Space debris research at Comenius University

Jiří Šilha
Matej Zigo, Peter Jevčák, Danica Žilková, Daniela Bártková,
Tomáš Hrobár, Daniel Kyselica, František Dráček

Faculty of Mathematics, Physics and Informatics
Comenius University Bratislava, Slovakia

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Email: jiri.silha@fmph.uniba.sk

www: https://fmph.uniba.sk/en/microsites/daa/division-of-astronomy-and-astrophysics/

Space Safety

Space Debris

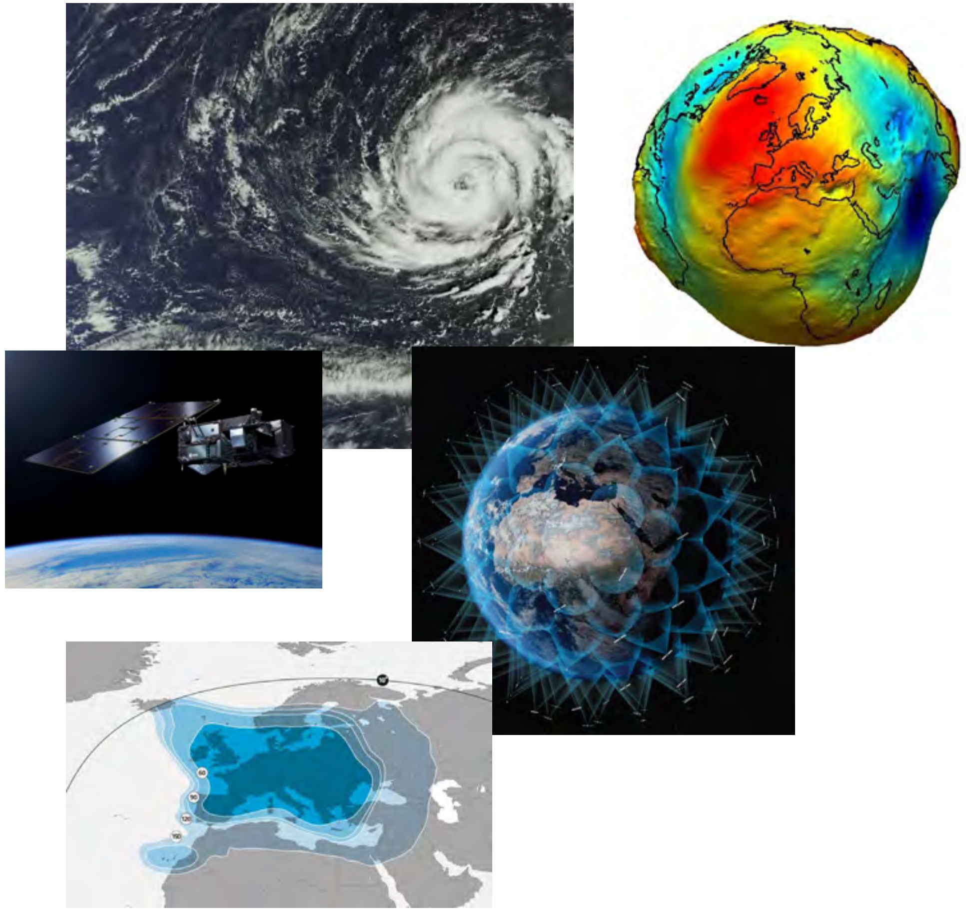
Clean Space

Planetary Defense

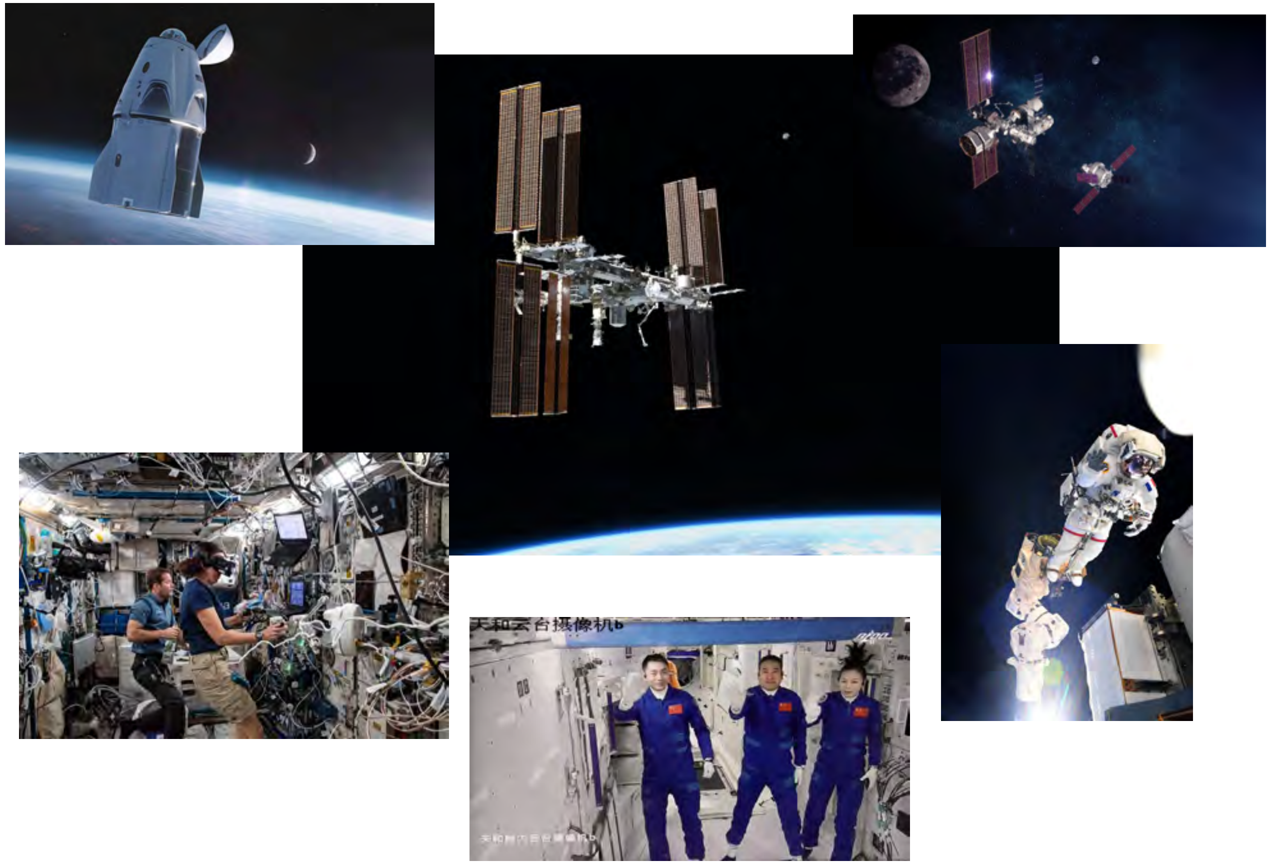
Space Weather

Human space activities

Satellite infrastructure



Manned flights



Space debris overview

- Everything created by human and its activities in space but no longer suit any purpose

