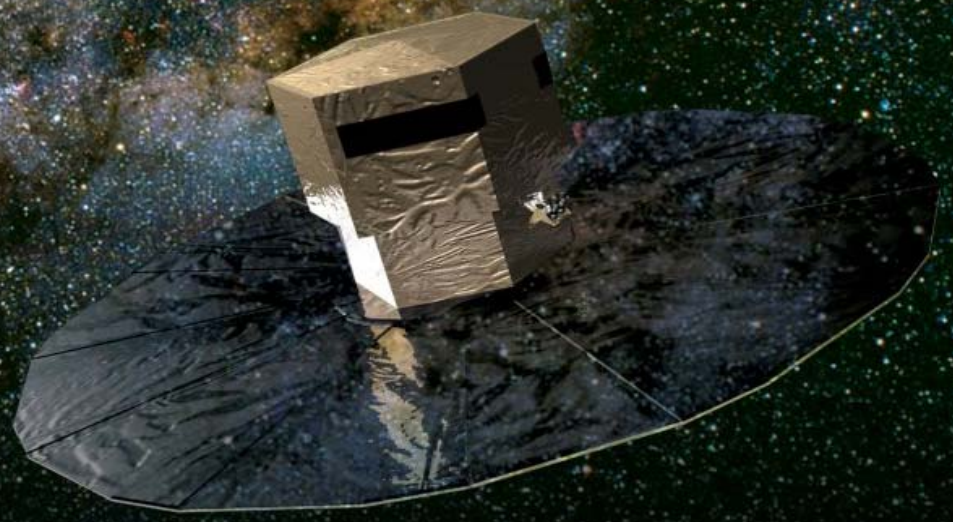
Overview of the Gaia Project

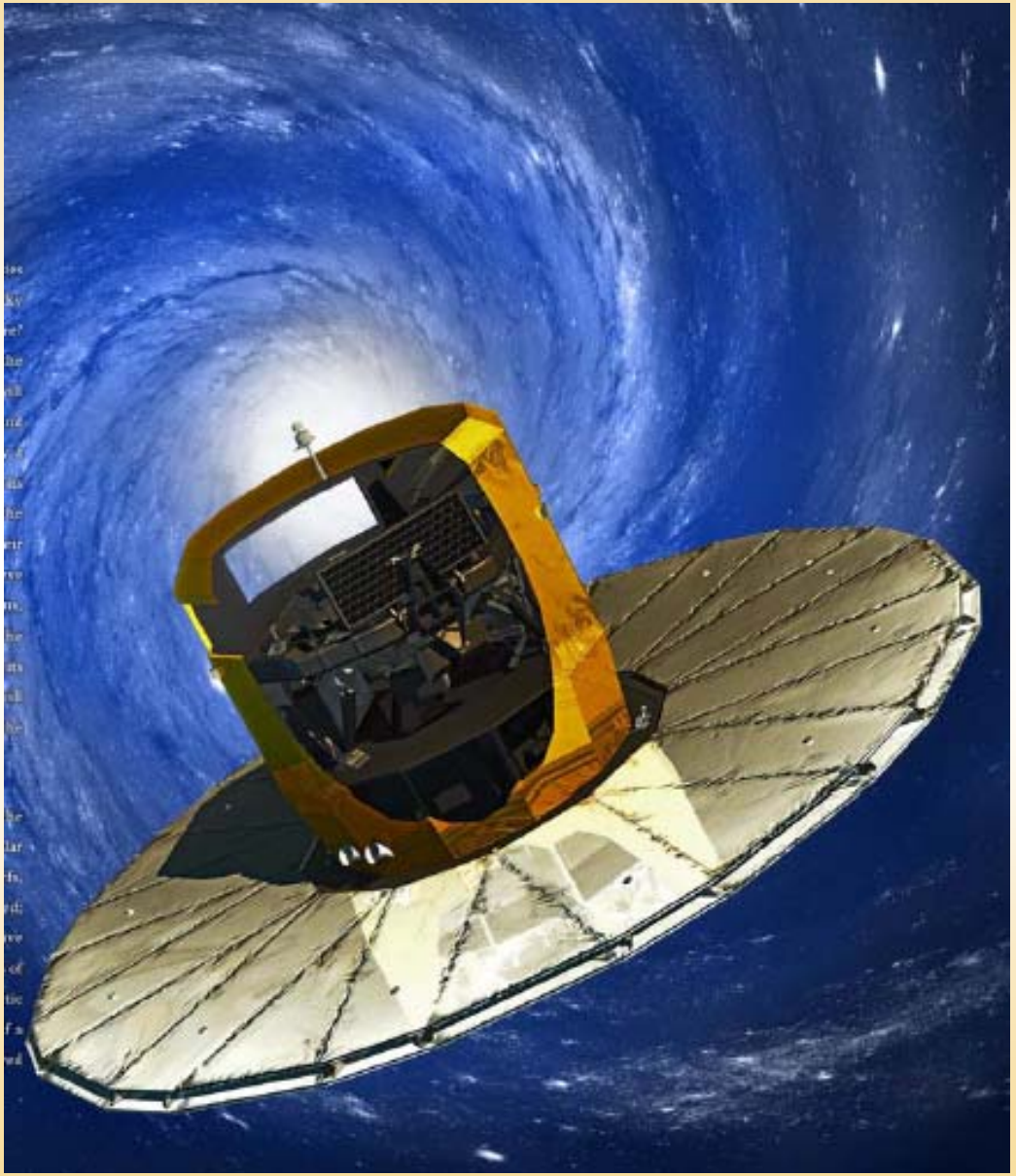
F. Mignard

Observatory of the Côte d'Azur, Nice.



Outline

- Mission context
- The instruments
- Gaia Performances
- Data releases



GAIA

- 10^9 stars
- 25 μas @ V = 15 mag

ESA mission
Launch: 2013
Mission : 5 yrs

- Photometry (~ 25 bands)
- Radial velocity
- Low resolution spectroscopy

Goals of Space Astrometry

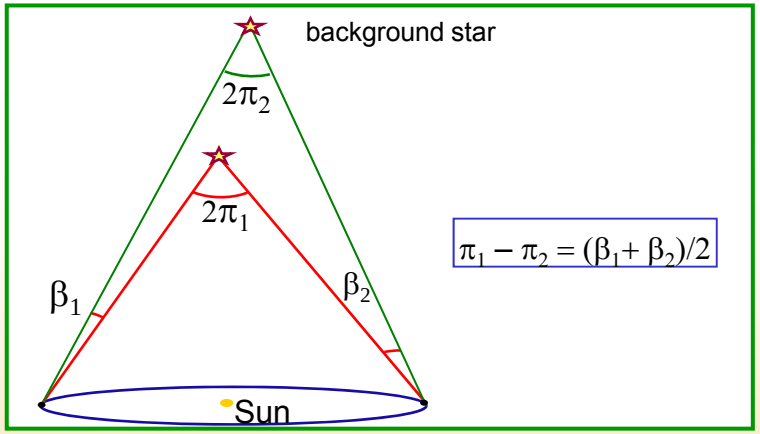
- Primary Objectives not achievable from Earth
  - Ascertain the distances of the stars
    - **absolute** stellar parallaxes for astronomers
  - Define and materialise the inertial frame
    - now based on extragalactic sources

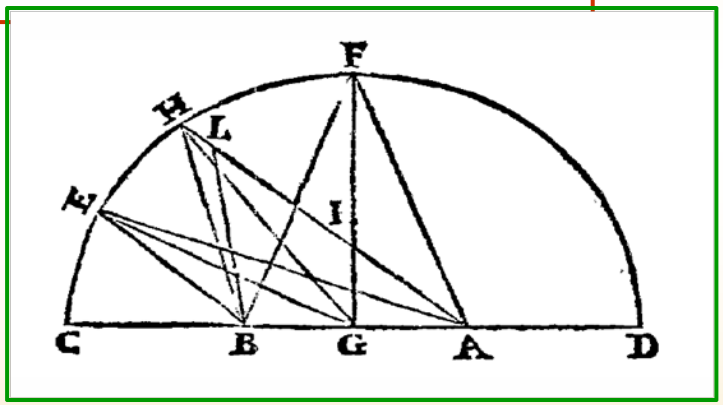
- Secondary objectives
  - Astrophysics with astrometry, photometry, spectroscopy
    - stellar and galactic physics
    - detection of extrasolar planets
    - solar system dynamics
  - Tests of fundamental physics in space
    - based on light path geometry

Galileo and the stellar parallax

Galileo, Dialogo 3rd day

perch'io non credo, che le
ſtelle ſiano ſparſe in vna ſferica ſuperficie egualmente diſtanti da vn centro, ma ſtimo, che le loro lontananze da noi ſiano talmente varie, che alcune ve ne poſſano eſſer 2. e 3. volte più remote di alcune altre; talchè quando ſi trouaſſe co'l Teleſcopio qualche piccoliſſima ſtella, vicinissima ad alcuna delle maggiori, e che però quella fuſſe altiſſima, potrebbe accadere, che qualche ſenſibil mutazione ſuccedeſſe tra di loro, riſpondente a quella de i pianeti ſuperiori.

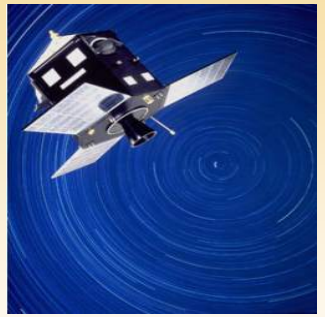




the planets. The text reads: *I do not believe that the stars are spread over a spherical surface at equal distances from the center; I suppose their distances from us to vary so much that some are 2 or 3 times as remote as the others. Thus if some tiny star were found by the telescope quite close to some of the larger ones, and if that one were therefore very remote it might happen that some sensible alteration would take place among them corresponding to those of the outer planets.* Translation of S. Drake, Univ. of California Press.

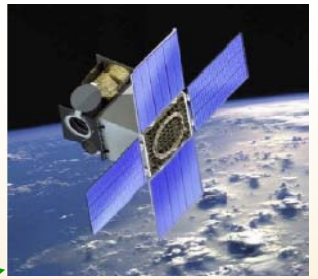
Space Astrometry: Past & Present

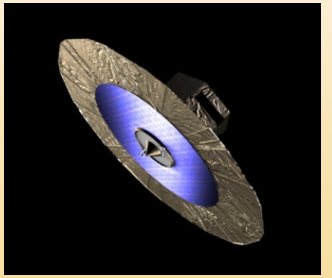
1 mas = 5 nrad 10 μas = 50 prad



- A successful forerunner: HIPPARCOS (ESA)
  - accuracy of 1 mas ~ a coin @ 1000 km
- The unfortunate followers
  - accuracy of 0.1 mas ~ a nail @ 1000 km
  - Roemer, FAME-1, FAME-2, DIVA, Lomonossov, AMEX

    ESA US US DE RU US
- Study phase
  - JASMINE (Japan) in the IR
- Cancelled (Dec 2010)
  - SIM (US) with 1 μas accuracy
- Funded – launch 2011 - 2013
  - NanoJasmine [4 mas], J-MAPS (US) [1mas]
  - Gaia (ESA) : 25 μas (a hairwidth @ 1000 km)



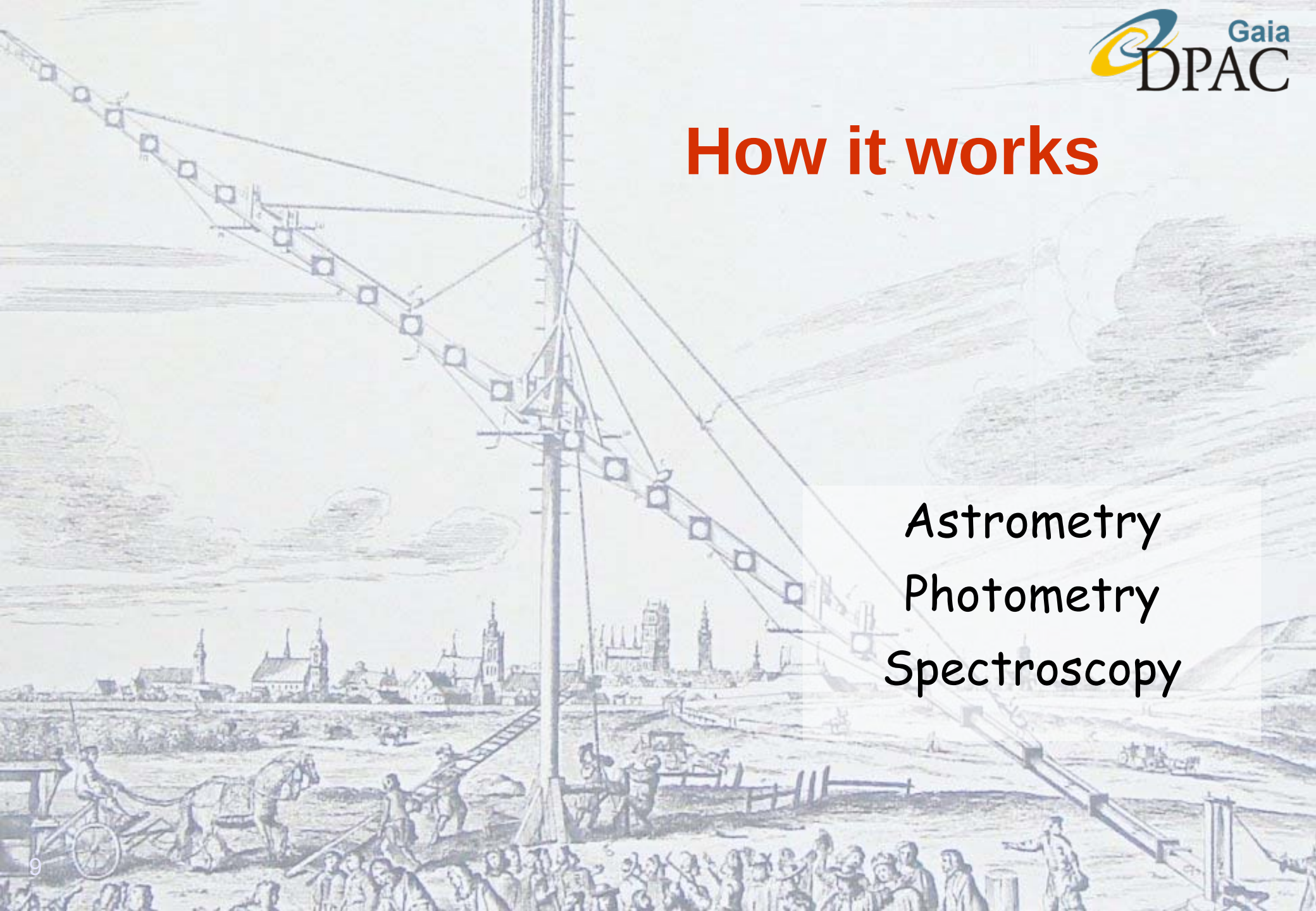


Mission requirements summary

- *A Stereoscopic Census of Our Galaxy*
- Astrometry (V < 20):
  - completeness to 20 mag (on-board detection) 10^9 stars
  - parallax accuracy: 7 μas at <10 mag; 12–25 μas at 15 mag 100–300 μas at 20 mag
- Photometry (V < 20):
  - astrophysical diagnostics (low-dispersion photometry) + chromaticity
  - 8–20 mmag at 15 mag: Teff ~ 200 K, log g, [Fe/H] to 0.2 dex, extinction
- Radial velocity (V < 16.5–17):
  - Third component of space motion, perspective acceleration
  - <1 km/s at 13-13.5 mag and <15 km/s at 16.5-17 mag

Assets of Gaia

- A single mission with three nearly synchronous data taking
  - Astrometric, photometric and spectroscopic data
- GAIA is a scanning mission
  - no pointing, no change in the schedule Uniform coverage of the sky
- Quasi regular time sampling over 5 years
  - ~ 80 observations ➔ photometry, orbits of binaries, asteroids
- Survey mission sensitivity limited
- Internal and autonomous detection system to G = 20
- Global astrometry of staggering precision
  - Internal metrology, thermal and mechanical stability
- Experienced and motivated community in Europe after Hipparcos
  - scientific and in industry



