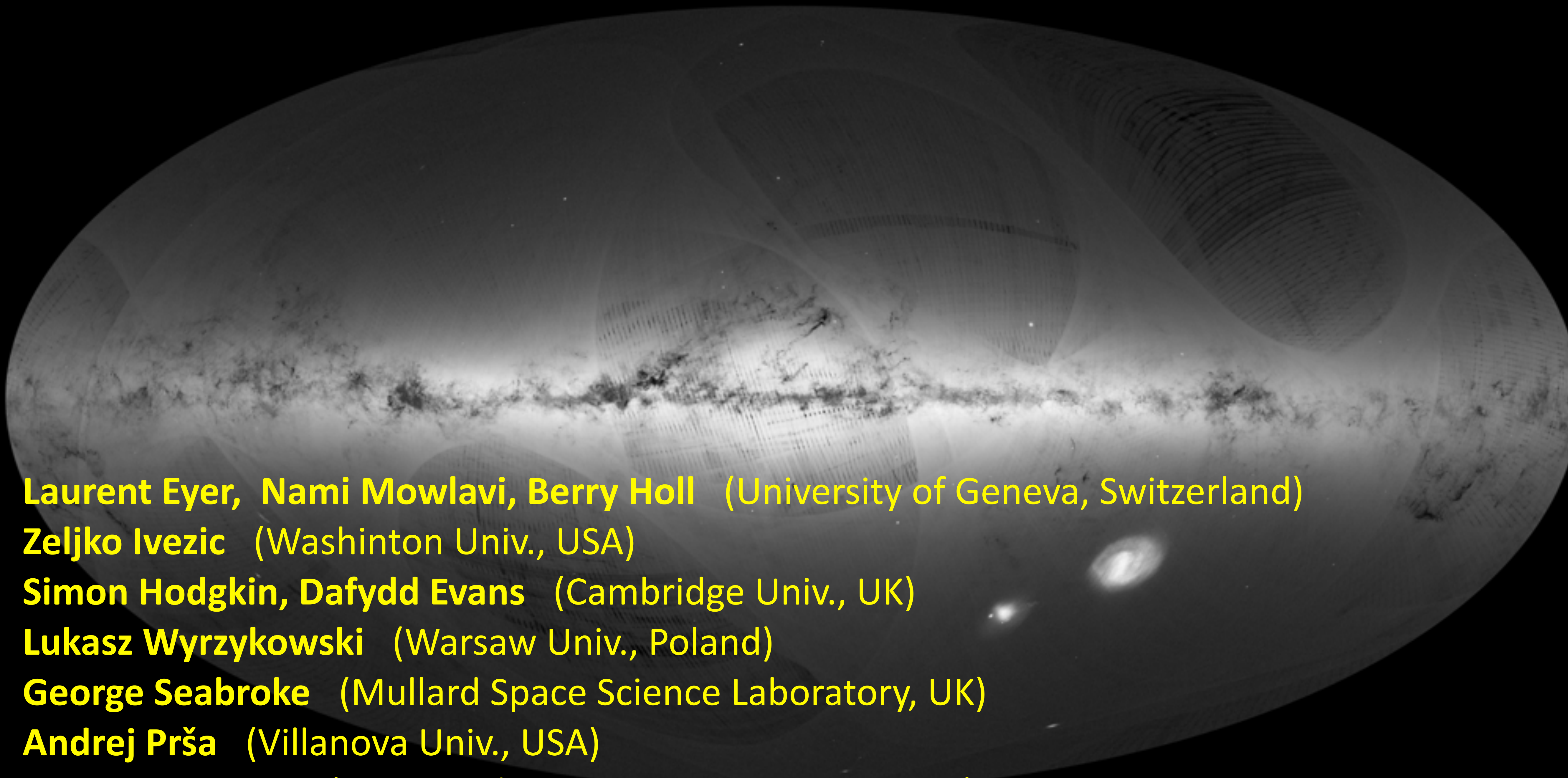
Gaia, LSST and binaries



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Friday, July 7, 2017

ESO, Garching, Germany

Era of large scale surveys

We are currently into an era of exceptional data growth

Large surveys produce "uniform" data:

Data acquisition

Reduction method

We are in a data driven period

e.g. 100 PBytes of data for LSST

Warning: the talk will be a bit biased towards Gaia, because of my association and because of the Gaia Data Release 1

The booming multi-epoch Surveys (non exhaustive)

Ground based

- Very Large Scale surveys: **LSST**, PanSTARRS, VVV
- Microlensing: **OGLE**, MACHO, **EROS**
- Planetary transits: OGLE-III, **HAT, HATPI,** SuperWasp, TrES
- Observations of clusters/ galaxies: ... **Geneva open cluster survey**, many ...
- **ASAS**, SkyMapper, Fly's Eye
- Transients: ROTSE, NSVS, PTF, **Catalina,** ZTF
- Asteroids: **LINEAR**, LONEOS
- Multi-site observations: DSN (Delta Scuti Network), WET, SONG (Doppler-velocity obs.), ...
- Antarctica: SIAMOIS, ICE-T, ASTEP, ...
- Cosmology: **SDSS**

Space

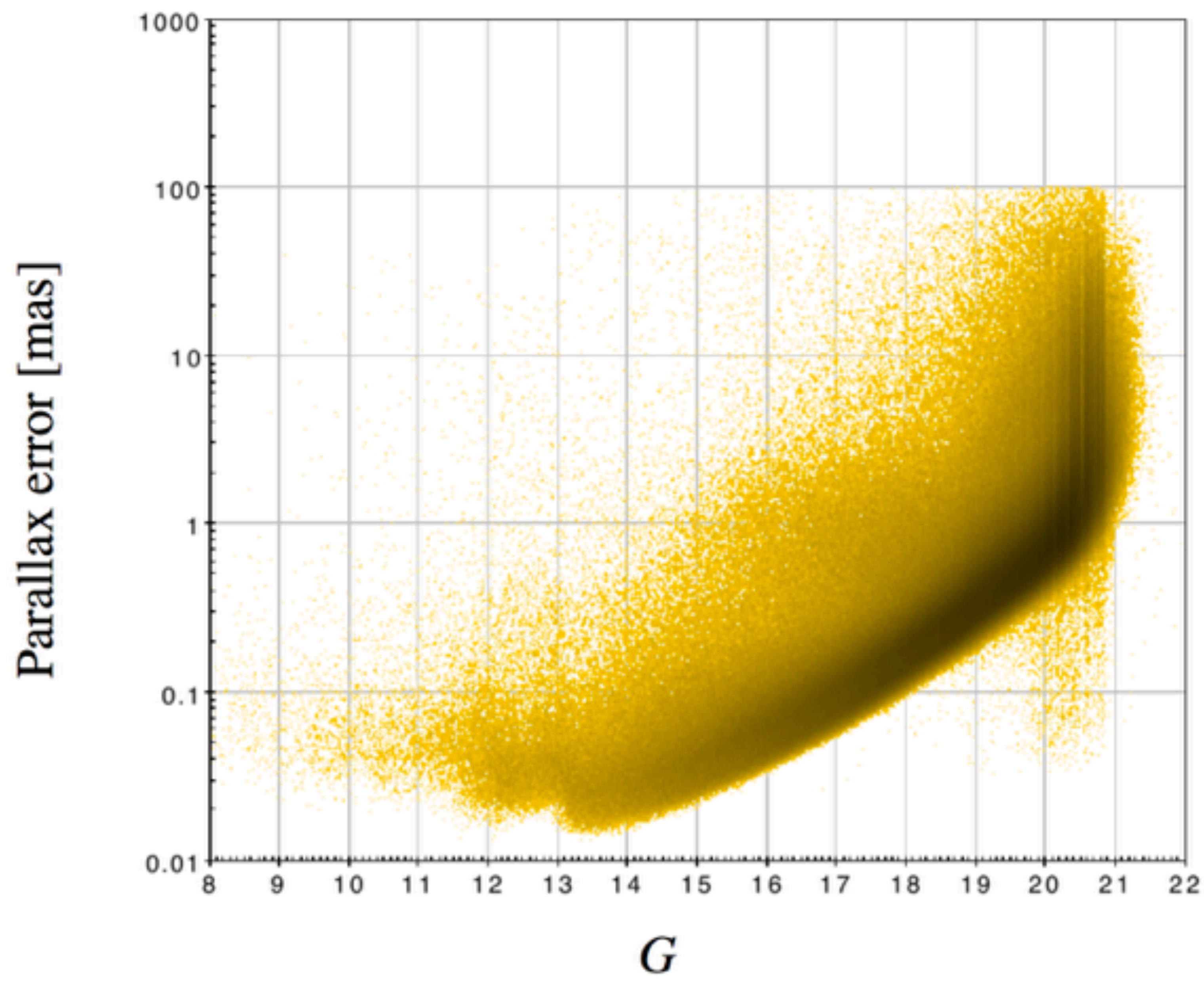
- **Gaia, Hipparcos** (ESA)
- JASMINE (Japan)
- **Kepler**, TESS (NASA)
- **COROT** (CNES/ESA)
- PLATO (ESA)
- BRITE (Canada+Austria+Poland)
- MOST (Canada)
- WIRE (NASA)
- CHEOPS (ESA)

The Gaia mission

- Spacecraft of the European Space Agency
- Observations of all the objects brighter than G = ~20.7, about 1.5 billion objects
- Astrometry, photometry, spectrophotometry, and spectroscopy (radial velocities)
- Length: 5 years (70 times all sky) + 5 year?
- Launch (Soyuz rocket, French Guyana) Dec 19 2013
- Final Results of the nominal mission: 2022

Location: L2
http://www.rssd.esa.int/Gaia

Astrometric precision for the `2018' Gaia Data Release 2



- Systematic errors below 100 μas
- Typical parallax precision:
  $G = 15$, 30 μas; $G = 18$, 150 μas;
  $G = 20$, 700 μas
- Improvements with respect to Gaia DR1
  - Gaia-only solution (no prior used) for the majority of sources
  - more/better input data
  - improved calibrations (in particular colour terms)
  - improved removal of attitude disturbances