Defunct spacecraft

Fig. – Astra GEO satellite Astra 1E/1F
Source: SES Astra

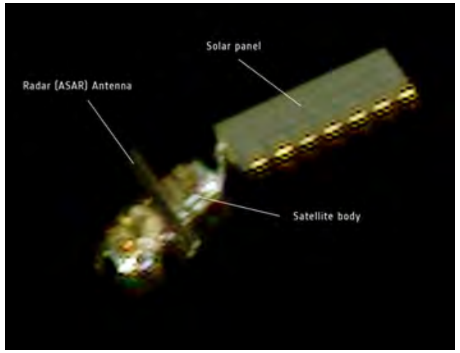


Fig. – ENVISAT, picture taken by Pleiades S/C
Source: ESA/CNES

Fragments

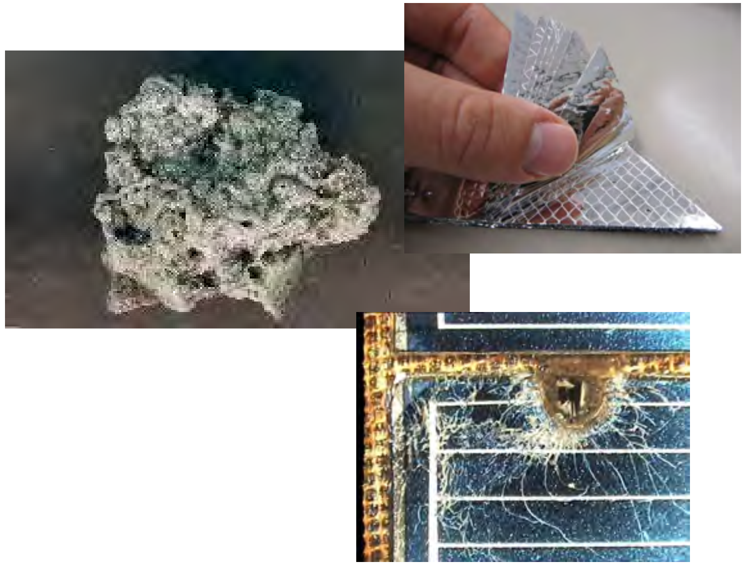
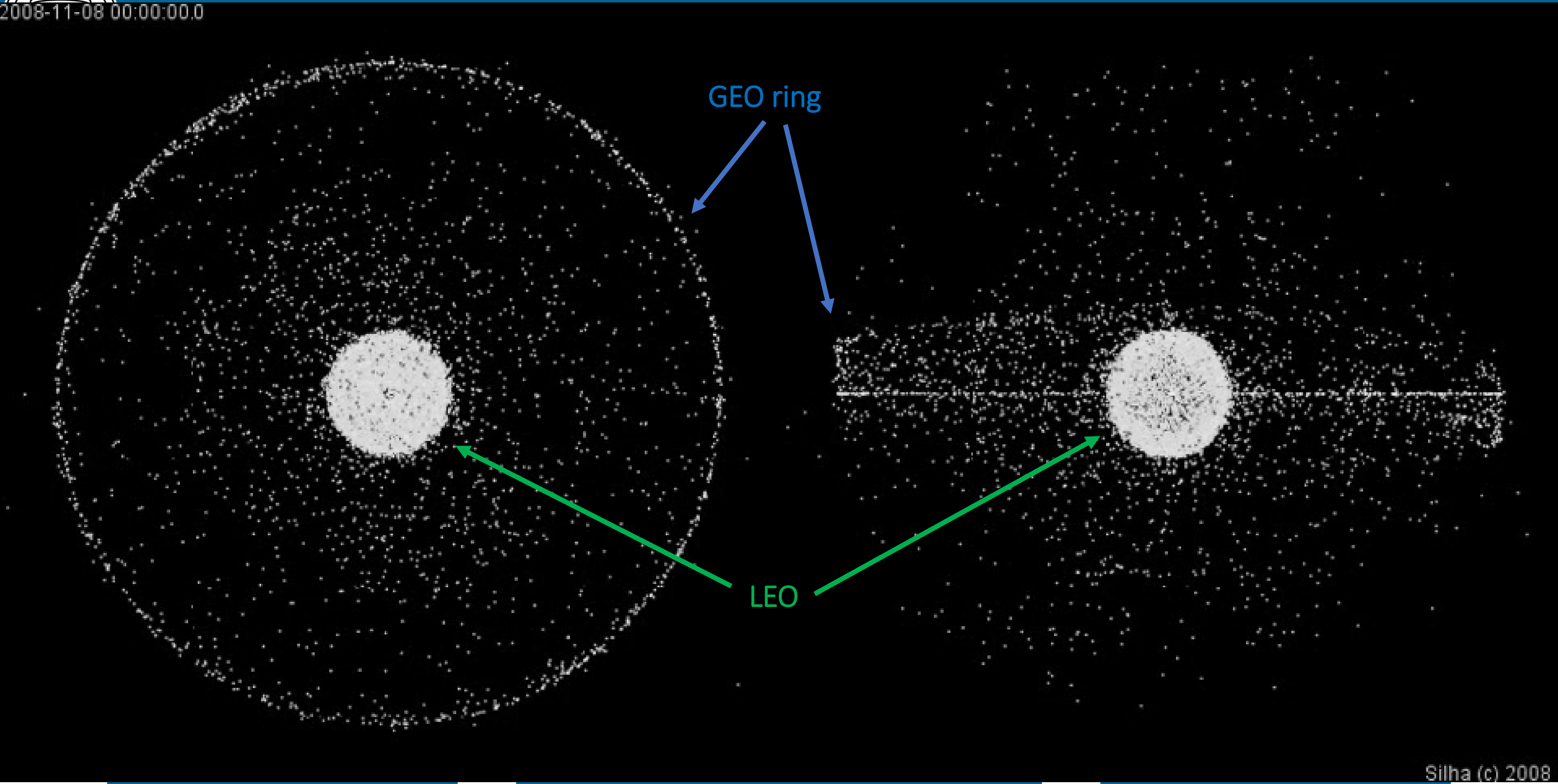


Fig. – Al2O3 slag, MLI foil, solar panel
Source: NASA

Rocket upper stages

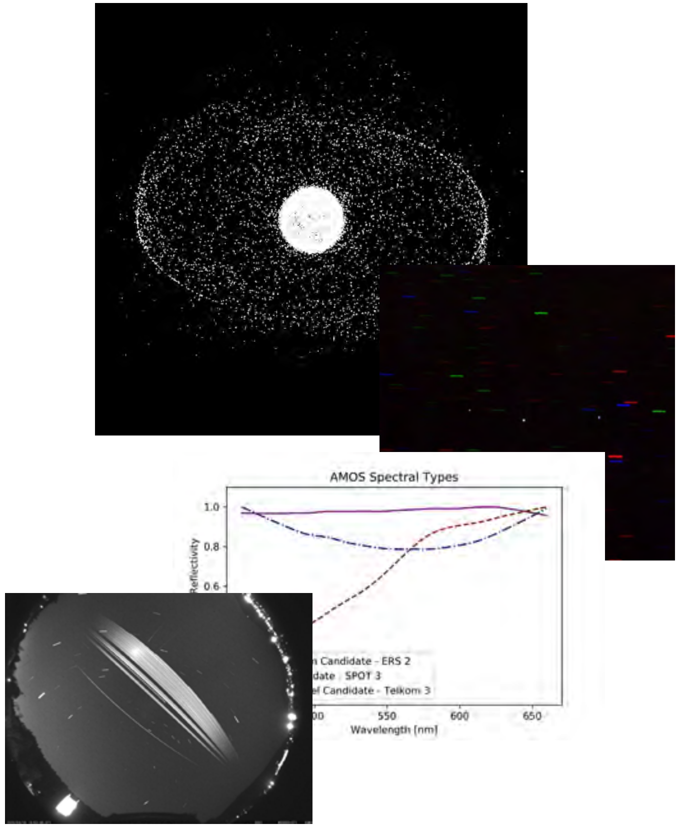
Fig. – Lunch of Ariane 5 rocket
Source: ESA

