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Asteroid Shape Modelling Driven by Archival Stellar Occultation Data

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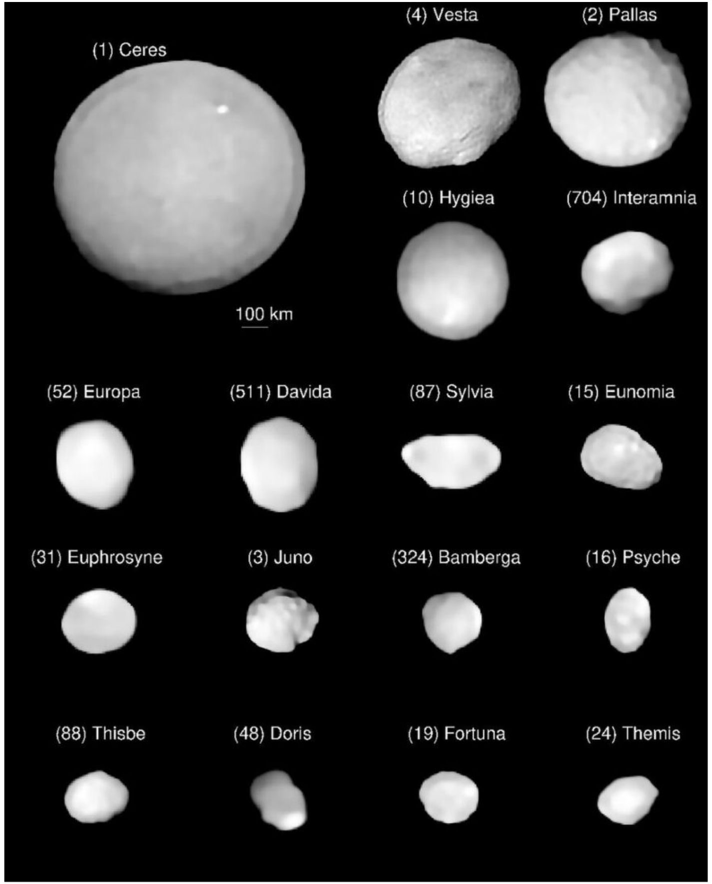
Credit: Vissiniti, Margaret Murphy

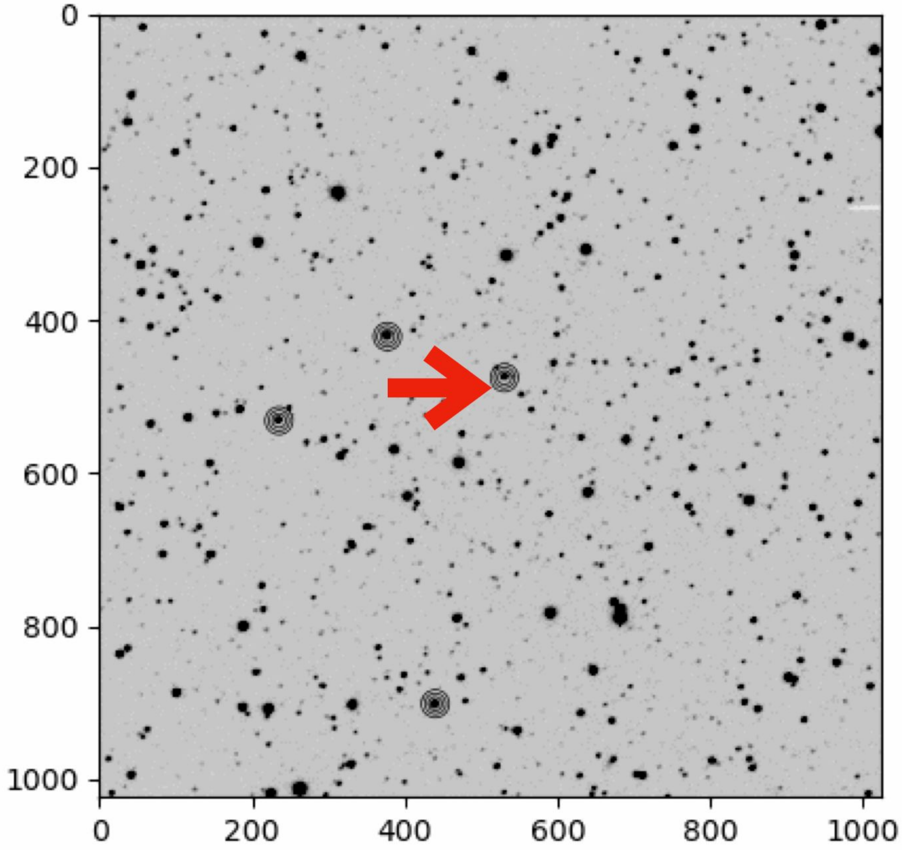
Larger asteroids observed by the biggest telescopes

