Stellar variability - I

Laurent Eyer
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Ile d'Oléron, France

Thursday, Octobre 5, 2023

09h00-10h30 (CET)

Plan

An other high level introduction on Gaia

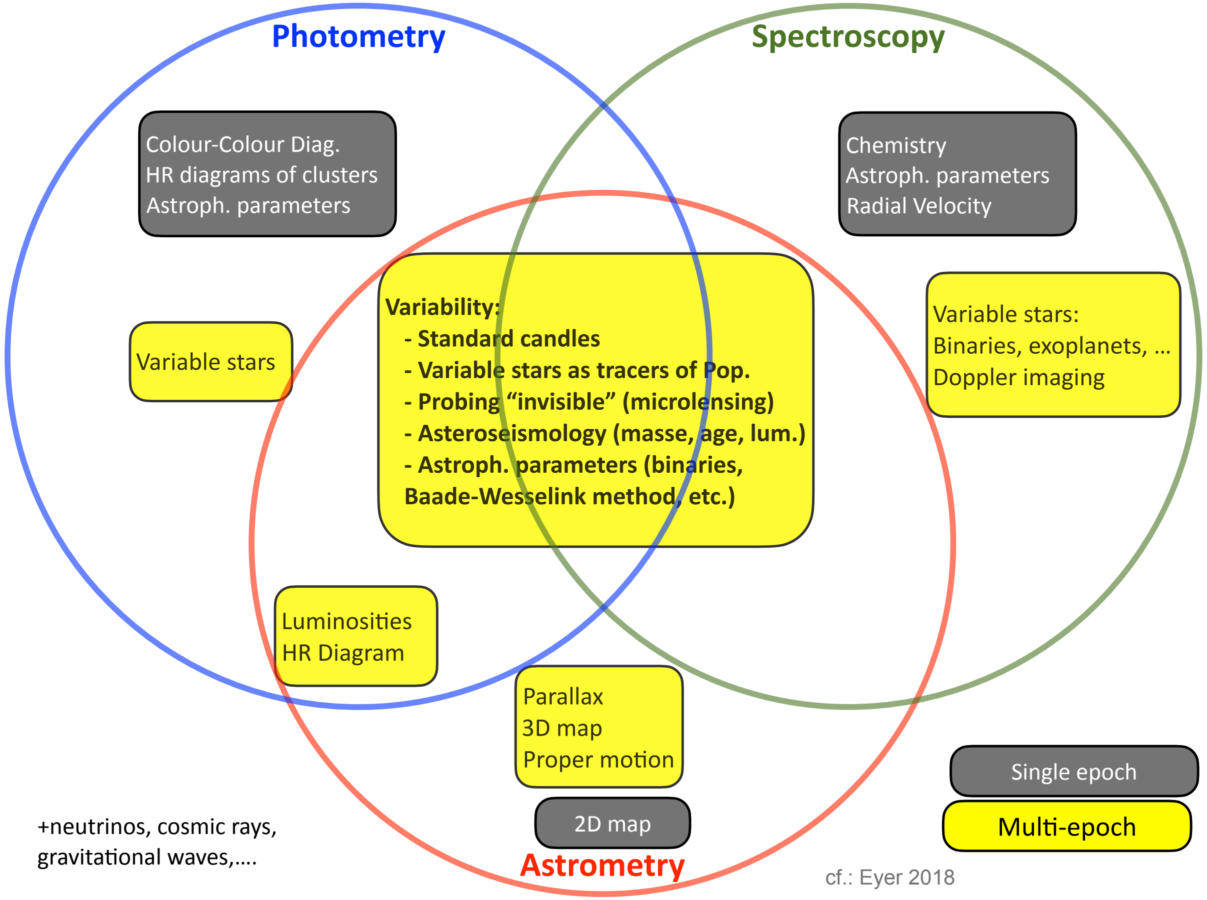
Variability in celestial objects

Variability analysis by the Gaia consortium

Gaia Citizen Science project

An other high level introduction on Gaia

Introduction: Observations in Astronomy



+neutrinos, cosmic rays,
gravitational waves,….

Booming era of optical surveys

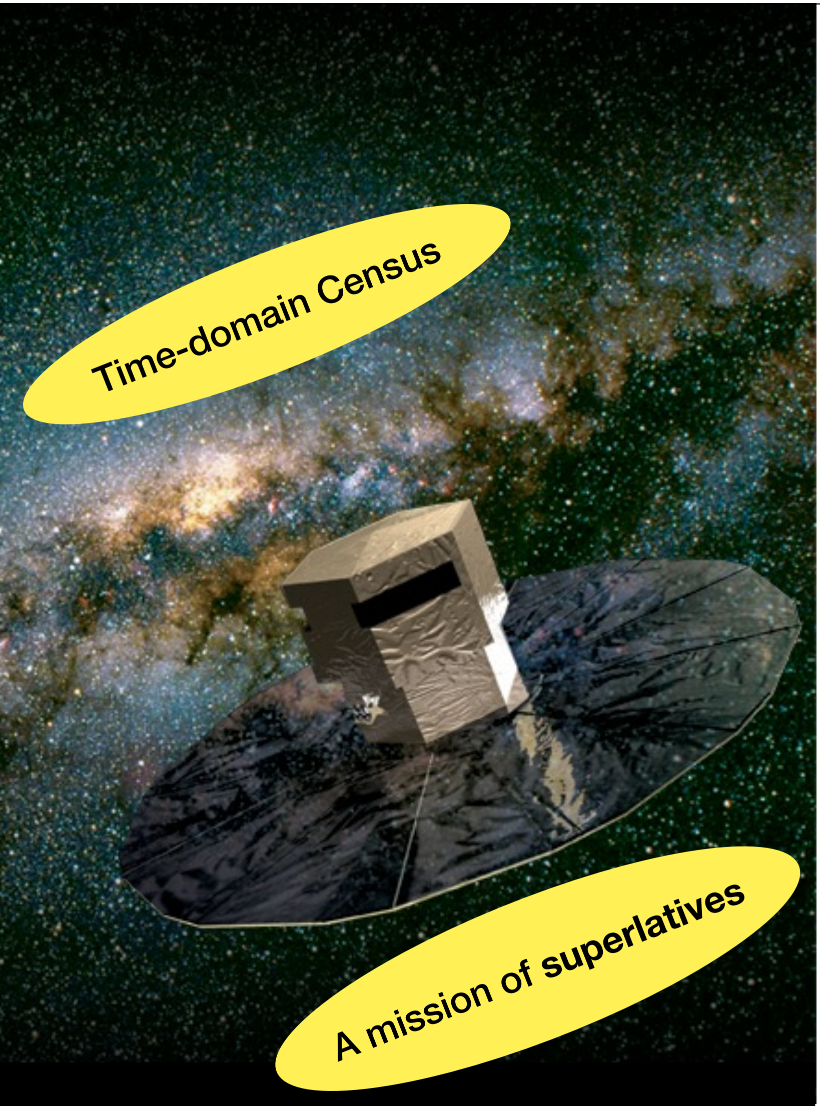
Ground based

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

Space

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

The Gaia mission: a systematic multi-epoch survey

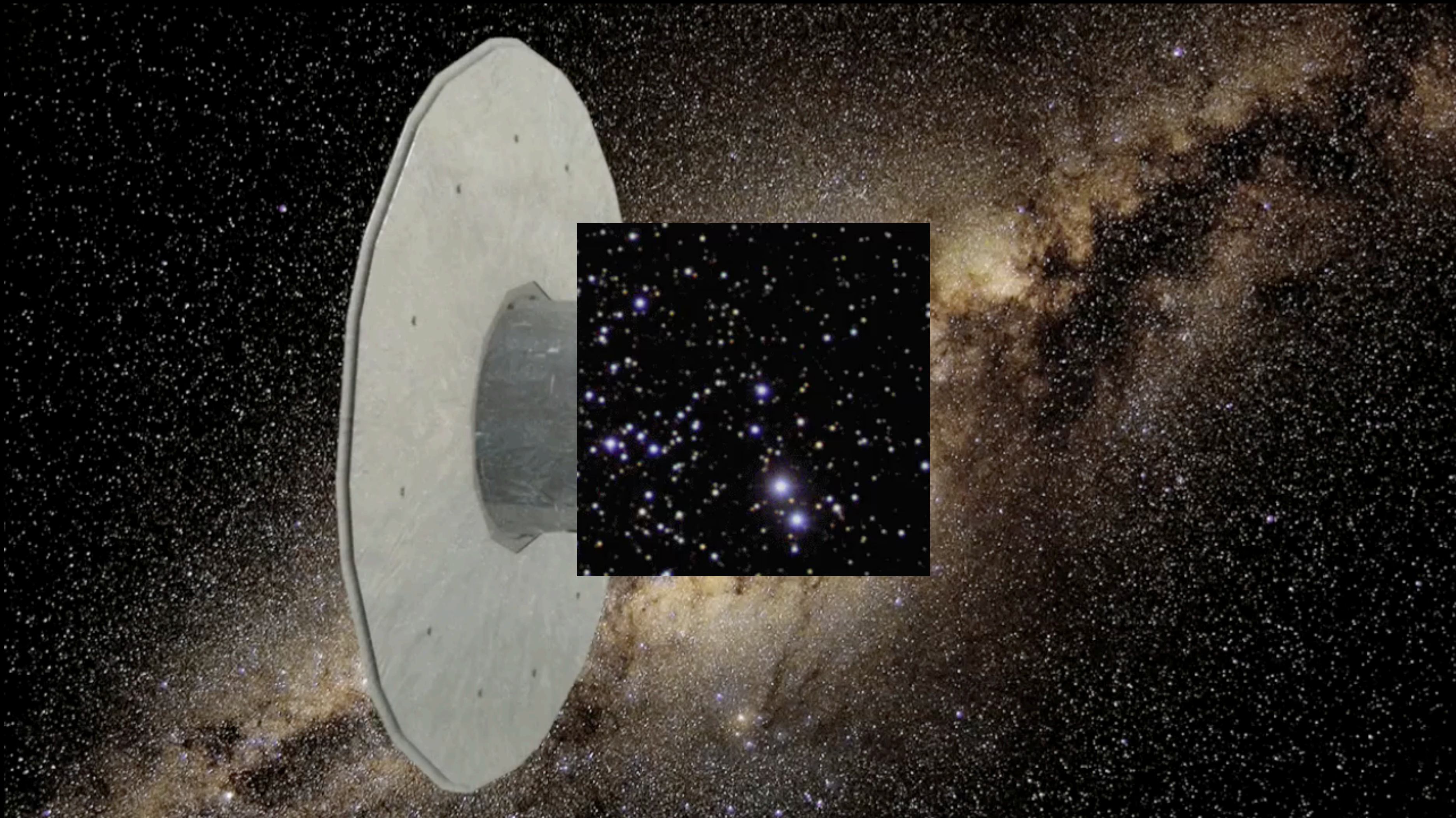


- A “cornerstone” mission of the European Space Agency
- Observations of all the objects brighter than G=20.7 (> **2 billion sources**)
- Measurements of:
  - positions (astrometry)
  - brightness, colours (spectro-photometry)
  - radial velocities (spectroscopy) > 100 million stars
- Launch (Soyuz rocket): December 19 2013
- End of data acquisition: 2025 (no ore cold gas)
- For a 10-year mission, on average
  - 140 times in each of the 9 CCDs (band G), and each BP and RP CCD
  - 80 times in the Radial Velocities Spectrometer Instrument
- The data is public through the “Data Releases”
  - DR4 & DR5: 2025 & 2030 respectively

Gaia spacecraft

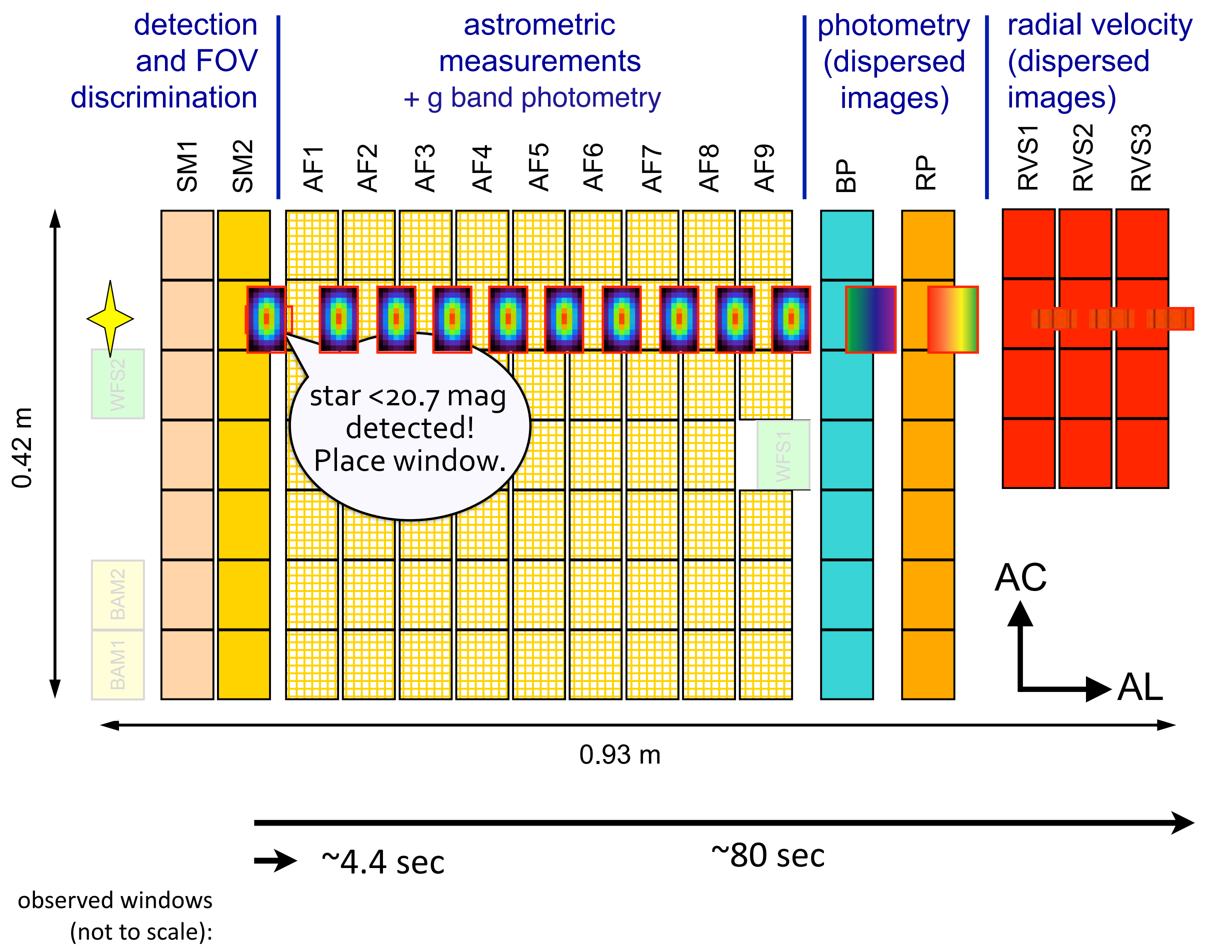
EADS/Astrium —> Airbus

Gaia continuously scans the sky (rotation period of 6 hours)



Gaia Focal plane

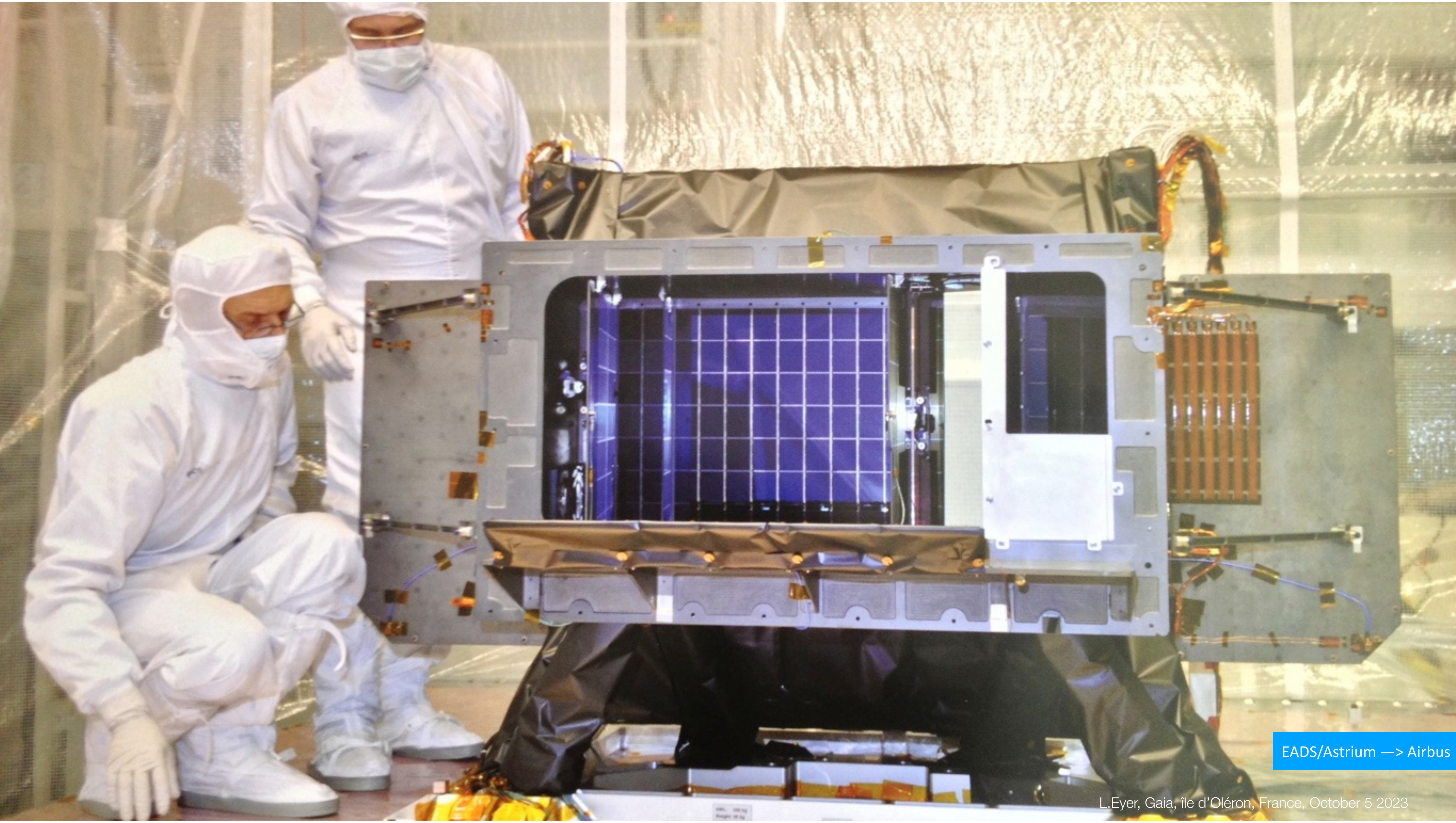
106 CCDs: 938 million pixels (still? the largest CCD camera in Space)



Such passage (Field-of-View transit)
should be linked
to which source?

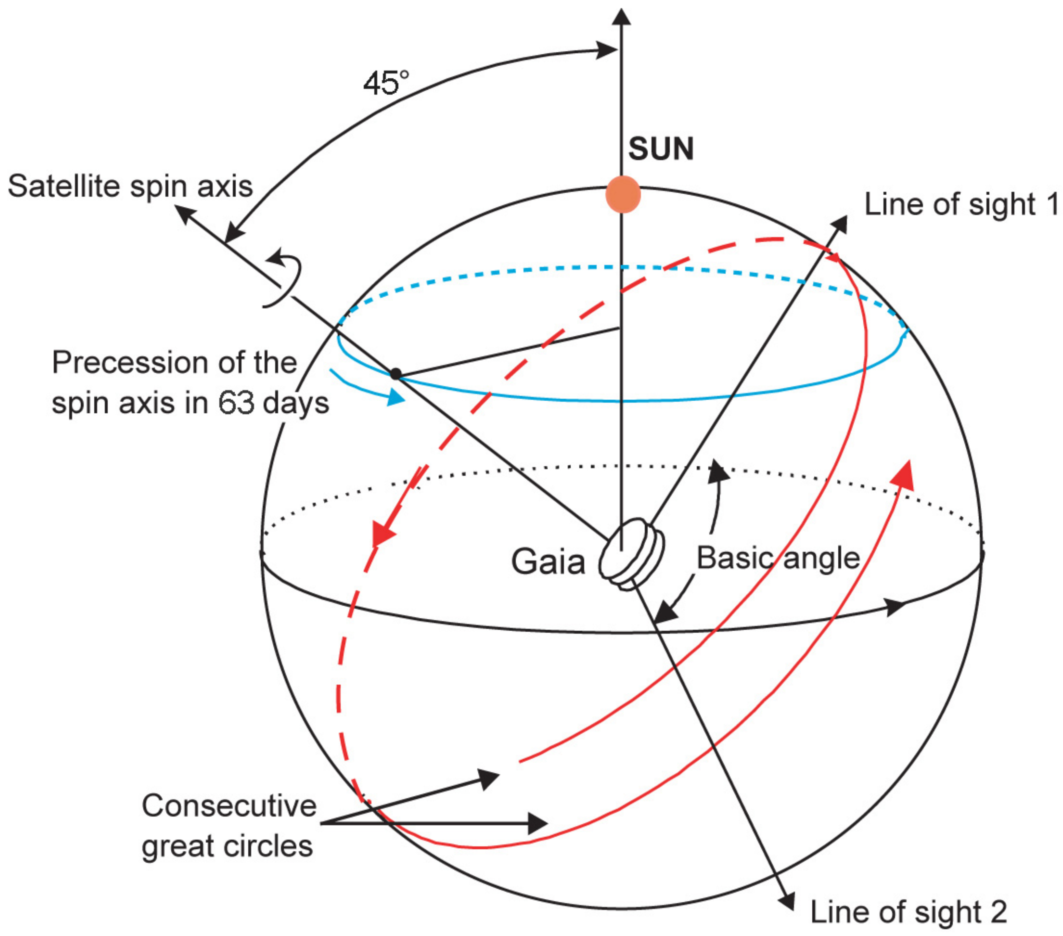
Courtesy of B.Holl

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

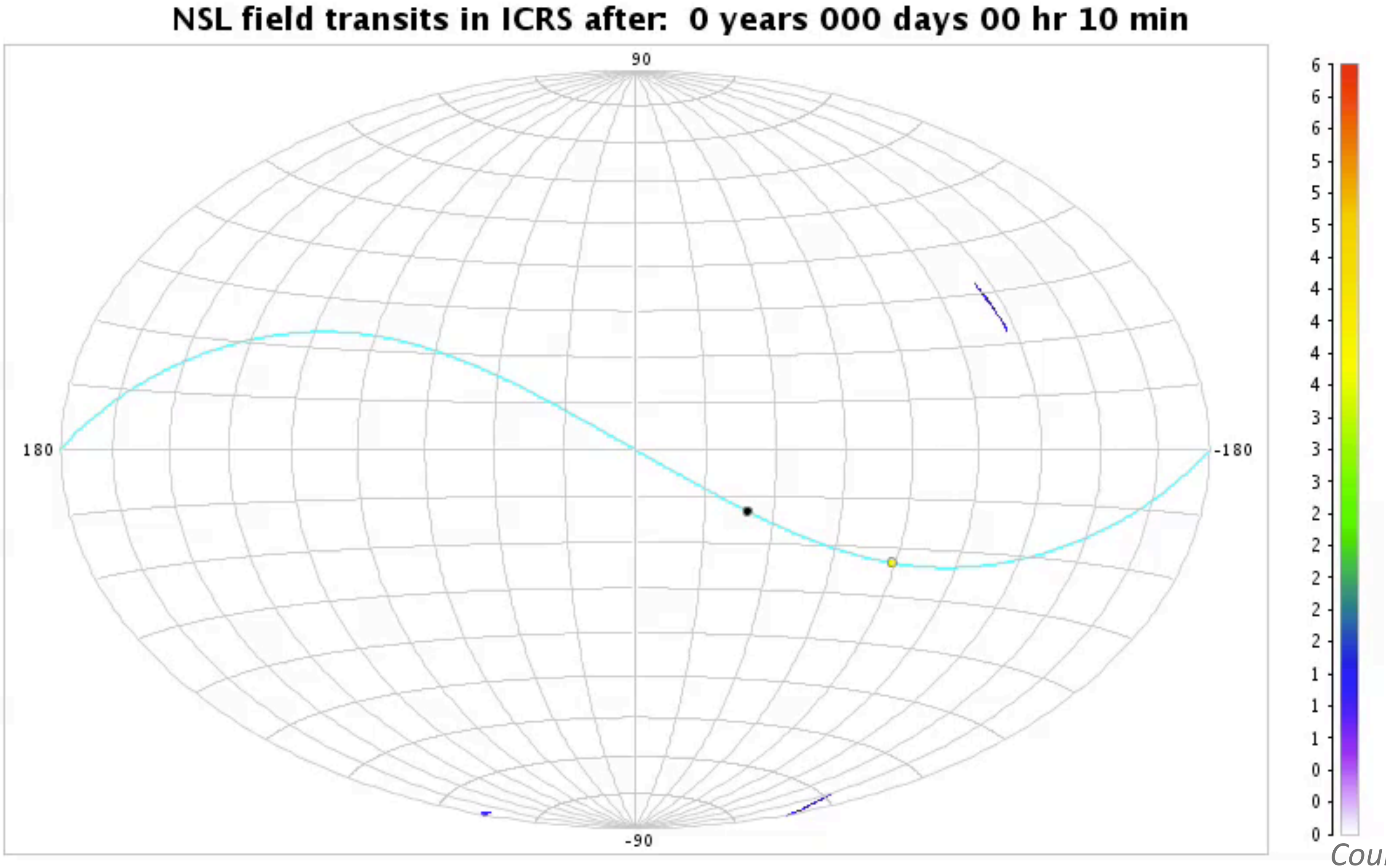

EADS/Astrium —> Airbus

The Gaia mission sampling properties

- Rotation of the satellite 6 hours, precession in 63 days
- From Line of sight “1” to “2”: 1h46
- From Line of sight “2” to “1”: 4h14
- Gaps of about 30 days

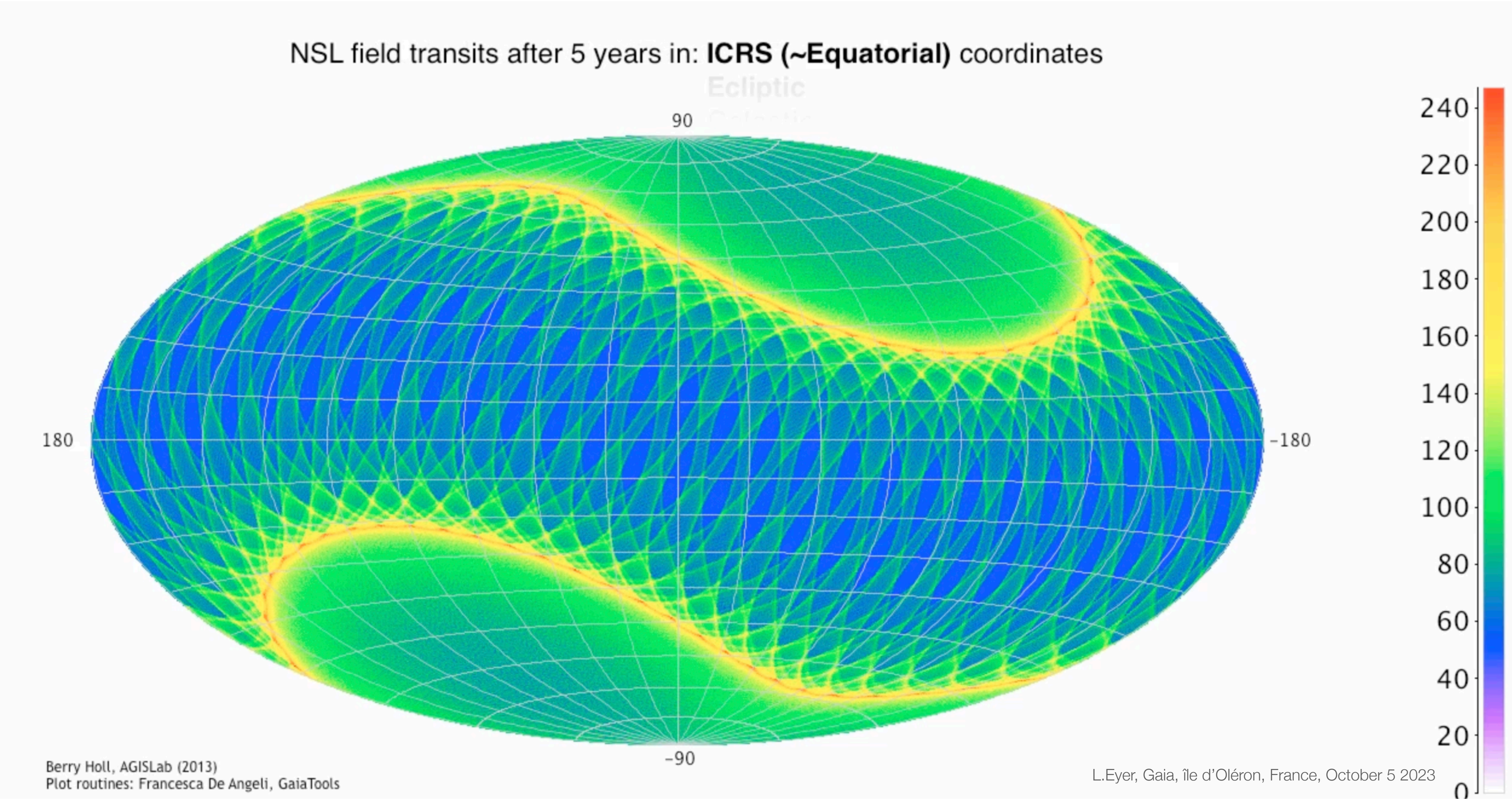


Projection Aitoff du nombre de mesures

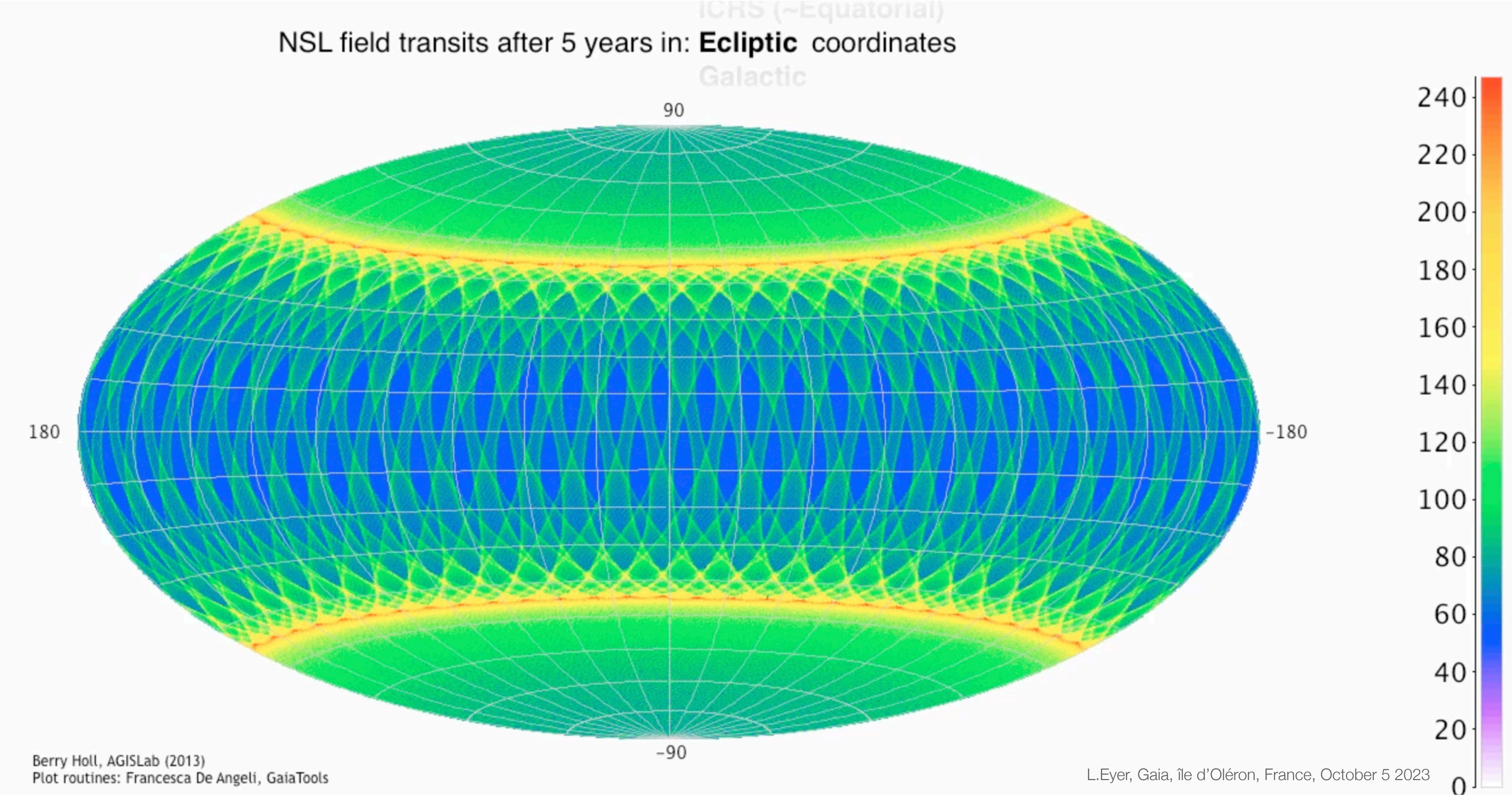


Courtesy of B. Holl

Gaia Nominal Scanning Law: Number of measurement

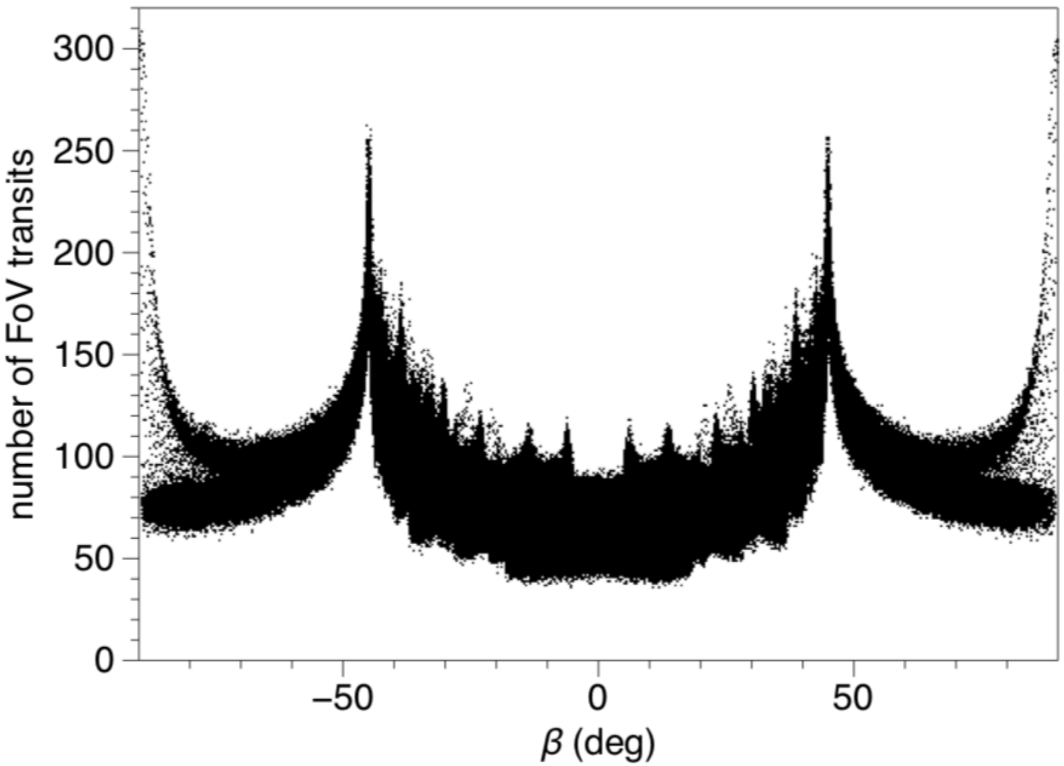


Gaia Nominal Scanning Law: Number of measurement



Gaia Nominal Scanning Law: Number of measurement

Mean of 86 Field of View transits
for a 5 year mission



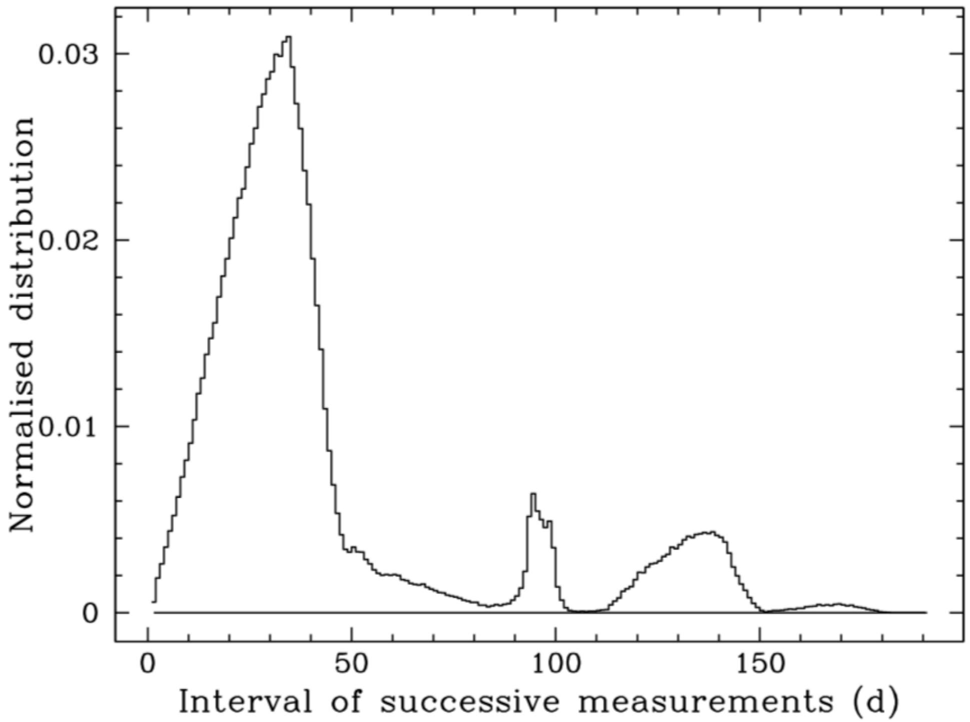
Eyer et al 2017

Gaia Nominal Scanning Law: Sampling

Probed time intervals

4.5 seconds to the minute

1h46, 4h14,… 6h to few days

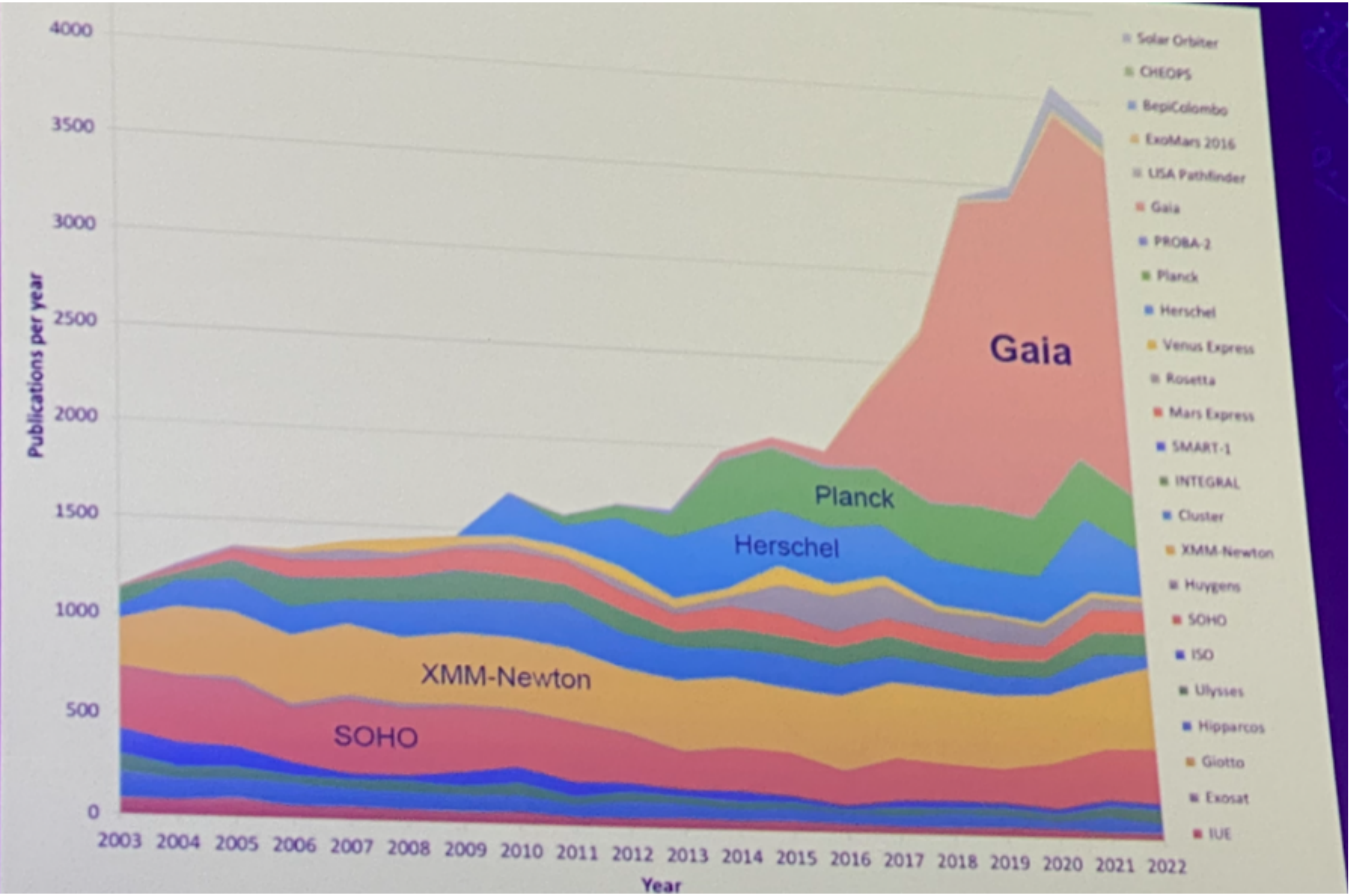


Eyer et al 2017

Why is Gaia so outstanding?

- An unprecedented astrometry (positions, parallaxes, proper motions) for so many stars
- Three instruments (astrometry, [spectro-]photometry, spectroscopy) on the same platform
- Quasi-simultaneous measurements
- Multi-epoch measurements of the entire sky
- Number of measurements (big data, for DR3 - 34 months - nearly 1 trillion CCD measurements)
- Time base of 10 years (if all is going well) - Frequency precision is very high for periodic objects
- High dynamical range from the brightest sources (G ~ 1.7 in DR3) to magnitude G ~ 21
- The time-domain selection function can be determined
- Gaia is in space (some stability and whole celestial sphere accessible from one platform)
- Cyclic improvements of systematic data analyses (more data, better calibrations, better detection of outliers and enhancement of problems identification)

ESA missions and their publications per year



Presented at EAS 2023 (Krakow) by Kissler-Patig

Gaia is “astrometry”

In Gaia third data release

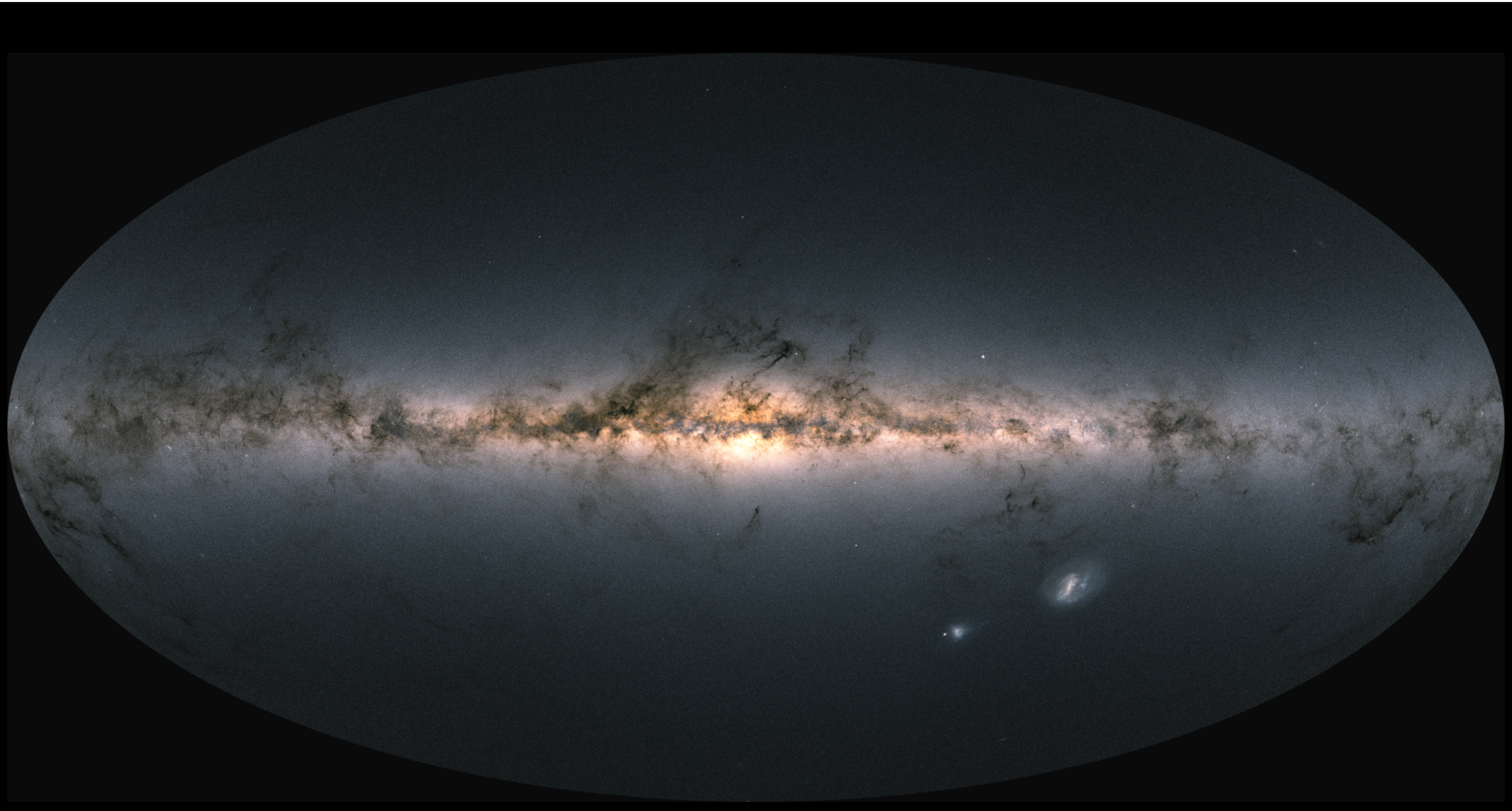
1.8 billion sources with positions

Multi epoch

1.5 billion sources with parallaxes and proper motions

169,227 astrometric non single stars

Black hole detection: Gaia BH1, Gaia BH2 (El Badry 2023a,b)



L.Eyer, Gaia, île d'Oléron, France, October 5 2023

Gaia is "photometry"

In Gaia third data release

1.8 billion in G band

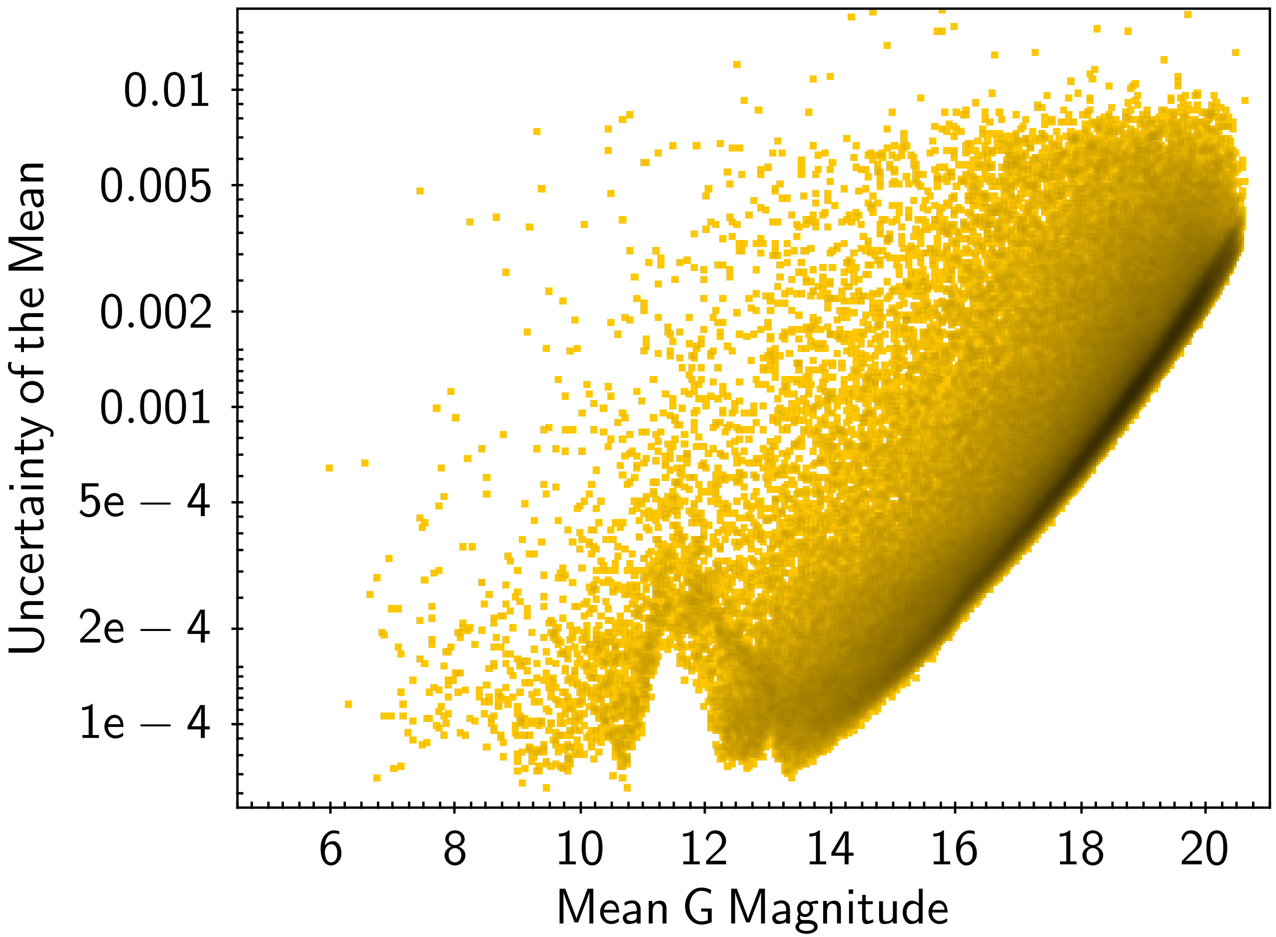
1.5 billion sources with BP and RP

Multi epoch

10.5 million classified variable sources

2.5 million galaxies (from spurious effect in the photometry)

The photometric precision on the G-band mean for DR3



N(CCD)$_{Max}$= 1555

N(CCD)$_{Min}$= 1130

Selection of 1/2 million sources with highest number of measurements and |ecliptic latitude| < 60

Gaia is “spectrophotometry”

In Gaia third data release

470 million astrophysical parameters (Temperature, mass, age, metallicity)

