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PHOTOMETRIC OBSERVATIONS AND DATA ANALYSIS OF NEA BINARY ASTEROID 5143 HERACLES

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Analysis of CCD photometric observations of the known binary asteroid 5143 Heracles (Taylor et al., 2012) was conducted at the Center for Solar System Studies based on observations obtained in 2021 October and November. A secure period of P1 = 2.70776 ± 0.00006 h was established for the rotation of the primary. The secondary period is ambiguous and depends on whether or not the rotation of the secondary is locked to its orbital period. Our analysis favors an independently rotating secondary with P2 = 46.41 h.

Observations of the near-Earth asteroid 5143 Heracles were made at the Center for Solar System Studies in 2021 October and November. They were made with a 0.35-m f/9.1 Schmidt-Cassegrain and FLI Microline CCD camera. The camera uses a KAF-1001E chip, which has a 1024×1024×24m array of pixels. The combination gives a field-of-view of about 25×25 arcminutes and image scale of 1.5 arcsec/pixel. The analysis of our data follows below.

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.

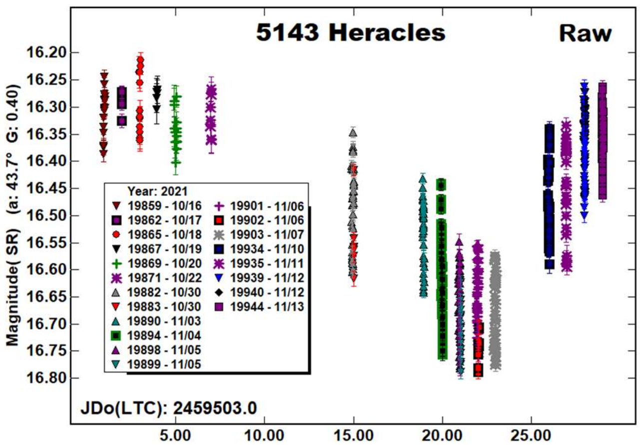
Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. To reduce the number of adjusted nightly zero points and their amounts, the analysis of the 2021 data used the ATLAS catalog r´ (SR) magnitudes (Tonry et al., 2018). The rare zero-point adjustments ≥ ±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 values are ATLAS SR "sky" (catalog) magnitudes. The two values in the parentheses are the phase angle (a) and the value of *G* used to normalize the data to the comparison stars used in the earliest session. This, in effect, corrected all the observations to seem to have been made at a single fixed date/time and phase angle, leaving 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*.

References to previous works were taken from the asteroid lightcurve database (Warner et al., 2009), known as "LCDB" from here on. Since most listed rotation periods for the primary were very similar, only a few of the LCDB references have been used.

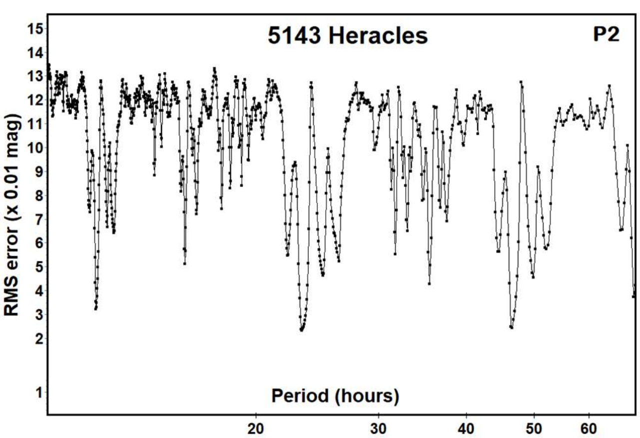
5143 Heracles is a known binary, first suspected by Pilcher et al. (2012) based on optical observations in 2021 November and then confirmed with radar observations in December of that year (Taylor et al., 2012).

The most notable feature when plotting the raw data was an apparently long period. We tried different values for the phase slope parameter (*G*), the default 0.15 and then 0.40. The latter was close to that derived from IR observations, e.g., Thomas et al. (2011) and Usui et al. (2011). As discussed below, using $G = 0.40$ kept nightly zero-point adjustments to less than ±0.03 mag while using $G = 0.15$ required more frequent adjustments of up to ±0.07 mag. These are generally much larger than when using SR magnitudes from the ATLAS catalog (Tonry et al., 2018).

