Stellar occultation
method of asteroids size and orbit determination

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ESOP XL 28.08.2021

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1995-09

Asteroids - groups

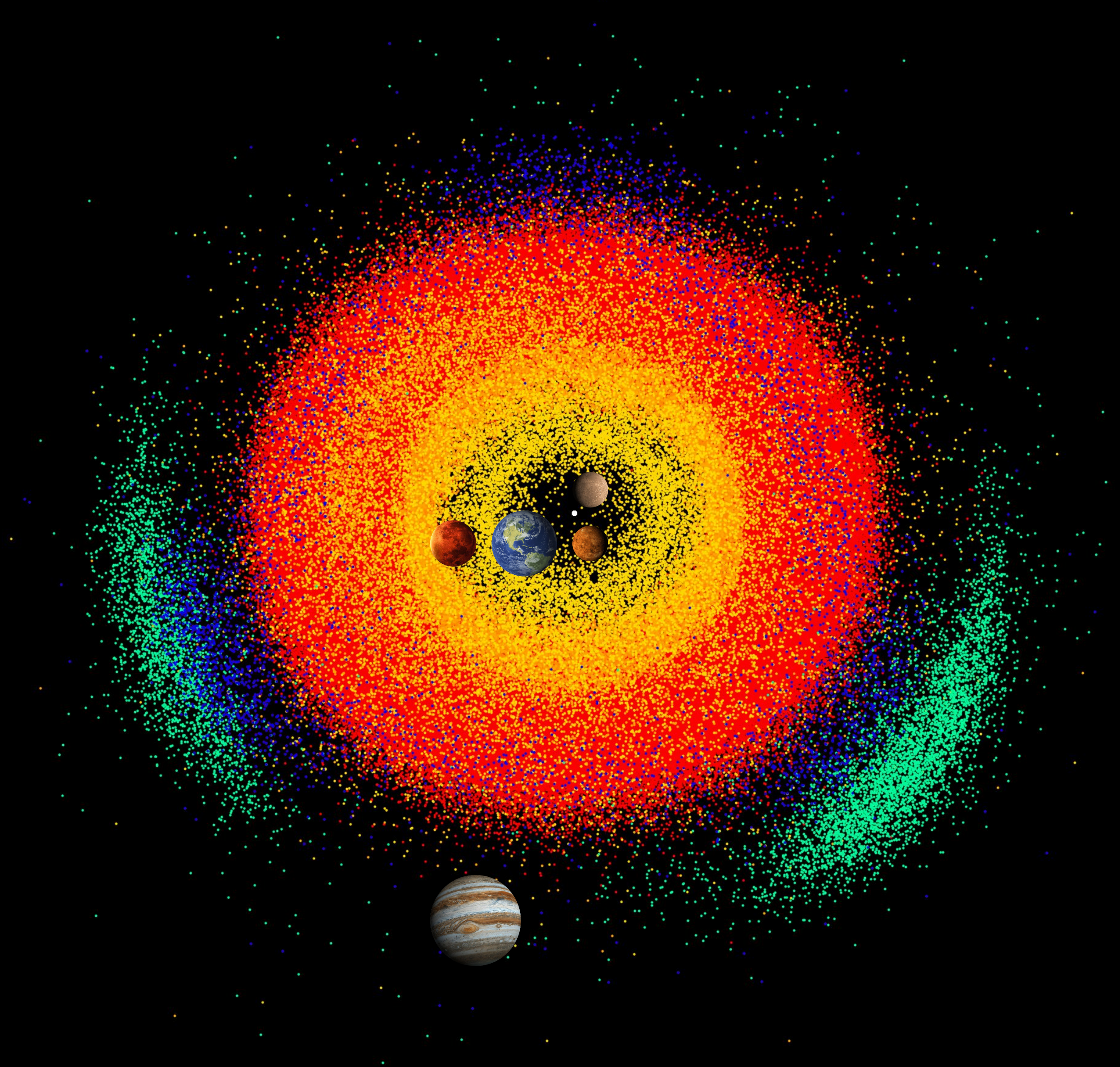
NEAs
- Atena
- Apollo
- Amora
- Mars-crosser
- Hungaria