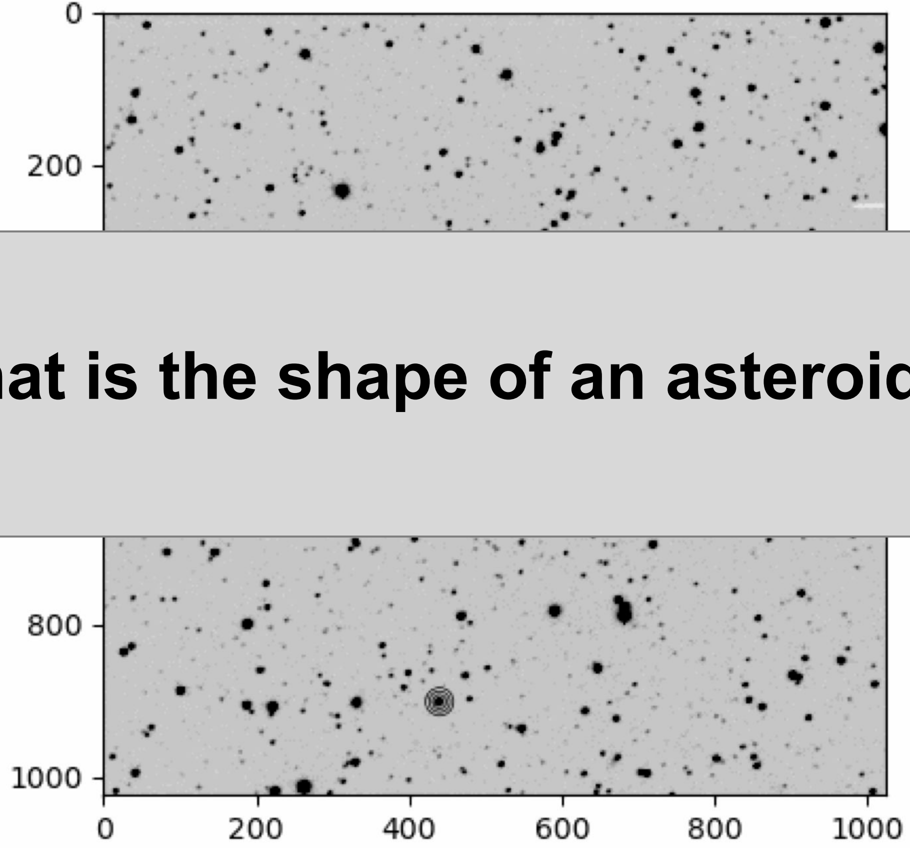
Credit: ESO



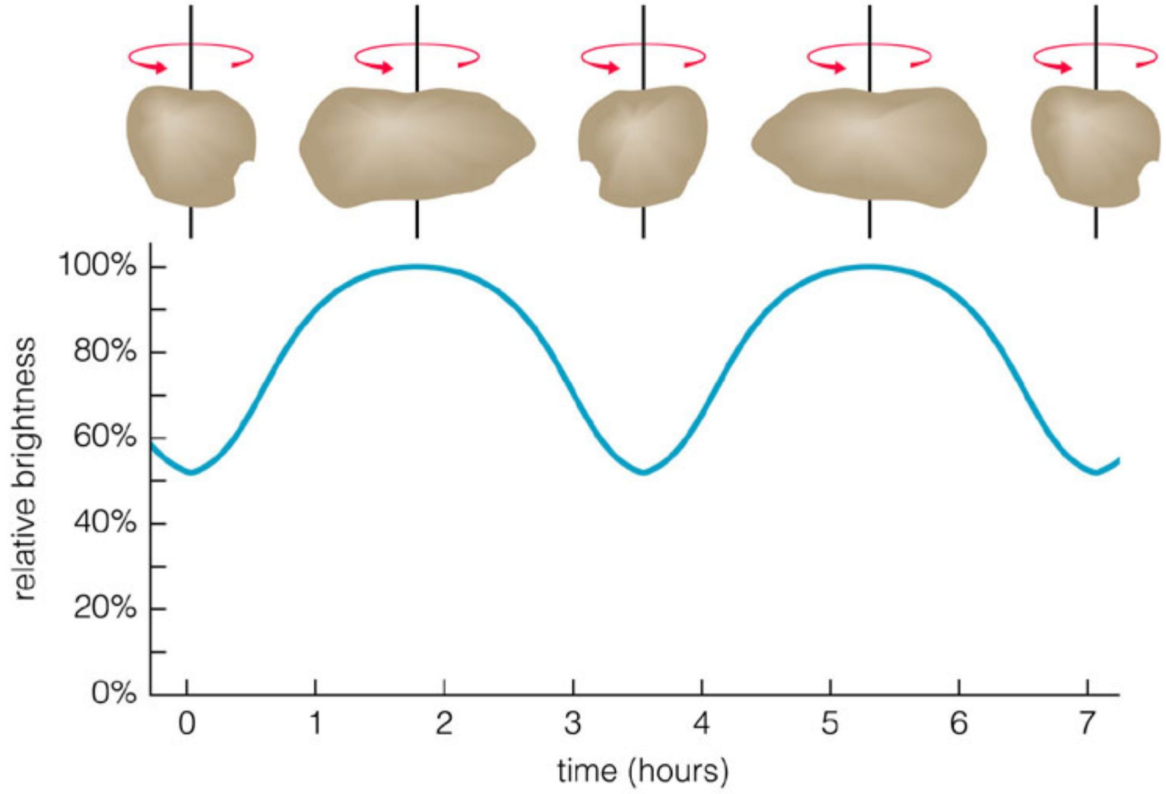
Credit: Vernazza et al. (2021)

Typical asteroid observations





What is the shape of an asteroid?

