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MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2021 APRIL-MAY

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CCD photometric observations of 11 main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2021 April-May. In addition, recovered data from 2019 allowed finding lightcurve parameters for 1413 Roucarie. New pole/shape modeling results are presented for 323 Brucia and 1106 Cydonia. The recovered data for 1413 Roucarie did not have an effect on a previously published shape model.

The Center for Solar System Studies (CS3) has nine telescopes which are normally used in program asteroid family studies. The focus is on near-Earth asteroids, but when suitable targets are not available, Jovian Trojans and Hildas are observed. When a nearly full moon is too close to the family targets being studied, targets of opportunity amongst the main-belt families were selected.

Table I lists the telescopes and CCD cameras that were used to make the observations. Images were unbinned with no filter and had master flats and darks applied. The exposures depended upon various factors including magnitude of the target, sky motion, and Moon illumination.

Telescope	Camera
0.30-m f/6.3 Schmidt-Cass	SBIG 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/10 Schmidt-Cass	SBIG 1001E
0.35-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.50-m F8.1 R-C	FLI Proline 1001E

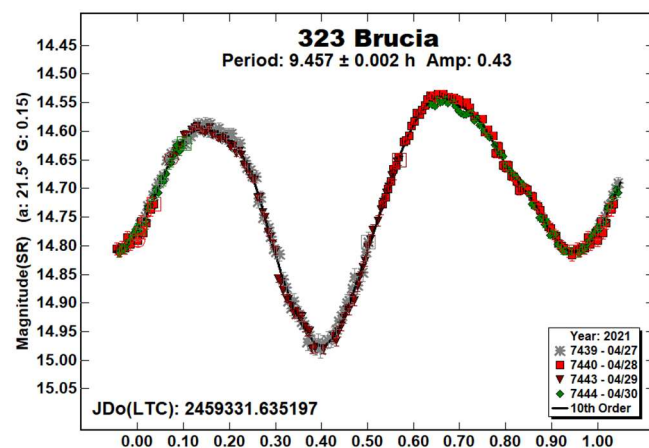
Table I: List of CS3 telescope/CCD camera combinations.

Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). For the images reduced in 2021, the Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color. Night-to-night calibration was done using field stars from the ATLAS catalog (Tonry et al., 2018), which has Sloan *griz* magnitudes that were derived from the GAIA and Pan-STARR catalogs and are "native" magnitudes of the catalog. Those adjustments are usually $\leq \pm 0.03$ mag. The rare greater corrections may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction.

The Y-axis values are ATLAS SR “sky” magnitudes. The two values in the parentheses are the phase angle (α) and the value of G used to normalize the data to the comparison stars used in the earliest session. This, in effect, made all the observations seem to be made at a single fixed date/time and phase angle, leaving any variations due only to the asteroid’s rotation and/or albedo changes. The X-axis shows rotational phase from -0.05 to 1.05 . If the plot includes the amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

For brevity, only some of the previously reported rotational periods may be referenced. A complete list is available at the asteroid lightcurve database (LCDB; Warner et al., 2009).

323 Brucia. This member of the Phocaea dynamical family has been observed several times in the past. Schober et al. (1993) and Behrend (2006web) who both reported periods near 9.46 h. We observed it twice (Warner 2014; 2018) also finding a period near 9.46 h. Our results this year is in good agreement with those prior results.



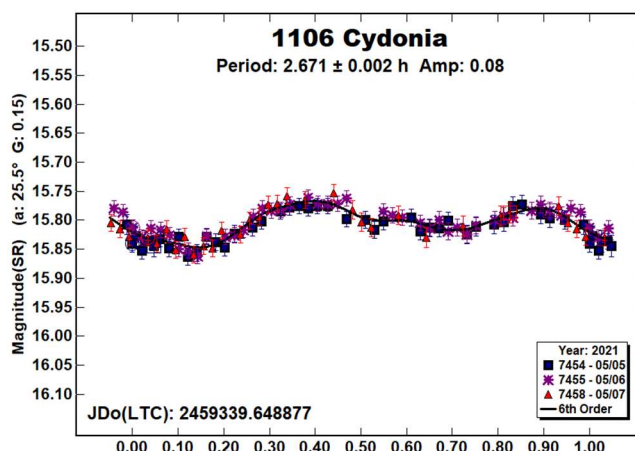
In addition to our dense data from the two apparitions, we used sparse data from the AstDyS-2 site to solve for the sidereal period and pole position and to create a shape model using *MPO LCInvert* (Bdw Publishing).

