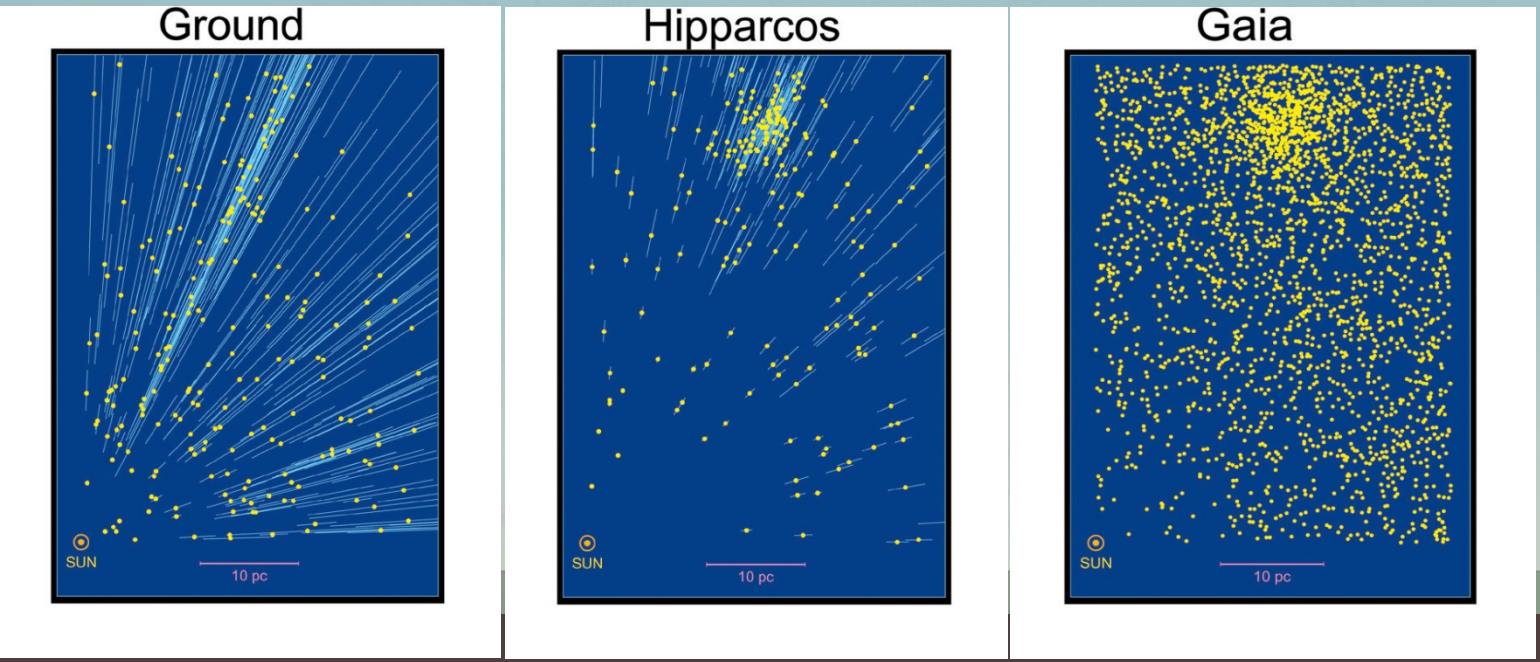
THE SPECTROPHOTOMETRIC STANDARD STARS GRID FOR THE GAIA ABSOLUTE CALIBRATION

Giuseppe Altavilla & the CU5 Bologna Gaia Team

2017 ESO Calibration Workshop

Gaia objectives

- The largest and most precise 3D chart of our Galaxy (6D space survey: α, δ, π, μα, μδ + complementary radial velocities) + astrophysical parameters
- Composition, Formation and Evolution of our Galaxy, unraveling the chemical and dynamical history of our Galaxy… And much more!

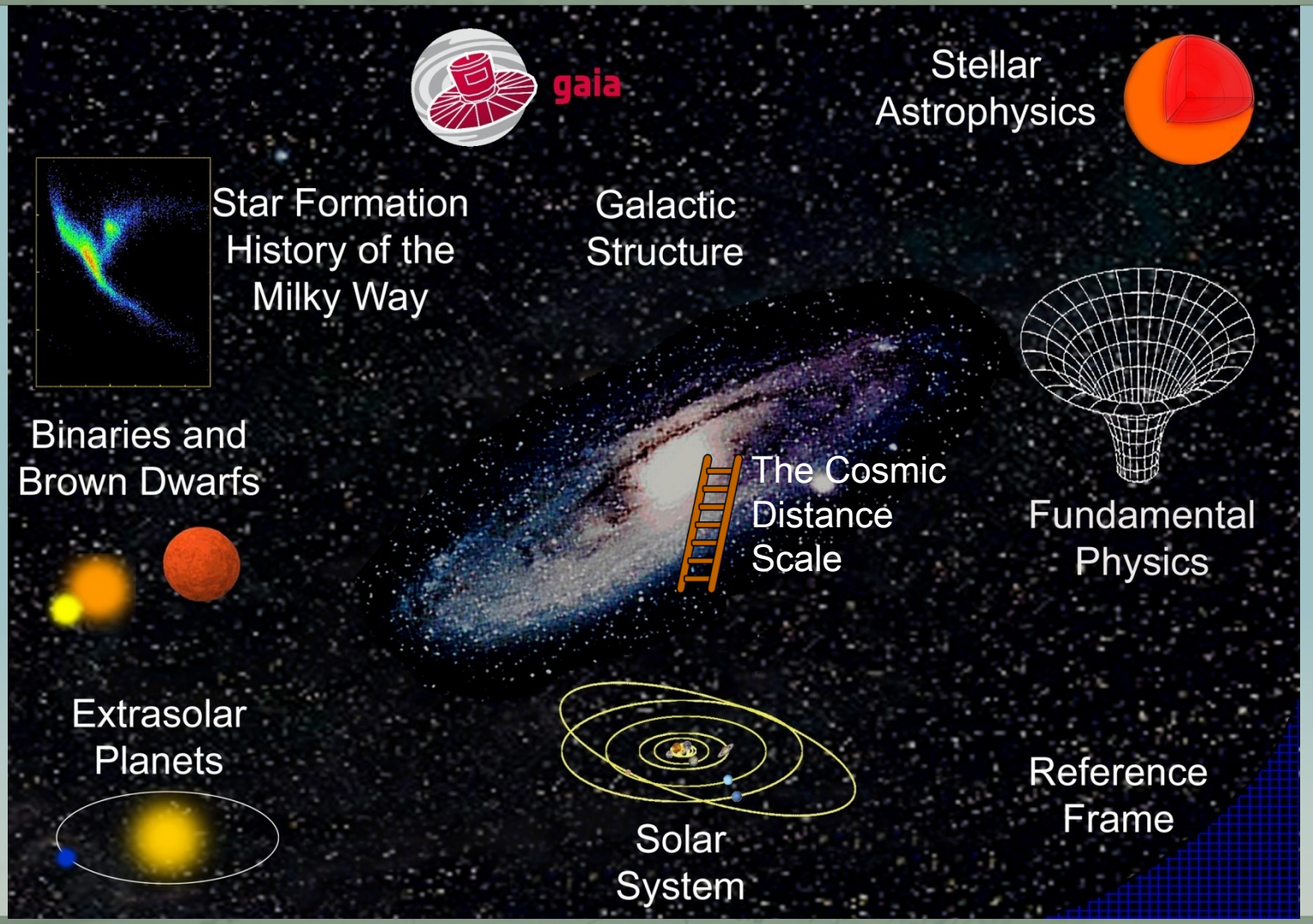


Astrometric accuracy: the Hyades D~47 pc

Gaia will provide:

- in our Galaxy …
  - the distance and velocity distributions of all stellar populations
  - a rigorous framework for stellar structure and evolution theories
  - a large-scale survey of extra-solar planets a large-scale survey of Solar System bodies … and beyond
  - definitive distance standards out to the LMC/SMC
  - rapid reaction alerts for supernovae and burst sources QSO detection, redshifts, microlensing structure fundamental quantities to unprecedented accuracy: γ to 10-7 (10-5 present)

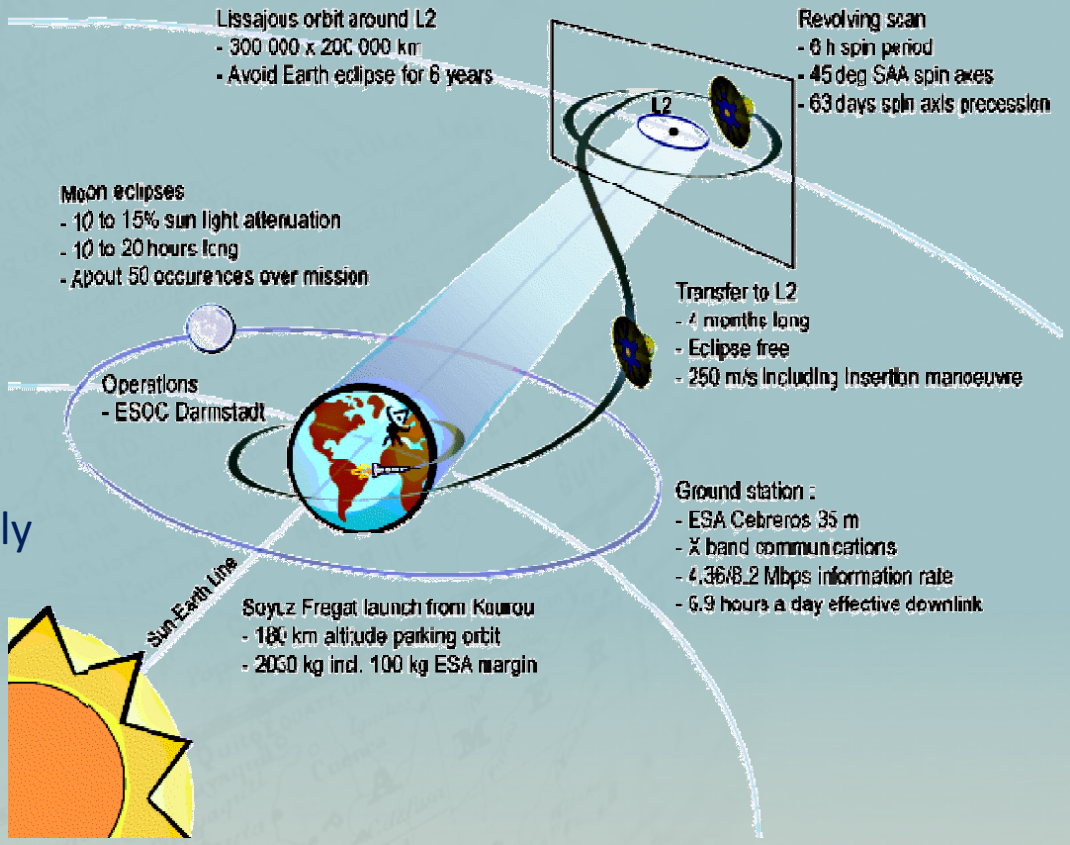
Gaia science:



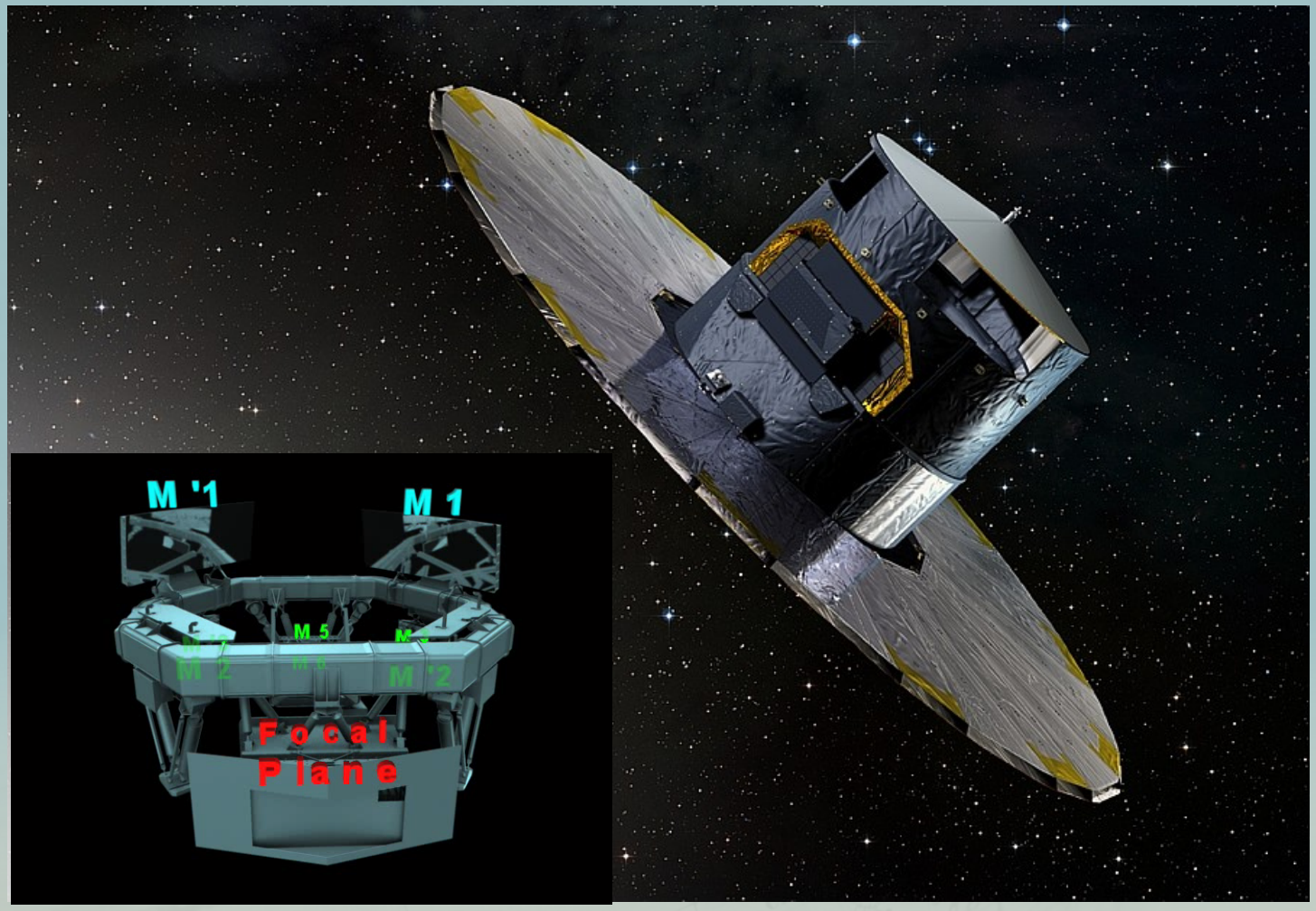
- Gaia
- The Gaia Spectrophotometric Standard Stars

Gaia

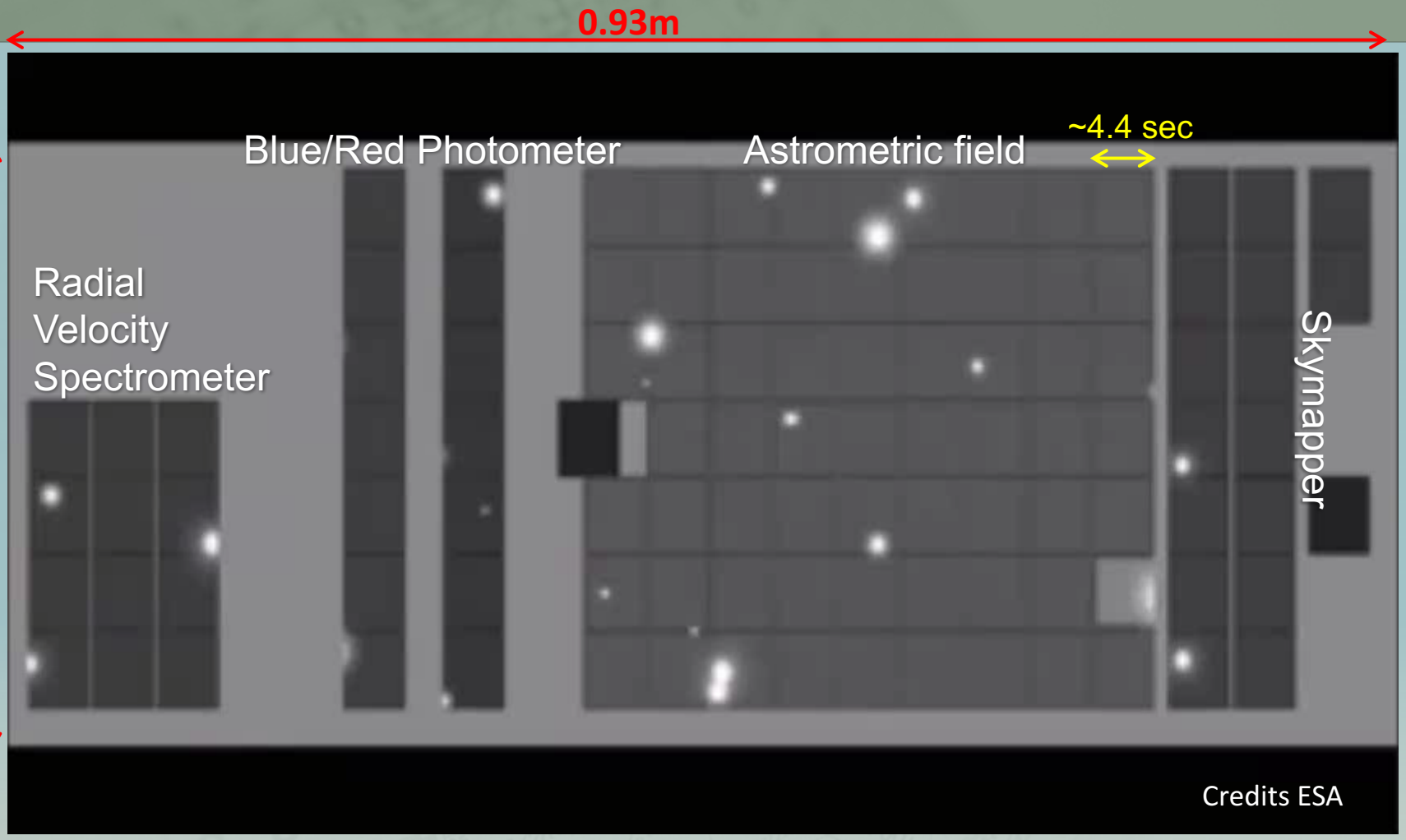
- L2, 1.5 million km from the Earth (~2 months cruise)
- stable thermal environment,
- high observing efficiency,
- moderate radiation environment (launch worst phase).
- Ground Based Optical Tracking (GBOT needed for solar system only (accuracy 20mas, 150m in L2)



