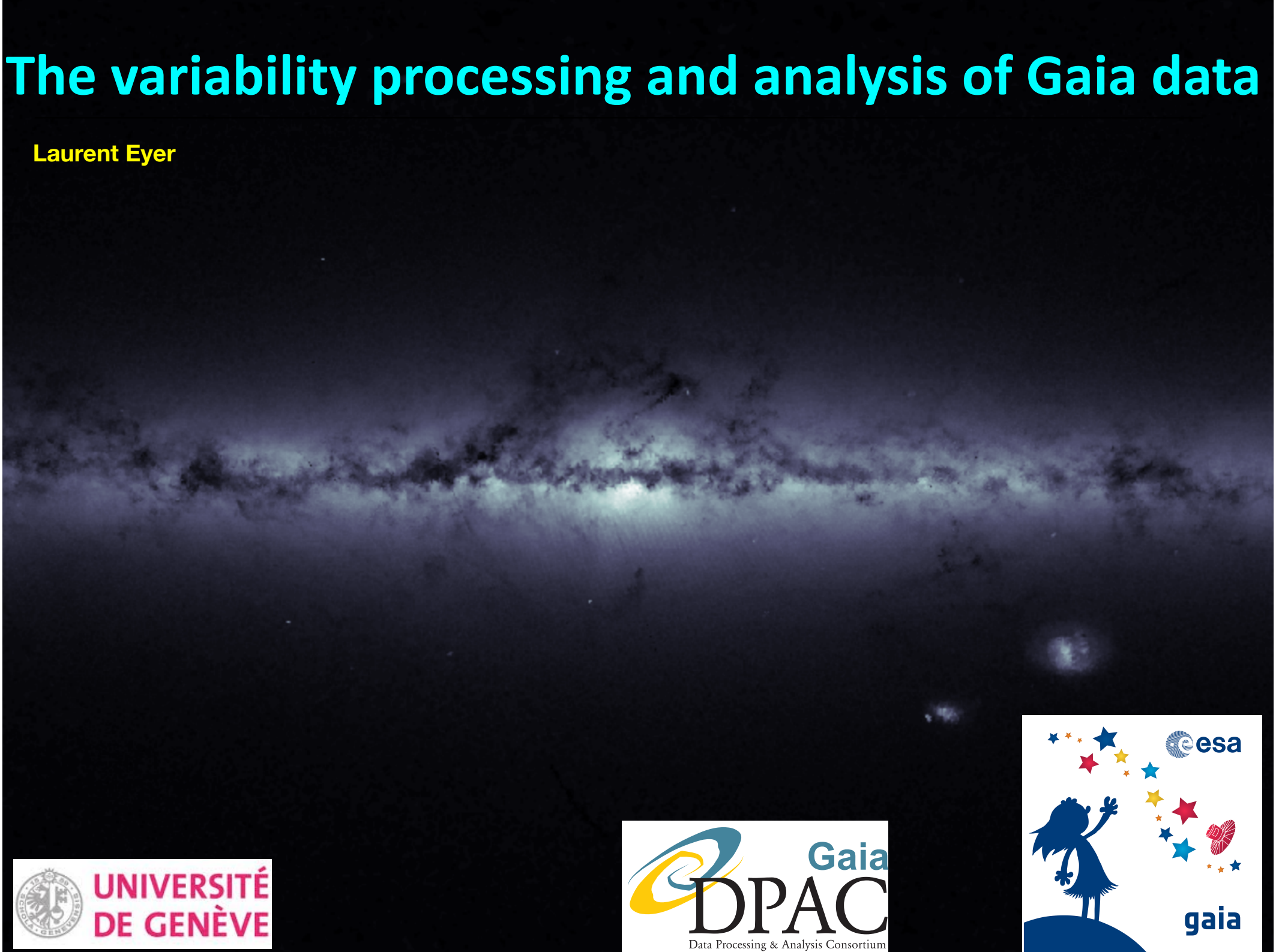
The variability processing and analysis of Gaia data

Laurent Eyer



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Gaia DPAC Data Processing & Analysis Consortium

esa gaia

The variability processing and analysis of Gaia data

Laurent Eyer[1]

Nami Mowlavi[1], Dafydd W. Evans[2], Berry Holl[1], Lorenzo Rimoldini[1], Alessandro Lanzafame[3], Leanne Guy[1], Shay Zucker[4], Brandon Tingley[5], Isabelle Lecoeur-Taïbi[1], Maroussia Roelens[1], Jan Cuypers[6], Joris De Ridder[7], Sara Regibo[7], Manuel López[8], Jonas Debosscher[7], Maria Süveges[1], Luis Sarro[9], Gisella Clementini[10], Silvio Leccia[11], Vincenzo Ripepi[11], Fabio Barblan[1], André Moitinho[12], Krzysztof Nienartowicz[1], Diego Ordoñez-Blanco[1], Jonathan Charnas[1], Grégory Jévardat de Fombelle[1], and many other distinguished colleagues

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[2]Institute of Astronomy, University of Cambridge, Cambridge, United Kingdom
[3]Dipartimento di Fisica e Astronomia, Universita di Catania, Catania, Italy
[4]Department of Geosciences, Tel Aviv University, Tel Aviv, Israel
[5]Institut for Fysik og Astronomi, Aarhus Universitet, Aarhus, Denmark
[6]Royal Observatory of Belgium, Brussels, Belgium
[7]Instituut voor Sterrenkunde, KU Leuven, Leuven, Belgium
[8] Centro de Astrobiologia, Departamento de Astrofisica, Villanueva de la Canada, Spain
[9]Departamento de Inteligencia Artificial, UNED, Madrid, SpainI
[10]INAF Osservatorio Astronomico di Bologna, Bologna, Italy
[11]INAF-Osservatorio Astronomico di Capodimonte, Napoli, Italy
[12]Faculdade de Ciencias de Universidade de Lisboa, Lisboa, Portugal

LSST
Zira Hotel, Belgrade, Serbia
Friday June 24, 2016

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The Gaia mission

- Cornerstone mission of the European Space Agency
- Observations of all the objets brighter than a certain limit V ~ 20 (**>1 billion objects**)
- Measurement of:
  - positions (astrometry)
  - brightness, colors (spectro-photometry)
  - radial velocities (spectroscopy)
- Launch (Soyuz rocket): December 19 2013
- Length: 5 years (70 times all sky) (+5 year??)
- Final Catalogue: 2021-2022 (+ 5??)

Gaia: a spinning and scanning spacecraft

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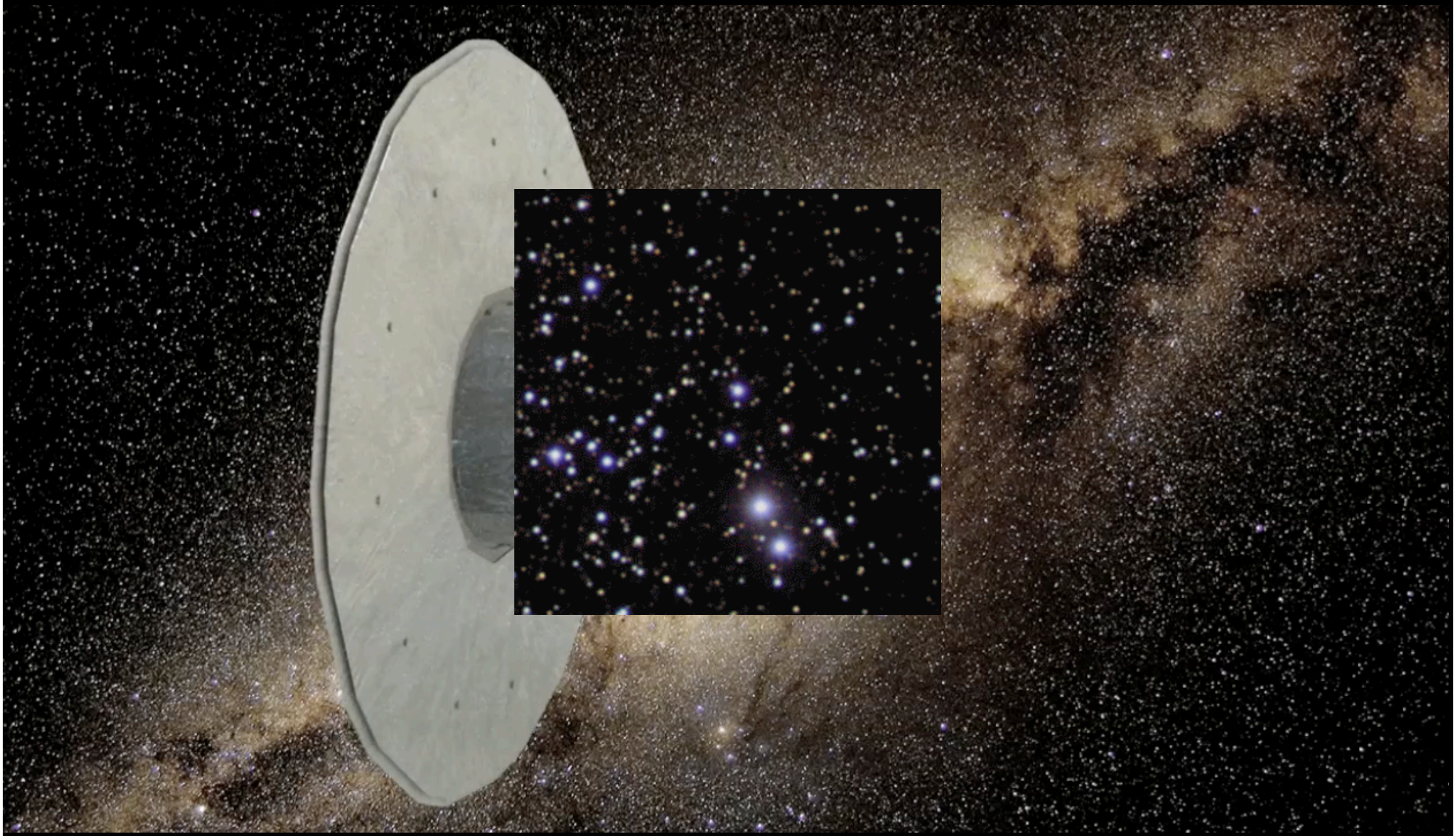
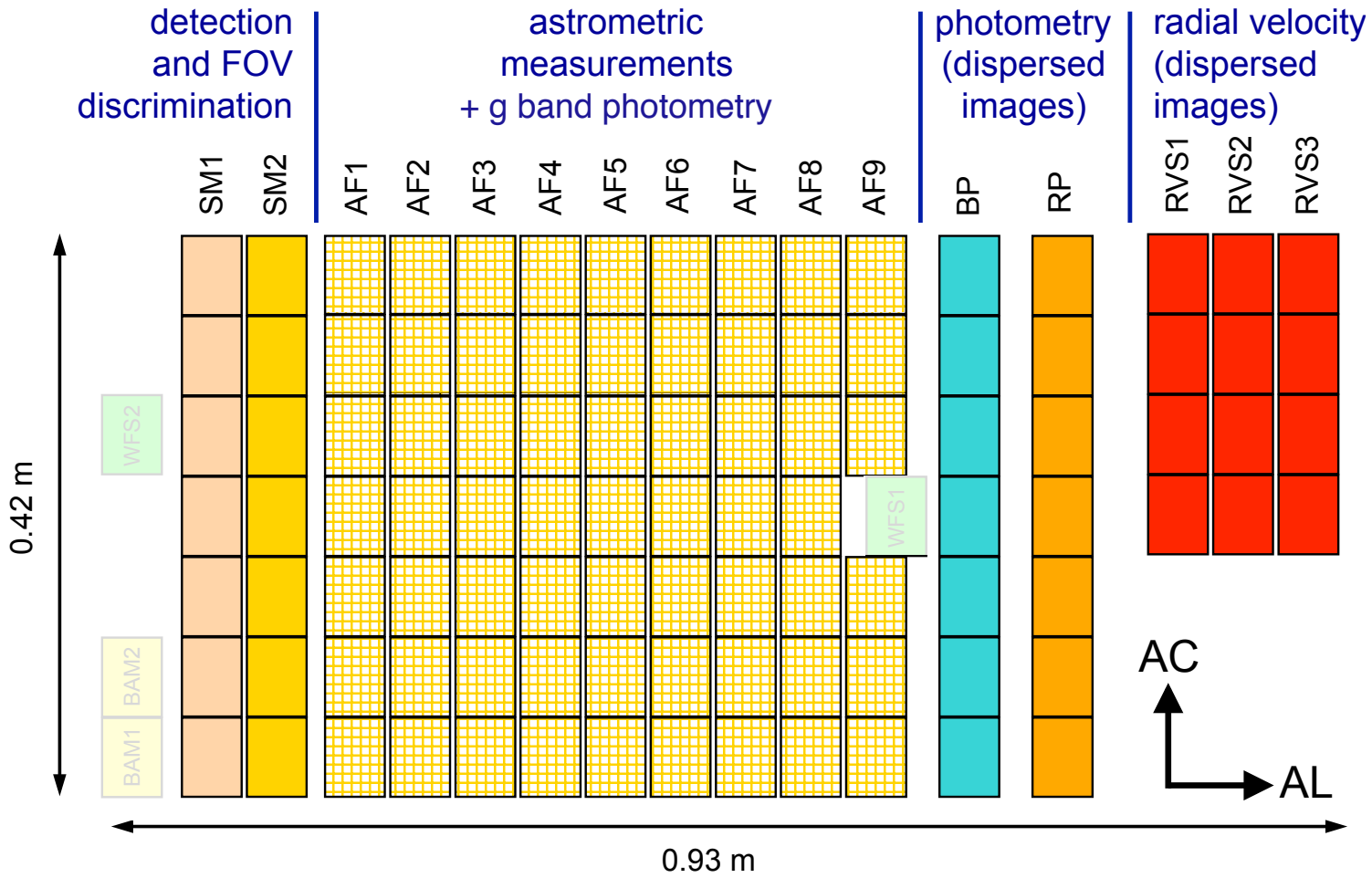


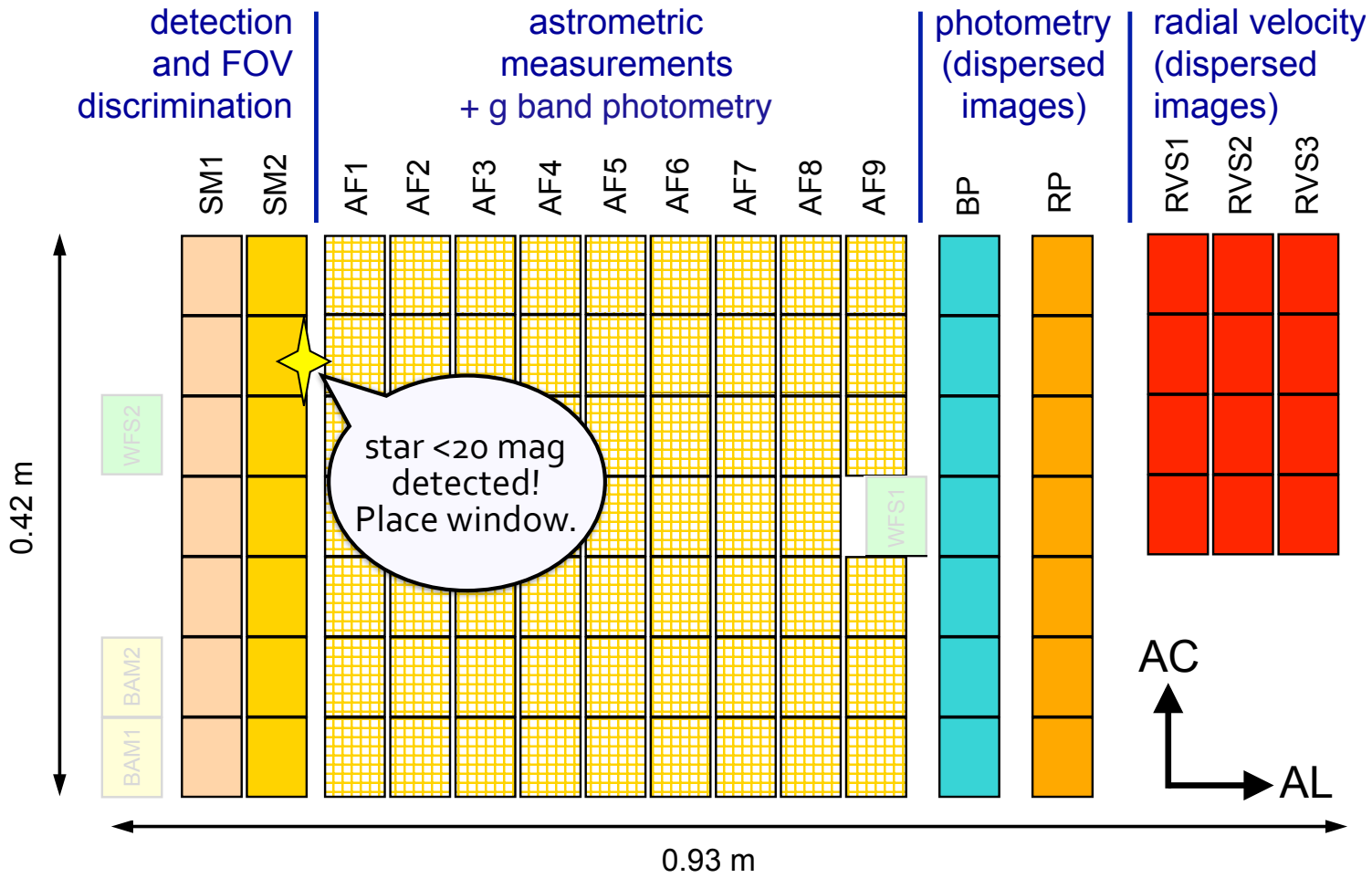
Focal plane



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

Courtesy of Berry Holl

Focal plane



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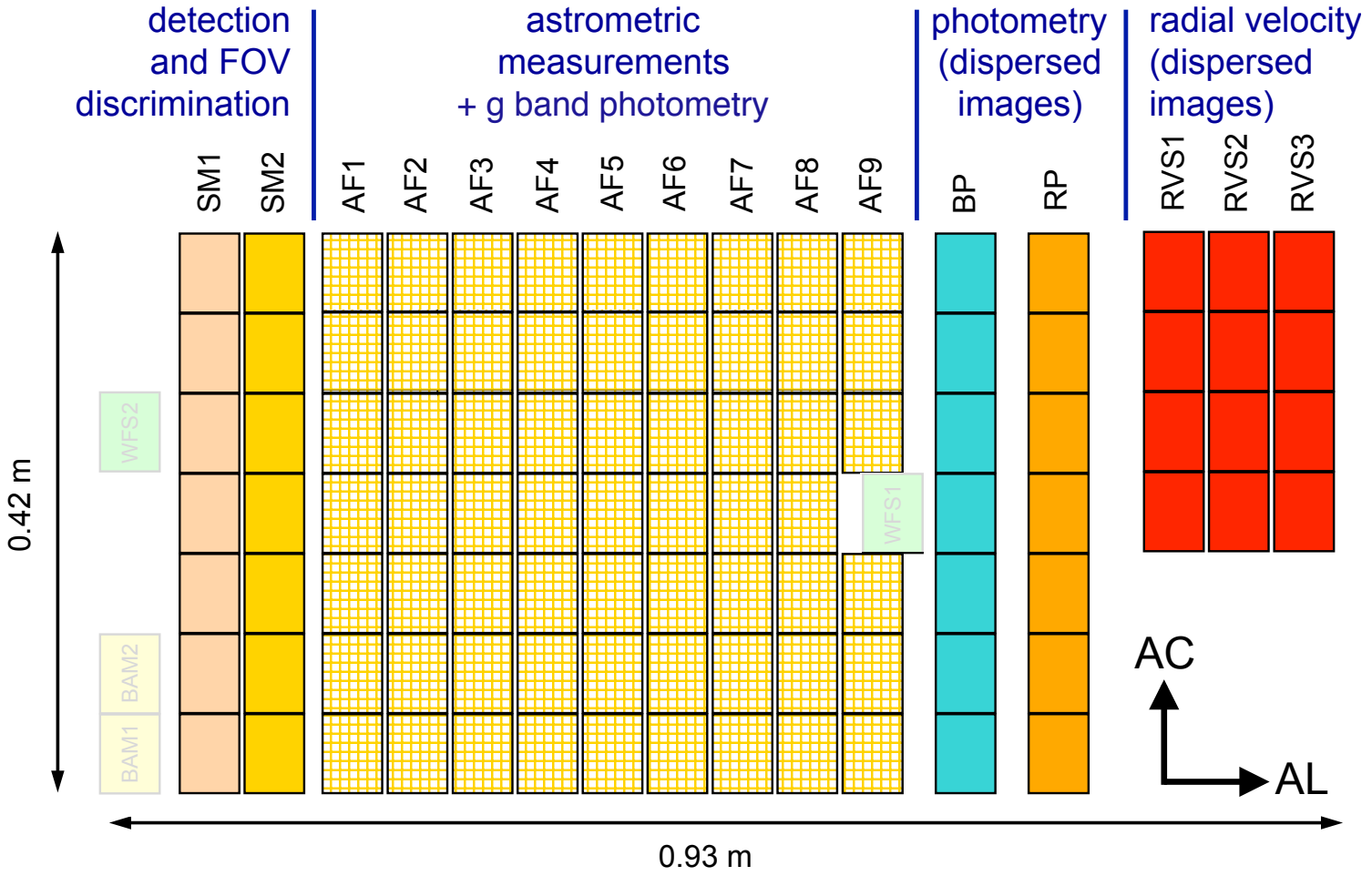
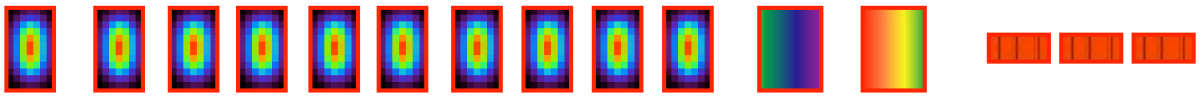


observed windows (not to scale):