The model showed two possible solutions 180° apart; $(\lambda, \beta, P) = (237^\circ, 16^\circ, 9.459492 \text{ h})$ and $(\lambda, \beta, P) = (57^\circ, -19^\circ, 9.459500 \text{ h})$. Our preferred solution is $(237^\circ, 16^\circ)$. Assuming $c = 1.0$ for a triaxial ellipsoid, $a/b = 1.2$ and a/c ratio 1.6.

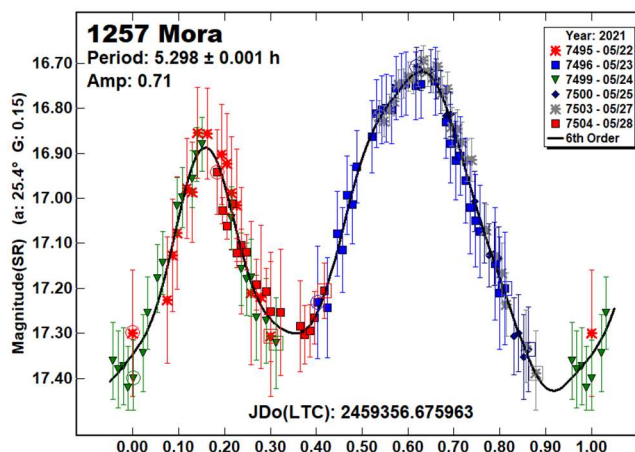
1106 Cydonia. This member of the Eunomia dynamical family has been observed three times in the past. Klinglesmith et al. (2016) and Aznar (2017) each found a period near 2.67 h. We observed it (Stephens and Warner 2020) finding a period of 2.678 h. Our result this year is in good agreement with these prior periods.

Using the Klinglesmith et al. data found on the ALCDEF website, our dense data from the two apparitions, and sparse data from the AstDyS-2 site to solve for the sidereal period and pole position and create a shape model, using *MPO LCInvert* (Bdw Publishing).

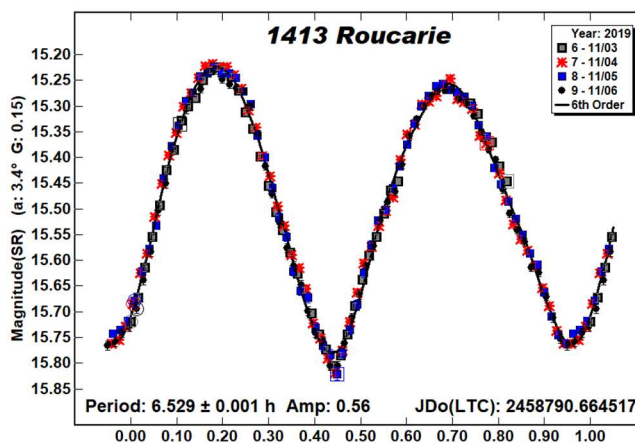
Our pole model showed two possible solutions about 180° apart; $(\lambda, \beta, P) = (336^\circ, -25^\circ, 2.679720 \text{ h})$ and $(\lambda, \beta, P) = (145^\circ, -22^\circ, 2.679720 \text{ h})$. Our preferred solution is $(336^\circ, -25^\circ)$. Assuming $c = 1.0$ for a triaxial ellipsoid, $a/b = 1.2$ and $a/c = 1.5$.



