The Gaia Galactic Survey Mission

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Gaia in a nutshell

high accuracy astrometry:
parallaxes, proper motions

radial velocities, photometry

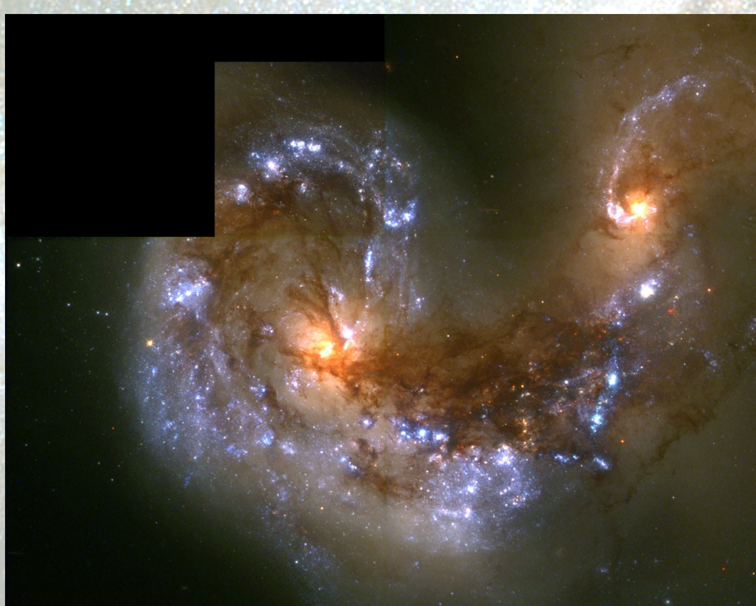
Entire sky to G=20, 100 times over 5 years

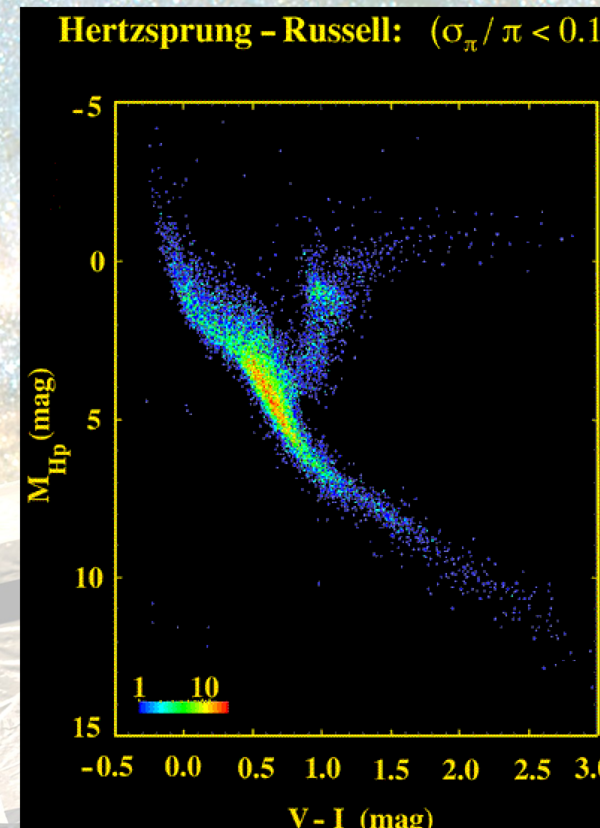
extinction, astrophysical parameters

ESA mission for 2011 launch

Major science topics

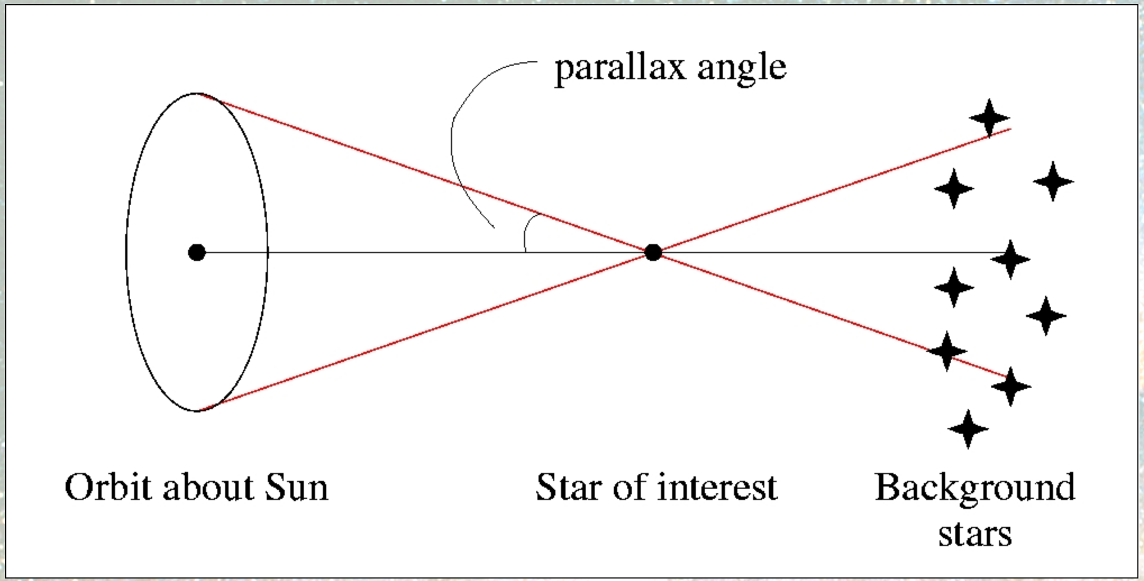
- How and when did the Galaxy form?
  - substructure in disk and halo (mergers)
  - star formation history
- What is the Galaxy made of?
  - chemical evolution
  - distribution of dark matter

