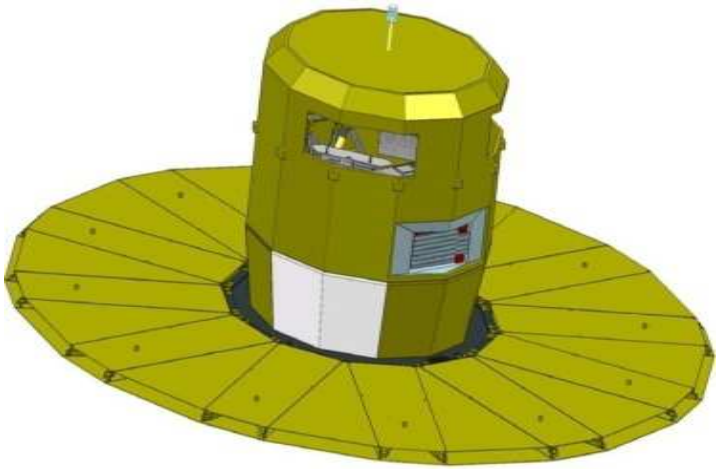
Gaia

Carla Cacciari
INAF – Osservatorio Astronomico
Bologna

The primary objective of Gaia is the Galaxy: to observe the physical characteristics, kinematics and distribution of stars over a large fraction of its volume, with the goal of achieving a full understanding of the MW dynamics and structure, and consequently its formation and history.
(Concept and Technology Study Report, ESA-SCI(2000)4

Satellite and System



- ESA-only mission (Airbus Defence & Space Contractor)
- Lifetime: 5 yr (+ 1yr possible extension)
- Launcher: Soyuz-Fregat, from Kourou (French Guyana)
- Orbit: L2 (1.5 million km from Earth)
- Ground stations: Cebreros, New Norcia & Malargüe

Launch date:
19 December 2013

Payload and Telescope

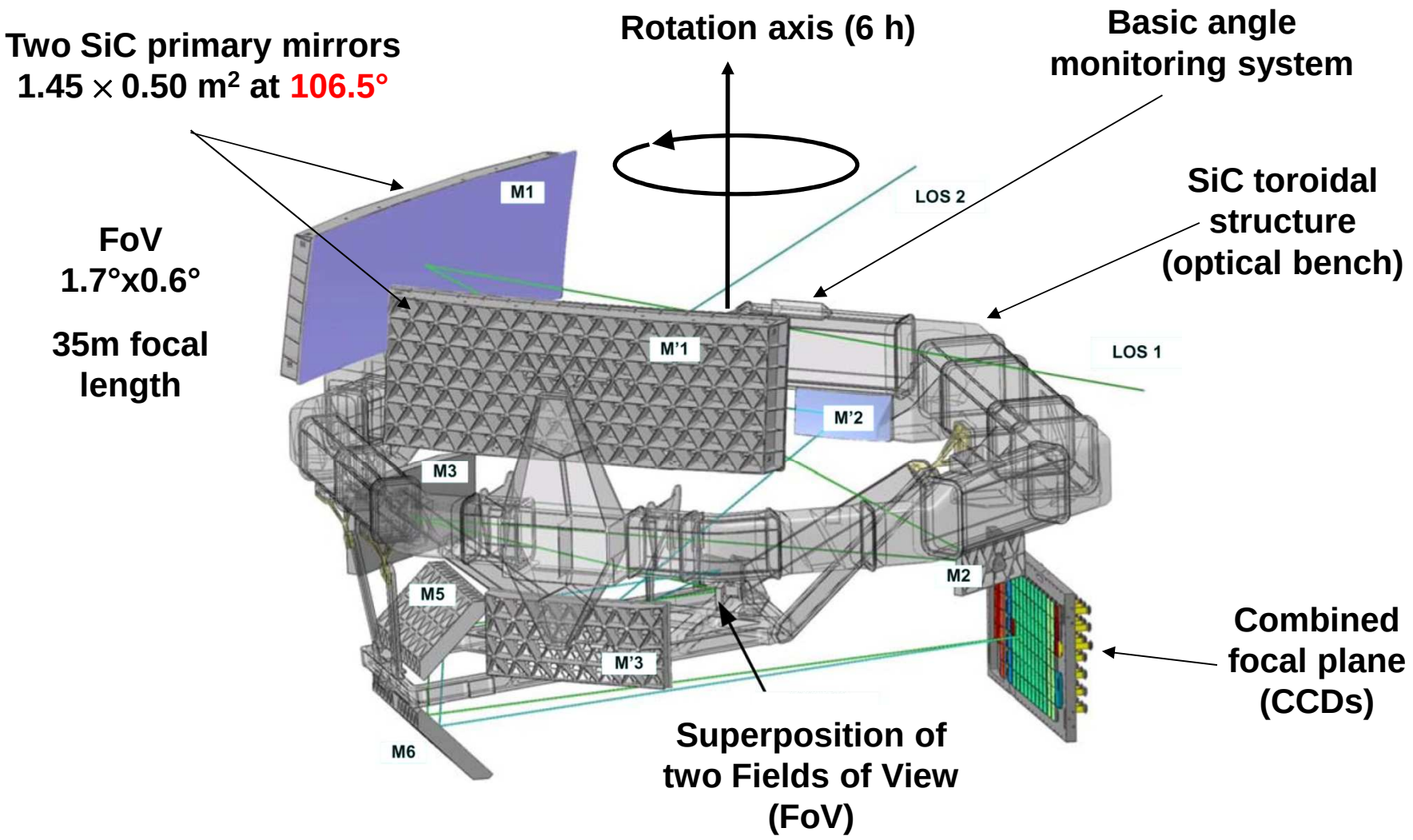
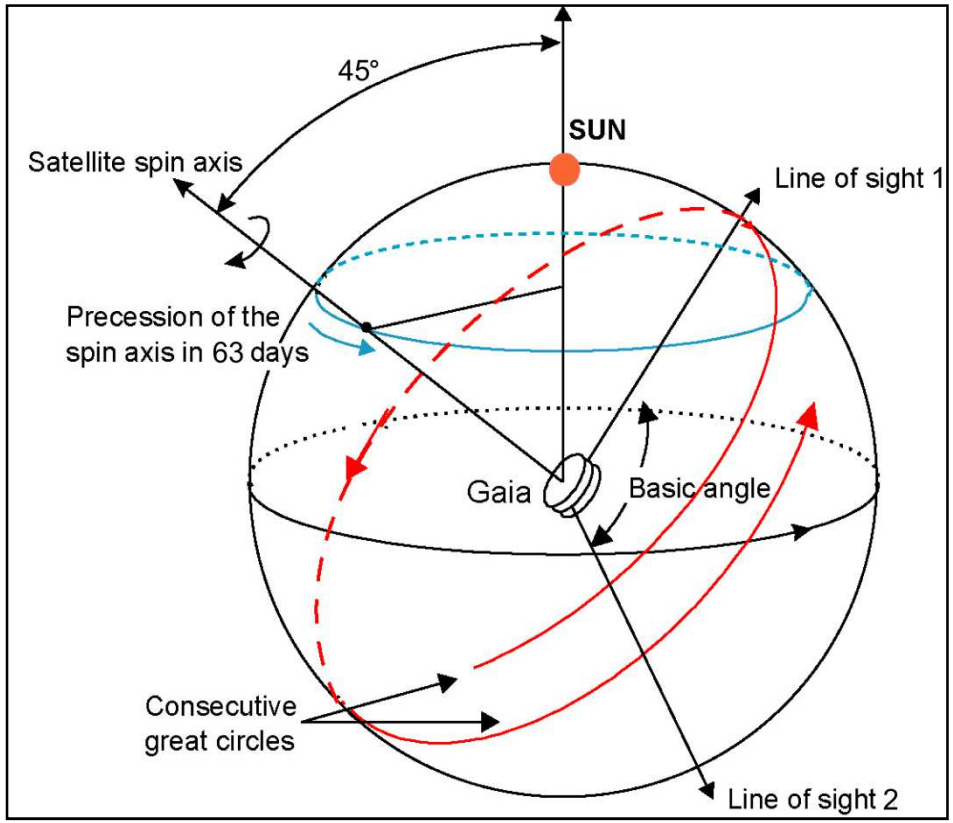


