Gaia and Alerts: Status

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http://gsaweb.ast.cam.ac.uk/alerts
Mission Status

➢ Spacecraft operations are generally running smoothly
  • Safe mode in Jun-2017
    • Re-focus needed – Astrometry Focus now ‘best ever’
    • Root cause in micropropulsion system has now been cured
  • Sailed very stably through intense solar flare(s) ➔ But memory was filled with false detections and it took a while to empty the memory
    • Procedures in planning to delete such data on-board in a possible future occasion
    • Impact on CCD corresponded 1-1.5 years of radiation damage, but globally still below expected level
  • Loss-of-convergence through micro-meteorites and tank ‘bubbles’ continue with the usual frequency
  • Significant event on 24-Nov
    • Max AL angle error = ~11 arcsec
    • Max AC angle error = ~45 arcsec
    • Recovered autonomously
  • Ground station equipment moved to new technology
    • Test – Gaia switching to Low Gain Antenna - performed successfully 23-Nov
Event ~ July 15th (was the highest PPE peak of mission so far, but short-lived)

High-energy weekend event

Event mid-week
A big step from Gaia DR1 to DR2

<table>
<thead>
<tr>
<th>Gaia DR1</th>
<th>Gaia DR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 months input telemetry</td>
<td>22 months input telemetry</td>
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<tr>
<td>Parallaxes and proper motions from Gaia-Hipparcos combination</td>
<td>Stand-alone Gaia astrometric solution</td>
</tr>
<tr>
<td>Limited/incomplete calibrations leading to significant systematics</td>
<td>Much improved calibrations, much reduced systematics</td>
</tr>
<tr>
<td>G-band only</td>
<td>G, G$<em>{BP}$, G$</em>{RP}$, pass-bands</td>
</tr>
<tr>
<td>Small set of variable star light curves</td>
<td>Much expanded variable star catalogue</td>
</tr>
<tr>
<td></td>
<td>Radial velocities</td>
</tr>
<tr>
<td></td>
<td>Solar system objects</td>
</tr>
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</table>
A big step from Gaia DR1 to DR2

<table>
<thead>
<tr>
<th>Data product</th>
<th>Very preliminary source numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(\alpha, \delta), G, G_{BP}, G_{RP}$</td>
<td>$\sim 1.5$ billion</td>
</tr>
<tr>
<td>Parallax, proper motion</td>
<td>$\sim 1$ billion</td>
</tr>
<tr>
<td>Median $v_{\text{rad}}$ at $G_{\text{RVS}} &lt; 12$</td>
<td>$3$–$5$ million</td>
</tr>
<tr>
<td>Estimates of $T_{\text{eff}}$ and possibly $A_V$; radii, luminosities for subset</td>
<td>sources at $G &lt; 17$</td>
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<tr>
<td>Photometric data for a variety of variable star types, all-sky RR Lyrae survey</td>
<td>TBD</td>
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<tr>
<td>Epoch astrometry for a pre-selected list of asteroids</td>
<td>$&gt; 10,000$</td>
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</table>
AGIS-2.1: preliminary astrometry solution

- Systematic errors below 100 μas
- Typical parallax precision: 
  \( G = 15, 30 \) μas; \( G = 18, 150 \) μas; 
  \( G = 20, 700 \) μas
- Improvements with respect to Gaia DR1
  - Gaia-only solution (no prior used) for the majority of sources
  - more/better input data
  - improved calibrations (in particular colour terms)
  - improved removal of attitude disturbances
Longer term data release schedule

Gaia DR3

- Targeted for mid to late 2020
- Examples of new data products
  - Source classification and astrophysical parameters
  - BP/RP and RVS spectra for sources with astrophysical parameters
  - Rotational velocities for bright stars
  - Non-single stars: various levels of astrometric binary solutions (where possible), eclipsing binaries
  - Updated and extended variable star catalogue
  - Updated and extended solar system objects catalogue
Longer term data release schedule

