

NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2022 FEBRUARY-MARCH

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Lightcurves of six near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies (CS3) in 2022 February and March were analyzed for rotation period, peak-to-peak amplitude, and signs of satellites or tumbling. There are good indications that (138971) is in a low-level tumbling state.

CCD photometric observations of six near-Earth asteroids (NEAs) were made at the Center for Solar System Studies (CS3) in 2022 February and March. 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.

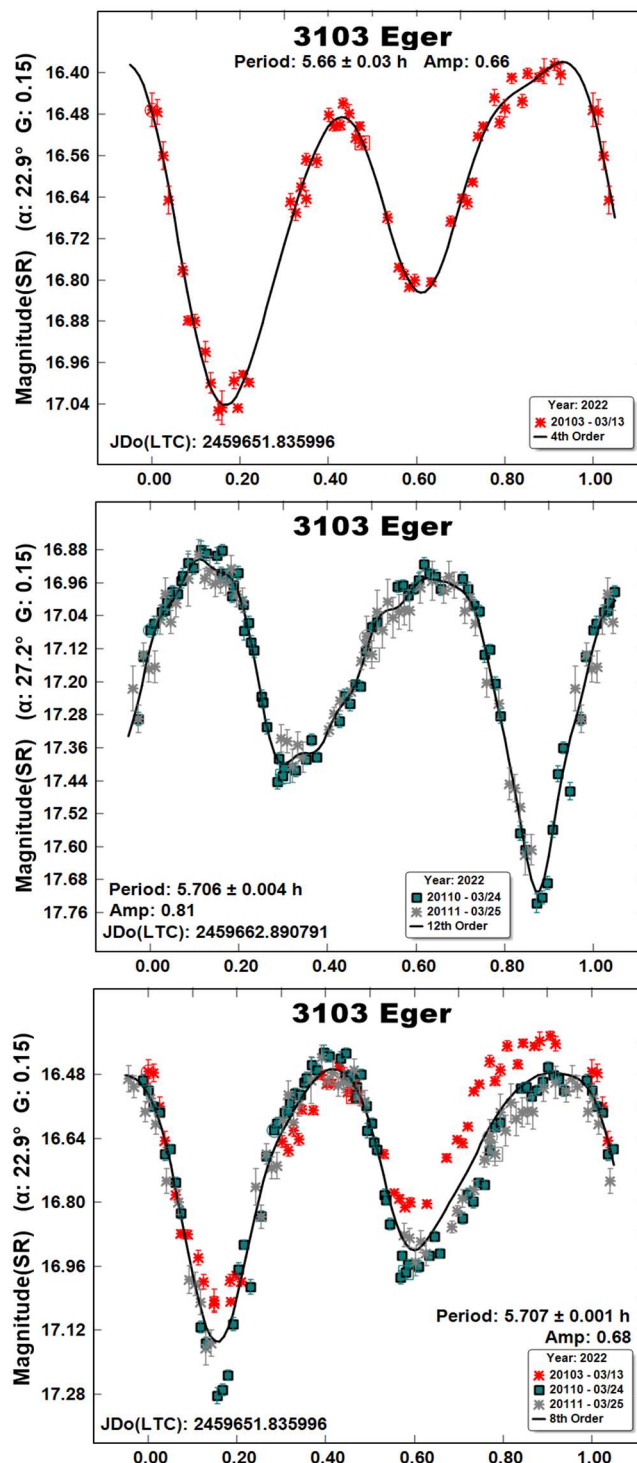
Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. To reduce the number of times and amounts of adjusting nightly zero points, we use the ATLAS catalog r' (SR) magnitudes (Tonry 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 (α) 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

albedo changes. The X-axis shows rotational phase from -0.05 to 1.05 . If the plot includes the amplitude, e.g., "Amp: 0.65", this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

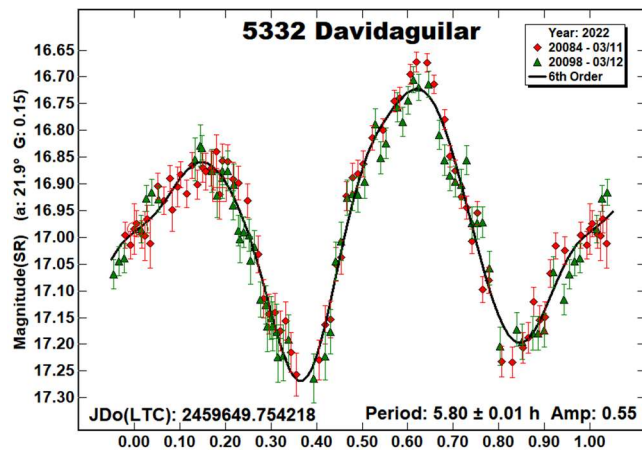
"LCDB" substitutes for "Warner et al. (2009)" from here on.

