LIGHTCURVES FOR INVERSION MODEL CANDIDATES

Daniel A. Klinglesmith III, Jesse Hanowell, Curtis Alan Warren
Etscorn Campus Observatory, New Mexico Tech
101 East Road
Socorro, NM USA 87801
dklinglesmith@mro.nmt.edu

(Received: 13 June)

We present lightcurves for four inversion model candidate asteroids that will benefit from additional data at another phase angle bisector phase angle. We obtained synodic periods for each asteroid that were within ±0.002 h. Most have lightcurves that differed from previously published lightcurves in both amplitude and shape.

Observations of asteroid lightcurves were obtained at the Etscorn Campus Observatory (ECO, 2014). We used three Celestron 0.35-m Schmidt-Cassegrain telescopes (SCT) on Software Bisque Paramount ME mounts (SB, 2014). Two of the telescopes use SBIG STL-1001E CCD cameras that have 1024x1024 24-micron pixels. These provide a scale of 1.25 arcsec/pix and a 22x22 arcminute field-of-view. The third telescope uses an SBIG ST-10XME with an Optec 0.5x focal reducer. The ST-10XME is binned 2x2, giving an array of 1092x736 13.6-micron pixels. The scale is 1.28 arcsec/pix and the field-of-view is 20x16 arcminutes.

All images were obtained through clear filters. Exposure times varied between 2 and 5 minutes depending on the brightness of the object. Each evening a series of 11 dome flats were obtained and combined into a master flat with a median filter. The telescopes were controlled with Software Bisque's *TheSky 6* (SB, 2014) and the CCDs were controlled with *CCDsoft* v5 (SB, 2014). The images were flat-field corrected using image processing tools within *MPO Canopus* version 10.4.1.9 (Warner, 2014). The multi-night data sets for each asteroid were combined with the FALC routine (Harris *et. al*., 1989) within *MPO Canopus* to provide synodic periods for each asteroid.

Observed Asteroids

The four asteroids observed were taken from the list of possible inversion model candidates by Warner *et al.* (2014). All have periods less than 8 hours. This allowed us, in many cases, to obtain at least one complete cycle per observing night. The information about asteroid discovery dates and names comes from the JPL small bodies Database (JPLSBD, 2014). The list of observed asteroids is given Table I. This table contains the asteroid number, name, date range, solar phase angle, average solar bisector phase angles, period determination, period error, amplitude, and amplitude error. Table II summarizes the solar bisector phase angles of published lightcurves for these asteroids. The previously observed solar bisector phase angles were obtained from the lightcurve database (LCDB; Warner *et al.*, 2014).

446 Aeternitas is a main-belt asteroid discovered by M. Wolf and A. Schwassmann at Heidelberg on 1899 Oct 27. It is also known as 1899 ER. The original period determination was done by Florcak *et al*. (1997), who reported 15.85 h with an amplitude of 0.33 mag. Behrend (2006) published a period from P. Antonini of 15.7413 ± 0.00036 h. Fauerbach *et al*. (2008) reported a period of 15.7413 ± 0.001 h with an amplitude of 0.48 mag. Lucas *et al.* (2011) determined a period of 15.74 ± 0.003 h with an amplitude of ~0.40 mag. Lucus *et al*. (2012) presented a 3-D shape model using data from 3 apparitions (2006, 2008, and 2009). We observed 446 Aeternitas on 7 nights between 2014 May 9 and June 7. Our period of 15.745 ± 0.001 h is consistent with previous determinations. The lightcurve amplitude is 0.47 ± 0.05 mag.

502 Sigune is a main-belt asteroid discovered by M. Wolf at Heidelberg on 1903 Jan 19. It is also known as 1903 LC, 1925 AD, and 1929 EK. The first period determination was 10.5 h by Tedesco (1979). Stephens (2007) refined the period to 10.922 ± 0.002 h with an amplitude of 0.44 mag. Behrend (2001) reported the results from Rene Roy of 10.9656 h and Maurice Audejeam of 10.96416 ± 0.0002 h. We observed 502 Sigune on 8 nights between 2014 April 24 and May 16. Our period of 10.927 ± 0.001 h is consistent with previous determinations. Our amplitude of 0.59 ± 0.05 mag is slightly larger than the value reported by Behrend.