How it works

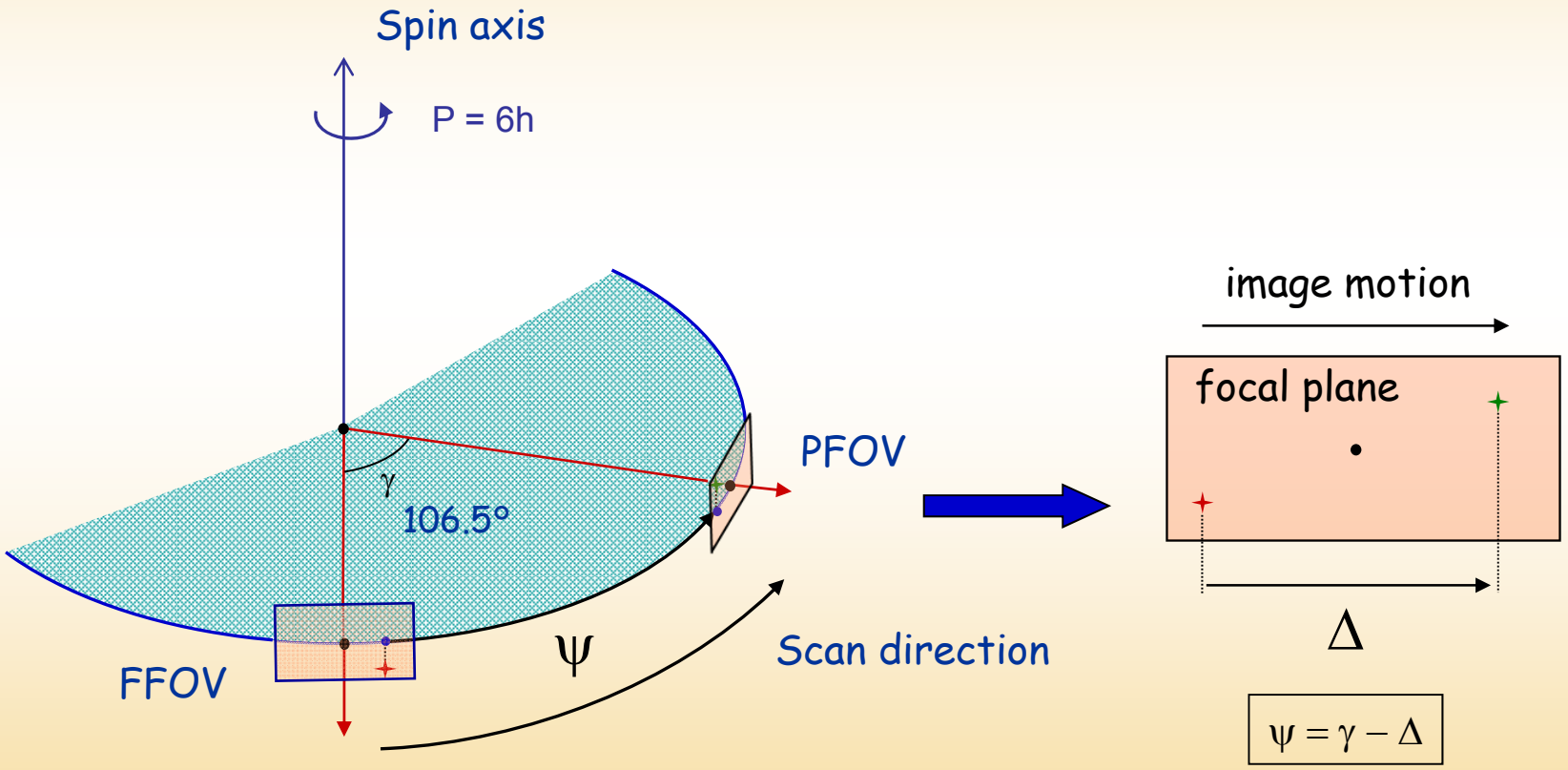
Astrometry

Photometry

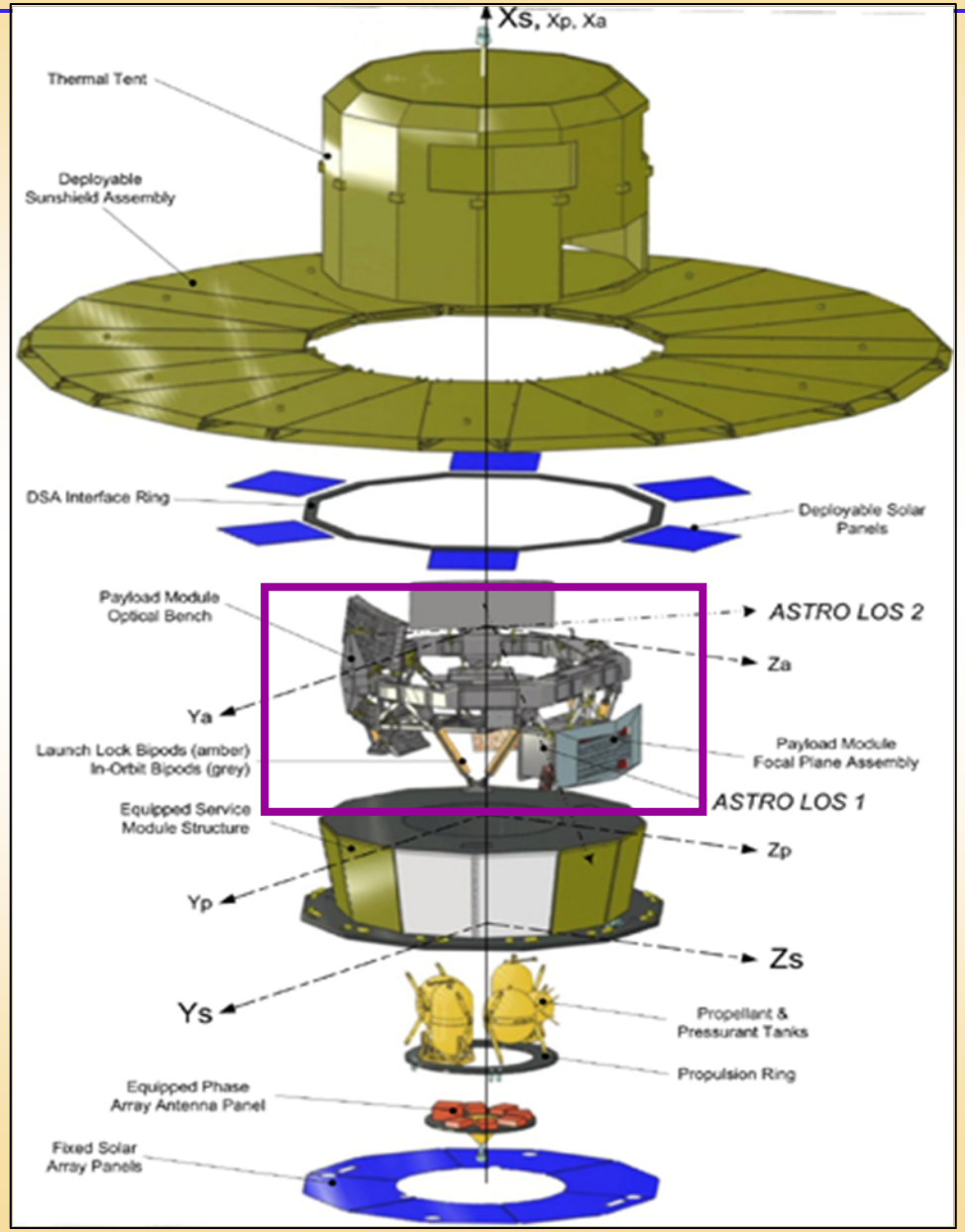
Spectroscopy

Global astrometry in space

- Wide angle measurements with overalapping fields



Gaia: The Spacecraft



Thermal shielding

Ø ~ 10 m

Solar panels

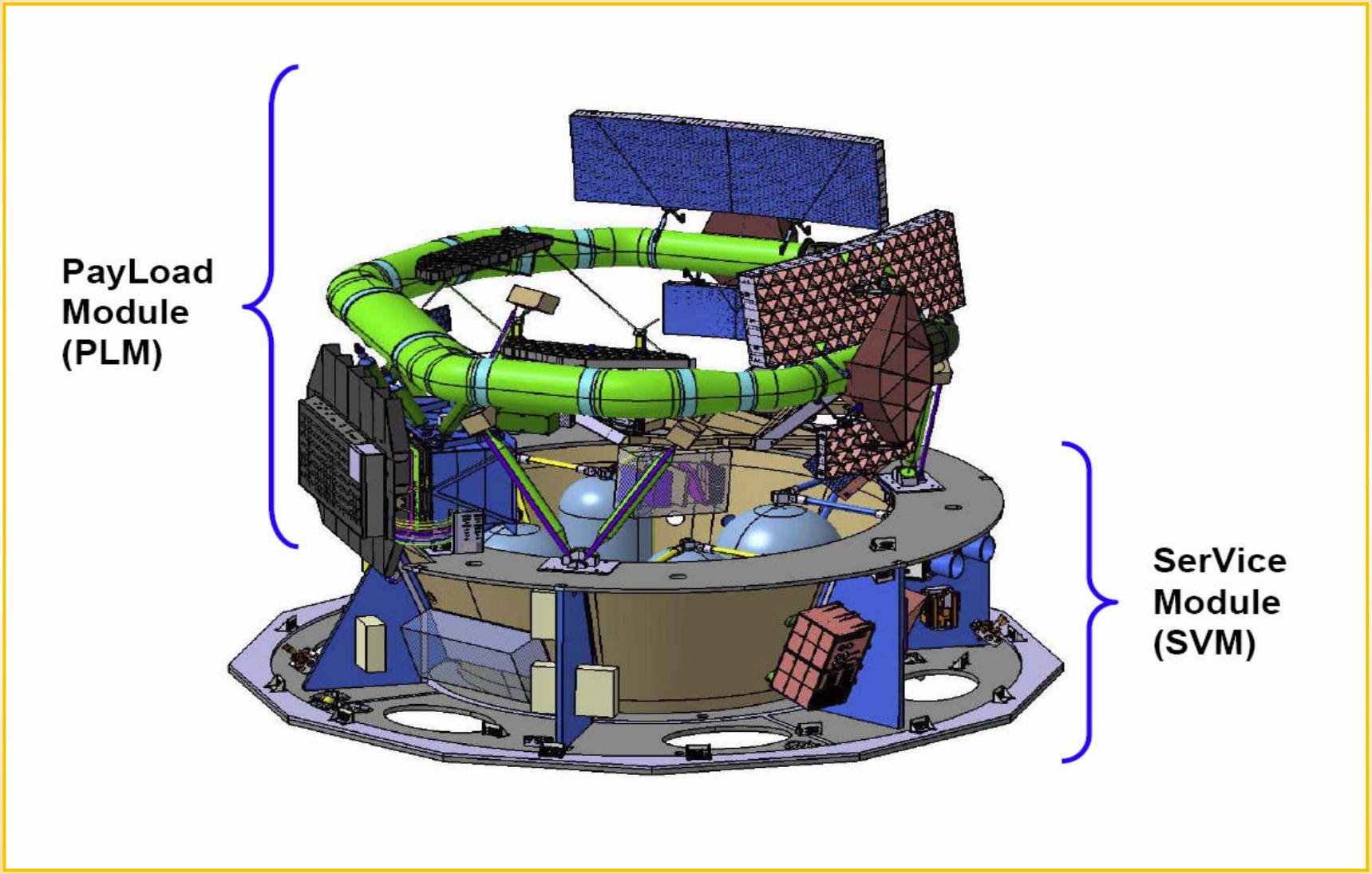
Telescopes

focal plane

Propulsion module

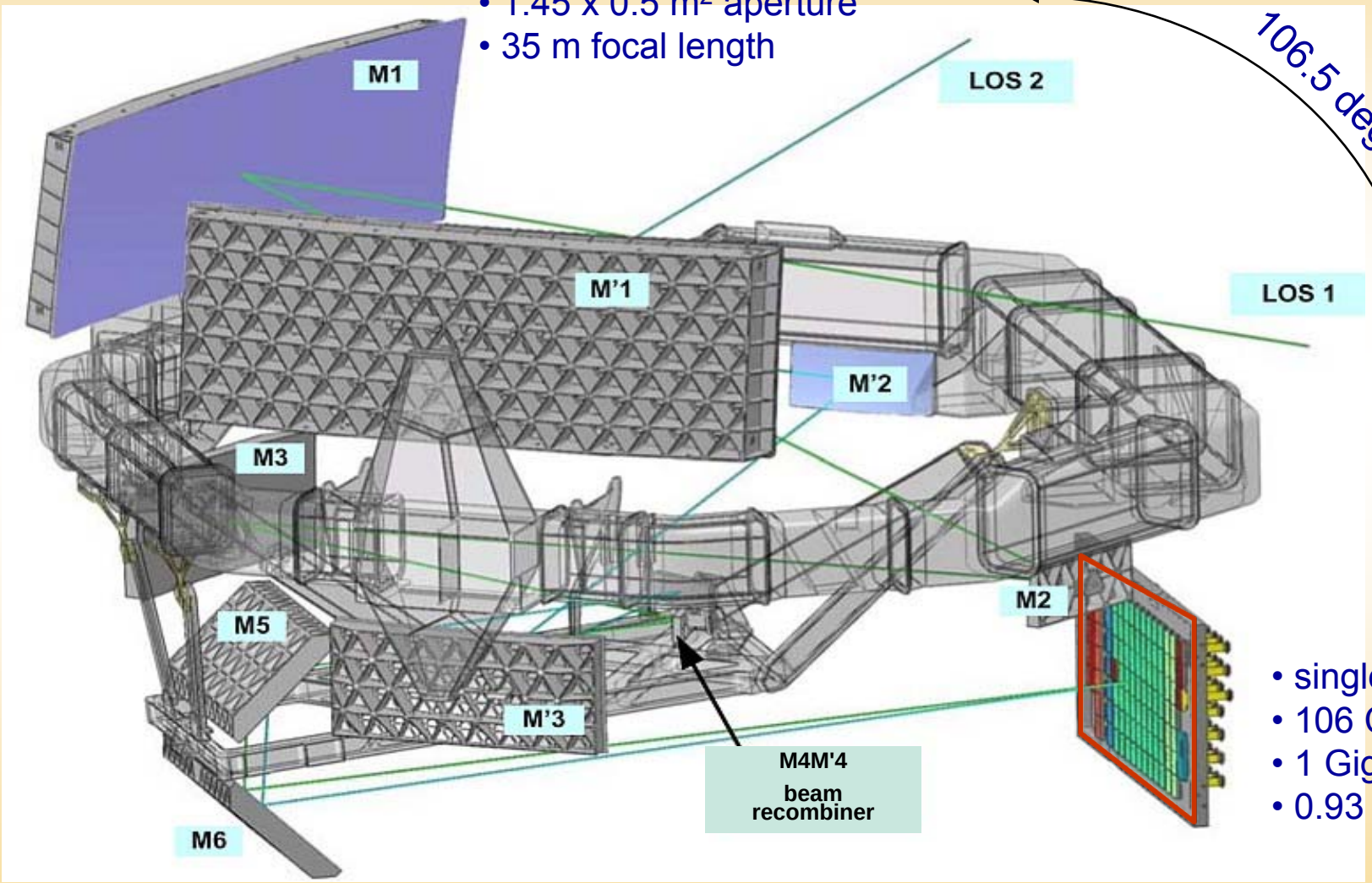
Antenna (1- 4 Mbit/s)

The Gaia Spacecraft with PLM & SVM



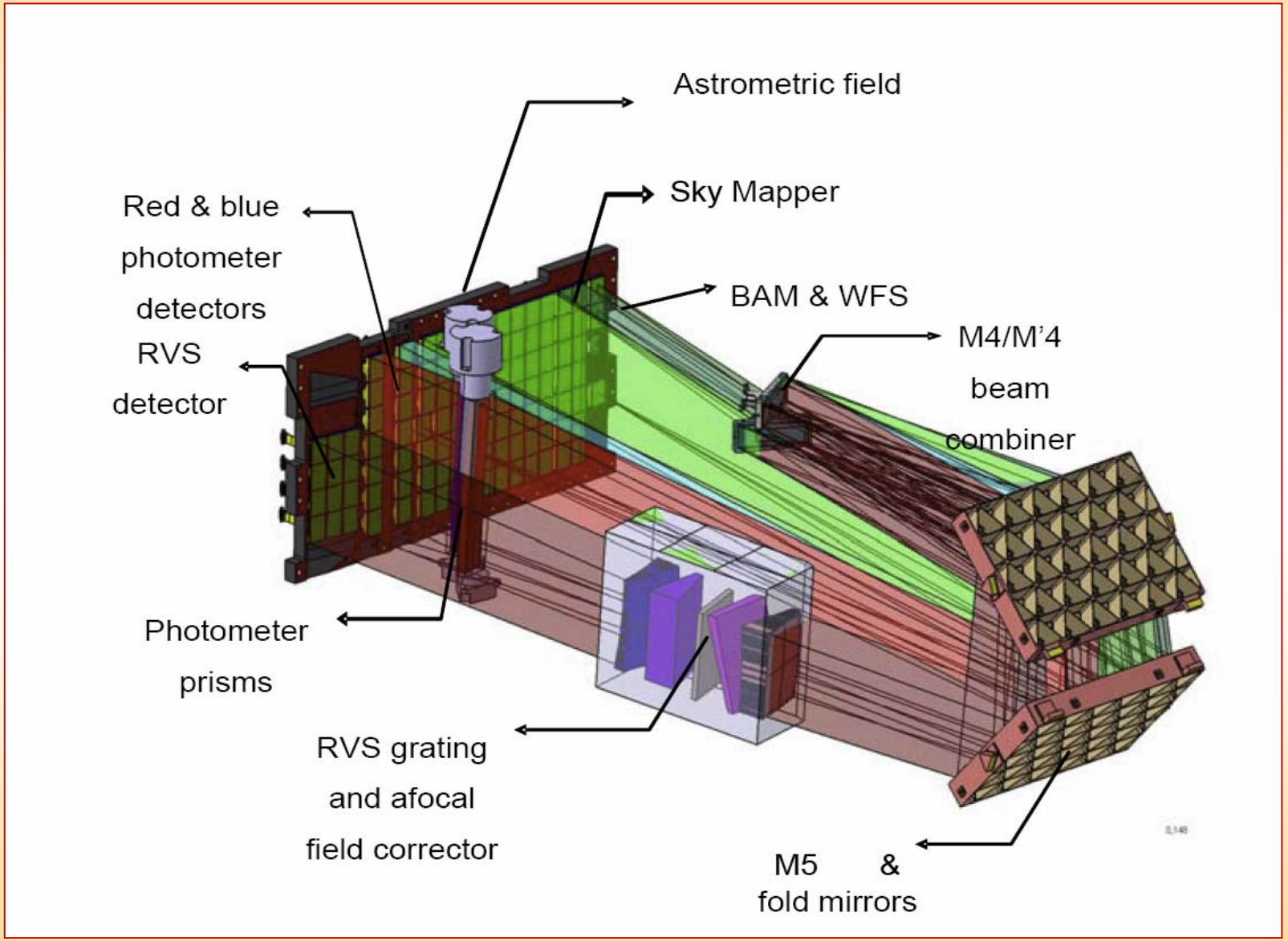
Gaia : telescopes and detector

- 2 off-axis telescope
- 1.45 x 0.5 m^2 aperture
- 35 m focal length



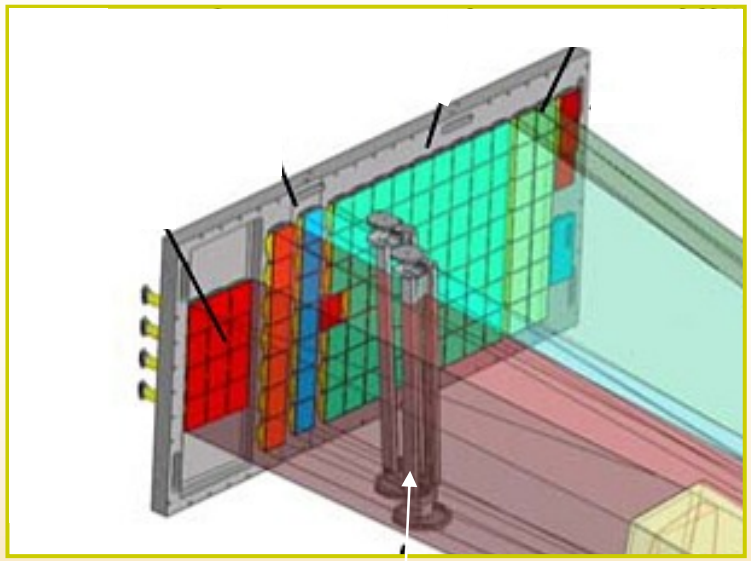
- single focal plane
- 106 CCDs
- 1 Gigapixel
- 0.93 x 0.42 m^2