Figure courtesy ADSC

Sky Scanning Principle



Spin axis: 45° to Sun
Scan rate: 60 arcsec/s
Spin period: 6 hr

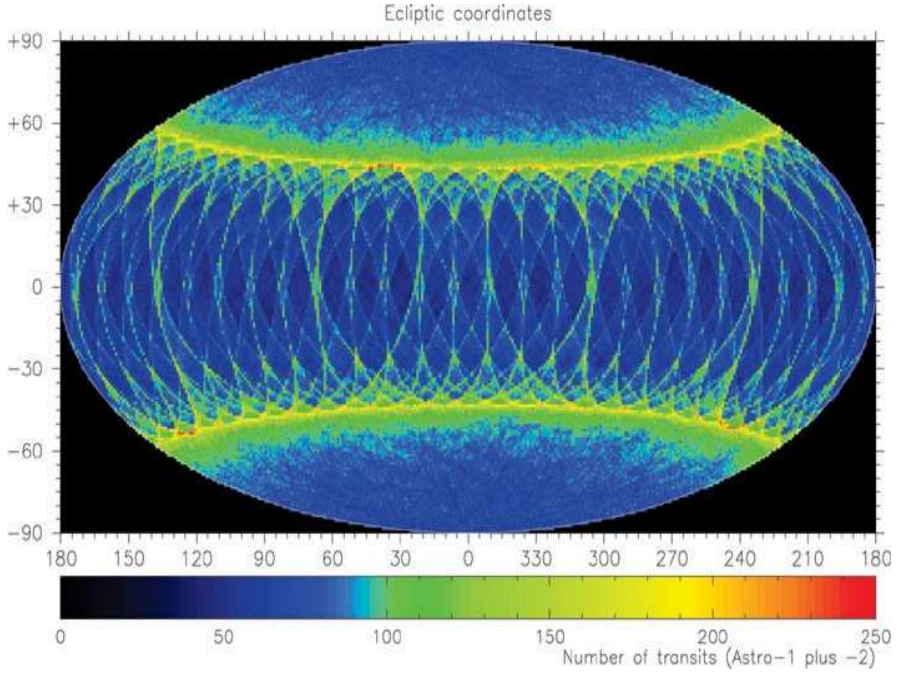
FoV-1: t_0; t_0 + 6hr
FoV-2: (t_0; t_0 + 6hr) + 106.5 m
repeated 10-30 days later
whole set repeated every ~ 6 months

➔ less transits per FoV than Hipparcos (2.13 hr spin period)

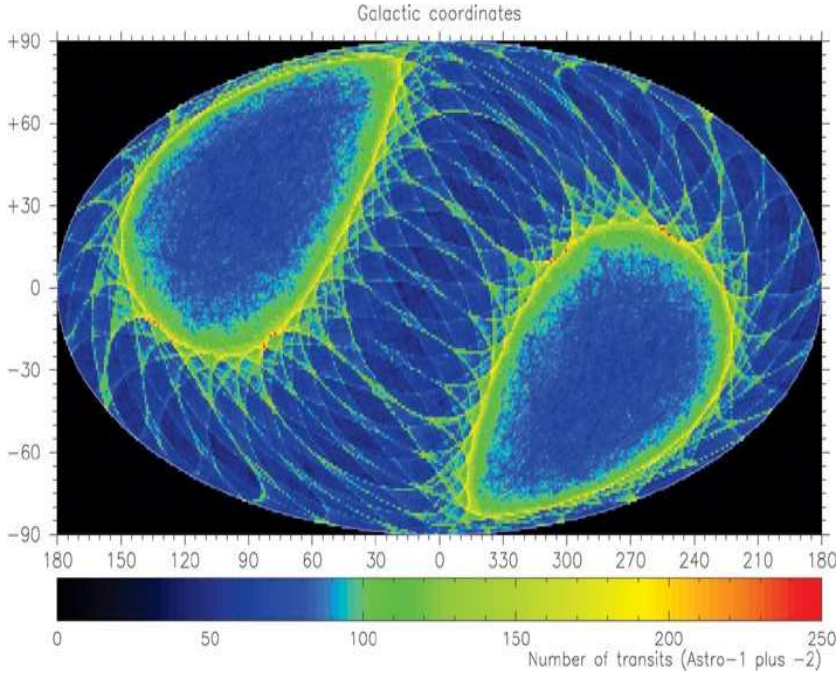
➔ higher spatial resolution on focal plane (~ 0.1 arcsec)