3103 Eger. The earliest reported period in the LCDB is from Wisniewski (1987). We observed the asteroid on four previous occasions (Warner, 2014; 2016; 2017; Warner and Stephens, 2019). All previous results put the rotation period close to 5.71 h. Our 2022 result using the full data set is in good agreement.

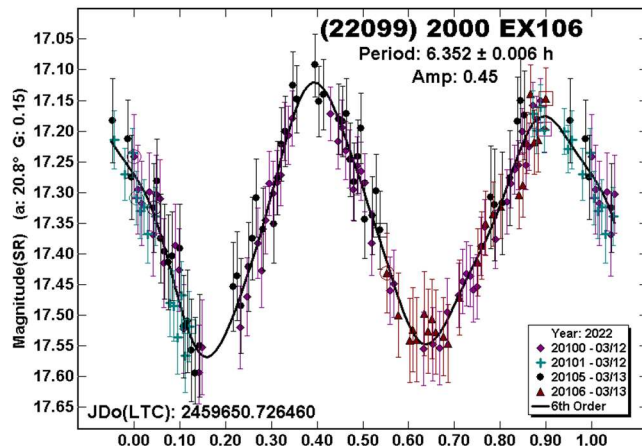


Over the fortnight of our 2022 observations, the shape and amplitude of the lightcurve changed noticeably. In mid-March, the amplitude was 0.61 mag at phase angle 22.7° . Towards the end of the month, the phase angle increased to about 27.4° and the amplitude to 0.81 mag. This is expected behavior (Zappala et al. 1990) but the amount of amplitude change is larger than expected for a relatively small change in phase angle. The phase angle bisector longitude and latitude (Harris et al, 1984) were almost constant, adding no insight for the large amplitude change.

5332 Davidaguilar. Binzel (1990) first reported a period of 5.82 h for this 3-km NEA, which has shown a large range of amplitudes over the years: 0.20-1.2 mag. The period from our latest data set of 5.80 h is in good agreement with earlier results, including ours (Warner and Stephens, 2019).

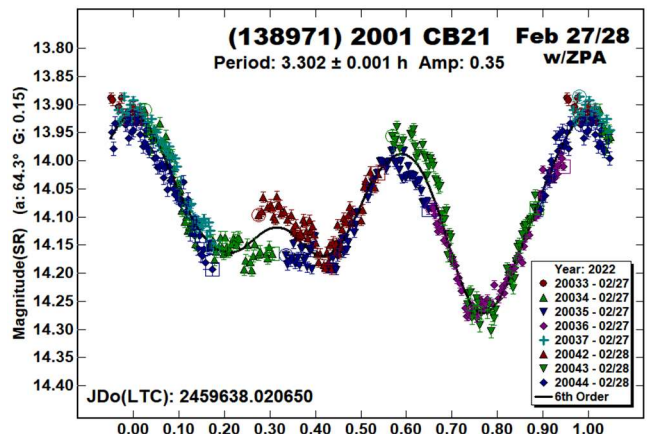
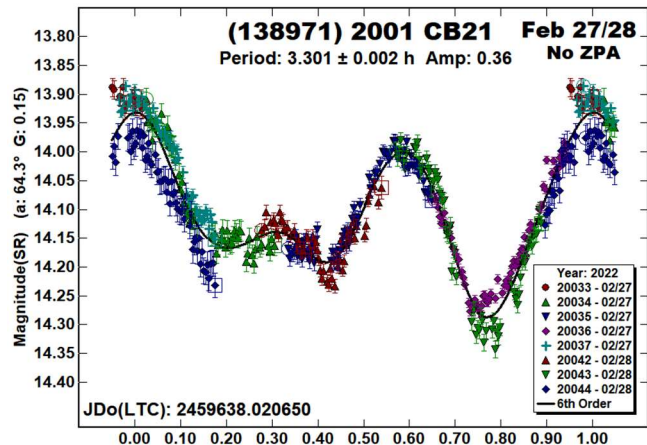
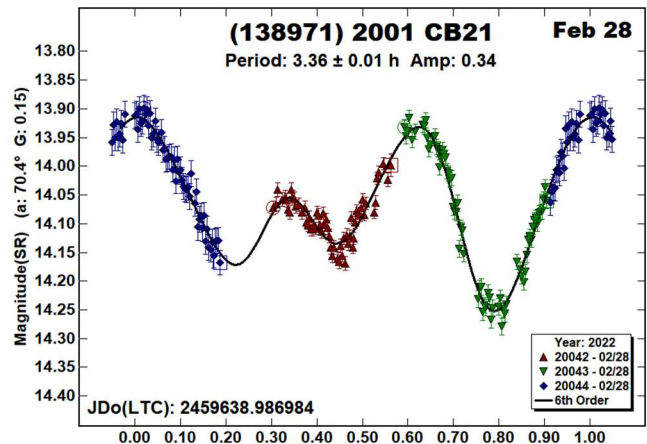
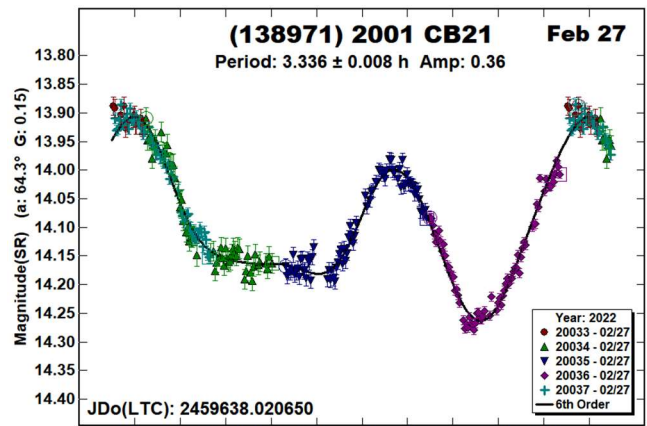


