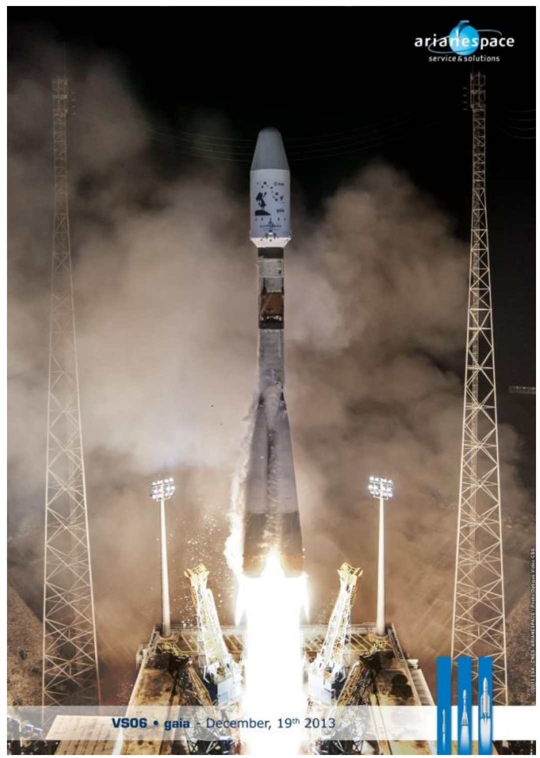
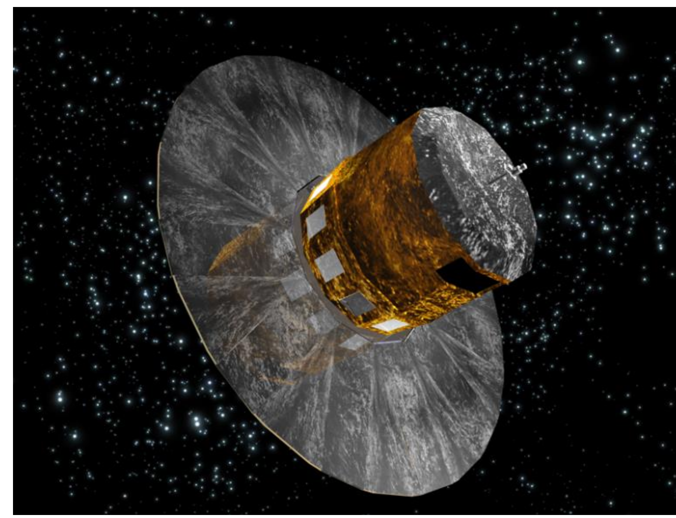
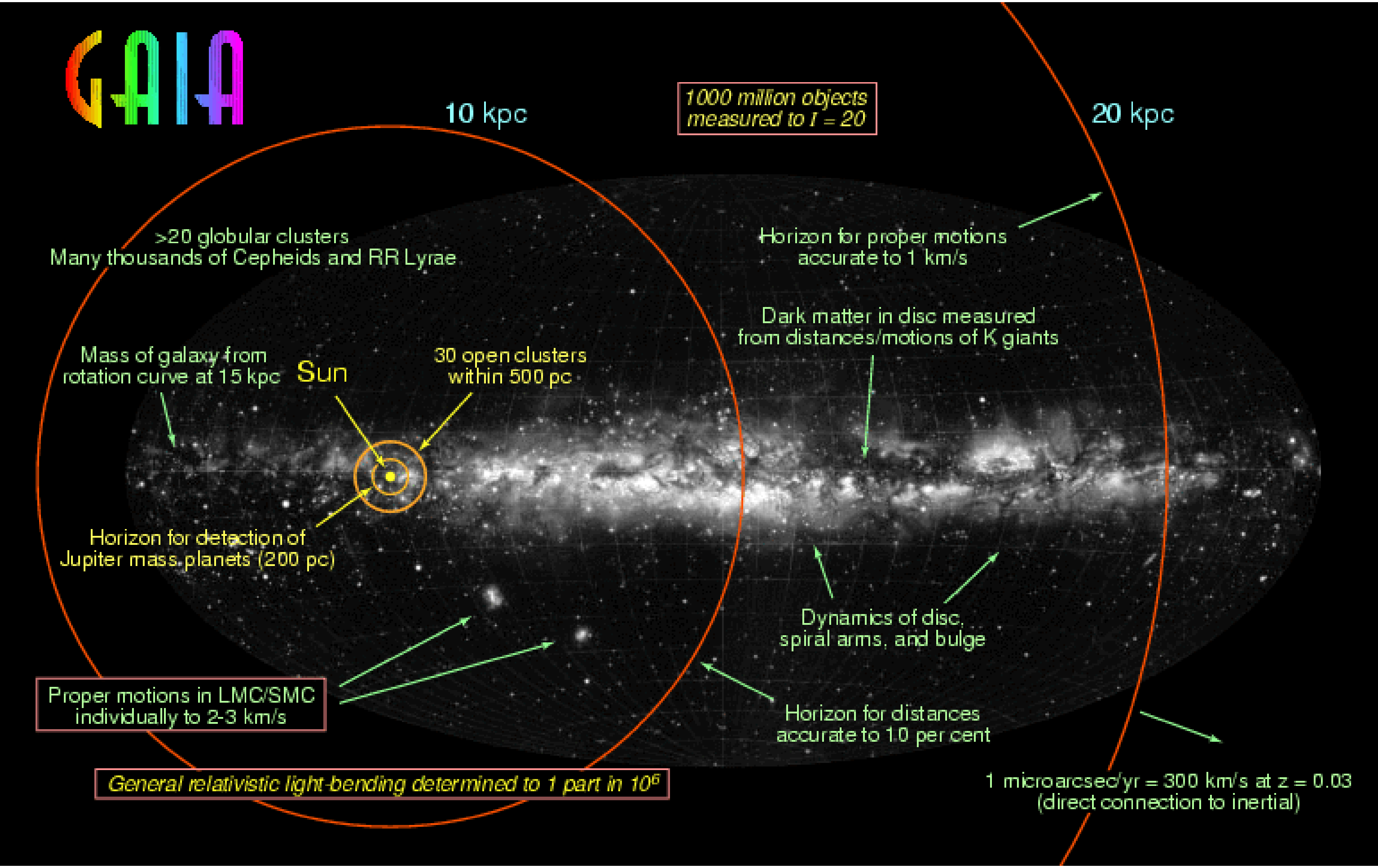
Gaia mission: current status and spectroscopic capabilities

C. Jordi

(on behalf of Gaia-UB group, Gaia Science Team & Data Processing and Analysis Consortium)



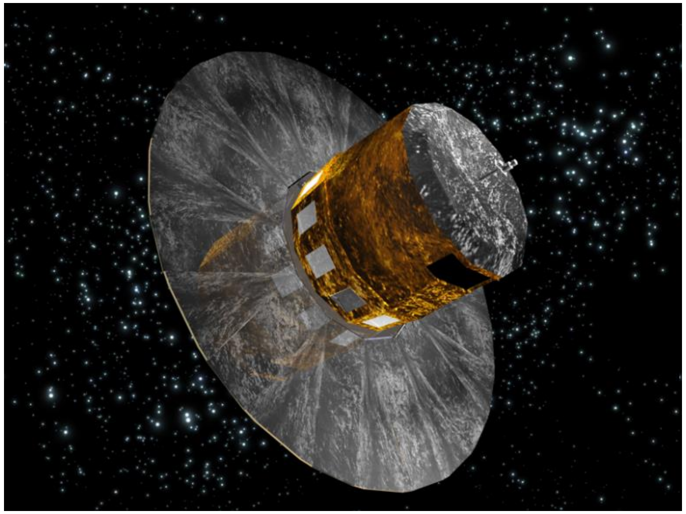



GAIA
10 kpc
1000 million objects measured to I = 20
20 kpc
>20 globular clusters
Many thousands of Cepheids and RR Lyrae
Horizon for proper motions accurate to 1 km/s
Dark matter in disc measured from distances/motions of K giants
Mass of galaxy from rotation curve at 15 kpc
Sun
30 open clusters within 500 pc
Horizon for detection of Jupiter mass planets (200 pc)
Dynamics of disc, spiral arms, and bulge
Proper motions in LMC/SMC individually to 2-3 km/s
Horizon for distances accurate to 10 per cent
General relativistic light-bending determined to 1 part in 10^6
1 microarcsec/yr = 300 km/s at z = 0.03
(direct connection to inertial)

Launch December 19 2013 09:12:19 UTC

First 1h43m: First signal acquisition and automatic start-up sequence monitoring

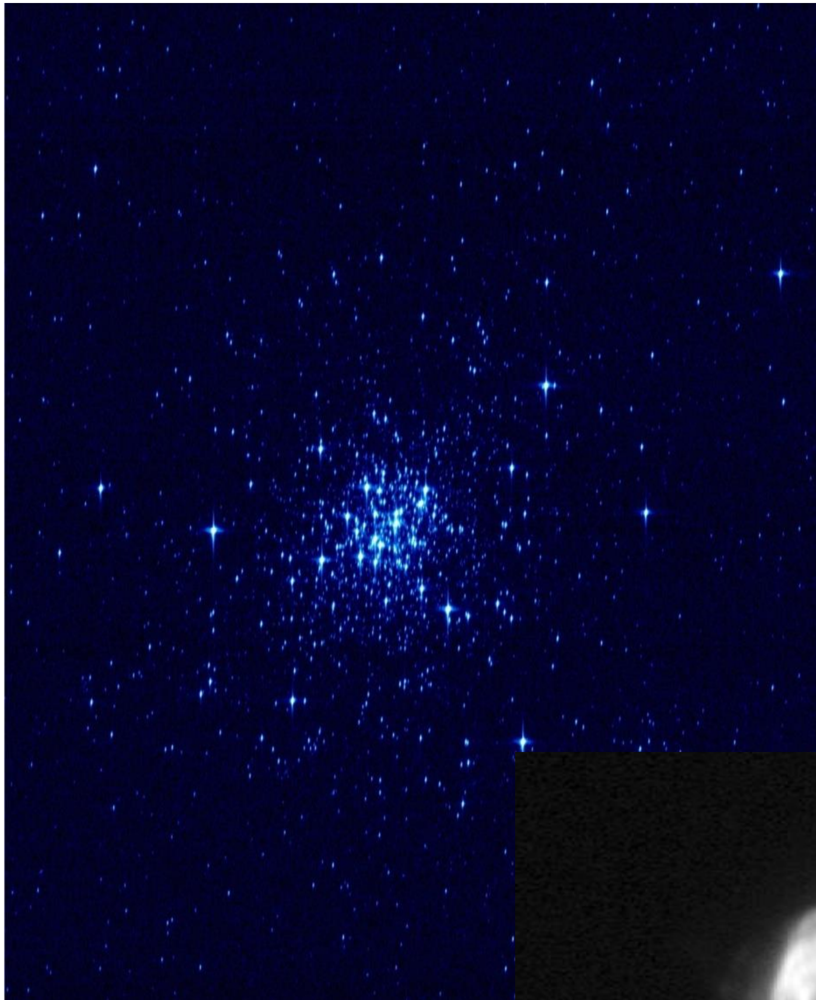
- ✓ transmitter, gyroscopes, PLM bipod release, CPS priming, thermal control configuration



DSA deployment end 10:38 UTC

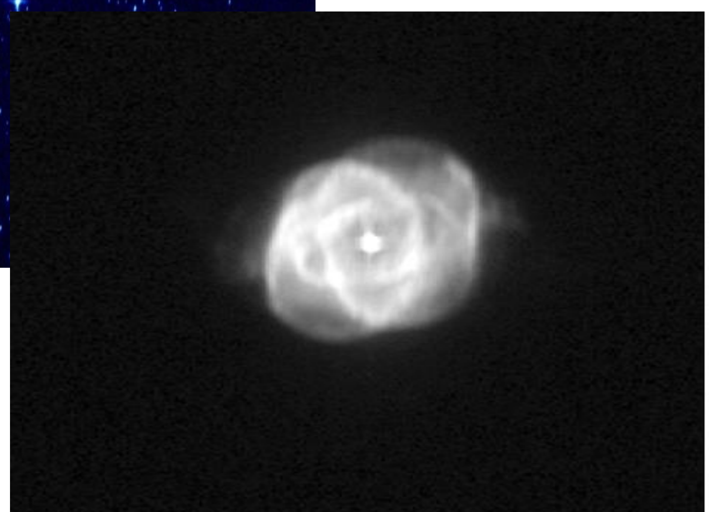
First images

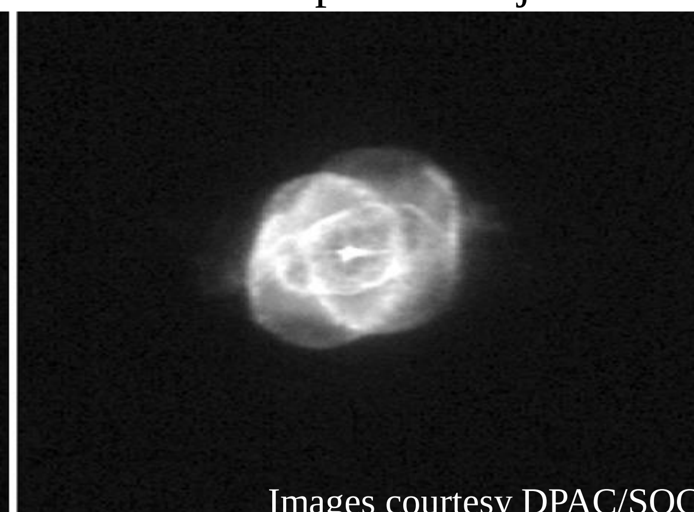
Telescopes not aligned and focused at this stage



NGC 1818
2.85 second integration,
212×212 arcsec^2

Effect of Gaia spin rate adjustment





Images courtesy DPAC/SOC

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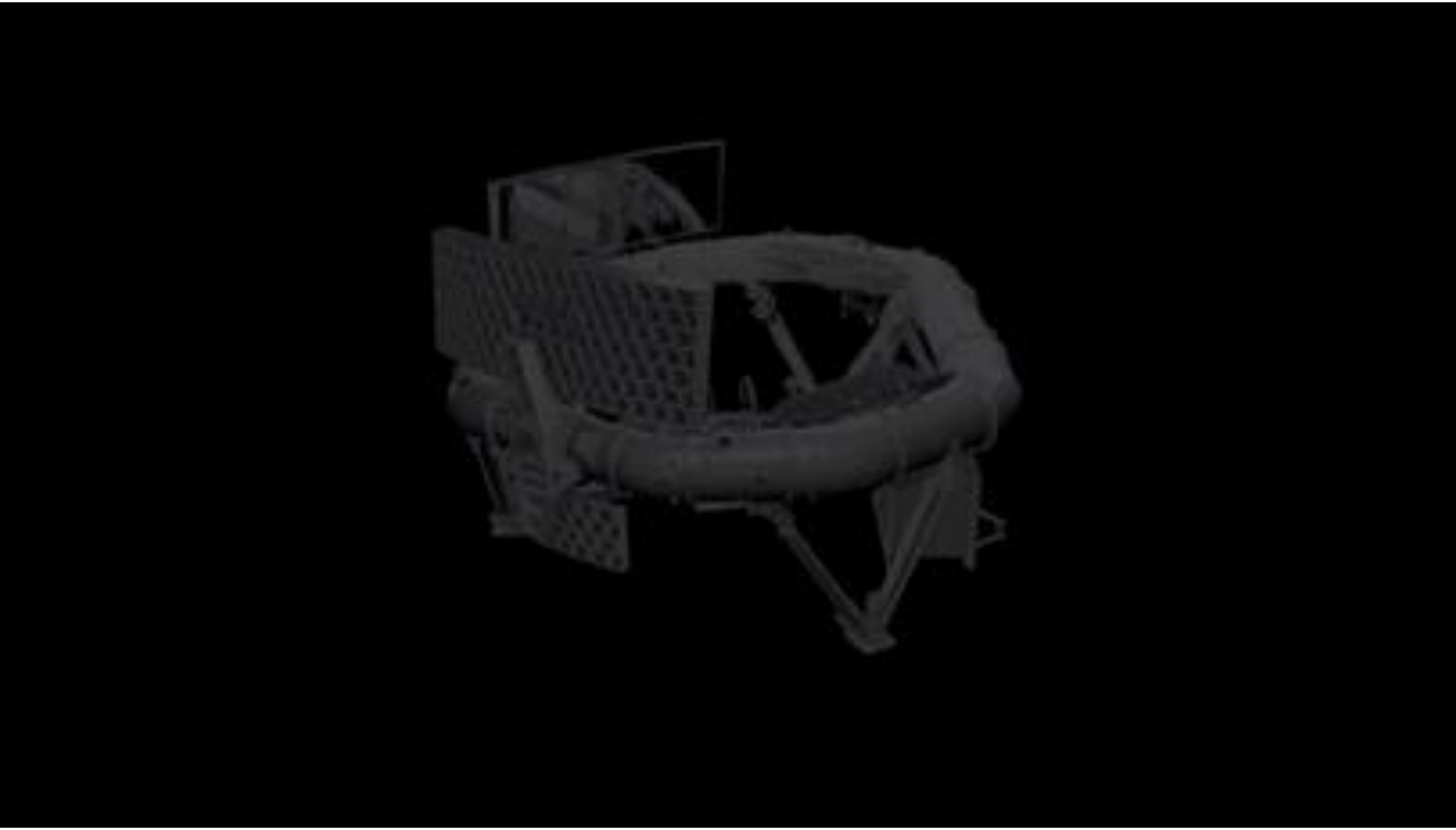
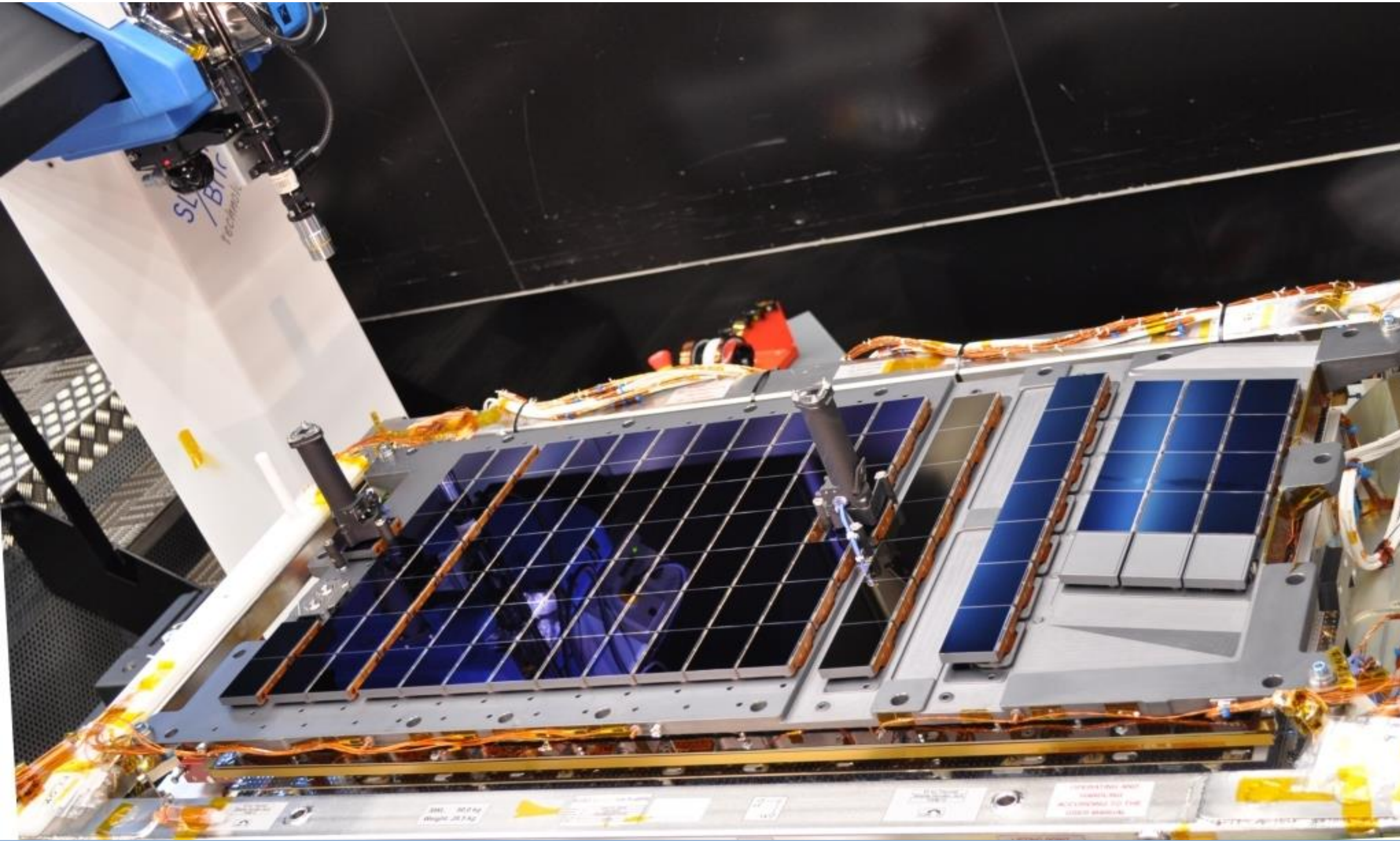
Two telescopes



Focal plane: 1 bilion pixels



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Data Processing and Analysis Consortium

