Gaia Photometric Science Alerts: One Year In

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- all co-I’s on our numerous proposals.
Routine operations

• In 5-year routine phase since 18 July 2014

• Nominal scanning law optimised for Jupiter quadrupole moment general relativity experiment

• Data collection:
  — 225 billion astrometric measurements
  — 45 billion photometric measurements
  — 4.4 billion spectra

• Magnitude limits
  — Astrometry and photometry between $2 < G < 20.7$ mag
  — Stars brighter than $G = 3$ mag captured with Sky Mapper imaging
  — Spectra till $G_{\text{RVS}} = 16.2$ mag (and $G > 2$ mag)
Variability

- Cepheids in LMC observed by Gaia during Ecliptic Pole Scanning
- Data processed through DPAC system with periodicity analysis as the last step

Credits: ESA/Gaia/DPAC/CU5/DPCG/CU7/INAF-OABo/INAF-OACn Gisella Clementini, Vincenzo Ripepi, Silvio Leccia, Laurent Eyer, Lorenzo Rimoldini, Isabelle Lecoeur-Taibi, Nami Mowlavi, Dafydd Evans, Geneva CU7/DPCG and the whole CU7 team. The photometric data reduction was done with the PhotPipe pipeline at DPCI; processing data were received from the IDT pipeline at DPCE.

see talk from Laurent Eyer
Scanning Law

- 2
- 1
- spin period
- precession period
- FOVs 1+2 sep by
- Time between scans:
- Field revisited every
- Average of
- Densest
Scanning Law

NSL field transits in ICRS after: 0 years 000 days 00 hr 10 min
Gaia Focal Plane

FoV: 0.7 deg x 0.7 deg
pixel: 0.059"(AL) x 0.177"(AC)

~1 billion pixels every 4.4 seconds.
Whole sky survey at very short time-scales
Sampling of light curve

~ weeks

Each source observed many times in mission; sampling is predictable but uneven.

Each visit, typically 2 transits in each of 2 fields of view:

FoV transit → avg. mag.

Each FoV includes up to 9 equivalent flux samples that can be averaged or used separately.
BP/RP spectra: classification

- two low-res fused-silica prisms
- BP 330-680nm @ 4-32 nm/pixel
- RP 640-1000nm @ 7-15 nm/pixel
Photometry per transit

- 1% at $G=19$ (colours to $\sim 10\%$)
- $<2$ millimag precision up to $G=12$

Stars brighter than $\sim 10–12$ mag pose a special challenge. Pixel saturation is avoided for such objects by dedicated activation of CCD TDI gates, effectively reducing the CCD integration time.
Astrometry per transit

- OGA1: 50 milli arcsec (with IDT)
- OGA2: 100 micro arcsec (24 hours later)

Figure 5: Astrometric performance across scan for a point source from a single transit as a function of G magnitude

4.2 Photometric Performance

The main photometry stream from Gaia is obtained from AF CCDs and is a broad filter photometry called G. Another source of the photometry is based on low-resolution dispersive spectrophotometry using the Blue and Red Photometers (BP and RP) from which we derive G, BP, and G, RP magnitudes. DU will receive both streams of the photometry in uncalibrated form. Figure 6 shows the expected error as a function of magnitude for each field of view transit.

4.3 Spectroscopic Performance

The underlying low-resolution epoch spectra from BP and RP will also be available from the IDT in a raw form. The BP spectrograph comprises two low-resolution fused silica prisms. The BP disperser covers 640 to 715 nm with resolution 7.4 nm/pixel, while the RP covers 500 to 700 nm with resolution 5.0 nm/pixel.
Gaia data processing is a Pan-European cooperation

- Academic institutions and national space agencies
- Supported through national funding
- Processing power spread over 6 centres
- ESAC team integral part of DPAC

DPAC participating countries ~450 members

Including:
BR
CA
DZ
ESA
IL
US

Including:

- DPAC
- DPCI
- DPCG
- DPCC
- DPCB
- DPCT
- DPCE
Timeline for Data Flow

one operational day

backlog

real time

8h visibility

acquisition Gaia

transmission MOC

transmission SOC

Madrid, Spain

Initial Data Treatment

First Look

Astrometry (100 mas)

Astrometry (100 μas)

Science Alerts (Cambridge)
Promptness of publication

• Upstream processing delivers data \(~24+ \text{ hours after observation}\), roughly one run per day

• Alerts processing (light-curve assembly, calibration, transient detection and classification) takes up to \(6 \text{ hours per run}\)

