Science Alerts with Gaia

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Introduction

Gaia is before all a survey mission designed to observe the sky in a continuous manner. The sky coverage results from the spin of the satellite over a period of 6h, combined with a much slower motion of the spin axis, allowing after six months complete sky coverage. The CCD counts are stored on-board and sent to the ground station every day during the visibility period of the spacecraft by the ground antenna. The satellite design has been optimized for a survey mission, with ground treatment and not for an immediate access to the data, let alone to some scientifically immediately usable information. The processing comprises several more or less independent pipelines, each involving some sort of global processing requiring the accumulation of a substantial amount of data over several weeks or months. However, it remains possible to carry out a quick, but crude in regard of the accuracy achievable on a longer term, analysis of the data stream arriving on the ground to detect transient phenomena, like photometric burst or fast motion of solar system objects. This dedicated processing, largely distinct from the general processing, and the associated validation systems put in place, is referred to as *Science Alerts* within the DPAC community.

1. The Gaia Science Alerts

1.1. Constraints set by the Gaia observing principle

Compared to the baseline observing principle of Gaia, the distinguished feature of the Science Alerts mode is the need of a short reaction time. To understand this constraint it is useful to delve into the timeline between the data acquisition and the earliest availability of alerts information.

In its survey mode, Gaia observed continuously with an internal detection system allowing achieving astrometric and photometric observations for every sufficiently point-like source brighter than V~ 20. The spectroscopic survey does not go fainter than V ~ 15-17, according to the stellar type, being more efficient in the redder part of the spectrum. Gaia is not a pointing mission with adjustable integration time to the source brightness and it is operated with a well defined and fixed scanning law. Upon receiving the raw data collected on-board a quick initial and simplified treatment can be done within 24h, using the best current knowledge of the instrument parameters and solving for the satellite attitude with 1D astrometry. The Alert system will work only on the basis of this short timescale processing, ending with a selection of alert events.

1.2. Definition of a Gaia Science Alert

In a very generic way, one can define a Gaia Science Alert (GSA) ad **a piece of science data that would have little or no value without quick ground-based follow up**. Typically a transient photometric event evidenced in the Gaia data, or a fast-moving solar system object without known orbit. In both cases, something scientifically interesting is spotted, but there is no possibility to monitor the event further with the spacecraft. The only way to possibly benefit from this observation will be to set off quickly additional observations from the ground to sample the time-varying phenomena.

This definition implies several general features attached to a Gaia Science Alert:

- an alert must be produced by the near-real time processing
- an alert is released to the science community by the Gaia scientists
- it needs a quick ground-based monitoring
- astrometry, photometry and possibly spectroscopy could be the source of a Gaia Alert
- immediate follow-up needs the participation of the astronomical community
- alerts will be intermingled with false alerts, whatever the quality of the Gaia validation system.

