The Gaia mission

Laurent Eyer, Observatoire de Genève, Switzerland
University of Bologna (founded in 1088), Italy
Thursday April 4 2013

Monday, April 8, 2013


esa
esa
Less than 6 months


esa
Less than 6 months
September

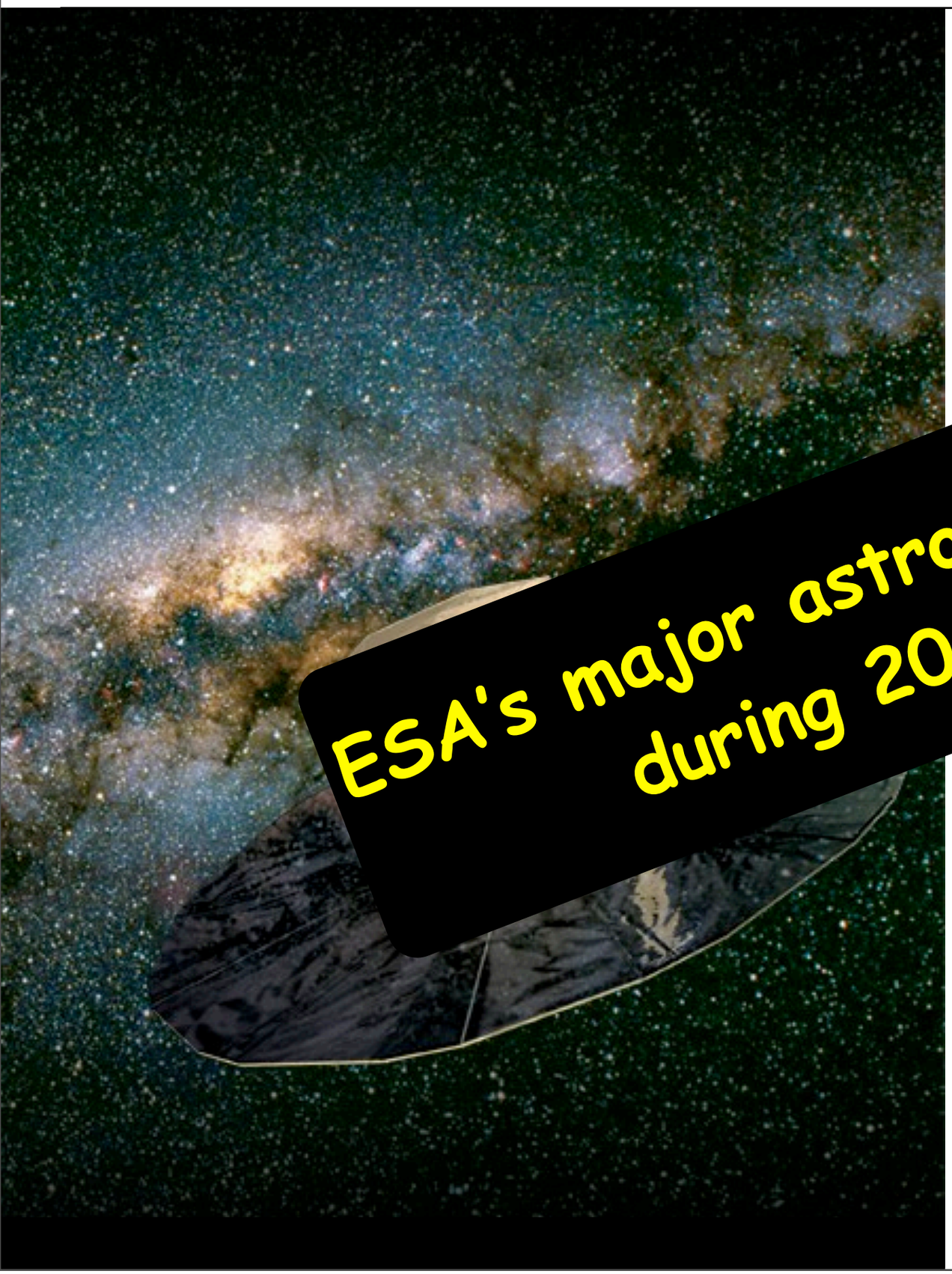

esa
Less than 6 months
September 2013


esa
Less than 6 months
September 2013
Launch # 13

The Gaia mission

- Satellite of the European Space Agency
- Observations of all the objets between ~6 < V < ~20 (**1 billion objects**)
- Measurement of:
  - positions (astrometry)
  - brightness, colors (spectro-photometry)
  - radial velocities (spectroscopy)
- Launch (Soyuz rocket): Sept. 2013
  - other candidates: Sentinel3, Galileo, Ariane
  - Cost of Gaia delay: 5 million EUR/month
- Length: 5 (+1) years (70 times all sky)
- Final Catalogue: 2021-2022

The Gaia mission



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ESA's major astrophysics mission during 2013-2018

The Gaia mission: Observed Objets

- 1 billion stars

- 1 million galaxies

-astrometry, photometry
-spectro-photometry

- 0.5 million QSO

- 0.3 million asteroids of our solar system

-Radial Velocity
Spectrometer

The Gaia mission: Observed Objets

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-astrometry, photometry
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~70 measurements

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-Radial Velocity Spectrometer

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~70 measurements

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-Radial Velocity
Spectrometer

~40 measurements

Science objective of the Gaia mission: Its diversity

- Our Galaxy, its history and formation (dark matter)
- Stellar interiors and evolution, stellar variability (photometry)
- Double stars, exo-planets
- Asteroids
- Distance scale in the Universe
- Fundamental physics (General relativity)

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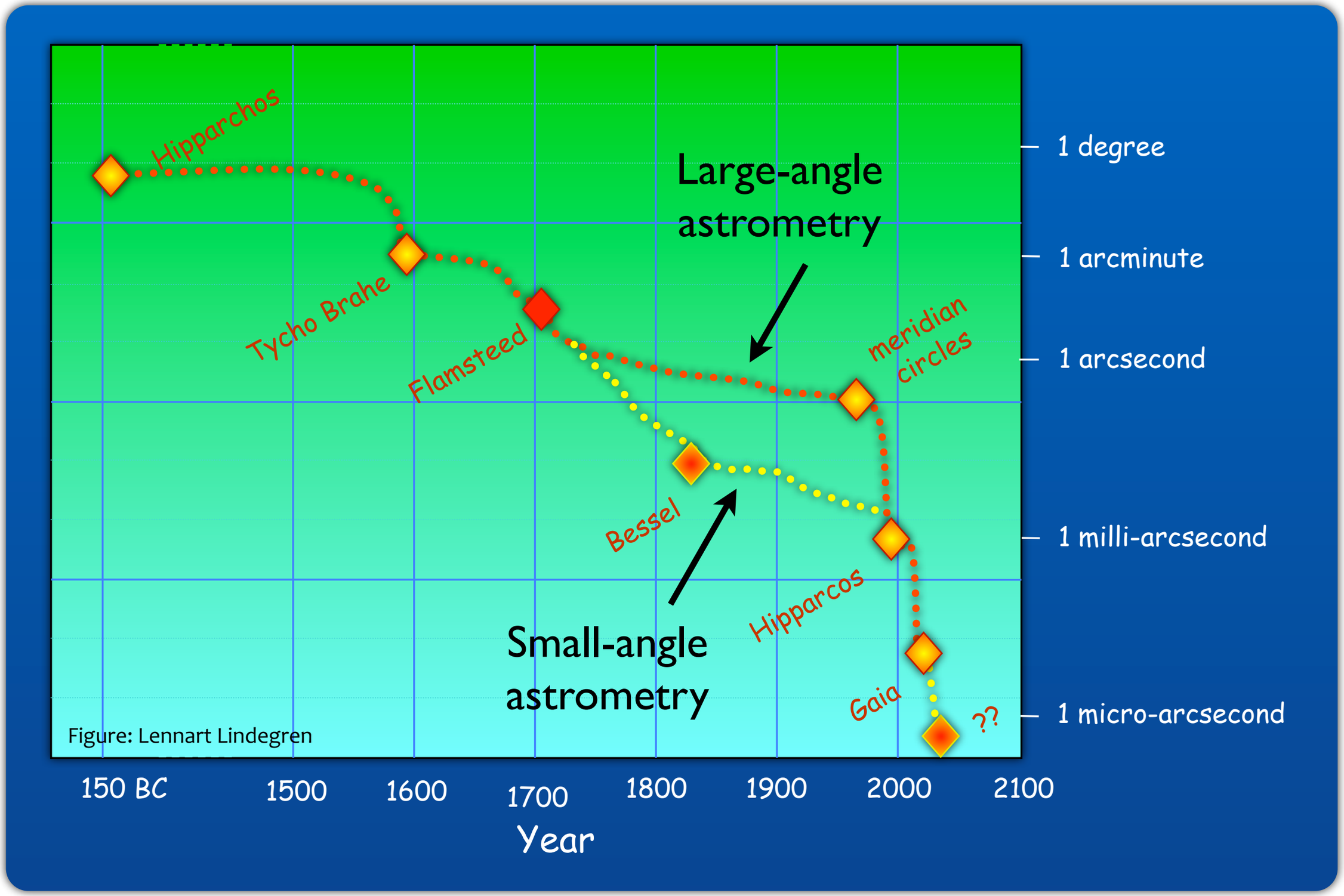
An extremely Broad contribution to Astrophysics

The Gaia mission: astrometry at its heart
a historical perspective



10 micro arcsec is very,

10 micro arcsec is very,very,

10 micro arcsec is very, very, very,

10 micro arcsec is very, very, very, very small

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La mission Gaia: Hipparcos versus Gaia

	1989-1997	2012-2021
	Hipparcos	**Gaia**
Magnitude limit	12	20 mag
Completeness	7.3 – 9.0	20 mag
Bright limit	0	6 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Quasars	1	5×10^5
Galaxies	None	10^6
Accuracy	1 milliarcsec	7 μarcsec at V = 10 10-25 μarcsec at V = 15 300 μarcsec at V = 20
Photometry	2-colour (B and V)	Low-res. spectra to V = 20
Radial velocity	None	15 km/s to V = 16-17
Observing programme	Pre-selected	Complete and unbiased

Prusti 2009

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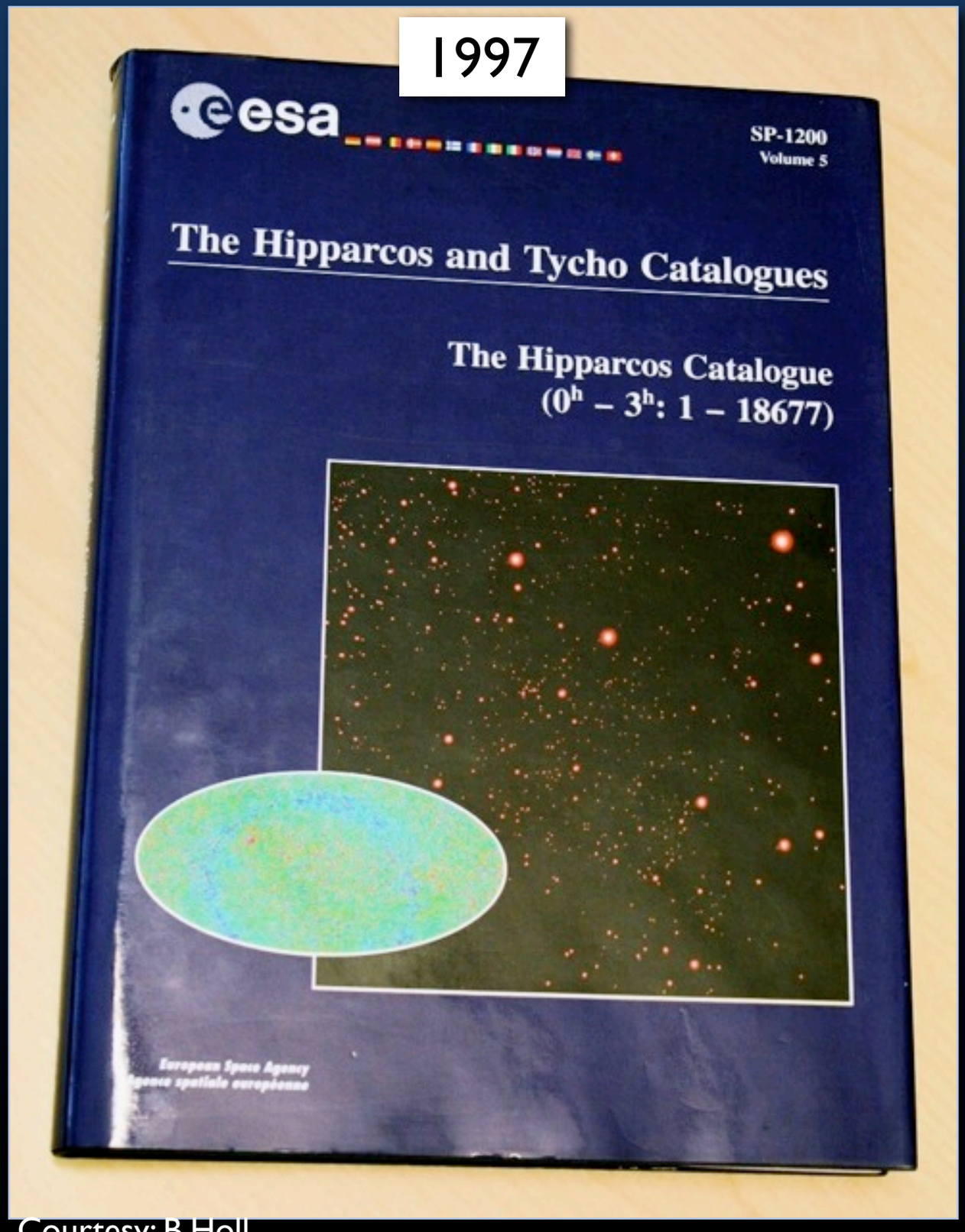
Prusti 2009

Hipparcos vs Gaia catalogue



Courtesy: B.Holl

Hipparcos vs Gaia catalogue

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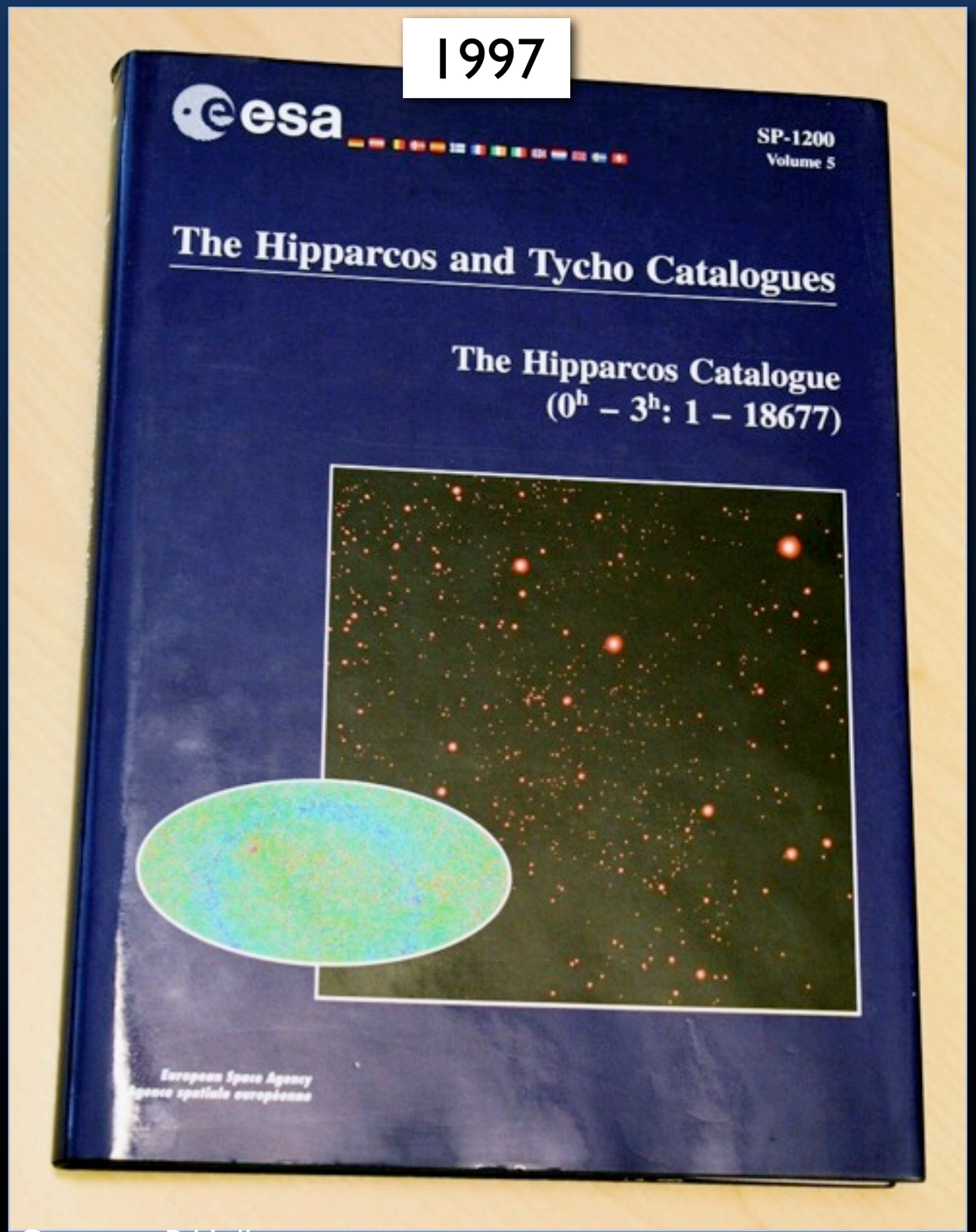
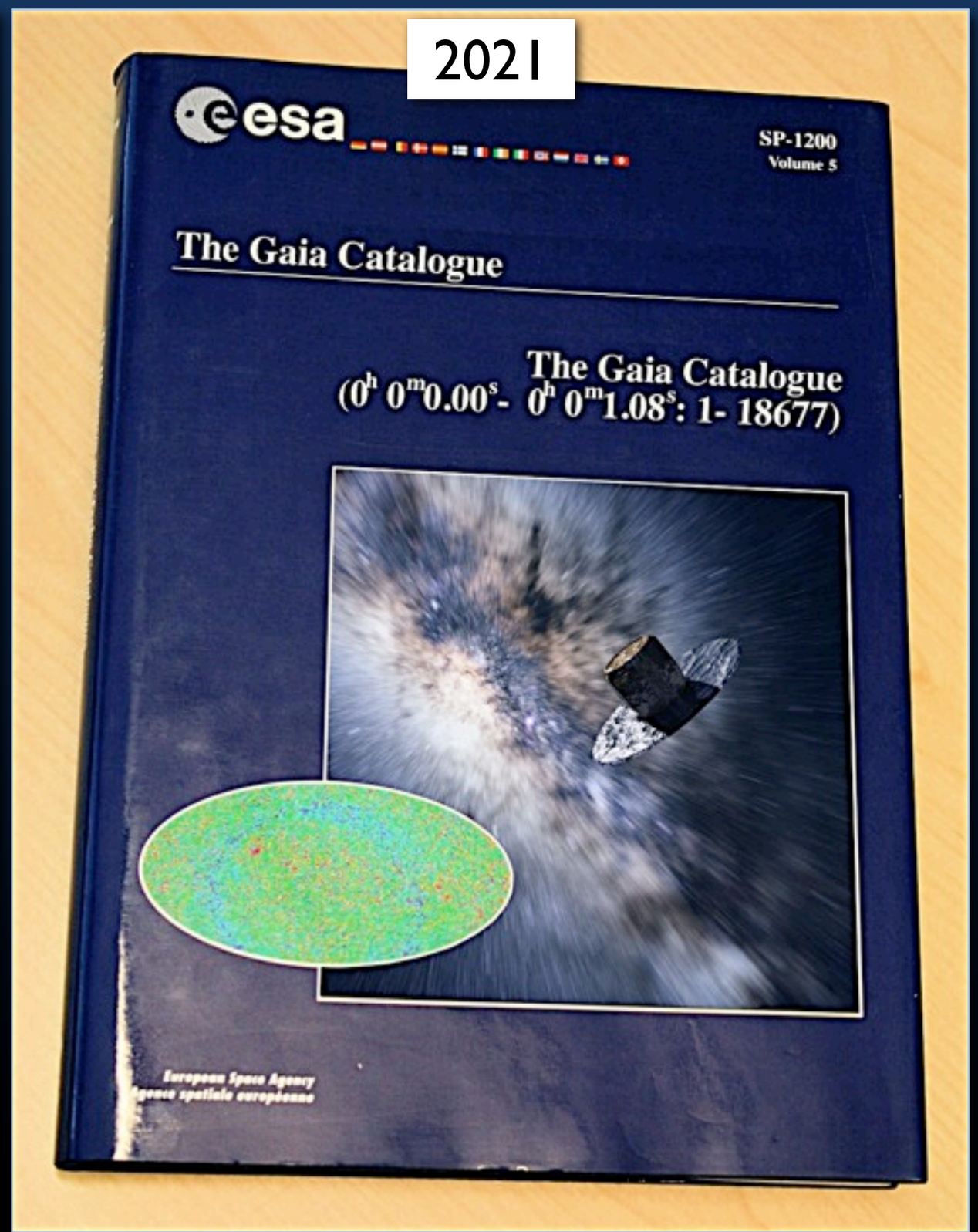


2021



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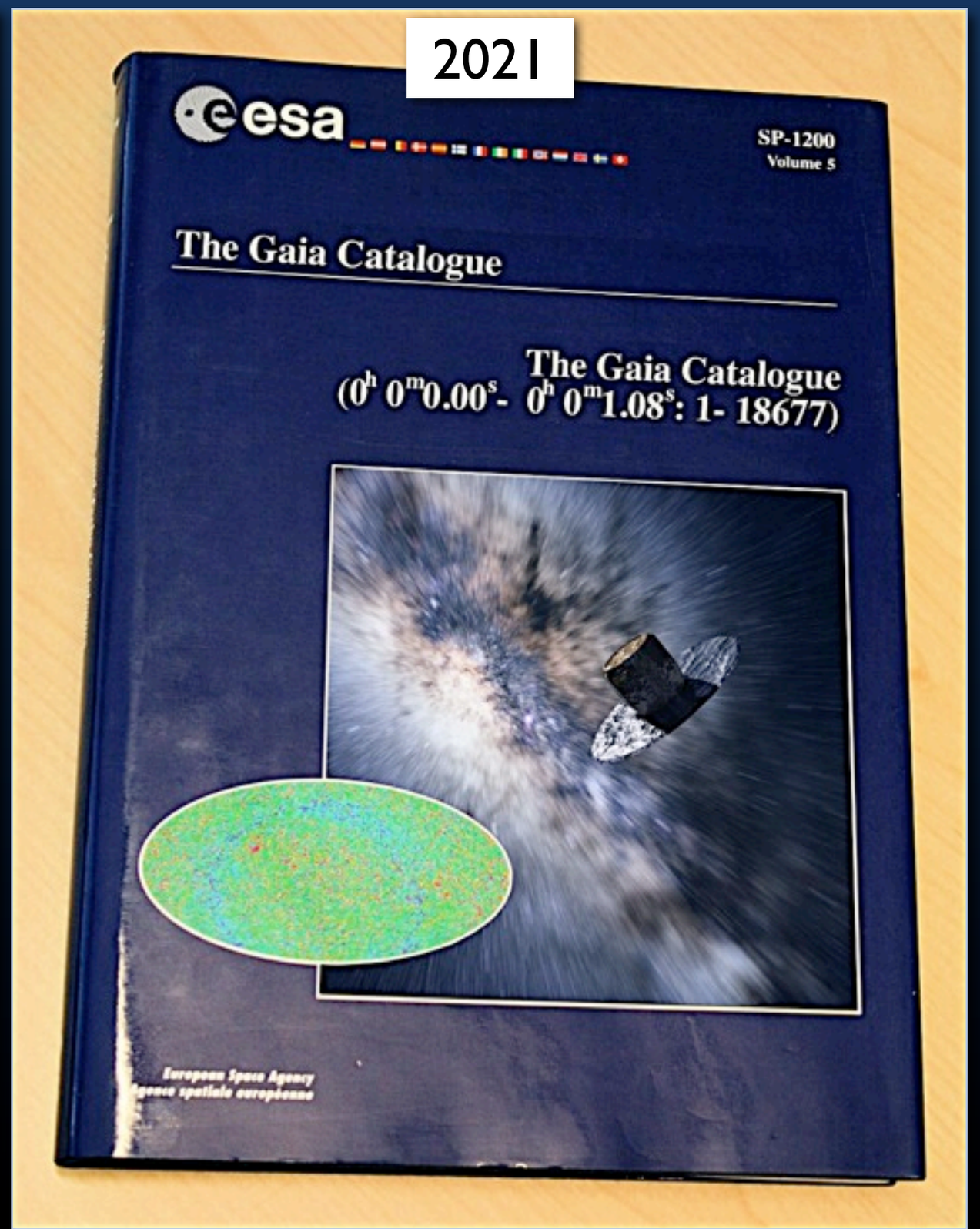

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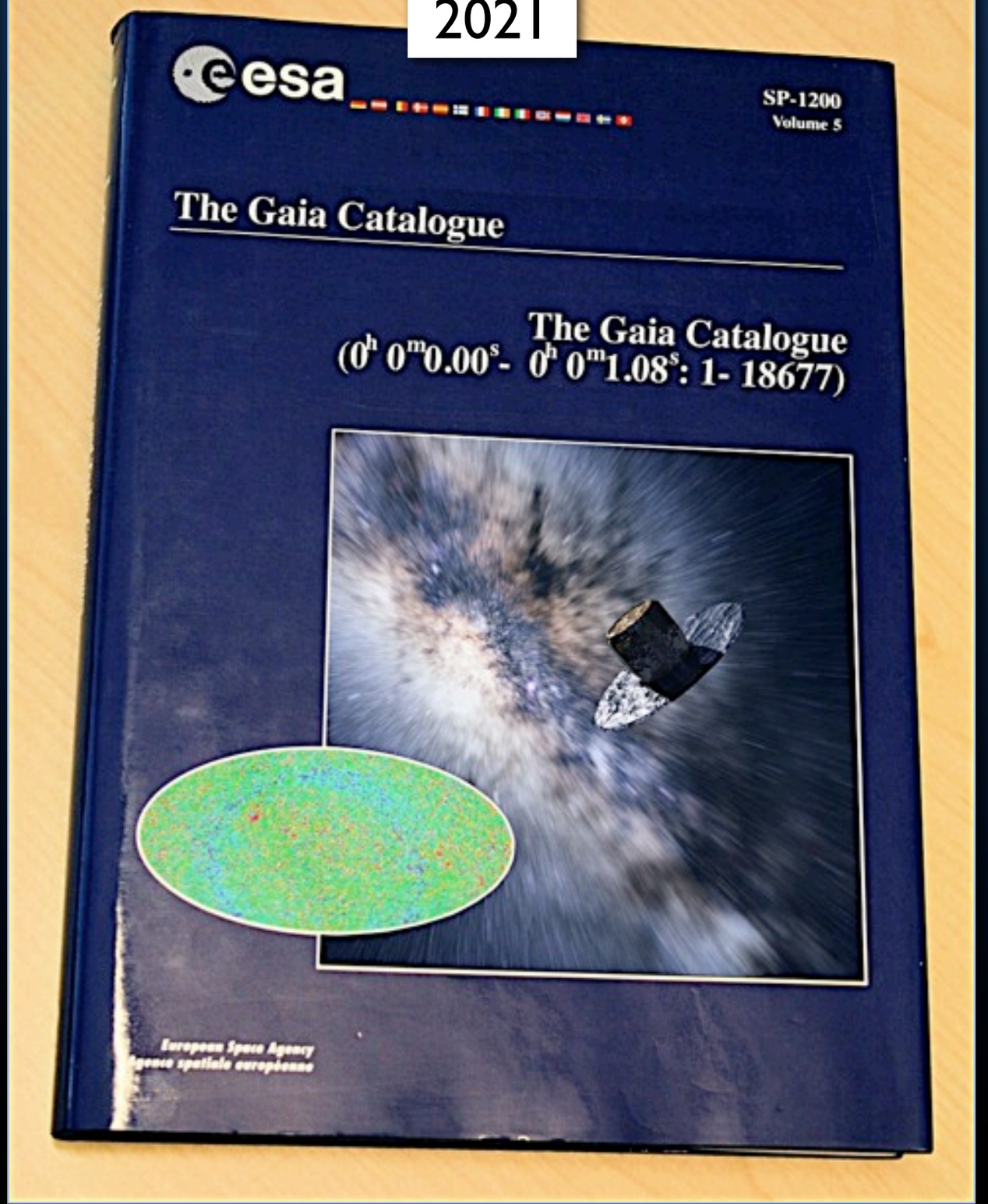
Hipparcos vs Gaia catalogue

1997

Hipparcos books
in my office

2021



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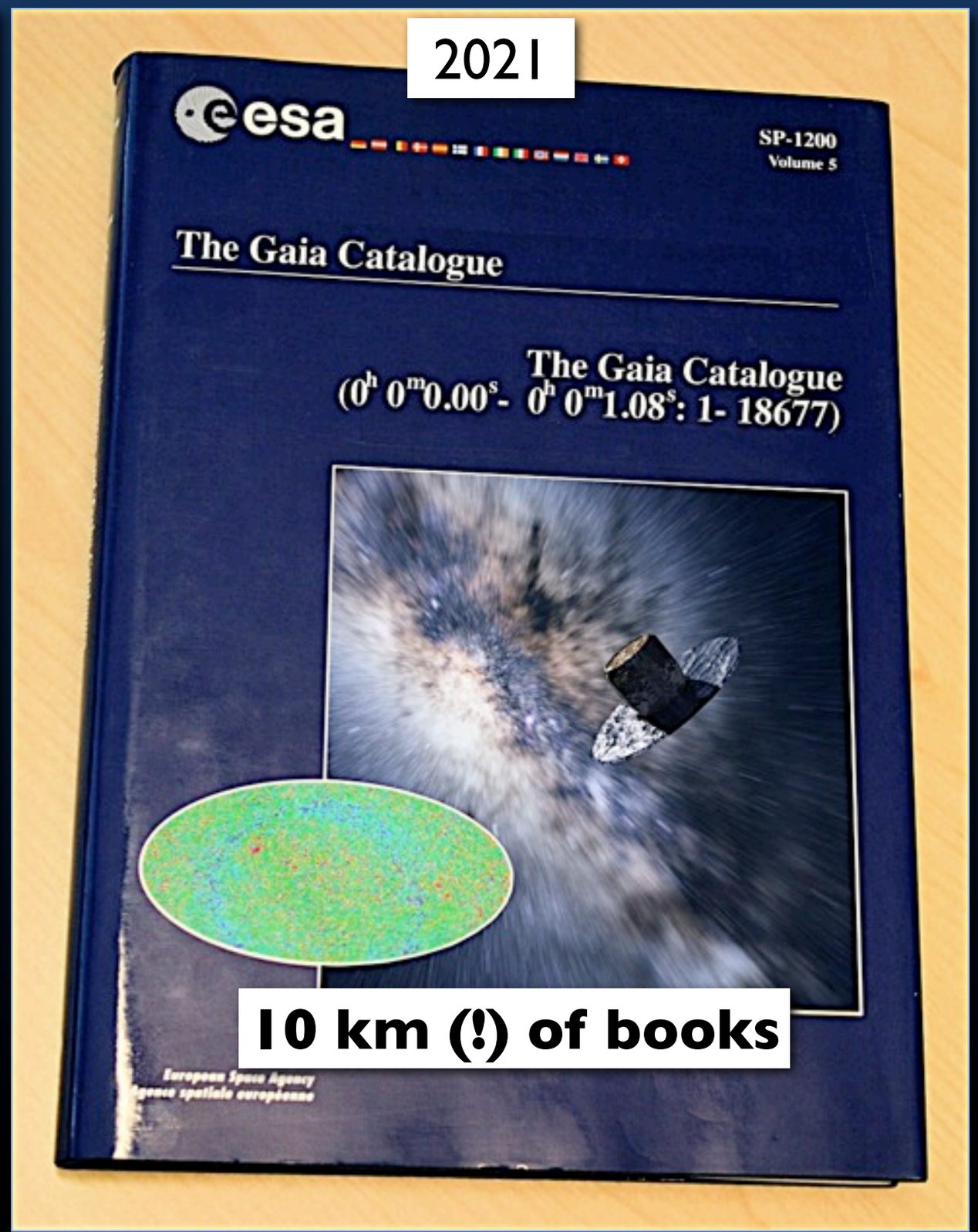

