

## Preparing GAIA for the Solar System

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### Abstract

The GAIA satellite will observe a large number of solar system objects, mainly asteroids, and although most of them shall be already known in the next decade, it will possibly discover new ones. The major scientific outcomes of this mission for the science of the Solar System is the survey of the inner-Earth orbits region, the determination of asteroids' physical parameters (masses, sizes, taxonomy, ...) for a large number of objects, detection of binary asteroids, accurate orbits determination, and tests of general relativity. Here we discuss the preparative work that should be done before launch regarding the scientific case, the software or instruments requirements, the catalogues output, and complementary ground-based observations.

## 1 INTRODUCTION

The GAIA mission will have a major impact on the science of the Solar System going from the inner part to the trans-neptunian region. Ideally no special treatment should be applied for the observations of solar system objects, i.e. they will be considered as stars in the raw data acquisition. However these objects have non-negligible or even large motions in the sky (specially for near-Earth objects), can be resolved, or saturate the CCD. The full sky coverage of the scanning law, the relatively faint limiting magnitude, the possibility to observe at small solar elongations, the (modest) imaging resolution, and the high precision astrometric and photometric data that will be acquired during the 5 years of the mission are all together of high importance for the science of solar system objects. We shall first give an evaluation of what objects can be observed, and what measure can be obtained (photometry, astrometry, radial velocity). Next we shall discuss what science can be achieved with the available data for asteroids' physical parameters and dynamics determination, reference frames determination, and for fundamental physics. Finally one should also consider the output catalogues: completeness and detection efficiency, what data should be published, is there a need of complementary (ground- or space-based) observations, etc.

## 2 THE SCIENTIFIC CASE

### 2.1 Orbits and physical parameters

GAIA will provide very accurate, basically uni-dimensional, directions of a huge number of asteroids and they should hence enable tremendous ephemerides improvement [1]. Nevertheless the situation may be less favorable for a fraction of the observed asteroids: newly detected

objects and less observed ones. One should hence extend the analysis and study in more scrutiny those particular cases. It should be stressed that the efforts made nowadays by ground-based asteroids surveys (e.g. NEAT, LONEOS, LINEAR) will provide an almost complete catalogue of objects brighter than  $V < 19.5$  and very likely  $V < 21.5$  [2], so that most of the asteroids detected by GAIA will be already known with more or less accurate orbits. In a similar way the ESA mission Bepi-Colombo includes a NEA experiment that should discover asteroid inside the Earth orbit [3]. In fact discovering a new object is by itself of limited value; one will also foreseen for an orbit determination in order not to loose it on a next apparition. This is usually done by an appropriate follow-up which is in contradiction with a regular scanning law. The GAIA observations alone (including the measures of the velocity) may enable the recovery of newly discovered objects and provide sufficiently accurate orbits for this purpose, but this has to be carefully assessed (see Sect 3.3).

The photometry gathered in the various filters should also provide information on the asteroids taxonomy. Further analysis should determine which taxonomic classes can be derived and with what confidence limits, and the best suited photometric system. For instance one may test the efficiency of the G-mode method [4] regarding the photometric precision available as a function of the magnitude, and the need of complementary data. The efficiency of the GAIA instrument for detecting (by direct imaging or via an astrometric signature) binary asteroids or satellites of asteroids and characterize their orbits should be analyzed.

The mass and density are essential parameters that are in general barely known for asteroids. Presently less than a dozen of asteroids have mass estimates (with precisions that can reach 50%), and accurate density determinations are available for about the same number of bodies. GAIA should provide a huge step in this field with mass estimates for hundreds of objects. Asteroids masses can be determined from the effect of a close encounter on the astrometry of a perturbed body even if the astrometric measures are uni-dimensional and cover a small time-span as was the case for Hipparcos [5]. Further simulations should provide the actual number of deflectors that will be involved in asteroid-asteroid close encounters and more important, the precision of the mass determination (depending also on the actual astrometric precision and distribution of the observations of the perturbed asteroid).