Total of ~ 29 revolutions of spin axis around solar direction in 5 yr

Transit maps



Ecliptic coordinates



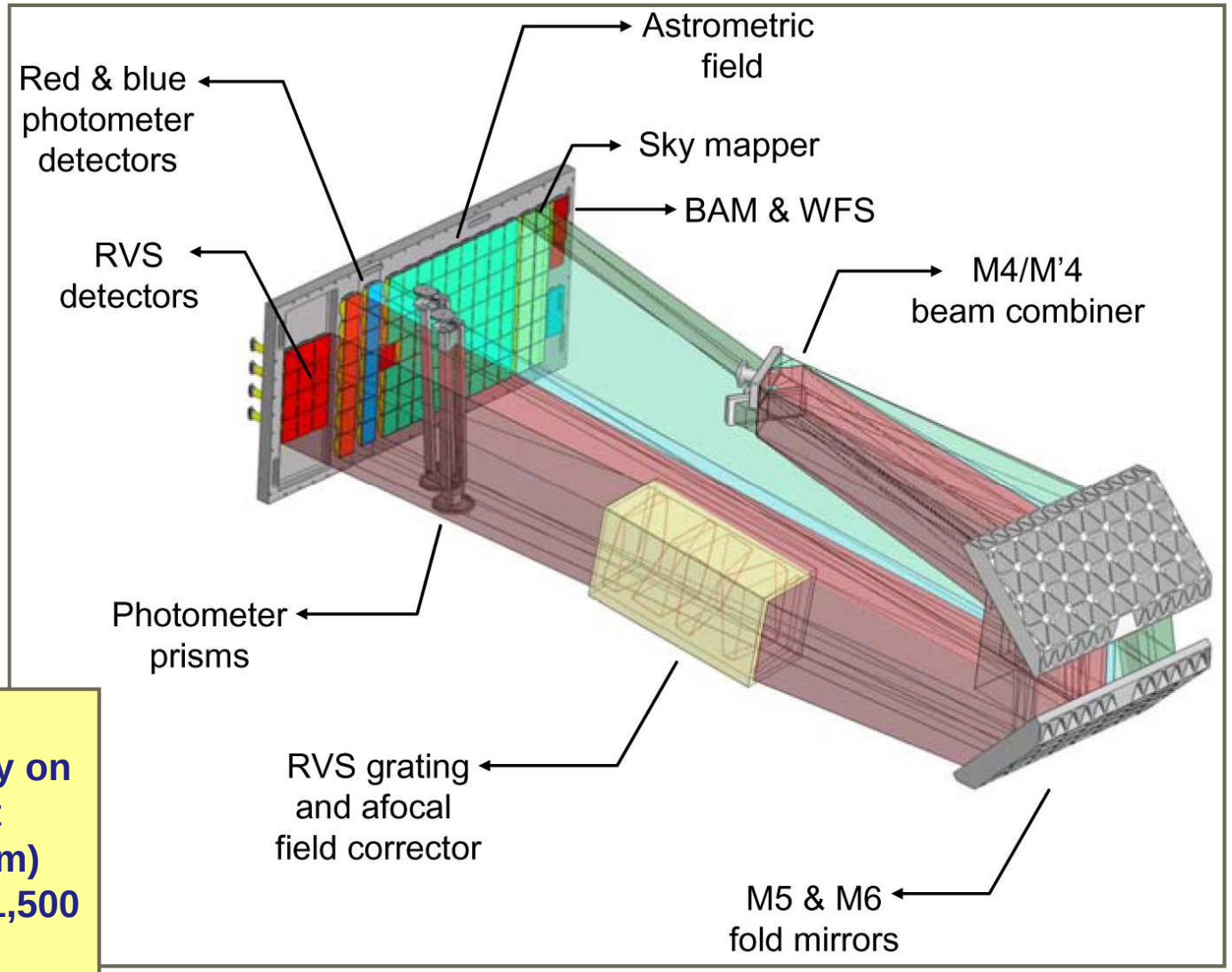
Galactic coordinates

End of mission sky-average number of transits: ~ 70
(max $\geq$ 200 at $|\beta|$ = 45° ± 10°)

