GAIA OBSERVATIONS OF ASTEROIDS: SIZES, TAXONOMY, SHAPES AND SPIN PROPERTIES

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ABSTRACT

Extensive simulations of the predicted performances of Gaia as a powerful tool to determine physical properties of asteroids are currently being performed by several teams working in the Gaia Solar System Working Group. Gaia is expected to produce a major breakthrough in asteroid science. Among several outstanding results we can expect from this mission, there are direct determinations of masses and sizes (and hence average densities), a new taxonomic classification, and derivations of spin properties and overall shapes for a substantial sample of objects. Current state-of-the-art of the simulations, dealing with the derivation of sizes, taxonomy and spin properties, is briefly reviewed. The importance and the implications of the expected results are also discussed.

Key words: Gaia; Asteroids; Sizes; Shapes; Spin Properties; Taxonomy.

1. INTRODUCTION

In several respects, asteroid science would currently need a revolution. The reason is that, in spite of impressive advances that have been obtained in recent years, especially after the first, successful space missions having asteroidal targets (Galileo, NEAR-Shoemaker) it is clear that there is no hope to have in the future a sufficient number of missions to explore all the large variety of physical properties (in terms of sizes, compositions, structures, thermal, collisional and dynamical histories) which characterize this vastly heterogeneous population of minor bodies. At the same time, it is also true that, apart from a handful of objects that are fairly well known due to *in situ* investigations, we still know so little about the most fundamental physical properties of these objects, including masses, sizes and average densities.

The chances to improve significantly our overall knowledge of the asteroids by means of remote observations in the near future are not so high, in spite of the expected development of new instruments which should produce large amounts of spectrophotometric data (Pan-STARRS, the Large-Aperture Synoptic Survey Telescope, etc). These new observing facilities will be very suited to derive an improved knowledge of the overall inventory of Main Belt asteroids and near-Earth objects (NEOs). However, the capabilities of these surveys will be affected by intrinsic limitations due to the simple fact of being ground-based. As an example, several years of observations will be needed to derive detailed information on properties like the spin axis orientations of the objects from disc-integrated photometry, a task particularly suited to dedicated asteroid surveys. More important, none of new observing facilities will be able to make direct measurements of fundamental physical parameters like size and albedo (surface reflectivity), not to mention asteroid masses, which will remain also essentially unknown in the future, but in the few cases of fly-bys by space missions, and/or of discovered binary systems.

For the above reasons, a primary objective of asteroid science today is to develop new tools to derive, possibly in relatively short times, reliable measurements of masses, sizes (and hence, average densities), in addition to reflectance and rotational properties, for a statistically significant sample of the whole population. The development of such facility(ies) would mark a real milestone in asteroid science, and would produce a real revolution in this field. In this paper, we show that Gaia can be this tool.

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 breakthrough in our knowledge of the asteroids.

According to a large body of simulations that have been, and are being, carried out by different teams active in the Gaia Solar System Working Group, Gaia astrometric data will be so accurate that asteroid orbits computed using Gaia observations spanning over five years, will be more accurate than orbits resulting from all ground-based observations obtained over two hundred years of ground-based astrometry, including also new observations 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. What is tremendously important, is that the unprecedented accuracy of Gaia astrometric data

