Gaia science performance

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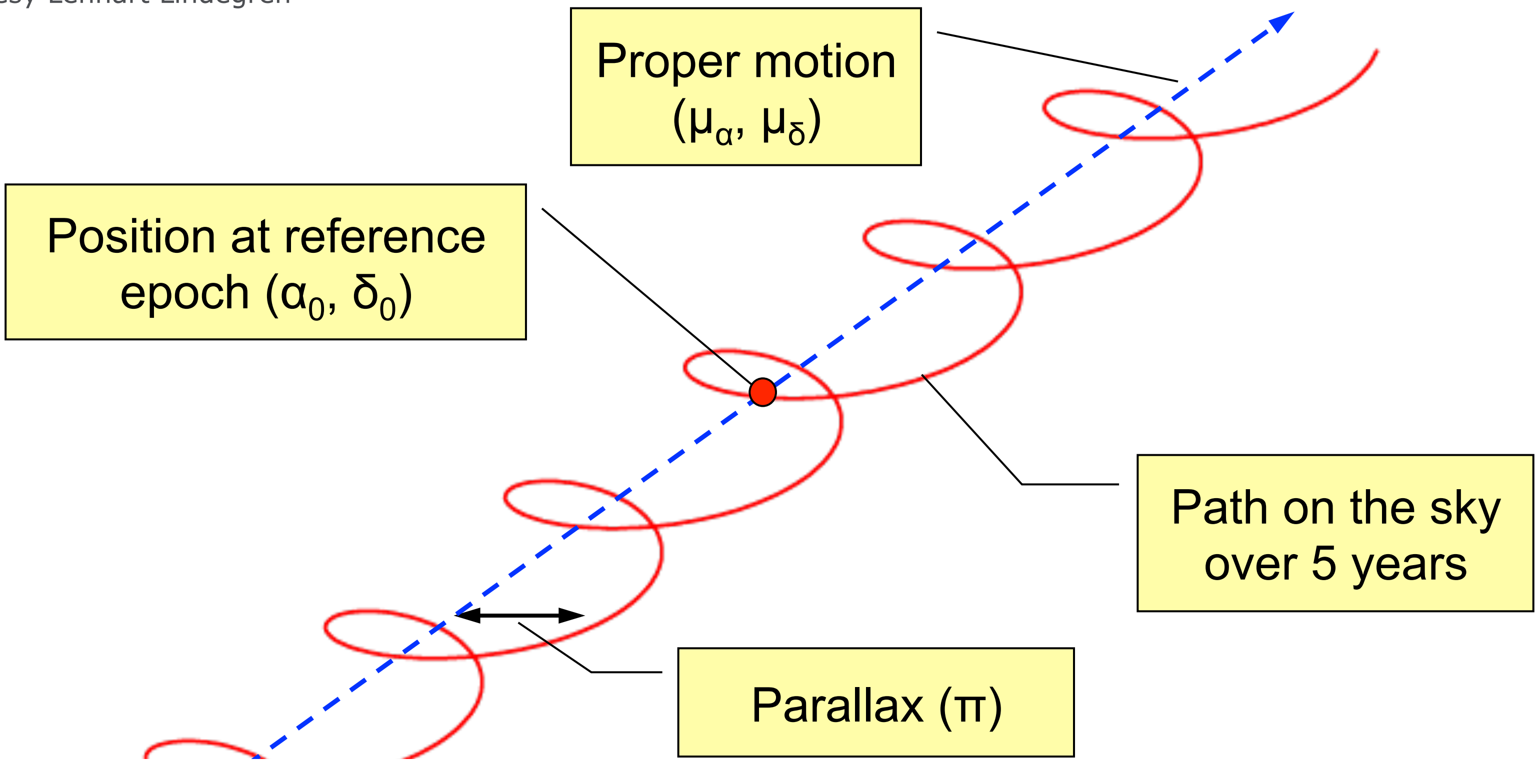
		Session 2 (cont): The Physics and Science Promise of Gaia	
09.15-09.30	C2.4	Gaia Radial Velocity Spectrograph Performance	Mark Cropper

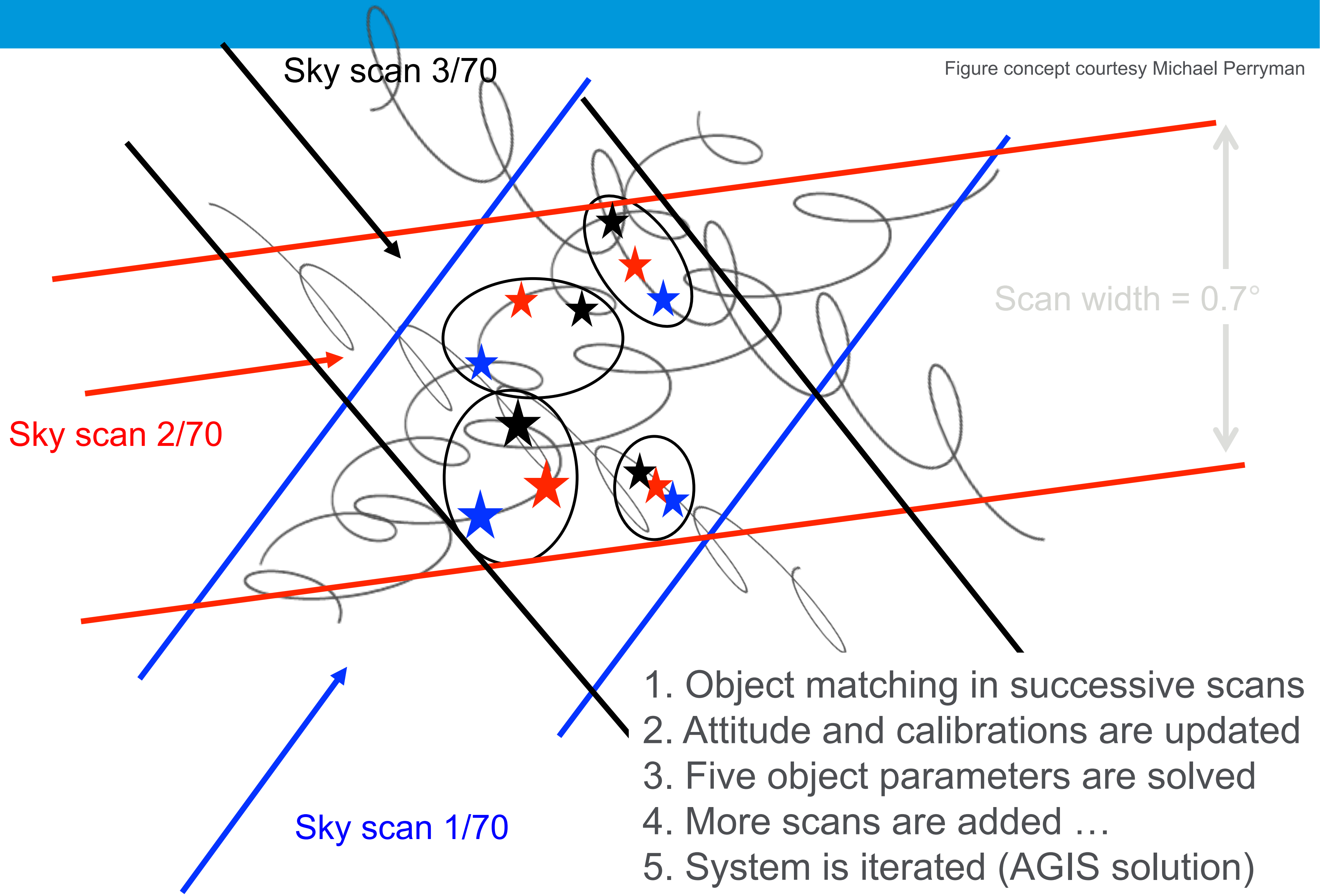
Gaia astrometry in one viewgraph

Figure courtesy Lennart Lindegren



Monitor this path for 10^9 stars during 5 years and fit, for each object, a 5-parameter model to retrieve reference position, proper motion, and parallax (for a "given" instrument calibration and attitude)