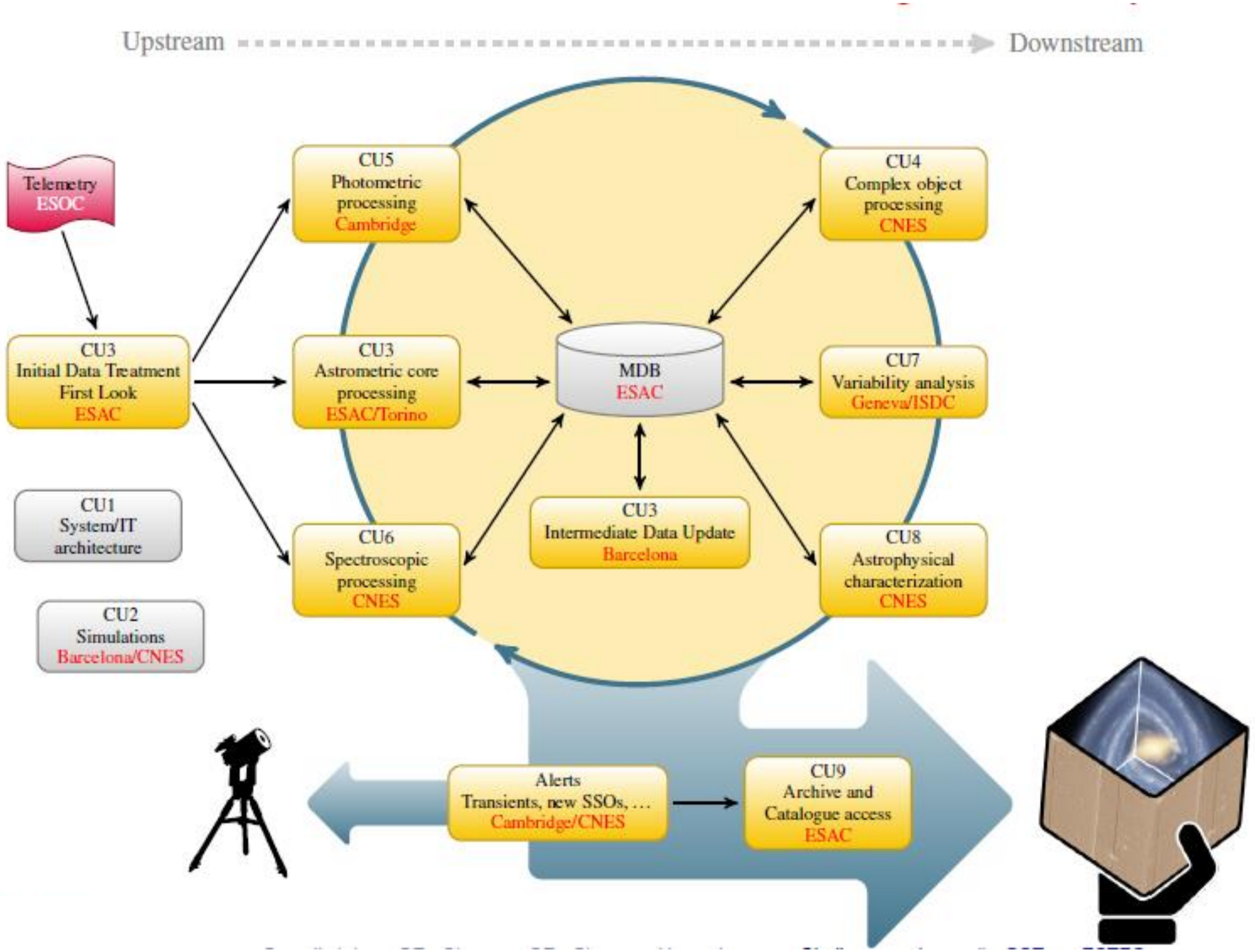
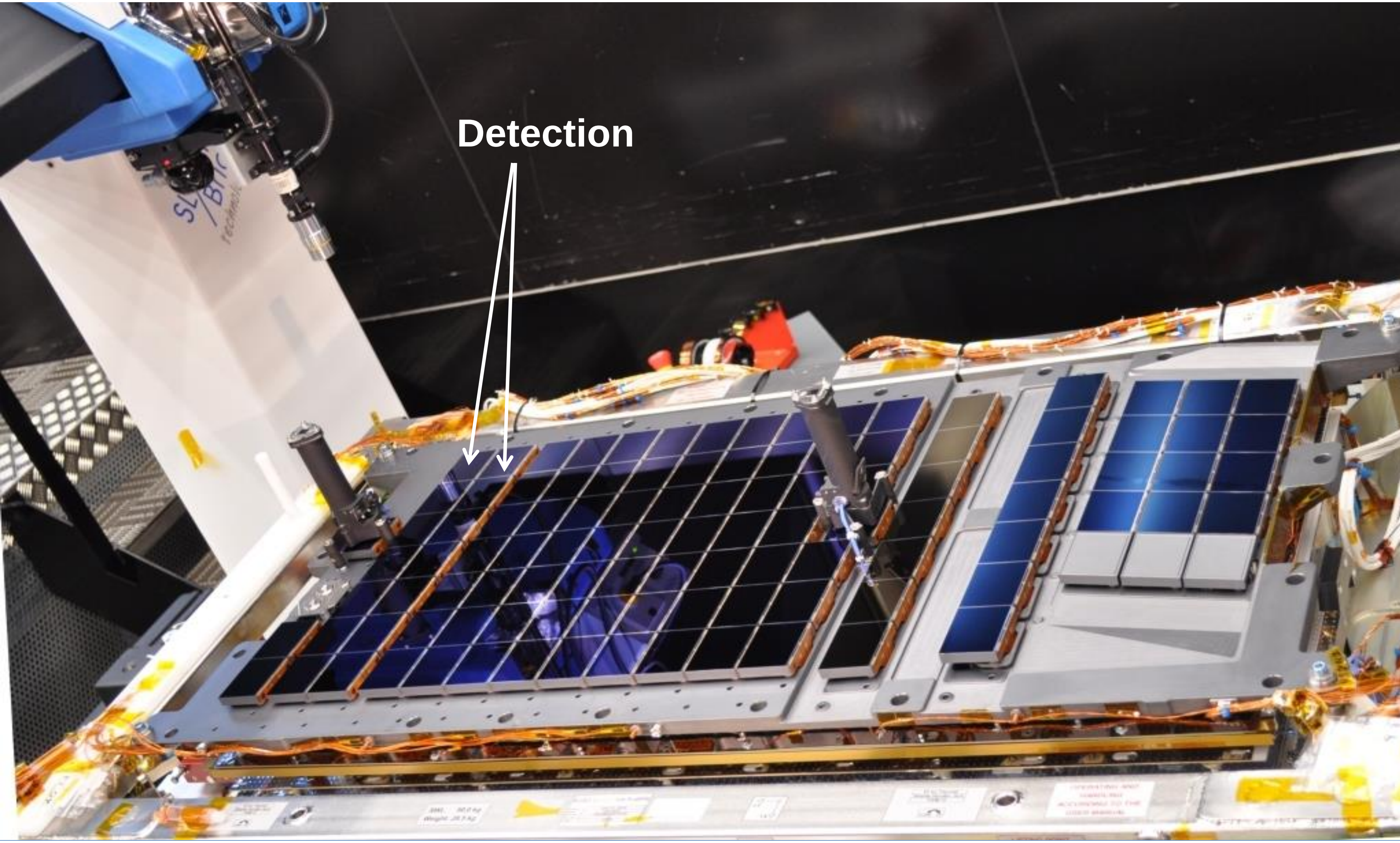
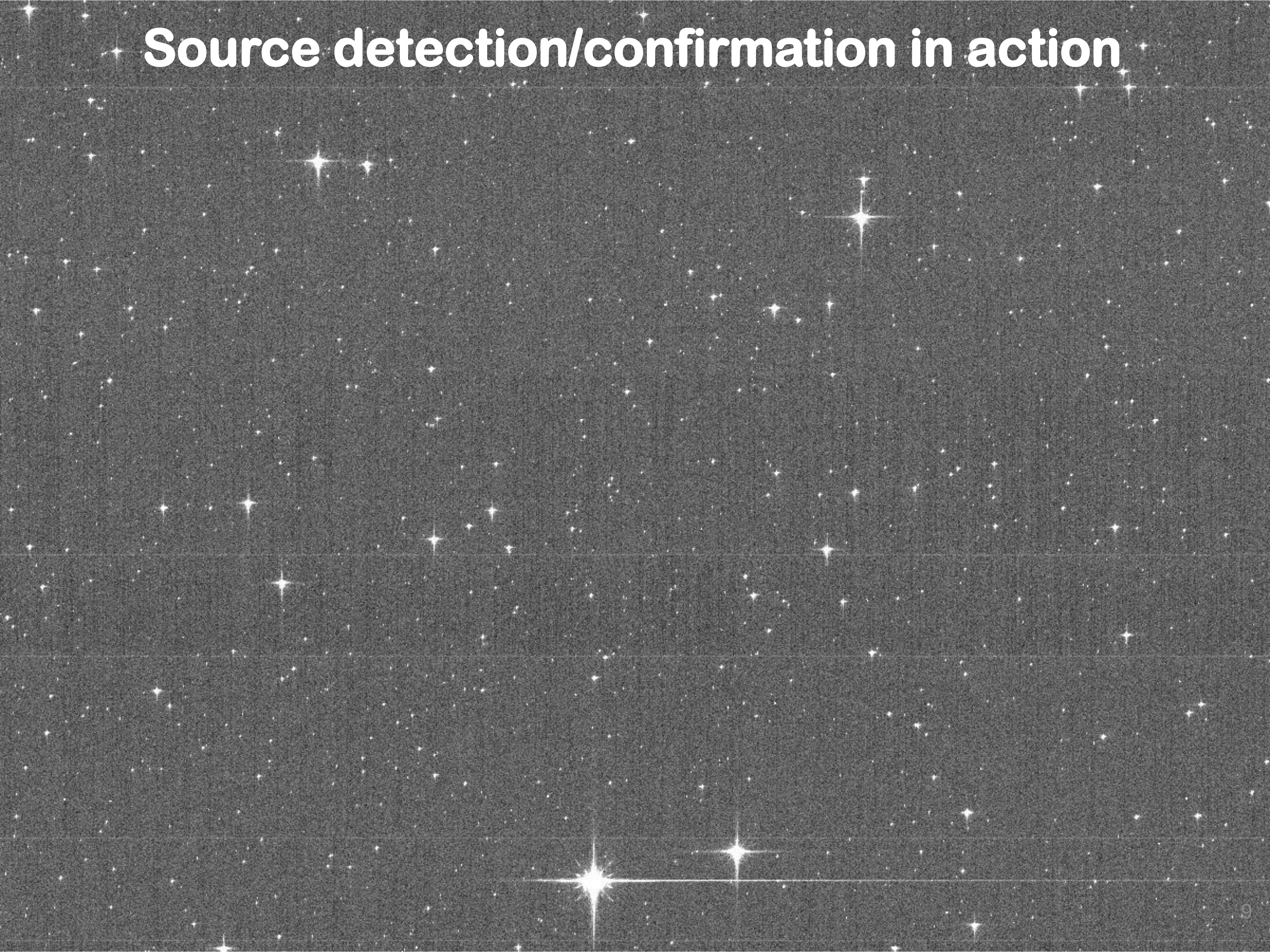