(22099) 2000 EX106. Pravec et al. (2000web) found a period of 6.334 h and we (Warner, 2015) reported 6.31 h. The 2022 data set gives similar results. The amplitude of 0.45 mag is within the small range of 0.40-0.45 mag reported so far.



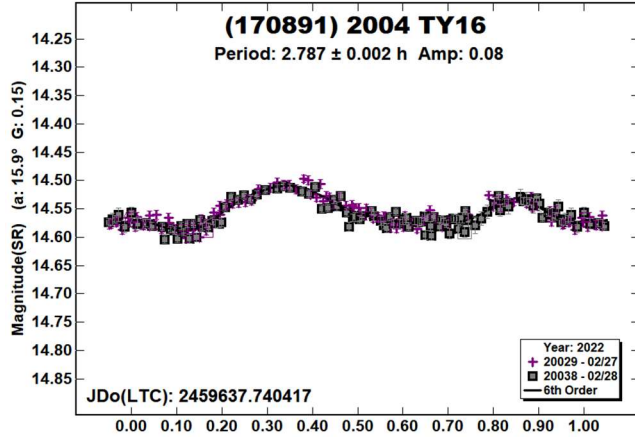
(138971) 2001 CB21. There are good indications that this asteroid is in a state of non-principal axis rotation (NPAR; see Pravec et al., 2005; 2014). It was not possible to find a single period to get a good fit to the data set. We tried a dual-period search in *MPO Canopus*, but to no avail. We considered the alternate period of 4.953 h found by Galad et al. (2005), also with unsatisfactory results.

The “No ZPA” and “w/ZPA” plots (“Zero-point Adjustment”) show that the mismatch in the data was not strictly due to catalog errors for the comparison stars and other systematics.

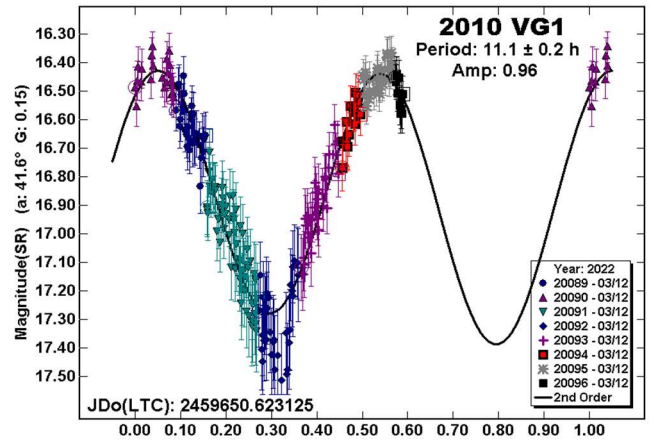
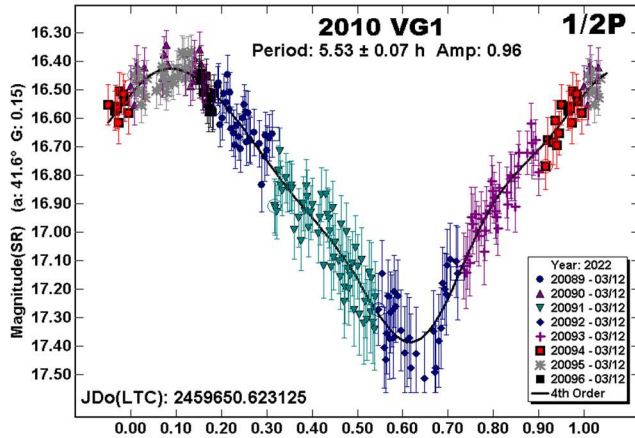


We should note, however, that the phase angle was very large, $\alpha > 65^\circ$, which can lead to strong shadowing effects. This may be why we could not find a single-period, even with zero-point offsets.

