

**299 THORA AND 496 GRYPHIA:
TWO MORE VERY SLOWLY ROTATING ASTEROIDS**

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CCD observations of the asteroids 299 Thora and 496 Gryphia were made to determine the synodic rotation periods. For 299 Thora, the period is 272.9 ± 0.9 h with a maximum amplitude 0.47 mag. No evidence of tumbling was found. We measured a color index of $V-R = 0.52$. Using average lightcurve magnitude, we found $H = 11.68 \pm 0.06$, $G = 0.27 \pm 0.06$. For 496 Gryphia, we found a rotation period near 1072 h and amplitude of 1.25 mag. Tumbling behavior was found but not quantified. The color index is $V-R = 0.48$. Using average lightcurve magnitudes, we found $H = 12.21 \pm 0.05$, $G = 0.18 \pm 0.04$.

A strategy for observing very slowly rotating asteroids has been described by Pilcher et al. (2017). Briefly, a short session is obtained every clear night for several months using calibrated solar-colored stars from the CMC15 catalog (VizieR web site) to determine the asteroid's brightness. Alternating V and R filter exposures are obtained on at least one night to find a color index V-R and a search for tumbling is made with simultaneous two-period software.

Observations to obtain the data used in this paper were made at the Organ Mesa Observatory with a 0.35-meter Meade LX200 GPS Schmidt-Cassegrain (SCT) and SBIG STL-1001E CCD. Exposures were 60 to 120 seconds, unguided, with a clear filter. All measurements were calibrated from CMC15 Sloan r' (SR) values to Cousins R magnitudes for solar-colored field stars. Photometric measurement was done with *MPO Canopus*. To reduce the number of points on the lightcurves and make them easier to read, data points on all lightcurves constructed with *MPO Canopus* were binned in sets of 3 with a maximum time difference of 5 minutes between points in each bin.

To find the V-R color index, images in both R and V filters were obtained alternately on one night for each object in the study. The same solar-colored comparison stars with SR and 2MASS J and K magnitudes read from the CMC15 catalog (VizieR web site) were

used to measure both image sets. For the R filter images, conversions to Cousins R magnitudes used (Dymock and Miles, 2009)

$$R = r' - 0.22 \quad (1)$$

For the V filter images, conversions to Johnson V magnitudes used Dymock and Miles (2009)

$$V = 0.9947r' + 0.6278(J-K) \quad (2)$$

The converted magnitudes for each color are plotted together. The V magnitude data points can be adjusted upward to obtain the best fit between R magnitude and V magnitude overlapping sessions. The amount of the adjustment is then the color index V-R. For each session, R magnitudes were estimated at maximum, mid, and minimum light for the rotational cycle. Each measured R magnitude was converted to its corresponding V magnitude by adding the derived V-R.

The H-G calculator function of *MPO Canopus* was used to find the values for absolute magnitudes (H) and phase slope parameter (G) based on the V magnitudes at maximum, mid, and minimum light. Using maximum light has a better geometric foundation but the H-G system assumes mid-light, i.e., the average magnitude of a lightcurve at any given time.

299 Thora. The only previously published rotation period and amplitude is by Pilcher et al. (2014), who obtained a period of 274 h and amplitude of 0.39 mag based on numerous dense all-night lightcurves obtained over a two month interval. However, there were calibration problems related to systematic differences between the equipment used by Pilcher and Alvarez that prevented finding whether or not small amplitude tumbling was occurring. Small-amplitude, short-period variations were not definitively observed.

New observations, mostly of 20 minutes to 2 hours duration, were obtained on 73 nights between 2016 Oct 31 and 2017 Mar 26. All images were obtained using the same telescope and CCD camera at Organ Mesa Observatory. A single-period lightcurve constructed from *MPO Canopus* software including all observations in this interval (Fig. 1) provides a good fit to a period of 272.65 h and amplitude 0.47 mag but with considerable scatter among individual sessions.

However, when the data over the intervals of 2016 Oct 31 to 2017 Jan 7 (Fig. 2; 272.2 h, 0.47 mag) and 2017 Jan 8 to March 26 (Fig. 3; 273.2 h, 0.38 mag) are plotted separately, most of the scatter is removed. The scatter over the full interval is attributed to changes in the phase angle between the two data sets.