MBA

Hilda

Trojans

Other
- TNO
- Kuiper Belt



Kaolina Dziadura

1. Spacecrafts

951 Gaspra
18.2 km × 10.5 km × 8.9 km
Galilego, 1991

243 Ida
59.8 × 25.4 × 18.6 km
Galileo, 1993

Dactyl
1.6 × 1.4 × 1.2 km
Galileo, 1994

253 Mathilde
66×48×46 km
NEAR Shoemaker, 1997

433 Eros
34.4 × 11.2 × 11.2 km
NEAR Shoemaker, 1998

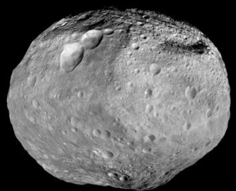
9969 Braille
2.1 km × 1 km × 1 km
Deep Space 1, 1999

5535 Annefrank
6.6 x 5.0 x 3.4 km
Stardust, 2002

25143 Itokawa
0.535 × 0.294 × 0.209 km
Hayabusa, 2005

2867 Šteins
6.83 × 5.70 × 4.42 km
Rosetta, 2008

21 Lutetia
121 ± 1 × 101 ± 1 × 75 ± 13 km
Rosetta, 2010

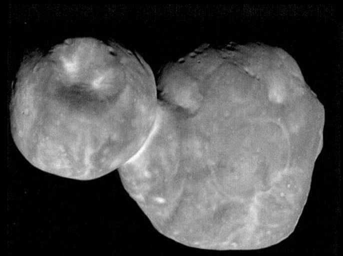


4 Vesta
572.6 × 557.2 × 446.4 km
DAWN, 2011

4179 Toutatis
4.26 × 2.03 × 1.70 km
Chang'e 2, 2012

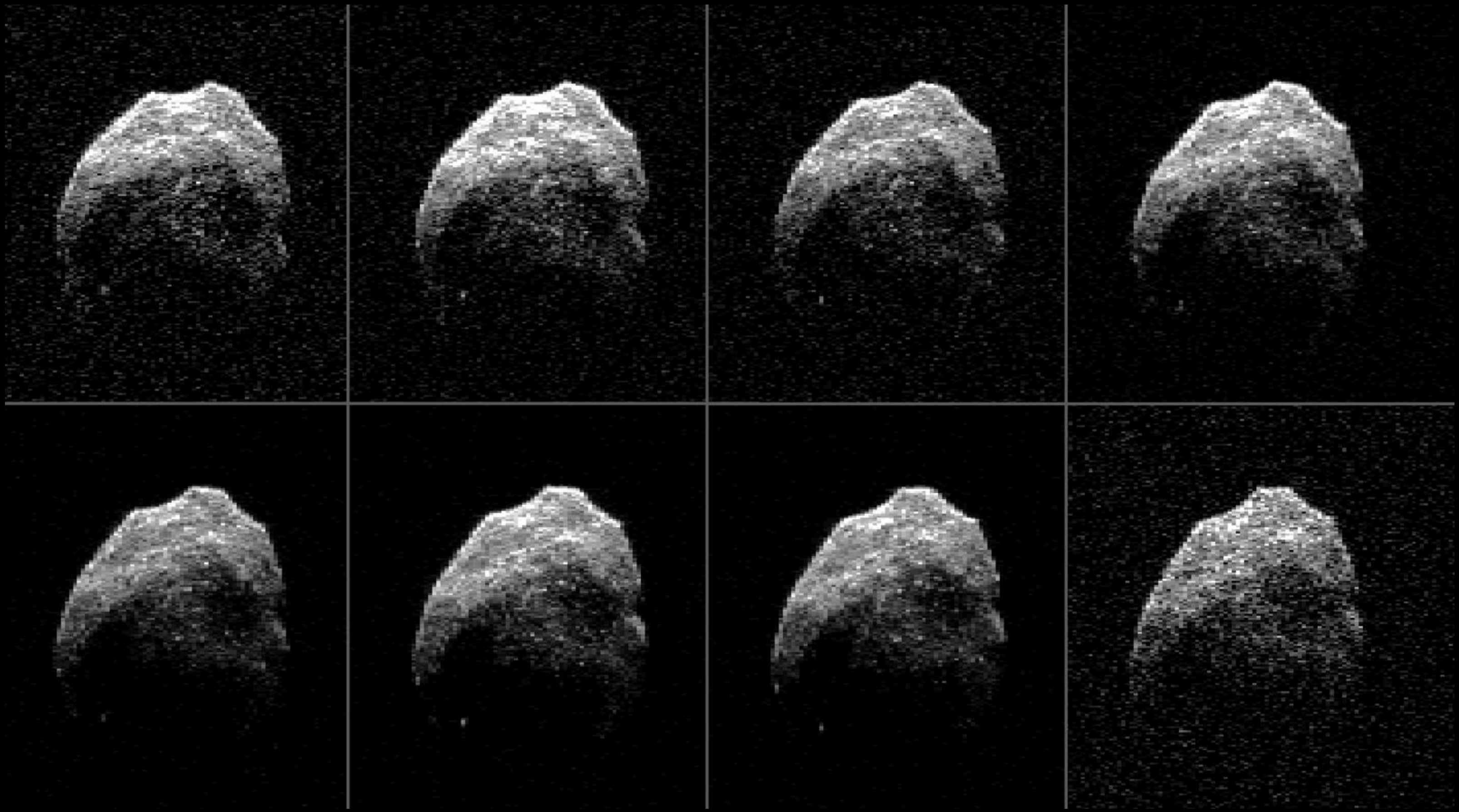
162173 Ryugu
0.865±0.015 km
Hayabusa-2, 2018

