Lightcurve Analysis of Imminent Impactors for Planetary Defense Using Innovative Trail Technique

Background: Near-Earth objects (NEOs) on an impact course with Earth can move at high angular speeds. Understanding their properties, including their rotation state, is crucial for assessing impact risks and mitigation strategies. Traditional photometric methods face challenges in accurately collecting data on fast-moving NEOs.

Observation of fast moving objects

Small NEOs can only be observed when performing close approach to or impacting the Earth. However, when these objects are close to Earth their motion on the sky can be extremely fast.

This results in the impossibility of observing them using regular techniques (i.e. performing short exposures such that both the stars and the object appears as a point source in the image).

Fig 1. shows an observation of 2024 BX1 obtained by Luca Buzzi at the Schiaparelli observatory a few minutes before entering the Earth shadow.

This is a 30 seconds exposure time and the asteroid is moving at speed of 32”/sec trailing over 915 pixels.

It can be seen, even by eye, that the flux is varying over the length of the trail, we thus decided to develop a method to extract and calibrate the flux of asteroids that are observed as trail due to their very fast sky motion.

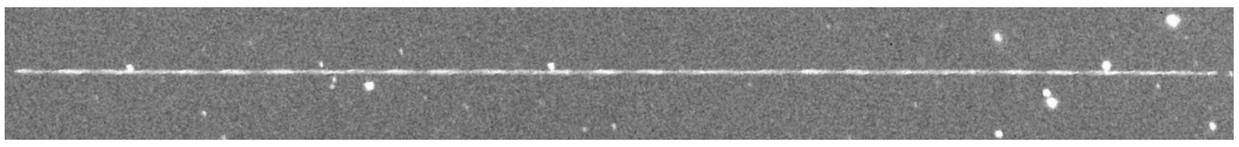


Fig 1 – Trailed observation of 2024 BX1 just before entering the Earth shadow

Aperture photometry on asteroid trails

We are using square apertures (Fig. 3) instead of typical circular apertures (Fig. 2) to match the topology of the trailed observation.
To extract time dependent measurement over the trail, we stepped along the trail. The time corresponding to each aperture is determined using ephemerides.

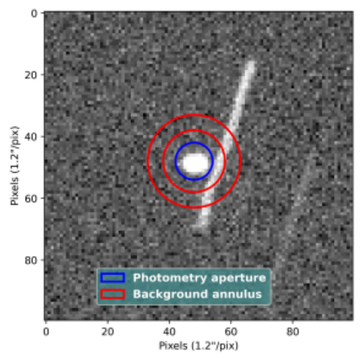


Fig 2 – Example of circular aperture photometry on a fast moving object while tracking the asteroid.

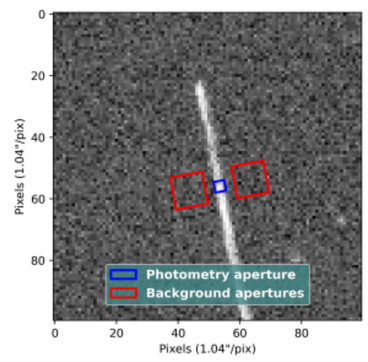
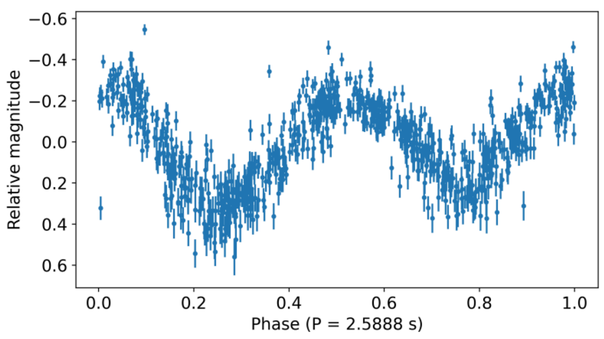
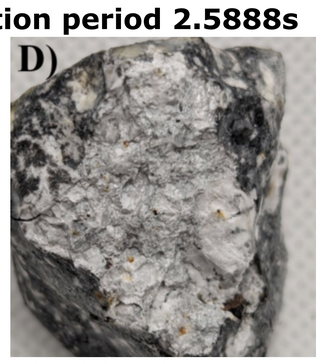


Fig 3 – Example of a square aperture on the trailed observation of a fast moving asteroid.

