Gaia mission overview and early data releases

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- Gaia status and survey overview
- Science performance
- Limitations of the Gaia survey
- Data release scenario
- Extra material for weekend reading

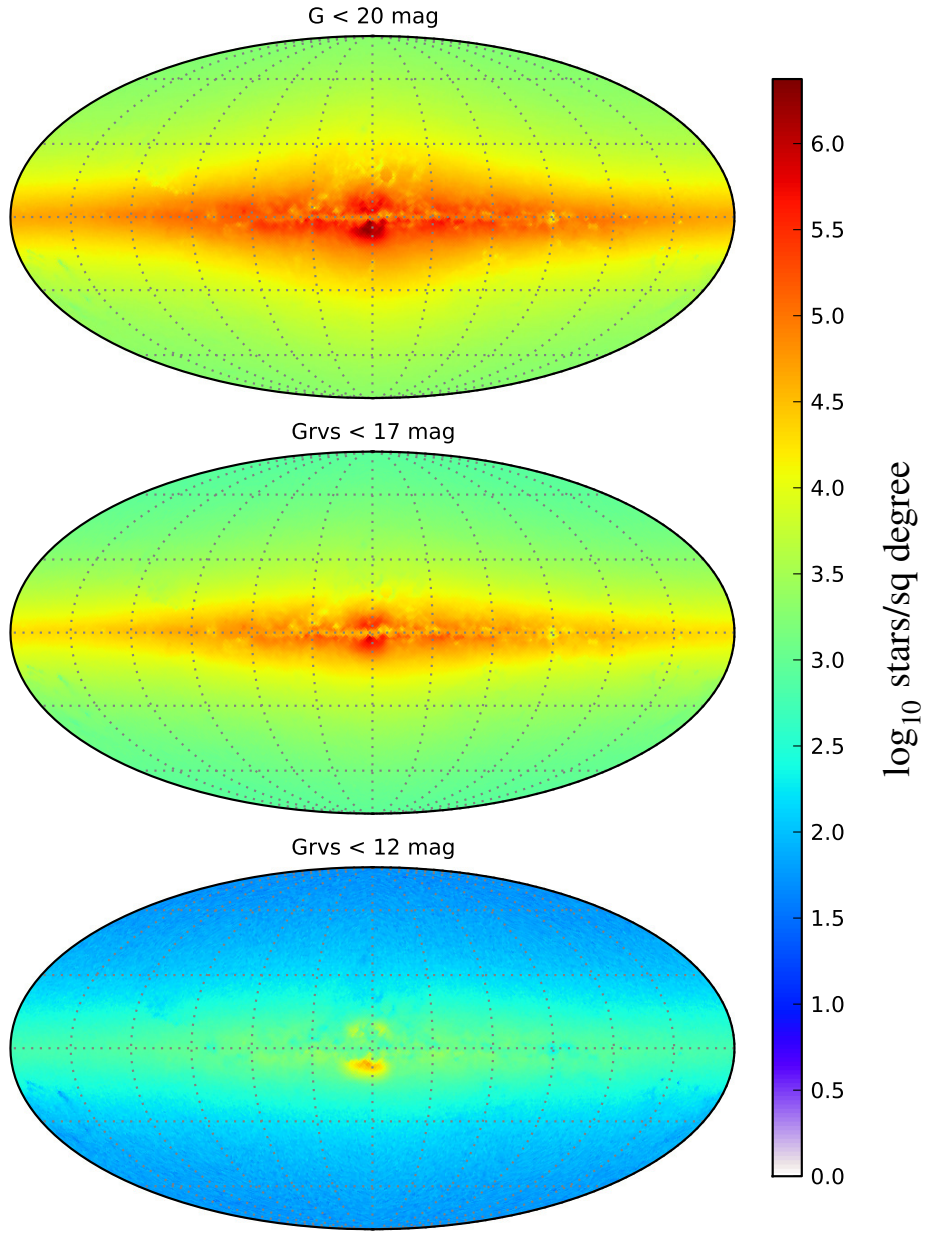
Survey capabilities

- Three simultaneous observing modes
- Complete to $G = 20$ ($V = 20$–22)
- Observing programme: autonomous on-board detection and unbiased
- Quasi-regular time-sampling over 5 years ($\sim$ 70 observations)
- Angular resolution comparable to HST

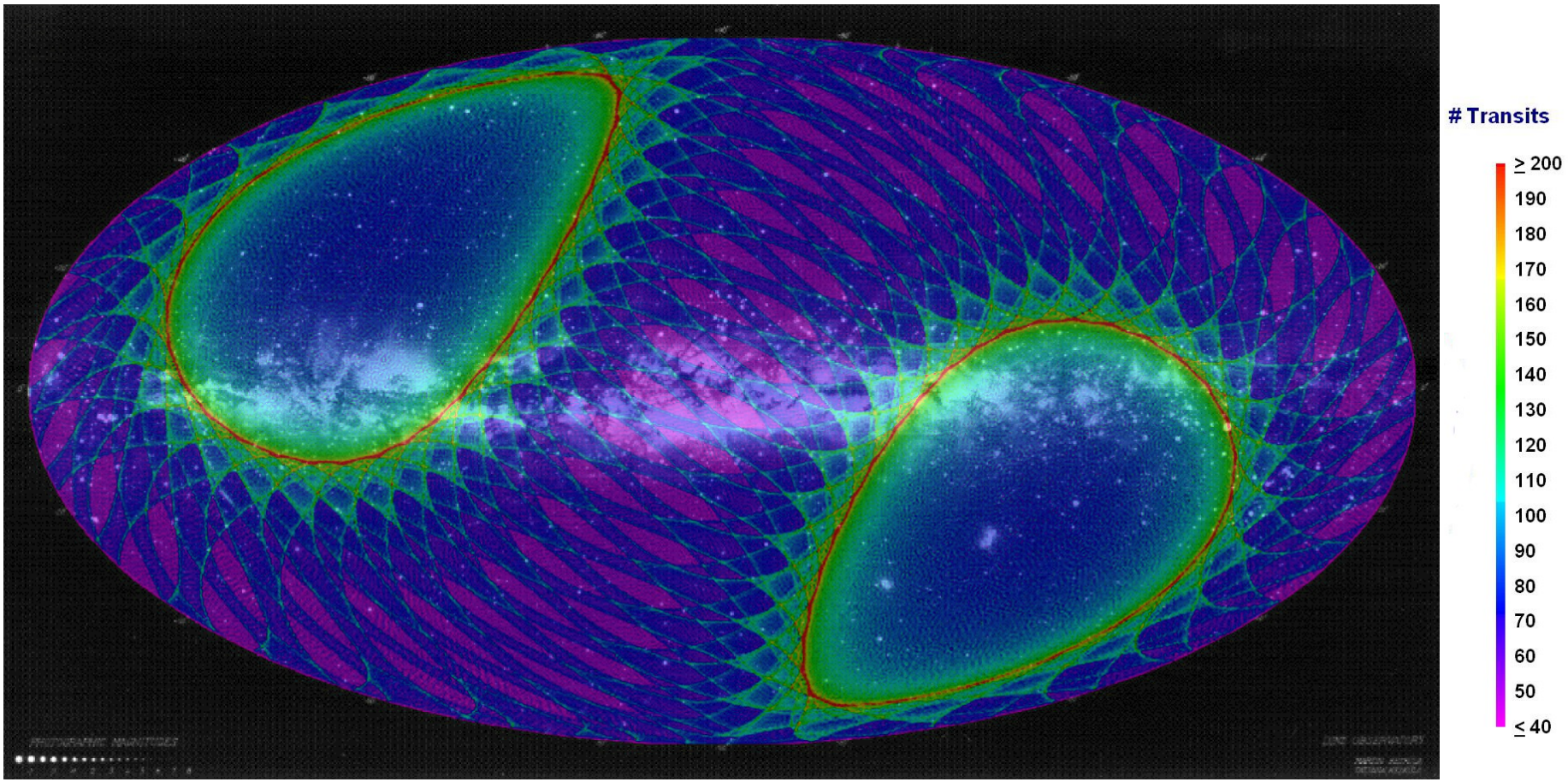
Number of objects

- 1 billion stars to $G = 20$
- 10^6–10^7 galaxies
- 500 000 quasars
- 3×10^5 solar system bodies
- tens of thousands of exoplanets

