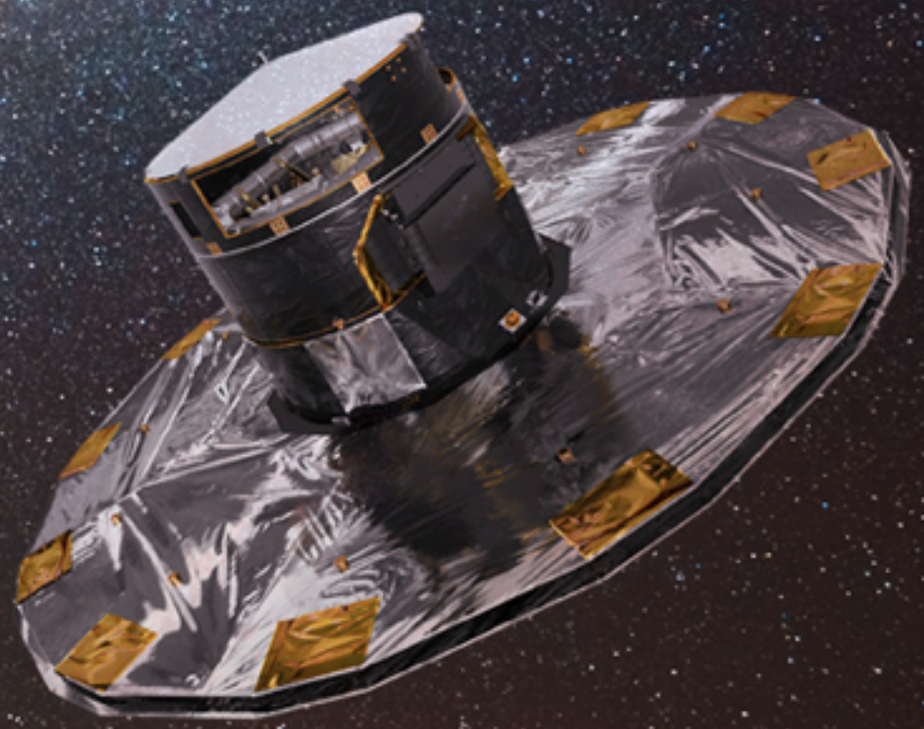
# First Year of Gaia Alerts

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# COLLABORATORS

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Krzysztof Ulaczyk -> *Warwick*
+students and OGLE team

and follow-up partners (YOU!)

Gaia DPAC

*Łukasz Wyrzykowski*

# GAIA AS A TRANSIENT SURVEY

| | Gaia | OGLE-IV | Catalina Sky Survey | PTF | LSST (from 2020??) |
|---|---|---|---|---|---|
| $deg^2\ day^{-1}$ | **≈ 1230** | 150 | 1200 | 1000 | 5000 |
| Avg Cadence | **≈ 30 days** | 20min–5d days | 14 days | 5 days | 4 days |
| Limiting mag | **~20.5** | 22 | 19,5 | 21 | r=24.7 |
| $f_{sky}$ | **all sky** | 0,07 | 0,6 | 0,2 | <0.48 |

+ PS1
+ ASAS-SN
+ MASTER
+ MOA-II

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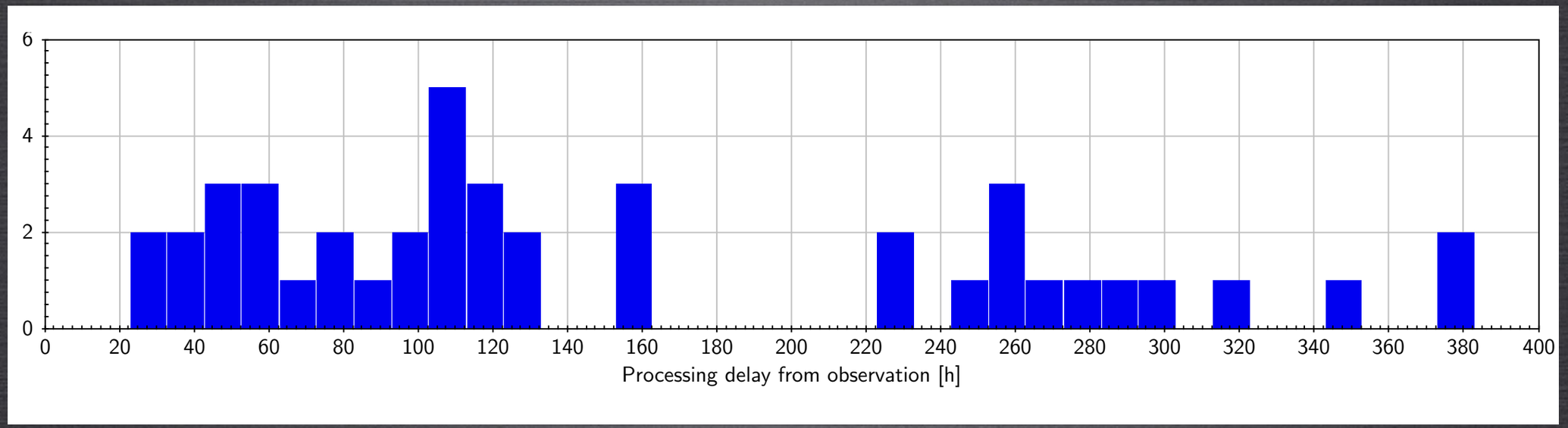
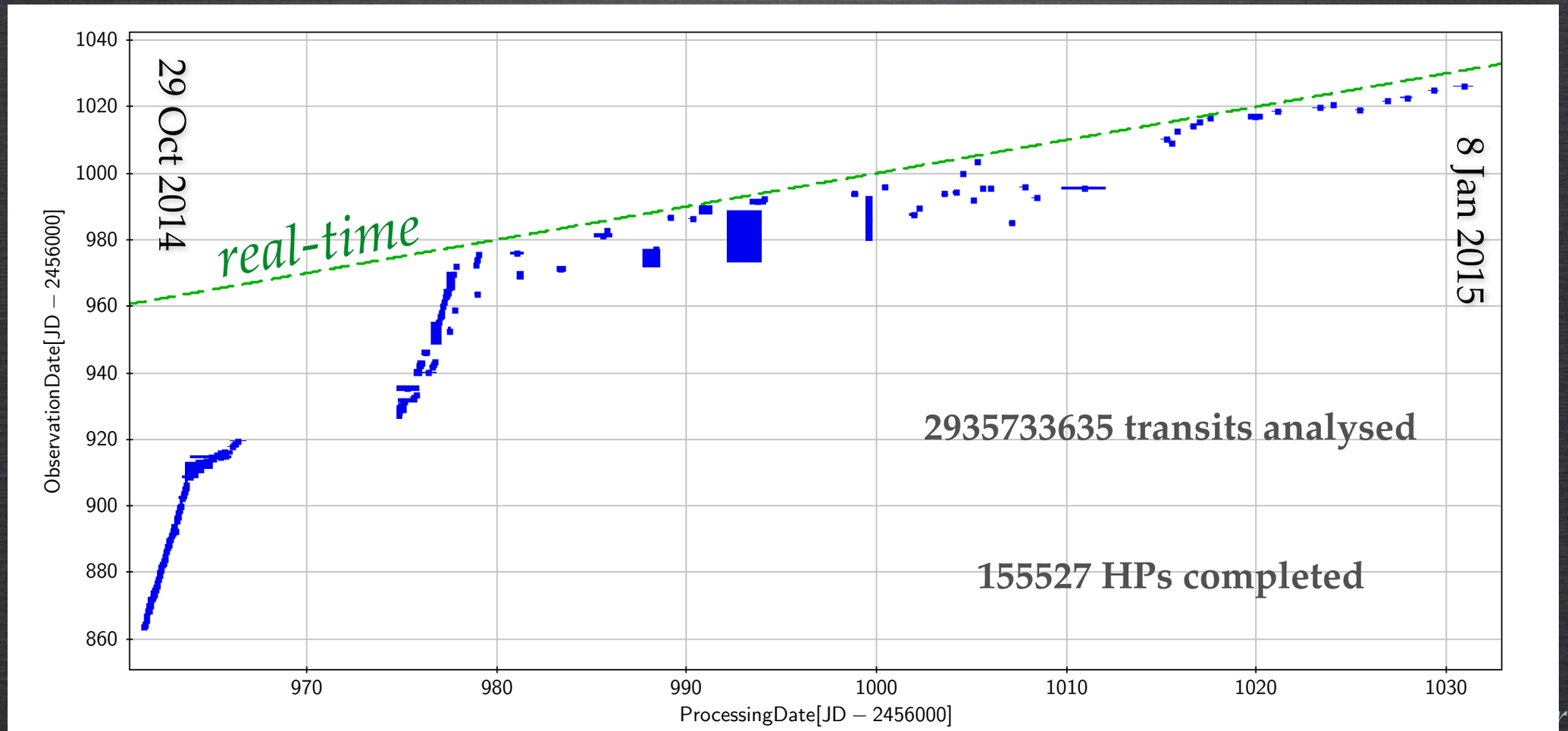
# PROCESSING REAL GAIA DATA

## Delay between observation and end of processing

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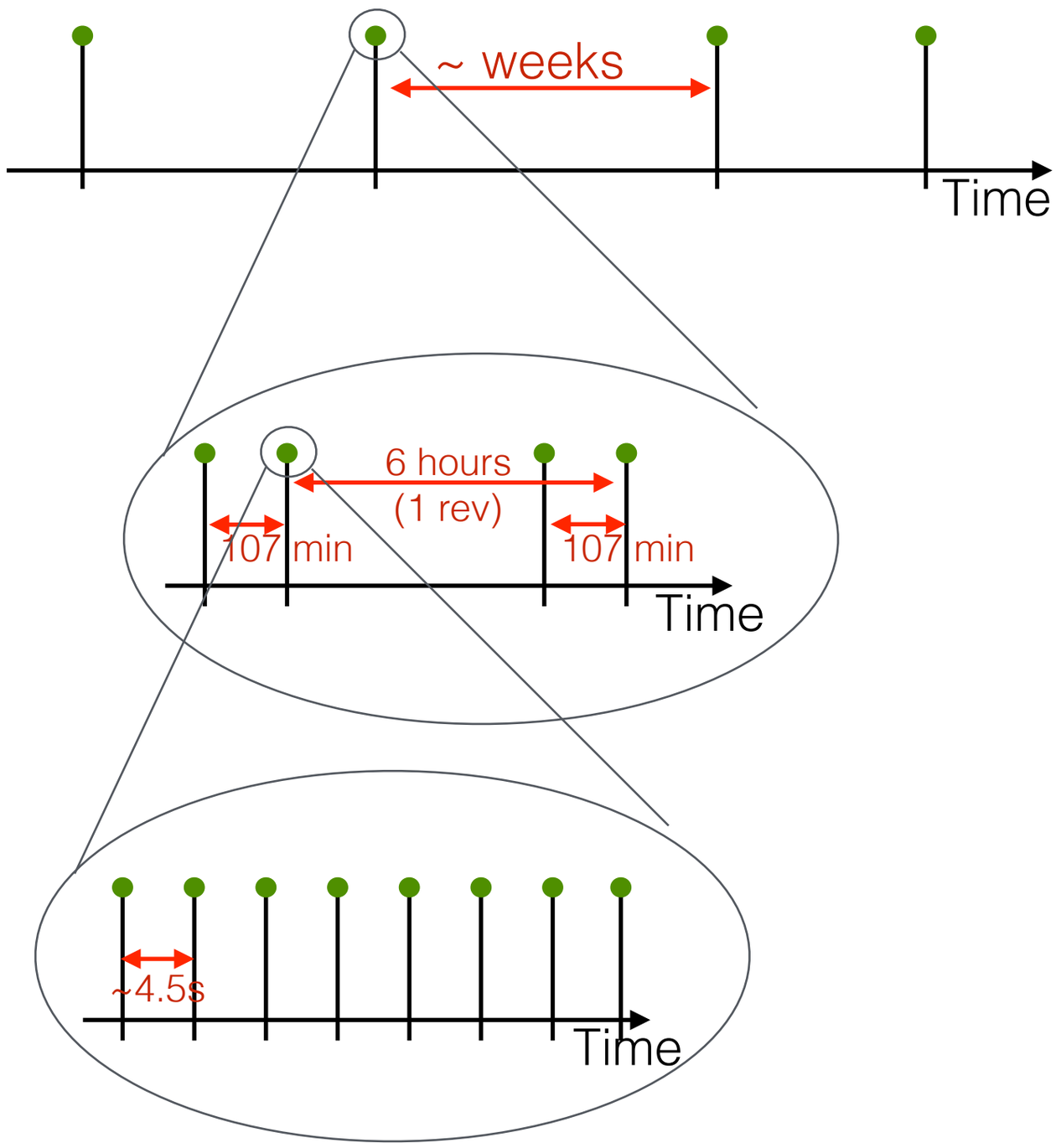
# SAMPLING OF LIGHT CURVE




