Orbit of potentially hazardous asteroids using Gaia and ground-based observations

David Bancelin, Daniel Hestroffer, William Thuillot

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ORBIT OF POTENTIALLY HAZARDOUS ASTEROIDS USING GAIA AND GROUND-BASED OBSERVATIONS

D. Bancelin[1], D. Hestroffer[1] and W. Thuillot[1]

Abstract. Potentially Hazardous Asteroids (PHAs) are Near Earth Asteroids characterized by a Minimum Orbital Intersection Distance (MOID) with Earth less to 0,05 A.U and an absolute magnitude H<22. Those objects have sometimes a so significant close approach with Earth that they can be put on a chaotic orbit. This kind of orbit is very sensitive for exemple to the initial conditions, to the planetary theory used (for instance JPL's model versus IMCCE's model) or even to the numerical integrator used (Lie Series, Bulirsch-Stoer or Radau). New observations (optical, radar, flyby or satellite mission) can improve those orbits and reduce the uncertainties on the Keplerian elements.

Keywords: Gaia mission, b-plane, Potentially Hazardous Asteroids, orbit determination, astrometry

1 Introduction

Gaia is a 5-years astrometric mission scheduled for spring 2013. The main aim is to make a three dimensional map of our Galaxy. There are a lot of science outcomes from this mission: a better understanding of the star formation and the history of the Milky Way; study on stellar astrophysics, on the Galactic structure and on Binaries and Brown dwarfs. The Solar System Science goal is to map thousand of Main Belt Asteroids (MBAs), Near Earth Asteroids (NEAs) (including comets) and also planetary satellites. The principal purpose is 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 NEAs in the region down to the solar elongation (45°) which are harder to detect with current ground-based surveys. The aim of this study is to analyse the impact of Gaia data on the orbit of Potentially Hazarouds Asteroids (PHAs) and also the advantage of combining space-based and ground-based data.

2 Statistical observations of NEAs by Gaia

During the 5-years mission, Gaia will continuously scan the sky with a specific strategy: 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 (influencing the date of observations) and the initial precession angle (influencing the number of observations). These latter will be fixed at the start of the nominal scientific outcome (possibility of performing tests of fundamental physics) together with operational requirements (downlink to Earth windows). Hense several sets of observation will be provided according to the initial precession angle. Figure 1 shows the number of NEAs that would be observed by Gaia. This number represents about 30% of the NEAs population.

3 Astrometry for known PHAs

Asteroid Apophis is a PHA discovered in 2004 and was reveled to be a threatening asteroid for the Earth, since, because of a deep close encounter (~ 38000km) with Earth in 2029, there is some risks of collision mainly in 2036. In order to better prepare future space missions towards this asteroid, it is important to well quantity the uncertainty in 2029. To better represent the state of an asteroid approaching the Earth, we better use the

[1] Institut de Mécanique Céleste et de Calcul de Éphémérides, 77 Avenue Denfert-Rochereau 75014 Paris, France

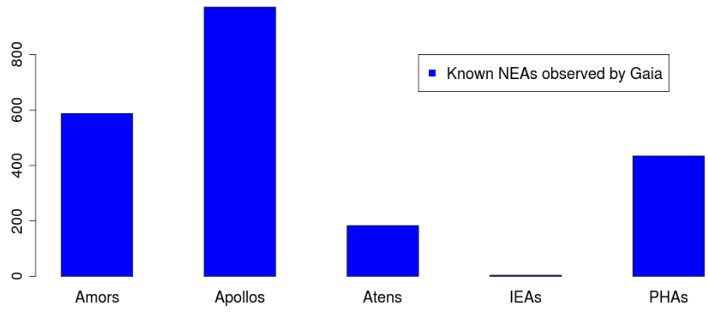

Fig. 1. Number of known NEAs possibly observed by Gaia

b-plane or target plane (Valsecchi et al. 2003) . It passes through the Earth's center and is perpendicular to the geocentric velocity of the asteroid. In this plane, the asteroid will have two geocentric coordinates (ξ,ζ). Thus the projection of the 6-dimension region uncertainty of the Keplerian elements in the 2029-b-plane is a 3σ ellipse uncertainty. Fig. 2 represents the 3σ ellipse in (ξ,ζ) in the 2029-b-plane with (blue) and without (grey) additional Gaia data. For completeness, we represented primary($\star$) and secondary keyholes leading at collision at the ascending (■) and descending node (■). Keyholes are regions in the b-plane of 2029 where the asteroid has to pass in order to collide the Earth at some dates indicated in Fig. 2.

