

BINARY ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES

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 91730

Alan W. Harris
MoreData!
La Cañada, CA 91011

(Received: 2020 April 6 Revised: 2020 August 9)

We report on the discovery at the Center for Solar System Studies of four confirmed binary asteroids: 1656 Suomi, (85275) 1994 LY, (85628) 1998 KV2, and (539940) 2017 HW1 along with the suspected candidate (184990) 2006 KE89.

CCD photometric observations at the Center for Solar System Studies in 2020 April to July of four near-Earth and one Hungaria asteroid led to finding four confirmed binaries and one strong candidate. Table I lists the telescopes and CCD cameras that were combined to make the observations.

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. 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, and are the “native” magnitudes of the catalog.

To reduce the number of times and amount of resetting nightly zero points, we use the ATLAS r' (SR) magnitudes. Those adjustments are mostly ≤ 0.03 mag. The occasions where larger corrections were required may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction terms.

The Y-axis of the primary lightcurves gives ATLAS SR “sky” (catalog) magnitudes. The values on the Y-axis of the secondary

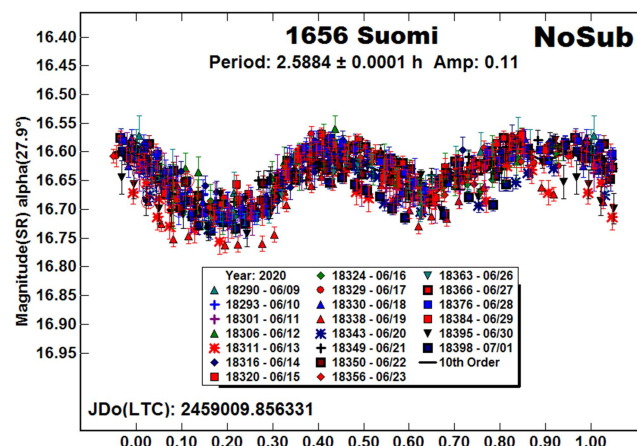
lightcurves are usually differential magnitudes with 0.0 corresponding to the average magnitude of the primary curve.

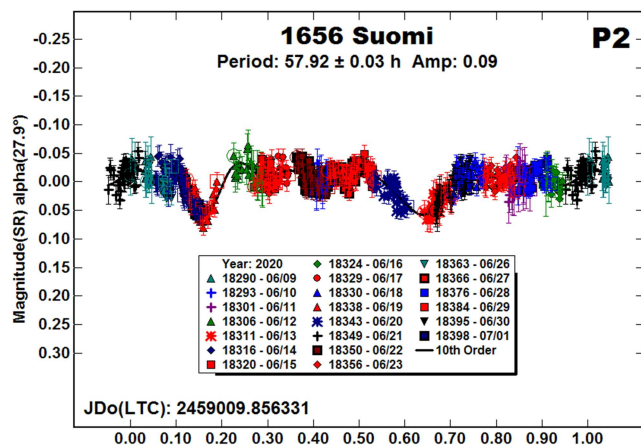
During period analysis, the magnitudes were normalized to the comparison stars used in the earliest session and to the phase angle given in parentheses using $G = 0.15$. The X-axis shows rotational phase from -0.05 to 1.05 . If the plot includes the amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

Our initial search for previous results started with the asteroid lightcurve database (LCDB; Warner et al., 2009) found on-line at <http://www.minorplanet.info/lightcurvedatabase.html>. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB. From here on, we'll use only “LCDB” to reference the paper by Warner et al. (2009).

1656 Suomi. Stephens (2004) observed this Hungaria in 2004 and found a period of 2.59 h. There were no indications of a satellite. Subsequent observations by Brinsfield (2008) and Warner (2012; 2014a; 2017) also produced negative results. On the other hand, observations by Warner (2016a) in 2015 hinted at a second period of 12.60 h, but no obvious mutual events (occultations/eclipses) due to a satellite were noted.

The observations in 2020 almost immediately showed what appeared to be attenuations (deviations from a single period lightcurve) but they were seen only occasionally. This suggested a long secondary period.