1257 Mora. This inner main-belt asteroid was originally observed by Binzel (1987). Periods were later reported twice by Behrend (2009web; 2011web). All of the prior periods were near 5.3 h. Our results this year is in good agreement with those prior results.

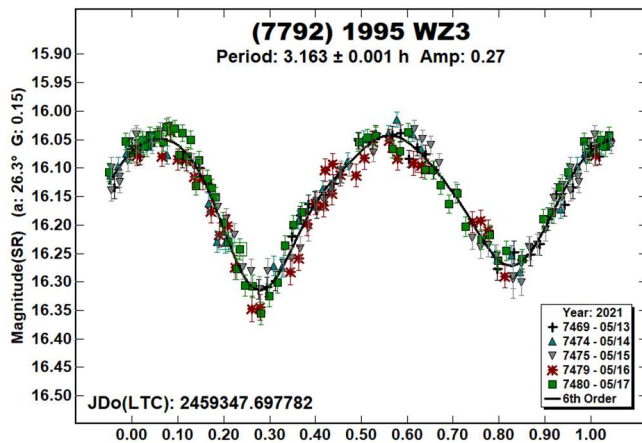


1413 Roucarie. We observed this member of the EOS dynamical family in 2011, 2013 and 2021 finding periods near 6.53 h (Stephens et al., 2021; and references therein). Subsequent to that report, we recovered more data from 2019 which are consistent with the prior results.

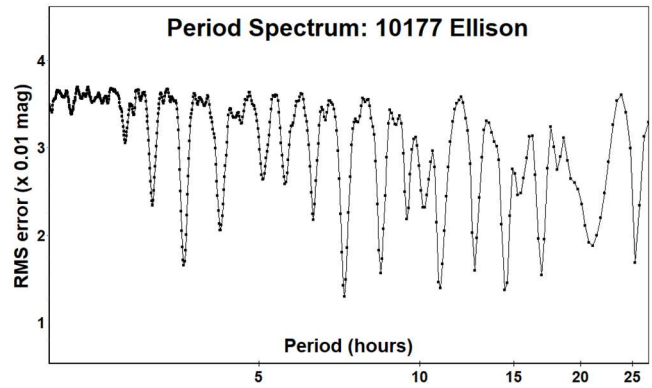
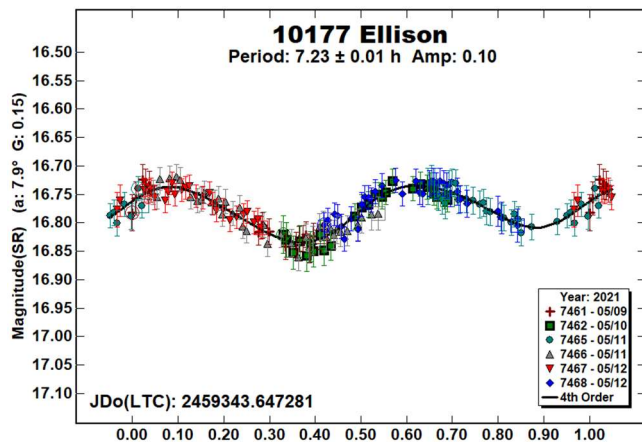


Using sparse data from the Lowell Photometric Database and WISE data, Āurech et al. (2018) reported a spin axis model with $(\lambda, \beta) = (124^\circ, 5^\circ)$ or $(310^\circ, 5^\circ)$ and a sidereal period of 6.53058 h. Without including our new data from 2019, we previously found two possible pole solutions that are about 180° apart: $(\lambda, \beta, P) = (122^\circ, 10^\circ, 6.530557 \text{ h})$ and $(311^\circ, 37^\circ, 6.530558 \text{ h})$. Our preferred solution is $(122^\circ, 10^\circ)$.