The instruments

R ~ 80 – 20

R ~ 90 – 70

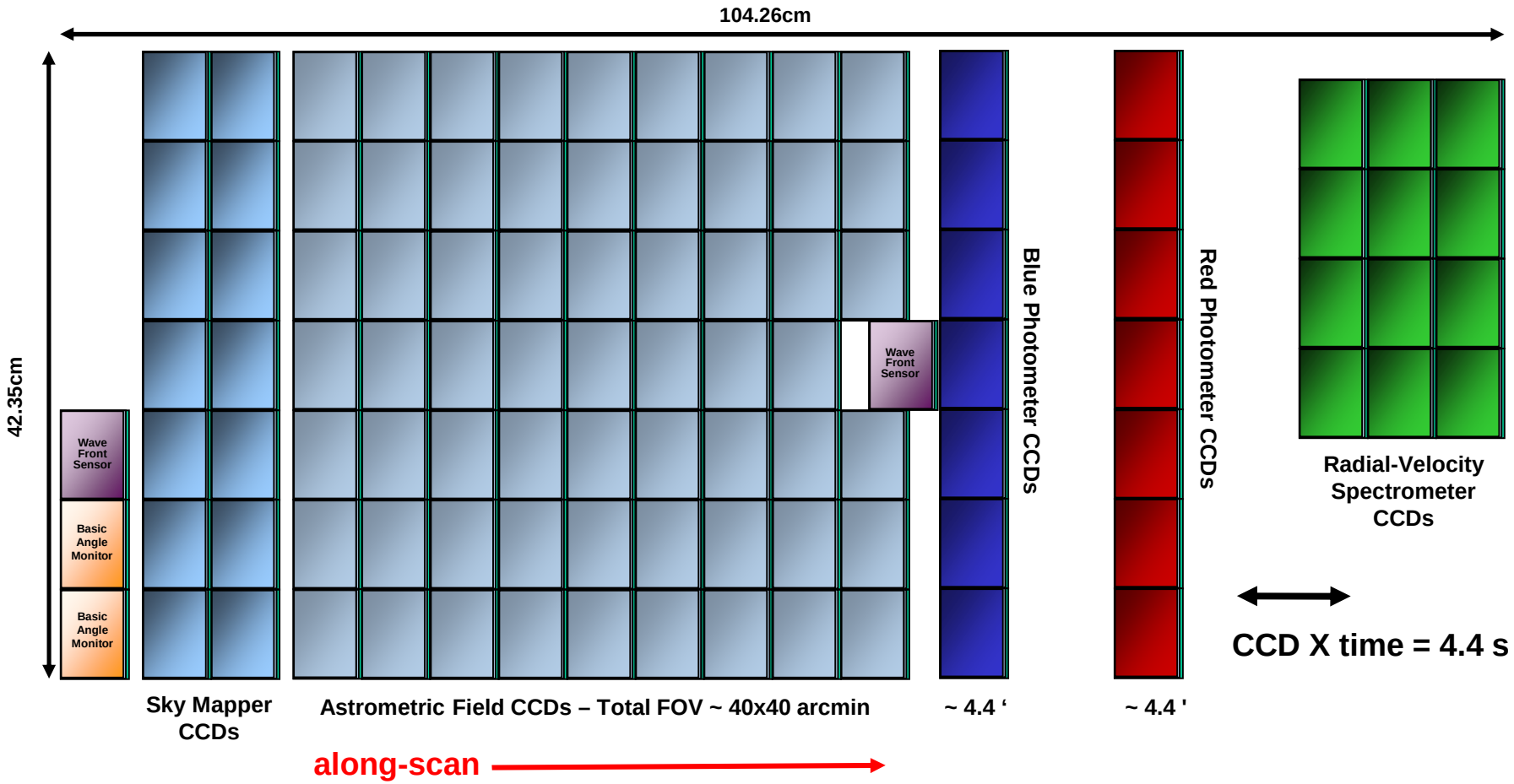


Slitless spectroscopy on Ca triplet (847–870 nm) Resolution 11,500

Figures courtesy ADSC

Focal Plane

Figure courtesy Alex Short



Total field:

- active area: 0.75 deg^2
- CCDs: 14 + 62 + 14 + 12 = 102 (+4)
- each CCD: 4500x1966 px (TDI)
- pixel size = 10 µm x 30 µm
  = 59 mas x 177 mas

Sky mapper:

- detects all objects to 20 mag
- rejects cosmic-ray events
- FoV discrimination

Astrometry:

- total detection noise: 6 e$^-$

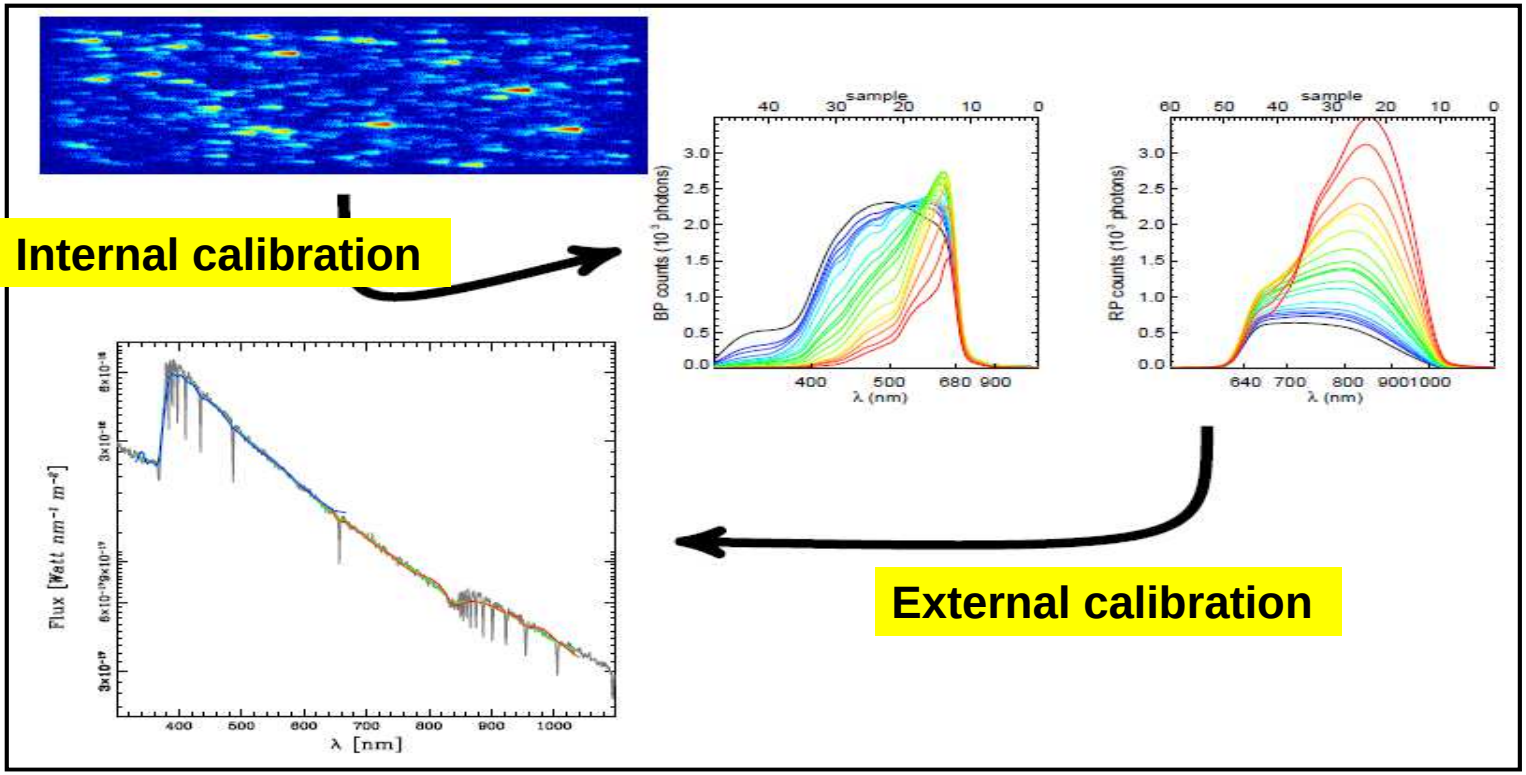
Photometry:

- spectro-photometer
- blue and red CCDs

Spectroscopy:

- high-resolution spectra
- red CCDs

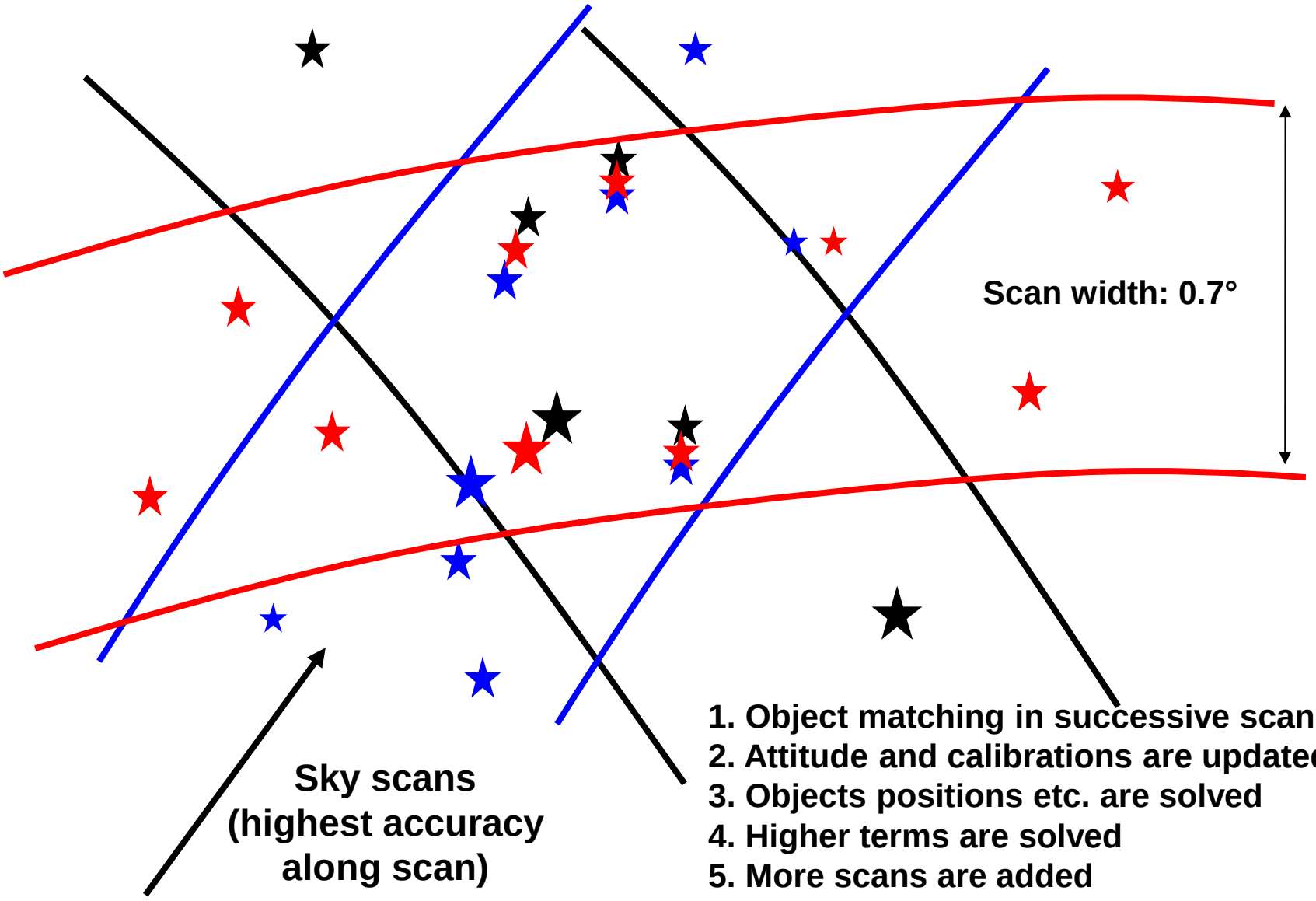
Gaia spectro-photometric system



- same principle as for classical spectrophotometry
- much more complicated instrument model

Courtesy A. Brown

Astrometry: data reduction principles



1. Object matching in successive scans
2. Attitude and calibrations are updated
3. Objects positions etc. are solved
4. Higher terms are solved
5. More scans are added
6. System is iterated (Global Iterative Solution)

