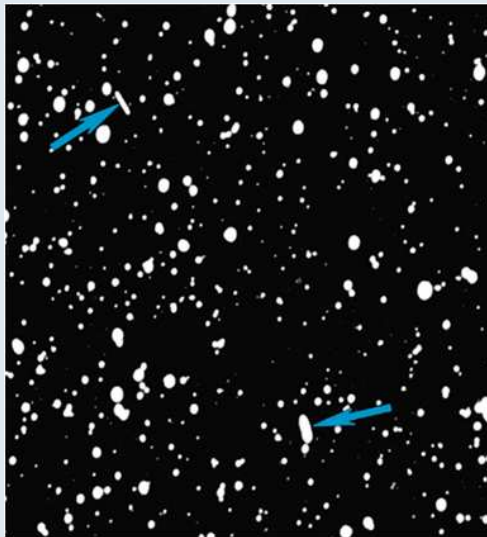


Planetoidy w trójwymiarze

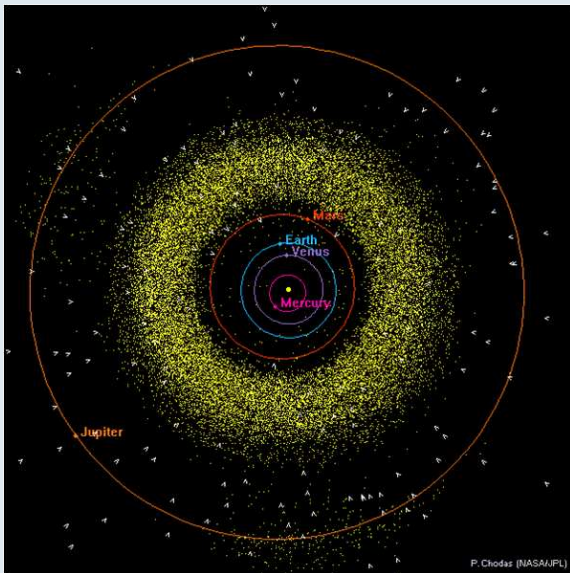
Anna Marciniak

Obserwatorium Astronomiczne
Uniwersytetu im. Adama Mickiewicza
Poznań

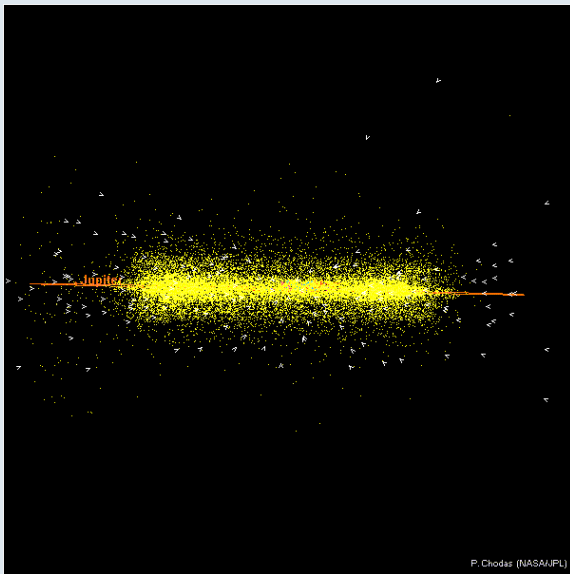
Planetoidy. Kosmiczne robactwo?



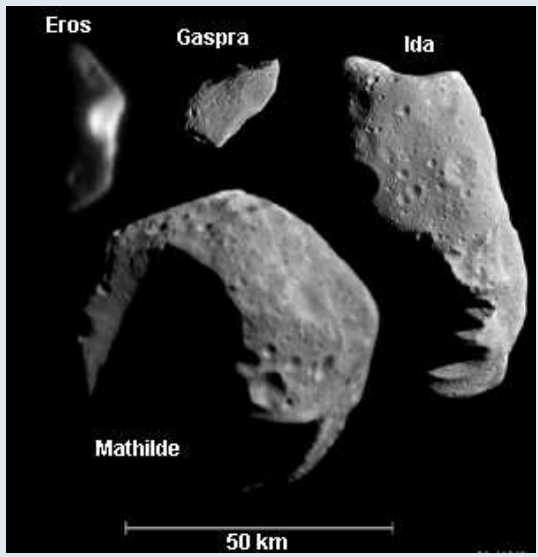
Położenie planetoid w Układzie Słonecznym



