Gaia: A brief overview of the ESA space astrometry project

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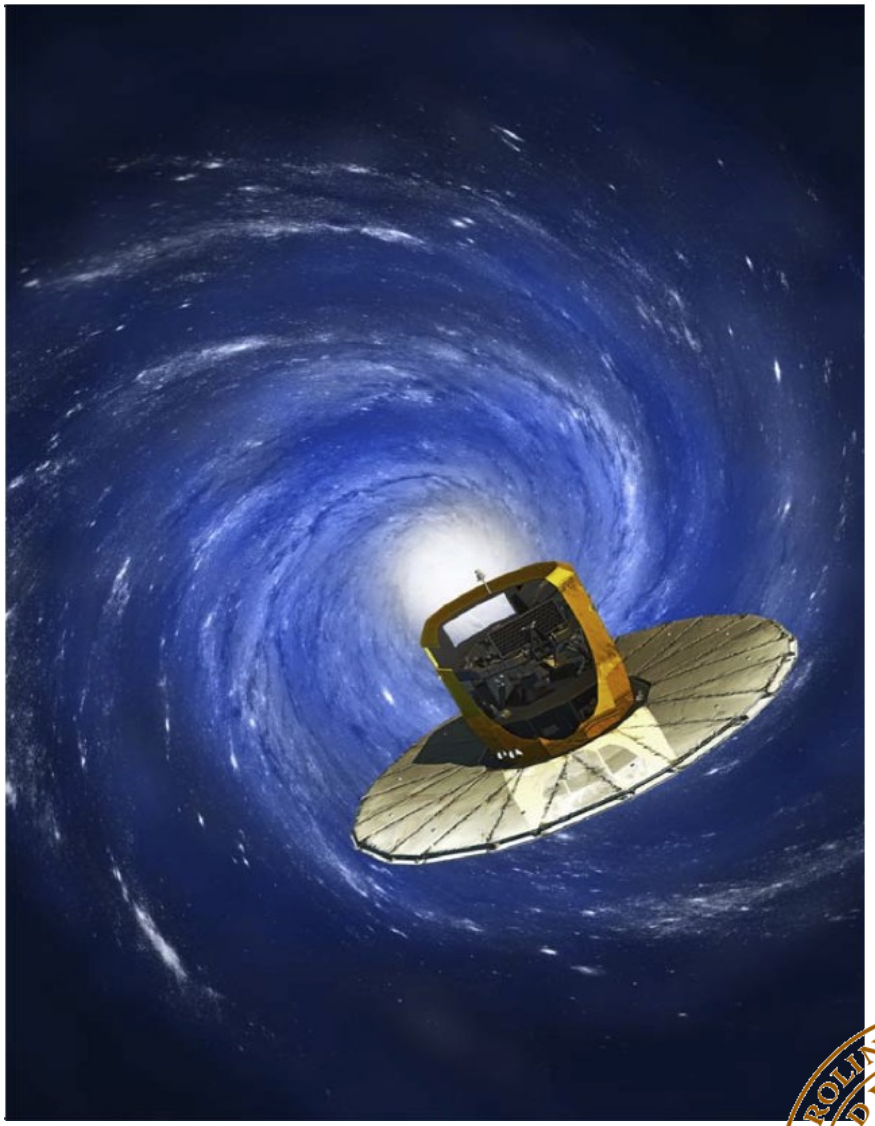
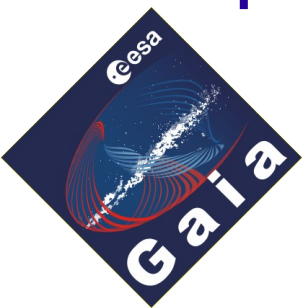
Outline of talk

- Gaia in a nutshell
- Organization and schedule
- Observation principle
- Hardware
- Software
- What we do in Lund



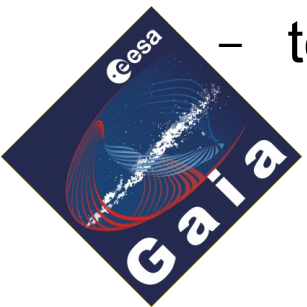
Gaia in a nutshell - project

- **All-sky astrometric survey carried out 2012 – 2017**
  - final results around 2020
  - positions, parallaxes (distances), proper motions (transverse vel.)
  - flux measurements at low spectral resolution $\lambda/\Delta\lambda \sim 30$
- **All point objects between magnitude 6 and 20**
  - stars, asteroids, quasars, extragalactic supernovae, etc
  - about 10^9 objects
- **Using Hipparcos principle (scanning, two fields of view)**
  - positional accuracy from 6 μas (bright stars) to 200 μas (faint)
  - tied to a non-rotating frame via ~500,000 quasars
- **Spectroscopic radial velocities (V < 16, few km/s)**

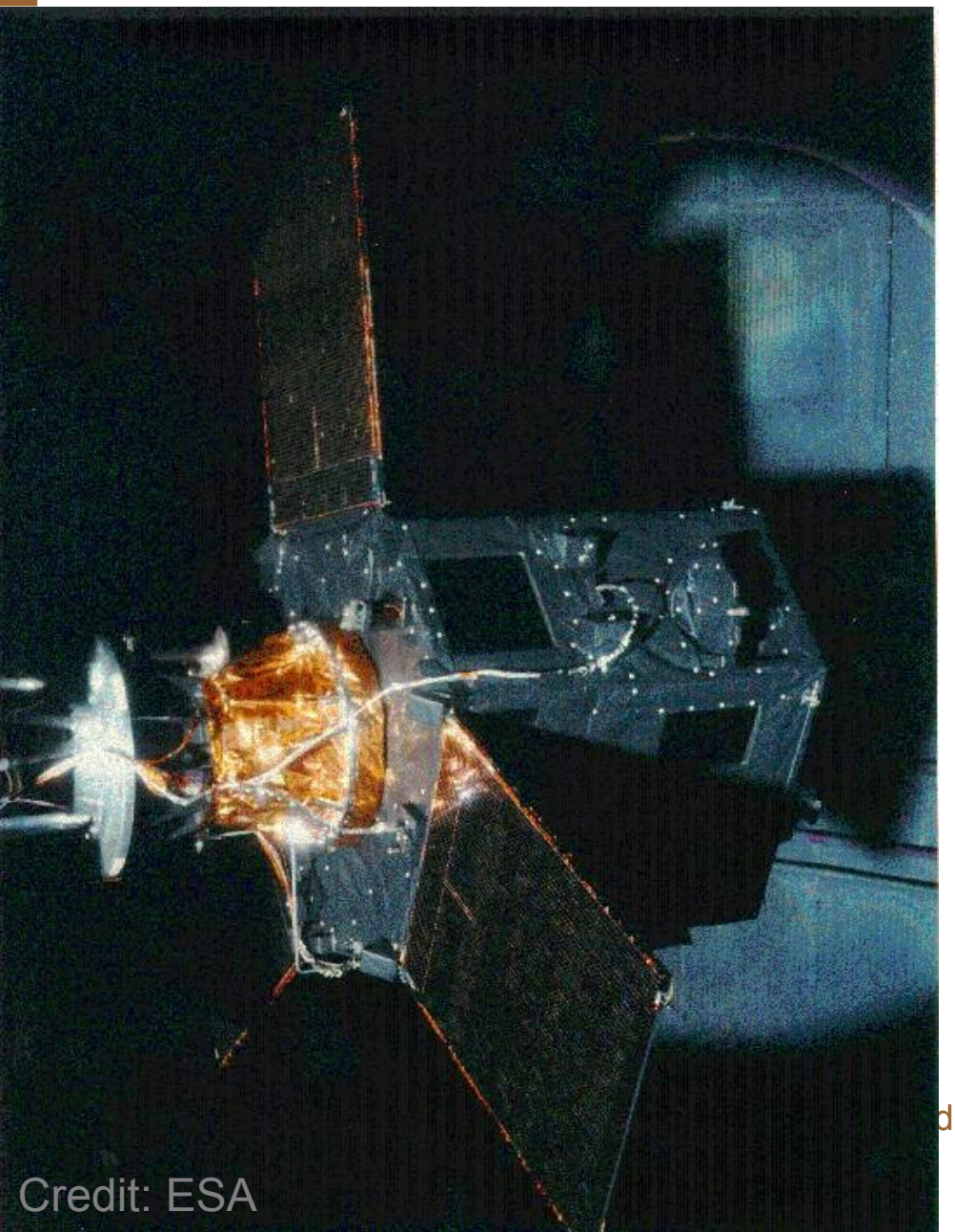


Gaia in a nutshell - science

- **Stellar astrophysics:**
  - accurate (< 1%) parallax distances to millions of stars
  - astrometric detection of (large) planetary companions
- **Galactic astrophysics:**
  - space motions of large, volume-complete stellar samples
  - galactic potential, distribution of (dark) matter
  - history of star formation and how the Galaxy was put together
- **Solar system physics:**
  - about 300,000 asteroids observed (orbits, masses)
- **Reference frame and fundamental physics:**
  - dense and accurate optical frame tied to the extragalactic frame
  - tests of General Relativity (PPN γ, β)



