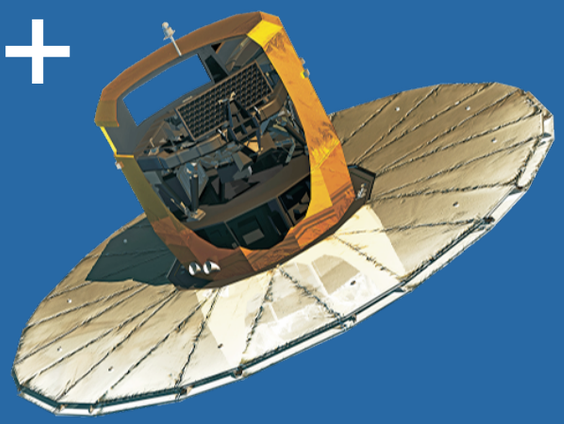
Building an automated 100 million+ variable star catalogue for Gaia



Berry Holl[1]
presented by: Laurent Eyer[1]
Nami Mowlavi[1], Dafydd W. Evans[2], Gisella Clementini[3], Jan Cuypers[4], Alessandro Lanzafame[5], Joris D. Ridder[6], Luis Sarro[7], Diego Ordoñez-Blanco[1], Krzysztof Nienartowicz[1], Jonathan Charnas[1], Leanne Guy[1], Grégory Jévardat de Fombelle[1], Isabelle Lecoeur-Taïbi[1], Lorenzo Rimoldini[1], Maria Süveges[1], François Bouchy[8,1], Sara Regibo[6], Mauro López[9], Jonas Debosscher[6], Fabio Barblan[1]

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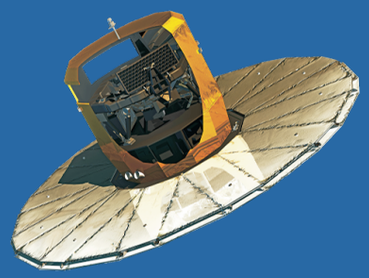
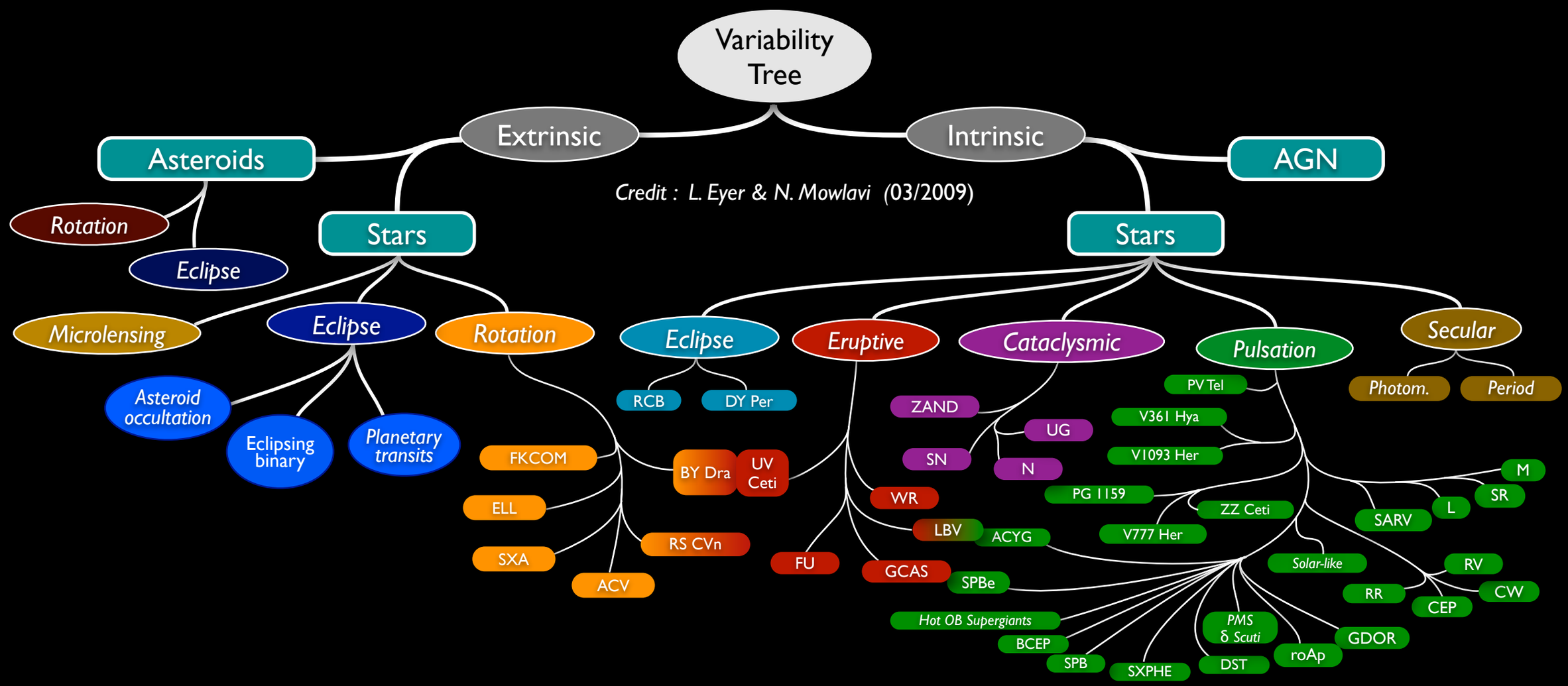
IAU XXIX General Assembly, Hawaii, Division G: Large-Scale Surveys and Variability (DG.6.02)

Gaia challenge



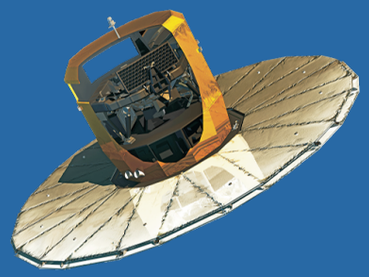
~72 epochs in 5 years

>1,000,000,000 objects, ~10% variable



How to automatically detect, classify and characterise?