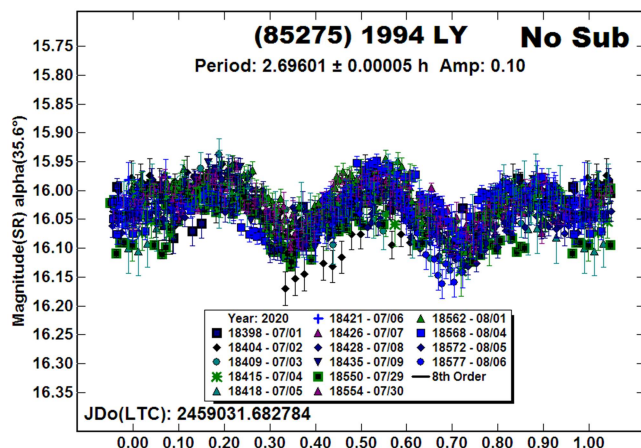




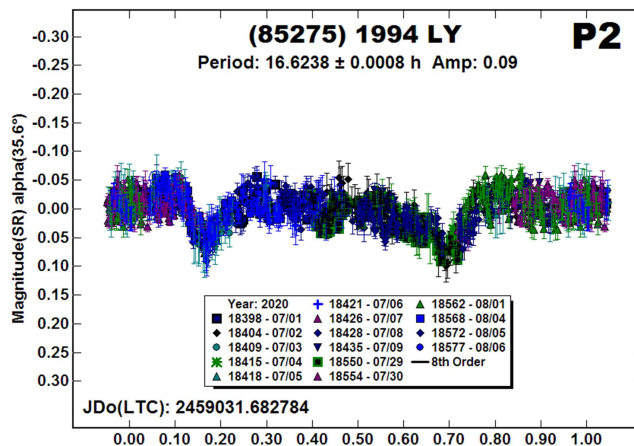
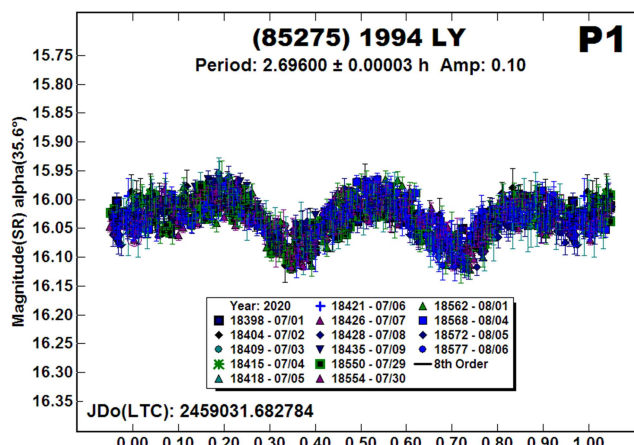
After following the asteroid for more than a month, mutual events were confirmed. The coverage of each event is not complete but it is sufficient to confirm an orbital period of 57.92 h. Based on the 0.07 mag events, the estimated ratio of the effective secondary-to-primary diameters is $D_s/D_p \geq 0.26 \pm 0.02$. A CBET (Central Bureau Electronic Telegram) submission was made in early 2020 July to the Central Bureau for Astronomical Telegrams (CBAT).

The long period suggests an orbit of about six primary radii. At 28° phase angle, the image and the shadow are well separated. Depending on geometry, this could lead to double events at the primary and secondary events or missing one of the two entirely. The narrower event (duration about 7 h) is probably a single (eclipse or transit) event while the broader event (duration about 12 h) is perhaps an eclipse combined with a transit or occultation event.

(85275) 1994 LY. Based on an extensive data set, Pravec et al. (2007web, private communications) reported a period of 2.6962 h and a suspected secondary period 48.5 h. Brinsfield (2008) reported a period of 2.6960 h based on data obtained at about the same time as Pravec et al. but did not indicate seeing mutual events or attenuations.