Hipparcos: pioneering space astrometry

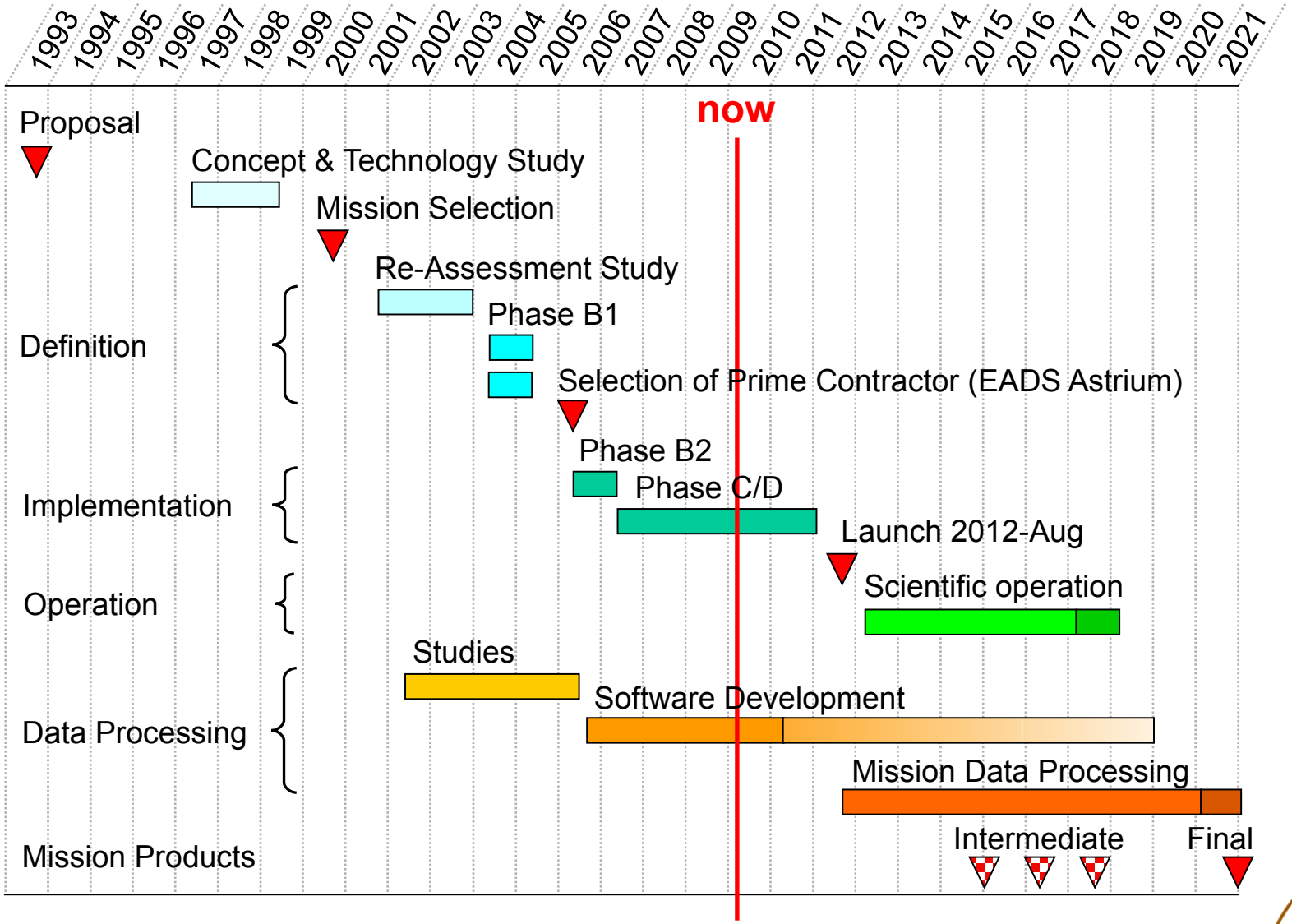


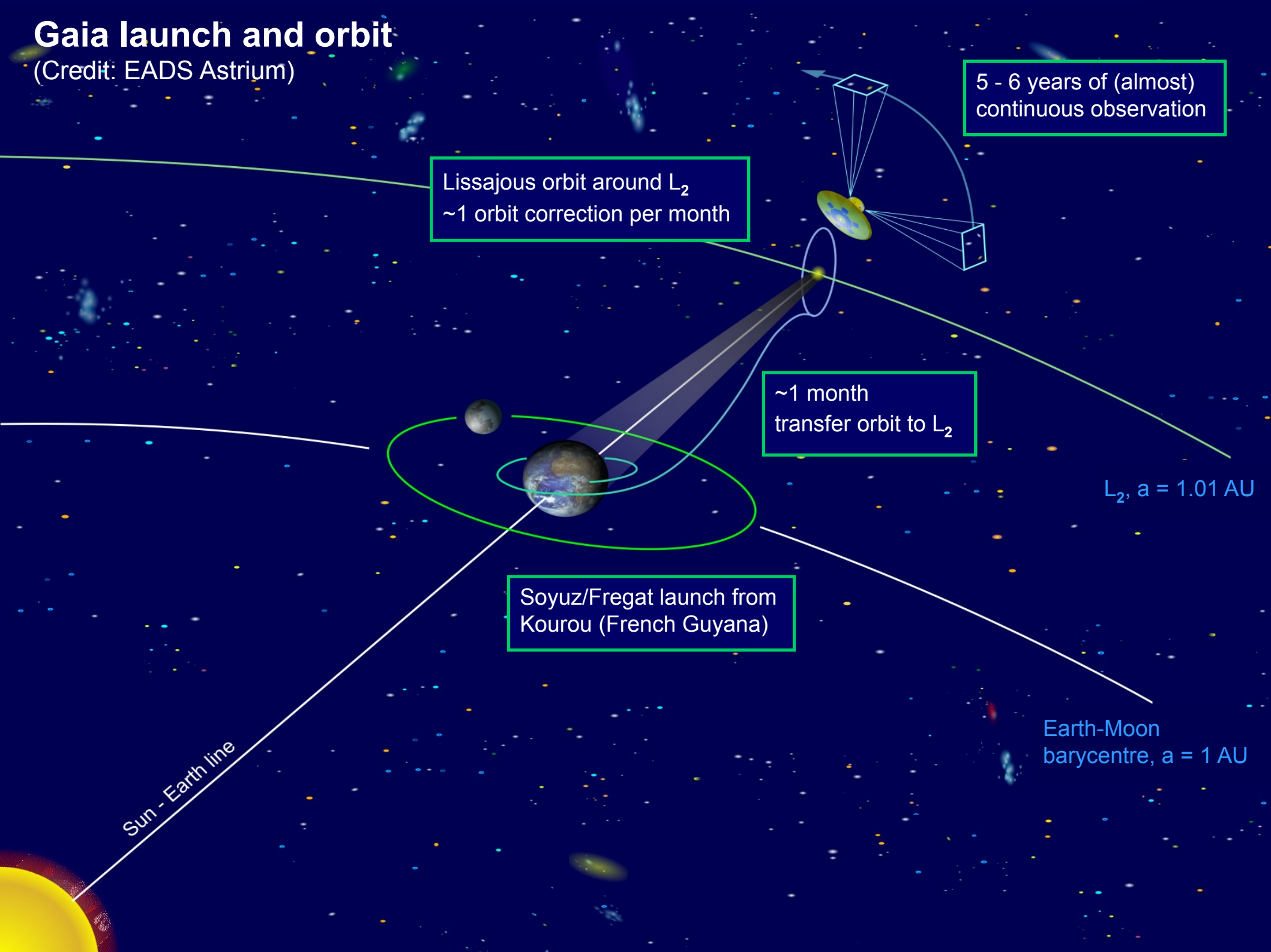
- The Hipparcos satellite was launched by ESA in 1989
- ~ 100,000 stars, typical accuracy 1-2 mas
- The Hipparcos Catalogue (1997) is a main source of fundamental data for stars in the solar neighbourhood
- Gaia is 10-100 times more accurate, for 10,000 times as many stars
- Total cost roughly the same (~ 600 M€)