10 km (!) of books

Courtesy: B.Holl

Astrometry

- Time resolved Position

  - parallaxes

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  - proper motion

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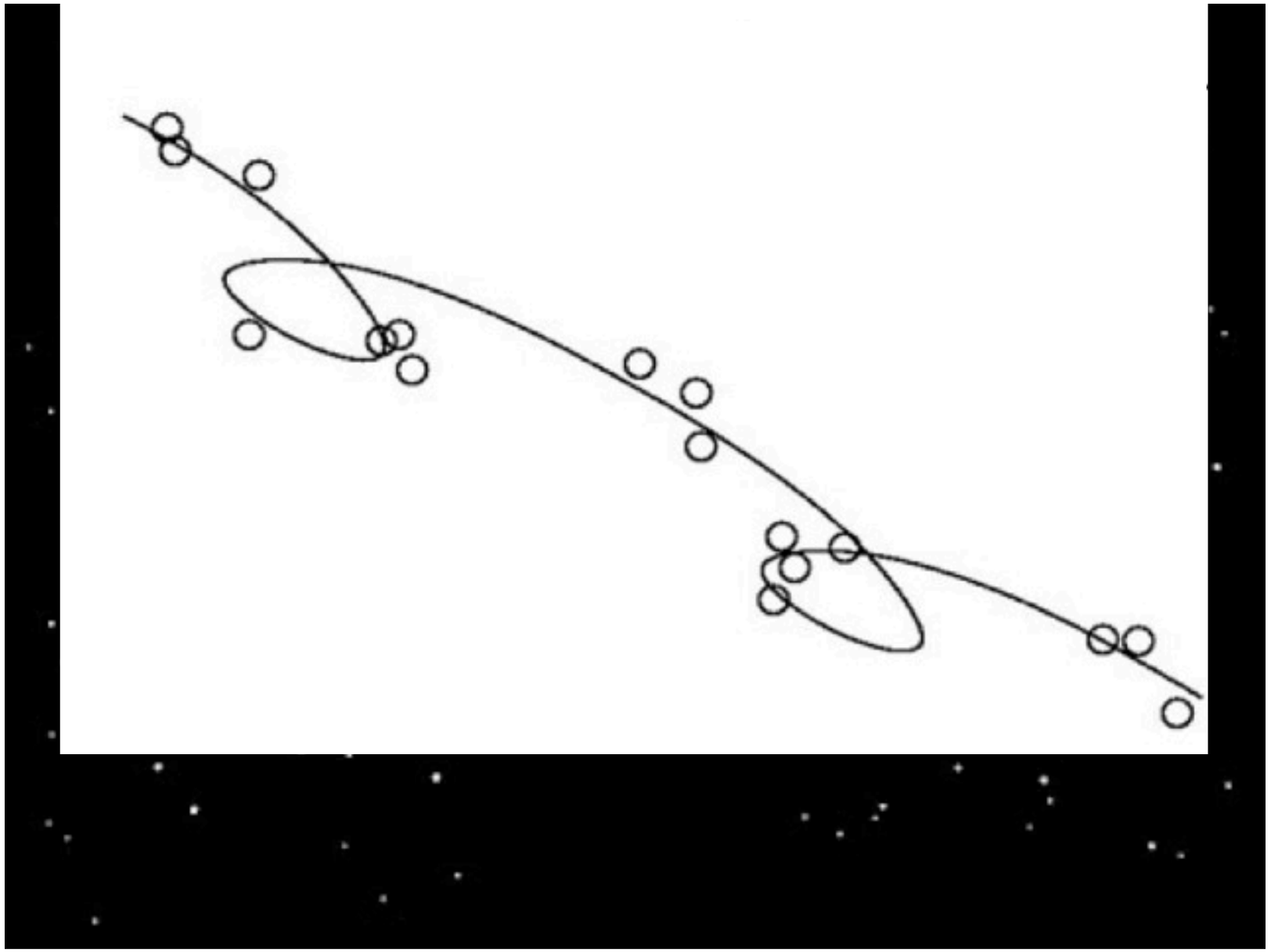


Astrometry

- Time resolved Position

  - parallaxes

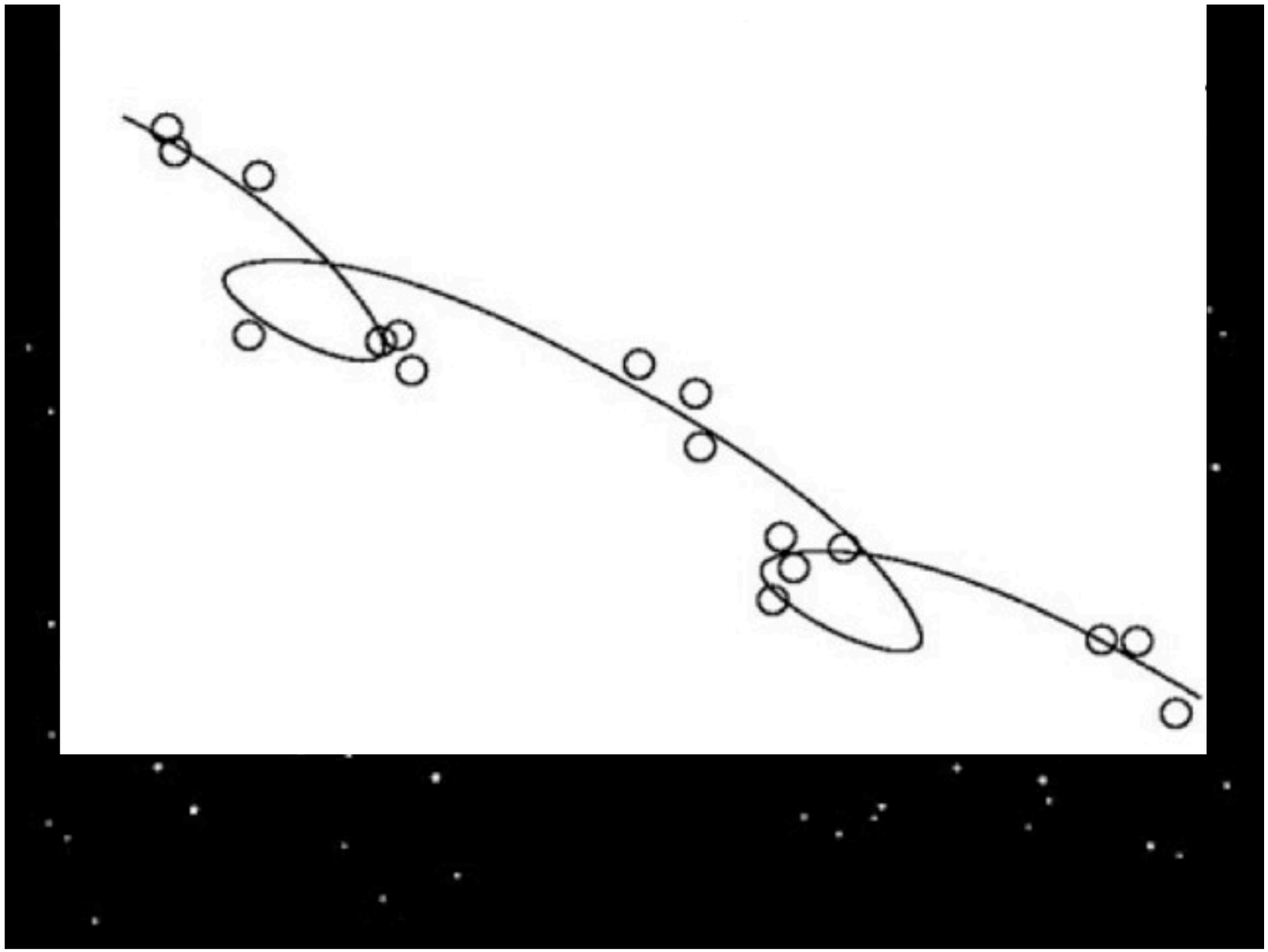
  - proper motion

- Problems

  - Fixed reference?

  - streaming motion

  - residual parallax



Principle of Gaia on astrometry

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Comparison of angles between stars

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Produce a map by triangulation

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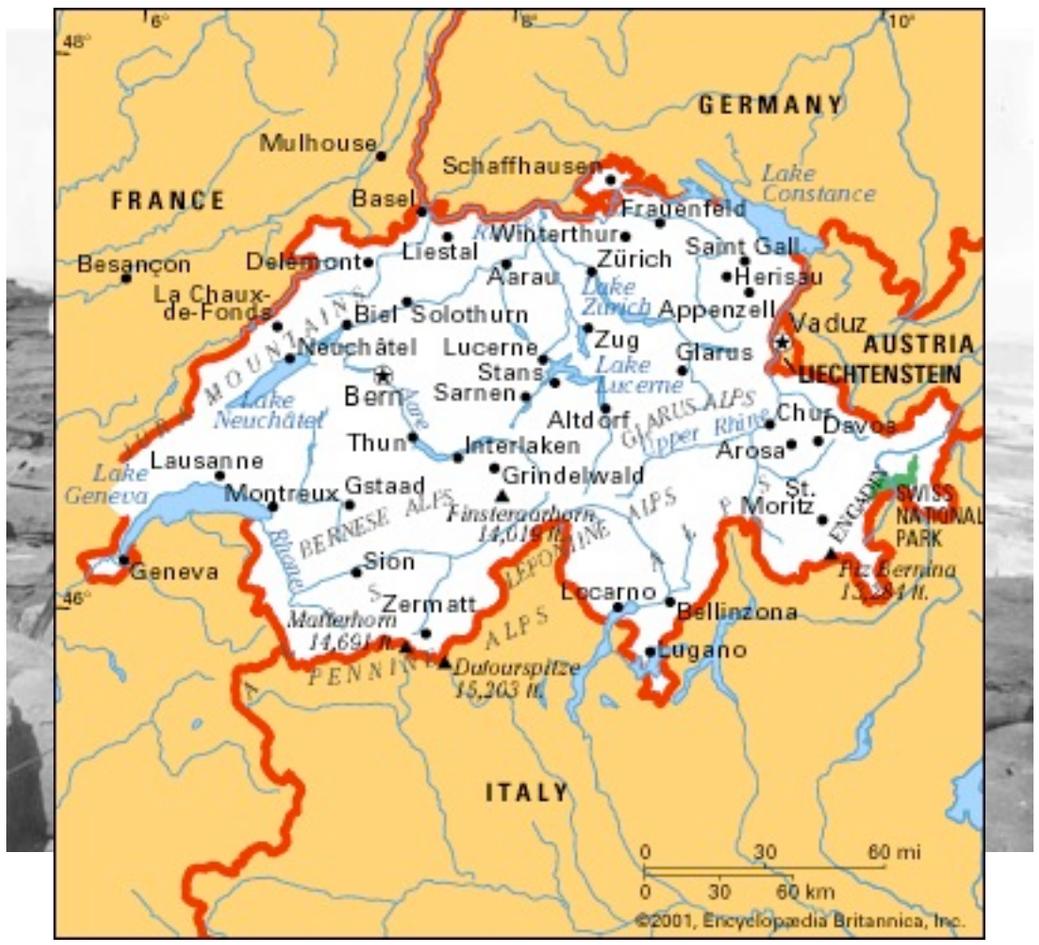

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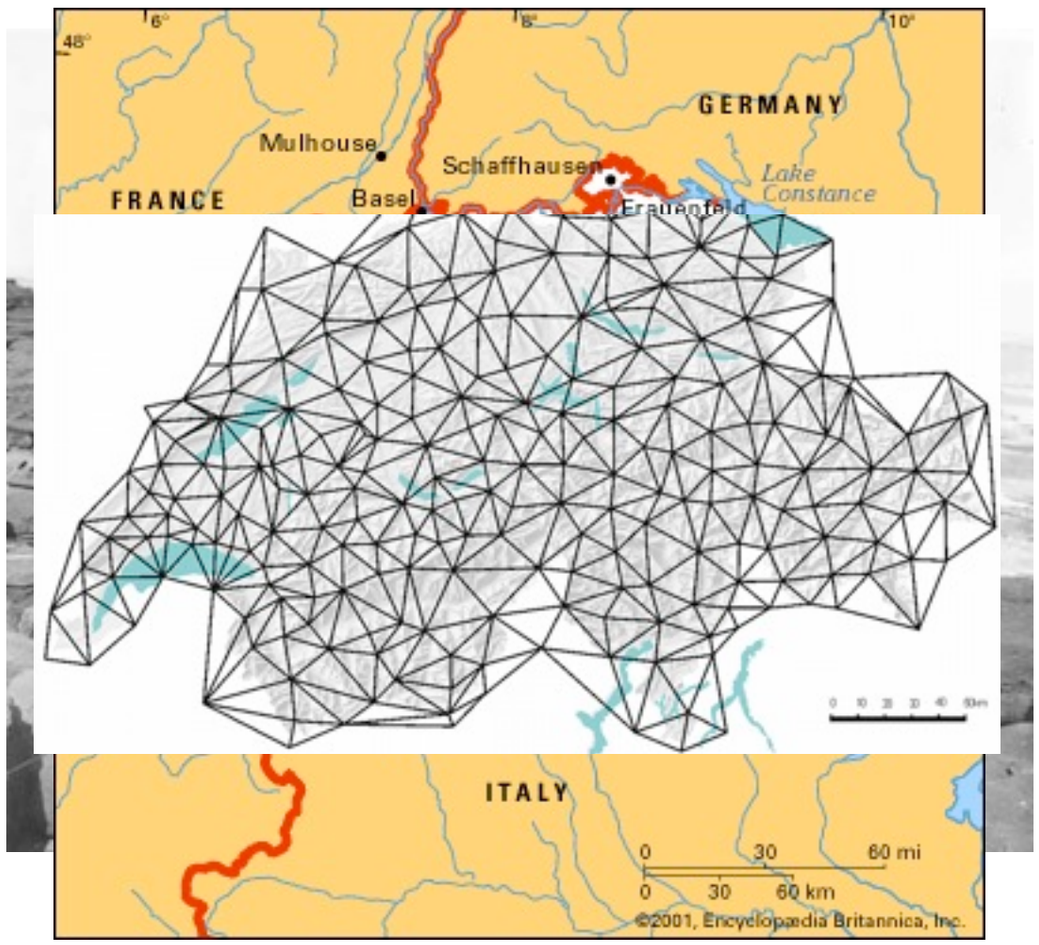
Comparison of angles between stars

Produce a map by triangulation



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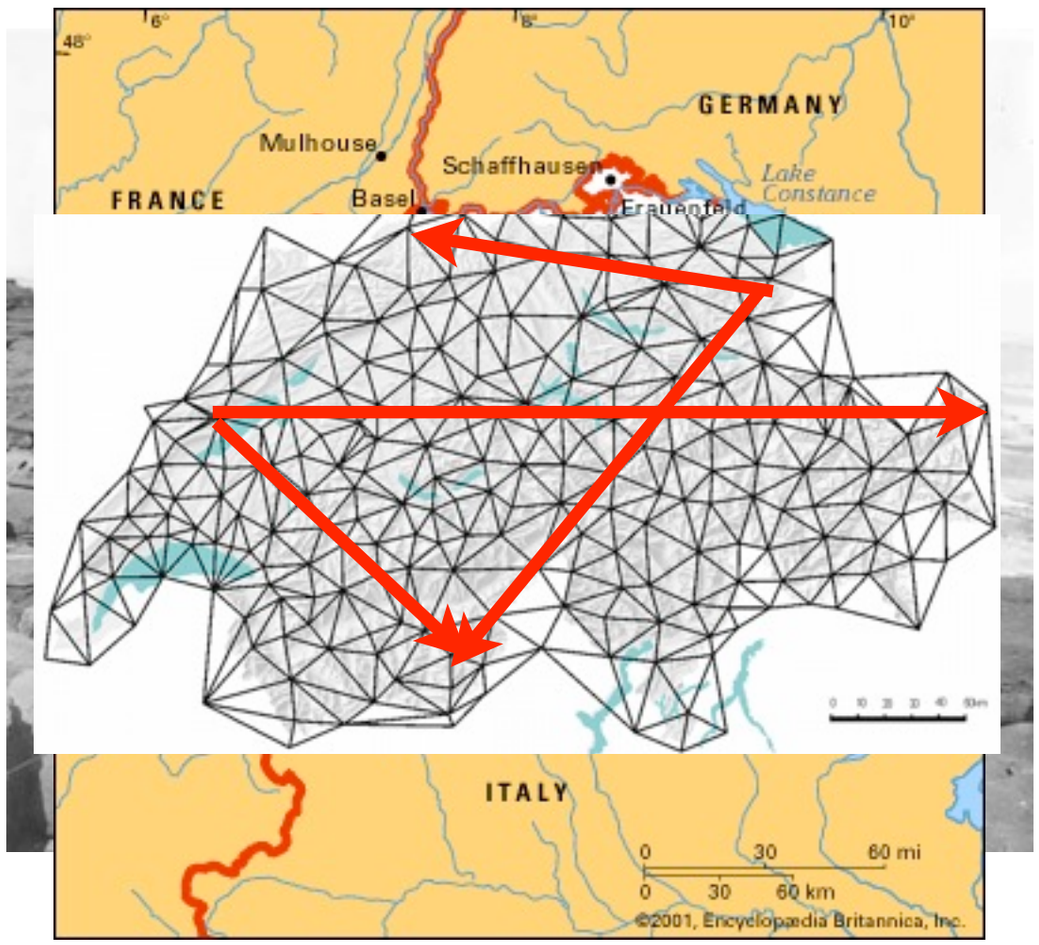
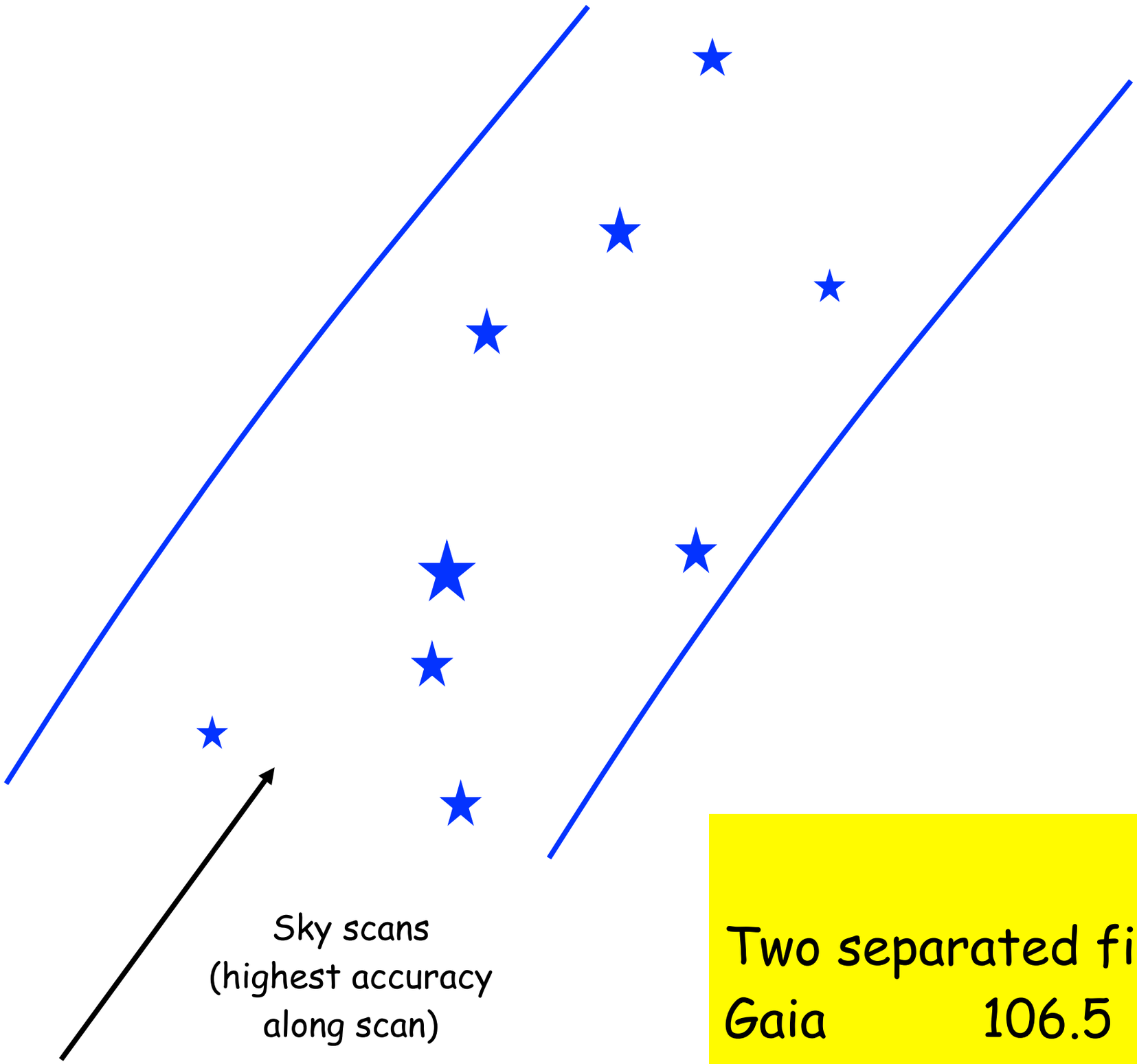


Principle of Hipparcos- Gaia for global astrometry

Two separated field of views
Gaia 106.5 degree

Figure courtesy Michael Perryman

Principle of Hipparcos- Gaia for global astrometry



Sky scans
(highest accuracy
along scan)

Figure courtesy Michael Perryman

Two separated field of views
Gaia 106.5 degree

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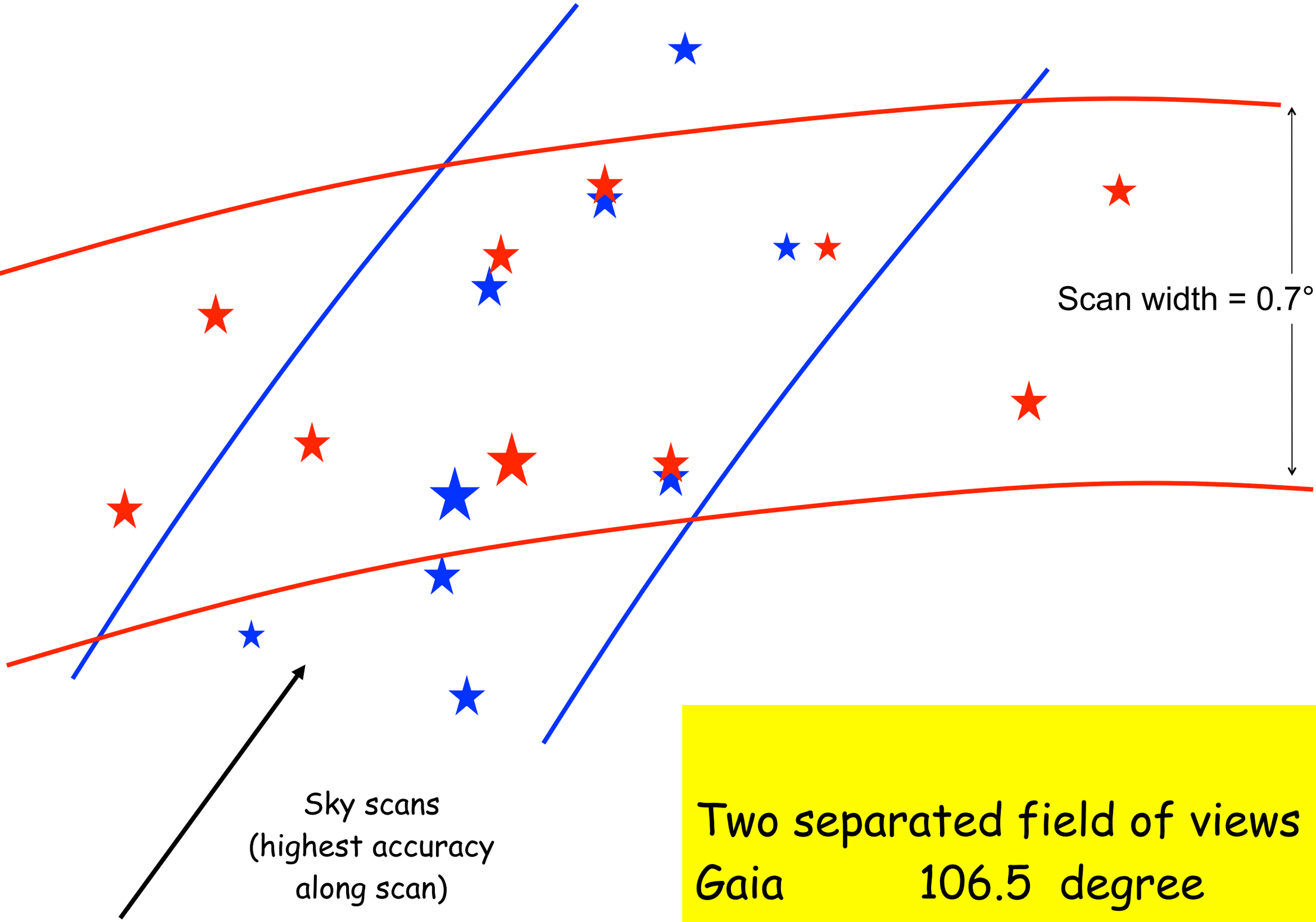

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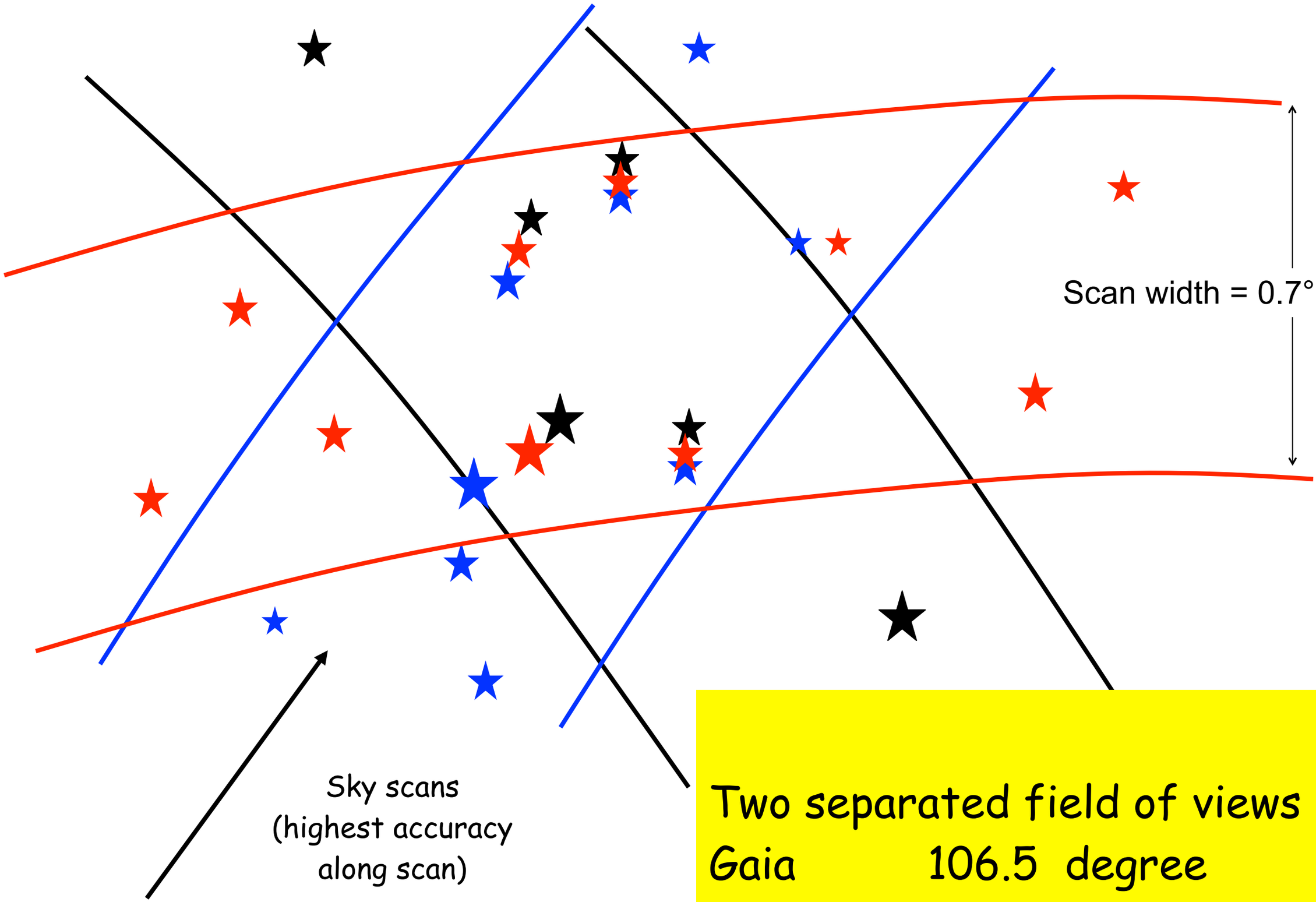

