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PARTIAL ASTEROID LIGHTCURVES FROM JANUARY 2005 AND JUNE 2006

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ABSTRACT

We present partial lightcurve data for asteroids 252 Clementina, 329 Svea, 334 Chicago, 392 Wilhelmina, 596 Scheila, 517 Edith, 521 Brixia, and 713 Luscinia. Data for Clementina, Scheila, Edith and Svea were taken in 2005 Jan 5-6. Data for Chicago, Wilhelmina, Brixia and Luscinia were taken over a four day run in 2006 June 15-18.
Subject headings: Asteroids

1. INTRODUCTION

The shape, magnitude and rotation period of many asteroids are not well known. The purpose of these observations was to collect data on such asteroids in order to create lightcurve fragments. These fragments can then be used to verify the findings of other researchers in order to more accurately determine the characteristics of said asteroids. It is the hope of the observers that the lightcurve fragments presented in this paper may be used in conjunction with past and future observations in order to produce complete lightcurves for these bodies and thereby determine definite rotational periods for them.

2. METHOD AND MATERIALS

These asteroids were chosen because their periods were not well known and they met other criteria (C class or subclass, mid- to outer-main belt, brighter than 14.5 magnitude) pertaining to an ongoing spectroscopic survey of primitive asteroids to search for water of hydration–evidence of silicates altered by water, forming phyllosilicates (Leake et al. 2001). From the Minor Planet Observer CALL list and the Minor Planet Center Lightcurve Data list asteroids were selected when they met the criteria above and were in an optimum observing position so that they could be observed for the greatest period of time, and during optimal conditions.

The team of observers traveled to Kitt Peak National Observatory (KPNO) to obtain photometry of asteroids using the SARA 0.9-m telescope over four nights from 2006 June 15-18. Brixia was observed on the night of June 15. Data for Chicago were taken on June 16 and 17, and data for Luscinia and Wilhelmina were taken on June 18. The 2005 Jan 5-6 data were obtained using the SARA 0.9-m telescope remotely. During that run, data for Edith were collected Jan 5, data for Clementina and Scheila were gathered Jan 6, and data for Svea were taken on both days. A standard Johnson *R* filter was used for all observations. All finder charts were derived from Lowell Observatory Asteroid Data Services ASTFINDER routine.

Various CCD cameras were used with the SARA 0.9-m telescope at KPNO over the period of observations during 2005 to 2006. The camera used for each set of data is listed in Table 1. The images and imaging conditions were stored in fits files by the software program MaxIm DL. Exposures varied from 30 seconds to 300 seconds to reach acceptable signal to noise without saturation.

The Apogee Alta U42, Apogee AP7p and the Finger Lakes cameras were used during these observations. The different characteristics that affect images produced by each camera can be seen in Table 2. The observers treated images produced by each camera in a different way to account for these variations.

All data processed for this paper were reduced with the analysis software MIRA Pro 6.0. The reduction included subtraction of master bias frames and master dark frames, division by master flat frames, hot and cold pixel elimination and cosmic ray removal, followed by aperture photometry. Right ascension and declination coordinates for each asteroid were entered into Lowell Observatory Asteroid Data Services REFNET to find red filter magnitude values of selected stars from the USNO-A2.0 Catalog in the field (available through `asteroid.lowell.edu`). These stars, called "reference field stars" hereafter, were tested for variability and stability each night. Red magnitudes of up to eight reference field stars were entered into the aperture photometry option of MIRA, yielding magnitudes of the asteroid and the stars in the field (after sky subtraction). Once selected, the same reference field stars were used during that asteroid's data set. The results were plotted for each asteroid in the form of differential magnitude. Differential magnitude calculated in this paper is defined as the difference of the magnitude value of the asteroid from the averaged value of standard stars. In the graphs that follow, increases in this difference indicate a brighter asteroid.

