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THREE UNUSUAL HUNGARIA ASTEROIDS

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Three Hungaria asteroids observed at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2015 January-March showed unusual characteristics. 2449 Kenos, a probable member of the Hungaria *collisional family*, is likely to be a binary object with period $P_1 = 3.8481$ h and $P_2 = 15.85$ h. The 2015 observations of 6901 Roybishop, a member of the Hungaria *orbital group*, showed signs of a weak secondary period, $P_2 = 10.58$ h. The secondary period is in contradiction with previous results. (23615) 1996 FK12 may be another example of so-called *wide binaries*, showing a strong short period, $P_2 = 3.6456$ h, presumably due to a widely-separated satellite that is not tidally locked to a very long orbital period. The primary in such a system has a very long period, $P_1 = 368$ h in this instance. The main question for 1996 FK12 is the validity of the long period.

CCD photometric observations of three Hungaria asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2015 January-March: 2449 Kenos, 6901 Roybishop, and (23615) 1996 FK12. Analysis of the data indicated that each might be a binary object.

Table I lists the telescope/CCD camera combinations used for the observations. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel.

Desig	Telescope	Camera
Squirt	0.30-m f/6.3 Schmidt-Cass	ML-1001E
Borealis	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
Eclipticalis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Australius	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Zephyr	0.50-m f/8.1 R-C	FLI-1001E

Table I. List of CS3-PDS telescope/CCD camera combinations.

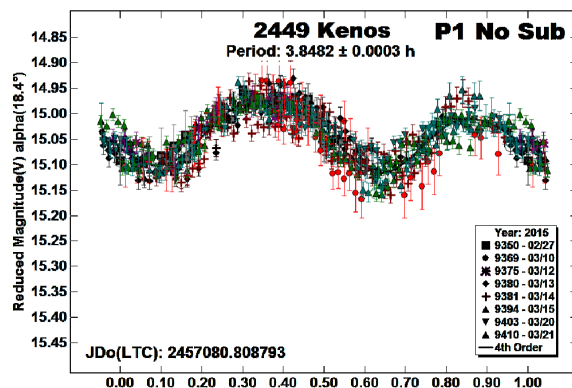
All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposure duration varied depending on the asteroid's brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

Measurements were done using *MPO Canopus*. If necessary, an elliptical aperture with the long axis parallel to the asteroid's path was used. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were usually taken from the MPOSC3 catalog, which is based on the 2MASS catalog (<http://www.ipac.caltech.edu/2mass>) but with magnitudes converted from J-K to BVRI using formulae developed by Warner (2007b). When possible, magnitudes are taken from the APASS catalog (Henden *et al.*, 2009) since these are derived directly from reductions based on Landolt standard fields. Using either catalog, the nightly zero points have been found to be consistent to about

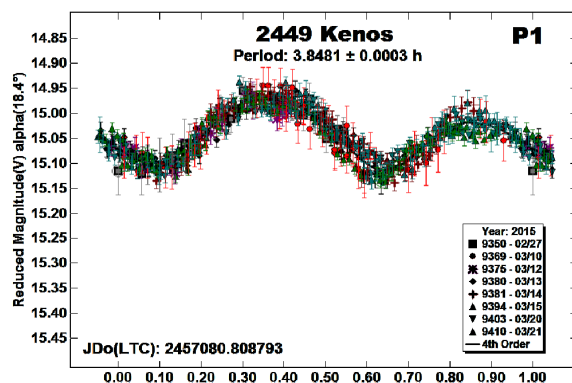
± 0.05 mag or better, but on occasion are as large as 0.1 mag. Period analysis was also done using *MPO Canopus*, which implements the FALC algorithm developed by Harris (*Harris et al.*, 1989).

In the plots below, unless stated otherwise, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the given phase angle, *e.g.*, $\alpha(6.5^\circ)$, using $G = 0.15$. The X-axis is the rotational phase, ranging from -0.05 to 1.05 .