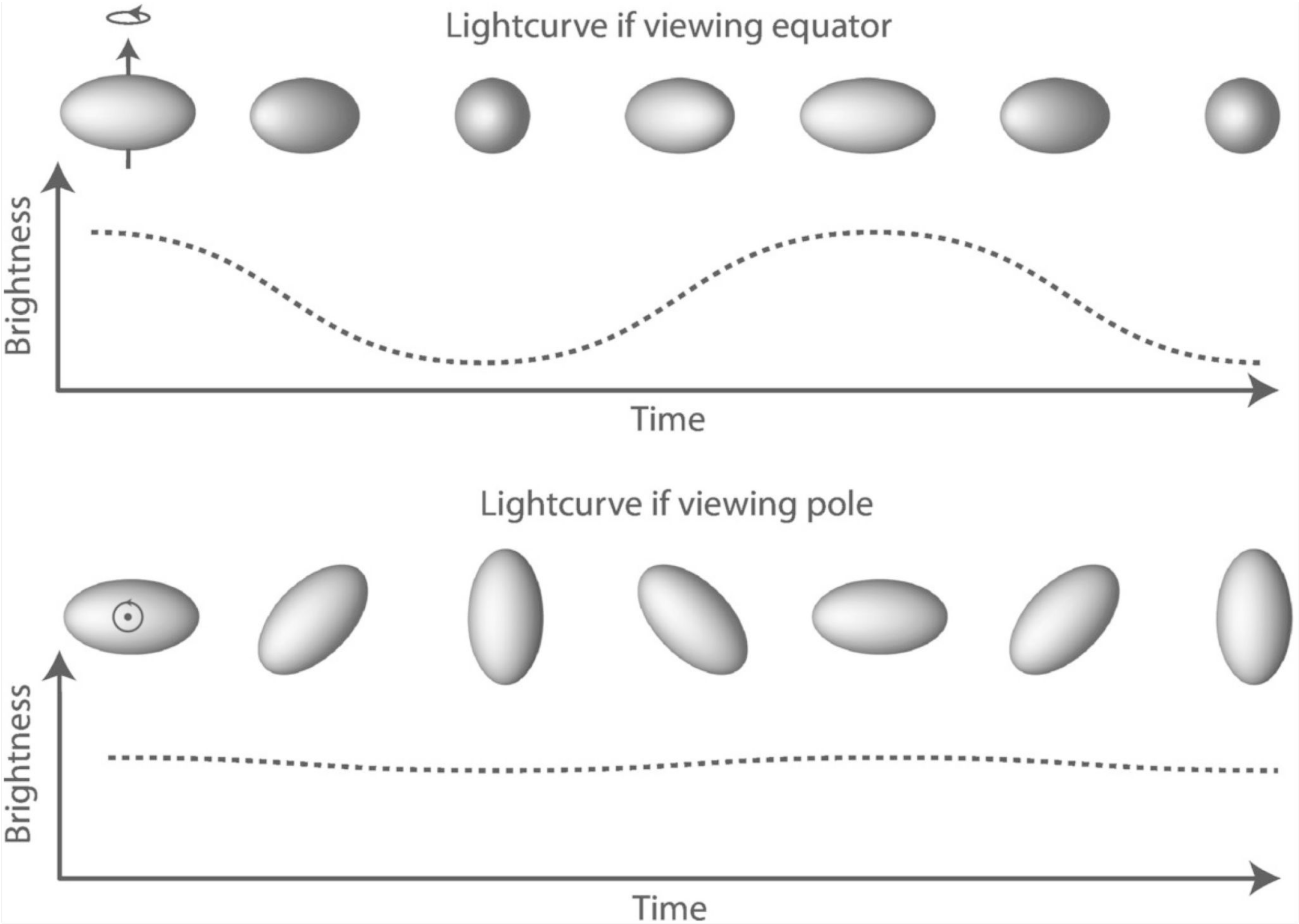


Credit: NASA/JPL/Caltech

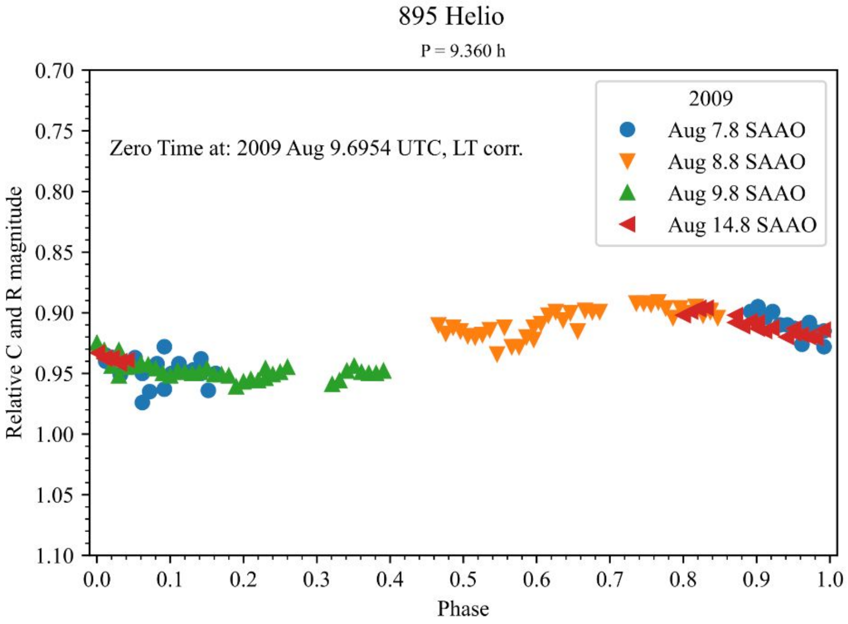
1. Measure asteroid brightness as a function of time (**lightcurve**).

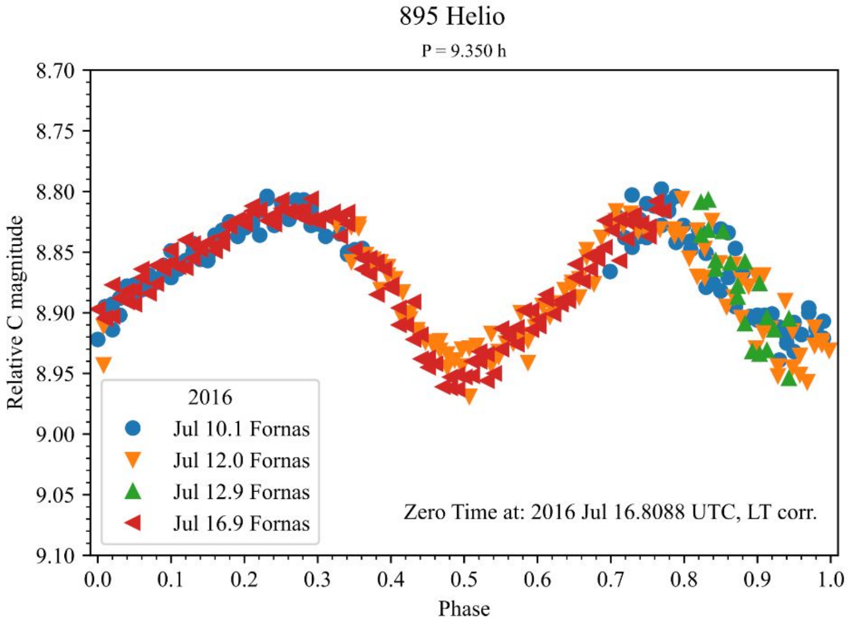
2. Brightness of an asteroid is directly proportional to its illuminated area:

