

Acknowledgements

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SPIN-SHAPE MODEL FOR 50 VIRGINIA

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We present a shape and spin axis model for main-belt asteroid 50 Virginia. The model was achieved with the lightcurve inversion process, using combined dense photometric data acquired from seven apparitions between 1995-2020 and sparse data from USNO Flagstaff. Analysis of the resulting data found a sidereal period $P = 14.31233 \pm 0.00005$ h and two mirrored pole solutions (ecliptic coordinates) at $(\lambda, \beta) = (112^\circ, 41^\circ)$ and $(295^\circ, 47^\circ)$ with an uncertainty of ± 10 degrees.

The minor planet 50 Virginia was observed for seven oppositions from 1995 to 2020, mainly by co-author Pilcher at Organ Mesa Observatory. The 1995 legacy data was downloaded a few years ago from the Standard Asteroid Photometric Catalogue by Piironen et al. (2001), hosted at the University of Helsinki but no longer available online. Moreover, we used sparse data from the USNO Flagstaff Station (MPC Code 689), downloaded from the Asteroids Dynamic Site (AstDyS-2, 2020).

The observational details of the dense data sets are reported in Table I with the mid-date, number of the lightcurves used for the inversion process, and longitude and latitude of the phase angle bisector (L_{PAB} , B_{PAB}).

Reference	Mid date	# LC	L_{PAB}°	B_{PAB}°
Shevchenko (1997)	1995-09-20	8	352	0
Pilcher (2009)	2008-09-25	9	7	-1
Pilcher (2011) (*)	2011-03-30	1	212	2
Pilcher (2016)	2016-06-16	7	259	4
Pilcher (2018)	2018-01-13	8	90	-4
Pilcher (2019)	2019-04-23	6	175	0
Pilcher (2020)	2020-05-15	5	234	3

Table I. Observational details for the data used in the lightcurve inversion process for 50 Virginia.* Published on alcddef.org web site.

Lightcurve inversion was performed using *MPO LCInvert* v.11.8.2.0 (BDW Publishing, 2016). For a description of the modeling process, see *LCInvert Operating Instructions Manual*, Durech et al. (2010 and references therein). In order to reduce the overall processing time, Pilcher’s dense data were binned at a time interval of 5 minutes.

Figure 1 shows the PAB longitude/latitude distribution for the dense and sparse data used in the lightcurve inversion process. Figure 2 (top panel) shows the sparse photometric data distribution (intensity vs JD) and (bottom panel) the corresponding phase curve (reduced magnitudes vs phase angle).

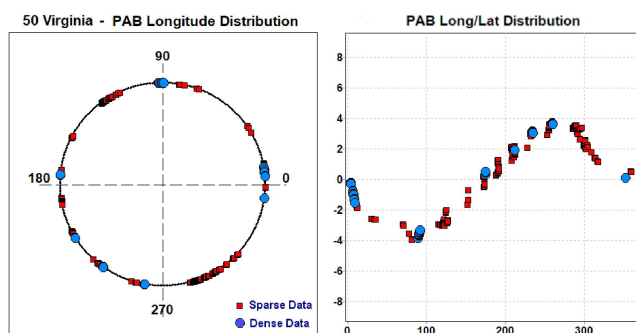


Figure 2: PAB longitude and latitude distribution of the data used for the lightcurve inversion model.

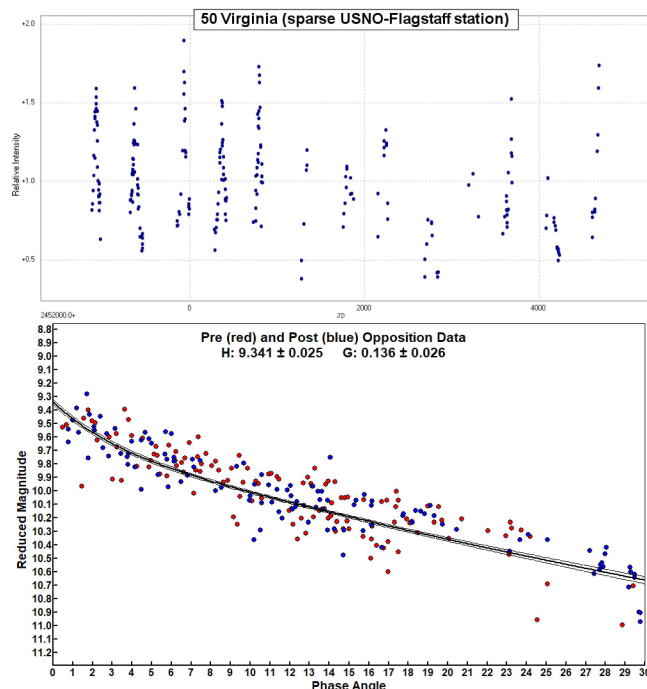


Figure 3: Top: sparse photometric data point distribution from (689) USNO Flagstaff station (relative intensity vs Julian Day). Bottom: phase curve obtained from sparse data (reduced magnitude vs phase angle).

