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Rotational properties of asteroids from Gaia disk-integrated photometry: A "genetic" algorithm

A. Cellino [a,*], M. Delbò [a], V. Zappalà [a], A. Dell'Oro [a], P. Tanga [b]

[a] *INAF–Astronomical Observatory of Torino, Strada Osservatorio 20, 10025 Pino Torinese (TO), Italy*
[b] *Observatoire de la Côte D'Azur, B.P. 4229, 06304 Nice Cedex 4, France*

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Abstract

An extensive set of simulations of the predicted performances of Gaia as a powerful tool to extract physical information about asteroids is currently under way. In this paper, we focus on a subject whose importance has been only recently recognized, namely the disk-integrated photometric data produced by the satellite. Gaia will observe all asteroids down to magnitudes much fainter than $V = 18$ tens of times during its operational lifetime. These detections will produce a huge database of very accurate photometric measurements. We have developed a "genetic" algorithm to invert these sparse data, in order to derive reliable estimates of the rotational period, the orientation of the spin axis, and the overall shape, assuming for simplicity that the objects can be approximated by means of triaxial ellipsoids. We expect to be able to apply our method to a set of about 10,000 objects. The relevance of these data for asteroid science is briefly discussed.

Keywords: Gaia; Asteroids; Photometry

1. Gaia integrated photometry

According to current plans of the European Space Agency (ESA), Gaia is expected to be one of the flagship missions of the decade starting in 2010. Gaia will be primarily an astrometric mission, reaching a level of unprecedented accuracy in the measurement of positions and proper motions of celestial bodies. In addition, Gaia will also have powerful photometric and spectroscopic capabilities. A large number of major advances in practically all fields of modern Astrophysics are expected to come from Gaia. In particular, Gaia will also produce a major advance in the field of asteroid science.

In what follows, we briefly summarize some results of a number of investigations carried out since a couple of years by ourselves and by a number of other scientists from different European countries who have worked in the Gaia Solar System Working Group. Interested readers may find copies of several presentations given by different authors during the past meetings of the Gaia SSWG at the URL address http:www.obs-nice.fr/tanga/SSWG/ (and links within it).

According to a large number of simulations, Gaia astrometric data will be so accurate that a vast majority of asteroid orbits computed using Gaia observations collected during five years of operational time, will be more accurate than those resulting from ground-based observations obtained in the past two hundred years, plus those that will be still obtained from the ground in the lapse of time between now and the end of the operational lifetime of the mission.

The unprecedented accuracy of Gaia astrometric data will also make it possible to derive the masses of about 100 objects, by means of measurements of tiny mutual perturbations occurring when asteroid–asteroid close approaches take place. Another major application of Gaia will be the direct measurement of sizes of objects having

* Corresponding author. Tel.: +39 011 810 1933; fax: +39 011 810 1930.
E-mail address: cellino@to.astro.it (A. Cellino).

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diameters down to a few tens of kilometers. Coupled with the above-mentioned mass derivations, Gaia will produce a data-set of about one hundred average densities of asteroids, a major milestone in the history of asteroid science.

This does not mean, however, that Gaia contributions will come uniquely from astrometric and high-resolution data. Very important applications will come also from disk-integrated spectrophotometric observations. An obvious application of the multi-band data collected by Gaia will be asteroid taxonomy. This will be achieved mainly by means of data coming from the MBP (Gaia Multi-Band Photometer), which will cover 11 colors in the visible region of the reflectance spectrum, including also the Blue region. This is important, because the U and B regions of asteroid spectra, which were well covered by classical UBV spectrophotometry based on photoelectric photometers several years ago, tend now to be missed using modern spectrographs present in many ground-based observatories. This is a problem, because the blue region is very useful to distinguish among different sub-classes of primitive objects (Bus, 1999). Hundreds of thousands of asteroids are expected to be taxonomically classified using the Gaia spectrophotometric database, and the good coverage of the blue region will make it possible to distinguish different classes of primitive objects. We note that the Sloan Digital Sky Survey (SDSS) is also providing multicolor observations of asteroids down to magnitudes comparable with the expected limit of Gaia (around 20 in V color). The SDSS observations actually cover also the blue part of the spectrum, but a significant limit of an SDSS-based taxonomy is that of being based on only four filters (Ivezić et al., 2001).

In the present paper, however, we focus on another major application of Gaia asteroid observations, namely the derivation of spin properties and overall shapes for thousands of asteroids as a nice exploitation of Gaia disk-integrated photometric data.

Photometry at visible wavelengths has traditionally been a major tool to derive physical information about asteroids. Lightcurves trivially provide information on the spin rates of the objects. Lightcurve morphology is also analyzed in order to derive some estimate of the overall shapes of the bodies. It is well known also that having at disposal asteroid lightcurves taken at different oppositions (corresponding to a variety of aspect angles, namely the angles between the direction of the spin axis and the direction of the observer) makes it possible to derive the direction of the spin axis ("asteroid poles"). Different techniques have been developed for this purpose, and an extensive review is given, for instance, by Magnusson et al. (1989). The reliability of the predictions about asteroid shapes and spin axis direction based on ground-based photometry has been found to be noticeably good, according to the results of in situ investigations carried out by space probes (Kaasalainen et al., 2002).

2. Gaia photometric data and expected results

One major advantage of observations from an orbiting platform with respect to conventional ground-based activities is that in principle from space it is easier to observe the objects in a wide range of observational circumstances, not limited to a "window" around opposition. In particular, the objects can be seen at relatively small solar elongation angles, which are not achievable from the ground. This is also the case of Gaia: the satellite will observe typical Main Belt asteroids tens of times during its operational lifetime. The exact number of detections depends on the orbits of the objects and is different for different detectors, since the angular sizes of the fields of view are not identical. The simulations indicate that the objects will be detected over a wide range of observational circumstances, and in particular over wide ranges of ecliptic longitudes, corresponding to an interval of aspect angles which can be covered from the ground only over much longer times. This a priori opens exciting perspectives concerning the possibility to use Gaia detections to derive the poles of the objects, as well as the sidereal periods and the overall shapes.

The main difference with respect to the situation corresponding to traditional studies in asteroid photometry, is that in the case of Gaia we will not have at disposal full lightcurves, but only a number of sparse, single photometric measurements obtained according to the law that determines the scanning rate of the sky by the satellite. This would seem in principle a crucial limitation, but it is more than compensated by the high number of detections for each object, by the fact to have data belonging to one single, homogeneous photometric system, and by the good accuracy of the single photometric measurements. The latter depends, in turn, on the brightness of the target and varies for different detectors. However, it is expected to be better than 0.01 mag for objects as faint as $V = 18.5$, using the Gaia astrometric field detectors.

We note that the data-set of sparse Gaia photometric detections will be of the same kind as what is expected to come in the future from ground-based asteroid surveys like Pan-Starrs or the Large-Aperture Synoptic Survey Telescope. This means that the same techniques of photometric inversion techniques that we are developing for Gaia will be also useful for the above-mentioned surveys. The main difference, however, is that Gaia will be able to sample the possible range of ecliptic longitudes (hence, aspect angles) of the objects at a much faster pace than ground-based surveys, due to the above-mentioned capability to obtain accurate photometric measurements also when the objects are located at small solar elongation angles.

The magnitudes of the objects detected by Gaia at different epochs will depend on several parameters: the most important are the sidereal period, the overall shape and the orientation of the spin axis. Light scattering from the surfaces, and in particular the general change in apparent magnitude for different illumination conditions (mainly described by the phase angle) will also play an important