Figure courtesy Michael Perryman

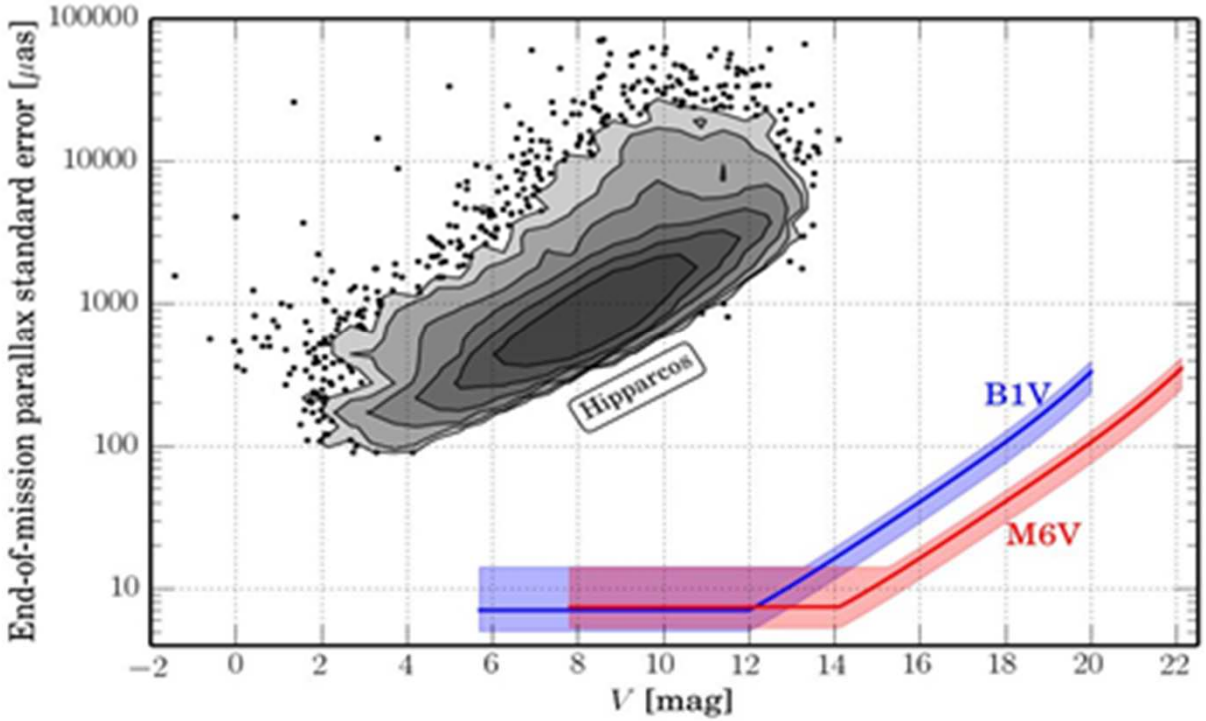
From Hipparcos to Gaia

	Hipparcos (1997)	Gaia (2020-22)
Magnitude limit	12	20 mag
Completeness	7.3-9.0	~ 20 mag
Bright limit	~0	~5-7 mag
Number of objects	1.2 10^5	2.6 10^7 to V=15 2.5 10^8 to V=18 1.0 10^9 to V=20
Quasars	None	~5 10^5
Galaxies	None	~ 10^6 - 10^7
Astrometric Accuracy	**1 ~ mas**	**~7-10 μas at V ≤ 12** **10-25 μas at V=15** **100-300 μas at V=20**
Broad band photometry	2 (B and V)	3 (to V=20) + 1 (to V=17)
Spectrophotometry	None	2 bands (B/R) to V=20
Spectroscopy (CaT)	None	1-15 km/s to V=16-17
Observing programme	Pre-selected targets	All-sky complete and unbiased

Sky-averaged end-of-mission standard errors

(specifications)

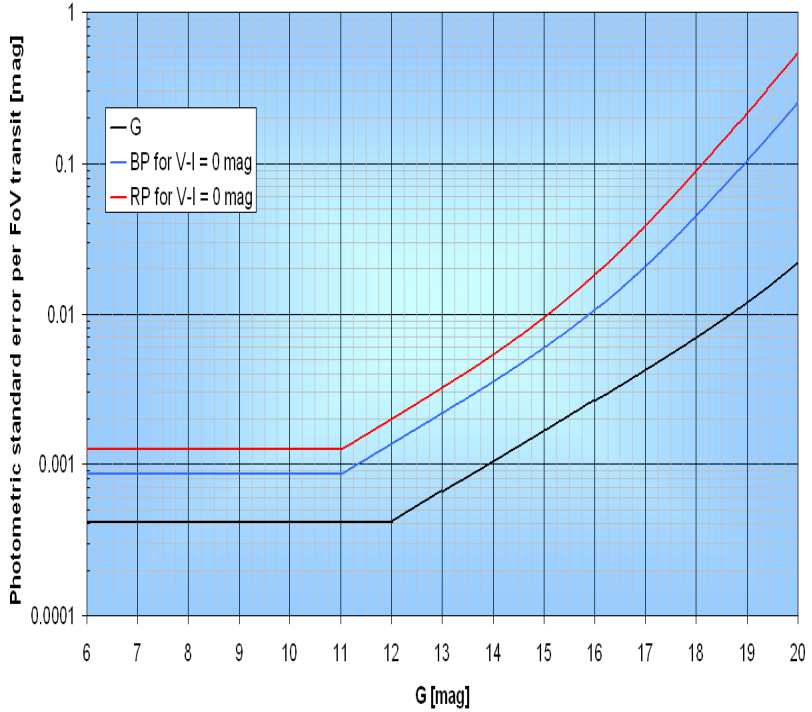
Astrometry



$\sigma_\omega \leq 300$ μas $\sigma_{pos} = 0.74\,\sigma_\omega$ $\sigma_\mu = 0.53\,\sigma_\omega$

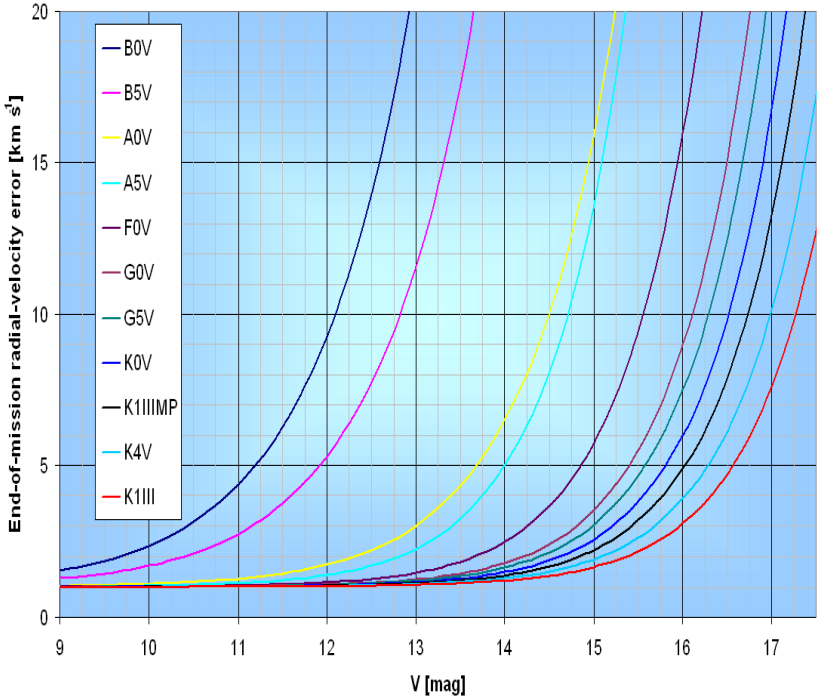
Sky-averaged standard errors
(specifications)

