Artificial space objects characterization using low- and high-resolution spectroscopy

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Outline

- Motivation for artificial space objects characterization
- Instrumentation and methods
- Laboratory measurements
- Observations
- Conclusions

Motivation

Motivation

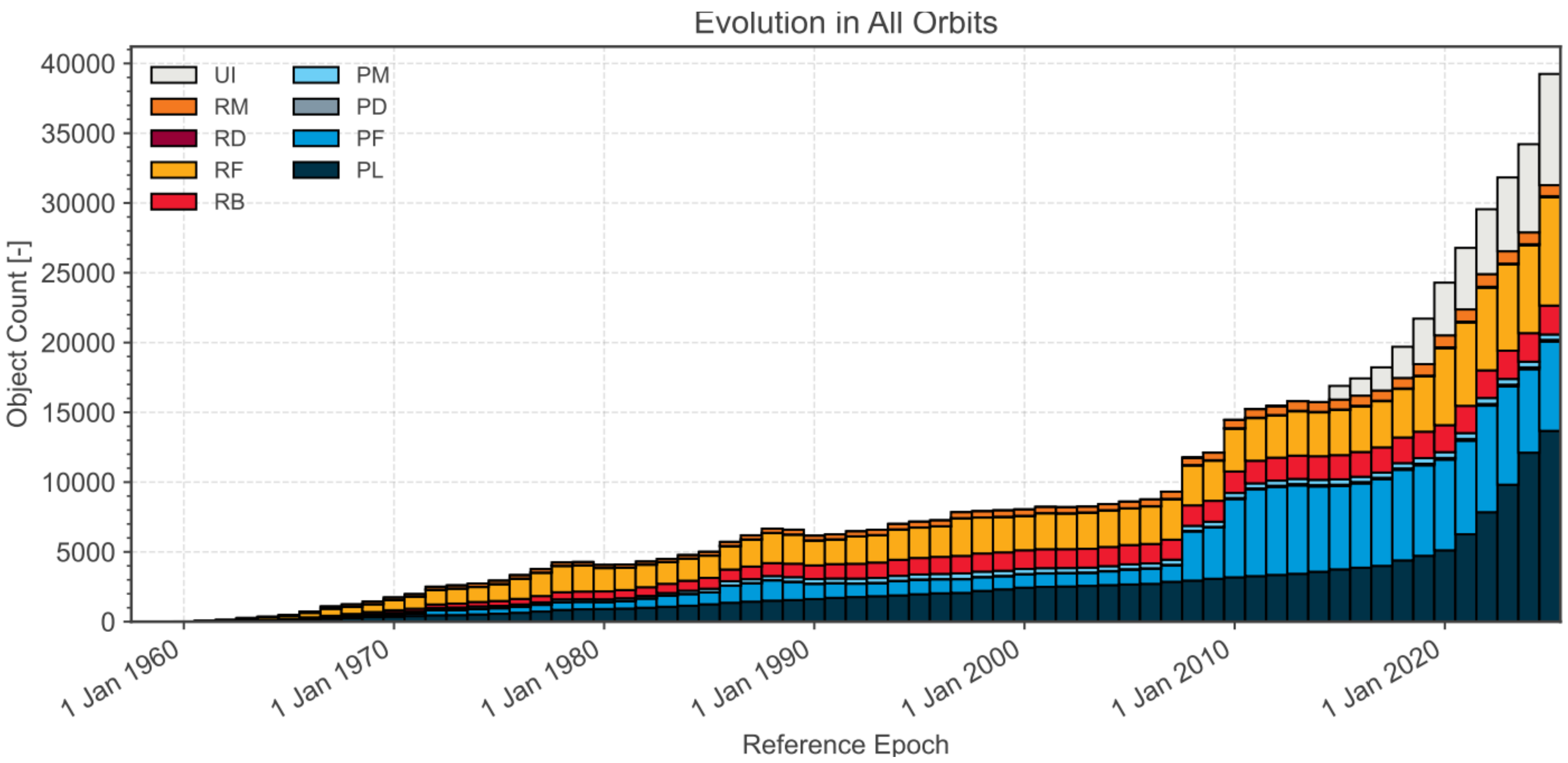


Figure: Evolution of number of objects in geocentric orbit by object class. Source: ESA (2025).

Motivation

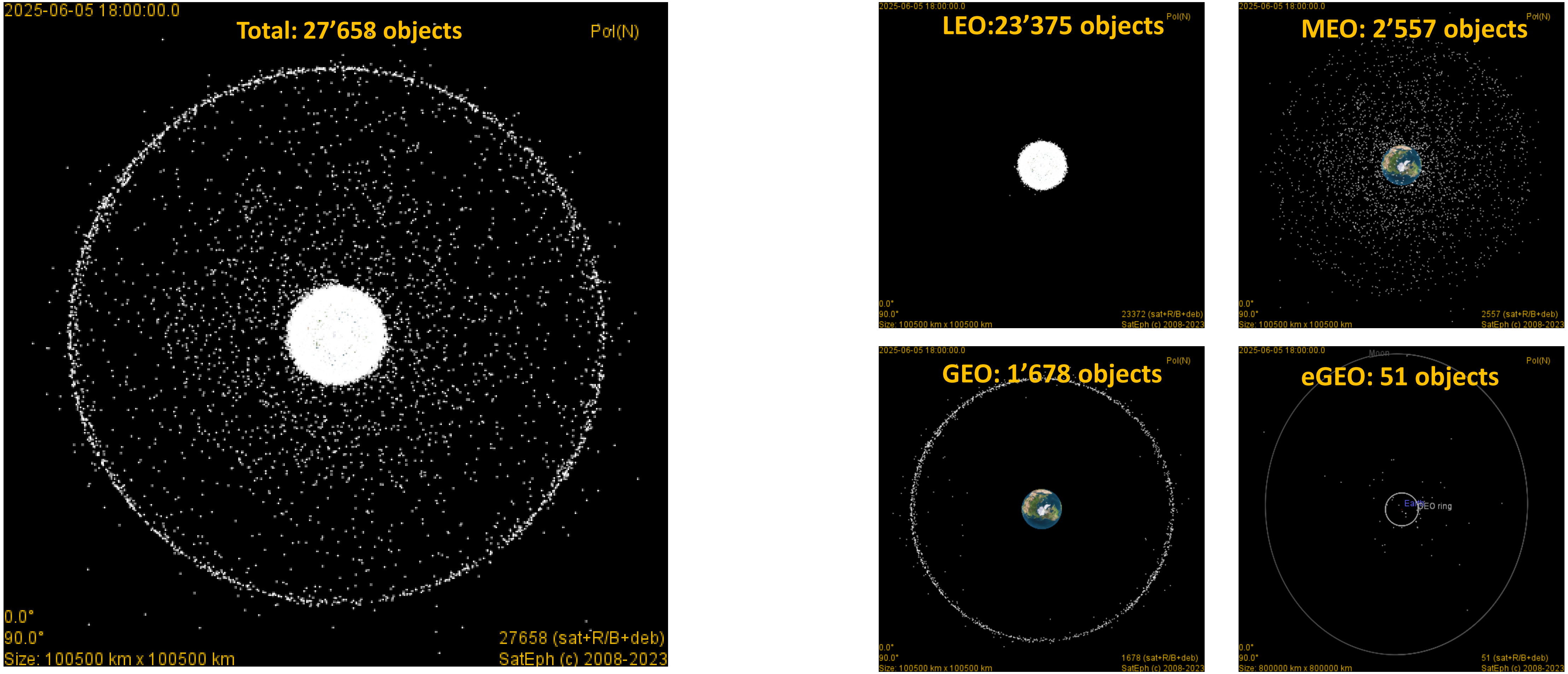
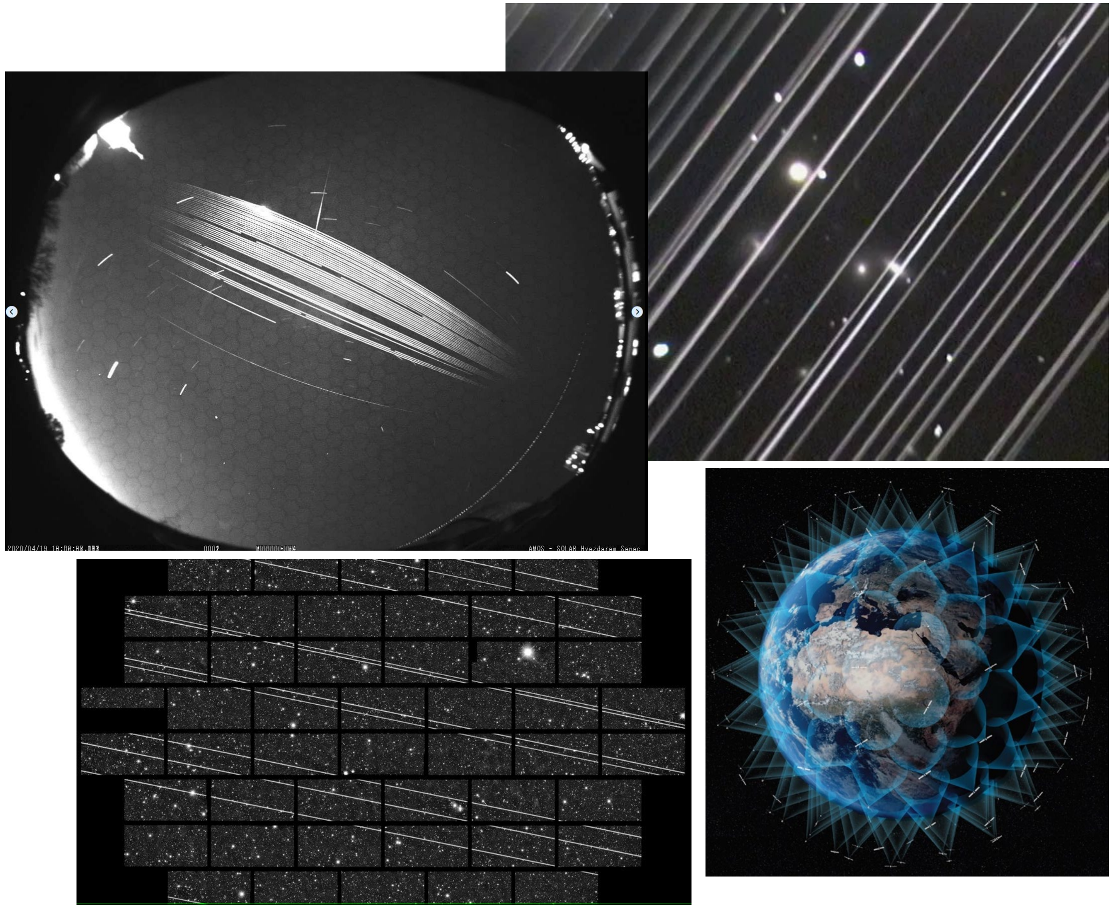