Gaia challenge



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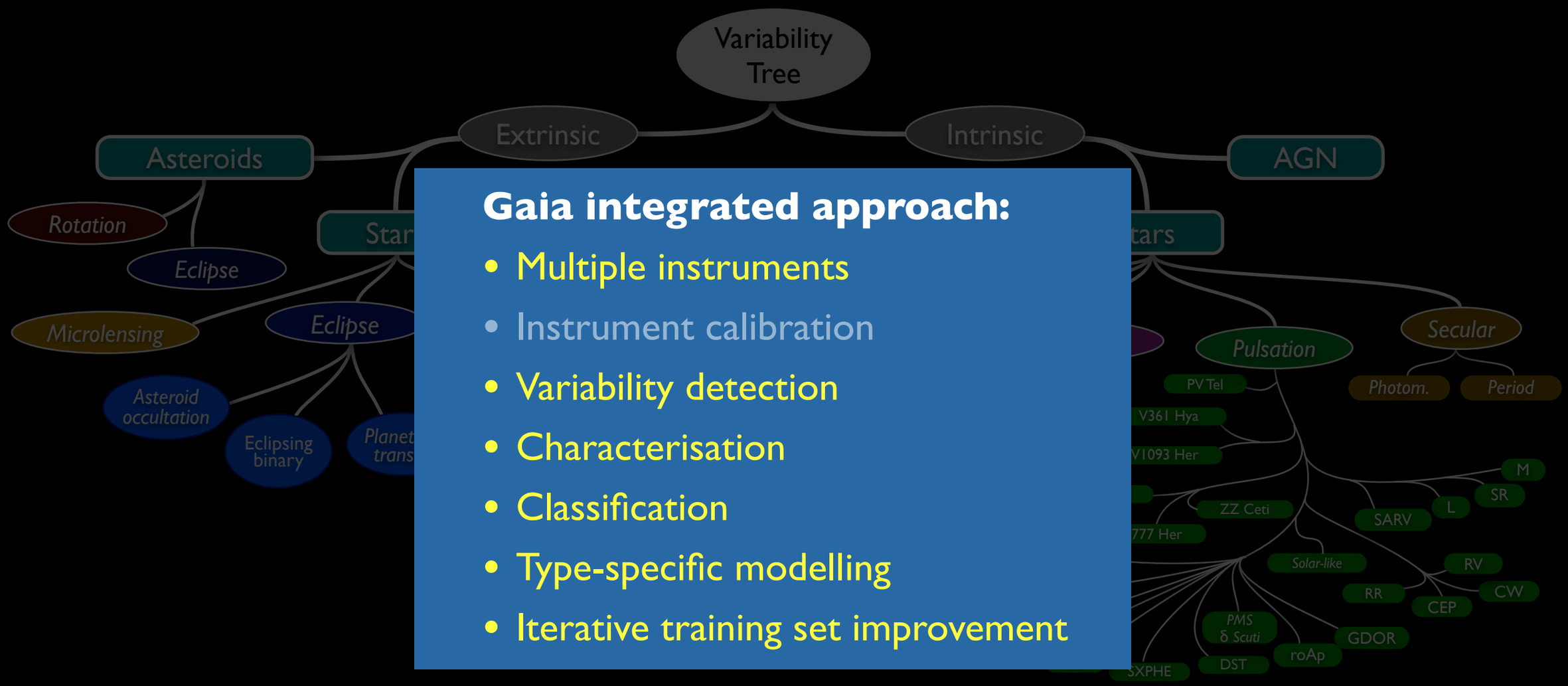
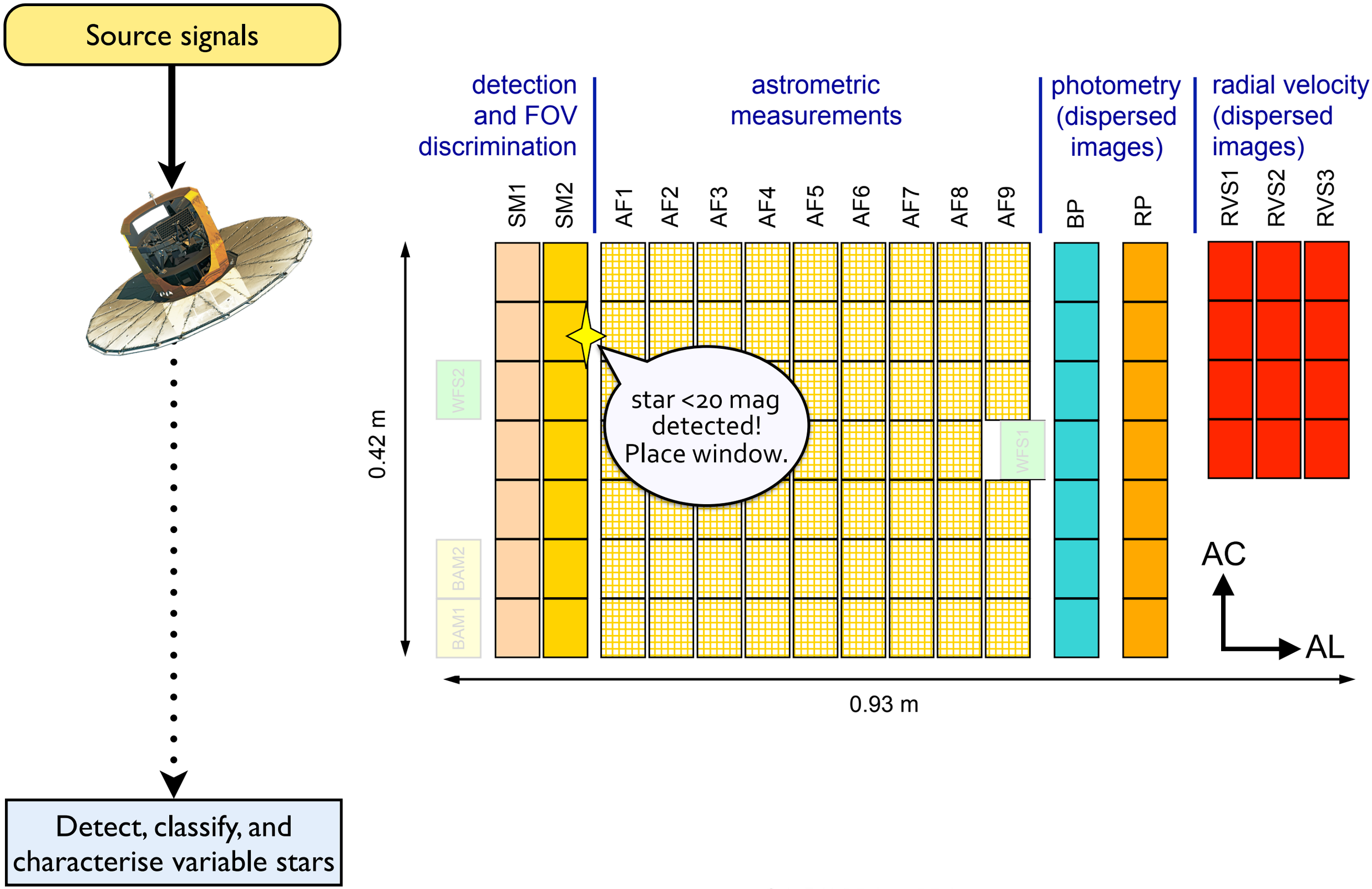


Gaia integrated approach:

- Multiple instruments
- Instrument calibration
- Variability detection
- Characterisation
- Classification
- Type-specific modelling
- Iterative training set improvement

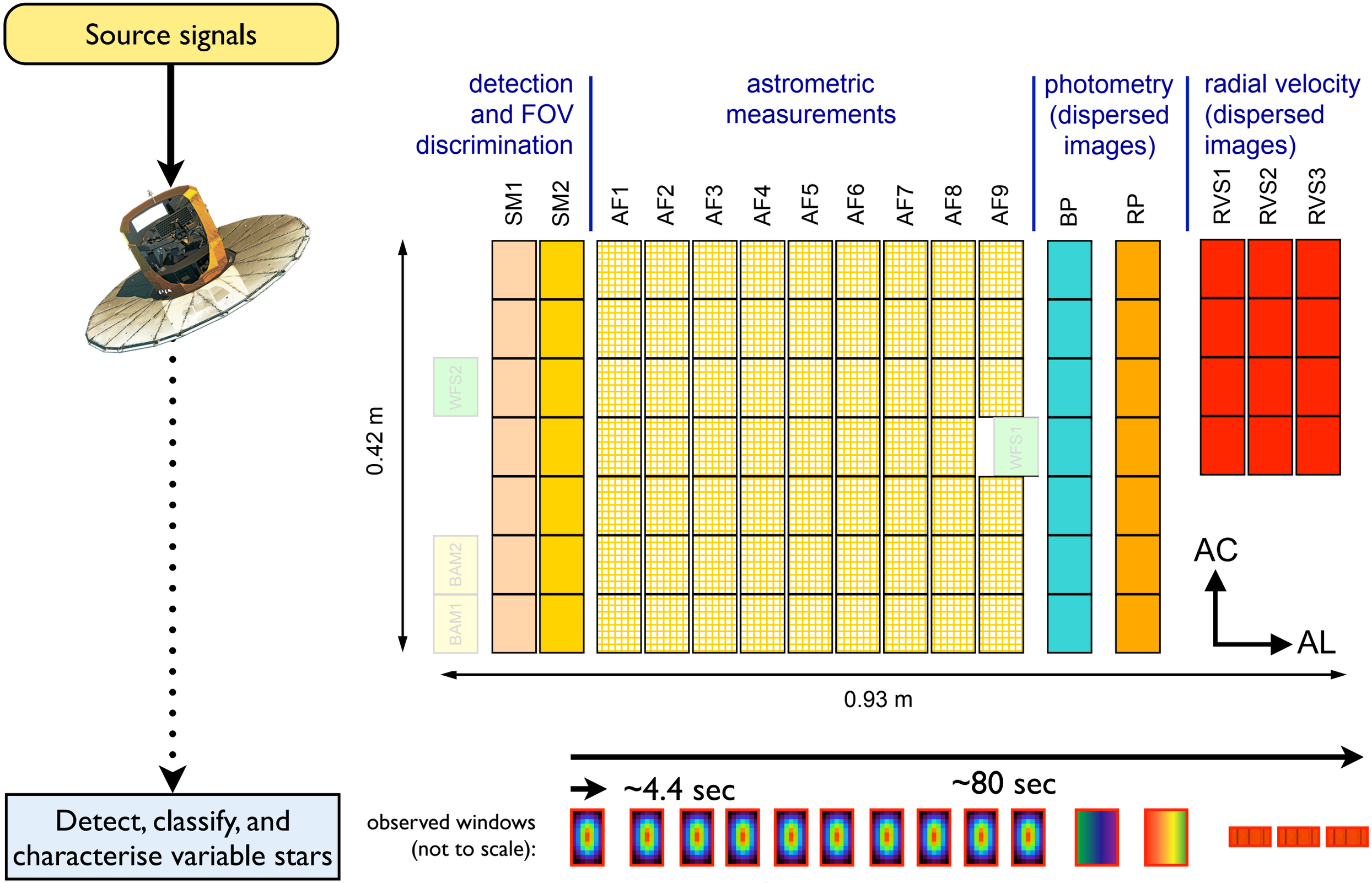
How to automatically detect, classify and characterise?

