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ROTATION PERIOD DETERMINATION FOR 5143 HERACLES

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The Earth crossing minor planet 5143 Heracles made in late 2011 its closest approach to Earth since discovery. A consortium of observers found a synodic rotation period near 2.706 hours and amplitude increasing from 0.08 ±0.02 magnitudes at phase angle 20 degrees to 0.18 ±0.03 magnitudes at phase angle 87 degrees, with 3 unequal maxima and minima per cycle. Magnitude parameters H = 14.10 ±0.04 and G = 0.08 ±0.02 are found, and the color index V-R = 0.42 ±0.07. For an asteroid of taxonomic class Q, a suggested albedo pv = 0.20 ±0.05 yields estimated diameter D = 4.5 ±0.7 km. Three possible binary events were recorded, but these are insufficient for binary detection to be secure. Retrograde rotation is suggested.

Minor planet 5143 Heracles is an Apollo type object that made in late 2011 its closest approach to Earth since discovery. To illustrate the circumstances of the approach we provide a diagram (Figure 1) showing the path in the sky, and another diagram (Figure 2) showing phase angle and Earth distance Delta, both through the interval of observation. Previous unpublished photometry was obtained by co-author Krugly in 1996 October which were made with a precision of 0.03 – 0.05 mag and showed an apparently random 0.1 magnitude scatter. These data have been reanalyzed and confirm a rotation period of 2.7 hours. Pravec et al. (1998) also obtained observations in 1996 with no detected periodicity and found H = 14.27 ±0.09. These are also referenced by Warner et al. (2011), which suggests only a possibly long period. Daniel Klinglesmith on 2011 Nov. 7 performed photometry with a 15 cm Takahashi. The resultant lightcurve was very noisy but suggested a short rotation period near 2.7 hours. He communicated this result to Frederick Pilcher, who used a 35 cm Meade LX200 GPS S-C with SBIG STL-1001E CCD for further observations. Klinglesmith also subsequently used a much larger telescope, a 35 cm f/11 Celestron with STL-1001E CCD. The use of 35 cm telescopes greatly improved the SN ratio. Independently Lorenzo Franco also found a period of 2.7 hours with a 20 cm f/5.5 SCT and SBIG ST7-XME CCD. John Briggs with a DFM Engineering 40 cm f/8 Ritchey-Chretien and Apogee Alta U47 CCD, also provided observations. The four observers agreed to exchange data via *MPO Canopus* export files, combine their data, and publish jointly.

Later Petr Pravec (personal communication) kindly informed the first author of two additional sets of observations. Joe Pollock used a DFM Engineering 40 cm f/8 Ritchey-Chretien and Apogee Alta U47 CCD, clear filter with IR blocker. Raguli Inasaridze, Yurij Krugly, and Igor Molotov used the 70 cm Maksutov telescope AC-32 with IMG6063-E (FLI) CCD unfiltered at Abastumani. These people kindly accepted the first author's invitation to contribute their observations and become co-authors of the paper. A total of 41 lightcurves were obtained in the interval 2011 Oct. 21 - Dec. 11, showing a synodic period 2.706 ±0.001 hours with three maxima and minima per cycle. During this interval as the phase angle increased from 20 degrees to 87 degrees the amplitude correspondingly increased from 0.08 ±0.02 magnitudes to 0.18 ±0.03 magnitudes, and the shape of the lightcurve also changed appreciably. Magnitude measurements were made with the MPO Canopus Comp Star Selector. These are based on the Sloan r' reference star magnitudes in the CMC14 catalog and J and K magnitudes in the 2MASS catalog. The conversion to V magnitudes was obtained from the standard formula (Dymock and Miles 2009):

$$V = 0.6278*(J-K) + 0.9947*r'$$

To illustrate these changes we provide seven lightcurves (Figures 3-9) each covering only a few closely spaced dates.

