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Science from NEOs – Limitations and Perspectives

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Introduction

The Gaia mission, in addition of doing astrometry of stars and a 3D census of our Milky Way, has specific objectives for solar system objects (Tanga, 2011). In that respect it follows the Hipparcos/Tycho mission that already observed a few solar system objects. The astrometric accuracy involved with Gaia is however 1 to 2 orders of magnitude higher, and the total number of targets observed is incomparably larger. Here we describe several scientific outcomes from the astrometry of asteroids and comets with particular emphasis on the Near Earth Objects (NEOs), their specificities and limitations.

1. Astrometry from Space – Hipparcos & Gaia

The ESA Hipparcos/Tycho mission (1989-1993:1997) observed 48 asteroids, a few planetary satellites, and two major planets. It basically provided positions at 10mas precision level and photometry at 0.05 mag level, which data are catalogued in the Hipparcos solar system annex, and available at the CDS[1] (ESA 1997). These observations provided some scientific output (see Perryman 2008, and reference therein), we will emphasise here that already at that level of astrometric precision the photocentre effect is visible (Hestroffer 1998), and that photometric inversion with sparse data can be applied to targets with enough observation points (Cellino 2009). Besides, the availability of the Tycho catalogue of stars has also been valuable for the science of solar system objects by improving astrometric reductions and stellar occultations predictions. In contrast, the Gaia mission is much more than just a Hipparcos II.

One major technical difference with Gaia comes from the use of CCDs is TDI mode (Hipparcos used an old technology of photomultiplier and a modulating grid) which enables to simultaneously observe all objects brighter than magnitude $V \leq 20$ in the field of view (given it is not in a over-crowded region in the galactic plane). Gaia will also provide photometry in a large G-band as well as low resolution spectrophotometry (high resolution spectroscopy is obtain over a very small range and of little use for asteroids except for the purpose of calibrating the instrument). There will be about 250.000 asteroids observed, about 25 planetary satellites, and JFC as well as LP comets. The images on the CCD will enable to derive sizes of a few thousands of asteroids to compare to those of the IRAS catalogue, and shape or binarity information for several. The photometry will enable to derive the spin state (direction and period) as well shape information (tri-axial model) for almost all observed body. Of course, being an astrometric mission, the main output will be the astrometry. Gaia will provide high accuracy positions for all asteroids over 5 years and directly connected to a homogeneous reference frame of distant quasar (and hence connected to the ICRF).

[1] URL: http://cdsarc.u-strasbg.fr/viz-bin/Cat?I/239

2. Gaia

As said before the limiting magnitude is V≤20 (besides the fact that very bright objects won't be observed, as well as in very crowded region a selection will be applied, but all this does not affect asteroids much). There is also a limit of size at about 0.7–0.9 arcsec; objects larger than that will not be detected and hence not be observed, this concerns mainly planetary satellites. Fast moving object should be detected but they might not be observed through all the 9 CCDs of the FOV, unless a specific windowing scheme is applied. The given satellite's scanning law makes that the objects are observed when they cross the FOV (this is no pointing telescope) which results in a random pattern of observation distribution. Nevertheless the observations are rather well distributed in time and in space for a typical main belt asteroid, with 60-70 observations on the average over 5 years (Fig. 1). The situation is not the same for a NEO or an object close to the limiting magnitude, where observations can be scarce and clustered over a short period of time.