Detection and measurement systems

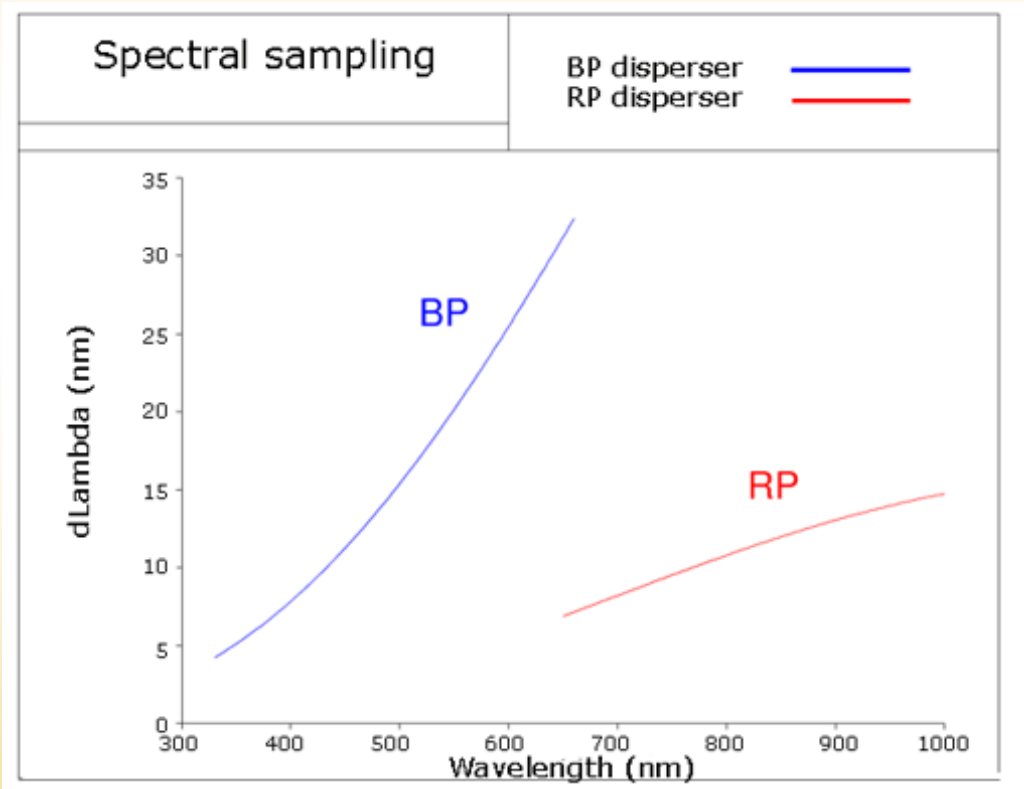


Spectrophotometer

- Two photometers with dispersed images
  - R ~ 50
- Red and Blue enhanced detectors

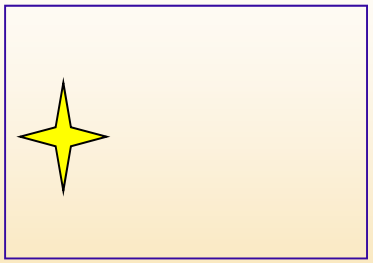


prisms

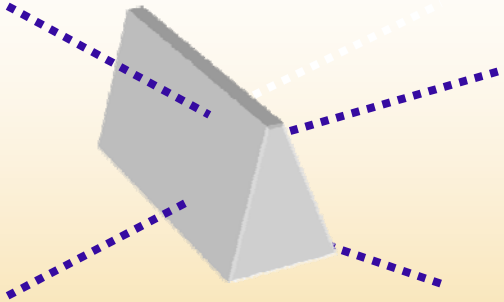


Spectrometer main features

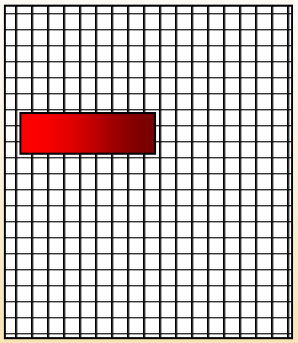
- Integral field spectrograph
- Operated in Time Delay Integration scan mode
- Multi-epoch scan : ~40 observations (on average)
- Dispersive power : $R = \lambda / \Delta\lambda = 11\,500$
- Wavelength range : [8470 – 8740] A ~ 1100 px on the CCD
- $\sigma(v_r) = 1$ km/s ➔ $\delta\lambda \sim 0.003$ nm = 0.12 pixel



Field of view

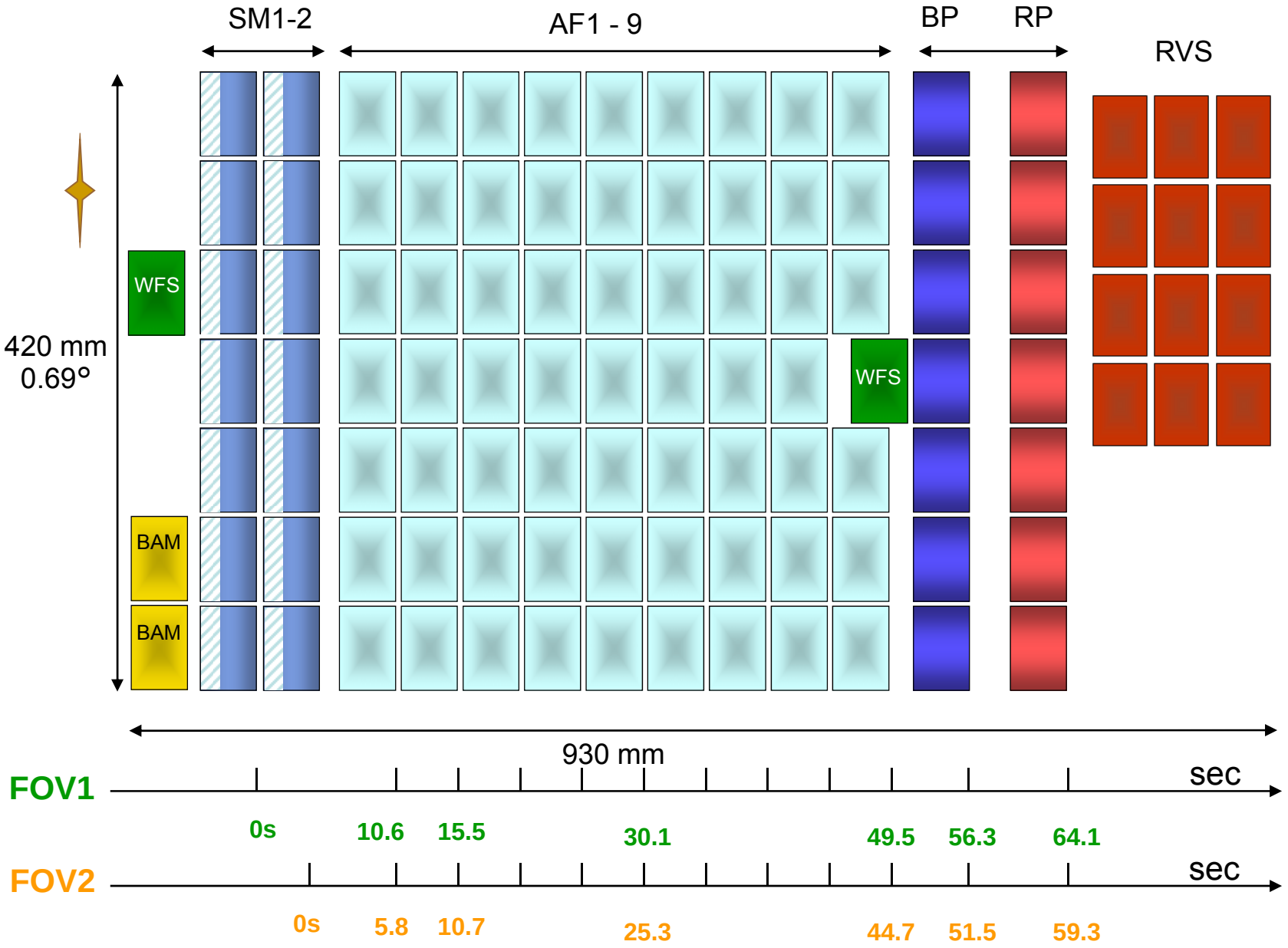


Spectrograph



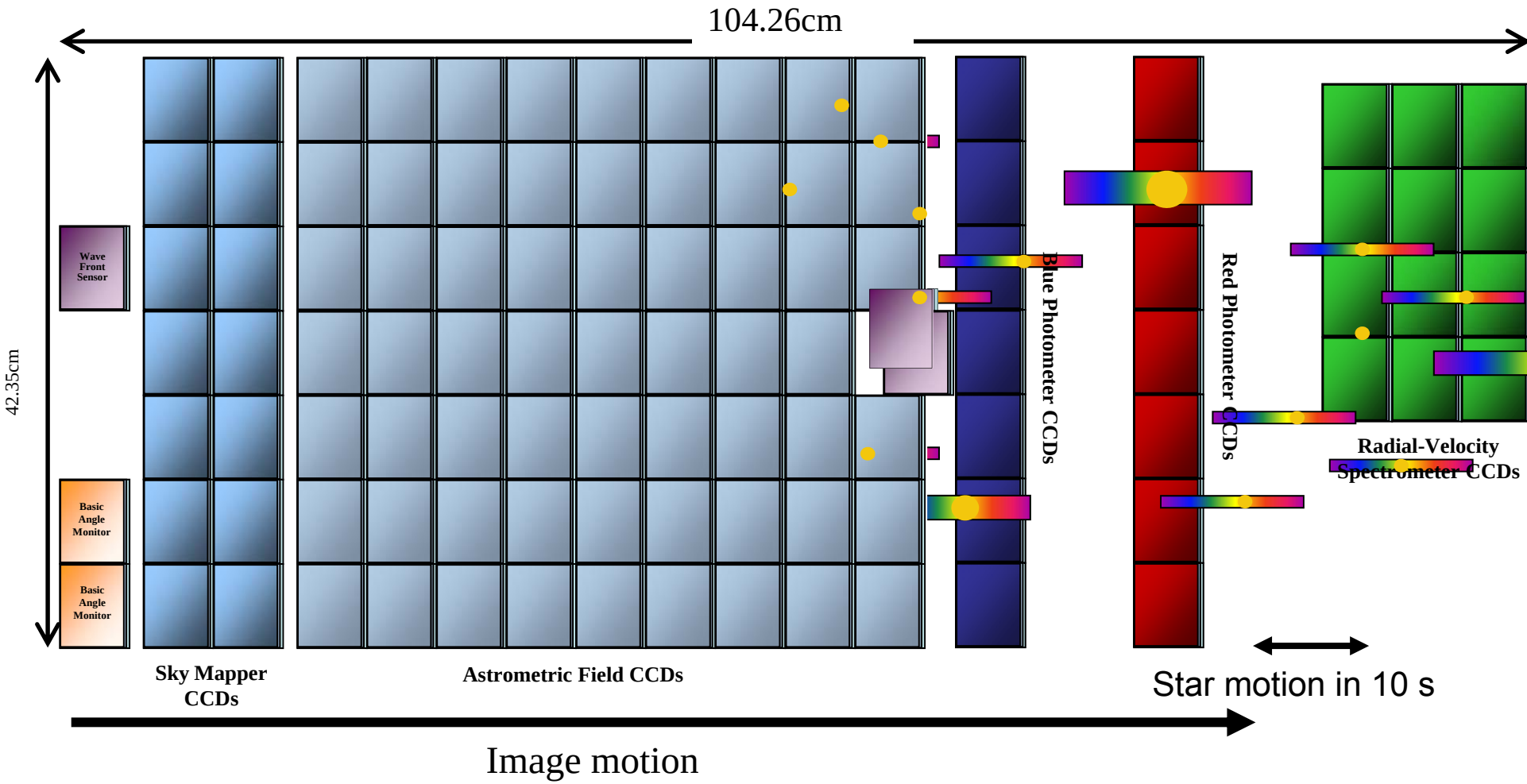
RVS CCD

Focal Plane Assembly



Multiplexing observations

106 CCDs , 938 million pixels, 2800 cm^2



Credit: A. Short, W. O'Mullane

Number of sources per day

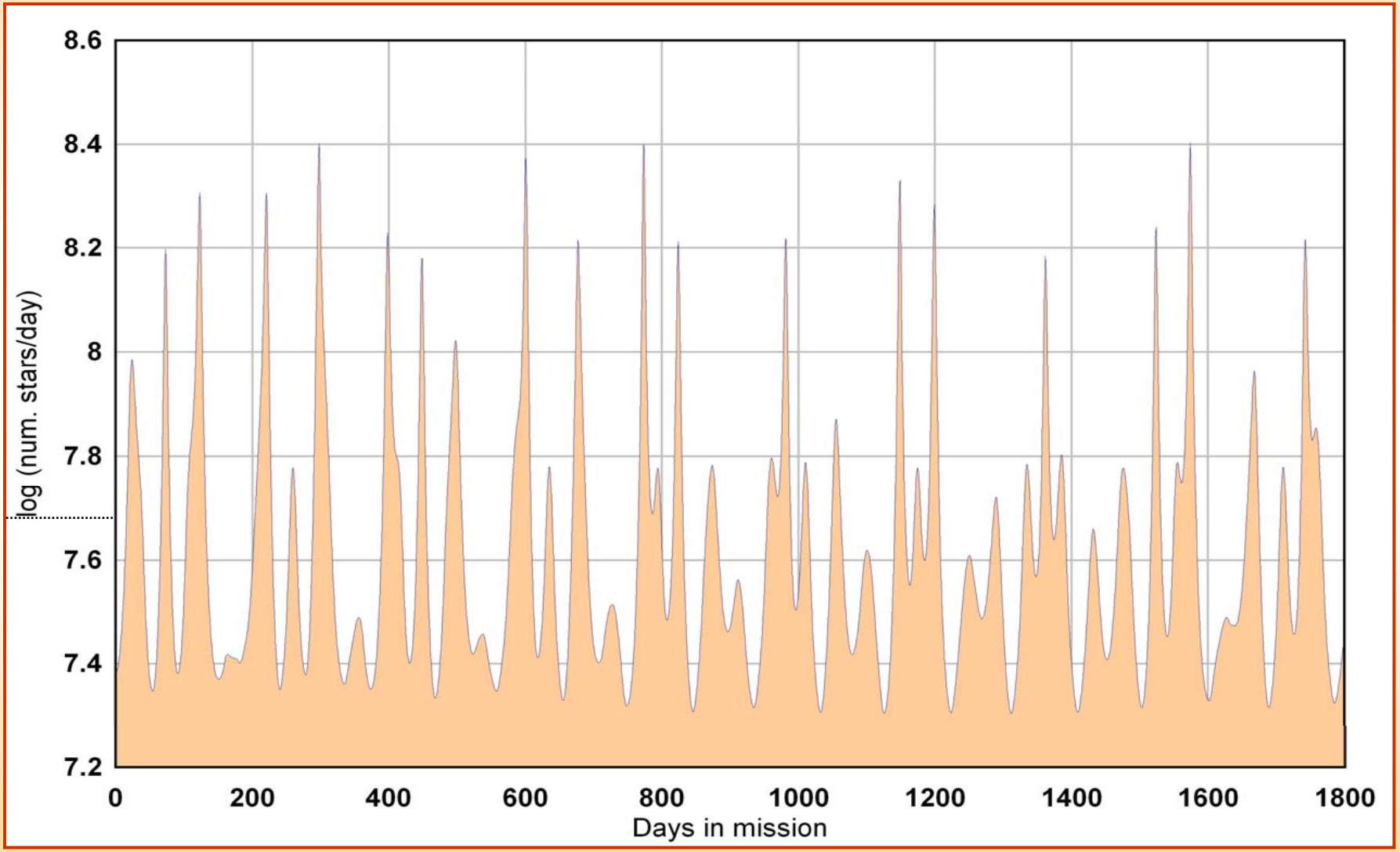
- How many sources per day to be processed on board ?
  - number of sources brighter than 20 mag — ~ 10^9
  - duration of the nominal mission — 1800 days
  - average number of field transits per source — ~ 80 *(no dead time)*
  - average number per day — ~ 10^9*80/1800 = ~ 45 x10^6

- But large scatter with the orientation of the scan wrt the Galactic plane.