Small asteroids with short rotation periods less than 3 hours are especially likely to possess satellites derived from centrifugal disruption. Petr Pravec made a special search and found three dips in the lightcurve of the form characteristic of binary transit/occultation/shadow events. These events were centered 2011 Nov. 22 3.36h UT, Nov. 22 6.24h UT, and Nov 26 6.24h UT. They are shown on three additional diagrams (Figures 10-12). In these the 8th order Fourier series most closely approximating the lightcurve in the interval Nov. 22 - 26 is shown. A segment below this curve represents observations inferred to be the binary event. Below this with the same time axis the value of the Fourier averaged lightcurve for each phase is flattened to show the time variation of the additional dip caused by the binary event. With only three events observed the revolution period could not be found. The evidence for binary nature is strong but is insufficient to be considered secure. The appearance of binary events separated by only 2.88 hours (Nov. 22 3.36h and 6.24h UT, respectively) is remarkable. At phase angle 31 degrees these probably indicate transit followed by shadow, or vice versa.

Minor planet 5143 Heracles will have an even closer approach in 2016 November. A global campaign should be organized to maintain nearly continuous photometric coverage over an interval of several weeks. Binary events, if they occur, should be sufficiently sampled at this time to fully define the parameters of the system.

The large range of phase angles possible only for Earth approachers has enabled the construction of a phase plot with especially well defined parameters in V band. This study sampled phase angles from 23 to 87 degrees. Observations in 1996 by Pravec et al. (1998) extend the range of phase angles to 6 degrees. Combining current data with those from 1996 enables the construction of a very accurate H-G plot (Fig. 13) showing H = 14.10 ±0.04 and G = 0.08 ±0.02. This value of H is in fair agreement with 14.27 by Pravec et al. (1998). Heracles was observed in both the V and R bands at Balzaretto Observatory 2011 November 18. This allowed the finding of the color index V-R = 0.42 ±0.07. The taxonomic class of 5143 Heracles is unambiguously Q, (Binzel et al. 2010) and the geometric albedo of class Q is typically pv = 0.20 ±0.05 (Pravec et al. 2012). From these values of H and pv the diameter D may be calculated by the formula by Pravec and Harris (2007):

$$\log D(km) = 3.1235 - 0.2 H - 0.5 \log (pv)$$

This leads to an estimated diameter D = 4.5 ±0.7 km, a value which compares favorably with the WISE satellite infrared radiometry value of 4.8 ±0.4 km (Mainzer et al. 2011).

The daily motion was always retrograde and increased steadily throughout the apparition. A table and graph (Figure 14) of mean synodic period versus mean daily motion are presented, which shows an increase of synodic period with increasing retrograde daily motion with, however, a low determination coefficient of only 0.3542. Such increase is characteristic of retrograde rotation, which is suggested for 5143 Heracles.

Acknowledgement

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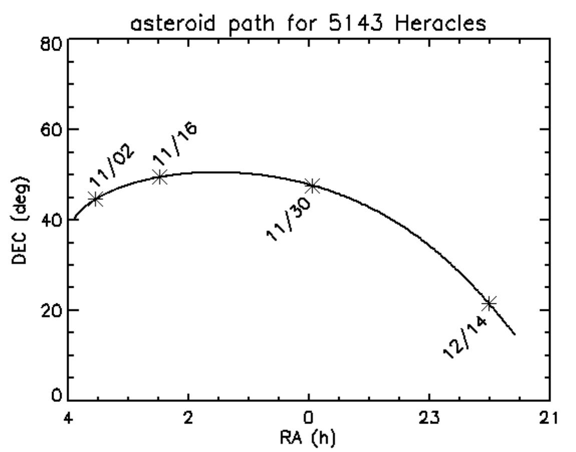

