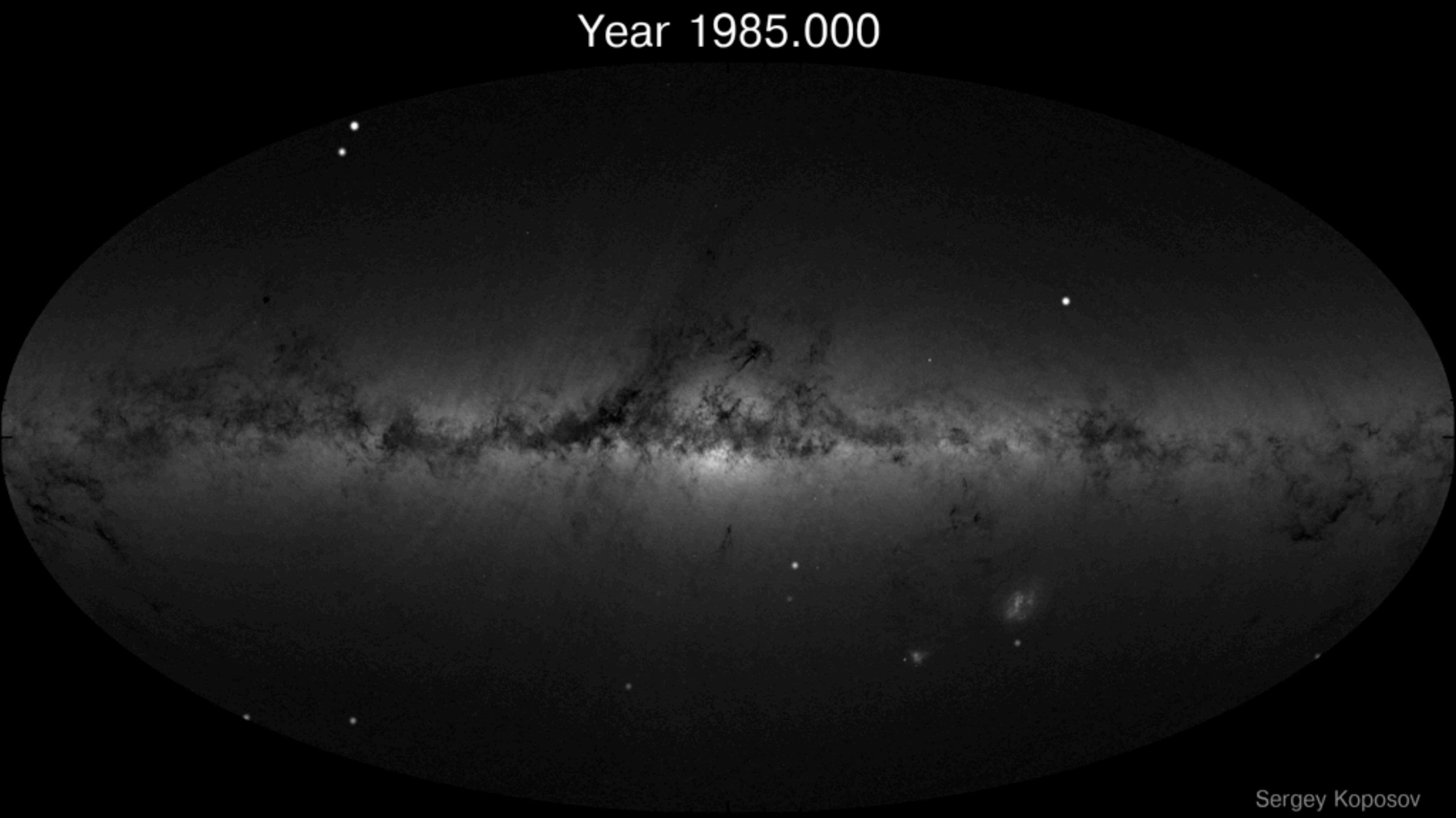

www.youtube.com/watch?v=Iv8HtH-O3uQ

Gaia Photometric Science Alerts: One Year In

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Arancha Delgado*
Diana Harrison

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Floor van Leeuwen
Abdullah Yoldas

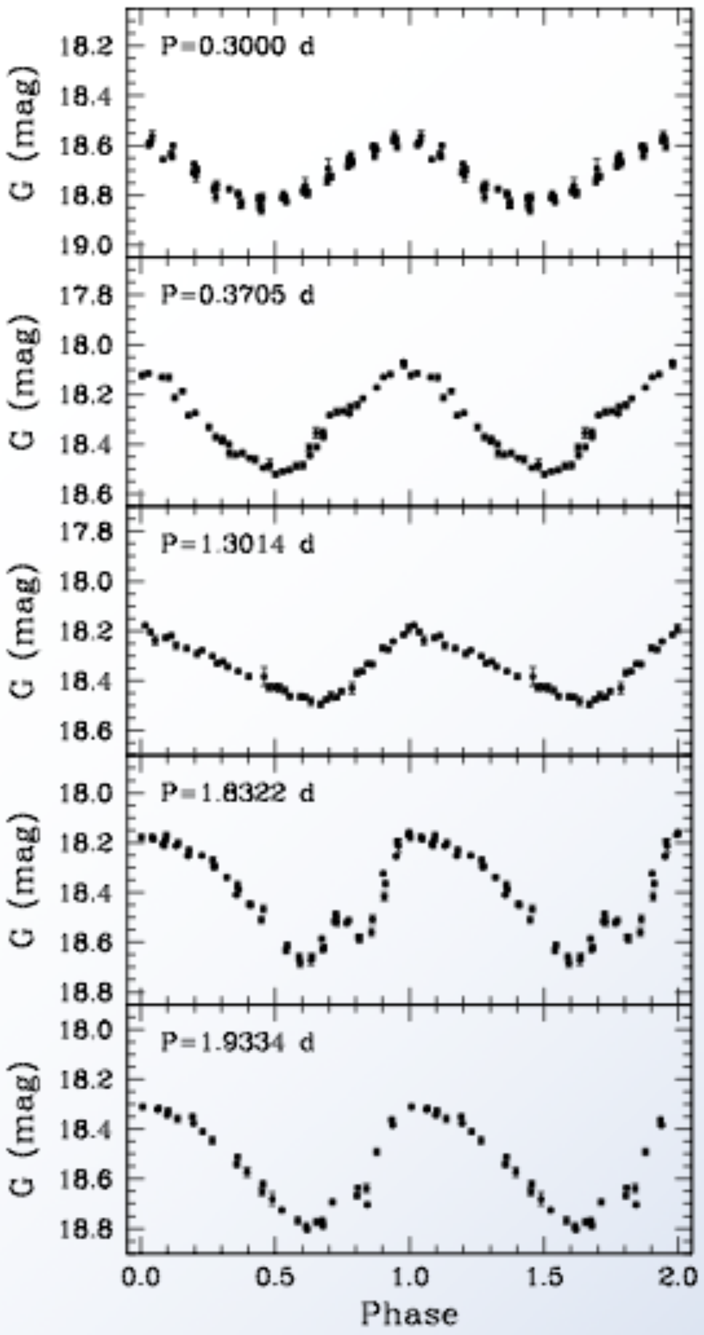
With thanks and acknowledgements to

- Giuseppe Altavilla
- Vasily Belokurov
- Josh Bloom
- Elme Breedt
- Ross Burgon
- Nadejda Blagorodnova
- Heather Campbell
- Gisella Clementini
- Chris Copperwheat,
- Michel Dennefeld
- Andrew Drake
- Laurent Eyer
- Morgan Fraser
- Gerry Gilmore
- Liam Hardy
- Diana Harrison
- Jorge Fernandez Hernandez
- Anna Hourihane
- Peter Jonker
- Uli Kolb
- Zuzanna Kostrzewa-Rutkowska
- Sergey Koposov
- Floor van Leeuwen
- Goska van Leeuwen
- Ashish Mahabal
- Francois Mignard
- Lovro Palaversa
- Andrzej Pigulski
- Timo Prusti
- Guy Rixon
- Iain Steele
- Rachel Street
- Lina Tomasella (and team),
- Manuel Torres
- Yiannis Tsapras
- Massimo Turatto
- Nic Walton
- Thomas Wevers
- Sjoert van Velzen
- Patricia Whitelock
- Roy Williams
- Lukasz Wyrzykowski
- Abdullah Yoldas
- 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 $G_{RVS} = 16.2$ mag (and $G > 2$ mag)

Variability



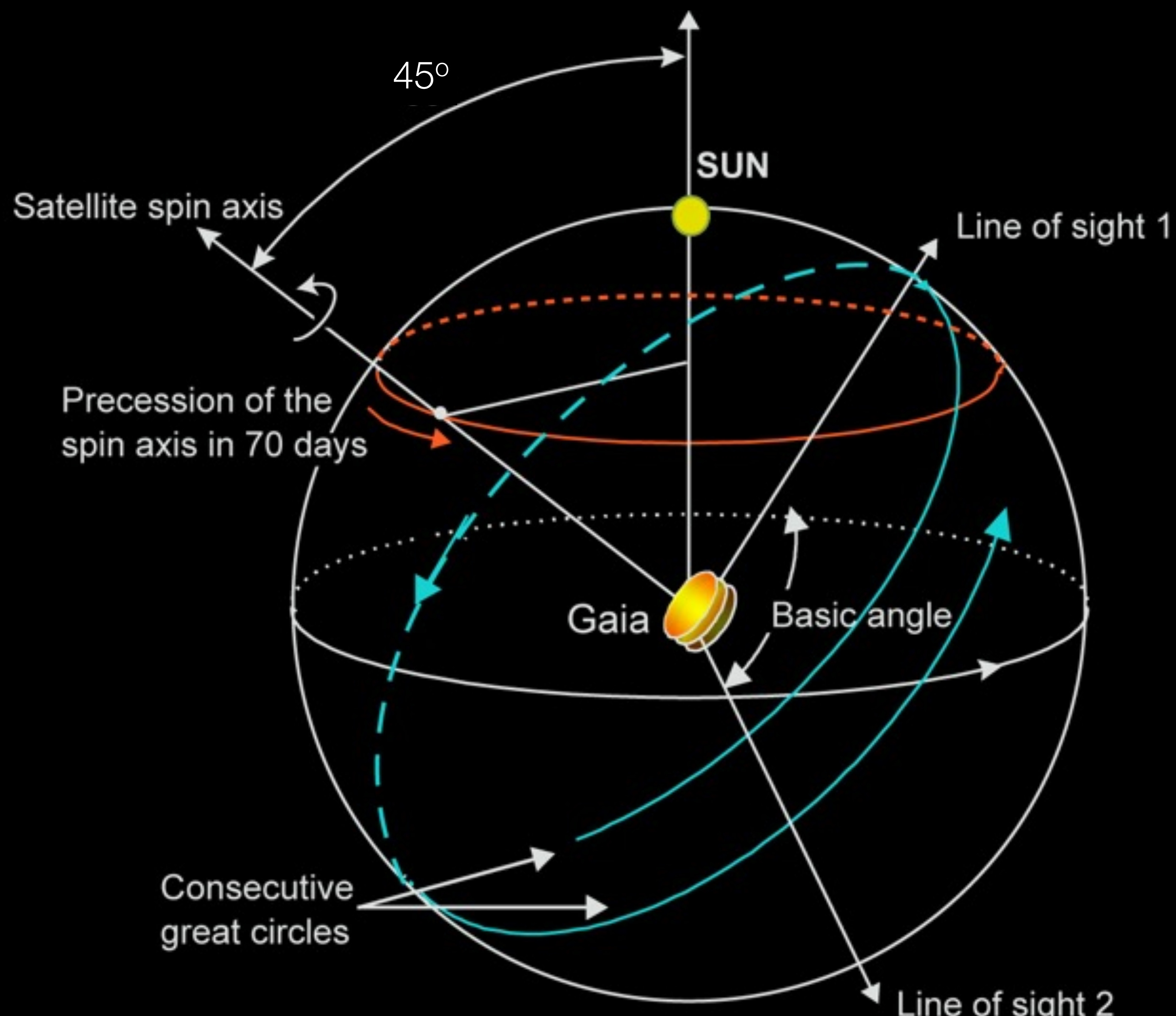
- Cepheids in LMC observed by Gaia during Ecliptic Pole Scanning
- Data processed through DPAC system with periodicity analysis as the last step

Credits: ESA/Gaia/DPAC/CU5/DPCI/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.

