Group Meeting

Aperture photometry on asteroid trails: detection of the fastest rotating near-Earth object

Maxime Devogèle[1], Luca Buzzi[2], Marco Micheli[1], Juan Luis Cano[1], Luca Conversi[1], Emmanuel Jehin[3], Marin Ferrais[4], Francisco Ocaña[1,5], Dora Föhring[1], Charlie Drury[1], Zouhair Benkhaldoun[6], and Peter Jenniskens[7]

Reporter: Yuhao Liu

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I. Introduction

Main-belt objects rarely move at speeds larger than one arc-second per minute (″/min).
In the case of near-Earth objects (NEOs), their motion is usually on the order of several ″/min and can reach very high speeds when performing a close Earth fly-by.

Such high angular speed requires short exposure times, leading to most of the observing time being spent on CCD read-out rather than on-sky observations.

Their rapid motion and variation in motion over short periods of time, which are often shorter than the typical exposure time, present challenges for observatories. Some observatories need to manually provide motion rates and cannot adjust them during the observations.

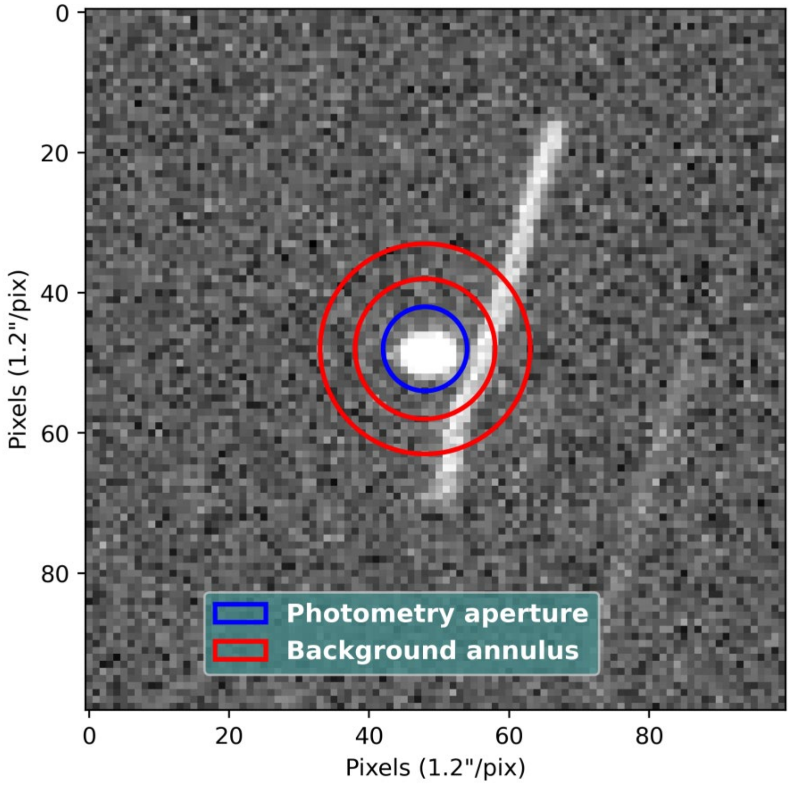
For these reasons, and because fast read-out cameras are rarely available, even traditional tracked observations with short exposure times can lead to both the stars and asteroid appearing trailed in the image. These observations are hard to analyse and even if the asteroid is perfectly tracked, the trailed star images can overlay the asteroid image or the selected background field, making the measurement useless.

I. Introduction

In this example, the observation is performed tracking the asteroid.

The flux of the target is captured by the first innermost blue aperture, while the gap between the innermost and second aperture is ignored. The pixels between the outermost and second aperture (two red apertures) are used to compute the sky-background level.

Therefore, the easiest and most reliable technique for obtaining high-quality data on these objects, when only slow read-out time CCD is available, is to perform sidereally tracked observations, allowing the asteroid to trail in the images.



