

# **ASTEROID LIGHTCURVE ANALYSIS AT THE CENTER FOR SOLAR SYSTEM STUDIES PALMER DIVIDE STATION: 2023 SEPTEMBER-OCTOBER**

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CCD photometric observations of three Hungaria asteroids were made at the Center for Solar System Studies Palmer Divide Station in 2023 September and October. 10737 Bruck and (48470) 1991 TC2 were found to be new binary discoveries. Bruck has a primary rotation period of 2.3446 h and orbital period of 15.39 h. The estimated effective diameter ratio ( $D_s/D_p$ ) of the satellite vs. primary is 0.22. (48470) 1991 TC2 has a primary rotation period of 2.5141 h and orbital period of 11.179 h. The estimated  $D_s/D_p$  is 0.28.

CCD photometric observations of three Hungaria asteroids were carried out at the Center for Solar System Studies Palmer Divide Station (CS3-PDS) during 2023 September to October as part of an ongoing general study of asteroid rotation periods with a concentration on near-Earth, Hungaria, and Hilda group/family asteroids.

| Telescope                     | Camera              |
|-------------------------------|---------------------|
| 0.30-m f/6.3 SCT              | SBIG STL-1001E      |
| 0.35-m f/9.1 SCT (x3)         | FLI Microline 1001E |
| 0.50-m f/8.1 Ritchey-Chrétien | FLI Proline 1001E   |

Table I. List of available telescopes and CCD cameras at CS3-PDS. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

Table I lists the five telescope/CCD camera pairs available at CS3-PDS. All the cameras use CCD chips from the KAF 1001 blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24-1.60 arcsec/pixel. All lightcurve observations were made with no or a clear filter. The exposures varied depending on the asteroid's brightness.

To reduce the number of times and amounts of adjusting nightly zero-points, the ATLAS catalog  $r'$  magnitudes on the Pan-STARRS photometric system (SR; Tonry et al., 2018) are used. Those adjustments are usually  $\leq \pm 0.03$  mag. The rare larger corrections 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.

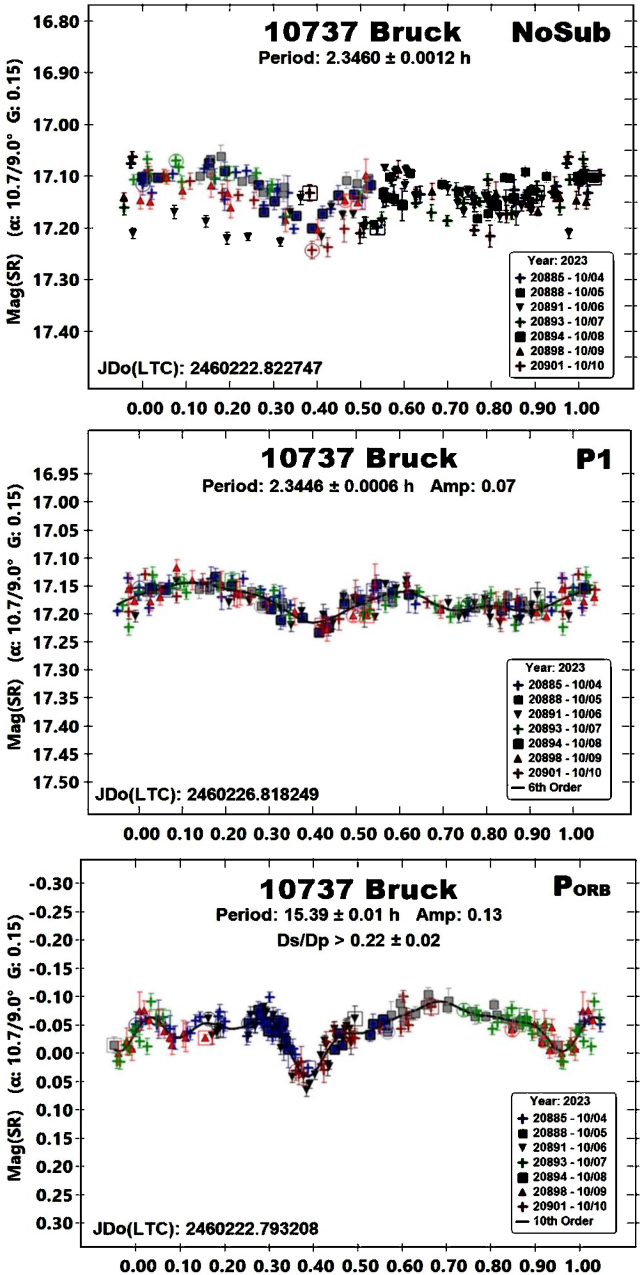
The Y-axis values are ATLAS SR “sky” (catalog) magnitudes. The values in the parentheses give the phase angle(s),  $\alpha$ , along with the value of  $G$  used to normalize the data to the comparison stars and asteroid phase angle used in the earliest session. This, in effect, adjusts all the observations so that they seem to have been made at a single fixed date/time and phase angle. Presumably, any remaining variations are due only to the asteroid's rotation and/or albedo changes.