Simulated Gaia sky — Robin et al., arXiv:1202.0132

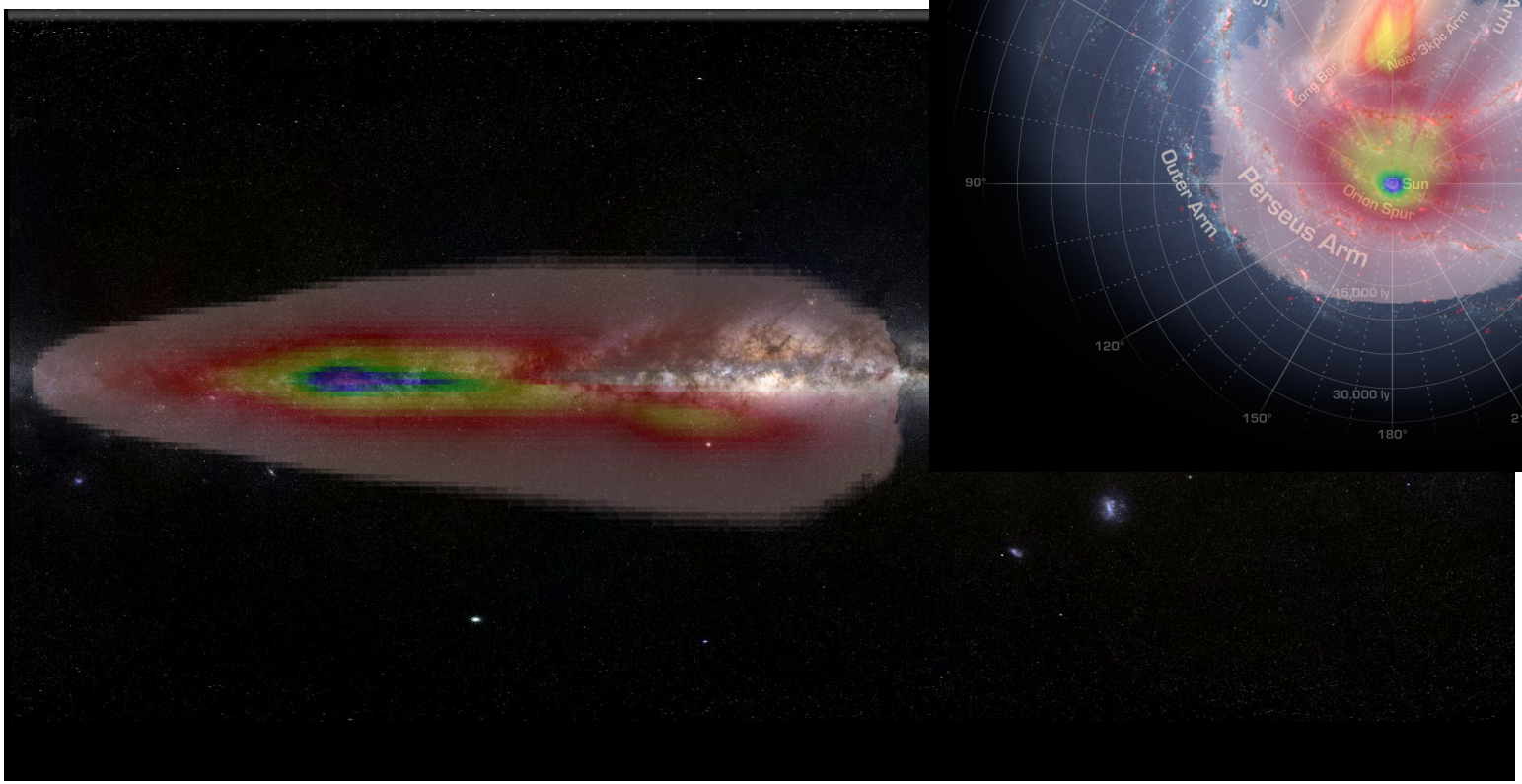


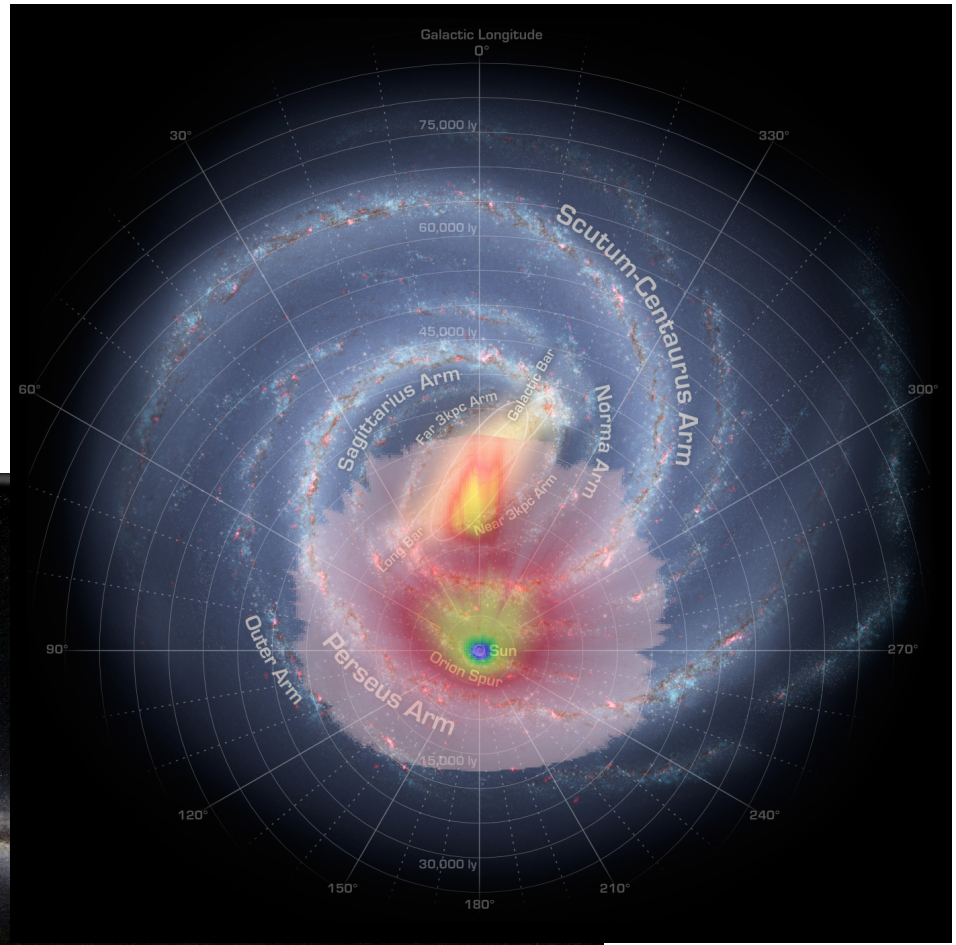
Number of field of view transits



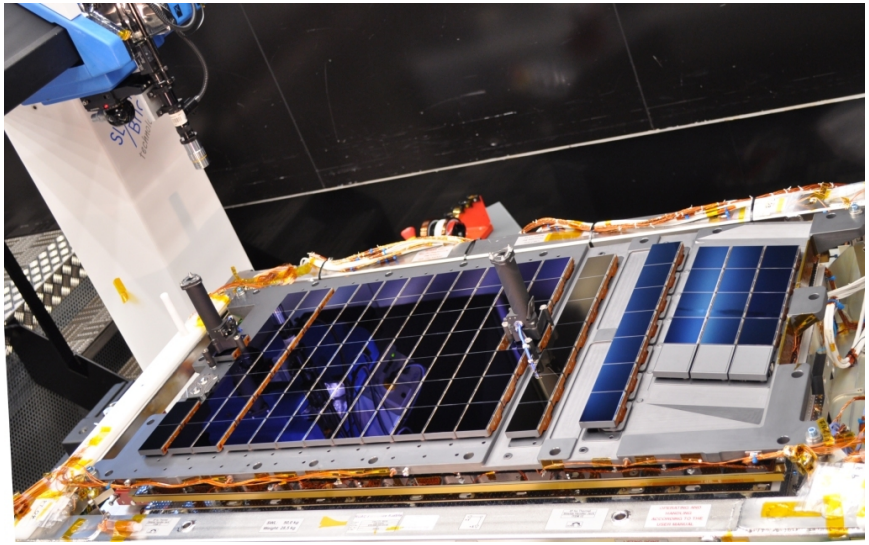
Survey capabilities

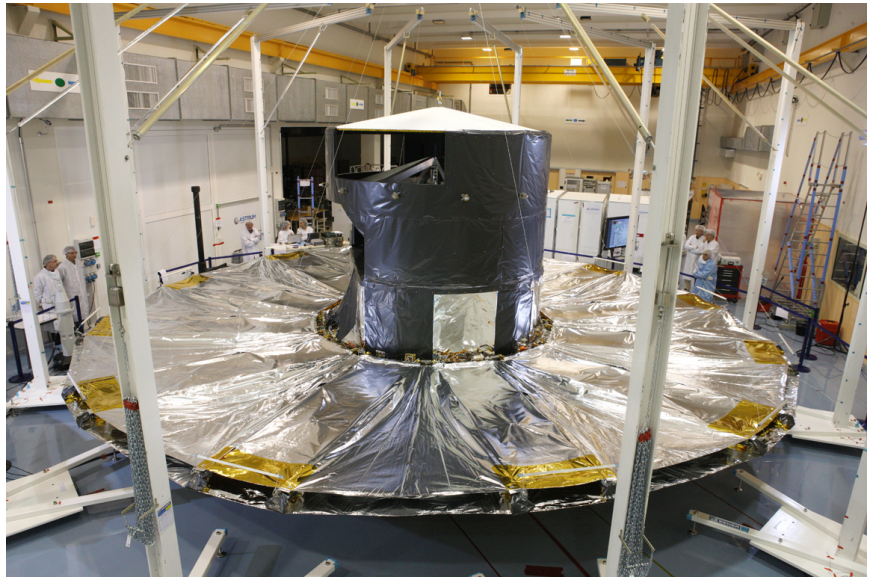
Figures courtesy Xavier Luri, DPAC-CU2 and NASA/JPL-Caltech/R. Hurt





Launch October 2013





Images courtesy EADS-Astrium and ESA

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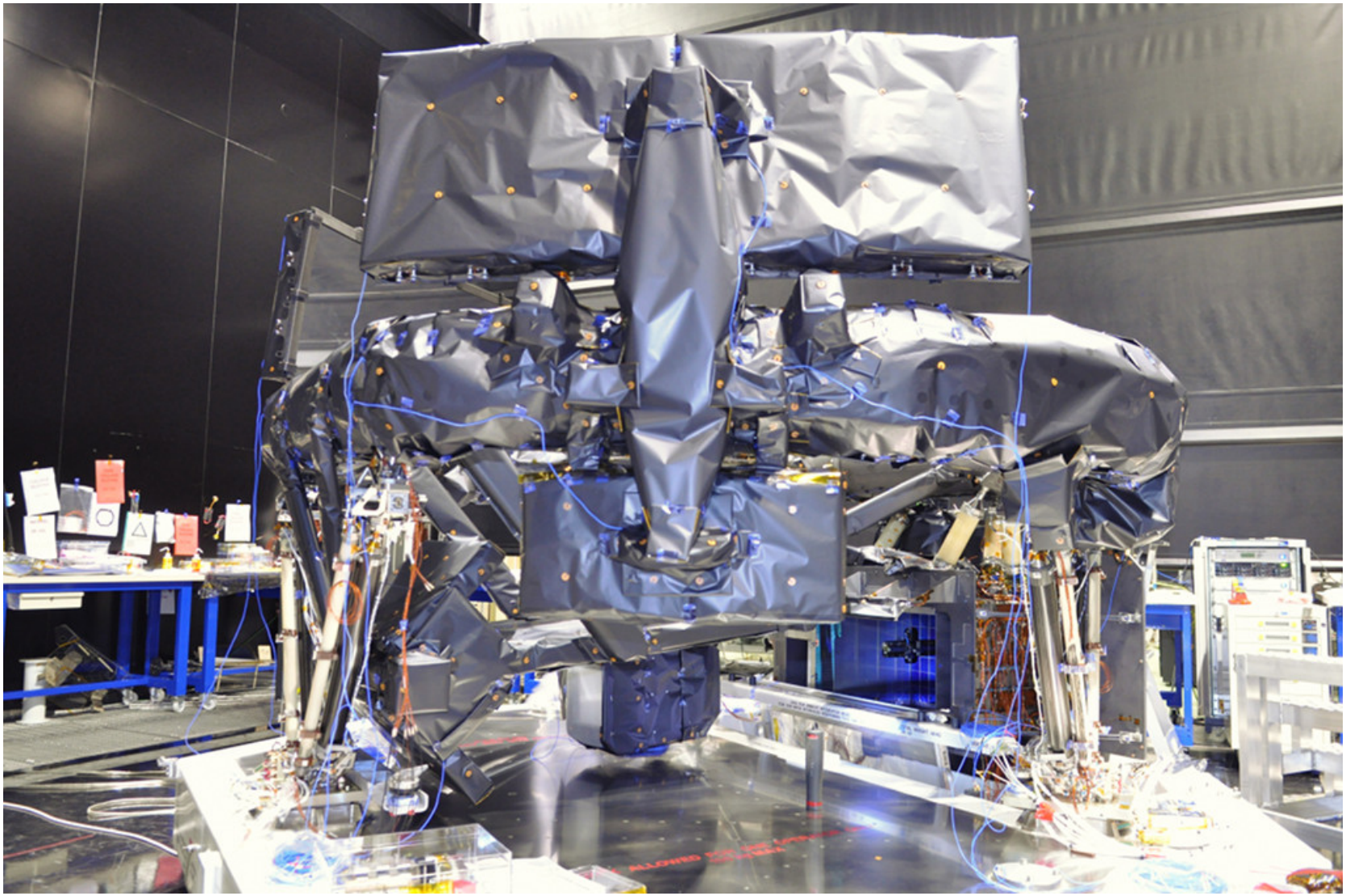
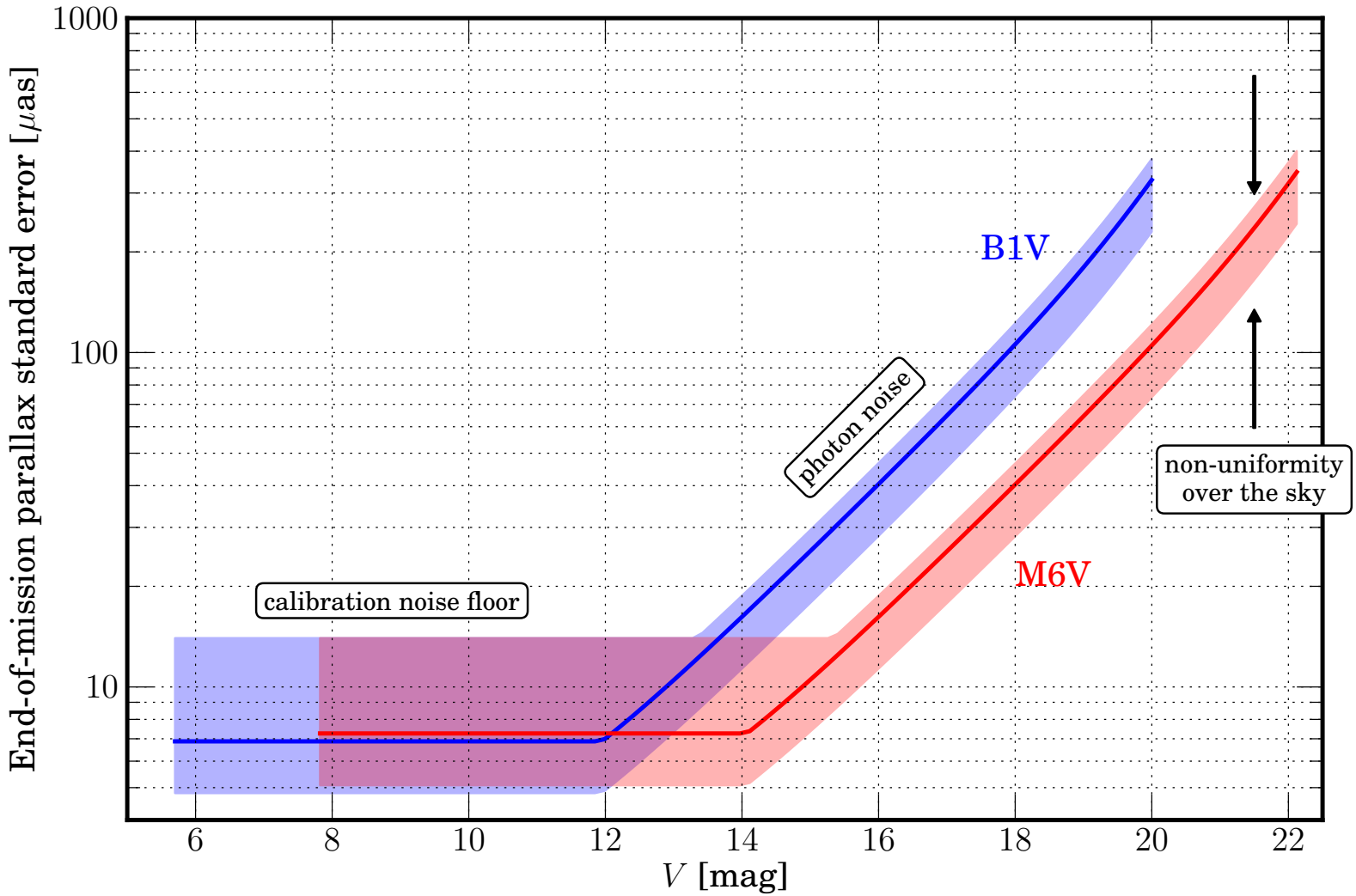


Payload currently undergoing major tests in cold vacuum

Gaia astrometry



Apply factors ~ 0.5 and ~ 0.7 for positions and proper motions

Gaia spectrophotometry

Photometer

- Two channels: 330–680 nm (BP), 640–1000 nm (RP)
- Low resolution ($\sim$ 3–30 nm/pixel) prism spectra
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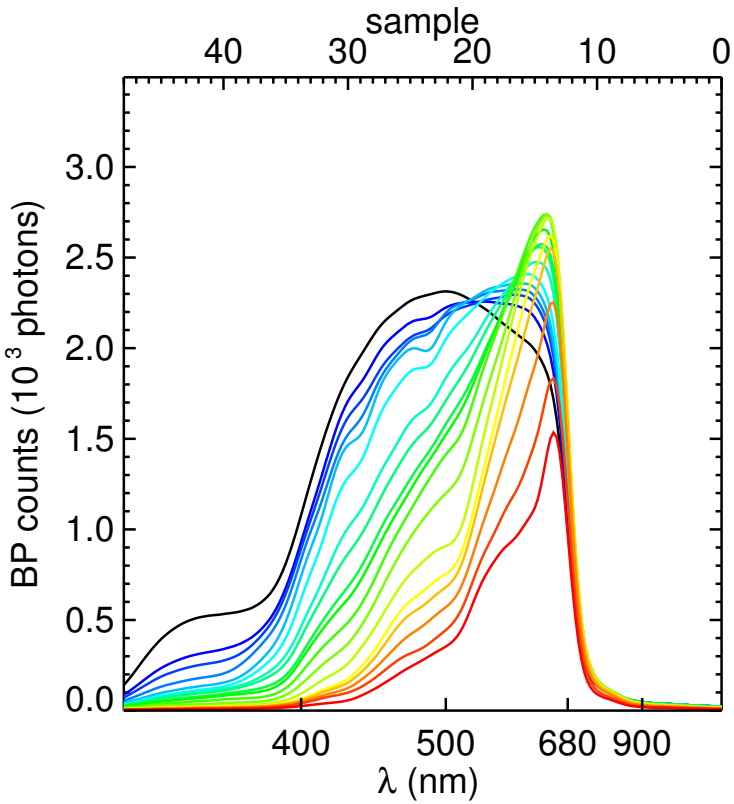