Figure: Population of artificial space objects as a function of given orbital region to date 2025-06-05. Seen 10% increase comparing to 2023, ~30% for LEO S/C . Data taken from: www.space-track.org. Generated by SatEph.

Motivation

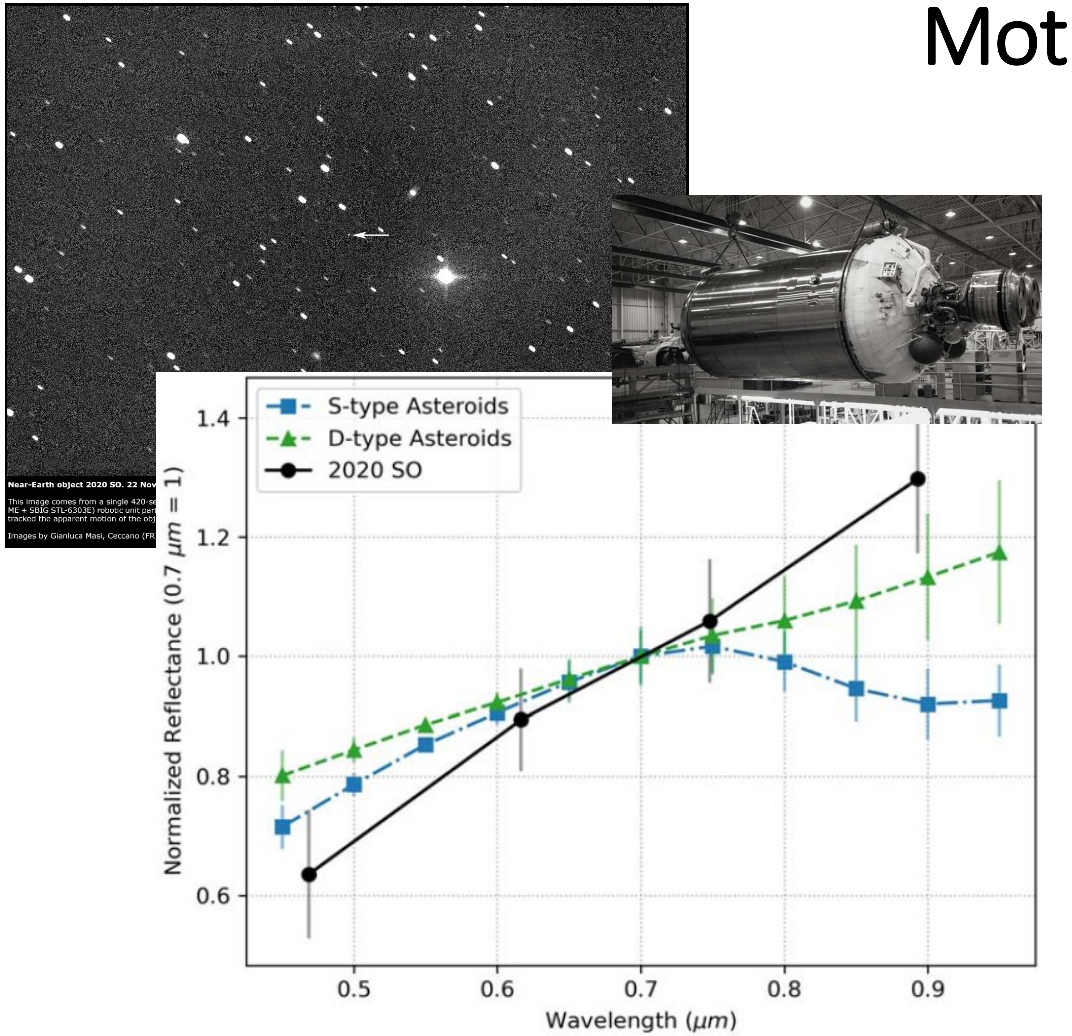


Sources: Comenius University, NSF's National Optical-Infrared Astronomy Research Laboratory, Lowell Observatory in Arizona, SOLAR. Vera C. Rubin Observatory, space.com, Canon

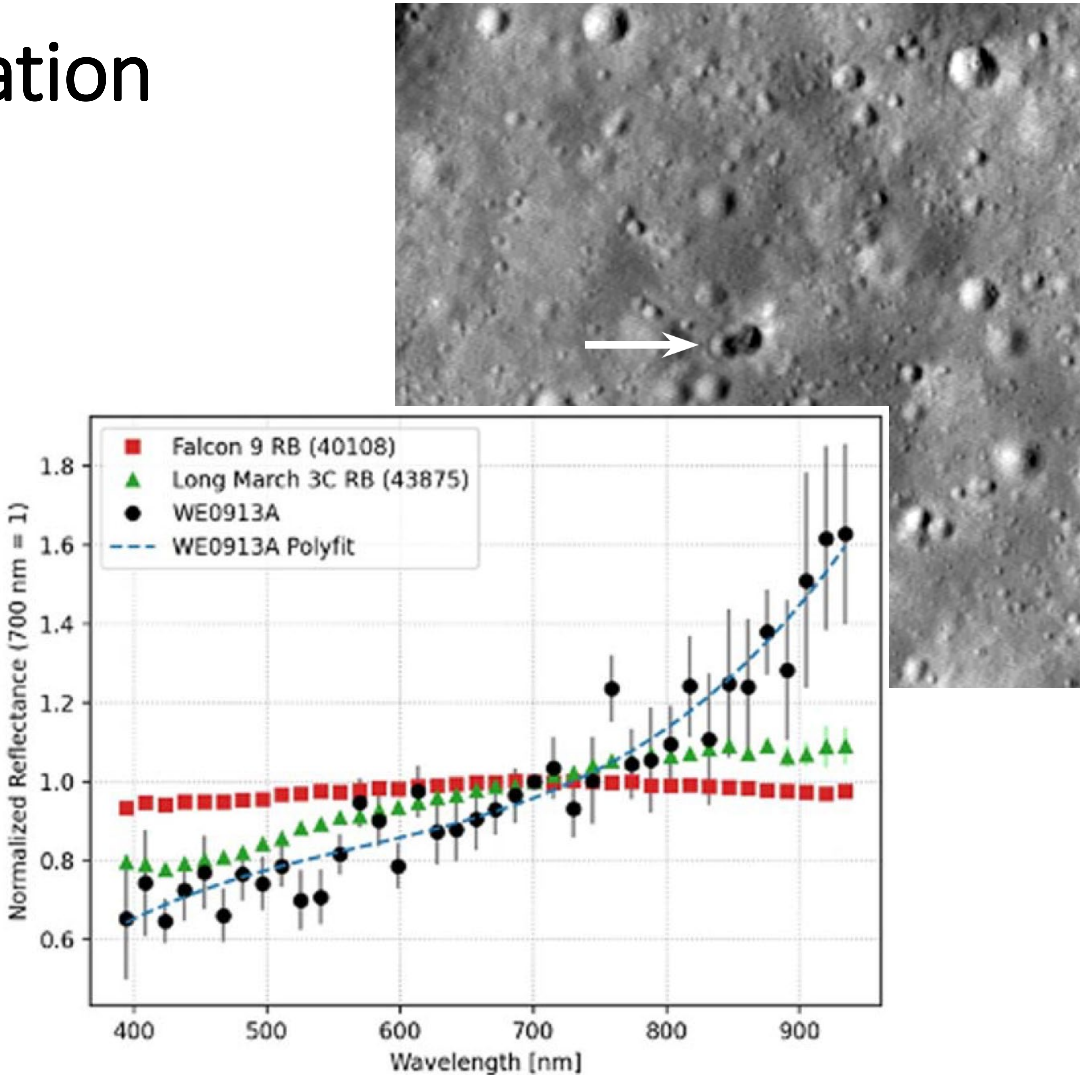
Fig. - Up: AMOS cameras detection of CZ-3B R/B re-entry in October 2020. Bartková et al. (2024)

Fig. - Left: A piece of debris linked to the Crew-7 Dragon trunk that landed in North Carolina in May 2024. **Right:** Damage to Alejandro Otero's Florida home after being hit by debris. Credit: Collectspace.com.