Figure by A. Brown

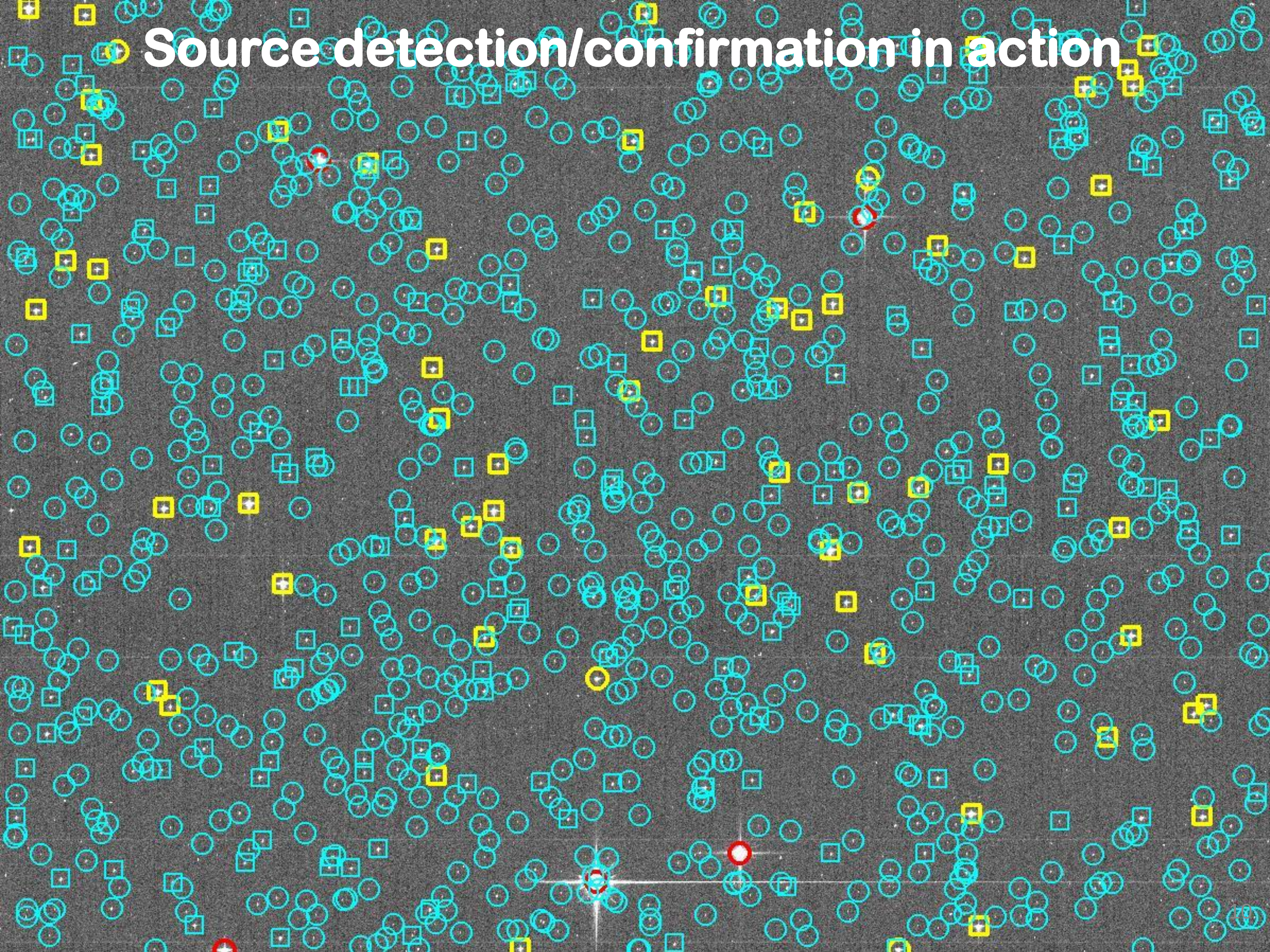
Focal plane: three instruments



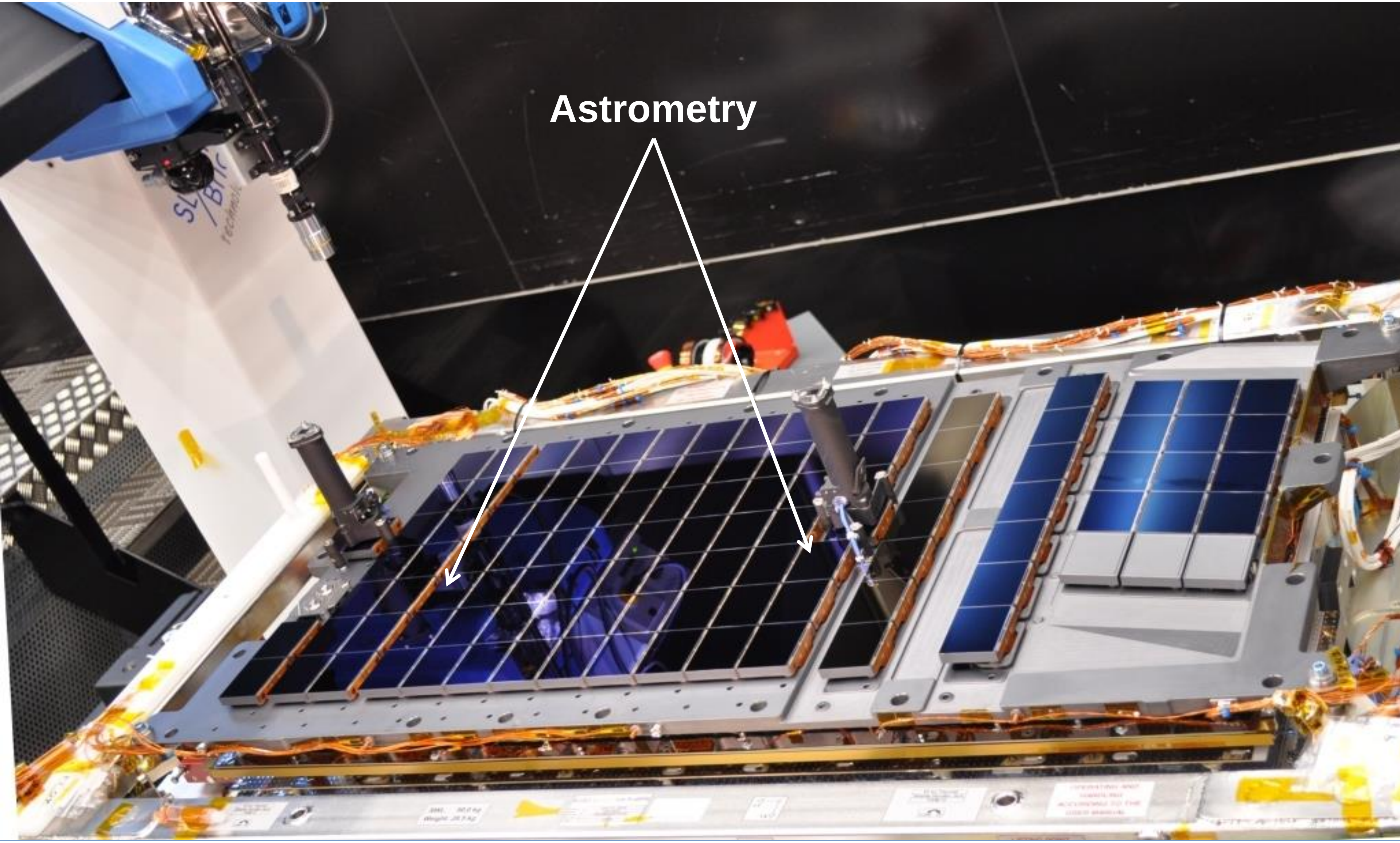
Source detection/confirmation in action



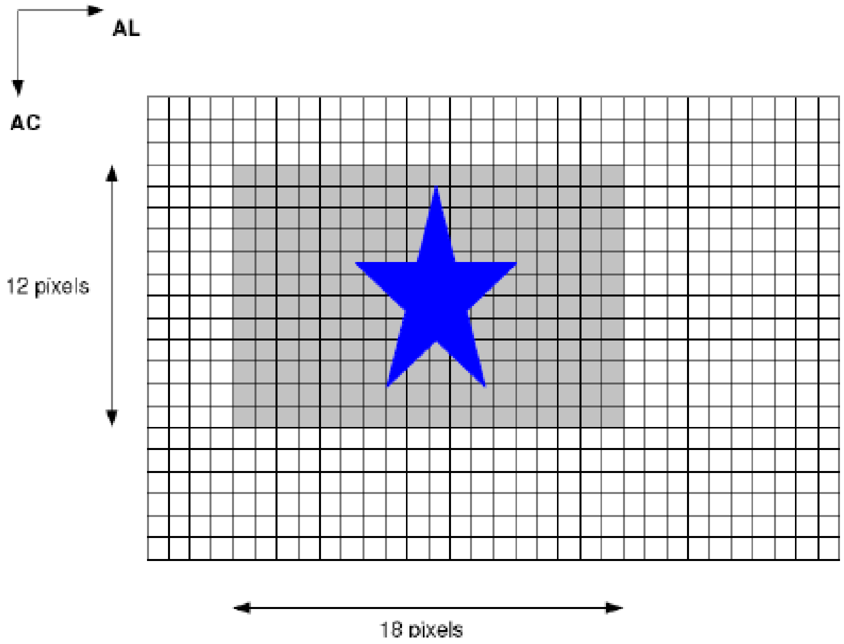
Source detection/confirmation in action

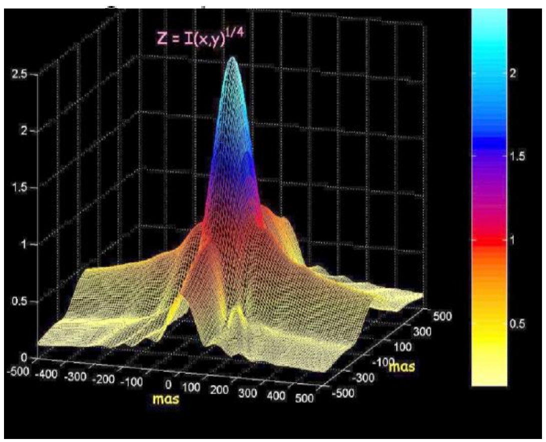


Focal plane: three instruments



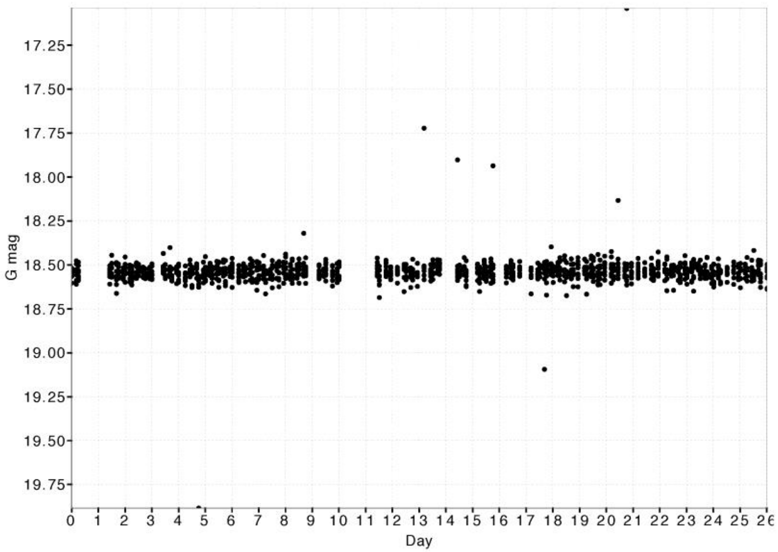
Astrometric instrument

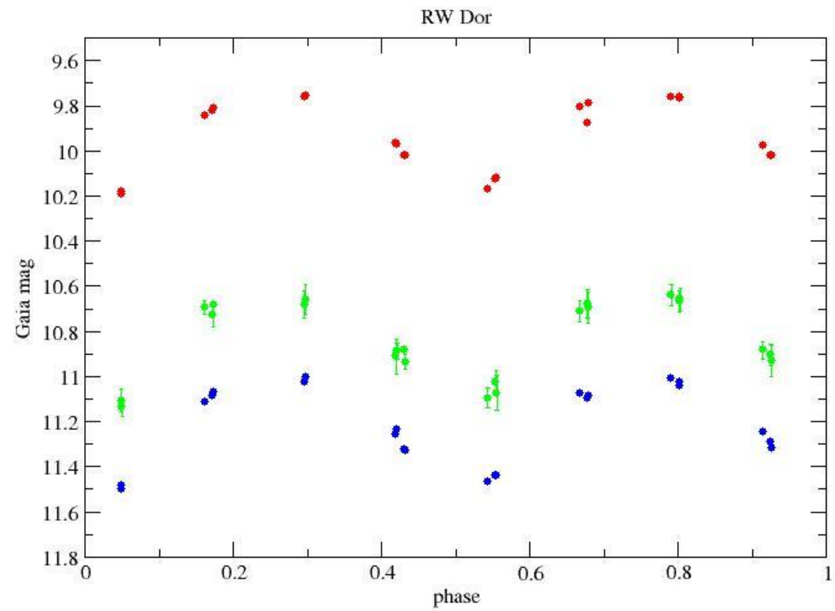


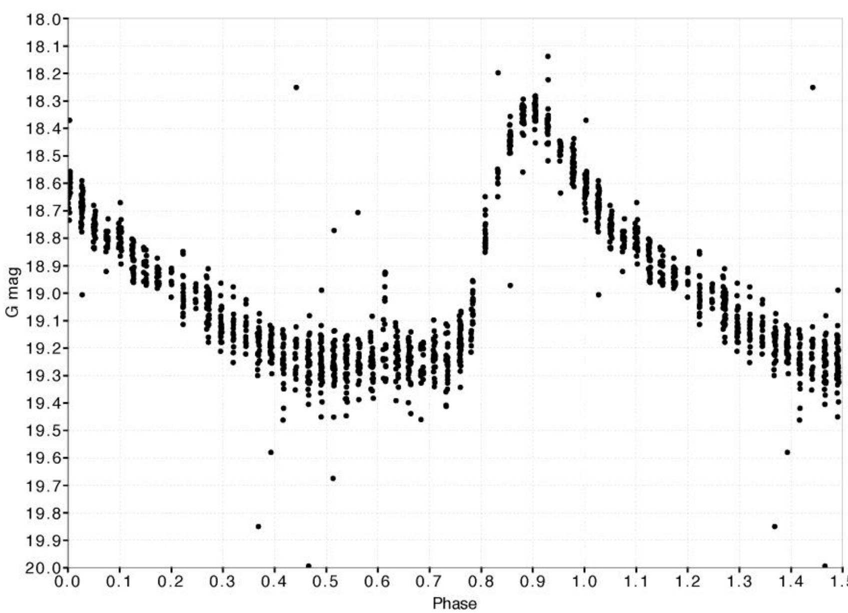


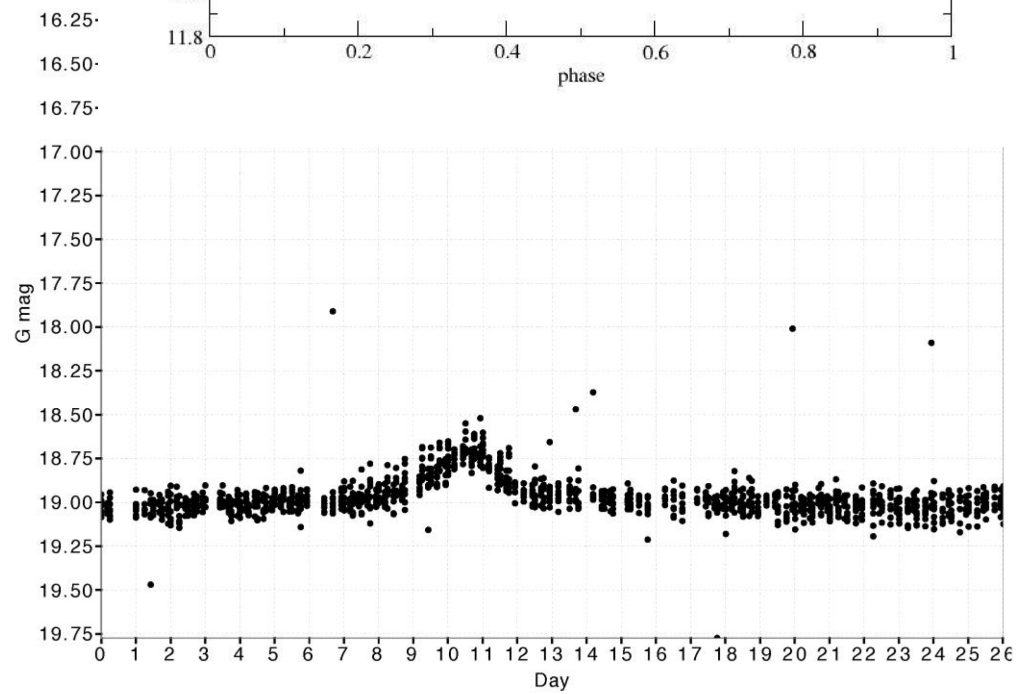
Centroiding and flux

G band: white light photometry

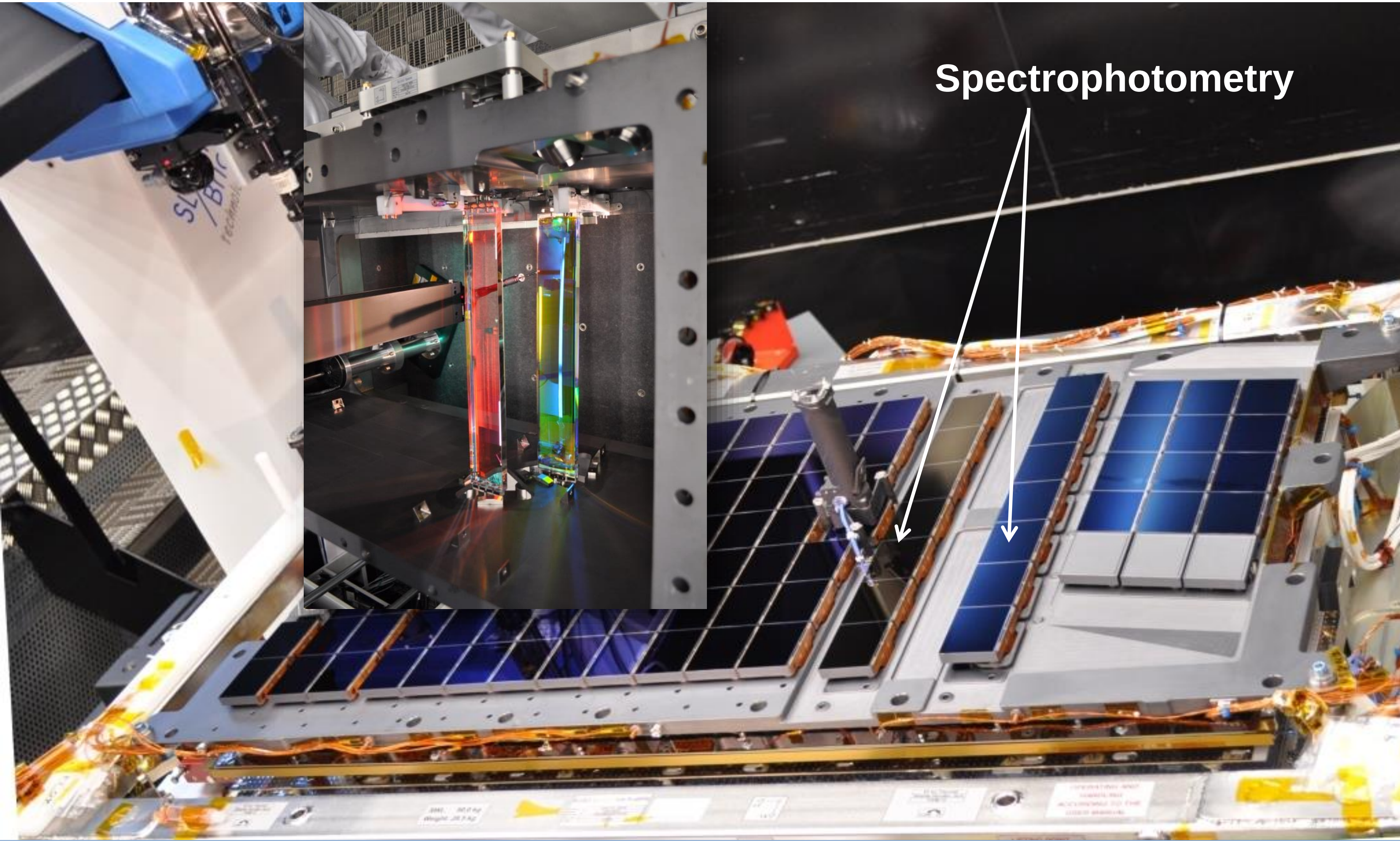








Focal plane: three instruments



Spectrophotometry

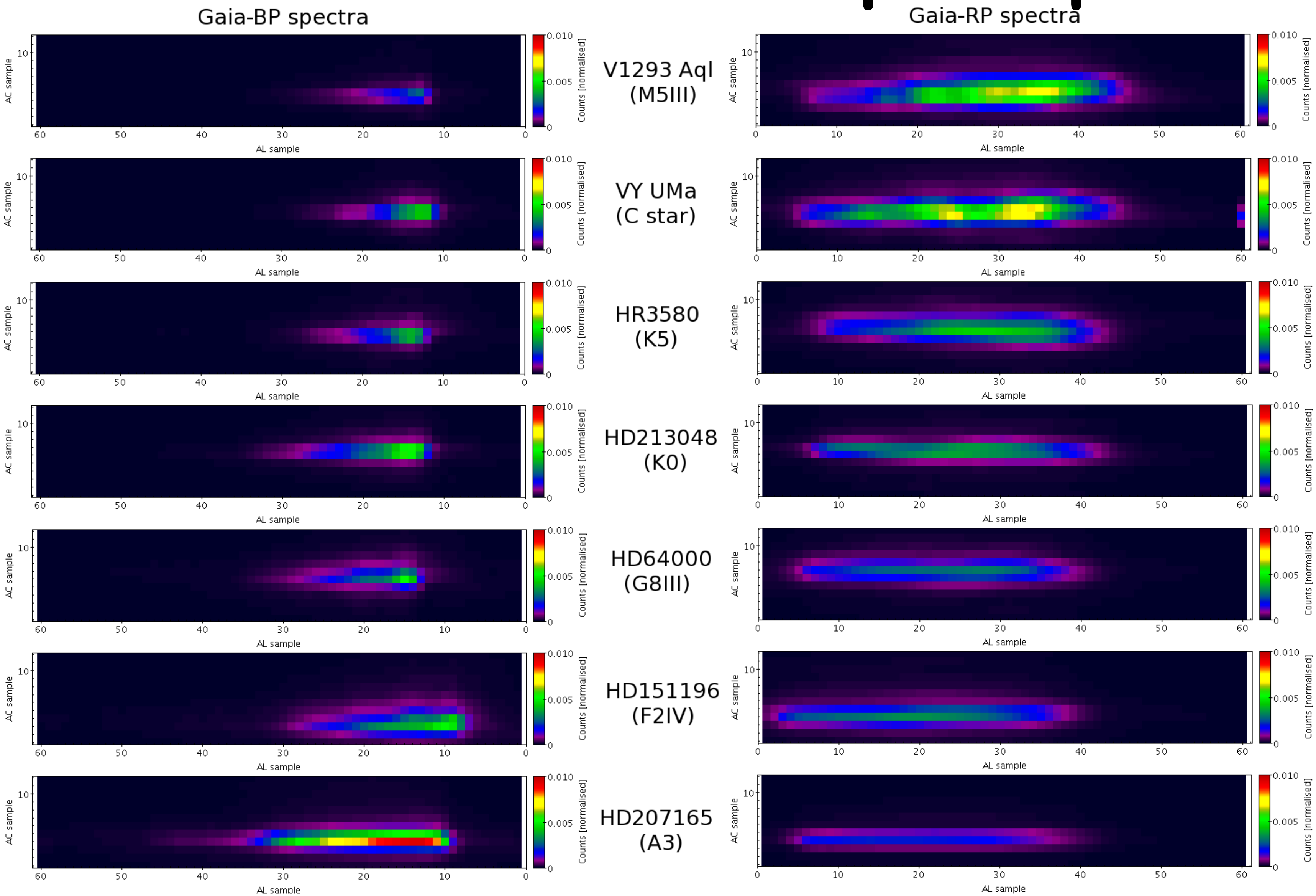
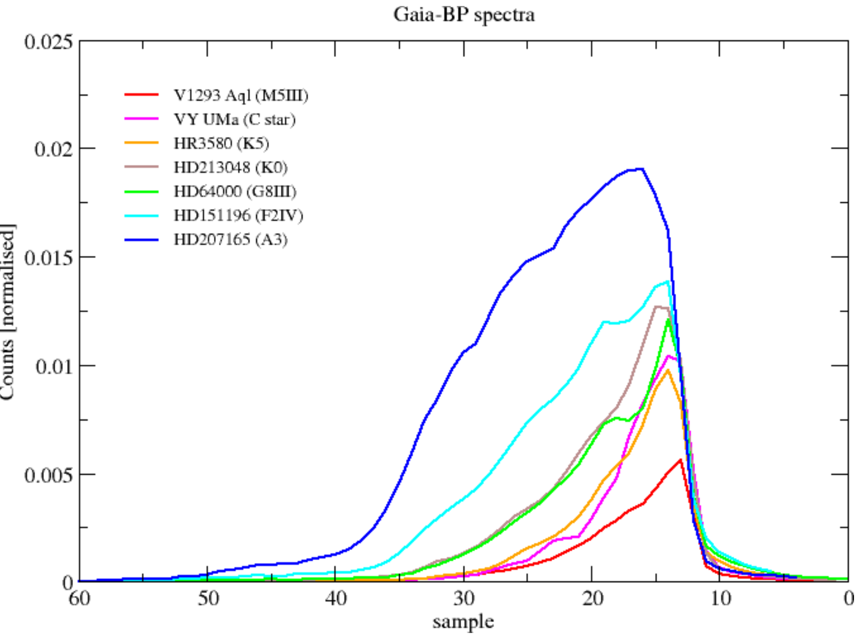
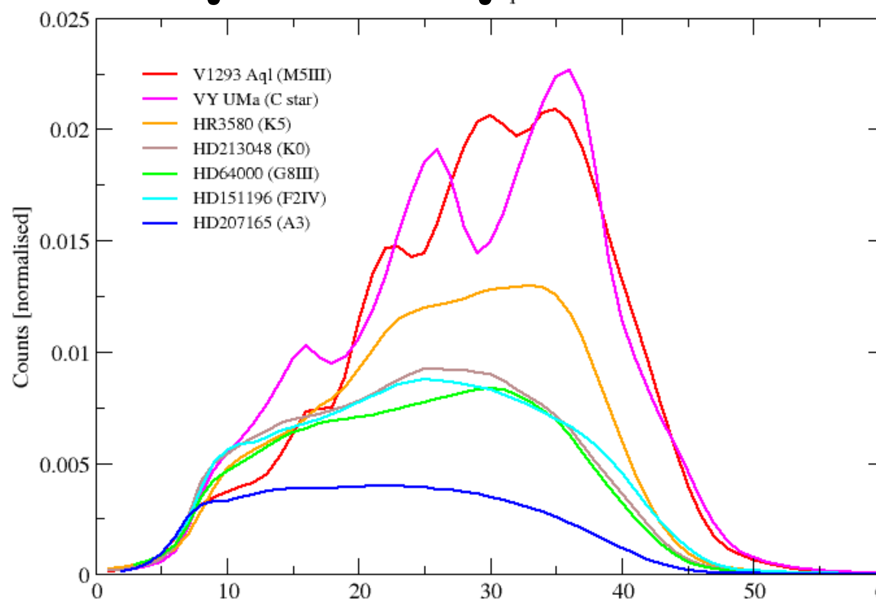


