Planetary and Space Science 73 (2012) 21–29

Contents lists available at SciVerse ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Dynamics of asteroids and near-Earth objects from Gaia astrometry

D. Bancelin*, D. Hestroffer, W. Thuillot

IMCCE, Paris Observatory, CNRS, UPMC 77, Avenue Denfert-Rochereau, 75014 Paris, France

ARTICLE INFO

Article history:
Received 25 July 2011
Received in revised form
21 January 2012
Accepted 31 January 2012
Available online 3 March 2012

Keywords:
Gaia
Asteroids
Near-Earth objects
Astrometry
Dynamics

ABSTRACT

Gaia is an astrometric mission that will be launched in spring 2013. There are many scientific outcomes from this mission and as far as our Solar System is concerned, the satellite will be able to map thousands of main belt asteroids (MBAs) and near-Earth objects (NEOs) down to magnitude ≤ 20. The high precision astrometry (0.3–5 mas of accuracy) will allow orbital improvement, mass determination, and a better accuracy in the prediction and ephemerides of potentially hazardous asteroids (PHAs).

We give in this paper some simulation tests to analyse the impact of Gaia data on known asteroids's orbit, and their value for the analysis of NEOs through the example of asteroid (99942) Apophis. We then present the need for a follow-up network for newly discovered asteroids by Gaia, insisting on the synergy of ground and space data for the orbital improvement.

1. Introduction

Science of asteroids and comets, from near-Earth objects (NEOs) to trans-Neptunian objects (TNOs), and small bodies of the Solar System at large is fundamental to understand the formation and evolution of the Solar System starting from the proto-Sun and the planetary embryos. Having little geological evolution and being atmosphere free, their pristine character makes them good tracers of the constitution of the primordial Solar System. Being numerous and spread over a wide range of heliocentric distances they act also as good constraints for planetary formation scenario and the Solar System dynamical evolution at large. Last, knowledge of the process within our Solar System is useful if not mandatory to understand formations and evolution of other planetary system than our own Solar System.

While some objects can be considered as small world on their own, such as targets of space probes, the vast majority will be considered through general groups and classes. Some asteroids are planet crossers or evolving in the vicinity of Earth's orbit. Among the latter, a small fraction of potentially hazardous asteroids (PHAs) can show particular threat of collision with the Earth while others have no incidence at all. Near-Earth objects are also of interest to understand the physics process as non-gravitational forces (in particular the Yarkovsky effect) and fundamental physics with local tests of General Relativity.

2. Gaia detection and observations of asteroids

Gaia will observe a large number of asteroids, however with some specificity and limits. The limiting magnitude is modest when compared to present and future ground-based surveys aimed at making a census of small bodies.[1] On another hand Gaia will enable observations with a single instrument of the entire celestial sphere and also at low solar elongation, making a difference between space-based observations – such as AsteroidFinder (Mottola et al., 2010) and NEOSSat (Hildebrand et al., 2004) – and typical ground-based observations and surveys. As seen in Mignard et al. (2007), the Gaia satellite will have a peculiar scanning law enabling a full coverage of the entire sky over 6 months, whose coverage is repeated over the 5 years mission providing stellar parallaxes and proper motions. Besides, only objects detected and confirmed in the front CCDs forming the sky mapper will be subsequently observed through the main astrometric field of view. This ensures that no cosmic rays are treated as scientific sources and enables to download to ground only small windows around a scientific source and not all the pixels of the large CCD mosaic. Nevertheless the detection algorithm is so that extended sources, when too wide, are not detected by the on-board algorithm. As shown in Fig. 1, there is no clear detection limit, solar system objects in the size range 0.7–0.9 arcsec will not be systematically detected, while objects larger than 0.9 arcsec will not be observed.

The sequence of observation of any object hence depends on this scanning law, the on-board detection, and the limiting magnitude. Starting with the astorb database (Bowell et al., 1994) of orbital

* Corresponding author. Tel.: +33 1 4051 2271.
E-mail address: bancelin@imcce.fr (D. Bancelin).

[1] The object if reclaimed to the NASA by the US congress is to catalogue 90% of NEOs larger than 140 m.

