

Figure 5: P_1 model rendering of (1443) Ruppina, fully illuminated using an artificial scattering law to better visualize the shape. In absence of information in the lightcurves to scale the model along the polar axis, only the pole-on view shown is constrained.

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LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2021 FEBRUARY-MARCH

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New CCD photometric observations of the Hilda member 1038 Tuckia were made at the Center for Solar System Studies in 2021 February and March. Analysis of the resulting data indicate that the asteroid may be in non-principal axis rotation (NPAR), i.e., tumbling.

CCD photometric the Hilda asteroid 1038 Tuckia were made at the Center for Solar System Studies (CS3) as part of an ongoing study of this family/group that is located between the outer main-belt and Jupiter Trojans in a 3:2 orbital resonance with Jupiter. The goal is to determine the spin rate statistics of the Hildas and to find pole and shape models when possible. We also look to examine the degree of influence that the YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) effect (Rubincam, 2000) has on distant objects and to compare the spin rate distribution against the Jupiter Trojans, which can provide evidence that the Hildas are more "comet-like" than main-belt asteroids.

Telescopes	Cameras
0.30-m $f/6.3$ Schmidt-Cass	FLI Microline 1001E
0.35-m $f/9.1$ Schmidt-Cass	FLI Proline 1001E
0.35-m $f/11$ Schmidt-Cass	SBIG STL-1001E
0.40-m $f/10$ Schmidt-Cass	
0.50-m $f/8.1$ Ritchey-Chrétien	

Table I. List of available telescopes and CCD cameras at CS3. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

Table I lists the telescopes and CCD cameras that are combined to make observations. Up to nine telescopes are commonly used for observations. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24-1.60 arcsec/pixel. All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposures varied depending on the asteroid's brightness.

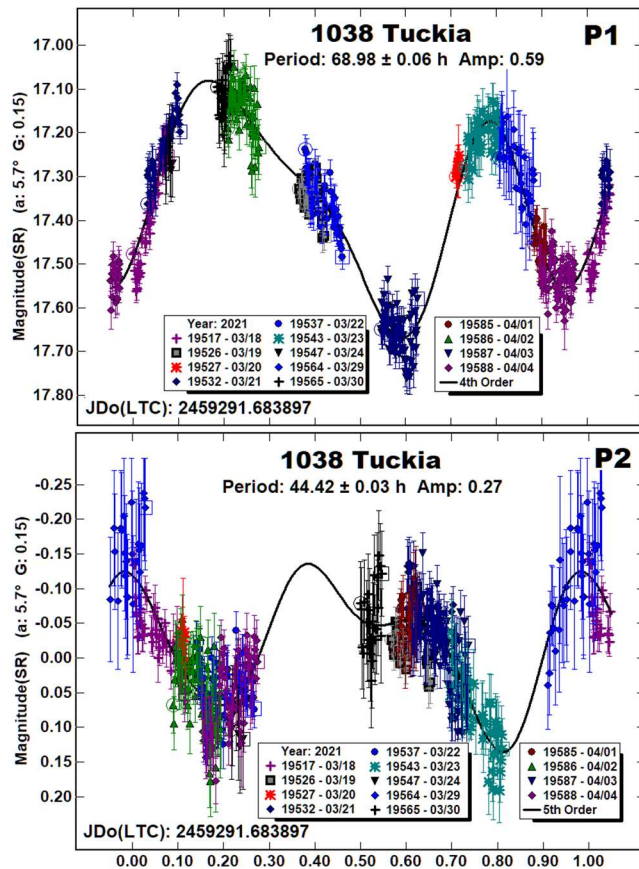
To reduce the number of times and amounts of adjusting nightly zero points, we use the ATLAS catalog r' (SR) magnitudes (Tonry et al., 2018). Those adjustments are usually $\leq \pm 0.03$ mag. The rare greater corrections may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction. Another cause may be selecting what appears to be a single star but is actually an unresolved pair.

Number	Name	20yy/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
1038	Tuckia	21/03/18-04/04	5.7, 8.7	154	10	^T 68.98 44.42	0.06 0.03	0.59 0.29	0.04 0.04
1038	Tuckia	19/01/26-02/17	19.5, 16.7	194	-11	^T 177.5 9.55	0.3 0.01	0.21 0.07	0.02 0.01