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TABLE 1
OBSERVATION PARAMETERS

#	Name	Observed (JD)	Duration (UT)	Camera	RA	DEC	Phase Angle[a]
252	Clementina	2453376	08:35:20 - 10:01:09	Apogee AP7	$7^h\ 57^m$	06° 14’	6.1°
329	Svea	2453376	09:43:06 - 13:07:10	Apogee AP7	$12^h\ 33^m$	-07° 37’	23.6°
329	Svea	2453377	10:53:55 - 12:43:50	Apogee AP7	$12^h\ 34^m$	-07° 39’	23.5°
334	Chicago	2453903	06:11:00 - 10:44:56	Finger Lakes	$18^h\ 28^m$	-19° 32’	3.0°
334	Chicago	2453904	07:50:42 - 10:59:40	Finger Lakes	$18^h\ 27^m$	-19° 33’	2.7°
392	Wilhelmina	2453905	07:56:44 - 10:27:42	Finger Lakes	$21^h\ 29^m$	04° 55’	19.0°
517	Edith	2453377	04:39:57 - 09:26:23	Apogee AP7	$5^h\ 03^m$	23° 26’	10.5°
521	Brixia	2453902	04:59:07 - 08:44:44	Apogee Alta	$4^h\ 29^m$	-17° 26’	5.2°
596	Scheila	2453377	02:56:53 - 08:13:57	Apogee AP7	$4^h\ 02^m$	21° 53’	11.4°
713	Luscinia	2453905	03:53:42 - 07:31:18	Finger Lakes	$15^h\ 50^m$	-13° 07’	8.6°

[a]Phase Angle computed using Minor Planet & Comet Ephemeris Service.

TABLE 2
CHARACTERISTICS OF CCD EQUIPMENT USED.

CCD Type	Gain (e-/ADU)	Read Noise (e-)	Full Well Depth (K e-)	Bias Setting (ADU)	Dark Count (e/p/s)
AP7p	6.1	12.2	368	5200	2.7
Apogee Alta U-42	1.2	10.4	80	1108	0.39
Finger Lakes	3.5	< 12	350	18000	< 1

The reduction software MIRA computes a theoretical and an empirical error estimate; the empirical 1-sigma estimate was used for the error bars in the data displayed here. The increased size of error bars typically occurred in fields that were somewhat saturated in stars. The program increased the error bars near contaminating stars and decreased near empty regions of space as expected. The observers would like to re-analyze these data using IRAF to compare the results with the MIRA program, to understand the MIRA “empirical” error, and to correct asteroid magnitude in crowded star fields (see Section III).

3. RESULTS

Physical data for the asteroids observed are presented in Table 3. Note that most of these asteroids are C-class, low albedo, and large (>40 km). The “reliability code” for the published rotation periods varies from a quite unreliable “1” for 392 Wilhelmina and 521 Brixia to a “secure” “3” for 329 Svea (Pray 2006). All others are “2”, indicating some ambiguity in the period because of incomplete coverage (Minor Planet Center Lightcurve Data 2006).

The asteroid 252 Clementina was observed on 2006 Jan 6 for 1.5 hours. The data show an amplitude of 0.15 magnitudes (Figure 1). Assuming that over the 1.5 hours one sees a decrease from maximum to minimum brightness, the period for this body is at least 7.5 hours. No published rotational period could be found for this asteroid. Somewhat similar (and enigmatic) light curve fragments for Clementina were collected in 2002 (Jeffery & Leake 2002). Observations are therefore needed for longer periods of time in order to better determine the rotational period for 252 Clementina.

The asteroid 329 Svea was observed 2005 Jan 5–6. On the first night it was observed for 3.5 hours (Figure 2) and on the second night it was observed for an additional 1.5 hours (Figure 3).

Figure 4 is a lightcurve created from both nights of data.

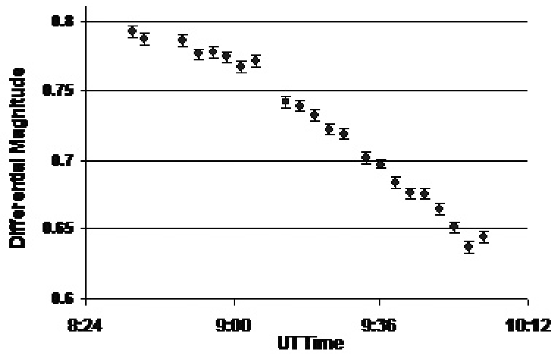

FIG. 1.— Differential magnitude versus time for 252 Clementina.