Figure 1. Sky path of 5143 Heracles

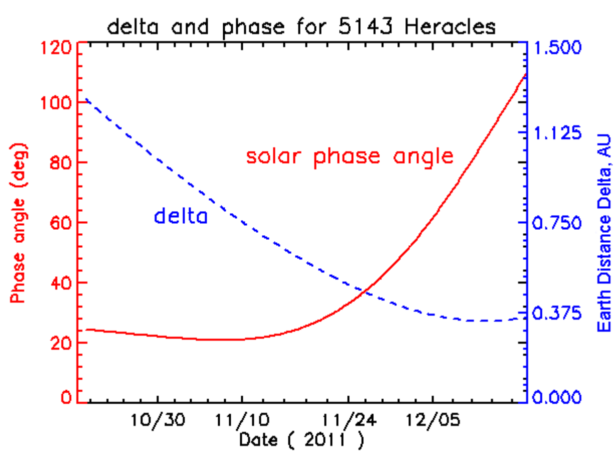

Figure 2. Phase angle and Earth Distance Delta of 5143 Heracles

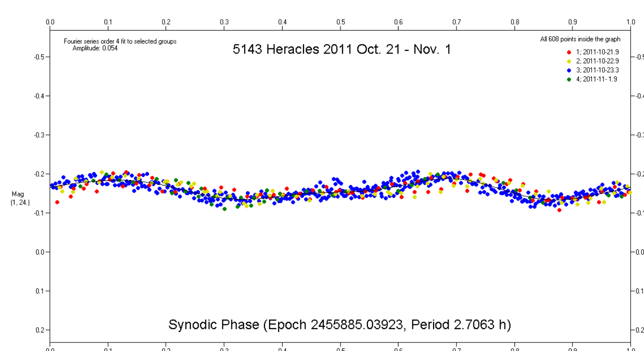

Figure 3. Lightcurve of 5143 Heracles 2011 Oct. 21 - Nov. 1

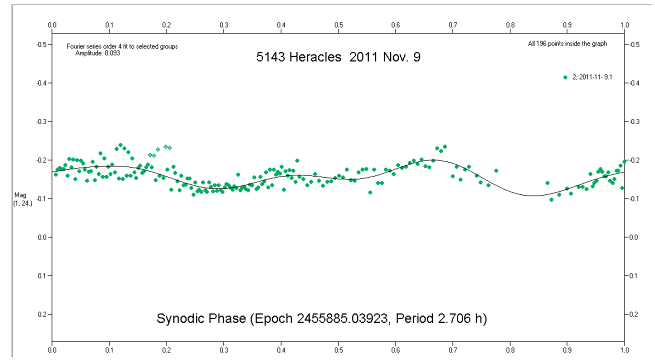

Figure 4. Lightcurve of 5143 Heracles 2011 Nov. 9

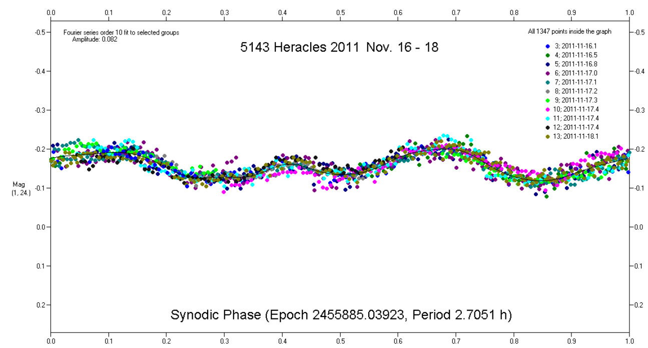

Figure 5. Lightcurve of 5143 Heracles 2011 Nov. 16 - 18

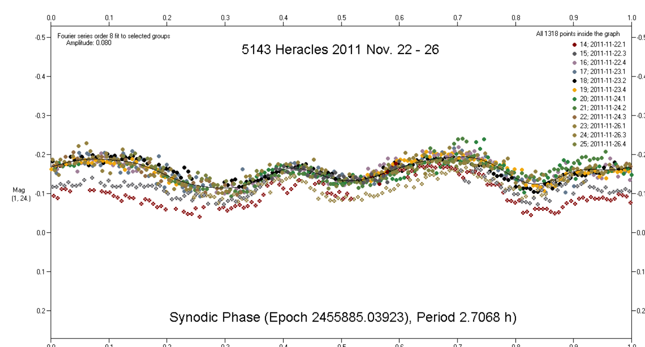

Figure 6. Lightcurve of 5143 Heracles 2011 Nov. 22 - 26

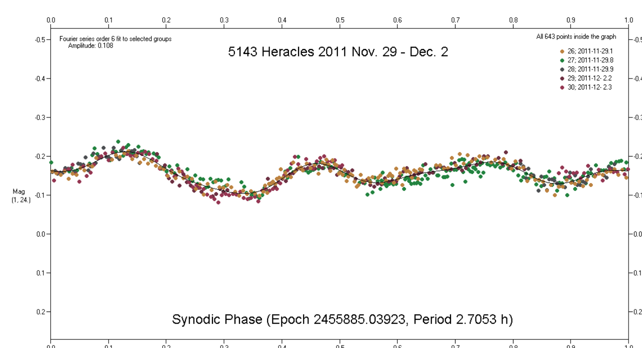