Brightness $\propto$ Area

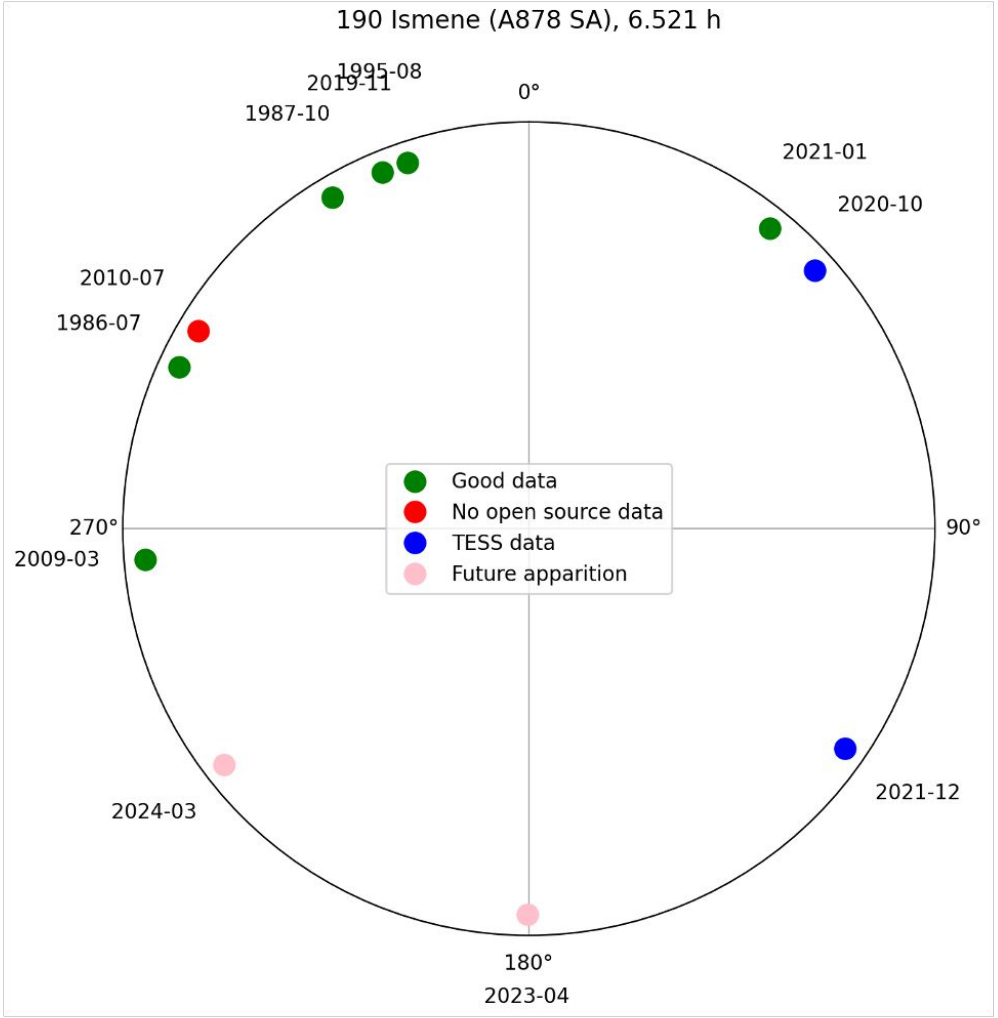


Credit: Shepard MK. Planetary Disk-Integrated Photometry. In: Introduction to Planetary Photometry. Cambridge University Press; 2017:170-203.





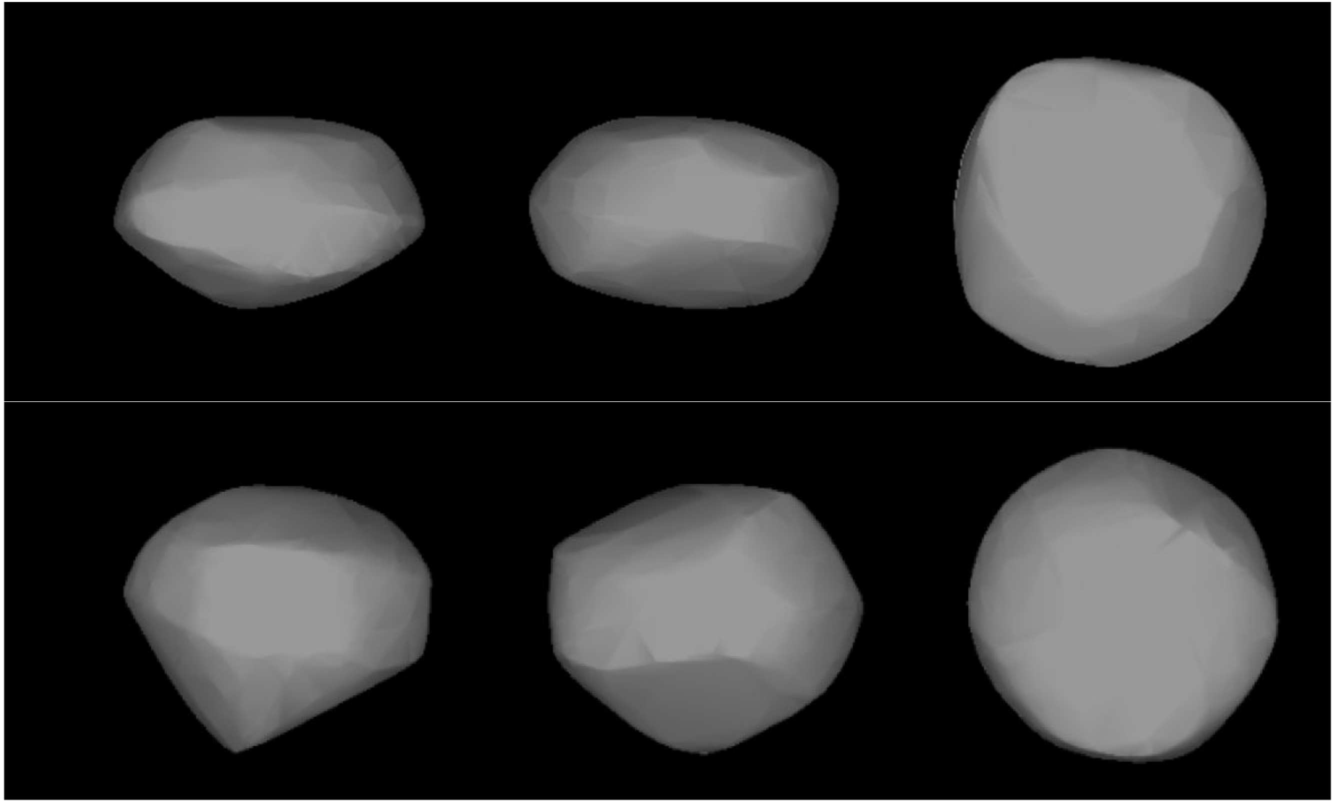
Data from (Brines et al., 2017)