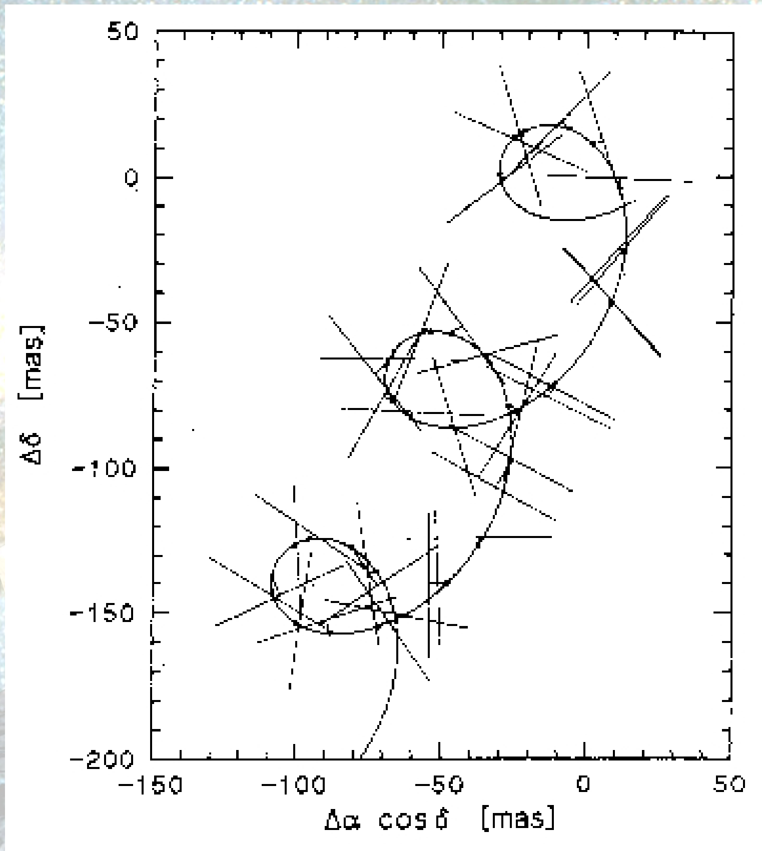




- Stellar structure and evolution: improving models across the whole HRD

What is astrometry?



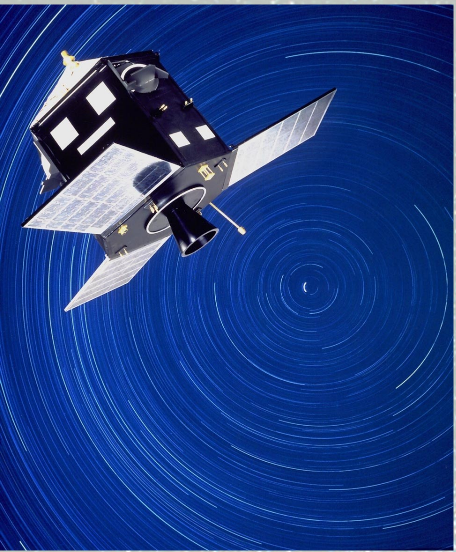


6D phase space: 3D spatial, 3D velocity

A brief history of astrometry

- 125 B.C.: Precession of the equinoxes (Hipparchus)
- 1717: First proper motions (Halley)
- 1725: Stellar aberration (Bradley), confirming:
  - Earth’s motion through space
  - finite velocity of light
  - immensity of stellar distances
- 1761/9: Transits of Venus across the Sun (various)
  - solar parallax
- 1783: Sun’s motion through space (Herschel)
- 1838-9: First parallaxes (Bessel/Henderson/Struve)

Hipparcos vs. Gaia



	Hipparcos	Gaia
Magnitude Limit	12.4	20
No. sources	120 000	1000 000 000
No. quasars	none	0.5-1 million
No. galaxies	none	1-10 million
Astrometric accuracy	~1000 μas	7 μas at G<10
		12-25 μas at G=15
		100-300 μas at G=20
Photometry	2 bands	low resolution spectra
Radial velocities	none	1-10 km/s to G=17-18
Target selection	input catalogue	real-time onboard selection

Distances

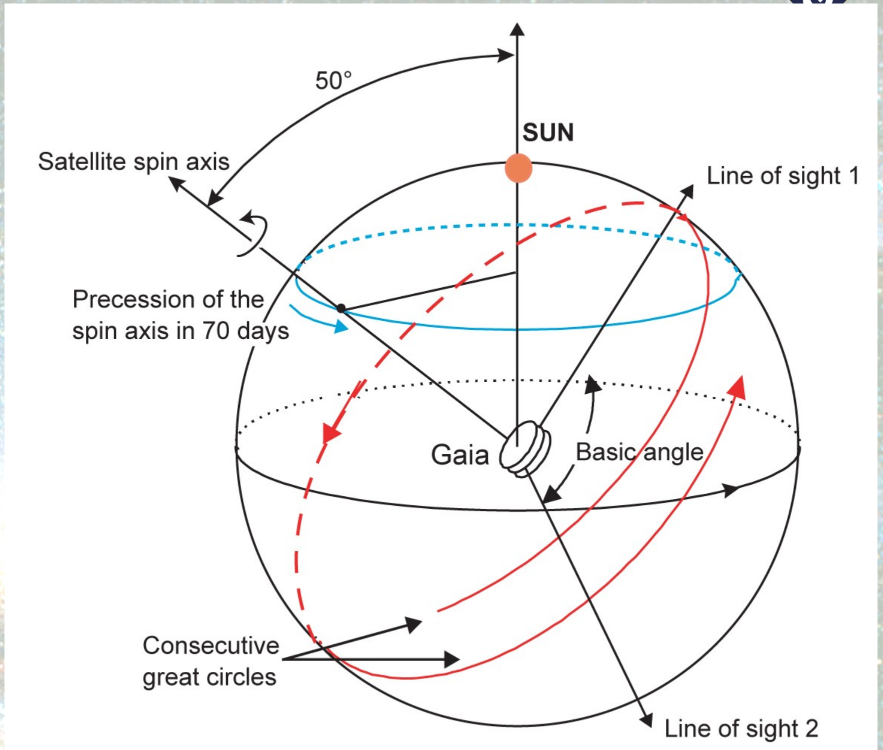
- corresponds to 1–2% distance accuracy at 1kpc for G=15
  - 100,000 stars with distance accuracy better than 0.1%
  - 11 million stars 1%
  - 150 million stars 10%
- important in every area of astronomy
  - angular scales → length scales
  - 3D spatial structure
  - proper motions → velocities
  - intrinsic stellar luminosities
- strength of Gaia is accuracy *and* statistics