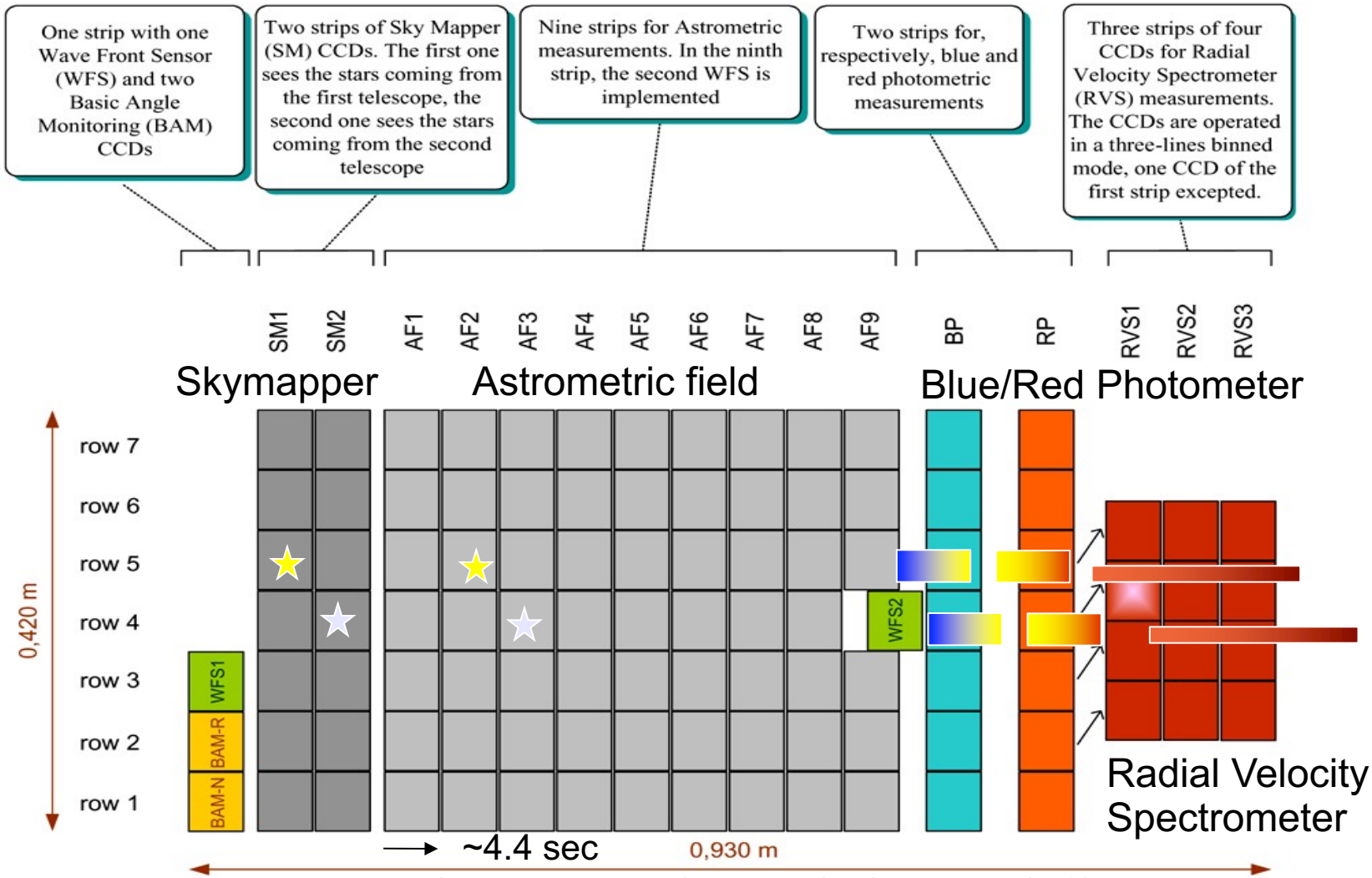
Gaia



Gaia focal plane



FoV: 0.7 deg x 0.7 deg, pixel (10 µm x 30 µm): 0.059”(AL) x 0.177”(AC)
106 CCD 4500x1966 px (TDI)



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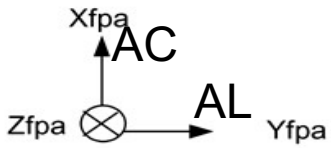
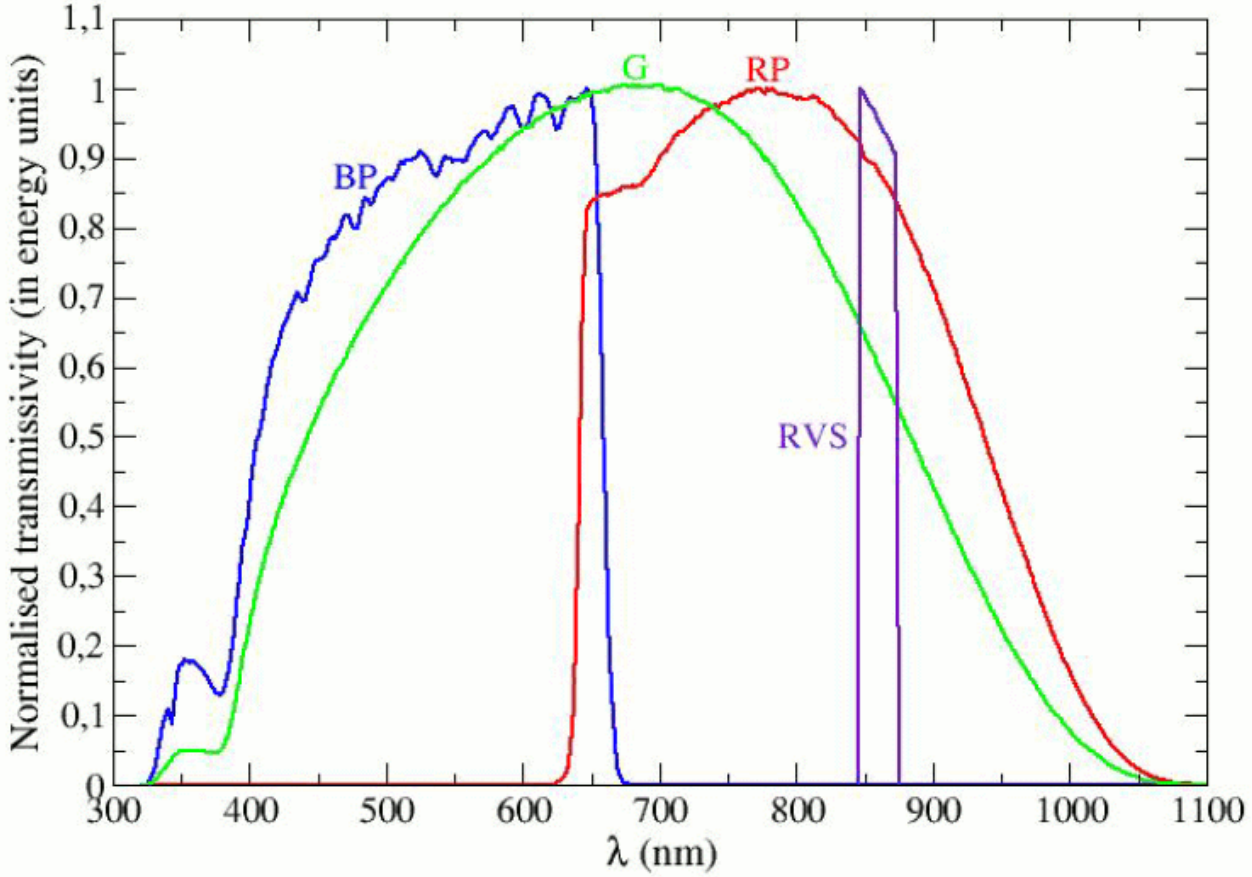


Gaia passbands



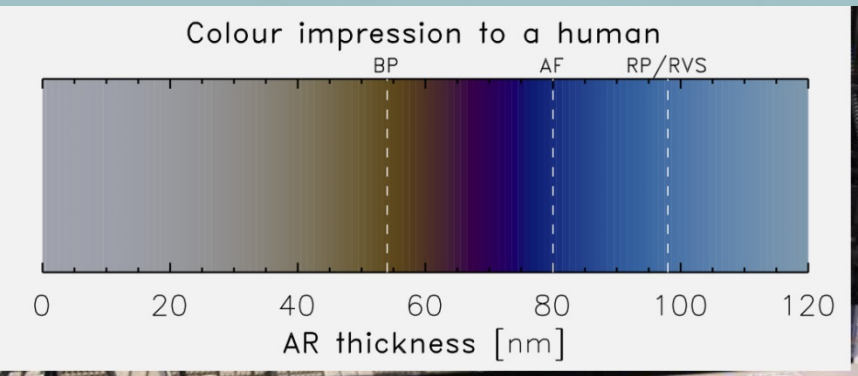
BP 3300-6800Å, R=80-20

G 3300-10500Å

RP 6400-10500Å, R=90-70

RVS 8470-8740Å, R=11500

Examples of Gaia imaging capabilities



ESA/Gaia/Airbus DS/DPAC/IEEC-ICCUB/M.Weiler

Gaia's focal plane for 2 telescopes 1.49 x 0.54 m

- Time to cross a CCD: 4.4s
- Time to cross the FOV: 45s
- Time between FOVs: 106.5m & 4h 13.5m
- Time between scans: 6h

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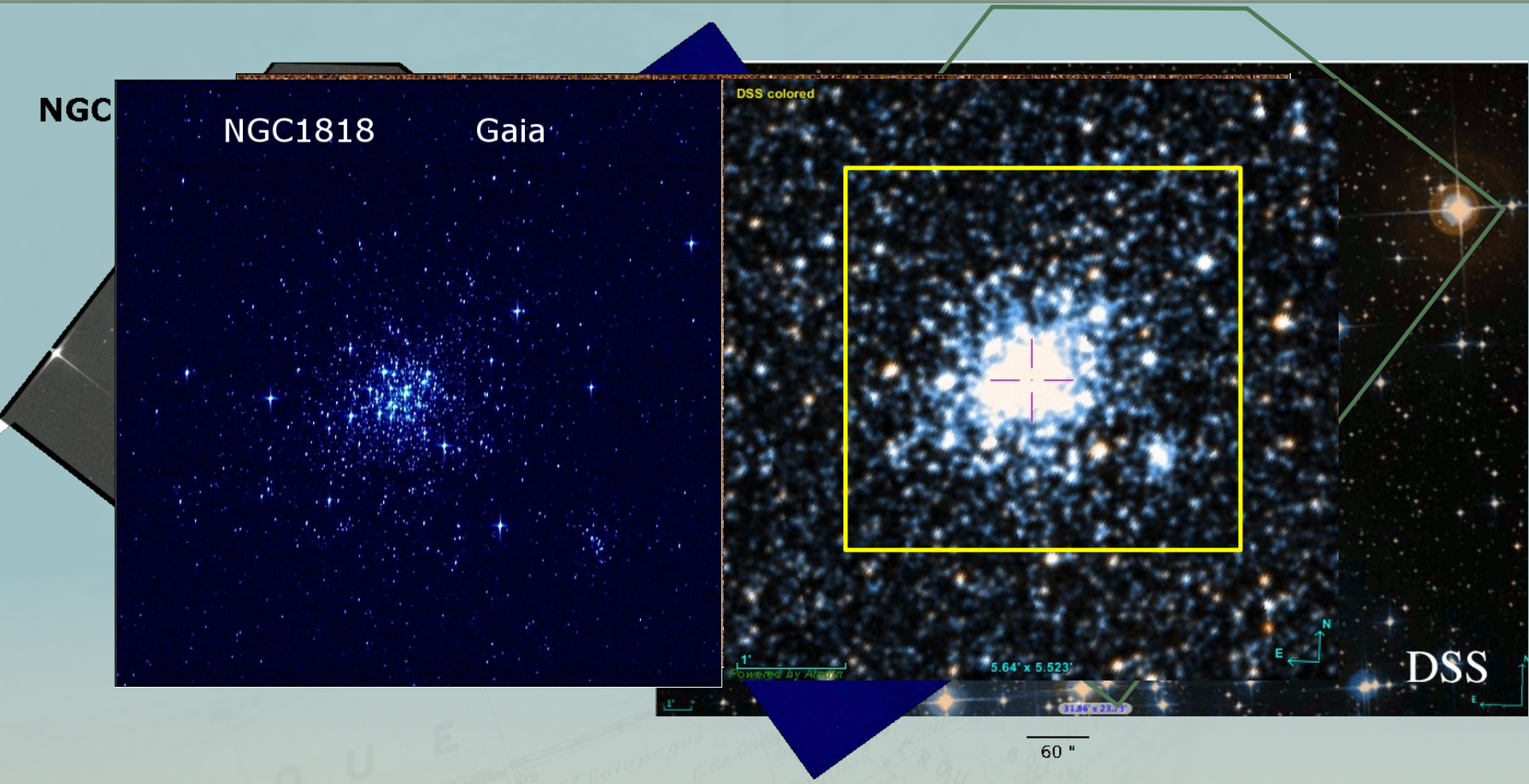

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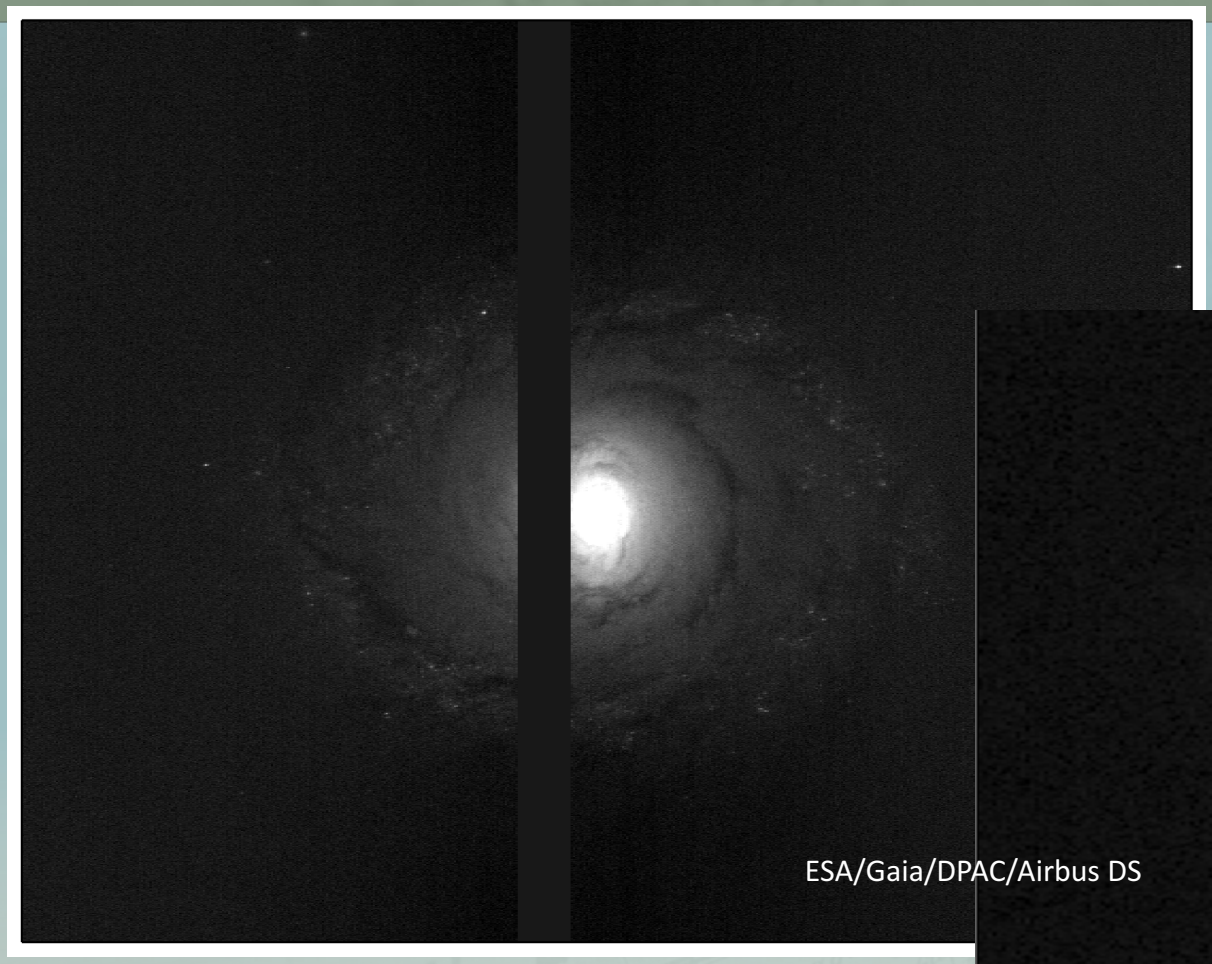
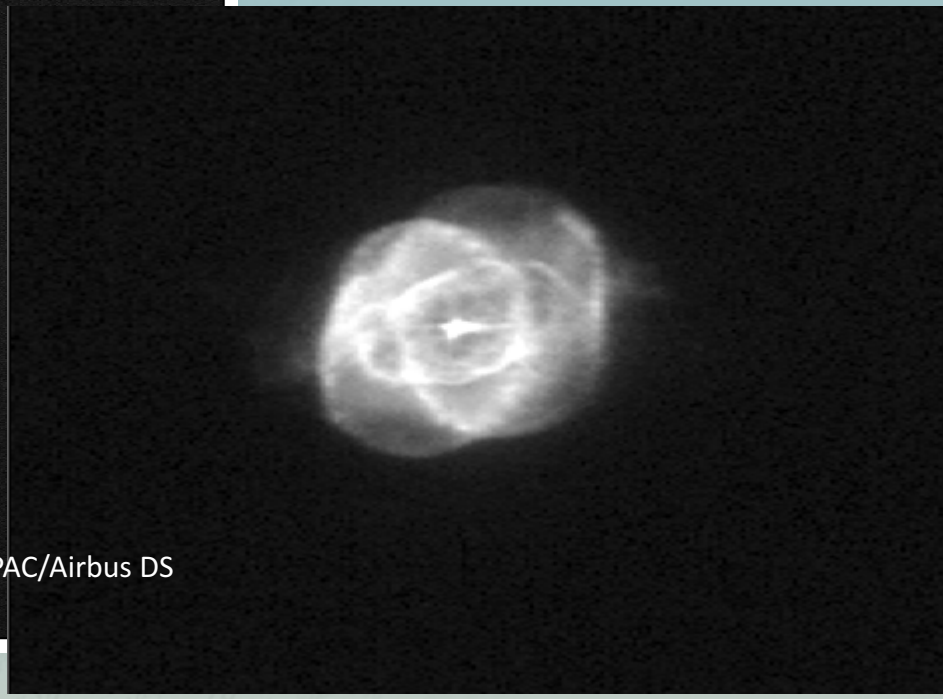