101955 Bennu
0.565 x 0.535 x 0.508 km
OSIRIS-Rex, 2018



486958 2014 MU69 (Ultima Thule)
35 ± 1 × 20 ± 1 × 10 ± 3 km Ultima
22 ± 0.6 × 20 ± 1 × 7 ± 2 km Thule
New Horizons, 2019

2. Radar

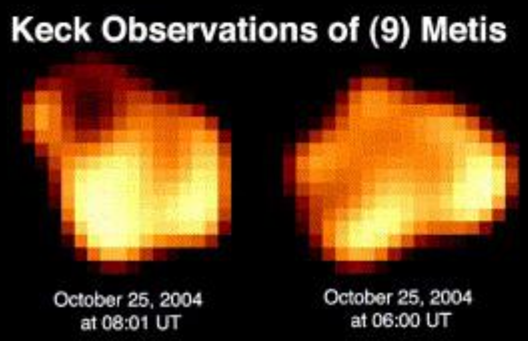


Credit: NASA

Only for relatively big and close objects

The use of radar observations to determine the sizes of asteroids requires the knowledge of the asteroid's rotation speed, its orbit, the inclination of the rotation axis, and the coordinates of the poles. This means that the radar data should be supplemented with relative photometry and glare curves.

2. Adaptive optics

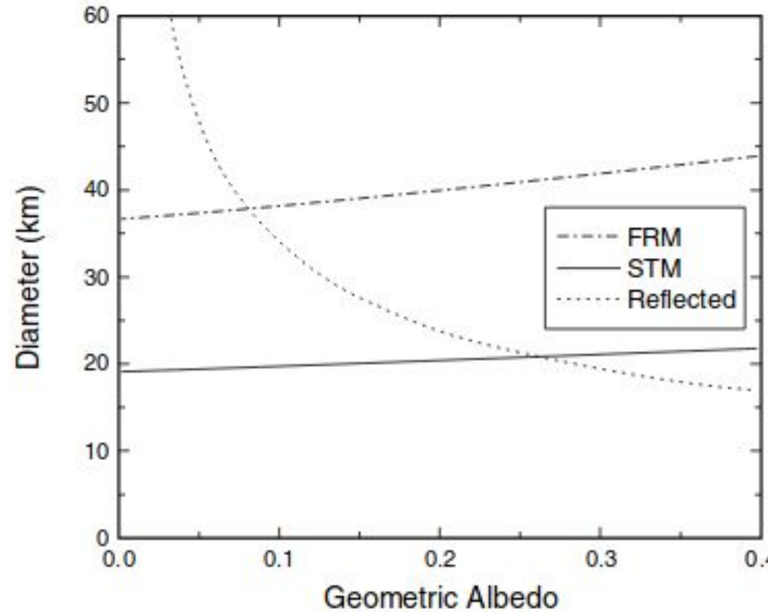


Marchis, F., et al. *Icarus* 185.1 (2006): 39-63.