Figure courtesy of DPAC

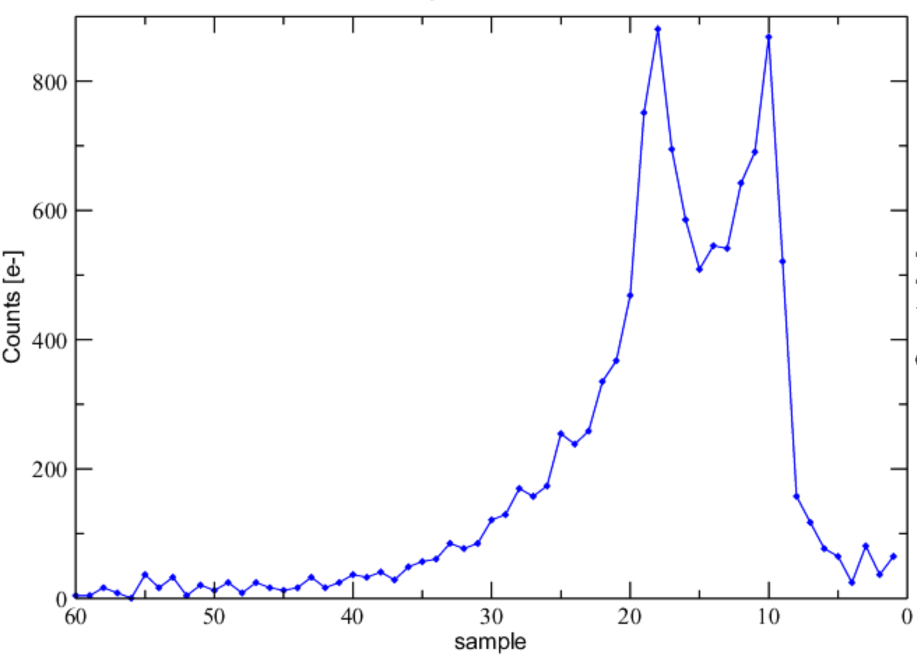
Spectrophotometry

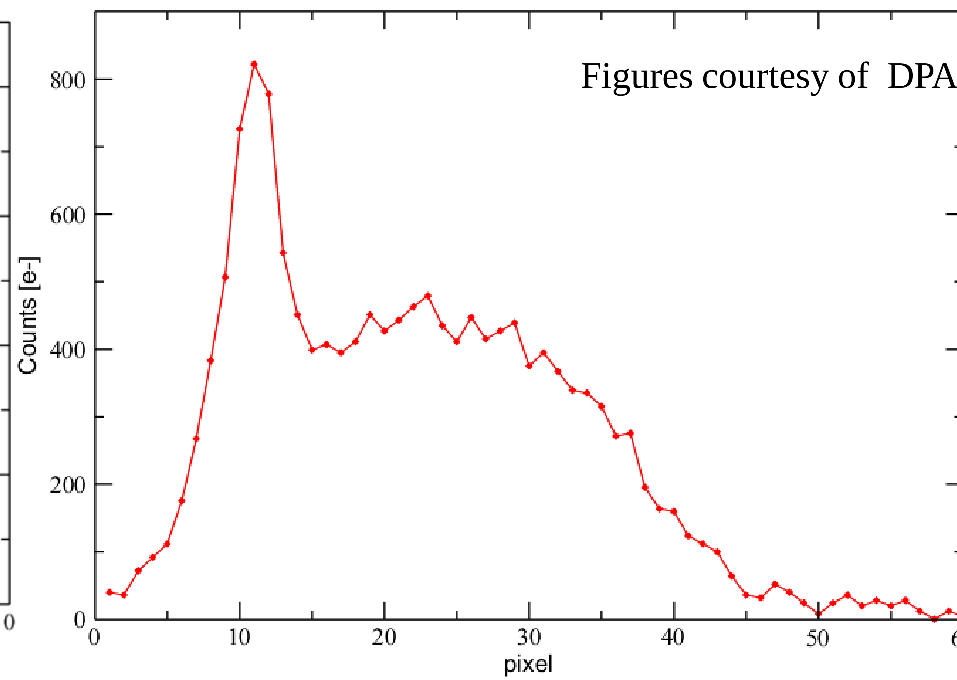




Gaia-RP spectrum of NGC 4395

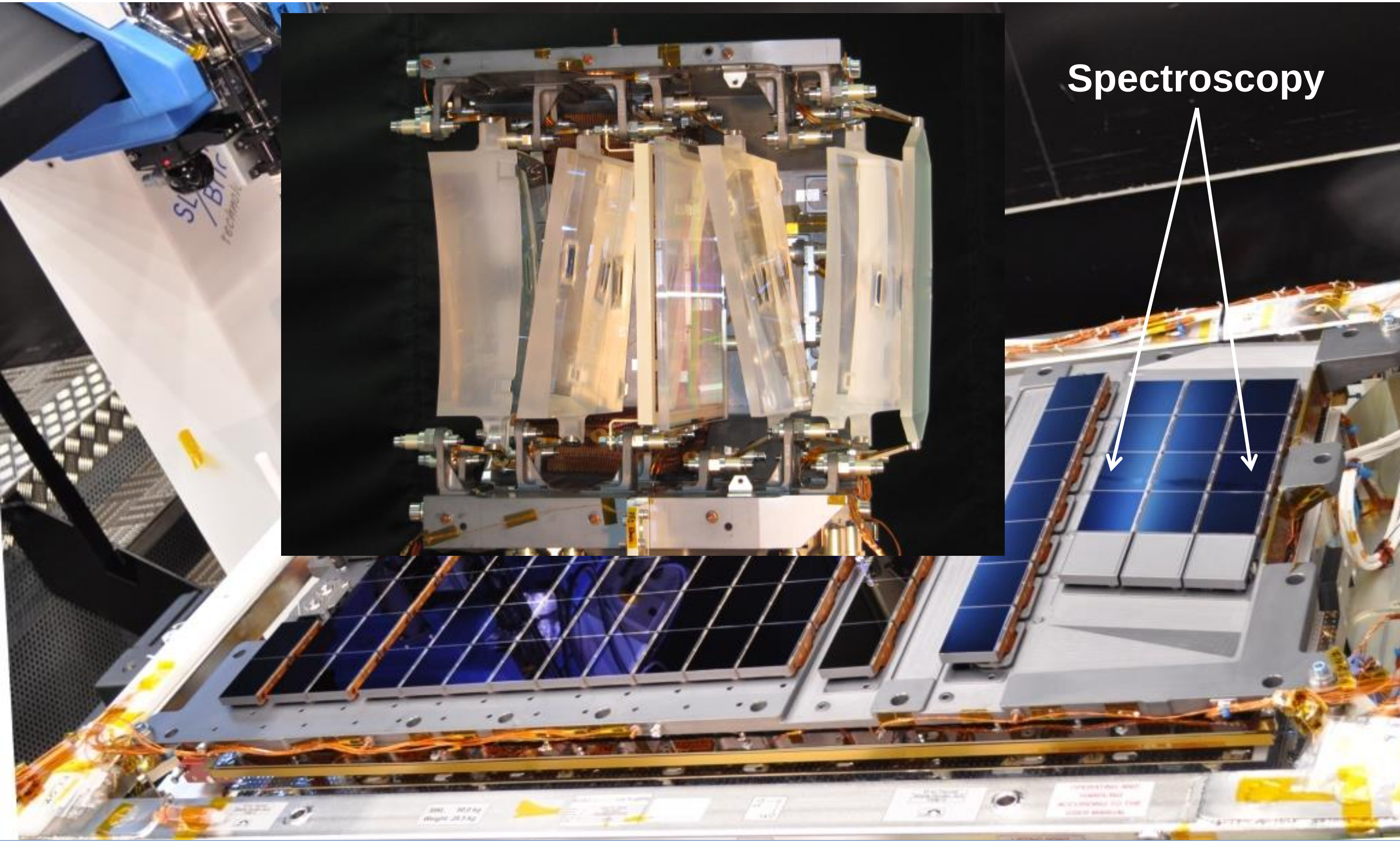
Gaia-BP spectrum of NGC4395



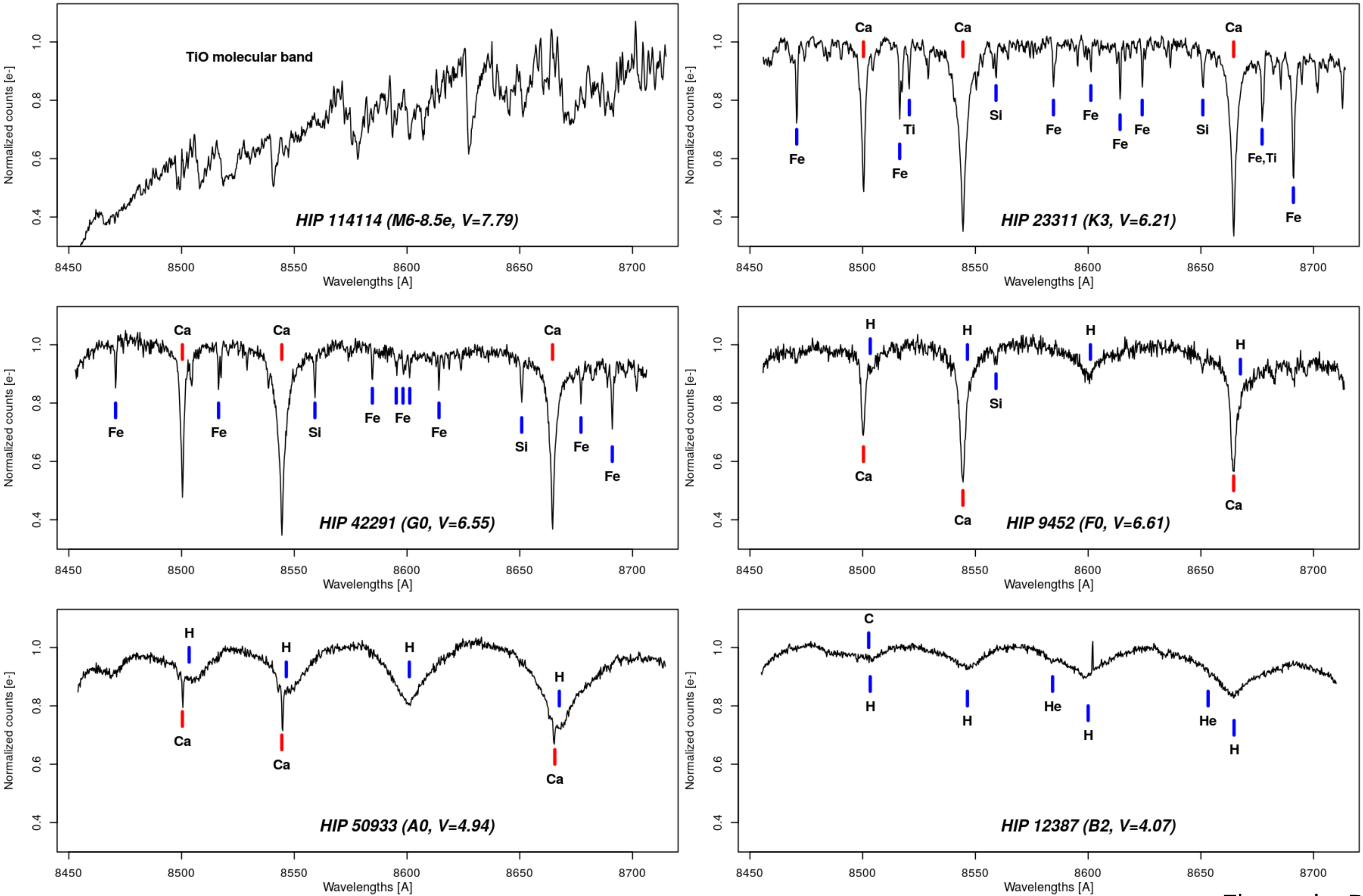


Figures courtesy of DPAC

Focal plane: three instruments



Spectroscopy



Figures by DPAC

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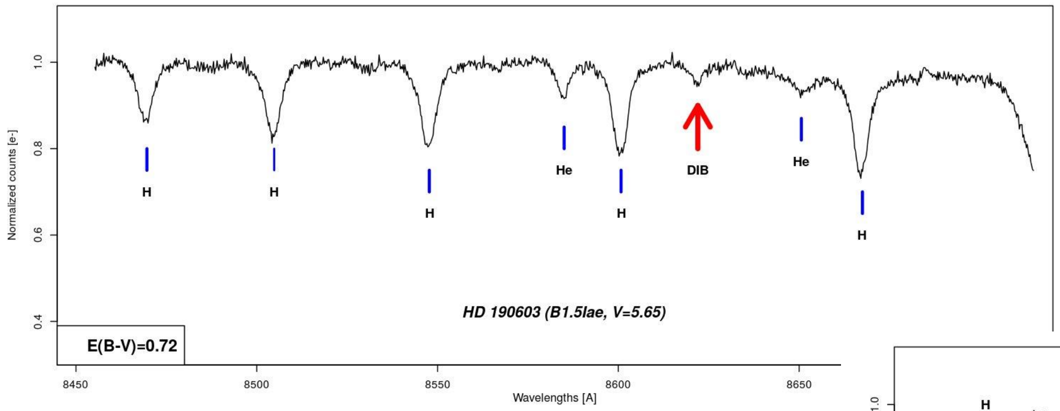
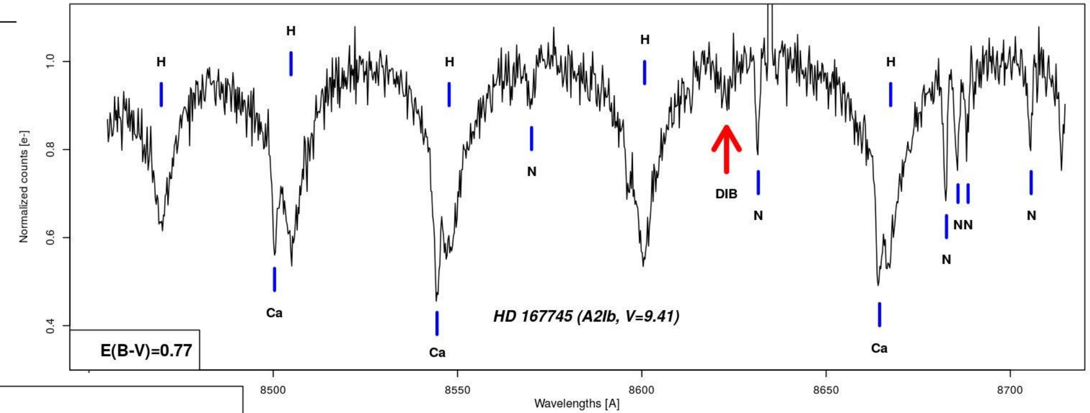
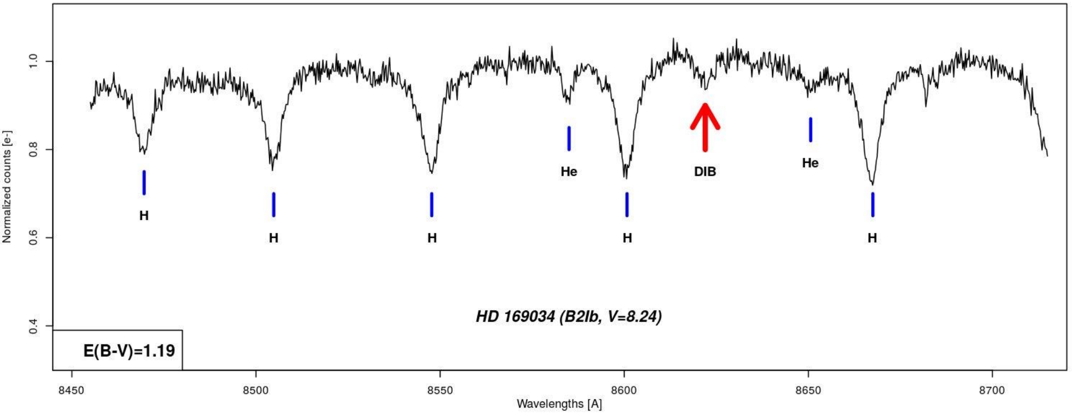
Diffuse Interstellar Bands







Sky coverage since mid-July 2014

Number of observations per square degree since start of nominal operations

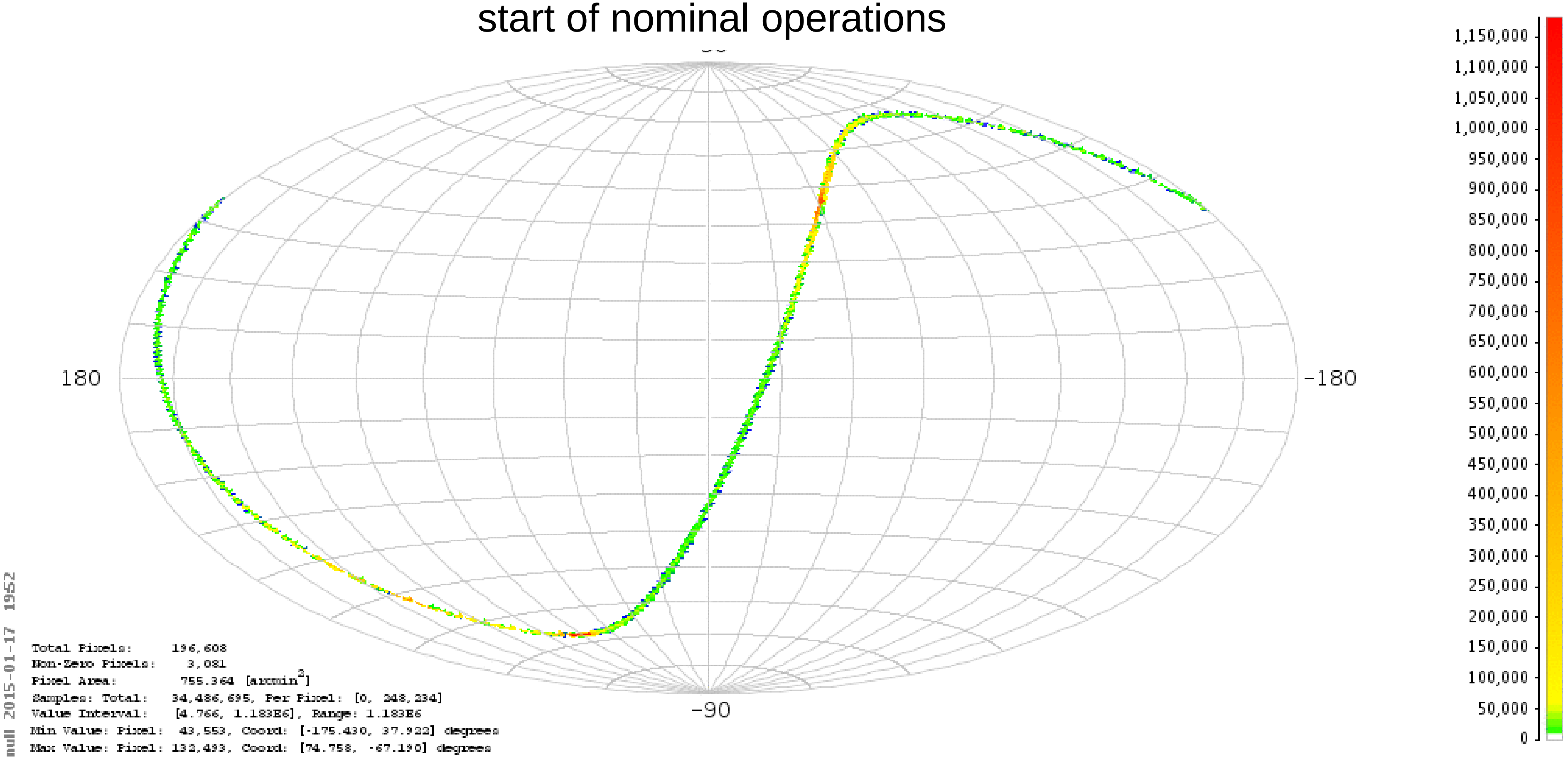


Figure by J. Portell

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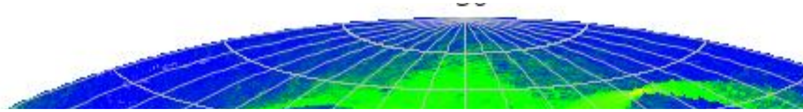
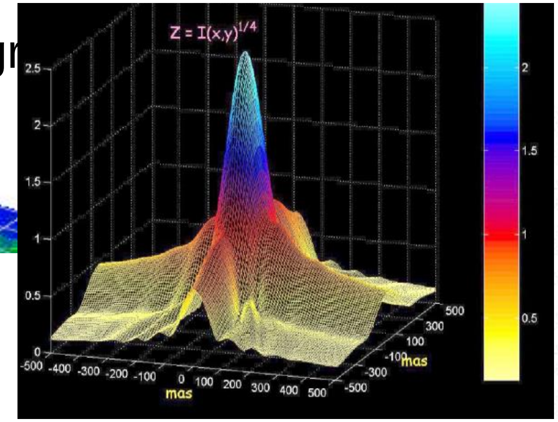
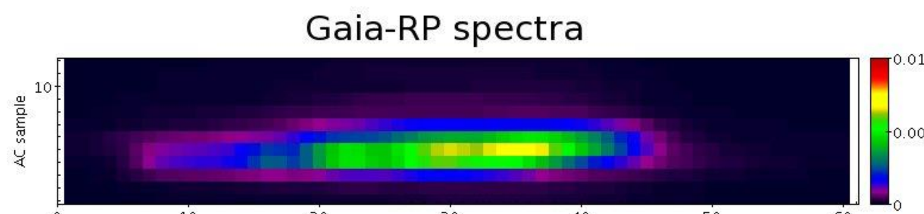
Sky coverage since mid-July 2014

Number of observations per square degr
start of nominal operations



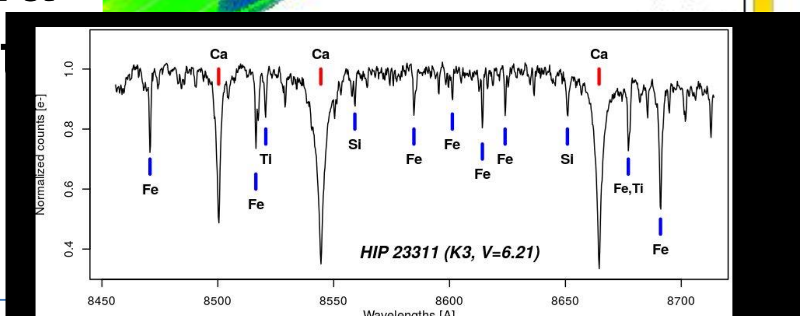


6 months of nominal mission:
full sky coverage
10 billion observations

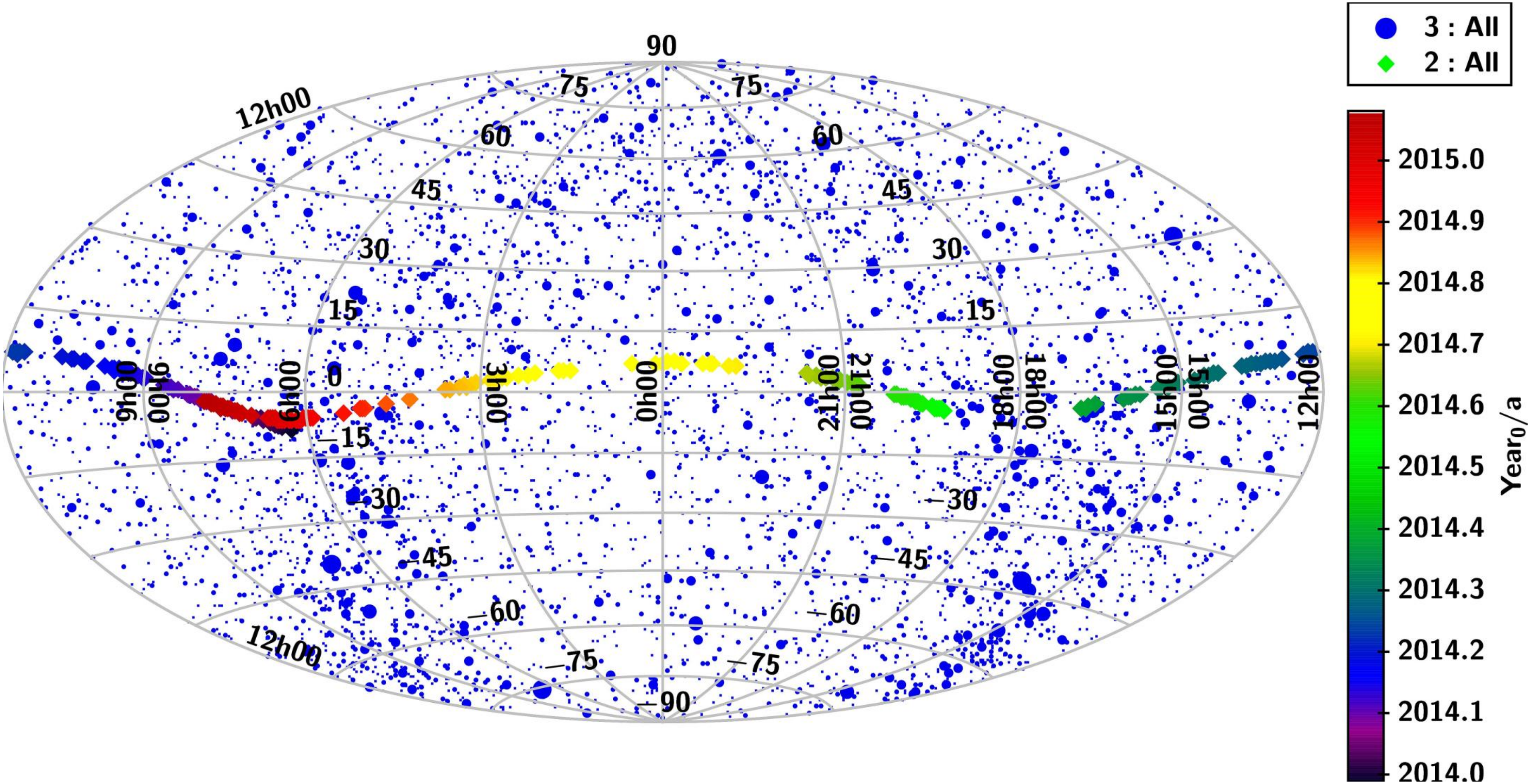


90 billion of individual images
20 billion of low-resolution spectra
2.4 billion of high-resolution spect