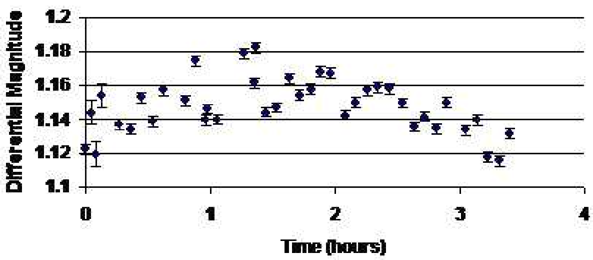

FIG. 2.— Differential magnitude versus time for 329 Svea on 2005 Jan 5.

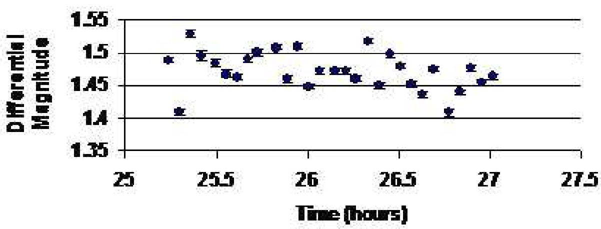

FIG. 3.— Differential magnitude versus time for 329 Svea on 2005 Jan 6.

With a published period of 15.201 hours (Harris et al. 2006), it is apparent that a large portion of this lightcurve is missing between the times of the two observations, and only about one-third of the period has been covered here. Amplitudes of Svea’s light curve fragments are consistent with the pub-

TABLE 3
PUBLISHED DATA FOR THE ASTEROIDS OBSERVED.

Number	Name	Type[a]	Diameter[b] (km)	Rotation[b] Period (hr)	Amplitude[b] (mag.)	Albedo[a]
252	Clementina	??	69.29			0.08
329	Svea	C	77.8	15.201	0.09-0.26	0.04
334	Chicago	C	155.82	7.35	0.15-0.67	0.06
392	Wilhelmina	C	62.88	8.54	0.11	0.06
517	Edith	X	91.2	9.274	0.12-0.18	0.04
521	Brixia	C	115.65	>24	>0.09	0.06
596	Scheila	PCD	113.34	15.848	0.09	0.04
713	Luscinia	C	105.52	8.28	0.21	0.04

[a]Data taken from the Small Bodies Data Base
[b]Data taken from the Minor Planet Center Lightcurve Data

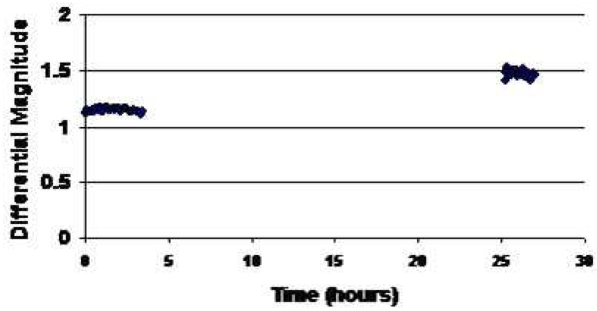

FIG. 4.— Differential magnitude for 329 Svea over 30 hour period.

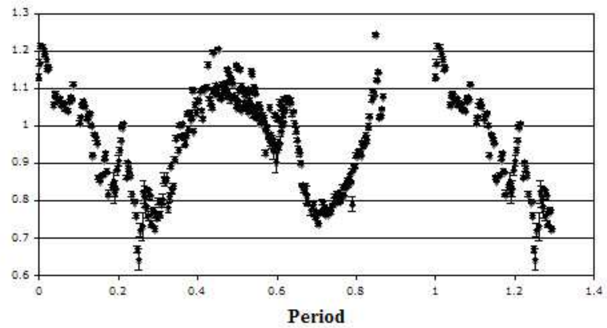

FIG. 5.— Differential magnitude (vertical axis) versus period for 334 Chicago. These results reflect all data points taken over two days for Chicago including those that are contaminated by background stars.

