Inference with Gaia

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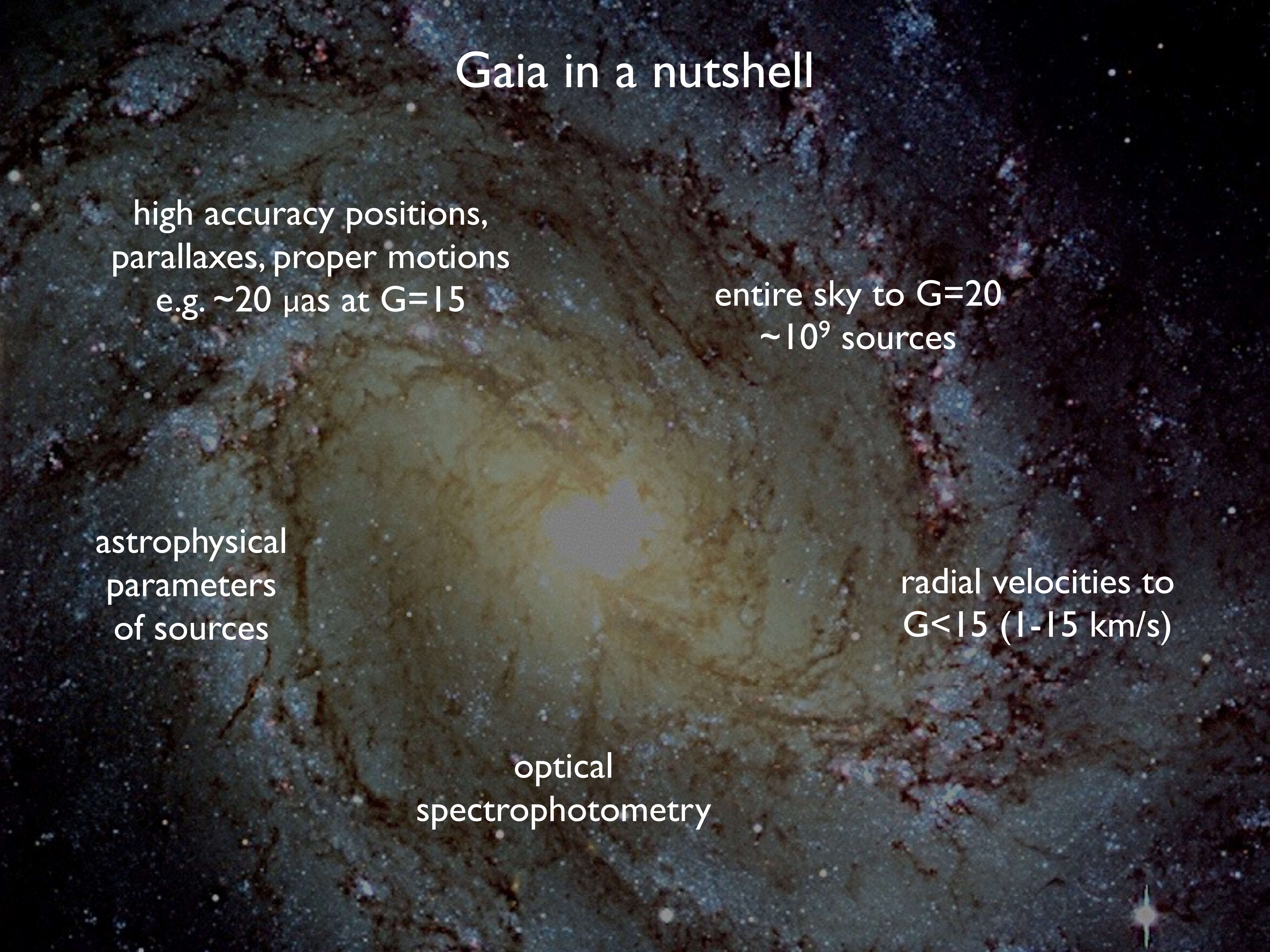