Each source observed many time 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

brighter than 19 mag*

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

various detection criteria

old

upward

- microlensing
- dwarf novae
- supernovae on top of galaxies
- novae
- Be stars
- AGN flares
- FUOrs, EXOrs

downward

- RCrB
- DY Per
- single eclipses
- dark clouds

from 2017 (tbc)

astrometric

- microlensing
- AGNs

* tunable parameter, will evolve during the mission

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# ANOMALY DETECTION SYSTEM

## Classification


``supernova''

bump

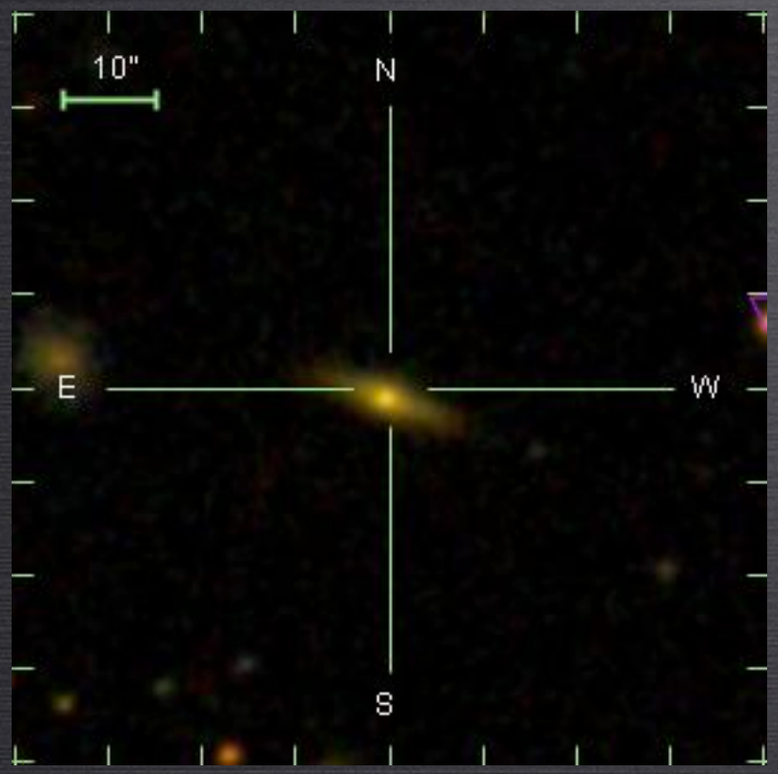
artefact

dip

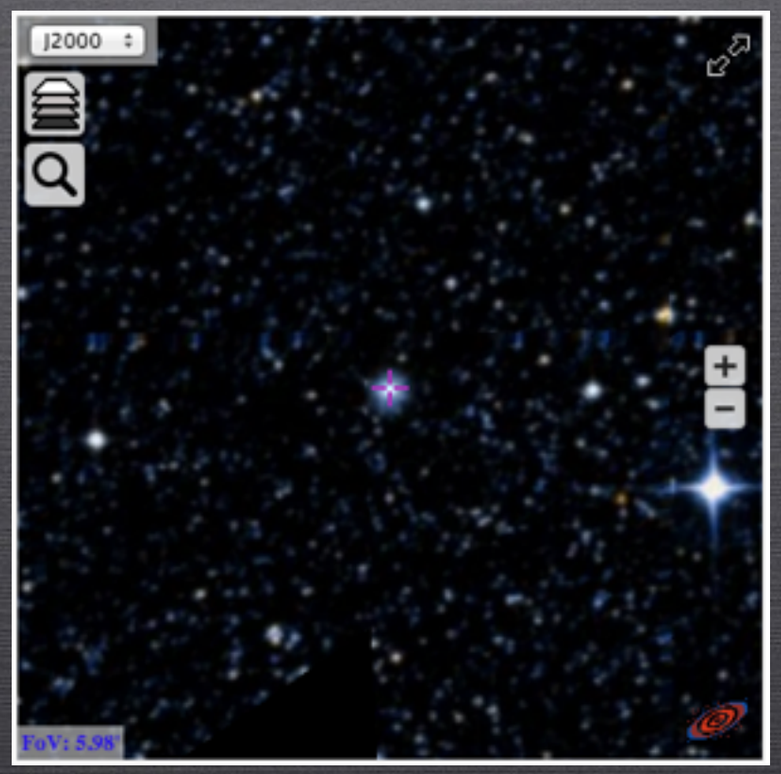
# ANOMALY DETECTION SYSTEM

## Cross-match with archives

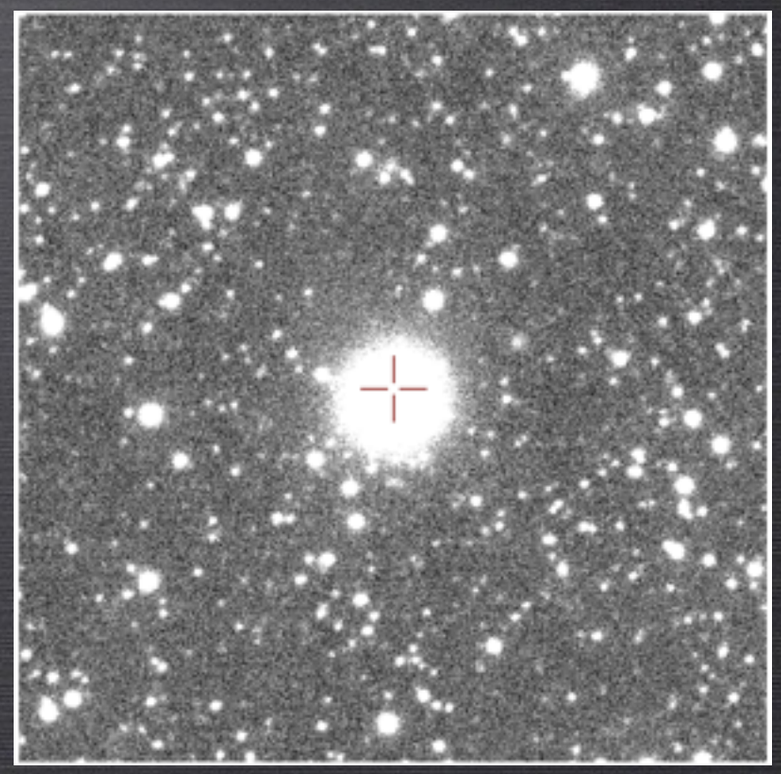
SDSS




DSS




OGLE-IV



+WISE
+2MASS
and many others

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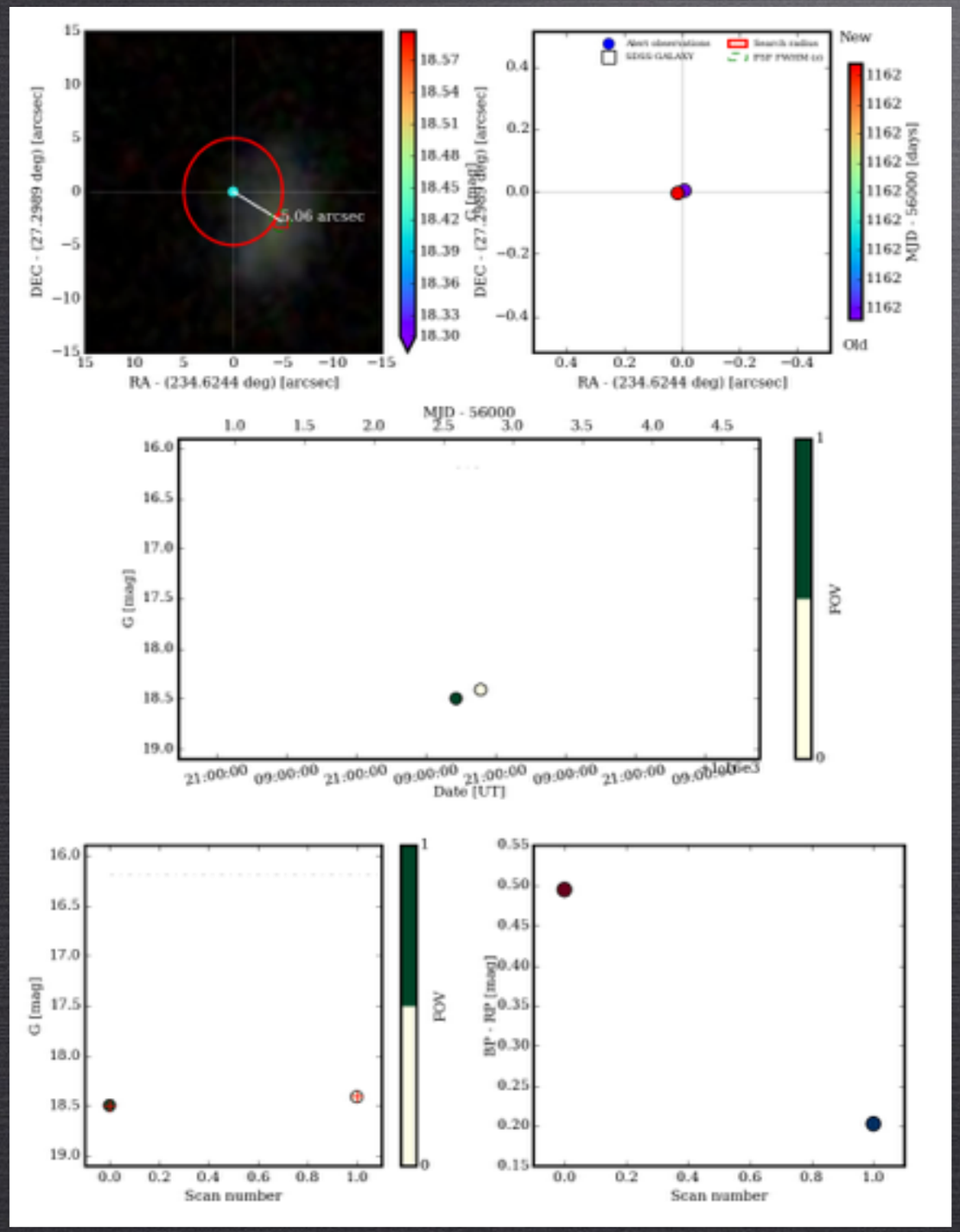
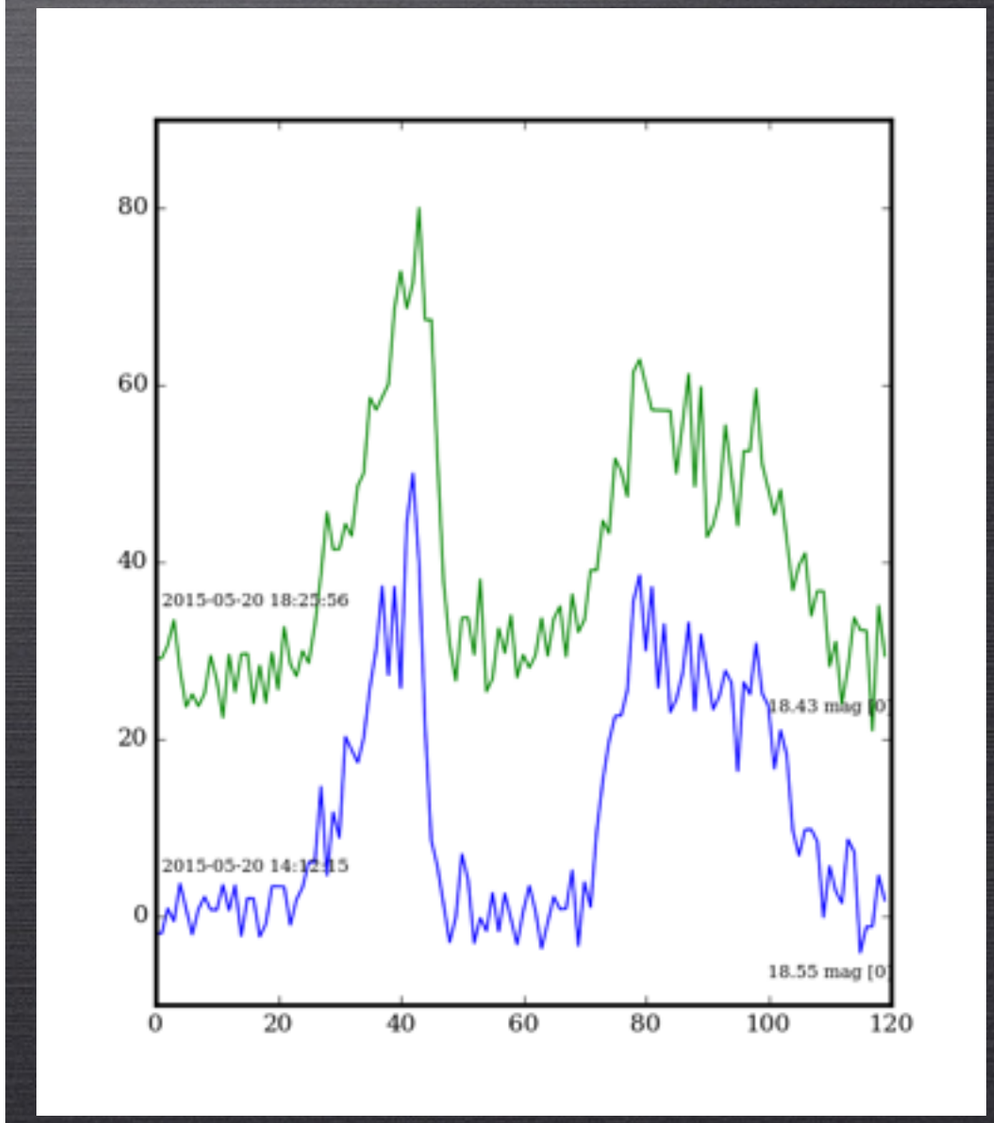
# ANOMALY DETECTION SYSTEM

## 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

| Date | Cand Name | Runid | Yes Eyeballers | No Eyeballe | Comments | Approved for publication? | Published? |
|---|---|---|---|---|---|---|---|
| | GaiaCandid15-0184 | 503 | NBM, LW,STH? | | SN close to galaxy core (2.13 arsec). It does not seem a binary star from the spectrum. The SN is too far away to be one of the spurious detections. LW: too red for a young SN, but let's try. I'd say the spectrum is galaxy dominated :( | STH | Gaia15afy |
| | GaiaCandid15-0185 | | LW,NBM,STH? | MF,HC | LW: OldSource channel - SDSS galaxy getting brighter from 20 to 19 mag, BPRP change a bit, but not very blue. Still, clearly change in mag. SDSS gal with spec_z=0.1. cool! this one really seems to be in the nucleus! It has raised over 1 mag. How reliable is the photometry as we change scan angles on this ? Can we run getlc on it and check with a larger aperture or something ? LW: you can see larger aperture photometry in ENV plots. There is clearly a jump in photometry. http://kohav.astrouw.edu.pl/~wyrzykow/cgi-bin/displayEnvironmentHtml.py?sourceid=1307577160902814464&ra=250.968109&dec=27.586195&name=GaiaCandid15-0185. LW: WHY you people do not like this one???? STH - because it's a gradual trand of only <=1 mag in brightness. I thought it was okay. | | |
| 30-05-2015 | GaiaCandid15-0187 | 505 | LW,STH,NBM | | LW: likely CV: from 18.8 to 15 mag in 60 days, change in spec to quite blue, slow rise, or just past maximum already and declining. Nice single source detection. | STH | Gaia15afz |
| | 188 | | LW,STH,NBM | | LW: new blue source on top of very faint SDSS galaxy | STH | Gaia15aga |
| | 190 | | LW,STH,NBM | | new blue source next to gal. NBM: Looks line an old SN IA | STH | Gaia15agb |
| | 191 | 510/511 | LW,sth,NBM | | bright new source 17.8 mag, BPRP looks like SN to my eye, hostless, nothin on SDSS image. STH : yep - looks good | STH | Gaia15agc |
| 1-Jun-2015 | GaiaCandid15-0192 | 510 | NBM,STH, MF | | SN in low surface brightness galaxy classified as starburst at z=0.03. Probable SN II. I could see a bit of H alpha there, so could b 2w old. No detection in other surveys at the moment of writing. STH: looks good | STH | Gaia15agd |

