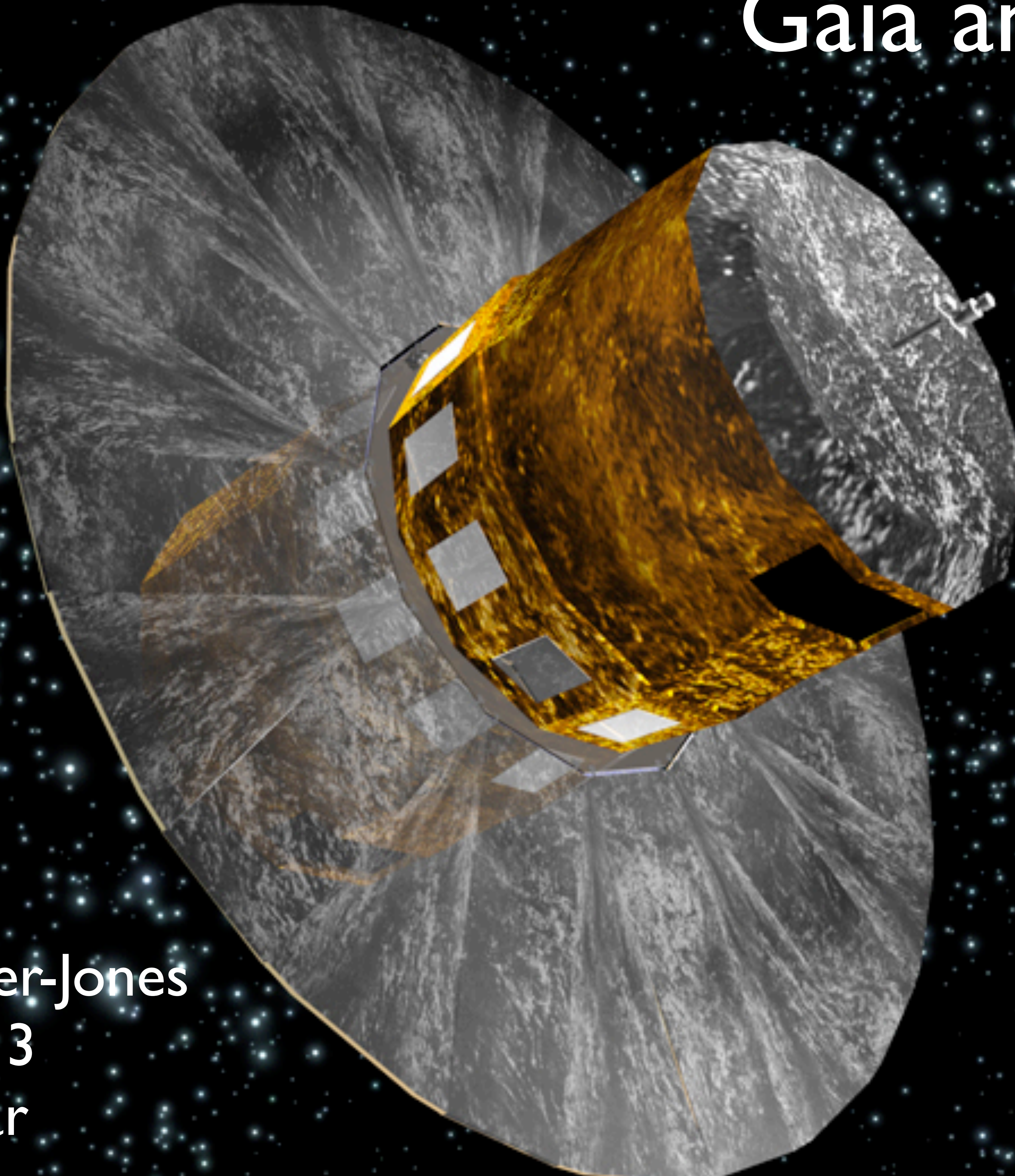
Gaia and MPIA



Coryn Bailer-Jones
20 Feb. 2013
PSF Seminar

Gaia in a nutshell

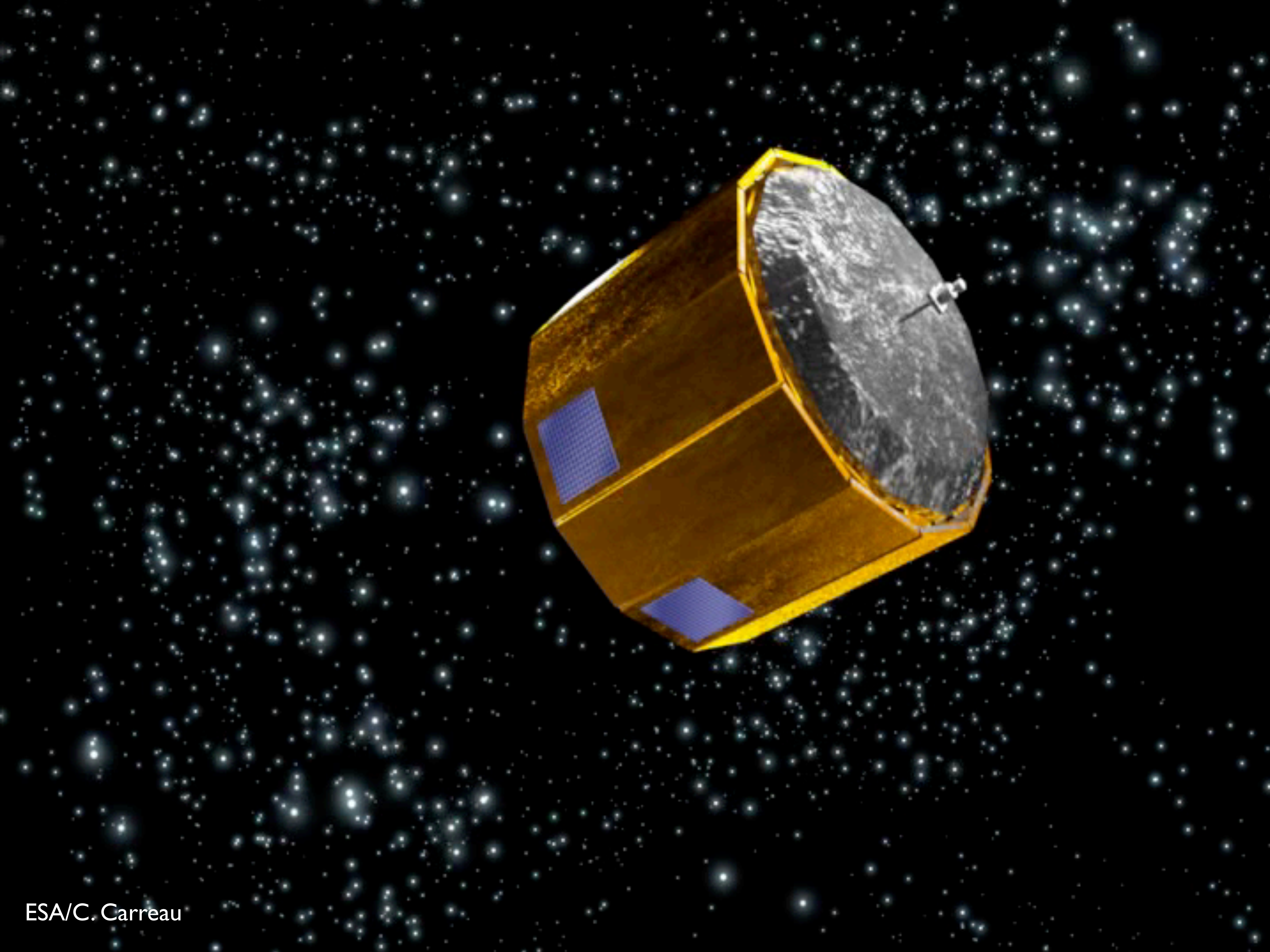
high accuracy positions, parallaxes, proper motions e.g. 15-25 μas at G=15

