36. Science alerts

As the Gaia satellite scans the sky, it detects and observes all objects brighter than a given threshold. This avoids the use of a pre-defined observing programme, and it ensures that all objects bright enough at the specific time of their observation – whether regular or irregular variables, or moving objects within the solar system – are detected and observed.

An important type of object, which could never appear in a pre-defined observing programme, and which this sort of onboard detection was specifically designed to include, are the class of 'transients' sources. These are objects which can suddenly, and usually unexpectedly, increase in brightness for a number of reasons, and which therefore suddenly become measurable. With this kind of onboard detection capability, Gaia could hope to discover new transients, and contribute astrometric and photometric measurements as the source changes in brightness.

The most obvious objects in this class are supernovae, the explosive brightening of an otherwise unremarkable progenitor star. Amongst a number of dedicated supernovae search programmes, the ASAS–SN (All Sky Automated Survey for SuperNovae) operates 20 robotic telescopes which can survey the entire sky once a day. In the past two decades, a few hundred supernovae are discovered each year.

But there are many other sorts of transient events, including Galactic novae, cataclysmic variables, stellar flares, comets, gravitational microlensing events, and even tidal disruption events.

Simulations made during the early studies in the 1990s showed that Gaia could detect supernovae out to distances of 500 Mpc, or to redshifts of about 0.1, corresponding to perhaps 100 000 detections over its 5-year nominal lifetime (Høg et al., 1999). Although the satellite observations would be too sparse to produce the all-important light-curve from Gaia data alone, alerts to ground-based observers with rapid follow-up monitoring could perhaps provide light curves for perhaps 50 000. Estimates of the number of gravitational microlensing events were made around the same time.

A group at the Cambridge Institute of Astronomy is leading the processing of the satellite photometric data. A sub-group, led by Simon Hodgkin, has taken responsibility for the handling of these Gaia 'alerts'.

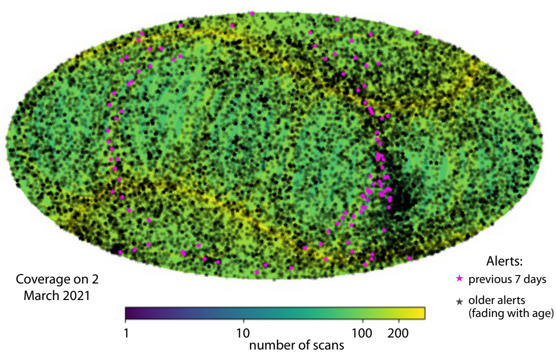
The repeated, high-precision measurements which form the basis of the high-precision measurements of stellar positions, are also ideal to look for variations in brightness as well. The group runs a dedicated data processing pipeline to look for transient events in the Gaia data, picking up 'new' sources where nothing had been detected previously, or sudden dramatic changes in brightness of previously detected stars.

These Alerts are made public immediately after the data processing and alert identification, typically just 2–3 days after the observation by the satellite.

Their `www alert pages` include all the data Gaia has collected for each source, including detected and historic G-band magnitudes, the light curves and the low-resolution Gaia ($B_\mathrm{P}/R_\mathrm{P}$) spectra.

Dedicated apps allow the discoveries to be followed up by ground-based astronomy facilities. Both professional and amateur astronomers, and even groups of school children, are now involved.

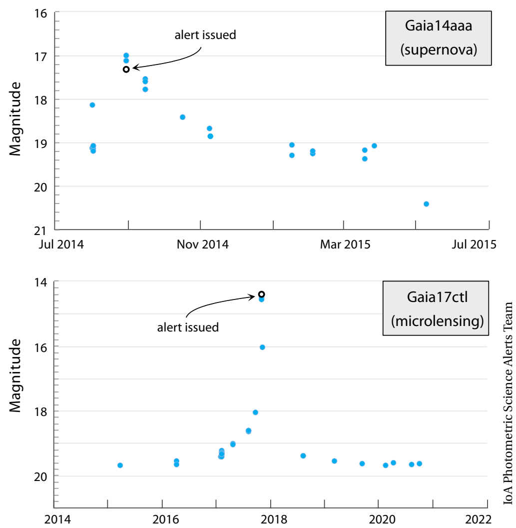
Following the convention used for supernova discoveries (the prefix SN, followed by the year of discovery, suffixed with a one or two-letter designation), the Gaia discoveries are designated GaiaYYaaa, GaiaYYaab, GaiaYYaac,… where YY encodes the discovery year.