20 TB of raw data



Position of Gaia in the sky since launch



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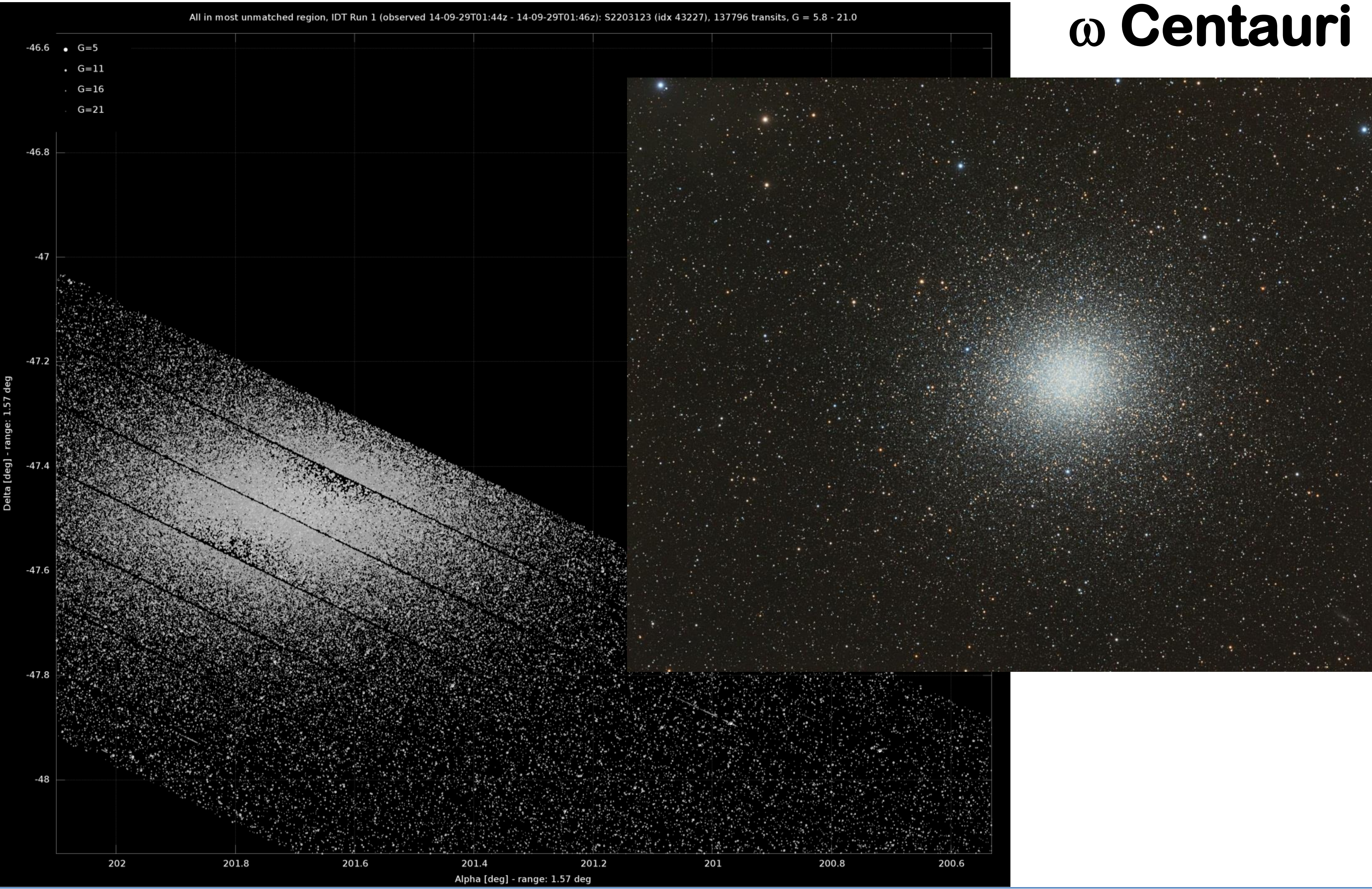
ω Centauri



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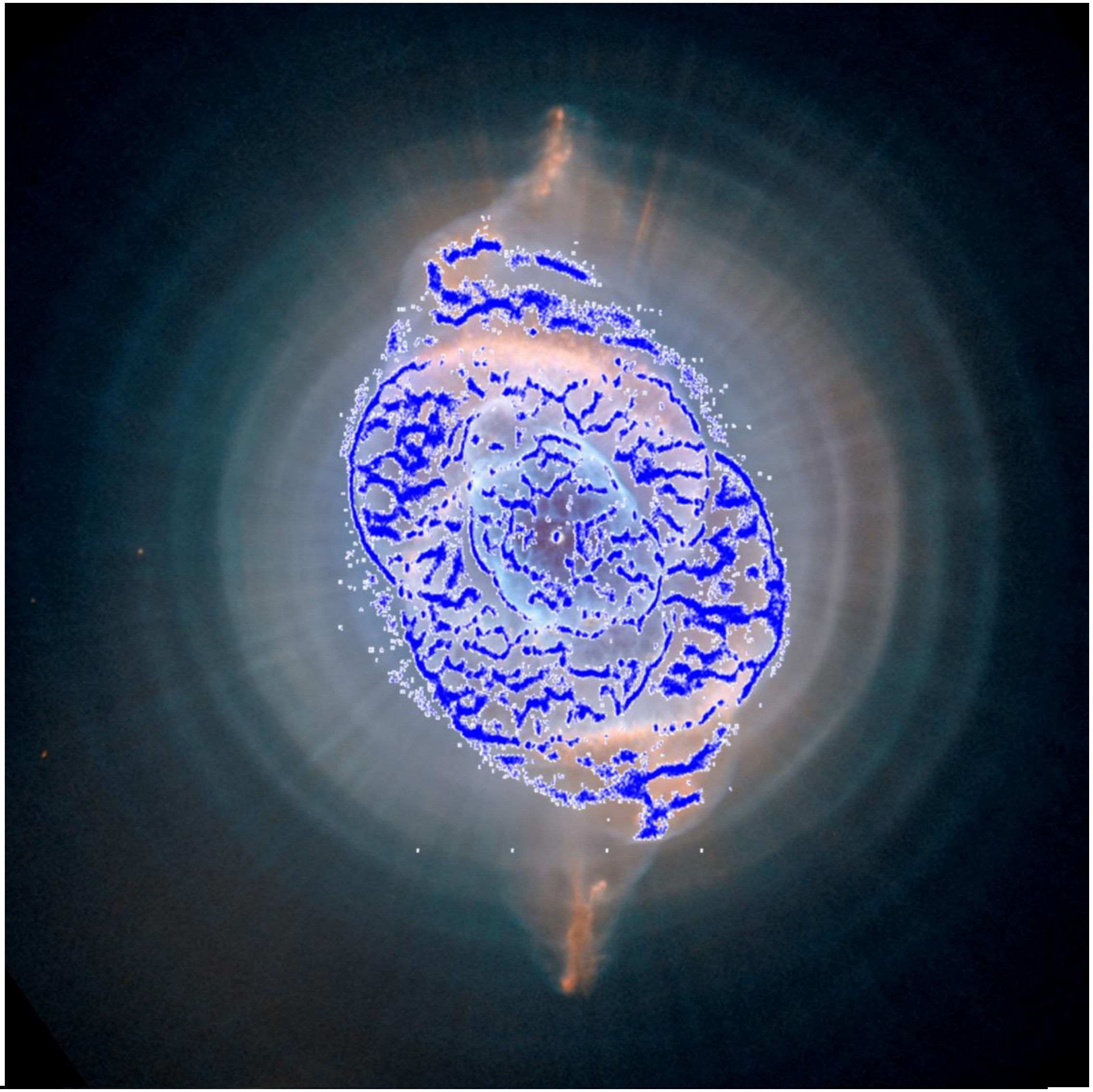
Unexpected views: Cat's eye nebula



Gaia performance predictions at IOCR (July 2014)

Performance predictions for G2V star

V-magnitude	Astrometry (parallax)	Photometry (BP/RP integrated)	Spectroscopy (radial velocity)
3 to 12	5-14 μas	4 mmag	
3 to 12.3			1 km/s
15	24 μas	4 mmag	
15.2			15 km/s
20	540 μas	60 (RP) – 80 (BP) mmag	

Up-to-date information always at:
http://www.cosmos.esa.int/web/gaia/science-performance

Astrometry: de Bruijne et al (2015): arXiv:1502.00791

Optimization of spectroscopy

- Increased background: loss of ~1.4 mag wrt to nominal: less sources, less telemetry
- Operating the RVS in high resolution mode only (since Jul 2014)
- Calibration of the background (more VO, already implemented)
- Adaptive window AC width as a function of OBMT, G_{RVS}, FoV, strip and CCD AC position (VPU 2.8)
- Adaptive limiting magnitude to the external conditions (VPU 2.8), G_{RVS} limit ~16 mag, σ_{rv} ~13 km/s

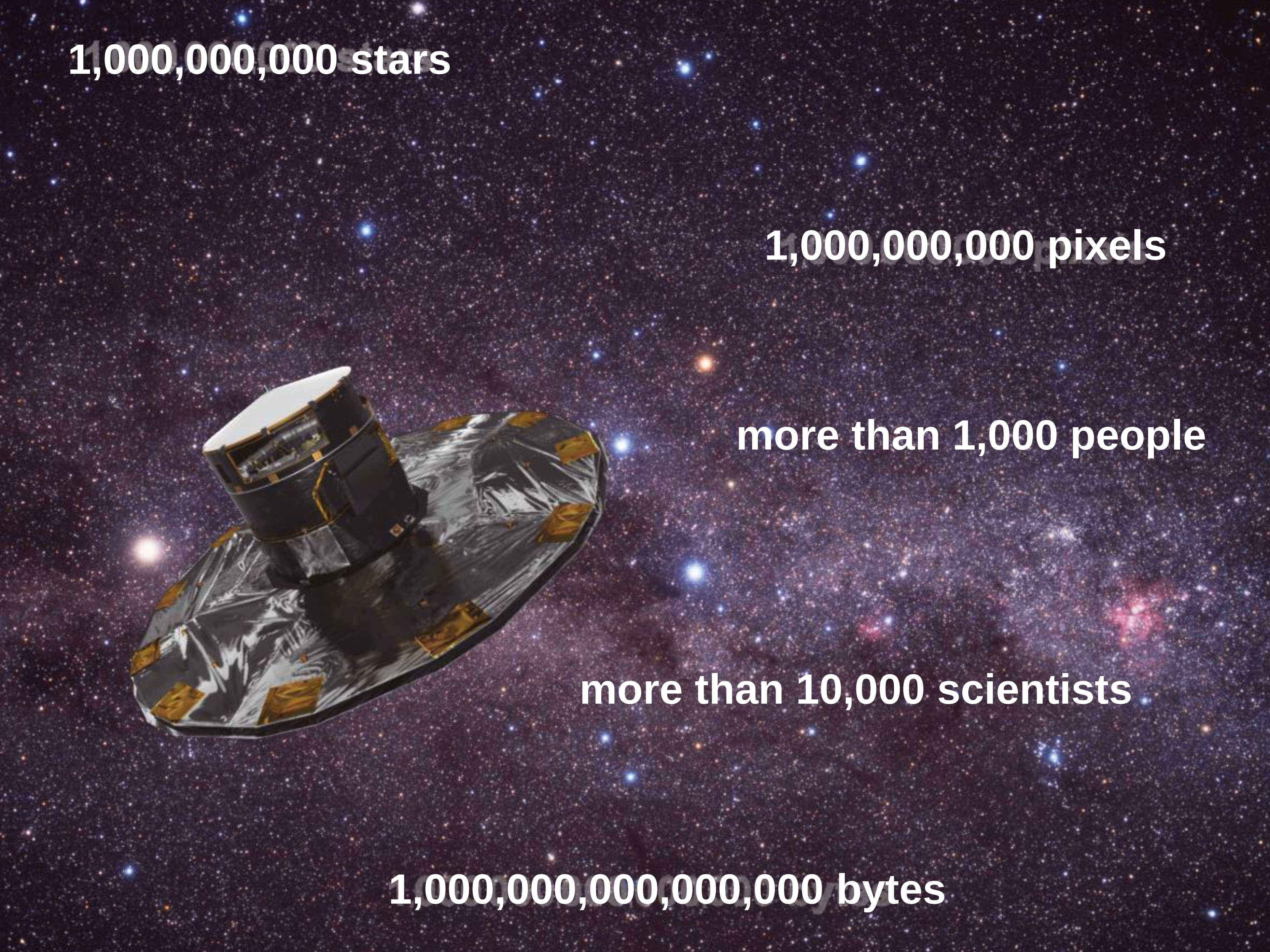
Data processing is more complex than expected, anyway … all checks of the data until now point to

the confirmation that Gaia is able to deliver the expected scientific output

Data release scenario

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

First release: Summer 2016	• **Positions** (α,δ) and **G-mag** for single-like stars (90% of the sky) • **Ecliptic pole** data during commissioning • the **Hundred Thousand Proper Motions (HTPM)** catalogue based on the Hipparcos stars → **Tycho-Gaia (TGAS)**?
Second release: Early 2017	• **Positions, proper motions, parallaxes** and **G-mag** (90% of the sky) • **Integrated XP photometry for sources with Astrophysical parameters** estimated with appropriate standard errors. • **Mean radial velocities for stars** with non-variable radial velocity (90% of the sky)
Third release: 2017/2018	• Astrometric solutions + radial velocity + orbital solutions for **binaries** (2 months – 75% of the observing time) • Object **classification and astrophysical parameters**, together with **XP and RVS spectra** for well-behaved objects. • **Mean radial velocities** and **atmospheric parameter** estimates for non-variable stars.
Fourth release: 2018/2019	• **Variable star classifications and parameters** as available, and the epoch photometry • **Solar system results** with preliminary orbital solutions and individual epoch observations • **Non-single** star catalogue
Final release: 2022	• **Full** astrometric, photometric, radial velocity catalogue • All available **variables and non-single** stars solutions • Source **classifications** (probabilities) + multiple **astrophysical parameters** derived from BP/RP, RVS and astrometry for **stars, unresolved binaries, galaxies and quasars**. Some parameters may not be available for faint(er) stars. • List of **exoplanets**. • All **epoch and transit data** for all sources • All **Ground Based Observations** made for data processing purposes (or links to it)


1,000,000,000 stars
1,000,000,000 pixels
more than 1,000 people
more than 10,000 scientists
1,000,000,000,000,000 bytes

Performances: astrometry

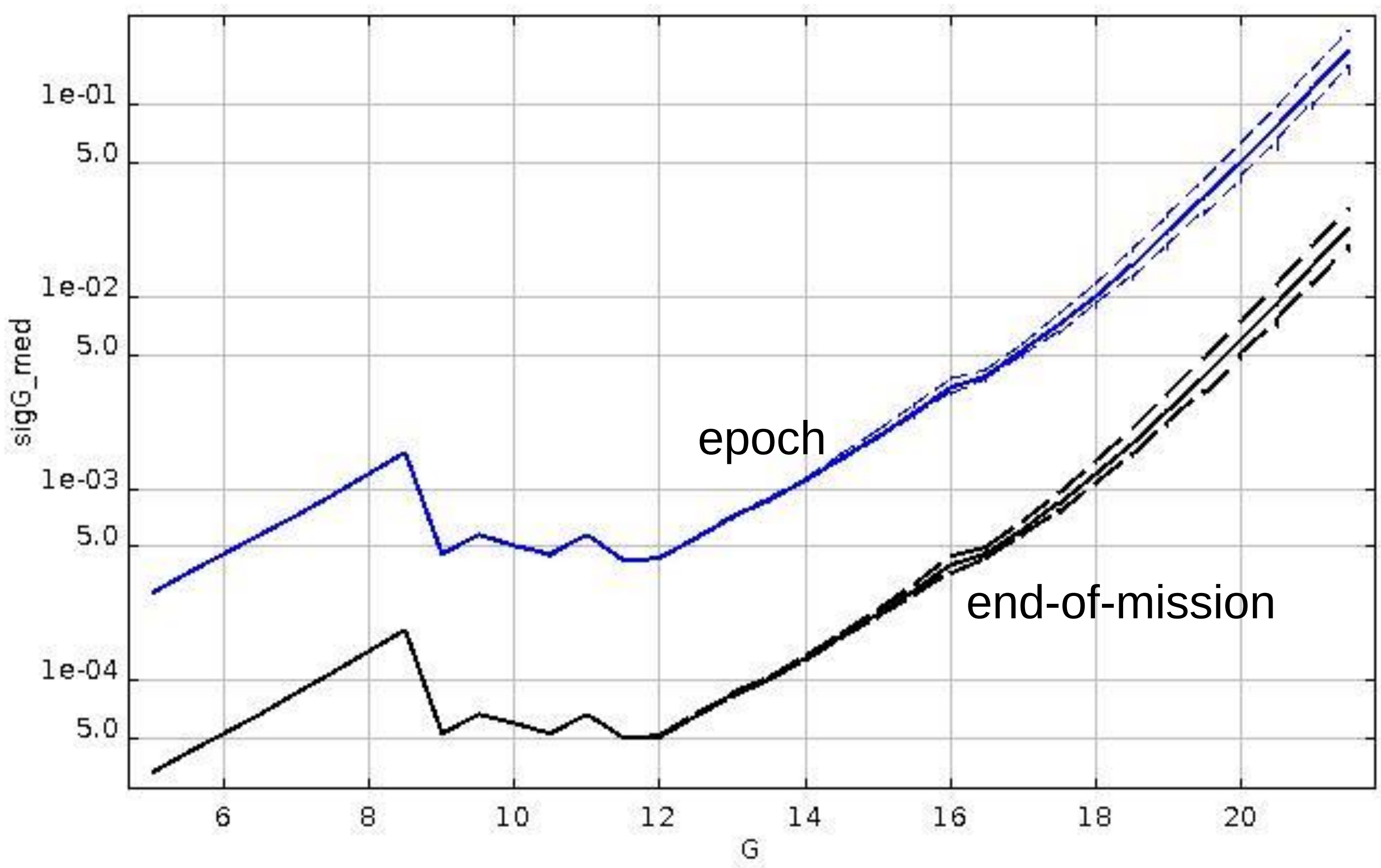
de Bruijne et al (2015): arXiv:1502.00791

Table 1. Sky-average, end-of-mission, astrometric standard errors – σ_0 in μas for position at mid-epoch, σ_ϖ in μas for parallax, and σ_μ in μas yr^{-1} for proper motion – as function of Gaia G magnitude for an unreddened G2V star ($V-I = 0.75$ mag and $V-G = 0.16$ mag). For stars in the range G = 3–12.09 mag, the numbers refer to "average errors" (see text).

G [mag]	3–12.09	13	14	15	16	17	18	19	20
σ_0 [μas]	5.0	7.7	12.3	19.8	32.4	55.4	102	208	466
σ_ϖ [μas]	6.7	10.3	16.5	26.6	43.6	74.5	137	280	627
σ_μ [μas yr^{-1}]	3.5	5.4	8.7	14.0	22.9	39.2	72.3	147	330

Up-to-date information always at:
http://www.cosmos.esa.int/web/gaia/science-performance

Performances: photometry



Up-to-date information always at:
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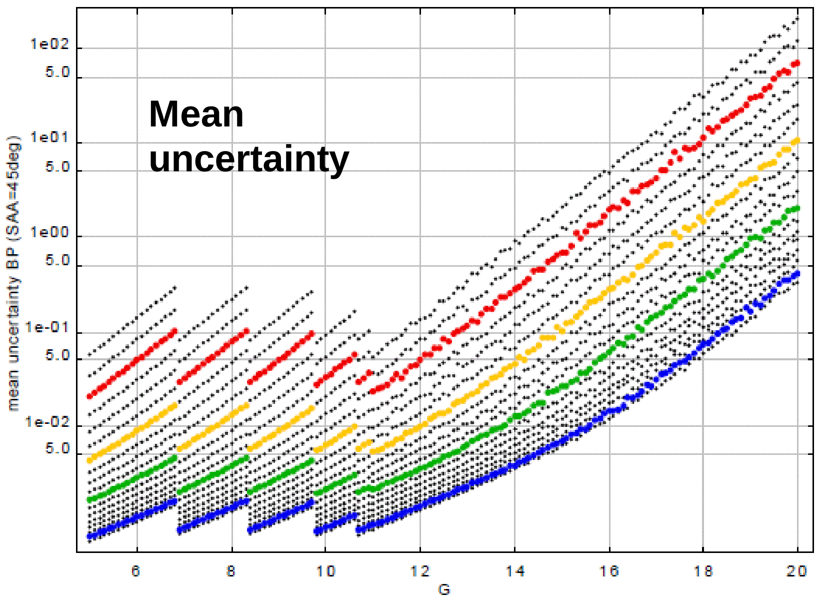
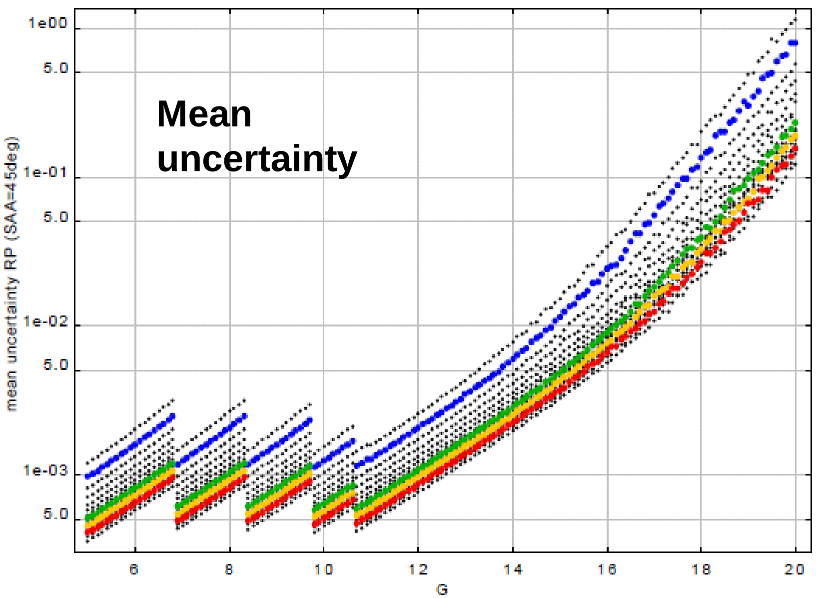
Performances: photometry

BP



RP



Up-to-date information always at:
http://www.cosmos.esa.int/web/gaia/science-performance

Performances: spectroscopy

End-of-mission radial-velocity errors averaged over the sky

Spectral type	V (mag)	Radial-velocity error [km s^{-1}]
B1 V	7.5	1
	11.3	15
G2 V	12.3	1
	15.2	15
K1 III	12.8	1
(metal-poor)	15.7	15

Up-to-date information always at:
http://www.cosmos.esa.int/web/gaia/science-performance

The degradation in limiting magnitude due to the increase of the background light is estimated

to 1.4 magnitudes (see Sect. 5.2). This lead to a major loss of about 70%3 of the RVS targets:

i.e. from about 200 millions (TBC) stars expected to about 60 millions (TBC) stars.