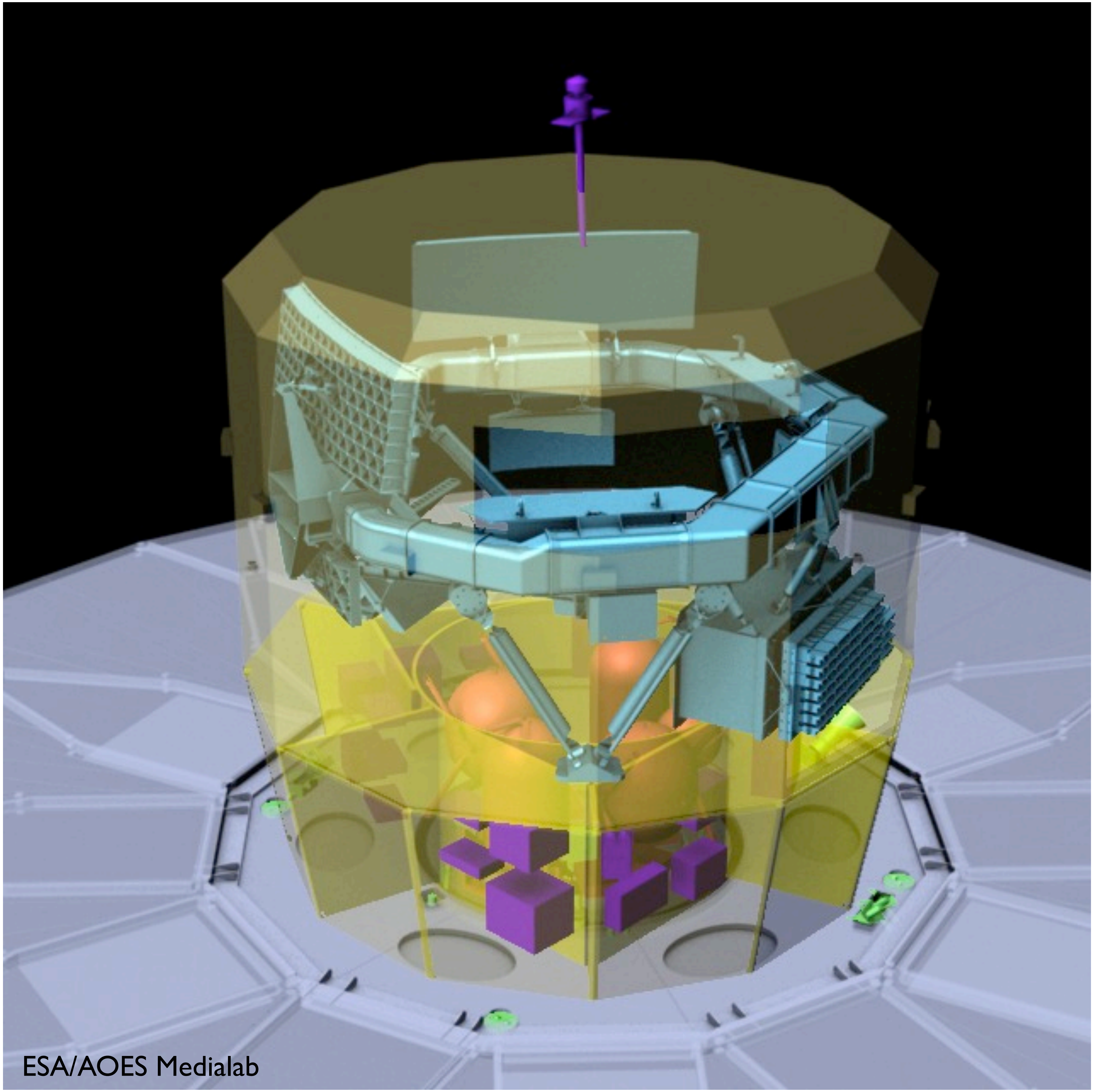
optical spectrophotometry

pure survey: entire sky to G=20 $\sim 10^9$ sources

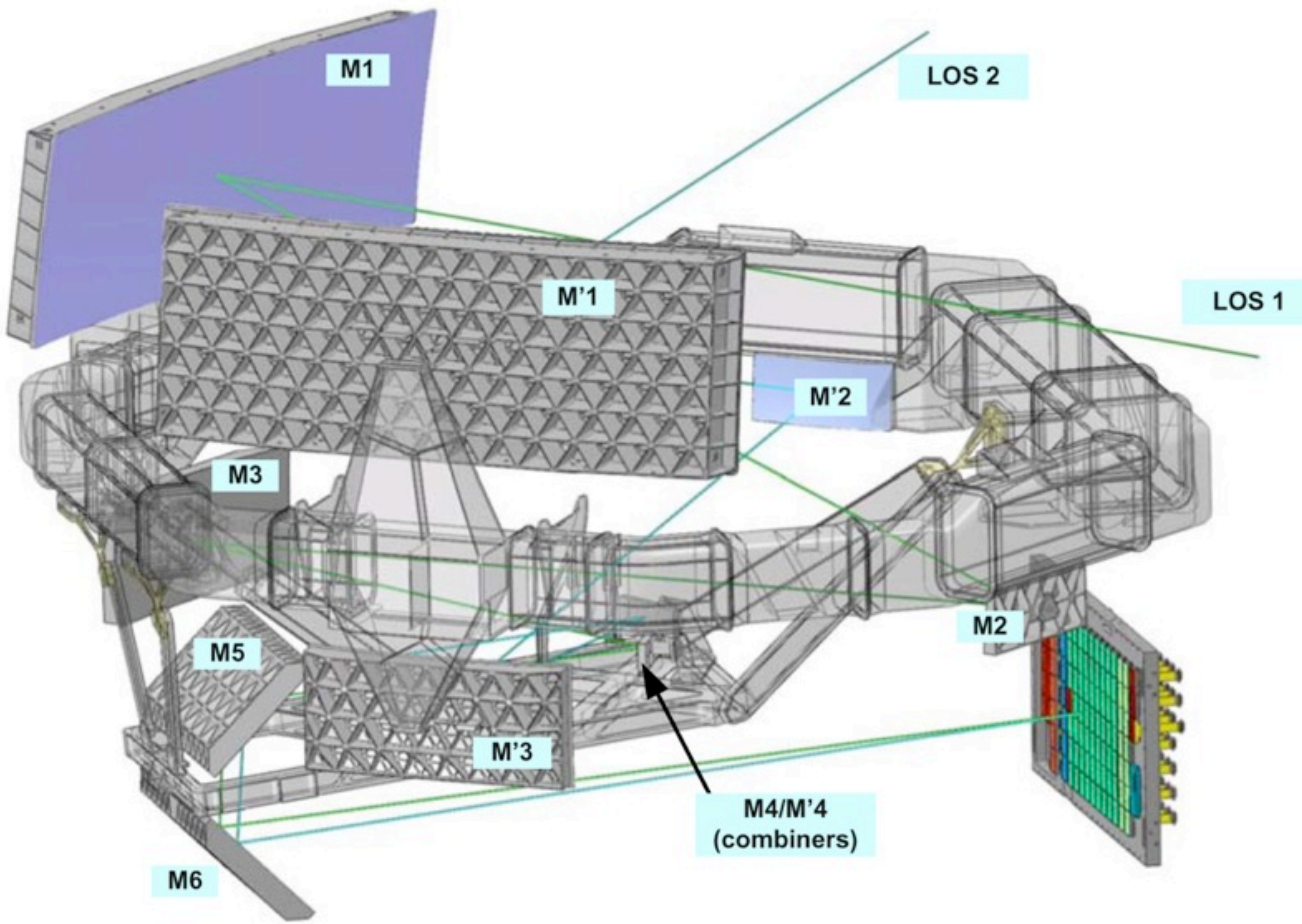
astrophysical parameters

radial velocities to G<17 (1-15 km/s)

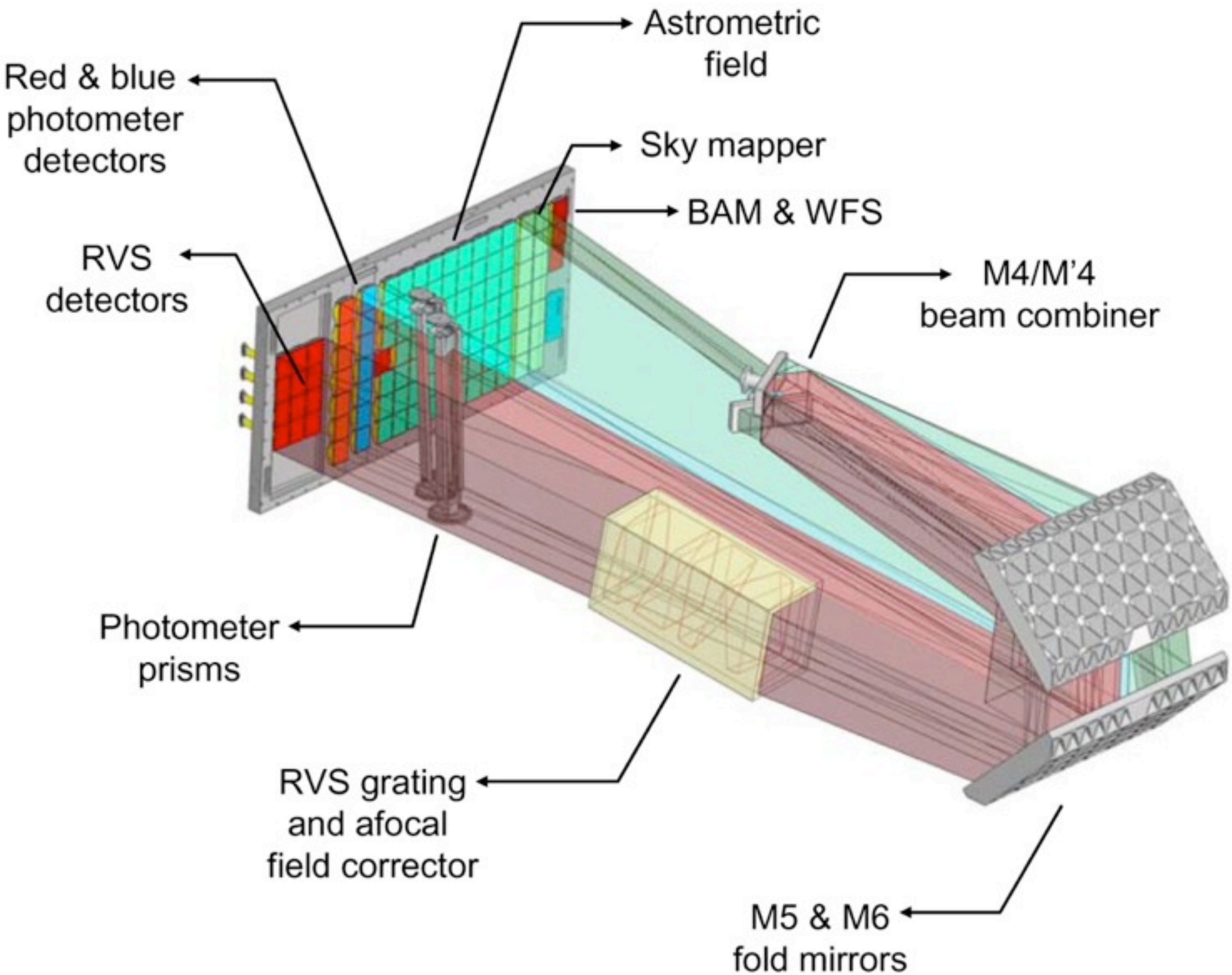

ESA/C. Carreau


ESA/AOES Medialab

Payload module



Instruments



Gaia characteristics

	Hipparcos	**Gaia**
Magnitude limit	H =12.4	G = 20.0
No. sources	120 000	~ 1 000 000 000
quasars	0	~ 0.5 million
galaxies	0	~ 5 million
Astrometric accuracy*	~ 1000 μas	9-26 μas at G=15
		100-330 μas at G=20
Photometry	2 bands	spectrophot. 330-1000 nm
Radial velocities*	none	1-13 km/s to G=17
Target selection	input catalogue	real-time onboard selection