The split-halves plot for the data set covering 2017 Jan 8 to Mar 26 for the double-period of 548 hours is shown in Fig. 4. The tenth-order Fourier approximations for the two halves are almost identical, which makes the double period extremely unlikely. A split halves plot for the same data set for the 273 hour period (Fig. 5) shows much greater differences for the tenth-order Fourier approximations for the two halves and rules out the half period. An independent analysis by co-author Pravec established a period

Number	Name	yyyy/mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
299	Thora	2016/10/31-2017/03/26	3685	21.4, 1.0, 24.7	127	-2	272.9	0.9	0.47	0.04
496	Gryphia	2016/09/22-2017/02/11	3222	16.3, 0.3, 27.8	33	-1	1072.0	2.0	1.25	0.10

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first date, minimum value, and last date. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

of 272.9 ± 0.9 h and found no evidence of tumbling. This period is in fairly close agreement with 274 hours found by Pilcher et al. (2014). Using the tumbler rating system from Pravec et al. (2005), the asteroid is rated PAR = +2, tending to +3.

Twenty-five images each in R and V filters were obtained alternately on 2017 Jan 26 and plotted together (Fig. 6) in which the R and V magnitudes are separated by V-R = 0.52. An H-G plot using the data obtained in this investigation (Fig. 7) shows

Maximum light: $H = 11.53 \pm 0.02, G = 0.29 \pm 0.03$
 Mean light: $H = 11.68 \pm 0.06, G = 0.27 \pm 0.06$
 Minimum light: $H = 11.82 \pm 0.05, G = 0.25 \pm 0.06$

A parallel study using sparse data from USNO Flagstaff Station (Fig. 8) yields mean light values of $H = 11.616 \pm 0.046, G = 0.268 \pm 0.050$, in good agreement with the results of this study. There is also good agreement with JPL (2017), $H = 11.3$ and with Nugent et al. (2016) $H = 11.54, G = 0.24$.

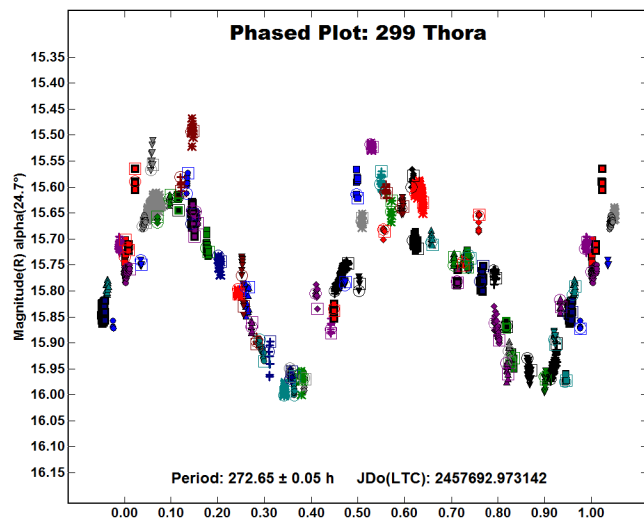


Fig. 1. Phased lightcurve of 299 Thora based on 73 sessions from 2016 Oct 31 to 2017 Mar 26.

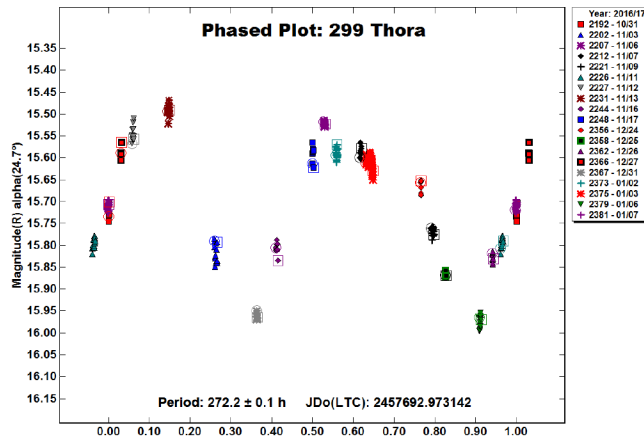


Fig. 2. Phased lightcurve of 299 Thora based on 19 sessions covering 2016 Oct 31 to 2017 Jan 7.

