Exploring asteroid shape model uncertainties in occultation fitting

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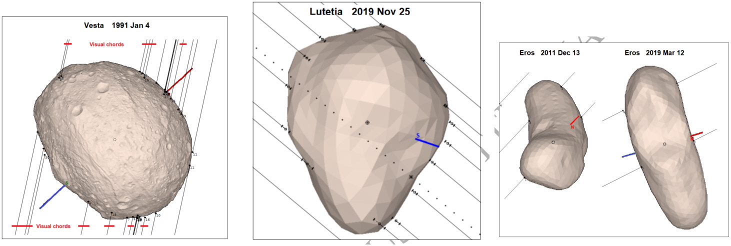
ESOP XLII, 16-17 September 2023, Armagh

Occultations significance: Precise size determinations for asteroids

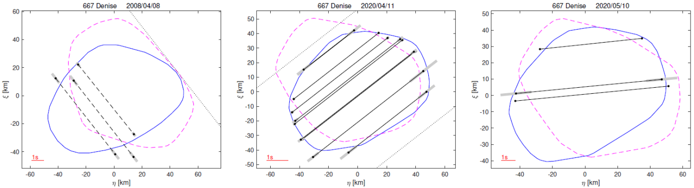


Herald et al. 2020

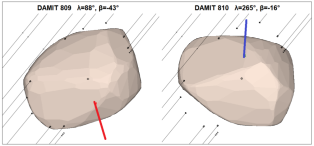
Vesta:	Lutetia:	Eros:
D_{DAWN} = 521.5 km D_{occult} = 524 km difference: 0.5%	$D_{Rosetta}$ = 98 km D_{occult} = 100 km difference: 2%	D_{NEAR} = 16.8 km D_{occult} = 16.7 km difference: 0.06%

Close negative observations are also important.
Ellipsoids often invalid as shape approximation.

Occultations significance: Removing ambiguity in spin pole solutions



Asteroid 667 Denise. Mirror pole solution can be rejected.
Diameter of equivalent volume sphere: 83 ± 2 km.

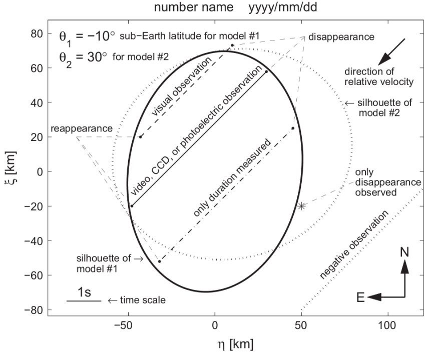


Asteroid 489 Comacina. Second pole solution can be rejected. D = 128.0 ± 4.3.

Marciniak et al. 2021; Herald et al. 2020; Hanuš et al. 2016

Uncertainty of the shape model in size determination

- Free parameters in asteroid shape models fitting to occultations:
  - size of the 2D silhouette,
  - position of the body center on the fundamental plane.
- Asteroid size - diameter of equivelent volme sphere.
- Formal uncertainites of asteroid sizes from occultations fitting is based on timing uncertainties only.
- But: What is the influence of the shape model uncertainty?



Uncertainty of the shape model

- Shape models from (relative) lightcurve inversion are often insensitive to vertical stretch along spin axis.
- This size should be smallest, since the relaxed rotation is around the axis of greatest inertia (but: small slow rotators tend to enter excited rotation mode).
- Models too much stretched along rotation axis can be excluded in the modelling process as non-physical.
- Models too much squeezed along rotation axis - what is "too much"?

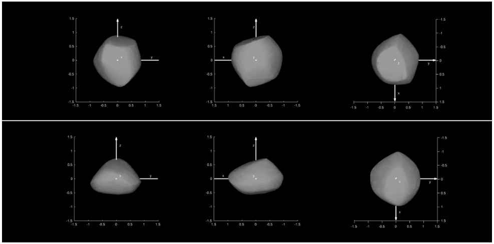


Fig. 1: Two versions of shape model 2 for (566) Stereoskopia: without shape regularization (top) and with regularization applied (bottom), using the same starting parameters otherwise. The three views show, from left to right: two equatorial views 90° apart in phase, and the pole-on view (rightmost one). Note that the pole-on silhouettes generally agree between two versions of the shape model, as it is the equatorial cross-section that effectively influences the lightcurves most.

