Transients classification for the Gaia Science Alerts

- status and ideas

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(or just lucas)

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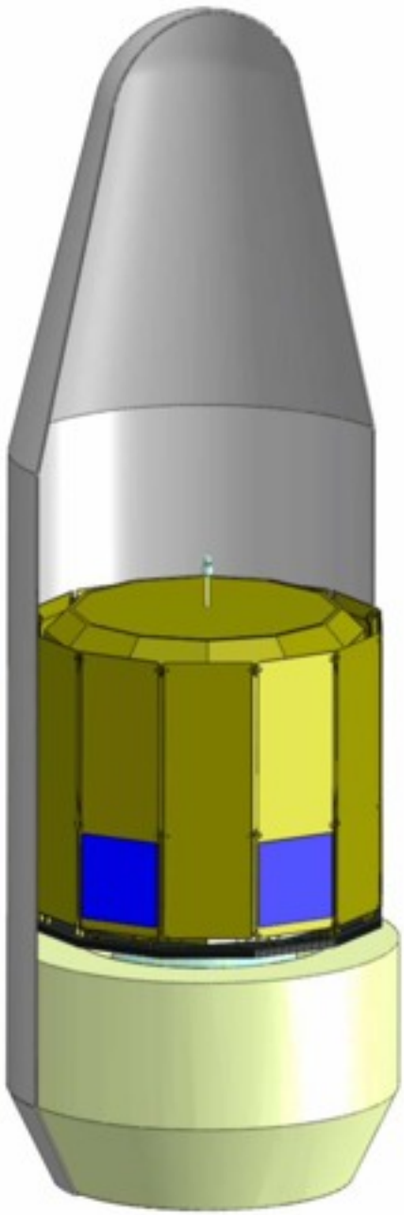
Gaia in brief

- GAIA is a scanning mission
  - no pointing, no change in the schedule, uniform coverage of the sky
- Simultaneous astrometry, photometry and spectroscopy
- Astrometry (V < 20):
  - completeness to 20 mag (on-board detection) 10^9 stars
  - parallax accuracy: *7* μas at <10 mag; 12–25 μas at 15 mag 100–300 μas at 20 mag
- Photometry (V < 20):
  - low-dispersion spectro-photometry
  - 8–20 mmag at 15 mag: Teff ~ 200 K, log g, [Fe/H] to 0.2 dex, extinction
- Radial velocity (V < 16.5–17):
  - Third component of space motion, perspective acceleration
  - <1 km/s at 13-13.5 mag and <15 km/s at 16.5-17 mag

Satellite



ESA-only mission

Launch date: spring 2012

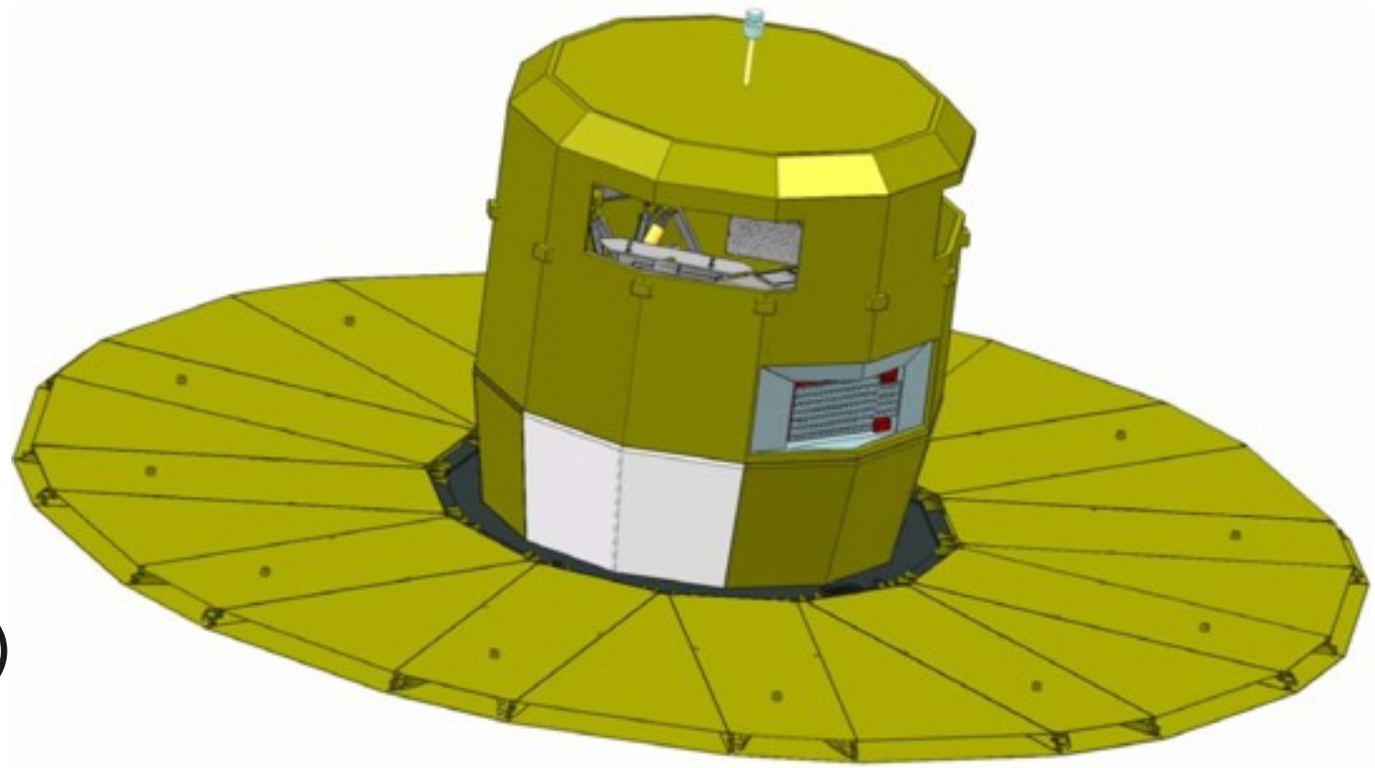
Lifetime: 5 years (1 year potential extension)

Launcher: Soyuz–Fregat from CSG

Orbit: L2 Lissajous orbit

Ground station: Cebreros and New Norcia

Downlink rate: 4–8 Mbps

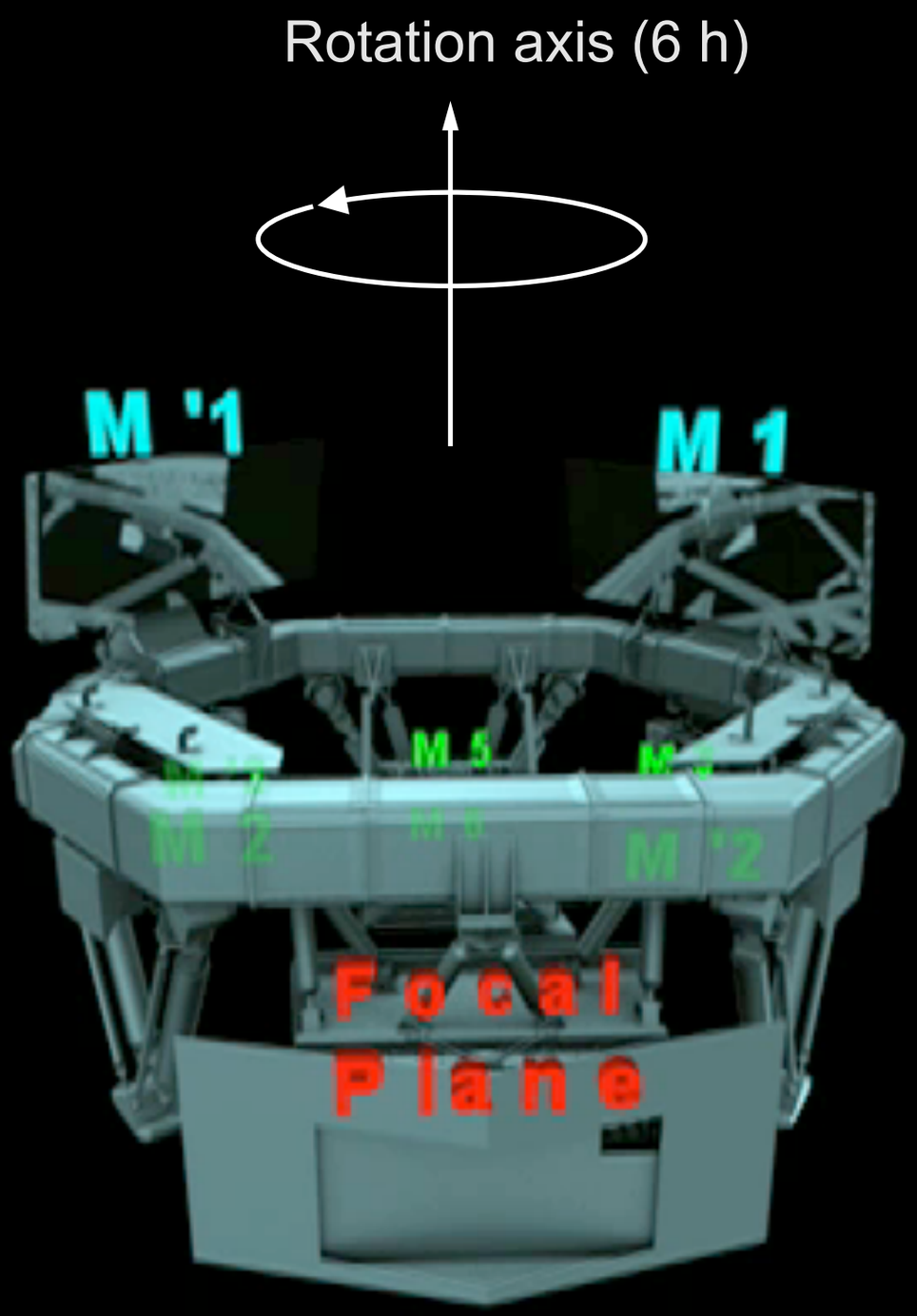


- Mass: 2120 kg (payload 743 kg)
- Power: 1631 W (payload 815 W)

Figures courtesy EADS-Astrium

Payload and Telescope

Two SiC primary mirrors
1.45 × 0.50 m² at 106.5°

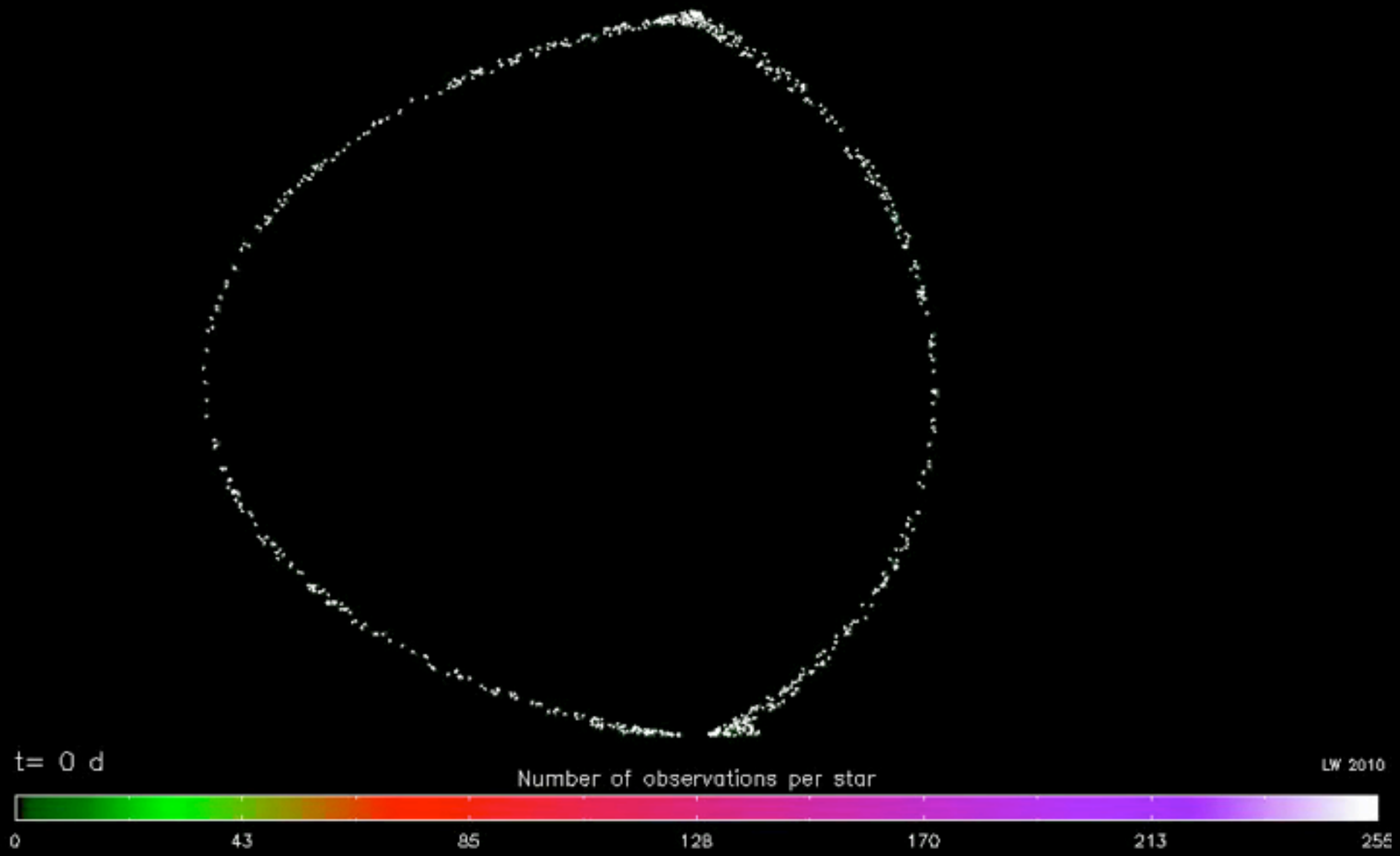


SiC toroidal structure (optical bench)

Combined focal plane (CCDs)

Superposition of two Fields of View (FoV)