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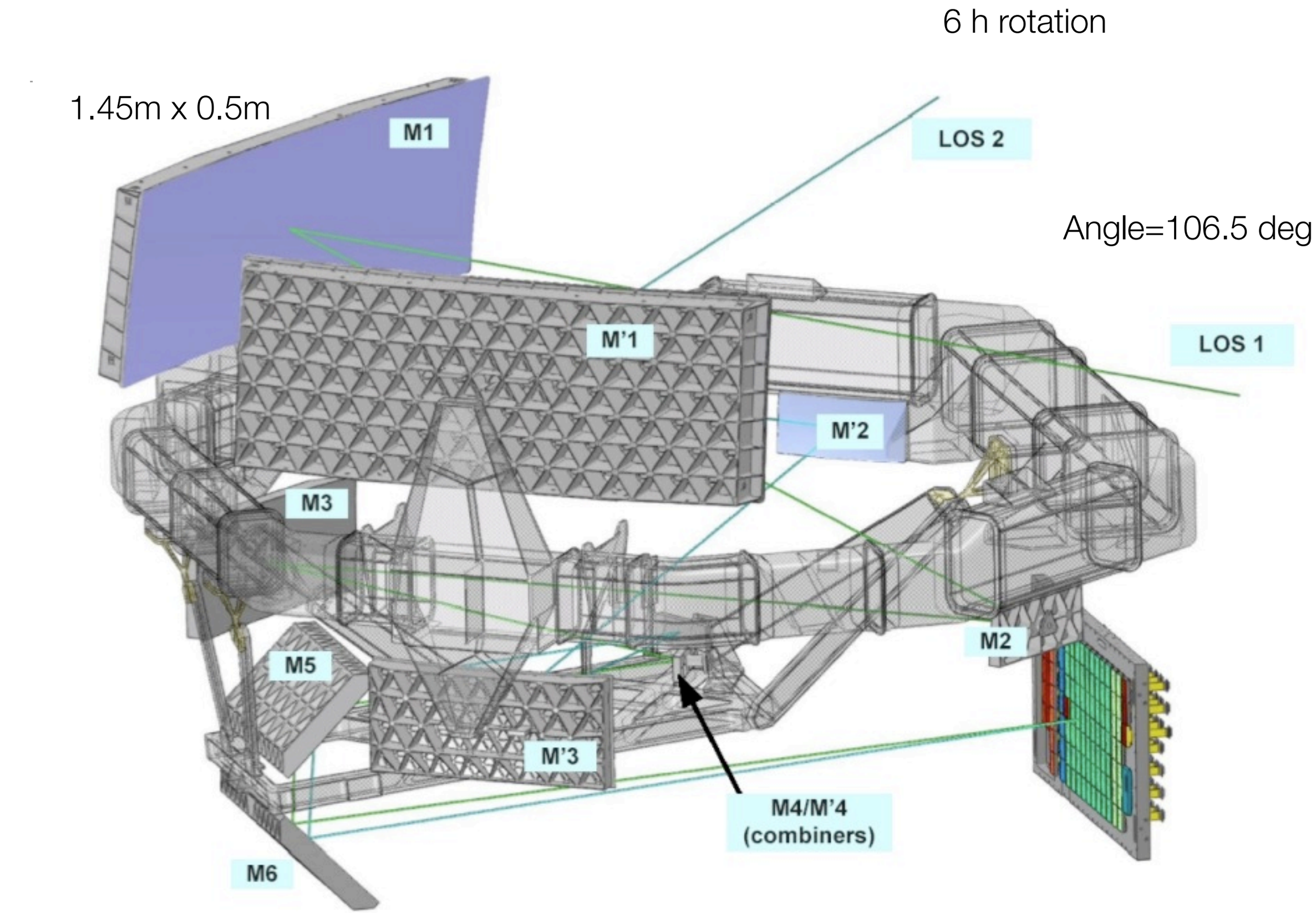
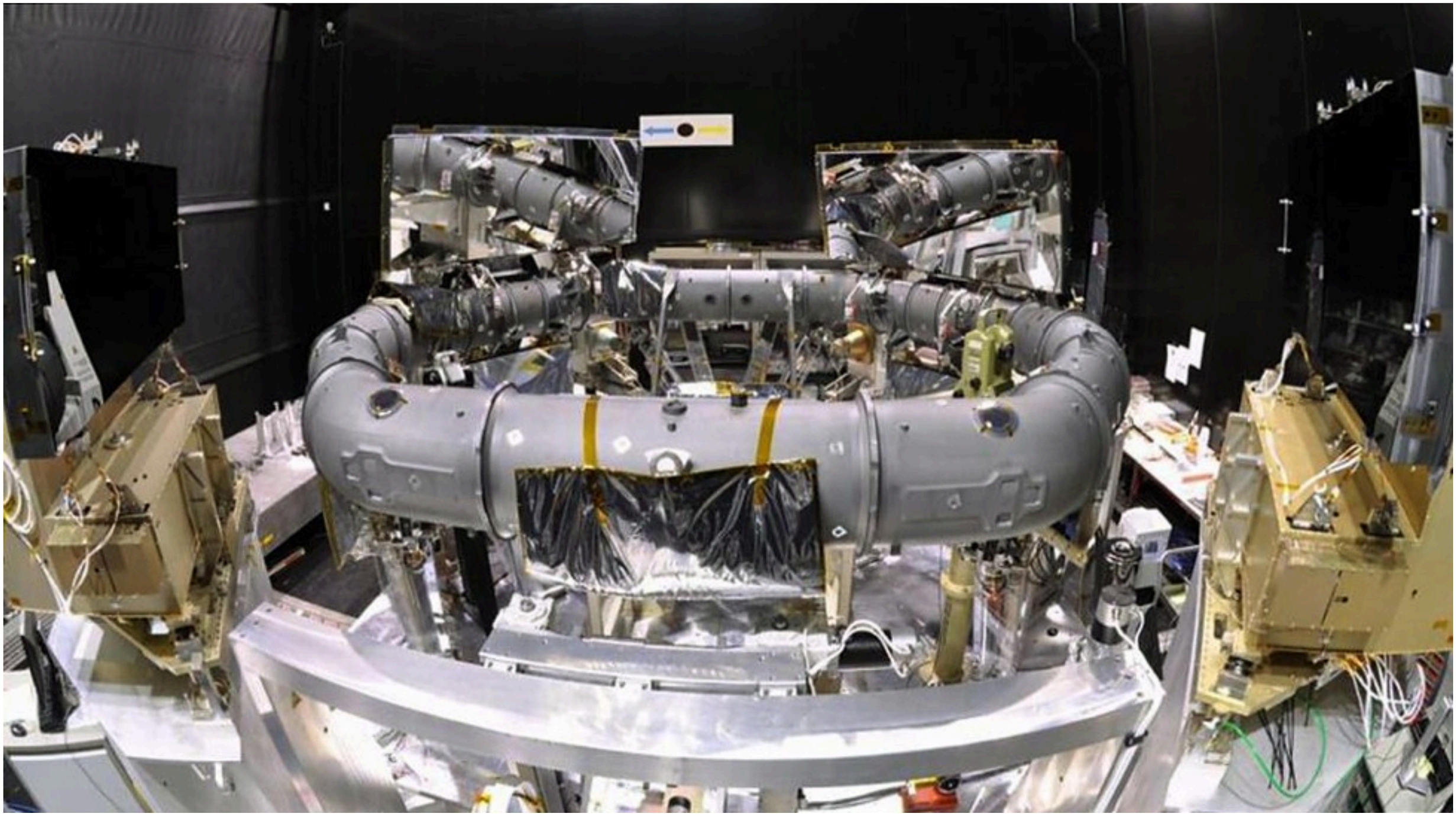
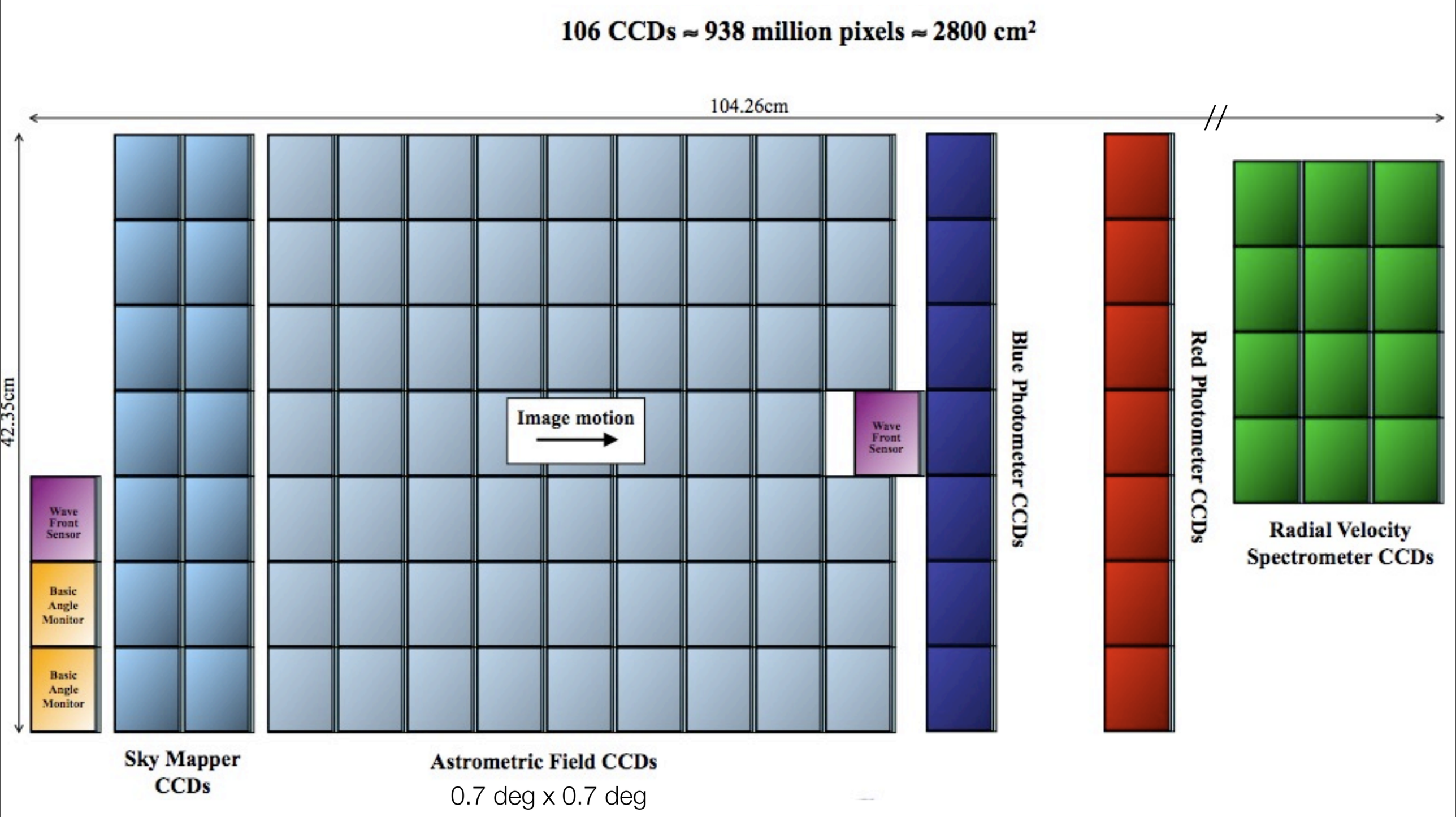
Instrument involved



Torus and mirrors



Gaia Focal Plane



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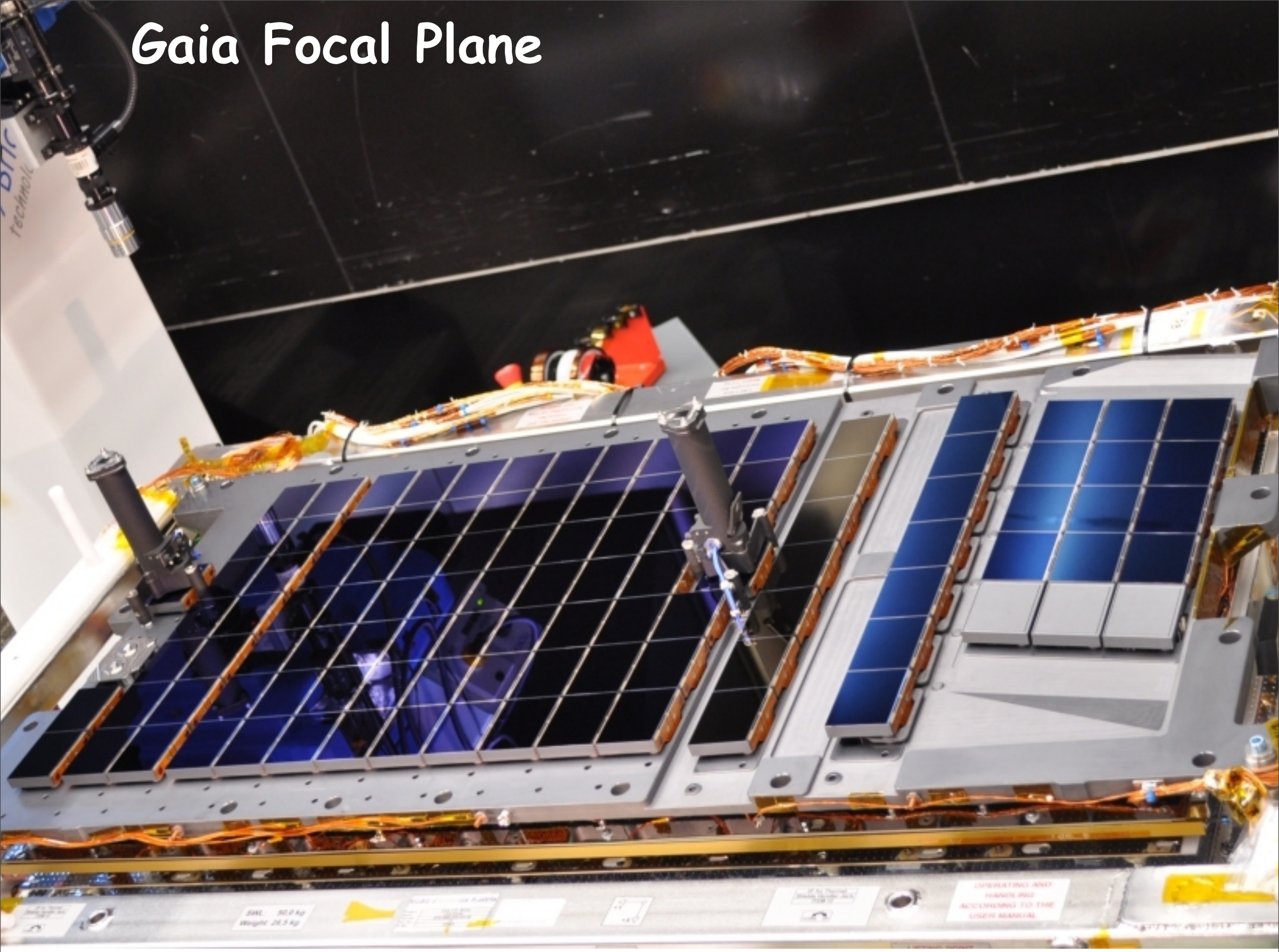
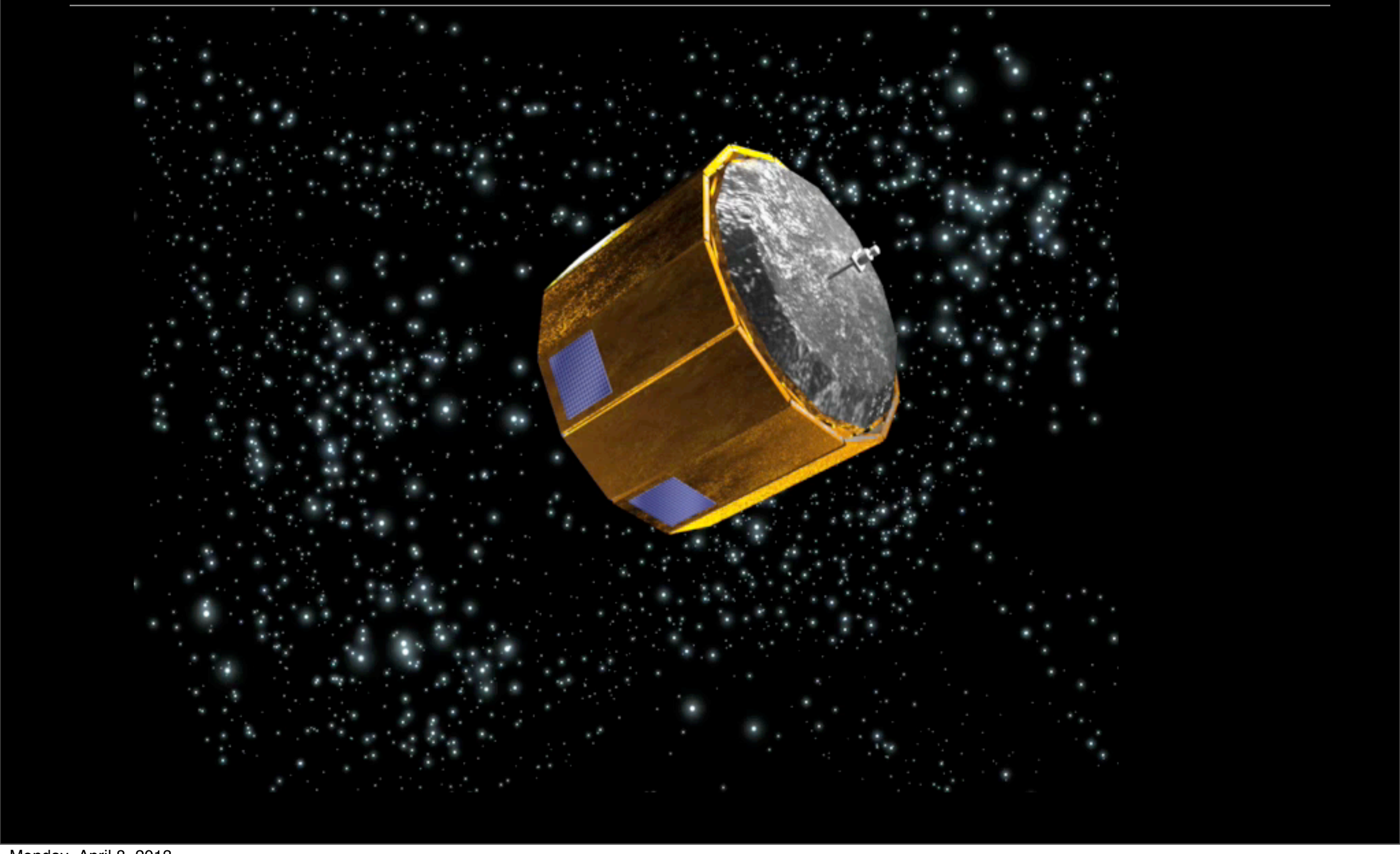
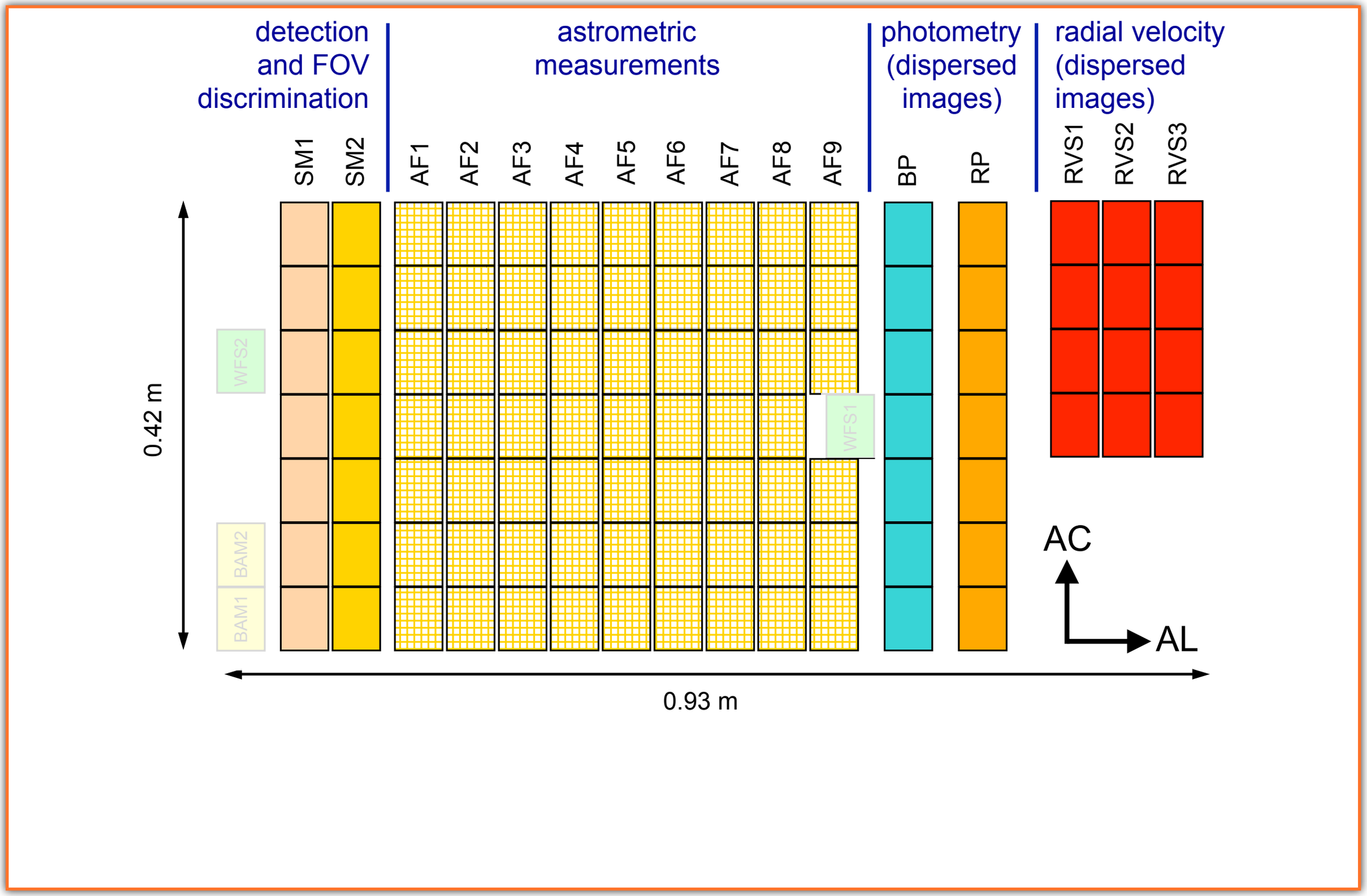


The Gaia mission: its rotation period of 6 hours



Transit observation



Courtesy: Berry Holl

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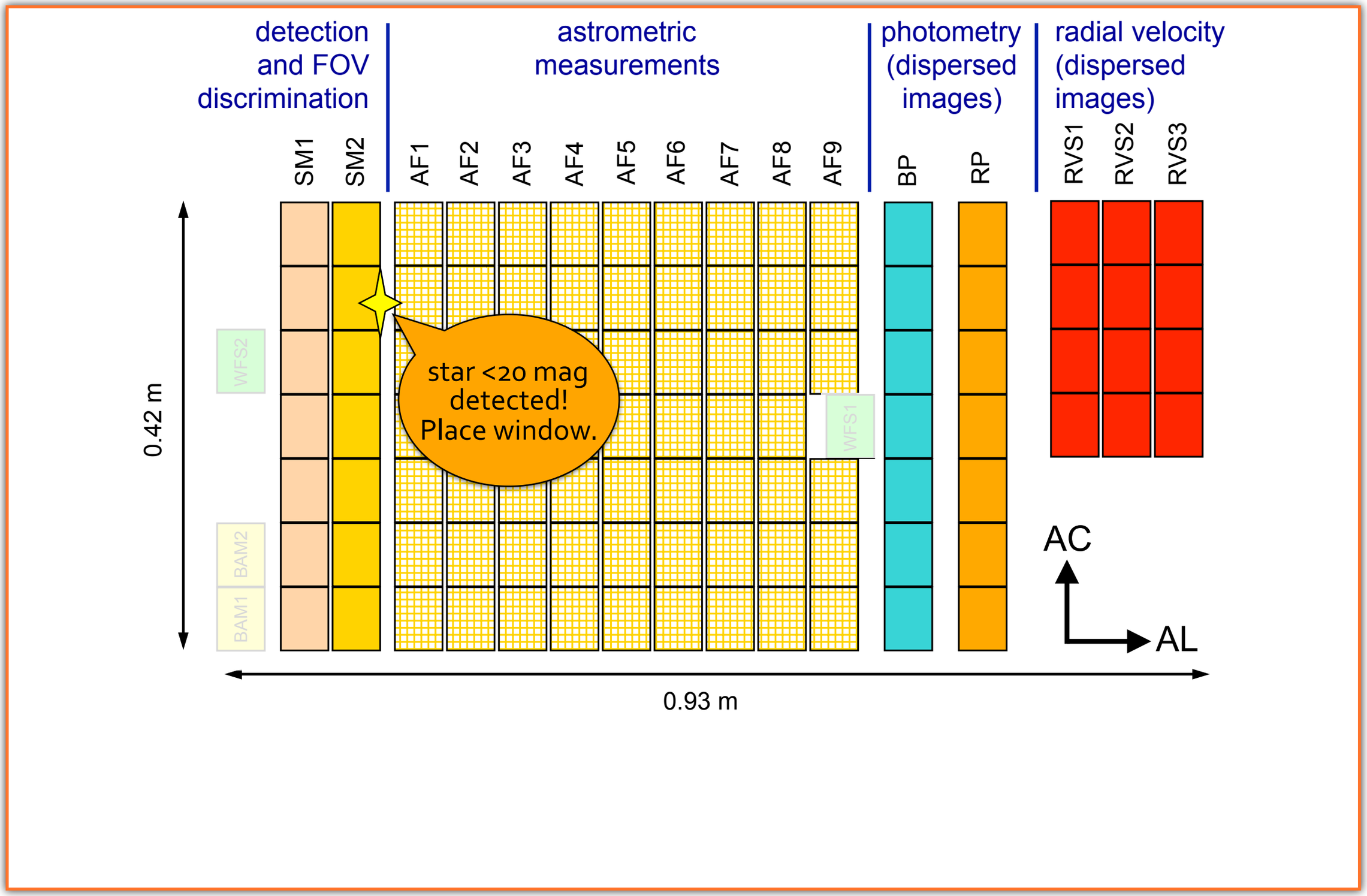

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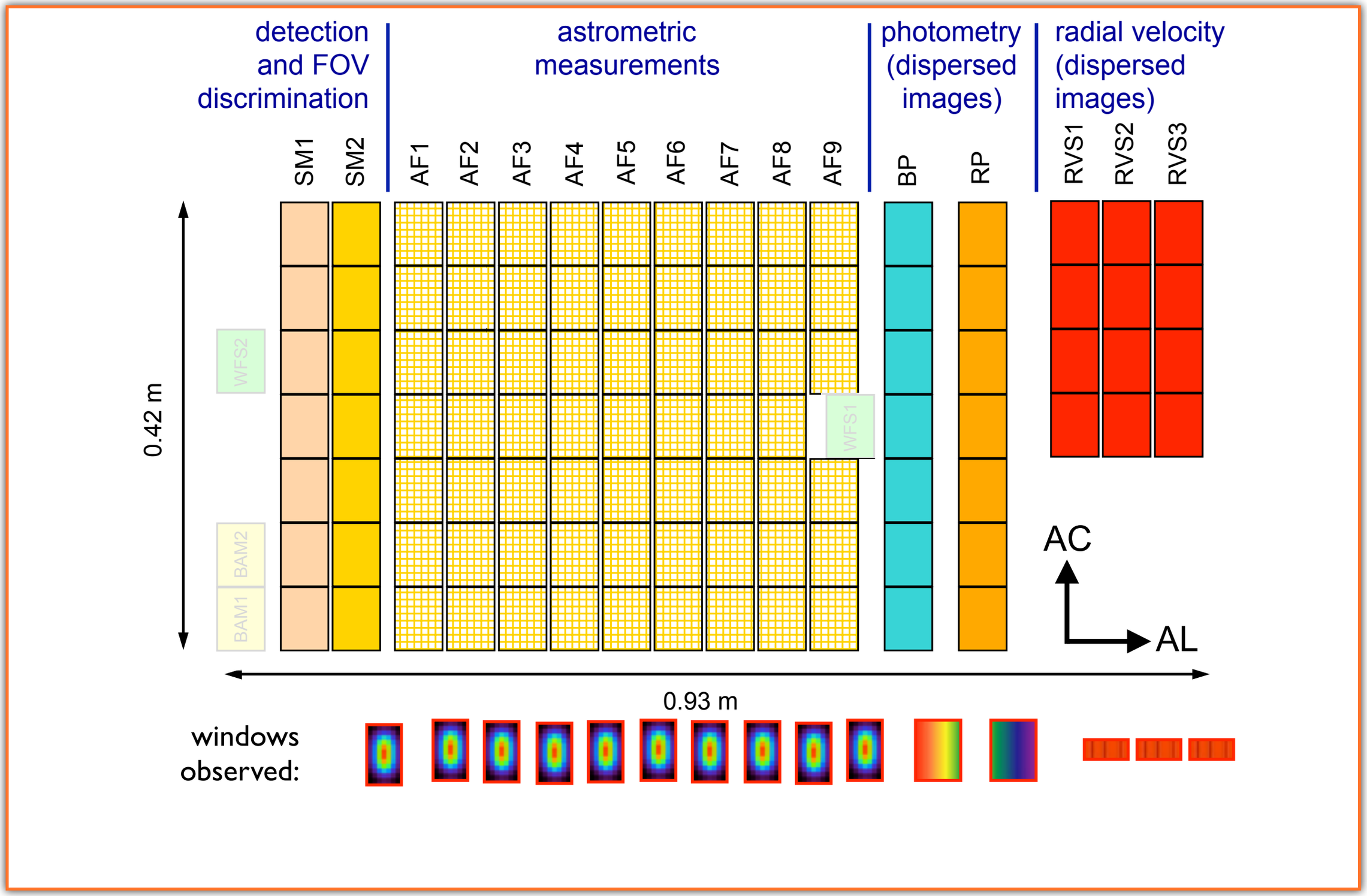

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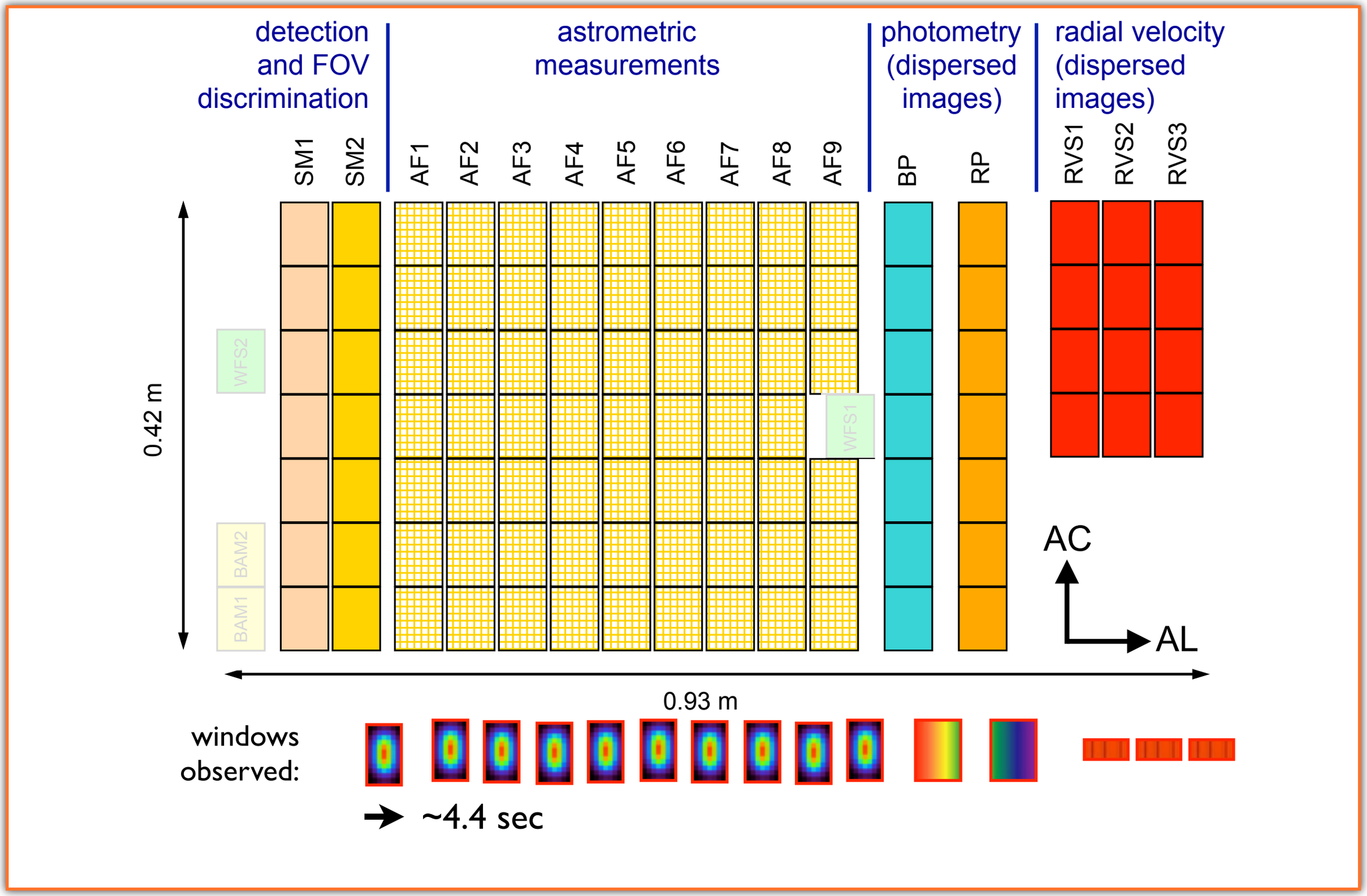

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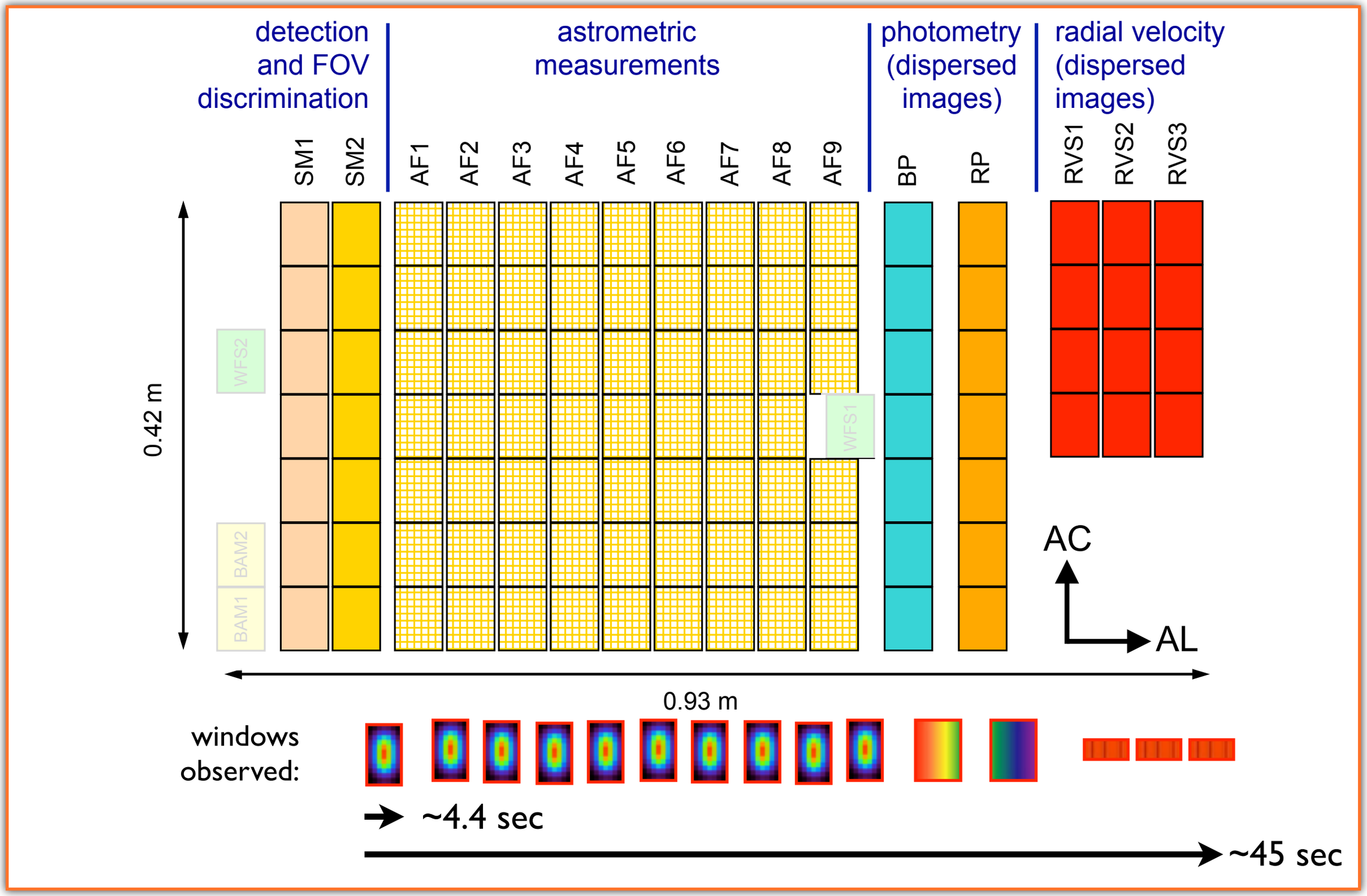
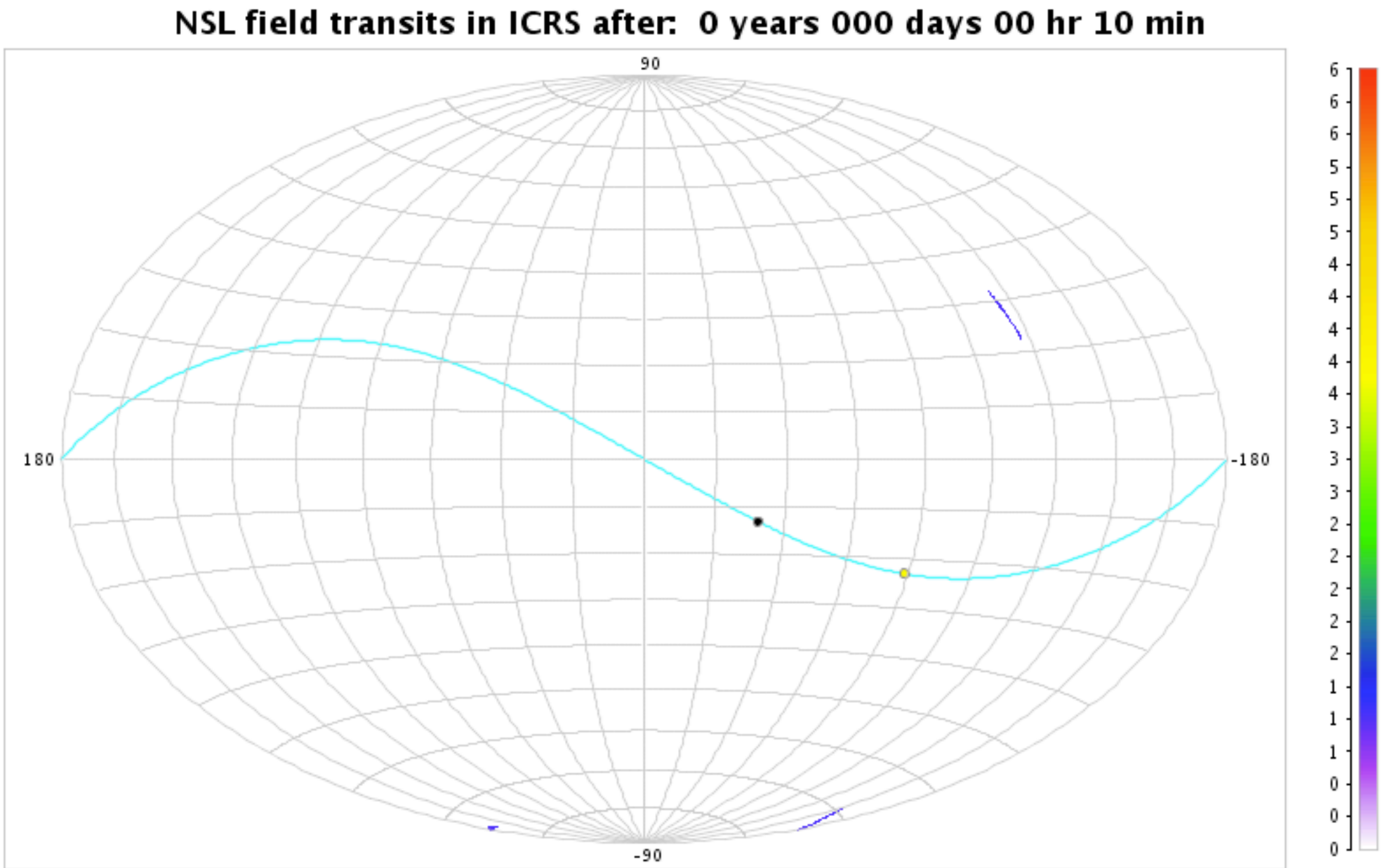


