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PHOTOMETRY AND LIGHTCURVE ANALYSIS OF 7 MAIN-BELT ASTEROIDS

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ABSTRACT

We report the synodic periods and lightcurves for three main-belt asteroids and provide lightcurves for four other main-belt asteroids. 676 Melitta has a period of 8.35 ± 0.05 hours, with an amplitude of 0.056 ± 0.026 magnitude; 688 Melanie has a period of 16.10 ± 0.05 hours, and an amplitude of 0.091 ± 0.019 magnitude; 1677 Tycho Brahe has a period of 3.89 ± 0.06 hours, and an amplitude of 0.564 ± 0.011 magnitude.

Subject headings: asteroids: lightcurve, photometry, 676 Melitta, 688 Melanie, 1677 Tycho

1. INTRODUCTION

The history and evolution of asteroids has long been analyzed to extract information about the Solar System. A particularly useful resource for asteroid comprehension is its lightcurve. We presently know that most asteroids are not perfectly spherical; in fact, most of them could be described as tri-axial ellipsoids or, in ordinary language, potato-shaped. If an asteroid is spinning and reflecting light towards the observer, we expect variations in the amount of light reflected as it rotates. When these variations of light are plotted against time, we can detect a sinusoidal curve, hereinafter referred to as a lightcurve.

From lightcurve analysis, we can determine the period of rotation of an asteroid, as well as the ratio between its longest and smallest faces, which is obtained from the amplitude of the lightcurve. From the great number of lightcurves presently available, we can say that the most common shape is a bimodal curve, with two minima and two maxima, but this is not always the case. Some lightcurves have been found to have 3 or 4 maxima and minima, and there are also cases where there is just one peak and one trough (Warner 2006). These variations in lightcurve modes are often due to albedo properties of the asteroids, irregular shapes, or even smaller satellites orbiting the body, making the period determination a more complicated process. From lightcurve analysis we can also obtain valuable information to determine its shape. Although this is outside the scope of this paper, this is one of the reasons we collect and study lightcurves. With higher quality lightcurves at different phase angles, one can invert the process to determine the shape (Harris & Pravec 2006) and spin pole orientation. With such information, it is possible to analyze shape changes, match spectra anomalies with the location on the asteroid, and study its collisional evolution.

Our understanding of asteroid rotation rates can be helpful in working back to the formation and evolution of the Solar System. Sizes of asteroids and their inherent periods help point out differences and anomalies that require justification. Possible explanations for such anomalies include radiation pressure effects and interaction with other bodies, either through collision or gravitational influence (Pravec et al. 2002).

The study of asteroid lightcurves is an international effort to gather as much information as possible. It is crucial in some cases to have access to as much data as available (e.g., light curves at various phase angles, the Sun-target-observer angle).

2. OBSERVATIONS & REDUCTION METHOD

Data was obtained from observations conducted at Kitt Peak National Observatory in Arizona with the f/7.5 SARA North (0.9-m) telescope, and the f/13.5 SARA South (0.6-m) telescope at the Cerro Tololo Inter-American Observatory, in Chile. Camera specifications can be found in Table 1. The dates of the observations range from 2006-2012, and the filters used were either Johnson R or Bessel R. Exposure times vary from 30-240 seconds, depending on the asteroid's magnitude, comparison stars, and signal-to-noise ratio.

Raw data was reduced using Mira Pro 6. This software was also used to do differential photometry on the processed images to analyze the light variations of an asteroid when compared to 4-5 background stars. Comparison stars' magnitudes were found using the USNO-A2.0 Catalogue (Monet et al. 1998) through the VizieR service. Some websites that were useful when finding the asteroids and comparison stars can be found in the references section, including VizieR, JPL Horizons, Lowell Observatory ASTFINDER, SkyView Virtual Observatory, and Small Bodies Node Data Ferret. The information obtained from the photometry session on Mira Pro 6 was then organized and analyzed in Excel. The periods of rotation of the asteroids were found using Brian Warner's MPO Canopus software. The ephemerides were generated in the JPL Horizons system website.

Some data points were removed after careful analysis. Reasons for this choice include the asteroid passing in front or near another star, presence of hot pixels in the annuli of comparison stars, meteors or satellites in the

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TABLE 1
CAMERA INFORMATION

Telescope	Camera	Gain	Readout Noise (e^-)
SARA North	U42	1.2	6.3
SARA South	QSI	0.46	12.4
SARA South	Alta_E6	1.5	8.9

field, cloud coverage during part of the run or refocusing of the telescope.

