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LIGHTCURVE ANALYSIS OF THE NEA BINARY ASTEROID 5381 SEKHMET

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Radar observations in 2003 (Nolan *et al.*, 2003) showed that the near-Earth asteroid (NEA) 5381 Sekhmet was a binary. CCD photometry observations made from the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) during the 2014 apparition confirmed the discovery and found the first precise values for the primary rotation period, $P_1 = 2.8233 \pm 0.0001$ h, and the orbital period of the satellite, $P_{ORB} = 12.379 \pm 0.004$ h. The estimated effective size ratio of the two bodies is $D_s/D_p \geq 0.25 \pm 0.02$, which is in good agreement with the sizes estimated by radar.

Using the Arecibo radar facility in 2003 May, Nolan *et al.* (2003) discovered that the near-Earth asteroid (NEA) 5381 Sekhmet was a binary object. Their analysis indicated sizes of 1 km and 0.3 km for the primary body and satellite, respectively. They also estimated the orbital period to be on the order of 12 hours, with 24 hours being less probable.

The NEA was favorably placed for optical observations in 2014 May and June, at which time CCD photometry was conducted at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS). A 0.3-m *f*/9.4 Schmidt-Cassegrain was used along with a Finger Lakes Instrumentations MicroLine-1001E operating at -30° C. The 1024x1024 array of 24-micron pixels provided a field of view of about 29.5x29.5 arcminutes and a plate scale of 1.7 arcsec/pixel. All images were guided and taken with no filter. Exposures were 120 seconds in late May and decreased to 90 seconds in June as the asteroid's sky motion increased. Dark frames and flat fields were applied in *MPO Canopus*.

Measurements were done using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* finds up to five comparison stars of near solar-color to be used in differential photometry. Catalog magnitudes were taken from the APASS catalog (Henden *et al.*, 2009) since these are derived directly from reductions based on Landolt standard fields. Period analysis was also done using *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris *et al.*, 1989).

In the lightcurve plots below, the "Reduced Magnitude" is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses, e.g., $\alpha(6.5^\circ)$, using $G = 0.15$, unless otherwise stated. The horizontal axis is the rotational phase, ranging from -0.05 to 1.05 .

Photometry Analysis

The asteroid was observed from 2014 May 23 through June 6. A total of 724 data points were used in the analysis. Since this was a known binary, an initial period search used the entire data set to find an approximate period for the primary rotation, i.e., the apparent mutual events of the satellite were not subtracted beforehand.

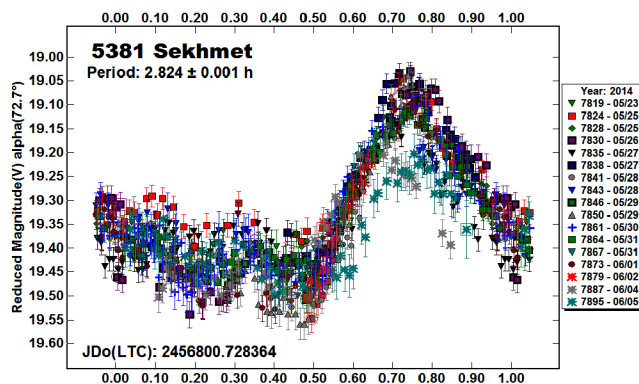


Figure 1. The lightcurve of 5381 before dual period analysis.

Figure 1 shows the lightcurve before using the dual period analysis tool in *MPO Canopus* and serves to demonstrate what would prompt the belief that the asteroid may be a binary, the fact that it was already known to be one notwithstanding. The most telling feature is that two sessions (7887 and 7895, June 4 and 5, respectively) showed distinct deviations, or attenuations, from the general curve near rotation phase 0.75. Note that satellite events *never* cause the lightcurve to be *brighter* than expected. In such a case, it's better to look for a faint field star, a variable comparison star, or some systematic cause.

Just one session with such a deviation is not enough. Two can be good cause for suspicion while three or more is better. In fact, session 7835 (May 27) does show a few data points that may also have been part of an attenuation. In addition, the general noisy nature of the lightcurve between 0.10 and 0.50 can also be a sign of a satellite event. However, this is not as strong an indicator and, in fact, noise is sometimes just noise.

Once a preliminary lightcurve, such as in Figure 1, was found, the corresponding Fourier curve was subtracted from the data and another period search in the range of 10 to 26 hours was run. This produced the initial lightcurve that included the mutual events (occultations and/or eclipses) caused by the satellite. This Fourier curve was then subtracted from the entire data set when a second search for the primary period was run. The process continued back and forth until the shape and periods of the two lightcurves stabilized.

Complicating the analysis somewhat was the very high phase angle of the asteroid during the observations ($\sim 73^\circ$). At such angles, even a nearly spheroidal body can have a large amplitude lightcurve due to shadowing effects. Furthermore, the primary's shadow projects well beyond the disc on the sky plane. This can create a very complex lightcurve for the satellite's mutual events.

Figure 2 shows the lightcurve for the primary body after subtracting the effects of the satellite. It is not the common nearly symmetrical monomodal or bimodal lightcurve seen for many binary primaries when observed at small phase angles.