Organization - the main partners in Gaia

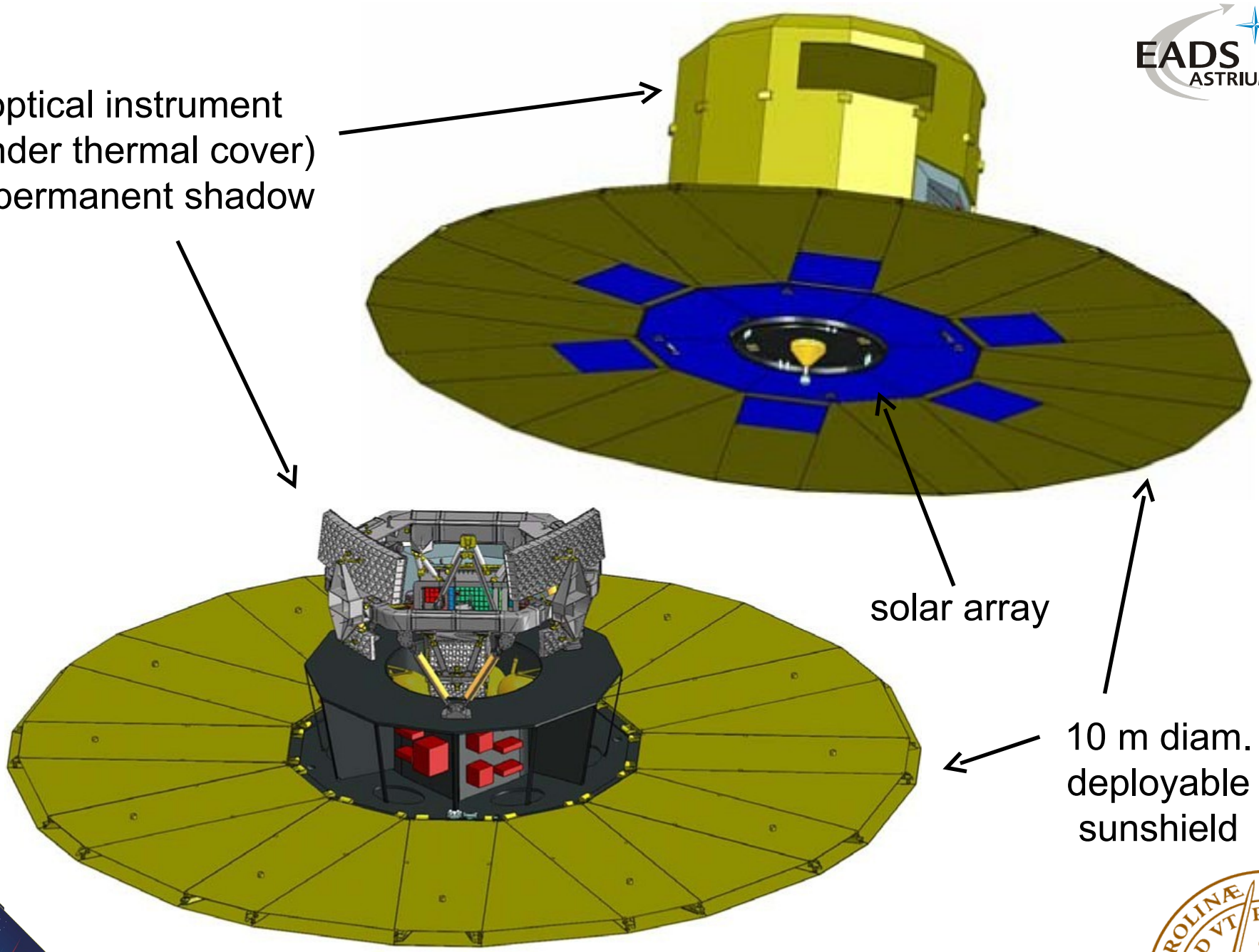
- **European Space Agency (ESA):**
  - overall project responsibility
  - procurement and funding of satellite, launch and operations
  - Gaia Science Team (LL is a member)
- **EADS Astrium:**
  - prime industrial contractor for designing and building the satellite
- **Gaia Data Processing and Analysis Consortium (DPAC):**
  - scientific processing of the satellite data Gaia Catalogue
  - this is our main involvement
- **International scientific community:**
  - end users of the Gaia Catalogue (no data rights restrictions)

Gaia - schedule




Gaia launch and orbit
(Credit: EADS Astrium)
5 - 6 years of (almost) continuous observation
Lissajous orbit around L_2
~1 orbit correction per month
~1 month transfer orbit to L_2
L_2, a = 1.01 AU
Soyuz/Fregat launch from Kourou (French Guyana)
Earth-Moon barycentre, a = 1 AU
Sun - Earth line

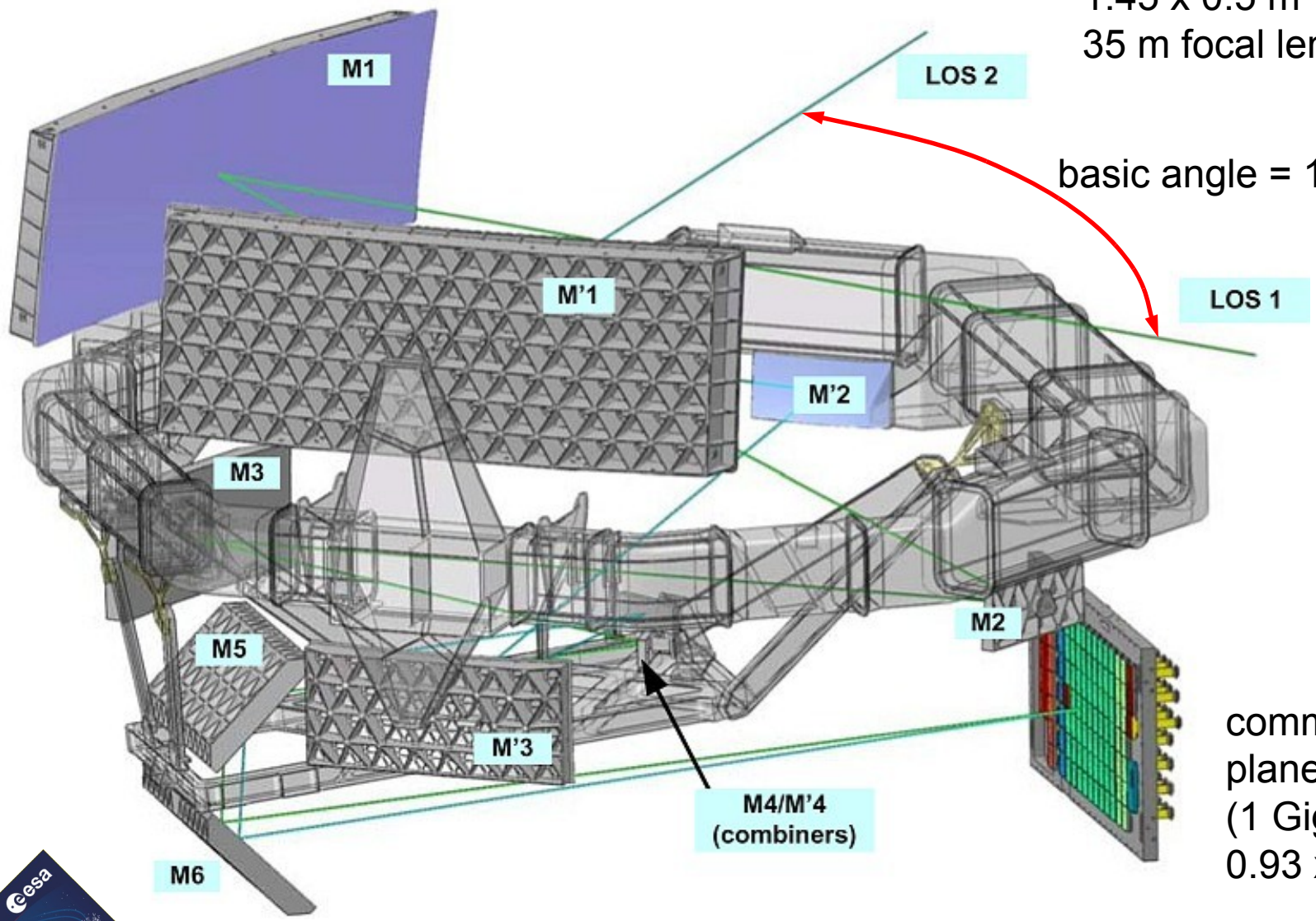
optical instrument
(under thermal cover)
in permanent shadow