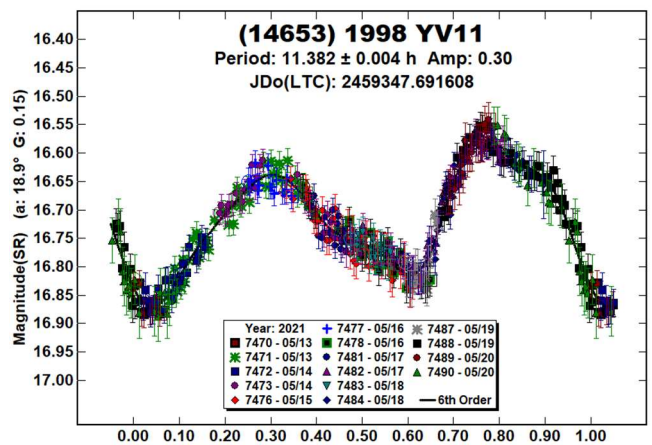
(7792) 1995 WZ3. This inner main-belt asteroid was observed by the Photometric Survey for Asynchronous Binary Asteroids (Pravec et al., 2007web) who found a period of 3.16001 h. Our results this year is in good agreement with that prior result.



10177 Ellison. This member of the Vesta dynamical family has been observed only once in the past. Erasmus et al. (2020) using data from the ATLAS survey found a period of 7.271 h. Our result this year is in good agreement with that prior result. With an amplitude of only 0.10 mag., there is no assurance of a bimodal lightcurve (Harris et al., 2014). The period spectrum shows possible solutions near 3.5 h, 10.8 h, and 14.4 h. However, those solutions are single modal, trimodal, and quadrimodal lightcurves, and are not more likely than our bimodal solution.

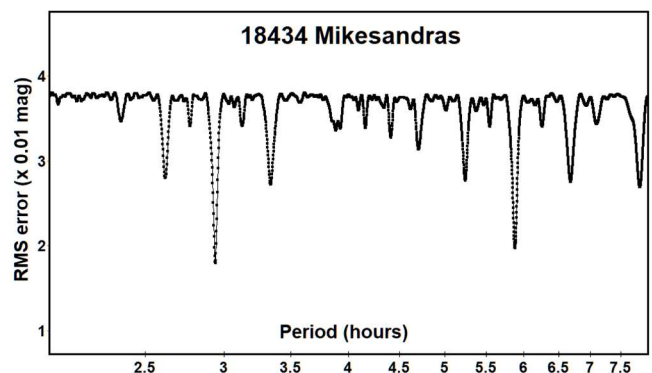


(14653) 1998 YV11. This Mars-crosser was observed by Higgins (2005) finding a period of 11.389 h. Using TESS survey data, Pál et al. (2020) found a period of 11.391 h. Our results this year is in good agreement with those prior results.

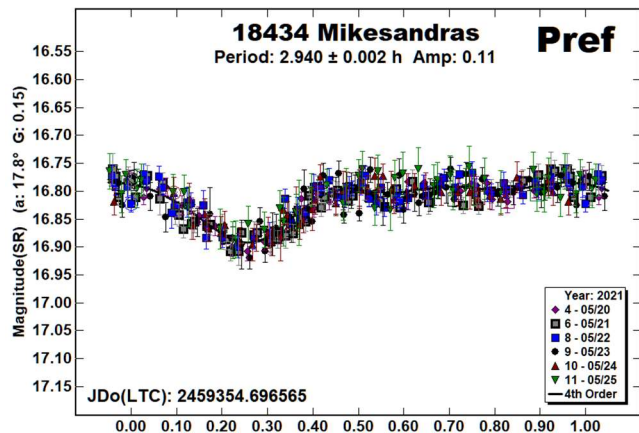


18434 Mikesandras. Carbo et al. (2009) found a period of 3.137 h for this 5.3 km member of the Phocaea dynamical family (LCDB: 701). On the other hand, Pál et al. (2020) used data from the TESS mission to find a period of 42.8675 h. This raised the possibility that they had found a long-period component and overlooked the shorter period found by Carbo et al. (2009).

However, after importing their data into *MPO Canopus*, a period search from 2-100 hours found what was an essentially flat line for the period spectrum and a plot to their period showed only the slightest trace of a period within a significant amount of noise.