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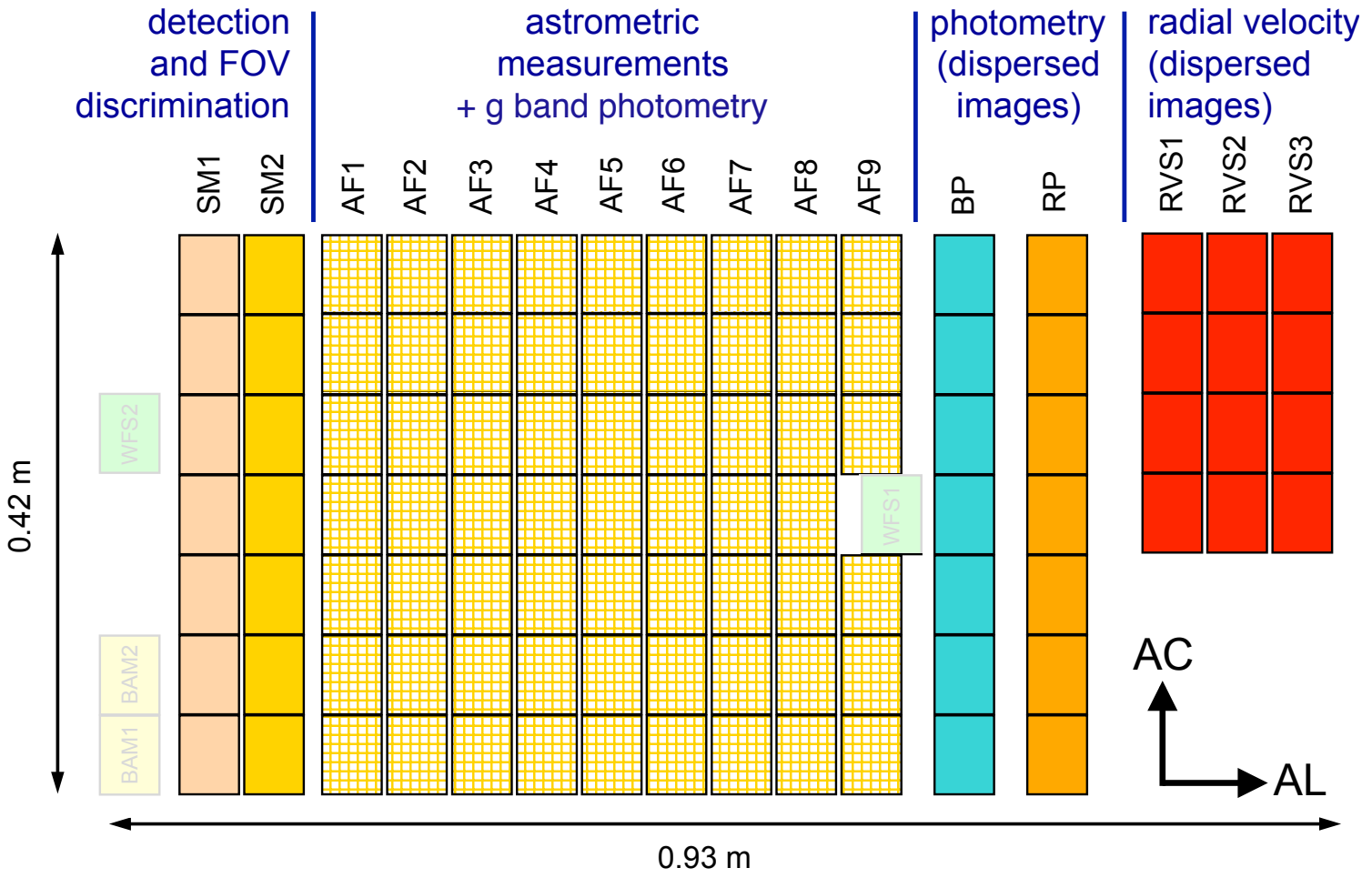

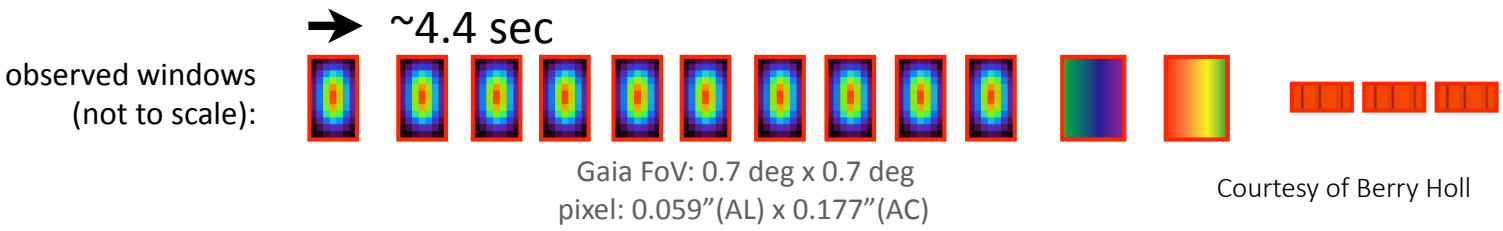

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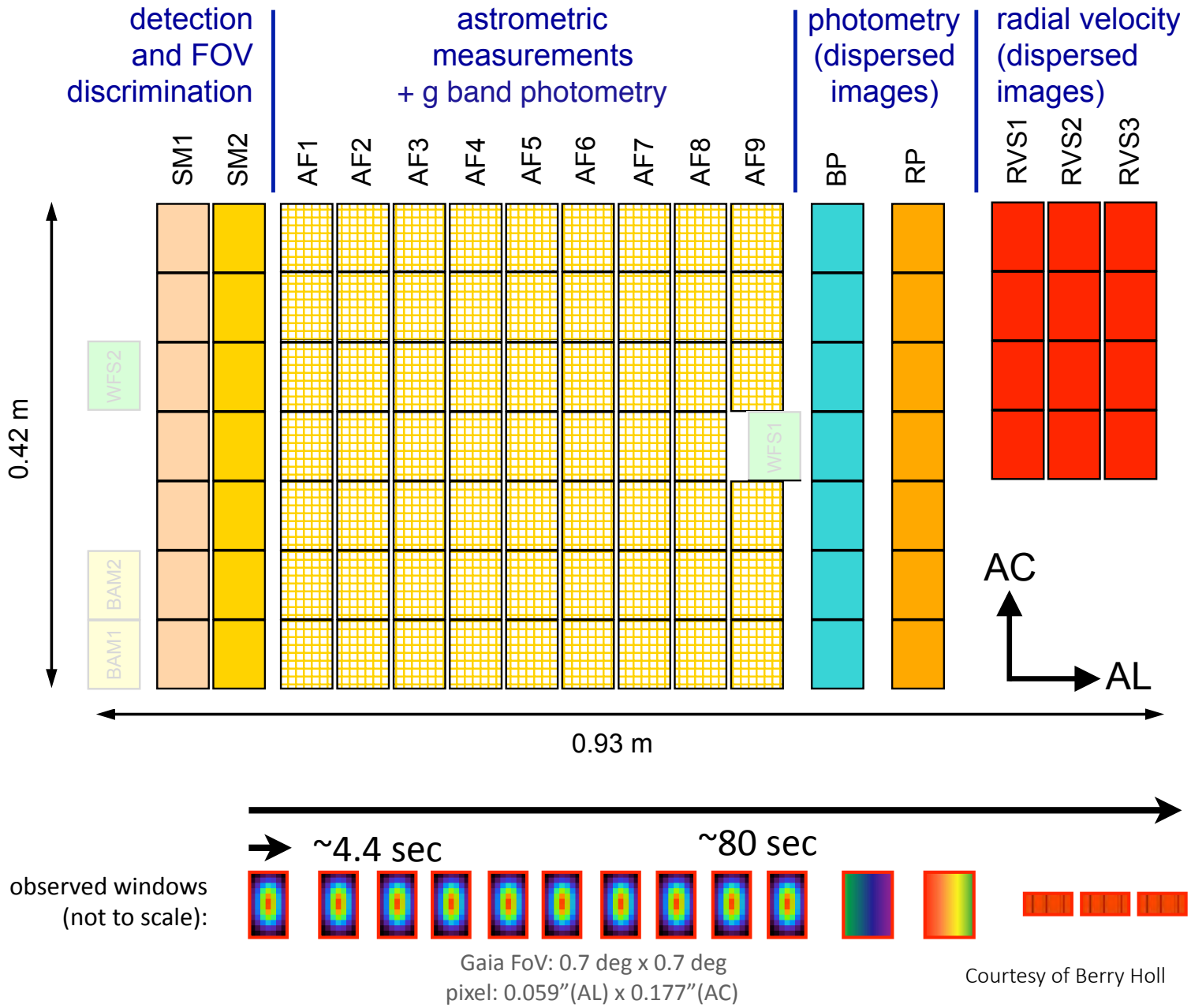
detection and FOV discrimination
astrometric measurements + g band photometry
photometry (dispersed images)
radial velocity (dispersed images)
SM1
SM2
AF1
AF2
AF3
AF4
AF5
AF6
AF7
AF8
AF9
BP
RP
RVS1
RVS2
RVS3
WFS2
WFS1
BAM2
BAM1
0.42 m
AC
AL
0.93 m
~4.4 sec
~80 sec
observed windows (not to scale):
Gaia FoV: 0.7 deg x 0.7 deg
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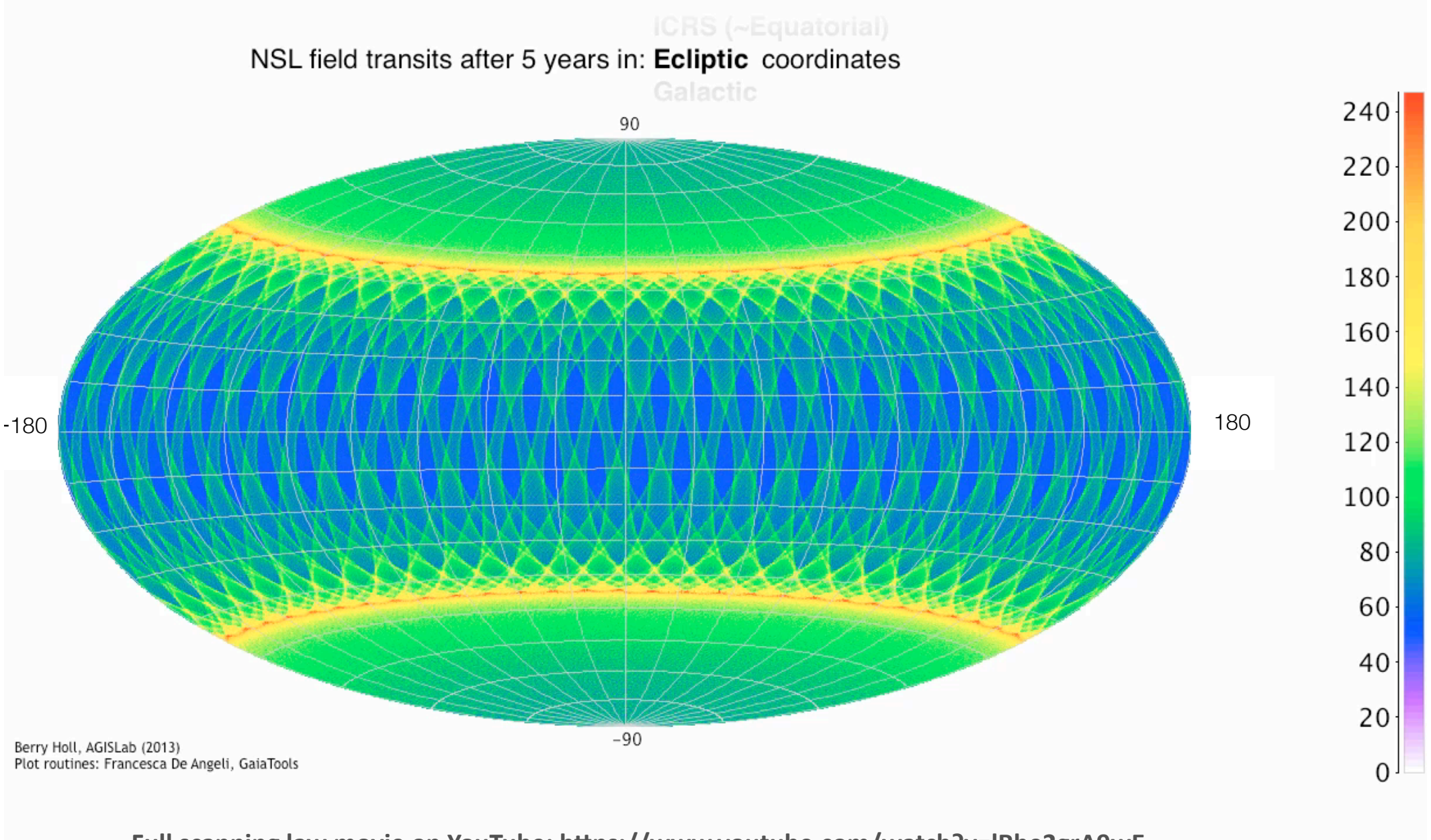
Courtesy of Berry Holl

Five year nominal scanning law (NSL)



Full scanning law movie on YouTube: https://www.youtube.com/watch?v=lRhe2grA9wE

Courtesy of Berry Holl

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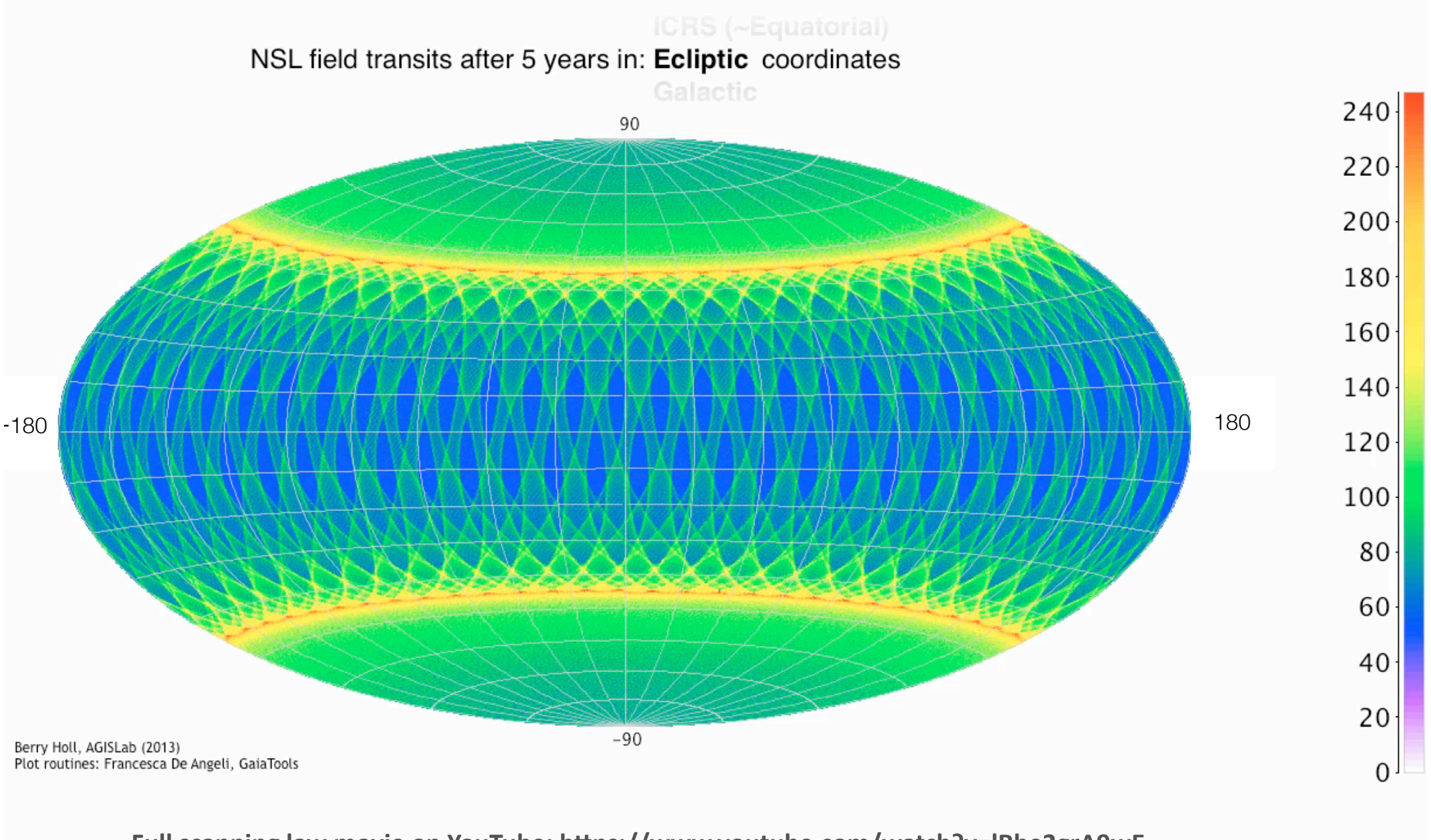

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Properties of the Gaia cadence

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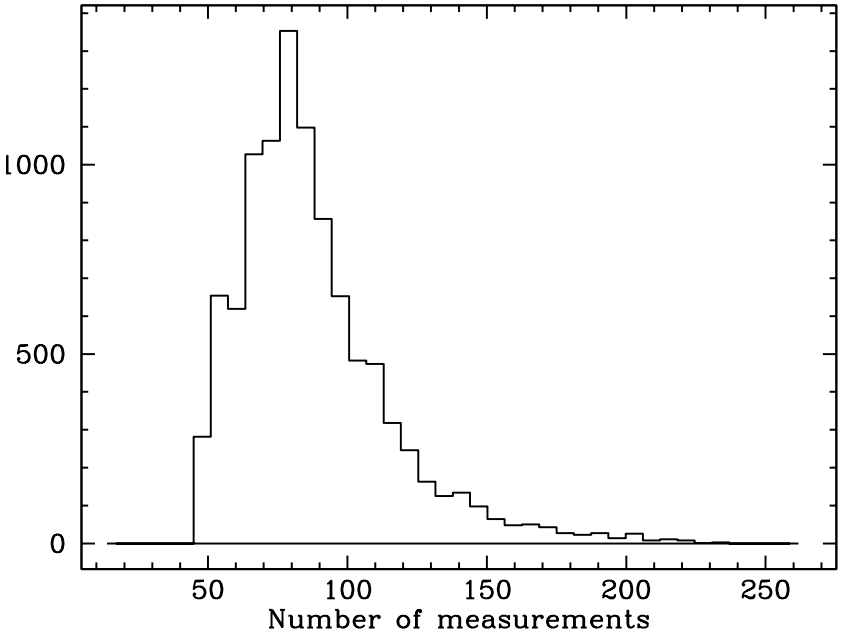
1) Histogram of number of measurements
Mean number ~70 (dead time included)



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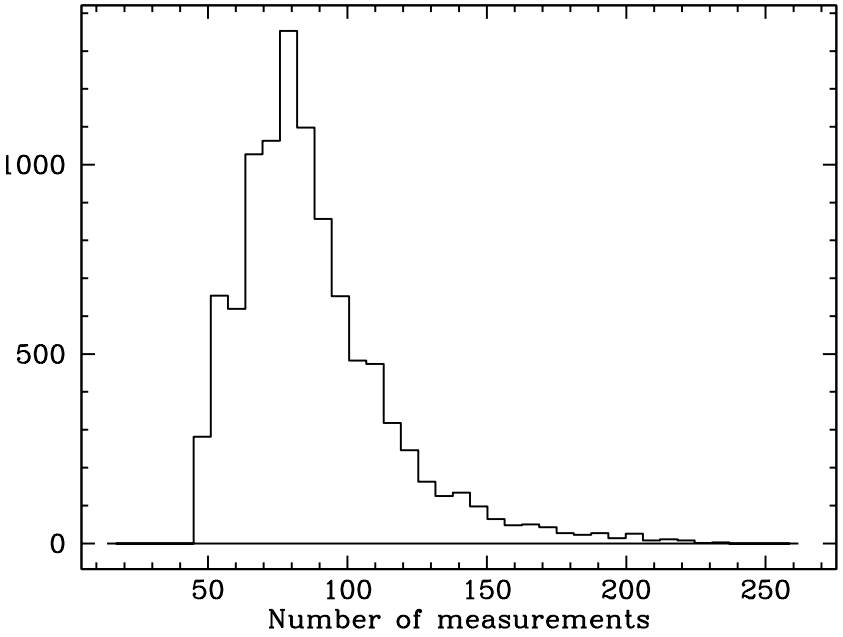
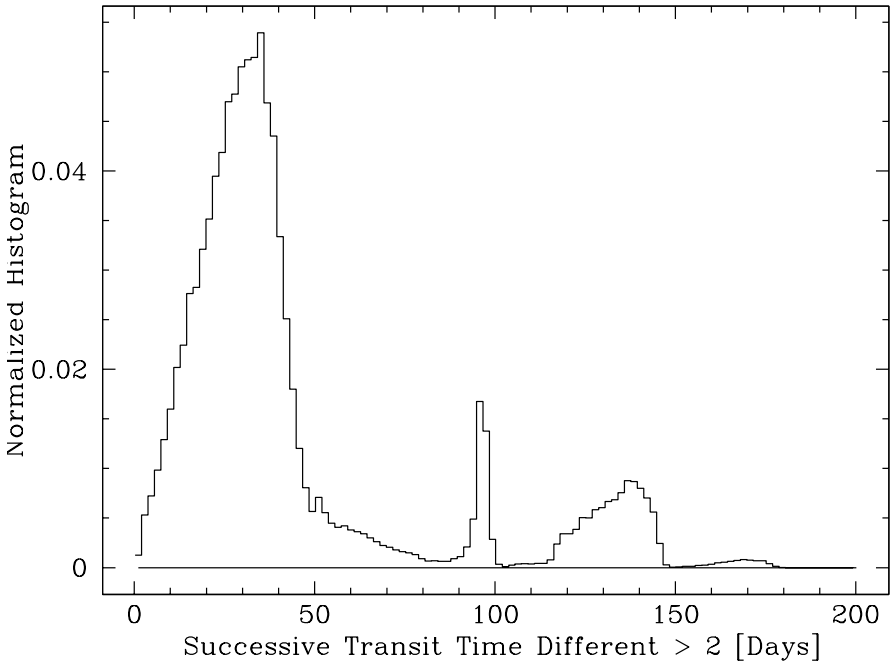


2) Histogram of successive time intervals



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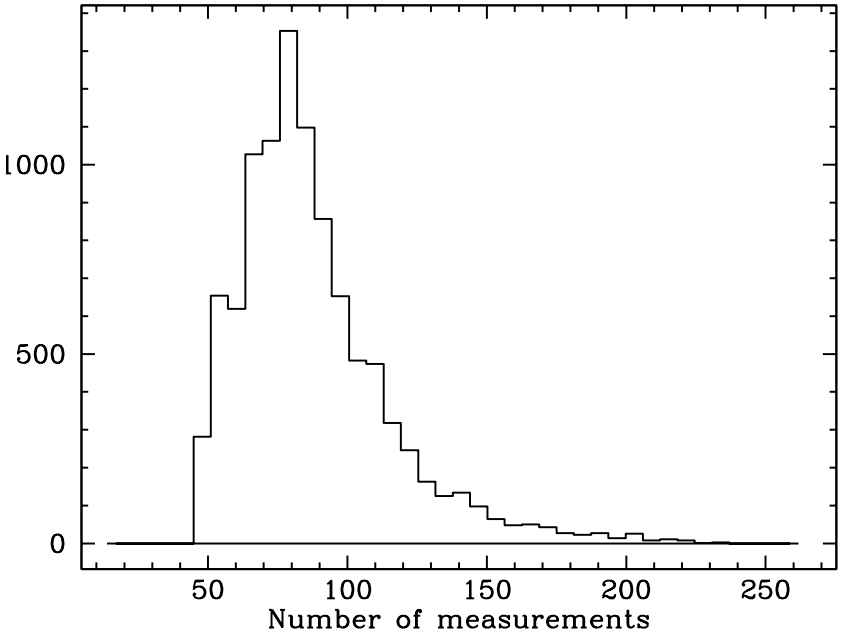