190 Ismene (A878 SA), 6.521 h
1995-08
2019-11
0°
1987-10
2021-01
2020-10
2010-07
1986-07
Good data
No open source data
TESS data
Future apparition
270°
90°
2009-03
2021-12
2024-03
180°
2023-04

Solution 1

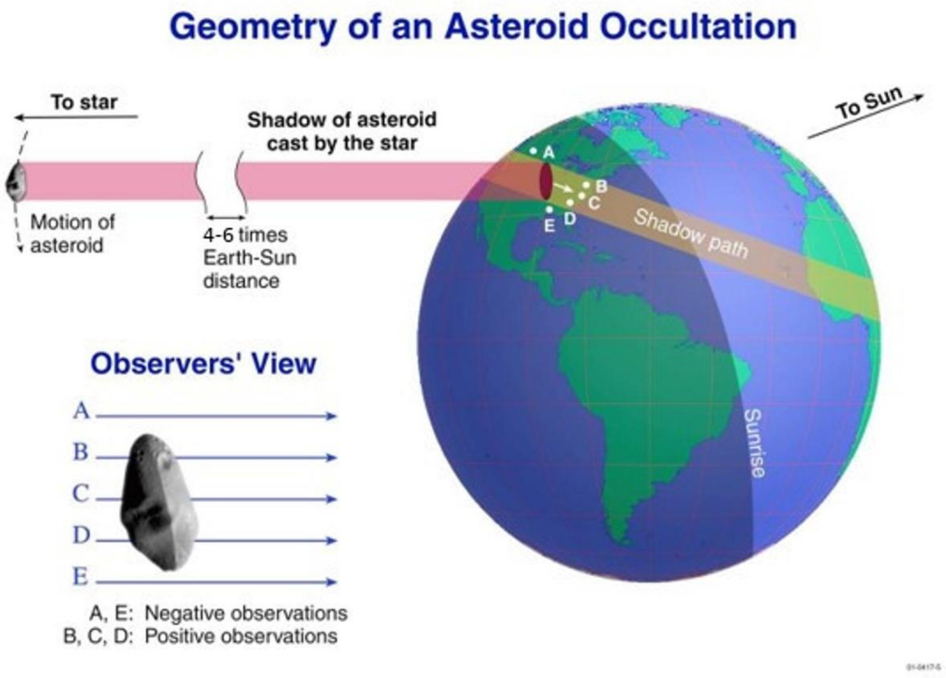
Solution 2



	λ_p	β_p	P_{sid}	N_{lc}	N_{app}
Solution 1	$(48 \pm 9)°$	$(39 \pm 4)°$	(9.394360 ± 0.000008) h	62	11
Solution 2	$(214 \pm 3)°$	$(-8 \pm 5)°$	(9.394362 ± 0.000006) h	62	11