Fig. – Upper stage Agena D
Source: NASA


2008-11-08 00:00:00.0
GEO ring
LEO
Silha (c) 2008

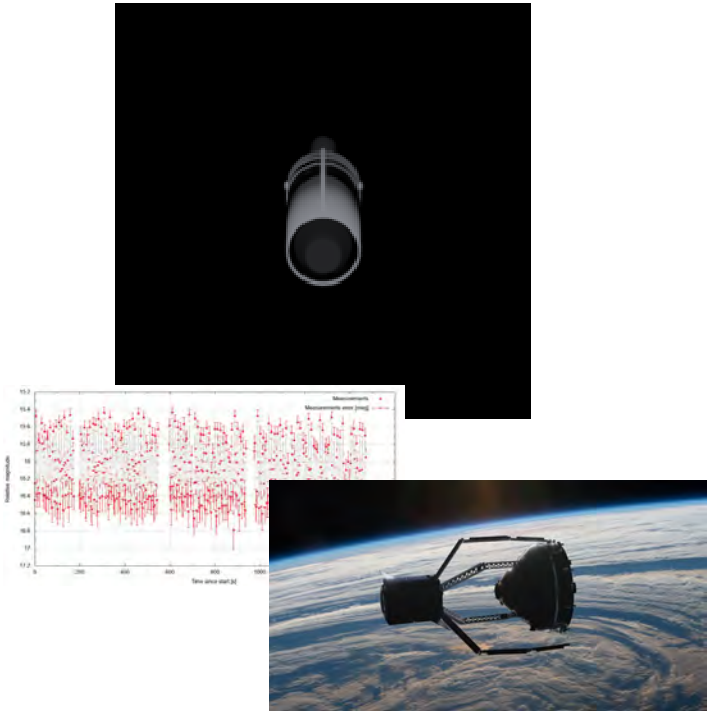
Research at Comenius University

Object characterization



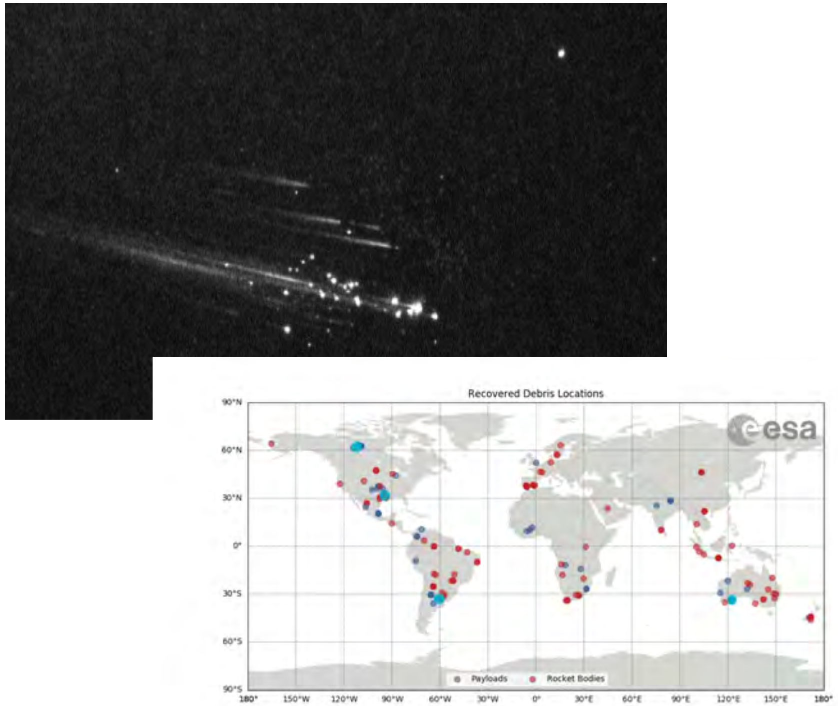
On-orbit, possessing threat

Attitude analysis



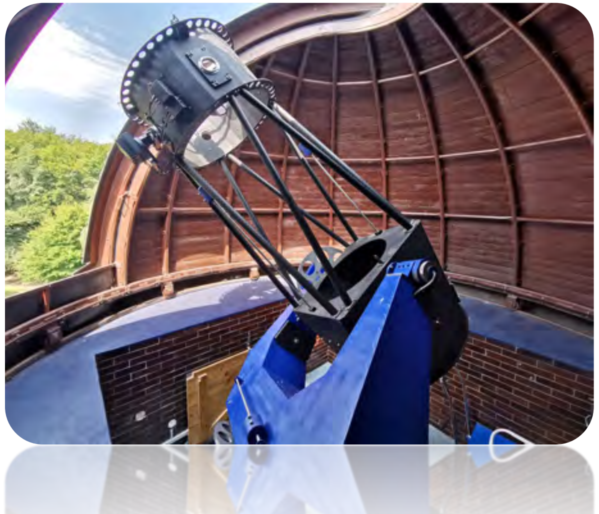
Actively to remove from orbit

Re-entry analysis



Danger to ground population

Space debris characterization



Space debris characterization - motivation

- Space debris objects threat to the space environment – satellite infrastructure and manned flights
- Characterization to understand object’s physical properties (size, material, surface properties, albedo, shape, etc.), threat assessment
- Understanding the object’s origin, prevention of creation, e.g., fragmentation, surface degrading etc.
- Material aging, space-weathering effects monitoring, influence on the final data interpretation
- Sky background light pollution (Kocifaj et al., 2021, Walker et al., 2020, Mallama et al., 2022)
- Potential targets for future scavenging? (Shankar, 2019)

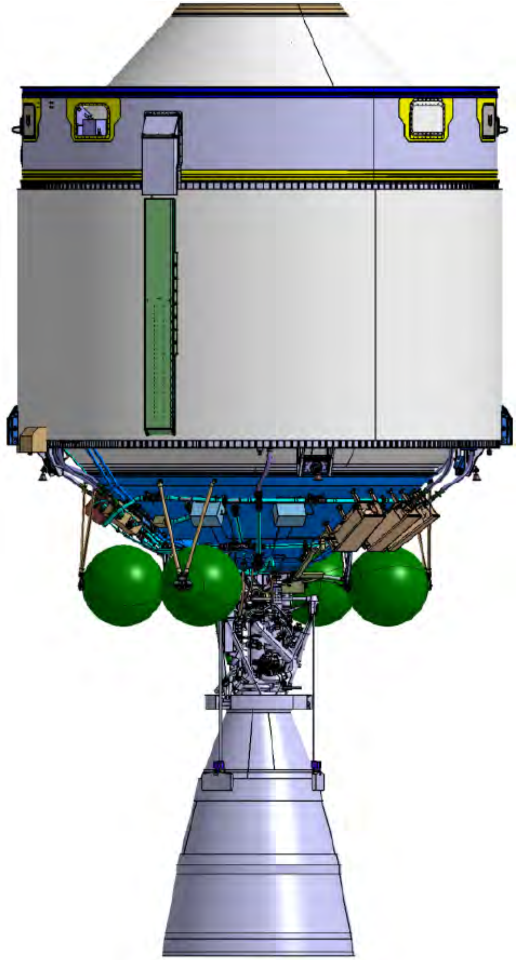
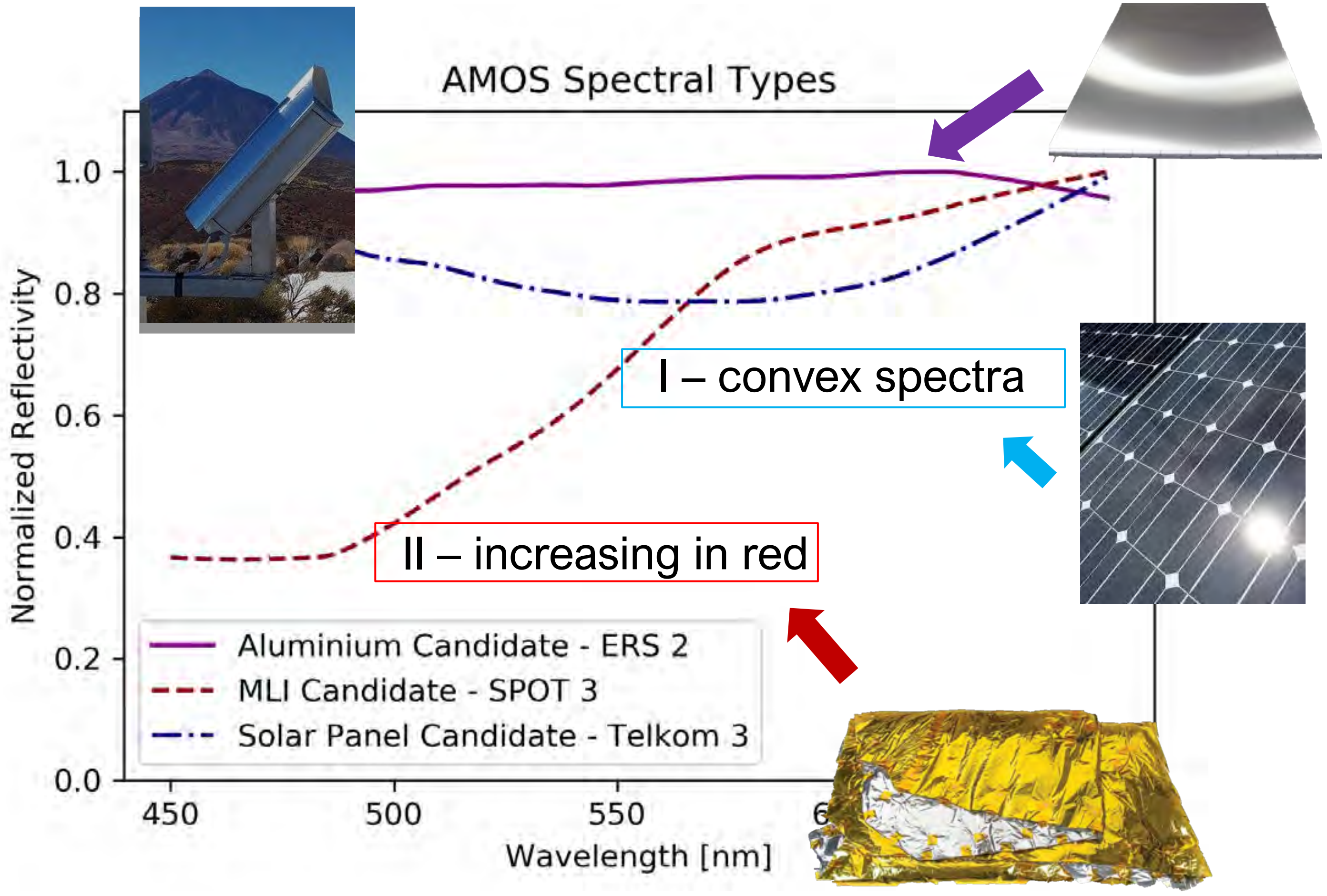


Fig. Upper stage Ariane 6

Reflectance spectroscopy

- Analysis of solar light spectra reflected from the surface of the target.
- Slope of the spectra and shape assessed to identify the material and to monitor its change over time.
- Several different teams dedicated work to spectral analysis of debris (**<u>Žilková et al., 2022</u>**, Vananti et al., 2017, Engelhart et al., 2017, Jorgensen et al. 2004 and others)



III – straight-lined spectra

I – convex spectra

II – increasing in red

Fig. Reflectance spectra of LEO satellites acquired by AMOS-Spec cameras. Žilková (2022)

BVRI photometry

- Study of the optical properties in the visible light spectrum, extracted from the ultra-low resolution spectroscopy.
- The methodology is based on the differences between object's reflective properties in different parts of the spectra.
- It is called BVRI photometry according used photometric filters type.
- Several teams working on BVRI (**Zigo et al. 2021**, Cowardin et al., 2014, Zhang et al. (2017) and others)