The optical distortions and transverse motion produce a 3 hours periodic broadening of the AC LSF: up to 50% broadening with respect to the optical AC LSF. In addition, the background level varies with OBMT and across the focal plane (see bullet 3). Both background level and AC broadening should be combined to determine the best window width as a function of OBMT. The optimal width of the window will also depend on GRV S.

Table 4 presents the post-launch end-of-mission signal to noise ratios per LR sample for the 3 G_{RVS} magnitudes: 12, 15 and 16.5. **The degradation with respect to the pre-launch configuration is 1.35 magnitude.**

G_{RVS} (mag)	Star (e^-)	Bckgd (e^-)	RoN^2 (e^-)	S/N
11.15	13803.53	25429.38	1080.00	68.75
13.70	1318.23	25429.38	1080.00	7.90
15.15	346.73	25429.38	1080.00	2.12

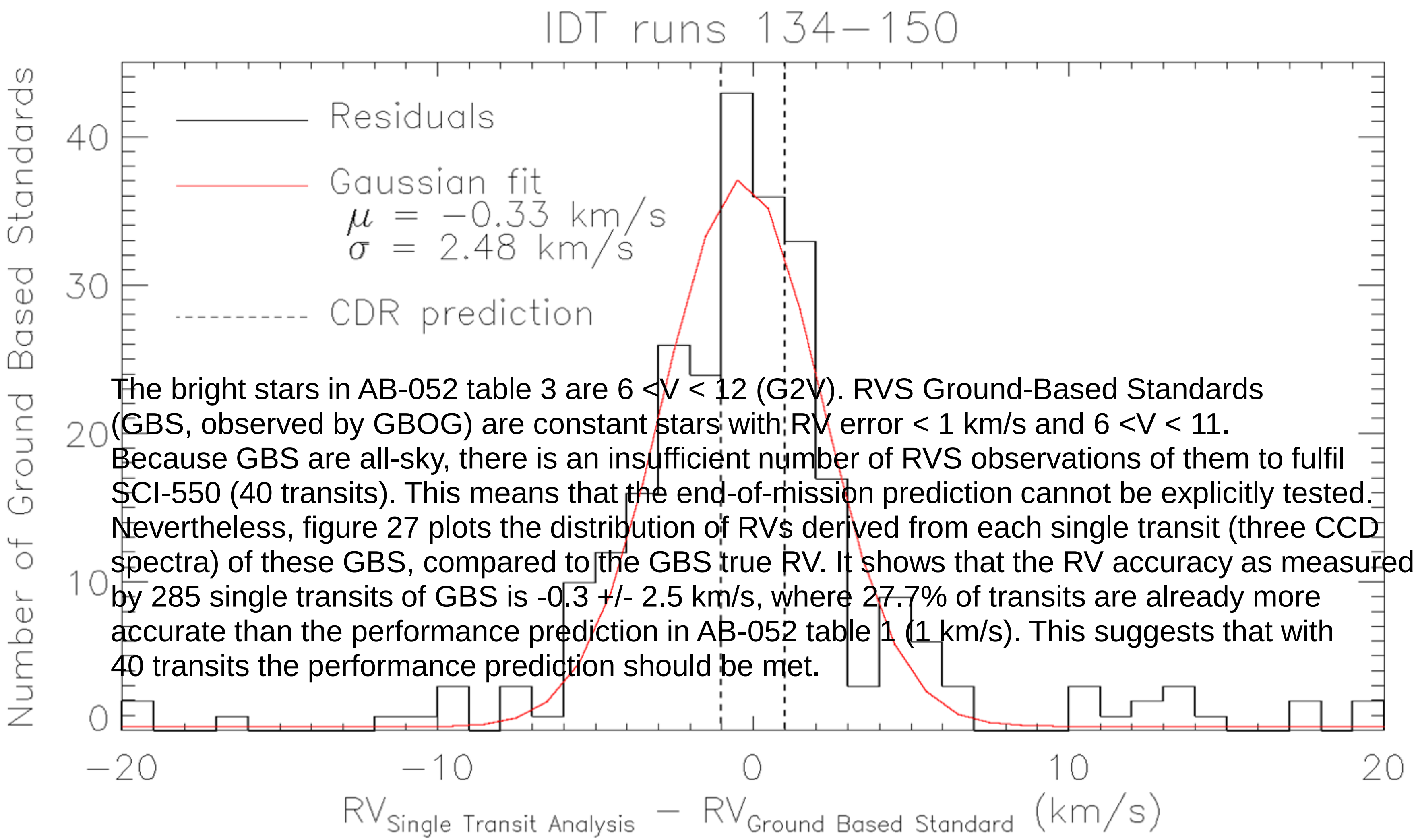
TABLE 4: Post-launch signal to noise ratios versus G_{RVS} magnitudes. The SN are per LR samples.

G_{RVS} (mag)	Star (e^-)	Bckgd (e^-)	RoN^2 (e^-)	S/N
11.10	14454.07	25429.38	3240.00	69.60
13.65	1380.35	25429.38	3240.00	7.96
15.10	363.07	25429.38	3240.00	2.13

TABLE 11: Post-launch signal to noise ratios versus G_{RVS} magnitudes for 3 HR pixels.

Bckgd /transit (e^-)/pixel	G_{RVS} (mag)	Star /mission (e^-)/sample	Bckgd /mission (e^-)/sample	RoN^2 /mission (e^-)/sample	S/N /mission /sample
0.3	16.50	100.00	1080.00	1080.00	2.10
1.0	16.10	144.54	3600.00	1080.00	2.08
5.0	15.35	288.40	18000.00	1080.00	2.07
10.0	15.00	398.10	36000.00	1080.00	2.06
15.0	14.75	501.18	54000.00	1080.00	2.13
20.0	14.60	575.43	72000.00	1080.00	2.12
25.0	14.50	630.94	90000.00	1080.00	2.08
30.0	14.40	691.82	108000.00	1080.00	2.09

TABLE 12: Post-launch signal to noise ratios versus G_{RVS} magnitudes for different background illumination level.



The bright stars in AB-052 table 3 are 6 <V < 12 (G2V). RVS Ground-Based Standards (GBS, observed by GBOG) are constant stars with RV error < 1 km/s and 6 <V < 11. Because GBS are all-sky, there is an insufficient number of RVS observations of them to fulfil SCI-550 (40 transits). This means that the end-of-mission prediction cannot be explicitly tested. Nevertheless, figure 27 plots the distribution of RVs derived from each single transit (three CCD spectra) of these GBS, compared to the GBS true RV. It shows that the RV accuracy as measured by 285 single transits of GBS is -0.3 +/- 2.5 km/s, where 27.7% of transits are already more accurate than the performance prediction in AB-052 table 1 (1 km/s). This suggests that with 40 transits the performance prediction should be met.

FIGURE 27: Single transit RV accuracy as measured by comparing the barycentric RVs derived from 285 single transits (three CCD spectra) of GBS with the barycentric GBS true R

RVS Performances

BP

RP

Mean uncertainty

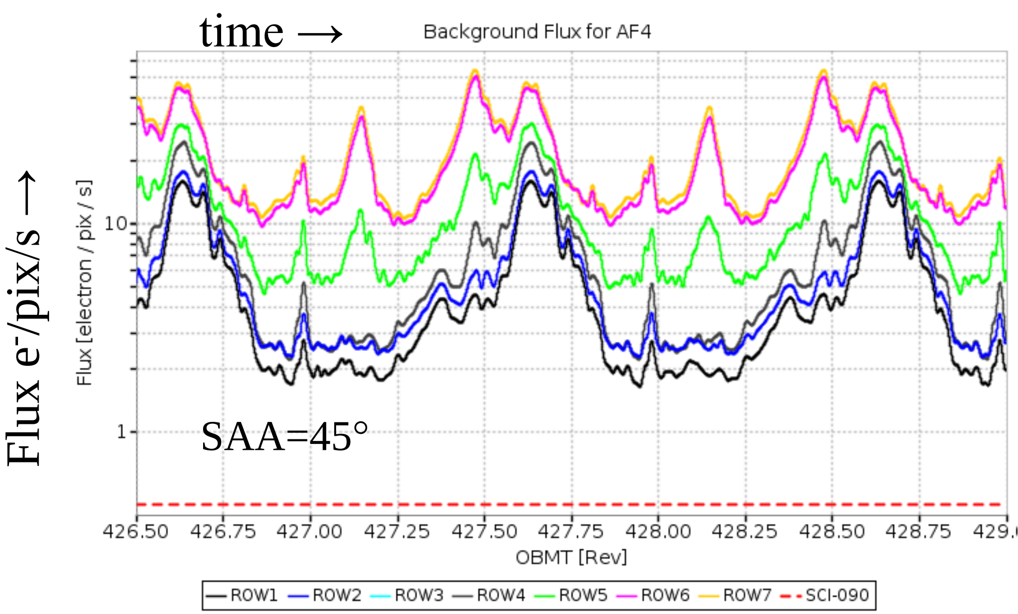
Mean uncertainty

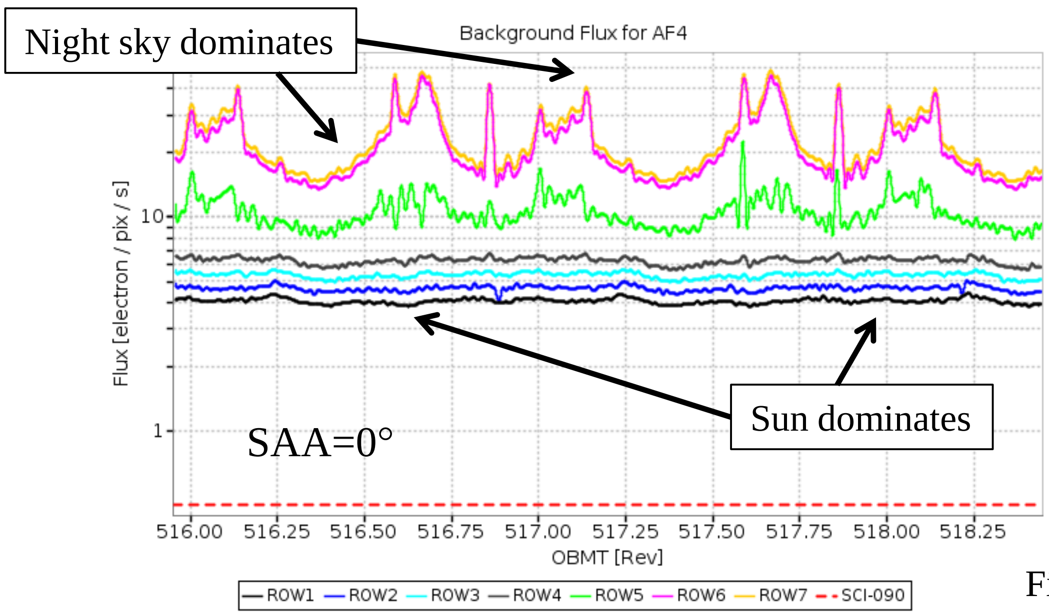
Performances de RVS

Epoch uncertainty

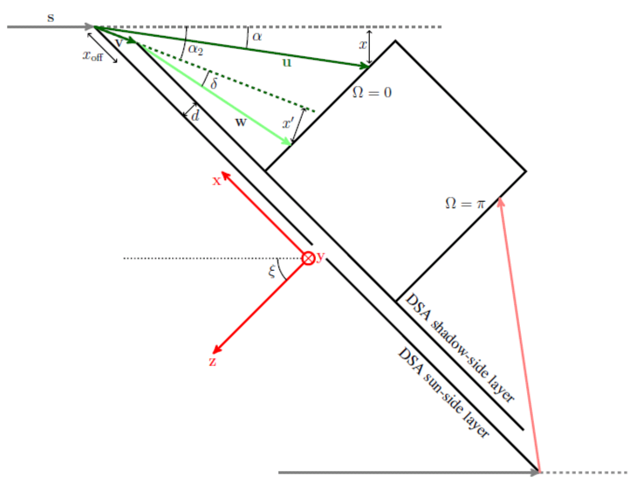
Epoch uncertainty

Stray light



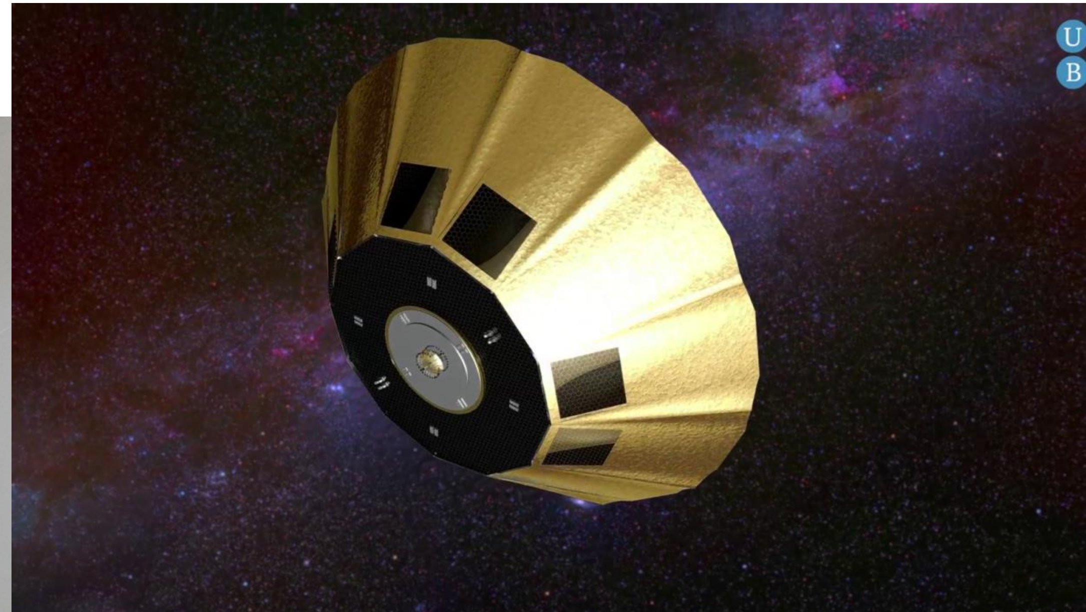


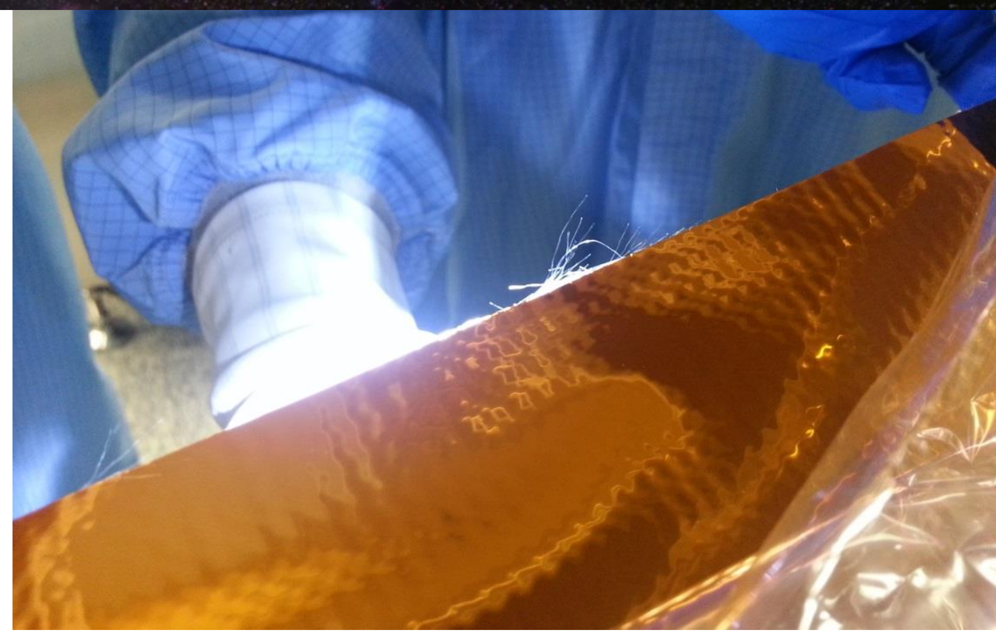
- Sun light diffracted and scattered at sunshield edges
- Light from night sky sources along unforeseen paths



Figures by M. Davidson


UPPER SEGMENT
ASTRIUM





Conclusion

- Gaia is at L2
- Gaia is observing
- Ground-segment is working (ESOC + ground stations)

- DPAC is working
- We have to deal with more complexities than expected
- There are some unknowns about basic angle variations and their couple with astrometry

Looking forward the first data release

Credits

DPAC Payload Experts at institutes throughout Europe

Initial Data Treatment, First Look, and AVU/BAM+AIM teams

Operations teams at ESAC, Torino, CNES-Toulouse, Cambridge, Barcelona, Geneva

ESA Gaia-SOC calibration team

DPAC Project Office

ESA Gaia Project Scientist team

ESOC flight control team

ESA Gaia project team

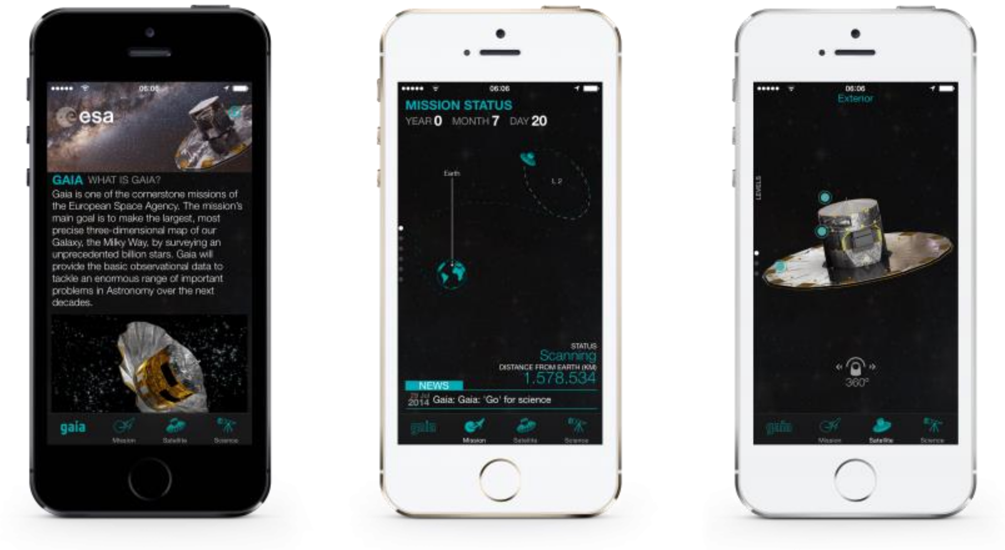
Airbus Defence & Space

Arianespace, Soyuz, CNES-Kourou launch teams

More info

http://www.cosmos.esa.int/web/gaia
http://blogs.esa.int/gaia/
http://gaia.ub.edu

Gaia App iPhone and Android



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Stray light

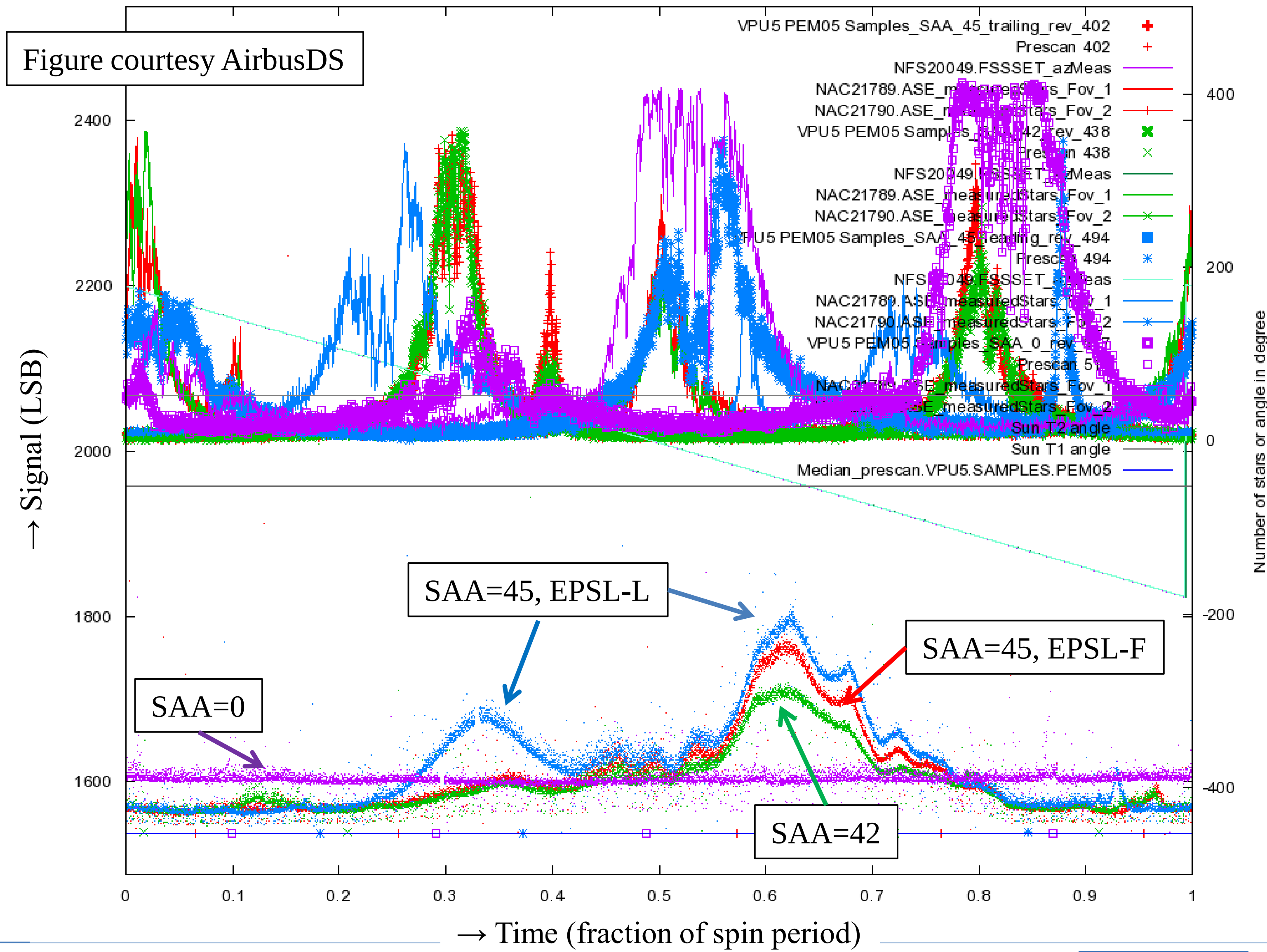

Figure courtesy AirbusDS
VPU5 PEM05 Samples_SAA_45_trailing_rev_402
Prescan 402
NFS20049.FSSSET_azMeas
Sun T2 angle
Sun T1 angle
Median_prescan.VPU5.SAMPLES.PEM05
SAA=45, EPSL-L
SAA=45, EPSL-F
SAA=0
SAA=42
→ Signal (LSB)
Number of stars or angle in degree
→ Time (fraction of spin period)
2400
2200
2000
1800
1600
400
200
0
-200
-400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Throughput loss