Sky Scanning Principle



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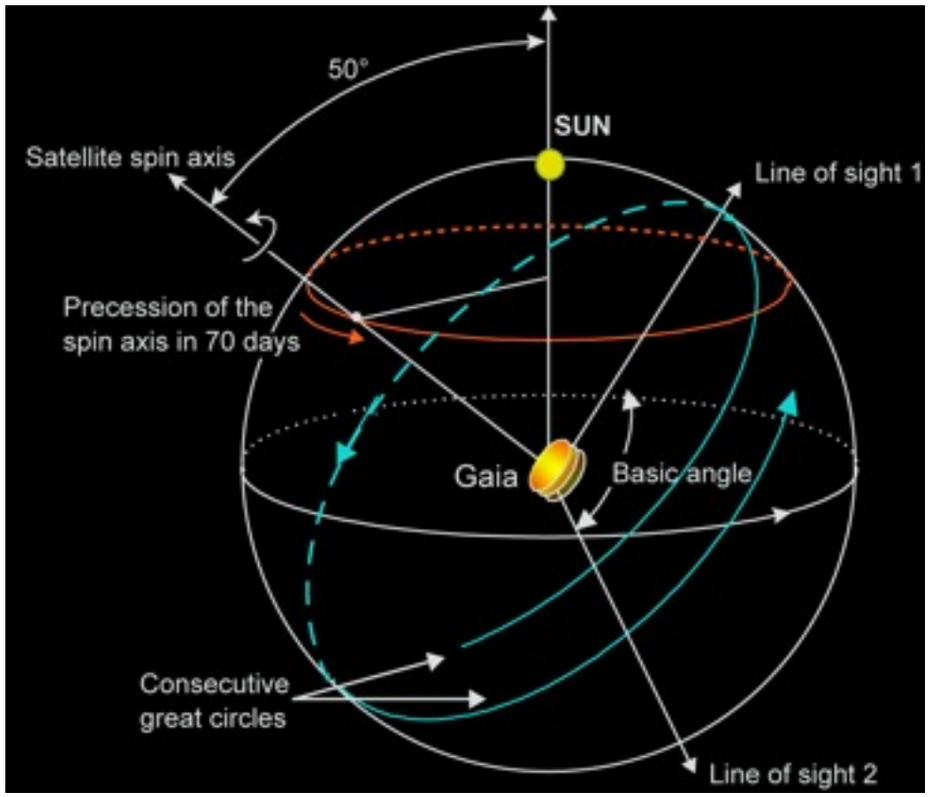
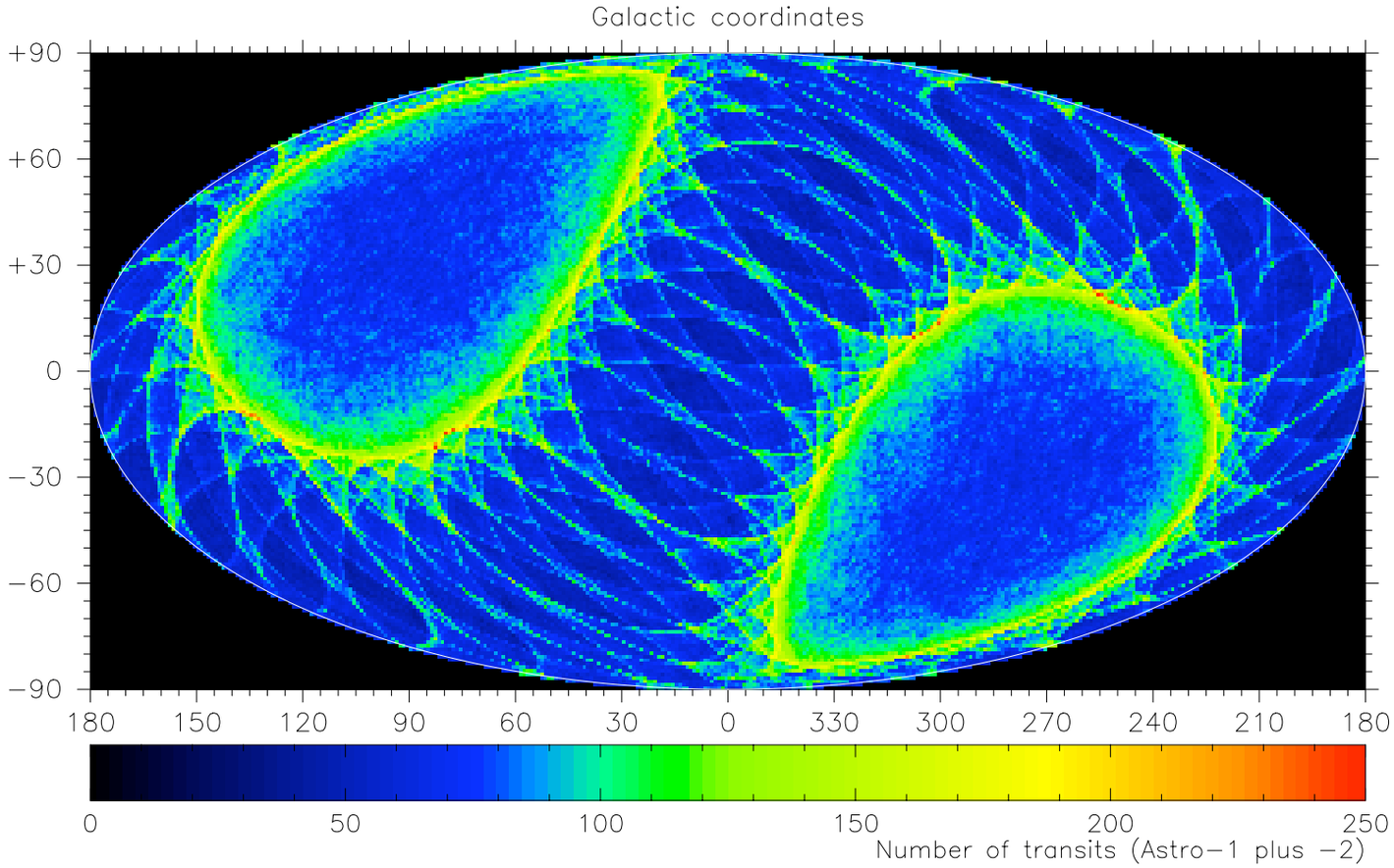
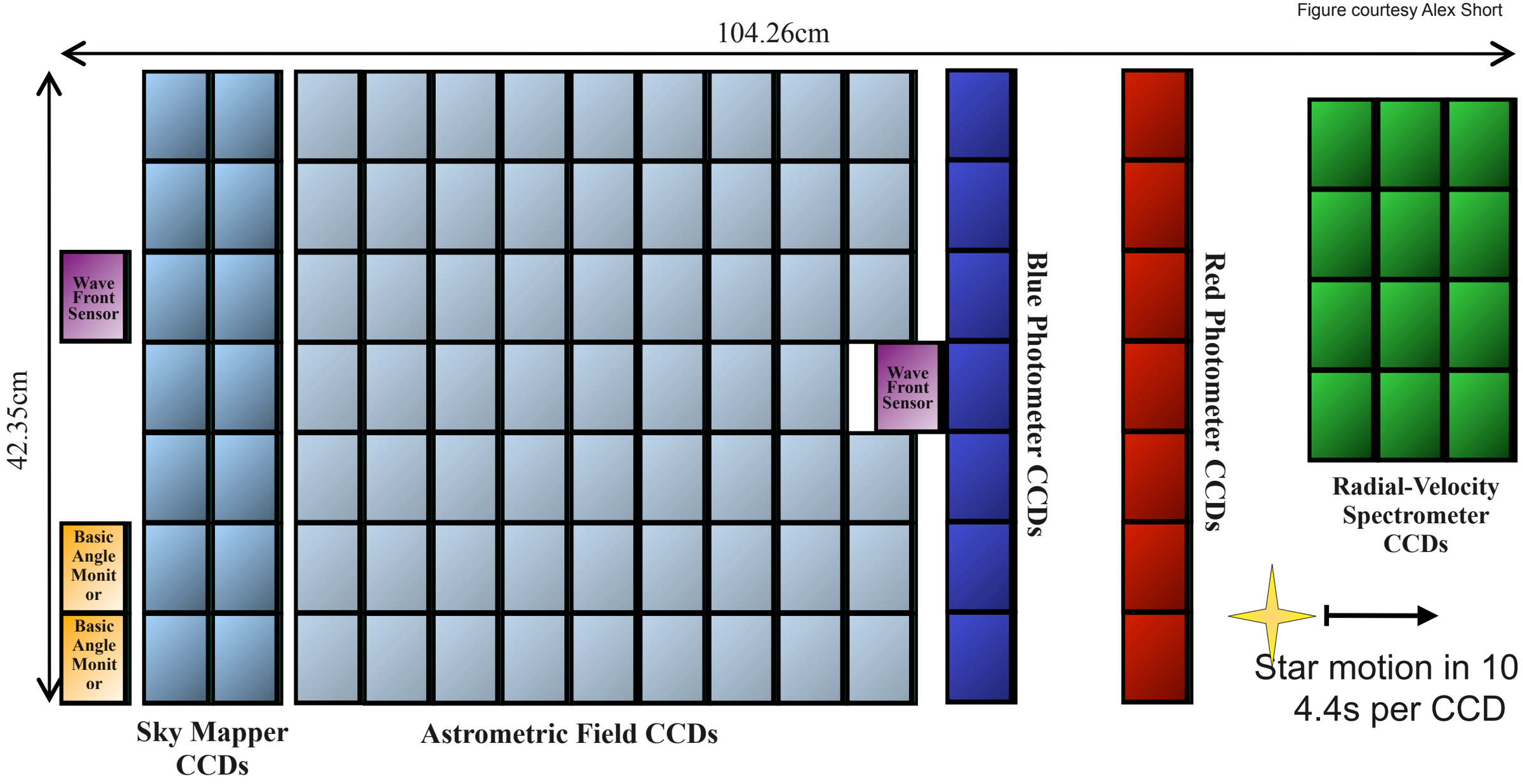




- Two telescopes - time between subsequent FOVs: 106.5m
- Time between successive scans: 6 h
- Field revisited every ~70 days
- Each object measured ~80 times (200 at the nodes)

Focal Plane

Figure courtesy Alex Short



Total field:

- active area: 0.75 deg^2
- CCDs: 14 + 62 + 14 + 12
- 4500 x 1966 pixels (TDI)
- pixel size = 10 μm x 30 μm
  = 59 mas x 177 mas

Sky mapper:

- detects all objects to 20 mag
- rejects cosmic-ray events
- FoV discrimination

Astrometry:

- total detection noise: ~6 e$^-$

Photometry:

- spectro-photometer
- blue and red CCDs

Spectroscopy:

- high-resolution spectra
- red CCDs

Timeline for the data flow

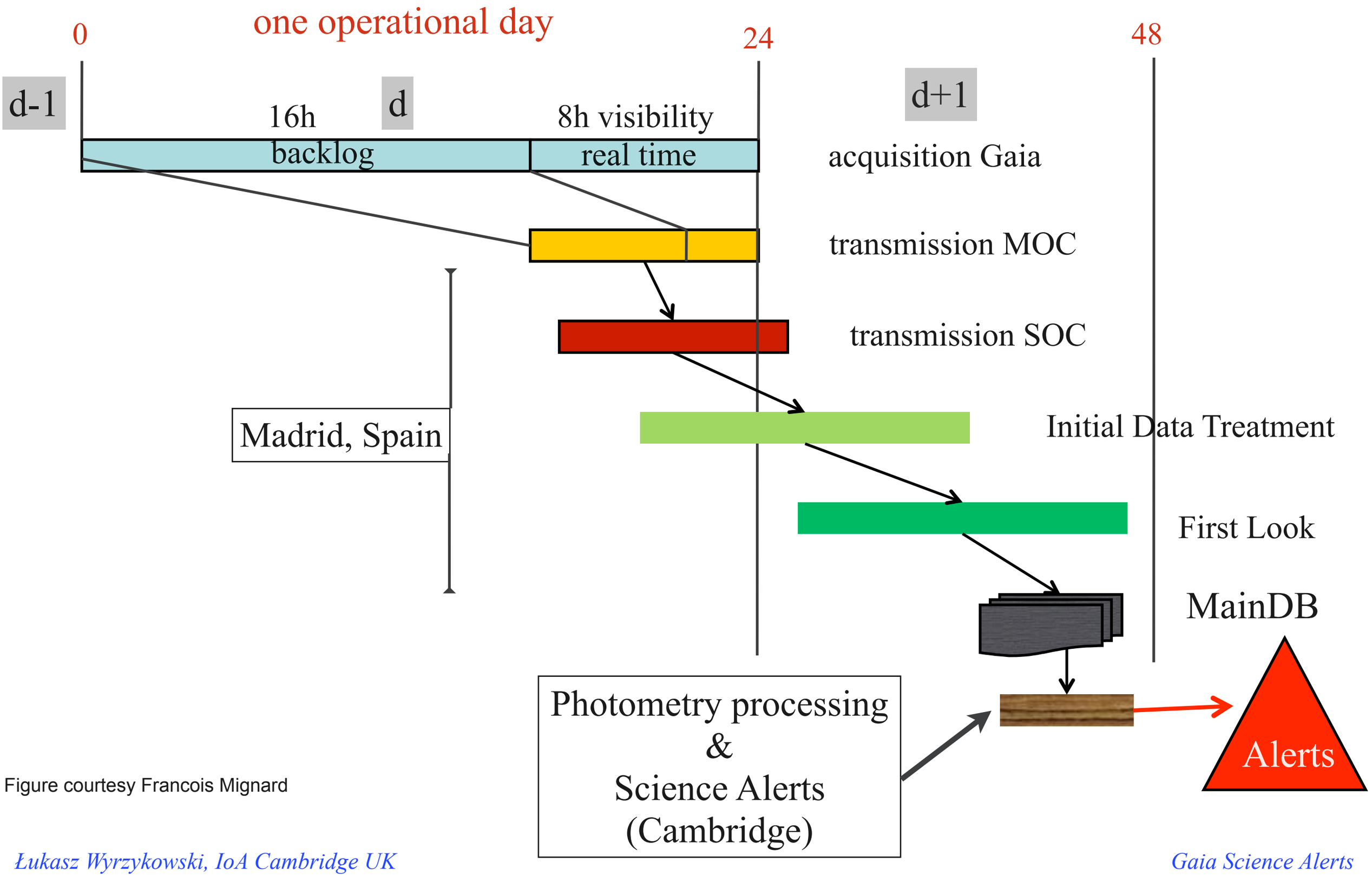
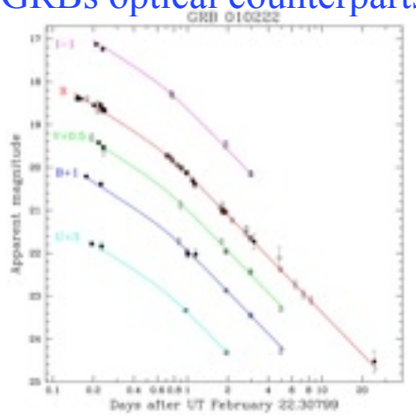