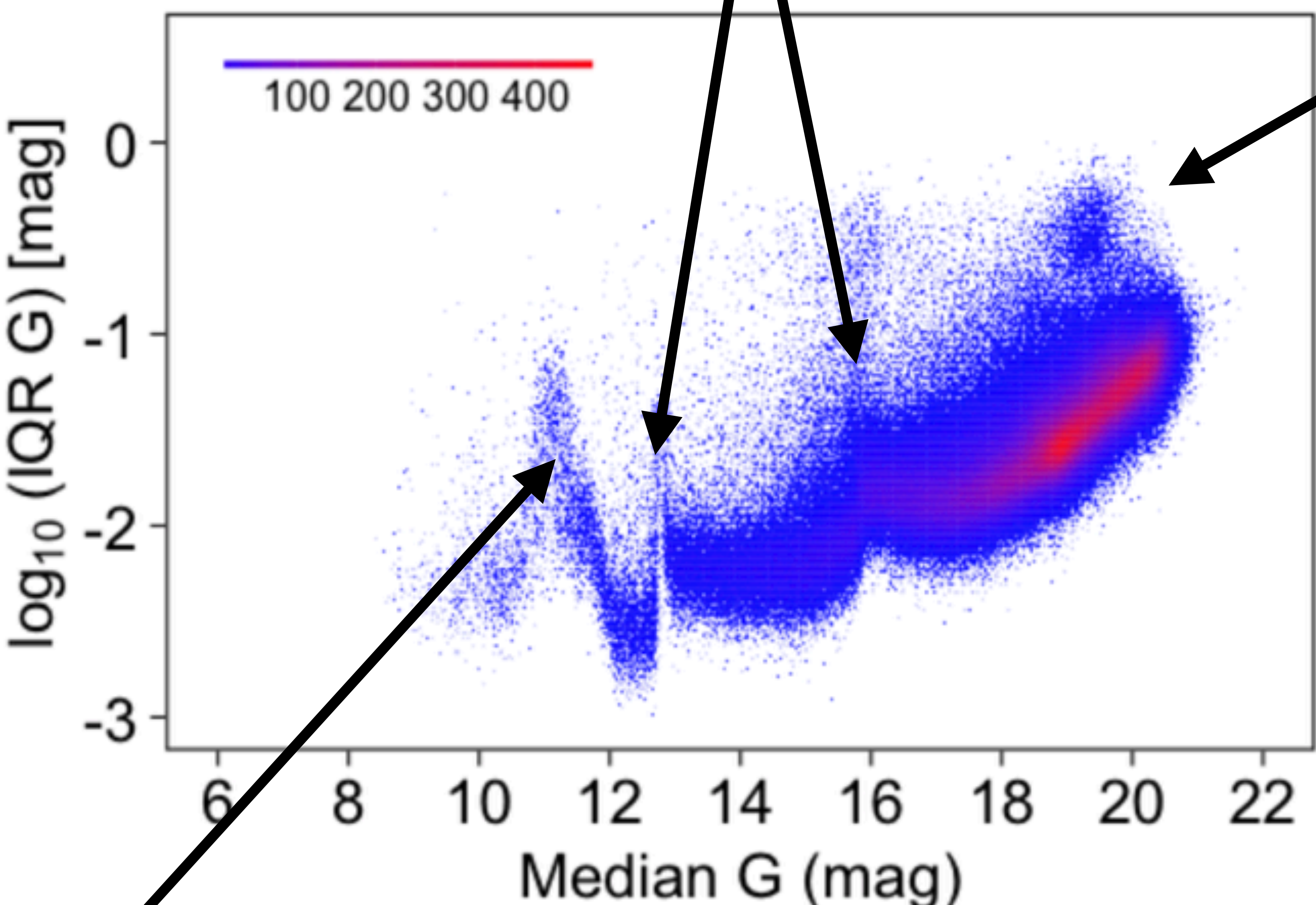
Courtesy of A.Brown

Properties of the G band from Gaia Data Release 1

Field-of-View G band photometry

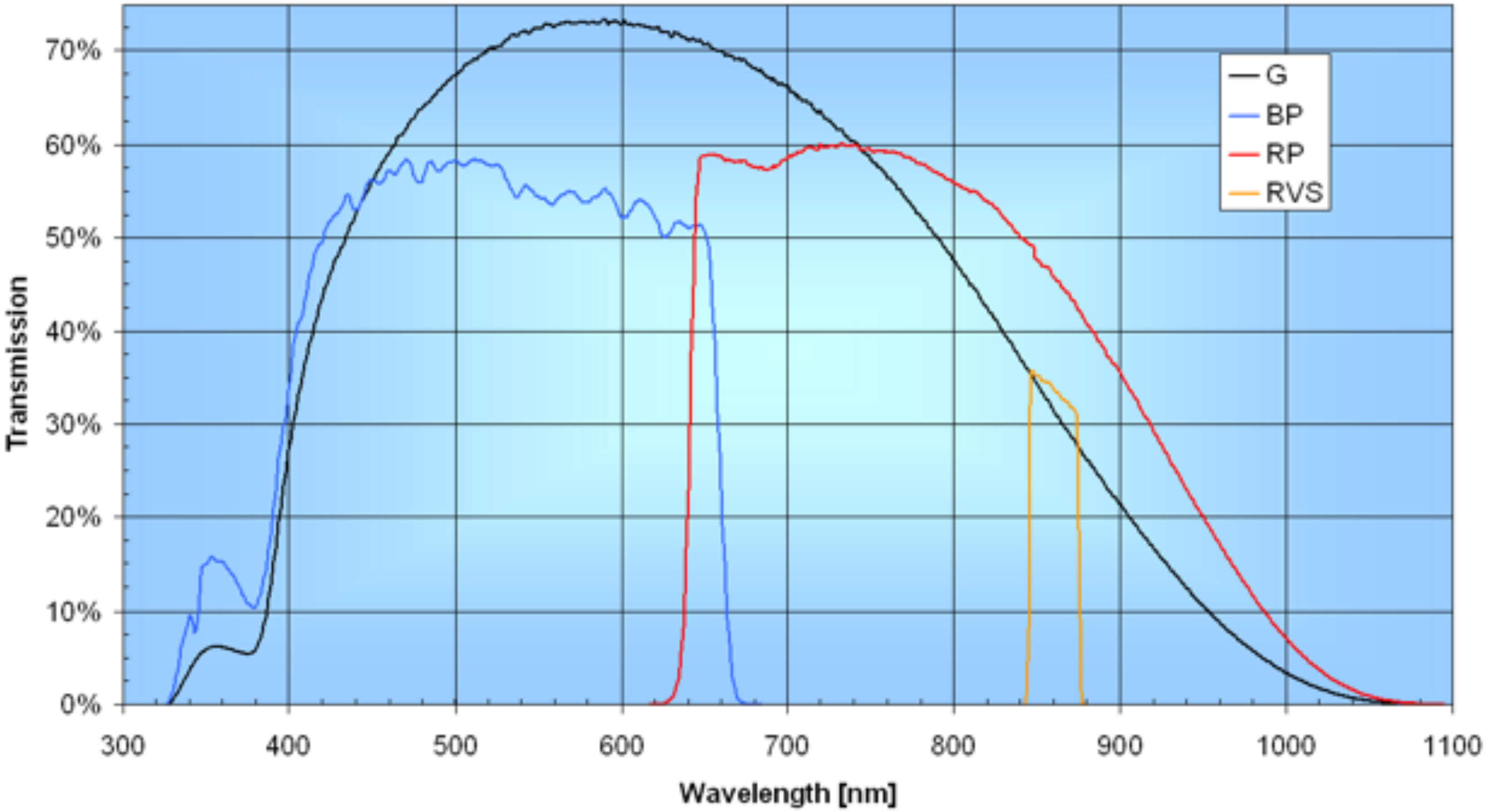
Window class change

Variable stars



Saturation/gating effects

Properties of BP and RP spectrophotometry



With G-band photometry, there is as well

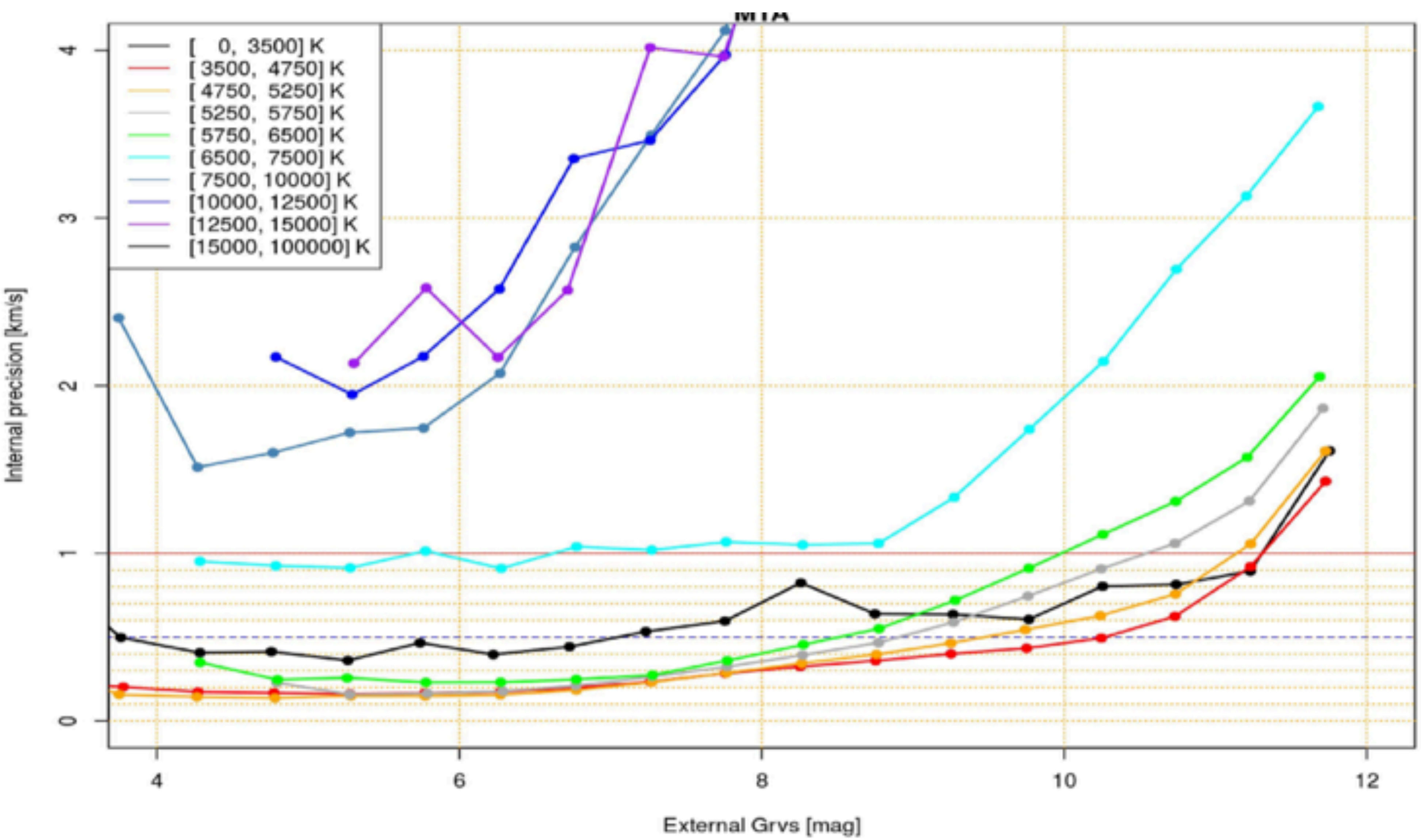
Integrated BP (330-680 nm), and RP (640-1050 nm)

Spectra of 60 samples each: BP, RP

Gaia Data Release 2 will contain BP and RP integrated measurements

Properties of RVS precision for Gaia Data Release 2

RVS instrument: 845-872 nm, R=11,500 (around Calcium triplet)

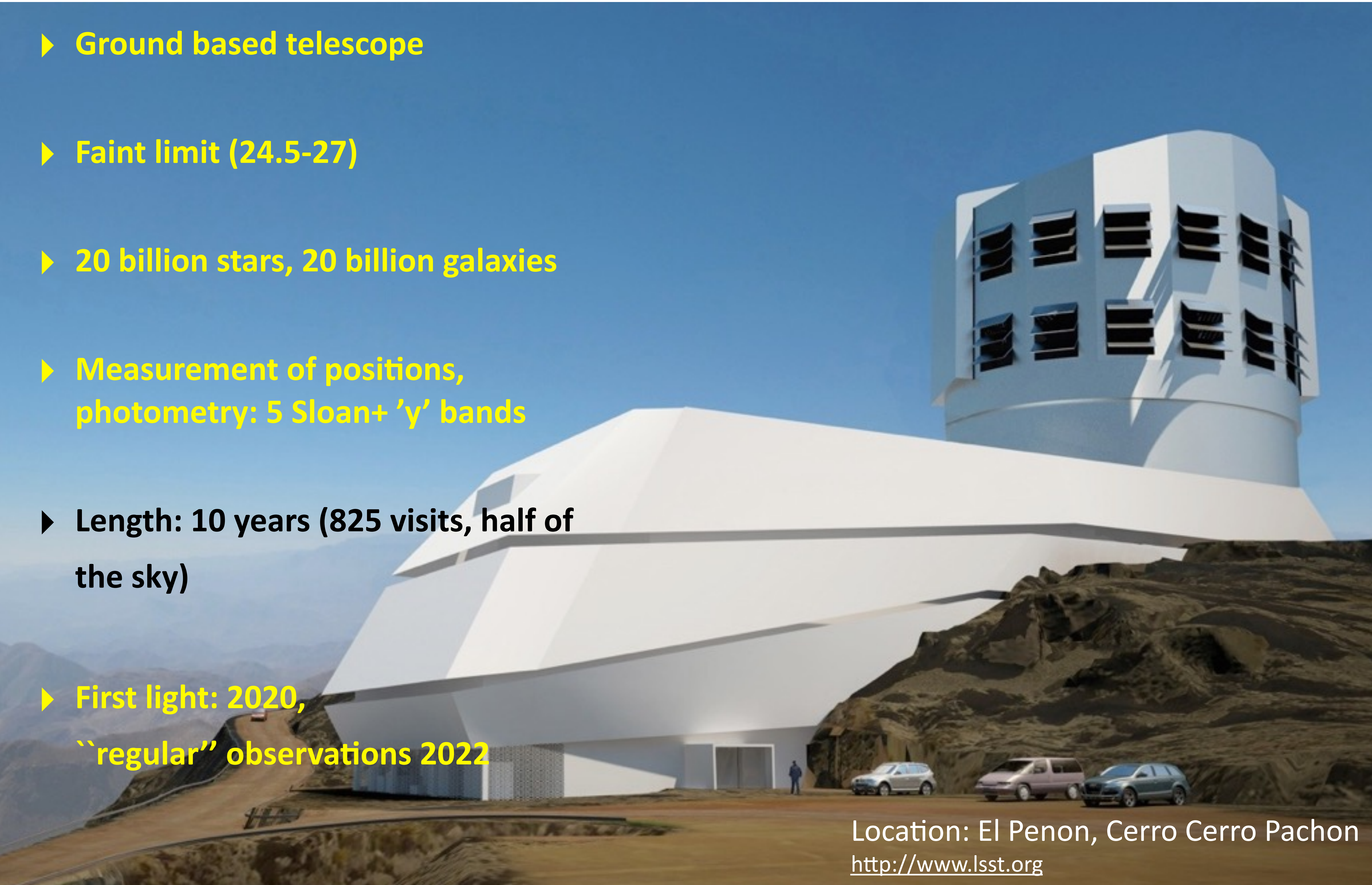


In Data Release 2: 3-5 million stars will have median radial velocities up to G_{RVS} = 12