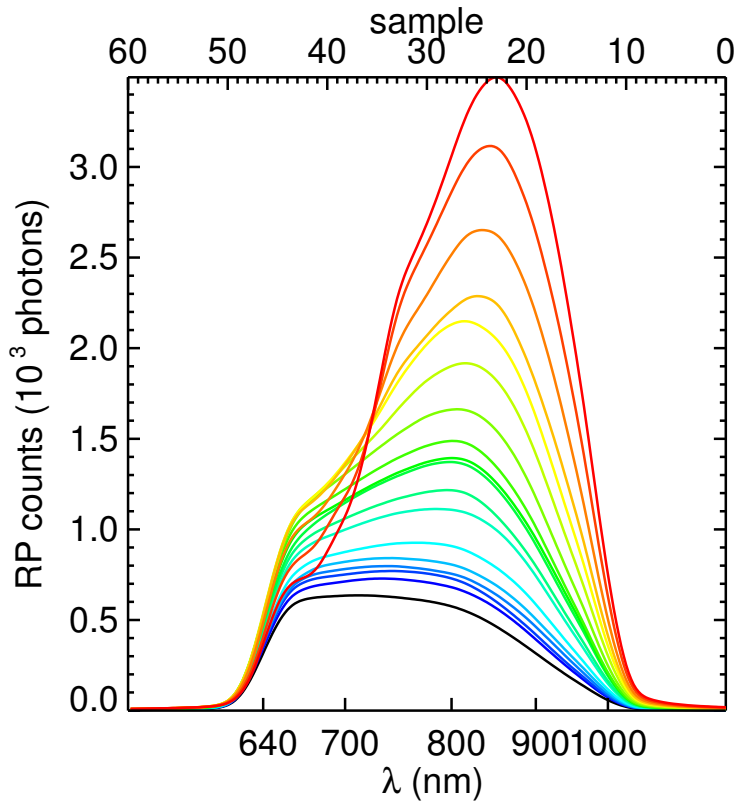

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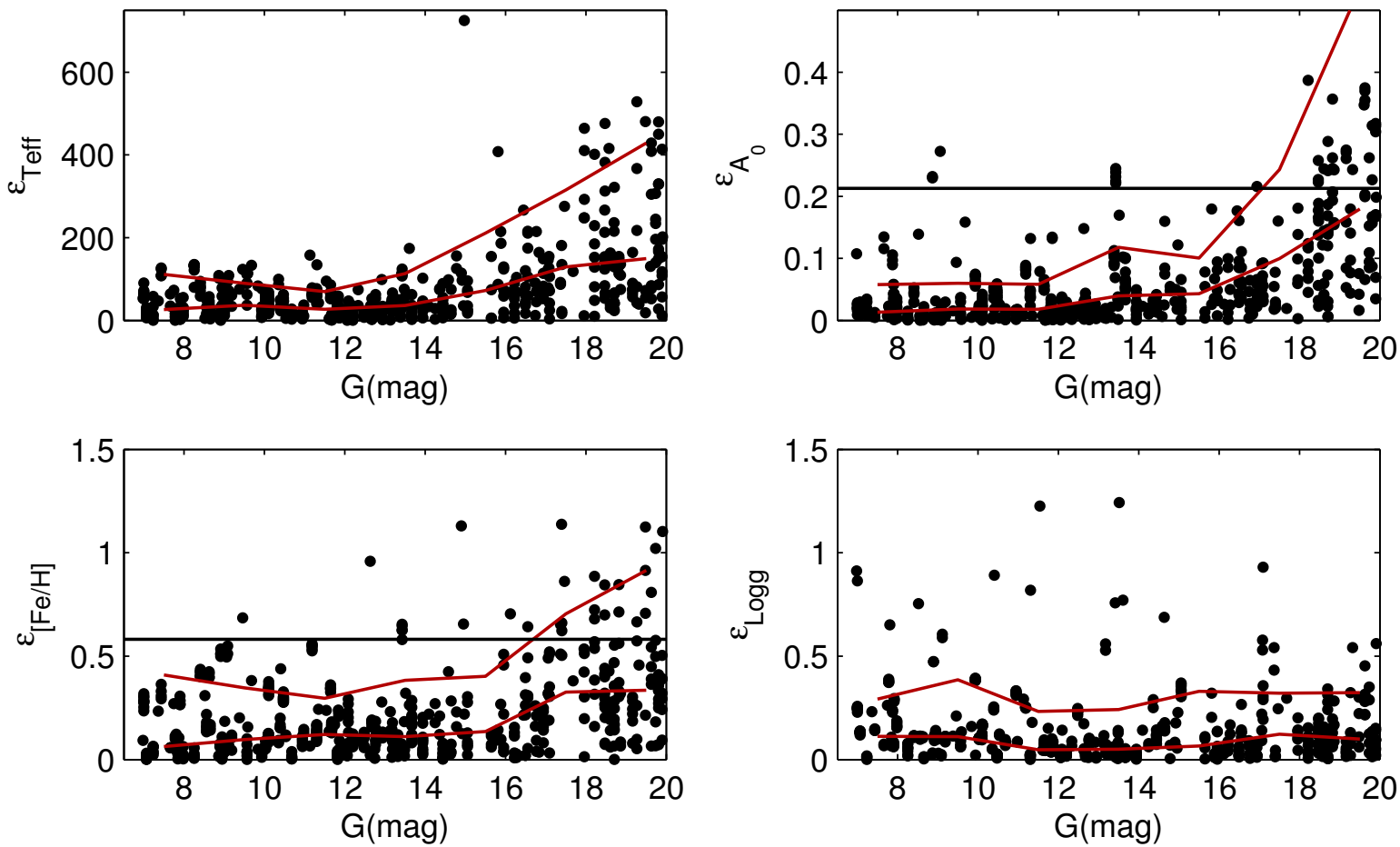
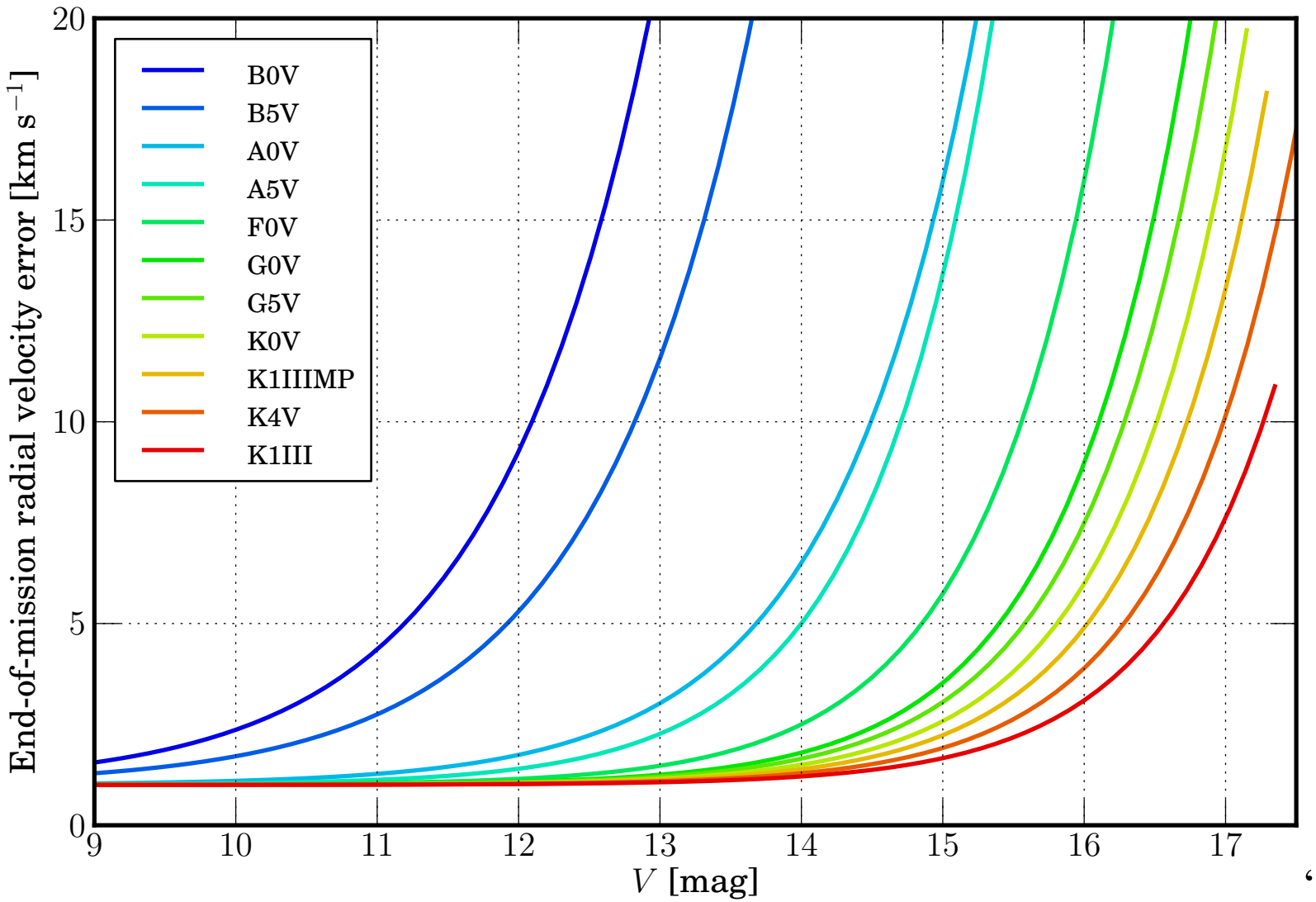


Example of stellar parametrization performance (in this case with SVM).
From Liu et al., 2012, MNRAS 426, 2463

Gaia spectroscopy

- Slitless spectroscopy in Ca triplet region (847–874 nm)
- $\lambda/\Delta\lambda \sim 11\,000$



Stellar and interstellar parameters (conservative estimates)

◆ Radial velocities	$V \leq 17$	$\sim 150 \times 10^6$ stars
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Diagnostics

- Binarity/multiplicity, variability
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- Long period classical Cepheids $\sigma_{v_r} < 7$ km/s $\rightarrow$ 20–30 kpc

Gaia's 'limitations'

- Sky-coverage non-uniformity
  - Average $\sim$ 70 observations over 5 years ($\sim$ 20% dead time)
  - Varies over the sky between $\sim$ 50 and $\sim$ 130 ($\sim$ 20% dead time)

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  - Astrometric limit is $\sim 1\,000\,000$ stars deg^{-2} (without bright stars)
  - Photometric limit is $\sim 750\,000$ stars deg^{-2} (without bright stars)
  - Spectroscopic limit is $\sim 36\,000$ stars deg^{-2} (without bright stars)
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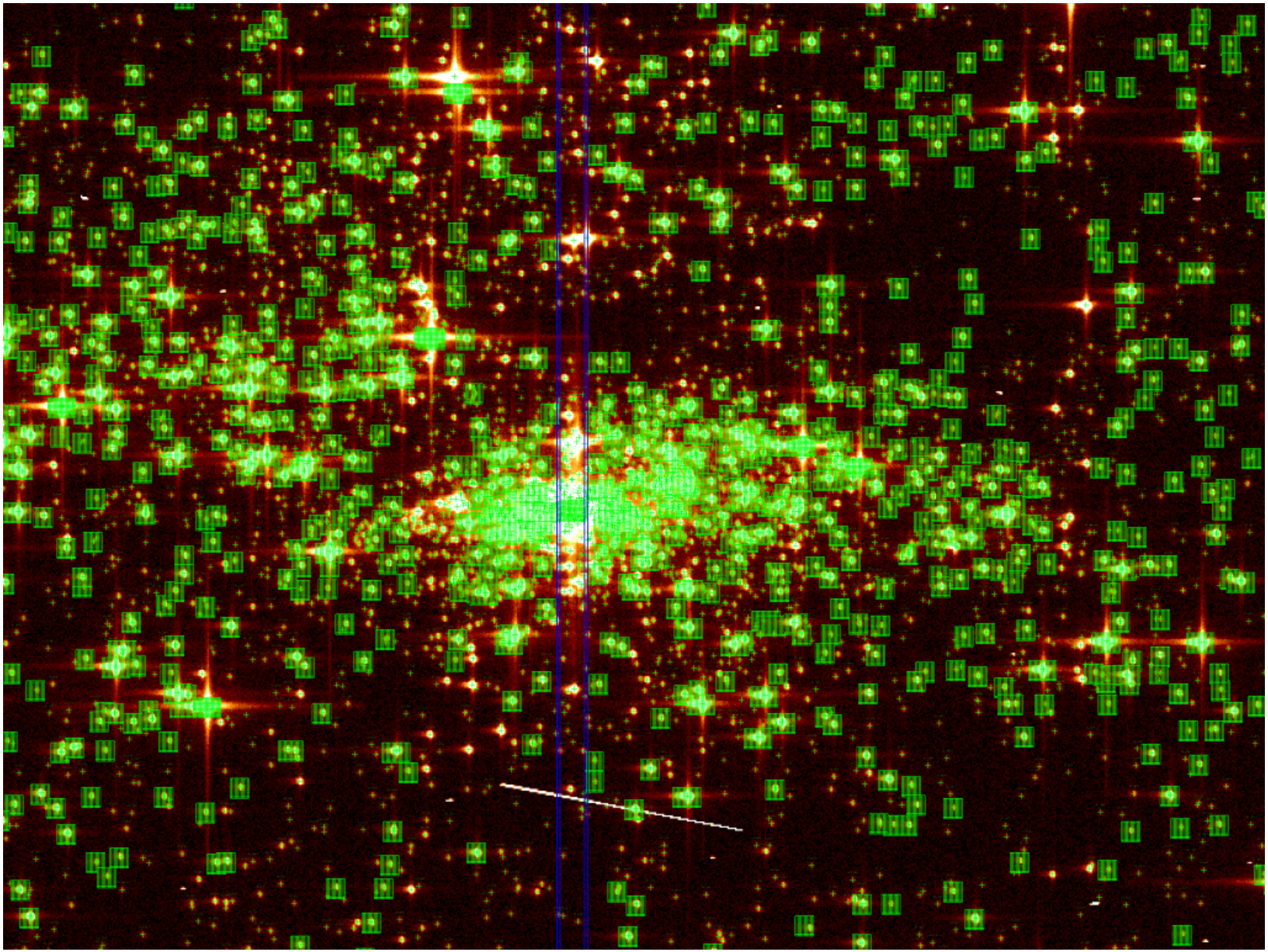

