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Daily Processing of Solar System Object Observations by Gaia

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Introduction

By definition, an alert system has to be activated as fast as possible in response to a selected event. For this reason, a pipeline performing fast processing of Gaia observations of Solar System objects (SSO) is being implemented. Its output will concern moving objects that are not matched against an up-to-date catalogue of known asteroids. These "new" Gaia asteroids will have an approximate short-arc orbit determined which can be used to disseminate alerts toward ground-based observers. Without a preliminary orbit (or a bundle of possible orbits) ground-based recovery would be extremely hard, especially for NEOs passing close to Earth, due to the fact that Gaia will orbit around the Lagrangian point L2, thus resulting in a large parallax (see Bancelin et al., this volume).

1. Main Gaia data properties and the processing of Solar System objects

Solar System objects will be processed by a specific pipeline capable of dealing with their peculiar properties, especially their high apparent speeds. Additionally, the pipeline will produce output quantities that are specific to this category of celestial objects. All the dedicated software is implemented in an architecture provided by the related Data Processing Centre (the CNES in Toulouse, France in this case), and written by the planetology community of the DPAC (Data Processing and Analysis Consortium).

Two separate processing lines exist, in fact. The first one, called "daily processing", will operate on the shortest possible time scale, i.e. as soon as new data will become available. In practice, data sets are made available daily, so this pipeline will run once per day. It will essentially operate on the most recent observations in a ~48 hours window, meaning that a typical object will have up to 2-3 detections in the focal plane.

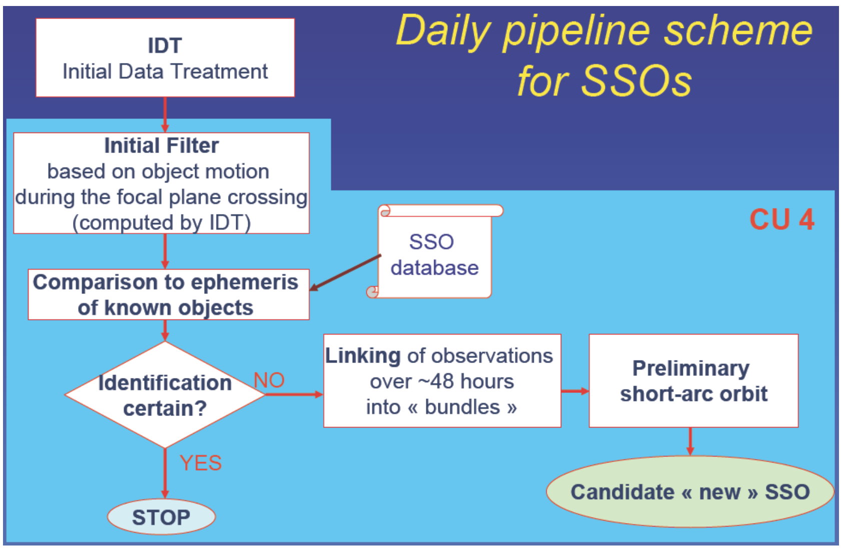

Fig. 1 – Schematic drawing of the main functions accomplished by the Solar System processing pipeline that will run at daily cadence.

The other procedure involves more complex operations, devoted to obtain the best accuracies in the output. It will operate on data obtained from the beginning of the mission and its output will be mostly meaningful at the end of the mission, when all observations will be available.

Clearly, this last context is not related to the fast response required for a ground-based alert/follow-up system, so we will devote this text to provide some details about the "daily processing" only.

For more details concerning Solar System observations with Gaia other publications offer a rather complete technical and scientific overview, such as Mignard et al. 2007 and Hestroffer et al. 2010.

While timescales and delays in processing are discussed elsewhere in this volume (F. Mignard 2011), we can focus here on the peculiar properties of Gaia observations having an impact on the operation of a ground based network, namely: the selection of the sources and the single-epoch astrometric accuracy.