Courtesy: Berry Holl

The Gaia scanning law



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

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Mean parallax error end of mission

	B1V	G2V	M6V
V-I_C [mag]	-0.22	0.75	3.85
Bright stars	5-14 μas (6 mag < V < 12 mag)	5-14 μas (6 mag < V < 12 mag)	5-14 μas (8 mag < V < 14 mag)
V = 15 mag	26 μas	24 μas	9 μas
V = 20 mag	330 μas	290 μas	100 μas

Position error (μas): ... x ~0.7

Proper motion error (μas/year): ... x ~0.5

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

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

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

Parallax horizon for G0V stars

10 kpc

A_V = 0

A_V = 5 mag

20%

1

2

5

10

20%

Figure courtesy Lennart Lindegren

Parallax horizon for K5III stars

20%

10

$A_V = 0$

$A_V = 5$ mag

10 kpc

1

2

5

10

20%

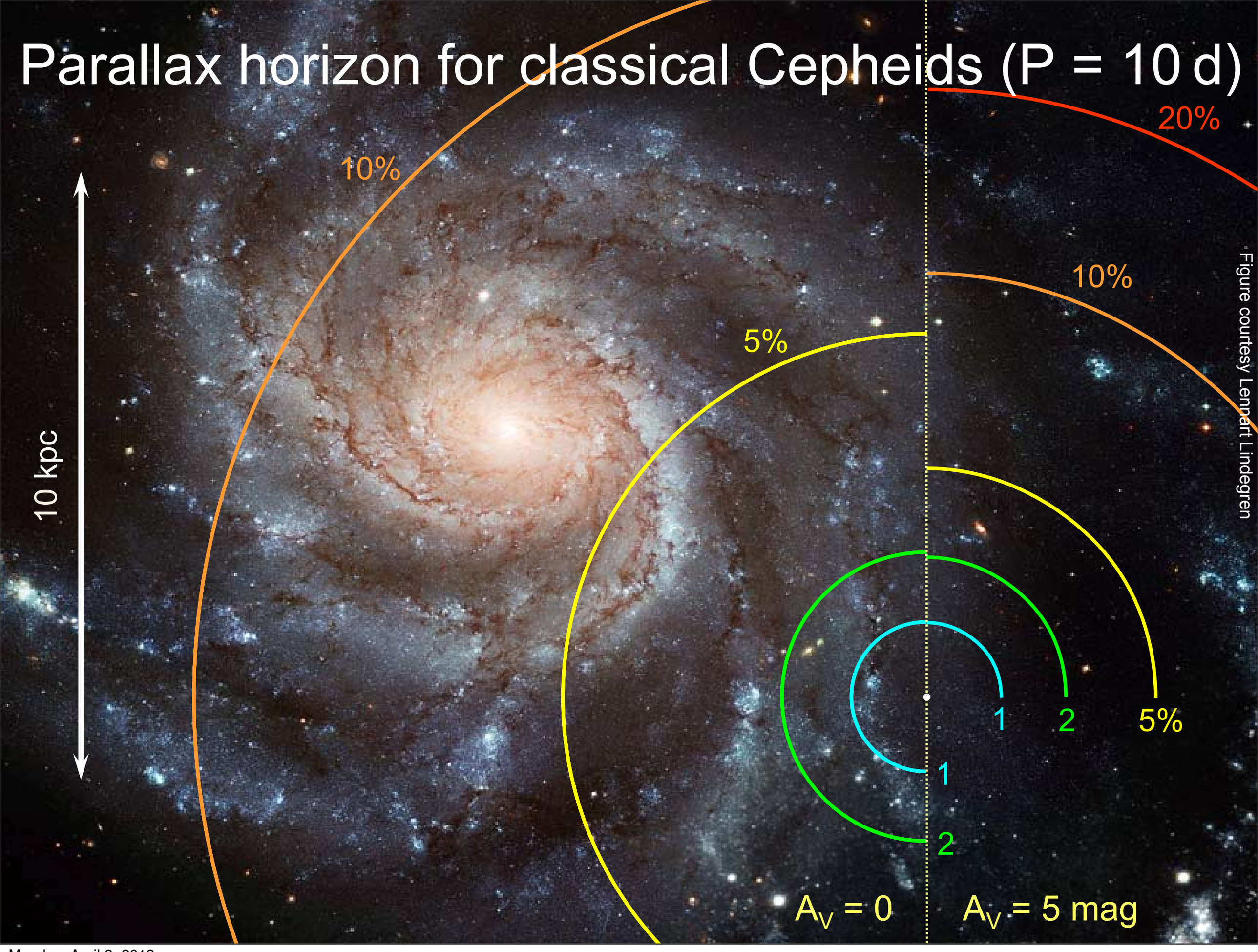
1

2

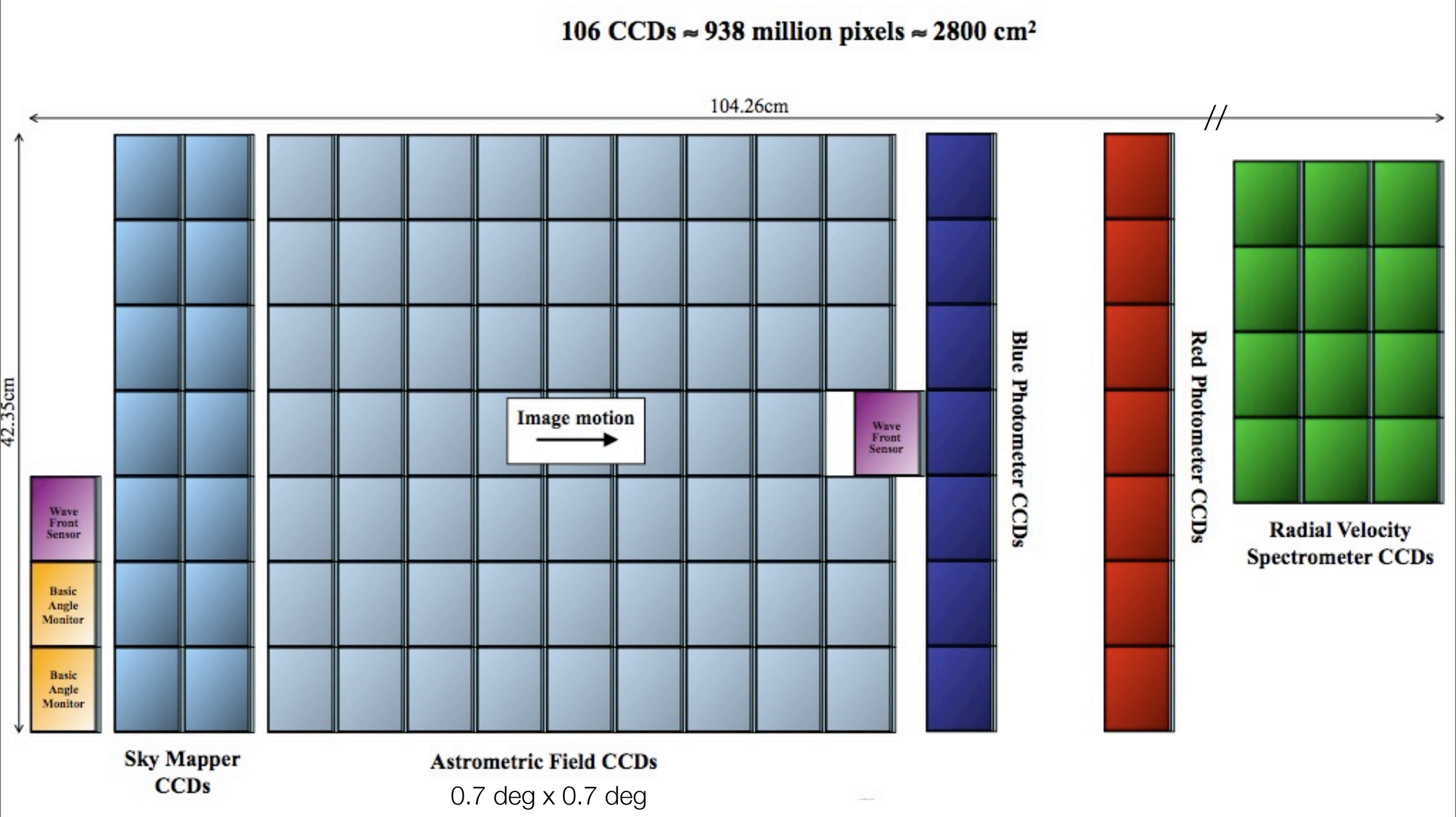
5

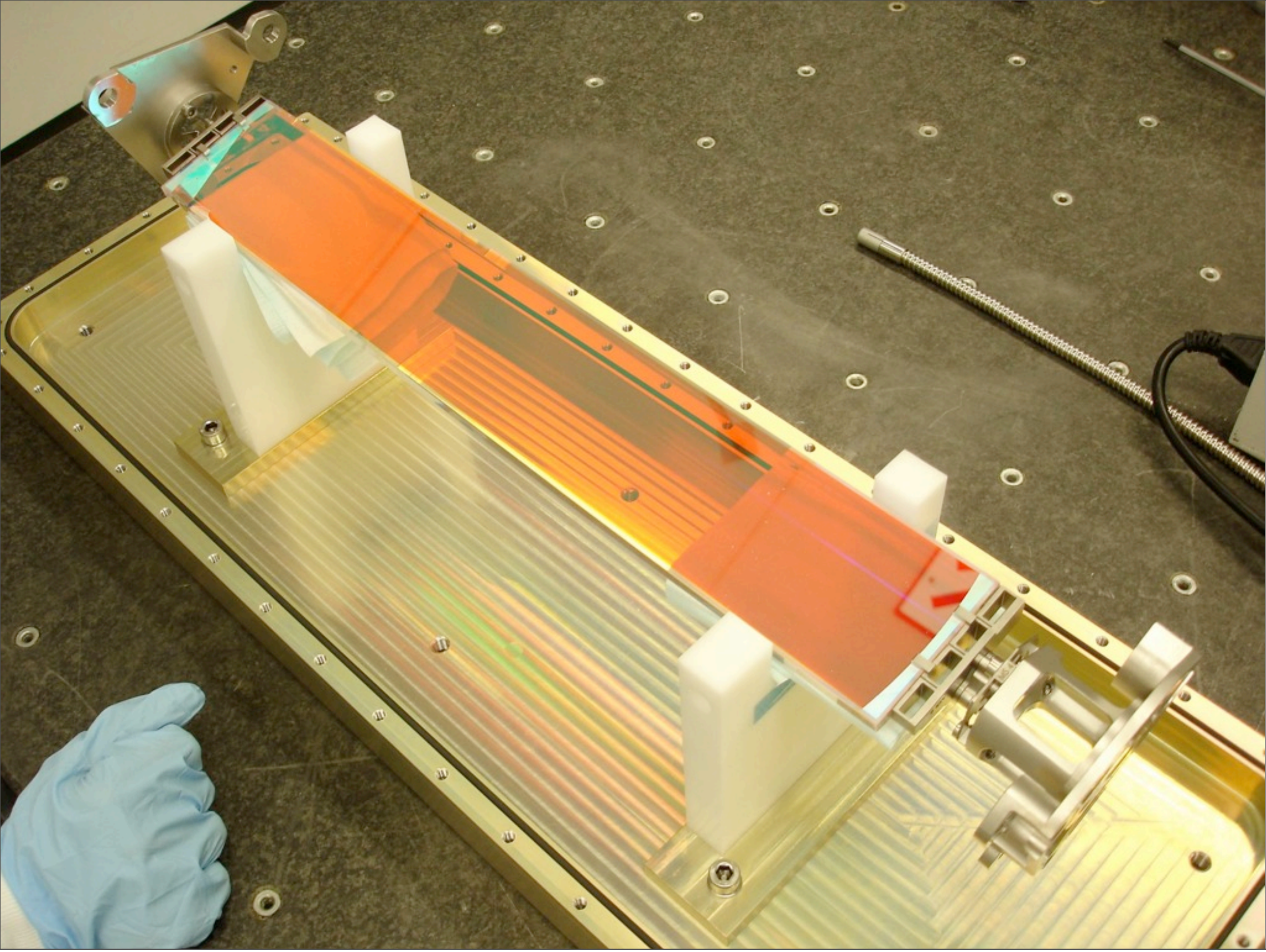
Figure courtesy Lennart Lindegren

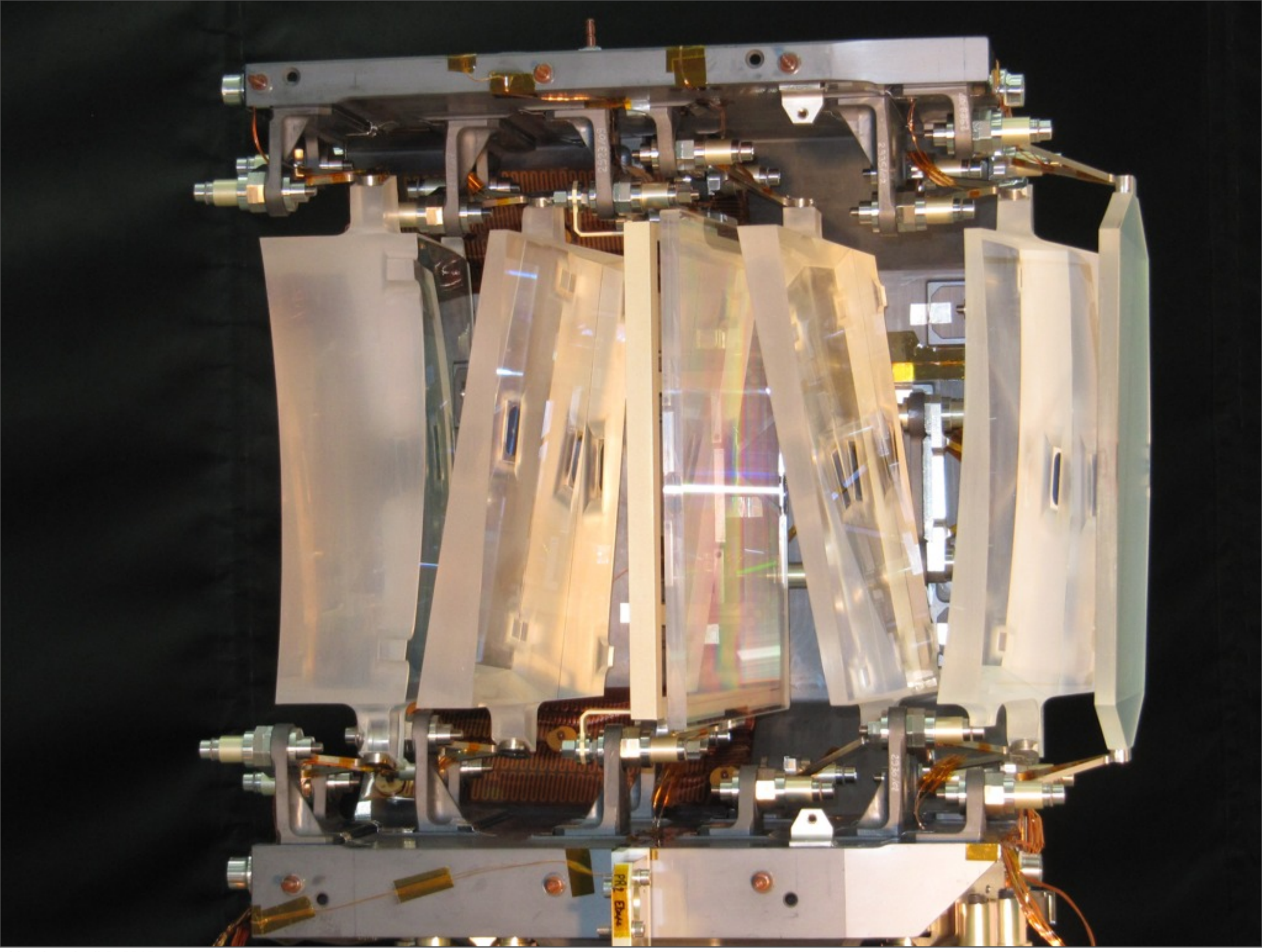
Parallax horizon for classical Cepheids (P = 10 d)



Gaia Focal Plane







Gaia photometric / spectro-photometric / radial velocity performances (end of mission)

Photometry

G ~ 330 - 1050 nm

Spectro-photometry

BP ~ 330 - 680 nm 60 samples

RP ~ 640 - 1050 nm 60 samples

	B1V			G2V			M6V		
G [mag]	**G**	**BP**	**RP**	**G**	**BP**	**RP**	**G**	**BP**	**RP**
6 - 13	1	4	4	1	4	4	1	4	4
14	1	4	4	1	4	4	1	5	4
15	1	4	5	1	4	4	1	6	4
16	1	4	5	1	5	5	1	9	4
17	2	5	7	2	5	5	2	20	5
18	2	7	14	2	9	8	2	49	5
19	2	13	34	2	18	18	2	120	8
20	3	29	83	3	43	43	3	301	17

[milli-magnitude]

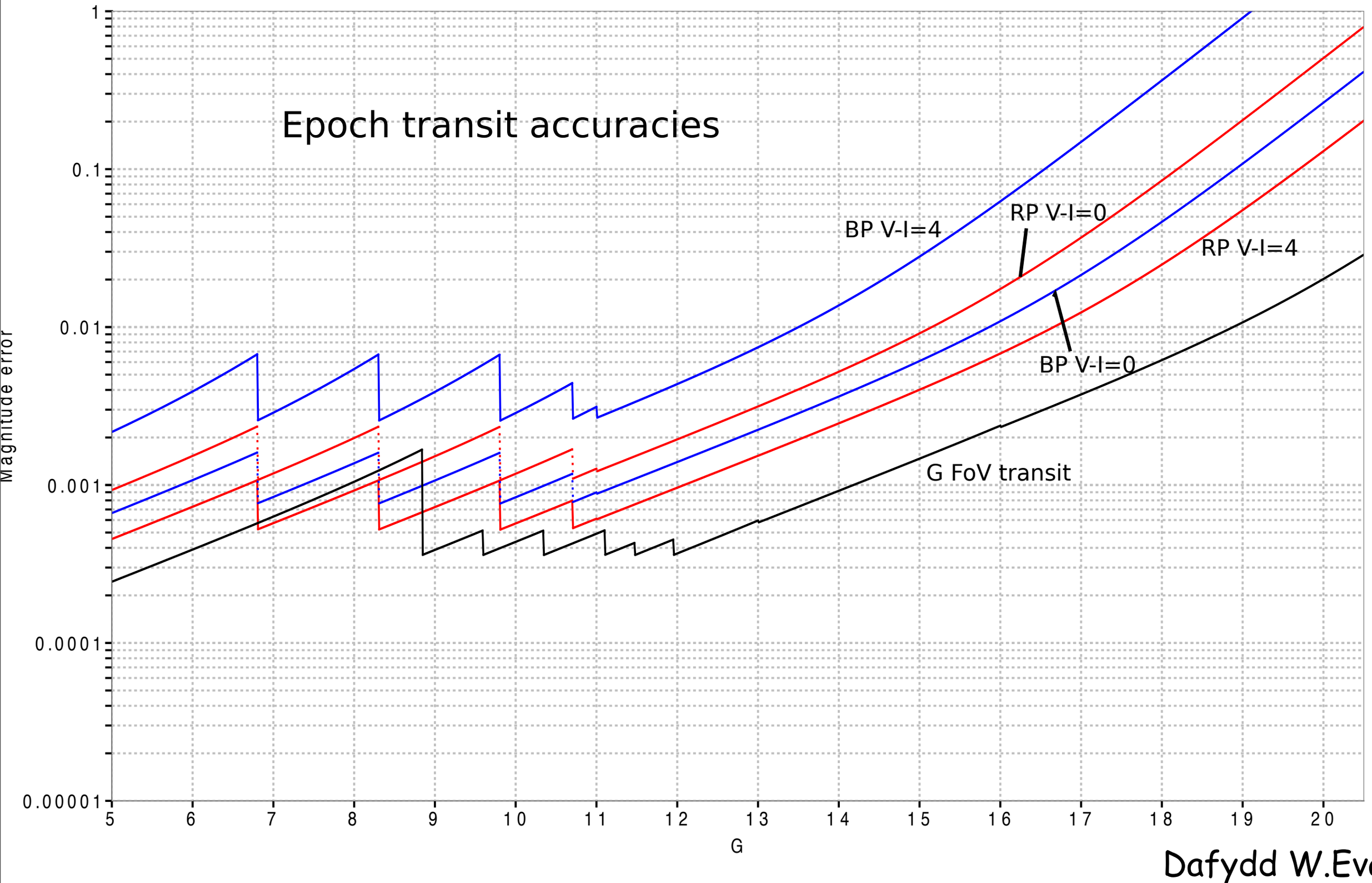
Radial Velocity

RVS ~ 847 - 871 nm

R = 11,500

Spectral type	V [mag]	Radial-velocity error [km s^{-1}]
B1V	7	1
	12	9
G2V	13	1
	16.5	13
K1III-MP (metal-poor)	13.5	1
	17	13

Gaia: Epoch photometric accuracies



Dafydd W.Evans

The Gaia Data Processing:

Ground-based Data Processing is a huge task

Huge data volume:

Raw data : ~100 Terabytes

Final database : ~1 Petabytes

Challenging data transfer:

Data is to be transferred several times between European Centres

Complex data analysis:

Interdependence of measurements (astrometry-photometry-spectra)
Data access: I/O speed
Data organization

Long processing time:

1 sec per object, 1 billion ⟹ 33 years

⟹ distributed processing on a PC farm

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The Data Processing and Analysis Consortium: the global view

Two main concepts:

The Data Processing and Analysis Consortium: the global view

Two main concepts: 1. Coordination Units

CU1
Architecture

CU3
Astrometry

CU2
Simulation

CU4
Objects

CU5
Photometry

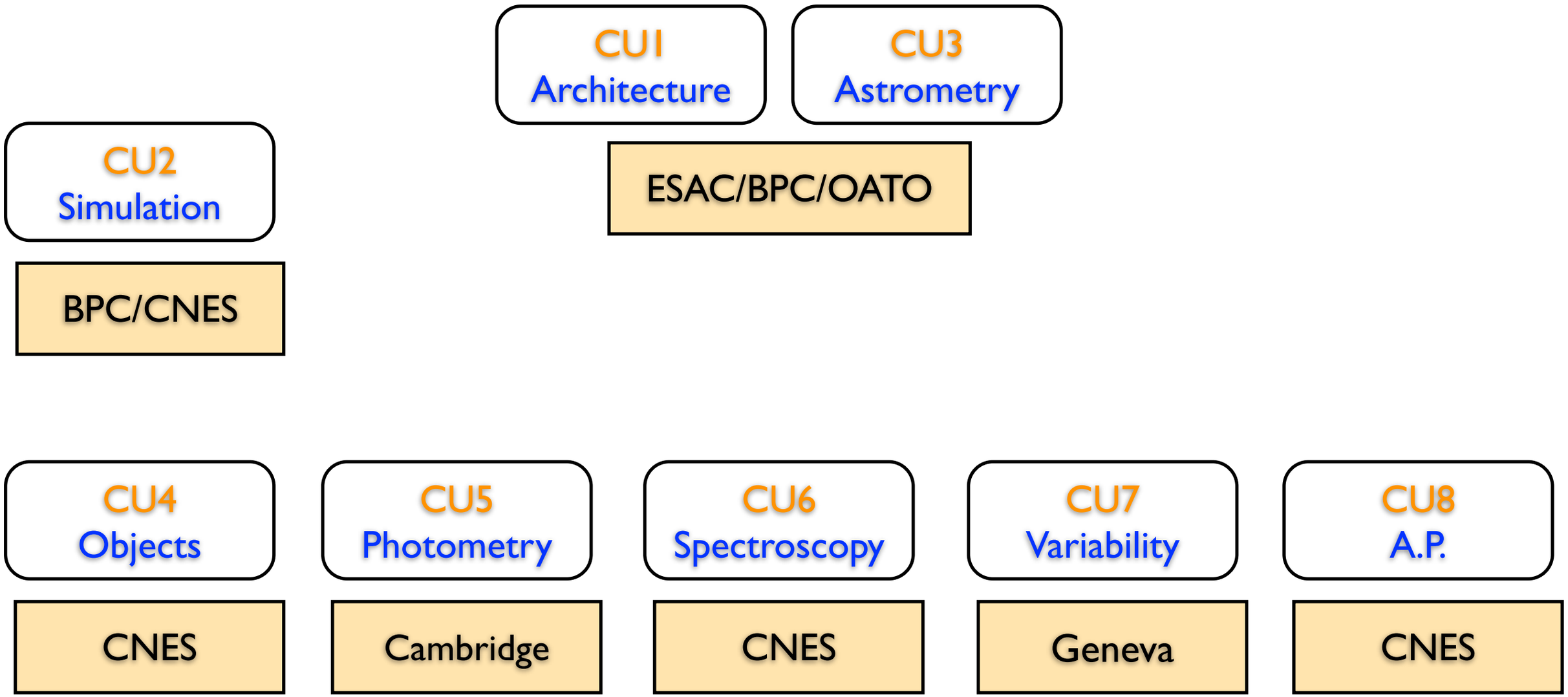
CU6
Spectroscopy

CU7
Variability

CU8
A.P.

The Data Processing and Analysis Consortium: the global view

Two main concepts: 1. Coordination Units
2. Data Processing Centers



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CU1 Architecture

CU3 Astrometry

ESAC/BPC/OATO

Cloud computing at Amazon.com

CU2 Simulation

BPC/CNES

CU4 Objects

CNES

CU5 Photometry

Cambridge

CU6 Spectroscopy

CNES

CU7 Variability

Geneva

CU8 A.P.

CNES

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> 400 people

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ESAC

CU4 Objects

CU5 Photometry

CU6 Spectroscopy

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CU8 A.P.

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Geneva

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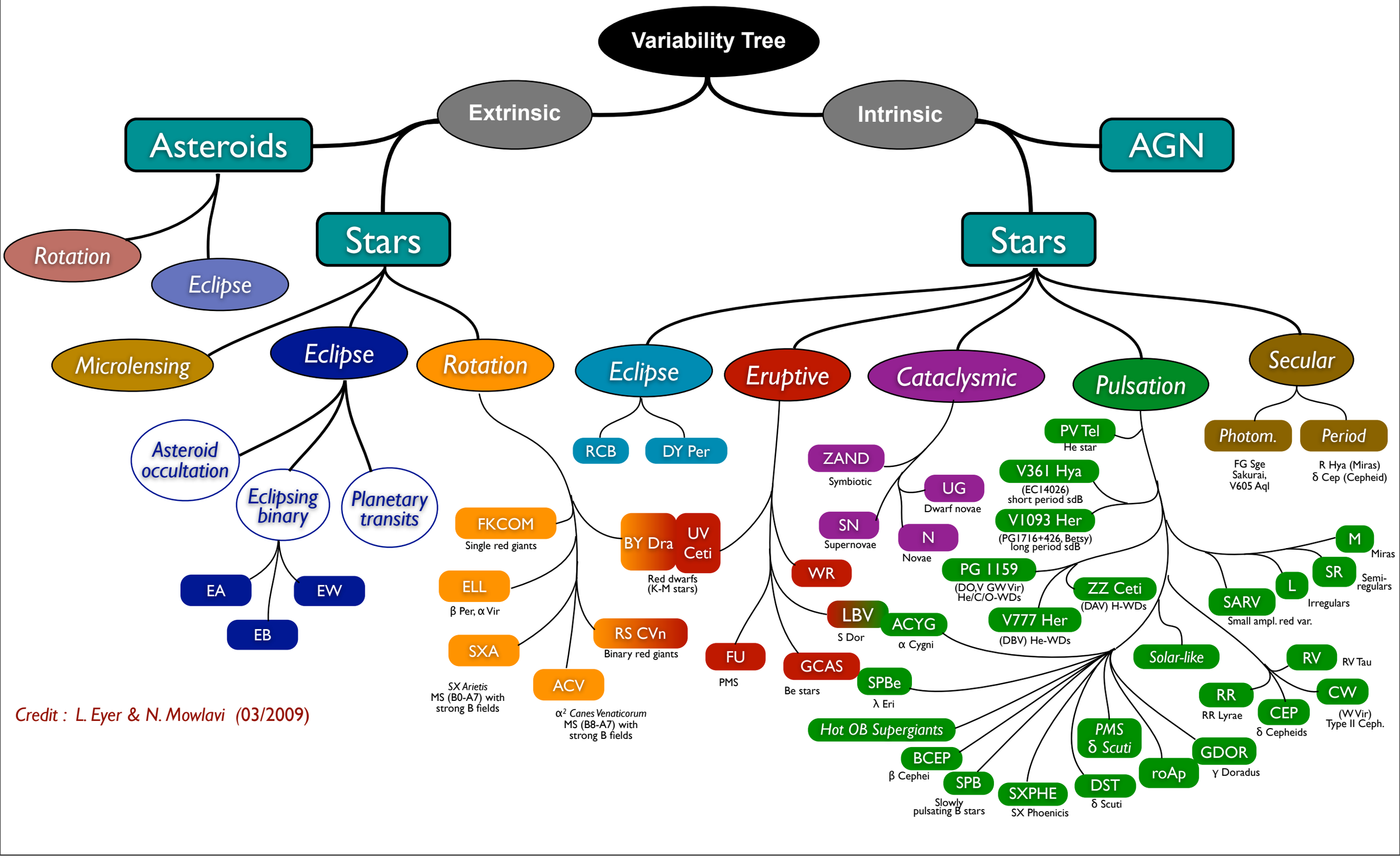
> 400 people

Variability processing and analysis: Detect, characterize and classify time series



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

Examples of light curves

100 million variable objects?