1146 Biarmia is a main-belt asteroid discovered by G. Neujmin at Simeis on 1929 May 07. It is also known as 1929 JF. The first period determination was by Warner (2000) of 11.514 ± 0.004 h with an amplitude of 0.32 mag. Durkee (2009) obtained a period of 5.4700 ± 0.0002 h with an amplitude of 0.20 mag. Warner (2011) revised his earlier determination to a period of 5.33 ± 0.01 h with an amplitude of 0.20 mag. We observed 1146 Biarmia on 7 nights between 2014 Apr 22 and May 15. Analysis found a period of 5.468 ± 0.004 h and an amplitude of 0.22 ± 0.10 mag. It is interesting to note that this light curve has 4 minima. It should also be noted that we used 8 orders in the FALC fit rather than the normal 4 orders, which allowed a closer fit to the extra minima.

1175 Margo is an outer main-belt asteroid discovered by K. Reinmuth at Heidelberg on 1930 Oct 17. It is also known as 1930 UD, 1953 VK, 1957 KU, and A907 VA. Behrend (2005) reported a period of 6.1038 ± 0.0002 h and an amplitude of 0.31 mag. Oliver (2008) determined a period of 11.99 ± 0.03 h with an amplitude of 0.22 mag. Brinsfield (2010) determined a period of 6.015 ± 0.001 h and an amplitude of 0.40 mag. Montgomery *et al.* (2013) determined a period of 6.01 ± 0.02 h and an amplitude of 0.32 mag. They pointed out that since the period was very close to an integer fraction of 24 hours, it was difficult to determine if the true period was 6.01h or 11.99 h. We observed 1175 Margo on 5 nights between 2014 Apr 11 and 2014 May 8. Our best fit period is 6.017 ± 0.001 h with an amplitude 0.28 ± 0.10 mag.

Acknowledgments

The Etscorn Campus Observatory operations are supported by the Research and Economic Development Office of New Mexico Institute of Mining and Technology (NMIMT). Student support at NMIMT is given by NASA EPSCoR grant NNX11AQ35A, the Department of Physics, and the Title IV of the Higher Education Act from the Department of Education.

References

Behrend, R. (2003, 2005, 2006, 2010, 2012). Observatoire de Geneve web site.
h*ttp://obswww.unige.ch/~behrend/page_cou.html*

Brinsfield, J.W. (2010). "Asteroid Lightcurve Analysis at the Via Capote Observatory: 2009 3rd Quarter." *Minor Planet Bul.* **37,** 19-20.

Durkee, R. I. (2009). "The lightcurves of 1146 Biarmia and 5598 CarlMurray." *Minor Planet Bul.* **36,** 170.

#	Name	2014 (mm/dd) UT	Phase	PABL	PABB	Period	P. E.	Amp.	A. E.
446	Aeternitas	05/09 - 06/07	5.4, 15.6	215.8	0.2	15.745	0.001	0.47	0.05
502	Sigune	04/24 - 06/16	19.1, 18.7, 22.6	221.1	32.6	10.972	0.001	0.59	0.05
1146	Biarnia	04/22 - 05/15	2.0, 11.9	208.1	-1.0	5.468	0.004	0.22	0.10
1175	Margo	04/11 - 05/08	5.7, 13.4	184.0	-14.6	6.017	0.001	0.28	0.10