In Data Release 3: 35 million stars will have radial velocities up to G_{RVS} = 14

Courtesy of G.Seabroke/D. Katz

LSST: Large Synoptic Survey Telescope

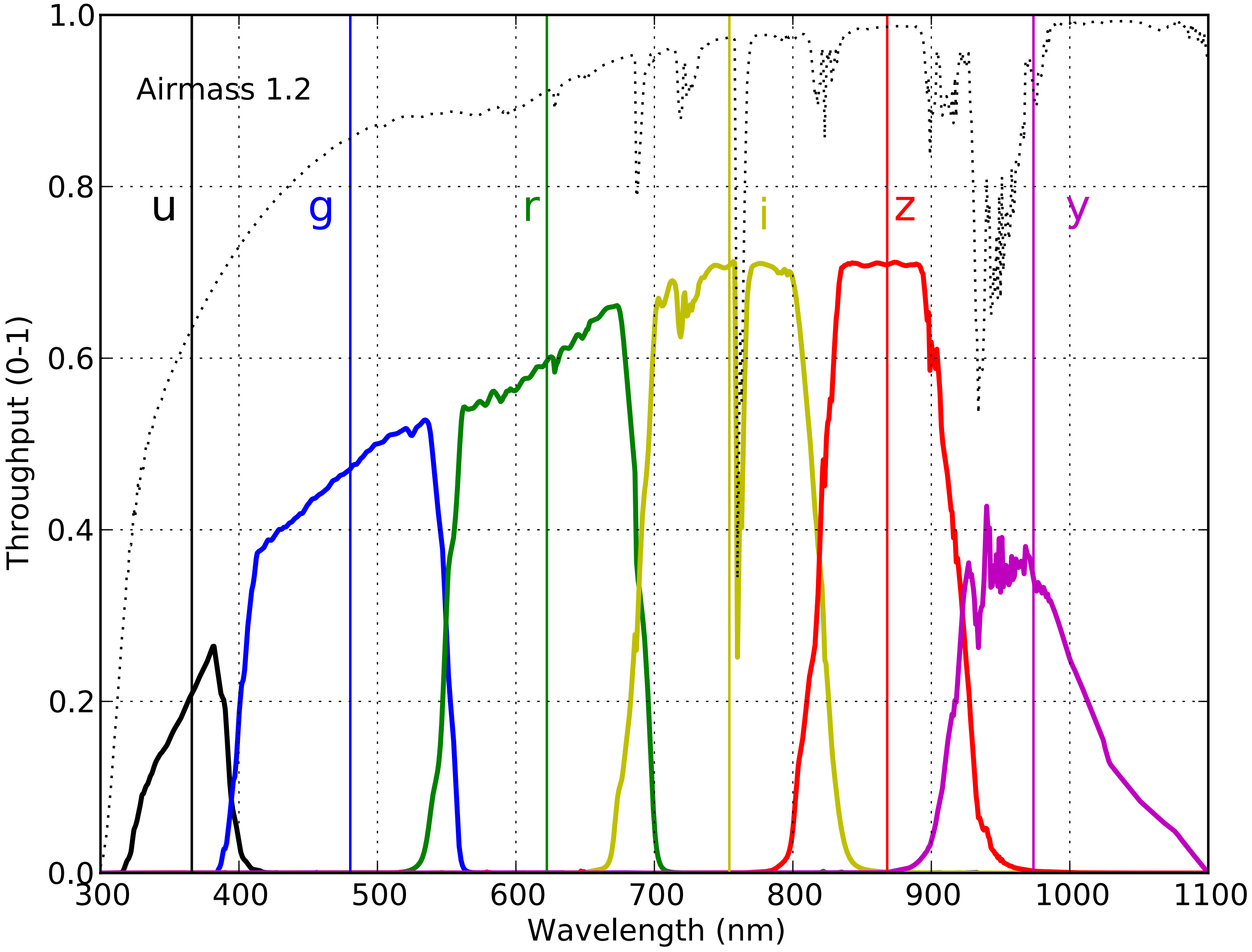


- Ground based telescope
- Faint limit (24.5-27)
- 20 billion stars, 20 billion galaxies
- Measurement of positions, photometry: 5 Sloan+ ’y’ bands
- Length: 10 years (825 visits, half of the sky)
- First light: 2020, ``regular’’ observations 2022

Location: El Penon, Cerro Cerro Pachon
http://www.lsst.org

The LSST photometry

One visit corresponds to one photometric band observation
(non-simultaneous, filter are non-sequential for a given field)



Time allocation:

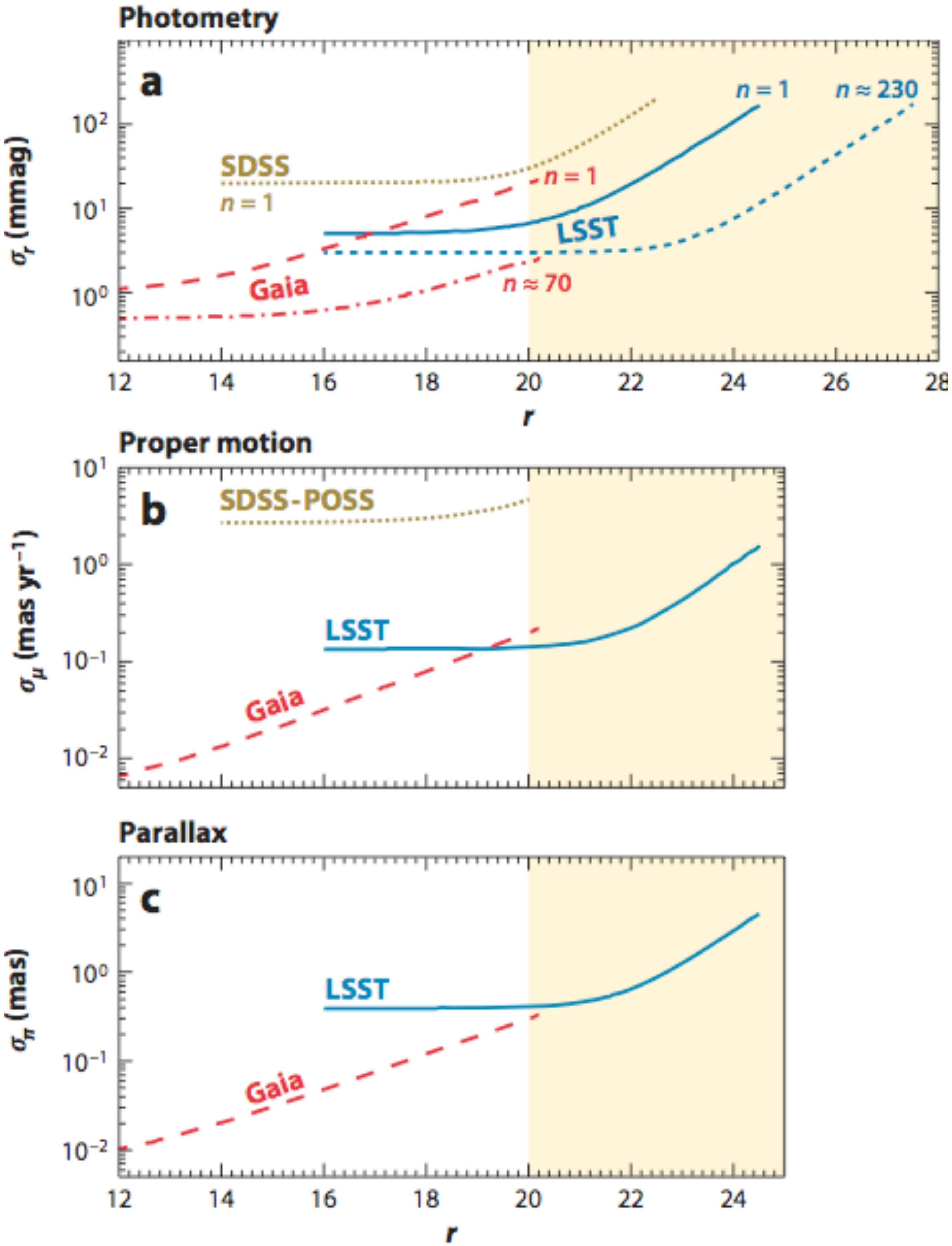
u: 8%; g: 10%

r: 22%; i: 22%

z: 19%; y: 19%

Courtesy of Z.Ivezic

LSST/Gaia precision



Ivezić, Beers, Jurić 2012, ARA&A, 50, 251

Complementarity of the two surveys: photometric, proper motion and trigonometric parallax errors are similar around r=20

LSST/Gaia Sampling

LSST:

Two exposures of 15 seconds (or maybe one of 30 seconds)

3-5 days back on the same field

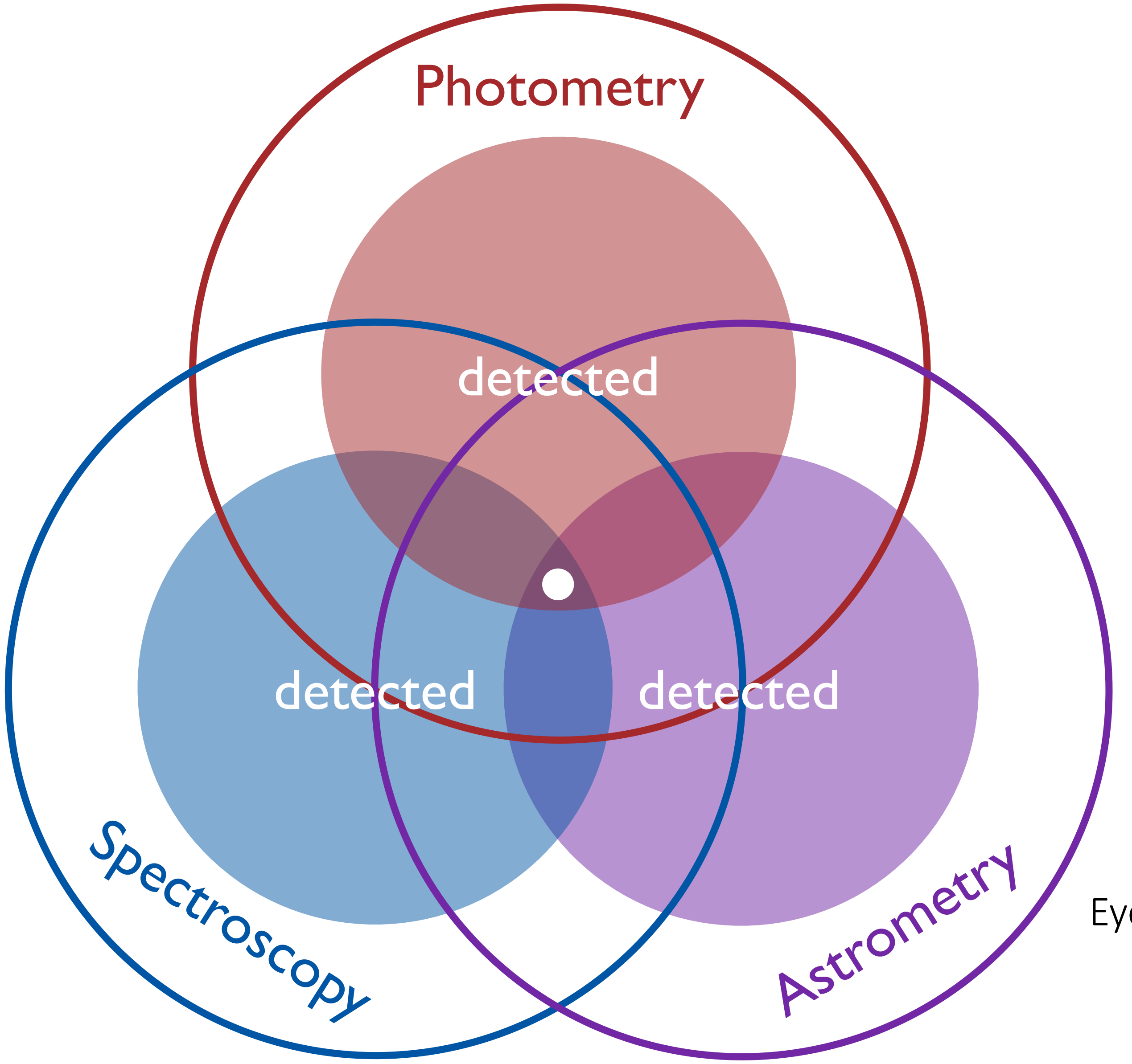
Gaia:

9 per-CCD measurements separated by 4.85 seconds

gaps: 1h46 and possibly 4h14 (usually one star will have 1 day coverage)

gaps: typically 3 weeks

Detection of binary systems



Eyer et al. 2013

There are furthermore two domains: “single/averaged measurement” or “time series”

Detection of binaries: Astrometry

Predicted number of astrometric binaries from Gaia:

30 million processed as non single star

At best:

Period, eccentricity, inclination, semi-major axes and masses

There is also the solution for Variability Induced Movers

LSST: we are waiting for estimations!

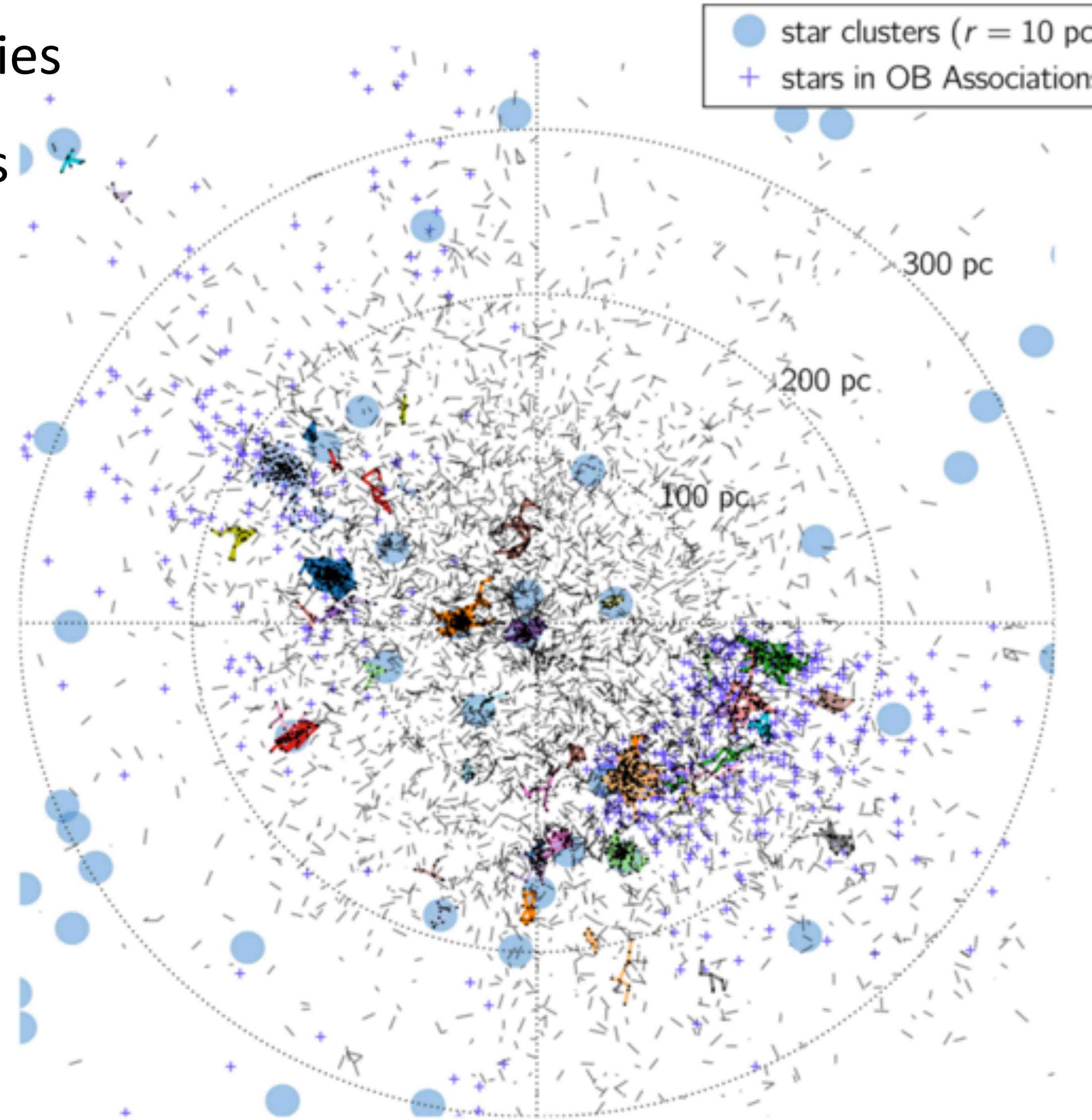
Detection of binaries: Astrometry (proper motion)

Co-moving pairs is a way to detect wide binary stars and moving groups

Using Gaia Data Release 1:

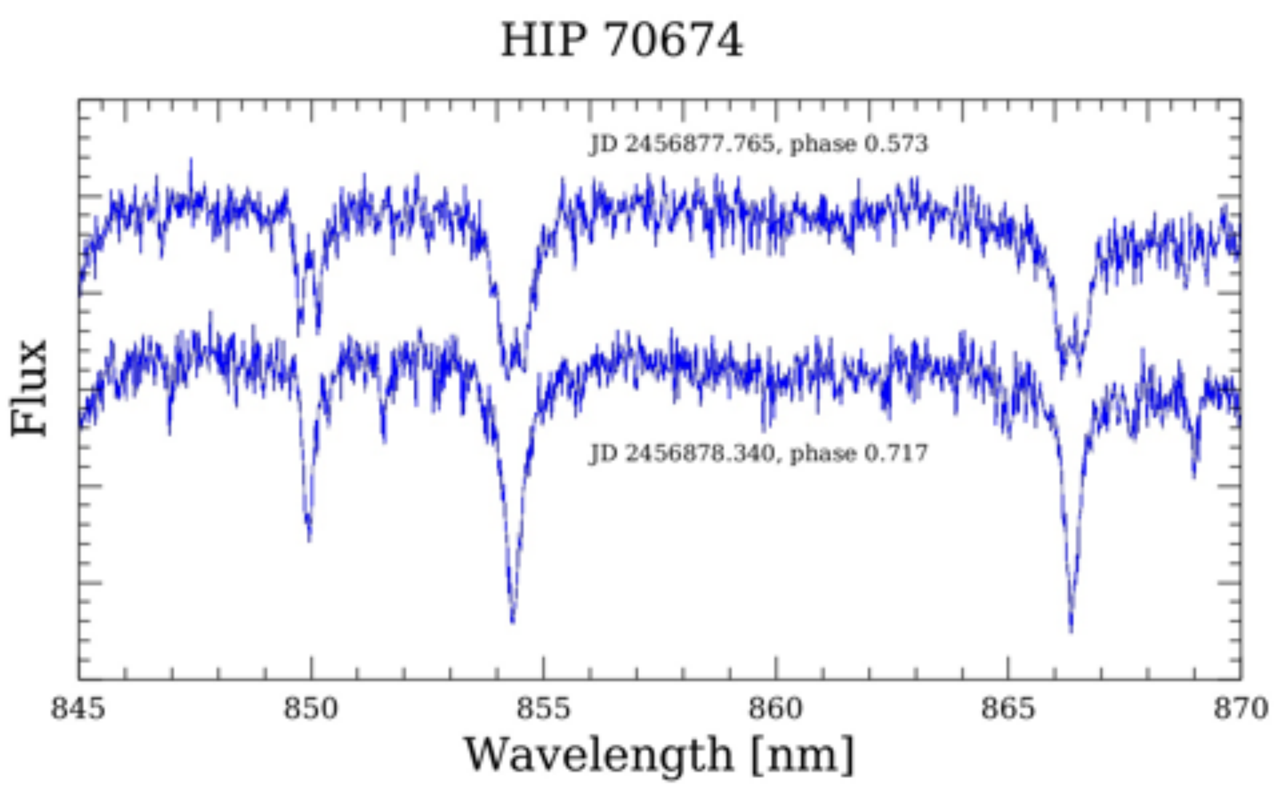
Andrews et al. 2017 found 6,196 wide binaries

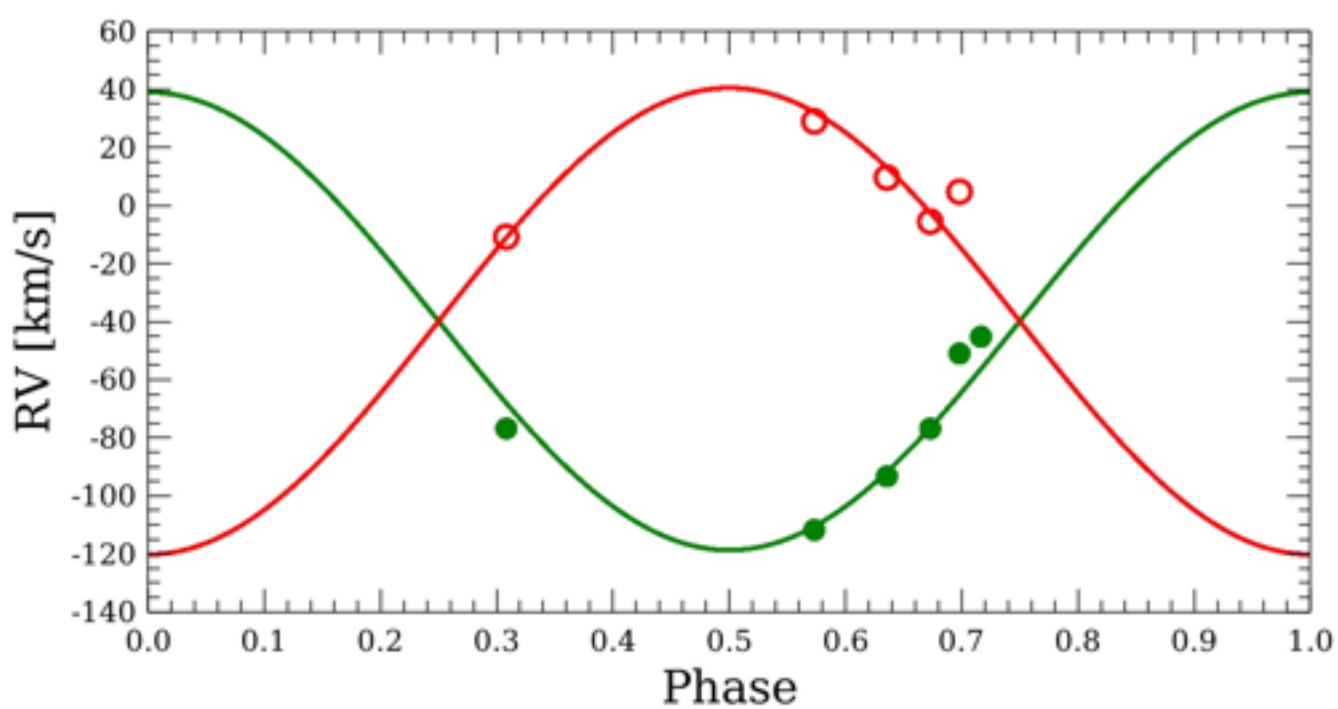
Oh et al. 2017 found 13,000 co-moving pairs