*for 72 observations (i.e. average end-of-mission accuracy)

Gaia distances

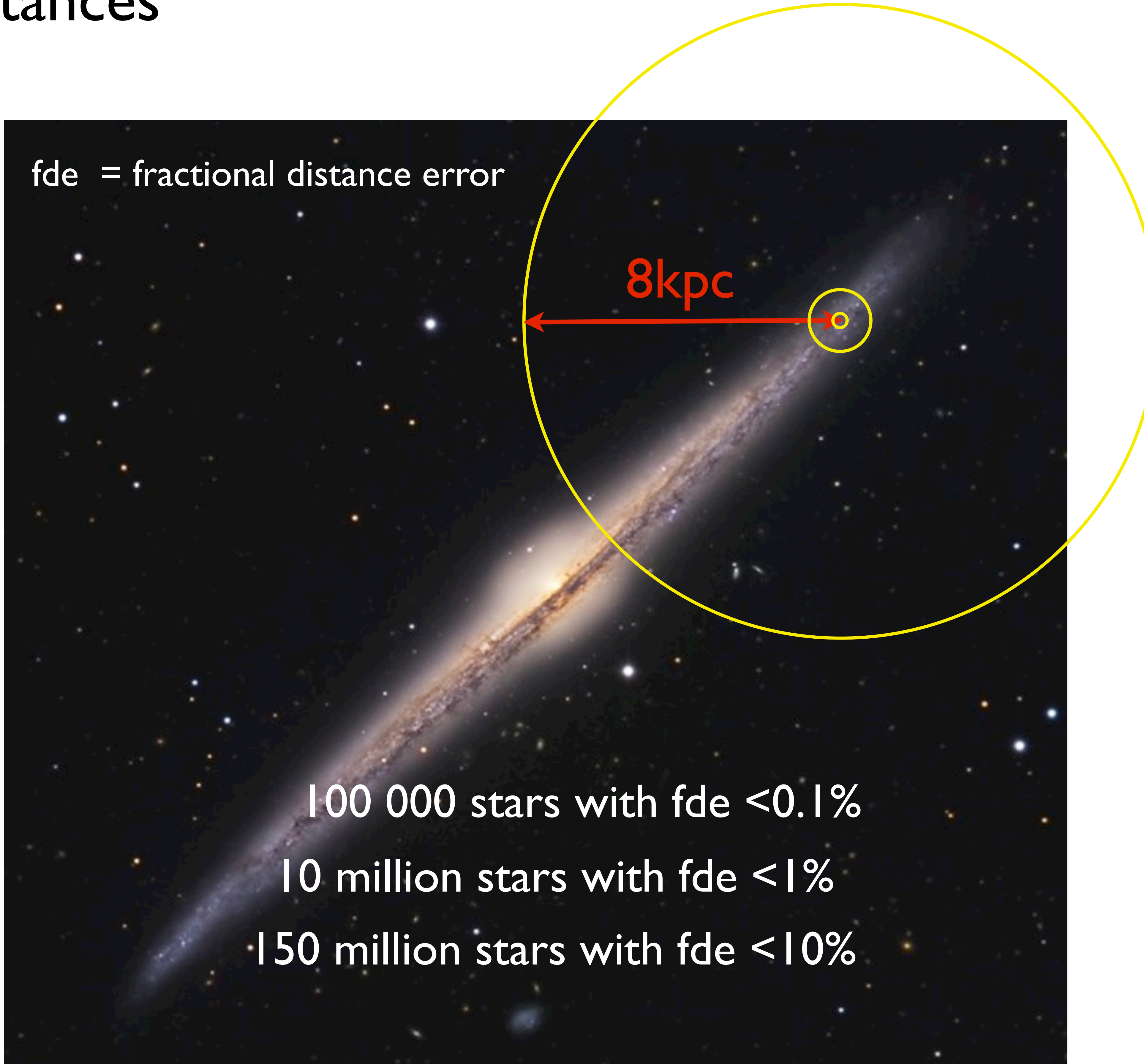
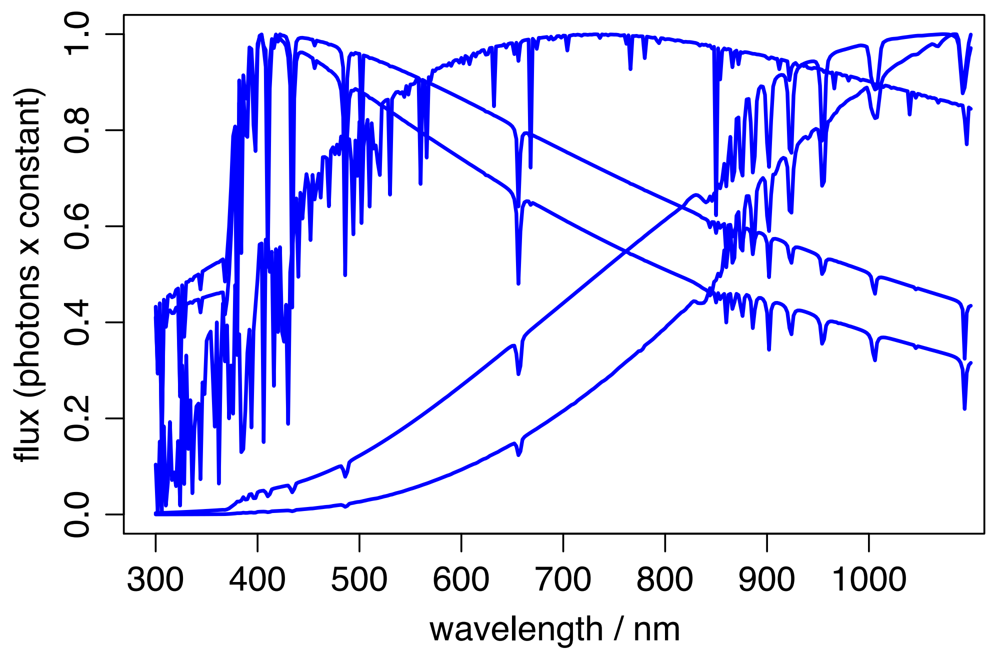


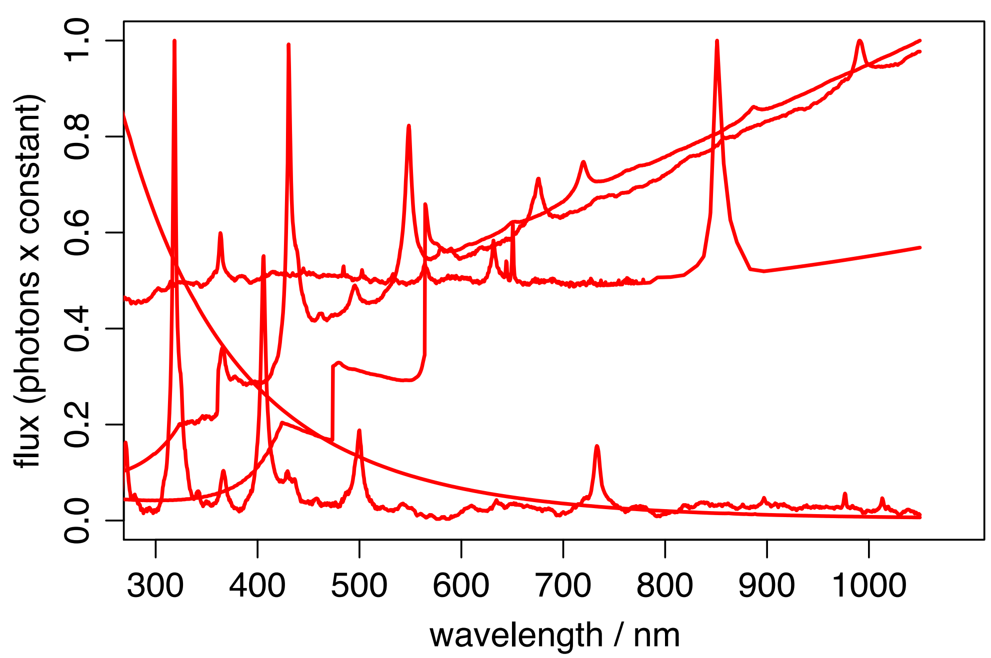
Image: NGC4565 from panther-observatory.com

How the astrometric accuracy varies

- astrometric errors dominated by photon statistics
- parallax error: $\sigma(\varpi) \sim 1/\sqrt{\text{flux}}$
- for fixed M_G
  - ⋆ $\sigma(\varpi) \sim$ distance, d
  - ⋆ fractional parallax (and distance) error, $\sigma(\varpi)/\varpi \sim d^2$
  - ⋆ transverse velocity error, $\sigma(v) \sim d^2$
- example accuracy
  - ⋆ K giant at 6 kpc (G=15): frac. dist. error = 2%, $\sigma(v)$ = 1 km/s
  - ⋆ G dwarf at 2 kpc (G=16.5): frac. dist. error = 8%, $\sigma(v)$ = 0.4 km/s

Spectrophotometry (BP/RP)

