Gaia
et
l'exploration des objets variables

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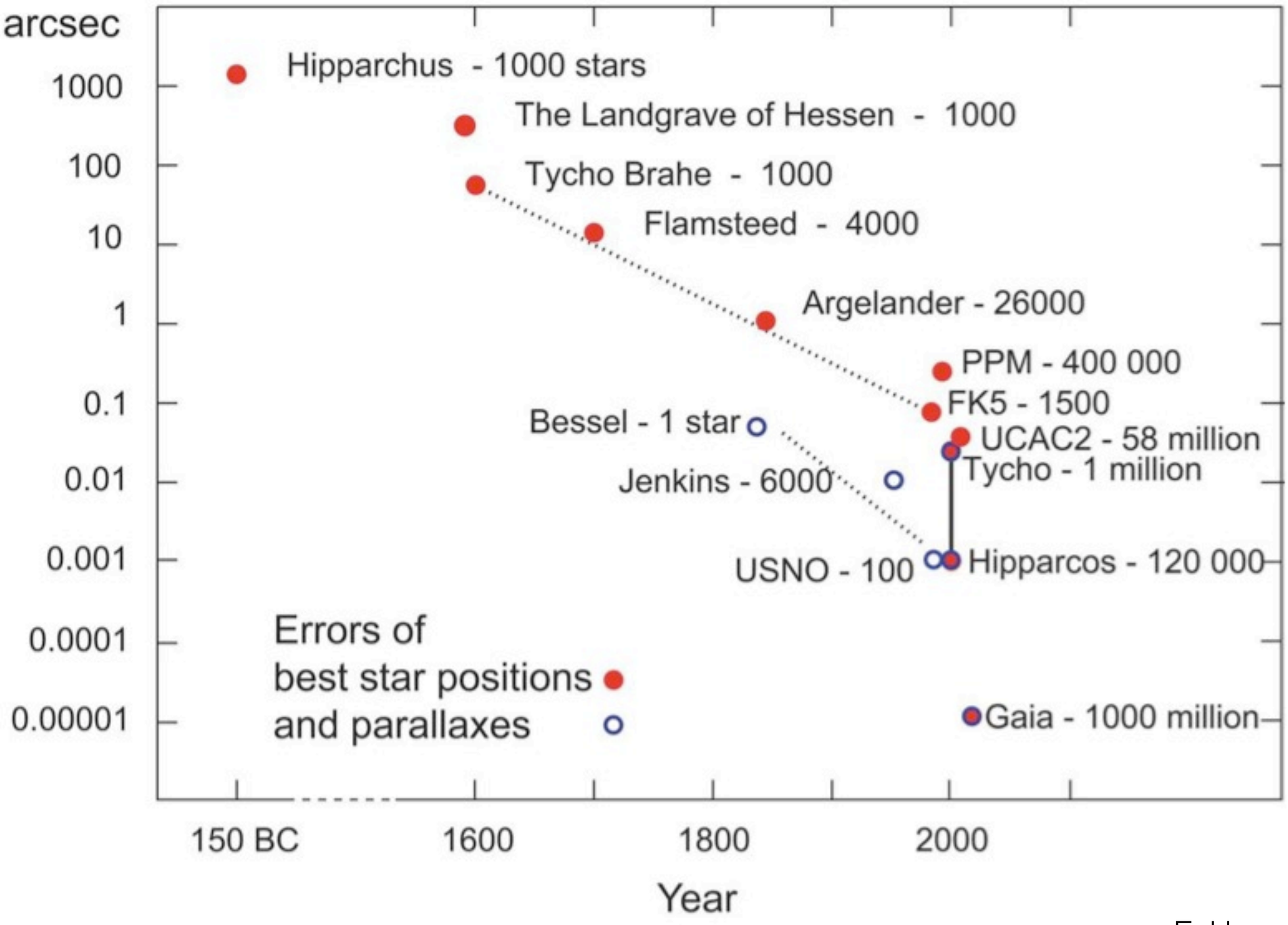
A. La mission
B. Status
C. Quelques résultats
D. Participations à la mission

A. La mission

The Gaia mission

- Cornerstone mission of the European Space Agency
- Observations of ~1.5 billion objects 2 mag < V < 20.7 mag,
- Astrometry, photometry, spectrophotometry, and spectroscopy (radial velocities)
- Launched 19/12/2013 (Soyuz rocket, French Guyana)
- Duration: 5 (+1) years (~70 times all sky)
- Final Catalog: 2021-2022

The Gaia mission - Astrometric performance



E. Hoeg 2003

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%

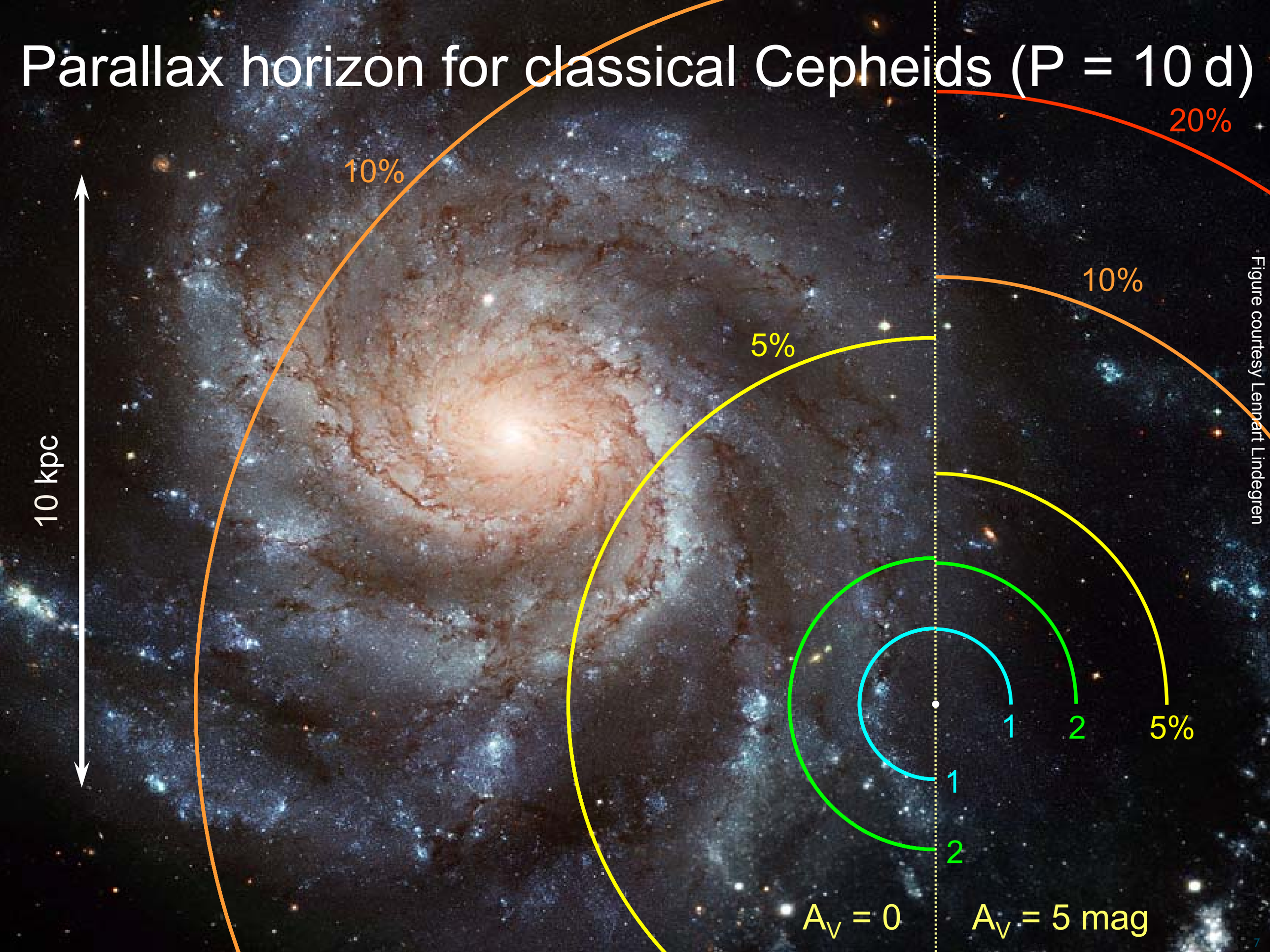
1

2

5

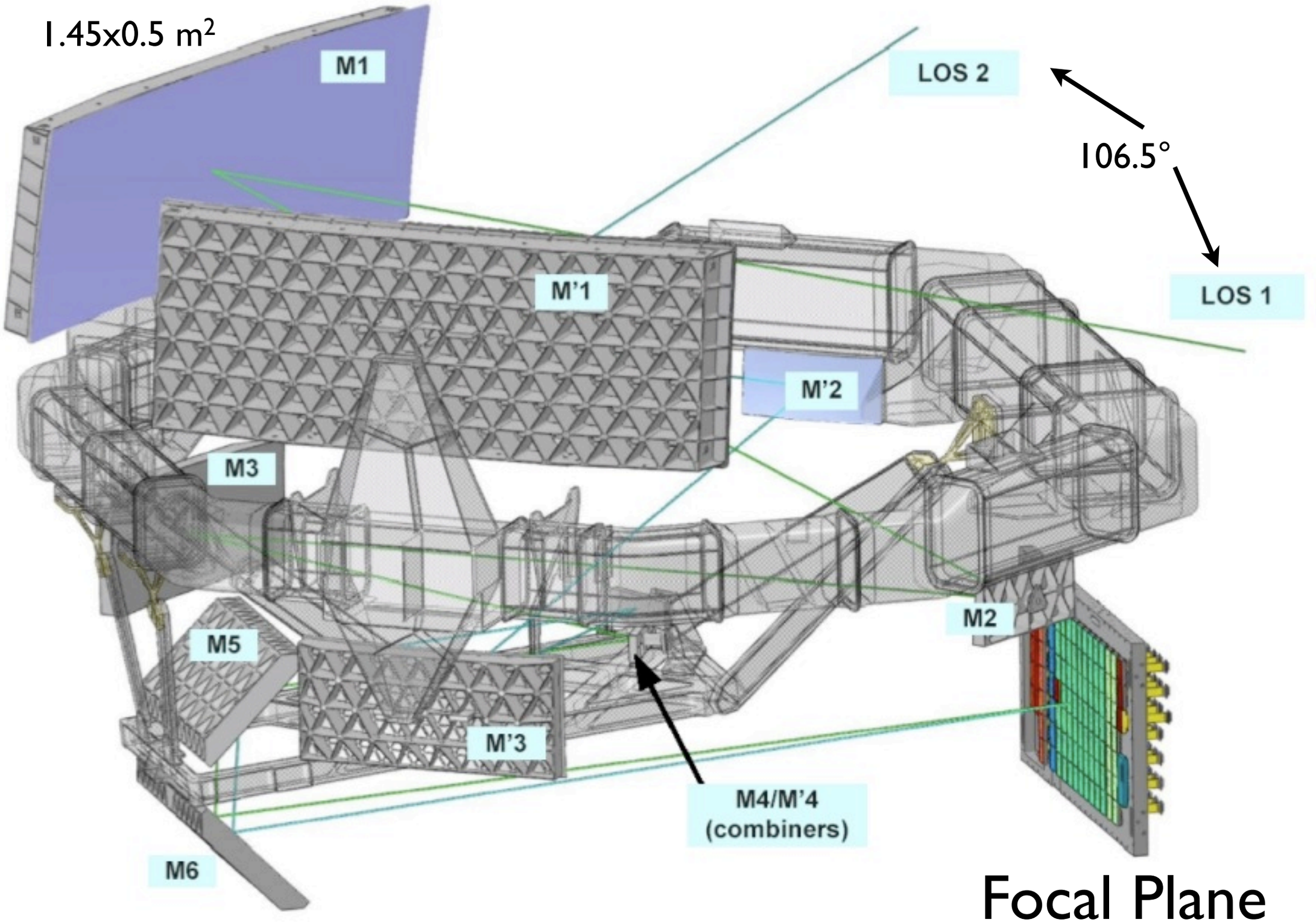
Figure courtesy Lennart Lindegren

Parallax horizon for classical Cepheids (P = 10 d)



The instruments

Two fields of view



The instruments

Primary mirror

The instruments

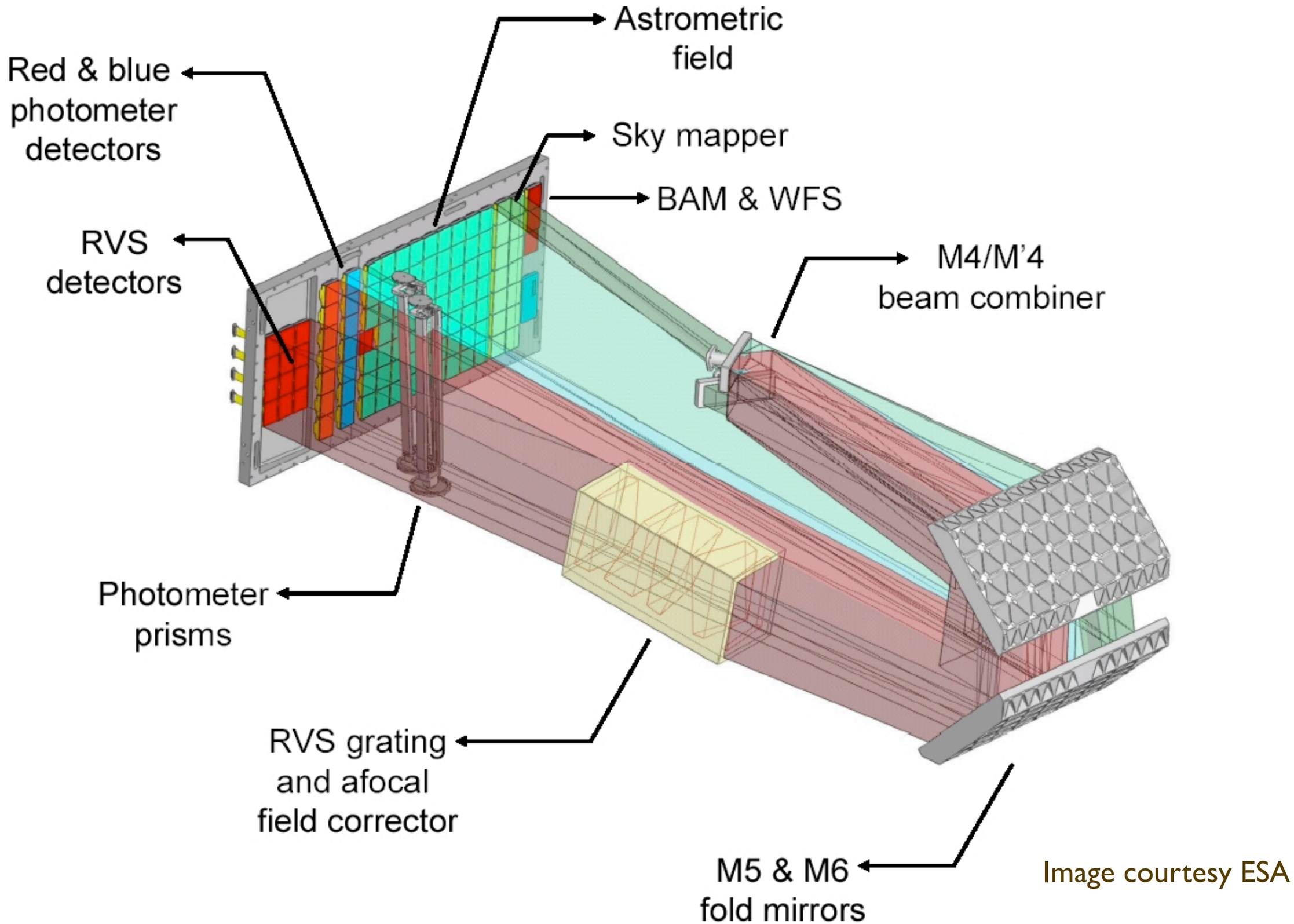
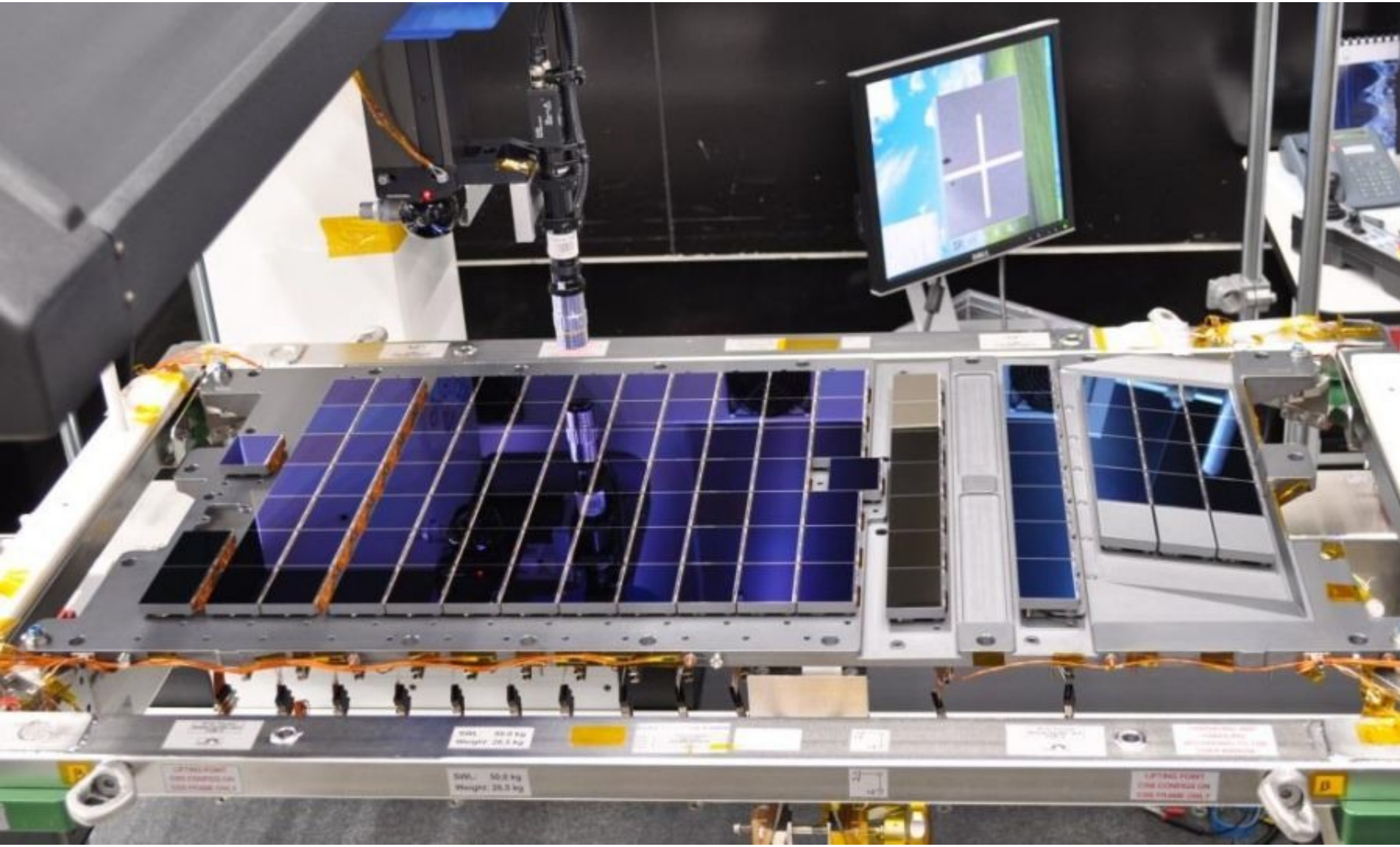