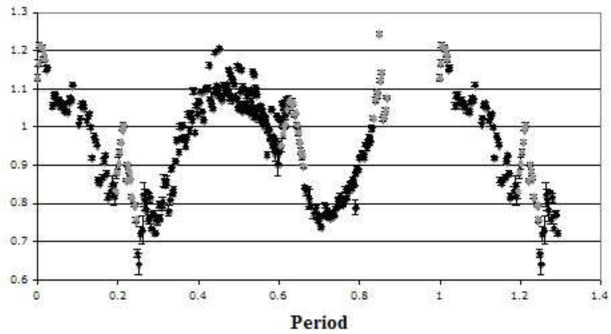

FIG. 6.— Differential magnitude (vertical axis) versus period for 334 Chicago. These results reflect the non-contaminated data represented in black and the contaminated data in gray. Each data point is a representation of a 30 second exposure of Chicago.

lished values (Table 3). Since different reference field stars were used to determine the magnitude of the asteroids on each night, it is not possible to determine how bright the magnitudes on the second day are relative to the first day. The observers would like to perform more observations on this asteroid in order to better fit together these two nights of data, and apply the techniques used in the Chicago observations noted below.

Chicago was observed over consecutive nights 2006 Jun 16 and 17. The first night resulted in nearly 4.5 hours of data, while the second night resulted in slightly over 3 hours of observation. All observations were exposed for 30 seconds with a high signal to noise ratio. The observations represent a lightcurve of Chicago near the phase angle of 3 degrees. Given the published 7.35 h period, the data span about 87% of a complete curve (Hartmann et al. 1988, Harris et al. 2006; Behrend et al. 2006).

The Chicago data were analyzed using a technique that allowed for a standardization of differential magnitude. The observers were aware that the asteroid would be imaged for multiple nights, thus imaged additional fields ahead of time to keep track of the motion of the asteroid for the following night. Reference field stars from the first night were applied to the additional fields to measure the magnitudes of new field stars from the second night. The magnitudes were used to obtain the value representing the magnitude of the asteroid over the two nights. The process resulted in a relative magnitude that matched differentially, without an unknown differential magnitude offset between the data obtained from the two nights.

The observers obtained results that are consistent with the 7.35 hour rotational period. To determine the rotational phase, the initial data point on the first night was set as the zero point for the periodic lightcurve. The remainder of the data taken on the first night was assumed to have the period stated above. The UT time for each point was then subtracted by the initial zero point and was then divided by the value of the period to derive the estimated rotational phase. The second night required adding 24 hours to the UT time, then subtracting out the periods that had passed during the day. The data from the second night was then divided by the accepted period. The overall result is provided above in the graph of Chicago (Figure 5). It is easily seen that the data points match over the two nights and show the two maxima and two minima often expected over a full rotation of an asteroid. The matching of photometric data points over the various nights provides reason to believe that the period has been reconfirmed and matches the results published by Harris et al. (2006) and the Small Bodies Data Base.

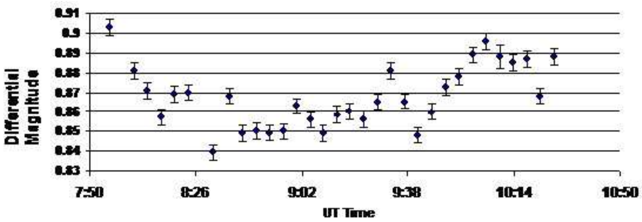

FIG. 7.— Differential magnitude (vertical) versus time for 392 Wilhelmina.

