MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2019 JANUARY - MARCH

Robert D. Stephens
Center for Solar System Studies (CS3)/MoreData!
11355 Mount Johnson Ct., Rancho Cucamonga, CA 91737 USA
rstephens@foxandstephens.com

Brian D. Warner
Center for Solar System Studies (CS3)/MoreData!
Eaton, CO

(Received: 2019 April 10)

CCD photometric observations of 10 main-belt asteroids were obtained from the Center for Solar System Studies from 2019 January to March. In light of recent period analysis, images of 2120 Tyumenia obtained in 2004 were re-examined. The resulting analysis found a period of 17.515 h, which is consistent with the recent results.

The Center for Solar System Studies (CS3) has seven telescopes which are normally used in program asteroid family studies. The focus is on near-Earth asteroids, but when suitable targets are not available, Jovian Trojans and Hildas are observed. When a nearly full moon is too close to the family targets being studied, targets of opportunity amongst the main-belt families were selected.

Table I lists the telescope/CCD camera combinations that were used. All the cameras use the KAF-1001E blue-enhanced CCD chip and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel. Images were unbinned with no filter and had master flats and darks applied. The exposure duration varied depending on the asteroid's brightness and sky motion.

Telescope	Camera
0.30-m f/6.3 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.40-m f/10 Schmidt-Cass	FLI Microline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.50-m F8.1 R-C	FLI Proline 1001E

Table I: List of CS3 telescope/CCD camera combinations.

Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Comp star magnitudes were taken from ATLAS catalog (Tonry et al., 2018), which has Sloan *griz* magnitudes that were derived from the GAIA and Pan-STARR catalogs, among others. The authors state that systematic errors are generally no larger than 0.005 mag, although they can reach 0.02 mag in small areas near the Galactic plane. BVRI magnitudes were derived by Warner using formulae from Kostov and Bonev (2017). The overall errors for the BVRI magnitudes, when combining those in the ATLAS catalog and the conversion formulae, are on the order of 0.04-0.05 mag.

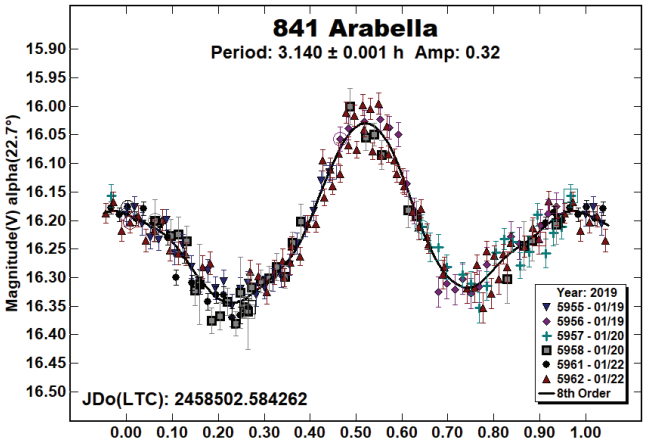
Even so, we found in most cases that nightly zero point adjustments on the order of only 0.02-0.03 mag were required during period analysis. There were occasional exceptions that required up to 0.10 mag. These may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction terms. Regardless, the systematic errors seem to be considerably less than other catalogs, which reduces the uncertainty in the results when analysis involves data from extended periods or the asteroid is tumbling.

In the lightcurve plots, the "Reduced Magnitude" is Johnson V corrected to a unity distance by applying $-5*\log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and the Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses using $G = 0.15$. The X-axis gives the rotational phase from –0.05 to 1.05.