220 million low resolution spectra

Multi epoch

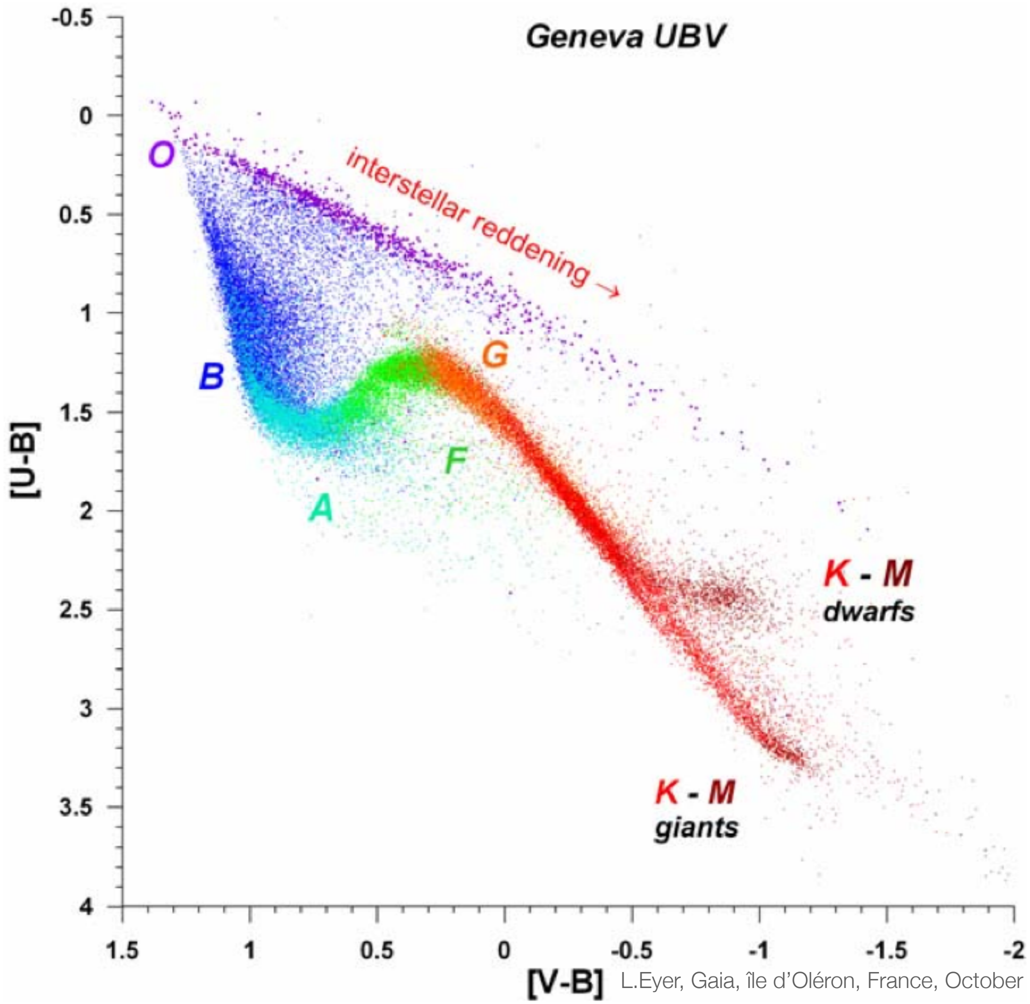
1.7 million Long Period Variables

546,468 Carbon rich star classification

Colour-colour diagram: Geneva Photometry

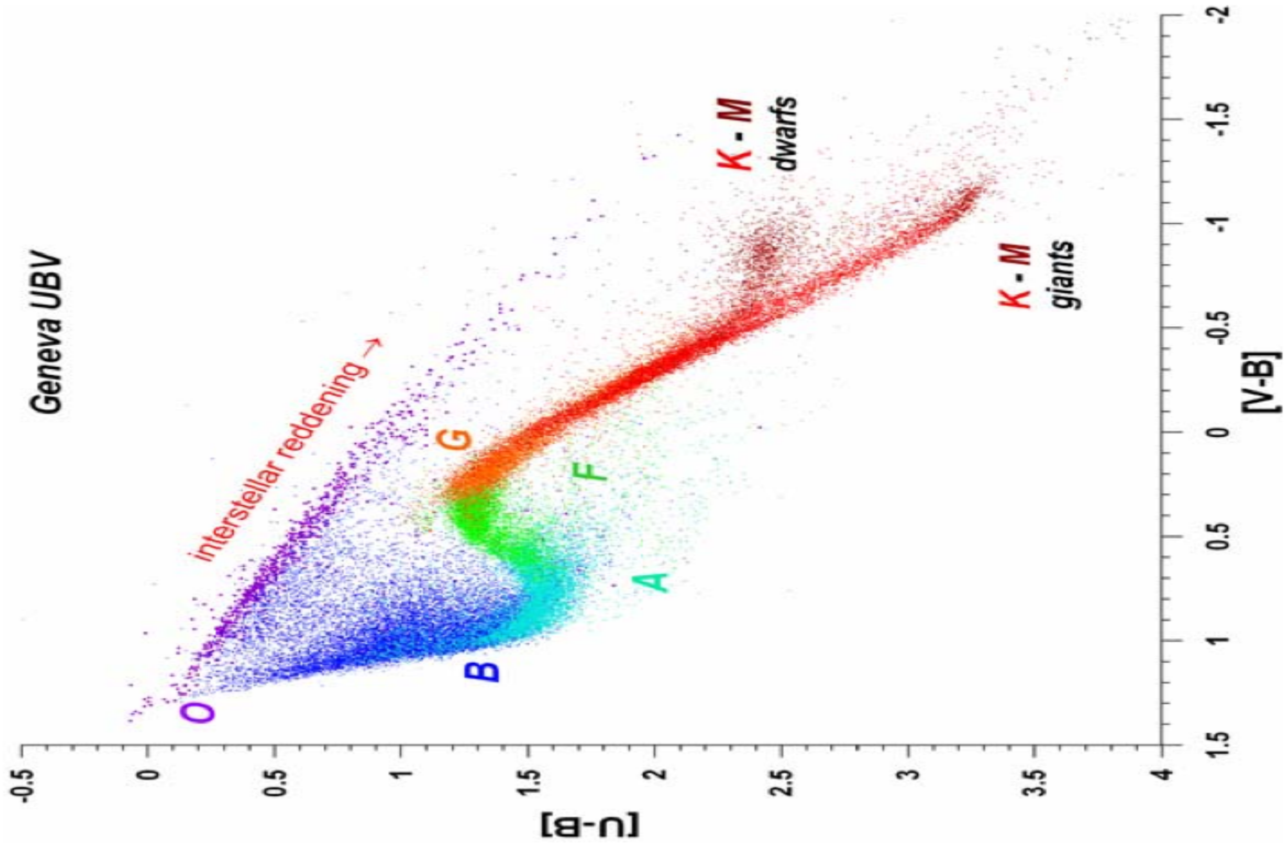
The HR diagram of the “poor”

50’000 stars
396’000 measurements



Credit: Cramer 1994

Colour-colour diagram: Geneva Photometry

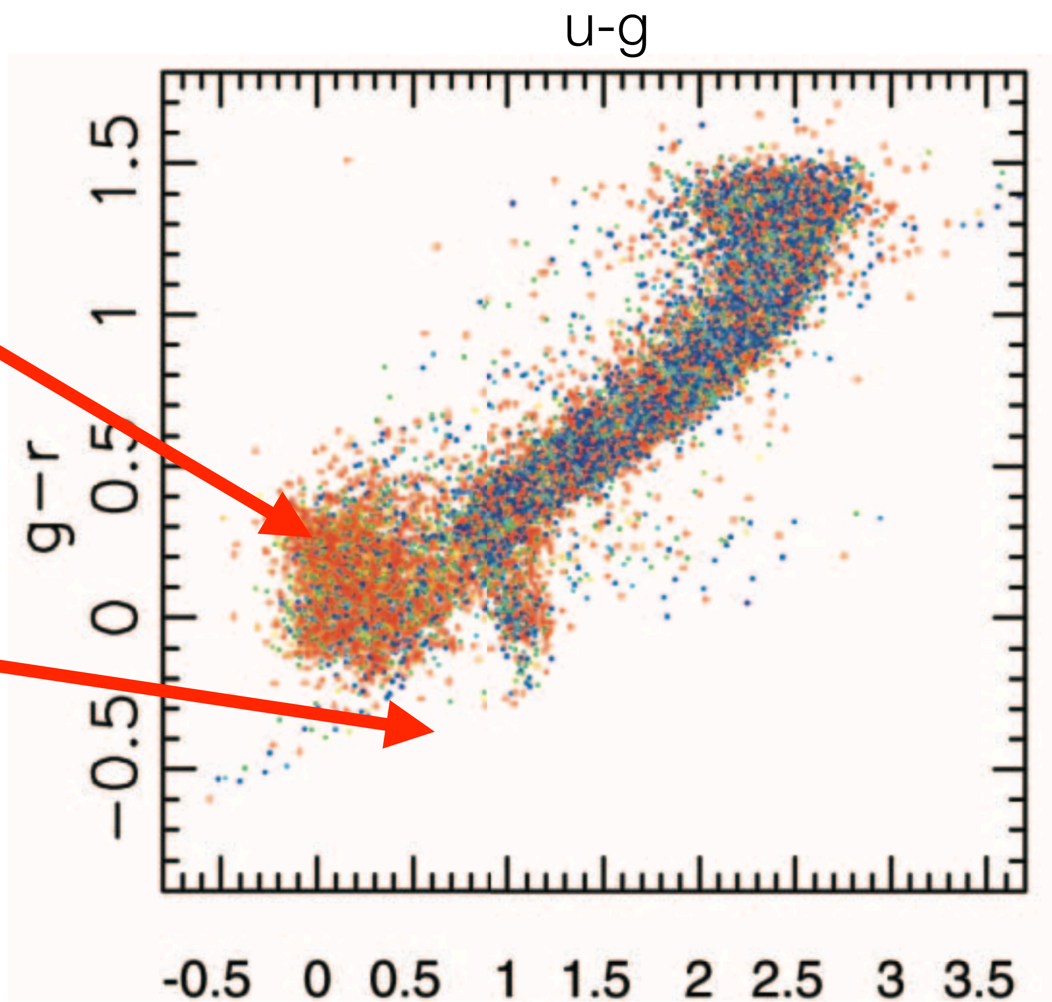


Credit: Cra

Colour-colour diagram: Sloan Digial Sky Survey (SDSS)

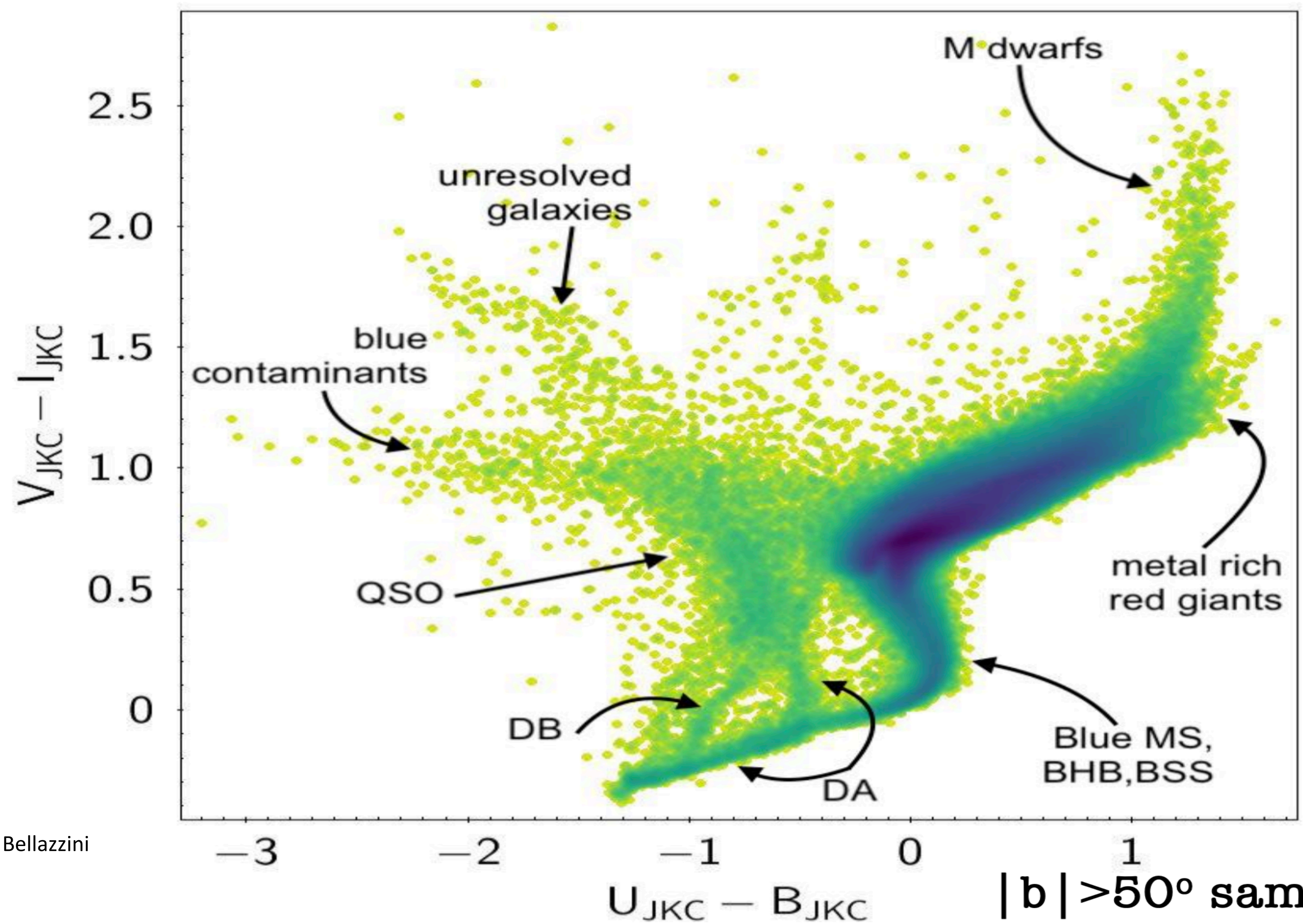
What is this?

Where are the stars?



Ivezic et al. (200X)

BP/RP spectra can be used to derive pseudo bands



Courtesy of M. Bellazzini

|b|>50° sample

Montrgriffo De Agneli, Andrea+ 2023

Gaia is “spectroscopy” and “radial velocities”

In Gaia third data release

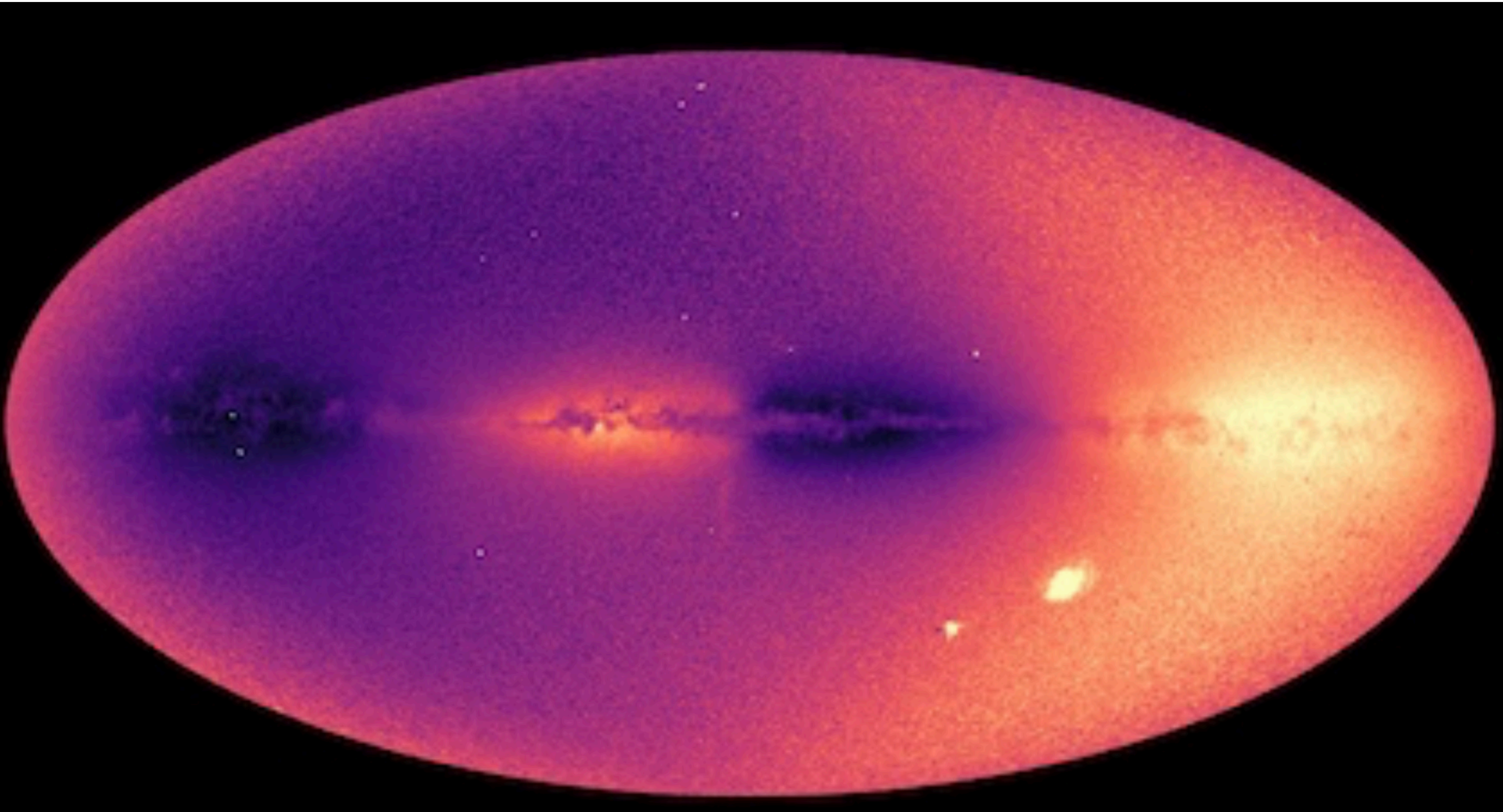
33 million radial velocities
5.6 million astrophysical parameters
2.5 million chemical compositions
1 million spectra published

Multi epoch

186,905 Spectroscopic binary stars (SB1/SB2)

1,898 Cepheids and RR Lyrae stars with radial velocities

9,614 LPVs with radial velocities time series (focused product release October 10 2023)



L.Eyer, Gaia, île d’Oléron, France, October 5 2023

Gaia strengths

Large numbers…

but…

… more importantly when the different **time domain** data sets are combined together

especially to decipher the properties of variable sources and binaries…

Questions?

Colour absolute Magnitude Diagram

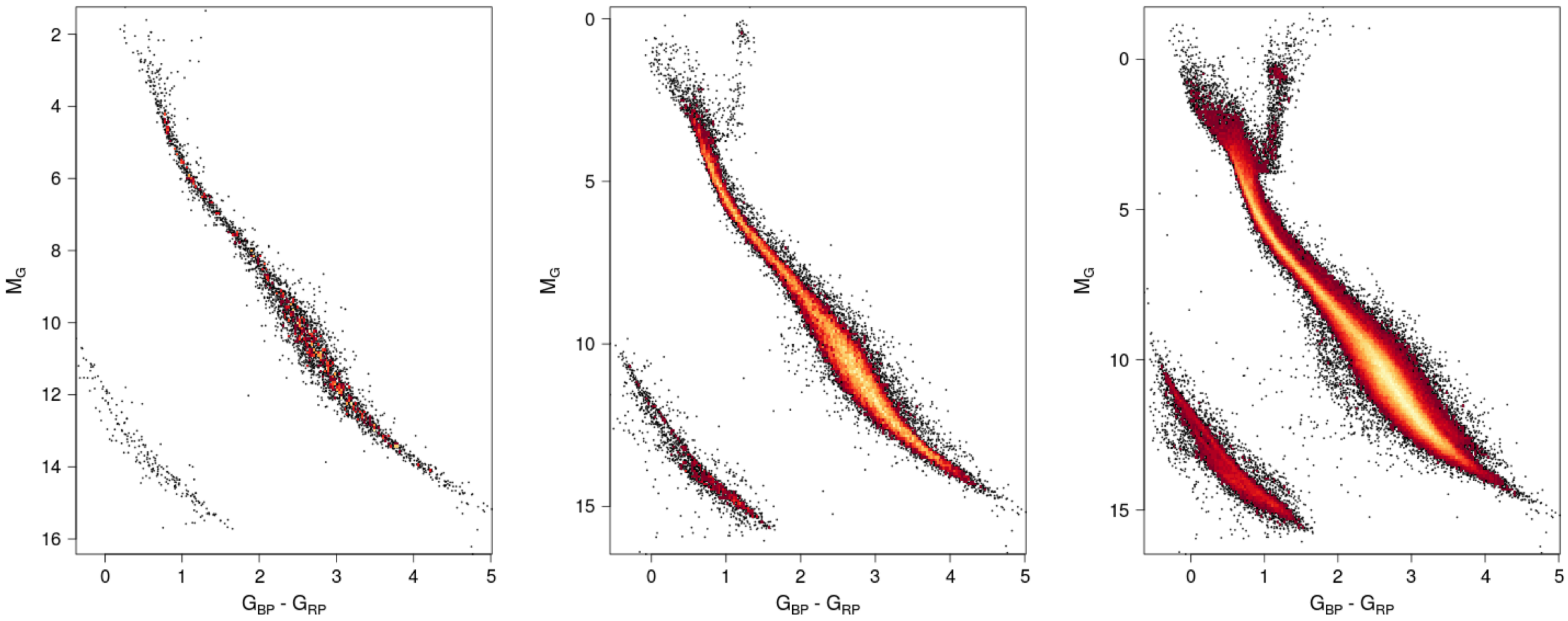
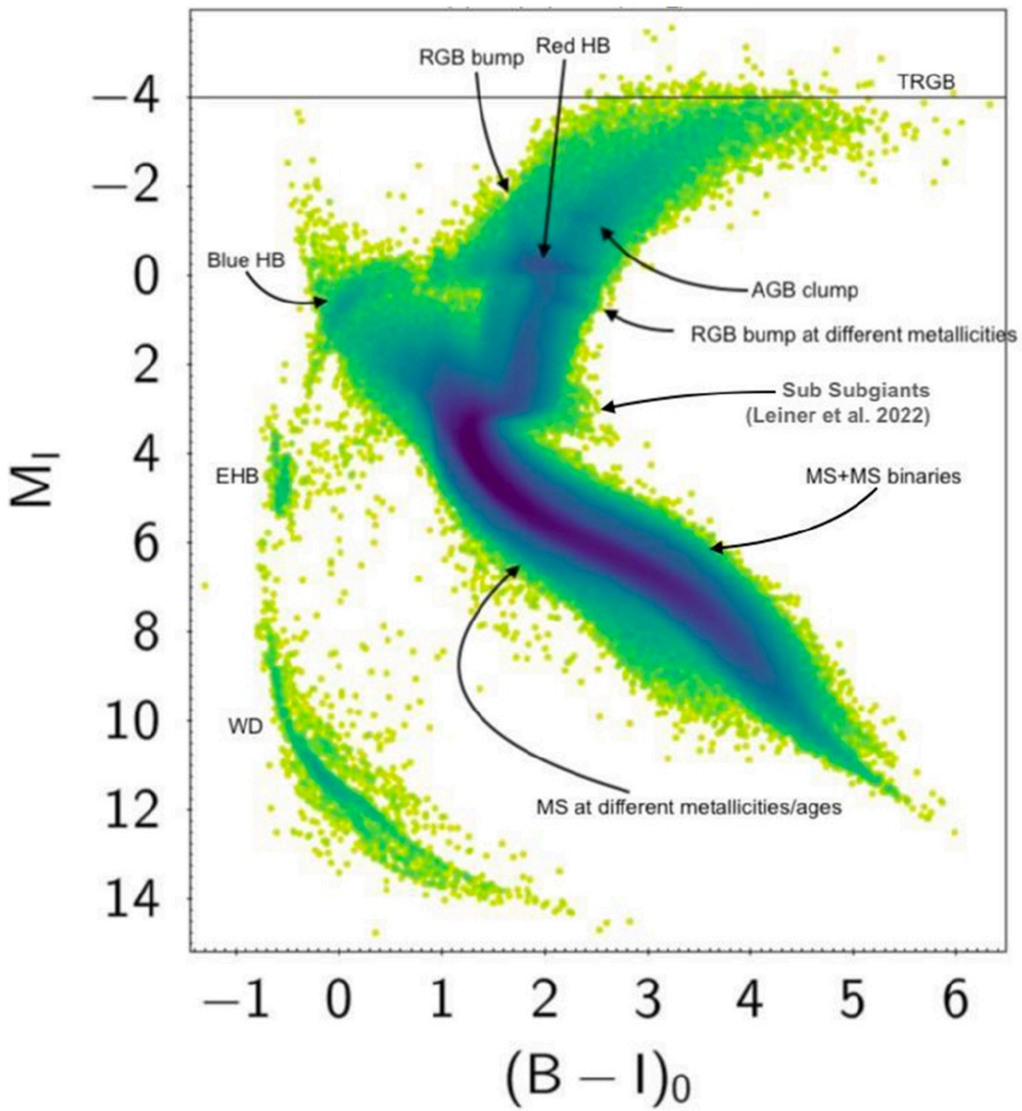


Fig. 6. Solar neighbourhood *Gaia* HRDs for a) $\varpi > 40$ mas (25 pc, 3,724 stars), b) $\varpi > 20$ mas (50 pc, 29,683 stars), and c) $\varpi > 10$ mas (100 pc, 212,728 stars).

Gaia collaboration, Babusiaux, van Leeuwen+ 2018

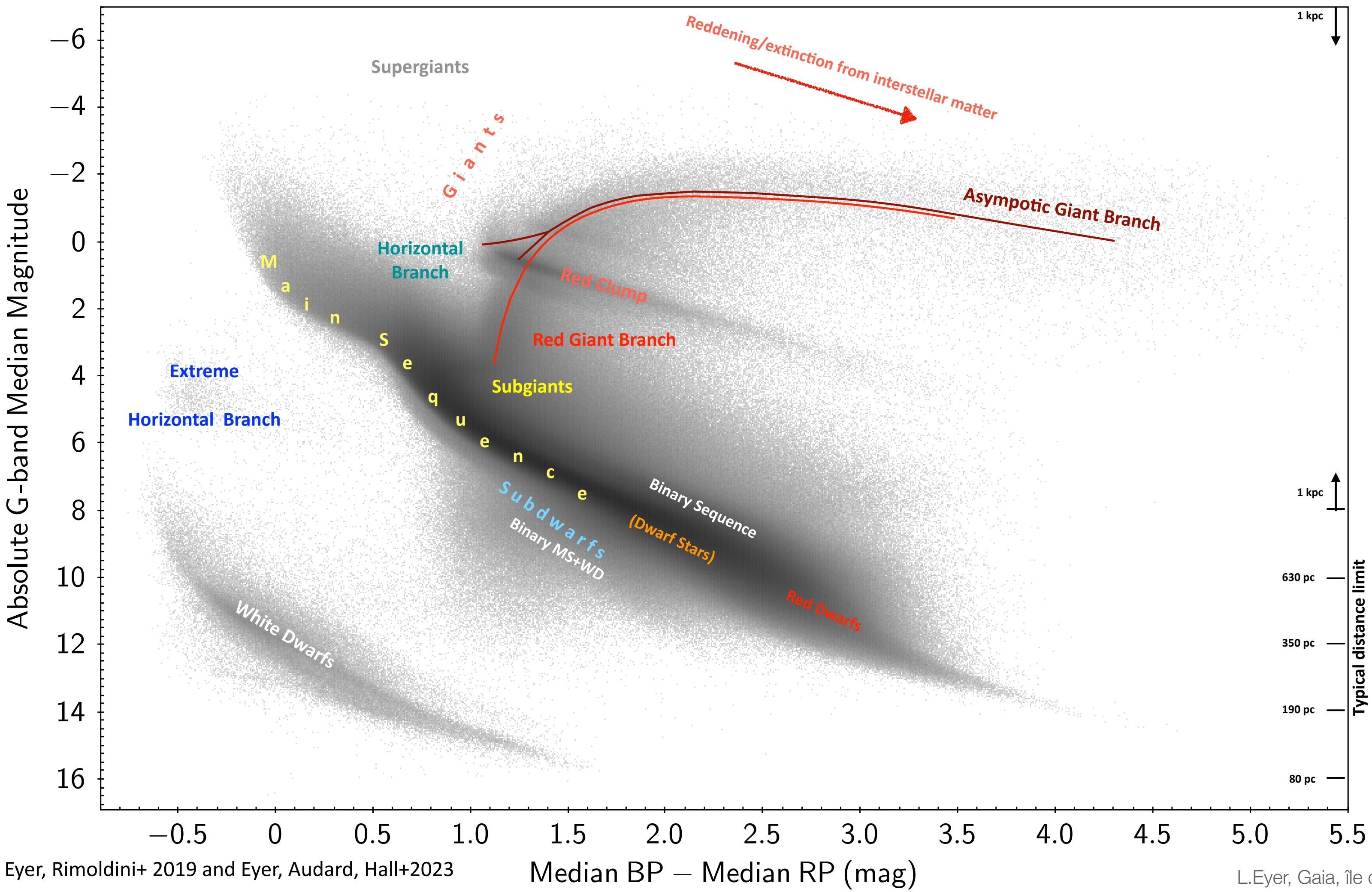
Colour absolute Magnitude Diagram



Courtesy of M. Bellazzini

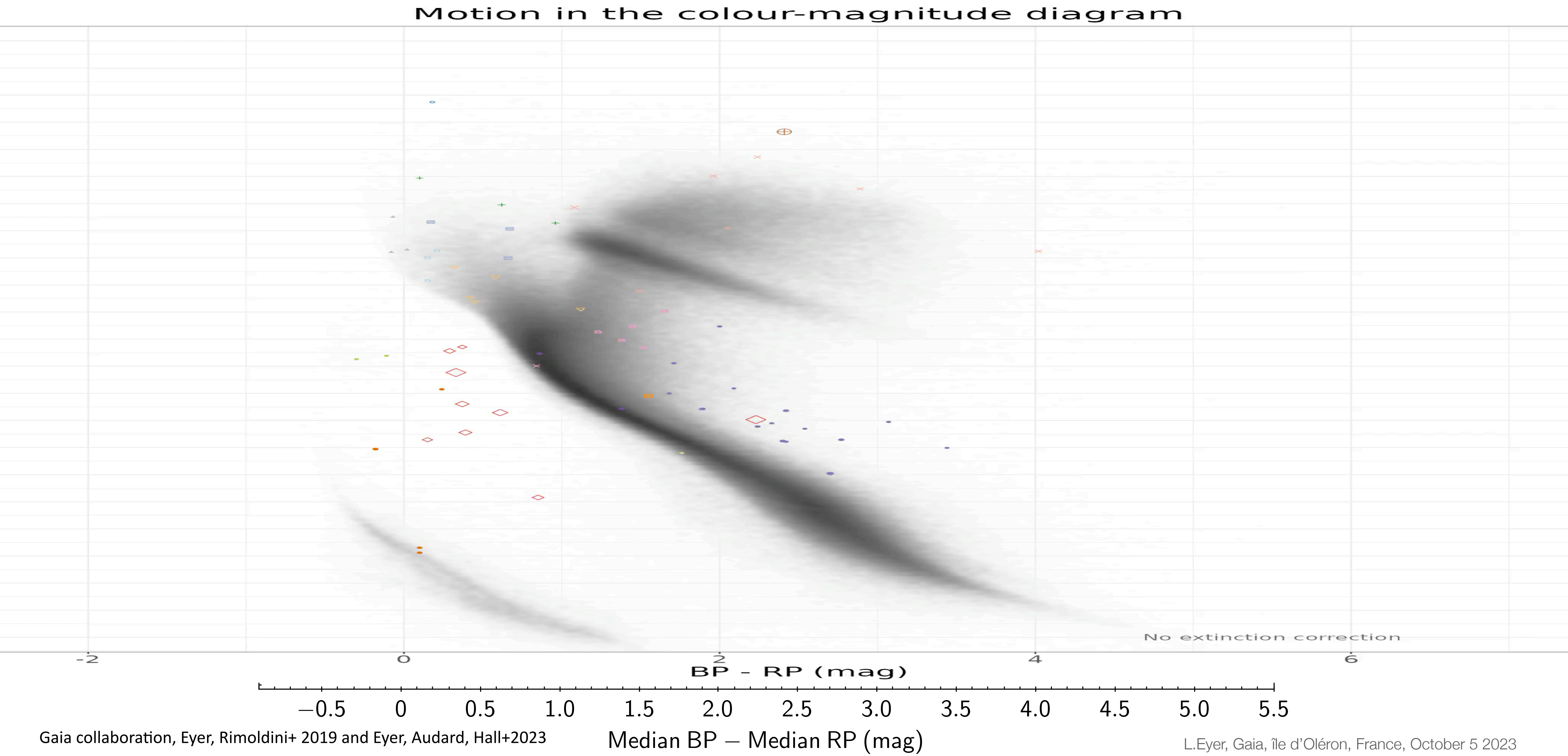
Montrgriffo De Agneli, Andrea+ 2023

Colour absolute Magnitude Diagram



Gaia collaboration, Eyer, Rimoldini+ 2019 and Eyer, Audard, Hall+2023

Colour absolute Magnitude Diagram

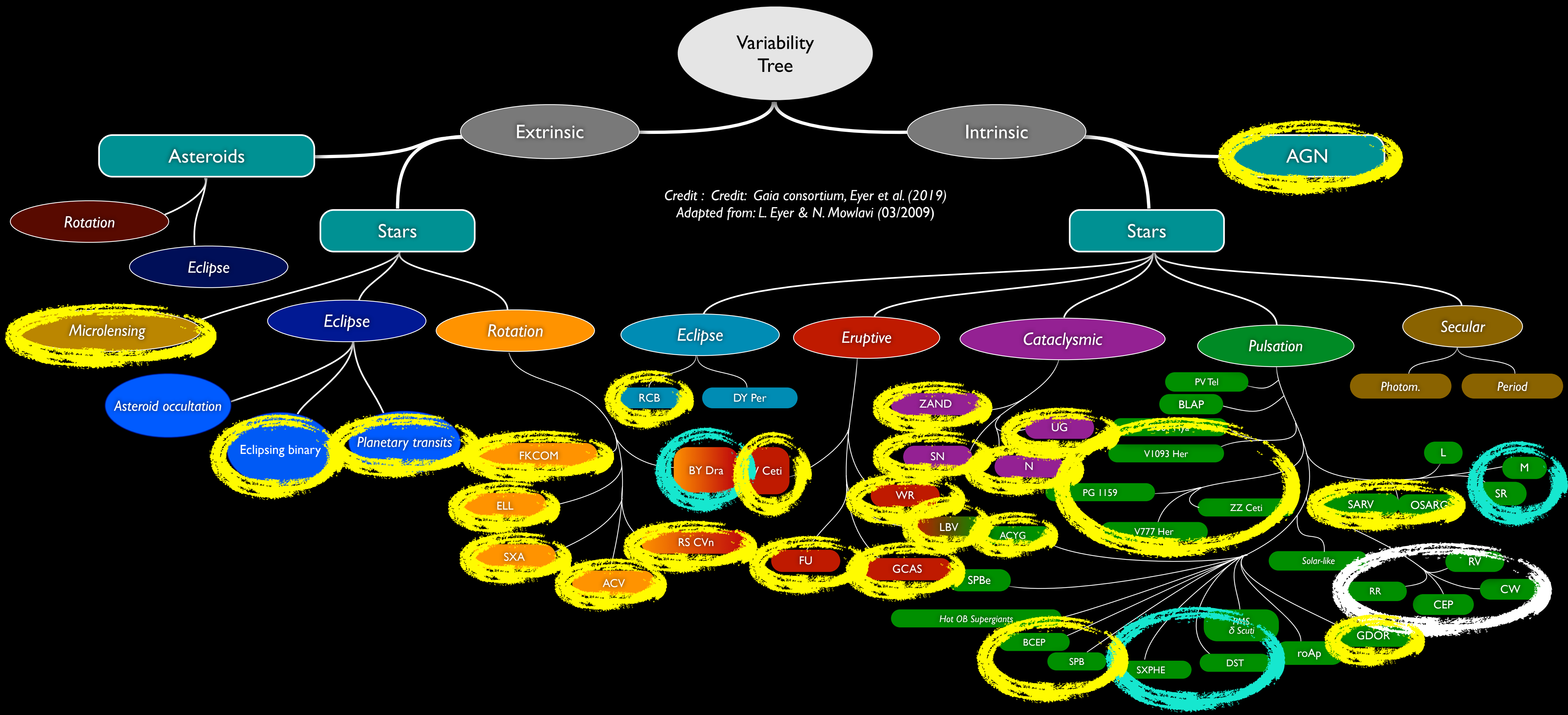


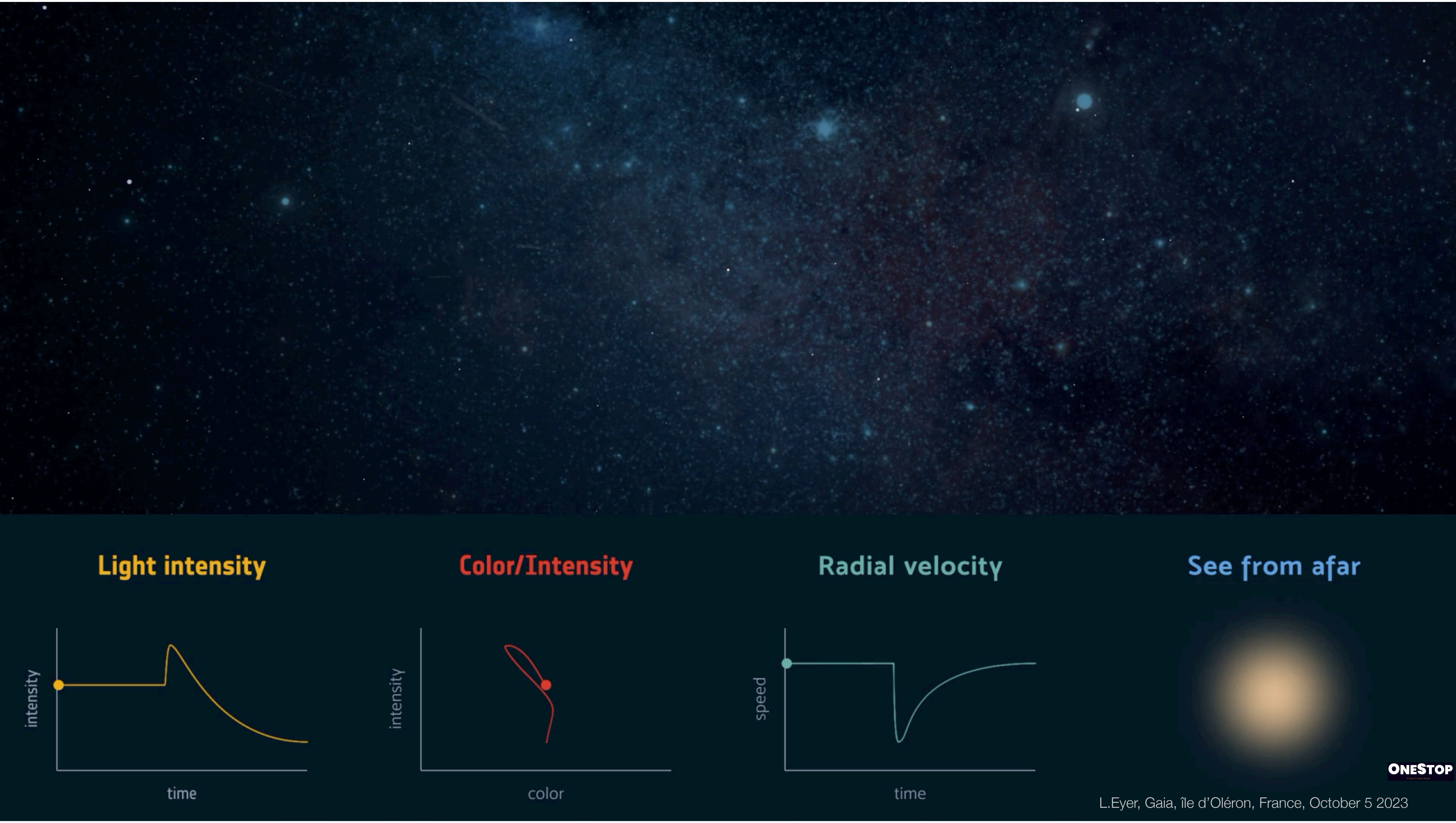
Gaia collaboration, Eyer, Rimoldini+ 2019 and Eyer, Audard, Hall+2023

Questions?

Variability in celestial objects

The Variability tree

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ONESTOP
L.Eyer, Gaia, île d'Oléron, France, October 5 2023

SuperNovae

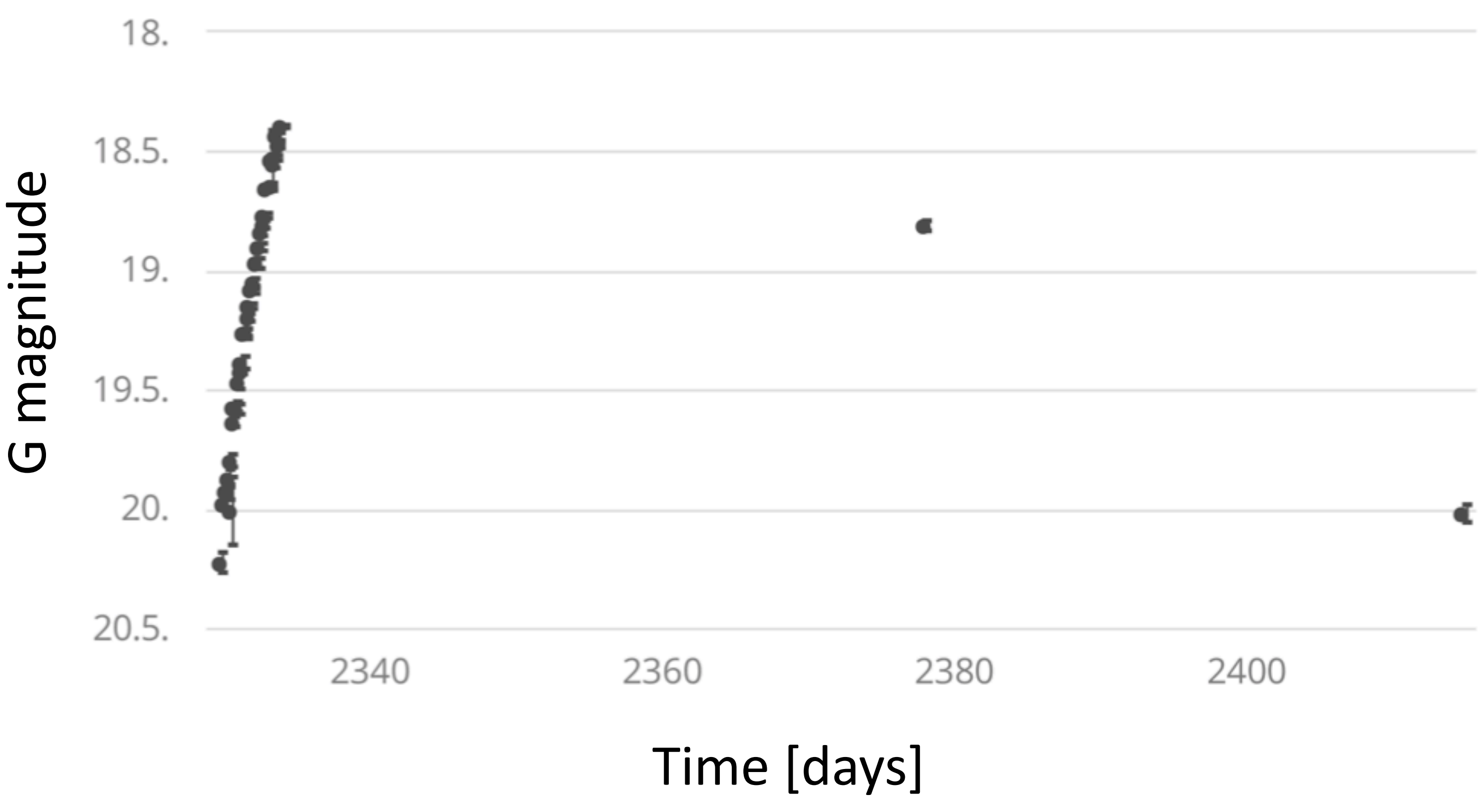
1006: Monks of Sankt Gallen reported it, Iranian, Egyptian, Chinese “astronomers”

1054: Reported by Chinese, Isalmic sources, Crab Nebula

1572: Observed by Tycho Brahe (Tycho’s Nova), English, Chinese “astronomers”

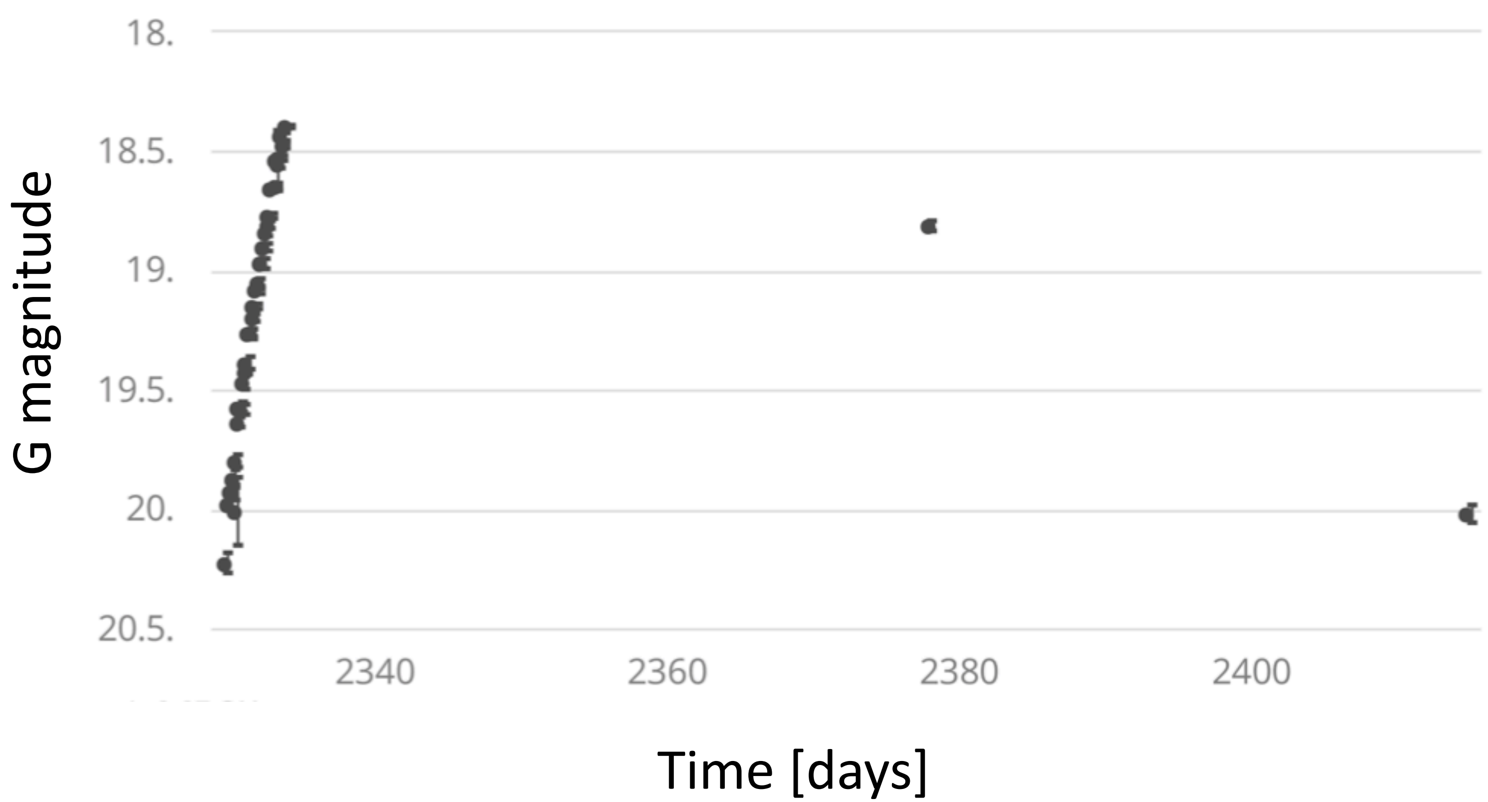
1604: Kepler’s Nova, Chinese, Korean, Arabic sources

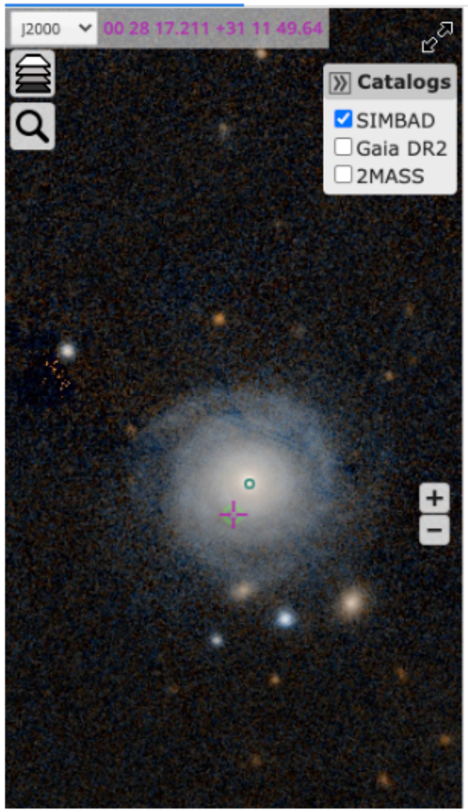
SuperNovae



Courtesy of Panos Gavras

SuperNovae



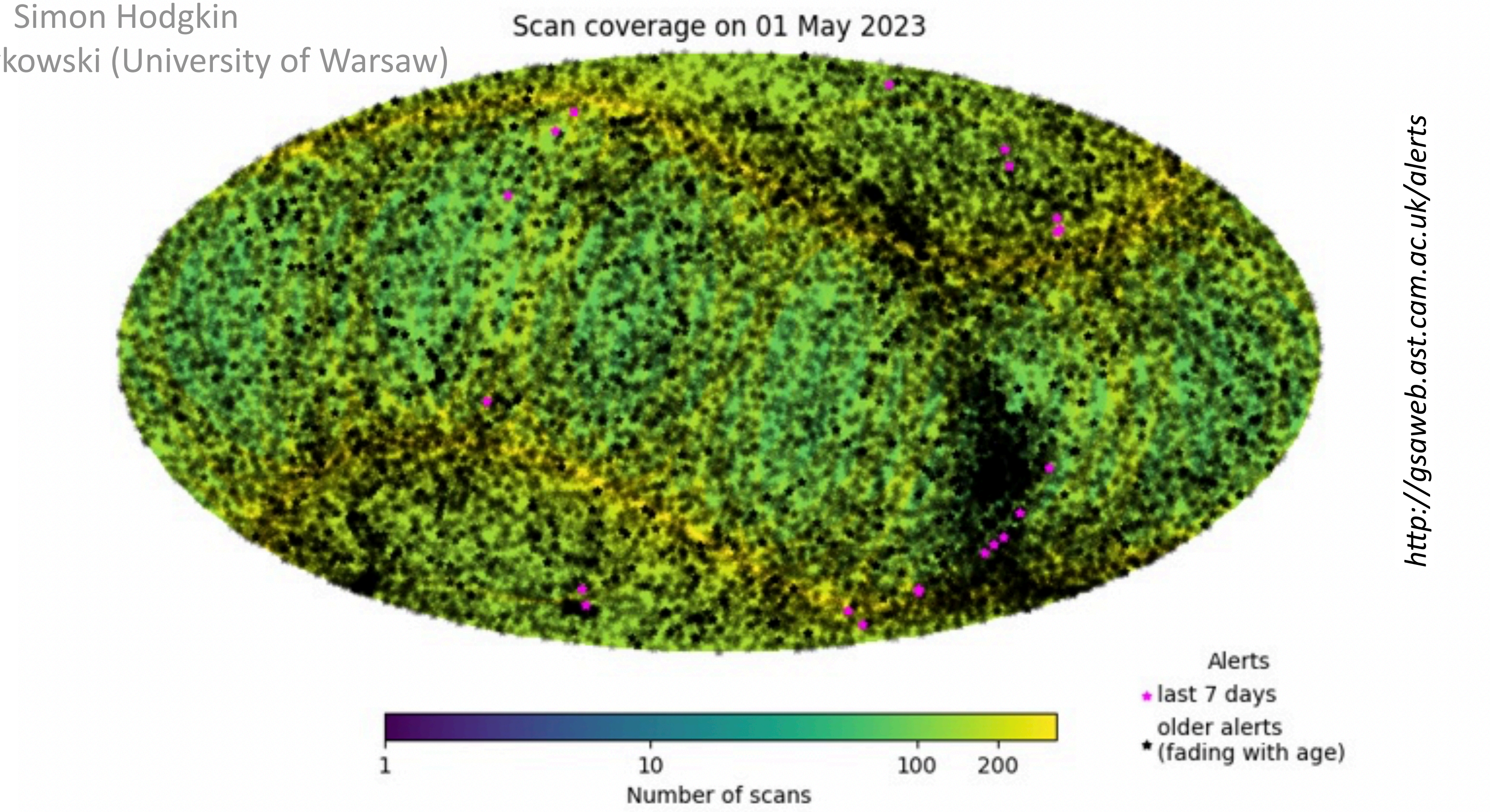


Courtesy of P. Gavras

Gaia Science photometric Alerts

Coordinated by Cambridge University

Simon Hodgkin
Lukasz Wyrzykowski (University of Warsaw)