# PUBLICATION OF ALERTS

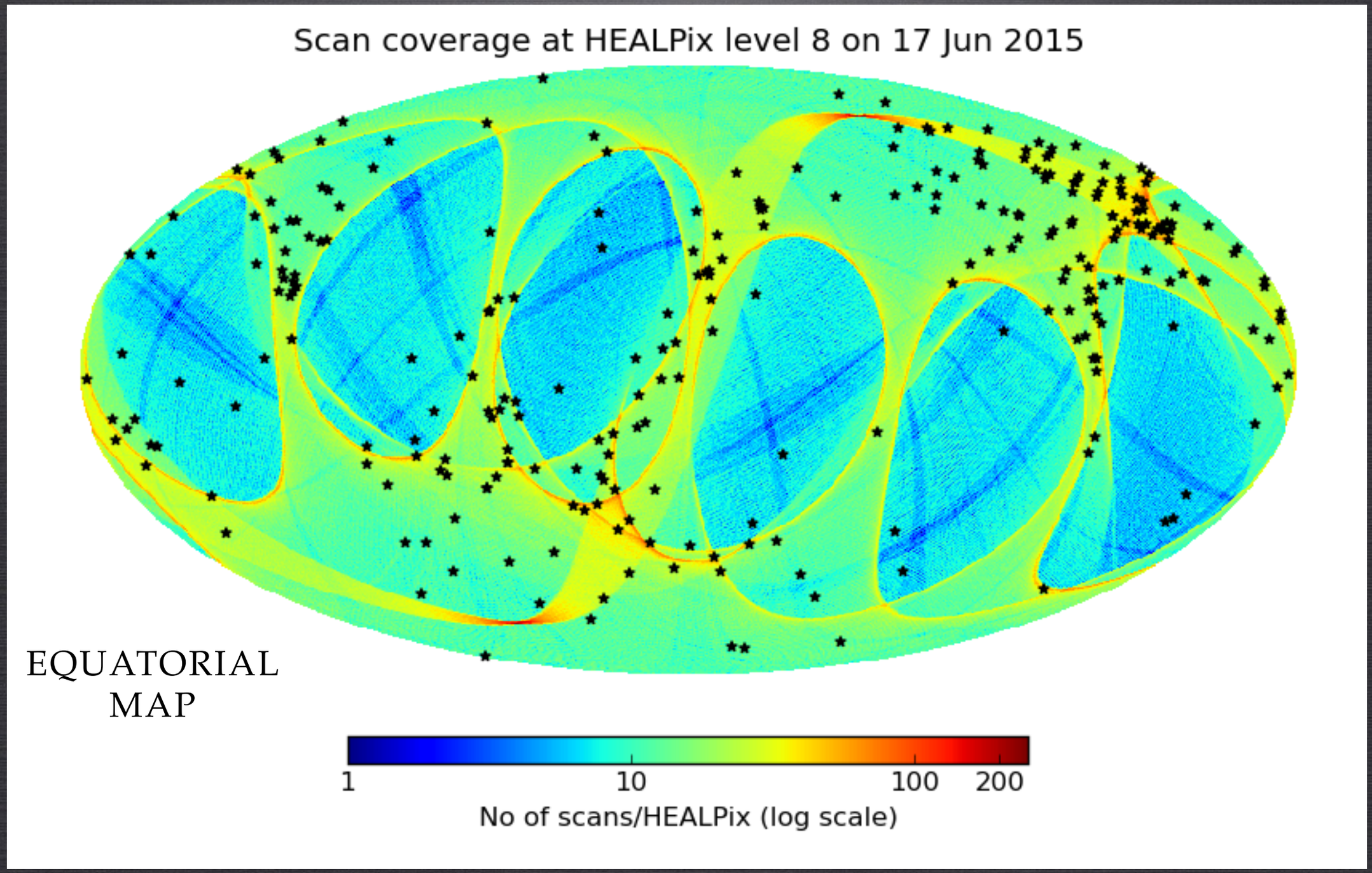
http://gaia.ac.uk/selected-gaia-science-alerts

**Gaia in the UK**

Taking the Galactic Census

| Name | UTC timestamp | RA | Dec | AlertMag | HistMag | HistStdDev | Class | Comment | Published |
|---|---|---|---|---|---|---|---|---|---|
| Gaia15agi | 2015-01-24 09:32:33 | 43.08181 | 60.57638 | 18.97 | Not known | Not known | unknown | Galactic plane red transient, brightened from 20 to 18 mag in 100days | 3 Jun 2015, 15:16 |
| Gaia15agh | 2015-05-25 01:24:24 | 181.02133 | 14.06805 | 17.58 | Not known | Not known | unknown | candidate SN in spiral starforming SDSS galaxy (z=0.043) | 2 Jun 2015, 15:06 |
| Gaia15agg | 2015-05-29 15:41:03 | 64.10105 | -28.49464 | 18.96 | Not known | Not known | unknown | Candidate SN on edge of DSS galaxy | 2 Jun 2015, 13:22 |
| Gaia15agf | 2015-05-29 08:17:25 | 330.62236 | -20.32945 | 18.54 | Not known | Not known | unknown | Candidate young and blue SN on the edge of a DSS galaxy | 2 Jun 2015, 13:19 |
| Gaia15age | 2015-05-29 22:00:29 | 83.48209 | -20.78890 | 16.96 | Not known | Not known | unknown | aka CSS101214:053356-204720 : CV candidate | 2 Jun 2015, 00:15 |
| Gaia15agd | 2015-05-29 07:24:33 | 171.57245 | 28.36723 | 18.42 | Not known | Not known | unknown | SN candidate in low surface brightness starburst galaxy at z=0.03 | 2 Jun 2015, 00:09 |
| Gaia15agc | 2015-05-30 07:38:04 | 184.59674 | 35.61824 | 17.84 | Not known | Not known | unknown | hostless bright transient with SN-like spectrum in BP/RP | 2 Jun 2015, 00:02 |
| Gaia15agb | 2015-05-24 | 134.27829 | 8.72550 | 18.24 | Not | Not known | unknown | blue transient next to galaxy | 31 May 2015 |

# ALERTS SO FAR




EQUATORIAL MAP

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

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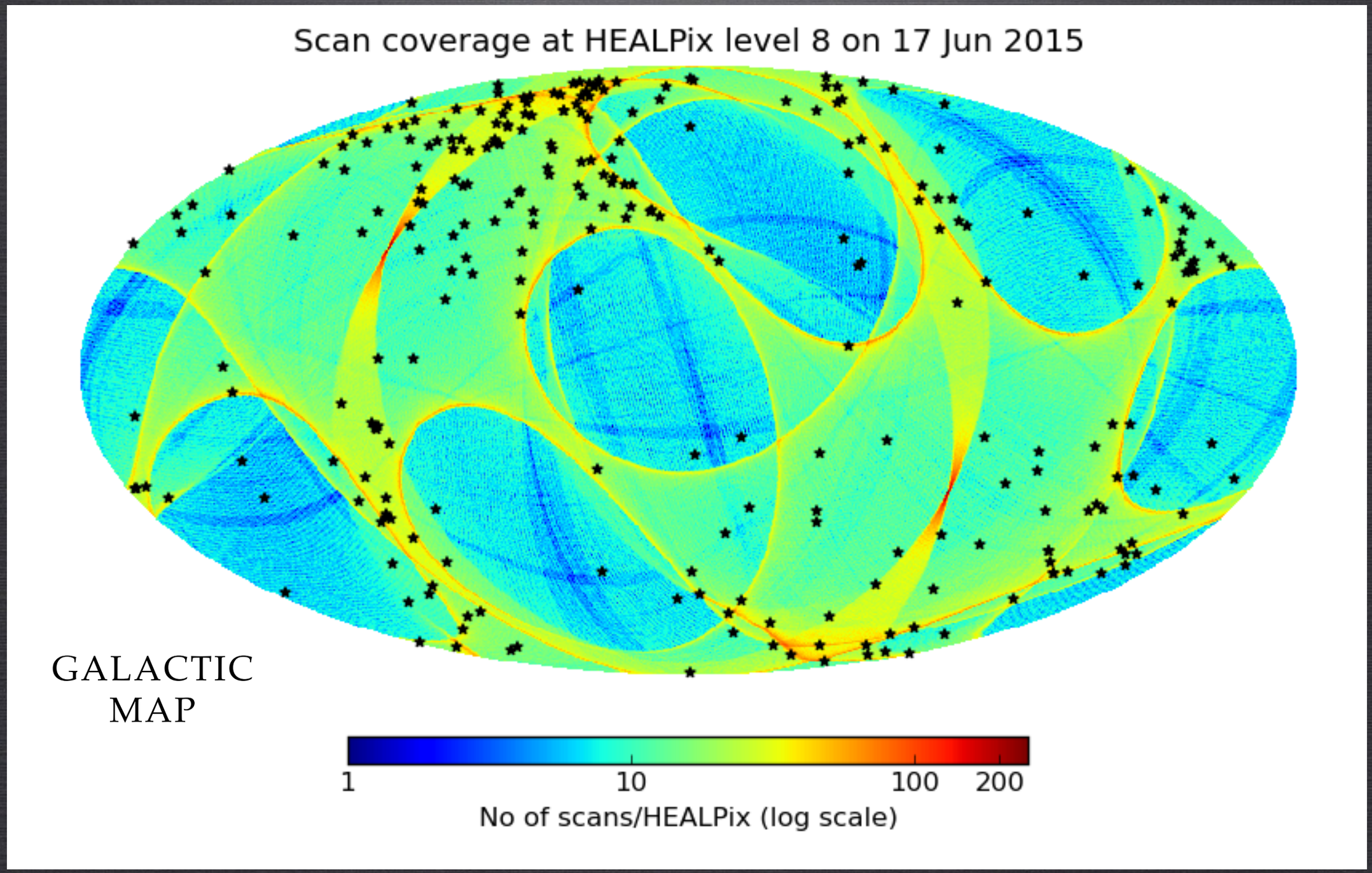
# ALERTS SO FAR