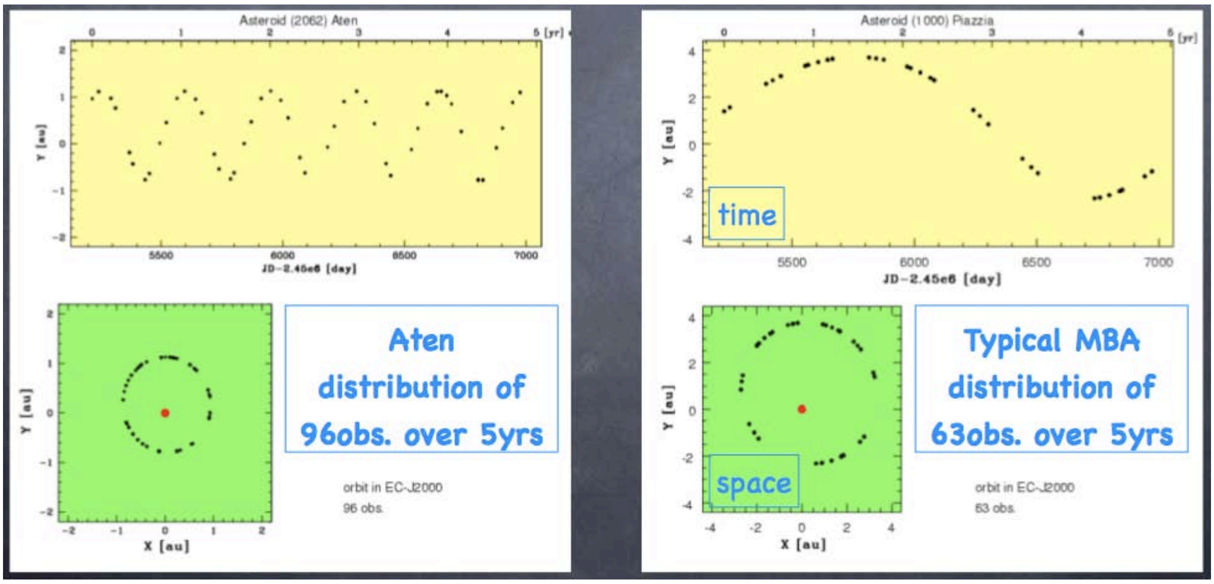

Fig. 1 – Observation distribution in time and space for typical asteroids. The total number of observations can decrease to a few for NEOs and objects close to the limiting magnitude.

Binary asteroids will also be observed by Gaia enabling improvement of their mass, or determination de novo. The cases of binaries can be of particular interest for Gaia, whether the two components are well separated and detected as two different bodies (resolved binary) or whether the system appears as a single object but the motion of the photocentre shows a wobble effect around the centre of mass that is not correlated with the spin of the body (astrometric binary). Further work should be carried out to determine how many resolved or astrometric binaries will be detected as such. The detection of an astrometric binary necessitates to have good absolute positions, with good precision and hence a good stellar catalogue, which Gaia will provide. The signature depends also on the separation of the bodies and mass ratio; it is most sensitive for mass ratio of the order of 0.05–0.5. Application to a known transneptunian binary (TNB) system have shown some interesting potential (Ortiz 2010). Gaia will also observe a handful of trans-Neptunian objects among, which the Pluto/Charon system. Making use of the GIBIS focal plane simulator (Babusiaux 2005) and the Gaia scanning law *rendez-vous* simulator, it is found that about 70 relative positions will be acquired of the system as a resolved binary, which—when combined to future or past astrometric observations—will enable to monitor the orbit evolution over several decades. Making use again of the GIBIS simulator, it is found from a population of synthetic binaries, that system with a separation larger than 0"3 and a magnitude difference smaller than 2 (going up to Δmag=5 at 1" separation, see Fig. 2) will be resolved by the sky mapper.

