# Astrometry of asteroids with the Gaia space mission.

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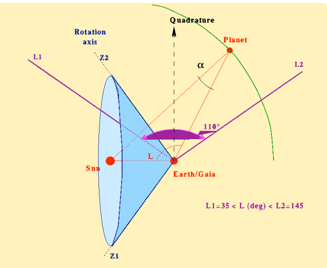
## Abstract

**The ESA cornerstone space mission Gaia [1], to be launched in 2011, will observe a huge number of stars with an unprecedented accuracy (approx. 20 micro-arcsecond at V~15). In addition to the '3D census of the Galaxy' this satellite will provide — from the survey character of the mission to a limiting magnitude of V<20 — astrometric and photometric measurements for a large number of solar system objects, mainly asteroids. Focusing on the astrometric measurements, we will present the peculiarities of solar systems observation with the Gaia scanning satellite, detailed simulation of the focal plane observation and data acquisition for such objects, and the particular effect on the astrometric precision of such resolved and moving targets.**

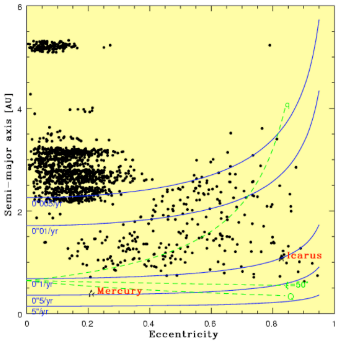
**Next we show how Gaia observations of Trojans, main-belt, and near-Earth asteroids will provide 1) orbit improvement, 2) asteroids mass determination, 3) direct determination of the solar $J_2$ and relativistic PPN parameters, and 4) reference frames linking. From realistic simulations of the observations' geometry and timing for subsets of the above-mentioned asteroids classes, we will analyse the asteroids orbit improvement, as well as the solar quadrupole and PPN $\beta$ determination, and derive the formal precision that can be achieved for such global parameters. Interestingly these parameters will be obtained directly and simultaneously, without any assumption on the internal structure of the Sun. In all aspects the scientific results achievable with Gaia appear to be competitive with present and future ground- or space-based experiments in the Solar system yielding $\beta$ to $10^{-3}$–$10^{-4}$ and $J_2$ to $10^{-7}$–$10^{-8}$ [e.g. 2,3].**

## 1. Observations of Solar System Objects

Due to the particular scanning law of the satellite, observations of Solar System objects are different from classical ground-based observations and also somewhat different from Gaia observations of stars. Solar system objects are crossing the two telescopes' FOV in a (large) zone around their quadratures, i.e. at relatively large phase and not at maximal brightness. There is no particular pointing nor particular TDI reading planned so far for these resolved and moving targets.



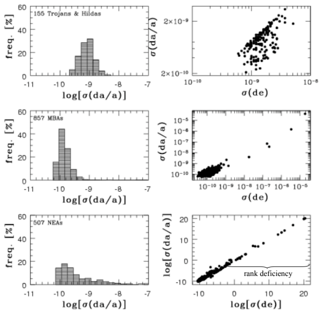
Estimation of the achievable astrometric precision is based on the focal plane simulation of the image from GIBIS simulator [4] combined with detection-tracking from Pyxis [5]. These estimates are taken to be the precision for one 'observation' (i.e. crossing). Taking into account the size and motion of the objects during the integration time degrades the astrometry, but it essentially remains a function of the target brightness, ranging from 0.2 mas for V<12 to ~3 mas for V=20).



We shall in the following consider only the along-scan one-dimensional astrometry. The astrometry in the perpendicular direction is much less precise, and it can be shown that it adds little to the foreseen precision. We will consider a subset of asteroids observable by Gaia including NEA, MBA, and Trojans. In contrast to the two others known and generally bright objects, the NEA population is based on a more extended simulated population following unbiased distributions given in [6].

