LIGHTCURVE INVERSION FOR 65 CYBELE

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We present a shape and spin axis model for main-belt asteroid 65 Cybele. The model was obtained with lightcurve inversion process, using combined dense photometric data obtained during fifteen apparitions from 1977 to 2014 and sparse data from USNO Flagstaff. Analysis of the resulting data found a sidereal period P = 6.081434 ± 0.000005 hours and two possible pole solutions: (λ = 208°, β = –7°) and (λ = 27°, β = –14°) with an error of ±15 degrees.

The main-belt asteroid 65 Cybele has been observed for fifteen apparitions from 1977 to 2014 with a variety of phase angles and phase angle bisectors. Dense photometric data were downloaded from the Asteroid Photometric Catalogue (APC) by Lagerkvist *et al.* (2001) and from the Asteroid Light Curve Database (ALCDEF, 2014). The observational circumstances for the fifteen apparitions are reported in Table I.

Year	#LCs	Data Points	PA°	PABL°	PABB°	Ref.
1977	3	150	2/3	332	0	(1)
1978	1	9	-3	38	-4	(1)
1982	11	92	17/16	213/219	3/4	(2)
1983	11	119	18	299/314	3/1	(2)
1984	2	29	17/12	10/16	2/3	(2)
1985/6	3	91	11/12	73	-4	(2)
1987	1	44	4	126	-2	(3)
1988	1	63	3	189	2	(3)
1989	1	28	4	272	4	(4)
1994	2	44	7/5	165	0	(5)
2007	2	56	5	182	2	(6)
2009	7	1590	12/2	345	-1	(7)
2010/1	5	1234	12/15	46/49	-4	(6)(8)
2011/2	6	1841	11/1	99	-4	(9)
2014	5	1030	2/8	264	4	(10)

Table I. Observational circumstances for 65 Cybele over fifteen apparitions. A total of 61 lightcurves were used for lightcurve inversion analysis. PA, PABL and PABB are, respectively, the phase angle, phase angle bisector longitude and latitude. References: (1) Schober *et al.* (1980); (2) Weidenschilling *et al.* (1987); (3) Weidenschilling *et al.* (1990); (4) Gil Hutton (1990); (5) Shevchenko *et al.* (1996); (6) Behrend web; (7) Pilcher and Stephens (2010); (8) Pilcher (2011); (9) Pilcher (2012); (10) Pilcher (2014)

In order to improve the solution, we also used sparse data from USNO Flagstaff Station, as has been shown by Kaasalainen (2004) and Ďurech *et al.* (2009). Sparse data were taken from the Asteroids Dynamic Site (AstDyS-2, 2014) for a total of 484 data points (Figure 2). Figure 1 (left) shows the phase angle bisector (PAB) longitude distribution for dense and sparse data points from 689 USNO Flagstaff station. Figure 1 (right) shows the PAB latitude distribution.

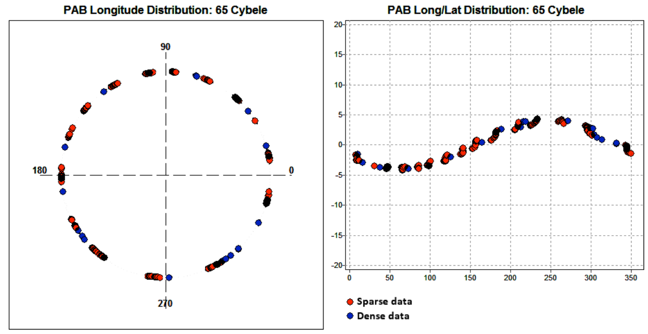

Figure 1. PAB longitude and latitude distribution of the data used for lightcurve inversion model. Dense data are in blue and sparse data are in red.

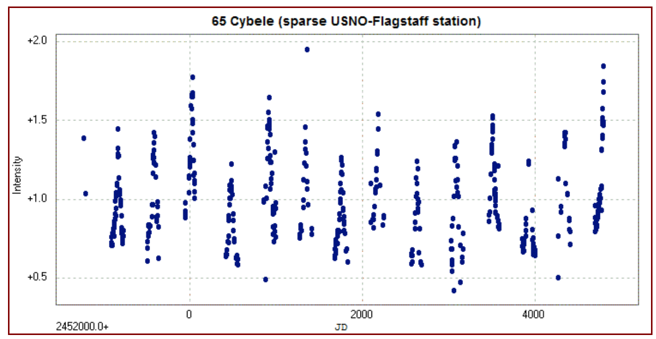

Figure 2. Sparse photometry data points from 689 USNO Flagstaff station.

Lightcurve inversion was performed using *MPO LCInvert* v.11.1.0.2 (Bdw Publishing), which implements algorithms and code provided by Mikko Kaasalainen and Josef Ďurech. For guidelines and a description of the modeling process see the *MPO LCInvert* operating instructions manual and Warner *et al.* (2008).

All data from the sixty-one dense lightcurves and one sparse dataset were imported in *MPO LCInvert* for analysis, assigning them a different weighting factor, from 1.0 for the dense data to 0.3 for sparse data. The period search was started around the average of the synodic periods previously published in the literature. The search process found an isolated sidereal period with lowest chi-square value (Figure 3).

