Near-Earth Asteroids Astrometry with Gaia and Beyond

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Introduction

Gaia is an astrometric mission that will be launched in 2012 and will observe a large number of Solar System Objects down to magnitude 20. The Solar System Science goal is to map thousand of Main Belt Asteroids (MBAs), Near Earth Objects (NEOs) (including comets) and also planetary satellites with the principal purpose of orbital determination (better than 5 mas astrometric precision), determination of asteroid mass, spin properties and taxonomy. Besides, Gaia will be able to discover a few objects, in particular NEOs in the region down the solar elongation (45°) which are harder to detect with current ground-based surveys.

In the first section, we detailled the nominal scanning law of Gaia and its impact on the number of observations of NEAs. Then we focus our study on asteroid Apophis were we analyze the effect of Gaia observations on the actual position uncertainty, and on the 2029-target b-plane. In the last section, dedicated to the astrometry of newly discovered objects by Gaia, we analyze the combination of ground-based and space-based data on the short-term ephemerides.

1. Nominal Scanning Law of Satellite Gaia

During the 5-years mission, Gaia will continuously scan the sky with a specific strategy (fig. 1): objects will be observed from two lines of sight separated with a constant basic angle. Five constants already fixed determinate the nominal scanning law but two others are still free parameters: the initial spin phase and the initial precession angle. These latter will be fixed at the start of the nominal scientific outcome (possibility of performing test of fundamental physics) together with operational requirements (downlink to Earth windows).

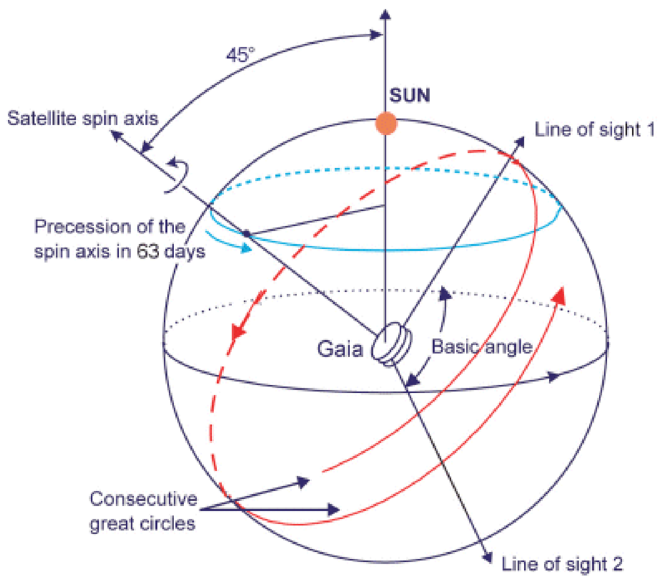

Fig. 1 – Nominal Scanning Law of Gaia. (Credits: ESA)

Several sets of observations of NEOs will hence be provided according to the initial precession angle. We used a Java *rendez-vous* simulator which provided us 35 sets of Gaia observations. Figure 2 shows the number of NEAs and PHAs that could be observed by Gaia. The number of asteroids does not really change according to the value of the initial precession angle. The mean values of possible observed asteroid are ~1650 NEAs and ~ 405 PHAs.

2. Study case of asteroid 99942 Apophis (previously 2004MN4)

We study here the effect of Gaia observations on Apophis orbit. This asteroid has a so deep close-approach with the Earth on April 2029 that its post close-approach orbit becomes chaotic. Thus, the uncertainty on the geocentric position and distance becomes large. From a linear propagation of the covariance matrix, figure 3 shows the impact of Gaia astrometry done in 2014 (date of last Gaia observations) on the position uncertainty of Apophis. To this purpose, we considered only one of the sets provided by Gaia.

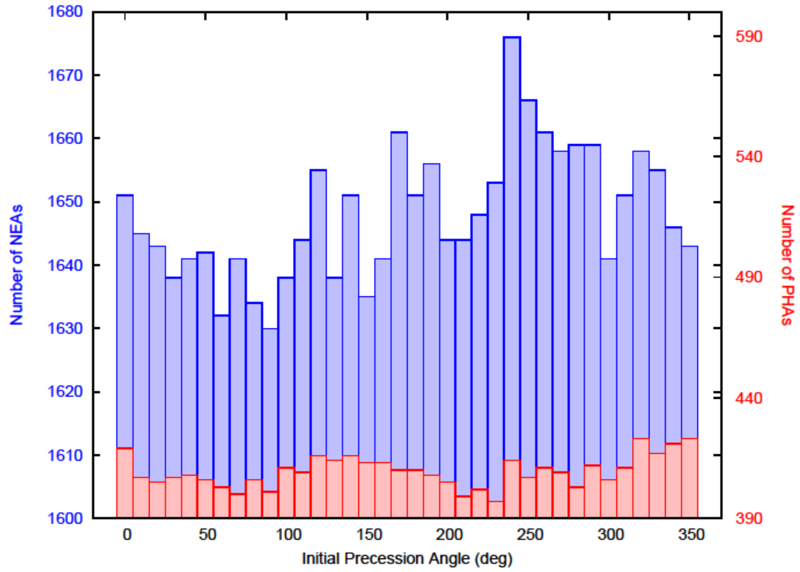

Fig. 2 – Number of NEAs and PHAs observed by Gaia with respect to the initial precession angle.