Multiple instruments



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

Multiple instruments



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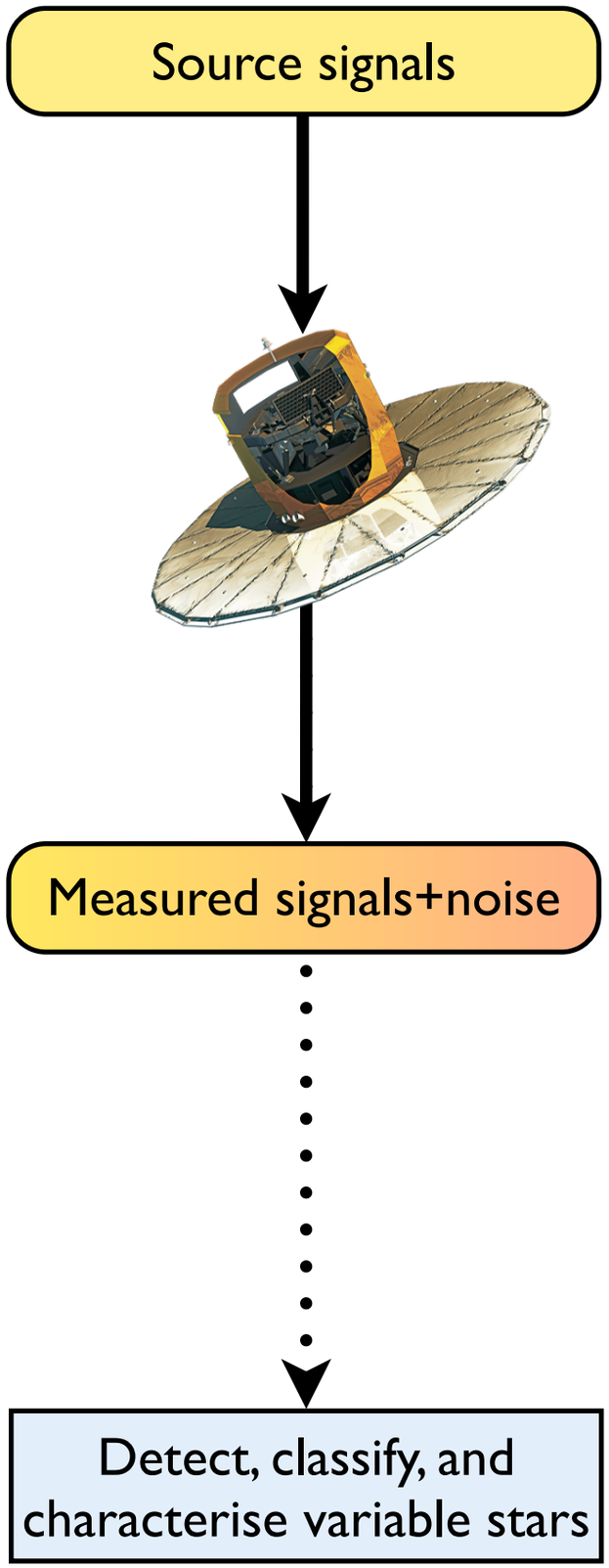
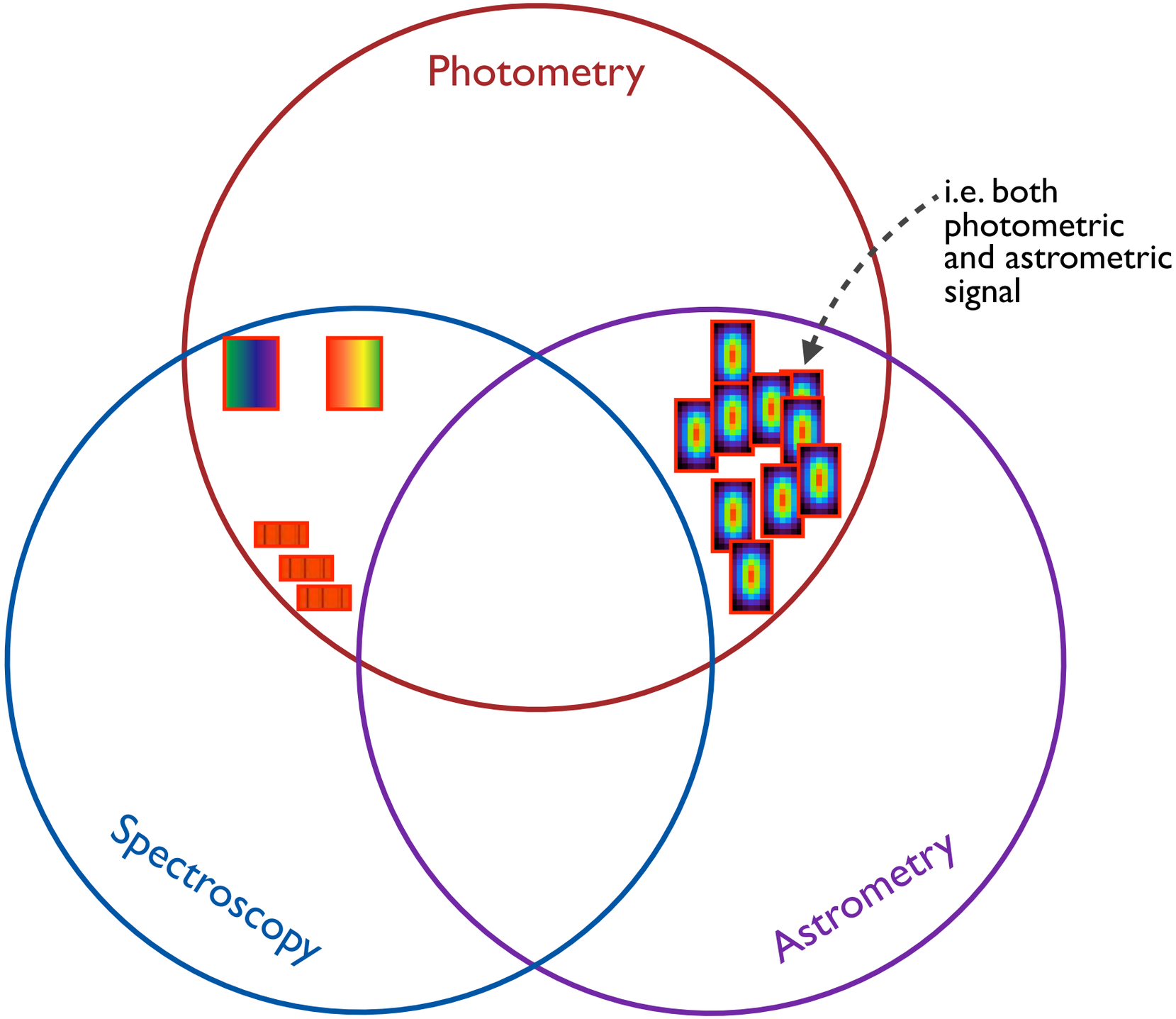
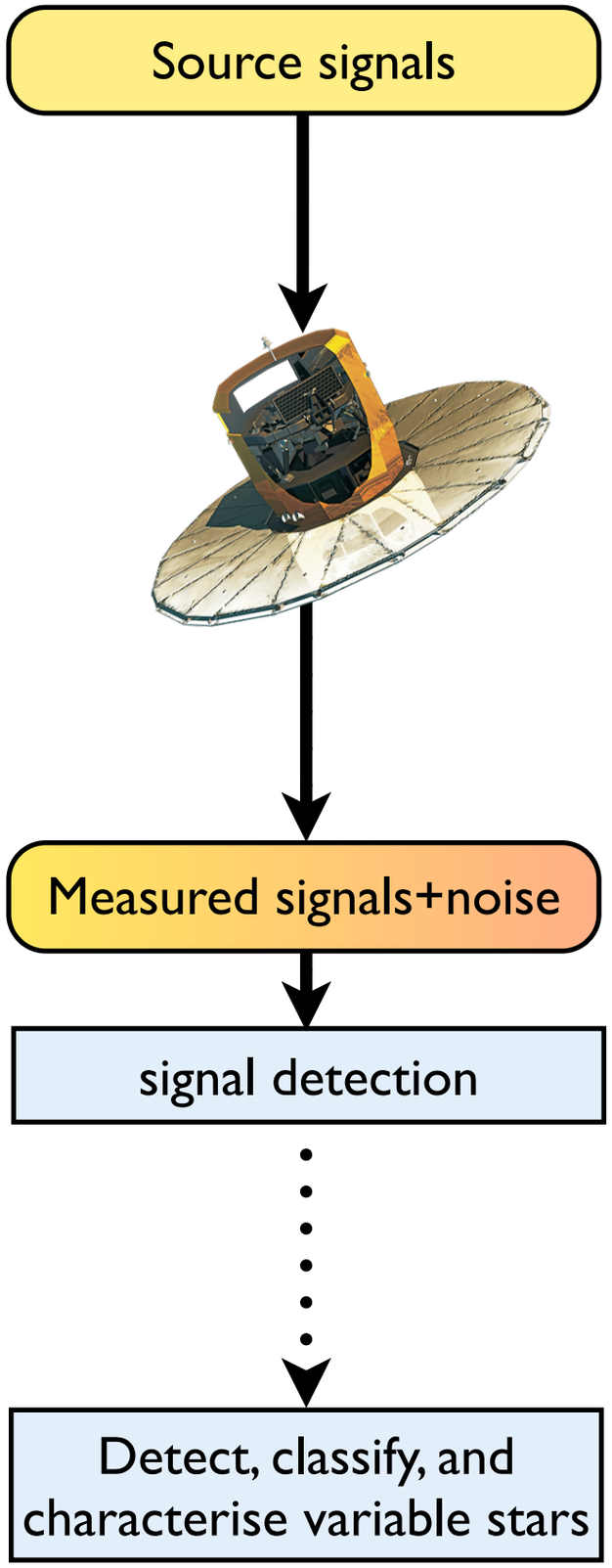




