Solar System science before and after Gaia

Pisa, Italy, 2011 May 4-6

The representation of asteroid shapes: a test for the inversion of Gaia photometry

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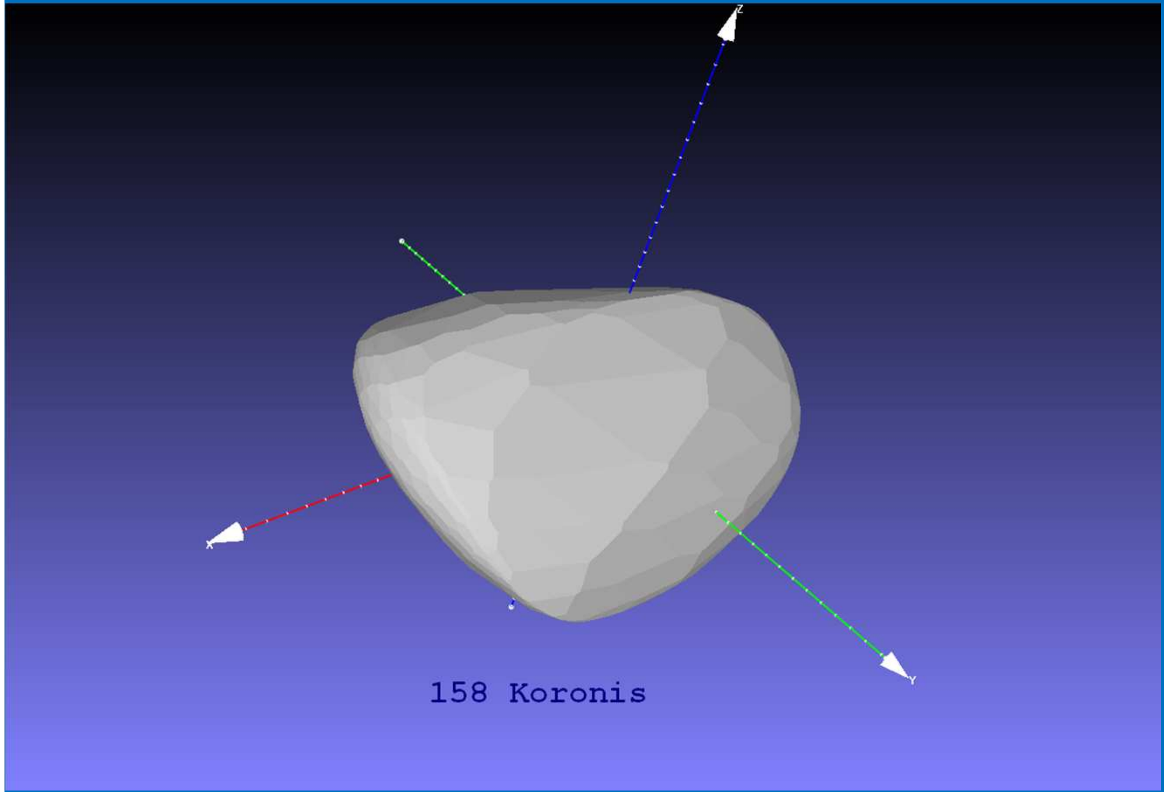
Photometry and shapes



Photometry has been one of the first observing techniques adopted to derive information about the physical properties of asteroids.

The rotation period can be derived from an analysis of the lightcurve and with lightcurve at different apparitions it is possible to determine the sky orientation of the spin axis and the object's shape.

An example of asteroid shape: 158 Koronis (Database of Asteroid Models from Inversion Techniques, DAMIT).

Asteroid photometry with Gaia

1. Gaia will produce a large amount of sparse photometric data.
2. Each object will be observed 50-100 times, at a variety of observing circumstances.
3. Gaia will observe all asteroids down to visible magnitude +20 (about 300,000 objects).
4. Deriving rotational and shape properties from photometric data is a challenging problem.
5. Inversion of Gaia asteroid photometry will be made assuming that the objects have three-axial ellipsoid shape. But how accurate is this approximation?

Simulation of Gaia data processing

1. A pipeline of simulations (called "runvisual") has been implemented to assess the expected performances of asteroid photometry inversion.

2. Asteroid complex models (convex shapes) are used to (a) extract best-fit ellipsoidal models of the assumed shapes, and (b) to simulate Gaia photometric observations.

