

NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2021 MARCH - APRIL

Brian D. Warner
Center for Solar System Studies / MoreData!
446 Sycamore Ave.
Eaton, CO 80615 USA
brian@MinorPlanetObserver.com

Robert D. Stephens
Center for Solar System Studies / MoreData!
Rancho Cucamonga, CA

Daniel R. Coley
Center for Solar System Studies
Corona, CA

(Received: 2021 July 12)

Lightcurves of four near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies (CS3) from 2021 March through April were analyzed for rotation period, peak-to-peak amplitude, and signs of satellites or tumbling.

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

Up to nine telescopes can be used for the campaign, although 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/6.3 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.

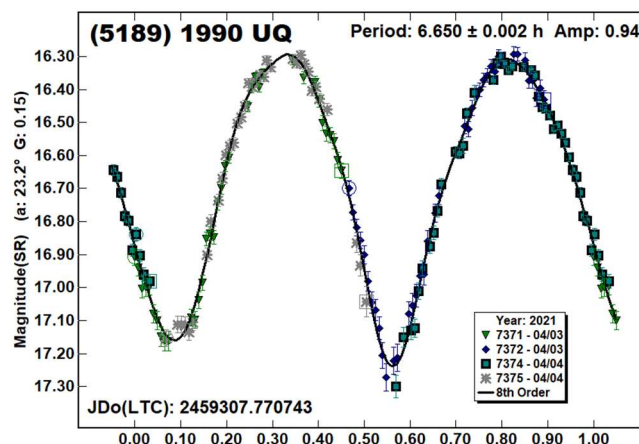
The Y-axis values are ATLAS SR "sky" (catalog) magnitudes. The two values in the parentheses are the phase angle (a) and the value of G used to normalize the data to the comparison stars used in the

earliest session. This, in effect, had all the observations 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*.

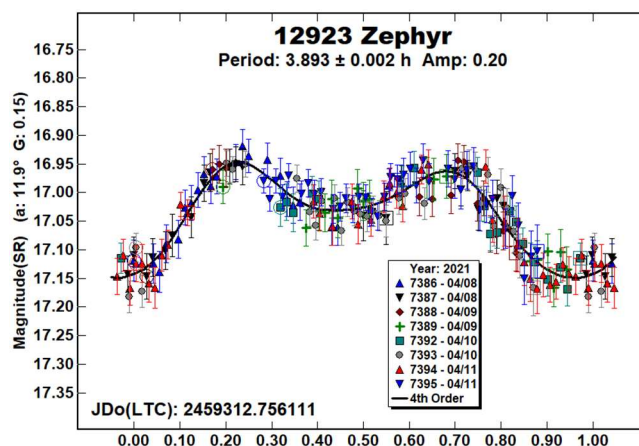
"LCDB" refers to Warner et al. (2009) from here on.

(5189) 1990 UQ. Warner (2018b) found a period of 6.676 h based on observations in 2017 November. We (Warner and Stephens, 2019) found a similar period of 6.640 h using data from 2019. Díaz-Vachier and Cotto-Figueroa (2020) reported a period of 6.653 h using data obtained in 2017. Oey (2020) followed the asteroid from 2017 September 25 to October 1. Due to a changing viewing aspect, he reported amplitudes range from 0.62–0.92 mag. At the time, he also suspected that the asteroid might be binary.

We observed the asteroid again in 2021 and derived a period of 6.654 h. Behrend (2021web) reported a period 6.644 h and Pravec et al. (2021web), observing six weeks earlier found 6.6570 h. An increasing synodic period as the asteroid approaches opposition usually indicates that the asteroid has retrograde rotation (a negative ecliptic latitude). This was supported by our shape model that found a pole of $(\lambda, \beta, P) = (317, -79, 6.657399 \text{ h})$. The full results of that analysis are presented in a figure at the end of this paper.