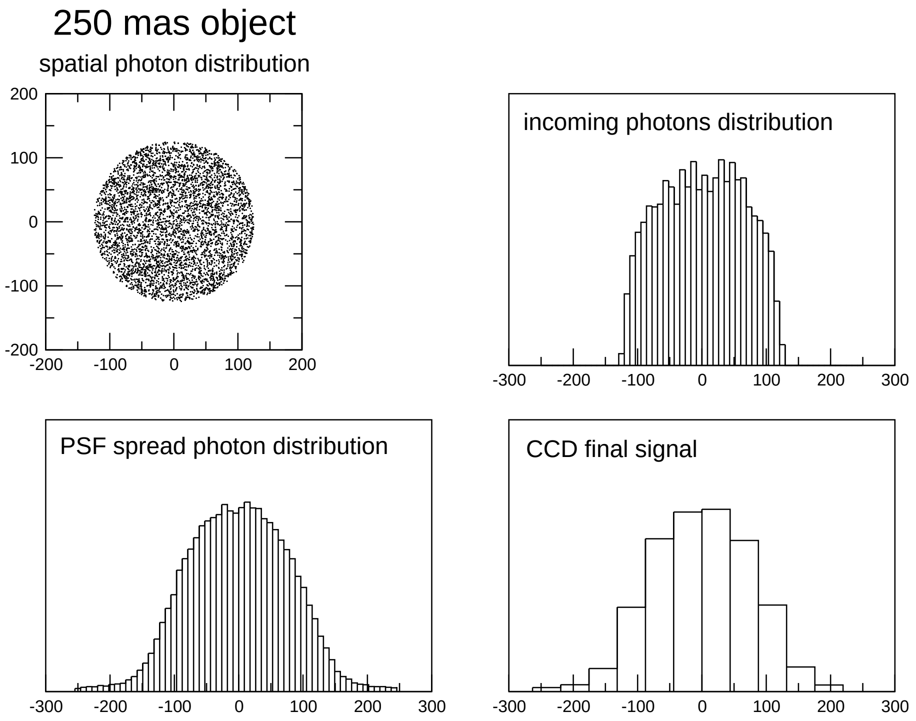

Figure 1. Example showing how the incoming signal from a spherical, ideal object is finally converted into a recorded Gaia signal. Note also that, according to current plans, only the six central bins will be actually recorded.

will also make it possible to derive the masses of about 100 objects, by means of measurements of tiny mutual perturbations occurring during mutual asteroid–asteroid close approaches. This particular topic is extensively discussed elsewhere in this volume (Tanga 2005), and will not be covered in the present paper. Another major application of Gaia will be the direct measurement of sizes of objects having 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 research.

This does not mean, however, that Gaia contributions will come uniquely from astrometric and high-resolution data. Very important applications will come also from disc-integrated spectrophotometric observations. An obvious application of the multi-band data collected by Gaia will be asteroid taxonomy. Another major application of Gaia asteroid observations will be then the derivation of spin properties and overall shapes for thousands of asteroids as a nice exploitation of Gaia disc-integrated photometric data.

In this paper we will summarize the expected performances of Gaia with regard to its ability to measure asteroid sizes, to build a new taxonomic classification, and to infer spin properties and overall shapes from disc-integrated photometry. Each of the above subjects will be covered in a separate Section. In Section 5 the relevance of the expected information coming from Gaia observations will be summarized and discussed.

2. THE DERIVATION OF ASTEROID SIZES

A detailed explanation of the procedures for the derivation of asteroid sizes from Gaia observations, including all the relevant effects that must be taken into account when assessing the expected performances of Gaia in performing this particular task, is given elsewhere in this volume (Dell'Oro & Cellino 2005). In this Section, we limit ourselves to a general summary of the basic ideas and algorithms that have been developed to attack the problem of asteroid size measurements, and to the general results of the simulations.

An assessment of the capability of Gaia in determining asteroid sizes is obviously based on a detailed simulation of the actual signals that will be produced by asteroids in the focal plane. In particular, for the purposes of size determinations, we deal with the Gaia Astrometric Focal Plane. Asteroidal sources detected by Gaia will have two major properties: first, they will be extended sources; second, they will have an apparent and measurable motion across the Gaia focal plane during each single detection. We recall here that every object will be observed many times (typically several tens, according to simulations performed by F. Mignard) in different sky locations, during the operational lifetime of the mission.

The first property just mentioned above simply states that asteroids are not point-like sources. The measurement of asteroid sizes will then be possible in principle, down to a limit of apparent angular size that must be determined. The fact of dealing with moving objects, on the other hand, is an important property that will influence the final signal recorded by the Gaia detectors. A detailed model of the predicted signals from asteroids is an obvious pre-