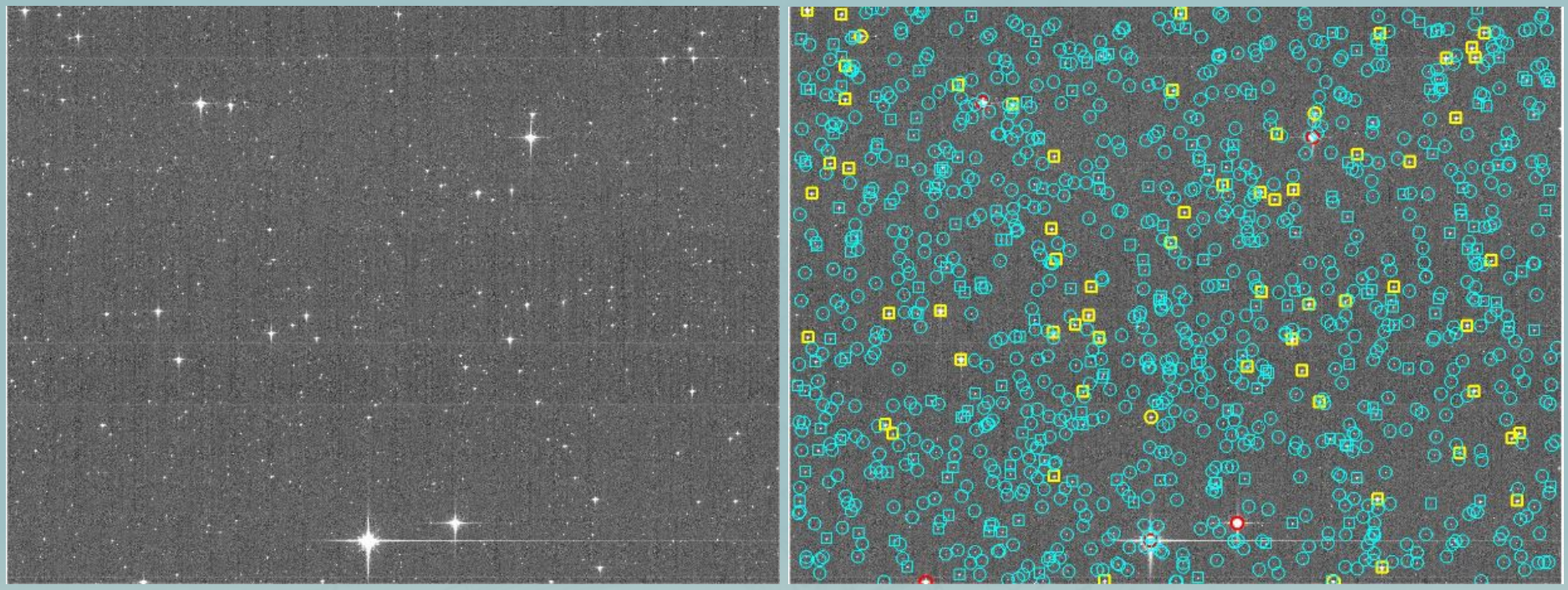
Messier 94



Cat's Eye Nebula

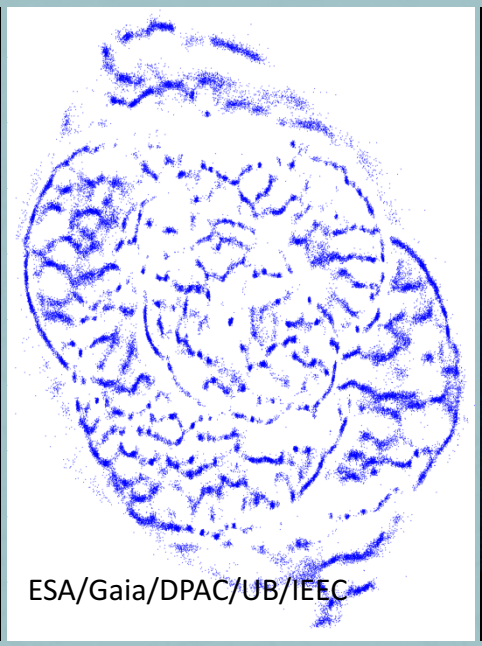
ESA/Gaia/DPAC/Airbus DS

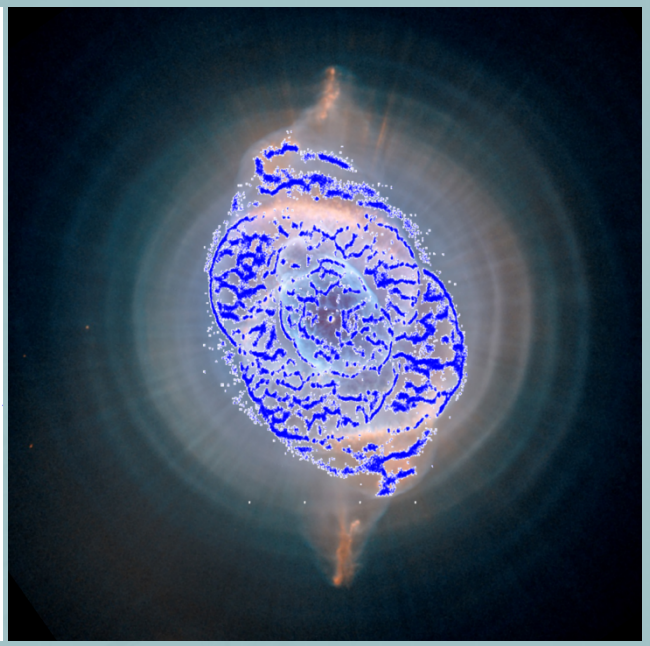
Examples of real Gaia “images”



An image of the sky as recorded by one of the sky mapper CCDs and the assignment of windows to all point-like sources detected and confirmed above a given threshold. The limiting magnitude of Gaia for this image is G = 20.7. Several symbols and colours encircling the sources are used for different ranges of magnitudes

Examples of real Gaia "images"





Left: HST ACS/WFC image of the Cat's Eye nebula (integration time 1.2 h; north is up and east is left). The scale of the image is ~1 x1 arcminute. Middle: the ~84,000 Gaia detections that were made in this area from 25 July to 21 August 2014. Right: a superposition of the two images

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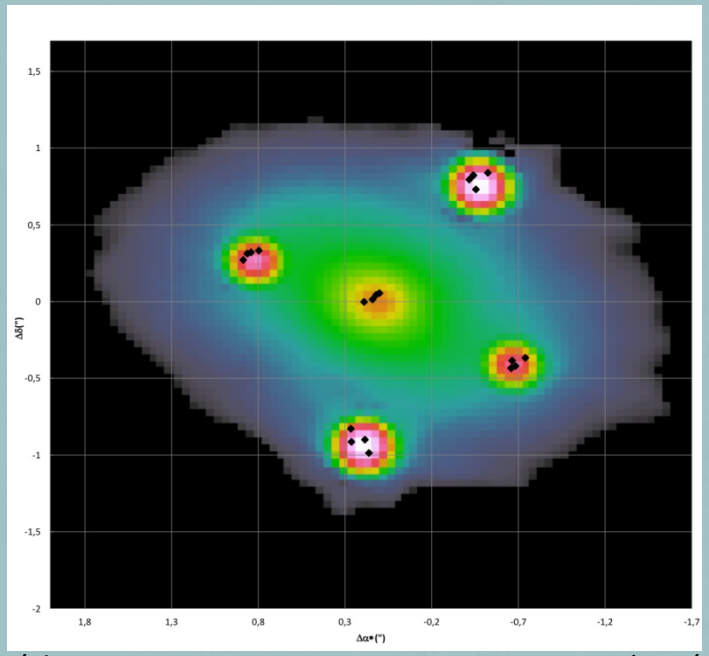
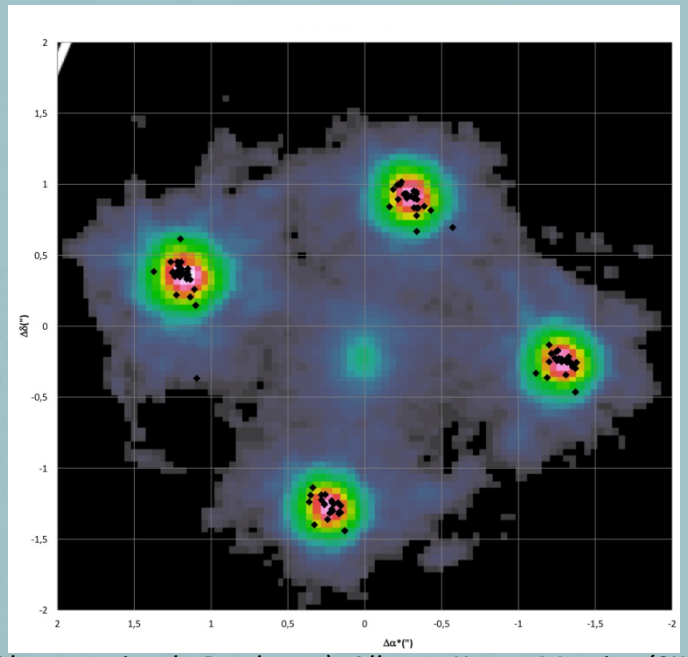
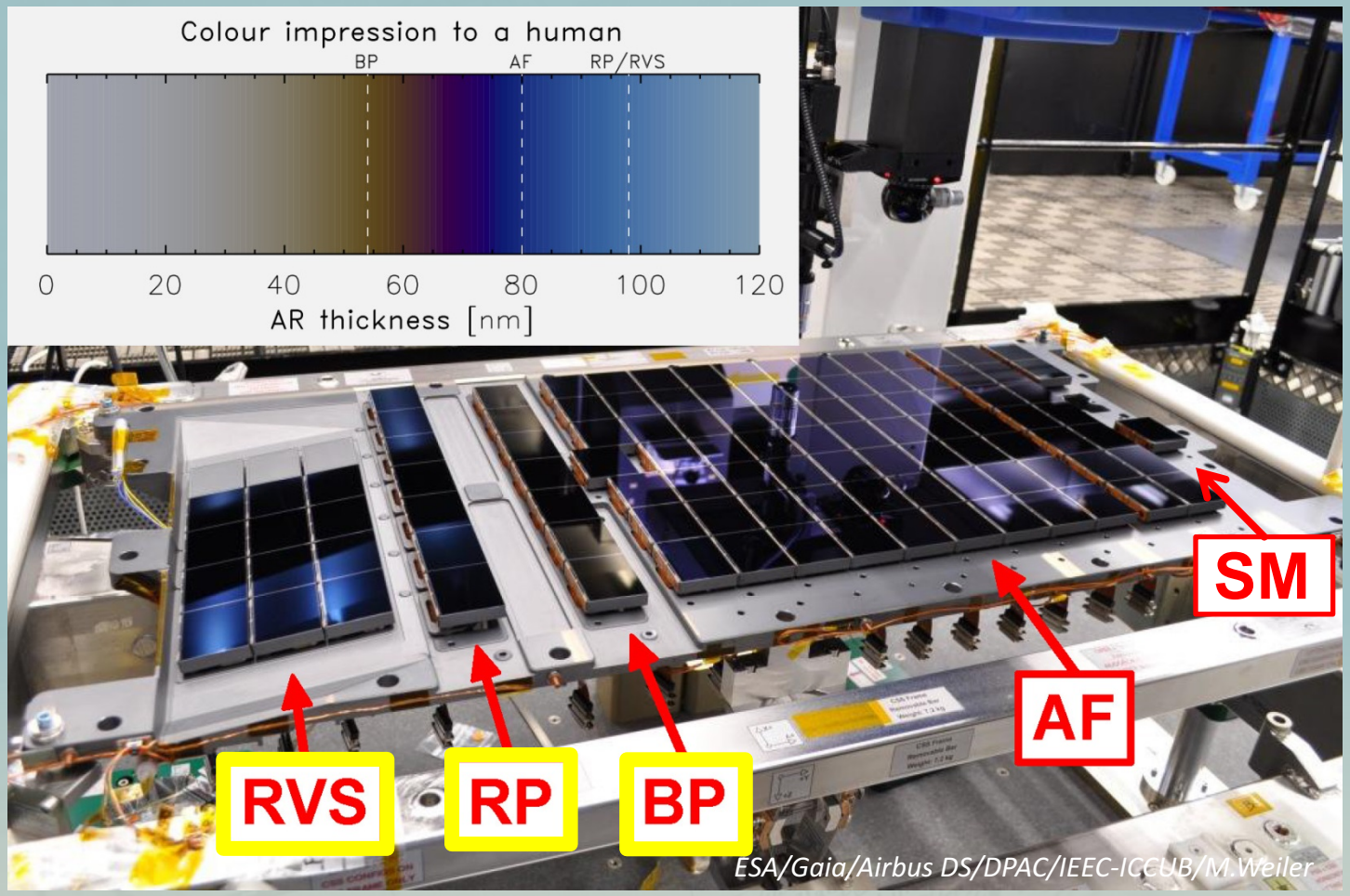




ESA/Gaia/DPAC/Christine Ducourant, Jean-Francois Lecampion (LAB/Observatoire de Bordeaux), Alberto Krone-Martins (SIM/Universidade de Lisboa, LAB/Observatoire de Bordeaux), Laurent Galluccio, Francois Mignard (Observatoire de la Côte d'Azur, Nice)

Einstein Cross (left) and HE0435-1223 (right) with Gaia astrometric positions placed over HST images. Magnitude ranges: 17 to 19 ; astrometric accuracy of each position in this preliminary reduction is ~100 mas. It will be much improved during the global astrometric processing where spacecraft attitude will also be solved together with the source astrometry.

Examples of Gaia spectroscopic capabilities



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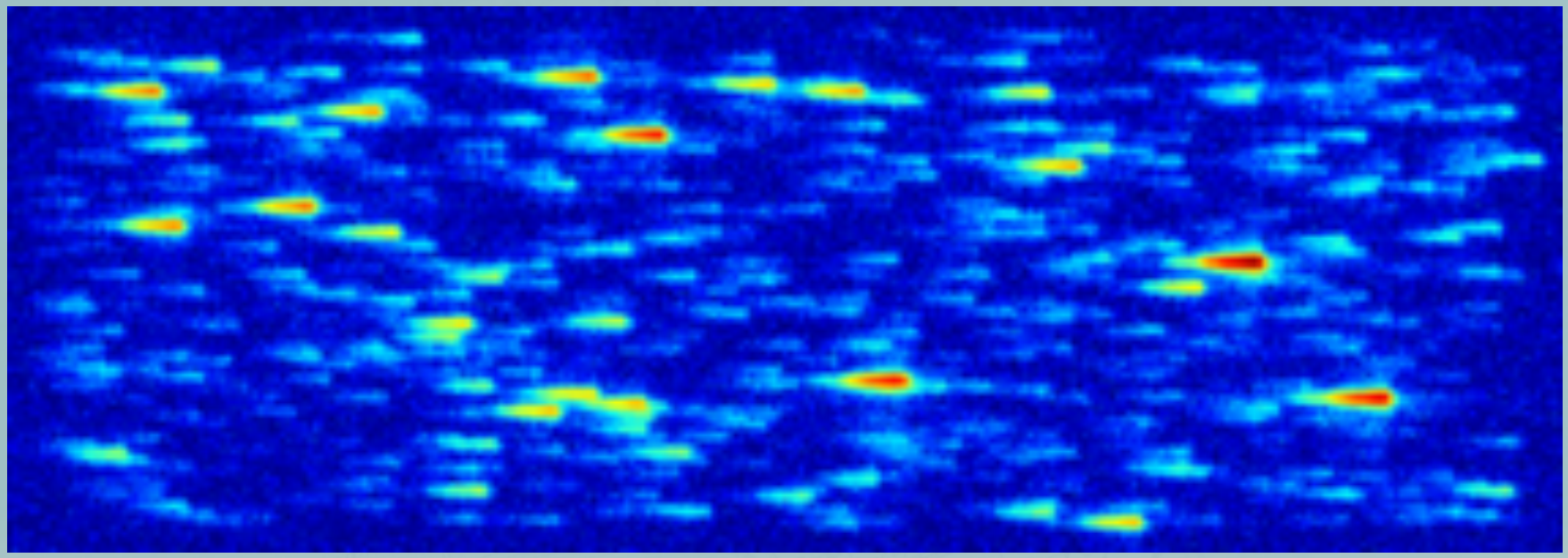
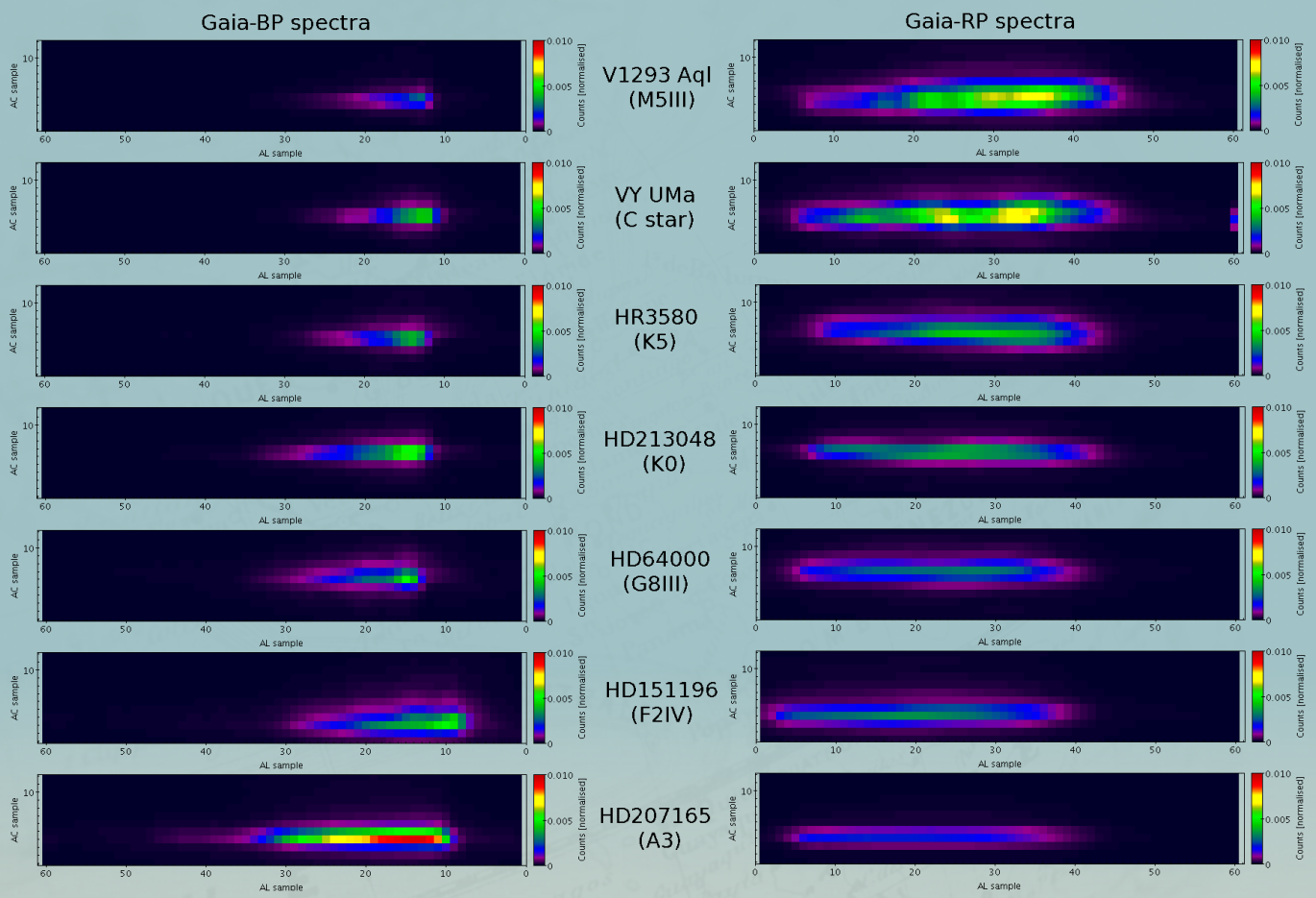