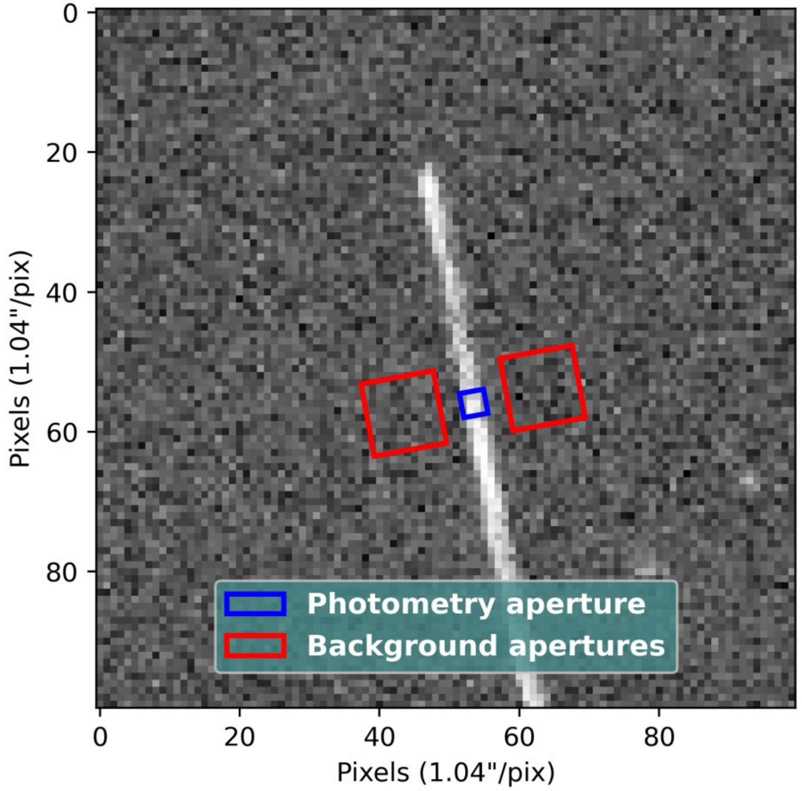
Asteroid: 2024 EF
Telescope: TRAPPIST-North
Exposure: 10 second

II. Aperture photometry on trailed objects

To perform aperture photometry on trailed observation of asteroids, we use a square or rectangular aperture aligned with the direction of the NEO's trail.

This technique maximizes the signal-to-noise ratio of the extracted photometry over a small section of the trail. We then step along the trail to collect the photometry as a function of time.

Example of square apertures on a trailed observation



Asteroid: 2024 BX_1
Exposure: 30s
Observed at the Schiaparelli Observatory

III. Observations and results

The method is applied to three recently observed NEOs: 2023 CX_1, 2024 BX_1 and 2024 EF.

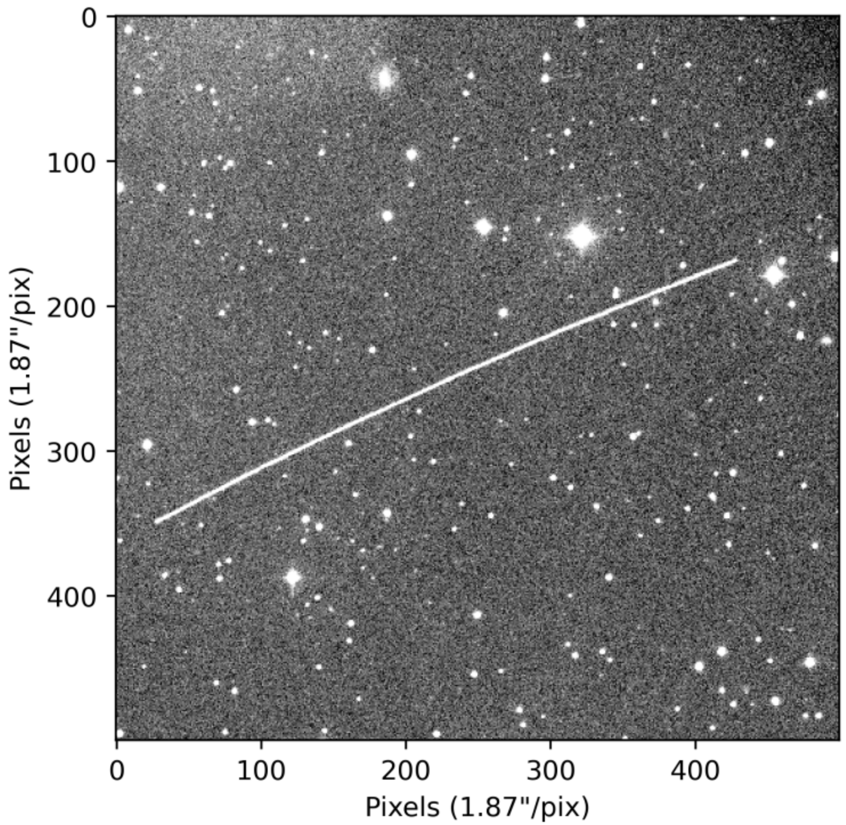
Of these, 2023 CX_1 and 2024 BX_1 impacted the Earth on 2023 February 13 and 2024 January 21 respectively.
The third one, 2024 EF, performed a close fly-by at a distance of only 57614.5±2.4 km from the Earth's center on 2024 March 4.

