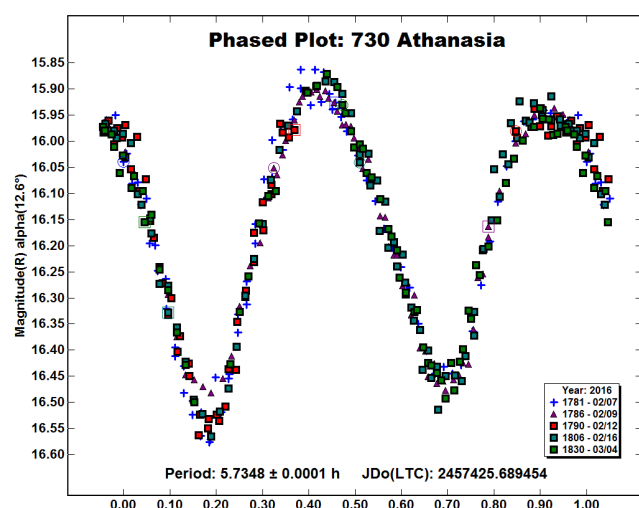




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SHAPE AND SPIN AXIS MODEL FOR 53 KALYPSO

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We present shape and spin axis model for main-belt asteroid 53 Kalypso. The model was achieved with the lightcurve inversion process, using combined dense photometric data acquired from six apparitions between 1979-2012 and sparse data from USNO Flagstaff. Analysis of the resulting data found a sidereal period $P = 9.035058 \pm 0.000008$ hours and two mirrored pole solutions at $(\lambda = 168^\circ, \beta = 12^\circ)$ and $(\lambda = 349^\circ, \beta = 8^\circ)$, with an error of ± 5 degrees.

The main-belt asteroid 53 Kalypso has been observed for six apparitions from 1979 to 2012 over a wide range of phase angles and phase angle bisectors. Dense photometric data were mainly downloaded from the Asteroid Photometric Catalogue (APC, 2001) by Lagerkvist et al. (2001) and from the Asteroid Light Curve Database (ALCDEF, 2016). The observational circumstances over six apparitions are reported in Table I.

Year	#LCs	Data Points	PA°	PABL°	PABB°	Ref.
1979	1	10	6	23	-6	(1)
1981	3	157	3/8	191	5	(2) (3)
2006	8	204	8/22	126/131	-2/0	(4)
2009	7	1625	18/4	73/76	-6.8	(5)
2011	14	2734	13/18	223/226	6	(6)
2012	7	800	7/11	297/296	3/2	(7)

Table I. Observational circumstances for 53 Kalypso over six apparitions, a total of 40 lightcurves were used for lightcurve inversion analysis. PA, PABL and PABB are, respectively, the phase angle, phase angle bisector longitude and latitude. References: (1) Harris et al. (1989); (2) Debehogne et al. (1982); (3) Surdej et al. (1981); (4) Pray et al. (2006); (5) Pilcher (2010); (6) Pilcher (2011); (7) Audejean web.

In order to improve the solution we have also used sparse data from USNO Flagstaff Station, as has been shown by Kaasalainen (2004), Āurech et al. (2009). Sparse data were taken from the Asteroids Dynamic Site (AstDyS-2, 2016) for a total of 237 photometric data points. Figure 1 shows the phase angle bisector (PAB) longitude and latitude distribution for dense and sparse data used for the lightcurve inversion model. Figure 2 shows the distribution of the sparse photometric data points from (689) USNO Flagstaff station.

Lightcurve inversion was performed using *MPO LCInvert* v.11.7.2.1. Software (Bdw Publishing, 2012), which implements algorithms and code provided by Mikko Kaasalainen and Josef Āurech.

All data from forty dense lightcurves and one sparse dataset were imported in *LCInvert* for analysis, assigning them a different weighting factor, from 1.0 for best dense data to 0.3 for sparse data.

The period search was started around the average of the synodic periods previously published in literature. The search process found a well-defined sidereal period with lowest chi-square value (Figure 3).