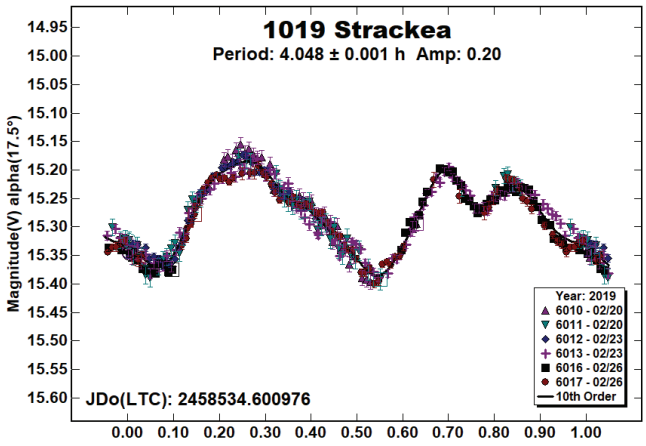
The amplitude indicated in the plots (e.g. Amp. 0.20) is the amplitude of the Fourier model curve and not necessarily the adopted amplitude of the lightcurve.

For brevity, only some of the previously reported rotational periods may be referenced. A complete list is available at the asteroid lightcurve database (LCDB; Warner et al., 2009).

841 Arabella. Klinglesmith et al. (2016) previously observed this Flora family member, finding a rotational period of 3.142 h. This year's result is in good agreement with their period.

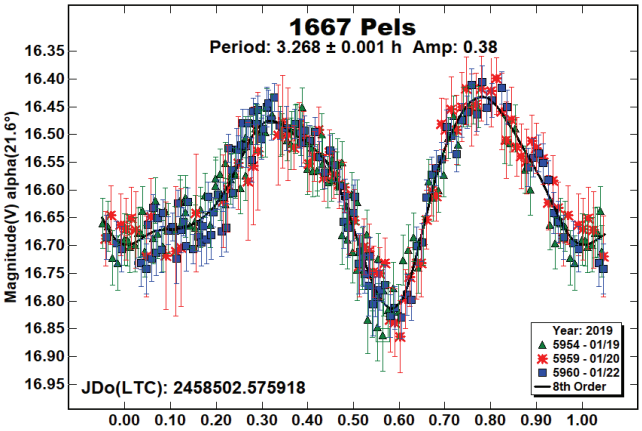


1019 Strackea. We studied this member of the Hungaria family three times in the past (Warner, 2009; 2011a; 2014a), each time finding a rotational period near 4.05 h. The result found this year is consistent with those findings.

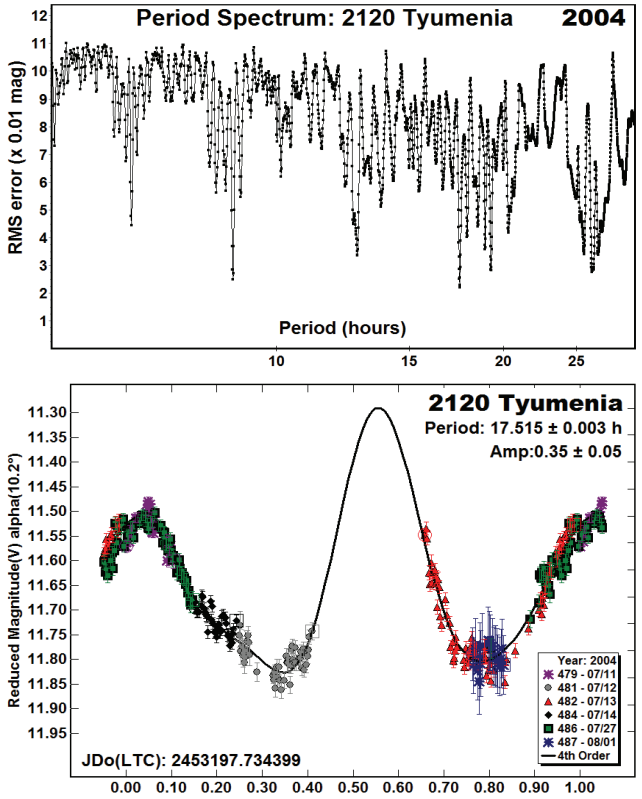


A previous shape and spin model (Warner 2019) found (λ, β) = (227°, –52°) or (219°, +54°) and $P_{\_SIDEREAL}$ = 4.047270 h. It is hoped that this year's data will improve upon that model.