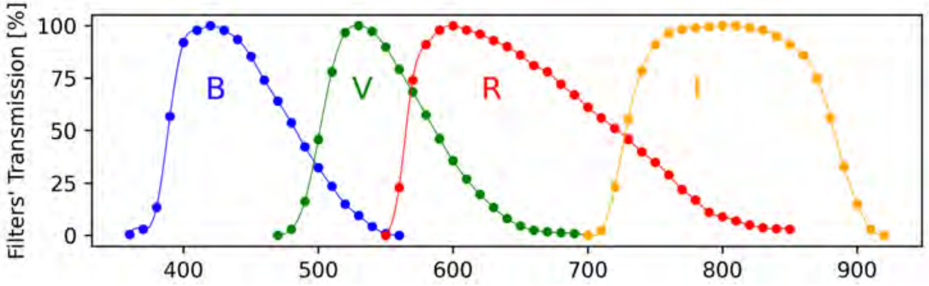


Figure: Spectral transmissivity of the Johnson/Cousin's photometric filters. **Source:** M. Bessel, 1990

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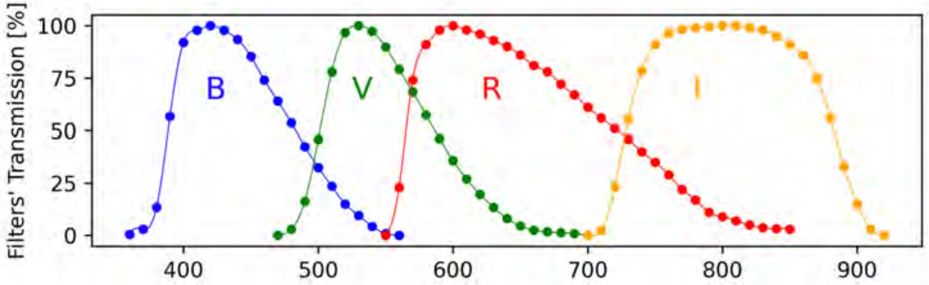


Figure: Spectral transmissivity of the Johnson/Cousin's photometric filters. **Source:** M. Bessel, 1990

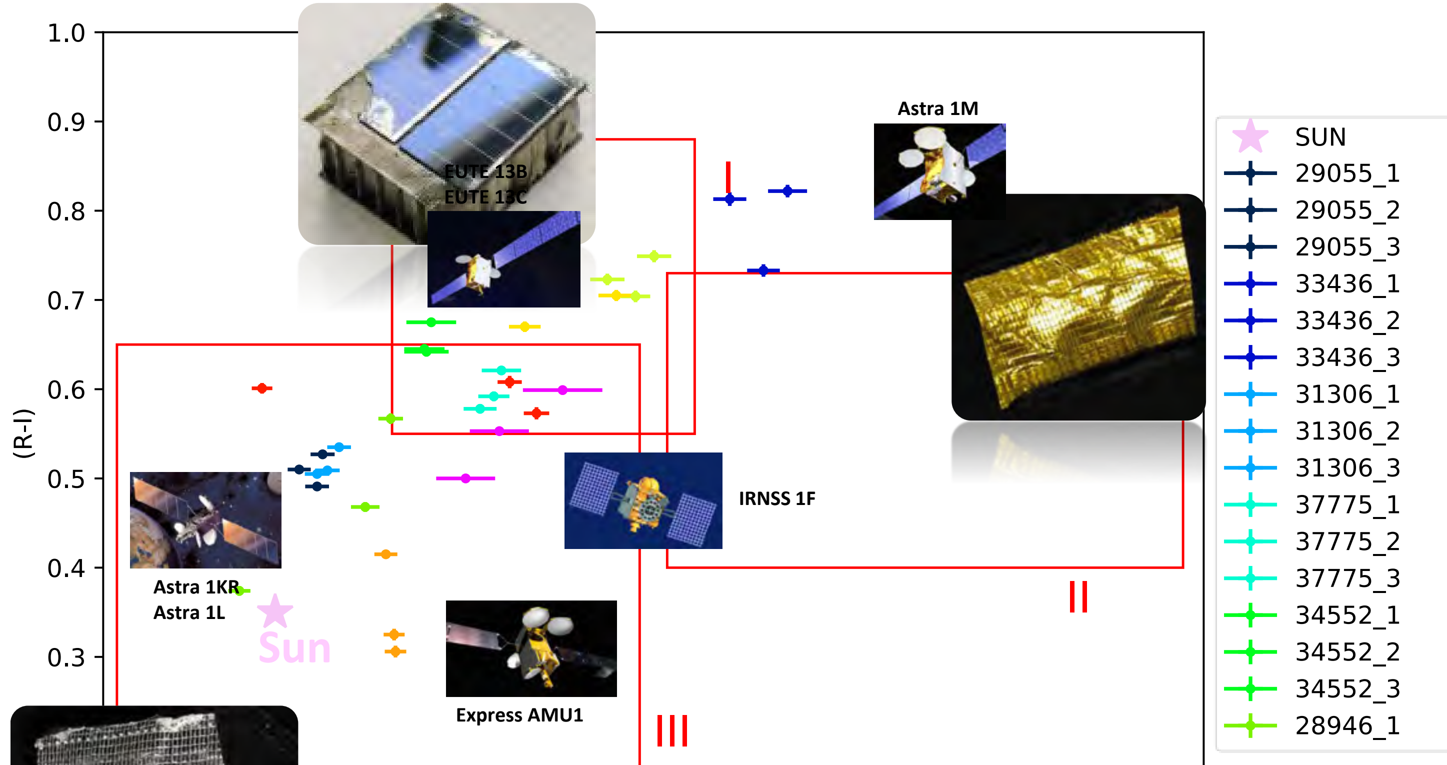


Fig. BV vs RI diagram for several operational GEO satellites. Data acquired by AGO70 telescope. Zigo (2022)

Phase function, main terms

- Change of mean brightness as a function of phase angle.
- In minor planets community high interest to investigate surface properties such as porosity, roughness, particle size, complex refractive index, etc. (Muinonen et al., 2012, Hapke 2012, Shevchenko et al., 1996, Belskaya and Shevchenko, 2000, Bowel et al., 1989, Shkuratov et al., 1999).
- For artificial objects some laboratory measurements conducted already for different materials such as glass fabrics, solar panels (Murtazov, 2015; Hostetler and Cowardin, 2019), simulations conducted for different shapes of materials (Hejduk et al., 2012).

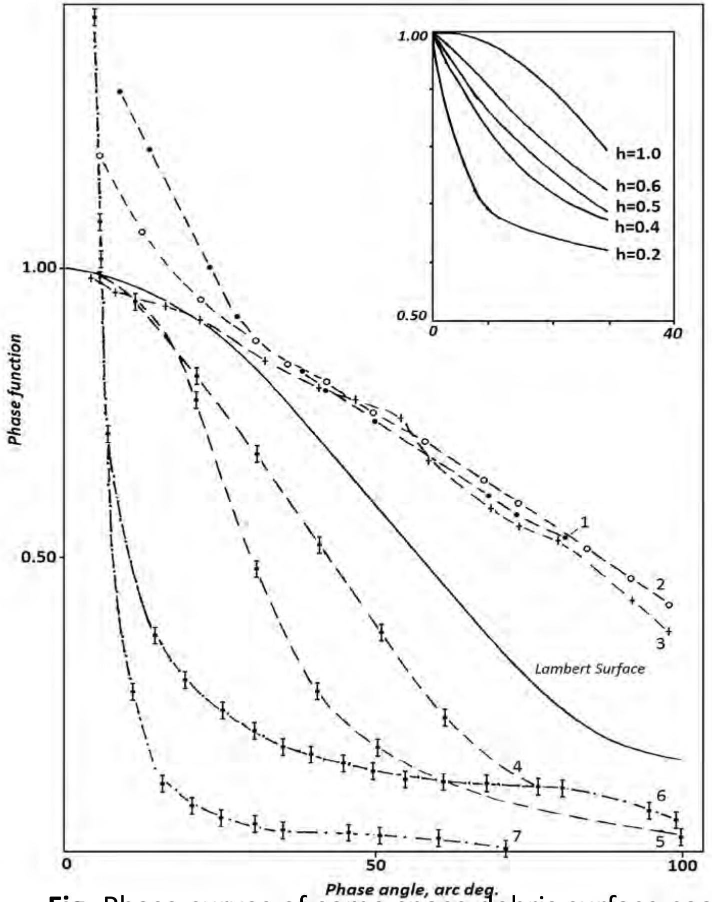


Fig. Phase curves of some space debris surface coating materials as compared to phase curves of ideal scatterers (solid line) and lunar surface – insert (Hapke, 1963): 1-3 – glass fabrics, 4-5 – asteroid-like surfaces, 6-7 – solar panels (Murtazov, 2015).

