SF2A 2014
J. Ballet, F. Bournaud, F. Martins, R. Monier and C. Reylé (eds)

GAIA-FUN-SSO: A NETWORK FOR GROUND-BASED FOLLOW-UP OBSERVATIONS OF SOLAR SYSTEM OBJECTS

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Abstract. Gaia-FUN-SSO (shortly described at https://www.imcce.fr/gaia-fun-sso/) is a ground-based network of observatories set up in the framework of the Gaia consortium (DPAC-CU4) for the follow-up of critical Solar System objects to be discovered from space by the Gaia satellite. Its goal is to retrieve from the ground a newly detected object and to complement the astrometry measurements carried out by Gaia to determine its heliocentric orbit. Data from both Gaia and the ground-based network will be sent to the Minor Planet Center, used to determine the orbit and thus to update the database of minor planet orbits, which is subsequently used by Gaia for the identification of moving objects. We are expecting the detection of many asteroids, mainly from the main belt, and also new near-Earth objects (NEO) at low solar elongation. Owing to the specific conditions of Gaia observations, we even expect the detection of objects whose orbit is fully contained within Earth's orbit (called inner-Earth or Atira asteroids). Several training campaigns have already been organized with the network and it is now able to enter in an operating mode when alerts will be triggered. We describe here the expected number of discoveries, the network, its activity, and the data processing of the central node of the network set in place for the operating mode.

Keywords: Gaia, Solar System Objects, asteroids, follow-up

1 Introduction

Launched in December 2013, the Gaia mission was commissioned in the first half of 2014 and entered in operations over the summer 2014. Owing to the observational mode, i.e. a survey based on a specific scanning law, transient events will be detected by Gaia but will not be monitored. Among these events, detection of supernovae, variable astrophysical objects, and so on are expected, but there will be detection of Solar System Objects (SSO) as well. All these detections require a rapid ground based follow-up. Otherwise the different phases of the photometric events (e.g., supernovae lightcurves) will not be observed and thus analysed. Furthermore the orbit of the moving objects may not be determined and these objects themselves may subsequently become intractable. To characterize these events, the Gaia Data Processing and Analysis Consortium (DPAC) has implemented the triggering of alerts to activate different follow-up networks which have been set up. Our team is particularly concerned with the SSO follow-up within the frame of the Coordination Unit 4 (CU4 - object processing) of the Gaia DPAC consortium. This article describes the deployed workchain for organizing such ground-based observations upon receiving an alert. This task is within the scope of the SSO short term data processing through a specific task (DU459 according to the Gaia designation) entitled "Ground-based follow-up observations". It combines two main objectives: ensuring quick astrometric observations on alert for validation of SSO discovery, and ensuring an astrometric follow-up for determination and improvement of the orbital parameters. For these goals two important actions have been performed: the set-up of a network of observing stations and the development of a data processing chain to feed the network with ephemerides of the critical objects.

2 Expected number of discoveries

Since the discovery of (1) Ceres in 1801, minor planets have been constantly discovered. The number of discoveries has strongly increased in the last 20 years, with new objects discovered daily. The current census

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of minor planets, from near-Earth asteroids to Kuiper Belt objects, is of 656,000 (October 2014). How many objects can we expect to be discovered by Gaia, with a limiting magnitude of 19.5? To answer this question we proceed as follows.

The evolution of the size-frequency distributions (based on their absolute magnitude H), for each population of small bodies – near-Earth asteroids (NEA), main-belt asteroids (MBA), Jupiter Trojans, Centaurs, and Kuiper Belt objects (KBO) –, are dominated by collisions, and follow power law (Dohnanyi 1969), as seen in Fig. 1. Therefore a fit to each of a power law can be used to extrapolate the number of objects observable within the limiting apparent magnitude of Gaia, at $V \approx 19.5$. The populations' 25%, 50%, and 75% quartiles semi-major axis and eccentricity, can be used to convert this limit into an absolute magnitude assuming an observing geometry at a solar elongation of 90^o. The phase function is computed using Bowell H-G system. The resulting limiting magnitudes are plotted as vertical dashed lines in Fig. 1.