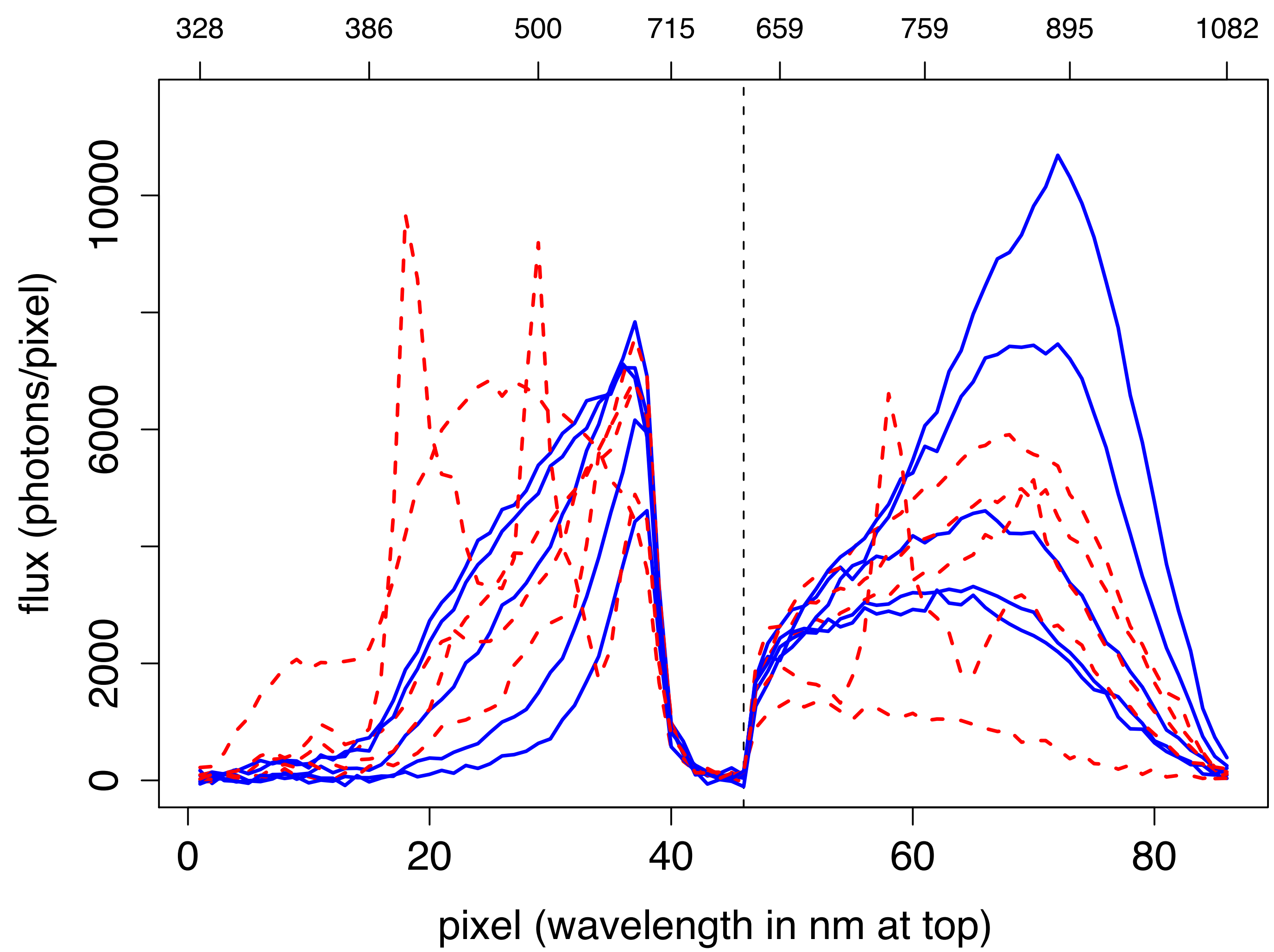




source spectra:

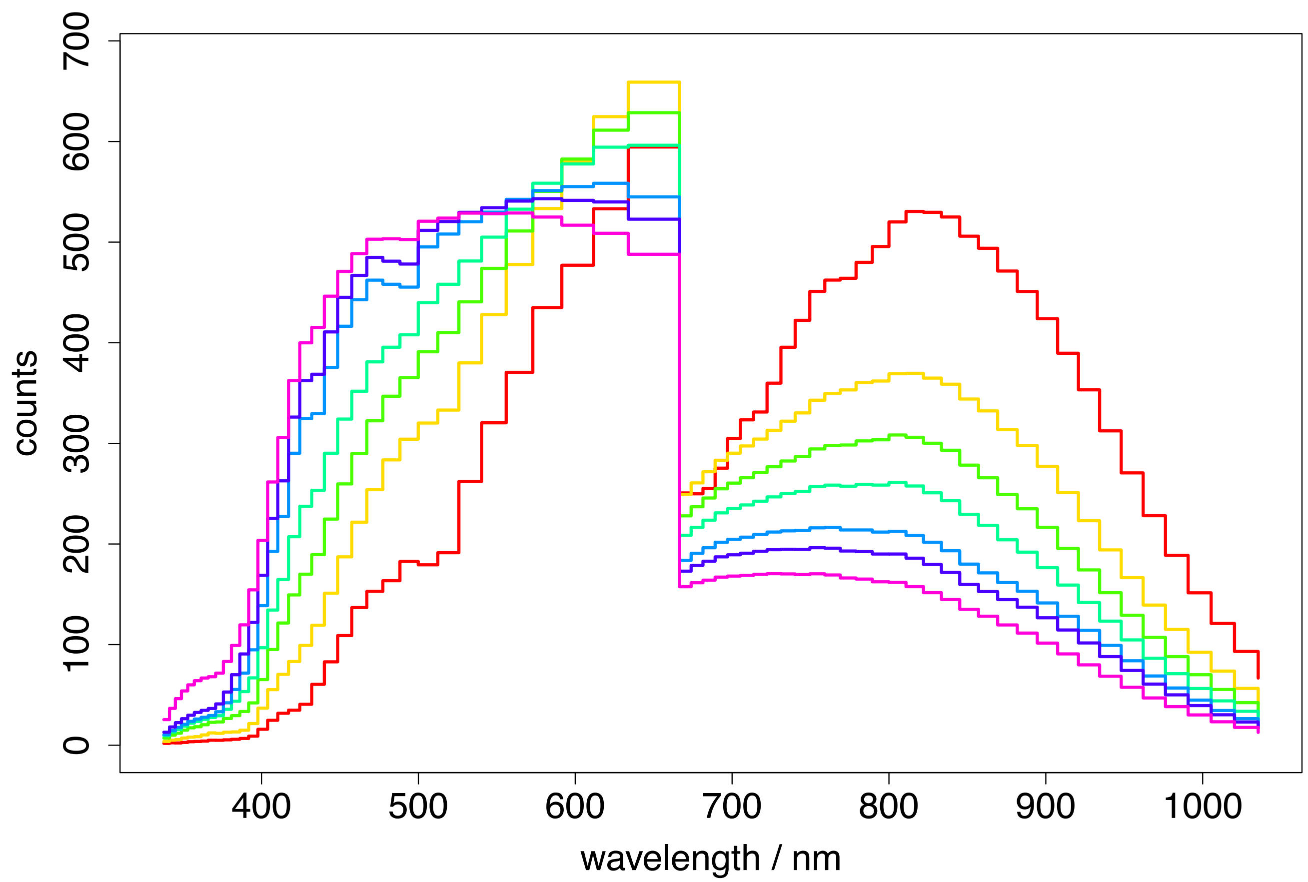
blue = stars

red = quasars

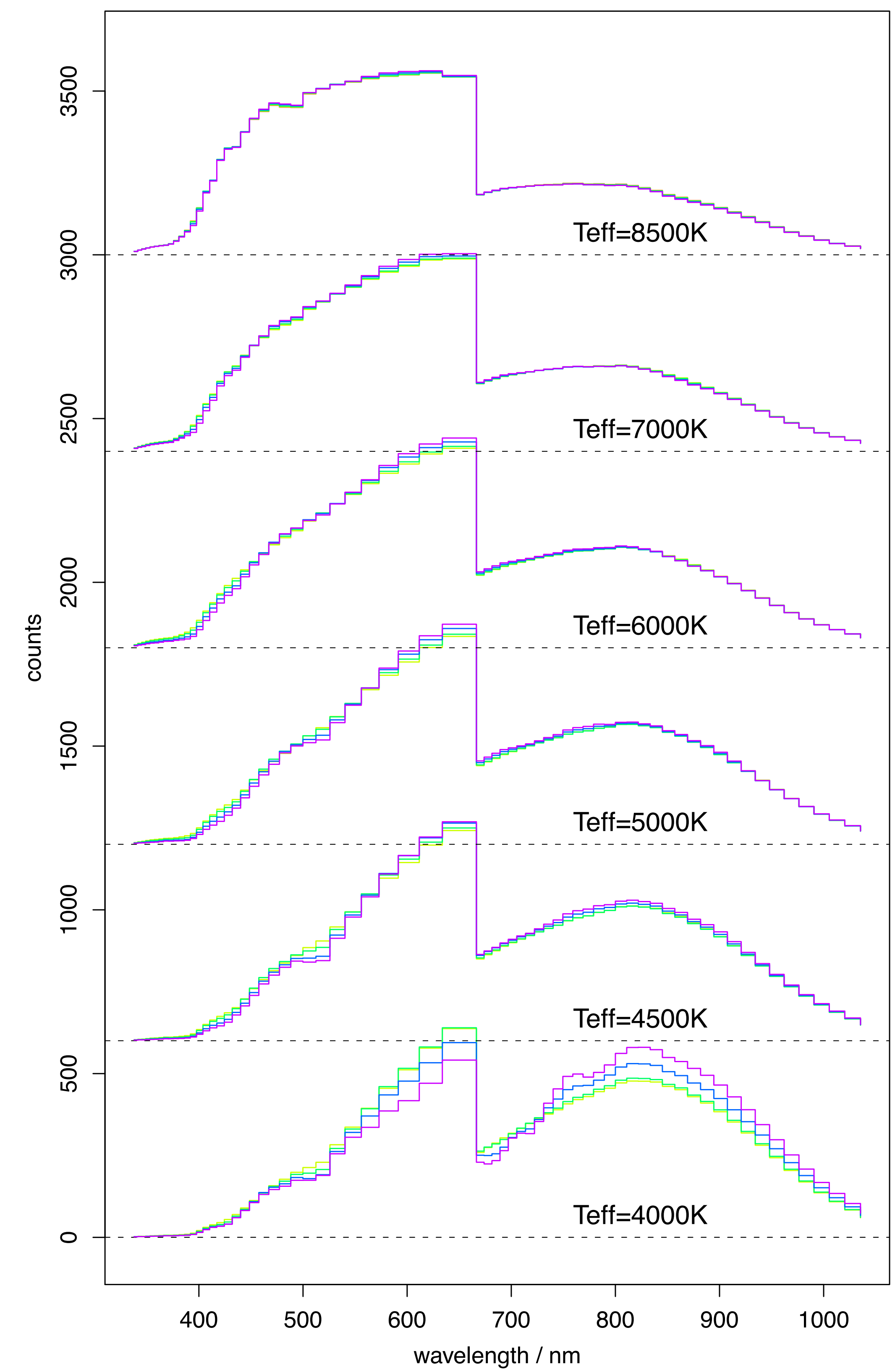


resulting spectra
350 - 1050 nm

Stellar parameters from spectrophotometry (BP/RP)