Since Gaia won't use any input catalogue, all sources brighter that V~20 and crossing its FOV are candidate for on-board detection, observation acquisition and transmission of related data to ground stations. In simple terms, on-board detection (relying on a double step for confirmation) determines the position of a source when it begins its passage – under the action of the scanning motion – in the Gaia FOV. If the source obeys to some criteria (involving flux and size, mainly) it attributes a logical "window", representing the portion of the CCD image that is read-out for a given source, for each CCD column. This image is then transmitted to the ground, but for most sources (V>13) the pixel values will be binned in the Across Scan (AC) direction, preserving the maximum resolution "along scan" (AL), only. In other terms, for most objects the signal will be mono-dimensional, retaining 2D information for the brightest sources only.

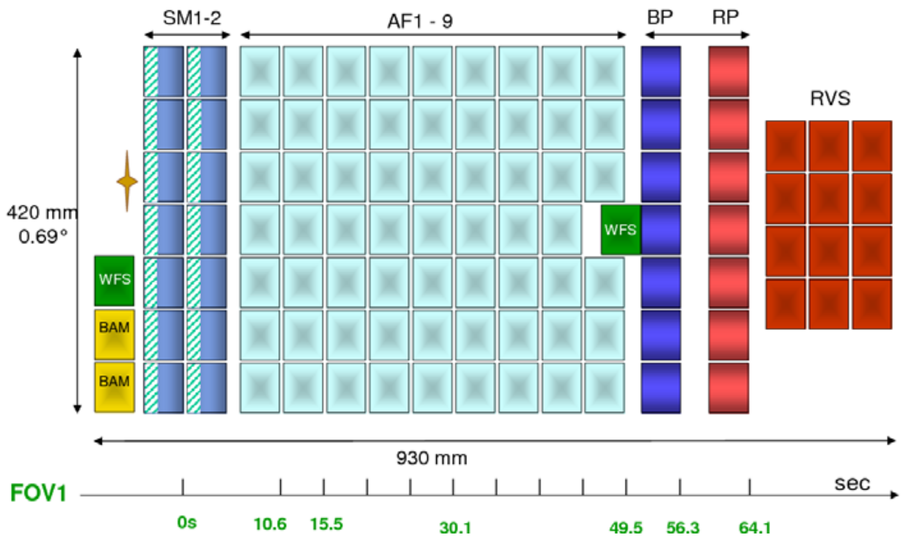

Fig. 2 – The Gaia focal plane array. Each coloured area indicates one CCD 4 X 6 cm^2 in size. The direction of the star image motion is toward the right indicated at the bottom. The bottom lines indicate the time (in seconds) needed to reach the different parts of the field. It takes a star image about 4.4 sec to cross one of the CCDs, this interval defining the effective exposure time. The CCDs in the SM (Sky Mapper) columns operate the source detection. The source is then observed in the Astrometric Field (AF), the BP- RP spectrophotometers (Blue – Red Photometers) and the RVS (Radial Velocity Spectrometer).

This procedure is capable of successfully detecting moving sources belonging to the Solar System, provided that their apparent diameter is not larger than ~500-600 mas – thus excluding the main planets, some planetary satellites and few asteroids at given epochs.

The transmitted data flow will contain the information pertaining to all sources mixed together. Their distinction into specific categories is a task of the software running at ground-based facilities. Mostly relevant for us are the procedures called “First Look” and “Initial Data Processing” (IDT), which are performed as soon as data are available. IDT won’t directly flag Solar System objects, but will try to match the position of any source against the position of sources detected in the same region of the sky, during previous scans. Of course, fixed stars should be matched, while observations of moving objects will not match – in general – the position of other sources.

The Coordination Unit n. 4 (among others) is in charge of processing the sources that are unmatched by IDT, which will reach SSO pipeline.

Several problems are hidden in the details of the process, related to its efficiency (non-SSO, unmatched sources; false matches, etc) or its intrinsic properties (SSO passing very close to stars; evolution of efficiency with the improvement of the source catalogue along the mission, etc.). For this reason, a certain (essentially unpredictable) degree of contamination of the SSO data transmitted to CU4 has to be anticipated.