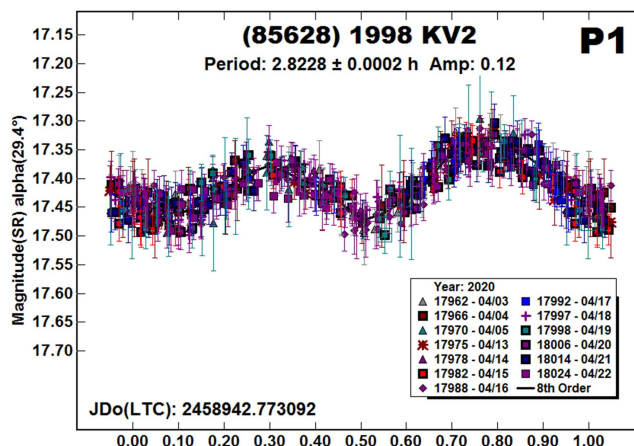


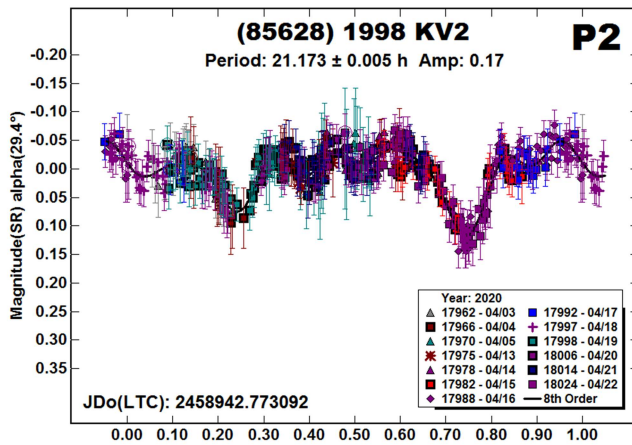
Our observations were made between 2020 July 1-9 showed obvious attenuations early on. Despite the secondary period being close to commensurate with an Earth day, we were able to get full coverage of the satellite's lightcurve. Analysis by Petr Pravec (private communications) confirmed that our data set supported a second period of about 16.6 h. Additional data from July 29 – Aug 6 confirmed and refined the results. The event depths range from 0.06-0.08 mag, which leads to an estimated $D_s/D_p \geq 0.24 \pm 0.02$.



(85628) 1998 KV2. Warner (2014b) first observed this 1-km NEA in 2014 April, finding a primary period of 2.819 h but no signs of attenuations in the lightcurve. Follow-up observations in 2016 February to May (Warner 2016b; 2016c) were also negative for indications of a satellite. The 2018 June observations (Warner, 2018) led to a period of 2.999 h and a suspected secondary period of 13.28 h.

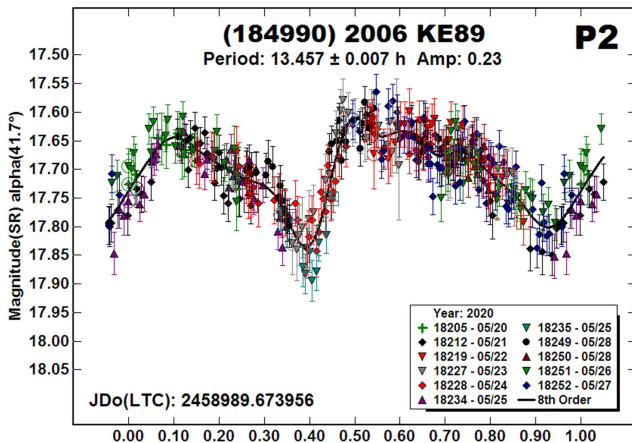
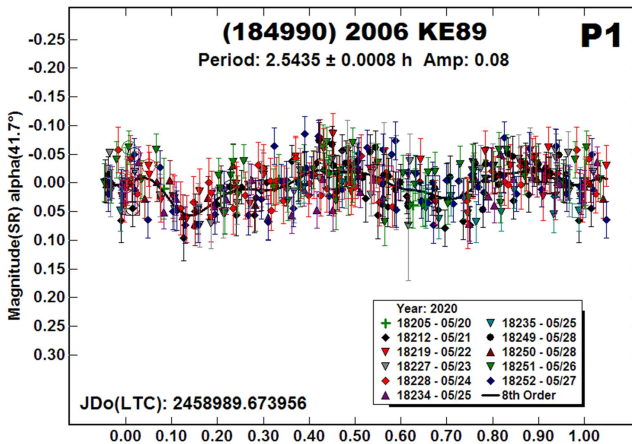
Conclusive evidence of a satellite was found with the 2020 April observations, with the data leading to an orbital period of 21.173 h and mutual events ranging from 0.08-0.13 mag that give $D_s/D_p \geq 0.28 \pm 0.02$.