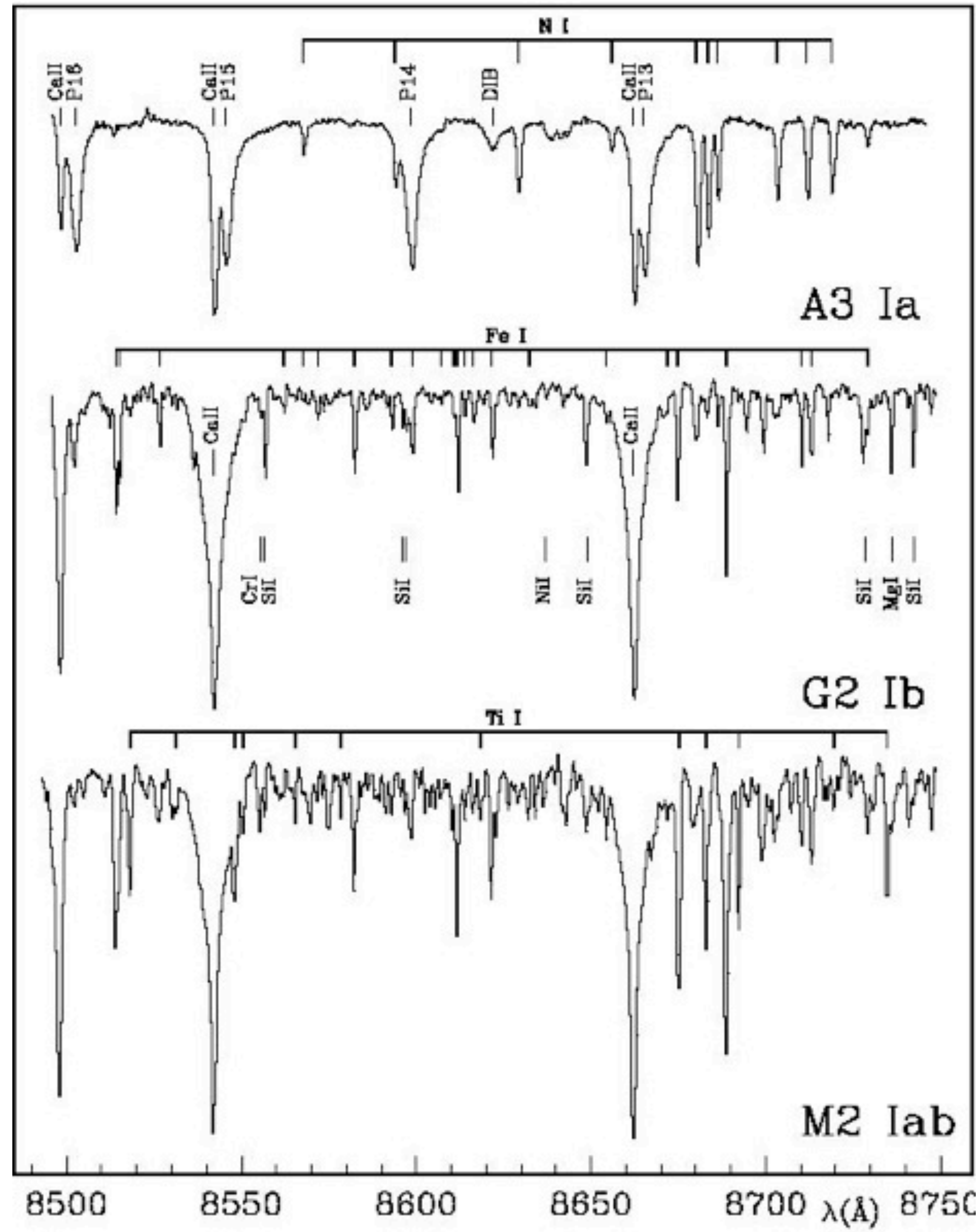
strong temperature (T_{eff}) signature (likewise extinction)
shown: T_{eff} = 4000 to 15 000 K



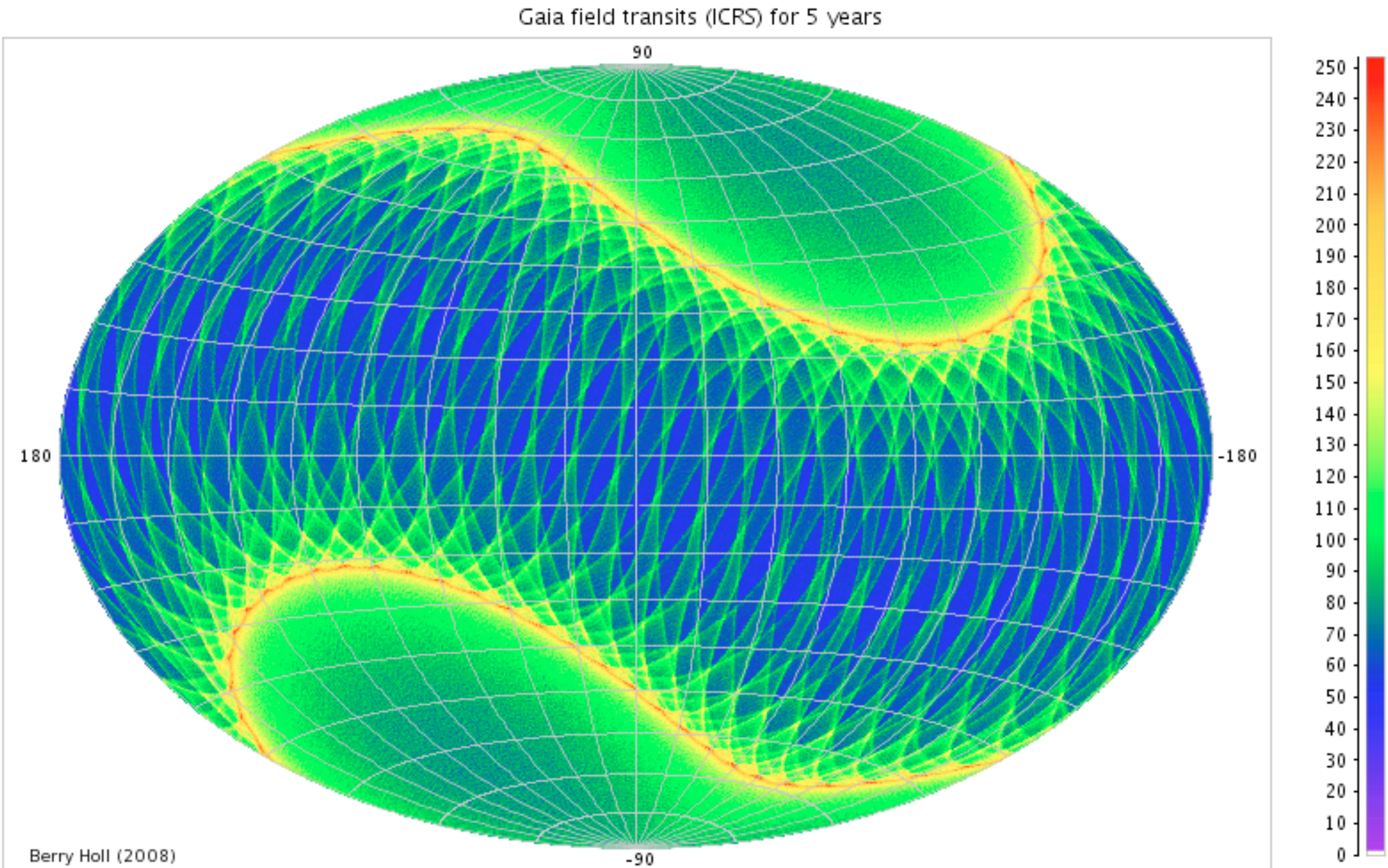
much weaker metallicity signature (likewise surface gravity)
shown: [Fe/H] = -2.5 to +0.5 dex

Radial velocity spectra

- slitless spectrograph
- R = 11 500, around CaII triplet
- Vrad to 1-10 km/s for V < 17
- higher SNR spectra for millions of stars with V < 14 (helps parameter estimation)



Scanning law: No. observations in equatorial coords



Some science objectives

- Galactic structure
  - ★ formation of disk and halo (substructure, merger history)
  - ★ dark matter content
  - ★ chemical evolution, star formation history
- Stellar structure and evolution
  - ★ accurate luminosities
  - ★ stellar cluster structure, kinematics, ages
- Binary systems (including exoplanets)
- Solar system asteroids, including near-earth objects
- General Relativity tests