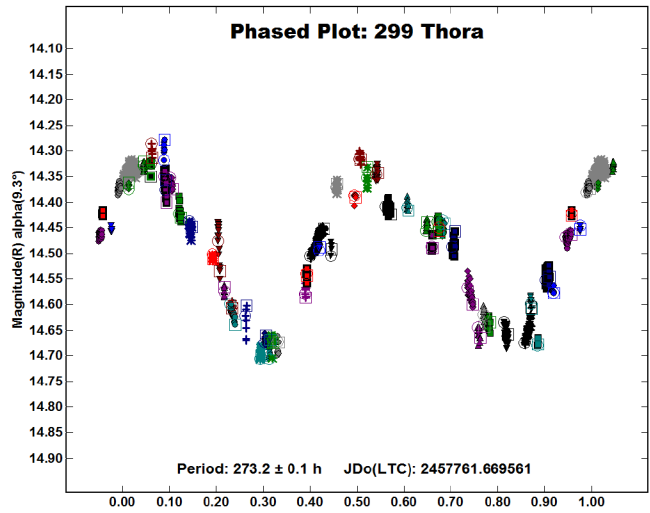


Fig. 3. Phased lightcurve of 299 Thora based on 54 sessions covering 2017 Jan 8 to Mar 26.

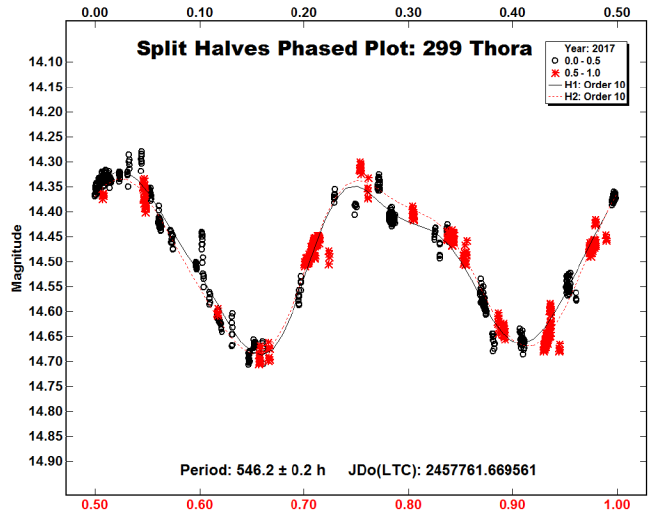


Fig. 4. Split halves lightcurves of 299 Thora over the interval 2017 Jan 8 to Mar 26 for a presumed double period of 546.2 h.

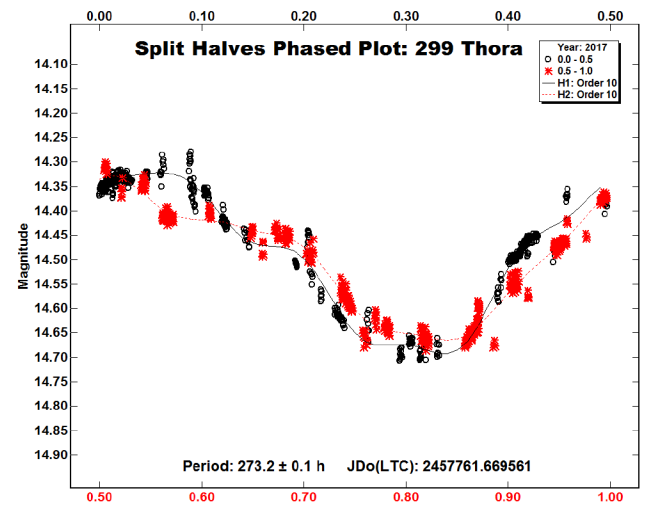


Fig. 5. Split halves lightcurves of 299 Thora over the interval 2017 Jan 8 to Mar 26 for a presumed period of 273.2 h.

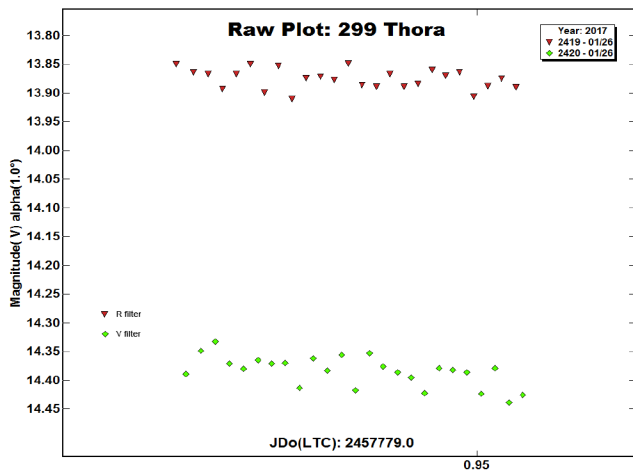


Fig. 6. Observations of 299 Thora 2017 Jan. 26 in R and V magnitudes.