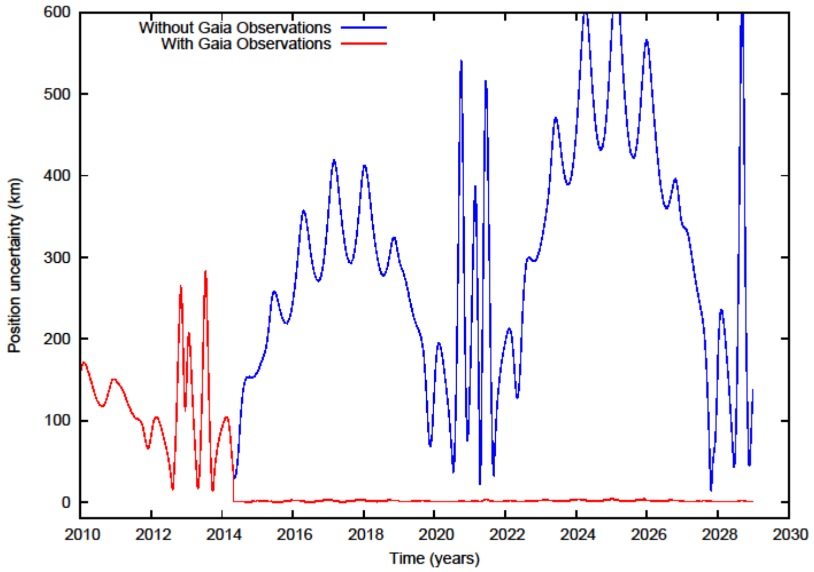

Fig. 3 – Position uncertainty of Apophis considering Gaia observations.

The position uncertainty is reduced to less than 2 km with Gaia observations. This value remains almost constant until the 2029 close approach (at distance 38000 km to Earth) where the uncertainty will start increasing. We can also analyze the impact of Gaia observations on the geocentric coordinates (ξ, ζ) of the 2029-target b- plane [1]. The b-plane passes through Earth's center and is perpendicular to the geocentric velocity of the asteroid. The initial covariance of the (ξ, ζ) elements are propagated to this date. Figure 4 represents the 3σ scattering ellipse where the semi minor axis is defined by $3\sigma_\xi$, the semi major axis by $3\sigma_\zeta$ and its center by the values of (ξ, ζ) on the nominal solution.

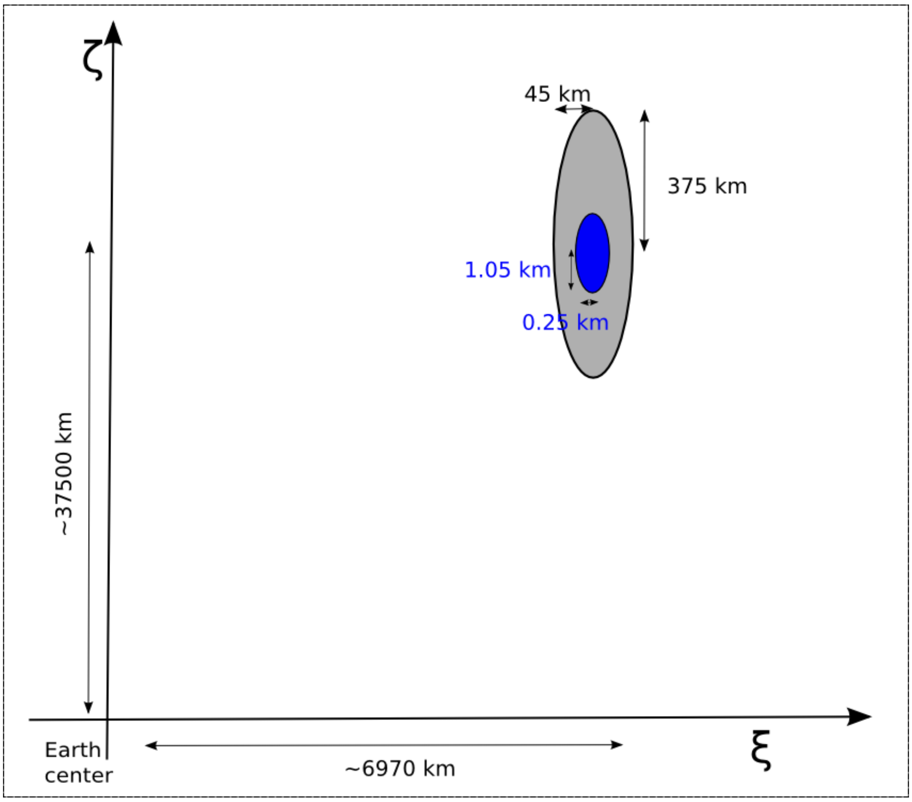

Fig. 4 – Scattering ellipse on the target plane on date of close approach (2029/01/13.907) with (blue) and without (grey) Gaia observations.