Our period spectrum showed two distinct possibilities, a monomodal solution at 2.940 h and a bimodal solution at 5.870 h. As noted by Harris et al. (2014), given the low amplitude and relatively small phase angle, either solution was plausible and so we used a split-halves plot to see which period to favor. That showed highly-symmetrical halves for the 5.879 h period, too symmetrical for our liking, and so we adopted a period of 2.940 h for this paper despite the somewhat unusual lightcurve shape.



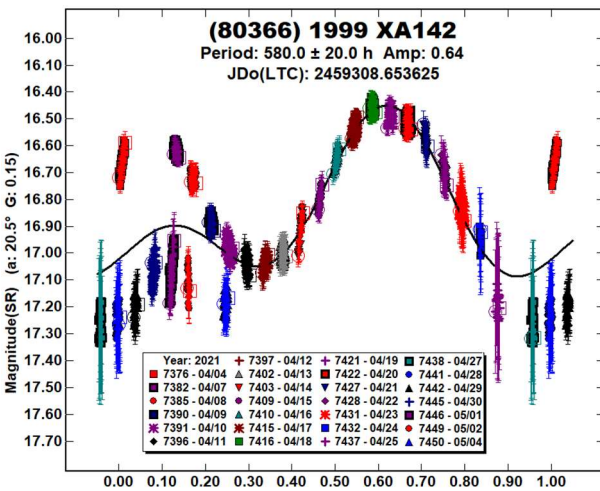
Number	Name	2021/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
323	Brucia	04/27-04/30	21.5, 21.6	148	24	9.457	0.002	0.43	0.01	701
1106	Cydonia	05/05-05/07	25.5, 25.7	159	-6	2.671	0.002	0.08	0.02	502
1257	Mora	05/22-05/28	25.4, 25.6	169	-2	5.298	0.001	0.71	0.03	9104
1413	Roucarie	2019/11/03-11/06	3.4, 3.9	38	-8	6.529	0.001	0.56	0.01	606
7792	1995 WZ3	05/13-05/17	26.4, 27.3	187	6	3.163	0.001	0.27	0.02	9104
10177	Ellison	05/09-05/12	7.9, 9.2	216	8	7.23	0.01	0.10	0.02	401
14653	1998 YV11	05/13-05/20	19.0, 22.4	206	9	11.382	0.004	0.30	0.02	9103
18434	Mikesandras	05/20-05/25	17.8, 17.4	244	32	^P 2.940 5.879	0.002 0.002	0.11 0.11	0.01 0.01	701
30958	1994 TV3	05/18-05/21	16.7, 17.2	237	24	5.81	0.001	0.86	0.02	003
53134	1999 BG1	05/15-05/18	20.0, 20.9	211	21	2.612	0.001	0.14	0.01	9105
66846	Franklederer	05/19-05/28	*18.2, 18.4	252	27	4.272	0.001	0.19	0.01	801
80366	1999 XA142	04/04-05/04	*20.5, 22.7	194	24	580	20	0.6	0.3	701

Table II. Observing circumstances and results. ^PPreferred solution for an ambiguous result. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009; Warner and Harris, 2021). A number < 2000 indicates a dynamical family member as determined from Nesvorný (2015) and Nesvorný et al. (2015). Numbers in the range of 2000-3000 are additional families from the AstDys site (2021June). Numbers > 9000 are objects in an orbital space defined by osculating orbital elements. See the recent LCDB documentation or use <https://minplanobs.org/MPInfo/php/oneasteroidinfo.php> to look up an asteroid's family or group number.

Number	Name	λ	β	Period	λ	β	Period	a/b ratio	a/c ratio
323	Brucia	237	16	9.459492	57	-19	9.459500	1.2	1.6
1106	Cydonia	336	-25	2.679720	145	-22	2.679720	1.2	1.5

Table III. Results of Pole/Shape modeling. The preferred solution is listed first in bold text. For the ratios, c = 1.0.