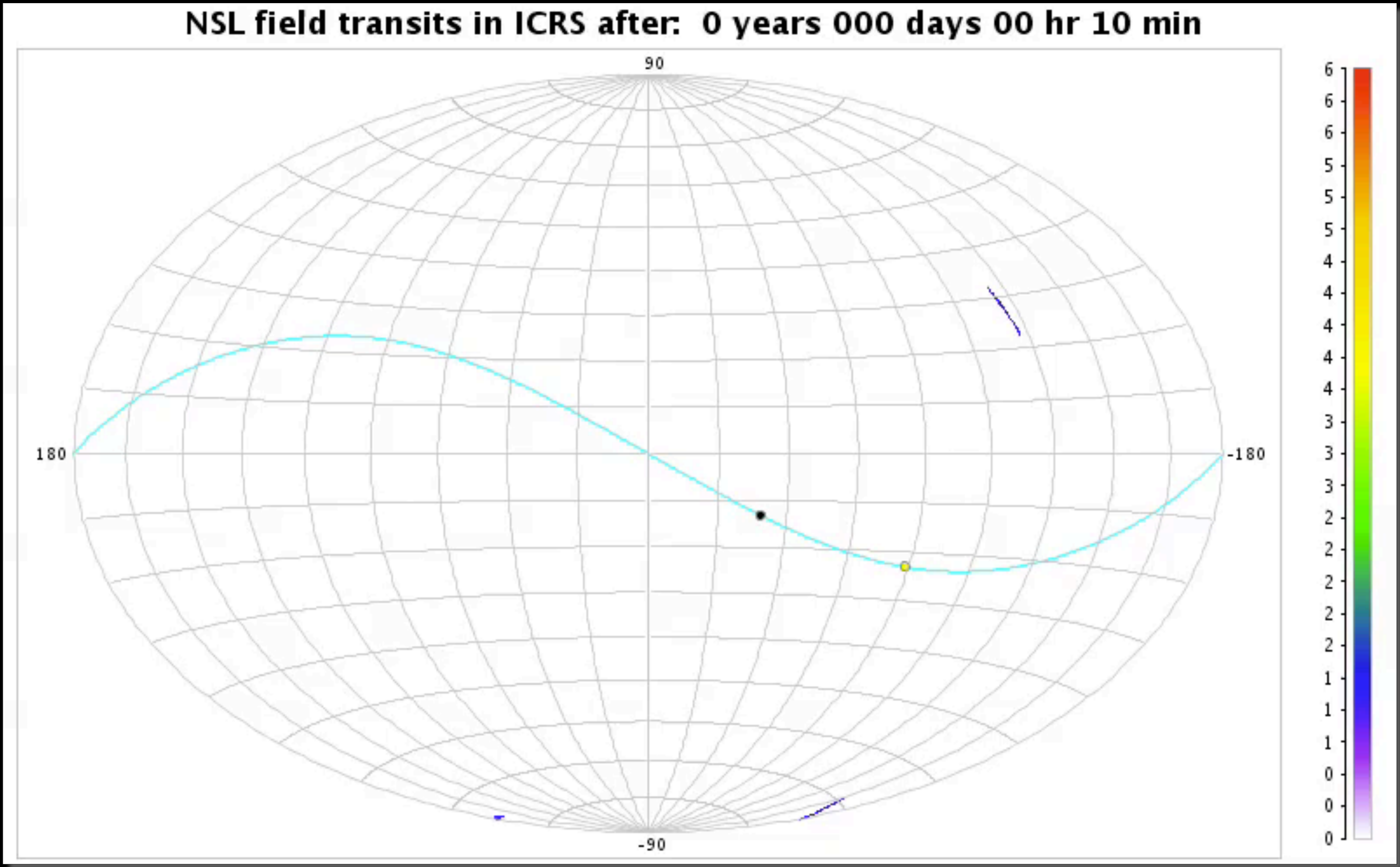
see talk from Laurent Eyer

Scanning Law

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

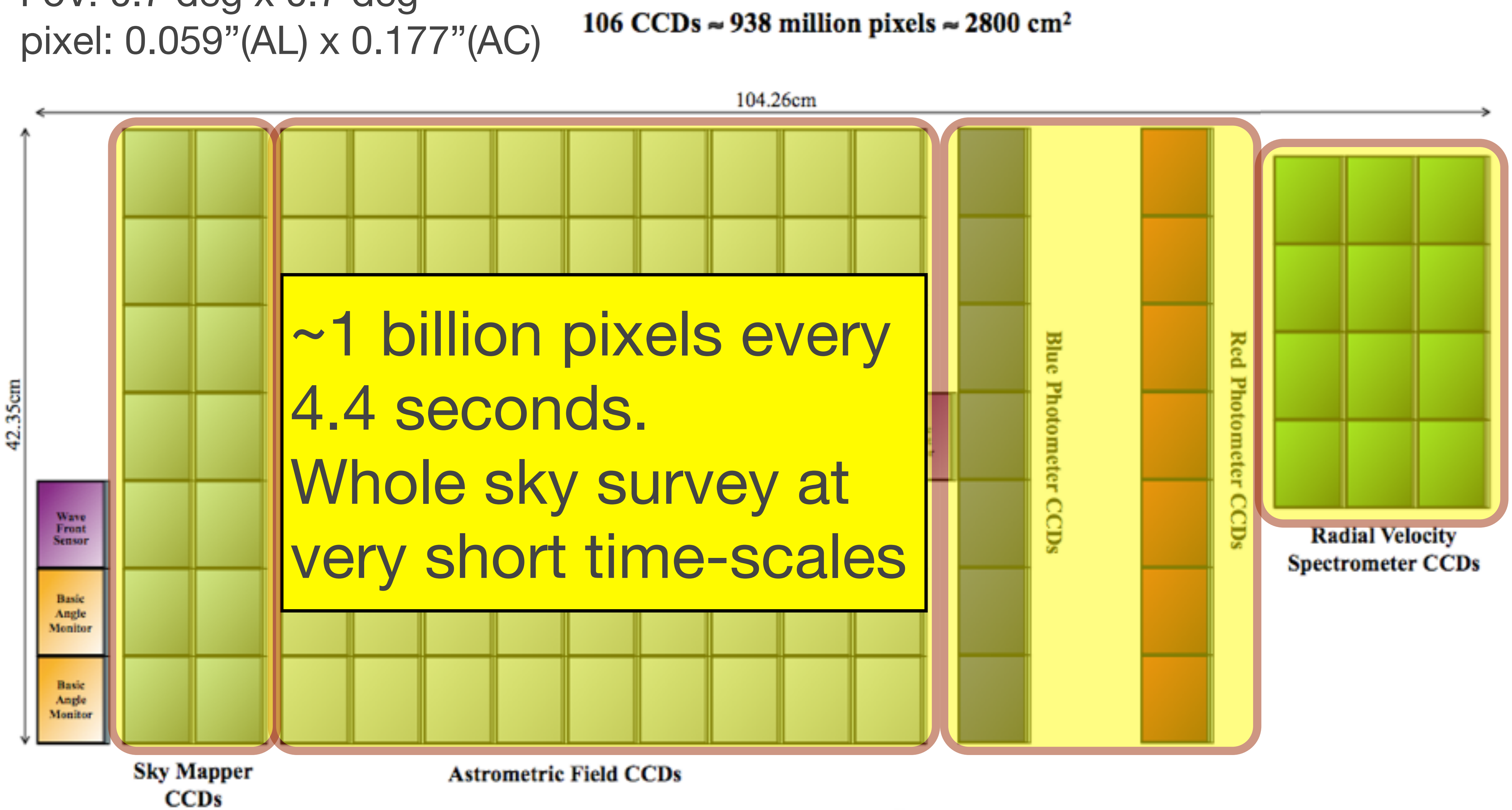


Scanning Law

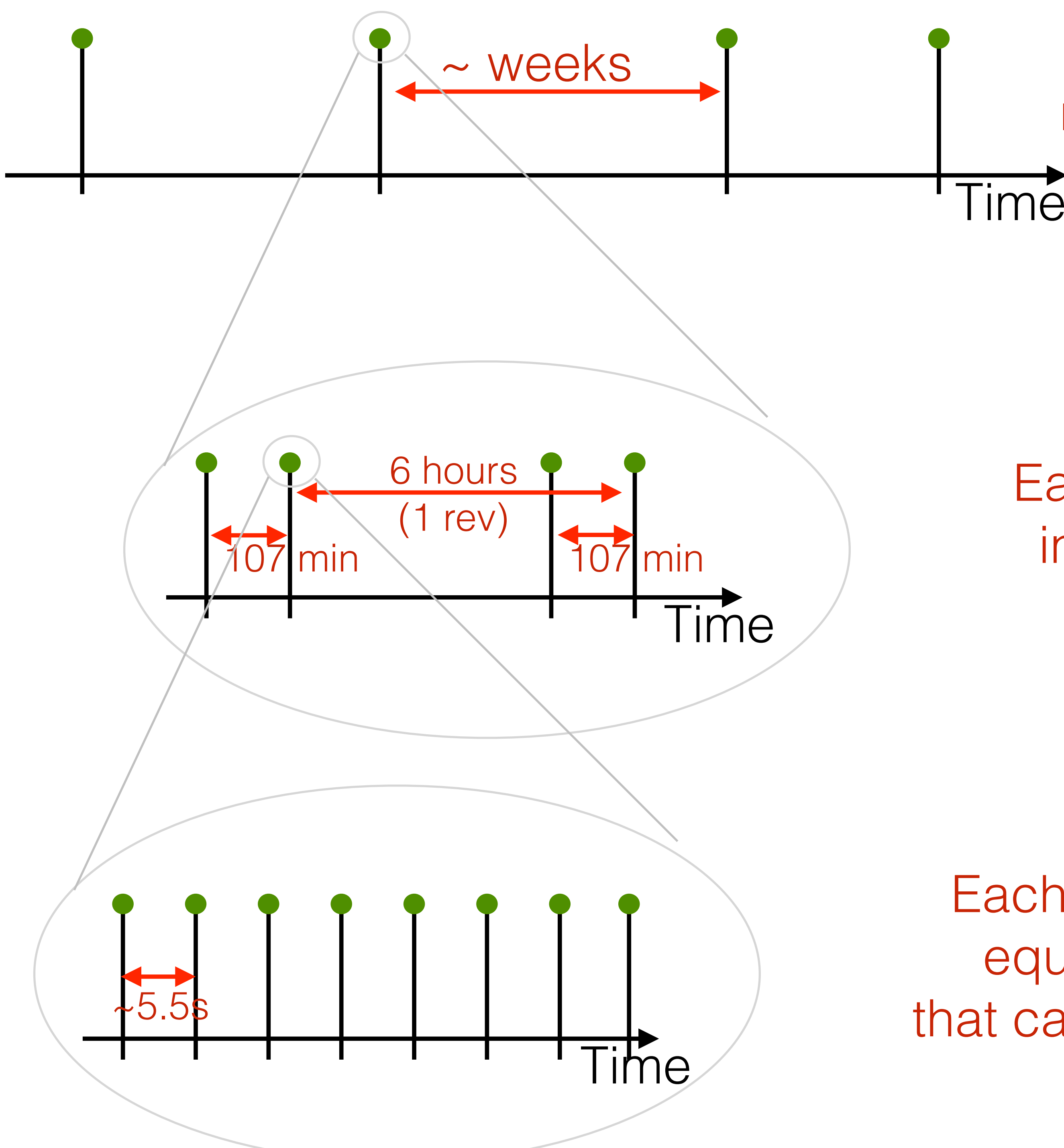


Gaia Focal Plane

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



Sampling of light curve

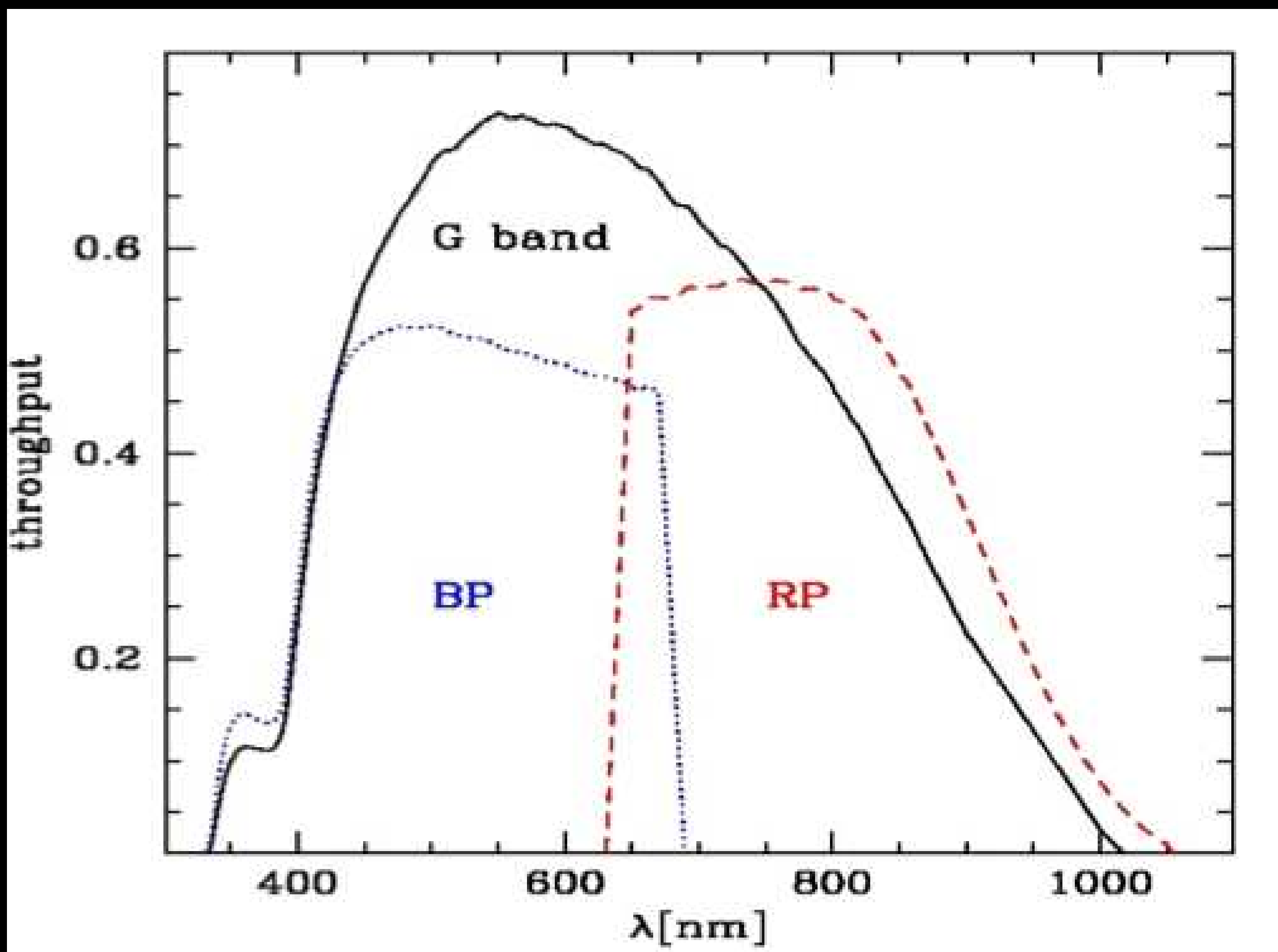


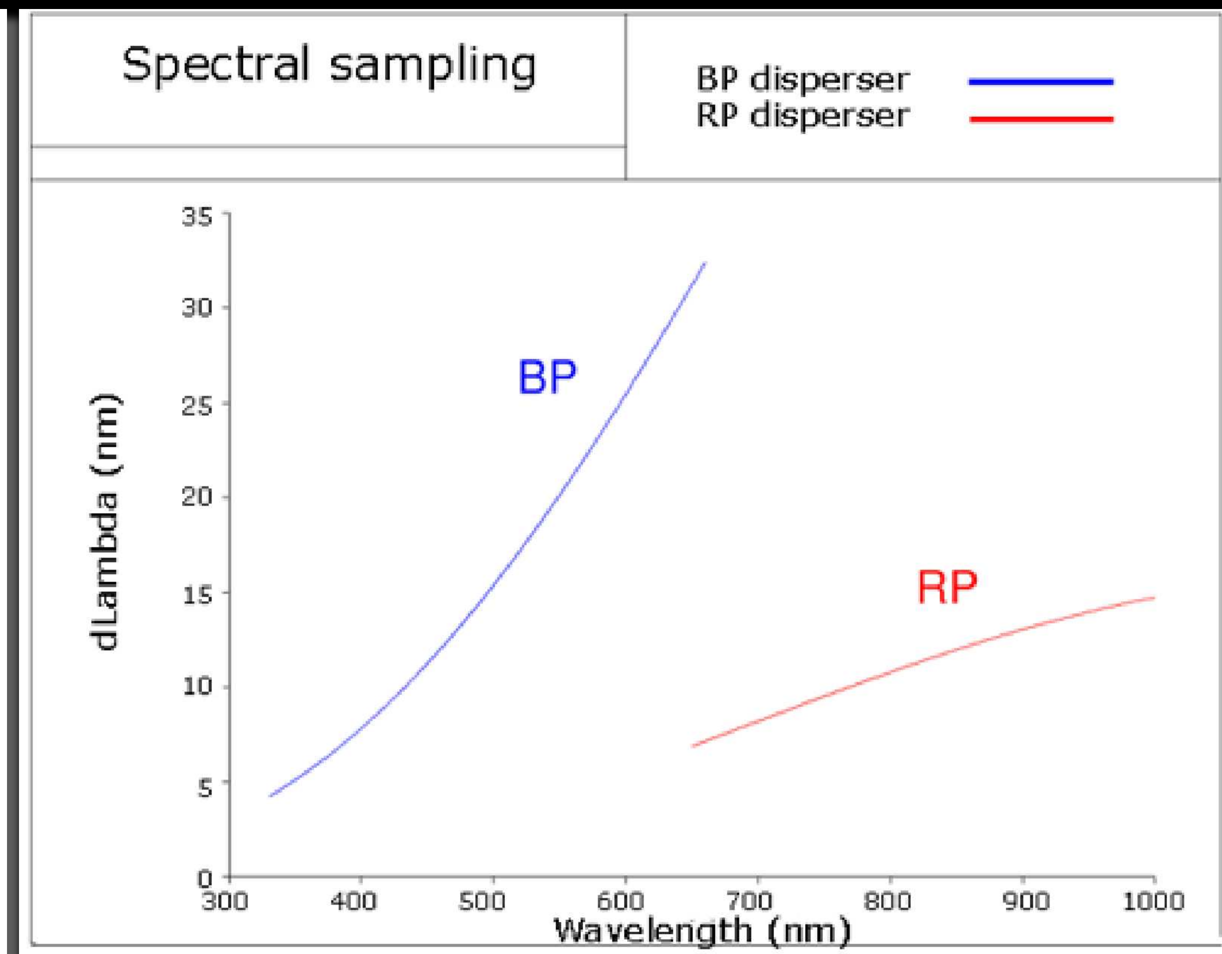
Each source observed many time in mission; sampling is predictable but uneven

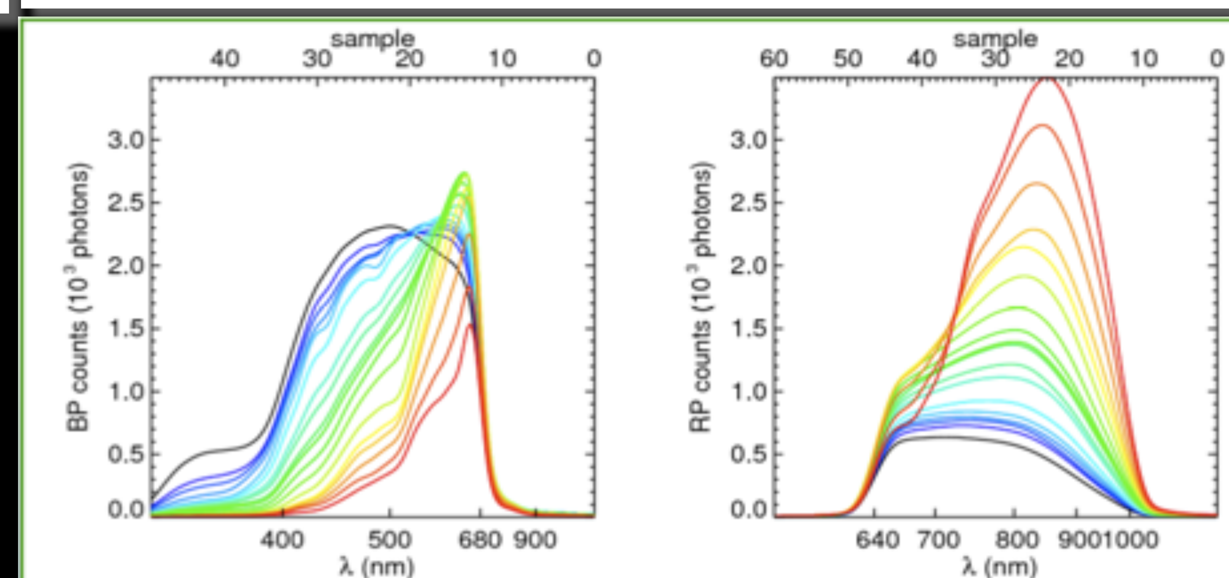
Each visit,typically 2 transits in each of 2 fields of view: FoV transit → avg. mag

Each FoV includes up to 9 equivalent flux samples that can be averaged or used separately