Well, actually two viewgraphs …



1. Object matching in successive scans
2. Attitude and calibrations are updated
3. Five object parameters are solved
4. More scans are added …
5. System is iterated (AGIS solution)

Astrometry in one equation

End-of-mission parallax standard error:

$$\sigma_\pi \; [\mu\mathrm{as}] = m \cdot g_\pi \cdot \sqrt{\frac{\sigma_\xi^2 + \sigma_{\mathrm{cal}}^2}{N_{\mathrm{eff}}}}$$

m = scientific contingency factor (margin)

g_π = geometrical parallax factor (CCD to end-of-mission)

σ_ξ = single-CCD location-estimation (centroiding) error (µas)

σ_{cal} = residual calibration error (µas)

N_{eff} = end-of-mission number of detected CCD transits

Astrometry in one equation

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Scientific contingency factor *m*

A 20% science margin (*m* = 1.2) has been added to all calculations

- All estimates are for "perfect stars" (single, non-variable, non-crowded region, no background peculiarities, …)

- Covers residual "scientific calibration errors" (e.g., mismatch of the model PSF, sky-background-estimation errors, …)

Astrometry in one equation

End-of-mission parallax standard error:

$$\sigma_\pi \ [\mu\text{as}] = m \cdot \boxed{g_\pi} \cdot \sqrt{\frac{\sigma_\xi^2 + \sigma_{\text{cal}}^2}{N_{\text{eff}}}}$$

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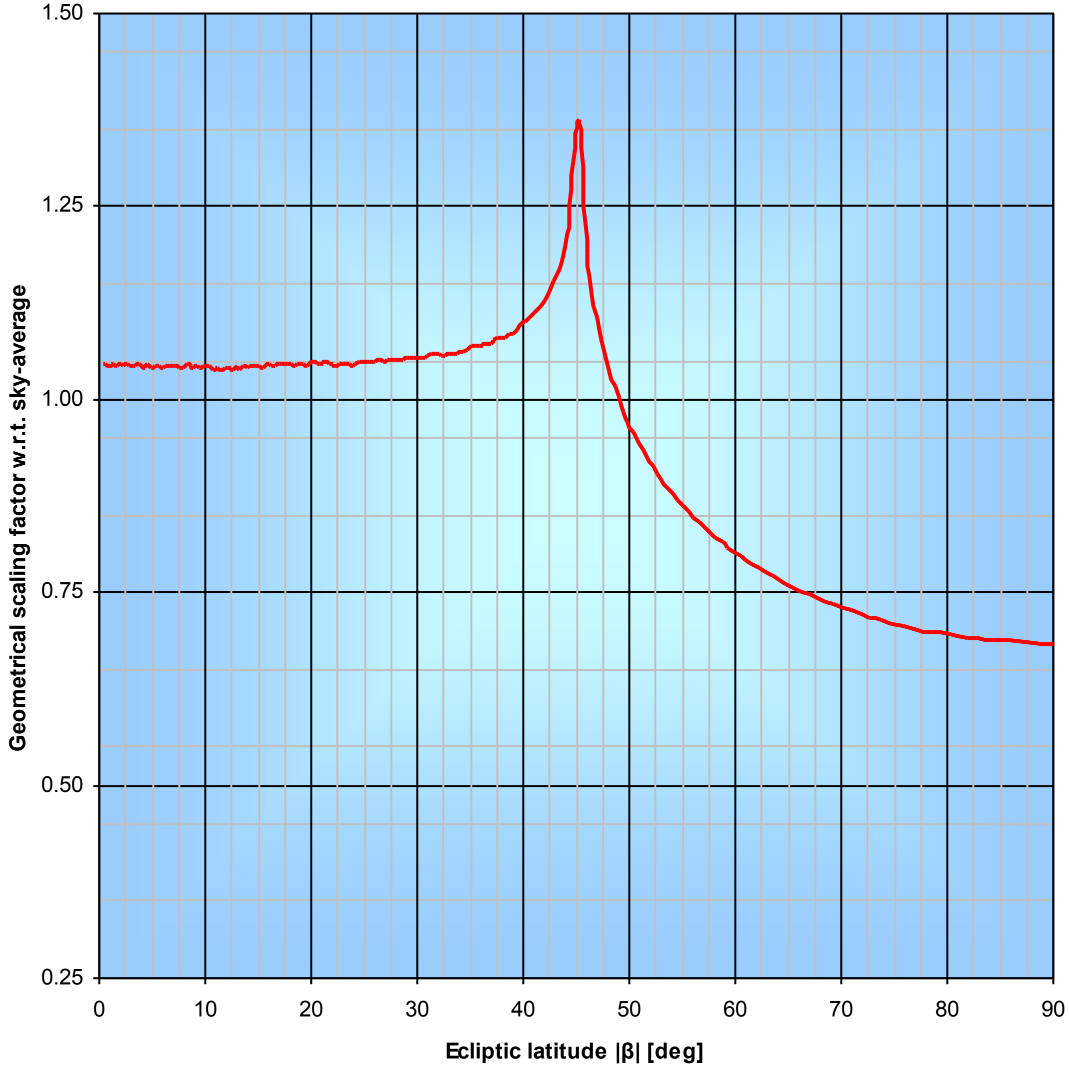
Geometric parallax factor g_π



The parallax factor g_π connects the along-scan centroiding and parallax signals

Optimum astrometry: make the solar-aspect angle ξ as large as possible and keep it constant (45° for Gaia)

Scanning-law simulations yield g_π = 2.08 for the sky-average factor

Figure from http://www.cosmos.esa.int/web/gaia/science-performance

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Single-CCD centroiding error σ_ξ