All of these asteroids are small, with H magnitudes ranging from $H = 29.1$ for 2024 EF to $H = 32.7$ for both 2023 CX_1 and 2024 BX_1. These magnitudes correspond to sizes ranging from less than 0.5 m (Spurny et al. 2024) to approximately 5 m, enabling them to display very fast rotation periods (Beniyama et al. 2022; Thirouin et al. 2016, 2018).

III. Observations and results | 2023 CX_1

For asteroid 2023 CX_1, we analyse four observations obtained at the Schiaparelli Observatory located in northern Italy, atop mount Campo dei Fiori near Varese, 1230 m above sea level. The observations were unfiltered, with an exposure time of 60 s.

asteroid	**2023 CX_1**
Observatory	Schiaparelli Observatory
telescope	0.84 m Newtonian telescope
camera	SBIG STX-16803
field of view	42′ × 42′
pixel size	1.87″ when operated in 3 × 3 binning mode
exposure time	60 s
Observation time	2023 Feb. 13 02:29 to 02:51 UT



The last image of 2023 CX_1 was obtained at 02:50 UT, only 9 min before impact, when CX_1 was located at 7 000 km from the observer.

III. Observations and results | 2023 CX_1

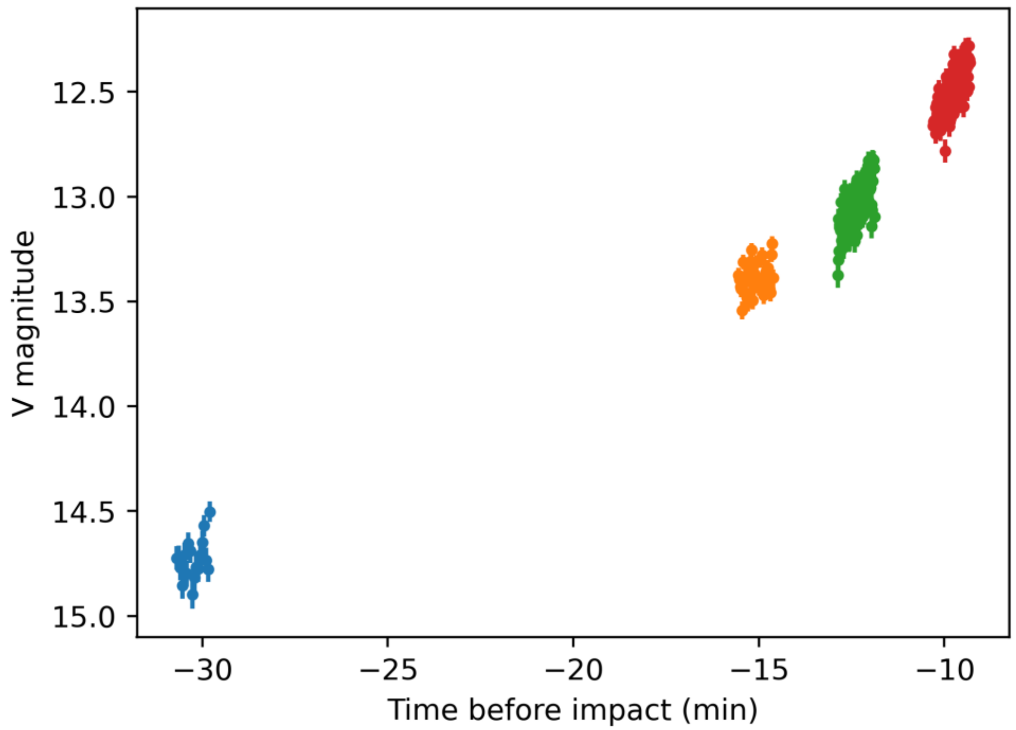
Each color representing a different observation.

The magnitude has been calibrated in the V band independently for each acquisition using the field stars.

The time is expressed in minutes before the impact.

The fast brightening of 2023 CX_1 is clearly visible as it approaches Earth.