## 2.2 Fundamental physics

Asteroids astrometry can provide tests of general relativity, the most common one being derived from the perihelion precession. For this topic the preferred targets are asteroids with small semi-major axis and large eccentricities, but past tentative did not yield competitive results [6] mainly because of the limited precision of the measures. Among the 100 000 asteroids cataloged today, about 300 show a perihelion precession larger than 20 mas/s and about 10 would have a precession of the order of that of Mercury. The asteroids population is an interesting one because it provides a test at different distances from the Sun and is less sensitive to the not well known solar quadrupole<sup>1</sup> [7]. The actual number of target asteroids, their observations distribution (including the scanning law and the detection efficiency) and their related astrometric precision should be analyzed in more details to better estimate how accurately the  $\beta$  parameter of the PPN<sup>2</sup> can be determined. Such a study could also be extended to the analysis of planetary satellites with relatively large eccentricities. It has also be shown that observations of trojans and objects in a 2:1 mean-motion resonance may provide Nordvedt's  $\eta$

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<sup>1</sup>One should however keep in mind that a) the range in semi-major axis will remain relatively limited and b) that in the next decade, the solar quadrupole can be known with good accuracy by other means.

<sup>2</sup>The  $\gamma$  parameter is determined with enough accuracy within the GAIA mission [8]

parameter and a test of the equivalence principle [9, 10]. The GAIA observations even if very accurate may however cover a too small time-span to be valuable, but this topic should be addressed in more details.

The linking of quasi-inertial reference frames can be made through the observations of QSOs and asteroids. Not all available objects may be retained for such a link; one will prefer those asteroids with very accurate orbits where e.g. photocenter displacement or mutual perturbations can be neglected or modeled with enough accuracy. Apart from the geodetic precession, there should be no rotation between these two reference frames. A significant rotation could be the trace of a vortex in the Universe and violate Mach's principle. The precision with which one can actually test this principle with the GAIA observations has to be estimated more carefully.

It is stressed that for these topics not only the Earth orbit but also the asteroids' center-of-mass orbits must be accurate and free of any systematic errors.

### 2.3 Other objects

GAIA will mainly observe main-belt asteroids (about  $0.5-1 \times 10^6$  objects) but it will also observe or discover Atens, IEOs, trojans of Venus or of the Earth. In the outer region it will observe Chiron, Pluto-Charon and other bright KBOs or Centaurs [12]. Also other solar system objects brighter than magnitude  $V < 20$  will cross the fields of view of the different GAIA instruments. The scientific value and the specificities of observations of comets and planetary satellites has not been addressed yet. Major planets may saturate the CCDs; for Uranus, Neptune accurate positions will be obtained over a short time span. It is stressed that the orbits of the inner planets are better defined than those of the external ones which are not frequently observed. Many planetary satellites will be observed by GAIA and the observations will be different in some aspects to those of the asteroids. The proximity to the faint satellite of the parent planet or its rings has to be taken into account for the detection and measurements efficiency. Also the velocity distribution is different to that of asteroids. Orbits improvement has to be analyzed considering for instance the particular distribution in time of the GAIA observations.

## 3 SOFTWARE AND INSTRUMENTS REQUIREMENTS

### 3.1 Instruments

For completeness I add some requirements even if their implementation on GAIA is impossible (x) or highly un-probable (o):

- x extend the photometry in the near-IR toward  $1.1 \mu\text{m}$  to better separate some taxonomic classes;
- x spectral range around  $0.5-0.6 \mu\text{m}$  for the spectra acquisition;
- x modify the scanning law with a smaller ( $< 55$  deg) angle to the Sun for a better detection efficiency of inner-Earth orbiting objects (Atens, trojans of Venus, etc.).
- o special tracking along the AMF of moving objects via an adapted CCD reading. The astrometry of rapidly moving objects is not ensured in the Astro main field by a CCD reading phased to the motion of a star, this will decrease the number of observations and the precision on the astrometry (which may already be poor because of the blurring by the TDI mode);
- o increase the mission duration to better model or detect secular effects;
- o go to fainter magnitude  $V < 22$  for the Spectro instrument, see [11] for position (detection) and also photometry (physical parameters). This is of special importance for the NEO and even more for the Centaur and KBO population which will be only marginally surveyed by GAIA.