Multiple instruments



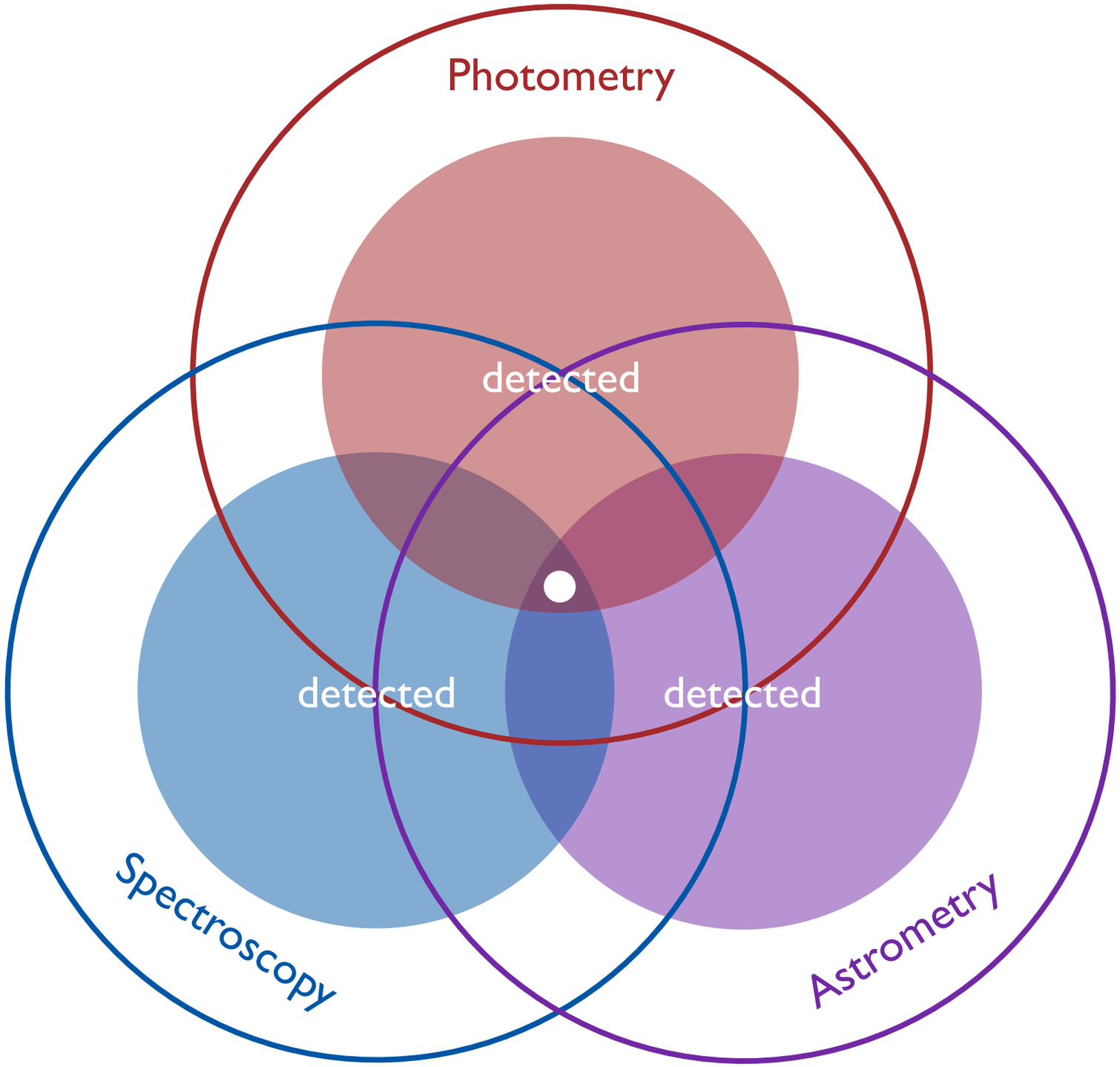
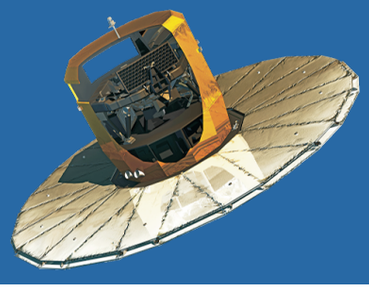


Figure adapted from Eyer & Holl, et al. (2013)

Gaia challenge

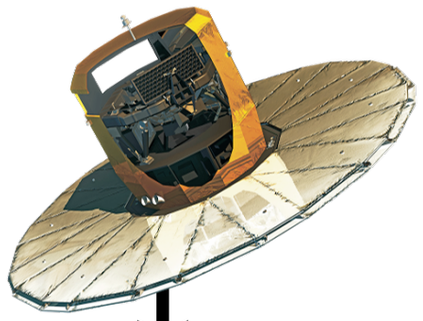


How to automatically detect, classify and characterise 100 million+ variable stars?

Gaia integrated approach:

- Multiple instruments
- Instrument calibration
- **Variability detection**
- **Characterisation**
- **Classification**
- **Type-specific modelling**
- Iterative training set improvement

Variability detection



Measured signals+noise

Variability detection

Classify and characterise variable stars

>1,000,000,000 time series
(spectro)photometric bands, radial velocity, ...