Gaia's view of R136, image courtesy Jos de Bruijne and Guido de Marchi

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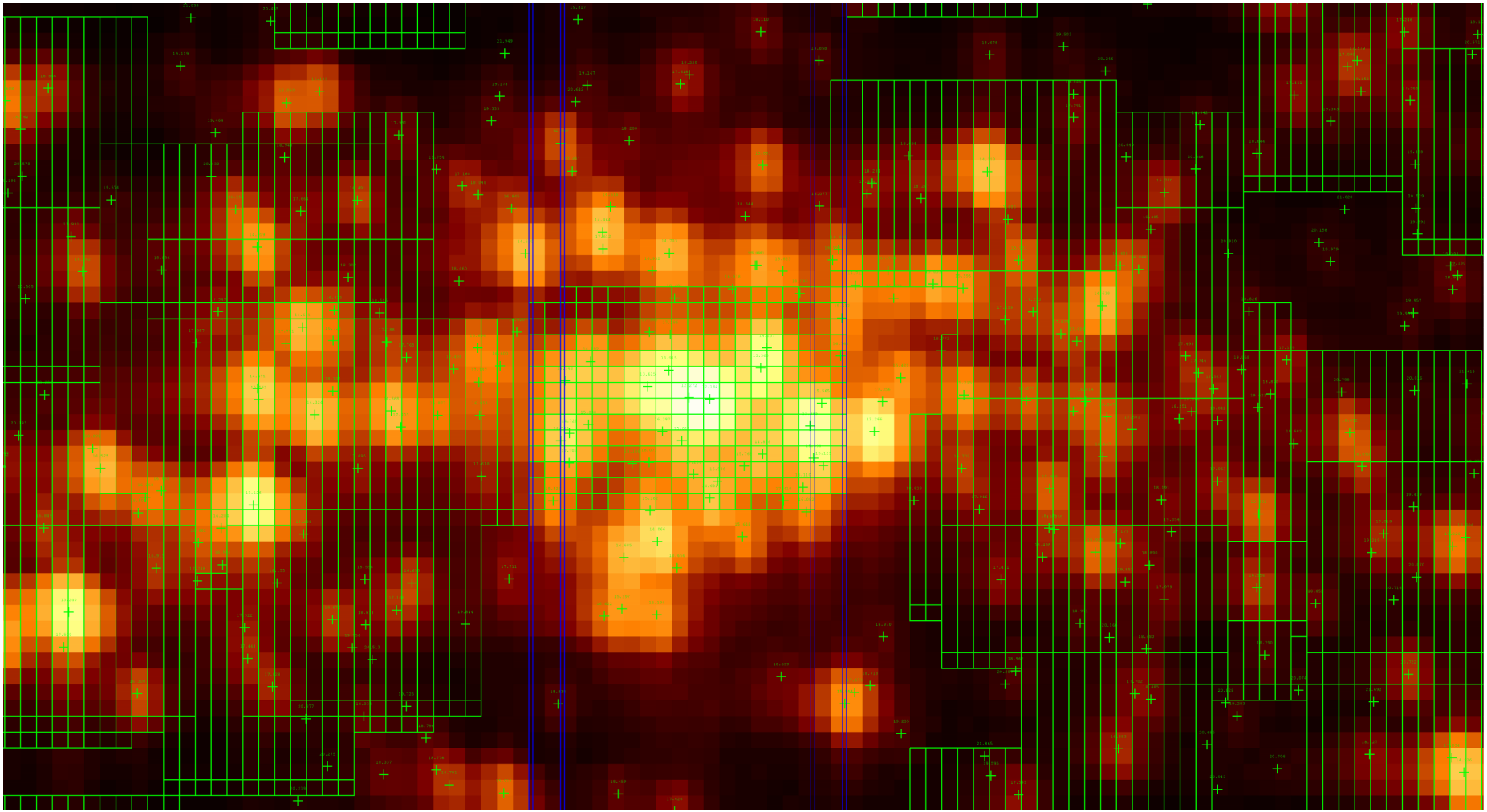

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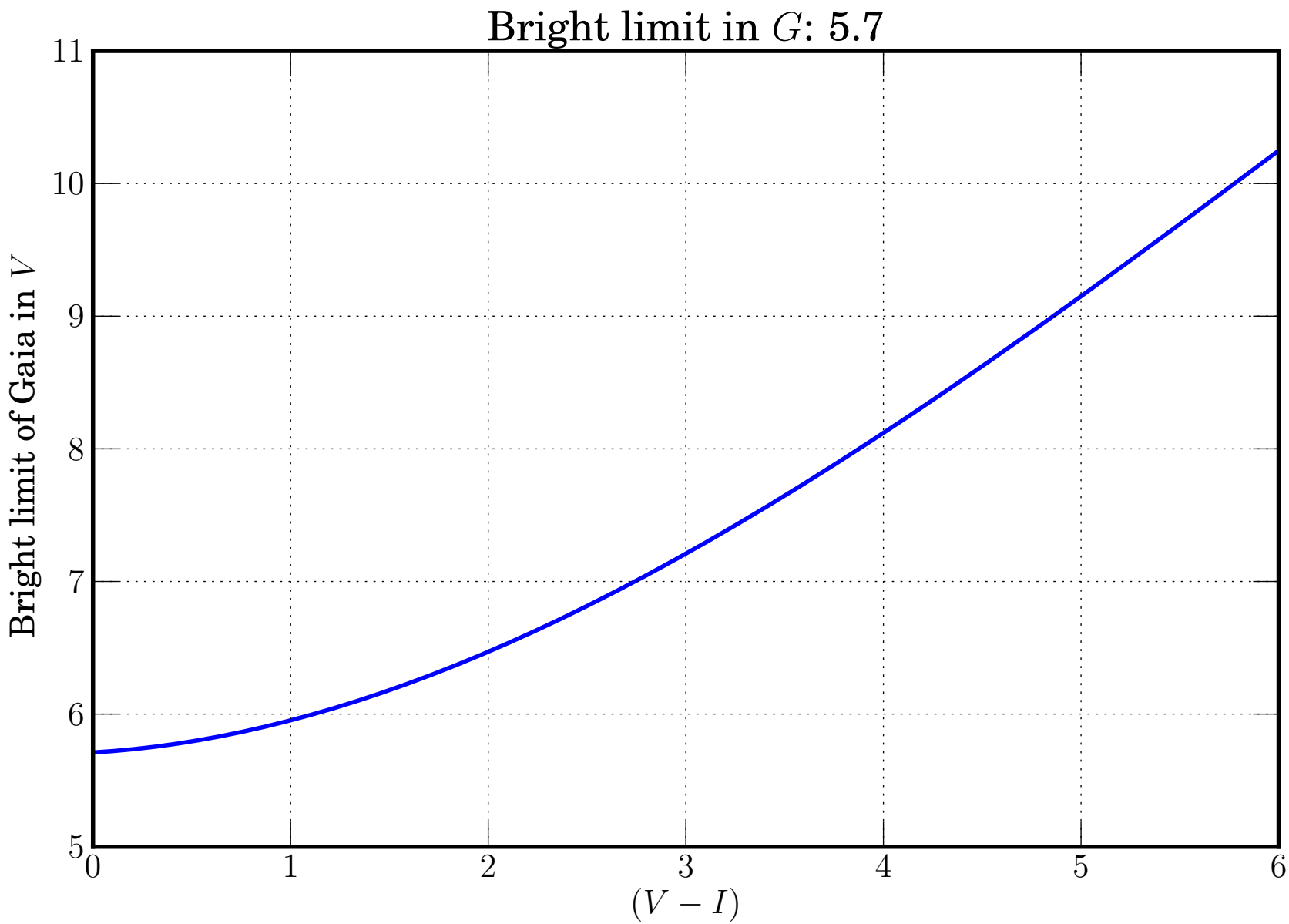
  - In reality, extended objects up to 700 mas are detected
- Dynamic range: existence of a bright limit
  - The paper limit is $G = 5.7$ mag ($V = 6$ mag is normally quoted)
  - The real limit is a bit better (and varies from CCD row to row)
  - Investigations are ongoing to extend to $G \sim 1.5$

Gaia's 'limitations'



Data release scenario

Release

L + 22m

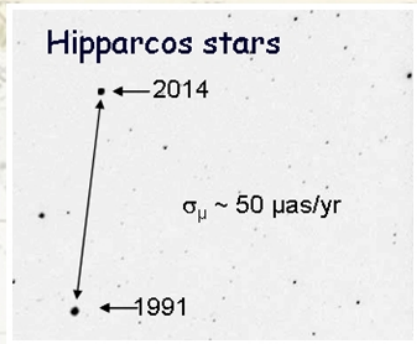
L + 28m

L + 40m

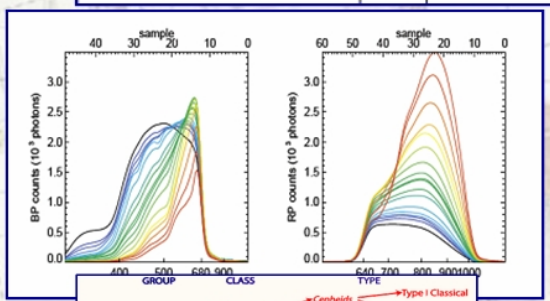
L + 65m

α deg 8	δ deg 9
4.18700521	41.06905721
57.84982093	−25.93298679
87.24506095	63.69702032

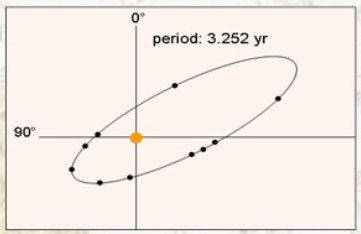
α deg 8	δ deg 9	π mas 11	μ_{α^*} mas/yr 12	μ_δ mas/yr 13
4.18700521	41.06905721	18.92	190.14	27.75
57.84982093	−25.93298679	21.42	273.72	167.93
87.24506095	63.69702032	4.12	5.07	−98.19
97.98452970	−27.72950422	17.95	21.31	217.87
106.43757563	26.14031575	21.74	18.58	−10.54
109.41026120	−29.01434479	7.92	−4.53	−7.01

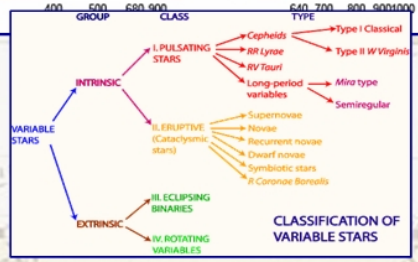


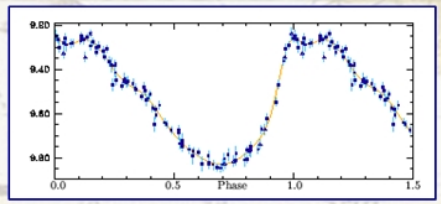
G G_{BP} G_{RP}



⟨Vr⟩







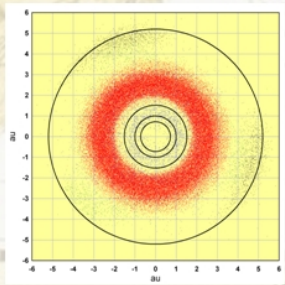


Figure by François Mignard

Data release scenario

- Assumes smooth operations!
- Each release updates the previous and contains significant new additions

October 2013 launch

L+22M Positions + G magnitude ($\sim$ all sky, single stars)
- Includes more often scanned Ecliptic pole regions
- Hundred Thousand Proper Motions (Hipparcos-Gaia, ~ 50 μas/yr)

L+28M radial velocities for bright stars, two-band photometry, and full astrometry (α, δ, ϖ, $\mu_{\alpha*}$, μ_δ) where available.