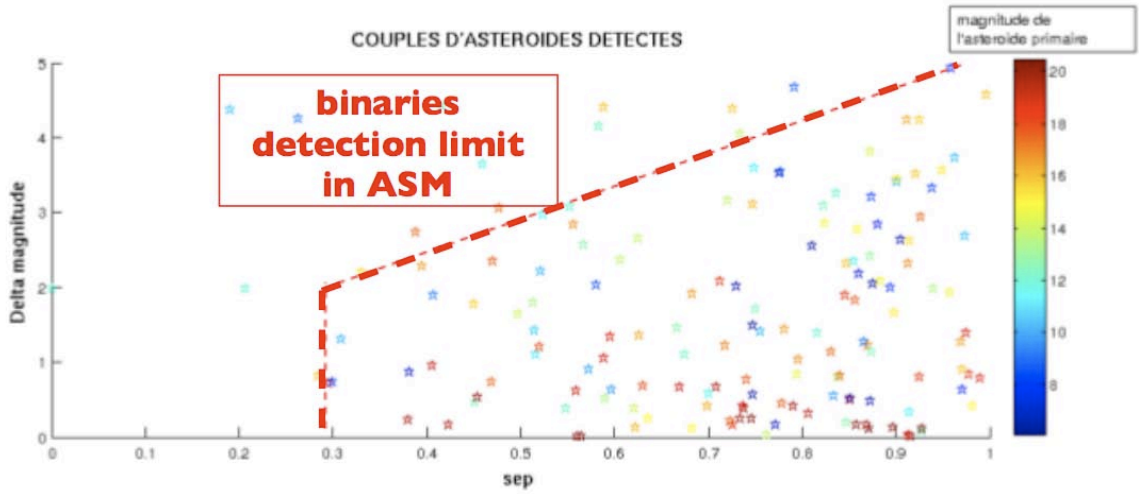

Fig. 2 – Binaries detection limit in ASM. Simulation form a synthetic population as a function of separation and magnitude difference (credit J. Blanchot).

There are several timelines involved in the Gaia mission either in the data reduction pipeline (Berthier 2011) or in the data release (intermediate or in alert, Pristi 2011). For what concerns the long-term treatment of the astrometry of solar system objects, there will be basically two kind of outputs: The catalogue of measured positions (asteroids, comets, and satellites) in the final reference frame, and also derived parameters concerning either a specific object (*local* parameters) or the solar system and physical constant in general (*global* parameters). We describe in the following some of the aspects of the parameters estimation.

2.1 Orbits

Gaia will provide astrometry of solar system objects on a transit level basis, on the order of 0.3 mas for objects brighter than V≤14 mag, going up to approx. 3 –5mas at the magnitude limit V=20. Because a fast moving object will not be observed through its whole FOV transit, we consider in the following the pessimistic case where only one CCD observation is available per crossing. On the other hand, the ephemerides are computed by numerical integration of the perturbed two-body problem, taking into account the perturbations of the planets. The computation additionally takes into account previously selected perturbing asteroids, relativistic effect (for the equation of motion and observation reduction), and the photocentre offset due to phase. In case of comets, we also include non-gravitational forces through empirical A_i parameters. Last, we also perform the integration of the variational equations to derive the partial derivatives with respect of our parameters to estimate. Once the O-C vector and Jacobian matrix are computed, we perform a linear least-squares inversion.

The astrometry acquired will enable orbit *improvement* by a factor≈30 when compared to what is obtained presently from ground-based data only. In the case where the number of Gaia observations for a given object is insufficient however, there will be no particular orbit improvement but the data will be useful to derive global parameters, and later, for orbit improvement when combined to all existing ground-based observations. Besides given the relatively short period of observations, one will cover a full orbital period of a typical main-belt asteroid, but not enough to derive longer-term effects as can be present for instance in the planetary satellites motion, or Trojans long term librations.

Mass of asteroids can be derived from the monitoring of the relative orbit in binary system as seen before, but also from monitoring the orbit of a target asteroid when perturbed by a massive perturber asteroid; there will be about 150 mass determination of asteroid involving several thousands of asteroid-asteroid close encounter. In some cases the mass determination of a few asteroids can be enhanced by complementary ground-based astrometric observations (Ivantsov et al. 2011), the same holds for the density determination by considering additional observations from ground to better characterise the shape and size of the object. Other global parameters entering the dynamical model for the equations of motion can also be adjusted. For instance by monitoring the precession rate of all the asteroids' perihelion together, one will enable to derive the relativistic PPN parameter ß as well as a direct estimation of the solar dynamical flattening J_2. Besides one will be able to derive the link of the dynamical reference frame to the Gaia (and hence ICRF) reference frame, and a possible time variation dG/dt of the gravitational constant (Hestroffer et al. 2009).

2.2 NEOs

The astrometry of asteroids will also enable orbit *determination* or linking in case a new object is discovered. Given the modest limiting magnitude when compared to ongoing and future ground-based surveys, Gaia will not discover a huge amount of asteroids. However being in space and free of atmospheric diffusion and airmass, it might be more efficient at discovering objects at low solar elongations (down to 45°) and in particular objects orbiting inside the orbit of the Earth (IEOs). Orbit determination in this case will be done on the short-term level by use of an MCMC algorithm which will provide a whole set of possible solutions (Granvik et al. 2009). In such cases it is of importance to have additional observations and astrometry in support to avoid loosing the object and help further identification when the object crosses back the satellite's FOV several weeks or months later (Thuillot 2010).