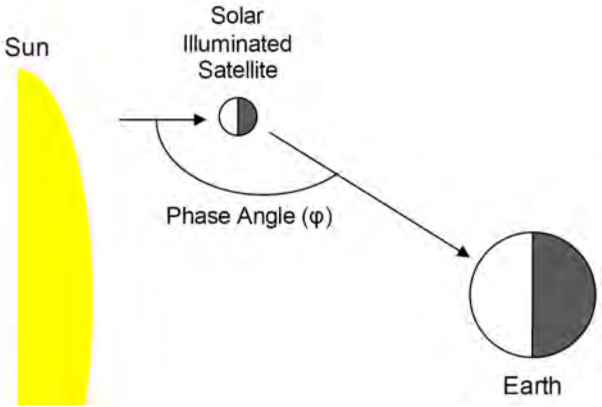
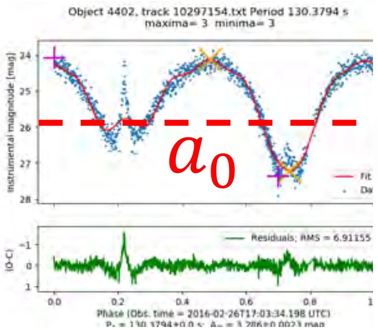


Fig. Definition of phase angle (Hejduk, 2011).

Case of CZ-3B R/B (2006-048B)



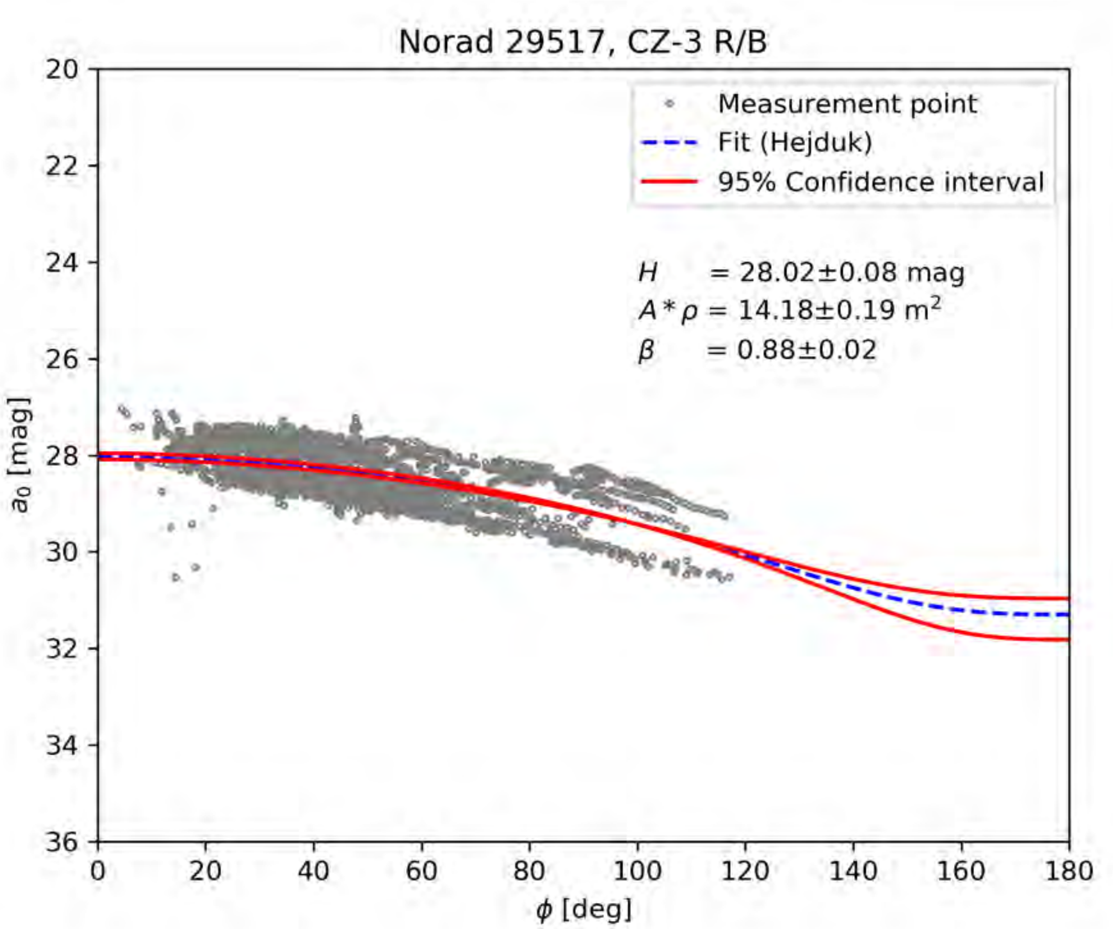
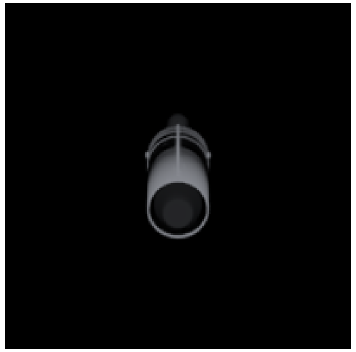
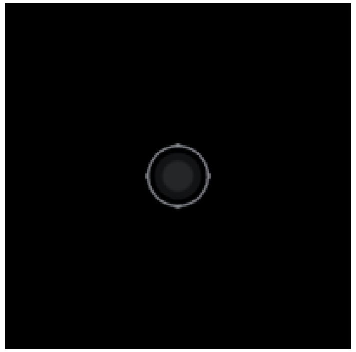
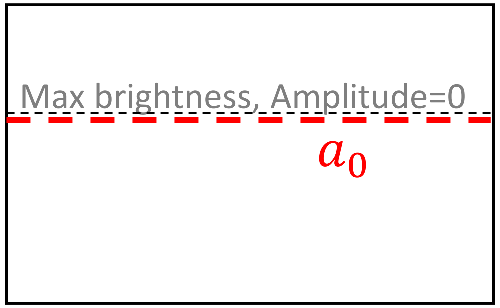
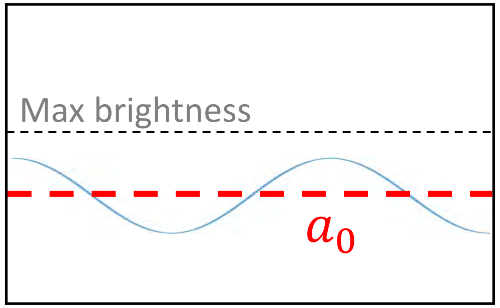


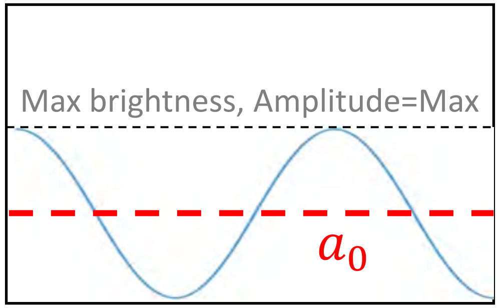
Fig. Coefficient a0 (from reduced magnitude) vs phase angle for object CZ-3B R/B (2006-048B) (gray points), its Hejduk fit their selected maxima (red), minima (blue) and median values (green).











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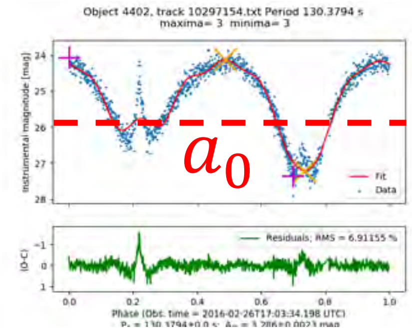