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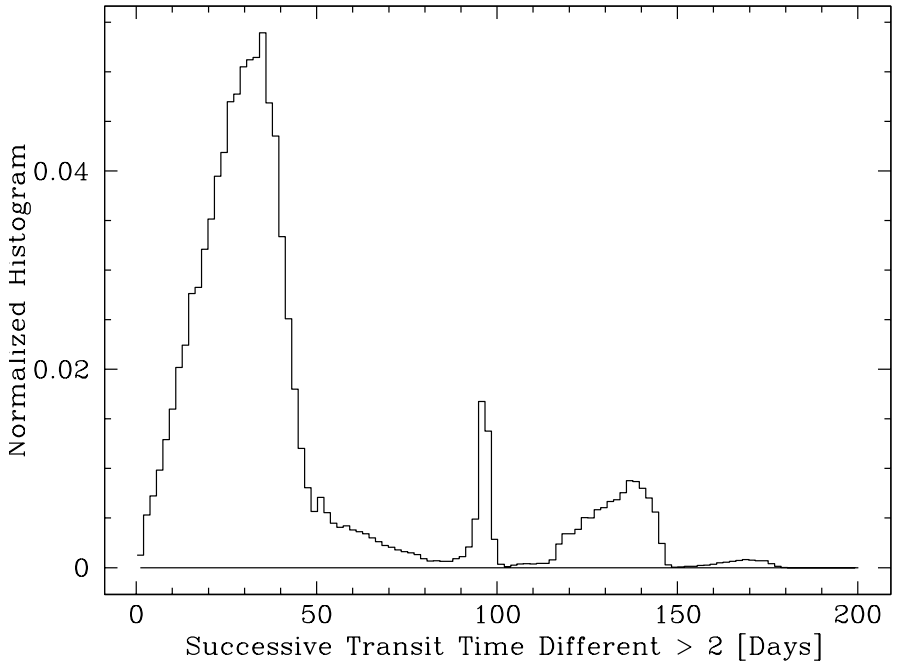
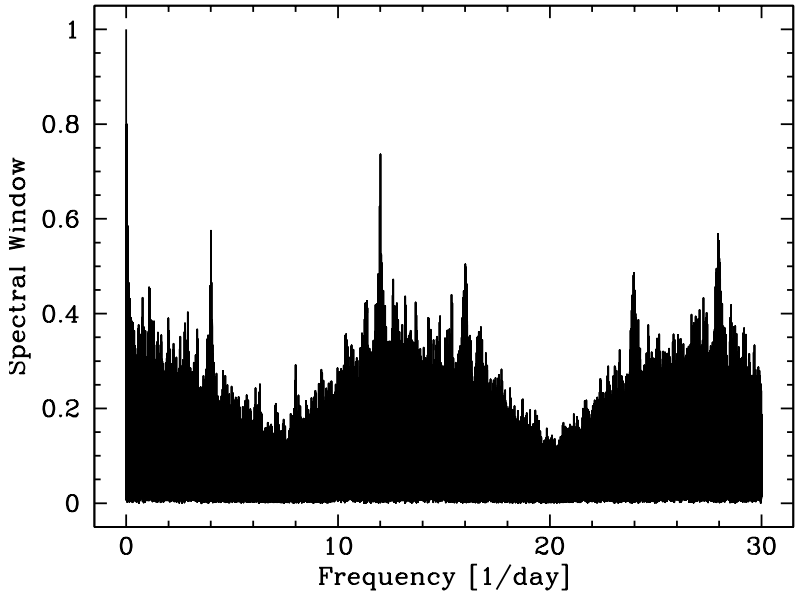


3) Spectral window



The Gaia astrometric performance: Mean parallax error (end-of-mission)

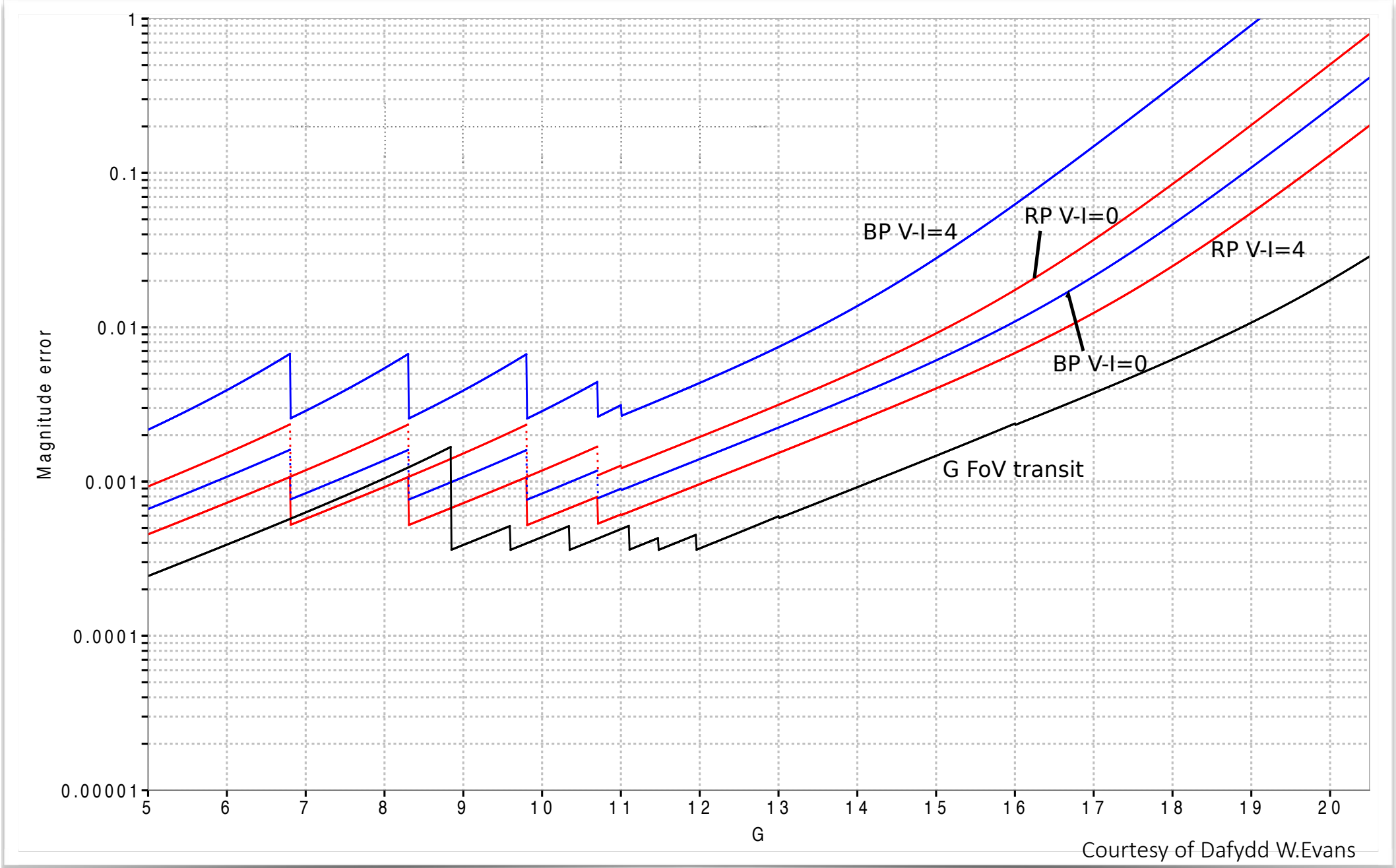
Mean parallax error end-of-mission (5 year)

	B1V	G2V	M6V
$V-I_C$ [mag]	-0.22	0.75	3.85
Bright stars	5-14 μas (3 mag < V < 12 mag)	5-14 μas (3 mag < V < 12 mag)	5-14 μas (5 mag < V < 14 mag)
V = 15 mag	26 μas	24 μas	9 μas
V = 20 mag	600 μas	540 μas	130 μas

Position error (μas): ... x ~0.7 ~ $1/(\text{mission length})^{0.5}$

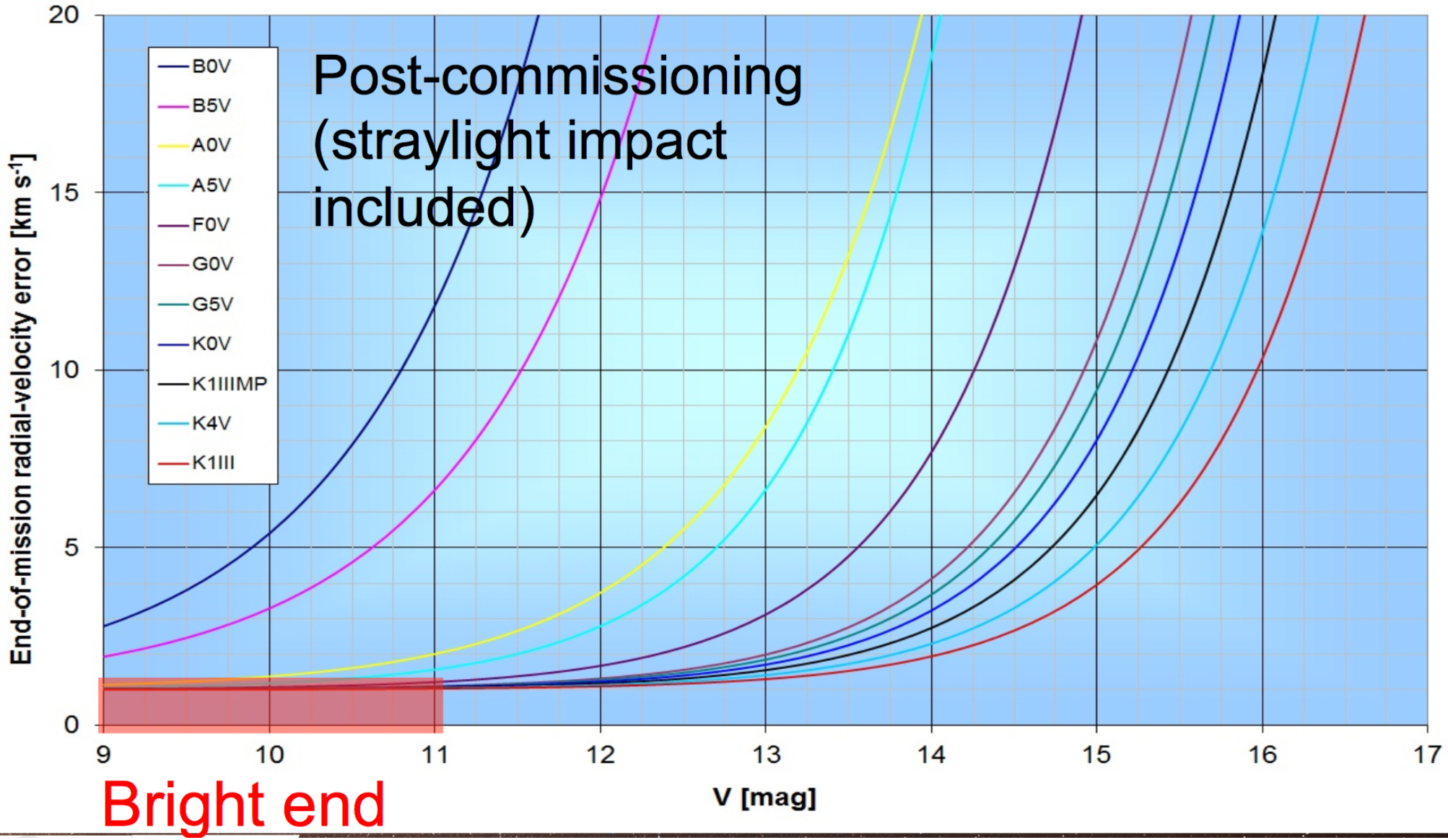
Proper motion error (μas/year): ... x ~0.5 ~ $1/(\text{mission length})^{1.5}$

Epoch Field-of-View photometric precision



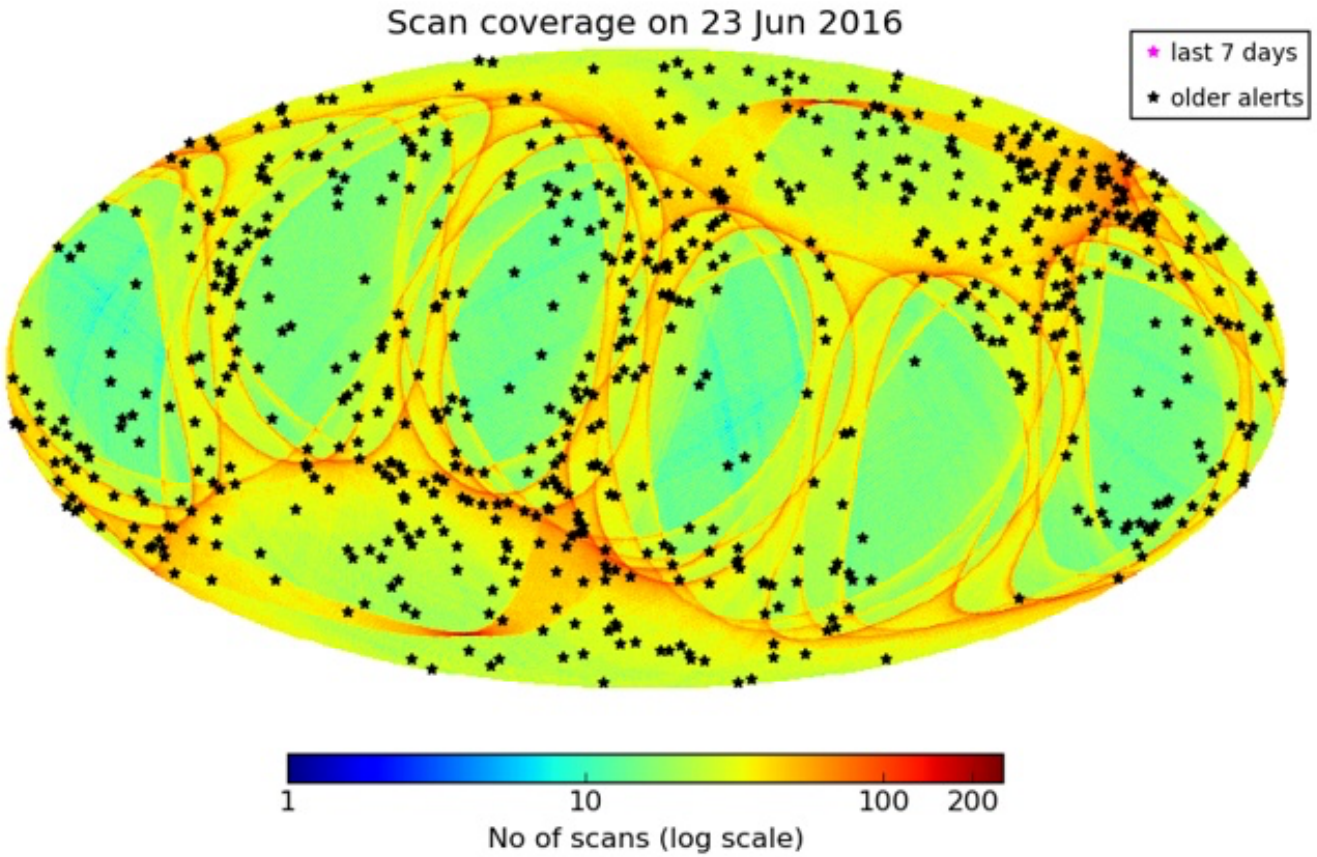
Courtesy of Dafydd W.Evans

Radial velocity end of mission precision



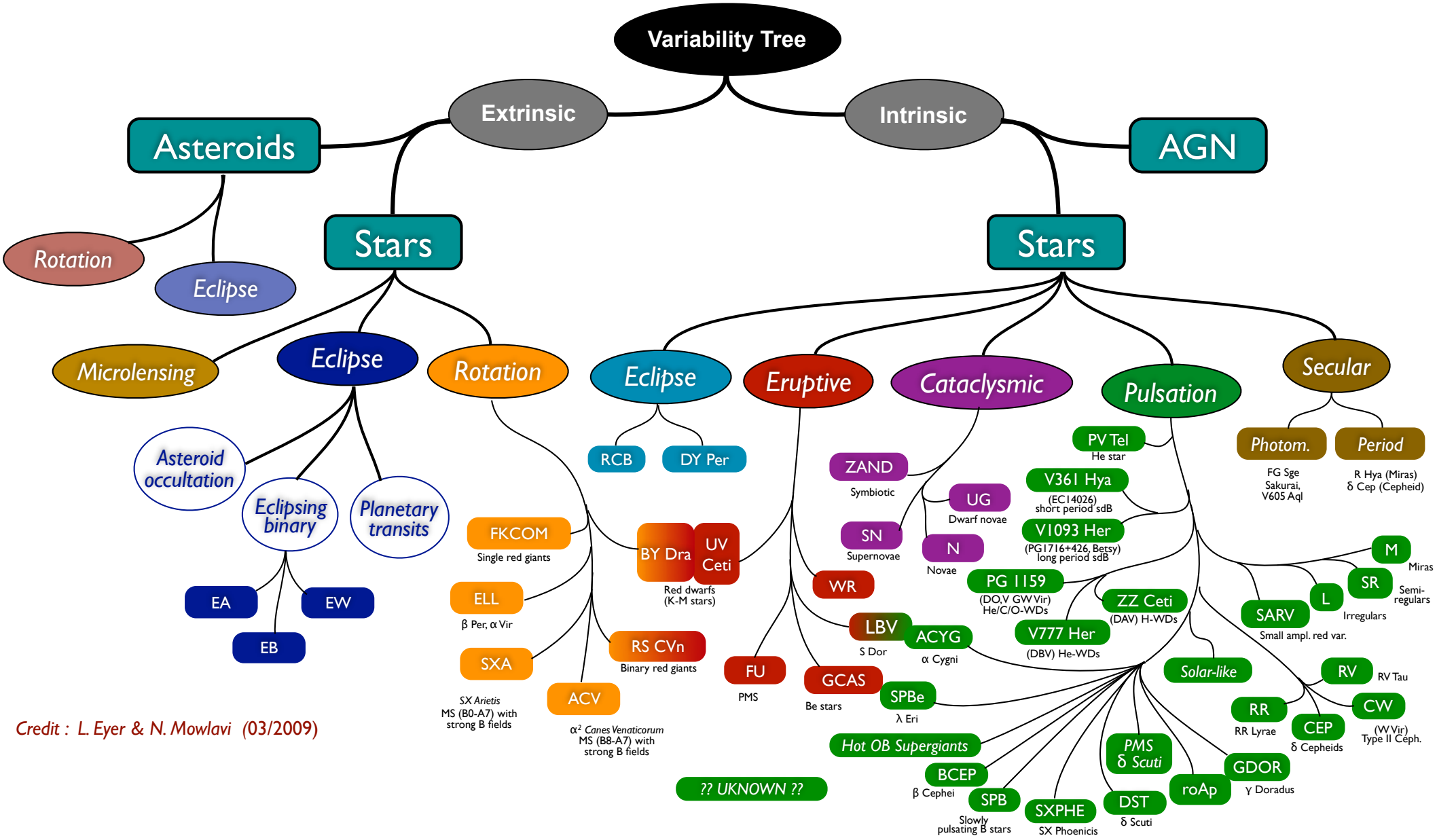
Courtesy of Georges Seabrook

Variability I: Gaia Science Alerts (Cambridge Univ.)



As of today: 696 Gaia alerts

Variability II

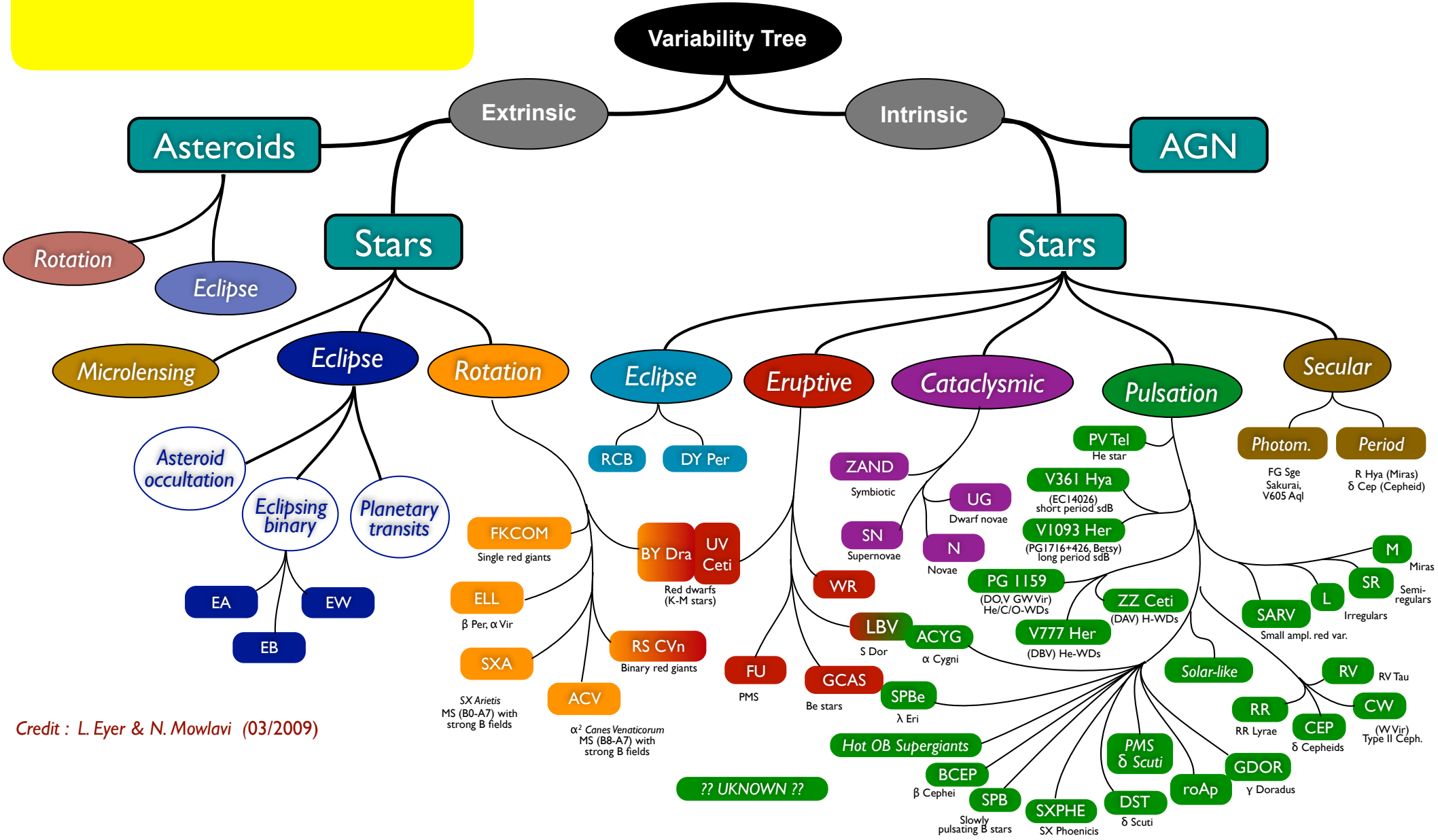


Credit : L. Eyer & N. Mowlavi (03/2009)