There can be up to three phase angles. If two, the values are for the first and last night of observations. If three, the middle value is the

extrema (maximum or minimum) reached between the first and last observing runs. 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*.

For brevity, only some of the previous results are referenced. A more complete listing is in the asteroid lightcurve database (Warner et al., 2009; “LCDB” from here on).

**10737 Bruck.** Observations of this Hungaria were made form 2023 Oct 4-10. The phase angle decreased from 10.6° to 9.0° while the phase angle bisector longitude and latitude were about 21° and -11°, respectively. The “NoSub” plot shows clear indications of a secondary lightcurve. Dual-period analysis using *MPO Canopus* determined the asteroid to be a binary with an orbital period of 15.39 h and effective diameter ratio  $D_s/D_p \geq 0.28 \pm 0.02$ . The asymmetric spacing of the events warrants confirmation.



| Number | Name     | 2023/mm/dd  | Phase      | L <sub>PAB</sub> | B <sub>PAB</sub> | Period(h)                     | P.E.            | Amp          | A.E.         | Grp<br>Ds/Dp |
|--------|----------|-------------|------------|------------------|------------------|-------------------------------|-----------------|--------------|--------------|--------------|
| 10737  | Bruck    | 10/04–10/10 | 10.6, 9.0  | 21               | –11              | <sup>B</sup> 2.3446<br>15.39  | 0.0006<br>0.01  | 0.07<br>0.13 | 0.01<br>0.01 | H<br>0.22    |
| 48470  | 1991 TC2 | 09/27–10/09 | 12.0, 6.3  | 15               | –9               | <sup>B</sup> 2.5141<br>11.179 | 0.0002<br>0.004 | 0.11<br>0.10 | 0.01<br>0.01 | H<br>0.28    |
| 52748  | 1998 JJ1 | 10/04–10/05 | 14.3, 14.0 | 19               | 17               | 4.243                         | 0.005           | 0.71         | 0.03         | H            |