- Detailed study done with a simulation using the nominal scanning law and a galactic model

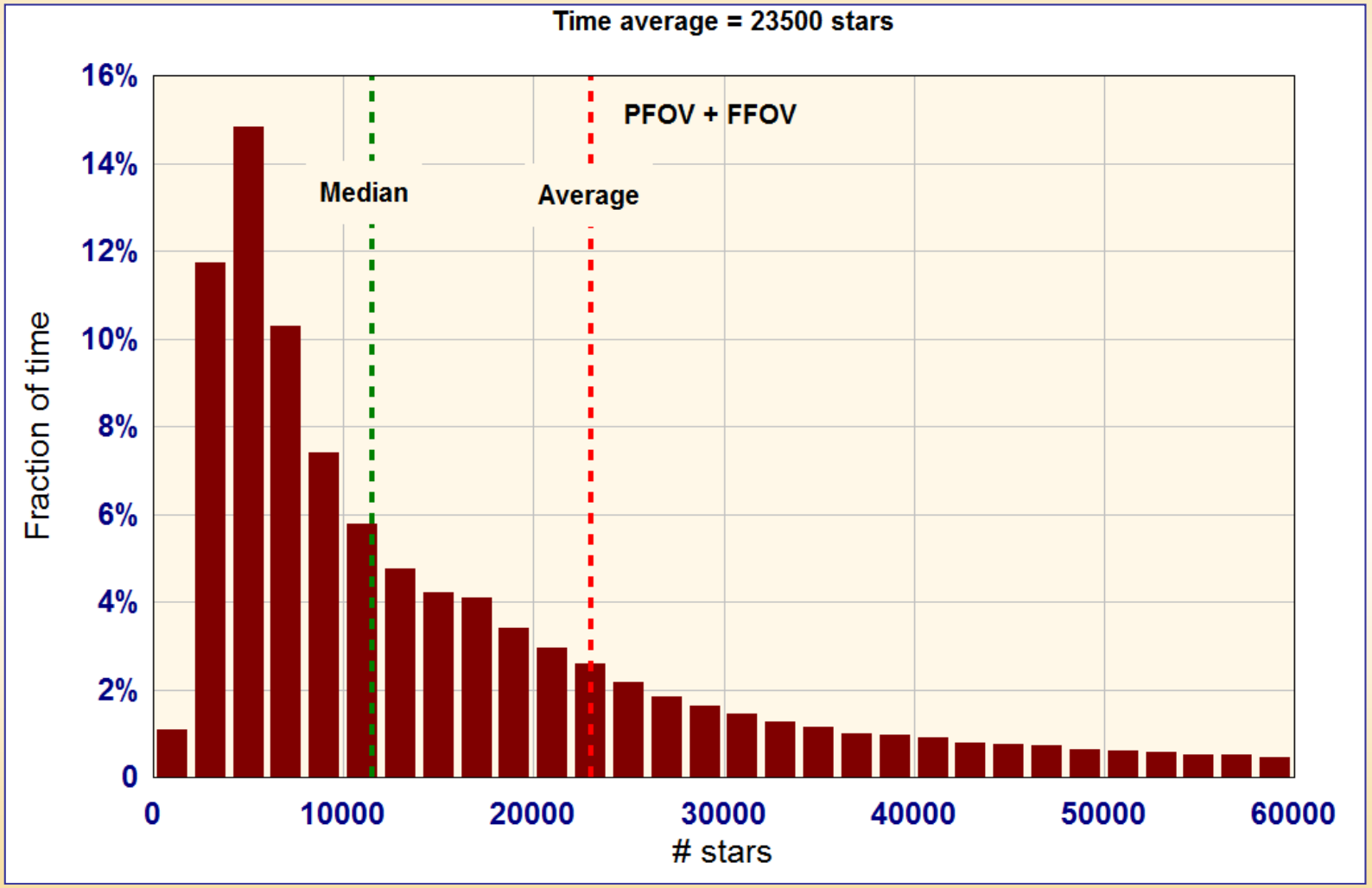
Number of sources per day

- Number of sources detected per day (log scale) during the mission



Number of stars in the FOVs

- # stars measured at any time in the combined FOVs



The sky mapped onto the focal plane

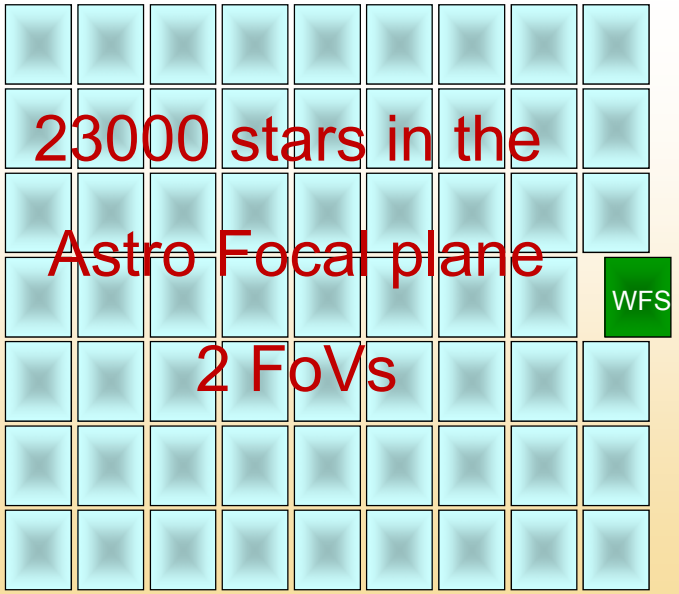
- Sky average density to V = 20 : 25000 */deg^2
  - **But with large concentration near the galactic plane**
- However Gaia spends more time in low-density areas
  - **Time average is smaller ➔ sky is "empty" outside the galactic plane**
- But the two FoVs are not superimposed as independent samplings

On the average on the one has:

350 stars

in

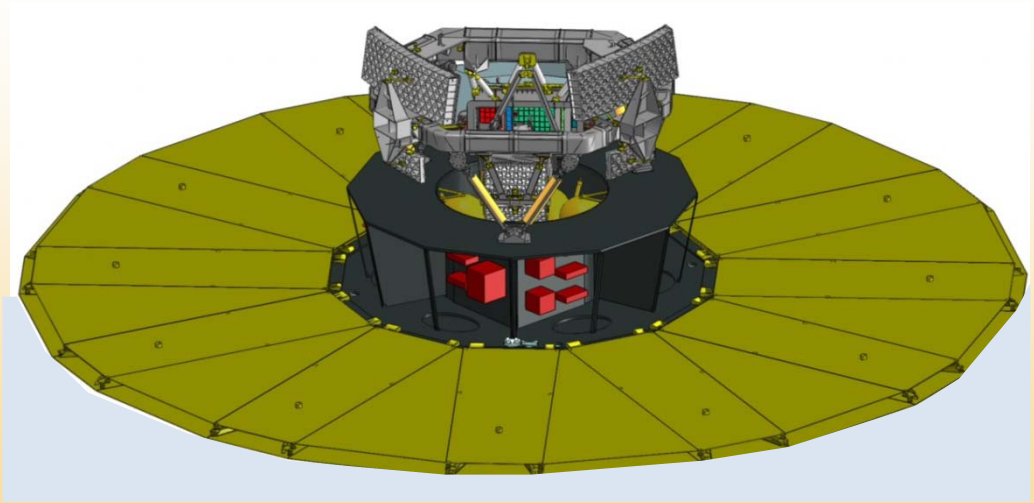
one CCD

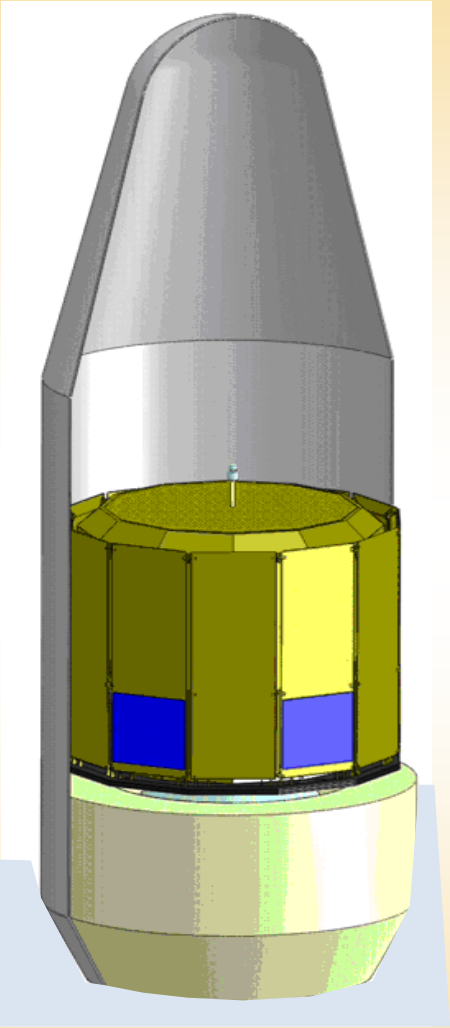


Astro FP ~ 1 deg^2

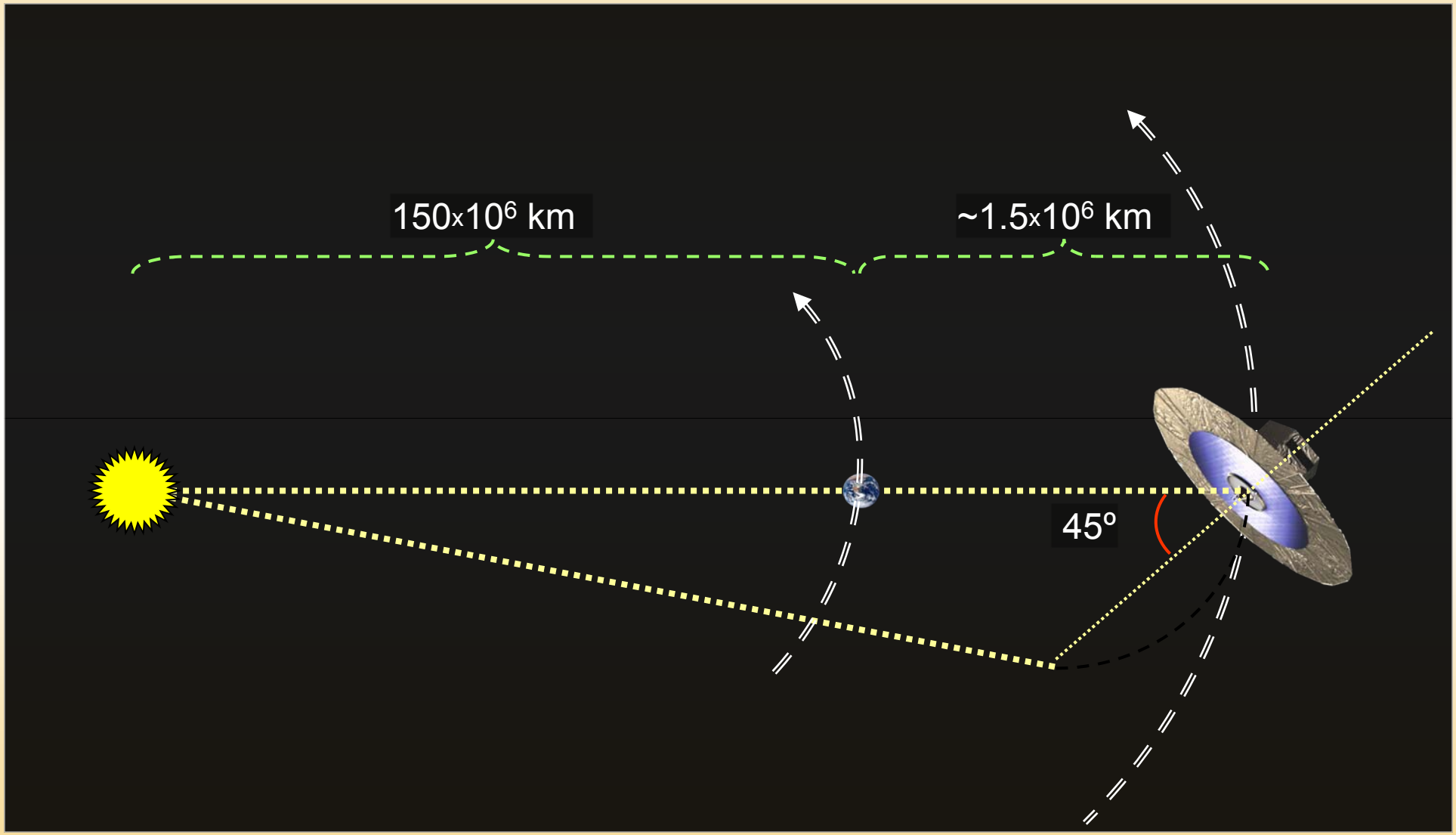
S/C main characteristics

- S/C launch mass : 2 t
- Power available : 2 kW
- S/C height : 3 m
- Sunshield diameter : ø = 10 m
- Payload
  - entrance pupil : 1.45 x 0.5 m^2
  - focal length : 30 m
  - focal plane : ~ 1 G pixels





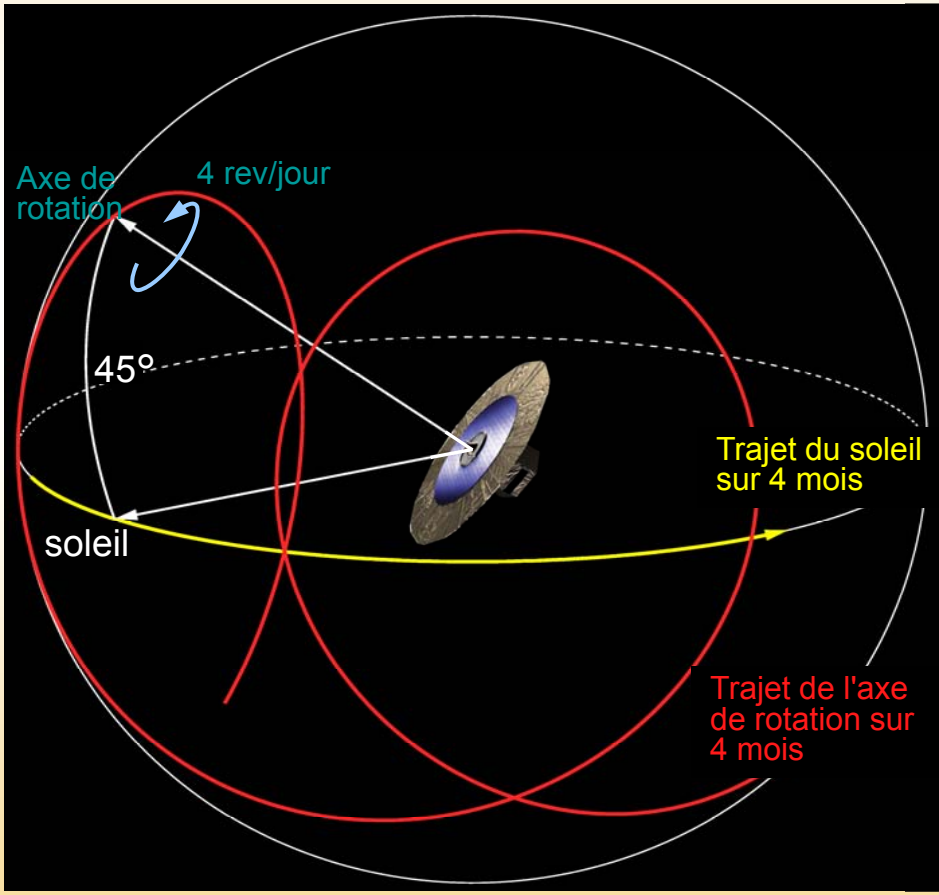
Orbit and sun-aspect angle



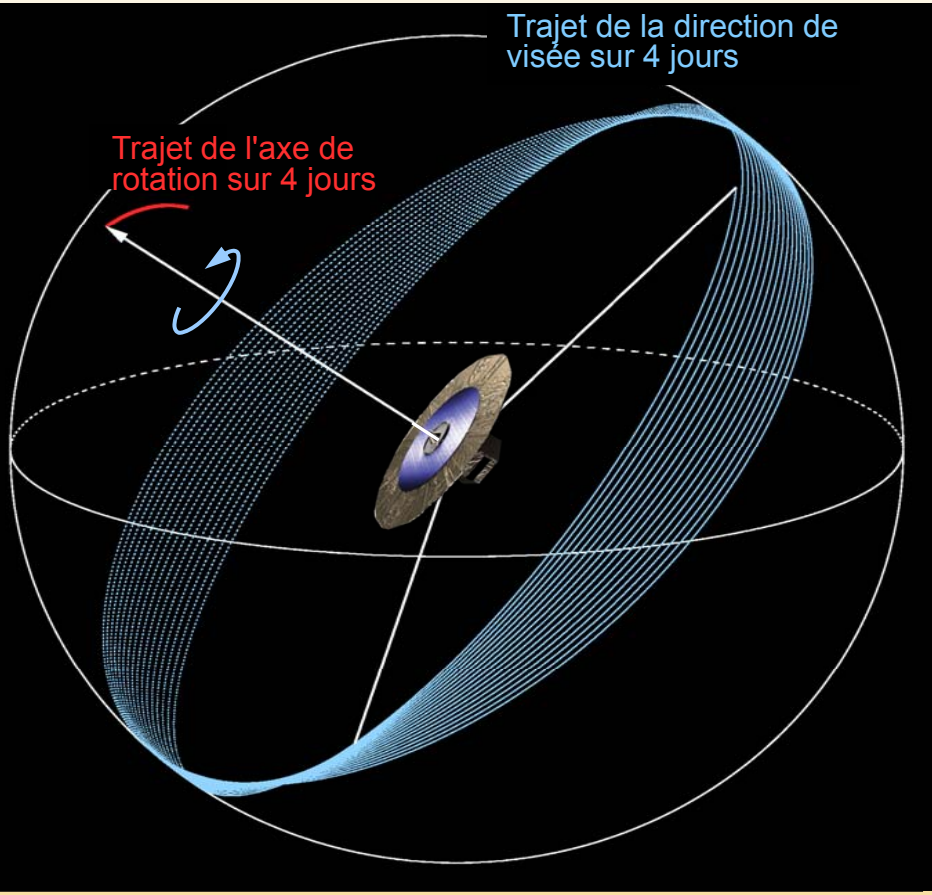
Gaia : Scanning

(diagrammes L. Lindegren)