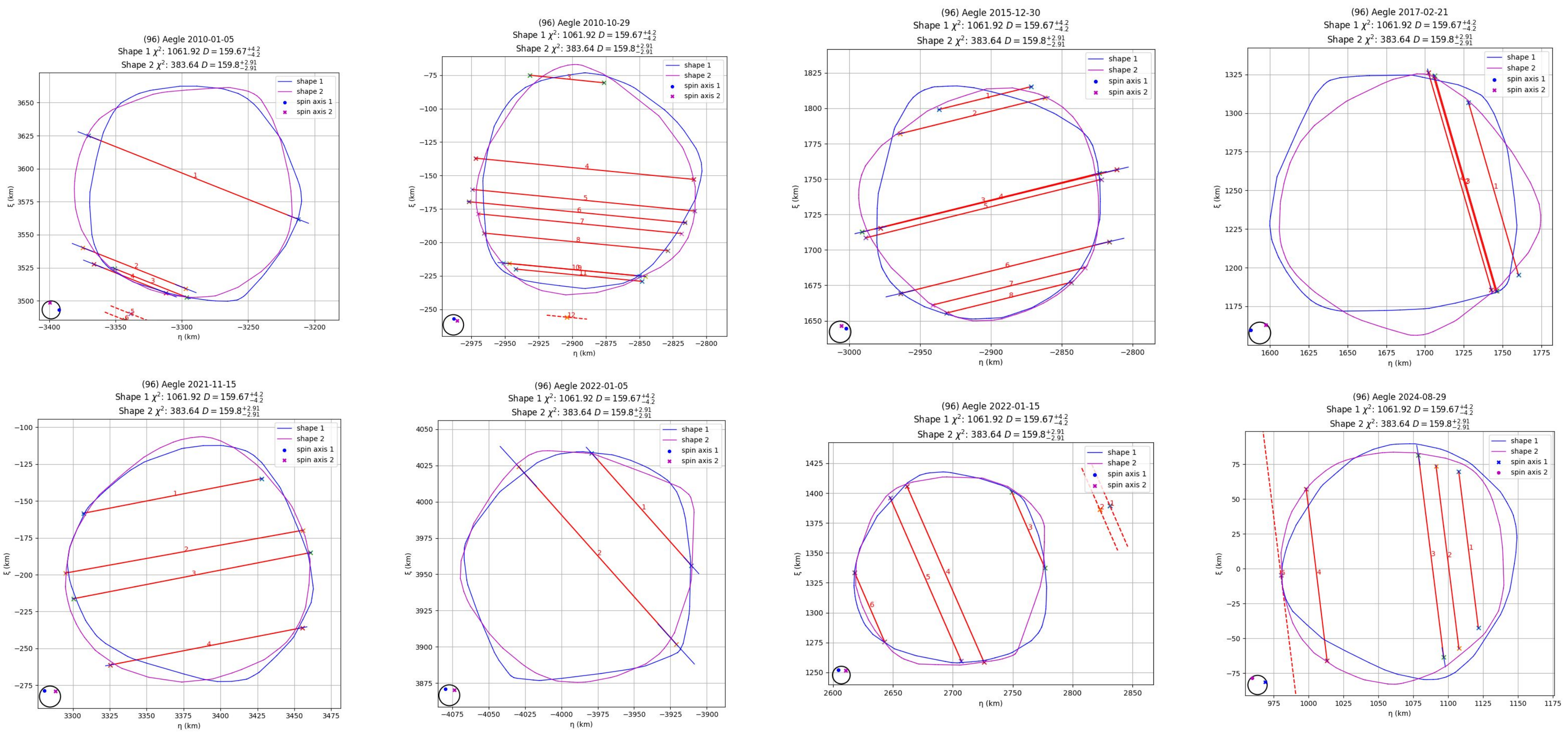
However, those models are scale-free — they define spin and shape, not size!

