6764 KIRILLAVROV: A BINARY ASTEROID

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Mutual events appearing in the lightcurve of 6764 Kirrillavrov unambiguously show that it is a binary asteroid with a rotation period of 4.739 ± 0.001 h, and an orbital period of 30.41 ± 0.01 h. Follow-up observations conducted during the 2021 opposition did not detect the mutual events due to unfavorable viewing geometry. Further observations during subsequent oppositions are encouraged.

While the primary purpose of the Transiting Exoplanet Survey Satellite (TESS) is detection of exoplanets, its images are also useful for the construction of lightcurves for asteroids. Pál et al. (2020) obtained 9912 such lightcurves. In addition to supplying 15 documents containing raw and phased lightcurves for all of these objects, the authors made available the raw photometry data.

Main-belt asteroids typically spend 2 to 4 weeks in the TESS frames, which are gathered with a cadence of 30 minutes. This is often sufficient coverage for determination of rotational periods. Since these periods are shown in The Asteroid Lightcurve Database (LCDB; Warner et al., 2009), they form a suitable basis for comparing results.

This principal author's discovery of the binary nature of 1803 Zwicky (Polakis, 2021) led to an inspection of the TESS raw and phased data. Pál et al. published only the short rotation period of roughly 2.7 hours, but their raw lightcurve contained a clear signature of deep, mutual events occurring with an interval of greater than 14 hours. This prompted a review of thousands of raw TESS lightcurves for similar mutual event signatures that the authors may have missed.

The raw TESS lightcurve of 6764 Kirillavrov, gathered over the course of 26 days, contains such a signature. Pál et al. published a rotation period of 30.4318 ± 0.0005 h. Their data shown in Figure 1 was downloaded, and a dual-period search in *MPO Canopus* (Warner 2020) revealed that this is in fact an orbital period overlaid on a shorter rotation period of lesser amplitude. The rotation and orbital periods derived from the TESS data are 4.740 ± 0.002 h and 30.41 ± 0.01 h, and amplitudes are 0.08 and 0.25 mag, respectively. These rotation and orbital lightcurves appear in Figures 2 and 3.

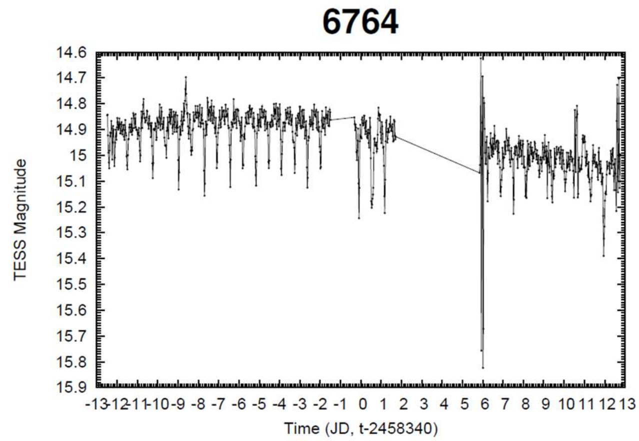

Figure 1. TESS data: raw lightcurve.

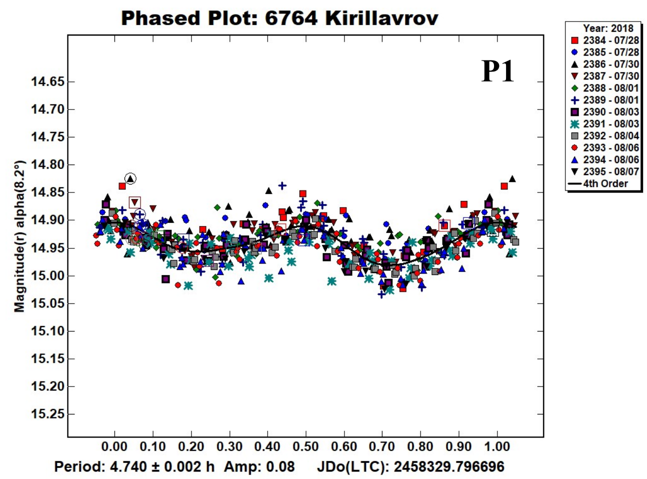

Figure 2. TESS data: phased lightcurve showing rotation period.