BP/RP spectra: classification

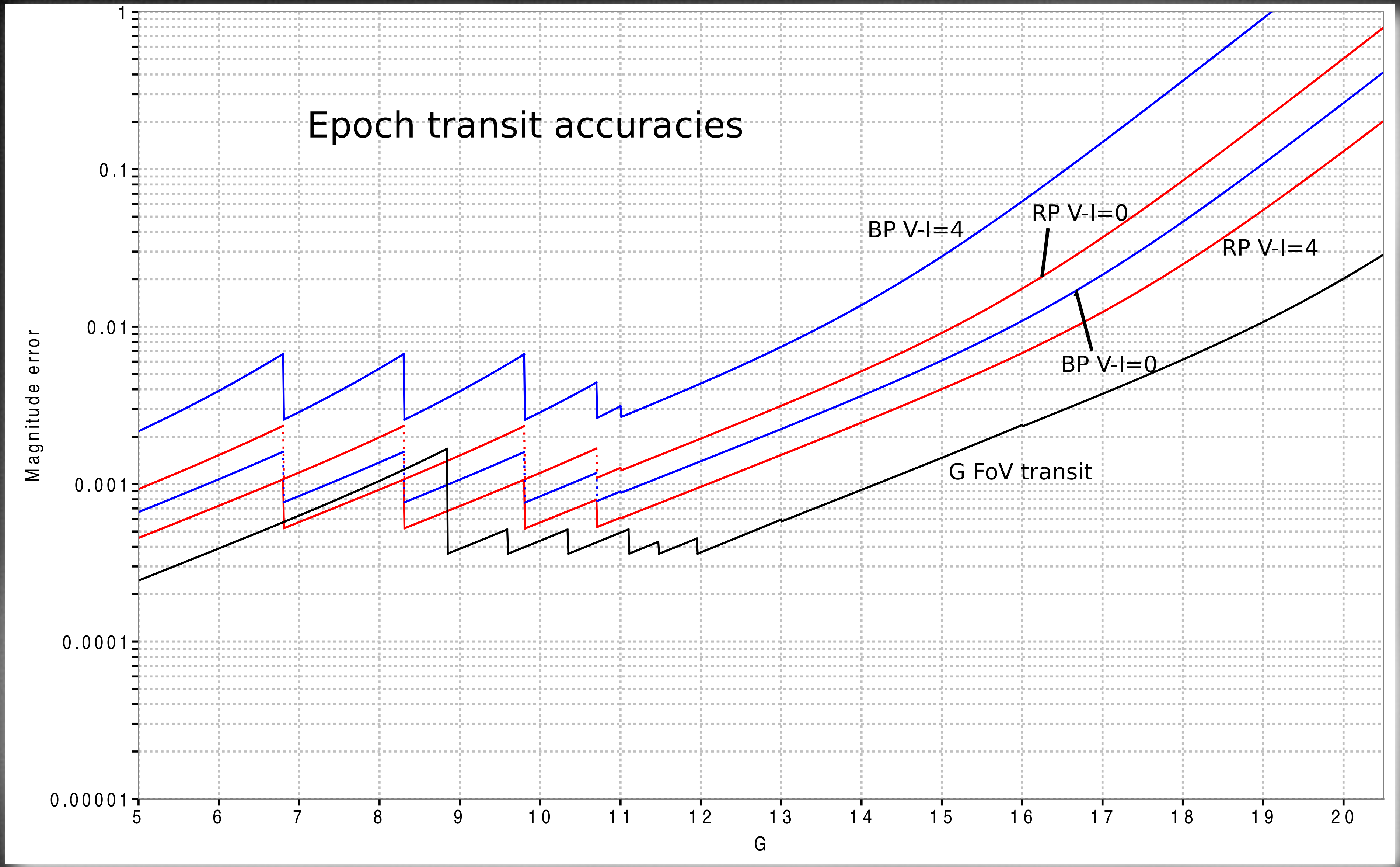






- two low-res fused-silica prisms
- BP 330-680nm @ 4-32 nm/pixel
- RP 640-1000nm @ 7-15 nm/pixel

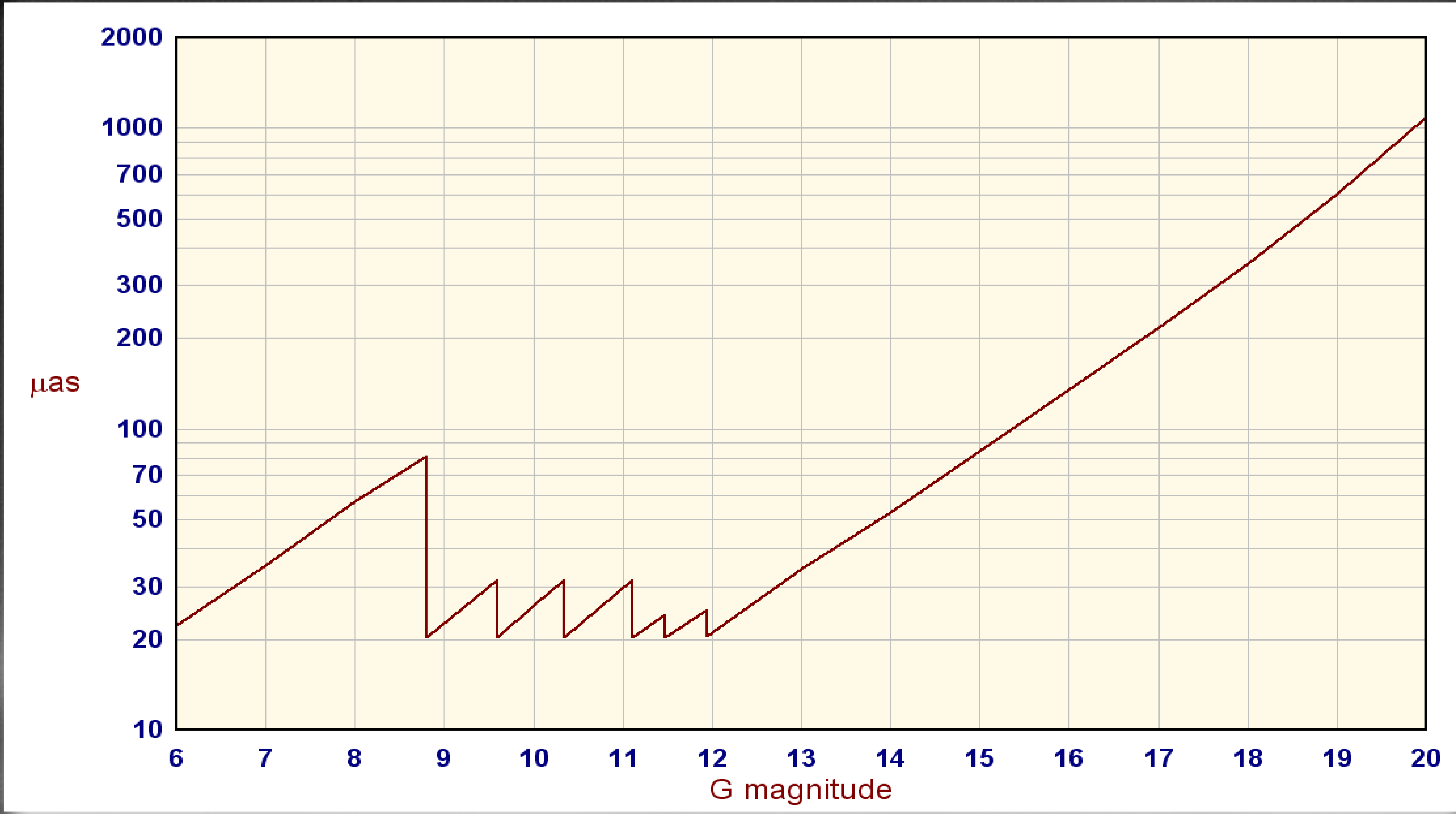
Photometry per transit



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

Stars brighter than ~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

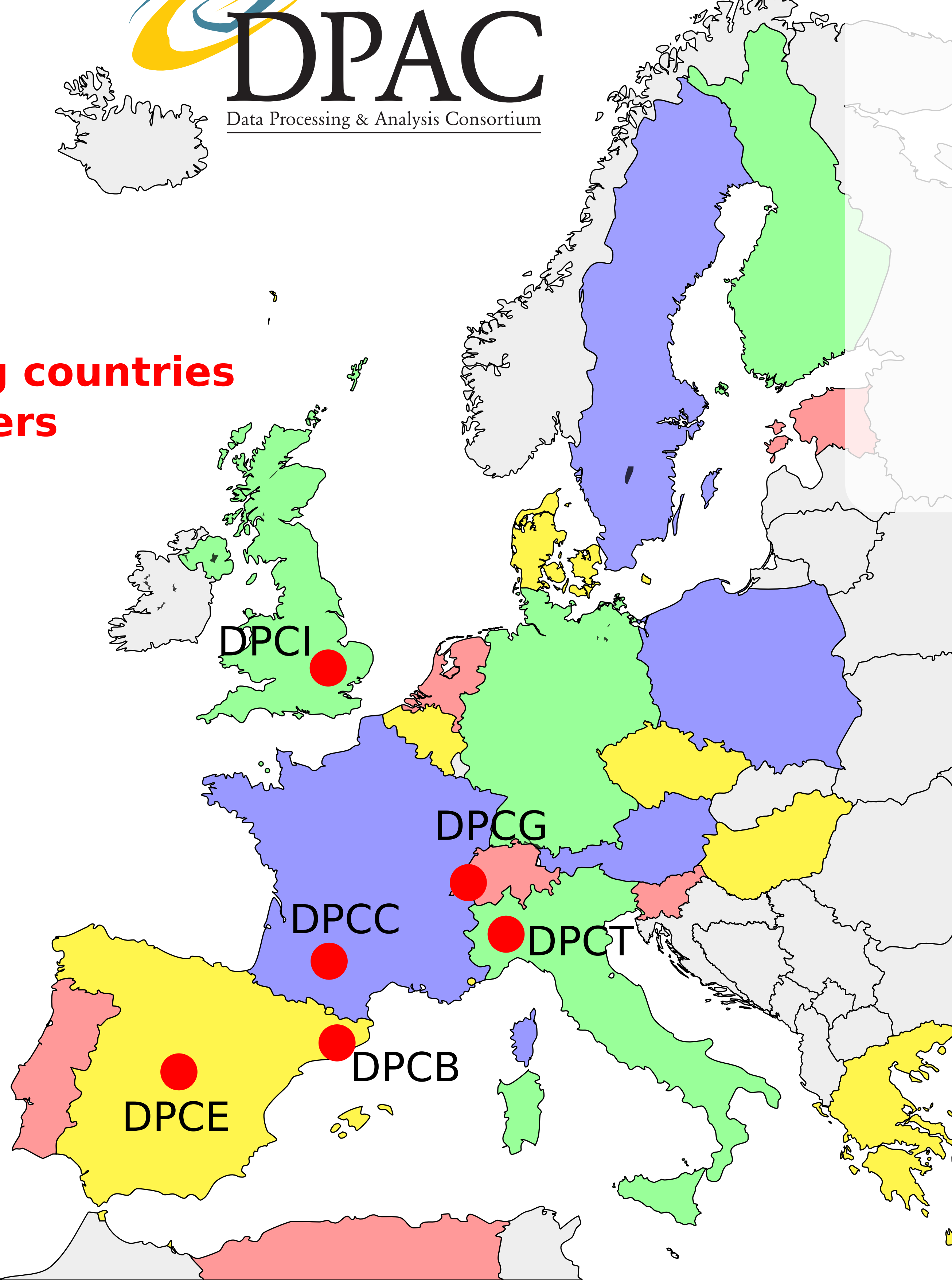


- OGA1: 50 milli arcsec (with IDT)
- OGA2: 100 micro arcsec (24 hours later)

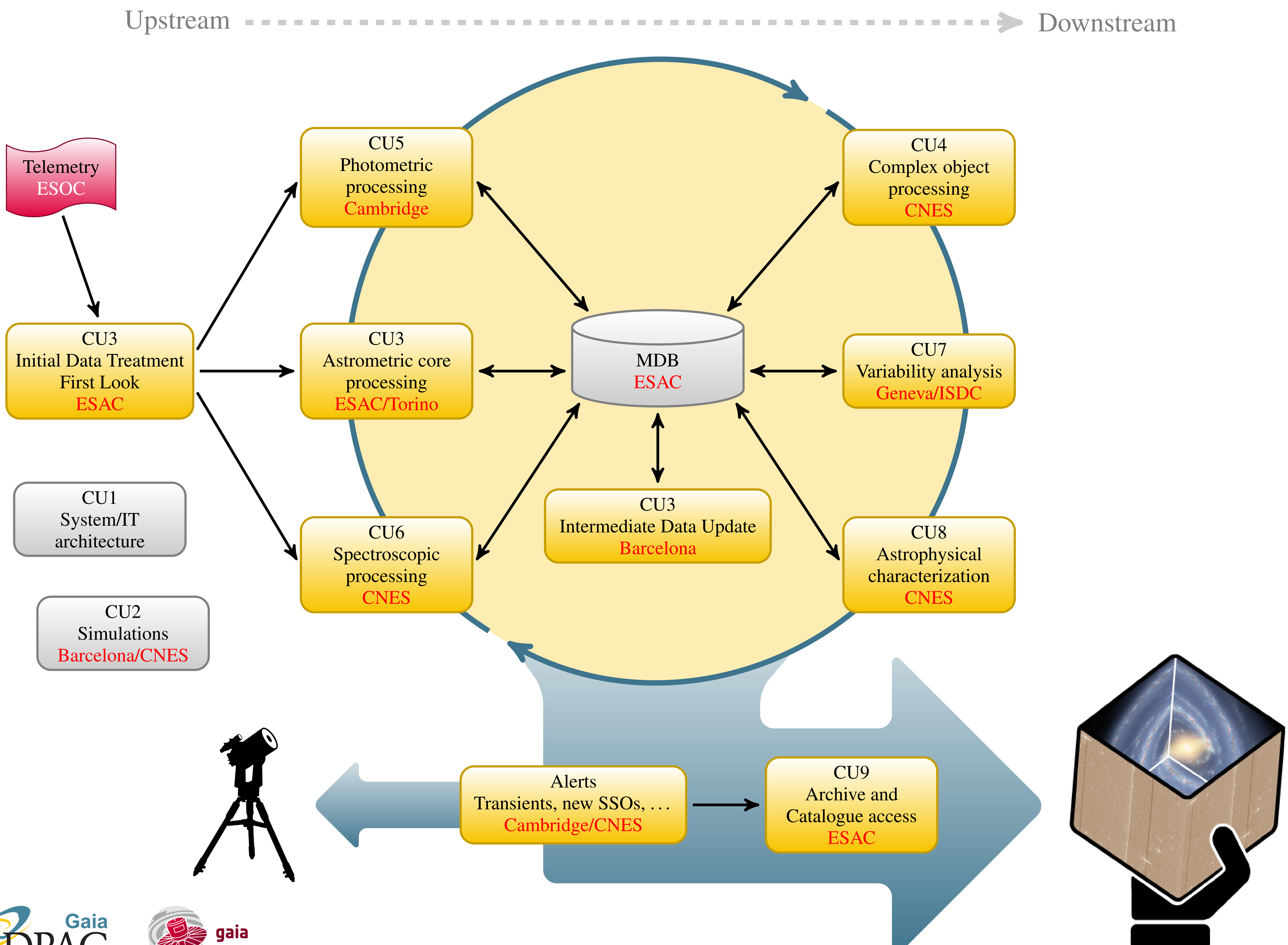
- Gaia data processing is a Pan-European cooperation
  - Academic institutions and national space agencies
  - Supported through national funding
  - Processing power spread over 6 centres
  - ESAC team integral part of DPAC