Motion of the spin axis



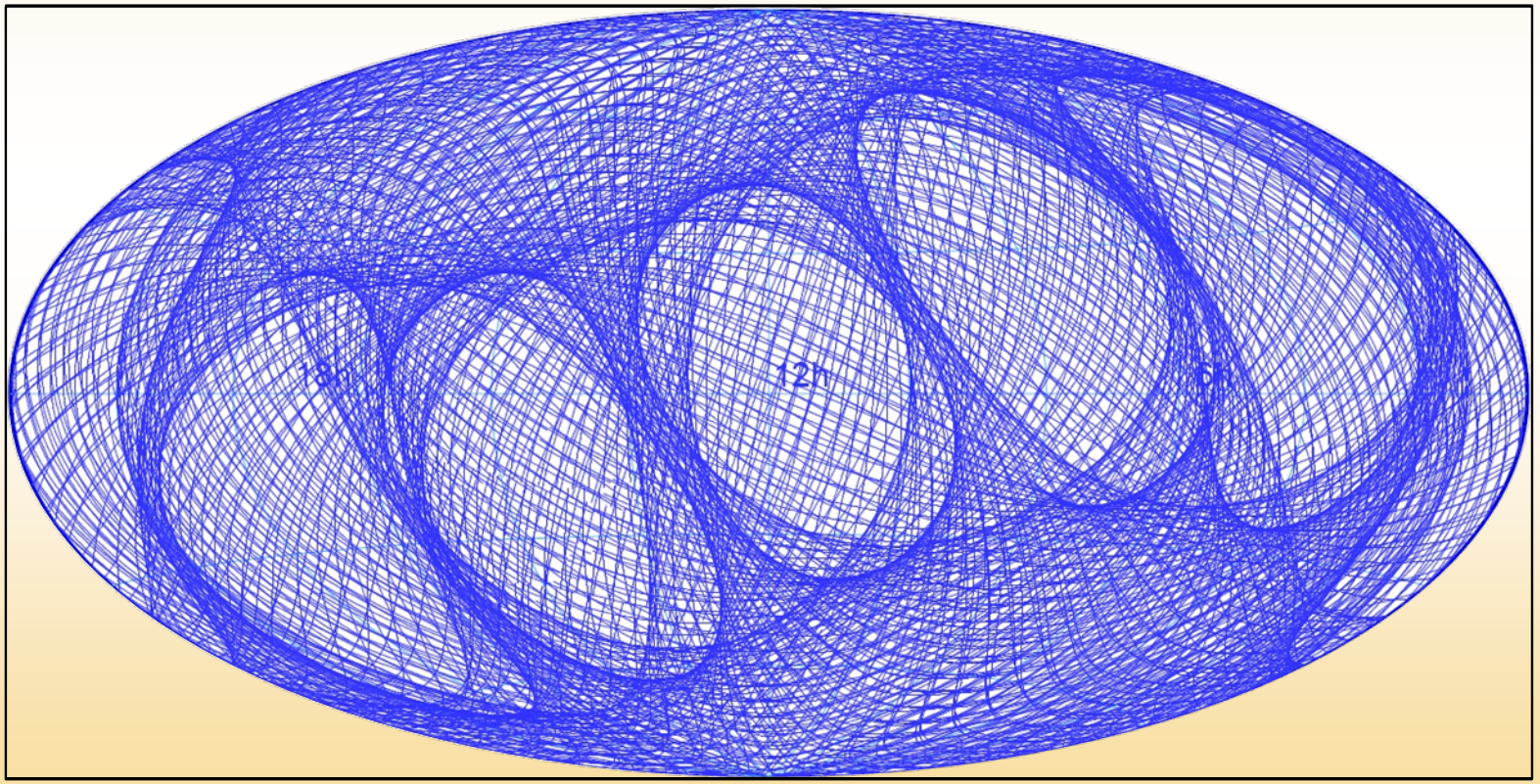
Sky covered over 4 days



Crédit : L. Lindegren

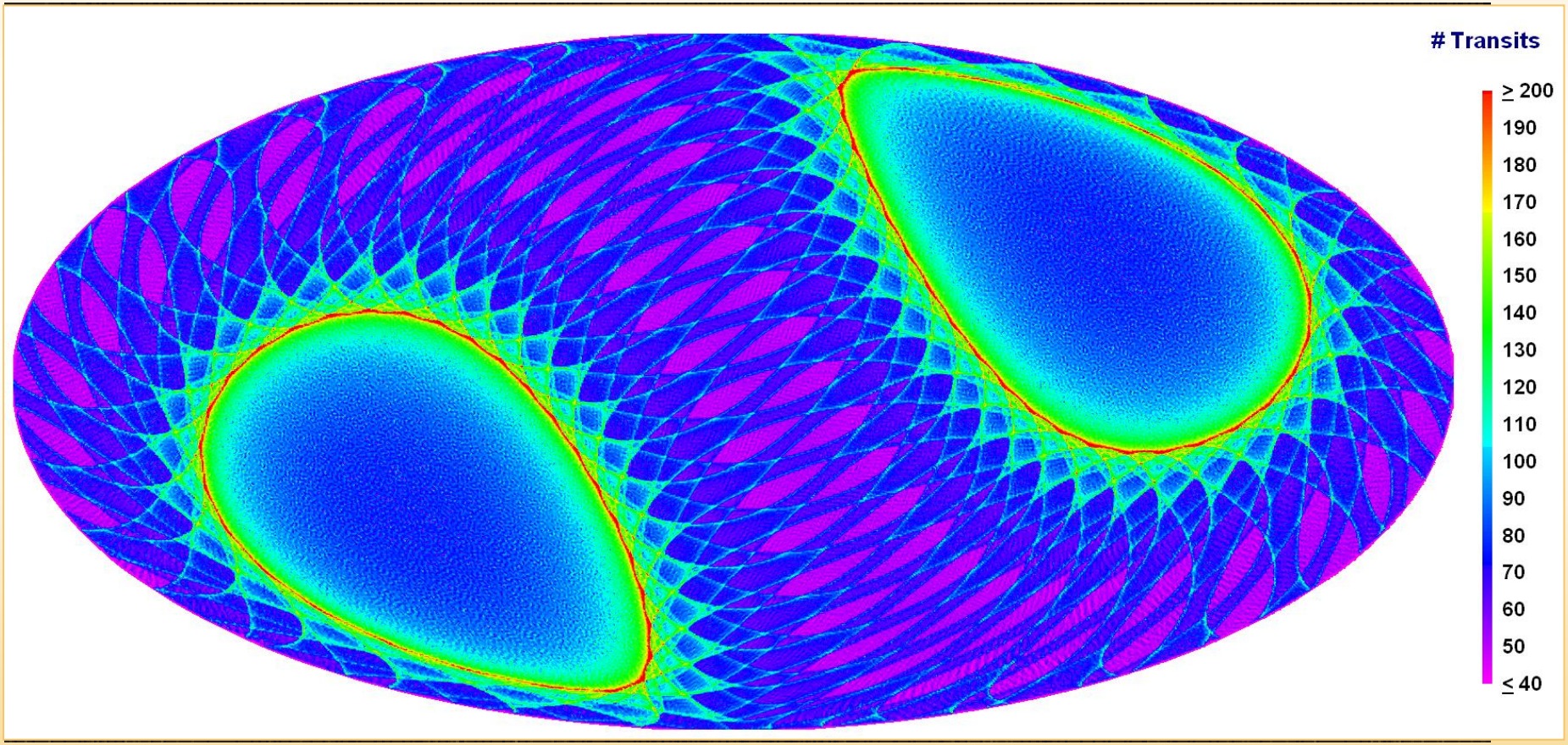
Sky Scanning with Gaia

- Sky coverage over 4 months and one year:
  - 4 months (one colour per month)
  - One full year (one scan per day plotted)



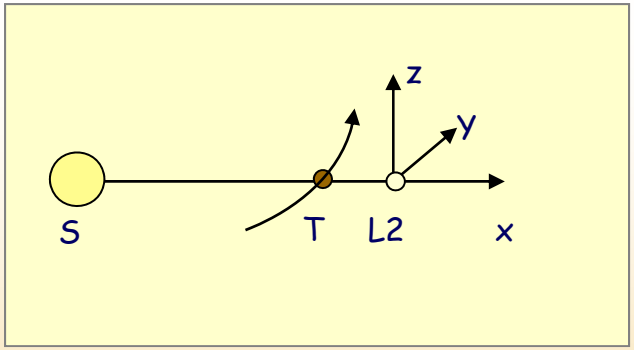
Sky coverage

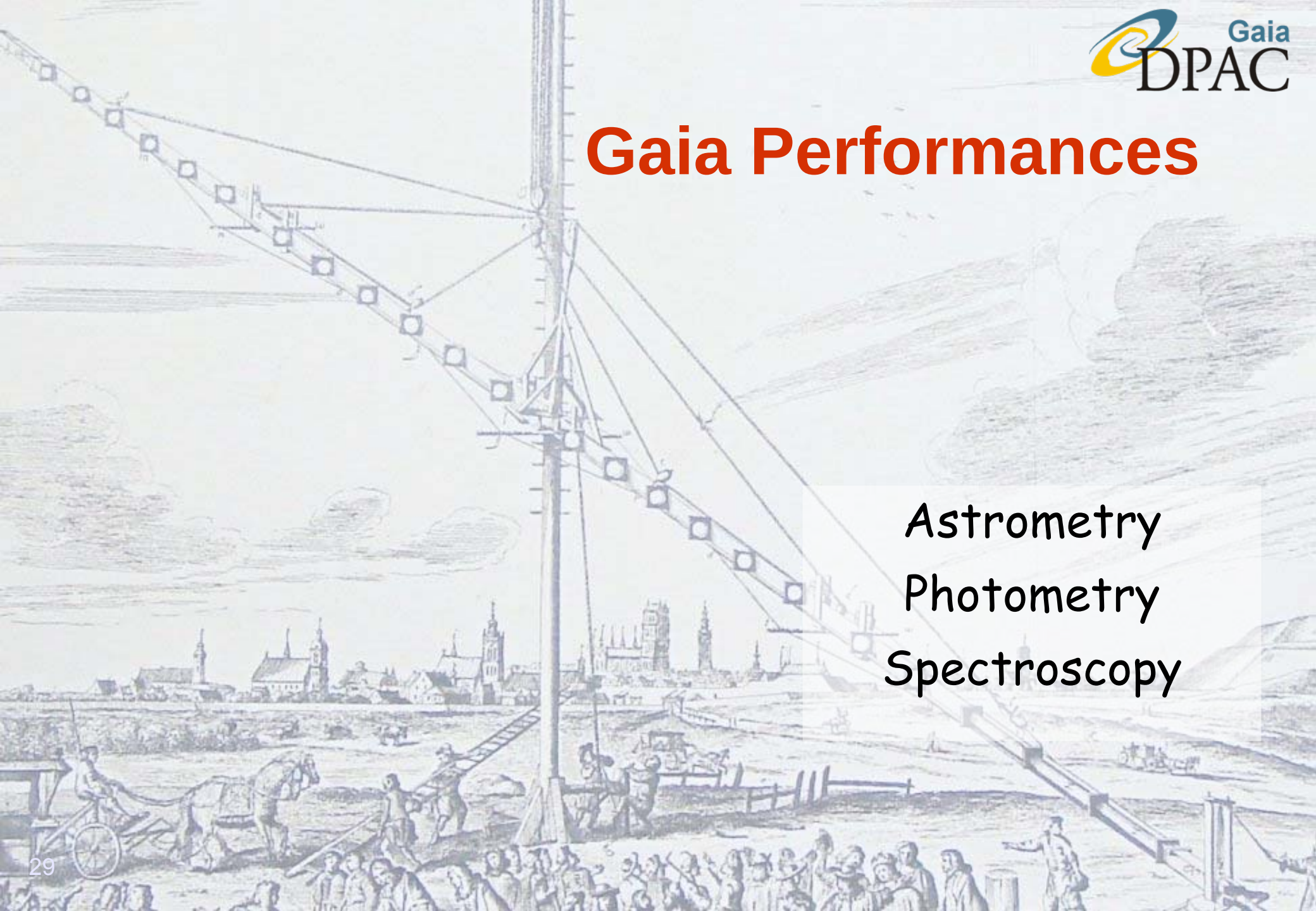
- Time average is a combination of the sky distribution and the scanning law
  - two different symmetries: galactic plane and eclitpic plane



Timeline of the mission

- Selection by ESA in 2000 (and confirmed in 2002)
- Prime contractor selected in February 2006
- Data analysis consortium formed in June 2006
  - selected by ESA SPC in March 2007
- Launch : spring 2013
  - from Kourou with a Soyuz + Fregat
- Orbit around L2
- Continuous observation to 2018
- End of data processing to 2020
- Results and data available in 2021
  - intermediate releases planned during the mission