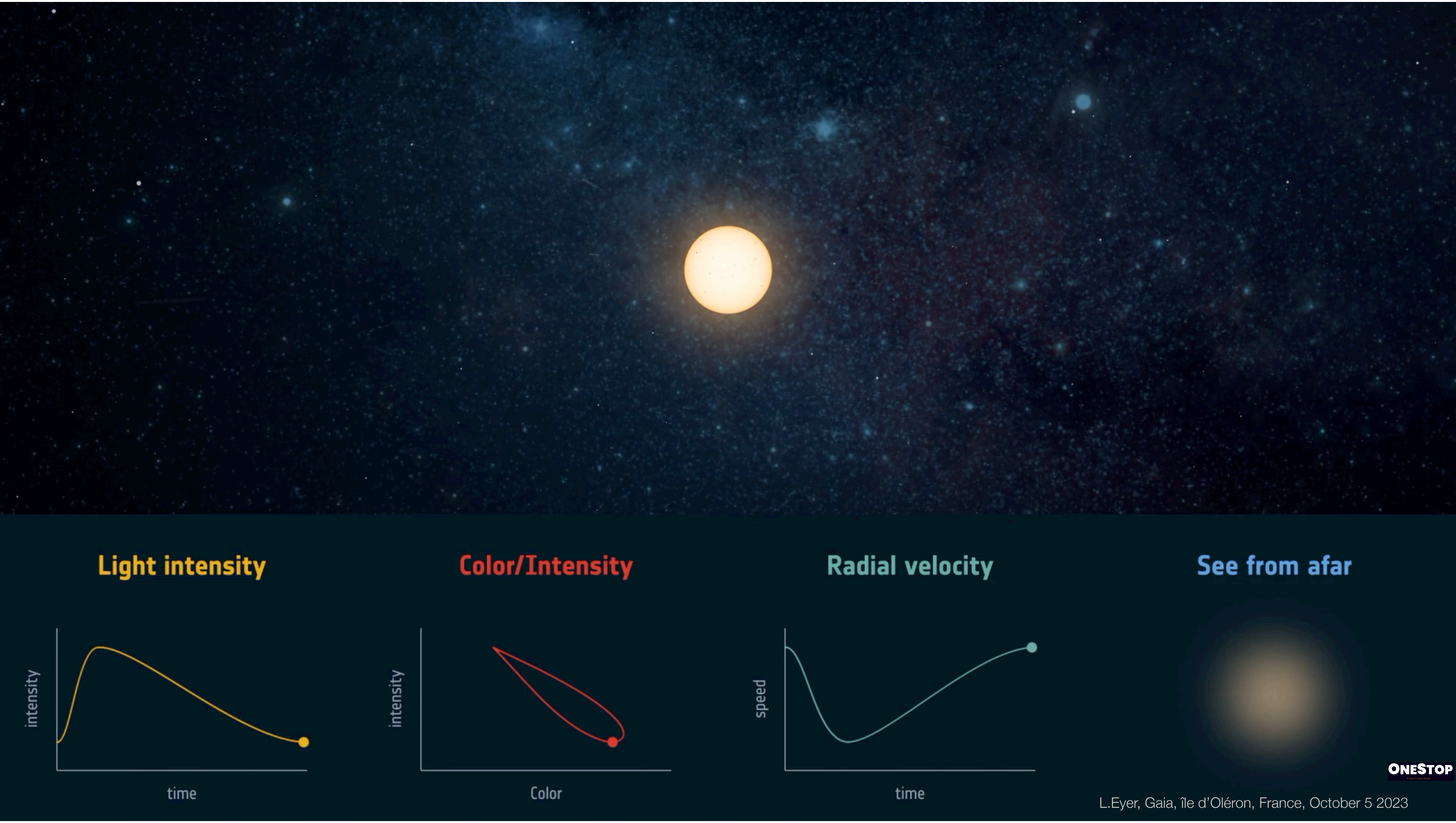


http://gsaweb.ast.cam.ac.uk/alerts

23,045 alerts

~28% classified sources

80% Supernovae



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L.Eyer, Gaia, île d’Oléron, France, October 5 2023

Eclipsing binaries

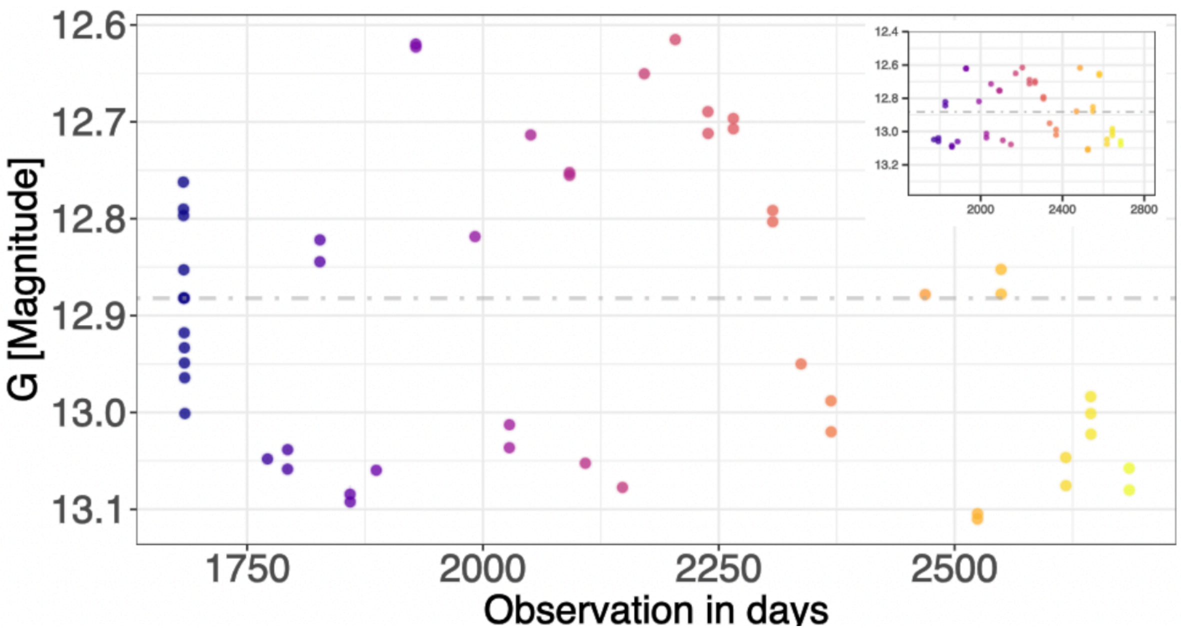
1596: Fabricius described the Mira star as nova…

1784: Goodricke and Pigott discovered eta Aql and delta Cep

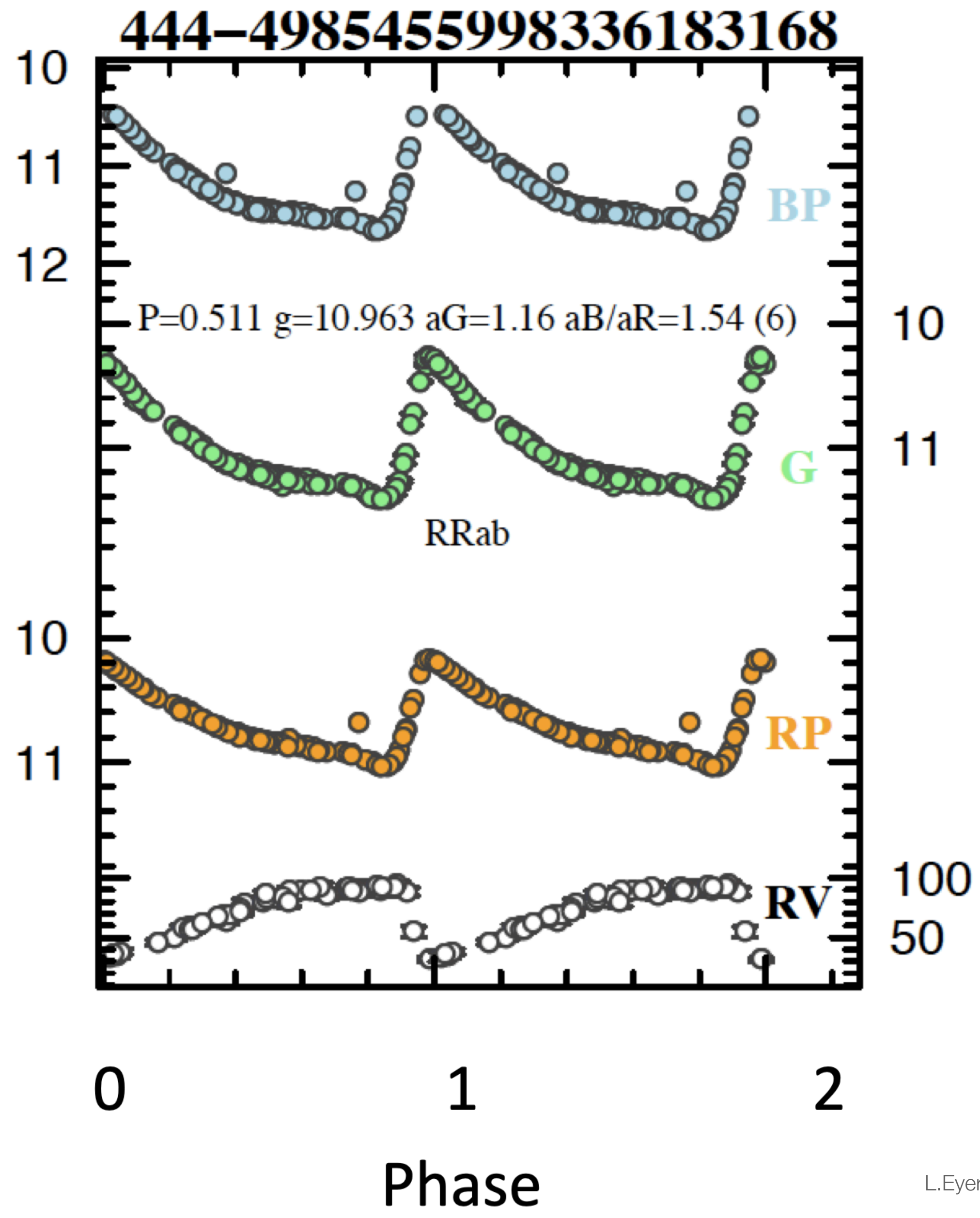
It took a long time to recognise that the origin of variability was pulsation

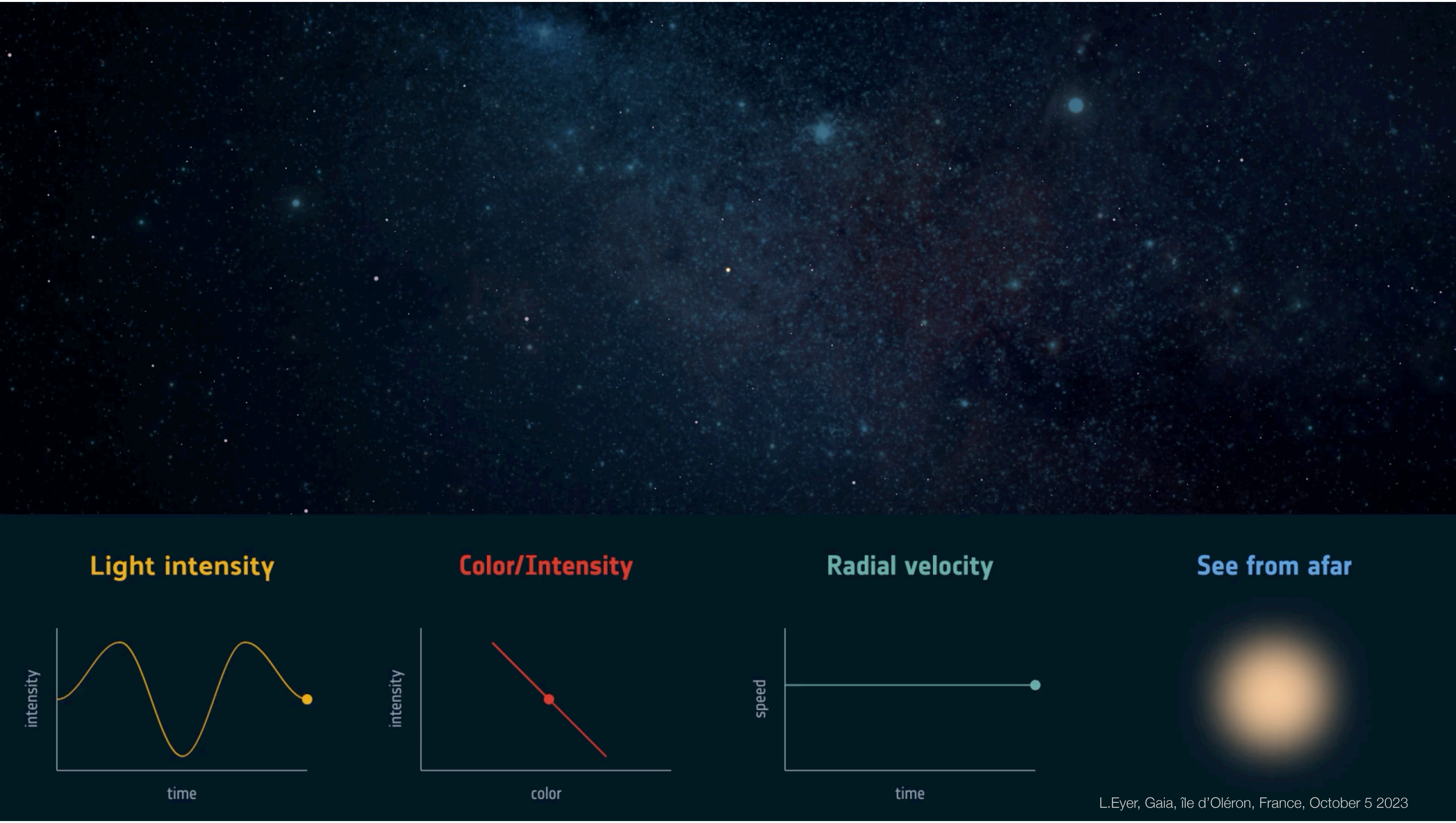
Ritter (1879) explained it, but was neglected by the community, Emden (1907) and Eddington (1918)

Pulsating star



RR Lyrae stars

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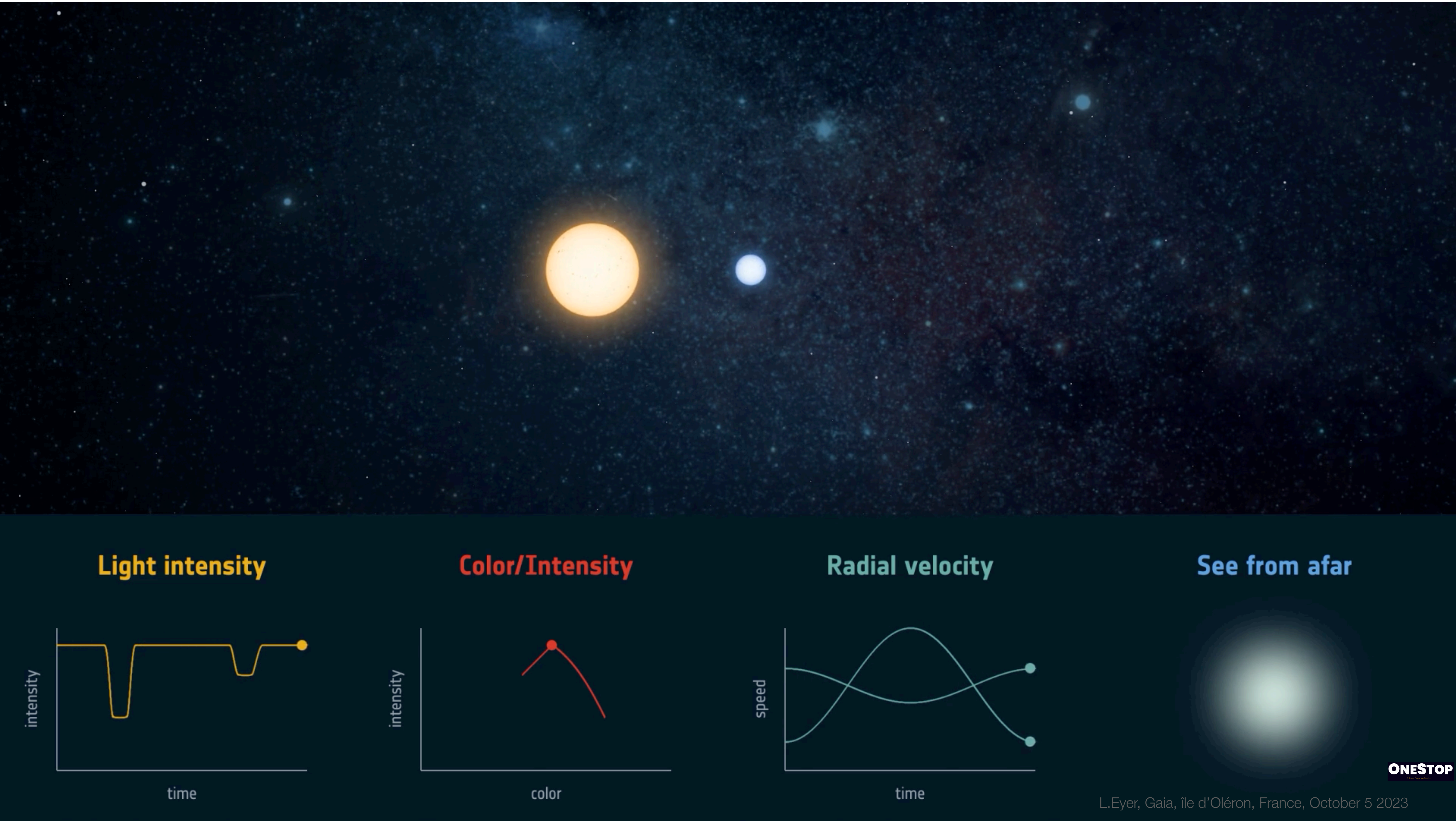
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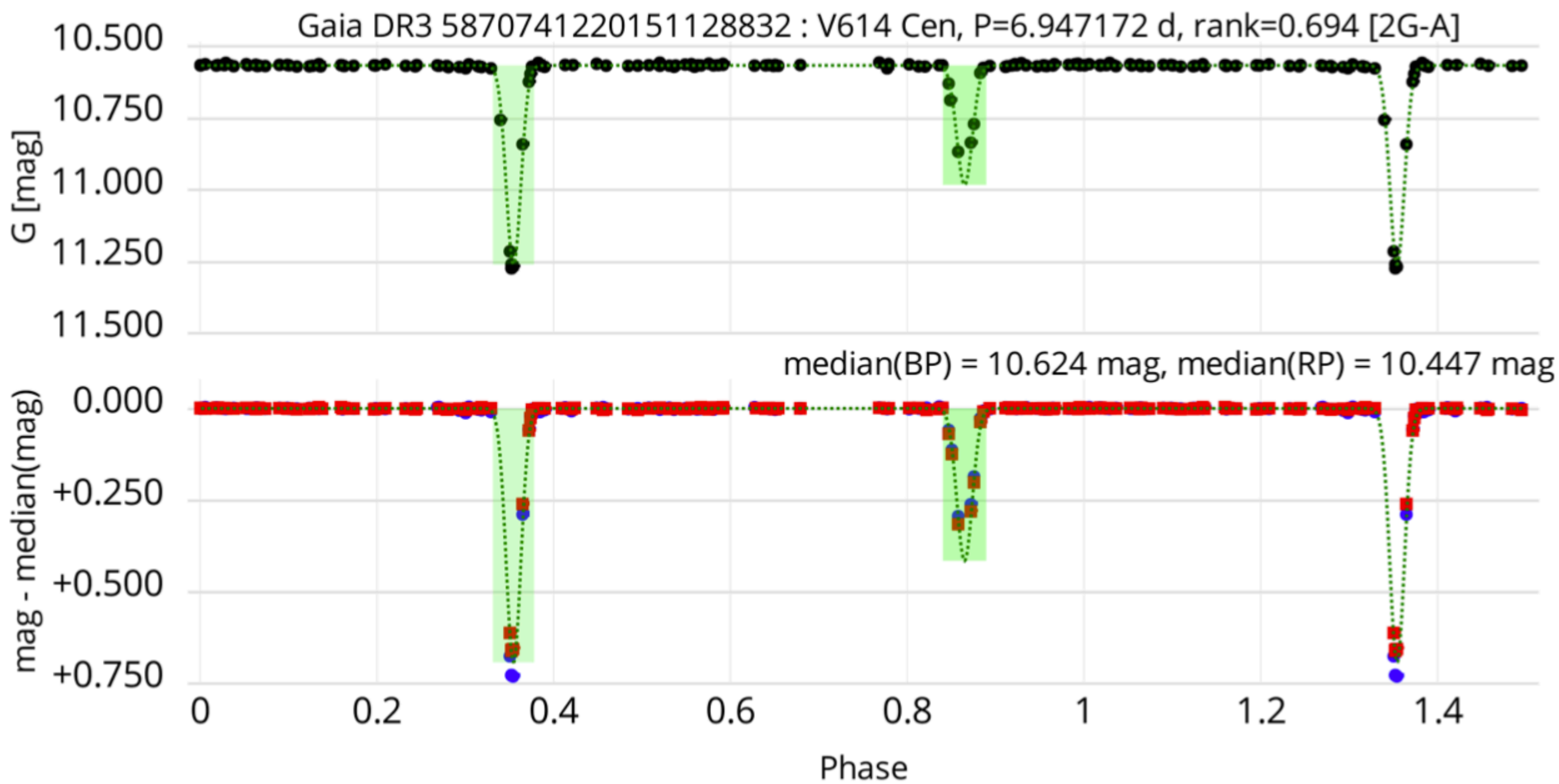
Eclipsing binaries

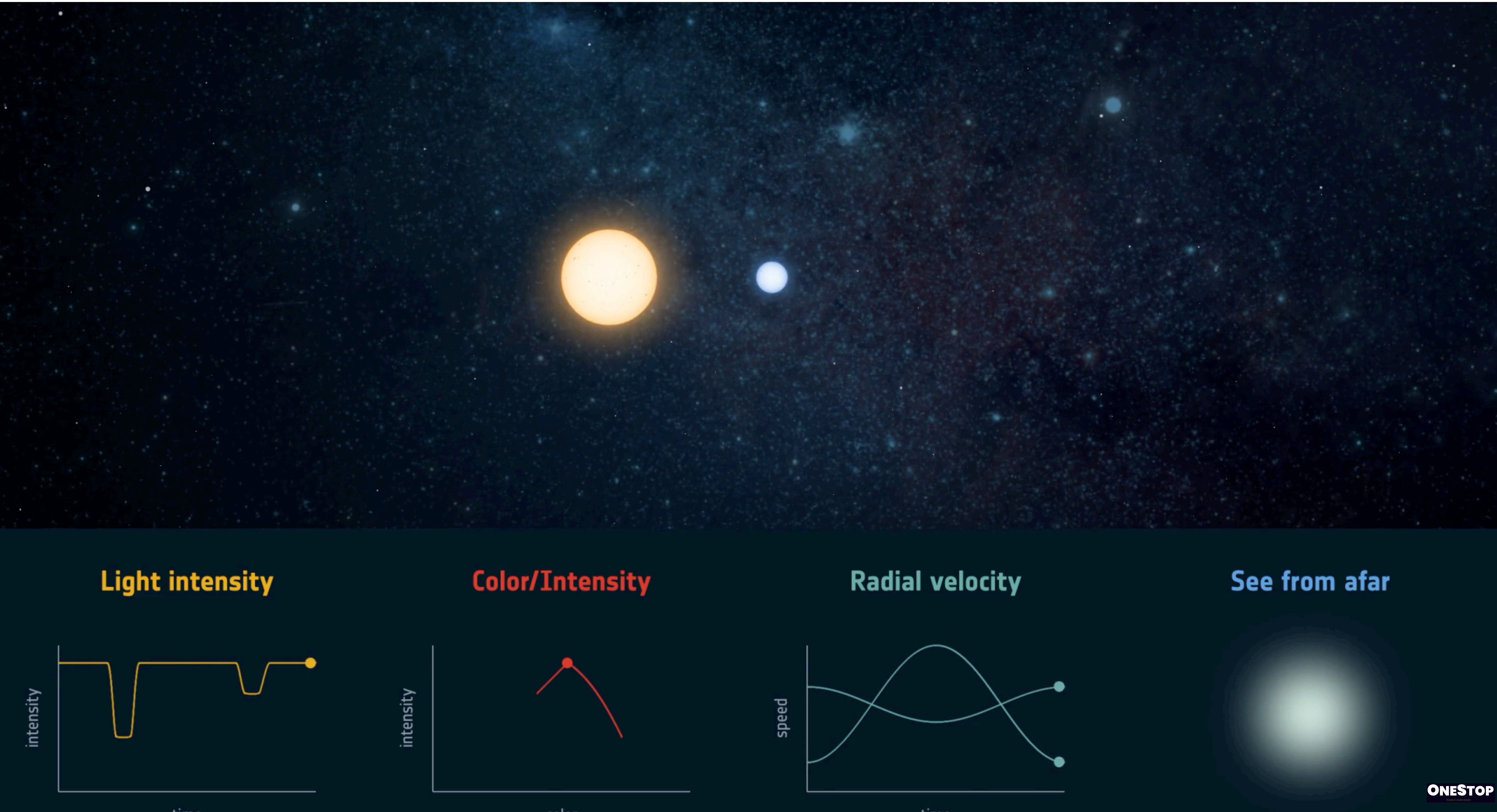
1669: Algol variability was discovered Montanari

1784: Goodricke gave the correct explanation

Eclipsing binaries



Mowlavi et al. 2023



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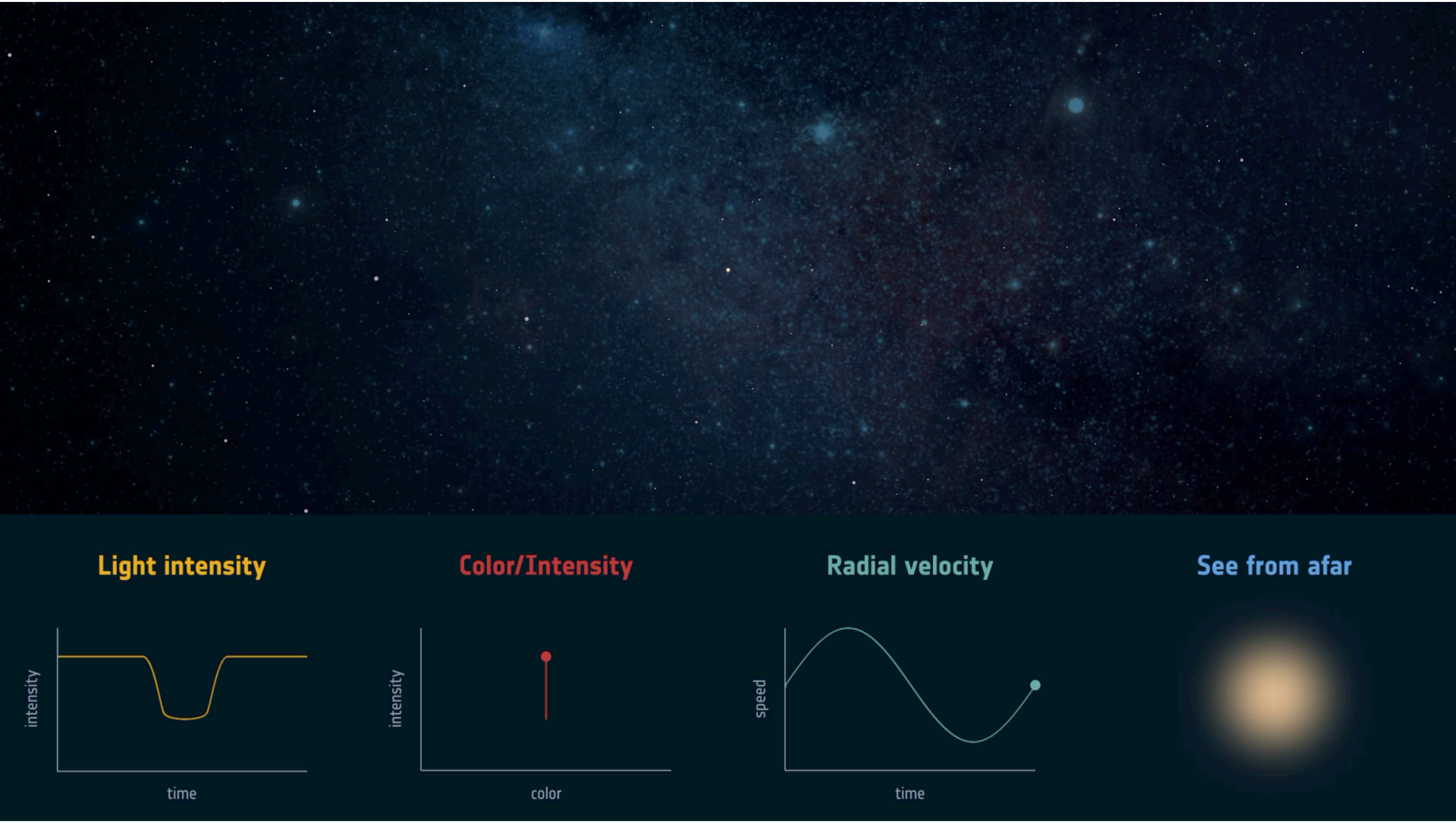
Don’t you see anything special?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Small is also beautiful: Exoplanetary transits

214 candidates

173 are known systems

41 are new systems

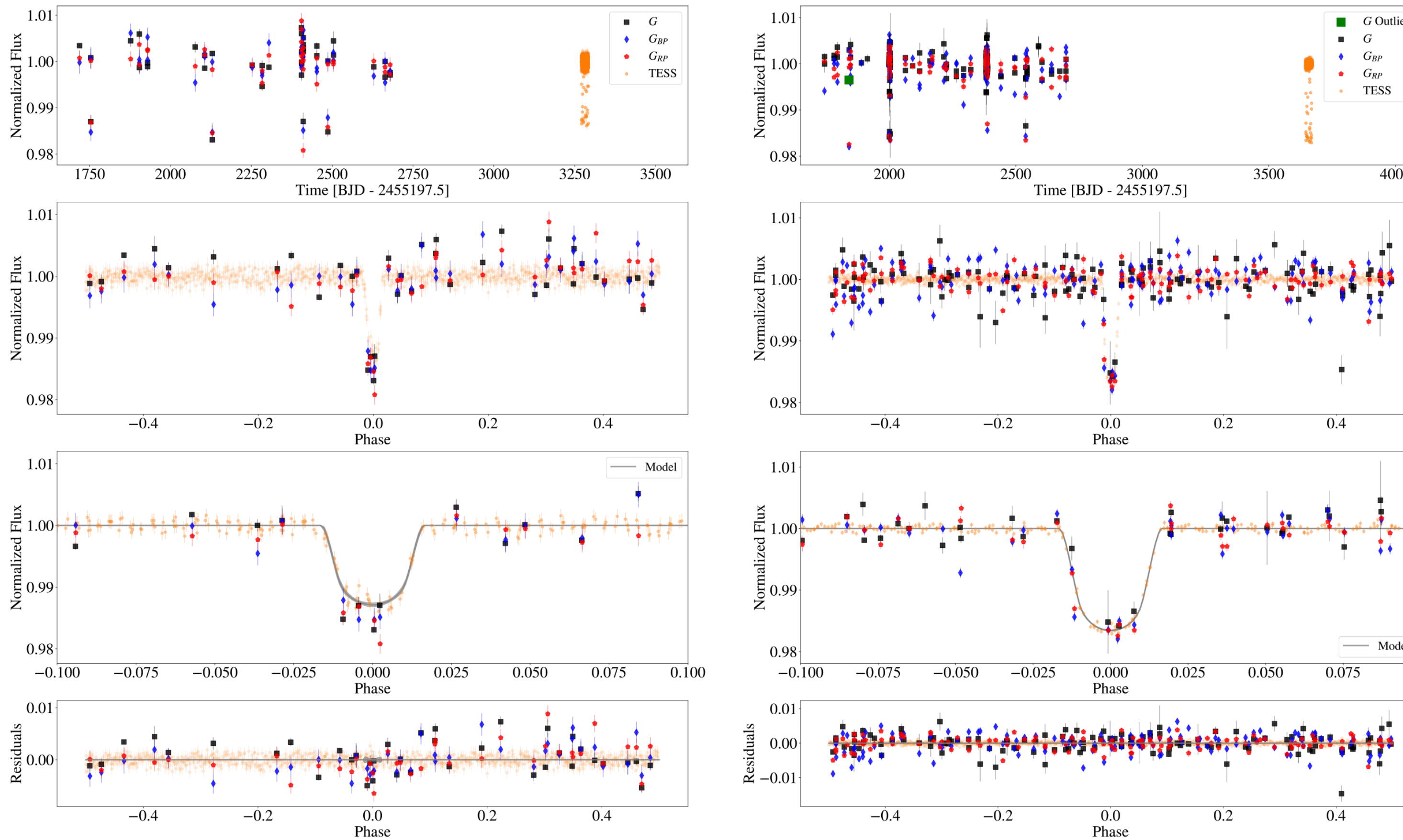
-> 2 confirmed cases

Panahi et al (2022a)

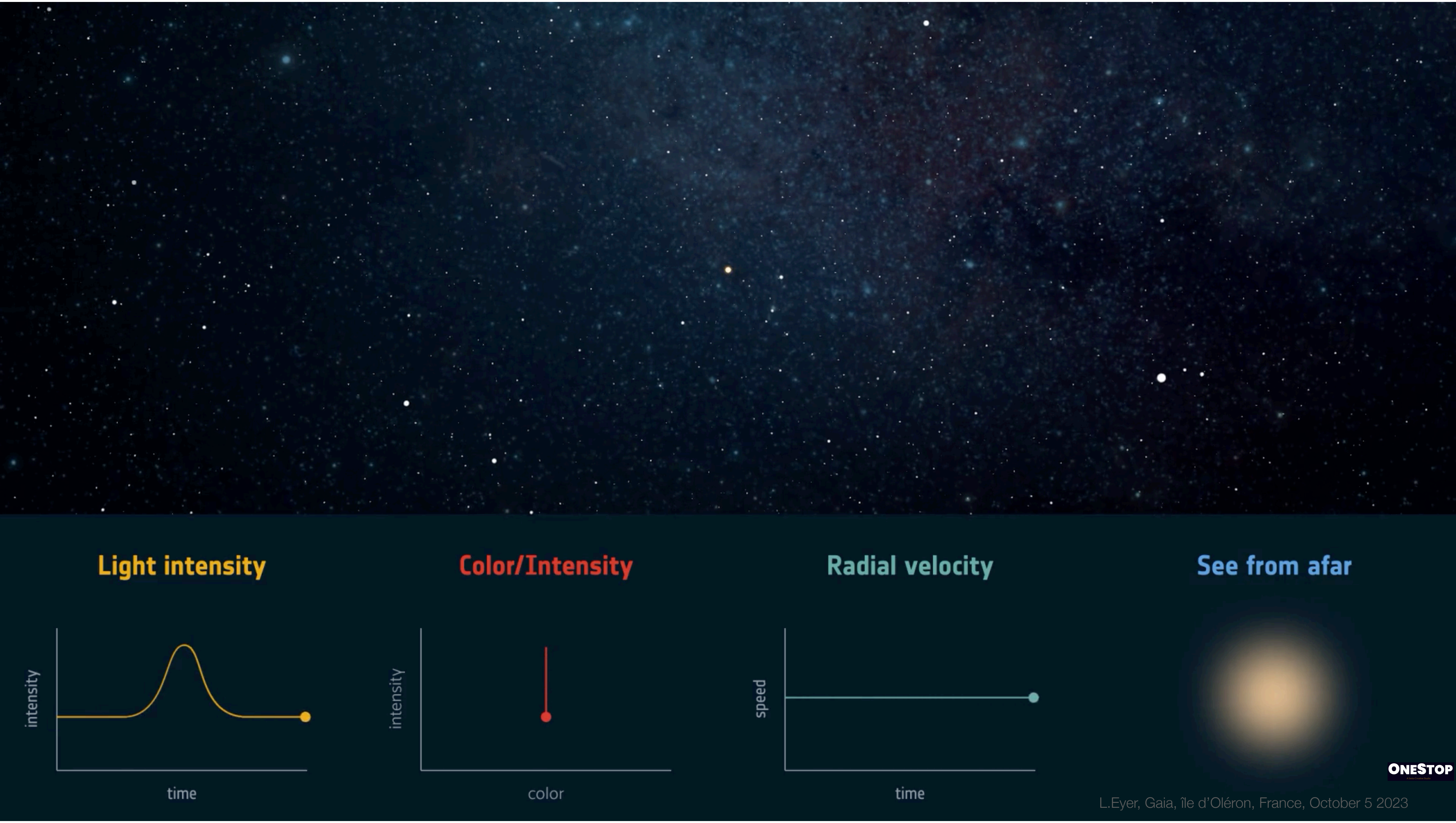
Warning for the Gaia archive:

gaiadr3.vari_planetary_transit

Now corrected



ALSO: Collaboration with NASA TESS mission to confirm the transit or identify background eclipsing binaries (Panahi et al 2022b): 5% BEB, 5% confirmation of the transit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Microlensing

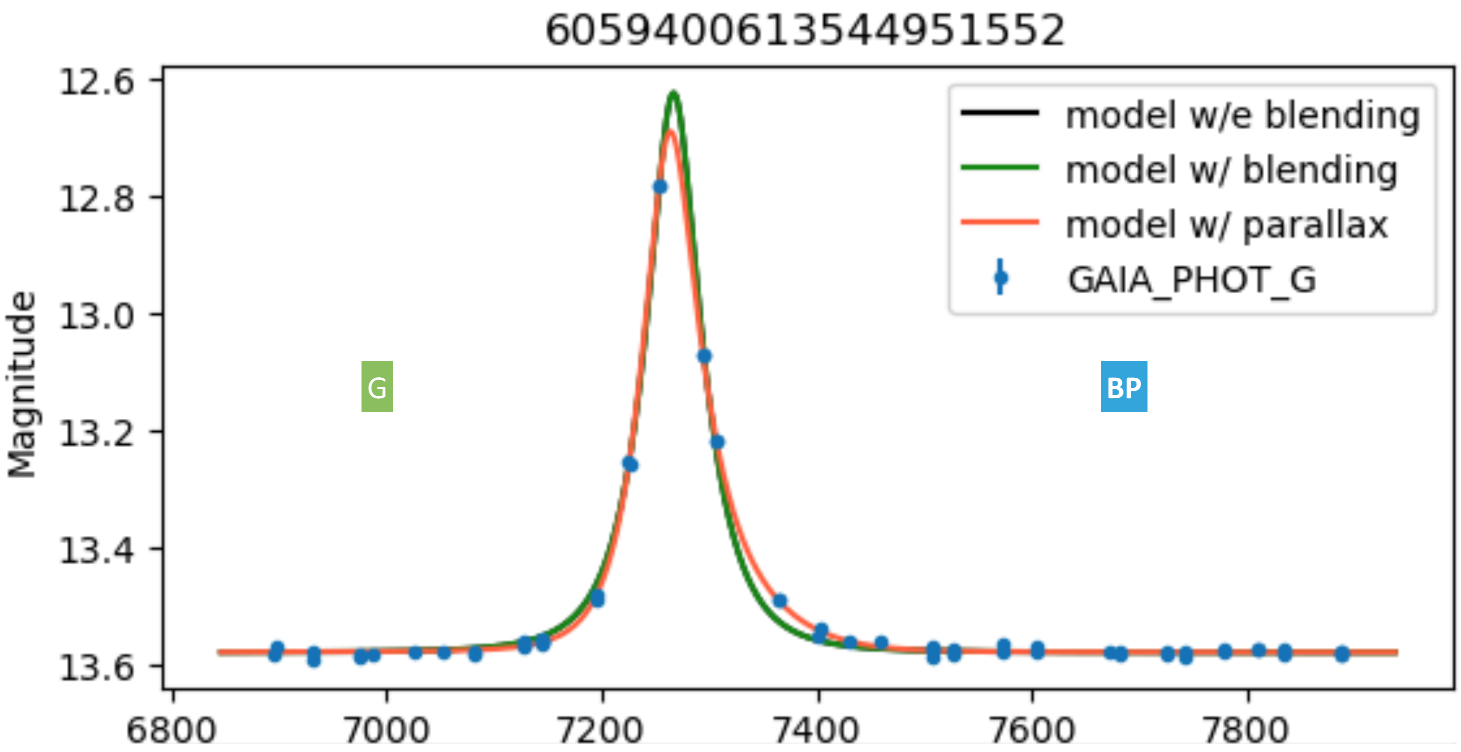
1936: Einstein: computed but said there is no great chance of observing this phenomenon

1964: Refsdal made the modelling

1986: Paczynski proposed to do a survey to detect dark matter in the form of dark dense objects

It turns out that in the bulge microlensing is common it is about 1 in 500 variable stars!

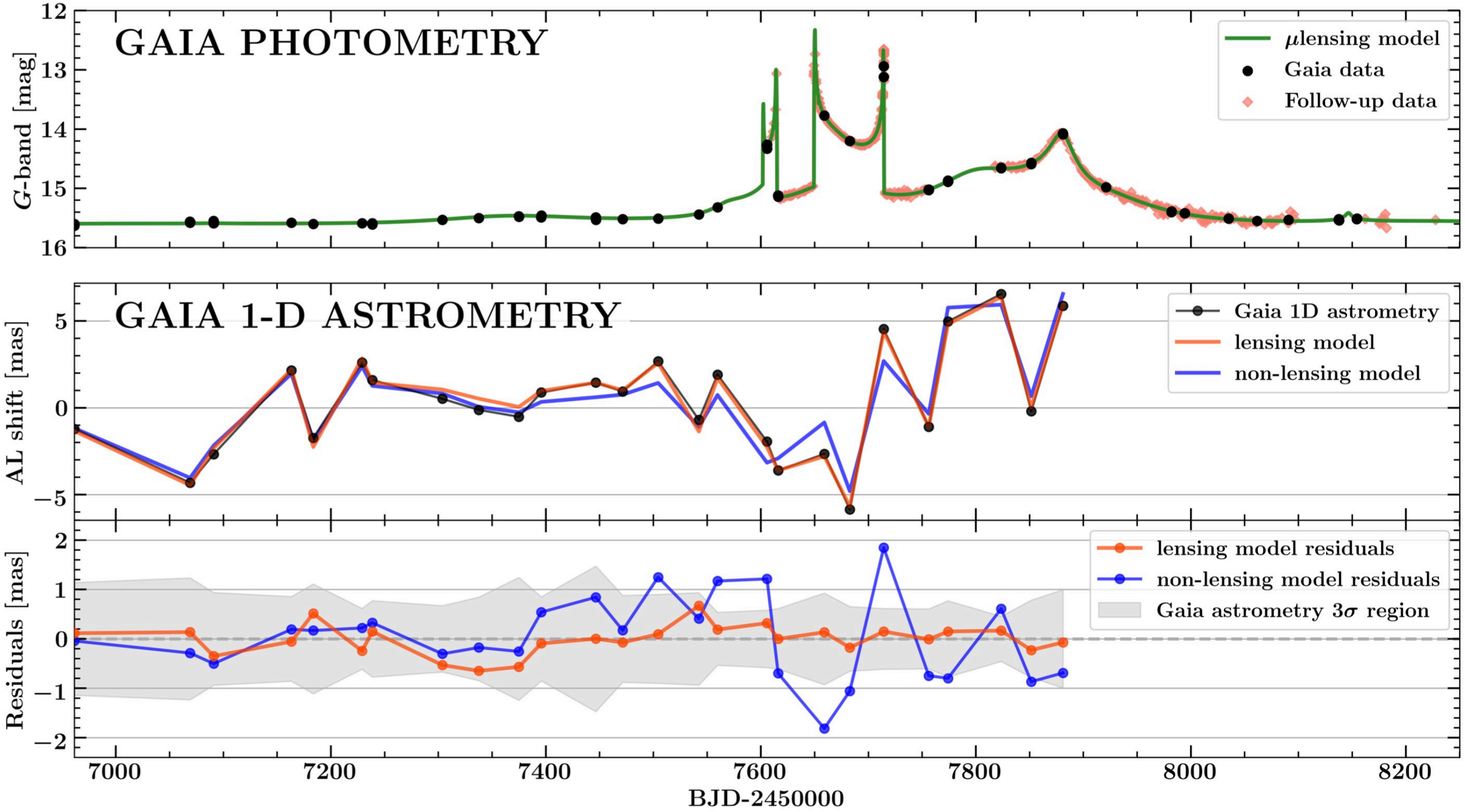
Microlensing: A new event



Time [days]

Since then some results of Gaia

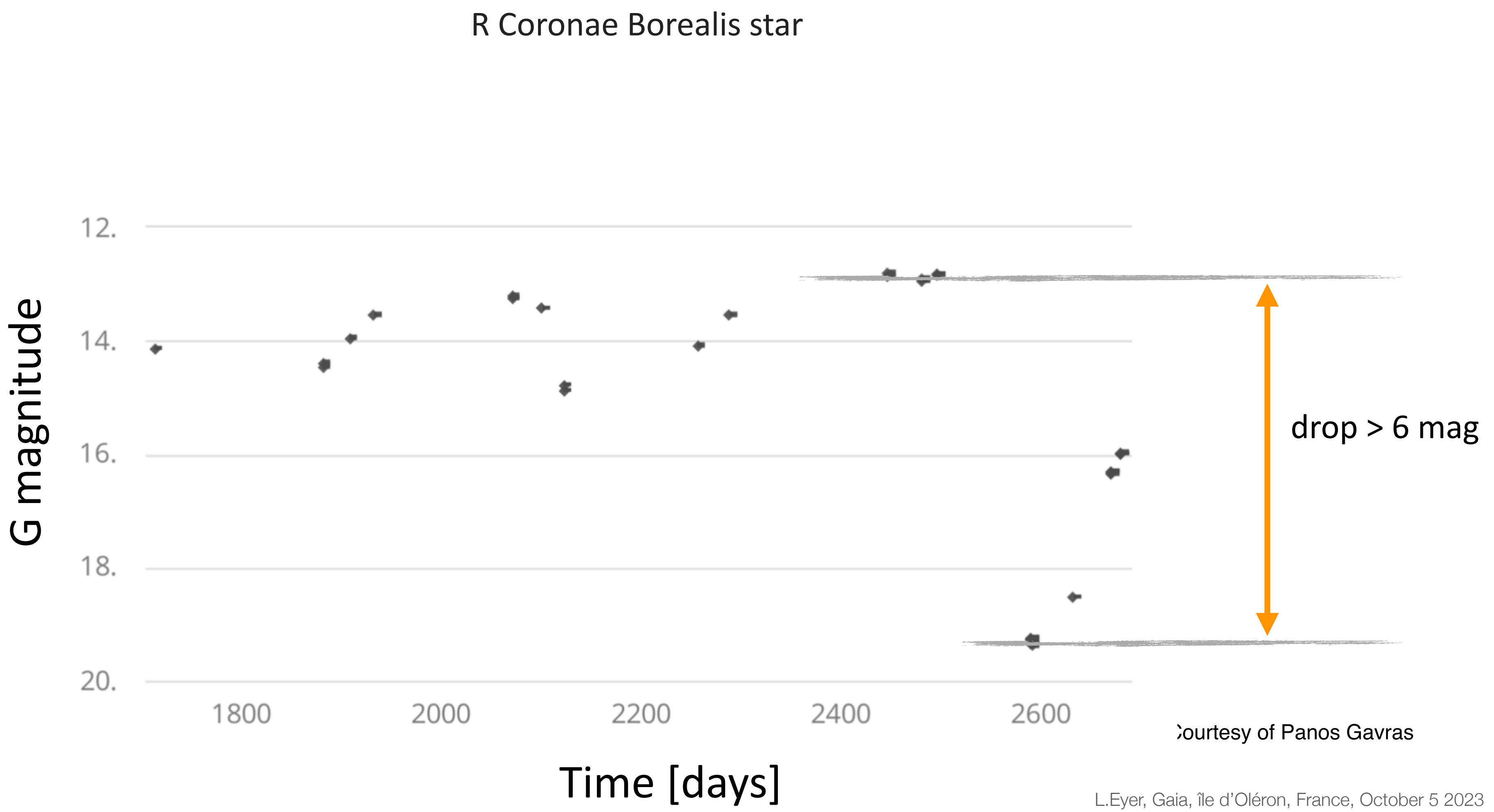
Astrometric microlensing
(October 9, 2021)



Only way
to detect
single black holes

etc...

R Coronae Borealis stars



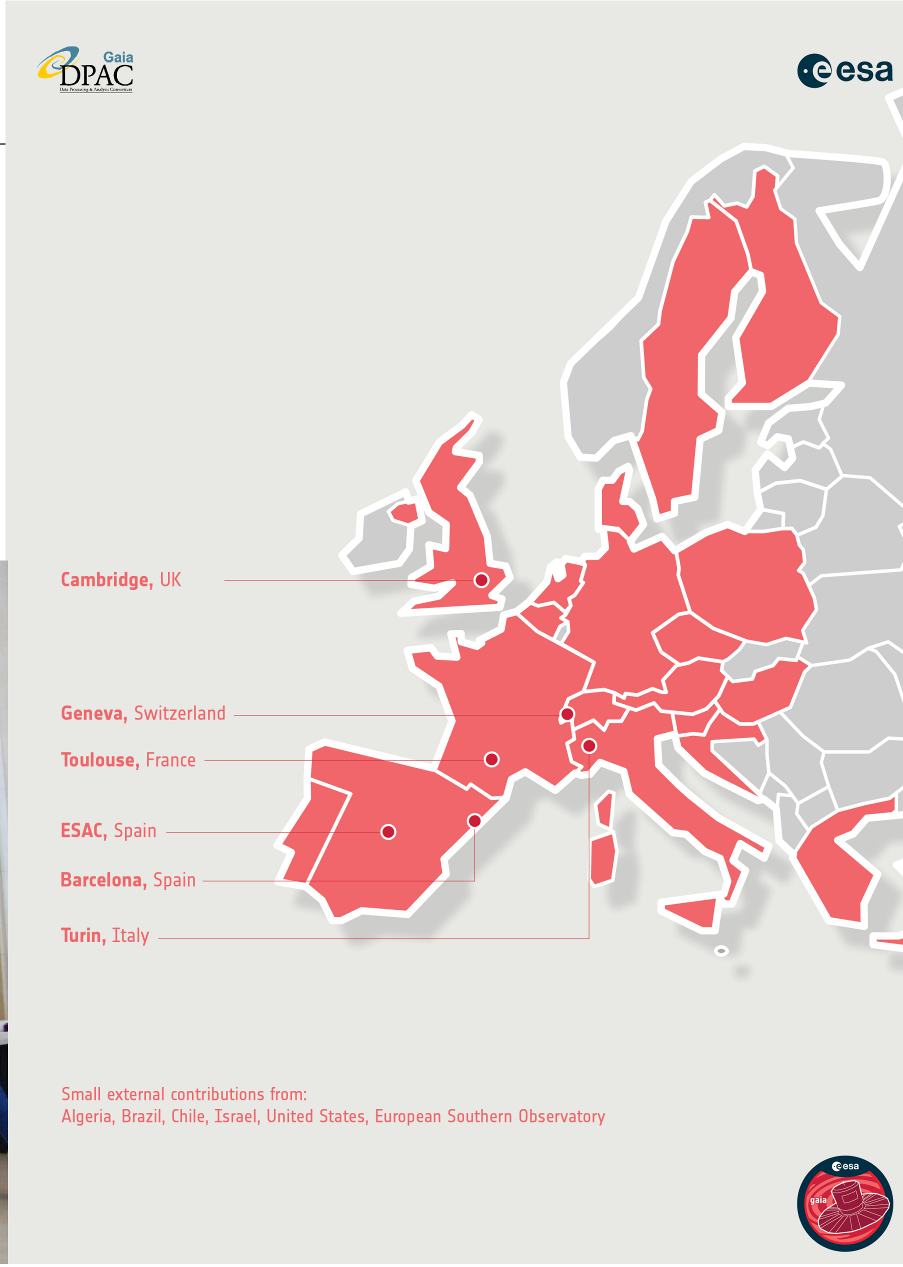
etc…

Questions?

