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+students and OGLE team

and follow-up partners (YOU!)
# GAIA AS A TRANSIENT SURVEY

<table>
<thead>
<tr>
<th></th>
<th>Gaia</th>
<th>OGLE-IV</th>
<th>Catalina Sky Survey</th>
<th>PTF</th>
<th>LSST (from 2020??)</th>
</tr>
</thead>
<tbody>
<tr>
<td>deg$^2$ day$^{-1}$</td>
<td>$\approx 1230$</td>
<td>150</td>
<td>1200</td>
<td>1000</td>
<td>5000</td>
</tr>
<tr>
<td>Avg Cadence</td>
<td>$\approx 30$ days</td>
<td>20min–5d days</td>
<td>14 days</td>
<td>5 days</td>
<td>4 days</td>
</tr>
<tr>
<td>Limiting mag</td>
<td>$\sim 20.5$</td>
<td>22</td>
<td>19,5</td>
<td>21</td>
<td>r=24.7</td>
</tr>
<tr>
<td>$f_{\text{sky}}$</td>
<td>all sky</td>
<td>0,07</td>
<td>0,6</td>
<td>0,2</td>
<td>&lt;0.48</td>
</tr>
</tbody>
</table>

+ PSI  
+ ASAS-SN  
+ MASTER  
+ MOA-II
PROCESSING REAL GAIA DATA

Delay between observation and end of processing

- 293573635 transits analysed
- 155527 HPs completed
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.
ANOMALY DETECTION SYSTEM
Run daily in Cambridge

object type

new

various detection criteria

old

upward

donward

astrometric

from 2017 (tbc)

brighter than 19 mag*

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
FUOrs, EXOrs

RCrB
DY Per
single eclipses
dark clouds

* tunable parameter, will evolve during the mission

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ANOMALY DETECTION SYSTEM
Classification

object type

new
``supernova``
artefact

old
bump
dip
ANOMALY DETECTION SYSTEM
Cross-match with archives

SDSS

DSS

OGLE-IV

+WISE
+2MASS
and many others

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ANOMALY DETECTION SYSTEM
Visual inspection of candidates
ANOMALY DETECTION SYSTEM
Internal verification/discussion on candidates

~2 people eyeballing few 100s candidates a day (different filtering)
at least 2 people had to confirm/verify/comment
assign Gaia name and publish if agreed
## PUBLICATION OF ALERTS

http://gaia.ac.uk/selected-gaia-science-alerts

### Gaia in the UK

Taking the Galactic Census

<table>
<thead>
<tr>
<th>Name</th>
<th>UTC timestamp</th>
<th>RA</th>
<th>Dec</th>
<th>AlertMag</th>
<th>HistMag</th>
<th>HistStdDev</th>
<th>Class</th>
<th>Comment</th>
<th>Published</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaia15agi</td>
<td>2015-01-24</td>
<td>43.08181</td>
<td>60.57638</td>
<td>18.97</td>
<td>Not known</td>
<td>Not known</td>
<td>unknown</td>
<td>Galactic plane red transient, brightened from 20 to 18 mag in 100days</td>
<td>3 Jun 2015, 15:16</td>
</tr>
<tr>
<td>Gaia15agh</td>
<td>2015-05-25</td>
<td>181.02133</td>
<td>14.06805</td>
<td>17.58</td>
<td>Not known</td>
<td>Not known</td>
<td>unknown</td>
<td>candidate SN in spiral starforming SDSS galaxy (z=0.043)</td>
<td>2 Jun 2015, 15:06</td>
</tr>
<tr>
<td>Gaia15agd</td>
<td>2015-05-29</td>
<td>171.57245</td>
<td>28.36723</td>
<td>18.42</td>
<td>Not known</td>
<td>Not known</td>
<td>unknown</td>
<td>SN candidate in low surface brightness starburst galaxy at z=0.03</td>
<td>2 Jun 2015, 00:09</td>
</tr>
<tr>
<td>Gaia15agc</td>
<td>2015-05-30</td>
<td>184.59674</td>
<td>35.61824</td>
<td>17.84</td>
<td>Not known</td>
<td>Not known</td>
<td>unknown</td>
<td>hostless bright transient with SN-like spectrum in BP/RP</td>
<td>2 Jun 2015, 00:02</td>
</tr>
</tbody>
</table>

Łukasz Wyrzykowski
ALERTS SO FAR

Scan coverage at HEALPix level 8 on 17 Jun 2015

EQUATORIAL MAP

No of scans/HEALPix (log scale)

http://gsaweb.ast.cam.ac.uk/alerts/maps/alerts-equatorial-coverage-map.png
ALERTS SO FAR

Scan coverage at HEALPix level 8 on 17 Jun 2015

http://gsaweb.ast.cam.ac.uk/alerts/maps/alerts-galactic-coverage-map.png
http://gsaweb.ast.cam.ac.uk/alerts/maps/alerts-ecliptic-coverage-map.png
ALERTS SO FAR

SDSS

by Nadia Blagorodnova

Łukasz Wyrzykowski
For release in late 2015

Note: alerts are currently published with preliminary calibrations for photometry, spectroscopy and astrometry but those will improve with time.
GAIA ALERTS IN NUMBERS

40 million of observations on average processed everyday up to 180 million seen in one day

48h typical delay between observation and processing (min 20h)

1-2h typical processing time (80h in extreme case)