Variability II

For a source:

Gaia data



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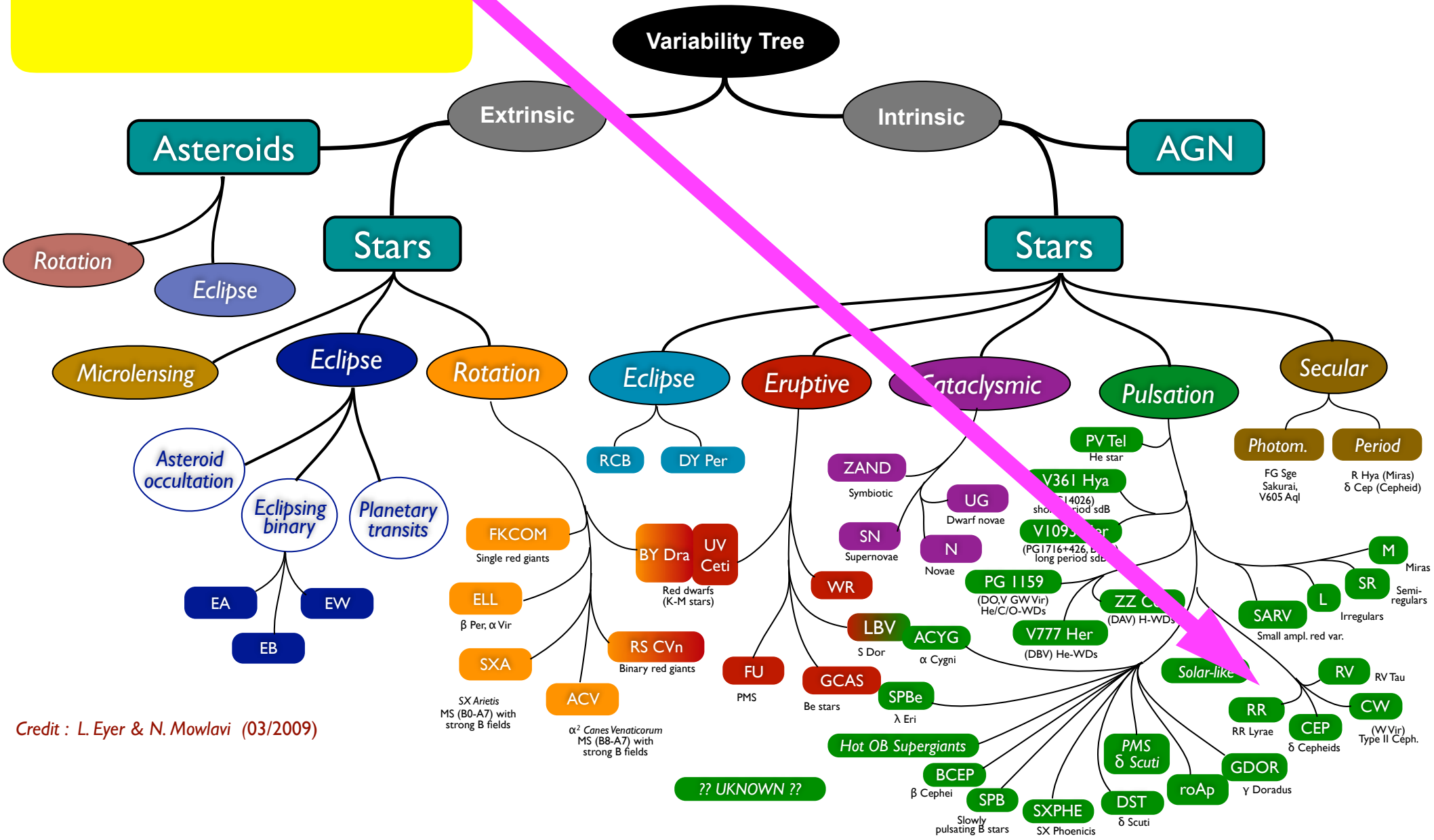

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Photometry + radial velocities + astrometry

Example:
Hipparcos and CORAVEL

We searched for stars variable in Hipparcos
who had CORAVEL measurements

~ **160 Hipparcos variables** with more than 10 radial velocities measurements with CORAVEL (σ_{VR} ~ 1 km/s)

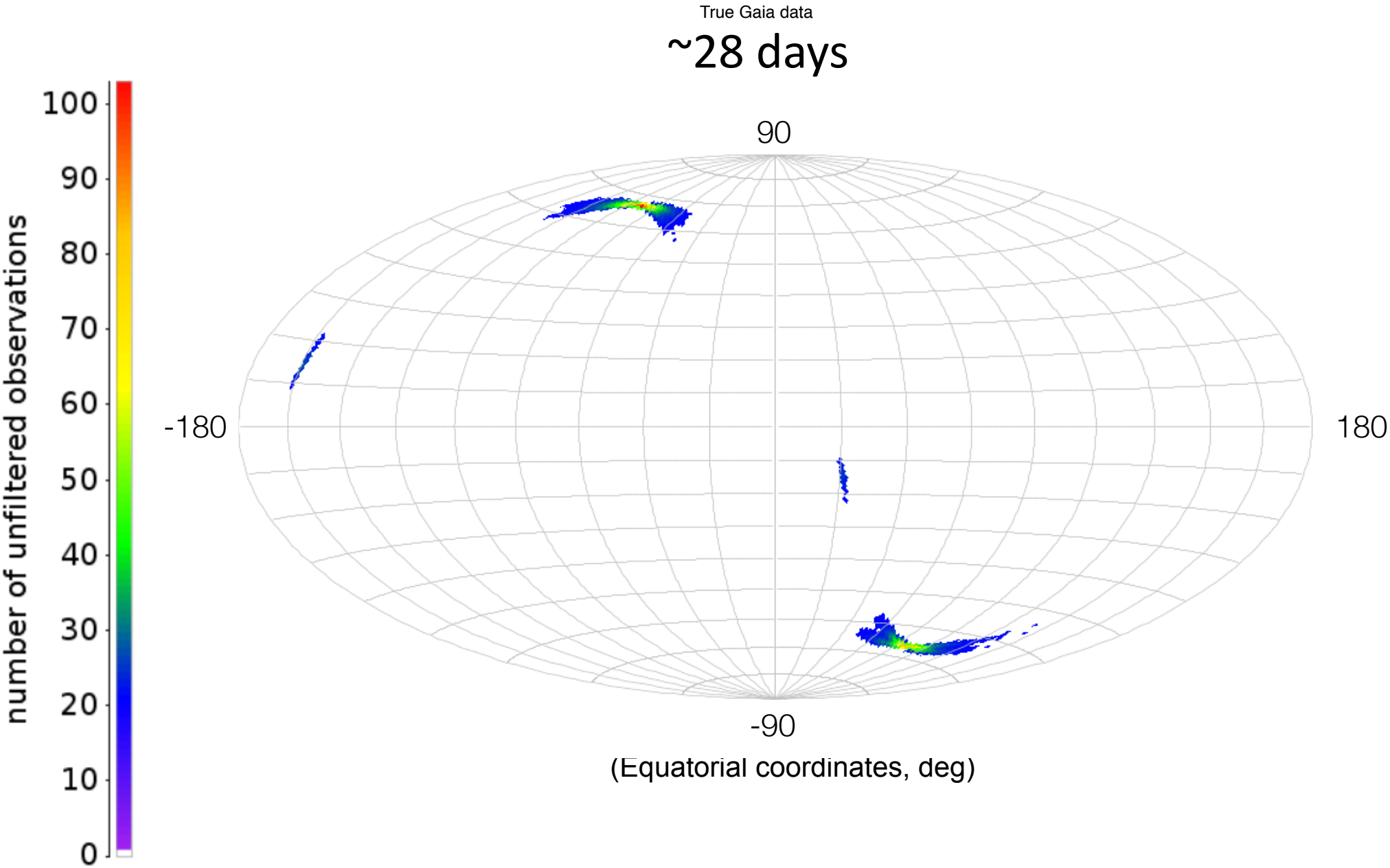
With parallaxes better than 10%

~30 stars

Variability Processing and Analysis: Pragmatic approach

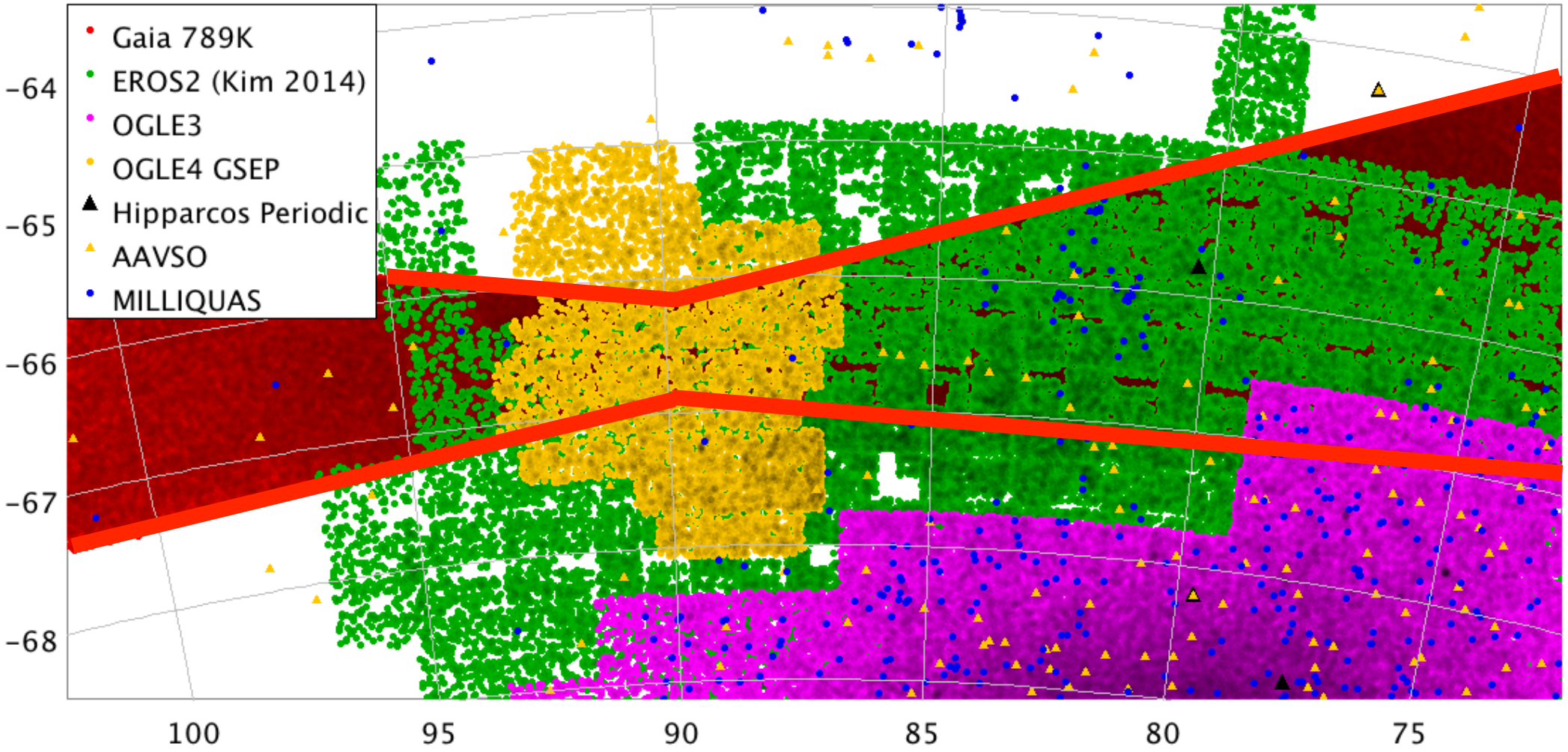
- **Develop a "method"**
  - Test on simulated data (often very simple modeling)
  - Test on real data
    - OGLE, EROS
    - Kepler
    - SDSS
    - Hipparcos-Coravel, etc.
- **Apply it to real Gaia data**
  - Start on "easy" signals (Cepheids/RR Lyrae stars), e.g. large signal to noise ratio, "regular" variables
  - Start with G-band, then include BP/RP, then astrometry, then RVS data (not really a choice)
  - Start with law numbers of objects
- **Interact with the data (subsamples) at all levels of the analysis**

Selection of sources observed by Gaia from Ecliptic Pole Scanning Law (790,000 sources) with 20+ measurements



Warning: **Sampling regular, different from Nominal Scanning law**

South Ecliptic Pole region (part of Large Magellanic Cloud): Gaia and other surveys

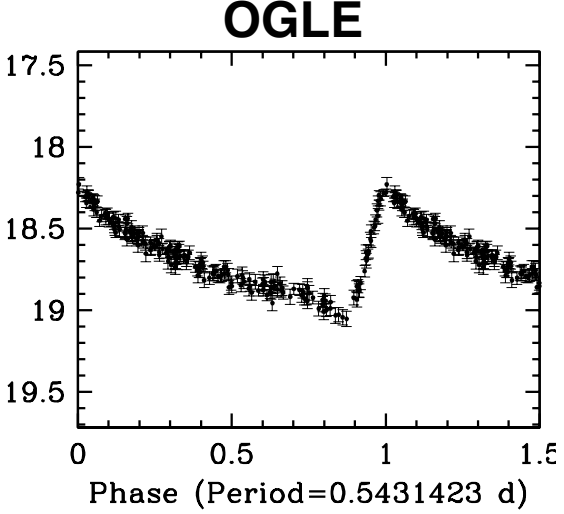


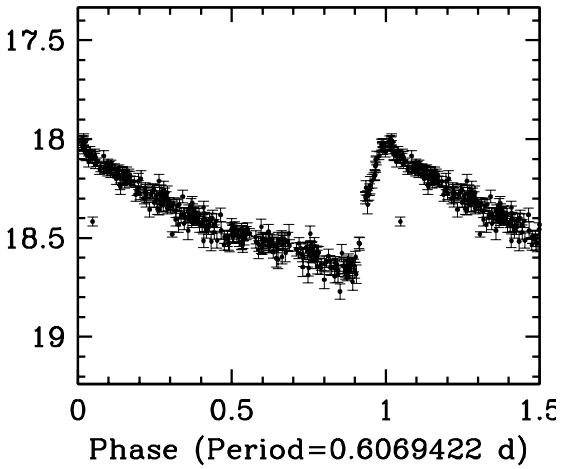
True Gaia data

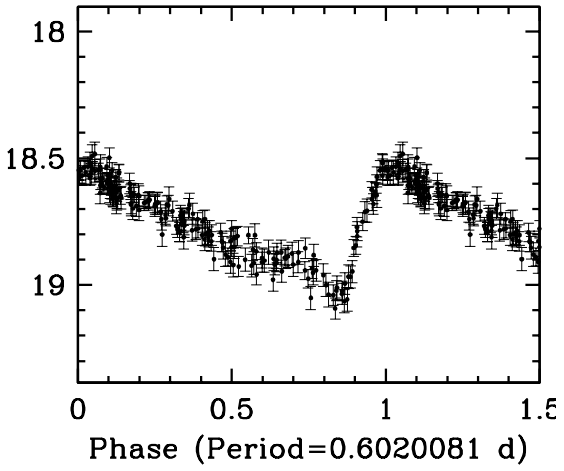
To get the data flavour
Comparison with OGLE

Image of the Week (March 05, 2015):
RR Lyrae stars

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.







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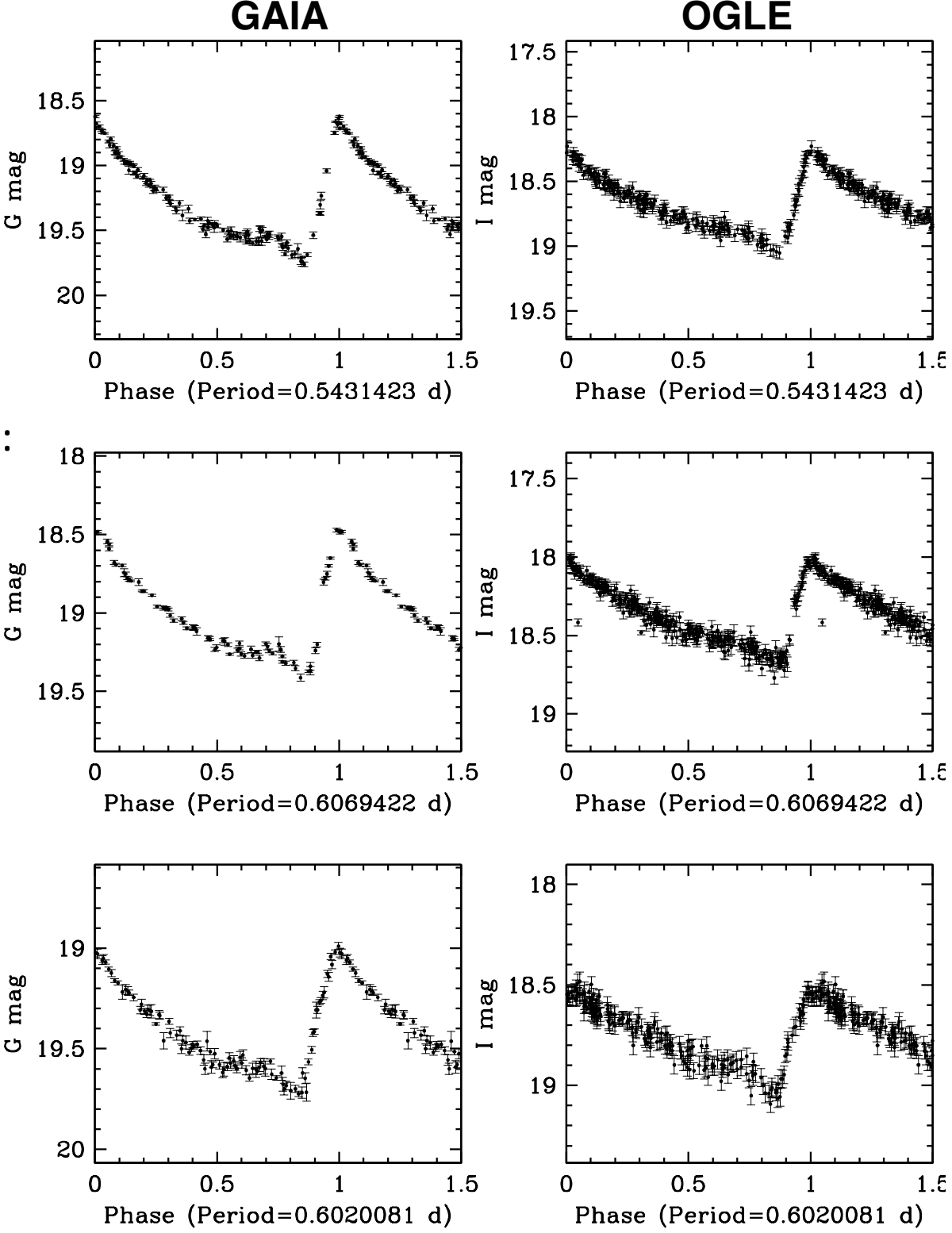

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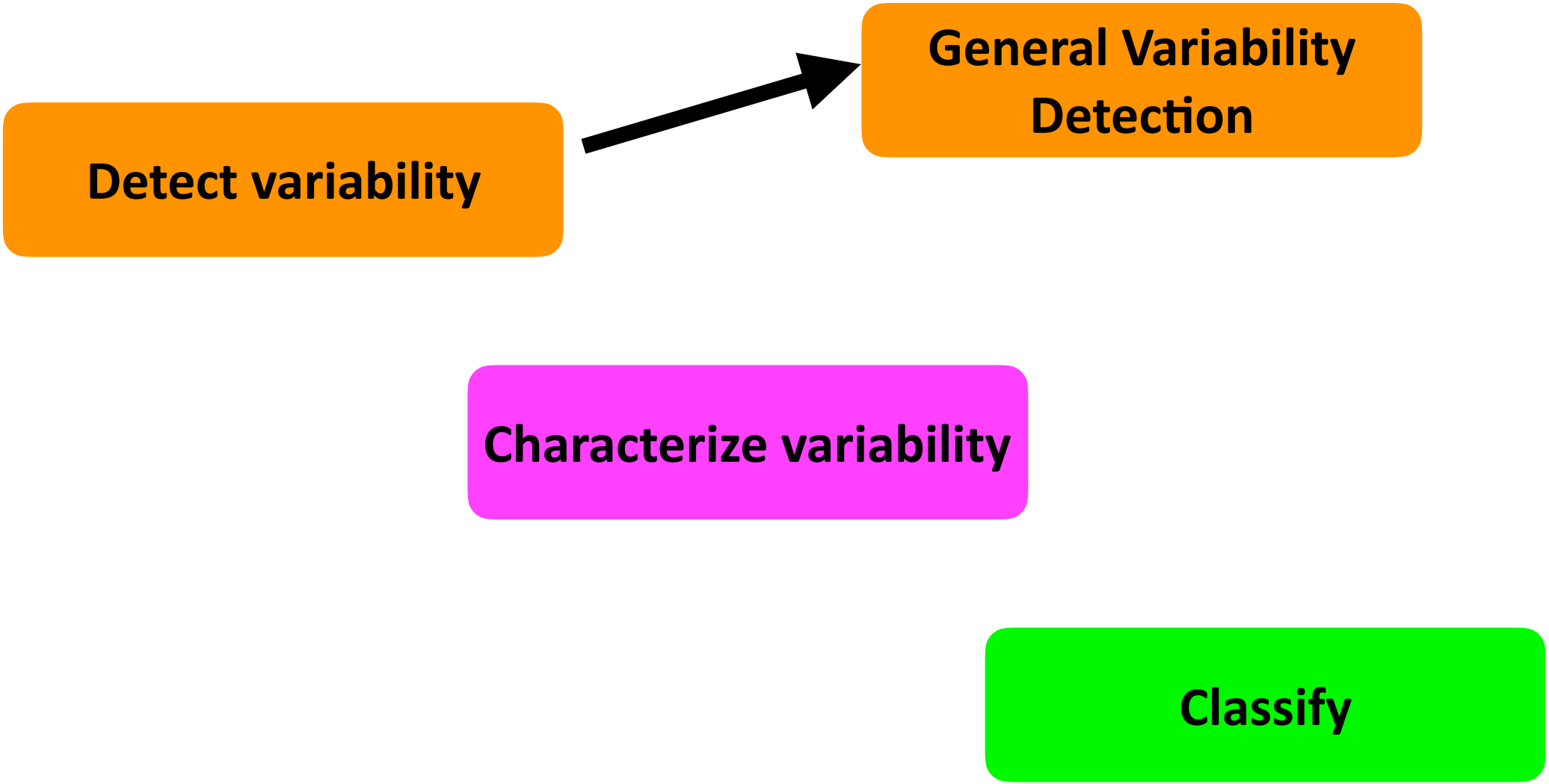
Gaia Variability Processing and Analysis