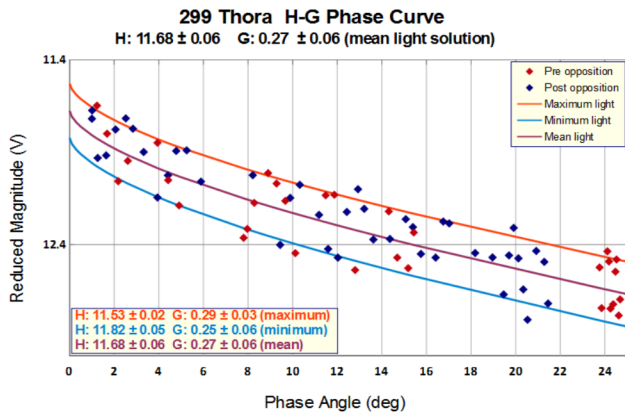


Fig. 7. H-G plots for 299 Thora for maximum, mean, and minimum light data.

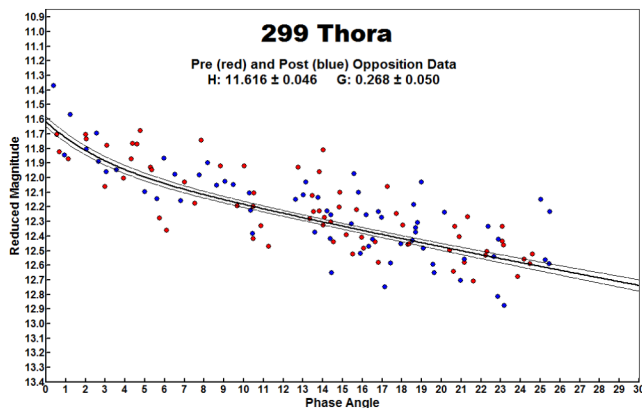


Fig. 8. H-G plot for 299 Thora using USNO Flagstaff Station data.

496 Gryphia. The only previously published results are from Behrend (2006; $P = 18.0$ h, $A = 0.05$ mag) based on a sparse lightcurve. Pilcher obtained a six-hour lightcurve on 2015 May 15 that showed little variation and is published here for the first time (Fig. 9). The first lightcurve of the next apparition was obtained 2016 Sep 22 and also showed very little variation. On the basis of these results, very slow rotation was suspected.

On subsequent nights, the recommended procedure of obtaining short sessions on every clear night was followed. Fig. 10 is a raw

plot of the first four sessions covering 2016 Sep 22-25 and reveals a very slowly changing lightcurve. Another raw plot (Fig. 11) of the seven-hour session on Oct 11 between short sessions on Oct 10 and 12 shows smooth behavior on the rising part of the lightcurve. From 2016 Sep 22 to 2017 Feb 11, a total of 97 sessions, most of them 15 to 30 minutes, were obtained. All observations were obtained with using the same equipment and camera at Organ Mesa Observatory.

A single-period lightcurve was constructed with *MPO Canopus* with best fit to a period of 1069.5 ± 0.5 h and amplitude 1.25 mag with one minimum much deeper than the other (Fig. 12). Three full rotational cycles are included. While a period of 1069.5 hours is well defined by the data, there are variations up to 0.2 magnitudes between successive cycles, a variation much larger than the internal accuracy of the CMC-15 catalog.

Fig. 13 shows the raw lightcurve using data from 2016 Sep 22 to Dec 1. Fig. 14 shows a raw plot of data from 2016 Dec 1 to 2017 Feb 11. Splitting the full set this way spreads out the data horizontally and displays more clearly both smooth night-to-night variation and considerable variation among the three cycles. This variation among the three cycles strongly suggests tumbling behavior.

For tumbling asteroids, the systematic errors are much larger than the formal error in the single period plot. A simultaneous two-period solution was used to find a principal period of 1072 ± 2 h and confirm tumbling, $PAR = -2$ (Pravec et al., 2005) but with only three cycles, a second period was indeterminate. Twenty images each in R and V filters were obtained alternately on 2016 Nov 9 and plotted together (Fig 15), in which R and V magnitudes are separated by $V-R = 0.48$.