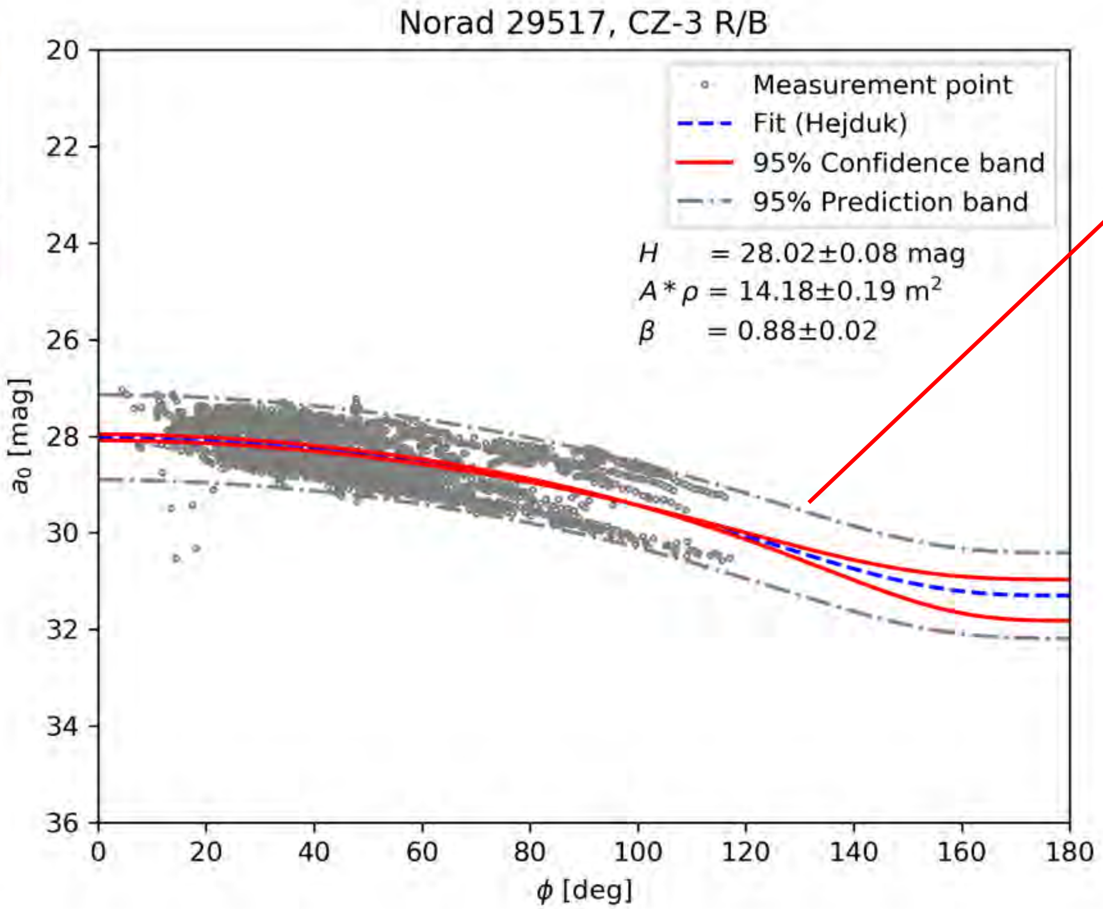

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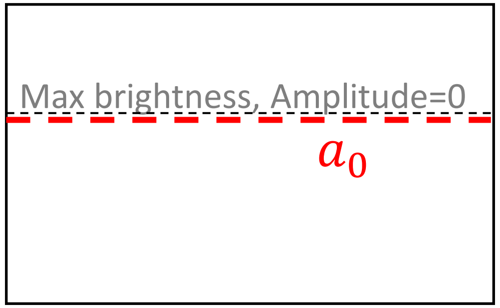


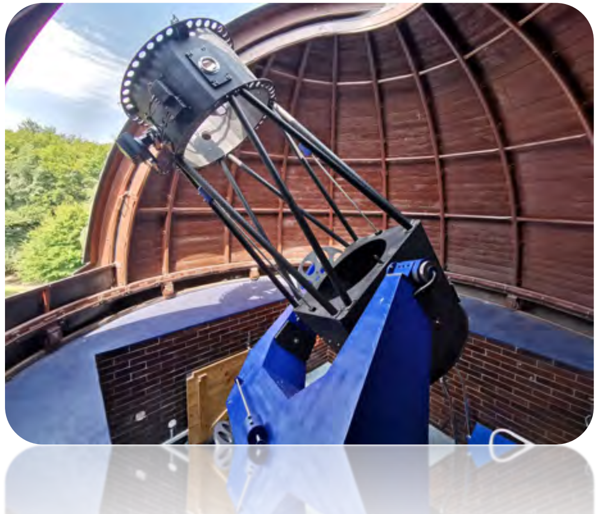
$$h_{real} = 12.375\ m$$
$$d_{real} = 3.0\ m$$
$$A = 37.125\ m^2$$

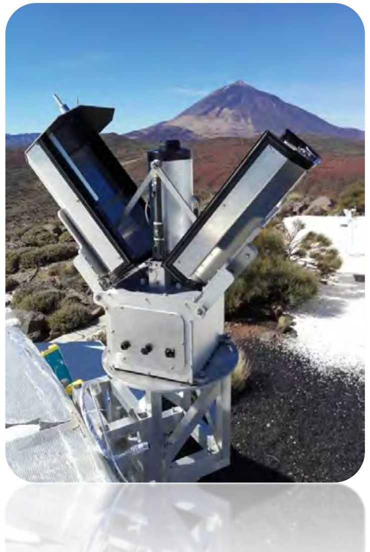
$$A * \rho_{geom} + p_{pred\_band} = 31.9 \pm 0.19\ m^2$$

$$\boldsymbol{\rho_{geom} = 85.9\% \pm 0.5\%}$$
$$\boldsymbol{\beta = 0.88 \pm 0.02}$$

Albedo

Attitude estimation





Light curves, attitude estimation

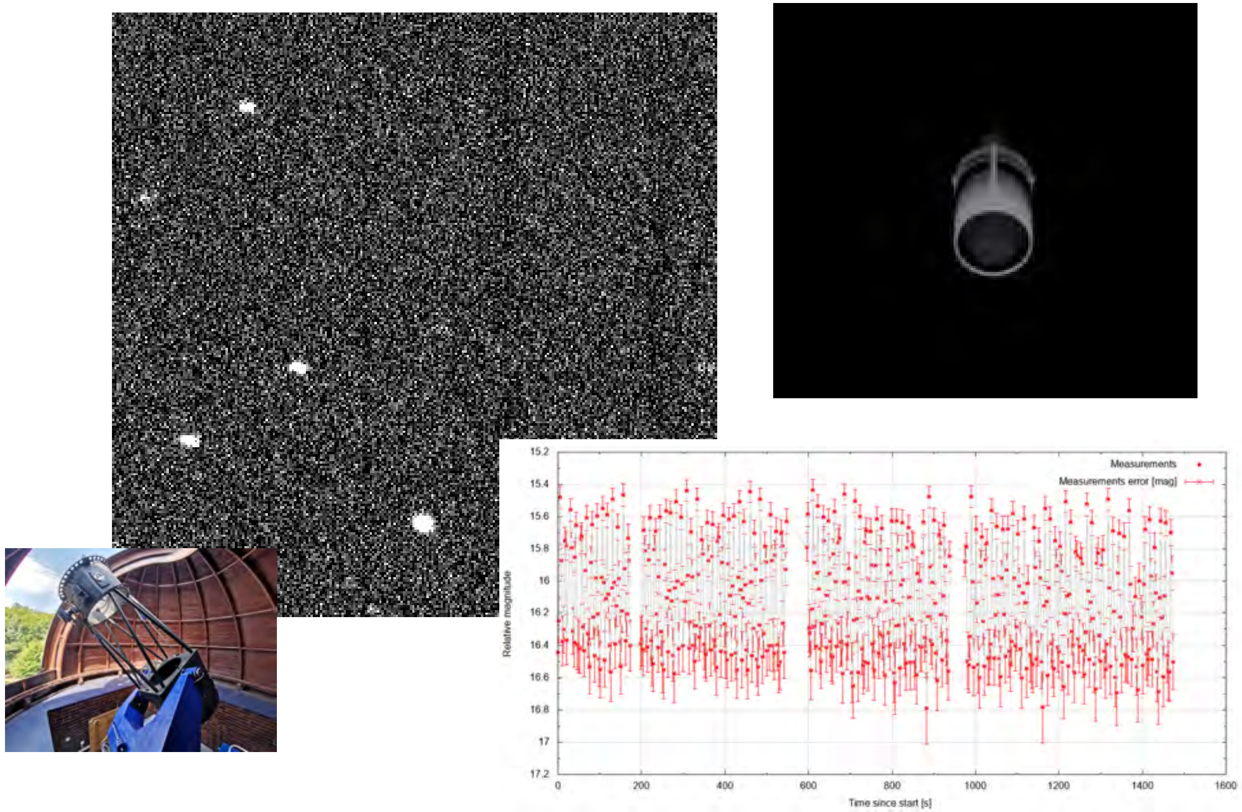


Fig.– Photometric measurements acquired by AGO 70cm telescope during night 20181016 (left) and the constructed light curve (middle) and its phase diagram (right) for the object Titan 3C Transtage R/B (74039C). **Hrobár et al. (2022)**, **Kyselica et al. (2022)**

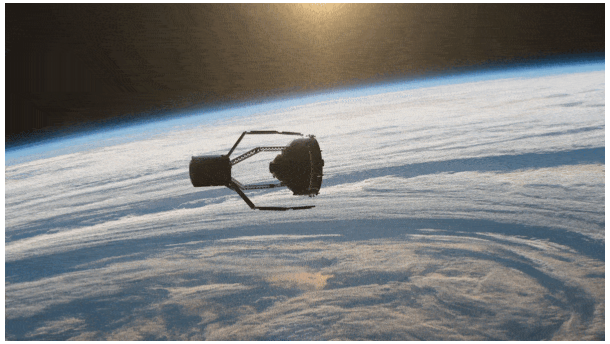


Fig.– Animation depicting ClearSpace-1 captures Vespa. Credit: ESA

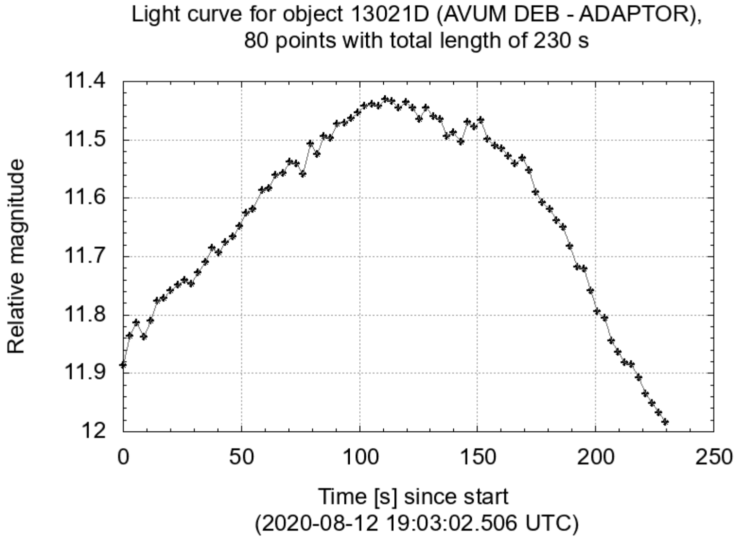


Fig.– Photometric light curve acquired by AGO 70cm telescope during night 20200812 (left) for the object Avum Deb Adaptor (13021D). Šilha et al. (2021)