Variability processing and analysis by the Gaia consortium

Data Processing and Analysis consortium

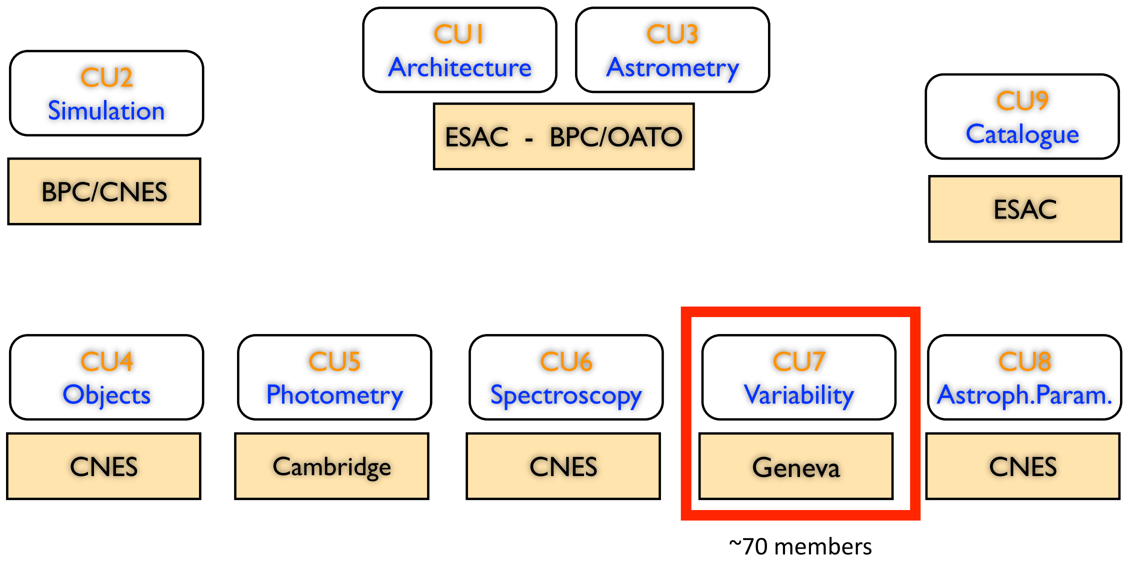
A mostly European Consortium
of 450 people



Gaia Data Processing and Analysis Consortium (DPAC)

A consortium of ~450 people to deal with the data

Two concepts:
1. Coordination units
2. Data Processing Center



There is a coordination done by the Consortium executive (DPACE) and a “project office” (PO)

After launch: Unexpected issues detected during commissioning

Happy launch, then:

- Gaia seen from Earth is fainter than thought
- There is a varying stray-light on the focal plane
- The Basic Angle Monitor measures larger variations than expected
- Some evaporation escapes from the service module and contaminates the mirrors
- There are many more clanks/micrometeoroid hits than initially thought

Cyclic improvements in the Gaia consortium

Intermediate releases contain variability information with the delivery of time series data, this from DR1

	DR1 (Sept. 2016)	DR2 (Apr. 2018)	DR3 (June 2022)	DR4 (2025)	DR5 (2030)
CU7/DPCG	3,194 stars	550,737 stars	10.5 millions	50-100 millions	80-120 millions
	FoV G-band	FoV G-band (per CCD Phot.) Astrometry BP/RP integrated	FoV G-band per CCD Phot. Astrometry BP/RP integrated BP/RP spectra Radial Velocity	All information	All information
	2 Variability Types	7 Variability Types	24+1 Variability Types	All Possible Variability Types	Variability types we missed... and new types!

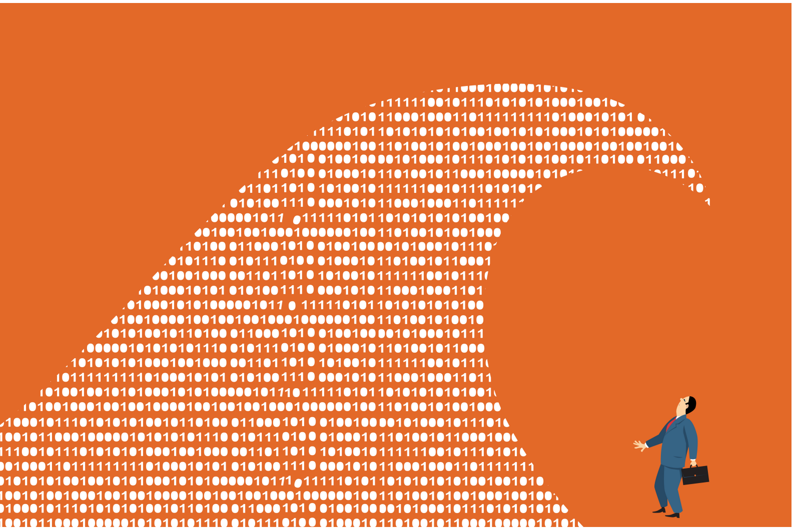
This progressive and iterative approach is lowering risks

http://www.materaphoto.com/outdoor-adventure/

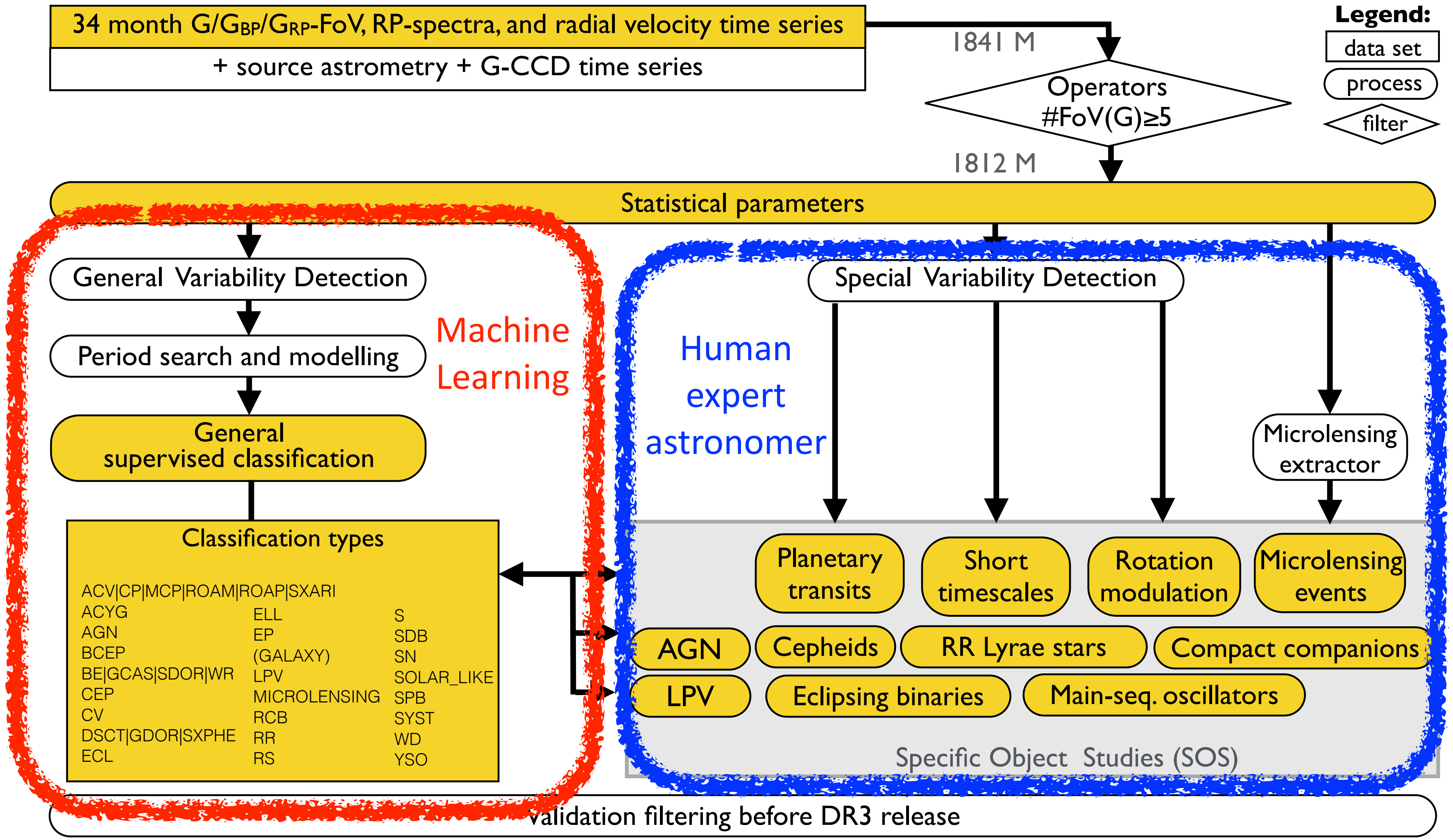
Gaia data

Diverse data:
- Unprecedented astrometry (positions, parallaxes, proper motions)
- Unprecedented photometry (G, BP, RP)
- Unprecedented Spectroscopy

Enormous amount of data: **DR3 nearly one trillion photometric measurements!**



Software pipeline



DR1: just a show case in a part of the Large Magellanic Cloud

(September 2016)

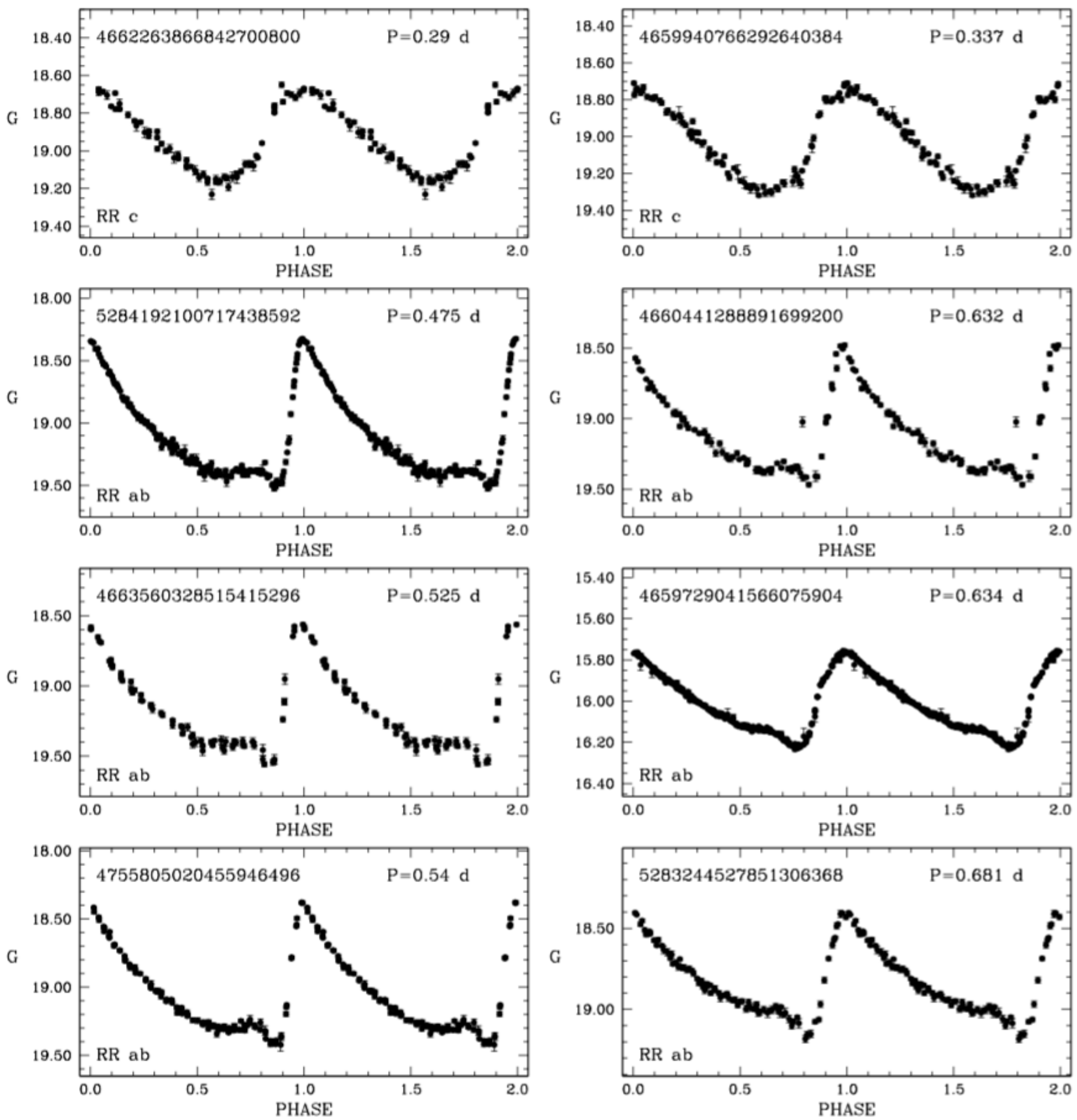
Variables in the First data release
G-band photometric time series:

3,194 variables (386 new)

599 **Cepheids** (43 new)

2,595 **RR Lyrae stars** (343 new)

>1,000 new !
An OGLE release “just” before DR1



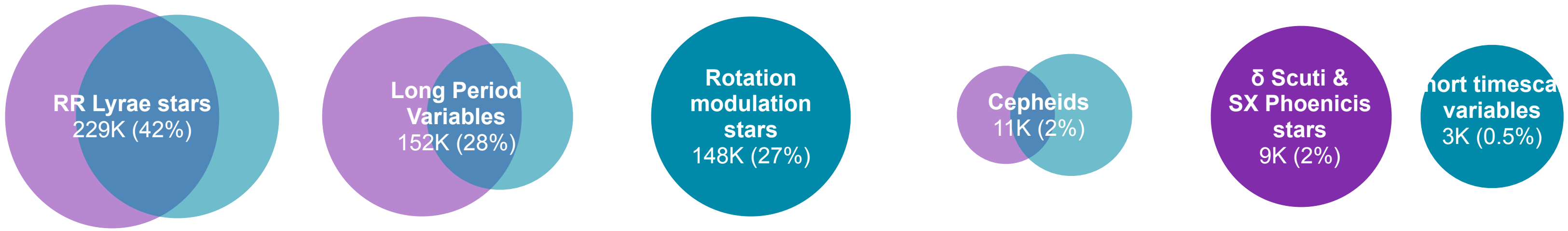
L.Eyer, Gaia Science Alert, Malta, October 4 2023

Variable stars in Gaia DR2

(April 2018)

550,737 Variable Stars

Violet filled circles: Classification
Rimoldini et al. 2019



Clementini et al. 2019

Mowlavi et al. 2018

Lanzafame et al. 2018

Clementini, Ripepi et al. 2019

Rimoldini et al. 2019

Roelens et al. 2018

Lebzelter et al. 2018

Ripepi et al. 2019

Muraveva et al. 2018

Courtesy of B.Holl, modified by L.Eyer

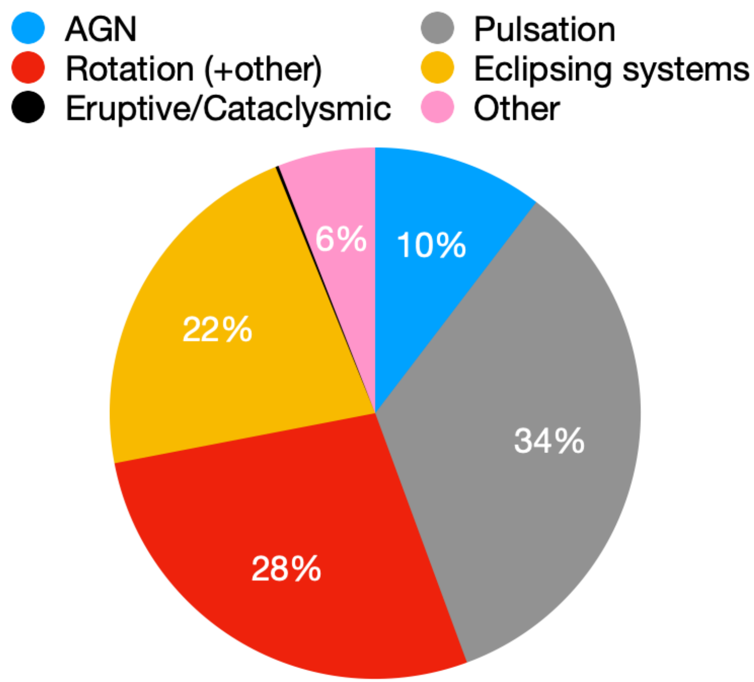
The variability content of DR3

Reminder about the DR3 for variables:

Largest data set of classified variable on the whole sky

10.5 million variable sources {
- **9.5 million variable stars**
- **1 million AGN/quasars**

2.5 million galaxies



DR3 articles related to variability

Variability in DR3: 16 published articles

GAIA ANDROMEDA PHOTOMETRIC SURVEY

(01) The Gaia Andromeda Photometric Survey, Evans, et al.

VARIABLE STAR CLASSIFICATIONS AND LIGHTCURVES

(02) Summary of the variability processing and analysis, Eyer, et al.

(03) Classification of 12 million variable sources into 25 classes, Rimoldini, et al.

(04) Cross-match of Gaia EDR3 sources with variable objects from the literature, Gavras, P.

(05) Ellipsoidal Variables with Possible Neutron-Star or Black-Hole secondaries, Gomel, et al.

(06) Solar like variability, rotation modulation stars, Di Stefano, et al.

(07) Validating the classification of Young Stellar Object Candidates, Marton, et al.

(08) The second Gaia catalogue of long-period variable candidates, Lebzelter, et al.

(09) The first catalogue of Gaia eclipsing binaries - Candidate identification, Mowlavi, et al.

(10) Specific processing and validation of all-sky RR Lyrae and Cepheid stars - the Cepheid sample, Ripepi, et al.

(11) Specific processing and validation of all-sky RR Lyrae and Cepheid stars - the RR Lyrae sample, Clementini, et al.

(12) The first catalogue of variable active galactic nuclei, Carnerero, et al.

(13) Microlensing events from all over the sky, Wyrzykowski, et al.

(14) Scan-angle dependent signals and spurious periods, Holl, et al.

PERFORMANCE VERIFICATION PAPERS

(15) Pulsations in main-sequence OBAF stars as observed by Gaia, Gaia Collaboration, De Ridder, J., et al.

(16) The extragalactic content, Gaia Collaboration, Bailer-Jones, C.A.L., et al.

DOCUMENTATION

(17) Gaia DR3 documentation, van Leeuwen

Gaia DR3 is breaking many records

2.3 million LPVs (Lebzelter 2023, Rimoldini et al. 2023)

2.3 million stars with rotation modulation-BY Dra/UV Ceti stars (Distefano et al. 2023, Rimoldini et al. 2023)

2.2 million eclipsing binaries (Mowlavi et al. 2023)

0.3 million RR Lyrae stars (Clementini et al. 2023, Rimoldini et al. 2023)

…

The DR3 results for the variable sources

Variability type/type group	Total
α^2 CVn and associated stars	10 779
α Cygni stars	329
Active galactic nuclei or QSO	1 035 254
β Cephei stars	1475
Be stars, γ Cas and associated stars	8560
Cepheids	16 175
Cataclysmic variables	7306
δ Scuti/γ Doradus/SX Phoenicis stars	748 058
Eclipsing binaries	2 184 496
Ellispoidal variations	65 300
Exoplanetary transits	214
Long-period variables	2 326 297

Variability type/type group	Total
R Coronae Borealis stars	153
RR Lyrae stars	297 981
RS Canum Venaticorum	742 263
Subdwarf B stars	893
Short-timescale	983 185
Supernovae	3029
Solar-like variability	2 306 297
Slowly pulsating B star	1228
Symbiotic System	649
Variable white dwarfs	910
Young stellar objects	79 375

Eyer, Audard, Holl+ 2023

Completeness and Contaminations

Group	Variability type	Catalogue (and region)	Completeness	Contamination
AGN	agn	Gaia-CRF3	51%	$\leq$ 5%
AGN	agn	SDSS-DR16Q[a]	47%	$\leq$ 5%
Cepheids	Classical Cepheids	OGLE IV (MW)	> 86%	<2%
Cepheids	All Cepheids	OGLE IV (LMC & SMC)	~ 90%	<1%
Eclipsing binaries	eclipsing_binary	OGLE-IV (LMC/SMC/Bulge)	33/45/19%	~5%
LPV	long_period_variable	ASAS-SN and OGLE III-LPV [b]	79–83%	0.7–2%
Microlensing	microlensing	OGLE-IV (Bulge, Disk)	30-80%	< 1%
Rotation modulation	rotation_modulation	ZTF	0.4 % [c]	6%
Rotation modulation	rotation_modulation	ASAS-SN	0.4%	14%
RR Lyrae stars	rrlyr	OGLE-IV (LMC)	83%	<1.8%
RR Lyrae stars	rrlyr	OGLE-IV (SMC)	94%	<8%
RR Lyrae stars	rrlyr	OGLE-IV (Bulge-up)	79%	<0.15%
RR Lyrae stars	rrlyr	OGLE-IV (Bulge-down)	82%	-

Eyer, Audard, Holl+ 2023

Summary of properties - SOS

Variability type	Number	Trimmed range Q01 /Q50/ Q99	BP/RP median (Q50)	Period/Time scale Q01/Q50/Q99
AGN	872 184	0.11/0.39/0.91	1.1	
Compact Companions	6 336	0.13/0.16/0.21	1.0	0.25/0.42/1.5
Cepheids	15 238	0.10/0.46/1.1	1.6	1.0/3.9/58
Eclipsing binaries	2 184 477	0.04/0.28/0.85	1.1	0.22/0.48/29
Long Period Variables	1 720 588	0.10/0.2/2.5	2.2	37/246/861
Microlensing events	363	0.08/0.52/3.0	1.0	8.7/60/1845
MainSequence Oscillators	54 476	0.02/0.04/0.5	1.7	0.04/0.09/7.9
Planetary transits	258	0.005/0.017/0.05	1.2	0.51/1.3/20
Rotation Modulation	474 026	0.007/0.03/0.19	1.5	0.32/2.2/26
RR Lyrae stars	272 428	0.19/0.54/1.1	1.6	0.39/0.57/0.81
– RRab	272 428	0.20/0.67/1.1	1.5	0.39/0.57/0.81
– RRc	272 428	0.17/0.38/0.7	1.6	0.22/0.32/0.43
– RRd	272 428	0.35/0.51/1.0	1.4	0.36/0.49/0.59
Short time scale	471 679	0.07/0.13/0.8	1.2	0.01/0.14/0.86

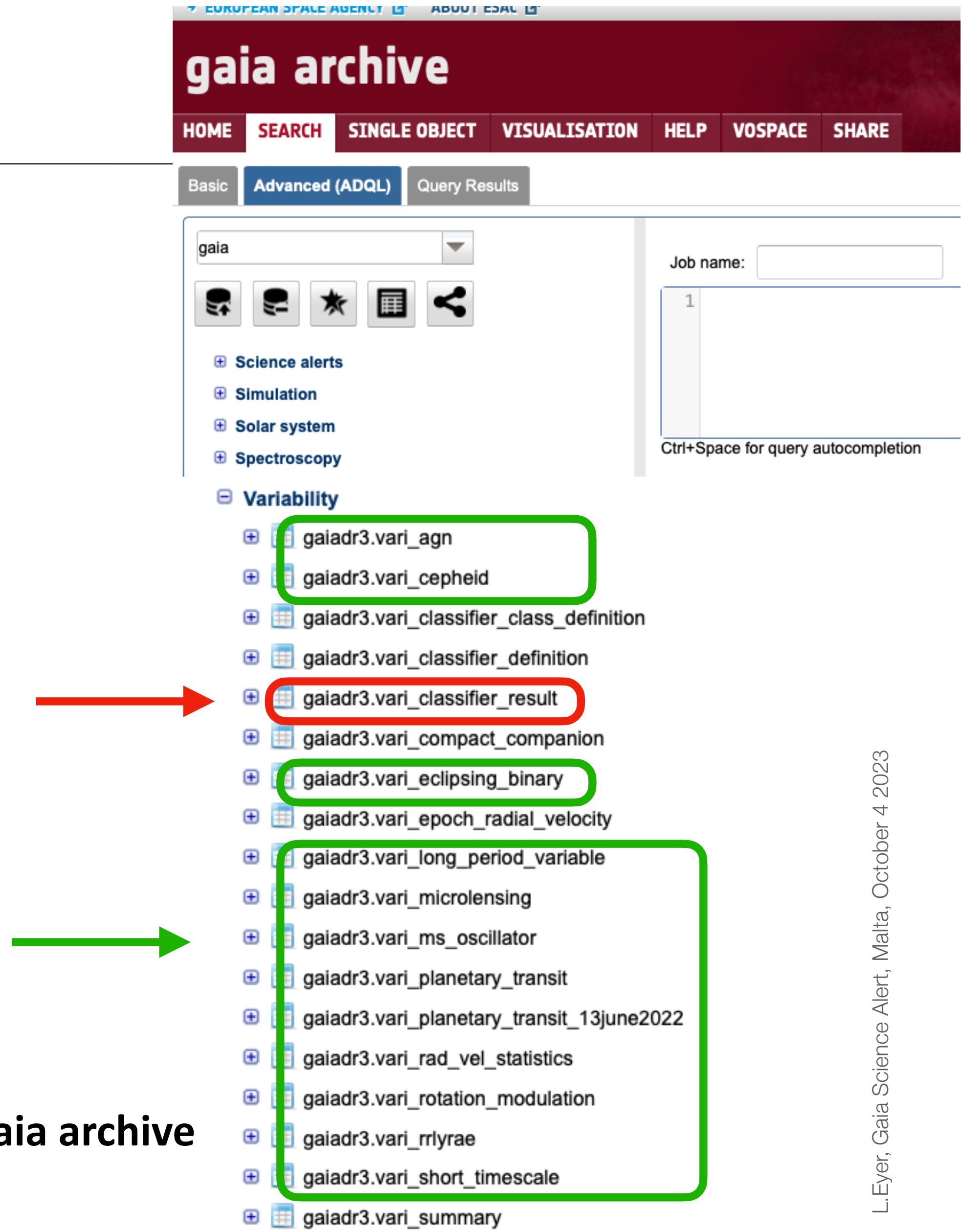
Eyer, Audard, Holl+ 2023

The Gaia DR3 results on variables

There are two sources for the variability classes

(1) the general classification

(2) the Specific Object Studies (SOS)



All the time series are published and are available from the Gaia archive

Colour magnitude diagram

The Large Magellanic Cloud

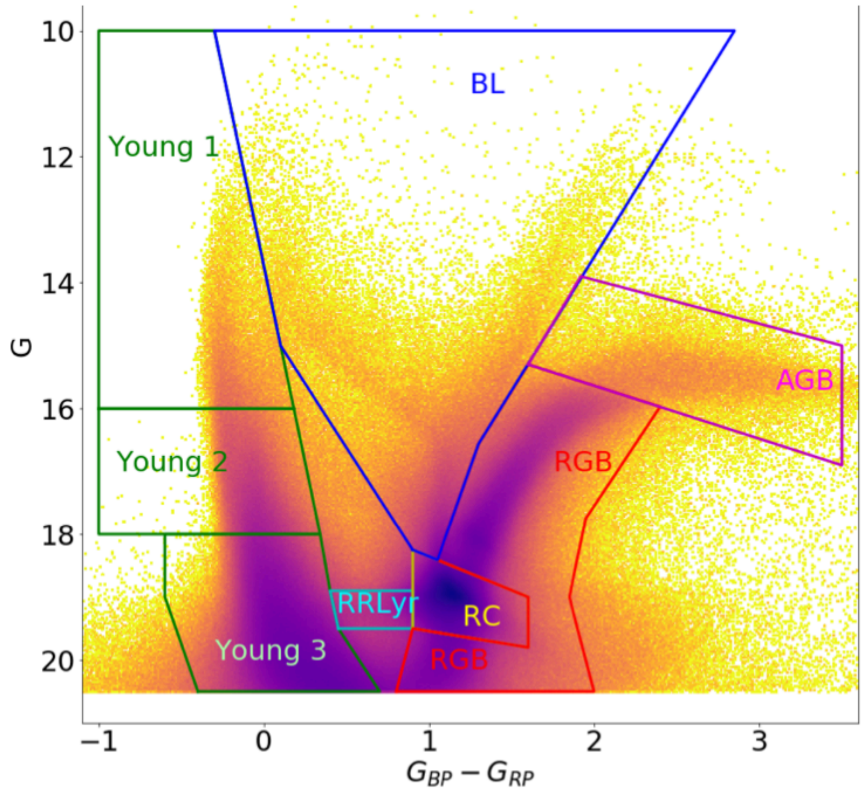
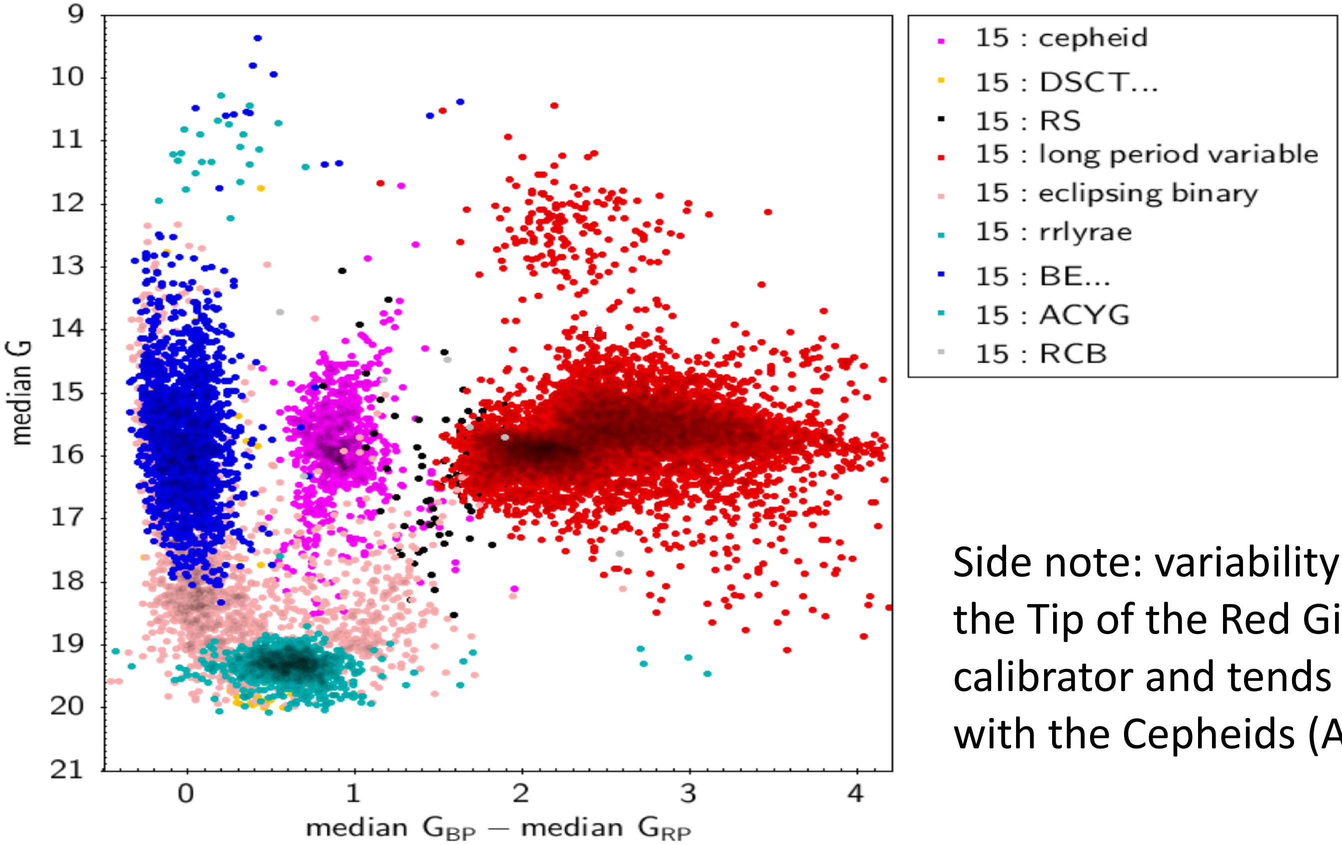


Fig. 2. Areas (as defined by the polygons given in the text) of the CMD for the LMC not corrected for reddening for the selection.

Gaia collaboration, Luri et al. 2021

Colour magnitude diagram

The Large Magellanic Cloud



Side note: variability helps to understand better the Tip of the Red Giant branch as a distance scale calibrator and tends to reconcile TRGB estimate with the Cepheids (Anderson, Koblischke, Eyer 2023)

Eyer, Audard, Holl+ 2023

Gaia Citizen Science project

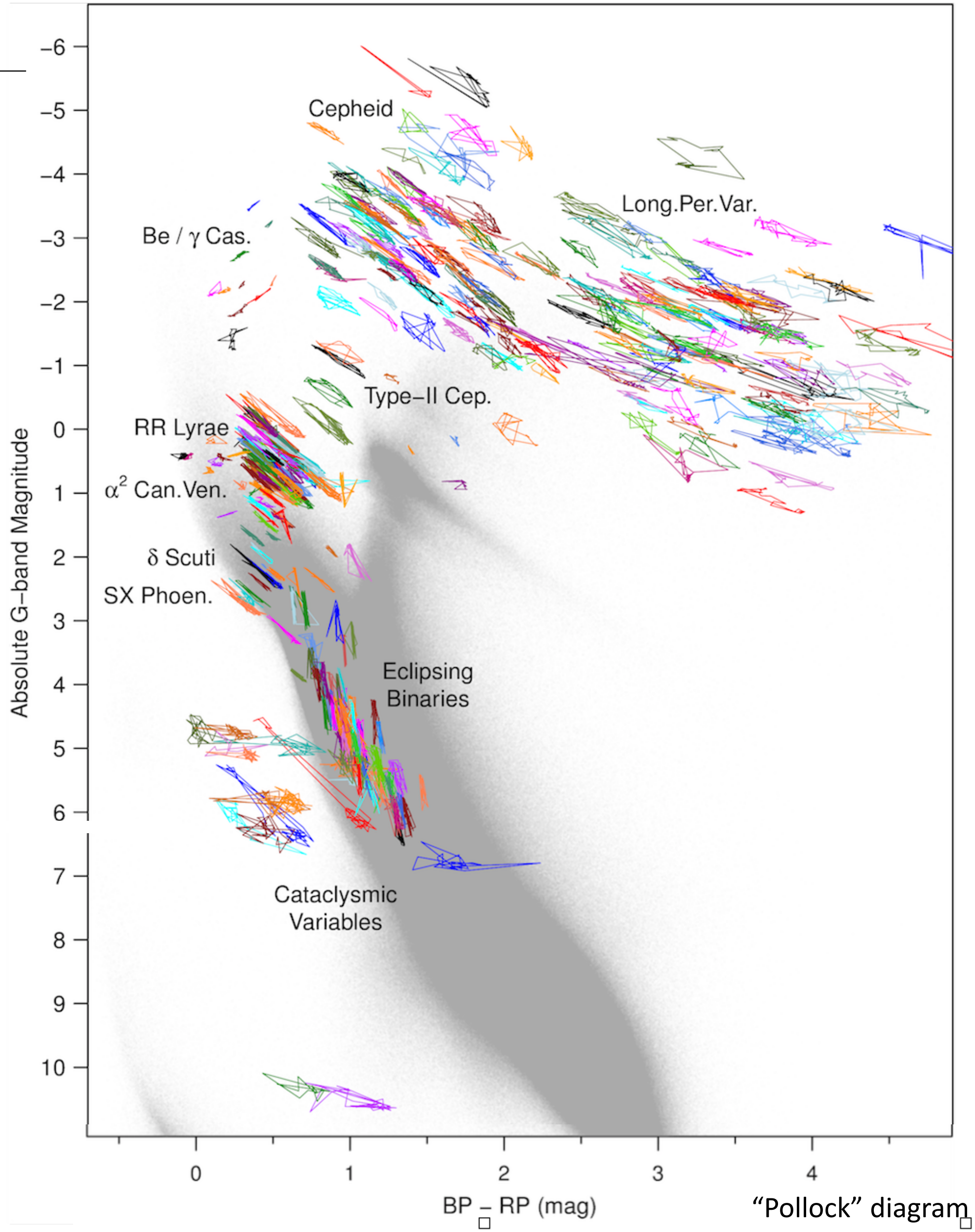
Variable stars in the Hertzsprung-Russell

Results of our "Gaia" work in Gaia DR3:

10.5 million classified variables sources

Classification with Artificial Intelligence:
Machine Learning
Expert Astrophysicist Procedural approaches

with the help from Citizen Science
It acts as a validation of the classification of DR3



"Pollock" diagram

GaiaVari: A Citizen Science Project around variable stars observed by Gaia

Pedro Garcia Lario wrote a successful proposal to ESA

Two goals

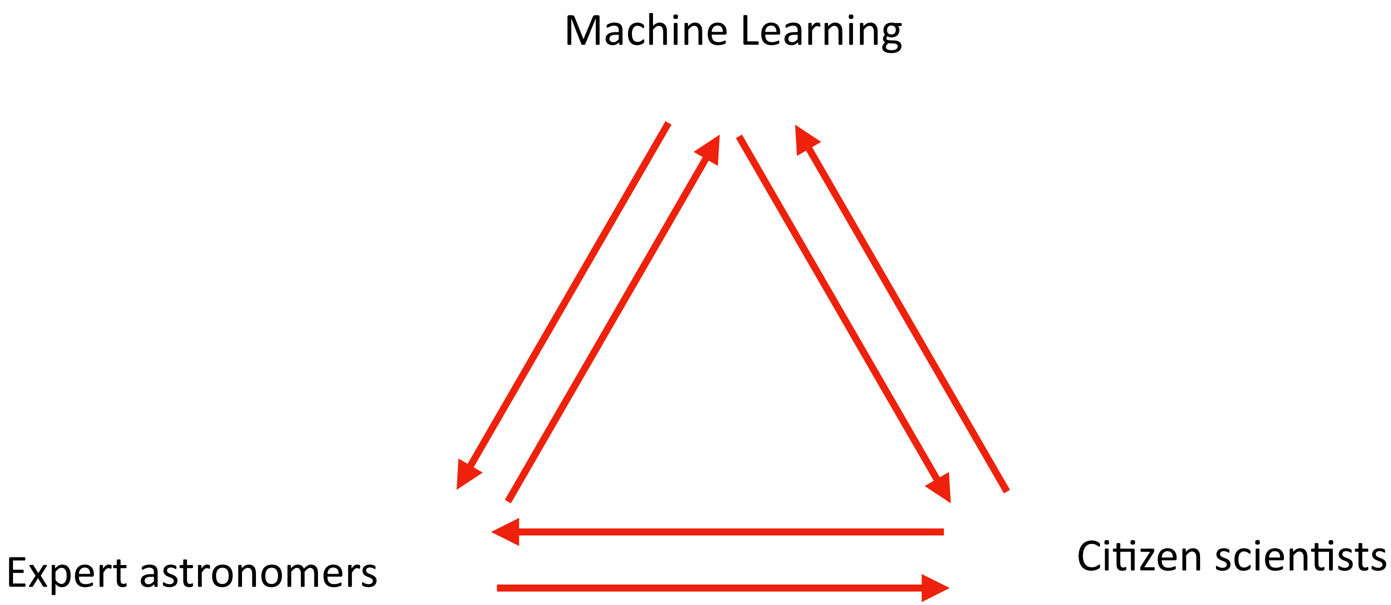
1. Enhance Gaia awareness —> Public Relation, improve visibility
2. Help the processing for the future DR4/DR5, improve knowledge of the variable sky

Chosen Platform: Zooniverse

Main actors:

ESA - Pedro Garcia Lario
Sednai company - Krzysztof Nienartowicz and Elsa Mathias
University of Geneva - Laurent Eyer and Grégoire Pingeon, Marc Audard, +
ScienceNow - Milena Ratajczak and Jan Pomierny

GaiaVari: A Citizen Science Project around variable stars observed by Gaia



One of the most read tabloids in Switzerland

20 minutes

Lausanne
MERCREDI
26 AVRIL 2023
4 °C / 14 °C

Experts du vol de sacs dans les trains

VAUD Un homme est accusé d'avoir sévi pendant quatre mois sur la ligne Genève-Zurich. Avec, à la clé, un butin de près de 20'000 fr. Selon la justice, le voleur de bagages profitait des siestes des passagers ou les distrayait à l'arrêt du train pour dérober leurs affaires. Deux complices les débarquaient du wagon et faisaient main basse sur les valeurs. Une partie des objets dérobés a été retrouvée dans un appartement de Bienne (BE), qui leur servait de camp de base. Jugé hier au Tribunal de Nyon, l'accusé risque la prison ferme et l'expulsion. **PAGE 2**

Monde 8
Joe Biden, 80 ans, veut rempiler jusqu'en 2028

Musique 15
Irène Drésel soufflera les vingt bougies d'Electron

Sport 19
En s'imposant, Bienne s'offre un match décisif

Sur notre app

En vidéo 14
La victoire du duo des «Apprentis aventuriers»

Football 18
Servette - Zurich est à suivre en direct dès 20 h 30

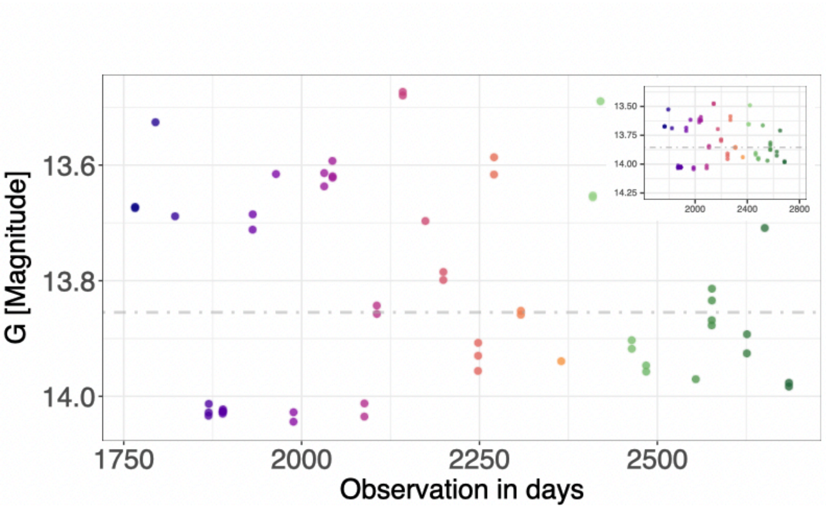
Leur passion: compter les étoiles

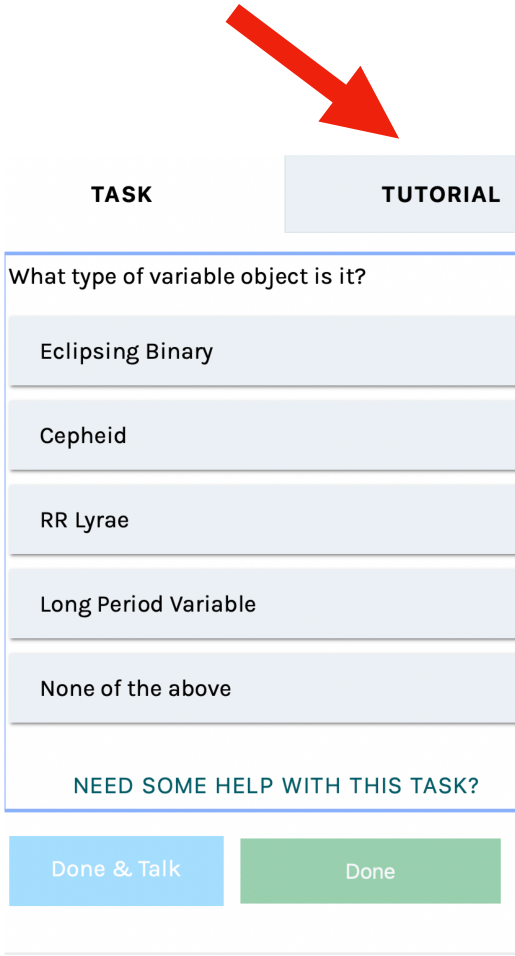
Les amateurs sont appelés à décortiquer les images collectées par le satellite de l'Agence spatiale européenne. -ESA

GENÈVE L'Uni recrute des yeux pour aider les astronomes professionnels à cataloguer les innombrables astres de la Voie lactée. Leur mission: analyser les images récoltées par le satellite Gaia. Actuellement, quelque 600 amateurs y contribuent. «Il y a des cas où les citoyens sont meilleurs que les scientifiques», souligne le chercheur Laurent Eyer. D'ici à la fin de l'année, le but est de classer 100'000 étoiles parmi les 10 millions déjà recensées. **PAGE 3**

GaiaVari a citizen science project

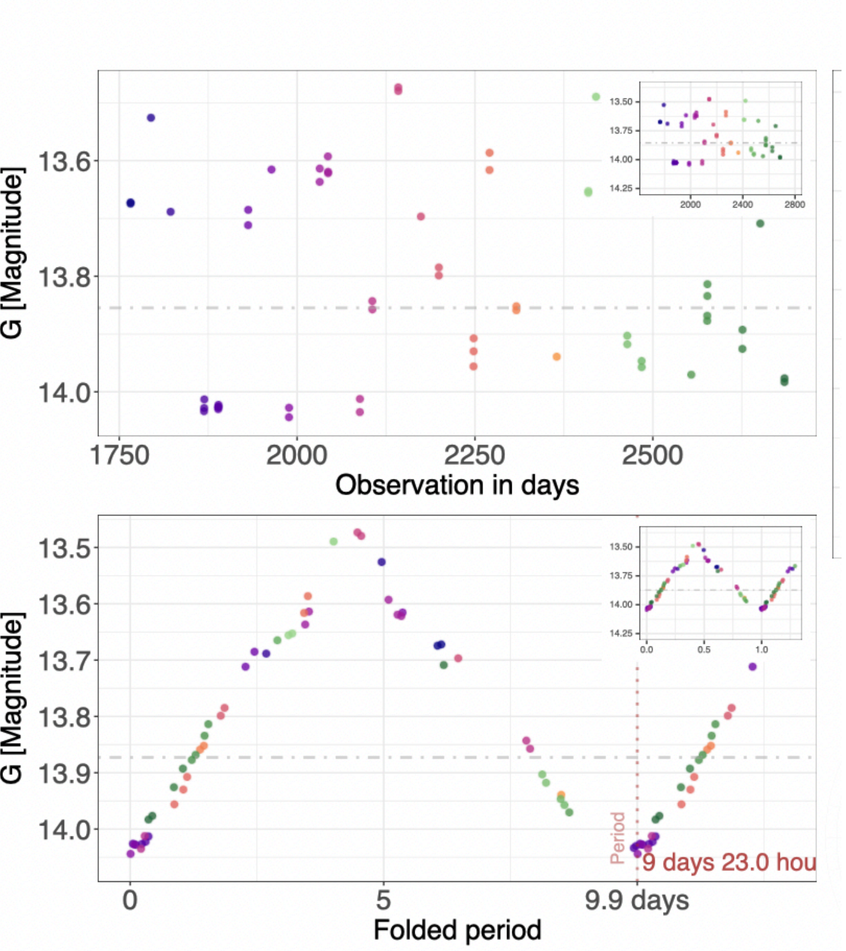
https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari

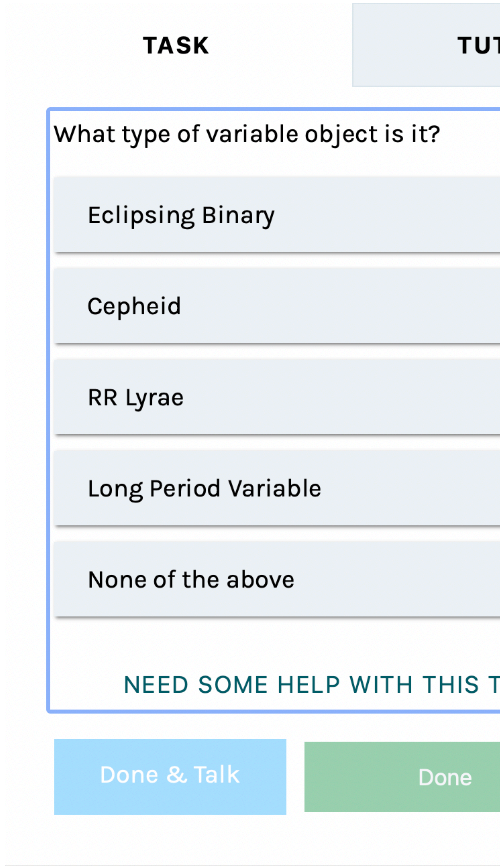




GaiaVari a citizen science project

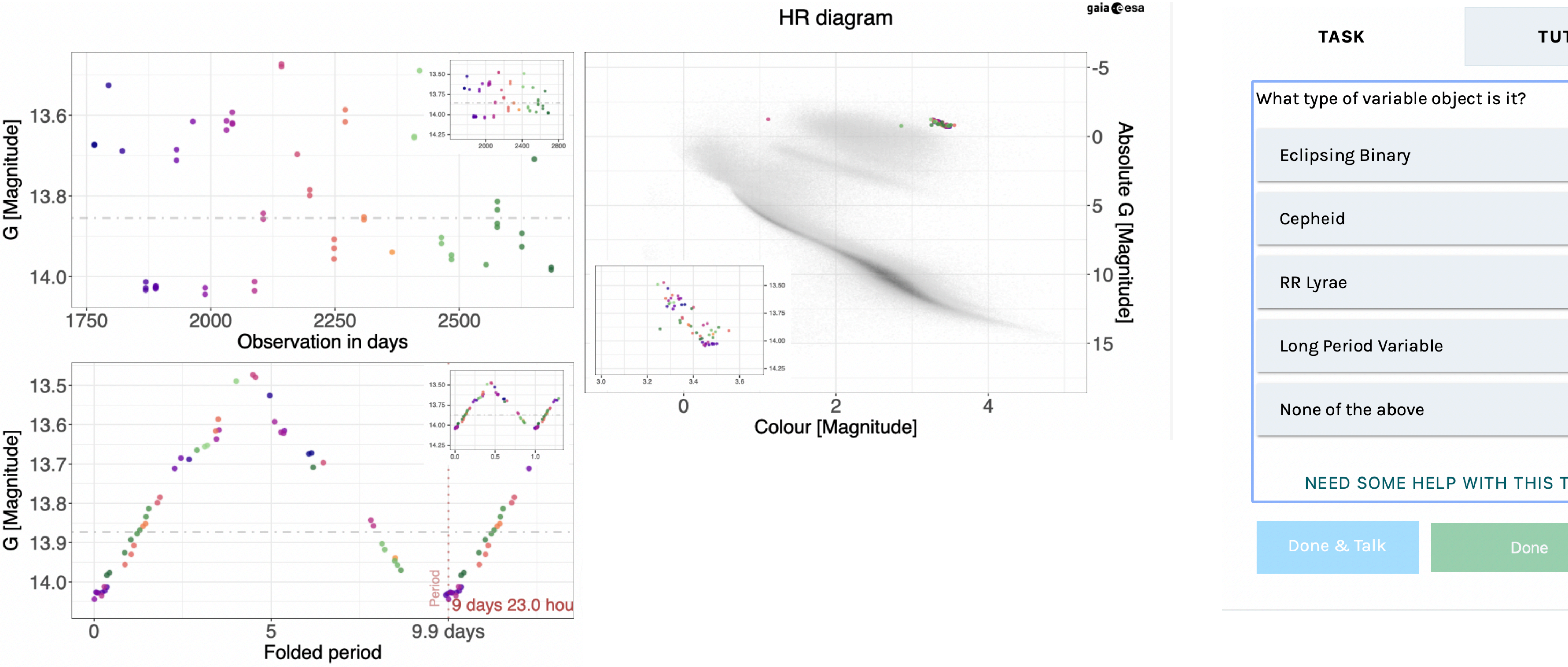
https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari





GaiaVari a citizen science project

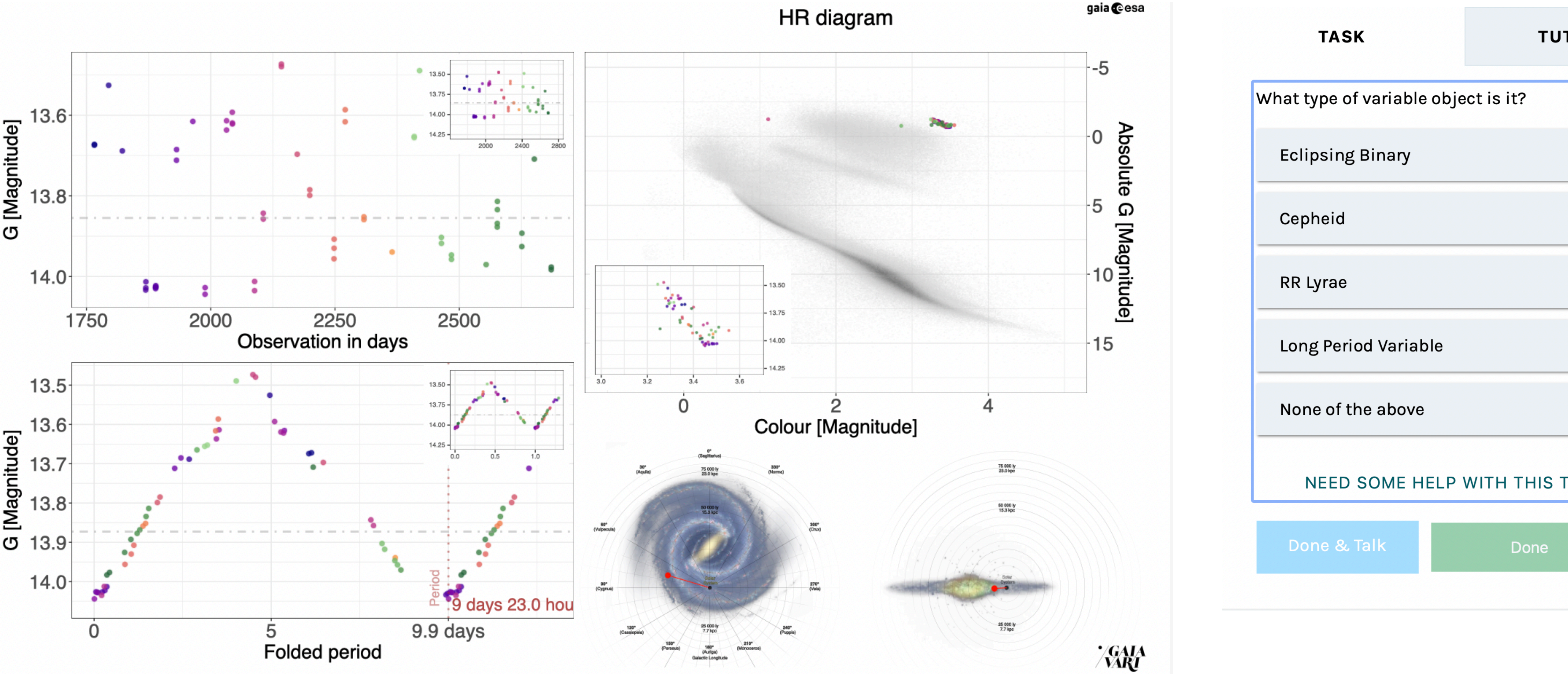
https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari



GaiaVari a citizen science project

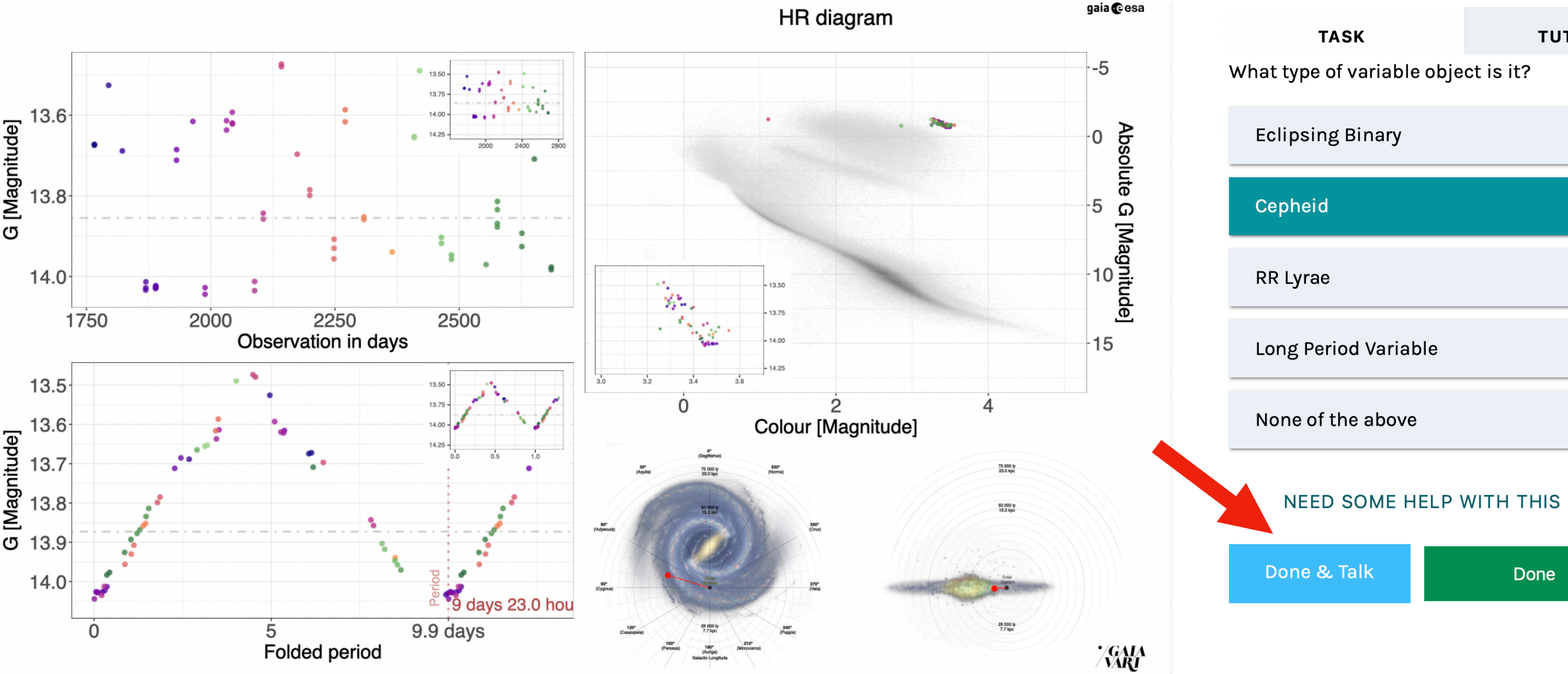
https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari

Any guess?