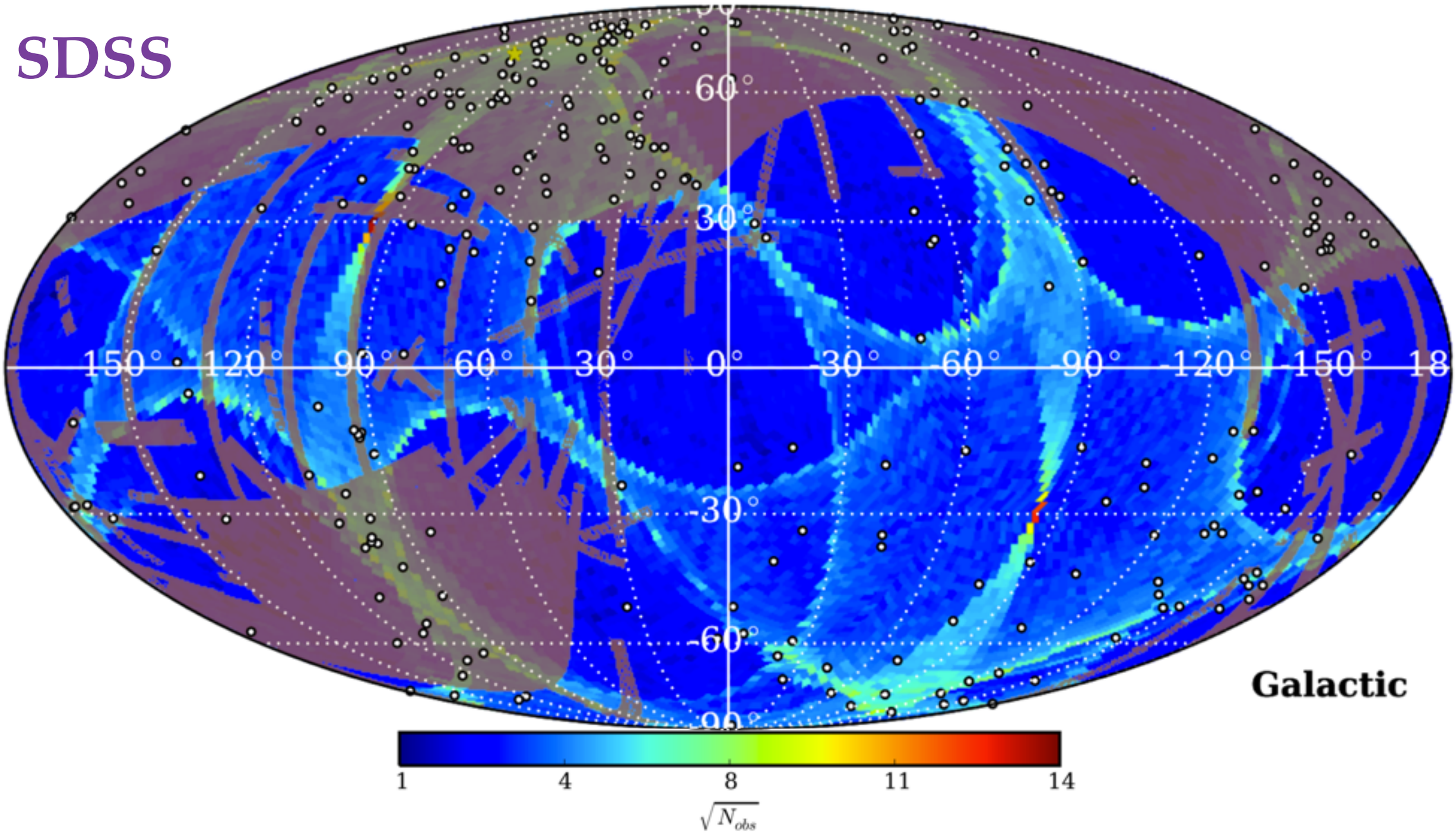



http://gsaweb.ast.cam.ac.uk/alerts/maps/alerts-galactic-coverage-map.png

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

# ALERTS SO FAR

SDSS




*by Nadia Blagorodnova*

*Łukasz Wyrzykowski*

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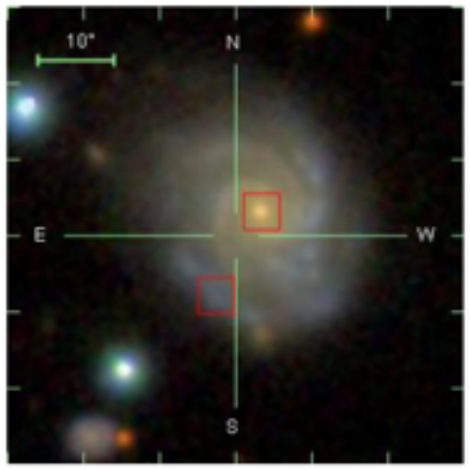
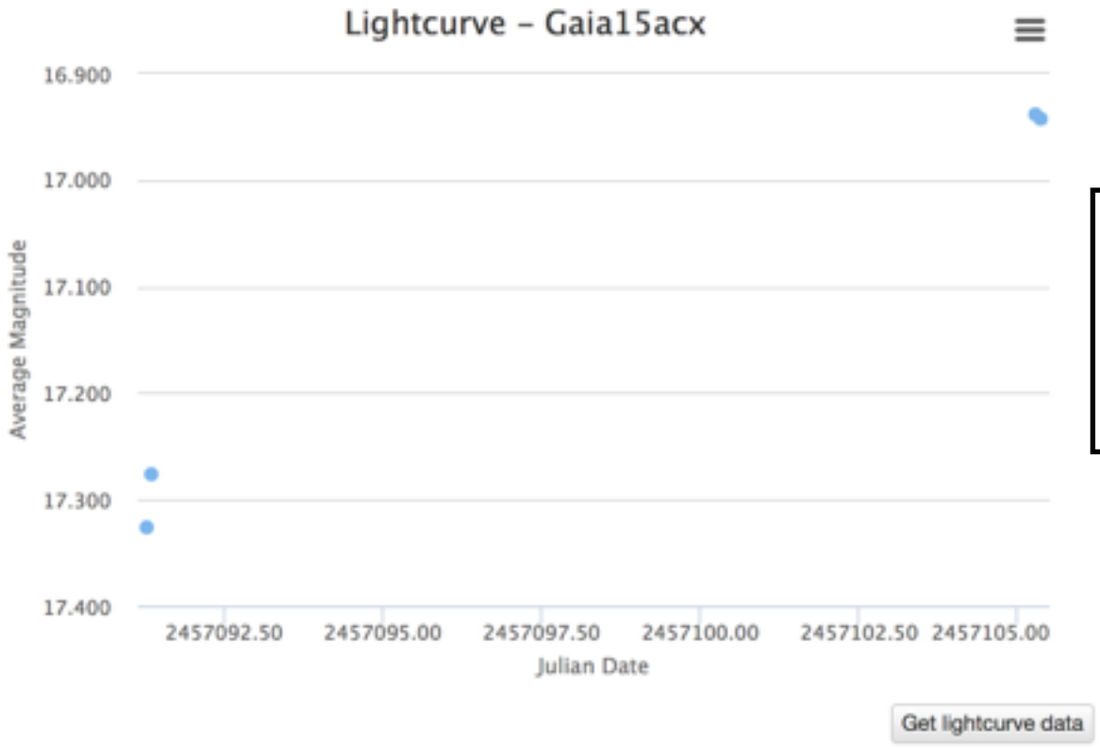
# Gaia15acx



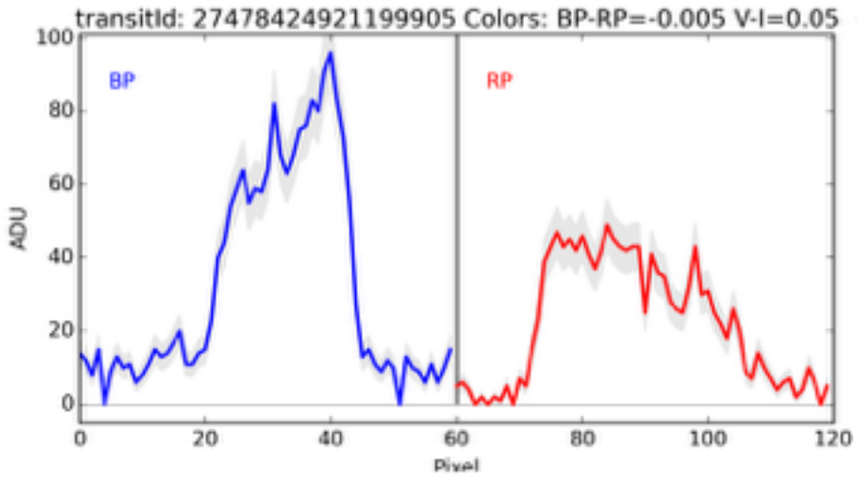

**Other surveys detections**
PSN_J08593491+4555343 magnitude 16.64, distance 1 arcsec, RA 134.895750, dec 45.926028

**Comments**
aka PSNJ08593491+4555343, ATEL #7222

**RA (deg)**
134.89546
**Dec (deg)**
45.92583
**Julian date**
2457091.28
**Observed**
March 9, 2015, 6:38 p.m.
**Alert magnitude**
17.28
**Historic magnitude**
None
**Historic StdDev**
None
**Class**
SN Ia
**Published**
March 18, 2015, 6:03 p.m.




Get lightcurve data




light curve

low-res spectra

**Note:**
alerts are currently published with preliminary calibrations for photometry, spectroscopy and astrometry

but those will improve with time

**For release in late 2015**

# 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

*Łukasz Wyrzykowski*

# 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

**Gaia15add and Gaia15adj transients confirmed by Euler imaging**

ATel #7277; *L. Palaversa, S. Saesen, T. Semaan, N. Mowlavi, L. Eyer (Department of Astronomy, University of Geneva, Switzerland)*
*on 23 Mar 2015; 16:31 UT*

**Spectroscopic Classification of Gaia15abn as a Type Ia Supernova**

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

**Spectroscopic Classifications of 7 Optical Transients**

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

**PESSTO spectroscopic classification of optical transients**

ATel #7068; *L. Le Guillou (LPNHE), A. Mitra (LPNHE), S. Baumont (LPNHE), N. Chotard (IPNL), P-F. Leget (LPC-Clermont), J. Anderson (ESO), N. Elias-Rosa (INAF-OAPd), C. Inserra (QUB), K. Maguire (ESO), S. Smartt (QUB), K. W. Smith (QUB), M. Sullivan (Southampton), S. Valenti (LCOGT), O. Yaron (Weizmann), D. Young (QUB), Ilan Manulis (Weizmann), C. Baltay, N. Ellman, E. Hadjiyska, R. McKinnon, D. Rabinowitz, S. Rostami (Yale University), U. Feindt, M. Kowalski (Universitat Bonn), P. Nugent (LBL Berkeley)*
*on 14 Feb 2015; 17:07 UT*

**Spectroscopic classification of Gaia Alerts**

ATel #7177; *H. Campbell, M. Fraser, S. T. Hodgkin, S. Koposov, N. Blagorodnova (University of Cambridge), L. Wyrzykowski, Z. Kostrzewa-Rutkowska (Warsaw University Observatory), P. Jonker, T. Wevers (University Nijmegen/SRON), M. A.P. Torres (ESO), S. Van Velzen (Johns Hopkins)*
*on 5 Mar 2015; 09:53 UT*

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

ATel #7328; *N. Blagorodnova, H. Campbell, A. Delgado, M. Fraser, S. Hodgkin, D. Harrison, S. Koposov, G. Rixon, N. Walton (University of Cambridge), L. Wyrzykowski, Z. Kostrzewa-Rutkowska (Warsaw University Observatory)*
*on 31 Mar 2015; 18:49 UT*

**Gaia15abn transient confirmed by Mercator imaging**

ATel #7110; *L. Palaversa, T. Semaan, N. Mowlavi, L. Eyer (Department of Astronomy, University of Geneva, Switzerland)*
*on 19 Feb 2015; 15:20 UT*

*Łukasz Wyrzykowski*

# 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

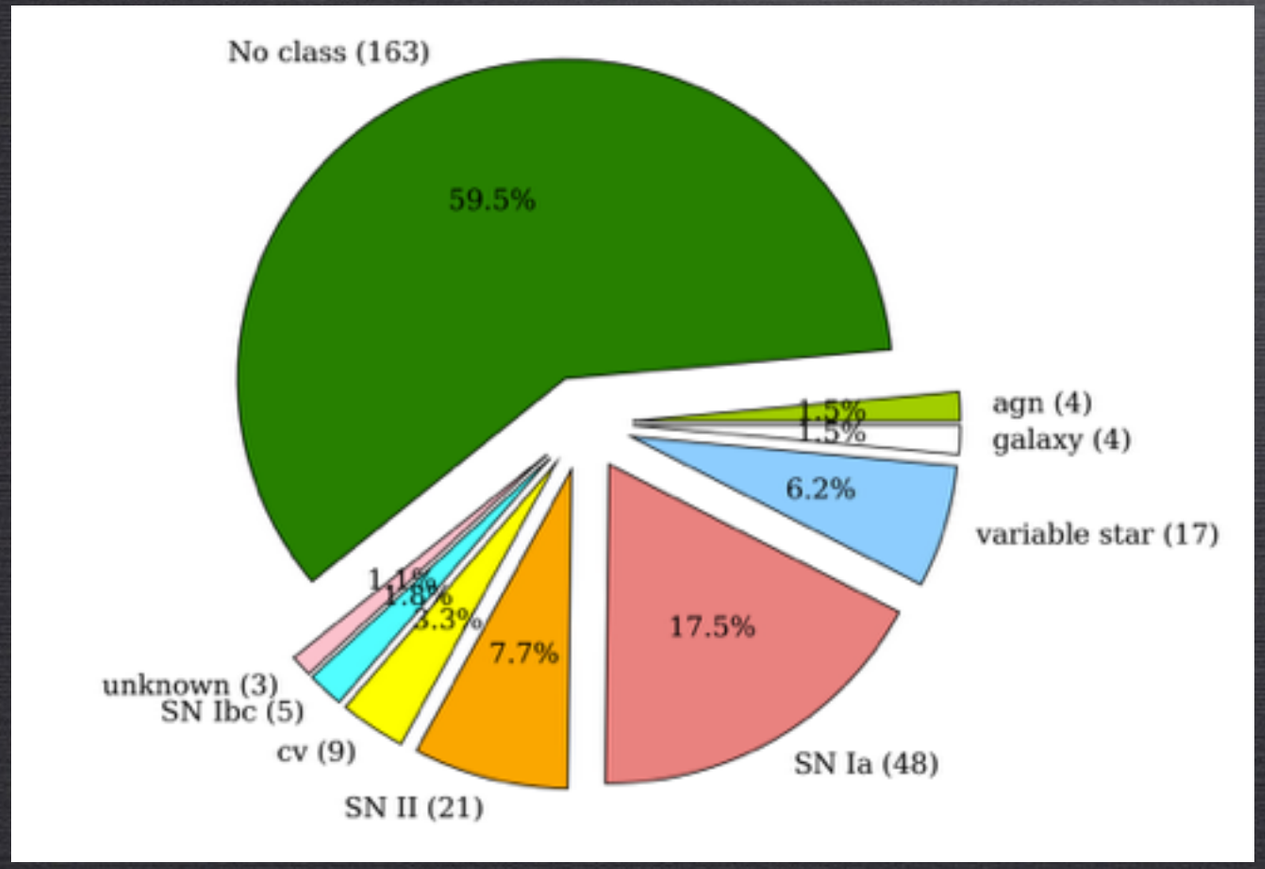
# ALERTS VERIFICATION PHASE

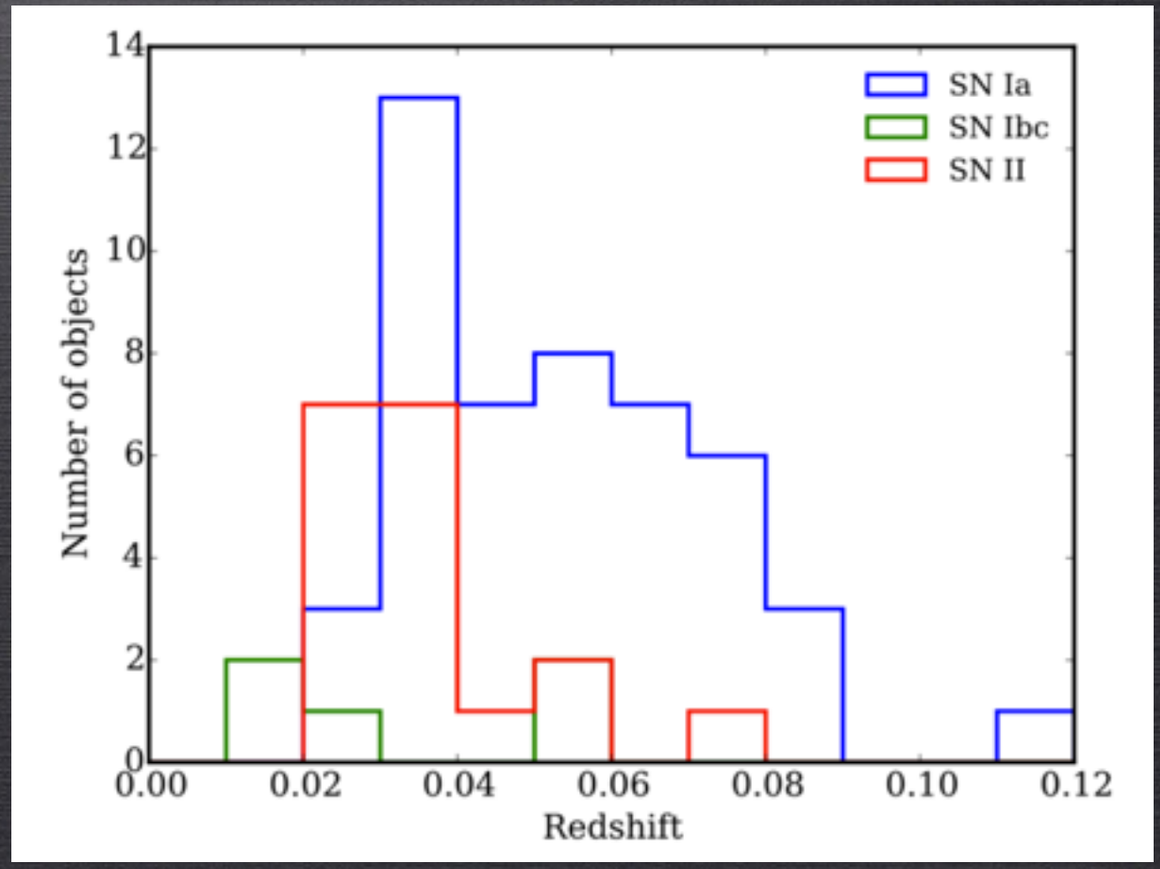
SPECTRA

271 alerts so far (166 in 2015)