L+40M full astrometry, orbital solutions for short period binaries, $(G_{\rm BP} - G_{\rm RP})$, BP/RP Spectrophotometry and astrophysical parameters , radial velocities, RVS spectra

L+65M Updates on previous release — including more sources, source classifications, multiple astrophysical parameters, variable star solutions and epoch photometry for them, solar system results

End+3yr Everything

Extra material on expected Gaia performances

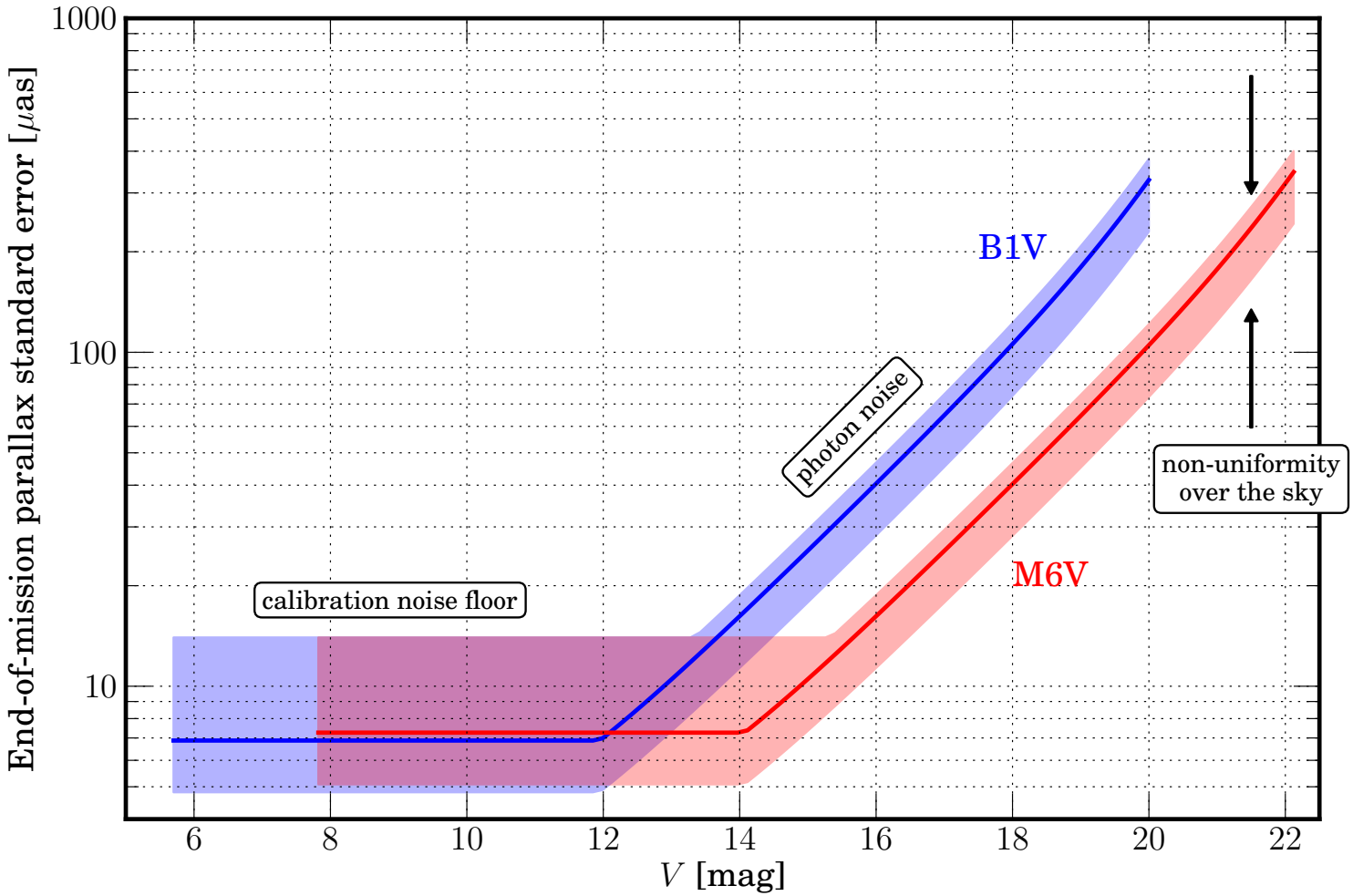
Gaia astrometric performances

Sky averaged parallax accuracies (μas)

	B1V	G2V	M6V
Bright stars	$(6 < V < 12)$	$(6 < V < 12)$	$(8 < V < 14)$
	5–14	5–14	5–14
$V = 15$	26	24	9
$V = 20$	330	290	100

- Single stars, no extinction
- Apply factors ~ 0.5 and ~ 0.7 for positions and proper motions
- Radiation-damage effects on CCDs taken into account approximately
- Estimates include a 20% margin (factor 1.2) for unmodelled errors
- Astrometric instrument designed for up to 750 000 stars/degree^2

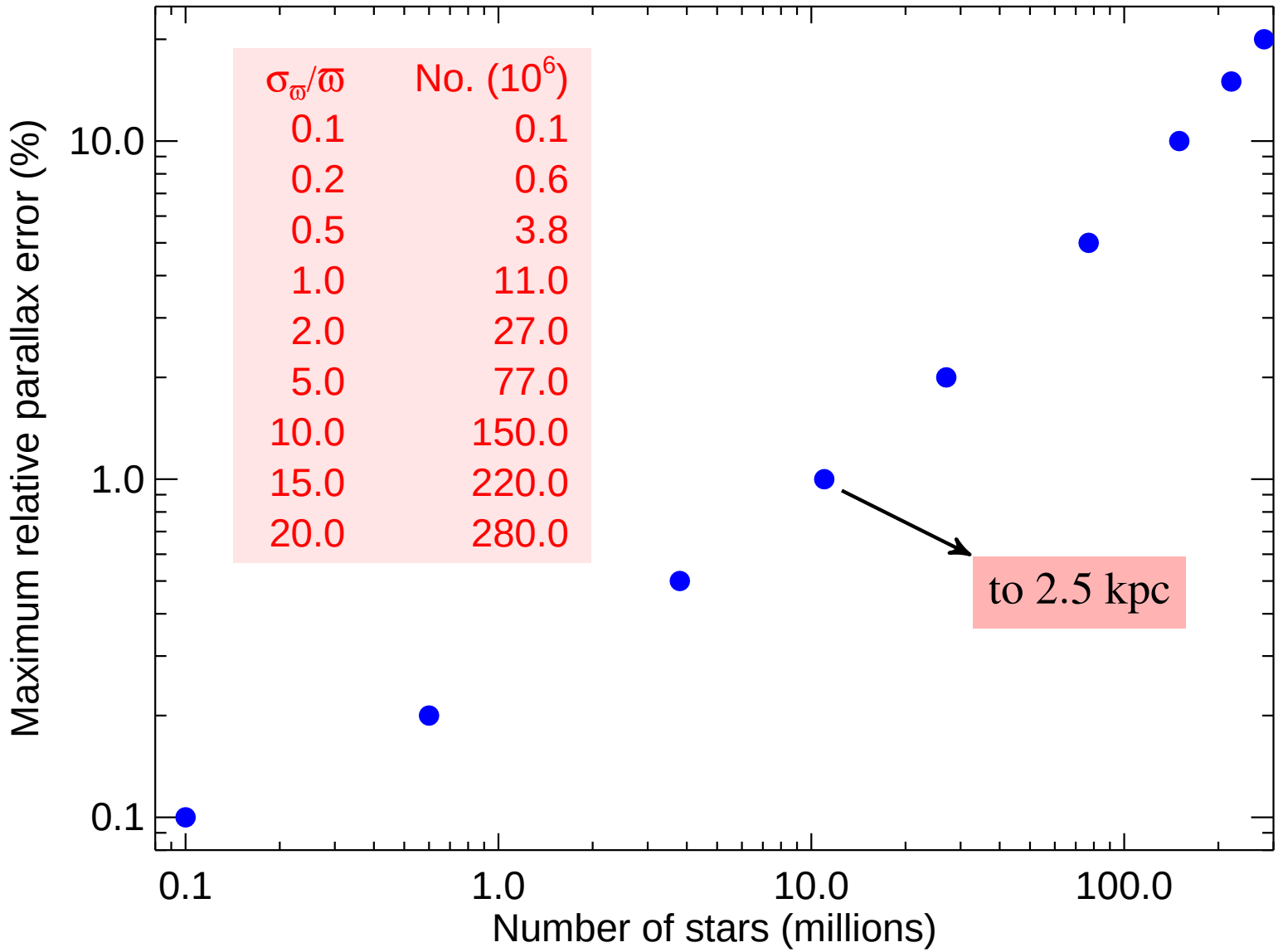
Gaia astrometric performances



1. $6 < G < 12$: bright star regime (calibration errors, CCD saturation)
2. $12 < G < 20$: photon-noise regime, sky-background and electronic noise setting in at $G \sim 20$

Gaia astrometric performances

Statistics of relative parallax accuracies achieved by Gaia



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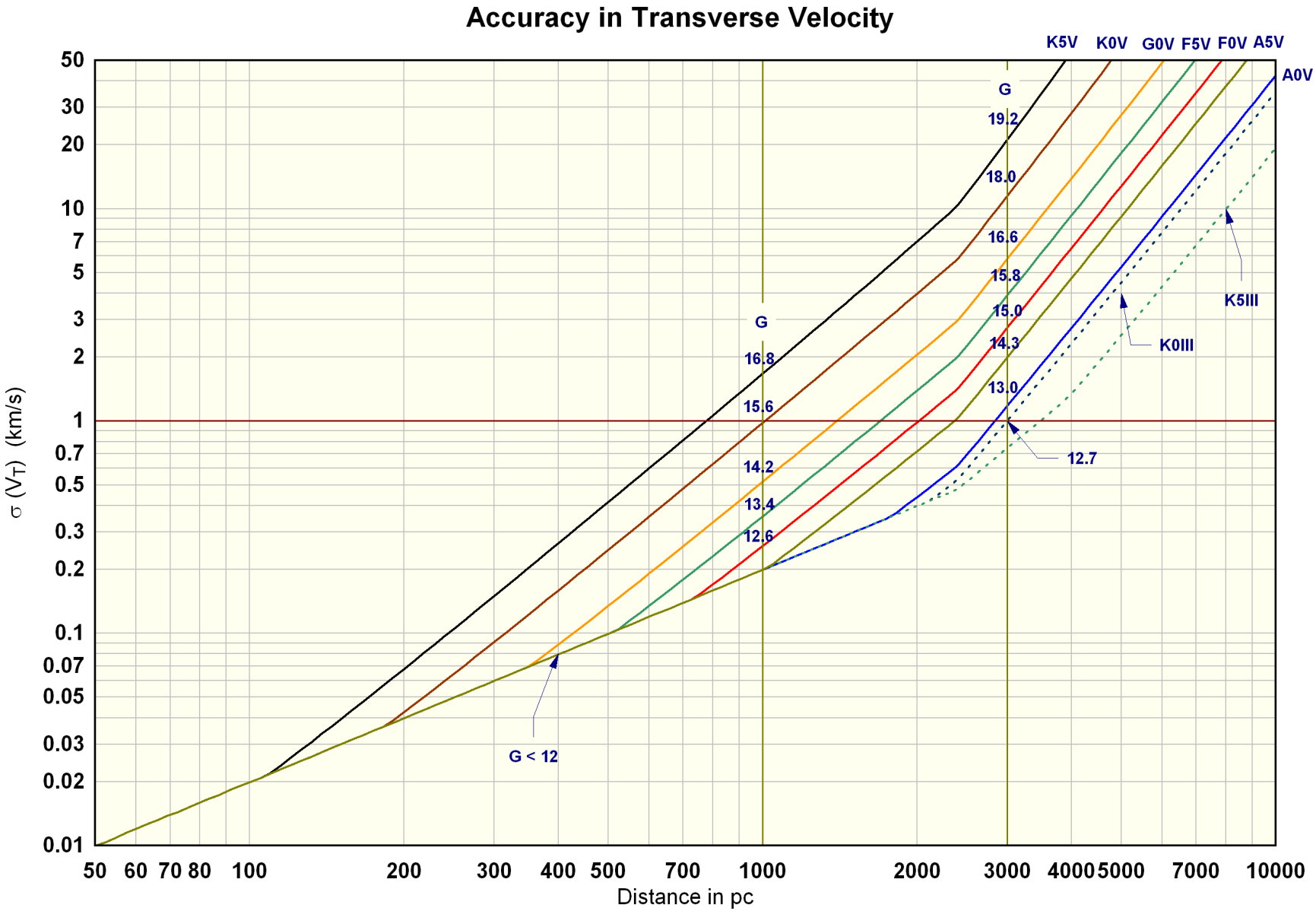