Detection of binaries: Spectroscopy

Gaia Radial Velocity Spectrometer





https://www.cosmos.esa.int/web/gaia/iow_20151009

Number of stars with radial velocities:

Predicted number of spectroscopic binaries (Eyer et al. 2013):

About 8 million

SB2: ~5 million

Detection of binaries: Spectroscopy with the Gaia-ESO survey

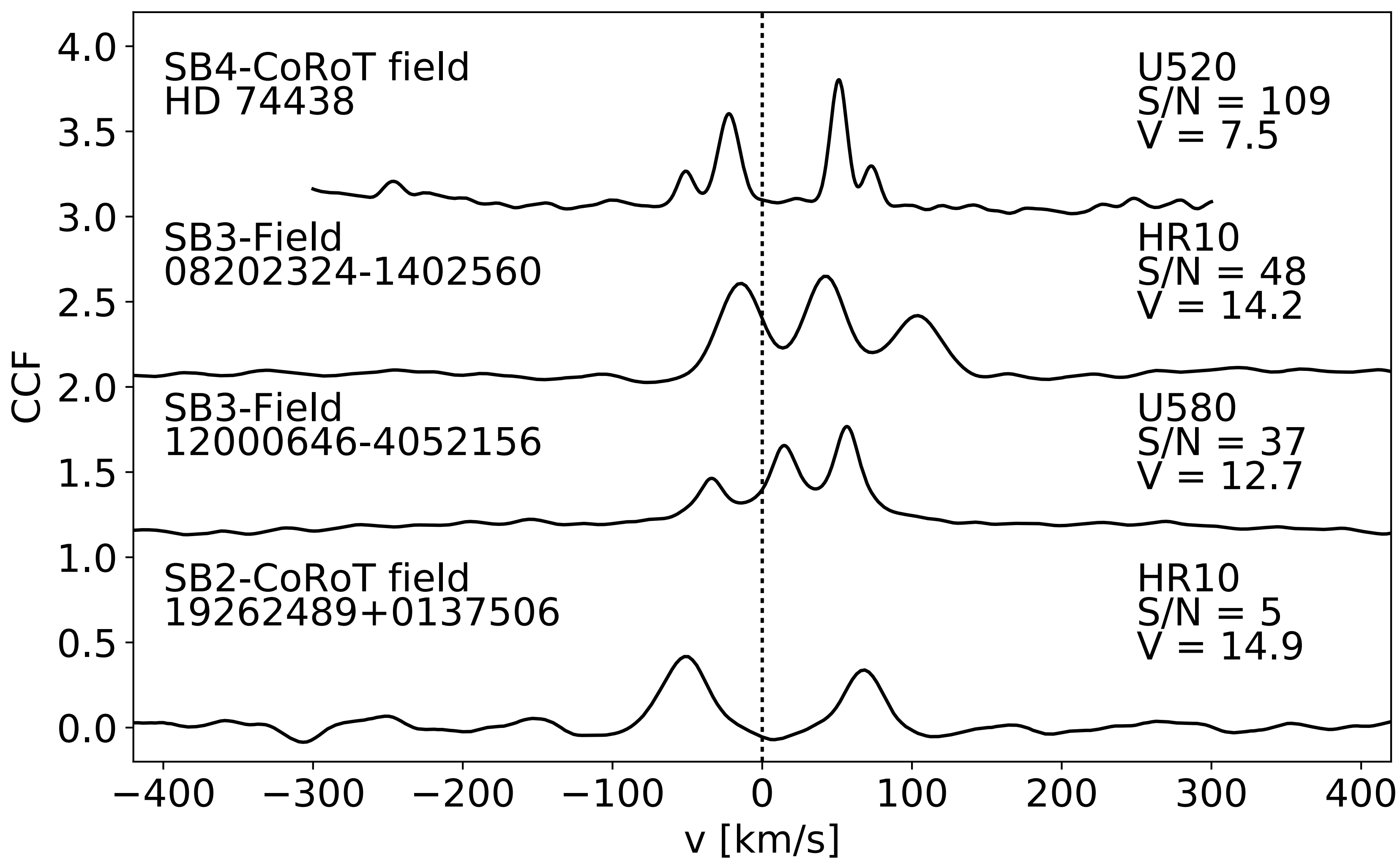
300 nights over 5 years at the VLT (UVES+ GIRAFFE)

Spectroscopy for about 100,000 stars:

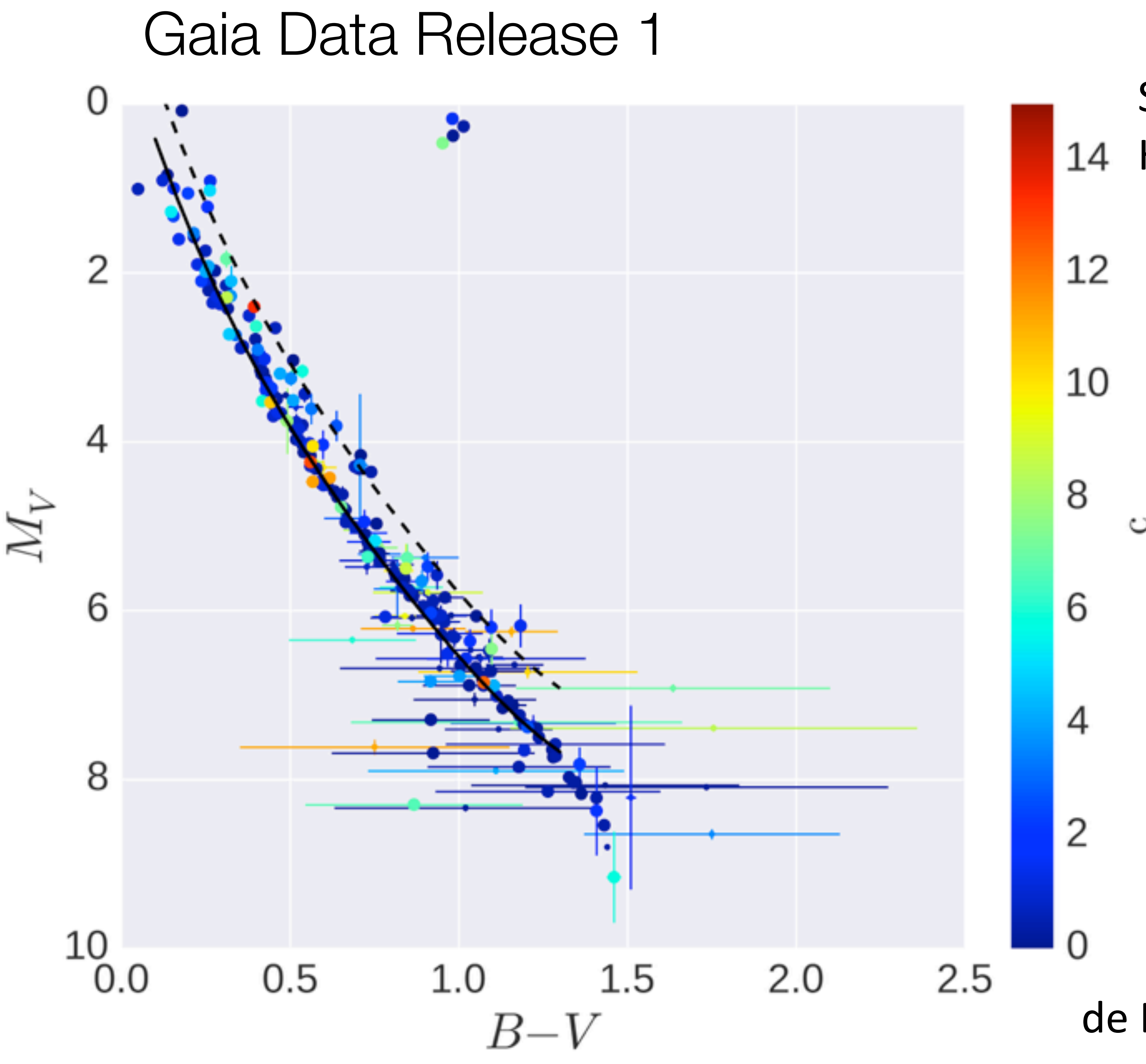
➡temperature
➡gravity
➡chemical composition

and binarity see Merle, Van Eck et al. on astro-ph yesterday!

354 SBn candidates:
342 SB2,
11 SB3 and
even one SB4



Detection of binaries: Astrometry/Photometry, the HR diagram

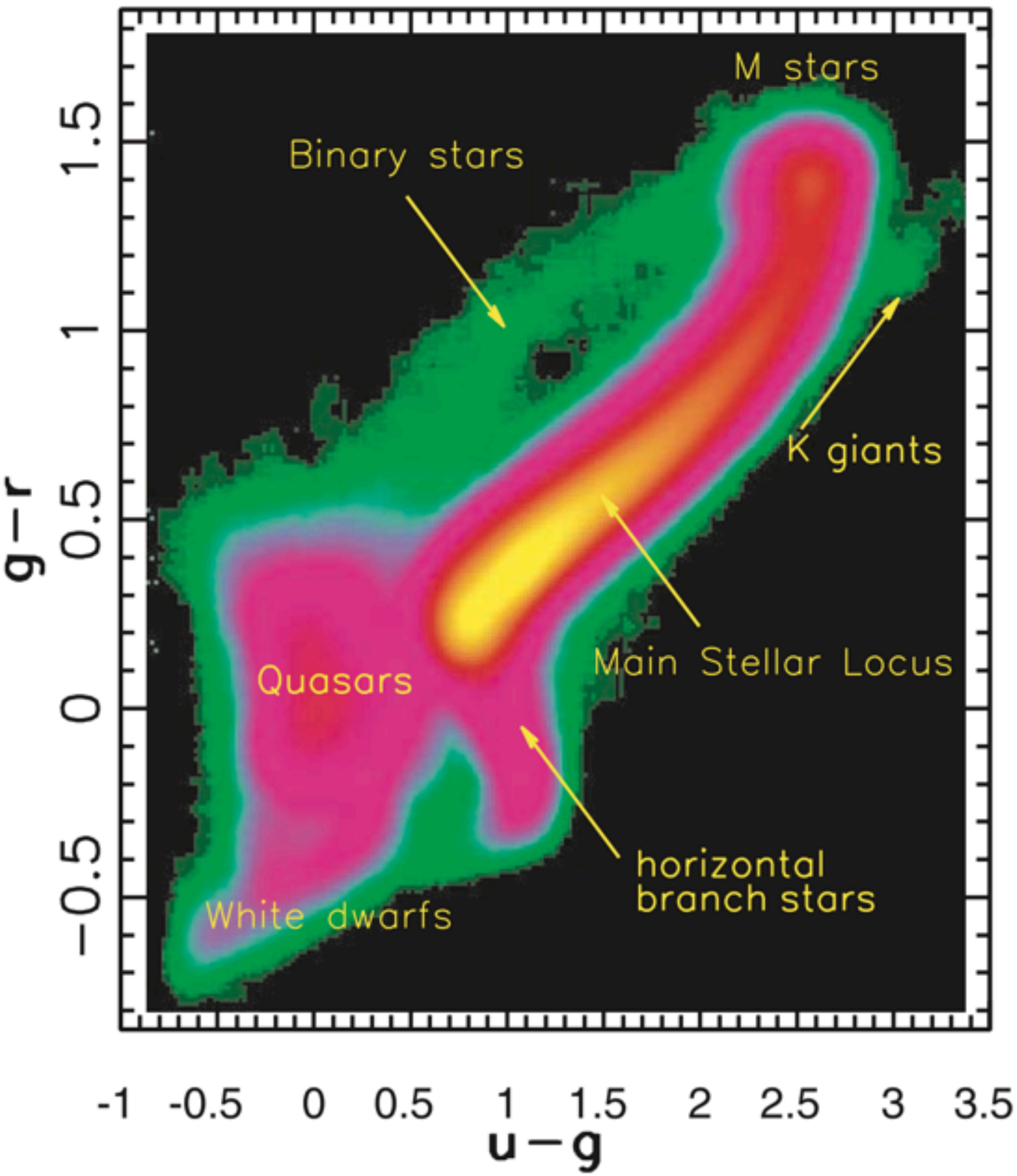


Star cluster Hyades

c: Confidence level to be a member (kinematic)

