

References

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LIGHTCURVES AND ROTATION PERIODS OF 111 ATE, 169 ZELIA, 421 ZAHRINGIA, AND 580 SELENE

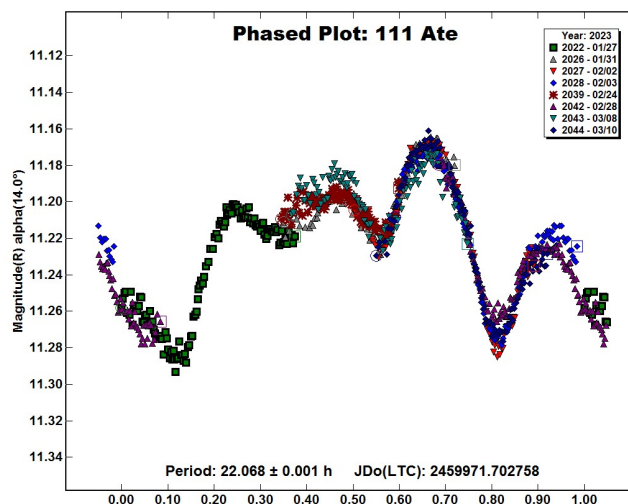
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Synodic rotation periods and amplitudes at their early 2023 oppositions are found for 111 Ate 22.068 ± 0.001 hours, 0.11 ± 0.01 magnitudes; 169 Zelia 14.539 ± 0.001 hours, 0.17 ± 0.01 magnitudes; 421 Zahringia 25.509 ± 0.002 hours, 0.14 ± 0.01 magnitudes; 580 Selene 9.494 ± 0.001 hours, 0.19 ± 0.01 magnitudes.

The new observations to produce the results reported in this paper were made at the Organ Mesa Observatory with a Meade 35 cm LX200 GPS Schmidt-Cassegrain, SBIG STL-1001E CCD, 60 to 120 second exposures, unguided, R filter for 11th magnitude 111 Ate, clear filter for all other targets. Image measurement and lightcurve construction were with *MPO Canopus* software with calibration star magnitudes for solar colored stars from the CMC15 catalog reduced to the Cousins R band. Zero-point adjustments of a few $\times 0.01$ magnitude were made for best fit. To reduce the number of data points on the lightcurves and make them easier to read, data points have been binned in sets of 3 with maximum time difference 6 minutes.

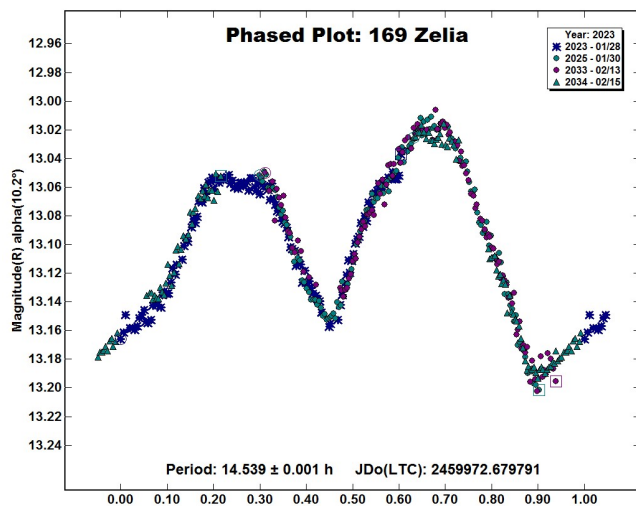
111 Ate. Previously published rotation periods for 111 Ate are by Harris and Young (1983), 22.2 hours; Behrend (2006web), 20 hours; Pilcher (2010), 22.072 hours; Pilcher (2011), also 22.072 hours; Szabó et al. (2016), 20.63 hours; Pál et al. (2020), 22.0497 hours. New observations on 8 nights 2023 Jan. 27 - March 10 provide an excellent fit to a lightcurve with period 22.068 ± 0.001 hours, amplitude 0.11 ± 0.01 magnitudes and four unequal maxima and minima per rotational cycle. This value is in good agreement with most of the previously found periods.