(80366) 1999 XA142. There are no entries in the LCDB for this Mars-crosser estimated to be 3 km in size. That is not a surprise given its long period and that the asteroid is tumbling, which is likely given the period (Pravec et al., 2005; 2014). The tumbling frequencies cannot be confirmed from our data set alone.



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SPIN/SHAPE MODEL FOR 323 Brucia

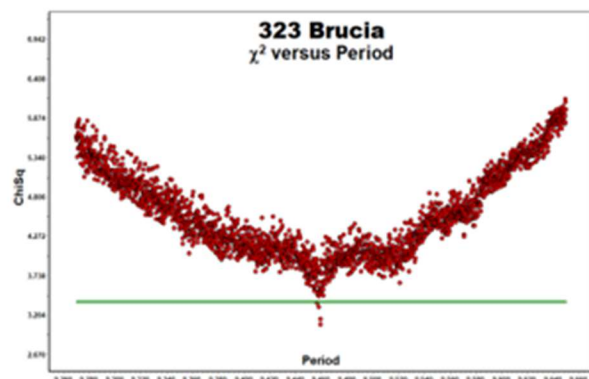


Figure 1. The initial period search results.

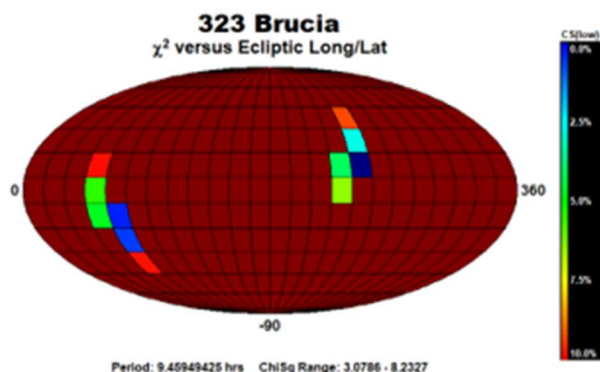


Figure 2. The pole search found two probable solutions.

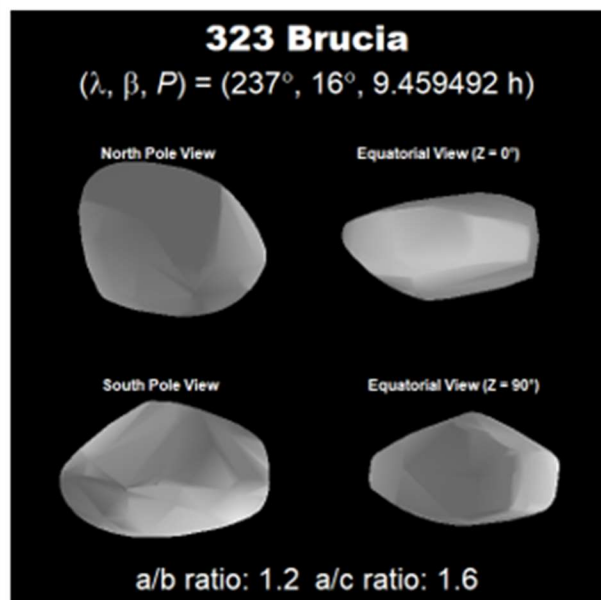


Figure 3. The shape of the asteroid based on the preferred solution.