The pole search was started using the “medium” search option (312 fixed pole position with 15° longitude-latitude steps) and the previously found sidereal period set to “float”. The “dark facet” weighting factor was set to 0.7 to keep the dark facet area below 1% of total area and the number of iterations of processing was set to 75. In this step we found two rough solutions with lower chi-square values differing by 180° in longitude. See Figure 4 for log(chi-square) values distribution, where the darker blue indicates the better solutions, while orange-red the worst ones.

The pole search process was then refined with “fine” option (49 fixed pole steps with 10° longitude-latitude pairs) and previous period/longitude/latitude set to “float”. Figure 5 shows the distribution of the better solutions with chi-square values below 5% than the others. These solutions are clustered within 5 degrees in longitude-latitude pairs and the two mirrored best solutions (lower chi-square) are reported in Table II. Typical errors in the pole solution are ± 5 degrees and the uncertainty in sidereal period has been evaluated as a rotational error of 10° over the total time-span of the dense observations.

λ°	β°	Sidereal Period (h)	ChiSq	RMS
168	12	9.035058 ± 0.000008	1.6513	0.0169
349	8		1.6612	0.0170

Table II. The two best spin axis solutions for 54 Kalypso. The sidereal period was the average of the two solutions found in the pole search process.

Figure 6 shows the shape model (first solution) while Figure 7 shows the fit between the model (black line) and observed lightcurves (red points).

The model and the data will be stored in Database of Asteroid Models from Inversion Techniques (DAMIT, 2016).

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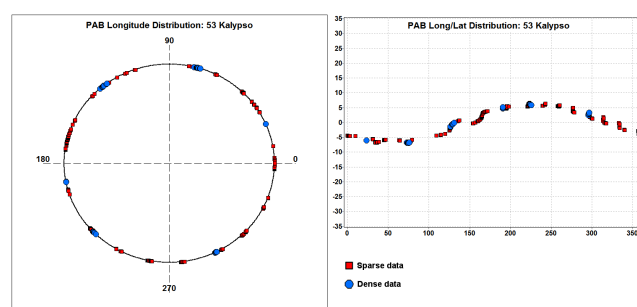


Figure 1. PAB longitude and latitude distribution of the data used for lightcurve inversion model.

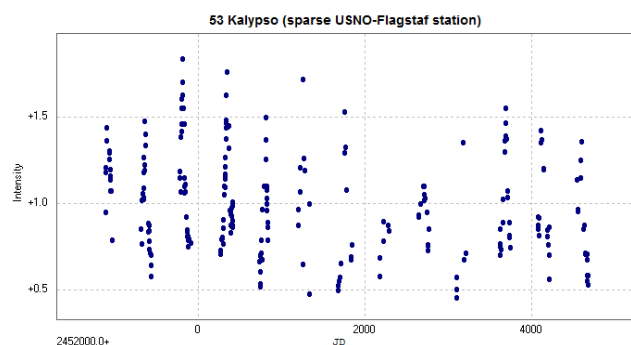


Figure 2. Sparse photometric data points from (689) USNO Flagstar station.

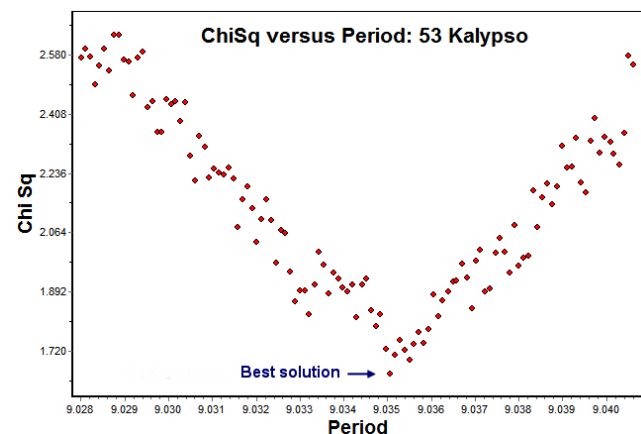


Figure 3. The period search for 53 Kalypso shows a well-defined lowest chi-square minimum.