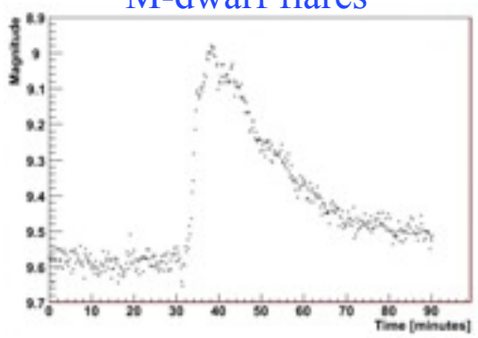
Figure courtesy Francois Mignard

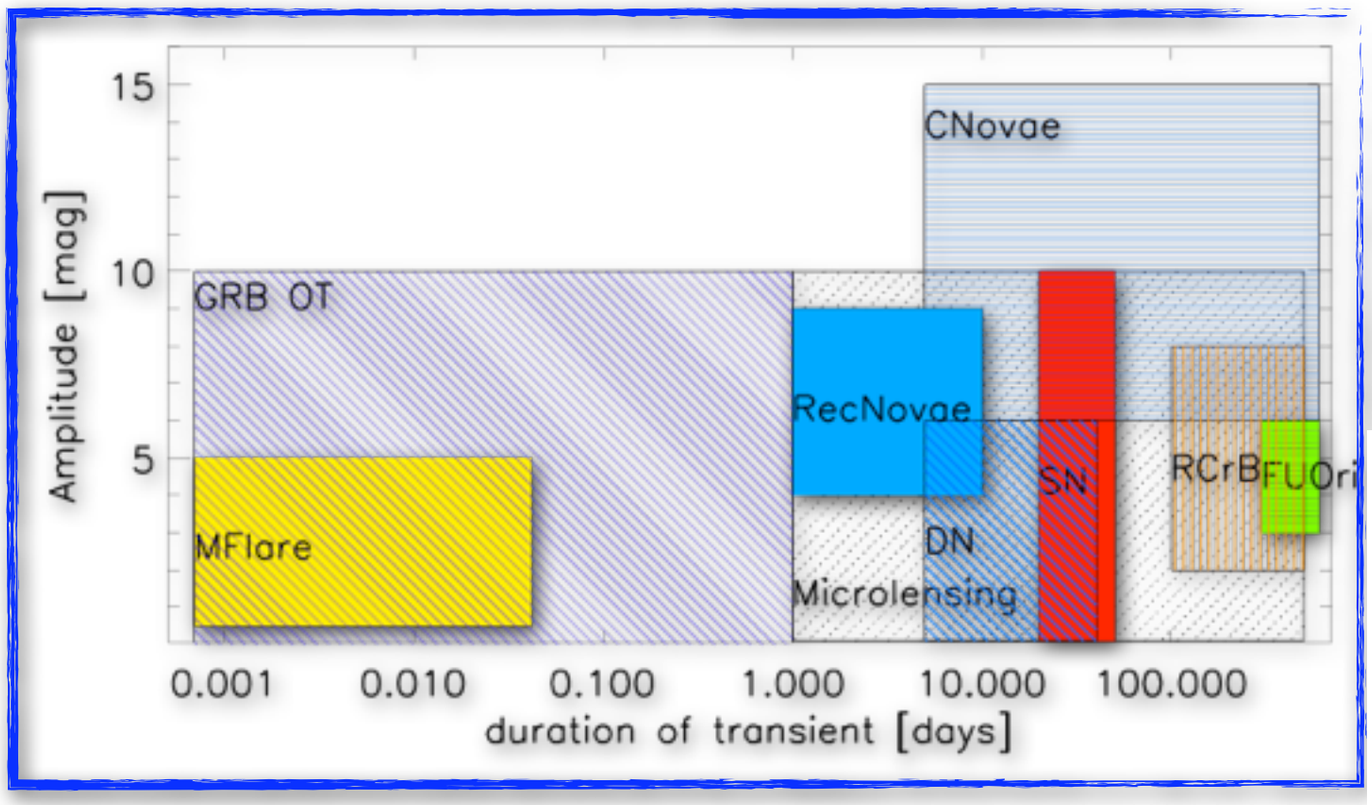
Potential Triggers

GRBs optical counterparts

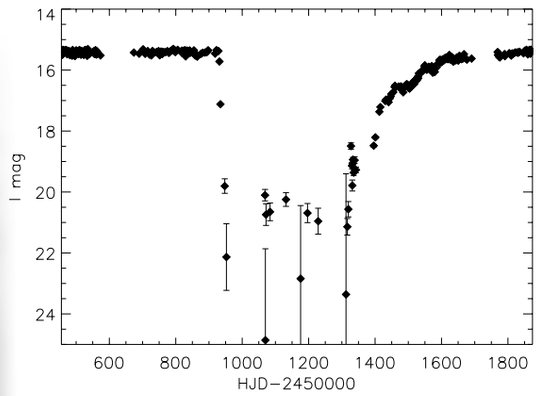


M-dwarf flares

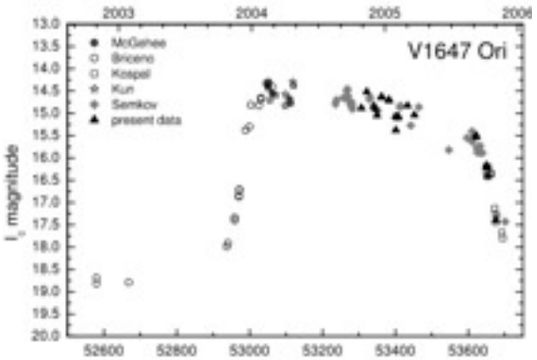




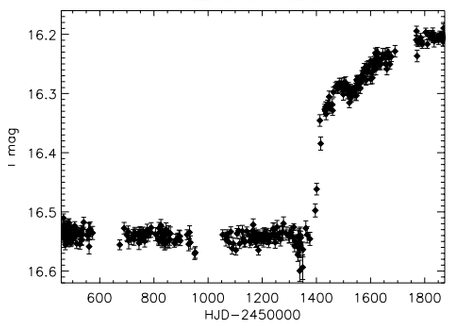
R Coronae Borealis



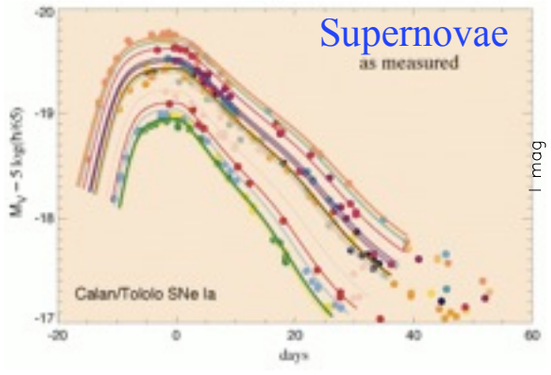
FU Orionis and similar

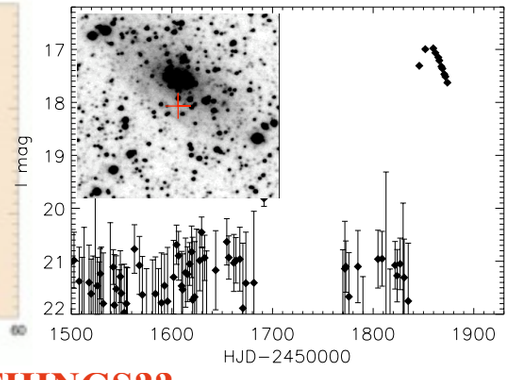


Be stars

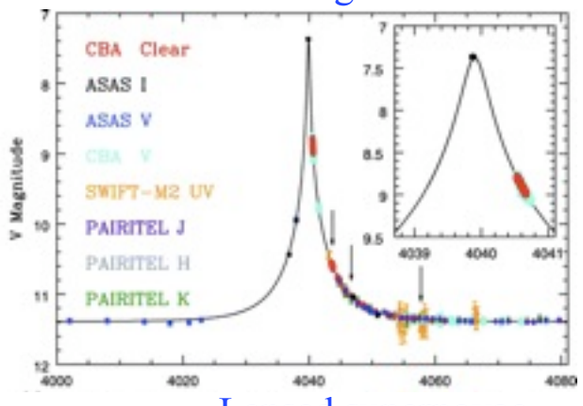


Supernovae

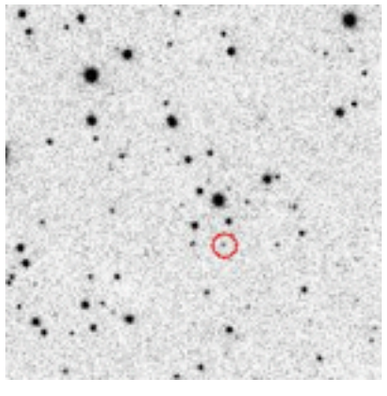




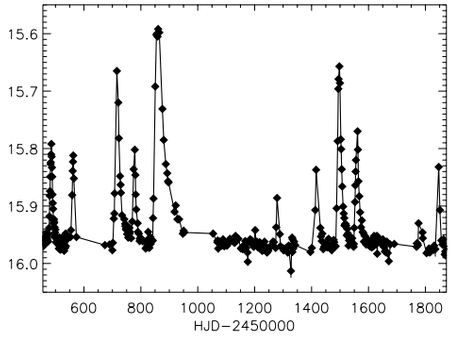
Microlensing events



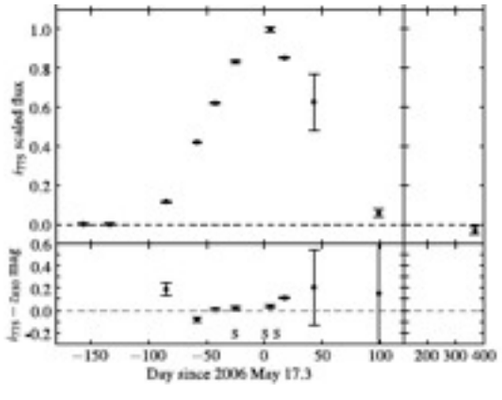
Asteroids



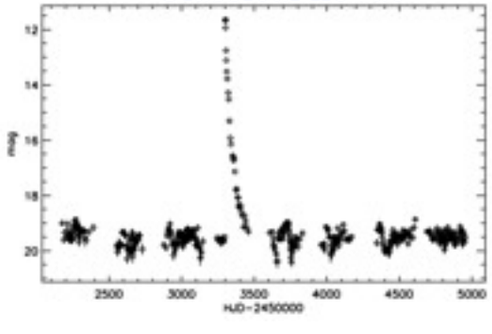
Dwarf novae



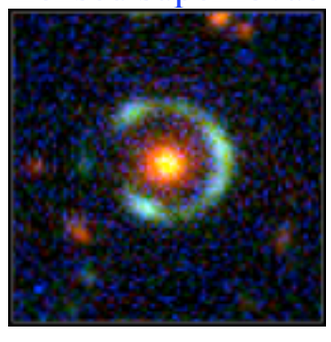
NEW THINGS??



Classical novae



Lensed supernovae

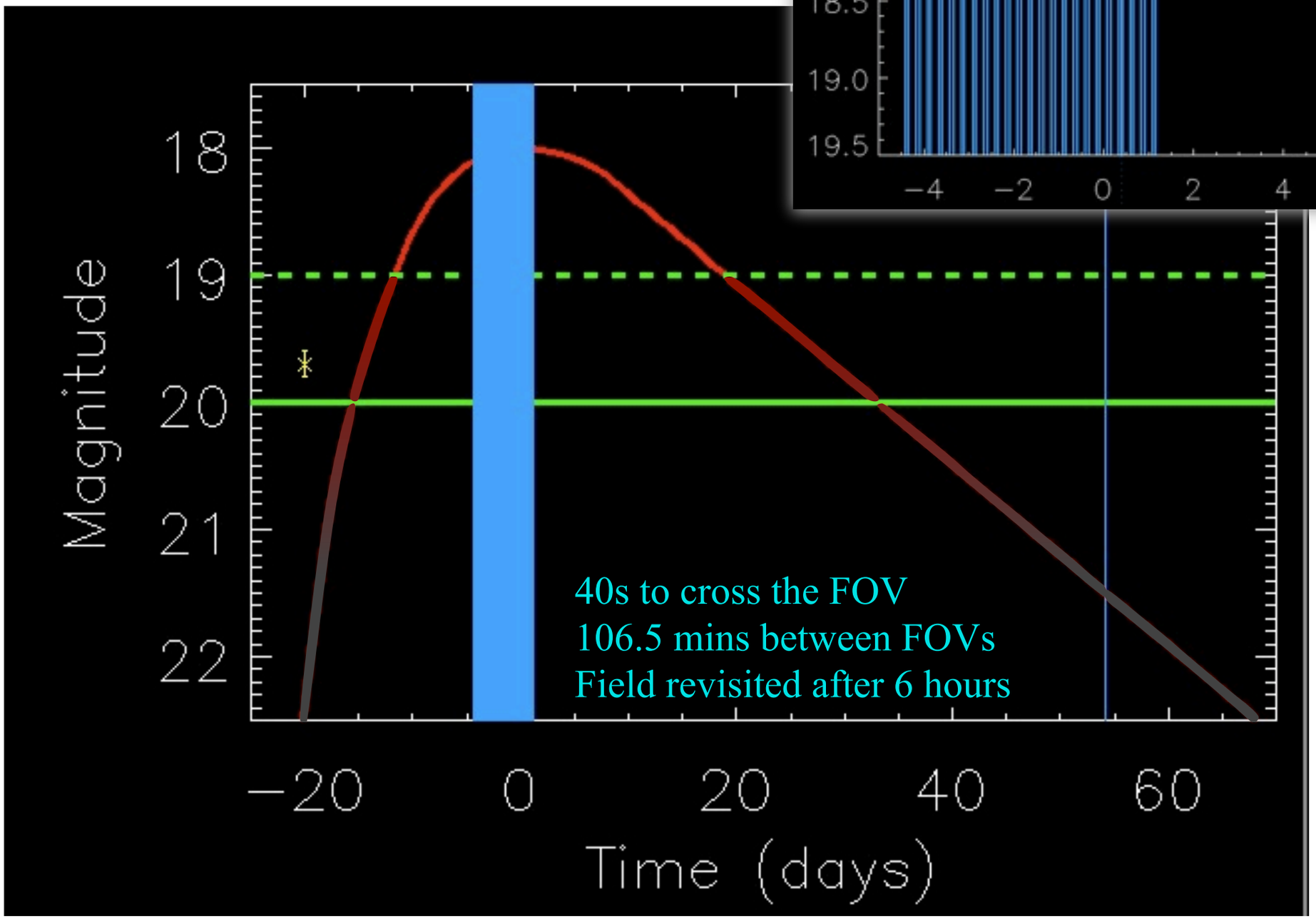


Łukasz Wyrzykowski, IoA Cambridge UK

Gaia Science Alerts

Supernovae

- 6000 SNe to G=19
- Around 1/3 before maximum



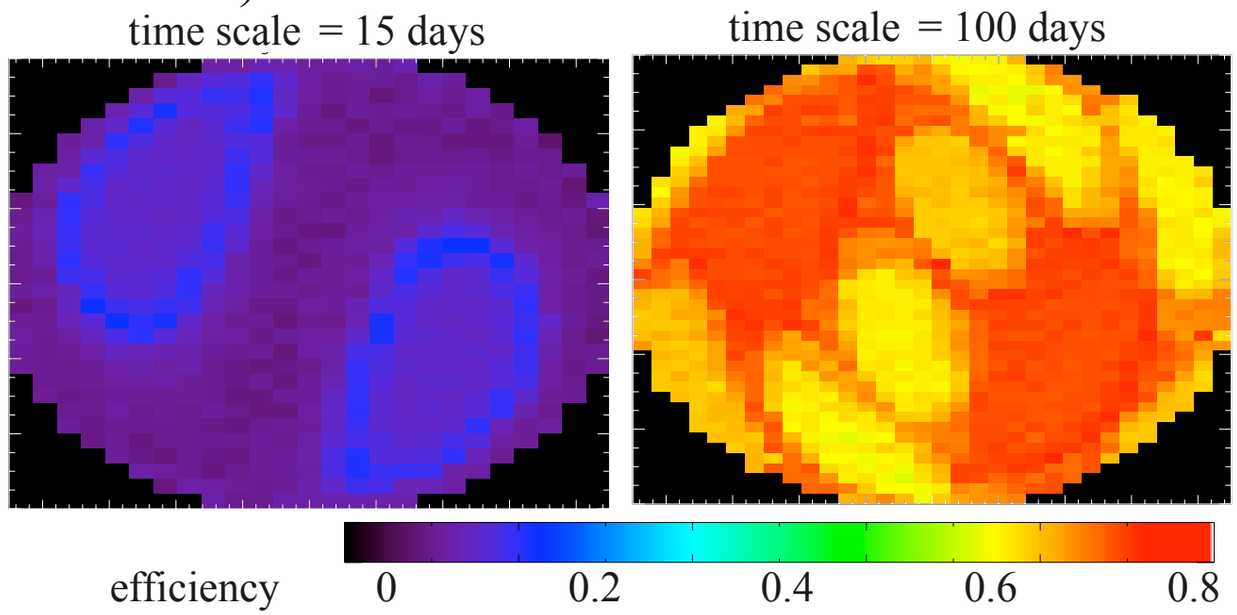
- Successive transits will measure consistency and slope.

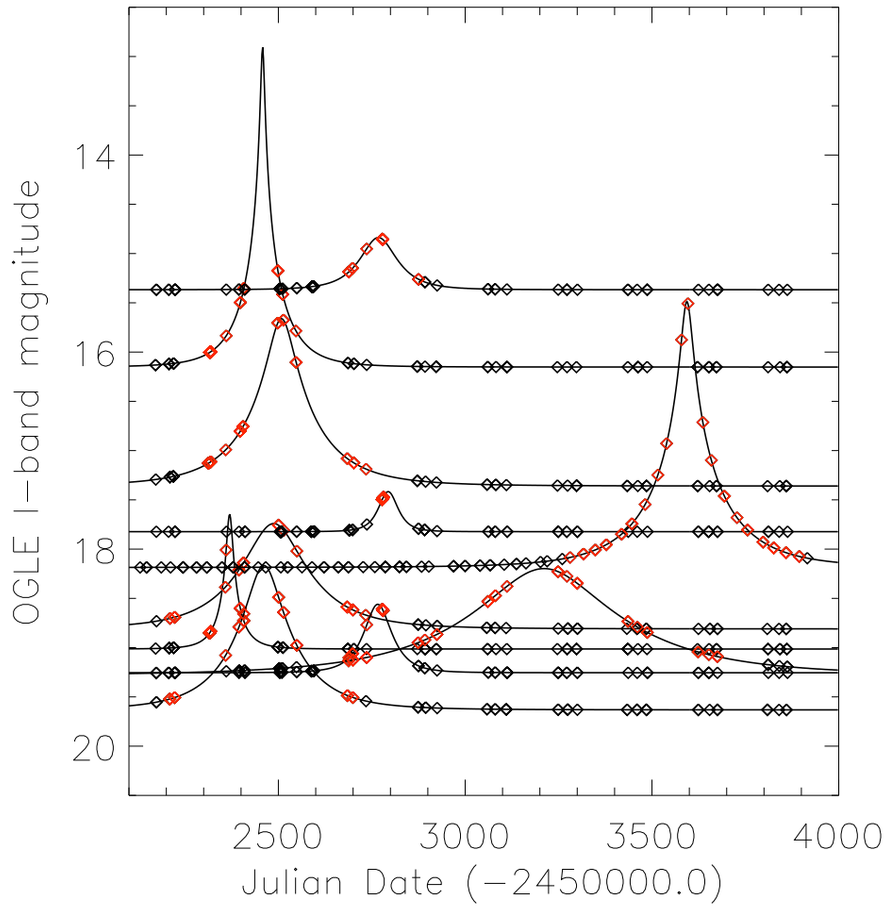
- Host galaxy contribution determines whether source is new to Gaia.

Microlensing Events

- >3000 events expected to occur towards the bulge,
  but many lost due to crowding (exception: Baade's Window)
- ~ 700 events expected over all sky
- photometric alerts on **1000+** events
- ~100% long events detected - the most interesting ones
  (nearby or massive lens)

Gaia microlensing detection efficiency on the rise





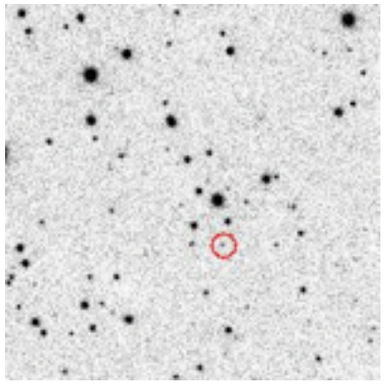
OGLE-III microlensing events as seen with Gaia

When alerted in time and followed-up:

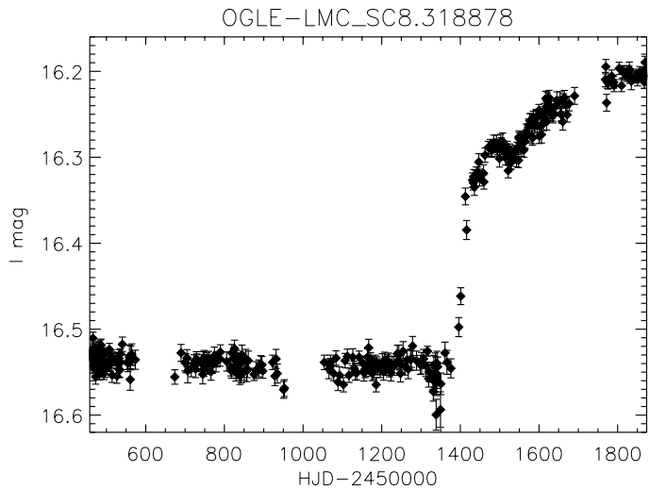
- ★ luminous and dark mass distribution in the Galaxy
- ★ dark matter in compact objects
- ★ extra-solar planets

Common and not interesting(?)