Marciniak et al., accepted to *Astronomy Astrophys.*

Example of extreme shape flattening

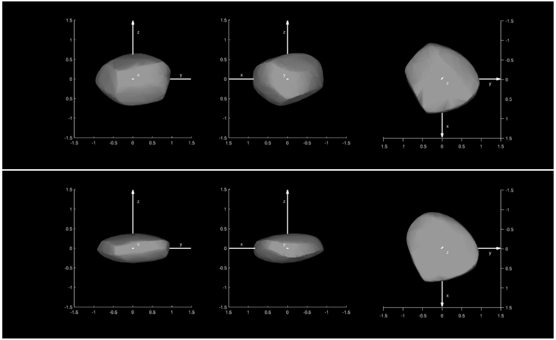
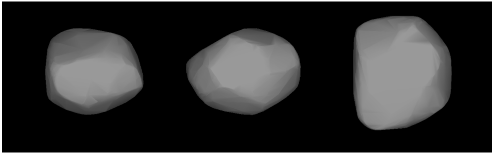


Fig. 2: Two versions of shape model 2 for (412) Elisabetha. High regularization model (bottom) still fits the lightcurves on formally acceptable level, but is unrealistically flat. See Section 4 for discussion.

Marciniak et al., accepted to *Astronomy Astrophys.*

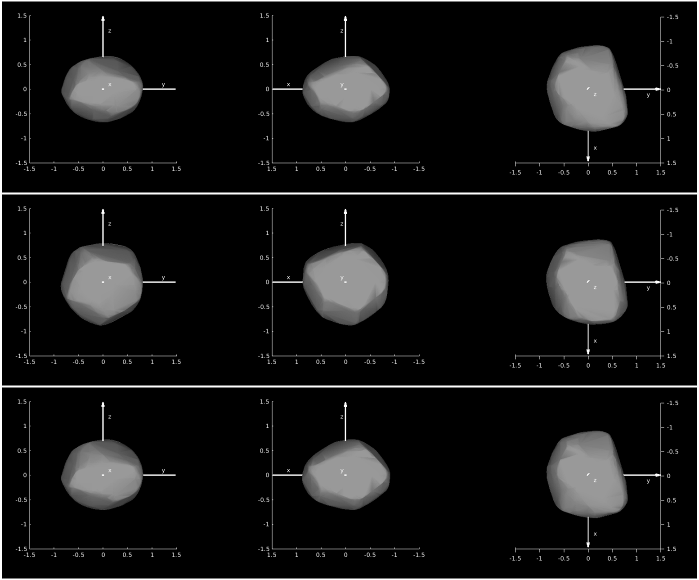
New approach

- Modified lightcurve inversion method, with inertia regularisation
- Based on the fact that shape model cross-section viewed from the pole direction should be largest
- Created 10 versions of each shape model with both flatter and rounder shapes, using various weights of inertia regularisation.
- All shapes required to fit lightcurves similarly well as the nominal one, and to be physical.
- Each version of the model was fitted to occultations.
- Main result: a pool of plausible sizes, their scatter being a better measure of size uncertainty.
- Sometimes this scatter was smaller than RMS of the single fit: uncertainty here is dominated by occultation timing errors or convex approximation of the shape.