de Bruijne et al., in preparation

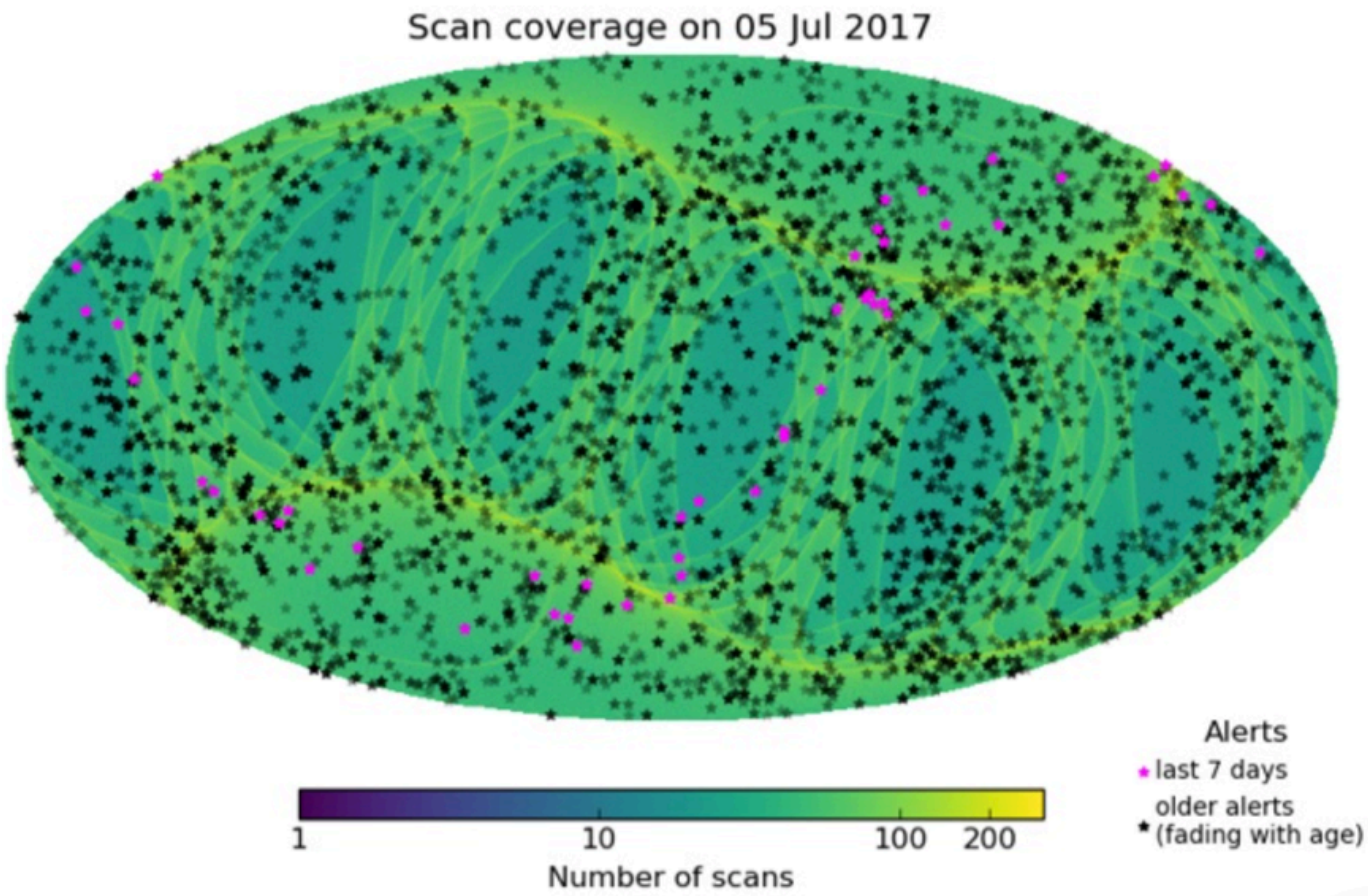
Detection of binaries: Photometry Colour-Colour diagram



SDSS data

Smolcic et al. 2004

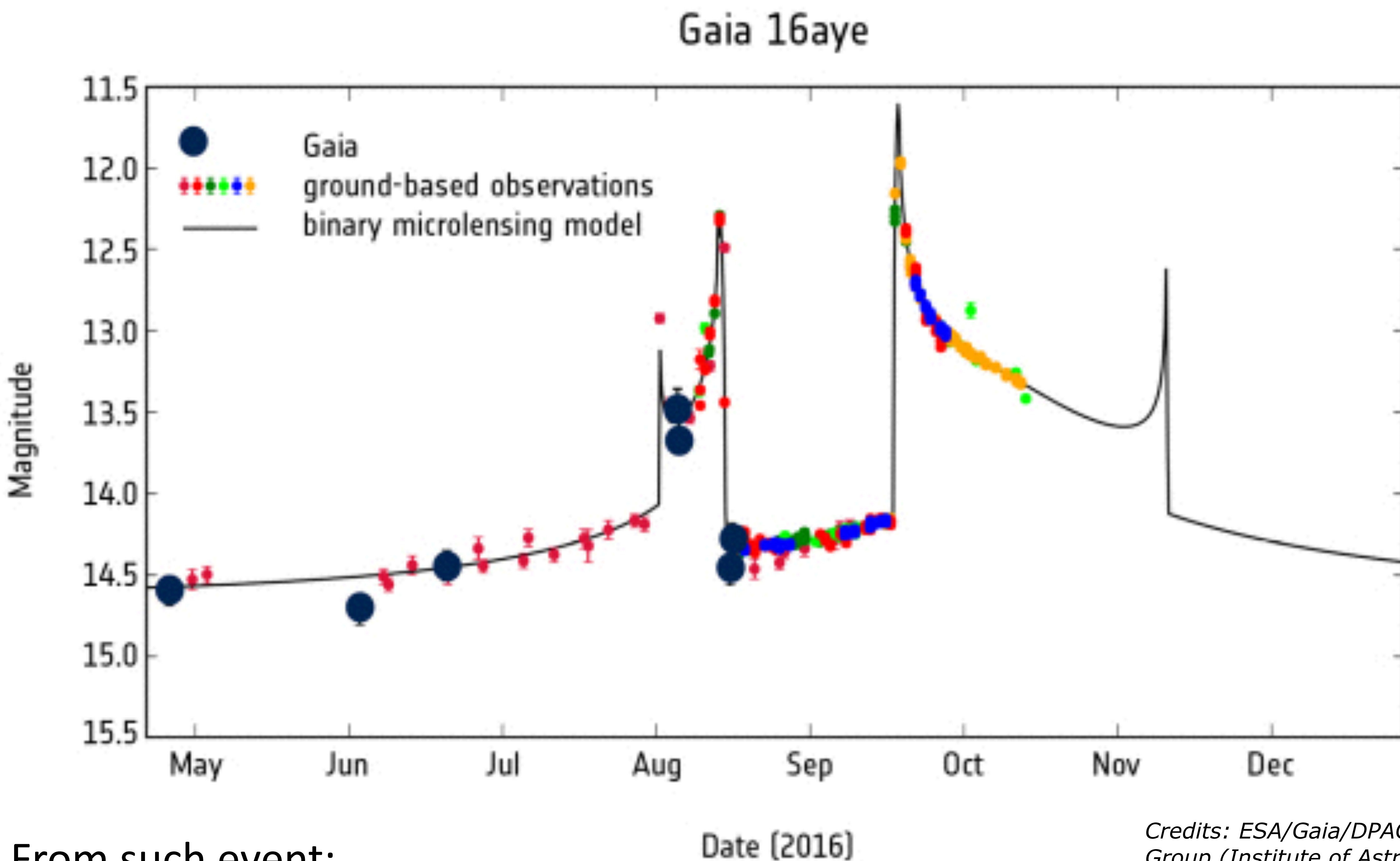
Detection of binaries: Gaia science alerts



2,945 Alerts

http://gsaweb.ast.cam.ac.uk/alerts

Detection of binaries: Photometry, Microlensing



Credits: ESA/Gaia/DPAC, Gaia Science Alerts Group (Institute of Astronomy, Cambridge), Lukasz Wyrzykowski (Warsaw)

From such event:

Mass ratio

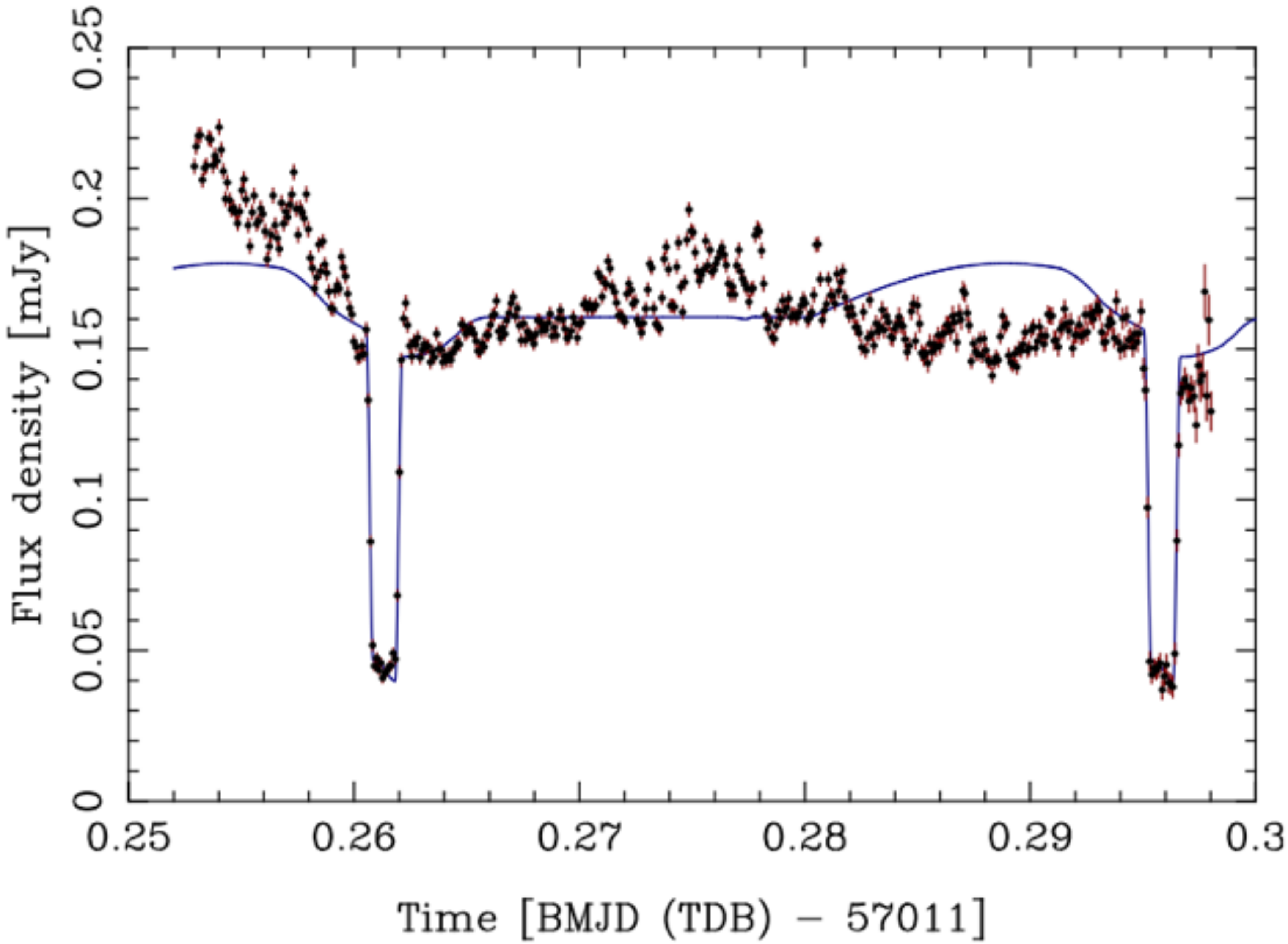
In some cases total mass, distance, inclination, orbital period

Luck with Gaia, will be "easy" for LSST (if cadence in disk and bulge is high)

Detection of binaries: Photometric time series

AM CVn star discovered!

