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Gaia observations of Solar System objects: Impact on dynamics and ground-based observations

Paolo Tanga [a,*], M. Delbò [a,1], D. Hestroffer [c], A. Cellino [b], F. Mignard [a]

[a] *Laboratoire Cassiopée UMR 6202, Observatoire de la Côte d'Azur, BP 4229, 06304 Nice Cedex 04, France*
[b] *INAF – Astronomical Observatory of Torino, strada Osservatorio 20, 10025 Pino Torinese (TO), Italy*
[c] *IMCCE, Observatoire de Paris, 77 avenue Denfert-Rochereau, F-75014 Paris, France*

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Abstract

The Gaia mission will observe all asteroids and other small Solar System objects for 5 years, at a magnitude limit $V \sim 20$. The expected precision for each observation is around 0.2 mas at $V \sim 15$, or 2 mas at $V \sim 20$. At this level, subtle dynamical effects due to mutual gravitational interactions or non-gravitational forces are measurable. In particular, several deflections of small asteroid trajectories due to close encounters with the largest masses in the belt will be detected. The deflection measurement is the main technique employed to derive asteroid masses by Earth-based observations. However, due to the high sensitivity of the Gaia astrometry, the simultaneous deviations due to several masses will be detected, and will require a specific method of investigation. The same applies to the Yarkovsky thermal effect measurements, that will be present in the observations and that demands specific orbital inversion algorithm to be taken into account. At the end of the mission, the knowledge of ∼100 masses at 10% level and several measurements of the Yarkovsky effect can be expected.

Keywords: Gaia; Asteroids; Solar System dynamics

1. Introduction

The ESA mission Gaia will represent a major advancement in astrometry. It follows the path of the previous Hipparcos mission, that measured the positions of ∼120,000 stars, contained in an input catalogue, with a completeness limit around $V \sim 8$. Gaia will observe the whole sky for 5 years, starting in 2012, from the L2 Lagrangian point of the Earth. It will not make use on an input catalogue, indeed an on-board system will limit detection to sources brighter than $V \sim 20$, for a total of 1.3×10^9 stars. The typical astrometric accuracy at the end of the mission will be ∼25 μas at $V = 15$, or 300 μas at $V = 20$, to be compared with the Hipparcos typical value of ∼1 mas.[2]

Beside astrometry, Gaia will perform radial velocity determination at a 2–10 km s^{-1} level for stars with $V < 17$, low resolution spectroscopy in the same brightness range, and spectrophotometry in ∼25 colours for $V < 20$.

From these figures, it is clear that Gaia will offer an unprecedented accuracy on star astrometry, and will be an innovating tool for studying both single objects and large samples statistics. Each object will also be associated to its physical properties.

This wealth of data will allow to map the Milky Way and its kinematics in three dimensions, and to address problems such as the distance indicators, the age of the Galaxy and of the Universe, the detection of extrasolar

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[*] Corresponding author.
E-mail address: tanga@obs-nice.fr (P. Tanga).
URL: www.obs-nice.fr/tanga/ (P. Tanga).

[1] Also at INAF, Astronomical Observatory of Torino, Italy. Presently supported by the European Space Agency (ESA).

[2] We use the following notation: as ≡ second of arc; then, of course: μas = 10^{-6} as; mas = 10^{-3} as.

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planets, the construction of reference frames and the determination of relativistic parameters (Mignard et al., 2005). This non-exhaustive list also include, of course, Solar System objects. As we will see, some 10^5 asteroids (mainly in the Main Belt) will be observed, but the data set will include planet satellites, comets, Near Earth Asteroids, Centaurs, and a few among the brightest Trans-Neptunian Objects as well.

As a consequence we can expect that Gaia will greatly reduce orbit uncertainties for those bodies, and will allow the study of subtle dynamical effects. In particular, the detection of mutual interactions will allow the determination of some asteroid masses. The reachable accuracy should also open the access to direct Yarkovsky effect measurements.

The impact of those observations, together with the physical measurements (see Cellino et al., this volume) will be strong, especially on the evolution of the asteroid belt, the formation of asteroid families, and the transport of small bodies toward the inner planets.