2023 CX1 photometric observations



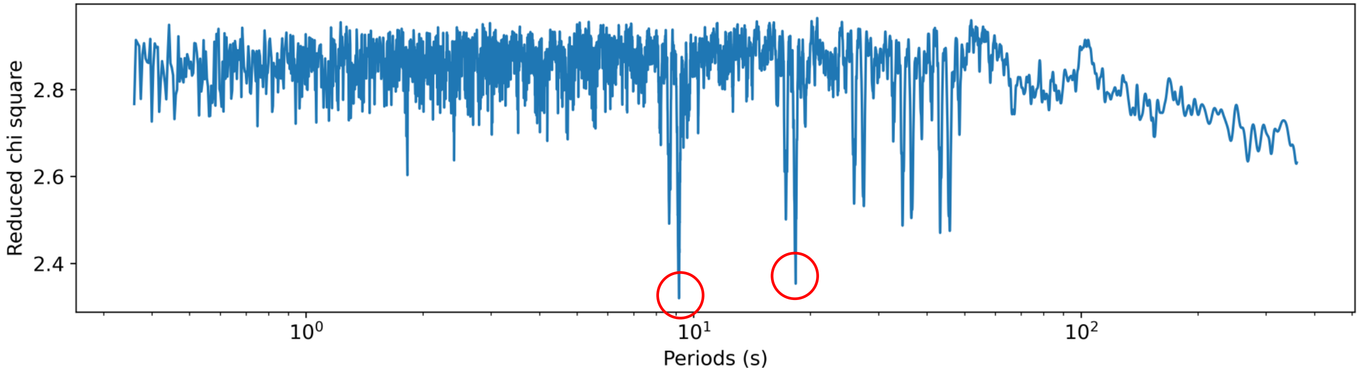
III. Observations and results | 2023 CX_1

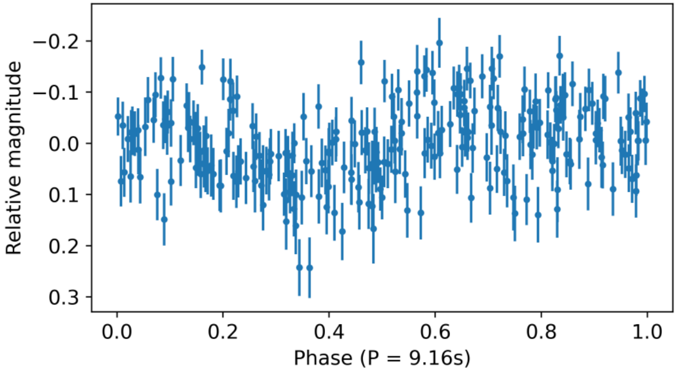
We searched for the signature of rotation by folding all the data according to trial periods. For each period, a Fourier series of order 5 is fitted and the chi-square of the fit to the data is computed. The phase curve is expected to have two minima for one rotation, but can be complicated if the object is tumbling.

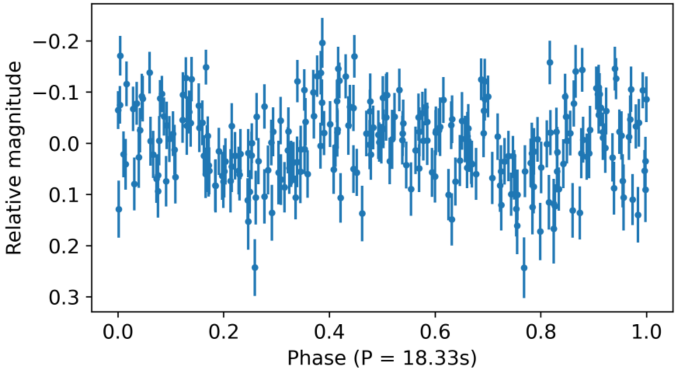
Upper plot: Periodogram for all the observations of 2023 CX1, testing periods between 0.36 s to 6 min.

Bottom plots: Observations phased according to the two best test periods.

The periodogram exhibits several chis-square minima.