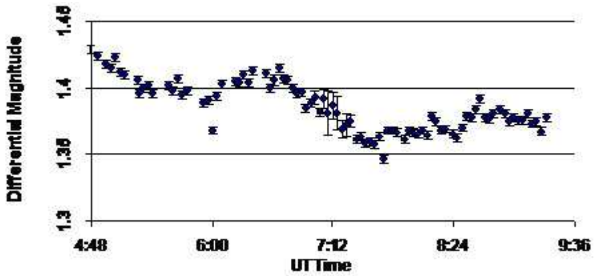

FIG. 8.— Differential magnitude (vertical) versus time for 517 Edith.

The noise in the data may be a reflection of the crowded star field or the inclusion of somewhat variable reference field stars. The empirical error bars are smaller than the observed noise. The reference field stars were plotted against UT time to determine the fluctuation in magnitude to justify that variable stars were not used to determine the differential magnitude of the asteroid. Indeed, two of these stars were noisy, possibly accounting for some of the observed "asteroid" noise.

The overall results are a nearly complete lightcurve for Chicago. Though the final 13 percent is missing, there appear to be no extreme fluctuations prior to that gap and it appears to be safe to infer it reaches a maximum in that area. Data on 334 Chicago from observers at Ob. Geneva (Behrend et al. 2006) support that conclusion. The lightcurve is extremely well defined except for a few regions that were influenced by background stars. During the motion of Chicago across an extremely star-saturated field, the asteroid passed in front of stars. The results produced from the program MIRA would not allow the observers to reject the additional light introduced by the background stars, except when they were within the sky annulus. The contaminated data points have been displayed in gray on Figure 6 to distinguish them from the asteroid data. Currently the stellar points (appearing to be a typical point spread function) should be ignored and the remainder of the curve can be inferred with a strong sense of reliability. In the future, the observers desire to re-reduce the data using IRAF and DAOPHOT to remove the stellar point spread functions from the light curve. Re-reducing the data will provide a more reliable lightcurve that will result in missing no more than 13% the complete lightcurve for 334 Chicago.

Asteroid 392 Wilhelmina was observed for 2.5 hours on 2006 Jun 18 (Figure 7). The lightcurve fragment covers about one-third the published period of 8.54 hours and spans over half the published amplitude (Table 3). It is possible that this fragment displays a minimum of this lightcurve, however longer duration observations are needed to confirm that assumption.

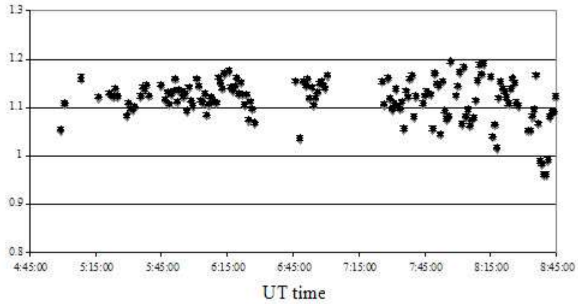

FIG. 9.— Differential magnitude (vertical) versus time for 521 Brixia.

Edith has a recently published rotation period of 9.274 hours (Table 3) which is not reflected in the 2005 Jan 6 fragment presented here (but see Harris 1992). Data from Behrend et al. (2006) show a lightcurve in which the two peaks and two troughs reach approximately the same maximum and minimum magnitude, respectively. The lightcurve constructed from data presented here demonstrates a staggered decrease in magnitude over 4.75 hours time, over half the published period (Figure 8). This variation may be due to a phase angle difference between the two data sets. It is also possible that the first minimum as well as the portion of the lightcurve at 7:12:00 may be affected by stars in the asteroid's path. The observers intend to use the IRAF program in the future in order to eliminate the effects of these stars.

Brixia was observed for a single night on 2006 Jun 15. The overall data points represent about 3 hours of observations of 30 second exposures, with some gaps in the curve (Figure 9). The asteroid is believed to have a period greater than 24 hours, which would require multiple nights of observation to complete the asteroid's lightcurve (Surdej et al. 1983).