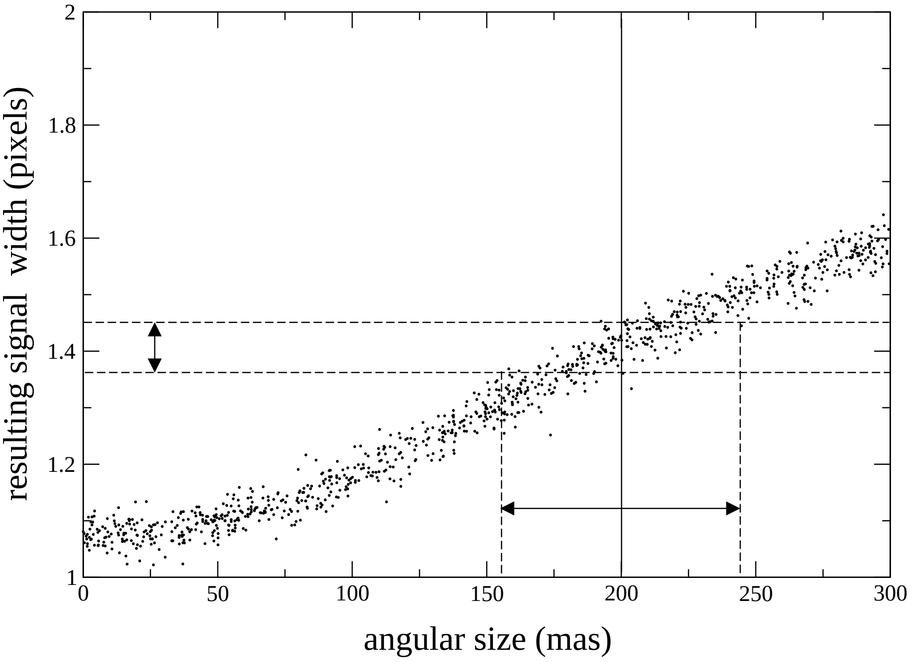

Figure 2. This example qualitatively shows how the measurement of the angular size for a spherical asteroid having an apparent magnitude $G = 20$ is affected by an uncertainty due mainly to photon noise.

requisite to carry out any analysis of the performances of Gaia in measuring asteroid sizes, and also to derive the predicted shift between the photocentre of a recorded signal and the projection of the object's barycentre on the sky plane. In turn, this latter effect will play a decisive role in determining the final accuracy in the measurement of the astrometric positions of asteroids, with obvious implications for the derivation of the orbital motion of the objects, and the measurement of their masses from the measured effects of mutual perturbations.

The big advantage of Gaia, with respect to ground-based telescopes of larger aperture, will be obviously the fact of being diffraction-limited. The image of an object on the Gaia focal plane will be the result of the convolution of the incoming wave front with the optical system of Gaia. In addition, several other subtle effects will play a role in the generation of the final signal recorded by the detectors: these effects include the motion of the asteroid across the focal plane, the discrete (not ideally uniform) implementation of the Time-Delayed Integration (TDI) read-out strategy, the fact that the detector is constituted of arrays of discrete pixels, so that the exact location of the incoming light on the grid of pixels has some influence on the recorded signal. Other important facts to be taken into account are the quantum efficiency of the detectors, and, more important, the fact that the signals will consist of the numbers of photoelectrons collected along a limited number of pixel lines. The physical size and rectangular shape of the pixels is also, obviously, to be taken into account. In addition to the above properties of the interaction of the incoming wave front with the Gaia optics and detectors, one has also to model the intrinsic properties of the signals. Asteroid emission at visible wavelengths consists of sunlight scattered by the surface. The exact flux of photons incident on the Gaia focal plane will then be the final result of a complex interaction of solar photons with the asteroid surface. The object's size, albedo, shape, macroscopic and microscopic roughness, and light-scattering properties will all play a role in the final properties of the incoming signal. We should stress that this complex process is currently not fully tractable by means of purely analytic means, and no definitive theory of light scattering is presently available.

The formation of an asteroid signal on the Gaia astrometric focal plane has been modelled by means of a numerical algorithm, in which all the effects mentioned above are taken appropriately into account. The general algorithm is based on a ray-tracing approach, and a Monte Carlo implementation. An example showing how an incoming signal is finally converted into a recorded Gaia signal, is shown in Figure 1.

According to current plans, the signals from asteroid sources actually recorded by Gaia will be sets of six numbers, corresponding to the numbers of photoelectrons received in six pixel lines centred around the object's image. The basic idea is then to be able to discriminate the properties of these signals with respect to the signals coming from point-like sources, and to be able to distinguish the signals from extended objects of different angular sizes. The basic property of the signals that can be used to perform the above mentioned task is simply the resulting signal width (the σ of the photon distribution over the six recorded channels). In other words, if one can derive an expected angular size *versus* signal width relation, a simple measurement of the signal width would be in principle sufficient to derive the angular size of the asteroidal source. As extensively explained by Dell'Oro & Cellino (2005) in this volume, the most important effect that has to be taken into account, in this respect, is photon noise.