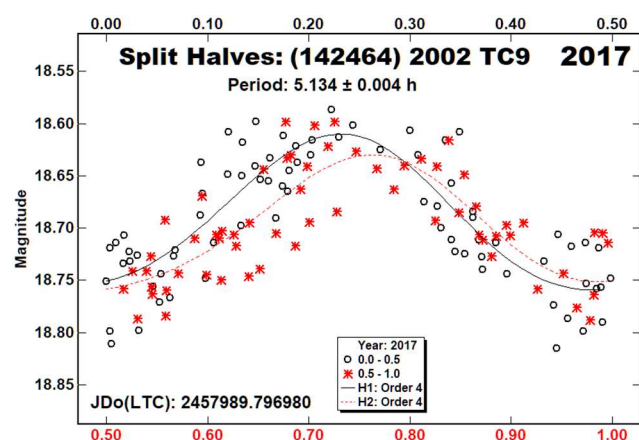
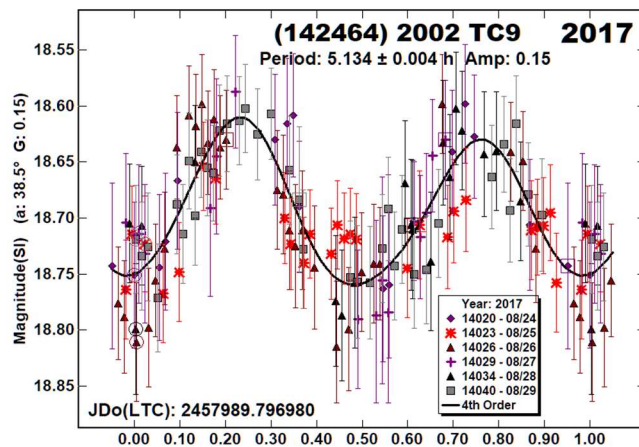
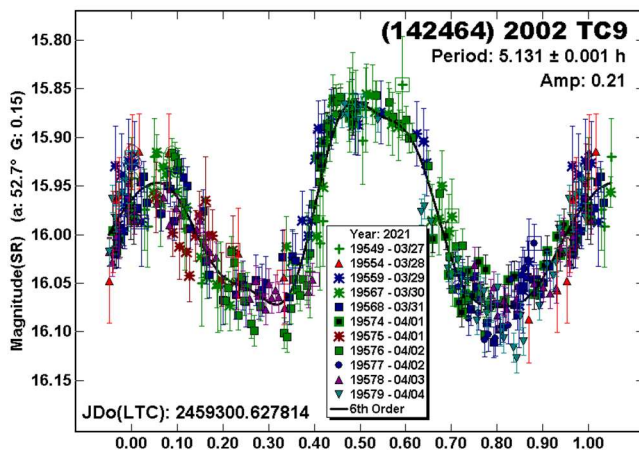


12923 Zephyr. The only previously reported period is from Pravec et al. (1999web) who found 3.891 h. Our observations in early 2021 April led to $P = 3.893$ h, which agrees with Pravec et al.



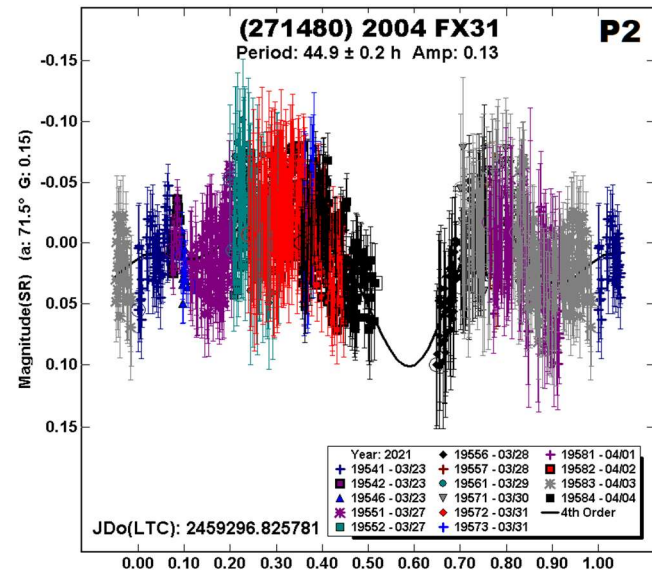
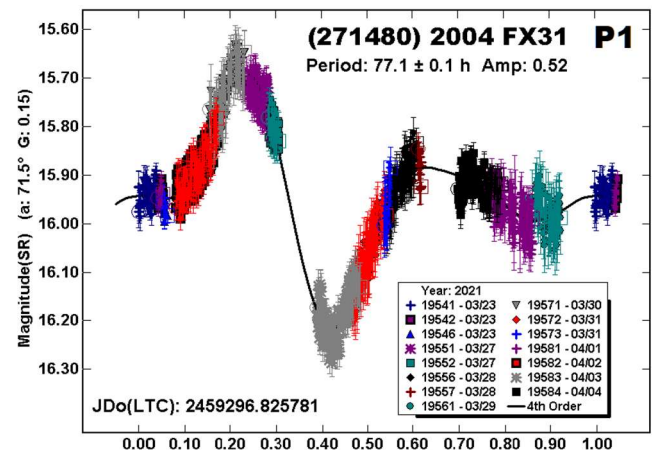
(142464) 2002 TC9. Warner (2018a) found a period of 2.320 h for this 890-m NEA (Mainzer et al., 2019). The solution was not fully secure ($U = 2+$). Our observations in 2021 led to, we believe, a secure period of 5.131 h. The bimodal lightcurve at 5.131 h with an amplitude of 0.21 mag is too asymmetrical, as shown in the split-halves plot, to adopt a shorter, monomodal solution (see Harris et al., 2014).