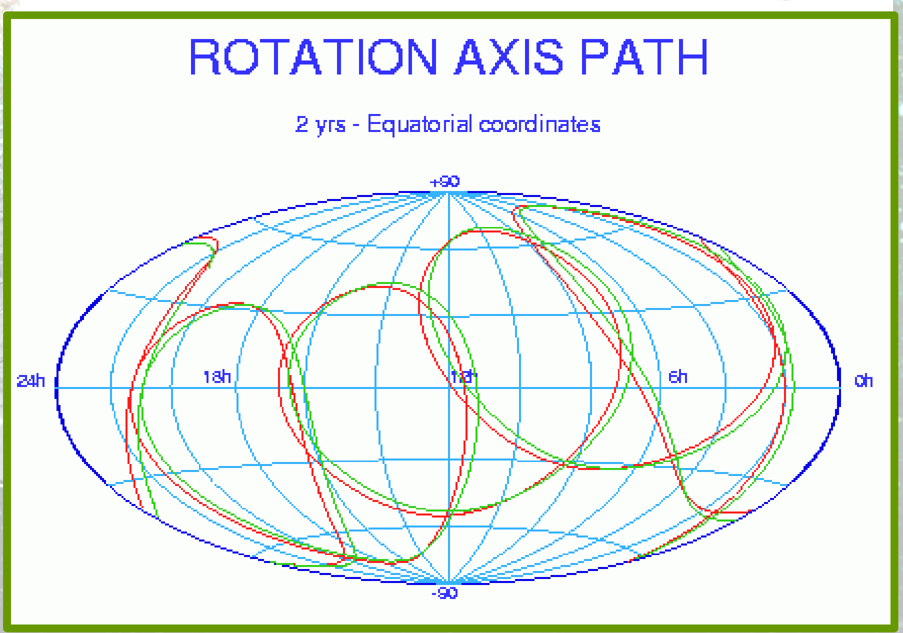
Many science areas

- Galaxy structure *(dark matter potential, abundances)*
- Galaxy evolution *(substructure, star formation history)*
- Stellar populations *(ages, open clusters, SFRs)*
- Stellar structure *(He abundances, luminosities, difusion)*
- Binary stars *(M-L relation)*
- Exoplanets *(orbits, masses, transits*)
- Solar system *(taxonomy, Near-Earth asteroids)*
- Extragalactic *(local group galaxies, supernovae)*
- Cosmic distance scale *(Cepheids, RR Lyr)*
- Reference frame *(quasars)*
- Fundamental physics *(light bending, γ to $5x10^{-7}$)*

Global astrometry

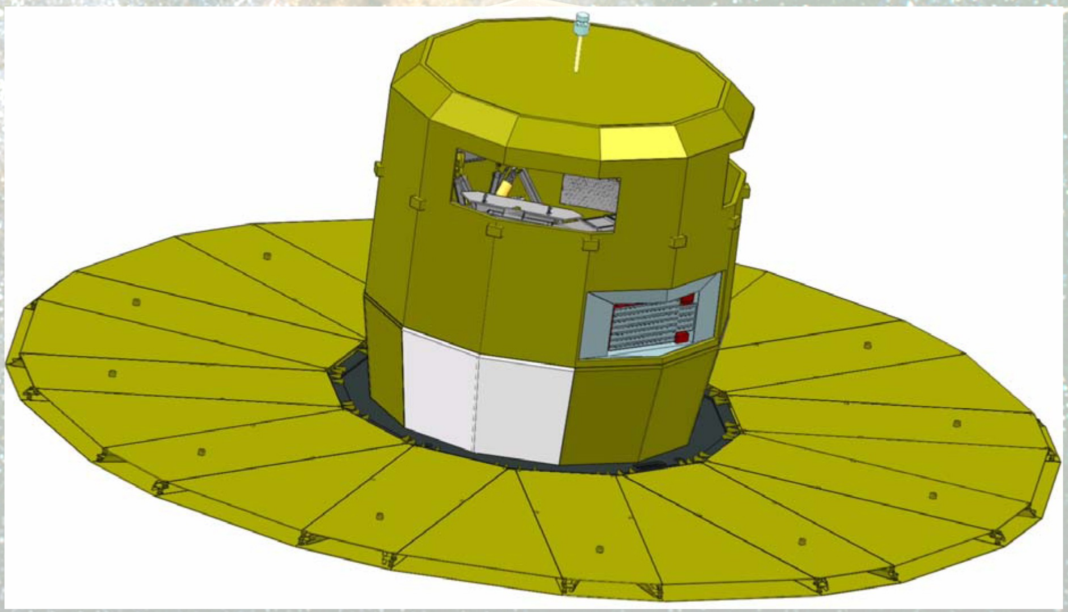
- Space platform required
  - wide field
  - rapid sky coverge
- Scanning principle
  - observe simultaneously in two widely separated fields separated by a fixed *basic angle*
  - measure relative positions along great circle
  - repeat for many orientations over whole sky (for 5 years)