Gaia in a nutshell

high accuracy positions, parallaxes, proper motions e.g. ~20 μas at G=15

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

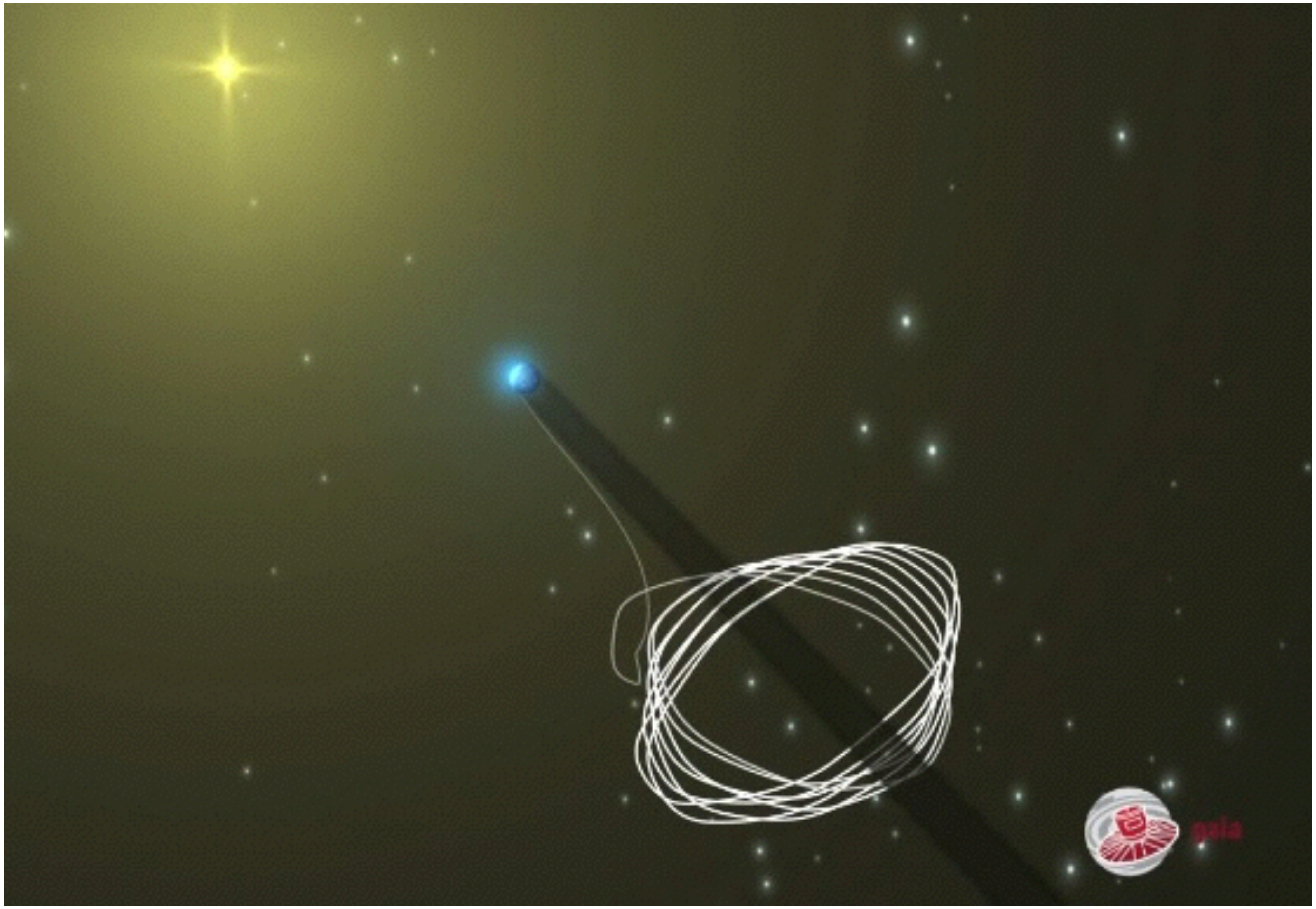
astrophysical parameters of sources

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

optical spectrophotometry

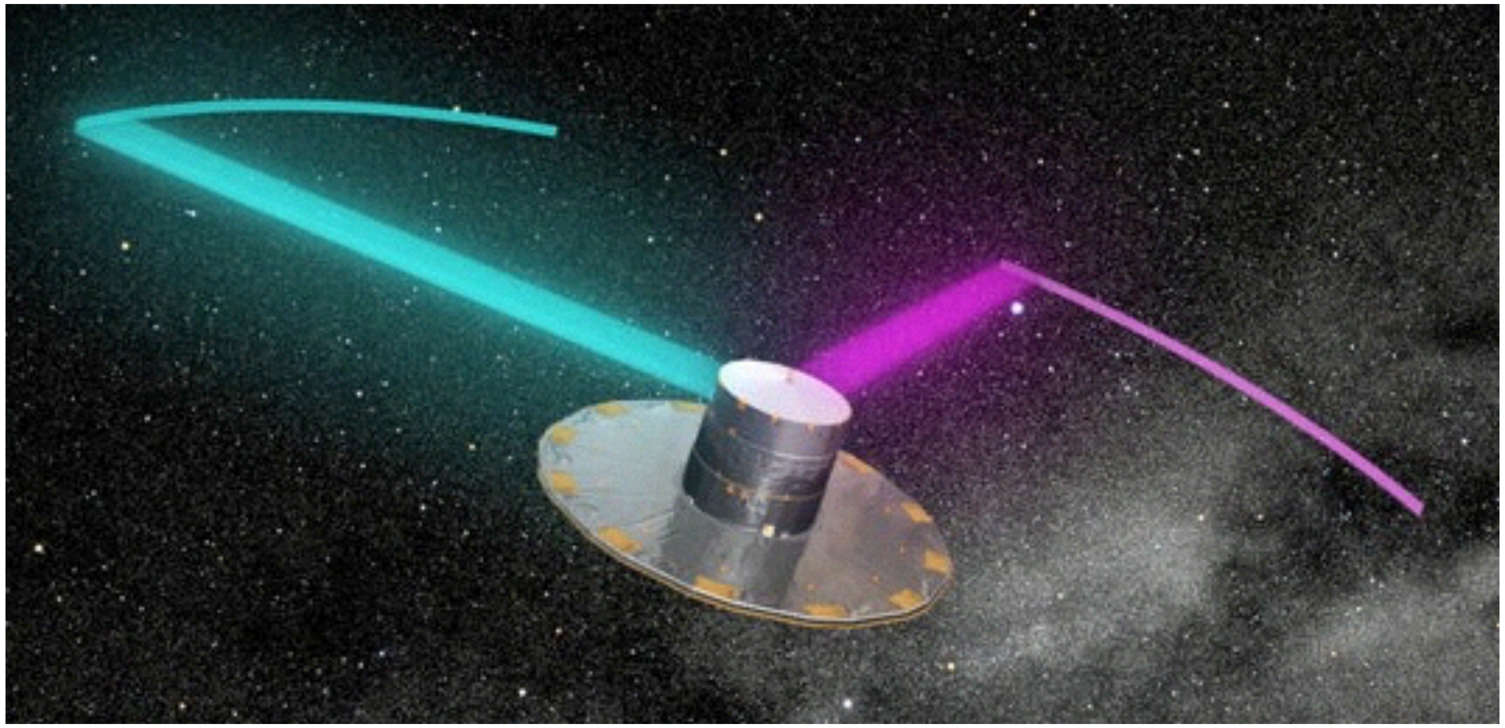