This simple computation, based on current census of asteroids, shows that the number of main-belt asteroids yet to be discovered within Gaia limiting apparent magnitude is of the order of 10^4, up to 3.10^4. The number of NEAs is much lower, only of the order of a few 10^2. Here, only the number of yet unknown asteroids is estimated and should be understood as an upper limit on the possible number of discoveries by Gaia.The following caveats need to be remembered. Slight changes in the power law, and/or different observing geometries (Gaia will observe from 45^o to 135^o solar elongation) yield slightly different estimates. Gaia may not observe all these objects, or other surveys may discover some of them before Gaia.

Therefore, under the assumption that 500 NEAs and 25,000 MBAs will be detected by Gaia, the expected number of alerts is of the order of a hundred per week, 2% of which will concern NEAs.

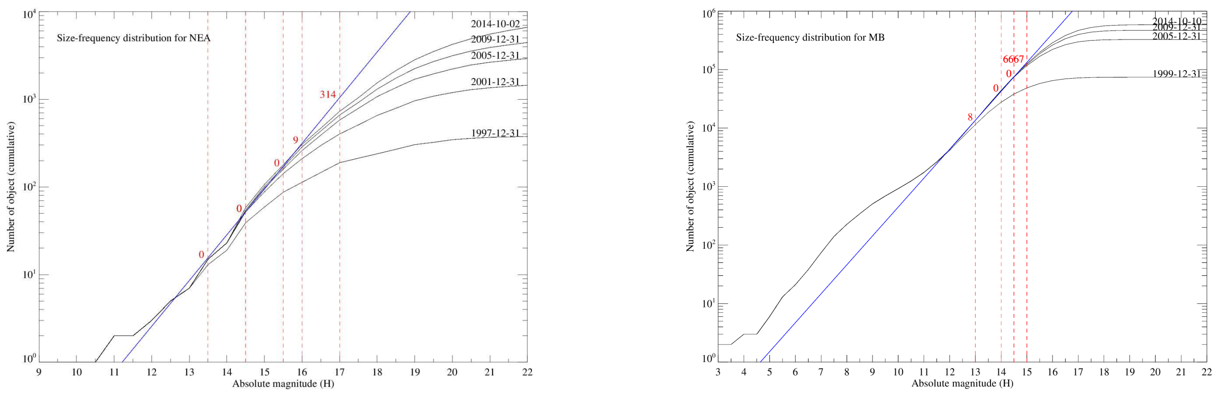

Fig. 1. Size-frequency distribution (in black) of Near-Earth Asteroids (NEA) and Main Belt Asteroids (MBA) , with fitted power law distribution (in blue).

3 The data processing and distribution chain

During the short term data processing, detected moving objects are considered to belong to the Solar system. Their measured positions are compared to the computed model ephemerides which use initial conditions provided by the ASTORB database (Muinonen & Bowell 1993) of orbital elements from the Lowell observatory, which is periodically updated to include all recent observations. This allows, at least in principle, the discrimination between known and unknown objects. Once a detection of a possibly new object is inferred, a series of tasks are performed, accurate astrometry measurement, the possible links with previously observed positions, and finally a simulation which provides all the orbits which are compatible with the observations using a MCMC (Monte Carlo Markov Chain) method (Muinonen et al. 2012), i.e. a list of all the possible orbital elements.

The IMCCE-Paris Observatory laboratory is the central node of a ground-based network, the Gaia-FUN-SSO network (Gaia Follow-Up Network for Solar System Objects). It will receive the lists of orbital elements, which are the essence of the alert for newly detected Solar System Objects, to be processed locally for dissemination to the observer community.

The role of this central node is to propagate (i.e., to compute the ephemeris of) the aforementioned preliminary orbits of the alert, and to identify regions of interest on the sky where observers are invited to search for the new object. For this, knowledge of topocentric parameters and instrumental characteristics (e.g., field of view, limiting magnitude) of each station allows to disseminate the alert in an efficient way: viz. only to observatories capable of performing the observation. A pipeline has been developed to carry out this task automatically.