## 2. Orbit Improvement

Partial derivatives wrt correction to the orbital elements (**dq**$_i$) are obtained following Brouwer & Clemence [6]. We next compute the precision of the orbit correction $\sigma$(**dq**$_i$) for different asteroids. The orientation of the orbits should be given to ~$10^{-7}$–$10^{-8}$ degrees, the semi- major axis to ~$5.10^{-10}$.



Hildas and Trojans asteroids shall have well defined orbits albeit their synodic period is considerably larger than the mission duration. In some cases however the observations are to sparse to obtain a complete orbit refinement (rank deficiency). This is essentially the case for NEOs where the number of crossing is highly variable between the various objects; it will limit the orbit refinement to fewer parameters but will not affect the determination of global parameters addressed in Sect.3.

| | dlo+dr [rad] | dp [rad] | dq [rad] | e.dr [rad] | de | da/a | d$\Gamma$+d$J_2$ |
|---|---|---|---|---|---|---|---|
| NEO (Icarus) | 1.0E-08 | 6.8E-09 | 9.3E-09 | 1.4E-09 | 3.3E-09 | 6.7E-10 | 3.2E-03 |
| MBA (aver.) | 2.3E-10 | 3.1E-10 | 3.1E-10 | 1.7E-10 | 1.4E-10 | 1.6E-10 | 2.1E-03 |
| Trojan (aver.) | 1.9E-09 | 4.2E-09 | 3.6E-09 | 8.8E-10 | 1.5E-09 | 1.E-09 | 1.8E-02 |

## 3. PPN β, solar J2 & Reference Frame Link

In addition to parameters for individual asteroids (orbital elements, light scattering, mass, etc.), one can derive global parameters common to all targets that affect the observed positions. We consider the secular precession of the orbit and perihelion, and a global rotation of the ecliptic reference frame. While planetary perturbations shall be known with sufficient accuracy, the combined effect of the relativistic perihelion drift (through $\Gamma$=(2+2$\gamma$−$\beta$)/2) and the perturbation due to the Sun oblate gravitational potential (through its quadrupole moment $J_2$) on the orbital nodes and perihelion can be derived from the Gaia measurements. Also a global rotation **W** and rotation rate d**W**/dt of the ecliptic dynamical reference frame w.r.t the ICRF can be introduced as additional parameter. Considering the set of ~1500 asteroids including NEAs, MBAs and Trojans, observed by Gaia during 5 years, we obtain the precision estimation in the Table below. The correlation between $\Gamma$ and $J_2$ is 0.76, the others drop to a few percent at most. One will hence be able to derive directly and separately the solar dynamical flattening and the PPN $\beta$ without any additional assumption on the internal structure of the Sun from helioseismology or measures of its external shape. Keeping in mind that we have considered a restricted subset of targets, these results appear to be competitive with present and future ground- or space-based experiments in the Solar system yielding $\beta$ to $10^{-3}$–$10^{-4}$ and $J_2$ to $10^{-7}$–$10^{-8}$ [e.g. 2,3].

| | σ(β) | σ($J_2$) | σ(W) µas | σ(dW/dt) µas/yr |
|---|---|---|---|---|
| ~1500 asteroids | 6.3E-05 | 1.1E-08 | x y z<br>2.5 2.5 11.0 | x y z<br>2.7 1.7 5.3 |

## 4. Perspective

The precision of a single measure is conservative since an LSF fitting could be applied instead of the barycentre estimator, and one will have more than one single CCD observation during a transit (typically 10 for MBAs but less for fast moving NEAs). On the other hand the oblique illumination by the Sun will introduce a photocentre offset that can be important for the NEAs and not always fully modelled, introducing hence an additional noise or bias. Analysis of the photocentre offset and unmodelled perturbations by other massive asteroids shall be done in future work. Considering a larger hypothetical set of 500,000 asteroids observed by Gaia will increase the precision on the global parameters. The solar quadrupole moment $J_2$ could hence - by simple extrapolation - be determined *formally* to ≈$10^{-9}$, and the PPN $\beta$ to ≈$5.10^{-6}$, both with unprecedented precision.

## References

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