As a notable example, we can cite the Yarkovsky thermal effect, believed to play a major role in modifying the dynamical structure of small family members (Nesvorný and Bottke, 2004). It depends upon effects that remain very difficult to model as the thermal conductivity of asteroids.

Beside special cases visited by probes, we can state that the present knowledge of asteroid masses and sizes cannot offer robust constraints on internal structures. Future data in this domain will thus be of the outmost importance.

In the following, we will briefly review the Gaia mission characteristics (Section 2), and the observational product that can be expected concerning the Solar System (Section 3). Later, we will focus on mass determination and Yarkovsky measurement problems (Section 4).

2. The Gaia mission concept

Gaia observes simultaneously in two directions, separated by what is called the "basic angle". In the satellite, two main mirrors having a size of 0.5×1.45 m collect the incoming signal in the two viewing directions.[3] The two light beams are then combined and focused on the same focal plane instruments. The probe spins around an axis perpendicular to the plane containing the lines of sight with a rotation period of 6 h. Being separated by 106.5°, the same field will be seen by the two fields of view at an interval of 106.5 min. The scheme in Fig. 1 shows the structure of the huge matrix of CCDs, one of the largest ever conceived. All the 106 CCDs have the same characteristics: 4500×1966 pixels, each pixel 59×177 mas in size. The photoelectrons accumulated on the CCDs follow the image movement due to the satellite rotation by using the technique known as Time Delay Integration. In practice, the CCDs are read-out at a constant rate of 1.018 pixels s^{-1}, corresponding to the angular rotation rate. In the scheme of Fig. 1, a star will thus enter from the left, and will drift toward the right.

The data transmission bandwidth is the limiting factor imposing to send to Earth just small patches of CCD images (windows). A set of windows differing in size as a function of star brightness, has been defined and is assigned to each source by the on-board system.

When entering the field of view, a star is first "seen" by one of the two Sky Mappers (SM), each one receiving the light beam of a single viewing direction. This allows to appropriately tag the observation with the identifier of the field of view.

Afterwards, the star drifts in the Astrometric Field (AF), crossing the nine columns of AF CCDs. Here, if the SM observation determined a brightness $V < 13$, a reduction of the exposure time is obtained by the activation of gates, i.e. by resetting the charge content of the pixels when they have crossed an appropriate distance on the CCD. This way, stars as bright as $V \sim 4$ can be observed without saturation.

The SM detection implies also an on-board centroiding that allows to assign the window positions in AF. For stars with $V > 13$, a binning perpendicular to the scan direction ("across scan", AC) is always performed. As a consequence, full single-pixel resolution is only available "along scan" (AL). On the other hand, for $V < 13$ a fully resolved, 2D window is read and transmitted. In all cases, the window size is not larger than 1.1 as AL (0.7 as for $V > 16$), and 2.1 as AC.

Valuable physical data concerning all sources will come from the Blue Photometre (BP) and the Red Photometre (RP). In the case of Solar System objects, they will constitute a precious multi-band data set that can be used for building a completely revised taxonomic classification for asteroids (Cellino et al., this volume).

The Radial Velocity Spectrometre (RVS) is a near IR (847–874 nm) spectrograph of medium resolution ($R = 11{,}500$). It has been designed in order to provide details about a spectral region rich in features, allowing to study rotational velocities, atmospheric parameters (effective temperature, surface gravity, metallicity), and abundances of chemicals relevant for tracing the Galaxy evolution. No specific use of RVS for Solar System is foreseen although observations of well-known asteroids will be used to calibrate the instrument, thanks to the accurate predictability of their radial velocities.

As illustrated above, the satellite operates by continuous scanning for 5 years. Three rotational movements are accomplished by Gaia. In fact, the spin axis precedes with a period of 63 days on a cone centred on the Sun. Further, a change in orientation of the precession cone axis takes place over 1 year. The spin axis makes a constant angle of 45° with the Sun direction.

The combination of the three movements allows a gradual shift of the scan circle over time. This way, about 80

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[3] For more details about the Gaia satellite and its focal plane, see for example Pace (2005), Lindegren (2005), or the Gaia site of ESA: http://www.rssd.esa.int/GAIA.