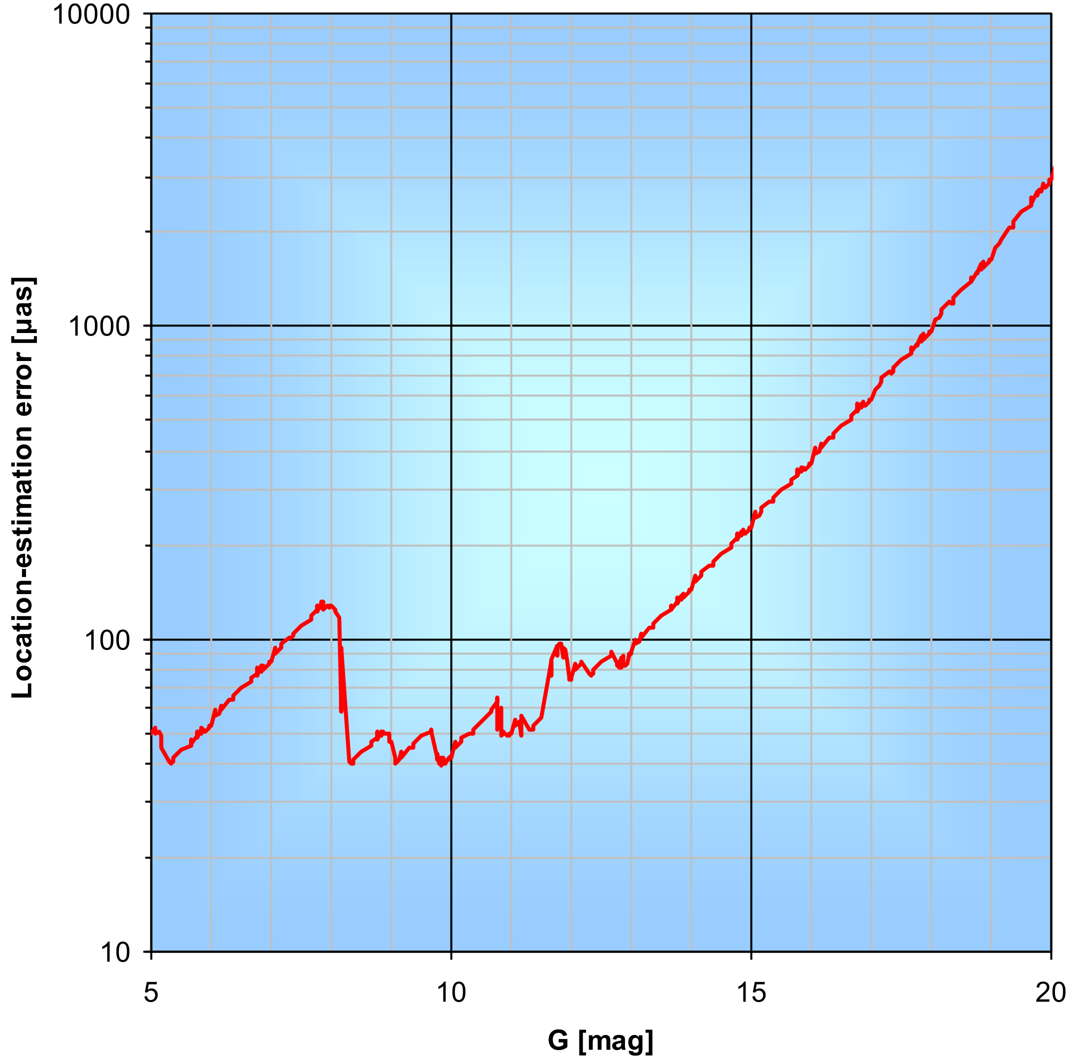

Figure from GAIA-CA-TN-ESA-JDB-053

Based on Monte Carlo simulations, including "everything", e.g., CCD QE + MTF, telescope wave-front errors + transmission + optical distortion, LSF smearing due to attitude jitters + TDI motion, CCD noise + offset non-uniformity, radiation-damage-induced charge loss + bias calibration, sky background, windowing / sampling, magnitude, extinction, spectral type, …

Single-CCD centroiding error σ_ξ

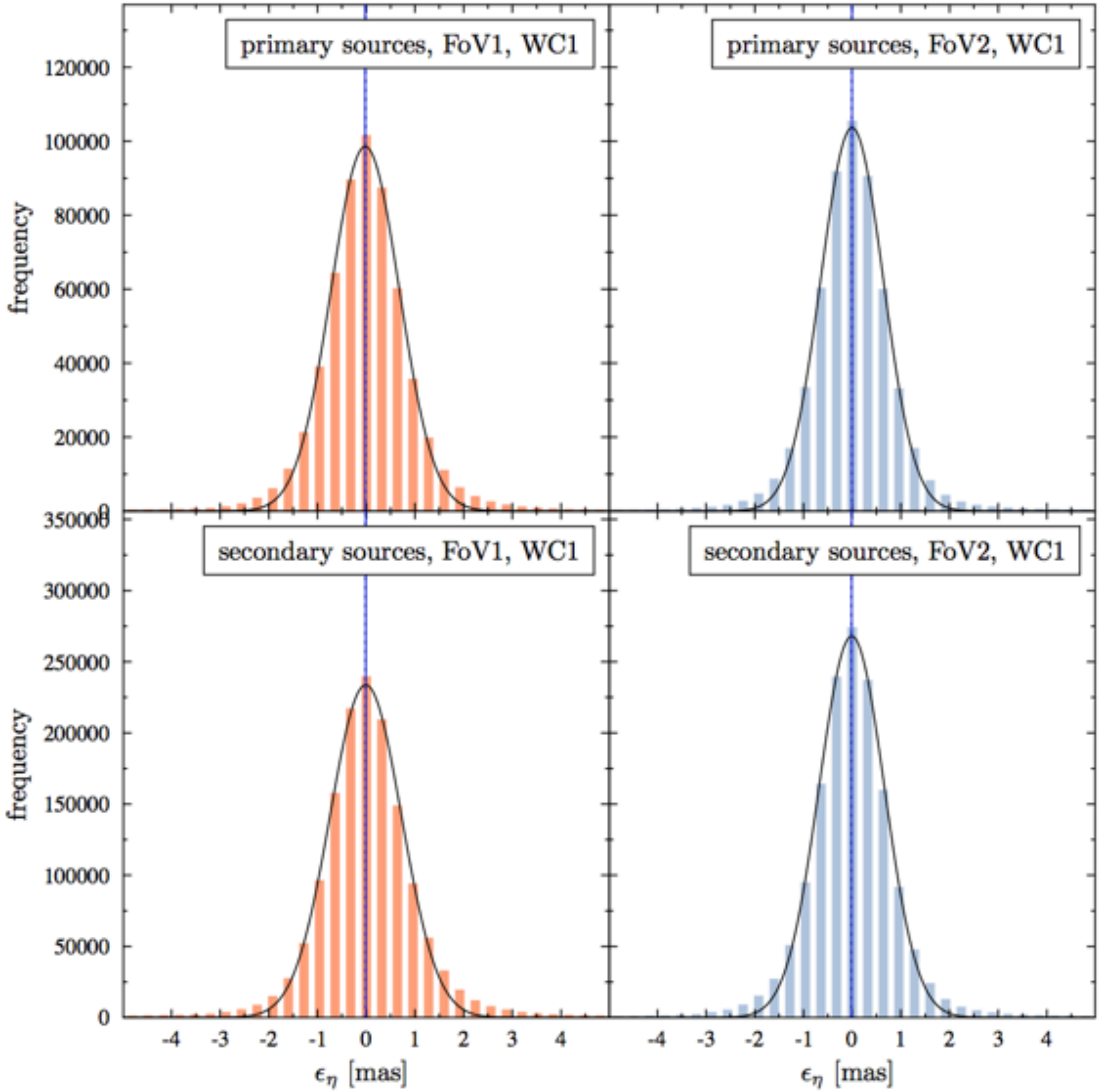

Figure from First Look team (Heidelberg)

Centroiding error at G~15 mag based on early in-flight measurements, with preliminary PSF calibration (e.g., without colour correction)

Astrometry in one equation

End-of-mission parallax standard error:

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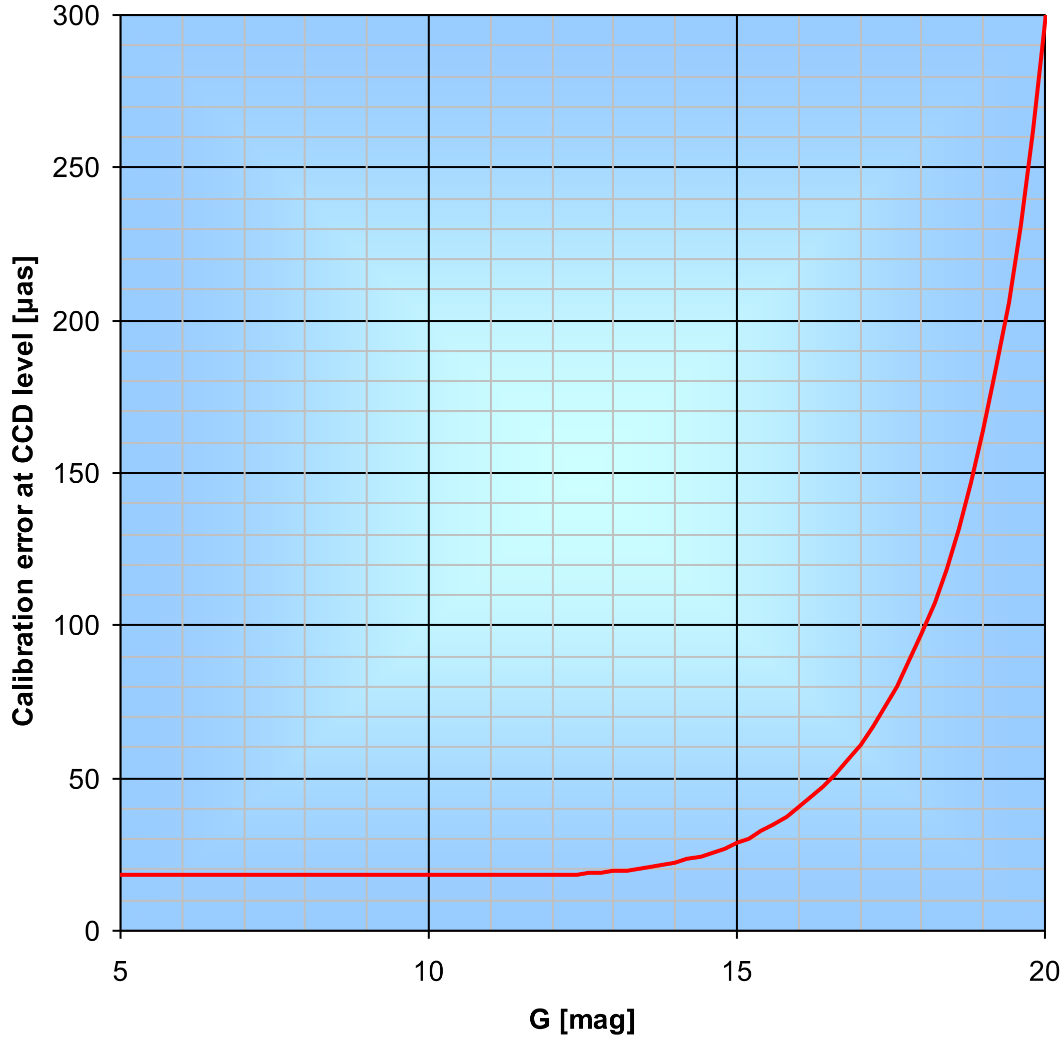
Residual calibration error σ_{cal}