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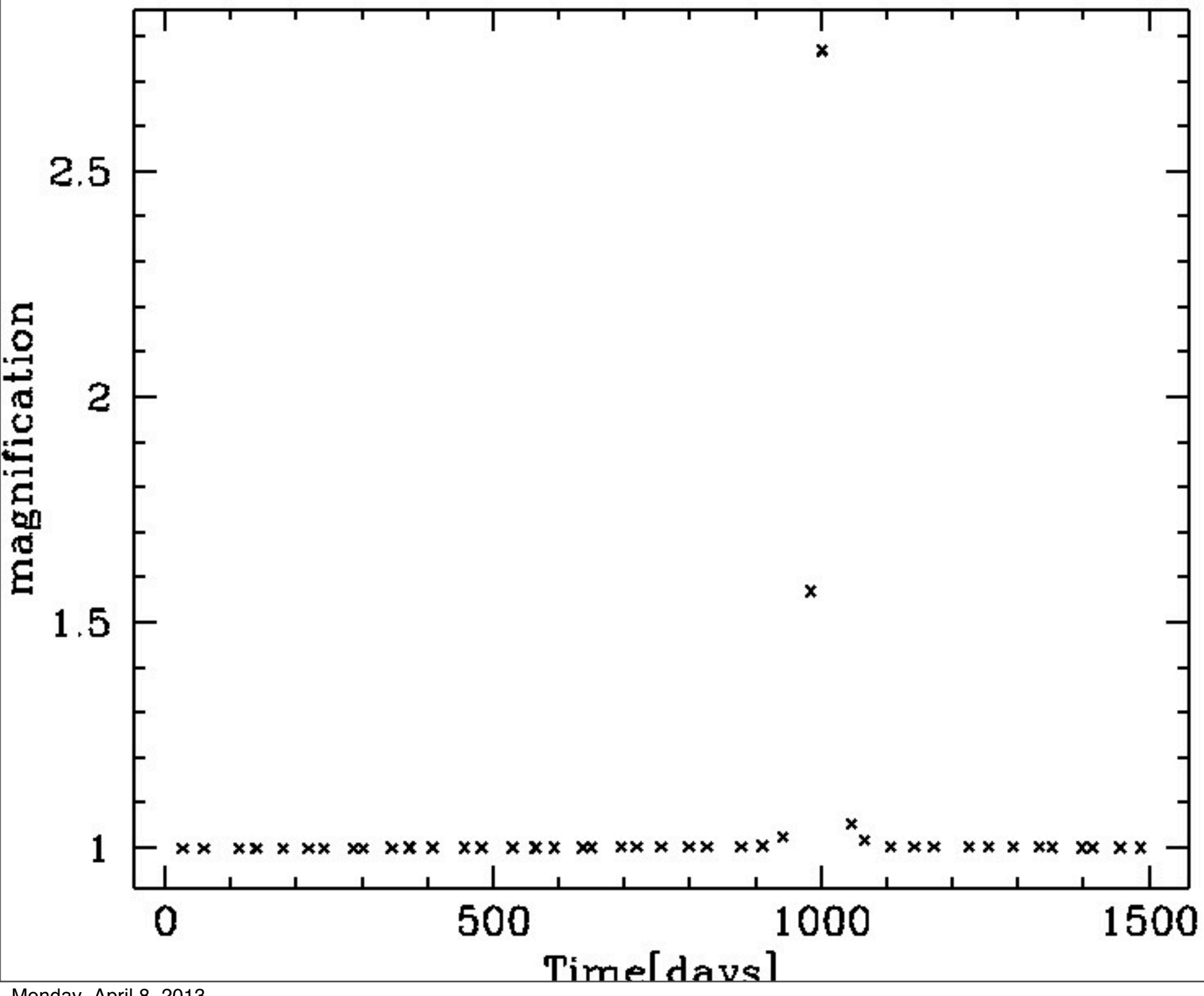

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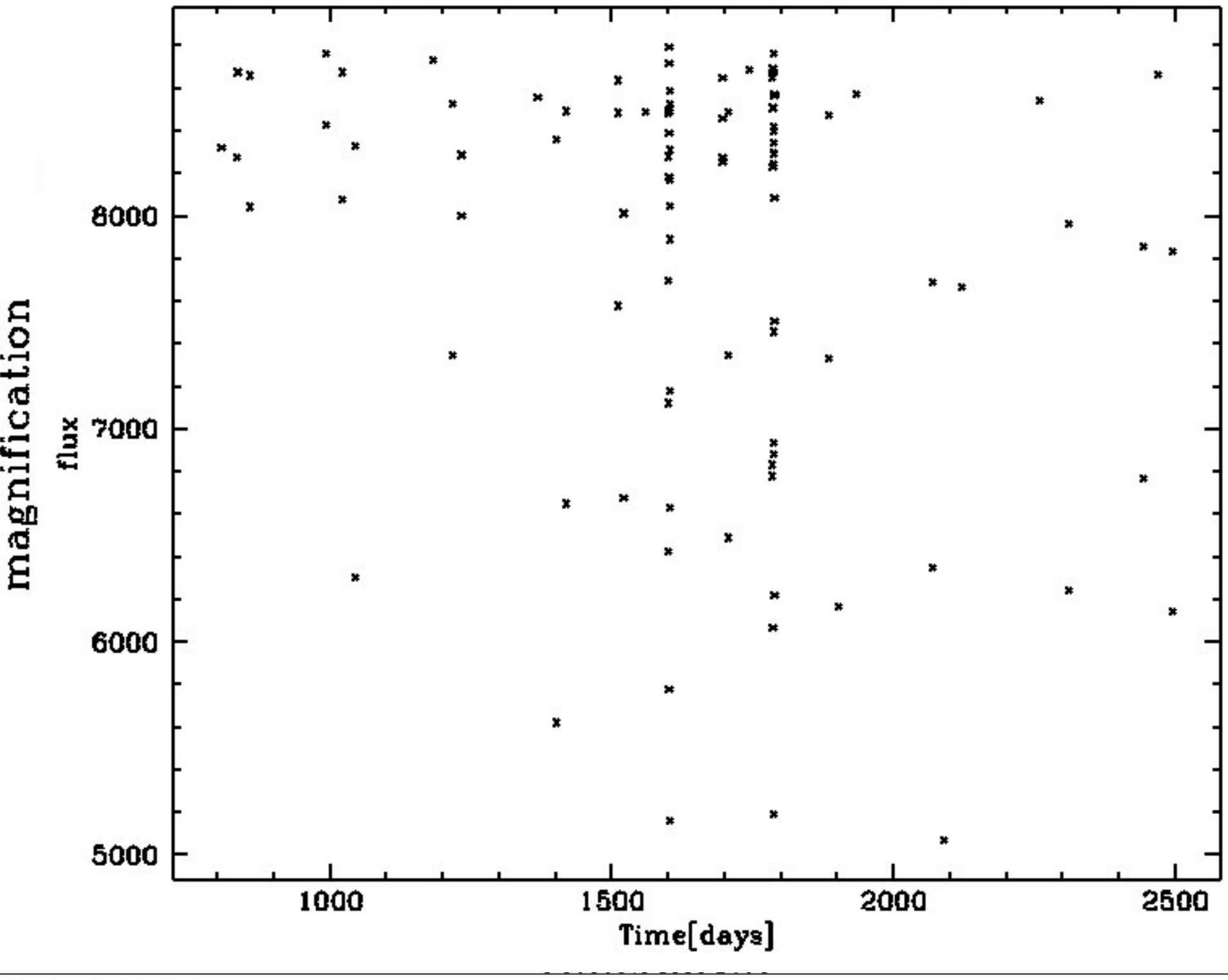

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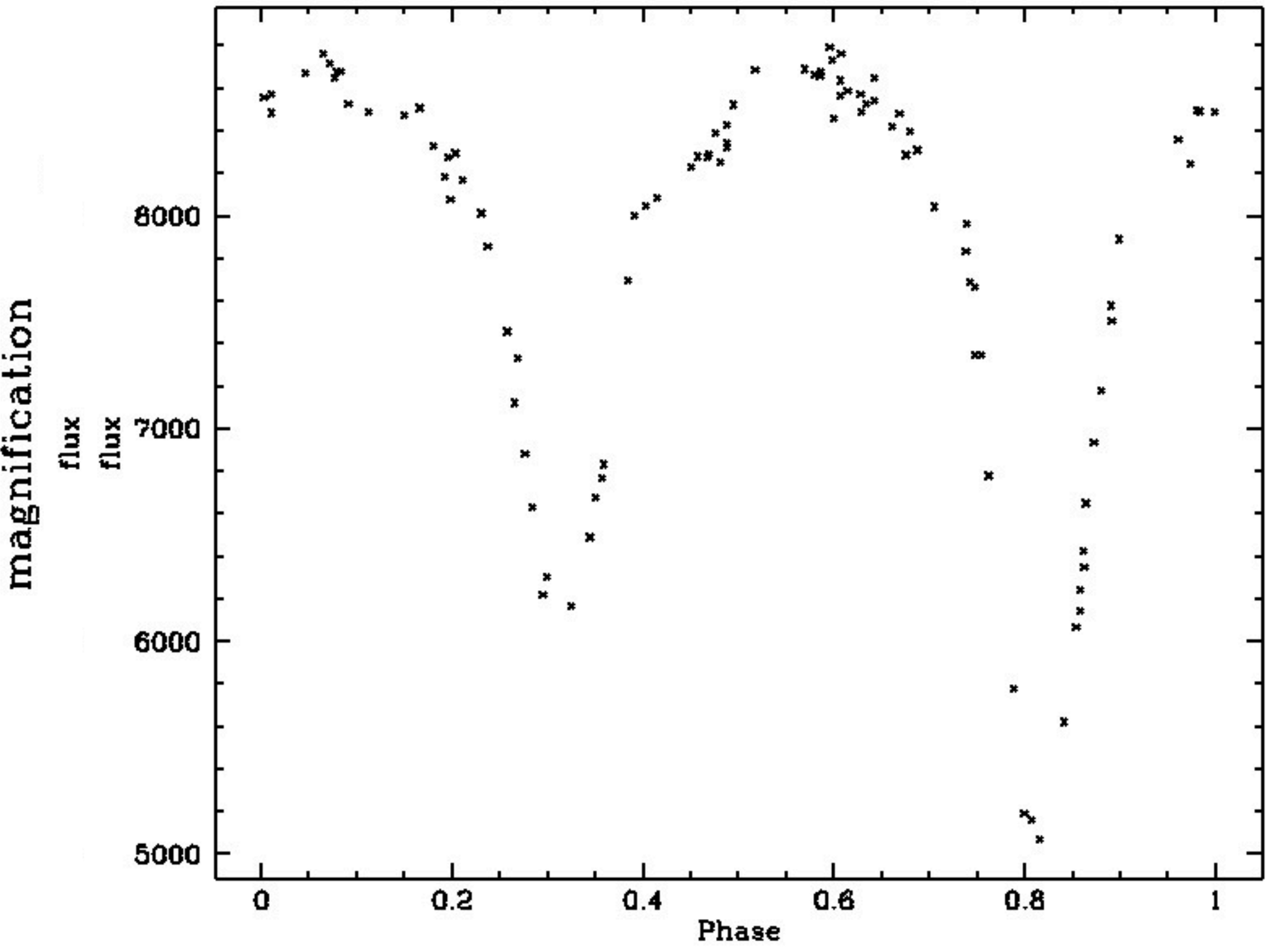

Examples of light curves

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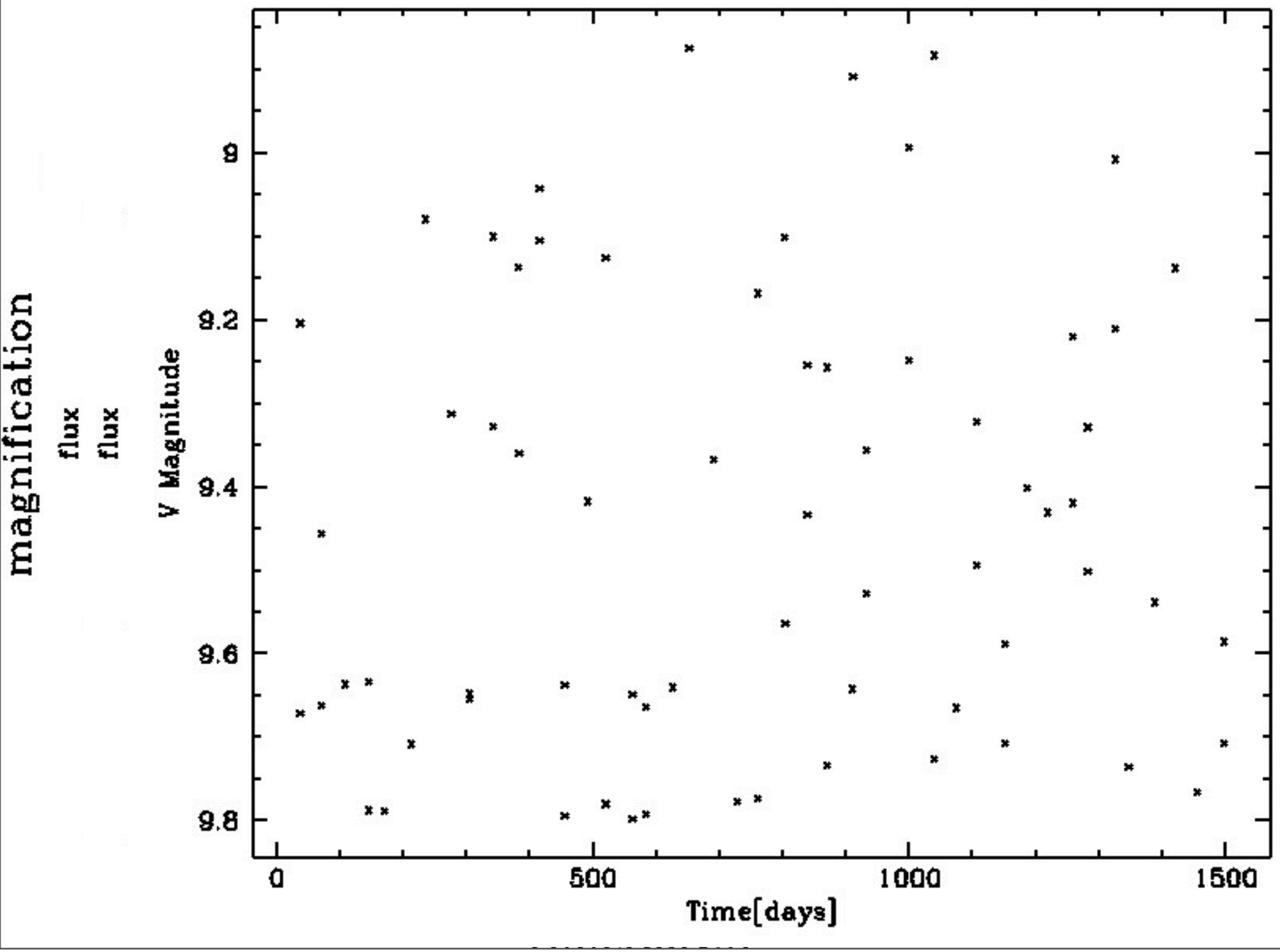

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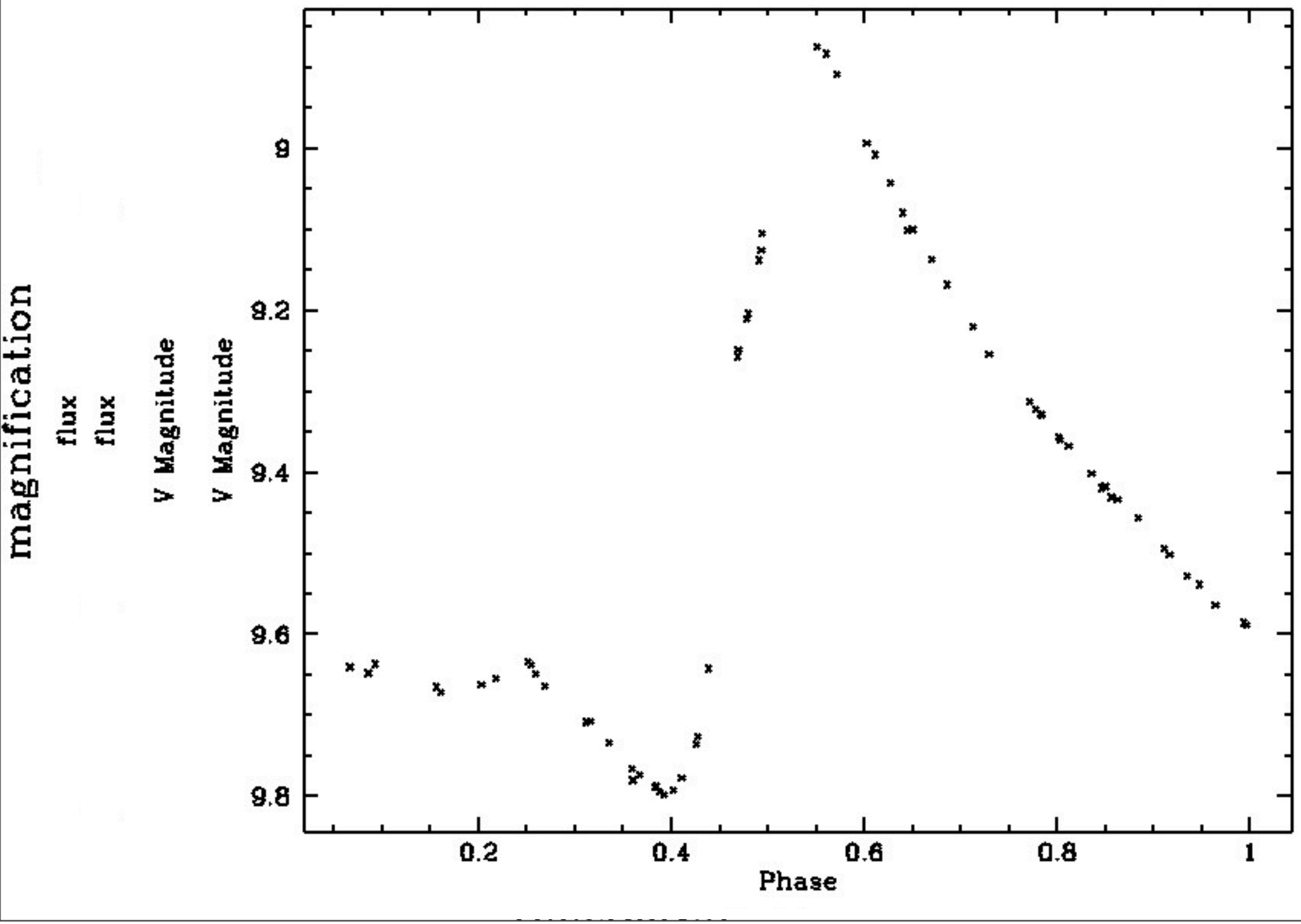

Numbers of variable objects for Gaia

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Estimations of ~ 50-150 million variable objects

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- 0.5 or 2-3 or 7 million Eclipsing Binaries (Söderhjelm 2004, Eyer & Cuypers 2000, Zwitter 2002), 4 million (Eyer et al. 2013)
- 5,000-30,000 Planetary transit systems (Robichon 2002), 100s-1000s (Dzigan Zucker 2012)
- 60,000-240,000 δ Scuti stars (Eyer&Cuypers 2000)
- 70,000 RR Lyrae stars (Eyer&Cuypers 2000)
- 2,000-8,000 Cepheids (Eyer&Cuypers 2000), 9,000 (Windmark et al. 2011)
- 6,000 Supernovae, 2,000 before peak (Gilmore, Belokurov 2009, Altavilla et al. 2012)
- 1,000 microlensing events (Wyrzykowsky 2011)

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Big difference between the signal presence and its detection

Fraction of variables (Hipparcos precision)

β Cep (p mode)

Be stars

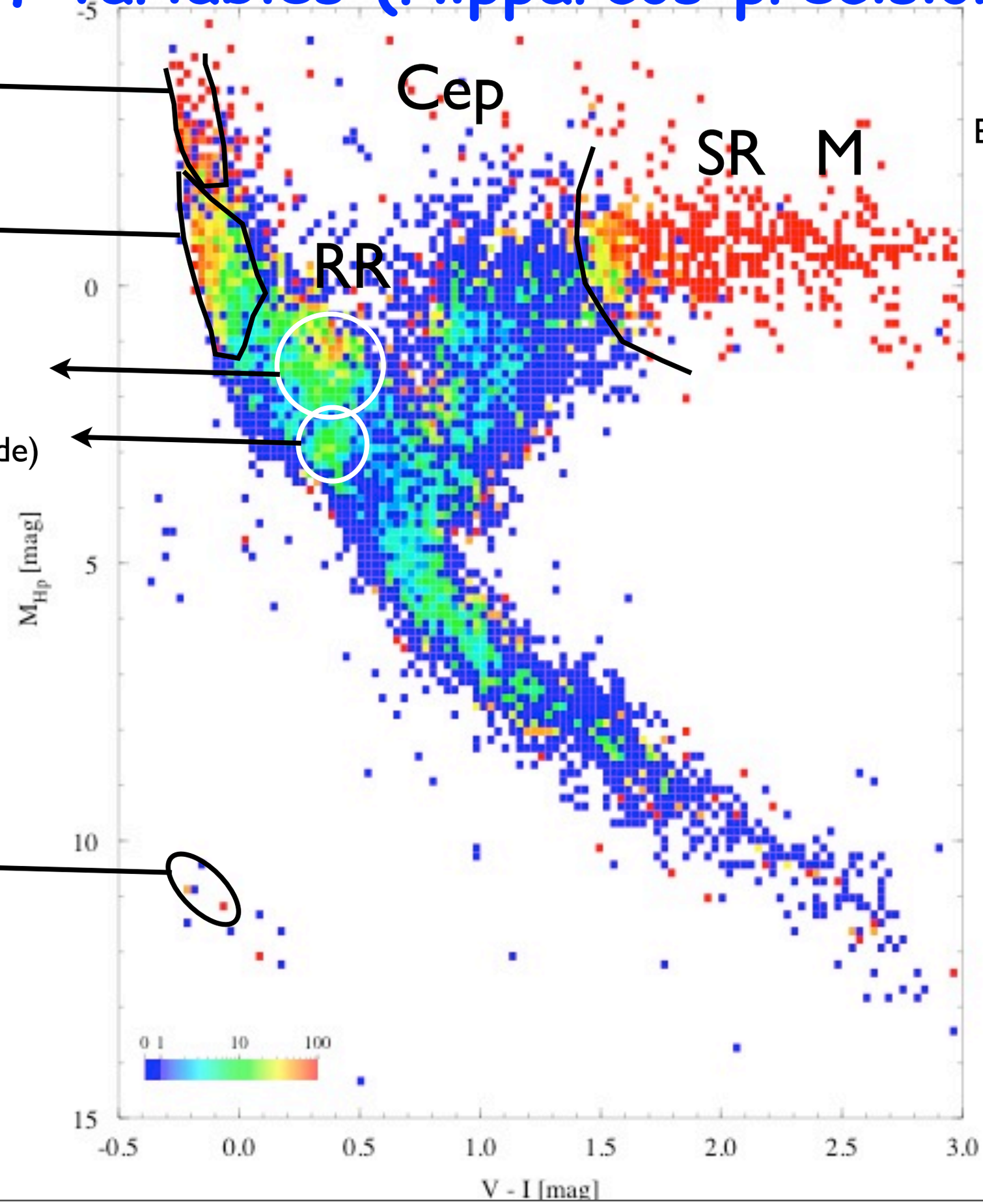
SPB (g mode)

δSct (p mode)

γDor (g mode)

ZZ Ceti

DAV (g mode)

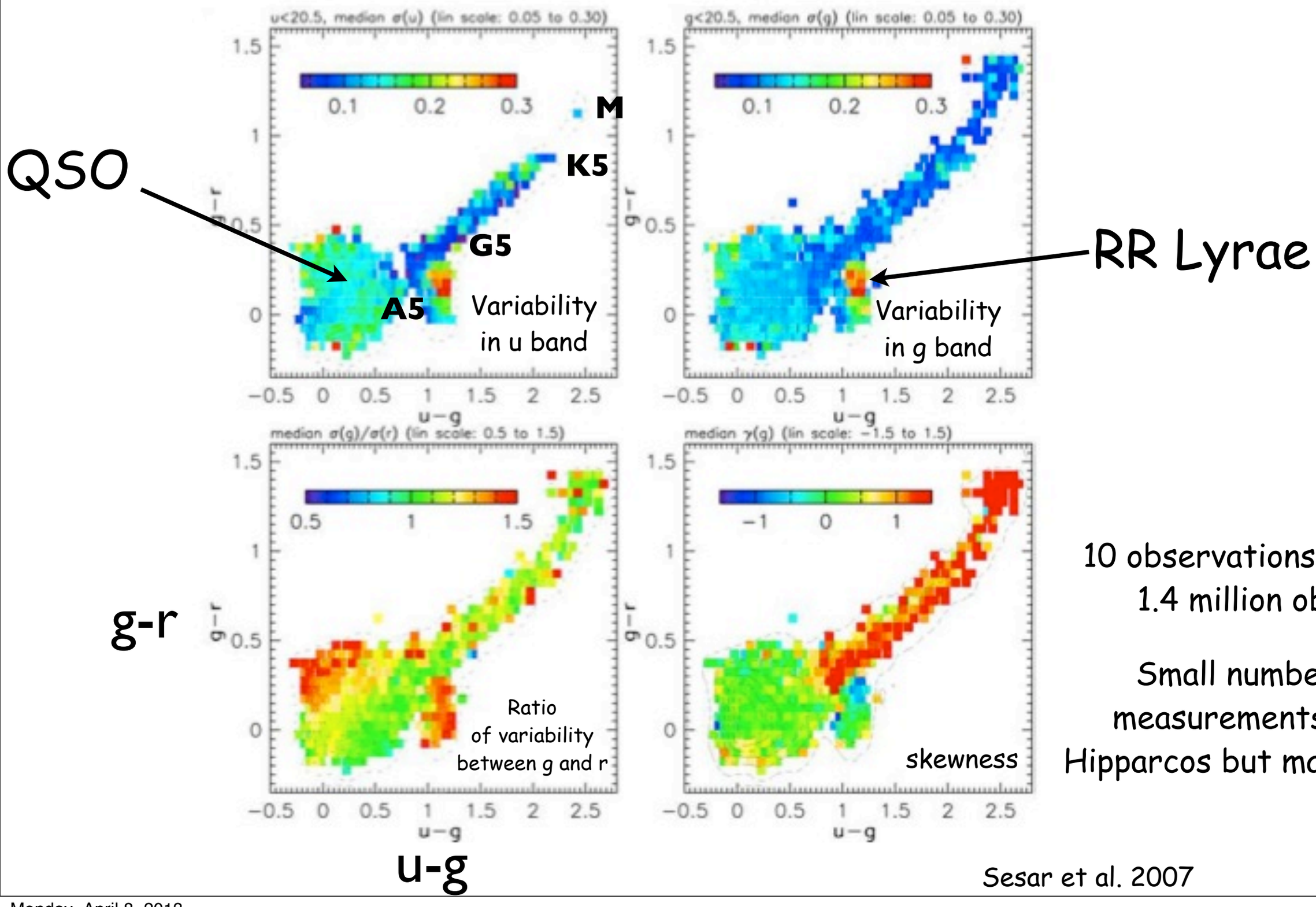


ESA SP-1200 1997

11,587 variables
118,204

Colour-Colour Diagram

SDSS (Sloan Digital Sky Survey)

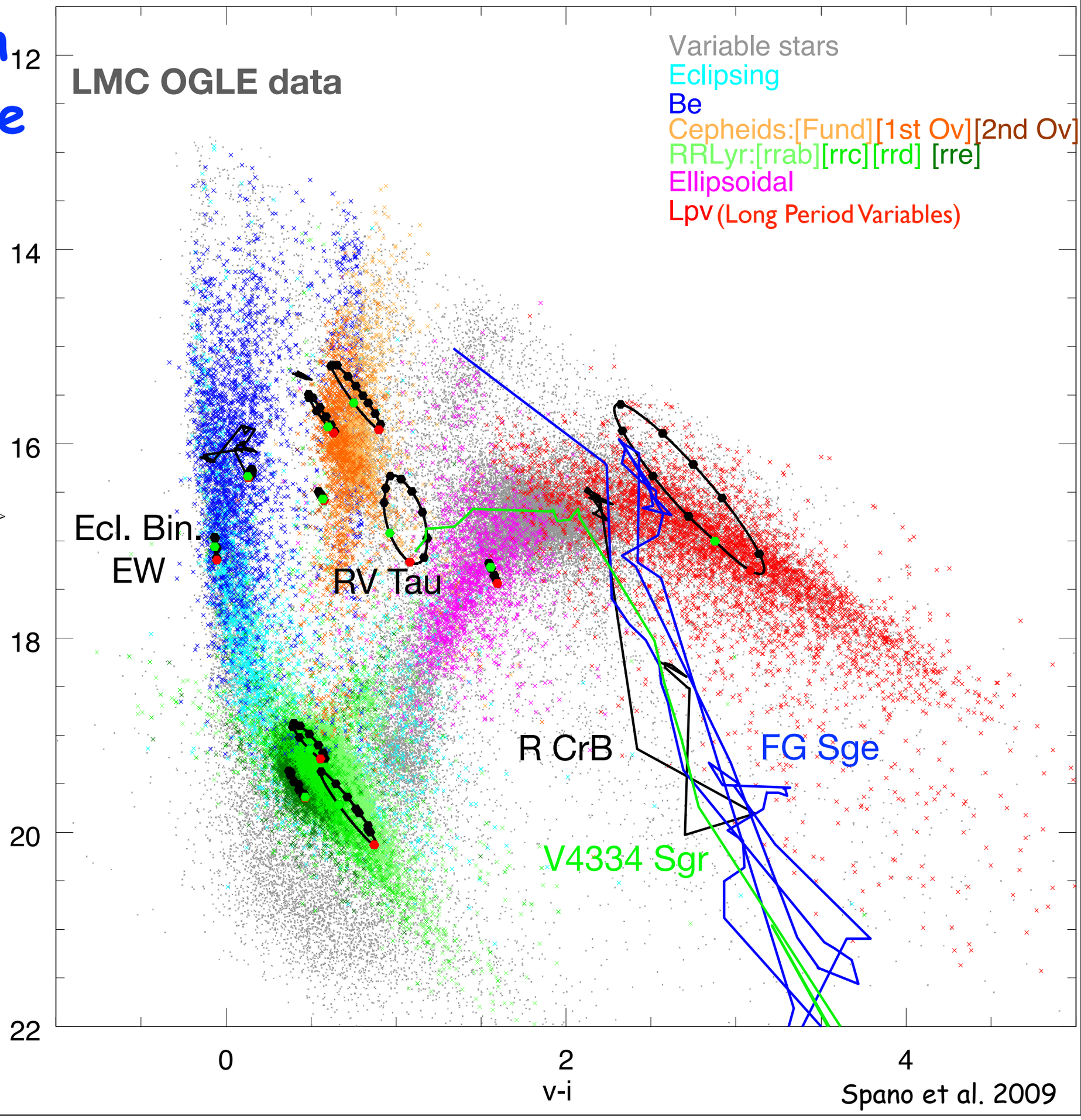


10 observations (5 years)
1.4 million objects

Small number of measurements than Hipparcos but many stars!