• Publication latency after alerts processing:
  • If classification & selection is automatic: \(\sim \text{ minutes}\)
  • If classification & selection is manual: \(\sim \text{ hours to } \sim \text{ days}\)
Gaia data per transit

For each alerting source at every epoch we publish:

• White-light (G) magnitude
• Position and time
• Low-resolution (prism) spectra
• B-R colour (from prism spectra)
• Finding chart (SDSS, DSS)
• Results of crossmatch against other transient surveys

• see talk from Arancha Delgado (Friday)
Not the main, data-release

- Photometry:
  - alerts: $\sim \pm 0.01\text{mag}$, extrapolated, best-effort calibration
  - data release: $\sim \pm 0.001\text{mag}$, internal, best-possible calibration

- Spectra:
  - alerts: no photo calibration; basic wavelength calibration
  - data release: full spectrophotometric calibration

- Positions:
  - Alerts: preliminary positions $\sim \pm 0.1$ arcsec
  - Data release: positions $\sim \pm 24$ μarcsec at end of mission
The Einstein Cross (left) and HE0435-1223 (right) with Gaia astrometric positions placed over HST images. Gaia's on-board system was able to detect four images of the distant quasar in both cases and the intervening lens at the middle of the Einstein Cross. The positions are supplied by the Gaia Initial Data Treatment in a routine mode, with a very preliminary attitude determination. The magnitude of the images ranges from 17 to 19 and the astrometric accuracy of each position in this preliminary reduction is around 100 mas. It will be much improved during the global astrometric processing where spacecraft attitude will also be solved together with the source astrometry.
Science Alerts: Interfaces

- **MDB**
  - Gaia observations

- **DPCI**
  - Gaia observations + calibrations

- **Observers**
  - Follow-up observations

- **Science Alerts**
  - Alerts + source histories
  - Thematic selections

- **Professional scientists**
  - Alerts + source histories

- **Citizen scientists**
  - Alert records
  - Alert records
AlertPipe

• **Calibration**
  - Two calibrations available:
    - Homegrown - based on UberCal [Koposov]
    - CU5 large scale
  - Both are being tested now

• **Detection**
  - New Sources with history of non detections in Gaia
  - Strongly Variable Sources

• **Classification**
  - Spectral [Blagorodnova]
  - Lightcurve
  - Environment
ANOMALY DETECTION SYSTEM
Run daily in Cambridge

object type

new

various detection criteria

upward

old

downward

astrometric

brighter than 19 mag*

from 2017 (tbc)

• transients
• supernovae
• novae
• DNe
• TDE
• AGN flares
• GRB OT
• M-dwarf flares

• microlensing
• dwarf novae
• supernovae on top of galaxies
• novae
• Be stars
• AGN flares
• FUOJs, EXOJs

• RCrB
• DY Per
• single eclipses
• dark clouds

* tunable parameter, will evolve during the mission

Łukasz Wyrzykowski
Detection

We make use of all measurements down to $G=22$ (i.e. fainter measurements are not included in lightcurves). Recall detection limit for Gaia is 20.7

For a source to generate an Alert, either:

- median of historic transits must have $G \leq 19.0$, or
- the alerting transit must be $G \leq 19.0$

Bumps or Dips must change brightness by $\geq 1$ magnitude.

New sources must reach 19th mag
Main operations to date

- Ingest mission2 database
- Publish alerts
- Ingest mission5
- Rematch
- Test

Data segment 0 to Seg. 1 timeline:
- Aug 14 to Sep 15

Status summary

- AlertPipe is resting between data segments
- Publication of new alerts is suspended
- All data of segment 0 have been processed
- Nearly all data from segment 1 have been ingested
- Rematching has been completed
Year 1: in a nutshell

From 13 Oct 2014 — 9 Jun 2015

297 IDT runs processed (204..517)

~16 billion transits ingested

~52 million alert candidates

275 published alerts

see talks from Campbell, Fraser, Blagorodnova, Wyrzykowski, Wevers
Year 1: Operations

- Last year we ran in two modes:
  - **SKDetector**
    - Flux changes for known sources in external catalogues (SDSS, VST, 2MASS)
    - Using fluxes summed in large apertures (to protect against XMatch issues)
    - biased (in favour of eruptive variable stars, and near nuclear transients)
  - **AlertPipe**
    - Significant upfront filtering to minimize contamination:
      - exclusion radius for stars < 16
      - exclude Galactic Plane, Ecliptic Plane
      - require near Galaxy
      - biased (in favour of standard SNe)
galactic coordinates

Scan coverage on 09 Nov 2015

No of scans (log scale)
Filtering

We have:

- $\sim 10^8$
- $\sim 10^5$
- $\sim 1$

We need:

- $\sim 10^8$
- $< 10^3$
- $\sim 10$
EYE-BALLING

further detailed inspection of candidates

checking other Gaia detections nearby

false alert

-> spectrum suggests contamination from the host

-> cross-matching problem

-> old source observed again with new sourceid

checking Gaia BPRP spectra
EYE-BALLING

further detailed inspection of candidates

checking other Gaia detections nearby

checking Gaia BPRP spectra

=> Gaia15aek

Supernova type IIP 2 weeks past max
Why so many candidates?