Residual errors, including "everything", e.g., chromaticity calibration, geometrical transformation from focal plane to field coordinates, satellite attitude model, thermo-mechanical stability of telescope + focal plane, metrology errors associated with basic-angle monitoring, …

Small compared to random errors and relevant only for bright-star noise floor

Figure based on data from GAIA.ASF.RP.SAT.00005 (Science performance budget report)

Astrometry in one equation

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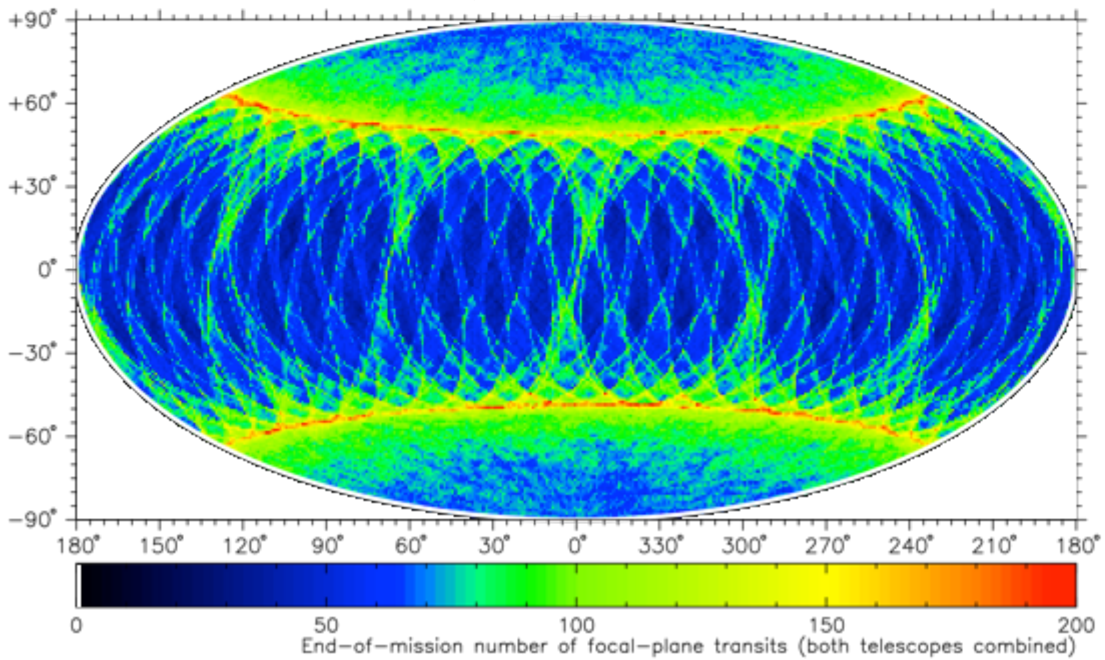
Number of CCD transits N_{eff} (1/3)



1: Number of focal-plane transits

The nominal scanning law during the 5-year mission introduces a non-uniform sampling of the sky

Figure from http://www.cosmos.esa.int/web/gaia/science-performance– Ecliptic coordinates

Number of CCD transits N_{eff} (1/3)

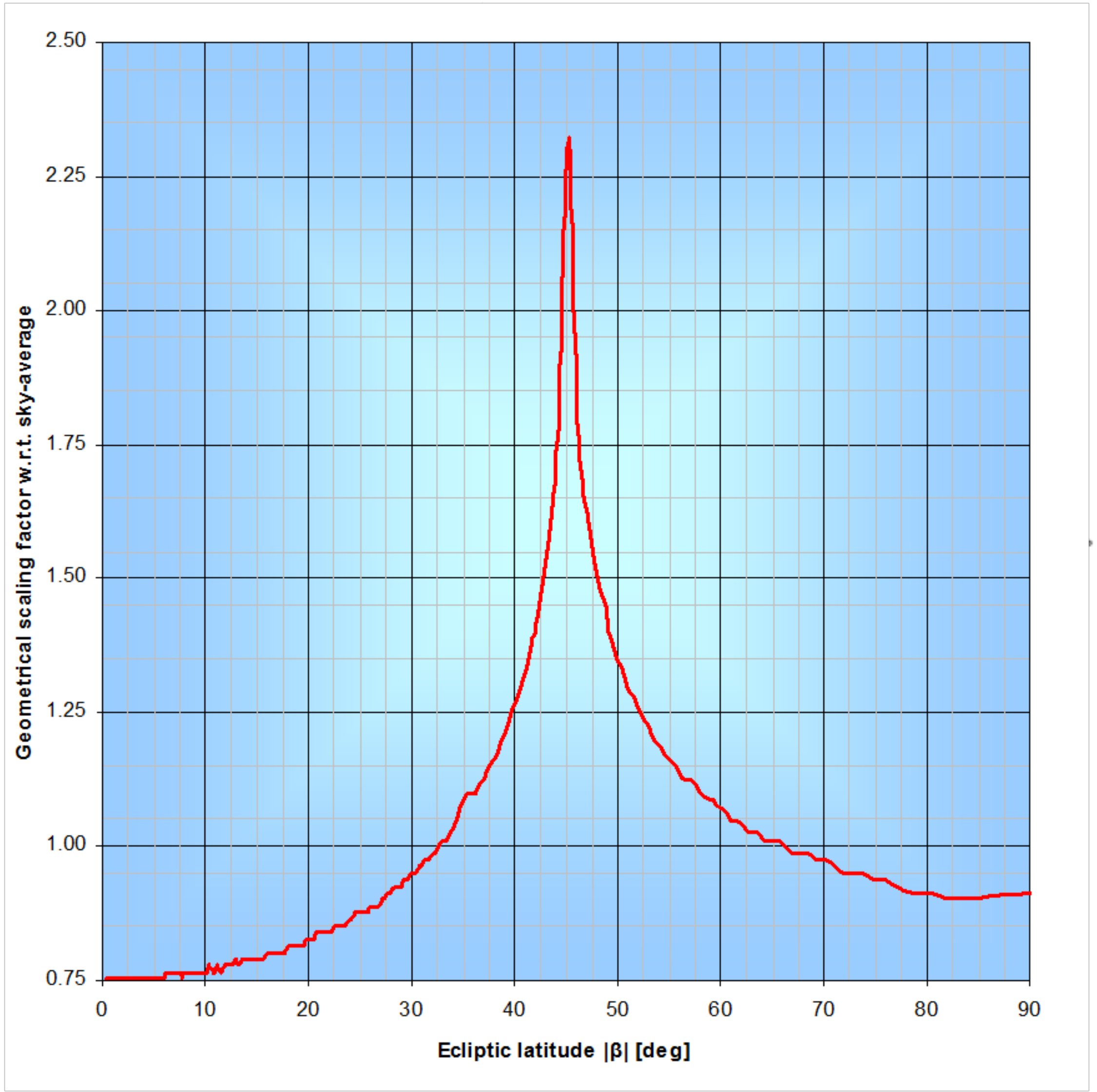


Figure from http://www.cosmos.esa.int/web/gaia/science-performance– Ecliptic coordinates