3. RESULTS

A total of 7 asteroids were analyzed: 293 Brasilia, 676 Melitta, 688 Melanie, 1183 Jutta, 1490 Limpopo, 1677 Tycho Brahe, and 3156 Ellington. Suggested synodic rotation periods for three of these are proposed and summarized in Table 2. The RMS column refers to the root mean square dispersion in units of 0.01magnitude. This unit is the a priori estimated uncertainty (i.e. 1.0 means the fit is exactly as good as the estimated noise level (Warner 1999)). Periods for some of the other four asteroids will be discussed but not reported as a result since the lightcurves for these were too noisy or not enough data was available to make a good estimate.

3.1. *676 Melitta*

For the determination of 676 Melitta's period, data sets from four different UT dates in 2012 were analyzed: June 10, 12, 13, and 30, at phase angles 7.2, 7.5, 7.7, and 11.9 degrees, respectively. Exposure times vary from 30 to 60 seconds. Clark & Joyce (2003) report a period of 7.870 ± 0.003 hours, which can be found in Behrend (2012), the Observatoire de Genevè lightcurve data base. Our results agree with those previously found (See Figure 1).

3.2. *688 Melanie*

For this asteroid we used data from UT dates July 22, 2006, September 21, 2011 and October 4, 2011, with phase angles of 15.7, 2.3, and 8.9 degrees, respectively. Exposures used were 30, 120, and 200 seconds. Observations by Bernasconi in 2005 and Roy in 2011 reported by Behrend (2012) yield a period of 19.97 ± 0.41 hours. Stephens (2012) suggests a period of 18.87 ± 0.01 hours. Even though we were able to reproduce similar results from our lightcurve, we found that the RMS values were smaller for our reported period of 16.10 ± 0.05 hours. Another period that also produced small RMS values was 14.74 ± 0.05 hours. Aliasing, which is described in the discussion section, may be an issue in the determination of this asteroid's period (See Figure 2).

3.3. *1677 Tycho Brahe*

We observed 1677 Tycho Brahe on two separate occasions, June 16 and July 13, 2012. The phase angles were 10.8 and 15.3 degrees, respectively. For the final determination of Tycho Brahe's period, we only used the data from the July 13 run, giving a result of 3.89 ± 0.06 hours. It is relevant to note that 30 second exposures were used for the first half of the run and 120 second exposures were used for the second half of the run, that is why part of the plot appears somewhat noisier. The data obtained on June 16 were extremely noisy and doubled the RMS values when plotted together with the other data set on MPO Canopus. Considering we followed the target for nearly 5 hours and, assuming a bimodal curve, we can corroborate the period of 3.89 ± 0.06 hours from the raw plot of magnitude difference versus time. To the best of our knowledge, no previous period has been proposed for this asteroid (Harris et. al 2011)(See Figure 3).

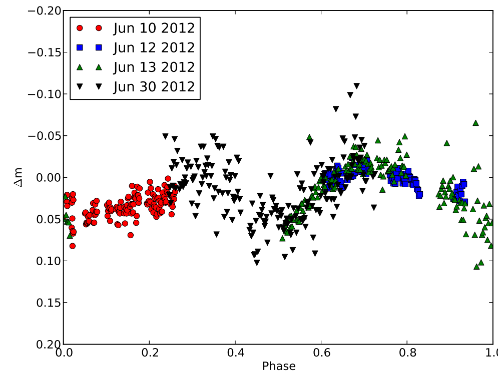

FIG. 1.— 676 Melitta, P=8.35 h

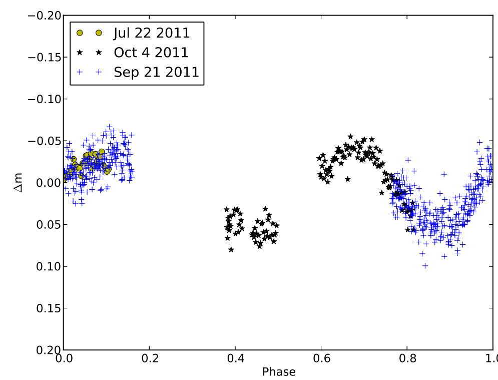

FIG. 2.— 688 Melanie, P=16.10 h

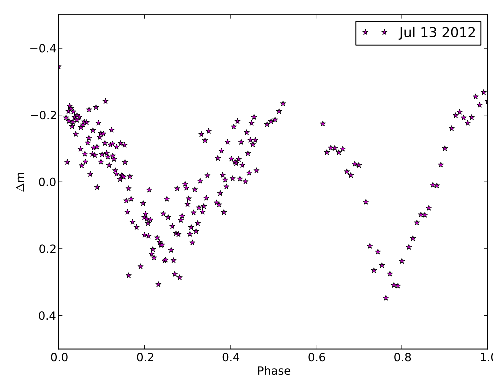

FIG. 3.— 1677 Tycho Brahe, P=3.89 h

3.4. *Other asteroids analyzed*

Data for four more asteroids were reduced and analyzed following the same process but the final lightcurves