Number	Name	yyyy/mm/dd	Phase	LPAB	BPAB	Period(h)	P.E	Amp	A.E.
111	Ate	2023/01/27–2023/03/10	*14.0 – 6.7	156	– 3	22.068	0.001	0.11	0.01
169	Zelia	2023/01/28–2023/02/15	10.2 – 2.6	151	3	14.539	0.001	0.17	0.01
421	Zahringia	2009/07/12–2009/08/15	* 7.7 – 11.9	301	10	25.460	0.003	0.16	0.03
421	Zahringia	2022/12/20–2023/01/25	18.9 – 5.0	125	–10	25.509	0.002	0.14	0.01
580	Selene	2023/02/25–2023/03/19	8.4 – 1.8	180	4	9.494	0.001	0.19	0.01

Table I. Observing circumstances and results. The phase angle is given for the first and last date, unless a minimum (second value) was reached. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

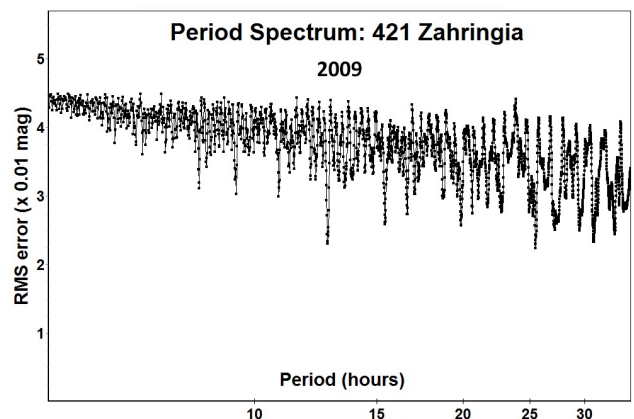
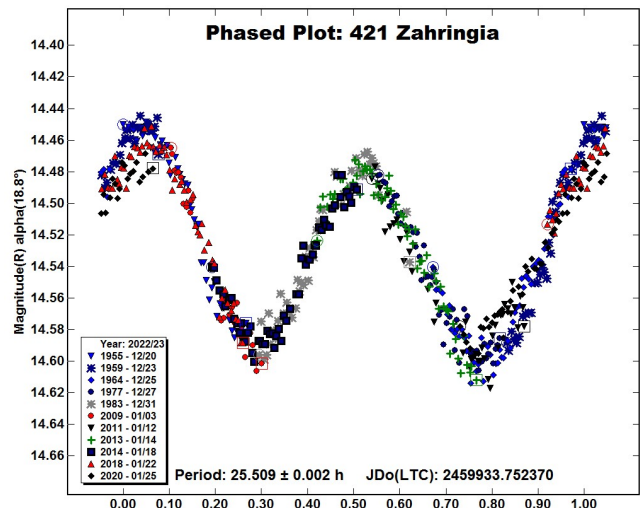
169 Zelia. Previously published rotation periods for 169 Zelia are by Harris *et al.* (1992), > 16 hours; Love (1997), 13.27 hours; Stephens and Pilcher (2009), 14.537 hours; and Behrend (2019web), 14.547 hours. New observations on four nights 2023 Jan. 28 - Feb. 15 provide an excellent fit to an unsymmetric bimodal lightcurve with period 14.539 ± 0.001 hours, amplitude 0.17 ± 0.01 magnitudes. This value is in very good agreement with Stephens and Pilcher (2009) and with Behrend (2019web), and rules out the periods by Harris *et al.* (1992) and Love (1997).