1: Number of focal-plane transits

The nominal scanning law during the 5-year mission introduces a non-uniform sampling of the sky

The sky-average number of transits is 86 (with 0% dead time) and varies mainly as function of ecliptic latitude

Number of CCD transits N_{eff} (2/3)

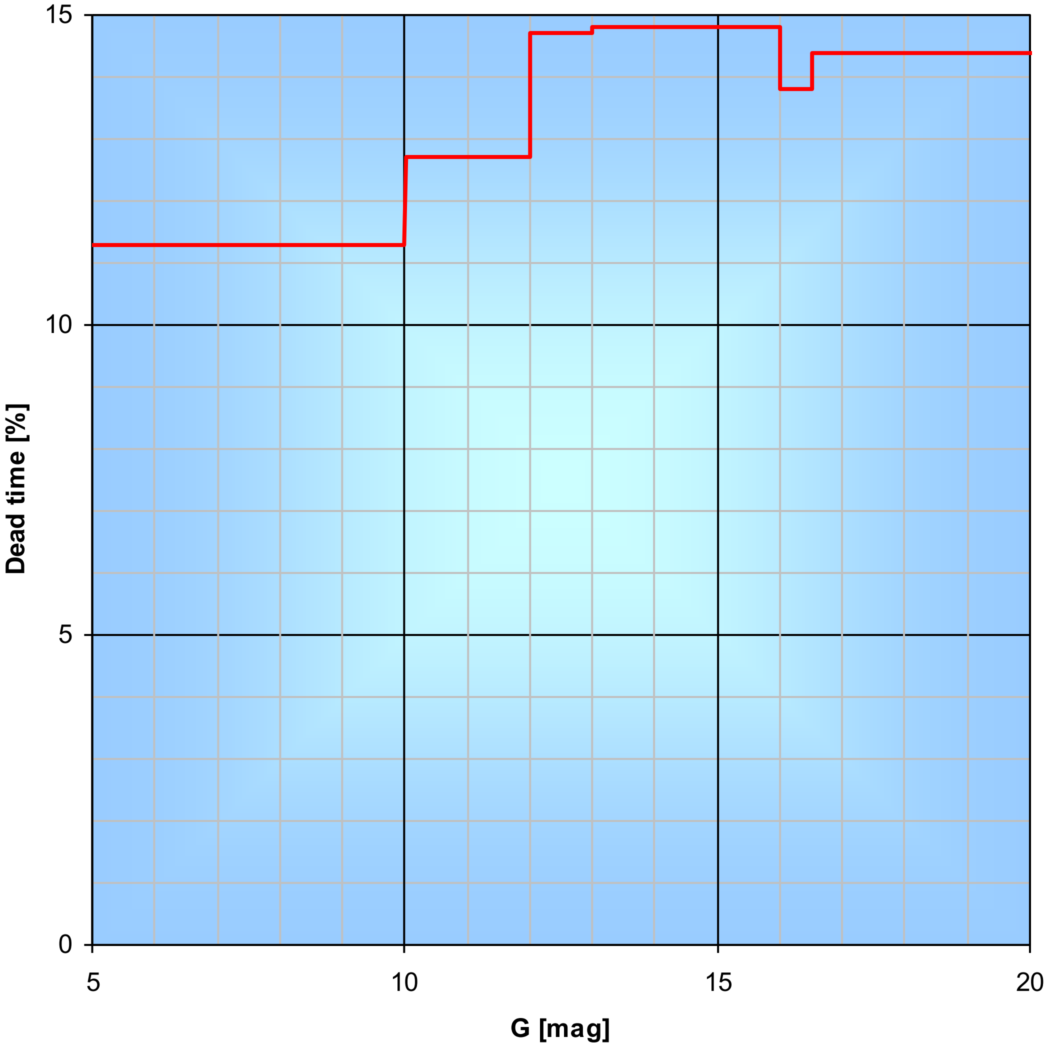


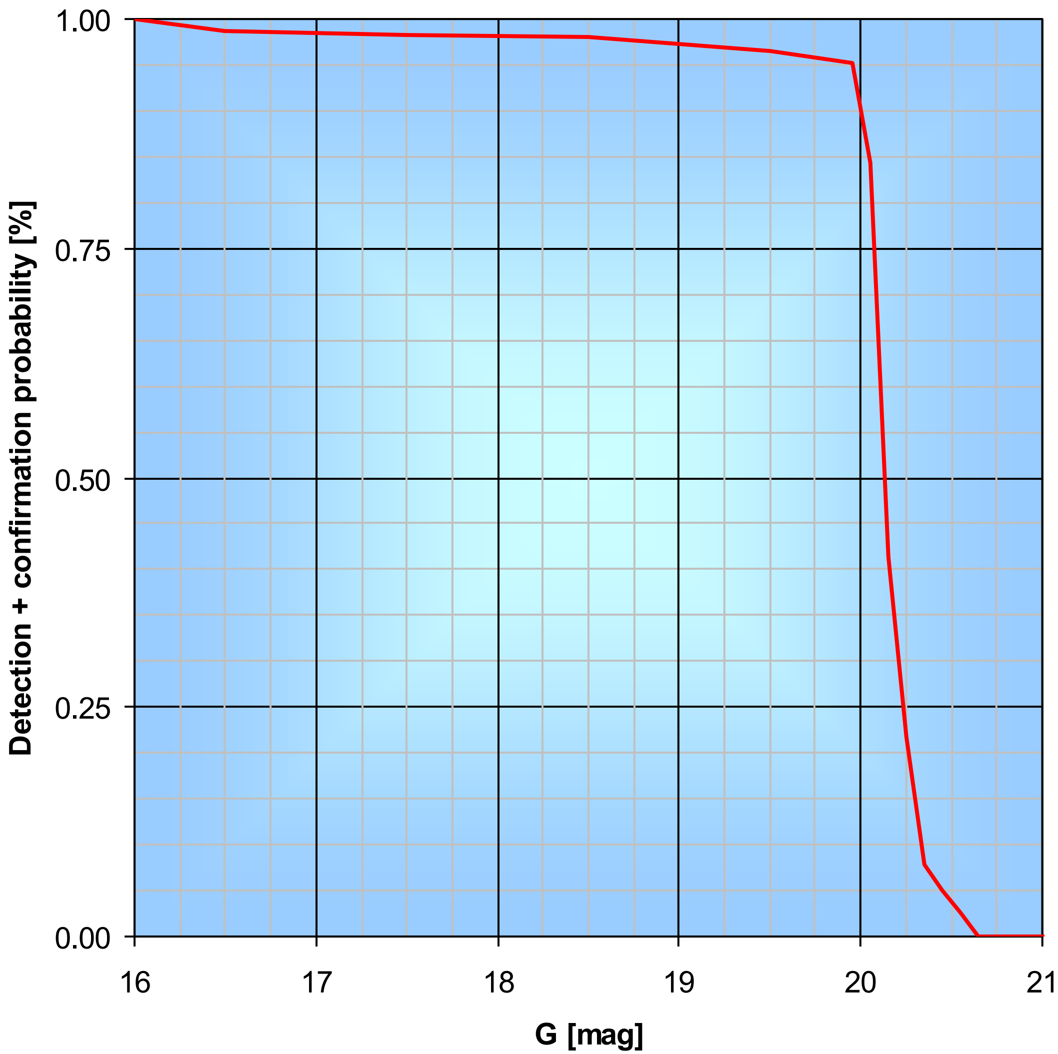
Figure based on data from GAIA.ASF.TCN.SAT.00133 (Dead-time report)

2: Dead time

All (known) effects are accounted for, e.g., moon eclipses, orbit maintenance, cosmic rays, outages during solar eruptions, CCD cosmetic defects, pollution caused by charge injections and TDI gates, on-board memory overflow, micro-meteoroids, virtual objects, …