Only for relatively big and close objects

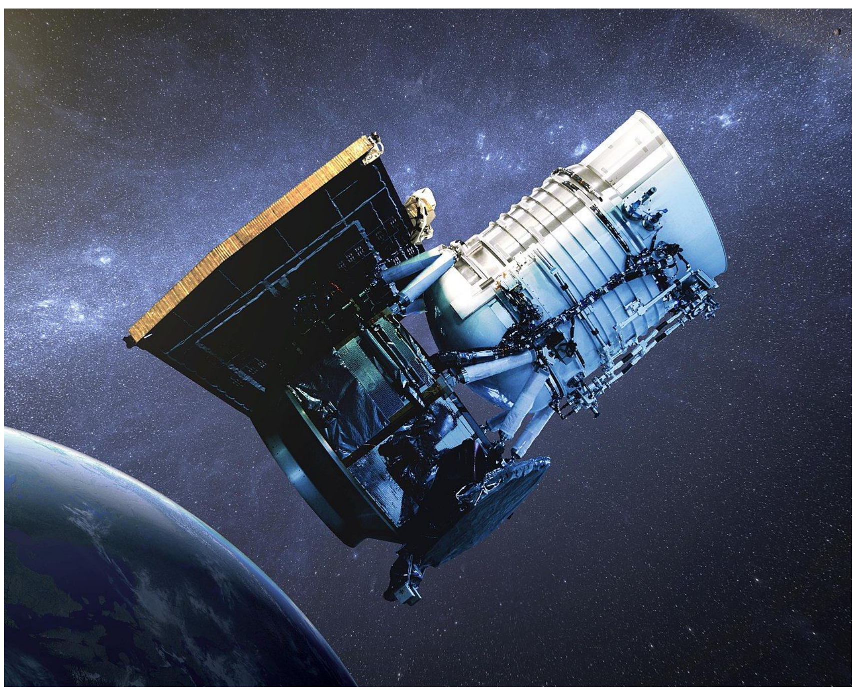
Due to the very high resolution of the obtained images, it is possible to obtain **high-quality images** of asteroids. Using the information about the **angular resolution** of the image and the asteroid **distance**, it is possible to determine the size of the object.

3. Photometric and infrared observations

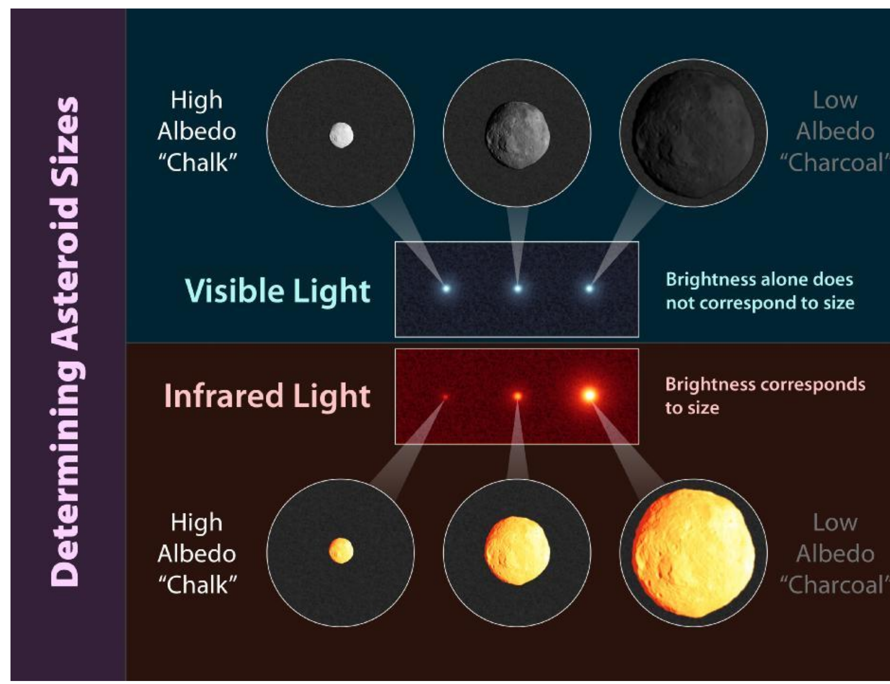


Harris, Alan W., and Johan SV Lagerros, *Asteroids III* 205 (2002).