solar array

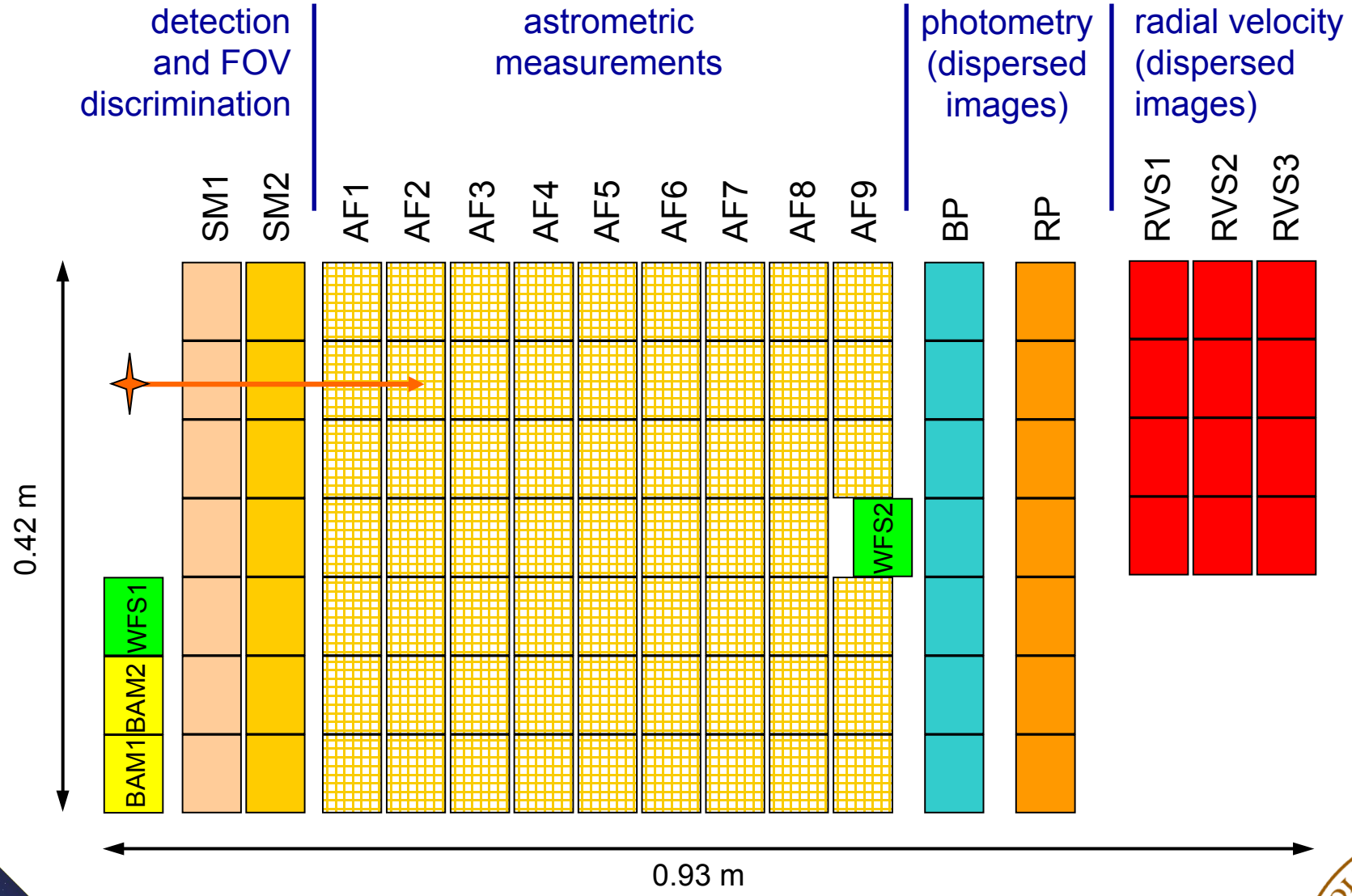
10 m diam.
deployable
sunshield

2 off-axis telescopes
1.45 x 0.5 m² aperture
35 m focal length



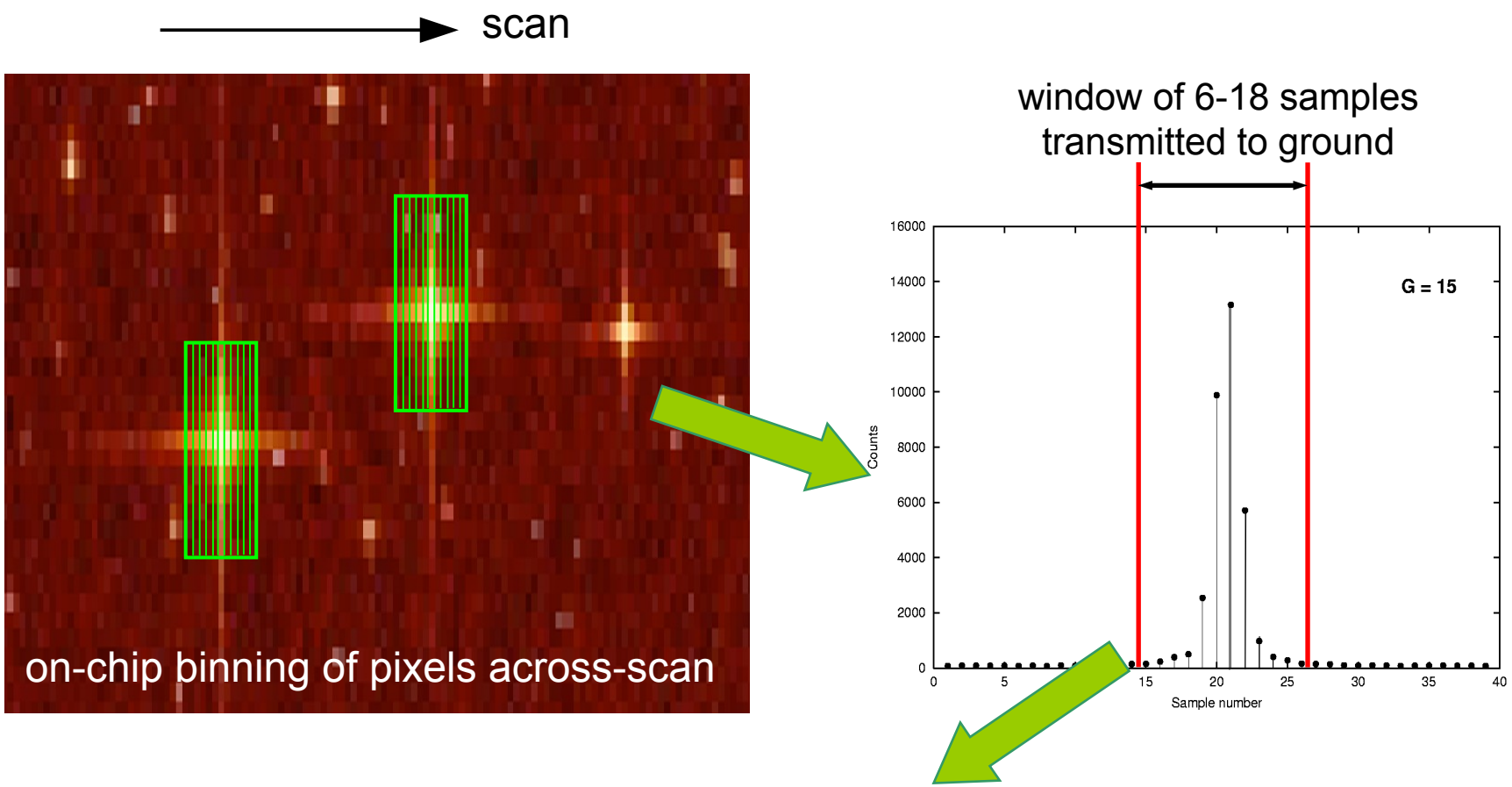
common focal plane, 106 CCDs (1 Gigapixel) 0.93 x 0.42 m²

Gaia focal plane (106 CCDs)



BAM = basic angle monitor, WFS = wavefront sensor

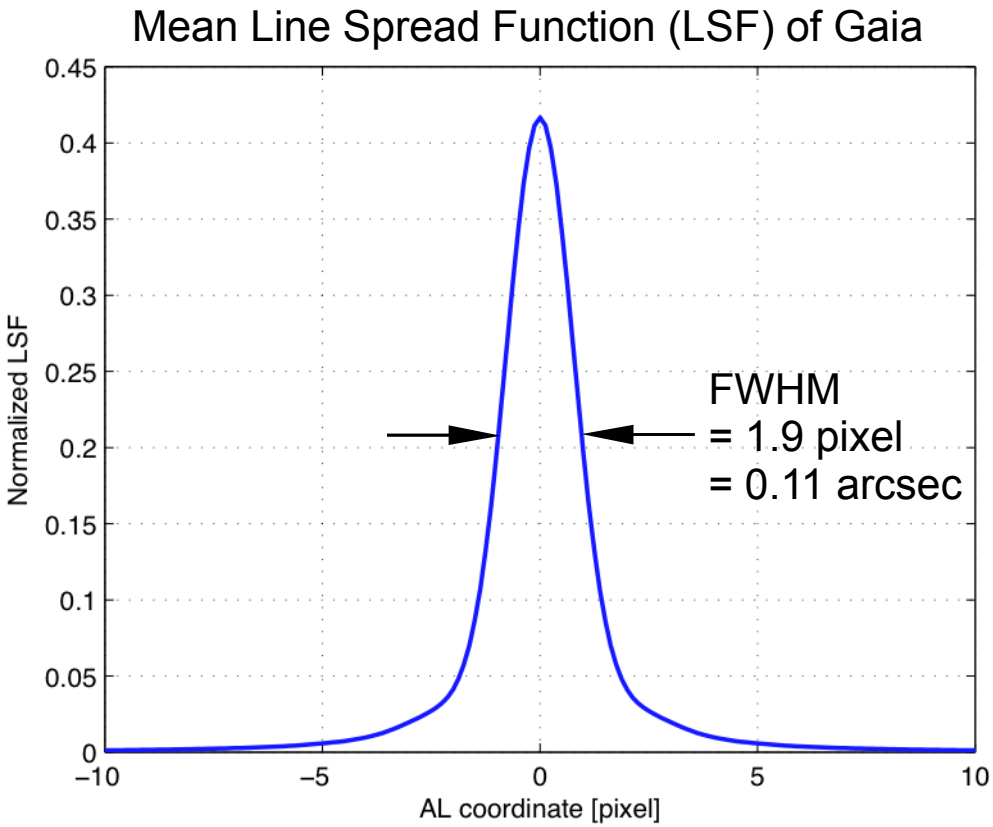
CCD data collection in the astrometric field



"Time of observation" for image centre relative to CCD determined to ~200 μas precision (magnitude 15)

Some 700 such measurements per object in 5 years

Precision of image location (”centroiding”)



- Theoretical precision (diffraction + photon noise):