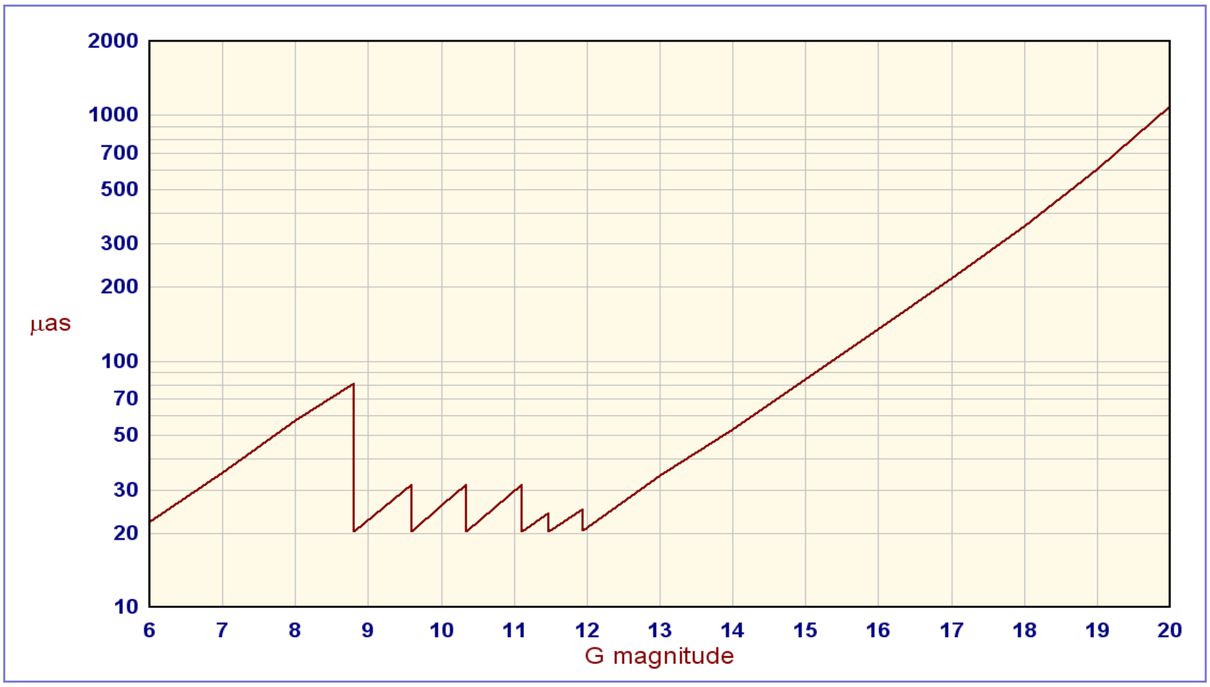

Fig. 1 – Astrometric accuracy expected over one transit of a point-like source. This is 1D accuracy along the scan direction.

2. The Astrometric and Photometric Science Alerts

2.1. Astrometric alerts

The only valid alerts of this kind will come from the observation of fast moving solar system object, typically NEO moving with angular velocity above 50 mas per second. Over a transit of 40s on a Gaia FOV, this translates into a shift of several pixels in the scanning direction and should be easily seen in the data. The local astrometric accuracy at this level is shown in Fig. 1, where the saw-tooth shape near the bright end follows from the handling of the CCD saturation. Most of the alerts, if not all, will come out with rather faint objects, fainter than V~ 18, giving a small field astrometric accuracy slightly better than one mas.

With the current calibration and the available attitude reconstruction done in nearly real-time, the position on the sky should be obtained with a 50 to 100 mas accuracy, in apparent direction as seen from Gaia. This is sufficient to match the observations to precomputed positions of all the already catalogued minor bodies and decide whether a genuine new object has been detected.

Correcting for the contribution of Gaia velocity to aberration won't be a problem, but without knowing the actual distance of the object, there is no accurate way to compute the light-time. For the same reason, the geocentric direction cannot be estimated without an assumption on the true position of the source. The shift at the time the object has been observed could be as large as one degree for a NEO at a distance less than one AU. On top of that, there will be the displacement between the observation by Gaia and the trigger of the alert, at least one day, meaning another degree shift.