Image courtesy ESA

The instruments

Focal plane



The instruments - the focal plane

106 CCDs (4500 x 1966 pixels each; pixel size = 10 µm x 30 µm = 59 mas x 177 mas)

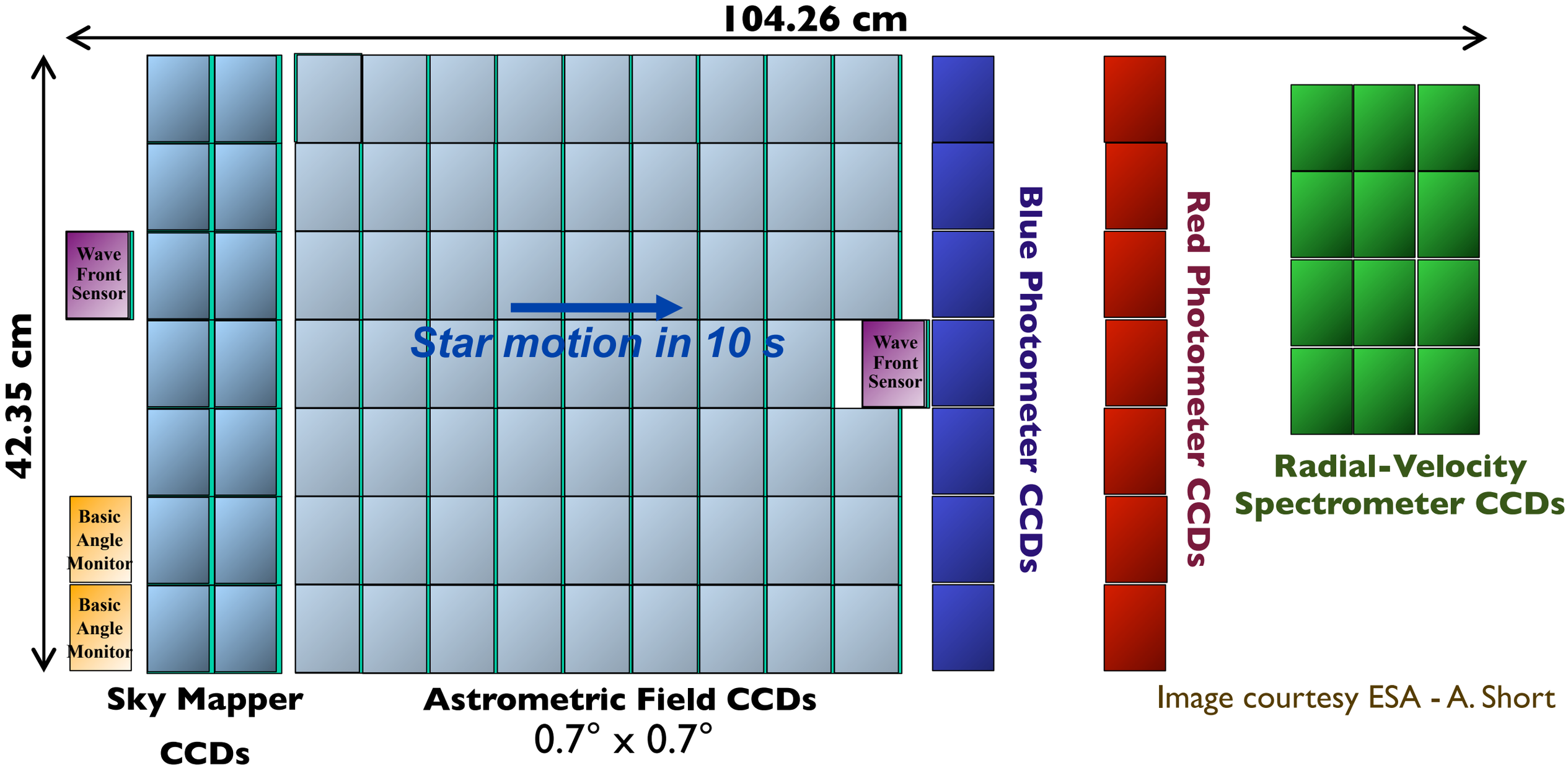


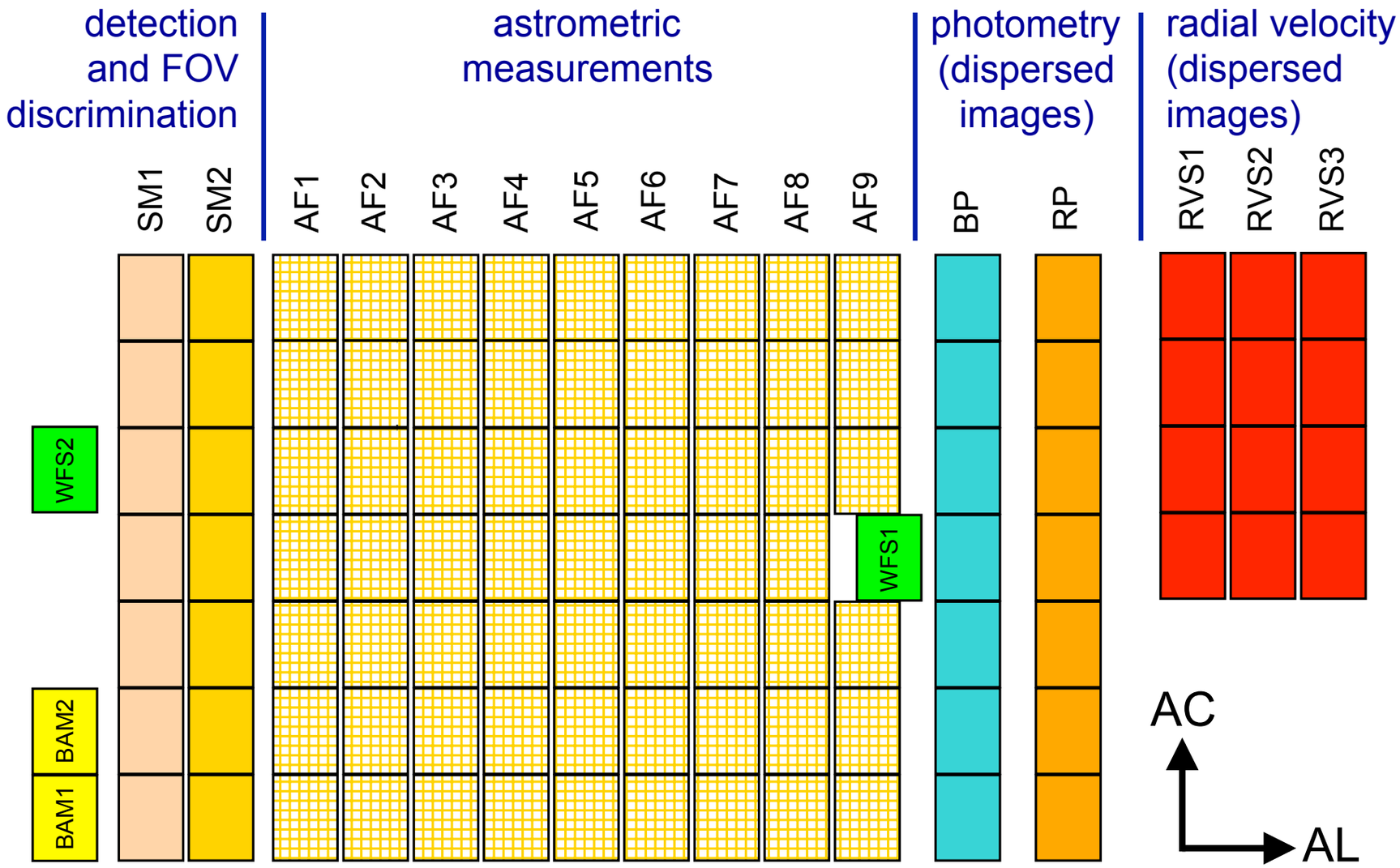
Image courtesy ESA - A. Short

Astrometry
G band photometry
Time Delay Integration
4.4 sec to cross a CCD

Spectro-photometry
Low-resolution spectra
BP : 320 - 660 nm
RP : 650 - 1000 nm

Spectroscopy
847 - 874 nm
$\lambda/\Delta\lambda$ = 11500

Transit observations

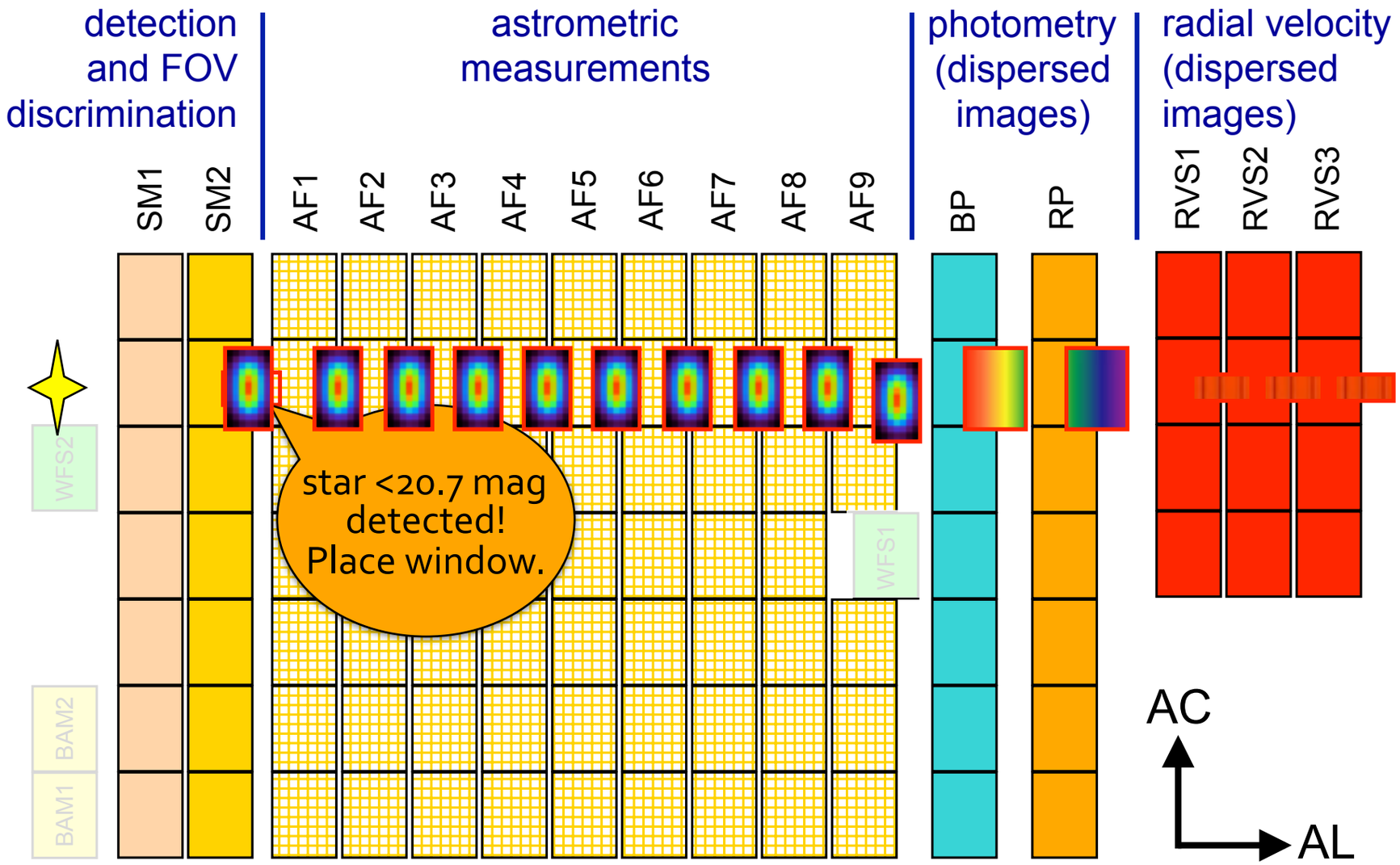


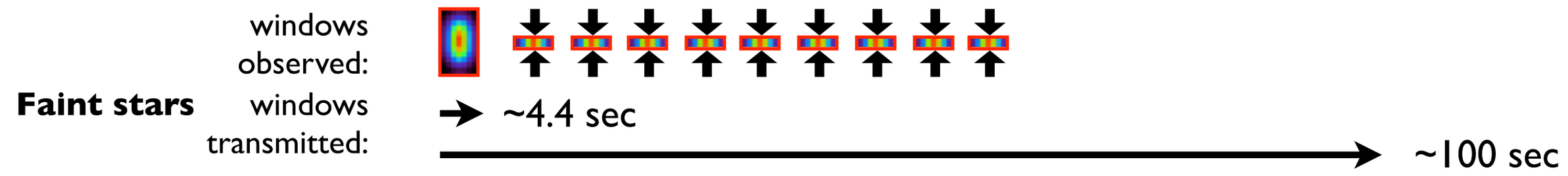
FoV: 0.7 deg x 0.7 deg
pixel: 0.059”(AL) x 0.177”(AC)

Courtesy B. Holl

Transit observations

50 GB / day





Alternative ESA video: http://sci.esa.int/gaia/53281-inside-gaias-billion-pixel-camera/

Courtesy B. Holl

Transit observations

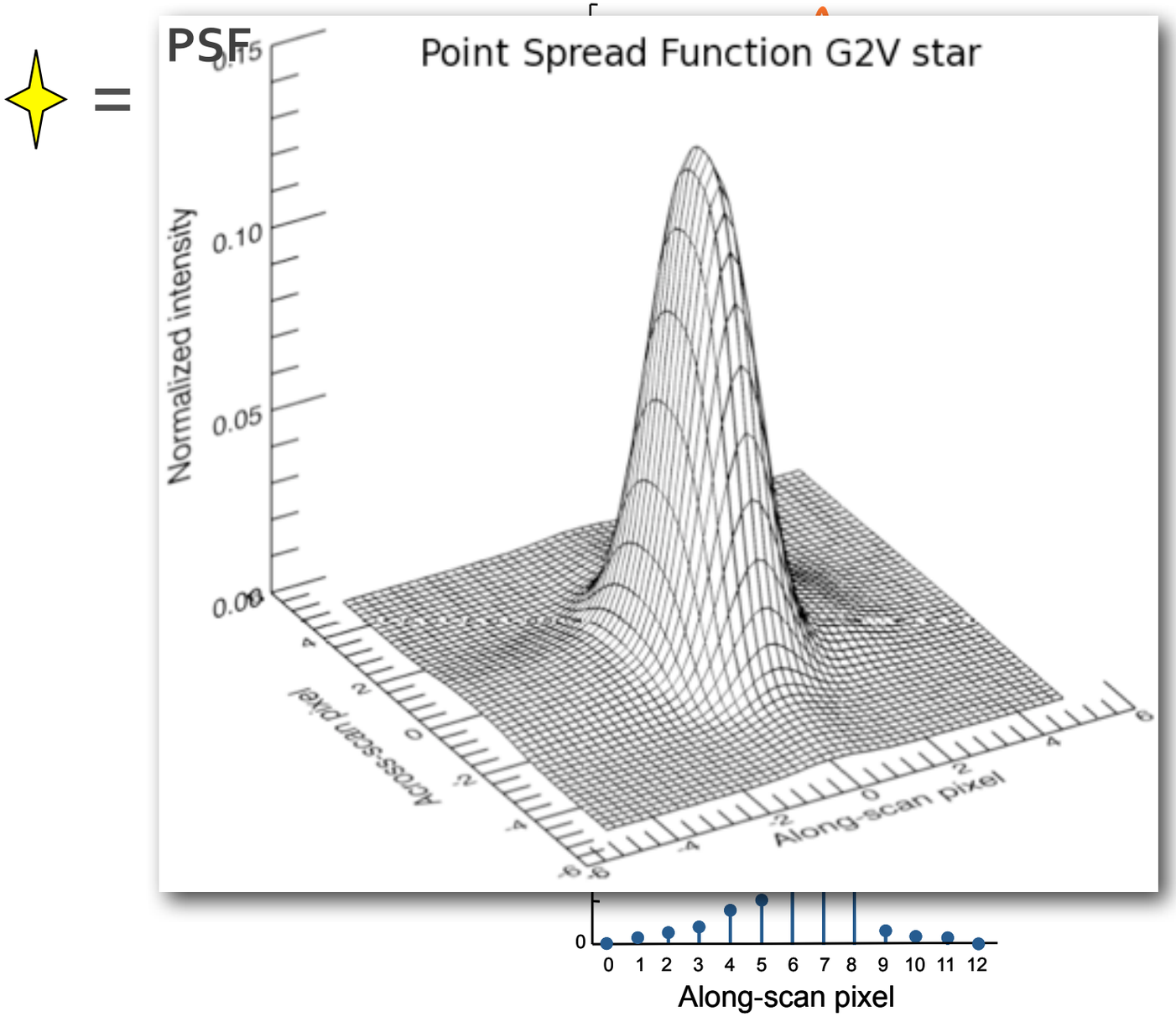


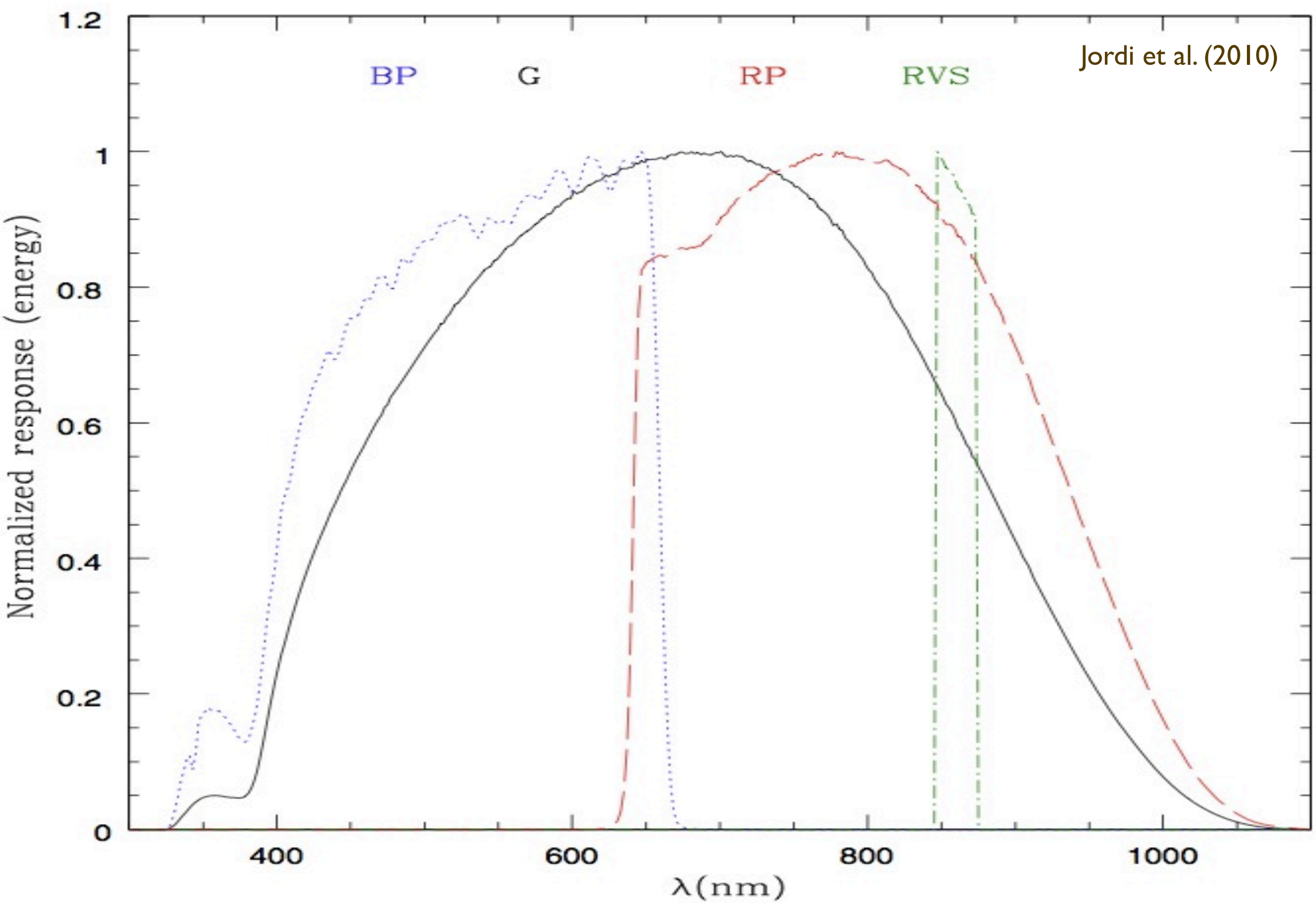
Image parameter estimation

'centroiding' gives:

$t_l \rightarrow t_1,\ t_2,\ t_3,\ \ldots$

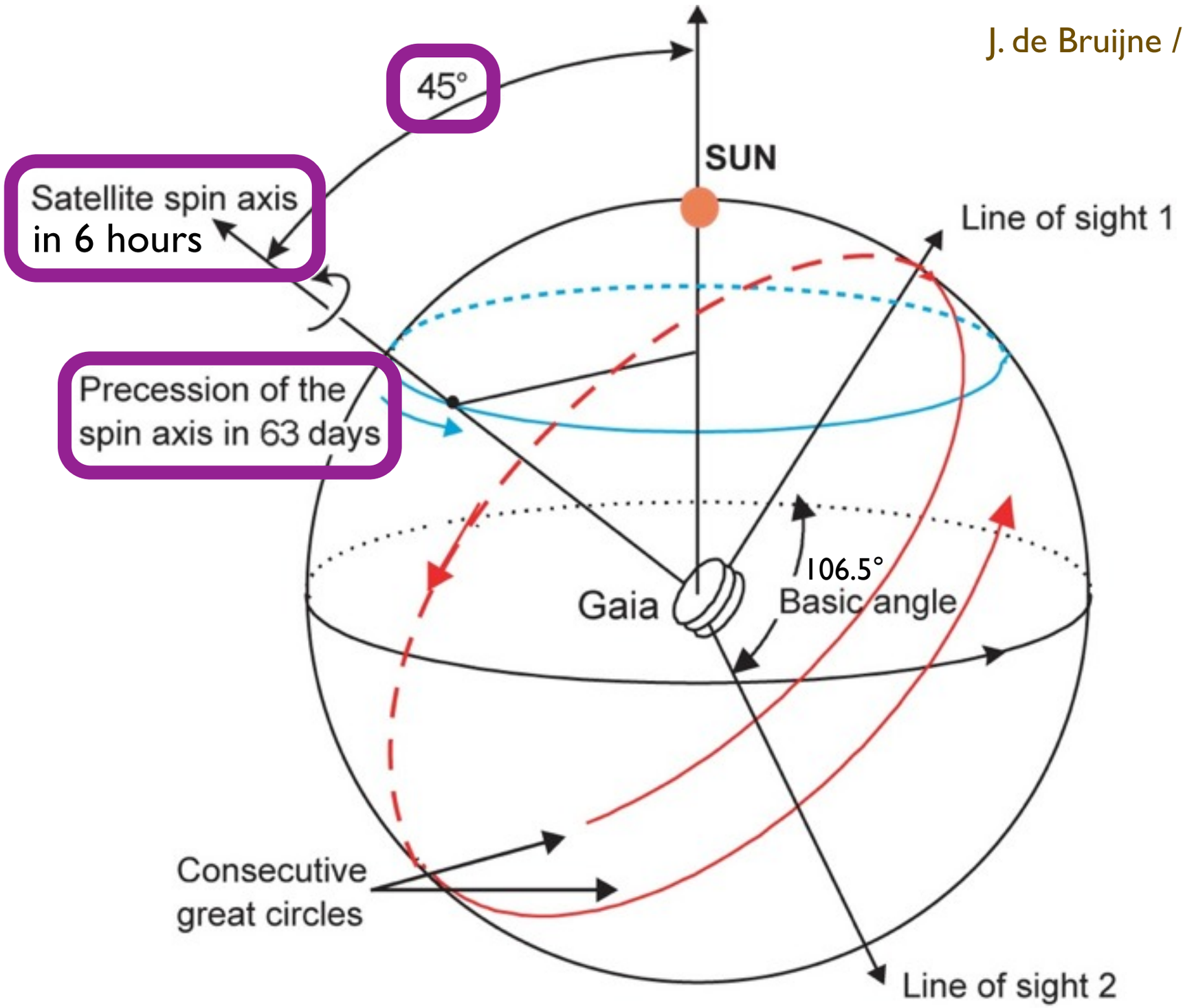
Courtesy B. Holl

The instruments - spectral coverage



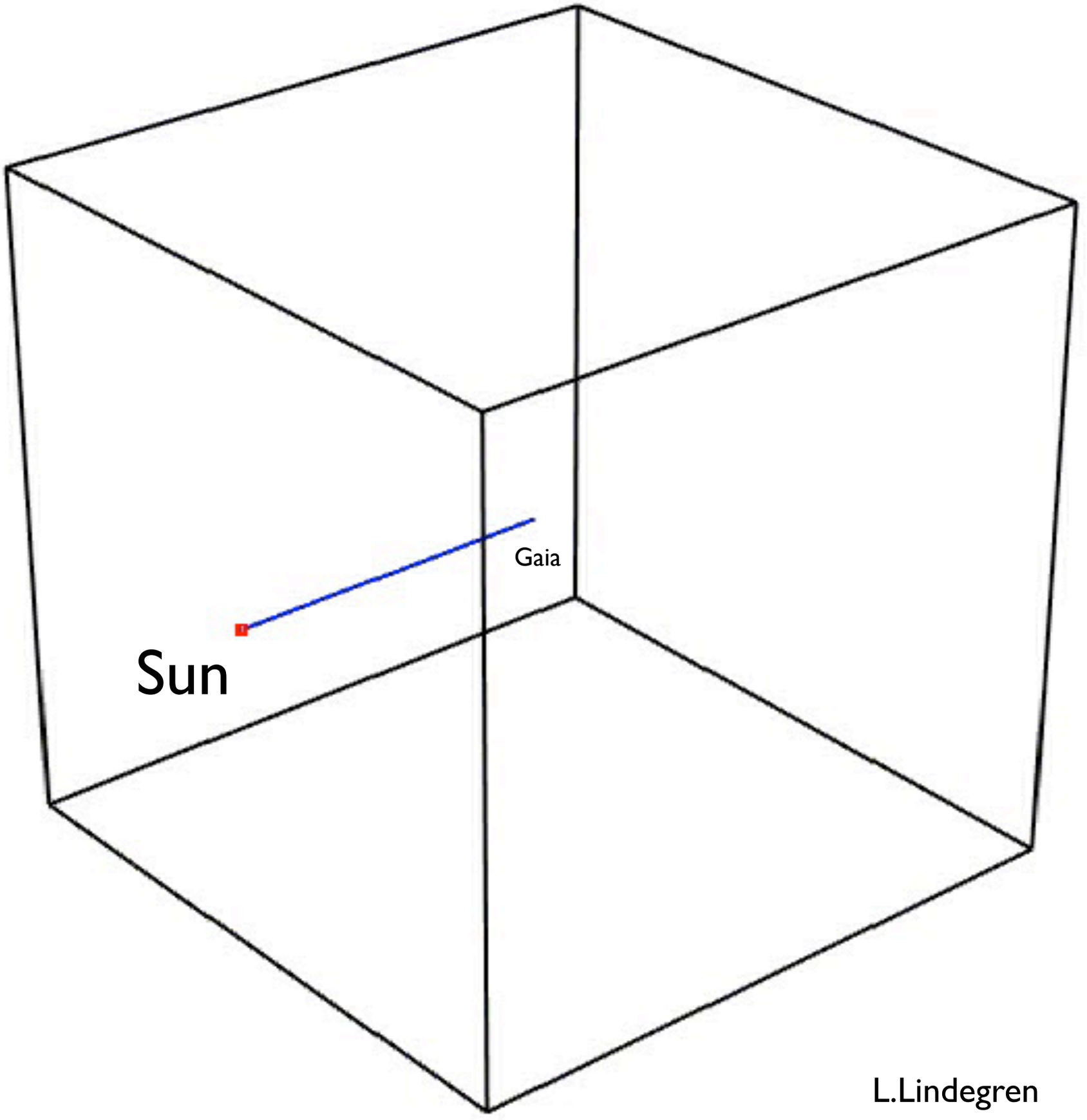
The scanning law

J. de Bruijne / ESA



The scanning law

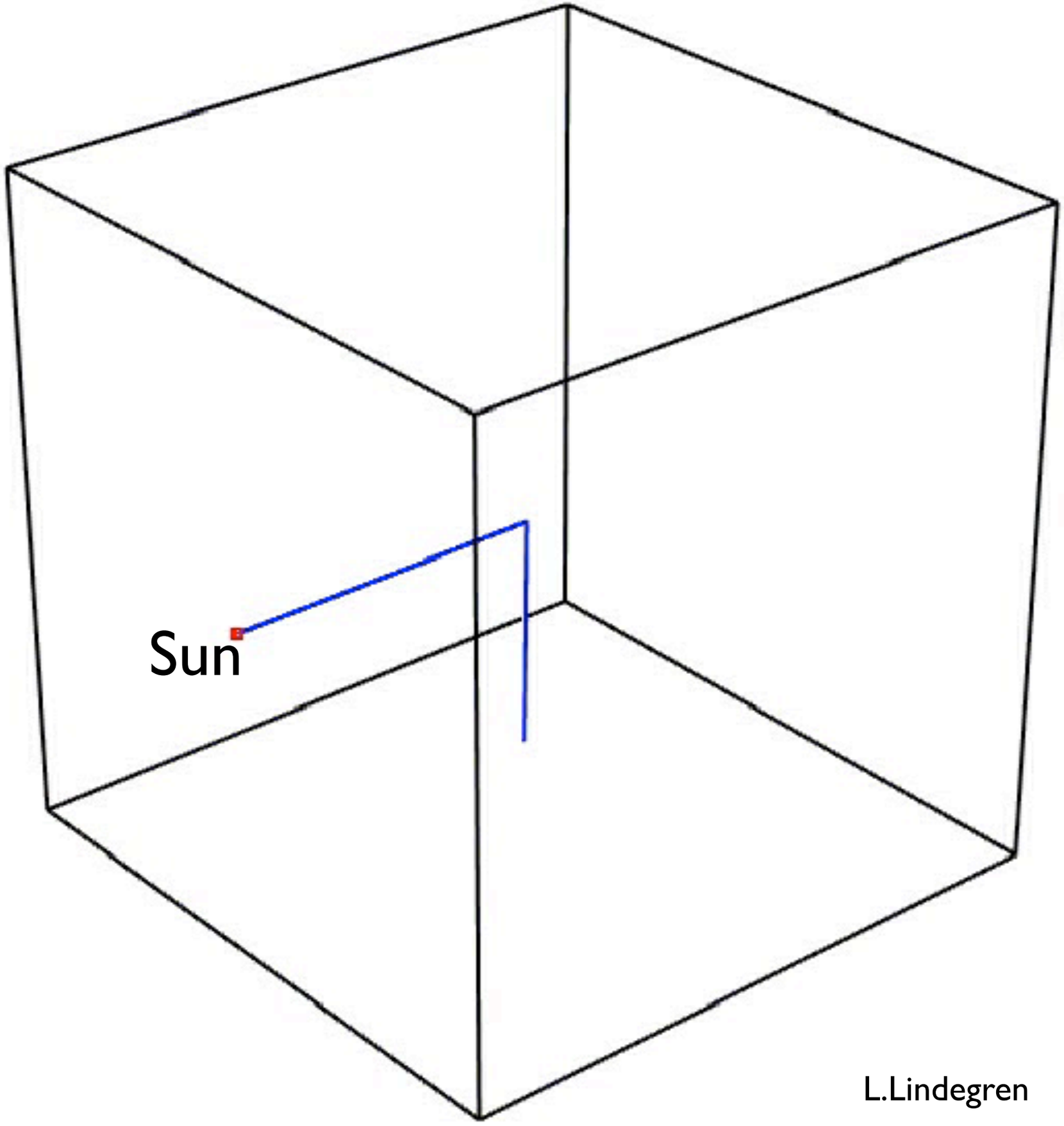
1. Sun motion



The scanning law

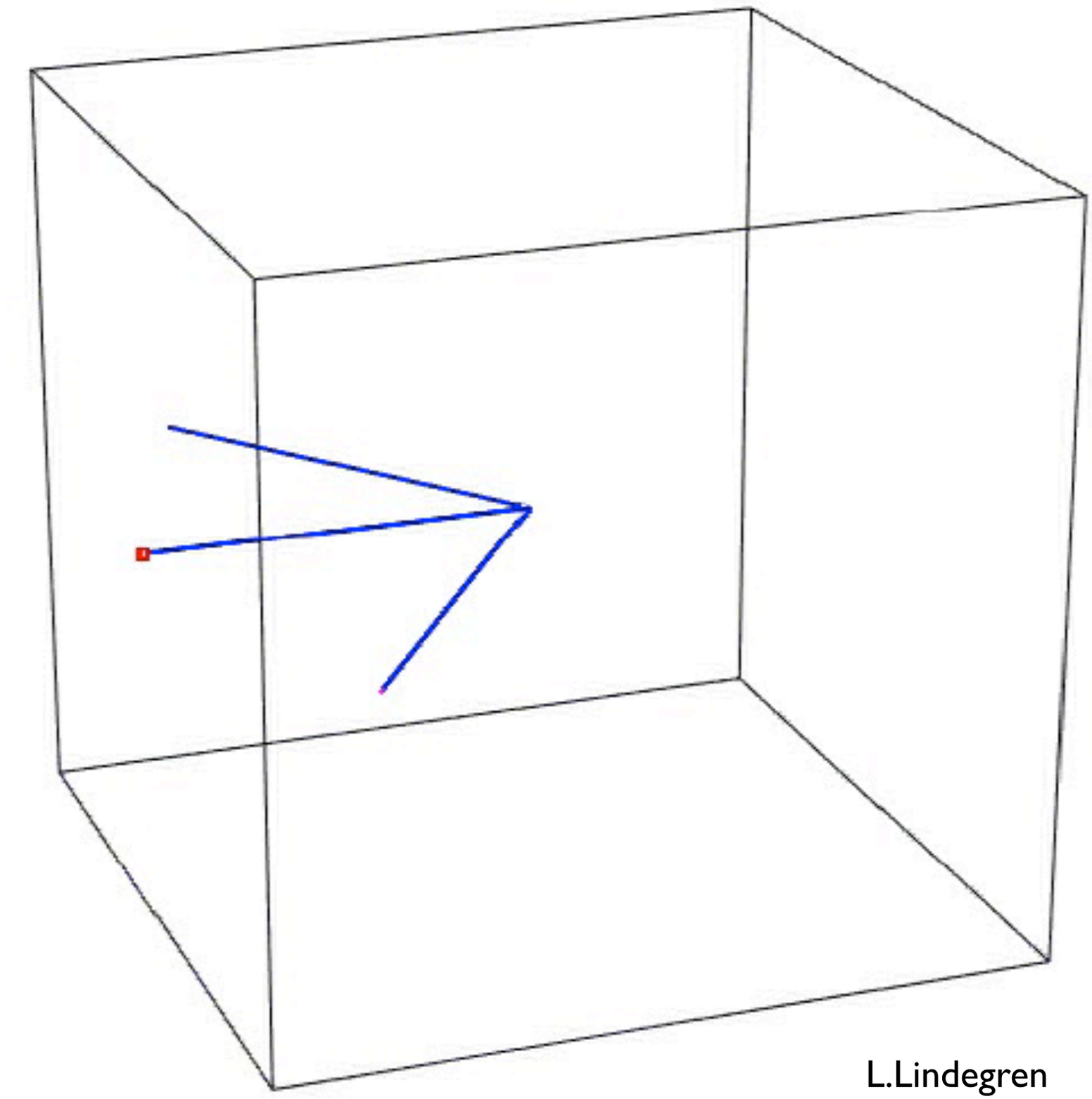
1. Sun motion
2. Gaia rotation axis
   *precession in **63 days***

Constant angle to the Sun: 45°



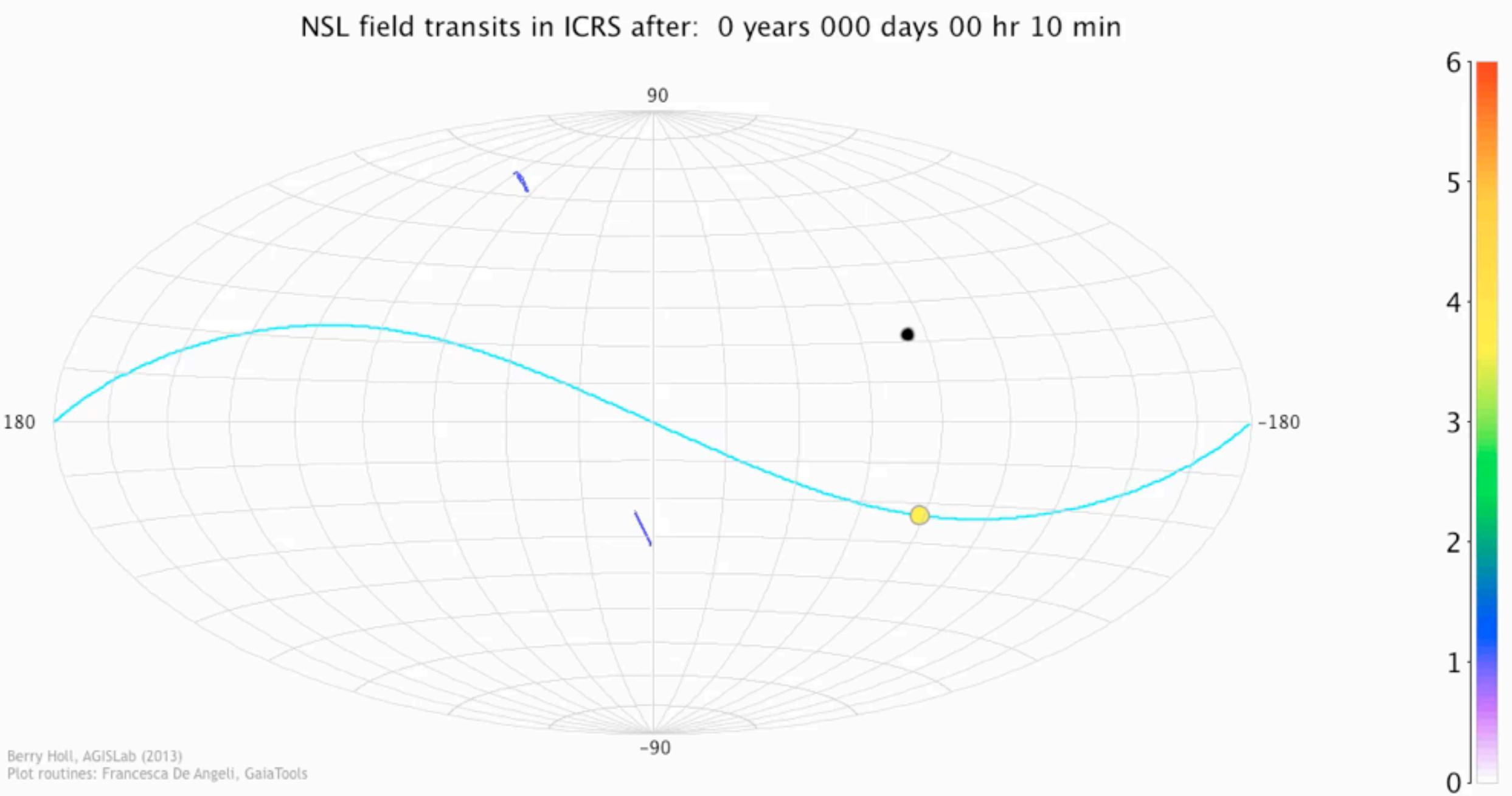
The scanning law

1. Sun motion
2. Gaia rotation axis
   *precession in **63 days***
3. One astrometric FOV
   *rotation in **6 hours***



L.Lindegren

The scanning law

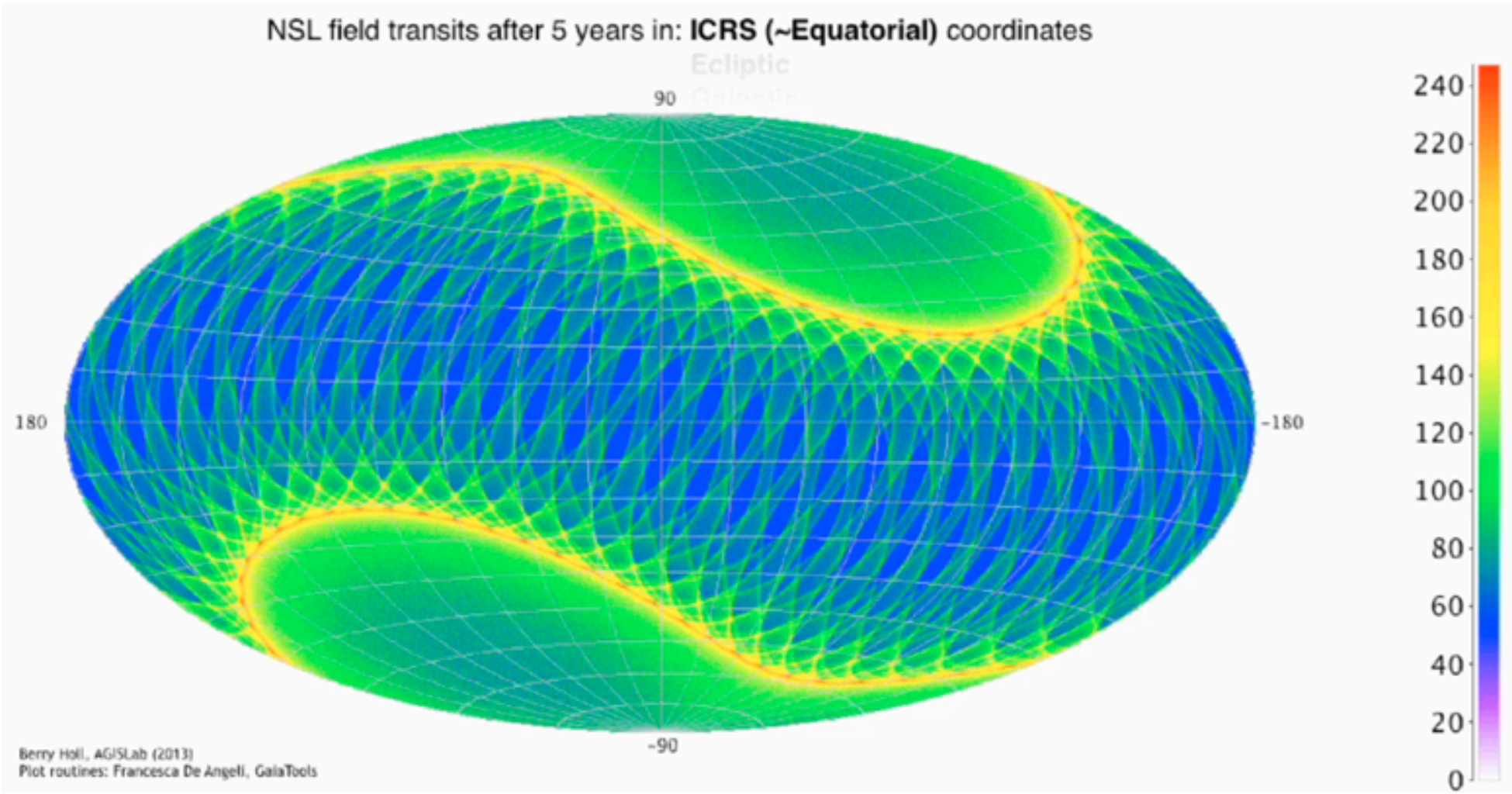


Mean of 70 measurements (40 - 250)