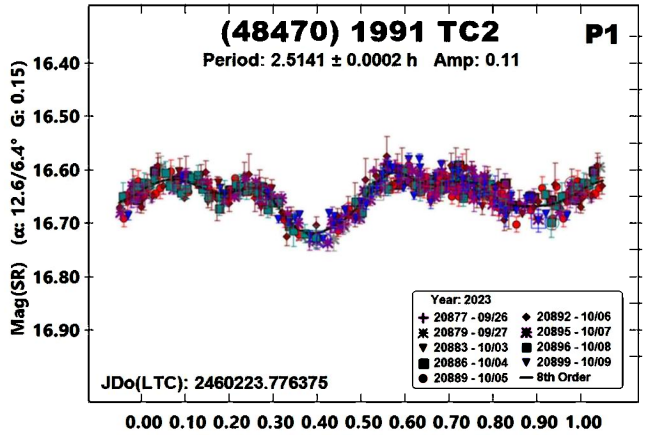
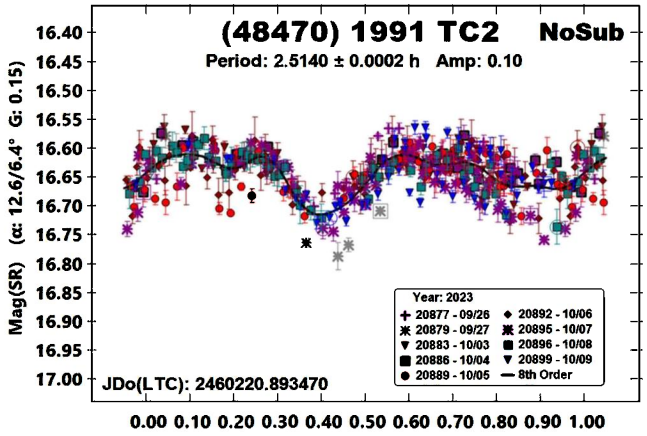
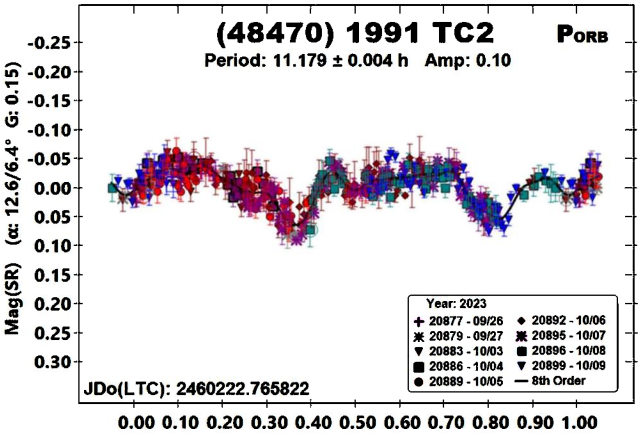
Table II. Observing circumstances and results. <sup>B</sup>Period of primary with one or more confirmed or suspected satellites. If a confirmed or suspected binary with mutual events, the second line gives the secondary (or orbital) period and the effective diameter ratio (*Ds/Dp*) based on the shallower (if unequal) event. The amplitude is the maximum amplitude of the secondary lightcurve. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum during the period. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). The Grp column gives the asteroid family or group (Nesvorny, 2015; Nesvorny et al., 2015). H = Hungaria.

Several previous observations of the asteroid, e.g., Warner (2016), Stephens (2017), Stephens and Warner (2020), did not indicate any signs of the asteroid being binary.

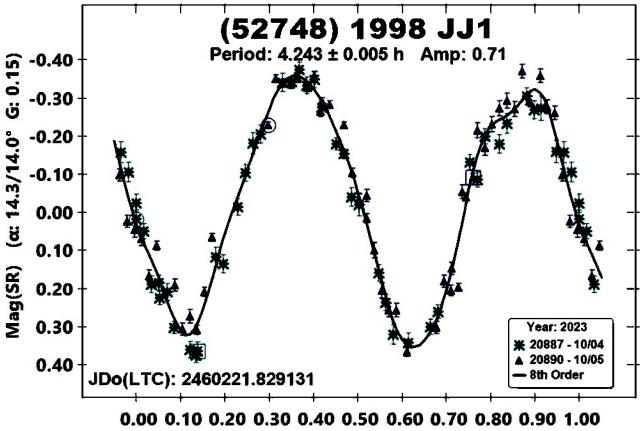
(48470) 1991 TC2. Observations of this Hungaria were made between 2023 Sep 27 – Oct 9.