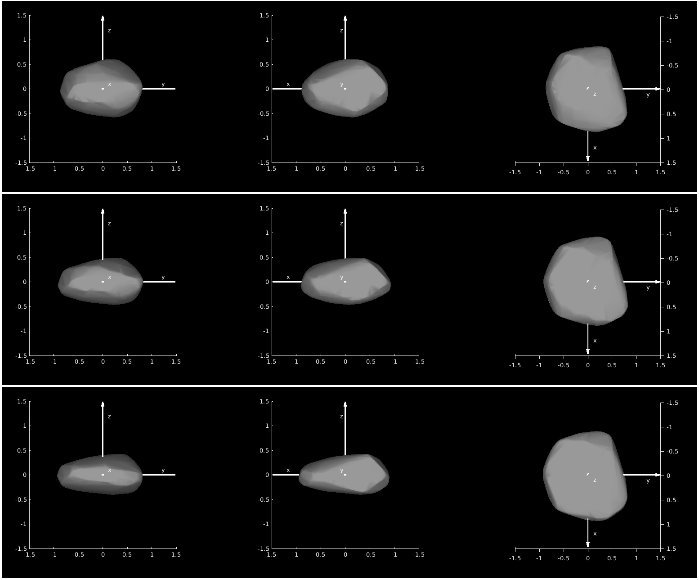
Asteroid: (426) Hippo, Model: nominal, λ=223°, β=-89°, P=67.5041 hours

Models with various inertia regularisation weights



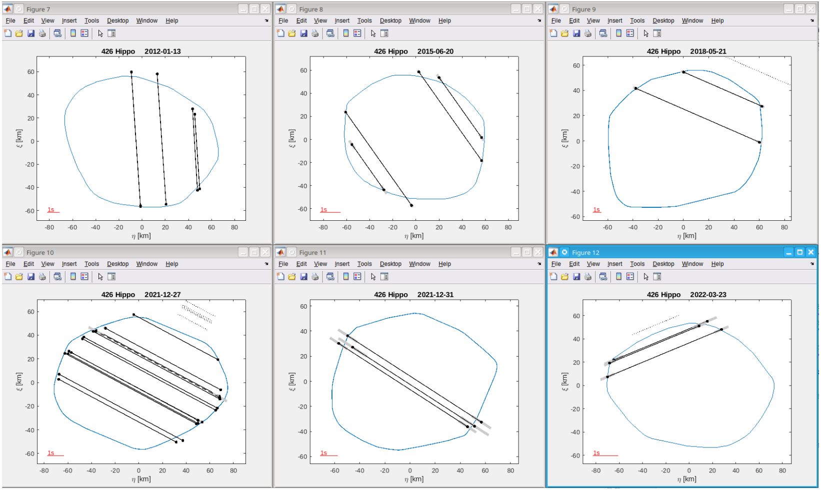
Rounder shape models

Models with various inertia regularisation weights



Flatter shape models

Models with various inertia regularisation weights fitted to occultations



Asteroid: (426) Hippo, Model: nominal, λ=223°, β=-89°, P=67.5041 hours
Size: 121.99, RMS: 4.21

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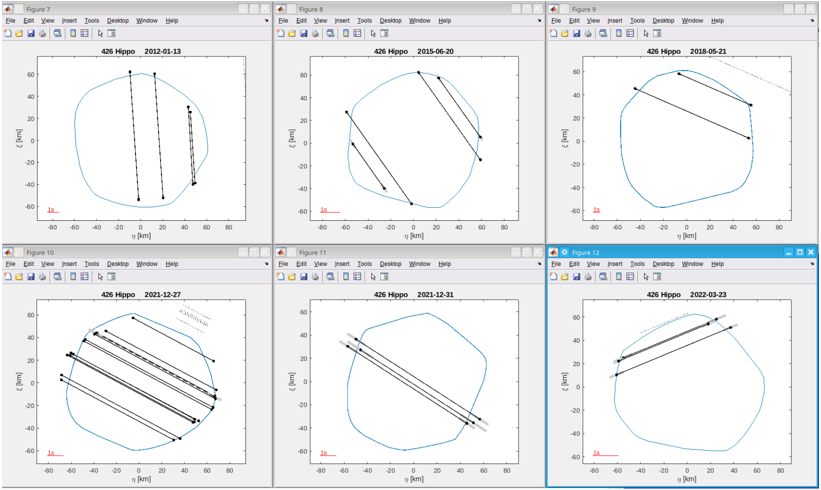
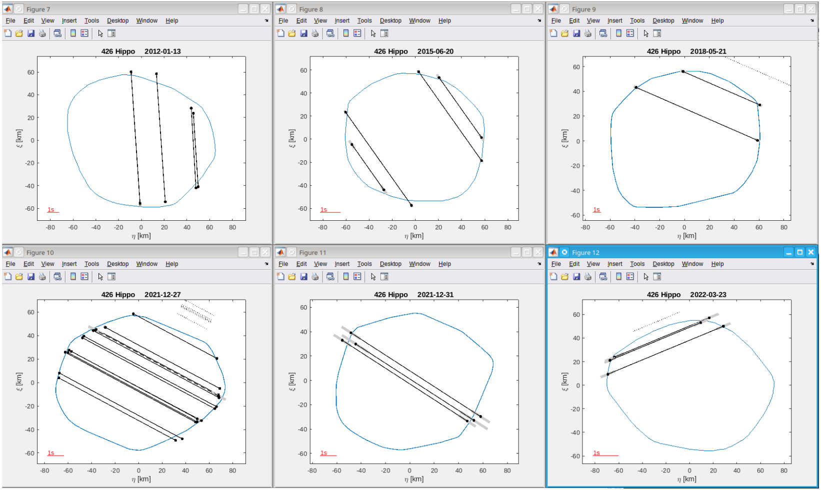
Models with various inertia regularisation weights fitted to occultations