Pravec et al. (2020web) independently discovered the satellite but did not have complete coverage of the satellite lightcurve. They used our orbital period to derive $P_1 = 2.8229 \pm 0.0004$ h. The discovery was announced in CBET 4757.

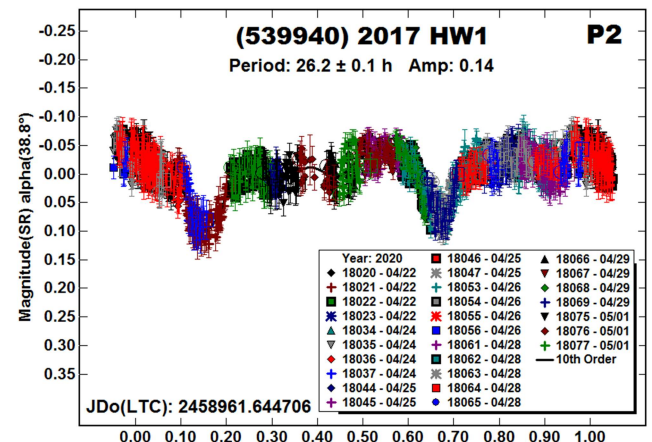
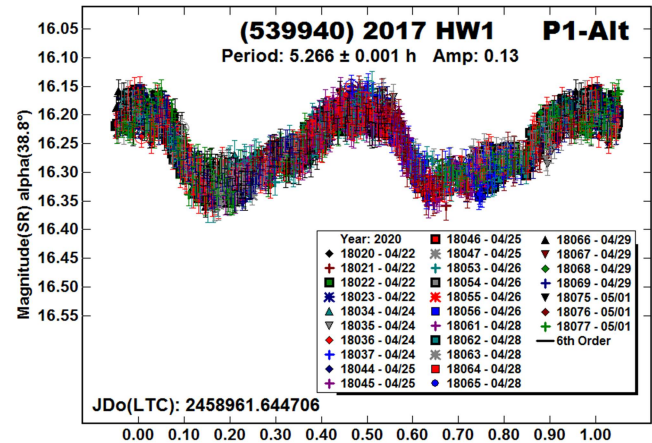
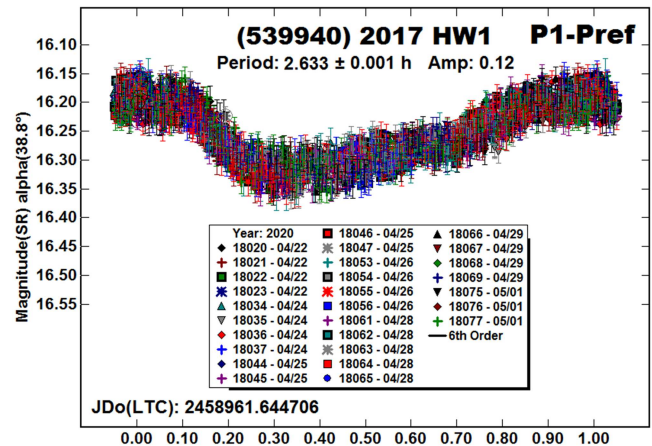
(184990) 2006 KE89. Behrend (2006web) reported a period of 5.187 h based on observations from mid-June 2006. Skiff et al. (2019b) found a low-quality result of 5.16 h. Our observations in 2020 May led to a proposed primary period of 2.5435 h, or half that given by Behrend and Skiff. A secondary period of 13.457 h was also found.



Both periods are in the expected range for a small binary asteroid but the shape of the P_2 lightcurve is puzzling. One interpretation is a very elongated satellite that *may* be producing mutual events on the order of 0.07-0.11 mag. If so, then this gives $D_s/D_p \geq 0.26 \pm 0.02$.