The phase angle decreased from 12.0° to 6.3° while the phase angle bisector longitude and latitude were about 15° and -9°, respectively. The “NoSub” plot shows clear indications of a secondary lightcurve. Dual-period analysis using *MPO Canopus* determined the asteroid to be a binary with an orbital period of 11.179 h and effective diameter ratio  $Ds/Dp \geq 0.28 \pm 0.02$ .

Observations by Warner (2011; 2014) and Stephens (2016) did not apparently show signs of the asteroid having a satellite.



(52748) 1998 JJ1. Clark (2016) reported a period of 4.3260 h while Stephens (2016) found 4.258 h. Durech et al. (2020) used wide-field survey data to find a *sidereal* period of 4.25749 h and ecliptic pole solution ( $\lambda, \beta$ )<sub>J2000</sub> = (323 ± 2°, -4 ± 11°).



Acknowledgements

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## LIGHTCURVE ANALYSIS FOR NINE NEAR-EARTH ASTEROIDS OBSERVED BETWEEN 2009 - 2023

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Lightcurves and amplitudes for 9 near-Earth asteroids observed from Great Shefford Observatory during close approaches between 2009 - 2019 and August - November 2023 are reported. All are fast or superfast rotators, seven having periods less than 4 minutes, with 2023 TC7 having a period of 12.7 seconds. One has a reliably detected tumbling rotation and another is a possible tumbler.

Photometric observations of near-Earth asteroids during close approaches to Earth in 2009 - 2019 and August - November 2023 were made at Great Shefford Observatory using a 0.40-m Schmidt-Cassegrain and Apogee Alta U47+ CCD camera. All observations were made unfiltered and with the telescope operating with a focal reducer at f/6. The 1K×1K, 13-micron CCD was binned 2×2 resulting in an image scale of 2.16 arc seconds/pixel. All the images were calibrated with dark and flat frames and *Astrometrica* (Raab, 2023) was used to measure photometry using APASS Johnson V band data from the UCAC4 catalogue (Zacharias et al., 2013). *MPO Canopus* (Warner, 2023), incorporating the Fourier algorithm developed by Harris (Harris et al., 1989) was used for lightcurve analysis.

No previously reported results have been found in the Asteroid Lightcurve Database (LCDB) (Warner et al., 2009), from searches via the Astrophysics Data System (ADS, 2023) or from wider searches unless otherwise noted. All size estimates are calculated using H values from the Small-Body Database Lookup (JPL 2023b), using an assumed albedo for NEAs of 0.2 (LCDB readme.pdf file) and are therefore uncertain and offered for relative comparison only.

2009 DO111. This Apollo made a very favourable approach to 1.2 Lunar Distances (LD) from Earth on 2009 Mar 20.2 UTC, nearly 1 month after discovery (Tubbiolo et al., 2009) and will not come closer before 2146. It was followed on four nights, observations starting on 2009 Mar 16.07, 16.94, 18.81 and 19.80 UTC as it brightened from 15<sup>th</sup> to 12<sup>th</sup> magnitude on its approach. Reductions from each night produced very similar period spectra, period determinations of 0.04889 h = 176 s and trimodal lightcurves. A representative period spectrum is given from the night of 2009 Mar 18.81, all the minima are related, either integer multiples or small integer fractions (3/2, 4/3, 2/3, 1/2, 1/3) of the best fit period. Independent lightcurves are given for the four nights, for each the Y-axis has been forced to 1.4 magnitudes to aid comparison of the changing amplitude (increasing from 0.37 to 1.29 magnitudes) as the phase angle increased from 16° to 73°. Small zero-point corrections have been made to sessions in the individual lightcurves to minimise scatter in the curves, RMS values of the adjustments for the four nights Mar 16.1, 16.9, 18.8 and 19.8 are 0.01, 0.04, 0.07 and 0.05 respectively. A 'Lightcurve Evolution' plot is given, aligning the deepest minima apparent on each separate night and displacing each night by 0.5 magnitudes vertically to avoid overlap. The key indicates the dates and range of phase angles each covers.