3. The "genetic" algorithm developed by Cellino et al. (2009) for Gaia data processing is used to derive the rotation period, pole coordinates, ellipsoidal shape (b/a, c/a), and phase-mag slope for each simulated set of observations.

4. The results of the inversion are compared with the correct solution, and it is also checked whether the obtained shape corresponds to the best-fit triaxial ellipsoid model of the complex shape.

A. Cellino, D. Hestroffer, P. Tanga, S. Mottola, A. Dell'Oro, Astronomy & Astrophysics, 935-954 (2009).

Runvisual algorithm

- Input of the model file, pole solution, diameter, scattering model, geometric albedo and ephemeris file.

- Scale the mesh according to the asteroid effective diameter.

- Start loop for visual magnitude computation:

  - Read from ephemeris file JD, asteroid's heliocentric and geocentric coordinates.
  - Rotation of the model in the ecliptic coordinate system.
  - Computation of the normal vector to the asteroid faces in the ecliptic system.
  - <u>Computation of the faces illuminated from the Sun and seen from Earth.</u>

- Compute the asteroid magnitude with the selected scattering model: geometric, Lambert, Lommel-Seeliger and Lommel-Seeliger-Lambert.

- End magnitude loop.

<u>Runvisual</u> was written in <u>classical C-language under Linux OS</u>.

Choice of complex models

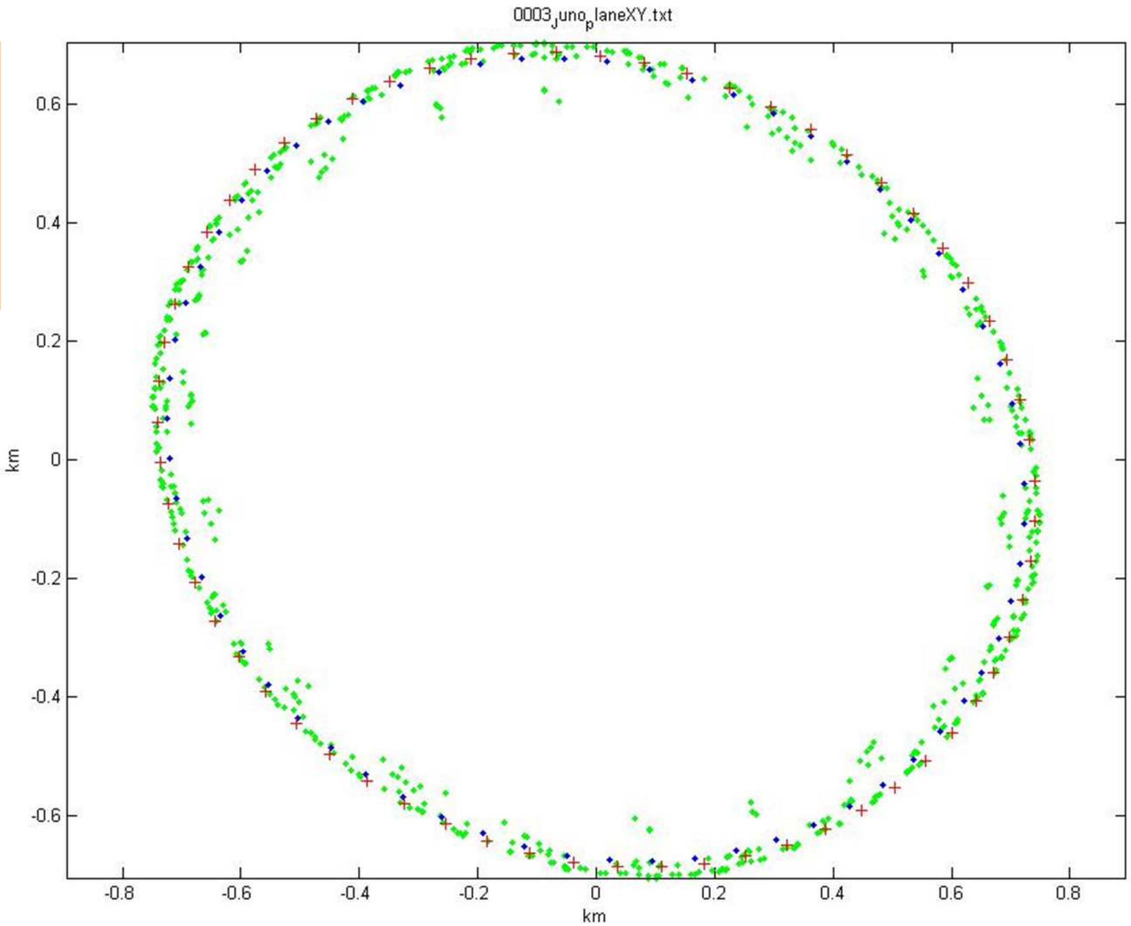
1. The analysis has been so far limited to Main Belt asteroids. Complex models (convex shapes) were taken from the Database of Asteroid Models from Inversion Techniques (DAMIT).