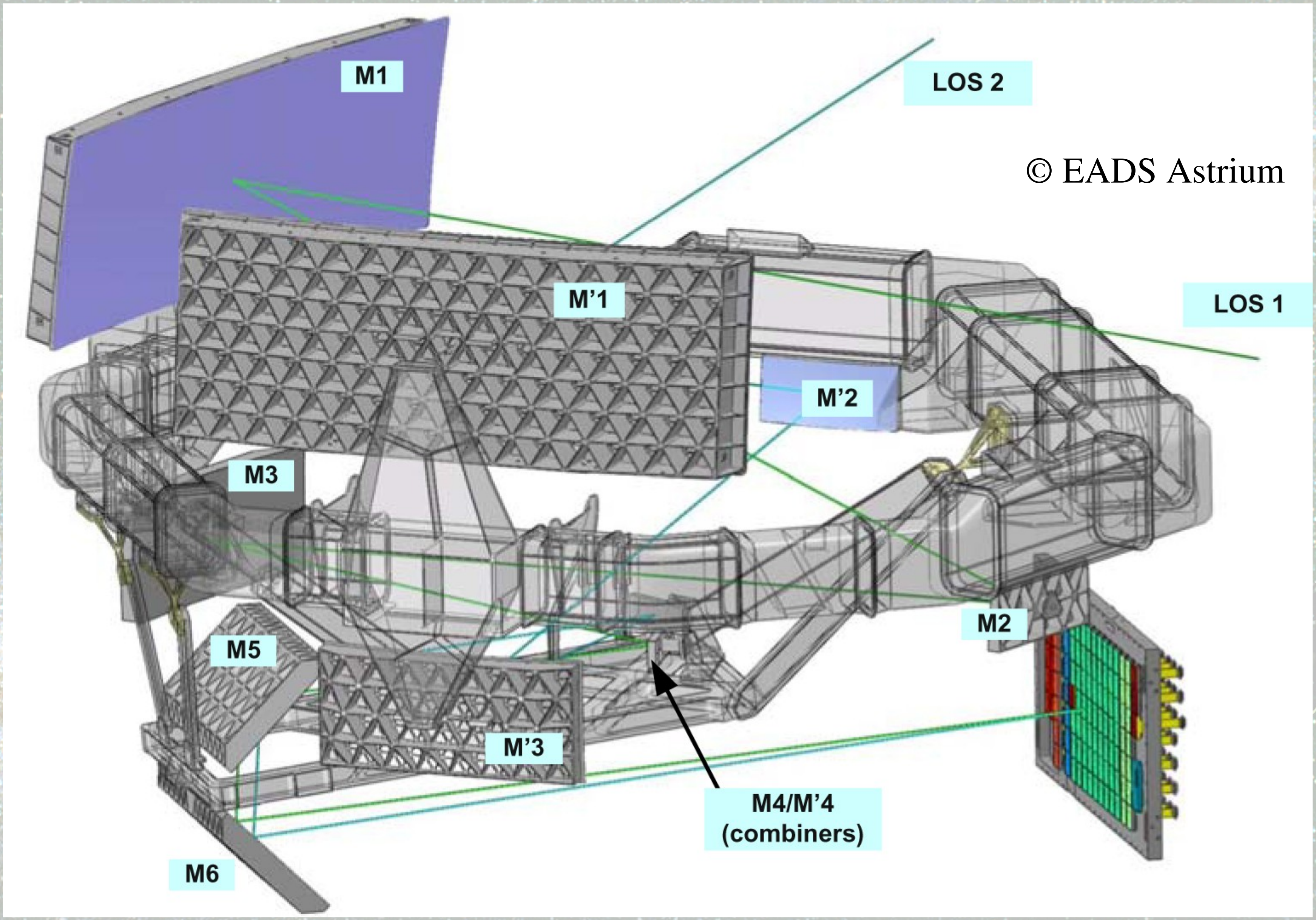
The satellite

- very high thermal and mechanical stability demanded
  - L2 Lissajous orbit
  - no moving parts (phased array antenna)
  - passively cooled
- Soyuz-Fregat launch from Kourou



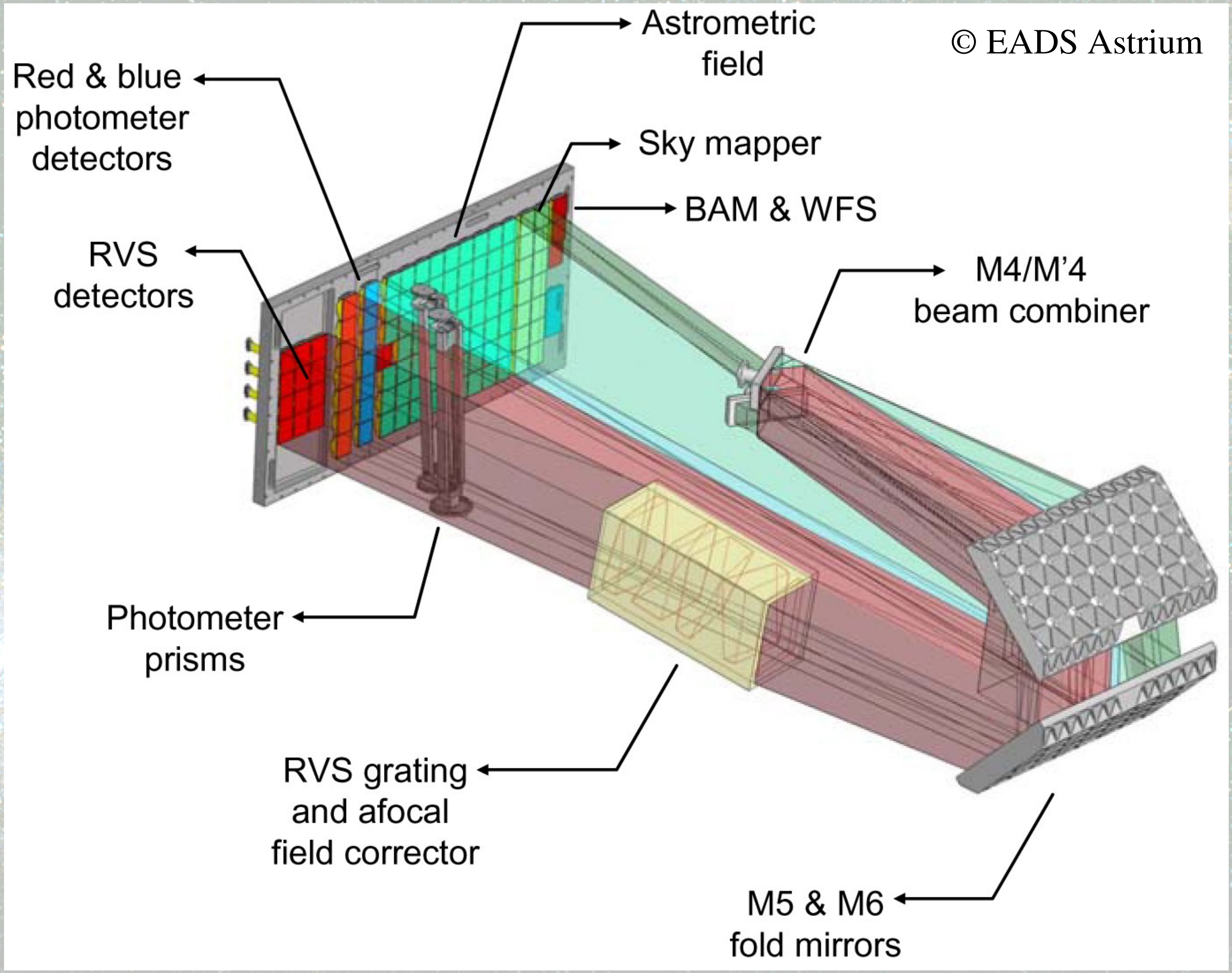
Sunshield diameter = 10m
Total mass = 2000kg
Solar array power = 12 kW