Detect variability

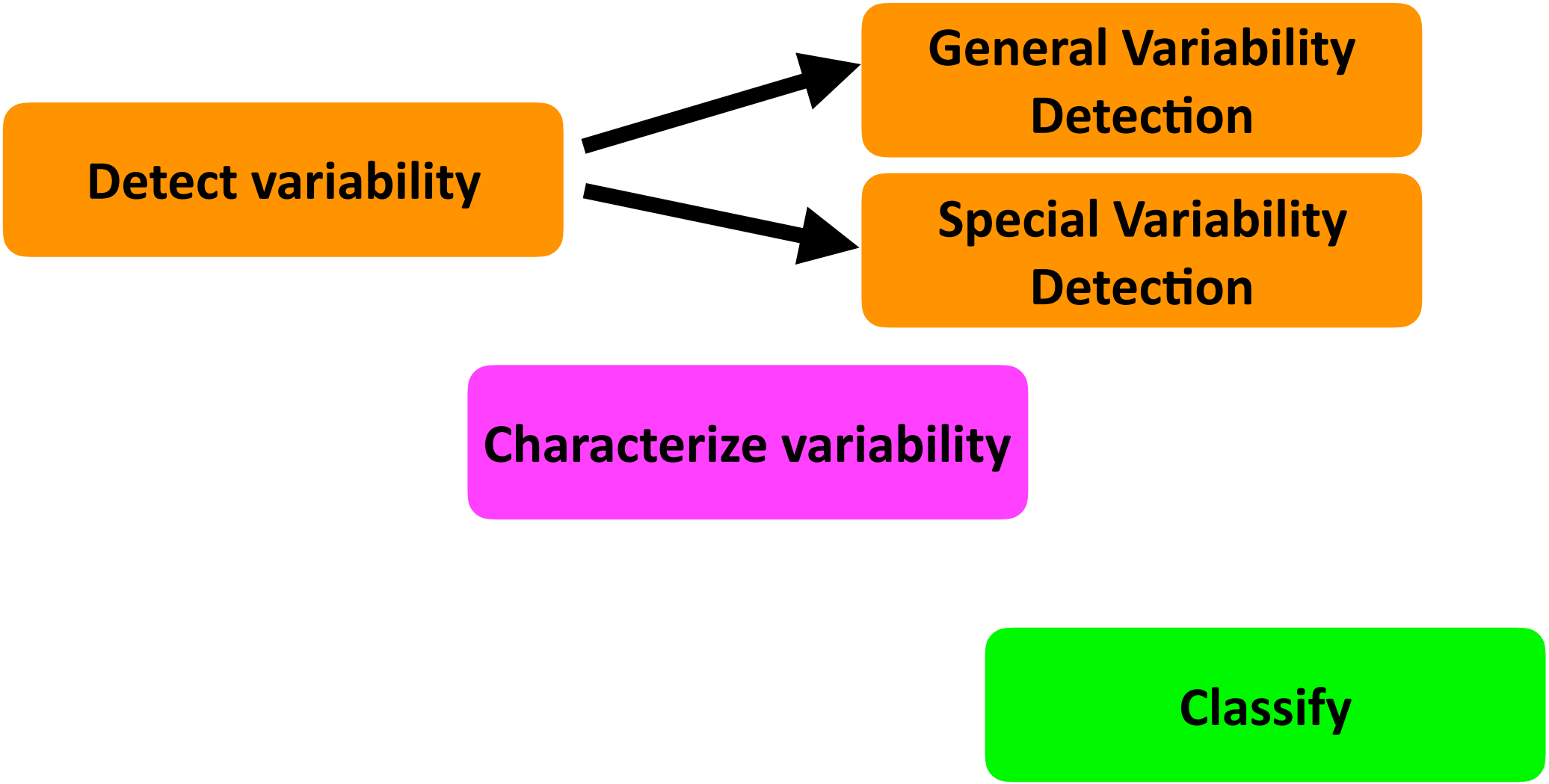
Characterize variability

Classify

Gaia Variability Processing and Analysis



Gaia Variability Processing and Analysis



General Variability Detection

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For LSST: Importance to have other surveys (e.g. Kepler , Gaia, etc.) for preparation of simulations, calibration and comparison (K2)

Special Variability Detection

Solar like (magnetic) activity

Exo-planetary transits

Small amplitude

Short time scale (per FoV, per CCD data)

Variable type	Period range
β Cep	1.6h - 12h
δ Scuti	20min - 8h
roAp	5min - 25min
EC 14026	80s - 8min
Besty stars	30-150min
RR Lyrae	5h - 1d
ZZ Ceti	30s - 25min
V777 Her	2-16min
GW Vir	5-80min
AM CVn	5min - 65min

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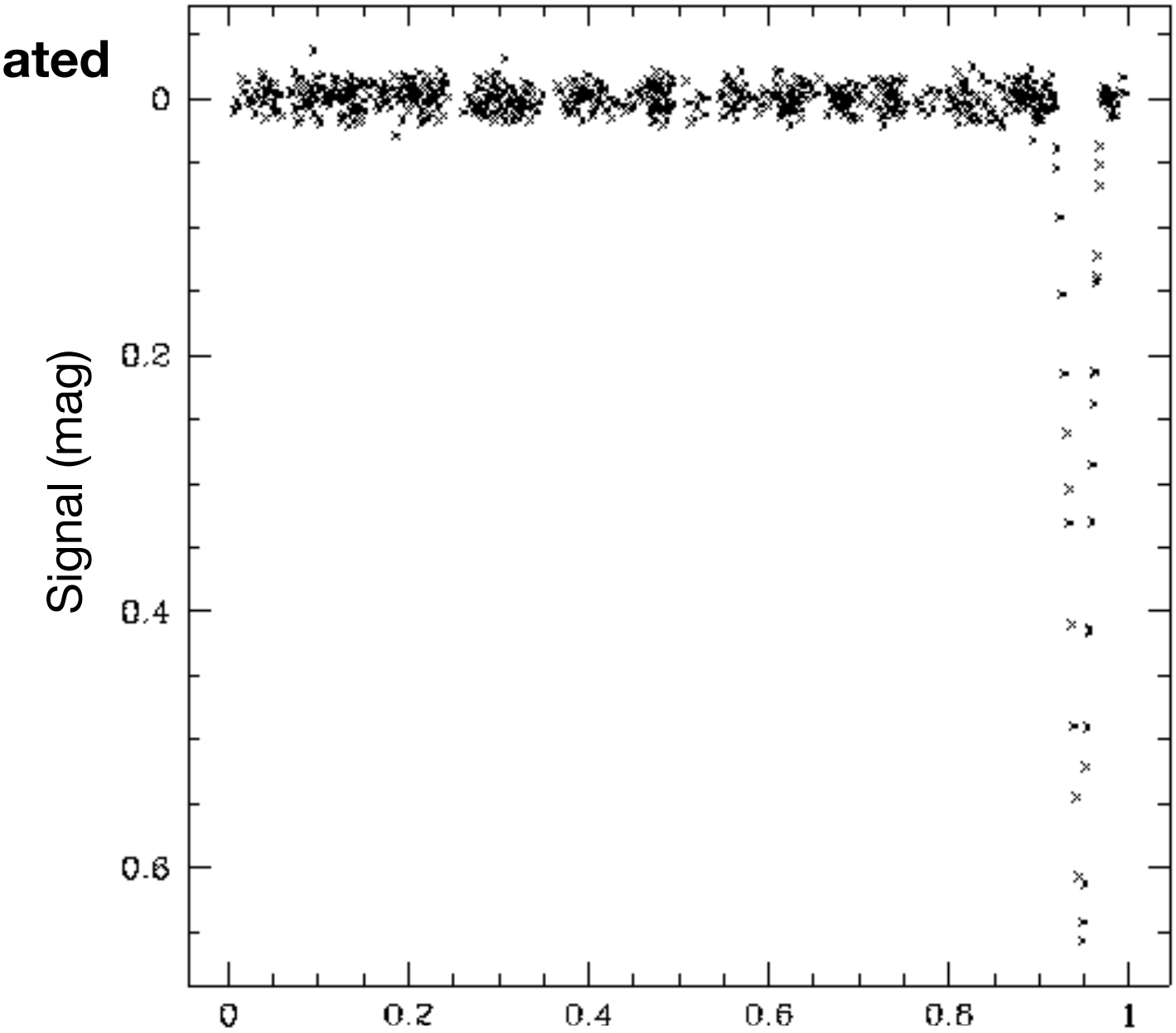
LSST: Many interesting objects for short cadence twilight survey, light curve should be simulated to study the performance of LSST

Special Variability Detection: short time scales

Simulated



Per CCD photometry

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

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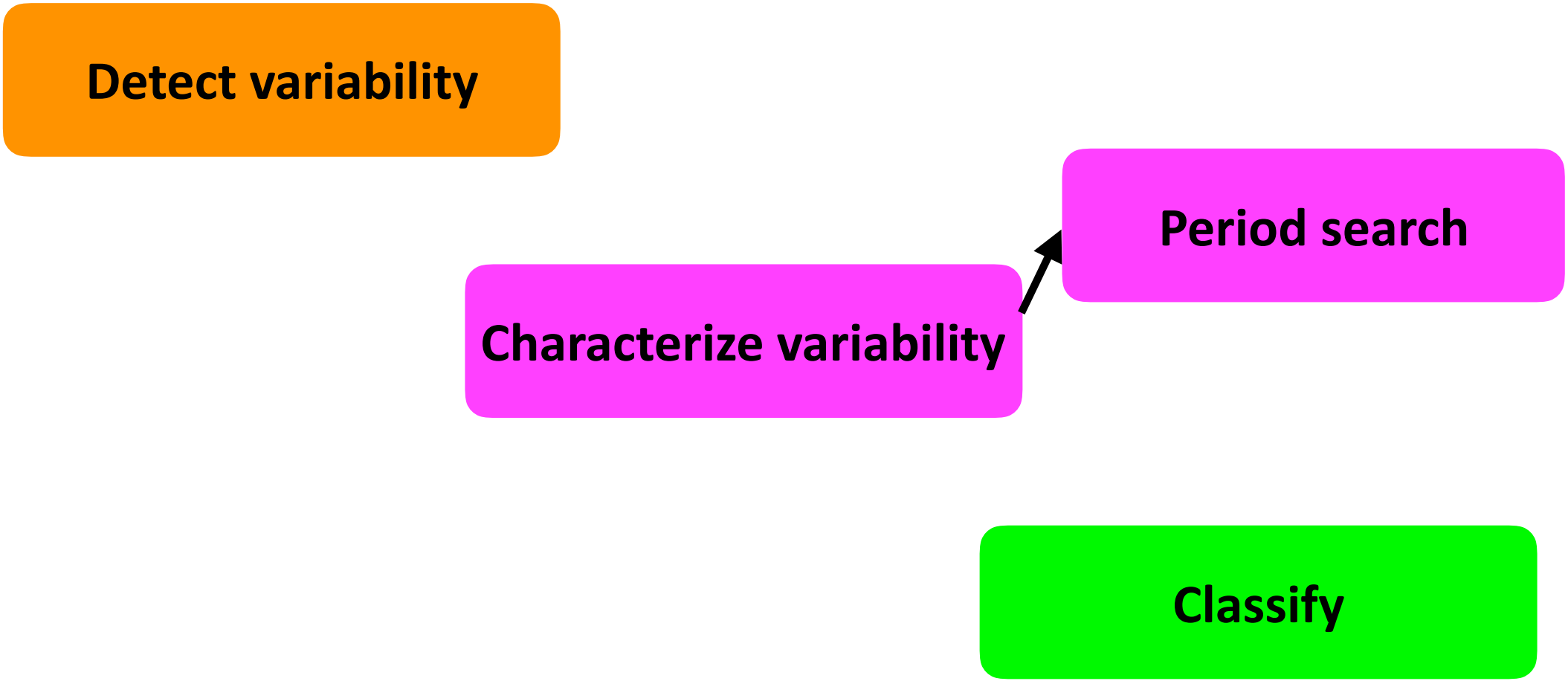
Characterize variability

Classify

Gaia Variability Processing and Analysis



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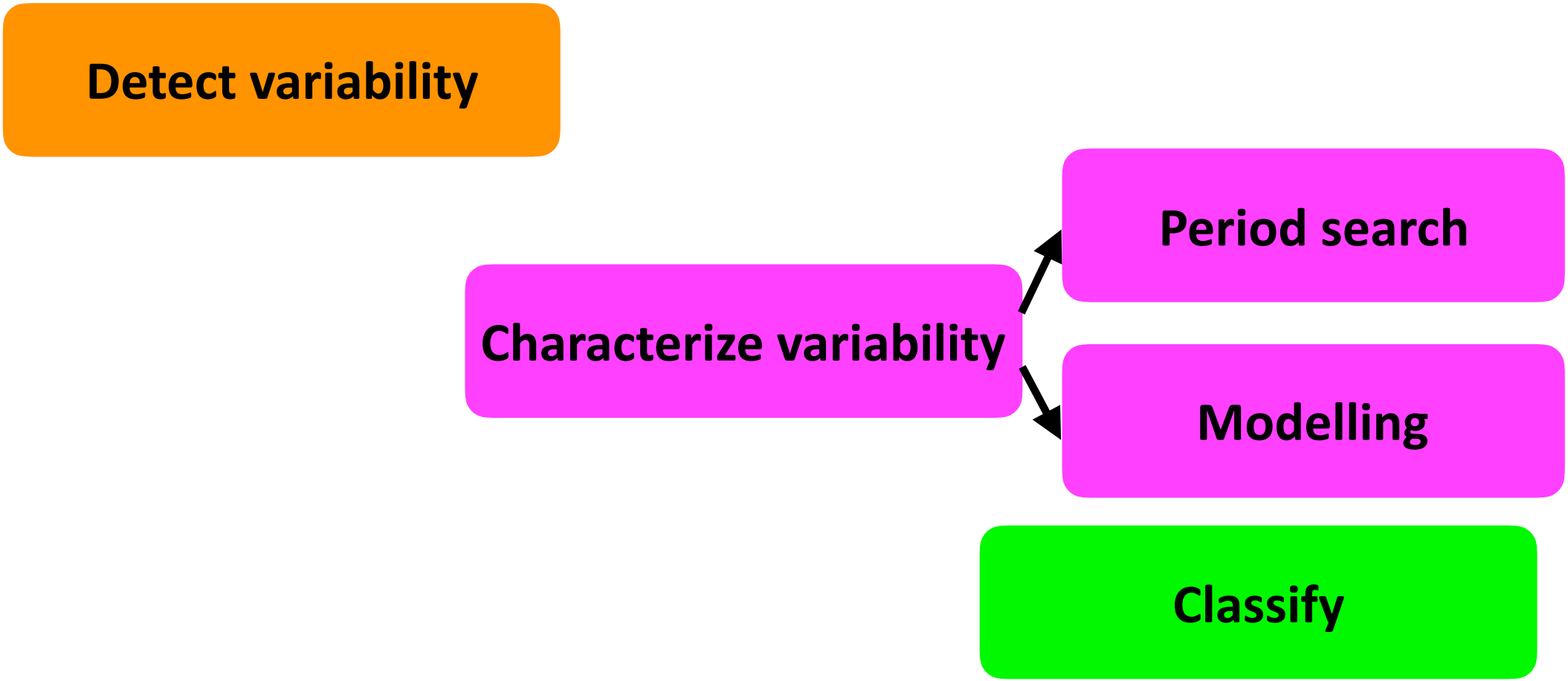
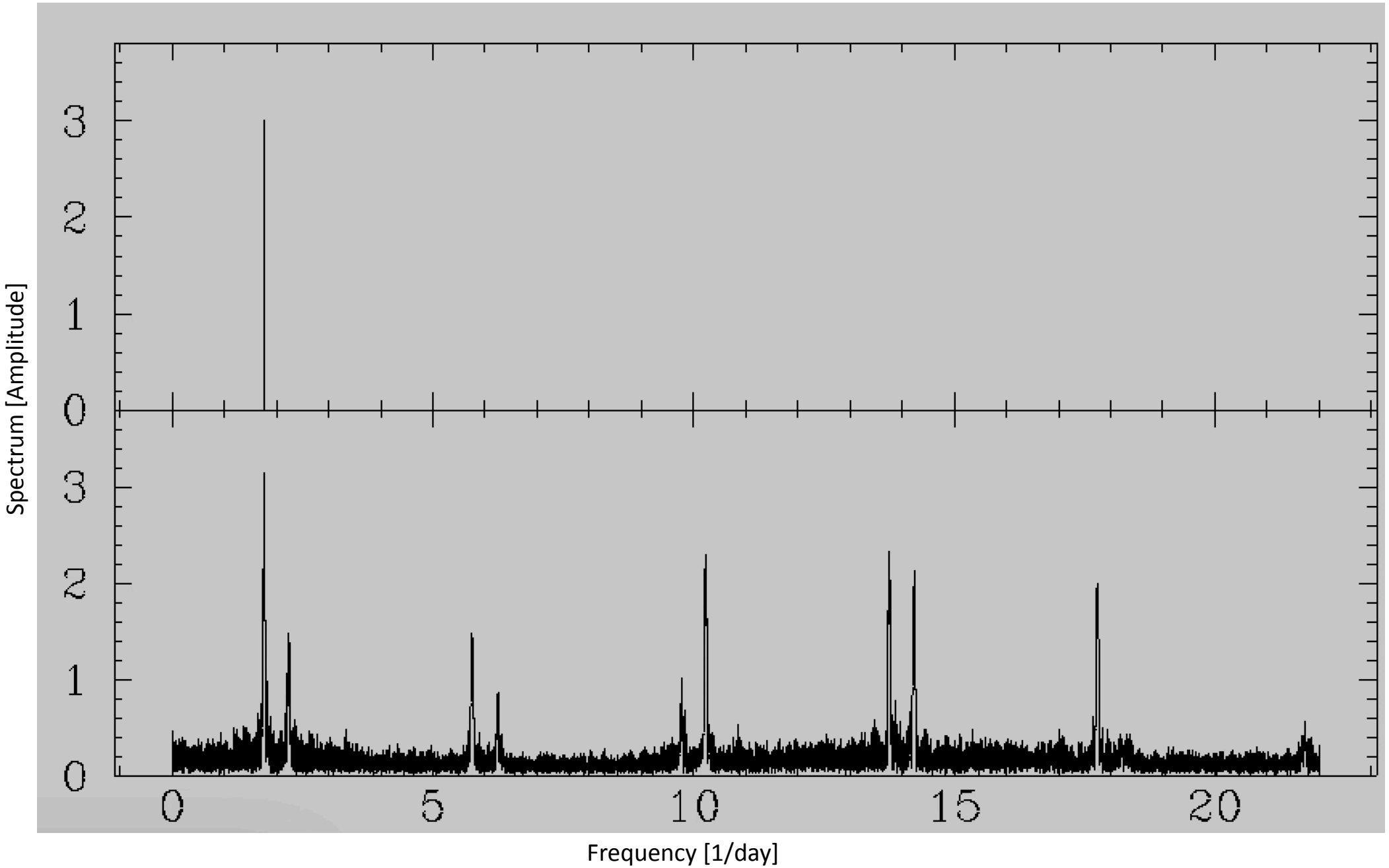
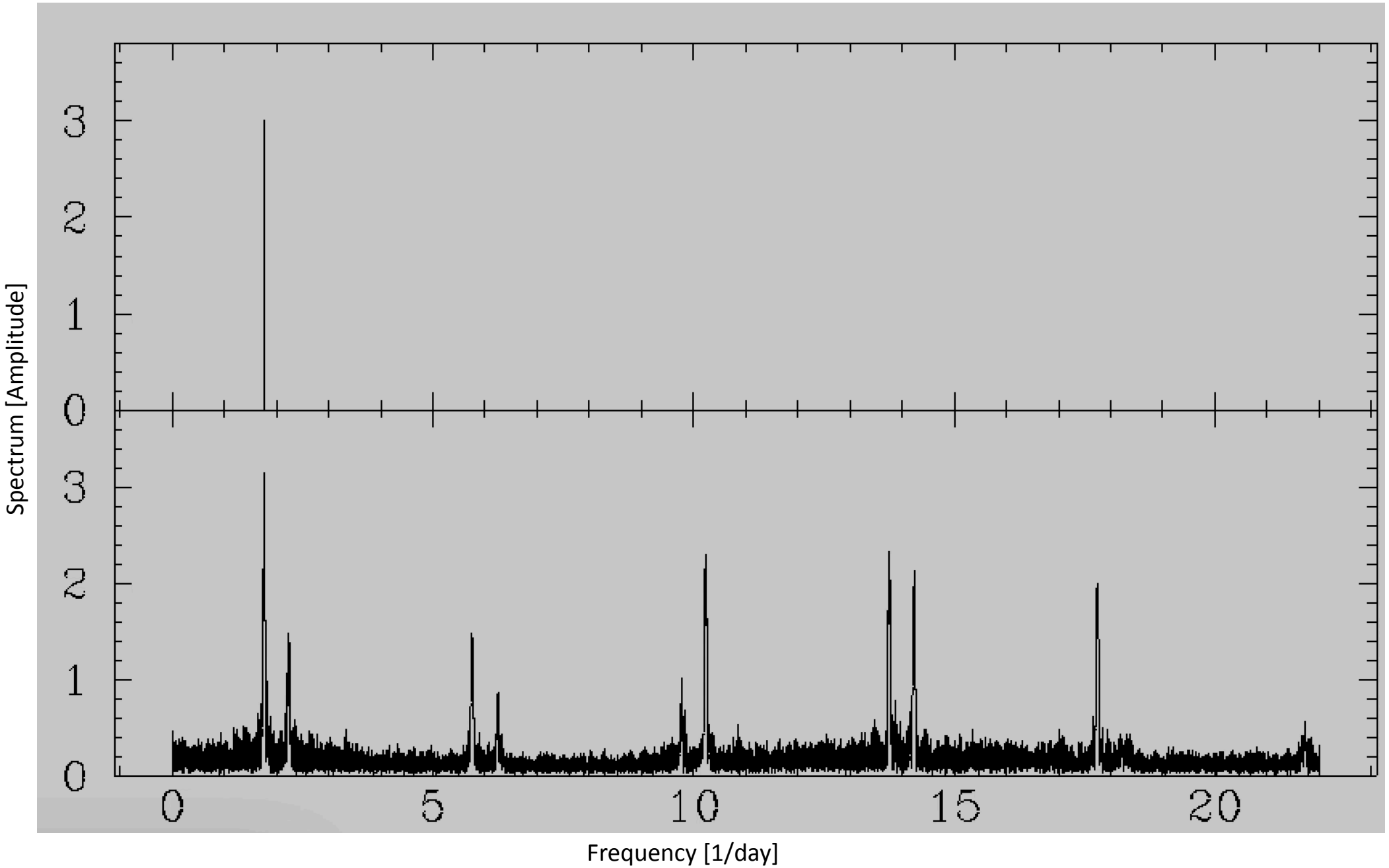


