

ON CONFIRMED AND SUSPECTED BINARY ASTEROIDS OBSERVED 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

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

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Using data from observations made at the Center for Solar System Studies from 2021 May to July, we report that minor planets 6009 Yuzuruyoshii and (18503) 1996 PY4 are very likely binary systems. The lightcurves for (18503) changed significantly over the range of observations, including the near disappearance of mutual events by the end of the observing sessions.

Data from CCD photometric observations made at the Center for Solar System Studies in 2021 May to July were used to look for indications of an asteroid being binary. Confirmed binaries are those that show mutual events (occultations/eclipses) while suspected binaries include those with two periods, no obvious mutual events, and periods consistent with binary asteroids.

Table I lists the telescopes and CCD cameras that were combined to make the observations. The cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales were 1.24 arcsec/pixel.

Telescopes	Cameras
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E

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.

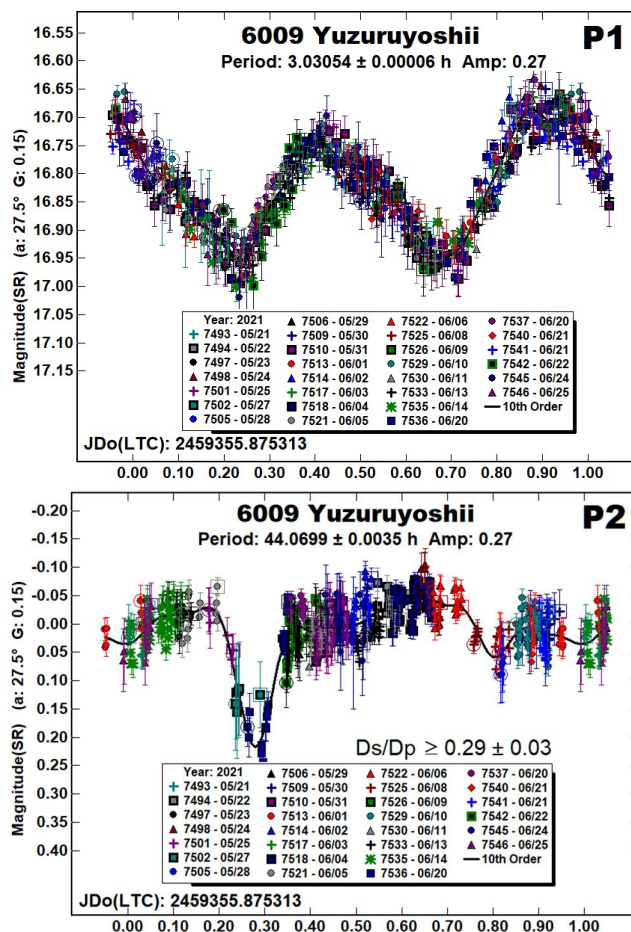
Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. To reduce the number of adjusted nightly zero points and their amounts, the analysis of the 2021 data used the ATLAS catalog r' (SR) magnitudes (Tonry et al., 2018). The rare zero-point adjustments $\geq \pm 0.03$ mag may be related in part to using unfiltered observations, poor centroiding of the reference stars, not correcting for second-order extinction, or selecting a star that is an unresolved pair.

The Y-axis shows the catalog (“sky”) magnitudes for the “primary” period (P_1) while the “secondary” (P_2) plots give the differential from the average magnitude in the P_1 plot. “SR” indicates that the ATLAS catalog was used.

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 as well as the mid-date/time of that session. Ideally, this leaves 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*.

From here on, “LCDB” refers to the asteroid lightcurve database (Warner et al., 2009).

6009 Yuzuruyoshii. Three previous works found similar periods for the now presumed primary: Behrend (2006web, 3.03038 h) and Pravec et al. (2006web, 3.0302 h; 2017web, 3.0306 h). Pál et al. (2020), however, reported a period of 14.6585 h. Our results support the previous works giving a period near 3.03 h.



None of those previous works indicated the likelihood of a satellite, let alone confirm that one existed. However, our observations revealed the mutual events (occultation/eclipse), ranging from 0.09 to 0.20 mag, that give evidence to the presence of a satellite. The coverage of the events, in particular the secondary one, is less than ideal, making future observations required to improve the putative orbital period.