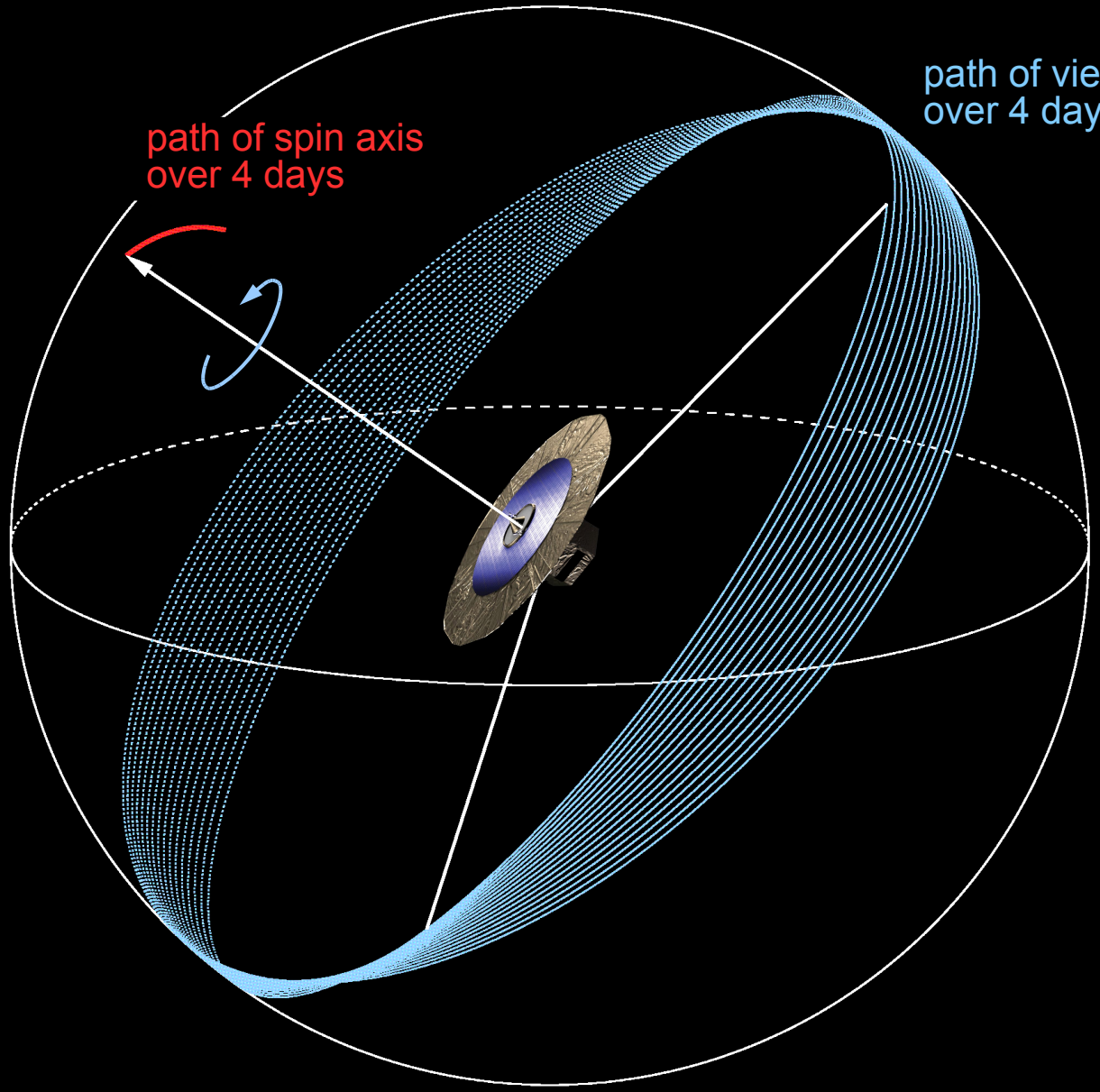
$$\sigma \geq \frac{\sqrt{3}}{2\pi} \frac{\lambda_{\mathrm{eff}}}{D\sqrt{N}}$$

- λ_{eff} = 700 nm
- D = 1.45 m
- N = 80000 e^- (15 mag G2V)

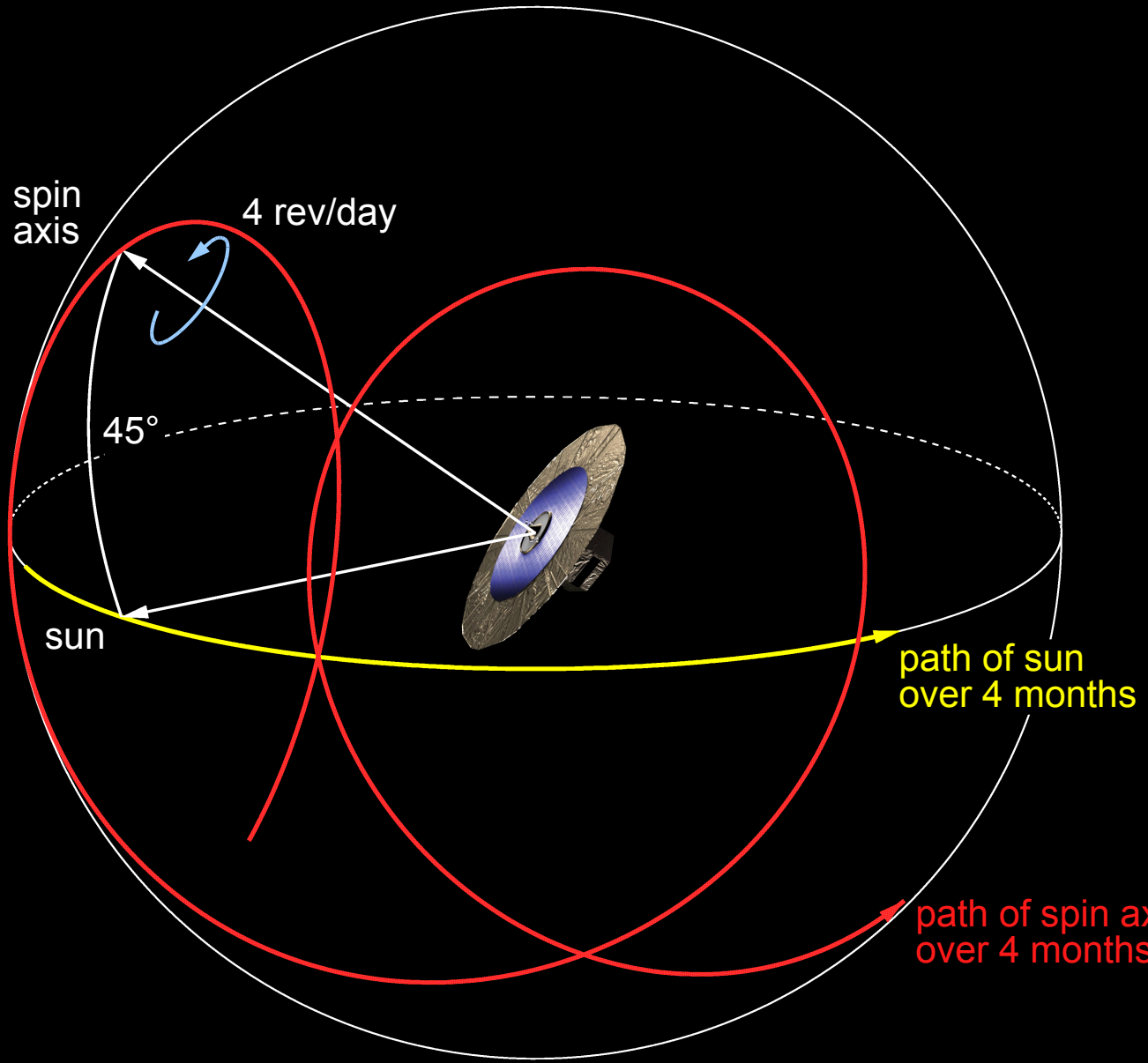
σ ≥ 100 μas
per CCD crossing (4.4 s)

- budget σ = 240 μas

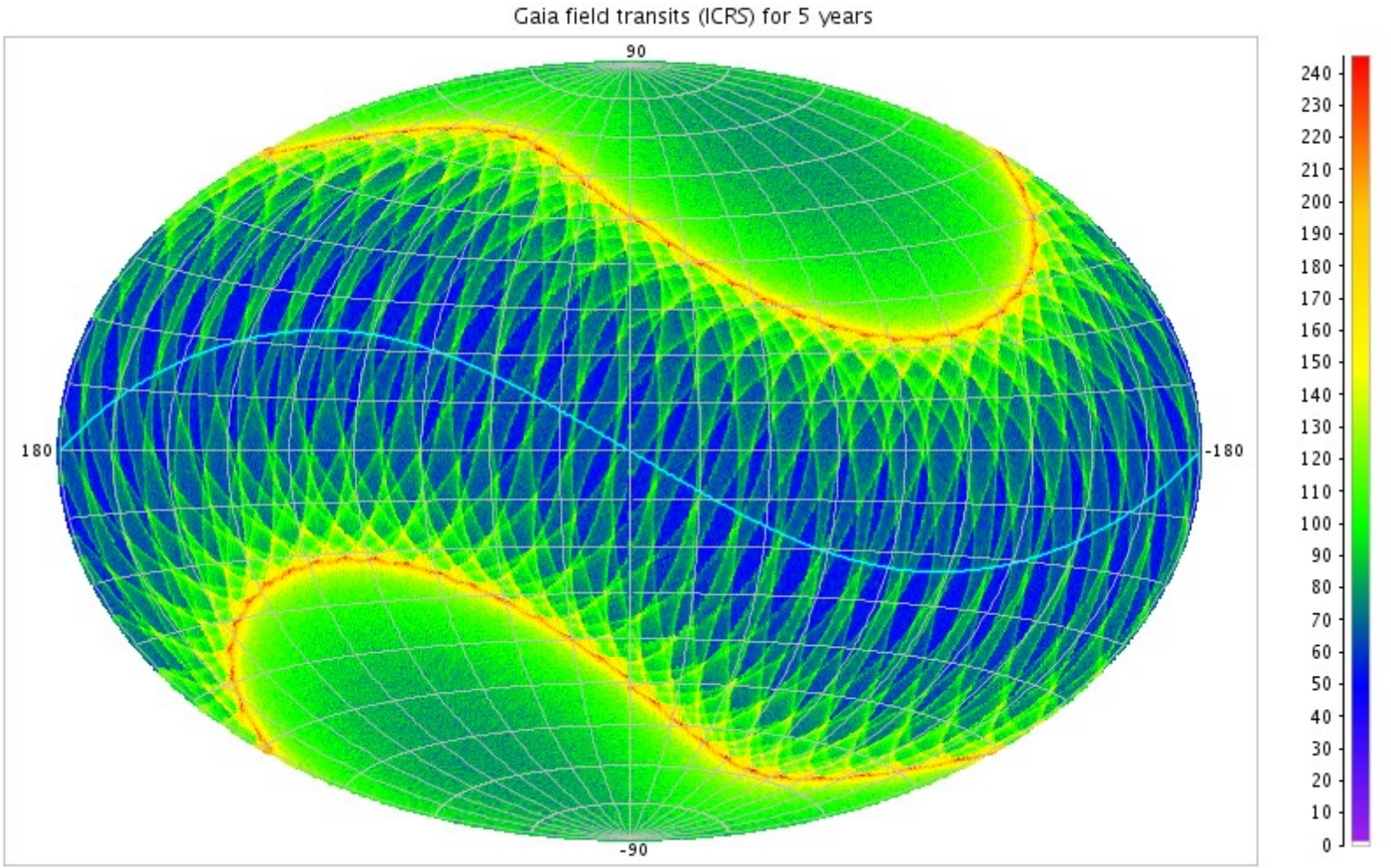
Gaia scanning: Motion of viewing directions over 4 days