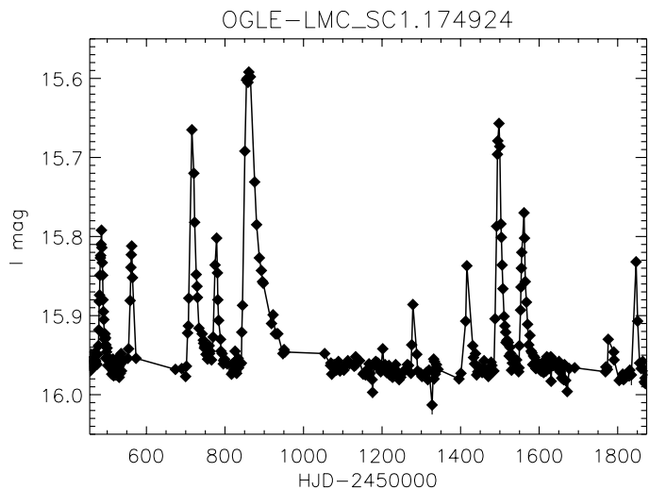
➡ **Asteroids** - **loads**!
- faster ones can be removed after second FOV transit
- predominantly known asteroids
- the orbits will be calculated and new objects will be cross-matched



➡ **Be stars** - low amplitudes, blue colours



➡ **Dwarf Novae** - low amplitudes, repeating



➡ and many more...

Methods

Science Alerts operation scheme

New Data

Database

Photom.

Data Ingestion

Calibs.

Photom.

Flux Alert Detector

Detection Algorithms

Candidate Alerts

Curator

Gaia data Classifier

Cross-match Classifier

Publisher

Asteroids

Catalogues

- SDSS
- 2MASS
- NED
- ASAS
- OGLE

+ Gaia pre-launch catalogue

VOEvent

skyalert.org

Gaia Alerts Server

- New Data arrive to Cambridge after basic pre-processing within 1 day and are stored
- Detection is run on data calibrated with the most recent calibration available
- Numerous detection algorithms are used
- Candidate alerts are classified using Gaia data
- Sources are cross-matched with available catalogues and classified further
- Cross-matched asteroids are removed
- Alerts are stored on the Server and released

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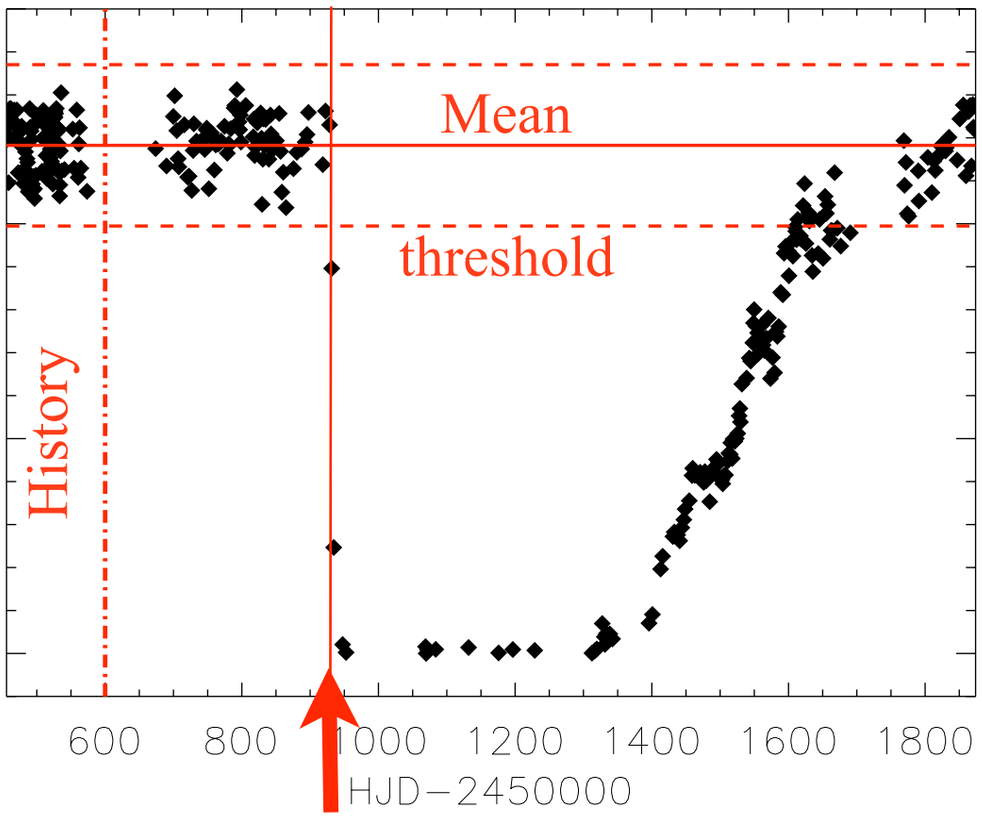
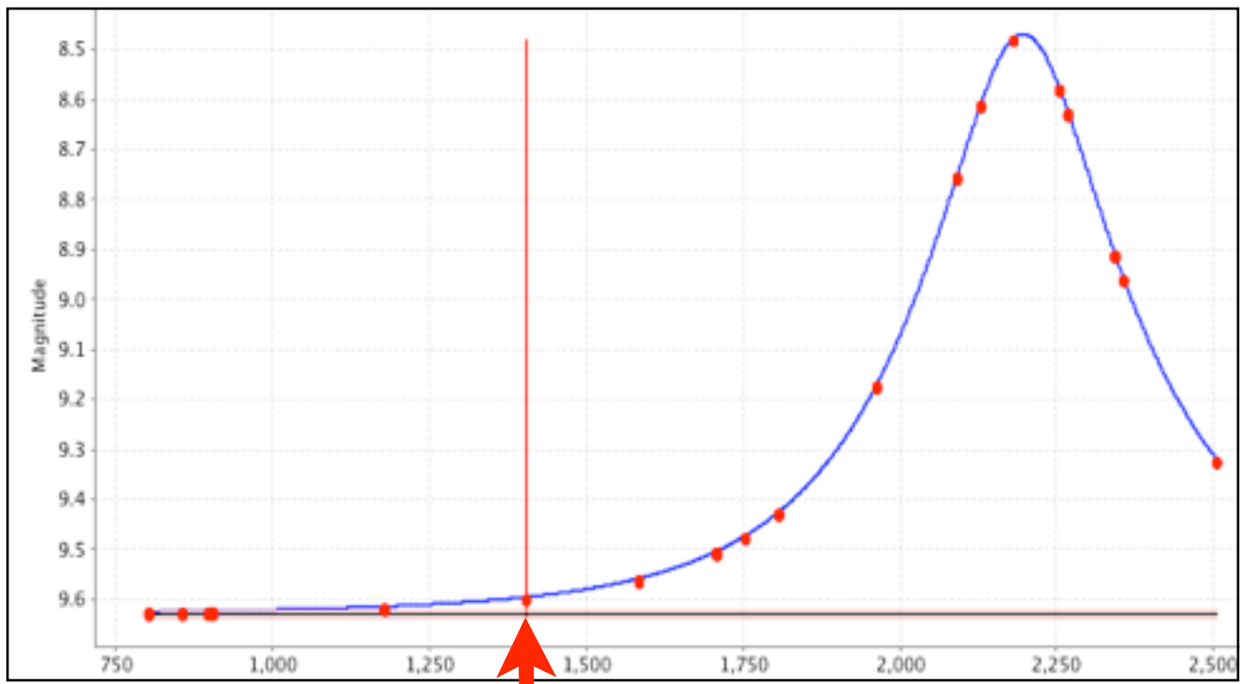
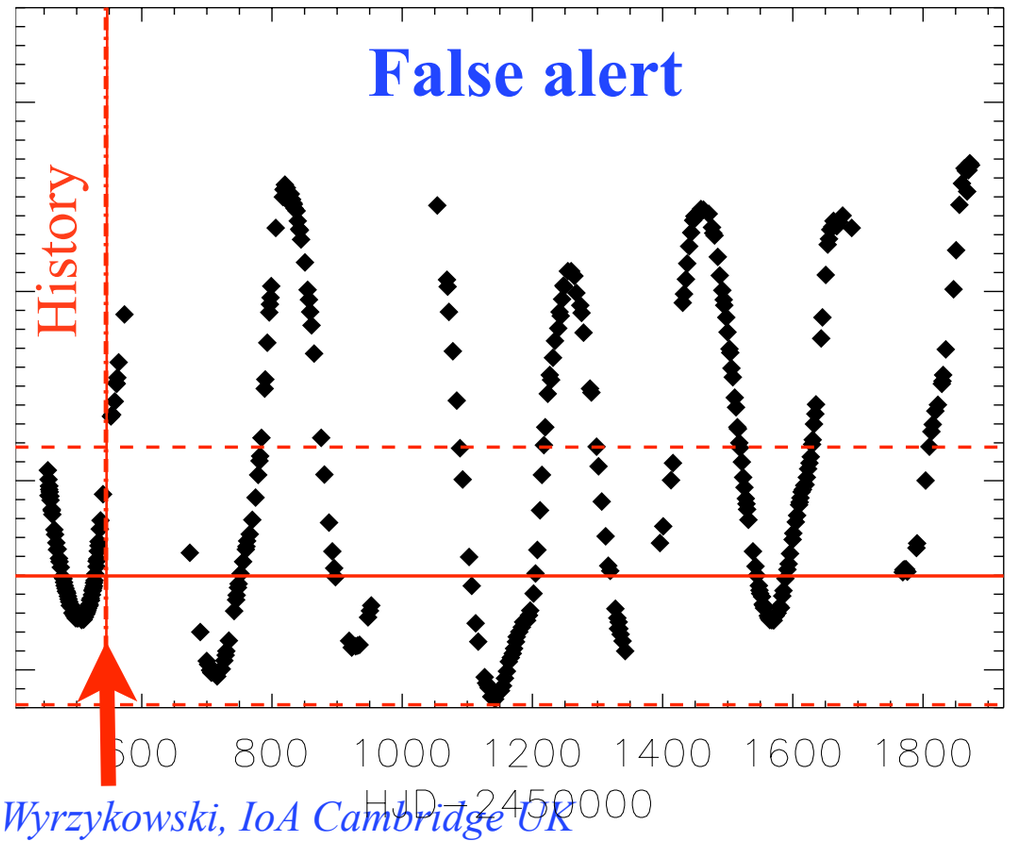
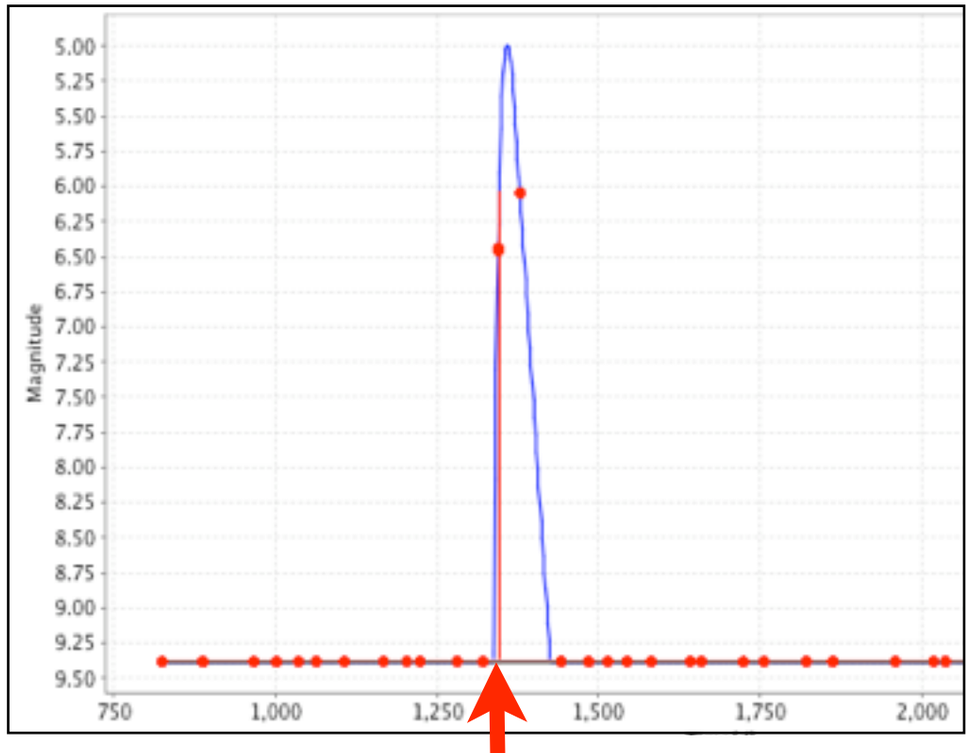
Detection algorithm









Curation - Gaia Classification:
data available

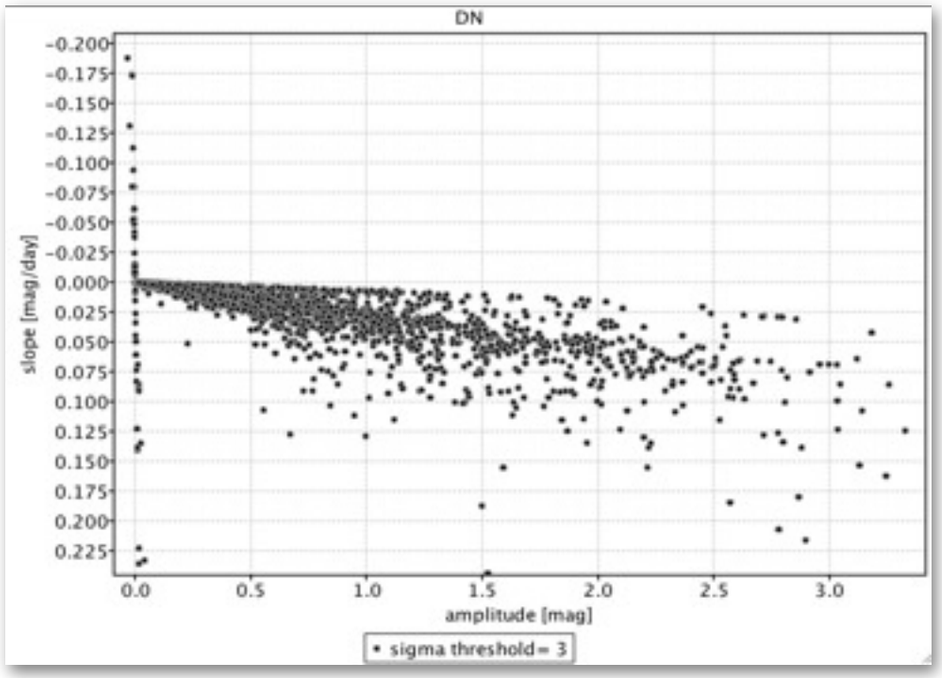
- G-band photometry (light curve)
- BP/RP colour
- raw BP and RP spectra
- morphology of the source (galaxy/star)
- source motion flags (fast asteroid?)
- Gaia catalogues (later in the mission)
  - galaxies
  - variable stars classified into types
  - astrophysical parameters, e.g. T_{eff}, spectral type

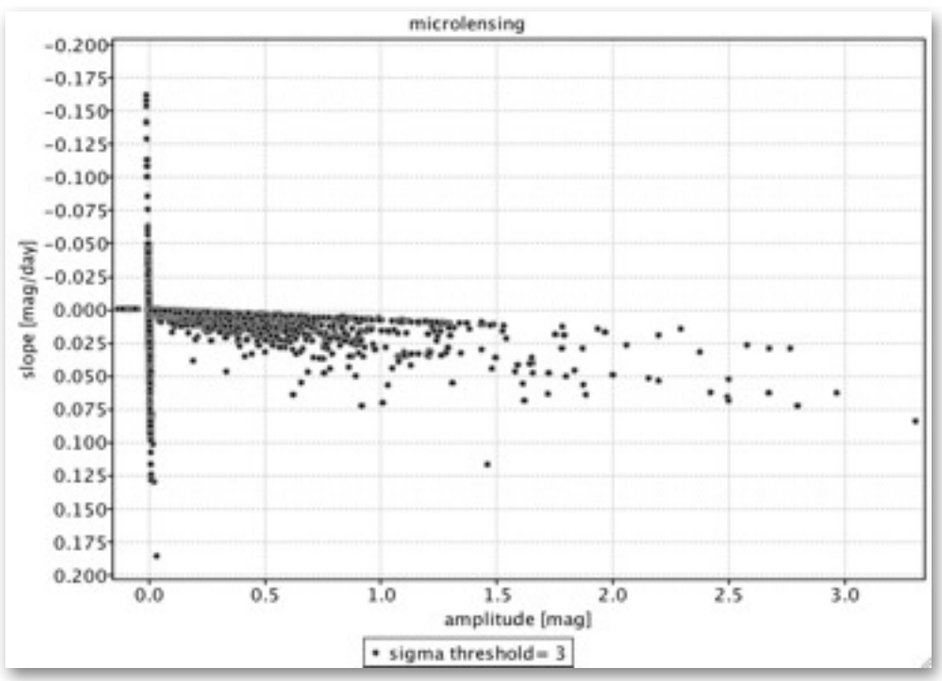
Transient light curves classification - challenges