Courtesy B. Holl

On youtube: https://www.youtube.com/watch?v=IRhe2grA9wE

The scanning law

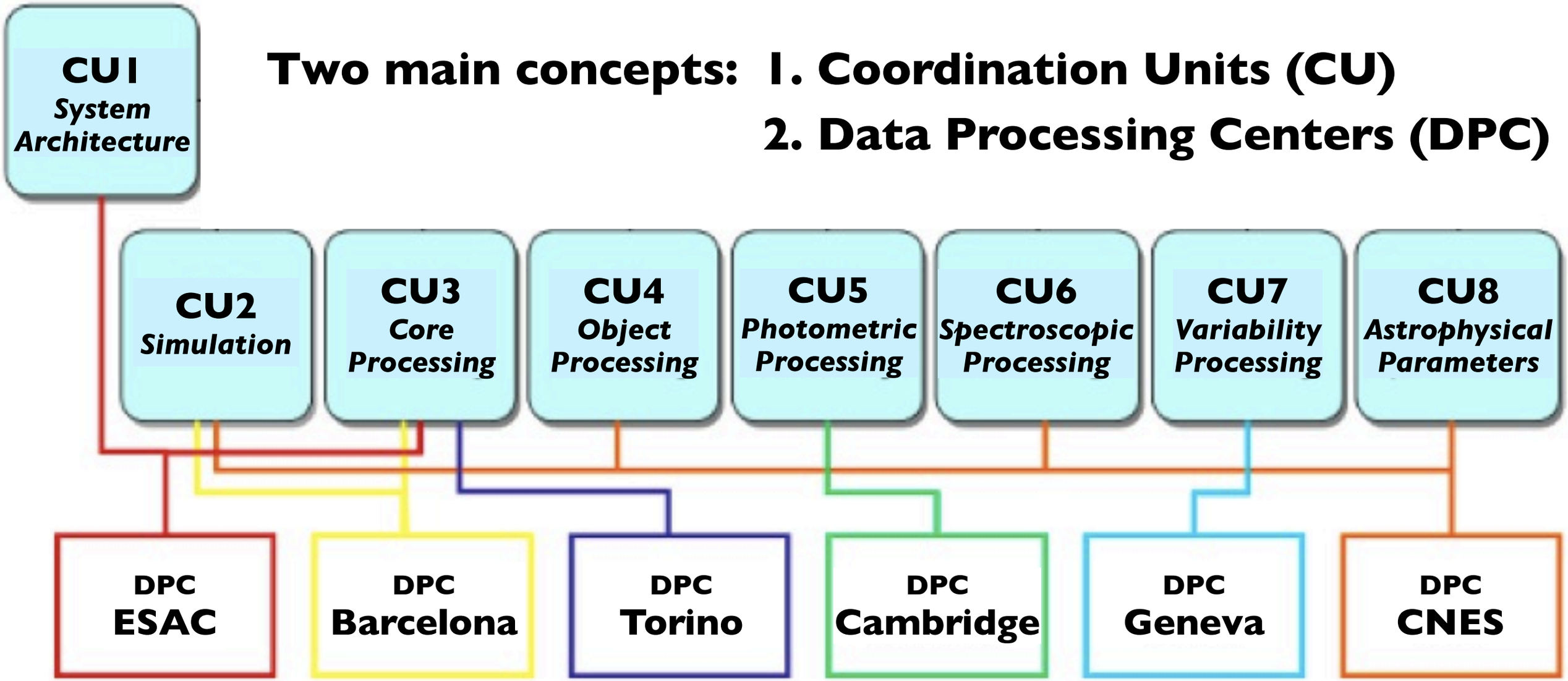


+ Ecliptic Pole Scanning Law
during 1 month commissioning

Data processing

The Data Processing and Analysis Consortium (DPAC)

Two main concepts: 1. Coordination Units (CU)
2. Data Processing Centers (DPC)



~500 people (scientists + software engineers)

Variability processing

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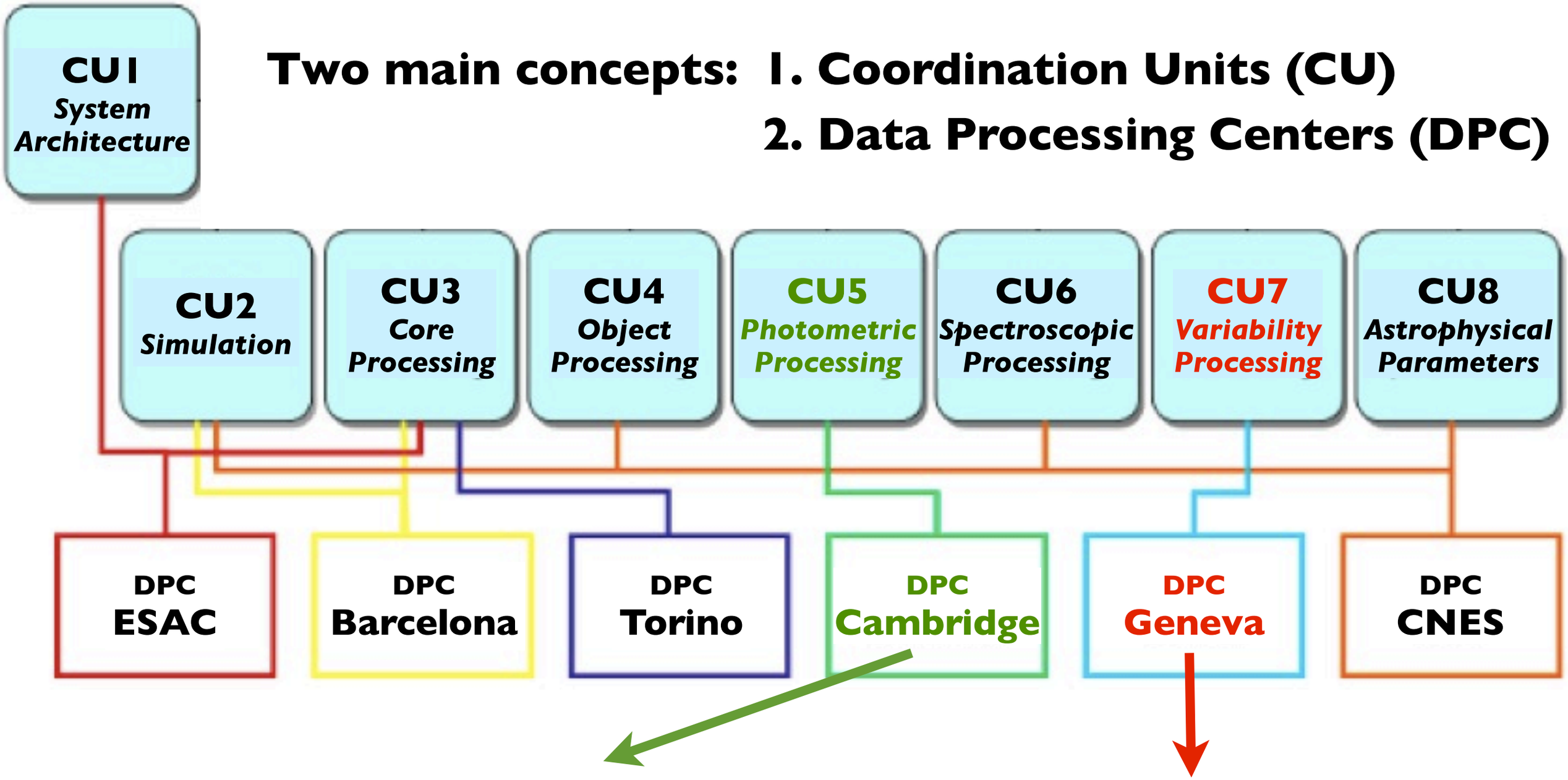
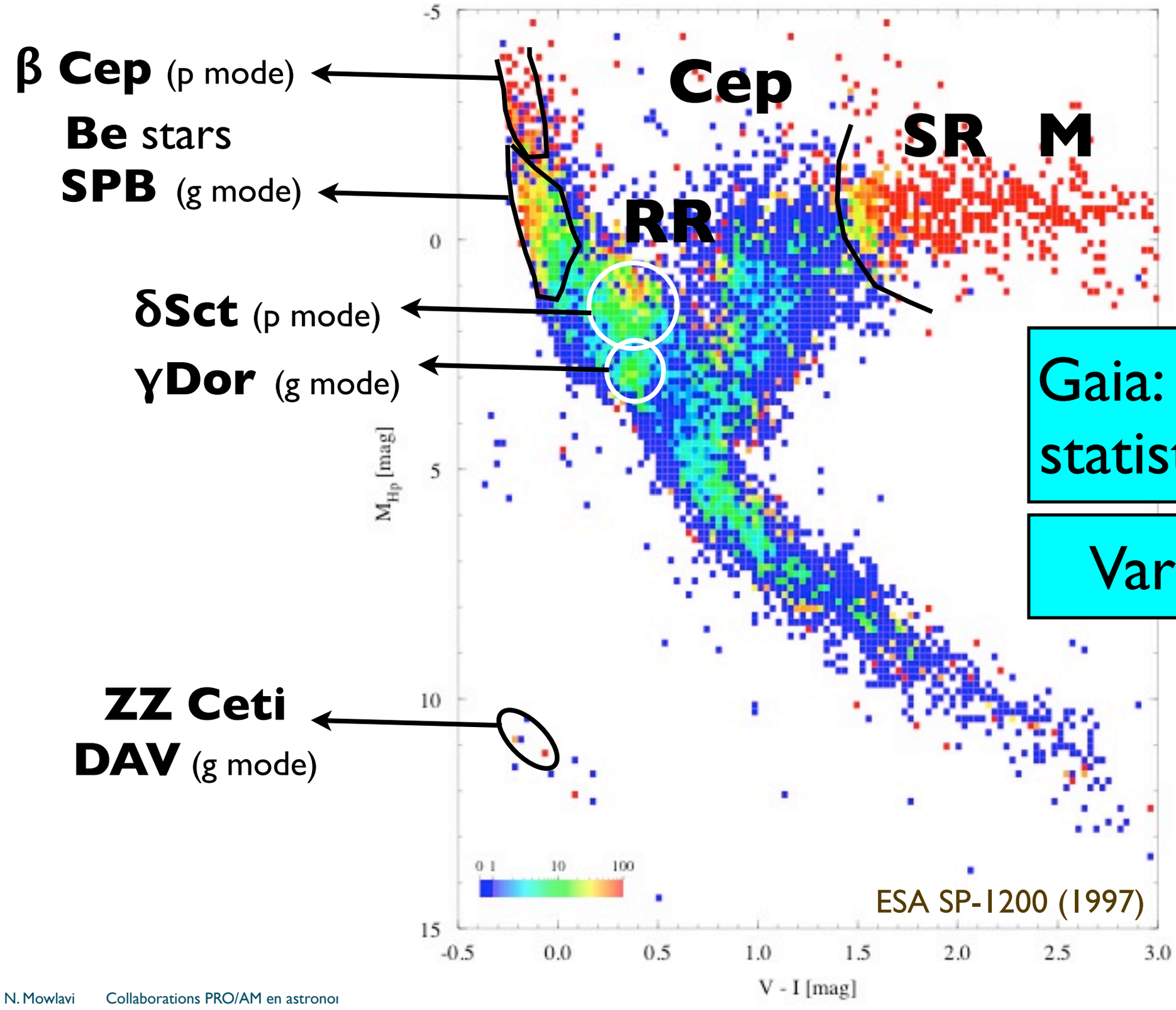


Transients handling
→ *Alerts*

Variabilité charact.
→ *Gaia catalogues*

Variability processing

Fraction of variables (Hipparcos precision)



Gaia: Extremely good statistical description

Variability movie!

Limited to "good" parallaxes

Variability processing

~50-150 million variable objects for Gaia

- 0.5 or **4** or 7 million **Eclipsing Binaries**
  (Söderhjelm 2004, Eyer etal. 2013, Zwitter 2002)
- few 100s to few 1000s or 5,000-30,000 **Planetary transits**
  (Dzigan & Zucker 2012, Robichon 2002)
- 60,000-240,000 **δ Scuti stars** (Eyer&Cuypers 2000)
- 70,000 RR **Lyrae stars** (Eyer&Cuypers 2000)
- 2,000-8000 or 9,000 **Cepheids** (Eyer&Cuypers 2000, Windmark et al. 2011)
- 6,000 **SuperNovae** to G=19 for alert system (Gilmore, Belokurov 2009)
- 1,000 **Micolensing events**
- 500,000 **Quasars**

The case of binaries

Estimations (Eyer et al. 2013)

→ **30 million astrometric non-single stars**

→ **8 million spectroscopic binaries** (with 59% SB2)

→ **4 million eclipsing binaries** (with 12% spectroscopic binaries)