DPAC
participating countries
~450 members

Including:
BR
CA
DZ
ESA
IL
US



Data processing flows



Timeline for Data Flow

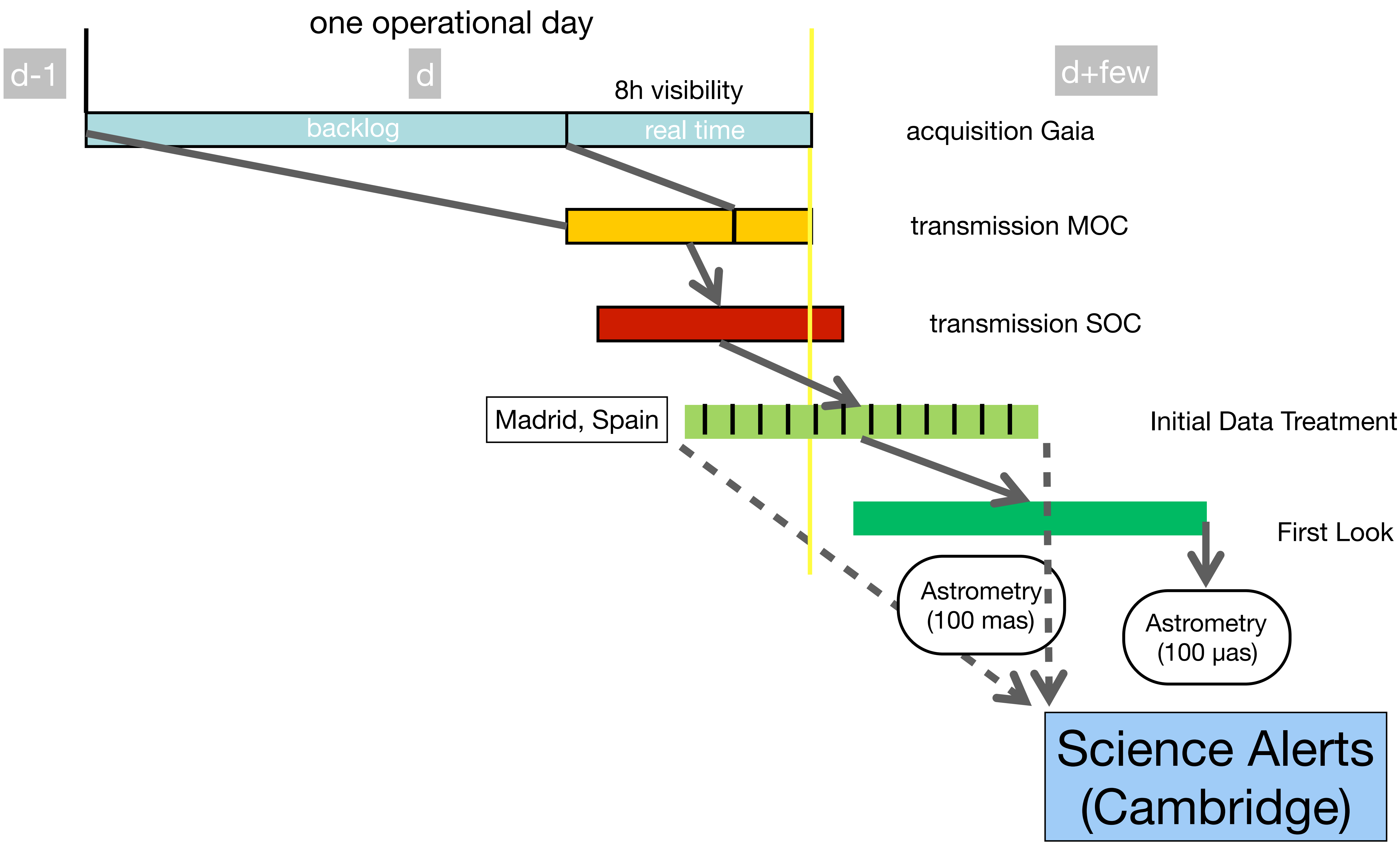


Figure courtesy Francois Mignard, updated by LW+STH

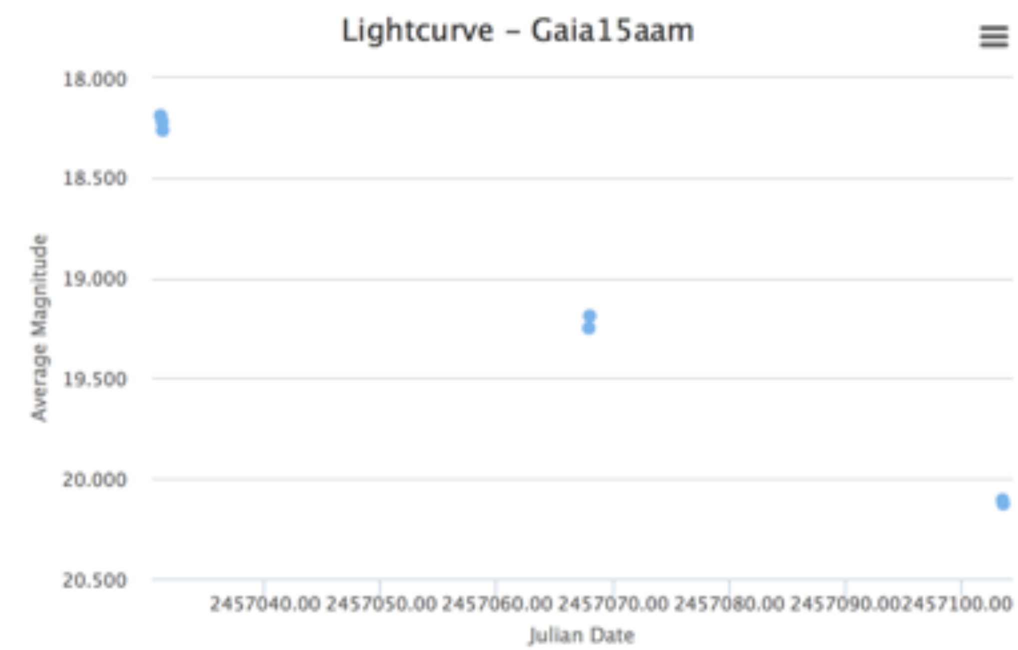
Promptness of publication

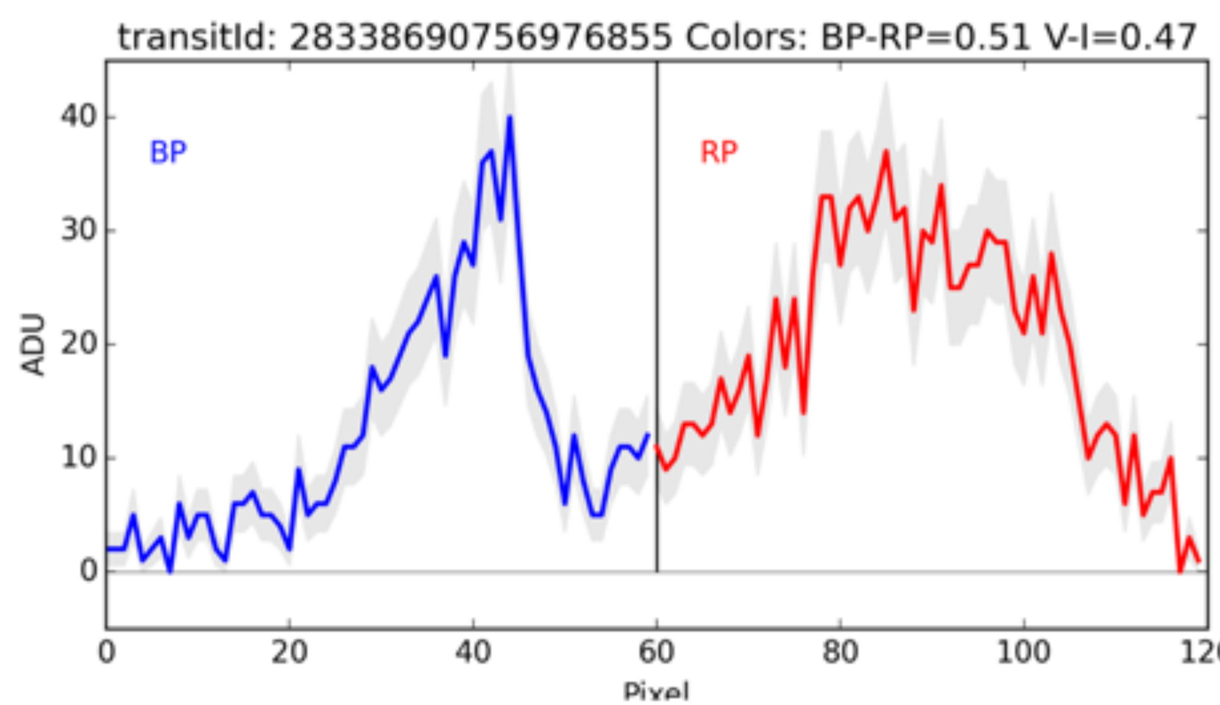
- Upstream processing delivers data **~24+ hours after observation**, roughly one run per day
- Alerts processing (light-curve assembly, calibration, transient detection and classification) takes up to **6 hours per run**
- Publication latency after alerts processing:
  - If classification & selection is automatic: ~ **minutes**
  - If classification & selection is manual: ~ **hours** to ~ **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)*

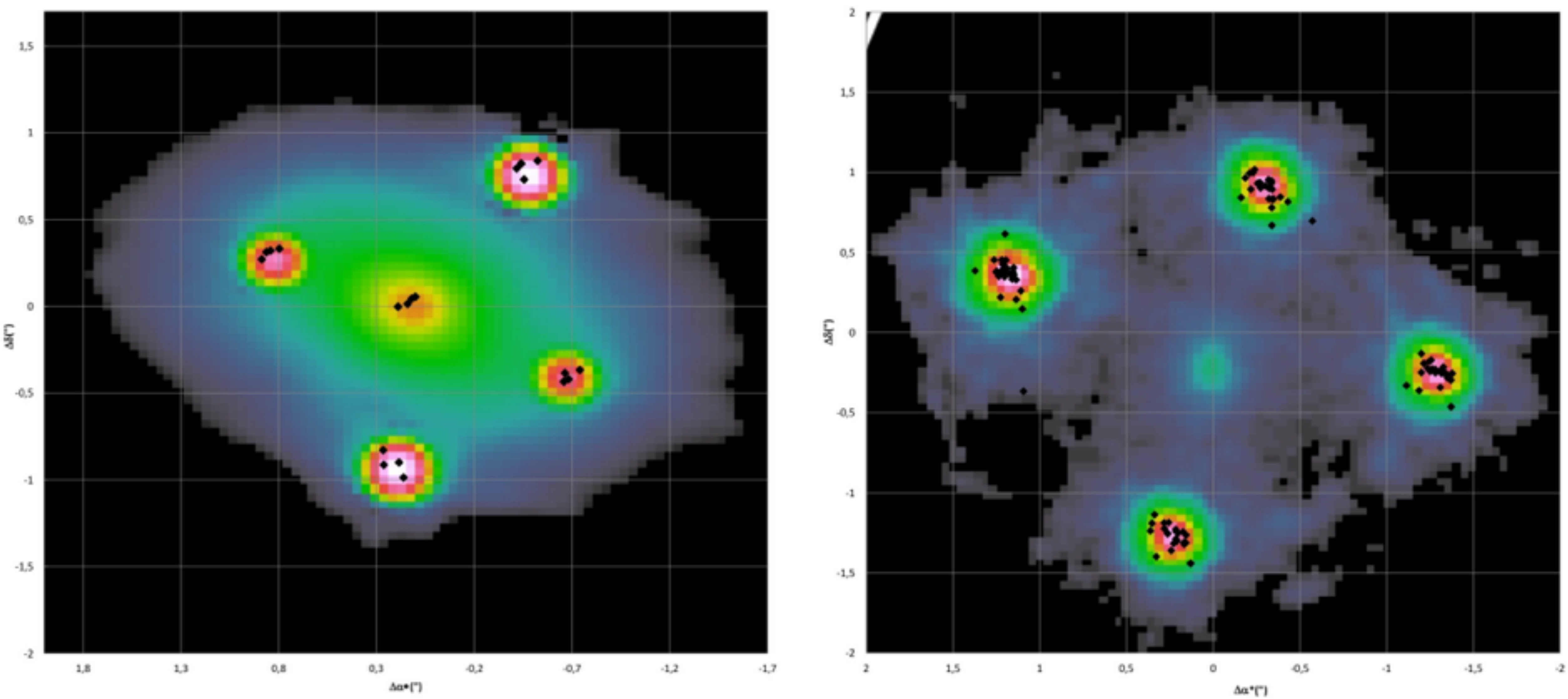




Not the main, data-release

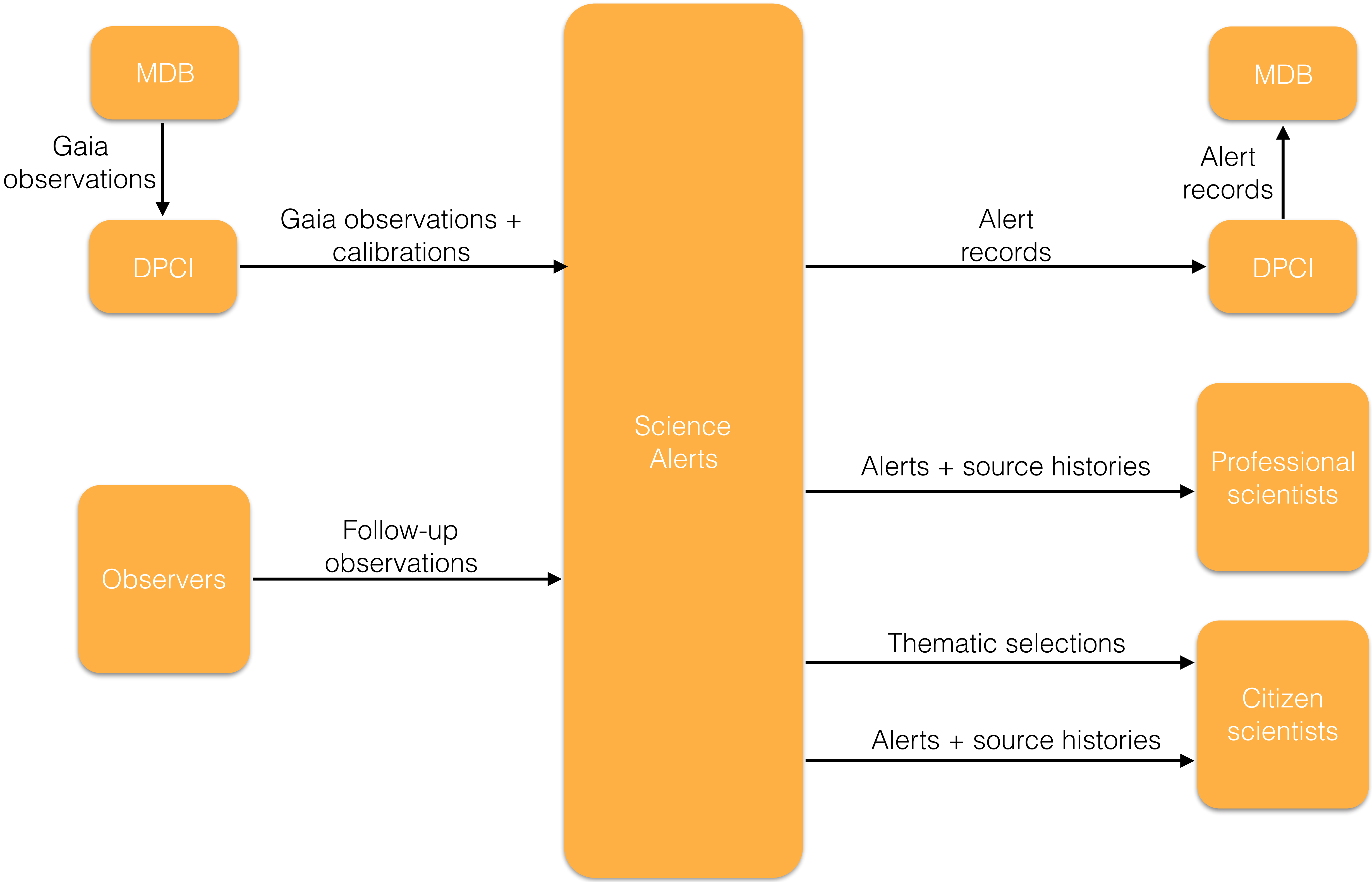
- Photometry:
  - alerts: ~ ±0.01mag, extrapolated, best-effort calibration
  - data release: ~ ±0.001mag, internal, best-possible calibration
- Spectra:
  - alerts: no photo calibration; basic wavelength calibration
  - data release: full spectrophotometric calibration
- Positions:
  - Alerts: preliminary positions ~ ±0.1 arcsec
  - Data release: positions ~ ± 24 μarcsec at end of mission