Gaia DR4

- Targeted for end 2022
- Final release for the nominal mission
- Foreseen data products
  - Full astrometric, photometric, and radial-velocity catalogues
  - All available variable-star and non-single-star solutions
  - Source classifications (probabilities) plus multiple astrophysical parameters (derived from BP/RP, RVS, and astrometry) for stars, unresolved binaries, galaxies, and quasars
  - An exo-planet list
  - All epoch and transit data for all sources, including all BP/RP/RVS spectra
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<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
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<tr>
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<td>Actual Mission End?</td>
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</table>

WHERE ARE WE?
PROGRESS OVER THE YEAR

- Stable Ops: little downtime, and no major Dev changes (useful for tests: see Zuzanna)
- Retraction of unpublished Alert Candidates - can re-trigger (marginal cases -> more convincing)
- Swap to new hardware: 10 days downtime
- Implement the rematch tables (for the next [DR2] catalogue), 10 days downtime.
- Add RVS spectra
since Jan 2016

Publication Delay

median delay: 3.3d

since July 2016
From 11/9/16 until now:

0.43% of alerts have RVS spectra published with them

On average, 1 RVS spectra published every 2 weeks
Gaia17aeq

Onboard $G_{RVS} = 14.3$ mag

The vertical dashed lines delineate the rest wavelengths in vacuum of the CaII triplet lines: 850.035, 854.444 and 866.452 nm.
Gaia17aeq

Onboard $G_{\text{RVS}} = 15.3$ mag

The vertical dashed lines delineate the rest wavelengths in vacuum of the CaⅡ triplet lines: 860.335, 854.444 and 866.452 nm.
NEXT STEPS FOR GAIA ALERTS

• Addition of GS-TEC classification for all Alert Candidates (now, run for filtered candidates)
• Improved astrometry (100 microarcsecond, 1 day later)
• Improved Photometry (PODC: Photometric One-Day Calibration .. good to ~1.5%)
NEXT STEPS FOR GAIA ALERTS

• Calibrate BP/RP spectra
• Predictive classifications for everything (LC and environment classifiers [input from Konkoly])
• Implement the Watch List [replace with external triggers approach]
CLASSIFICATION

- Most transient surveys can only follow-up a fraction of their detections
- Thus the majority are lost
- Follow-up is necessarily biased
MOTIVATION

• To understand biases and completeness
• To measure rates, luminosity functions, feed formation/evolutionary models
• To prepare for dedicated transient surveys (e.g. LSST)
• To pick out the rare and exciting stuff (Gaia14aae: eclipsing AM CVn)
• To ensure optimised follow-up (e.g. Gaia16aye)
• To pick out new kinds of transient
• Step towards automation
### TNS Transients Statistics and Skymaps

**ALL transients** reported since Jan 1, 2016: 9024

**PUBLIC transients** reported since Jan 1, 2016: 7547

**PUBLIC transients** for the top 5 contributing groups:
- Pan-STARRS1: 4867
- GaiaAlerts: 1644
- ATLAS: 350
- ASAS-SN: 204
- iPTF: 113

**PUBLIC classified SNe** reported since Jan 1, 2016: 696

**PUBLIC classified SNe** for the top 5 contributing groups:
- ASAS-SN: 160
- Pan-STARRS1: 109
- iPTF: 98
- GaiaAlerts: 85
- ATLAS: 81

**ALL spectra** reported to the TNS: 831

**PUBLIC spectra** reported to the TNS: 798

**PUBLIC classifications** for the top 5 contributing groups:
- PESSTO: 243
- iPTF: 133
- ASAS-SN: 75
- LCOGT SN-KP: 46
- Padova-Asiago: 39

**PUBLIC classified SNe** by type:
- SN Ia: 455
- SN II: 103
- SN IIP: 33
- SN Ia-91T-like: 19
- SN IIn: 17
- SN Ib: 14
- SN Ia-91bg-like: 10
- SN Ic: 9
- SN Ic-BL: 5
- SN Ia-pec: 5
- SLSN-I: 4
- SN Ia-02cx-like: 3
- SN Ib/c: 2
- SN Ic-pec: 1
- SN Ia-CSM: 1
- SN IIL: 1
- SN IIn-pec: 1
- SLSN-II: 1
- SN Ibn: 1
- SN Ib-pec: 1

[https://wis-tns.weizmann.ac.il](https://wis-tns.weizmann.ac.il)
ASAS-SN (m~17)
- Classified: 78%
- Unclassified: 22%

Pan-STARRS1 (m~21, 23)
- Classified: 2%
- Unclassified: 98%
WHAT DOES GAIA OFFER?

