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Current status and development of the SSO FUN alerts

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Introduction

The astrometry mission Gaia of the European Space Agency (ESA) will scan the entire sky several times over 5 years, down to a visual apparent magnitude of 20. Apart for its primary targets, the stars, that will be mapped during the course of the mission, Gaia is expected to observe more than 300,000 asteroids (Mignard et al., 2007). Although our census of asteroids is about complete at a such magnitude limit, the location of Gaia at L2 may allow the detection of yet-unknown near-Earth asteroids (NEAs). The pre-defined and smooth scanning law of Gaia, however, is not meant for pointed or follow-up observations. A ground-based network of observers has therefore been set up, the Follow-Up Network for the Solar System Objects (FUN SSO), centered around a central node (the DU459 of the Gaia Data Processing and Analysis Consortium, the DPAC). The aim of this network is to quickly observe from the ground the NEAs newly discovered by Gaia to secure an accurate orbit.

Following the description of the overall organization and status of the network presented by Thuillot et al. (2012), we present here the details of its central node host at the Institute for Celestial Mechanics and Ephemeris Computation (IMCCE) in Paris, France. The role of the node will be, upon detection by Gaia of a target judged as interesting for or requiring a follow-up, suitable for observations by the network, to release calls for observations, and to provide support to the observers. We describe in particular the current implementation and development of the system that will be used by the node and of the various solutions envisaged to interact with the network of observers.

1. Organization of the central node of the network

Each observation of a non-fixed source by Gaia will be handled by the forth Coordination Unit (CU4) of the DPAC. Any source entering the pipeline will be first checked against the list of known Solar System Objects at that time. The Gaia Follow-up Network for the Solar System Objects (FUN SSO) will deal with all the sources not yet cataloged at the time of their observations. For each of these, we will

1. Receive a bundle of possible orbits as determined by the DU459,
2. Predict the future positions of the targets as seen from Earth,
3. Select appropriate targets for follow-up according to their observability,
4. Release a call for observations, *i.e.*, the so-called **alert**,
5. Provide support to and manage the network of observers,
6. Update the alert continuously with incoming observations from the network,
7. Withdraw the alert upon completion.

The proper completion of these different points, hence the success of the FUN SSO, present several challenges both in delay of execution and in the influx rate of new detections (we expect a few alerts per week). Time constraints add to the complexity of observing geometry the observers will face: the FUN SSO alerts will concern faint ($V > 18-19$) and fast-moving (rate $> 50-100''/h$) objects, most likely at a low solar elongation ($\psi < 70^\circ$). Moreover, the *a priori* unknown parallax between Gaia and the Earth for a given target may result in up to a degree of uncertainty on the apparent position.

Regarding the timing, the central node will receive the bundle of orbits 24 h to 48 h after the observation by Gaia at the earliest. Such a delay is imposed by the time line of the data flow and telemetry scheme: for each *operational day*, Gaia will observe without communicating with the Earth during 16 h, storing the observations on-board into a *backlog*. These 16 h will then be followed by 8 h during which Gaia will both observe and download all the observations performed during the 16+8 h (*i.e.*, both backlog and real-time). Upon reception of the data by the Mission Operation Center and transfer to ESA, the initial data treatment will take place (*e.g.*, decompression, decoding, PSF-fitting). Identification of an unknown moving target can only be done after these first steps are performed. Hence, depending if the targets was observed during the backlog or real-time part of the operational day, the delay between its observation by Gaia and its acknowledgment to the central node may last between 24 h and 48 h.

The central node must therefore avoid any further delay: with a typical non-sidereal motion of $\approx 100''/h$, NEAs move by about a degree on the plane of the sky each day. Additionally, because of the poor preliminary knowledge on the orbit and parallax, the predictions for the position and apparent magnitude of each newly discovered asteroid may be valid for only a very short period of time, typically a few days. A short reactivity time for both the node and the observers will therefore be required to quickly trigger the first observations and subsequently updates the alerts.

2. Current development at IMCCE

2.1 Subjacent structure

Owing to the timing constraints described above, most of the processes within the node must be automatized. Nevertheless, a regular human supervision for reliability and sanity checks is still required. The observations, linked with the observers of the network, will be used to compute the orbital elements of each target, which will be used in turn to predict future positions (Fig. 1). Based on a series of threshold on the viability of the prediction (*i.e.*, is such target observable by the network?), an alert containing all the necessary information for completion is released. The orbital elements, predictions, and alert will be updated upon follow-up observations by network (*i.e.*, steps 2 to 6 in Sect. 1.) until the orbit of the target is secured.