Photometry



Per FoV transit.
End-of-mission expected accuracy : ~ 1 to a few %

Spectroscopy



End-of-mission

GAIA science products: census of …

Stellar pops in the Galaxy

(based on the Besançon Galaxy model - *Robin et al. 2003, 2004*)

- Disk: 9.0 x 10^8
- Thick disk: 4.3 x 10^8
- Spheroid: 2.1 x 10^7
- Bulge: 1.7 x 10^8

Special objects in the Galaxy

- Solar System bodies (~ 10^5)
- extra-solar planets (~ 10^4)
- binaries & rare stellar types (fast evolutionary phases)
- WDs (~ 2 x 10^5), BDs (~ 5 x 10^4)

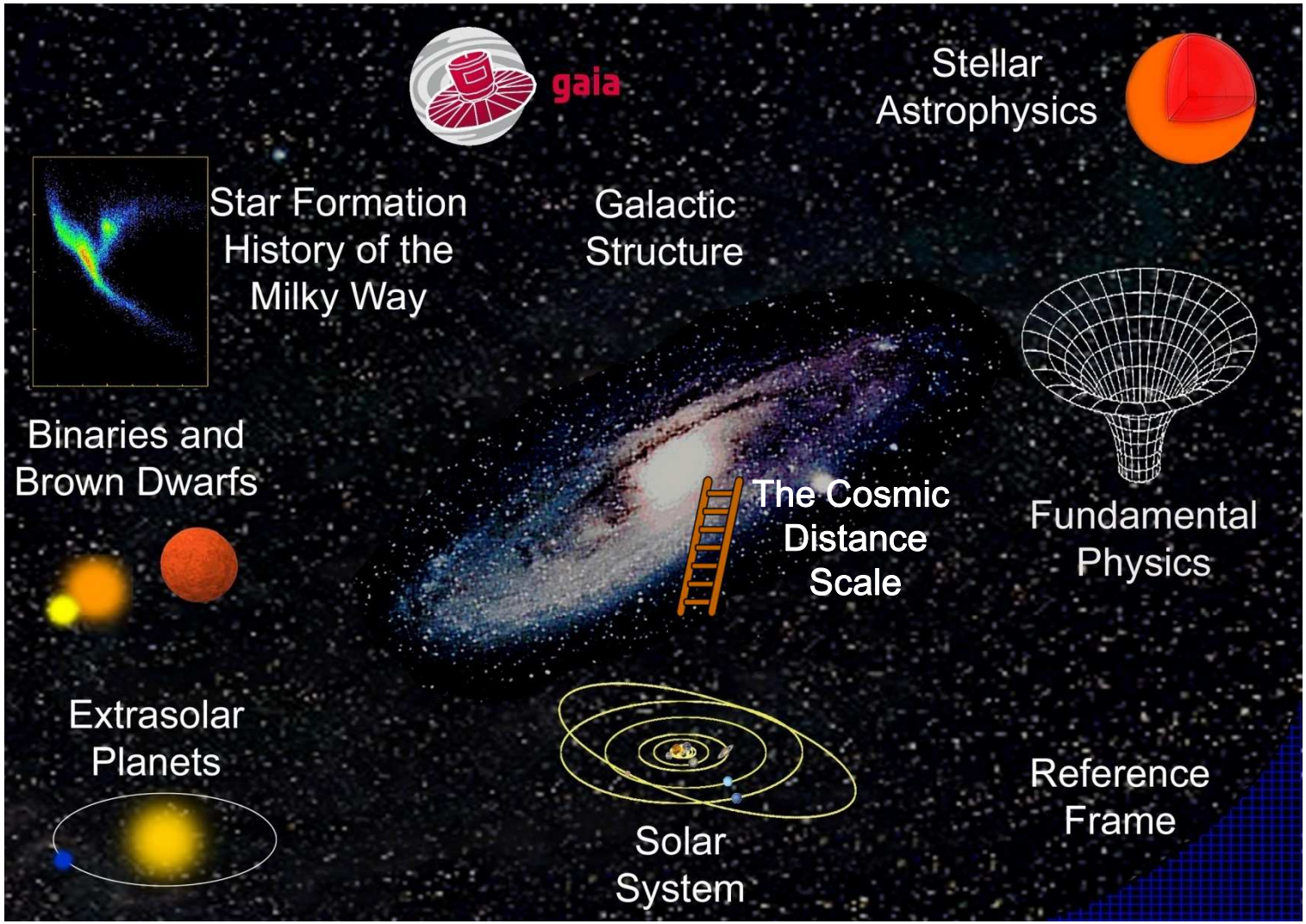
Outside the Galaxy

- brightest stars in nearby (LG) galaxies
- supernovae and burst sources (~2x10^4)
- galaxies (~ 10^7)
- QSOs (~ 10^6)
- gravitational lensing events: < 10^2 photometric; a few 10^2 astrometric

Fundamental Physics

- γ to ~ 5x10^{-7} (10^{-4} - 10^{-5} present)

Many areas of science addressed by the Gaia mission



One billion stars in 5D (6D … 9D) will provide:

in the Galaxy …

- detailed study of the structure, dynamics, formation and chemical history of the Milky Way, e.g. accretion/interaction events, star formation history etc.
- a rigorous framework for stellar structure and evolution modelling

  ➔ dating of all spectral types and Galactic populations
- microlensing distribution and rate ➔ map dark matter distribution

… and beyond

- definitive and robust definition (zero-point) of the cosmic distance scale (local calibrators, SNe)
- QSO detection and definition of rest frame
- structure and stellar population studies in nearby (LG) galaxies

Data processing & distribution

- Data Processing and Analysis Consortium (**DPAC**): ~ 450 people
  (Italy among top contributors with ~ 70 people for ≥ 30 FTE)