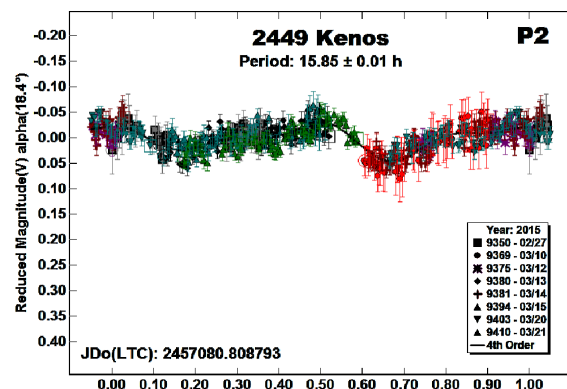
2449 Kenos. Wisniewski *et al.* (1997) reported a preferred period of 4.188 h for Kenos but mentioned an alternate solution of 3.862 h. Subsequent observations by Warner (2007, 3.8492 h; 2010, 3.846 h) showed that the shorter period from Wisniewski *et al.* was more likely. None of the previous papers indicated the possibility of a satellite.



The best-fit single period solution using the 2015 CS3-PDS observations (“P1 No Sub”) shows several sessions with apparent attenuations. This prompted a dual-period search that found $P_1 = 3.8481 \pm 0.0003$ h, $A_1 = 0.14 \pm 0.02$ mag and $P_2 = 15.85 \pm 0.01$ h, $A_2 = 0.04$ -0.10 mag. Even after this, the short period lightcurve showed some apparent deviations from the model curve, *i.e.*, at about 0.5 rotation phase in the “P1” lightcurve. A search for a third period was fruitless and the deviations are best attributed to the evolution of the P_1 lightcurve over the nearly three weeks of observations.



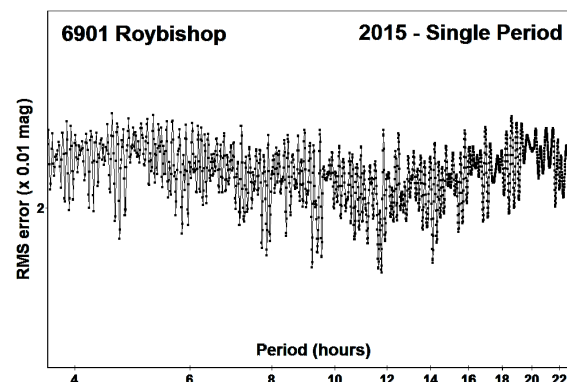
The constantly changing shape of the “P2” lightcurve seems more indicative of the rotation of a satellite, probably tidally locked to its orbital period, but with a viewing geometry that prevented seeing *mutual events*, *i.e.*, occultations and/or eclipses.



It’s worth noting that the viewing aspects (phase angle bisector, PAB; see Harris *et al.*, 1984) in 2007 ($L_{PAB} 172^\circ$) and 2015 ($L_{PAB} 188^\circ$) were similar, with only 16° difference in longitude. Normally, this is not enough to see signs of a satellite at one apparition and not at the other, especially since there were no *mutual events* seen in 2015. The 2007 data set covered only three nights from 2007 March 9-14. It’s possible that the less extensive data set in 2007 didn’t allow finding the subtle deviations seen in 2015.

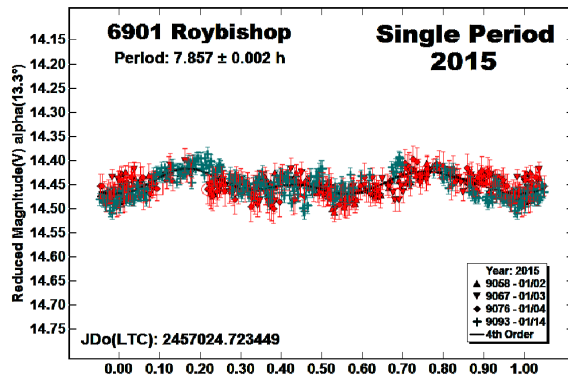
At this time, 2449 Kenos cannot be definitely declared as a binary object, but it is likely. In either event, additional observations, especially at different viewing aspects, are strongly encouraged.

6901 Roybishop. This Hungaria asteroid was a known suspected binary (Warner, 2009). Analysis at that time by the author and independent work by Petr Pravec (Astronomical Institute, Czech Republic) found several possible solutions for the suspected primary and orbital period of a satellite. Updated lightcurves from that original work using the adopted values of $P_1 = 4.684$ h, $P_2 = 17.16$ h are presented below (the magnitudes in the lightcurves are relative to a zero point of $R = 16.04$).