We used the most recent data to find the H-G parameters for the asteroid:

- Maximum light: $H = 11.79 \pm 0.03, G = 0.34 \pm 0.03$
- Mean light: $H = 12.21 \pm 0.05, G = 0.18 \pm 0.04$
- Minimum light: $H = 12.64 \pm 0.04, G = 0.02 \pm 0.03$

These results are shown in Fig. 16. A parallel study with sparse data from USNO Flagstaff Station shows a large scatter due to the large rotational amplitude. Using mean light, we found $H = 12.062 \pm 0.094, G = 0.204 \pm 0.092$ (Fig. 17), which agree within the expected errors with the mid-light value from the current study.

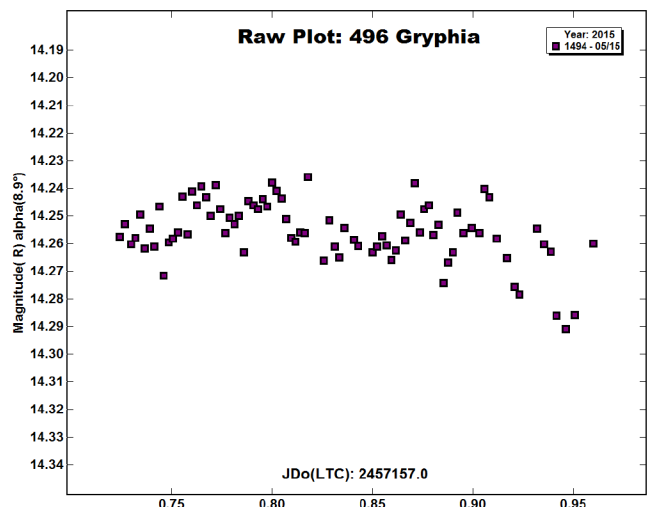


Fig. 9. Raw lightcurve of 496 Gryphia (2015 May 15).

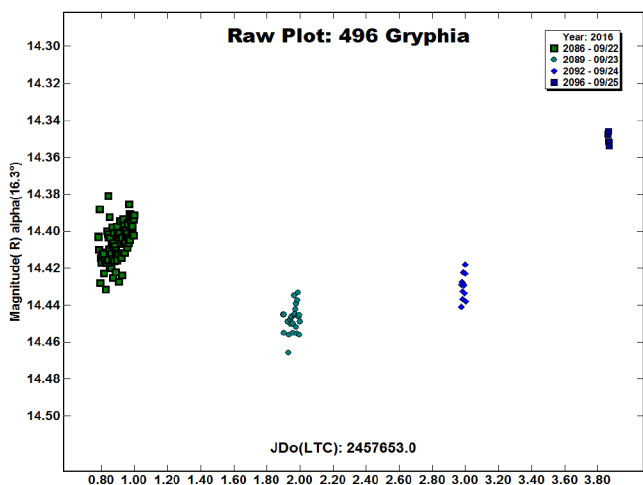


Fig. 10. Raw lightcurve of 496 Gryphia (2016 Sept. 22-25).

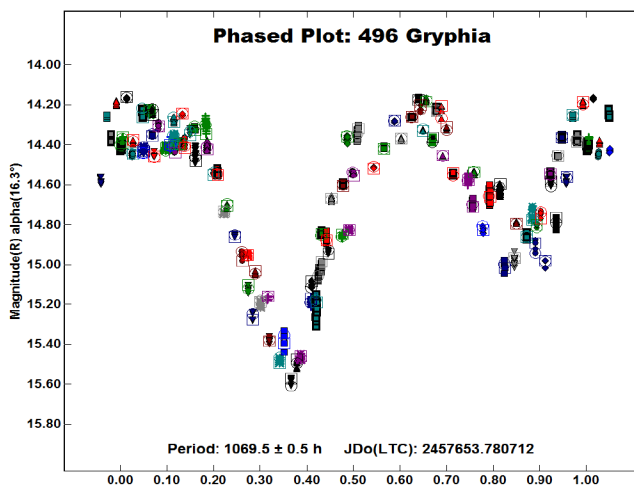


Fig. 12. Single period lightcurve of 496 Gryphia based on 97 sessions 2016 Sep 22 to 2017 Feb 11 in R band magnitudes, corrected for changes in phase angle and geocentric-heliocentric distances using *MPO Canopus*.