Sesar et al. 2007

Variable stars in Colour-Magnitude Diagram



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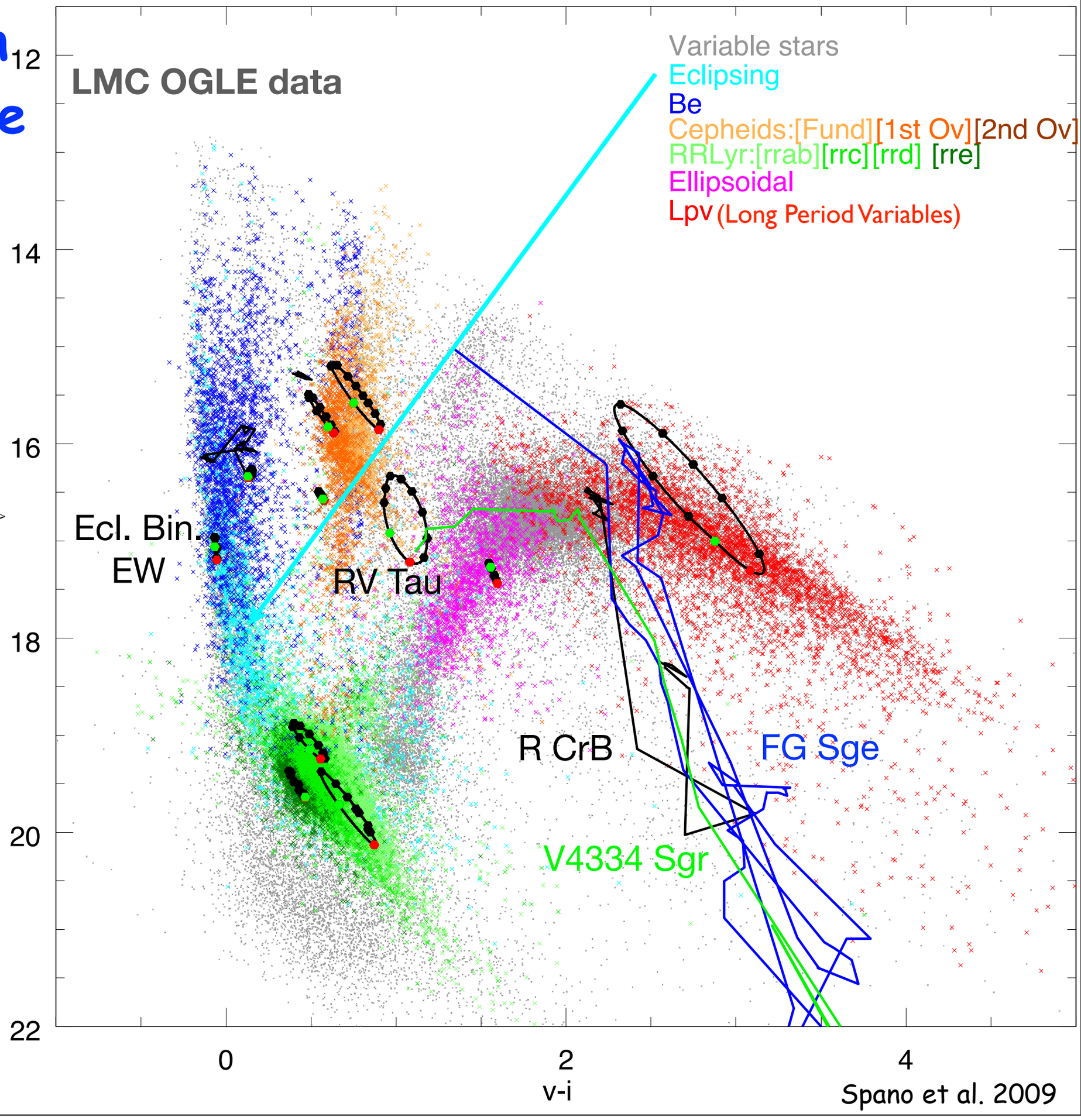

Spano et al. 2009

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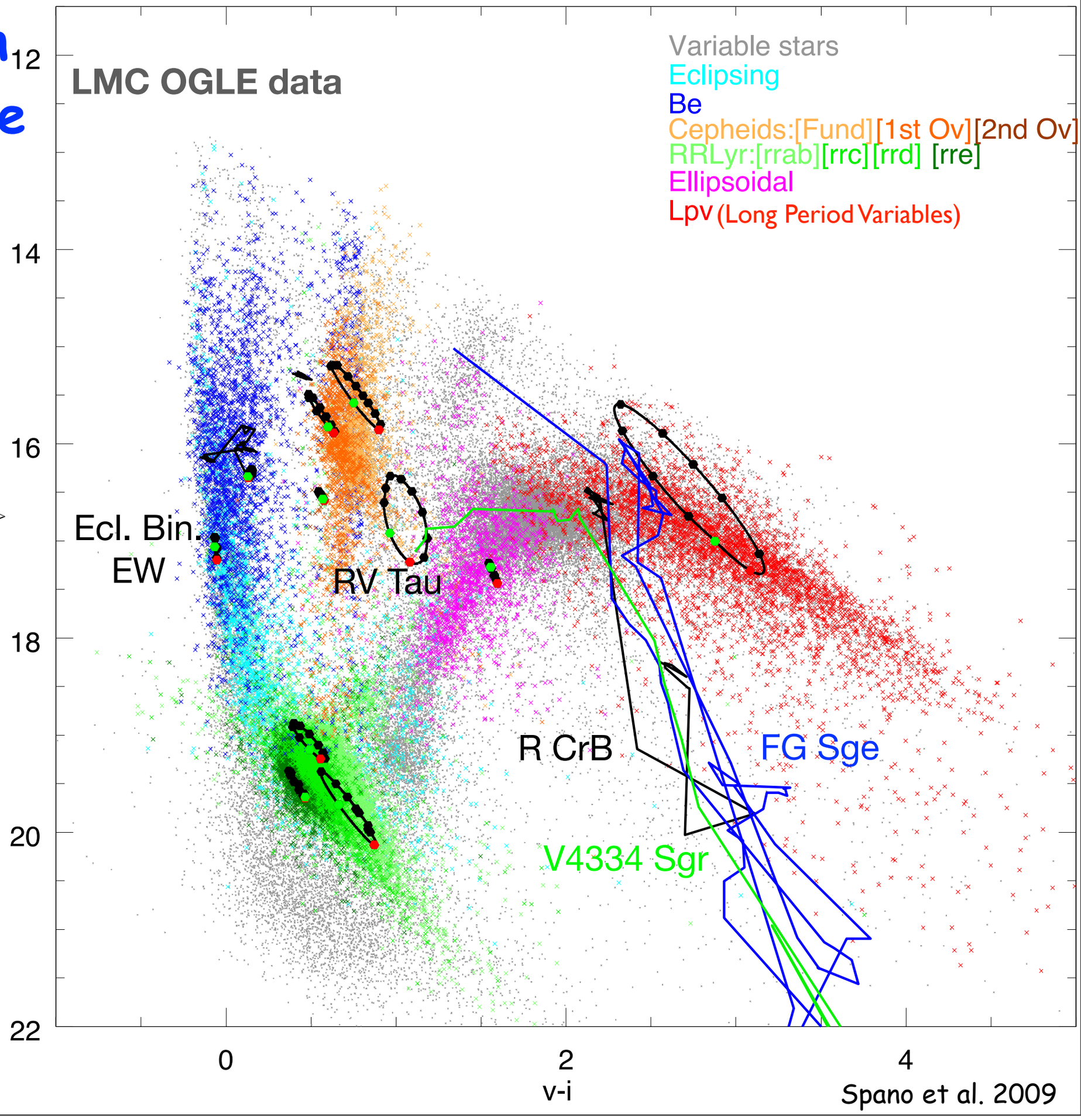

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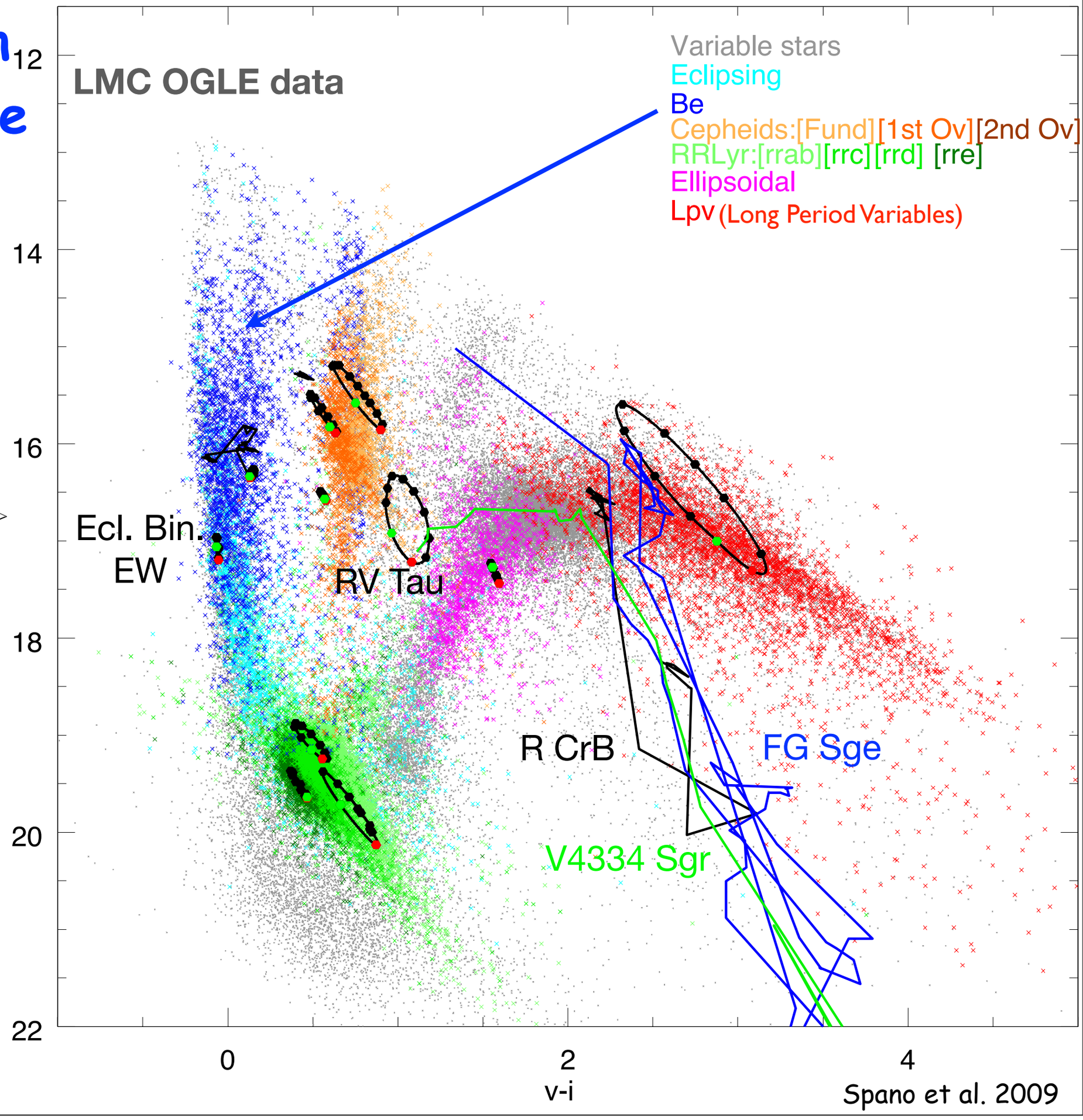

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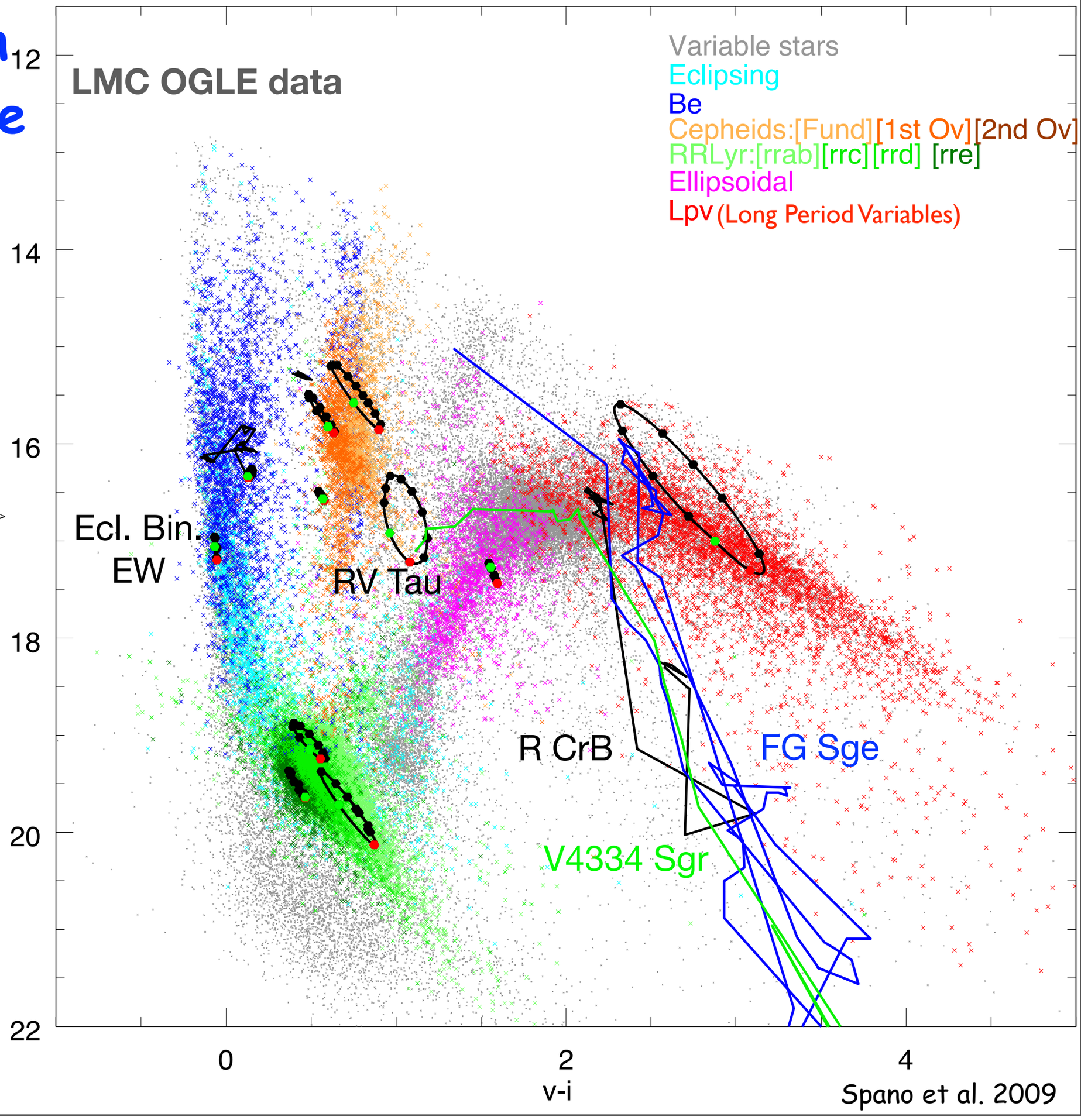

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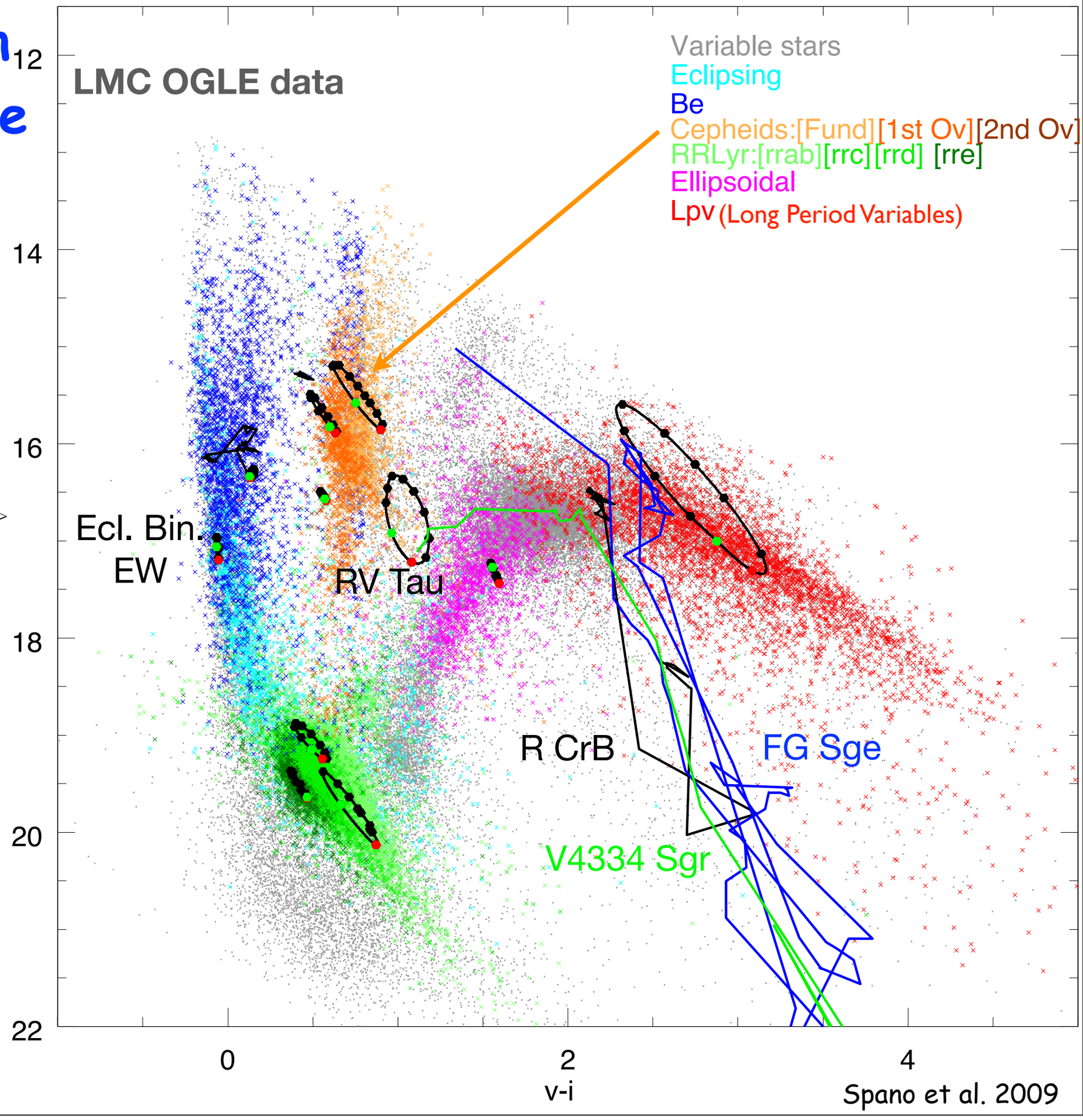
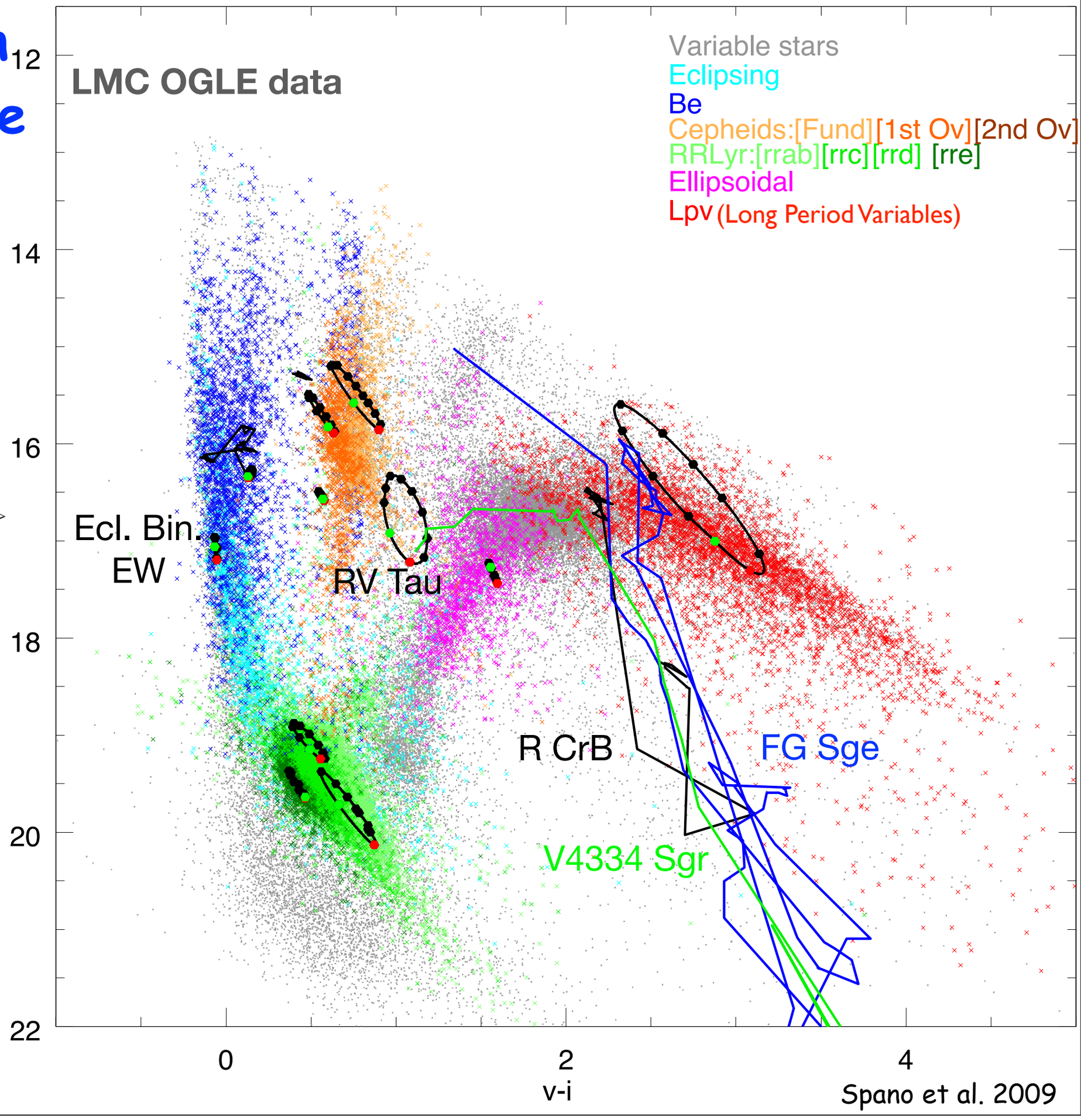


Variable stars in Colour-Magnitude Diagram



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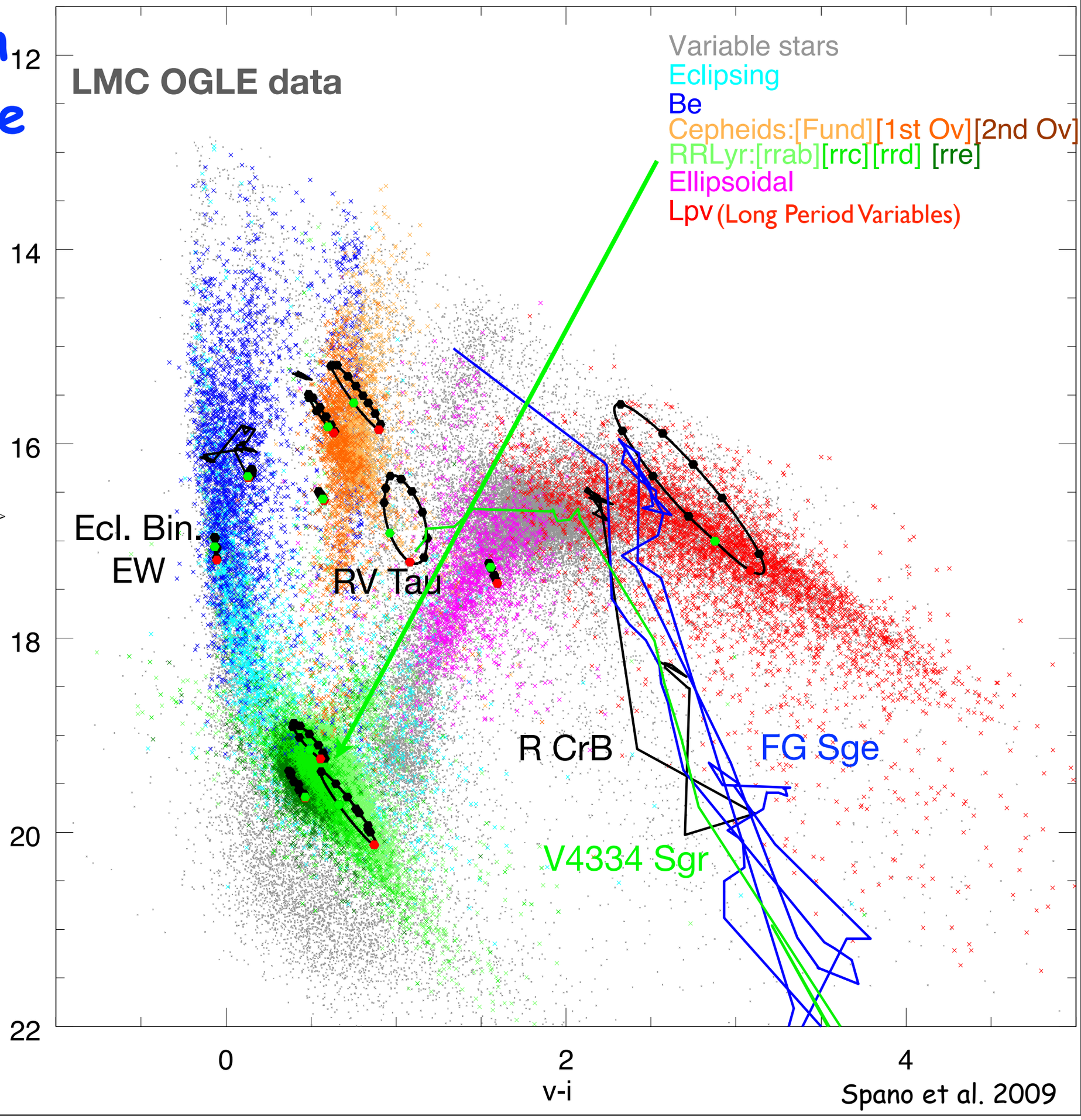
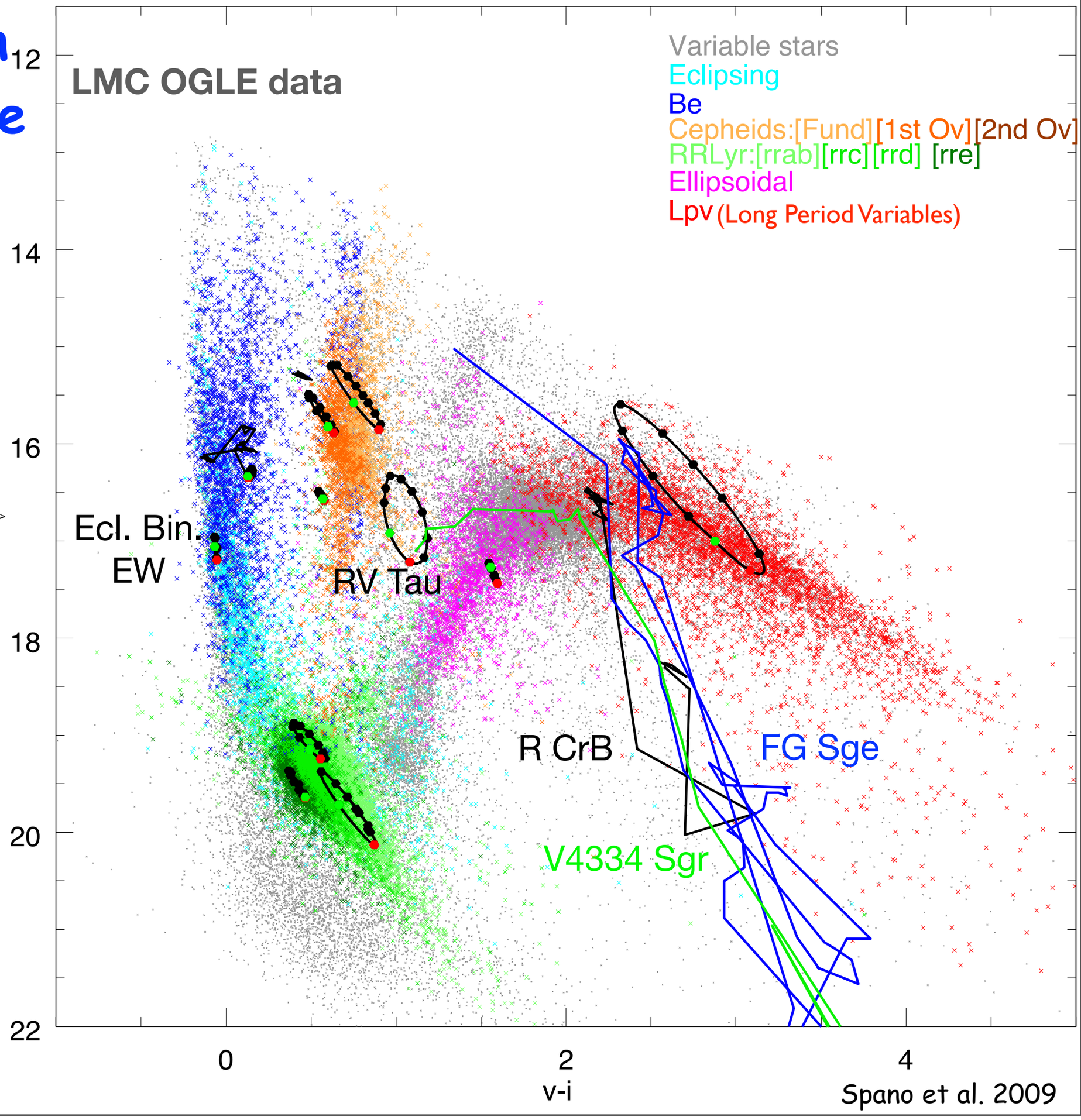


Spano et al. 2009

Variable stars in Colour-Magnitude Diagram



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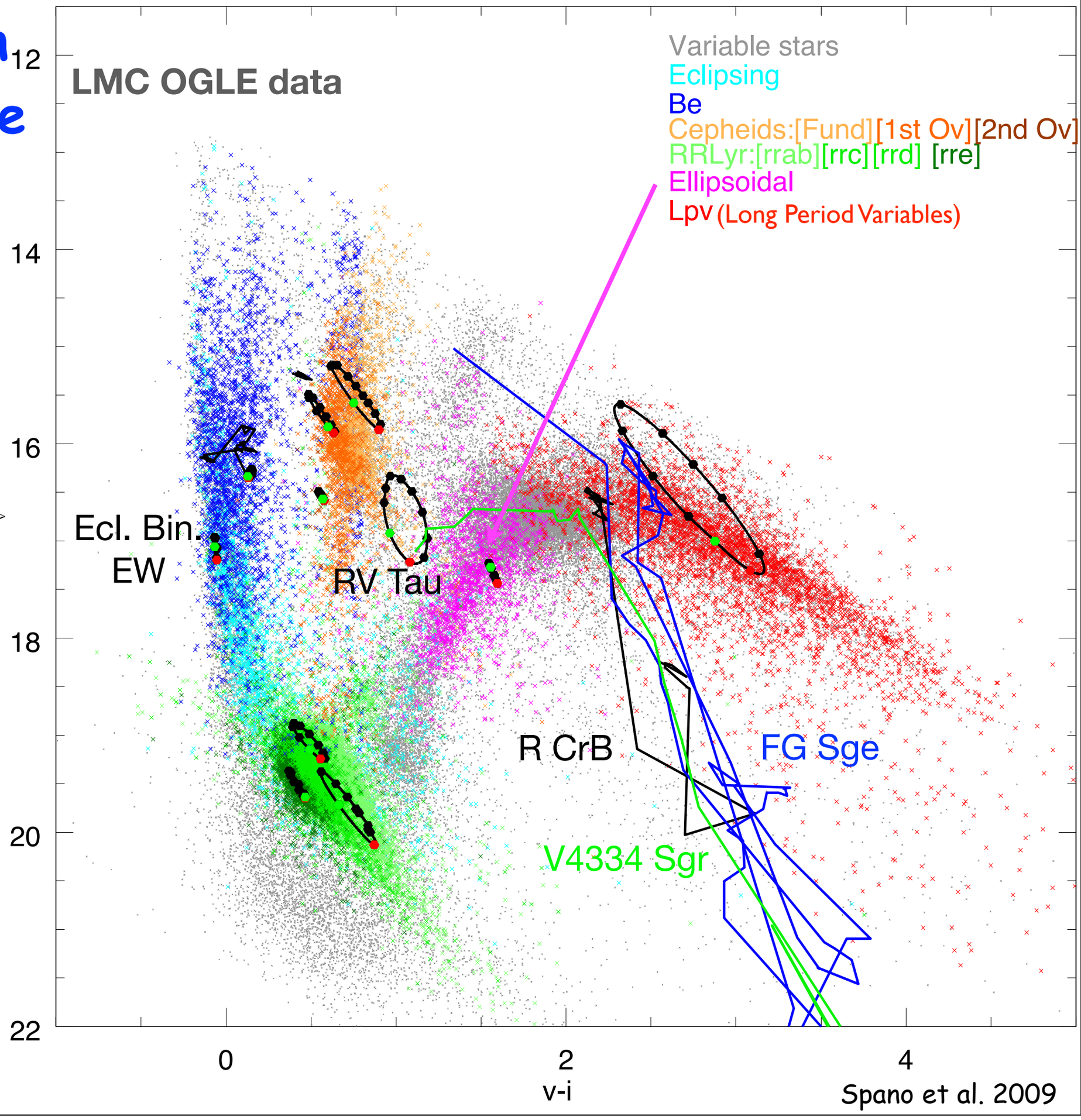