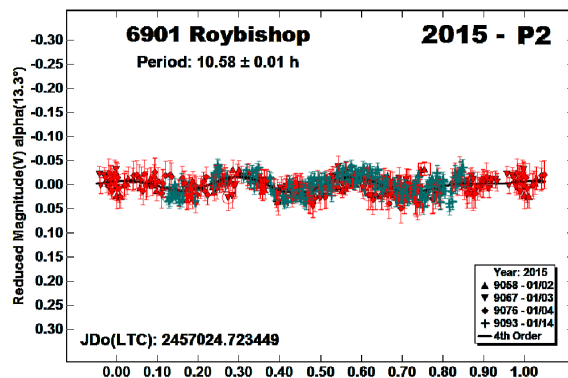
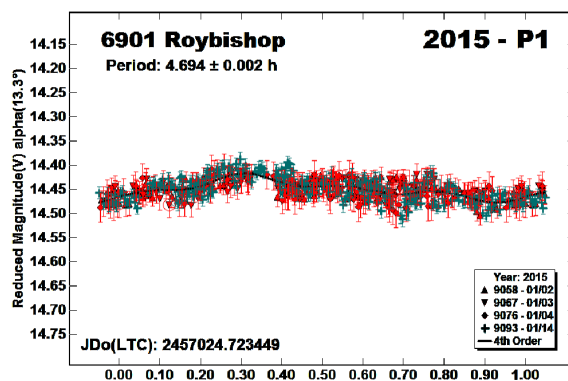


The 2015 observations from CS3-PDS led to even more ambiguity. The period spectrum when looking for a single period features several solutions, many of which have in common that of being nearly commensurate with an Earth day. Given the phase angle and low amplitude, $A = 0.07$ mag, the lightcurve for the correct

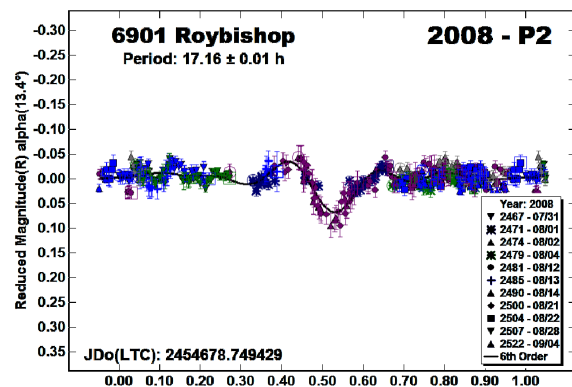
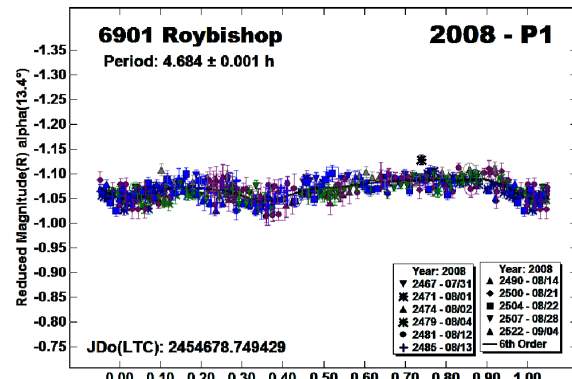
solution could have one or multiple maximum-minimum pairs (Harris *et al.*, 2014). The “2015 Single Period” lightcurve shows just one example.



On the presumption that the previously found period of about 4.7 hours was correct, a dual-period search was performed on the 2015 data set. This produced $P_1 = 4.694 \pm 0.002$ h, in reasonable agreement with the earlier results from 2007 and 2012 (Warner, 2012; 4.785 h). The “2015 – P1” lightcurve shows this result.



When subtracting this period from the data set, the best fit for a second period was at 10.58 h. However, this one of many possible solutions and so cannot be taken at face value. The end result is that the true nature and period(s) for this Hungaria asteroid remain undetermined. It will better-placed for southern observers in 2016 July, but close to the galactic plane. The next best chance for northern observers is not until 2019 September.