### 3.2 Simulations

The data acquisition and reduction pipe-line has to be written and tested for all instruments (Spectro and Astro). This includes the modeling of the PSF (taking into account the target's velocity, size and shape, and its location in the focal plane), the detection and identification algorithm, the orbit restitution from a short arc and the analysis of the catalogues completion. Once a moving object is detected from the Astro or Spectro instrument one should first check if it is an already known one. This can be done on ground by ephemerides calculation via an up-dated catalogue. The efficiency and robustness of such a minor planet checker has to be tested. If it appears that the object is a newly discovered one, one should ensure first to be able to recover it on the successive transits in the various FOVs and next to derive an approximate orbit in order to recover it on the next observation epoch. The knowledge of the velocity (tangential and eventually radial) and the use of the Spectro instrument with an additional sky mapper (SSM2) can be helpful for such a procedure. If such an identification procedure or orbit determination cannot be achieved by GAIA observations alone, one would require ground-based observations on the following night to avoid losing the object.

### 3.3 Ground-based observations

Ground-based observations (or more generally complementary observations including DIVA, FAME, DENIS, etc.) can be needed for newly discovered objects (time complement) or to provide additional data (e.g. in the IR or near IR domain). If the recovery<sup>3</sup> process cannot be ensured from GAIA observations alone, an alert procedure and a follow-up by other pointing telescopes would be helpful or necessary. It should be noted however that the problem of asteroids identification is already encountered in ground-based observations too when one tries to link observations over two short arcs obtained at two different epochs [13]. The necessity and cost of having dedicated telescopes (in both hemispheres), their efficiency in observing at small solar elongations, their size and automation must all be addressed. Note that the Japanese BSGC observatory is designed for such a purpose [14]. In any case, if the orbit determination and dedicated follow-up are not possible within the GAIA mission, an alert procedure should be implemented. For instance the NEO Coordination System of the Spaceguard Foundation provides to the interested community a list of observing priority [15].

## 4 CATALOGUE OUTPUTS

Stellar data (astrometric, photometric and spectrographic) can be corrupted by an asteroid close approach, this has to be properly identified and flagged at the quick-look level. Regarding the solar system, a few points have to be analyzed to know what/how data should be published. GAIA basically provides the gaiacentric uni-dimensional direction of the body's photocenter and magnitudes in various filters. For practical reasons one would prefer to publish astrometric positions (i.e. the direction of the object as seen from the center of the Earth), but in order to derive this direction the planet's distance has to be known with a precision of about 30 km [16]. In a few cases the ephemerides may not be accurate enough to allow such a construction and one would need to publish the gaiacentric position as well as the satellite orbitography (possibly with a geocentric position with lower accuracy). Since the ephemeris improvement shall be undertaken during the reduction procedure one may think of publishing also the

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<sup>3</sup>Identify an object as a previously observed one, or in other words to ensure that 2 short arcs observations correspond to the same object

derived osculating elements. Such ephemeris improvement will have to take into account the perturbations of the more massive asteroids and the photocenter offset. The latter depends on the target size, shape, and light diffusion on its surface, and is generally non predictable. It may be derived during the ephemeris improvement for the largest bodies [17], but for medium sized asteroids the situation is more troublesome. In a similar way other catalogues could be published: taxonomy, masses, etc.

## A GLOSSARY

- Aten: objects evolving on orbit crossing that of the Earth (semimajor axis  $a < 1$  AU and aphelion distance  $Q > 0.983$  AU) and spending most of their time inside the Earth's orbit. These could represent 20% of the Earth-crossing population.
- Centaur: object with an orbit between Saturn and Neptune, thought to be a dynamical transient from the Kuiper-belt to the inner region with eventually some cometary activity.
- quadrature: position of a planet corresponding to a solar elongation of 90 degrees.
- solar elongation: difference between the geocentric longitudes of the Sun and the planet. It is sometimes given as the angle between the Sun and the planet as seen from the Earth.
- AMF: astrometric main field.
- IEO: inner-Earth object. Objects with an orbit inside that of the Earth that could represent 50% of the Atens population.
- KBO: Kuiper-belt object (or TNO). Object with a trans-neptunian orbit.
- MBA: main-belt asteroid.
- NEA or NEO: near Earth asteroid or near Earth object.
- TNO: trans-neptunian object (or KBO).

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