0032-0633/$ - see front matter
doi:10.1016/j.pss.2012.01.013

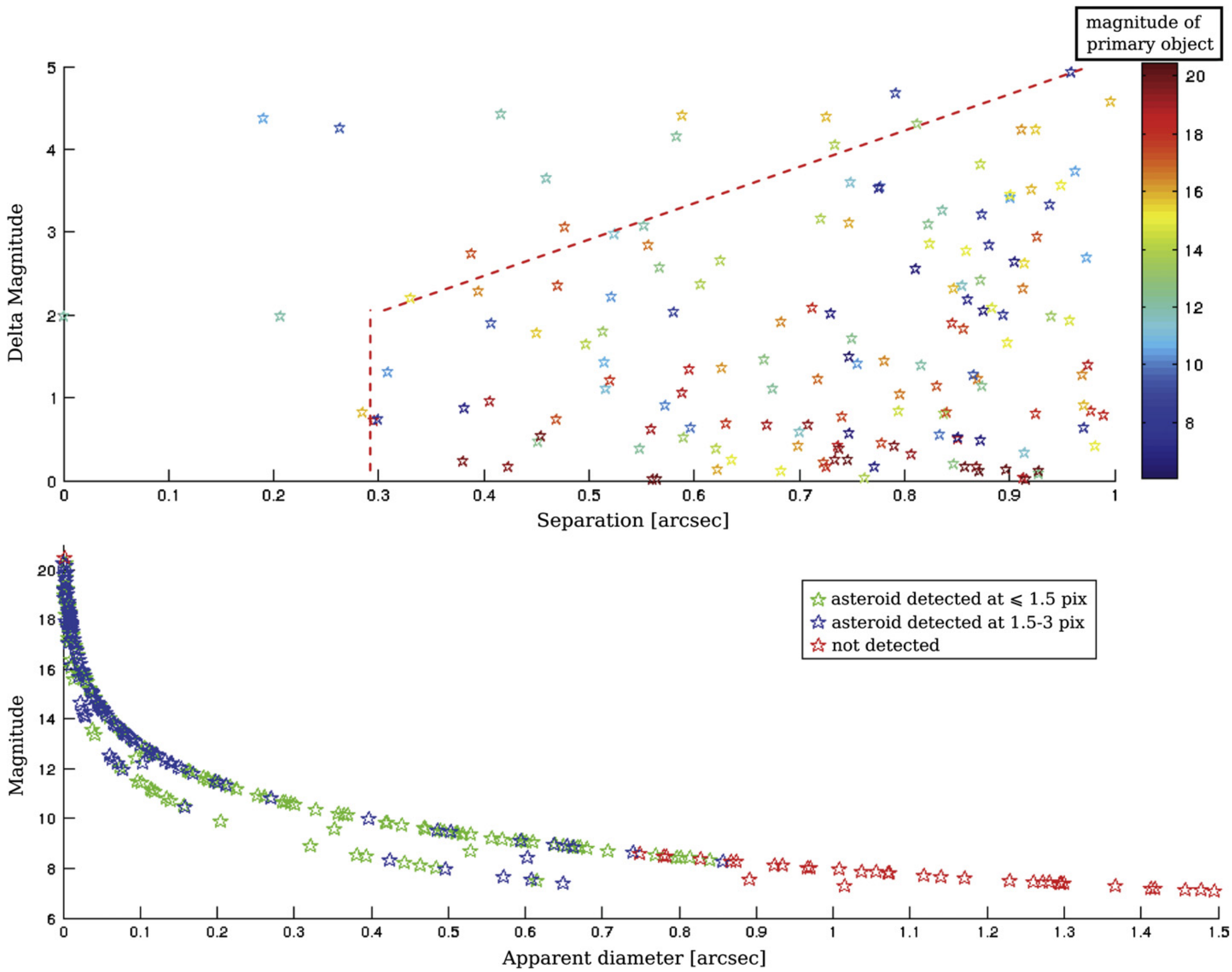

Fig. 1. Detection limits, in the sky mapper, for binary objects (top) and large asteroids (bottom). Top panel: the detection is given as a function of the separation of the pair (irrespective of its position angle) and the magnitude difference between the secondary and the primary; the colour code indicates the magnitude of the primary. The detection in the binned sky mapper CCDs stops at a separation of less than approximately 0.3 arcsec (corresponding to ≈ 2.5 binned pixel). Bottom panel: the detection is given as function of the apparent diameter of the object. The corresponding apparent magnitude is derived for a given albedo and three different heliocentric distances. Objects larger than 0.7 arcsec will not be systematically detected; when detected, their predicted position can show an offset from the true one by several pixels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

elements, one can compute dates of rendezvous of asteroids crossing the Gaia FOV with the CU4 Solar System Simulator. Simulations in the focal plane of images making use of the GIBIS tool (Luri and Babusiaux, 2011) will enable to set the detection of large asteroids and planetary satellites. Making use of the GIBIS tool, Fig. 1 shows some detection limits for binary objects and large asteroids. These are, in the case of binary systems, the detection in the SM CCD that are binned (2×2) and hence of lower resolution. In such case each component will be treated individually with an associated patch and windowing for observation in the subsequent CCDs. While not detected at the SM level, binary systems can still be observed in the AF field, with higher, but basically one dimensional patches resolution (personal communication). Concerning large asteroids, it appears that even Ceres and some planetary satellites will be basically detected and observed.

Statistics on observations of asteroids have been reported in Mignard et al. (2007) and Hestroffer et al. (2010a). On the average there are 60 transits (or observations) per object over the mission duration. Fast moving objects will not be observed correctly through the whole astrometric field of view because the windowing scheme is adapted to the relative motion of a star (personal communication). Objects like fast NEOs will however be observed in good conditions in the first and middle CCDs (which has a larger associated window).

3. Dynamic of asteroids

Gaia will provide astrometry of asteroids and comets with unprecedented accuracy. Being a space-mission designed optimally for doing astrometry it has some obvious advantages. Gaia will in particular enable both local astrometry from relative positions and refined calibration, and global astrometry with absolute positions. Compared to classical ground-based observations, there are—among other—no limitation between northern and southern hemisphere, no atmospheric refraction or turbulent effects, reduced zonal errors, and positions directly in the Gaia sphere of reference and the optical ICRF. Such astrometry will yield improved orbital elements for almost all objects observed (see Fig. 2), together with detection of small effects and determination of dynamical parameters. In particular, one will be able to derive masses of asteroids (from close encounter