IoA Photometric Science Alerts Team

After satellite commissioning in mid-2014, the first reported discovery, Gaia14aaa, was a supernova of Type Ia, observed on 30 August, and reported on 12 September. It had an observed magnitude of 17.32, compared with a historic magnitude of 19.22 ± 0.42.

By the end of 2020, with 6 years of observations, nearly 15 000 events had been issued via the Cambridge alerts page, around 50 brighter than $G = 12$, and some also detected by other monitoring programmes.



Although some two thirds of these events have not (so far) been classified, around 5000 have. Some 500 are listed as cataclysmic variables, 100 as active galactic nuclei, more than 600 as variable quasars, 1500 as supernovae Type Ia, and 500 as supernovae Type II.

Nearly 50 gravitational microlensing events have been discovered as part of the Gaia alerts pipeline, mostly in the Galactic plane where lensing cross-sections are highest. Some of these were also detected by OGLE. One of the brightest to date, Gaia 17ctl, showed a brightness increase of 4.5 mag at peak amplification.

The subject of microlensing, both photometric and astrometric, is a broader one for Gaia than simply event detection, and is picked up elsewhere. It touches on questions of exoplanet discovery and characterisation, as well as astrometric microlensing event prediction due to future close alignments as a result of rapidly moving nearby stars.

One of the areas that the Gaia alerts may impact in future is the detection of 'tidal disruption events'. These were predicted, 50 years ago, to occur when a star approaches sufficiently close to a supermassive black hole, and a fraction of the star's mass can be captured into an accretion disk around the black hole. This should result in a temporary flare of electromagnetic radiation as matter in the disk is consumed by the black hole.

Possible candidates were first discovered by the X-ray satellite Rosat in 1990, while more convincing examples have only surfaced in the last 3–4 years, with observations from ASAS, WISE, and TESS.

Although the Gaia transients include 100 classified as originating in active galactic nuclei, none are explicitly confirmed as such tidal disruption events. But analysis by Kostrzewa-Rutkowska et al. (2018), using different detection criteria, yielded nearly 500 nuclear transients, only five of which had been published by the Cambridge group, raising the prospects that this new type of transient may be more routinely detectable in the future.

The information on the variability of the Gaia alert events is extracted from the source's average magnitude over the 45 second crossing time of the full astrometric field of view, and compared with previous magnitudes measured over previous scans. The 45-second average results from the star images passing across 10 individual CCD detectors, each with a sampling period of 4.5 seconds. Whether this faster time sampling can contribute significantly to studies of 'fast' transient sources has been studied by Wevers et al. (2018).

With their finding that transient brightness variations down to an amplitude of 0.3 mag could be probed on time-scales ranging from 15 s to several hours, they identified four candidate fast transients within an area of just 20 square degrees. Two were tentatively classified as flares on M-dwarf stars, one as a flare on a giant star, and one potentially a flare on a solar-type star.

Another example of the potential relevance of the Gaia alerts comes from the emerging field of gravitational wave astronomy. The first such detection was announced by LIGO in February 2016. Since then, and until the end of 2020, 20 such events have been discovered by LIGO and VIRGO. In just one of these, GW 170817 (a binary neutron star coalescence), an electromagnetic counterpart was discovered, firstly in the optical, and a few days later in the X-ray and radio.

Studies of the Gaia data by Kostrzewa-Rutkowska et al. (2020) have shown that, from the current gravitational wave observing run (O3, which began in April 2019), about 16–25 per cent should fall in sky regions observed by Gaia 7–10 days after the event. They suggest that their specific detection algorithm would provide about 20 candidates per day over the whole sky.

This focus on photometric 'transient alerts' is quite distinct from the vastly broader topic of stellar variability, and the huge impact that Gaia will have on the quantity and quality of data on both regular and irregular variables, as well as on stellar rotation.

Neither has it touched on the detection of moving solar system objects and their orbit reconstruction, nor on the photometric detection of planetary transits.