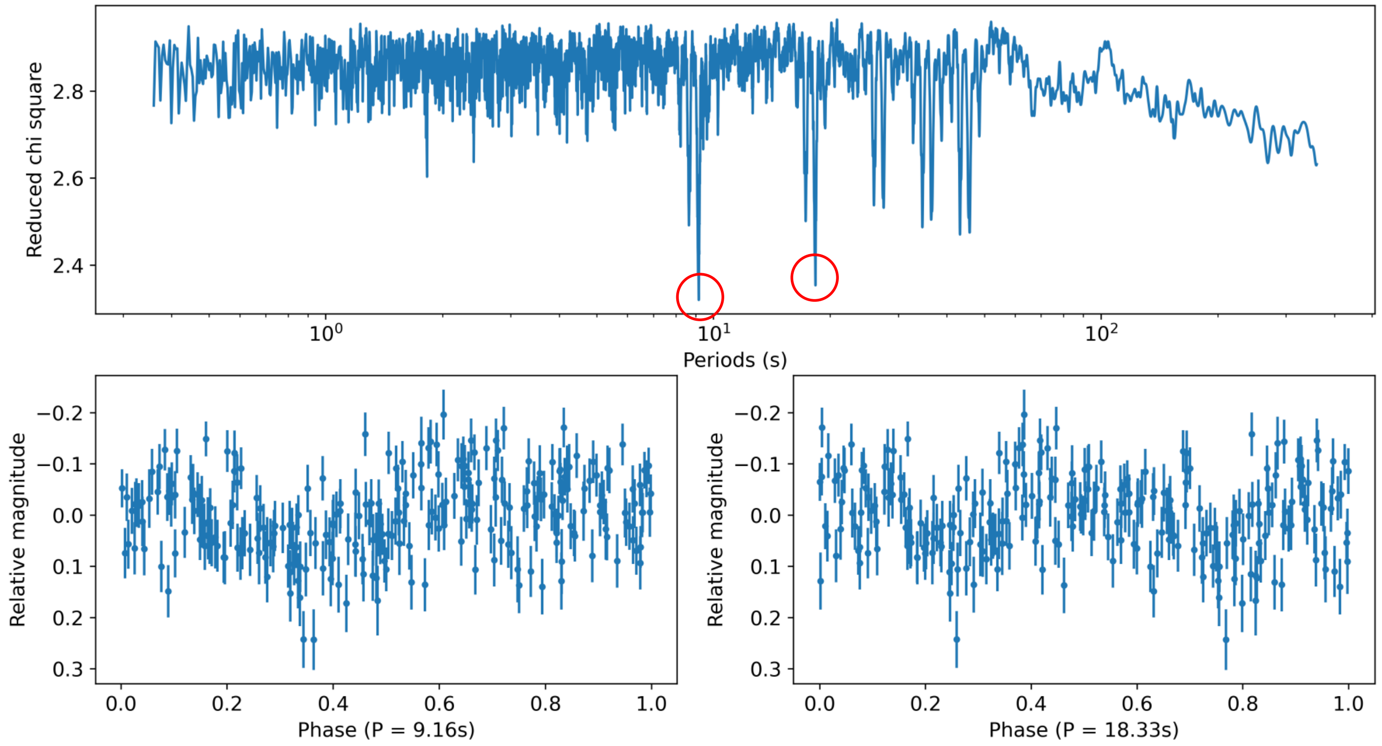


III. Observations and results | 2023 CX_1

We searched for the signature of rotation by folding all the data according to trial periods. For each period, a Fourier series of order 5 is fitted and the chi-square of the fit to the data is computed. The phase curve is expected to have two minima for one rotation, but can be complicated if the object is tumbling.

- A period of 9.16 s (left diagram) does not show the expected double minimum in the phased lightcurve, which may represent just half a period.

- A period of 18.33 s does result in the expected double minimum, but the amplitude is small leading to poor significance and likely due to noise rather than the asteroid rotation.