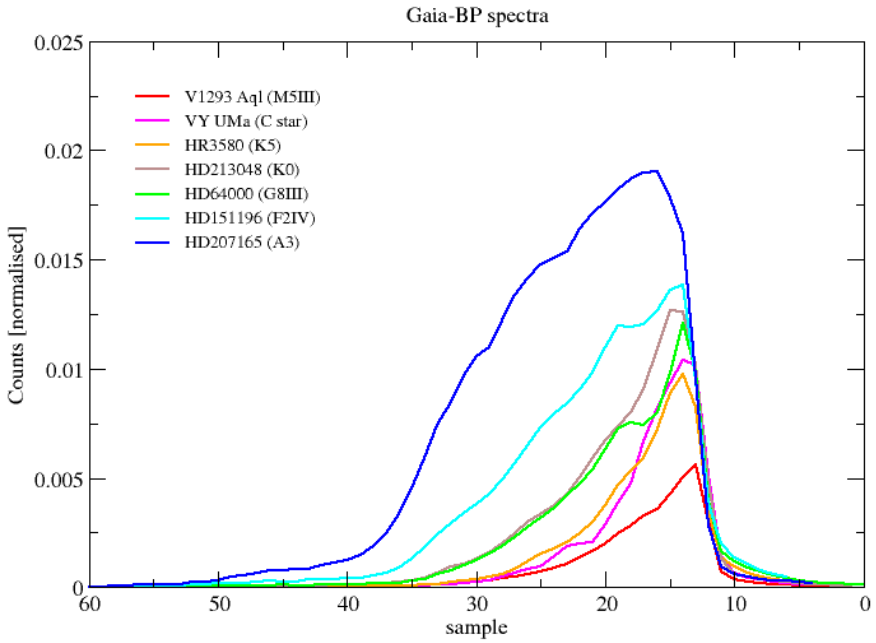
A simulation of a crowded stellar field as observed by Gaia's photometric instruments.

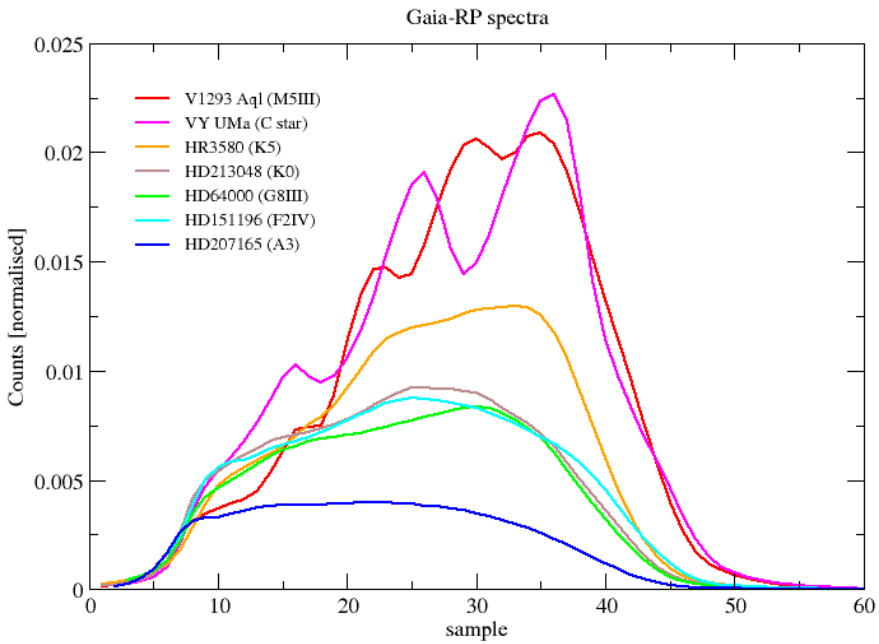
Examples of Gaia spectroscopic capabilities



Blue and Red Photometer 2D spectra for 7 bright cool (~3000°C) and hot (~8000°C) stars.

Gaia BP/RP spectra





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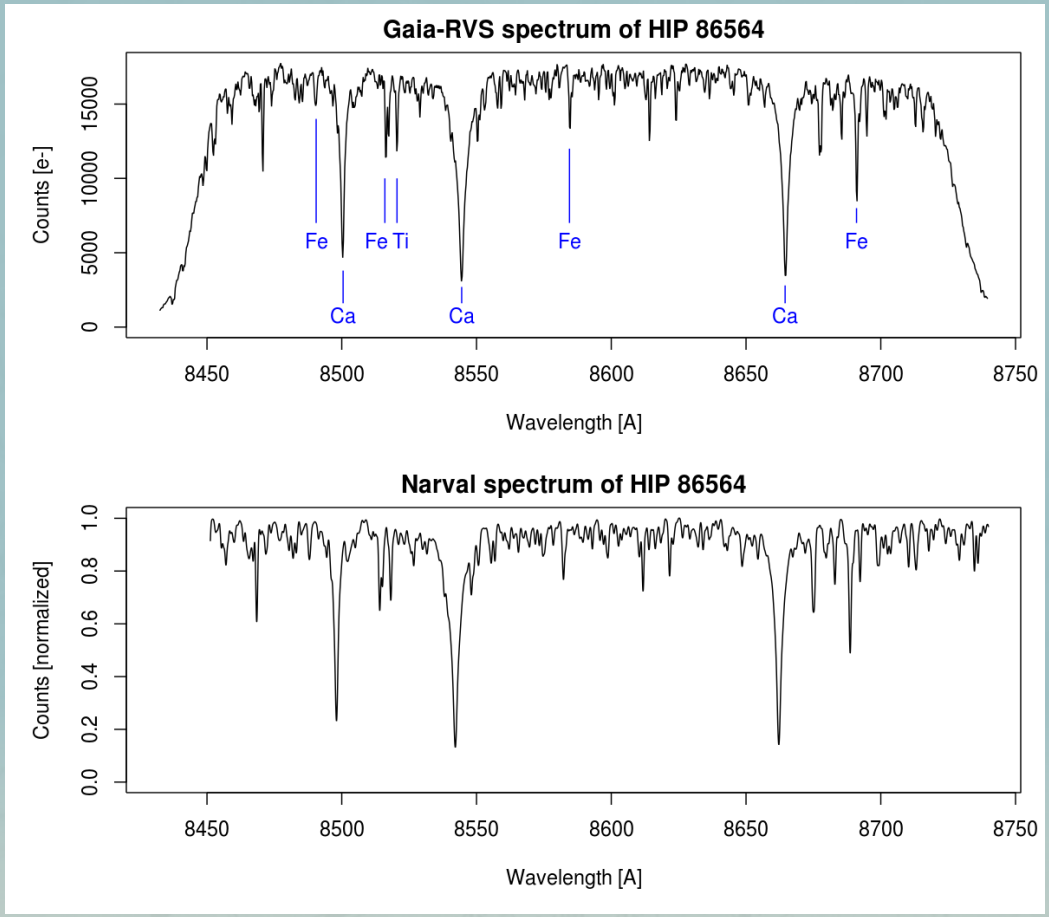
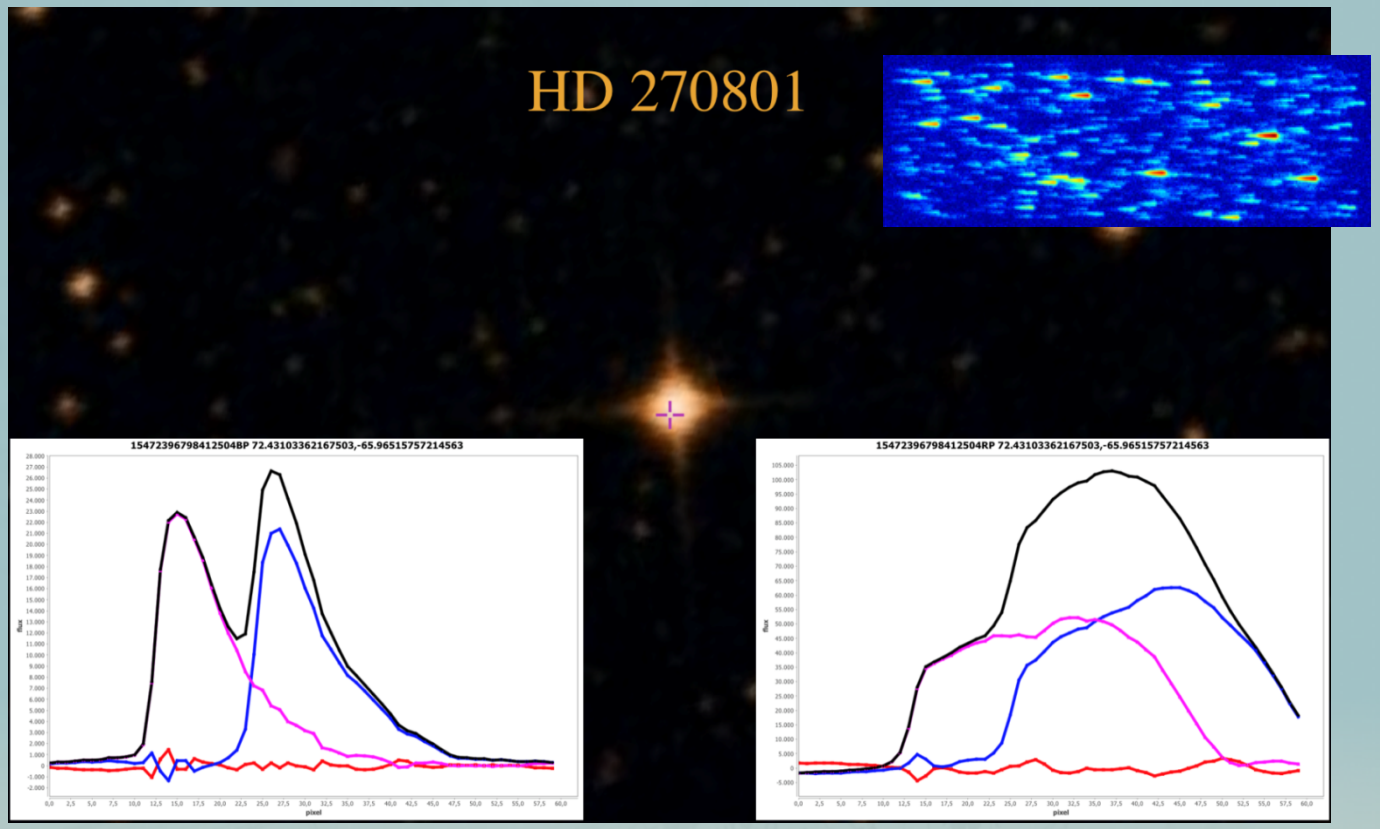
Gaia RVS spectrum



HIP 86564 (K5, V=6.6), RVS & Narval@Bernard Lyot 2m spectra R=11500

First Gaia BP/RP deblended spectra



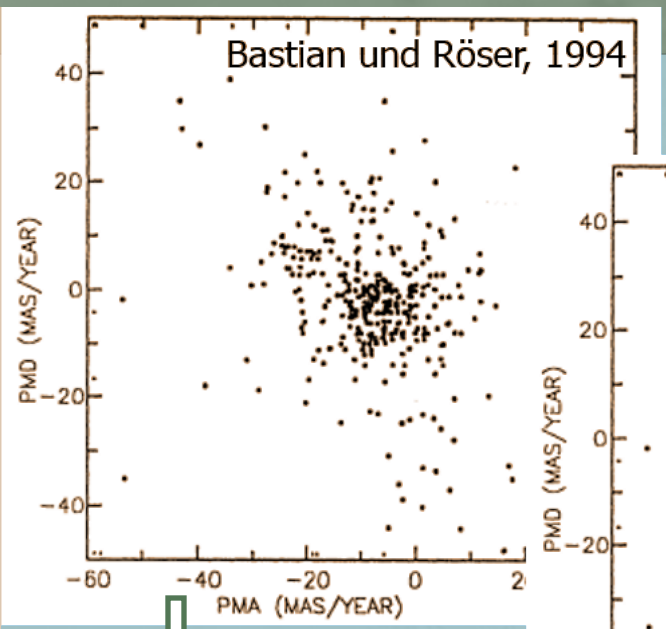
DSS coloured image of the double star HD270801. Bottom left: the observed BP spectrum in black and the two extracted spectra in magenta and blue; in red the extraction residuals. Bottom right: the same for RP

Tales of two clusters retold by Gaia

John Herschel, 1835
L. E. Dreyer , NGC2451 in 1888

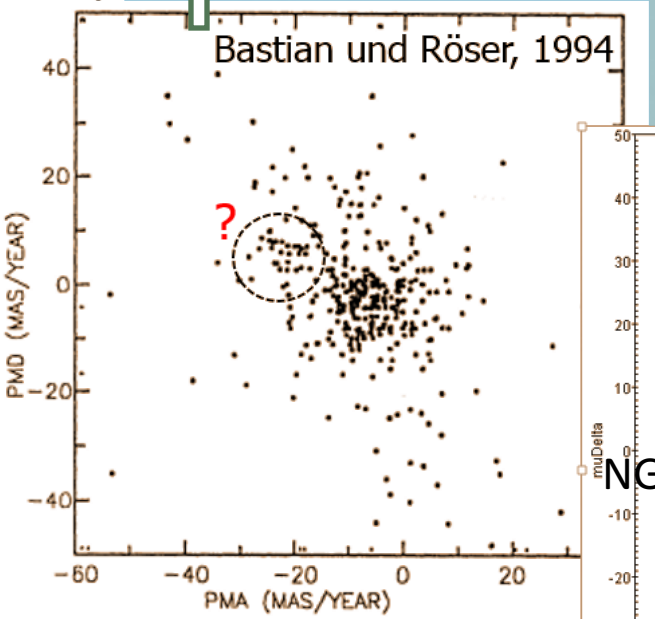
S. Röser and U. Bastian 1994
Proper Motions Catalogue (PPM)
more than 100 years of position measurements! The cluster was finally proven to be non-existent

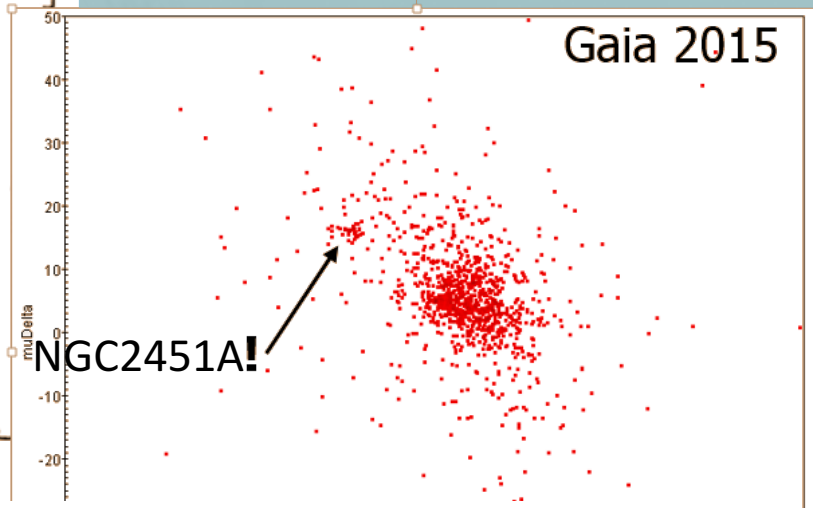
Tales of two clusters retold by Gaia



S. Röser & U. Bastian 1994
NGC2415 NON existent

A barely discernible density enhancement?