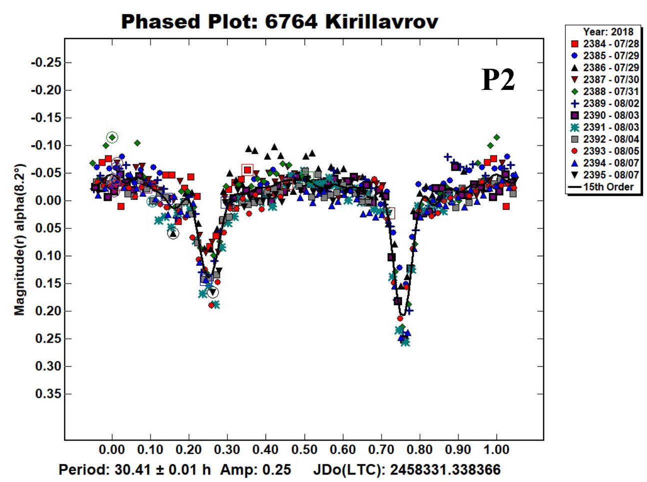

Figure 3. TESS data: phased lightcurve showing orbital period.

Brian Skiff (private communication) provided an agreeing rotation period of 4.737 ± 0.002 h, using data acquired in 2014 March. The LCDB shows the orbital period of Behrend et al. (2020web): 30.43 ± 0.05 h. Their web site states, "Provisional: binary asteroid in season of eclipses."

Number	Name	yy/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
6764	Kirillavrov	21/04/13-04/18	12.2,6.0	222	-3	4.739	0.001	0.08	0.03	FLOR
						30.41	0.01	0.25	0.06	

Table I. Observing circumstances and results. The first line gives the primary (adopted) period for the system. The second line gives the secondary period. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

6764 Kirillavrov came to opposition in 2021 May at magnitude 15. Unfortunately for northern observers, the declination was -21°. Observers in the Southern Hemisphere were solicited for observations. Julian Oey in Australia and Milagros Colazo in Argentina kindly obliged, providing data from ten nights.

CCD photometric observations by Oey (MPC code Q68) were conducted on six nights between 2021 April 18 and 24, using a 0.35m Schmidt Cassegrain telescope, SBIG ST8XME camera, and a clear filter. Image scale was 0.88 arcsec/pixel. Exposure time was 3 minutes.

Colazo (MPC code 821) performed her observations during four nights from 2021 April 12 through 15 with a 1.5m Newtonian telescope, Apogee Alta F16M camera, and without filter. Her images have a scale of 0.74 arcsec/pixel. She used an exposure time of 80 seconds.

Both observers provided all of their photometric data to the principal author for reduction. The data reduction and period analysis were done using *MPO Canopus* (Warner, 2020). The clear-filtered images were reduced to Sloan r′ to minimize error with respect to a color term. Comparison star magnitudes were obtained from the ATLAS catalog (Tonry et al., 2018), which is incorporated directly into *MPO Canopus*. Period determination was done using the *MPO Canopus* Fourier-type FALC fitting method (cf. Harris et al., 1989). Phased lightcurves show the maximum at phase zero. Magnitudes in these plots are apparent and scaled by MPO Canopus to the first night.

A raw plot of the full dataset is provided in Figure 4, followed by a phased lightcurve in Figure 5.

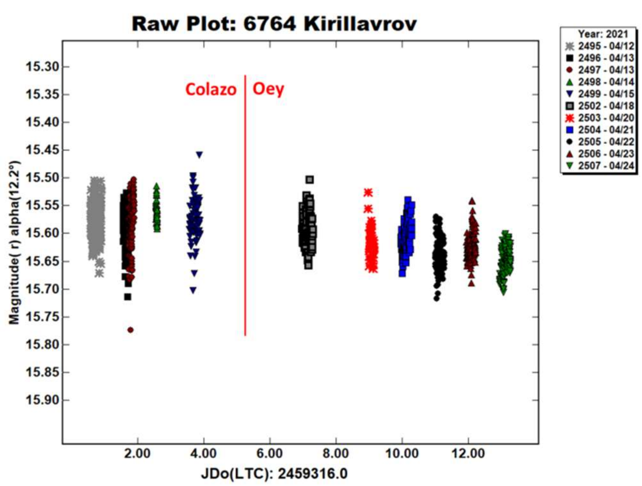

Figure 4. Colazo and Oey data: raw lightcurve.