Motivation



Obr. – **Top:** Object 2020 SO observed with The Virtual Telescope Project. **Center:** Surveyor 2 Centaur upper stage during installation in 1962. Source: **NASA**. **Down**: Photometric color spectrum of 2020 SO taken with the LBT compared to the average visible spectrum for S- and D-type asteroids in the Bus–DeMeo taxonomy. Error bars represent 1σ uncertainties and all spectra are normalized at 0.7 μm. **Source**: Battle et al. (2024)



Obr. – **Up:** Two craters formed during impact of object WE0913A on 4th of March 2022 with diameters of 18 a 16 meters. **Right:** Collision trajected of unknown object with Moon. **Source:** NASA, Campbell et al. (2023).

Motivation

- ESA established initiative **Zero Debris Charter** which covers several different topics concerning the sustainability of space activities, including **Dark&Quite skies** (D&QS) activities

- **IAU** the main initiator for D&QS (e.g. UN COPUOS), establishing AIU **Centre for the Protection of Dark and Quite Sky** (CPS)

- UNIBA prime in the ongoing **ESA activity** - Artificial space objects characterization using laboratory and ground-based optical measurements (**ArtSPOC**), Comenius + SK industry + IT science institute

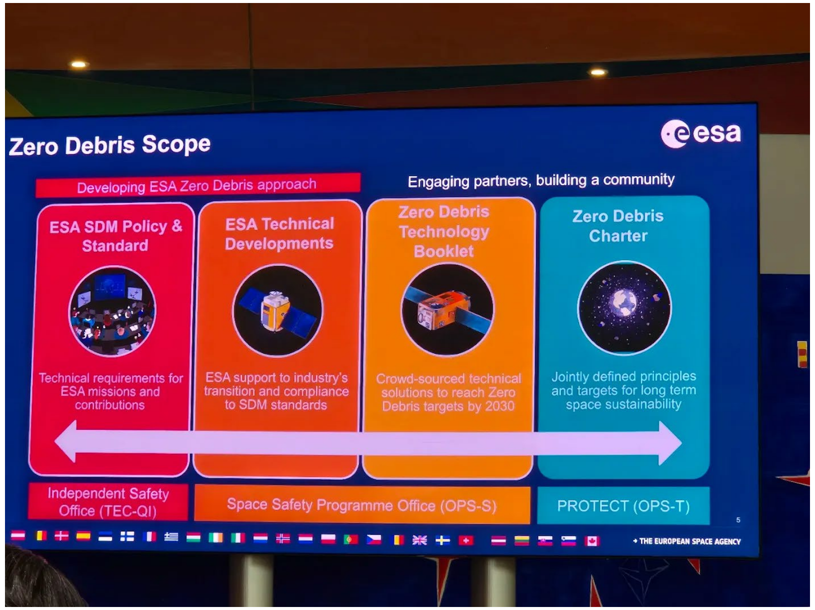
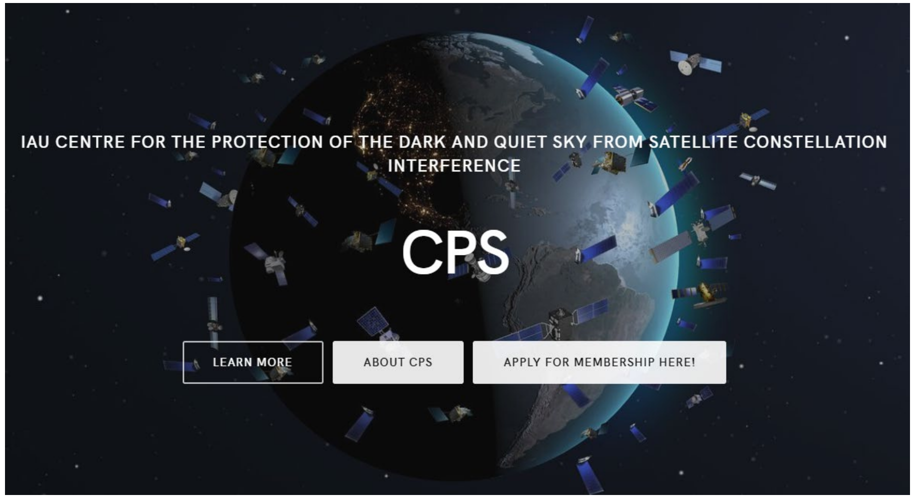


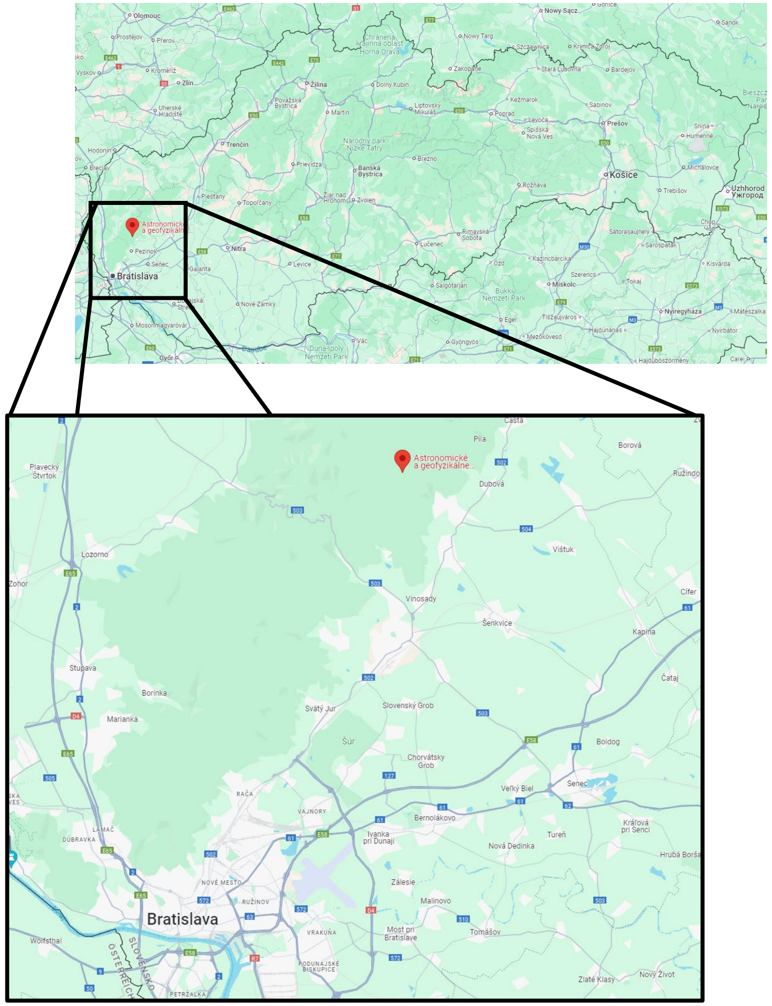
Fig. – Zero Debris Scope presented on European Space Debris Confernce, Bonn 2025.



Instrumentation and methods

Instrumentation

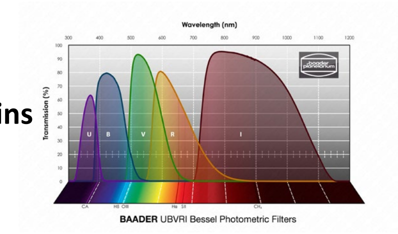
- AGO - Astronomical and Geophysical Observatory in Modra, Slovakia



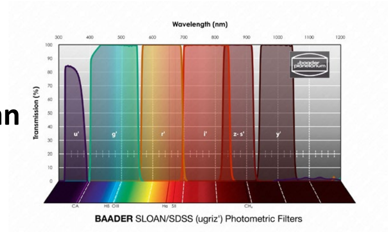
Instrumentation

- Developed own software, e.g., LLTC, CSA, etc. (Šilha et al., 2020)
- Transformed to space debris instrument in 2016-2021 within ESA R&D projects, science recently extended to NEA
- AGO70 – MPC M34, location: Modra, Slovakia.

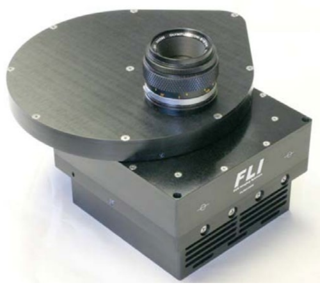
Johnson/Cousins



Sloan



CCD FLI Proline PL1001E



CMOS FLI Kepler KL400 back illum.

European Space Agency

Telescope design	Newton
Mount	Equatorial (Open fork)
Camera	CCD
Dimension	1024 x 1024
Primary mirror diameter [m]	0.7
Focal length [mm]; focal ratio	2962.0; f/4.2
FOV [arc-min]	28.5 x 28.5
iFOV [arc-sec/pix]	1.67

Figure: AGO70 telescope at Astronomical and Geophysical Observatory in Modra, Slovakia (AGO70).