Application of the method to imminent impactors and close fly-bys

2024 BX1 - Ribbeck meteorite - Rotation period 2.5888s

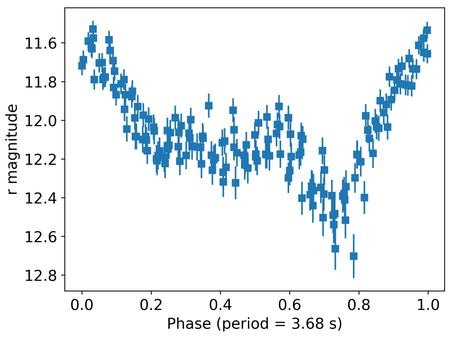


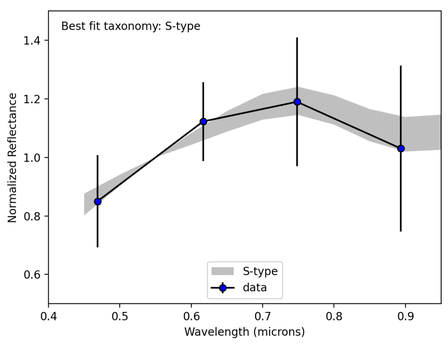


Kołodziej et al. Nature 2025

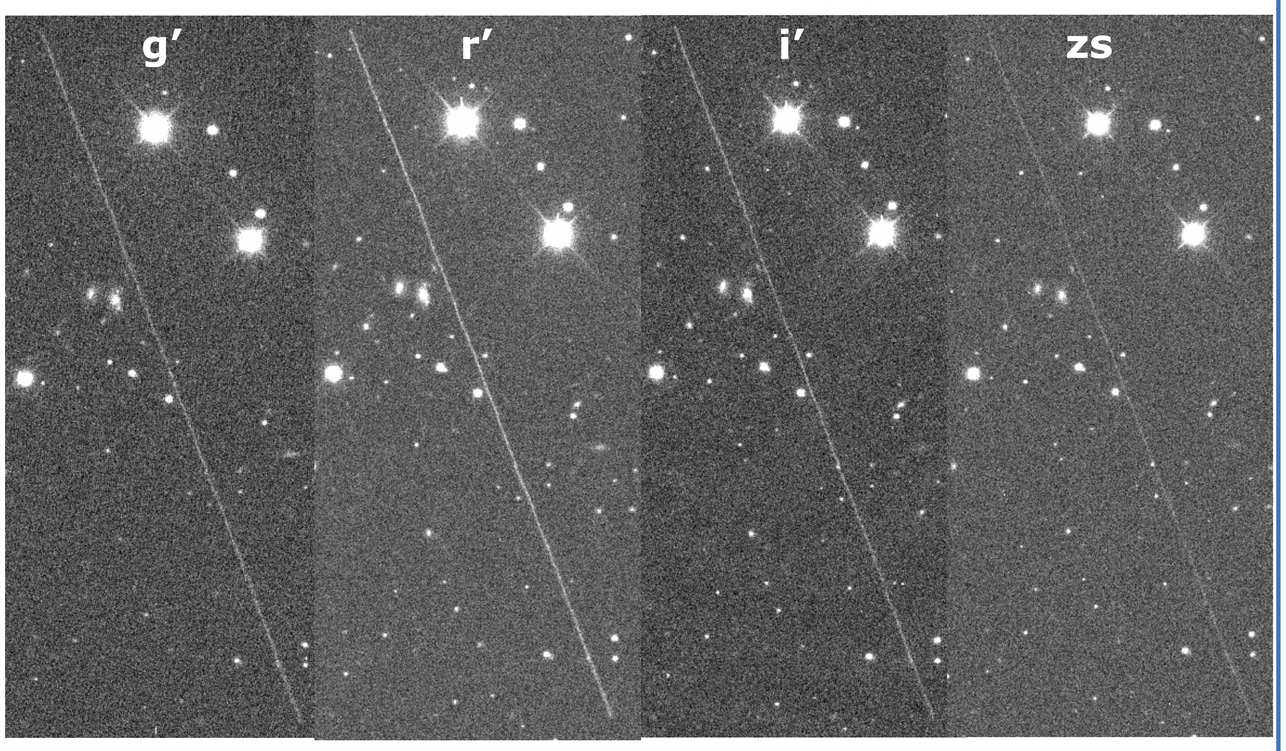
2024 BX1 was discovered on 2024 Jan 20 just three hours before its impact in Ribbeck Germany. Analysis of the meteorite shows that it is a rare Aubrite type (Jenniskens et al. 2025, submitted). Using our method we found a rotation period of 2.5888s for this object estimated to be ~47 cm in size (see Fig. 1 for the image of the trail).