Payload overview

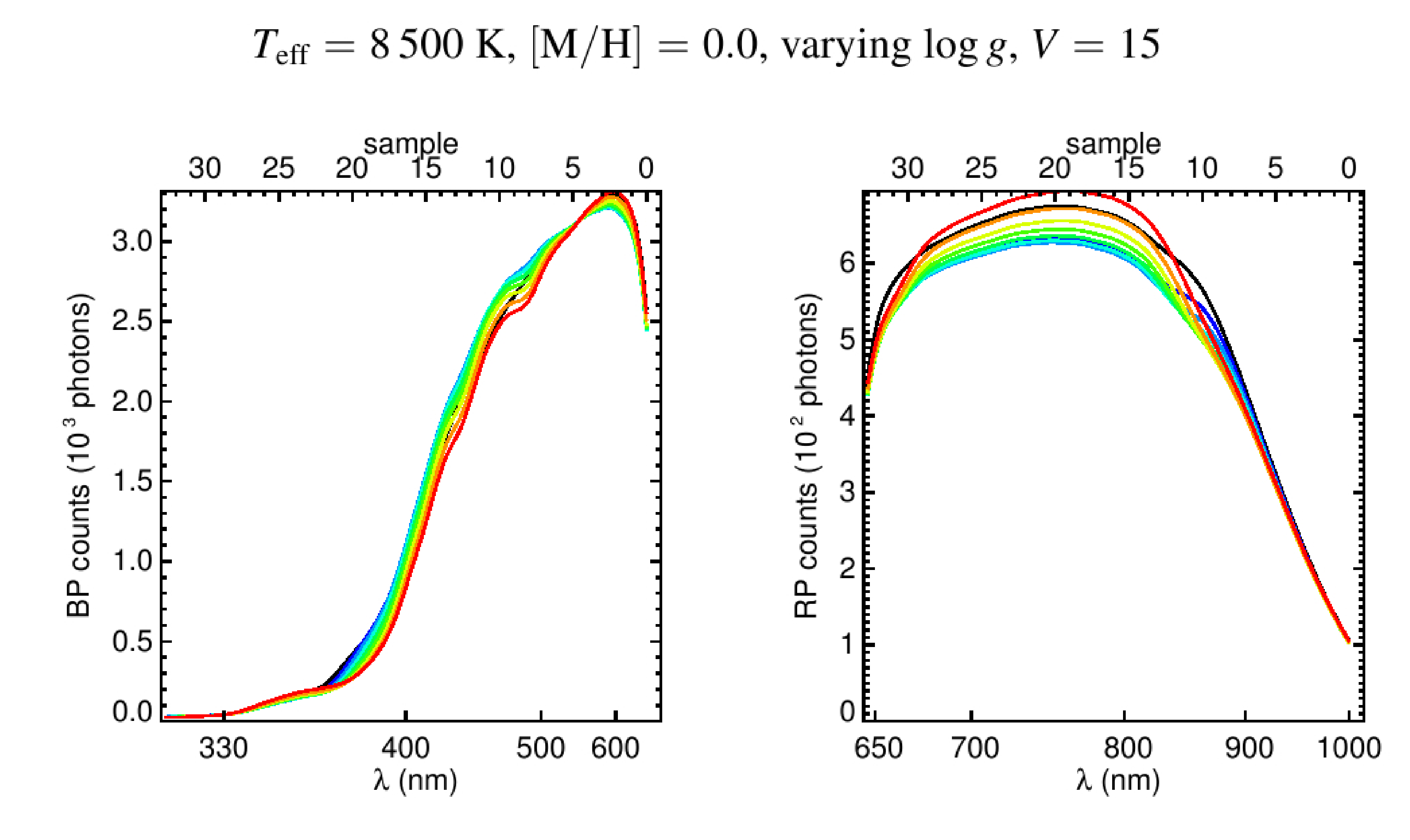


Two fields-of-view superimposed on a common focal plane

Instruments



Spectrophotometry



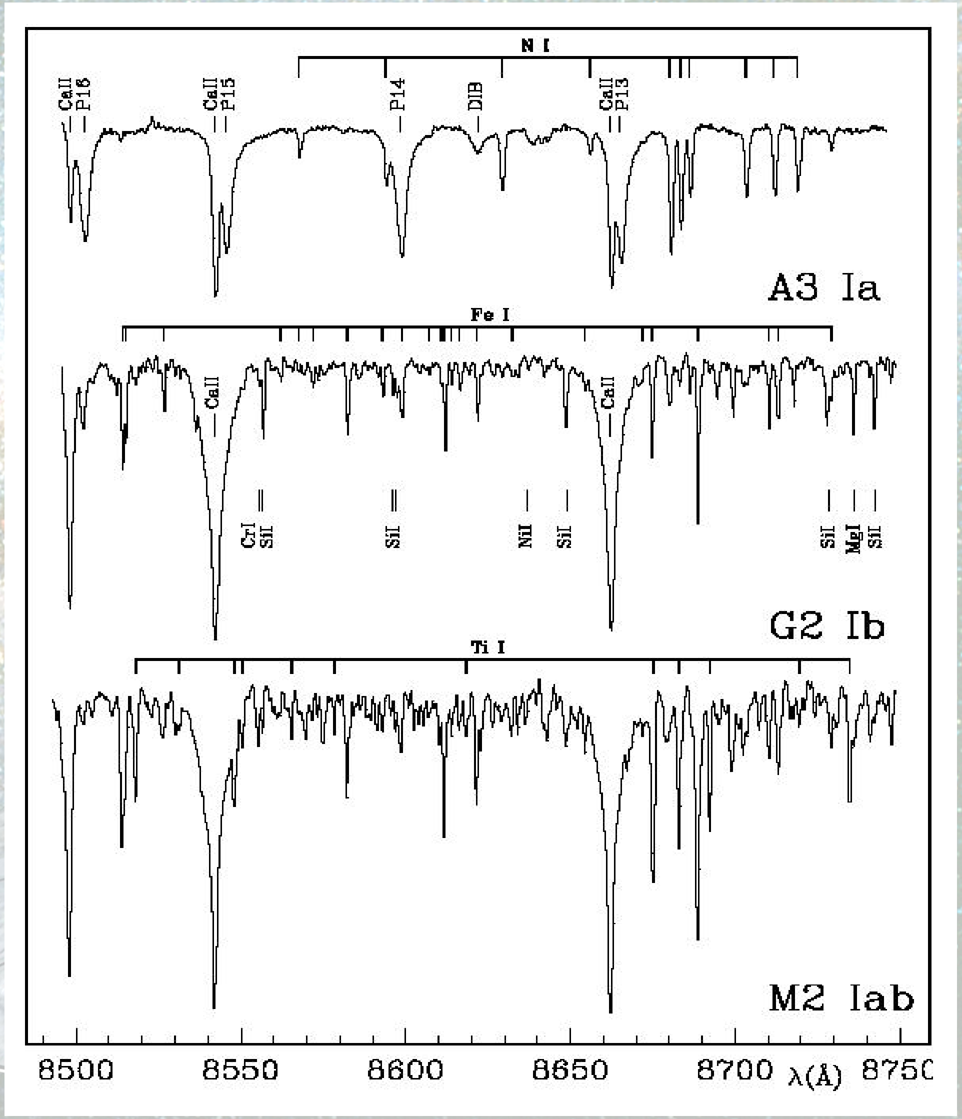
Brown (2006)