Satellite

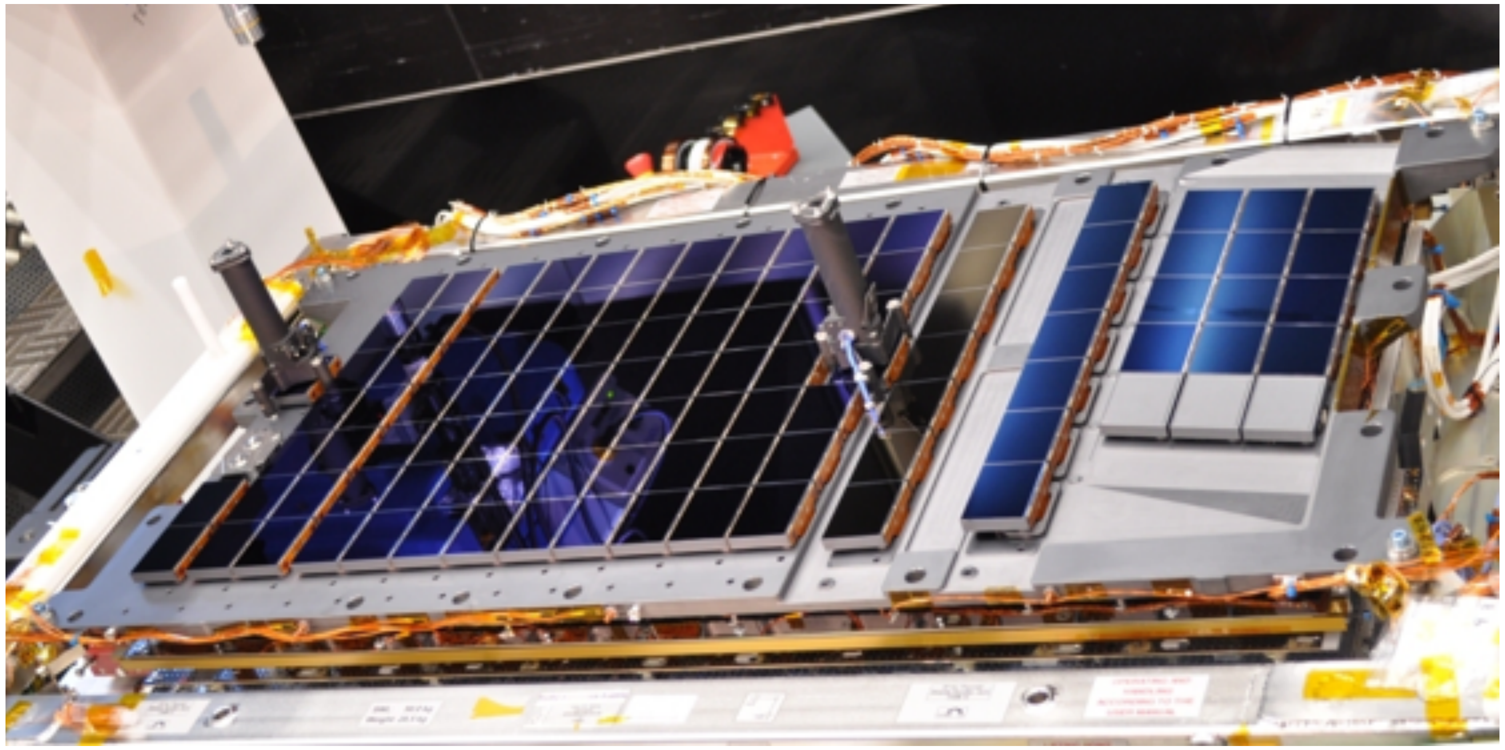
Orbiting around Earth-Sun L2 point



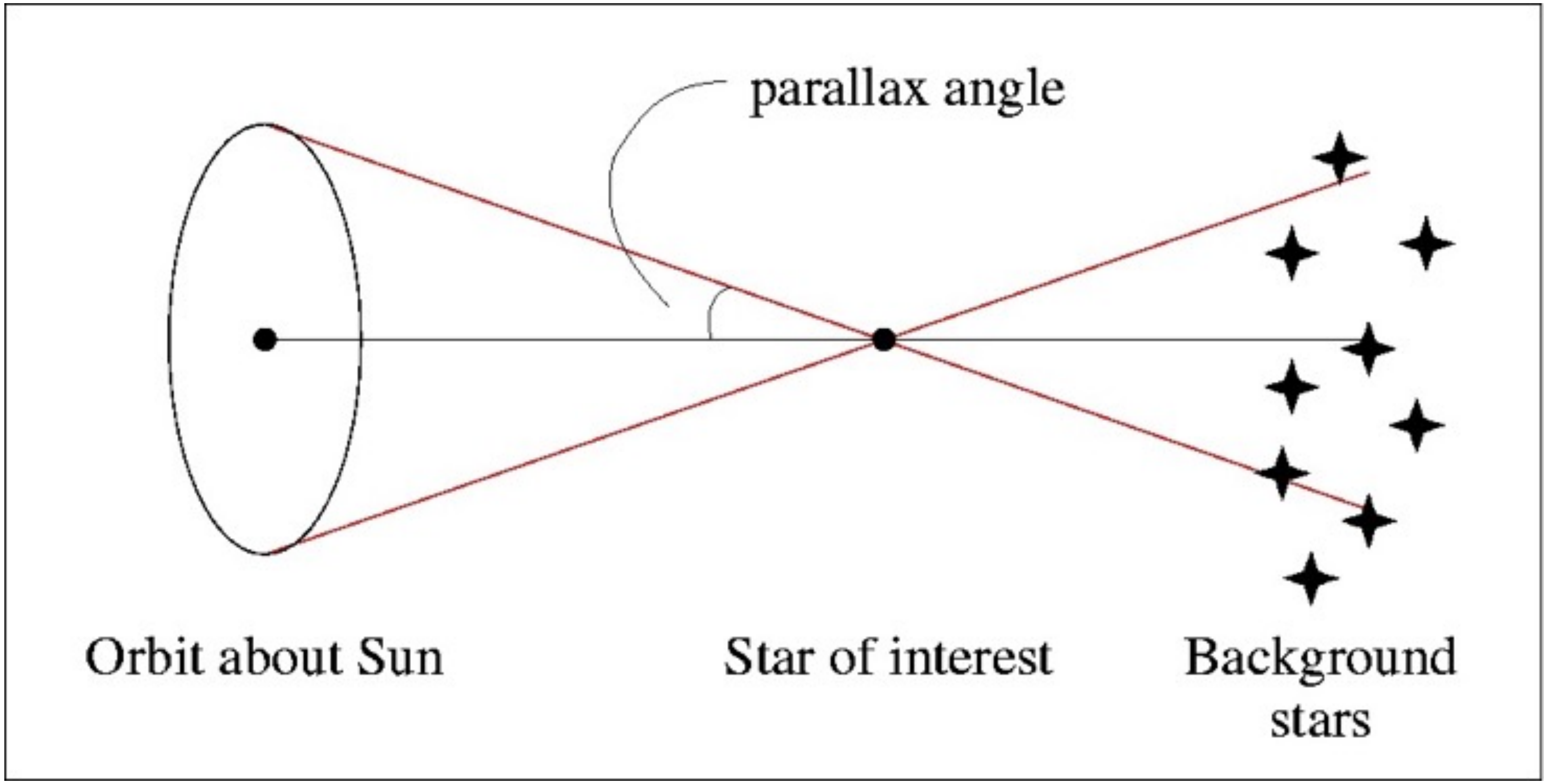
Observing mode

- satellite spins continuously, observing in two directions
- CCDs read out synchronously with spin rate
- satellite precesses, and orbits Sun to observe full sky