2. The database and its web interface is operated by The Astronomical Institute of the Charles University in Prague, Czech Republic. The DAMIT Web address is: *http://astro.troja.mff.cuni.cz/projects/asteroids3D/web.php*

From complex shape to best-ellipsoidal shape - 1

Equatorial plane of asteroid 3 Juno.

Green dots = projection of the vertices of the convex model with quote under 0.2 of the z extension.

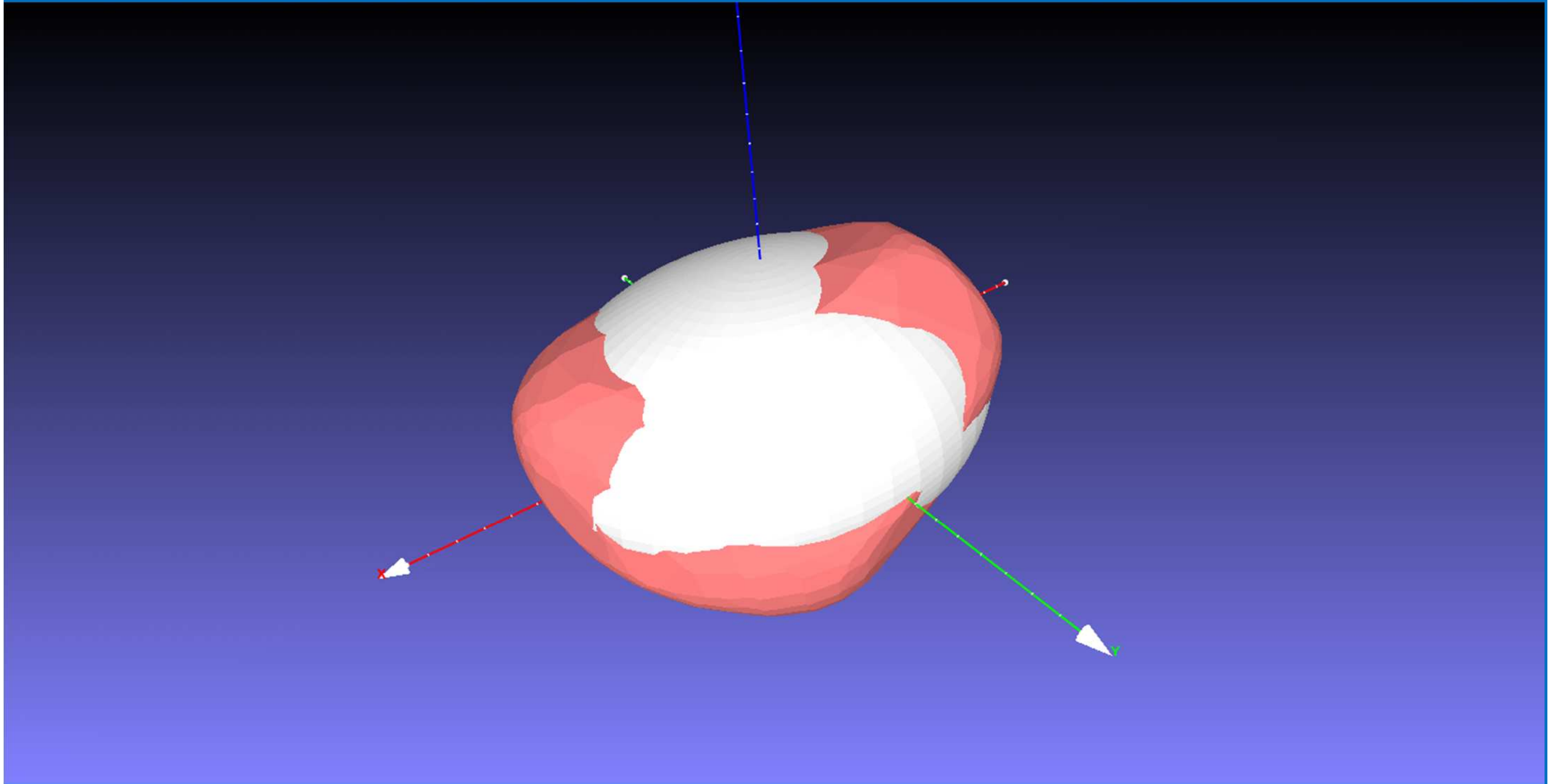


The best-ellipsoid fit is a two step processes:

1. Calculation of the major axis and of the second axis of the ellipsoid in the asteroid X-Y plane as best-fit ellipse.
2. Compute the third ellipsoid axis so that to have equal volumes between complex and ellipsoidal shape.

The spin is the same for complex and best-ellipsoidal shape.

From complex shape to best-ellipsoidal shape - 2



Asteroid 9 Metis. Red: complex shape. White: best-ellipsoidal shape.