Wide-field Infrared Survey Explorer (WISE)
Size for over 100 000 objects

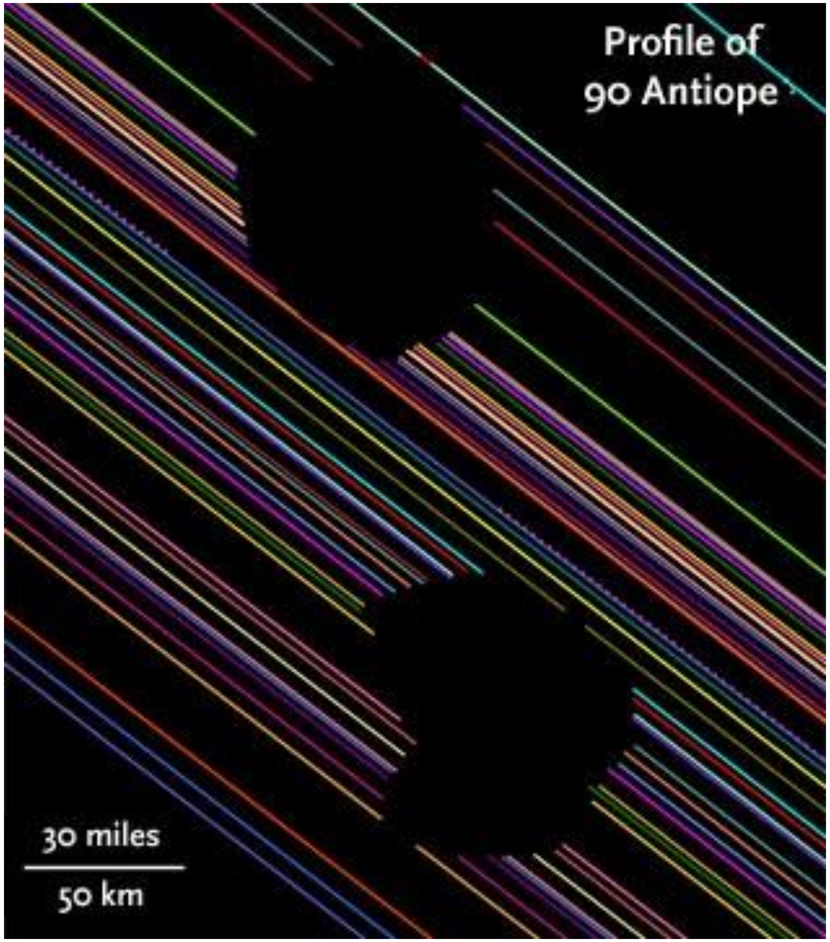


Credit: NASA



Credit: NASA

4. Stellar occultations



Credit: http://www.asteroidoccultation.com

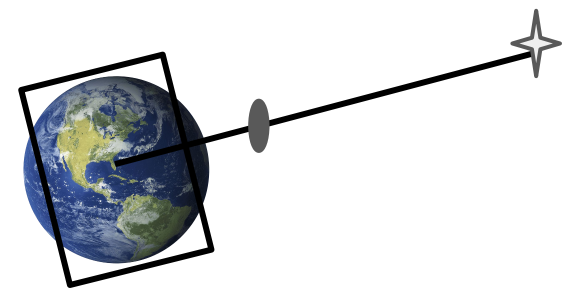
- determine the <u>size</u> of the asteroid;
- determine a precise measurement of the relative <u>astrometric</u> position of the star and asteroid at the time of the event;
- verify the asteroid <u>shape model</u>;
- verify the <u>size</u> of the asteroid from other scientific methods;
- verify the <u>duality</u> of asteroids;
- discover the <u>rings</u> or moons of the celestial body (as in the case of the dwarf planet (136108) Haumea (Ortiz et al., 2017)

How to calculate the <u>size</u> of the asteroids based on:

- stellar occultation <u>time</u>;
- observer <u>coordinates</u>?

We define the coordinate system (ζ, η) on the base plane by unit vectors:

$$\overrightarrow{\widehat{S}}_{\zeta} = (-\sin\delta\cos\alpha, -\sin\delta sin\alpha, \cos\delta),$$
$$\overrightarrow{\widehat{S}}_{\eta} = (\sin\alpha, -\cos\alpha, 0).$$