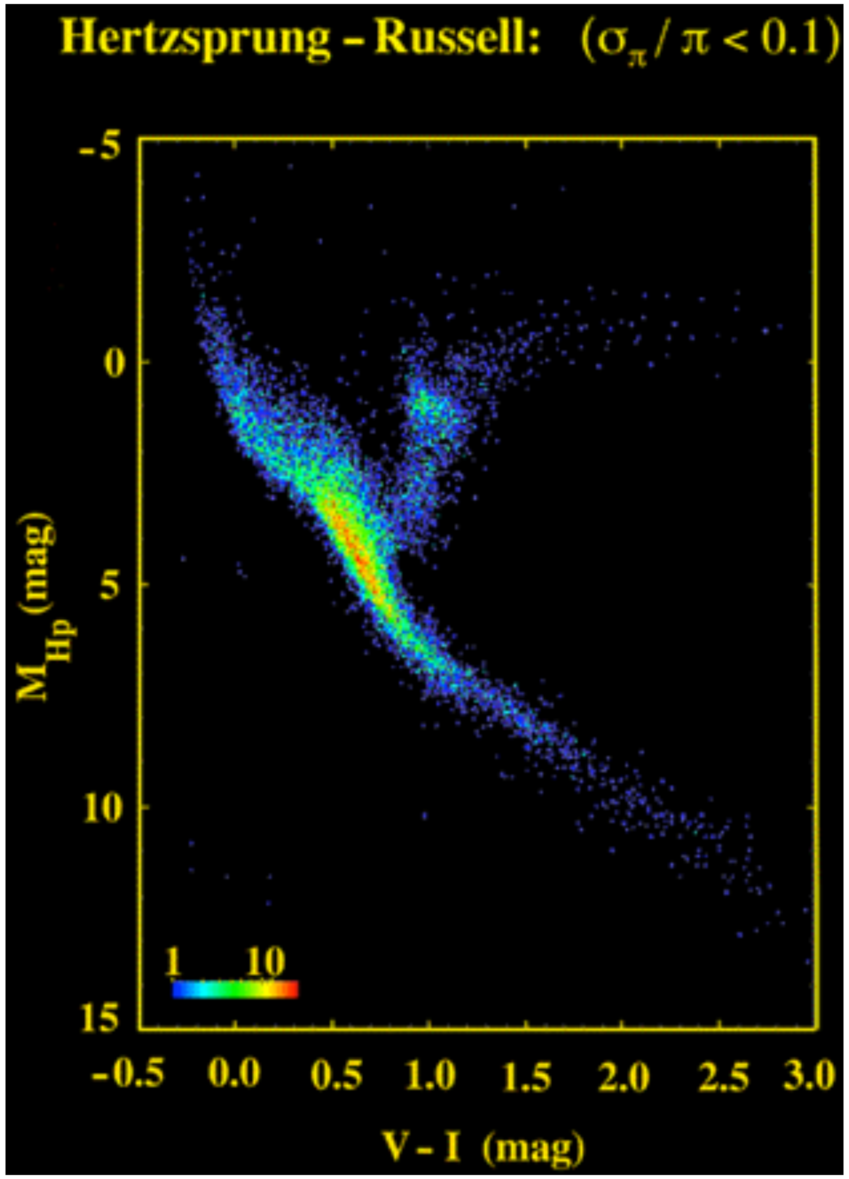


Parallaxes



parallax angle
Orbit about Sun
Star of interest
Background stars

Primary science goals



What is the Galaxy made of?

- distribution and properties of stars
- distribution of dark matter

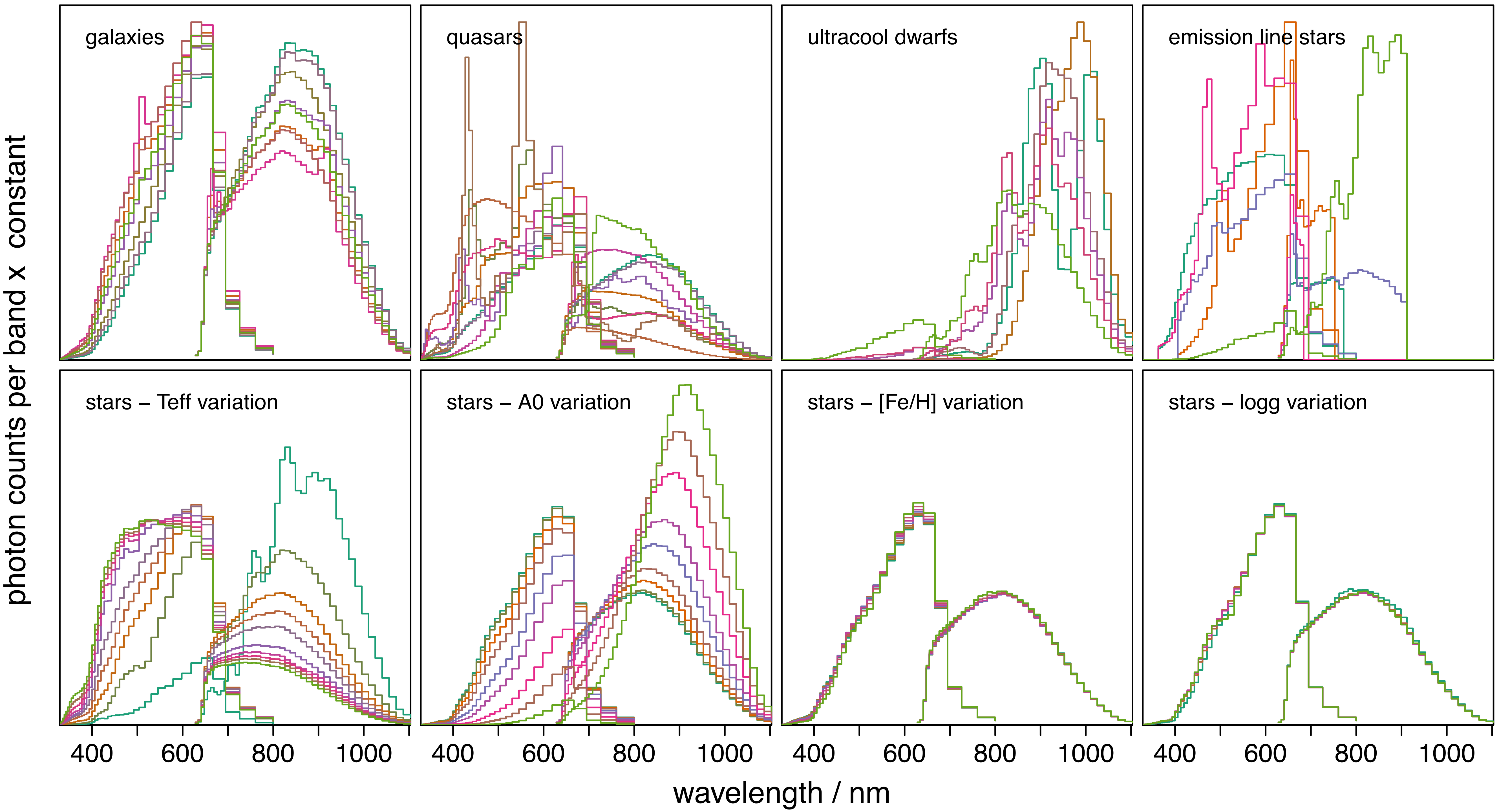
How did the Galaxy form?