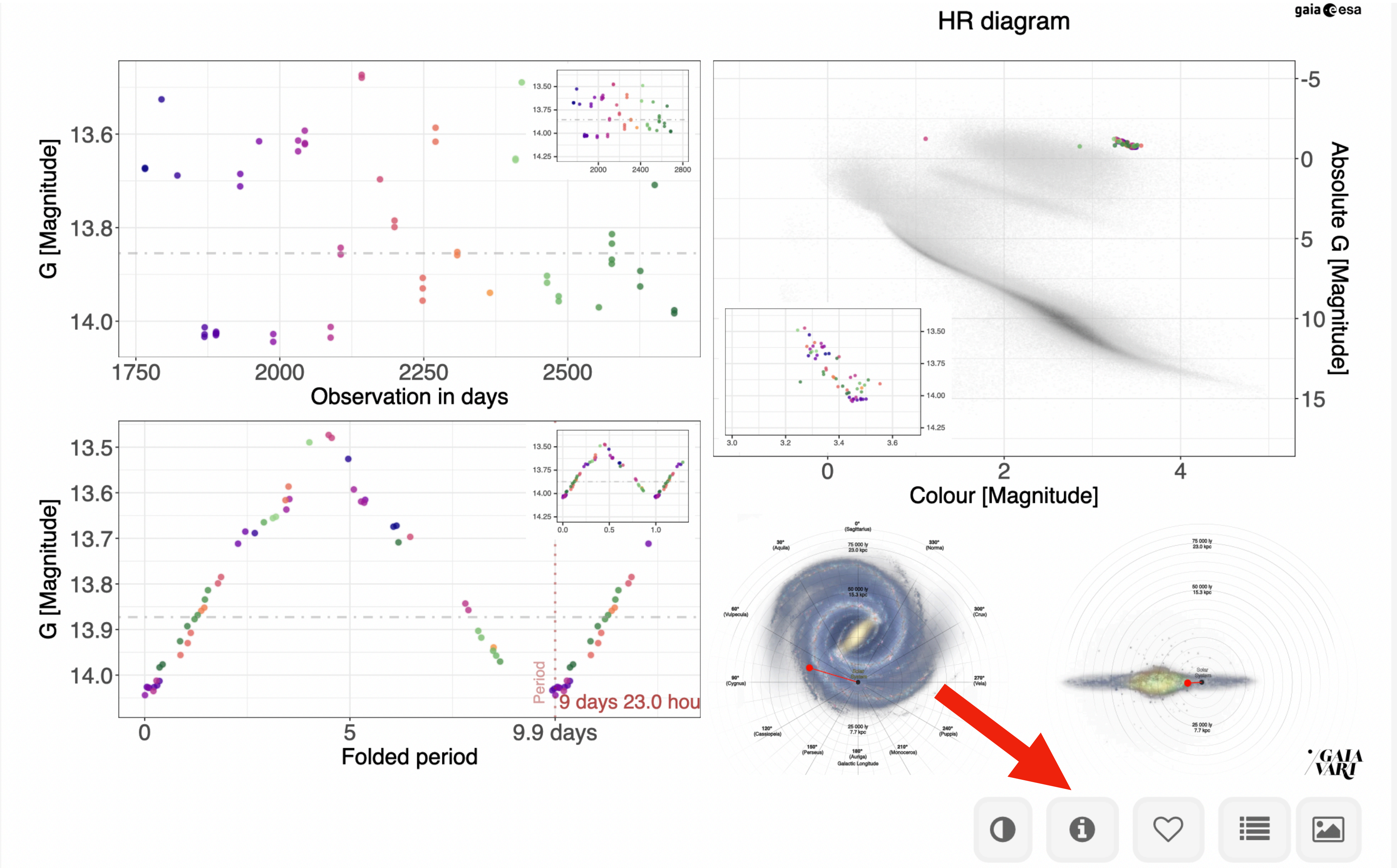
GaiaVari a citizen science project

https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari



GaiaVari a citizen science project

https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari



GaiaVari a citizen science project

SUBJECT METADATA

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delta_rad	0.61151341722628727
color_median	3.38140011
g_median_mag	13.8520002
g_amplitude_mag	0.545510017693157323
parallax_to_error	6.70240021
EsaSky_position_URL	https://sky.esa.int/esasky/?target=305.236393035616288%2035.0371379226888706&hips=DSS2+color&fov=0.33400777517464325&cooframe=J2000&sci=false&lang=en
g_absolute_median_mag	-0.863875338529165759
gaia_variability_type	CEP
gaia_classification_score	0.658270563422717947
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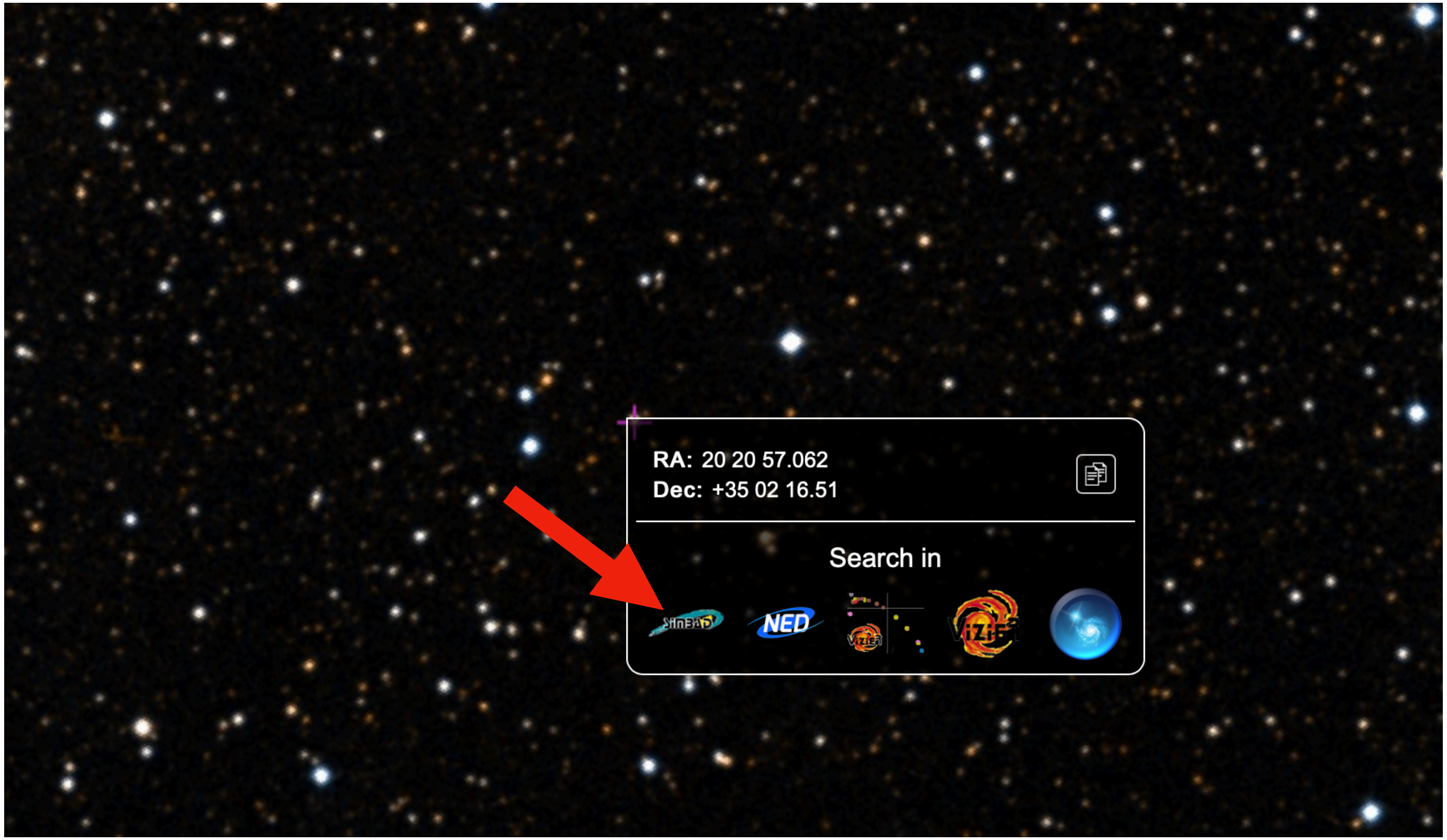
GaiaVari a citizen science project

ESASky



GaiaVari a citizen science project

Portal | Simbad | VizieR | Aladin | X-Match | Other | Help

ATO J305.2363+35.0371

other query modes : Identifier query | Coordinate query | Criteria query | Reference query | Basic query | Script submission | TAP | Output options | Help

Query : ATO J305.2363+35.0371

Basic data :

ATO J305.2363+35.0371 -- Classical Cepheid Variable

Other object types:	**cC*** (2019Sci), ***** (UCAC4,Gaia), **Pu*** (2018AJ), **V*** (ASASSN), **NIR** (2MASS), **Opt** (ATO)
ICRS coord. *(ep=J2000) :*	**20 20 56.7383977693 +35 02 13.773054249 (Optical) [0.0122 0.0145 90] A 2020yCat.1350....0G**
FK4 coord. *(ep=B1950 eq=1950) :*	20 19 01.2331233395 +34 52 39.272715834 [0.0122 0.0145 90]
Gal coord. *(ep=J2000) :*	073.7123918478962 -00.8957183981613 [0.0122 0.0145 90]
Proper motions *mas/yr* :	**-3.124 -4.783 [0.016 0.018 90] A 2020yCat.1350....0G**
Radial velocity / Redshift / cz :	**V(km/s) -26.72 [3.23]** / z(spectroscopic) -0.000089 [0.000011] / cz -26.72 [3.23] **(Opt) C 2022yCat.1355....0G**
Parallaxes *(mas)*:	**0.1140 [0.0170] A 2020yCat.1350....0G**
Fluxes (5) :	**R 14.944 [0.16] E 2012yCat.1322....0Z**
	G 13.830250 [0.008159] C 2022yCat.1355....0G
	J 9.793 [0.024] C 2003yCat.2246....0C
	H 8.832 [0.027] C 2003yCat.2246....0C
	K 8.460 [0.017] C 2003yCat.2246....0C

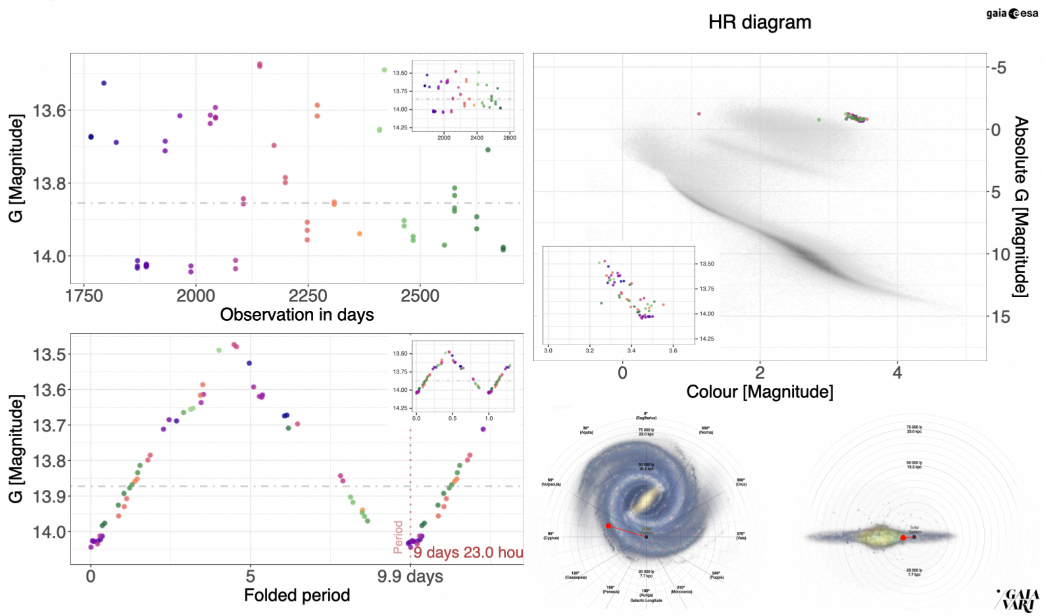
GaiaVari a citizen science project

https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari

d0ct0r
@d0ct0r

March 24th 2023, 10:07 pm

Subject 85156453



Beautiful Cepheid! The Hertzsprung progression in the Cepheid class is very interesting to study.

Helpful (1) Reply Link Report

Gaia Vari
@GAIA_Zooniverse
RESEARCHER MODERATOR TEAM

March 25th 2023, 12:02 am

#interesting case indeed!

Helpful (0) Reply Link Report

Maria W
@RoksolanaKot

April 15th 2023, 10:26 pm

#interesting #cep

Helpful (0) Reply Link Report

Wirg78
@Wirg78

April 20th 2023, 1:48 pm

very reddened #cepheid

Helpful (0) Reply Link Report

Travaglino
@Travaglino

May 1st 2023, 12:11 pm

#cep #reddened #known in #ASAS-SN as ASASSN-V J202056.73+350213.7 / ATLASJ305.2363+35.0371 period 9.9435319

Helpful (0) Reply Link Report

AlexScience

May 10th 2023, 5:05 pm

reddened #cep

A Citizen Science Project around variable stars observed by Gaia

Beta version

Mostly within the GaiaVari teams

Campaign 1

10,121 sources to be classified

From March to May 2023

850 Volunteers

205,000 Classifications

19,000 Comments

https://www.contractingbusiness.com/contracting-business-success/article/21256089/the-four-requirements-of-success

What are the outcomes of Campaign 1

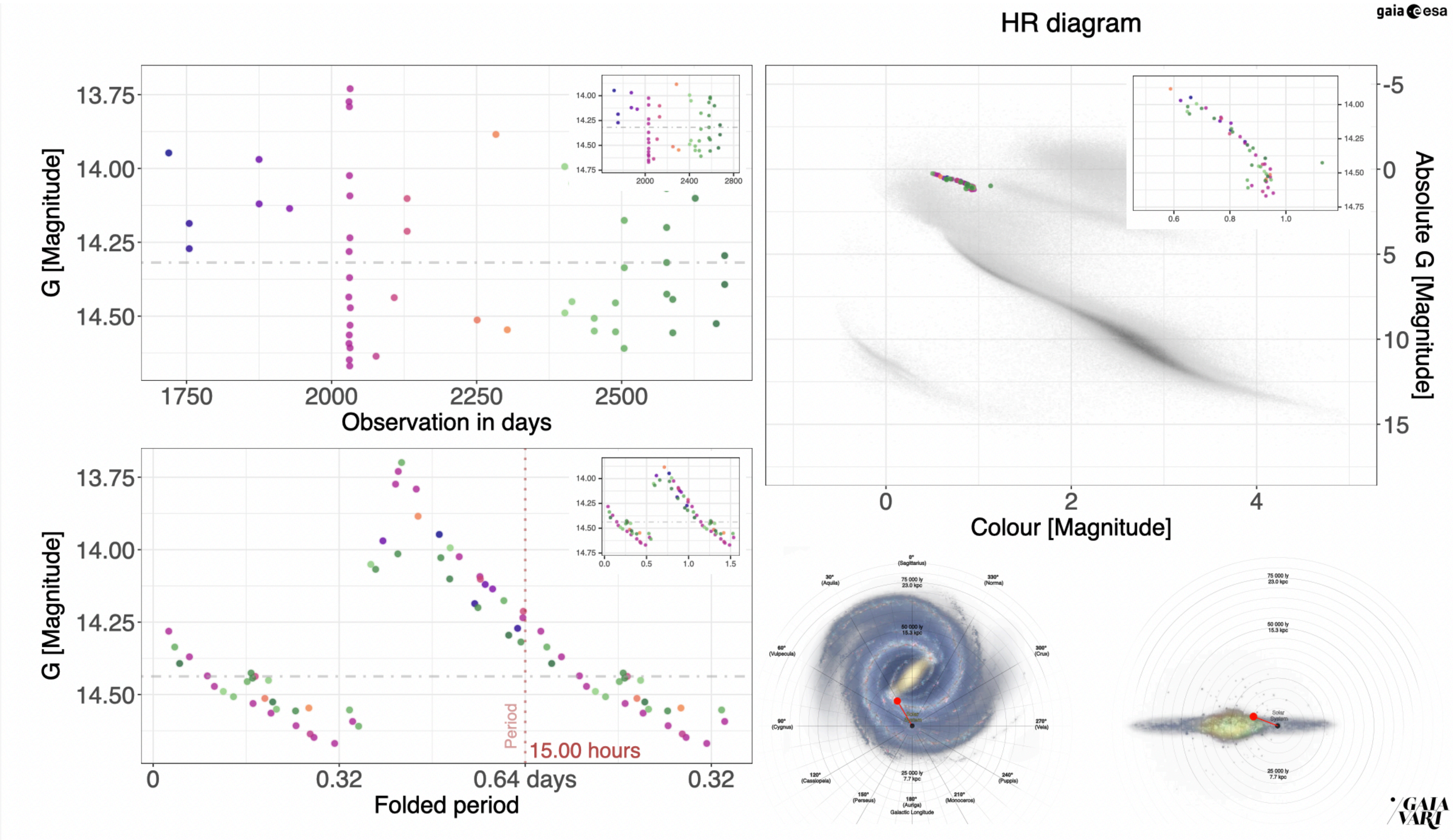
Some possible identified "problems" in DR3:

- Some misclassifications between RR Lyrae and Cepheid subtypes (in parallel a correction was issued V. Ripepi)
- Many wrong periods in Long Period Variables, given by characterisation Work Package, CORRECTED Long Period Variable Work Package; there are many small amplitudes LPVs
- Factor 2 in the periods of eclipsing binaries by characterisation (this was expected), CORRECTED by Eclipsing binary Work Package

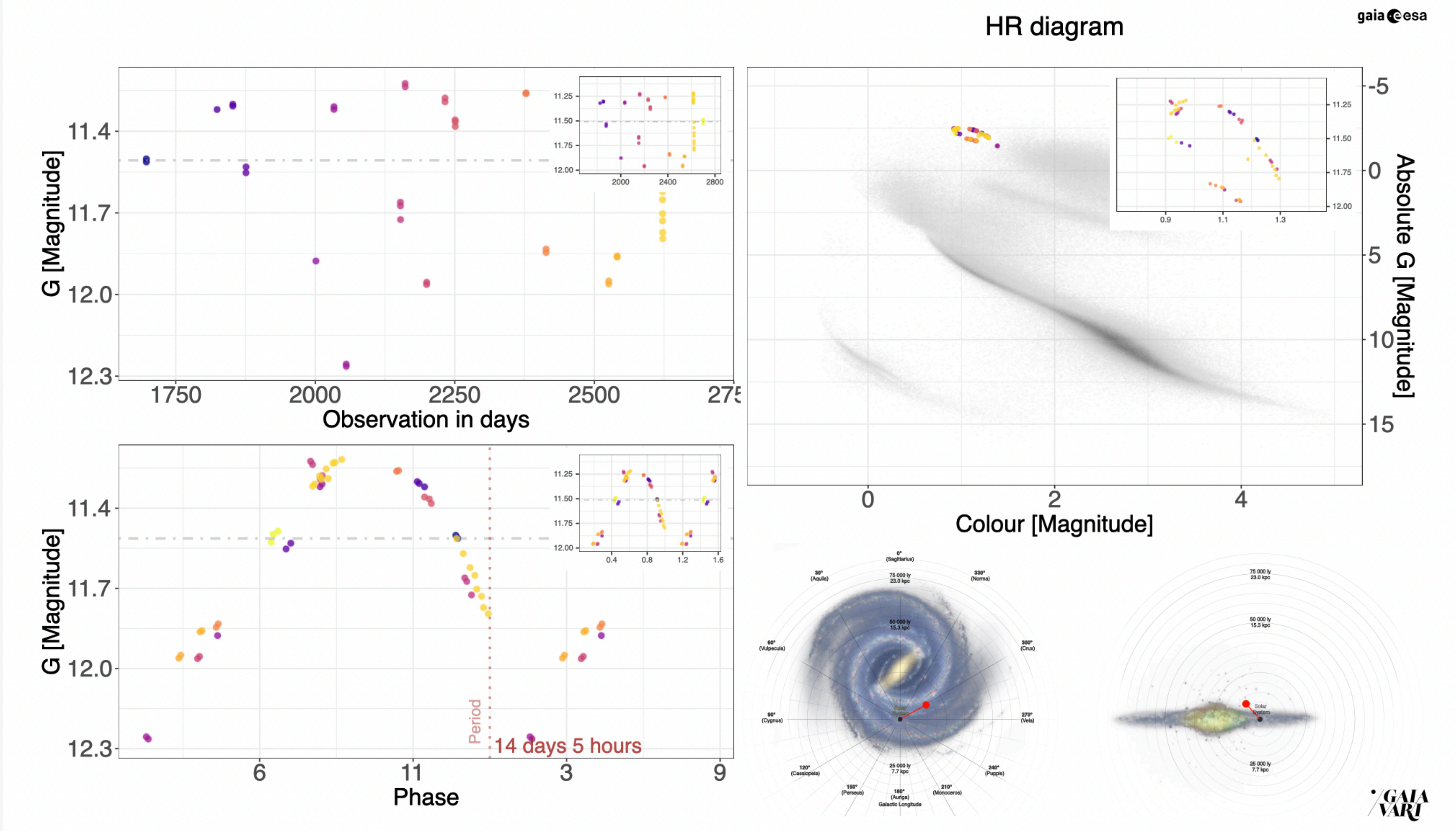
Some interesting results/remarks:

- Subclasses quite easily identified (RR Lyrae Bailey's types, RR Lyrae Blazhko effect, Cepheid sub-classification)
- Big loop in the colour magnitude diagram with many Type II Cepheids, to be confirmed
- Several new R Coronae Borealis stars candidates!
- One fascinating white dwarf remarked by many citizen scientists. This is to be studied.
- ZZ Ceti white dwarf location seems to host cataclysmic variables
- Classification between Ellipsoidal variability and RS CVn stars a bit fuzzy

What are the outcomes of Campaign 1



What are the outcomes of Campaign 1



The second Campaign

Campaign 2 - On-going

Dedicated mostly on overlaps of the classification (when two classifiers claim the star)

Astronomers can also be citizen scientist, **so register:**

https://www.zooniverse.org/projects/gaia-zooniverse/gaia-vari

Stellar variability - II

Laurent Eyer
University of Geneva

Ile d'Oléron, France

Thursday, October 5, 2023

11h00-12h30 (CET)

Gaia
DPAC

Practical goal

Some problems

HR diagram and variables

Distance scale

Other topics

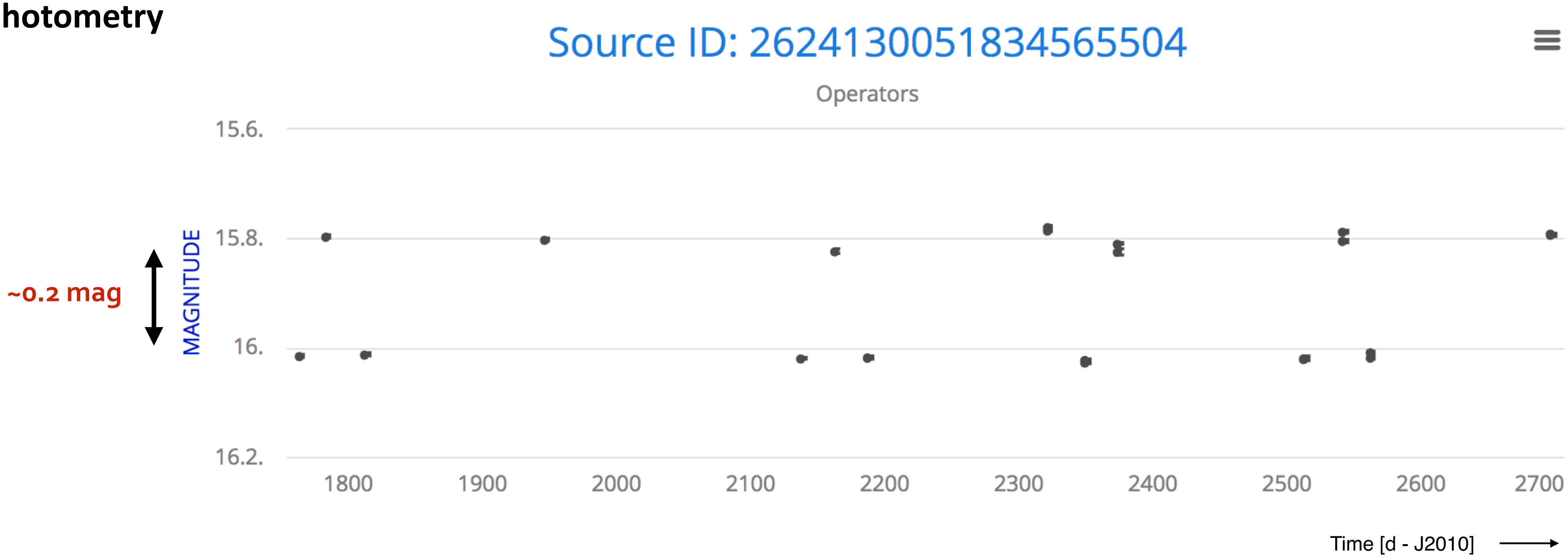
Pushing the limits

Foused Prodcut Release

Some problems

Not all is so rosy: strange sources

G-band FoV photometry



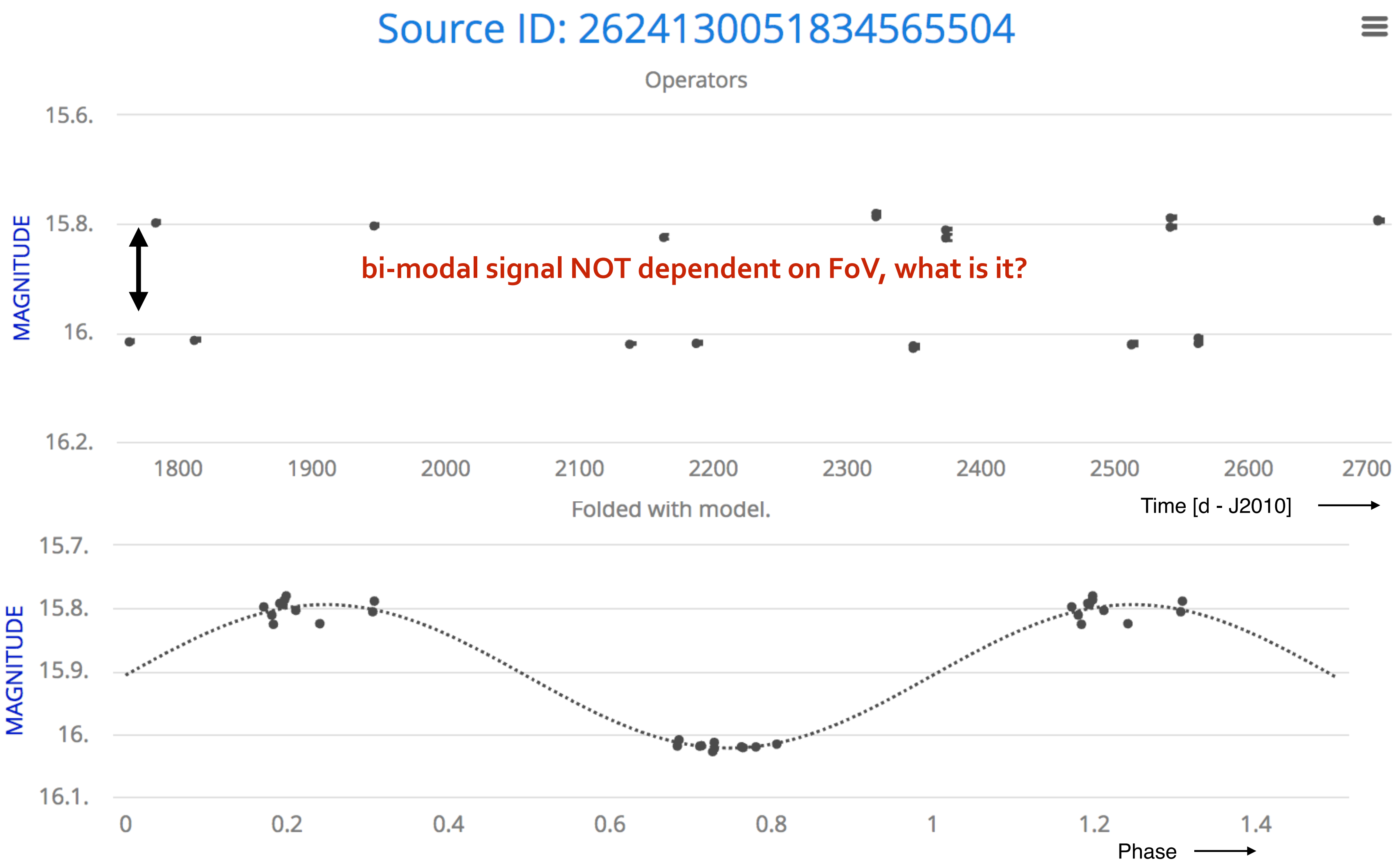
What is it? any guess?

Courtesy of B. Holl

Not so rosy: Strange sources

G-band FoV photometry

period = 54 d

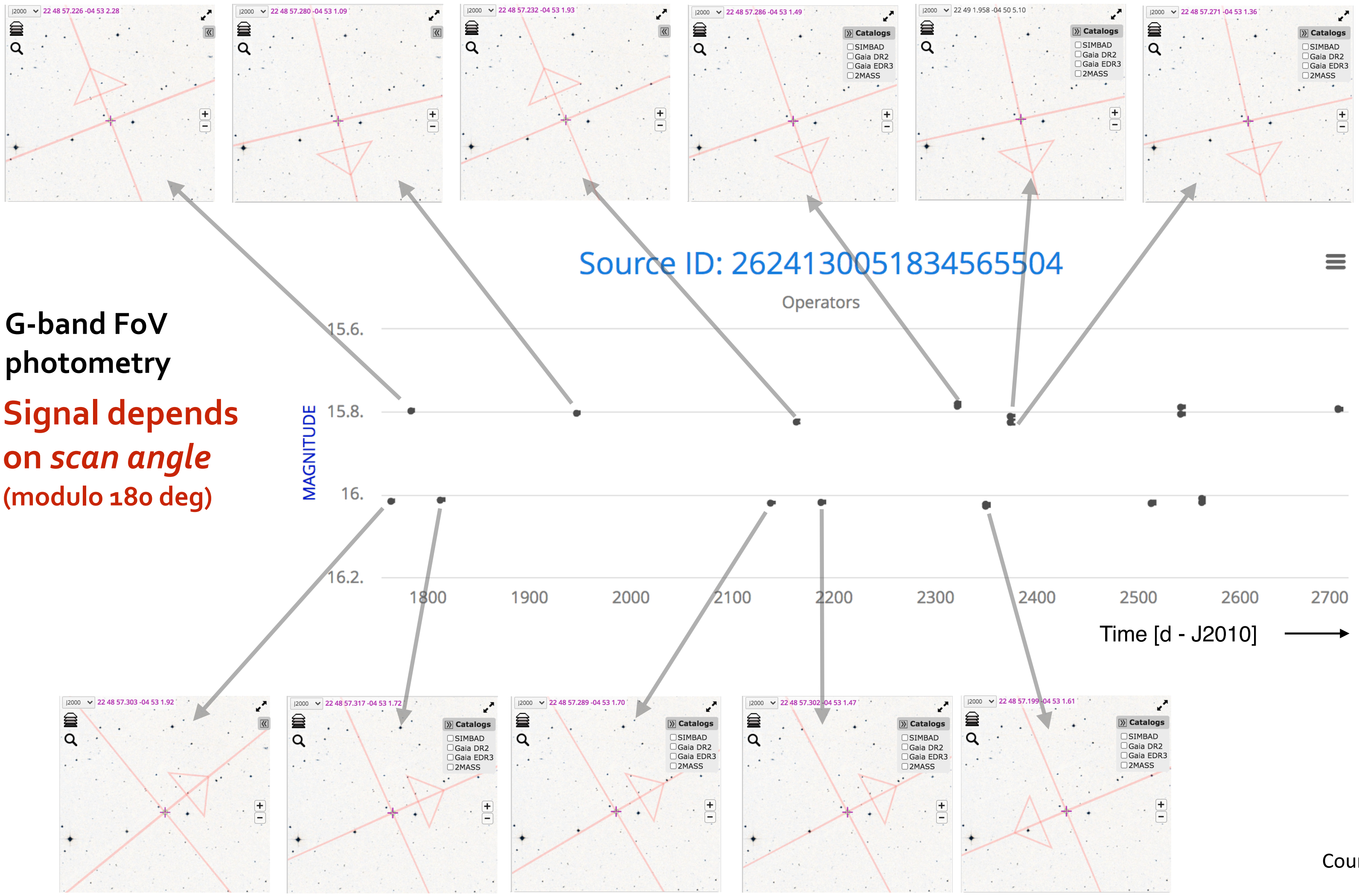


Courtesy of B. Holl

The modulation is correlated with the scan angle

G-band FoV photometry

Signal depends on *scan angle*
(modulo 180 deg)



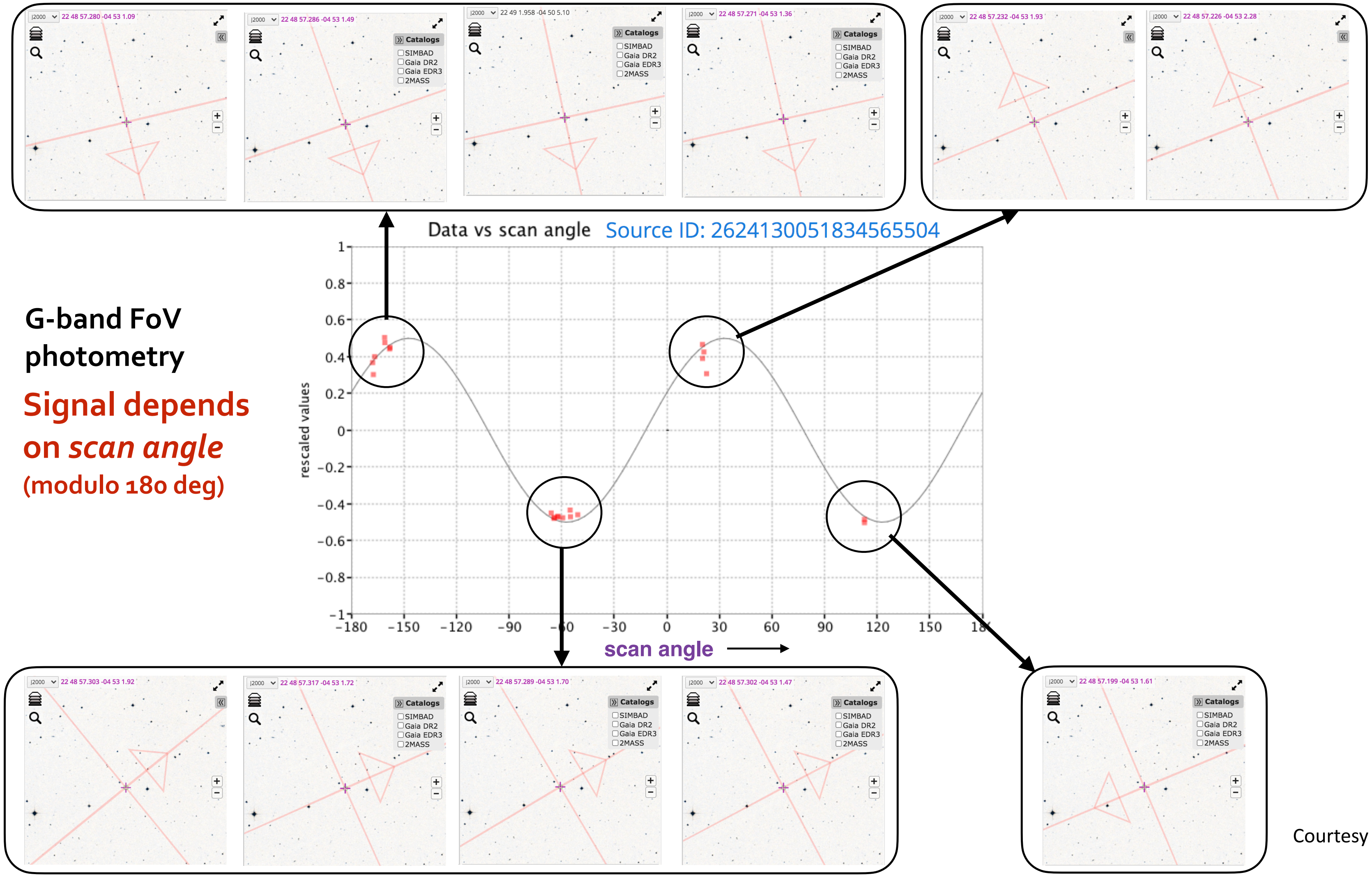
Courtesy of B. Holl

The modulation is correlated with the scan angle

G-band FoV photometry

Signal depends on *scan angle*

(modulo 180 deg)



Courtesy of B. Holl

Many spurious frequencies come from this

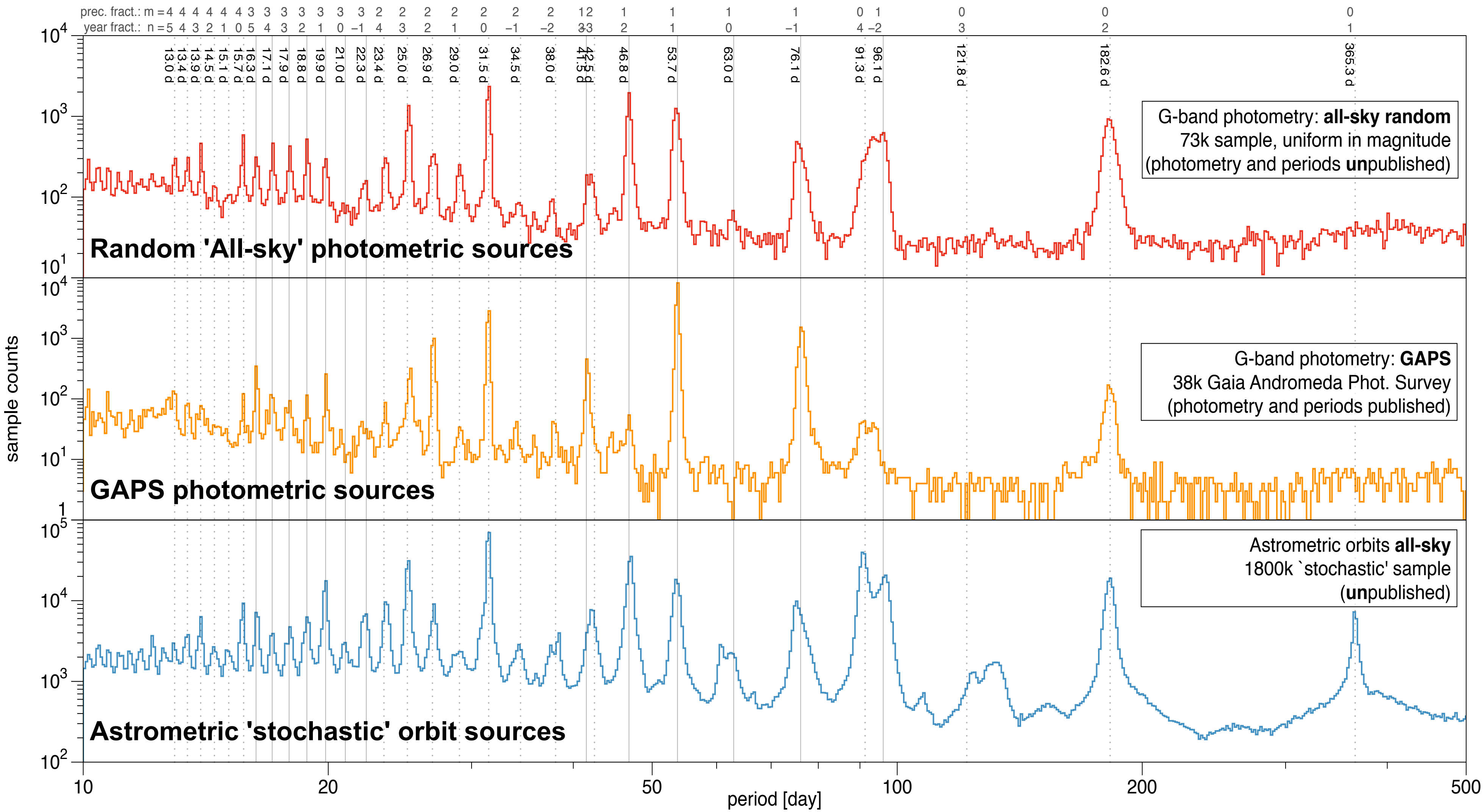
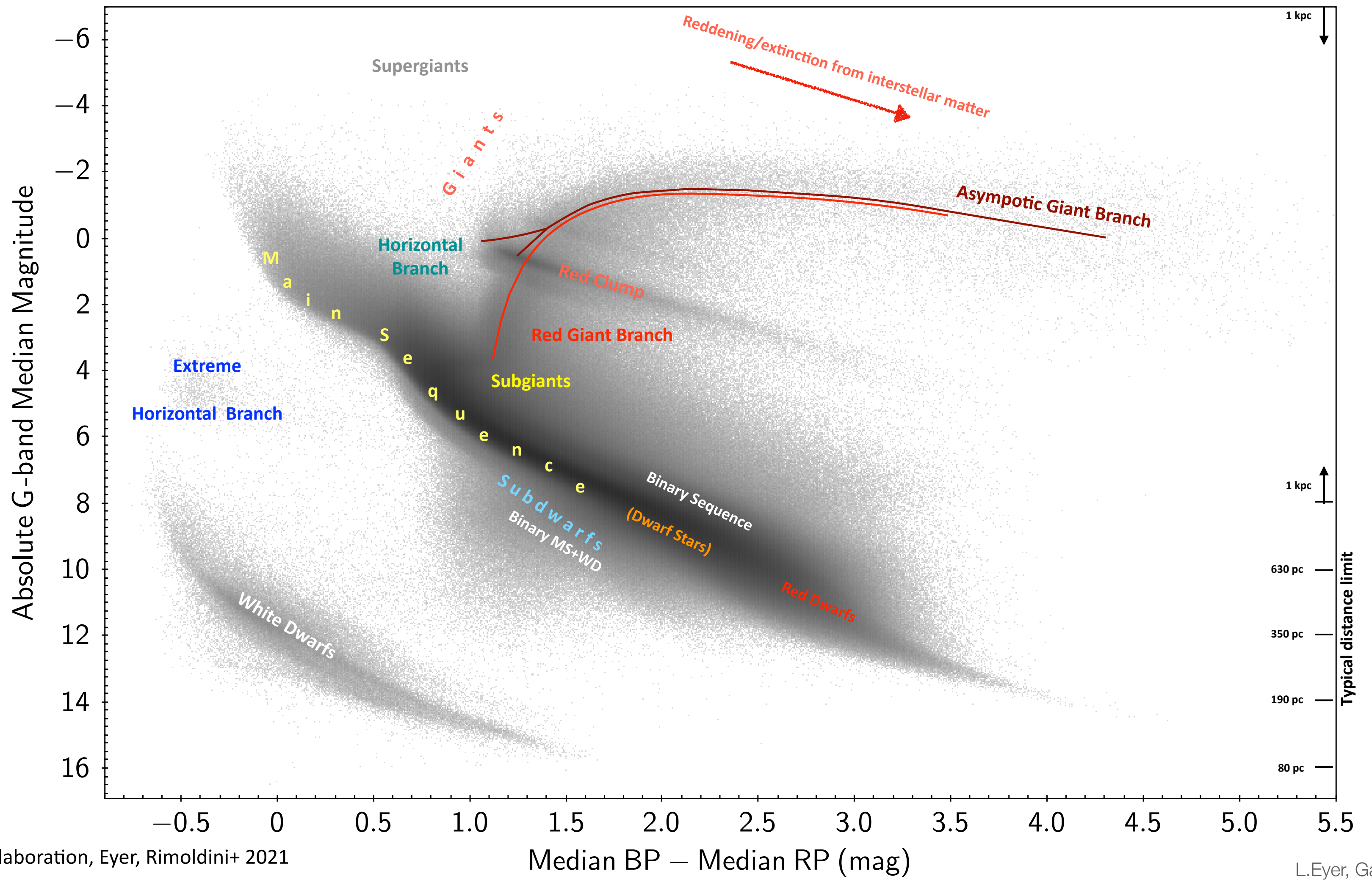


Fig 16 of Holl, Fabricius, Portell, et al. (2023)

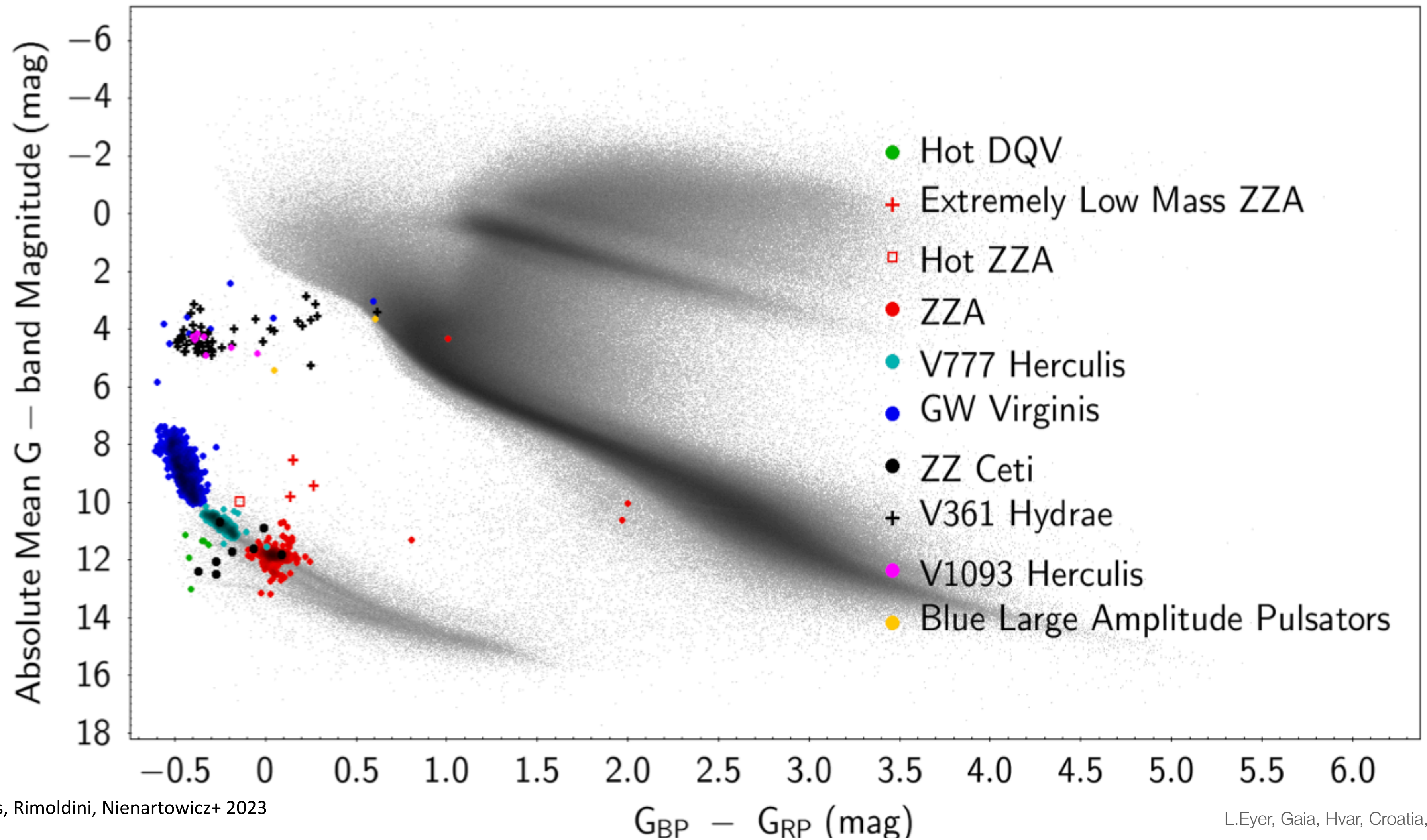
HR diagram and variables

Colour absolute Magnitude Diagram



Gaia collaboration, Eyer, Rimoldini+ 2021

White dwarfs from the literature



Gavras, Rimoldini, Nienartowicz+ 2023

Variable white dwarfs in the Colour absolute Magnitude Diagram from published excess scatter

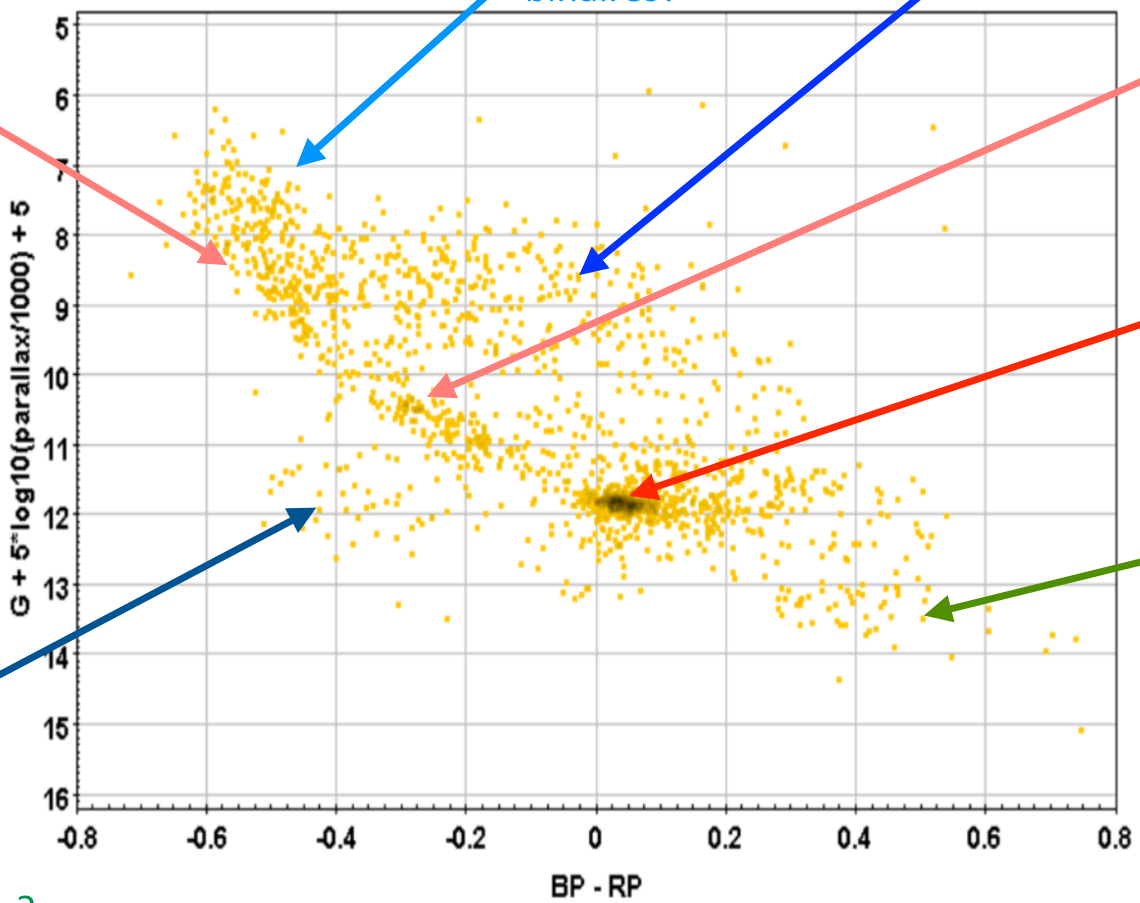
GW Virginis variables
Pulsation

Double White Dwarf
binaires?