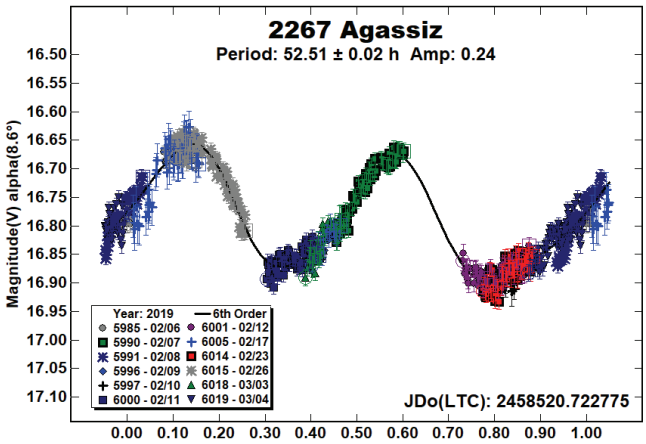
1667 Pels. Wisniewski et al. (1997) and Kryszczynska et al. (2012) found a rotational period near 3.27 h for this inner main-belt asteroid. The rotational period found this year is in good agreement with those results.



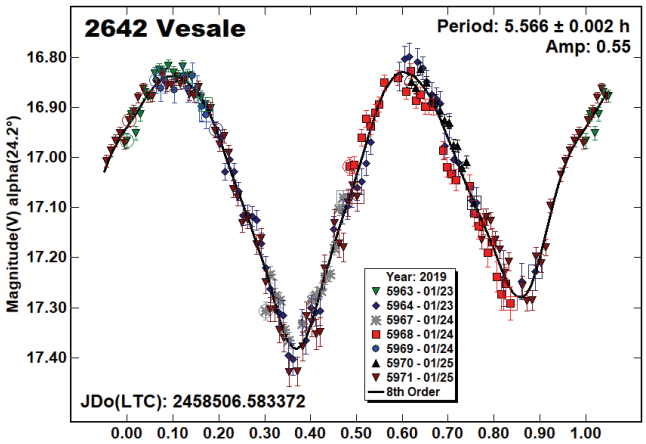
2120 Tyumenia. This outer main-belt asteroid has been observed several times. Oliver et al. (2008) and Pligge et al. (2011) both found results near 17.5 h. Warner (2005) observed the asteroid in 2004 July and found a period of 2.769h. Ďurech et al. (2018) used sparse-in-time photometry from the Lowell Observatory Database to find a sidereal period of 17.4991 ± 0.0002 h and pole solution (λ, β) = (244°, +45°) or (92°, +23°). They alerted Warner to the discrepancy; he then re-measured the original images using modern photometric catalogs and found a result consistent with the Ďurech et al. sidereal period.



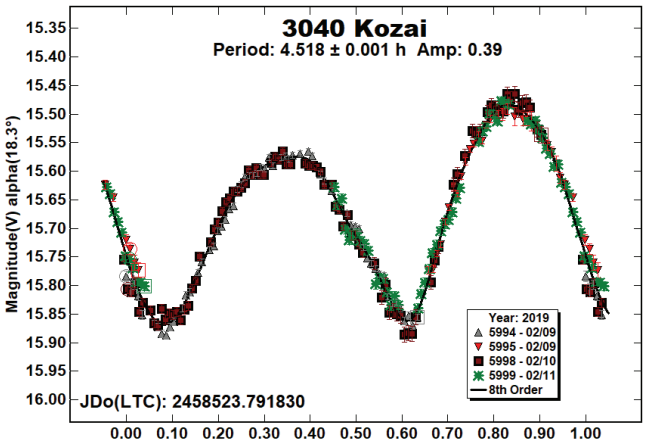
2267 Agassiz. No entry was found in the LCDB for this member of the Flora family/group.



