Transient astronomy with the 
\textit{Gaia} satellite

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\textit{Gaia} is a cornerstone European Space Agency astrometry space mission and a successor to the Hipparcos mission. \textit{Gaia} will observe the whole sky for 5 years, providing a serendipitous opportunity for the discovery of large numbers of transient and anomalous events, e.g. supernovae, novae and microlensing events, gamma-ray burst afterglows, fallback supernovae, as well as theoretical or unexpected phenomena. In this paper, we discuss our preparations to use \textit{Gaia} to search for transients at optical wavelengths, and briefly describe the early detection, classification and prompt publication of anomalous sources.

1. Introduction

\textit{Gaia} is planned for launch from Kourou (French Guiana) in September 2013. Upon reaching L2 (second Lagrange point), its 5 year mission is to measure astrometry, photometry and spectroscopy for one billion targets with magnitudes in the range $V \sim 6$–20. Each target star will be measured on average 80 times, leading to precise measurements of parallax, proper motions and photometric variability [1]. \textit{Gaia} will enable the study and classification of huge numbers of variable sources, including eclipsing binaries, RR Lyrae, Cepheids, long-period variables, pulsating stars, cataclysmic variables (CVs) and active galactic nuclei (AGNs).

\textit{Gaia}'s sensitivity to the variable sky also opens the door for the detection, classification and rapid reporting of transient phenomena. These science alerts are defined as events where \textit{the data would have little or no value without quick follow-up}. These will include astrometric alerts (for example, fast-moving Solar System objects,
Figure 1. The number of Gaia visits on the sky in equatorial (ICRS) coordinates. Taken from the ESA GAIA website (http://www.rssd.esa.int/index.php?project=GAIA&page=IG_20120207). Copyright Berry Holl 2008. (Online version in colour.)

near-Earth objects), photometric alerts (such as supernovae) and spectroscopic alerts (rapid phases of stellar evolution). In the rest of the paper, a brief summary of Gaia is presented, followed by discussion of the implications for the discovery of supernovae and microlensing events.1

Gaia has two telescopes (rectangular primary mirrors are $1.45 \times 0.5$ m), which are coincident on a single focal plane, with a field of view of $0.7^\circ \times 0.7^\circ$. As the satellite spins, star images are first seen by the sky-mapper charge-coupled devices (CCDs). Detected objects are allocated windows in the astrometric field with 62 CCDs (seven across scan and nine along scan), each read out in time-delayed integration mode, synchronized to the scanning motion of the satellite. Gaia is sensitive down to 20th magnitude in the broad-band ‘G’ filter [2]. Per-transit astrometry will be measured with a systematic error in the early astrometric solution of around 100 $\mu$arcsec. Per-transit photometry will range from a few milli-magnitudes for the brighter stars down to 0.01 magnitudes at $G = 19$ [2].

Before the stellar images leave the field of view, spectra are measured at low dispersion (approx. 4–30 nm/pixel) with the Blue (330–680 nm) and Red (640–1000 nm) Photometer (BP and RP) prism spectrographs, and then again at higher dispersion with the Radial Velocity Spectrograph (RVS) ($R \sim 11500$, centred on the Ca II infrared triplet).

Gaia orbits the Sun–Earth system at L2. The satellite spins on its axis at a constant spin rate of 60 arcsec$^{-1}$, once every 6 h. The two primary mirrors are aligned along a great circle perpendicular to the spin axis, and separated by 106.5$^\circ$; thus the second field of view trails the first by 106.5 min. The spin axis precesses slowly (period of 63 days) but with a fixed 45$^\circ$ angle to the Sun, thus building up repeated all-sky coverage over the 5 year mission lifetime. Figure 1 illustrates the coverage of Gaia in terms of numbers of transits for equatorial (International Celestial Reference System, ICRS) coordinates.

1As yet we have not performed detailed simulations for the likely event rates of other eruptive variables, such as CVs, AGNs, novae, etc.
2. Supernovae

Predictions from Belokurov & Evans [3], Wyrzykowski & Hodgkin [4] and Altavilla et al. [5] suggest that Gaia will be very efficient at discovering supernovae, especially in the local Universe. Our own simulations (in agreement with [5]) suggest that we will detect 15000 supernovae (SN) during the lifetime of Gaia down to \( G = 20 \). For SN Ia, Ib/c and IIL, we catch 30–40% of them on the rise; for type IIP, it is closer to 10 per cent. One supernova per day will be brighter than \( G = 18 \).

One of the key advantages of Gaia is that we obtain a BP/RP spectrum for every source, ideal for the classification of the various classes of transient phenomena. Early tests with simulated spectra (Nugent 2007\(^2\), [6]) degraded to the Gaia resolution and signal-to-noise ratio show that these spectra provide a large amount of information, not only on the supernovae type, but also on the redshift and epoch of the event, independently of additional information from the lightcurve (amplitude and slope).

3. Microlensing

Gaia will also detect numerous microlensing events in our Galaxy, when the light of a distant star is gravitationally magnified by a foreground lens object. The duration of the magnification can be written as the Einstein radius crossing time, \( t_E \approx \sqrt{\frac{M}{M_J}} \) days (where \( M_J \)) is the mass of Jupiter), and is therefore sensitive to planetary mass lenses. The duration also depends on the distance and transverse velocity of the lens. With Gaia sampling, we are rather more sensitive to longer-duration events from more massive lenses (e.g. 30 days for a 1 \( M_\odot \) lens). Most of the events will occur in the densest regions of the Galaxy, namely the Bulge and the Plane. We expect to detect and alert on more than 1000 events based on Gaia photometry alone.

Gaia has an extra trick up its sleeve though, with astrometry accurate to a few hundred \( \mu \)arcsec per transit (limited by systematics in the earlier stages of the processing). The astrometric signal lasts longer than the photometric signal [7] and could provide early warning to trigger dense ground-based photometric coverage, e.g. with OGLE (Optical Gravitational Lensing Experiment) [8]. The possibility of discovering extremely faint or dark lenses such as neutron stars or black holes is exciting.

4. Operations and alert publication

Gaia data will be downlinked from the spacecraft in an 8 h window once per day. Initial processing is completed before the science alert detection pipeline is run. We expect to publish alerts typically

within 24–48 h of their observation with Gaia. Transient discovery will be conducted down to \(V \sim 19\) and is based on either detection of a new source, or a significant deviation in brightness of a known source compared with previous Gaia measurements (the amplitude is a tunable parameter to avoid swamping the community). The alert stream will go live less than 1 year after launch, after a process of mapping (for source history: it takes six months to observe the whole sky at least once) and verification. Verification will include a significant programme of ground-based spectroscopic and photometric follow-up of Gaia alerts to (i) demonstrate that transient detection and classification works, (ii) help fine-tune detection thresholds, (iii) validate classification probabilities, (iv) investigate the Gaia science alert population (and measure completeness and contamination), and (v) build a training dataset for improved classification.

Published alerts will comprise Gaia astrometry, photometry and spectroscopy, and associated archival data. In addition to newly detected transients, it is planned to monitor a pre-selected (via community consultation) set of known interesting objects (the Gaia Watch List). Ideally, this will be dynamic, so that external (to Gaia) discoveries may also be included. Alerts will be disseminated to the entire community, as machine-readable VOEvents\(^3\) [9]. We are testing the use of Skyalert.org\(^4\) [10] as an interface to both the alert stream and follow-up data.

References


\(^4\)See http://skyalert.org/.