Instrumentation

- New program at AGO70 with focus on collecting and analyzing reflectance spectra
- Custom made by INAF Osservatorio Astronomico di Brera (team of A. Bianco)
- Currently being commissioned and tested within ESA RPA1 - Small NEO characterization through Spectroscopy (SNEOS)
- To be adapted and used in ESA RPA 2 activity - Artificial space objects characterization using laboratory and ground-based optical measurements (ArtSPOC)

No.	Component	Item	Manufacturer	Description
1.	Telescope	AGO70	AGO Modra	70-cm telescope at AGO Modra Observatory [RD-6]
2.	Dichroic mirror	DMLP950	Thorlabs	Ø1" Longpass Dichroic Mirror, 950 nm Cut-On
3.	Astigmatism correcting element	LJ1144RM-B	Thorlabs	f = 500.0 mm, Ø1", N-BK7 Plano-Convex Round Cyl Lens, ARC: 650 - 1050 nm
4.	Guiding camera	DMK51AU02.AS	The ImagingSource Astronomy Cameras	Sony ICX274AL progressive scan chip
5.	Slit	S50K	Thorlabs	Ø1" Mounted Slit, 50 ± 3 µm Wide, 3 mm Long
6.	Collimator	49-358	Edmund Optics	25mm Dia. x 75mm FL, VIS-NIR Coated, Achromatic Lens
7.	Window	37-006	Edmund Optics	25mm Dia., 3mm Thick, VIS-NIR Coated λ/4 N-BK7 Window
8.	Diffraction grating	VPHG	INAF	Table 2
9.	Detector	ASI294MM Pro	ZWO Astronomy Cameras	Sony CMOS IMX492 Sensor
10.	2nd order filter		Thorlabs	Table 4

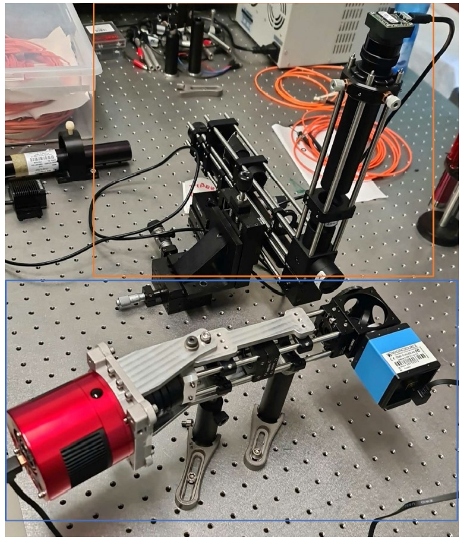
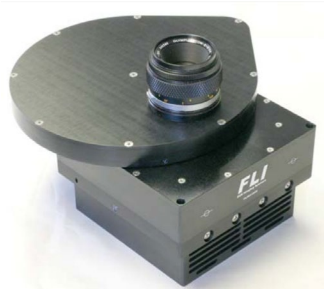


Fig. – Calibration of the AGO70 performed in INAF laboratory.

Fig. – Final installation of spectrograph on AGO70 performed in August 2024.

Instrumentation



CCD FLI Proline PL1001E

AGO70 Spectrograph

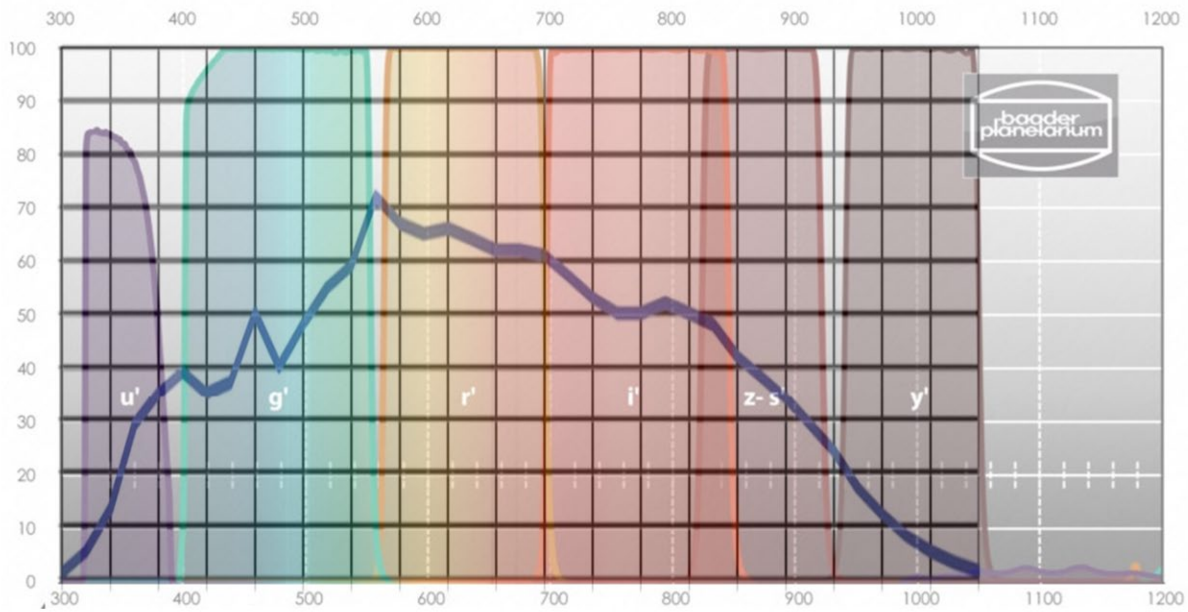


Figure: Quantum efficiency curve of CCD FLI Proline PL1001E and Sloan Baader filters. Source: Baader, FLI

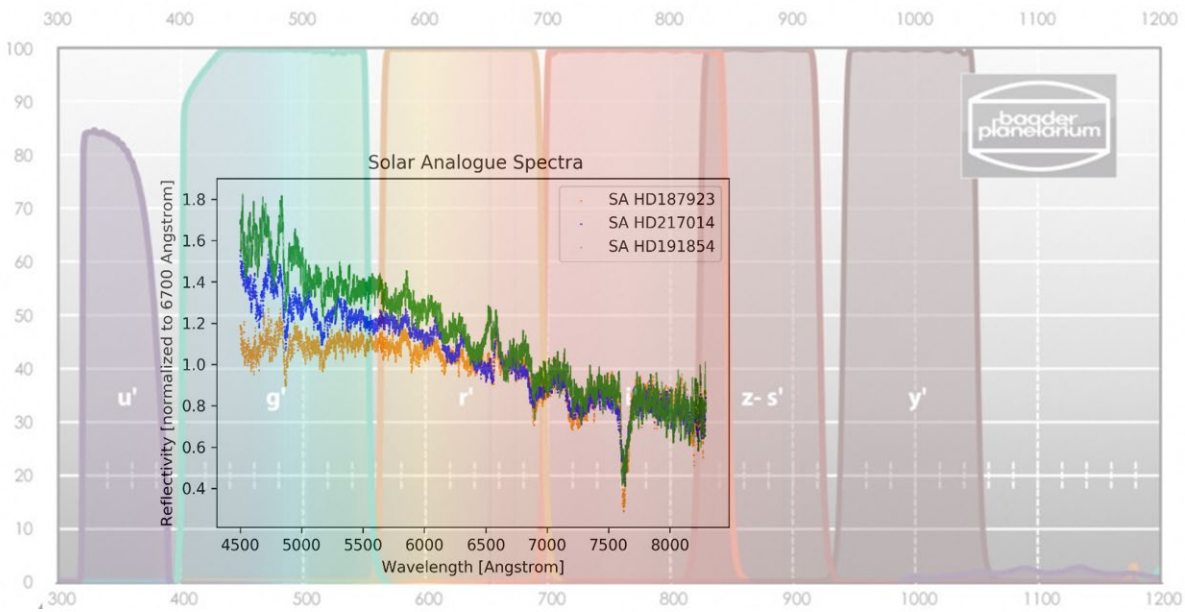


Figure: Comparison between AGO70Spec wavelength range and Sloan Baader filters transmissions. Source: Baader

Methods

- Inspiration for the object taxonomy from NEA/MBA community, e.g. DeMeo and Carry (2013).
- Class boundaries defined from magnitudes transferred to reflectances to compare them to taxonomic system based on reflectance data.

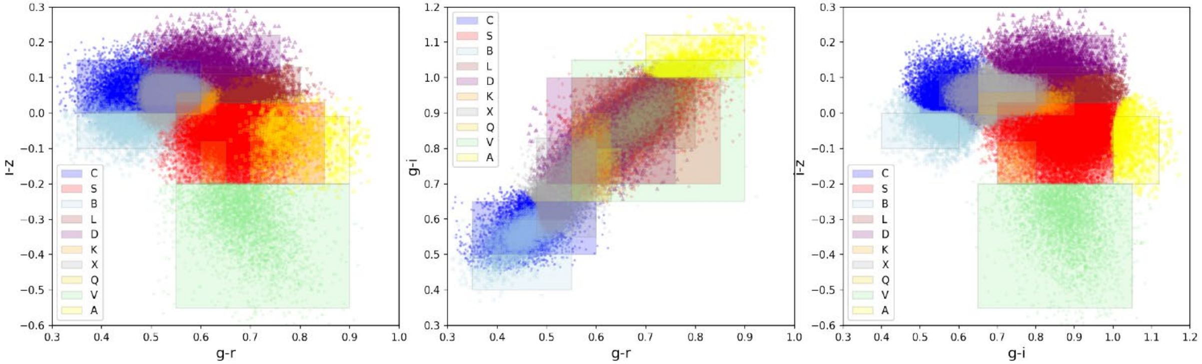


Figure: Taxonomy of Solar System Objects (SSOs). Boxes are boundaries of the taxonomic classes. Color points mark the classification of the 72 043 asteroid measurements that have color uncertainties smaller than 0.05 mag. Source: Sergeyev and Carry (2021)

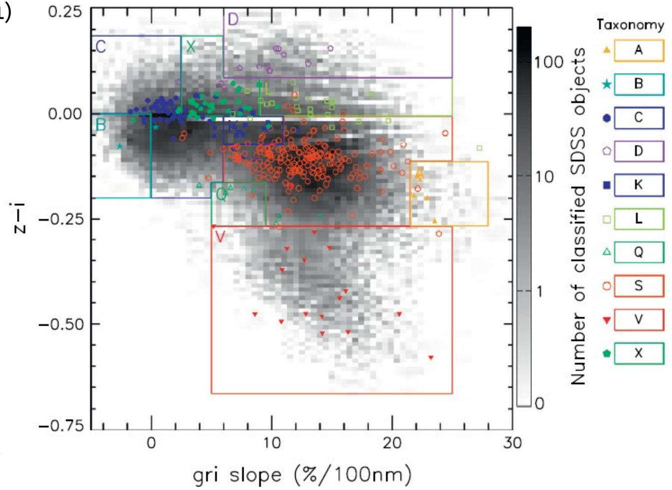


Figure: Boundaries used to classify SDSS data into taxonomic classes. The colored points are the spectra from the Bus-DeMeo taxonomy (DeMeo et al. 2009) converted to SDSS colors. Source: DeMeo and Carry (2013).