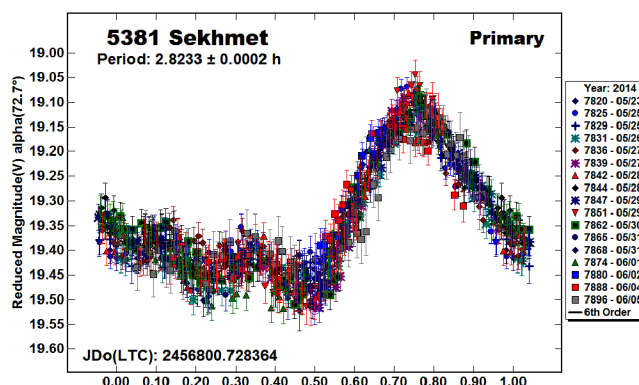


Figure 2. Primary lightcurve. The actual sky magnitude of the asteroid was $V \sim 16.7$ during the observing runs.

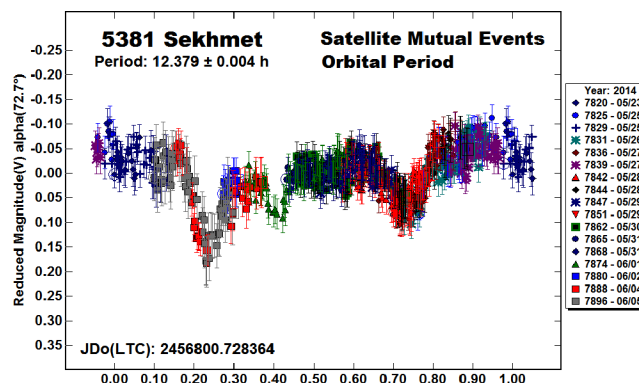


Figure 3. Lightcurve of the satellite showing the mutual events (occultations and/or eclipses). The period corresponds to the orbital period of the satellite. The magnitude zero level is the average magnitude of the primary.

Figure 3 shows the lightcurve after subtracting out the rotation of the primary, showing the mutual events and orbital period of 12.379 h. The depth of the shallower minimum can be used to estimate the ratio of the effective diameters of the two bodies. A drop of 0.07 magnitude gives $D_s/D_p \geq 0.25 \pm 0.02$. Had the event been flat-bottomed, meaning a total event, this value would have been a fixed value instead of a minimum. The derived ratio is in good agreement with the estimated diameters of the bodies from the radar observations.

The two events at 0.25 and 0.75 orbital phase (Figure 2) are likely *solar events*, eclipses involving shadows and the sun. There is a one-time event at about 0.40 phase that appears to be real and not an observing artifact. In this case, this is a *line-of-sight event*, i.e., the satellite going in front of or behind the primary as seen from the Earth.

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ASTEROIDS OBSERVED FROM CS3: 2014 APRIL - JUNE

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CCD photometric observations of 14 asteroids were obtained from the Center for Solar System Studies from 2014 April to June.

During most of this calendar quarter, the Center for Solar System Studies (CS3, MPC U81) was focusing on a study of Jovian Trojan asteroids. Many of the results described in this paper were 'Full Moon Projects,' when the moon is bright or close to the Trojan targets. Some of these targets were selected from the 'Shape/Spin Modeling Opportunities' list maintained by Josef Āurech the back of each Minor Planet Bulletin. These are targets with at least one high quality lightcurve which are not in the Database of Asteroid Models from Inversion Techniques (DAMIT). In addition, bright NEOs or Mars Crossers away from the Moon were selected for study.

All images were made with a 0.4-m or a 0.35-m SCT with a FLI-1001E or a SBIG STL-1001E CCD camera. Images were unbinned with no filter and had Master flats and darks applied to the science frames prior to measurement. Measurements were made using MPO Canopus, which employs differential aperture photometry to produce the raw data. Period analysis was done using MPO Canopus, which incorporates the Fourier analysis algorithm (FALC) developed by Harris (1989). Night-to-night calibration of the data (generally $< \pm 0.05$ mag) was done using field stars converted to approximate Cousins V magnitudes based on 2MASS J-K colors (Warner 2007). The Comp Star Selector feature in MPO Canopus was used to limit the comparison stars to near solar color.

113 Amalthea. Harris and Young (1983) observed Amalthea on 10 nights in 1979 November – December determining a period of 9.935 h with a single maxima/minima and $A = 0.19$ mag. Tungalak (2002) found a period of 9.93768 h. The synodic rotational period found this year is consistent with those results. Like in 1979, a complex curve with a single extrema was found. A period spectrum shows a 2:1 alias exists at about 20 h. However, due to the complex and repeating features in the lightcurve, I prefer the 9.950 h period.

232 Russia. With a rotational period near 24 h, it is difficult for a single station to get sufficient observations covering a complete cycle on this Inner Main Belt asteroid. Behrend (2014) reported observations from 2005 February covering about half of the phased lightcurve with a 21.7 h period. Torno et al (2008) got two nights in October 2007 covering a portion of the lightcurve and reported a period exceeding 20 h. Ruthroff (2009) observed Russia for 11 nights in 2009 January – March reporting a period of 21.91 h. This result of 21.882 h covers the complete phased lightcurve and is an improvement on those results.

402 Chloe. Results for Chloe were reported by Behrend (2014) in 2002, 2005, and 2010. The results for 2002 and 2005 were updated to agree with the 2010 findings of 10.664 h. Warner (2009) observed Chloe over 4 nights in 2009 February reporting a period