III. Observations and results | 2024 BX_1

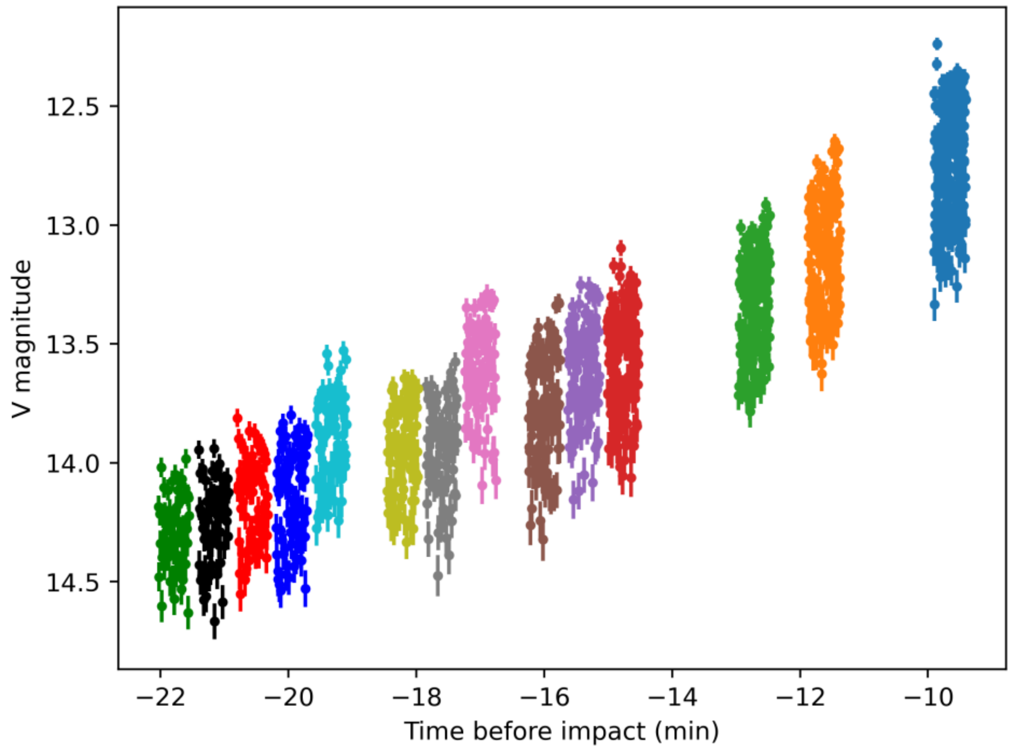
asteroid	**2024 BX_1**
Observatory	Schiaparelli Observatory
telescope	0.84 m Newtonian telescope
camera	QHY600M **CMOS**
field of view	$41.6' \times 27.8'$
pixel size	$1.04''$ when used in a 4 by 4 binning mode
exposure time	30 s
Observation time	2024 Jan. 21 00:09 to 00:22 UT

Each color represents a different image of 30 s each.

The x-axis represents the time in minutes before the impact time while the y-axis is magnitude in the V band.

We again see a clear brightening of the object as it approached Earth.

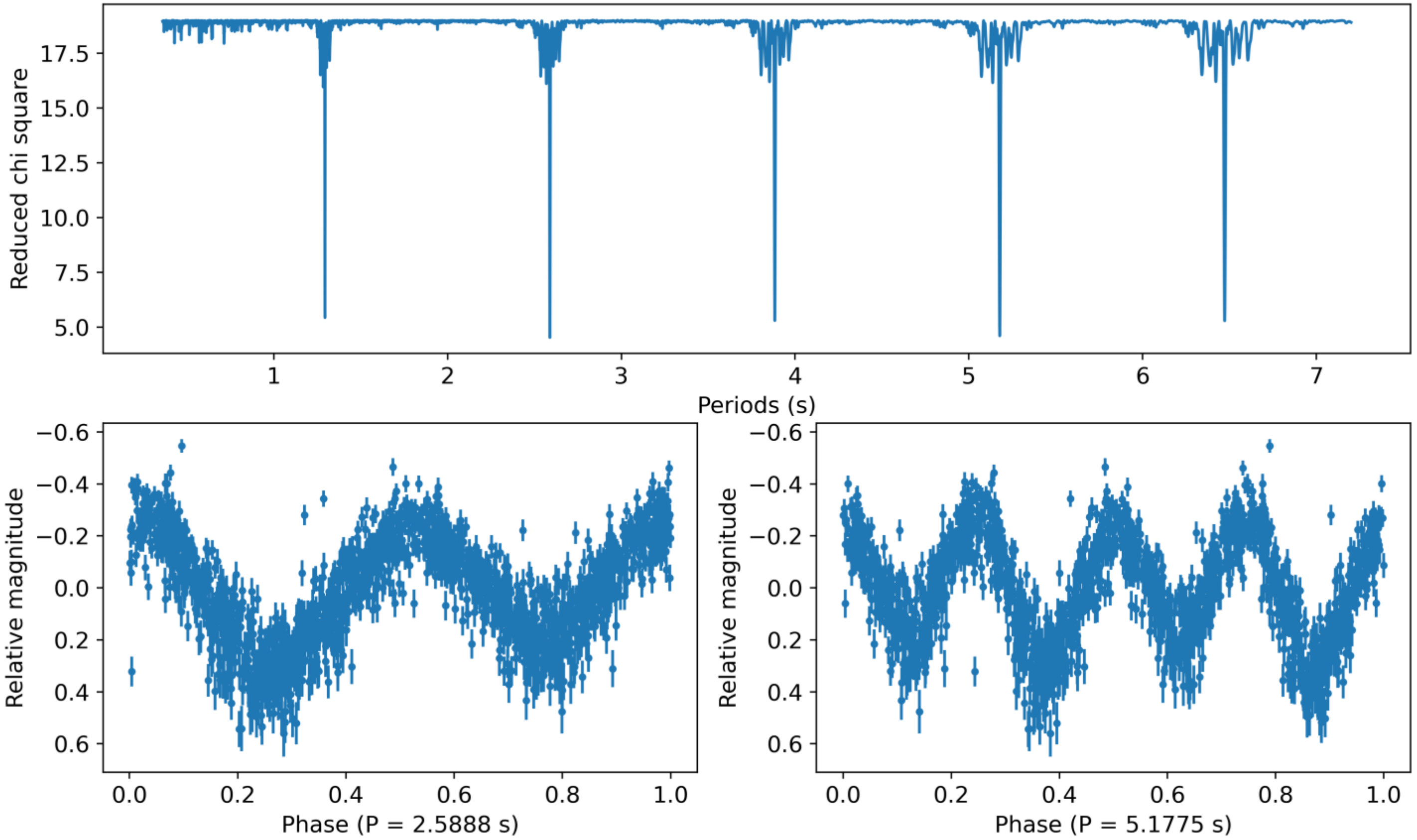
Photometry of 2024 BX1 on all the trailed images.