Gaia scanning: Motion of the spin axis over 4 months



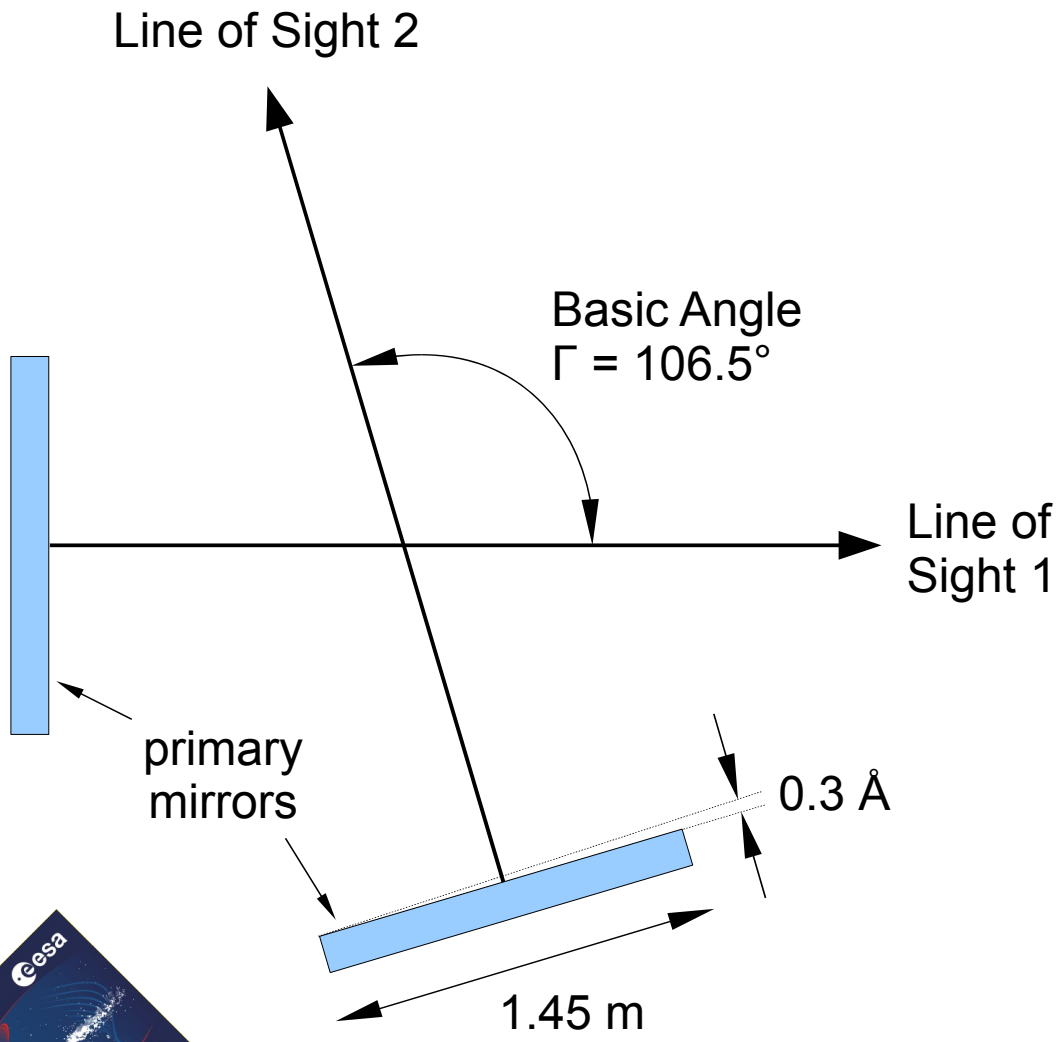
Number of FoV crossings per star (5 years)