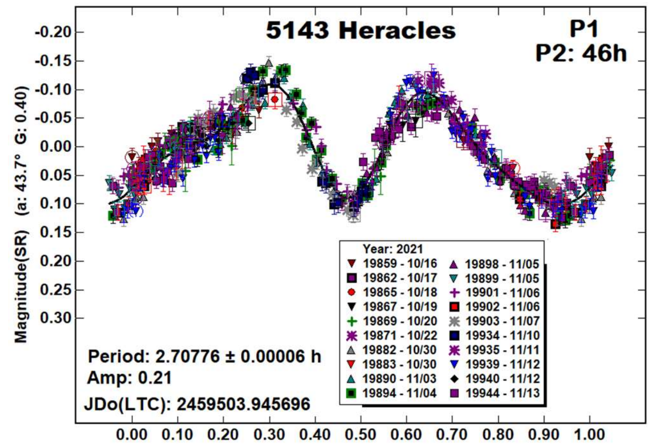


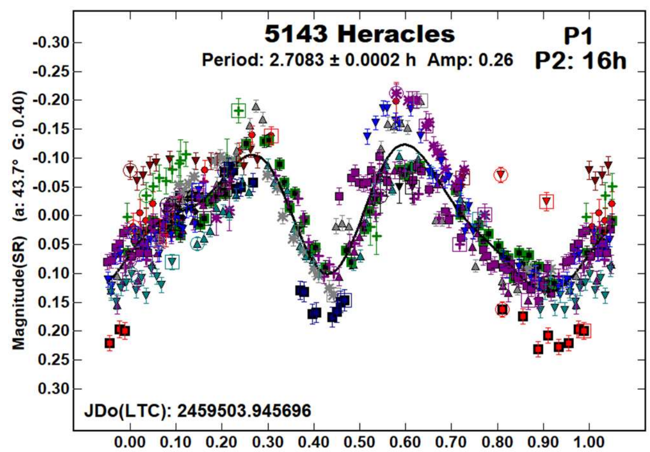
The search for a longer period in the data led to a period spectrum indicating a number of possible solutions. It was not the value of *G* but the number of orders in the Fourier search that had the more pronounced effect on the period search. We used 4th order to keep the undulations of the secondary period lightcurves in check.

Based on the raw data plot, we first opted to search for a long period between 40-50 hours. This was contradictory to the premise that the satellite was tidally locked to its orbital period but Taylor et al. (2012) did allow that an orbital period of 40-57 h was possible if the satellite rotation period was not also that of its orbital period.



After finding the primary rotation period and a secondary period of about 46 hours, we then forced the secondary period to a range of 13-18 h, the range considered more likely by Taylor et al. (2012). In both cases, a value of $G = 0.40$ was used because, as mentioned above, this reduced the nightly zero-point adjustments to acceptable and more typical values. We could and did try using $G = 0.15$ and allowed substantial zero-point adjustments. Even so, the quality of the two lightcurves was considerably diminished.





The two plots for the primary rotation period (P_1) show a dramatic difference in the quality of the fit between using a secondary period of about 46 h or 16 h. In this comparison, the zero-point adjustments were kept at the values used to find the higher-quality solution (P1, P2: 46h), i.e., ≤ ±0.03 mag. Even when allowing much larger adjustments, there was not much improvement in the P_1 and P_2 plots when using $P_2 = 16$ h.

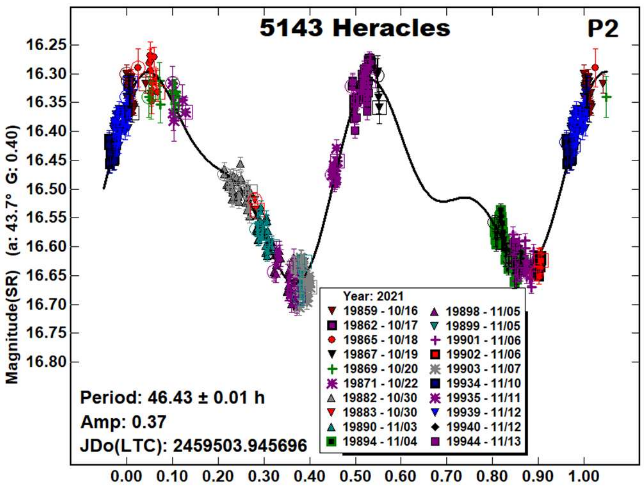
The two plots for the secondary period show a similar, dramatic difference in the quality of the lightcurve fits depending on the adopted period. Given the better fits to the P_1 and P_2 lightcurves, which do not appear to be the result of a *fit by exclusion*, i.e., minimizing the number of overlapping data points, the longer secondary period, $P_2 = 46.43$ h, has been adopted for this work.

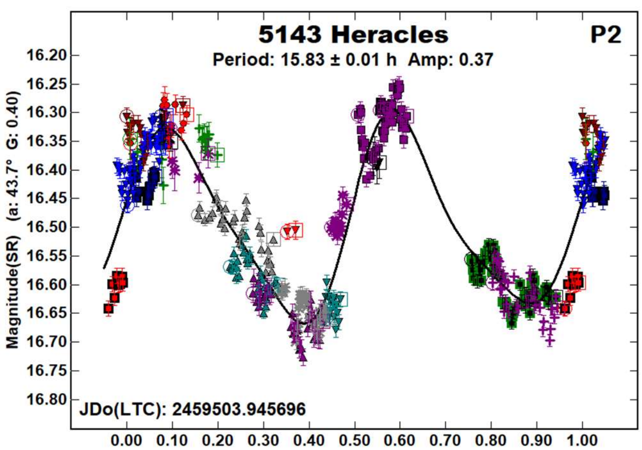
Looking at the results from other optical campaigns, Vaduvescu et al. (2017), using data from the 2016 apparition, found a secondary period of 17.114 h, which is more in line with the assumed tidally-locked satellite. Previous observations (Warner, 2017; 2018) found periods of 2.704 h and 2.758 h, respectively, for the primary but there were no obvious signs of a satellite in those data.

Number	Name	2021 mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
5143	Heracles	10/16-11/13	43.6,78.5	87	18	2.70776	0.00006	0.21	0.02	NEA
						46.41	0.01	0.37	0.03	

Table II. Observing circumstances. The first line gives the primary period for the system. The second line gives the secondary period. The phase angle (α) is given at the start and end of each date range. An asterisk indicates that 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: NEA: Near-Earth asteroid.

The next time the asteroid is V < 18 is in 2023 October. Maybe then the asteroid's true nature and parameters can be confirmed.





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