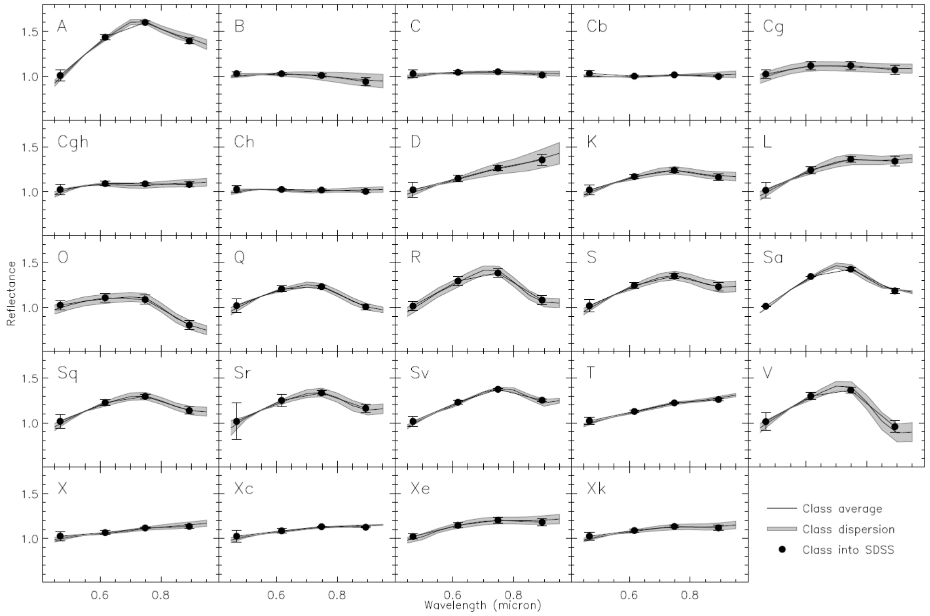
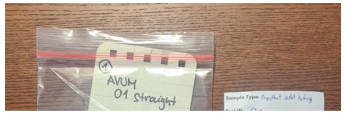


Figure: Average Bus-DeMeo (DeMeo et al. 2009) spectra converted to SDSS colors used to define the classification boundaries. The black dots (with 1 standard deviation from the mean plotted) represent the average Bus-DeMeo spectra converted into SDSS colors. The u′ filter is extrapolated from the data because the spectra do not cover those wavelengths (the u′ filter is not used in the classification of SDSS data, however). The gray background plots the average spectrum plus one sigma for comparison with the colors. Because the Cg, O, and R classes are defined by a single object the standard deviation is set to 0.1. DeMeo and Carry (2013).

Laboratory measurements

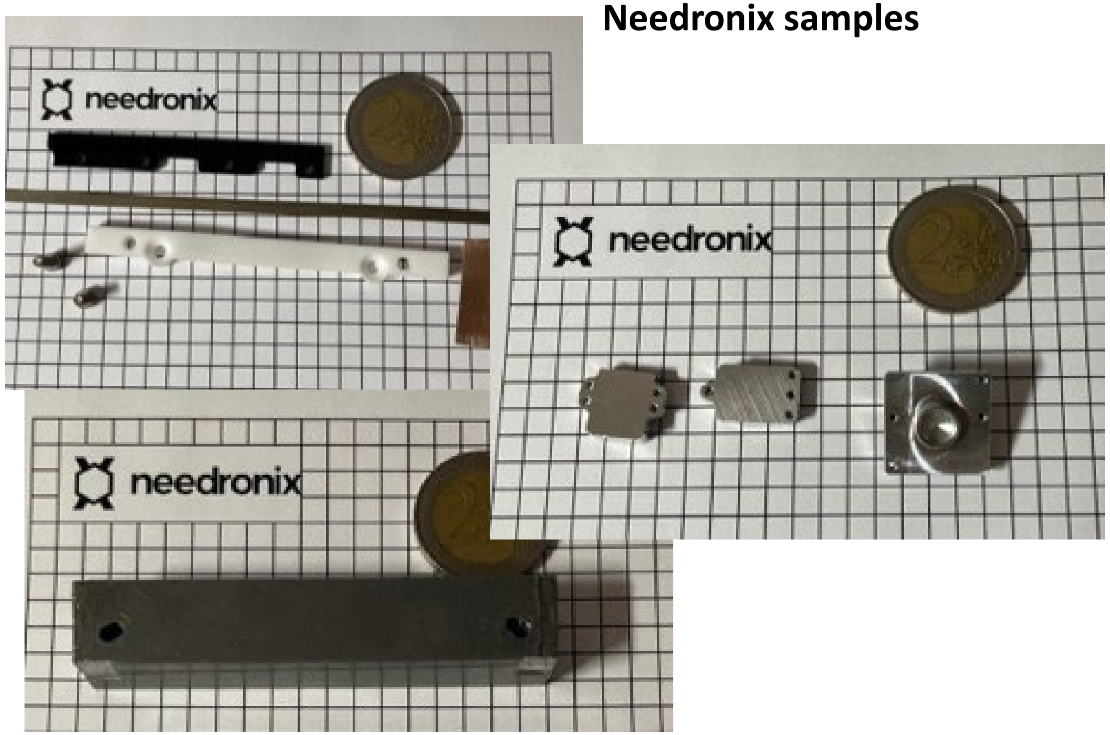
Laboratory measurements

- Collecting reflectance spectra of main material types (Žilková et al., 2024):
  Metals, Aluminium Alloys, Plastics, Paints, Solar cells and other more rare types of materials



- Samples (~60) provided by two major partners: ESA and Needronix s.r.o.

Needronix samples

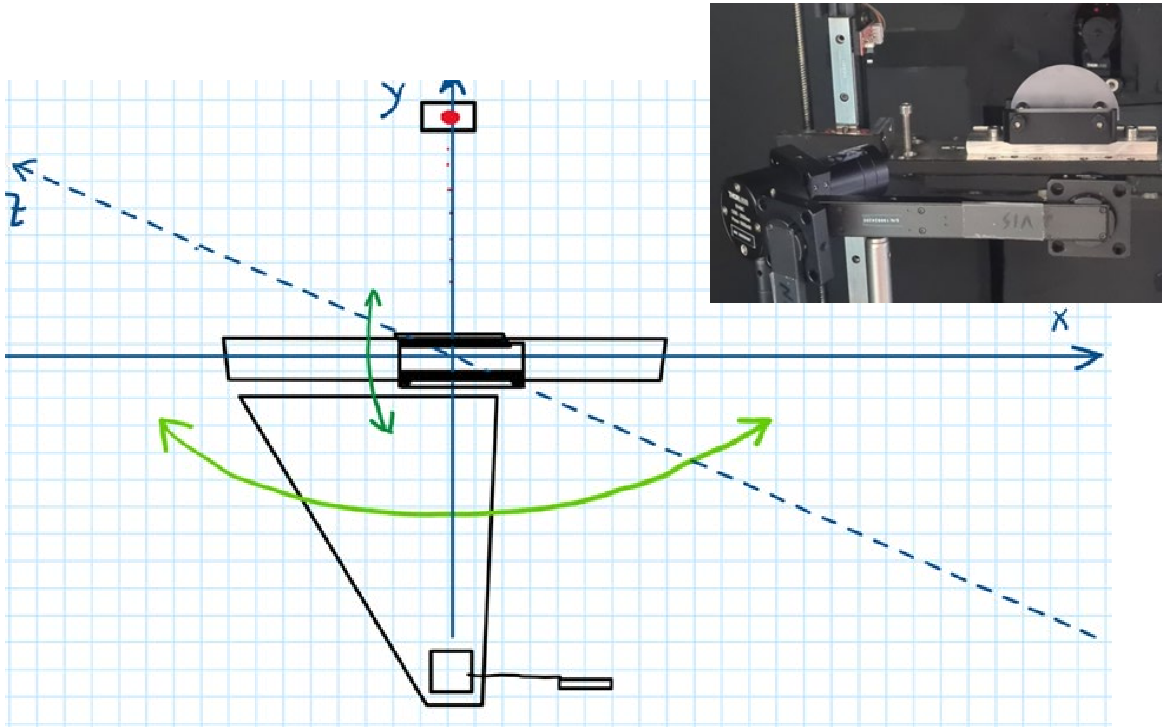


Laboratory measurements

- Laboratory measurements conducted at the INAF Osservatorio Astronomico di Brera