Dispersion: 7-15 nm/pixel (red), 4-32 nm/pixel (blue)

Purpose: object classification and estimation of stellar parameters

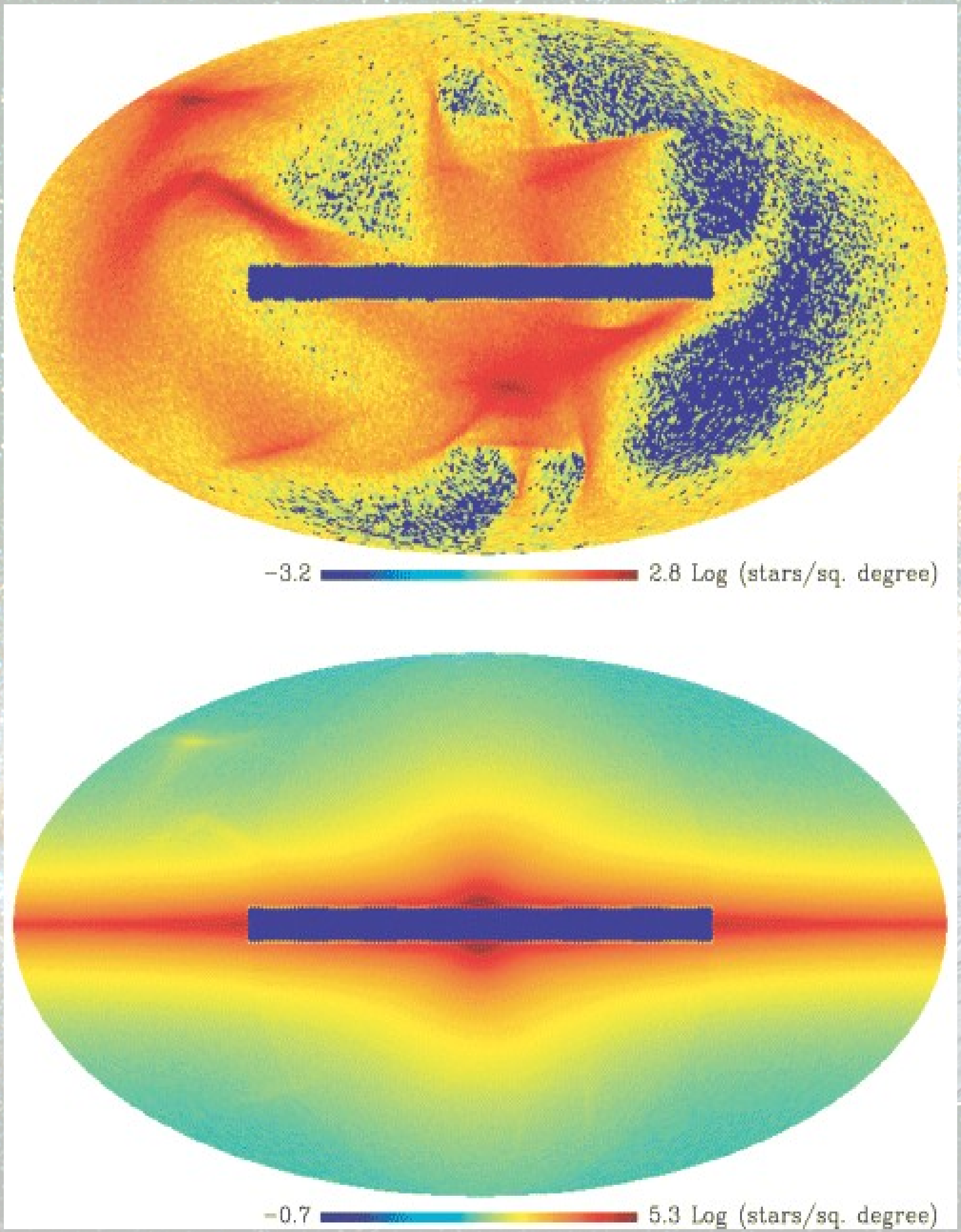
Radial velocity spectrograph

- slitless spectrograph
- R = 11 500
- around CaII triplet (848–874 nm)
- for determining radial velocities
- V_{rad} to 1–10 km/s for V < 17.5
- high SNR spectra for millions of stars with V < 14
  - physical stellar parameters, e.g. [α/Fe]