Another consequence of the windowing procedure and the adopted binning is the strongly correlated uncertainty for single-epoch objet coordinates, resulting from the transformation to astronomical coordinates of the mono-dimensional astrometric measurement, whose uncertainty is directed essentially across-scan.

2. Daily processing

The aim of the daily processing chain is the identification of peculiar asteroids – i.e. objects that are not known, or whose orbits are poorly constrained. All source positions that are sent to the chain will be compared to the predicted positions of known asteroids, as computed from a frequently updated catalogue (maintained by the Minor Planets Center). A probability of identification is then assigned. For objects whose identification is close to “certain”, no further computations are performed at this level (they will enter the “long term” chain). Given the magnitude threshold of Gaia (V~20), it can be expected that most of the observed asteroids will be known by the beginning of the mission, so most of them will be identified.

Among the un-identified sources, potentially new asteroids and comets will be found, and a number of ambiguous identification and contaminants. This difficult situation must be handled by the core of the daily chain, consisting of a numerical procedure trying to link detections belonging to a same source, over the last 2 days of observations. In fact, when an asteroid is observed in one of the two FOVs of Gaia, most frequently it will be (or was) observed in the other over a single rotation of the probe. Longer detection sequences (3, 4 or more observations) have been shown to be possible, but of course with rapidly decreasing probability.

The attribution of 2 or more consecutive detections to a same object requires a so-called “threading” procedure, whose complexity and efficiency grow with the number of unidentified sources and contaminants. However, the task is made easier by the duration of a whole transit over all the CCDs of the astrometric instrument of Gaia, about 60 s. During this interval, a motion (in the AL direction) at the ~1 mas/s level will be detectable by comparing the position on the different CCD columns.

When this procedure is successful, a Monte-Carlo Markov Chain method (Oszkiewicz et al. 2009) is used for computing a bundle of orbits, resulting in a more or less constrained region of the space of orbital elements. This bundles are the main output of the daily chain, and are transmitted (along with the object brightness and other auxiliary data) to the team coordinated the Gaia-FUN-SSO network (currently under the responsibility of W. Thuillot, IMCCE, Paris).

3. Interface toward ground-based observers

An appropriate interface for a network of ground based observers is dictated by the properties of the Gaia observations, for reasons that should appear as obvious at this point. In particular:

- An unknown degree of data contamination could result in an unpredictable amount of "false" alerts. A validation of the output is due before any observation of potentially new asteroid is diffused.
- Gaia will observe from the lagrangian point of the Earth L2, so the parallax for nearby asteroids (NEOs for example) can easily be so high that an object cannot be recovered from the ground, if Gaia astrometry alone was available. For this reason, a representative set of probable short-arc orbits must be used to produce usable sky search areas, to be diffused to the observers.
- Coordination among several observing stations is the most effective way for fast reaction, feedback and optimisation of the recovery efforts.

The points above do not exclude the standard procedures usually adopted for asteroid astrometry, involving the transmission of the measured positions to the MPC. This will be done for all sources that are confirmed to be asteroids. However, the contamination issue forces the adoption of a conservative procedure at least at the beginning of the mission, when a detailed verification of the chain output will be performed. In fact, since the IDT performance in the first few months (i.e. before the first full-sky coverage of Gaia) could be very poor – thus producing a large amount of contaminants – the best approach to filtering will be through motion detection. Only fast-moving sources will be processed, thus ensuring the reliability of the processing.

Along the mission, the performances of the cross-matching by IDT will also improve with the increasing number of Gaia observations of all sources. We thus estimate that a direct transmission to MPC, without filtering or delays, will be possible at a certain point during operations.

Conclusions

Although the discovery space of Gaia will be severely limited by its brightness detection threshold, a number of asteroids that are unknown or have poorly constrained orbits will be observed. This situation will be managed by a processing chain running daily whose specific aim is to allow their recovery by a network of ground-based observers, when possible.

The daily chain will produce sets of preliminary short-arc orbits by a statistical approach. These orbits can be used to produce prediction of sky areas where observers on Earth can try the recovery.

The detected positions should also be sent to the Minor Planet Center, a procedure that requires a validation phase of the whole data processing chain, for avoiding a potentially large number of false alerts.

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