Comparison between lightcurves of complex and best-fit ellipsoidal shapes

1. Simulated lightcurves of complex shapes and corresponding best-fit triaxial ellipsoid shapes were computed and compared at a variety of possible observing circumstances.

2. So far, we used the complex models of eight MBAs: 3 Juno, 9 Metis, 192 Nausikaa, 484 Pittsburghia, 532 Herculina, 584 Semiramis, 1088 Mitaka and 1270 Datura, corresponding to increasing irregularity in shape and decreasing effective diameter.

3. The simulated spin axis was not that of the real asteroid, but was taken on the ecliptic plane, in the reverse direction of the gamma-point, to maximise lightcurve variations. The orbit was assumed to be circular with a 3 UA radius.

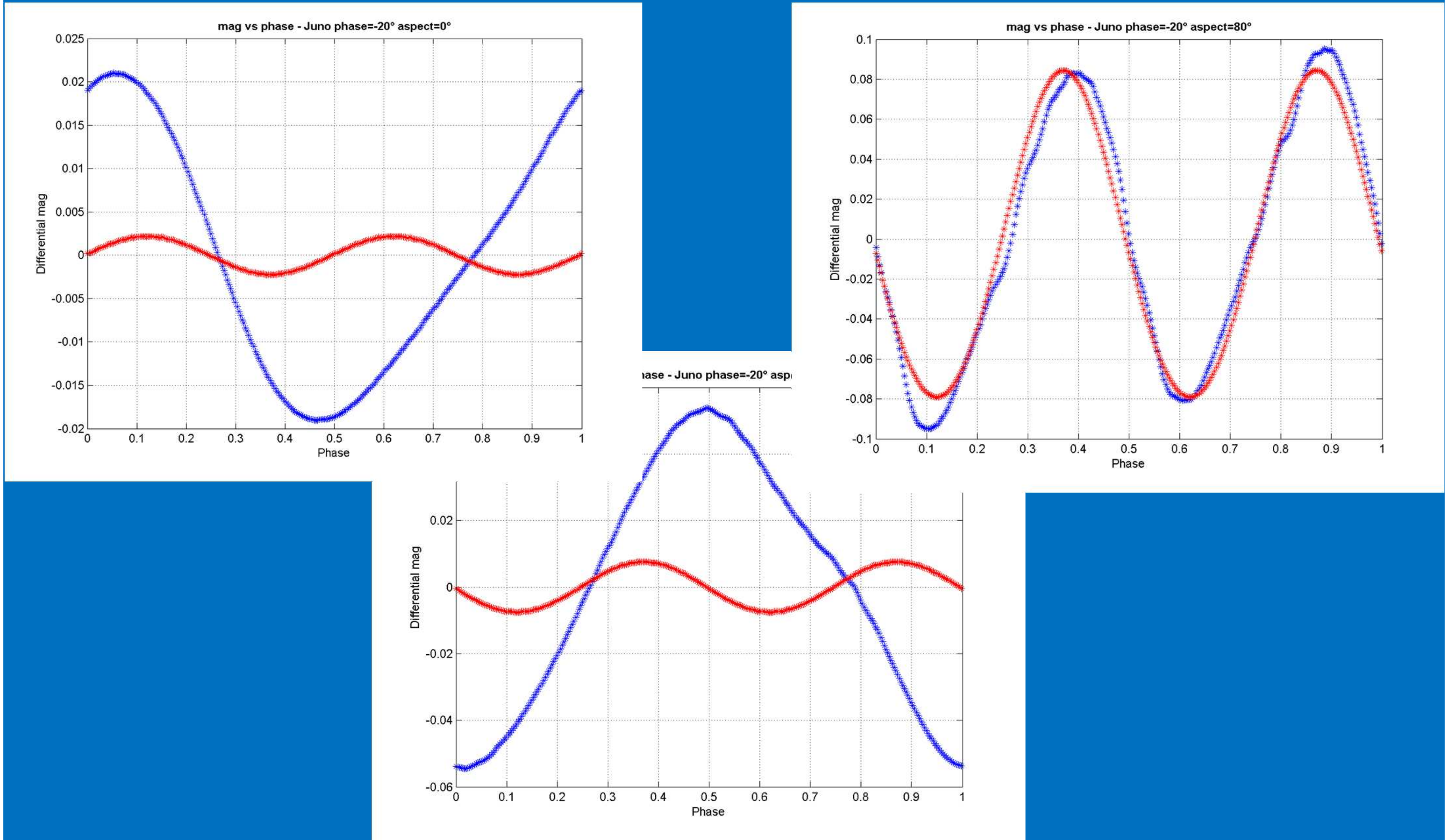
4. We found that a triaxial ellipsoid model provides a good fit of the real lightcurve only at high aspect angles (nearly equatorial view), at any phase angle. At low aspect angles the agreement is quite poor.