General variability detection

Constancy rejection
based on p-values of e.g.:
Chi^2, Abbe, Kurtosis, Skewness, ...

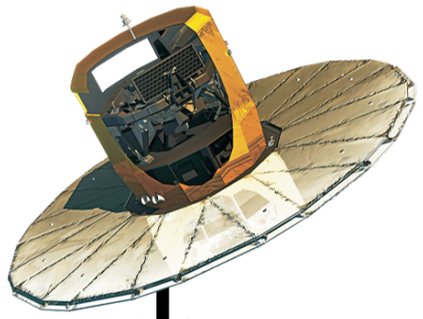
Special variability detection

Signal matching filters

- short timescale [10s, 2h]
  e.g. eclipsing binaries, pulsating stars
- solar-like activity (spots and flares)
- small periodic amplitude
- planet transits

Select for variable processing (~10%)

Signal characterisation



Measured signals+noise

Variability detection

Characterisation

Classify variable stars

>1,000,000,000 time series
(spectro)photometric bands, radial velocity, ...

General variability detection

Special variability detection

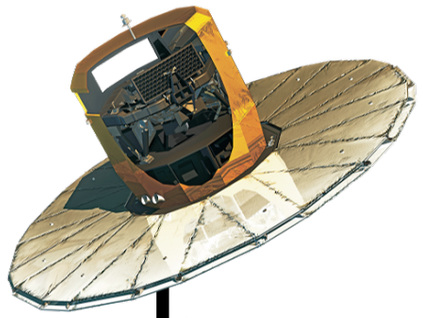
Periodicity / stochastic / ....

- **Periodic model:**
  multi-periodic harmonic Fourier with polynomial (e.g. trend)

Attribute computation

- **Many parameters available:**
  i.e. astrometric, astrophysical, radial velocity (for bright stars), etc.
- **Various attributes, e.g.:**
  absolute magnitude (using parallax),
  BP-RP (colour),
  peak-to-peak amplitude,
  period,
  skewness,
  A2/A1 (ratio of Fourier harm. ampl.),
  etc.

Classification



Measured signals+noise

Variability detection

Characterisation

Classification

>1,000,000,000 time series
(spectro)photometric bands, radial velocity, ...

General variability detection

Special variability detection

Periodicity / stochastic / ....

Attribute computation

Supervised

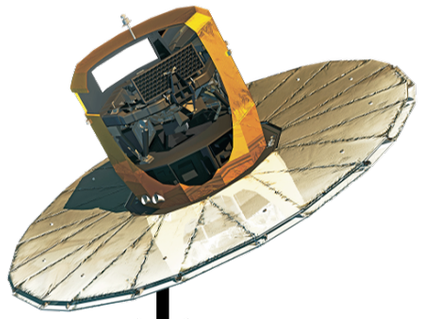
Unsupervised

- **Single and multi-stage:**
  Gaussian Mixture,
  Random Forest,
  Bayesian network, ...
- **Extractors:**
  transients,
  microlensing
- **Meta-classifier:** combination of classifiers for best performance.

Identify/confirm new classes

Hierarchical Modal Association Clustering (HMAC)

Type-specific modelling



Measured signals+noise

Variability detection

Characterisation

Classification

Detailed modelling

>1,000,000,000 time series
(spectro)photometric bands, radial velocity, ...

General variability detection

Special variability detection

Periodicity / stochastic / ....

Attribute computation

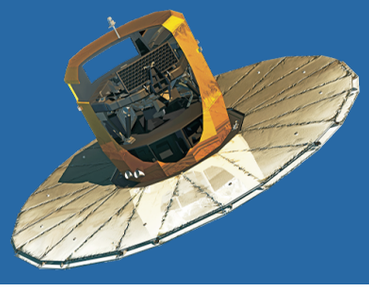
Supervised

Unsupervised

Specific Object Modelling

- **RR-Lyrae**
- **Cepheids**
- **Eclipsing binaries**
- **Long period Var.**
- **Cataclysmic**
- **BE stars**
- **Pre main sequence**
- **Rapid phase**
- **Microlensing**
- **AGN**
- **Planetary transit**
- **Solar like oscillators**
- **Flare stars**

Gaia challenge



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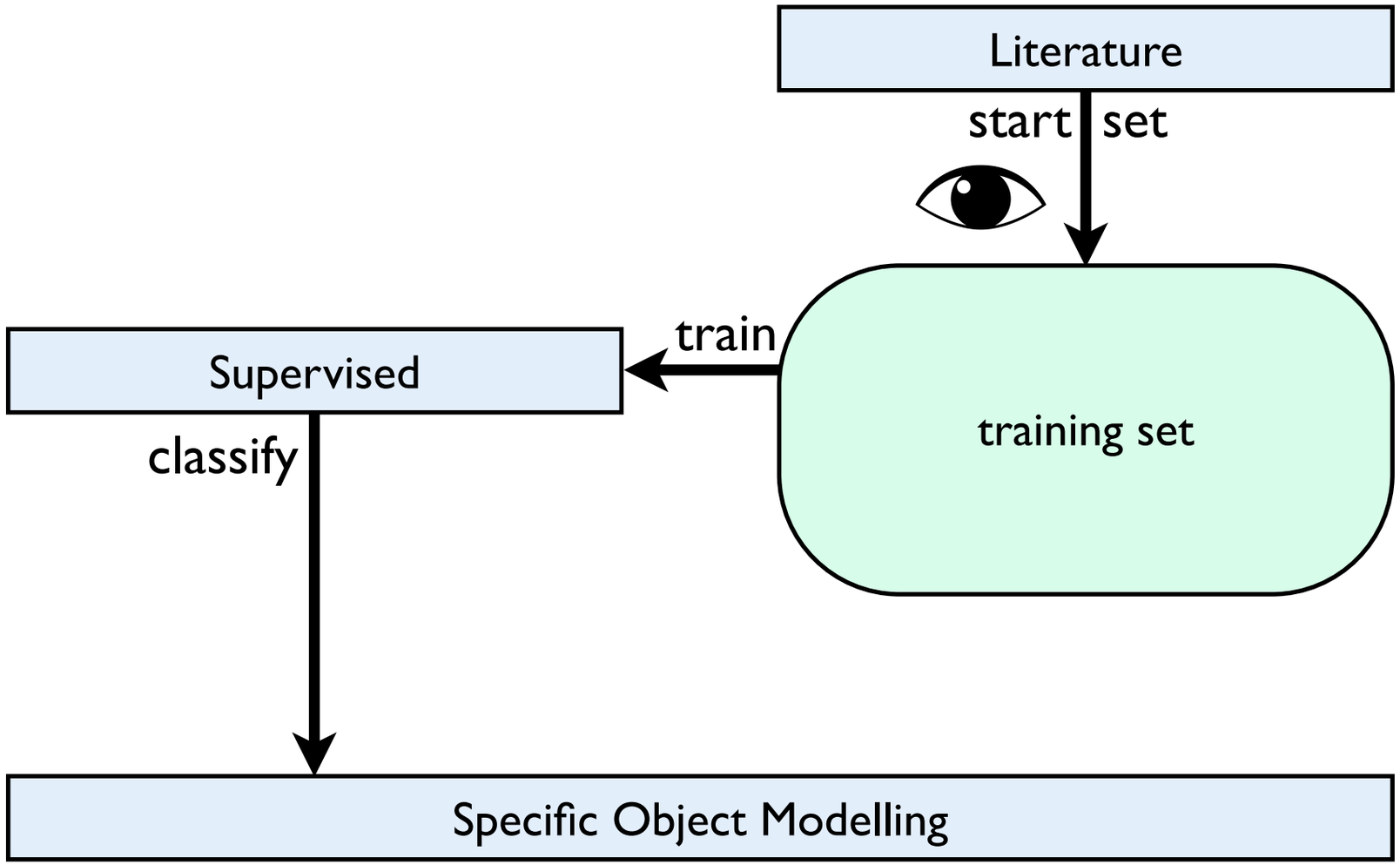
Iterative training set improvement

