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Introduction

Challenges for the scientific exploitation of Gaia observations of solar system objects ☆

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ABSTRACT

In this introductory paper, we review the subjects addressed during the meeting "Solar System Science before and after Gaia", which is at the origin of the content of this special issue. The several unknowns affecting our knowledge of the dynamical and physical properties of asteroids are briefly discussed, along with the perspectives opened by the availability of Gaia data and other surveys. The role of complementary observations is also stressed.

1. Introduction

The meeting "Solar System Science before and after Gaia" was held in Pisa, Italy, on the premises of the local University, from May 4 to 6, 2011.[1]

Participants to the workshop "Solar System science before and after Gaia", Pisa, May 4–6: J.-E. Arlot, D. Bancelin, L. Beauvalet, I. Belskaya, M. Buie, H. Campins, A. Carbognani, B. Carry, A. Cellino, F. Colas, P. Correia de Atos David, M. Delbo, A. Dell'Oro, F. De Meo, A. Derossoundiram, R. Duffard, J. Durech, A. Fienga, S. Fornasier, J. Gayon-Markt, G.F. Gronchi, J. Hanus, D. Hestroffer, A. Marciniak, T. Michalowski, F. Mignard, M. Mueller, K. Muinonen, N. Shaig, D. Oszkiewicz, P. Paolicchi, N. Peixinho, P. Pravec, H. Rickman, A. Rossi, P. Scheirich, D. Schierano, B. Sicardy, G. Tancredi, P. Tanga, W. Thuillot, M. Todd, G.P. Tozzi, E. Tresasco, G. Valsecchi, H. Varvoglis.

The aim of the meeting was to have a wide perspective on both the current status of Solar System observational studies, and the long-term context in the field in ~ 10 years, when data from Gaia and other large surveys will be available. The maximization of the scientific output of Gaia, by the optimal exploitation of the wealth of information it will provide, must be anticipated by increasing the awareness of the community about the scientific impact of such surveys. The exercise of brainstorming on the new possibilities that will open was also part of the meeting.

The oral contributions were organised around the following axes, which correspond to the content of this special issue:

- *Orbit determination and improvement*: thanks to the capabilities of Gaia, a strong improvement of the accuracy of orbits for known asteroids will be possible. Also, the determination of short-arc orbits will allow the recovery of asteroids discovered by Gaia from the ground.
- *Rotation and shape determination*: the Gaia data will increase significantly the number of asteroids for which rotation periods, orientation of spin axes and shapes can be determined. In turn, these Gaia results will help with the analysis of related data from other surveys.
- *Asteroid composition*: the availability of asteroid spectrophotometry from the RP/BP instrument will provide an impressive amount of data for the study of the compositional, collisional and dynamical evolution of the asteroid belt and, in particular, of dynamical families.
- *Observation of stellar occultations*: this activity will be strongly improved by the availability of precise orbits and stellar positions/proper motions, even from early and partial data releases. It will be of outstanding importance – in particular – for the determination of the size of Trans-Neptunian-Objects (TNOs).
- *Comets and TNOs*: although these objects represent a smaller sample in the brightness domain accessible to Gaia ($V < 20$), its importance is outstanding and thus deserves detailed studies for better assessing the impact of the mission.

☆ The event was made possible by the European Science Foundation (through the network GREAT—Gaia Research for European Astronomy Training); the Università di Pisa, the French Action Spécifique Gaia and Observatoire de la Côte d'Azur.

[1] https://www.oca.eu/workshop/Pise/

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2. Future organization of activities in the frame of the GREAT network

About half of 47 registered participants had never been involved in Gaia: a considerable fraction, implying a noticeable increase of awareness of the importance of Gaia for planetology.

Beside the several areas that can strongly benefit of the GREAT support, listed above, a couple of issues that address key aspects capable of fostering larger collaboration and activities were identified:

- *Binary/multiple asteroids*: these objects can offer a unique insight in the collisional and dynamical evolution. Gaia observations will be relevant for exploring them, either by examining the possible photocentre wobbling or directly detected companions. Specific studies concerning the performance of Gaia on binary objects are still largely unexplored. Our knowledge of binaries will strongly benefit from several ground-based observation techniques such as stellar occultations, interferometry, photometry, spectroscopy, adaptive optics imaging. Numerical approaches for simulating the birth and evolution of these objects are also part of this action.
- *Dynamical families*: physical properties of asteroids are deeply related to their evolution. For example, rotational properties and shapes determine Yarkovsky evolution; spectra are related to the composition of the parent body and linked to meteorites reaching Earth, etc. Several aspects of asteroid formation and evolution can be addressed by using Gaia data (Campins et al., in this issue).