In the analysis, the processing weighting factor was set to 1.0, 0.7 and 0.3, respectively, for Pilcher's data, Shevchenko's data, and the sparse data. The "dark facet" weighting factor was set to 0.5 to keep the dark facet area below 1% of total area and the number of iterations was set to 50.

The sidereal period search was started around the average of the synodic periods found in the asteroid lightcurve database (LCDB; Warner et al., 2009). We found one isolated sidereal period with a Chi-Sq value within 10% of the lowest Chi-Sq (Figure 3).

The pole search was started using the "medium" search option (312 fixed pole positions with 15° longitude-latitude steps) and the previously found sidereal period set to "float". From this step we found two roughly mirrored lower Chi-Sq solutions (Figure 4) separated by about 180° in longitude at ecliptic longitude-latitude pairs (105°, 45°) and (300°, 45°).

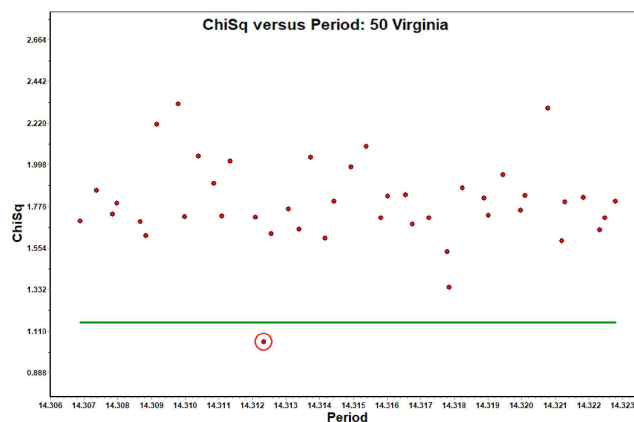


Figure 4: The period search for 50 Virginia shows one isolated sidereal period with Chi-Sq values within 10% of the lowest value.

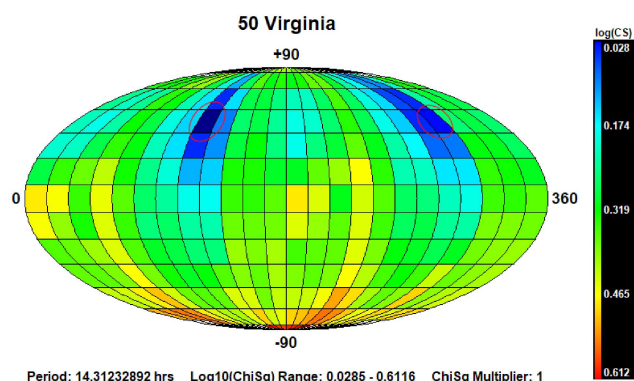


Figure 5: Pole search distribution. The dark blue region indicates the smallest Chi-Sq value while the dark red region indicates the largest.

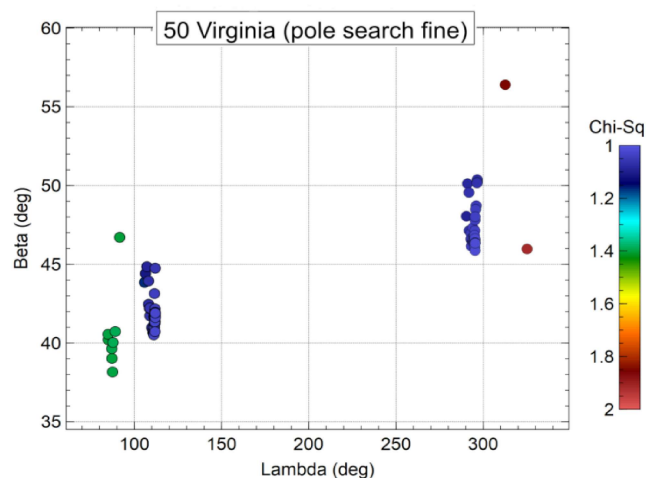


Figure 6: The "fine" pole search shows two clustered solutions centered at the ecliptic longitude/latitude (111°, 42°) and (295°, 47°) with radius approximately of 10° and Chi-Sq values within 10% of the lowest value.