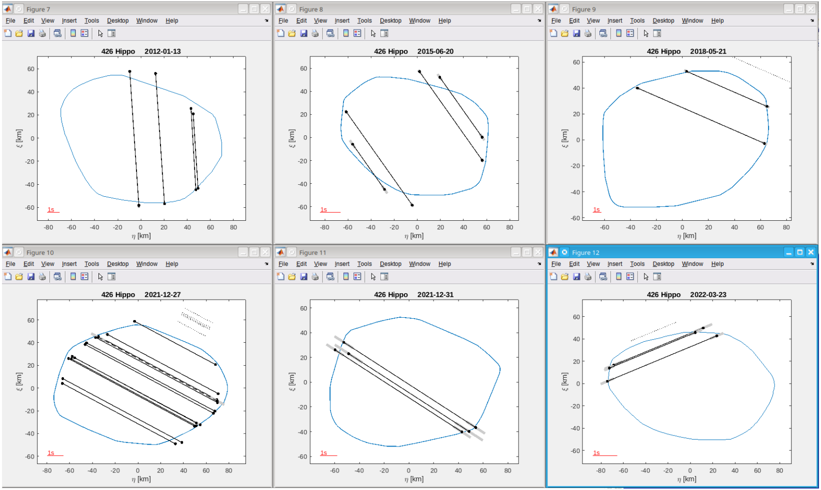
Size: 118.69, RMS: 5.49

Models with various inertia regularisation weights fitted to occultations



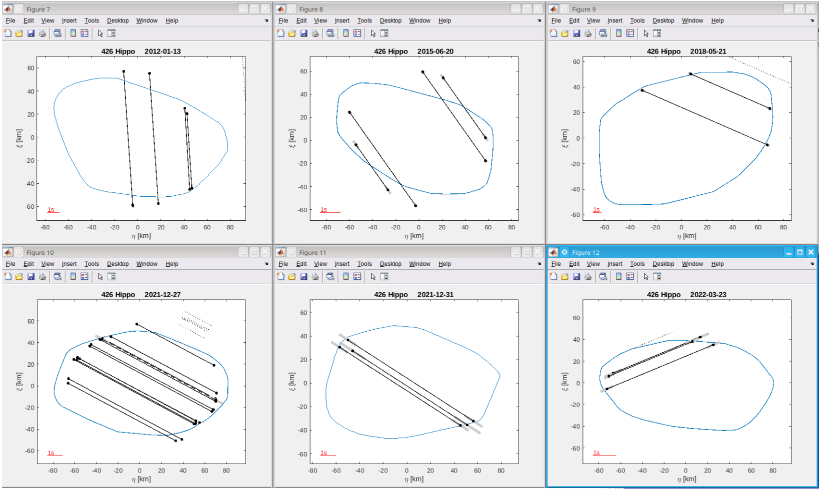
Size: 122.09, RMS: 3.99

Models with various inertia regularisation weights fitted to occultations



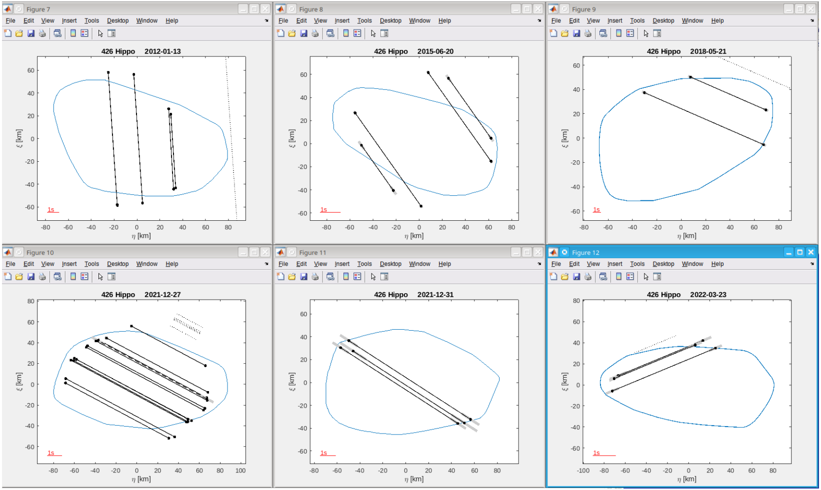
Size: 122.36, RMS: 6.34

Models with various inertia regularisation weights fitted to occultations



Size: 121.99, RMS: 11.14

Models with various inertia regularisation weights fitted to occultations



Size: 119.68, RMS: 14.62

Results for sizes

Table 1: Spin parameters and sizes of asteroid models obtained in this work. The columns contain asteroid name, J2000 ecliptic coordinates λ_p, β_p of the spin axis solution, and the sidereal rotation period P, with mirror pole solution in the second row. Next follow the main characteristics of the lightcurve dataset (same for both pole solutions): observing span in calendar years, number of apparitions (N_{app}) and number of lightcurves (N_{lc}.) Last two columns give volume-equivalent diameter D and its RMS residual from the stellar occultations fitting. Boldface highlights the solution preferred by means of occultation fits. See Section 4 for the discussion on diameter uncertainties.