(170891) 2004 TY16. The only previous report of a period in the LCDB is from Carbognani (2008), who found 2.795 h and amplitude of 0.18 mag at L_{PAB} 105°. Our observations, at L_{PAB} 168°, showed a similar period but much lower amplitude. This might suggest that the 2022 observations were more pole-on and, therefore, the asteroid's north pole has an ecliptic longitude in the vicinity of 170° or 350°.



2010 VG1. Circumstances did not allow finding a complete lightcurve for 2010 VG1, mostly because the period is nearly commensurate with an Earth-day and the observations were from a single location.



We found the half-period, which did provide full lightcurve coverage, to estimate the full period. Given the large amplitude, the large phase angle notwithstanding, a bimodal solution near 11 h is highly likely (Harris et al., 2014).

Acknowledgements

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Number	Name	2022 mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.
3103	Eger	03/13-03/25	*28.7, 27.6	137	6	5.707	0.001	0.80	0.03
5332	Davidaguiar	03/11-03/12	22.0, 21.6	191	26	5.80	0.01	0.55	0.03
22099	2000 EX106	03/12-03/13	20.8, 20.6	182	15	6.352	0.006	0.45	0.03
138971	2001 CB21	02/27-02/28	64.0, 69.9	184	26	3.301	0.002	0.36	0.03
170891	2004 TY16	02/27-02/28	16.0, 15.7	169	-6	2.787	0.002	0.08	0.01
	2010 VG1	03/12-03/12	41.1	149	8	11.1	0.1	0.96	0.03

Table II. Observing circumstances and analysis results. The phase angle (α) is given at the start and end of each date range. If there is an asterisk before the first phase value, the phase angle reached a maximum or minimum during the period. L_{PAB} and B_{PAB} are, respectively the average phase angle bisector longitude and latitude (see Harris et al., 1984).

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LIGHTCURVES FOR FIFTEEN MINOR PLANETS

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Photometric measurements were made for 15 main-belt asteroids, based on CCD observations made from 2022 January through 2022 March. Phased lightcurves were created for 14 asteroids, while one did not yield a period solution. All the data have been submitted to the ALCDEF database.

CCD photometric observations of 15 main-belt asteroids were performed at Command Module Observatory (MPC V02) in Tempe, AZ. Images were taken using a 0.32-m f/6.7 Modified Dall-Kirkham telescope, SBIG STXL-6303 CCD camera, and a 'clear' glass filter. Exposure time for all the images was 2 minutes. The image scale after 2×2 binning was 1.76 arcsec/pixel. Table I shows the observing circumstances and results. All of the images for these asteroids were obtained between 2022 January and 2022 March.

Images were calibrated using a dozen bias, dark, and flat frames. Flat-field images were made using an electroluminescent panel. Image calibration and alignment was performed using *MaxIm DL* software.

The data reduction and period analysis were done using *MPO Canopus* (Warner, 2022). The 45'×30' field of the CCD typically enables the use of the same field center for three consecutive nights. In these fields, the asteroid and three to five comparison stars were measured. Comparison stars were selected with colors within the range of $0.5 < B-V < 0.95$ to correspond with color ranges of asteroids. In order to reduce the internal scatter in the data, the brightest stars of appropriate color that had peak ADU counts below the range where chip response becomes nonlinear were selected. *MPO Canopus* plots instrumental vs. catalog magnitudes for solar-colored stars, which is useful for selecting comp stars of suitable color and brightness.

Since the sensitivity of the KAF-6303 chip peaks in the red, 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*. The ATLAS catalog derives Sloan $griz$ magnitudes using a number of available catalogs. The consistency of the ATLAS comp star magnitudes and color-indices allowed the separate nightly runs to be linked often with no zero-point offset required or shifts of only a few hundredths of a magnitude in a series.

A 9-pixel (16 arcsec) diameter measuring aperture was used for asteroids and comp stars. It was typically necessary to employ star subtraction to remove contamination by field stars. For the asteroids described here, I note the RMS scatter on the phased lightcurves, which gives an indication of the overall data quality including errors from the calibration of the frames, measurement of the comp stars, the asteroid itself, and the period-fit. 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