

INAF -- Osservatorio Astronomico di Torino

Alberto Cellino – Pisa GREAT Workshop, May 4-6, 2011

The determination of asteroid physical properties from Gaia observations





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Some important problems in current asteroid science:

- The determination of asteroid masses and densities
- The direct measurement of asteroid sizes (and shapes)
- The determination of spin properties for a larger sample
- The recovery of the blue part of reflectance spectra
- A better interpretation of taxonomy in terms of structure

and mineralogy

GAIA will play a decisive role in the solution of the above problems.



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Asteroid masses are sorely needed:

• To understand internal structure and evolution :



- The great unknowns : density, porosity...
 Gravitational aggregates or solid bodies?
 The origin of shapes
- The collisional history
- Impact risks and mitigation strategy
- To improve Solar System ephemerides

See talks by D. Hestroffer, F. Colas, A. Fienga, B. Carry and others





The size distribution of Main Belt asteroids is a major constraint for models of the collisional evolution of the asteroid belt. Moreover, sizes and shapes are needed to derive average densities when masses are known. However, asteroid size data are generally *not* known from direct size measurements!



GAIA: Angular size measurement accuracy for single transits







Photometric accuracy (single transit)

G	σ(mmag) G	σ (mmag) ${f G}_{{}_{\sf BP}}$	σ(mmag) G _{RP}
13.0	2.5	2.5	2.4
14.0	3.0	4.1	4.0
15.0	4.8	7.1	6.7
16.0	7.6	12.9	12.3
17.0	12.3	26.3	24.7
18.0	20.3	58.6	54.7
19.0	35.1	139.0	129.4
20.0	66.2	340.6	316.8



The inversion problem: The objects are assumed to be triaxial ellipsoids. <u>A "genetic" algorithm is used</u> to solve for the unknown spin period, spin axis direction, two axial ratios, rotational phase at t=0, and a phase-magnitude linear coefficient.



More than 10,000 asteroids should be potentially invertible



L'importanza della missione Gaia per gli studi degli asteroidi

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Alberto Cellino – Bormio, 21-25 Gennaio 2008

How it works

- 10,000 sets of parameters are randomly generated
- The "best" 50 sets are kept in an array
- The set of 50 best solutions starts to "genetically evolve", by coupling of different solutions or random mutation of the parameters of single solutions. At each generation, a check is made whether the newly born solution enters the Top 50 list.
- ~300,000 iterations are performed. The procedure starts again from the beginning every 10000 genetic generations. A good solution is usually found !! It is required to find it more than once.



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A systematic analysis of the old HIPPARCOS photometric data of asteroids has been carried out.

The data set includes measurements for 48 asteroids, for which the rotational periods are known from full lightcurves, as well as pole solutions in most cases.

Only 23 objects have numbers of photometric measurements and nominal photometric accuracies that put them (in some cases, marginally) in the domain of possible photometric inversion *for ideal triaxial ellipsoids*. Some of them are known to exhibit complex lightcurves suggesting irregular shapes and/or albedo features.

The right period has been derived for 13 (+4) objects.



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The cases of 4 Vesta and 1 Ceres are interesting.

Vesta is a spheroid with a hemispheric-scale albedo spot, dominates the photometric lightcurve.

The inversion algorithm finds a solution consistent

with the spin axis direction determined from

ground-based observations, but a spin period

which is exactly twice the correct one.

This is fully understandable, since the algorithm tries to fit a photometric variation with two maxima and minima.

The same happens for 1 Ceres, which has a shape very close to a sphere, and a very modest photometric variation. The results of the inversion suggest that the lightcurve should be dominated by albedo markings, and this is in agreement with some recent HST observations.



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We expect to find solutions (poles, periods and axial ratios) for no less than 10,000 asteroids (maybe many more).

General application: Spin properties as a new, important constraint to modern models of the collisional evolution of Main Belt asteroids.

Specific applications: (1) test of the existence of possible preferential alignments of the spin axes of family members, possibly due to YORP effect.

(311)(321)(208)(1223)(277)(720)(243)(167)(158)(534)

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<u>Spectroscopic observations and taxonomy</u> classification

Spectral characteristics				
	Blue Photometer	Red Photometer		
spectral range	330-680 nm	650-1000 nm		
spectral dispersion	4-34 nm/pixel	7-15 nm/pixel		

The construction of an extensive Gaia-based asteroid taxonomy will be a natural byproduct of the detections of about 300,000 asteroids down to magnitude 20.

This taxonomy will have two major advantages:

- 1. it will be homogeneous, since it will be derived by a single instrument;
- 2. it will include for many objects the Blue spectral region (not included in the most taxonomic classifications based on spectroscopic surveys carried out in recent years.

The Blue part of the reflectance spectrum is known to be very important, in particular as a diagnostic tool to distinguish among different sub-classes of primitive, low albedo objects, including the very interesting F-class asteroids.



$\log(D) = 3.1236 - 0.2H - 0.5 \log(albedo)$

Application to Gaia. In an ideal and simple world, Gaia determines the sizes D for many objects, based on shape information derived from photometric inversion, and measures magnitudes, too, then the above formula could be easily implemented to estimate the albedo. If the relation between phase angle and magnitude was perfectly known and independent on observational circumstances, it would be simple to extrapolate to zero phase angle the observed magnitudes to derive the value of H. Albedo would then be simply computed.

Unfortunately, the world is not ideal in many respects.

$\log(D) = Q - 0.2H - 0.5 \log(albedo)$

Minor problem:

The value of the constant (3.1236 in V light) must be recomputed taking into account that Gaia will observe in G light.

Or, conversely, G magnitudes might be preliminarily converted to Standard V.



The problem of the opposition effect for absolute mags

$\log(D) = Q - 0.2H - 0.5 \log(albedo)$

More important, Gaia will never observe at zero phase angle, nor at phase angles for which the opposition surge takes place. Magnitude extrapolations to zero phase will be necessary at each transit. This is not an easy task, since the opposition effect is non linear and is not known a priori for any object.

If one does not take into account the opposition effect, Gaia-derived albedo will not be immediately comparable with the values currently published in the literature.

This would be a pity, since Gaia will produce about 1,000 albedo determinations,

[Using extrapolated magnitude to phase angle around 5° would not be in any case a tragedy, based on physical considerations]

Some recent news



Contents lists available at ScienceDirect

Icarus



A three-parameter magnitude phase function for asteroids

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A new photometric system has been proposed, which might largely improve the situation



Expected Post-GAIA scenario in Asteroid science:

- Masses and average densities measured for ~ 100 objects.
- Sizes directly measured for ~1,000 objects
- Spin properties and general shapes of thousands of objects; spin as a constraint to collisional evolution models
- Assessment of size albedo relation, possibly interpreted in terms of space weathering
- New taxonomy of a very big sample of the population. Implications for the original gradient in composition of the Solar System, and for dynamical diffusion and collisional mechanisms.
- New "spectroscopic" families.

After Gaia : the occultation revival

Today

- poor predictability for objects <50 km
- bright Hipparcos/Tycho stars favoured
- ~0.1 events/objects/year
- Current practical limit: 100 km at 10% accuracy

After Gaia (100 X orbit improvement):

- Uncertainty smaller than the asteroid at >20 km
- 1-m automated telescope(s):
 - Single site: 20-40 events/yr for an object of ~20 km
 - Network: completeness of diameters
 - > 20 km in a few yr
- Projected shape known

Tanga, Delbo A&A 2007





Thank you!