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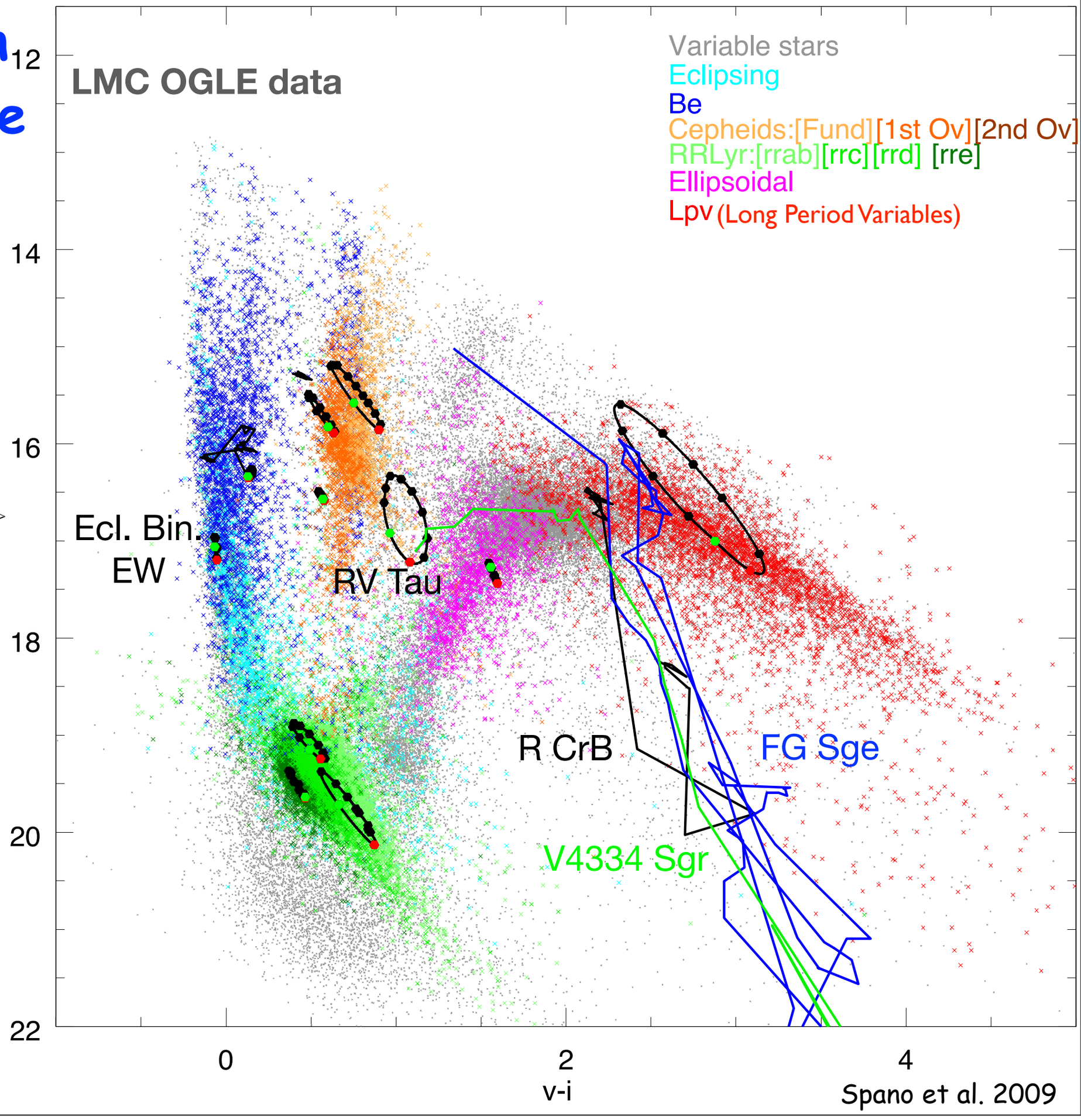

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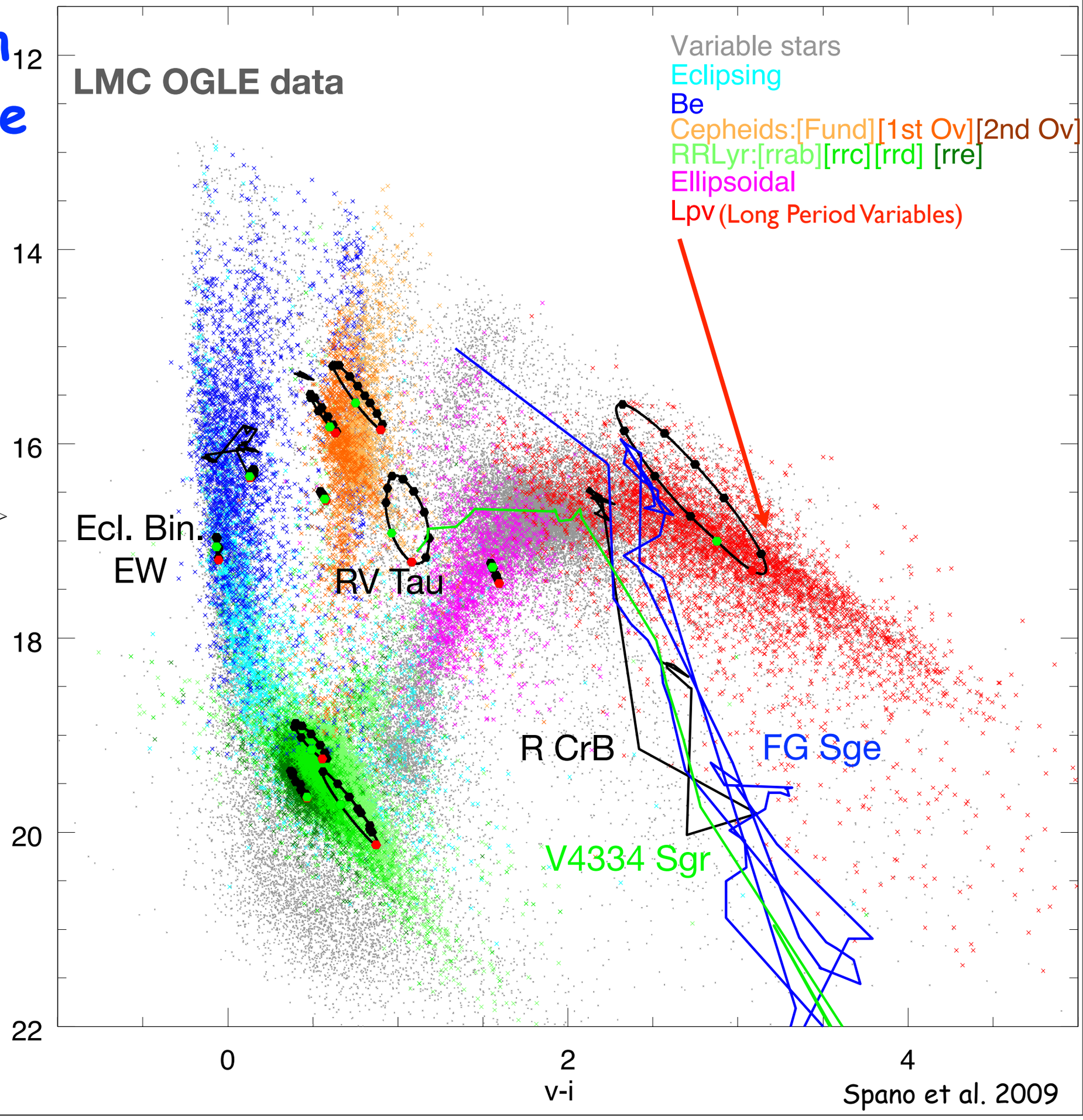

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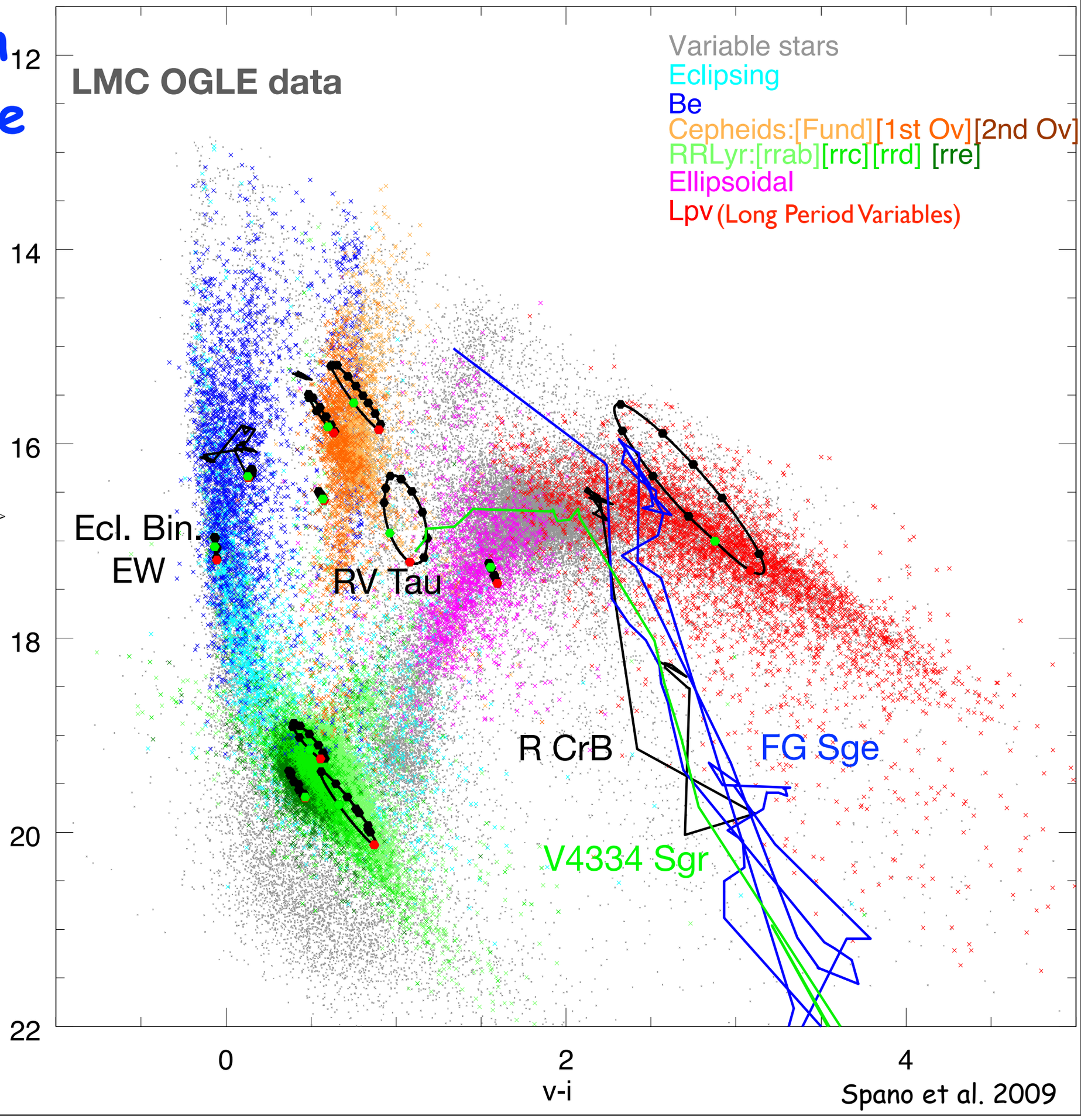

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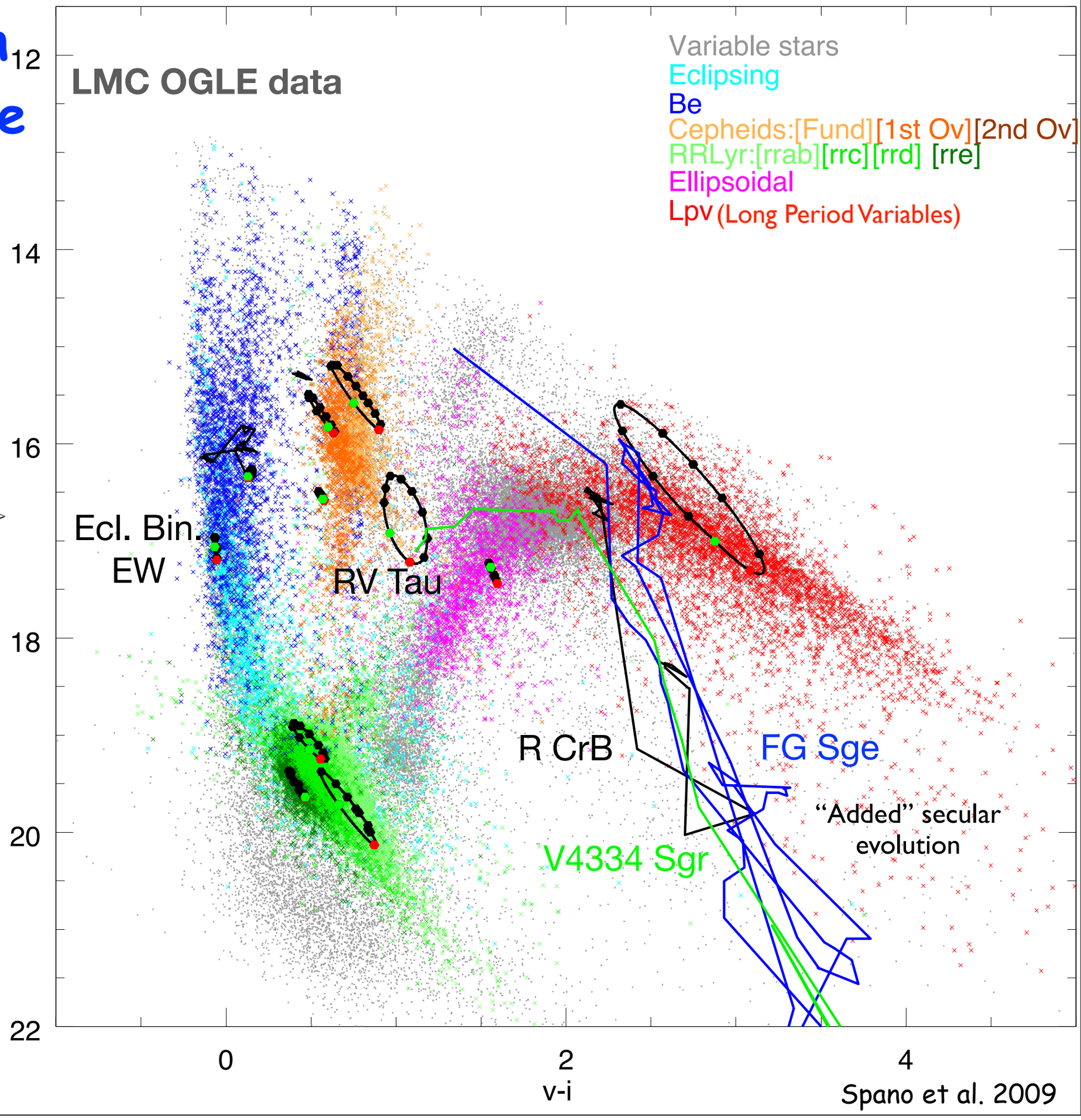


Variable stars in Colour-Magnitude Diagram

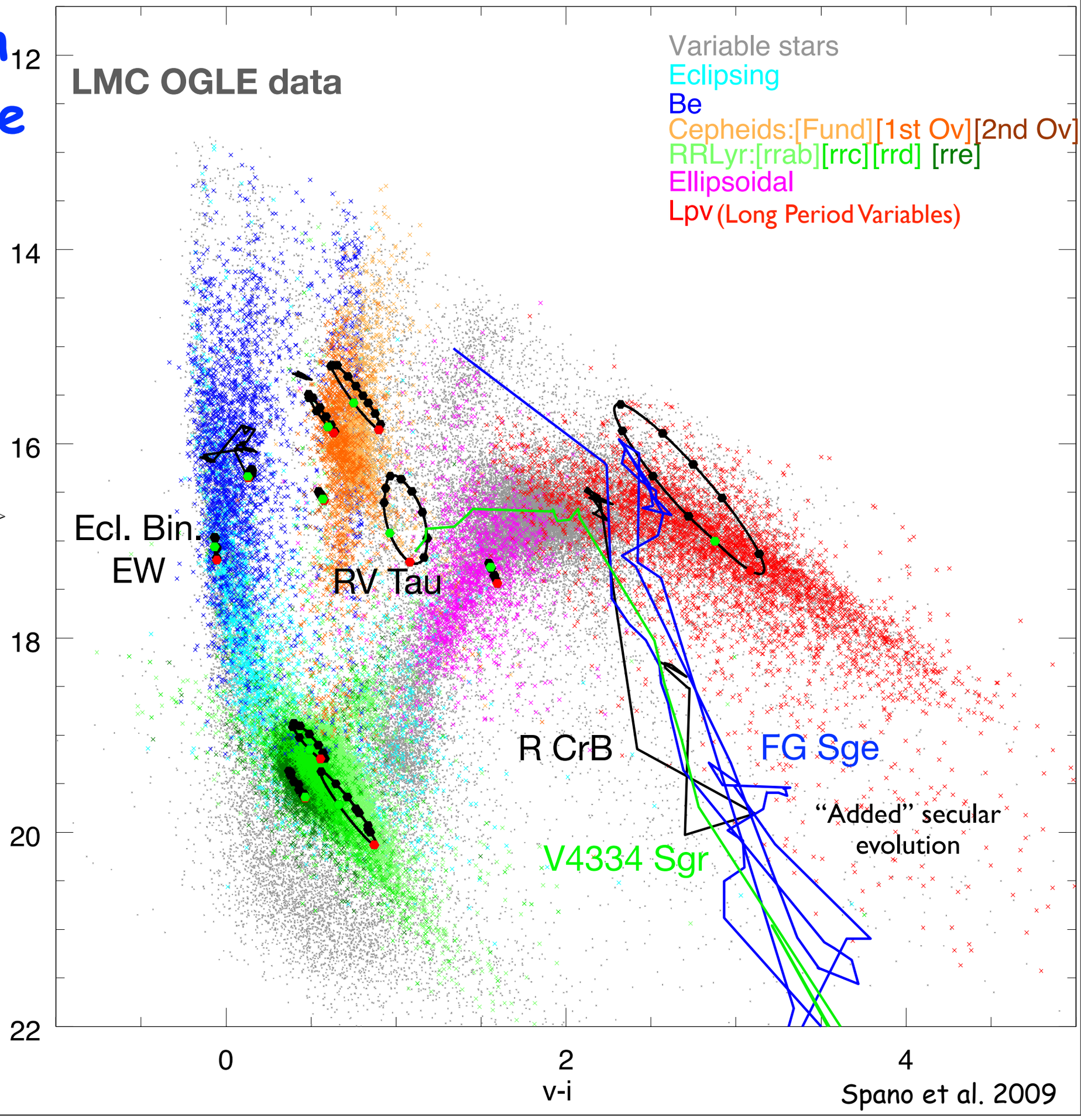
Gaia:

1) Full description of HR diagram (parallax)

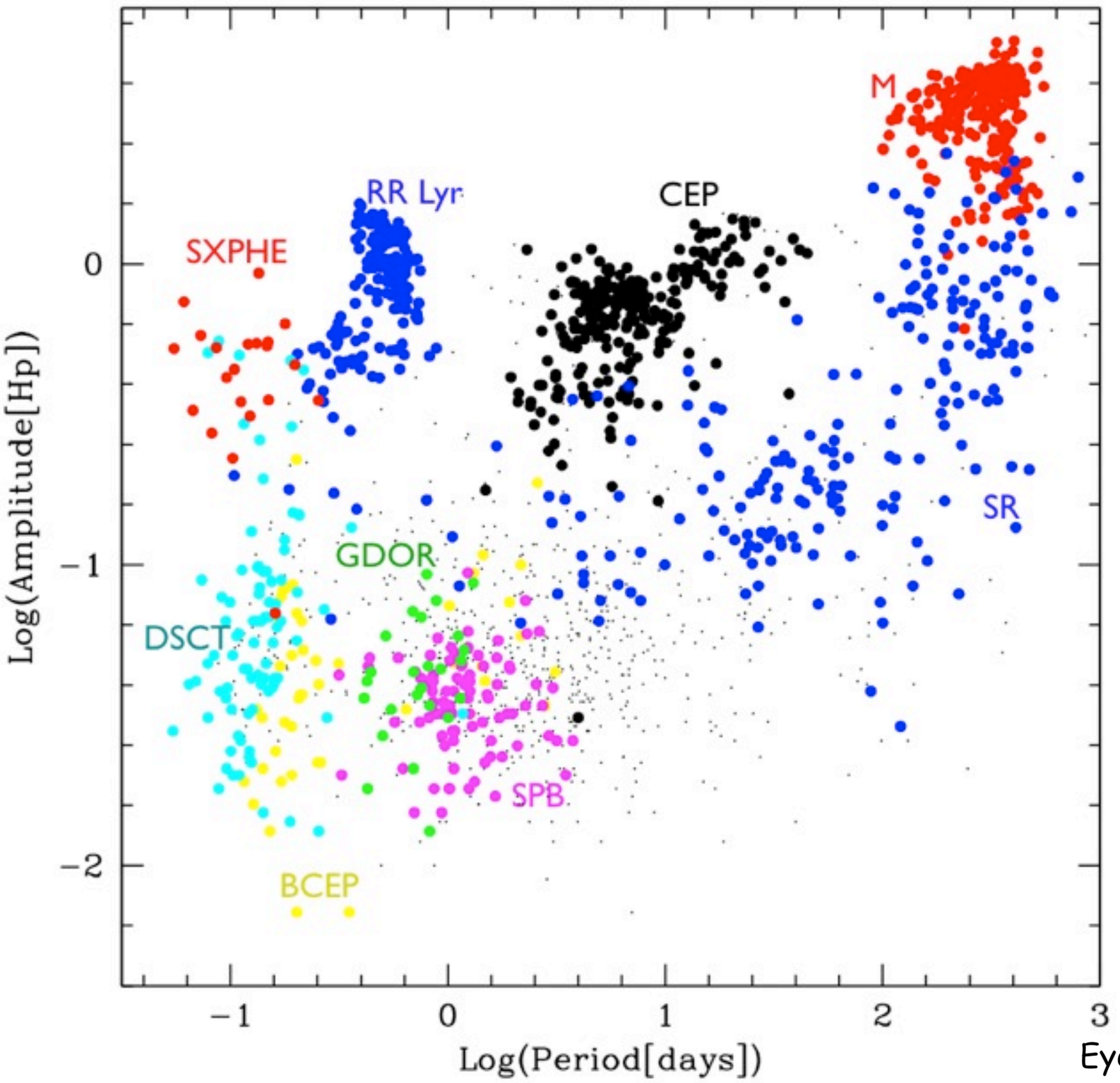
2) better precision (detection of many additional types)

3) simultaneous data in G, BP, RP (motion!)

4) Radial Velocities

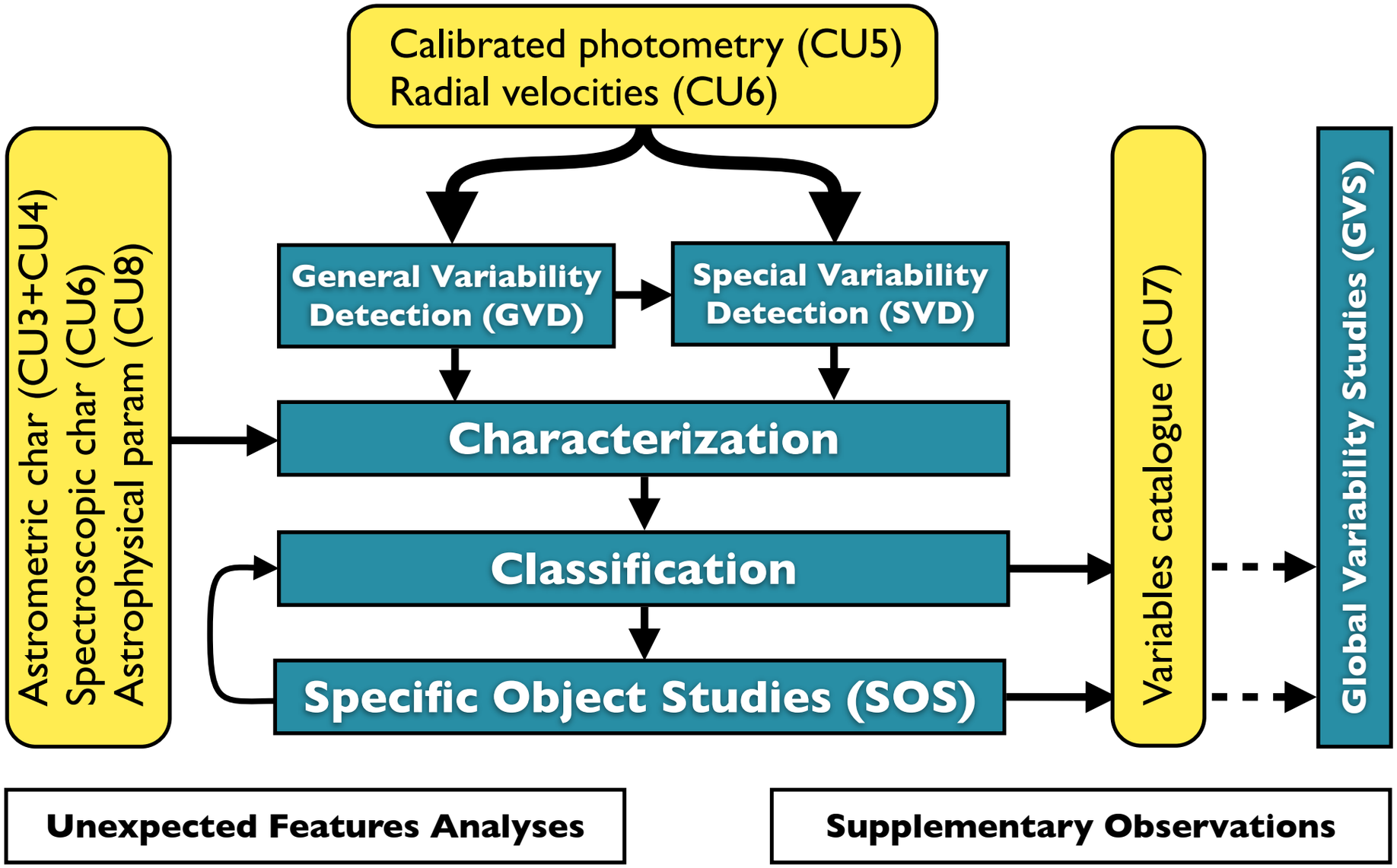


Hipparcos Period-Amplitude Diagram for pulsating stars



Eyer, Mowlavi 2008

CU7 / DPCG Variability Analysis



Test on periodic Hipparcos variable stars

Random Forest

Dubath et al 2011

Similar study by Richards et al. 2011

Predicted Class

True Class	EA	EB	EW	ELL	LPV	RV	CWA	CWB	DCEP	DCEPS	CEP(B)	RRAB	RRC	GDOR	DSCT	DSCTC	BCEP	SPB	BE+GCAS	ACYG	ACV	SXARI	BY+RS
EA	214	13									1												
EB	19	191	28	2	1				2					1		4		3		2	2		
EW		30	76							1													
ELL		14			1									1		1		3			5		2
LPV					285																		
RV		1			1				2	1													
CWA		2				1			5														1
CWB		1						2	2	1													
DCEP									183	5	1												
DCEPS		1							11	17													2
CEP(B)		1							4		6												
RRAB		1										69	1					1					
RRC		2	4									1	12		1								
GDOR														27									
DSCT		1	1									1			32	12							
DSCTC		1													1	77					2		
BCEP		1	1													1	26	1					
SPB				1													1	74		1	4		
BE+GCAS	1									1								5		2	4		
ACYG		1																	1	13	2		1
ACV		3								1				1				6			66		
SXARI		2																2			3		
BY+RS		1							1														33

Biases: Histogram of periods

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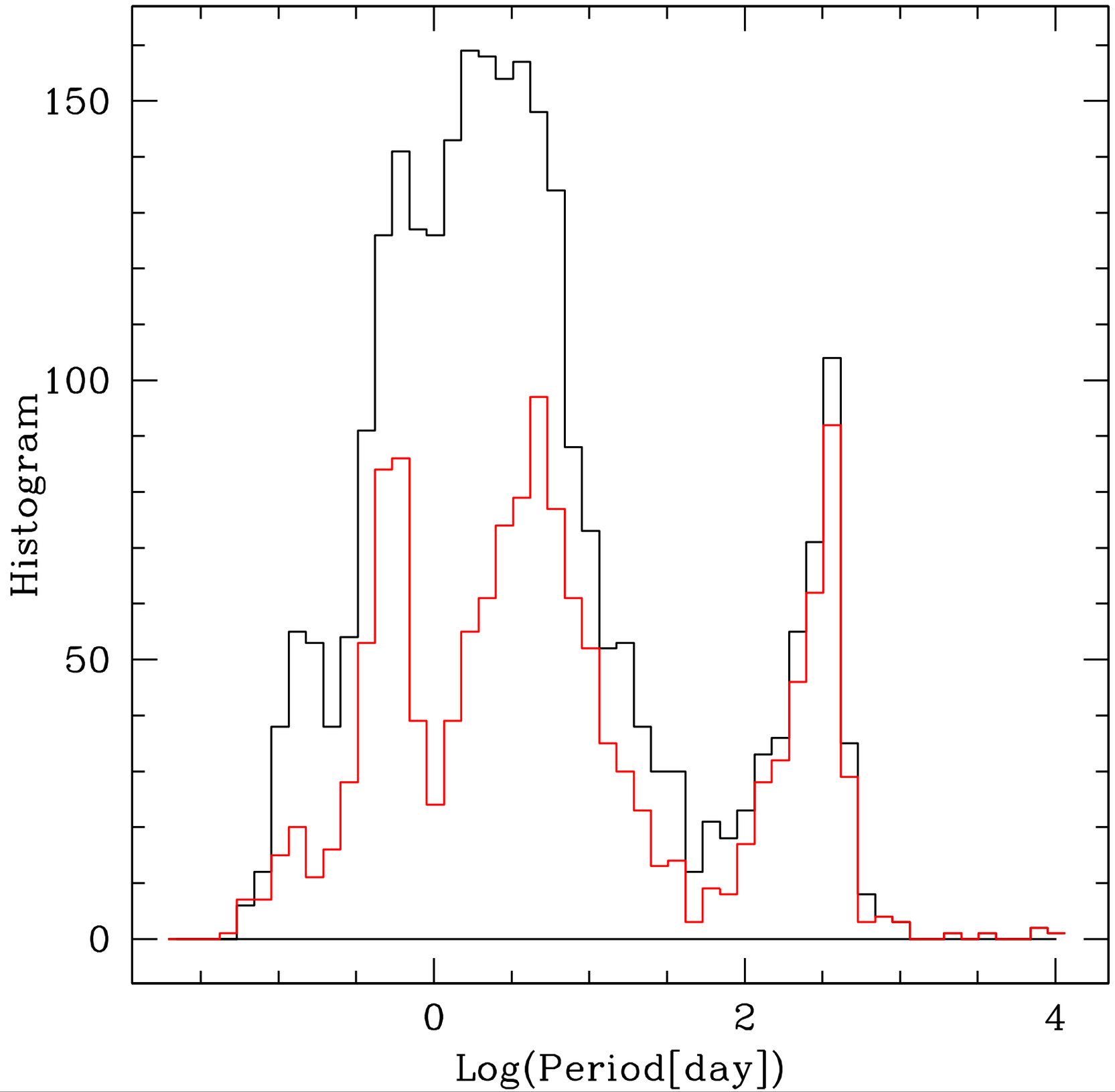

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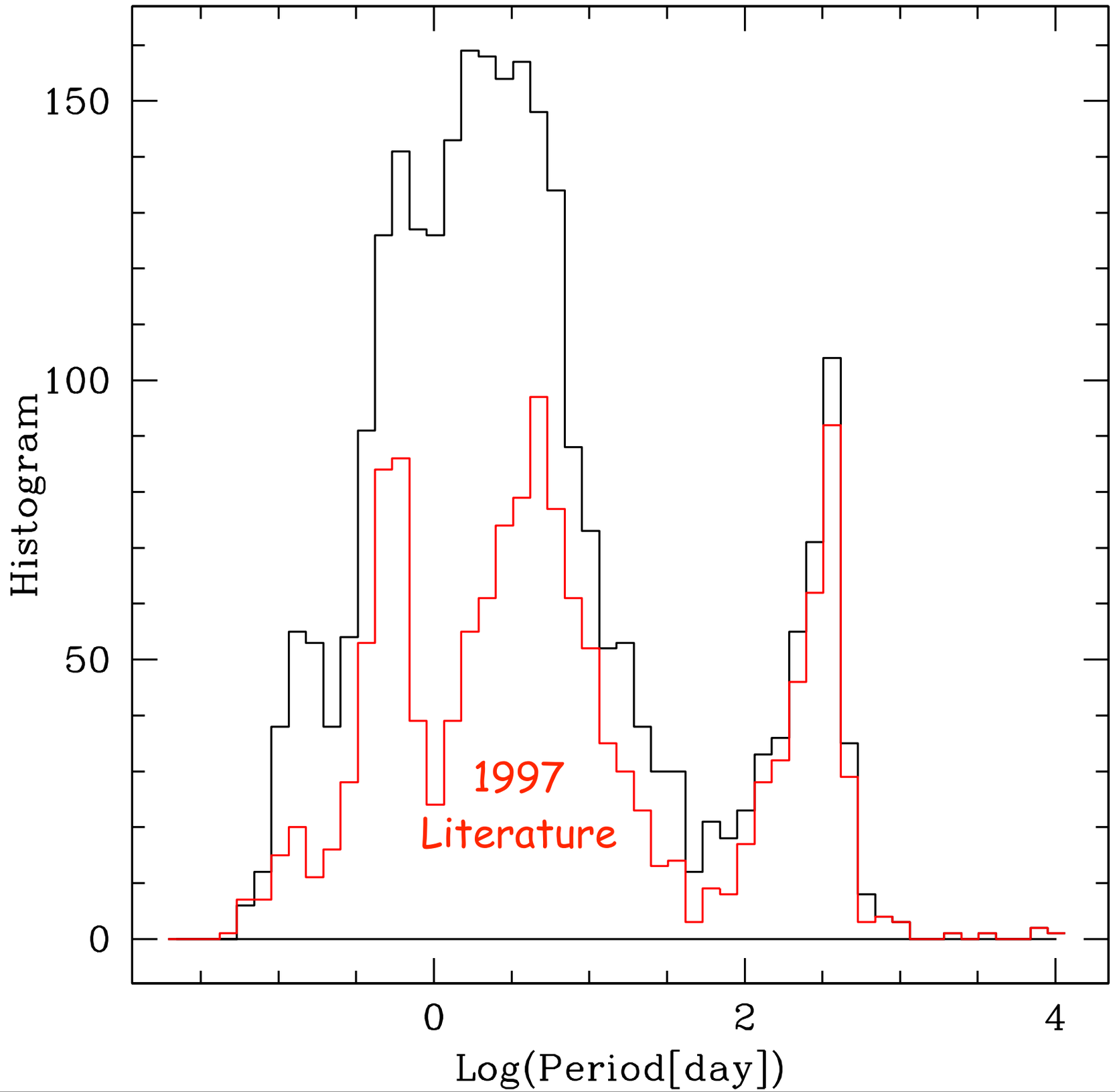