It's interesting to note that a good part of the incomplete Behrend (2006web) lightcurve bears some resemblance to the P_2 lightcurve given here. The next follow-up opportunity is in mid-2021 ($V \sim 18.4$, $\delta = 18^\circ$)

(539940) 2017 HW1. Pravec et al. (2020web) observed this NEA in 2020 February and April and found a primary period of 2.6346 h. They also reported a suspected secondary period of 15.69 h but did not get conclusive evidence of a satellite.



Number	Name	2020 mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp/Dr
1656	Suomi	06/09-07/01	28.0, 24.9	319	24	2.5885 57.92	0.0001 0.03	0.11 0.07	0.01 0.01	H 0.26
85275	1994 LY	07/01-08/06	35.5, 46.1	283	23	2.69600 16.6238	0.00003 0.0008	0.10 0.08	0.01 0.01	NEA 0.23
85628	1998 KV2	04/03-04/22	29.4, 15.1	216	16	2.8228 21.173	0.0002 0.005	0.12 0.17	0.02 0.02	NEA 0.28
184990	2006 KE89	05/20-05/28	*41.8, 46.2	242	44	2.5435 13.457	0.0009 0.007	0.08 0.23	0.02 0.03	NEA 0.26
539940	2017 HW1	04/22-05/01	38.6, 24.4	207	18	2.633 26.2	0.001 0.1	0.12 0.14	0.02 0.02	NEA 0.31

Table II. Observing circumstances. The second line gives the orbital period of the satellite and maximum depth of the mutual events. 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). For the Grp/Dr column, the first line gives the group/family based on Warner et al. (2009). H: Hungaria. The second line gives the ratio of the minimum effective secondary/primary diameters (Ds/Dp).

Our observations toward the end of 2020 April confirmed mutual events and led to a primary period of 2.633 h. A period of 5.266 h cannot be formally excluded but it does not fit with the general trend of other binary asteroids of similar size and orbital periods. The orbital period was found to be 26.2 ± 0.1 h with mutual events ranging from 0.09 to 0.12 mag. This indicates $Ds/Dp \geq 0.31 \pm 0.03$. The discovery announcement appeared in CBET 4771.

Acknowledgements

Funding for observations at CS3 and work on the asteroid lightcurve database (Warner et al., 2009) and ALCDEF database (alcdef.org) are supported 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. (2006web). Observatoire de Geneve web site. http://obswww.unige.ch/~behrend/page_cou.html

Brinsfield, J.W. (2008). "The Rotation Periods of 1465 Autonoma, 1656 Suomi, 4483 Petofi, 4853 Marielukac, and (85275) 1994 LY." *Minor Planet Bull.* **35**, 23-24.

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

Pravec, P.; Wolf, M.; Sarounova, L. (2007web, 2020web). <http://www.asu.cas.cz/~ppravec/neo.htm>

Skiff, B.A.; McLelland, K.P.; Sanborn, J.; Pravec, P.; Koehn, B.W. (2019). "Lowell Observatory Near-Earth Asteroid Photometric Survey (NEAPS): Paper 4." *Minor Planet Bull.* **46**, 458-503.

Stephens, R.D. (2004). "Photometry of 1196 Sheba, 1341 Edmee, 1656 Suomi, 2577 Litva, and 2612 Kathryn." *Minor Planet Bull.* **31**, 95-97.

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. (2012). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2012 March – June." *Minor Planet Bull.* **39**, 245-252.

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

Warner, B.D. (2014b). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2014 March-June." *Minor Planet Bull.* **41**, 213-224.

Warner, B.D. (2016a). "Asteroid Lightcurve Analysis at CS3 - Palmer Divide Station: 2015 June-September." *Minor Planet Bull.* **43**, 57-65.

Warner, B.D. (2016b). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2016 January-April." *Minor Planet Bull.* **43**, 240-250.

Warner, B.D. (2016c). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2016 April-July." *Minor Planet Bull.* **43**, 311-319.

Warner, B.D. (2017). "Asteroid Lightcurve Analysis at CS3 - Palmer Divide Station: 2017 April thru June." *Minor Planet Bull.* **44**, 289-294.

Warner, B.D. (2018). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2018 April-June." *Minor Planet Bull.* **45**, 366-379.

Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2020 June. <http://www.minorplanet.info/lightcurvedatabase.html>