Light curves, attitude estimation

- Williams method is suitable for cylindrical objects with moment of inertia about a transverse axis is the largest, then and end-over-end tumbling motion will be stable
- The observation data must be from three different dates with wide spread of phase angle value, but it must be within several days, because rotation axis orientation can be changed with time
- Inputs: amplitude of lightcurve, amplitude error, two-line elements
- Possible solutions are calculated in right ascension and declination in J2000

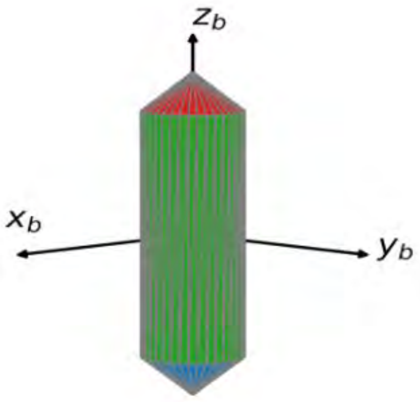


Fig. Rocket body model (Blacketer et al.,2019).

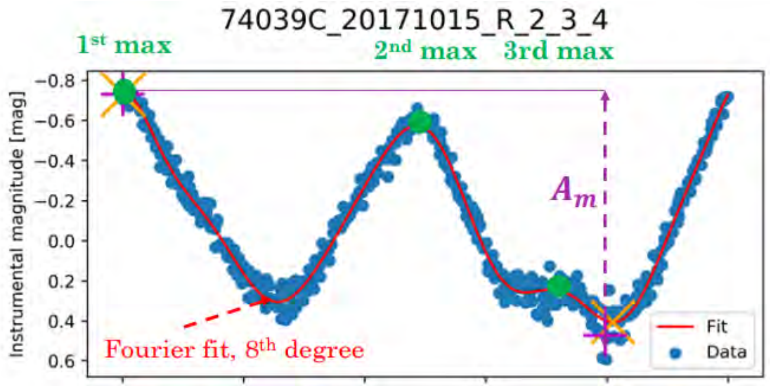


Fig. Photometric measurement acquired by AGO 70cm telescope for Titan 3C Transtage R/B (Šilha et. al, 2019).

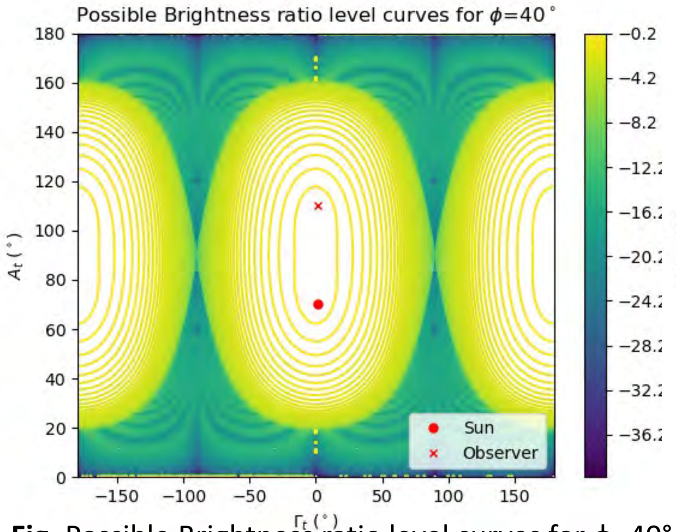


Fig. Possible Brightness ratio level curves for ϕ=40°. Hrobár et al. (2021)

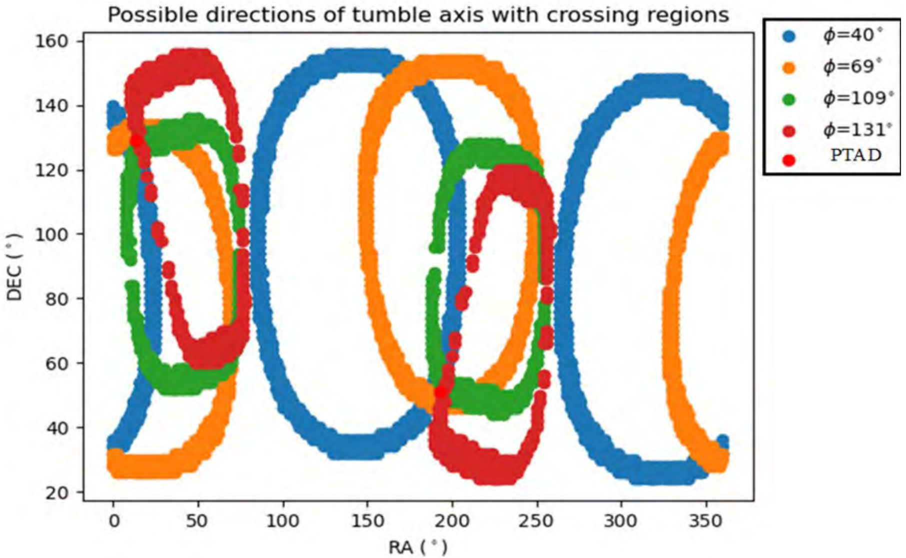
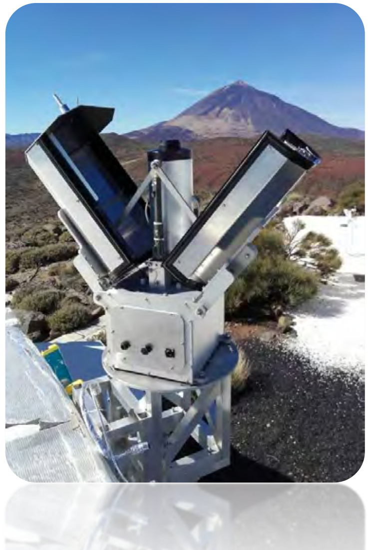


Fig. Possible directions of rotation axis with crossing regions. Hrobár et al. (2021)