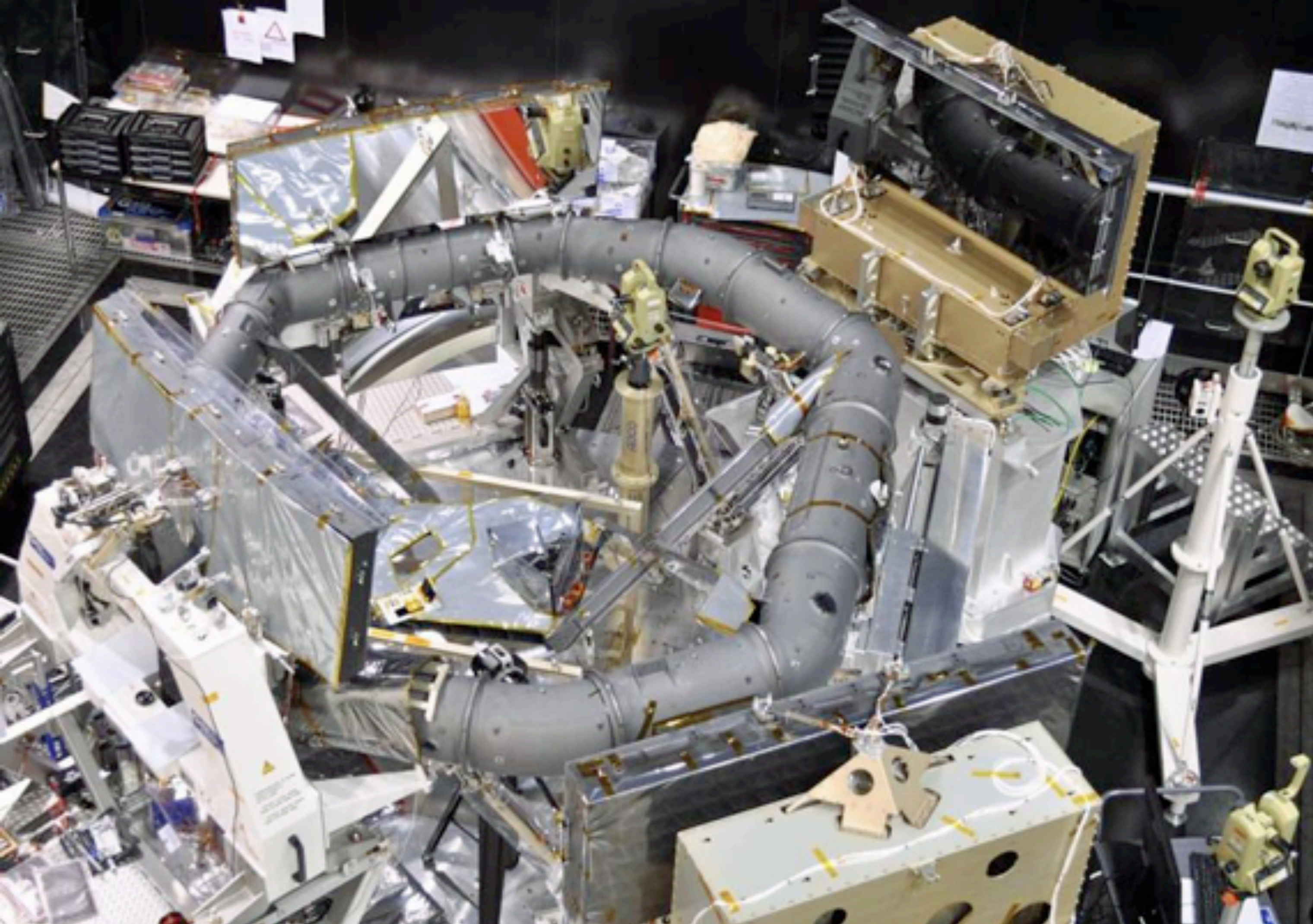
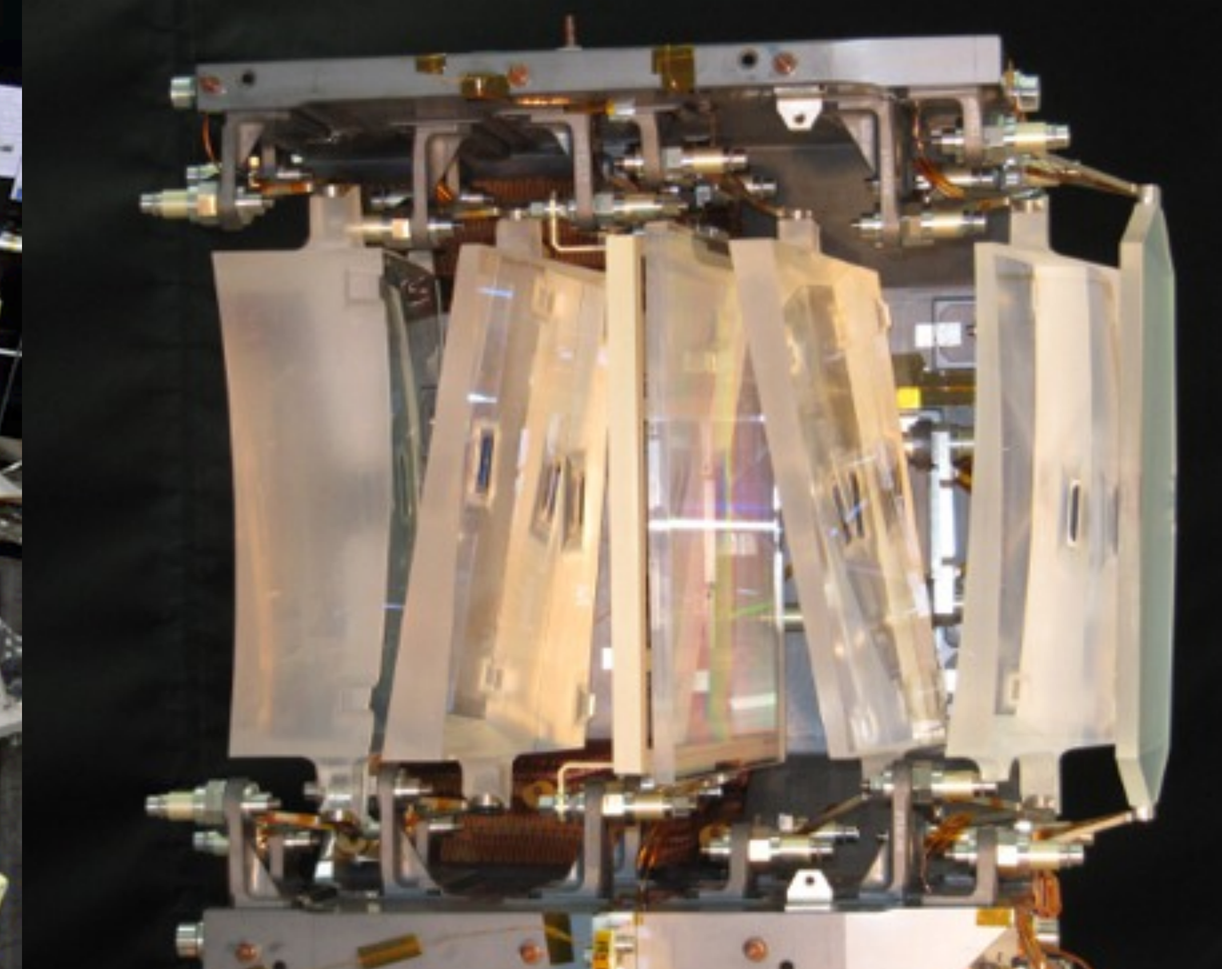
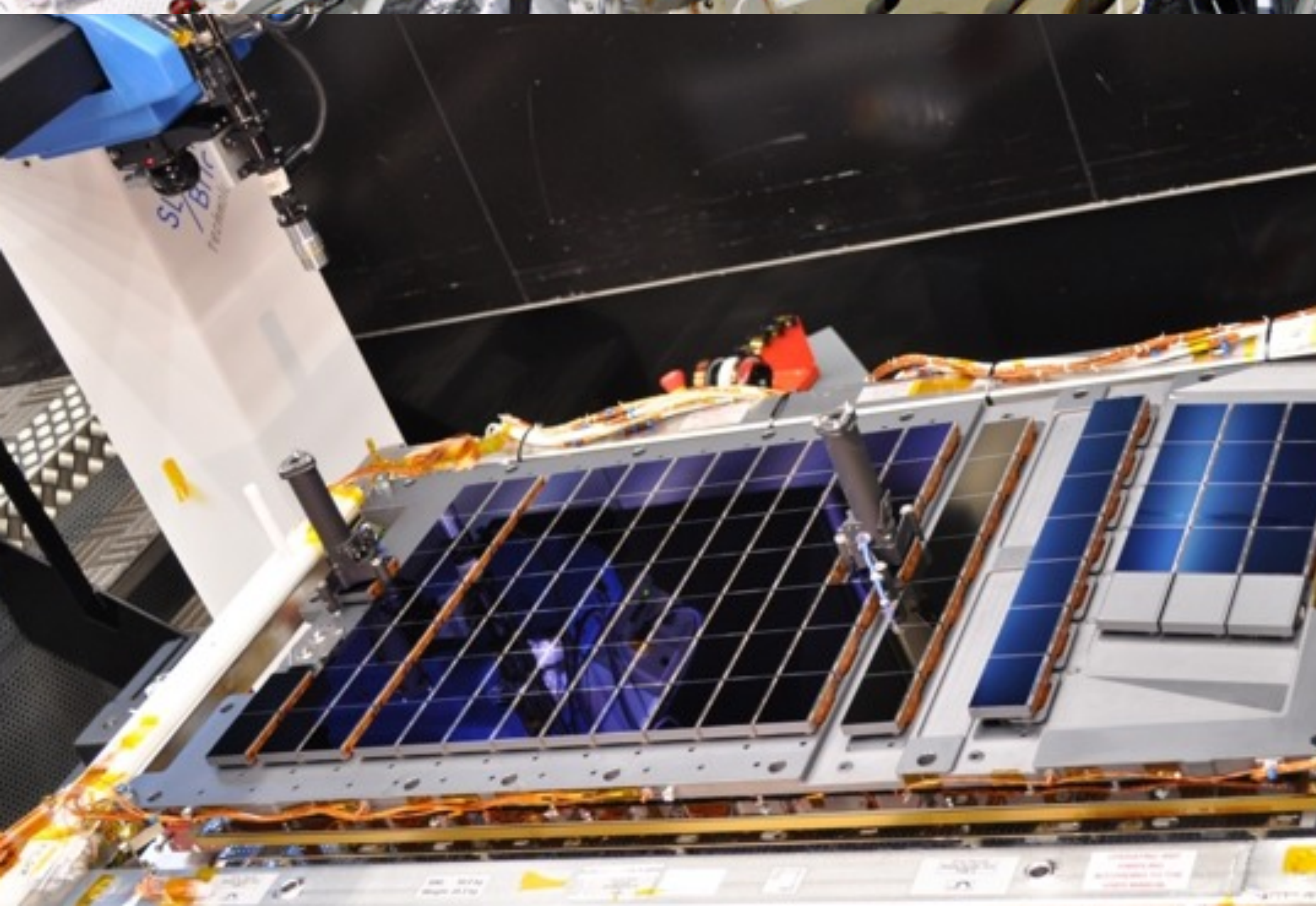
Stellar clusters