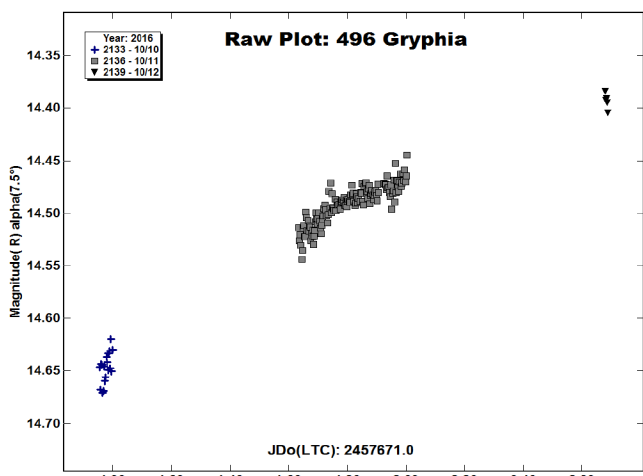


Fig. 11. Raw lightcurve of 496 Gryphia (2016 Oct. 10-12).

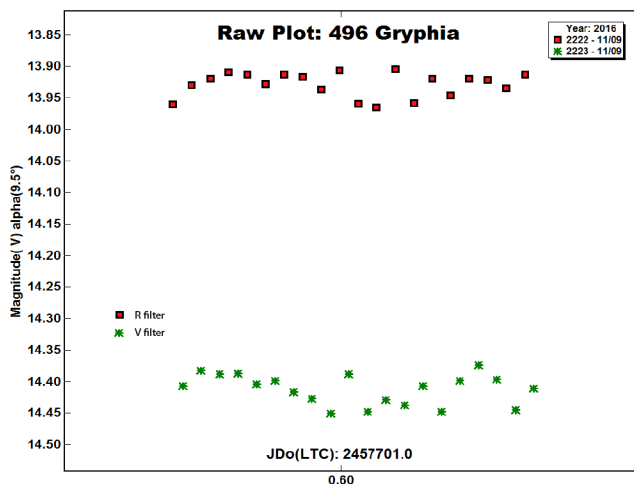


Fig. 15. R and V observations of 496 Gryphia (2016 Nov 9).

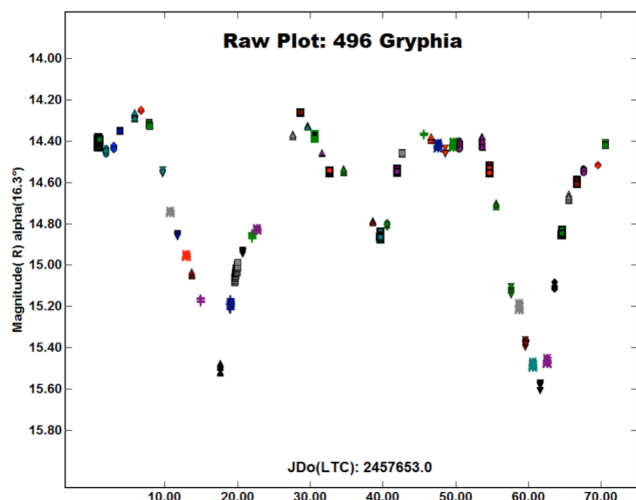


Fig. 13 (left) Raw lightcurve of 496 Gryphia for the interval 2016 Sept. 22 - Dec. 1.

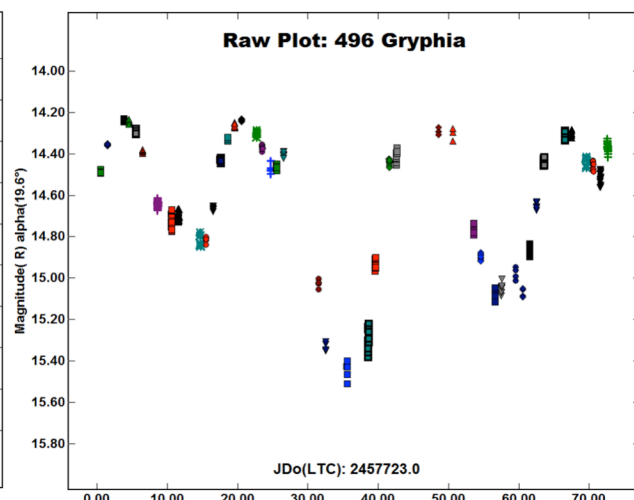


Fig. 14 (right) Raw lightcurve of 496 Gryphia for the interval 2016 Dec. 1 - 2017 Feb. 11