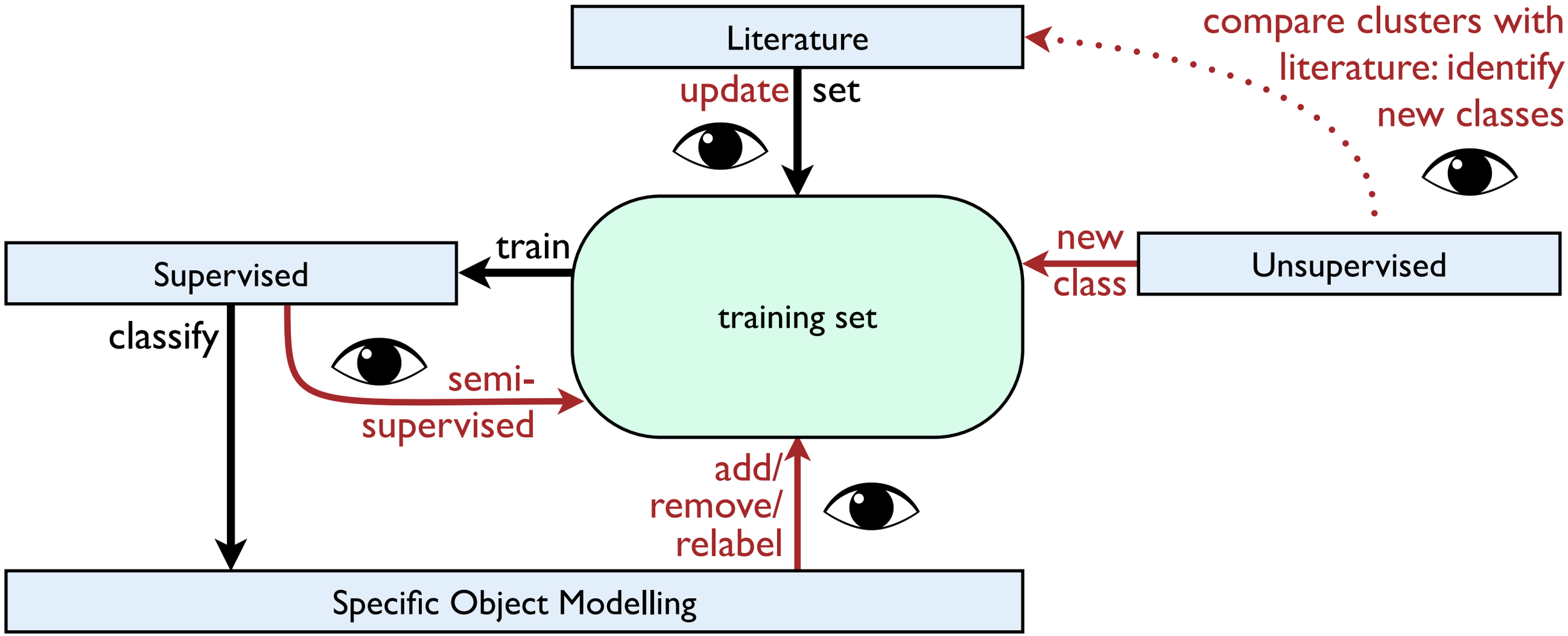
First iteration:



= requires visual inspection/confirmation

Iterative training set improvement

Further iterations:



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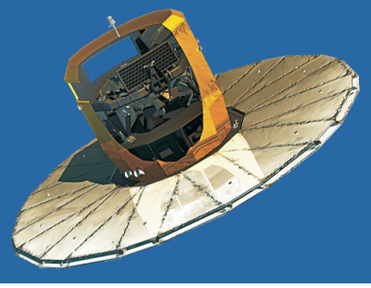
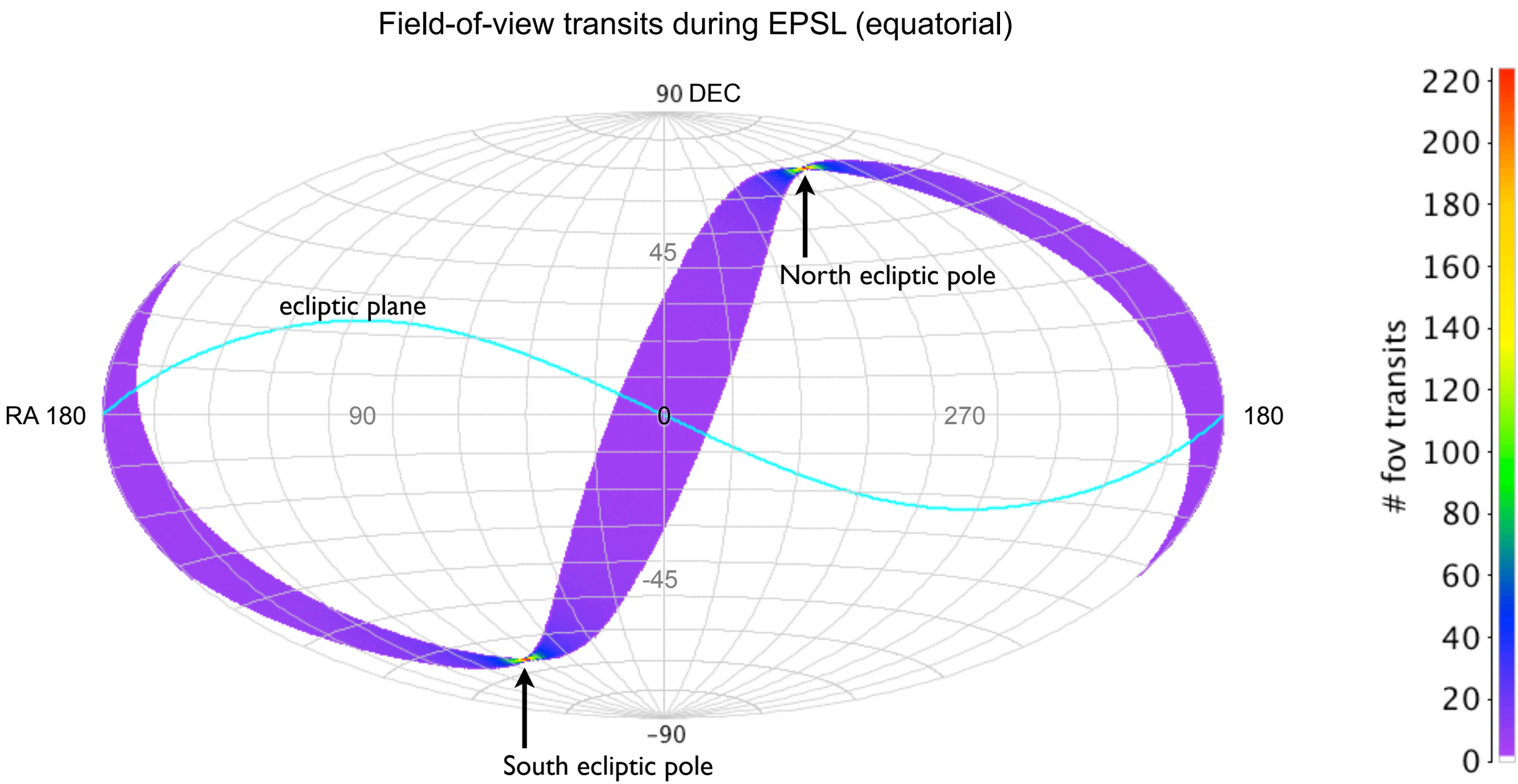
First Gaia data!