The subsequent "fine" search option (49 fixed pole steps with 10° longitude-latitude pairs set to "float") allowed us to refine the position of the pole (Figure 5). The analysis shows two sets of clustered solutions within 10° of radius that had Chi-Sq values within 10% of the lowest value, centered at ecliptic longitude-latitude (111°, 42°) and (295°, 47°).

λ°	β°	Sidereal Period (hours)	Chi-Sq	RMS
111	42	14.31233 ± 0.00005	1.02055	0.0181
295	47		1.01863	0.0181

Table II. The two spin axis solutions for 50 Virginia (ecliptic coordinates) with an uncertainty of ± 10 degrees. The sidereal period is the average of the two solutions found in the pole search.

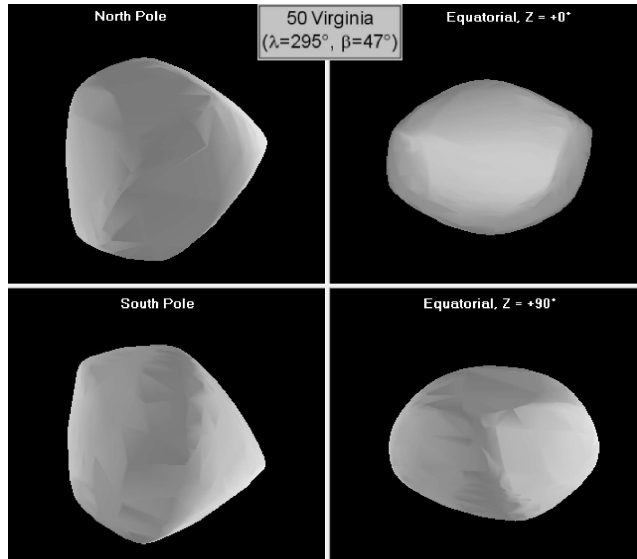


Figure 7: The shape model for 50 Virginia ($\lambda = 295^\circ$, $\beta = 47^\circ$).

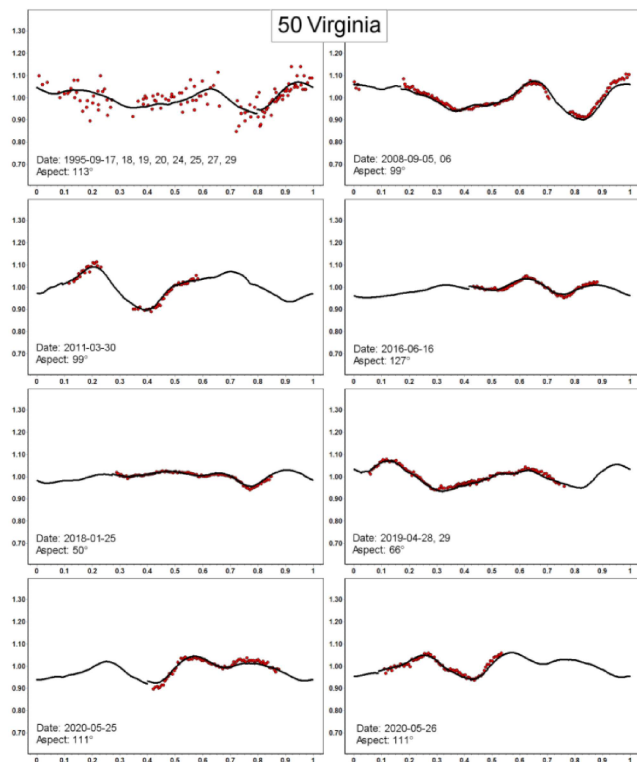


Figure 8: Model fit (black line) versus observed lightcurves (red points) for ($\lambda = 295^\circ$, $\beta = 47^\circ$) solution.

The two best solutions (lower Chi-Sq) are reported in Table II. The sidereal period was obtained by averaging the two solutions found in the pole search process. Typical errors in the pole solution are $\pm 10^\circ$ and the uncertainty in sidereal period has been evaluated as a rotational error of 20° over the total time span of the dense data set. Figure 6 shows the shape model (second solution with lower Chi-Sq) while Figure 7 shows the fit between the model (black line) and some observed lightcurves (red points).

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