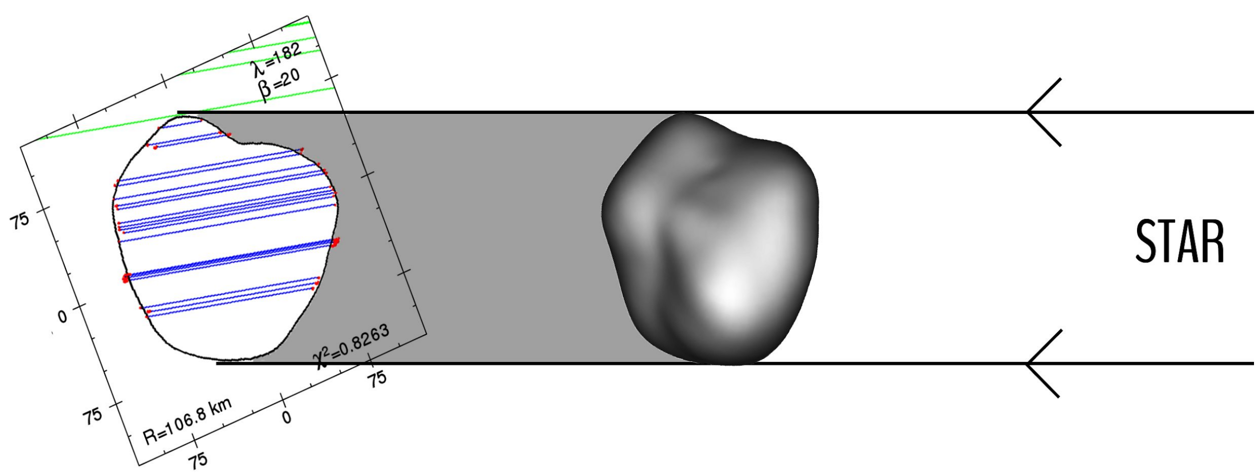


Then we projecting the observer's geocentric coordinates onto the plane

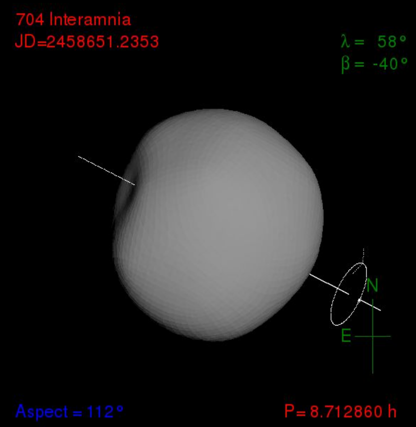
$$(\zeta, \eta) = [\overrightarrow{\widehat{S}}_{\zeta} \cdot (\overrightarrow{X} + \Delta\overrightarrow{v}\Delta t), \overrightarrow{\widehat{S}}_{\eta} \cdot (\overrightarrow{X} + \Delta\overrightarrow{v}\Delta t)]$$

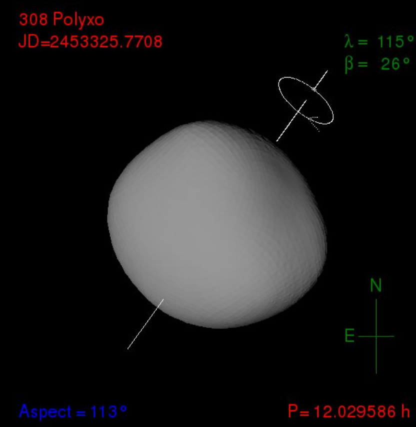
Finally, we scale the model for the best fit

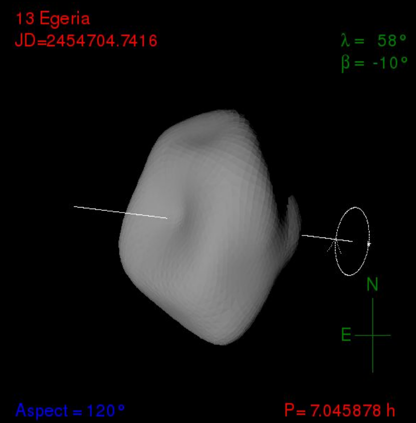
$$\chi^2 = \sum_{j=1}^{N} \frac{[(\zeta_j, \eta_j)_{OCC} - (\zeta_j, \eta_j)_{model}]^2}{\sigma_j^2}$$

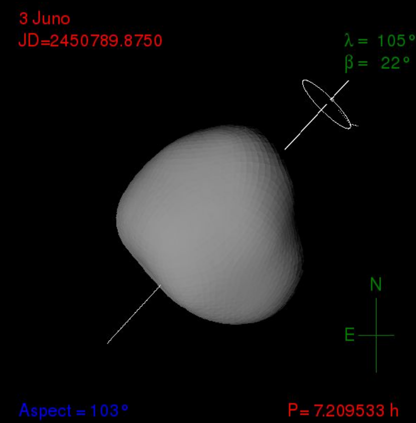


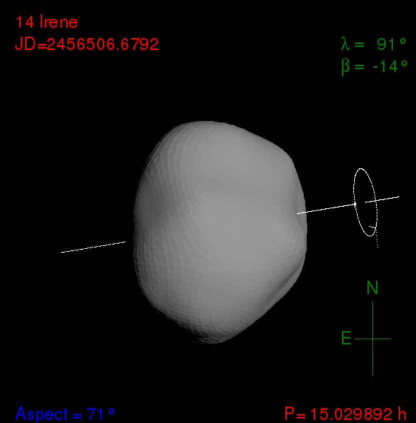
Ďurech, Josef, et al. "Combining asteroid models derived by lightcurve inversion with asteroidal occultation silhouettes." *Icarus* 214.2 (2011): 652-670.