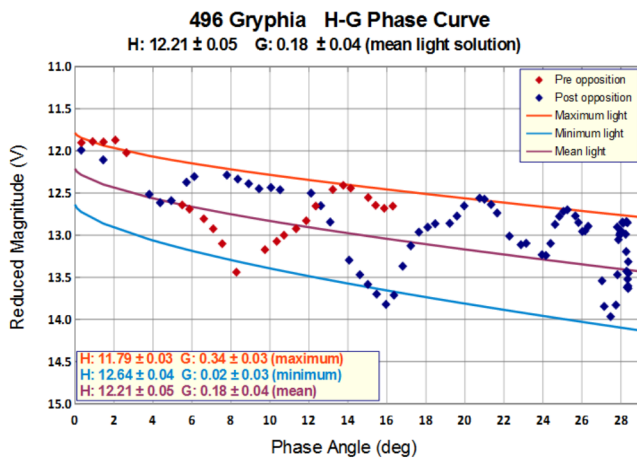


Fig. 16. H-G plots using maximum, mean, and minimum light.

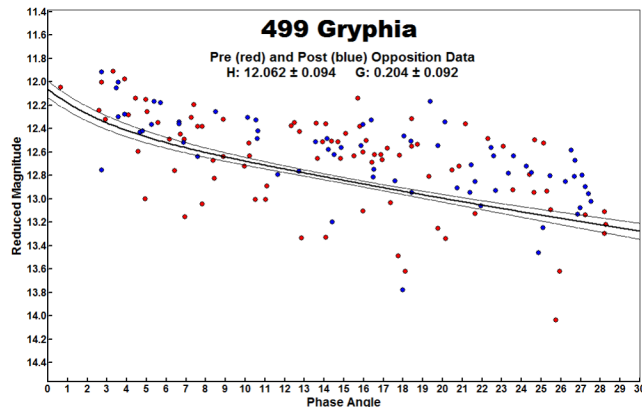


Fig. 17. H-G plot using USNO Flagstaff Station data.

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ROTATION PERIOD DETERMINATION FOR 2411 ZELLNER, 5293 BENTENGAHAMA, AND 9148 BORISZAITSEV

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Photometric observations of three main-belt asteroids were made from the Astronomical Observatory of the University of Siena (Italy) in order to determine their synodic rotation periods. For 2411 Zellner, we found a period of 2.975 ± 0.002 h with an amplitude of 0.33 mag. For 5293 Bentengahama, the period was 15.781 ± 0.002 h with an amplitude of 0.18 mag. For 9148 Boriszaitsev, we found 8.124 ± 0.02 h with an amplitude of 0.23 mag.

CCD photometric observations of three main-belt asteroids were carried out in 2017 January-March at the Astronomical Observatory of the University of Siena (K54). We used a 0.30-m $f/5.6$ Maksutov-Cassegrain telescope, SBIG STL-6303E CCD camera, and clear filter. The pixel scale was 2.30 arcsec when binning 2x2 pixels. All exposures were 300 sec. Data processing and analysis were made with *MPO Canopus* (BDW Publishing, 2017). All the images were calibrated with dark and flat-field frames and converted to R magnitudes using solar-colored field stars from a version of the CMC-15 catalogue distributed with *MPO Canopus*. Table I shows the observing circumstances and results.

A search of the asteroid lightcurve database (LCDB; Warner et al., 2009) indicates that our results may be the first reported lightcurve observations and results for these objects.

2411 Zellner (1981 JK) was discovered on 1981 January 3 by E. Bowell at Anderson Mesa and is named in honor of Benjamin H. Zellner, an astronomer at the University of Arizona, Tucson. He brought to fruition the polarimetric-photometric method of albedo and diameter determination for asteroids. According to MPC (2017), JPL (2017), and WISE (Masiero et al., 2014), the absolute magnitude is $H = 12.75$ and $D = 8.050$ km. This leads to an optical albedo of $p_V = 0.22 \pm 0.03$.