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M. Heydari-Malayeri, C. Reylé and R. Samadi (eds)

GAIA AND THE GROUND-BASED OBSERVATIONS OF THE SOLAR SYSTEM OBJECTS

Thuillot, W.[1], Tanga, P.[2] and Hestroffer, D.[1]

Abstract. An important part of the Gaia mission is devoted to the study of Solar System Objects. In this domain, ground-based observations can be favorably combined with the space observations and in some cases they appear as a unique support for completing the Gaia data. We have organized a workshop in Beaulieu/mer near Nice in October 2008 with the goal to discuss this topic. 26 participants attended this workshop, coming from several observatories in different countries. They have underlined different aspects of the ground-based observations related to the expected Gaia Solar System science. These aspects includes the determination of asteroid mass, shape and density, the measurement of Yarkorvsky effect, the astrometric follow-up of new objects, the improvement of astrometric measurements of ancient observations of natural satellites and those of the stellar occultation predictions.

1 Introduction

Among a huge amount of astrophysical objects, the Solar System bodies will be observed by the Gaia space probe during its five years mission. In the DPAC structure (Data Processing and Analysis Consortium) which deals with the data processing of this mission, the Coordination Unit 4 (CU4)is partly dedicated to prepare the data processing related to these objects. Beyond this data processing, several teams are thinking about the scientific impact of the mission which will certainly lead to an important update of our knowledge of the Solar System itself. Mignard et al. (2007), for example, describes the expected applications of the Gaia mission to the asteroid science. Therefore Gaia has the potential of changing our view of the asteroid population in particular. Furthermore, due to the peculiar characteristics of those bodies, and to their physical description, ground-based observations will be a fundamental mean to reinforce the scientific progress by complementing the Gaia data (Hestroffer et al. 2008). This situation is very different from that found, for example, in stellar physics where ground-based observations will essentially be used for calibration. In the Solar System domain, in fact, we deal with a possible concrete increase in the Gaia scientific impact. This is essentially due to the following:

- the mission duration (5 years) that could prevent extracting from Gaia data alone all the subtle dynamical effects;
- the geometry of observation, that could prevent obtaining precise orbits for dynamically peculiar objects discovered by Gaia itself (Inner-Earth and Earth-Crosser Asteroids);
- the possibility of opening new paths for future techniques, thanks to the availability of Gaia ultra-precise measurements;
- the contribution of other available techniques, namely adaptive optics and photometry.

In particular, it has been shown that an extension of the observation period to more than five years through ground-based instruments could improve the sample of masses measured by mutual perturbations; similar predictions can be formulated for non-gravitational forces such as the Yarkovsky effect. Also, the unprecedented precision of orbits and star positions could vastly improve predictions of star occultations by asteroids. Adaptive

[1] IMCCE, Paris Observatory, 77 av. Denfert-Rochereau, 75014 Paris (France)
[2] Cassiopée, OCA, Le Mont gros, 06300 Nice (France)

Optics and photometry could also contribute with shape and size measurements, especially valuable for determining the density of some key targets. Furthermore, a ground-based network is being structured for follow-up observations of possible discoveries.

The preparation and the optimization of ground-based complementary observations requires a good understanding of the expected Gaia results, and an international coordination effort. Dedicated and/or automated instruments could also be conceived and used for the future.

These are the reasons why we convened the interested people to discuss this subject at the workshop "Earth-based support to Gaia Solar System Science" which has been held in Beaulieu-sur-mer (near Nice, South of France) on 2008, October 27 and 28. 26 participants attended this workshop, coming from several observatories in different countries and addressed several questions involving mainly the small Solar System bodies.

2 Asteroids

Gaia will observe more than 250 000 asteroids down to magnitude 20 with an incomparable precision (0.1 to 1 mas for each single measurement). Near-Earth Asteroids (NEAs), Trojans and Centaurs will be concerned by these observations. Several contributions to the workshop have stressed the interest to organize ground-based campaign for some selected asteroids in order to improve the scientific return of these observations.