Typical value < 15%

Number of CCD transits N_{eff} (3/3)



3: Detection + confirmation probability

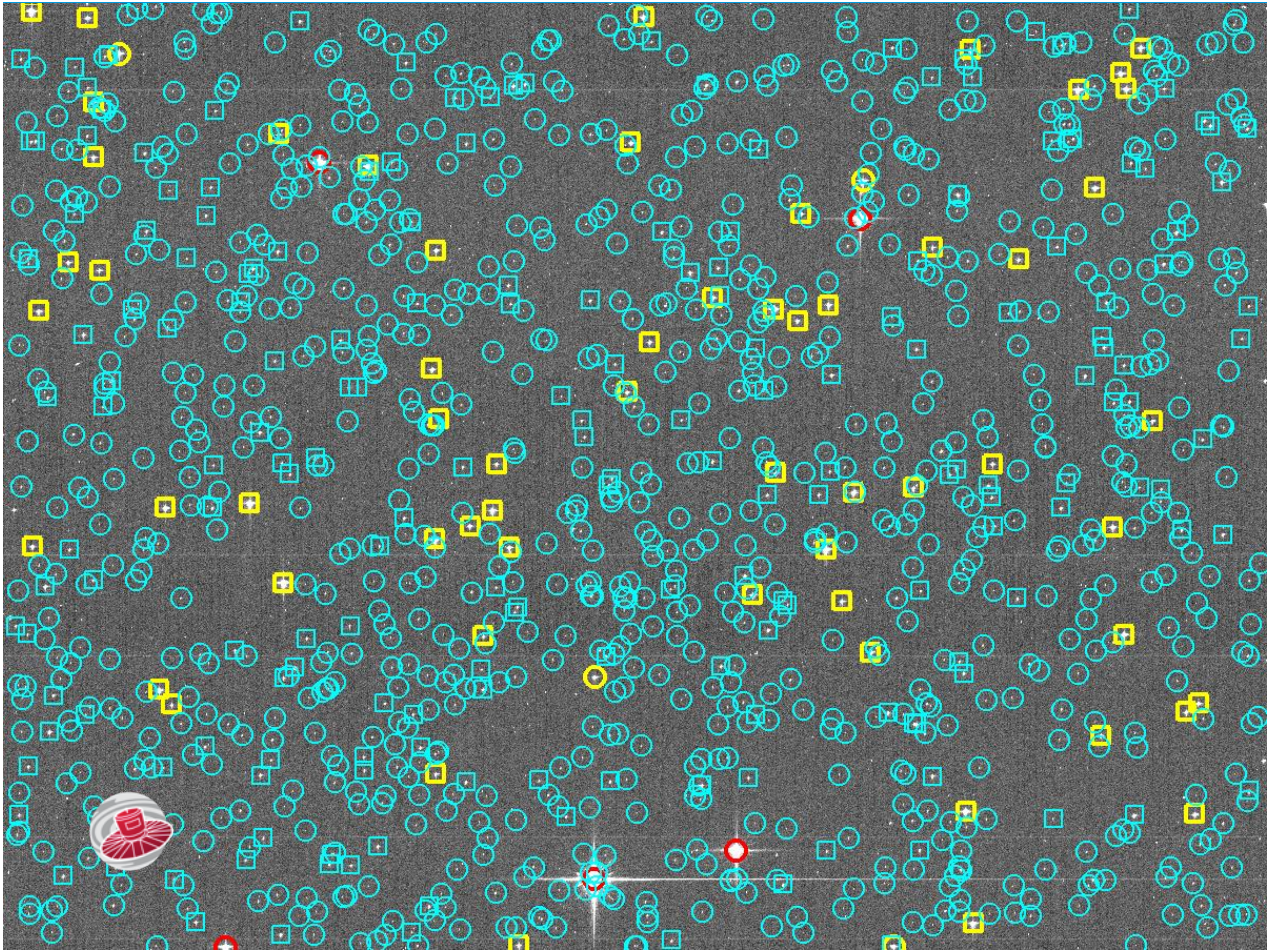
At the faint end, the on-board object-detection and confirmation probability is finite

The design completeness limit is G = 20 mag

Figure based on data from GAIA.ASF.BG.PLM.00015 (Video processing unit software validation report)

INTERMEZZO – START

Work presented in de Bruijne, Allen, Prod'homme, Krone-Martins, Azaz & Hestroffer, 2014, A&A, submitted



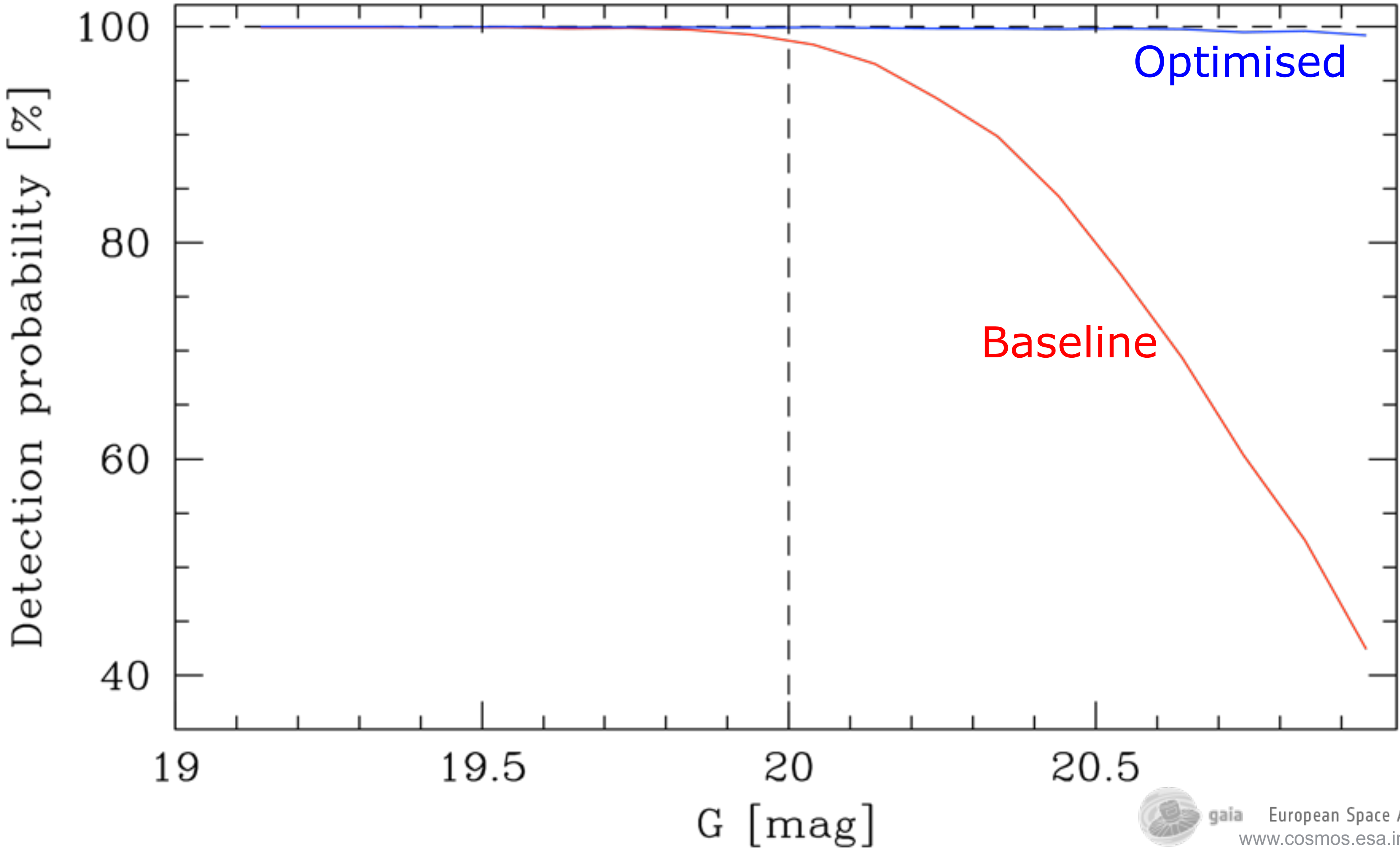
Magnitude-averaged detection percentages