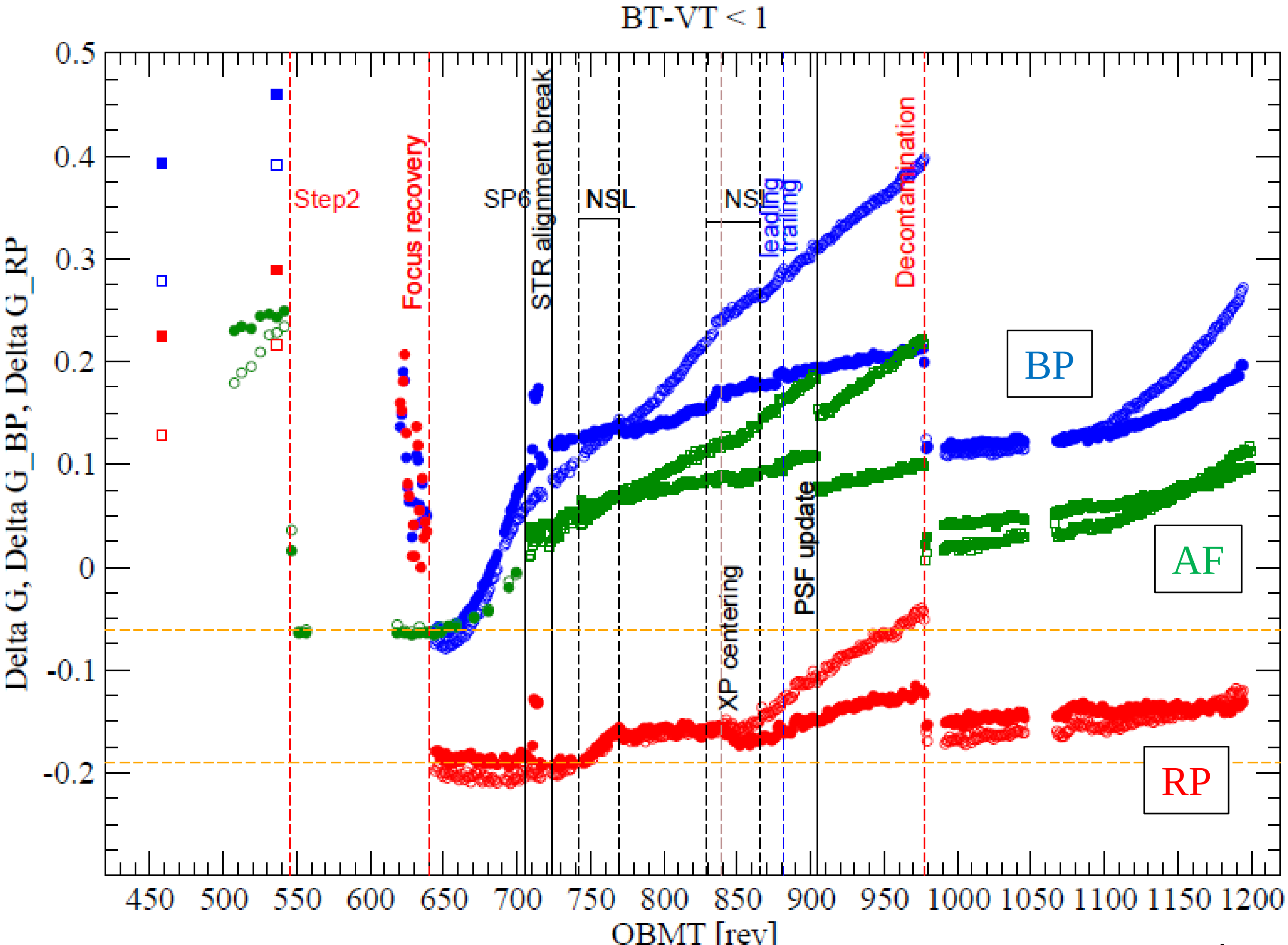

Figure by C. Jordi

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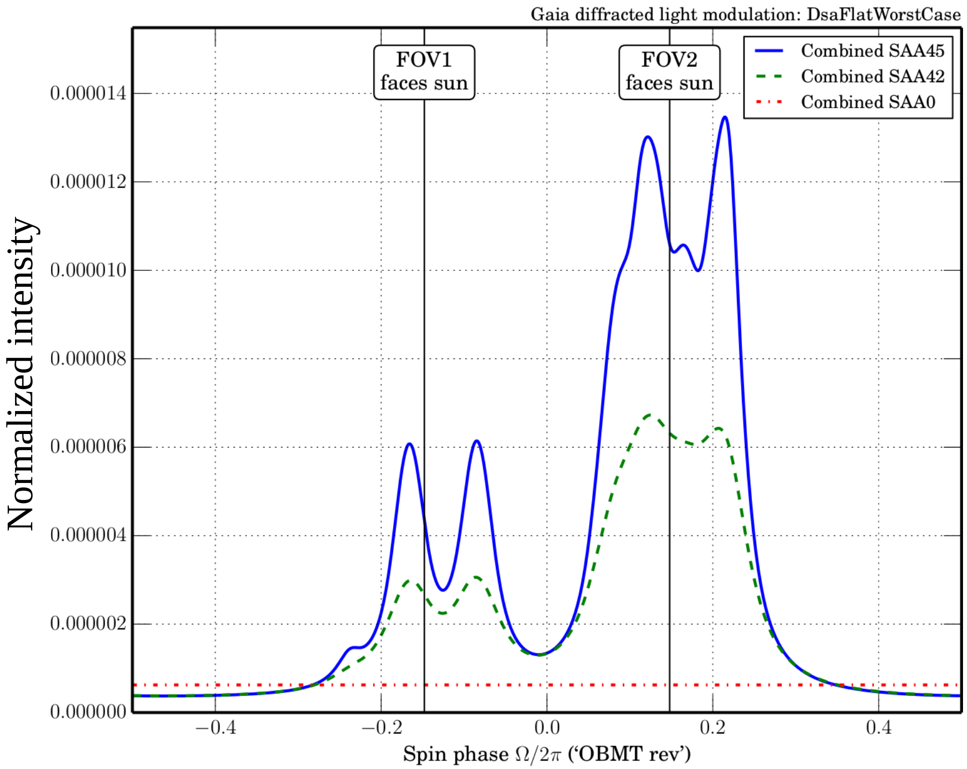
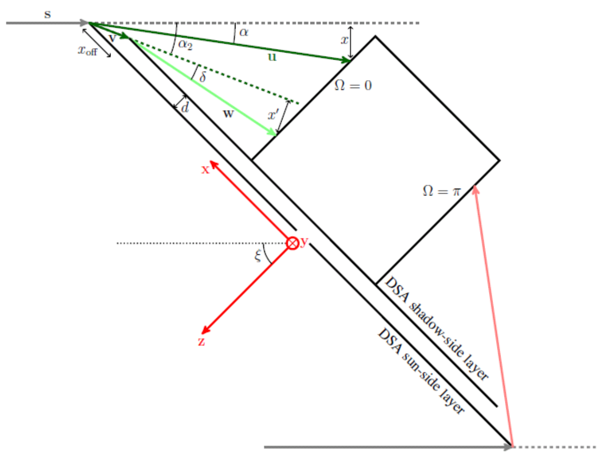
Stray light

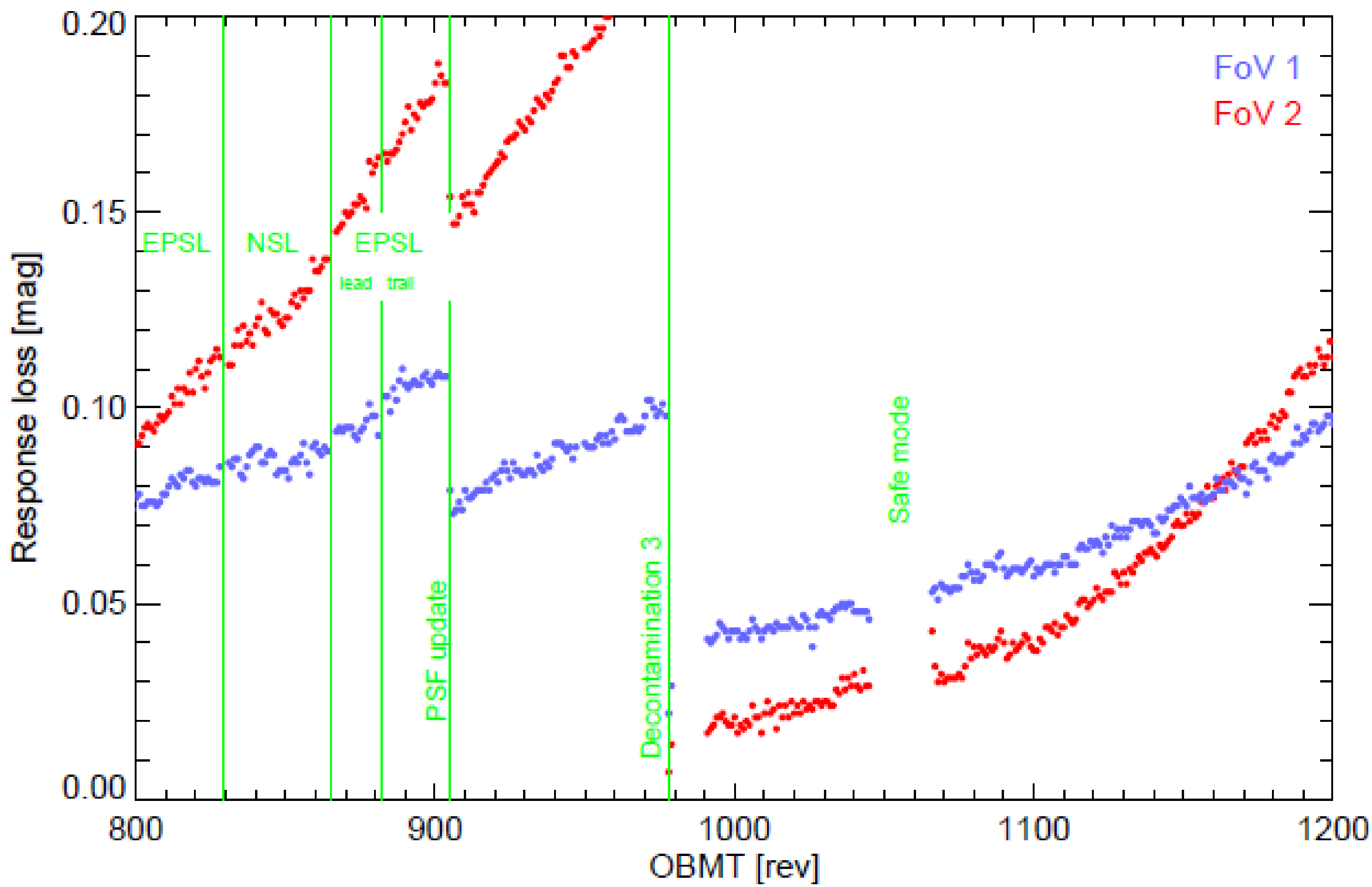




Model for diffracted sunlight variation as a function of spin phase by S. Jordan & A. Brown

- Diffracted sunlight modulation can be explained by varying FOV depths in sunshield geometric shadow, and sunshield shape
- DSA configuration within specified margins (at extremes) sufficient to *qualitatively* explain increase in diffracted light over nominal case
  - No quantitative model for stray light yet

Throughput loss



Monitoring of response by comparison to Tycho-2 photometry

Figure by C. Fabricius

Insertion into orbit around L2

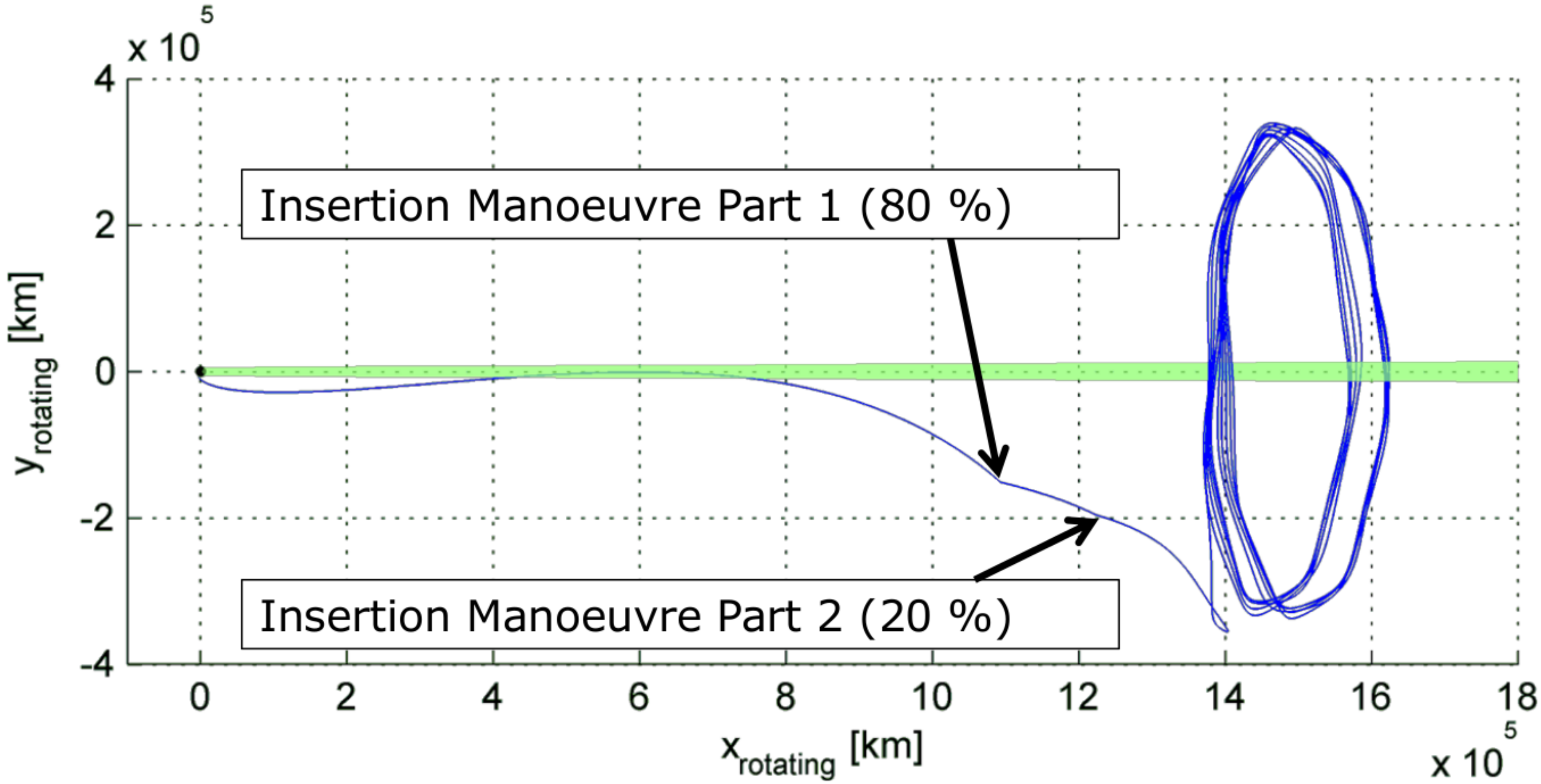
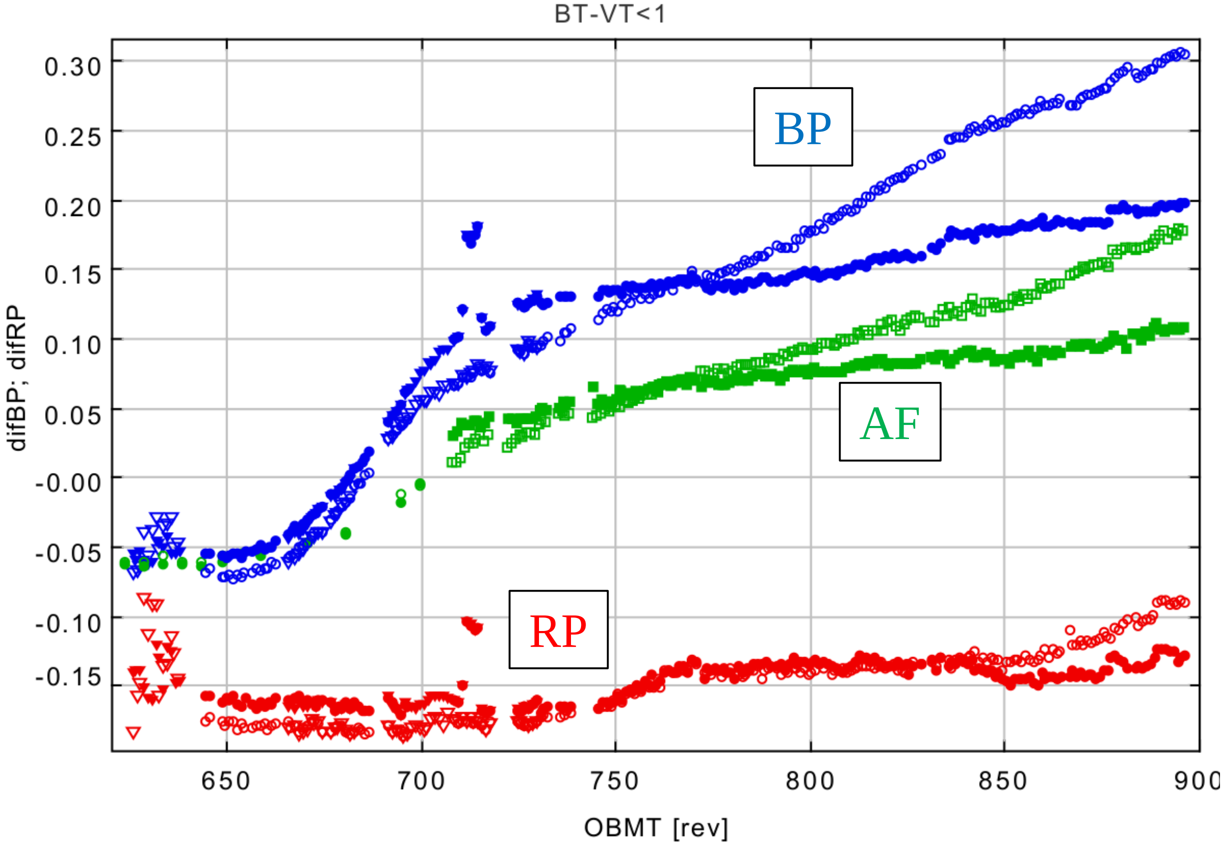


Image courtesy A. Rudolph and D. Milligan (ESOC)

Throughput loss



Throughput loss in BP and RP

- Colour effect since decontamination
- Future decontamination campaigns unavoidable