Figure courtesy François Mignard

Gaia photometric performances

Broad band photometry

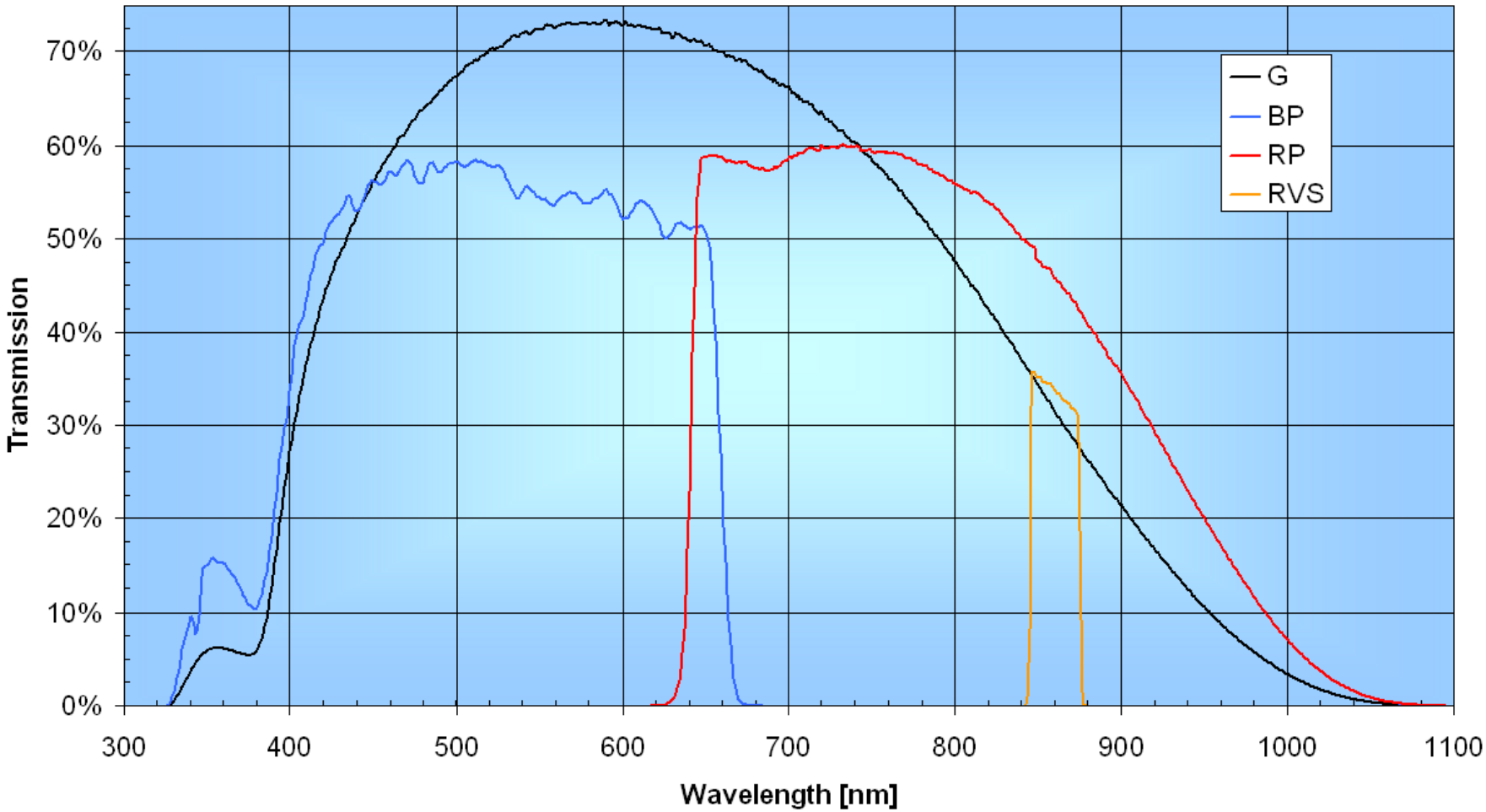
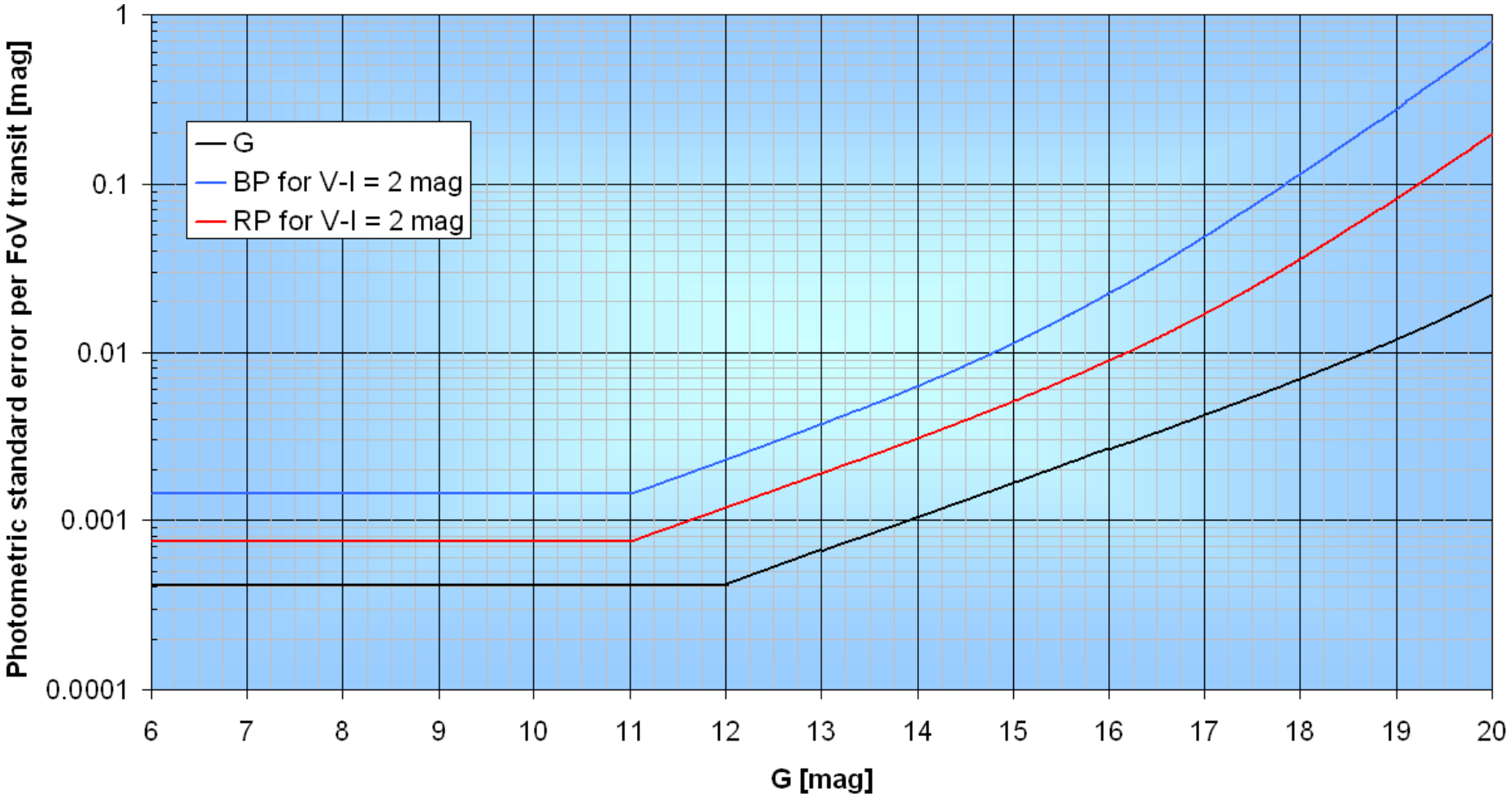


Figure courtesy Jos de Bruijne (ESA)

Gaia photometric performances

Broad band photometric accuracy per field of view transit



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Spectrophotometer

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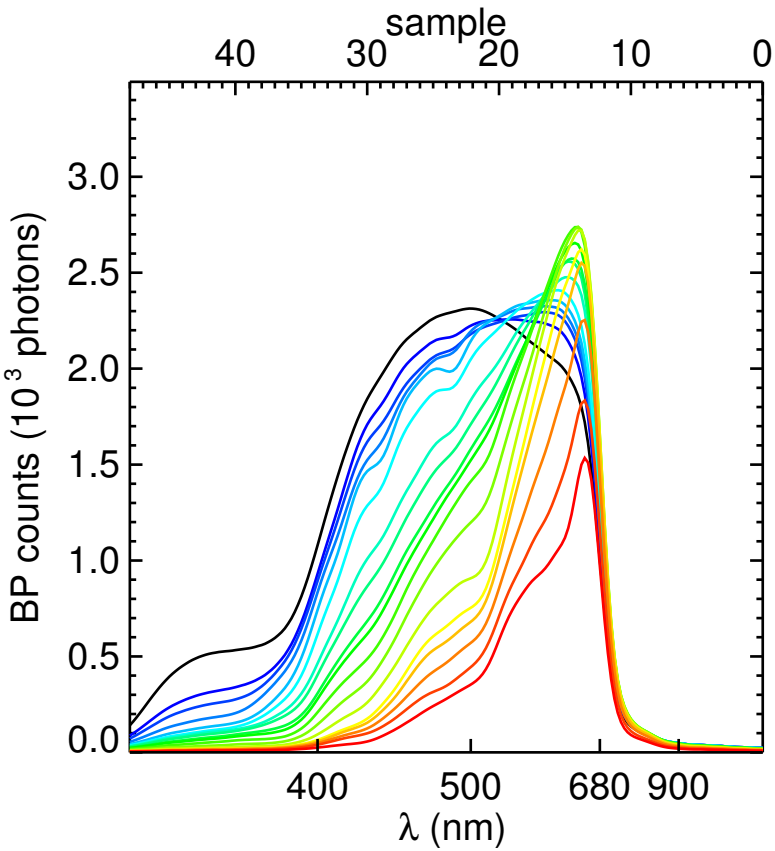

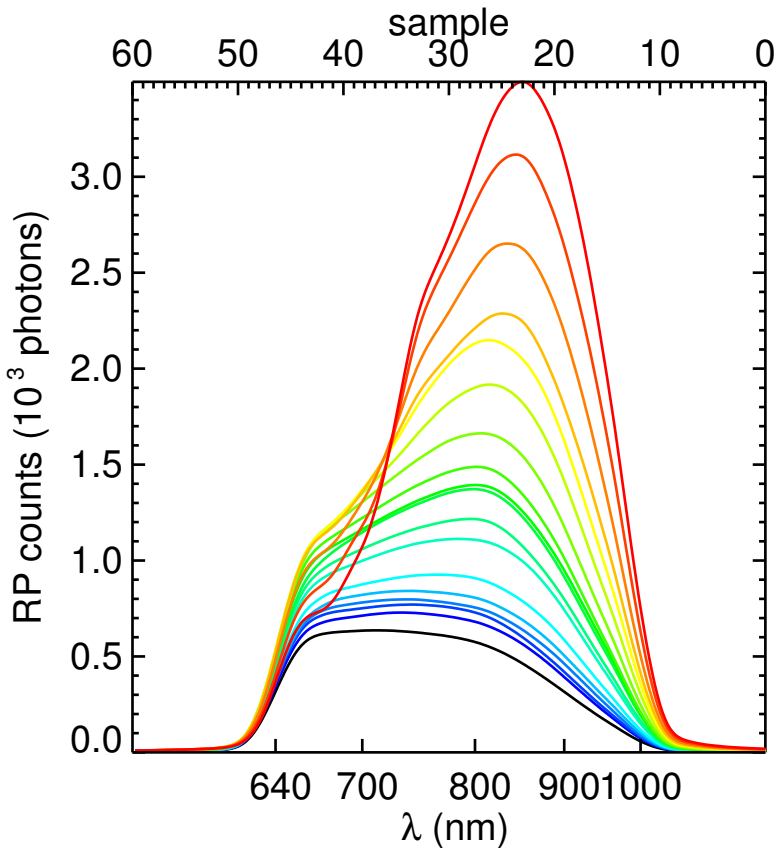

For expected the astrophysical parameter accuracies see Liu et al., 2012, MNRAS 426, 2463

Gaia spectroscopic performances

- Slit-less spectroscopy in Ca triplet region (847–874 nm)
- $\lambda/\Delta\lambda \sim 11\,000$

Sky averaged radial velocity accuracies (km s^{-1})

	V	$\sigma_{v_{\rm rad}}$
B1V	7.0	1
	12.0	9
G2V	13.0	1
	16.5	13
K1IIIMP	13.5	1
	17.0	13

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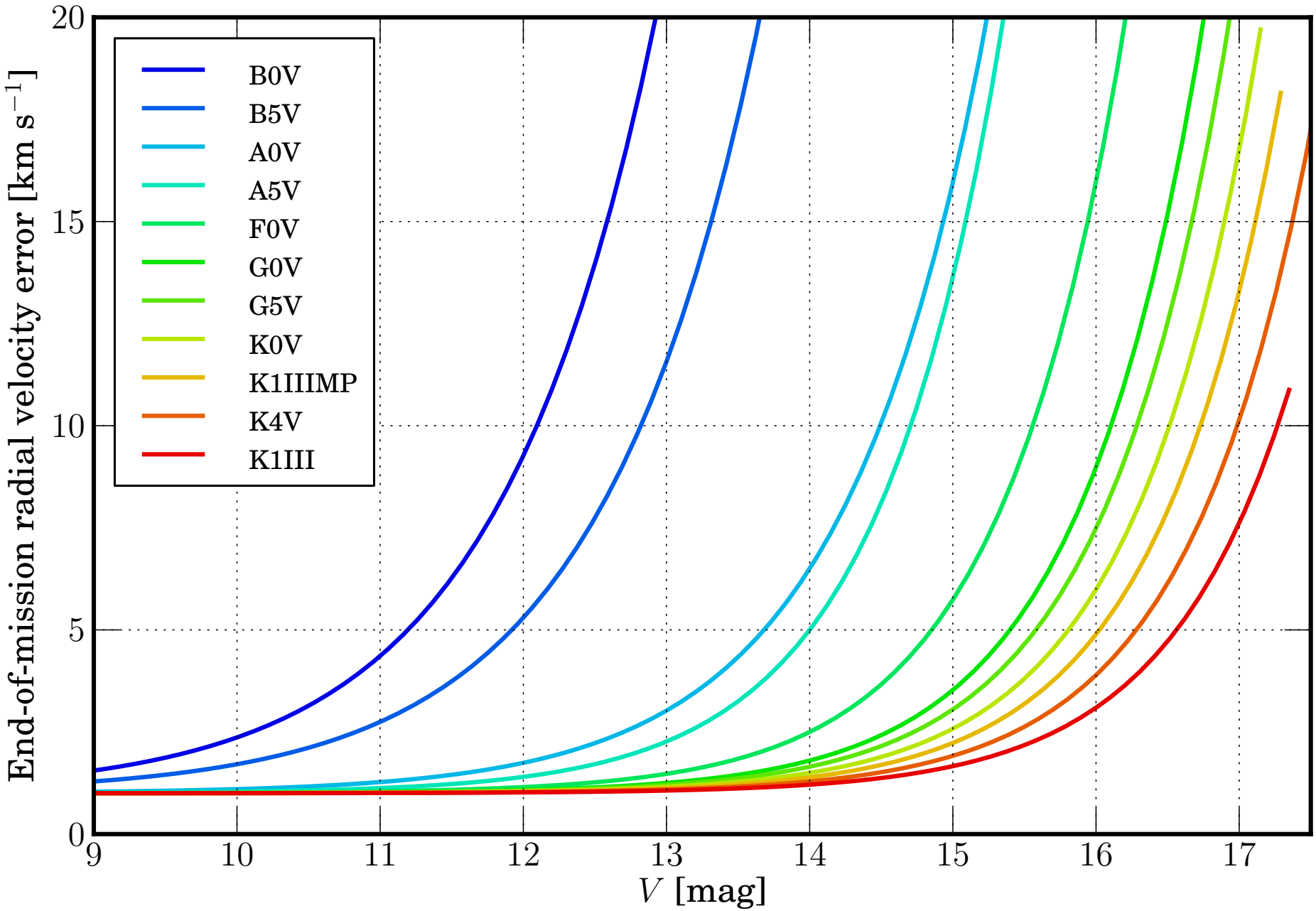