Detecting substructure

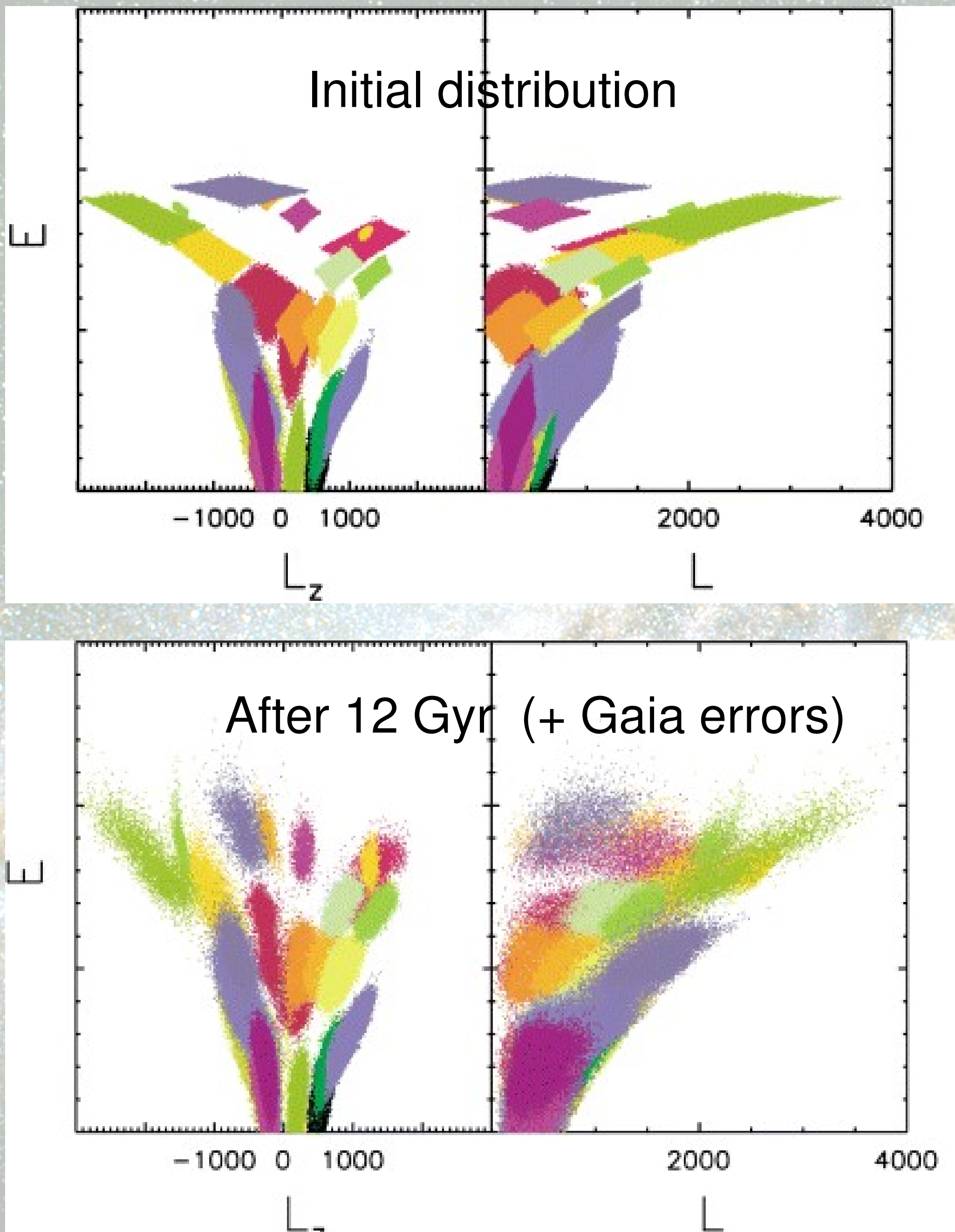
Brown et al. 2005



- spatial overdensities or streams found
  - Sagittarius dSph
  - Canis Major
- but limited discovery space
  - low contrast
  - projection effects
  - streams well-mixed spatially
- can improve with
  - radial velocities
  - better identification of tracers
- ultimately need astrometry

Accretion fossils in phase space

Helmi & de Zeeuw 2000



- evolution of accreting systems
- invariant phase space
- large numbers: statistical significance for low density structures
- improve identification further via astrophysical parameters
  - luminosity, age, metallicity
  - tracers: HB, RGB, MS

Summary

Formation and evolution of the Galaxy
Stellar structure and formation
Exoplanets
Solar system
Fundamental physics

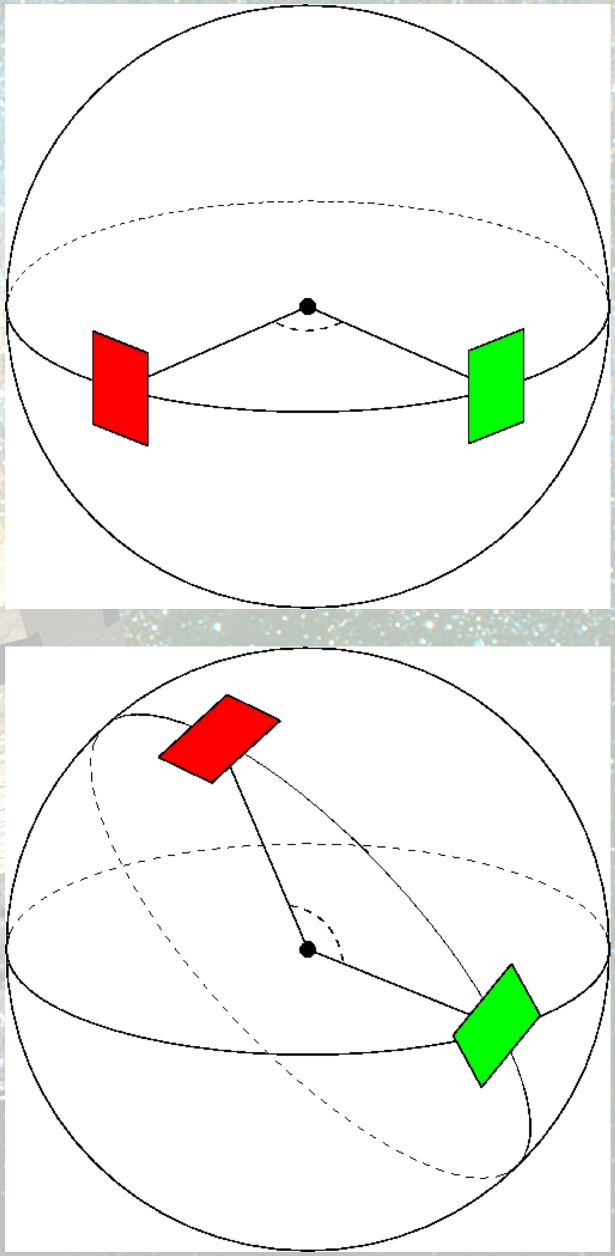
All sky survey to G=20 (10^9 stars)
5D phase space (6D to V~17)
spectrophotometry and RVs

Accuracy = 20 μas @ G =15:
⇒ distances to <1% for 20 million stars
⇒ transverse velocities to 1 km/s at 1 kpc at G=20