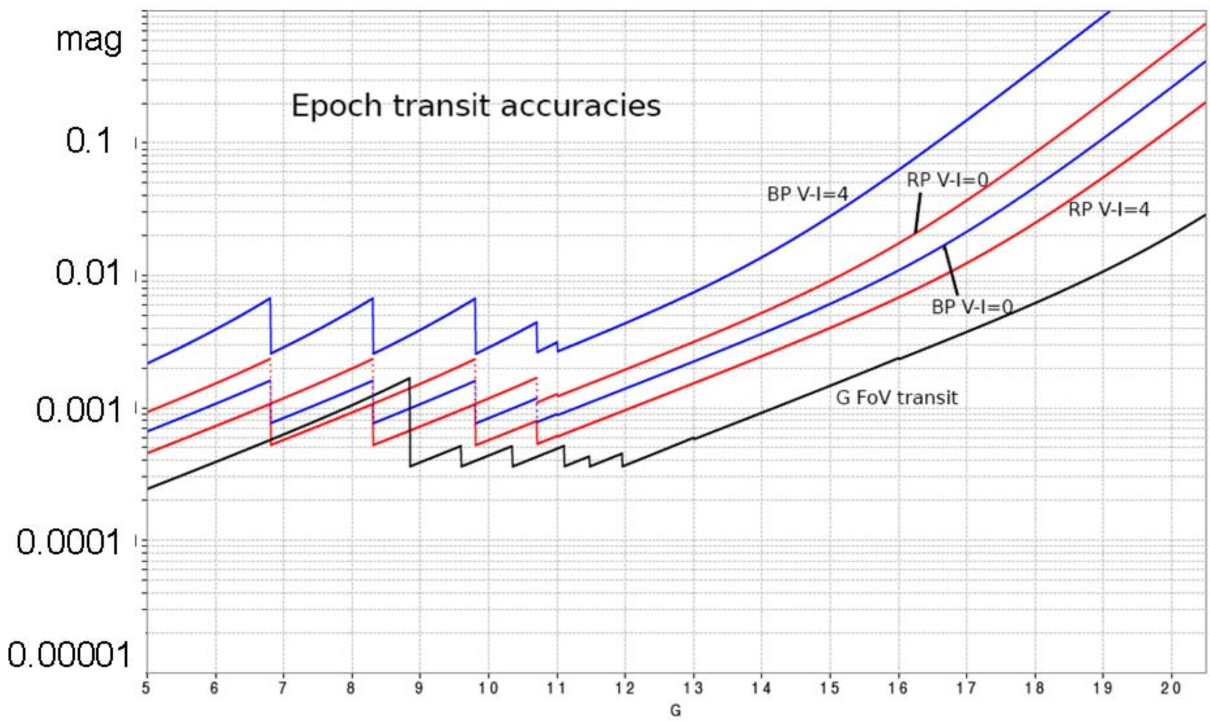

Fig. 2 – Photometric accuracy expected over one transit with the Gaia photometers. The G-band refers to the full light measurement on the astrometric CCDs.
(Fig: Courtesy of D.W. Evans)

2.2. Photometric Alerts

Photometric alerts are triggered by anomalous and unaccounted change in the light flux received from the observed sources, including that coming from new sources. The main photometric information comes from the Gaia astrometric CCDs in broad light, referred to as the G-band or equivalently the G magnitude. Another source is based on a low resolution spectrophotometer delivering two integrated magnitude in the blue and red bands. Alert will be based only on the G-band data, which is the most accurate, as illustrated in Fig. 2. The data received for the initial processing are uncalibrated and must enter first into a photometric pipeline to remove the instrumental effects and compute a magnitude in a well and stable photometric system.

Anomaly detection with an "old source" will rely on the history of that source, ideally incorporating both Gaia observations collected so far and historic ground-based data. Within a single processing batch of data we will investigate the most current observed transits (usually one or two) for each object by comparing them to the available historic measurements. The vast majority of the photometric changes will not trigger an alert to the community, but will have to be classified to eliminate all the known sources of variability, before one reach sufficient certainty that there is something worth to look at from the ground. The filtering will have to find the right balance to maintain the level of false alerts at an acceptable level and a period of internal validation will be necessary to set the various filters.

3. Basic time-line for the alerts

Compared to the baseline observing principle of Gaia, the distinguished feature of the Science Alerts mode is the need of a short reaction time. To understand this constraint it is useful to delve into the timeline between the data acquisition and the earliest availability of alerts information. The top-level description is shown in Fig. 3, sketching out the raw data flow within one operational day. An operational day starts at the end of the visibility period, when the data are acquired and no longer transmitted in real time to the ground and ends about 24h later, when the data stored during this day have been transmitted. The visibility period lasts on the average eight hours (longer in summer, shorter in winter as the declination of L2 is just the opposite of that of the sun), with the baseline of using a single ground station. When the transmission starts, there is about 16h of observations stored on board on the solid state memory to be downlinked during the next eight hours, together with the observations performed during this period.