We have studied the detection performance and consider three different sets of on-board detection parameters:

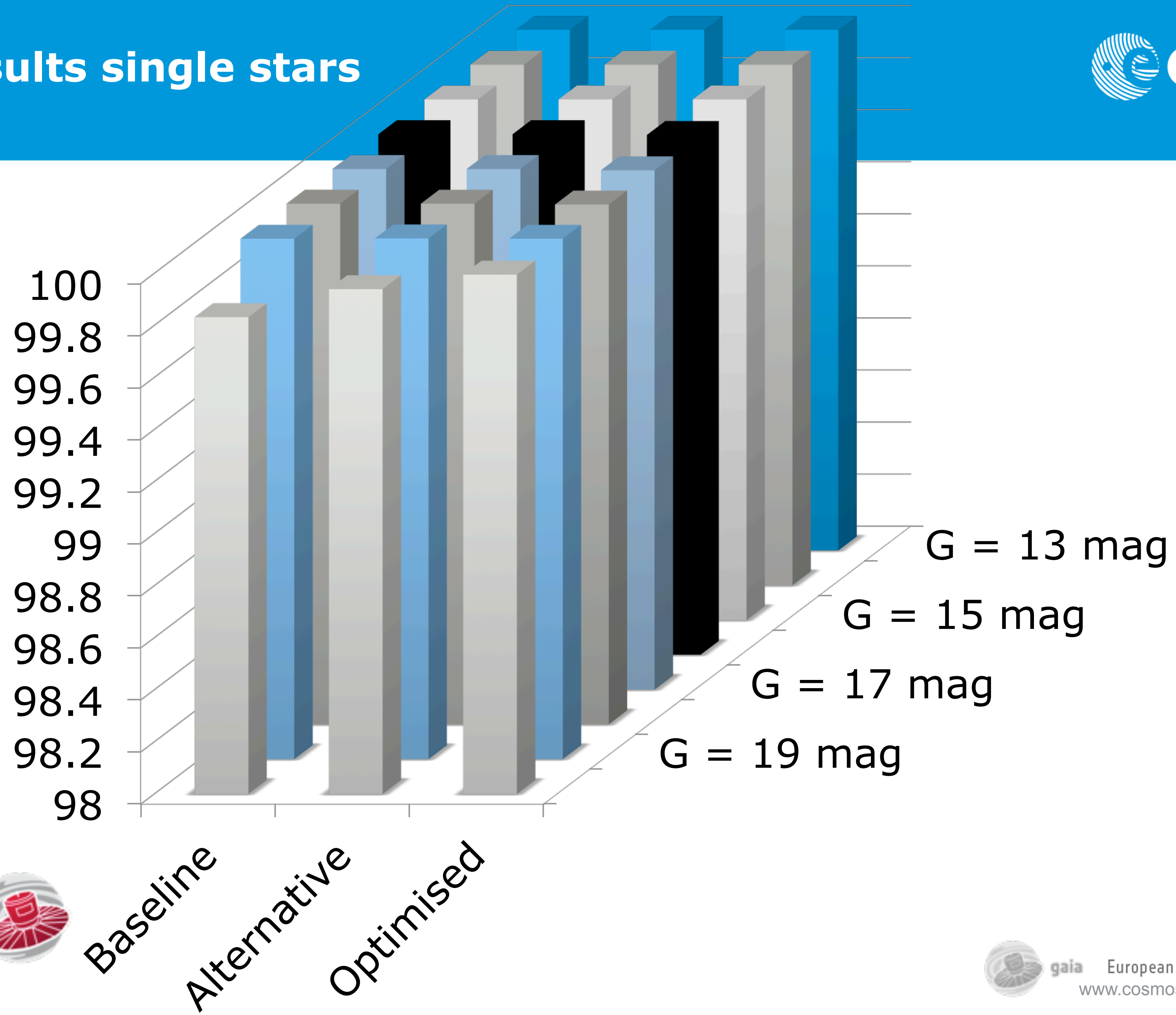
	Baseline
Single *	99.96
Unresolved **	98.42
Resolved **	98.27
Cosmic ray	6.35
Solar proton	3.40
Noise detection	1.80

de Bruijne, Allen, Prod'homme, Krone-Martins, Azaz & Hestroffer, 2014, A&A, submitted

