Characterization of Artificial Space Objects Using Astronomical Photometry and Spectroscopy

MatFyz CONNECTIONS 2026

Motivation and objectives

The characterization of artificial space objects has become increasingly important due to the rapid growth of satellite and space debris populations over the past five years. This leads consequently to increase of light being reflected from the objects toward the Earth.

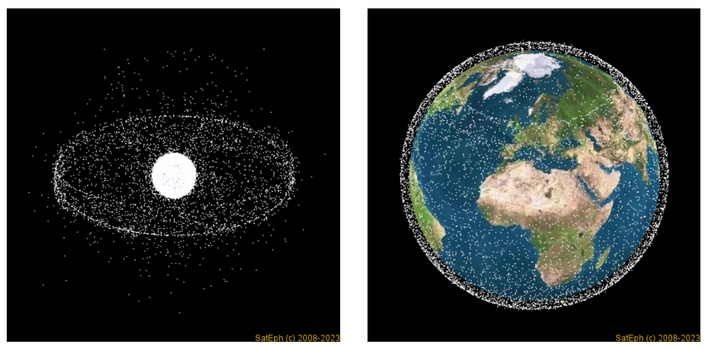


Figure 1. Left: Spatial distribution of artificial space objects including space debris. Right: Large satellite constellation Starlink. Data taken from www.space-track.org (to October 10 2026).

Ground-based spectroscopy and photometry measure sunlight reflected by satellites and debris space objects, ranging from those in low Earth orbit to those in cislunar space. Laboratory measurements of spacecraft materials support object classification, while understanding their reflective properties helps assess these objects' impact on astronomical observations.

Our primary instrument, the AGO70 telescope [1], has a science CCD camera, a filter wheel with Sloan (g',r',i',z') filters, and a visible spectrograph (R∼360) at its second focus. Additional observations come from the global optical sensor network owned and operated by Astros Solutions (www.astros.eu).



Figure 2. Left: The Astronomical and Geophysical observatory of Comenius University Bratislava (AGO) in Modra (MPC code M34) . Right: AGO70 telescope.

Rotation/attitude state estimation

Changes in the object's orientation are the primary driver of sudden brightness variations which influences the observations and their interpretation. We introduced method for estimation of the complex object's rotational state assuming precession [2].

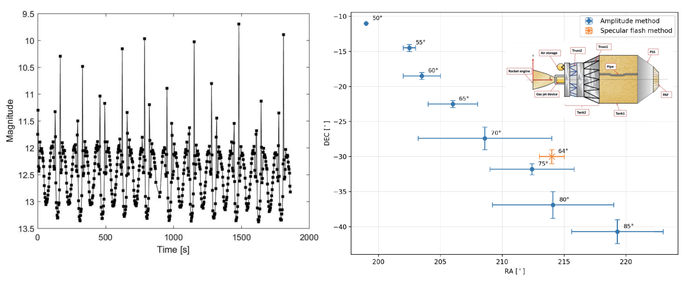


Figure 3. Left: Light curve of object H-2A rocket body. Right: Possible angular momentum vector directions of H-2A assuming different precession angles obtained using "diffuse" method (blue) versus single accurate solution obtained from "specular reflection" method (orange).

Reflectance spectroscopy

Spectroscopic measurements provide detailed information about the wavelength-dependent surface properties of space objects. To obtain a reflectance spectrum, the observed object spectrum is divided by a spectrum of solar analog stars, correcting for the solar spectral signature and atmospheric extinction effects. During the analysis, the focus is on identifying absorption lines and characterizing the overall trend of the reflectance spectrum, which provides information about the chemical composition of the surface material [3].

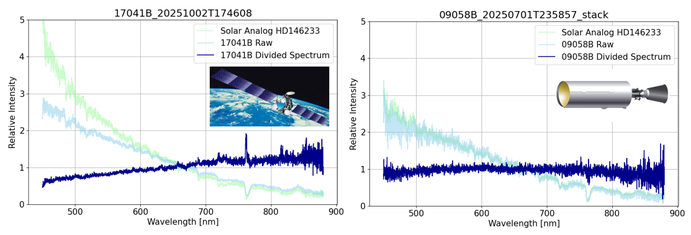


Figure 4. Reflectance spectra of GEO satellite Thor 6 (left) and rocket upper stage Falcon 9 (right).

Color photometry

Color observations, which measure a space object's brightness through different photometric filters, are a standard method for object characterization and taxonomic classification in asteroid research. They provide an initial indication of the physical properties of a space object's surface. We have adapted this approach for application to artificial space objects [4]. Complementary to reflectance spectroscopy, color observations offer the advantage of allowing measurements of multiple objects to be obtained during a single observing session, facilitating the compilation of large statistical samples.