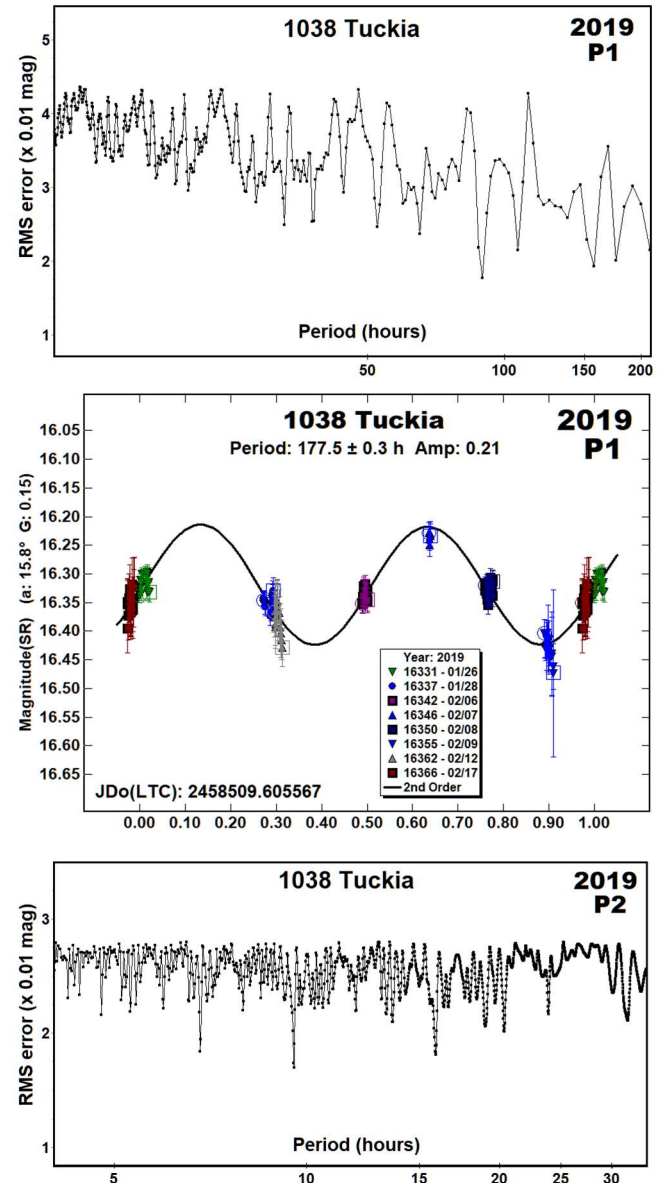
Table II. Observing circumstances. ^T The dominant period of a tumbling asteroid. The phase angle (α) is given at the start and end of each date range. L_{PAB} and B_{PAB} are the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984).

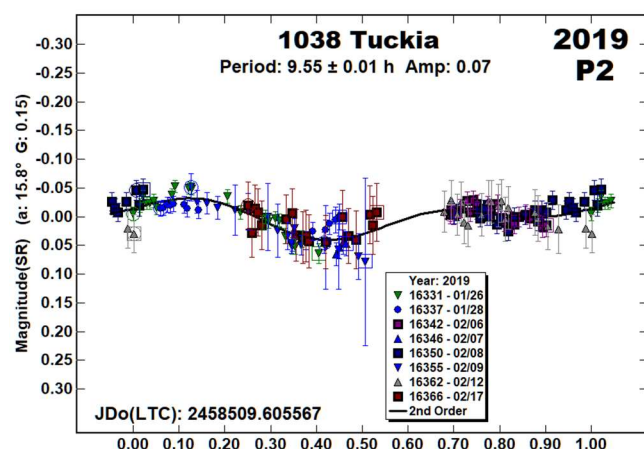
The Y-axis values are ATLAS SR “sky” (catalog) magnitudes. The two values in the parentheses are the phase angle (α) and the value of G used to normalize the data to the comparison stars used in the earliest session. This, in effect, made all the observations seem to be made at a single fixed date/time 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*.

1038 Tuckia. Dahlgren *et al.* (1998) reported a single-period result of 23.2 h, close to being Earth-day commensurate. Observations we made in 2019 (Warner and Stephens, 2019) led to a period of 18.020 h and amplitude of 0.21 mag.



The 2021 data from March to April led to the conclusion that the asteroid is tumbling (Pravec *et al.*, 2005; 2014). The two periods are best guesses since *MPO Canopus* cannot fully analyze tumbling asteroids.





These results prompted a return to the 2019 data, which used V magnitudes derived from Sloan SG and SR magnitudes. The values for the comps were reset to use SR magnitudes from the ATLAS catalog (Tonry et al., 2018) and reset the nightly zero points to 0. As a result, none of the individual sessions needed more than 0.01 mag adjustment to the zero point.

The number of data in 2019 was about 25% of that in 2021, so getting similar results was very unlikely, especially since the Fourier analysis was limited to only second order. Forcing the 2019 data to the most recent results gave unconvincing fits. Instead, we found a dominant period of $P_1 = 177.5$ h and a second period $P_2 = 9.55$ h.

The 177-hour period could be the result of a fit by exclusion and so a solution between 40-50 h, still bimodal, might also be possible. When limiting the search to that range, the fits of the slopes of the data to the Fourier curve on individual nights were considerably worse, even if taking tumbling into account.

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