In the following, we briefly recall the most important expectations concerning our understanding of the asteroid populations, stressing a few elements related to their physical and dynamical properties in light of recent results.

A follow-up workshop entitled "Asteroid Spectroscopy in Support of Gaia" is being organized in Nice, France, on June 6 and 7, 2013 – a few months before the launch of Gaia – to investigate even further the possibilities of optimization of the Gaia science outcome, specifically focused on the mineralogical properties. All interested planetologists will be welcome.

3. State-of-art and expectations

The general features of asteroid formation and evolution models are based on a large observational evidence mainly provided by ground-based observations, by space probe encounters, remote observation from space and analysis of meteorite samples.

The most widely accepted scenario of collisional and dynamical evolution is capable of explaining the main properties of dynamical families and the dynamical transport of objects through the Solar System, with the constant injection of a fraction of them into Earth-crossing orbits. However, several problems remain open, such as, for instance, the association of meteorite classes to parent bodies in the belt, which is a seminal step for linking the composition of laboratory samples to that of the asteroids in space, taking also into account surface alterations due to space weathering processes. Ultimately, understanding asteroid compositions, especially those suspected of being "primitive", can shed a light on the early planet formation steps taking place in the Solar nebula.

However, despite several decades of accumulating observational evidence, we can say today that the vast majority of the asteroid population is still unknown. While we are able to identify and follow more than 700,000 objects today, for only a tiny fraction of them (of the order of a thousand) we have the rotation period and photometric parameters roughly describing their flattening or elongation. For a part of these (not much more than hundred), the direction of the spin axis is known. The mass is precisely known for ~ 70 largest asteroids (Fig. 3 in Carry, this issue). The situation is now improving concerning the size census, mainly thanks to the results from the Wide-field Infrared Survey Explorer (WISE) telescope, which observed $\sim 160{,}000$ asteroids.

In such a situation, the derivation of certain basic but highly diagnostic quantities – such as density – for a meaningful set of objects remains subject to large uncertainties. However, having this information for several thousand asteroids would support a possible way for validating collisional models that predict the existence of highly fractured and re-accumulated bodies, in particular among family members. In fact, the combined information on density and shape (see below) can play a fundamental role. The bulk density of a rubble pile may be significantly smaller than that of the constituent rocky material, due to a relevant macroporosity.

Another major improvement of the dataset will involve the spin vectors (Paolicchi et al., in this issue). The information on asteroid rotation is very time-consuming to obtain and is now available only for about hundred objects, while it is extremely important for constraining dynamical effects such as Yarkovsky; moreover, the evolution of the spin vector is among the most significant consequences of the YORP effect. A better understanding of the impact of YORP requires a much larger sample of rotational properties, especially concerning moderately sized bodies (presently under-represented in the database). For them, the YORP effect should (according to the theory) dominate the spin evolution, causing a strong anisotropy of the vectors (rarely oriented close to the ecliptic plane), together with a simultaneous excess of very slow and very fast rotators. The increase of the data will also allow to analyze other possible interesting – maybe puzzling – features, such as the prograde vs retrograde excess. When considering the above, it is easy to understand the high expectations coming from a mission such as Gaia, which will provide the physical and dynamical characterization for 300,000 asteroids. The retrieval of asteroid rotation axis and shapes from photometry, as well as the expected increase in ephemerides accuracy, and the determination of sizes and masses for a subsample, are described elsewhere in this issue (Cellino et al., Delloro et al.).

Here we want to stress another specific aspect, namely the determination of size and shapes. Both these properties are not a major strength point for the Gaia mission, as directly measured shapes will remain a strict minority (some 100 s) and shapes will be described by just two parameters (axis ratios of the best-fitting ellipsoids). Still, they are very relevant for computing the volumes of asteroids, and for understanding how they were sculpted during the collisional history. In fact, shapes bring the signature of both minor and major impacts, which displaced surface material, excavated the surface creating concavities (possibly exposing underlying layers), modified the overall shape, modified the rotation period and axis direction, and maybe contributed to the formation of satellites. Finally, a significant amount of material may have been ejected and, later, reaccumulated, creating a "rubble pile". The shape of a rubble pile is not completely free: the interactions among the various rocky components of the body allow to deviate from the classical equilibrium shapes but within a well defined deformation pattern (Tanga et al., 2009).

The space probes that visited a few asteroids, despite providing an impressive amount of high-resolution pictures and other data which portray several of these mechanisms, left several important questions unanswered and opened new ones. For example, we have learned little about the internal nature of the