• Low Dispersion Spectrum of every transient
• Precise Astrometry and Astrometry
• High Spatial Resolution
• Stable Survey
Nearby Supernovae

This sequence of spectra charts the evolution of Gaia16aeg (SN IIb, ASASSN-15lv) as it transitions towards a nebular spectrum. Over a five month period, the continuum fades while strong emission lines of Calcium (including the Ca NIR triplet), Oxygen and Iron are seen to emerge in the red spectrum.
SPECTRAL CLASSIFICATION

Fig. 3.8 Confusion matrices for the faint end. The X axis represents the class type predicted by the classifier and the Y axis represents the true type. The number in parenthesis is the number of spectra used in the test set. The percentages are given relative to this number. The black line separates the real types from the artificial types: BB and Ambiguous. The color bar indicates the percentage of objects that belong to each category.

Blagorodnova et al 2014
Redshift

Epoch

GS-TEC: PARAMETER ESTIMATION

Blagorodnova et al 2014
WHAT DOES GAIA OFFER?

• Low Dispersion Spectrum of every transient
• Precise Astrometry and Photometry
• High Spatial Resolution
• Stable Survey
Gaia16aye

http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia16aye/
The figure shows the Gaia lightcurve combined with photometric follow-up photometry generously provided by the astronomical community using the Cambridge Photometry Calibration Server (CPCS). Multiple filters are shown in one figure and can be toggled on/off using the legend on the side. Click and drag in the chart to zoom in. Clicking on data points provides additional information of the observation.

Access to these photometric data may be requested from the individuals who took the data. Please contact us if you would like to ask for access and we will pass on your request.

Warning: The follow-up data is obtained using rough calibrations and we can not guarantee its complete correctness at this stage.
CAMBRIDGE CALIBRATION SERVER

- observers upload astrometrically calibrated catalogues
- we apply photometric calibration from APASS, SDSS
- about 25% of published alerts have follow-up data
- >17000 measurements for Gaia16aye from 33 telescopes

AAVSO, USA
APT2, Italy
Aristarchos Telescope, Greece
ASAS-SN, Hawaii, USA
Asaigo, Italy
ASV, Serbia
Białkow, Poland
Kryoneri, Greece
Leicester University, UK
LCOGT/SUPAscope network
Liverpool Telescope, La Palma, Spain
Loiano, INAF-OABO, Italy
Joan Oro Telescope, Montsec, Spain
Mercator, La Palma, Spain
Montarrenti, Italy
NOT, La Palma, Spain
Ondrejov, Czechia

OmicronC2PU, France
Ostrowik, Poland
Palomar 200-inch telescope (P200), Caltech, USA
PIRATE, Tenerife, Spain
pt5m, La Palma, Spain
RTT150, Turkey
SALT, South Africa
Skinakas, Greece
Sternberg Observatory, Russia
T100, Turkey
T60, Turkey
UIBTeo, Turkey
University College London, UK
Watcher, South Africa
Wis, Israel
Yerkes-41, USA
GAIA CADENCE: DETECTION VS DISCOVERY

Model by Przemek Mróz
GAIA16AYE (AYERS ROCK)

Preliminary solution

\( \sim 8 \text{kpc} \)

0.8kpc

2.3AU

\( M_1 = 0.4 \, M_{\text{Sun}} \)

\( M_2 = 0.6 \, M_{\text{Sun}} \)

\( P = 3.4 \, \text{yrs} \)

\( \text{incl} = 60 \, \text{deg} \)

\( \text{ecc} = 0.473 \)

K3 giant

\( R = \sim 10 \, R_{\text{Sun}} \)

Slide from Lukasz Wyrzykowski
WHAT DOES GAIA OFFER?