0.5-2% of observations produce an alert every day

~4 new candidate transients selected manually every day

271 alerts so far (166 in 2015)

55 Gaia alerts found also by other surveys (217 new)

verification phase lasted from Aug 2014 until Jun 2015
PUBLICATION OF ALERTS

787 objects were discovered by PS1 (prof)
153 objects were discovered by CRTS (prof)
113 objects were discovered by Gaia Photometric Science Alerts programme (prof)
86 objects were discovered by All Sky Automated Survey for SuperNovae (ASAS-SN) (prof)
81 objects were discovered by OGLE-IV wide field survey (prof)
64 objects were discovered by DECam (prof)
56 objects were discovered by PTF (prof)
50 objects were discovered by Subaru/Hyper Suprime-Cam (prof)
38 objects were discovered by La Silla-QUEST (prof)
32 objects were discovered by MASTER (prof)

http://www.rochesterastronomy.org/sn2015/snstats.html


Atel #7139: A. S. Piascik, J. A. Steele (Liverpool JMU) on 25 Feb 2015; 12:13 UT

Atel #7087: I. Shivers, A. V. Filippenko (UC Berkeley) on 17 Feb 2015; 06:54 UT

Atel #7068: L. Le Guillou (LBNHE), A. Mira (LBNHE), S. Baumont (LBNHE), N. Chotard (IPNL), P. F. Leget (LPC-Clermont), J. Anderson (ESO), N. Elias-Rosa (INAF-OAPD), C. Incerca (QUB), K. Maguire (ESO), S. Smartt (QUB), K. W. Smith (QUB), M. Sullivan (Southampton), S. Valentijn (LCOGT), O. Yaron (Weizmann), D. Young (QUB), Ilan Manulis (Weizmann), C. Balty, N. Ellman, E. Hadjiyska, R. McKinney, D. Rabinowitz, S. Rostami (Yale University), U. Feindt, M. Kowalski (University Rostock), P. Nugent (LBL Berkeley) on 14 Feb 2015; 17:07 UT

Gaia15add and Gaia15adj transients confirmed by Euler imaging

Spectroscopic classification of Gaia15abn as a Type Ia Supernova

Spectroscopic Classification of 7 Optical Transients

PESSTO spectroscopic classification of optical transients

Spectroscopic classification of Gaia Alerts

Gaia discovery of a Supernova candidate in ESO 297- G 008

Gaia15abn transient confirmed by Mercator imaging
ALERTS VERIFICATION PHASE
Gaia Follow-Up Network for Transient Objects = Gaia-FUN-TO

- verification if the object exists
- verification of errors of the pipeline and data
- detailed classification and verification of Gaia classification
- network composed of robotic and manually operated telescopes
- reaction within 24h
- automatised reductions
- central data repositories (photometry and spectroscopy)
- homogenous calibrations in Calibration Server:

Photometry:
- Loiano (Italy)
- Warsaw, Wrocław (Poland)
- Euler, Mercator (Swiss time)
- ASV (Serbia)
- RTT150, RTT100 (Turkey)
- pt5m
- Liverpool Telescope
- and many others

Spectroscopy:
- NTT (La Silla)
- WHT (La Palma)
- INT (La Palma)
- Asiago 1.8m
- SAAO 1.9m
- Loiano 1.5m
271 alerts so far (166 in 2015)

112 alerts followed-up with spectra (41%)

NTT, LT, INT, WHT, Lick, AAT

by Nadia Blagorodnova
271 alerts so far (166 in 2015)

143 alerts followed-up photometrically (53%)

~15,000 photometric follow-up datapoint collected
FIRST CONFIRMED SUPERNova

Gaia14aaa discovered on 30 Aug 2014

Gaia light curve with detection

Found based on BPRP spectrum match to SN Ia

Confirmation image from Liverpool Telescope

Spectrum from INT confirmed SN Type Ia

Łukasz Wyrzykowski
AM CVN-TYPE TRANSIENT

Gaia14aae

- very rare class of CVs (3rd!)
- candidate SN Ia progenitor
- WD accretes He material from another WD

Period 49.71 min
M1 ≥ 0.782 MSun, T1=13000
M2 ≥ 0.015 MSun

Campbell et al. 2015

Gaia light curve

WHT photometry

WHT spectroscopy

Campbell et al. 2015
EXAMPLES OF ALERTS AND THEIR FOLLOW-UP

Gaia15adb
SN Ia

Gaia15aby
SN Ia
EXAMPLES OF ALERTS AND THEIR FOLLOW-UP

Gaia15afz likely CV

Gaia15afo hostless unknown (CV?)
EXAMPLES OF ALERTS AND THEIR FOLLOW-UP

Gaia15aff microlensing event or var. star

Gaia15agi microlensing event?

Gaia15afp microlensing event?
CONTAMINANTS

numerous very red last moving stars appearing as New Sources
CONTAMINANTS

Alert:

ecliptic coordinates = 1.810217, -0.698089
Identified as planetoid 9197 Endo

raw Gaia data!
SUMMARY

• in 2014/2015 Gaia Alerts worked!
• it was the first ever Gaia data made public
• it delivered the first ever scientific Gaia paper (14aae)
• Gaia Alerts were noticed by the transients community
• tremendous follow-up effort (spec+photo)
• photometric follow-up data to be re-reduced and published soon (work in progress, more on Friday)

WELL DONE TO ALL!