CMD
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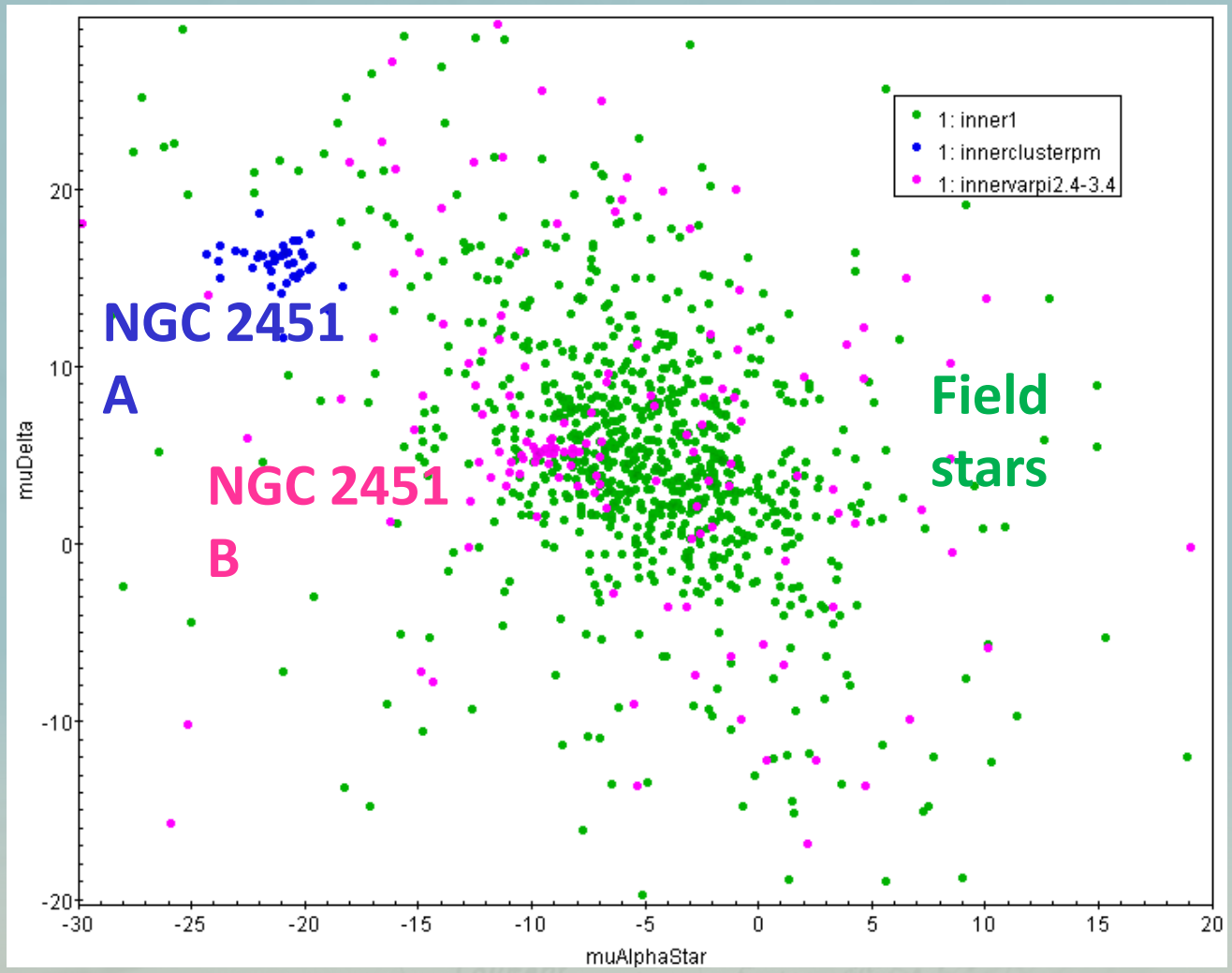
NGC

10 months of Gaia

NGC2451 nicely pop-out in the PM diagram. No need of CMD. NGC2451B still hidden…BUT Gaia distance measurements of all 1100 stars in the NGC 2451 area indicated two slight bumps at ~190 pc, and ~360 pc (in agreement with the supposed distances of the two clusters!)

ESA/Gaia/DPAC/DPCE/DPCB/CU3/U. Bastian

Tales of two clusters retold by Gaia



Gaia DPAC

DPAC: Data Processing and Analysis Consortium

- CU1: System Architecture
- CU2: Data Simulations
- CU3: Core Processing
- CU4: Object Processing
- CU5: Photometric Processing
- CU6: Spectroscopic Processing
- CU7: Variability Processing
- CU8: Astrophysical Parameters
- CU9: Catalogue Access

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Gaia @ INAF-OABo

CU5 - photometric processing

- **DU13**: Instrument absolute response characterization: ground-based preparation (E. Pancino, G. Altavilla deputy)
- **DU14**: Instrument absolute response characterisation: definition and application (C. Cacciari)

G. Cocozza, S. Galleti, S. Ragaini,
M. Bellazzini, A. Bragaglia, L. Federici, P. Montegriffo, E. Rossetti

- **DU17**: Flux and classification-based science alerts

CU7 - variability processing (G. Clementini)

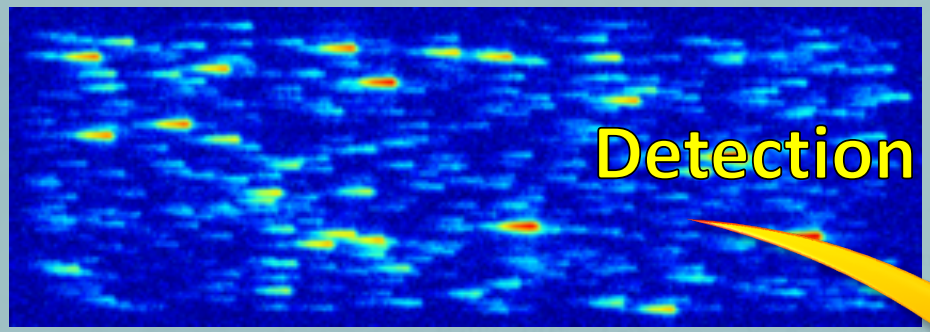
The Bologna CU5-DU13 goal

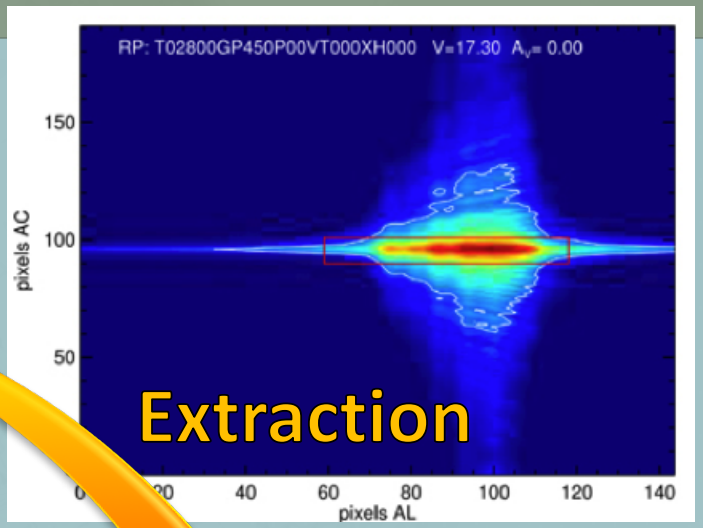
- **Provide a grid of ~200 Spectro-Photometric Standard Stars (SPSS) for the absolute spectro-photometric calibration of the Gaia G-band and low resolution (BP/RP) spectrophotometry**

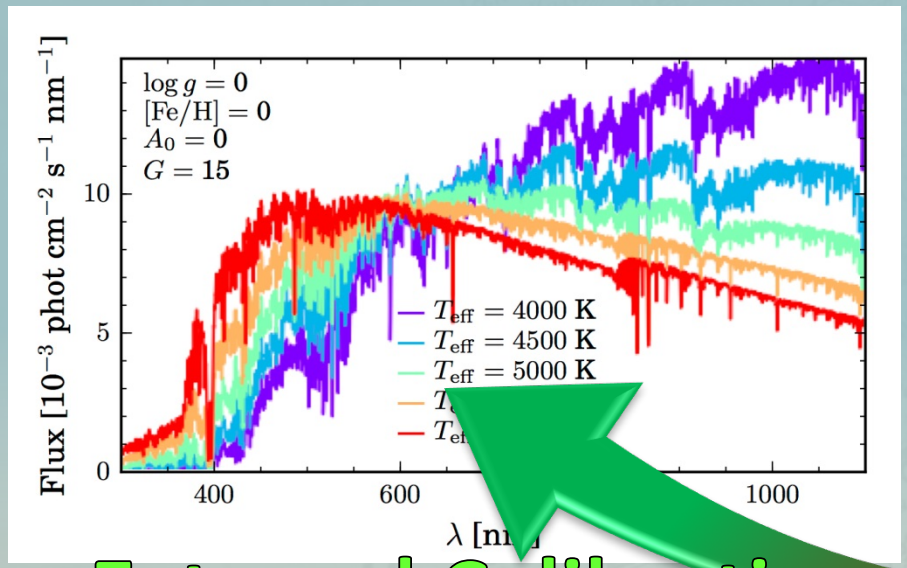
- Existing grids are not sufficient, we need:
  - Spectral type coverage (all spectral types)
  - Well distributed in the sky
  - Precision and accuracy of 1-3%
  - Good statistics (100-200)
  - Full coverage of Gaia range (330-1100 nm)

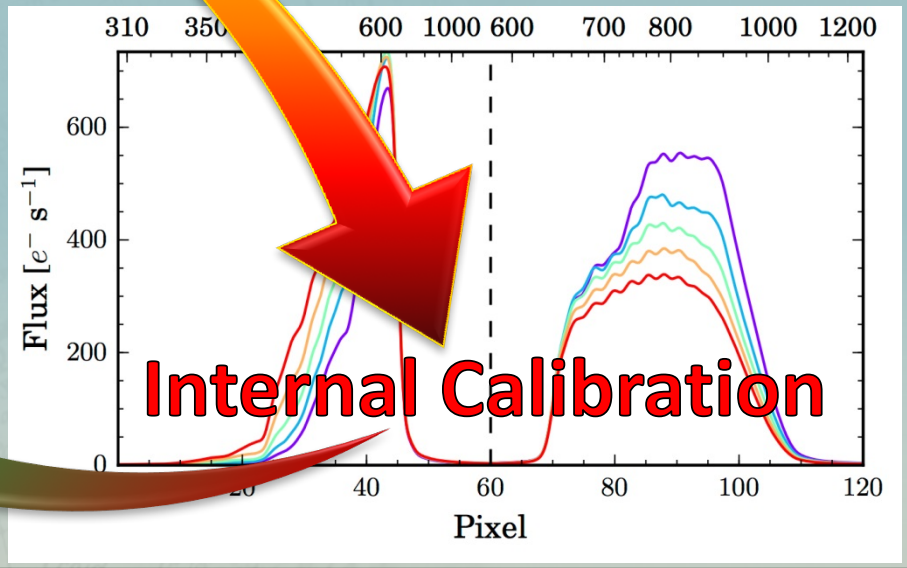
- **See Pancino et al., 2012, MNRAS, 426, 1767, Altavilla et al. 2015, AN, 336, 515**

Gaia Absolute Calibration





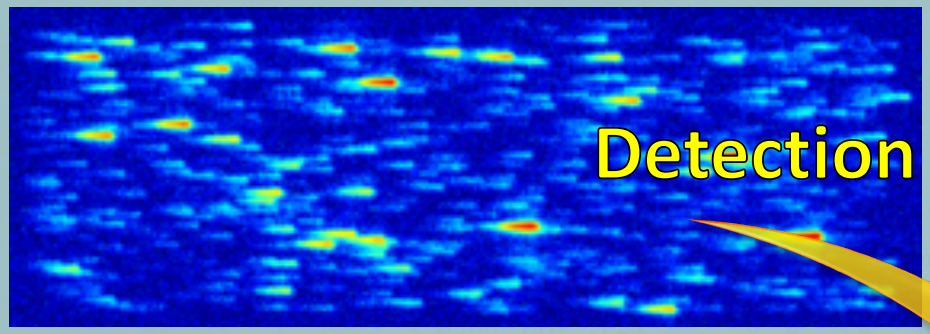


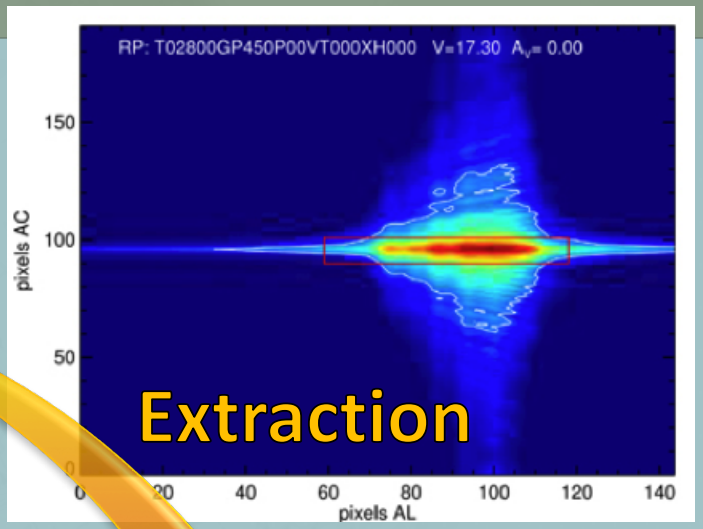


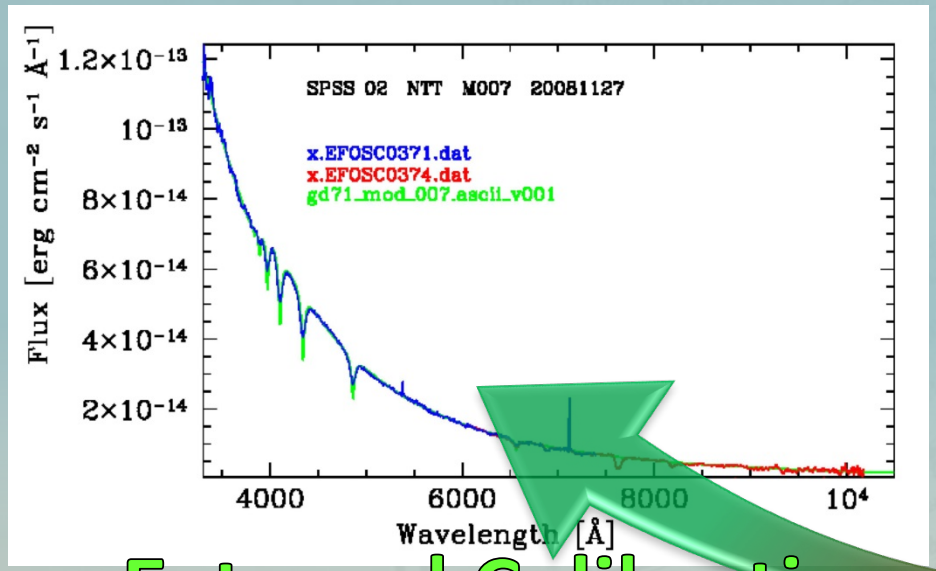
External Calibration

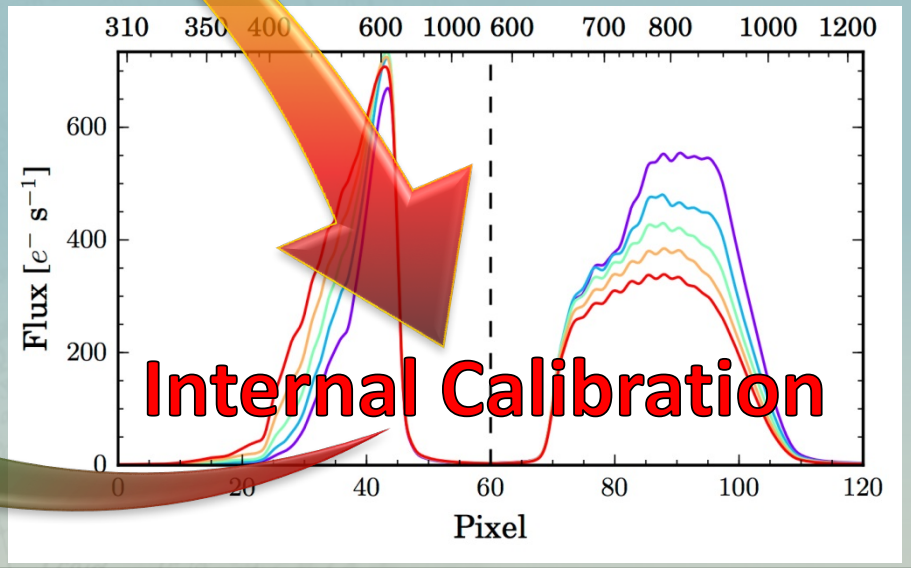
Astraatmadja, 2015, GAIA-C8-TN-MPIA-TLA-001