Observing campaigns on already known targets have already been issued by the node. We will continue these campaigns before the launch to test the data flow structure and improve our dialog with the network from the feedback provided by the observers on our services. Also, in the earliest stages of the mission, the thresholds will likely require adjustments so a workable compromise between too few and too many alerts (including possible false-positive) is reached.

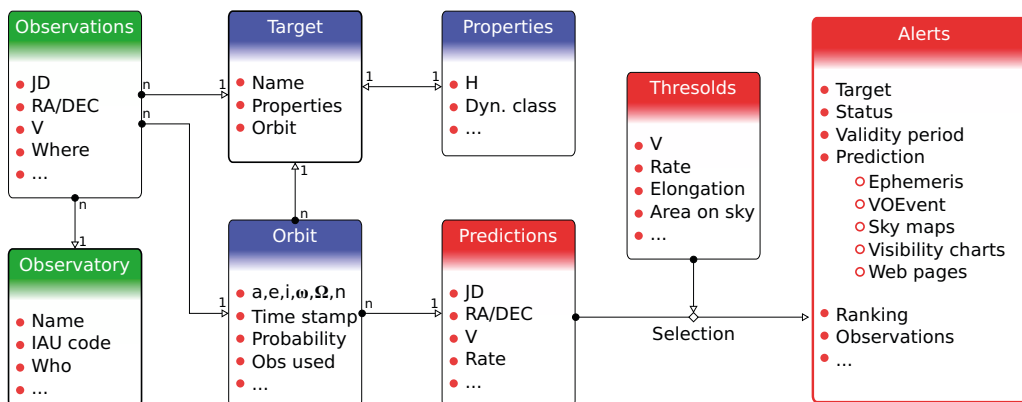


Figure 1: Overview of the work flow and data organization within the central node.

2.2 Means of interaction with the network

During the course of the Gaia mission, the network will have to deal with many concurrent alerts linked to different targets, with different levels of priority, feasibility, and urgency. The central node will have to manage the observing efforts to maximize the number of target recovery and orbit determinations. We have selected a series of tools to help the observers in choosing the alert(s) to follow at a given epoch. The base of the central node outputs will be machine-readable packages (VOEvent) containing all the required information to follow the alert. These packages are planned to be available via news feed (e.g., RSS flux) to ensure direct dialog with robotic telescopes without delay. A suite of human-readable displays (sky map, observability charts, interactive web pages) are also under development to help decision-making at the telescope.

VOEvent: VOEvent are XML files following the Virtual Observatory standards describing all the information needed to perform an astronomical observation (Fig. 2.A). The information is structured using simple markups, such as *Who* released the package, *WhereWhen* was it released, *What* should be observed (e.g., coordinates), and so on. VOEvent packages are routinely used to trigger observations of gamma-ray bursts or micro-lensing events, and most robotic telescope systems can interpret them.

Sky map: We will predict the apparent position of the targets from the preliminary orbits determined first by the DU456, then upgraded internally by the central node. These predictions will define the area of the sky to be covered to search for the target and will be available through the Aladin Sky Atlas¹. Displaying the evolution of these area with time (Fig. 2.B) will also provide an efficient criterion to attribute priority to alerts and define the period of time during which they are valid.

Visibility charts: For each object, indications on when and where to search will provided by the VO-Event and sky maps described above. We will also provide an overview of all the alerts observable from a given site to help observers optimizing their observing time during the nights. Over the last year, IMCCE has developed an efficient tool to generate visibility charts from a target list called ViSiON² (Fig. 2.C). Once the location and specific constraints (e.g., minimum elevation, limiting magnitude) of each observatory filled in the system by the observers, we can generate on-the-fly dedicated visibility charts for current alerts. ViSiON will greatly help observers as only the targets observable from their location and with their instrumentation will appear in the charts.

Web pages: We will also generate web pages for each alert, containing all the relevant information on the target and listing the observations performed by the network. A portal page is also foreseen. It will present a summary of all the alerts: status, validity period, observations, etc. We also study the possibility of displaying these quantities under a time line format (Fig. 2.D) for convenience. These pages will be accessible to the observers of the network. Several pages will also have to be created to upload observations and telescope characteristics to populate the data base (Sect. 2.1) and automatically generate ephemeris, visibility charts, etc. for the given site.