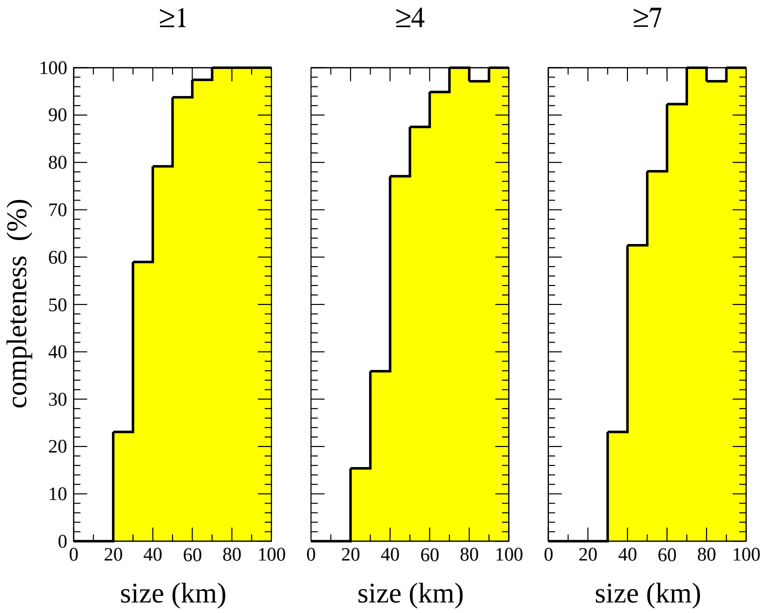

Figure 3. The percentage of existing asteroids whose sizes will be measured N times with an accuracy better than 10% as a function of size, according to an extensive body of numerical simulations. N is chosen to be equal to 1, 4, 7, from left to right.

Due to photon noise, the angular size *versus* signal width relation is not a rigorous one-to-one relation, but it is affected by a random variation due to photon statistics. As a consequence, as qualitatively shown in Figure 2, when one measures a given signal width, due to the intrinsic uncertainty of the measurement due to photon noise, there is a corresponding range of angular sizes which are compatible with the measured signal width. This uncertainty is obviously increasing for decreasing signal, or in other words for decreasing apparent brightness.

The complex interplay of magnitude (signal intensity), apparent angular size and resulting signal width has been explored by means of extensive numerical simulation. In this same volume, Dell'Oro & Cellino (2005) show how one can separate the apparent magnitude – apparent angular size plane into two distinct domains, according to the possibility to derive an angular size measurement having a relative accuracy better or worse than 10%. An alternative, even more instructive way to present the results of these simulations, is given in Figure 3, in which we take also into account the results of the simulations by F. Mignard of the actual detections of known Main Belt asteroids in a simulated Gaia survey lasting five years (starting since a given simulated starting date, which is not relevant for the present purposes). In particular, Figure 3 shows, as a function of the linear sizes of the objects (in km) the fraction (in per cent) of the real asteroids of that size that will be measured with an accuracy better than 10%, a number of times equal to 1, 4, and 7 (from left to right), respectively.

The results of the simulations show that above 30 km in diameter, more than one half of the known Main Belt asteroids will have their size measured at least once during the Gaia operational lifetime. The number of useful measurements rapidly increases for increasing size. Between 20 and 30 km, a fraction larger than 20% of the objects will also be measured at least once, or even a few times. The number of objects that will be measured is thus of the order of 1000. These results will have a tremendous impact on our knowledge of the asteroid population, as will be discussed in Section 5. Here, we only stress the fact that such a result will not be possible using any other observing facility existing today or planned to be operative in the next ten years.