Re-entry analysis



Re-entry analysis, CZ-3B R/B case

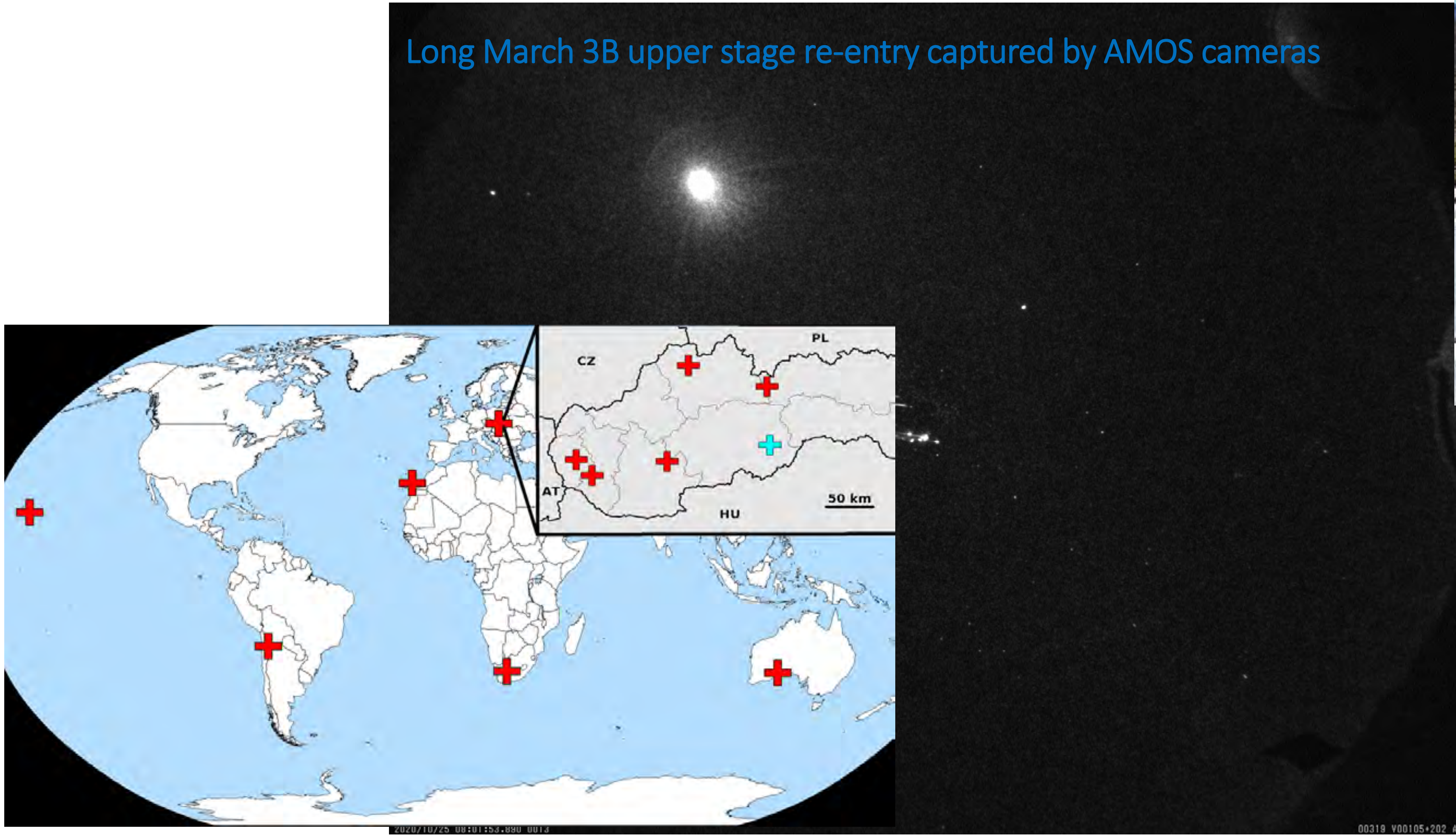

Long March 3B upper stage re-entry captured by AMOS cameras

Fig. – AMOS recording of CZ-3B R/B acquired by **AMOS-HK**, duration 51.65 s, 1033 frames

Video credit: Comenius University

Re-entry analysis, other cases

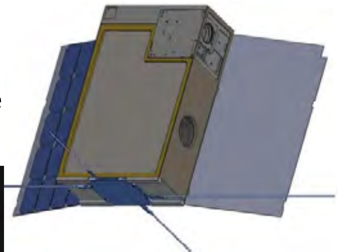
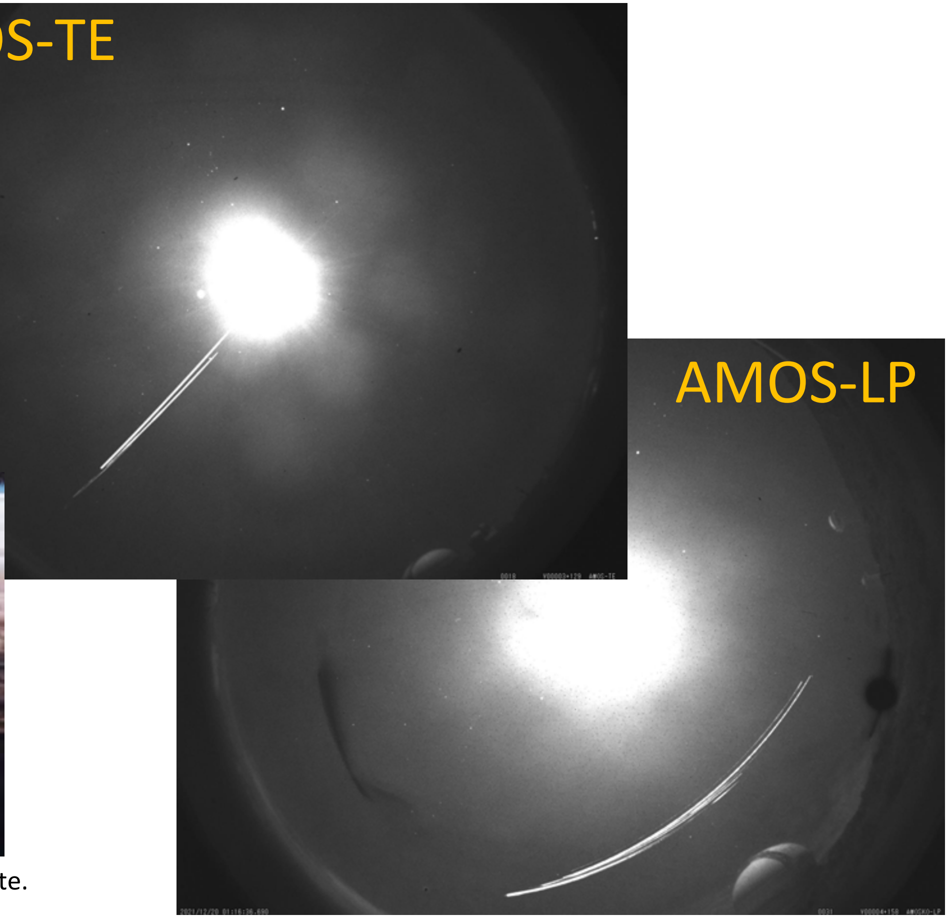


Fig. CIRiS satellite.
Photo: space.skyrocket.de



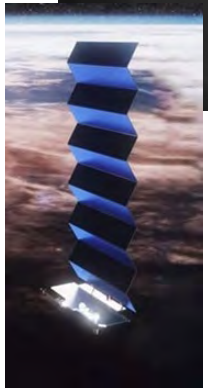


Fig. Starlink satellite.
Photo: SpaceX

Fig. Re-entry of Starlink satellite captured by Spanish AMOS cameras on 20th of December 2021. Photo: AMOS team

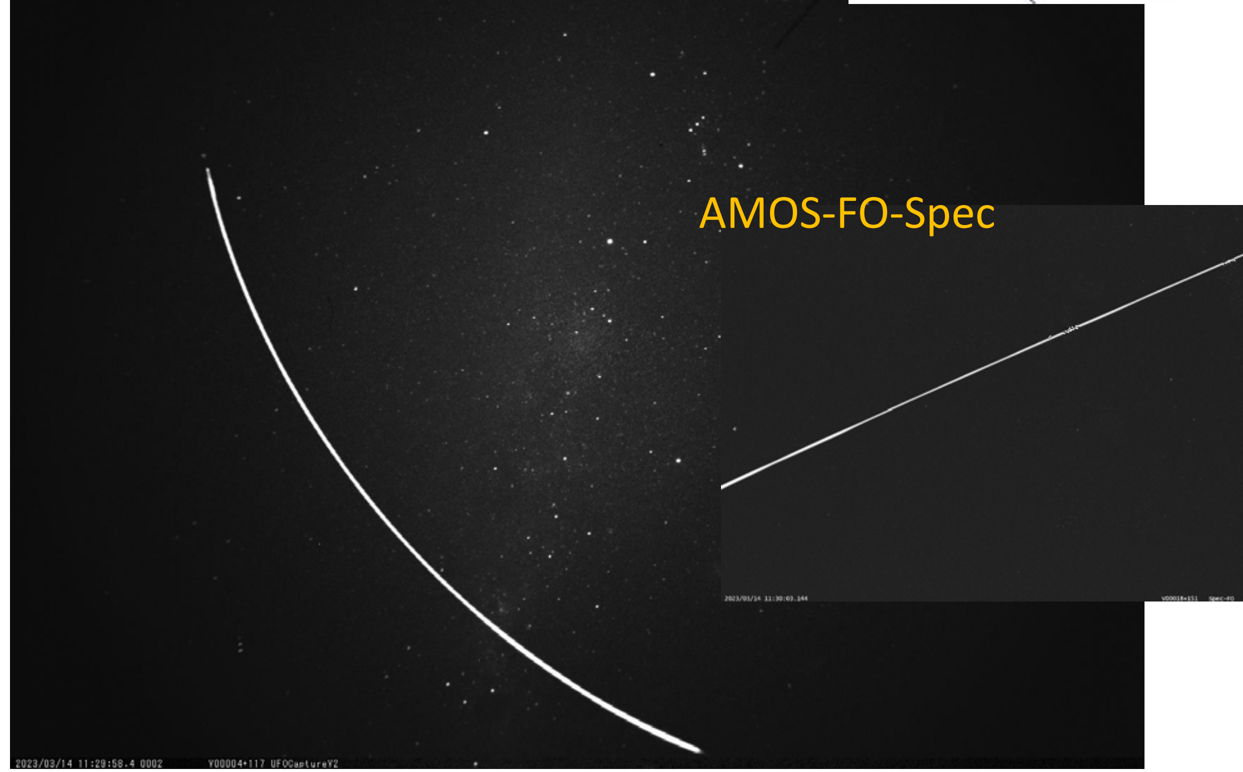


Fig. Re-entry of CIRiS (Compact Infrared Radiometer in Space) satellite captured by Australian AMOS cameras on 20th of December 2021. Photo: AMOS team

Conclusions

Way forward and conclusions

- Space safety and space debris research crucial for sustainability of space missions
- Large step for Slovakia becoming Associated MS of ESA
- Slovak academia and industry able to join ESA S2P activities and be part of international consortia
- Slovak strong potential contributions to ground-based observations, re-entry analysis, ADR and IOS support

Fig. – Map of ESA MS
Zdroj: ESA

Thank you for attention !

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Photometry, phase function

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