- **Final catalogue ~ 2020–22**

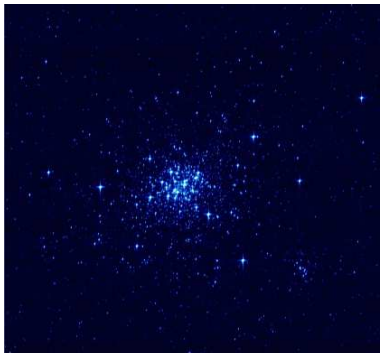
- **Intermediate data releases**
  L+22: single sources only, G mags, positions (if errors acceptable),
  ➔ proper motions for Hipparcos stars
  L+28: 5-par astrometry (single stars), BP/RP mags + verified APs,
  mean RV (if no RV variations)
  L+40: orbital solutions + astrometry for binaries, classification, APs &
  corresponding BP/RP and/or RVS spectra, mean RV
  L+65: variable star classification & epoch photometry, solar system
  preliminary results, non-single star catalogues

- **No proprietary data rights**

- **Science alerts data released immediately**

Update from commissioning

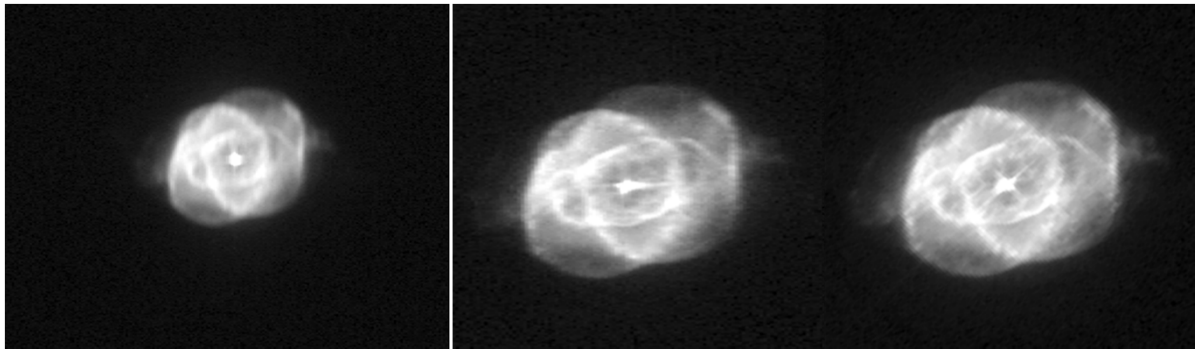
A. Brown (DPACE Chair), T. Prusti (ESA P.I.), http://www.cosmos.esa.int/web/gaia



NGC 1818: 2.85 s integration 212 x 212 arcsec^2

Image ESA/DPAC/Airbus DS (processed and cleaned by J. Sahlmann)

Cat's Eye nebula



Non-optimal spin rate ➔ spin rate adjusted (Feb. & Mar. 2014)

Only the sharpness in the along-scan direction (vertical in these images) is improved by changing the spin rate. The sharpness in the across-scan direction depends on the focussing of the telescopes which was constant between these exposures..

Image: Gaia-SOC

Summary

- **Good launcher and orbit insertion performance**
  - ➔ plenty of propellant left for future manoeuvres

- **Service module commissioning went smoothly**
  - ➔ Chemical propulsion system for large manoeuvres
  - ➔ Micro propulsion system to maintain Gaia's spin rate and compensate for solar radiation pressure torque
  - ➔ Attitude and Orbit Control System, thermal control
  - ➔ Phased array antenna operating very well → high data rates possible
  - ➔ Rubidium atomic clock working to specifications

- **Payload module**
  - ➔ 106 CCDs and 106 backend electronics units all working fine
  - ➔ 7 on board computers managing the CCDs and electronics
  - ➔ Payload and data handling unit for storing and downlinking data
  - ➔ Telescope alignment and focusing working as expected

- **Gaia → ESOC → DPAC/SOC → Airbus DS chain working smoothly and quickly**

all went very well, however …

… a few other aspects went somewhat less smoothly

(Gaia blog, posted on 24 April 2014)

Gaia's position in space needs to be known very accurately at any given moment in order to deliver extremely precise measurements of the positions of stars on the sky: the distance comes from radio signals, but the position on the plane of the sky needs ground-based telescope observations of the satellite.

Problem: Gaia is much **fainter** in the sky than hoped for, **21 mag rather than 18** ➔ the 1m class telescopes planned by Gaia's GBOT network are not big enough to detect Gaia in a reasonable amount of time.
Solution: by shifting the bulk of the observations to the 2.0-m Liverpool Telescope on La Palma and ESO's 2.6-m VST on Paranal, as well as introducing Very Long Baseline Interferometry radio measurements, the problem is now under control.

SOLVED

Problem: near the beginning of commissioning, a steady **drop in the transmission** of Gaia's telescopes was seen, due to **water-ice deposits** building up on the mirrors as trapped water vapour was liberated from the satellite after launch.
Solution: the transmission was fully recovered following a **decontamination** campaign, during which the payload was heated to remove the ice from the optics.

SOLVED

Unanticipated 'stray light' is seen hitting parts of the Gaia focal plane. Some of the stray light is thought to come from sunlight diffracted around the edges of the sunshield and entering the telescope apertures. There also seems to be a smaller contribution from night sky sources reaching the focal plane via unexpected paths.

Problem: although the diffracted sunlight component was foreseen, we think that it is enhanced by reflections off ice deposits on the ceiling of the 'thermal tent' structure surrounding the payload, allowing it to reach the focal plane. It was hoped that the decontamination campaign would also remove this ice layer, but unfortunately the stray light is still there at the moment.
Solution: careful preparations are being made for one more attempt to remove the water ice and, hopefully, the stray light. But in parallel, we are now continuing with the nominal commissioning and a detailed performance verification phase.

Even if the stray light remains, the current best assessment is that degradation in science performance will be relatively modest and mostly restricted to the faintest of Gaia's one billion stars.

Work in progress

For reactions and comments on this last sentence see

blogs.esa.int/gaia/2014/04/24/commissioning-update/

Conclusions @ 120 days into commissioning

- Gaia doing well in general: ESOC happy about how the S/C 'handles'
- DPAC people and sw working well in processing and interpreting data
- **nominal observations to start ~ end June**

Unexpected things seen:

- not unusual for space science mission at this stage
- solutions found and mitigation actions in place
- still one month of commissioning to come

No show stopper has been identified
→ Gaia will deliver amazing science!