28 day Ecliptic Pole Scanning data (summer 2014)



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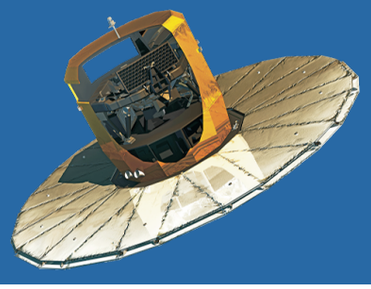
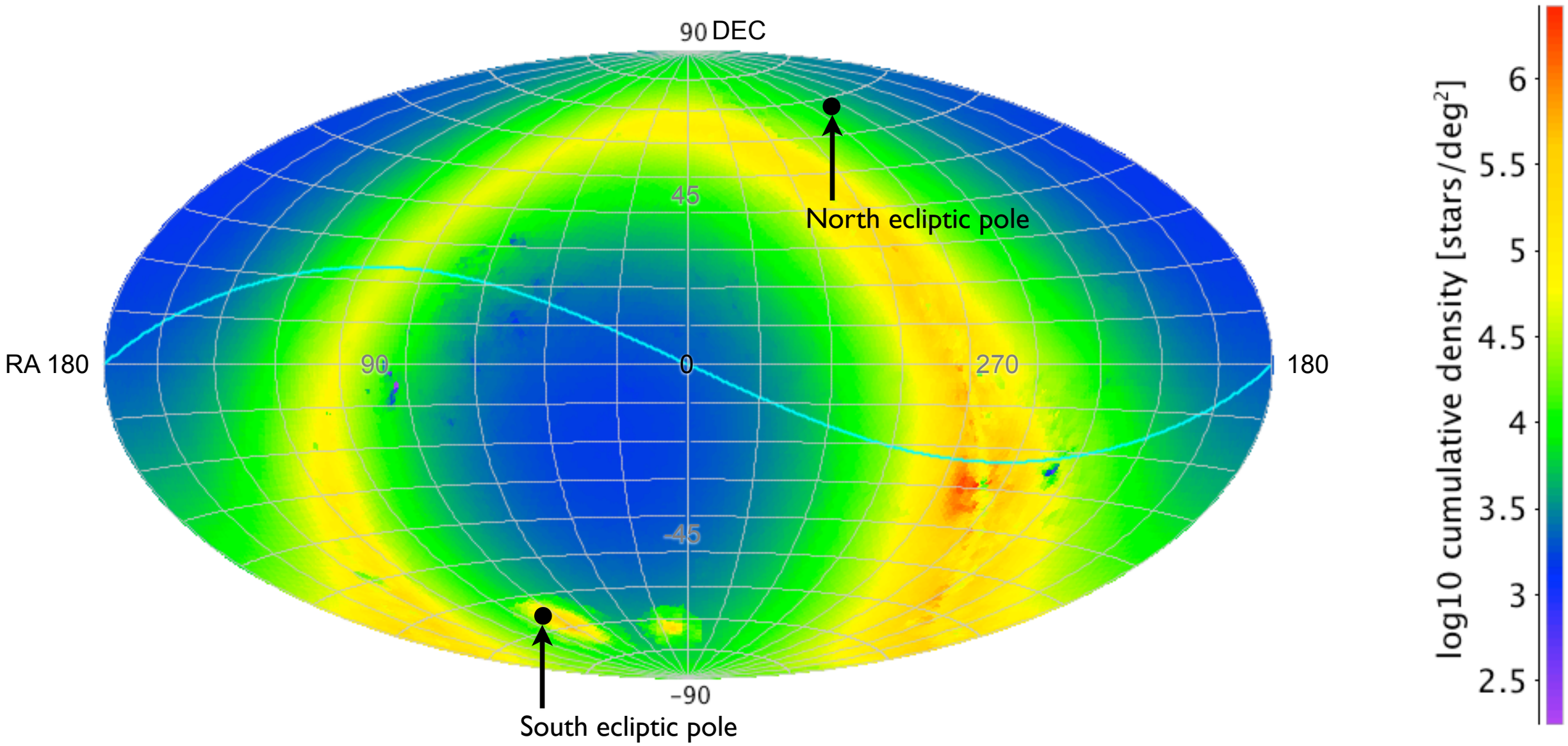


28 day Ecliptic Pole Scanning data (summer 2014)

Number density of stars up to magnitude 20



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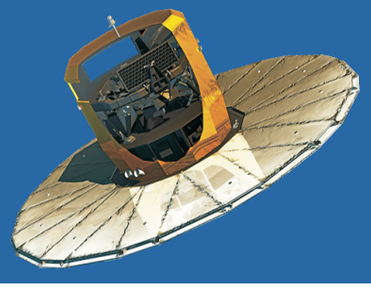
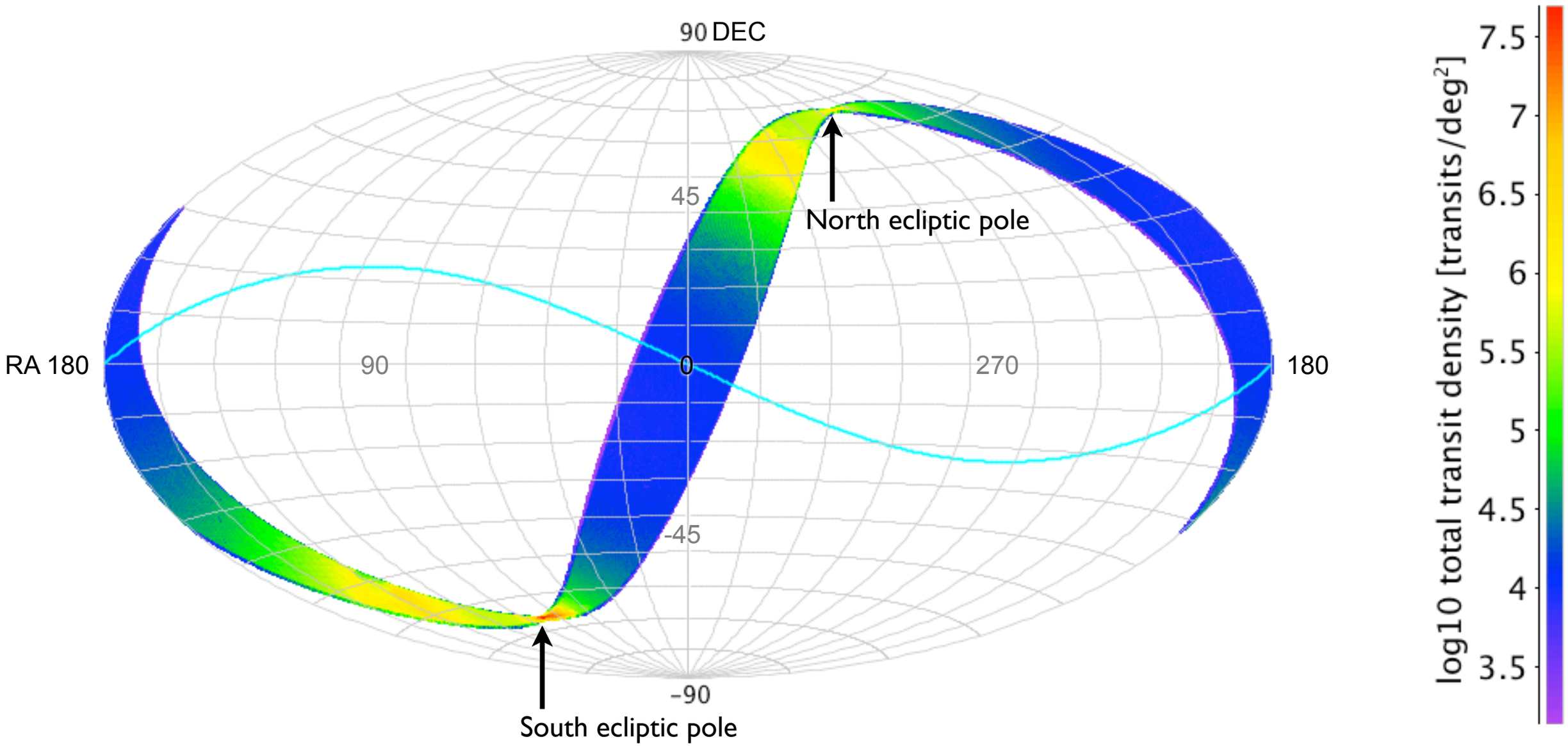


28 day Ecliptic Pole Scanning data (summer 2014)