- Transients differ from general variable stars
- Deviations to be alerted in real-time will usually have one/two data points
- Baseline ("History") will be accumulated in the first 6m of the mission
- Classification of "old sources" may rely solely on the baseline
- Classification of "new sources" is almost impossible on light curve level - need to rely on other parameters

Transient light curves classification - proposed method

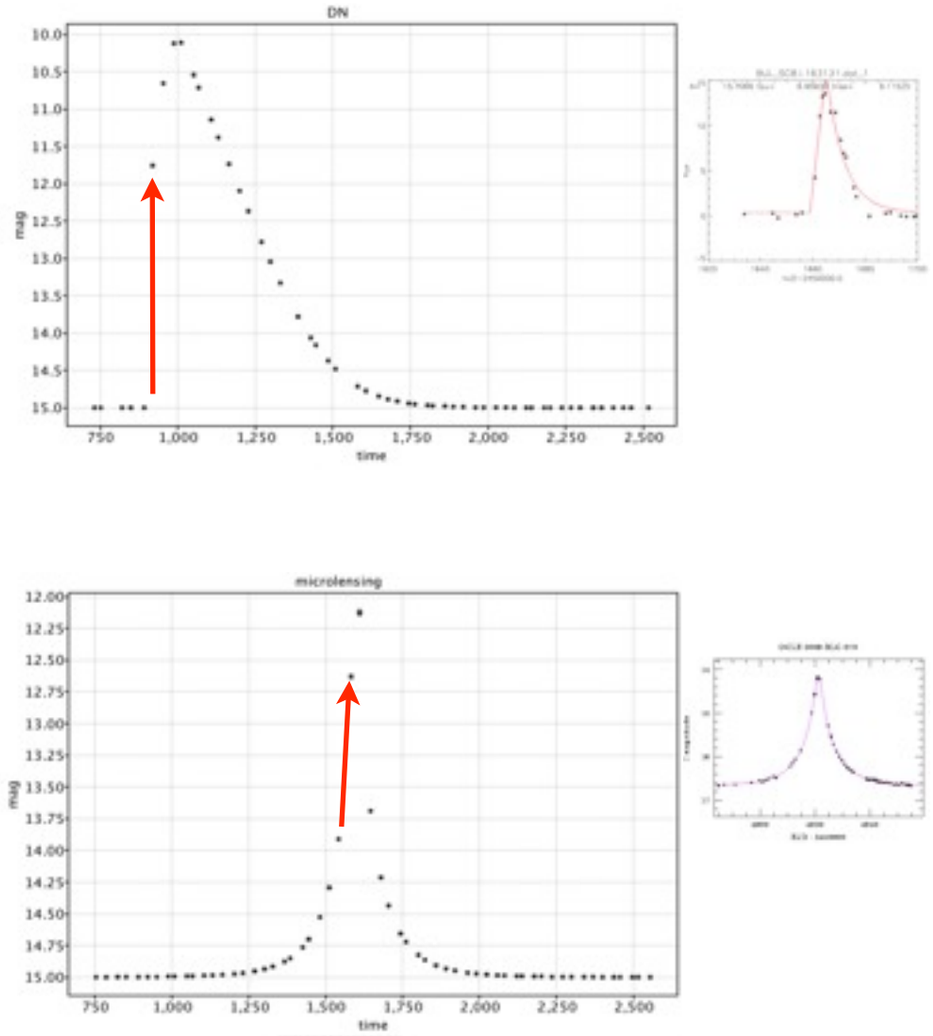
- **Gaussian Mixture Classifier (Debosscher et al. 2007)**
- part of Gaia variability package classification - uses e.g. Fourier decomposition of a l.c. as input parameters
- simple parameters: *amplitude* and *slope* at <u>detection</u>





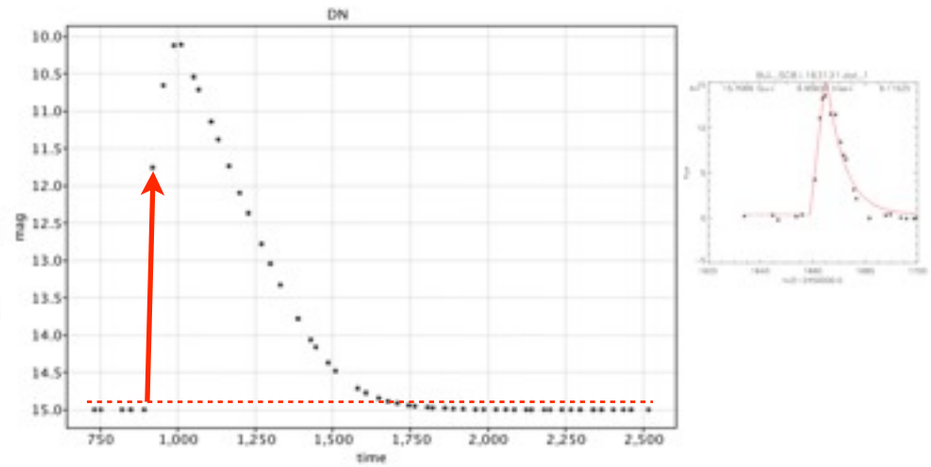
Transient light curves classification - first attempt

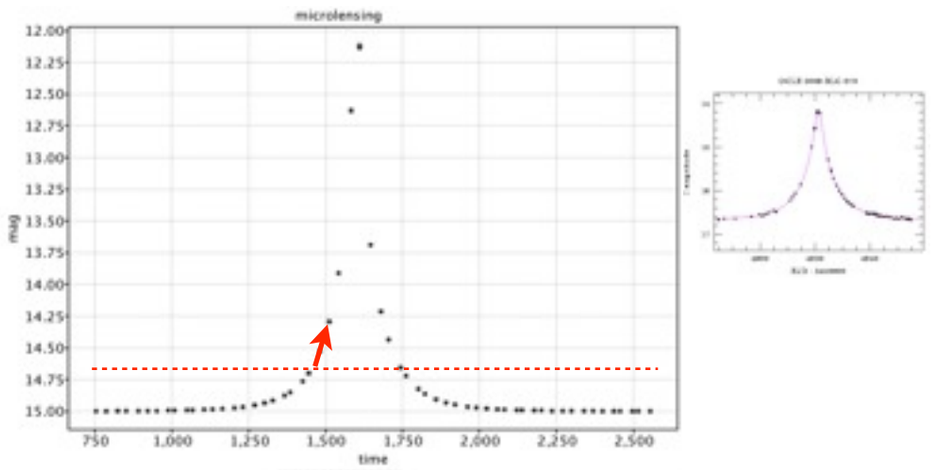
- **Dwarf Nova** vs. **Microlensing**
- Simple detector:
  deviation by 0.2 mag from previous point
  (not always baseline!)
- Training set:
  realistic parameters distributions from OGLE data
- Results:
  63% classified correctly (with P>0.5)
  (56% DN, 70% microlensing)



Transient light curves classification - second attempt

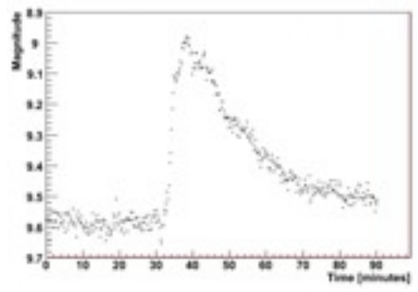
- **Dwarf Nova** vs. **Microlensing**
- Photometric **noise** added
- More sophisticated detector:
  deviation by 3 sigma from a noisy baseline
- Training set:
  realistic parameters distributions from OGLE data
- Results:
  71% classified correctly (with P>0.5)
  (86% DN, 57% microlensing)

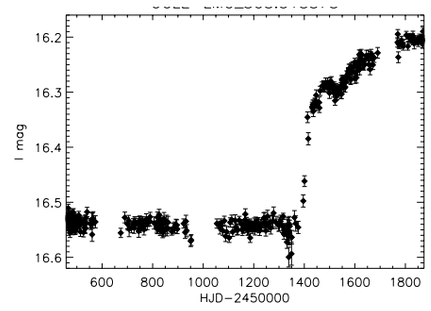




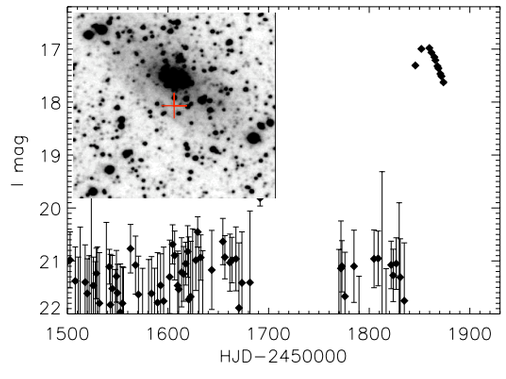
Transient light curves classification - future work

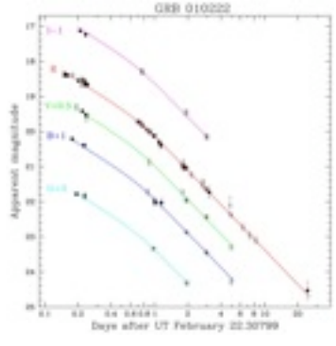
- come up with other l.c. parameters available at the moment of detection
- come up with different detection algorithms
- use after-detection data points too, at least the second FoV (106min)





- add M-dwarf flares, Be-type stars and other variables to blur the picture even more...
- apply to "new objects" like SN, GRBs (use both FoVs)