Few words about period search (Convolution)



Few words about period search (Convolution)



An example of aliasing in Gaia (same star with two different periods) in EPSL (too regular sampling)

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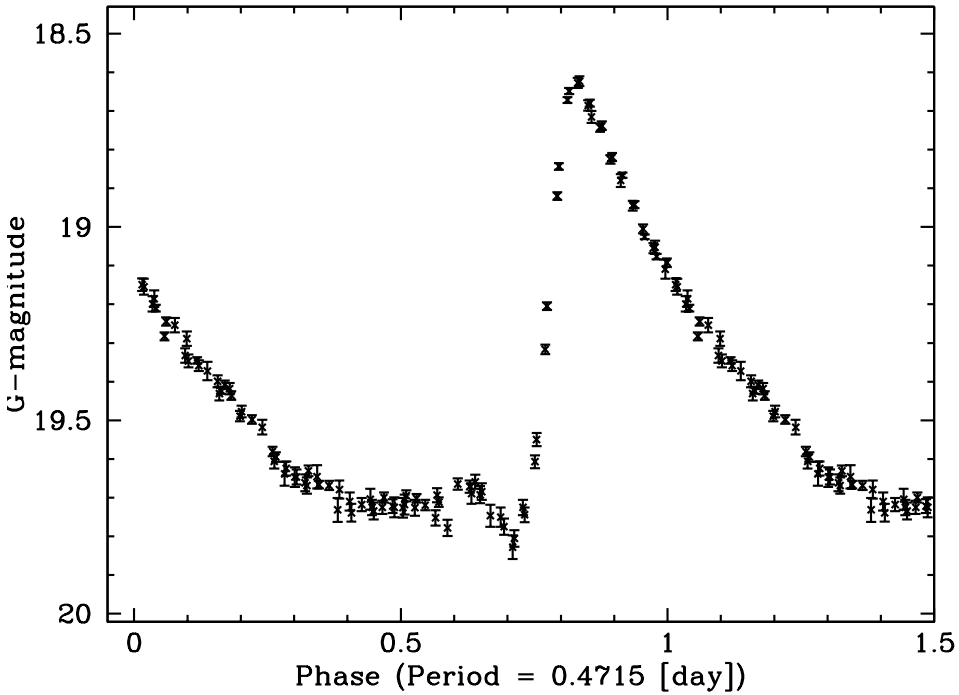

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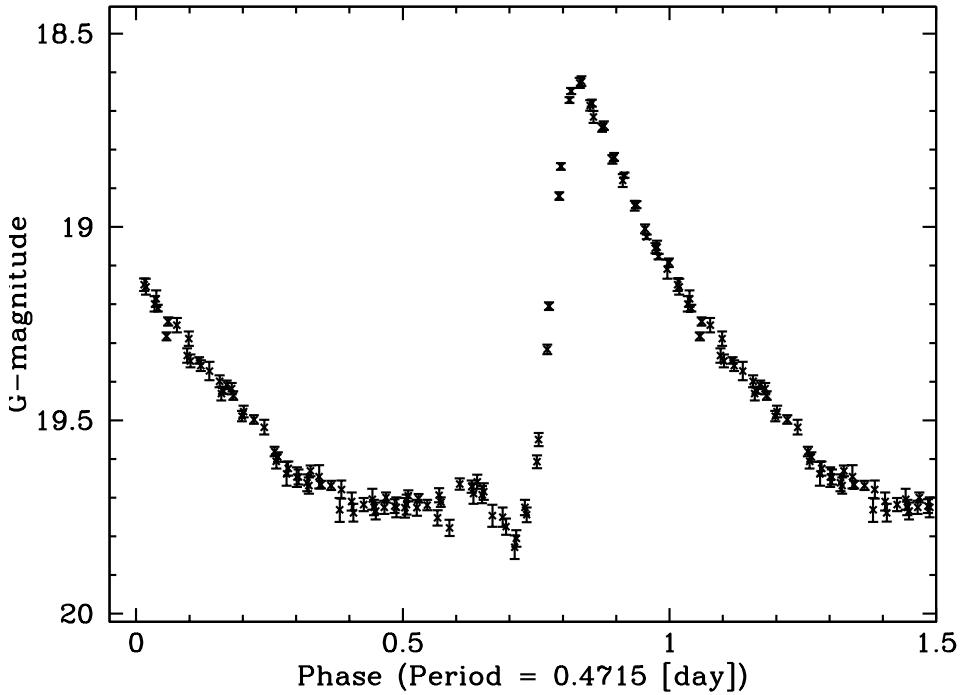

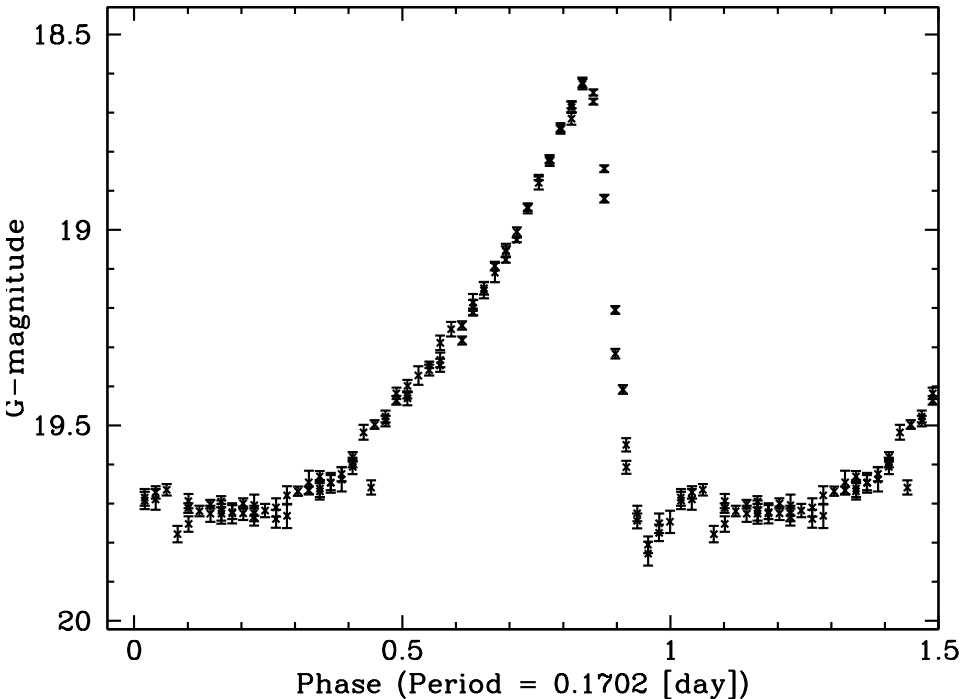

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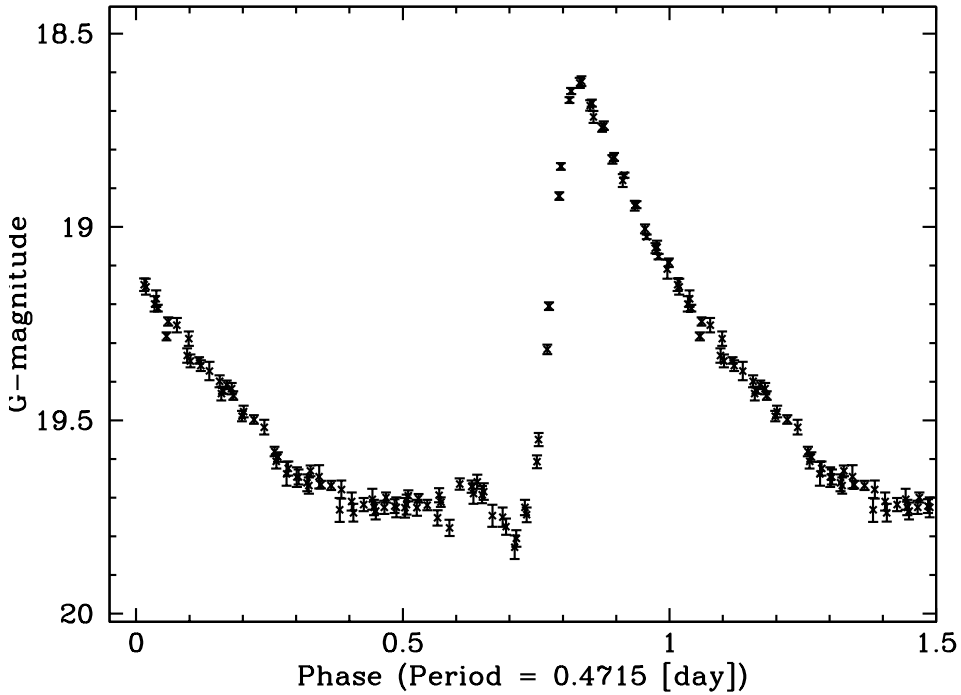

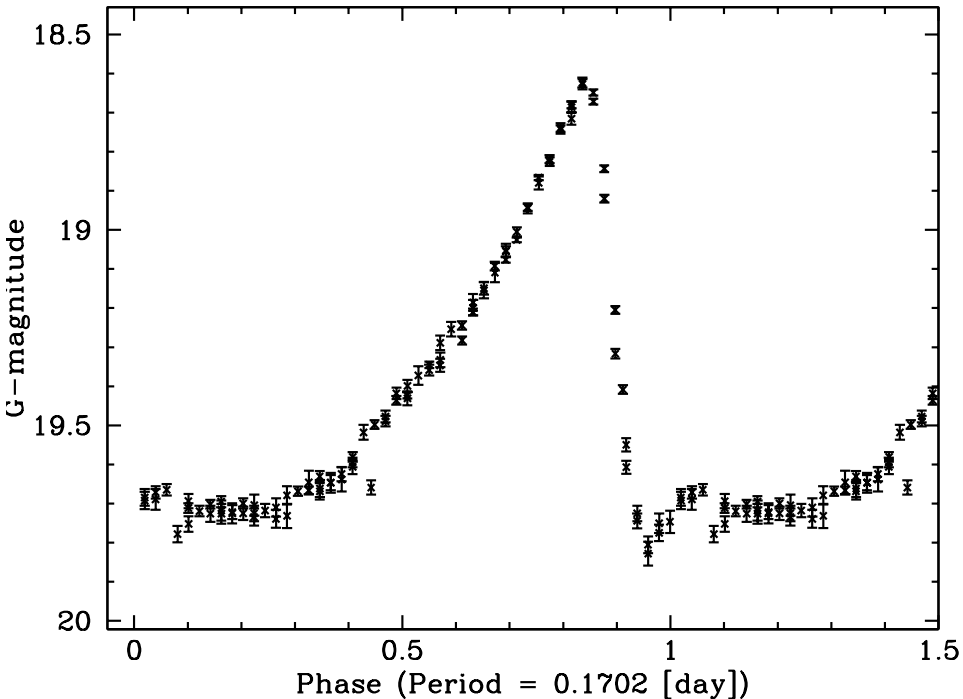

Stroboscopic effect/Wagon-wheel effect

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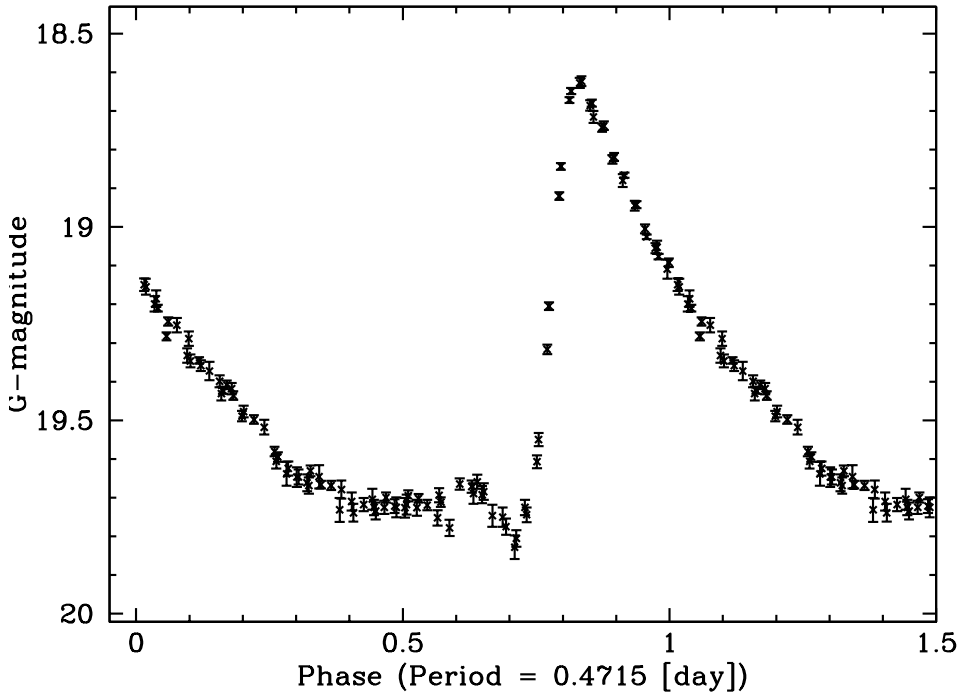

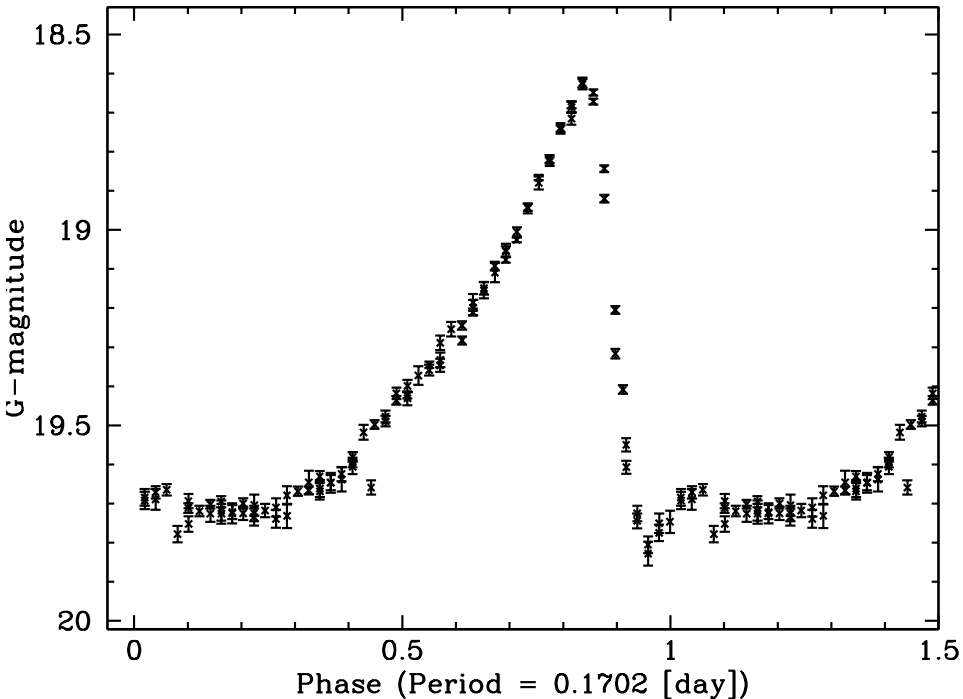

Stroboscopic effect/Wagon-wheel effect

For LSST:There are ways to deal with aliasing (it is not always a lost cause), see Dawson & Fabricki

Gaia Variability Processing and Analysis

Detect variability

Characterize variability

Classify

Classification

Supervised classification (several methods):

Classification

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Multistage tree:
Bayesian networks

Multistage tree:
Gaussian mixture

Random Forest

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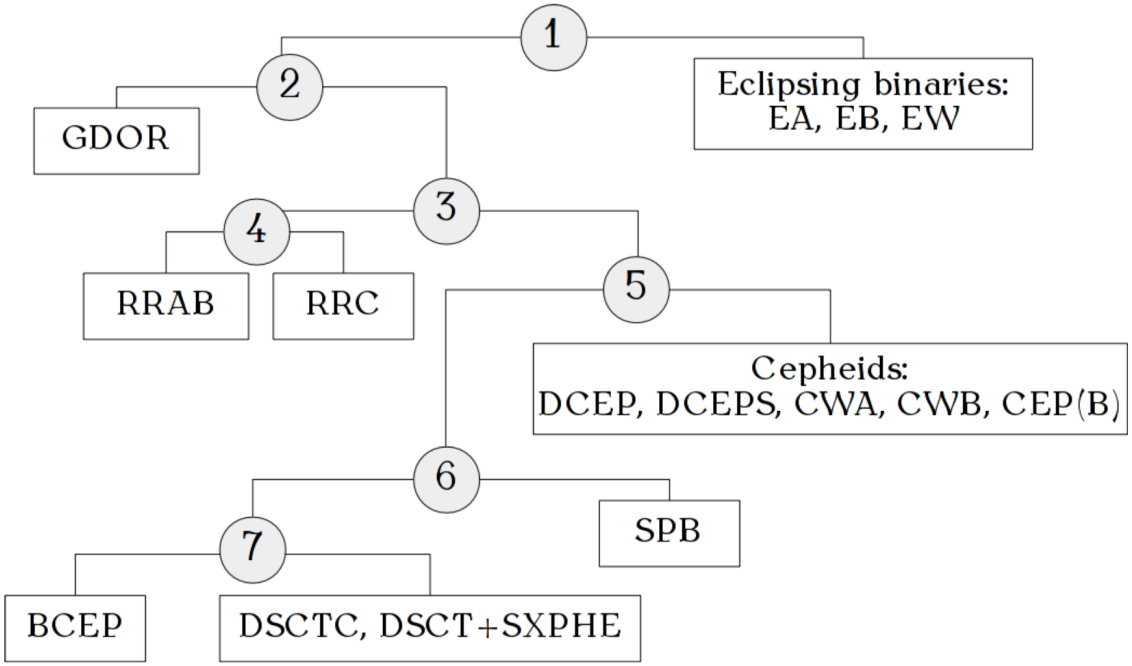
Multistage tree: Bayesian networks	Multistage tree: Gaussian mixture	Random Forest

Tree for Gaussian Mixture:



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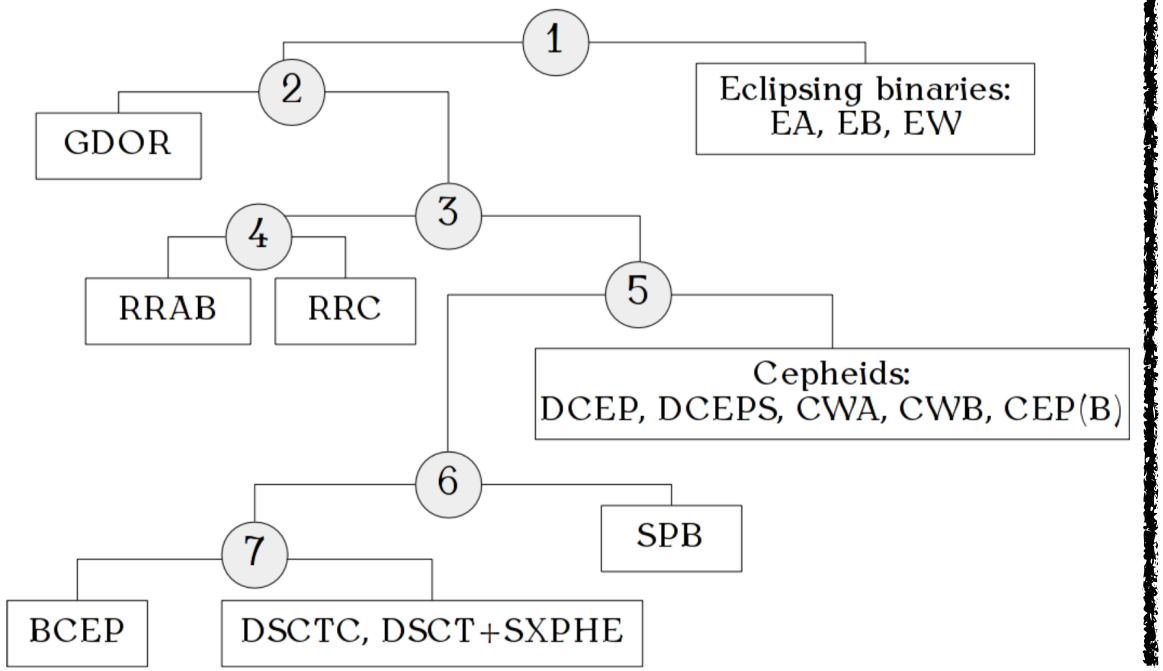

Furnish training set
built from Crossmatched data

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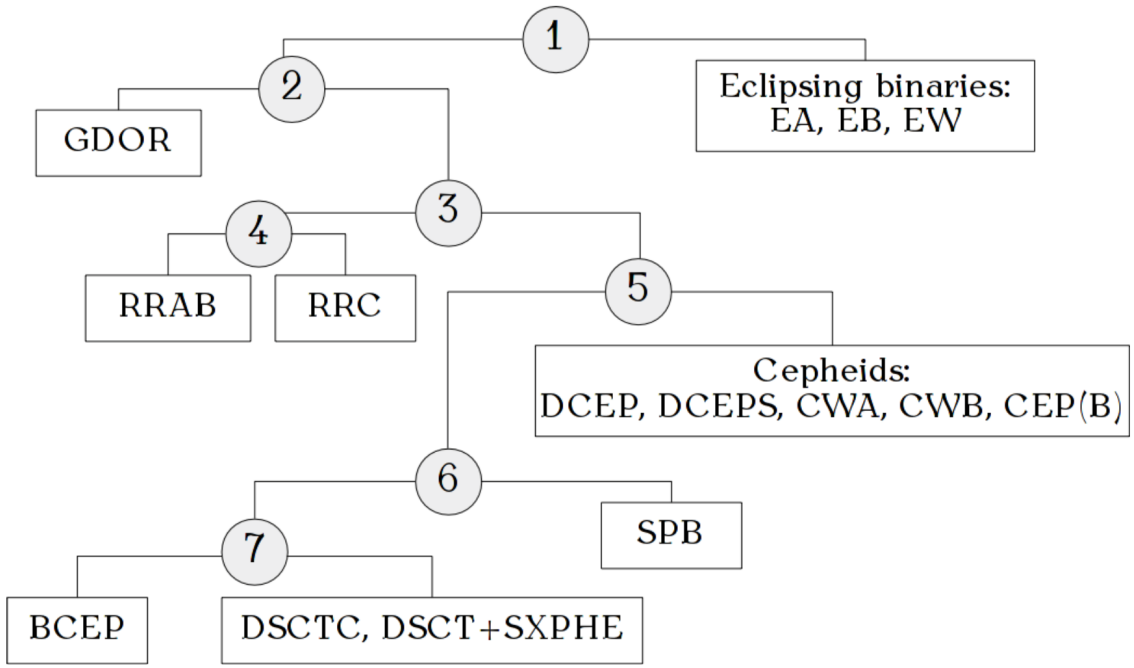