Q2237+030 **HE0435-1223**



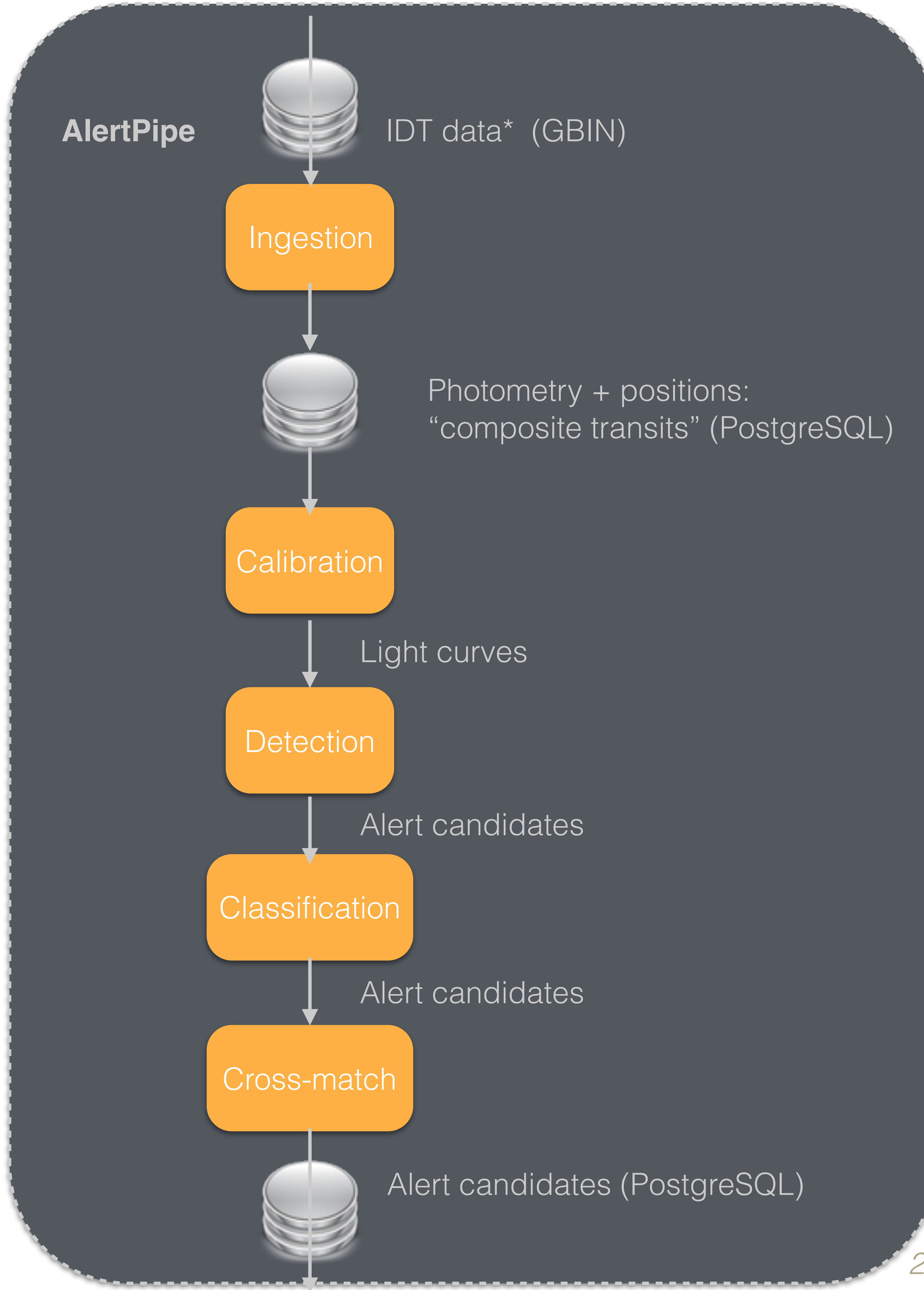
The Einstein Cross (left) and HE0435-1223 (right) with Gaia astrometric positions placed over [HST images](). Gaia's on-board system was able to detect four images of the distant quasar in both cases and the intervening lens at the middle of the Einstein Cross. The positions are supplied by the Gaia 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



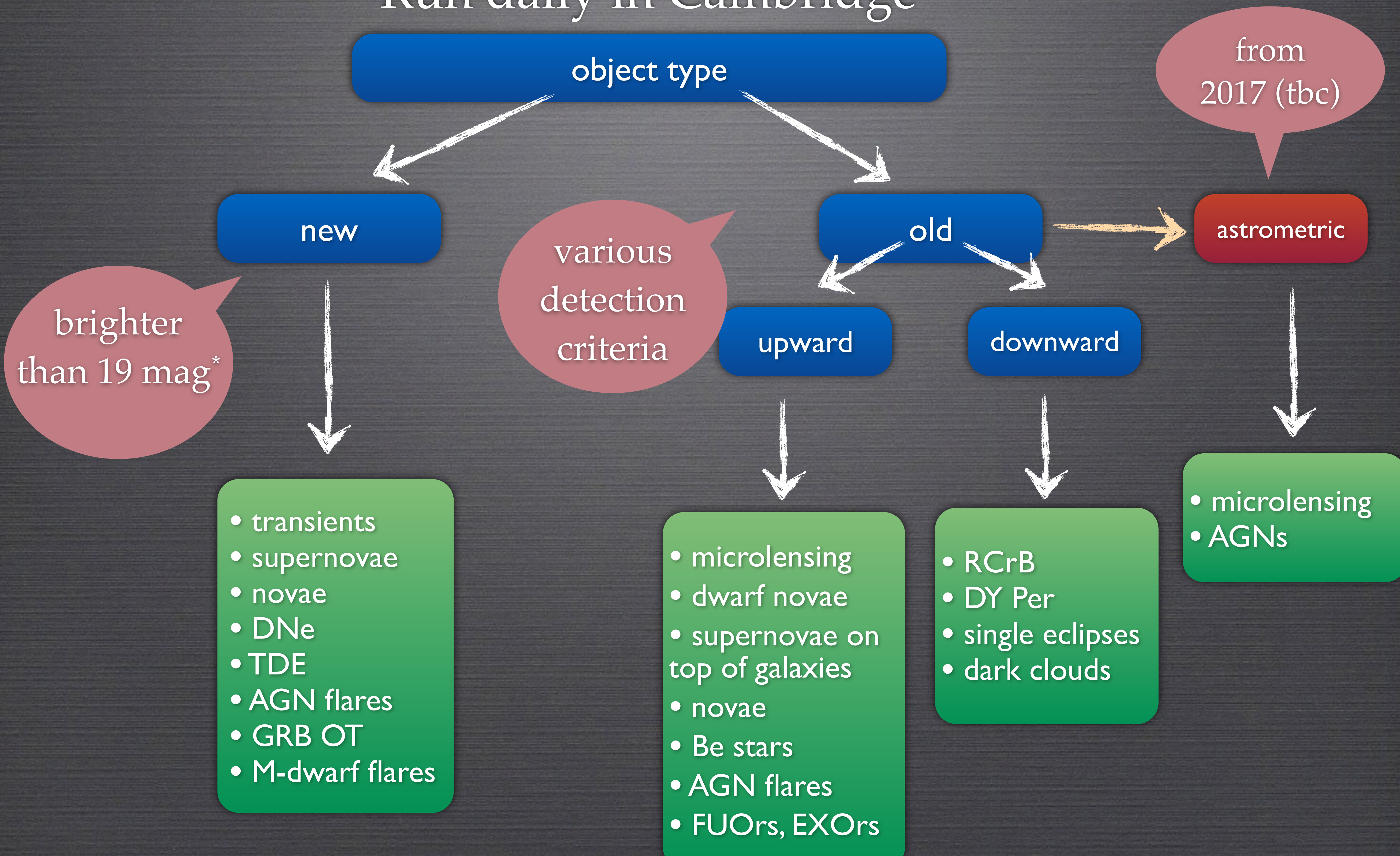
AlertPipe

- <u>Calibration</u>
  - Two calibrations available:
    - Homegrown - based on UberCal [Koposov]
    - CU5 large scale
  - Both are being tested now
- <u>Detection</u>
  - New Sources with history of non detections in Gaia
  - Strongly Variable Sources
- <u>Classification</u>
  - Spectral [Blagorodnova]
  - Lightcurve
  - Environment



ANOMALY DETECTION SYSTEM

Run daily in Cambridge



* 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

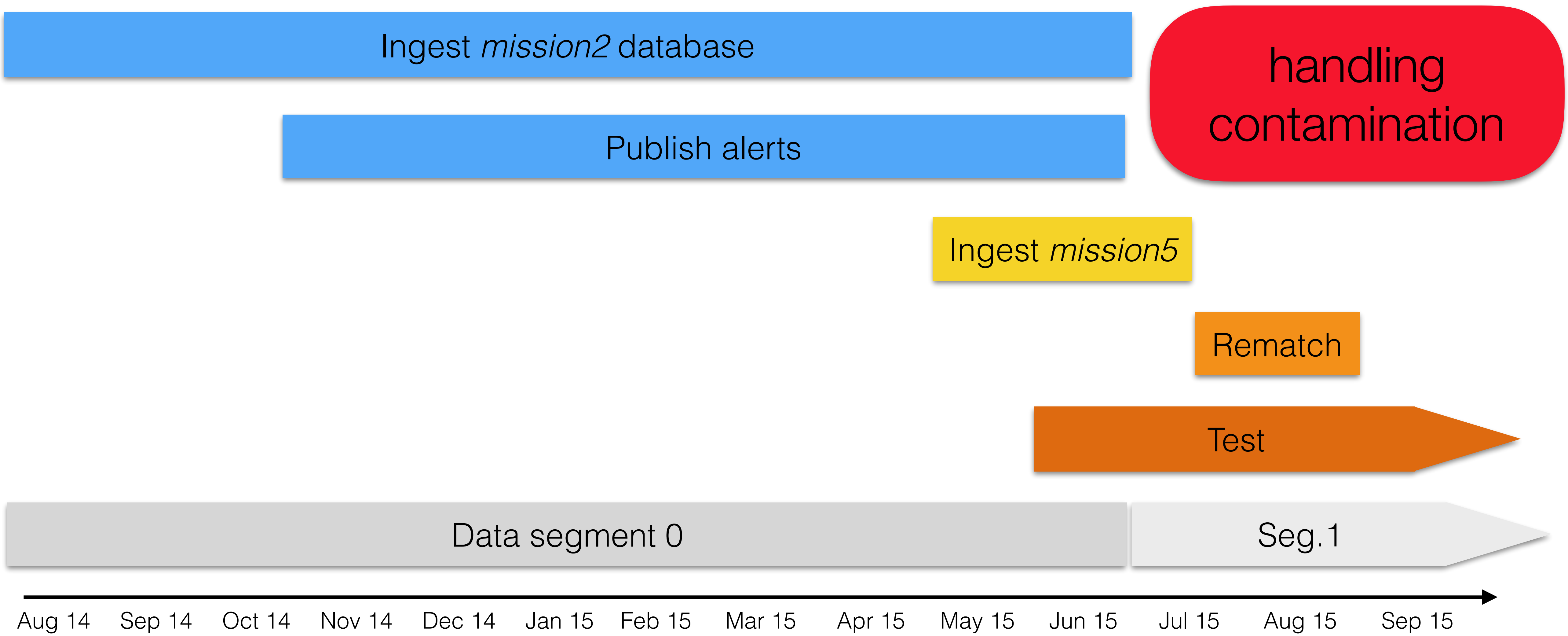
For a source to generate an Alert, either:

- median of historic transits must have G<=19.0, or
- the alerting transit must be G<=19.0

Bumps or Dips must change brightness by >=1 magnitude.