Even when taking phase angle into account, the amplitude of the primary lightcurve in 2021 was the deepest reported to-date. This implies a more equatorial view and so possibly why mutual events were reported for the 2021 apparition and not at those previous.

Number	Name	20yy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp/Dr
6009	Yuzuruyoshii	05/21-07/06	27.5,21.0	298	29	3.03067 44.0699	3.0E-5 0.0035	0.27 0.27	0.01 0.03	9104 ≥ 0.29
18503	1996 PY4	05/31-06/28	25.2,22.2	265	33	3.43912 19.914	0.00003 0.003	0.36 0.09	0.02 0.01	701 ≥ 0.24
18503	1996 PY4	06/28-07/06	22.2,22.4	268	31	3.4391 19.904	0.0001 0.001	0.37 0.05	0.02 0.02	701 ?

Table II. Observing circumstances. The first line for each object gives the primary period for the system and the second line gives the orbital/secondary period. The two solutions for (18503) are based on different date ranges. The phase angle (α) is given at the start and end of each date range. 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 the families list from the LCDB: 9104: inner main-belt; 701: Phocaea. See the LCDB documentation (https://minplanobs.org/MPInfo/docs/lcdb_readme.pdf) for a full list. The Dr column on the second line indicates a confirmed binary and is the estimated diameter ratio of the secondary to primary (Ds/Dp).

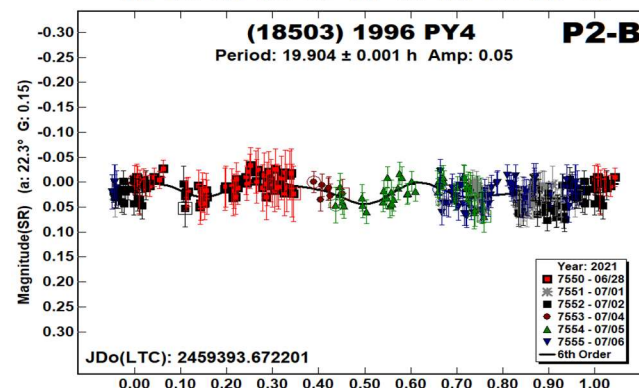
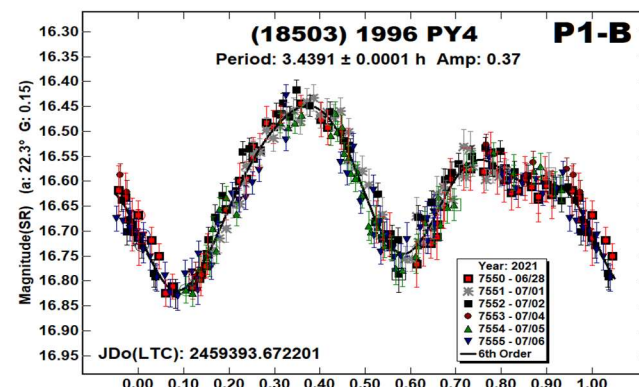
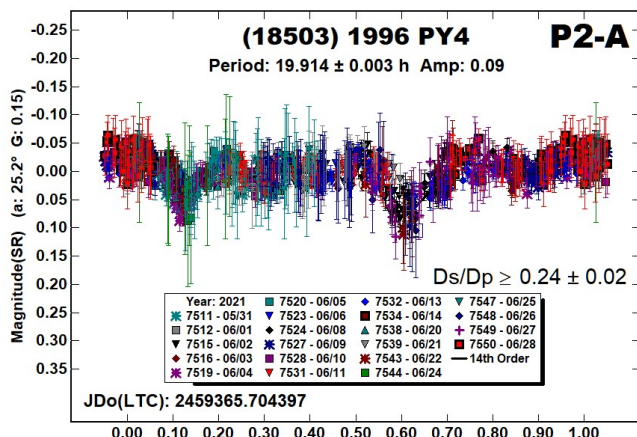
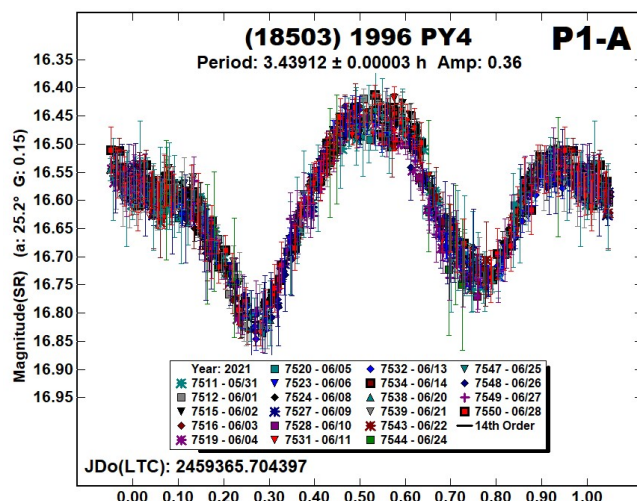
(18503) 1996 PY4. The only previously reported rotation period in the LCDB is from Pravec et al. (2010web), who found a period of 3.4390 h but did not report signs of a satellite. Mainzer et al. (2019) used WISE data to find an effective diameter for the system of 3.53 ± 0.05 km and, when using $H = 13.8$, an albedo of $p_V = 0.429 \pm 0.033$. This seems inordinately high for the Phocaea family, which has an average value nearer $p_V = 0.24$.