White Dwarf - Main Sequence binaries

V777 Herculis stars
Pulsation

Based on Eyer+2020
now with
Thinh Nguyen



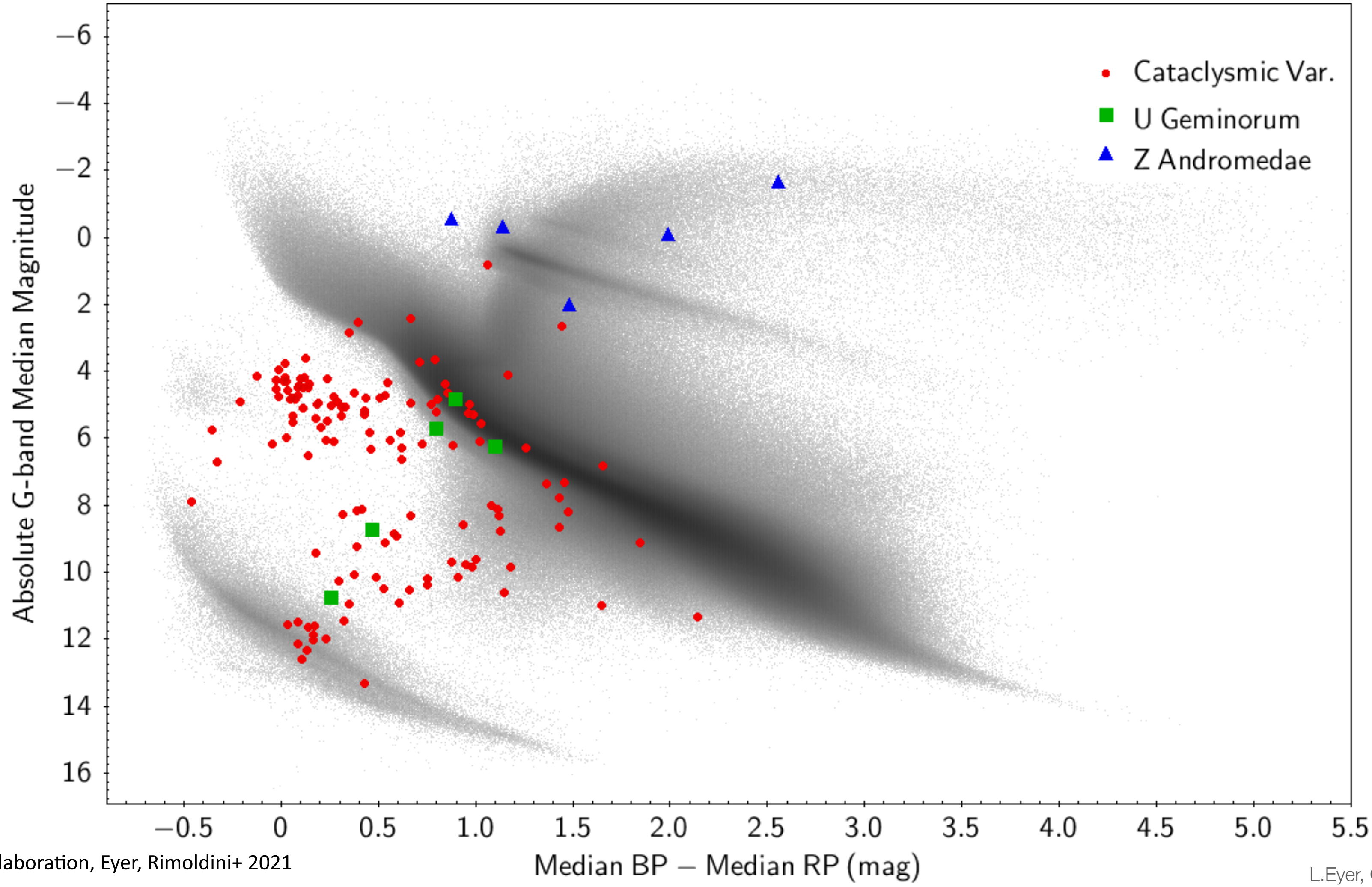
ZZ Ceti variables
Pulsation

DQ variables?
Rotation induced variability

Massive
double White Dwarfs
binaires
or
Rotation induced variability?

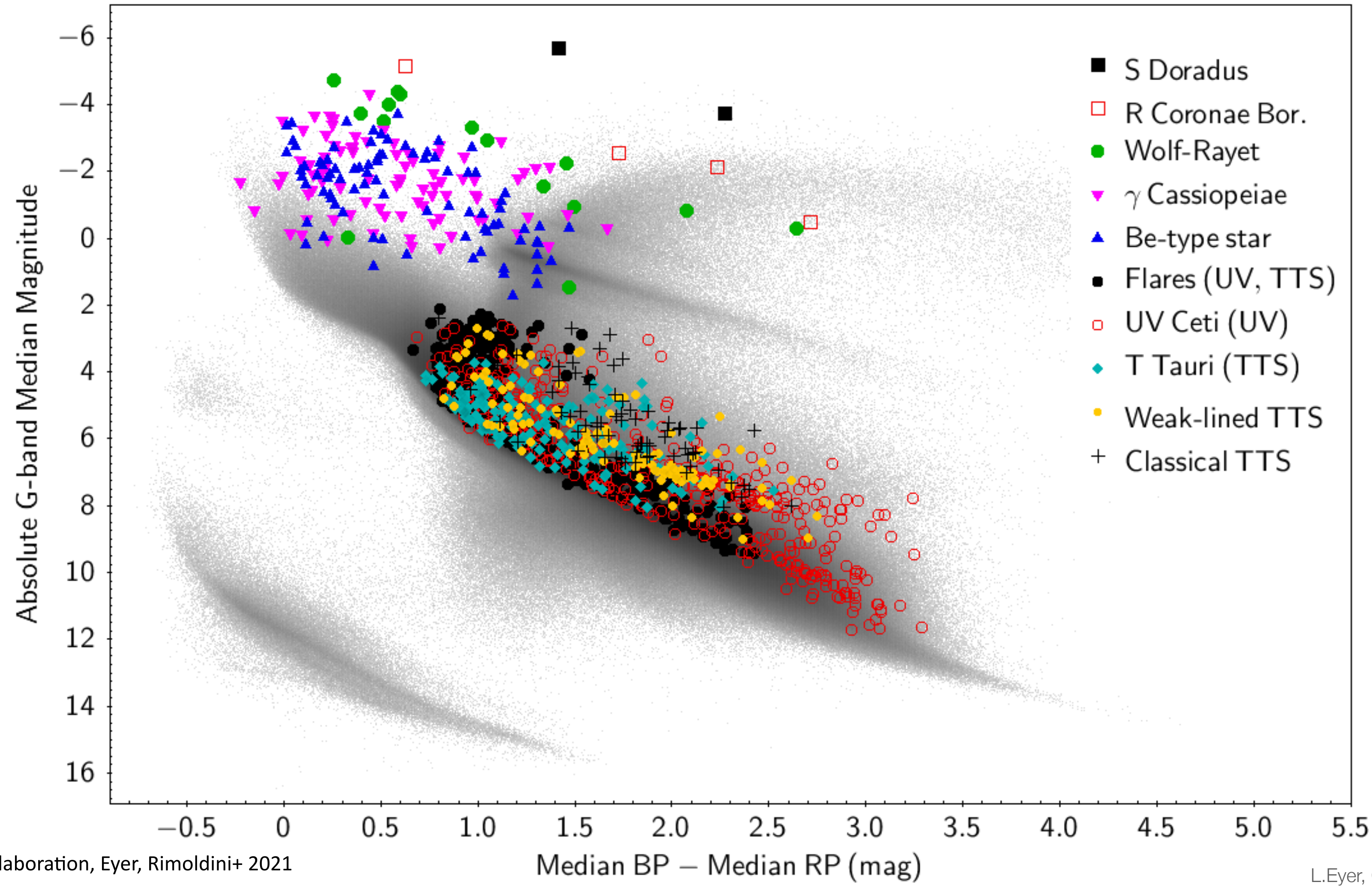
L.Eyer, Gaia, Hvar, Croatia, September 18 2023

Cataclysmic stars in the Colour Absolute magnitude Diagram



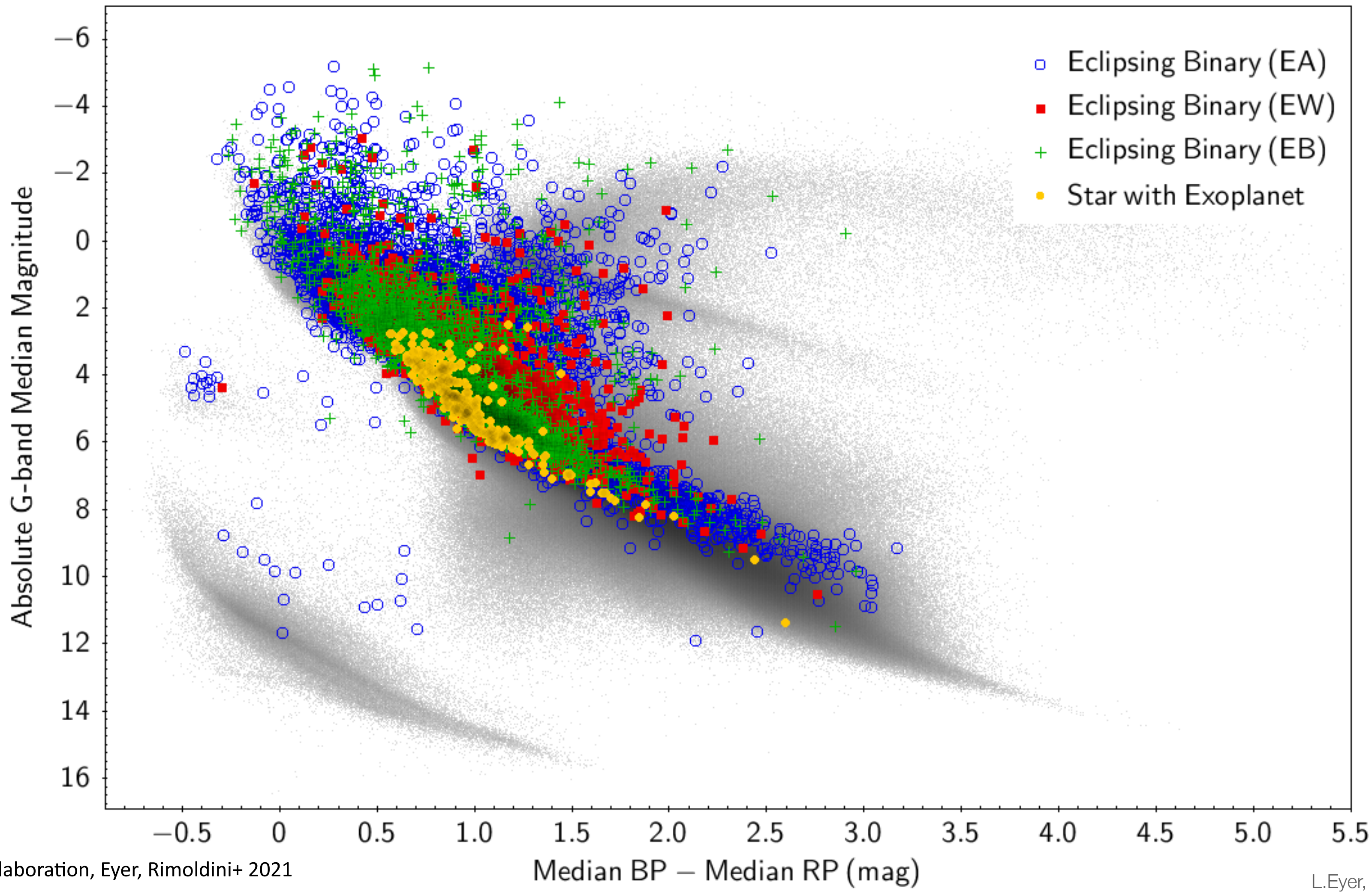
Gaia collaboration, Eyer, Rimoldini+ 2021

Eruptive stars in the Colour absolute Magnitude Diagram



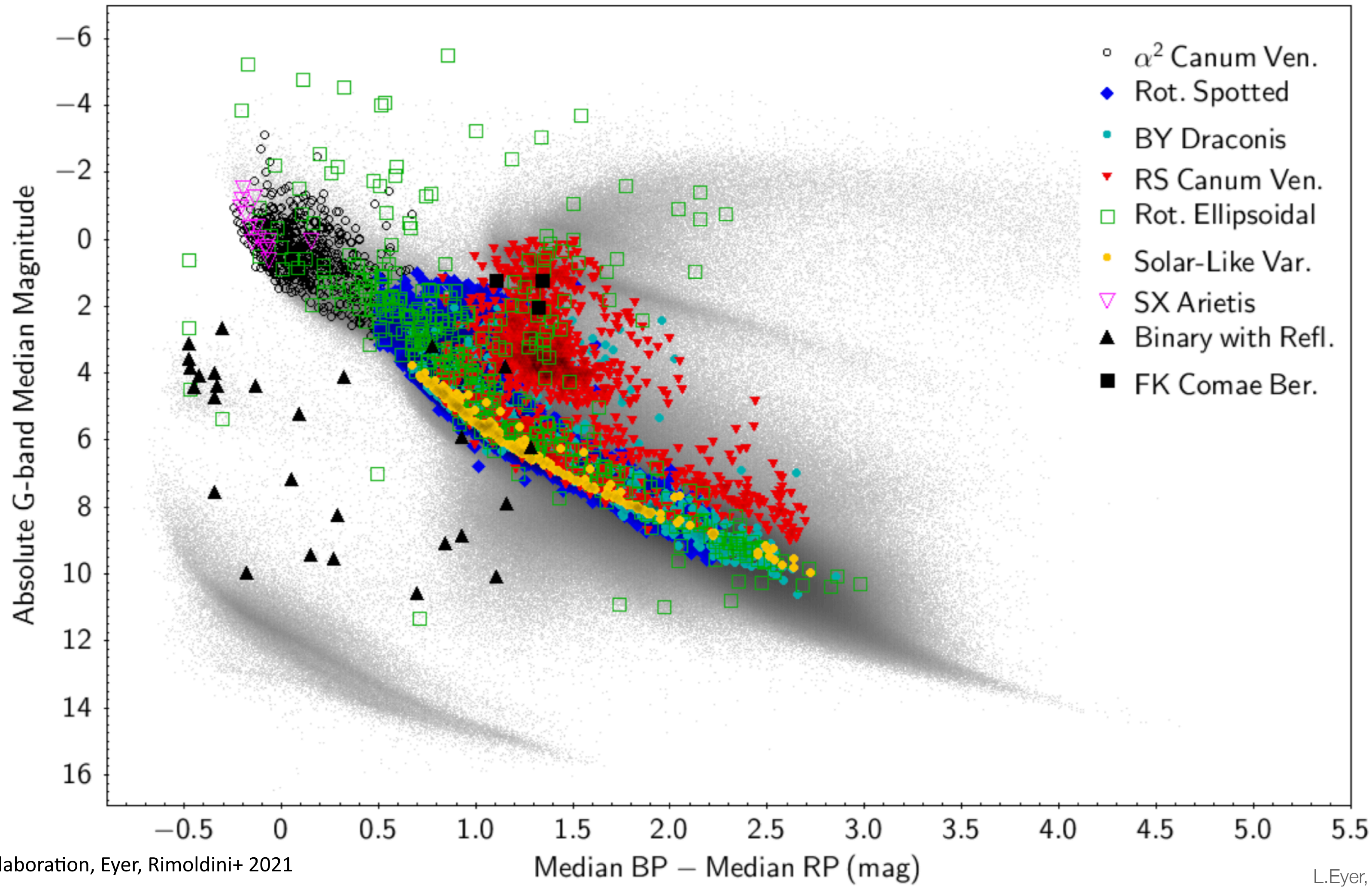
Gaia collaboration, Eyer, Rimoldini+ 2021

Eclipsing stars in the observational HR diagram



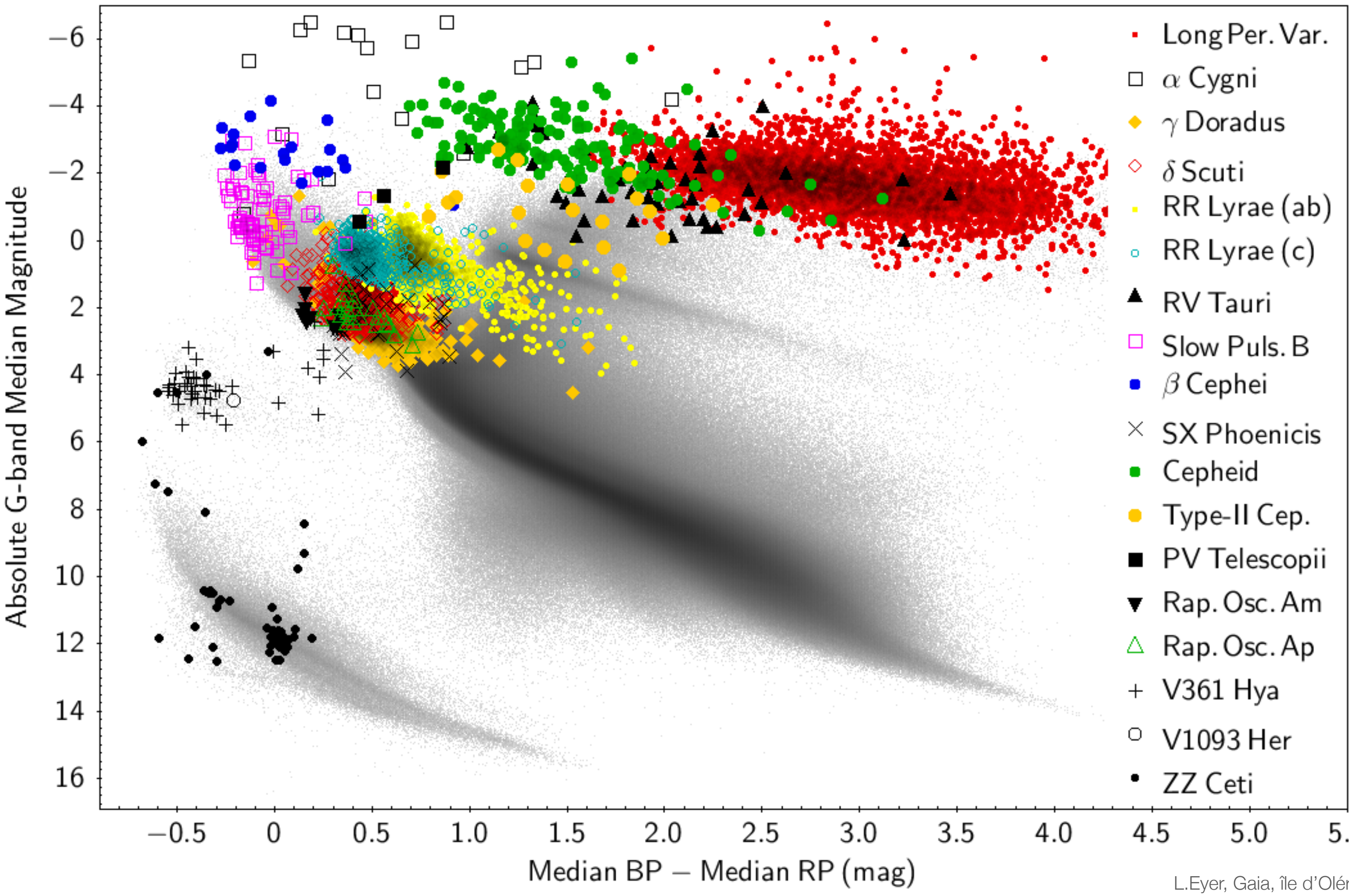
Gaia collaboration, Eyer, Rimoldini+ 2021

Variability induced by rotation in the observational HR diagram



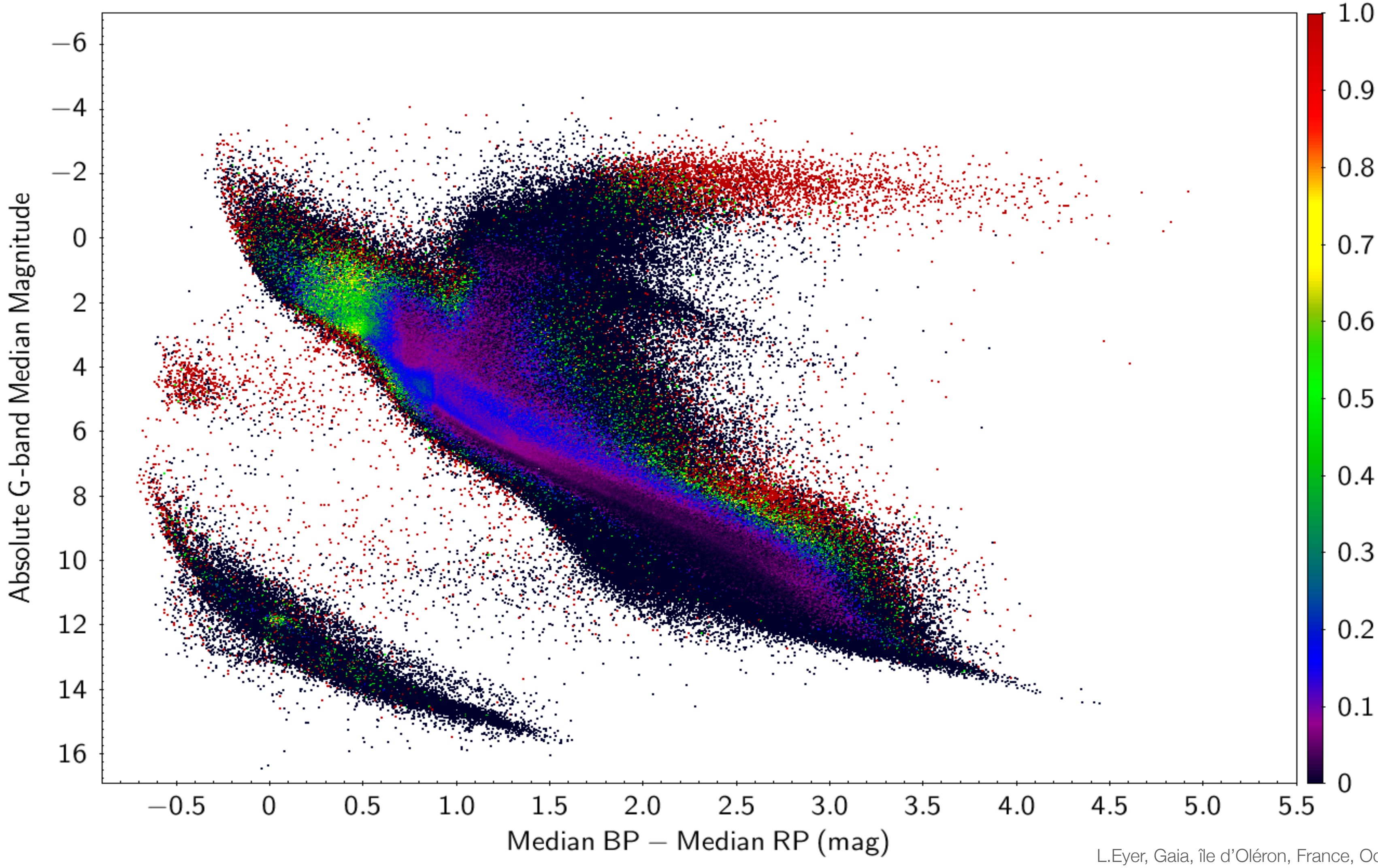
Gaia collaboration, Eyer, Rimoldini+ 2021

Gaia HR Diagram (from DR2)



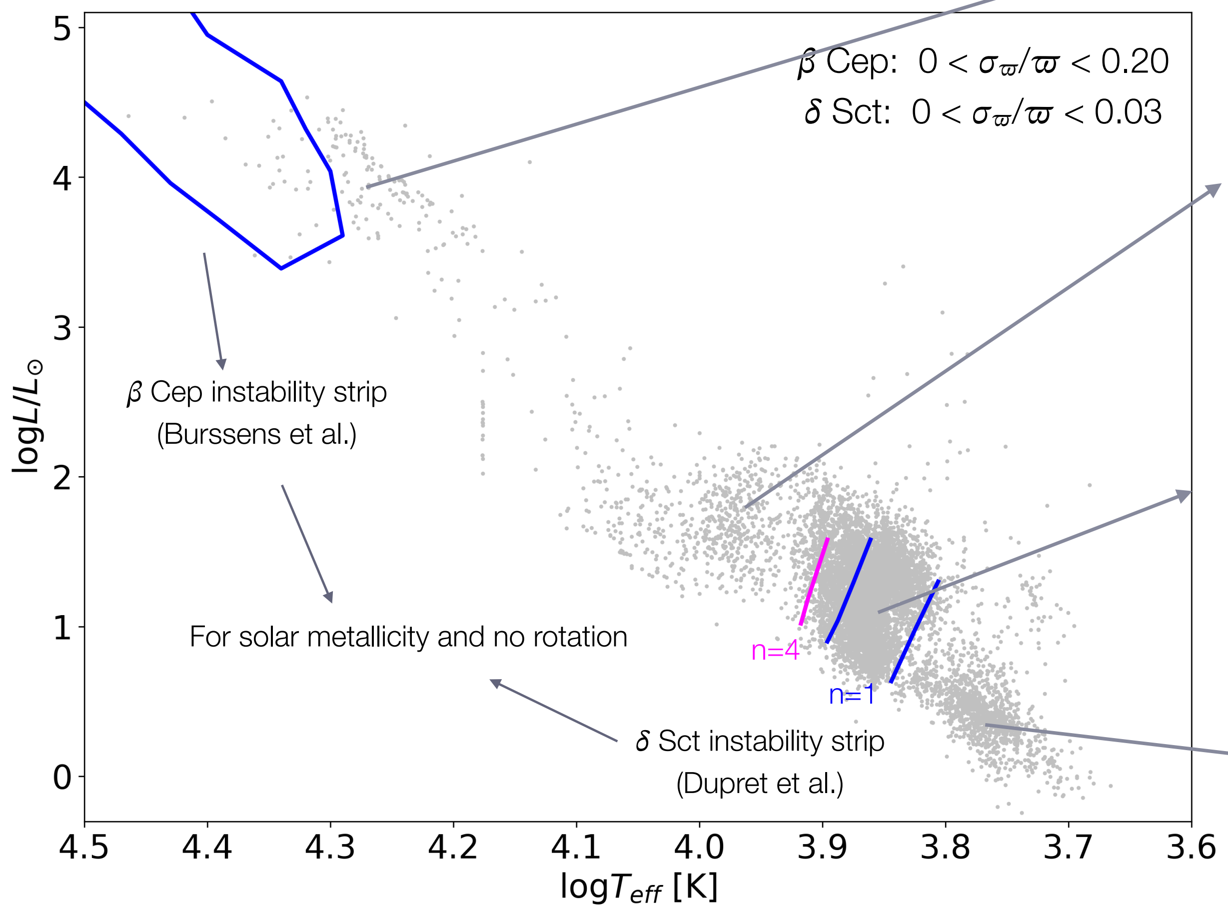
Gaia consortium,
Eyer et al. 2019

Gaia HR Diagram (from DR2): the fraction of variables



Gaia consortium,
Eyer et al. 2019

Instability regions: P-mode pulsators: β Cep and δ Sct variables



Gaia collaboration, De Ridder, Ripepi, Aerts+ 2021

from GSPPHOT (CU8)

Most β Cep candidates fall outside the instability strip. Difficult to explain.

Variability in this part of the HR diagram is seen before but is not well understood. Fast rotation and/or star spots likely play a roll.

Excellent match between theoretical strip and observations.
logL and logT_{eff} were not used to classify the pulsators!
Also shows the good quality of CU8 astrophysical parameters in this T_{eff} range.

Puzzling group of variables outside instability strip:

Fourier series

$$mag(t_j) = zp + \sum [A_i sin(i \times 2\pi\nu_{max}t_j + \phi_i)]$$

in fact the fit should be done in **a_i*sin(2 π ν t) + b_i*cos(2 π ν t)**

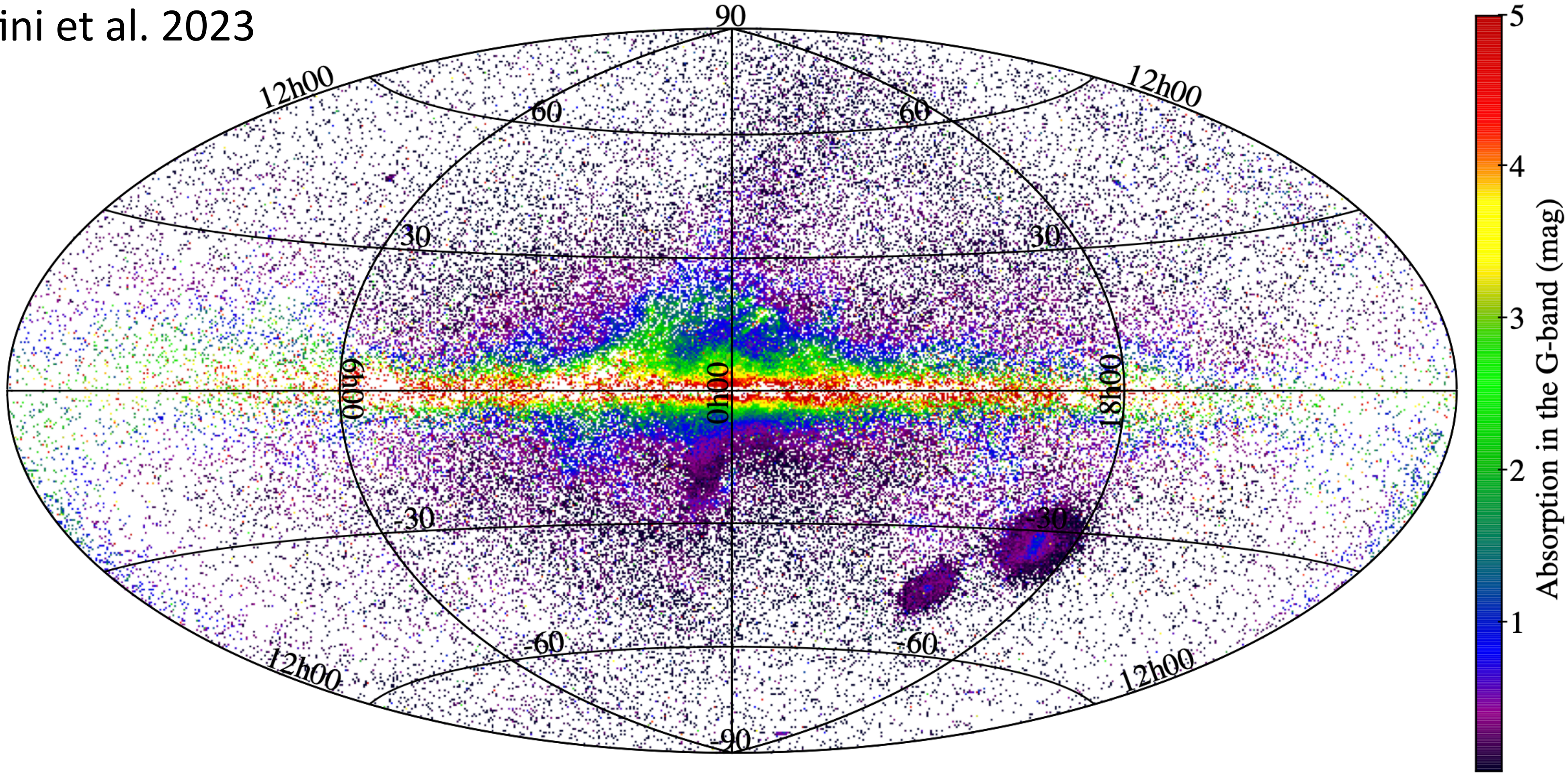
$$R_{ij} = A_i / A_j$$

$$\phi_{ij} = j \times \phi_i - i \times \phi_j$$

→ Calibration of absolute luminosities
Calibrate metallicities

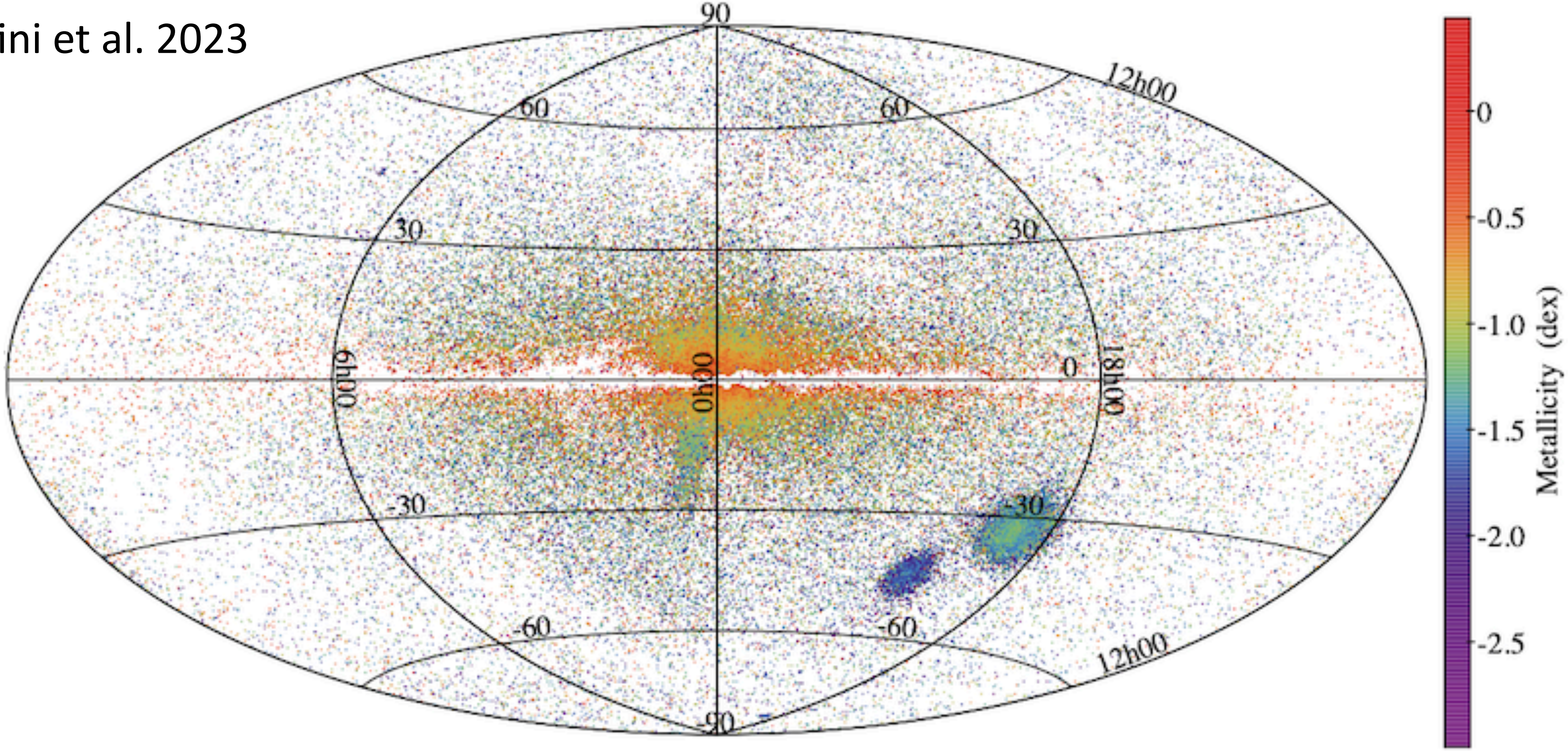
Absorption Map from RR Lyrae stars

Clementini et al. 2023



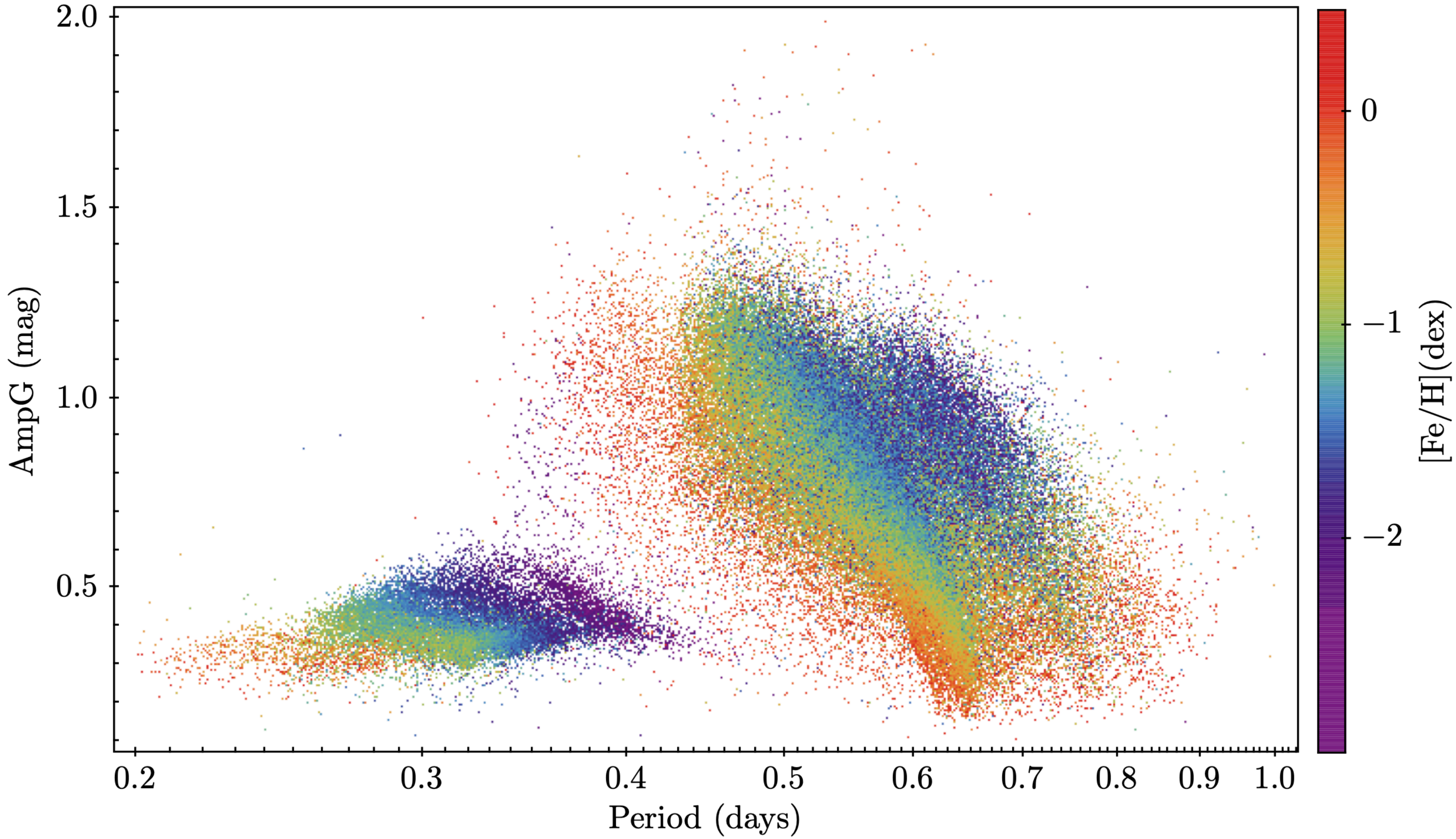
Metallcities from RR Lyrae

Clementini et al. 2023



Metallcities from RR Lyrae

Clementini et al. 2023



Distance scale

Period Luminosity Relation of Cepheids

M = α log$_{10}$(period) + β

Henrietta Leavitt and Charles Pickering at Harvard

Cepheids
in the
Small Magellanic Cloud
(same distance)

If distance know from parallax with good precision

distance = 1/ parallax

m-M = 5 log$_{10}$(distance) - 5

1912

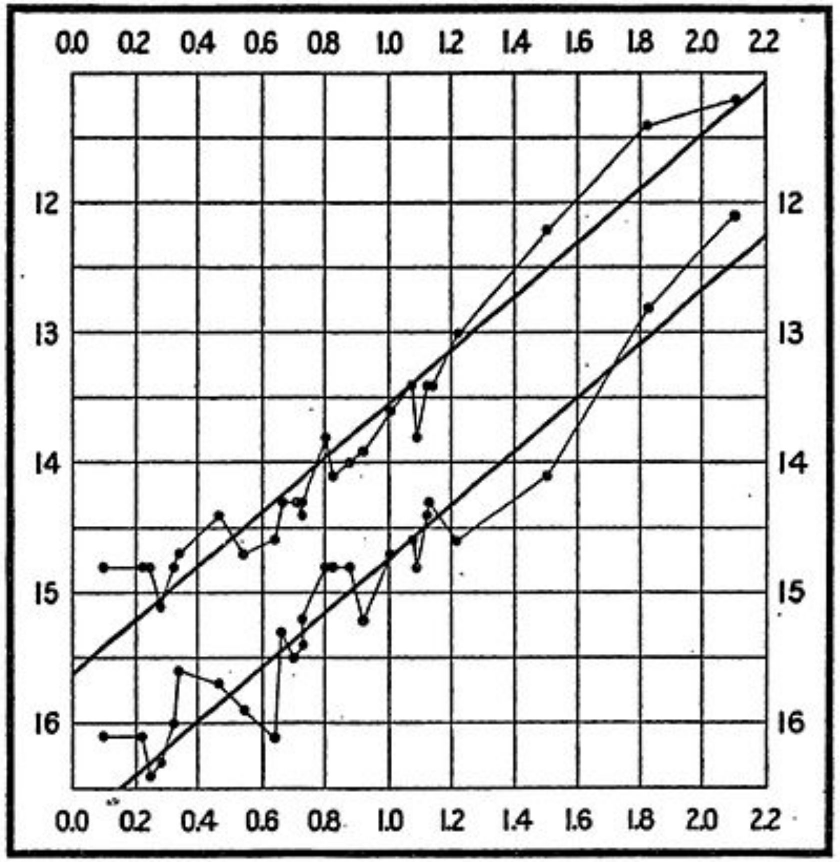


FIG. 2.