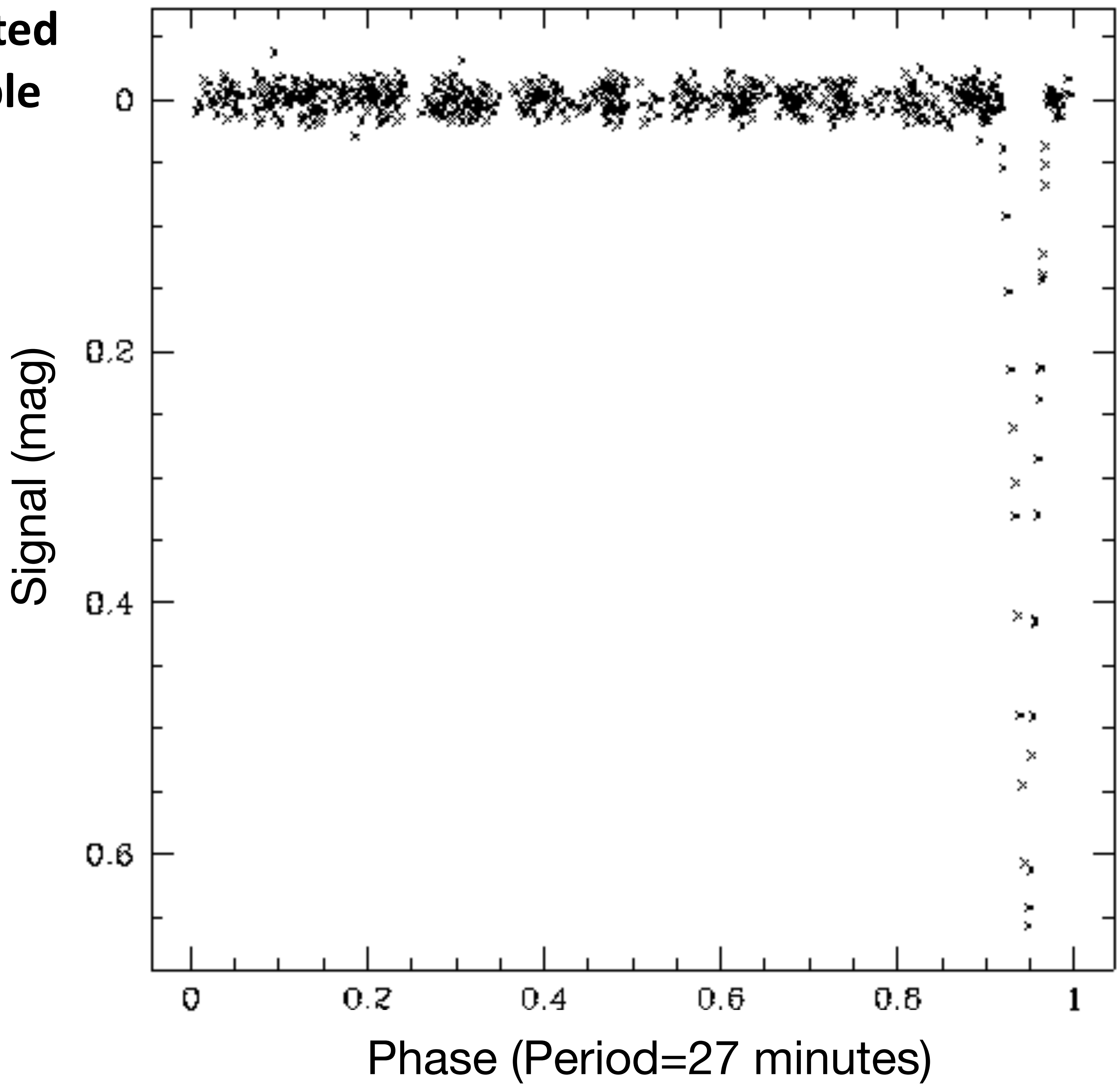
At the time, only fourth known such eclipsing system (only one with total eclipse)



Campbell et al. 2015, MNRAS 452, 1060

Detection of binaries: AM CVn with the eclipse

Simulated example



Per CCD photometry

Eyer et al. 2013

~30 are known, 200 AM CVn stars may be detected by Gaia (Nelemans 2013)

Detection of binaries: special eclipsing binaries
Double White Dwarf

Study by Korol et al. 2017

Ultra compact detached white dwarfs

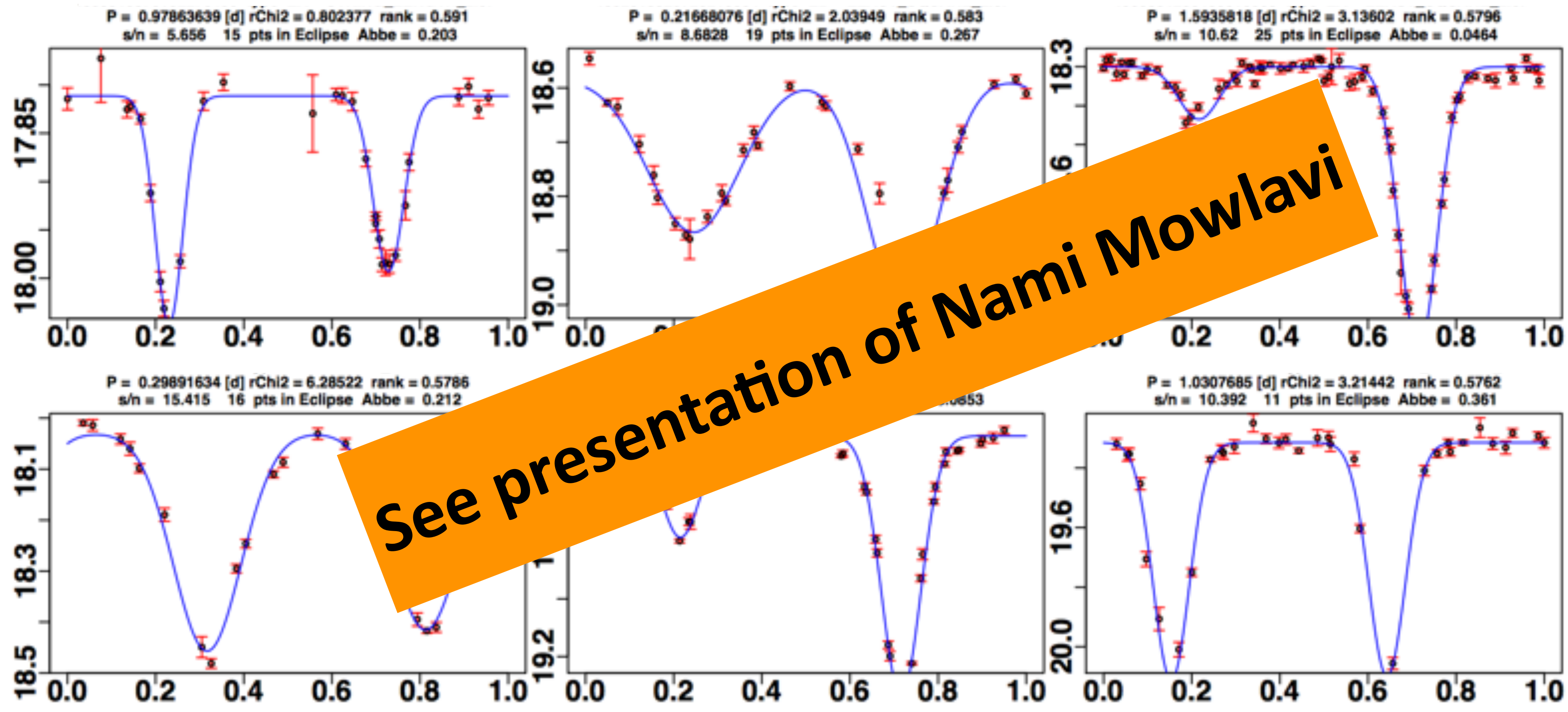
	Gaia	LSST	LISA
Gaia	189	93	13
LSST	93	1100	50
LISA	13	50	24508

(a) $\alpha\alpha$ CE model

	Gaia	LSST	LISA
Gaia	246	155	24
LSST	155	1457	73
LISA	24	73	25735

(b) $\gamma\alpha$ CE model

Detection of binaries: eclipsing binaries

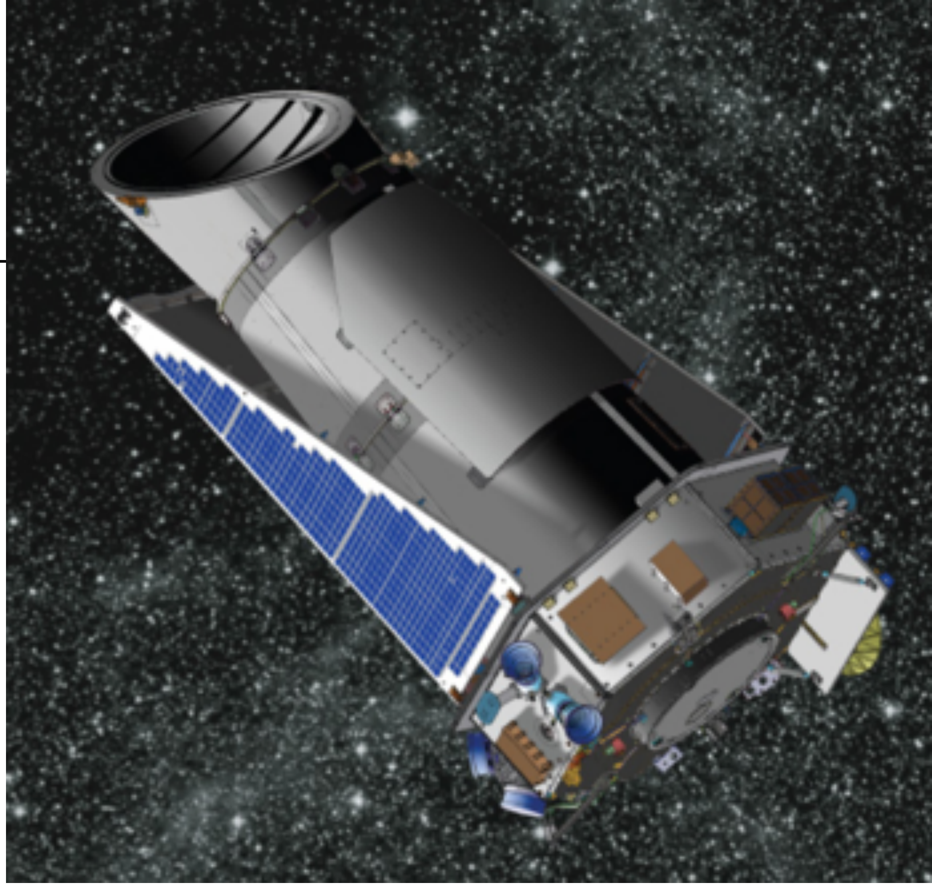


Gaia: 4 million eclipsing binaries (Eyer et al. 2013), estimates 1/2 to 7 million

LSST: 24 million eclipsing binaries (Prša et al. 2011)

Within Gaia, CU4 (Coordinator D.Pourbaix@ULB) is performing a detailed physical modelling of the eclipsing binaries

Focus on Eclipsing binaries of Kepler



Kepler is ``game-changer”,
unprecedented sampling/photometric precision

For eclipsing binaries:

Kepler is complete to 10 days for the selected sample of F, G, K stars (Kirk et al 2016)

One surprise: 18 % are not regular (with eclipses changing/disappearing)

Kepler allows to study performance for other projects

70% should be detected by Gaia (Kochoska et al. 2017)

70% should be detected by LSST - r band detection - (Wells et al. 2017)

80% when other bands are taken into account (Prša private com.)