Geometry for photometric comparison on circular orbit

Phase angle (°)	Aspect angle (°)	Aspect angle (°)	Aspect angle (°)
0	0	$2*\alpha_{max}$	$4*\alpha_{max}$
α_{max}	0	$2*\alpha_{max}$	$4*\alpha_{max}$
$-\alpha_{max}$	0	$2*\alpha_{max}$	$4*\alpha_{max}$

For each phase angle were tested different aspect angles. In our geometry $\sin(\alpha_{max})=1/3$ so $\alpha_{max} \sim 19.5°$.

Complex vs best-ellipsoidal lightcurves – circular orbit



Comparison of the lightcurves obtained at phase angle -20 (before opposition) and aspect angles (from left to right) 0 , 40 and 80 for the complex model (blue line) of the asteroid 3 Juno and the corresponding best-fit ellipsoid (red line). The scattering model is that of Lommel-Seeliger-Lambert.

Simulating Gaia photometry

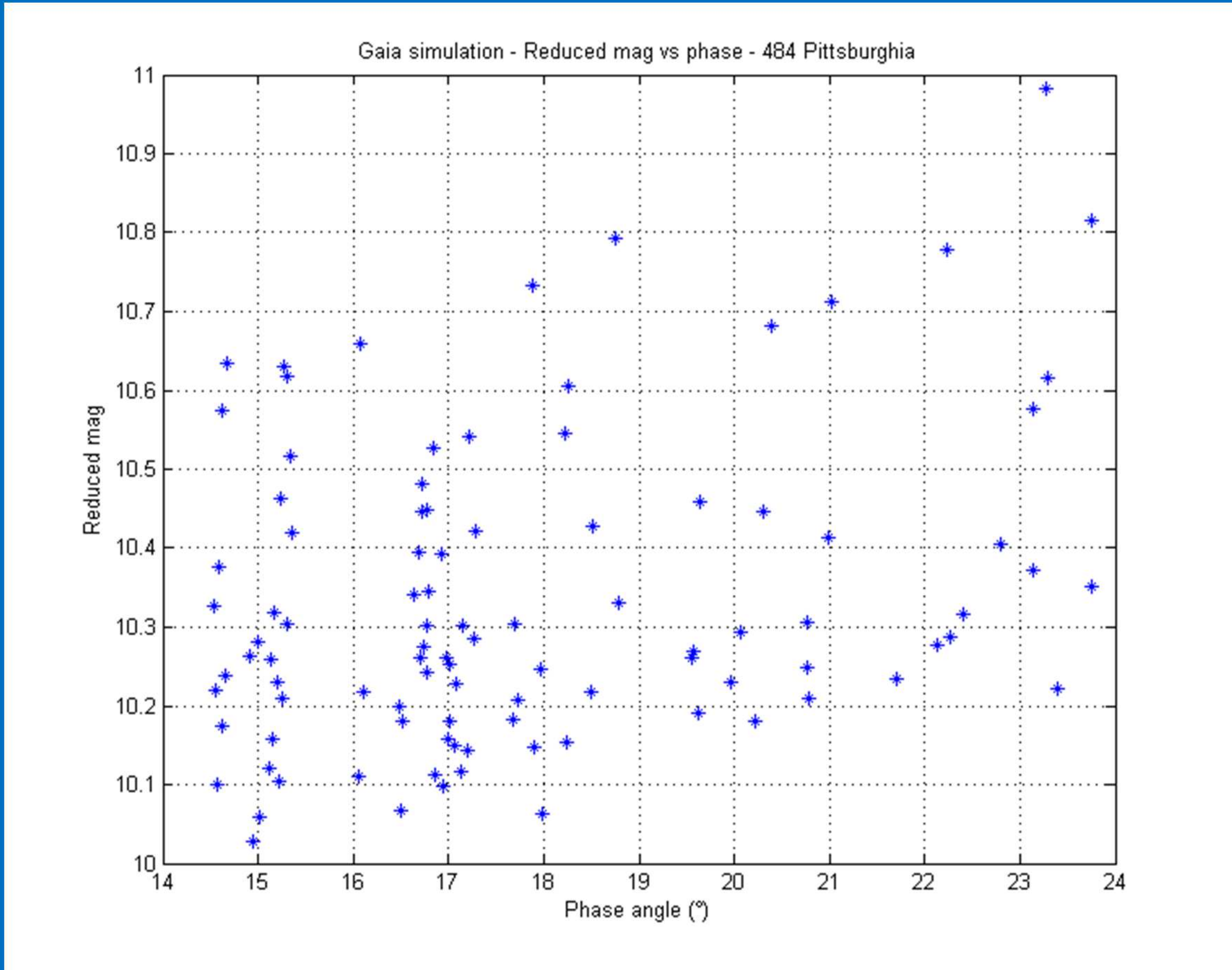
1. Gaia observations have been simulated using the software written by F. Mignard and P. Tanga and implemented in Java by Christophe Ordenovic (OCA). This software simulates the Gaia observation sequence for any Solar System object, giving for each observation the corresponding gaia-centric and heliocentric distances and the phase angle.

