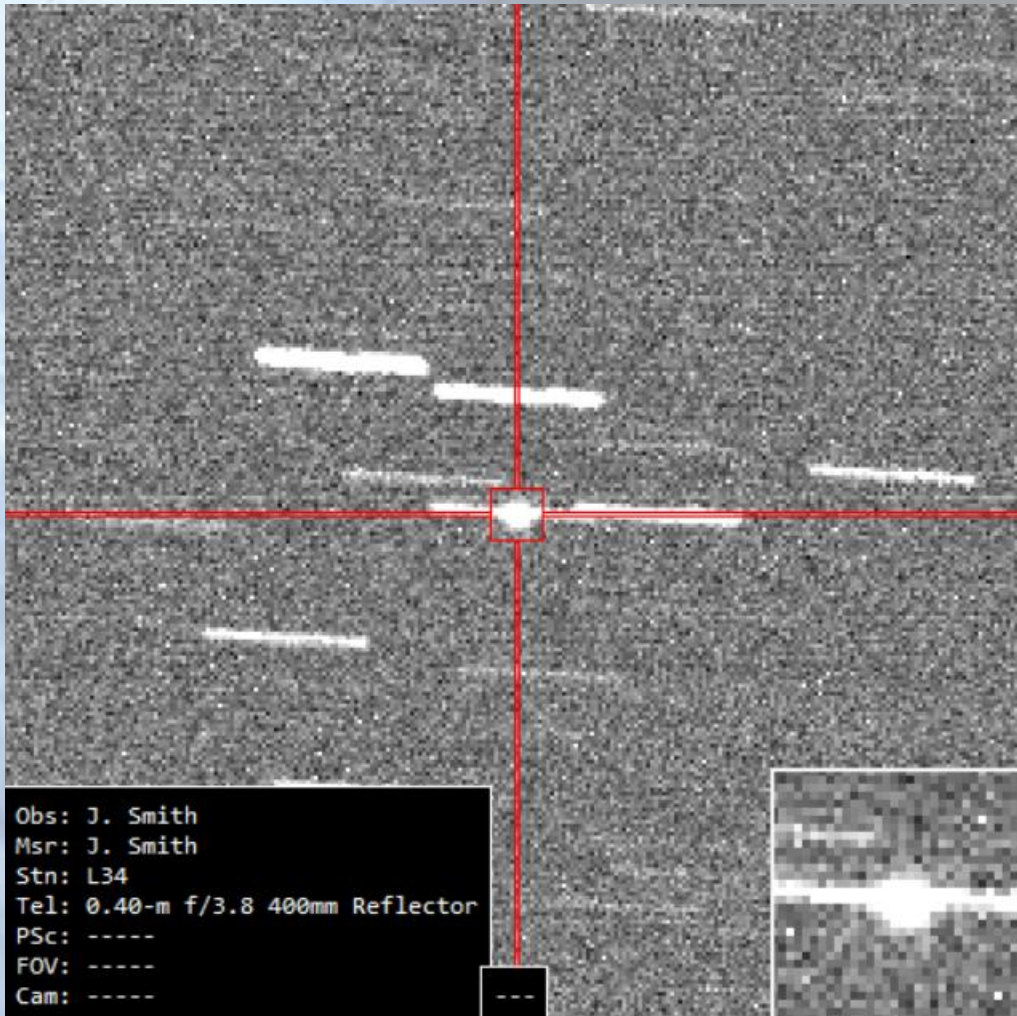


Plate solving of space debris images

- **Streak detection** via manual selection and Hough transforms
- Calculation of **trailed centroids**
- Plate solving
- Use of TLEs for artificial object identification.

Important for **differential photometry**

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.

The background of the slide is a detailed illustration of a space debris field. It shows a vast number of objects of various shapes and sizes, including small fragments, larger panels, and complex structures, all floating in space. A bright, glowing blue and white arc, likely representing the Earth's horizon or a celestial body, curves across the lower portion of the image. The overall color palette is dominated by cool blues and greys, with the bright light source providing a high-contrast area.