112 alerts followed-up with spectra (41%)

NTT, LT, INT, WHT, Lick, AAT




*by Nadia Blagorodnova*

*Łukasz Wyrzykowski*

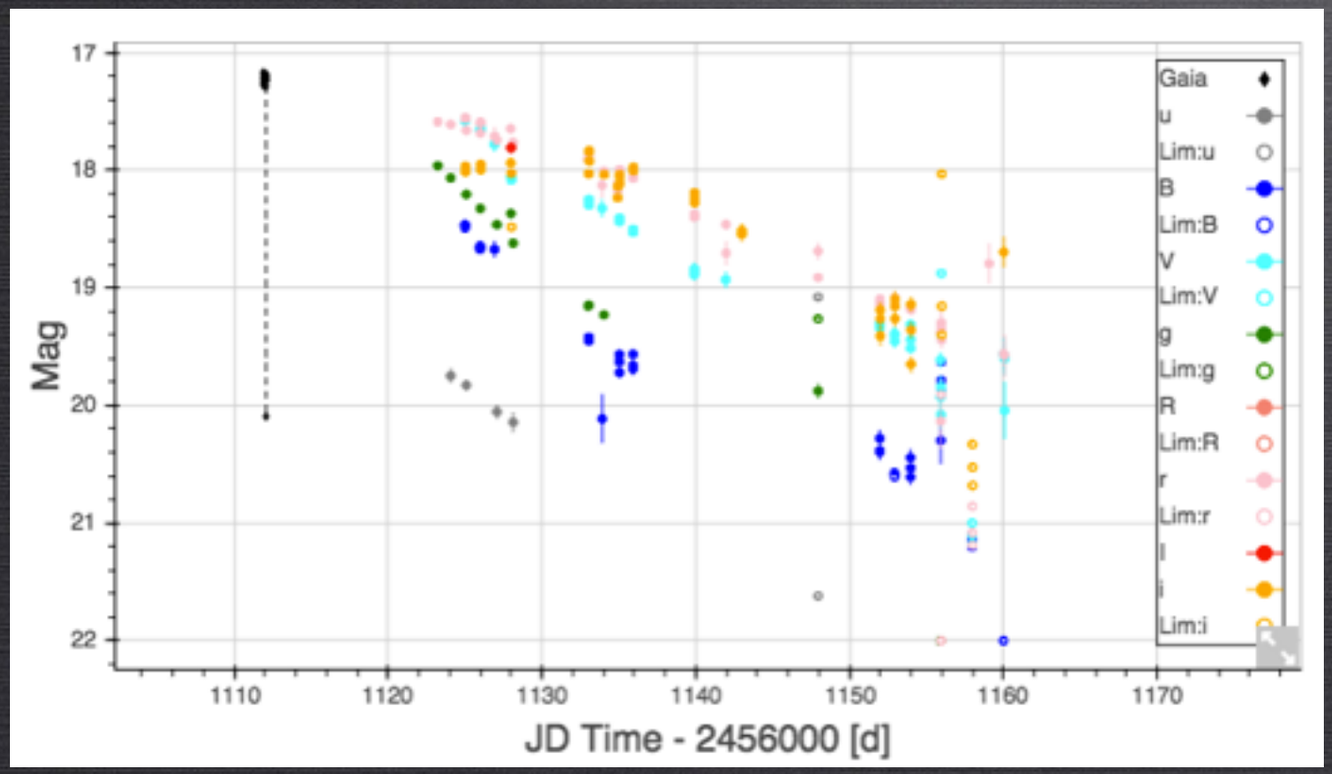
# ALERTS VERIFICATION PHASE

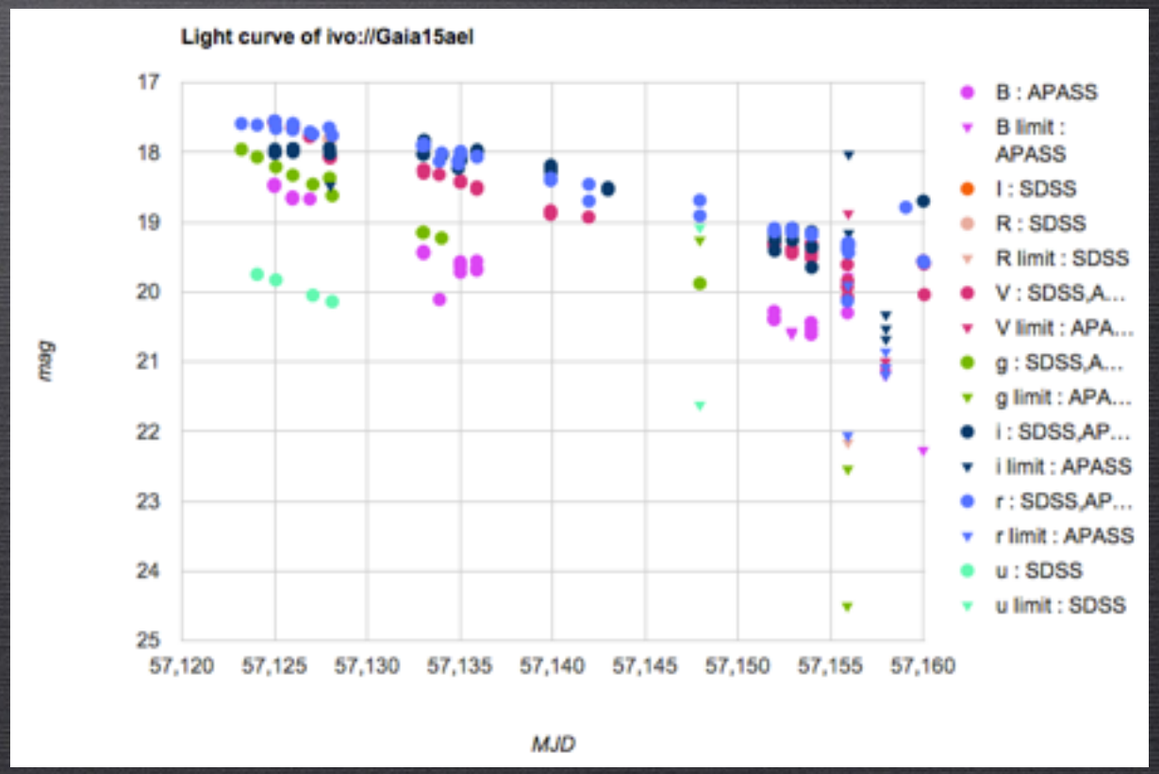
## *PHOTOMETRY*

271 alerts so far (166 in 2015)

143 alerts followed-up photometrically (53%)

~15,000 photometric follow-up datapoint collected

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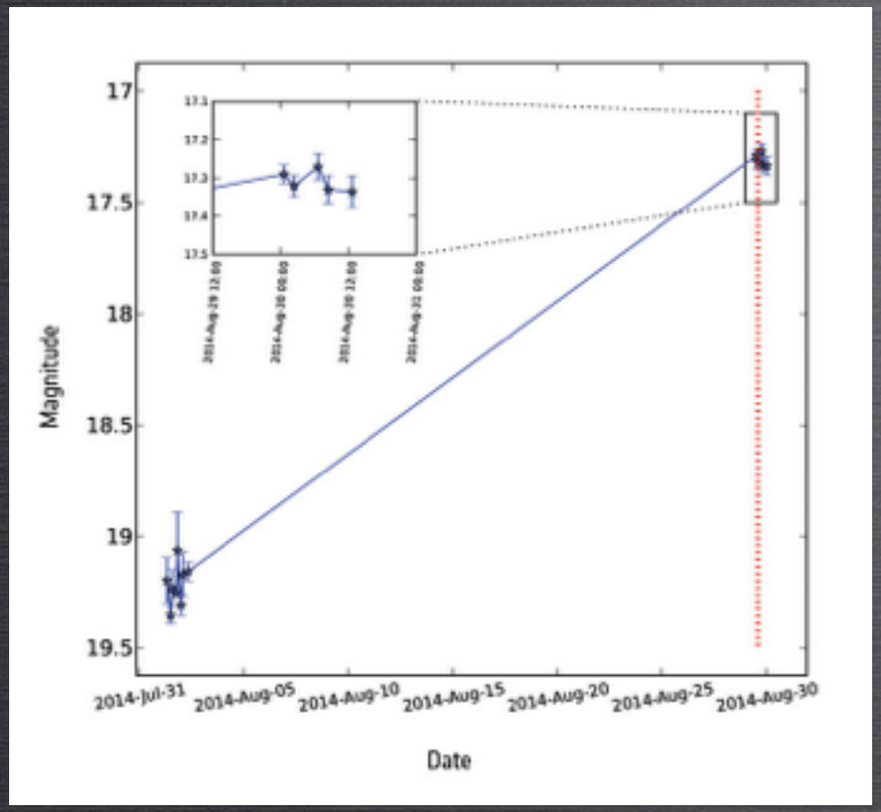
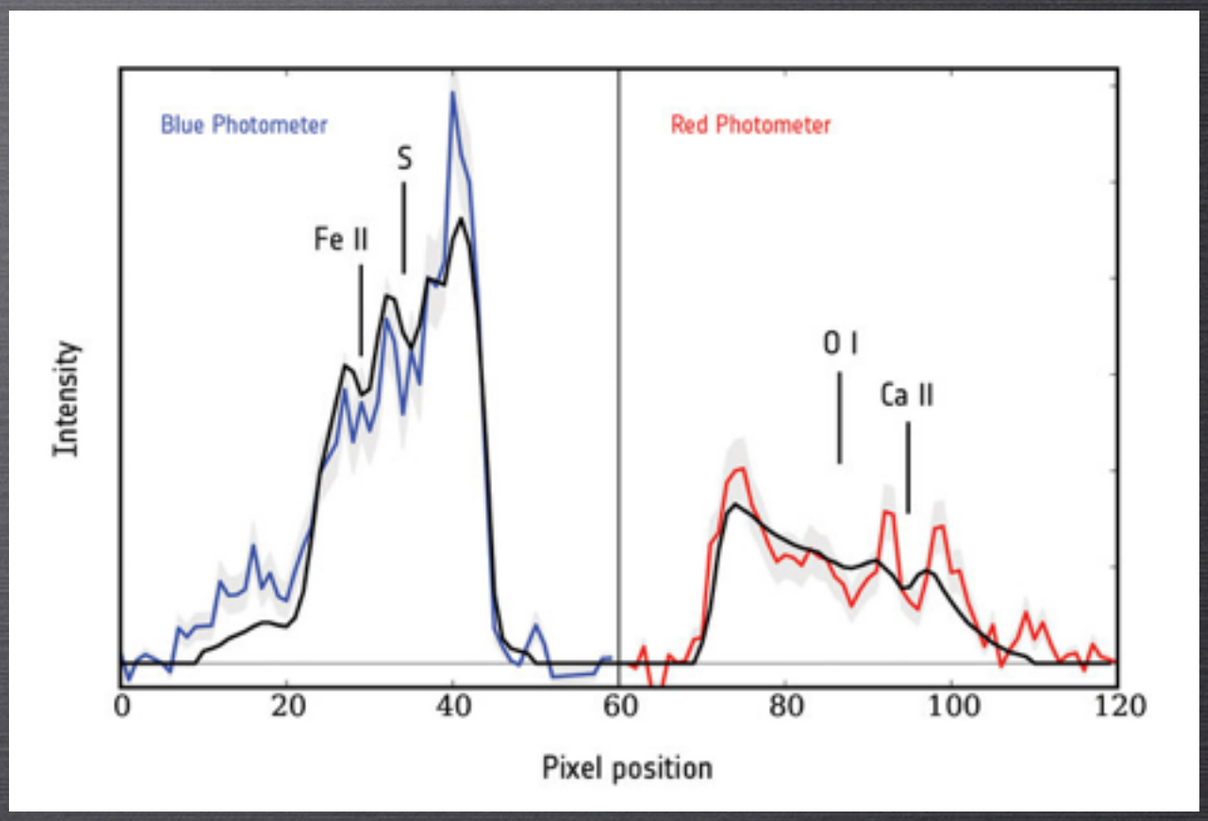
# FIRST CONFIRMED SUPERNOVA