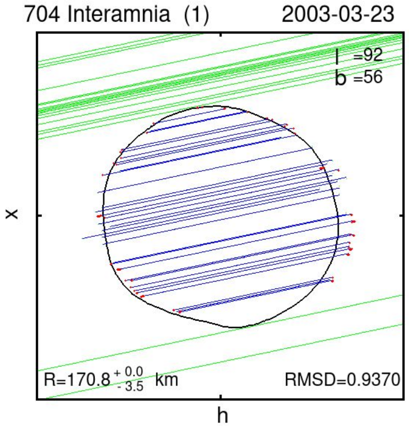


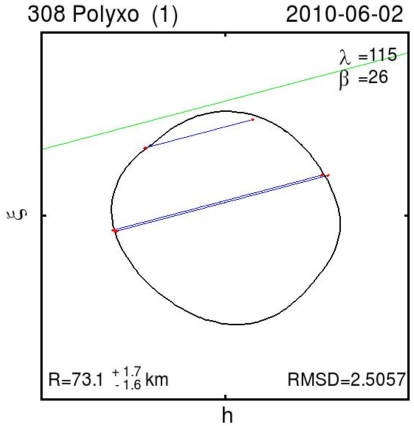


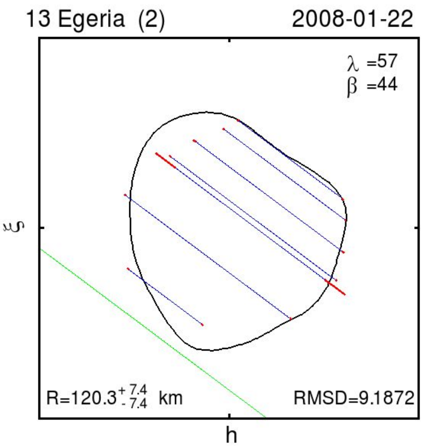


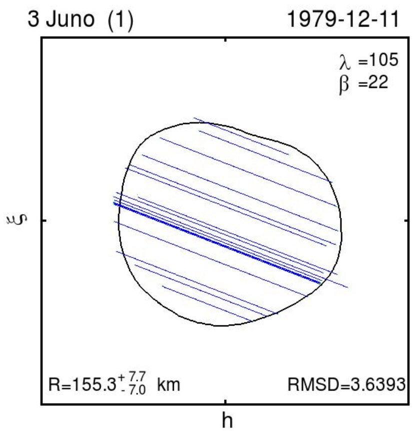


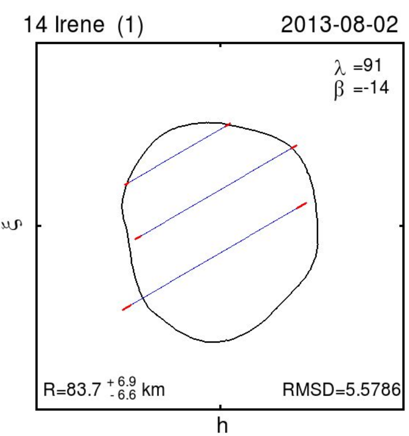
http://isam. astro.amu.edu.pl











Podlewska-Gaca, Edyta, et al. "Physical parameters of selected Gaia mass asteroids." *Astronomy & Astrophysics* 638 (2020): A11.