Położenie planetoid w Układzie Słonecznym

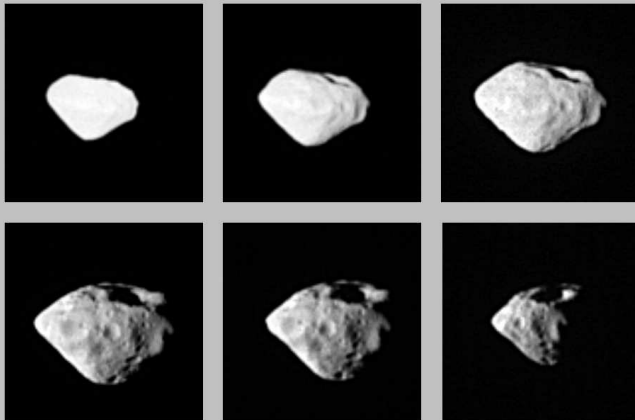


Porównanie rozmiarów planetoid odwiedzonych przez sondy kosmiczne



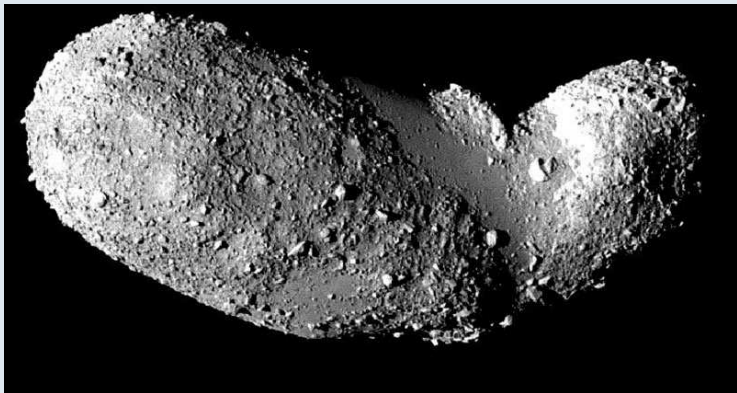
Planetoida 2867 Steins

OSIRIS Steins Fly-by



ESA ©2008 MPS for OSIRIS Team MPS/UPM/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

Planetka 45143 Itokawa



(JAXA)

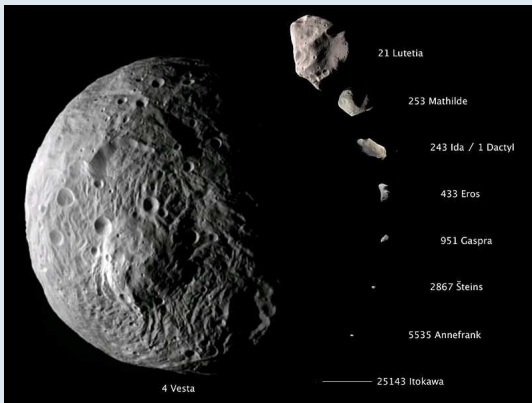
21 Lutetia z sondy Rosetta



4 Vesta w obiektywie sondy Dawn

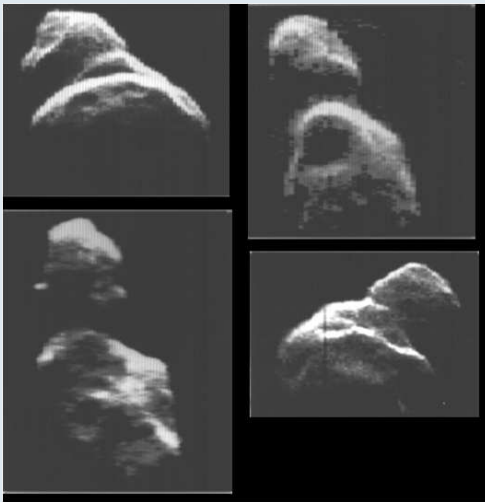


Porównanie planetek odwiedzonych przez sondy



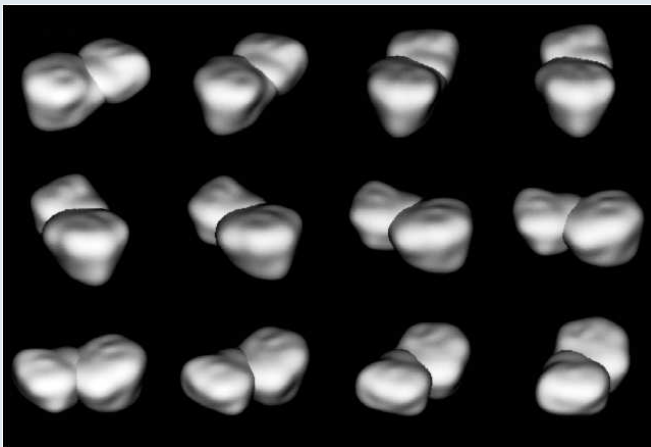
(NASA/JPL-Caltech/JAXA/ESA)