Conclusion

With the launch of Gaia in less than a year ahead, the central node is currently developing the tools required to interact with the network of observers with minimal delays and in a sustainable way given the expected inflow of alerts. During the course of 2012 up to Gaia start of operations, we will test these tools with the help of the network. Once the first real alerts from Gaia will be issued, in early 2014, a period of adaptation and definition of the different thresholds to trigger alerts will be undertaken.

¹Aladin Sky Atlas: <http://aladin.u-strasbg.fr/>

²ViSiON: <http://vo.imcce.fr/webservices/miriade/?vision>

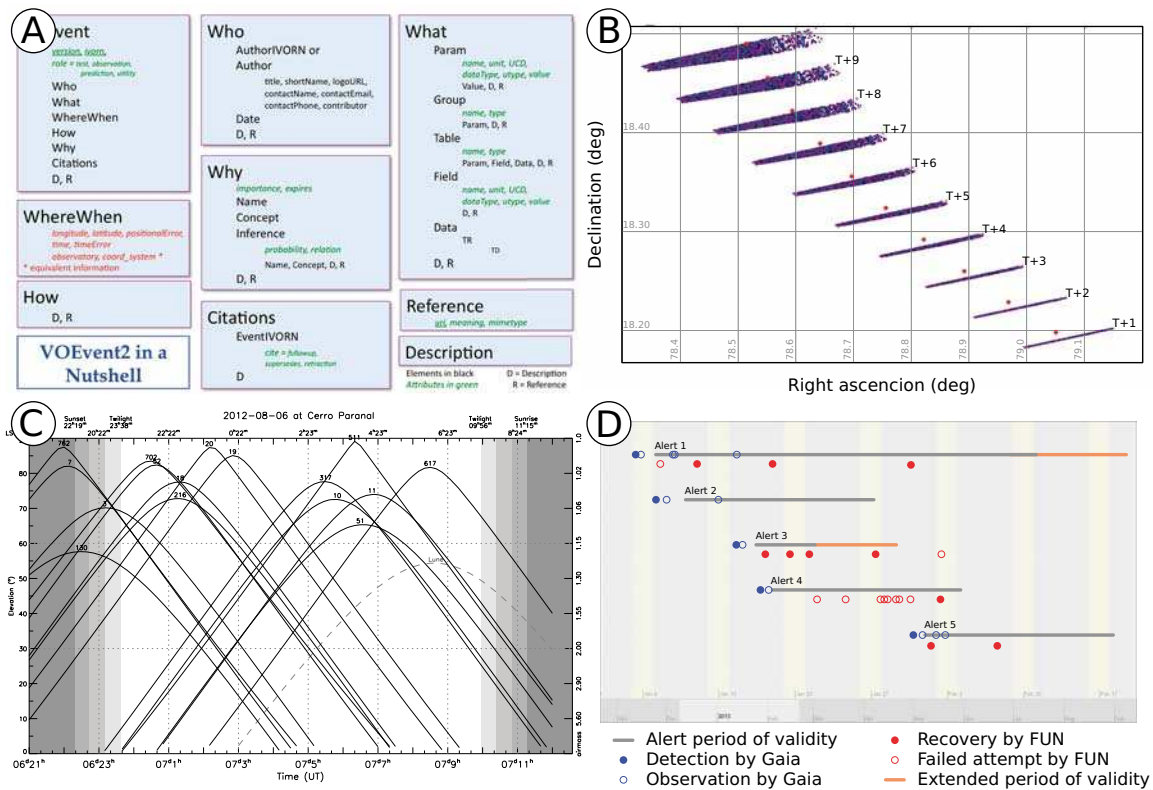


Figure 2: **A:** Schema diagram of the VOEvent table (credits IOVA). The detailed description can be found there <http://www.ivoa.net/Documents/VOEvent/>. **B:** Example of a possible representation of the area of the sky to cover for a simulated alert, displayed in Aladin. The series of red bullets represent the real trajectory of the NEA at 1, 2, ..., 10 days after detection (T). The bluish areas represent the predicted positions from the bundle of preliminary orbits. **C:** Example of a visibility chart for an arbitrary list of targets produced by ViSiON. All-sky views with trajectories are also generated by the system. ViSiON has a built-in source-selection algorithm and each curve corresponds to a target which is observable from the requested location under a set of specified constraints (e.g., apparent magnitude, solar and lunar elongation). **D:** Example of the typical usage of a time line representation of concurrent alerts. All the alerts and corresponding observations are summarized and this helps in identifying which alert need new observations.

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