As seen in Bancelin (2011) there will be about 1600 NEOs observed; only objects that can be identified will enter the long-term reduction pipeline. The number of observations per object is varying (about half of them will have less than 10 observations), but even if no orbit improvement can be obtained, they all enter into the global effects parameters estimation scheme. Moreover the NEOs with low semi-major axis and large eccentricity are the most sensitive to the General Relativity test. In that case, combination of long-term observations – because the effect is a secular drift – gives a higher leverage for the test. We shall here consider combination of present radar (Margot 2009) with future Gaia observations. For small objects close to the Sun the Yarkovsky effect and other non-gravitational effects can be noticeable. In a few cases a simple inversion can be performed to provide a basic scaling parameter for the Yarkovsky effect to better than 20%. This can be the diameter and thermal inertia, all other parameters of the model being assumed; or more generally a parametric force in the along track direction that is inversely proportional to the square of the heliocentric distance. Here again ground-based observation can be useful to constrain the dynamical system to be used.

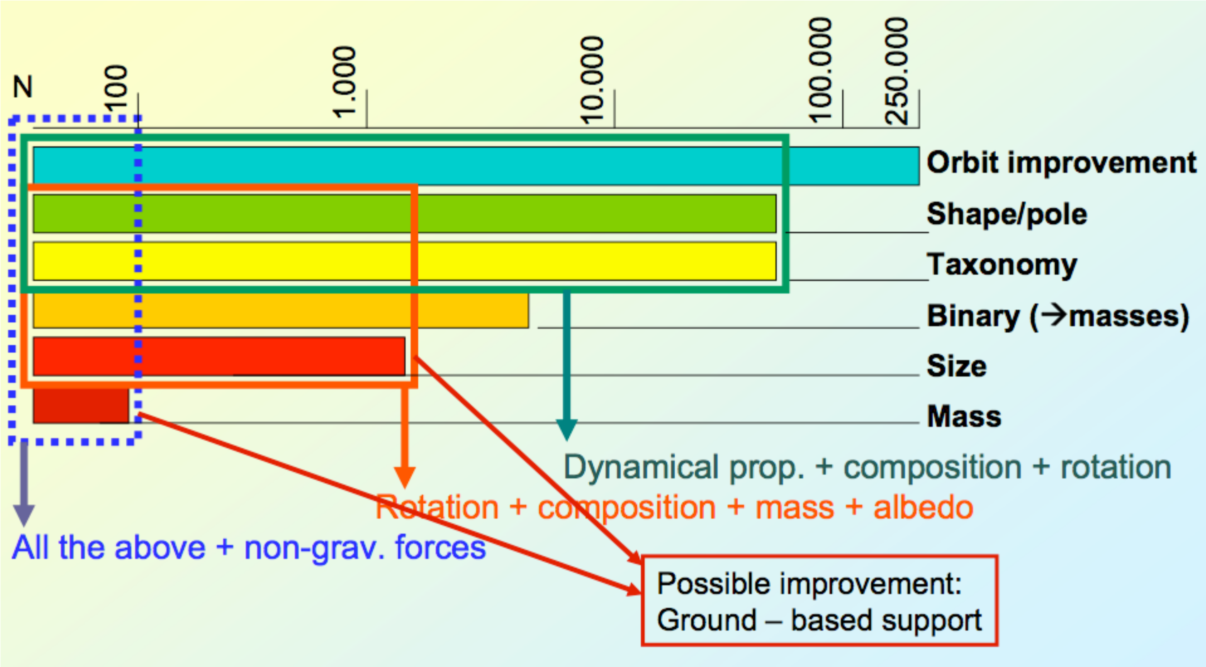

Fig. 3 – General scientific output from the Gaia observation of asteroids (credit: P. Tanga).

Conclusion

Gaia will observe a large number of solar system objects, much more than Hipparcos and Tycho could do. These will essentially be main belt asteroids, but about 1600 Near Earth Objects will be observed too, including some inner-Earth objects that might be discovered by Gaia. The astrometry, photometry, and colour-spectroscopy acquired will enable direct output by considering the Gaia data alone (Fig. 3). In some cases complementary ground-based data is mostly valuable.

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