- substructure in disk and halo (mergers)
- star formation history

Classification and parameter estimation

- probabilistic source classification
  - classes: star, binary, quasar, galaxy, ...
- astrophysical parameter (AP) estimation
  - for single and binary stars, quasars, and galaxies
- supervised learning:
  - use of various stellar libraries (plus empirical calibration)
- novelty detection (outlier analysis)

Simulated spectrophotometry (BP/RP)



5000 to 20 000 K

0 to 10 mag

-2.5 to +0.5 dex

0 to 5.5 dex

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Estimating stellar parameters

- Goal: intrinsic (T_{eff}, logg, [Fe/H]) and extrinsic (A_0) parameters for individual stars → ϕ
- Data: spectrum, apparent magnitude, parallax
- Three main algorithms
  - Support Vector Machine for approximate results
  - ILIUM (iterative forward modelling)
  - Aeneas (Bayesian model)
  - CBJ 2010, 2011; Liu et al 2012; CBJ+ 2013; Andrae et al. 2016

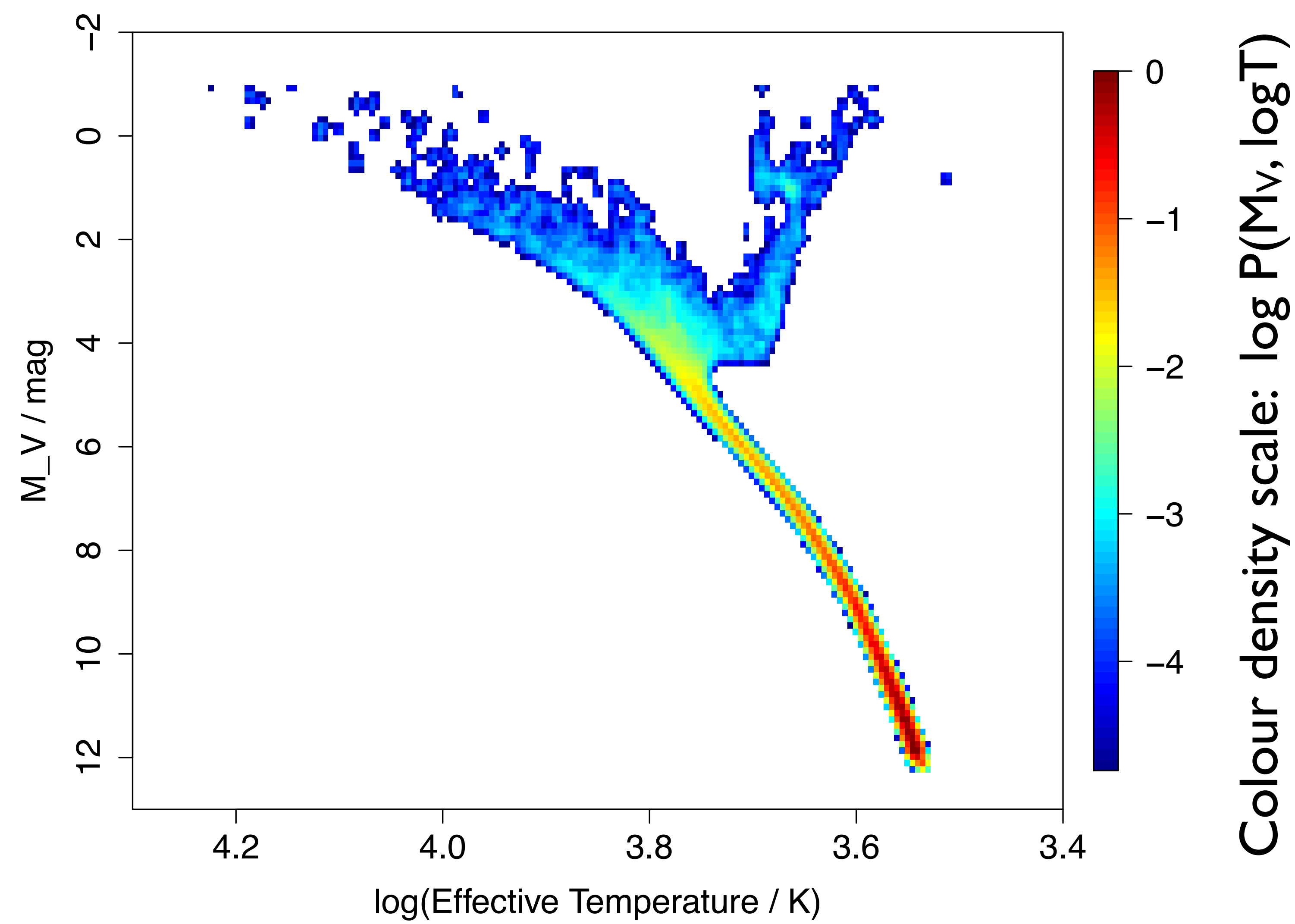
Aeneas

- Bayesian model
  - infer P(ϕ | data, priors)
  - build forward model to give likelihood of data as function of ϕ
  - use MCMC to sample posterior ⇒ AP estimates and conf. intervals
- Forward model fit using synthetic/semi-empirical libraries
  - flux in each pixel as multidimensional function of ϕ
  - later: also use Gaia data with ground-based calibration data

Information beyond the spectrum

1) parallax (ϖ), apparent magnitude (G)

2) Hertzsprung-Russell diagram



Combine information probabilistically, e.g.

- BP/RP spectrum constrains T_{eff} and A_G
- constrain $M_G + A_G$ via $$q \equiv G + 5\log\varpi = M_G + A_G - 5$$
- HRD ("prior") constrains M_G and T_{eff}