2. Apparent magnitudes were computed at simulated observation epochs for some Main Belt asteroids, using their (already known) spin, period and corresponding complex models (convex shapes). Light scattering effects on asteroid surfaces were modeled using both a purely geometric and a "Finnic" model (0.1 Lambert scattering + 0.9 Lommel-Seeliger scattering).

3. The simulated observations were inverted using the "genetic" algorithm developed for GAIA.

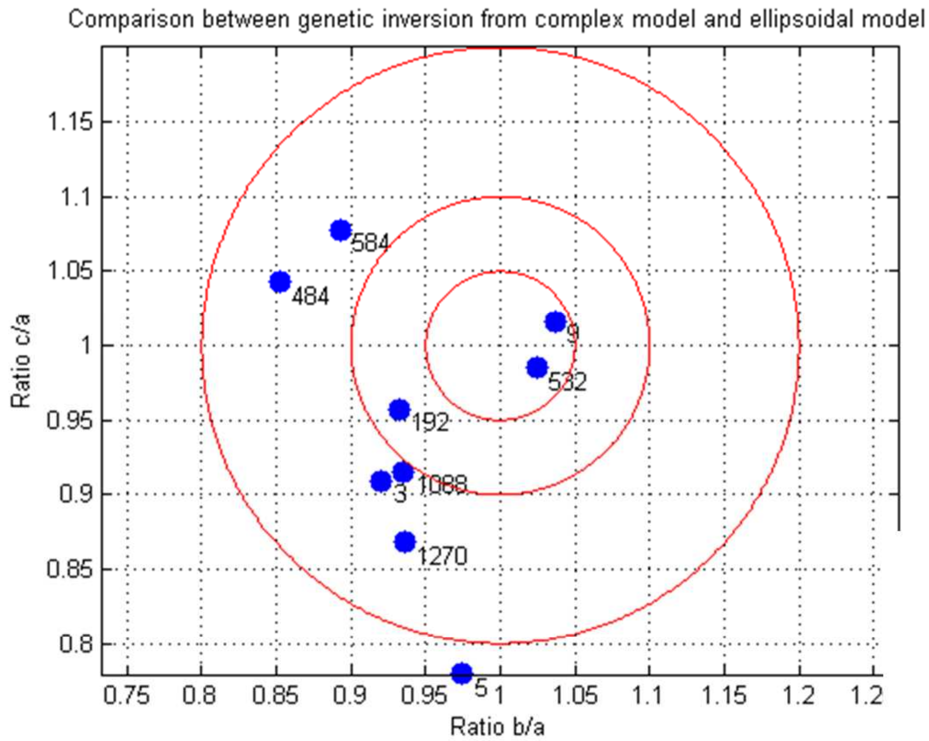
4. Preliminary results (work in progress), suggest that the "genetically derived" ellipsoids found by photometry inversion are strictly similar to the best-fitting ellipsoids of the simulated complex shapes. Moreover, it is found that the RMS between simulated observations and computed solutions is not very important for a good pole fit (confirming similar results by Cellino et al., 2009).