Obraz radarowy planetki 4179 Toutatis



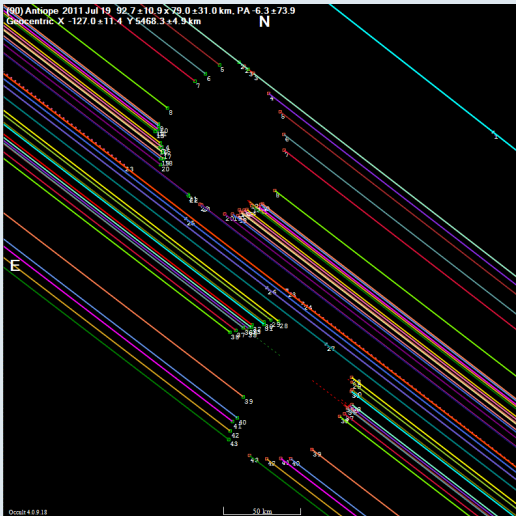
(Ostro et al. 1995)

Obraz radarowy planетки 4769 Castalia



(Hudson & Ostro 1994)

Obserwacje zakryć gwiazd przez planetoidy



Find best fit

Center X: 48.1 ✓ 30.3
 Center Y: -62.4 ✓ 27.4

Major axis (km): 92.7 ✓ 61.5 $ab=1.17$
 Minor axis (km): 79.0 ✓ 52.0 $dM=0.17$
 Orientation: -6.3 ✓ 0

Double star
 Sepn (massec): 0.0 0.0
 PA of 2nd: 0.0 0.0

Both Primary Secondary

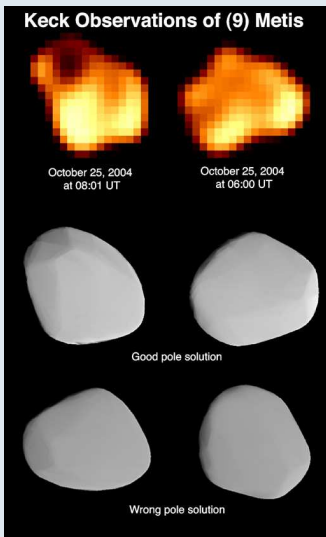
Circular Include Mas events

Plot scale: _____ Quality: Not fitted

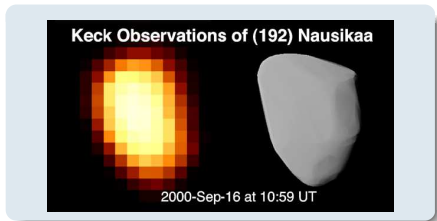
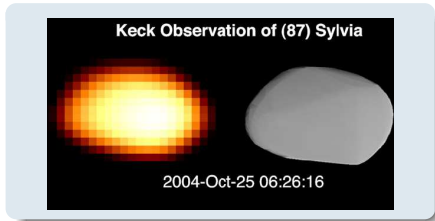
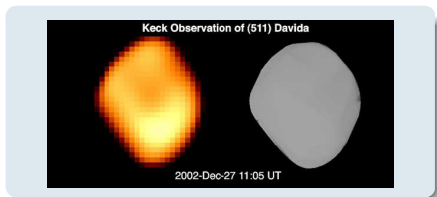
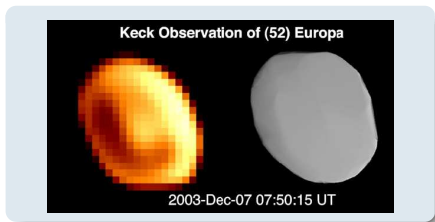
RMS fit: 52.4 ± 52.7 km