3. COLOURS AND TAXONOMY

The derivation of an asteroid taxonomy will be a trivial by-product of Gaia's spectrophotometric capability. According to current knowledge, there are more than 200 000 Main Belt asteroids that will exhibit apparent magnitudes brighter than 20 in V light when detected by Gaia. A new taxonomic classification will be then achieved, by exploiting the spectrophotometric data coming from the MBP (Gaia Multi-Band Photometer). In this respect, Gaia will have a couple of major qualities: first, this huge spectrophotometric data base will be obtained using a unique, homogeneous photometric system, and not merging together data coming from different instruments. Second, and equally important, the spectral coverage of the MBP will certainly include also the blue region of the reflectance spectrum. This is quite 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 by the most recent spectroscopic surveys, like SMASS and SMASS2 (Bus 1999; Bus & Binzel 2002). This is a problem, because the blue region is very useful to distinguish between several different sub-classes of primitive objects. Among the hundreds of thousands of asteroids that are expected to be taxonomically classified using the Gaia spectrophotometric data base, a large fraction will consist of primitive, dark objects belonging to the so-called C-class complex, which dominate the asteroid inventory in the outer region of the asteroid belt. In contrast to spectroscopic surveys like SMASS and SMASS2 that were mostly limited to an interval of wavelengths between 5000 and 9500 Å (Bus & Binzel 2002), Gaia spectrophotometric data are expected to be better for discriminating among different subclasses of the big C complex, and to determine the relative abundance of these different subclasses, also as a function of heliocentric distances. This will be important for studies of the compositional gradient of the solid matter in the Solar System (Cellino 2000). Other important applications of taxonomy will be discussed in Section 5. Here, we stress that a new taxonomy is something that can be conceivably obtained in the near future also by means of dedicated ground-based surveys like the planned Pan-STARRS and/or the Large-Aperture Synoptic Survey Telescope. *Per se*, the new taxonomic classification that will be produced by Gaia is not a result that would be sufficient alone to justify the costs of a space mission. The mentioned coverage of the B region of the spectrum, however, and the general link with other, unique results that will be produced by Gaia asteroid observations, make Gaia taxonomy a very welcome and extremely useful addition to the already very rich scientific output of this mission in the field of asteroid science.

4. DISC-INTEGRATED PHOTOMETRY

Photometry at visible wavelengths has been extensively used since many years to derive information on the rotational state of asteroids. Obtained lightcurves are used to determine the rotation periods of the objects. Lightcurve morphology is also analyzed in order to derive some estimate of the overall shapes of the rotating bodies. Moreover, having at ones disposal lightcurves taken at different oppositions of the same object, corresponding to a variety of aspect angles, namely the angles between the direction of the spin axis and the direction of the observer as seen from the object's barycentre, makes it possible to derive the direction of orientation 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 predictions concerning asteroid shapes and spin axis directions based on ground-based photometry have been found to be quite good, according to the results of *in situ* investigations carried out by space probes (Kaasalainen et al. 2002).

One major advantage of observing from an orbiting platform with respect to conventional ground-based observations is that in principle from space it is easier to observe the objects in a wide range of observational circumstances, not limited to an observing 'window' around the epoch of opposition. In particular, from space the asteroids can be seen at small solar elongation angles, which are hardly achievable from the ground. In this respect, Gaia will not be an exception. The satellite will typically observe Main Belt asteroids tens of times during five years of expected operational lifetime. The simulations indicate that during the mission each object will be detected when located in a wide variety of ecliptic longitudes, corresponding to a wide range of observational circumstances. In particular, Gaia will observe asteroids over a wide fraction of the interval of possible aspect angles reachable by each object. The same variety of aspect angles, which is strictly needed to derive the orientation of the spin axis, can be covered from the ground only over much longer times. This *a priori* opens exciting perspectives concerning the possibility to use Gaia disc-integrated photometry as a very efficient tool 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 usually occurring in traditional asteroid photometry, is that in the case of Gaia we will not have at our disposal full lightcurves, but only a number of sparse photometric measurements lasting a few seconds, 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 single photometric measurements for each object, by the fact of having data belonging to one single, homogeneous photometric system, and by the good accuracy of Gaia photometry. 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.

The magnitudes of the objects detected by Gaia at different epochs will depend on several parameters: the most important are the sidereal period, the shape and the orientation of the spin axis. Additional minor variations can come in principle also from possible albedo variegation of the surfaces, but this is not expected to be very relevant for the majority of the objects, especially those of relatively small sizes, which are thought to be mostly homogeneous in surface composition. Gaia will measure apparent magnitudes, but it will be convenient to analyze the data in terms of absolute magnitude (i.e., after reducing apparent brightness to unit distance from Sun and Earth). More precisely, it will be convenient to work in terms of *differences* of absolute magnitude with respect to a reference observation, which will be usually the first Gaia photometric measurement of each object.