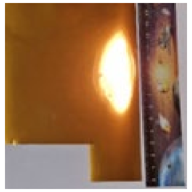
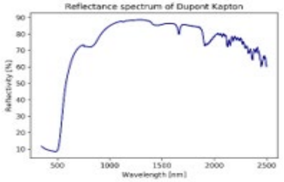
- **Jasco V770 spectrophotometer – already used**
- **Constrained sample size – 10x10 cm**

- **INAF custom set up – already used**
- **Can fit larger samples – more flexible**



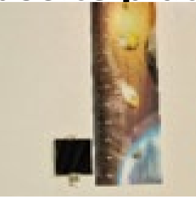
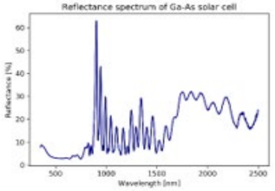
Laboratory measurements

- Types of spacecraft samples identified:
  1. **Foils (thermal insulations, MLI's, Kaptons...)**

Dupont, Kapton polyimide foil: shiny, copper colored
Supplier: Goodfellow

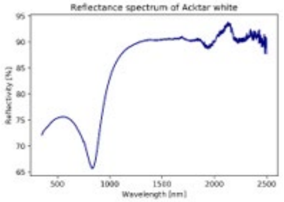
  2. **Metal and composite plates (copper, aluminum alloys, solar cells)**

Galium-Arsenide multijunction solar cell, smooth, black
Supplier: Needronix

  3. **Coatings (paints and thin films)**

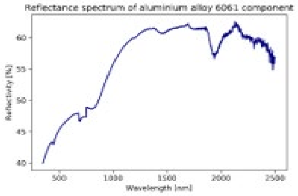




Acktar white coating, smooth matte white color.
Supplier: Needronix

  4. **Irregular components (screws, bolts, tubes, wires...)**

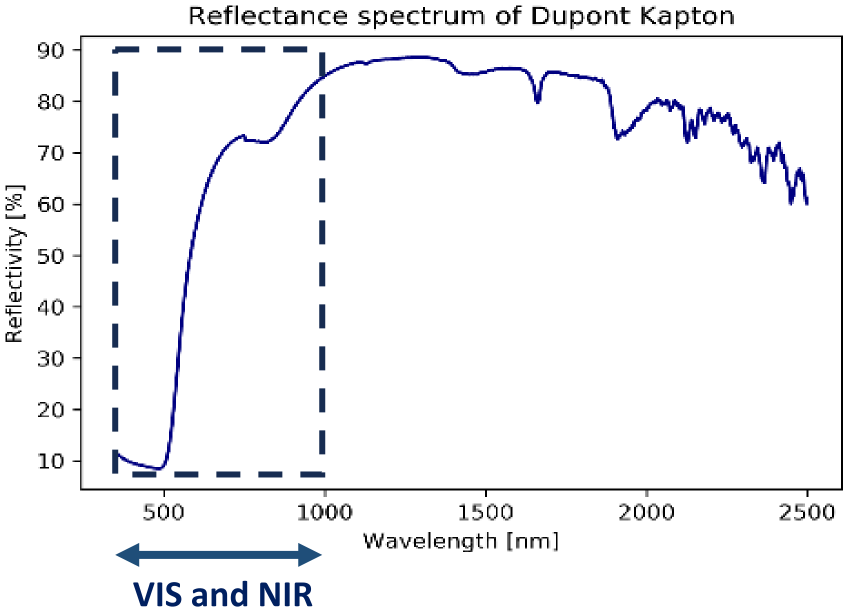




Aluminum alloy 6061 component, polished, rough, silvery
Supplier: Needronix

Laboratory measurements

Dupont, Kapton polyimide foil: shiny, copper colored
Supplier: Goodfellow



Aluminum alloy 6061 component, polished, rough, silvery
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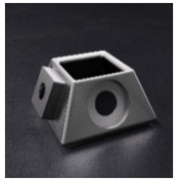
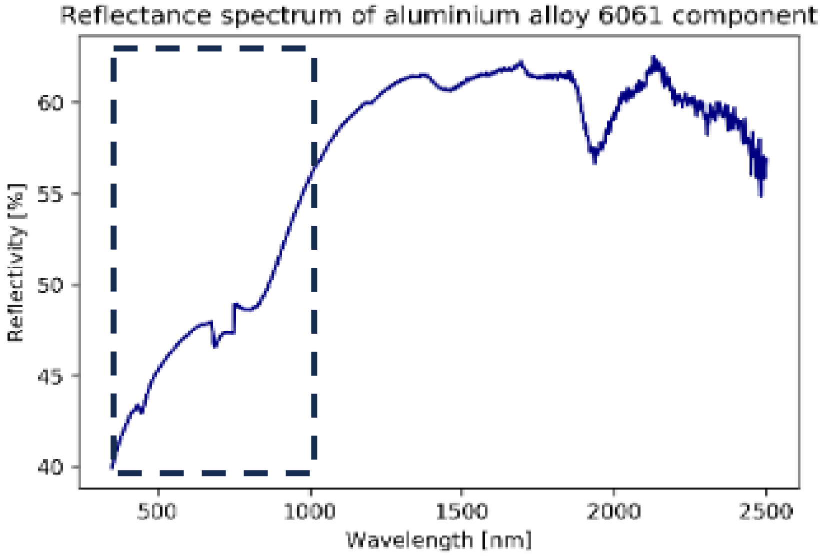




Laboratory measurements

- Classification of the materials according to their spectra shape as defined by Žilková et al. (2024) based on absorption features

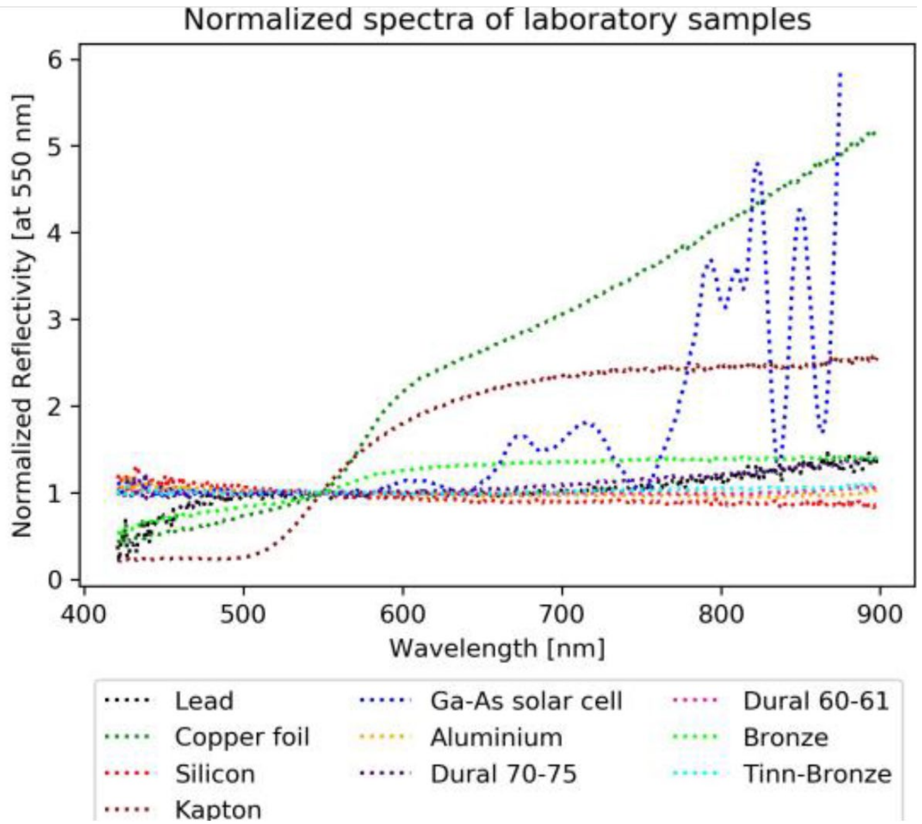


Figure: Reflectance spectra of aerospace material samples measured in a laboratory with absolute reflectivity relative to Silicon and normalized to 550 nm. Žilková et al. (2024).

$$Absorption = \left(1 - \frac{\overline{f(x_n)}}{\overline{f(x_{n+1})}}\right) * 100$$

B – blue wavelengths: 420 – 440 nm,
V – visible wavelengths: 520 – 540 nm,
R – red wavelengths: 650 – 670 nm,
I – infrared wavelengths: 800 – 820 nm,

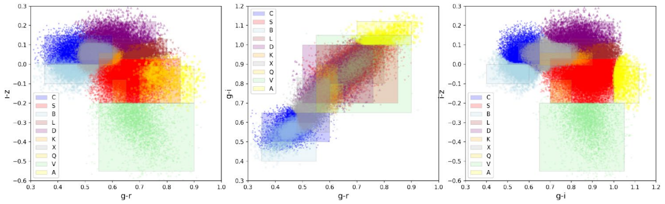
Table: Summary of absorption classes of different material spectra measured in a laboratory and absorption types identified within spectra of artificial space objects observed with ZimMain telescope operated by AIUB. Žilková et al. (2024).