| | |
|--------|----------------------|
| 9 | S Degenhardt, Chicao |
| 10 | F Maley, Cortena, C |
| 11 | S Degenhardt, Chico |
| 12 | F Sullivan, Sebasto |
| 13 | F Maley, Williams, |
| 14 | S Degenhardt, Orovi |
| 15 | F Maley, Williams, |
| 16 | F Maley, Geneva, C |
| 17 | S Degenhardt, Orovi |
| 18 | S Degenhardt, Honcu |
| 19 | F Maley/B Merline, |
| 20 | F Maley/B Merline, |
| 21 | F Maley/B Merline, |
| 22 | S Degenhardt, Honcu |
| 23 (P) | Predicted Centerli |
| 24 (M) | F Bredner, Woodlan |
| 25 (M) | F Maley/W Hopkins, |
| 26 (M) | R Venable, Standish |
| 27 (M) | S Maximoff, Vacavil |
| 28 | T Swift, Davis, CA |
| 29 | R Sunnez/R Bardara |
| 30 | F Dunckel, Grass Va |
| 31 | R Venable, Doyle, C |
| 32 | R Venable, Doyle, C |
| 33 | D Kenyon, Rocklin, |
| 34 | D Machholz, Colfax, |
| 35 | T Case, Walnut Cree |
| 36 | D Becker, Boise, ID |
| 37 | R Venable, Chilcoot |
| 38 | R Venable, Chilcoot |
| 39 | T Beard, Reno, NV |
| 40 | J Albers, San Jose, |
| 41 | F Colas, IMCEE |
| 42 | F Colas, IMCEE |
| 43 | F Colas, IMCEE |

Obrazy planetoid z Optyki Adaptatywnej



Porównanie modeli



Marchis et al. (2006)

Obserwacje i fotometria planetoid

The screenshot displays the Starlink software interface for photometry. The main window shows a field of asteroids with three objects circled in blue. A secondary window titled "GAIA: AperLuc photometry -> magnitudes" is open, showing a table of results.

Starlink GAIA: Sky cat: cose_c20002_db.dk.F1.a01 (1)

Object: Output from FLUTOR (41setpossc_c20002_db.dk.F1.a01)

X: 155.5 Y: 151.9 Value: 1786.31
 OC: 152.5 δ : 152.5 Equinox:

Min: -1447.500195325 Max: 2042.7529625 Auto Cut: []
 Low: 0.00116 High: 2011.61 Color Map: []
 Scale: 1x Intensity Map: [] Zoom

GAIA: AperLuc photometry -> magnitudes (1)

File Options Colours Help

Frame zero point (mags) : 50

Results: [] Choose file...

Aperture Parameters Results

View all measurements:

| Index | RA | DEC | Mag | Filter | SA |
|-------|-----------|-----------|----------|---------|---------------|
| 1 | 177.10000 | 120.42000 | 35.77000 | 0.01700 | 4021.02000 11 |
| 2 | 181.04000 | 125.79000 | 34.38000 | 0.01900 | 4369.54800 12 |
| 3 | 453.67000 | 345.50000 | 34.74500 | 0.01900 | 4025.67800 12 |
| 4 | 543.81000 | 408.85000 | 35.77500 | 0.01900 | 4041.49800 12 |

Define object aperture Define sky aperture

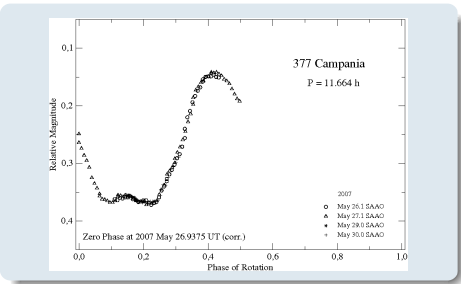
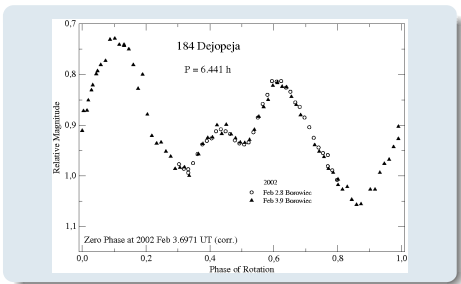
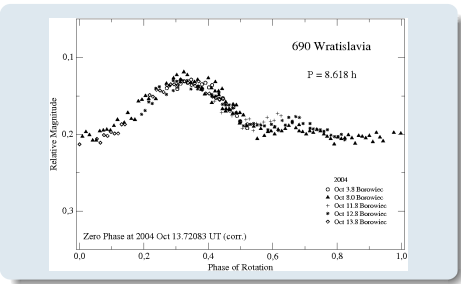
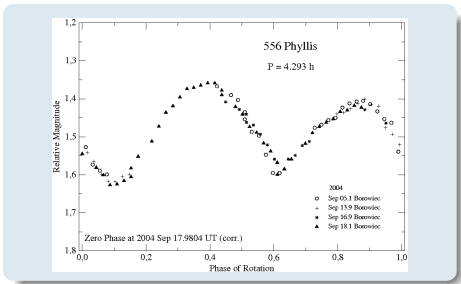
Copy aperture Calculate results