New sources must reach 19th mag

Main operations to date



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

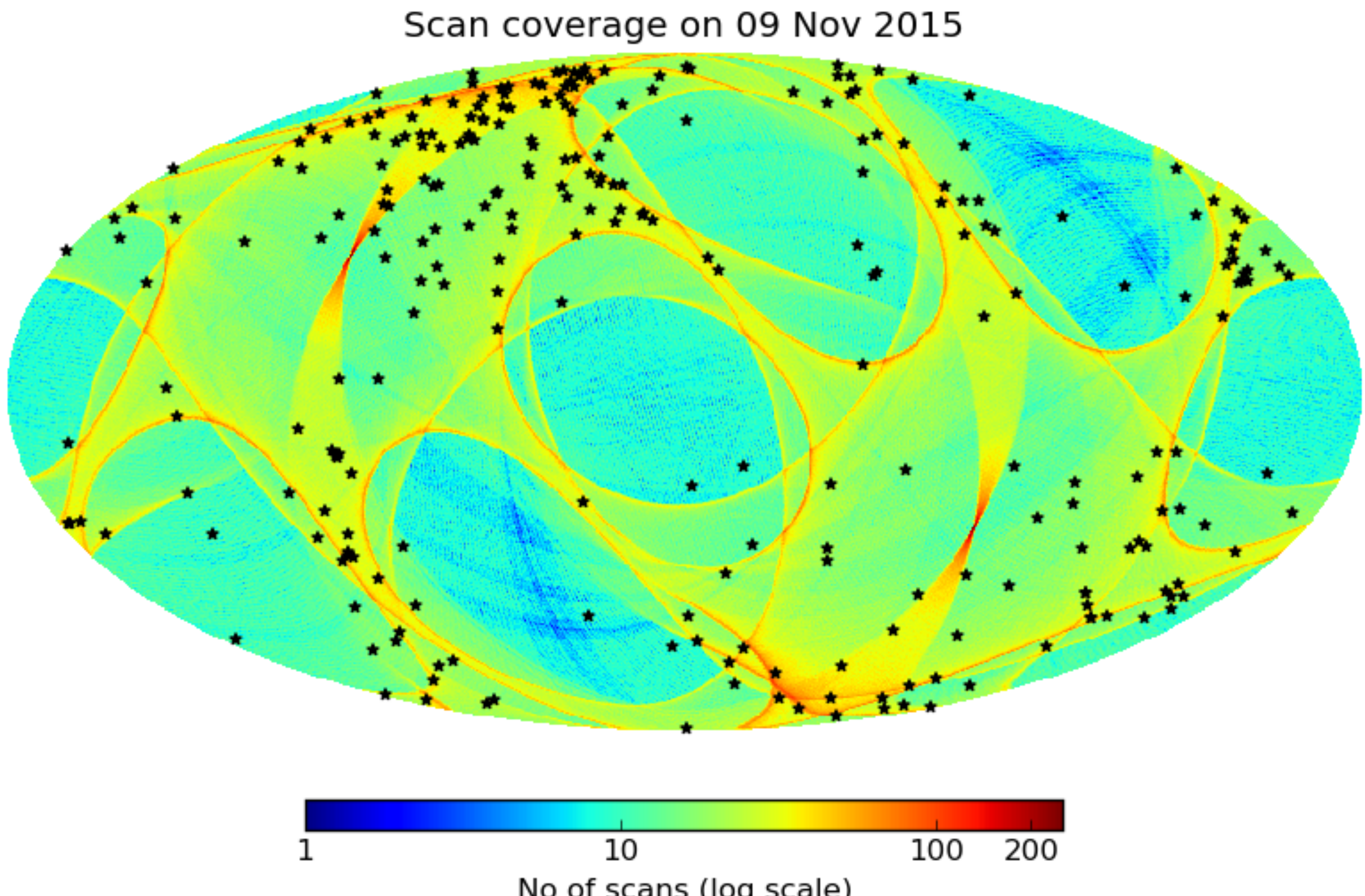
275 published alerts

see talks from Campbell, Fraser, Blagorodnova, Wyrzykowski, Wevers

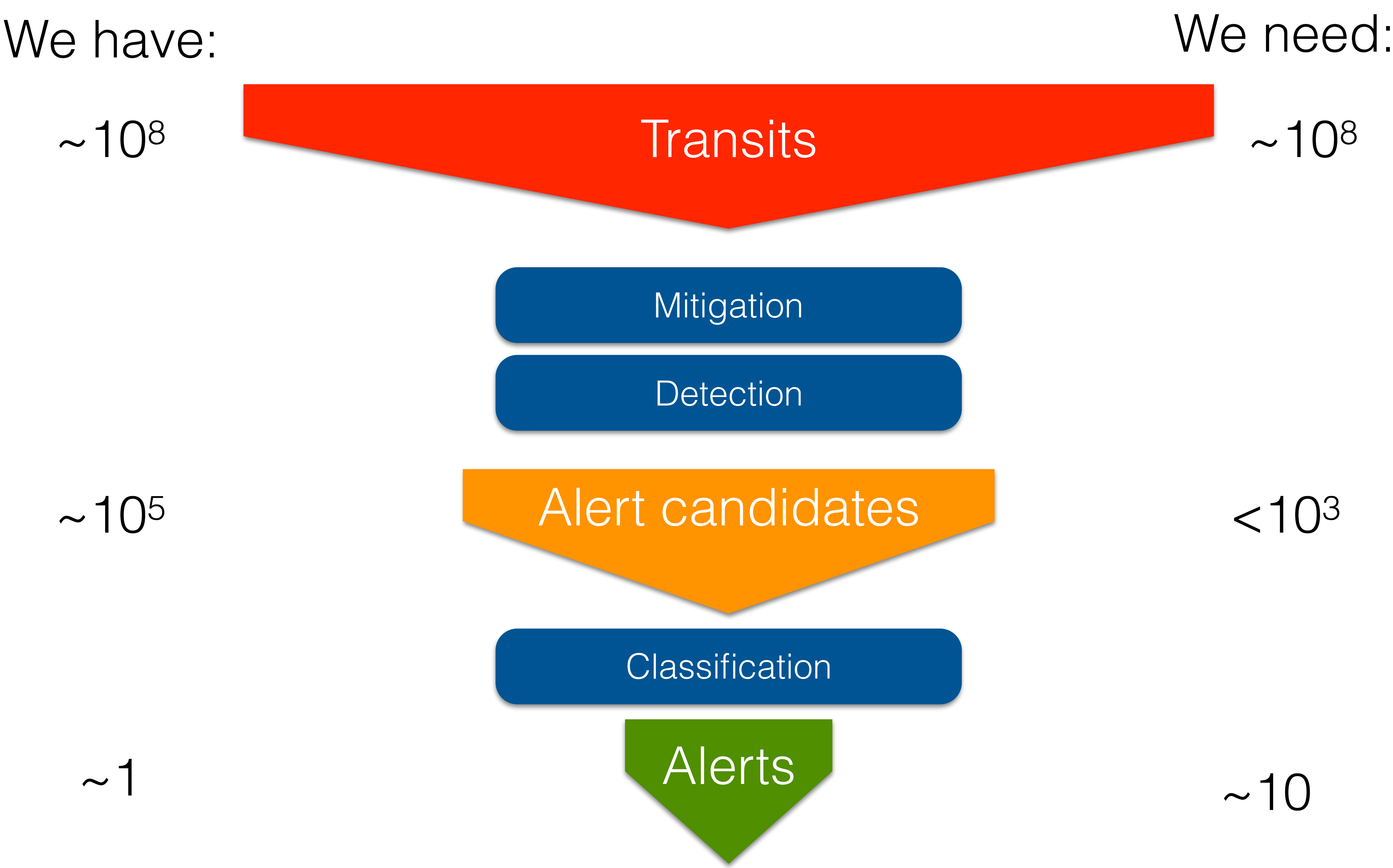
Year 1: Operations

- 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

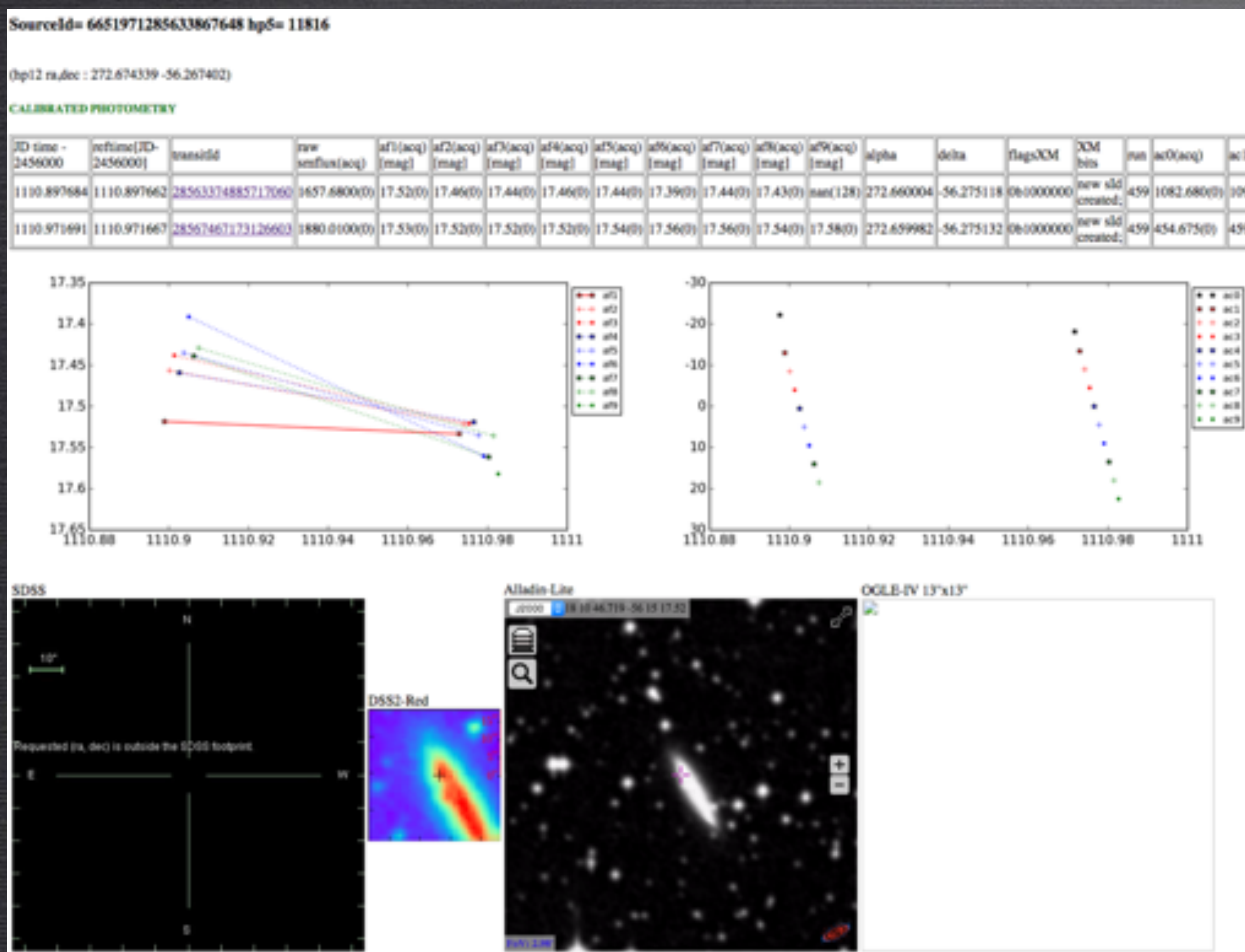


Filtering

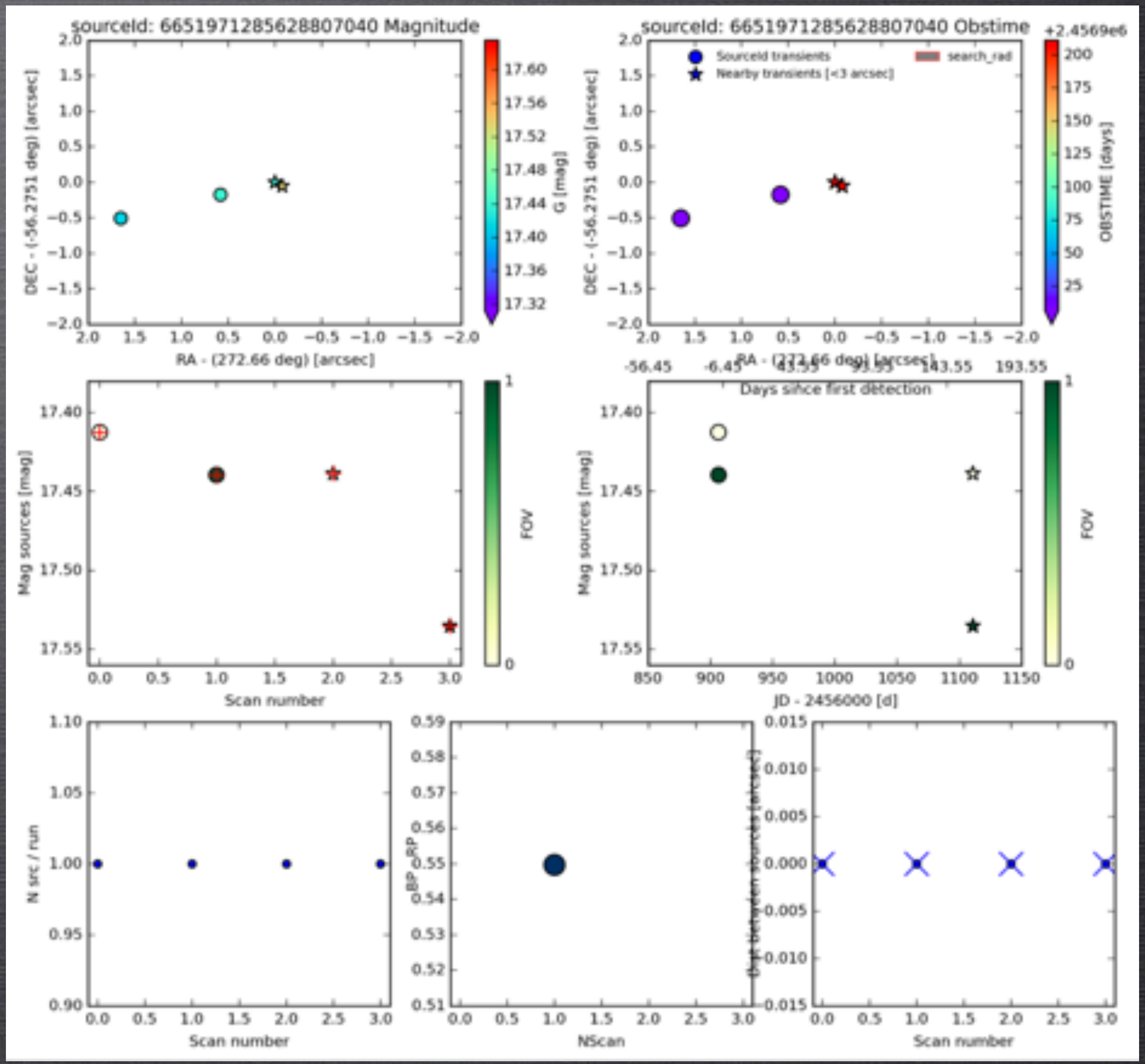

We have:
We need:
~10^8
Transits
~10^8
Mitigation
Detection
~10^5
Alert candidates
<10^3
Classification
~1
Alerts
~10

EYE-BALLING

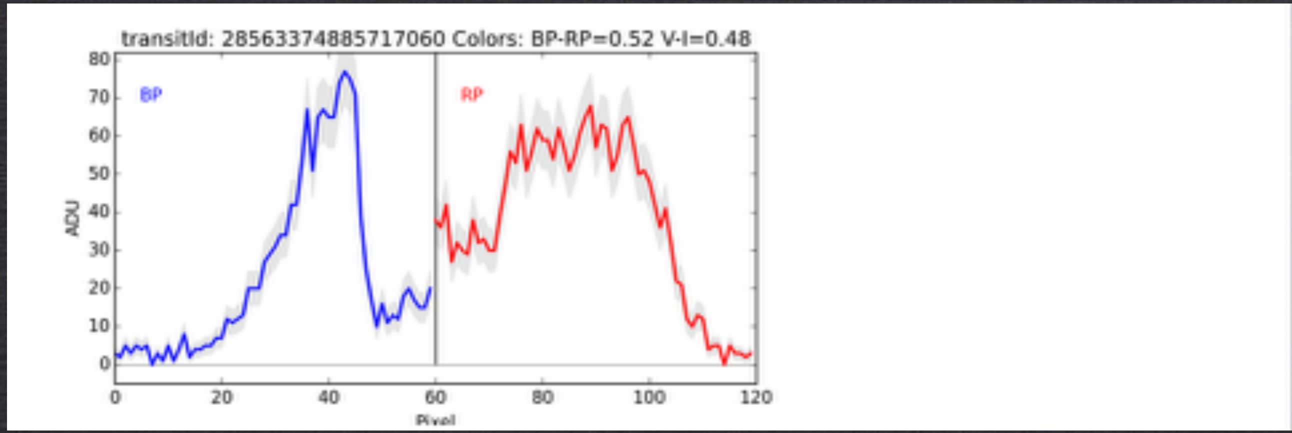
further detailed inspection of candidates



checking other Gaia detections nearby



checking Gaia BPRP spectra



false alert

-> spectrum suggests contamination from the host

-> cross-matching problem

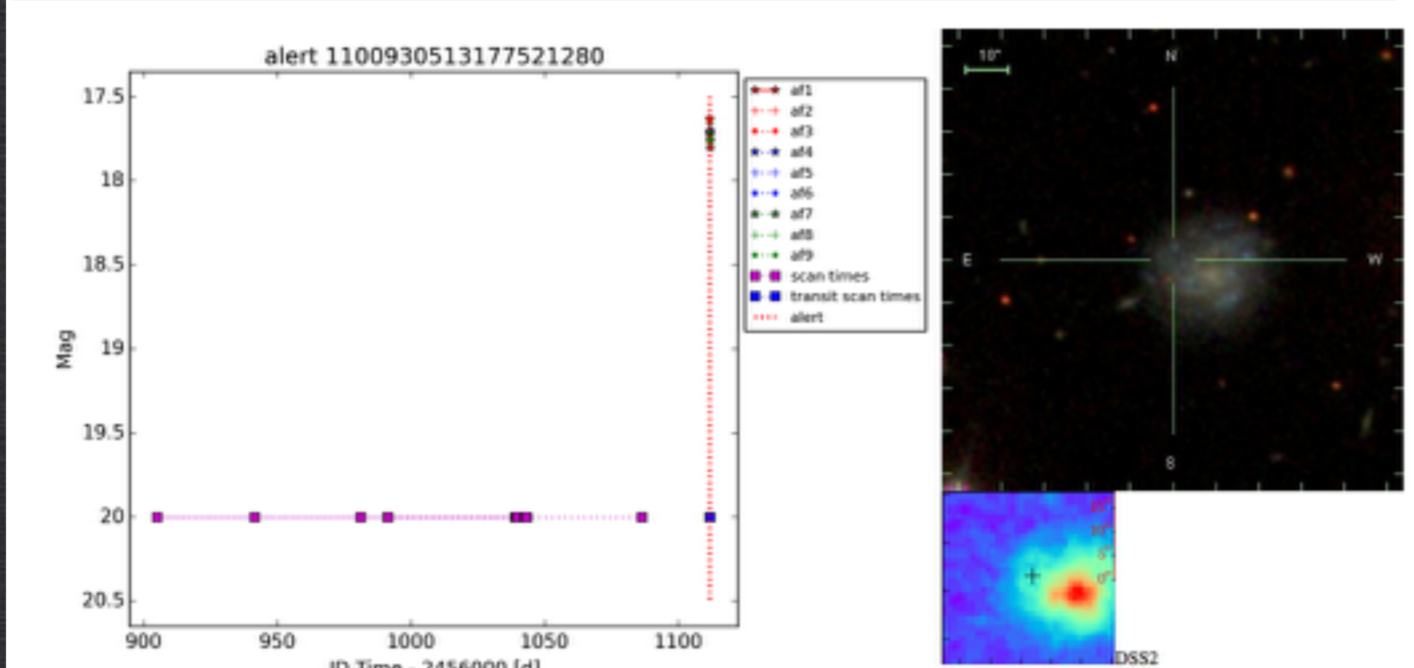
-> old source observed again with new sourceid

EYE-BALLING

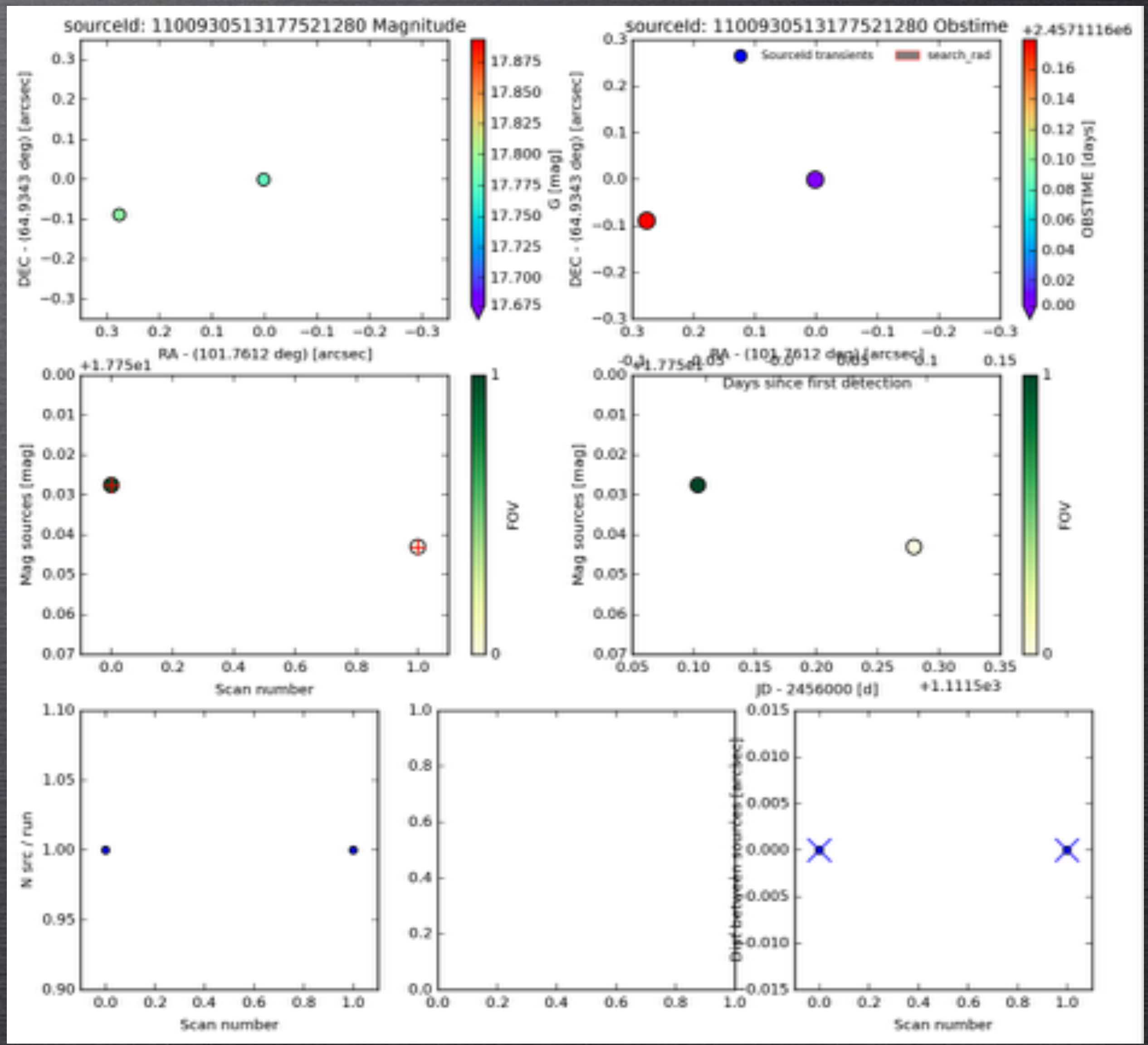
further detailed inspection of candidates

NewSource. Last non-detection date: 2015-03-04T20:39:42"