For example, the determination of around 100 asteroid masses by Gaia will be possible by measuring the gravitational deflection during close encounters (Mouret et al. 2007). But at the edge of the mission period, arcs of trajectories will be incomplete. In these cases, ground-based observations will allow to extend our knowledge of the orbital arcs and to add around 25 masses. This requires to organize campaigns of astrometric observations of these specific asteroids before the launch and after the end of the mission. This will be a valuable improvement of our knowledge, since at the present time only a small number of masses are known (only 40 masses are known with uncertainties better than 60 percent).

But other questions have also been addressed. High angular observations from the ground will allow to get a better understanding of the photocenter-barycenter offset and will give a mean to improve the determination of several orbits. It will allow to calibrate the sizes (Carry 2009) and in some case to reach the bulk density of several objects. On the other hand, such observations and also radar astrometry measurements, could lead to an important improvement of our knowledge of the Yarkovsky effect (Delbó et al. 2008)which is a main factor of uncertainties for NEAs in particular. Thus, the determination of size, shape, orientation and thermal properties could allow us to add more than 60 Yarkovsky effect detections to the 30-50 which will be detected by Gaia (detections for asteroids (6489) Golevka and 1992 BF are the only two direct detections known at this date).

The photometric measurements of asteroids by Gaia will give sparse measurements due to the scanning law, they will lead nevertheless to data very useful for the inversion problem. In some ambiguous cases, ground-based photometric observations of selected asteroids will allow us to get complementary data and to reach better results to model their shape.

The combination of Gaia astrometric observations with ground-based ones have been studied. The case of the orbits of newly detected NEAs appears to be drastically improved in some cases, when a too small number of Gaia measurements can be combined with ground-based astrometric measures. Nevertheless, due to the location of the probe at the Lagrange point L2, a strong parallax effect will affect the celestial coordinates of objects close to the Earth. This will require an accurate process for their detection from the ground after the discovery by Gaia and for the combination of the data. These problems have been discussed.

The figure 1 shows a global view of the asteroid science based on the Gaia data. It gives the number of asteroids involved in each of the six main fields of research: orbit improvement, shape and orientation, taxonomy, detection of binaries, estimate of the size, estimate of the mass. For three groups among these fields it gives the number of asteroids for which the following goals can be reached: estimate of the dynamical properties and composition and rotation parameters, estimate of the rotation parameters, composition, mass and albedo, estimate of all these parameters and of the non gravitational effects. For the two last groups, ground-based additional observations will bring an improvement for almost 2000 asteroids.

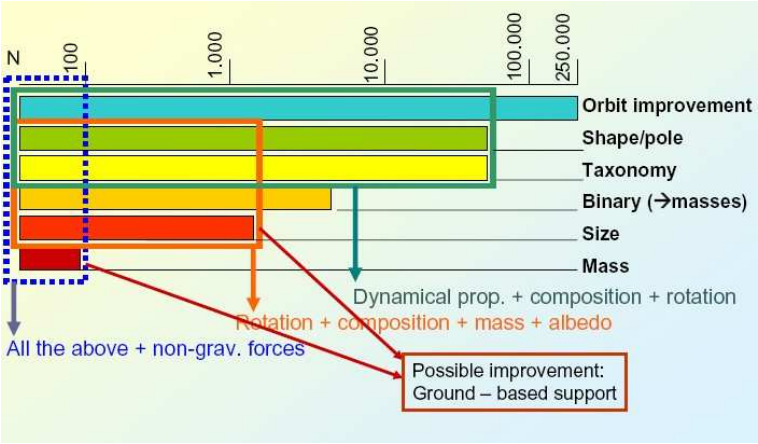

Fig. 1. A new global picture of the asteroids (courtesy P. Tanga)

3 Natural satellites

The Gaia astrometric measurements will be useful but not so efficient to improve the orbital models of the natural satellites. One main reason is that the duration of the mission is not long enough with respect to the periodic effects which have to be analyzed and which are generally much more long. The propagation of errors of the ephemerides of the main satellites of Saturn, in particular Mimas and Titan, has been studied (Desmars et al. 2009) by using the bootstrap method. One result is that in order to get a good accuracy of the models outside the period of observation, accurate observations on a short period is not necessarily better than average observations on a long timespan. The simulation of Gaia observations included in this analysis does not change significantly the global behavior.