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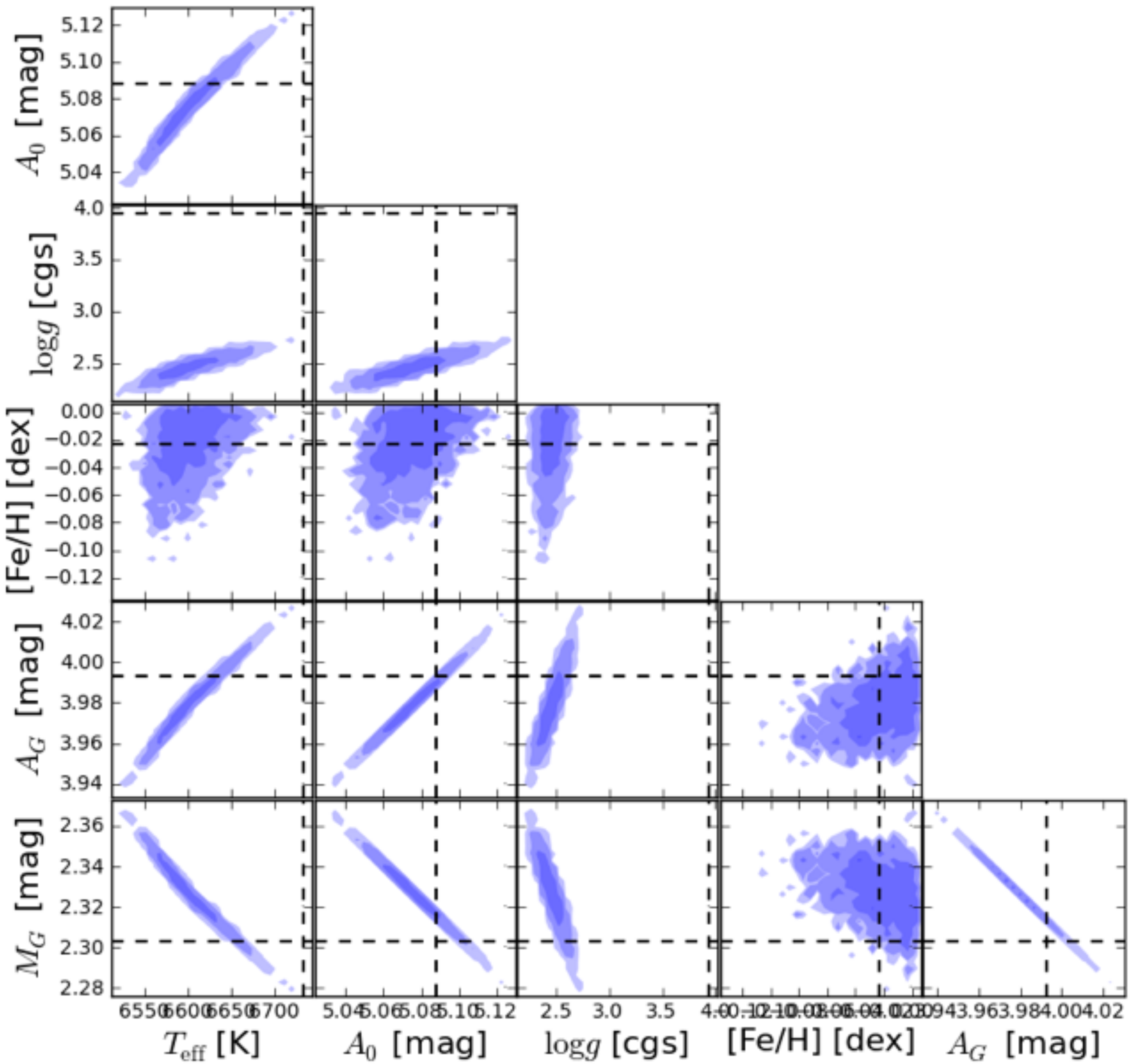
Example Aeneas result



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Inferring distance from parallax

ϖ	parallax
σ_ϖ	error in parallax
r	distance

$$\varpi/\mathrm{as} = \frac{1}{r/\mathrm{pc}}$$

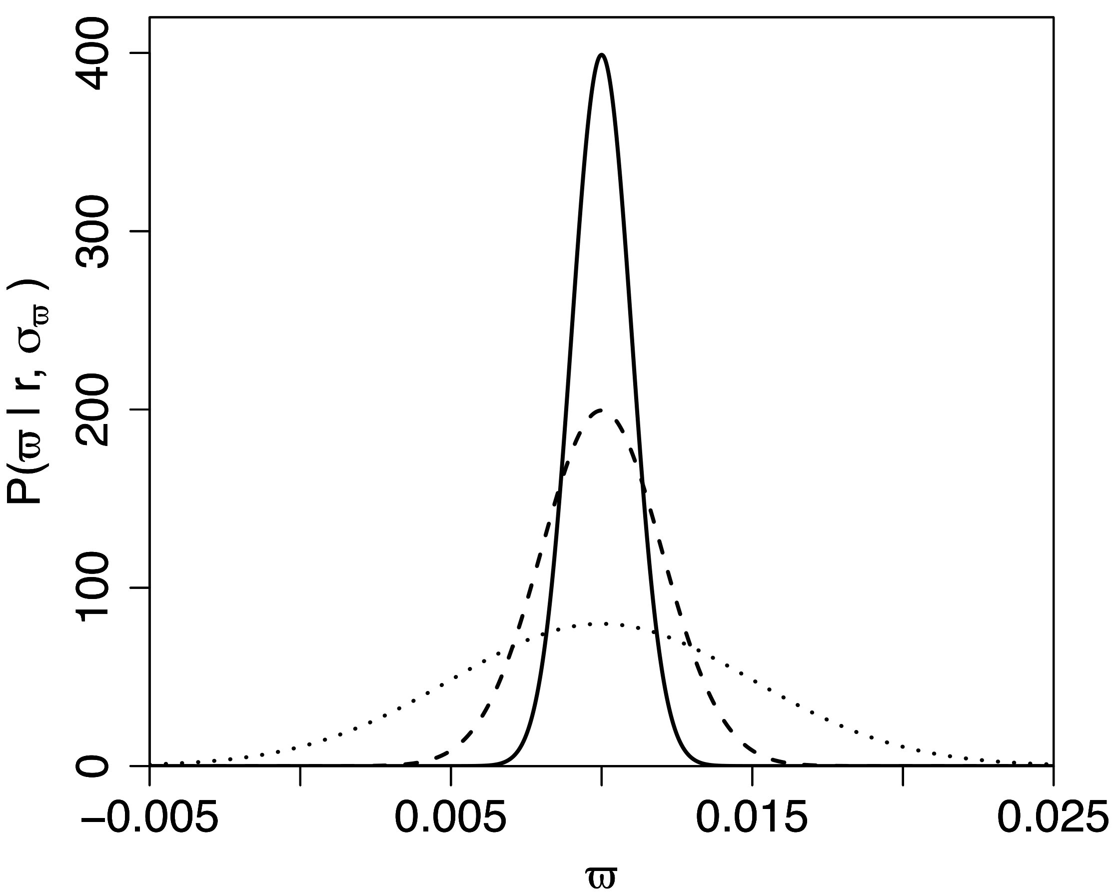
likelihood

$$P(\varpi \,|\, r, \sigma_\varpi) = \frac{1}{\sqrt{2\pi}\sigma_\varpi} \exp\left[-\frac{1}{2\sigma_\varpi^2}\left(\varpi - \frac{1}{r}\right)^2\right]$$

posterior

$$P(r \,|\, \varpi, \sigma_\varpi) \propto P(\varpi \,|\, r, \sigma_\varpi)\, P(r)$$