The overall results for Brixia show fluctuations of 0.1 to 0.2 magnitudes in amplitude over three hours, giving a noisy, but relatively flat, lightcurve. The reference field stars used to calculate the magnitude of Brixia also showed variations up to 0.1 magnitudes over time. These field stars were, by necessity, fainter than the bright asteroid, and had lower signal to noise. The lack of ability to image the fainter stars without saturating Brixia could have led to the noisy lightcurve. Therefore, the results for Brixia should be used cautiously. Due to the variations in noise produced by the reference field stars, the observers hope to re-process this data using IRAF as well.

Whether or not there is a slight trend to the lightcurve fragment (say, reaching a maximum) is problematical. The maximum differential amplitude variation also appears to be roughly 0.25 for this part of the lightcurve. The asteroid should be imaged for a longer duration of time, perhaps from observatories at widely separated longitudes, over several days. The asteroid should be observed for long enough to determine physical characteristics because of its unusually long period of rotation.

Scheila is one of the asteroids observed 2005 Jan 5. It was observed over a span of 6 hours; however approximately 2 hours were rejected due to clouds (Figure 10). The published period for this asteroid is 15.848 hours (Table 3), although other periods have been mentioned by observers of the Ob. Geneve (Behrend et al. 2006). Using the 15.8 hour period, it is expected that the lightcurve created from this data would show between one third and one half of the curve. Without the missing data it is unclear how the magnitude changes over that period of time. Note also the small amplitude of the lightcurve

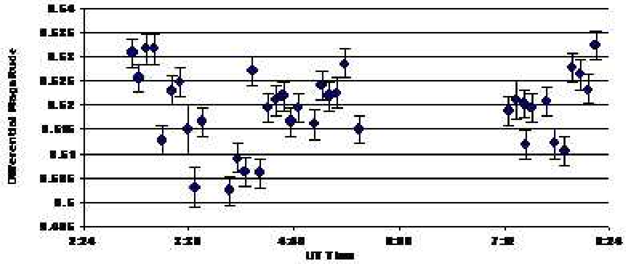

FIG. 10.— Differential magnitude (vertical) versus time for 596 Scheila.

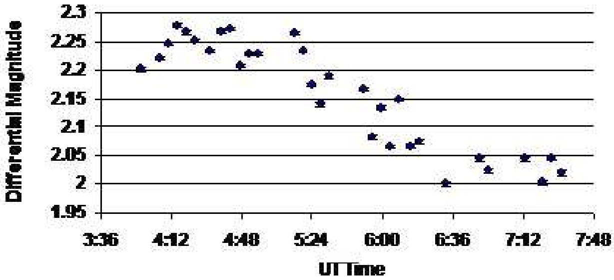

FIG. 11.— Differential magnitude (vertical) versus time for 713 Luscinia.

fragment; it is consistent with the published 0.09-magnitude value (Table 3). It is recommended that further observations be obtained.

The asteroid 713 Luscinia was observed for a 3.6 hour period on 2006 Jun 18. The lightcurve (Figure 11) appears to displays a nicely defined maximum and minimum over approximately 1.8 to 2.5 hours, implying a period of 7.2 to 10 hours, in rough agreement with the published value of 8.28 hours (Table 3). In the fragment above, brightness varies by approximately 0.28 magnitudes.

4. CONCLUSIONS

The periodicity and amplitude of the lightcurve fragments presented here help constrain the determination of rotation rate, and ultimately, shape and orientation of eight asteroids. Because the data are fragmentary, they are not definitive and are incomplete. More observations, over consecutive nights and for a longer duration each night, are needed to better characterize the lightcurves of these asteroids, especially those with apparently longer rotation periods (252 Clementina, 329 Svea, 521 Brixia, and 596 Scheila) and those with small lightcurve amplitudes (all). Observations stretching over more than one night can be accurately pieced together by examining the fields of view that the asteroid will pass through in advance. This process as shown by the observations made on 334 Chicago provides the ability for an observer to link together multiple nights when checking the accuracy of a specific rotational period. We recommend some coordinated observing campaigns at observatories at different longitudes (for instance, at the SARA observatories and those of REU participants) to achieve these goals. Finally, data reduction techniques which enable the observer to reject light from stars in the asteroid's path are desirable.

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