TABLE 2
Results

Name and Number	Period *hrs*	Time on target *hrs*	Amplitude *magnitude*	RMS
676 Melitta	8.35 ± 0.05	13.18	0.056 ± 0.026	2.03
688 Melanie	16.10 ± 0.05	13.92	0.091 ± 0.019	1.70
1677 Tycho Brahe	3.89 ± 0.06	4.66	0.564 ± 0.011	6.72

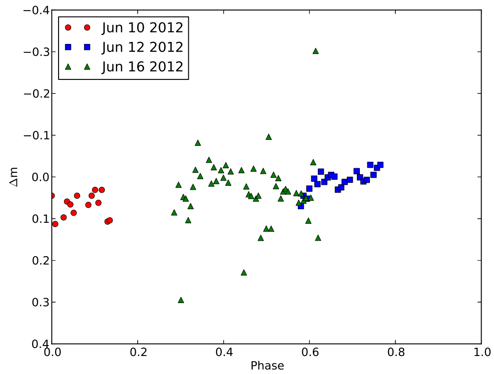

Fig. 4.— 1490 Limpopo, P=6.43 h

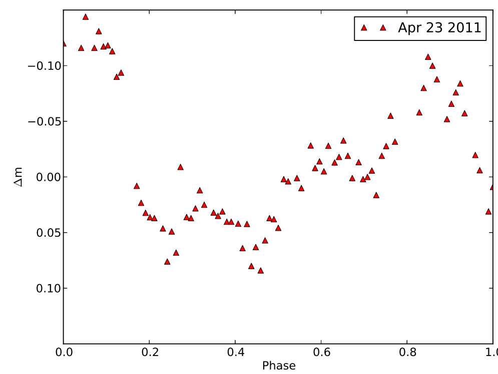

Fig. 5.— 3156 Ellington, P=7.37 h

were too noisy to make an accurate approximation of their periods. Asteroids included in this category are 1490 Limpopo, 3156 Ellington, 1183 Jutta, and 293 Brasilia.

1490 Limpopo was observed for a total of 4.2 hours distributed between June 10, 12, and 16, 2012. When the data sets were combined on MPO Canopus, there was no evident realistic period. Moreover, when the individual raw data was plotted, no obvious familiar lightcurves were produced. Figure 4 shows the phased plot from MPO Canopus with a period similar to the one reported by Behrend (2012), from observations by Bernasconi in 2005.

3156 Ellington was observed on April 23, 2011, for almost seven hours. A subtle set of minima and maxima are observable but when compared to the previous result of 12.48 hours reported by Behrend (2012), with observations by Crippa & Manzini in 2006. It is quite probable that our data is just noise and would need to be followed for a longer period of time and a better SNR in order to make a reasonable approximation. Nevertheless, the period found for 3156 Ellington was 7.37 ± 0.2 hours, assuming four maxima and four minima per rotation (See Figure 5).

1183 Jutta was observed in February and March of 2011, covering a span of six hours, but the data is extremely noisy as well. From observations by Antonini in 2011, Behrend (2012) reports a period of 36 hours, which is extremely difficult to confirm, and in our case, the data does not favor any particular result. Figure 6 is a phased plot of the March 13 data with a period of 5.20 ± 0.15 hours, but these results are not supported by any evidence.

293 Brasilia was only observed for less than an hour on July 13, 2012. Observations were limited because of poor seeing and equipment problems. Figure 7 is a raw plot of the differential magnitude versus modified julian date covering the hour of observations.