Equatorial projection

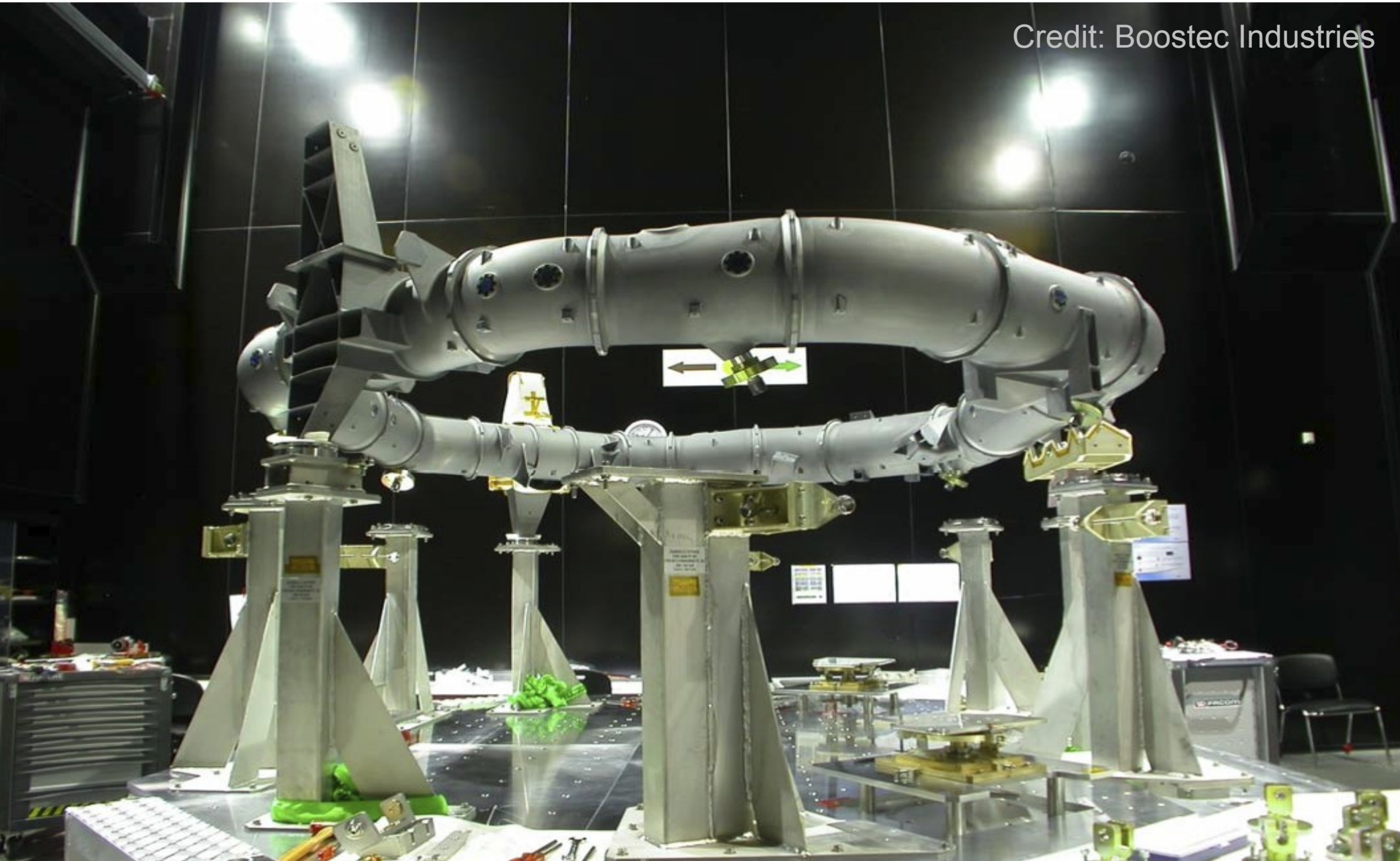
sky average
= 80

The extremely stable basic angle is the key to accurate large-angle measurements

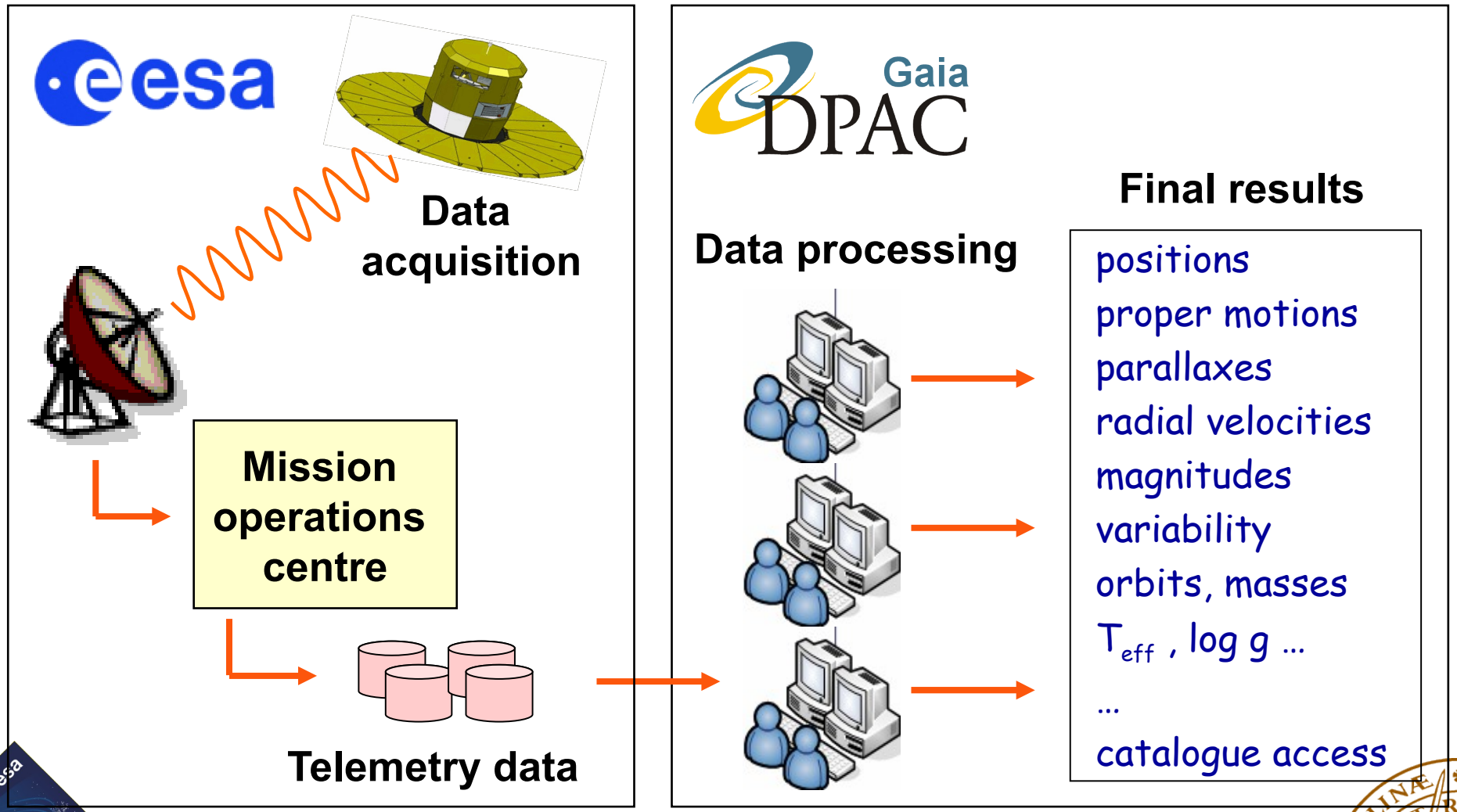


- Technical requirement: $\Delta\Gamma < 8$ μas RMS on time scales < 6 hr
- Corresponds to 0.3 Å at the edge of the primary mirrors
- Achieved by passive stabilization (few μK) and uniform, low-expansion material (SiC)
- Scientifically, we hope for 10x better performance!

SiC torus (optical bench) finished

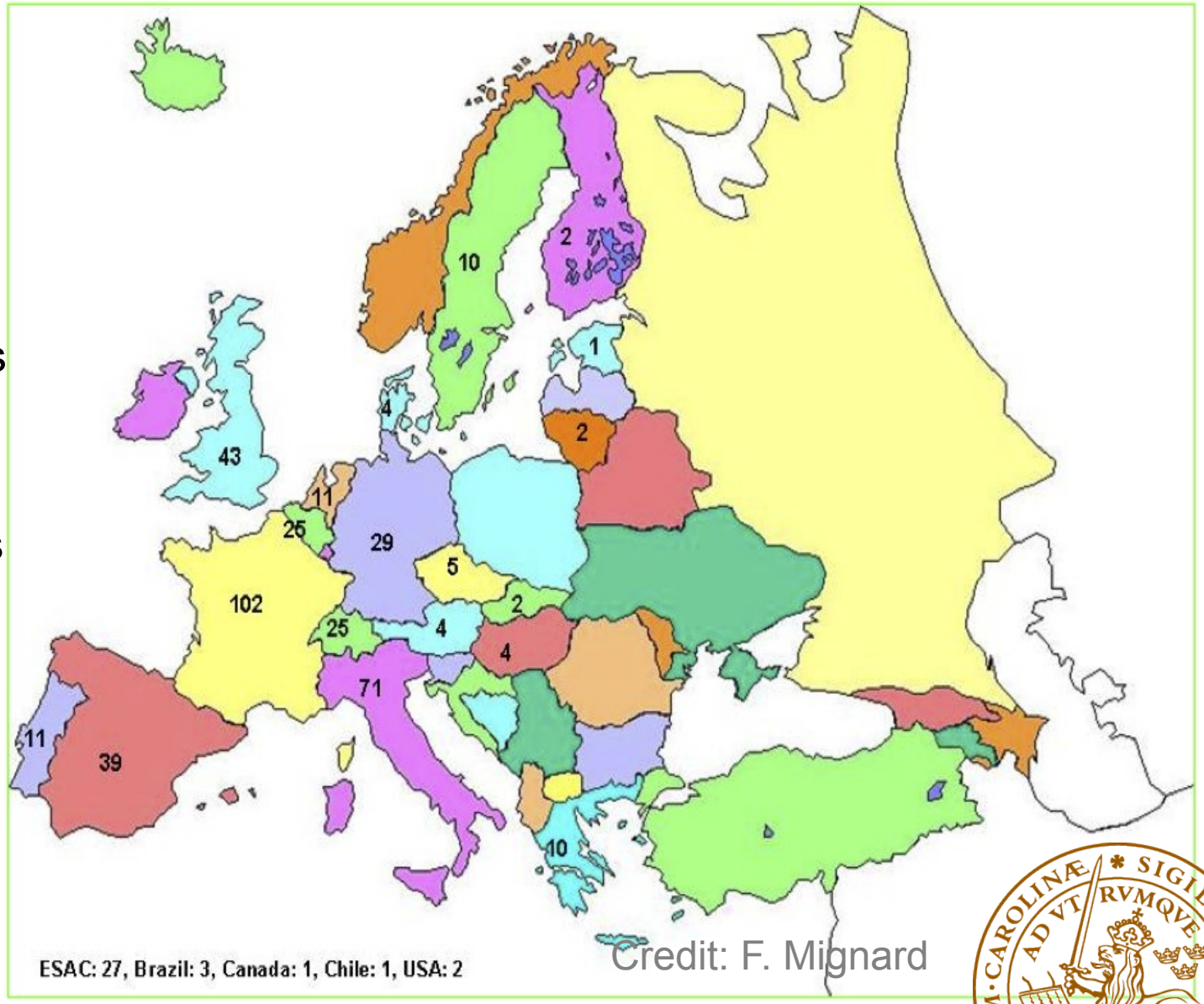


ESA and DPAC responsibilities



Gaia Data Processing and Analysis Consortium (DPAC)

- Individual persons organized in an ad hoc structure
- About 430 members (January 2010)
- 24 funding agencies
- 6 data processing centres



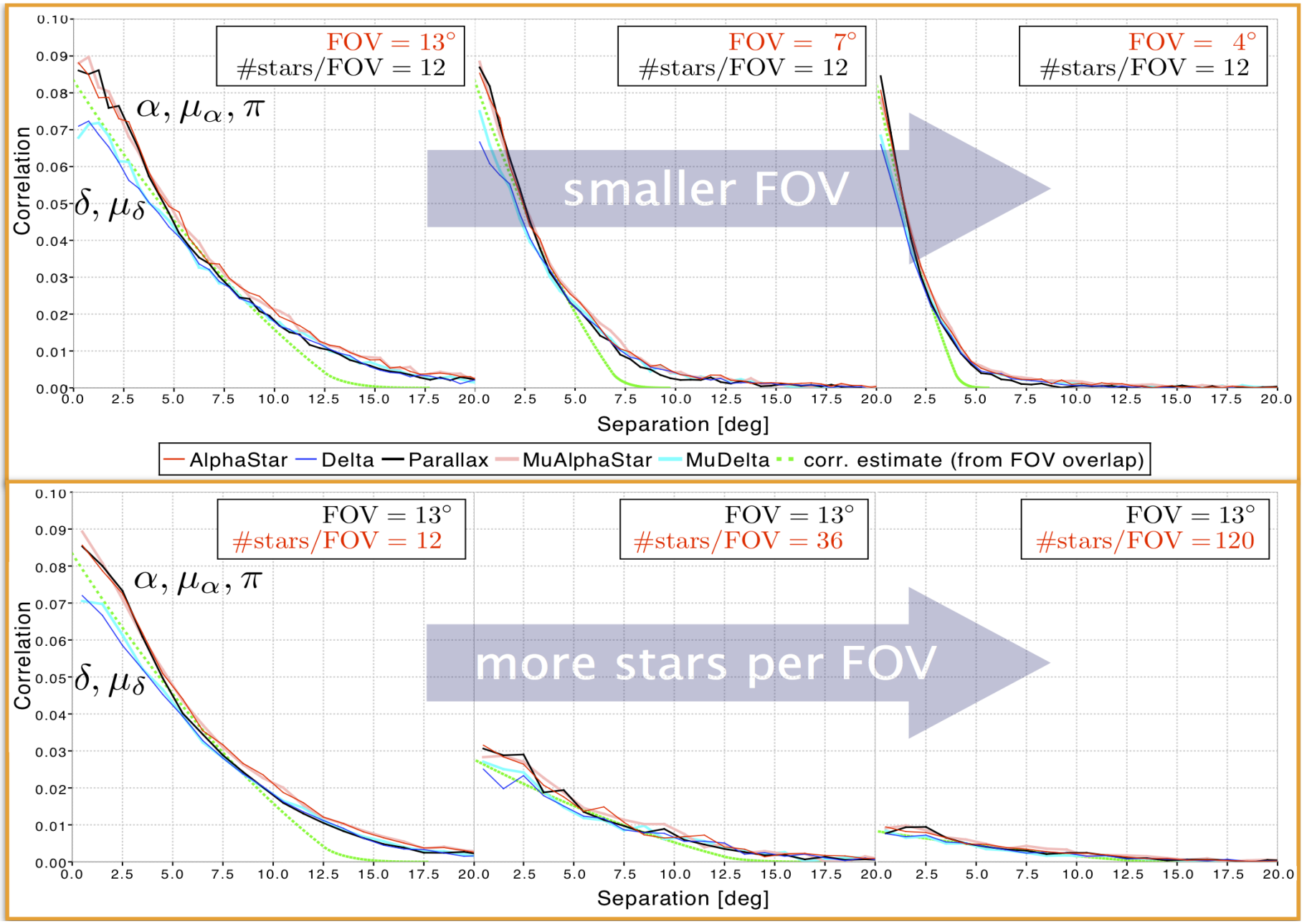
Credit: F. Mignard

Role of Lund in DPAC

- We provide algorithms and software for the core astrometric solution
  - AGIS = Astrometric Global Iterative Solution
  - must handle at least 10^8 ”clean” stars (i)
  - 500 million astrometric parameters (unknowns) $(s_1, s_2, s_3, s_4, s_5)^{(i)}$
  - 40 million attitude parameters (instrument orientation)
  - 1 million instrument calibration parameters
  - a few global parameters (e.g. PPN γ)