- about 70 clusters and associations within 500 pc
  - ★ *individual* stellar distances to 0.5-1% at G=15 (K3 V)
  - ★ *individual* stellar transverse velocity accuracy to < 50 m/s at G=15
- science possibilities
  - ★ ages, He abundance from model fitting
  - ★ examine mass segregation, cluster dispersion
  - ★ confirm new (refute old) clusters
  - ★ use as abundance tracers in disk out to tens of kpc
- saturation limit is G=1.5 to 5.7 (TBD)

Exoplanets

- astrometric signature of a companion $\alpha \sim \frac{M_p}{M_s} \frac{a_p}{d}$
  - ★ e.g. for 47 UMa b ($K = 49$ m/s, $M > 2.5\ M_{Jup}$, $P = 2.95$ years) $\alpha \sim 360$ μas
- identified as poor fit to 5-parameter single star solution
- all-sky, magnitude limited survey
  - ★ no spectral type selection
  - ★ expect 50 000 of the 20 million non-single star detections to be planets (mostly Jupiter-like at 1-4 AU from host out to 200pc)
  - ★ expect orbital solutions for about a third of these (periods up to ~10 yrs)


ASTRIUM


Timescale

- ESA mission, built by industry. Data processing by DPAC
- Timescale
  - ★ launch (L): October 2013
  - ★ science operations start: L + 6m
  - ★ data releases expected: L + 22m, 28m, 40m, 65m
  - ★ end of operations: end 2018 (or 2019)
  - ★ final catalogue: end of operations + 36m (end 2021 or 2022)
- Data policy: no proprietary period; DPAC does no “astrophysics”

Gaia catalogue data products

- astrometry: position, parallax, proper motion
- photometry: G, G_{BP}, G_{RP}, G_{RVS} (and time series)
- spectrophotometry (BP/RP)
- radial velocity spectra and radial velocities
- object class probabilities (star, galaxy, quasar, etc.)
  - ★ also outlier/novelty detection
- source astrophysical parameters (with probability distributions)
  - ★ T_{eff}, [Fe/H], logg, line-of-sight extinction, ...
- variable star classification
- (partial) orbital solutions for star/planet systems
- asteroid orbits and properties

Intermediate data release content

L = October 2013

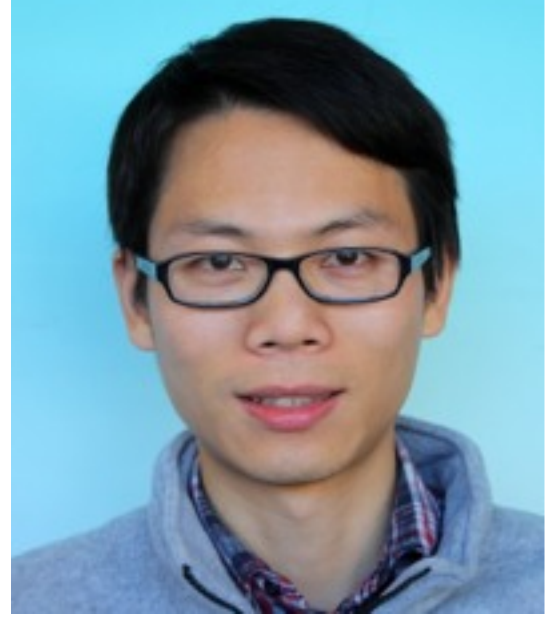
AP = (stellar) astrophysical parameter

- **L+22m**: position, G mag for 90% of sources; HTPM
- **L+28m**: position (+ some parallax, PM); integrated BP/RP photometry (+ rudimentary APs); mean RV of bright stars (90% of sources)
- **L+40m**: position, parallax, PM for 90% of sources; some binary orbits; BP/RP spectrophotometry plus (strong) APs; mean RVs; some APs based on bright RV spectra; ground-based auxiliary data
- **L+65m**: as L+40m (improved precision) plus: more detailed APs; variability classification + epoch photometry; solar system results; non-single star catalogue

Gaia group @ MPIA

- part of the Data Processing and Analysis Consortium (DPAC)
- CU8 “Astrophysical Parameters” (since 2006)
  - ★ probabilistic source classification (star, quasar, galaxy etc.)
  - ★ stellar parameter estimation (T_{eff}, A_0, [Fe/H], logg)
  - ★ using BP/RP and astrometry
  - ★ 4 postdocs (3 DLR funded)
- CU9 “Catalogue Access” (starting 2014)
  - ★ cross matching (with SDSS, UKIDSS, Pan-STARRS, etc.)
  - ★ valued-added catalogues (improved/extended parameters)
  - ★ 2 postdocs (1 DLR funded)

Richard Hanson
(PhD student)
Galactic 3D extinction & dust modelling



Fabo Feng
(PhD student)
solar orbit, astronomical impacts on Earth

Dae-Won Kim
(postdoc)
Gaia software, time series

Coryn Bailer-Jones
(staff)

Kester Smith
(staff)
Gaia software, BHB stars

Tri Astraatmadja
(postdoc)
Gaia software, (astroparticle physics)

Rene Andrae
(postdoc)
Gaia software, statistics

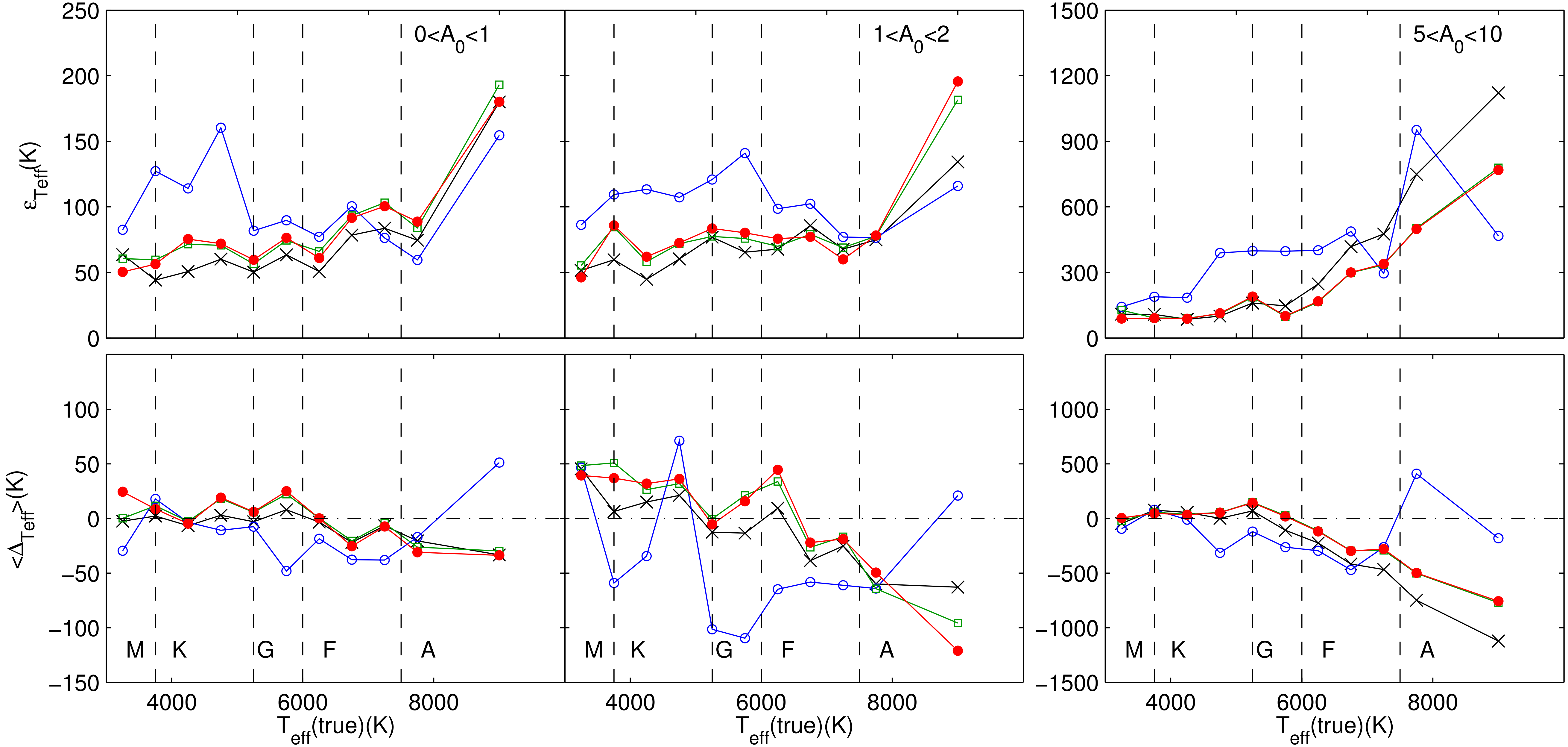
What now?