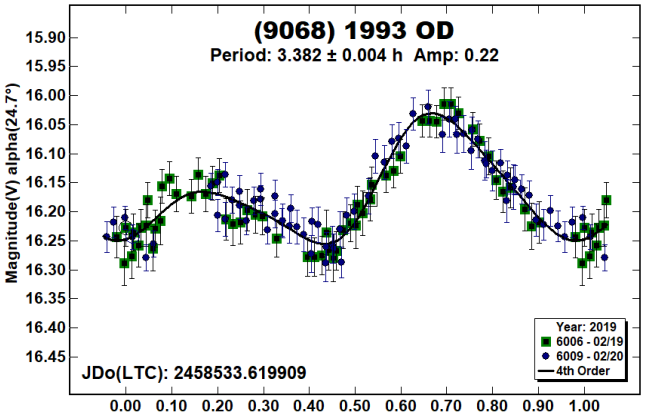
2642 Vesale. Warner (2011b) and Waszczak et al. (2015) both found periods near 5.56 h. The results this year are in good agreement with those findings.



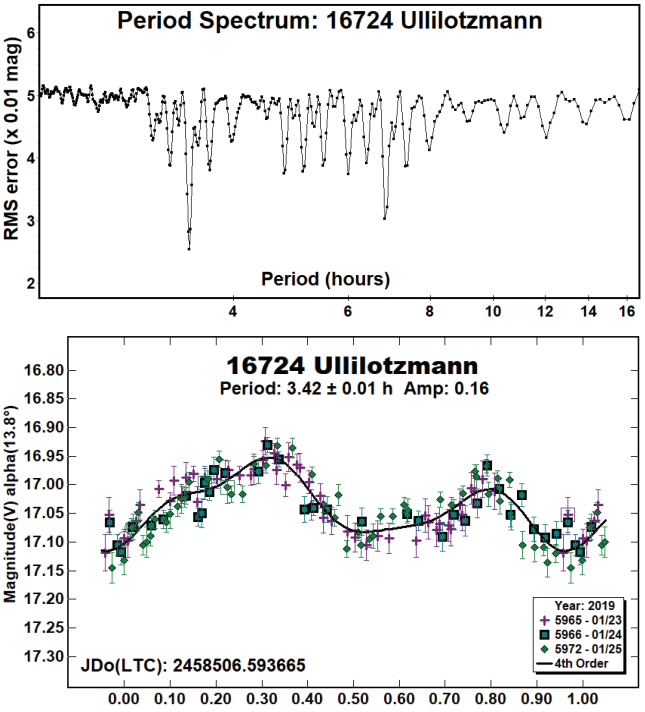
3040 Kozai. Pravec et al. (2019) found P = 4.515 h for this Mars-crosser during the Photometric Survey for Asynchronous Binary Asteroids. The period found this year agrees with Pravec et al.



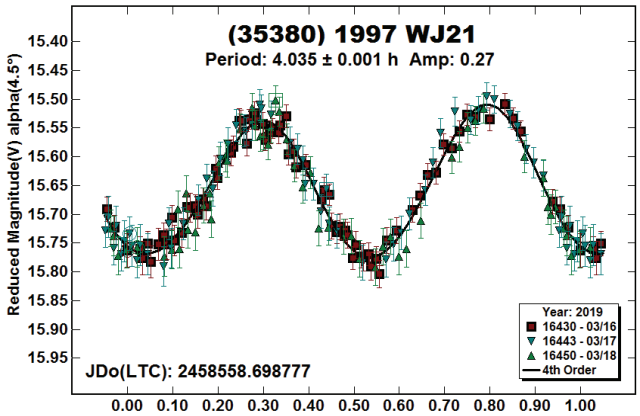
(9068) 1993 OD. This Hungaria family member has been observed several times in the past. Behrend (2019), Warner (2009; 2014b) and Pravec (2019) all reported periods 3.40 h. This result is in good agreement.