Figure by C. Jordi

Variability

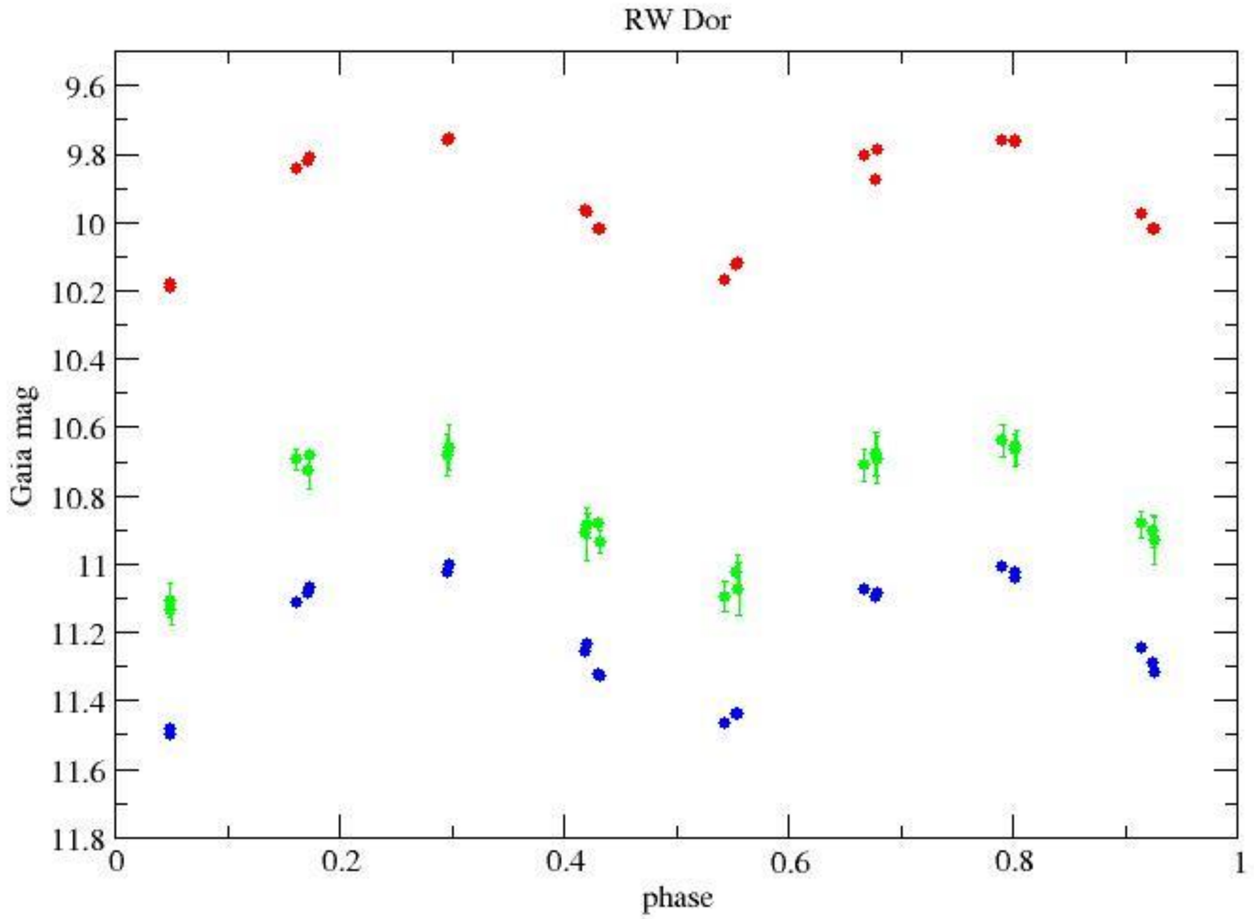
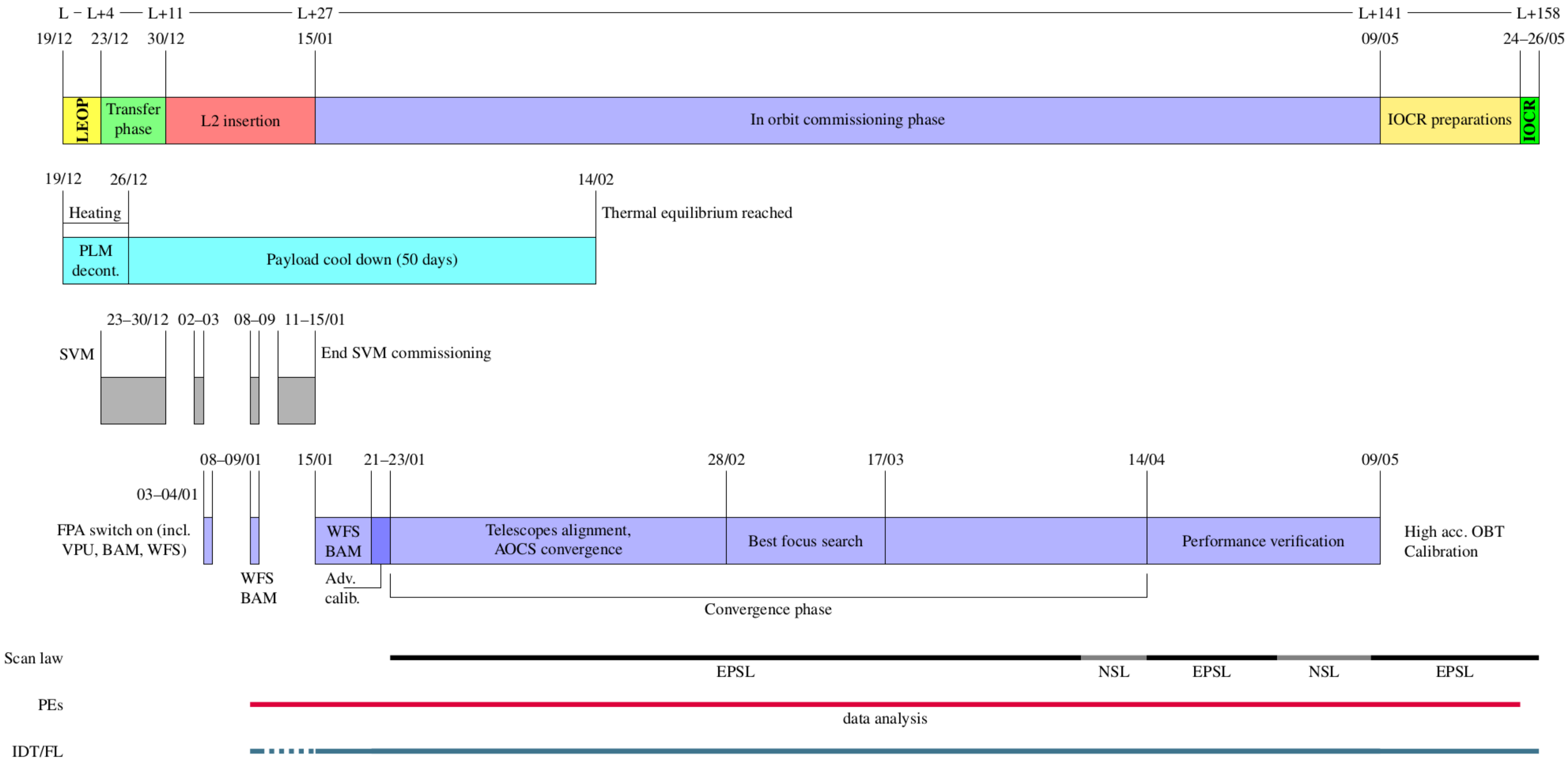


Figure by E. Masana & C. Jordi

Commissioning phase

- Planned operations started soon after launch
- Commissioning phase ended mid-July



Insertion into orbit around L2

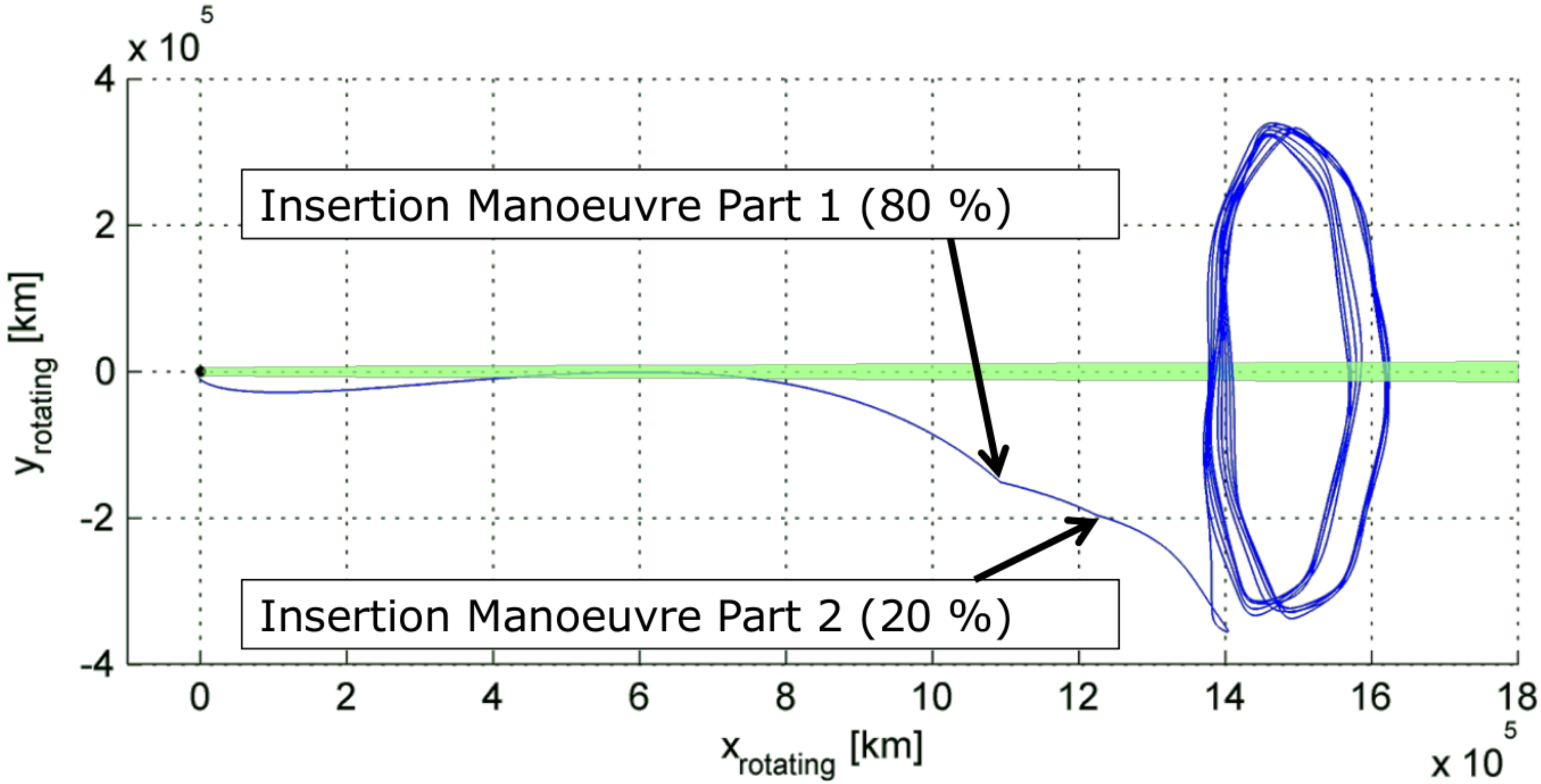


Image courtesy A. Rudolph and D. Milligan (ESOC)

Processing needs

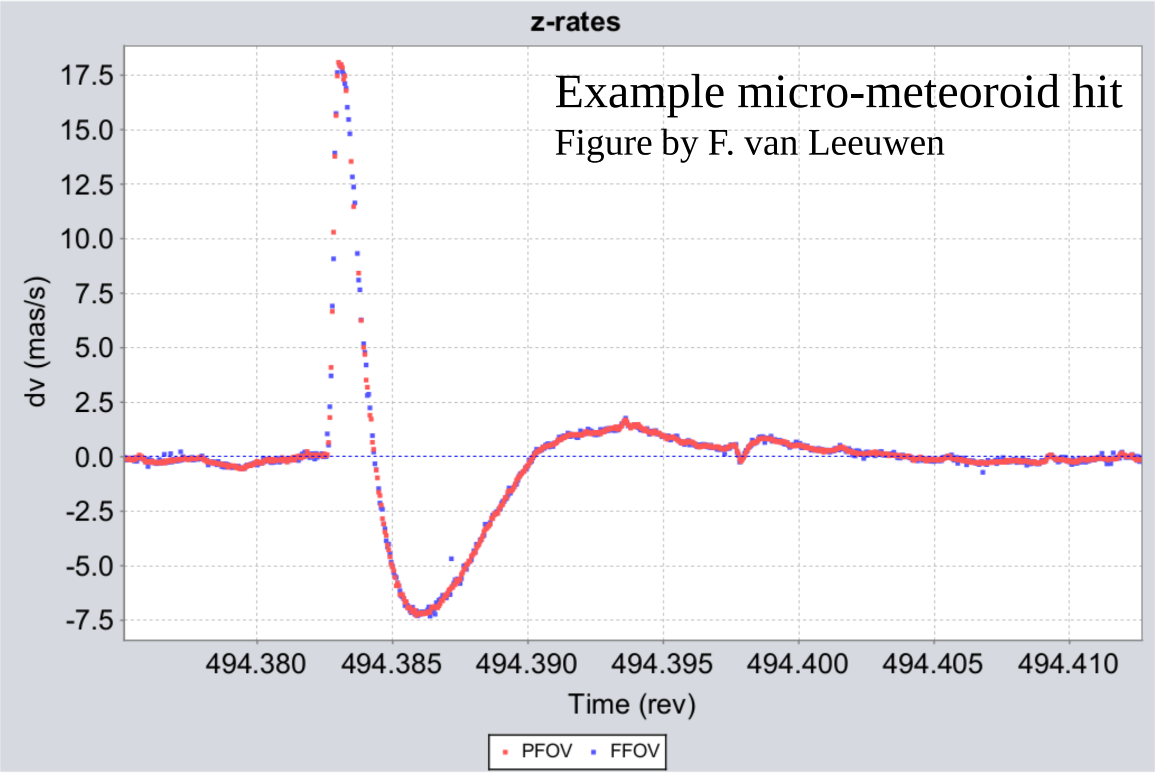
Raw data:
50 GB every day during 5 years → 100 TB

Ingestion
Pre-processing
Data reduction
Classification
Variability analysis
etc.

} **300 million hours of CPU time**

34,000 years !!!

L2 environment



Micrometeoroid hits

- Frequency large hits as expected
- For smallest sizes hits occur orders of magnitude more frequently than 'expected'
- Complicates attitude modelling and translates to more noise in astrometry at bright end
- Attitude control system copes very well with hits

Radiation damage

- So far no damage above pre-launch levels seen, despite increasing solar activity

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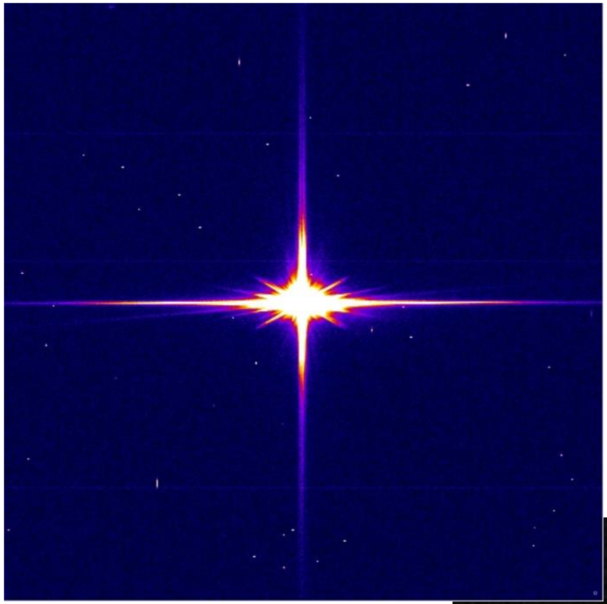
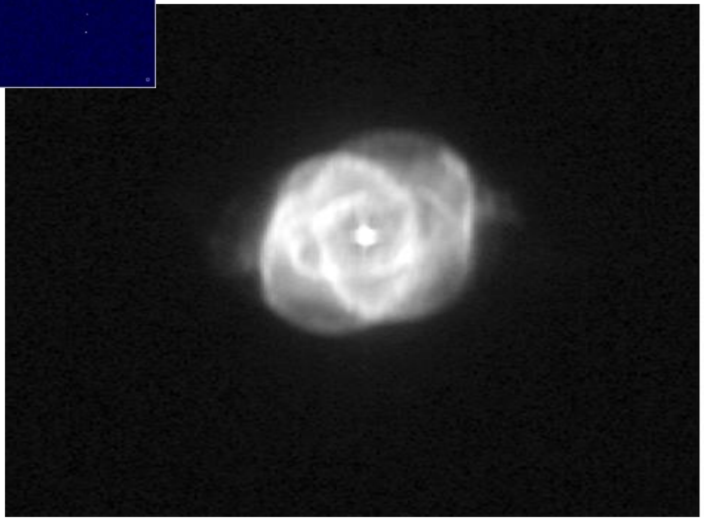
First images

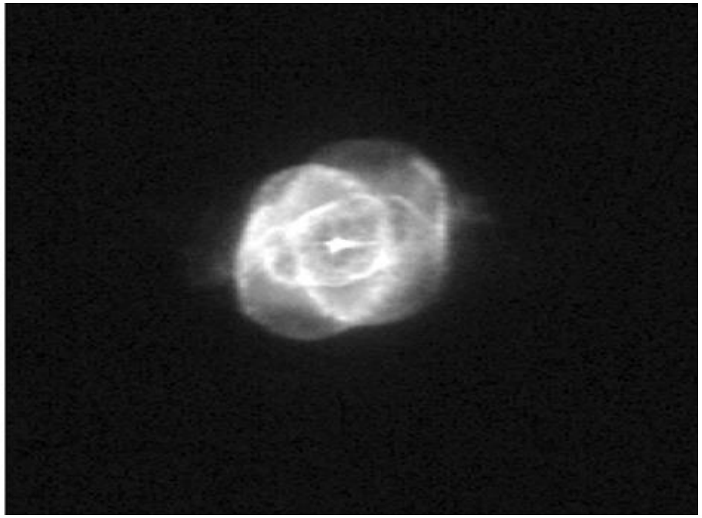


Telescopes not aligned and focused at this stage

Sadalmelik (α Aqr)

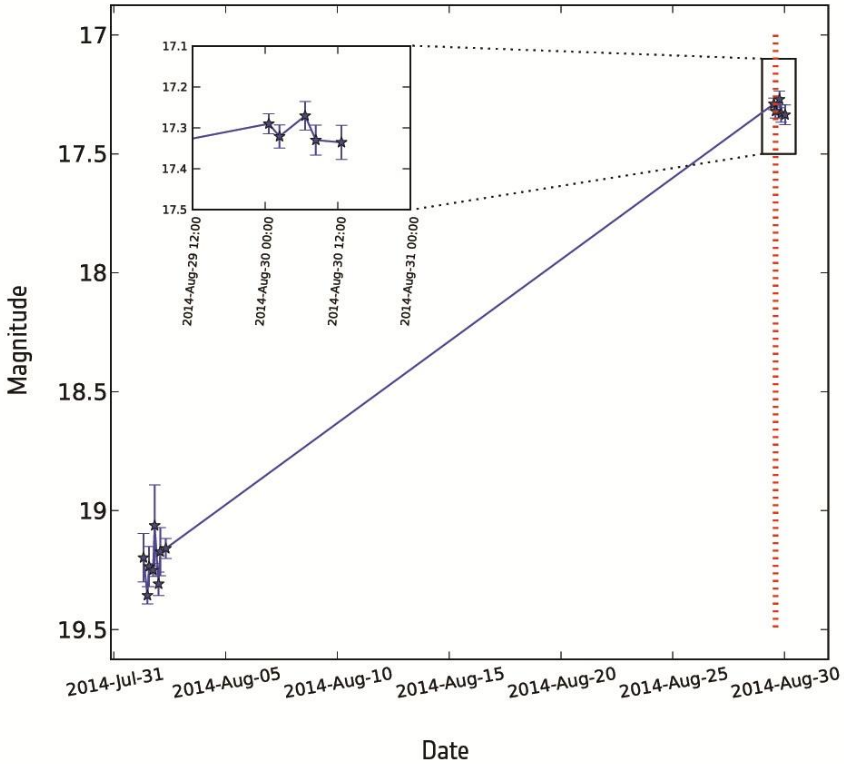
Effect of Gaia spin rate adjustment

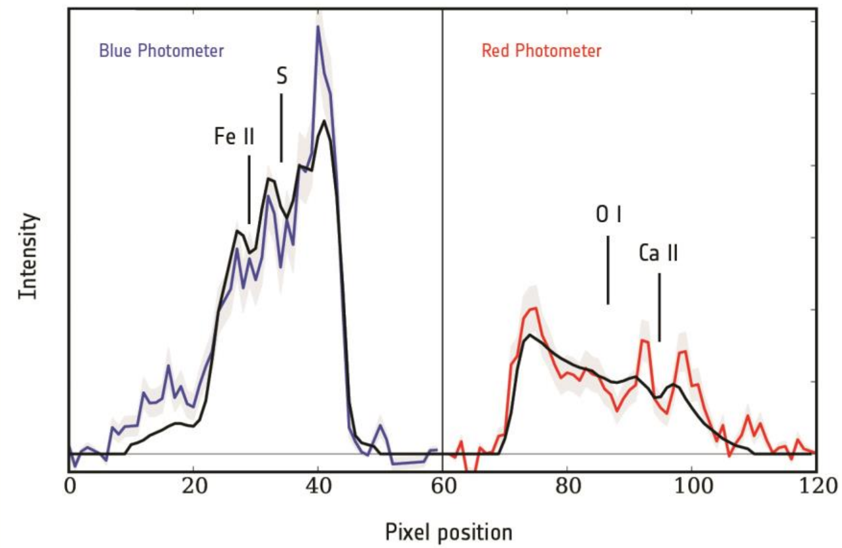




Images courtesy DPAC/SOC

Photometric alerts





http://www.gaia.ac.uk/selected-gaia-science-alert