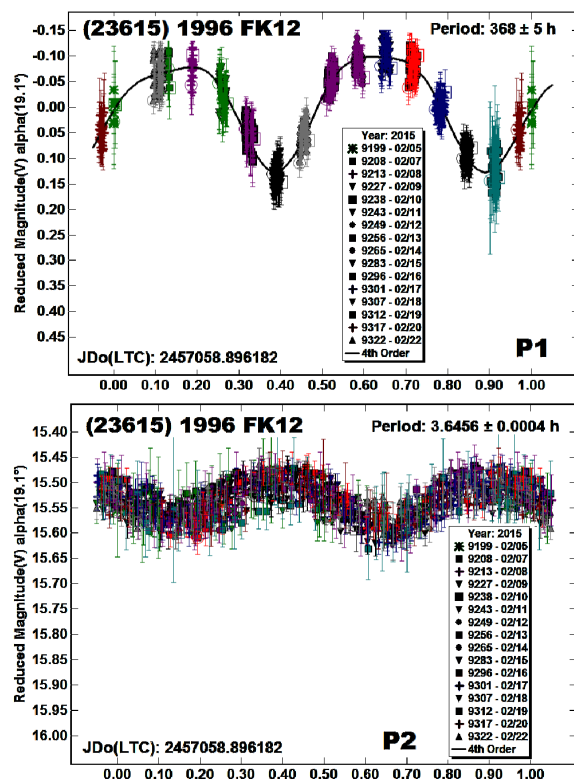


(23615) 1996 FK12. This Hungaria member may be among a small group of *wide binaries* which feature long-period, moderate-amplitude and short-period, low-amplitude components. One current theory is that the long period is due to a slowly rotating, elongated primary and the short period to a small, lesser elongated satellite that circles the primary at a relatively large distance and is not tidally-locked to the orbital period. The likelihood of seeing *mutual events* (occultations and/or eclipses), which would validate the binary nature, is extremely remote. Table II gives the current list of the suspected members of this group.

Number	Name	P ₁	P ₂	Ref
8026	Johnmckay	372	2.2981	MPB 38, 33–36
15778	1993 NH	113	3.320	MPB 42, 60–66
23615	1996 FK12	368	3.6456	This work
67175	2000 BA19	275	2.7157	MPB 40, 36–42
119744	2001 YN42	624	7.24	MPB 41, 102–112
190208	2006 AQ	182	2.621	MPB 42, 79–83
218144	2002 RL66	588	2.49	MPB 37, 109–111
2014	PL51	205	5.384	MPB 42, 134–136

Table II. List of suspected wide binary asteroids. P₁ is the primary's period (hours). P₂ is the satellite's, which is not tidally-locked to its orbital period. All references are Warner (*et al.*).

The primary concern about the legitimacy of these objects lies with the long period, *i.e.*, whether it is real or the result of systematic errors in catalog magnitudes, the reduction process, a combination of these, or other errors. On the other hand, there has been little or no doubt about the reliability of the solution for the purported satellite in most cases, as seen in the “P2” lightcurve for 1996 FK12.



In the case of 1996 FK12, two of the sessions required zero point adjustments on the order of 0.1 mag to get a smooth fitting lightcurve. Given that the amplitude of the long period is only 0.20 mag, this is a significant adjustment. However, the remaining sessions required zero point changes of < 0.05 mag to obtain the best-fit solution shown in "P1". These were similar, if not more extreme, to the adjustments required when fitting the data in many of the previous results shown in Table II. Since observing *mutual events* is virtually unlikely, the best way to establish the validity of the results given in Table II will be to observe the asteroid at subsequent apparitions and, if possible, use data calibrated to at least an internal, if not standard, system with an accuracy and precision of 0.02 mag or better.

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LOW RESOLUTION VISIBLE REFLECTANCE SPECTRUM FOR NEA (357439) 2004 BL86

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Low resolution spectroscopic observations of the near-Earth asteroid (357439) 2004 BL86 were acquired during the flyby of 2015 January 26. The spectrum analysis shows that its taxonomic class is very close to that of 4 Vesta in the visible wavelength.

The near-Earth asteroid (357439) 2004 BL86 was observed in the visible spectrum during the flyby of 2015 January 26 at Balzareto Observatory (A81) in Rome, Italy, using a 0.20-m Schmidt-Cassegrain (SCT) reduced to $f/5.5$ and an SBIG ST7-XME CCD camera equipped with a diffraction grating SA-200 (Paton Hawksley Education) mounted inside the filter wheel. With this simple slit-less configuration, it's possible to acquire low resolution spectra in the visible wavelength region of the relatively faint objects (up to 12-13 mag) with a spectral resolution $R \sim 100$.

Due to the fast movement of the asteroid in the sky (147 arcsec/min), a sequence of 62 images, each with a 5 second exposure time, was acquired. The images were stacked with sigma-clip to increase the final signal-to-noise ratio and remove the weak spectra of faint field stars (Figure 1).