With this in mind, we re-examined the data from 2017 after resetting the comparison star magnitudes to those from the ATLAS catalog (Tonry et al., 2018). We tried fitting the data near the original period but the fit was unsatisfactory. We eventually found $P = 5.134$ h, which is not double the shorter period but close to a 9:4 ratio, suggesting that rotational aliasing and/or overzealous zero-point adjustments led to the shorter period.



(271480) 2004 FX31. Mainzer et al. (2019) used WISE data to find a diameter of 709 m using $H = 17.5$, which led to an albedo of 0.352. This is on the high end of the range for S-complex asteroids (Warner et al., 2009). Unfortunately, the LCDB has no entries for taxonomic class other than the assumed type S for near-Earth asteroids.

It seems likely that this is a tumbler (in non-principal axis rotation; see Pravec et al., 2005; 2014). *MPO Canopus* cannot fully analyze this type of object. Even so, we were able to extract a dominant period of 77.1 h. Subtracting that found secondary period of 44.9 h. Given the software deficiencies, low SNR, and observations being from a single longitude, these periods should not be taken at face value but may serve future observations. The next apparition is 2023 September when 2004 FX31 will reach $V \sim 15.5$ at -8° declination.



Number	Name	2021 mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
5189	1990 UQ	04/03–04/07	23.2, 22.9	210	9	6.654	0.002	0.91	0.02
12923	Zephyr	04/08–04/10	11.9, 10.8	213	5	3.893	0.002	0.20	0.02
142464	2002 TC9	03/27–04/04	*52.8, 57.3	155	–9	5.131	0.001	0.21	0.02
271480	2004 FX31	03/24–04/04	69.5, 54.4	199	39	^T 77.1 44.9	0.1 0.2	0.52 0.13	0.04 0.04

Table II. Observing circumstances and analysis results. ^TTumbling asteroid. 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).

Number	Name	λ	β	Period	P.E.	a/b ratio	a/c ratio
5189	1990 UQ	317	–79	6.657399	0.000002	1.7	2.4

Table III. The pole solution for (5189) 1990 UQ. The pole coordinates are J2000.0 ecliptic. The a/b and a/c ratios are based on $c = 1.0$ in a triaxial ellipsoid.

Acknowledgements

Funding for observations at CS3 and work on the asteroid lightcurve database (Warner et al., 2009) and ALCDEF database (alcdef.org) were supported in part by NASA grant 80NSSC18K0851. The authors gratefully acknowledge Shoemaker NEO Grants from the Planetary Society (2007, 2013). These were used to purchase some of the telescopes and CCD cameras used in this research. This work includes data from the Asteroid Terrestrial-impact Last Alert System (ATLAS) project. ATLAS is primarily funded to search for near earth asteroids through NASA grants NN12AR55G, 80NSSC18K0284, and 80NSSC18K1575; byproducts of the NEO search include images and catalogs from the survey area. The ATLAS science products have been made possible through the contributions of the University of Hawaii Institute for Astronomy, the Queen's University Belfast, the Space Telescope Science Institute, and the South African Astronomical Observatory.

