PHOTOMETRY AND LIGHTCURVE ANALYSIS FOR NEAR-EARTH ASTEROIDS 65803 DIDYMOS, (86829) 2000 GR146 AND 161989 CACUS

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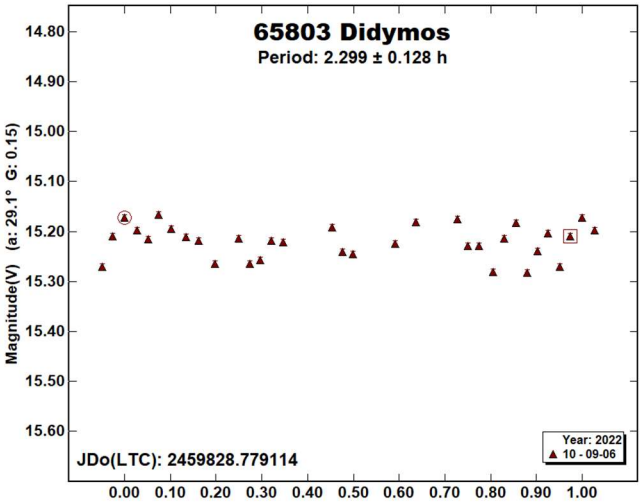
We present lightcurves for 65803 Didymos, (86829) 2000 GR146, and 161989 Cacus. These observations were conducted in 2022 September, prior to the NASA DART impact. Lightcurve analysis for 65803 Didymos is in excellent agreement with prior results, while data for the other two asteroids comes close to matching prior published rotational periods, but does not strictly overlap. A larger number of data points on nights with good seeing would be required for better solutions.

CCD photometric observations of near-Earth asteroids 65803 Didymos, (86829) 2000 GR146 and 161989 Cacus were carried out over four nights between 2022 September 6 and 9 at the Cerro Tololo Inter-American Observatory in La Serena, Chile (IAU code 807). The data were taken with the SMARTS 0.9-m *f*/13.5 Cassegrain telescope on the mountain, which is equipped with a 2048×2046 Tek2K CCD detector; however, we used only a quarter of the chip for the observations because doing so reduced image readout times significantly. As such, our observations are 1074×1024-pixel arrays of 0.401 arcseconds per pixel.

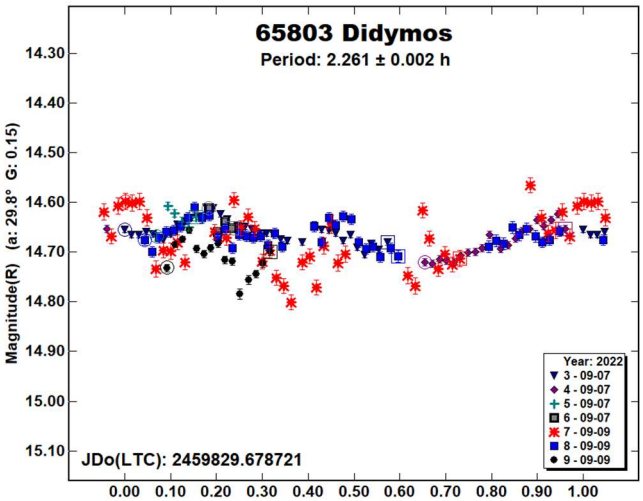
Data processing and analysis were done using *MPO Canopus* software (Warner, 2019). Images were calibrated using bias and flat field frames with the same software. *MPO Canopus* implements the Fourier Analysis of Lightcurves (FALC) algorithm developed by Alan Harris (Harris et al., 1989); this was used to find best-fit periods for our observational data for each asteroid.

65803 Didymos is a potentially-hazardous binary Apollo asteroid discovered on 1996 April 11 by the Spacewatch survey at Kitt Peak National Observatory in Arizona. Didymos' published rotational period is 2.2600 ± 0.0001 h (Naidu, 2020). Recently, Didymos and its companion Dimorphos (Pravec, 2003) were the target of the Double Asteroid Redirection Test (DART), a mission led by NASA, which deliberately impacted Dimorphos with a spacecraft on 2022 September 26. The observations described in this report were taken a few weeks prior to the impact, with the intent to bolster pre-impact rotational period analysis and comparisons with post-impact observational results. We observed Didymos in both V and R filters throughout the nights of 2022 September 6-9.