Absorption type materials	ZimMain Spectra
Abs B **$B > 30$, $V < 10$** Glass Epoxy Lead	
Abs B- **$10 < B < 30$, $V < 10$** Transparent POSS White POM White PET White POSS White Polyimide	CZ-3B (43247) CZ-3B (43624) CZ-3B (45864)
Abs B & V **B, $V > 30$** Copper Bronze (Cu + Al) Copper Polyimide	CZ-3B (43110) ERS-2_3, ERS-2_5, ERS-2 11 (23560) Iridium921 glint, Iridium921 noglint (24873) Glonass 86 (28510) Glonass 134 (40315) Lageos 1 (8820) Iridum 33 (24943)
No Abs **B, $V < 10$** Aluminium Dural 60-61 Dural 70-75 Stainless steel Black glass fiber Black Polyimide Silicon Tinned Bronze Transparent PET	ERS-2 _1 (23560)
Abs V **$B < 10$, $V > 30$** Ga-As solar cell	Starlink 1306 (45362)
Abs I **$I > 30$** Copper Glass Epoxy Ga-As solar cell	

Observations

Observations – MBAs colors

- Test observations with AGO70 of MBAs asteroids (Kuksenko et al., 2025)
- Calculated colors and color indices



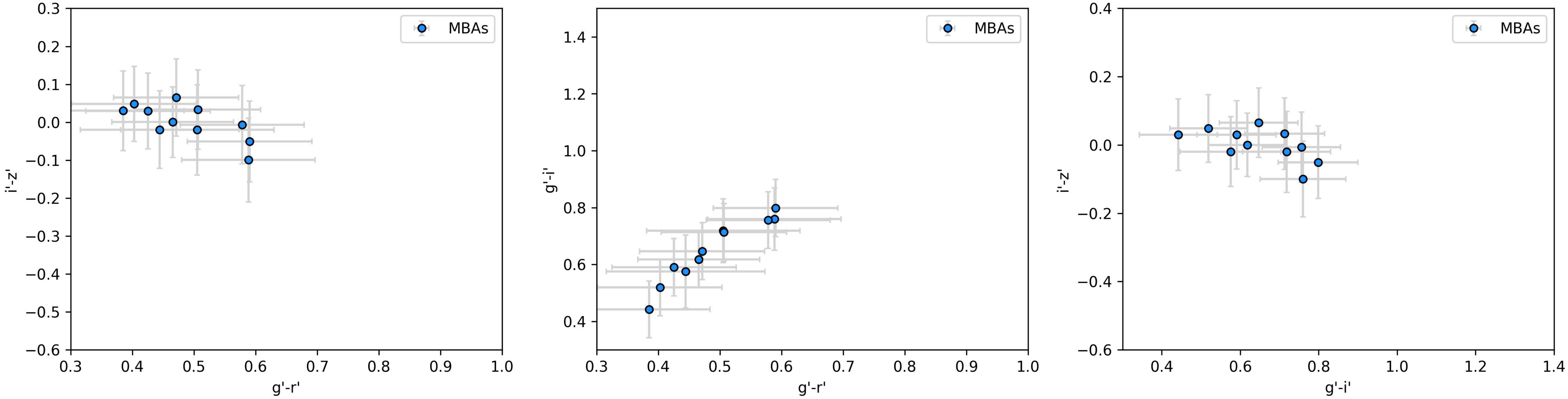


Figure: Color indices *g'-r'* vs *I'-z'*, *g'-r'* vs *g'-I'*, *g'-I'* vs *I'-z'* for selected Main-Belt Asteroids (MBAs) observed by AGO70 telescope in February 2025. Top: Shown taxonomy classes as defined by DeMeo, Sergeyev and Carry (2021).

Observations – MBAs pseudo-spectra

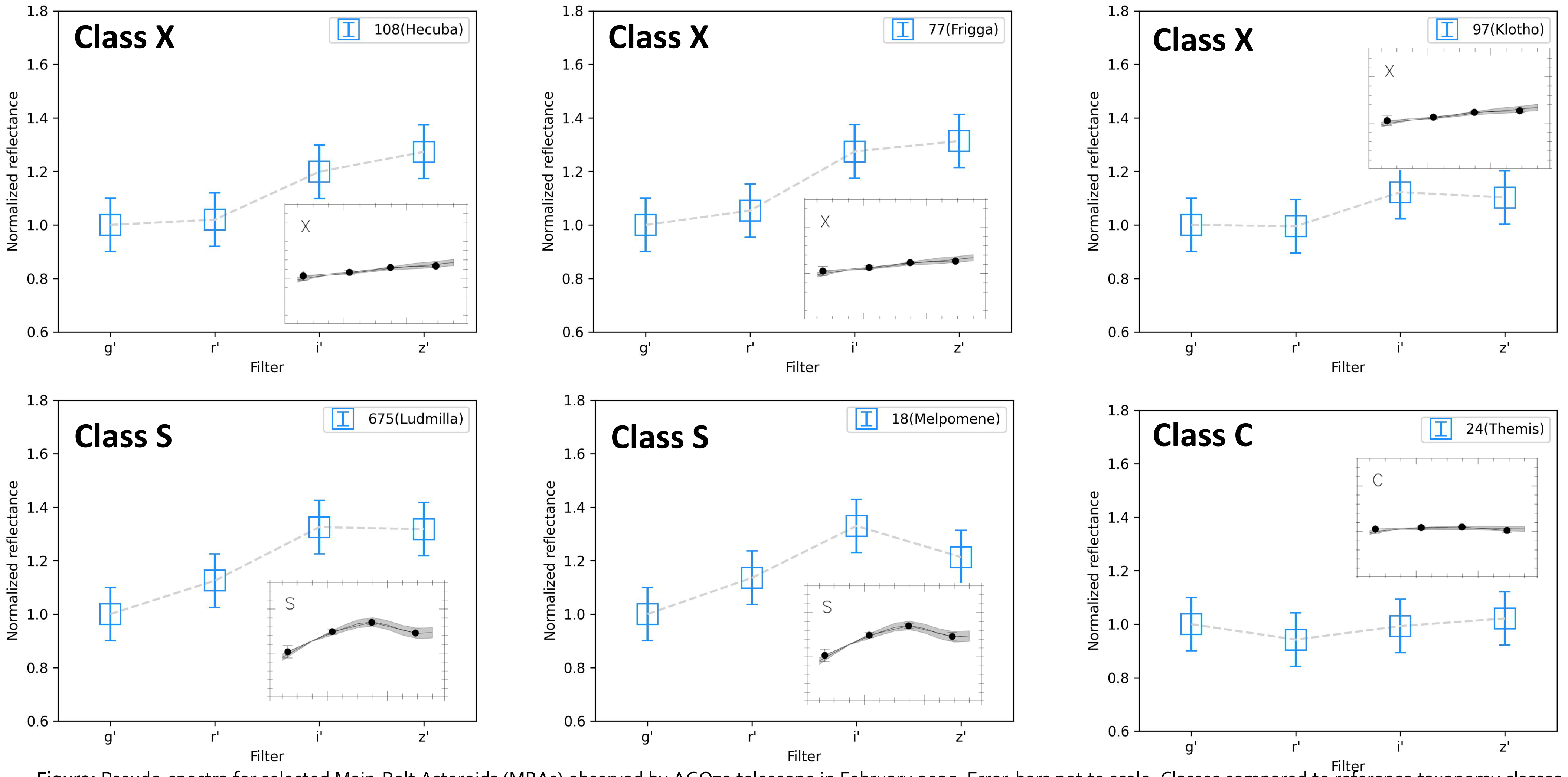


Figure: Pseudo-spectra for selected Main-Belt Asteroids (MBAs) observed by AGO70 telescope in February 2025. Error-bars not to scale. Classes compared to reference taxonomy classes published by DeMeo and Carry (2013).

Observations - JWST colors

- Test observations with AGO70 of JWST
- Object with slow apparent angular movement, object in opposition point
- Not rotating object