B. Statut

Current status

- **19/12/2013**
  Launch

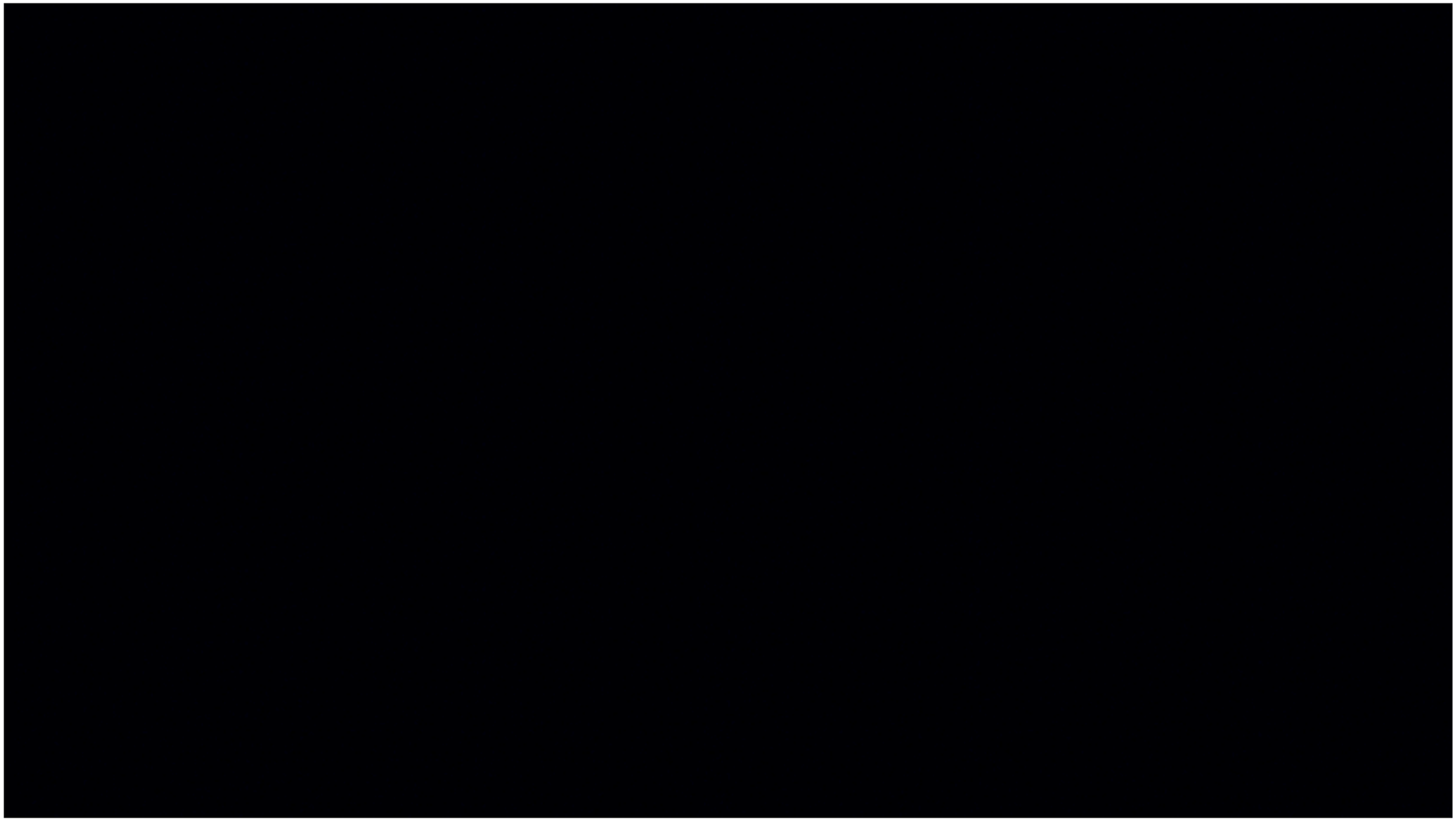

esa
00 : 15

Current status

http://sci.esa.int/gaia/53280-gaia-from-launch-to-orbit/

- 19/12/2013
  Launch

- ***08/01/2014***
  @ L2



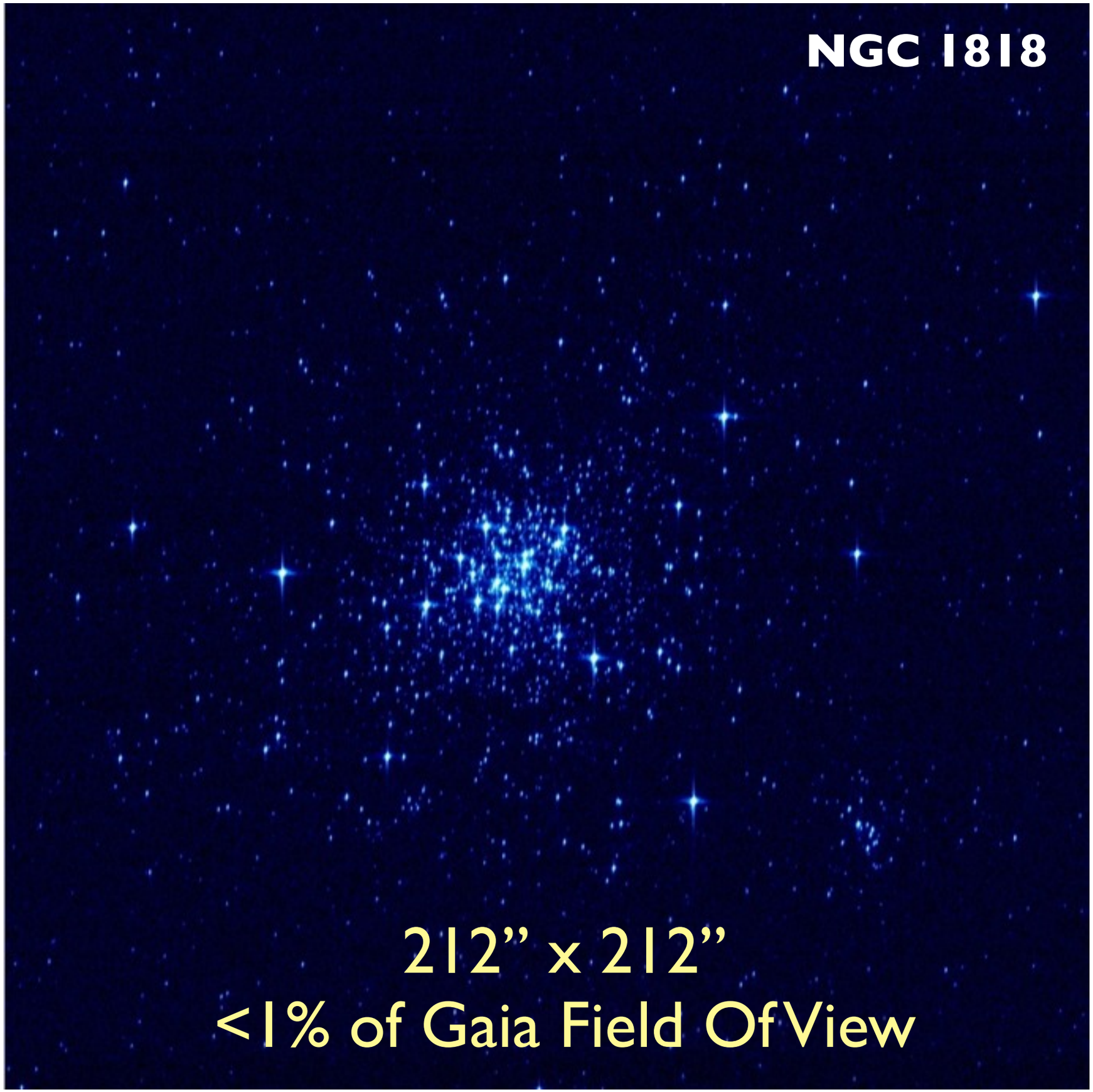
Current status

- 19/12/2013
  Launch

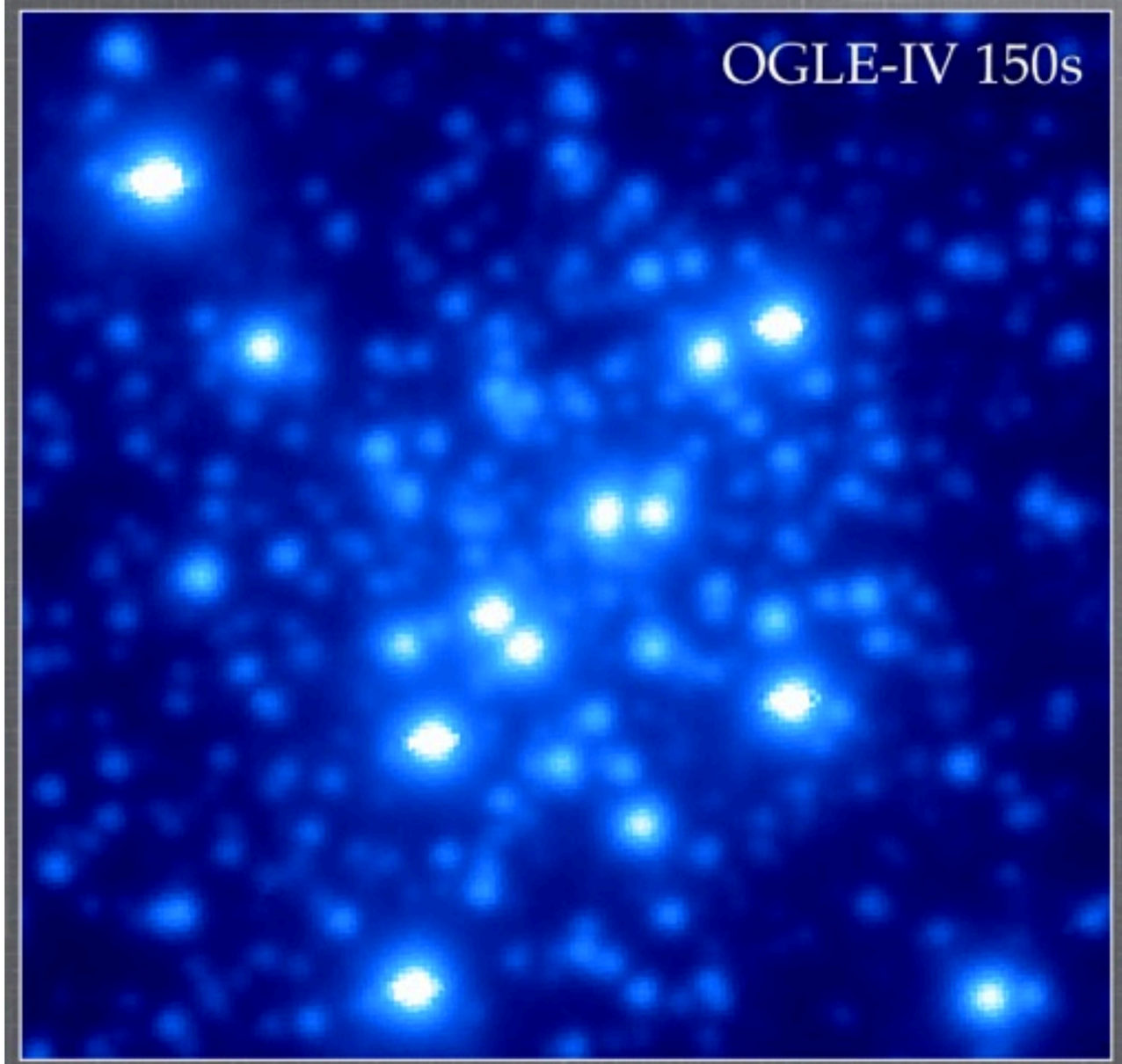
- *08/01/2014*
  @ L2

- ***06/02/2014***
  Comes into focus

http://www.esa.int/spaceinimages/Images/2014/02/Gaia_calibration_image

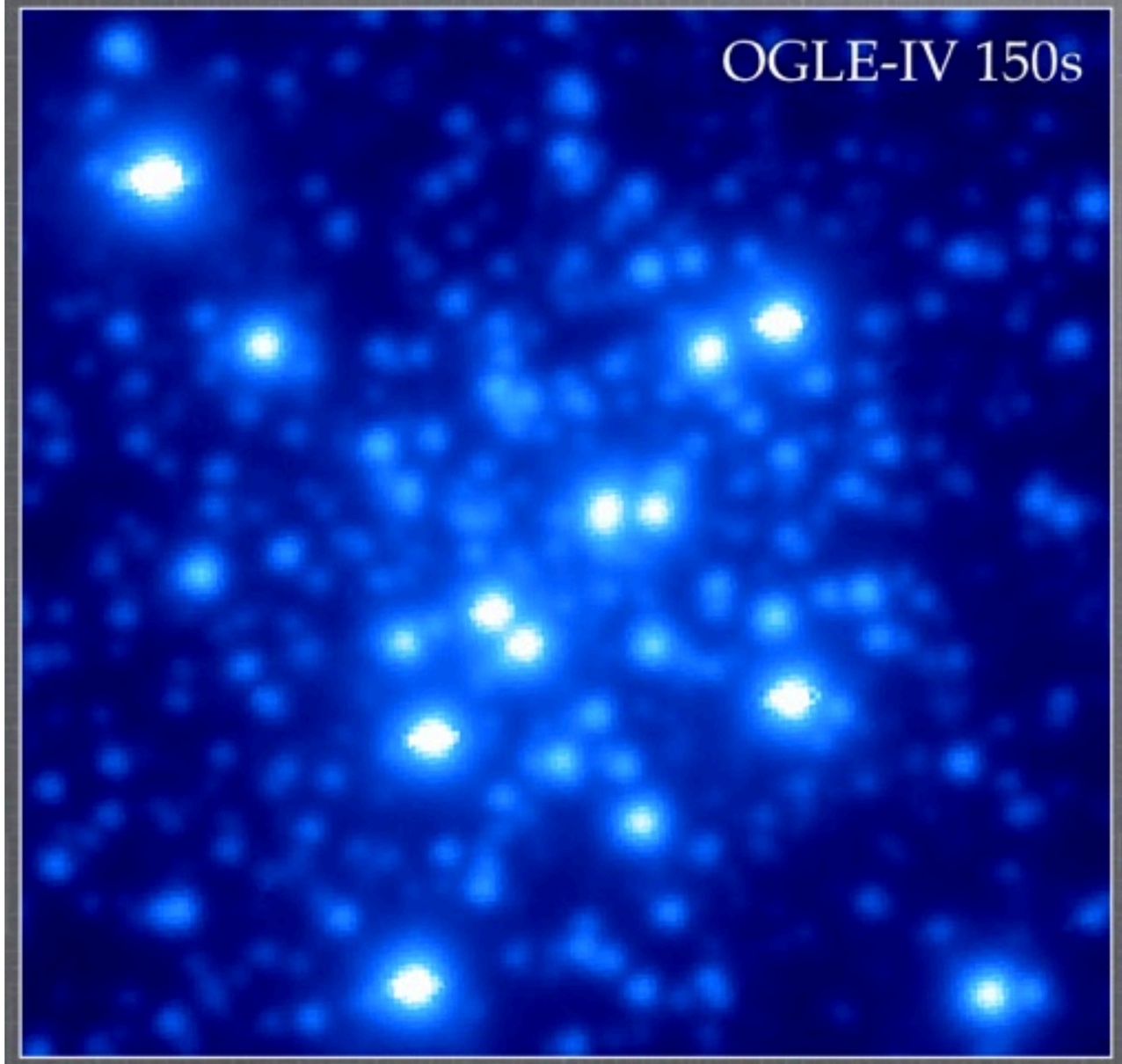


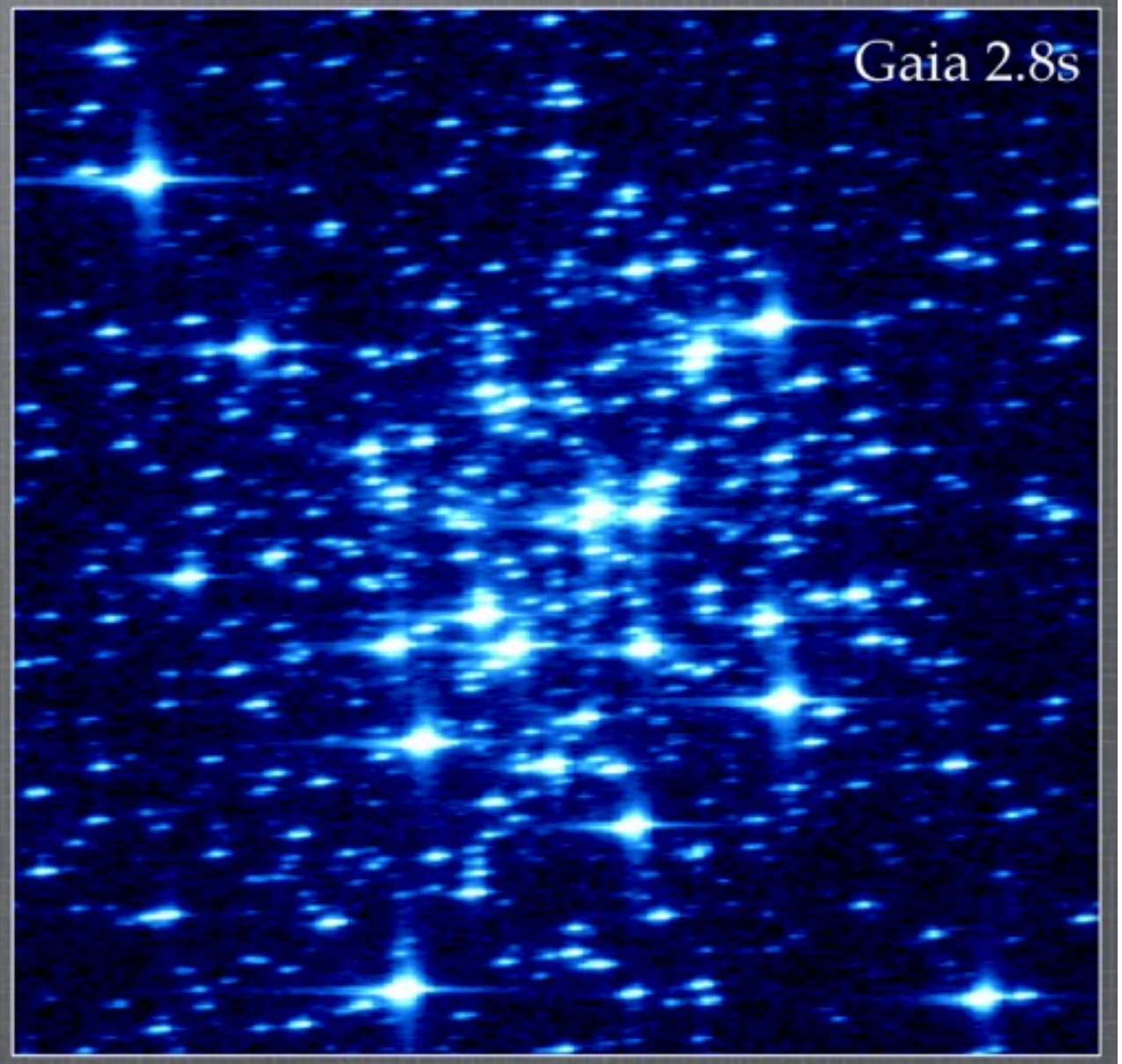
NGC 1818



Credit L. Wyrzykowski

NGC 1818

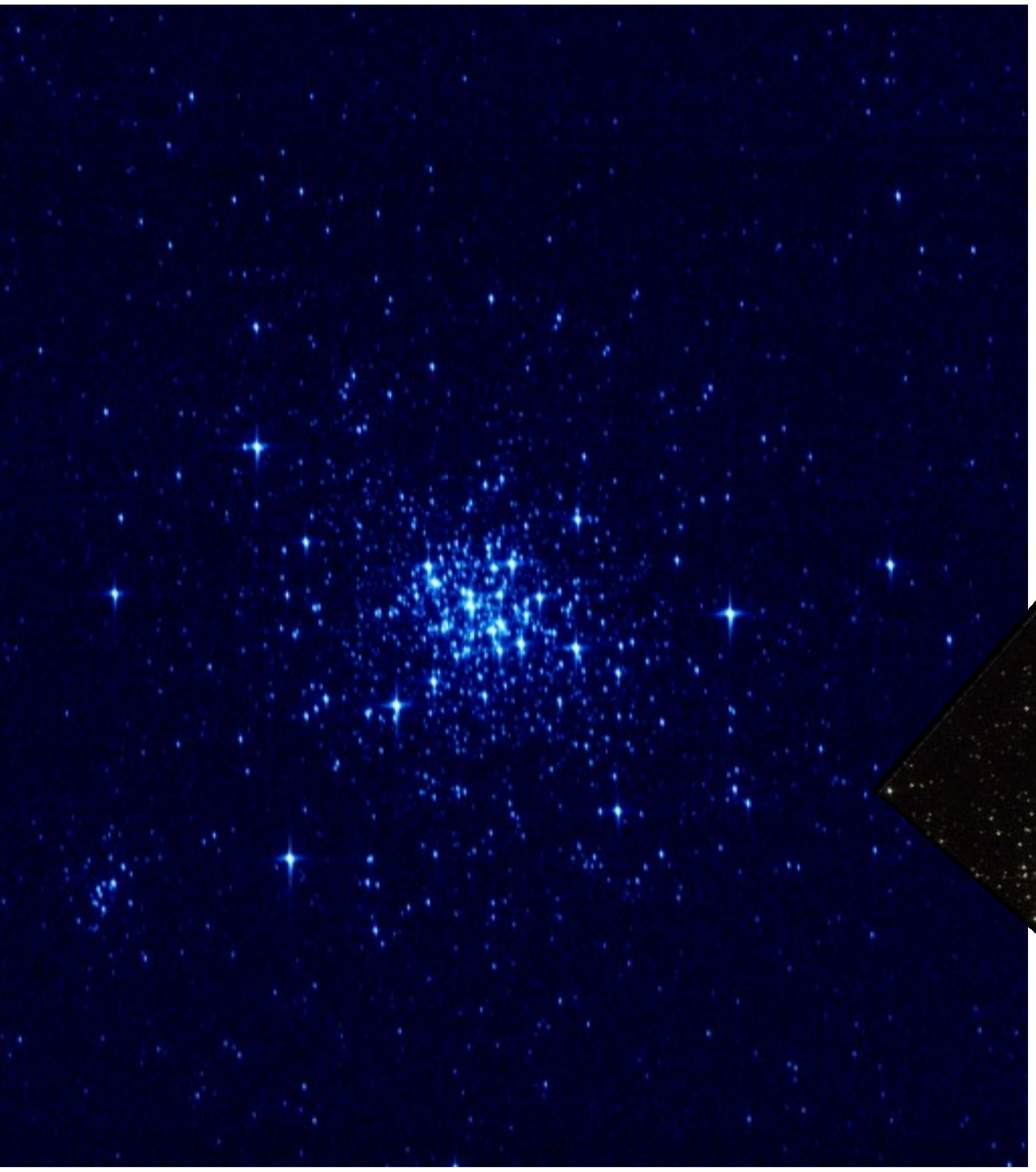




Credit L. Wyrzykowski

NGC 1818

Gaia (not with best focus)

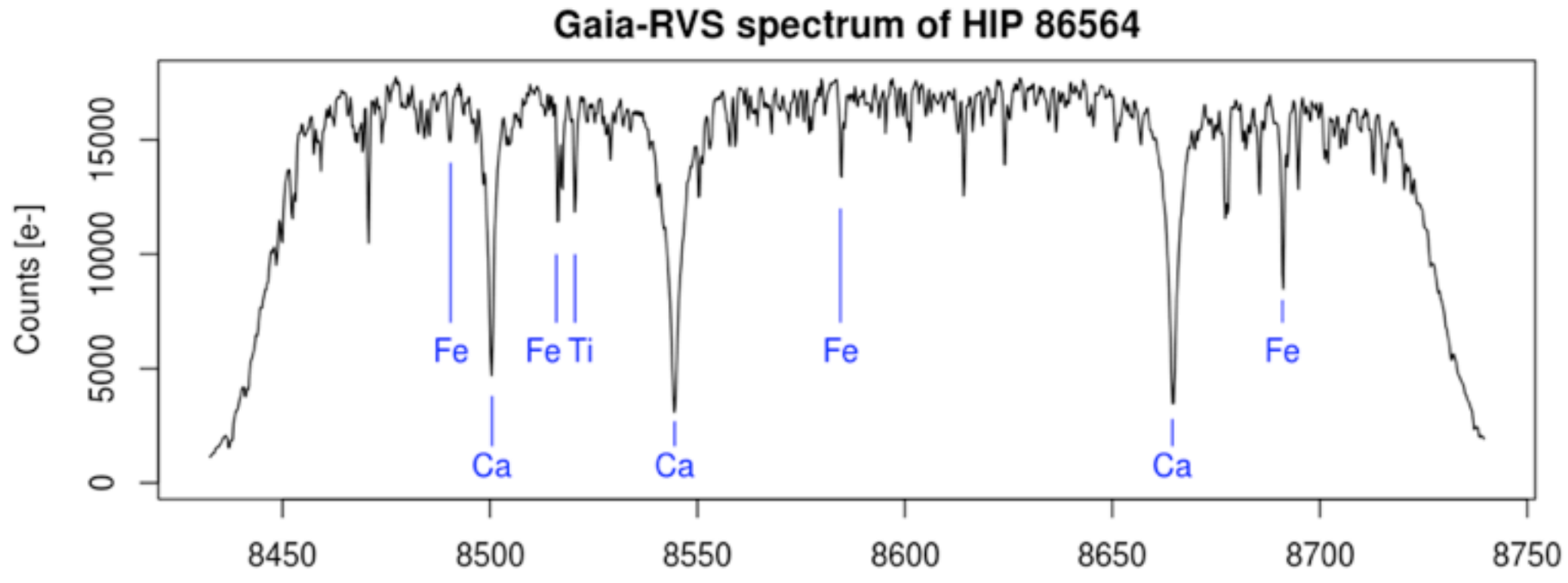


HST

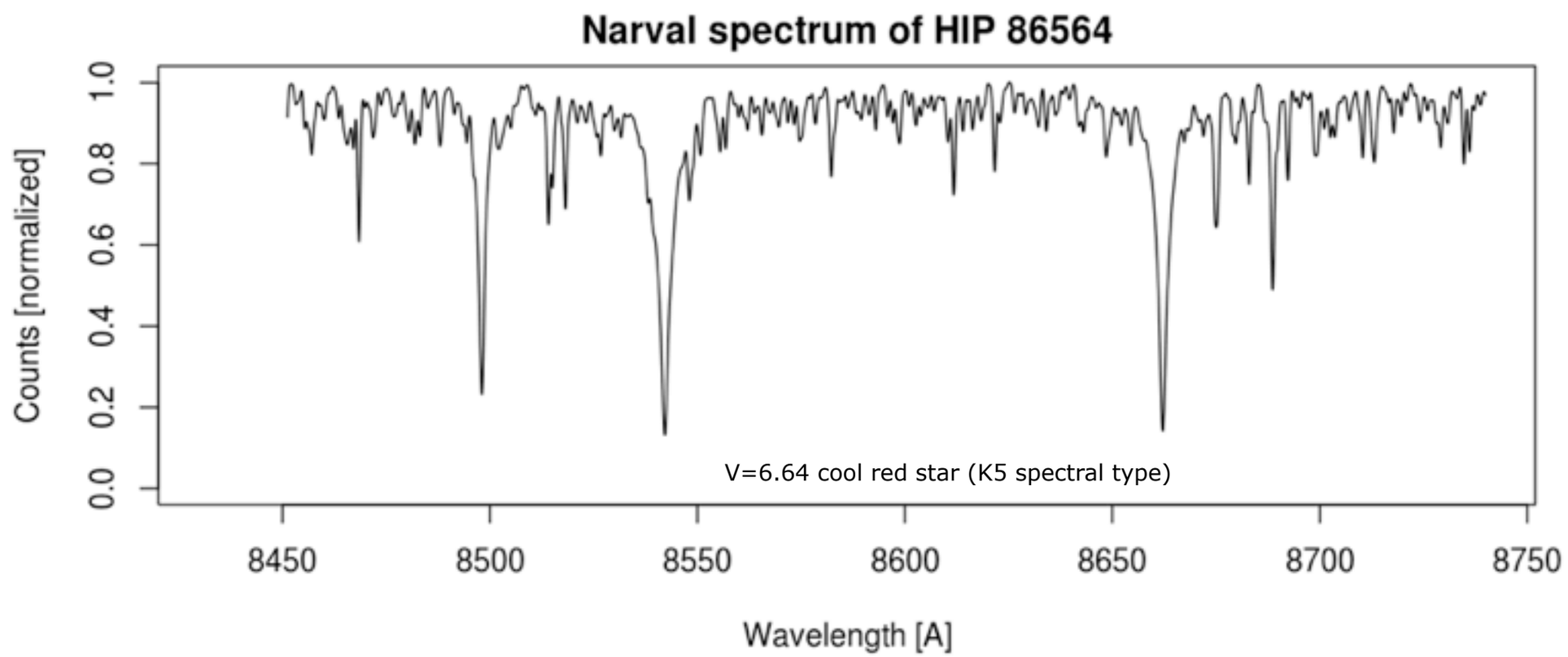
Current status

http://sci.esa.int/gaia

- 19/12/2013
  Launch
- *08/01/2014*
  @ L2
- *06/02/2014*
  Comes into focus
- ***05/06/2014***



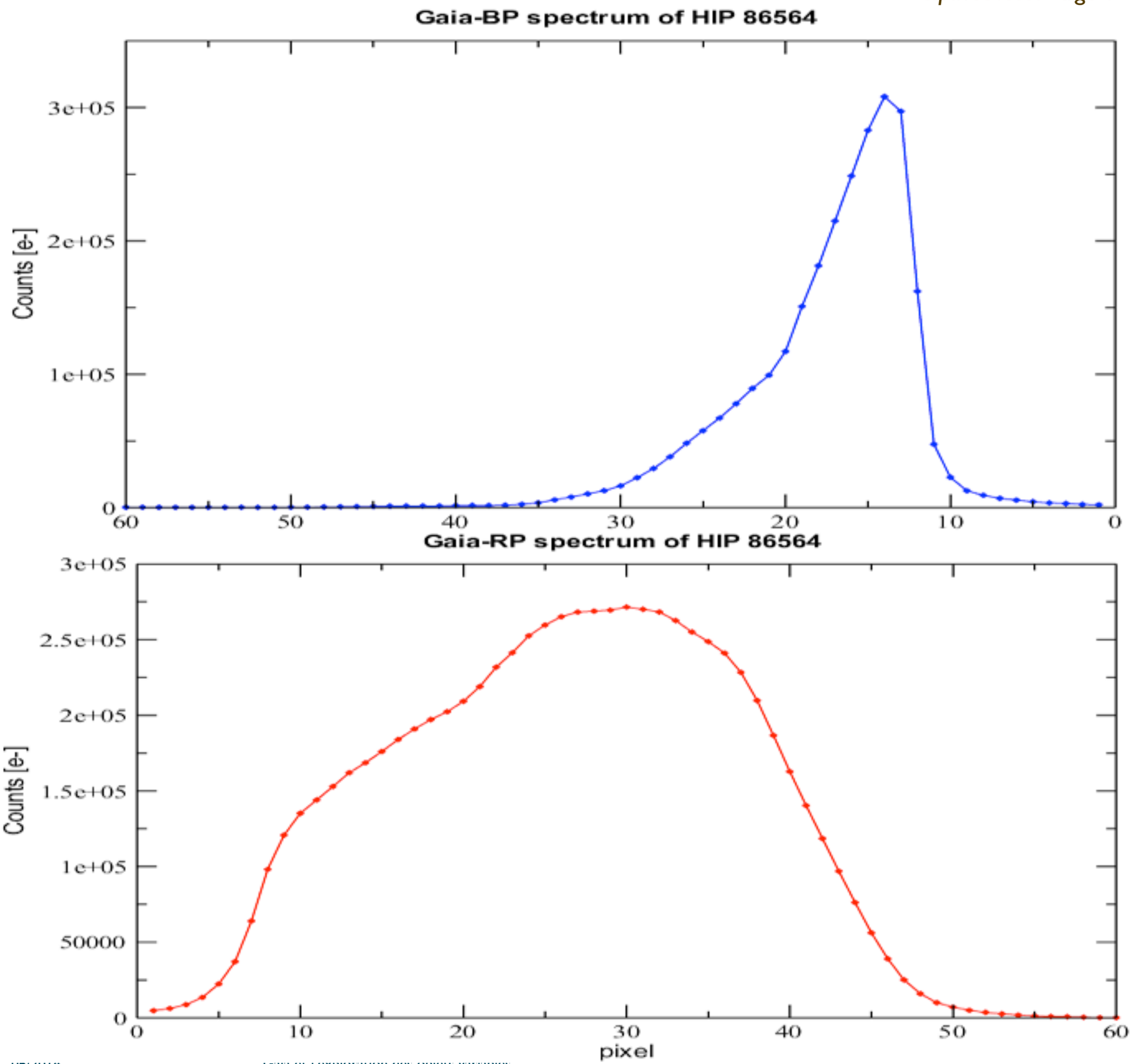
Gaia spectra



Current status

http://sci.esa.int/gaia

- 19/12/2013
  Launch
- *08/01/2014*
  @ L2
- *06/02/2014*
  Comes into focus
- ***05/06/2014***
  Gaia spectra