Gaia Performances

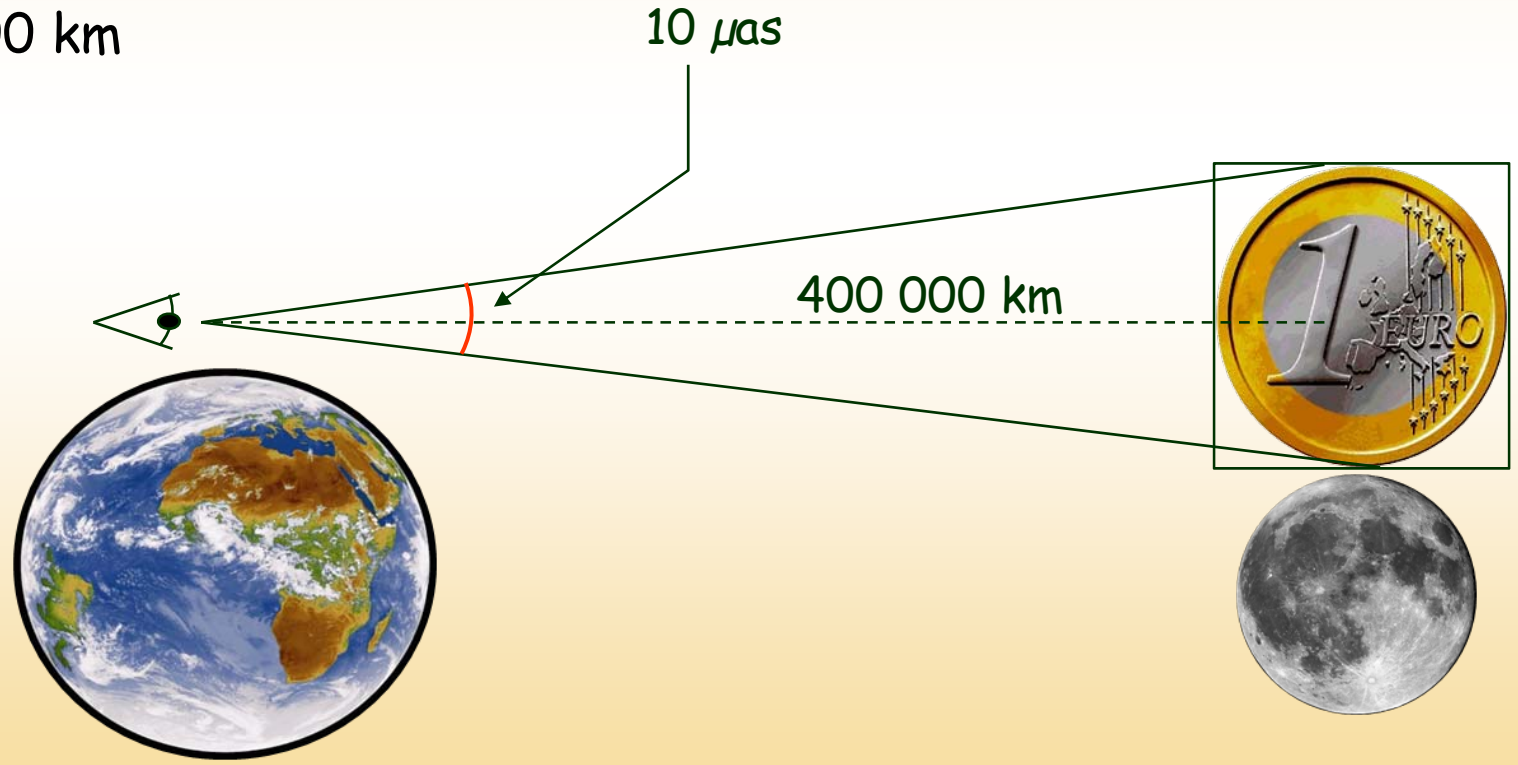
Astrometry

Photometry

Spectroscopy

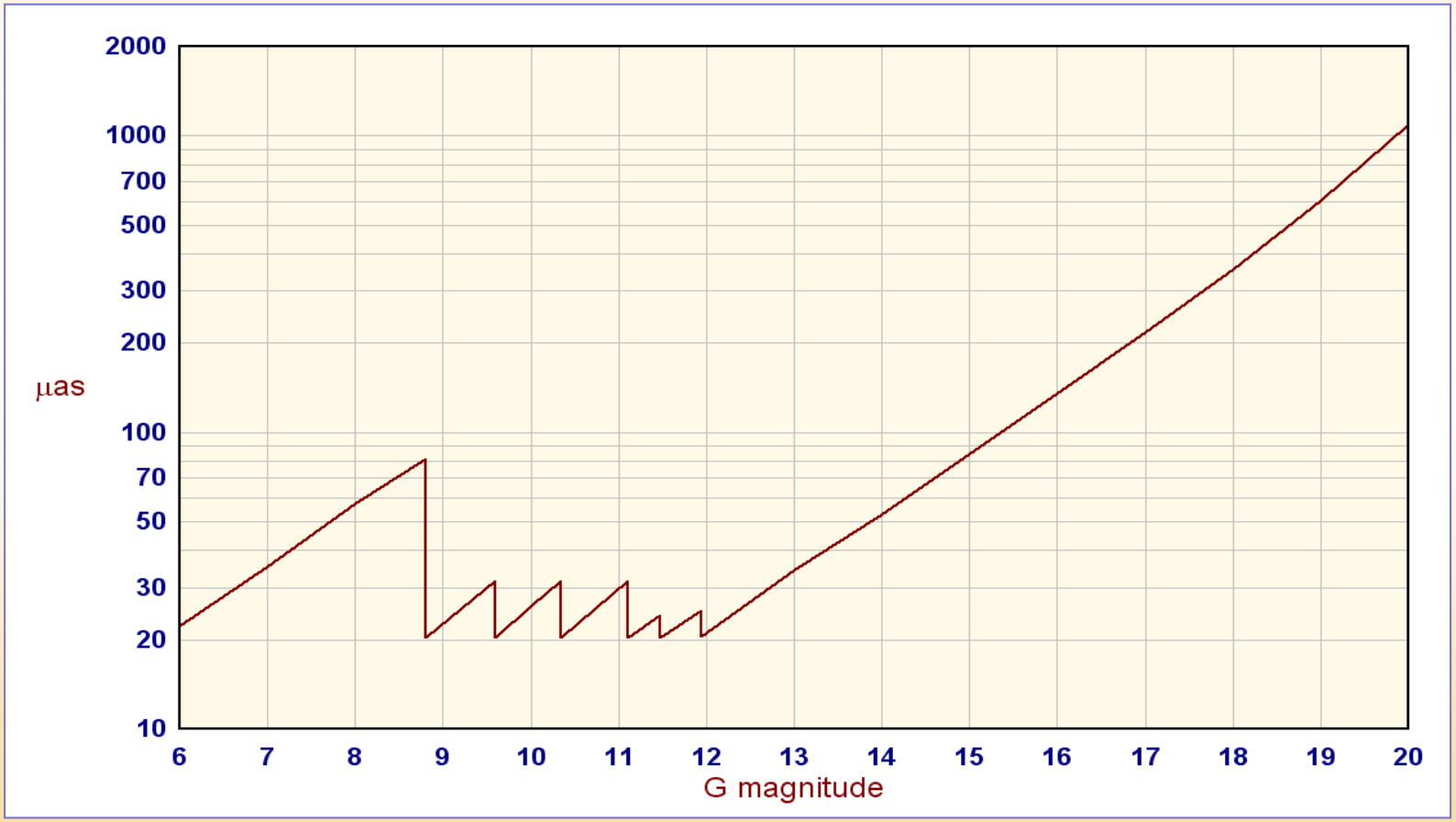
10 µas: Incredibly small !

- 0.3 mm displacement on the Earth
- Displacement of a 100 mas/yr star in one hour
- Motion of a fast moving minor planet in 100 *µs*
- edge-on sheet of paper @ 2000 km
- 1 hair @ 1000 km



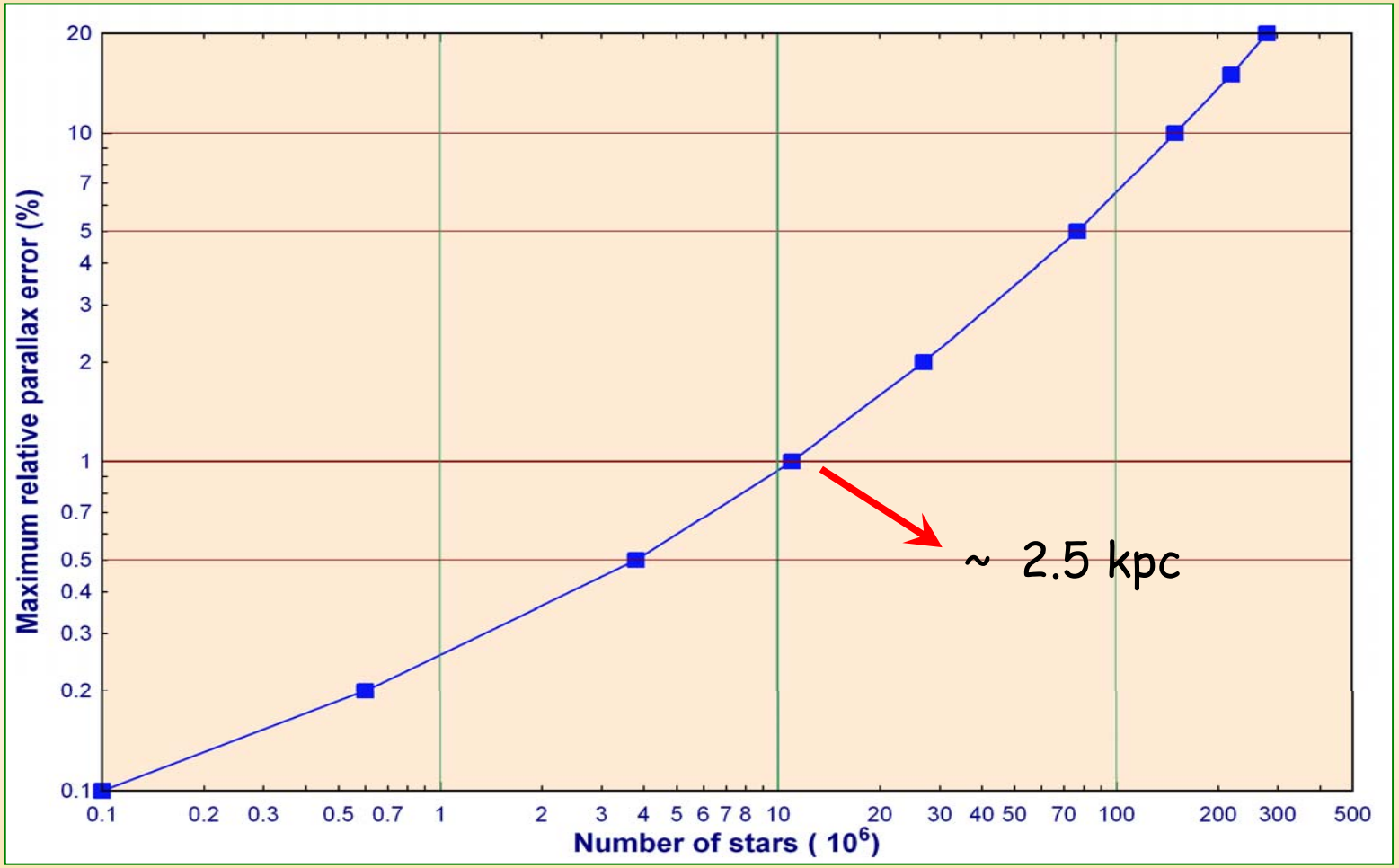
Astrometric accuracy: single transit

- Single observation accuracy ➔ orbit, solar system
  - one field transit: integration over 9 AF CCDs
  - point source



Distances for stellar physics

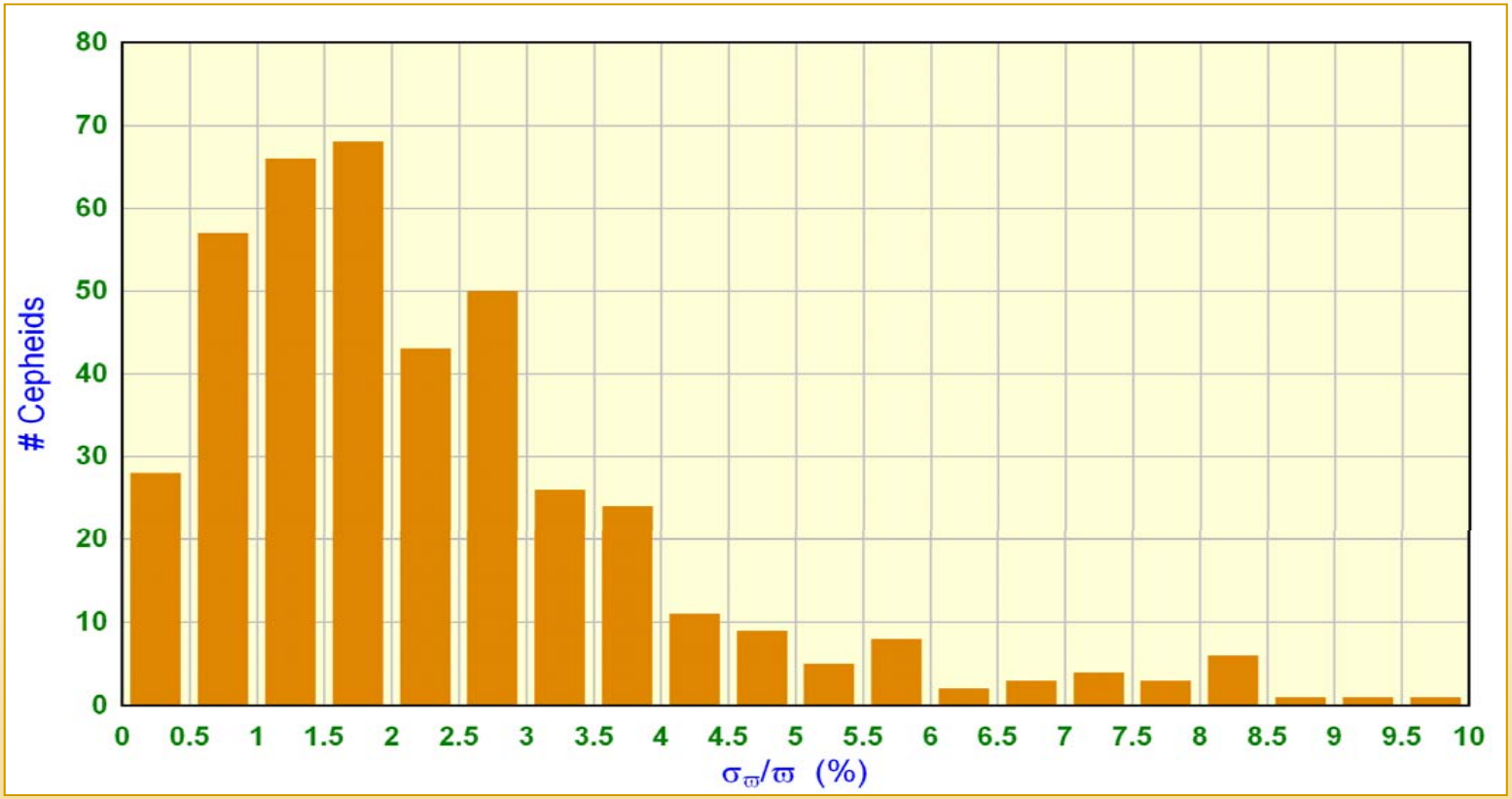
- Accurate distances through the Galaxy



Recall: Hipparcos : 20,000 stars with $\sigma_\pi/\pi < 10\%$

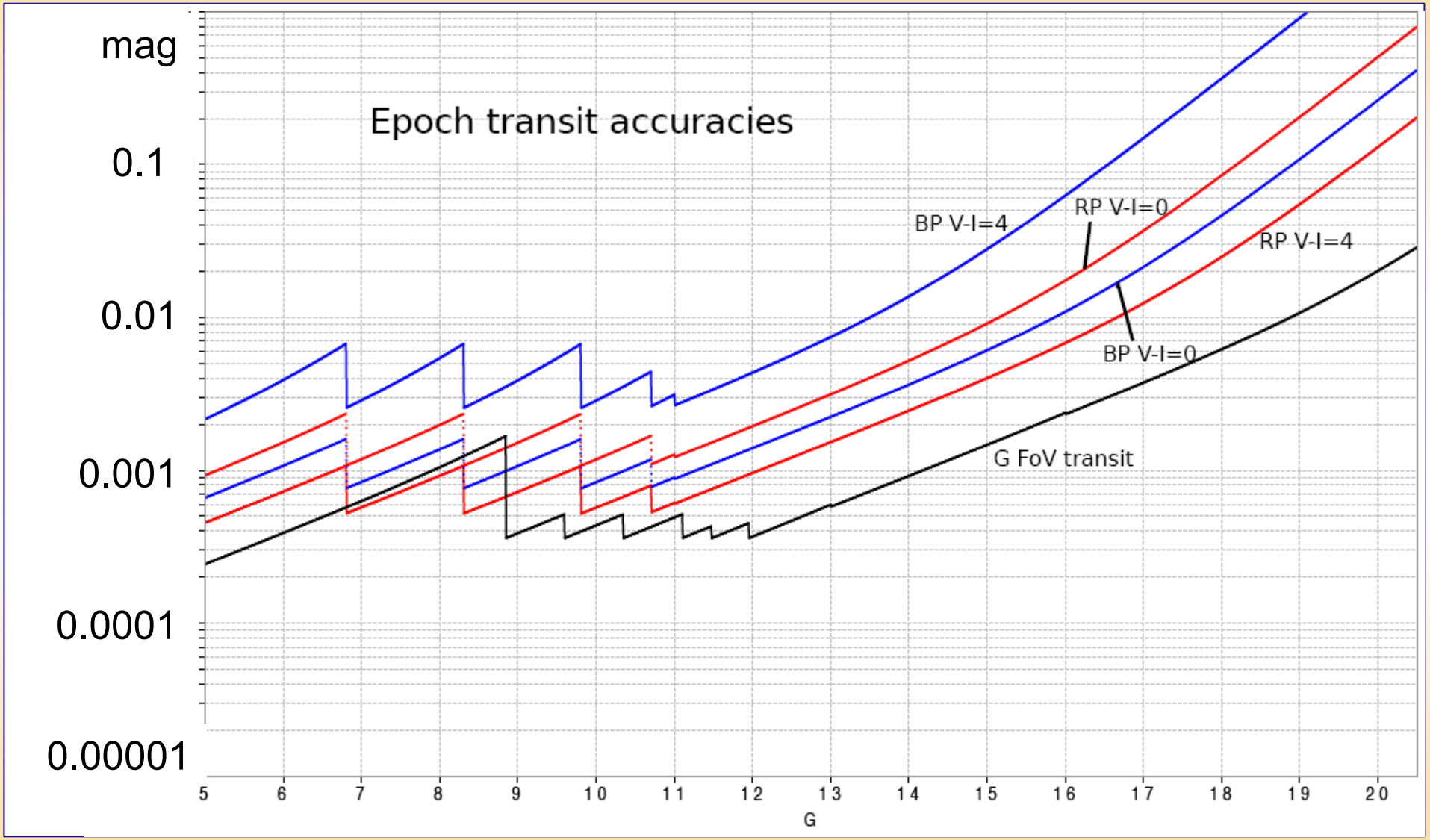
Cepheids with Gaia

- 15 d < 0.5 kpc, 65 d< 1 kpc, 165 d < 2 kpc
  - bright enough (V < 14)
- In the plot : 400 galactic cepheids from David Dunlap DB
  - distance and magnitude ➔ Gaia predicted accuracy for parallax