Number density of EPSL measurements up to magnitude 20



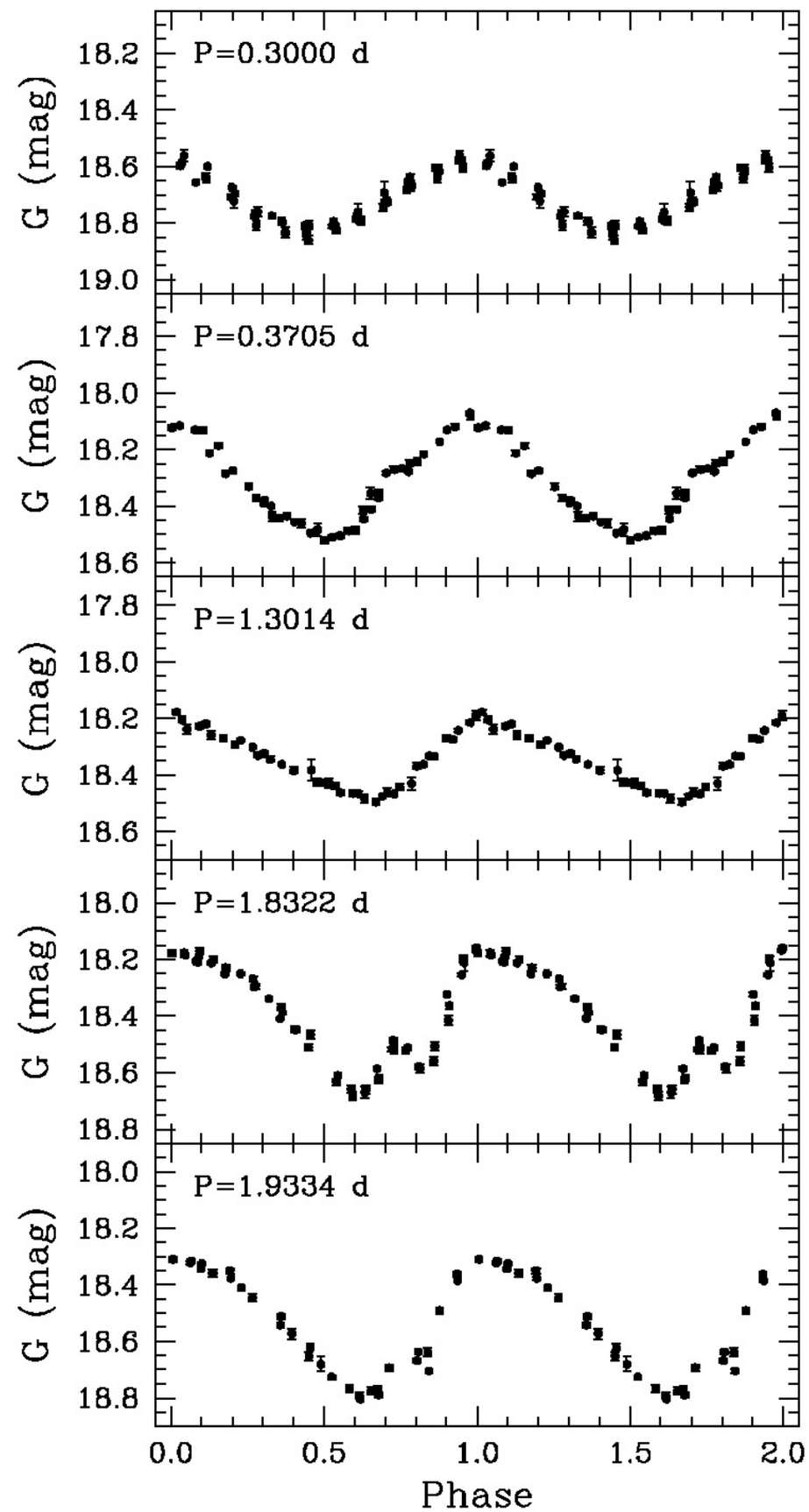
EPSL data examples

Gaia: G-band

Short period/faint magnitude Cepheids in the Large Magellanic Cloud

Gaia Image of the week:
http://www.cosmos.esa.int/web/gaia/iow_20150528

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.

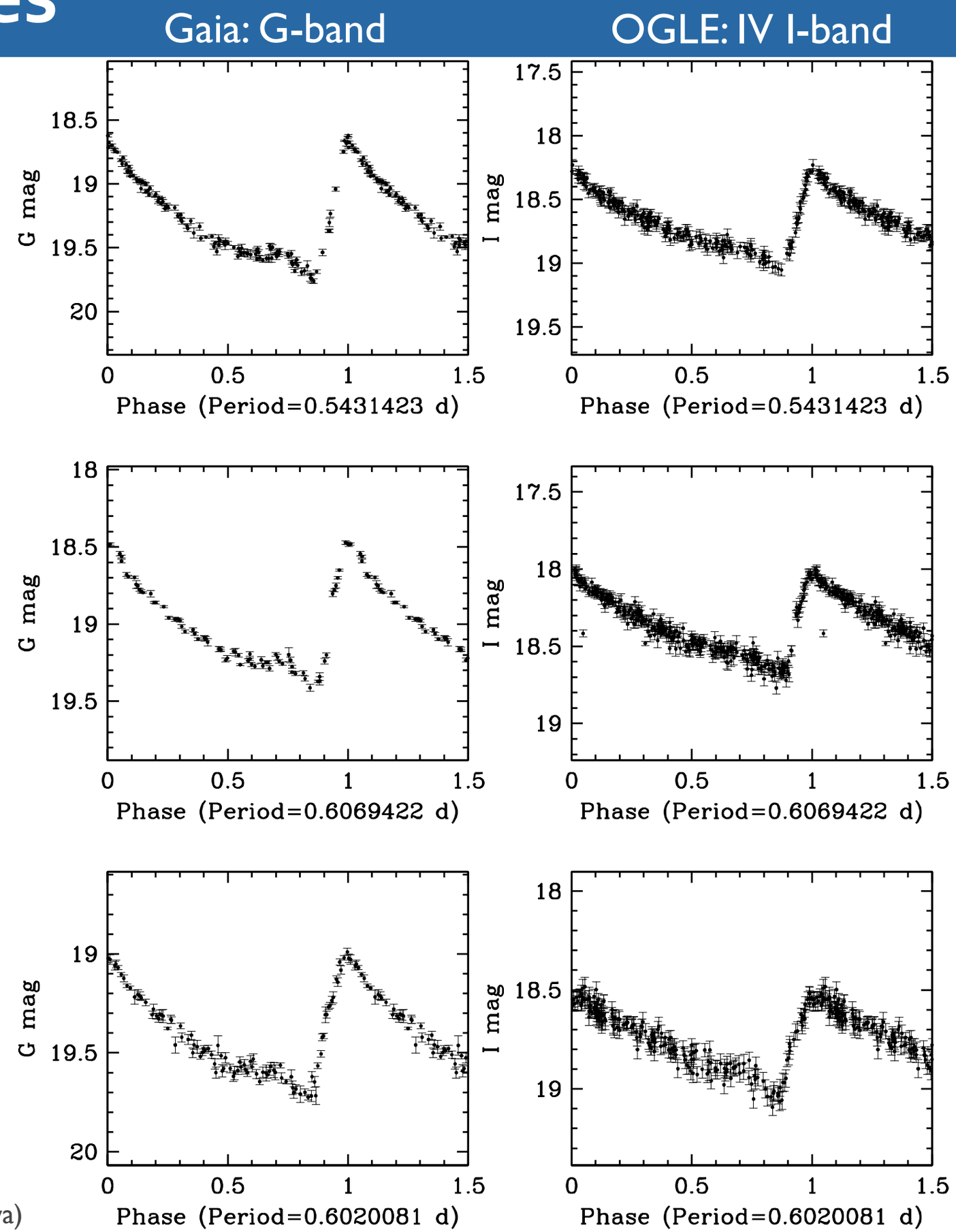


EPSL data examples

RR-Lyrae stars
in the Large Magellanic Cloud

Gaia Image of the week:
http://www.cosmos.esa.int/web/gaia/iow_20150305

Credits: ESA/Gaia/DPAC/CU5/CU7/INAF-OABo, Gisella Clementini, Dafydd Evans, Laurent Eyer, Krzysztof Nienartowicz, Lorenzo Rimoldini and the Geneva CU7/DPCG and CU7/INAF-OACN teams.



Gaia data releases