Twentynine images of Didymos in the V filter were taken on 2022 September 6 with exposure times of 90 s. The seeing remained consistently low throughout the night and, despite the small number of images, we were able to observe a complete rotation of the asteroid. The data taken in V show a rotational period of 2.299 ± 0.128 h, which overlaps with previous results, albeit with a significant uncertainty due to the low number of data points.



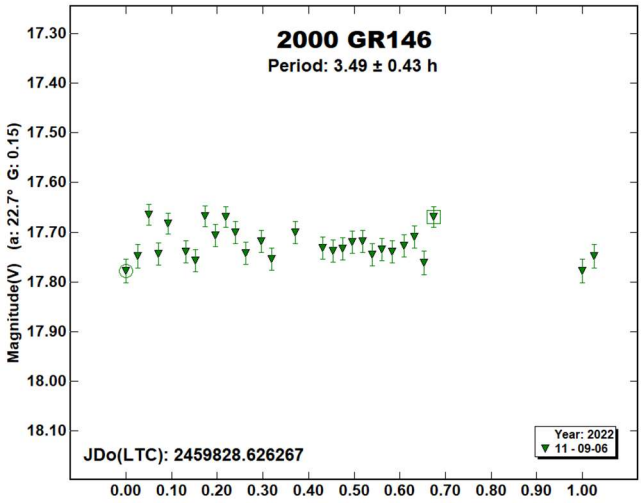
On the nights of 2022 September 7 and 9, we observed Didymos in the R filter, taking a total of 205 images at an exposure time of 60 s. Since the asteroid is brighter in the R filter than in V, we were able to use lower exposure times than the V filter images in order to take a larger number of observations. While the night of 2022 September 7 had pretty good seeing, the night of 2022 September 9 had higher humidity in the air than was desirable, as well as a bright, nearly-full moon, such that seeing fluctuated from 1.0 - 2.0 arcsec during the night - the fluctuations can be seen in the larger data spread for the 2022 September 9 data points in the lightcurve versus the 2022 September 7 data. Despite this, analysis of our observations in the R filter gives a rotational period of 2.261 ± 0.002 h, which is in excellent agreement with published results. Removing the 2022 September 9 data, on the other hand, gives a significantly worse solution.



Number	Name	yyyy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
65803	Didymos	2022 09/06-09/09	29.1,31.7	349.1	-18.2	2.261	0.002	0.10	0.01	NEA
86829	2000 GR146	2022 09/06	22.7	322.4	-21.8	3.49	0.43	0.11	0.04	NEA
161989	Cacus	2022 09/08-09/09	55.4,54.8	4.1	-26.1	3.74	0.01	1.32	0.02	NEA

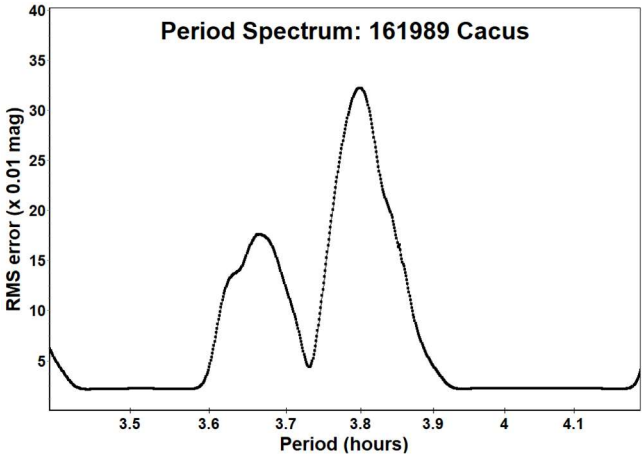
Table I. Observing circumstances and results. The phase angle is given for the first and last date. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

(86829) 2000 GR146 is an Apollo asteroid discovered on 2000 April 12 by LINEAR at Socorro, New Mexico. We took 35 images of (86829) 2000 GR146 in the V filter at an exposure time of 180 s early in the night of 2022 September 6. This asteroid has a published period of 3.0996 ± 0.0001 h (Pravec, 2007web). Using our data, we calculated a period of 3.49 ± 0.43 h, which does not overlap the published period, but comes close. Due to the small number of images that we obtained for the asteroid, as well as the fact that we were not able to observe a full rotational period, our calculated period has a significant uncertainty; many more observations would have been required to obtain a good period solution. As such, we believe the actual significant error in our period to be larger than reported by *MPO Canopus*.