III. Observations and results | 2024 BX_1

The periodogram (the same method as for 2023 CX1 is used to compute the periodogram) for test periods between 0.36 to 7.2 s.

The signal at a period of P = 2.5888 ± 0.0002 s, along with its aliases (varying numbers of maxima and minima), is evident. This is the fastest rotation period ever measured for an asteroid.

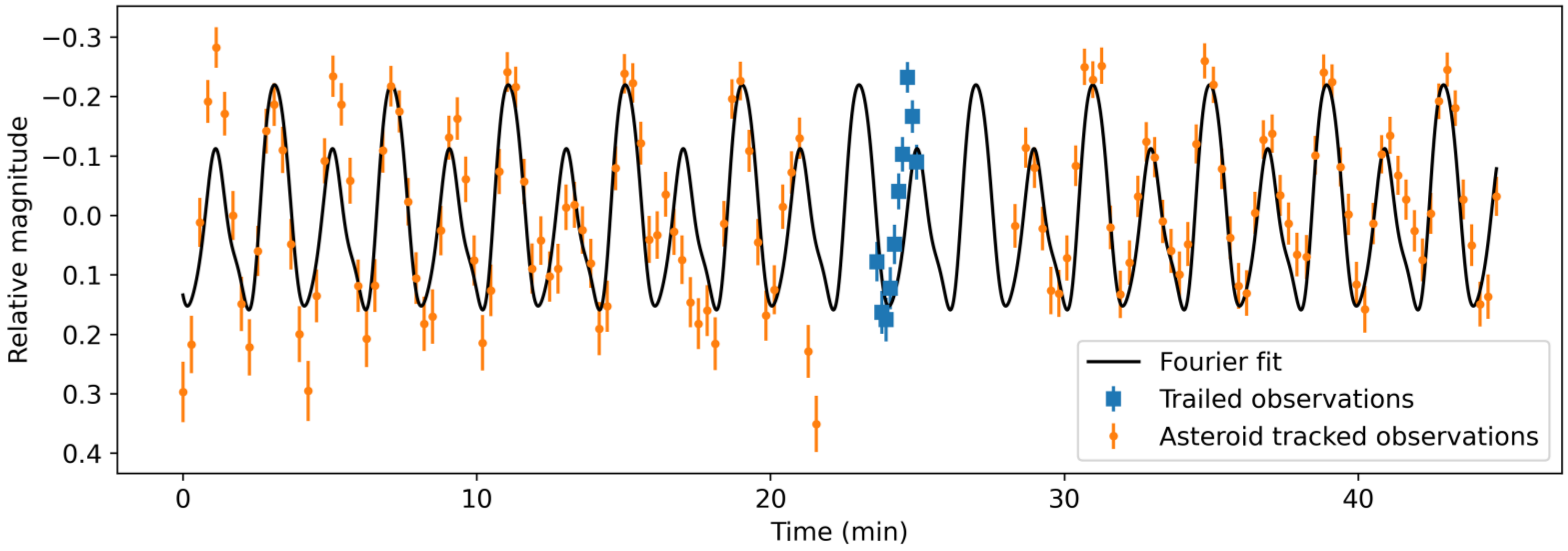


III. Observations and results | 2024 EF

asteroid	**2024 EF**
Observatory	Oukaimaiden observatory in Morocco
Telescope	TRAPPIST-North a robotic telescope using a 0.6 m Ritchey-Chrétien designs operating at f/8 on a German Equatorial mount.
Camera	Andor IKONL BEX2 DD ($0.60''$/pixel)
field of view	$20' \times 20'$
binning	2×2
exposure time	20, 10 and 3 s (Asteroid tracked observation) 90 s (Trailed observation)
Observation time	2024 Feb. 4 02:43 to 03:33 UT