F. Mignard 2002, 2009

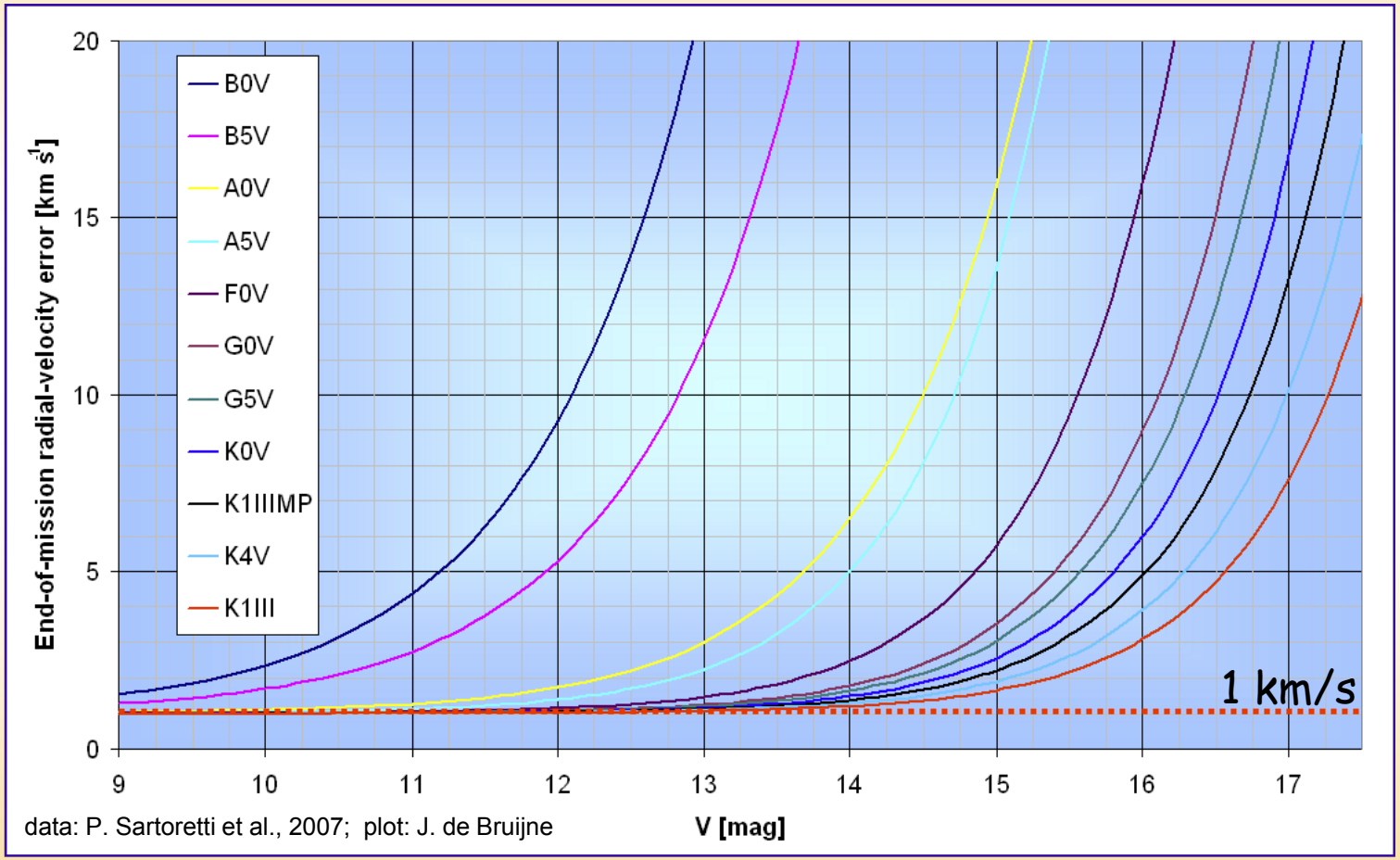
Photometric Performance over a transit



Credit: D. Evans

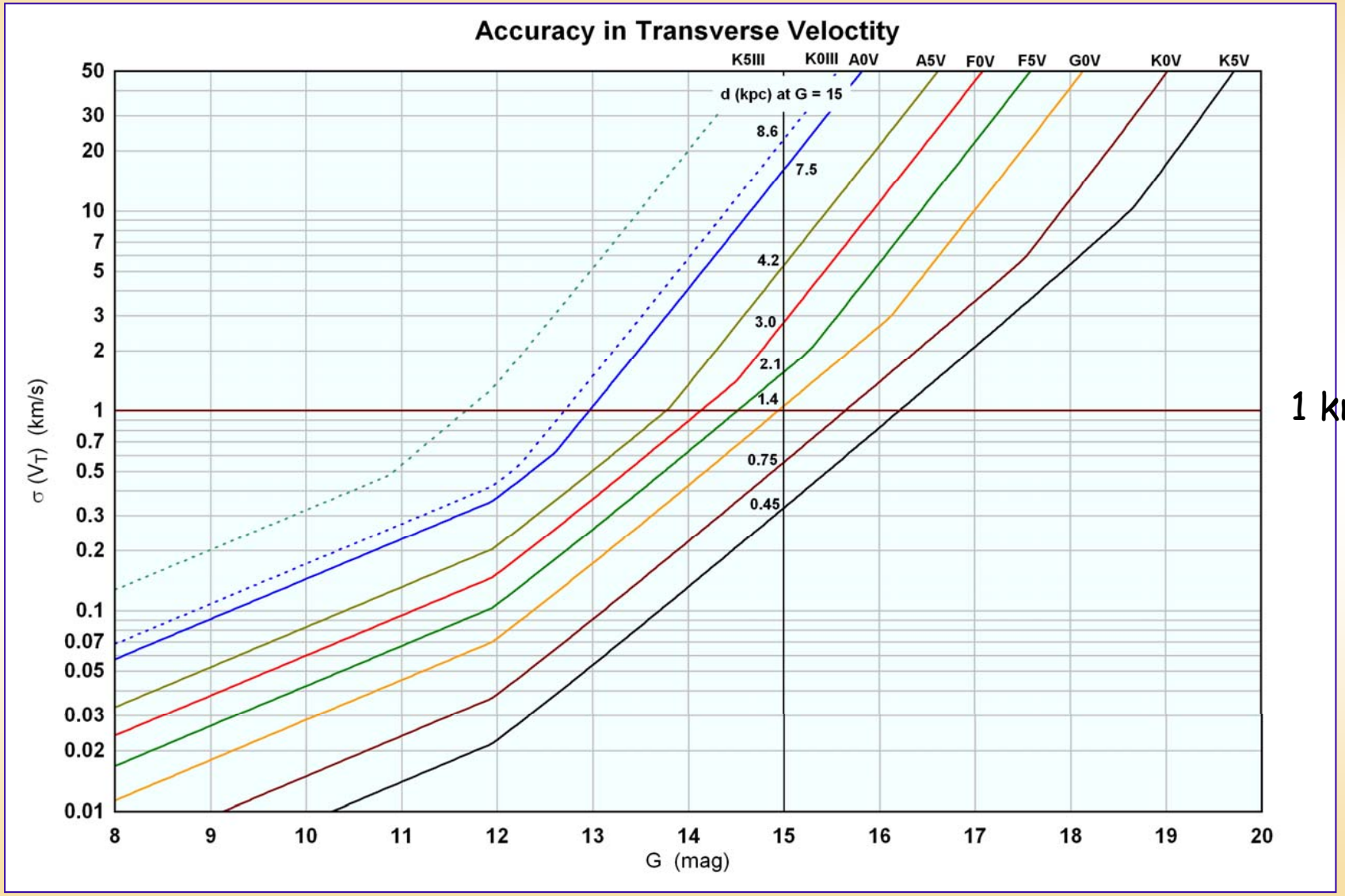
Radial velocity accuracy (EOM, km/s)

- Performances strongly dependent on stellar type
- Average of 40 transits (*i.e* 120 CCD crossings)



RAVE : $\langle V_r \rangle$ ~ 2 km/s, 9<I<12

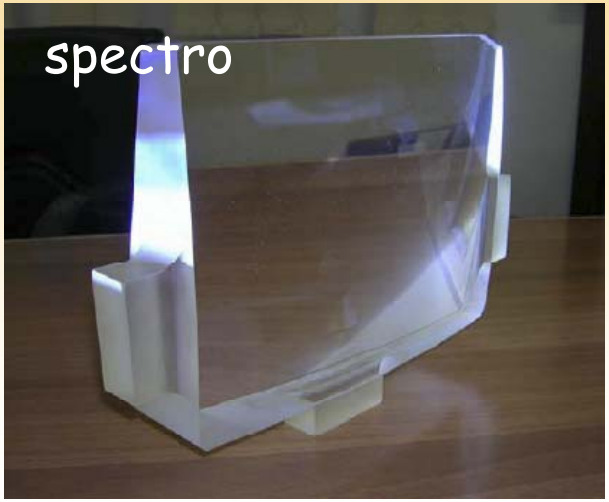
Transverse velocity estimate with Gaia

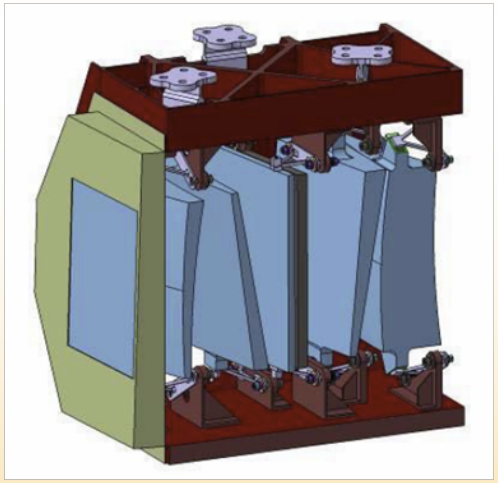


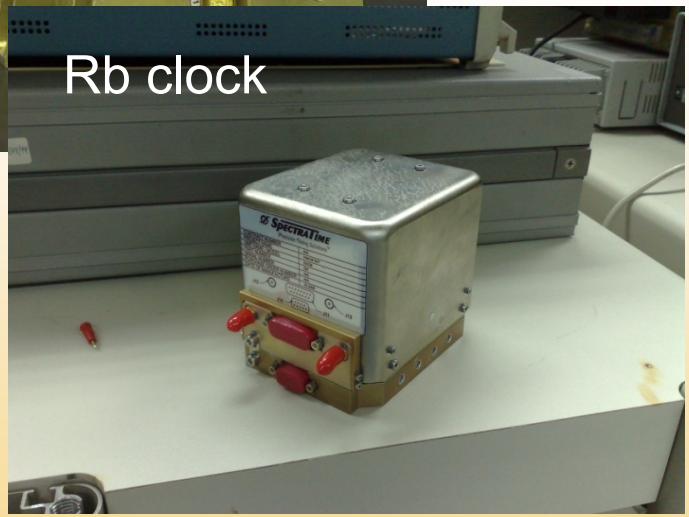
1 km/s

Gaia on the shelves

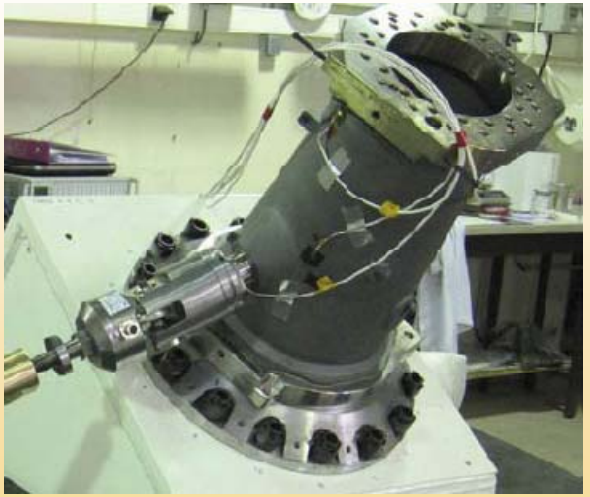
‘Hard stuff ' already manufactured





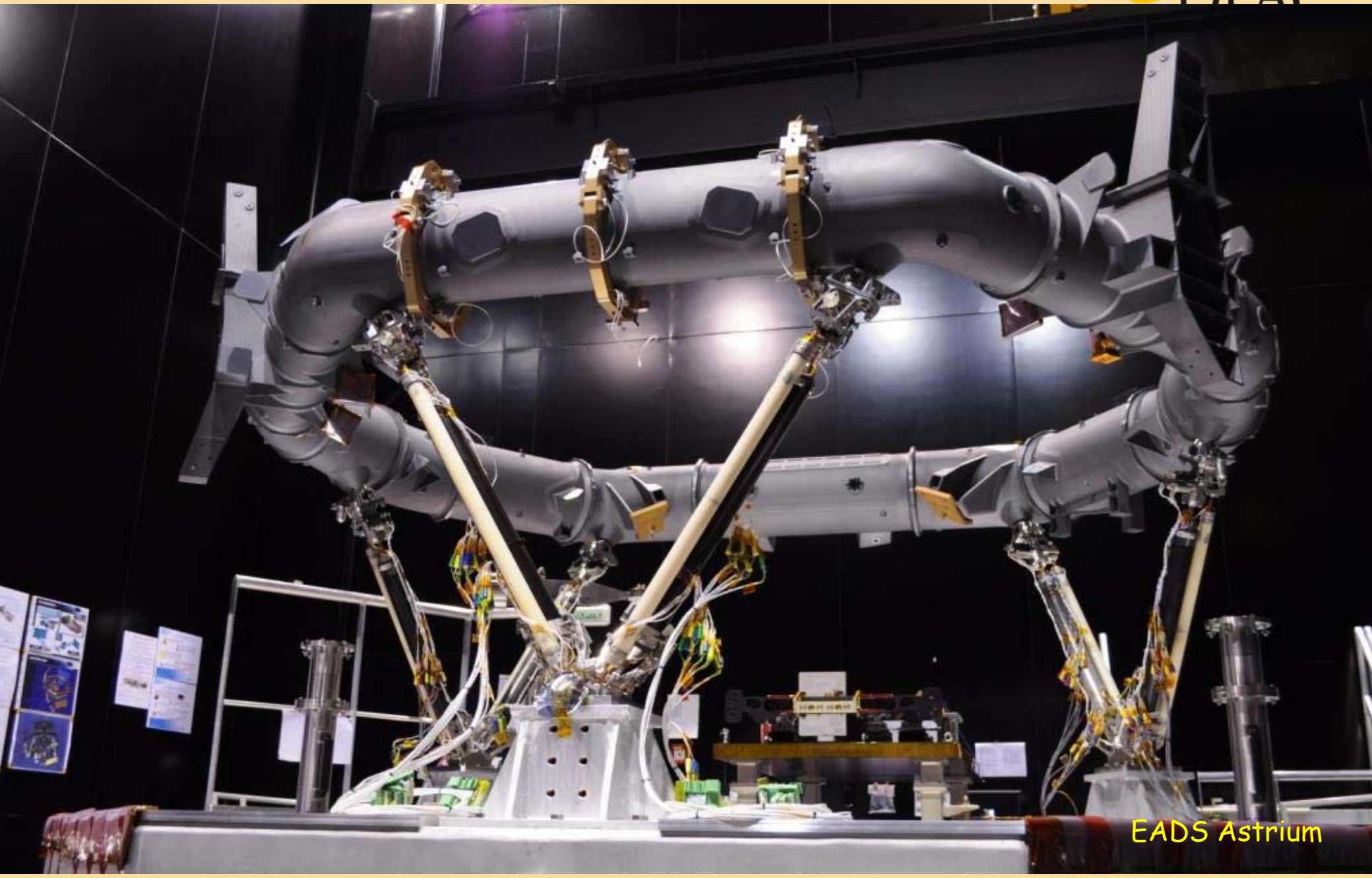


EADS Astrium

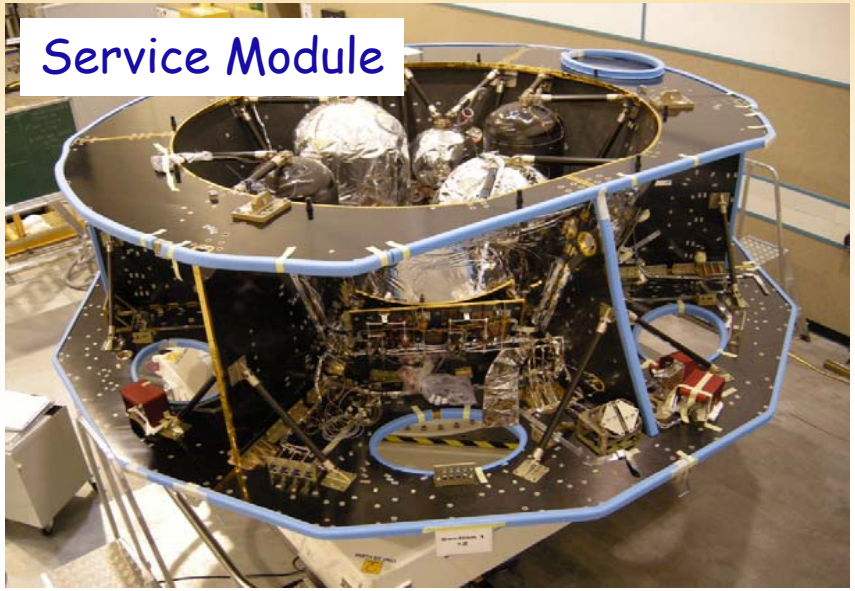


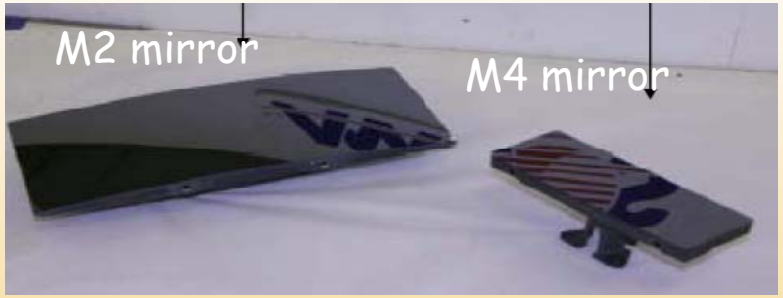
Gaia: Brased torus in place

Torus with supporting bipods (July 2010)