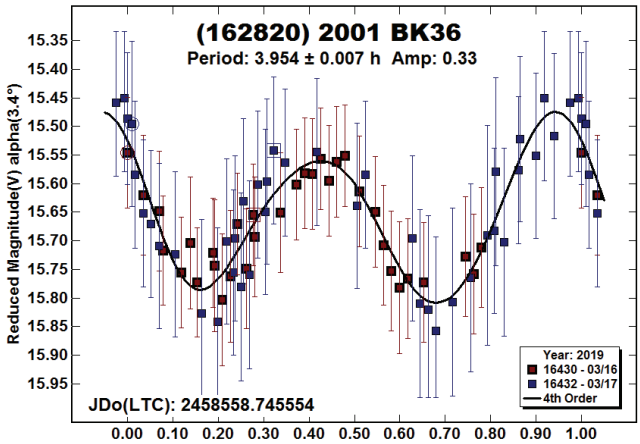
16724 Ullilotzmann. No entry was found in the LCDB for this Mars-crosser.



(35380) 1997 WJ21. No entry was found in the LCDB for this member of the Flora Family.



(162820) 2001 BK36. No entry was found in the LCDB for this member of the Eunomia family.



Acknowledgements

Funding for observations at CS3 and work on the asteroid lightcurve database (LCDB; Warner et al., 2009) and ALCDEF database (*alcdef.org*) are supported by NASA grant 80NSSC18K0851. 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. 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.

References

Behrend, R. (2019). Observatoire de Geneve web site, *http://obswww.unige.ch/~behrend/page_cou.html*

Ďurech, J., Hanuš, J., Alí-Lagoa, V. (2018). "Asteroid models reconstructed from the Lowell Photometric Database and WISE data." *Astron. & Astrophys.* **617**, 57.

Harris, A.W., Young, J.W., Bowell, E., Martin, L.J., Millis, R.L., Poutanen, M., Scaltriti, F., Zappala, V., Schober, H.J., Debehogne, H., Zeigler, K.W. (1989). "Photoelectric Observations of Asteroids 3, 24, 60, 261, and 863." *Icarus* **77**, 171-186.

Harris, A.W., Young, J.W., Scaltriti, F., Zappala, V. (1984). "Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gyptis." *Icarus* **57**, 251-258.

Klinglesmith, D., III, Hendrickx, S., Madden, K., Montgomery, S. (2016). "Asteroid Lightcurves from Estcorn Observatory." *Minor Planet Bull.* **43**, 234-239.

Kostov, A., Bonev, T. (2017). "Transformation of Pan-STARRS1 gri to Stetson BVRI magnitudes. Photometry of small bodies observations." *Bulgarian Astron. J.* **28**, 3 (AriXiv:1706.06147v2).

Number	Name	2019/mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period	P.E.	Amp	A.E.	Grp
841	Arabella	01/19-01/22	184	22.8,23.6	74	5	3.140	0.001	0.32	0.02	FLOR
1019	Strackea	02/20-02/26	362	17.6,20.2	124	-8	4.048	0.001	0.20	0.01	H
1667	Pels	01/19-01/22	301	21.6,22.0	61	-1	3.268	0.001	0.38	0.02	FLOR
2120	Tyumenia	[04]07/11-08/01	293	10.29.7,10.9	0	21	17.515	0.003	0.35	0.05	MB-O
2267	Agassiz	02/06-03/04	595	8.6,0.4,5.3	153	297	52.51	0.02	0.24	0.02	FLOR
2642	Vesale	01/23-01/25	203	24.2,24.5	68	-15	5.566	0.002	0.55	0.02	MB-I
3040	Kozai	02/09-02/11	243	18.3,17.5	160	15	4.518	0.001	0.39	0.02	MC
9068	1993 OD	02/19-02/20	127	24.8,25.2	115	-3	3.382	0.004	0.22	0.02	H
16724	Ullilotzmann	01/23-01/25	135	13.9,14.7	102	-8	3.42	0.01	0.16	0.02	MC
35380	1997 WJ21	03/16-03/18	178	4.5,3.9	178	-5	4.035	0.001	0.27	0.02	FLOR
162820	2001 BK36	03/16-03/17	73	3.4,3.2	178	-5	3.954	0.007	0.33	0.03	EUN