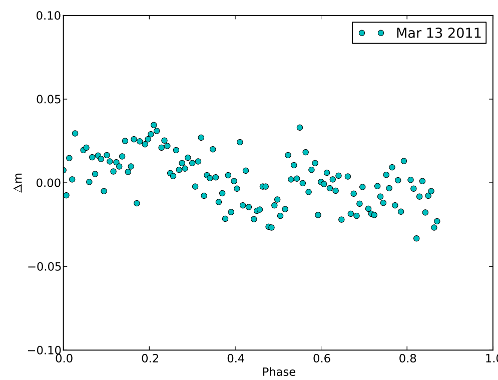

Fig. 6.— 1183 Jutta

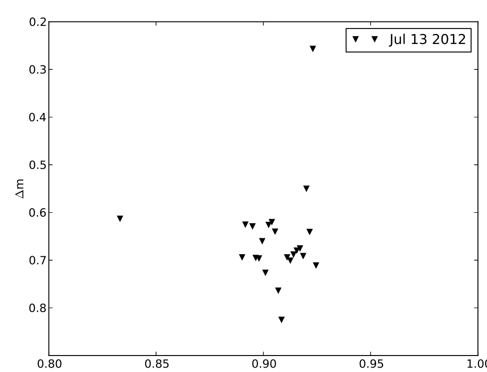

Fig. 7.— 293 Brasilia

4. DISCUSSION

The process of analyzing asteroid lightcurves has several limitations which will be discussed in this section. Most asteroids have rotation periods between 4 and 16 hours (de Pater & Lissauer 2007). Harris & Pravec (2006) state that the spin rates of bodies larger than ∼50 km in diameter can be fit by a Maxwellian distribution. Smaller asteroids can be both slow or fast rotators, but bodies smaller than a few hundred meters in diameter have been found to rotate at a rate faster than the "spin barrier," leading one to believe that they are monoliths instead of "rubble piles." Harris & Pravec (2006) help set the ranges and, sometimes, limits of asteroid rotation periods, but there is no absolute boundary on these standards.

One complication that arises when finding periods of rotation by fitting curves, is the possibility of encountering more than two maxima and two minima per complete rotation. Warner (2006) presents a few examples of asteroids with curves different than the "normal" bimodal curve (e.g., 3155 Lee). It is reasonable to begin searching for a period by assuming a bimodal curve, but this should not dictate the final result.

Another inherent problem when finding periods from lightcurves is aliasing. An alias for a period is another period that fits the data apparently well, but is incorrect. This happens when the interval between observations is an even or half multiple of the period, so we are most likely looking at the same part of the lightcurve each night (Warner 2006). Aliasing also emerges when the curve is symmetrical and the time between observations is a half-multiple of the period. Warner (2006) suggests plotting the half-period to eliminate some aliases. If the result is a monomodal curve, then the initial period has a good probability of being the correct one. Aliasing is almost never a problem when the target is observed for more than a complete rotation.

One of the major problems we encountered when analyzing our data was the lack of observation time for some of the asteroids (i.e., 1490 Limpopo, 3156 Ellington, 1183 Jutta, and 293 Brasilia). If the asteroid has an unusually long period, the difficulty increases. In the case of 1183 Jutta, the period reported on Behrend (2012) is 36 hours. With such long periods, it is extremely difficult to obtain a lightcurve that covers most of its rotation. This is also a problem when not enough time per night is available for analysis, when the noise may be mistaken for a peak or trough of a lightcurve. The determination of the amplitude is a slightly imperfect process. The method used in this paper was that described by Warner (2006). We averaged the set of points near the maxima and minima and took the difference, and used the formula

$$Error_{total} = \sqrt{(Error1)^2 + (Error2)^2} \quad (1)$$

to find the error, where Error1 and Error2 are the standard deviations of the sample. Another complication that seldom arises is called the YORP (Yarkovsky-O'Keefe-Radzievskii-Paddack) effect. This is a process where the spin rate of small asteroids can change by the absorption and re-radiation of heat from the Sun (Holsapple 2010). The YORP effect is a very slow and subtle process. Lowry et al. (2007) predict a change of less than a minute in the period of the near-Earth asteroid (54509) 2000 PH5 over the span of 10-100 My. This effect does not directly affect period determinations but it may be helpful in explaining the evolutional history or future of some of the smaller asteroids.

5. CONCLUSION

The periods for the asteroids 676 Melitta, 688 Melanie, and 1677 Tycho Brahe are proposed in this paper. Four other asteroids were observed but insufficient information was obtained to make an accurate estimate from the lightcurves. It is of vast importance that this does not discourage further work on these bodies. Indeed, this paper should stimulate further continuation in the acquisition of lightcurves for completion and accurate estimate of these and other asteroids' periods.

The study of asteroid history and evolution is of great significance to the understanding of the Solar System. The determination of a body's rotational period has its complications as discussed in the previous section but, with enough observations and international collaboration, precision and improvements in data gathering and processing can easily be achieved.

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