The Period Luminosity relations

First comment

In a large fraction of the HR diagram
Higher luminosity, means higher mass

A little calculation for the main sequence…

Higher mass means lower mean density

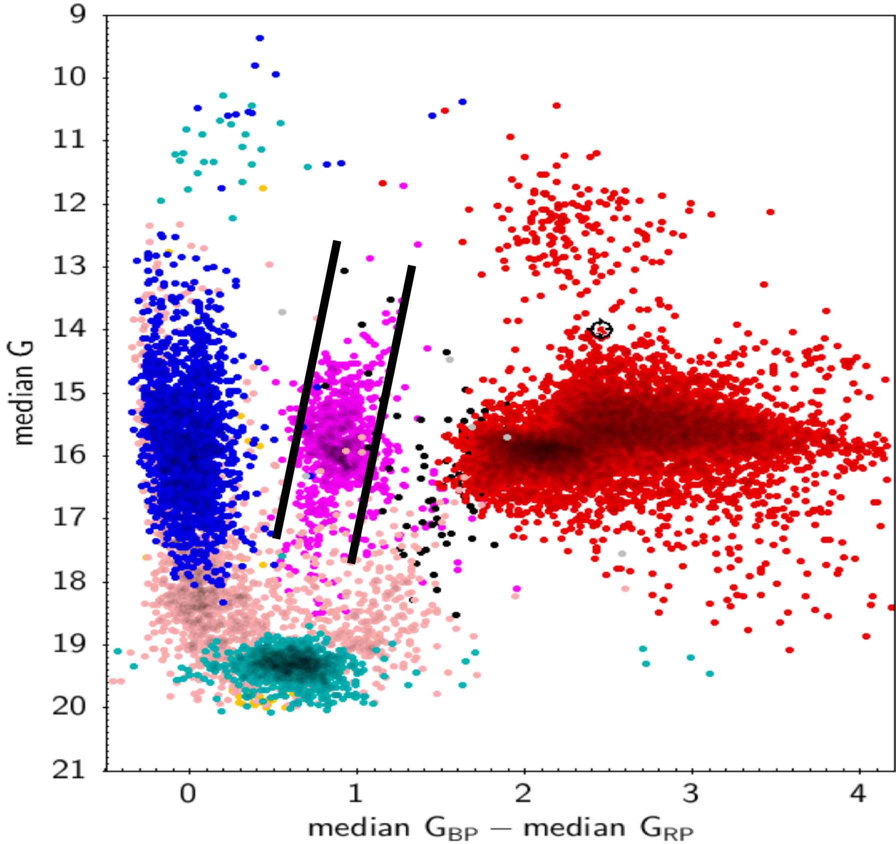
Second comment

Spherical oscillating body in fundamental mode

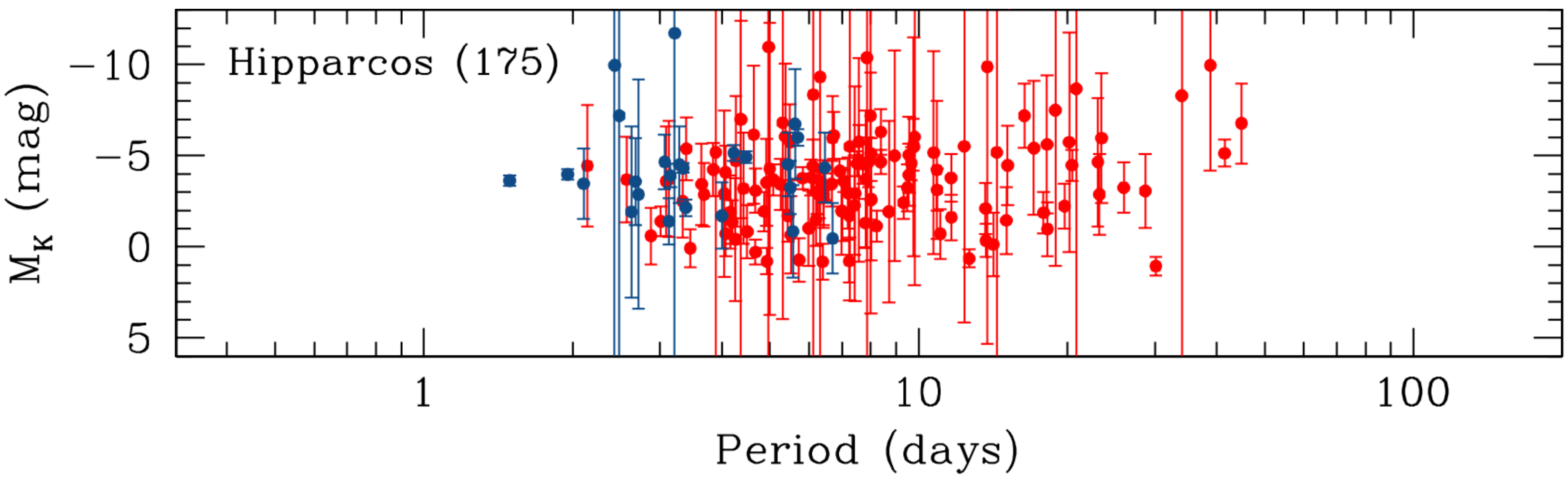
Period goes like the inverse of the square root of the density

Frequency goes like the square root square root of the denstiy

Nothing astonishing…

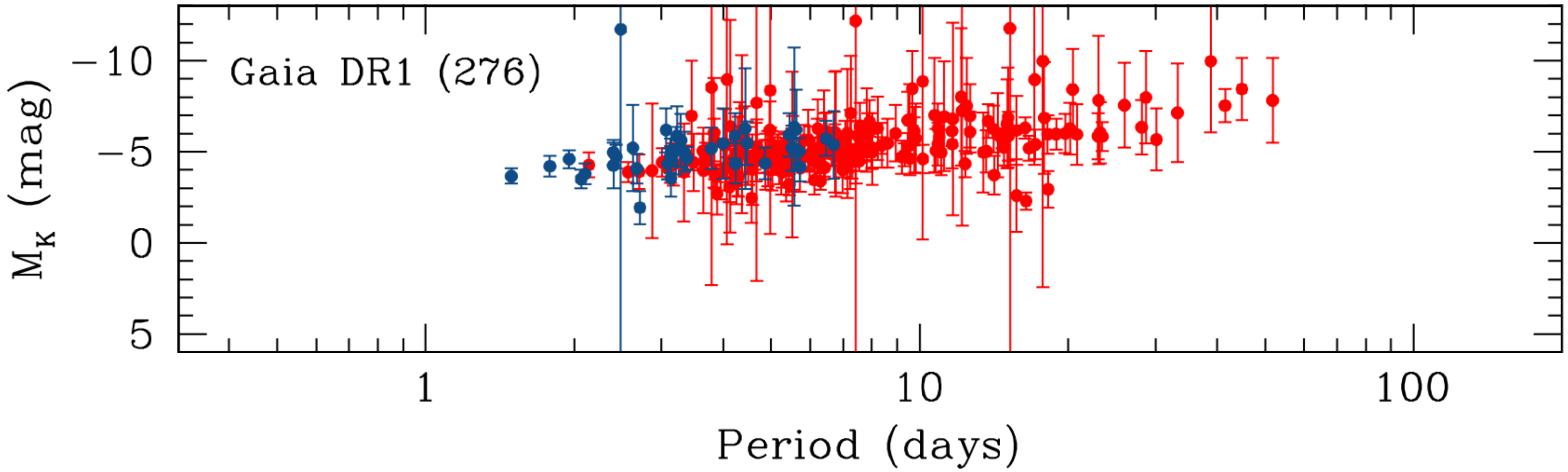


Period Luminosity relations for Cepheids



Courtesy of Gisella Clementini, Vincenzo Ripepi

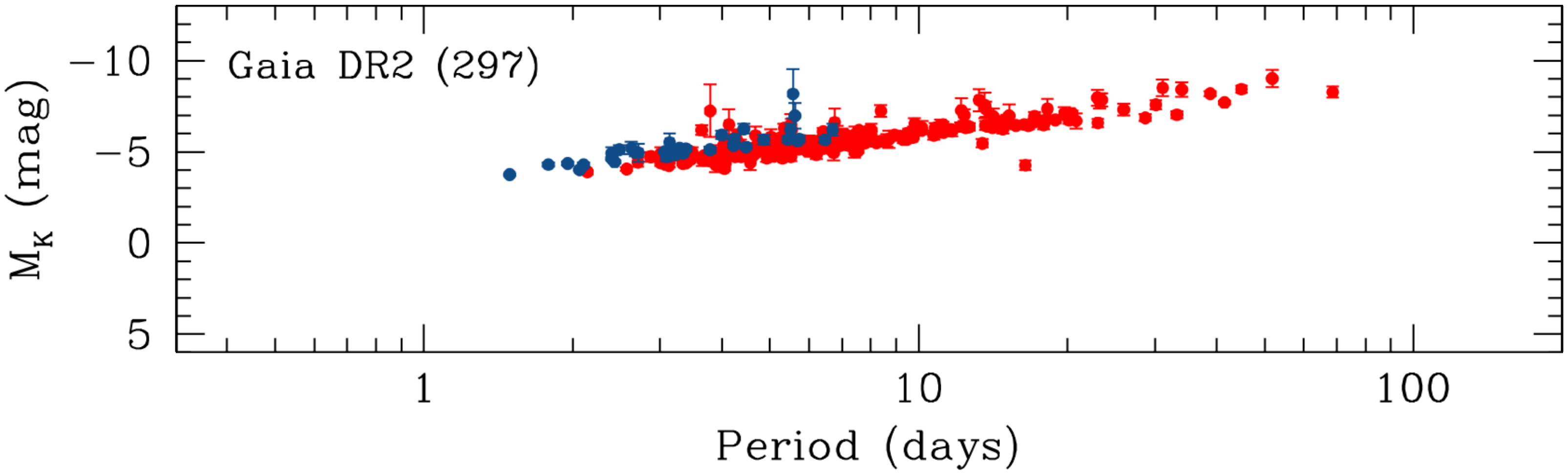
Period Luminosity relations for Cepheids



Courtesy of Gisella Clementini, Vincenzo Ripepi

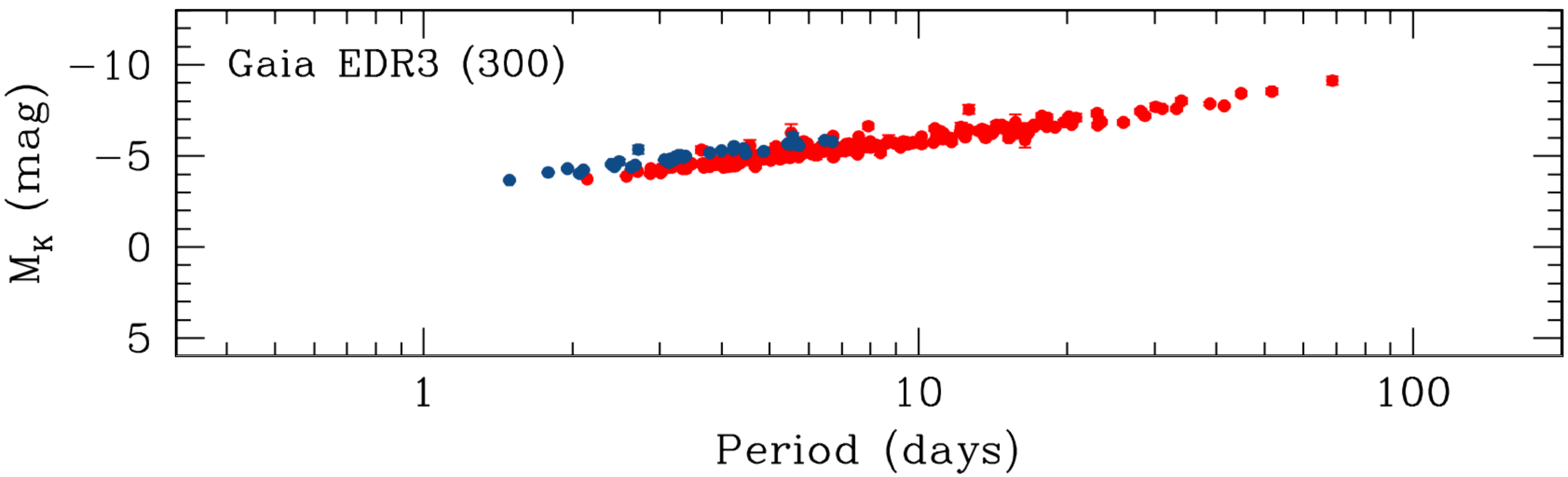
Study of the Period luminosity relation in Gaia Collaboration, Clementini, Eyer, Ripepi+2017

Period Luminosity relations for Cepheids



Courtesy of Gisella Clementini, Vincenzo Ripepi

Period Luminosity relations for Cepheids



Courtesy of Gisella Clementini, Vincenzo Ripepi

The Hubble-Lemaître law

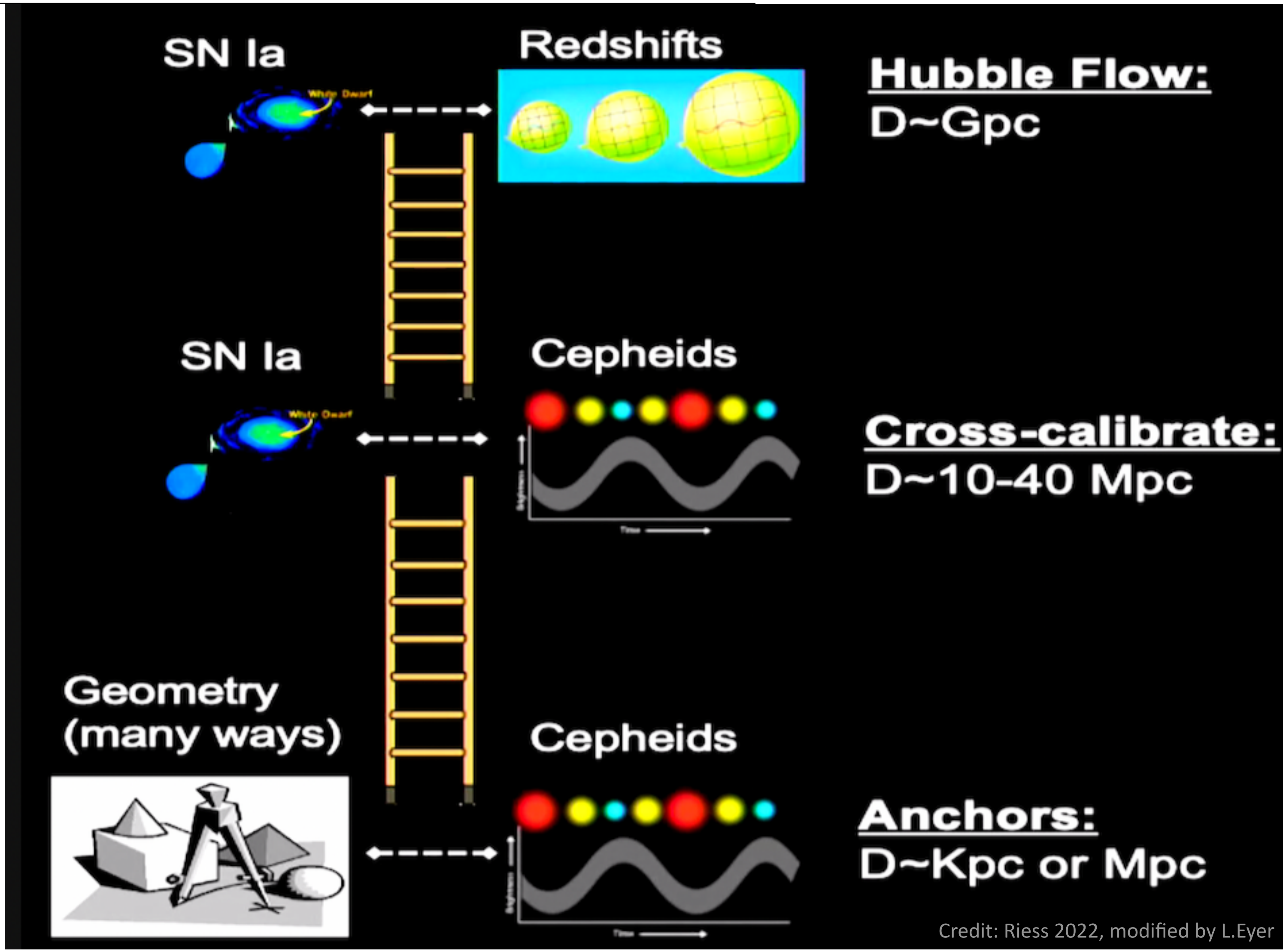
The Hubble-Lemaître law:

$V = H_0 \; d$

H_0 in km/s/Mpc

For decades there has been
an active research on the estimation of H_0

The distance measurement
"d" is problematic



Credit: Riess 2022, modified by L.Eyer

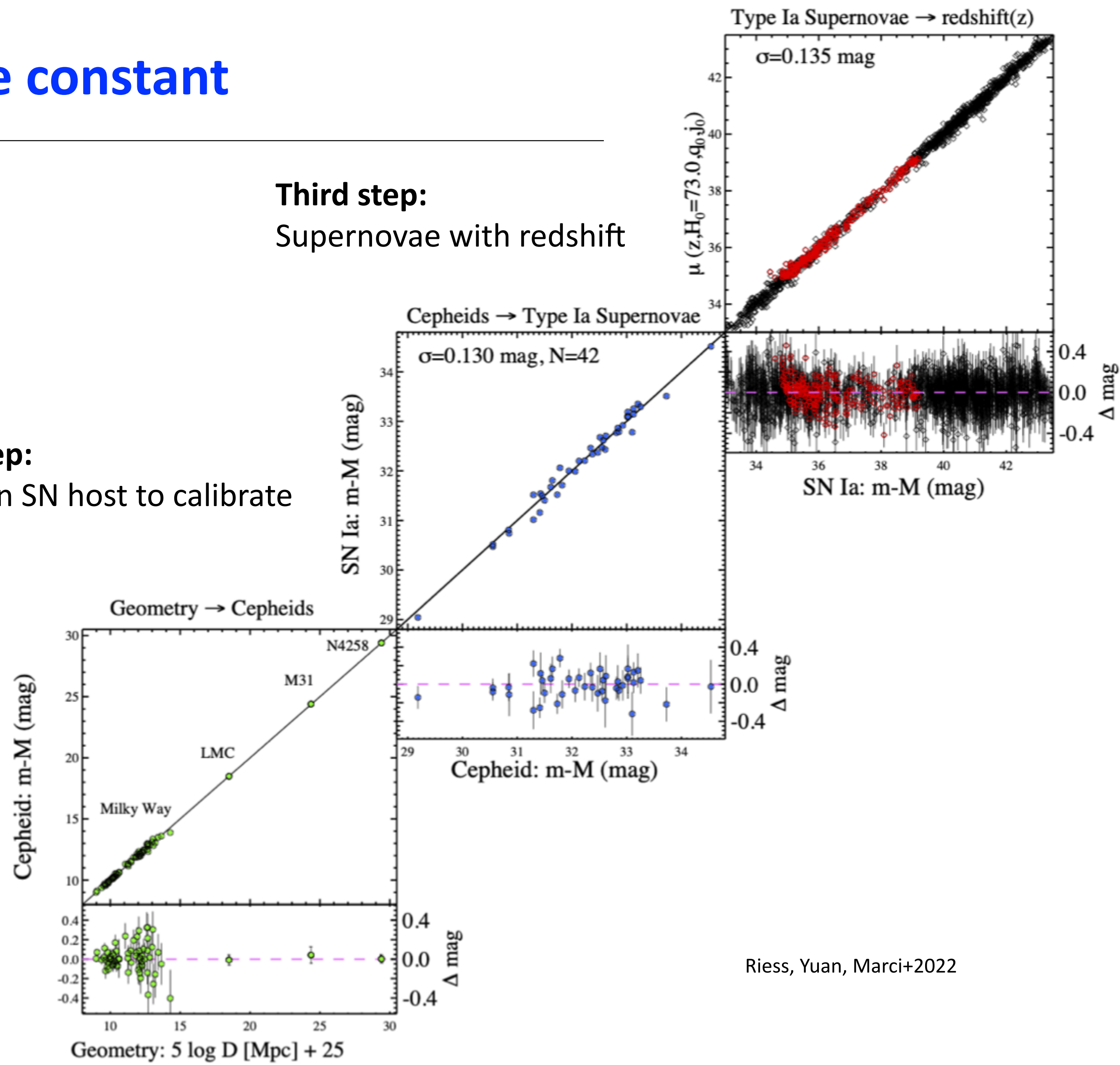
The measurement of Hubble constant

Third step:
Supernovae with redshift

Second step:
Cepheids in SN host to calibrate

First step:
Geometry (parallax, eclipsing binaries, Megamaser)

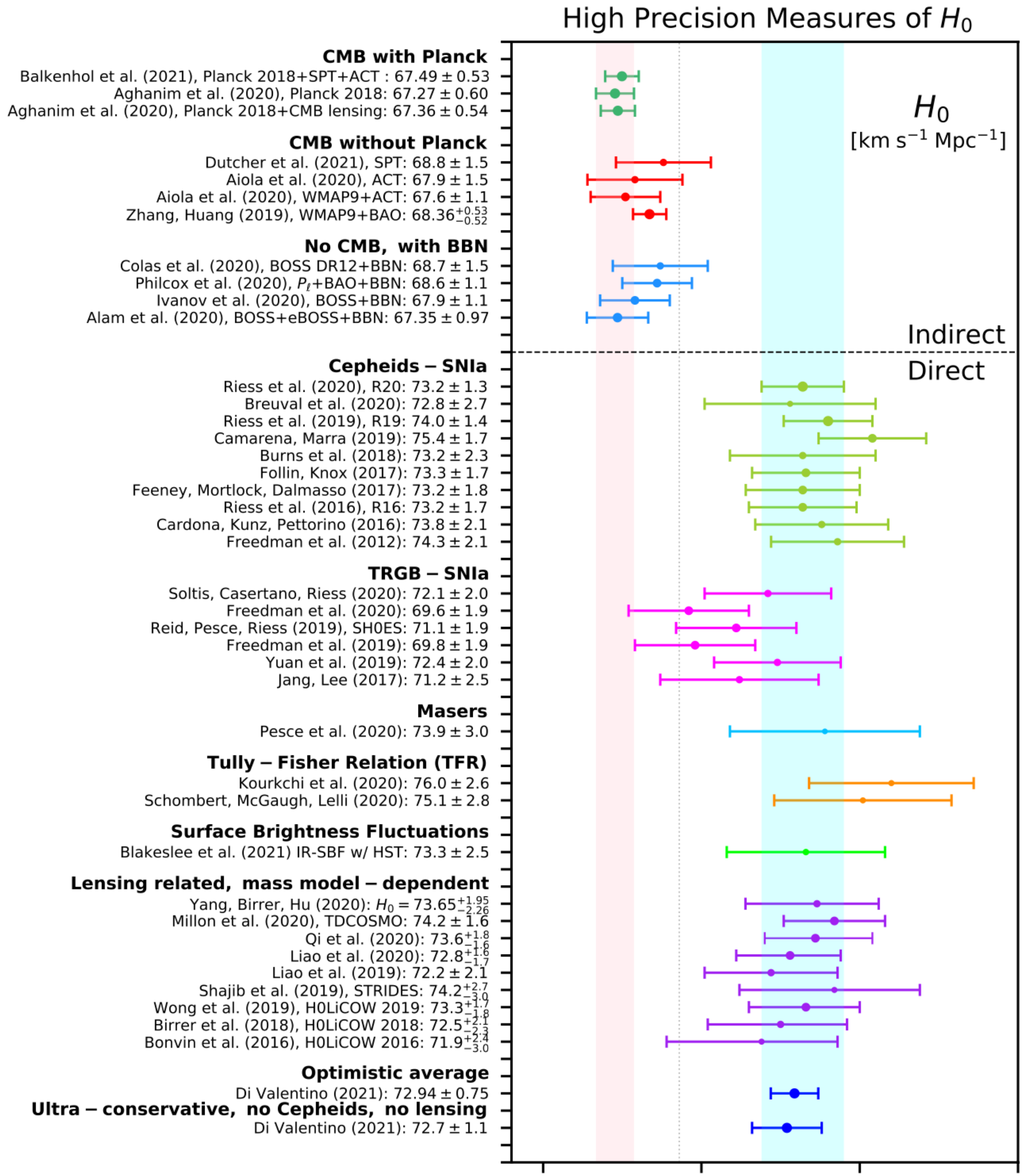
Most famous standard candles: Cepheids!
With their period luminosity relation



Riess, Yuan, Marci+2022

The Hubble tension/Hubble trouble

Hubble tension is at 5 sigma level



Di Valentino 2022

Assessing the error budget

SH_0ES team lead by Adam Riess

geometric distance

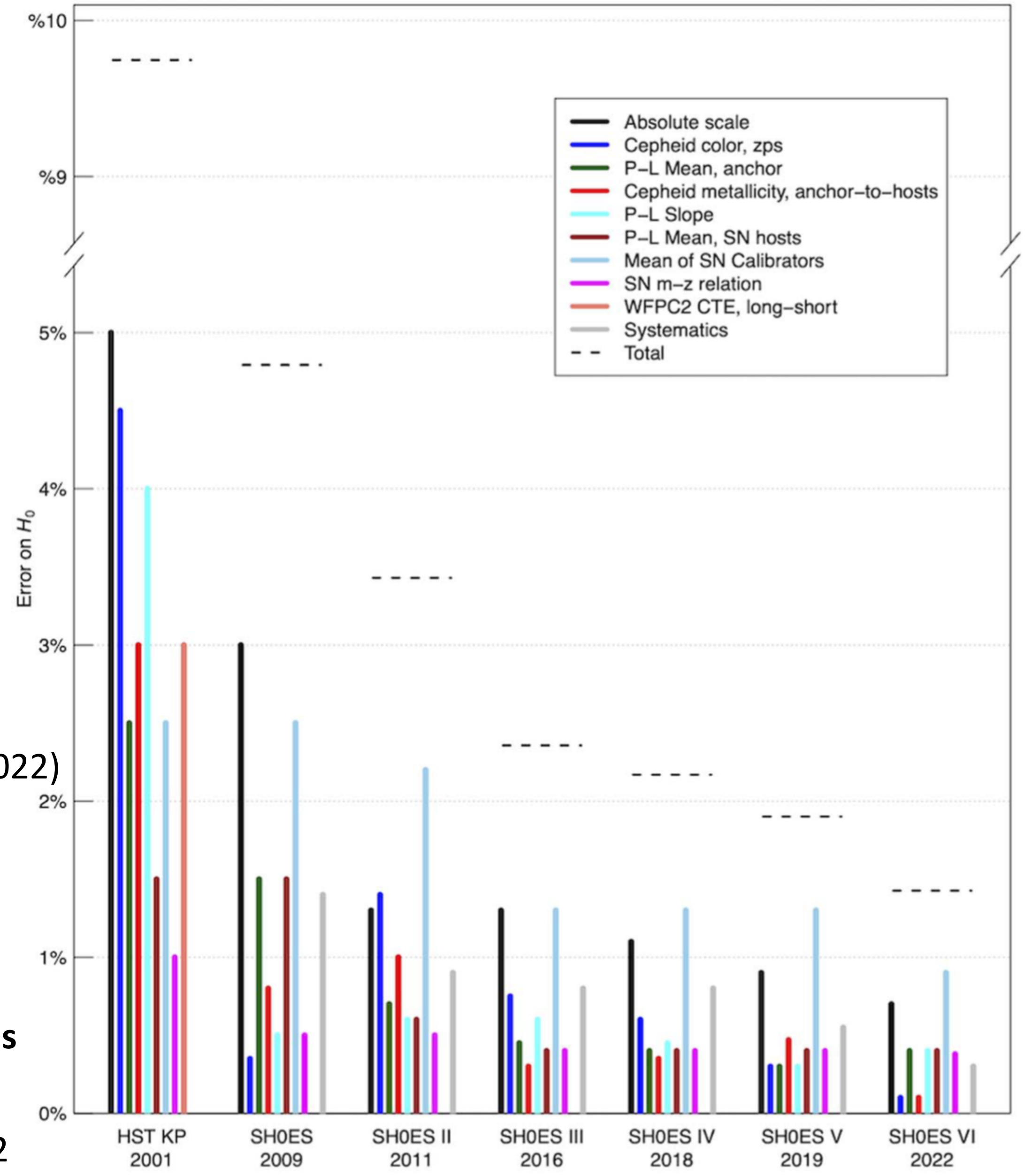
Same filter system

Error Budget:

Largest uncertainty: SN dispersion
Improvement is slow 1 source per year,
also an improvement by James Webb Telescope - better precision, homogeneity JWST, see Yuan, Riess, Casertano 2022)

Second largest uncertainty: Cepheids

From EDR3: Gaia is the best option to calibrate the Cepheids



Riess, Yuan, Macri+2022

Still Cepheids are problematic

Cepheids in the Milky Way are bright… too bright…

Saturation: Gaia gating system

In Gaia, colour variations (astrometric solution is using a mean colour)

How to solve this?

Wait until the Gaia consortium improves its solution…

or…

Problem with Cepheids

or…

Several Cepheids are in clusters —> determine the distance of the cluster with Gaia

Improved precision because many stars can be used to determine the distance of the cluster
Improved systematics, for example “the Lindegren correction” can be applicable

Systematic analysis Cruz Reyes, Anderson 2022:

—> Detection, calibration of Cepheids at the level 0.9% at 10 days

1 cluster cepheid is like 9 cepheids

Riess, Breuval, Yuan+2022 —> 5-7% improvements of the uncertainty, enhancing the tension

Closing remarks on Cepheid Distance scale (1/2)

Hubble tension is at a larger than 5 sigma level

Reasons still unknown

Field Cepheids surpass now LMC or NGC 4258 (maser)

The Gaia Parallax offset is a limitation, looking for improvements of DR4(2025)/DR5 (2030)

Closing remarks on Cepheid Distance (2/2): The improvements

More data

Lower random errors

Photometry .... $\propto 1/\sqrt{\text{mission\_length}}$

Positions, parallaxes .... $\propto 1/\sqrt{\text{mission\_length}}$

Proper motion .... $\propto 1/(\text{mission\_length} * \sqrt{\text{mission\_length}})$

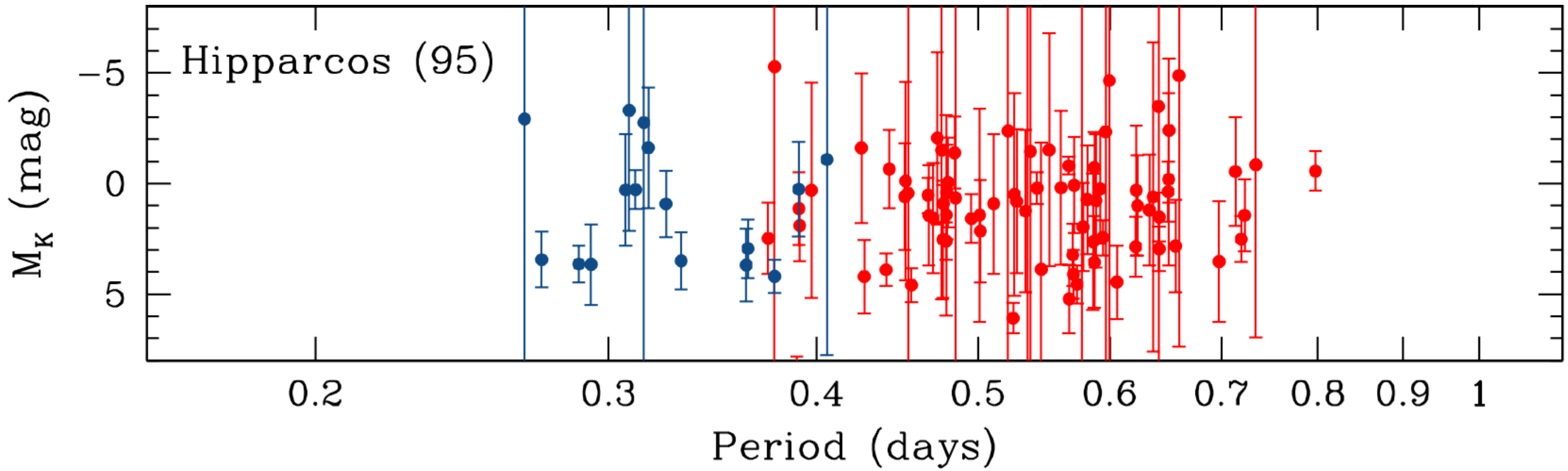
34 months (DR3) to 10 years (DR5) —> improvement of 1.9

Better calibrations/data reductions

Lower systematic erros

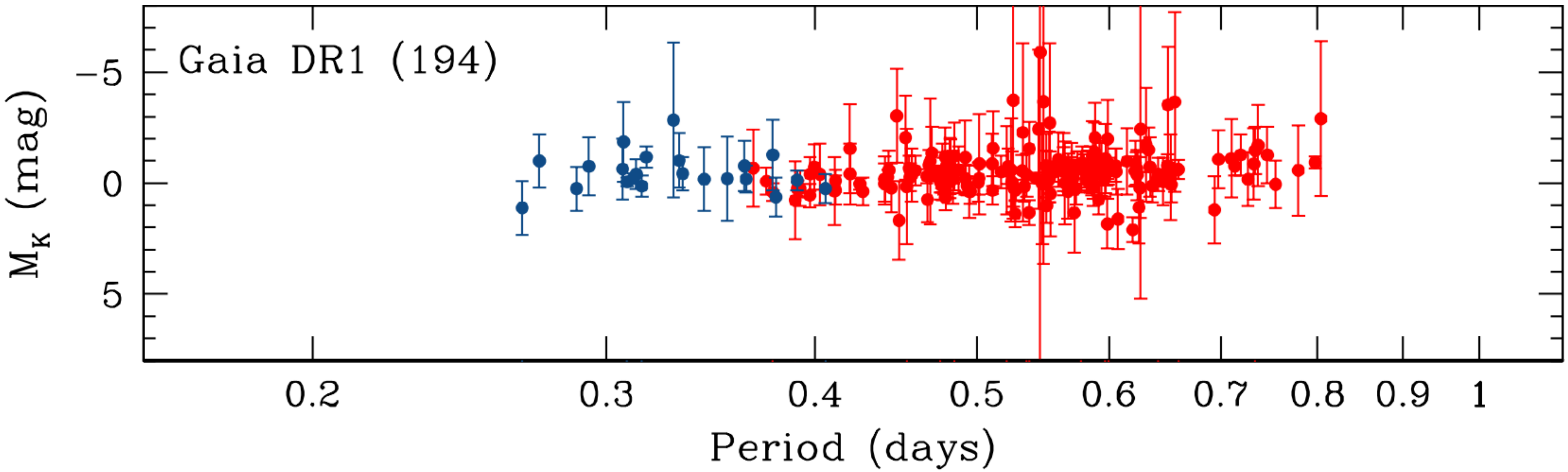
This topic will have significant improvements

Period Luminosity of RR Lyrae stars



Credit:ESA/Gaia/DPAC: T.Muraveva, A.Garofalo, V. Ripepi, G. Clementini

Period Luminosity of RR Lyrae stars



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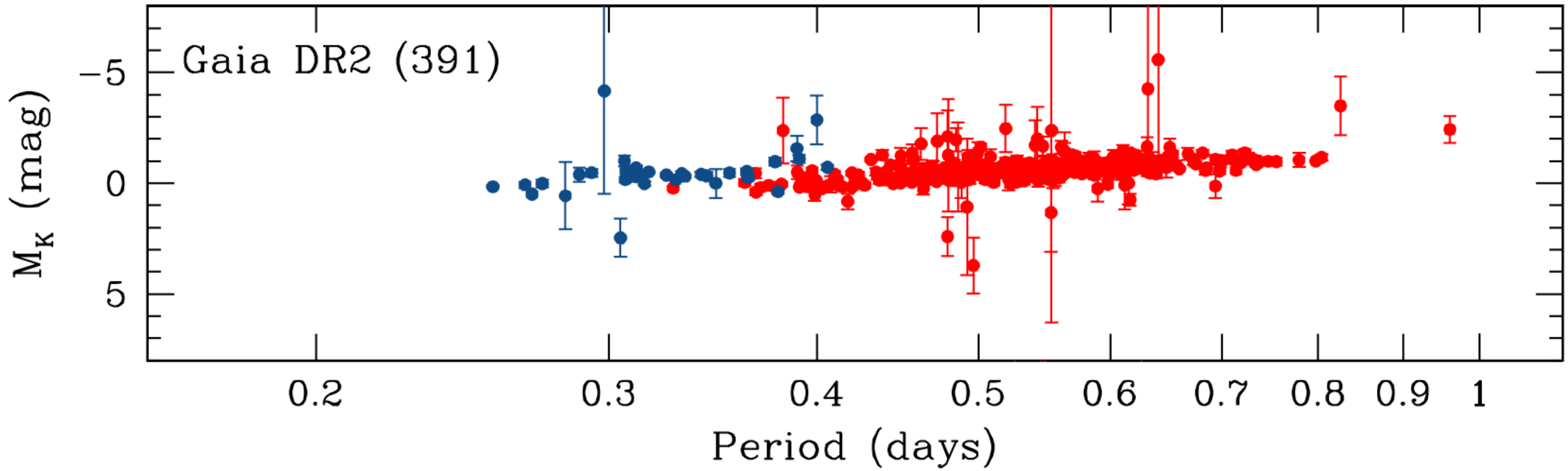

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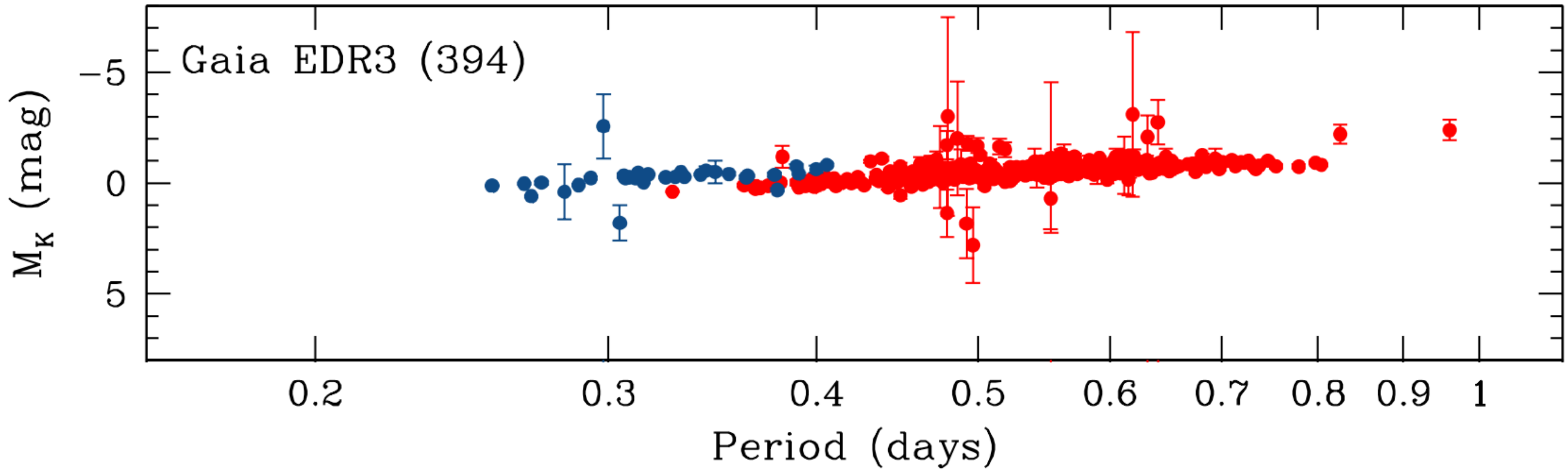
Period Luminosity of RR Lyrae stars

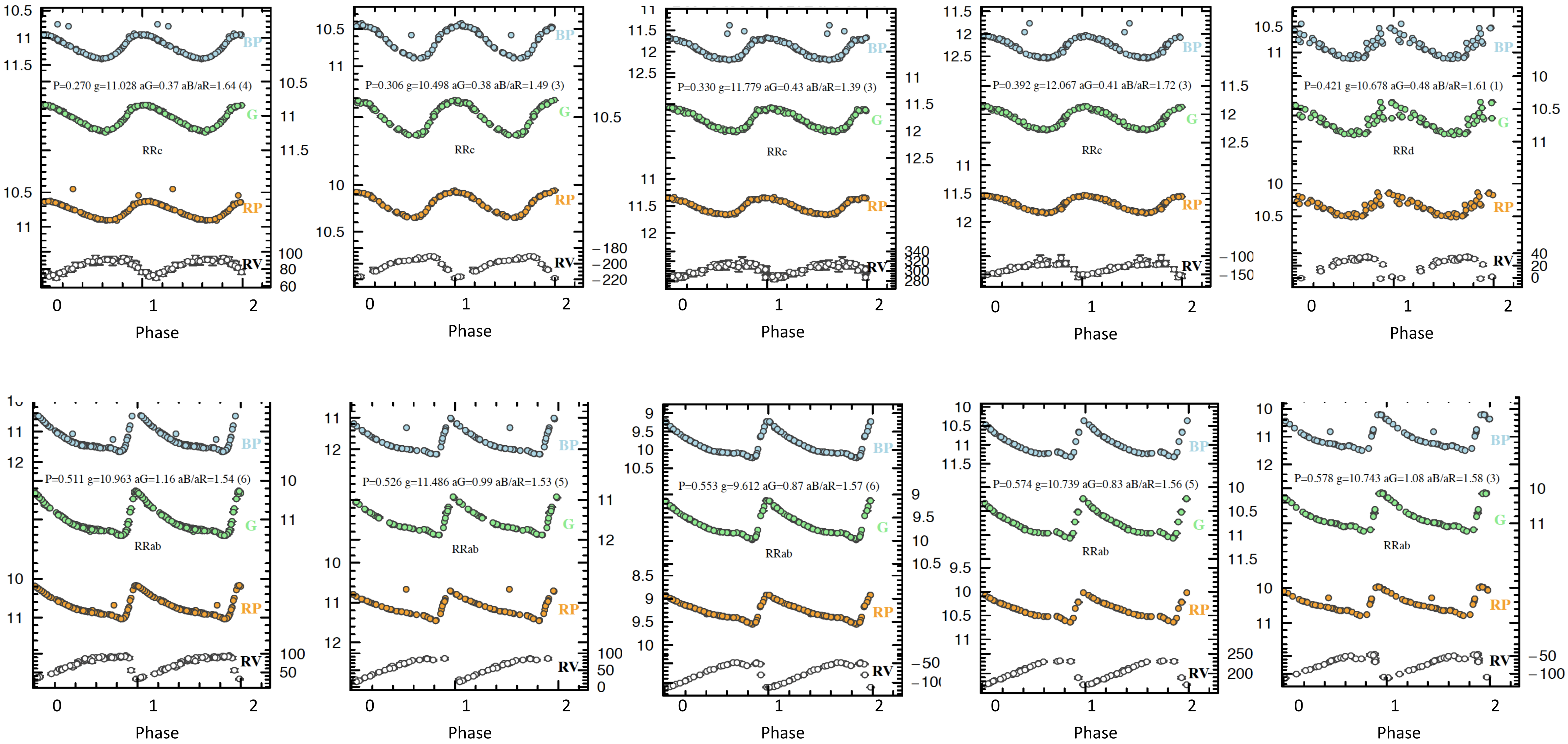


Credit:ESA/Gaia/DPAC: T.Muraveva, A.Garofalo, V. Ripepi, G. Clementini

RR Lyrae stars

Gisella Clementini, Vincenzo Ripepi, Alessia Garofalo, Tatiana Muraveva, Roberto Molinaro, Silvio Leccia

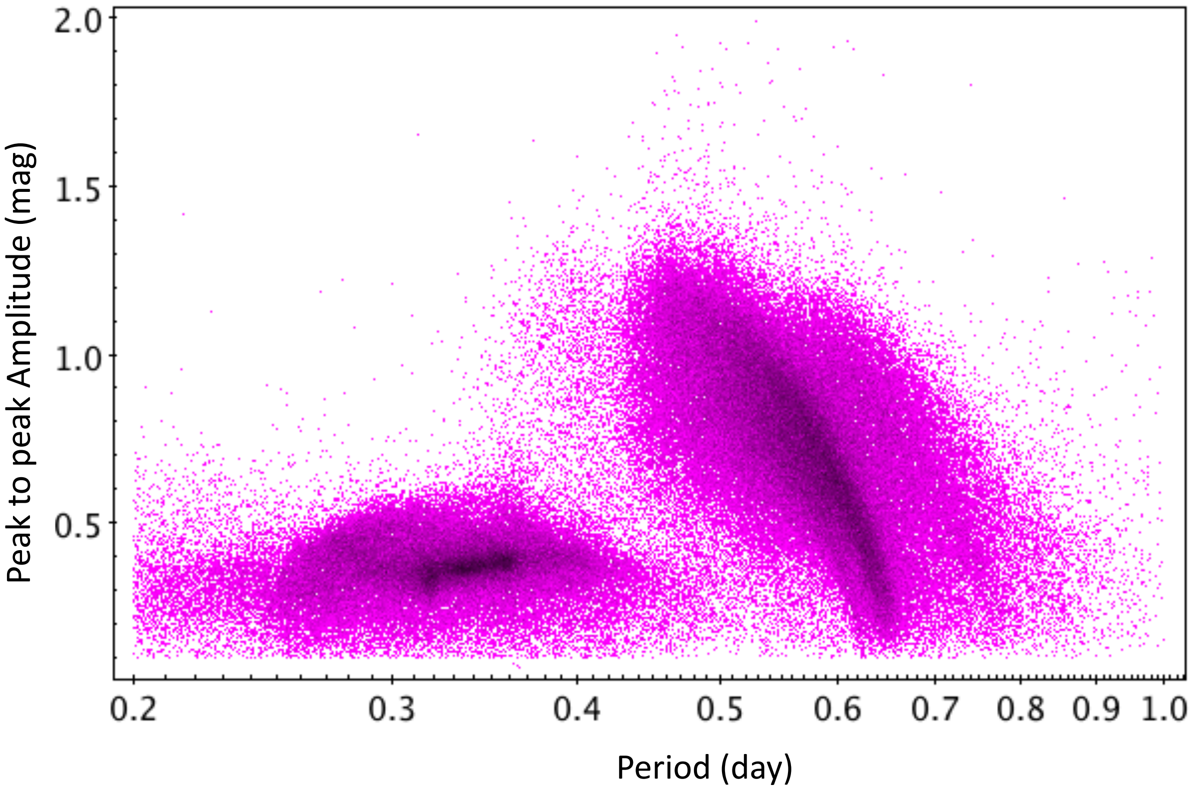
About 2,000 Cepheids and RR Lyrae stars with radial velocities



RR Lyrae stars

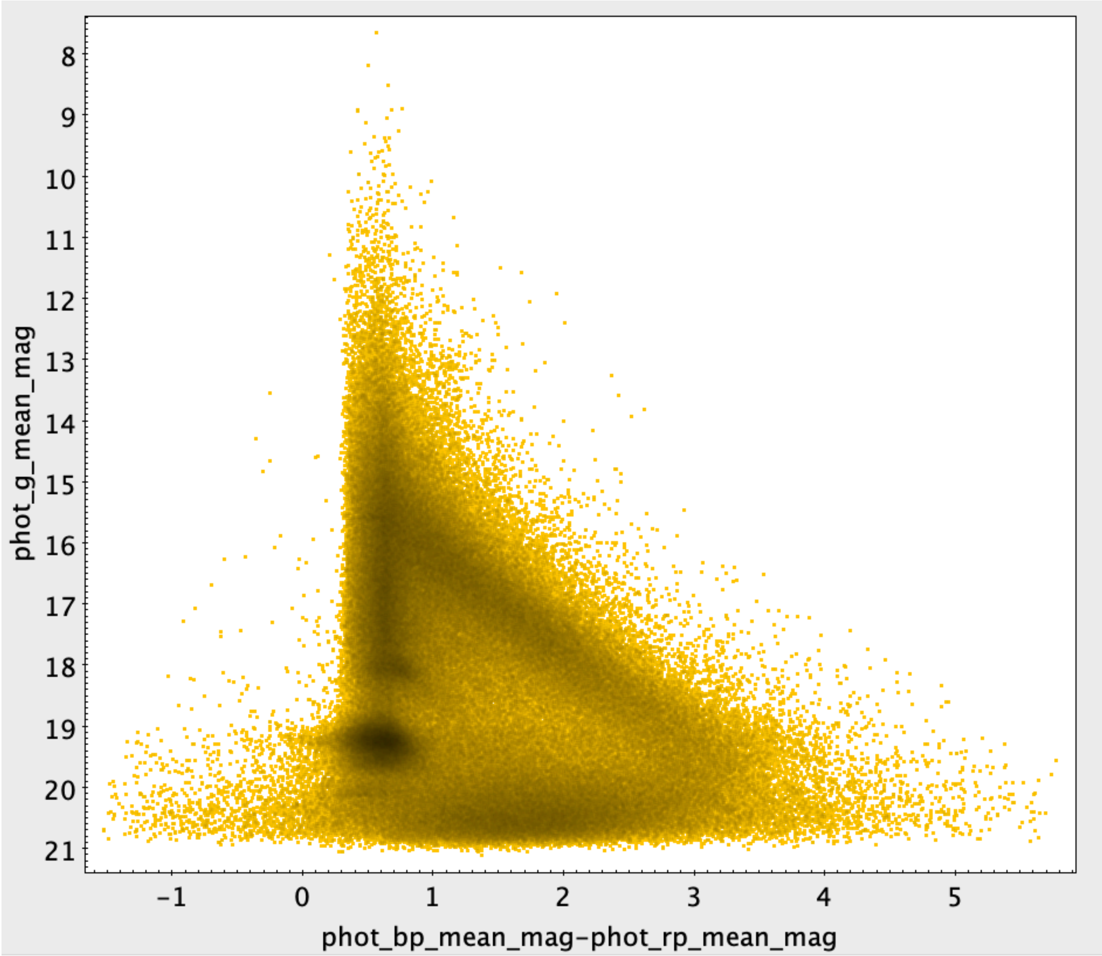
Gisella Clementini, Vincenzo Ripepi, Alessia Garofalo, Tatiana Muraveva, Roberto Molinaro, Silvio Leccia

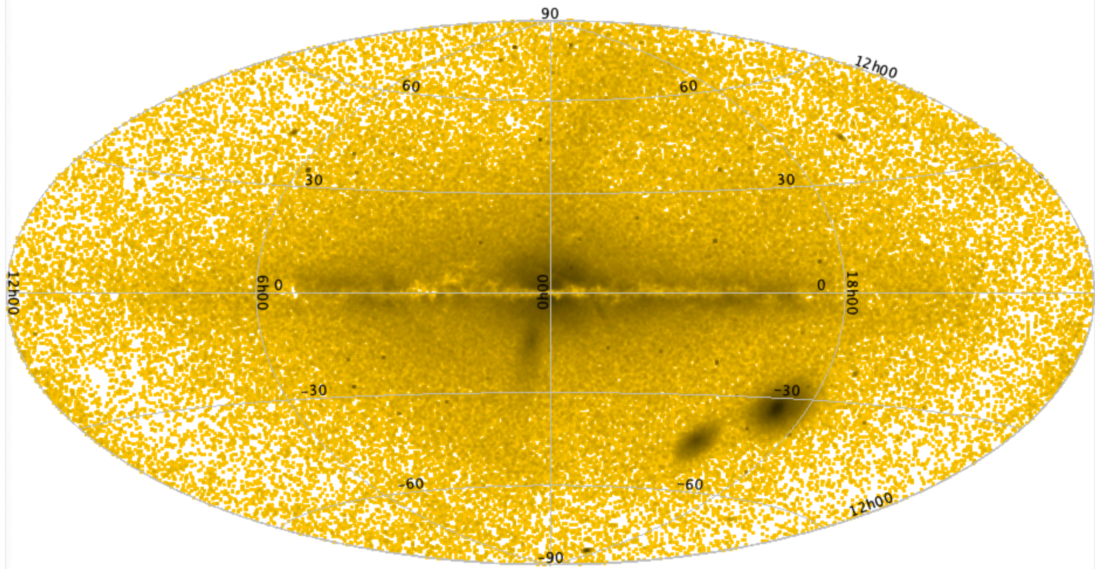
RR Lyrae stars: ~270,000 (with RVS time series for about 1,200)