Example of simulated photometric data



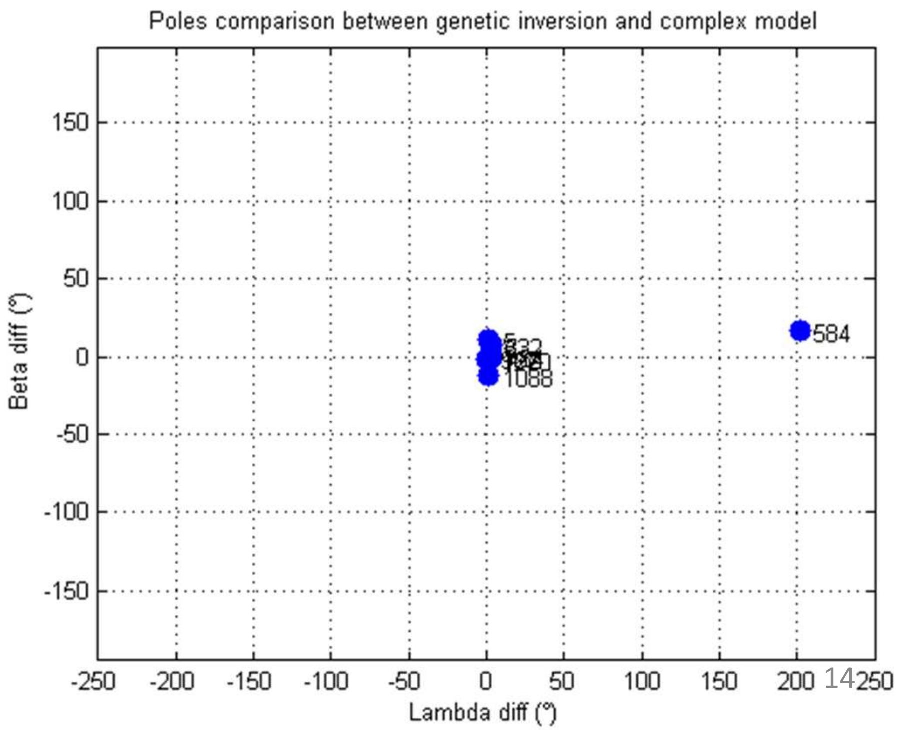
The simulated photometric plot for the asteroid 484 Pittsburghia.