Append Save

Close

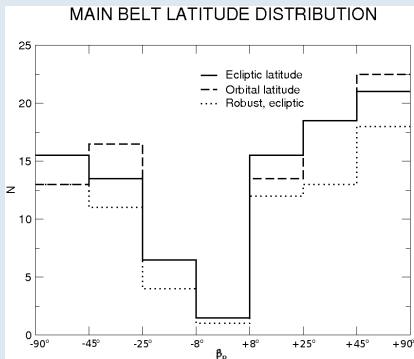
Image: [] - select object, [] - zoom image, [] - measure WCS, Control [] - select region

Krzywe zmian blasku planetoid

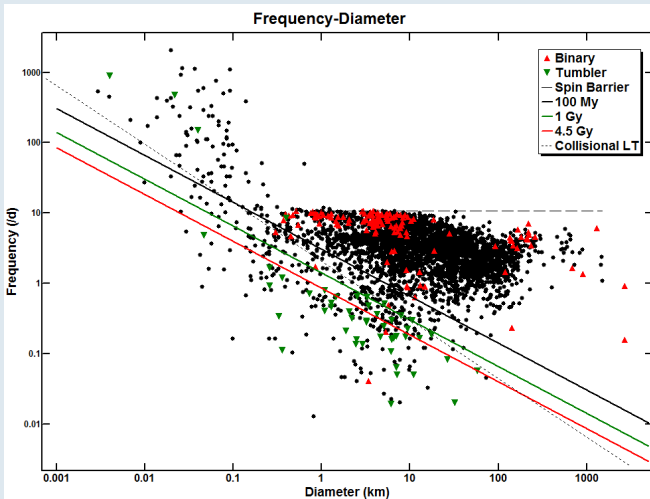


Modelowane parametry rotacji planetoid

- gwiazdowy okres rotacji
- położenie osi rotacji (λ_p, β_p)
- kierunek obrotu
- stosunki osi modelowej elipsoidy: $a/b, b/c$



Częstości rotacji a średnice planetoid



Warner & Harris, 2009

Metoda inwersji - podstawy teoretyczne

Powierzchnia sfery lub elipsoidy jest dzielona na trójkątne ścianki.
 Przyczynek do ogólnej jasności od jednej widocznej i oświetlonej ścianki:

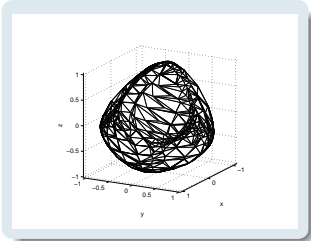
$$dL = S(\mu, \mu_0) \varpi ds$$

$$\mu = \mathbf{E} \cdot \mathbf{n}, \quad \mu_0 = \mathbf{E}_0 \cdot \mathbf{n}$$

S - prawo odbicia światła
 ϖ - albedo
 μ i μ_0 muszą być dodatnie.
 Problem inwersji wypukłej można przedstawić następująco:

$$\mathbf{L} = \mathbf{A}\mathbf{g}$$

Wektor \mathbf{g} – funkcja krzywizny obiektu (kształt), lub rozkład albedo. Parametry wektora \mathbf{g} – powierzchnie ścianek wypukłego wielościanu albo współczynniki szeregu harmonik sferycznych.