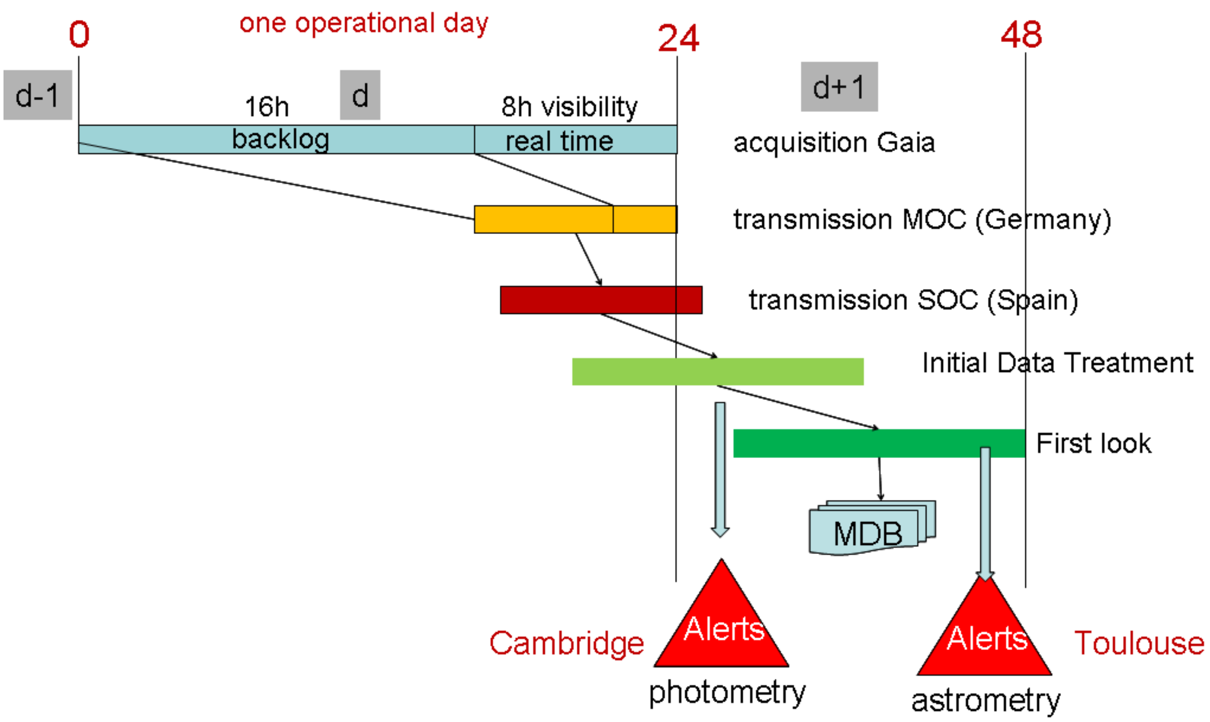

Fig. 3 – Short timescale data flow from the on-board acquisition to the alert production. The Initial Data Treatment processes the elementary images with local centroiding and photometry, while the First Look delivers the first astrometric solution.

Data are received by the ESA Mission Operation Centre (MOC) and then sent to the Science Operation Centre (SOC) near Madrid. They are in the form of telemetry packets in binary form and must be decompressed and rearranged to enter the DPAC first step of the processing. This Initial Data Treatment will isolate the CCD counts of each source detected on board and produce the raw image parameters (centroid of images, flux and background) and compute a first on-ground attitude, starting from the crude on-board star tracking. Observations will be cross-matched with the current best Gaia star list, to pair the observation to a source. This will fail for solar system objects at this stage, as the identifying tool is too heavy to be used during this phase (there are too many stars compared to planets to be effective). Normally, the unpaired observations should be essentially solar system objects, but there will be many exceptions to the rule.

Photometric data will be available first, since they do not require an attitude solution and are readily available in the form of uncalibrated fluxes. They are sent to the DPAC photometric data centre at Cambridge as soon they are available from the initial processing, in near real time. The astrometric data are available some time after when an attitude solution has been computed and are sent to the CNES computing centre in Toulouse where they enter a dedicated pipeline for the processing of solar system objects.