Assuming for the sake of simplicity an object having a triaxial ellipsoid shape, and orbiting around the Sun along a typical Main Belt asteroid orbit, one can plot how the absolute magnitudes are expected to vary as a function of time. An example is given in Figure 4. In this Figure, we consider a simulated object having the same orbit as the one of the Main Belt asteroid 39 Laetitia (which has a typical Main Belt orbit). We assume a given triaxial shape (b/a = 0.7, and c/a = 0.5 in this particular example) and a given spin axis orientation (ecliptic longitude of the pole at 30° and ecliptic latitude at $+60°$ in this case) and we show the region in the time *versus* magnitude-difference plane in which the object can be measured during a time span of five years. We remind that we plot here the absolute magnitude difference with respect to an arbitrary first observation obtained at a given epoch. As a consequence, the shape of the domain in

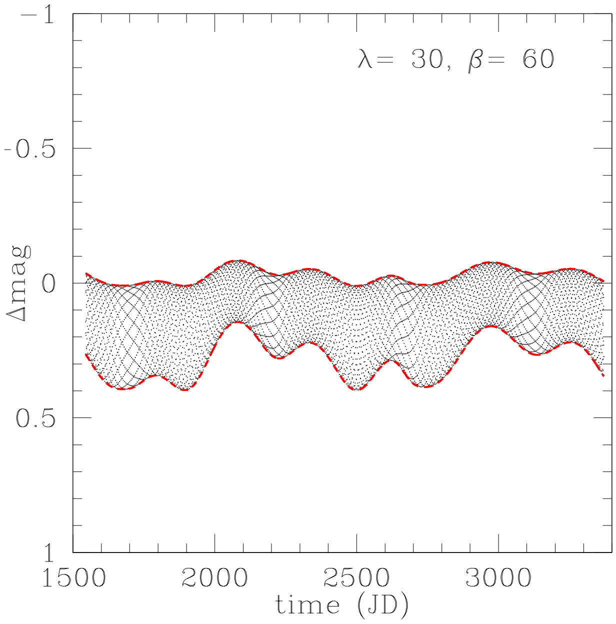

Figure 4. Absolute magnitude difference with respect to first detection as a function of time, for a simulated object having a given sidereal period, pole and axial ratios (see text).

which the asteroid can be observed during five years of mission depends not only on the assumed asteroid pole, axial ratios and sidereal period, but also on the rotational phase of the object at the epoch of the assumed first detection.

It is more instructive to plot the magnitude difference with respect to first detection as a function of ecliptic longitude, instead of time. Figure 5 (left) shows this kind of plot. Instead of the full theoretical domain of the plane where the object can be observed, in this Figure we show the location of the actual detections of the object by Gaia. This computation is based on a general simulation of asteroid detections by Gaia performed by F. Mignard. In this plot, we assume the same set of parameters (pole, axial ratio, sidereal period and rotational phase at first detection) as used in producing Figure 4. As one can see, Gaia will observe an object having the same orbit of 39 Laetitia many times (around 200 in this example, corresponding to the computed number of detections in the field of view of the Gaia MBP), and over a wide interval of ecliptic longitudes. In order to compare this with a typical set of ground-based data that have been sufficient to derive a reliable estimate of the asteroid pole, we show in the right panel of Figure 5 an analogous plot, showing the typical set of data (full lightcurves) used in the past to derive the pole of asteroid 22 Kalliope (Zappalà & Knežević 1984). It is easy to see that Gaia data taken in only five years of mission will be much denser than ground-based data obtained, in this particular example, by means of observations spanning over an interval of 25 years. For reasons like this, we expect that Gaia photometry will be a crucial resource for asteroid science in the future.

Since the number of unknowns (the value of the spin period, two coordinates for the pole axis orientation, a few parameters describing the shape, and an initial rotation phase at $t = 0$ which has also to be determined) is much smaller than the number of observations, it is in principle possible to develop techniques of inversion of photometric data, to determine from them the spin period, the spin axis orientation, and the overall shape. Different approaches are possible in principle, and have been independently considered by different teams. In this paper, we explain in greater details the algorithm developed by the Torino team.