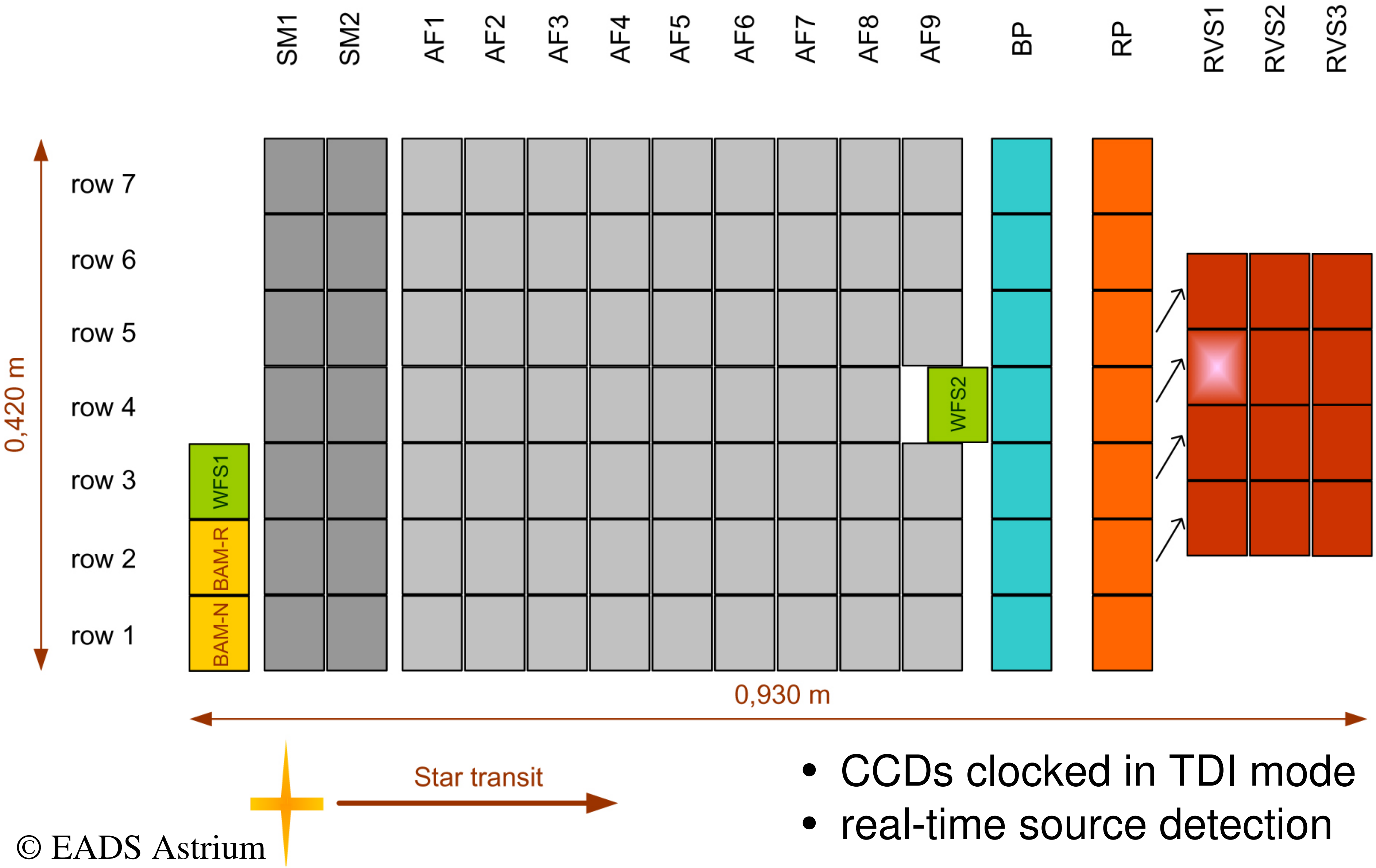
Launch 2011; 5 year mission
http://www.rssd.esa.int/Gaia

Global astrometry from space

- Ground-based astrometry
  - narrow (single) field
  - common parallax effect: only *relative* astrometry
  - limited to a few milliarcseconds precision
- Space-based astrometry
  - observe simultaneously in two widely separated fields separated by a fixed *basic angle*
  - measure relative positions along great circle
  - repeat for many orientations over whole sky



Focal plane



- CCDs clocked in TDI mode
- real-time source detection

106 CCDs. 4500 x 1966. Pixels: 10mm x 30mm 59mas x 177mas

Timeline

- fully approved by SPC in 2006
- PDR ongoing
  - some significant issues (RVS, radiation damage)
- launch December 2011
- observations 2012-2017 (+1 year possible extension)
- final data processing 2017-2019
- final catalogue release 2019-2020
  - early releases from 2013/2014

Data Processing and Analysis Consortium

- development and operation of entire data processing pipeline
  - from telemetry stream to final catalogue
  - analysis tools and value-added products
  - simulations, science alerts, ground-based calibration data
- geographically distributed, nationally-funded partners
  - currently ~250 members in 15 countries
- no data rights: all data go public after validation
- lifetime
  - formed June 2006 following five years of working groups
  - approved by ESA SPC May 2007 (following AO)
  - operates until catalogue publication

location of CU coordinator

Ground Station
ESOC

Main Data Base
ESAC

CU2
Simlulations
Barcelona +

CU3
Core Processing
ARI, Heidelberg +

CU4
Object Processing
Brussels +

CU5
Photometric Processing
Cambridge +

CU6
Spectroscopic Processing
Paris +

CU7
Variability Analysis
Geneva +

CU8
Astrophysical Parameters
MPIA, Heidelberg +

CU9
Catalogue Access
N.N.

Also Torino, Nice, CNES, Lund, Leiden, Dresden, London, Liege, Uppsala, Athens, plus others

Data processing overview

- Photometry
  - IDT, object matching, calibration
  - object classification and astrophysical parameter determination
  - variability
- Astrometry
  - global iterative astrometric solution over 100 million sources
  - special solutions (asteroids, binaries, perspective acceleration)
  - self-calibrating: absolute parallaxes (ICRS reference frame tie)
  - GR effects
- Spectroscopy
  - extraction, RV determination, calibration
  - stellar atmospheres

Data products

- position, parallax, proper motions (5 parameters)
- radial velocity for brighter sources (6^{th} phase space coordinate)
- G-band magnitude
- RP/BP spectrum
- RVS spectrum for brighter sources
- astrophysical parameters for stars, galaxies and QSOs
- (spectro)photometric variability information
- binary system parameters, orbital solutions (inc. exoplanets)
- solar system object (asteroid) orbits and taxonomy
- alerts of transient events (e.g. supernovae)