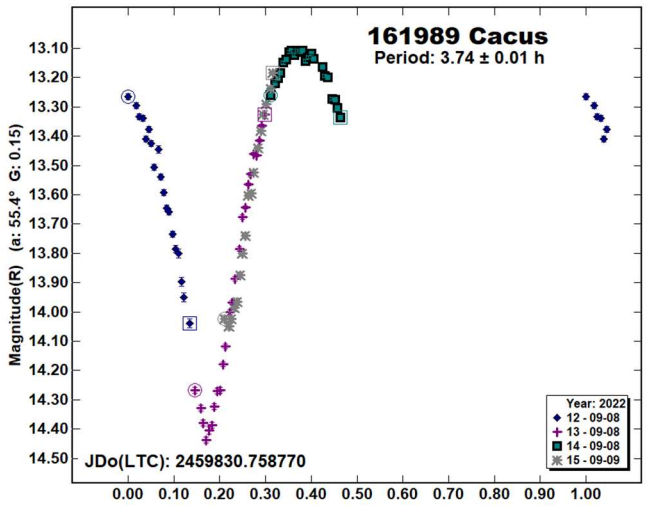


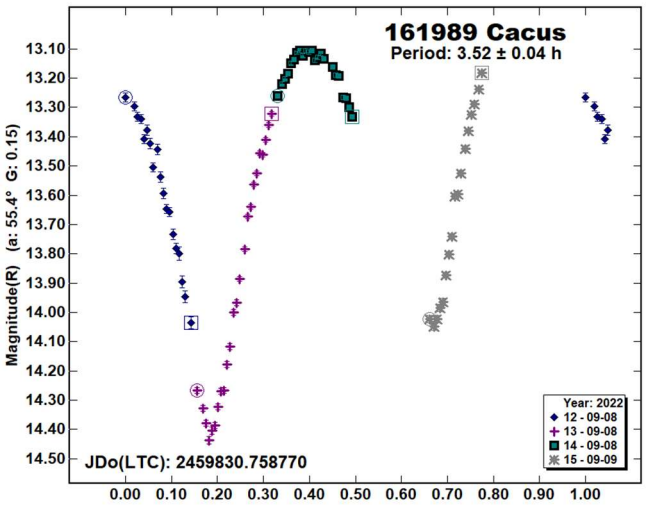
161989 Cacus is a potentially-hazardous Apollo asteroid initially discovered by German astronomer Hans-Emil Schuster at La Silla Observatory on 1978 February 8. We took 83 images of 161989 Cacus over the nights of 2022 September 8 and 9 in the R filter. Given its fast rate of in-sky motion and its comparative brightness in R, we took 15-s exposures, which we discovered was enough to get a significant signal while maintaining non-stretched, circular apertures. This asteroid has a published period of 3.7538 ± 0.0019 h (Pravec, 2003web).

The observing conditions on the nights we observed Cacus were far from ideal. On 2022 November 8, the humidity rose above 60% for almost the entire night; in fact, it went beyond the operational telescope limit of 80% for a couple of hours. This forced us to close the dome during that time, which prevented us from observing Cacus' full rotational period. As such, the seeing fluctuated at values consistently above 2.0 arcsec during that night. On 2022 November 9, the moon was nearly full, which also contributed to less-than-ideal conditions. Despite this, we were able to do good enough photometry that *MPO Canopus* reports confidently small error bars in its results.



Analysis of the period spectrum given by *MPO Canopus* for our data shows wide minima that peak at 3.52 h and 4.00 h, with an additional minimum at an intermediate value of 3.74 h. The software calculates this minimum as a less likely fit than the other two, but comparing it with published periods from prior results (Degewij, 1978; Pravec, 2003web; Koehn, 2014), it would seem this minimum matches prior reported rotational periods for the asteroid. We present lightcurves for both the 3.52 ± 0.04 h solution and the 3.74 ± 0.01 h solution for the purposes of comparison. Looking at these lightcurves, if the 3.74 h solution is indeed the right one (it comes closest to matching previous results for the asteroid), then a significant portion of the asteroid's rotational period was missed. As such, we note that a larger number of observations on nights with better seeing would have given us a more complete solution, and once again state that we believe the actual error in period to be larger than that reported by *MPO Canopus*.





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