SPACE DEBRIS CHARACTERIZATION THROUGH MULTIBAND PHOTOMETRY

Size Estimation

We have begun developing a code to estimate the size of the observed debris from multiband photometric data.

Based on differential photometry, object position, airmass, and altitude, the code derives the target's reflected energy to estimate its size using realistic albedo assumptions.

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).
- 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.

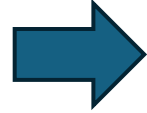
• **Paper under minor review**

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

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)

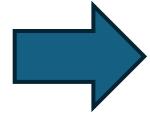


Comparison with the possible fragmentation scenarios hypothesized so far.

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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



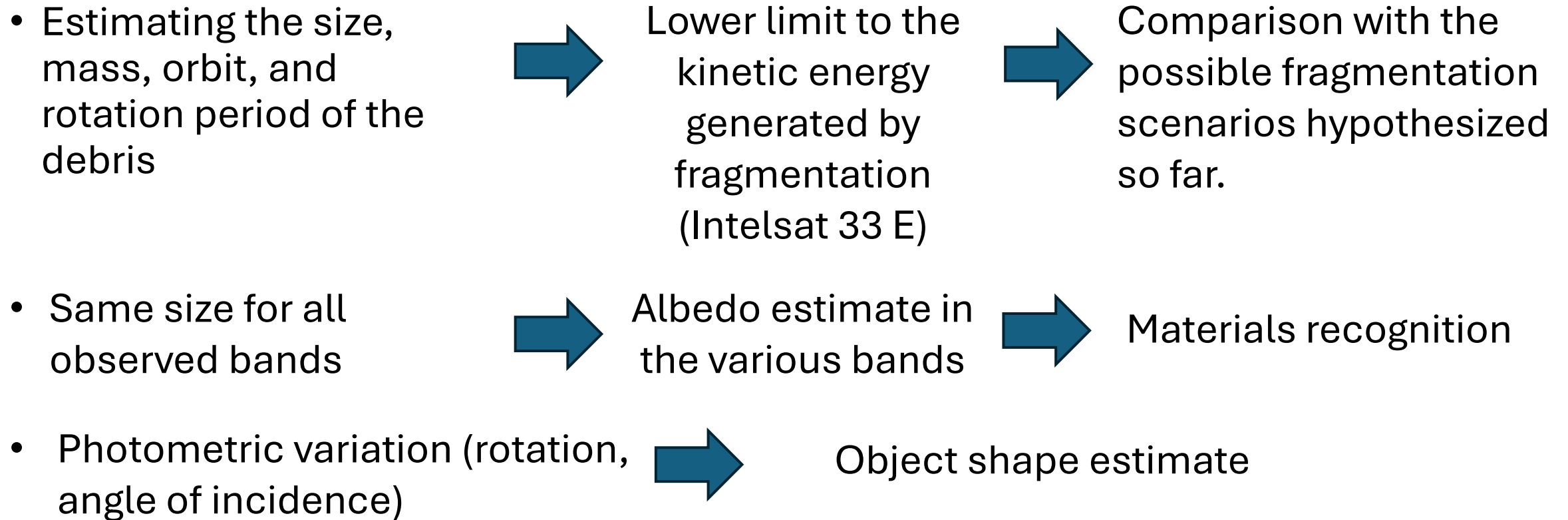
Albedo estimate in the various bands



Materials recognition

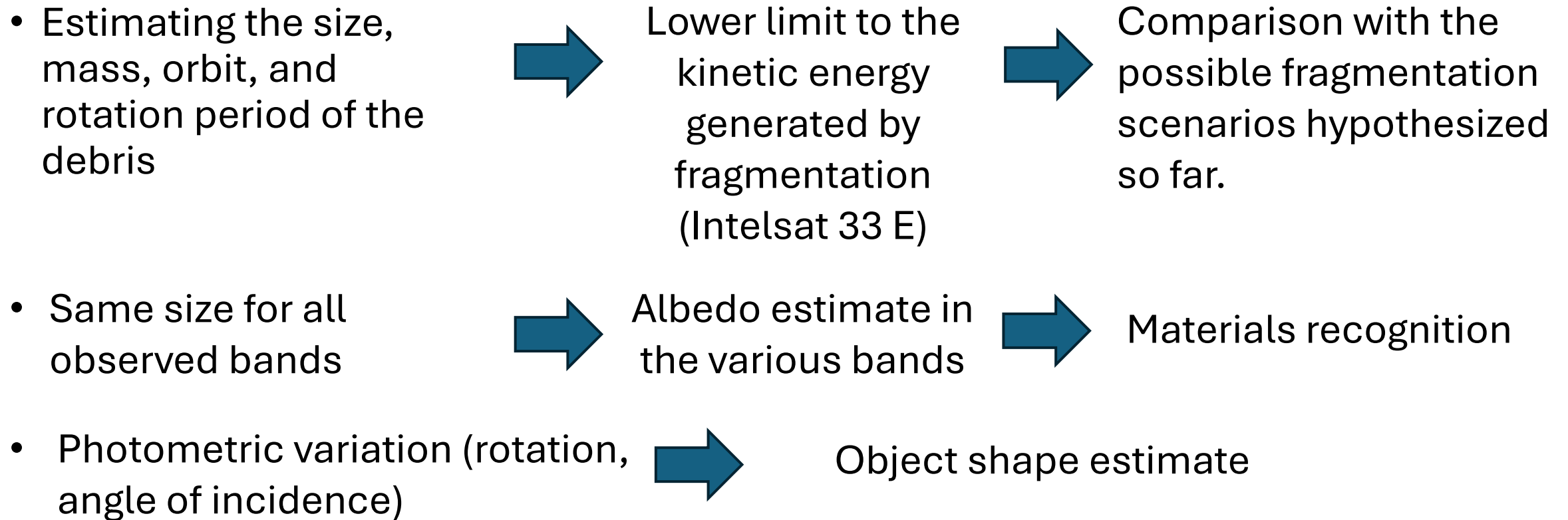
Outlook:

Determination of debris properties



Outlook:

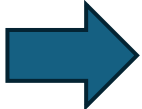
Determination of debris properties



TESTS ON KNOWN OBJECTS
(Falcon 9, GEO satellites, ...)

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

**MACHINE LEARNING REQUIRED
FOR COMPLEX DATA ANALYSIS**

(Radar, GEO satellites, ...)

SHAPE RETRIEVAL:

MACHINE LEARNING

Hardware (Already available at OAPa):

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

Software (Publicly available , already installed):

- BLENDER for space debris modeling (training and tests)