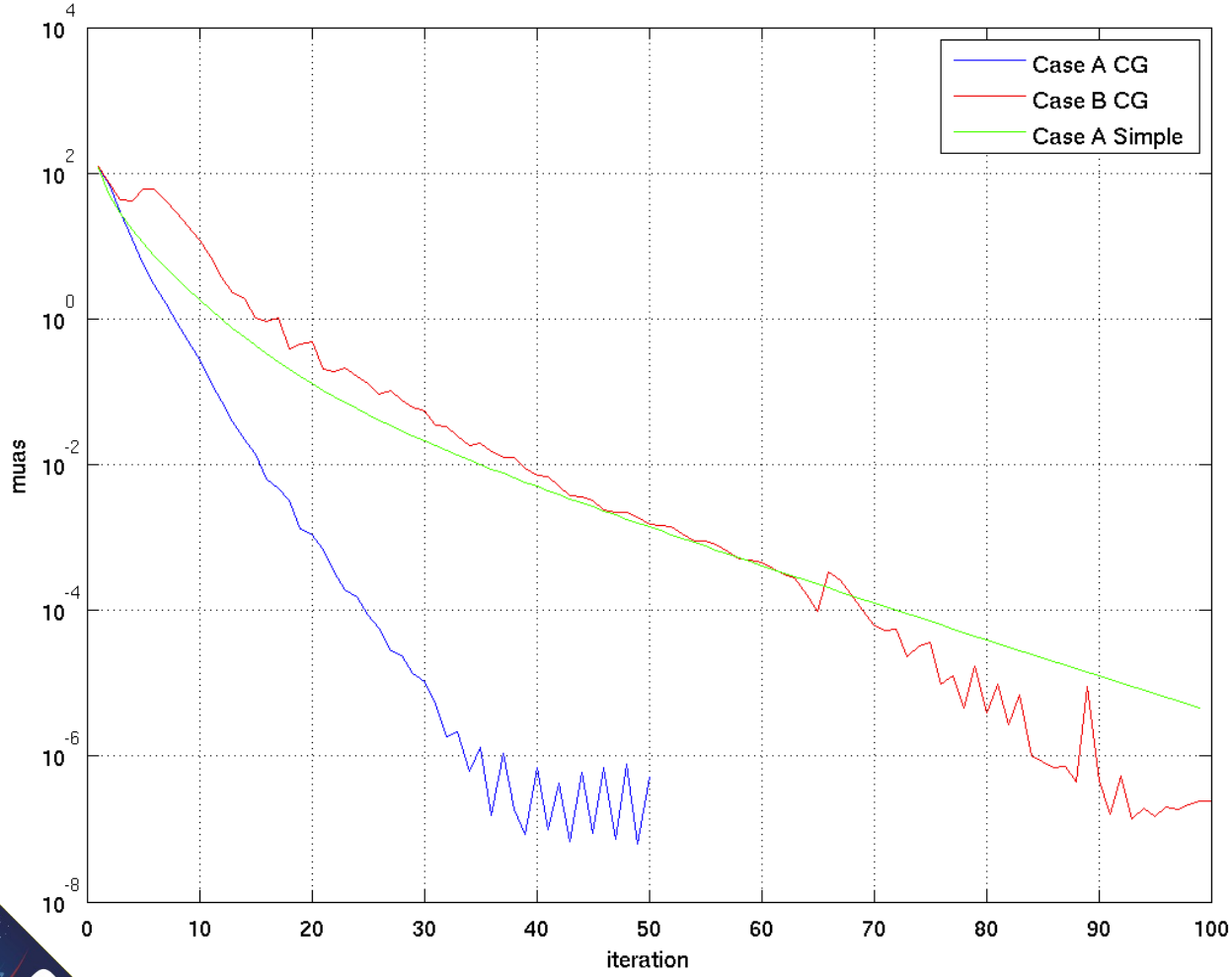
- We study expected properties of the astrometric errors in Gaia
  - e.g. estimate general covariances $\mathrm{Cov}(s_k^{(i)}, s_l^{(j)})$
  - Berry's thesis project
  - uses a scaled-down simulation testbed: AGISLab

First results on spatial correlations (Holl)

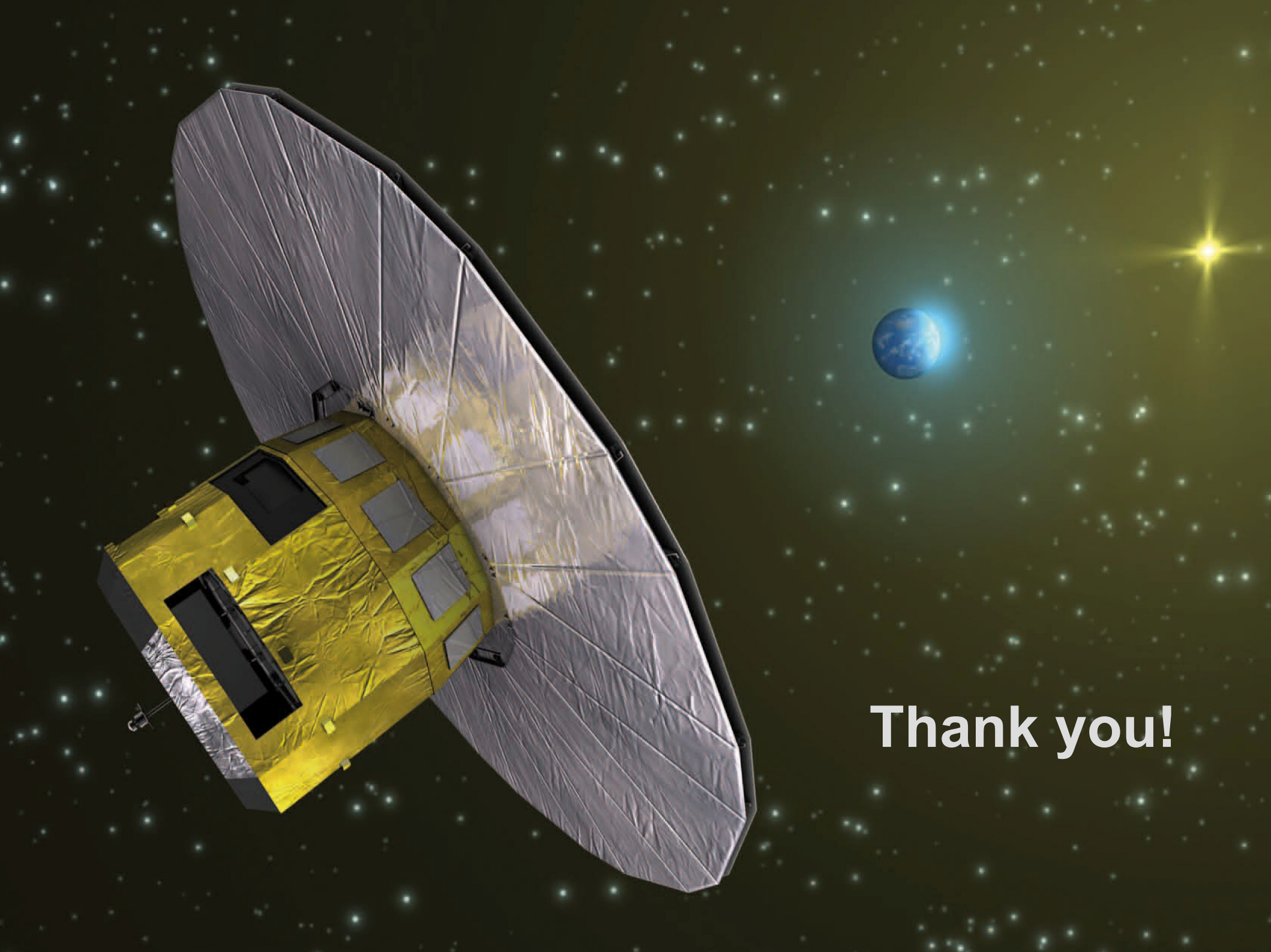


AGIS: Proof of convergence (2009)

- Using AGISLab, it was demonstrated that AGIS provides the rigorous solution of the least-squares estimation problem (full convergence)



Results obtained in collaboration with A. Bombrun (Heidelberg)


Thank you!