Applying the correction from Harris and Harris (1997) and the current value from the MPCORB file ($H = 14.51$), the albedo becomes $p_V = 0.24 \pm 0.02$, the average value for the Phocaea family, and a revised diameter $D = 3.38$ km. This demonstrates the strong dependency of albedos on H and so the need to confirm or improve H values whenever possible.

During the overall span of our observations, 2021 May 31 to July 6, the primary lightcurve shape and, to a lesser degree the amplitude, changed. Also changing, more dramatically, were the mutual events seen at the start of observations versus the end. This would seem to indicate that the viewing geometry of the system was leaving the “eclipse season” when mutual events can be observed. This information can be useful for finding a solution for the poles of the primary’s spin axis and the satellite’s orbit.

We’ve isolated two sets of data, the first (“A”) covering most of 2021 June and the second (“B”) the end of June into early July. In the first set, the mutual events are well-defined despite their amplitudes versus the error bars of the data. The shallower event, but only so by about 0.01 mag, gives an effective primary-to-secondary diameter ratio of $Ds/Dp \geq 0.24 \pm 0.02$.

The second data set, shows scant trace of the mutual events with the P_2 solution having been forced to a value near the one found with the first data set. In addition, the difference between the two maximums in the primary lightcurve increased from 0.10 mag in the first set to 0.15 mag in the second while the difference in the minimums remained about the same. These are both important data for future modeling.



Acknowledgements

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LIGHTCURVES AND ROTATION PERIODS OF 420 BERTHOLDA, 664 JUDITH, AND 2779 MARY

Frederick Pilcher
Organ Mesa Observatory (G50)
4438 Organ Mesa Loop
Las Cruces, NM 88011 USA
fpilcher35@gmail.com

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Synodic rotation periods and amplitudes are found for 420 Bertholda 10.987 ± 0.001 h, 0.32 ± 0.02 magnitudes; 664 Judith 19.305 ± 0.001 h, 0.32 ± 0.02 magnitudes; 2779 Mary 3.583 ± 0.001 h, 0.11 ± 0.02 magnitudes.

Observations to produce the results reported in this paper were made at the Organ Mesa Observatory with a Meade 35-cm LX200 GPS Schmidt-Cassegrain, SBIG STL-1001E CCD, unguided. Exposure times were 60 seconds for 420 Bertholda and 664 Judith, 120 seconds for 2779 Mary, with a clear filter. Image photometric measurement and lightcurve construction were done by *MPO Canopus* software. To reduce the number of data points on the lightcurves and make them easier to read, data points have been binned in sets of 3 with maximum time difference 5 minutes.

420 Bertholda. The Lightcurve Data Base (Warner et al., 2009) states a rotation period of 11.04 hours based on four independent determinations all between 10.97 hours and 11.04 hours. New observations on 9 nights 2021 May 9 at phase angle 9.3° to June 10 at phase angle 0.9° can be fit to a phased lightcurve with period 10.987 ± 0.001 hours, maximum amplitude 0.32 ± 0.02 magnitudes. The shape and amplitude of the lightcurve changed considerably as the phase angle decreased, but the period as shown by the timings of maxima and minima remained stable and may be considered secure. This new value of the rotation period is consistent with all previously published values.