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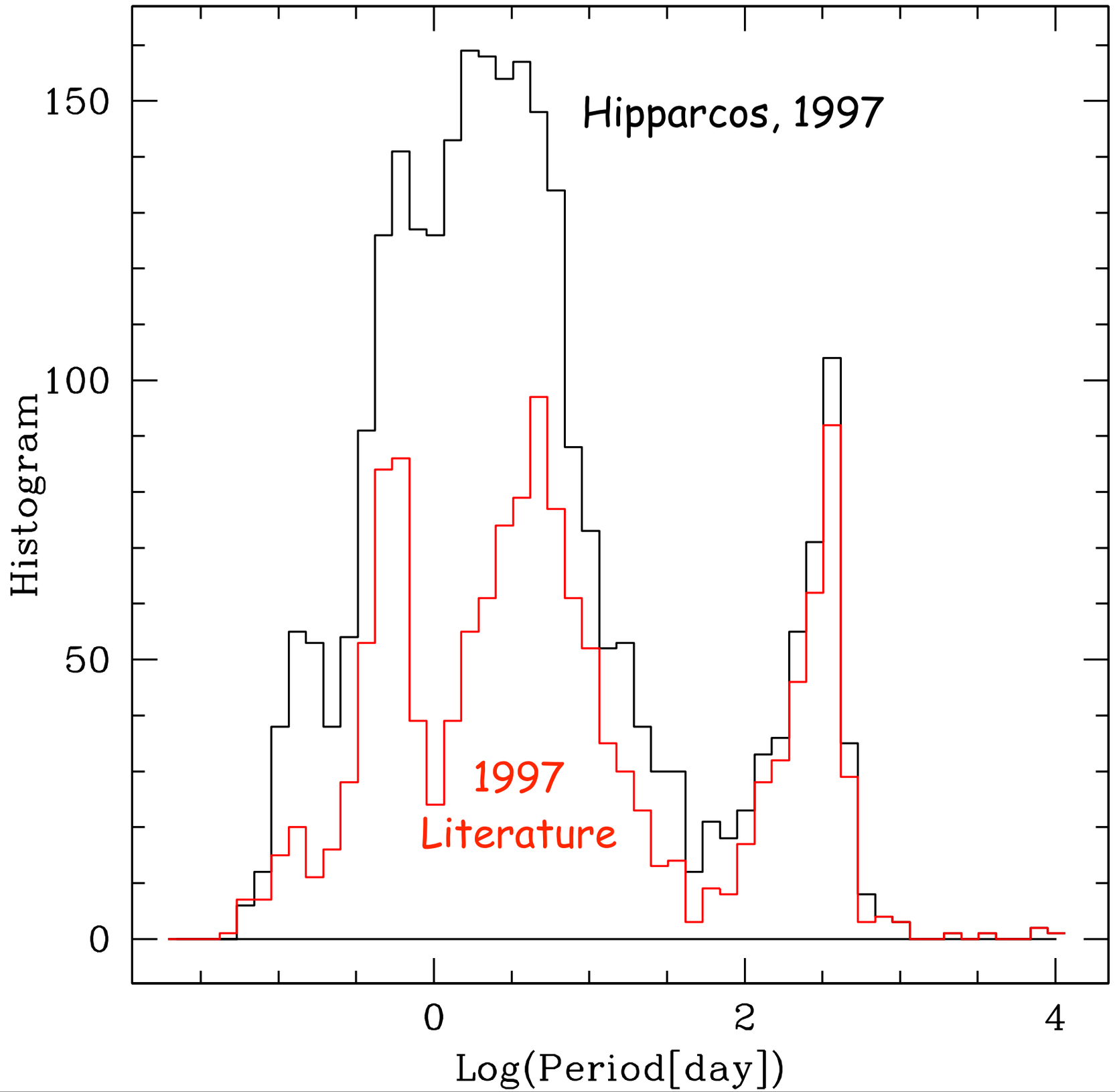
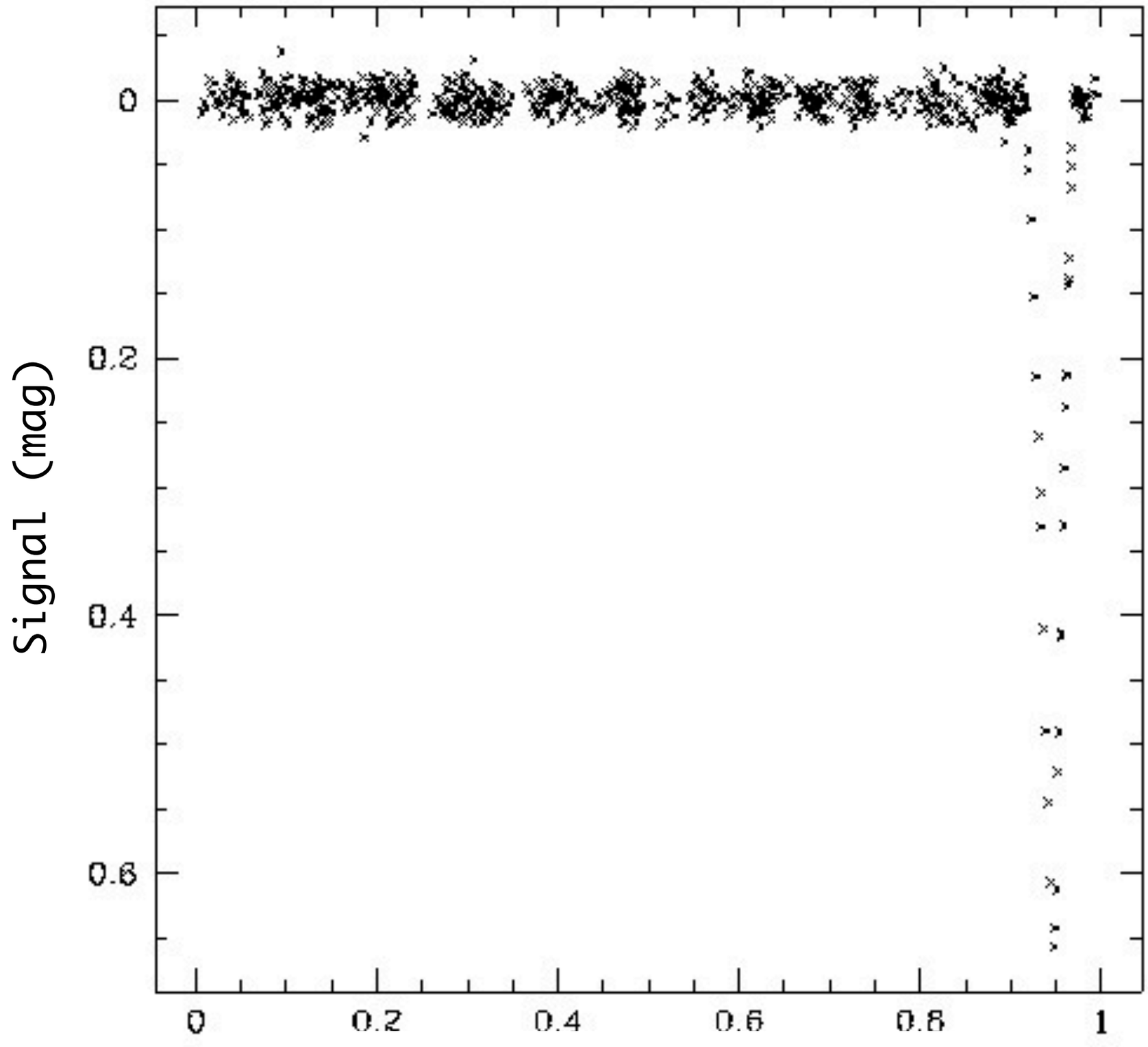
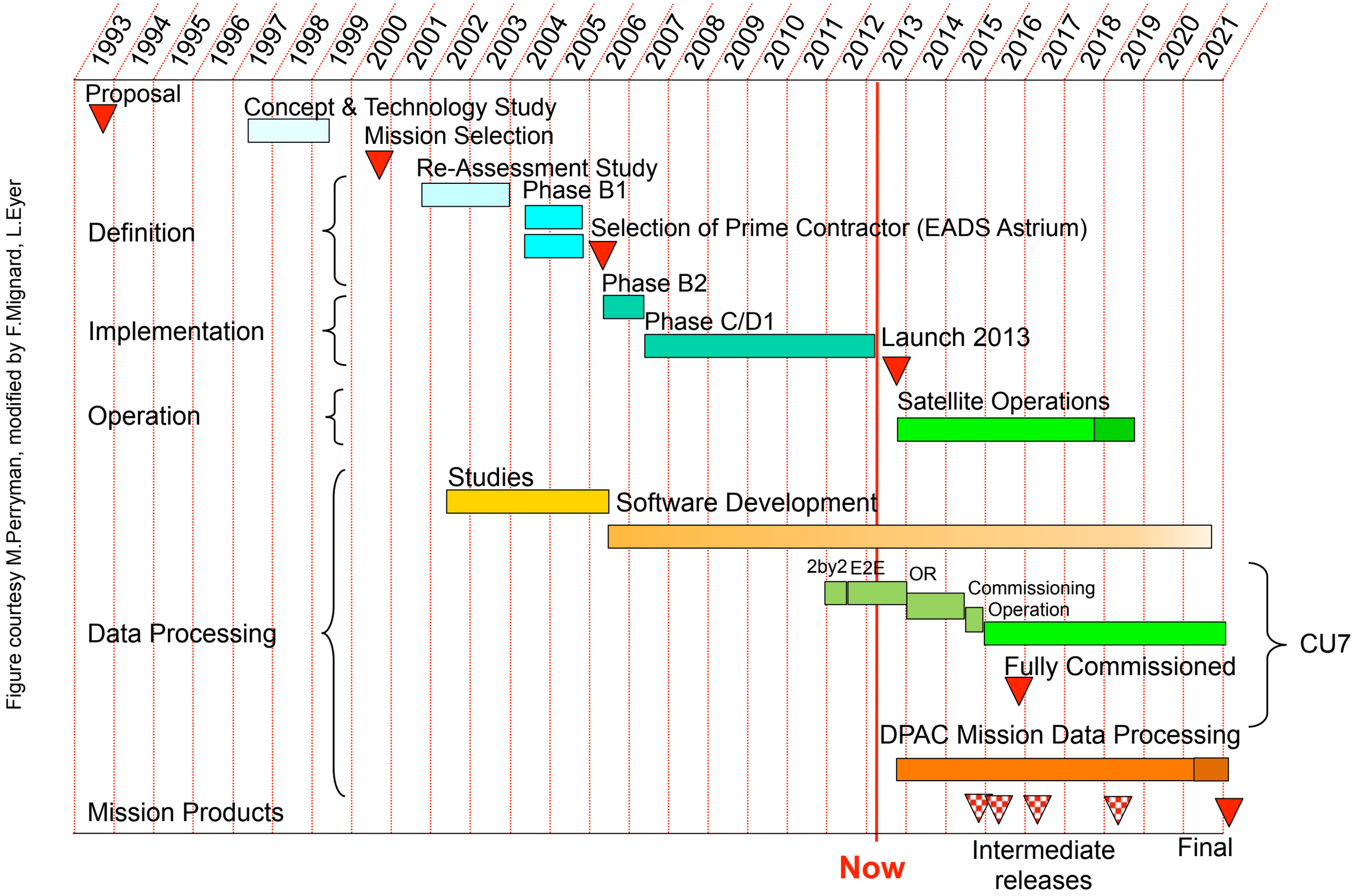


AM CVn stars



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

The schedule: more than a quarter of a century!



The Gaia release scenario (CU9)

•Launch+22 months: positions, G-magnitudes (all sky, single stars), proper motions for Hipparcos stars (~50 μarcsec/yr) – the Hundred Thousand Proper Motions (HTPM) catalogue

•Launch+28 months: + radial velocities for bright star

•Launch+40 months: + first 5 parameter astrometric results (α, δ, π, μα, μδ) BP/RP data, more RVS spectra, astrophysical parameters, orbital solutions for short period binaries

•Launch+65 months: + variability, solar system objects

•End+3 years: final data release (~ 2021/22)

- Photometric Alert Systems
- Solar System Objects

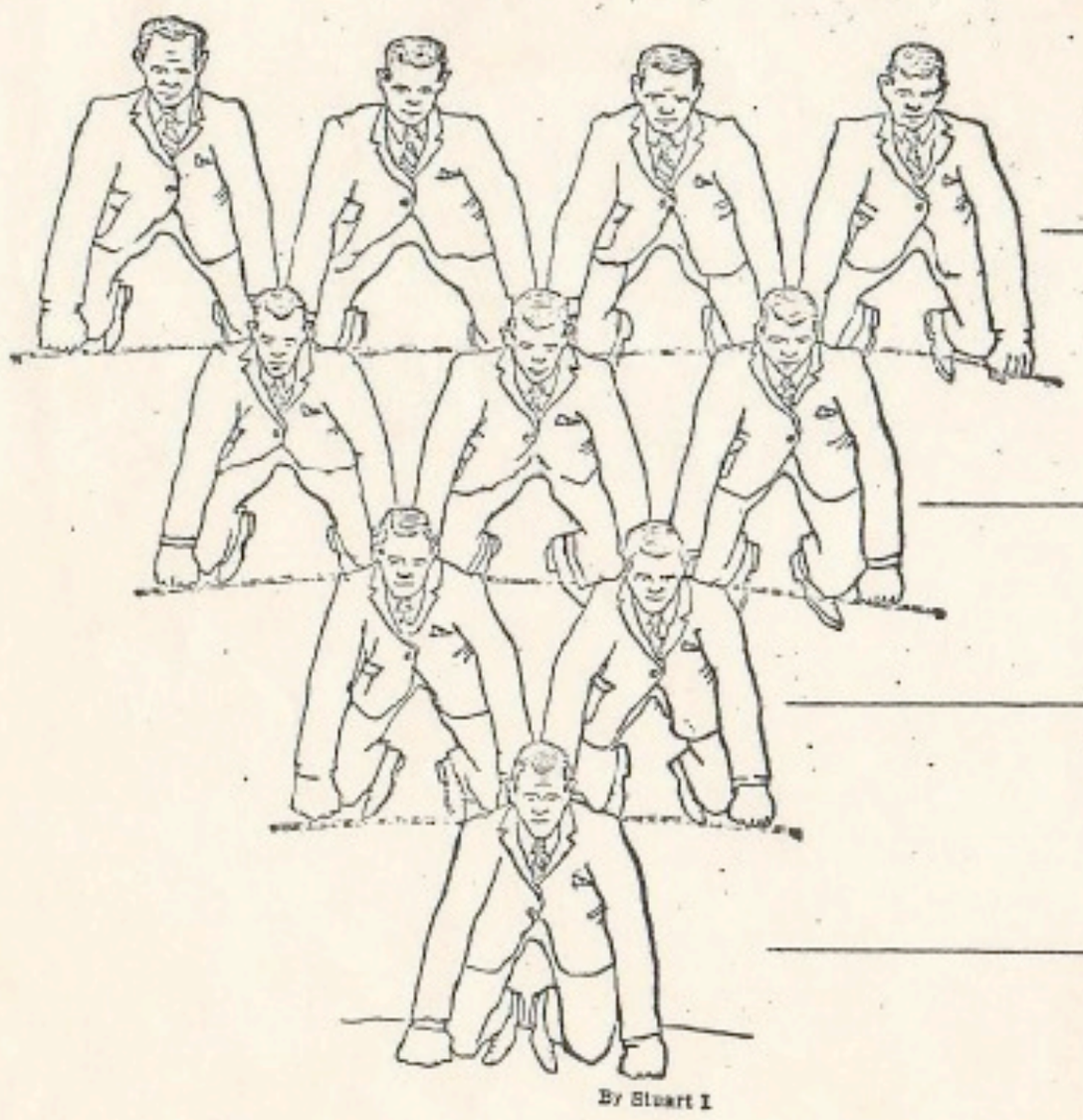
- Goal for variable object: Subgroups should be released

Probst 1974 pyramid

Probst 1974 pyramid

THE ASTRONOMICAL PYRAMID

ILLUSTRATING THE INTERDEPENDENCE OF THE VARIOUS AREAS OF STUDY



COSMOLOGISTS, GENERAL RELATIVISTS, CRANKS,
OTHER FUZZY-BRAINED PENCIL-PUSHERS.

ATMOSPHERES, INTERIORS, INTERSTELLAR MED.
THEORISTS

SPECTROSCOPISTS PHOTOMETRISTS

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Probst 1974 pyramid

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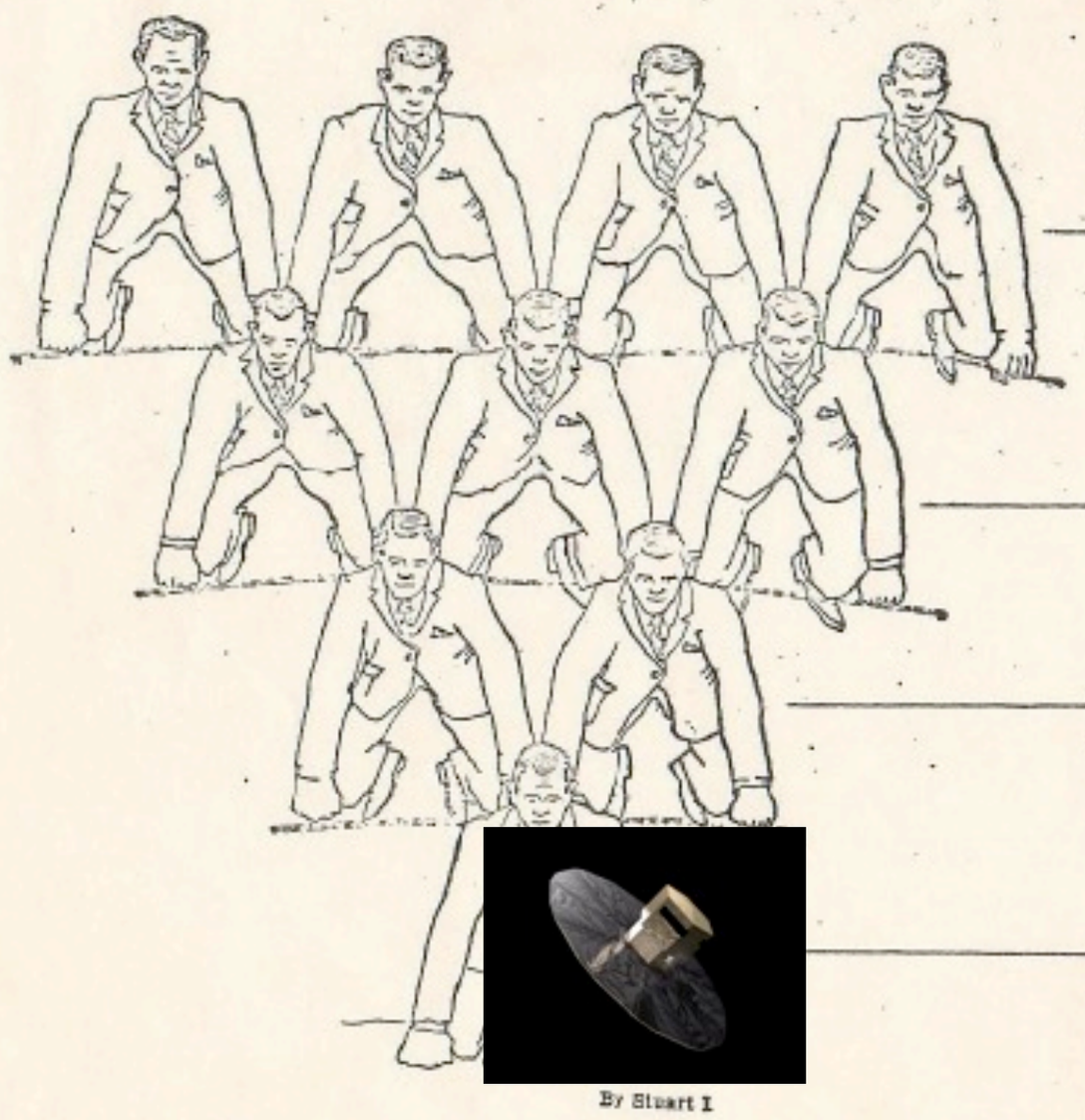

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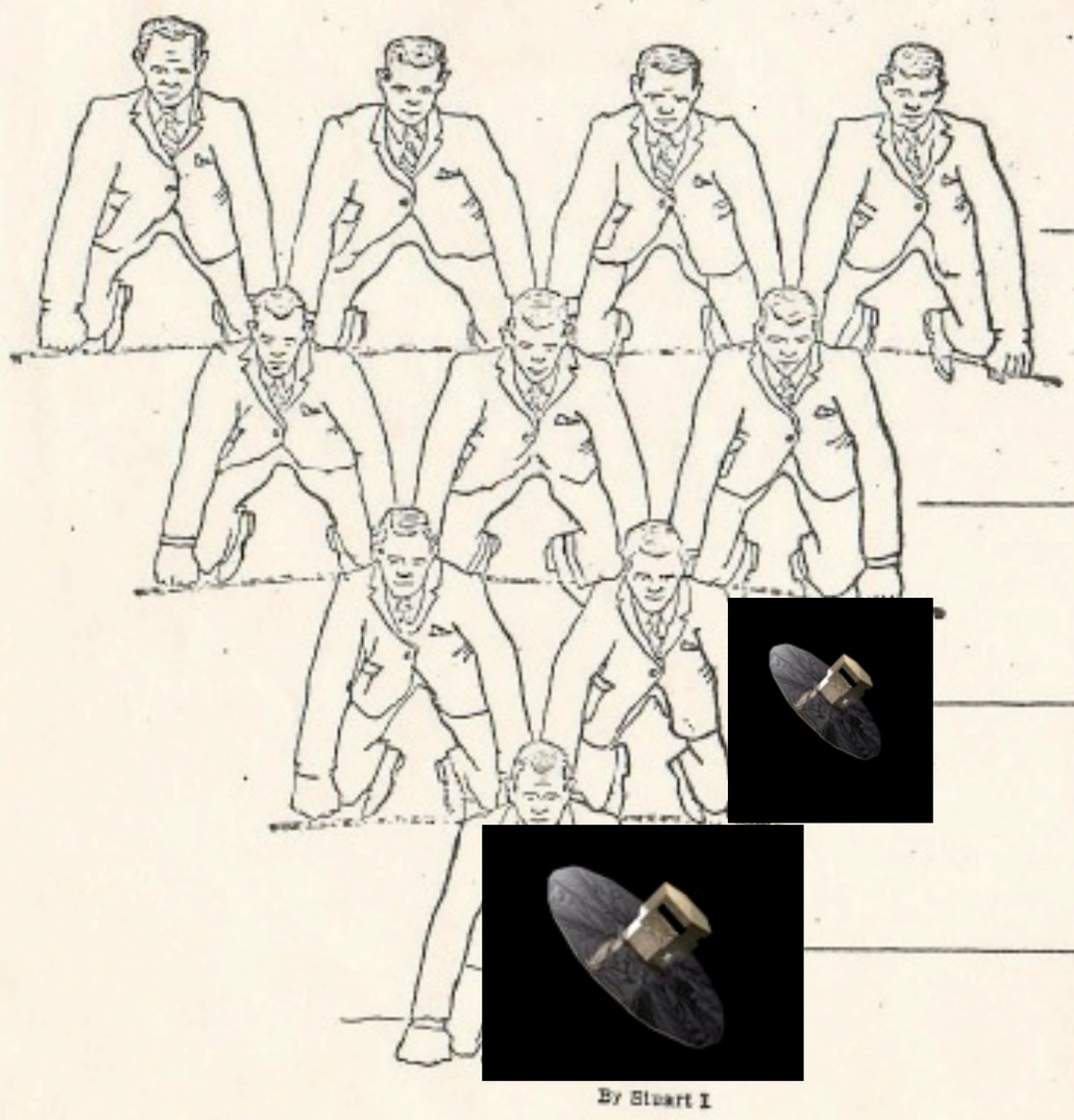

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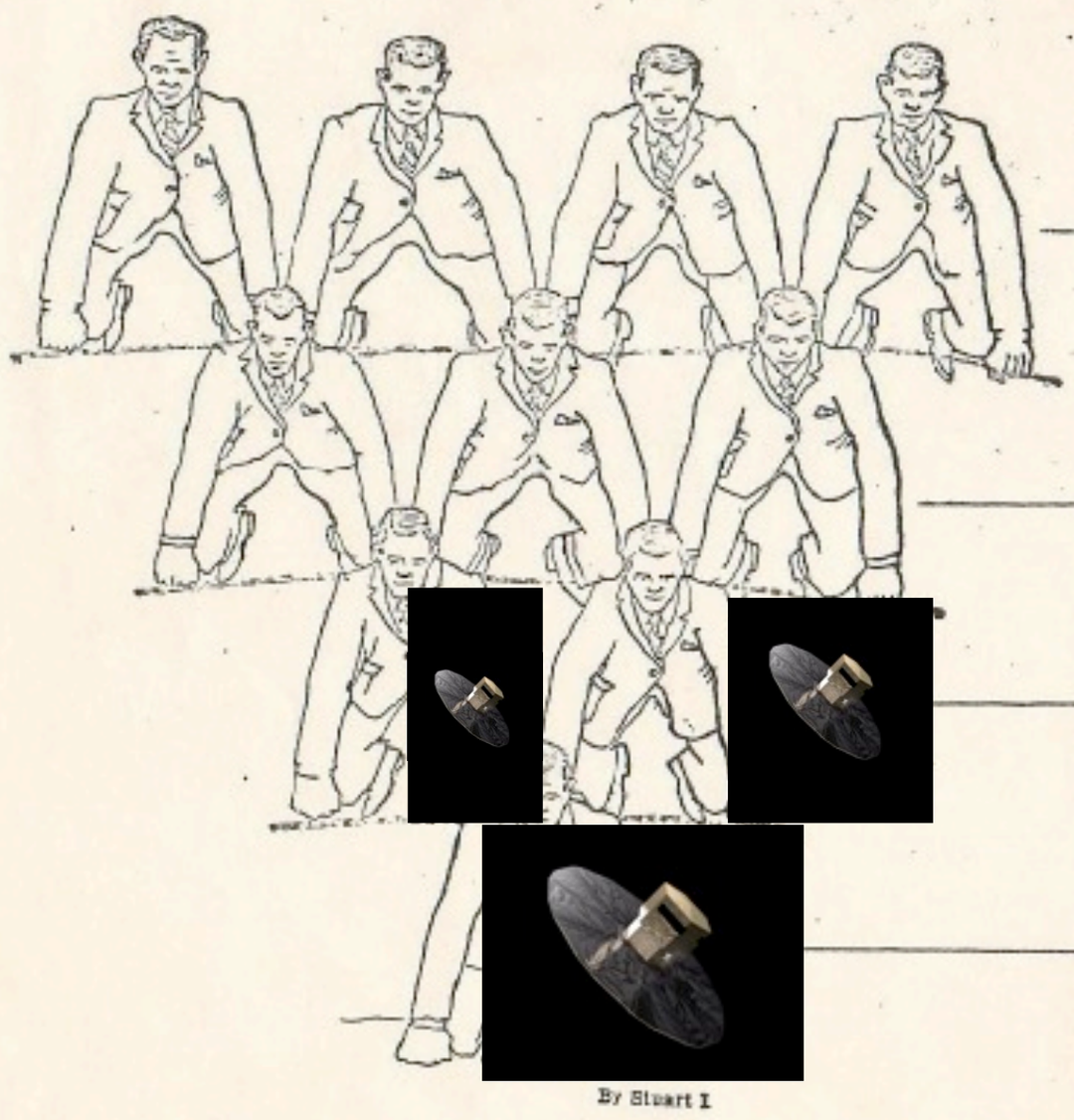

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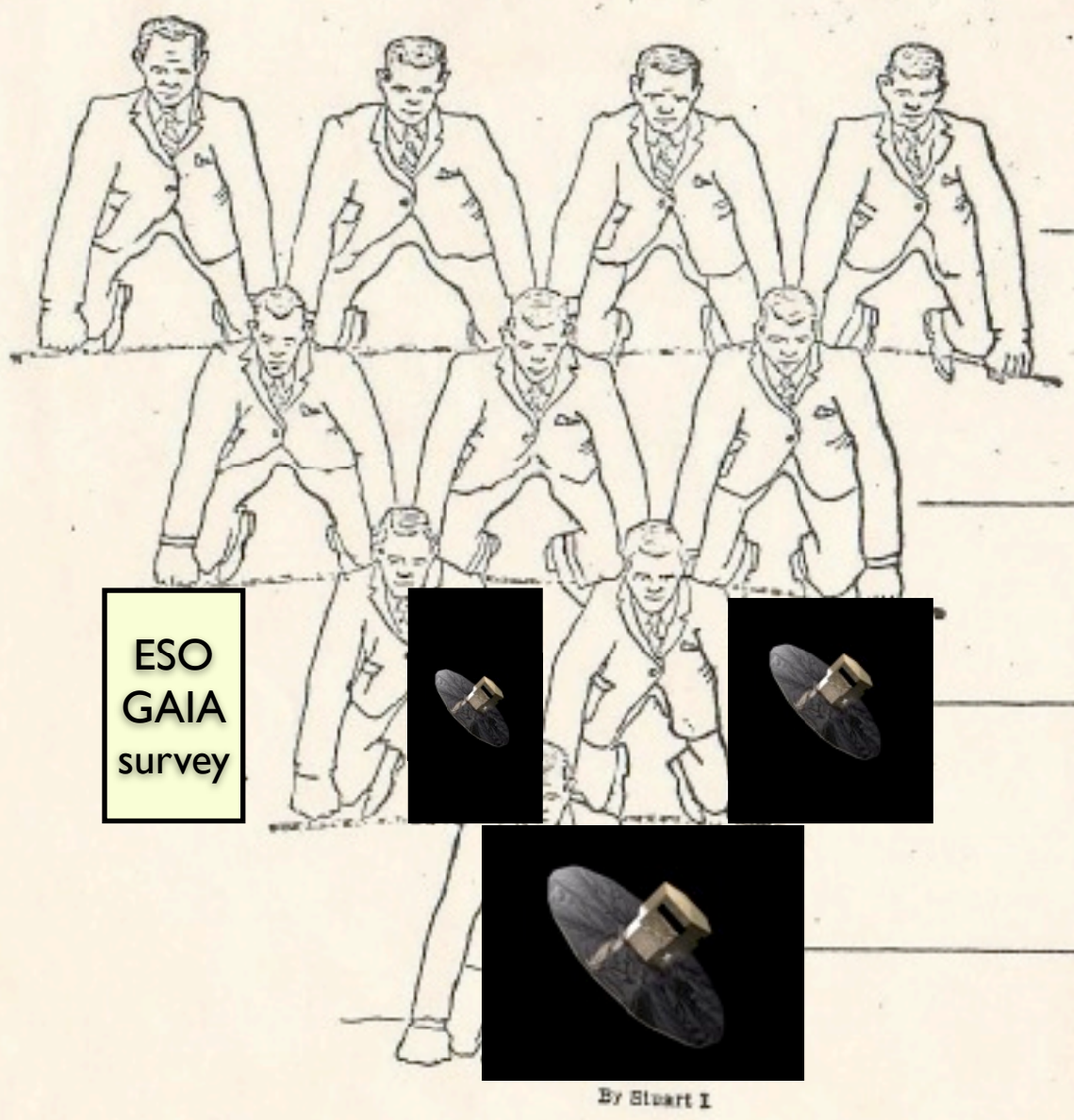

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ESO GAIA survey

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Thank you for
your attention!