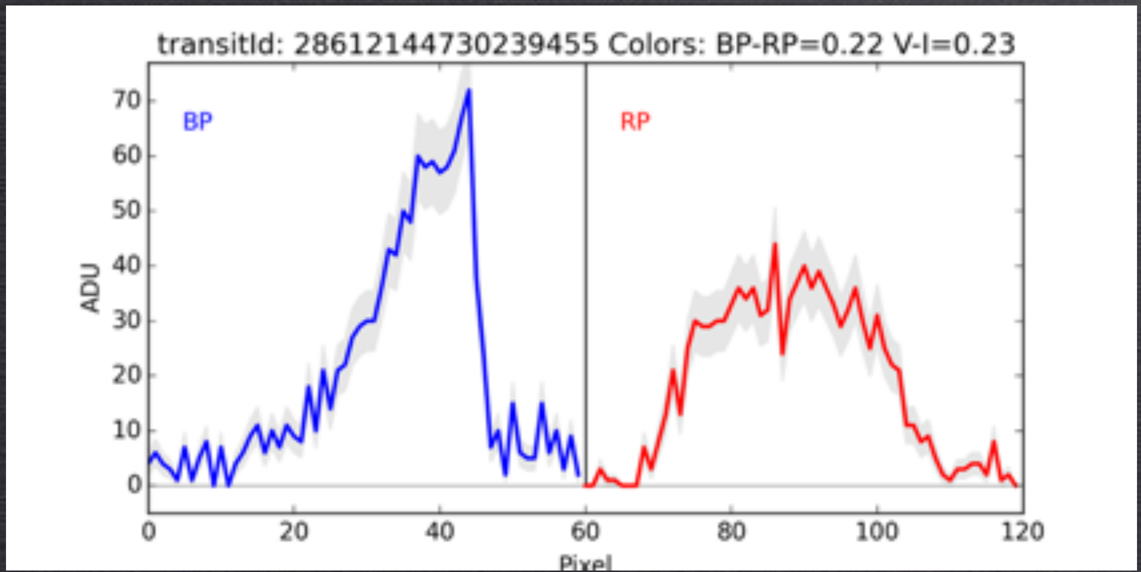
JD time-2456000	transitId	af1[mag]	af2[mag]	af3[mag]	af4[mag]	af5[mag]	af6[mag]	af7[mag]	af8[mag]	af9[mag]	mean
1111.603507	286024039179595 60	17.63	17.63	17.66	17.72	17.70	17.73	17.72	17.76	17.77	17.70
1111.779664	286121447302394 55	17.80	17.74	17.77	17.76	17.72	17.69	17.70	17.66	17.75	17.73



checking other Gaia detections nearby



checking Gaia BPRP spectra



NOT and LT spectroscopic classification of supernovae Gaia15acz and Gaia15aek

ATel #7378; *S. Mattila, J. Harmanen, T. Kangas (University of Turku), A. S. Piascik, C. Davis, I. A. Steele (Liverpool John Moores University), N. Blagorodnova, M. Fraser, H. Campbell, S. Hodgkin, N. Walton (University of Cambridge), L. Wyrzykowski (Warsaw University Observatory), E. Kankare, R. Kotak (Queen's University Belfast)*
on 13 Apr 2015; 11:49 UT

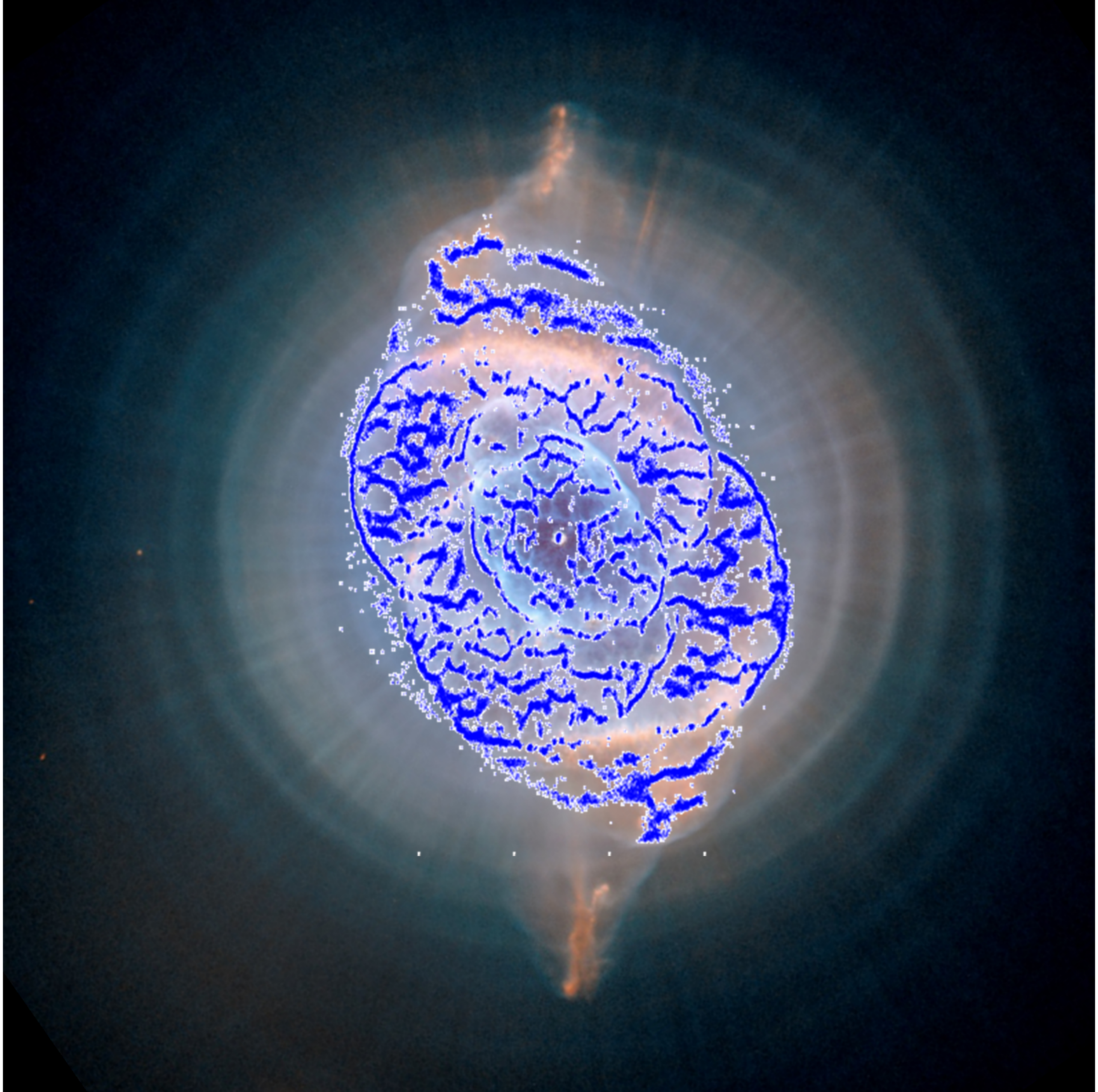
=> Gaia15aek

Supernova type IIP 2 weeks past max

Łukasz Wyrzykowski

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

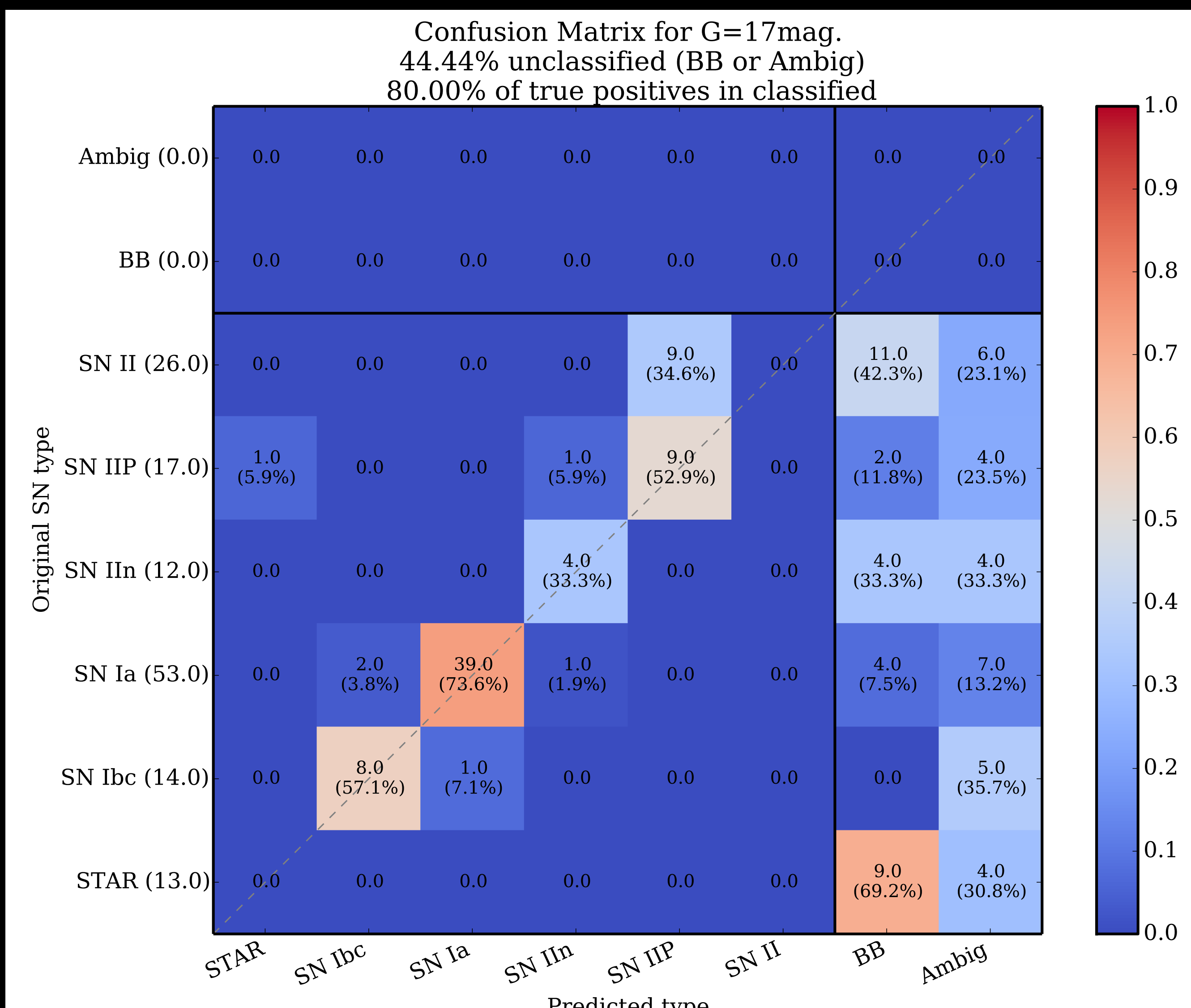


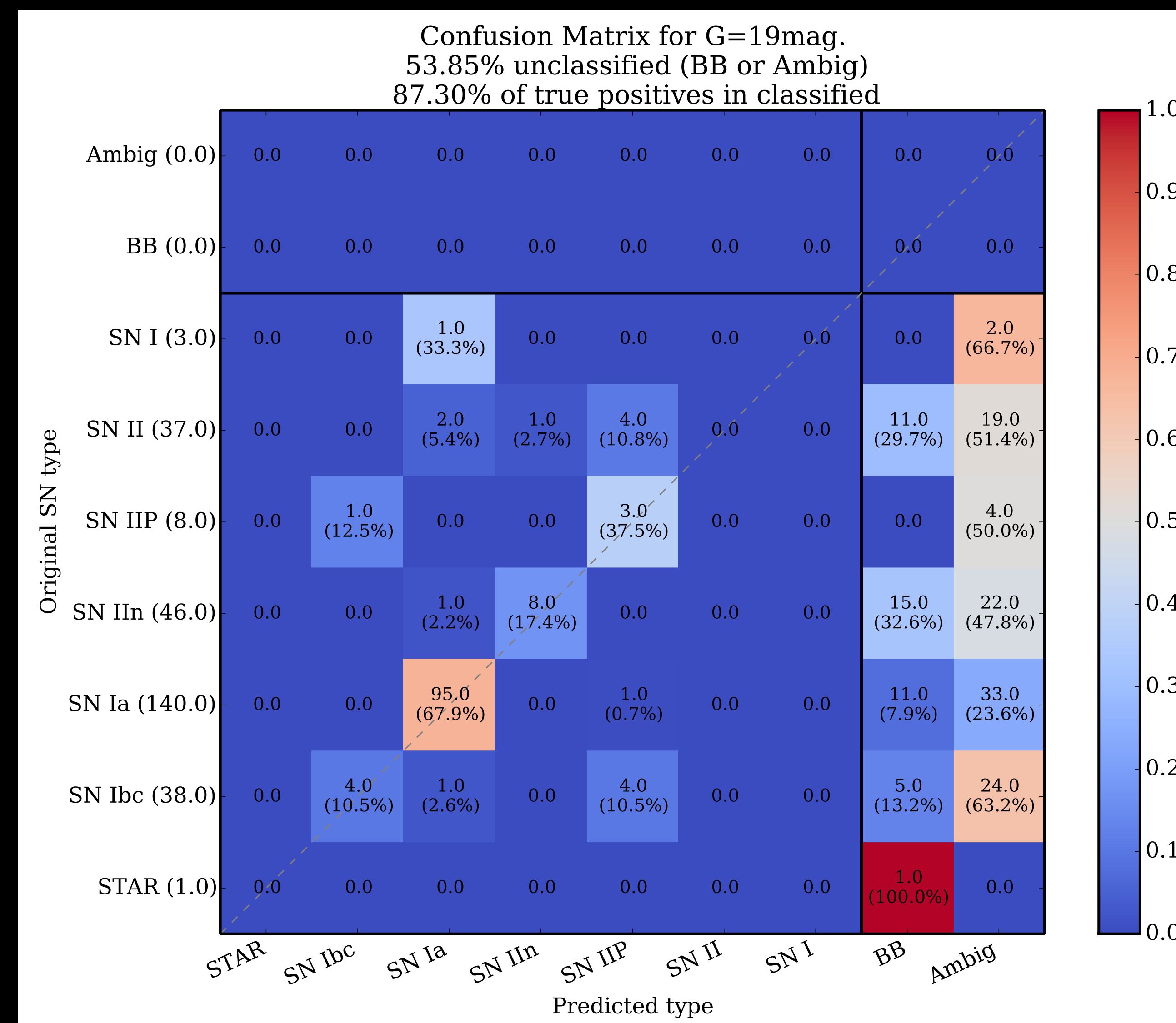
HST image credit: NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA)
Gaia image credit: ESA/Gaia/DPAC/UB/IEEC