Figure 7. Lightcurve of 5143 Heracles 2011 Nov. 29 - Dec. 2

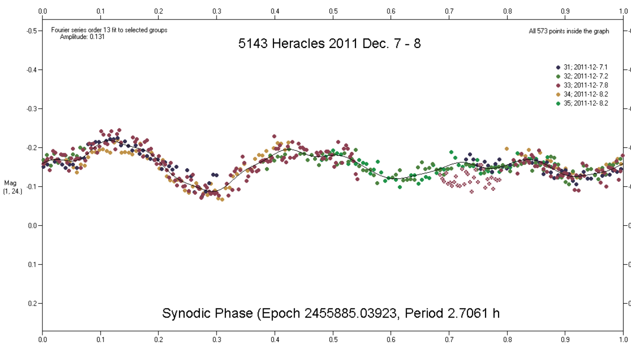

Figure 8. Lightcurve of 5143 Heracles 2011 Dec. 7 - 8

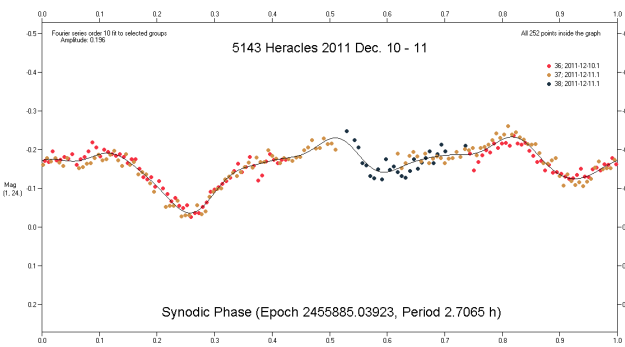

Figure 9. Lightcurve of 5143 Heracles 2011 Dec. 10 - 11

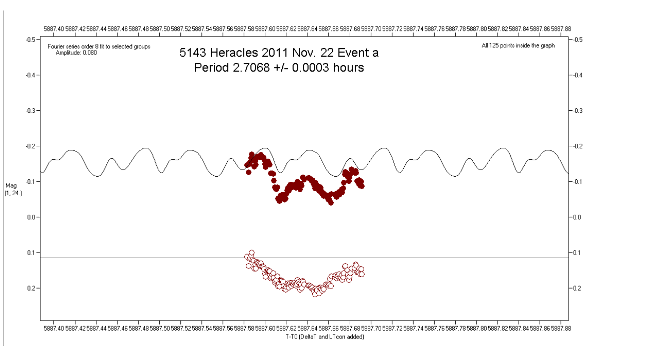

Figure 10. Dip in lightcurve of 5143 Heracles centered at 2011 Nov 22 3.36h UT

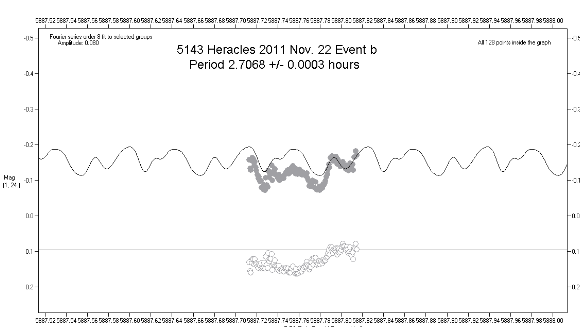

Figure 11. Dip in lightcurve of 5143 Heracles centered at 2011 Nov 22 6.24h UT

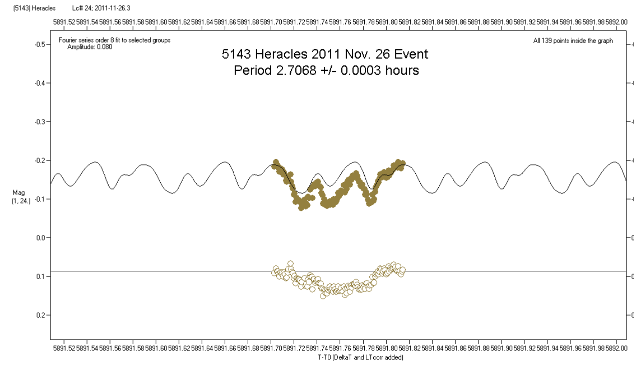

Figure 12. Dip in lightcurve of 5143 Heracles centered at 2011 Nov 26 6.24h UT