Gaia spectroscopic performances

Stellar and interstellar parameters (conservative estimates)

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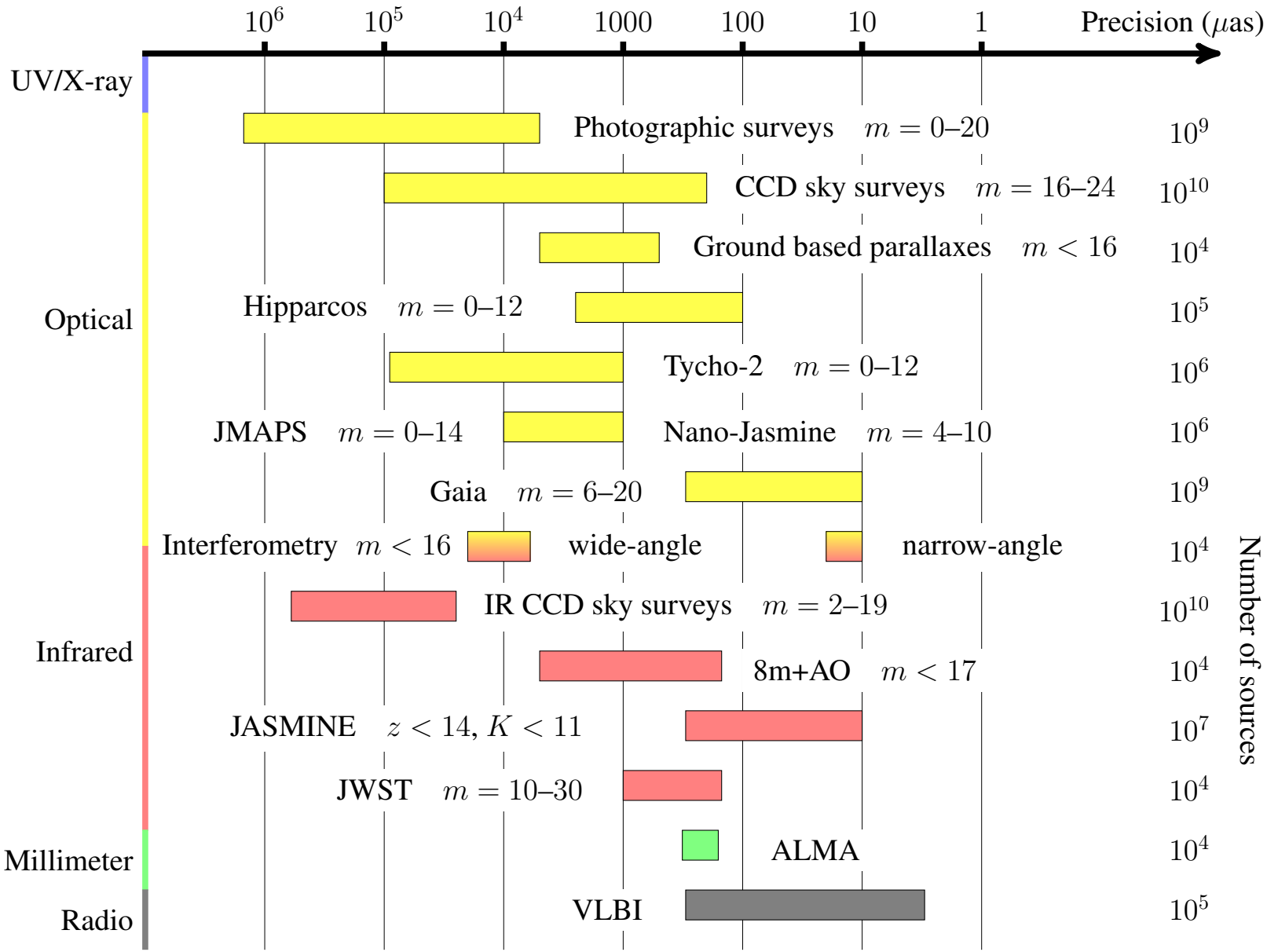
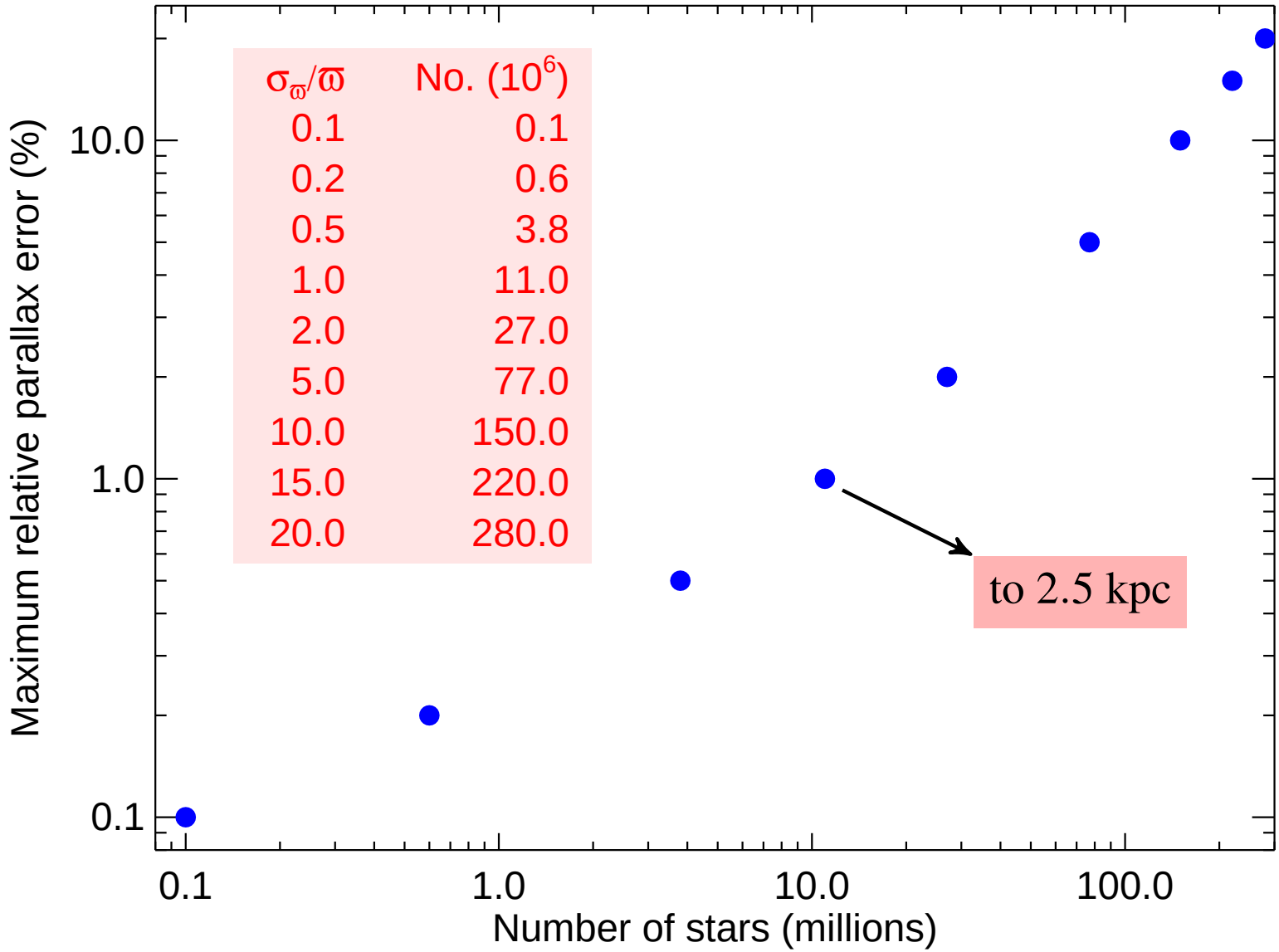
Gaia in context of other astrometric surveys



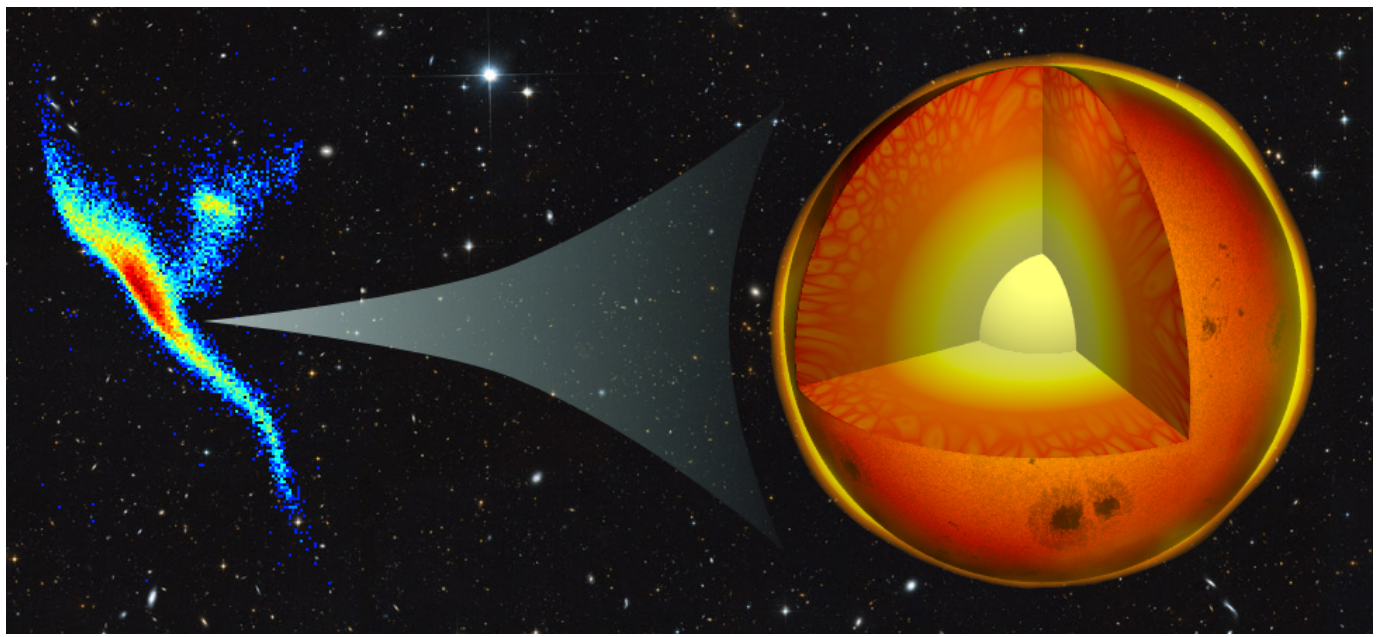
Examples of Gaia's impact on astronomy

Giant leap in parallax accuracy and reach



Accurate distances across the HR diagram

- luminosity calibration
  - calibration photometric and spectroscopic distance indicators
- astrometric detection of stellar, sub-stellar and planetary companions
  - 10 000 stars with masses to 1%
- fundamental parameters for rare stellar types
- precision tests of stellar interior models and stellar evolution



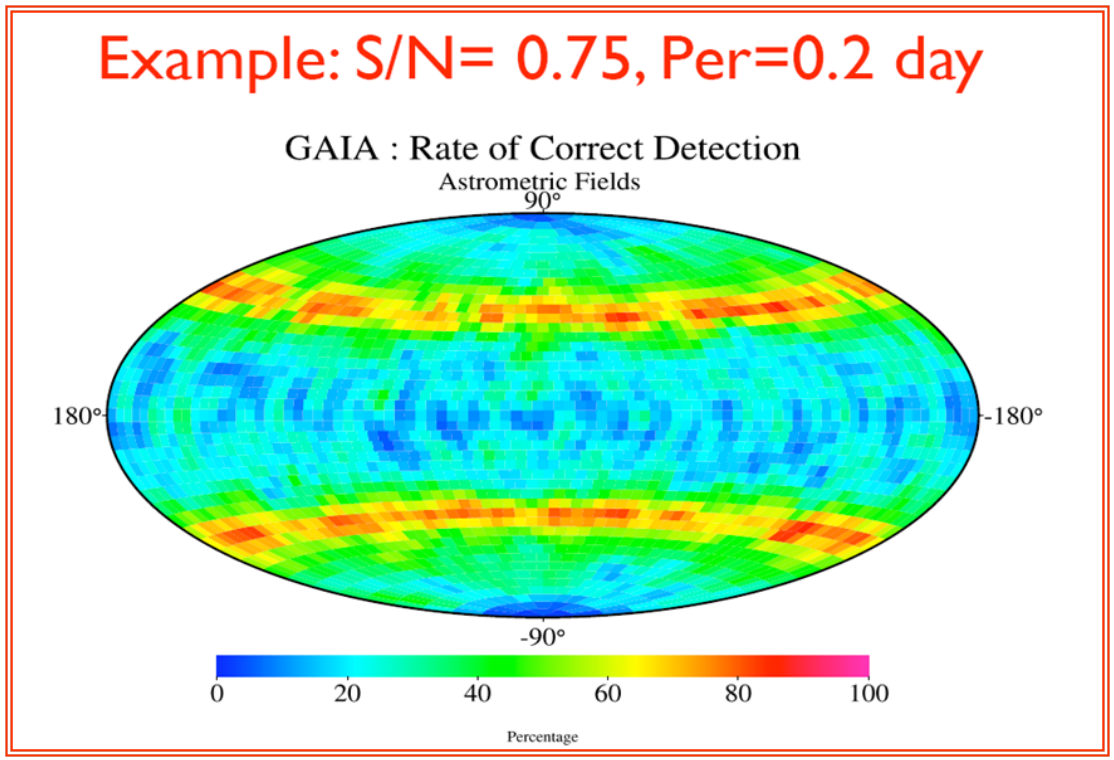
Stellar physics: variable stars

Gaia survey

- $\sim$ 70 epoch survey over 5 years
- mmag accuracy per single observation

Quantitative impact

- 20×10^6 classical variables
- 1–5 million eclipsing binaries
- $\sim$ 5000 Cepheids, 70 000 RR Lyr
  - RR Lyr visible out to $\sim$ 75 kpc