$r = 100$



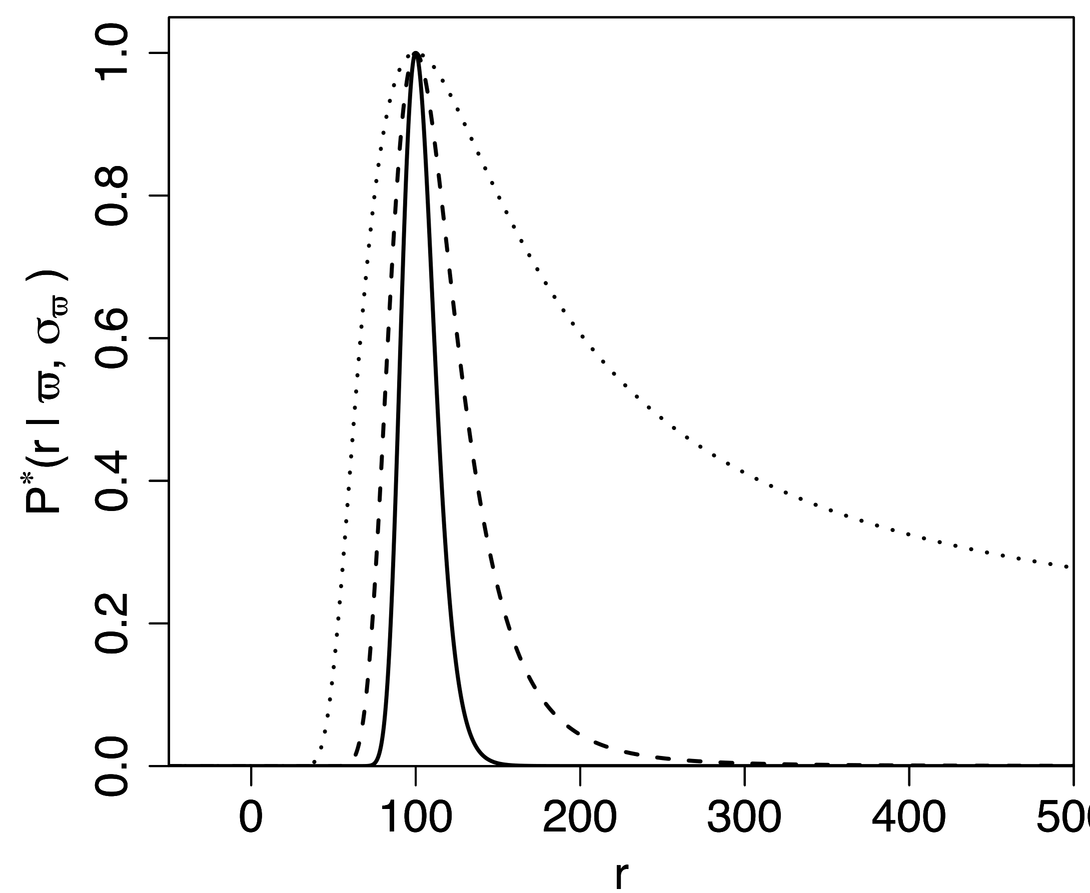
f = 0.1

f = 0.2

f = 0.5

uniform prior

$\varpi = 0.01$



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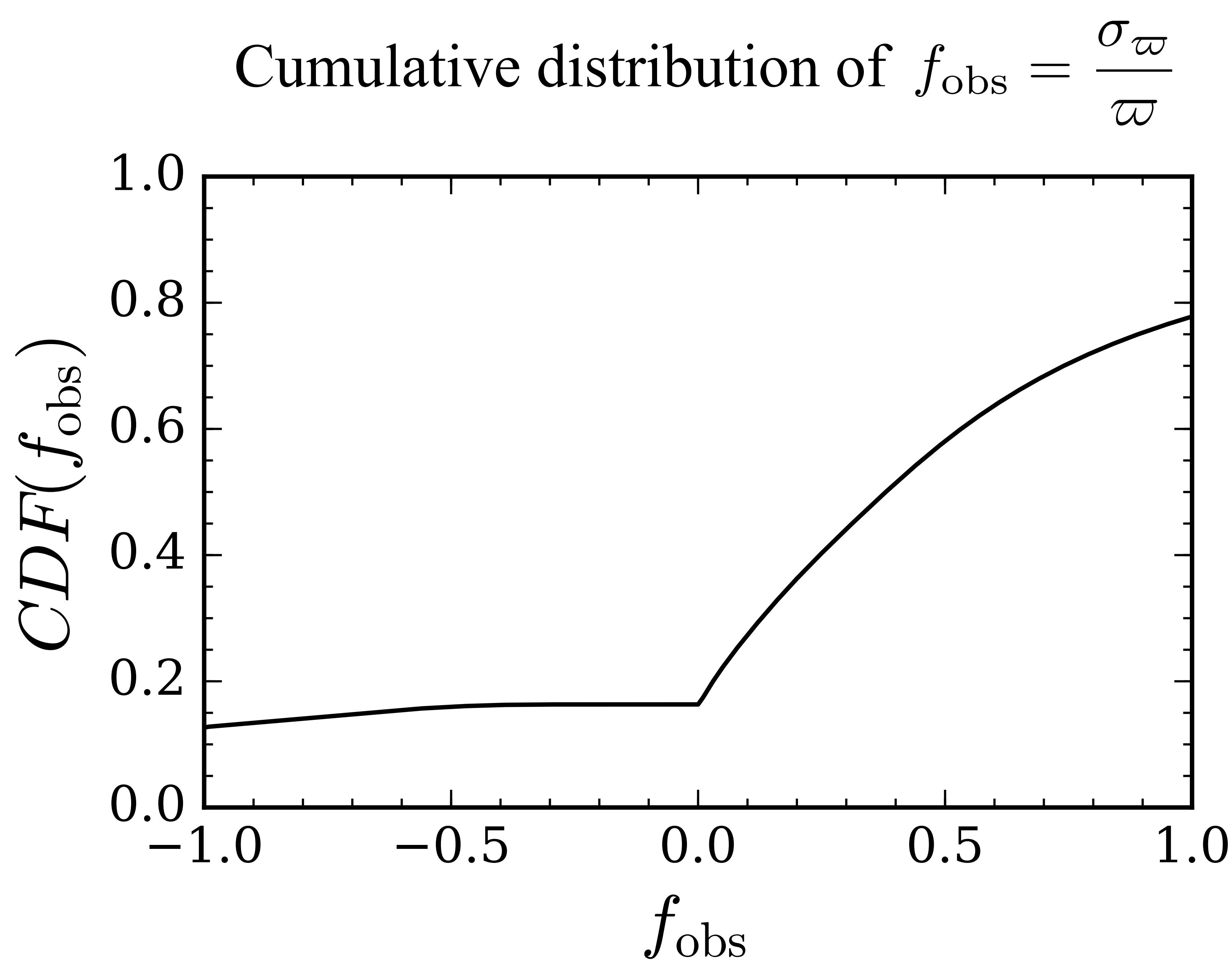
Expected Gaia parallax precisions