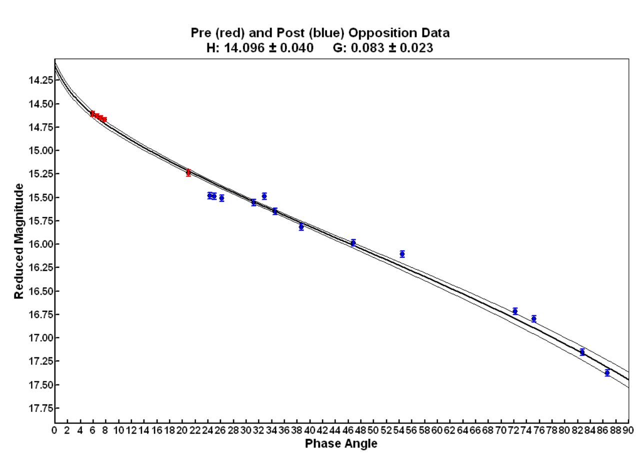

Figure 13. Phase curve of 5143 Heracles

Date (from-to)	PAB_L/day	Syn Period (h)	Period Err (h)
09-16 nov	-0.225	2.7061	0.0003
16-22 nov	-0.493	2.7055	0.0002
22-26 nov	-0.810	2.7072	0.0003
26-29 nov	-1.131	2.7067	0.0003
29-02 dec	-1.432	2.7055	0.0003
02-07 dec	-1.725	2.7074	0.0002
07-08 dec	-1.822	2.7071	0.0012
08-10 dec	-1.776	2.7074	0.0005
10-11 dec	-1.692	2.7072	0.0008

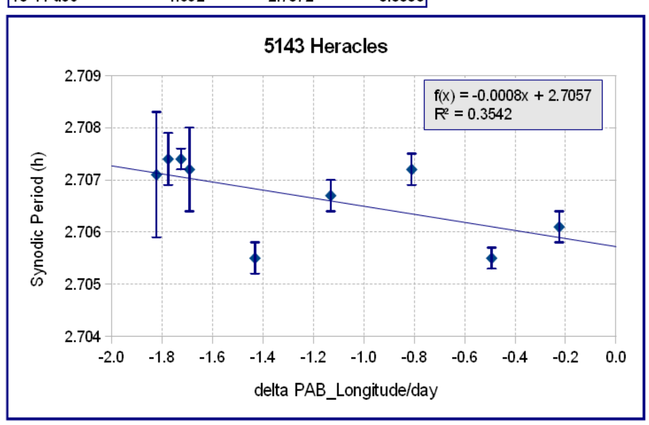

Figure 14. Table and plot of synodic period of 5143 Heracles versus daily motion of phase angle bisector