Gaia Absolute Calibration



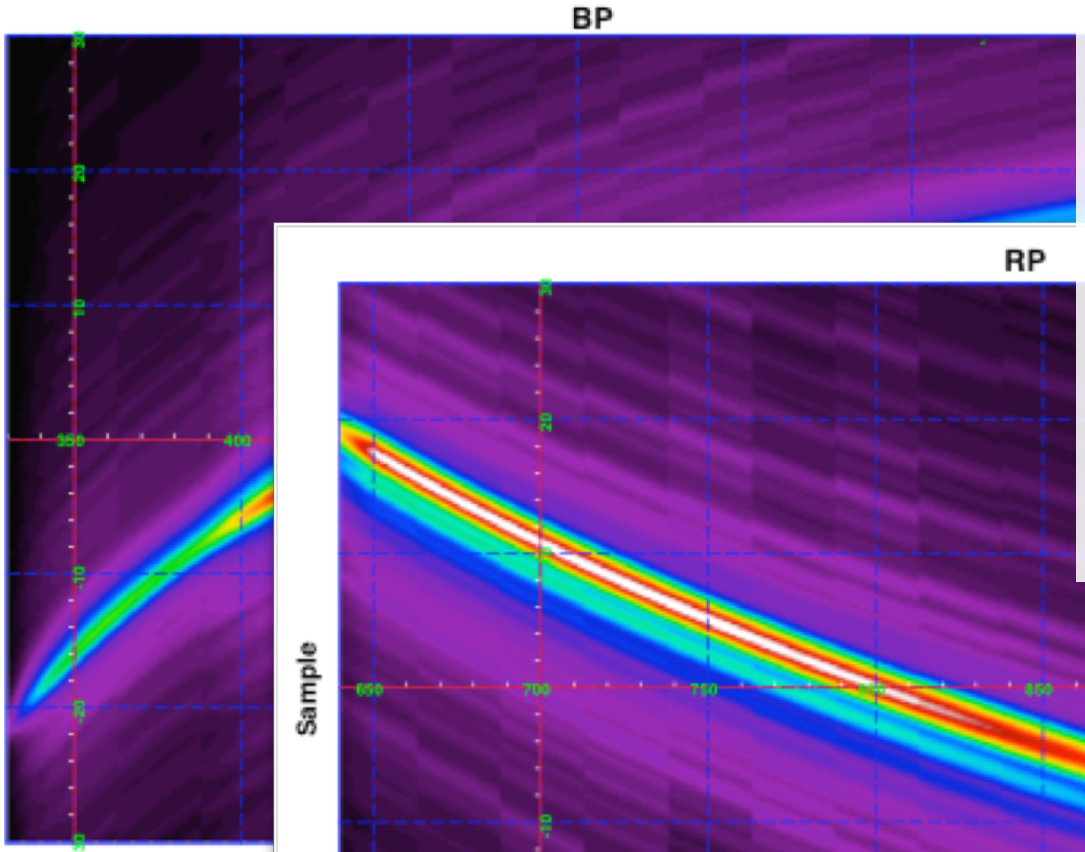






External Calibration

LSF smearing

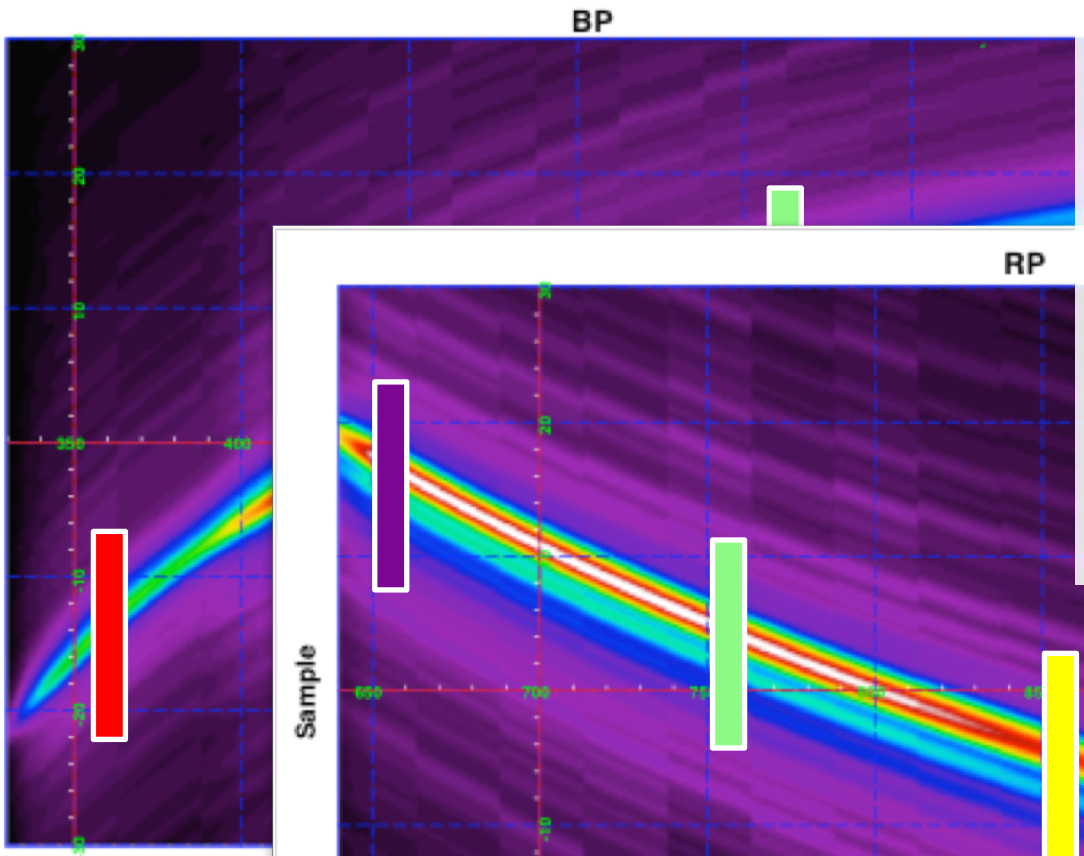


The BP dispersion ma

The RP dispersion matrix

Dispersion matrix for BP and RP instruments for FoV 1 and CCD row no 4: each column of the matrices represents a $LSF_{\lambda j}$ centred on the dispersion function at the corresponding wavelength, while the profile of the rows reveals the shape of the photometric band if seen from the edge

LSF smearing



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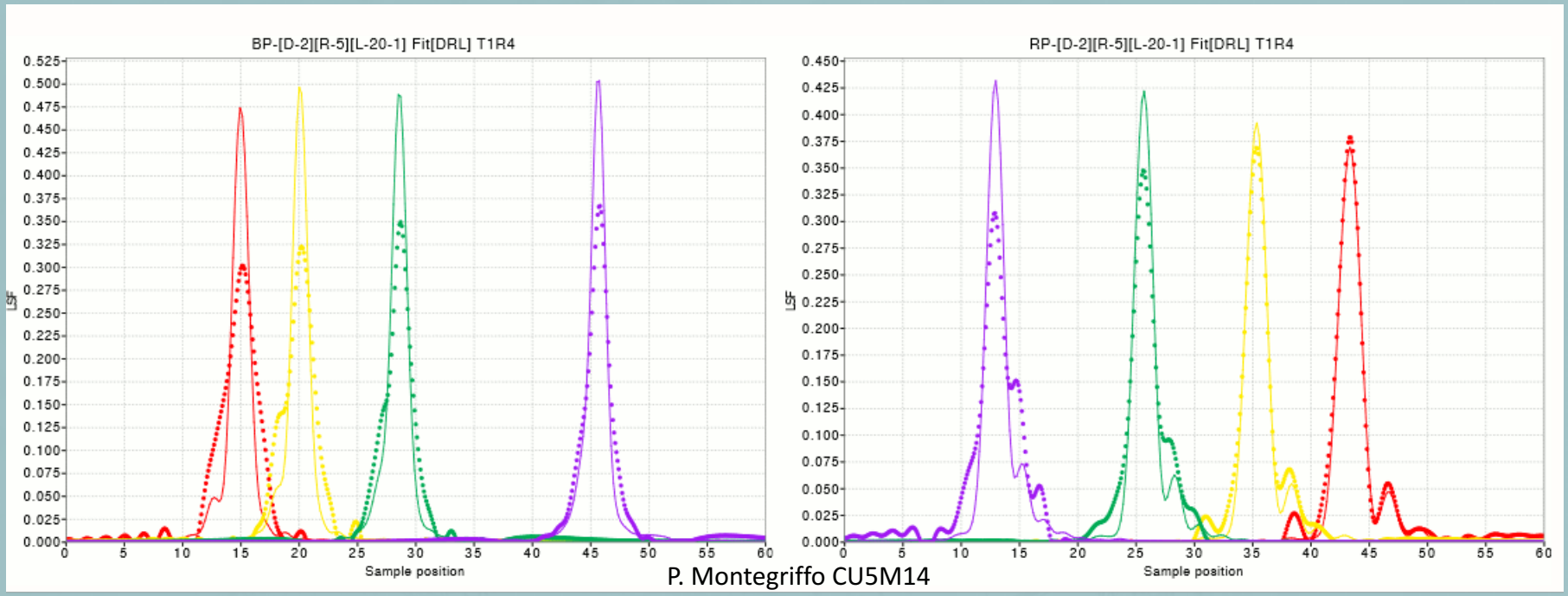
The BP dispersion ma

The RP dispersion matrix

Gaia LSF smearing



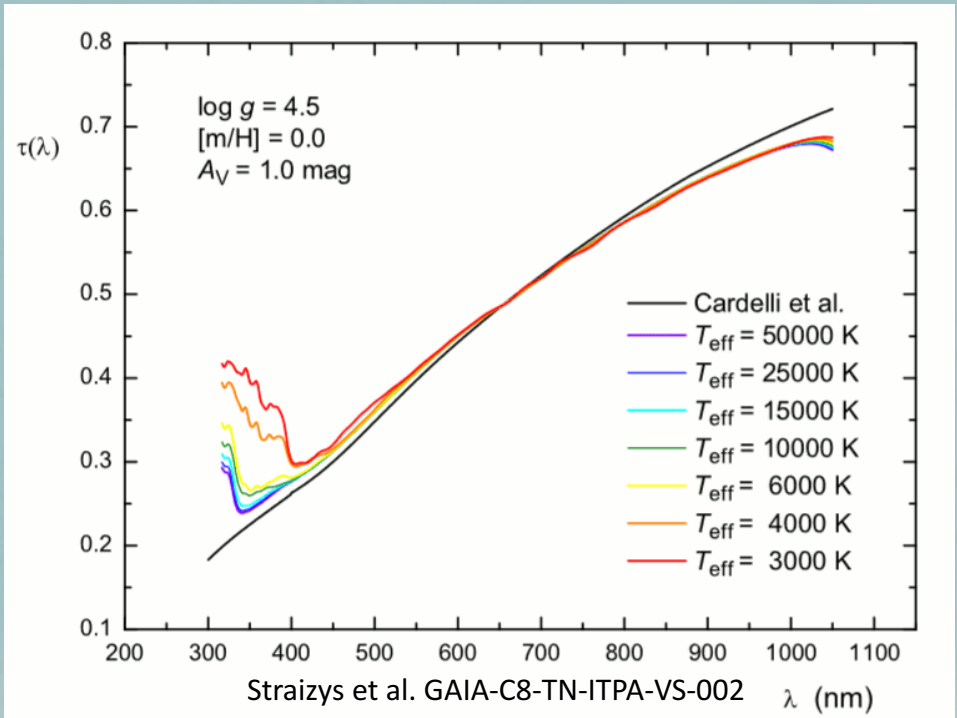
P. Montegriffo CU5M14

350 nm
450 nm
550 nm
650 nm

650 nm
750 nm
850 nm
950 nm

- line : starting model
- dots: fitted model

Gaia LSF smearing



Straizys et al. GAIA-C8-TN-ITPA-VS-002

The Gaia apparent interstellar extinction laws for different effective temperatures.

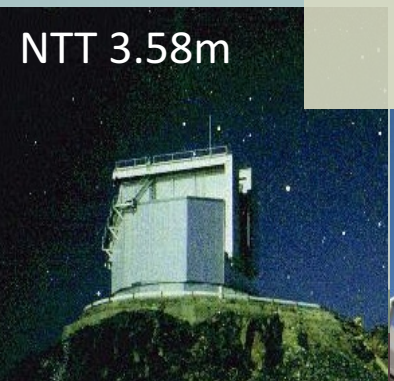
Gaia Absolute Calibration

Same principle as for classical spectrophotometry
but
much more complicated instrument model

~100-200 calibrators needed to model instrument response
mmag internal accuracy, a few % external accuracy

Gaia Absolute Calibration

- **A large observational effort to collect the required data started in 2006 and was completed in 2015**
- **Almost 5000 hours (the equivalent of 500 nights)**
- **Spread in >900 different nights in 66 observing runs from 2006 to 2015**
- **Using 6(+1) different telescopes and instruments**
- **Comparable to one of the large modern surveys (GES)**



Instruments characterization
Altavilla et al. 2015AN.336.515A

Menu: user altavilla

asdc ASI Science Data Center

GAIA.SPSS ARCHIVE

Data Management Back to home page

Session	Data Browsing	Data Metadata Editing
Logout	SPSS Reference	File Upload
Change Password, e-mail	Browse by Night	
	Raw Data...	
	Masterframe...	
	2DPreRed...	
	Extracted Spectra...	
	Fringing Corrected Spectra...	
	Slit Loss Corrected Spectra...	
	Photometric Catalogues...	
	Short-Term Light Curves...	

Output Columns Choice

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Search by: Source

Search by: Program and Scheduling

Night: = Observation Date – Observation Date

Run Type: IN (P, V, M)

Run ID: =

Sky Condition: IN (Clear, Cloudy, Veiled, Varying)

Instrument: IN (BFOSC@Cassini, CAFOS@CAHA2.2, DoLoRes@TNG, EFOSC2@NTT)

CCD: IN (EEV1300x1340OLD, EEV1300x1340NEW, SITE1d_15, E2V4240)

Search by: Observing Information

Search by: Setup Information

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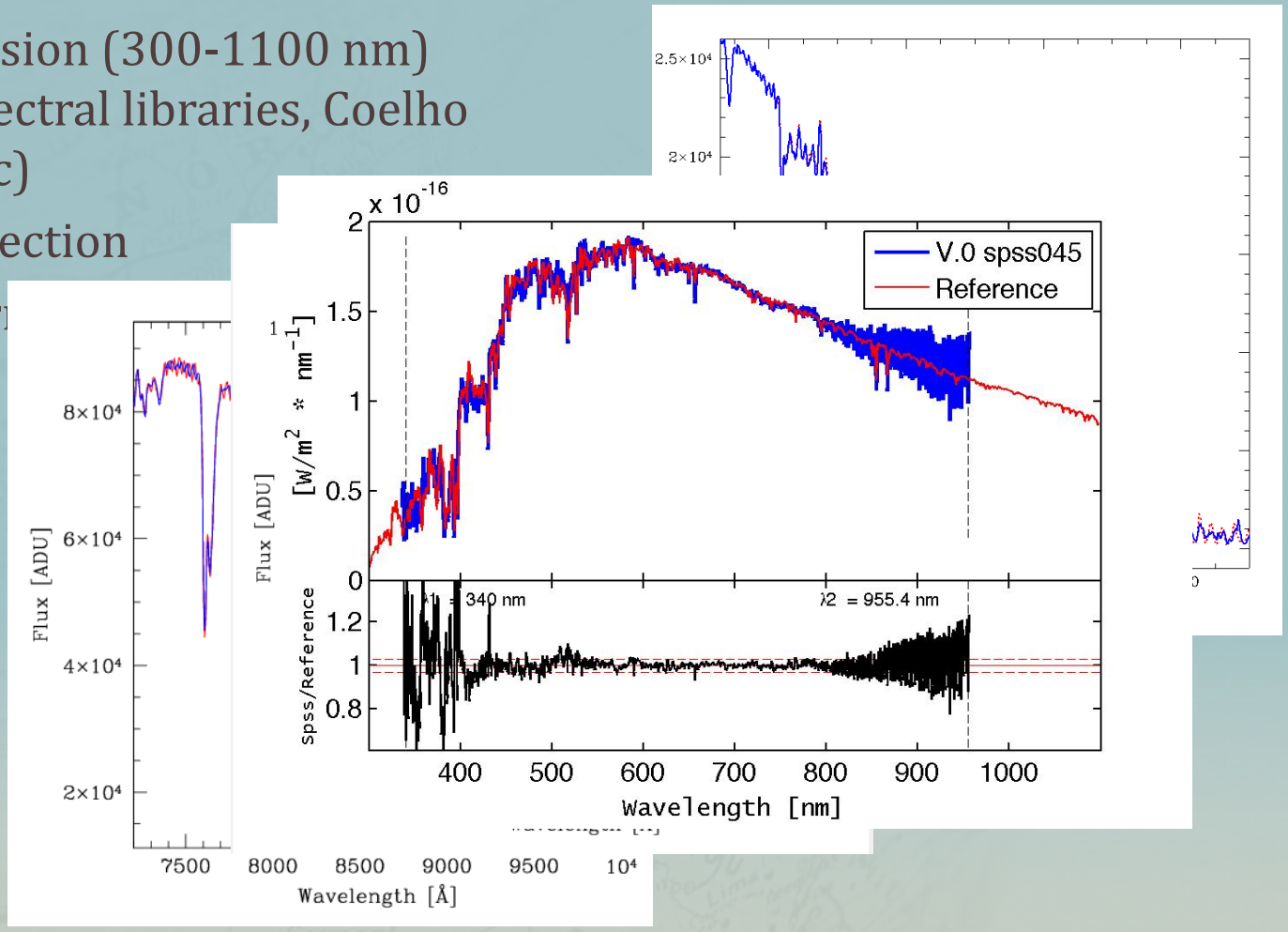
le Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		WaveLamp	05:08:47.64	+52:47:58.49	2007-10-31	22:33:58	2454405.44390024	1.5	1.403048	

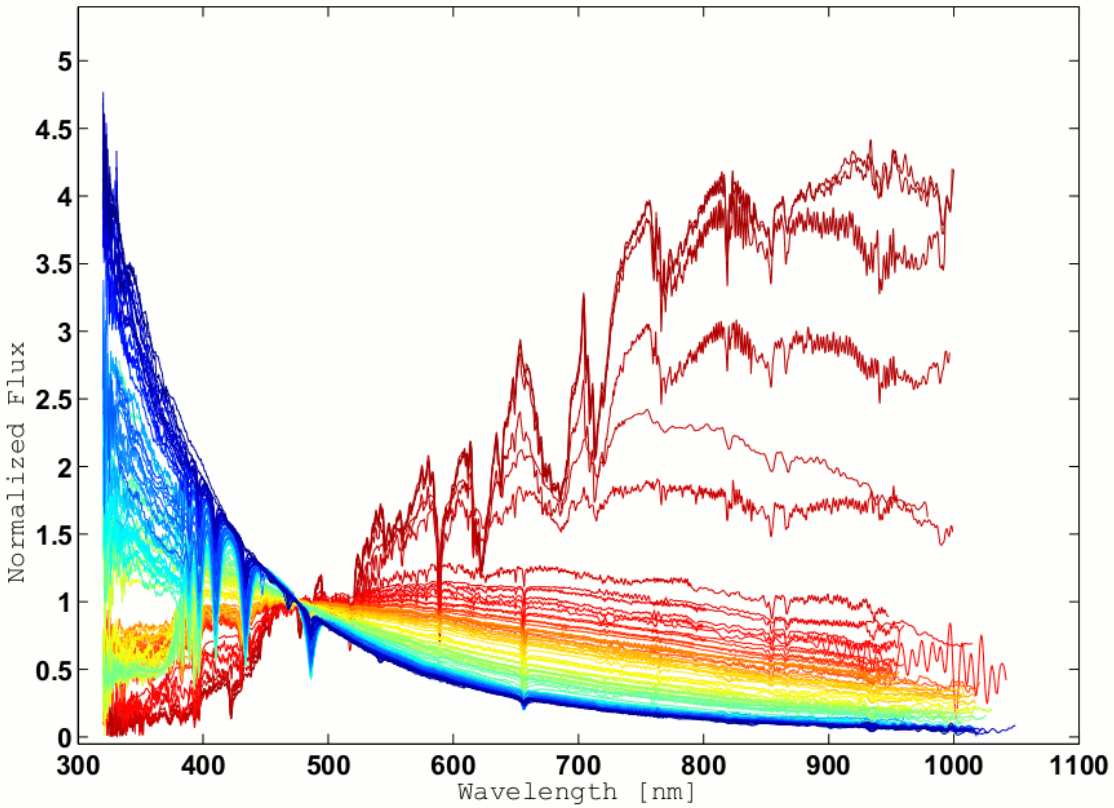
Advanced spectroscopy reductions

- Models extension (300-1100 nm) (Gaia CU8 spectral libraries, Coelho 2009, Calspec)
- Fringing correction
- Light loss cor