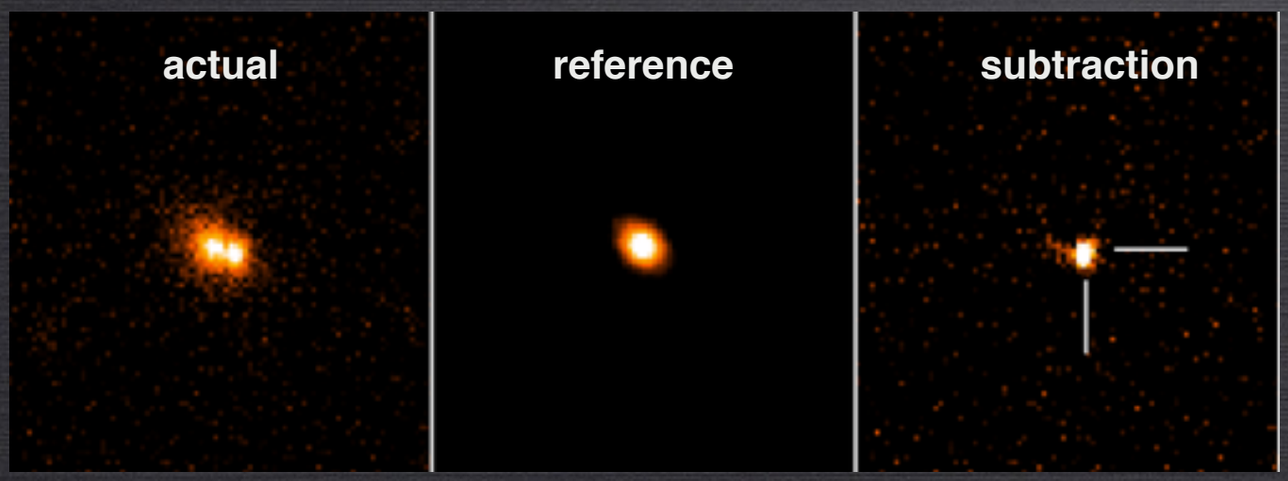
## Gaia14aaa discovered on 30 Aug 2014




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

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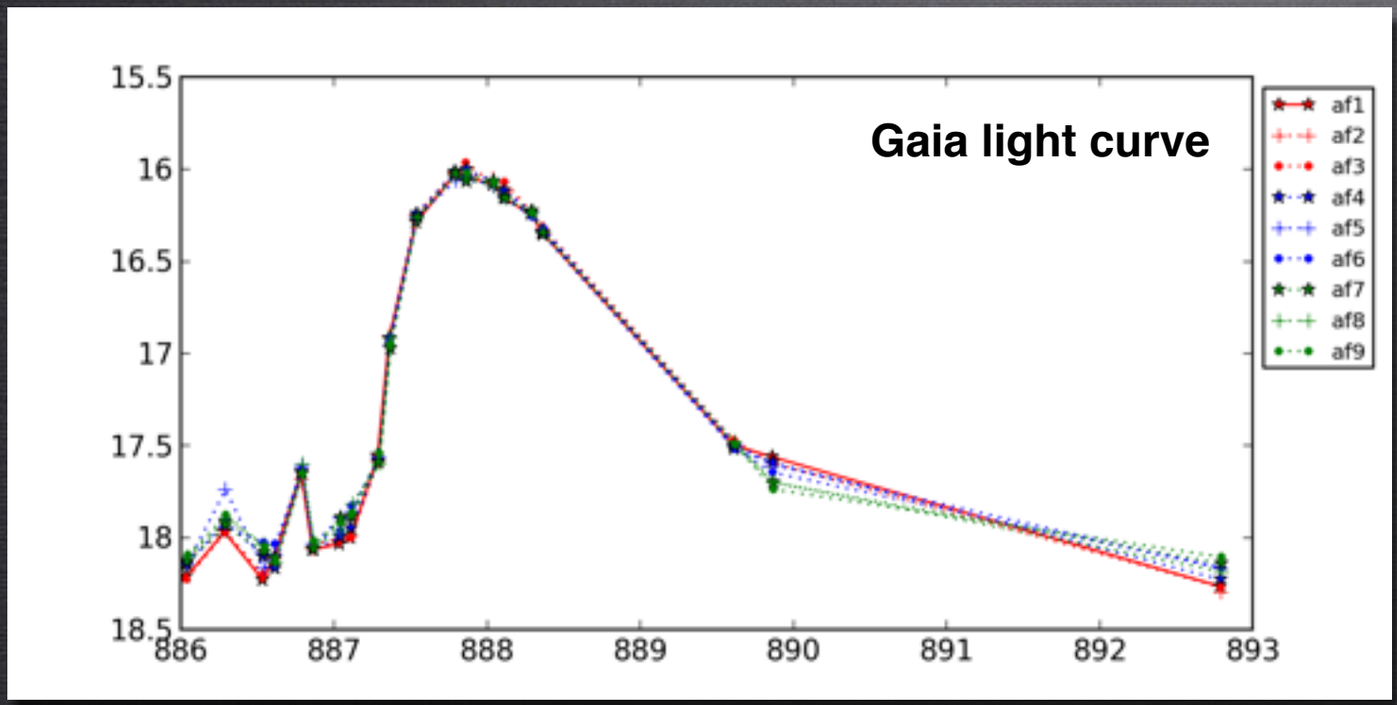
# AM CVN-TYPE TRANSIENT

## Gaia14aae

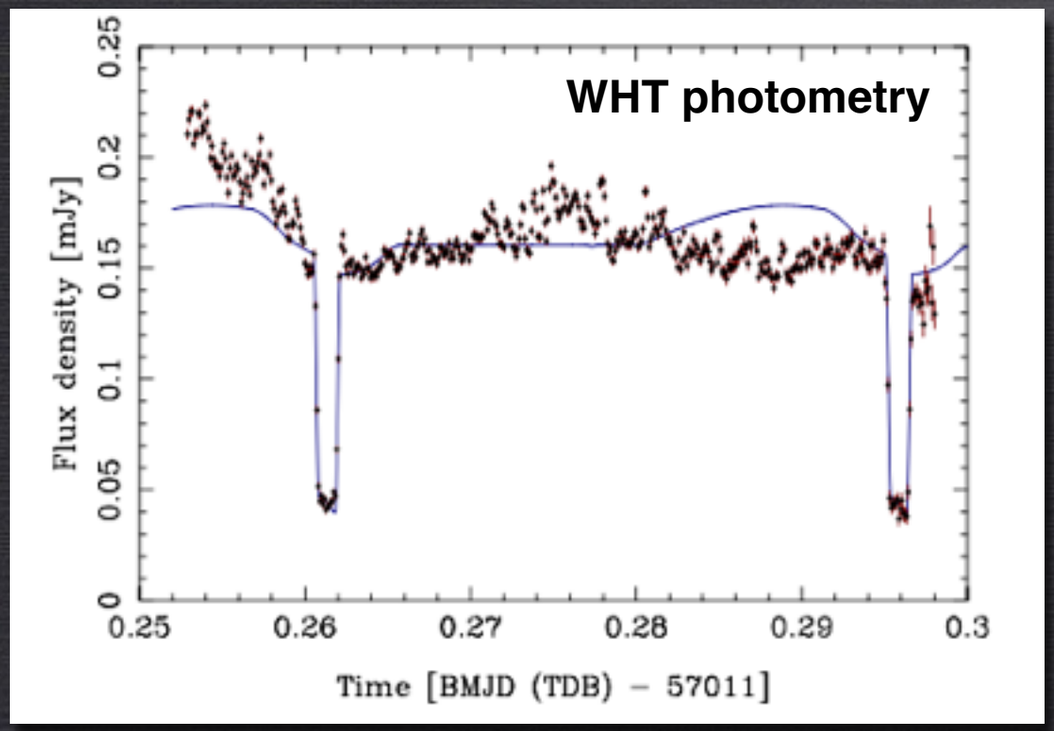



- very rare class of CVs (3rd!)
- candidate SN Ia progenitor
- WD accretes He material from another WD

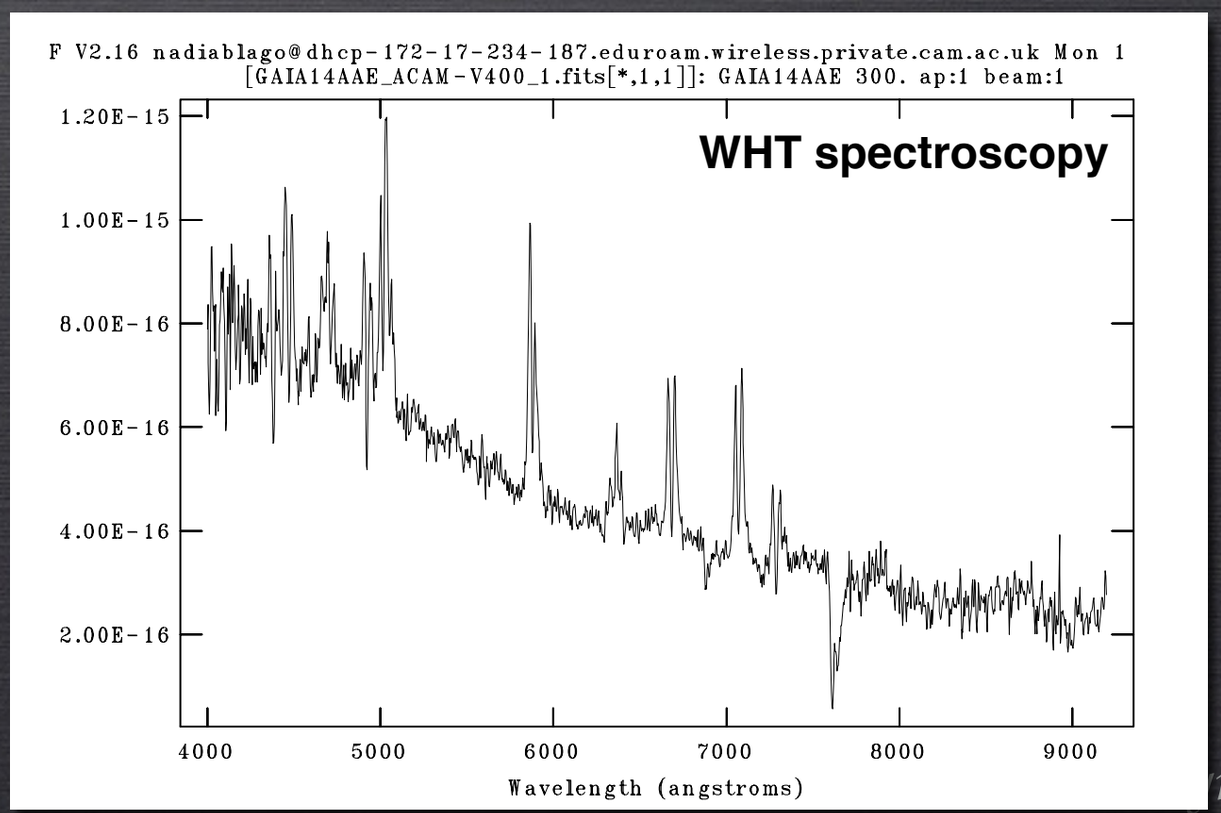
Period 49.71 min

M1 ≥ 0.782 MSun, T1=13000

M2 ≥ 0.015 MSun




Campbell et al. 2015

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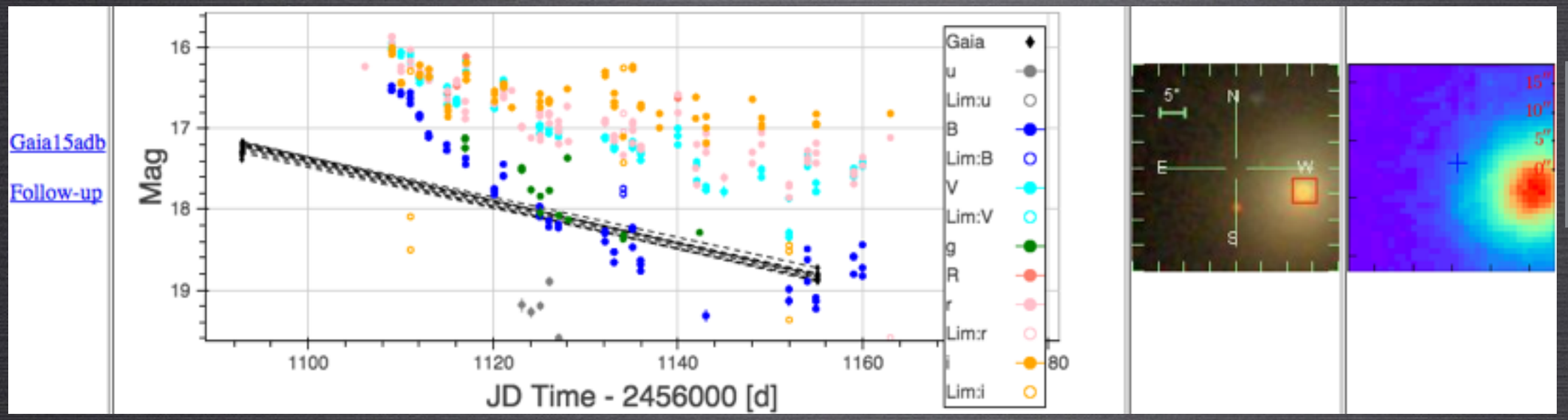
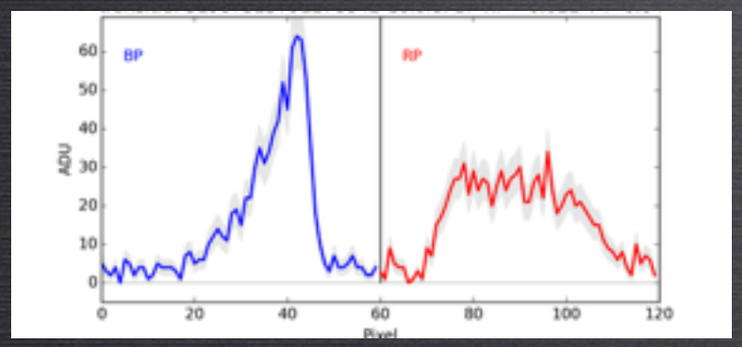
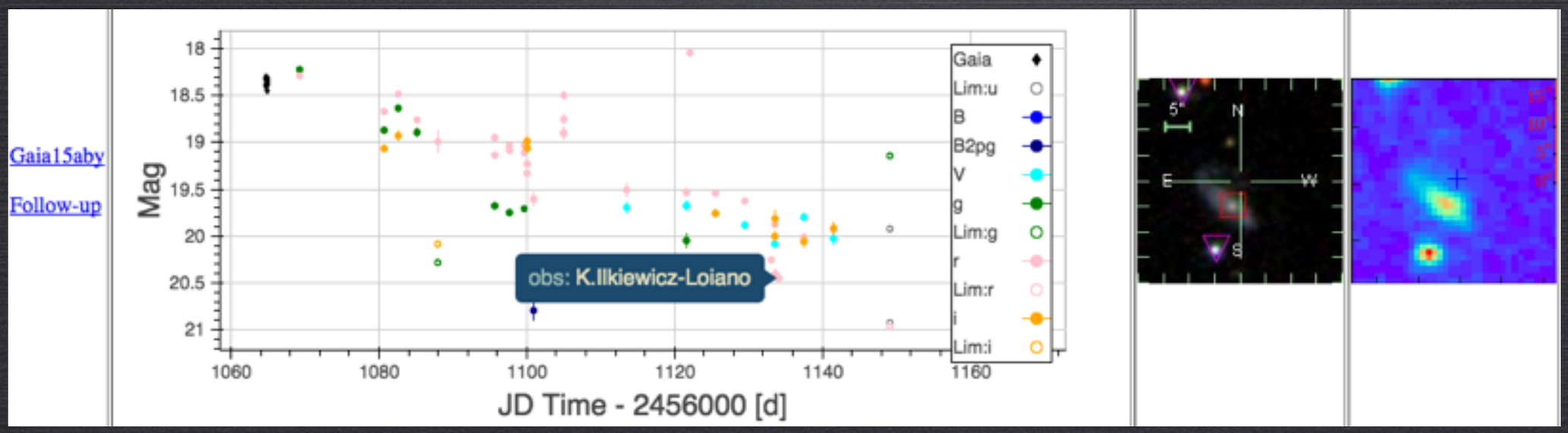
# EXAMPLES OF ALERTS AND THEIR FOLLOW-UP