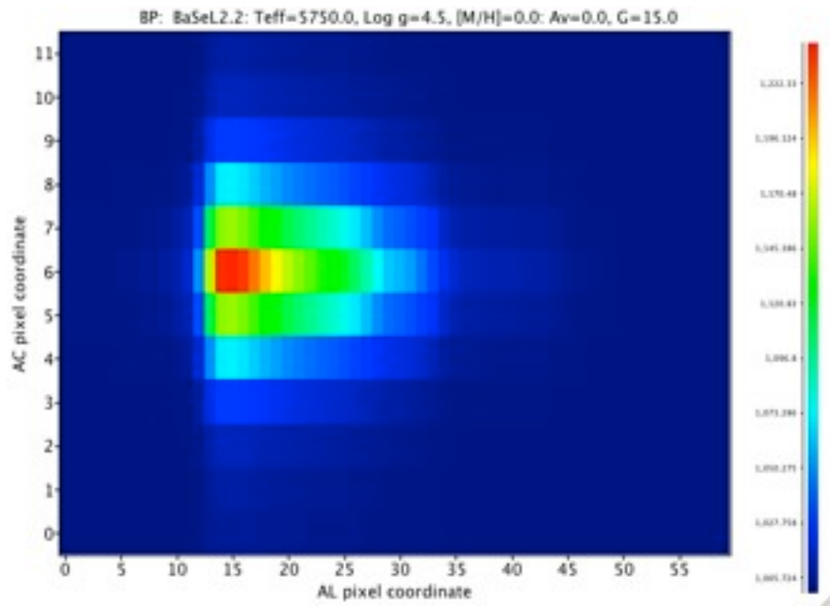




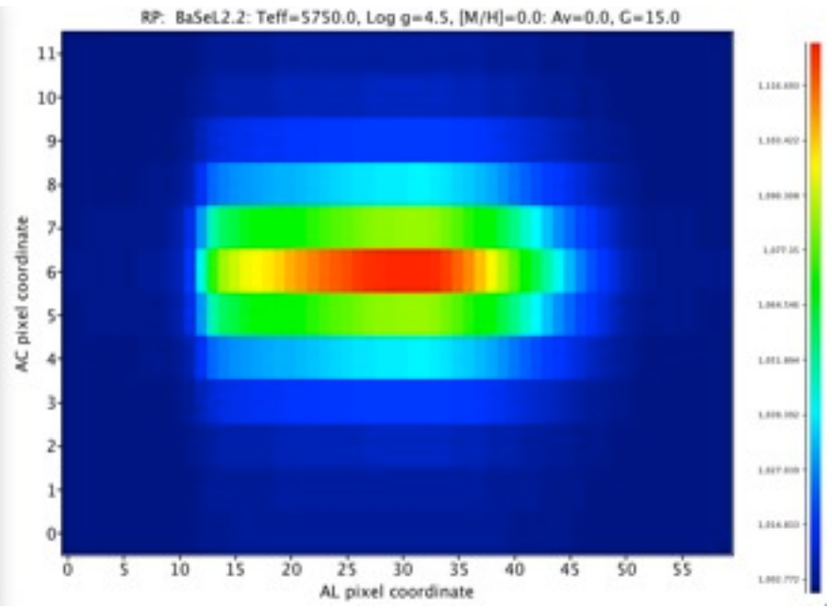
Input spectra

On the CCDs

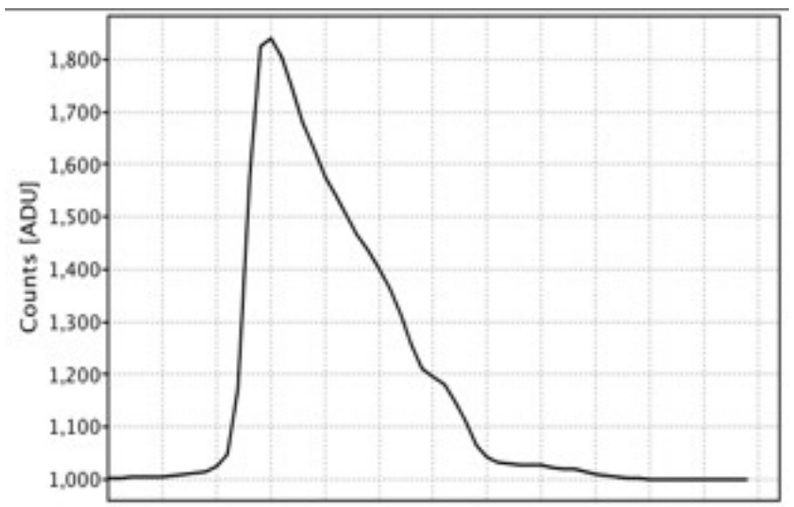
Blue photometer

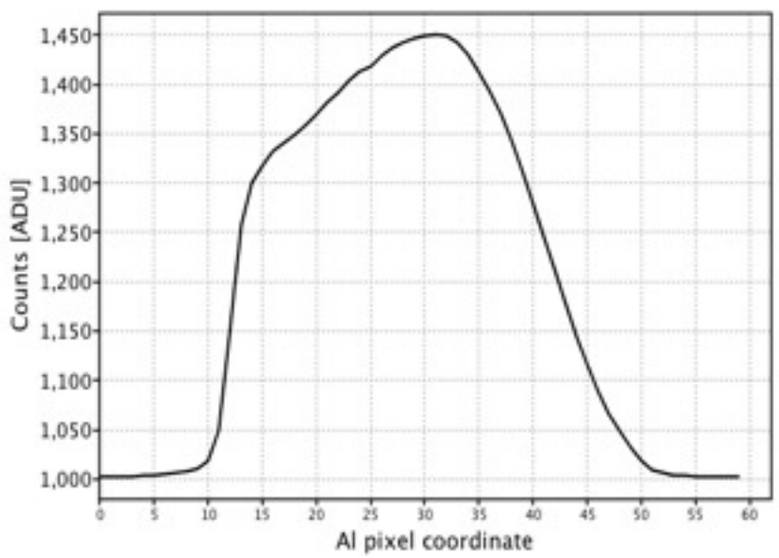


Red photometer



Measurements



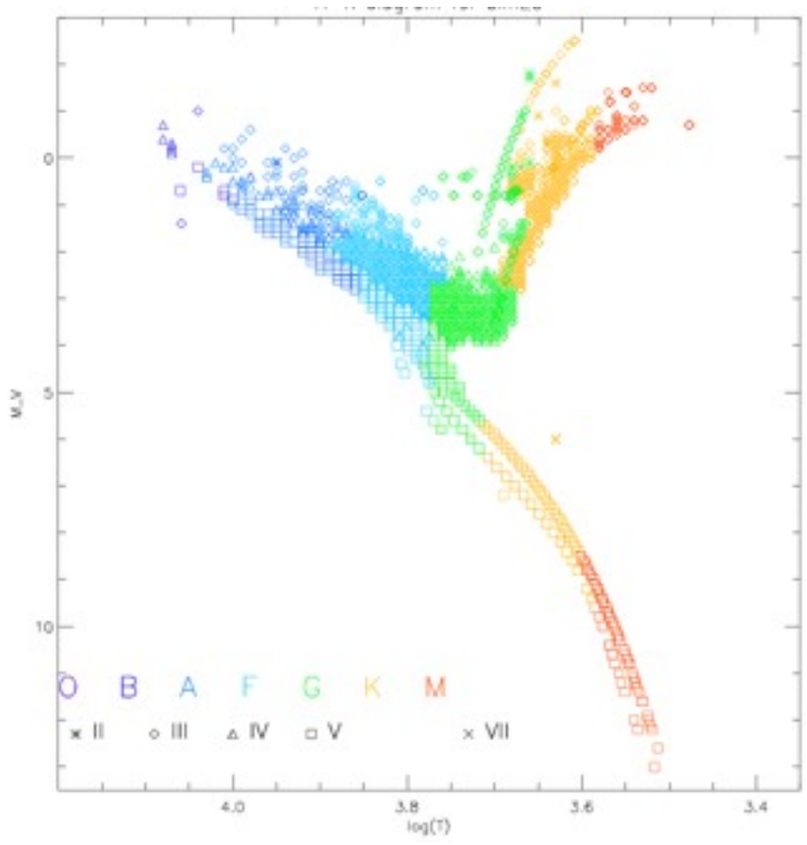


- In most cases the spectra will be 1D, only for the brightest will be 2D

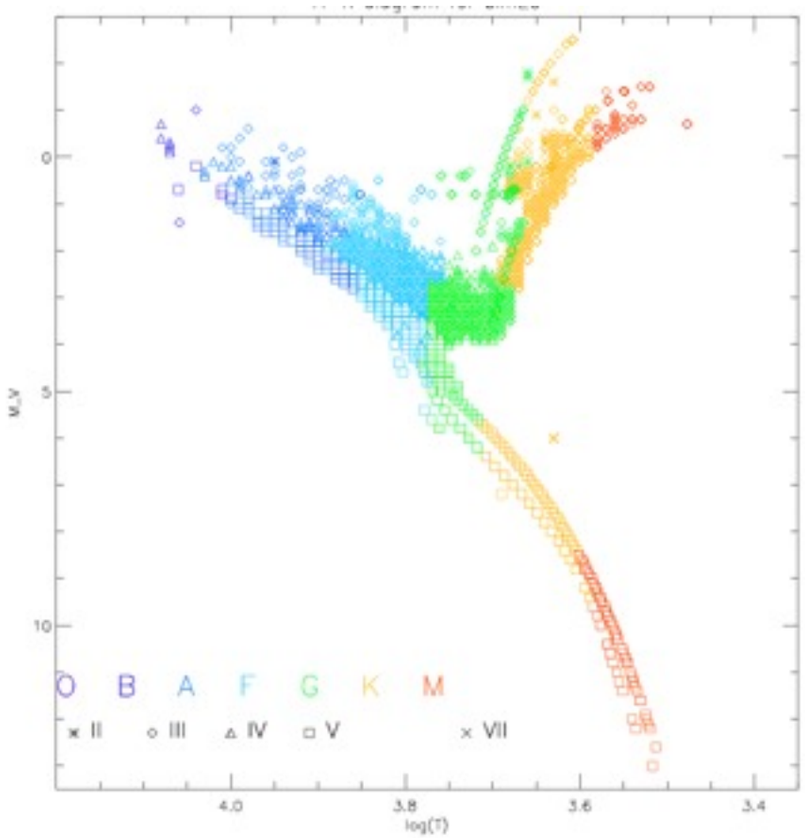
Spectra classification with SOMs - method

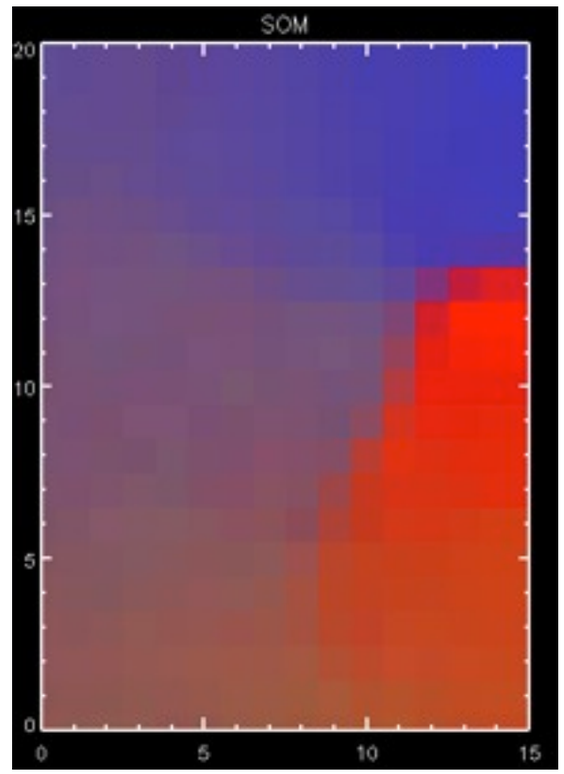
- Raw, low dispersion spectra will be available along with the photometry
- extracting spectral type of the source helps a lot in alerts classification,
  e.g. false-alarm: large amplitude faint Mira-type variable
- **Self Organizing Maps (SOMs) used in semi-supervised mode**
- SOM trained on either simulated data with known spectral type or real data cross-matched with ground-based classification
- *Alternative for the mission*: unsupervised mode SOM will sort spectra according to their type, but the type will not be returned.

Spectra classification with SOMs - results

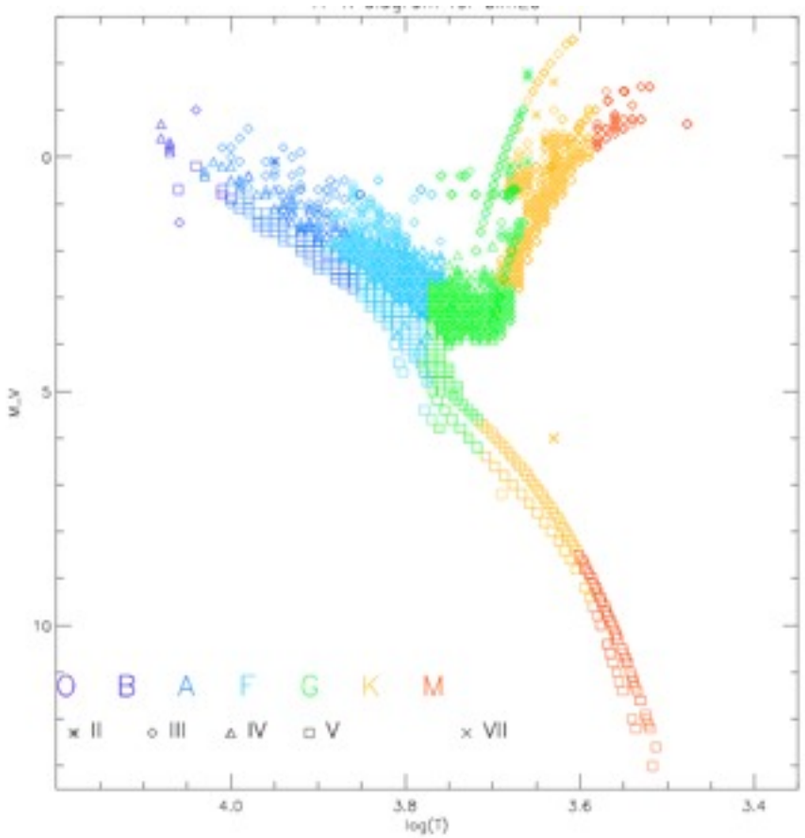


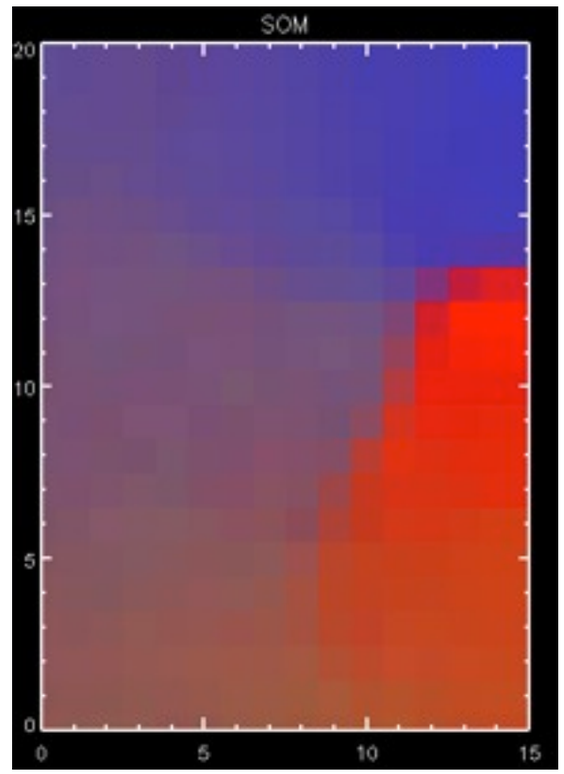
Spectra classification with SOMs - results

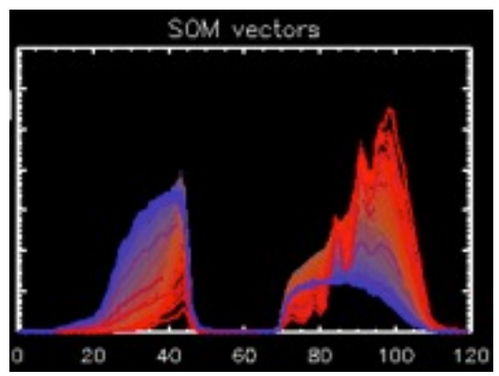




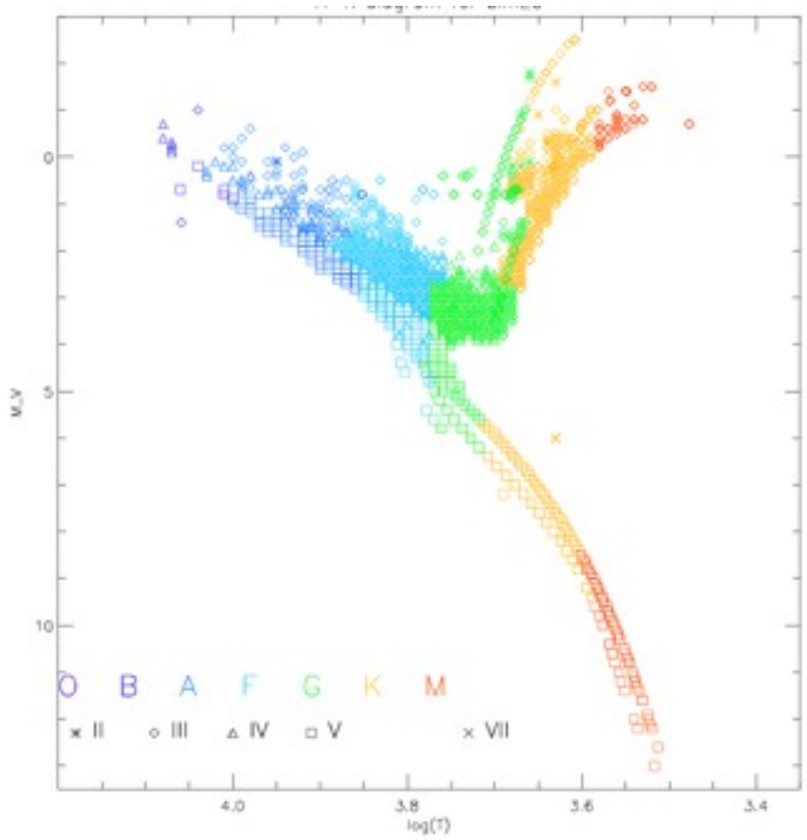
Spectra classification with SOMs - results