Special focus on RR Lyrae stars

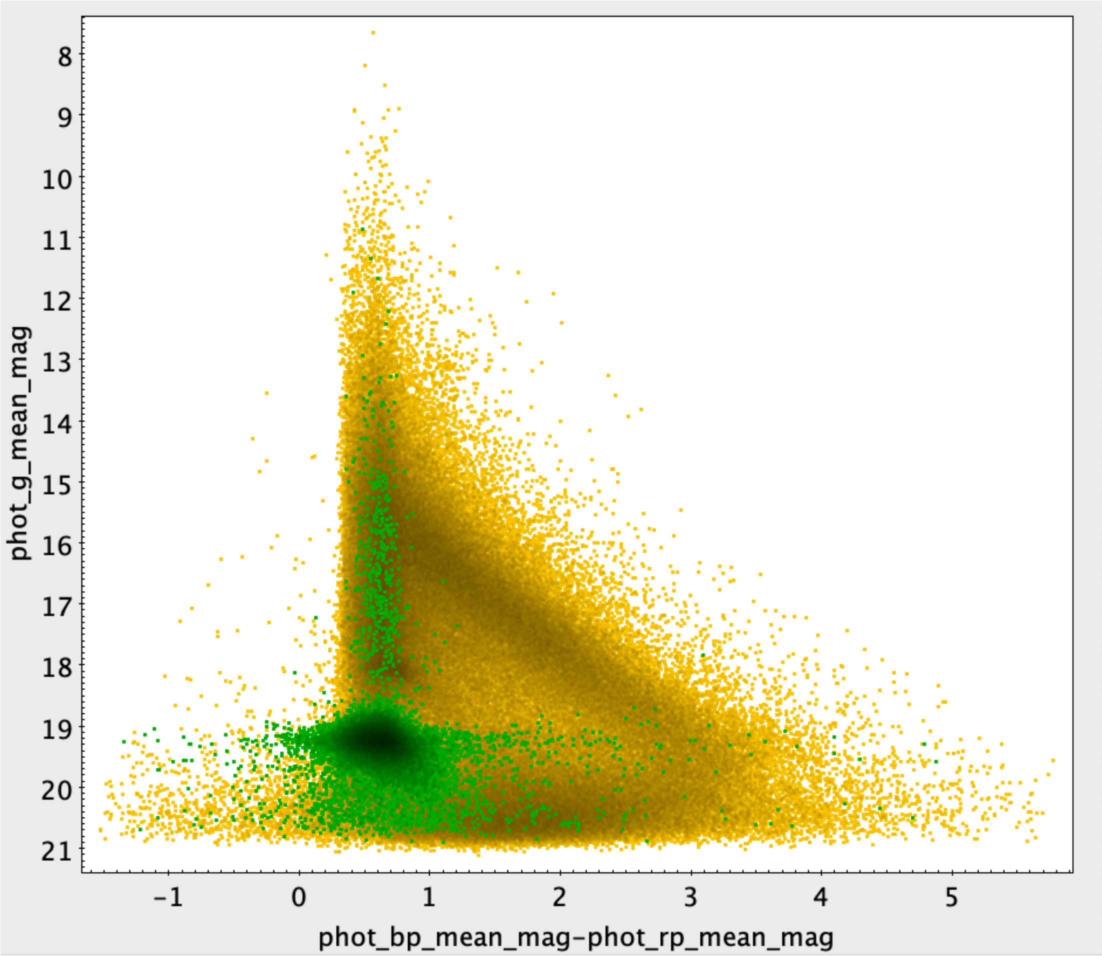
About 270,000 stars

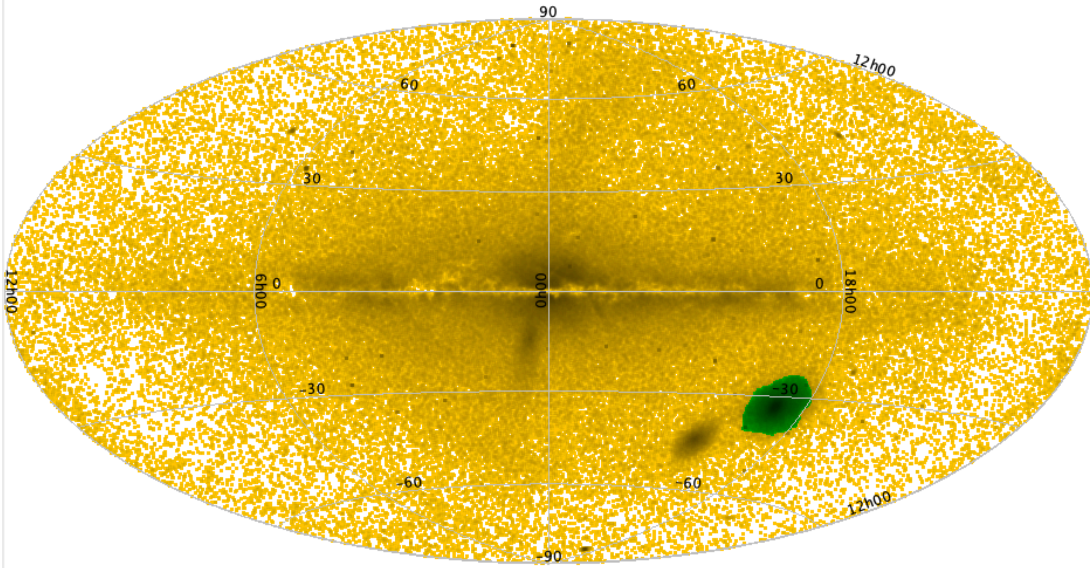




Special focus on RR Lyrae stars

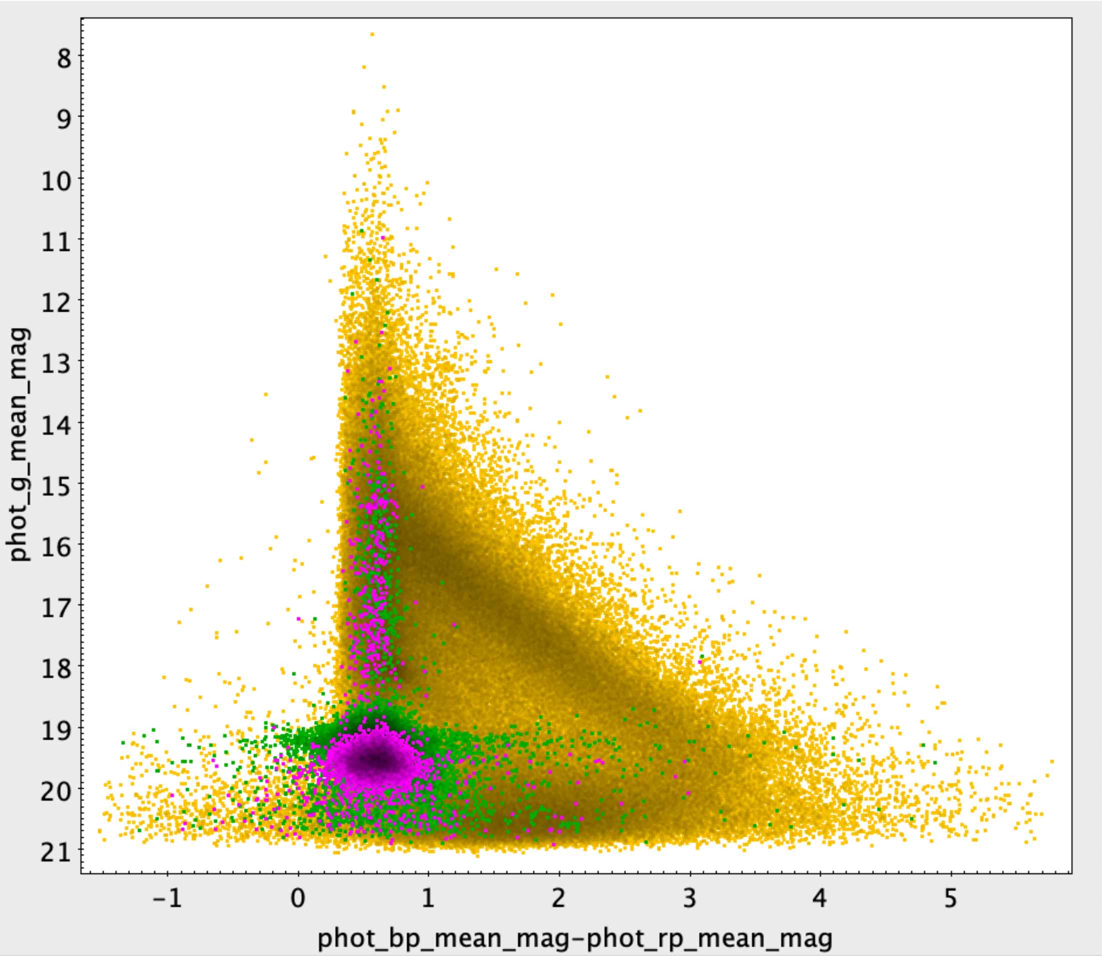
LMC

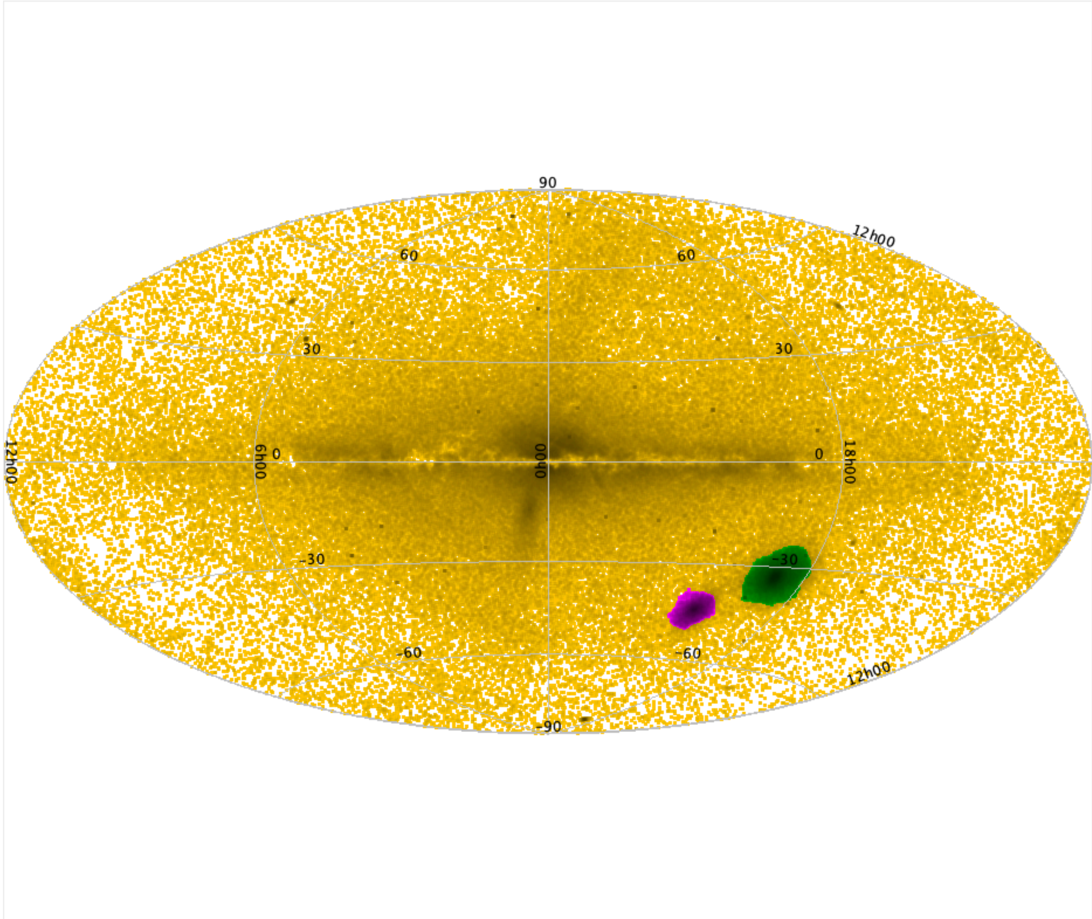




Special focus on RR Lyrae stars

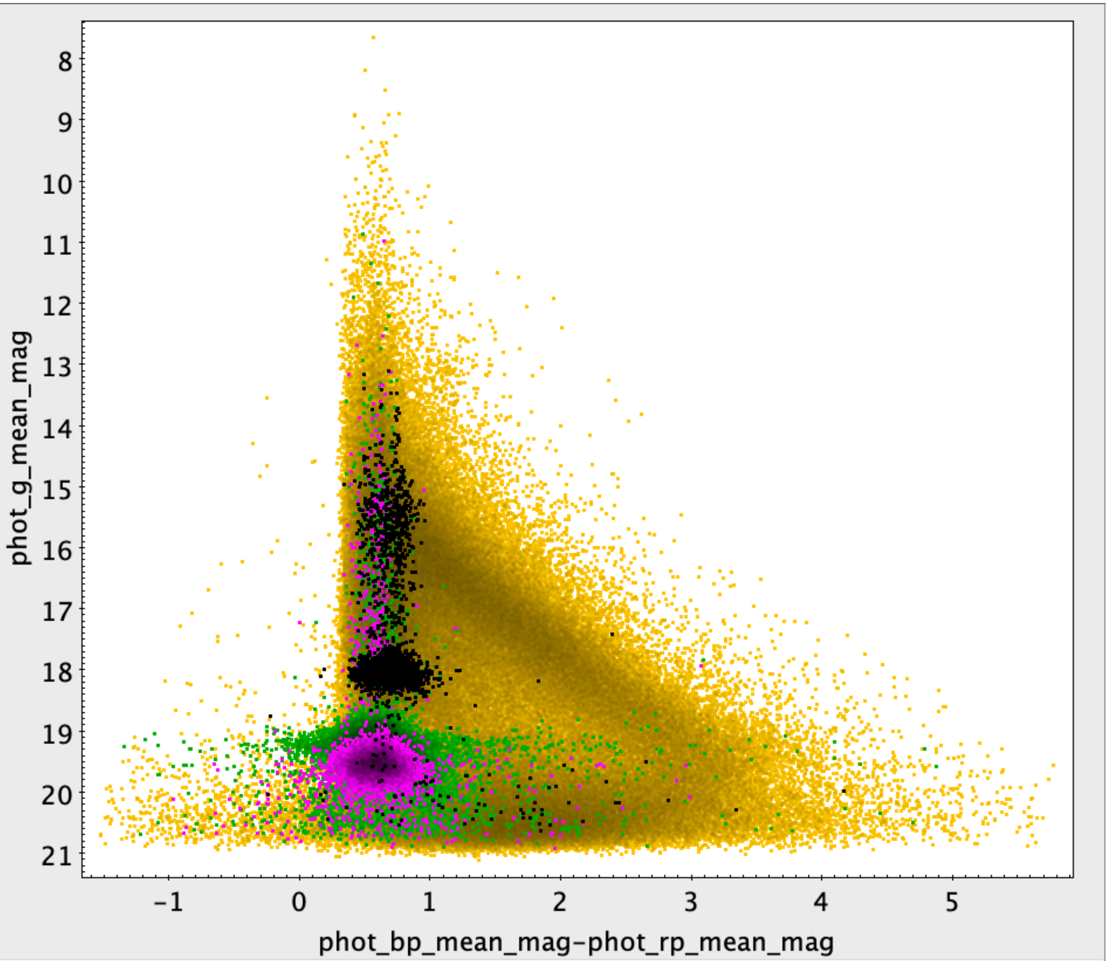
SMC

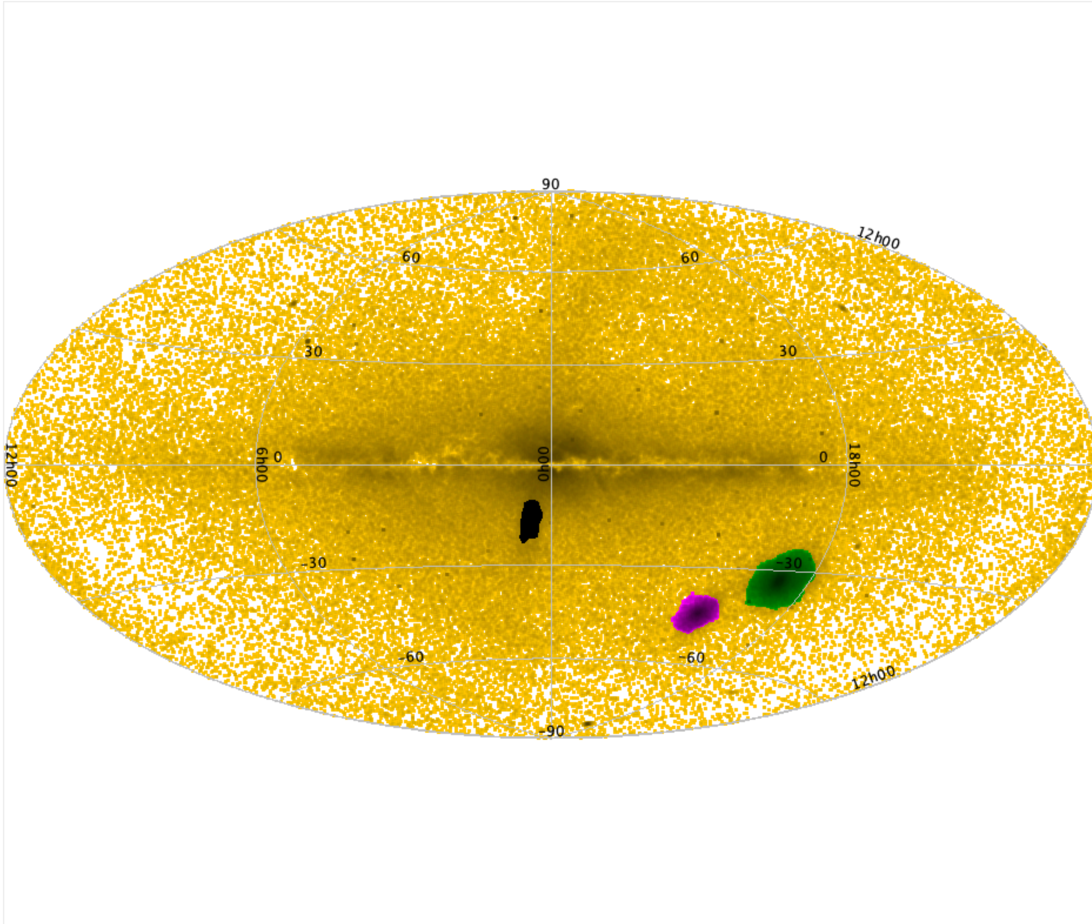




Special focus on RR Lyrae stars

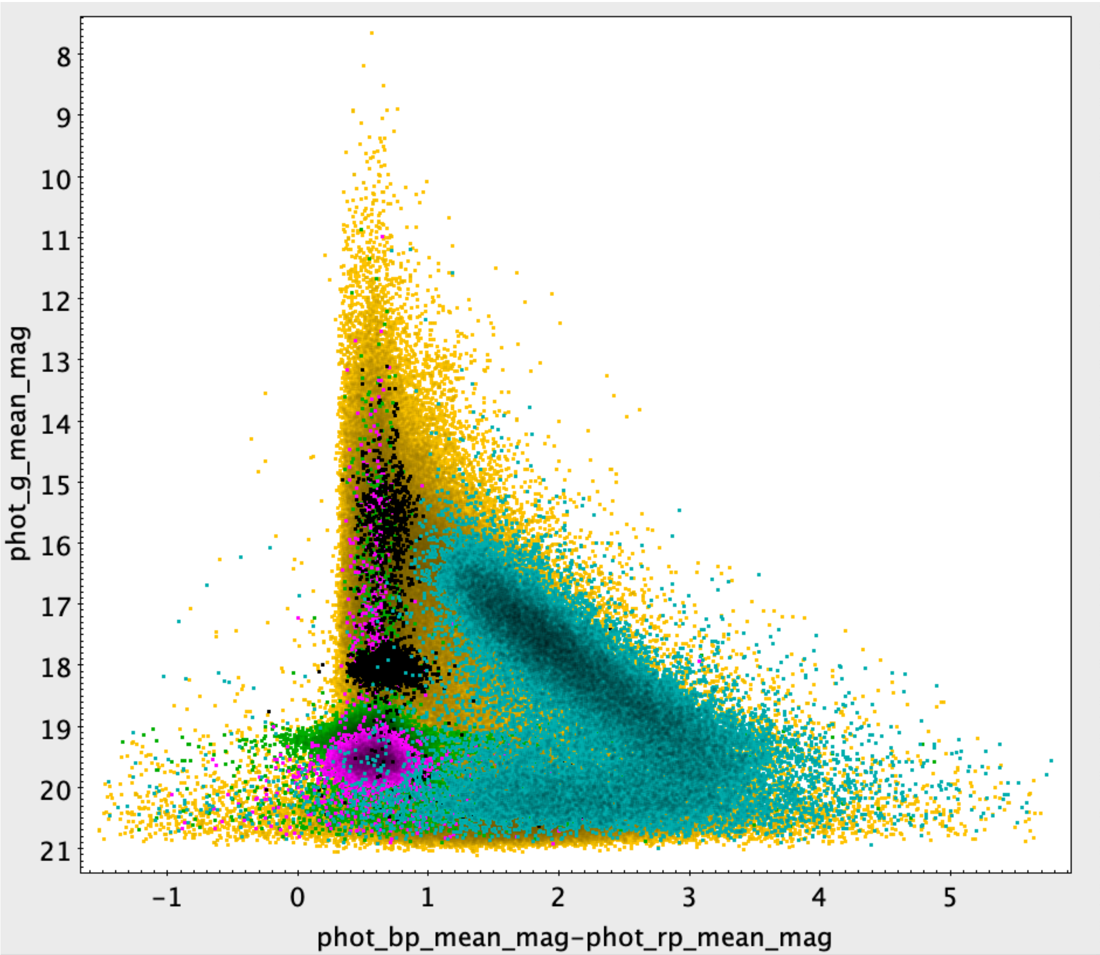
Sagittarius Dwarf

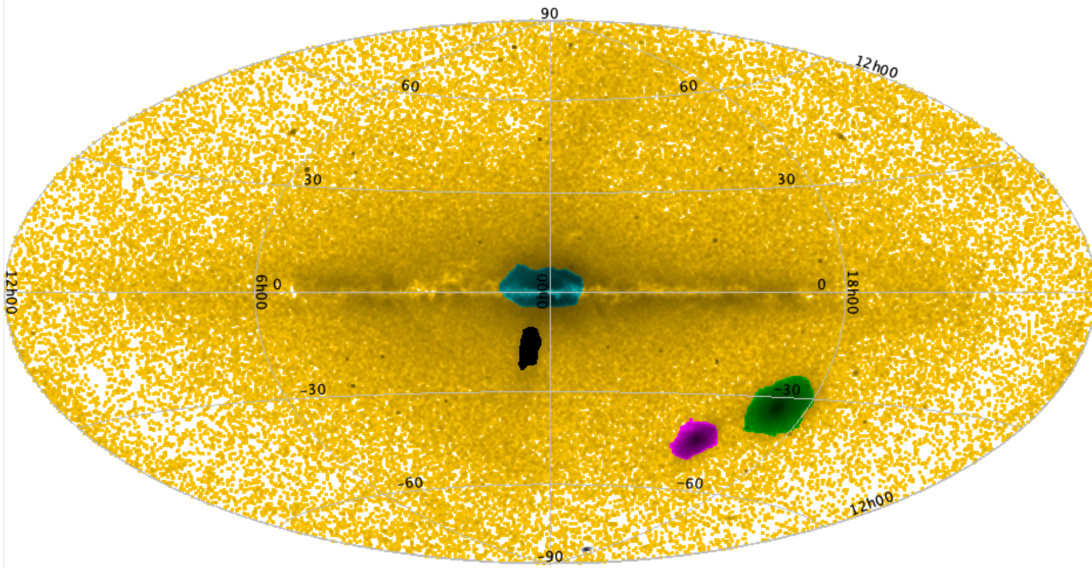




Special focus on RR Lyrae stars

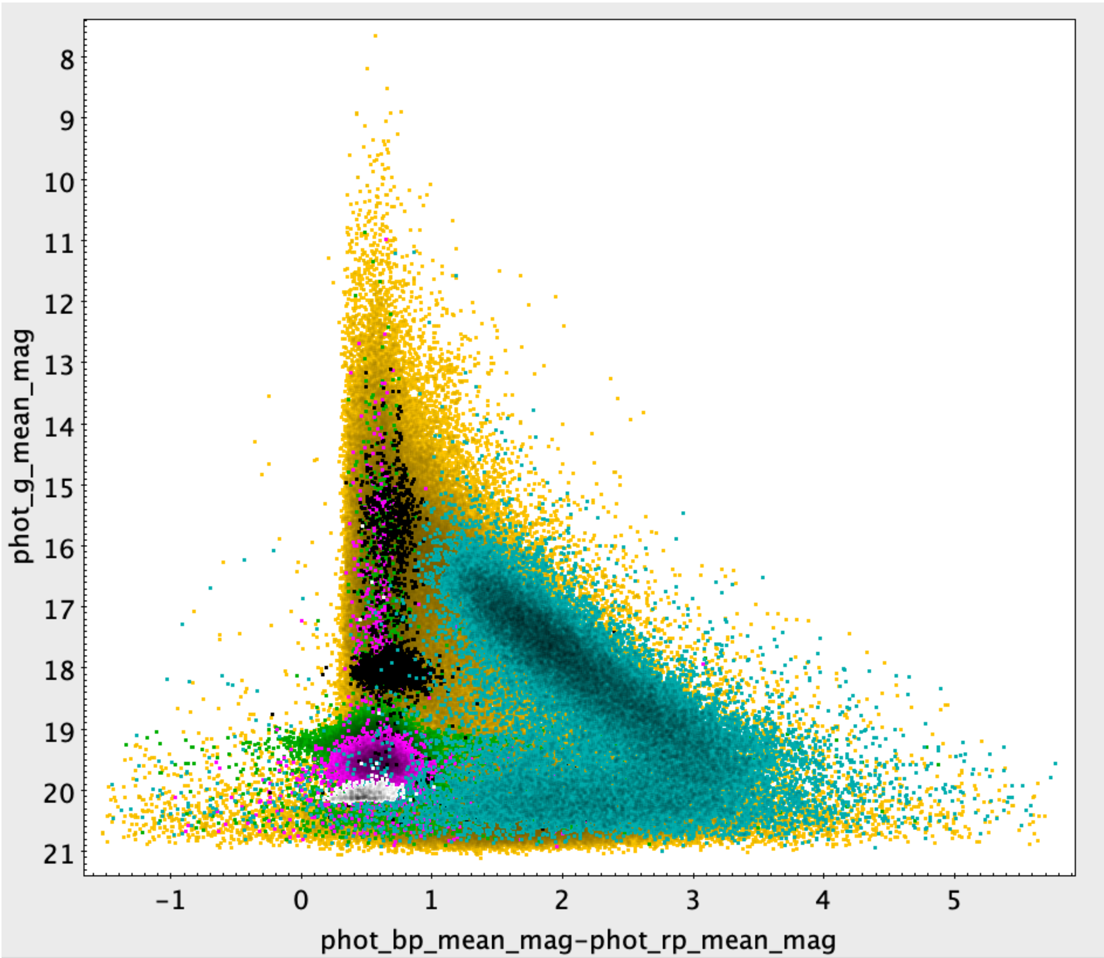
Bulge (with strong extinction)

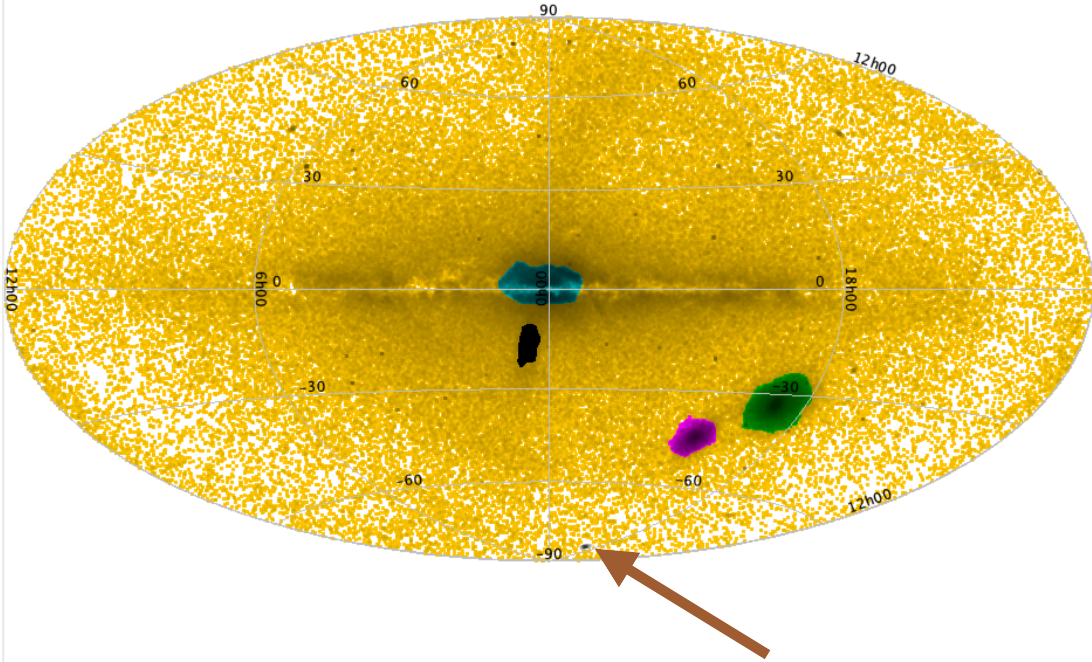




Special focus on RR Lyrae stars

Sculptor

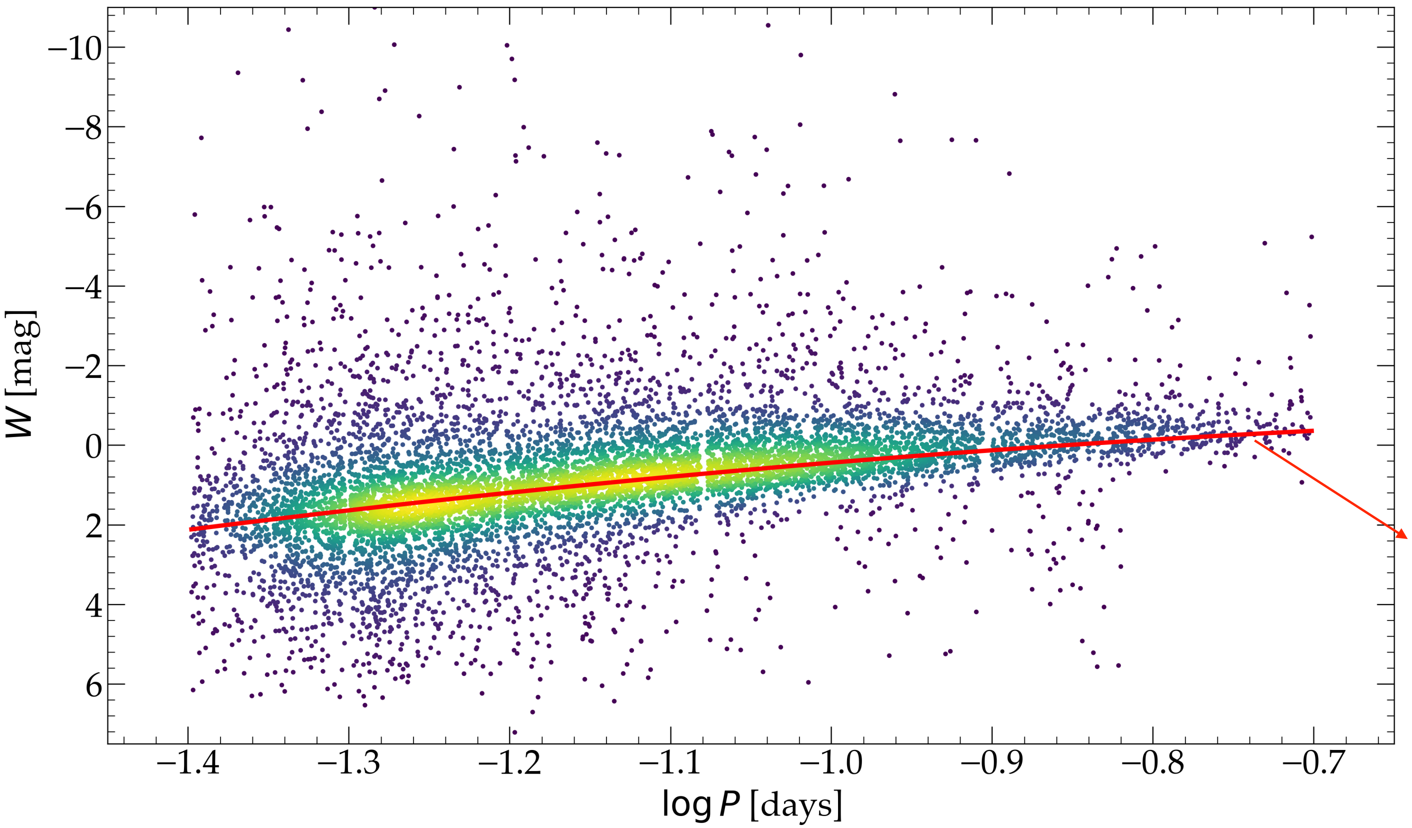





By L. Rohrbasser

The period-luminosity relation of δ Sct stars

8'894 sources with good parallax, ampl ≥ 50 mmag, Teff ∈ [6400, 8700] K



To our knowledge: the most extensive and precise empirical PW relation of δ Sct stars published!

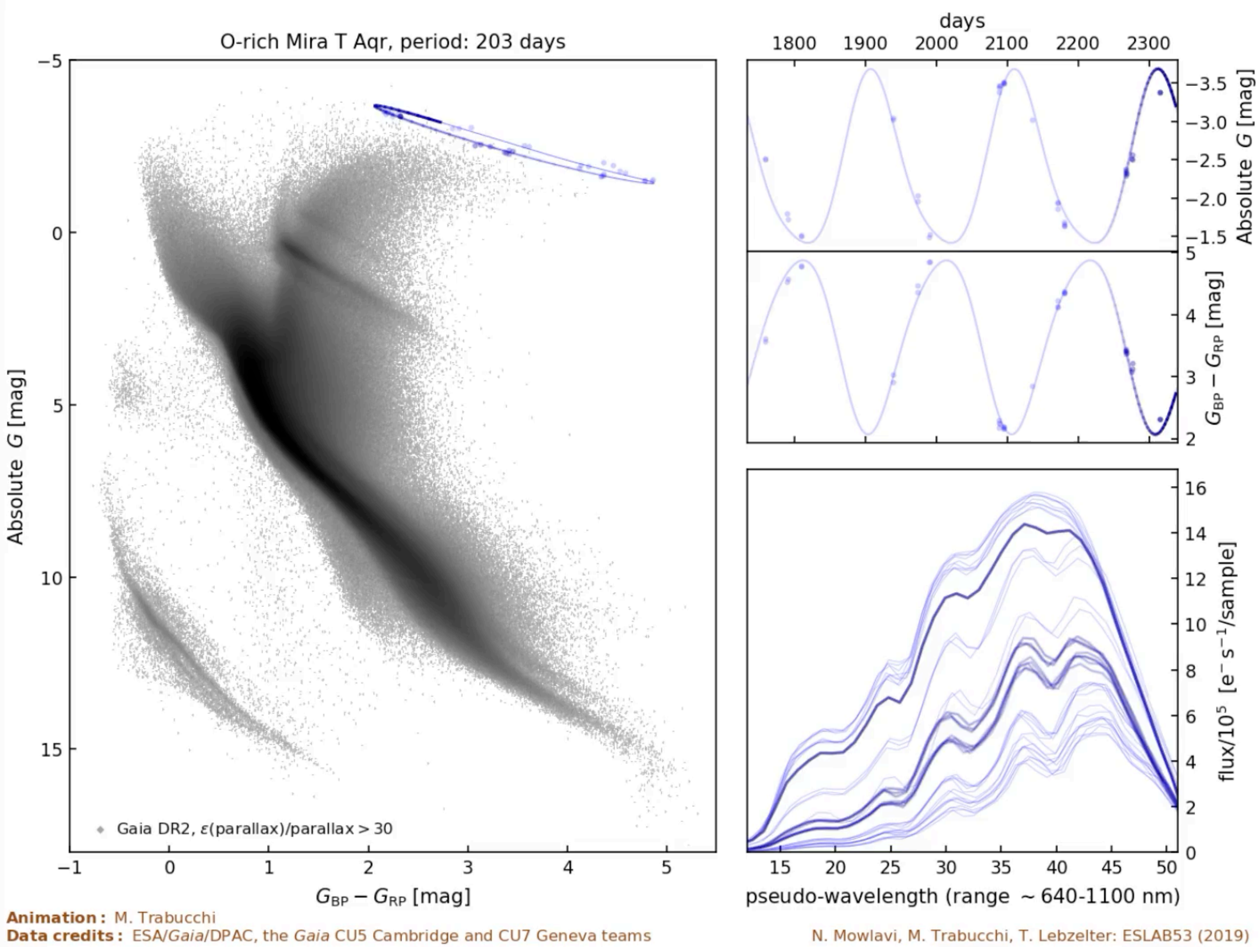
A simple linear relation does not represent well the empirical PW relation; a quadratic fit does.

→ the relation is either nonlinear or has two regimes

Back to RR Lyrae stars

Other topics

Variable stars alive in RP spectrophotometry



We are able to distinguish between Carbon-rich or Oxygen-rich stars

Carbon rich stars are
one of the most important contributor
to the enrichment of the interstellar medium

546,468 C-rich long period variable stars

Pushing limits

Period recovery rate for strictly period signals

1. Signal(t)= A sin(2 π ν t + ϕ) + noise

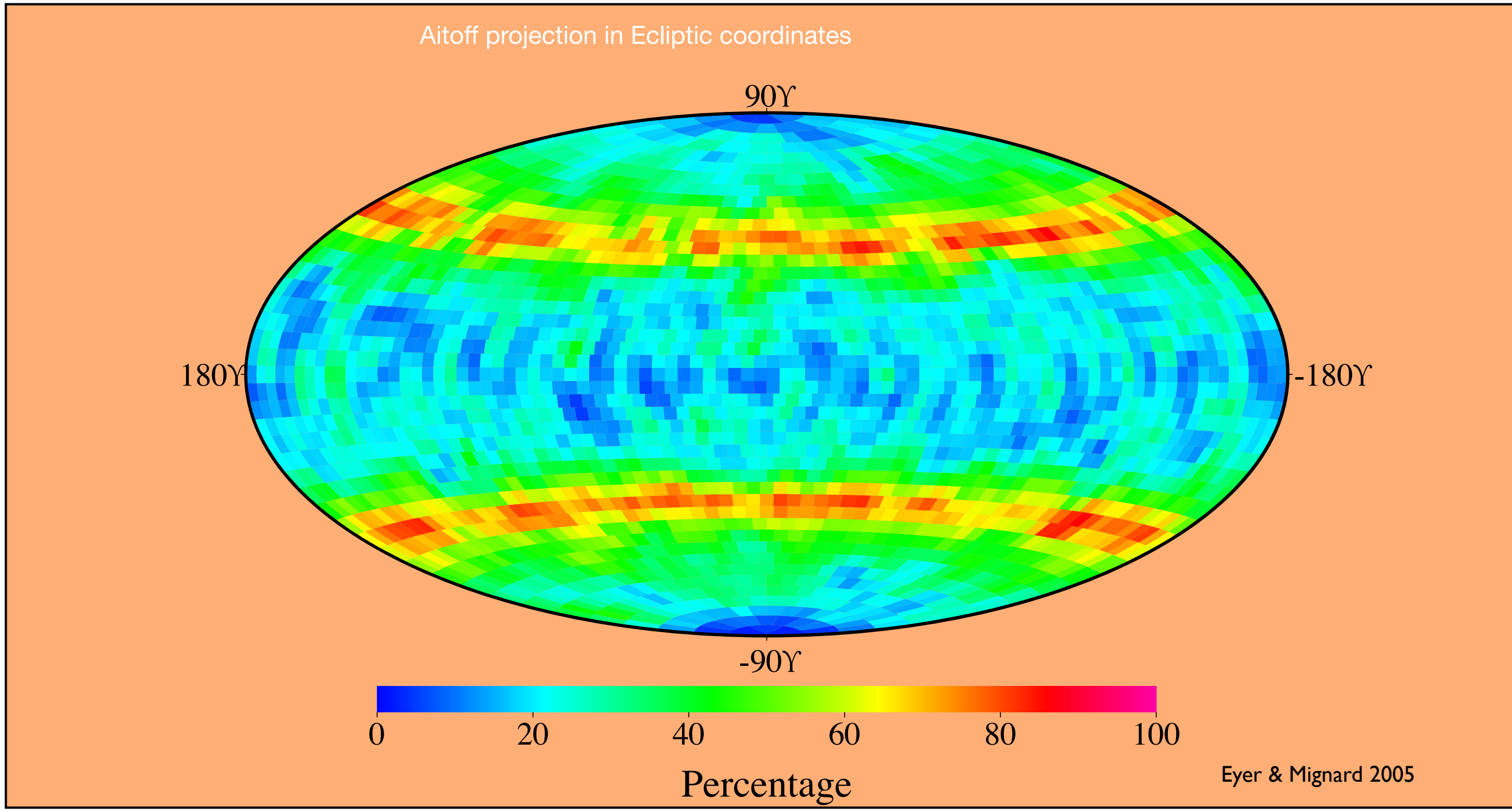
2. Two parameters:

a) S/N ratio = 0.75 (very unfavorable case)

b) Period = 1/ν = 0.2 day

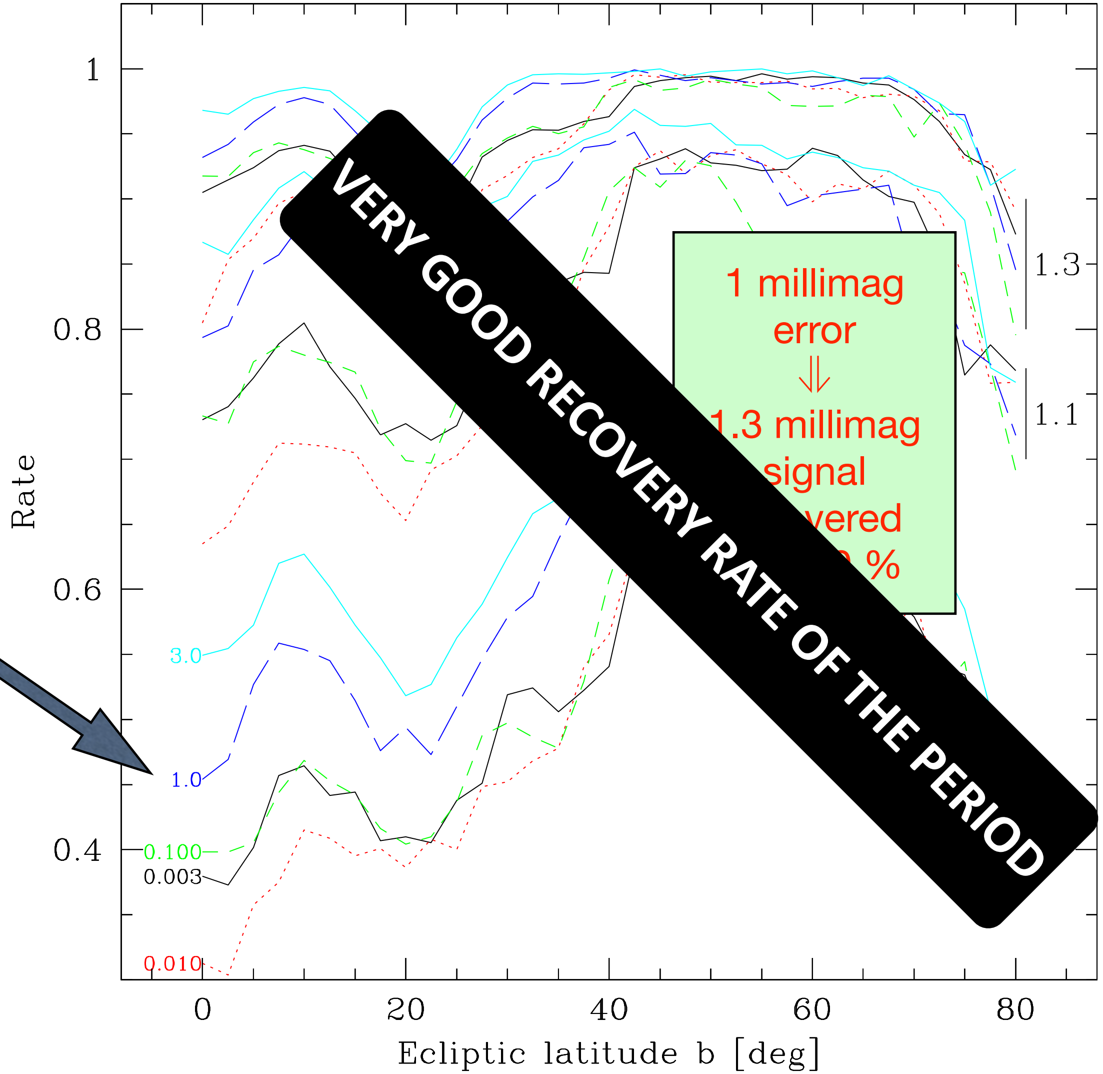
3. Gaia sampling

4. Period search algorithm
➔ determine the success rate



Period recovery rate for strictly period signals

Frequency cycle/day



Normalised S/N = sqrt(nmes/80) S/N

Eyer & Mignard 2005

Lower photometric amplitudes: pulsation

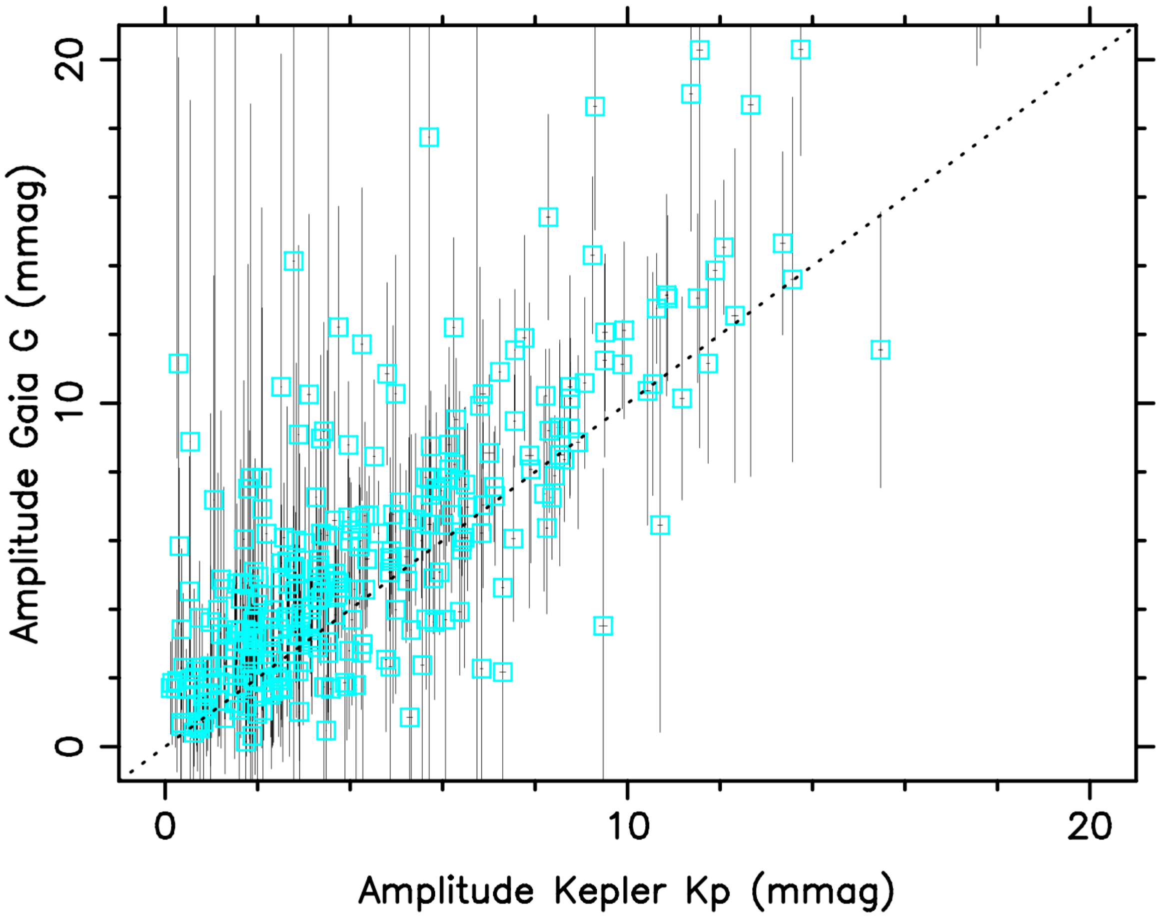
Pushing the limits

Conny Aerts at 2023 EAS's conference

Comparison with gamma Dor stars from Kepler

Already now, we detected amplitudes with uncertainties of 2 mmag (in RP!)

Gives hopes that few millmag amplitude will be detected in DR4/DR5!



Multi periodic behaviour

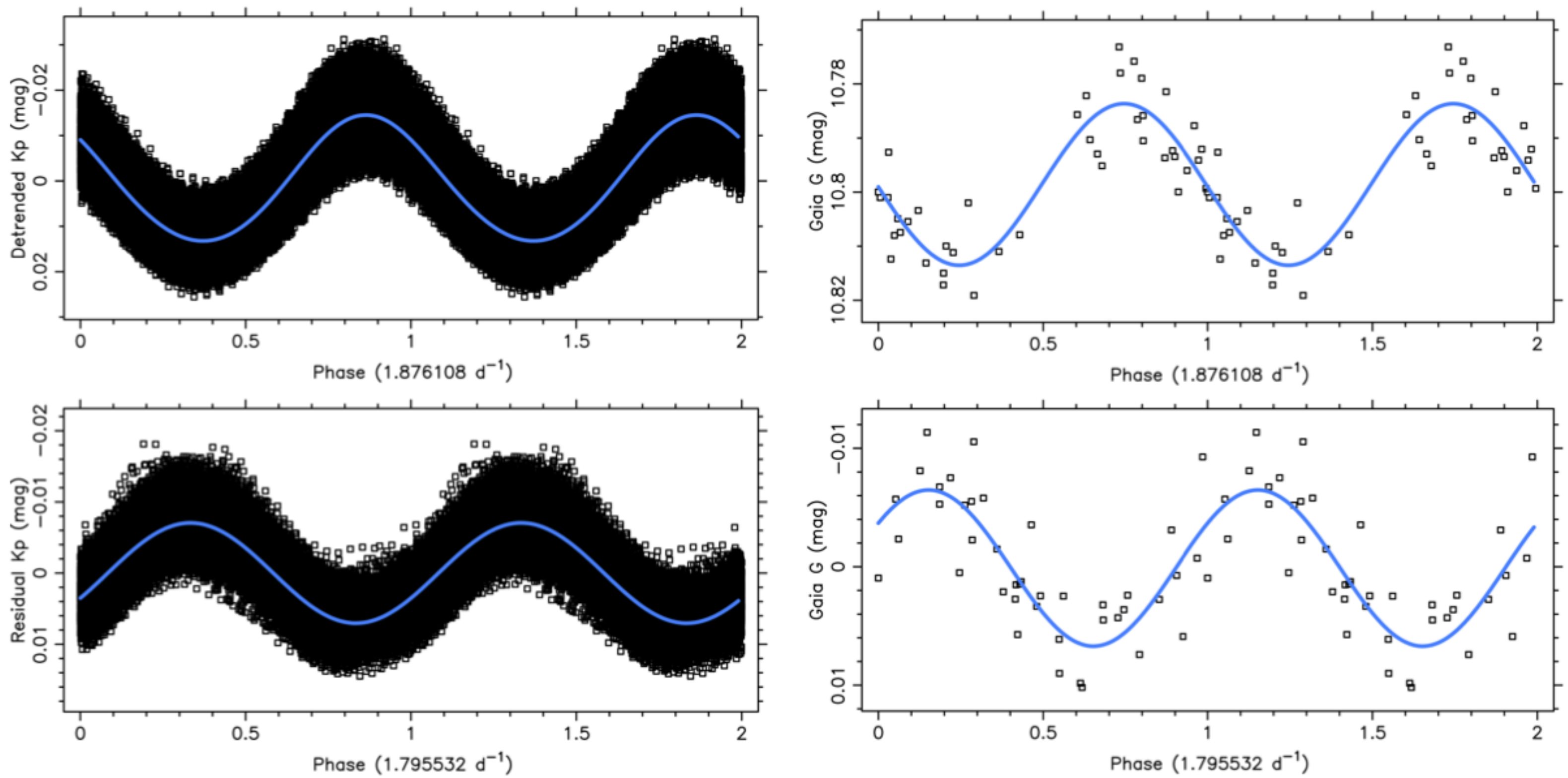
Article of Gaia consortium De Ridder, Ripepi, Aerts+2023

Kepler data

Gaia data

First frequency

Second frequency



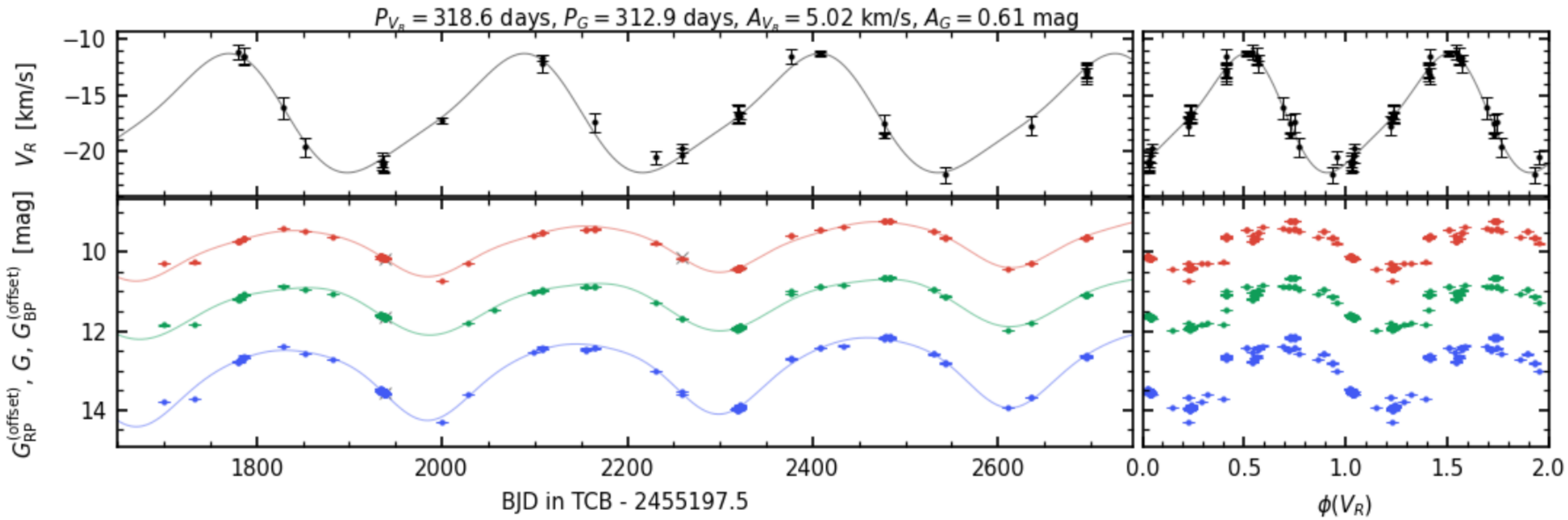
It opens the door of multi-periodic analysis in Gaia data

The Focused Product Release

Focused Product Release:
Time domain radial velocities for Long Period Variables

Stay tuned: NEXT WEEK: Tuesday October 10, 2023

- Reminder Gaia DR3: 1,720,588 LPVs
- 6 < G < 14
- Data interval: 34 months
- Total number of 9,614 stars with radial velocity time series



Trabucchi, Mowlavi, Lebzelter et al. 2023