V0 release

The pre-launch (internal) release, October 2013



94 SPSS

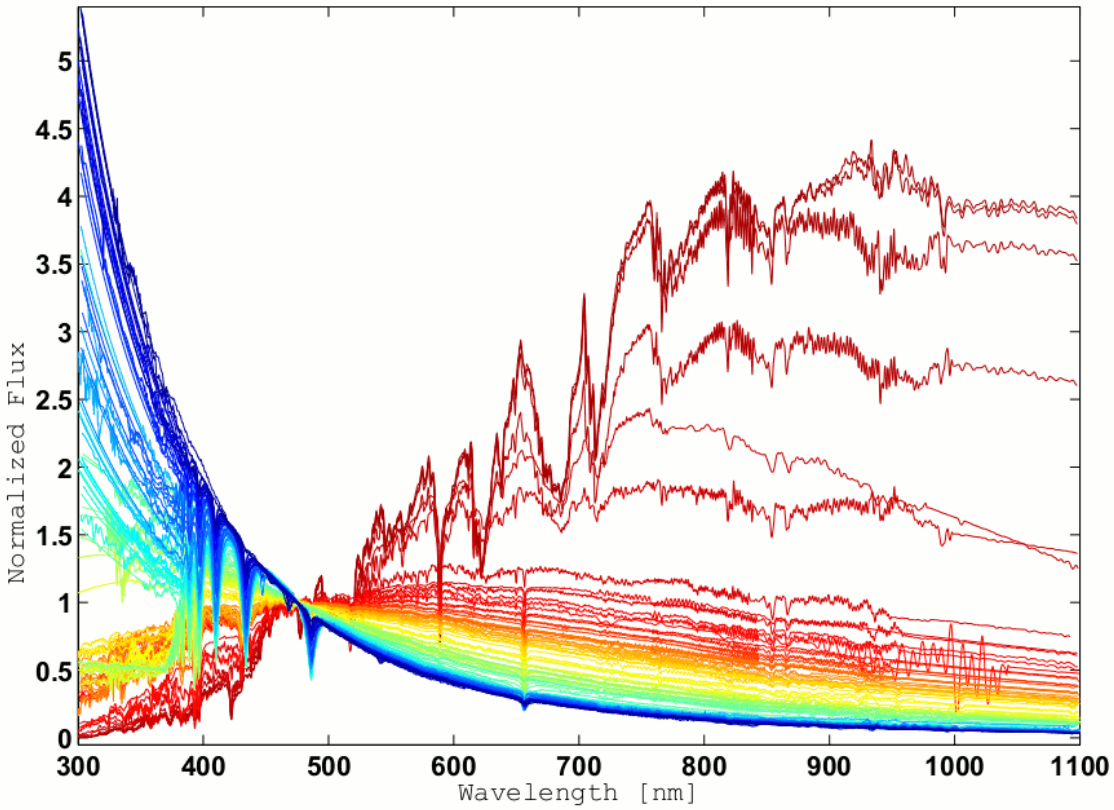
Goal:

- testing pipelines
- No fringing correction
- No narrow-slit spectra
- Cut borders (blue and red)
- Already exceeding DPAC requirements

Major problem :
Missing borders induce calibration errors > 0.1mag

V1 release

The V1 release, July 2015

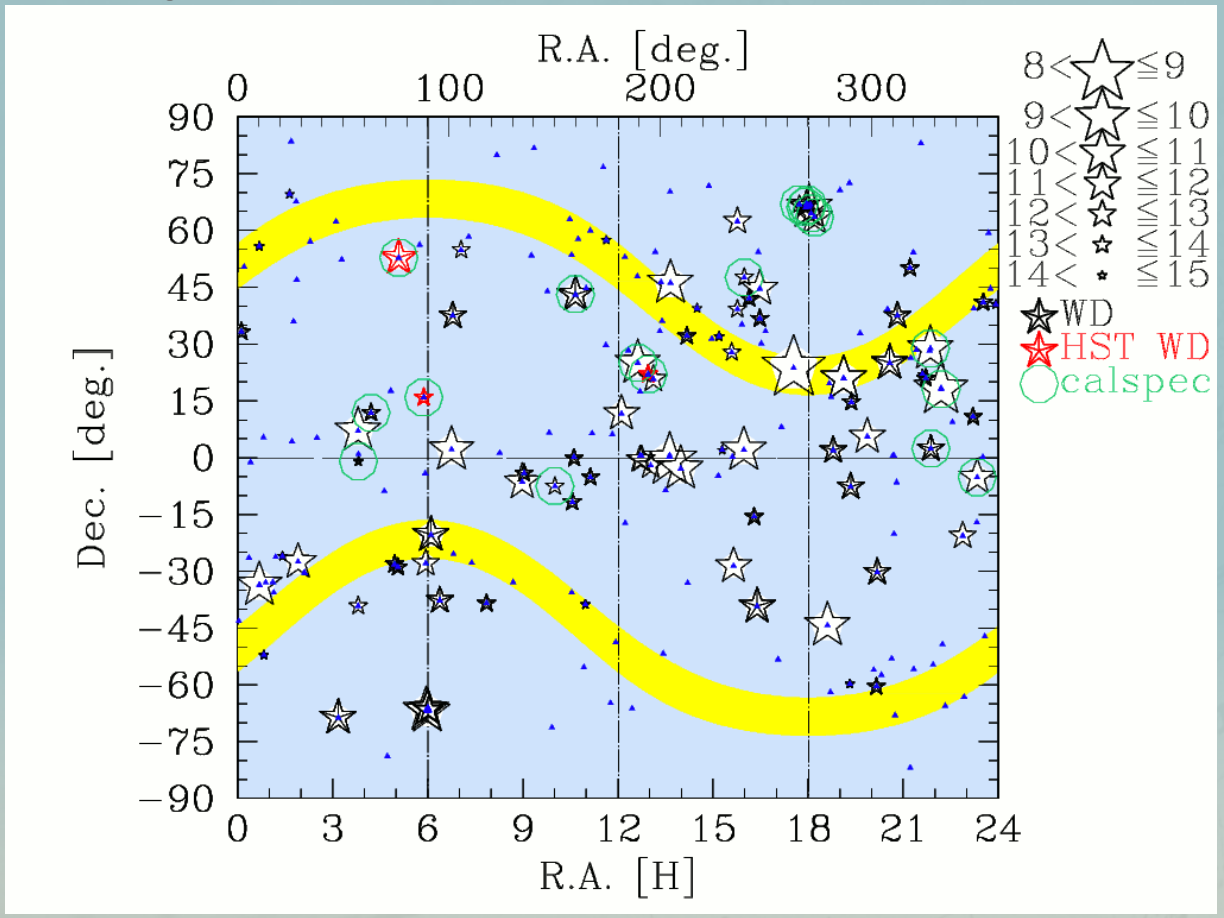


94 V0 SPSS

- Extended with theoretical or empirical template spectra (CALSPEC, Gaia spectral libraries, Public libraries)
- No new observational data
- Calibrate 1st , 2nd Gaia release
  Only G and only ZP in 1st

V1 release

July 2015

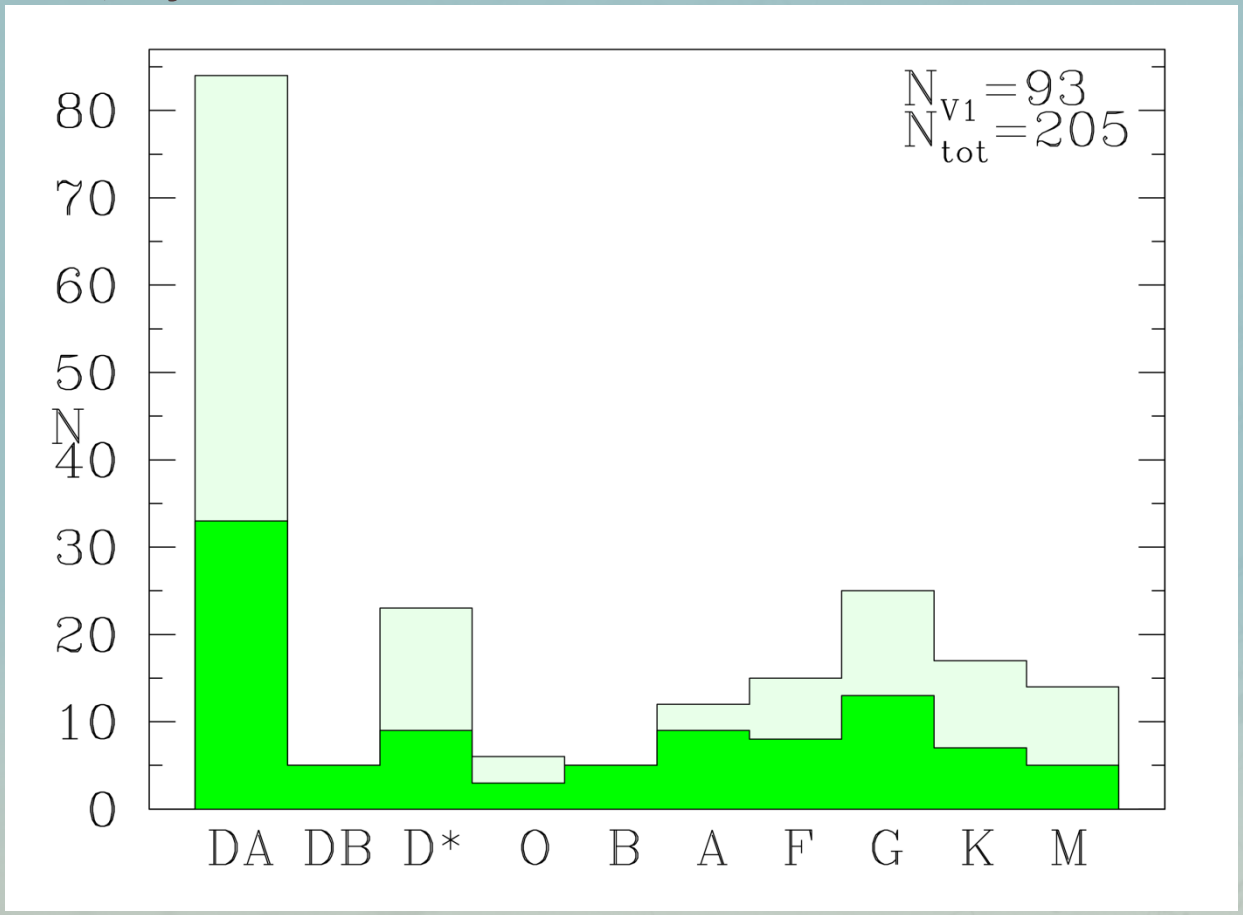


94 SPSS

- Extended with theoretical or empirical template spectra (CALSPEC, Gaia spectral libraries, Public libraries)
- Calibrate 1st Gaia release (Sept. 14 2016), G band only, and 2nd Gaia release
- Already exceeding DPAC requirements

V1 release

July 2015



94 SPSS

- Extended with theoretical or empirical template spectra (CALSPEC, Gaia spectral libraries, Public libraries)
- Calibrate 1st Gaia release (Sept. 14 2016), G band only, and 2nd Gaia release
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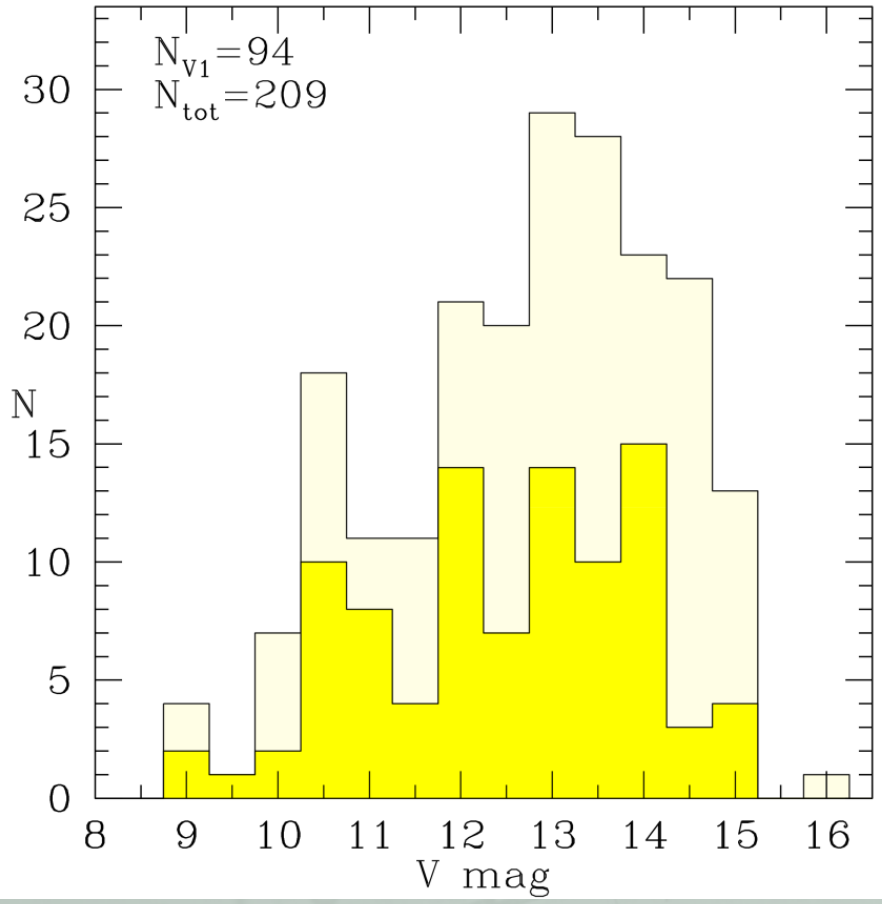
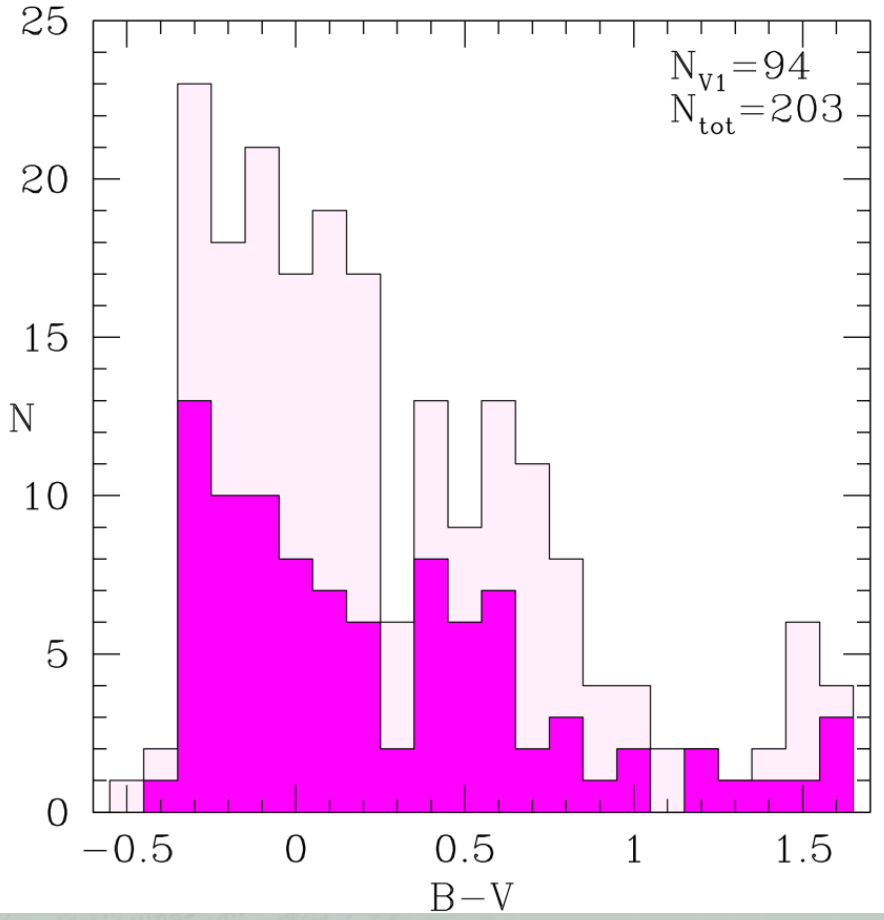
V1 release





V2 release

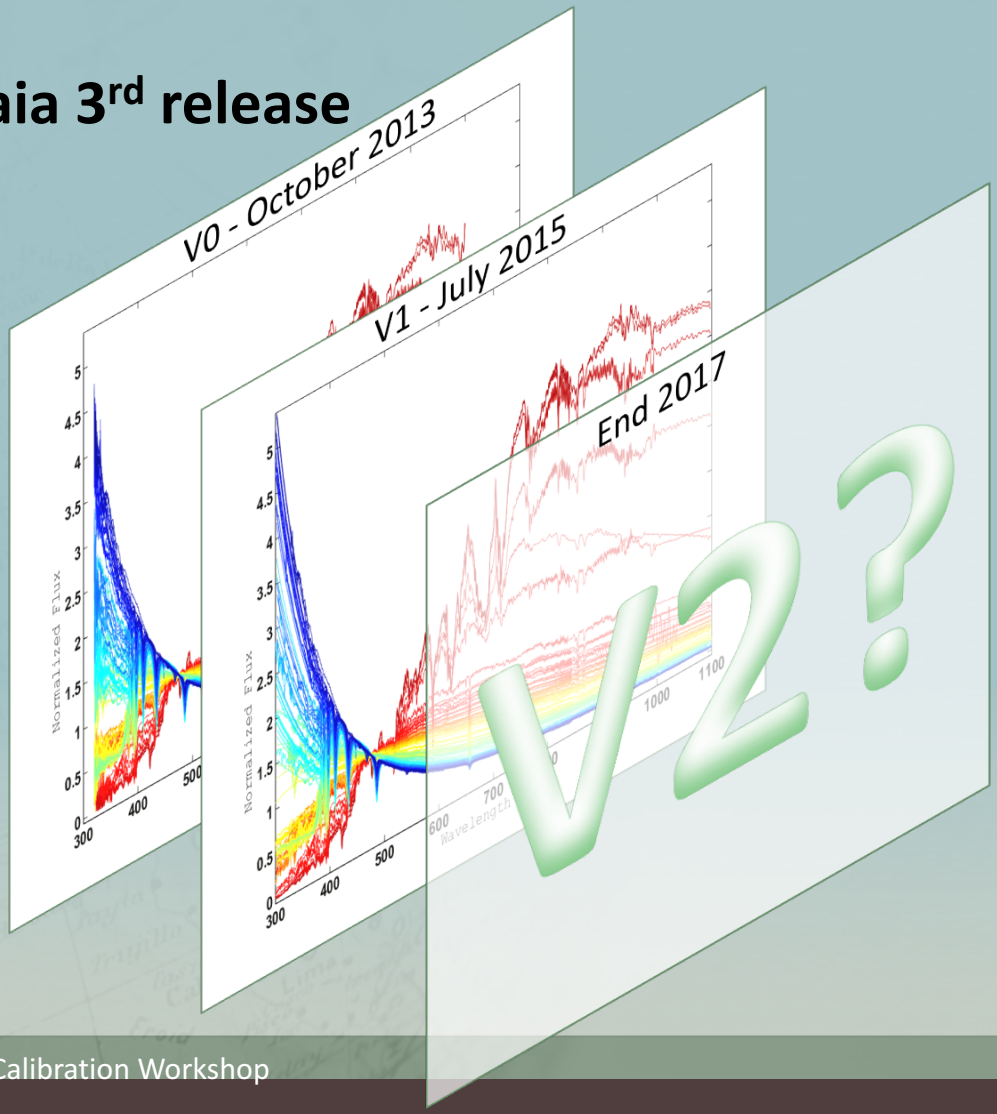
The V2 release, end 2017 for Gaia 3rd release