Gaia in construction 2011

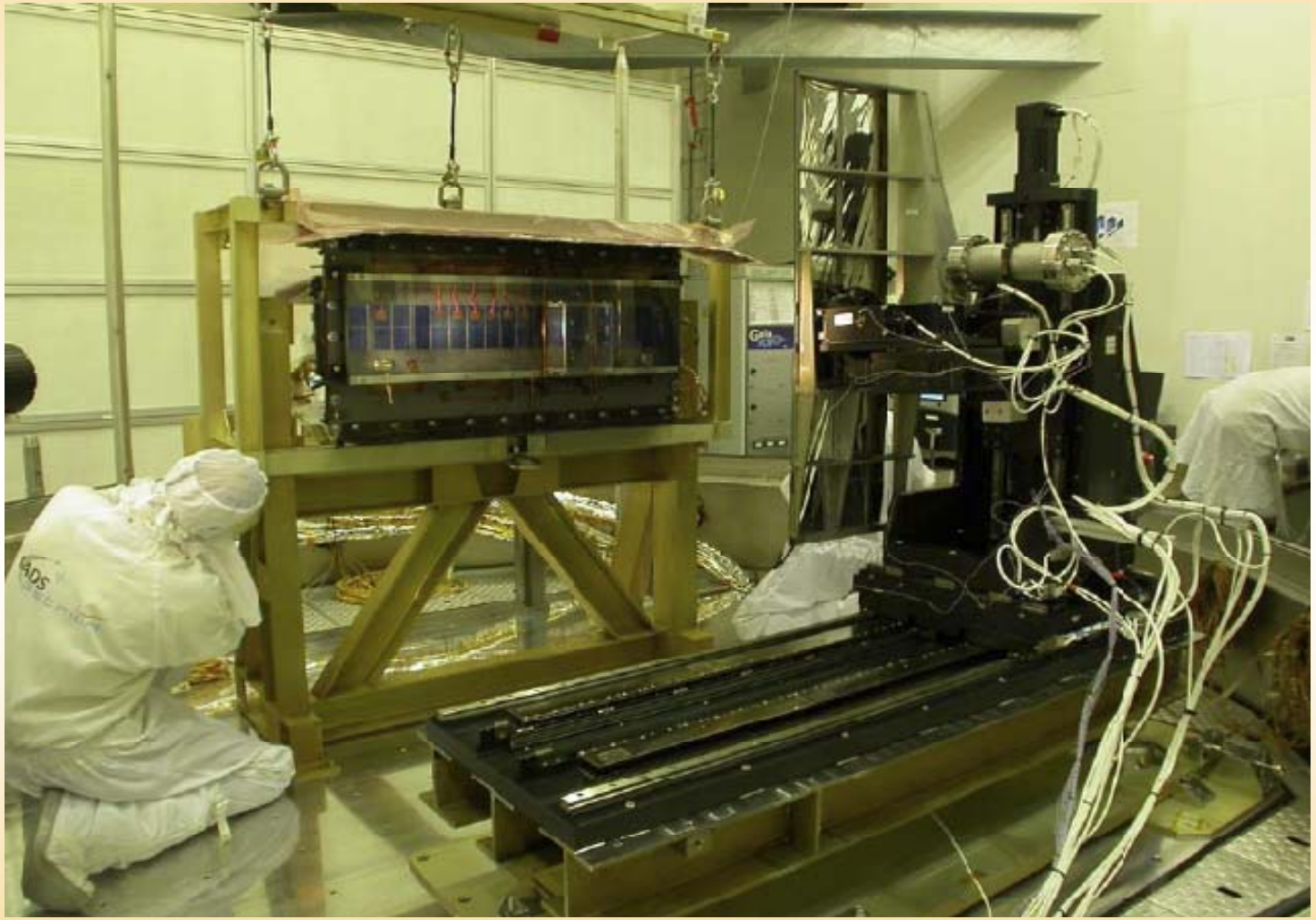




Credit: EADS Astrium

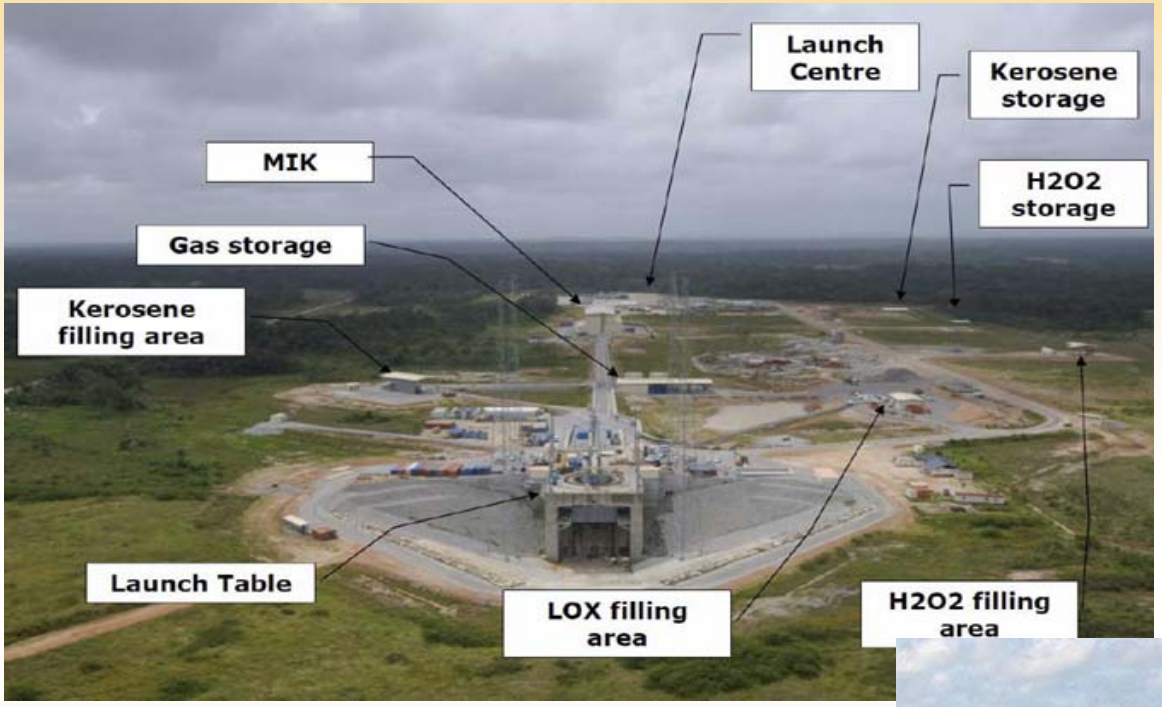
- Rehearsal of the M1 mounting (March 2011)

Testing CCD acquisition mode



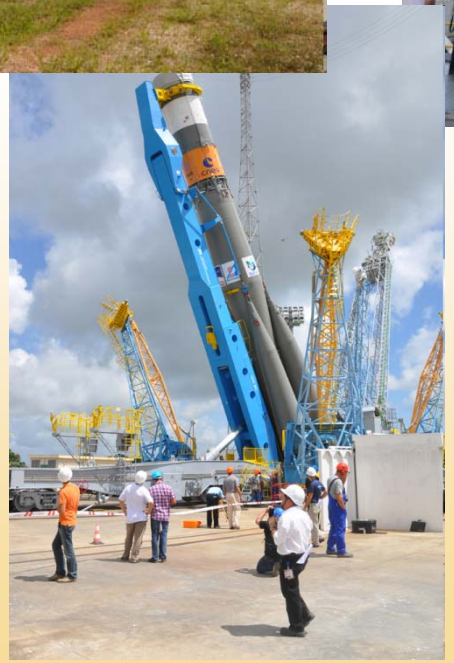
EADS Astrium

Soyouz Launchpad near Kouru (French Guiana)



Preparations for the simulated first Soyuz flight

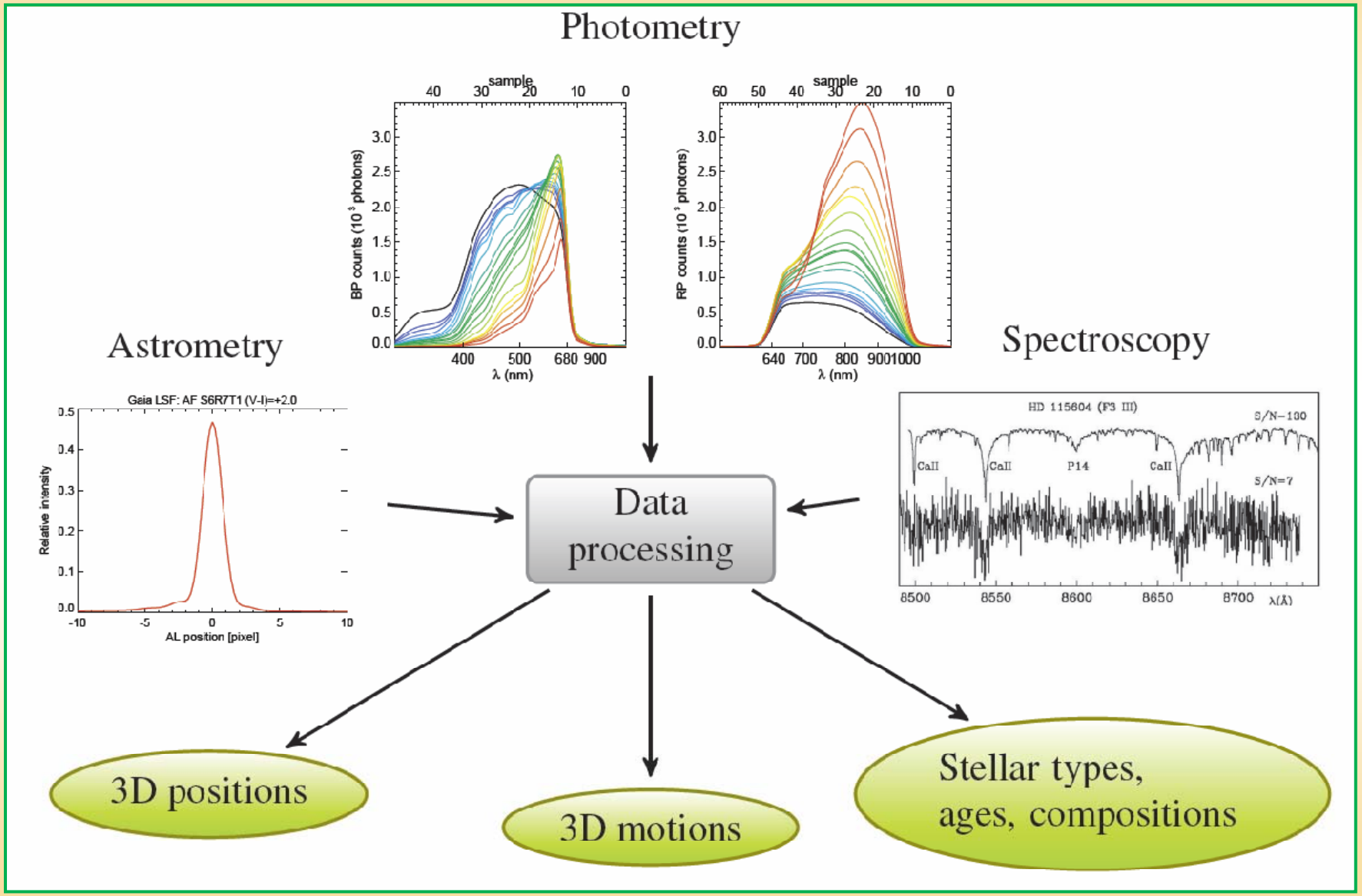
- Pictures taken on the 29/04 and 02/05
- First dry "lift-off" this week



Credit: Arianespace

Data Releases

What Gaia will deliver: wide variety



cartoon: A. Brown

Data Release

- Overall principles defined in the SMP (Science Management Plan)
  - Top level document ESA/SPC covering scientific aspects of the mission
- Intermediate results should be communicated to the Community
  - calibration will be still in imperfect state
  - feedback is expected to improve the final catalogue
- Intermediate catalogues should not delay the final catalogue
- There will be at least several intermediate coordinated release
  - this will include a first astrometric catalogue and integrated photometry
  - global accuracy will be already remarkable
    - but non statistical errors may lie everywhere
    - generic error (eg: $\sigma(G, \alpha, \delta)$) may replace source level error

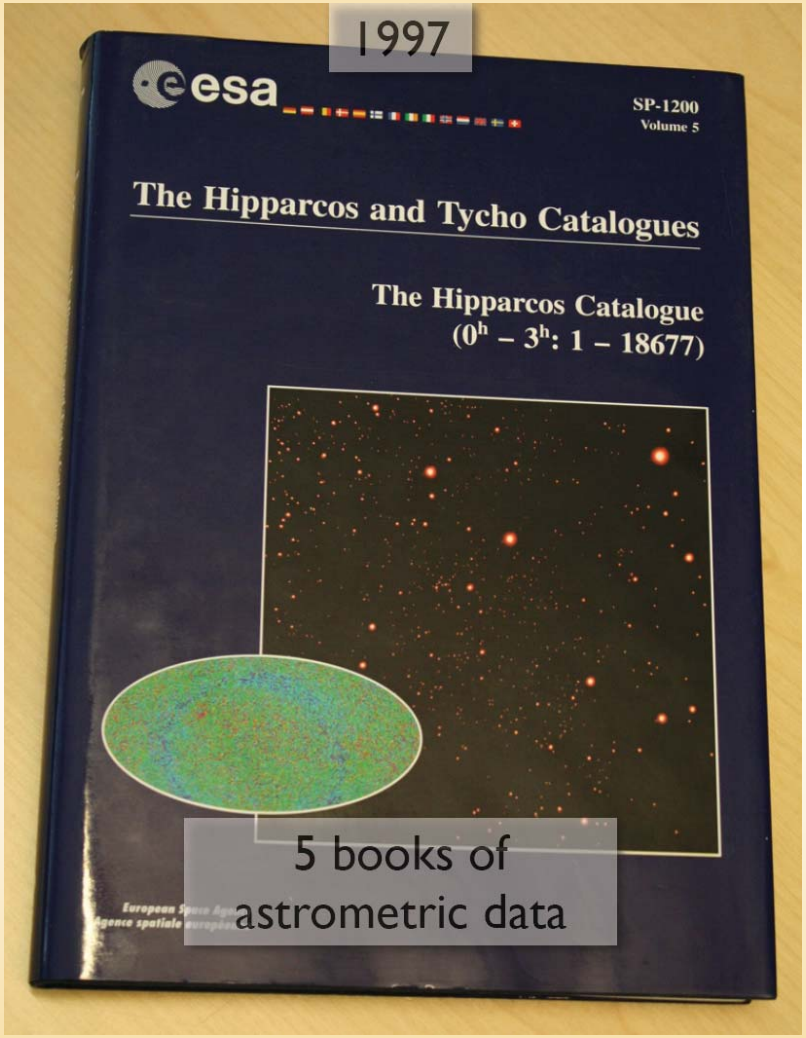
Possible content of the early releases

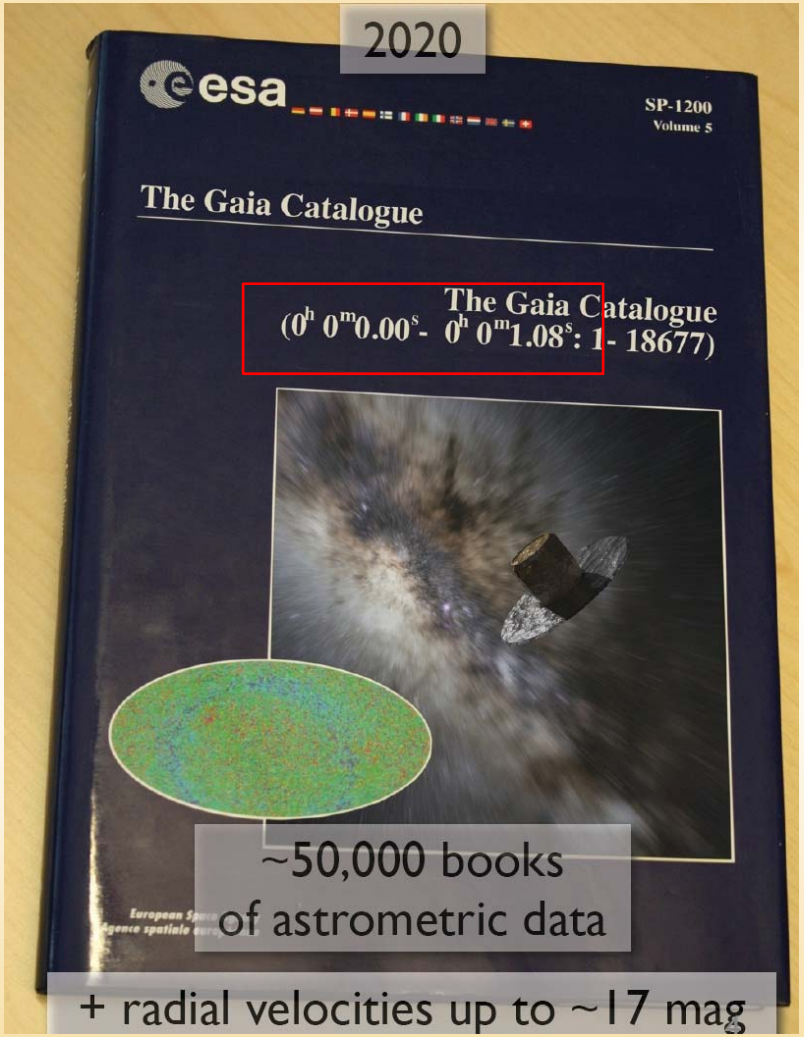
- A position catalogue (mas precision) and G mag, when 90% of the sky is covered
  - 6-8 month of data
- The Hundred Thousand Proper Motion catalogue based on Hipparcos and Gaia positions (~ 6-8 month of data)
- Special release for the ecliptic pole region observed in the Ecliptic Pole Scanning Law
- A 5-parameter astrometric solution of astrometrically well behaved stars when it can be done for at least 90% of the sky
  - possible early results for fundamental physics parameters
- BP/RP spectrophotometric data when 5% calibration accuracy has been reached
- Mean radial velocities for stars bright enough for single epoch Rv determination with sufficient epochs and 90% of the sky
- High resolution mean spectra for mag <10 and S/N at least 50 when 90% of the sky covered
- CU defined releases like Solar System astrometry, non single stars, Epoch variability data

Science Alert Mode & Release

- Gaia has a built-in science alert mode:
  - Science data that would have little or no value without quick ground-based follow up
- Astrometry, Photometry and Spectroscopy could be the source of a Gaia Alert
  - a transient photometric/spectro event evidenced in the Gaia data,
  - or a fast-moving solar system object without known orbit.
    - but without possible monitoring by the Spacecraft
- Gaia releases the alert to the science community
- Immediate follow-up needs the participation of the community

Gaia Catalogue:





Catalogue Access

- Intermediate and final release will be accessed on-line
- A dedicated CU (Coordination Unit) will be set up soon
  - it will be formed sometime in 2012
  - a dedicated AO will be released by ESA
  - An embryonic version is in place with the GAP group in the DPAC
    - GAP: Gaia Archive Preparation
  - It will develop all the necessary data mining tools to handle requests
- The actual tasks are in the process of early definition
  - requirements and specification document drafted
- Funding (not included in the current DPAC) being discussed with the national agencies
- large Expressions of Interest received from groups or countries


Thanks for your attention
esa