Asteroid	Pole λ_p[°]	Pole β_p[°]	P [hours]	Observing span (yr)	N_{app}	N_{lc}	D [km]	D RMS [km]
(70) Panopaea	42 ± 5	$+27 \pm 3$	15.80440 ± 0.00002	1980 – 2019	7	122	128 ± 7	7
	240 ± 6	$+26 \pm 4$	15.80439 ± 0.00001				128^{+7}_{-11}	7
(275) Sapientia	85 ± 11	-10 ± 18	14.93045 ± 0.00005	1998 – 2018	7	38	98^{+6}_{-11}	6
	$\mathbf{264 \pm 4}$	$\mathbf{-1 \pm 20}$	$\mathbf{14.93045 \pm 0.00005}$				$\mathbf{103^{+6}_{-7}}$	6
(275) Sapientia (ADAM)	82 ± 8	-11 ± 17	14.93044 ± 0.00005	1998 - 2018	7	38	100 ± 1	-
	$\mathbf{260 \pm 7}$	$\mathbf{-2 \pm 20}$	$\mathbf{14.93044 \pm 0.00005}$				$\mathbf{100 \pm 1}$	-
(286) Iclea	$\mathbf{31 \pm 5}$	$\mathbf{+13 \pm 4}$	$\mathbf{15.36120 \pm 0.00004}$	2002 – 2019	9	52	$\mathbf{86^{+13}_{-7}}$	**2**
	196 ± 5	$+44 \pm 7$	15.36114 ± 0.0007				69^{+3}_{-12}	3
(326) Tamara	$\mathbf{79 \pm 1}$	$\mathbf{-3 \pm 3}$	$\mathbf{14.46130 \pm 0.0005}$	1981 – 2019	9	69	$\mathbf{77^{+5}_{-10}}$	**5**
	242 ± 1	-36 ± 3	14.46136 ± 0.0004				81 ± 9	9
(412) Elisabetha	3 ± 20	$+17 \pm 7$	19.65610 ± 0.00003	1990 – 2021	7	77	119 ± 9	9
	$\mathbf{191 \pm 23}$	$\mathbf{+52 \pm 8}$	$\mathbf{19.65618 \pm 0.00004}$				$\mathbf{97^{+7}_{-14}}$	**4**
(426) Hippo	62 ± 55	-49 ± 20	67.5038 ± 0.0005	1993 – 2021	7	103	129^{+19}_{-8}	6
	$\mathbf{223 \pm 80}$	$\mathbf{-89 \pm 17}$	$\mathbf{67.5041 \pm 0.0005}$				$\mathbf{122 \pm 4}$	**4**