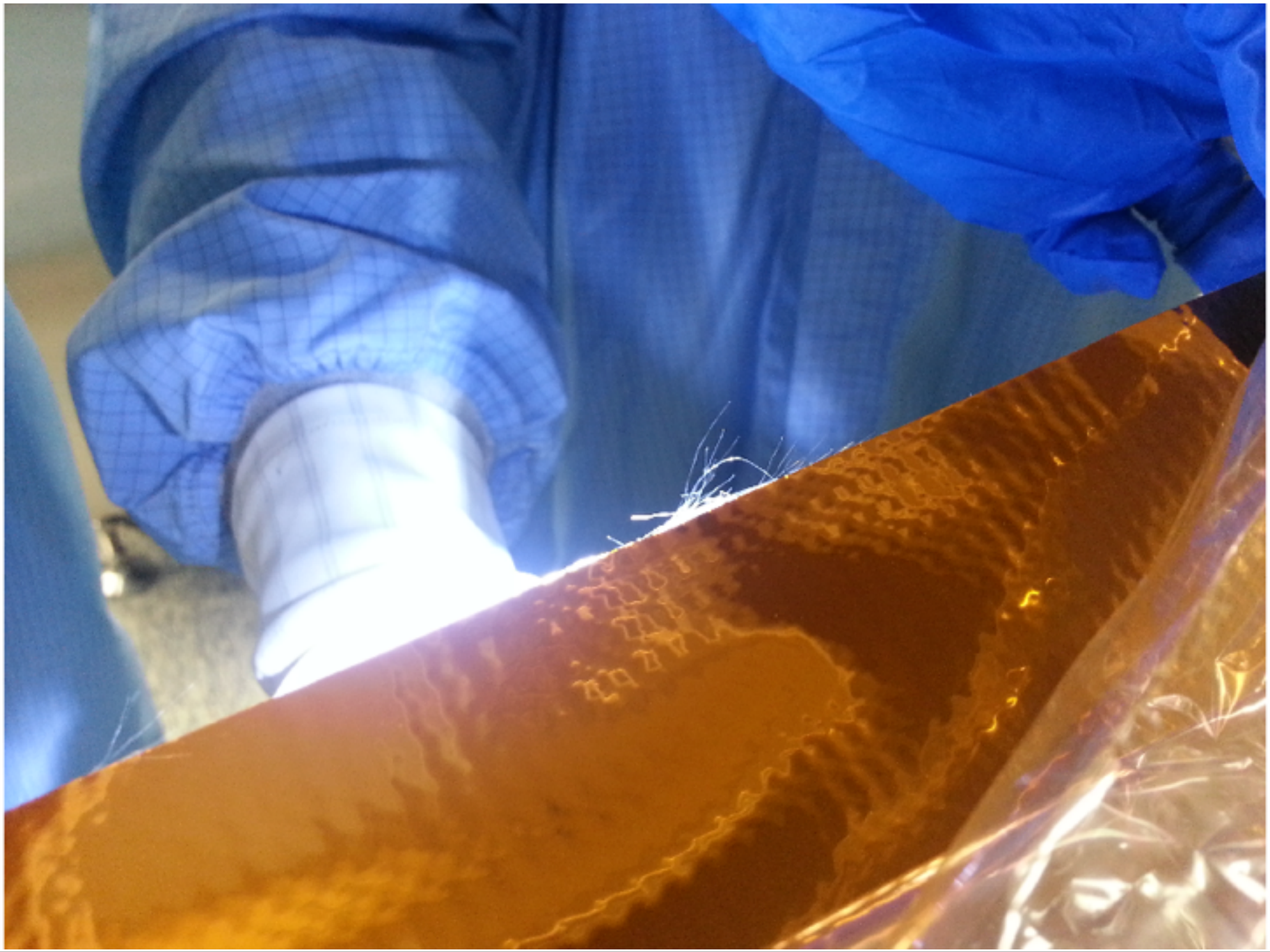
Unexpected issues detected during commissioning

- Gaia seen from Earth is fainter than thought ✔

Slide courtesy L. Eyer

Unexpected issues detected during commissioning

- Gaia seen from Earth is fainter than thought ✔
- There is a varying stray-light on the focal plane ~✔



Slide courtesy L. Eyer

Unexpected issues detected during commissioning

- 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

Slide courtesy L. Eyer

Unexpected issues detected during commissioning

- 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

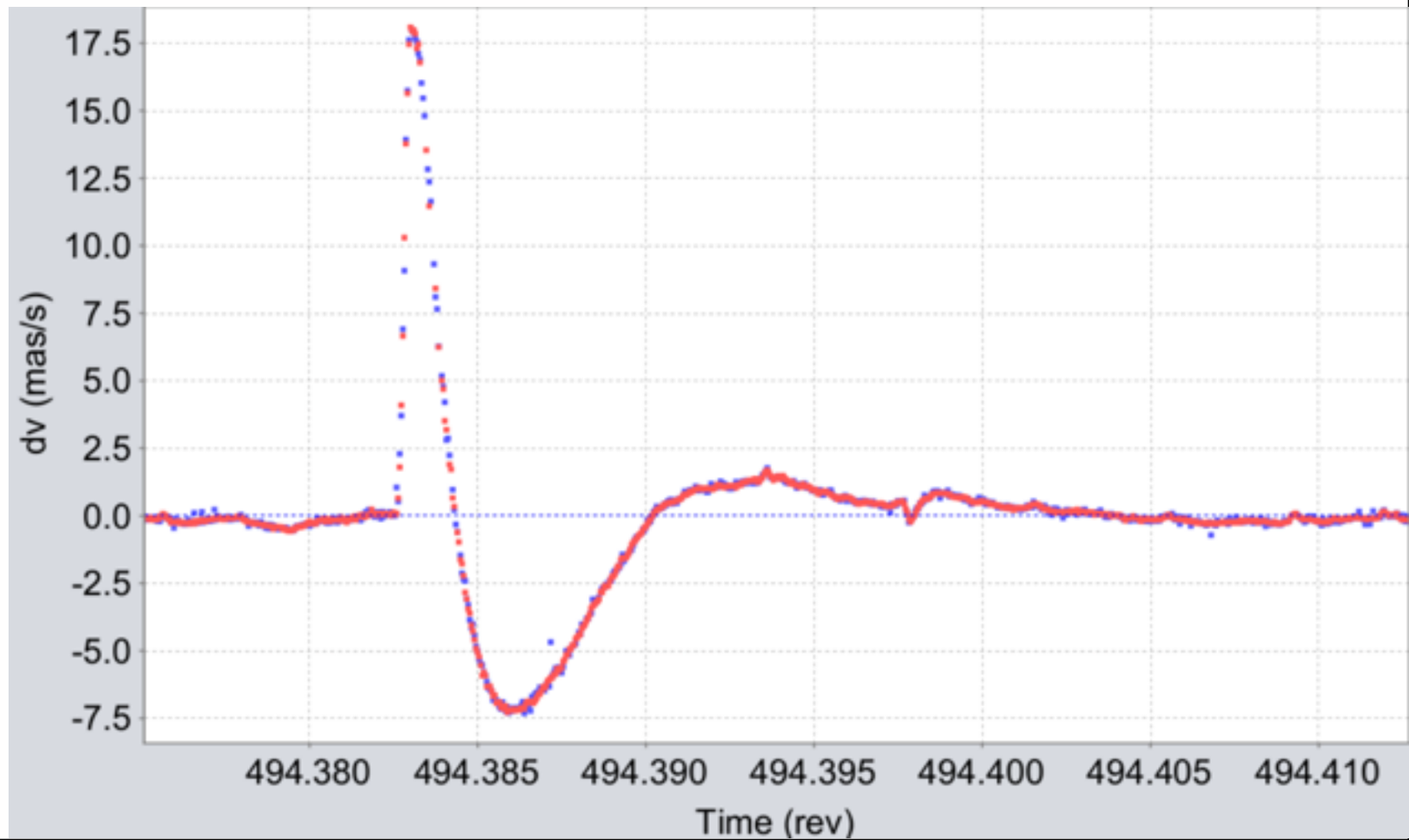
- Some evaporation escapes from the service module and contaminate the mirrors ✔

Slide courtesy L. Eyer

Unexpected issues detected during commissioning

- 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 contaminate the mirrors ✔
- There are clanks and micrometeoroid hits ✔

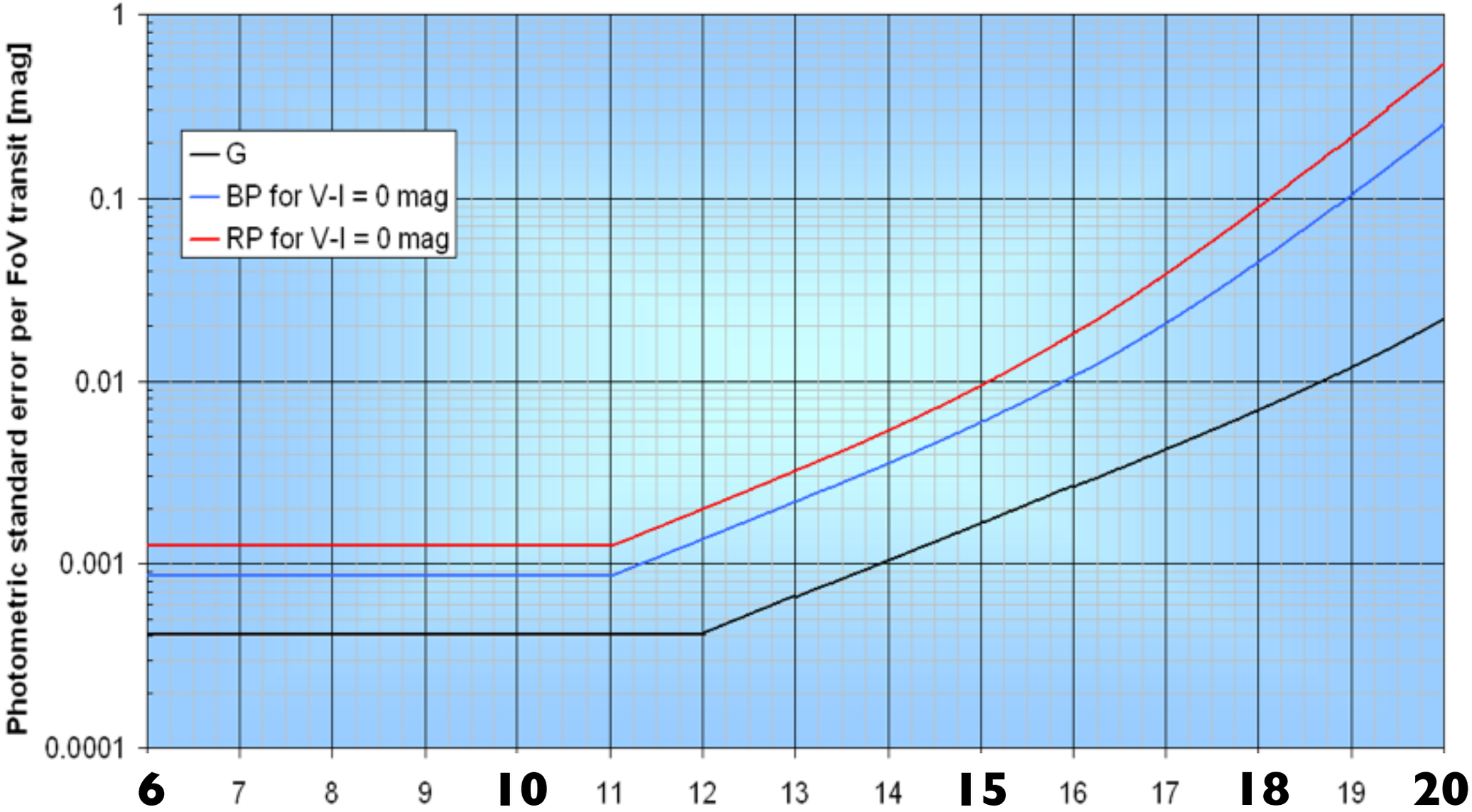


Micro-meteoroid hit example. Figure by F. van Leeuwen

Slide courtesy L. Eyer

The instruments - accuracies

http://www.cosmos.esa.int/web/gaia/fov



10 mmag

1 mmag

0.1 mmag

Number of stars : 26 million stars | 250 10^6 | 1000 10^6

Astrometric accuracy (G2V) : 5-16 µas | 25 µas | 540 µas

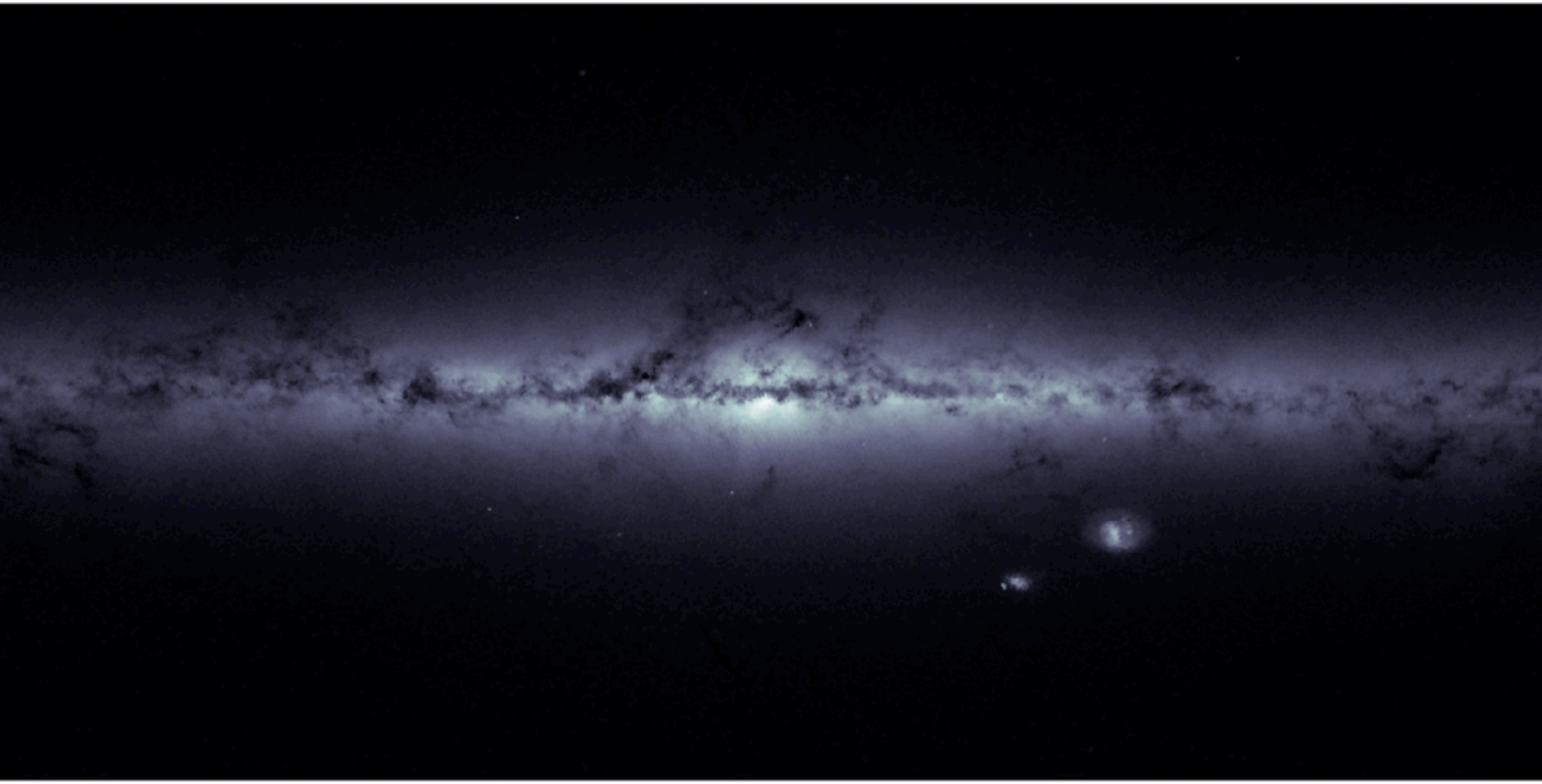
RV accuracy (G2V) : 1 km/s | 15 km/s

C. Les premiers résultats

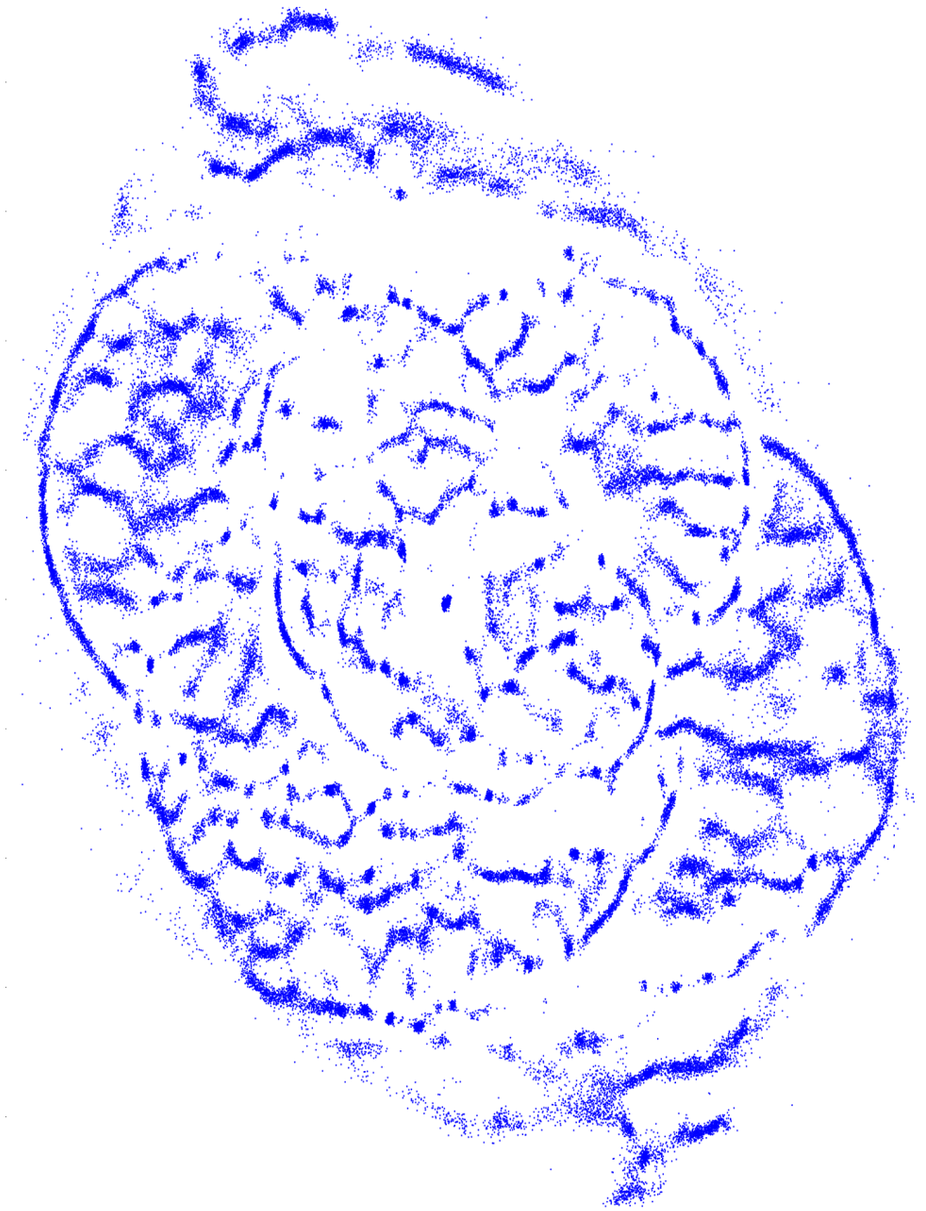
http://www.cosmos.esa.int/web/gaia/image-of-the-week