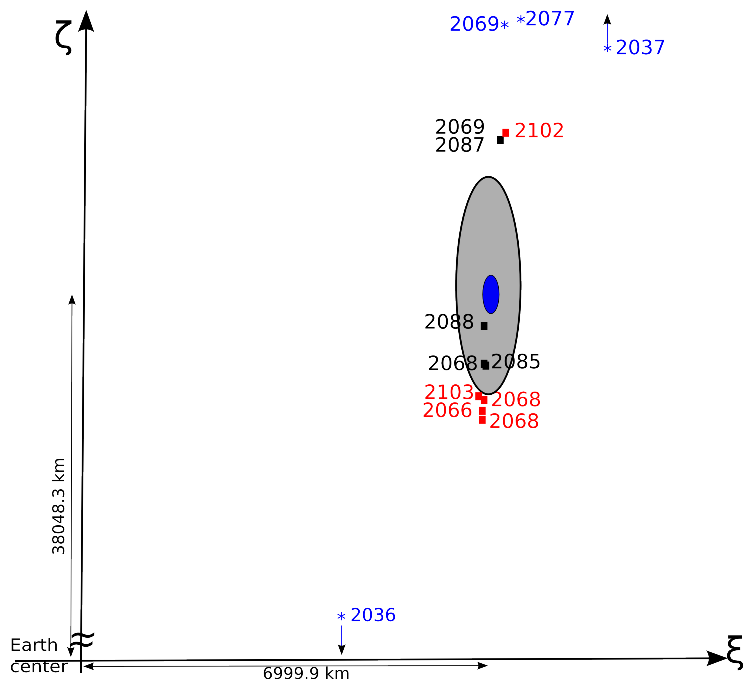

Fig. 2. 3σ ellipse uncertainty in the 2029-b-plane centered in the (ξ,ζ) nominal value: In blue: using Gaia data; in grey: without Gaia data The positions of the center of keyholes are also represented.

As shown in the Tab. 1, Gaia data enable to reach the kilometer knowledge level on the accuracy of the orbit of Apophis in 2029.

4 Astrometry for newly discovered PHAs

During the mission, we do expect Gaia to observe some new objects and among them new PHAs. But Gaia is not a follow-up mission and as a consequence, the newly discovered objects can rapidly be lost if no recovery process

Table 1. Impact of Gaia data on the size of the 3σ ellipse uncertainty in the 2029-b-plane.

b-plane uncertainty	Ground-based data only	Groud-based and Gaia data
σ_ξ (km)	10.5	0.3
σ_ζ (km)	87	1.4

of those potential alerts is done from Earth. We would like first to quantify the number of alerts expected. In a first approach, using a 20000-synthetic population of NEAs (Bottke et al. 2002) and comparing with Fig.1, we see that only a small number of alerts is expected: around one alert every four days. The statistical details are represented in Fig.3. Because of the scanning law, Gaia will provide only two (α,δ) observations (before being re-observed) and separated by Δt~1.5 hours. When observing a new object, Gaia will send, within 24 h, the coordinates to Earth, where a preliminary short arc orbit can be computed, using Statistical Ranging method (Virtanen et al. 2001)

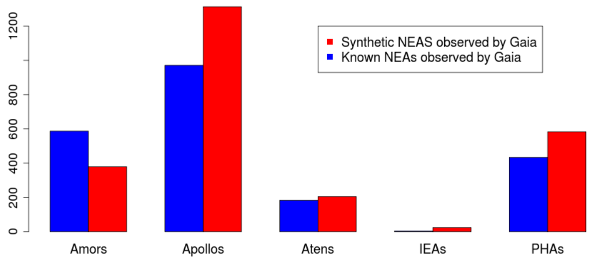

Fig. 3. Number of known and synthetic NEAs that would be observed by Gaia during the 5-years mission.

This yields to an (α,δ) prediction in the sky plane ($\circ$). As the (α,δ) distribution is large, we can extract its maximum likelihood (ML) and center a typical field of view (24'x24') on this ML ($\bullet$) in order to know where to look in the sky and how long the object can still be recovered. This test is done with an hypothetical asteroid (1620) Geographos that would be discovered by Gaia. In Fig. 4, when comparing with the expected position of Geographos ($\blacktriangledown$), we can see that up to 7 days, the asteroid may be lost with this size of field of view.
When recovered, this asteroid will be followed at least one night (and preferably more) in order to have an orbit improvement. Fig. 5 shows the advantage of combining, in real-time, ground-based (with 0.5 arcsec accuracy) and space-based data (5 mas accuracy). One can see that the (α,δ) distribution is drastically reduced when adding additional ground-based observations ($\circ$).