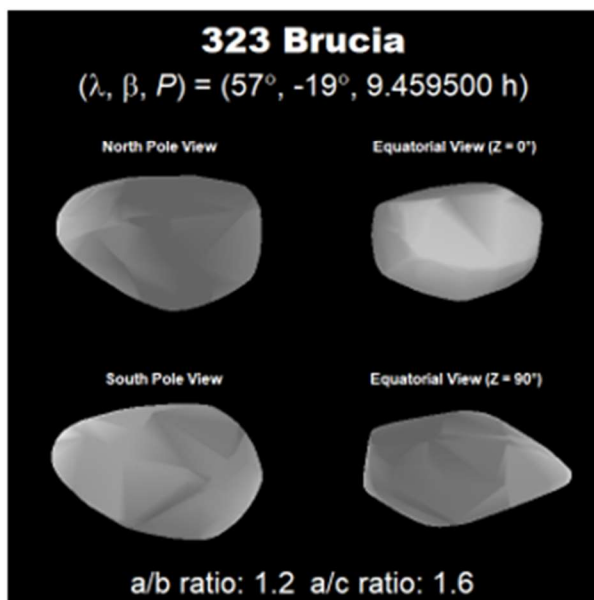


Figure 4. The shape of the asteroid based upon the secondary solution.

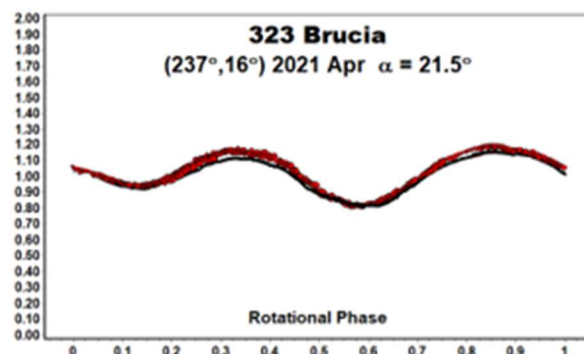
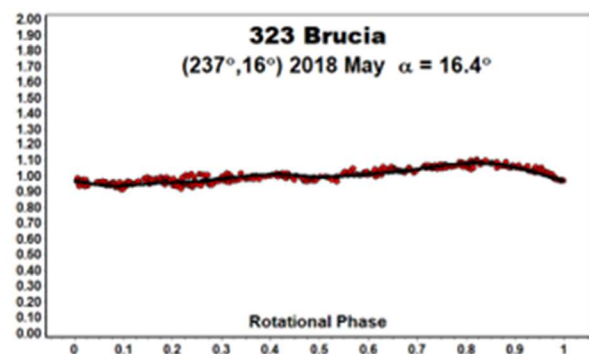


Figure 5/6. The comparison plots are against the preferred pole solution. The red dots indicate the data used for modeling while the black line is the smoothed lightcurve for generated by the shape at the time of the observations. The match is very close on both occasions, which gives confidence in the shape/spin axis model.

SPIN/SHAPE MODEL FOR 1106 Cydonia

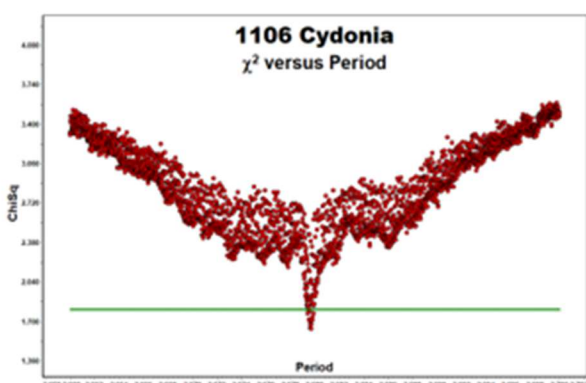


Figure 1. The initial period search results.

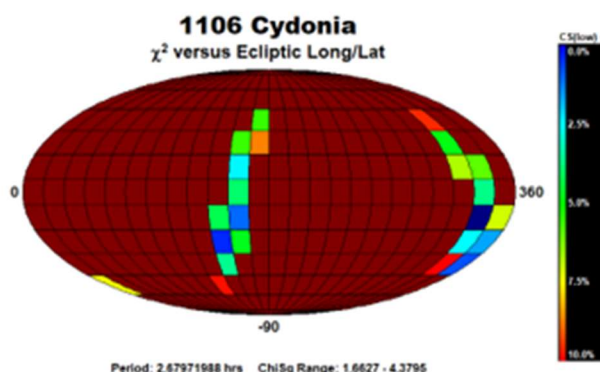


Figure 2. The pole search found two probable solutions.