Including

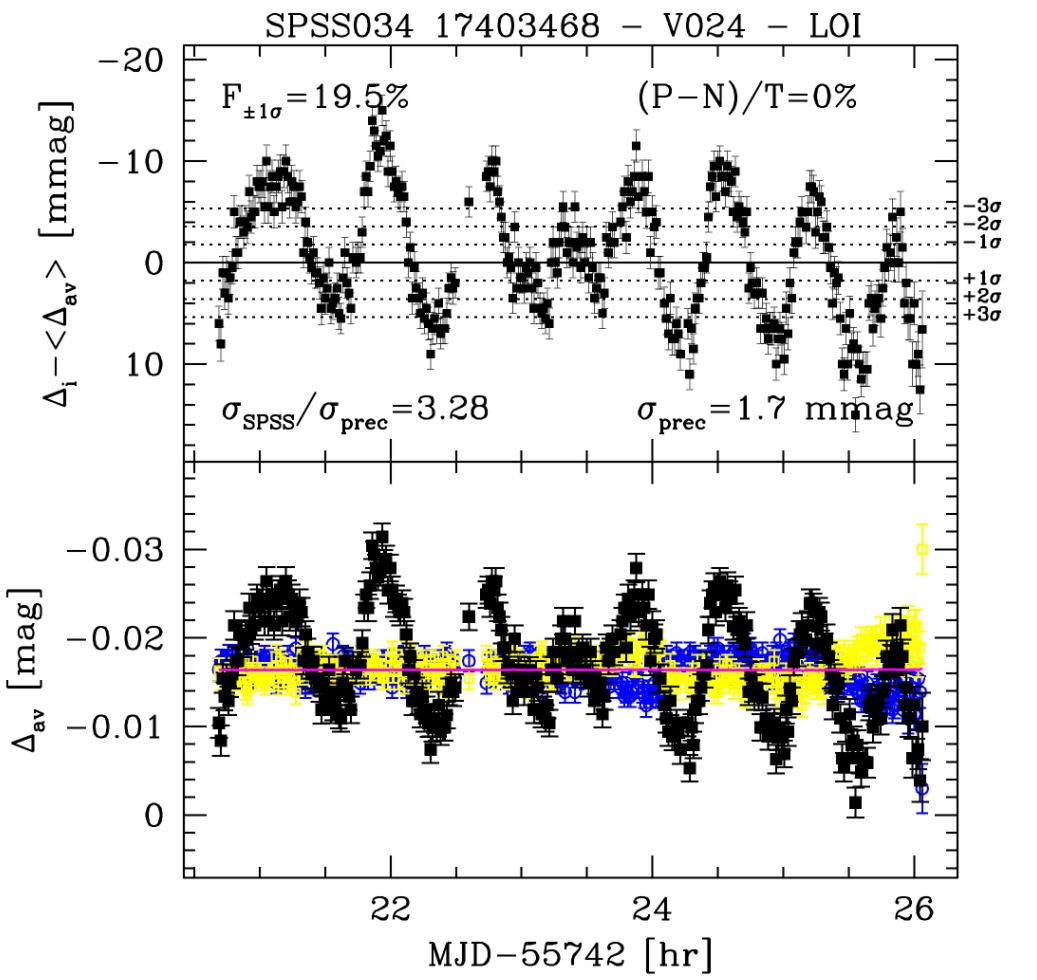
- constancy assessment
- absolute photometry

Improvements:

- Quality
- Quantity



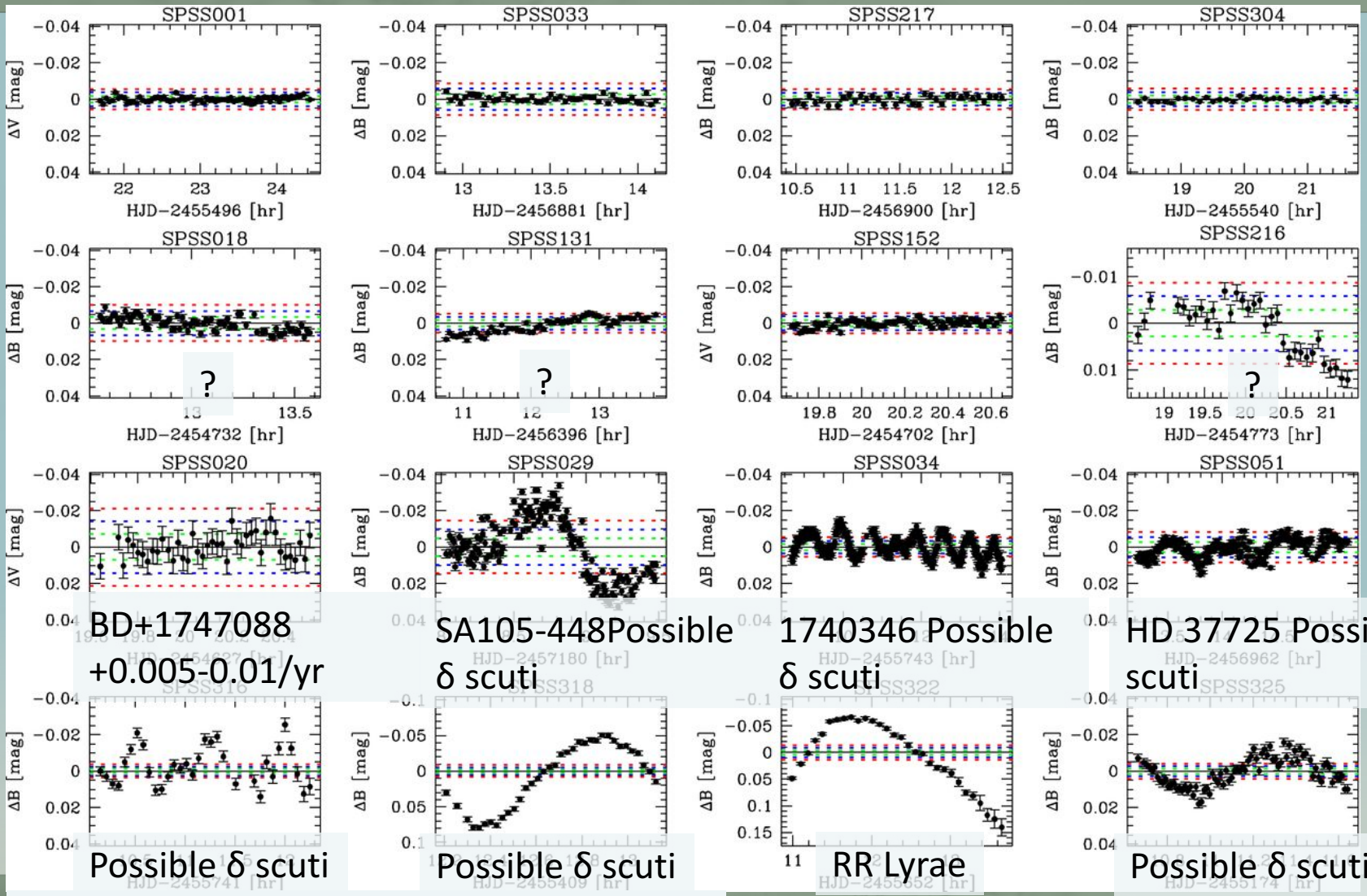
Relative Photometry



Constancy assessment:

- Short-term (1-2 h series)
- 173 SPSS monitored
- Found 12 variables
- >1 good curve per SPSS (a dozen exceptions)
- Marinoni et al. 2016MNRAS.462.3616M

Relative Photometry



BD+1747088 +0.005-0.01/yr

SA105-448Possible δ scuti

1740346 Possible δ scuti

HD 37725 Possible δ scuti

Possible δ scuti

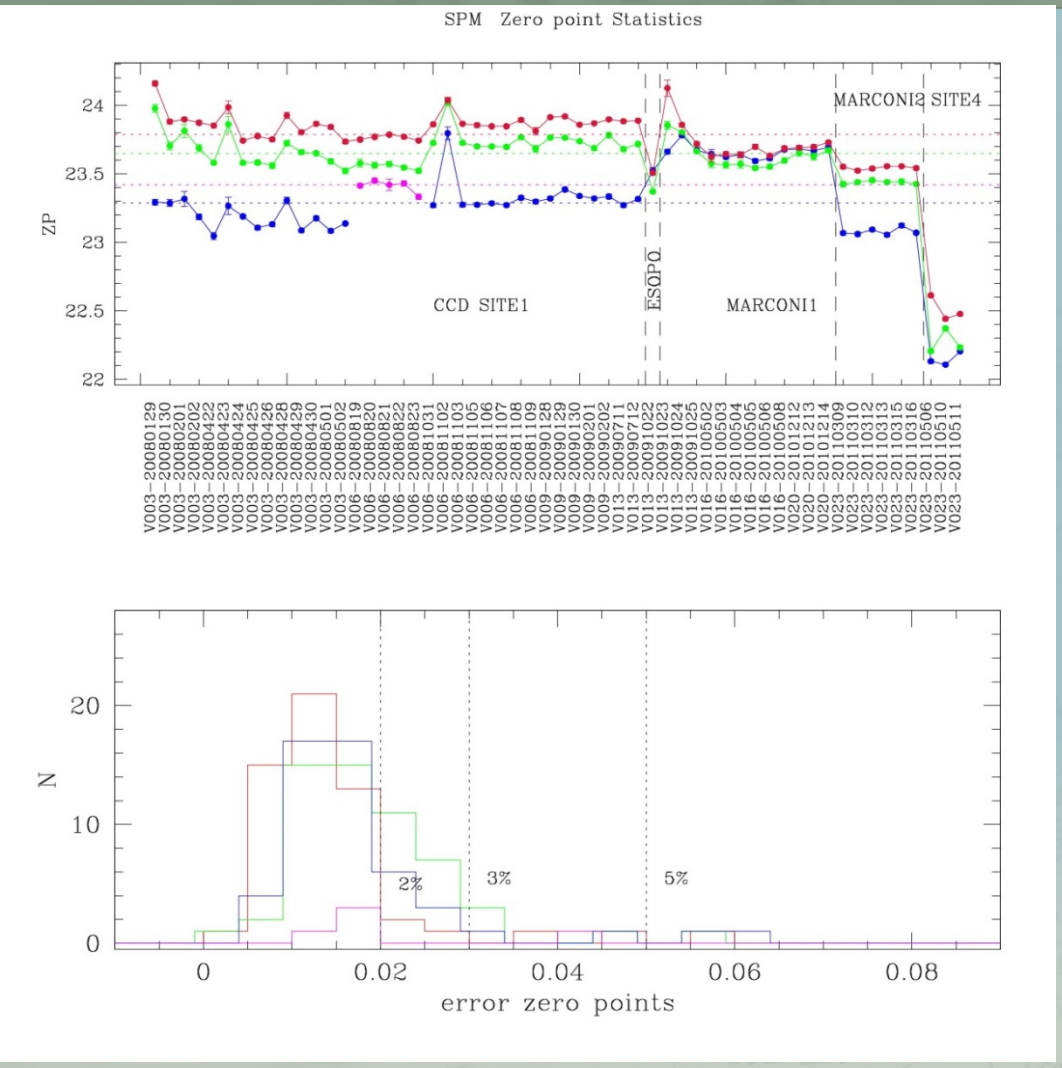
Possible δ scuti

RR Lyrae

Possible δ scuti

- Marinoni et al. 2016MNRAS.462.3616M

Absolute Photometry



ZP calibration of (grey) spectra:

- Synthetic photometry
- Night solutions
  - 32 good nights
  - 27 usable nights
  - 36 non-photometric
- Instrumental magnitudes
- First pass calibration

Now comparing internally and with literature

First release: Sept 14, 2016 ☑	Positions (α, δ) and G magnitudes (single-star and good astrometric behaviour). Photometric data of Ecliptic Poles Scanning RR Lyrae and Cepheid variable stars. The five-parameter astrometric solution - positions, parallaxes, and proper motions - for stars in common with the Tycho-2 Catalogue. The catalogue is based on the Tycho-Gaia Astrometric Solution (TGAS)
Second release: late 2017 ☐	Five-parameter astrometric solutions (single-star). Integrated BP/RP photometry. Mean radial (no radial-velocity variation).
Third release: summer 2018 (TBC) ☐	Orbital solutions, system radial velocity and five-parameter astrometric solutions, for binaries having periods between 2 months and 75% of the observing time will be released. Object classification and astrophysical parameters, together with BP/RP spectra and/or RVS spectra they are based on (well-behaved objects). Mean radial velocities (no radial-velocity and with available atmospheric-parameter estimates).
Fourth release: summer 2019 (TBC) ☐	Variable-star classifications will be released together with the epoch photometry used for the stars. Solar-system results will be released with preliminary orbital solutions and individual epoch observations. Non-single star catalogues.
Final release: 2022 (TBC) ☐	Full astrometric, photometric, and radial-velocity catalogues. All available variable-star and non-single-star solutions. Source classifications, astrophysical for stars, unresolved binaries, galaxies, and quasars. An exo-planet list. All epoch and transit data for all sources.All ground-based observations made for data-processing purposes.

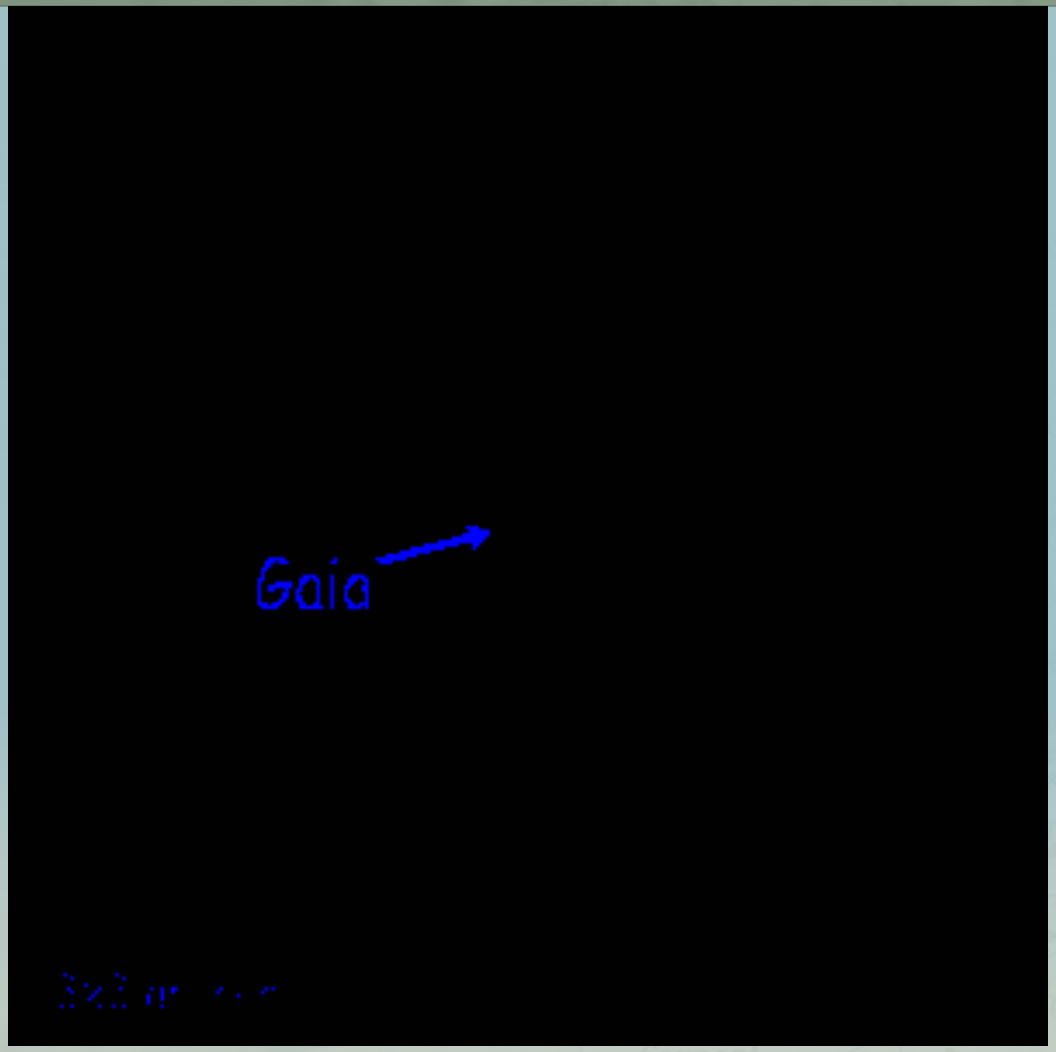
First release: Sept 14, 2016 ☑	Positions (α, δ) and G magnitudes (single-star and good astrometric behaviour). Photometric data of Ecliptic Poles Scanning RR Lyrae and Cepheid variable stars. The five-parameter astrometric solution - positions, parallaxes, and proper motions - for stars in common with the Tycho-2 Catalogue. The catalogue is based on the Tycho-Gaia Astrometric Solution (TGAS)

GDR1 available at archives.esac.esa.int/gaia

Also at ASDC http://gaiaportal.asdc.asi.it/

- Gaia data (GaiaSource, TgasSource, GaiaVariable, GaiaAuxQSO-ICRF2match);
- External Catalogues matched with Gaia (2MASS PSC, UCAC4, PPMXL, GSC2.3, SDSSdr9, AllWISE, URAT-1);
- Cross-Match Results tables;
- External Catalogues not matched with Gaia (RAVE4).
- Working at advanced science enabling tools (visualization, data analysis, statistics, data mining)

Gaia imaging… from Loiano (Italy)



Gaia Image of the Week 01 Dec 2014

www.cosmos.esa.int/web/gaia/iow_20141201

Gaia (R~21) observed with BFOSC@1.52m G.D. Cassini telescope at Loiano Observatory, Italy, on 17 October 2014

"Optical tracking of deep-space spacecraft in Halo L2 orbits and beyond: the Gaia mission as a pilot case" A. Buzzoni, G. Altavilla, S. Galleti, 2016 2016AdSpR..57.1515B

Thanks for your attention