- Spurious transits (VPU duplicates)
- Spurious new sources (diffraction spikes)
- Wrong light curves (bad source-transit matching)
- Running without calibration
- SSOs, periodic variables not excluded
- Internal mistakes with scan coverage
HST image credit: NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA)
Gaia image credit: ESA/Gaia/DPAC/UB/IEEC
Removing Contaminants

• Once we turned off AlertPipe, we started to work on contaminants.

• The goal was to minimise the alert rate without excluding large areas of sky (crowded regions and the ecliptic plane)…

• (although we can always do this as a backup)

• We are combining new data from onboard Gaia, IDT processing, and our own flags to reduce the Alert rate caused by false alarms.

• Current Alert Rates (from reruns of historic data) are 100s-1000s per day (depending on scan area)

• This means we can now run automated filtering and classification algorithms: Lightcurve Classifier (Random Forest), Spectral Classifier (Blagorodnova et al. 2014), XM and Environment Analysis
BP/RP spectral classification

Figure 12. Confusion matrices for the bright end. The X axis represents the class type predicted by the classifier and the Y axis represents the true type. The number in parenthesis indicates 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.

Figure 13. 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 indicates the number of spectra used in the test set. The percentages are 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.

Figure 14. Performance of redshift parameter estimation for the PESSTO dataset. Estimated values for redshift are plotted against the true values from the spectral archive.

These diffraction spikes are inherent in the trade-off we make between completeness and level of false detections.
All my flagged transits

UCAC4 source at (0,0) vmag=8.9

transits
alerts
ucac4

Diana Harrison
My whitelisted transits

UCAC4 source at (0,0) vmag=8.9

diana harrison
A lot of the kept alerts are *new* (no history) or have few point in their historical light curves

- Diana Harrison and Guy Rixon (IoA) have been implementing and testing black-list and low-quality flags
- Will be documented in a paper next summer, and on our webpages
Manual vs auto operation

Manual operation (last year)

• $\sim 10^{5-6}$ candidates/day

• Human selection of alerts

• Slow!

• $\sim 1$ alerts/day

• Classification after publication

Planned operation (mid Nov)

• $\sim 100$ candidates/day

• Automatic selection

• Quicker

• $\sim 10$ alerts/day

• Classification before publication
Automated Operation

We propose to start *publishing* automatically generated candidates, with a minimum of human selection (i.e. junk).

We aim to start this in **January**.

We will start testing it internally in ~weeks.

We can turn it on sooner if we are ready.

Follow-up will help fine tune the filtering and classification algorithms (and reduce the contaminant rate).

**Full operation (by Jan)**

- ~100 candidates/day
- near-automatic selection
Planned operations

We are going to be a little late; revised goal is now Jan.
Data release scenario

- Based on assumption of smooth development and operations!
- Each release updates the previous and contains significant new additions
- Science alerts started already

**Mid-2016** Positions + $G$ magnitude (≈ all sky, single stars)
  - Includes more often scanned Ecliptic pole regions
  - Hundred Thousand Proper Motions (Hipparcos-Gaia, ≈ 50 µas/yr)

**Early 2017** radial velocities for bright stars, two-band photometry, and full astrometry ($\alpha$, $\delta$, $\varpi$, $\mu_\alpha *$, $\mu_\delta$) where available.

**2017/2018 (TBC)** full astrometry, orbital solutions for short period binaries, ($G_{BP} - G_{RP}$), BP/RP Spectrophotometry and astrophysical parameters, radial velocities, RVS spectra

**2018/2019 (TBC)** Updates on previous release — including more sources, source classifications, multiple astrophysical parameters, variable star solutions and epoch photometry for them, solar system results

**2022 (TBC)** Everything
Alert record (VOEvent)

Your format here
(Suggestions invited)

E.g. http://gsaweb.ast.cam.ac.uk/alerts/Gaia15acx/VOEvent (These resources not released yet; URL paths might change)

• Details not designed yet

• We want to get it right once, not to churn the format

• Input invited from VOEvent experts at this meeting

• (We don’t plan to do custom formats for different consumers)