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

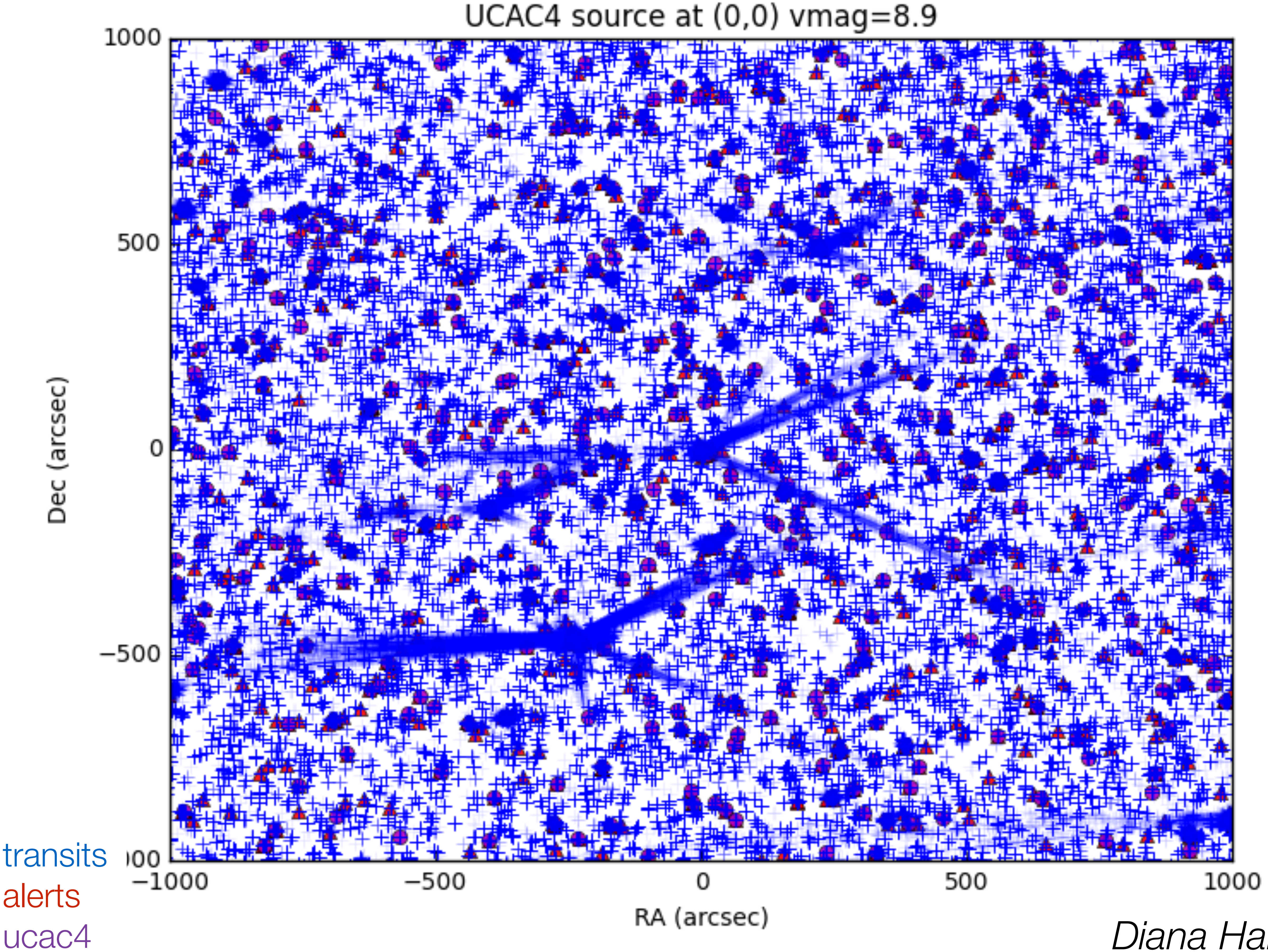
BP/RP spectral classification





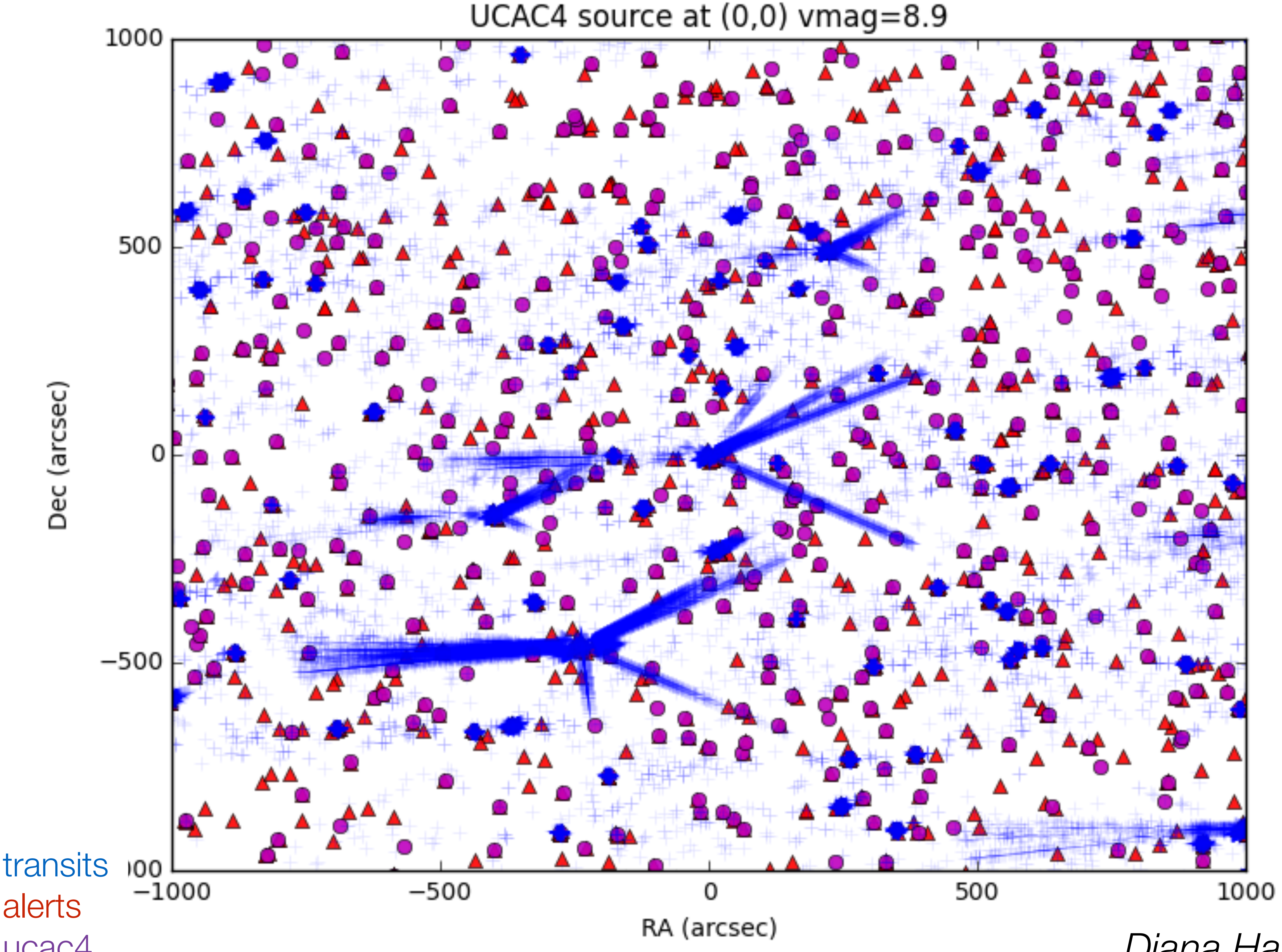
Blagorodnova et al. 2014, MNRAS, 442, 327, GS-TEC: the Gaia spectrophotometry transient events classifier

These diffraction spikes are inherent in the trade-off we make between completeness and level of false detections



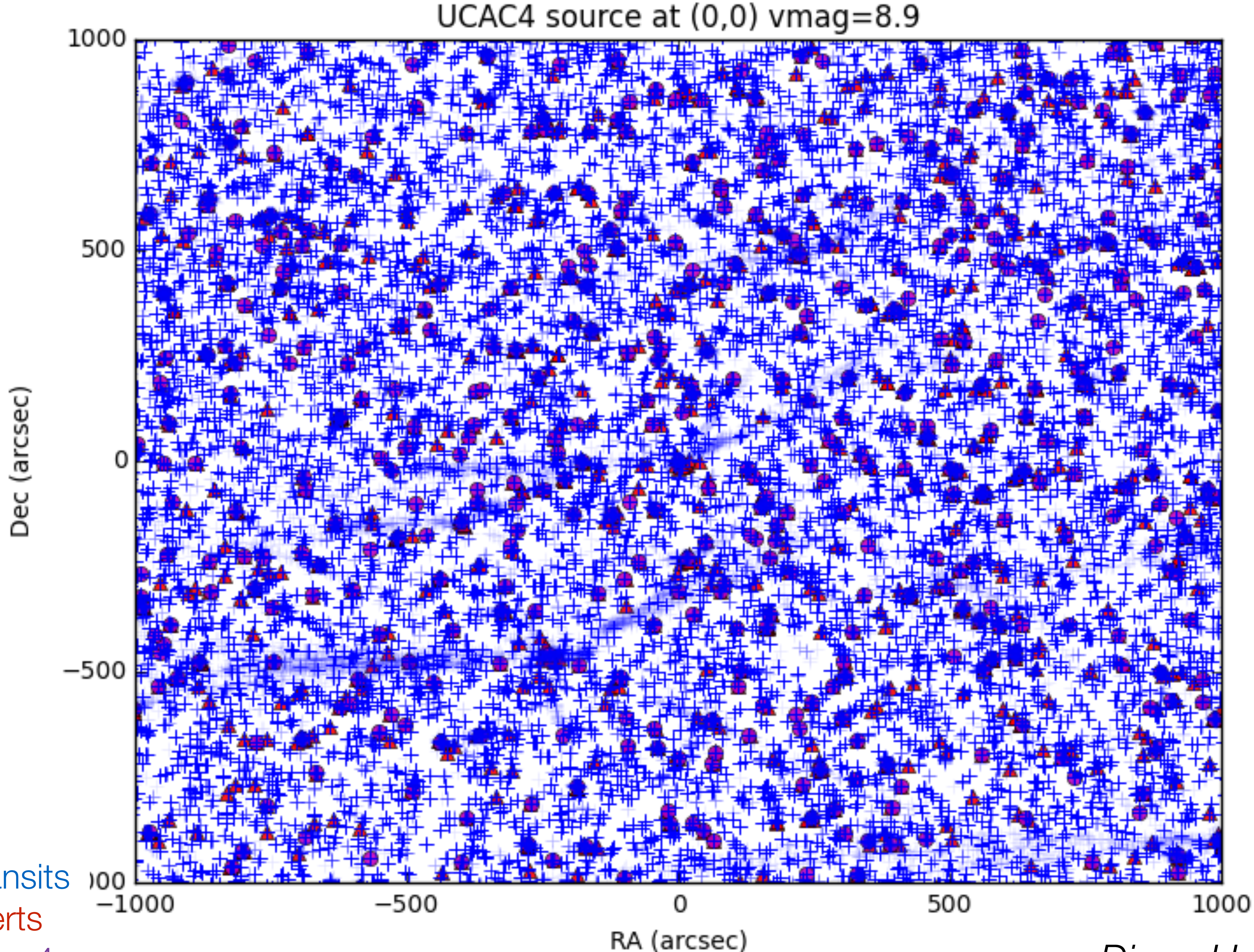
Diana Harrison

All my flagged transits



Diana Harrison

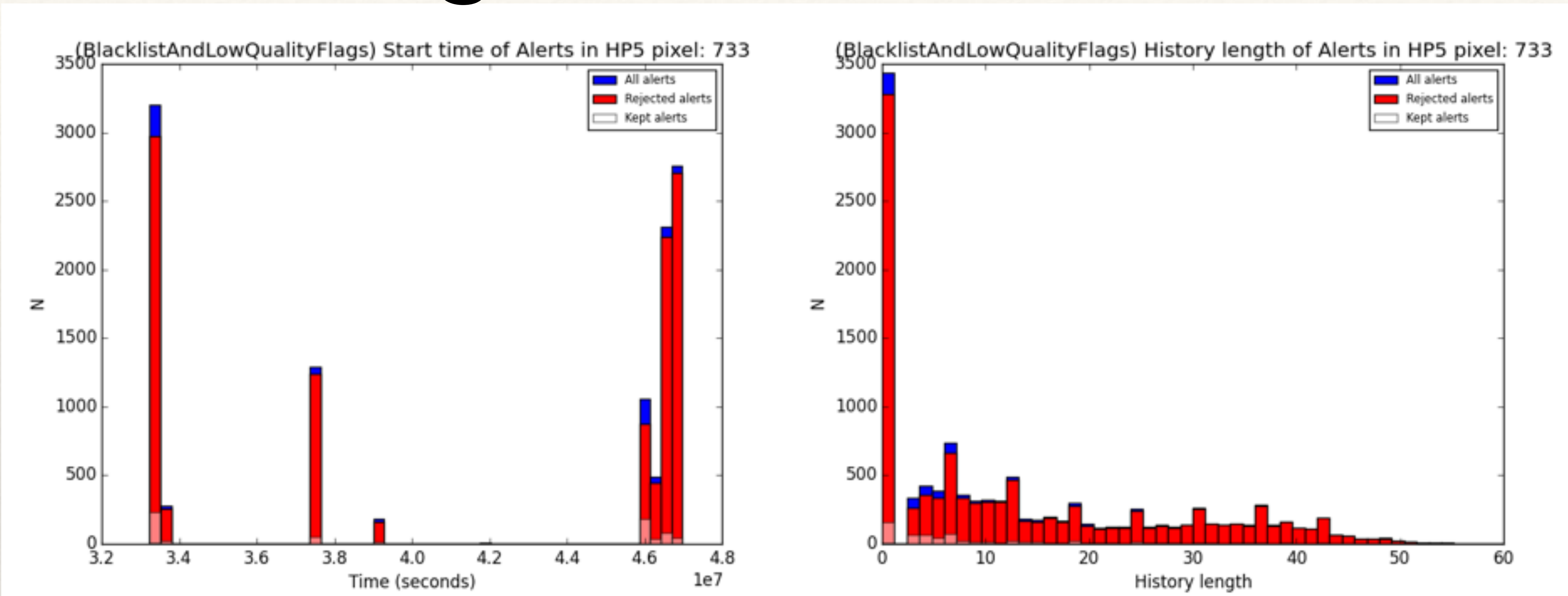
My whitelisted transits



transits
alerts
ucac4

Diana Harrison

Removing Contaminants



- 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

<u>Manual operation (last year)</u>

- ~$10^{5\text{-}6}$ candidates/day
- Human selection of alerts
- Slow!
- ~1 alerts/day
- Classification after publication

<u>Planned operation (mid Nov)</u>

- ~100 candidates/day
- Automatic selection
- Quicker
- ~10 alerts/day
- Classification before publication

Automated Operation

We propose to start **publishing** <u>automatically generated</u> 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.

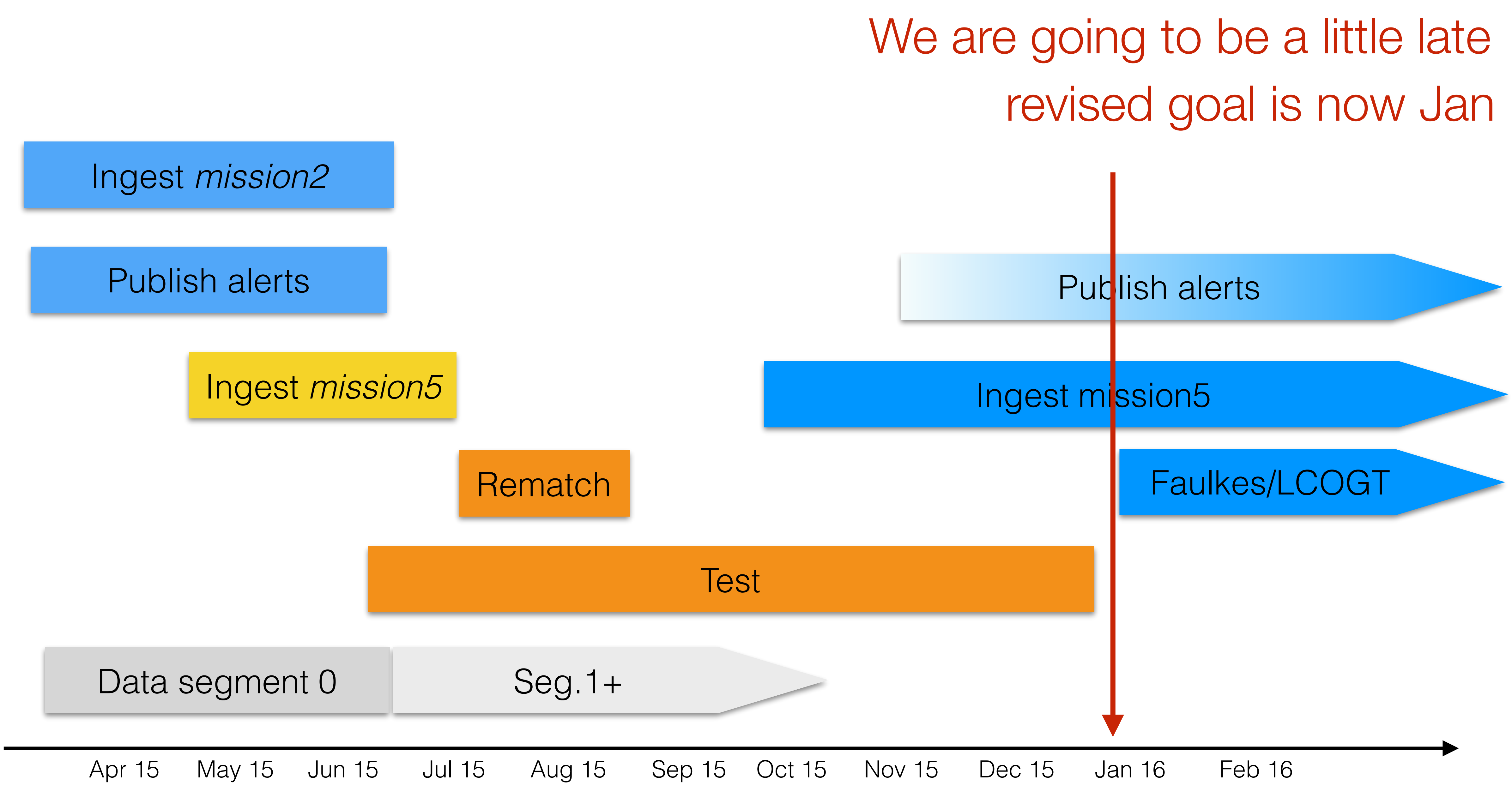
We can turn it on sooner if we are ready.

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

<u>Full operation (by Jan)</u>

- ~100 candidates/day
- near-automatic selection

Planned operations



Mar 15

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 ($\sim$ all sky, single stars)

- Includes more often scanned Ecliptic pole regions
- Hundred Thousand Proper Motions (Hipparcos-Gaia, $\sim 50\ \mu$as/yr)

Early 2017 radial velocities for bright stars, two-band photometry, and full astrometry (α, δ, ϖ, $\mu_{\alpha*}$, μ_δ) where available.

2017/2018 (TBC) full astrometry, orbital solutions for short period binaries, ($G_{\mathrm{BP}} - G_{\mathrm{RP}}$), 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)