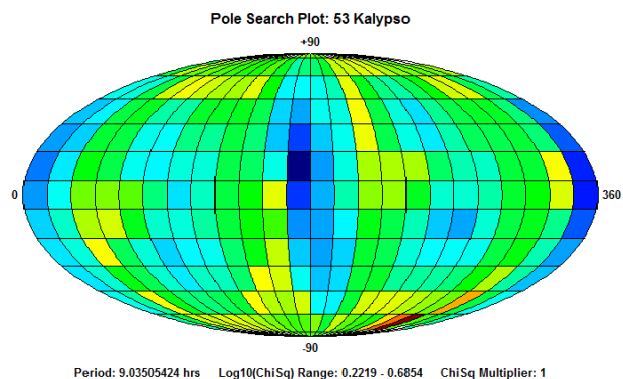


Figure 4. The pole search plot. Darker blue indicates the better solutions, while orange-red the worst ones.

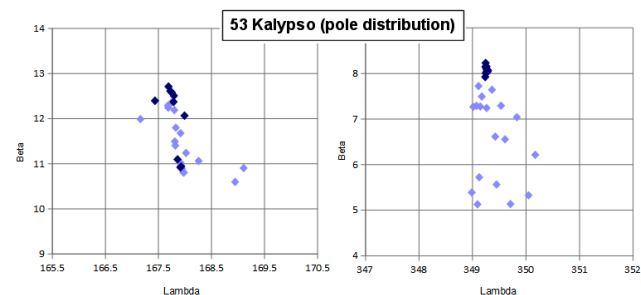


Figure 5. The distribution of the two clustered solutions obtained with "fine" option and chi-square values below 5% than the others. The lowest chi-square solutions are in dark blue.

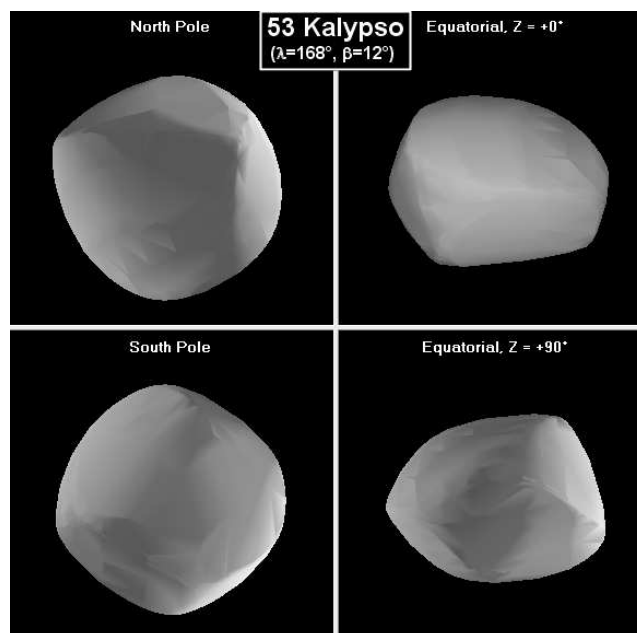


Figure 6. The shape model for 53 Kalypso ($\lambda = 168^\circ$, $\beta = 12^\circ$).

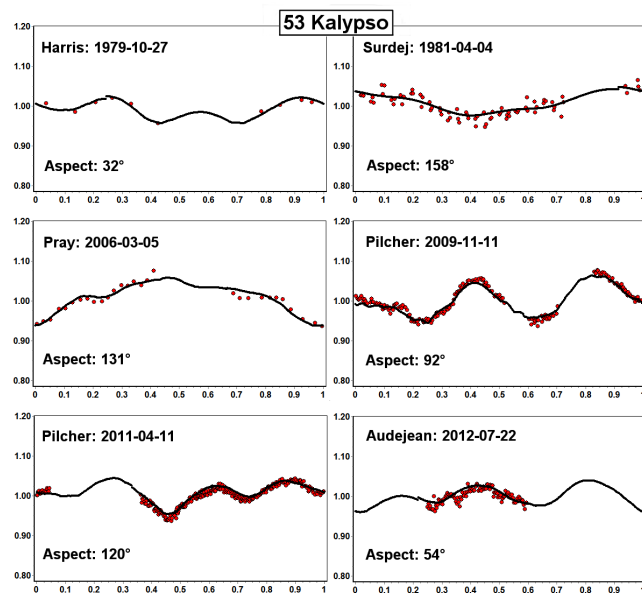


Figure 7. Model fit (black line) versus observed lightcurves (red points). Note the wide variety of lightcurve shapes.