Map of the Galaxy (with Sky Mapper)

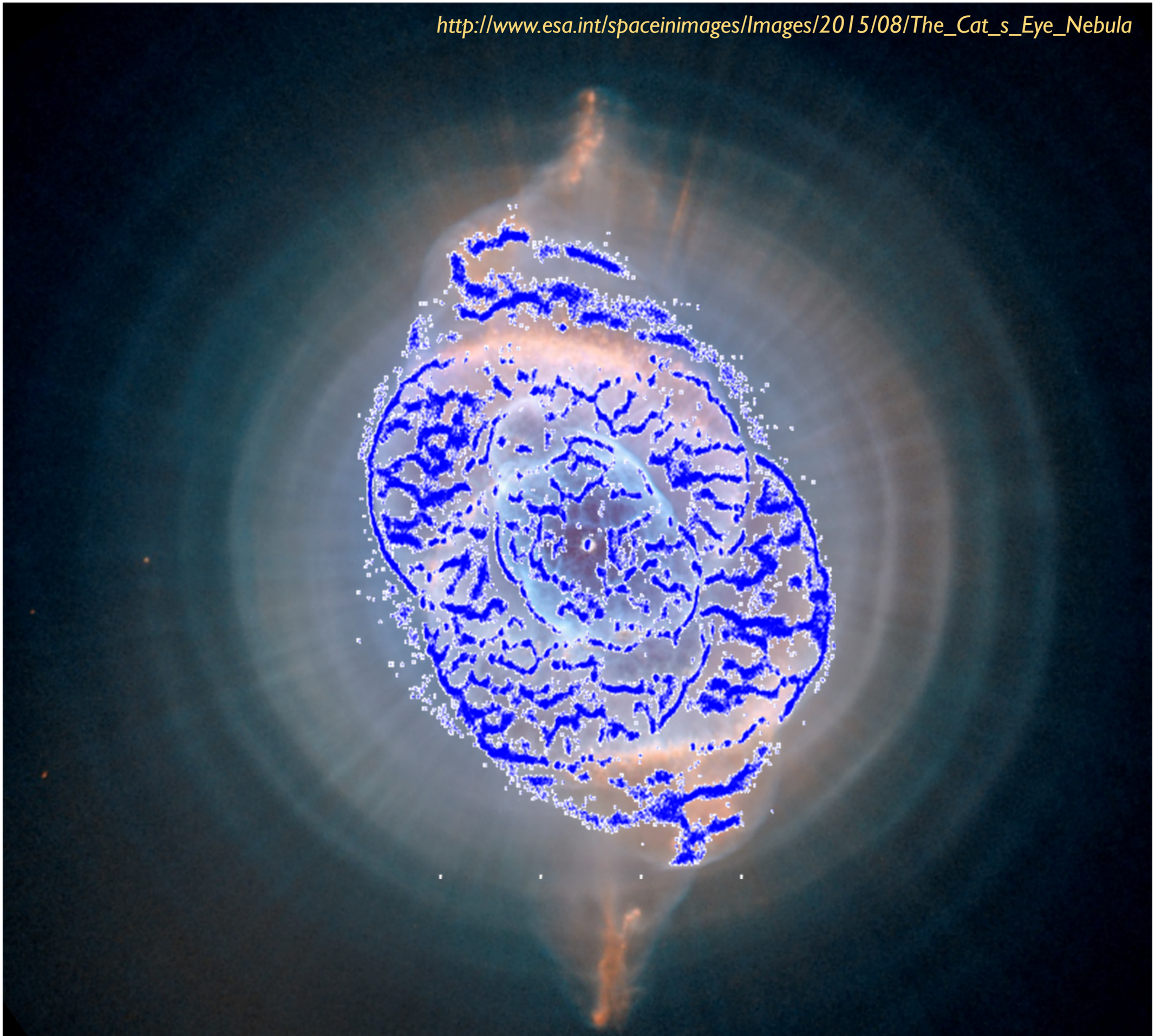
http://www.esa.int/spaceinimages/Images/2015/07/Stellar_density_map



Cat's Eye Nebula (on-board detection algorithm)



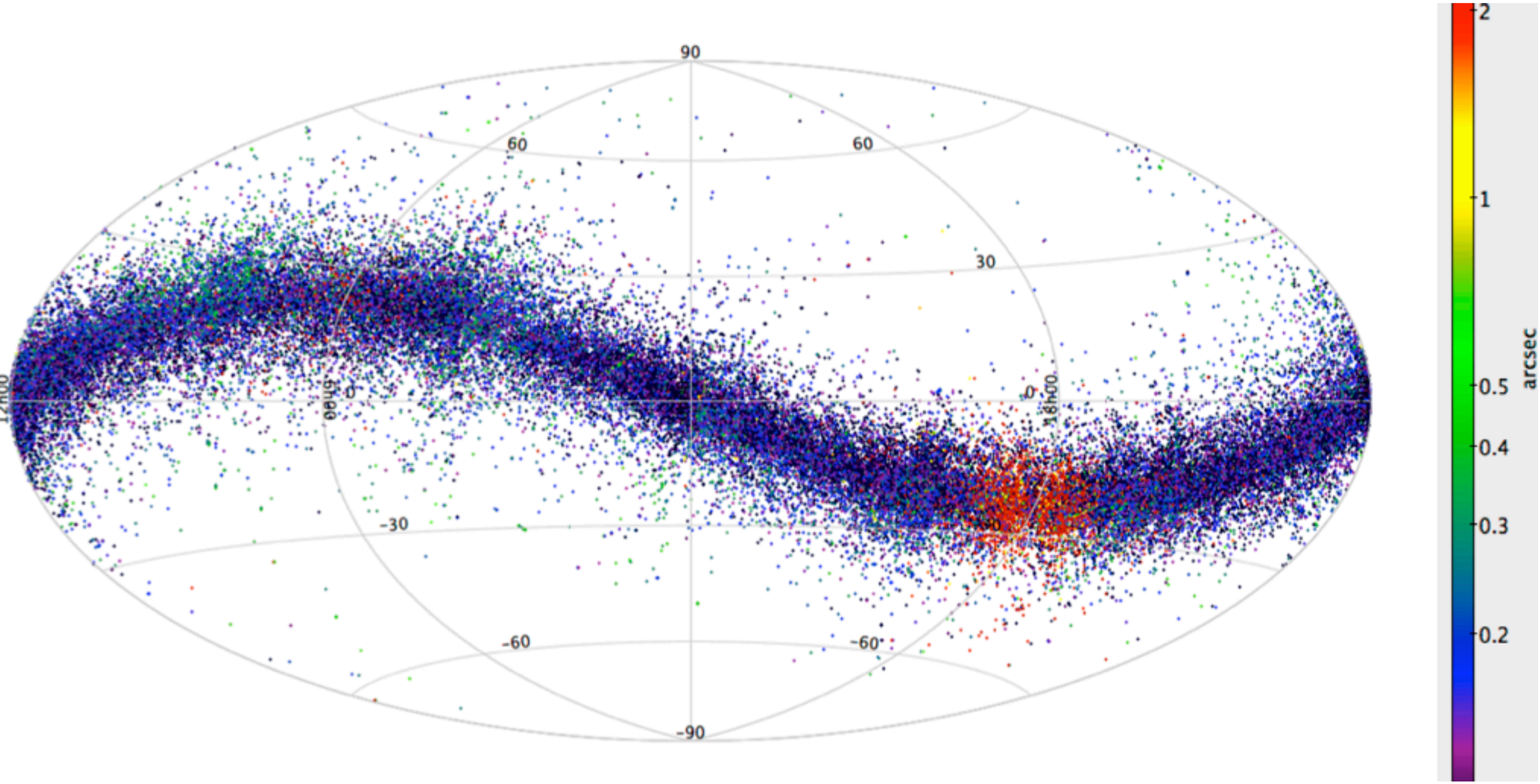
http://www.esa.int/spaceinimages/Images/2015/08/The_Cat_s_Eye_Nebula



HST image credit: NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA)
Gaia image credit: ESA/ Gaia/DPAC/UB/ IEEC

Asteroids detection (8 months detection)

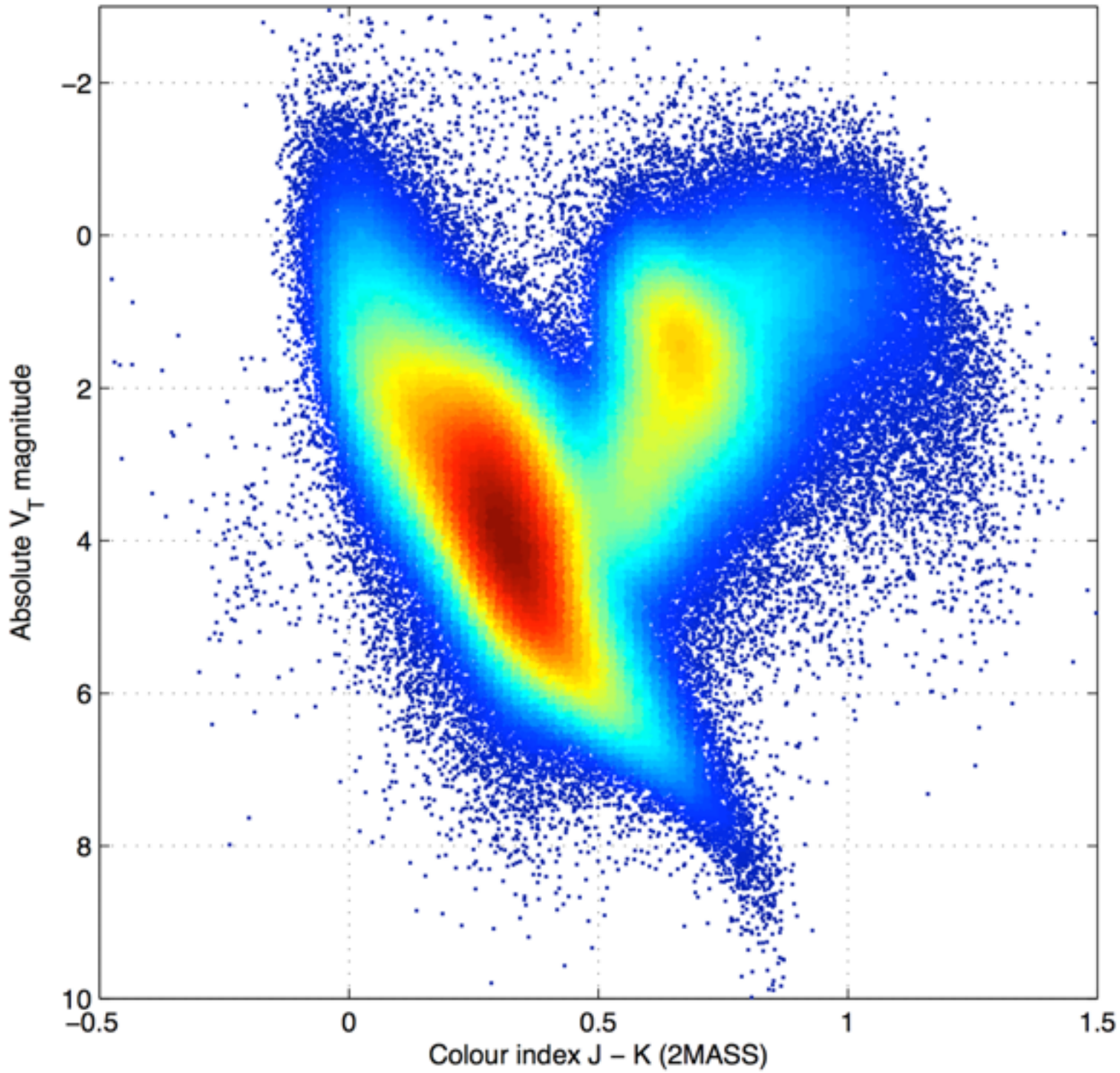
http://www.esa.int/spaceinimages/Images/2015/08/Gaia_s_asteroid_detections



Gaia's detections of asteroids in eight months' worth of data, compared with the positions on the sky of a sample of 50 000 known asteroids. The colour of the data points is an indication of the accuracy of the detections, showing the separation on the sky between the observed position of Gaia's detection and the expected position of each asteroid: blue indicates higher accuracy, whereas green and red indicate lower accuracy.

First HR diagram

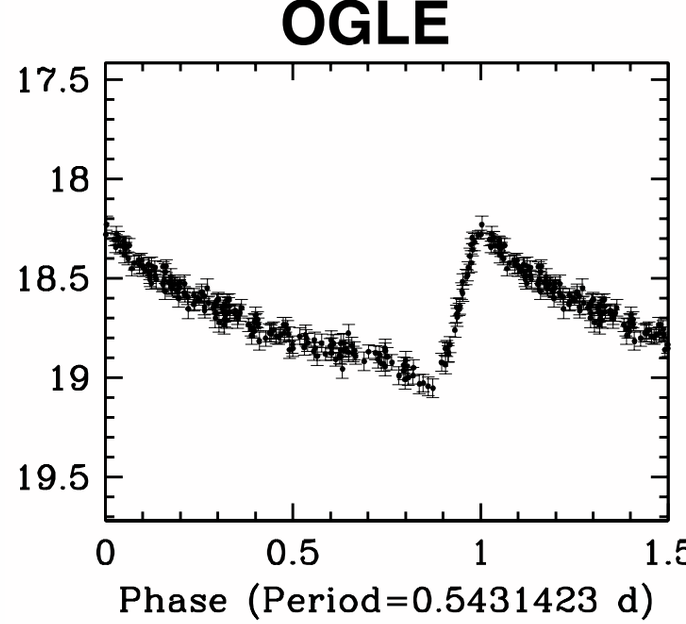
http://www.esa.int/spaceinimages/Images/2015/08/Gaia_s_first_Hertzsprung-Russell_diagram

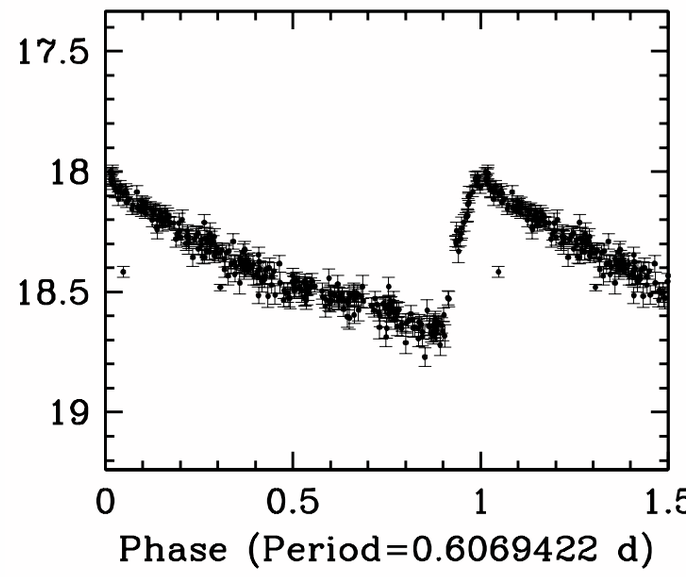


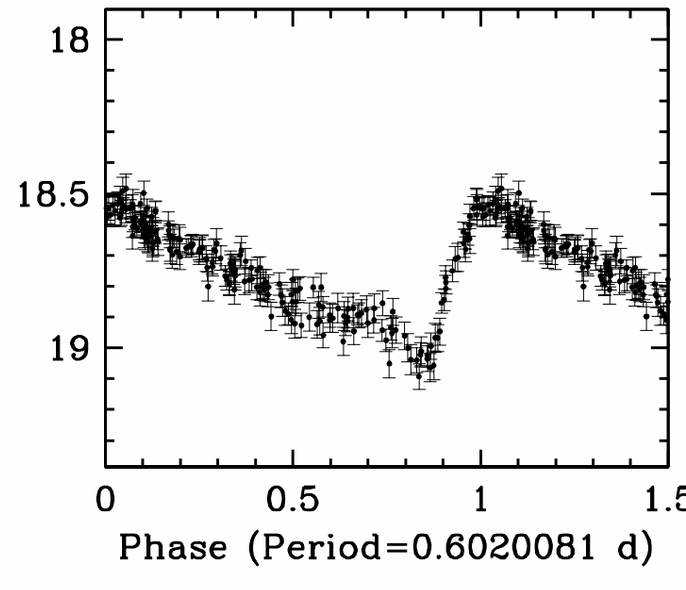
Parallax : Tycho (1989-1993) + Gaia (2014-2015) → proper motions

Luminosity & color : Hipparcos + ground-based observations

To get the data “flavour”
Comparison with OGLE







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.

Results: Classification of RR Lyrae and Cepheid stars

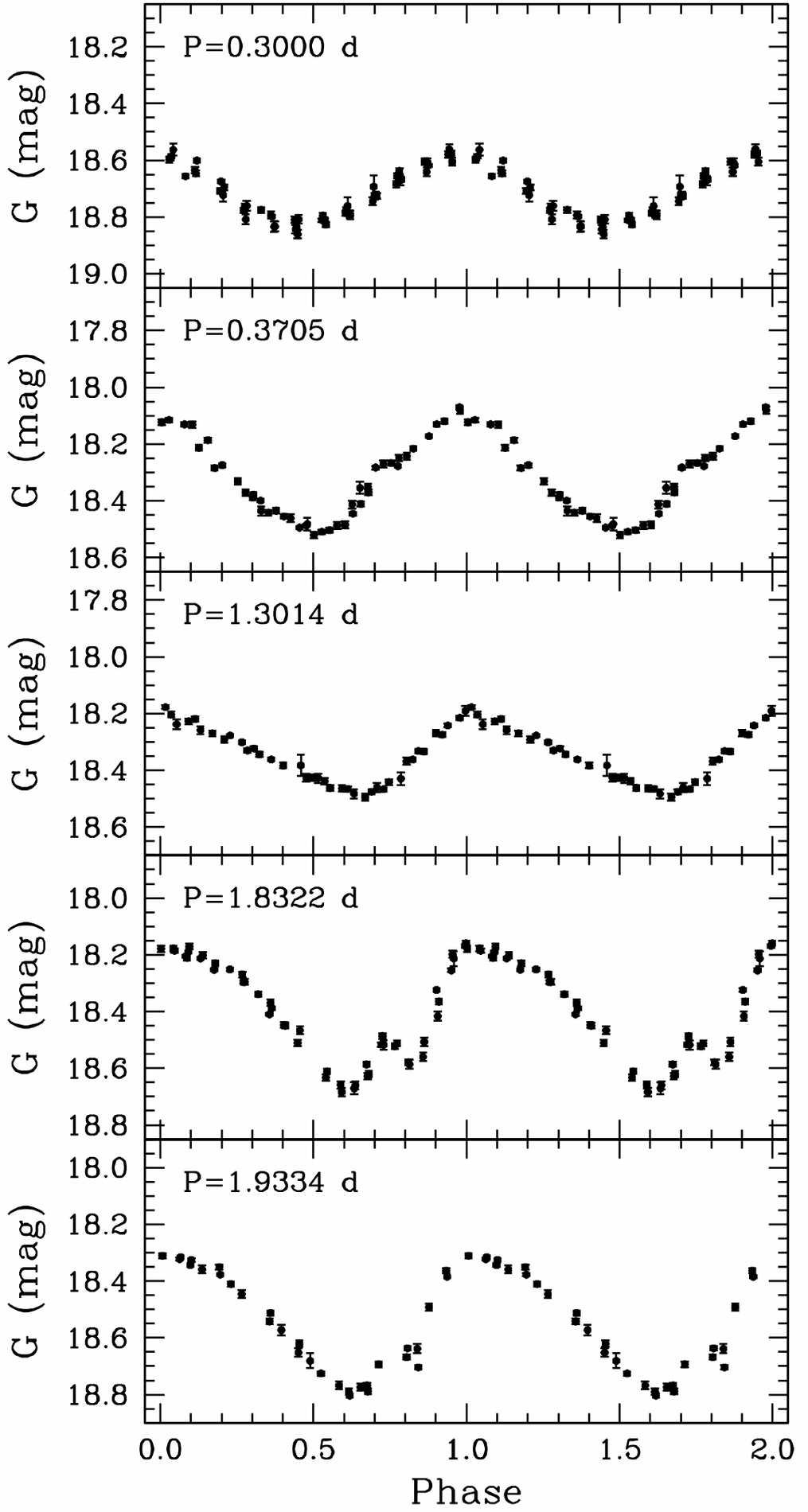
Gisella Clementini, Silvio Leccia, Vincenzo Ripepi, Nami Mowlavi, Isabelle Lecoeur

Classical overtone Cepheid

3 candidate anomalous Cepheids

Type 2 Cepheid

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.