2024 LH1 - 1750 km Earth fly-by - Rotation period 3.68s



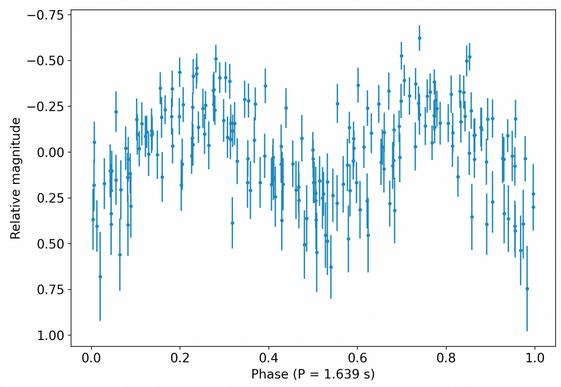


LCO - MuSCAT3 - Simultaneous observations in 4 bands

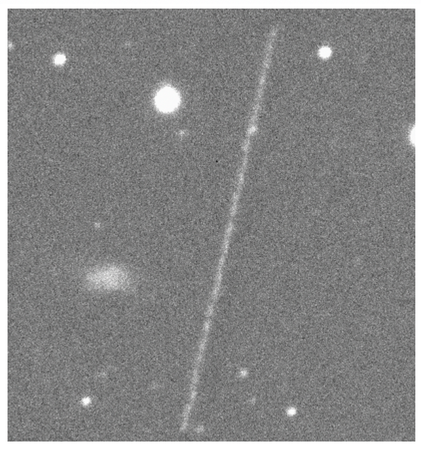


2024 LH1 is a 2-4 meters object that was discovered on 2024 Jun 6 a few hours before flying-by at a distance of 1750 km from the surface the Earth. We observed it with the Las Cumbres Observatory network of telescopes. We obtained a rotation period of 3.68 s and using simultaneous griz band observations, we determined an S-type taxonomy.

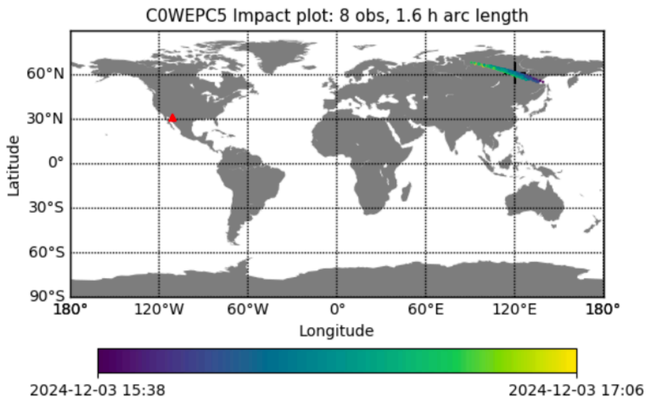
2024 XA1 - Imminent impactor - Rotation period 1.639s



Gianotto et al. 2025



Yunnan Observatory
Observers: Xi-Liang Zhang and Xiang-Yu Fan



2024 XA1 is the third impactor of 2024 (Gianotto et al. 2025). It was discovered on 2024 Dec 3 a few hours before impacting near the city of Olekminsk in Siberia. XA1 is a small ~70 cm object and we obtained trailed observations with Yunnan Observatory in China. Those observations shows the fastest rotation period observed so far for an asteroid with a period of 1.639 s. The fireball was observed live on Youtube.

Conclusions

We have developed a new pipeline for photometric reduction of NEO observations. This pipeline is focused on observations of NEOs that appear as streaks on the images. These observations occur when the object is moving too fast and even short exposures results in the object moving over multiple pixels.

We showed that letting these objects trail on the image and extracting the photometry over the trails allow for accurate period and color determination and to detect very short rotation periods undetectable with traditional observation techniques.

This method is highly effective to detect the very fast rotation period of small asteroids. We have detected the two fastest rotation period ever measured (2024 XA1: P=1.639s, 2024 BX1 : P=2.5888s) and the fourth fastest (2024 LH1: P=3.68s).

We also showed that the method allows for absolute calibration of the flux and to obtain colors of the observed object. The next step would be to obtain rotationally resolved colors. Up to now, no object was bright enough to perform such observation and analysis.

Scan QR code to access:

Devogele et al. 2024

NEOCC Portal

Authors Information:

M. Devogele[1], J.L. Cano[2], L. Conversi[1], D. Föhring[1], M. Micheli[1], F. Ocaña[3], C. Drury[1], T. Santana-Ros[4], M-T. Hui[5], X.-L. Zhang[6], X.-Y. Fan[6,7], L. Buzzi[8]

[1] Planetary Defence Office, NEO Coordination Centre, ESA/ESRIN, Largo Galileo Galilei, 1, 00044 Frascati (RM), Italy
[2] Planetary Defence Office, ESA/ESOC, Robert-Bosch-Straße 5, 64293 Darmstadt, Germany
[3] Planetary Defence Office, ESA/ESAC, Bajo del Castillo s/n, 28692 Villafranca del Castillo, Madrid, Spain
[4] Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal, Universidad de Alicante, Carr. San Vicente del Raspeig, s/n, 03690 San Vicente del Raspeig, Alicante, Spain
[5] State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Taipa, Macau
[6] Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China
[7] University of Chinese Academy of Sciences, Beijing 100049, China
[8] Schiaparelli Astronomical Observatory, Varese, Italy

Presenter email: maxime.devogele@ext.esa.int