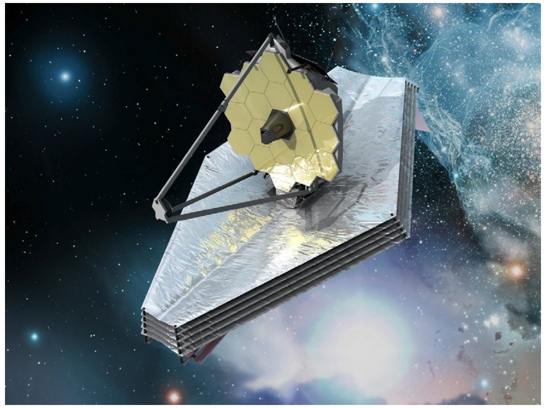


Figure: James Webb Space Telescope (ESA). Source: ESA

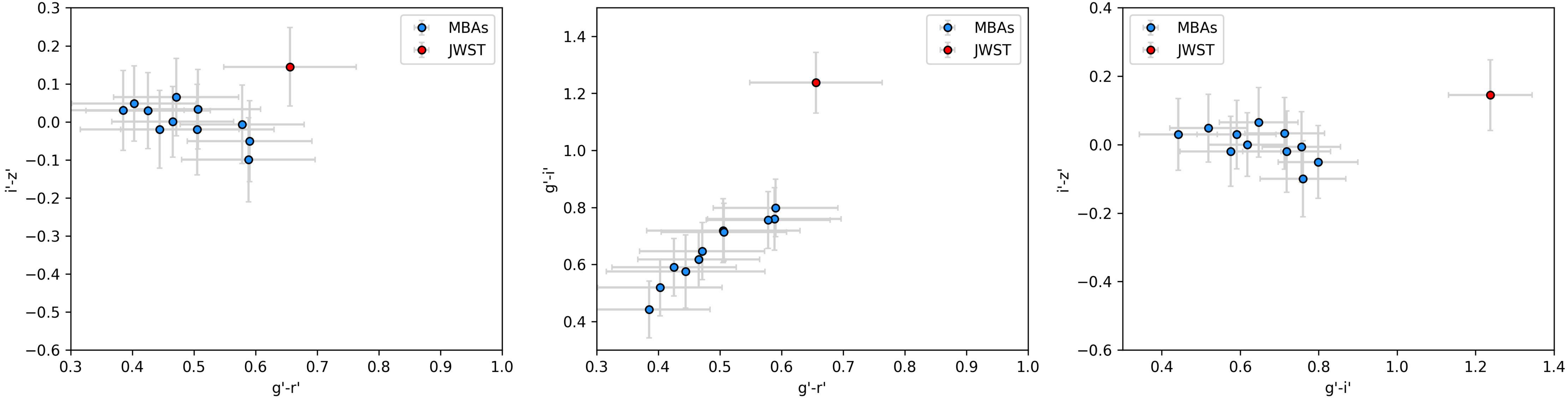


Figure: *g′-r′* vs *I′-z′*, *g′-r′* vs *g′-I′*, *g′-I′* vs *I′-z′* for selected Main-Belt Asteroids (MBAs) and JWST observed by AGO70 telescope in February 2025.

Observations – JWST pseudo-spectrum

- Test observations with AGO70 of JWST
- Object with slow apparent angular movement, object in opposition point
- Not rotating object

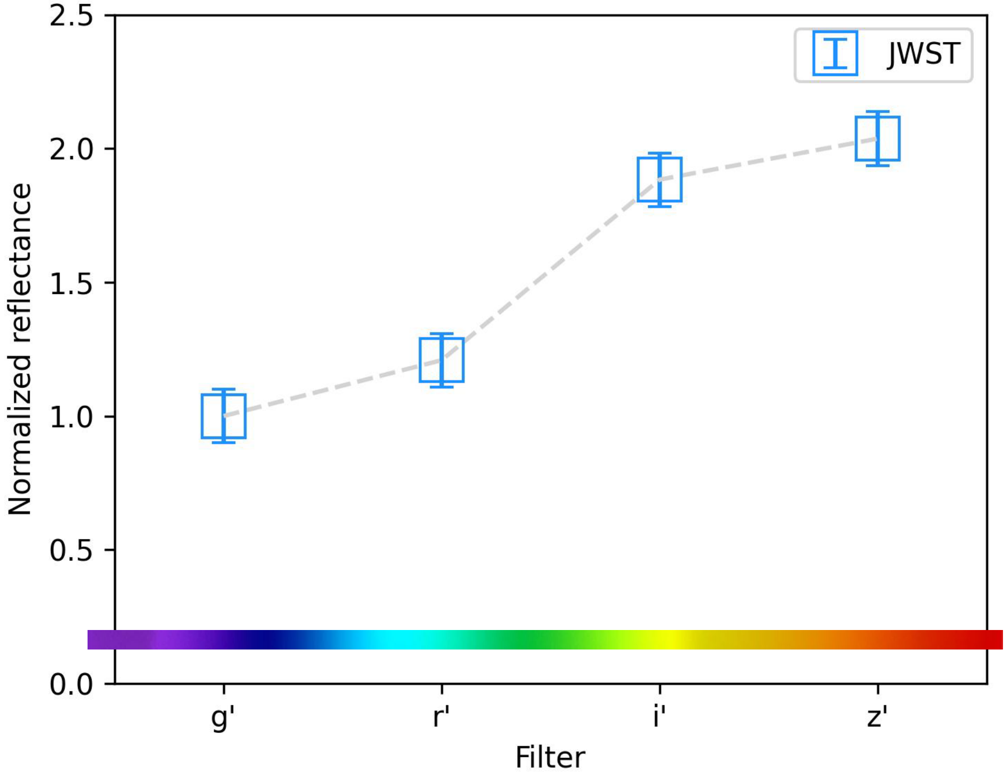
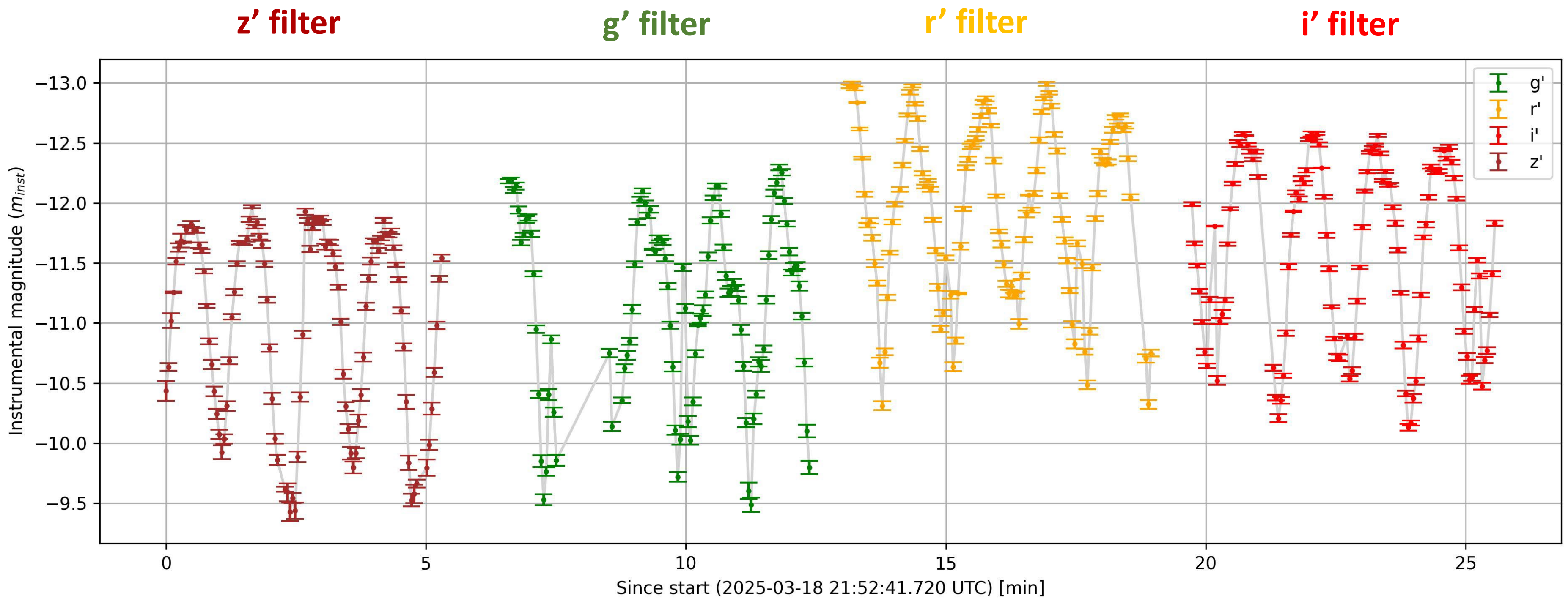


Figure: Pseudo-spectrum spectrum of JWST observed by AGO70 telescope in February 2025.

Figure: James Webb Space Telescope (artist concept) and its thermal protection foil (real photo). Source: NASA

Observations

- Expected present apparent rotation of the objects affecting the incoming signal, between seconds to minutes (Hrobár et al., 2024)
- Fast rotating objects challenging for multi-color observations and processing (Zigo et al., 2023)
- Example of Long March 3 third stage (CZ-3B R/B), cylinder with h=12.4m and w=3m
- Expected white color, data reduction ongoing…



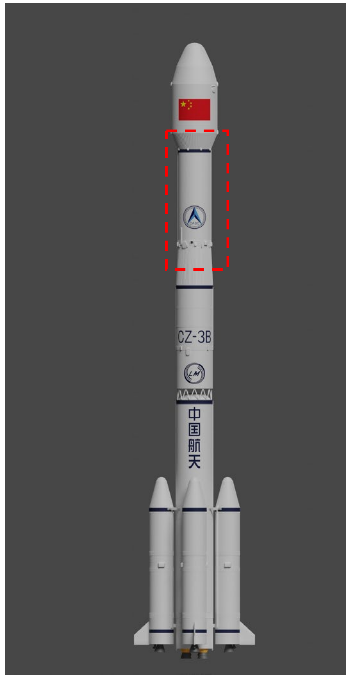


Figure: Light curves of objects CZ-3B R/B (ID 24087C) observed with AGO70 telescope during February 2025 using Sloan filters.

Conclusions and nest steps

- Currently finalizing laboratory data collection (to be published) and preparing to convert the artificial material taxonomy based on laboratory spectra to pseudo-spectrum system
- Collecting and processing photometric data of artificial space objects (GEO satellites and rotating upper stages) using AGO70 -> color indices to pseudo-spectra
- Collecting and processing spectroscopic data using AGO70Spec + comparison to convoluted laboratory spectra
- Linking Sloan photometry, spectroscopy and laboratory measurements, creating reliable methodology for surface/*material* taxonomy
- Tackle the issue of space weather (Zigo et al., 2025, Sabolová et al., 2024)

References

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Thank you for your attention!

Questions?

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