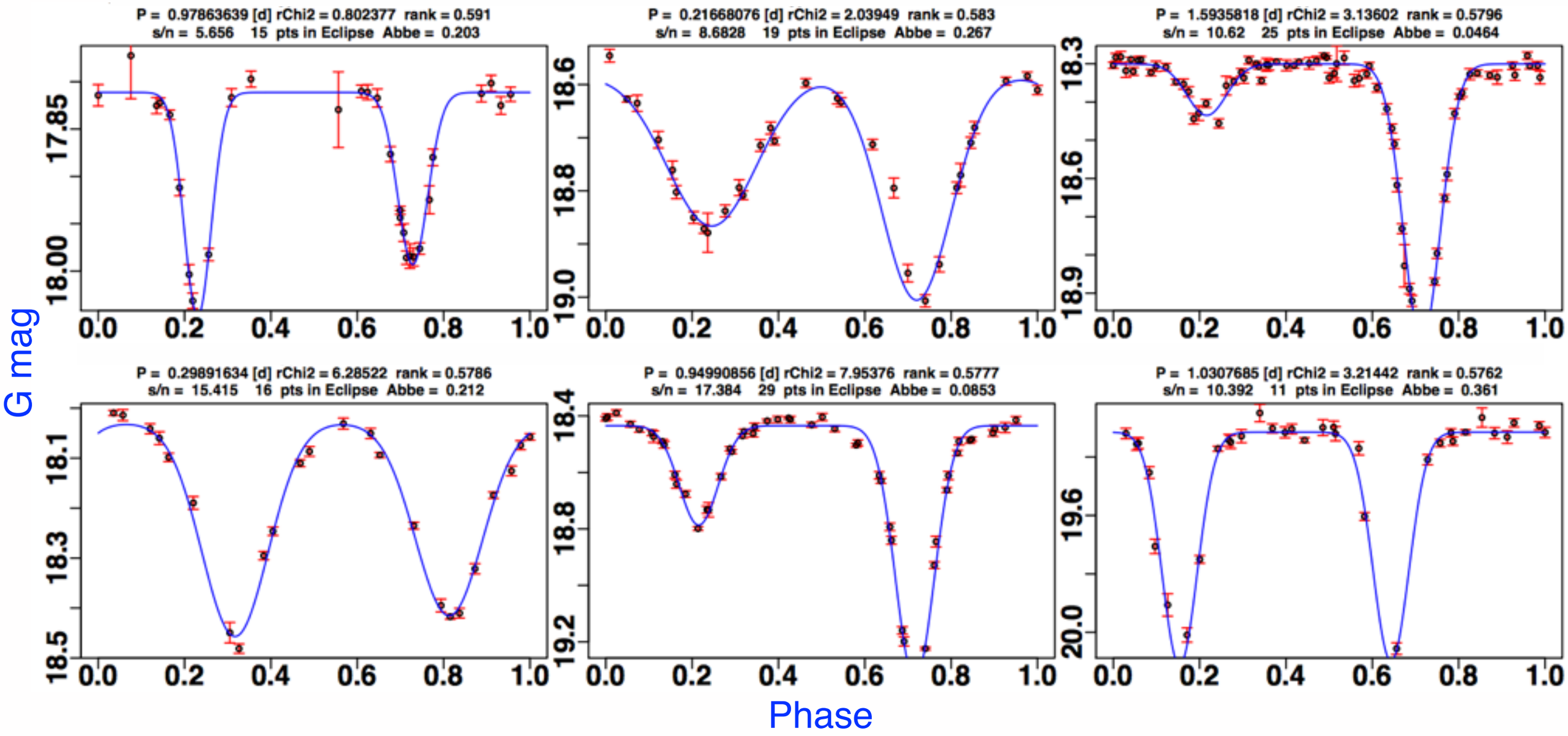
Results: Classification of Eclipsing binaries

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

Here, a simple modelling is performed

The solutions enable a ranking

Highest rank

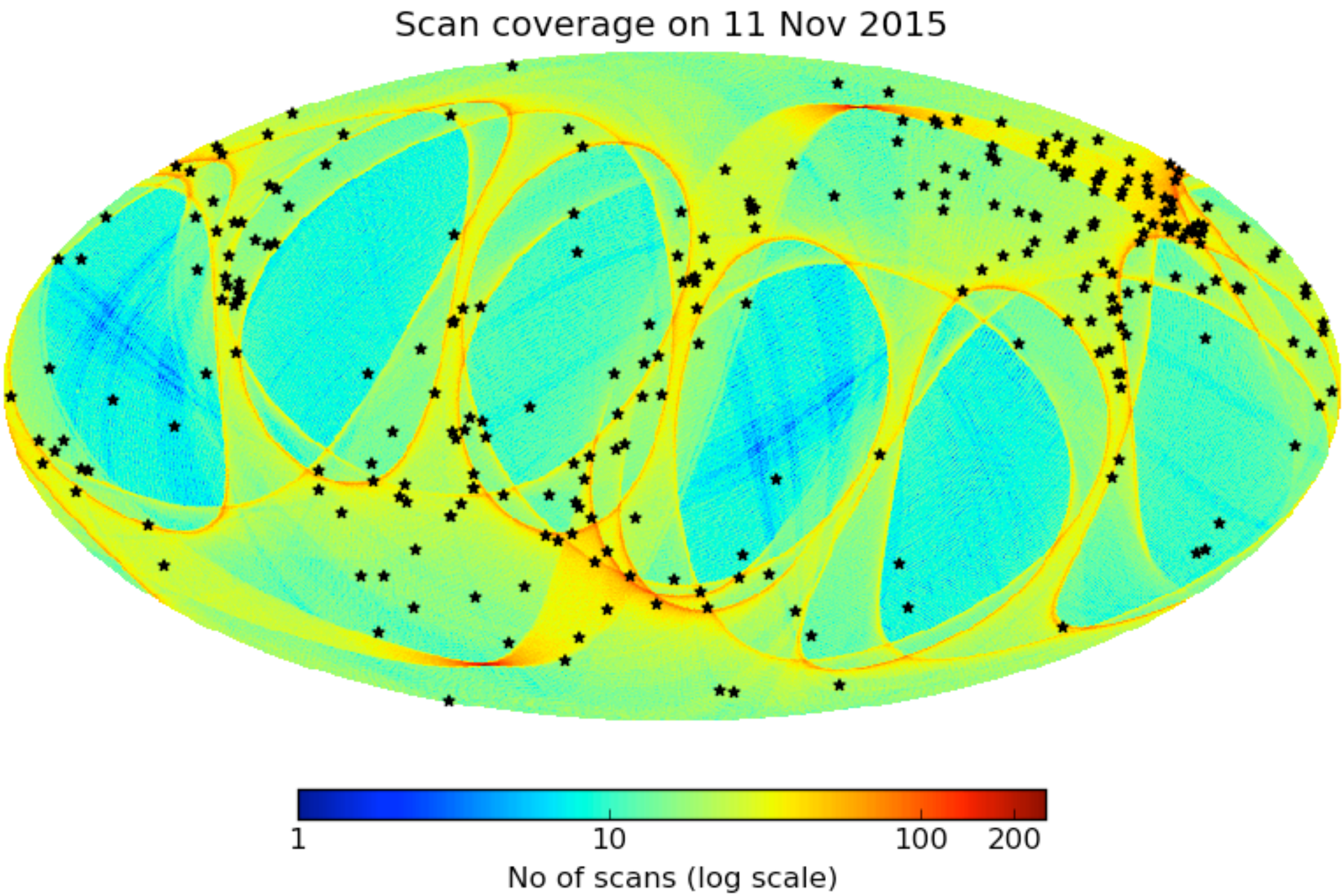


Credits: Geneva CU7/DPCG team.

D. Participations à la mission

D1. Gaia Science Alerts (Cambridge University)

http://gaia.ac.uk/alerts



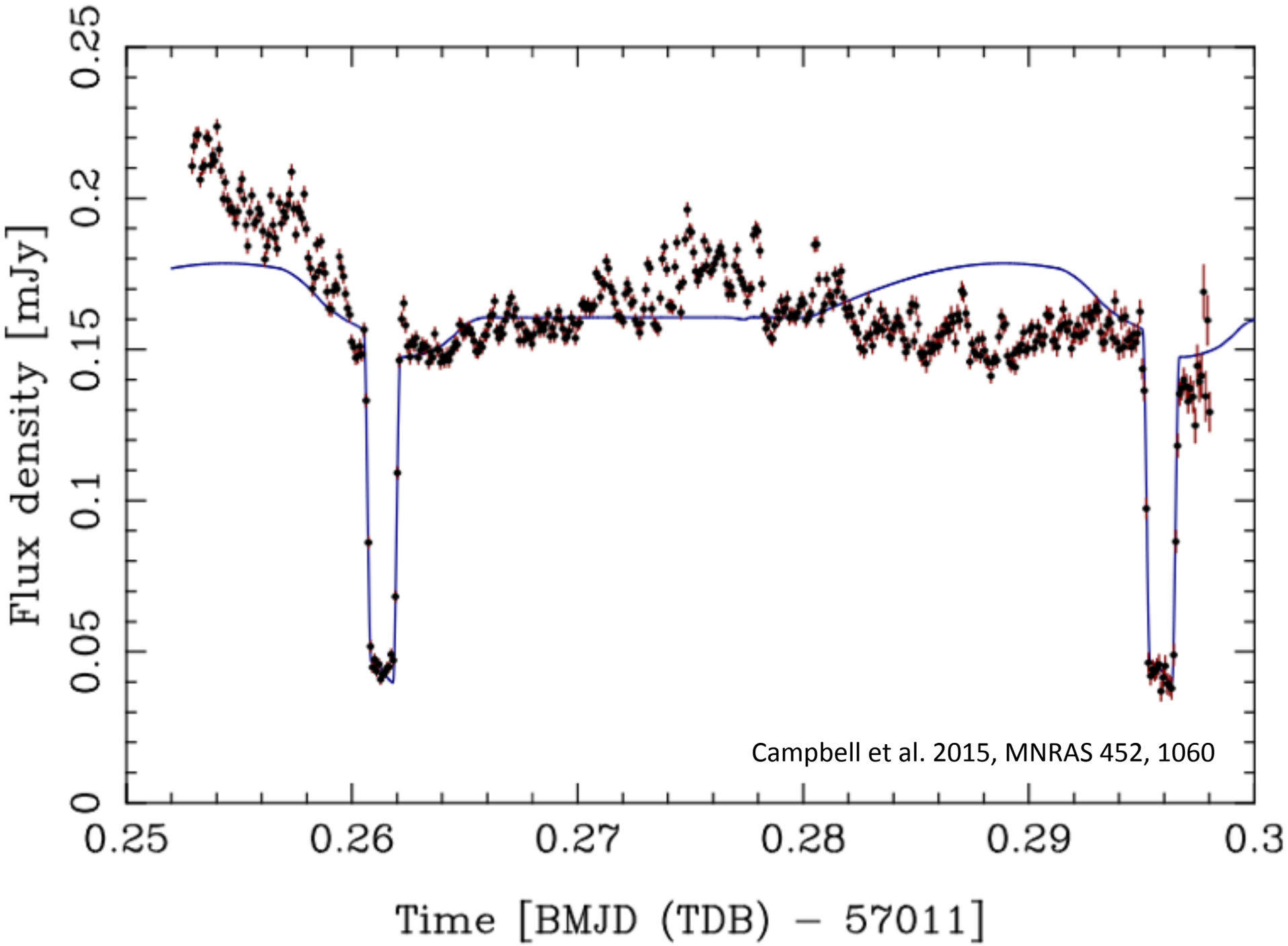
As of 9 June 15: 274 alerts of which 80 SN (confirmed or candidate)

D1. Gaia Science Alerts (Cambridge University)

AM CVn star discovered!

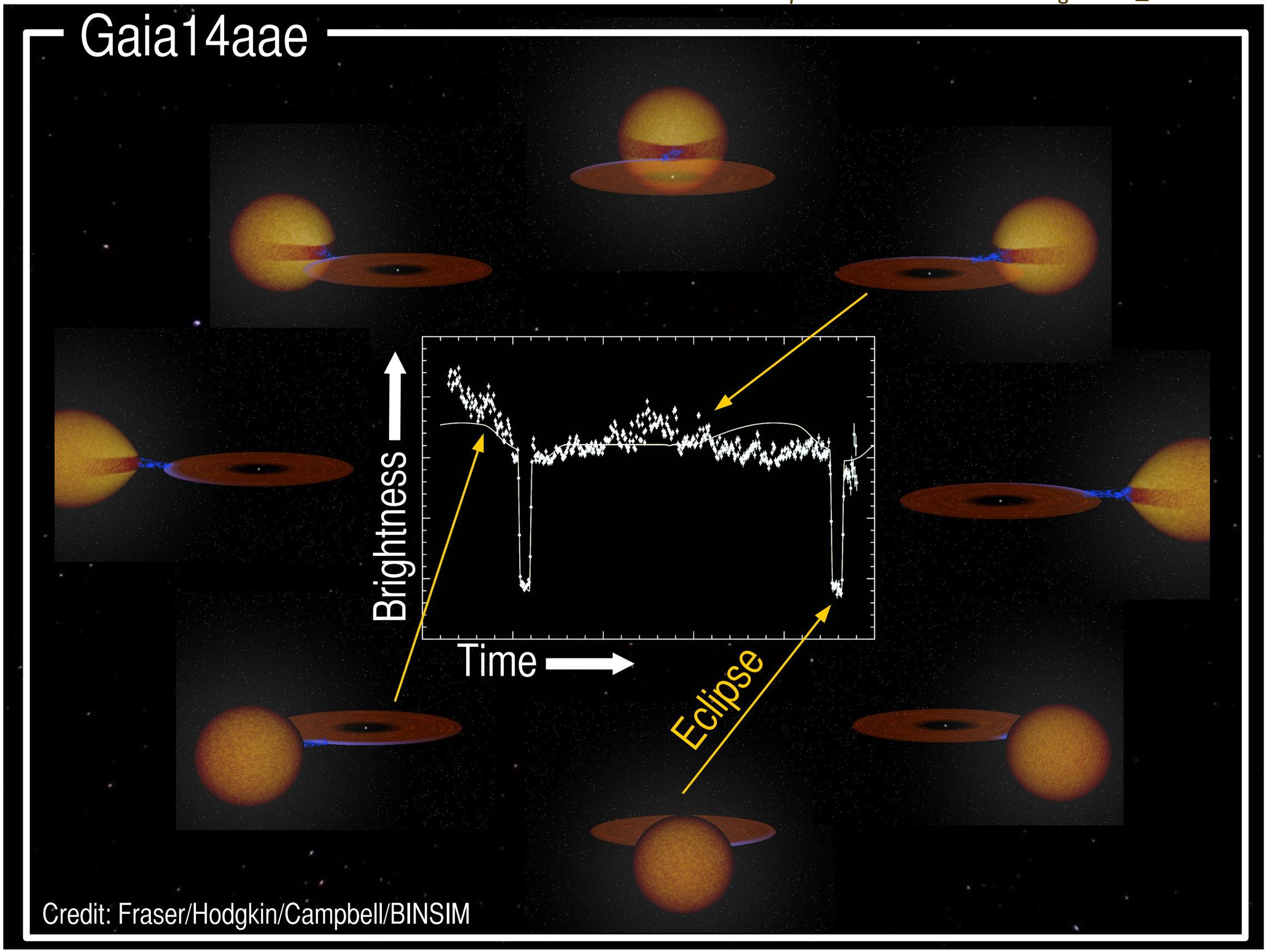
Fourth only known such eclipsing systems (only one with total eclipse)

Based on additional observations made by amateur astronomers



D1. Gaia Science Alerts (Cambridge University)

http://www.cosmos.esa.int/web/gaia/iow_20150717



D1. Gaia Science Alerts (Cambridge University)

http://gaia.ac.uk/alerts

Name	UTC timestamp	RA	Dec	AlertMag	HistMag	HistStdDev	Class	Comment	Published
Gaia15agm	2015-06-01 15:51:25	358.98623	-43.72412	17.35	Not known	Not known	SN Ia	candidate SN	9 Jun 2015, 12:27
Gaia15agl	2015-06-01 21:34:37	337.79327	-37.82735	18.71	Not known	Not known	unknown	candidate SN	9 Jun 2015, 12:27
Gaia15agk	2015-06-03 03:38:28	337.70660	-43.04732	18.80	Not known	Not known	unknown	candidate SN	9 Jun 2015, 12:27
Gaia15agj	2015-06-03 06:29:29	147.74682	37.96674	18.49	Not known	Not known	SN Ia	candidate SN	9 Jun 2015, 12:27
Gaia15agi	2015-01-24 09:32:33	43.08181	60.57638	18.97	Not known	Not known	unknown	Galactic plane red transient, brightened from 20 to 18 mag in 100days	3 Jun 2015, 16:16
Gaia15agh	2015-05-25 02:24:24	181.02133	14.06805	17.58	Not known	Not known	SN Ia	candidate SN in spiral starforming SDSS galaxy (z=0.043)	2 Jun 2015, 16:06
Gaia15agg	2015-05-29 16:41:03	64.10105	-28.49464	18.96	Not known	Not known	unknown	Candidate SN on edge of DSS galaxy	2 Jun 2015, 14:22
Gaia15agf	2015-05-29 09:17:25	330.62236	-20.32945	18.54	Not known	Not known	SN Ia	Candidate young and blue SN on the edge of a DSS galaxy	2 Jun 2015, 14:19
	2015-05-								2 Jun

D2. Gaia Follow-Up Network for Solar System Objects

(Gaia FUN-SSO)

React on alerts of moving objects (e.g asteroids)

→ Coordinate ground-based observations for:

- confirmation
- orbit determination/refinement

https://gaiafunsso.imcce.fr

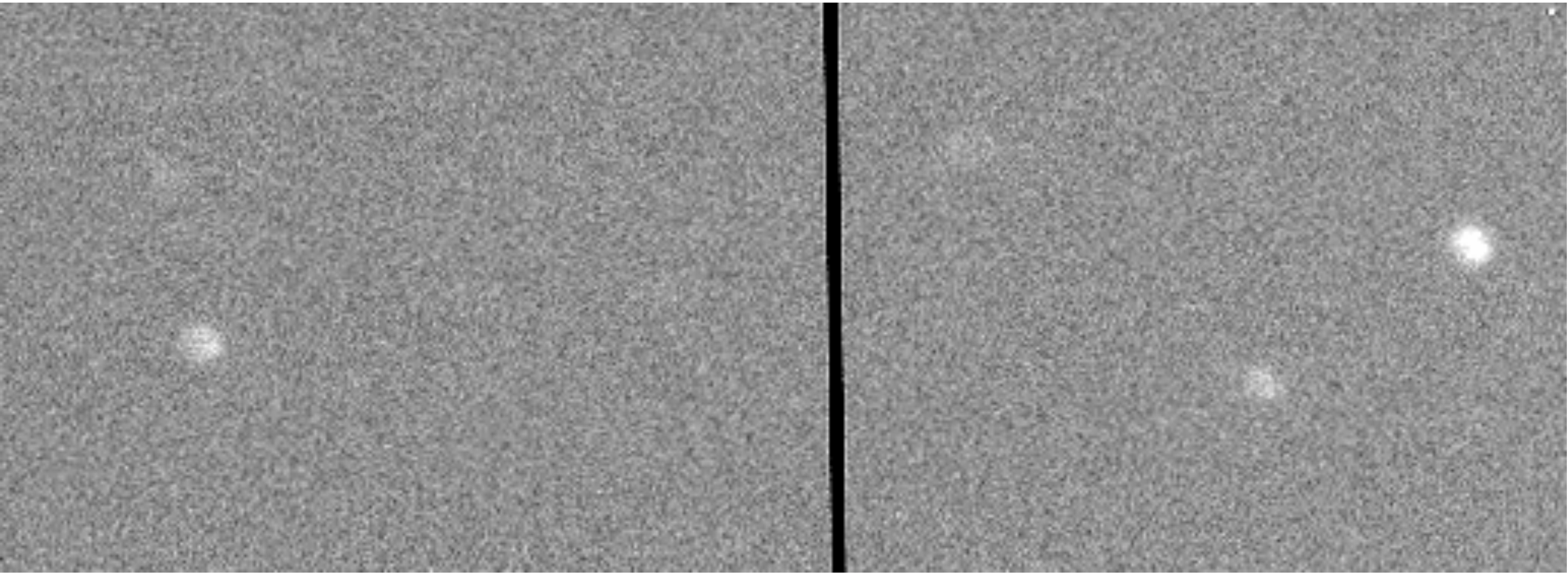
Institut de Mécanique Céleste de Calcul des Ephémérides - Paris Obs.

D2. Gaia Follow-Up Network for Solar System Objects

https://gaiafunsso.imcce.fr

D2. Gaia Follow-Up Network for Solar System Objects

Example: asteroid confirmed on 8/11/2015



Credit Sergi Blanco-Cuaresma, Geneva Observatory with the Mercator telescope, La Palma, Spain

D3. GBOG: ground-based observations for Gaia

- Une douzaine de télescopes (1-2 m) disponibles dans le GBOG
  - Initialement pour préparer la mission
  - Durant la mission pour valider / confirmer des observations

- Données non publiques → activités coordonnées au sein du Gaia DPAC (Data Processing and Analysis Consortium)

- Acquisition *et réduction* des données (courbes de lumière, ...)

- Ouverture pour des amateurs chevronnés:
  - Signature d'une 'Non-Disclosure Agreement'

Release scenario

spacecraft operations start

nominal mission end

extended mission end?

2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022

Release 1:

- **α and δ, mean G-magnitude**
- **Commissioning data**
- **100K proper motion stars (Hipparcos +Gaia)**

- **+ (?) TGAS: Tycho+Gaia astrometric solution (2 million stars)**
- **+ (?) Groups of variables: RR Lyrae stars + Cepheids + Short times scales**

Release 2:

- **5-parameter astrometric solutions for single star (parallax)**
- **Integrated BP/RP + Astrophysical parameters**
- **Mean V_{rad} (for non variable)**

Release 3:

- Mean V_{rad}
- 5-par astrometry
- Object classifications and Astrophysical Parameters
- **Orbital solution of binaries**
- **Mean RVS spectra**

Release 4:

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

Final release:

- everything !

Courtesy of B.Holl

Conclusions

- Gaia : mission unique, en très bonne voie

- Milliard d'étoiles

- Contributions d'amateurs chevronnés bienvenus