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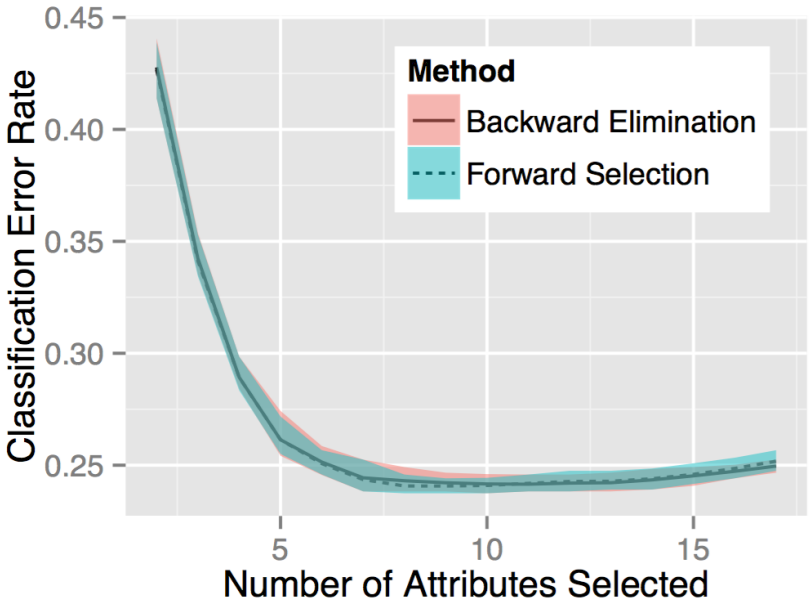

Classification

Confusion matrix of Random Forest
using cross-matched data (OGLE, Hipparcos, AAVSO, Milliquas)

		CONSTANT	QSO	ECL	OTHER	RRLYR	LPV	ELL	DSCT	DCEP	UG
103	CONSTANT	79	8	5	9						
100	QSO	7	88	2	3						
135	ECL	4	3	84	7	1	1	1			
108	OTHER	13	4	12	69		2	1			
106	RRLYR	3		1	2	94					
27	LPV	30	19	7	30		15				
8	ELL	25	12		62						
7	DSCT	14		29	29	29					
2	DCEP	50		50							
2	UG					100					
Contamination		34	20	19	34	5	43	100	_	_	_

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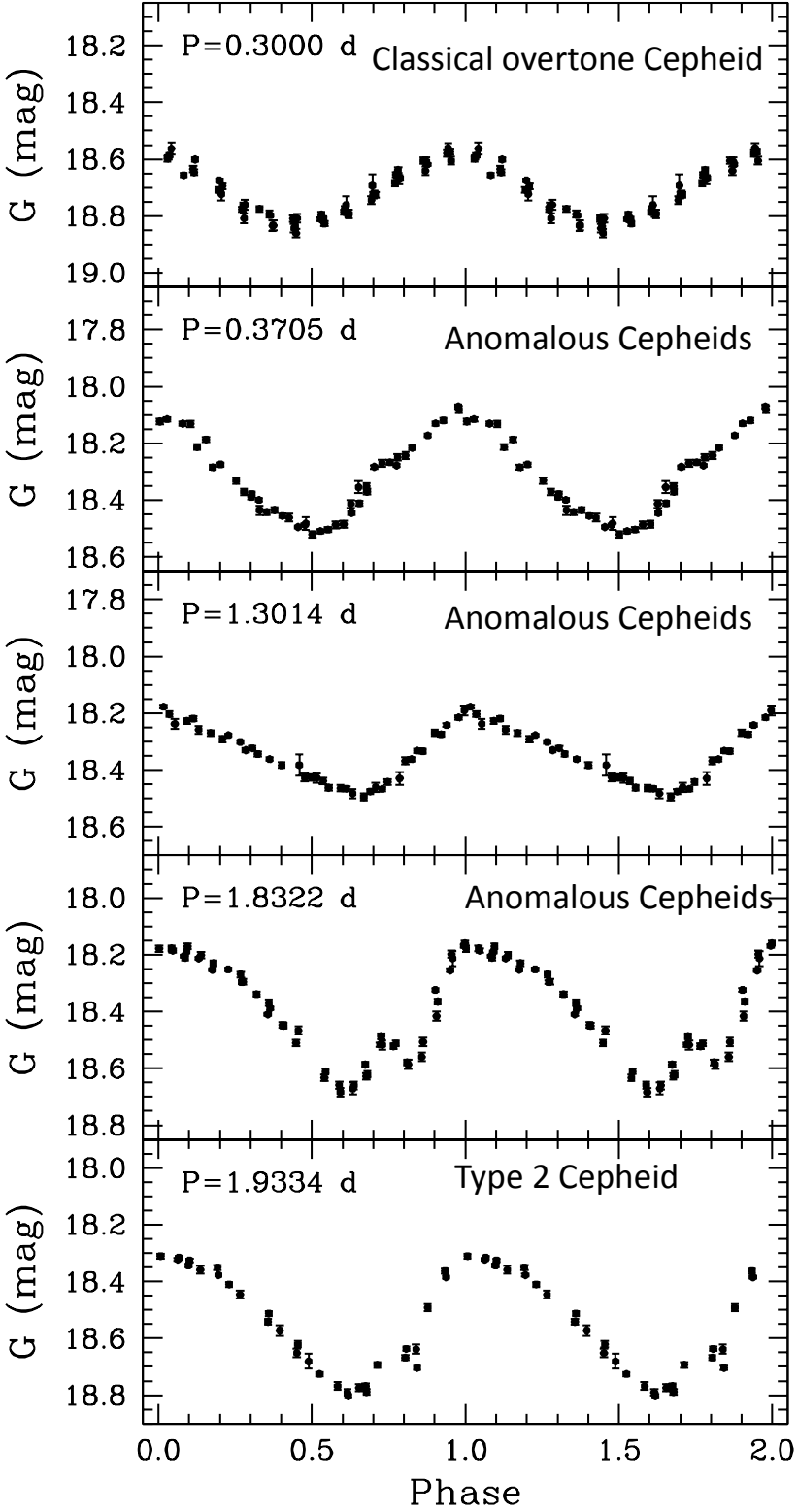
Specific object Studies

Specific object studies
RR Lyrae and Cepheid stars

- Verify the classification
- Derive specific parameters
- Perform a sub-classification
- Give a feedback to the classification



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.

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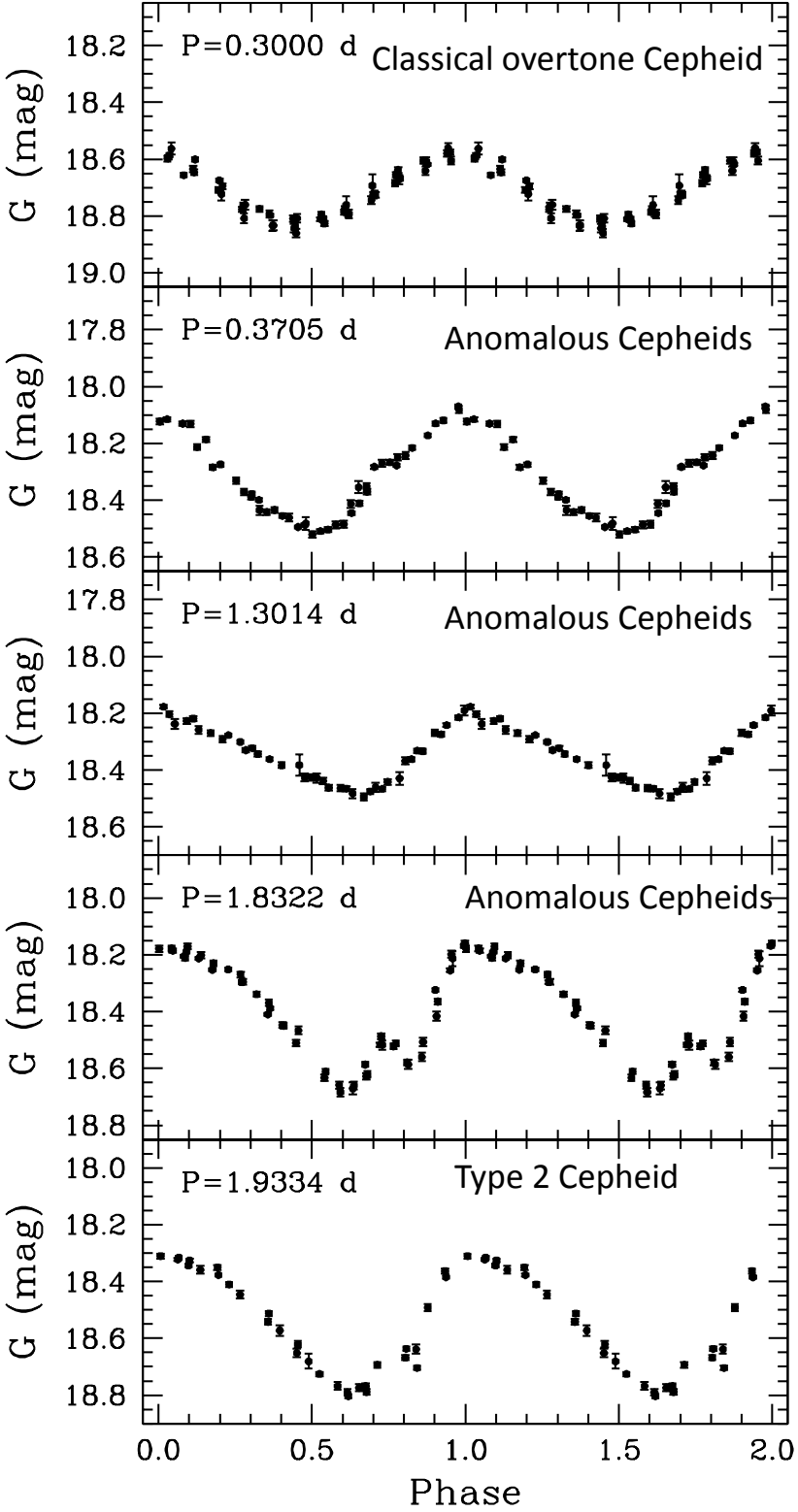
"Active learning"



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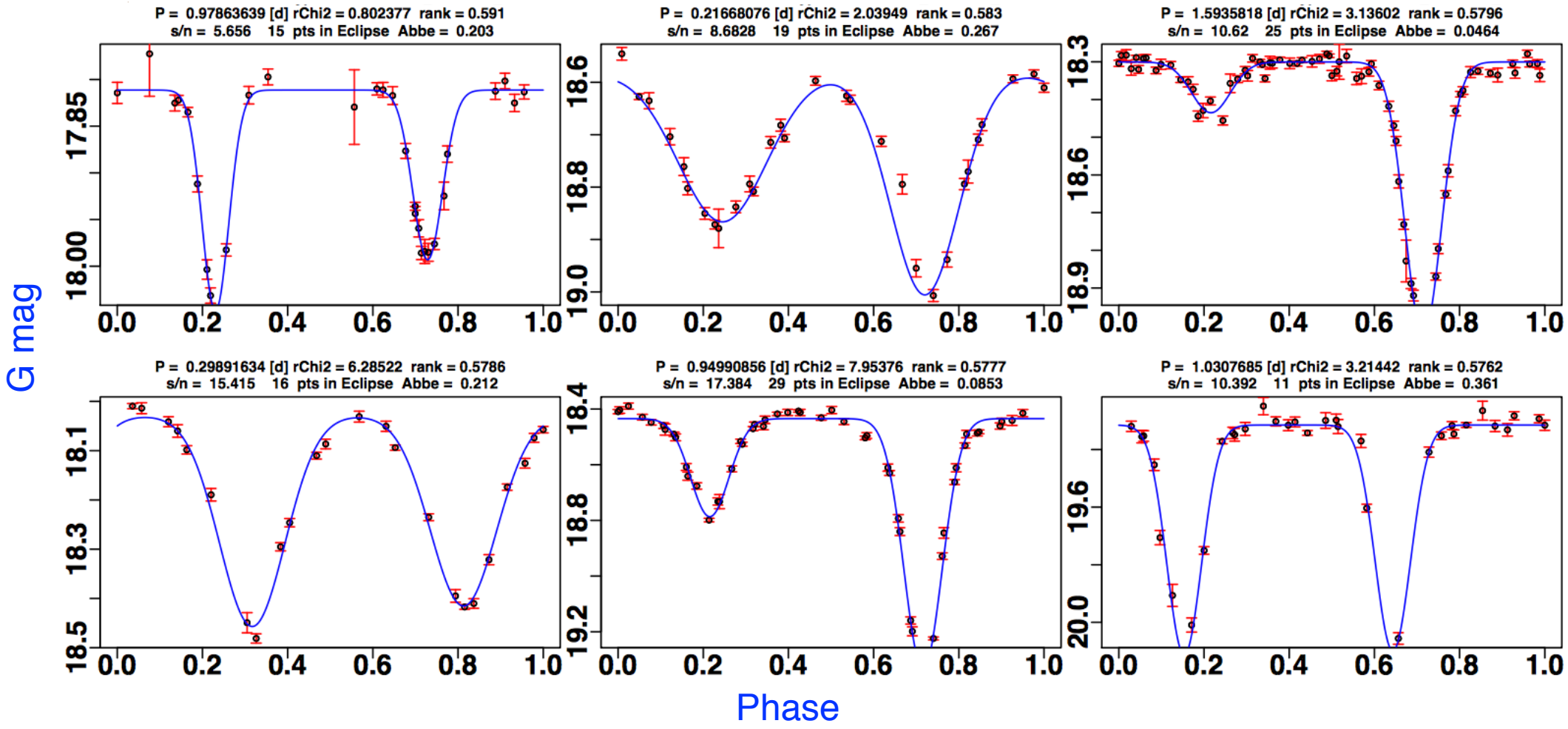
Specific Object Studies: An other example

Eclipsing binaries

Eclipsing binaries go to a dedicate treatment (Université Libre de Bruxelles) for a full modelling

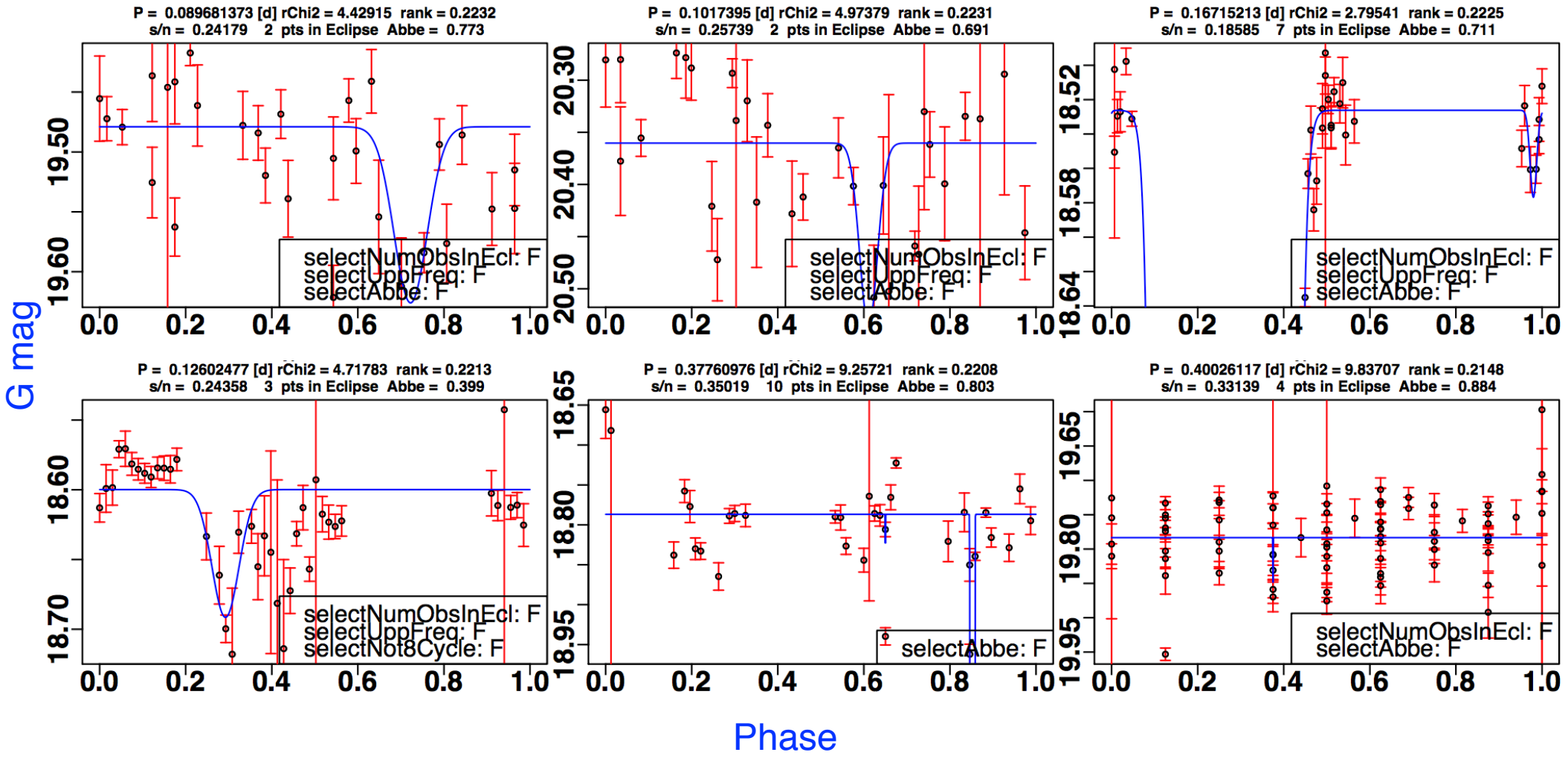
Here, simple modelling (fit with “two Gaussians”) are made
The solution enables a ranking

Highest rank



Specific Object Studies: Eclipsing binaries

Lowest rank



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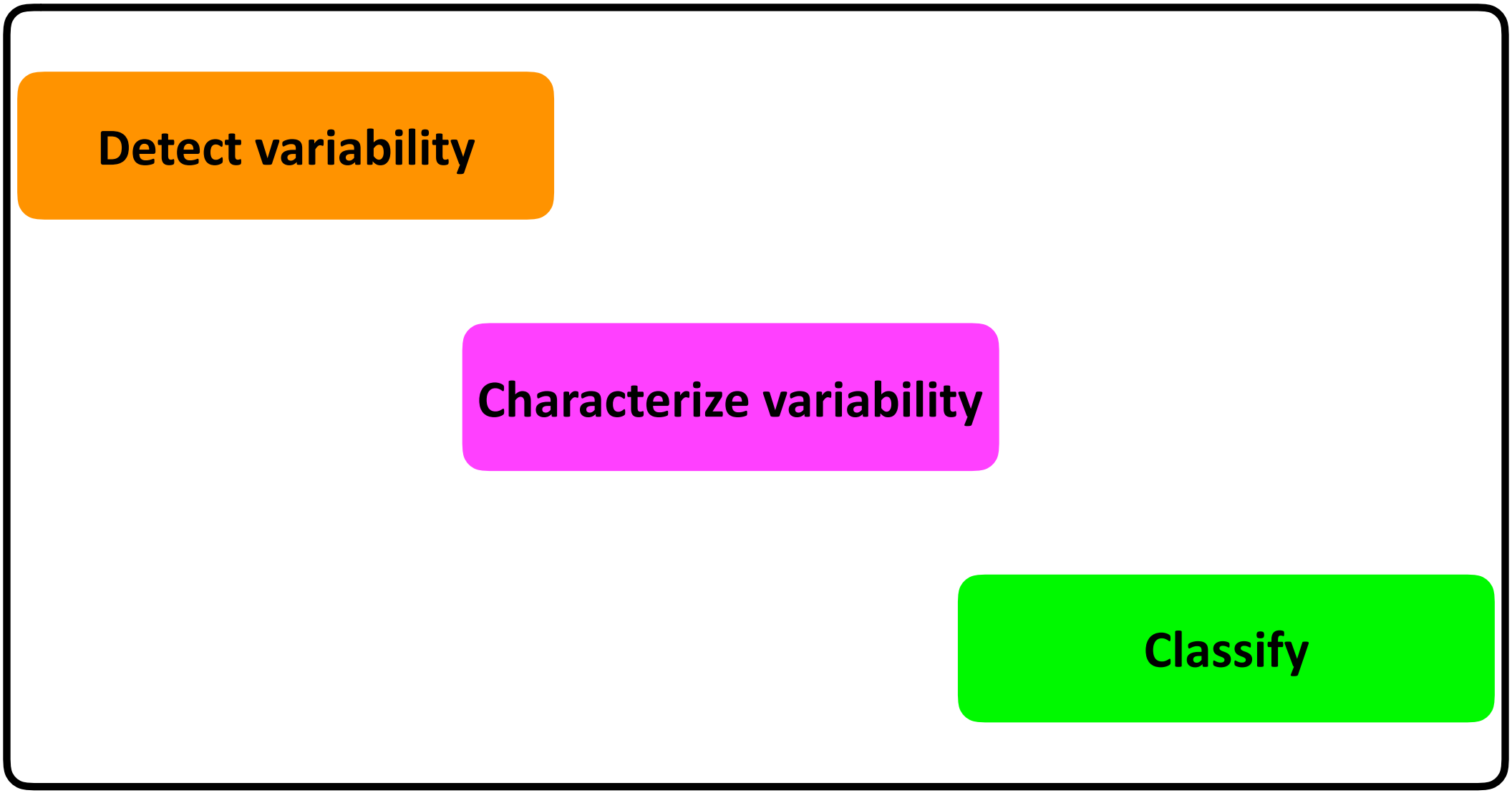
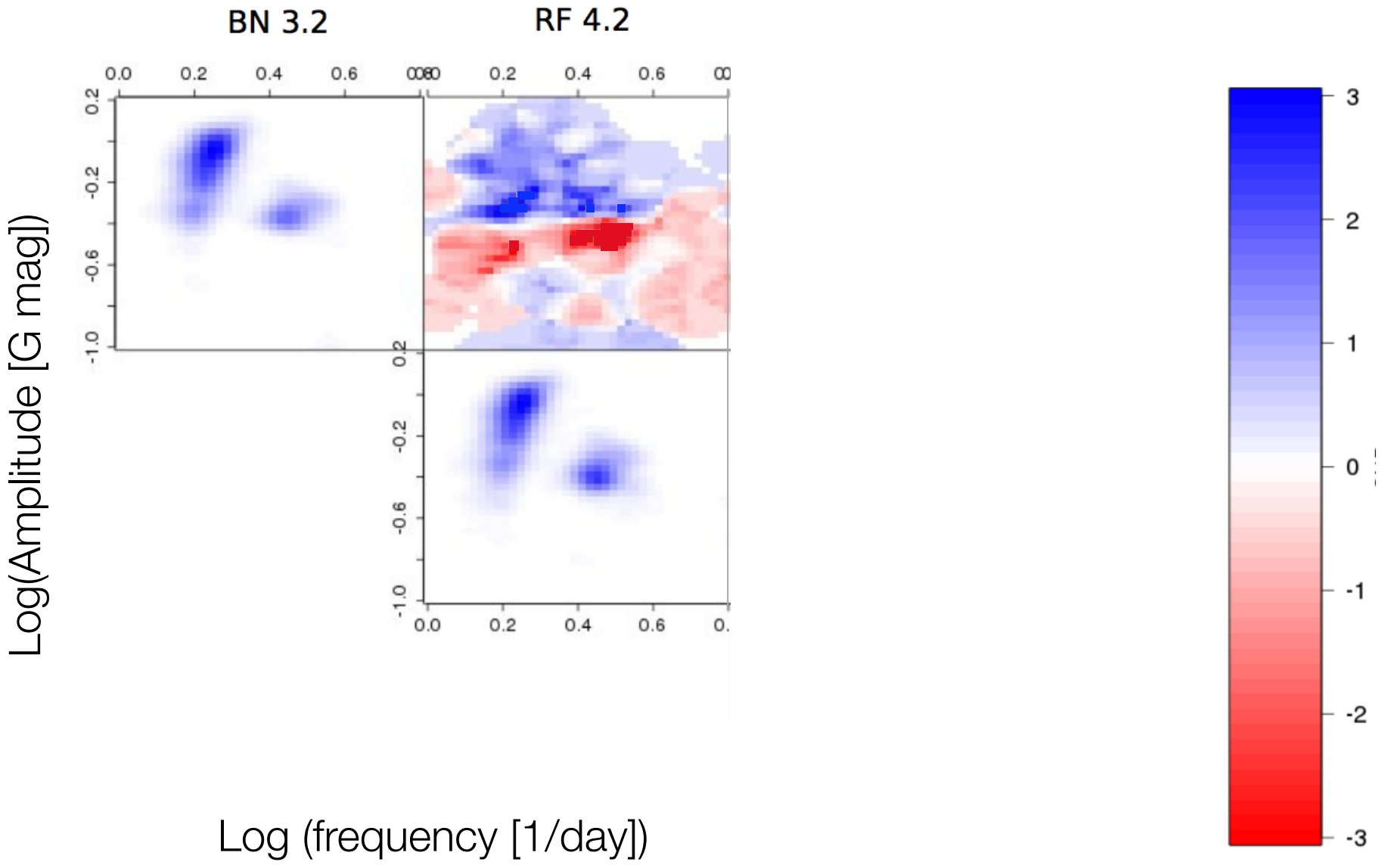