- Low Dispersion Spectrum of every transient
- Precise Astrometry and Astrometry
- High Spatial Resolution
- Stable Survey
GAIA RESOLVES SN AT 0.1-0.5 ARCSECS

Figure 4. GIBIS simulation results for transients in galaxies with \( B/T = 1 \), \( r_e = 1 \) arcsec, describing elliptical galaxies or compact bulges. Top: From the sample of detected SNe, the fraction of resolved ones as function of their angular separation, \( \theta \), and difference in magnitude \( m_{SN} - m_G \) (line colour). SNe which are 2–3 mags fainter than the host, have a low probability to be detected on board (see bottom left panel). The detection only happens when the scan orientation is favorable to resolve the SN from the host. Bottom left: on-board detection efficiency for transients as function of angular separation and difference in magnitude \( m_{SN} - m_G \) (line colour). Dashed lines represent the detection probability for resolved objects and the solid lines for unresolved objects. The curves are averaged values for bulges of magnitudes 16–20. The error bars are determined by the scatter on the average computed for each bin. The results are only shown for bulges with an effective radius \( r_e \) of 1 arcsec for clarity. The detection probability is computed as the number of detections over the total number of scans (or potential detections). Due to different scanning angles, some of the simulated object may fall into gaps between the CCDs. Therefore, the detection efficiency per simulated object is lower than 100 percent.

Bottom right: difference in magnitude between the transient input magnitude, \( m_{SN} \), and the on-board detected magnitude, \( G_{VPA} \), for bulge–transient pairs as function of angular separation. Same magnitude difference bins are used as in the left sub-figure. Dashed lines represent the magnitude change for resolved objects and the solid lines for unresolved objects.

probability of 0.85 to detect the transients. As we have accounted for a full sky survey with Galactic extinction, there is a small fraction of TDE that will be always obscured by the dust in the Galactic plane. The maximum redshift at which a TDE may be detected, albeit with a detection efficiency of 5 per cent or lower, is around 0.13 for \( m_{lim} = 19 \) and 0.2 for \( m_{lim} = 20 \).

The survey detection efficiency for PS1 TDE and LR11 TDE, assuming a limiting magnitude of 19 and \( \Delta m = 0.5 \), is shown in MNRAS 455, 603–617 (2015).
WHAT DOES GAIA OFFER?

• Low Dispersion Spectrum of every transient
• Precise Astrometry and Astrometry
• High Spatial Resolution
• Stable Survey
PESSTO classifications as of Jan 2017

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<tr>
<th>Survey</th>
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</table>
CLASSIFICATION:

We collate from TNS, ATels, our own follow-up, for (mostly spectral) classifications
GAIA-BASED CLASSIFICATION

- We will always be resource-limited for follow-up.*

- Gaia data are rich enough to do a good job of classification (c.f. other transient surveys).

- We have a large training set (>650 classified alerts) - but biased towards SN. OPTICON, ESO, ING, LT proposals focus on Galactic transients.

- Caveat - most of what we are preparing is based on supervised ML approaches.

*LSST
NEXT STEPS FOR GALACTIC TRANSIENT SCIENCE

• I would propose that we can do more, especially with the Galactic Transients (Gaia14aae, Gaia16aye are prime examples)

• Between us, we have phenomenal telescope access. Need to:
  • Coordinate Observations (LW has been doing the brunt of this)
  • Prioritise targets
  • Process + Analyse data
  • Write ATels (where appropriate), and papers

• The Gaia Marshall can support/enable the required interaction and discussion
NEXT STEPS FOR GALACTIC TRANSIENT SCIENCE

• Awarded 82 hours LCO 1m (Opticon, in 2 semesters)
• Awarded 89 hours REM 0.6m (Opticon in 2 Semesters)
• Awarded 13.5 hours Liverpool (Opticon + PATT)
• Awarded 1 night NOT (Opticon)
• Awarded 6 nights NTT (ESO)
• Primary science cases: Microlensing Events, CVs, Black Hole Binaries
IS IT A NOVA?
WITH THANKS TO

• DPAC
• Francesca De Angeli
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• Dafydd Wyn Evans
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• GREAT
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• Jorge Fernandez Hernandez
• Greg Holland
• Anna Hourihane
• Peter Jonker
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