Gaia15adb
SN Ia

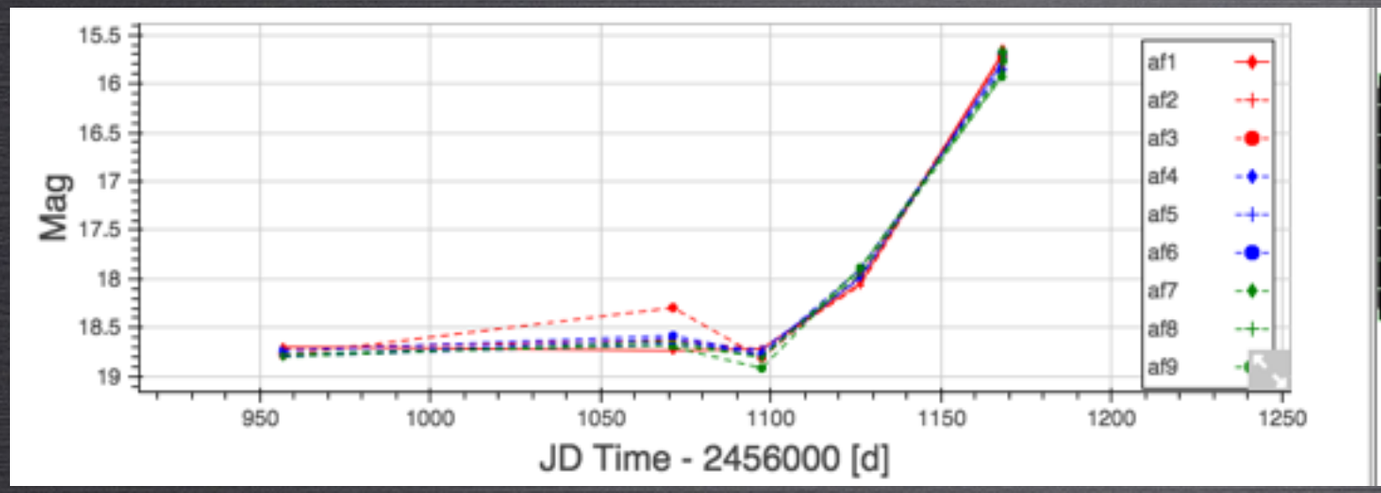


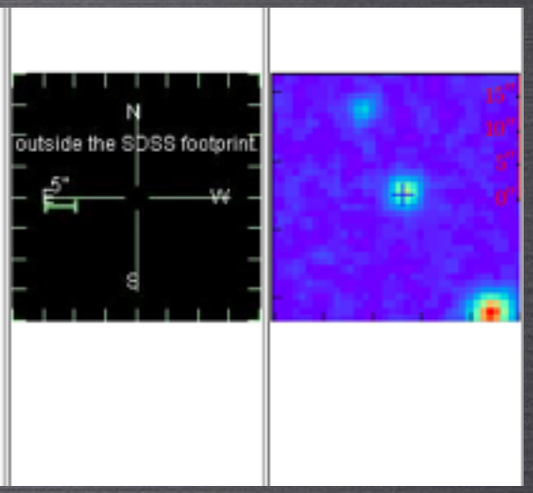




Gaia15aby
SN Ia

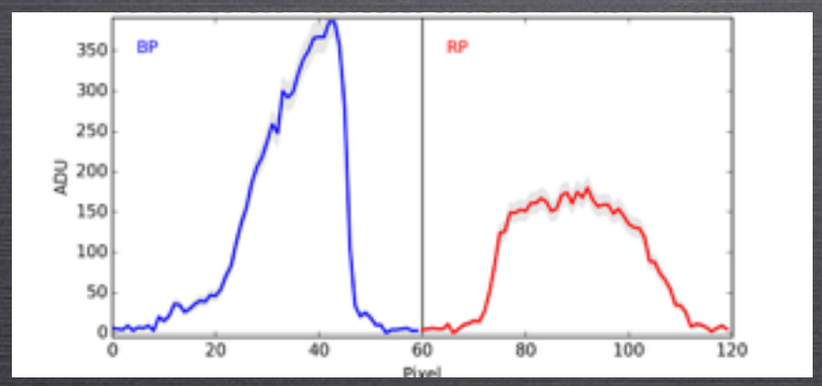
*Łukasz Wyrzykowski*

# EXAMPLES OF ALERTS AND THEIR FOLLOW-UP



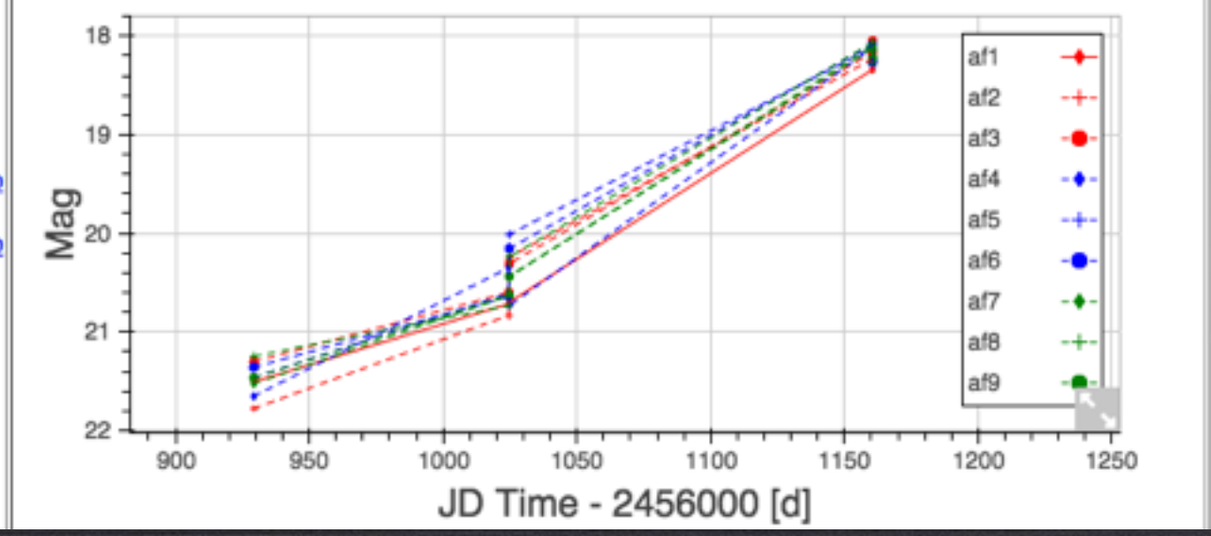



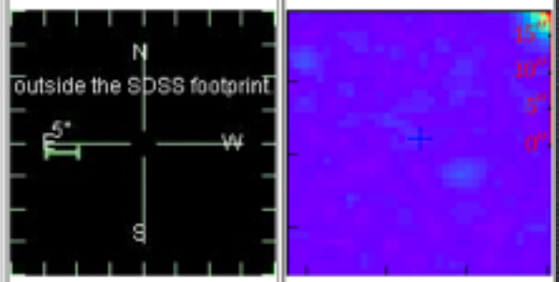

Gaia15afz
likely CV




Gaia15afo

Follow-up




Gaia15afo
hostless
unknown
(CV?)

*Łukasz Wyrzykowski*

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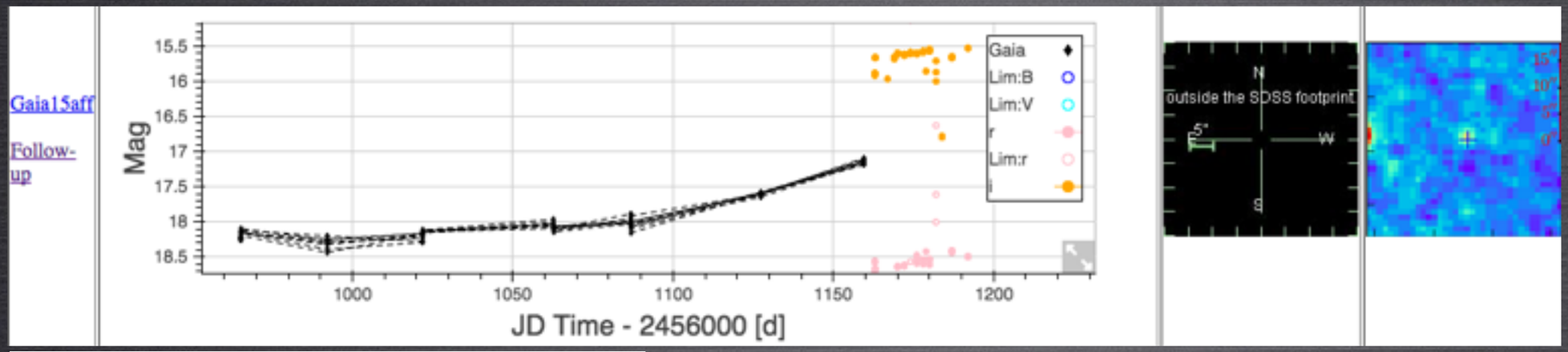
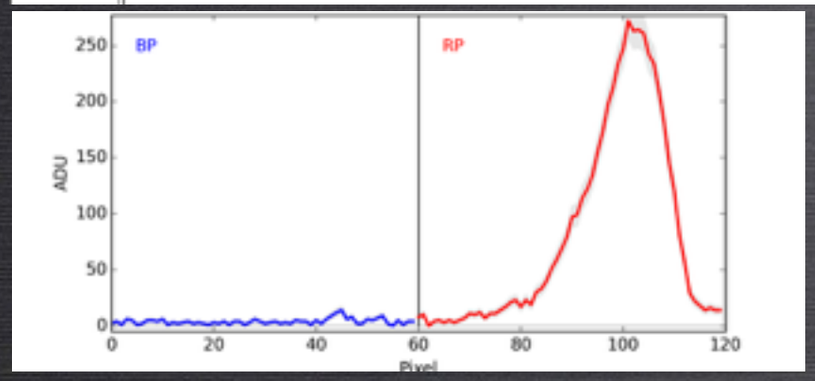
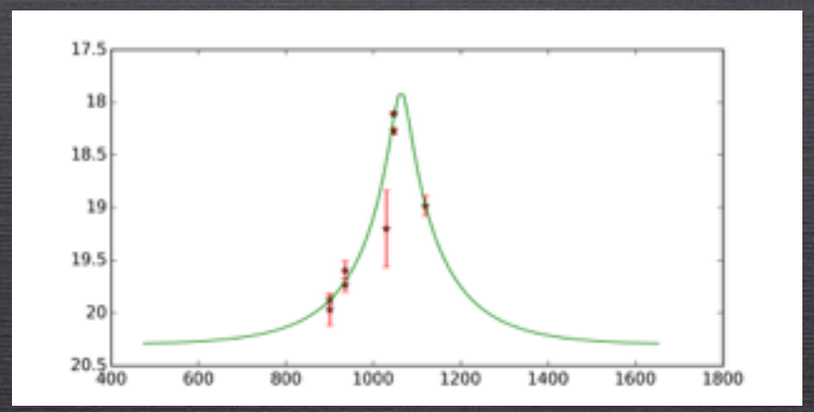
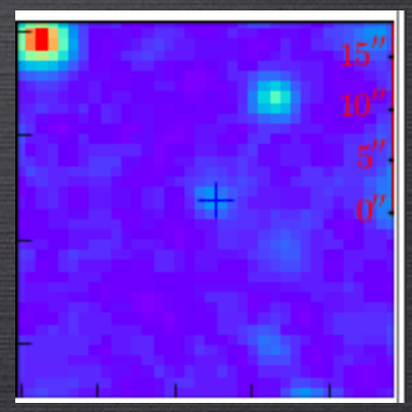


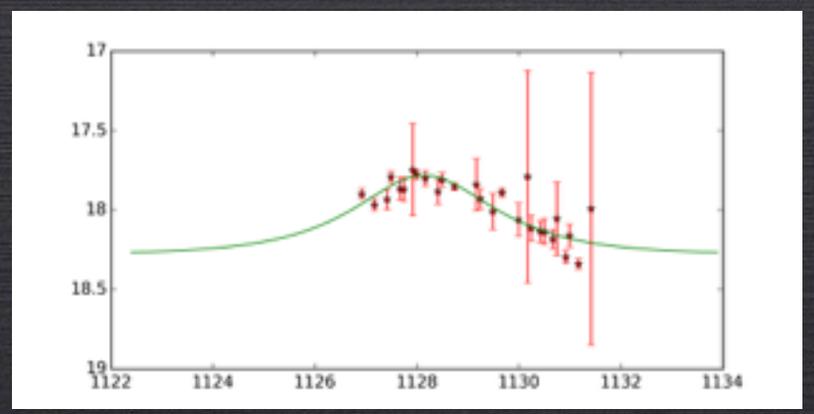

Gaia15aff microlensing event or var. star

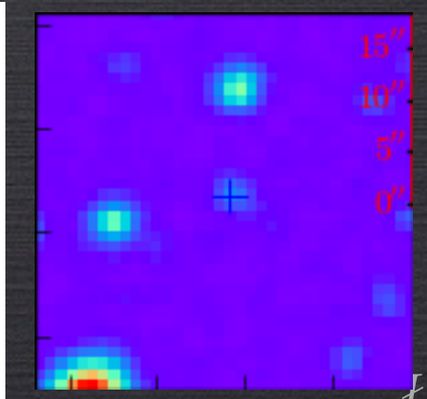





Gaia15agi microlensing event?