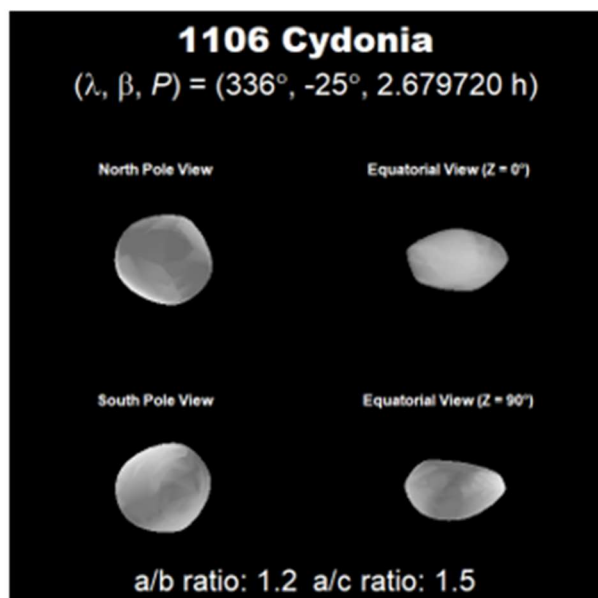


Figure 3. The shape of the asteroid based on the preferred solution.

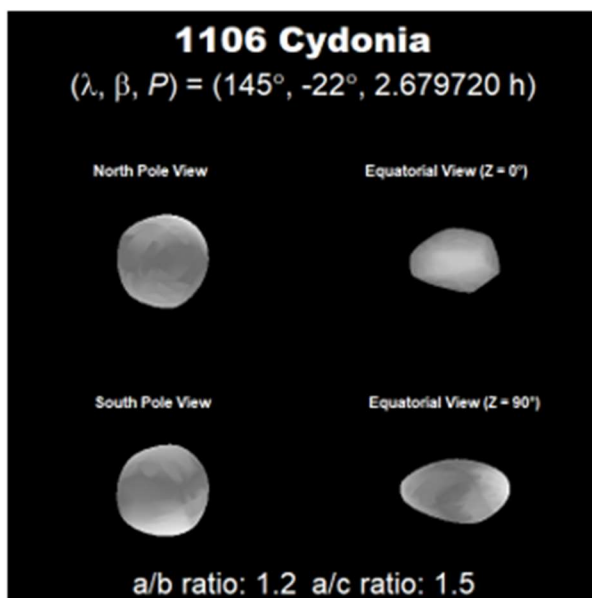


Figure 4. The shape of the asteroid based upon the secondary solution.

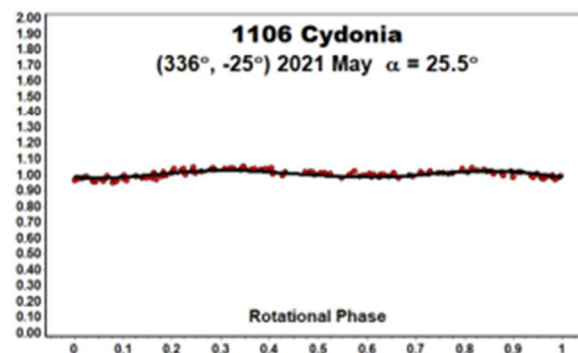
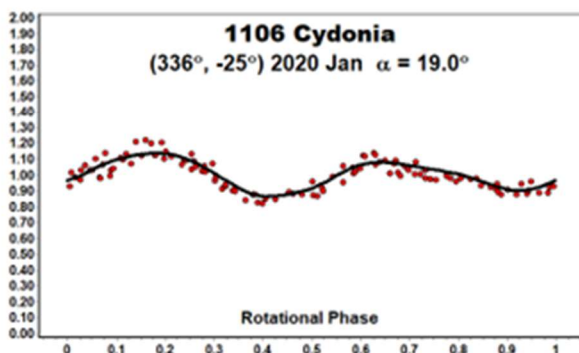


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