Global Variability Studies

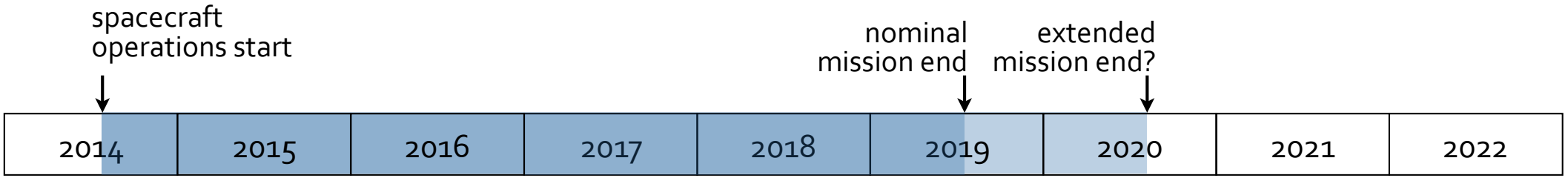
Global Variability Studies

Comparison of distribution functions of RR Lyrae stars



Courtesy of L. Sarro (modified by L.Eyer)

The data releases



Courtesy of B.Holl

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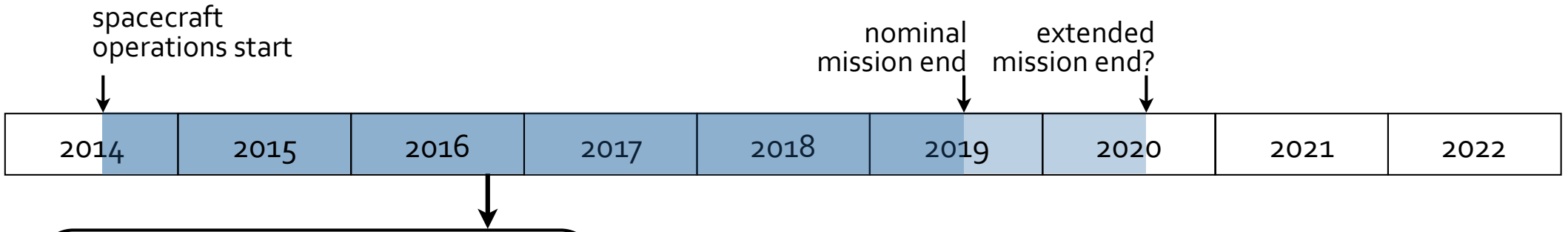

Release 1:

- **α and δ, mean G-magnitude for 1billion stars**
- **100K proper motion stars (Hipparcos+Gaia)**

Courtesy of B.Holl

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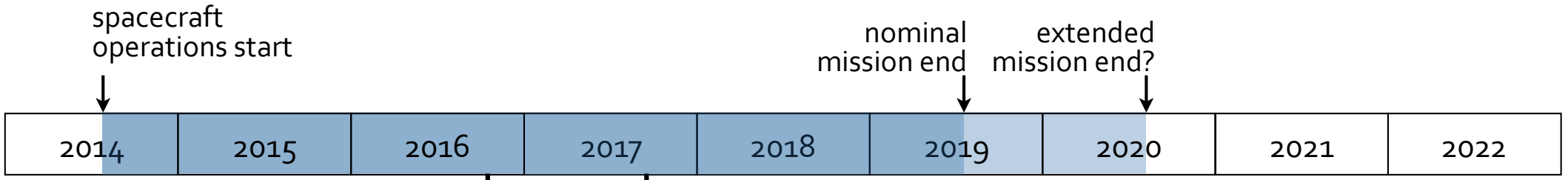

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- **Integrated BP/RP + Astrophysical parameters**
- **Mean V_{rad} (for non variable)**

Courtesy of B.Holl

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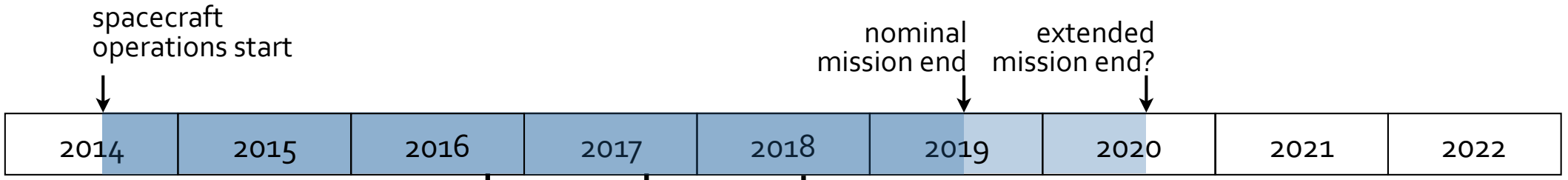

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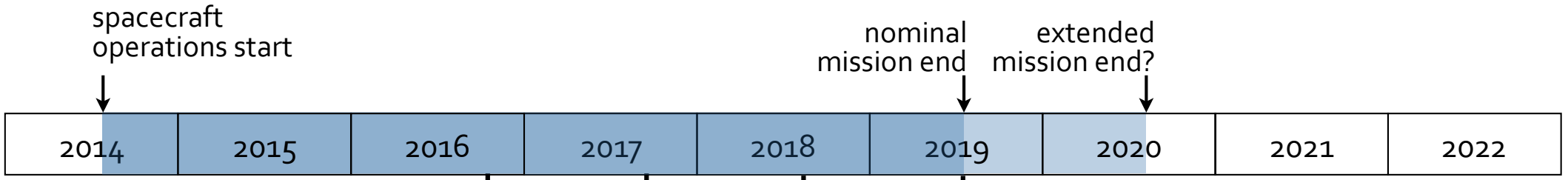

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Release 4:

- **Variable stars classification**
- **Non-single star catalogue**
- **Solar system objects**

Release 2:

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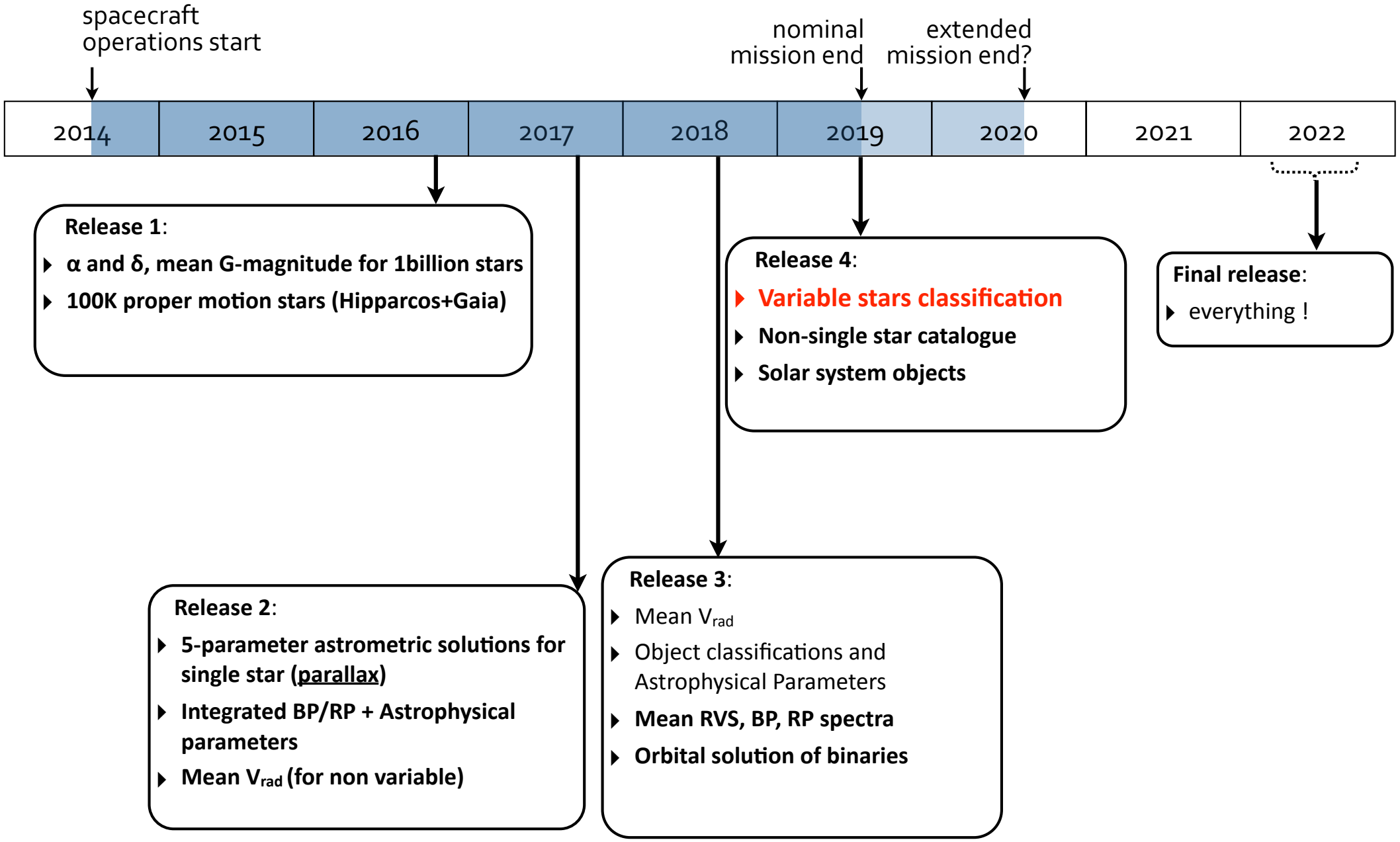

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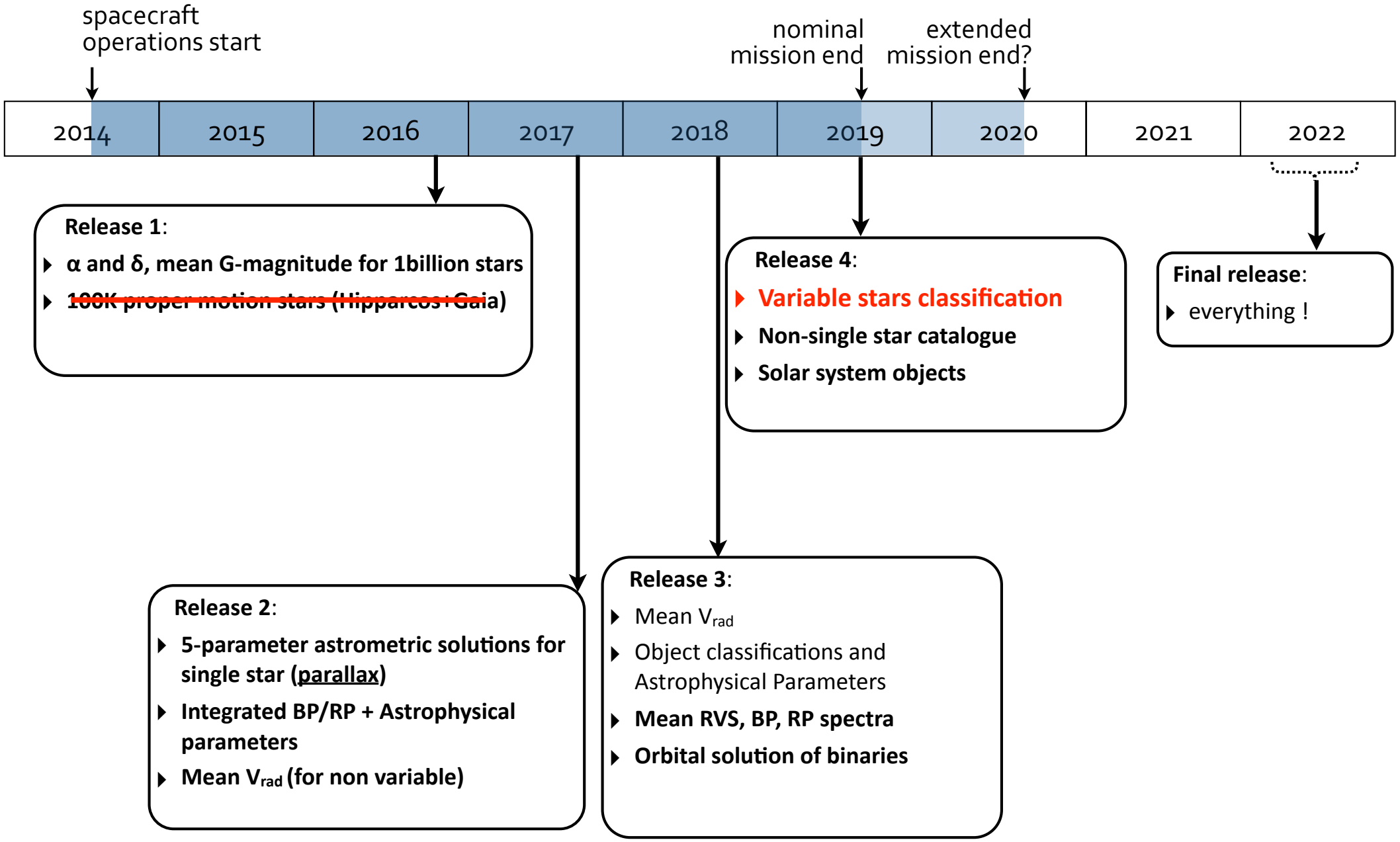

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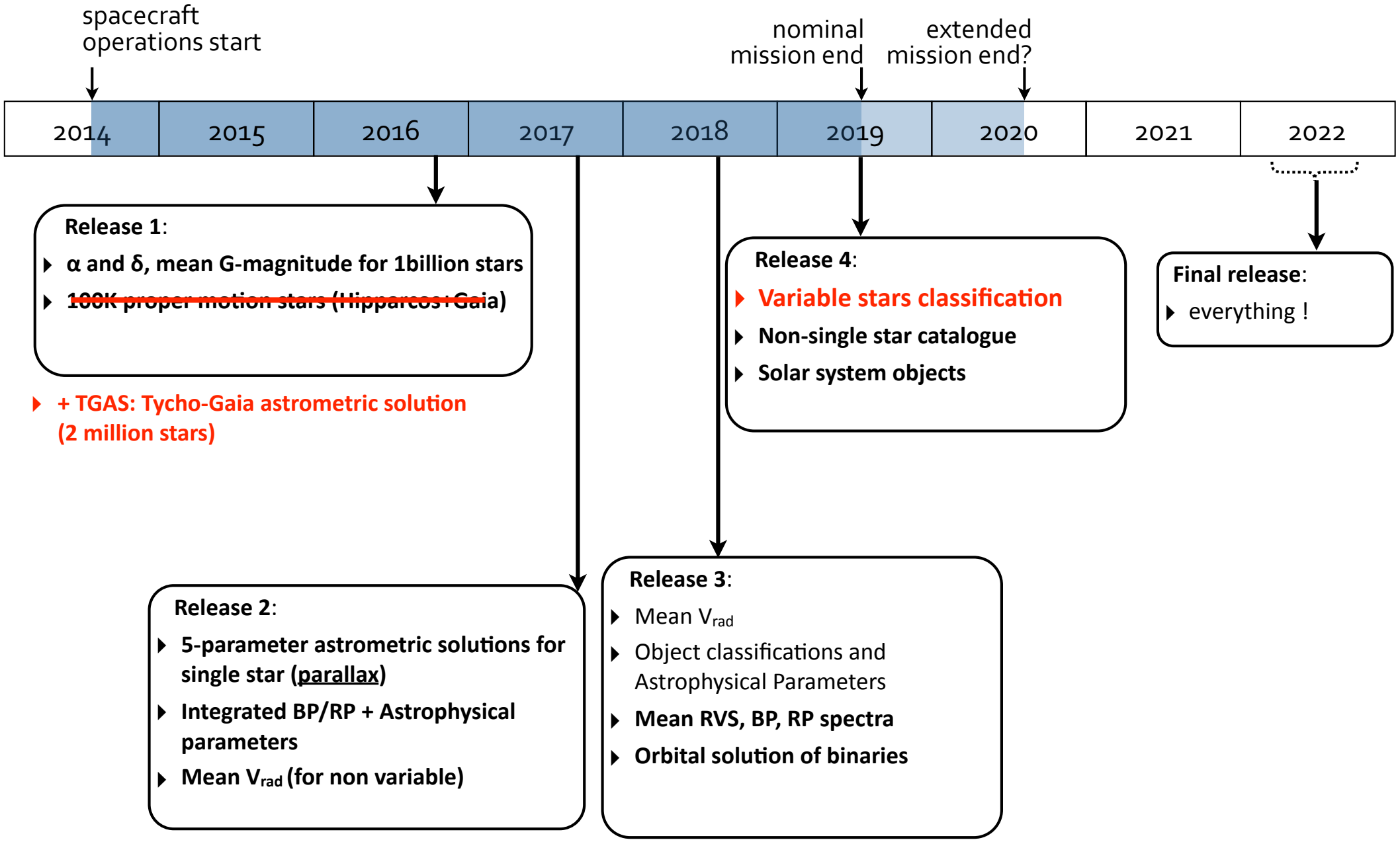

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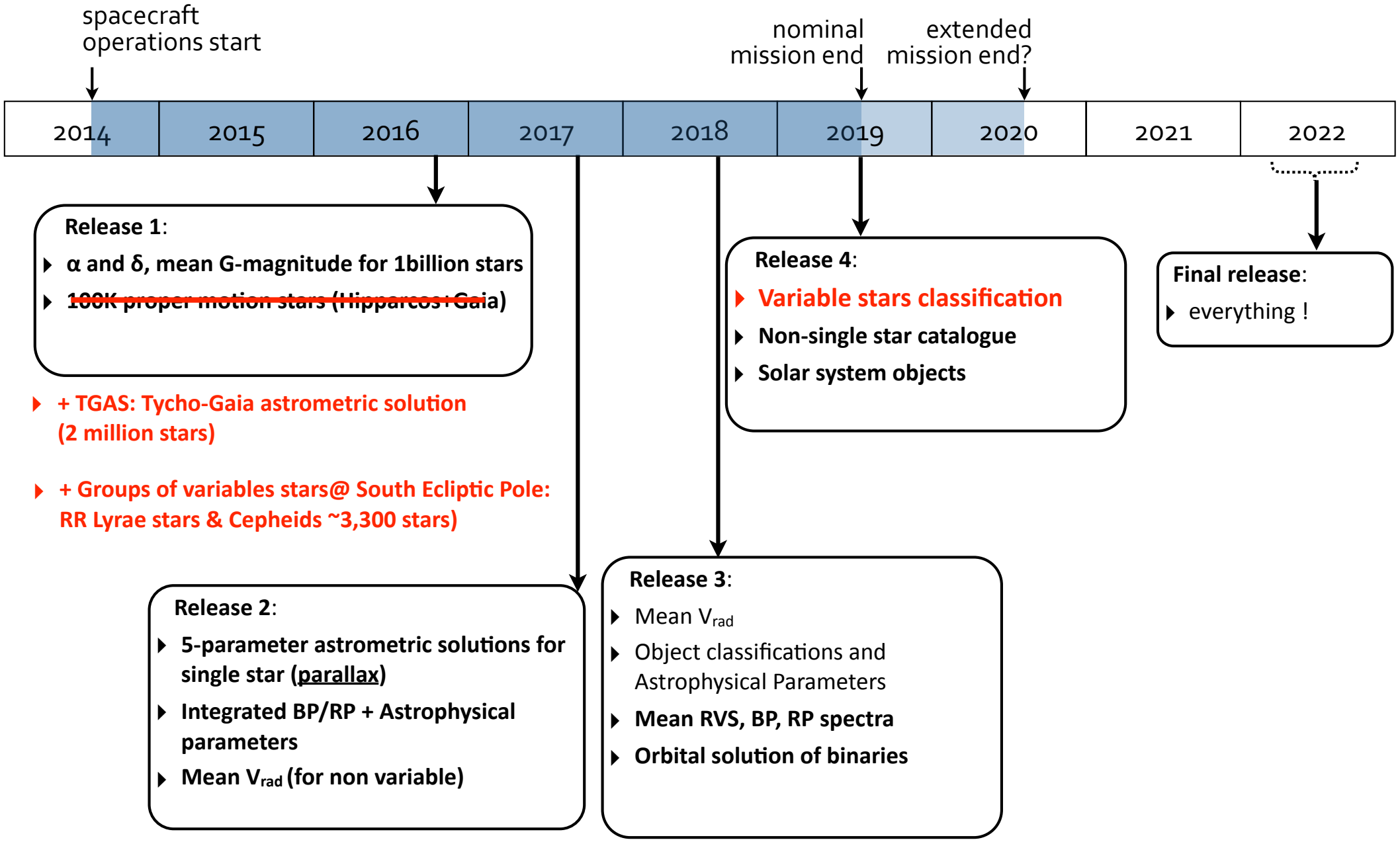

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Thank you for
your attention