References

- References from web sites should be considered transitory, unless from an agency with a long lifetime expectancy. Sites run by private individuals, even if on an institutional web site, do not necessarily fall into this category.
- Behrend, R. (2021web) Observatoire de Geneve web site. http://obswww.unige.ch/~behrend/page_cou.html
- Díaz-Vachier, I.; Cotto-Figueroa, D. (2020). “The Rotation Rates of Three Near-Earth Asteroids and a Mars-Crossing Asteroid.” *Minor Planet Bull.* **47**, 149-150.
- Harris, A.W.; Young, J.W.; Scaltriti, F.; Zappala, V. (1984). “Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gytis.” *Icarus* **57**, 251-258.
- Harris, A.W.; Pravec, P.; Galad, A.; Skiff, B.A.; Warner, B.D.; Vilagi, J.; Gajdos, S.; Carbognani, A.; Hornoch, K.; Kusnirak, P.; Cooney, W.R.; Gross, J.; Terrell, D.; Higgins, D.; Bowell, E.; Koehn, B.W. (2014). “On the maximum amplitude of harmonics on an asteroid lightcurve.” *Icarus* **235**, 55-59.
- Mainzer, A.; Bauer, J.; Cutri, R.; Grav, T.; Kramer, E.; Masiero, J.; Sonnett, S.; Wright, E., Eds. (2019). “NEOWISE Diameters and Albedos V2.0.” NASA Planetary Data System. [urn:nasa:pds:neowise_diameters_albedos::2.0](https://pds.nasa.gov/data/pds-100001/neowise-diameters-albedos-v2-0/). <https://doi.org/10.26033/18S3-2Z54>
- Oey, J. (2020). “Lightcurve Analysis of Near-Earth Asteroids in 2017 from BMO and JBL.” *Minor Planet Bull.* **47**, 136-140.
- Pravec, P.; Wolf, M.; Sarounova, L. (1999web; 2021web). <http://www.asu.cas.cz/~ppravec/neo.htm>
- Pravec, P.; Harris, A.W.; Scheirich, P.; Kušnirák, P.; Šarounová, L.; Hergenrother, C.W.; Mottola, S.; Hicks, M.D.; Masi, G.; Krugly, Yu.N.; Shevchenko, V.G.; Nolan, M.C.; Howell, E.S.; Kaasalainen, M.; Galád, A.; Brown, P.; Degraff, D.R.; Lambert, J.V.; Cooney, W.R.; Foglia, S. (2005). “Tumbling asteroids.” *Icarus* **173**, 108-131.
- Pravec, P.; Scheirich, P.; Durech, J.; Pollock, J.; Kusnirak, P.; Hornoch, K.; Galad, A.; Vokrouhlicky, D.; Harris, A.W.; Jehin, E.; Manfroid, J.; Opitom, C.; Gillon, M.; Colas, F.; Oey, J.; Vrástil, J.; Reichart, D.; Ivarsen, K.; Haislip, J.; LaCluyze, A. (2014). “The tumbling state of (99942) Apophis.” *Icarus* **233**, 48-60.
- Tonry, J.L.; Denneau, L.; Flewelling, H.; Heinze, A.N.; Onken, C.A.; Smartt, S.J.; Stalder, B.; Weiland, H.J.; Wolf, C. (2018). “The ATLAS All-Sky Stellar Reference Catalog.” *Ap. J.* **867**, A105.
- Warner, B.D.; Harris, A.W.; Pravec, P. (2009). “The Asteroid Lightcurve Database.” *Icarus* **202**, 134-146. Updated 2021 June. <http://www.minorplanet.info/lightcurvedatabase.html>
- Warner, B.D. (2018a). “Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2017 July Through October.” *Minor Planet Bull.* **45**, 19-34.
- Warner, B.D. (2018b). “Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2017 October - December.” *Minor Planet Bull.* **45**, 138-147.
- Warner, B.D.; Stephens, R.D. (2019). “Near-Earth Asteroid Lightcurve Analysis at the Center for Solar System Studies: 2019 January - April.” *Minor Planet Bull.* **46**, 304-314.