In addition, ground-based observations remain necessary for the large satellites which will not be observed by Gaia. One major point is that a new reduction of many ancient astrometrical observations (photographic plates but also CCD frames) on the basis of the stellar astrometry using the Gaia catalogue will have an important impact on the dynamical models of the natural satellites, but also of the models of the planets (observed positions of its satellites lead to observed position of the planet itself). Therefore, the re-reduction using the Gaia catalog will be an important level to get accurate ephemerides useful for planetology, and for example for the detection of small secular effects induced by the tidal forces.

4 Comets

Gaia is not well suited for cometary science because of its limiting magnitude, of the lack of large field, of the slitless spectroscopy. Nevertheless around 50 cometary observations are awaited with the capacity to give access to astrometric measurements of the nucleus and to estimate the non gravitational forces. The modeling and simulation of the Gaia cometary observations are still in progress. Complementary observations from the ground could be interesting for a follow-up of possible cometary and unexpected activity of some Solar System bodies.

5 Stellar occultations

The observation of stellar occultations is a powerful method probing the Solar System Bodies and to estimate the size, the shape and the possible duplicity of the planetary objects. It allows also the probe of the atmosphere if any is present (see for example Widemann et al. 2009 or Sicardy 2006). Applying this method to investigate the transneptunian objects (TNO) is nowadays a big challenge, since the apparent diameters of the biggest ones (30 to 100 mas) is equivalent to the accuracy of the stellar catalogs (around 40 mas). Thus predictions are generally not accurate enough to ensure the success of these observations.

The Gaia stellar catalogue will then lead to a huge improvement of this kind of observations : predictions of the events will be more accurate, events by small objects will be more predictable (Tanga and Delbó 2007). One

can foresee that in a few years of observations through a network, we could reach completeness of diameters measurements for asteroids down to 20 km .

6 Ground-based facilities

In some cases, complementary ground-based observations will required specific facilities. For example, transient events such as the detection of new fast moving objects by Gaia can be not reobserved by the probe due to the scanning law. The concerned objects (NEA, in particular Inner Earth Asteroid) may even be lost. A ground-based network of observing sites is then necessary and the setup of such a network is a task of the CU4 as well for observations on alert as for follow-up observations of specific objects.

In this context the robotic telescopes appear well adapted. A presentation of this facility, especially the TAROT system (Klotz 2008), has been presented at the workshop. The possibility to operate through a worldwide network of such telescopes (setted up with Tarot1 in France, Tarot2 in Chile, Zadko in Australia, Satino & Rosace in France) has been emphasized.

7 Conclusion

The Beaulieu workshop (Tanga 2008) was a nice opportunity to gather different teams interested by using the space data from Gaia and completing them with data from ground-based activities. Several physical and dynamical parameters of the Small solar System Bodies will be drastically improved. Asteroid astrometry will extend the number of the determined masses, will avoid the loss of some possible new objects, and help to get a better knowledge of some dynamical effects. Photometry will give help to determine the pole orientation. High Angular Resolution observations such as the adaptive optics, will give access to the bulk density of several asteroids, the mass of which will be estimated by Gaia. It will also permit the estimate of the Yarkovsky effect on several asteroids.

The observers that are running programs concerning physical properties of Minor Bodies have stressed the importance of having intermediate releases of Gaia astrometry. In particular, our knowledge of TNO possible atmospheres and asteroid sizes is strictly related to the capacity of providing predictions accurate enough for ensuring stellar occultation observations. The community has thus expressed a strong interest in the possibility of accessing intermediate releases (even degraded in quality or magnitude) of the Gaia star astrometry catalogue.

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