(704) Interamnia		
Dane	średnica efektywna [km]	niepewność [km]
Zakrycie 1996-12-17	338	+28 -24
Zakrycie 2009-01-11	302	+3 -6
Zakrycie 2007-09-09	341	+0 -4
Zakrycie 2012-11-12	334	+7 -14
Zakrycie 2003-03-23	321	+0 -7
Obserwacje podczerwone (Masiero i inni, 2011)	306.313	±1.031

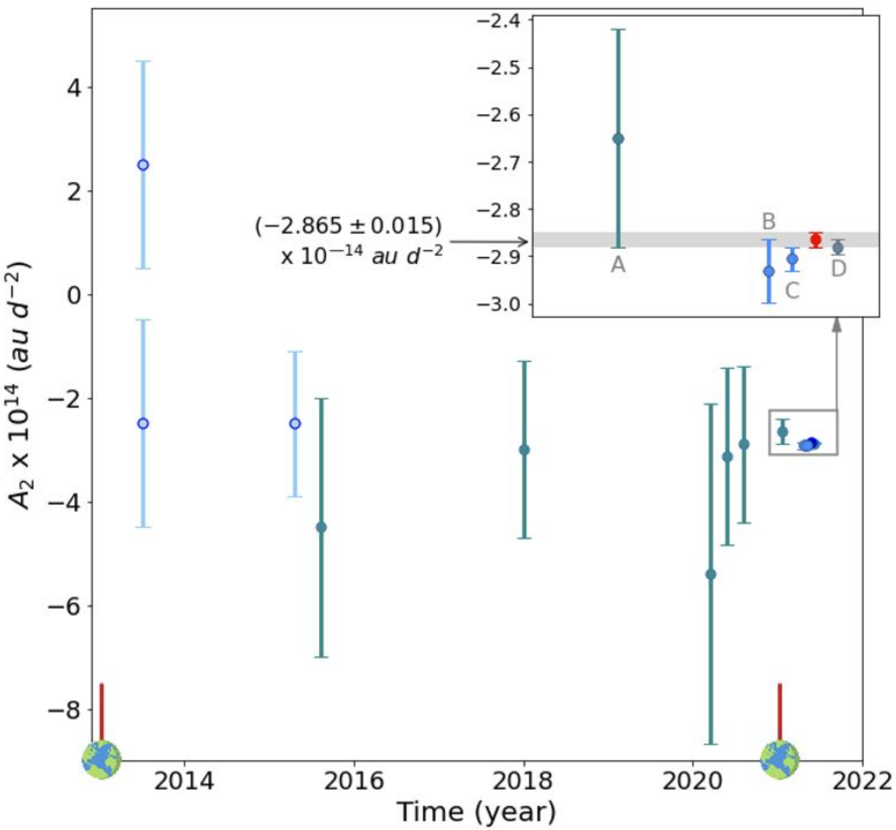
(13) Egeria		
Dane	średnica efektywna [km]	niepewność [km]
Zakrycie 2008-01-22 (rozw. 1)	219	+18 -16
Zakrycie 2008-01-22 (rozw. 2)	194	+12 -12
Zakrycie 2013-03-26 (rozw. 1)	216	+15 -17
Zakrycie 2013-03-26 (rozw. 2)	294	+7 -6
Obserwacje podczerwone (Nugent i inni, 2015)	202.636	±50.084

(14) Irene		
Dane	średnica efektywna [km]	niepewność [km]
Zakrycie 2013-08-02 (rozw. 1)	146	+12 -12
Zakrycie 2013-08-02 (rozw. 2)	145	+92 -18
https://ssd.jpl.nasa.gov	152	brak danych

(308) Polyxo		
Dane	średnica efektywna [km]	niepewność [km]
Zakrycie 2000-01-10 (rozw. 1)	133.5	+6 -6
Zakrycie 2000-01-10 (rozw. 2)	131	+5 -13
Zakrycie 2004-11-16 (rozw. 1)	125	+11 -9
Zakrycie 2004-11-16 (rozw. 2)	125	+11 -8
Zakrycie 2010-06-02 (rozw. 1)	129	+3 -3
Zakrycie 2010-06-02 (rozw. 2)	128	+4 -4
Obserwacje podczerwone (Masiero i inni, 2011)	128.578	±1.557

(3) Juno		
Dane	średnica efektywna [km]	niepewność [km]
Zakrycie 1979-12-11	260	+13 -12
Zakrycie 2000-05-24	236	+20 -17
Zakrycie 2014-11-12	250	+12 -11
Obserwacje podczerwone (Masiero i inni, 2011)	246.596	±10.594

Orbit and Yarkovsky effect determination with use of the stellar occultation data



www.cosmos.esa.int/web/gaia/iow_20210329

Summary

- Programming the method for asteroids size determination
- Size determination for 5 asteroids: Interamnia, Poluxo, Egeria, Juno, Irene
- Future work: the Yarkovsky effect determination with use of occ data

Small Bodies Near And Far

The research leading to these results has received funding from the European Union's

Horizon 2020 Research and Innovation Programme