Binary stars statistics

Derive many different statistics

- Number of stars

- Properties of binaries as function of star parameters (mass, mass ratios, age-range)

- Orbital properties

-Properties of stars

e.g. from DR1 mass-ratio of spectroscopic binaries on the main sequence
see Boffin and Pourbaix (Poster 12)

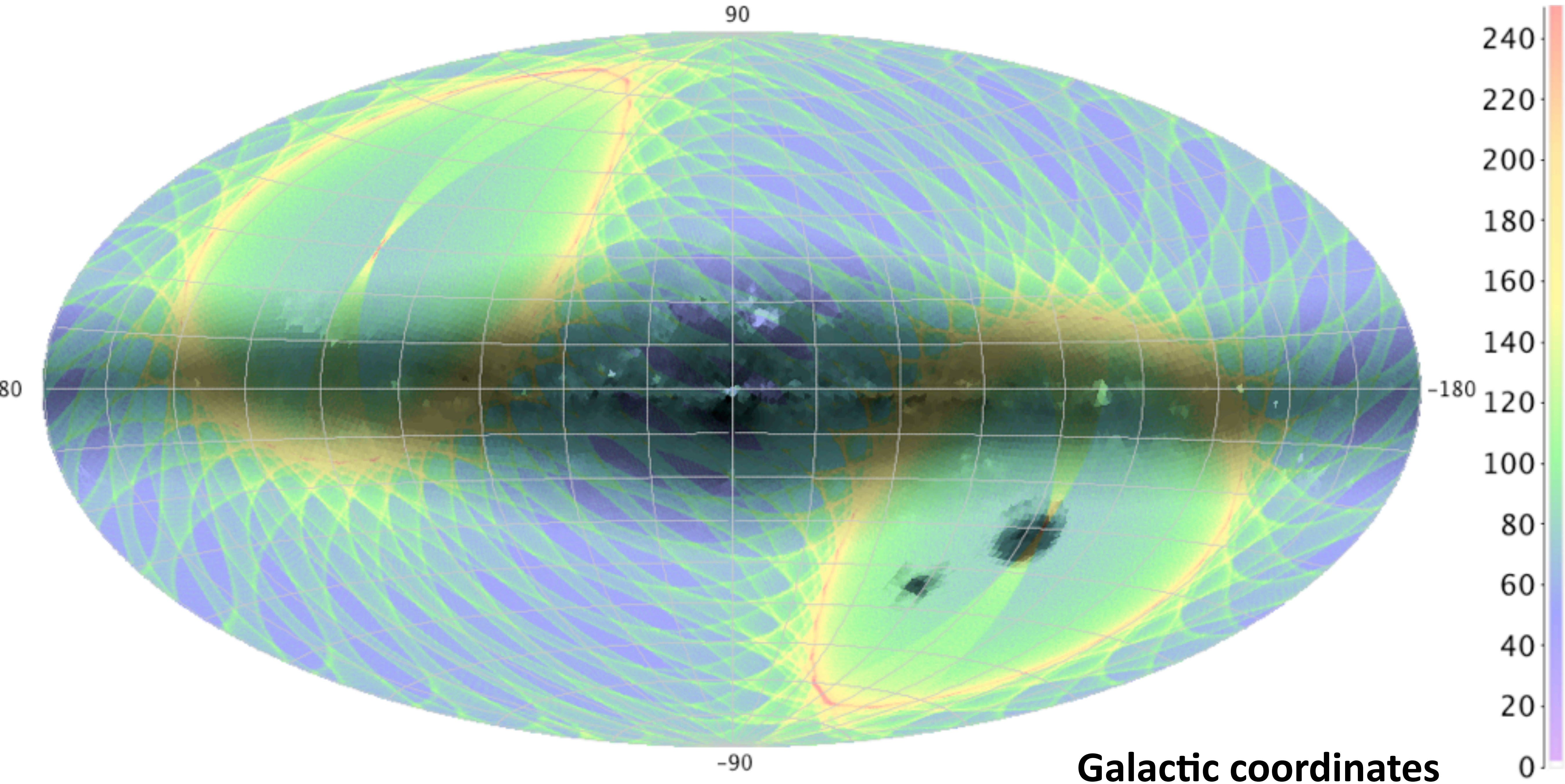
Warning

Understanding transfer function

Dealing correctly with parallaxes

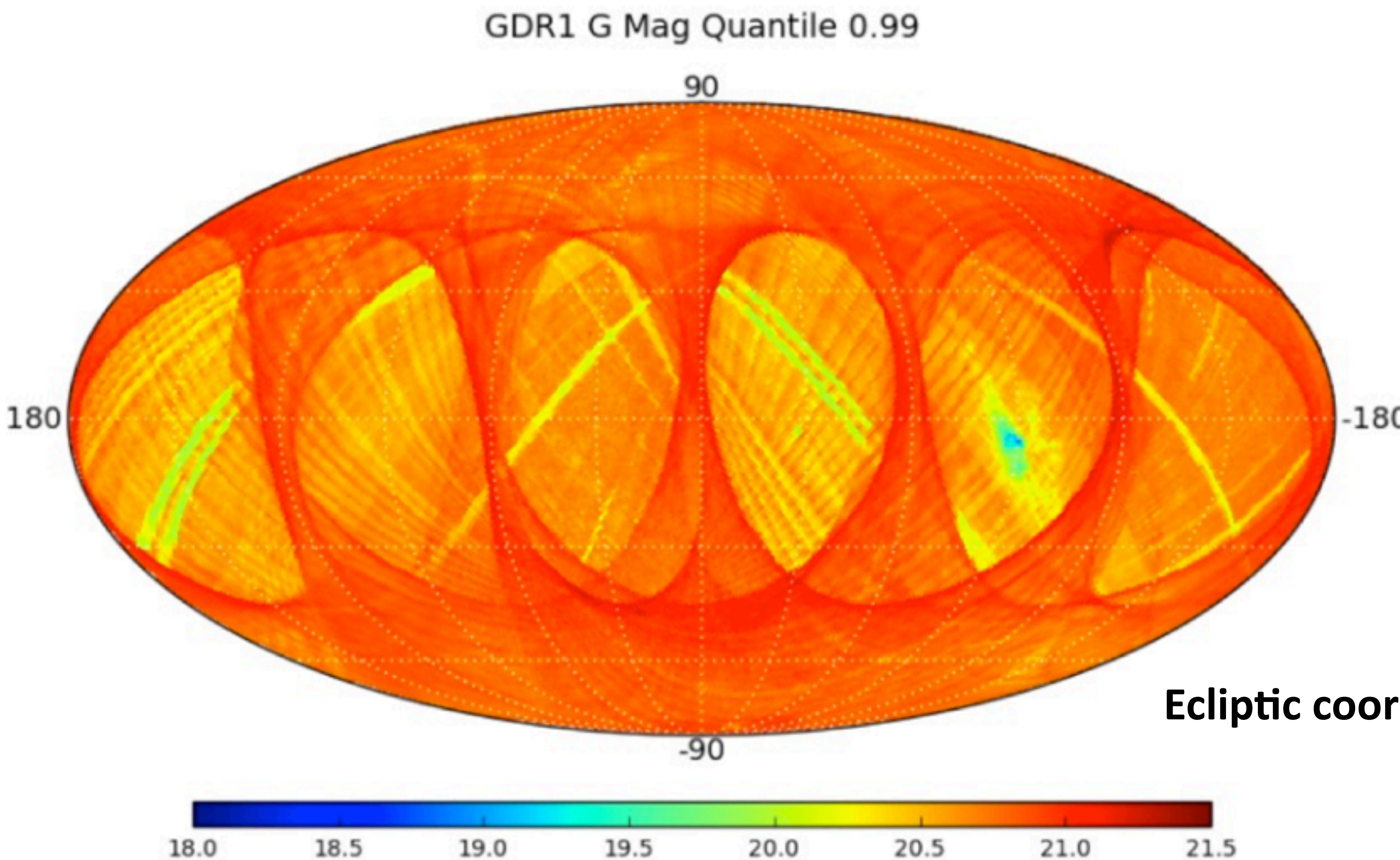
Parameter degeneracies (e.g. temperature/extinction)

Predicted coverage of 5-year scanning law of Gaia



Galactic coordinates

Example of Gaia Data Release 1



Ecliptic coordinates

Less difficulties with LSST, images are saved

The Gaia Data Releases

Proposal to extend Gaia by 5 years!

spacecraft operations start

nominal mission end

2014	2015	2016	2017	2018	2019	2020	2021	2022

Release 1:
- **α and δ, mean G-ma**
- **TGAS: Tycho-G**
- **3 194 ... tars**

14 September 2016
Accomplished! ✓

Release 2 (April 2018), 22 months solution:
- **5-parameter astrometric solutions (parallax)**
- **Integrated BP/RP for all sources**
- **Astrophysical parameters for G < 17**
- **Median Radial Velocity for G < 12**
- **Epoch astrometry for > 10,000 asteroids**
- **Selected sample of variable stars (though no eclipsing binaries)**

Release 3:
- Source classification and astrophysical parameters
- BP, RP, RVS spectra with astrophysical parameters
- Non single stars: astrometric, eclipsing binaries
- Updated and extended variable star catalogue
- Updated and extended solar system object

Final release for the Nominal mission:
- Full astrometric, photometric, radial velocity catalogue
- All variable-star and non-single star
- Source classifications (probabilities) plus multiple astrophysical parameters (derived from BP/RP, RVS, and astrometry) for stars, unresolved binaries, galaxies, and quasars
- An exo-planet list
- All epoch and transit data for all sources, including all BP/RP/RVS spectra

LSST From the User's Perspective:
A Data Stream, a Database, and a (small) Cloud

Nightly Alert Stream

- A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks within 60 seconds of observation.
- A catalog of orbits for ~6 million bodies in the Solar System.

Level 1

Yearly Data Releases

- A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion single-epoch detections ("sources"), and ~30 trillion forced sources, produced annually, accessible through online databases.
- Deep co-added images.

Level 2

Community Services

- Services and computing resources at the Data Access Centers to enable user-specified custom processing and analysis.
- Software and APIs enabling development of analysis codes.

Level 3

LSST Data Products: see https://www.lsst.org/about/dm/data-products

Courtesy of Z.Ivezic

Conclusions

Undoubtedly Gaia and LSST will have a tremendous impact in astrophysics

Binary star research will be one of the very impacted topic

Get informed about the data products and prepare yourself to analyse data


Thank you for your attention!

Back to basics: Spectroscopic Binaries

	Orbital parameters	"Stellar parameters"
• SB1	$a_1 \sin(i)$ Period P Eccentricity e	$f(m) = \frac{(m_2 sin(i))^3}{(m_1 + m_2)^2}$
• SB2	$a_1 \sin(i)$ $a_2 \sin(i)$ Period P Eccentricity e	$q = m_2/m_1$ $m_1 \sin^3(i)$ $m_2 \sin^3(i)$

Back to basics: Astrometric Binaries (absolute orbits)

	Orbital parameters	Stellar parameters
• One visible component	Eccentricity *e* Period *P* Inclination *i*	
with parallax	a_1	$m_2^3/(m_1+m_2)^2$
• Two visible components	Eccentricity *e* Period *P* Inclination *i*	$q = m_2/m_1$
with parallax	a_1 a_2	m_1 m_2

Back to basics: Photometric Binaries

- Colour

binary sequence, in colour magnitude diagram (mostly in clusters and twin companions!)

- Ellipsoidal variations (e.g. degenerate companion)

Period P

Inclination i (?)

- Eclipses

Back to basics: Photometric binaries: Eclipsing Binaries

	Orbital parameters	Stellar parameters
• Partial eclipse	Period *P* Inclination *i* $e\cos(\omega)$ $e\sin(\omega)$ (approx.)	mass ratio (approx.) $(R_1 + R_2)/a$
• Total eclipse	Period *P* Inclination *i* $e\cos(\omega)$ $e\sin(\omega)$ (approx.)	Ratio of radii Luminosity ratio $(R_1 + R_2)/a$
• With RVS		
• SB1	same as above	$m_2^3/(m_1 + m_2)^2$
• SB2	"Everything"	