As soon as an observer has recovered the object, he is invited to measure its astrometric position and to send the results to both the central node and the Minor Planet Center (MPC, Marsden et al. 1994) which centralizes all observations of minor planets. The MPC will take these observations and compare them with previous observations of poorly known asteroids and/or recent discoveries to test for possible links. The MPC will also compute the orbital elements of the objects and will integrate it into the following release (daily) of the public database. This will help subsequent identification of the object if observed by Gaia again because the update of the orbital database used in Gaia pipeline (ASTORB) closes the loop including the MPC and Lowell Observatory (see Fig. 2).

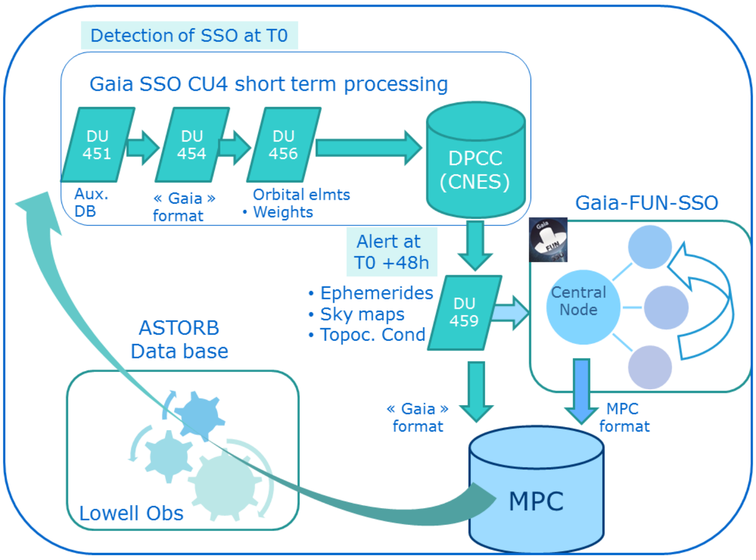

Fig. 2. Workchain of the ground-based network

4 The Gaia-FUN-SSO network

Since 2010, numerous observatories, both professional and amateur, have joined the Gaia-FUN-SSO network. A wiki has been set up at the address `https://www.imcce.fr/gaia-fun-sso/` to provide basic information and also to organize training observations. The network currently includes 54 observing stations, which represents 75 operating telescopes of different sizes. We took the opportunity of close approaches of near-Earth Objects with the Earth to organize nine training campaigns (2011 Nov-Dec. for 2005 YU55; 2012 Feb.-March for 1996 FG3; 2012 Feb.-March and 2012 Dec.-2013 Apr. for 99 942 Apophis; 2013 Feb.-March for 2012 DA14; 2013 Aug. for 2002 GT June; 2013 Oct.2014 Jan. for 2013 TV135; 2014 Apr. for 2007 HB15; 2014 June for 2014 HQ124) . These observations were similar (apparent magnitude, urge of observation, solar elongation) to those the network will have to conduct on alert.

In addition to the training campaigns, we also organized workshops in order to gather observers, to exchange information about the requirements and to be informed about the local instruments and activities. These workshops have been held in Paris Observatory in 2010 and 2012. A third one is organized on 24-26 November 2014 (see `http://www.imcce.fr/hosted_sites/gaiafun2014/`).

Fig. 3. Localization of the different stations of the Gaia-FUN-SSO network.

5 Conclusion

During its 5 year mission, Gaia will detect new Solar System Objects, up to a few hundred near-Earth asteroids and several thousands of asteroids in the main belt. Owing to the scanning mode of observation, there will be no possibility for Gaia to monitor these objects after detection, and their orbits are unlikely to be determined uniquely enough so as to not lose their track. To avoid this situation, a ground-based network, called the Gaia-FUN-SSO, has been set up. The Gaia mission will rely on the observatories of this network to observe, on alert and on a volonteering basis, the new objects and thus provide astrometric measurements to the Minor Planet Center. By this mean, the auxiliary database of orbital elements which allows Gaia to identify known objects, will be updated.

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