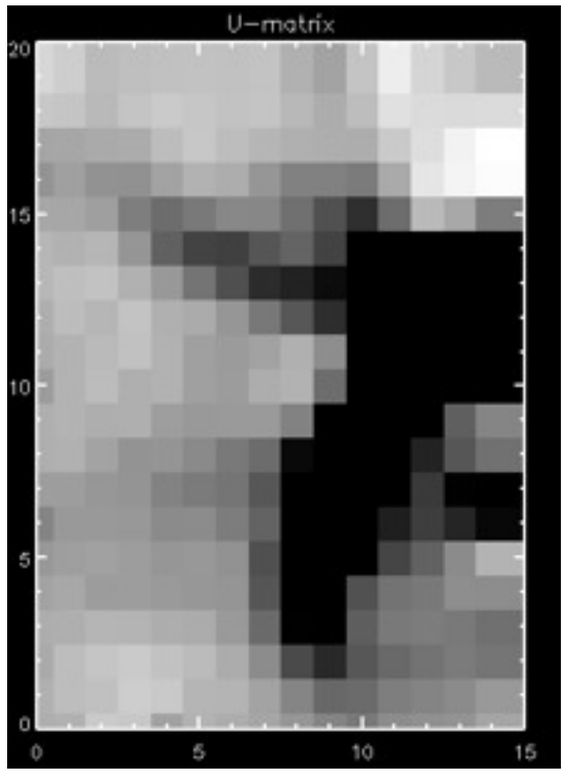


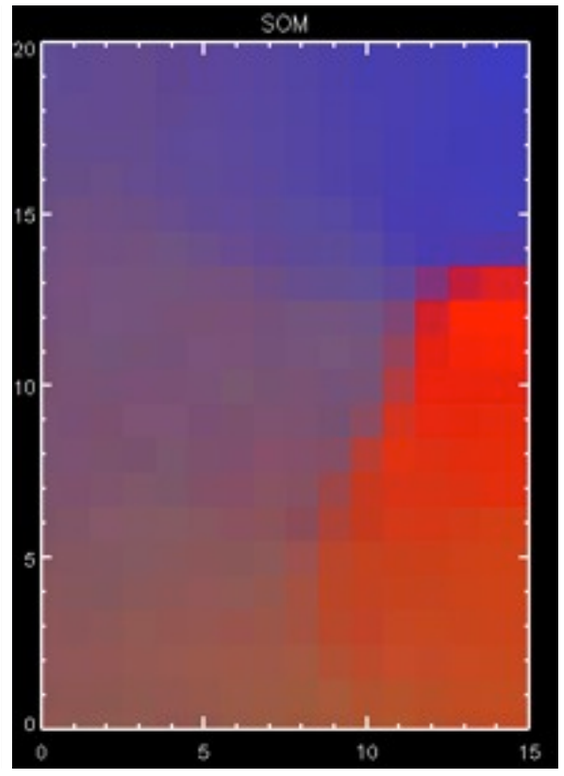


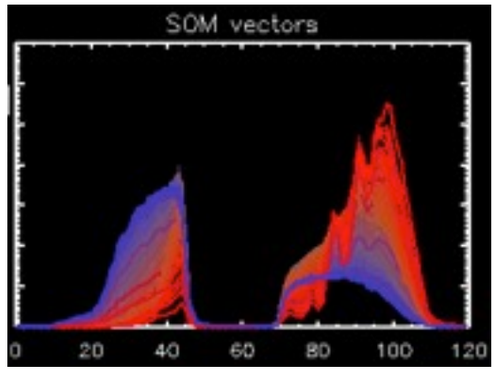


Spectra classification with SOMs - results

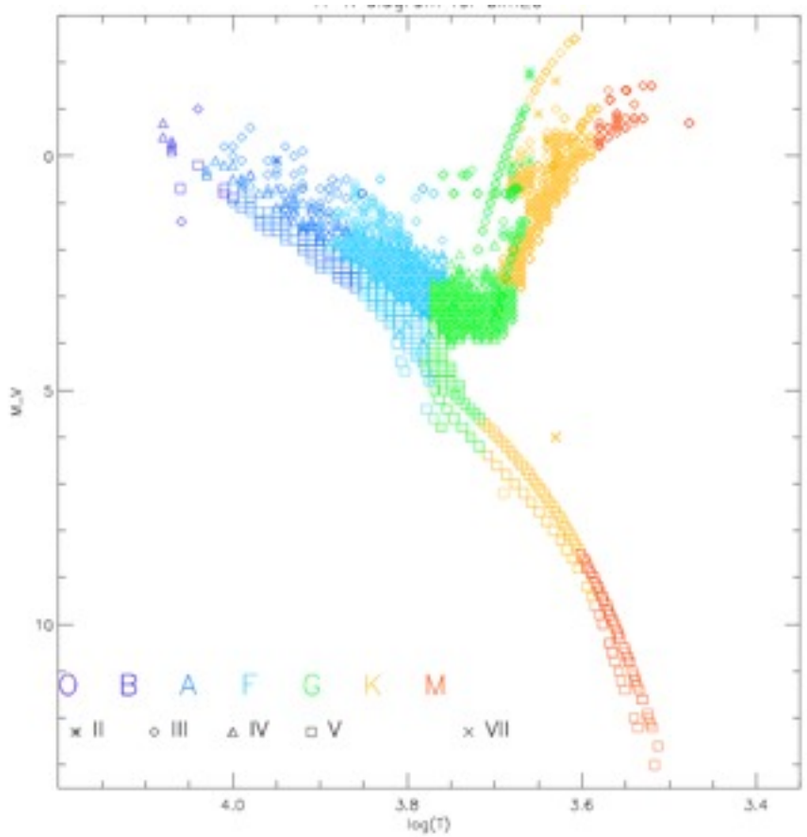


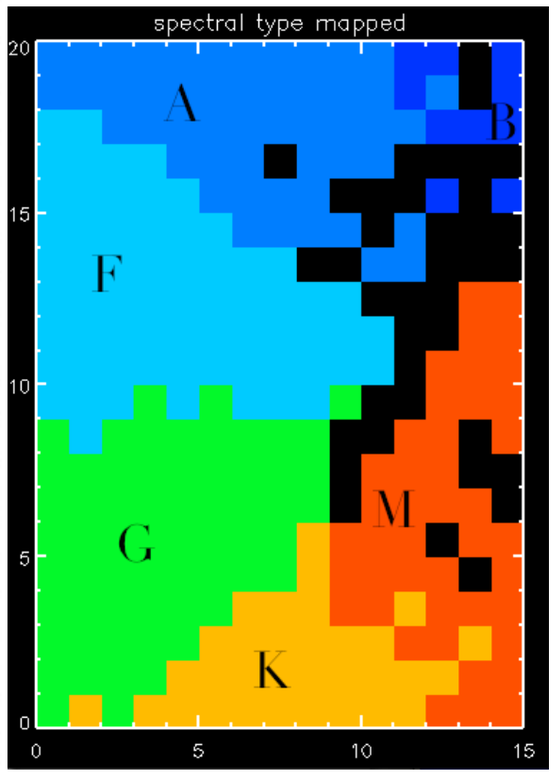


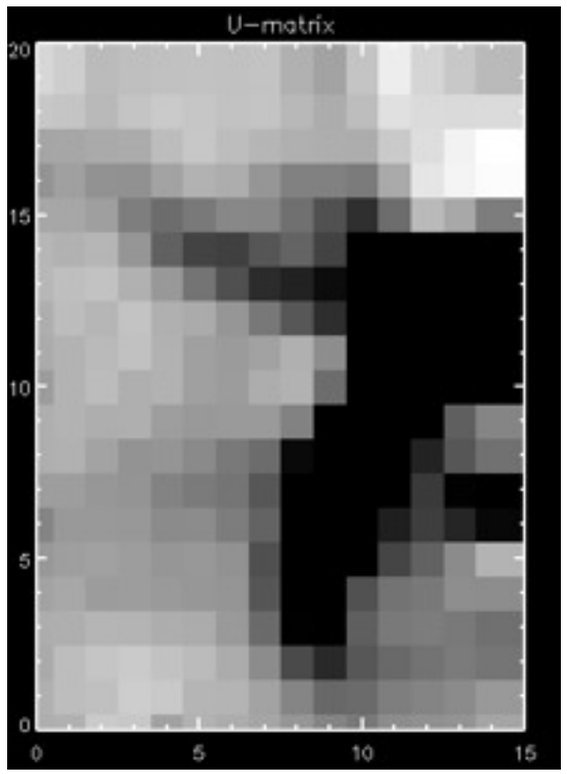


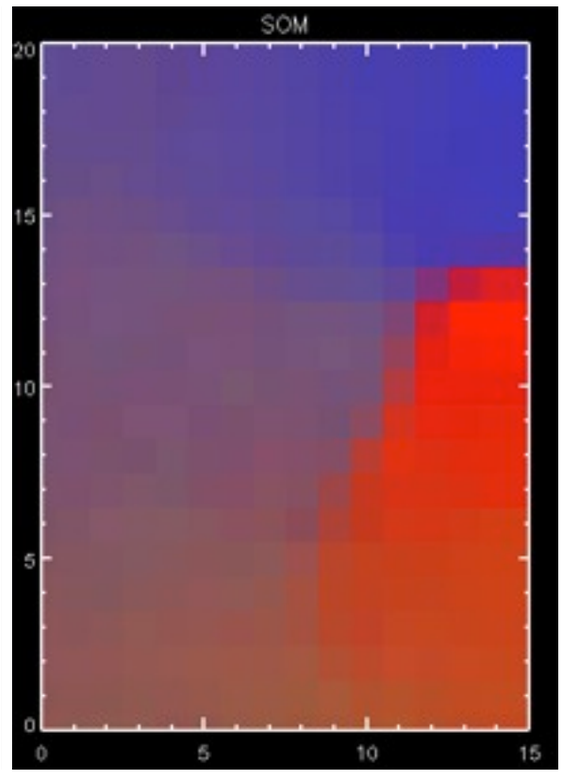


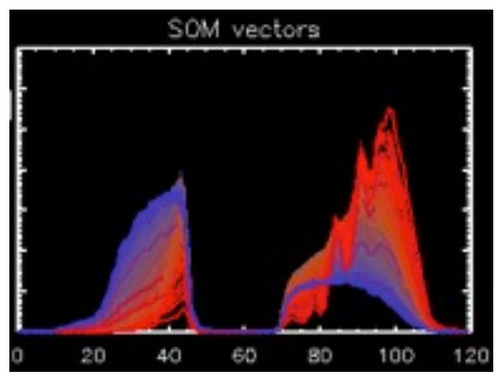
Spectra classification with SOMs - results



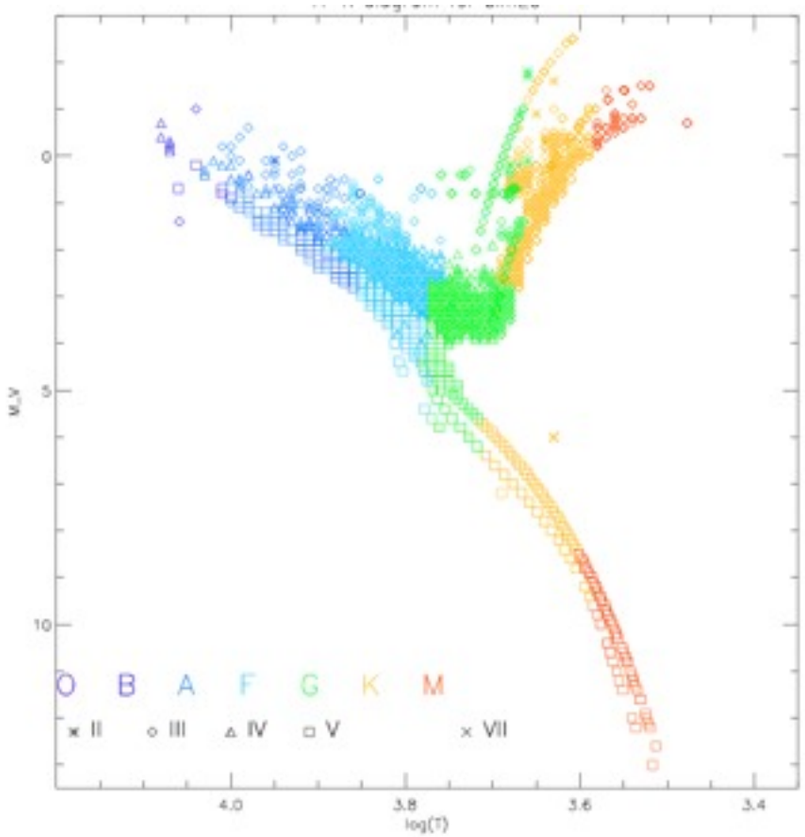


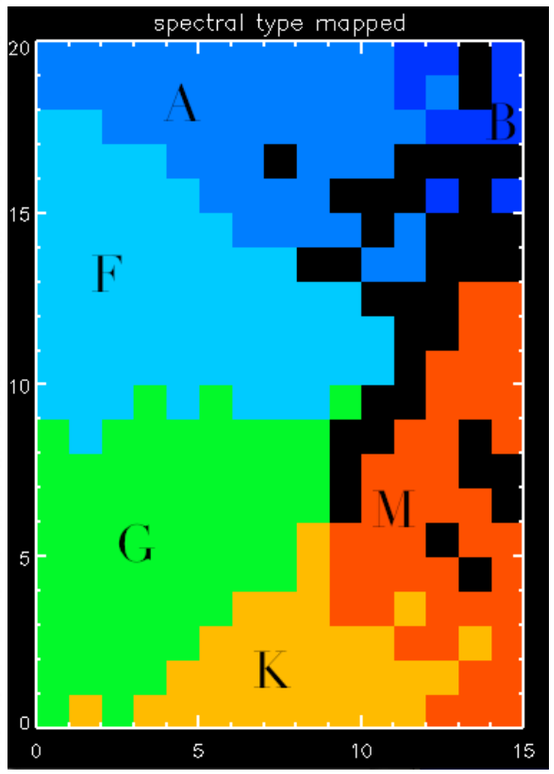


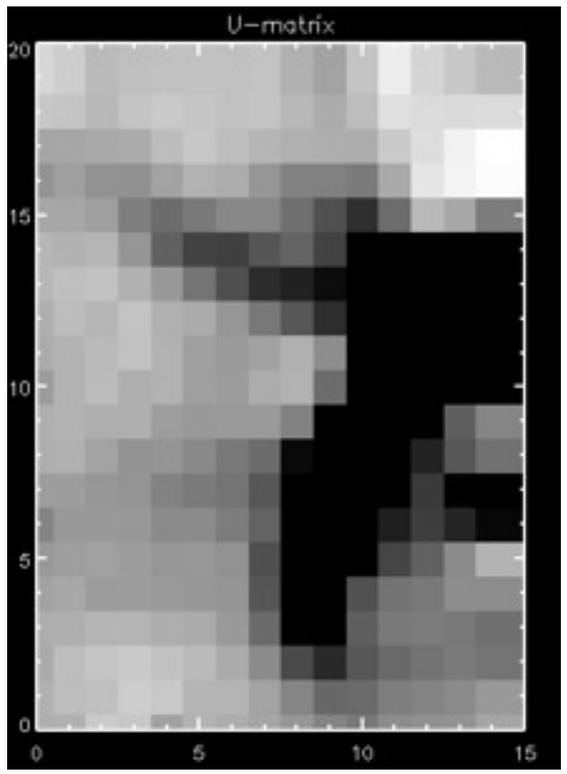


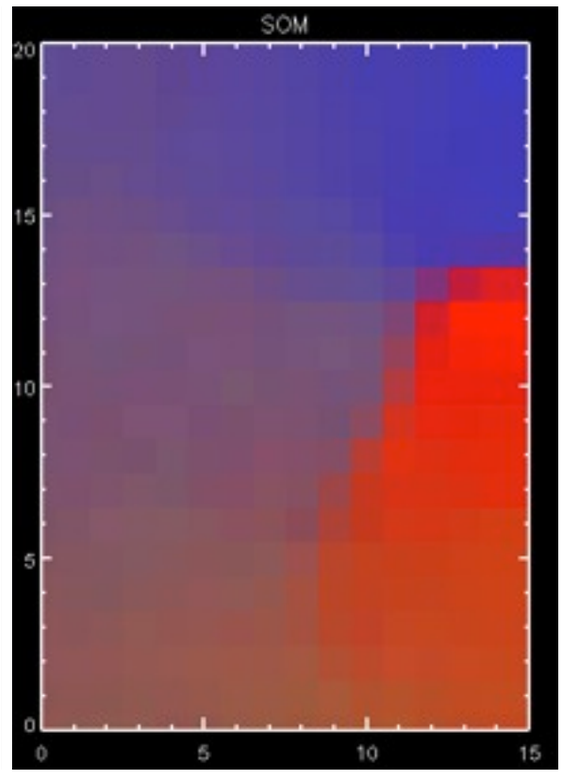


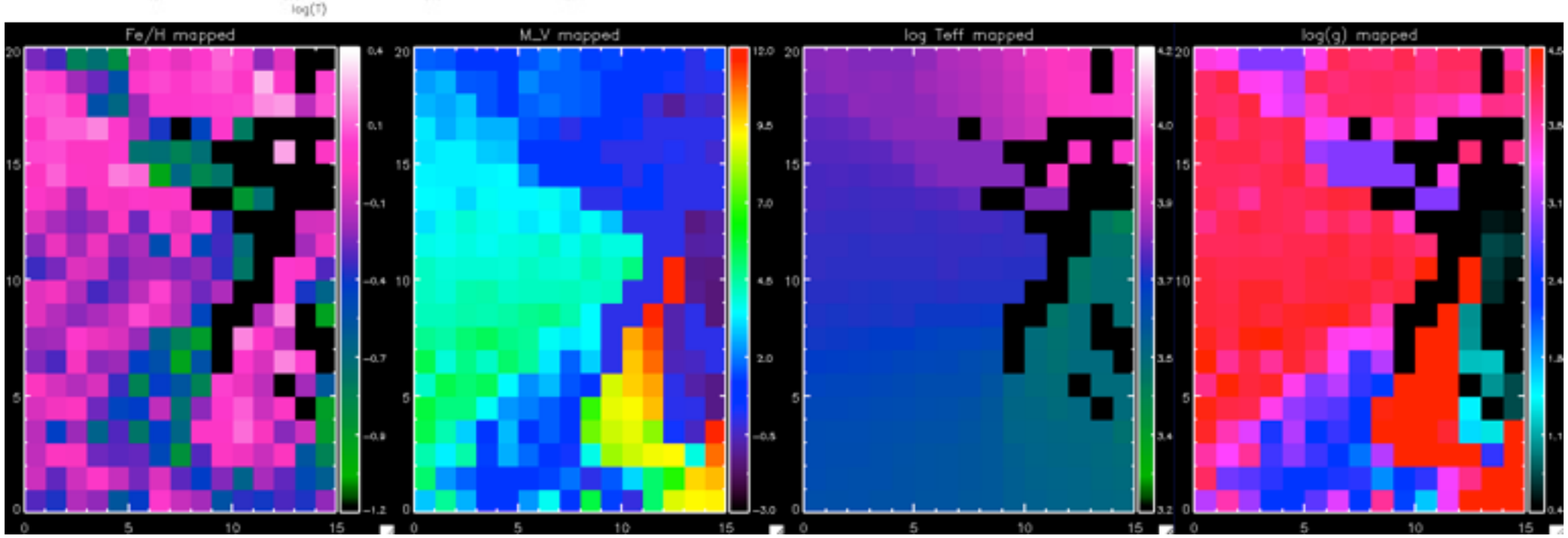
Spectra classification with SOMs - results