Experience gathered from ground-based photometry indicates that as a first, preliminary approximation it is sufficient to describe the shapes of the objects by means of triaxial ellipsoids. This is evidently a major simplification, but it has been found to be sufficient for the purposes of asteroid pole computation in a wide variety of cases (see Magnusson et al. 1989). In this approach, the shape parameters to be derived by photometry inversion are simply the two axial ratios b/a and c/a. In addition to the rotation period, the pole coordinates, and the unknown rotational phase at the zero-epoch, other parameters to be derived are the linear slope of the magnitude-phase angle variation, which is known to characterize the photometric behavior of real objects, and, at a higher degree of complexity, the coefficient of the linear increase of the lightcurve amplitude as a function of phase angle. This effect, observed for real asteroids (Zappalà et al. 1990), means that one must take into account that the linear variation of the magnitude as a function of phase angle is not constant at different rotational phases of the object.

In order to solve this inversion problem, we have explored both semi-analytical techniques and fully numerical options, based on techniques of ‘genetic’ computation. The latter approach seems to be particularly promising. This computational technique is based on concepts of ‘survival of the fittest’ which are inspired by classical studies of the evolution of living species. In particular, the possible

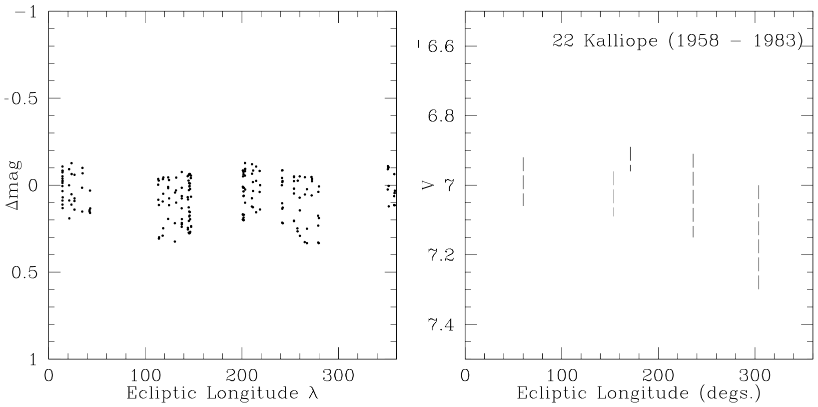

Figure 5. Absolute magnitude difference with respect to first detection as a function of ecliptic longitude for the same object simulated in Figure 4 (left panel). Gaia photometric measurements will sample the interval of possible observing circumstances more efficiently than typical ground-based observations. The right panel shows as an example the photometric data-set of asteroid 22 Kalliope, obtained since 1958 to 1983, used by Zappalà & Knežević (1984) to derive the pole of this object.

solutions of the problem are characterized by a set of parameters (spin period, pole coordinates, axial ratios, etc.) which can be seen as the ‘genes’, or the ‘DNA’ of a solution. The goodness of any given solution is assessed on the basis of its corresponding residuals with respect to a set of (real or simulated) observations. Better solutions give a better fit of the observational data, and the idea of the genetic approach is to simulate an evolution of the solution parameters, selecting at each step only those giving the best fit. This idea is implemented by means of a numerical algorithm, which initially generates a large number of completely random solutions, saving in memory only a limited subset, corresponding to those producing the smallest residuals. In general, these preliminary solutions are very bad, as one would expect *a priori* from a set of completely random attempts. At this time, the ‘genetic’ mechanism is switched on. This consists in random coupling of the parameters of the saved solutions, and in random variations (‘genetic mutation’) of some of the parameters constituting the ‘DNA’ of a single solution. If the newly born ‘baby’ solution is better than some of those saved until that step, it enters the ‘top list’, whereas the previously worst solution is removed from the same set. In this way, after a number of the order of one or two millions of ‘genetic experiments’, a very good solution is usually found, which produces small residuals and basically solves the inversion problem. Due to the intrinsically random nature of this ‘genetic’ approach, the right solution is not forcedly found always, but if the genetic algorithm is repeatedly applied to the same set of observed data (typically 30, 40 times) the right solution (giving the minimum residuals in different attempts) is usually found several times.

It is highly encouraging that so far we have been able to derive without exceptions the right sets of parameters producing given sets of simulated photometric observations, including also the sidereal period. This is particularly worth mentioning, because it should be taken into account that accuracies of the order of 10^{-5} hours are needed for this parameter. In spite of this difficulty, we have always been able so far to solve the problem in all the simulated cases, in which we have considered wide variations in all the relevant parameters (sidereal period, axial ratios, pole coordinates, initial rotational phase of the object). The tests have been performed so far using different simulators of Gaia photometric data developed independently by different teams in the Gaia Solar System Working Group.