Scaling, validating models and breaking mirror pole ambiguity

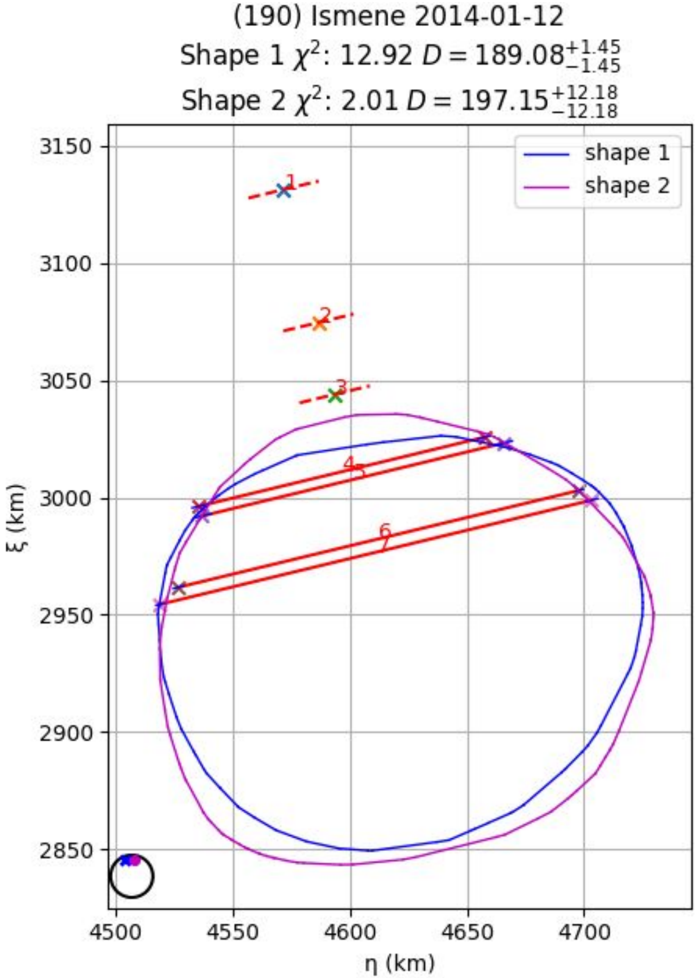


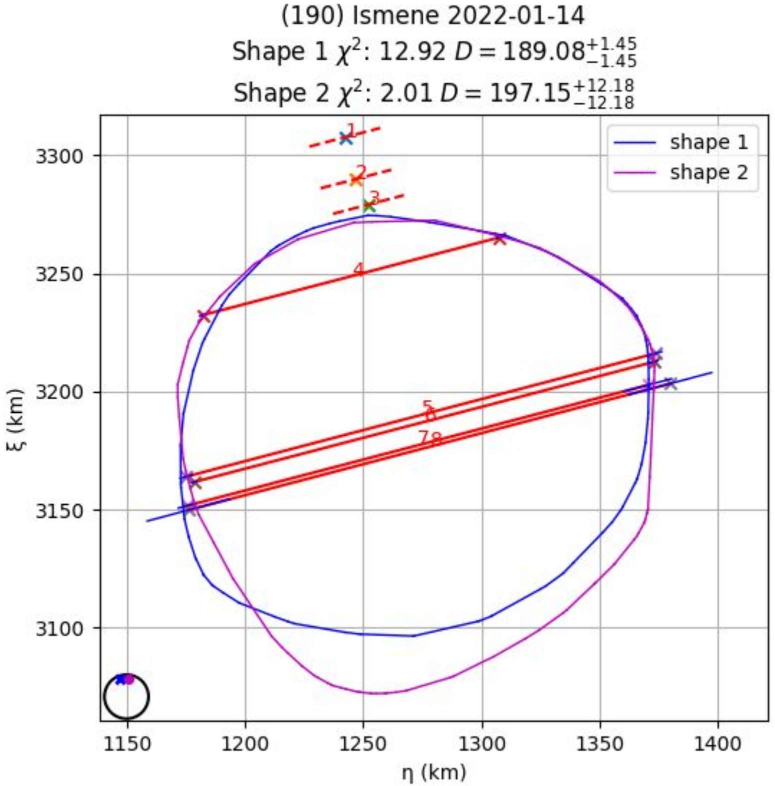
Credit: IOTA, David Dunham

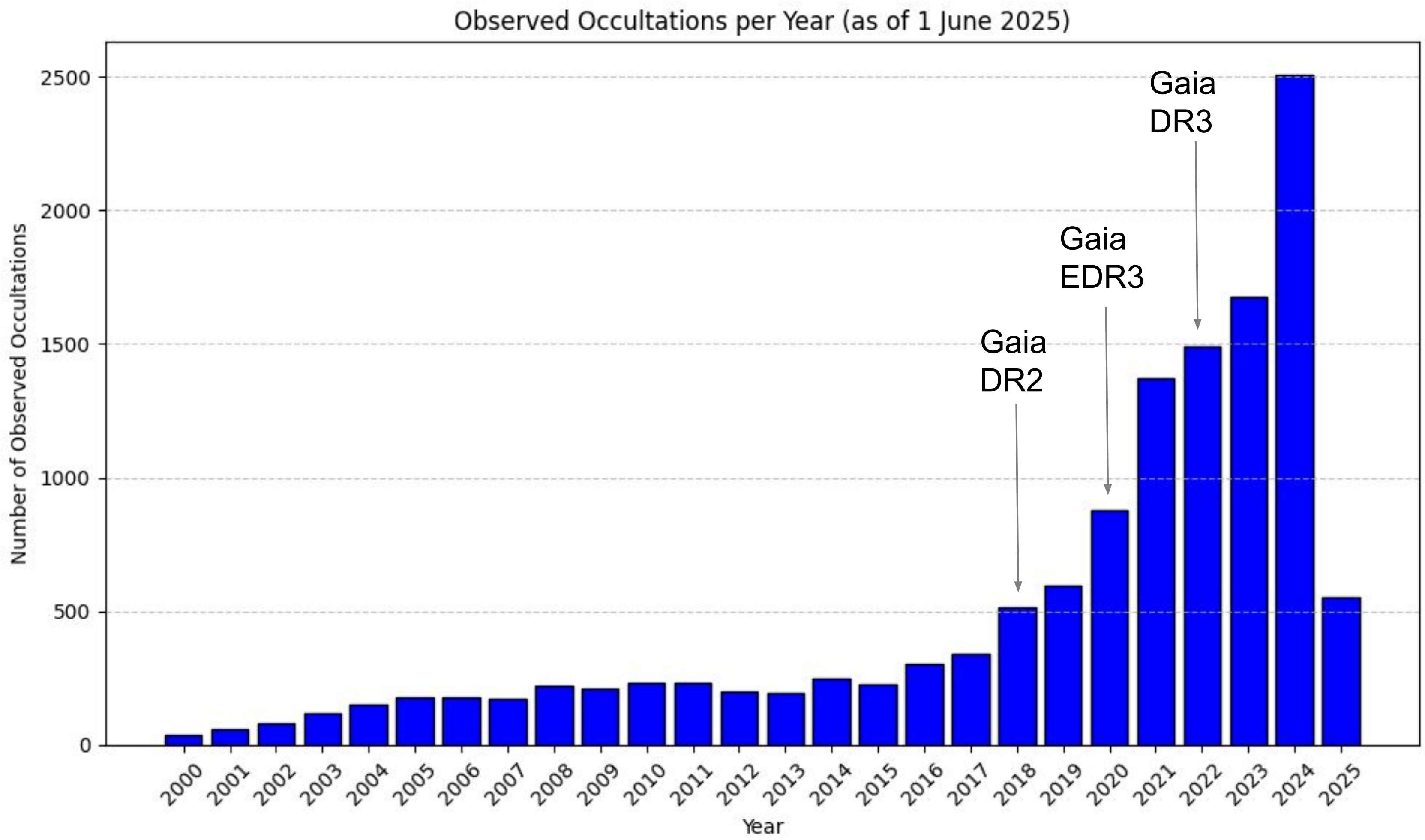
Fitting models to occultation chords



Based on occultationFit software by Antoine Choukroun (GitHub: antoinech13)


(190) Ismene 2014-01-12
Shape 1 χ^2: 12.92 $D = 189.08^{+1.45}_{-1.45}$
Shape 2 χ^2: 2.01 $D = 197.15^{+12.18}_{-12.18}$
shape 1
shape 2
ξ (km)
η (km)
3150
3100
3050
3000
2950
2900
2850
4500
4550
4600
4650
4700
1
2
3
4
5
6
7


(190) Ismene 2022-01-14
Shape 1 χ^2: 12.92 $D = 189.08^{+1.45}_{-1.45}$
Shape 2 χ^2: 2.01 $D = 197.15^{+12.18}_{-12.18}$
shape 1
shape 2
ξ (km)
η (km)
3300
3250
3200
3150
3100
1150
1200
1250
1300
1350
1400
1
2
3
4
5
6
7
8



Data from Occult by Dave Herald

We aim to model, using the convex inversion (Kaasalainen & Torppa 2001) and/or ADAM (Viikinkoski et al. 2015) methods, those asteroids with rich occultation data but no existing shape model. To this end, we have started an observational campaign to collect new lightcurves.

In OW/OWC these target asteroids are tagged as SlowRotators.