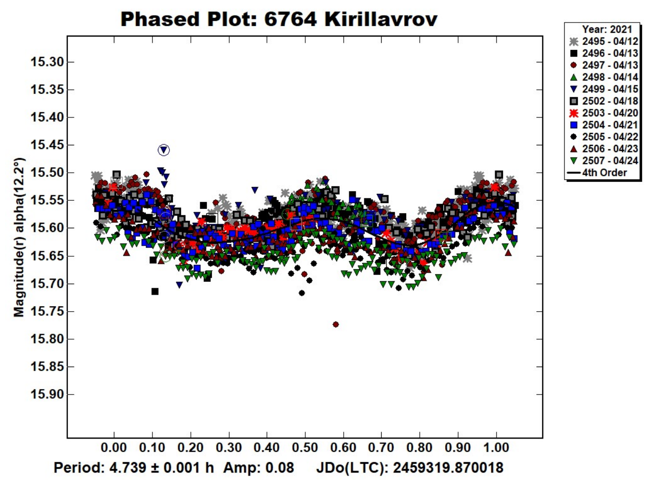

Figure 5. 2021 Colazo and Oey data: phased lightcurve.

Within the data scatter, mutual events were not detected during the ten nights during which data was gathered. The duration and frequency of these data were more than sufficient to capture some mutual events. It can only be concluded that the unfavorable viewing geometry resulted in misses rather than eclipses and occultations, at least within the precision of the scatter. The dense coverage does enable a refinement of the rotation period to 4.739 ± 0.001 h, with an RMS scatter on the fit of 0.034 mag. Results are summarized in Table I.

Since 2014, we now have four data sets for this asteroid, with two of them exhibiting mutual events. Table II summarizes PAB values for the four sets. Note that the Skiff data was sparse, so it is insufficient to conclude that mutual events did not occur.

Lightcurve	Date	Events?	PAB (°) Lon	Lat
Skiff	3/28/2014	?	183	3
TESS	8/2/2018	Y	313	-10
Behrend	1/19/2020	Y	85	8
Colazo & Oey	4/18/2021	N	221	-3

Table II. Viewing geometry for four datasets

Looking forward, the next two oppositions will favor northern observers. A summary of future oppositions through 2025 is presented in Table III. Follow-up observing with the aim of detecting mutual events is encouraged.

Opposition Date	Declination (°)	Magnitude	PAB (°) Lon	Lat
2022 Nov 05	20	16.3	42	4
2024 Feb 24	17	16.0	154	7
2025 Sep 14	-9	15.7	350	-5

Table III. Observing circumstances for upcoming oppositions

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NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2021 OCTOBER-DECEMBER

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Lightcurves of 16 near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies (CS3) from 2021 October through December were analyzed for rotation period, peak-to-peak amplitude, and signs of satellites or tumbling. The minor planets (87024) 2000 JS66 and 2019 XS were found to be in a tumbling state.

CCD photometric observations of 16 near-Earth asteroids (NEAs) were made at the Center for Solar System Studies (CS3) from 2021 October through December. Table I lists the telescopes and CCD cameras that were available to make observations.

Up to nine telescopes can be used but seven is more common. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24-1.60 arcsec/pixel.

Telescopes	Cameras
0.30-m *f*/10 Schmidt-Cass	FLI Microline 1001E
0.35-m *f*/9.1 Schmidt-Cass	FLI Proline 1001E
0.40-m *f*/10 Schmidt-Cass	SBIG STL-1001E
0.40-m *f*/10 Schmidt-Cass	
0.50-m *f*/8.1 Ritchey-Chrétien	

Table I. List of available telescopes and CCD cameras at CS3. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

All lightcurve observations were unfiltered since a clear filter can cause a 0.1-0.3 mag loss. The exposure duration varied depending on the asteroid's brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. To reduce the number of times and amounts of adjusting nightly zero points, we use the ATLAS catalog r´ (SR) magnitudes (Tonry et al., 2018). Those adjustments are usually $|\Delta| \leq 0.03$ mag. The larger corrections, which are rare, may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction. Another cause may be selecting what appears to be a single star but is actually an unresolved pair.

The Y-axis values are ATLAS SR "sky" (catalog) magnitudes. The two values in the parentheses are the phase angle (a) and the value of *G* used to normalize the data to the comparison stars used in the earliest session. This, in effect, corrected all the observations to seem to have been made at a single fixed date/time and phase angle, leaving any variations due only to the asteroid's rotation and/or