III. Observations and results | 2024 EF

Ligthcurve of 2024 EF

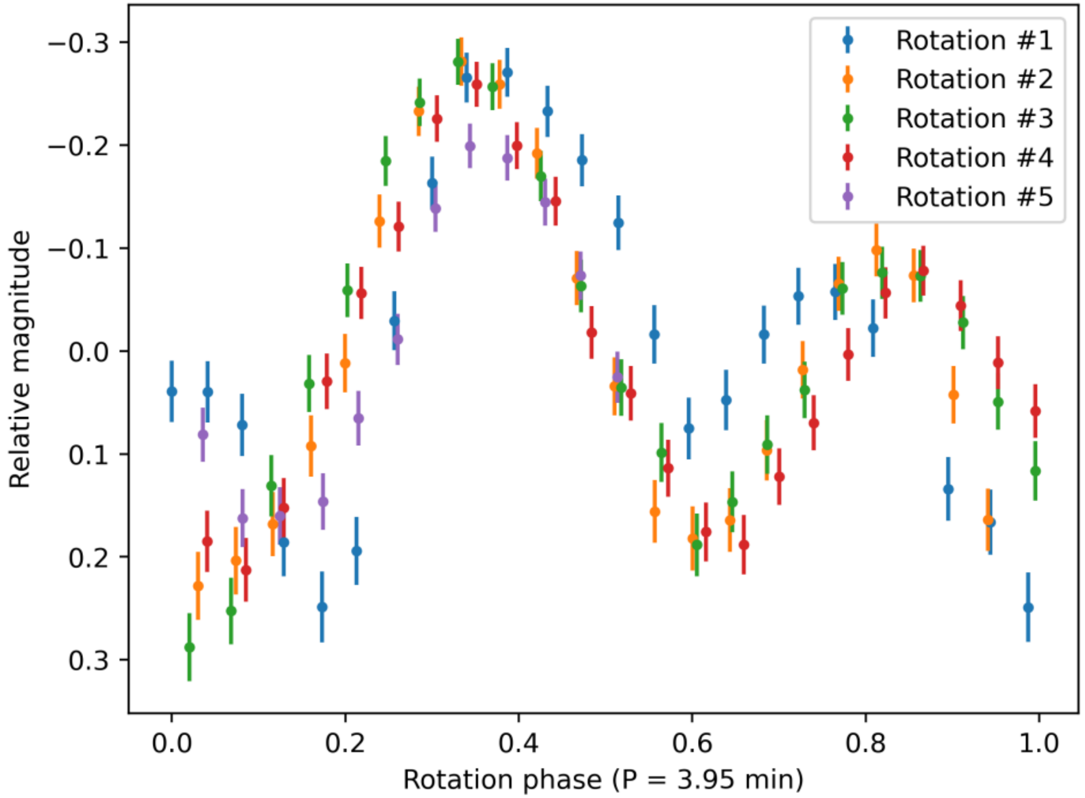


The orange dots corresponds to regular asteroid tracked observations,.
The blue squares corresponds to the photometry obtained in one single trailed observations of 90 s.
The black curve corresponds to the best Fourier fit on the orange observations only.

- We can determine a rotation period of 3.95 min.
- The trailed observation fits nicely the trend obtained with the orange observations only.

Additionally, we note that there is a hint that 2024 EF is in a **tumbling** state as we can see that the amplitude of the lightcurve appears to change over time following a regular decrease and increase.

Phased lightcurve of 2024 EF according to a period of 3.95 min.



IV. Conclusions

In this paper:

- a novel approach were presented to perform photometry of fast moving near-Earth asteroids.

- analyzed three recently observed targets, 2023 CX1, 2024 BX1, and 2024 EF.

- Based on these results, we encourage observers to obtain trailed observations of asteroids when the asteroids motion on the sky is so fast that the exposure time would be significantly shorter than the CCD read-out time.

- Fast spinning asteroids are expected to be small and thus faint when located far away from Earth. It is thus important to take advantage of their impacting and very close fly-by events to obtain reliable physical characterization on them.

Thanks