Marciniak et al., accepted to *Astronomy Astrophys.*

Occultation observers, asteroid (426) Hippo:

(426) Hippo, 2012-01-13

D. Ewald	DE
G. Wortmann, K. Walzel	DE
W. Rothe	DE
O. Canales, F. Campos	ES
E. Frappa, M. Lavayssière	FR
P. Lindner	DE
C. Schnabel, J. Juan	ES
J. Rovira	ES
A. Selva	ES

(426) Hippo, 2015-06-20

R. Baldridge	Los Altos Hills, CA
T. Swift	Davis, CA
J. Bardecker	Gardnerville, NV
C. McPartlin	Santa Barbara, CA

(426) Hippo, 2018-05-21

J. Broughton	Tumbulgum, AU
J. Broughton	Brunswick Heads, AU
J. Broughton	Ballina, AU

(426) Hippo, 2021-12-27

H. Yoshihara	Soja, Okayama, JP
M. Yamashita	Ikeda, Osaka, JP
T. Goto	Yamada Higashi, JP
M. Higuchi	Shigokamachi, JP
M. Nishimura	Kitakuzuhacho, JP
H. Kasebe	Osaka, JP
A. Asai	Kuwana, Mie, JP
A. Hashimoto	Chichibu, Saitama, JP
H. Watanabe, H. Watanabe	Tsu, Mie, JP
M. Ishida	Tsu, Mie, JP
R. Aikawa	Sakasdo, Saitama, JP
M. Ida	Tsu, Mie, JP
R. Kukita	Nabekura, JP
T. Horaguchi	Tsukuba, JP
K. Fukui	Nagakunidai, JP
K. Kouno	Miyazaki, JP
K. Terakubo	Kokubunji, Tokyo, JP
K. Kitazaki	Musashino, Tokyo, JP
S. Uchiyama	Kashiwa, Chiba, JP
T. Hirose	Ohtaku, Tokyo, JP
M. Owada	Hamamatsu, Shizuoka, JP

(426) Hippo, 2021-12-31

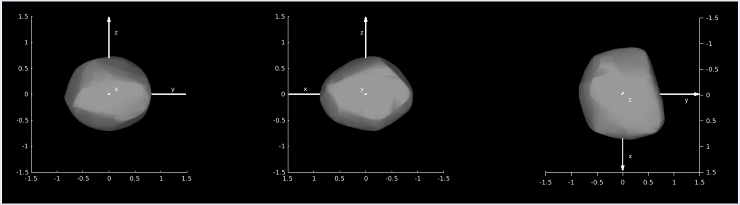
A. Selva	ES
J. Juan	ES
C. Schnabel	ES

(426) Hippo, 2022-03-23

J. Mánek	CZ
J. Kubánek	CZ
K. Halíř	CZ
M. Rottenborn	CZ
J. Polák	CZ
E. Kowald	AT
B. Kattentidt	DE

Summary

- Studied infuence of shape model uncertainty on size determination.
- Main aim: providing better constraints on size uncertainty, finding the dominant source of this uncertainty.
- Side effect: obtaining good constraints of the vertical stretch of the shape model, unavailable otherwise.
- Occultations capable of solving one of biggest problems of lightcurve inversion models.



Asteroid (426) Hippo model vertical stretch constrained by occultations.