Table II. Observing circumstances and results. [04] Observations in 2004. Pts is the number of data points. The phase angle values are for the first and last date. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009): H, Hungaria; MB-I/O, main belt inner/outer; MC, Mars-crosser; FLOR, Flora; EUN Eunomia.

Kryszczyńska, A., Colas, F., Polińska, M., Hirsch, R., Ivanova, V., Apostolovska, G., Bilkina, B., Velichko, F.P., Kwiatkowski, T., Kankiewicz, P., Vachier, F., Umlenski, V., Michałowski, T., Marciniak, A., Maury, A., Kamiński, K., Fagas, M., Dimitrov, W., Borczyk, W., Sobkowiak, K., Lecacheux, J., Behrend, R., Klotz, A., Bernasconi, L., Crippa, R., Manzini, F., Poncy, R., Antonini, P., Oszkiewicz, D., Santana-Ros, T. (1997). "Do Slivan states exist in the Flora family? I. Photometric survey of the Flora region." *Astron. & Astrophys.* **546**, 72.

Oliver, R., Shipley, H., Ditteon, R. (2008). "Asteroid Lightcurve Analysis at the Oakley Southern Sky Observatory: 2008 March." *Minor Planet Bull.* **35**, 149-150.

Pligge, Z., Hall, B., Ditteon, R. (2016). "Asteroid Lightcurve Analysis at the Oakley Observatory: 2010 September thru October." *Minor Planet Bull.* **38**, 137-138.

Pravec, P., Wolf, M., Sarounova, L. (1999). *http://www.asu.cas.cz/~ppravec/neo.htm*

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." *Astrophys. J.* **867**, A105.

Warner, B.D. (2005). "Lightcurve analysis for asteroids 242, 893, 921, 1373, 1853, 2120, 2448 3022, 6490, 6517, 7187, 7757, and 18108." *Minor Planet Bull.* **32**, 4-7.

Warner, B.D. (2008). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2008 May - September." *Minor Planet Bull.* **36**, 7-13.

Warner, B.D. (2009). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2009 March-June." *Minor Planet Bull*. **36**, 172-176.

Warner, B.D. (2011a). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2010 December- 2011 March." *Minor Planet Bull*. **38**, 142-149.

Warner, B.D. (2011b). "Lightcurve Analysis at the Palmer Divide Observatory: 2010 June-September." *Minor Planet Bull*. **38**, 25-31.

Warner, B.D. (2014). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2014 January-March." *Minor Planet Bull*. **41**, 144-155.

Warner, B.D. (2014b). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2013 September-December." *Minor Planet Bull*. **41**, 102-112.

Warner, B.D. (2019). "Hungaria Pole Solutions." *http://www.minorplanetobserver.com/Hungarias/*

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2018 Nov. *http://www.minorplanet.info/lightcurvedatabase.html*

Waszczak, A., Chang, C.-K., Ofek, E.O., Laher, R., Masci, F., Levitan, D., Surace, J., Cheng, Y.-C., Ip, W.-H., Kinoshita, D., Helou, G., Prince, T.A., Kulkarni, S. (2015). "Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry." *Astrophys. J.* **150**, A75.

Wisniewski, W. Z., Michałowski, T. M., Harris, A. W., McMillan, R. S. (1997). "Photometric Observations of 125 Asteroids." *Icarus* **126**, 395-149.