Eyer & Mignard 2005

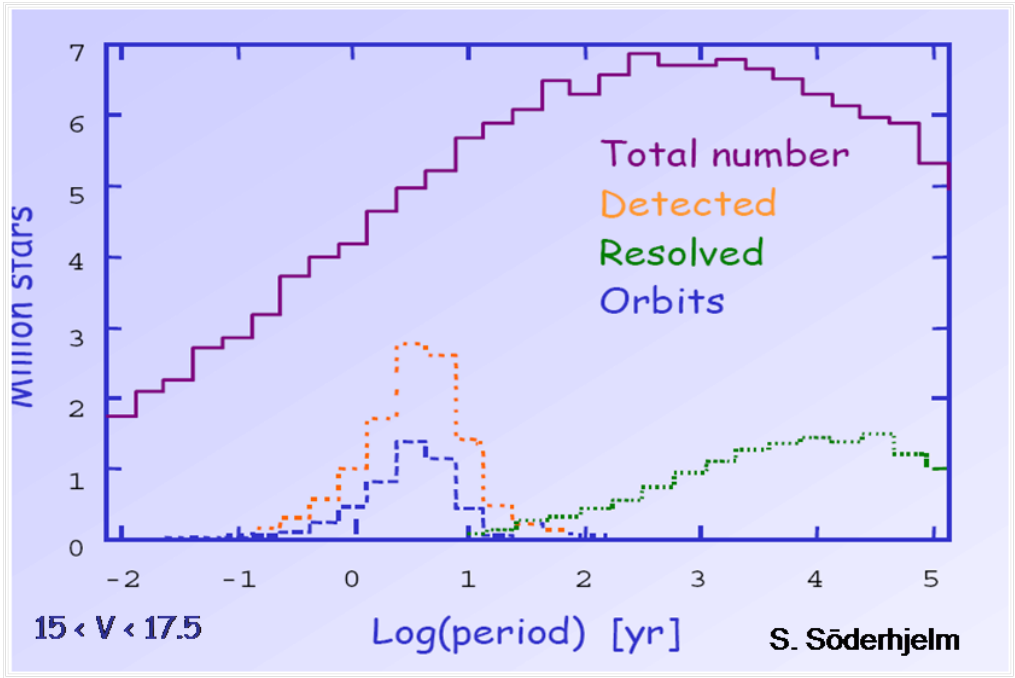
Stellar physics: small stellar systems

Power of Gaia

- Survey mode, sensitivity to non-linear motion
- quasi-regular time sampling over 5 yrs
- Large range of separations and Δm
- Spectroscopic measurements

Expected results

- various categories of binaries
  - 10^7 resolved within 250 pc (long period)
  - 10^7 astrometric binaries
  - 10^{6-7} eclipsing binaries, 10^6 spectroscopic
- 50% complete census to 250 pc
- masses to 1% for 10^4 stars
- constraints on evolutionary models



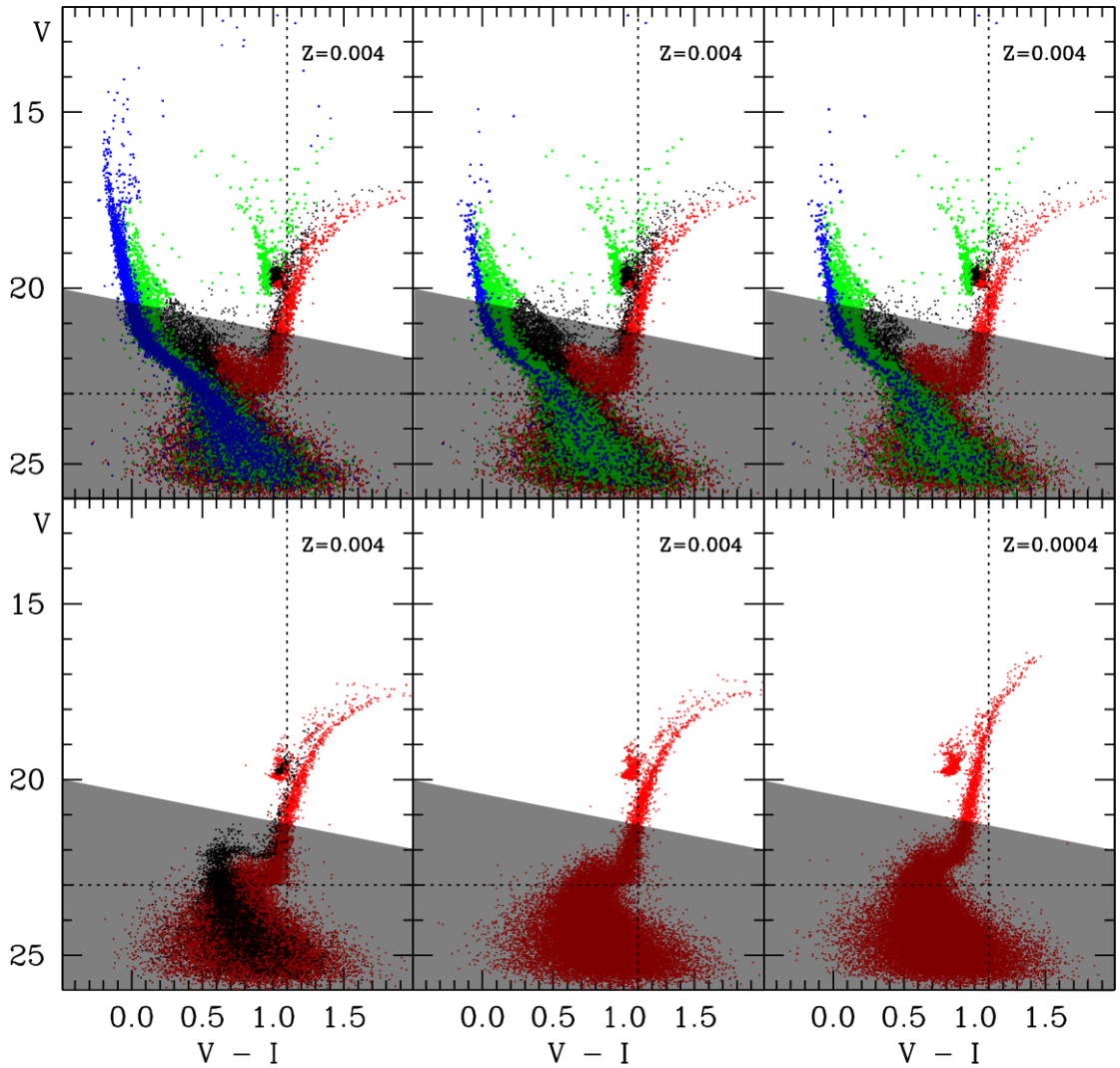
Söderhjelm 2005

Dissecting the Milky Way

- 6D phase $(\mathbf{r}, \mathbf{v})$ over full sky and large volume
- Mapping of stellar ages and compositions
  - in combination with complementary spectroscopic surveys
- Mapping of dynamical quantities (E, L_z, ...)
  - as a function of composition, age
- Study other 'solar neighbourhoods'
- Formation of inner halo
  - Gaia essential for detecting accretion signatures
- Mapping the ISM in 3D

Milky Way and Local Group

- Astrometry/photometry for *individual* stars in local group dwarf galaxies
- Survey limit $G = 20$ corresponds to $V = 20$–22

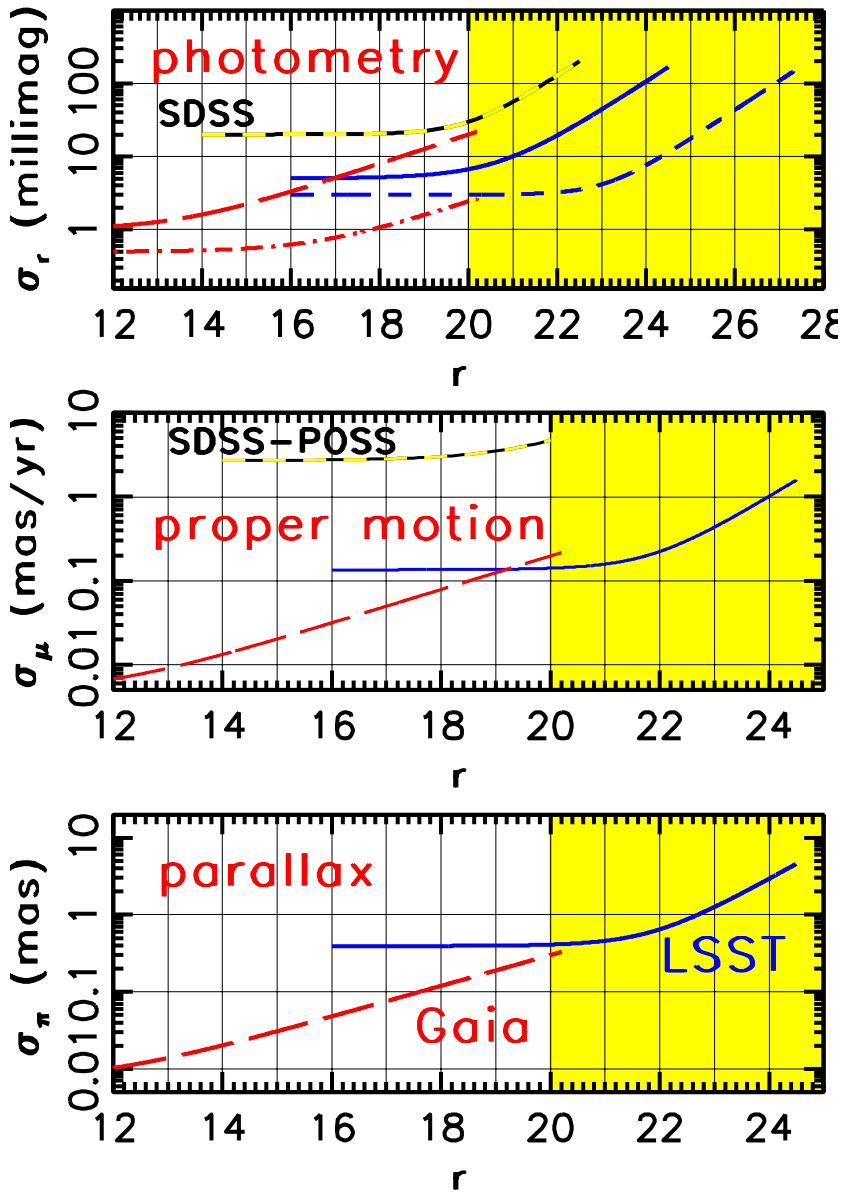


Tolstoy, Hill, Tosi 2009

Gaia and other surveys

What Gaia provides

- Excellent calibrations of standard candles that photometric surveys can see to 10× further distances
  - accurate distance moduli to main sequence stars of varying spectral types and abundances
  - same for brighter tracers including variables
- Reference frame for astrometry
- Target selection for spectroscopy (e.g., dwarf/giant separation with parallax)



LSST science book

Solar system science

- Accuracies: ground-based 0.1–1 arcsec, Gaia single measurement 0.1–1 mas
- Systematic survey down to 20 mag $\sim 3 \times 10^5$ objects
  - $\sim$ 50 000 new objects expected
  - Observations at high ecliptic latitudes and to within 45° from Sun $\rightarrow$ exotic orbits
- Orbits: for virtually all objects observed — $\times$30 better than now
- Masses from close encounters $\sim$ 100 masses expected
- Diameters for over 1000 asteroids: shape, density
- Photometric data in several bands: albedo, taxonomic classification
- Light curves over 5 years: rotation, pole, shape
- Space distribution vs. physical properties
- Perihelion precession for 300 planets: GR testing, solar J2

Exoplanets with Gaia

- Astrometric survey
  - monitoring of several 10^5 FGK stars to ~ 200 pc
  - detection limits $\sim 1\ M_{\rm J}$ and $P < 10$ yr
  - complete census of all stellar types over $P = 2$–9 yr
  - masses rather than lower limit ($m \sin i$)
  - multiple systems measurable
- Results expected
  - orbits for ~ 5000 systems
- Photometric transits
  - ~ 1000 to 10 000 with $a \lesssim 1$ AU

$d <$	stars	planets
100	60 000	1500–5000
200	500 000	5000–20 000

Fundamental physics

1. Light deflection
   - Monopole deflection from the Sun: $\sigma_\gamma \sim 10^{-6}$ (systematic errors remain a difficult challenge)
   - First detection of a number of subtle deflection effects from the planets: monopole, quadrupole, gravitomagnetic
2. Motion of the solar system: perihelion and node precessions, quadratic deviations in the mean longitudes

$$\sigma_\beta \sim 10^{-3}\,, \quad \sigma_{J_2^{\rm Sun}} \sim 10^{-7}\,, \quad \sigma_{\dot{G}/G} \sim 10^{-12}\ {\rm yr}^{-1}\,, \quad \sigma_\eta \sim 10^{-3}$$

3. Local Lorentz Invariance: Gaia is a kind of Michelson-Morley experiment
4. Pattern matching in proper motions and epoch astrometry:
   - Solar system acceleration $\sigma_a/a < 0.1$
   - Improved estimates of the stochastic background of primordial low frequency gravitational waves
5. Astrometric information for the optical components of some objects that are important for other relativistic tests