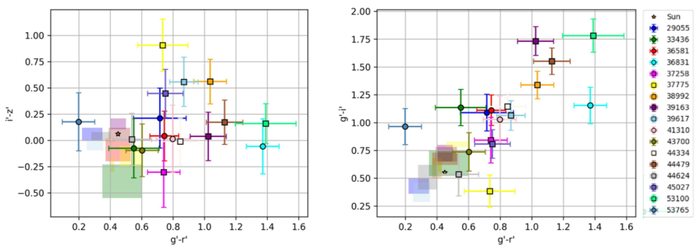


Figure 5. Color indices diagrams of GEO satellites observed during the night 20250619. Sun color indices and border lines for asteroid taxonomy classes are also shown for reference.

Bidirectional reflectance distribution function

Large photometric datasets enable the construction of empirical BRDF models for satellites belonging to large constellations. We use the Phong reflection model to fit empirical BRDFs for satellites in the Starlink, OneWeb, Qianfan, and Globalstar constellations [4].

$$\mathrm{BRDF} = \frac{K_d}{\pi} + K_s \frac{n+2}{2\pi} \left(\hat{w}_r \cdot \hat{w}_o\right)^n$$

Table 1. Phong coefficients for large constellations obtained from Astros network photometric measurements.

	Chassis			Solar Array		
Population	K_d	K_s	n	K_d	K_s	n
Globalstar	0.16	0.14	5.24	0.32	1.00	1.00
OneWeb	0.00	0.20	0.24	0.00	0.13	0.08

Laboratory measurements

Laboratory measurements of spectra of common spacecraft materials were conducted in collaboration with INAF at Brera Astronomical Observatory [3].

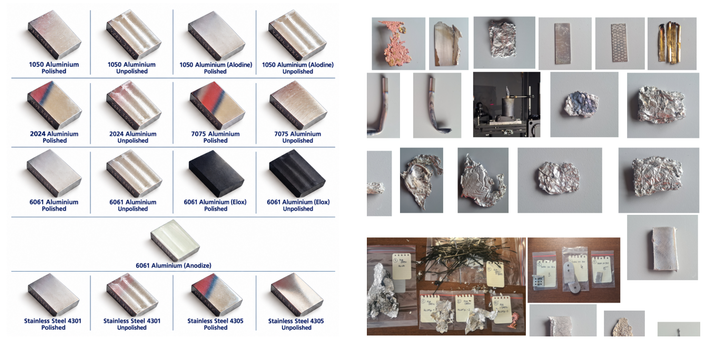


Figure 6. Left: Laboratory samples provided by Needronix s.r.o. Right: Samples provided by the European Space Agency.

The laboratory spectra were integrating over the Sloan filters response functions and compared to the observations. Furthermore, the absorption coefficients were calculated using [3,5].

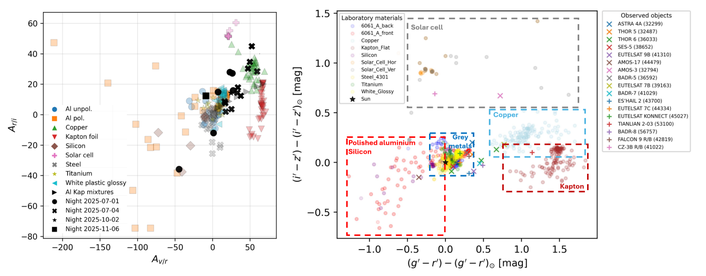


Figure 7. Left: Absorption plots for laboratory measurements vs reflectance spectra obtained by AGO70. Right: Sloan (g'-r')-(g'-r')$_{sun}$ vs (i'-z')-(i'-z')$_{sun}$ generated using laboratory spectra measurements converted to Sloan magnitudes vs observations from AGO70.

Future work

The population of artificial space objects continues to rise, consequently having an increasingly negative impact on the near-Earth environment. We will broaden the scope of our analysis by including a larger number of objects and extending our investigations from low-Earth orbit to the cislunar region. Photometric and spectroscopic observations will be complemented by polarimetry (APVV-25-0059). Our laboratory studies will encompass a wider range of material samples, allowing us to investigate the dependence of spectra and colors on illumination and viewing geometry (ESA 4000146796/24). Particular emphasis will be placed on strengthening the links between laboratory measurements and observational data. Furthermore, we will examine aging and space-weathering effects, which can alter object surfaces over time but have not yet been accounted for in our laboratory studies.

References

[1] Jiří Šilha, Stanislav Krajčovič, Matej Zigo, et al. "Space debris observations with the Slovak AGO70 telescope: Astrometry and light curves". In: *Advances in Space Research* 65.8 (2020), pp. 2018–2035. DOI: 10.1016/j.asr.2020.01.038.

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