Supervised machine learning trained on ~ 100 millions of lightcurves

BLENDER

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

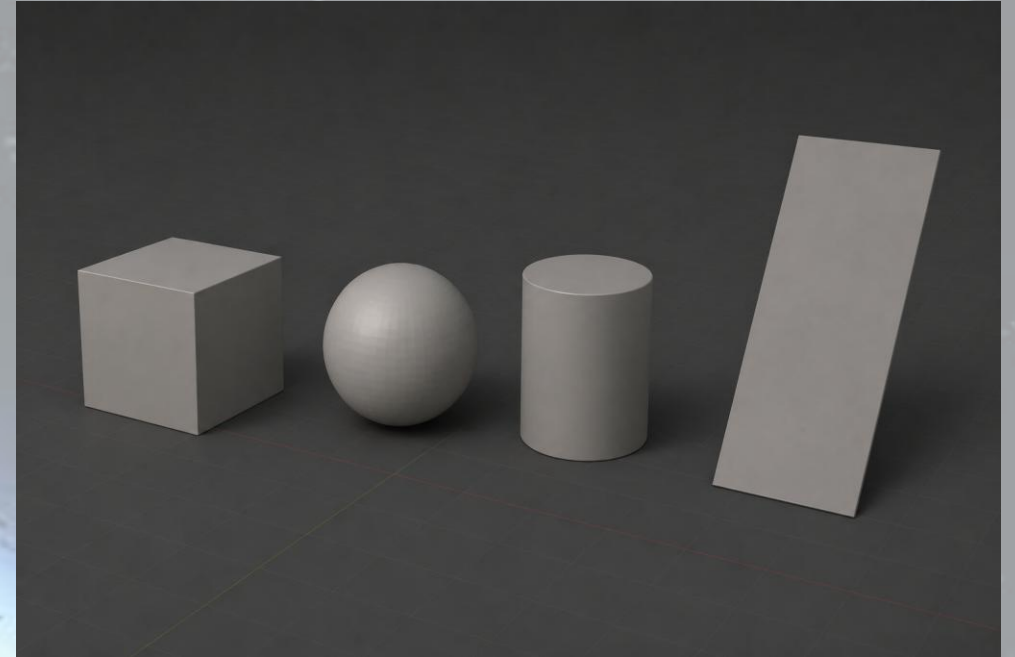
It can simulate the following features:

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



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

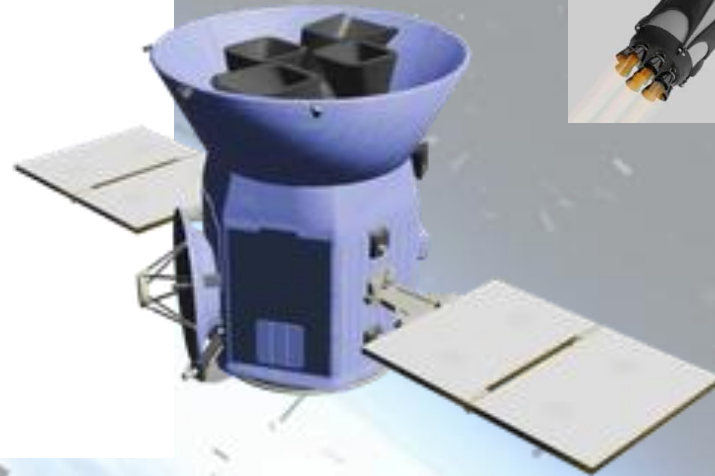


Fundamental shapes

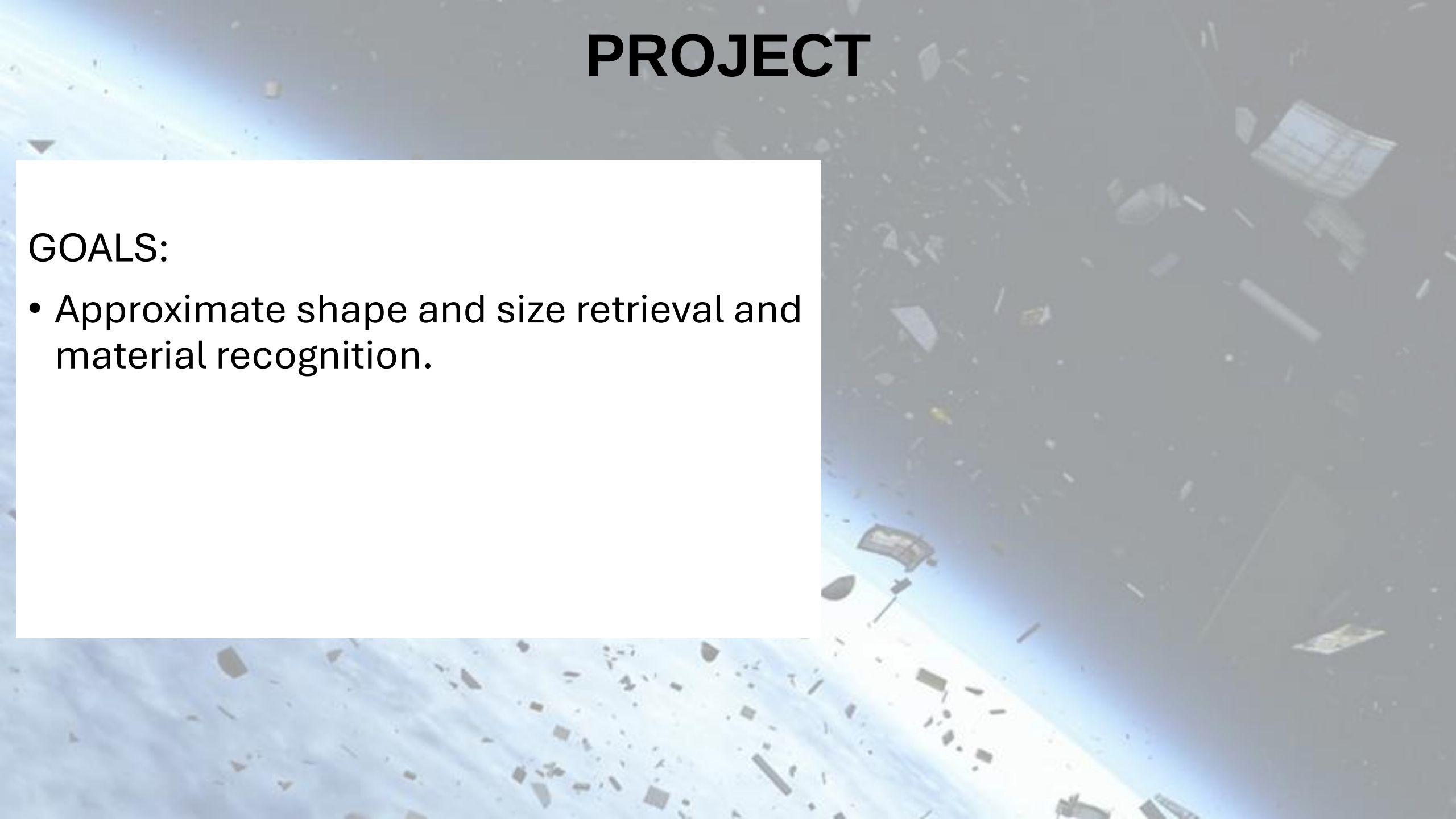
PROJECT

- 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

➡ ~ 100 millions of lightcurves



PROJECT

The background of the slide is a grayscale image of space debris. It shows numerous small, irregular fragments of metal and plastic floating in the void of space. In the lower-left corner, a portion of the Earth's curved horizon is visible, with a bright blue line representing the atmosphere. The overall scene conveys a sense of the vastness and danger of orbital waste.

GOALS:

- Approximate shape and size retrieval and material recognition.

PROJECT

GOALS:

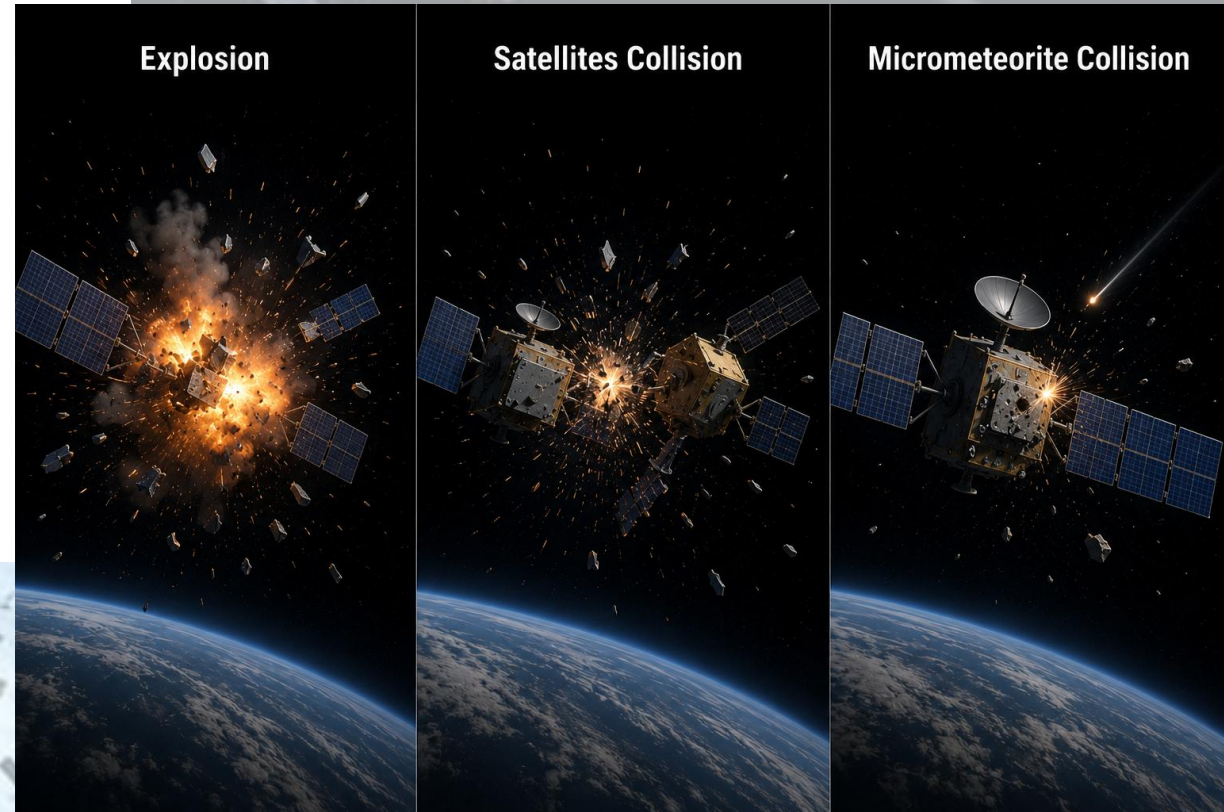
- Approximate shape and size retrieval and material recognition.
- Original body components recognition



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



EU SST
Space Surveillance and Tracking



#EUSpace



EU SST
Space Surveillance and Tracking

CONTRIBUTIONS

Publications:

We contributed to the following joint paper with the University of Padua as co-authors:

Trabachin N. et al., "Investigating INTELSAT 33E Breakup in GEO: Bridging Numerical Simulations and Ground-Based Observations," AIAA Journal of Spacecraft and Rockets, 2026-04-A36816

Presentations:

“Space Debris Characterization Through Multiband Photometry”, Space capacity allocation for the sustainability of space activities Workshop, Politecnico di Milano, 3-5 Giugno 2026

CONCLUSIONS

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

In the coming years, it will be crucial to bring the phenomenon under control to avoid unmanageable consequences.

CONCLUSIONS

Space debris represents one of the major obstacles to space exploration and the protection of the space environment.

SMALL and MEDIUM telescopes at ground-based observatories can make a substantial contribution to the space debris field

In the coming years, it will be crucial to bring the phenomenon under control to avoid unmanageable consequences.

The background of the image is a depiction of space debris, or orbital trash, floating in space. It consists of numerous small, dark, irregular fragments of varying sizes and shapes, some resembling pieces of metal or plastic. These fragments are scattered across the frame, with a higher density in the upper right and lower right areas. A bright, glowing blue and white diagonal streak, likely representing the Earth's atmosphere or a bright celestial body, runs from the bottom left towards the top right, creating a sense of depth and movement. The overall color palette is dominated by the cool blues and whites of the light source, contrasted with the dark, metallic grays of the debris.

THANK YOU!!