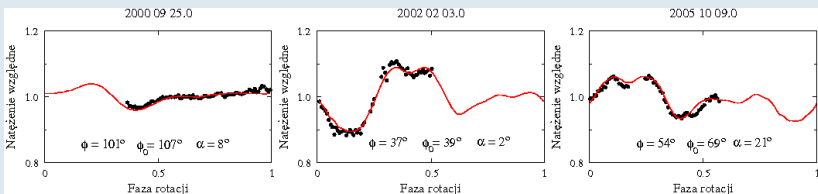
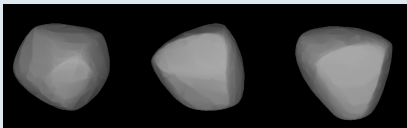


Rozwiązanie otrzymuje się poprzez minimalizację

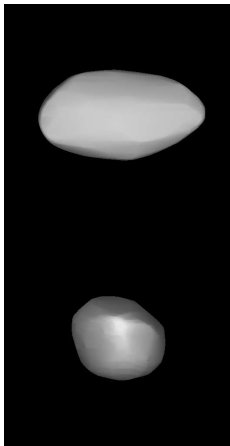
$$\chi^2 = \|\mathbf{L} - \mathbf{A}\mathbf{g}\|^2$$

Model planetki 160 Una

| Gwiazdowy okres rotacji (godziny) | Biegun | | | | Przedział obserwacji | N_{op} | N_k | odchyłki (mag) |
|-----------------------------------|------------------------------|-----------------------|------------------------------|-----------------------|----------------------|----------|-------|----------------|
| | Rozwiązanie 1 λ_p | β_p | Rozwiązanie 2 λ_p | β_p | | | | |
| 11.033176 ± 0.000003 | 125° $\pm 5^\circ$ | -33° $\pm 2^\circ$ | 308° $\pm 5^\circ$ | -41° $\pm 2^\circ$ | 1982-2008 | 7 (5) | 24 | 0.011 |

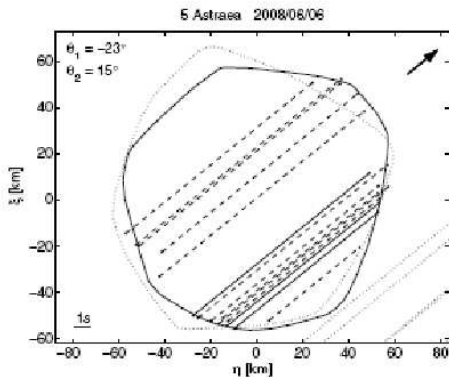


Model laboratoryjny



Kaasalainen et al. 2005


Modele z inwersji a zakrycia






(Durech et al. 2011)

Interaktywny Serwis Modeli Planetoid

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



Interactive service for asteroid models

184 Dejopeja (model 1)

Date: (dd-mm-yyyy)

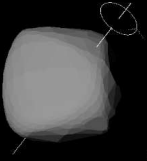
Time: (hh:mm:ss)

Legend:

- Show rotation axis
- Generate lightcurve
- 3D effect
- LT corrected view
- Full silhouette

184 Dejopeja
JD=2455762.3459

$\lambda = 200^\circ$
 $\beta = 52^\circ$

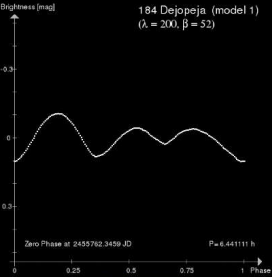


Aspect = 54°

$P = 6.441111$ h

Brightness [mag]

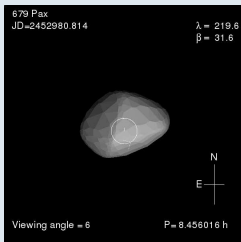
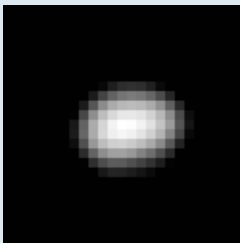
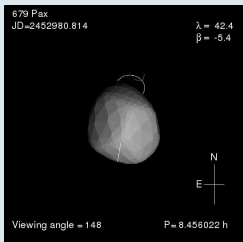
184 Dejopeja (model 1)
($\lambda = 200, \beta = 52$)



Zero Phase at 2455762.3459 JD $P = 6.441111$ h

[download data](#)