- identify science projects which build on the MPIA's strengths
- get ready for the data
  - ★ prepare models and analysis tools in advance
  - ★ acquire auxiliary data, observations, simulations etc.
  - ★ look at the simulated data
- more information
  - ★ http://www.rssd.esa.int/index.php?project=GAIA
  - ★ large number of technical notes and publications

Astrophysical parameter accuracy

- Accuracy (mean abs.) is a function of G and APs themselves
  - ★ T_{eff} 3000:1000K, A_0 0:10mag, [Fe/H] -2.5:+0.5dex, logg 2.5:5.5dex
- At G=15 for A_0 < 1mag
  - ★ Teff 60-110K, A_0 0.05mag, [Fe/H] 0.15dex (0.5dex A stars), logg 0.25dex
- At G=15 averaged over all A_0
  - ★ Teff 110-180K, A_0 0.07mag, [Fe/H] 0.4dex (0.7dex A stars), logg 0.3dex
- At G=19 for A_0 < 1mag
  - ★ Teff 250-400K, A_0 0.1-0.15mag, [Fe/H] 0.35 (G/K stars), logg 0.4dex

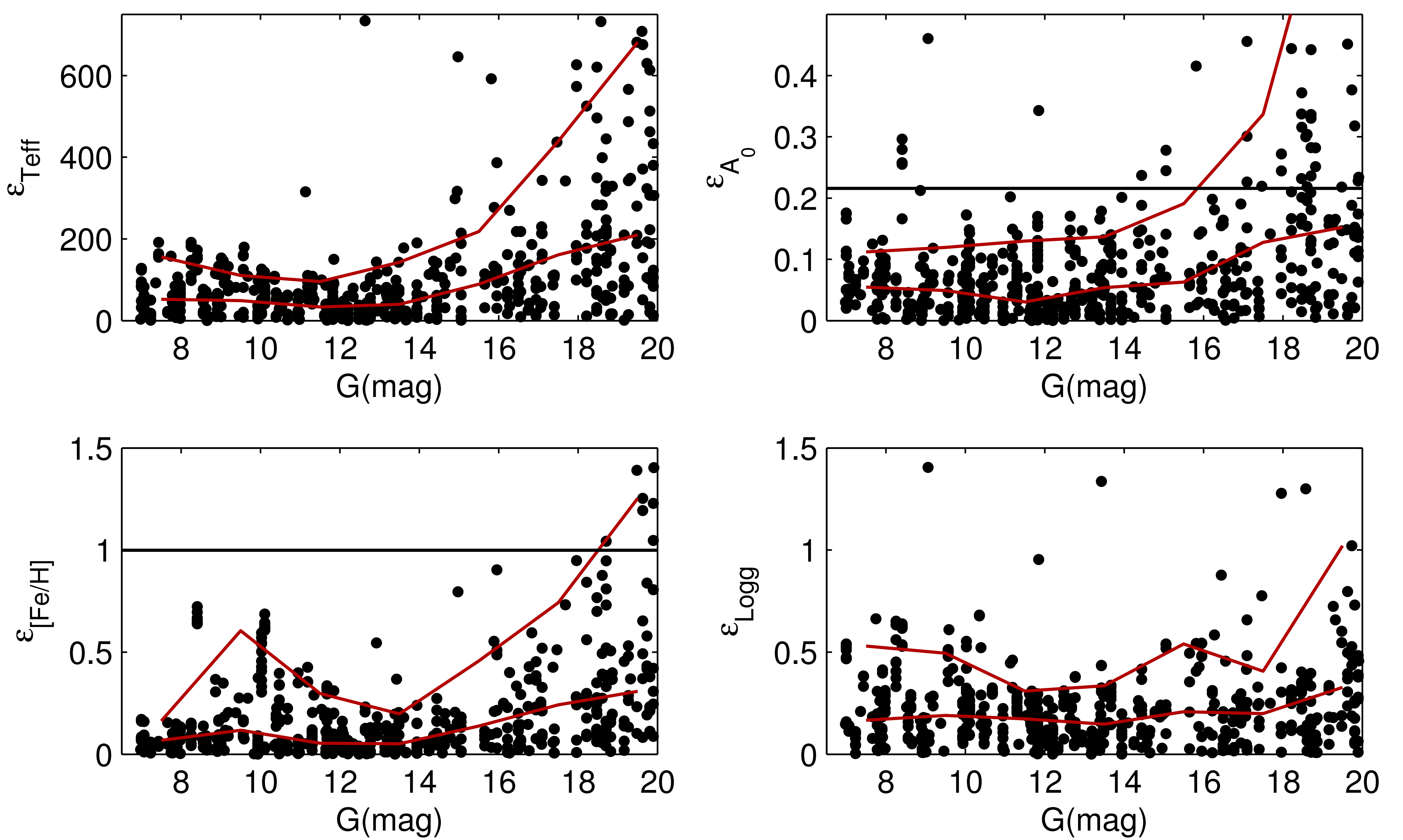
Astrophysical parameter accuracy (T_{eff})



upper row: mean absolute error (“random”) lower row: mean error (“systematic”)

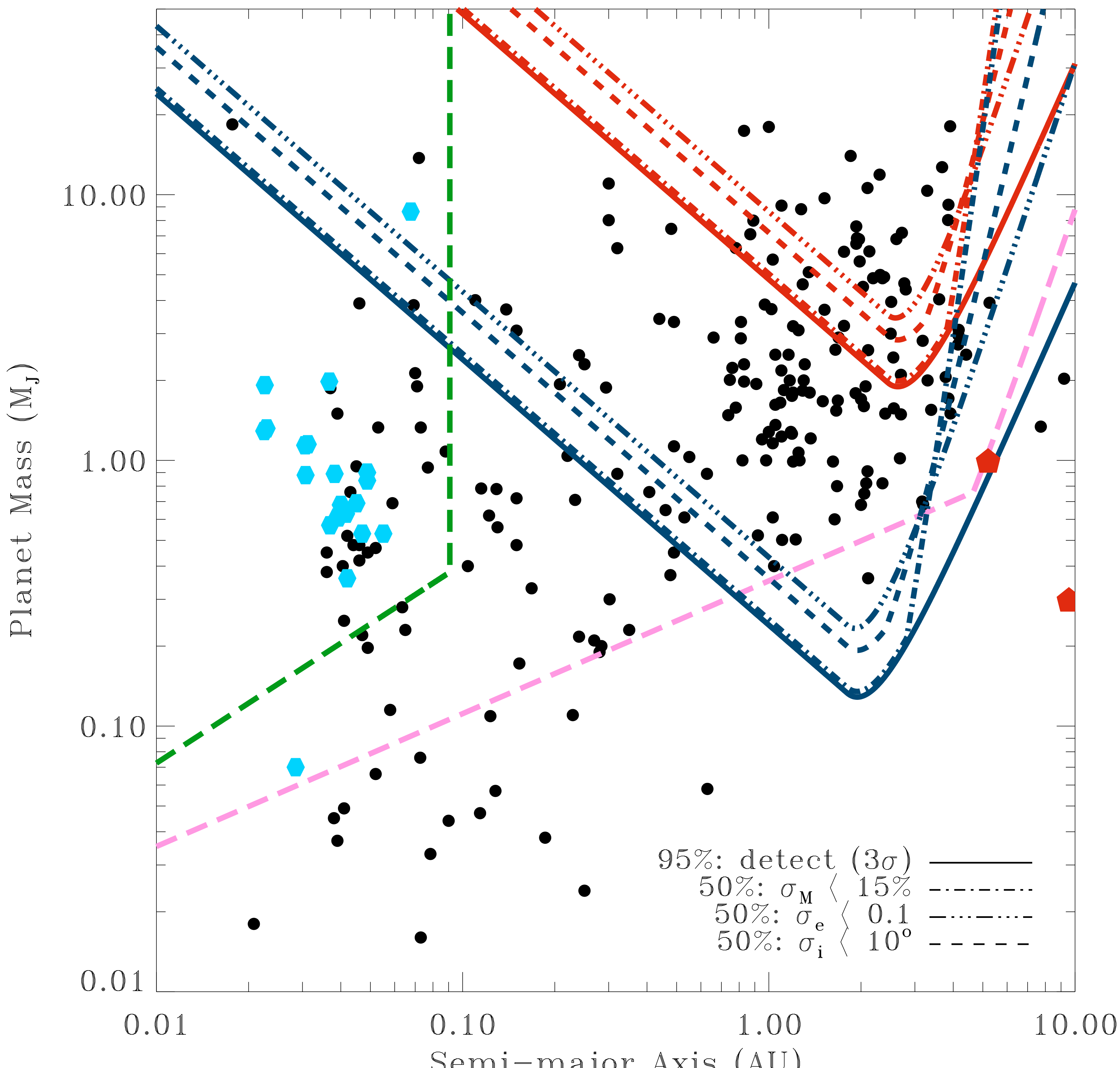
colours: four different algorithms

Astrophysical parameter accuracy



mean absolute accuracy variation with G
Red lines show 50% and 90% quantiles

Exoplanet discovery space (Gaia astrometry)



red: 1 $M_\odot$ host at 200pc

blue: 0.5 $M_\odot$ host at 25pc

pink: RV detection at 3sigma for 3 m/s accuracy

black points: planets as of September 2007

light blue: transiting systems

red pentagons: Jupiter and Saturn

Casertano et al. 2008