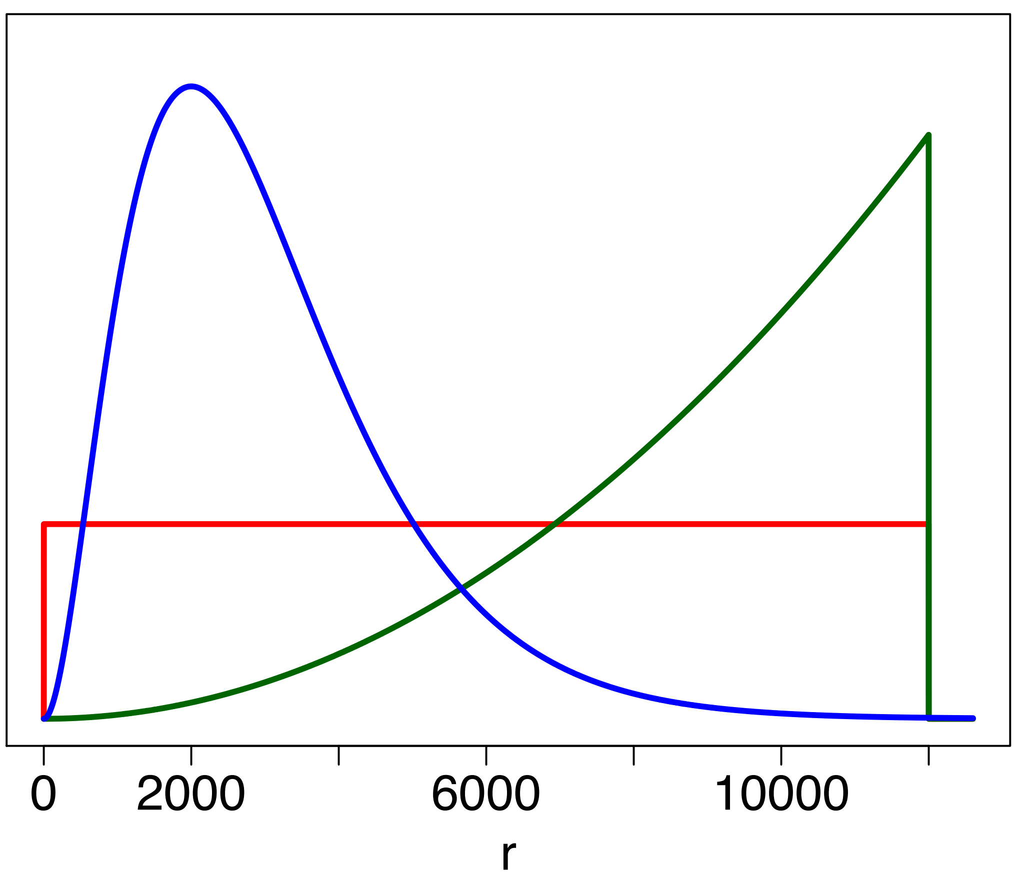


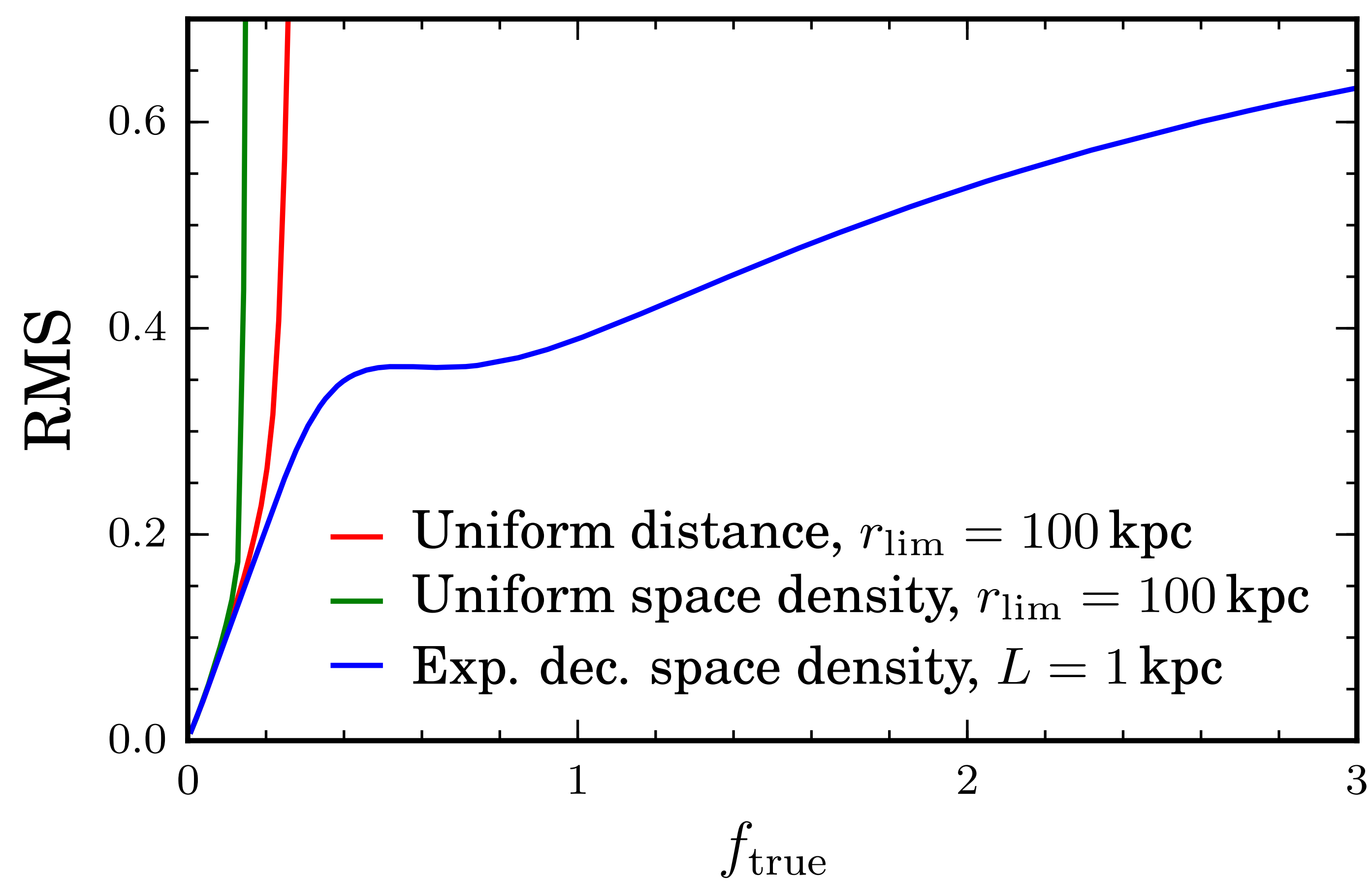
Testing different priors/estimators

- define prior
- compute posterior
- use mode as distance estimate
- compare to true distance (from simulation)

for details see CBJ 2015, Astraatmadja & CBJ 2016

prior PDFs





Summary

- Gaia is primarily an astrometric mission to study the Galaxy
- In addition to astrometry, the final Gaia catalogue will contain
  - source classifications
  - stellar parameters: T_{eff}, A_0, logg, [Fe/H]
  - multiple parameter estimates: different data/methods/libraries
- Distance is not simply the inverse of a noisy parallax
  - prior relevant even for modest uncertainties (above 10-20%)