5 Conclusions

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 object down to fainter magnitude) will be improved.

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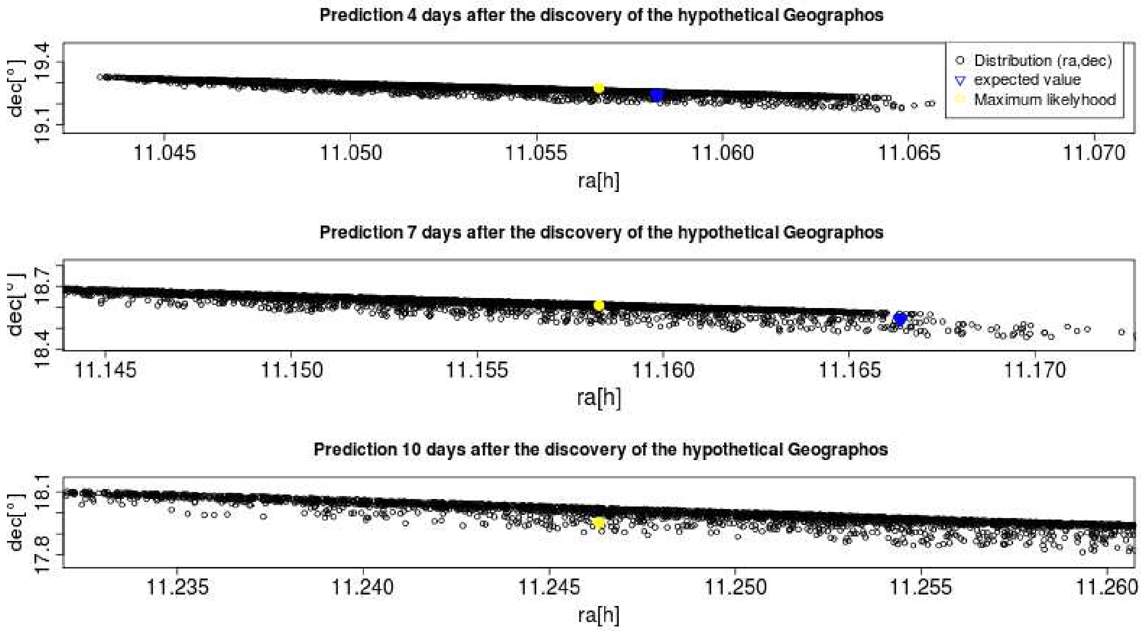

Fig. 4. Prediction on the sky plane of the hypothetical Geographos, until 10 days after its discovery by Gaia.

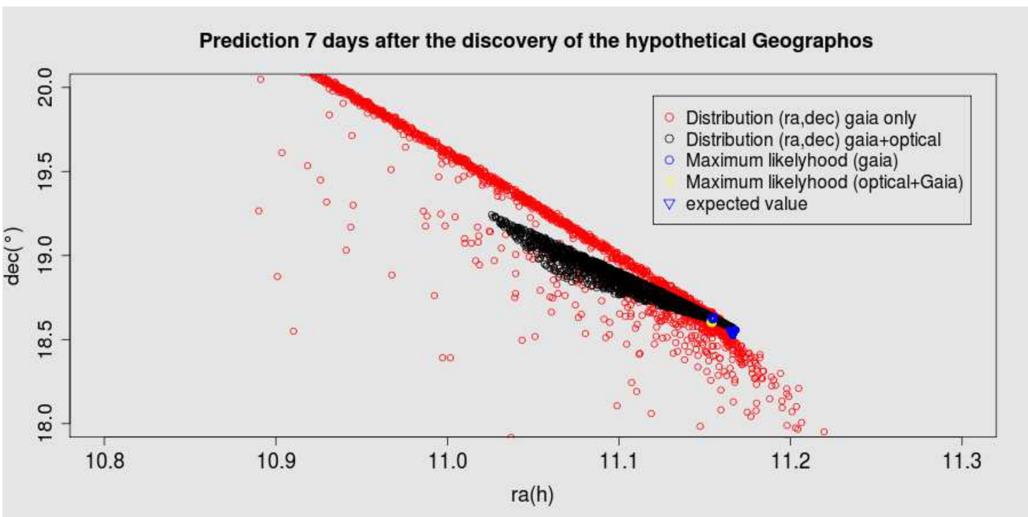

Fig. 5. Distribution (α,δ) combining ground and space-based data (∘), 7 days after the hypothetical discovery of asteroid Geographos.