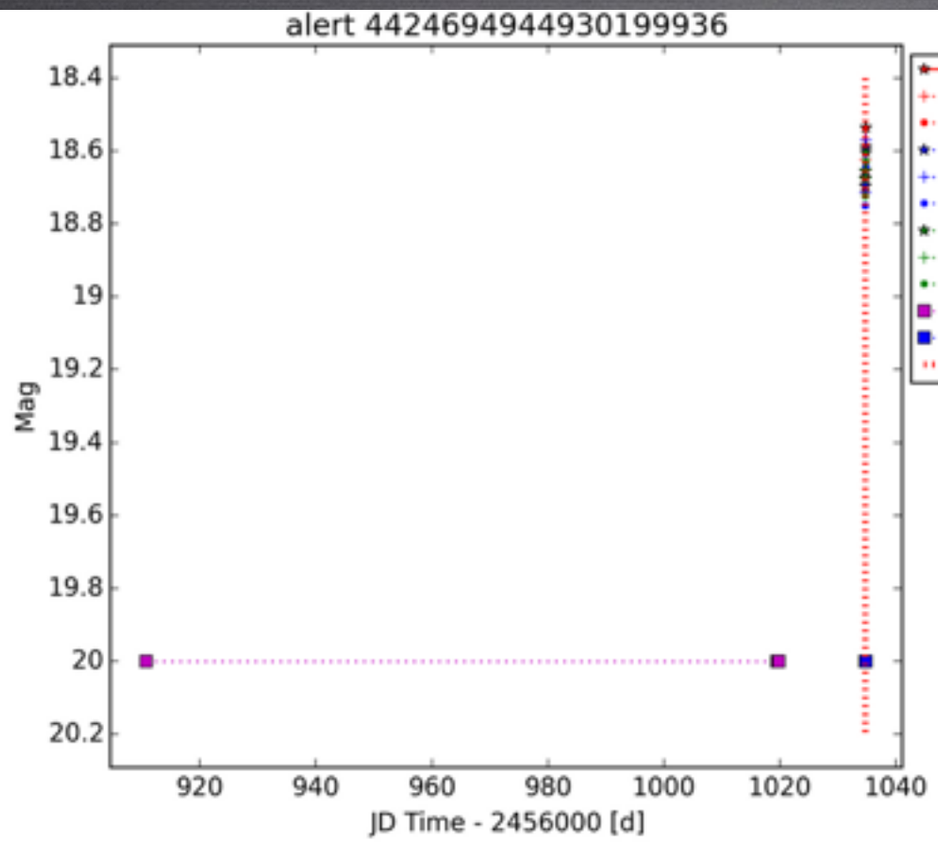


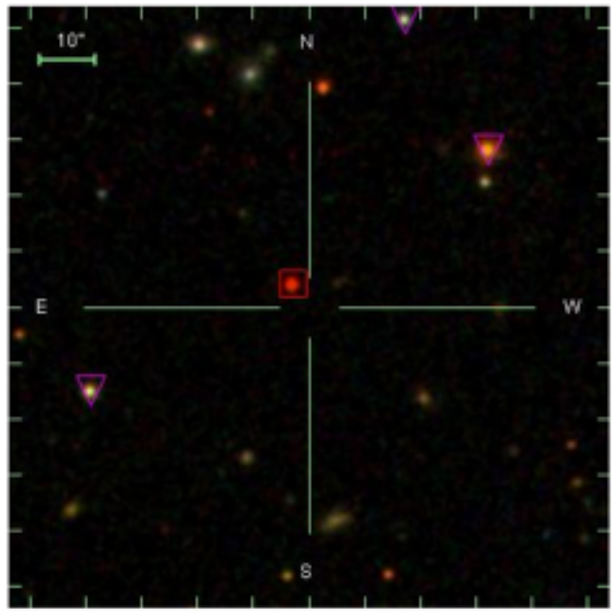

Gaia15afp microlensing event?

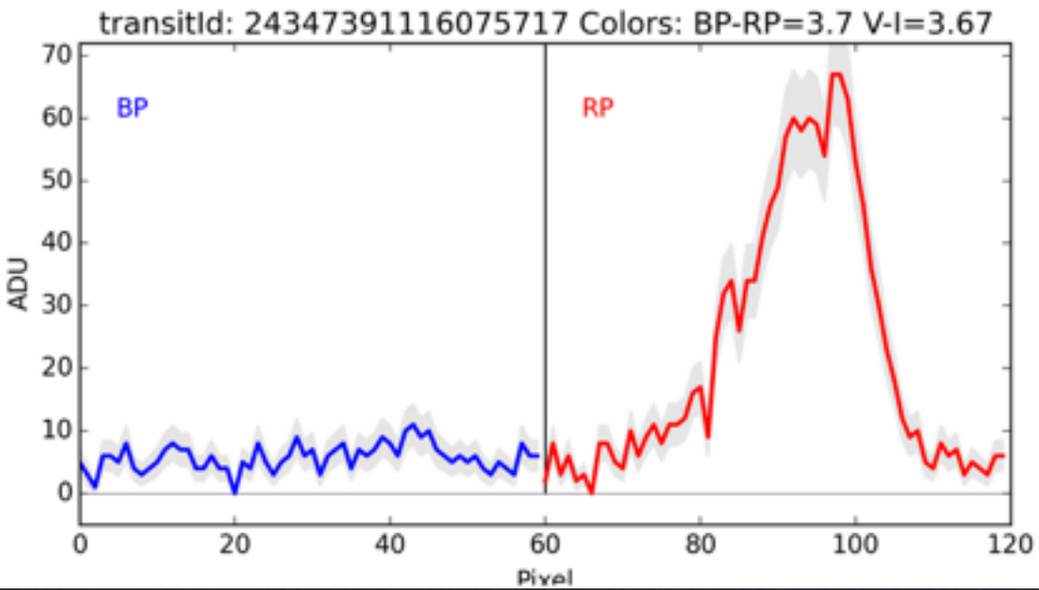
*Łukasz Wyrzykowski*

# CONTAMINANTS

numerous very red last moving stars
appearing as New Sources



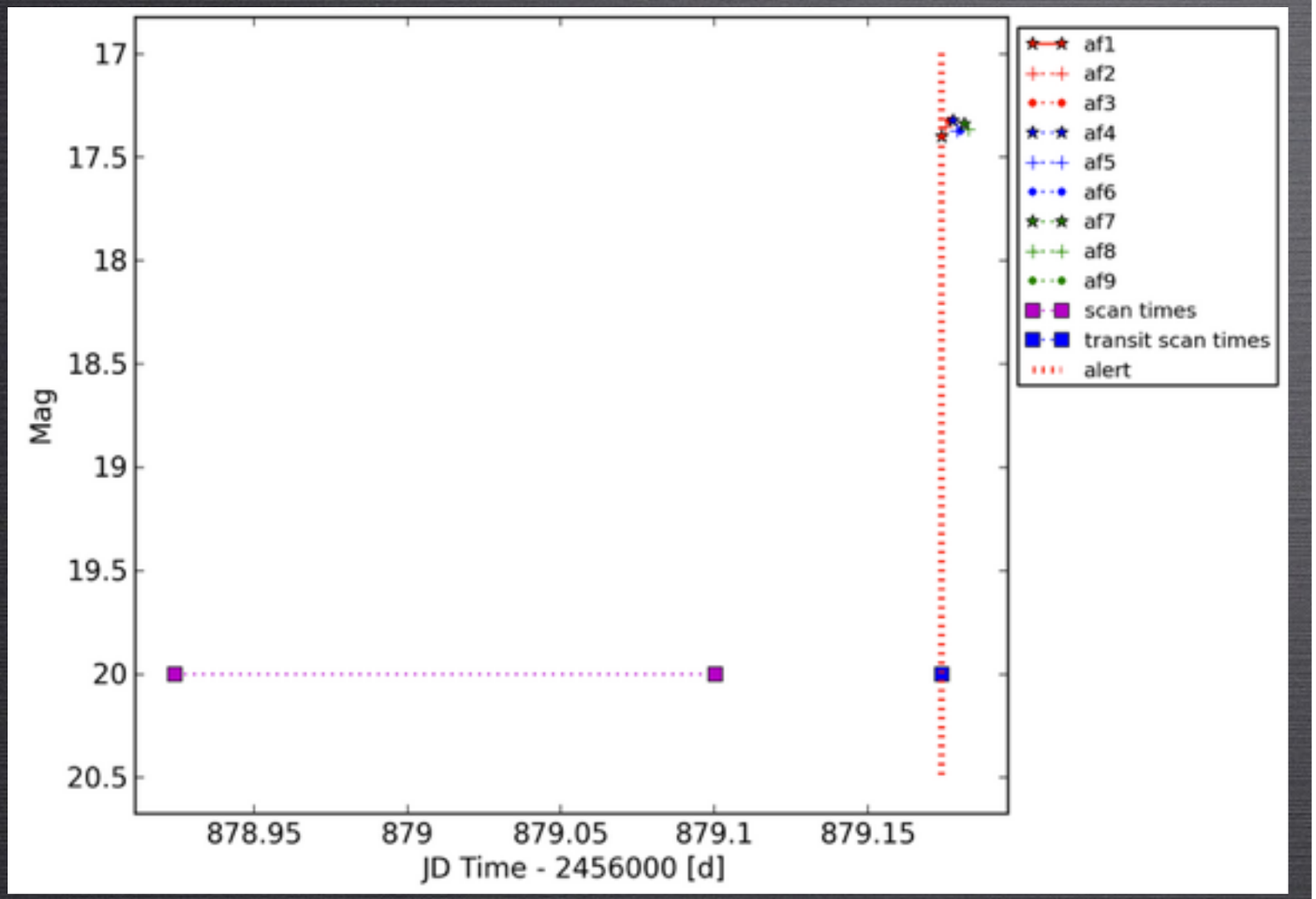



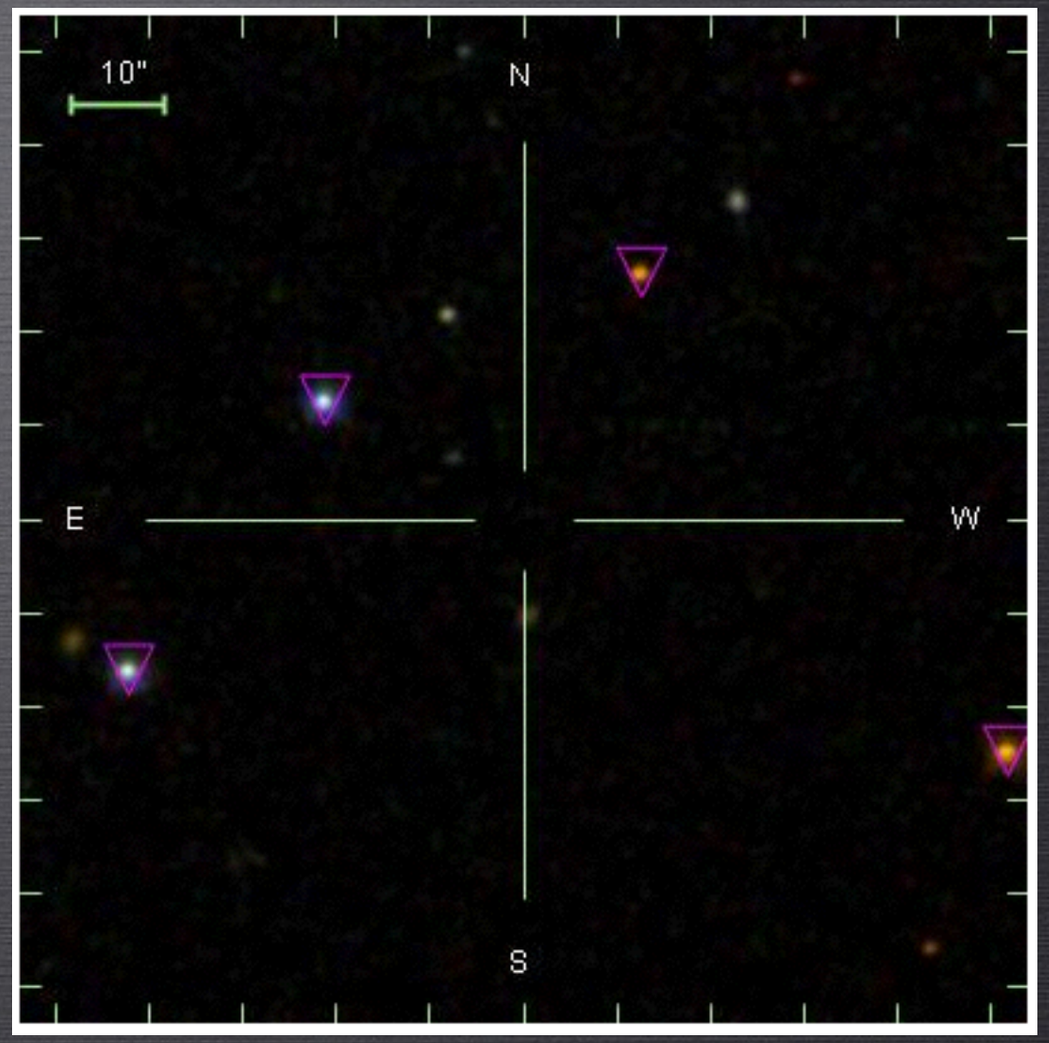




Wyrzykowski

# 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!**