Asteroid diameters from literature compared to our results

No.	Designation	D_{min} from IR [km]	Reference	D_{max} from IR [km]	Reference	D_{occ} [km]	Preferred pole solution λ, β [deg]
58	Concordia	82.64 ± 24.470	Masiero et al., 2021	106.52 ± 0.740	Masiero et al., 2012	99 ± 5	$25^{+2}_{-0}, 51^{+5}_{-1}$
96	Aegle	164.77 ± 2.540	Usui et al., 2011	177.77 ± 1.540	Masiero et al., 2012	160 ± 3	$31^{+11}_{-13}, 51^{+1}_{-3}$
190	Ismene	166.46 ± 33.29	Alí-Lagoa et al., 2018	214.66 ± 7.300	Grav et al., 2012	197 ± 12	$321^{+19}_{-19}, 49^{+15}_{-15}$
268	Adorea	125.75 ± 36.100	Nugent et al., 2016	169.83 ± 7.833	Ryan and Woodward, 2010	139 ± 2	$250^{+12}_{-3}, 55^{+3}_{-10}$
420	Bertholda	131.55 ± 13.16	Alí-Lagoa et al., 2018	160.33 ± 8.801	Ryan and Woodward, 2010	138 ± 4	$145^{+3}_{-3}, 67^{+5}_{-5}$
895	Helio	102.03 ± 2.870	Masiero et al., 2012	155.12 ± 7.646	Ryan and Woodward, 2010	118 ± 17	$48^{+9}_{-9}, 39^{+4}_{-4}$

Why accurate size is so important?

Bulk density:

$$\rho = \frac{M}{V} \approx \frac{M}{R^3}$$

- M is the mass of the object
- V is the volume of the object
- **R is the radius of the object**

Unfortunately, mass is usually known with low accuracy, but for some targets, precise measurements are available or planned. Then the size uncertainty becomes a dominant factor.

Summary

- The main goal is to select asteroids with good occultation results, model those asteroids, and scale them in size.
- To obtain lightcurves, an international observing campaign was organised to complete the data with the missing viewing geometries of target asteroids.
- 6 main belt asteroids modeled and scaled using occultation data so far
- ~50 additional targets selected for upcoming modeling and scaling

Acknowledgements

Many thanks to Anna Marciniak, Antoine Choukroun, the team of lightcurve observers, and 290 stellar occultation observers.

Stelar occultations by (96) Aegle: R. Aikawa, A. Asai, A. Hashimoto, M. Ida, M. Ishida, K. Kenmotsu, K. Kitazaki, M. Owada, M. Sato, H. Tomioka, S. Uehara, H. Watanabe, A. Yaeza, J. Yokomichi, D. Clark, S. Edberg, S. Herchak, E. Iverson, R. Jones, G. Lyzenga, L. Martinez, R. Peterson, G. Rattley, J. Stamm, R. Stanton, W. Thomas, S. Bock, D. Breit, T. Case, T. George, J. Heller, P. Maley, C. McPartlin, R. Nolthenius, C. Patrick, W. Thomas, R. Casas, C. Perello, J. Rovira, C. Schnabel, N. Carlson, P. Maley, V. Sempronio, M. Skrutskie, T. Haymes, S. Kidd, P. Baruffetti, G. Casalnuovo, P. Fini, J. Kubanek, A. Ossola, S. Sposetti, T. Barry, J. Broughton, D. Gault, P. Nosworthy

Stelar occultations by (190) Ismene: A. Hashimoto, M. Ida, M. Ishida, K. Kitazaki, M. Owada, H. Tomioka, H. Watanabe, P. Andre, J. Castellani, E. Fernandez, F. Garcia, P. Martorell, A. Noschese, J. Prat, A. Selva, G. Vaudescal

Bibliography

- Bartczak, P., et al. 2014. Monthly Notices of the Royal Astronomical Society, 443, 1802–1809.
- Bartczak, P., et al. 2017a. Monthly Notices of the Royal Astronomical Society, 471, 941–947.
- Carry, B. 2012. Planetary and Space Science, 73, 98.
- Carry, B., et al. 2019. Astronomy and Astrophysics, 623, A132.
- Choukroun, A., et al., **including Perła, J**. 2025. Astronomy and Astrophysics, 698, A298.
- Devogèle, M., et al. 2017. Astronomy and Astrophysics, 607, A119.
- Ďurech, J., et al. 2011. Icarus, 214, 652.
- Ďurech, J., et al. 2017. Astronomy and Astrophysics, 604, A27.
- Ďurech, J., et al. 2025. Astronomy and Astrophysics, 696, A76.
- Ferrais, M., et al. 2020. Astronomy and Astrophysics, 638, L15.
- Fuksa, M., et al. 2023. Astronomy and Astrophysics, 677, A189.
- Gaia Collaboration, et al. 2020a. Gaia EDR3: Summary of the contents and survey properties.
- Hanus, J., et al. 2017. Astronomy and Astrophysics, 600, A114.
- Hanus, J., et al. 2020. Astronomy and Astrophysics, 633, A65.
- Herald, D., et al. 2020. Monthly Notices of the Royal Astronomical Society, 499, 4570–4590.
- Herald, D., et al. 2024. NASA Planetary Data System, Asteroid Occultations V4.0.
- Kaasalainen, M., and Torppa, J. 2001. Icarus, 153, 24.
- Marciniak, A., et al., **including Perła, J.** 2023. Astronomy and Astrophysics, 679, A60.
- Marchis, F., et al. 2021. Astronomy and Astrophysics, 653, A57.
- Marsset, M., et al. 2020. Nature Astronomy, 4, 569–576.
- Mouret, S., et al. 2007. Astronomy and Astrophysics, 472, 1017–1027.
- Podlewska-Gaca, E., et al. 2020. Astronomy and Astrophysics, 638, A11.
- Tanga, P., et al. 2015. Monthly Notices of the Royal Astronomical Society, 448, 3382–3390.
- Vernazza, P., et al. 2018. Astronomy and Astrophysics, 618, A154.
- Viikinkoski, M., et al. 2015. Astronomy and Astrophysics, 576, A8.
- Occultation Prediction Software by David Herald (Occult), http://lunar-occultations.com/iota/occult4.htm