The fits of the single data are generally excellent when simulations of triaxial ellipsoid objects are performed, and when very simple light scattering laws are considered (geometric scattering). When more irregular shapes, and/or more realistic light scattering laws are used in the generation of simulated observations, the genetic algorithm still finds the correct solution, although the fit of the single simulated measurements obviously becomes significantly worse.

Our tests take obviously into account the nominal photometric accuracy of Gaia measurements for objects of different brightness. So far, we have seen that good solutions are found even when we simulate photometric error bars several times larger than the nominal values which will characterize the Gaia detectors, at least as long as triaxial ellipsoid objects are concerned. Moreover, we have also checked that our solutions are also able to determine the right sense of rotation of the objects, as theoretically expected.

We note that another fully independent approach, adopted by M. Kaasalainen, is also being tested for the treatment of Gaia photometric data. The method is based on photometry inversion techniques developed by the above author (Kaasalainen et al. 2002, and references therein). According to simulations, also this approach seems very effective.

It should be stressed that the data set of sparse Gaia photometric detections will be qualitatively similar to what we can expect 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 that are being developed 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 results of the simulations performed so far indicate that, whatever choice will be made of the most suitable algorithm of inversion of photometric data, the Gaia data set of disc-integrated photometry will be a major resource to derive spin properties and overall shapes for a number of objects that will not be smaller than 10 000, to be conservative. Again, we stress that this will be possible by means of only five years of Gaia observations.

5. DISCUSSION AND CONCLUSIONS

It should be clear that we can expect that in the future we will speak of two distinct phases in the history of asteroid science: a pre-Gaia and a post-Gaia phase. The post-Gaia phase will be much more advanced in many fundamental respects. Gaia astrometry will provide us with reliable measurements of mass for about 100 objects. For these same objects we will know also the size and the overall shape, again obtained from Gaia data, then we will have at our disposal reliable estimates of average densities. These objects will belong to different taxonomic classes, then it will be possible to assess the relation between density and taxonomy, to be possibly interpreted in terms of overall composition and structural properties. This will be a kind of knowledge that we cannot be realistically expected to achieve by any other means in the next two decades.

The direct measurement of sizes will allow us to have an improved knowledge of the asteroid size distribution down to 20 km in diameter. Today, the only size data we have come from indirect measurements (thermal radiometry, polarimetry) and are subject to considerable uncertainties. Direct size measurements, on the other hand, will allow us to derive the albedos of the same objects. In this way, we will check whether there are dependencies of albedo upon size, as old results of IRAS radiometric observations seem to indicate (Cellino 2000). An albedo variation due to space weathering processes has been convincingly shown to exist for S-type objects by the Galileo close-range images of asteroid 243 Ida (Chapman 1996), but it is not completely clear if the same processes can alter also the reflectance properties of objects belonging to other taxonomic classes (i.e., having different surface compositions). Gaia will give the correct answers to these major open questions.

The determination of the rotational state for a set of more than 10 000 Main Belt asteroids will make it possible to use the spin properties of Main Belt objects as a new powerful constraint to the models of the collisional evolution of this population. So far, the models have been mainly constrained by the size distribution, but since collisions strongly affect the spins, Gaia data will add a new full dimension to the problem.

The multi-band observations carried out by Gaia for tens of thousands of objects will be useful not only to derive a new taxonomy, but also to add spectral reflectance data as a further constraint to identify asteroid families. These are groupings of objects having similar orbital properties, which constitute the outcome of catastrophic events of collisional disruptions of single parent bodies. Families have been so far identified mostly on the basis of similarities in the orbital proper elements of their members (Bendjoya & Zappalà 2002), but it has become evident that spectral properties can be added as an additional element to identify objects having a common collisional origin (Bus 1999). At the same time, the spin properties derived for family objects will allow us to test the possible existence of preferential alignments in the spin properties, which have been recently found to likely exist in the case of the Koronis family (Slivan et al. 2003).

If current plans will be respected, Gaia will be launched in 2011. The revolution in asteroid science is thus not so far from now.

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