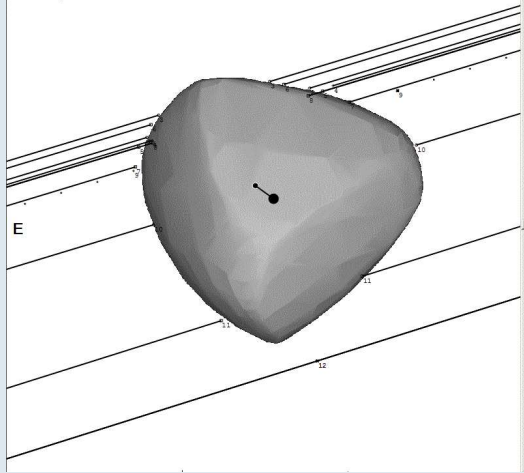
Interaktywny Serwis Modeli Planetoid



(Marciniak et al. 2011)

Interaktywny Serwis Modeli Planetoid

(160) Una 2011 Jun 24 79.0 ± 2.6 x 79.0 ± 2.2 km. PA 0.0
 Geocentric X -2172.6 ± 0.9 Y 2534.0 ± 1.0 km
 Double: Sep 0.0055 ± 0.0012". PA 54.2 ± 16.5"



Find best fit

Center X 0.0
 Center Y -0.4

Major axis (km) -9.2
 Minor axis (km) 6.2
 Orientation 0

Double star
 Sepn (masec) -2.0
 PA of 2nd -9.9

Both Primary Secondary

Circular Include Miss events

Plot scale Quality

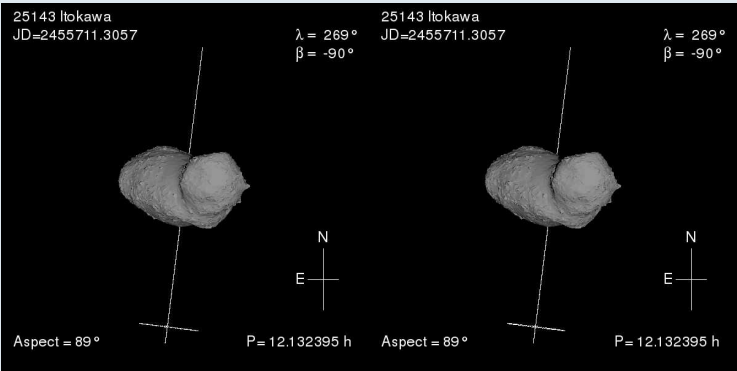
RMS fit -0.4 ± 3.7 km

- 2 D diCiccio, Sudbury, MA
- 3 D diCiccio, Sudbury, MA
- 4 W Hill, Marlboro MA
- 5 R Dantowitz/A Sleski, Clay Center, I
- 6 R Dantowitz/A Sleski, Clay Center, I
- 7 T Blank, Westborough, MA, USA
- 8 T Blank, Westborough, MA, USA
- 9 (D) Predicted Centeline w/Time
- 10 D Dunham, Holyoke, MA
- 11 T Beard, Reno, NV
- 12 (M) R Sumner/J Davis, Carson City, NV

(George et al. 2011)

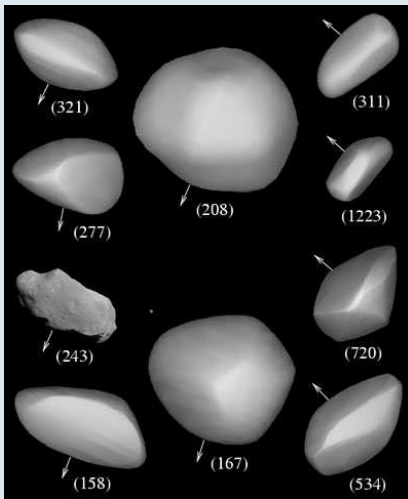
Interaktywny Serwis Modeli Planetoid

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



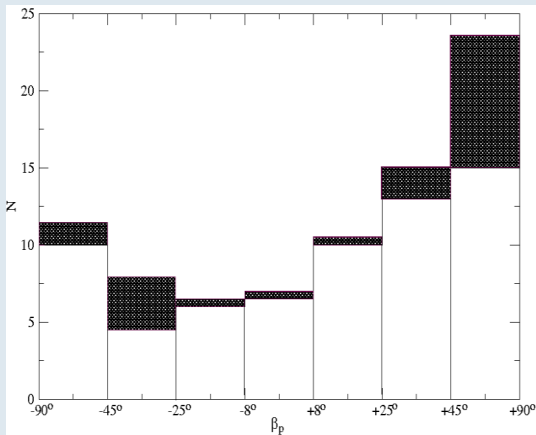
(Marciniak & Bartczak 2011)