Table I. Current results

#	Name	Reference	Date	PABL	PABB
446	Aeternitas	Behrend 2006	2006-Dec-06	22.0	-2.3
		Fauerbach 2008	2006-Nov-06	19.0	-4.2
		Lucus 2011	2009-Apr-26	186.5	6.6
		Lucas 2012	2006-Nov-07	19.1	-4.1
		Lucas 2012	2008-Feb-22	12.0	12.0
		this paper	2014-May-24	215.8	0.2
502	Sigune	Stephens 2007	2007-Jun-12	275.2	22.5
		Behrend 2010	2010-Apr-14	157.7	20.9
		Behrend 2011	2011-Jul-22	305.4	5.5
		this paper	2014-May-20	221.1	32.6
1146	Biarmia	Warner 2000	1999-Sep-27	357.9	13.0
		Behrend 2008	2008-Jan-27	153.0	-18.2
		Durkee 2009	2009-Jun-13	251.9	15.5
		this paper	2014-May-01	208.1	-1.0
1175	Margo	Behrend 2005	2005-Nov-21	26.3	8.5
		Oliver 2008	2008-Mar-02	169.8	-18.2
		Brinsfield 2010	2009-Jul-01	236.8	2.1
		Montgomery 2013	2011-Nov-30	44.5	3.0
		this paper	2014-Arp-29	184.0	-14.6

Table II. Previous Solar Bisector Phase Angles

ECO (2014). Etscorn Campus Observatory. *http://www.mro.nmt.edu/education-outreach/etscorn-campus-observatory*

Fauerbach, M., Marks, S.A., Lucas, M.P. (2008). "Lightcurve analysis of ten Main-Belt Asteroids." *Minor Planet Bul.* **35,** 44-46.

Florczak, M., Dotto, E., Barucci, M.A., Birlan, M., Erikson, A., Fulchignoni, M., Nathues, A., Perret, L., Thebault, P. (1997). "Rotational properties of main belt asteroids: photoelectric and CCD observations of 15 objects." *Planet. Space Sci.* **45**, 1423-1435.

Harris, A.W., Young, J.W., Bowell, E., Martin, L.J., Millis, R.L., Poutanen, M., Scaltriti, F., Zappala, V., Schober, H.J., Debehogne, H., Zeigler, K. (1989). "Photoelectric Observations of Asteroids 3, 24, 60, 261, and 863." *Icarus* **77**, 171-186.

JPLSBD. Small Body Database Search Engine. *http://ssd.jpl.nasa.gov/sbdb_query.cgi*

Lucus, M.P., Ryan, J.G. Fauerbach, M. Grasso, S. (2011). "Lightcurve Analysis of five Taxonomic A-class asteroids." *Minor Planet Bul.* **39,** 218-220.

Lucus, M.P., Ryan, J.G. Fauerbach, M. (2012). "A shape model of the Taxonomic A-class asteroid 446 Aeternitas." *Minor Planet Bul.* **38,** 173-176.

Montgomery, K.A., Davis, C., Renshaw, T., Rolen, J. (2013). "Photometric Study of Four Asteroids at Texas A&M Commerce Observatory." *Minor Planet Bul.* **40**, 212-213.

Oliver, R.L., Shipley, H., Ditteon, R. (2008). "Asteroid Lightcurve Analysis at the Oakley Southern Sky Observatory: March 2008." *Minor Planet Bul.* **35**, 149-150.

SB (2014). Software Bisque. *http://www.bisque.com/sc/*

Stephens, R.D. (2007). "Photometry from GMARS and Santana Observatories - April to June 2007." *Minor Planet Bul.* **34**, 102-103.

Tedesco, E.F. (1979). PhD Dissertation. New. Mex. State Univ. 280 pp.

Warner, B.D. (2000). "Asteroid Photometry at the Palmer Divide Observatory." *Minor Planet Bul.* **27**, 4-6.

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The asteroid lightcurve database." *Icarus* **202**, 134-146. Updated 2014 February 28. *http://www.minorplanet.info/lightcurvedatabase.html*

Warner, B.D. (2011). "Upon Further Review: III. An examination of Previous Lightcurve Analysis from the Palmer Divide Observatory." *Minor Planet Bul.* **38**, 21-23.

Warner. B.D. (2014). MPO Canopus software. *http://www.bdwpublishing.com*

Warner, B.D., Harris, A.W., Pravec, P., Durech, J., Benner, L.A.M. (2014). "Lightcurve photometry Opportunities: 2014 January-March." *Minor Planet Bul.* **40**, 61-65.