The uncertainty ellipse size is strongly reduced and the geocentric position of Apophis, at the date of closest approach, is better determinated, considering Gaia observations.

3. Astrometry for newly discovered objects

By combining, in real-time, ground-based to space-based data, it is possible to drastically improve the short-term ephemerides. Figure 5 shows an illustration of this improvement for the prediction of a newly discovered object by combining the two kinds of data. For our simulation, we considered a hypothetic Apophis that would be discovered by Gaia. When observing a new object, the satellite will send to Earth, as an alert, the coordinates of the unknown object. Thus, it is possible to make a prediction of the position of the hypothetic Apophis on the sky plane by computing a preliminary orbit (using Statistical Ranging method [2]). This prediction was made three days after its discovery by Gaia and the 1σ distribution is large (1 degree) and quite far from the expected value (triangle). If we make a geocentric observation on the 4th day after its discovery and combine it with the late Gaia observations, the (α, δ) uncertainty is reduced by a factor 30 and the ephemeris is well improved (note that here the 10σ distribution is given).

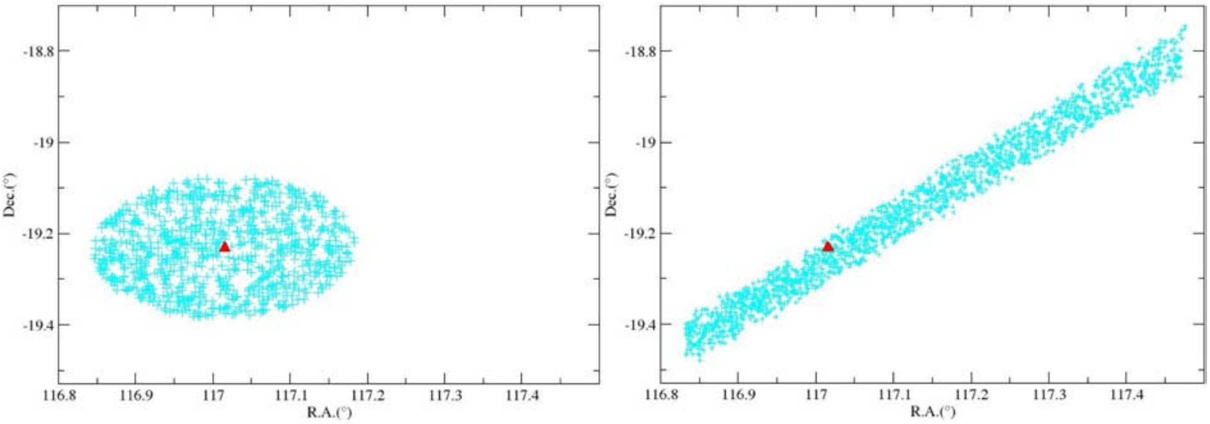

Fig. 5 – Example of geocentric distributions (α, δ) for the predicted positions on the 3th day after discovery with only Gaia observations (left 1σ uncertainty) and on the 4th day with an additional geocentric observation (right 10σ uncertainty). The triangle represents the expected value.

We can wonder now how many alerts are expected. To answer this question, we considered a sample of 20,000 of NEOs which could be either known or unknown objects. Figure 6 shows the statistic of the possible observed objects. This number appears to be around 12%. But if we compare this number to the one of known asteroid that will be observed by Gaia (~29%) we can just conclude that we have more chance to observe known objects than discovering new objects.

Amor	379	1.90 %
Apollo	1313	6.57 %
Atens	205	1.03 %
IEO	24	0.12 %
PHA	583	2.92 %
TOTAL	2614	12.52 %

Fig. 6 – Statistic of objects that would be observed by Gaia among a 20,000 synthetic population.

Conclusion

Even if Gaia will not be a big NEAs discoverer, it will provide unprecedented accuracy for NEAs orbit's improvement. Besides, this study can be continued considering the astrometric reduction due to the stellar catalogue provided by Gaia. As a matter of fact, this catalogue will be more precise and dense and almost free of zonal errors. Thus, classical ground-based astrometry (and concerning hence more objects down to fainter magnitude) will be improved.

References

[1] G. B. Valsecchi, A. Milani, G. F. Gronchi and S. R. Chesley: Resonant Returns to Close Approaches: Analytical Theory, *A&A*, 408:1179-1196, September 2003.

[2] J. Virtanen, K. Muinonen and E. Bowell: Statistical Ranging of Asteroid Orbits, *Icarus*, 154:412-431, December 2001.