SPIN/SHAPE MODEL FOR (5189) 1990 UQ

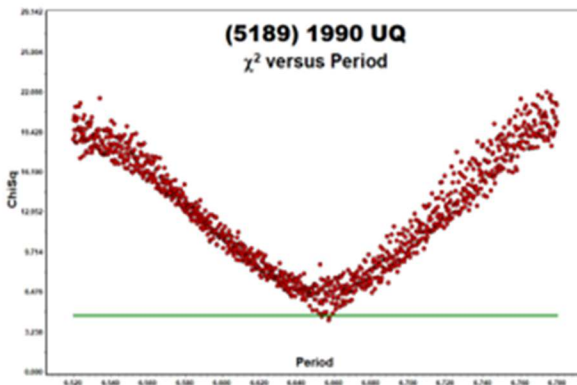


Figure 1. The initial period search results.

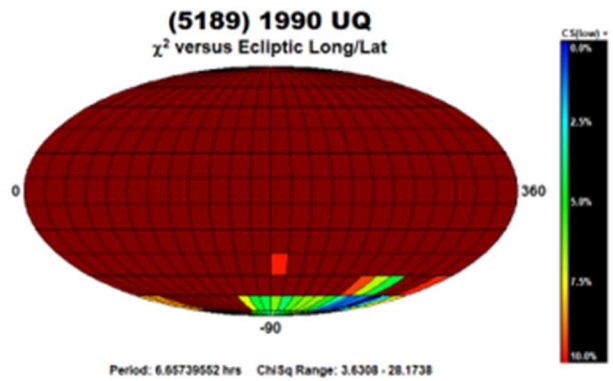


Figure 2. The pole search found one probable solution.

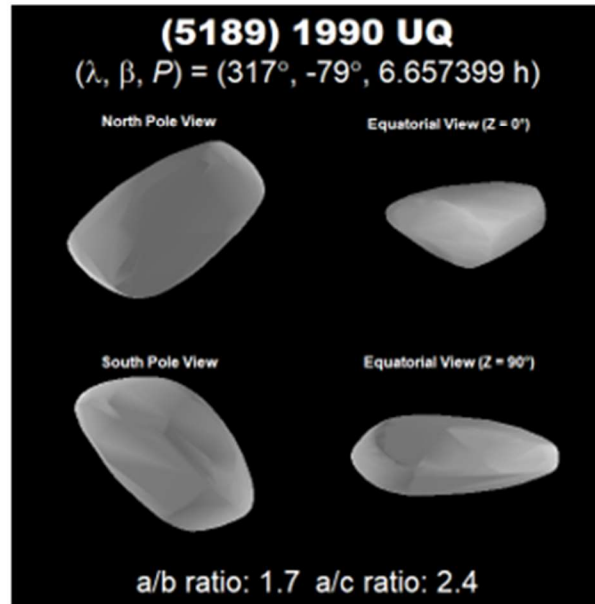


Figure 3. The shape of the asteroid.

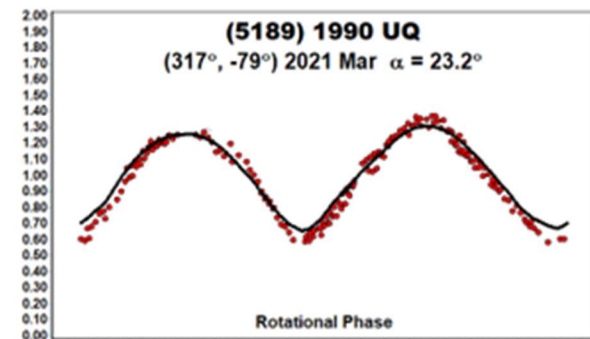
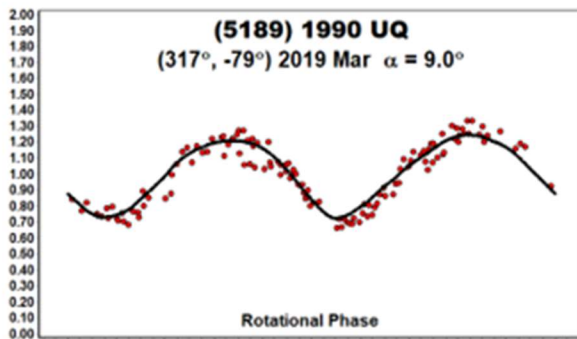


Figure 4/5. The comparison plots are against the preferred pole solution. The red dots indicate the data used for modeling while the black line is the smoothed lightcurve for generated by the shape at the time of the observations. The match is very close on both occasions, which gives confidence in the shape/spin axis model.