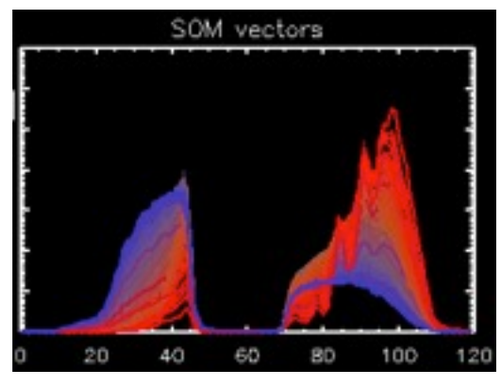




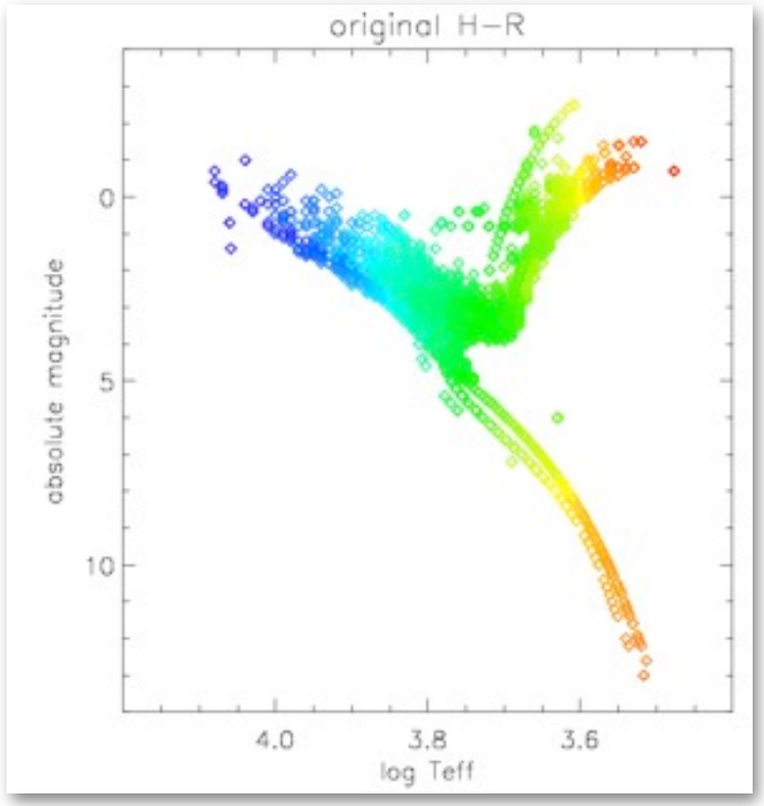


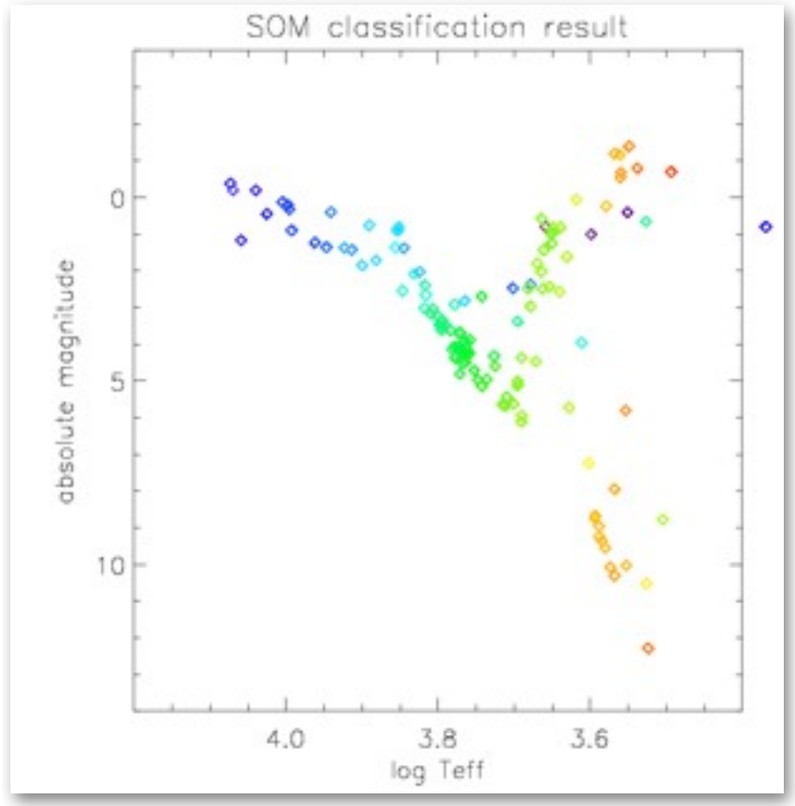




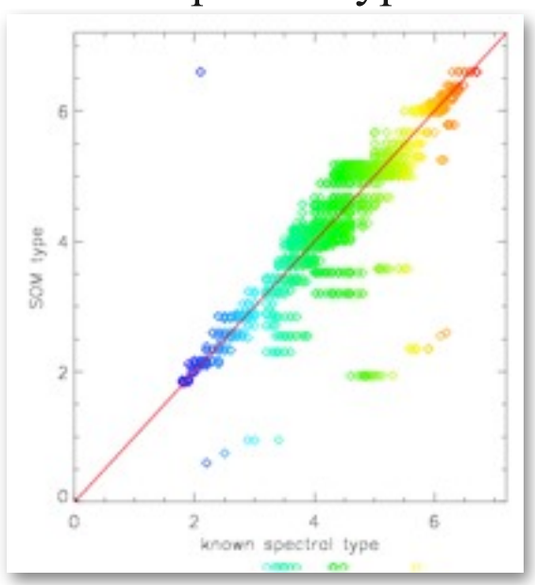


Spectra classification with SOMs - results

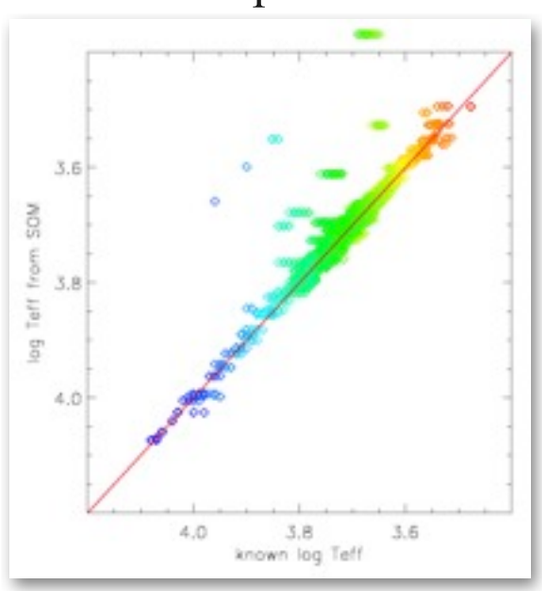




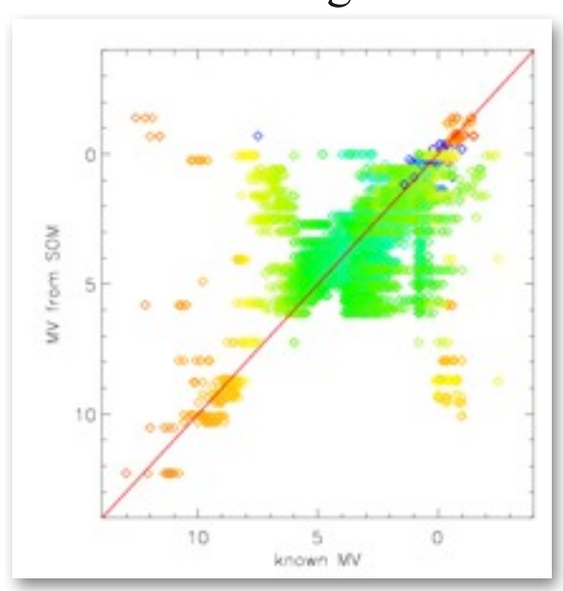
Spectral type



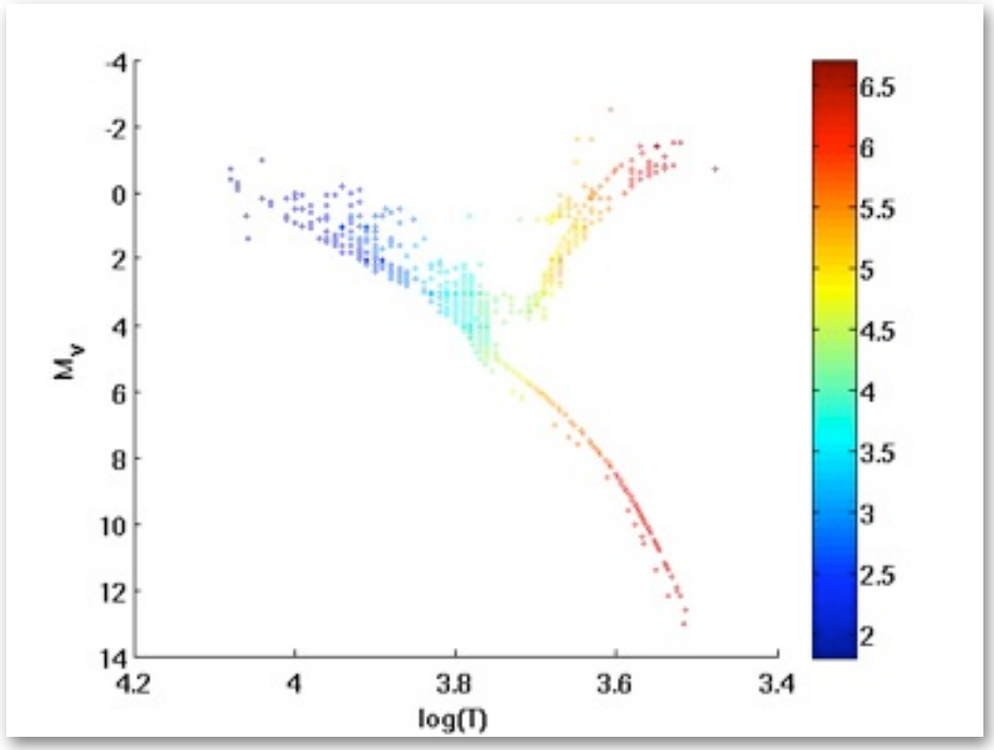
Temperature

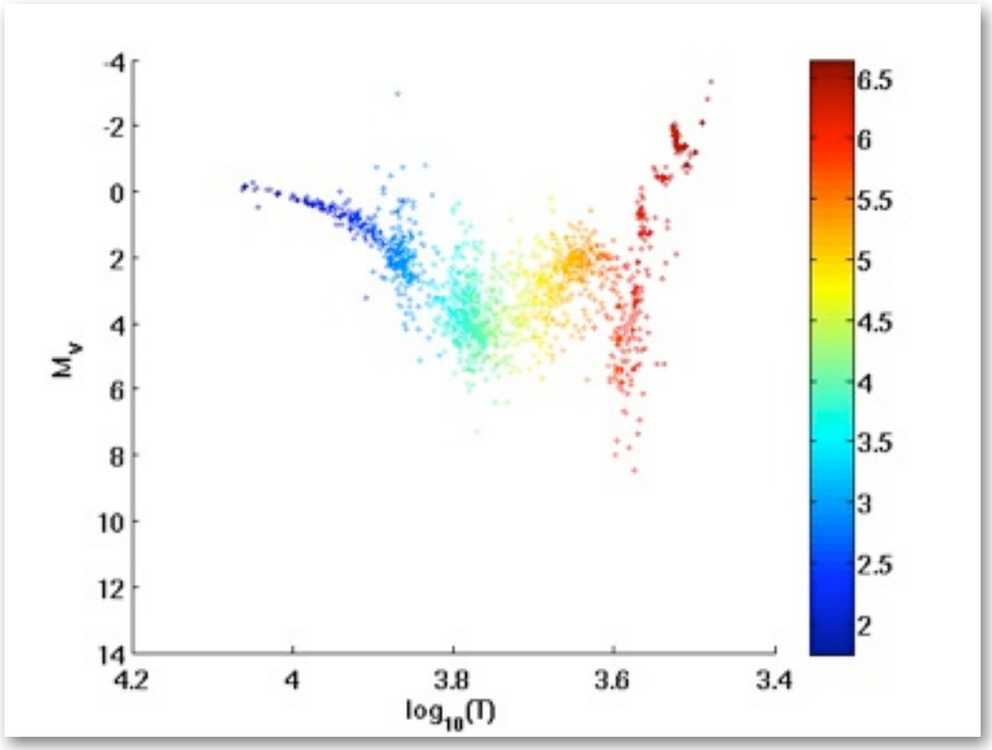


Absolute magnitude

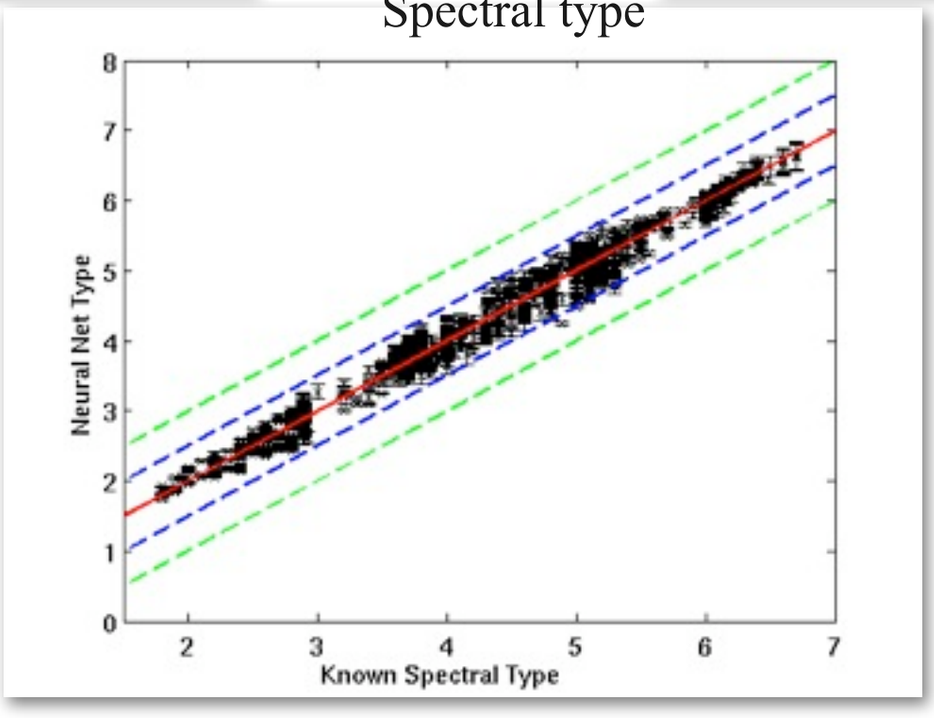


Spectra classification with ANN - results





Spectral type



credit: Manda Banerji, IoA

Curation - Cross-matching

work in progress

uses existing catalogues available through Virtual Observatory, Astrogrid or local copies, *e.g. SDSS, 2MASS, NED, ASAS, OGLE*

- star, source close to galaxy or orphan new source?
- magnitudes and colours in optical and IR
- X-ray source, gamma source?
- time-domain photometry
- variability classification (*e.g.* recurrent nova, eclipsing)
- asteroids flagged by other Gaia units
- anomalies alerted by other surveys (*e.g.* GRBs alerts)

http://www.ast.cam.ac.uk/research/gsawg/

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- Verification phase
- Follow-up

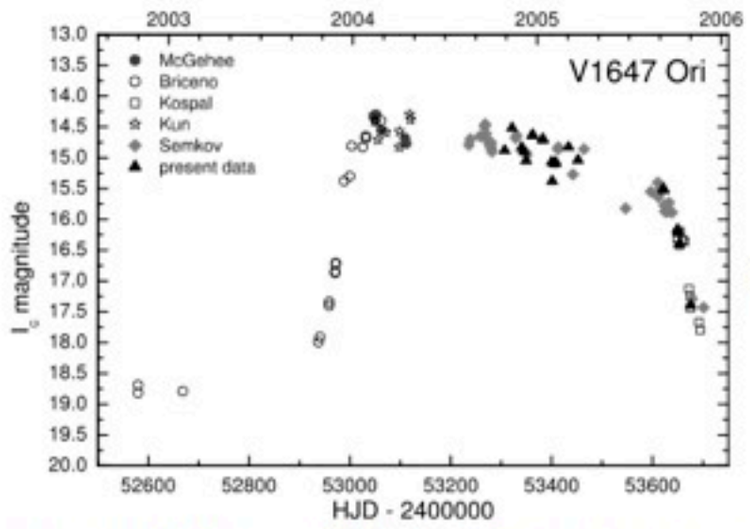
Main Page

Welcome to the web site of the Gaia Science Alerts Working Group!

The Science Alerts Working Group is focussed on the real-time detection of variable sources. These include supernovae, microlensing events, exploding and eruptive stars, etc.

FU Orionis (FUors)

FU Orionis (V1647 Ori) is young pre-main sequence stars, illuminating a McNeil's nebula in the vicinity of NGC 2068 star-forming region.



Plot from D.Chochol et al.

Figure 4. V1647 Ori light curve in the I_C passband. Our data and data from McGehee et al. (2004), Briceño et al. (2004), Kóspál et al. (2005), Kun et al. (2004) and Semkov (2004, 2006) were used.

Characteristics:

- Very rare
- Outbursts repeat with a time scale of 40 years (1978, 2003)
- Amplitude: 5 mag over 4 months
- Outbursts last for 2 years
- Spectra: F or G supergiants
- Spectrum: red, heavily veiled continuum with strong emission of H_α; in blue consistent with an early B spect
- X-ray variability present
- FU Ori and V1057 Cyg rise over 1 yr, whereas V1515 Cyg rise over 20 years

Triggers:Be

OGLE and MACHO data were studied for Be stars.

- OGLE (LMC,SMC): Sabogal et al. 2005, Mennickent et al. 2006
- OGLE (Bulge): Sabogal et al. 2008
- MACHO: Keller et al. 2002

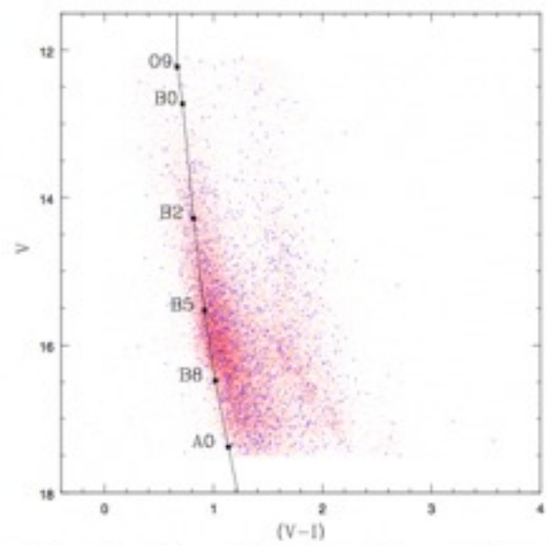


Fig. 4. V vs. $(V-I)$ diagram for the selected Be star candidates. The track of the main sequence (MS) (Allen 2000) is shown for reference. Apparent V magnitudes for it were calculated assuming the distance modulus of the Galactic bulge (14.5 mag) and $A_V = 2.23$ (obtained

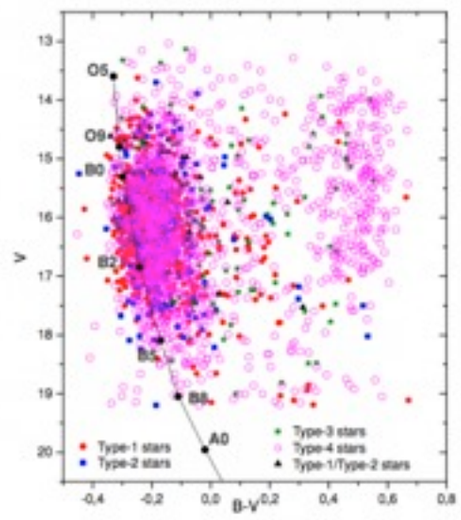


Figure 1. V versus $B-V$ diagram for the total sample of stars of the LMC. The track of the main sequence (Allen 2000) is shown for reference.

Łukasz Wyrz