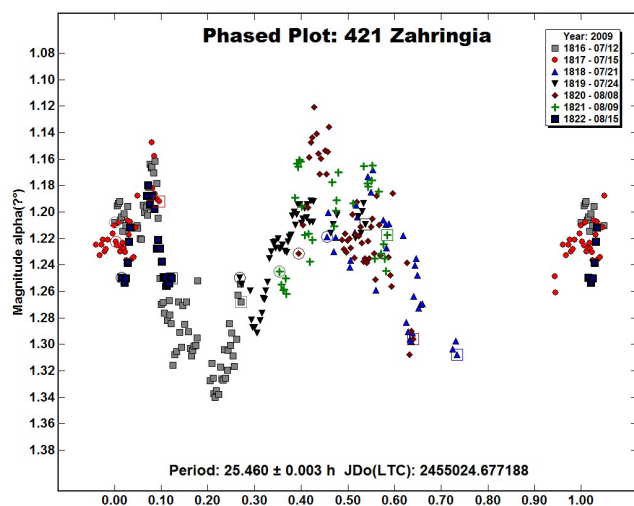


421 Zahringia. Earlier published rotation periods for 421 Zahringia are by Behrend (2001web and 2005web), 17.49 hours; Robinson (2002), 15.5 hours; and Warner (2010), 6.42 hours. This author obtained seven sessions on 421 Zahringia 2009 July 12-Aug. 15 in the poor weather of the local rainy/cloudy season. He was unable to fit the data to a shorter period and did not publish at that time.

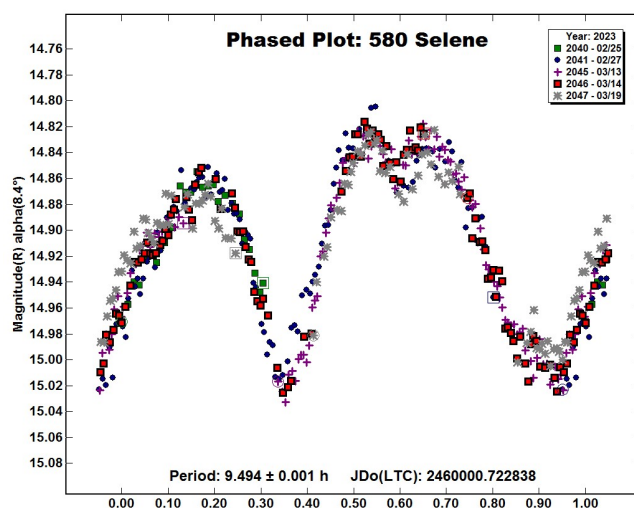
Several years later, Waszczak *et al.* (2015), using sparse data from the Palomar Transient Survey, found a period of 25.489 hours. Durech *et al.* (2020), on the basis of ATLAS photometry, obtained a sidereal period of 25.5041 hours. On the basis of a likely period near 25.5 hours, this author reexamined his uncalibrated year 2009 data. With *MPO Canopus* software the zero points were adjusted to best fit between 24.5 hours and 26.5 hours and a fit to a period of 25.46 hours, amplitude 0.16 magnitudes, was obtained. The lightcurve was very noisy with nearly 1/3 of the total phase coverage missing, but otherwise looked like 2/3 of a usual bimodal lightcurve. Attempts to fit the data to all of the other narrow minima on a period spectrum between 5 hours and 35 hours produced wildly unrealistic lightcurves.

Eleven sessions on 421 Zahringia were obtained 2022 Dec. 20 to 2023 Jan. 25, phase angles 18.9° to 5.0° . They provide an excellent fit to a slightly asymmetric bimodal lightcurve with period 25.509 ± 0.002 hours and amplitude 0.14 ± 0.01 magnitudes. The entire double period was covered and the split halves plot, not presented here but available from the author on request, shows that the two halves are identical except for the small change of amplitude commonly encountered with a phase angle change as large as was encountered here. This new result is very close to the values found by Durech *et al.* (2020) and to Waszczak *et al.* (2015) and rules out all of the earlier published shorter periods.





580 Selene. A lightcurve published by Behrend (2005web) provided a synodic period of 9.47 hours. Durech et al. (2019) utilized lightcurve inversion of sparse data to obtain a sidereal period of 9.49285 hours. New observations on five nights 2023 Feb. 25 - March 19 provide a good fit to an unsymmetric bimodal lightcurve with period 9.494 ± 0.001 hours, amplitude 0.19 ± 0.01 magnitudes. This value is in very good agreement with previously published periods.



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