Some spins and shapes results from simulation - 1



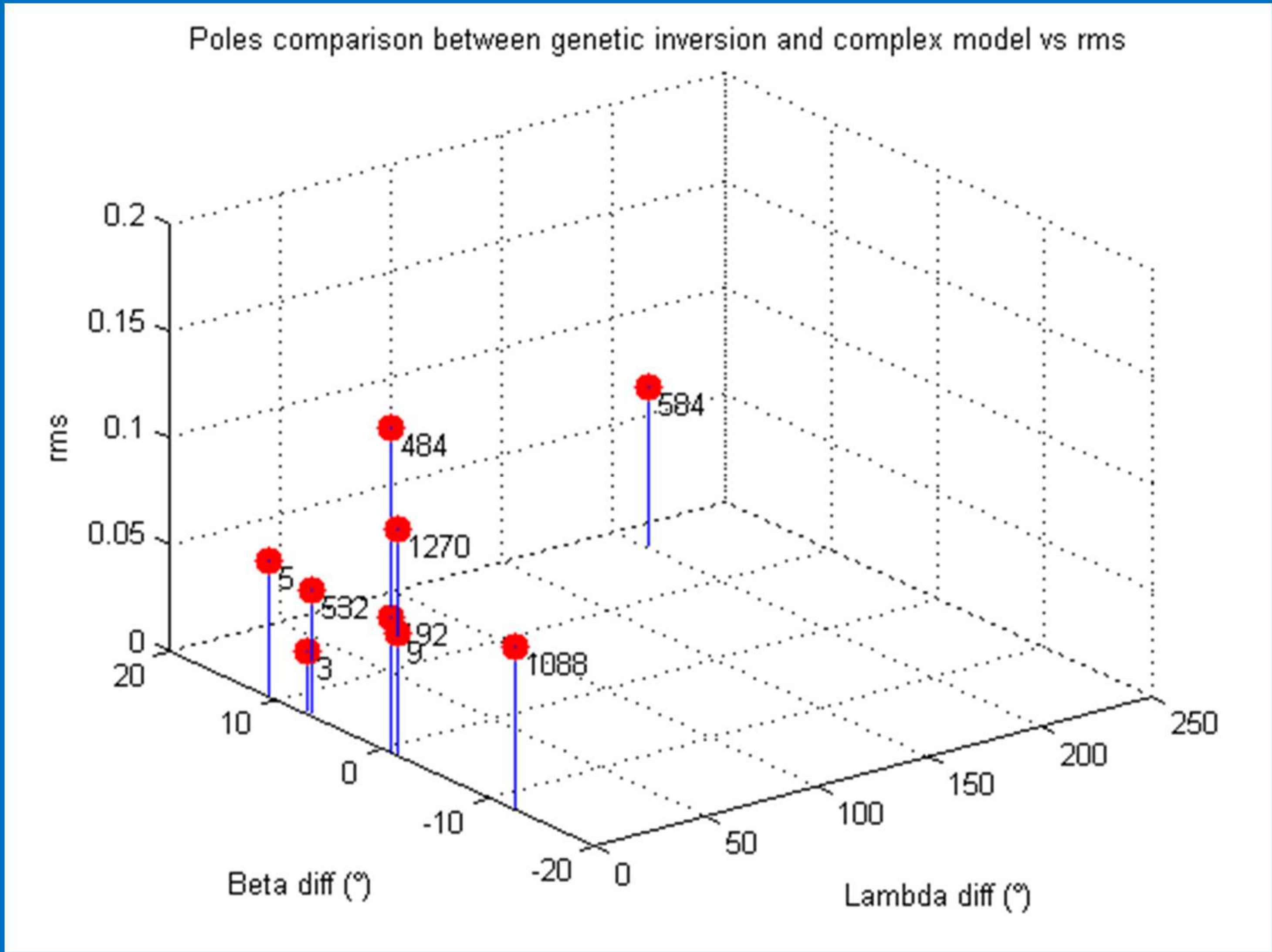
Axis ratio between the genetic inversion with the convex models and the best-ellipsoidal models.

The rotation periods are very good and are not compared.



Spin coordinates difference between the genetic inversion and the complex/best-ellipsoidal models. Whe have $\Delta\lambda_{max}$ 5 and $\Delta\beta_{max}$ 10 .

Some spins and shapes results from simulation - 2



The spin fit is not strongly sensitive to the RMS (Root Mean Square) between complex and best-ellipsoidal model.

Preliminary conclusions

1. Confirmed rotation periods with high accuracy.
2. Confirmed unique solution for the spin.
3. Confirmed the spin fit is not strongly sensitive to the RMS between complex and best-ellipsoidal model.
4. Axis ratio near that of the best-fit ellipsoid of the complex shape.
5. Best-fit ellipsoid and complex shape can have very different lightcurves.

…but much work remains to be done, eg:

- Which error is committed on the volume/density estimate?

The representation of asteroid shapes: a test for the inversion of Gaia photometry

Thank You!

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