Położenia biegunów planetoid rodziny Koronis



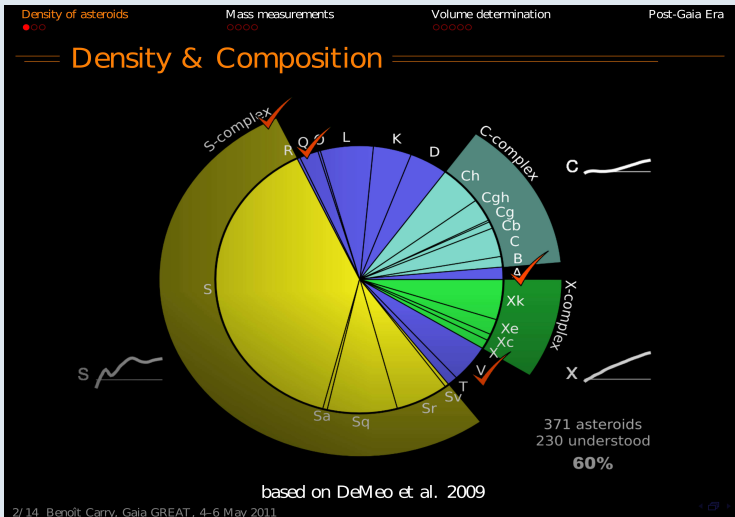
(Slivan et al. 2003)

Rozkład szerokości biegunów dla 82 planetoid - metoda inwersji



(Marciniak & Michałowski 2010)

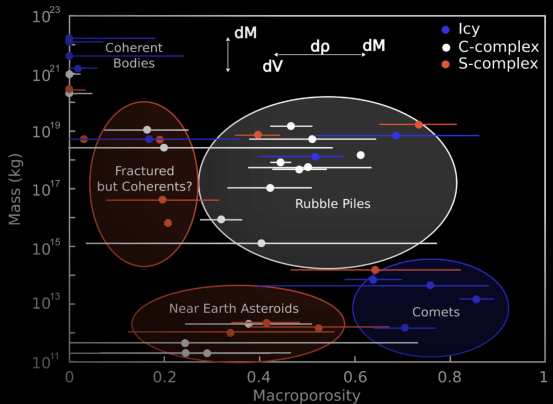
Skład mineralogiczny planetoid różnych typów taksonomicznych



Budowa wewnętrzna planetoid

Density of asteroids Mass measurements Volume determination Post-Gaia Era

Density & Structure



adapted from Britt et al. 2006

KOALA, czyli wzbogacona inwersja

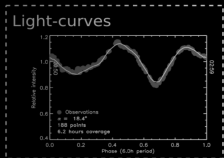
Density of asteroids
000

Mass measurements
0000

Volume determination
000●0

Post-Gaia Era

Volume with KOALA



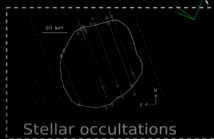
Indirect measurement
Shape
Spin

Direct measurement
Size
Shape

Knitted
Occultation
Adaptive optics
Light-curve
Analysis

Direct measurement
Size
Shape

Kaasalainen, IPI 2011



Stellar occultations

Sukcesy KOALI

Density of asteroids 000 Mass measurements 0000 Volume determination 000●0 Post-Gaia Era

Volume with KOALA

| | 13:48 | 15:16 | 15:41 | 15:47 |
|--------|-------|-------|-------|-------|
| OSIRIS | | | | |
| KOALA | | | | |

Pre-Flyby model **KOALA** vs. Rosetta Accuracy
 Carry et al. 2010 Shape: 2 km Volume: 15%
 Carry et al. 2011

12/14 Benoît Carry, Gaia GREAT, 4-6 May 2011

Dalszy rozwój KOALI

Density of asteroids
000

Mass measurements
0000

Volume determination
0000●

Post-Gaia Era

KOALA Development

- KOALA 1.0: Kaasalainen, Ďurech & Carry

Lightcurves (dense & sparse)

Disk-resolved imaging

Stellar occultations

Code being cleaned for release

- KOALA 1.x: Current development

Interferometry (optical): FGS on HST, J WST

Thermal radiometry: IRAS, Spitzer, WISE

Kaasalainen, Ďurech, Delbò, Carry

- KOALA 2.0: Planned development

Interferometry (thermal): VLTI, LBT

Radar: Arecibo, LOFAR+EISCAT 3d