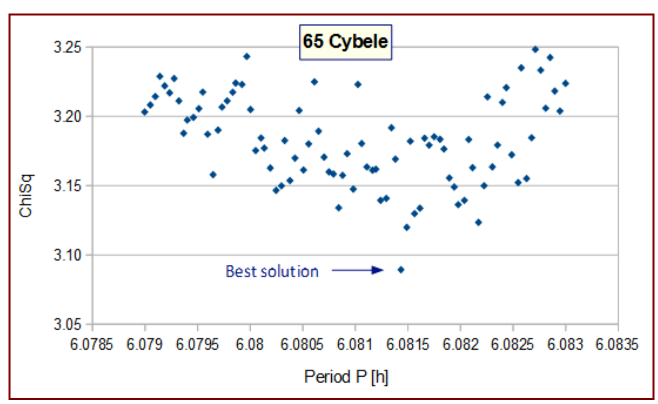

Figure 3. The period search for 65 Cybele shows an isolated minimum.

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 allowed to "float." The "dark facet" weighting factor was set to 1.8 to keep the dark facet area below 1% of total area and the number of iterations of processing was set to 75.

Data analysis shows the two lower chi-square solutions with a possible ambiguity for λ ± 180° at (λ = 208°, β = –7°) and (λ = 27°, β = –14°) with a sidereal period $P = 6.081434 \pm 0.000005$ h; see Figure 4 for log(chi-square) values distribution.

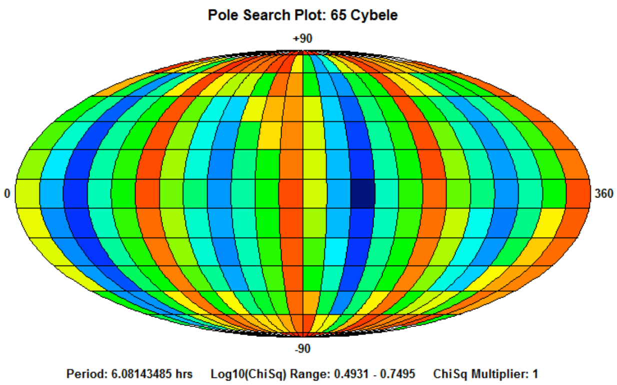

Figure 4. The pole search plot. Darker blue indicates the better solutions while red indicates the least-favorable solutions.

Typical errors in the pole solution are ±15 degrees and the uncertainty in period has been evaluated as a rotational error of 15° over the total time-span of the dense observations. This pole solution agrees with those reported by Pilcher (2011) using the simple amplitude-aspect method and found by Durech (private communication) using lightcurve inversion method with a similar dataset.

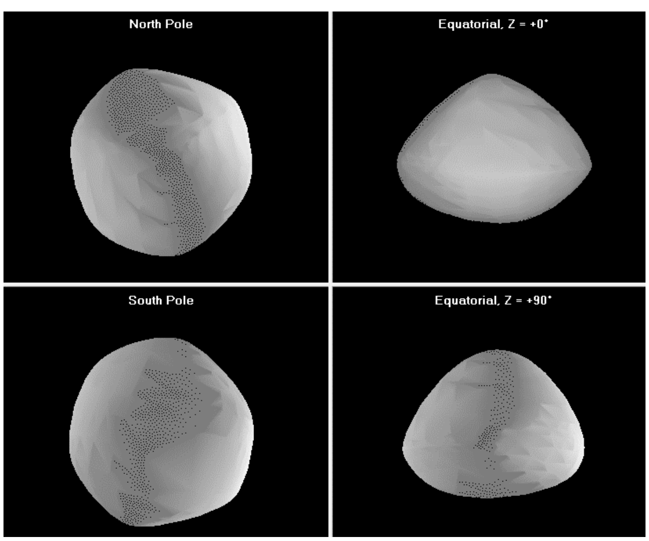

Figure 5. The shape model for 65 Cybele (λ = 208°, β = –7°).

Figure 5 shows the shape model (first solution) while Figure 6 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; Ďurech 2015).

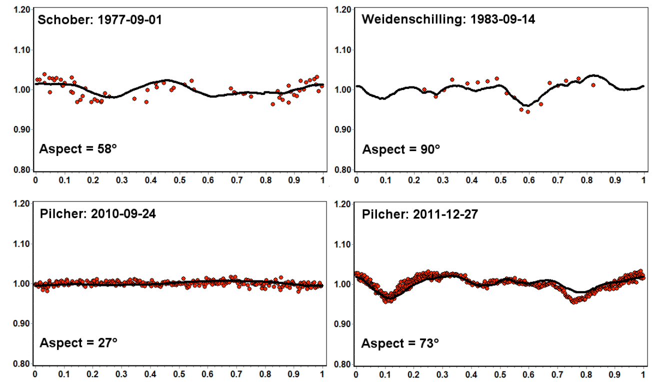

Figure 6. Model fit (black line) versus observed lightcurves (red points)

Acknowledgement

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