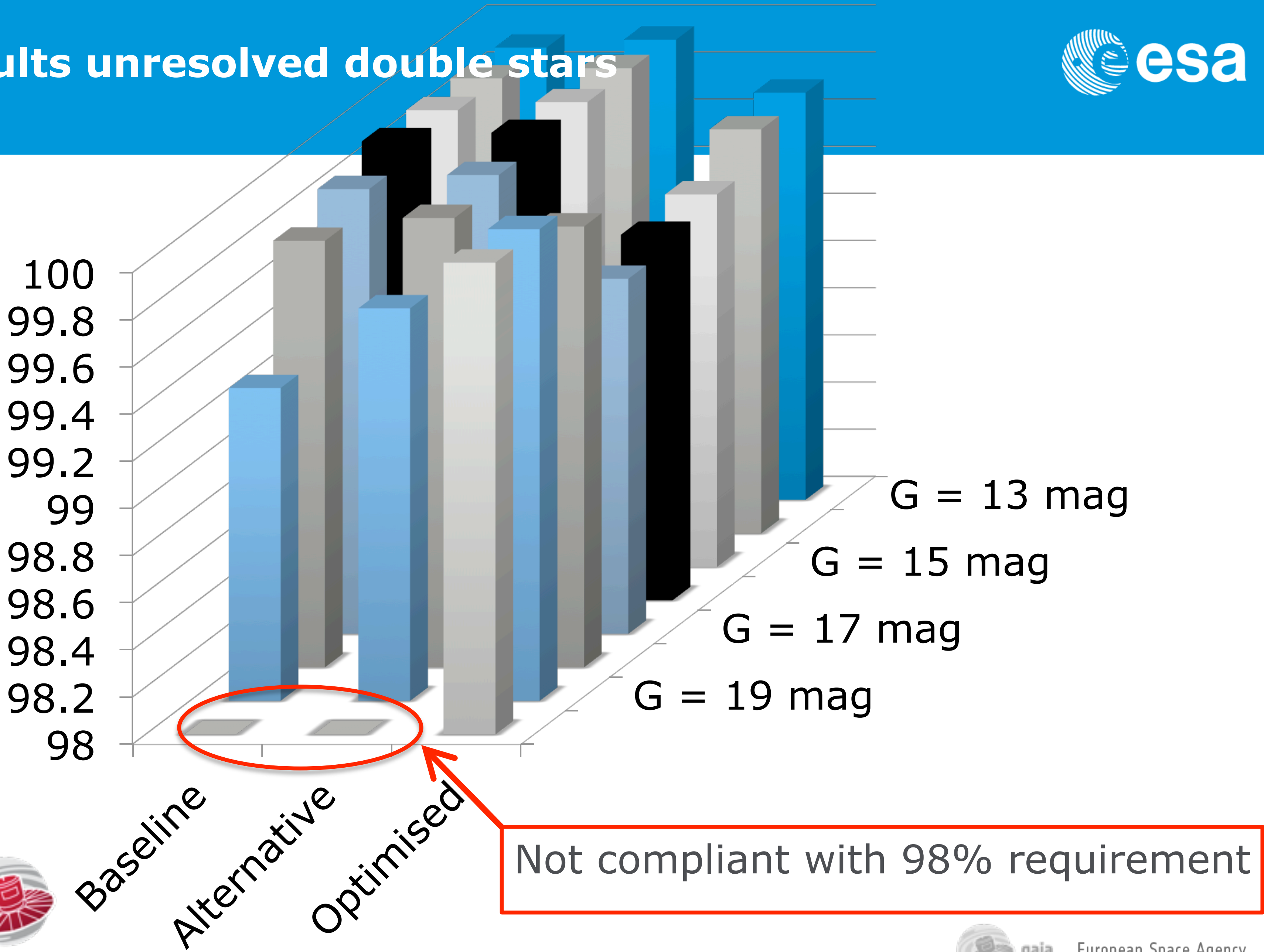
Results single stars



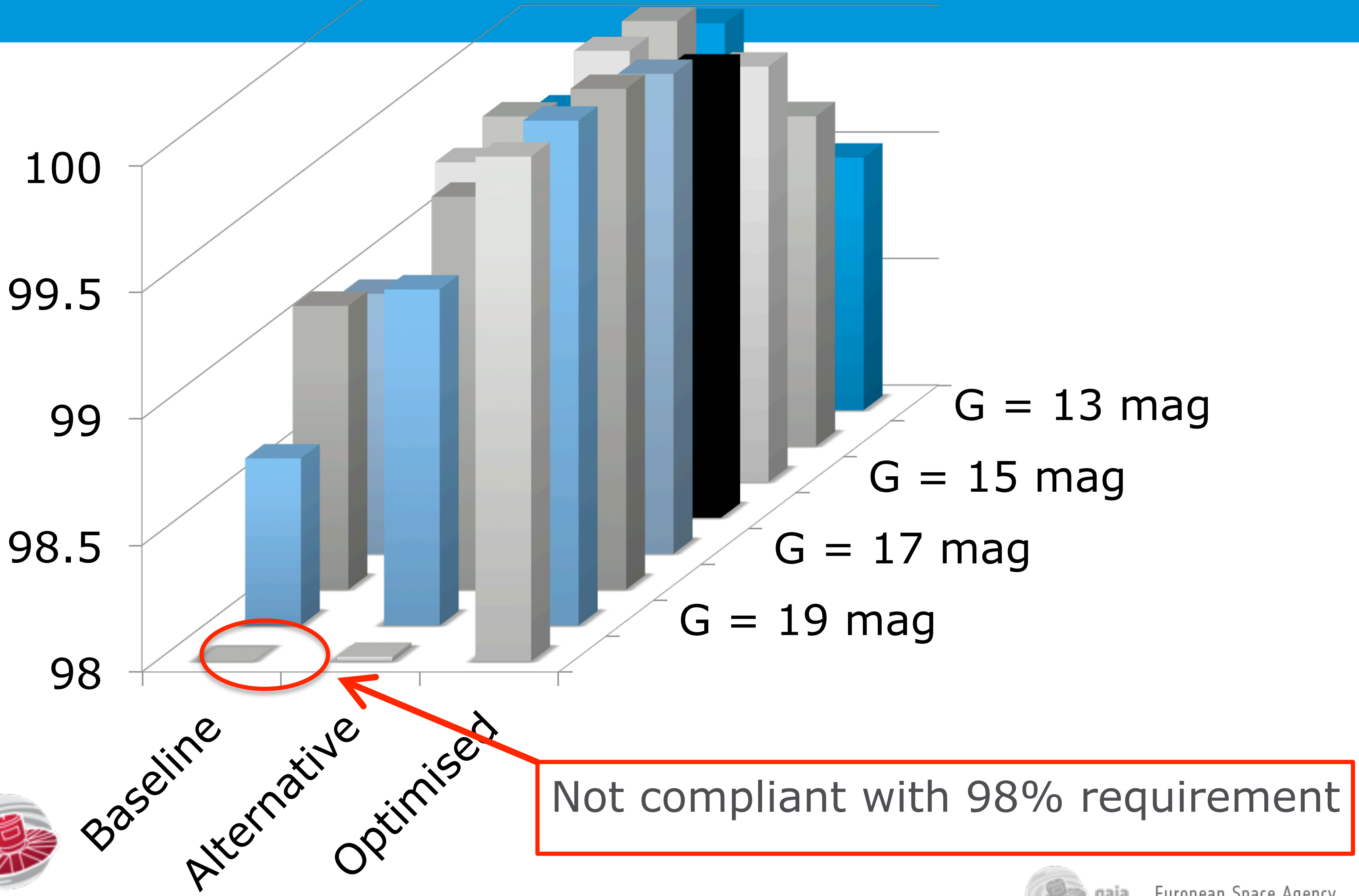
Results single stars



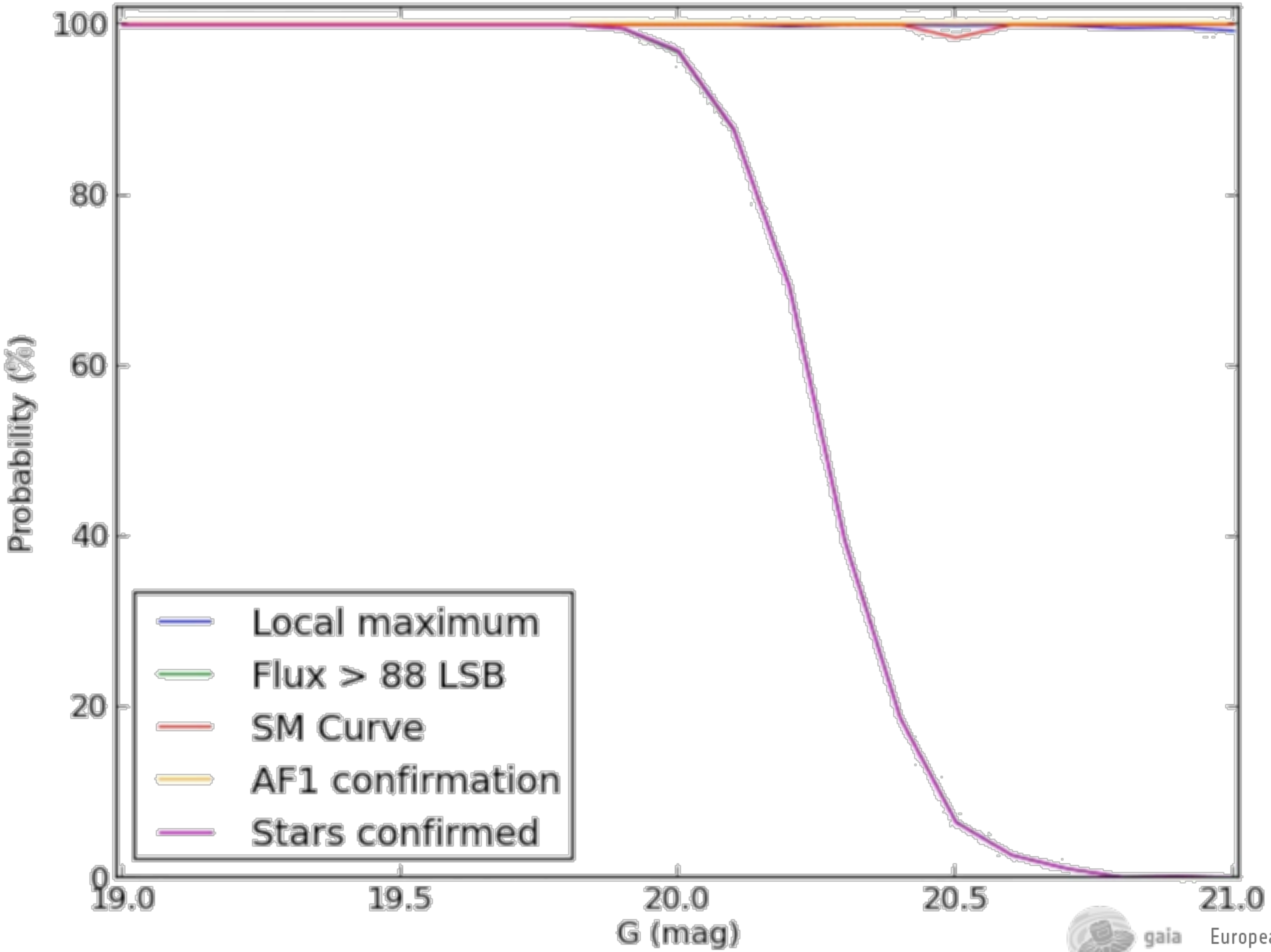
Results unresolved double stars



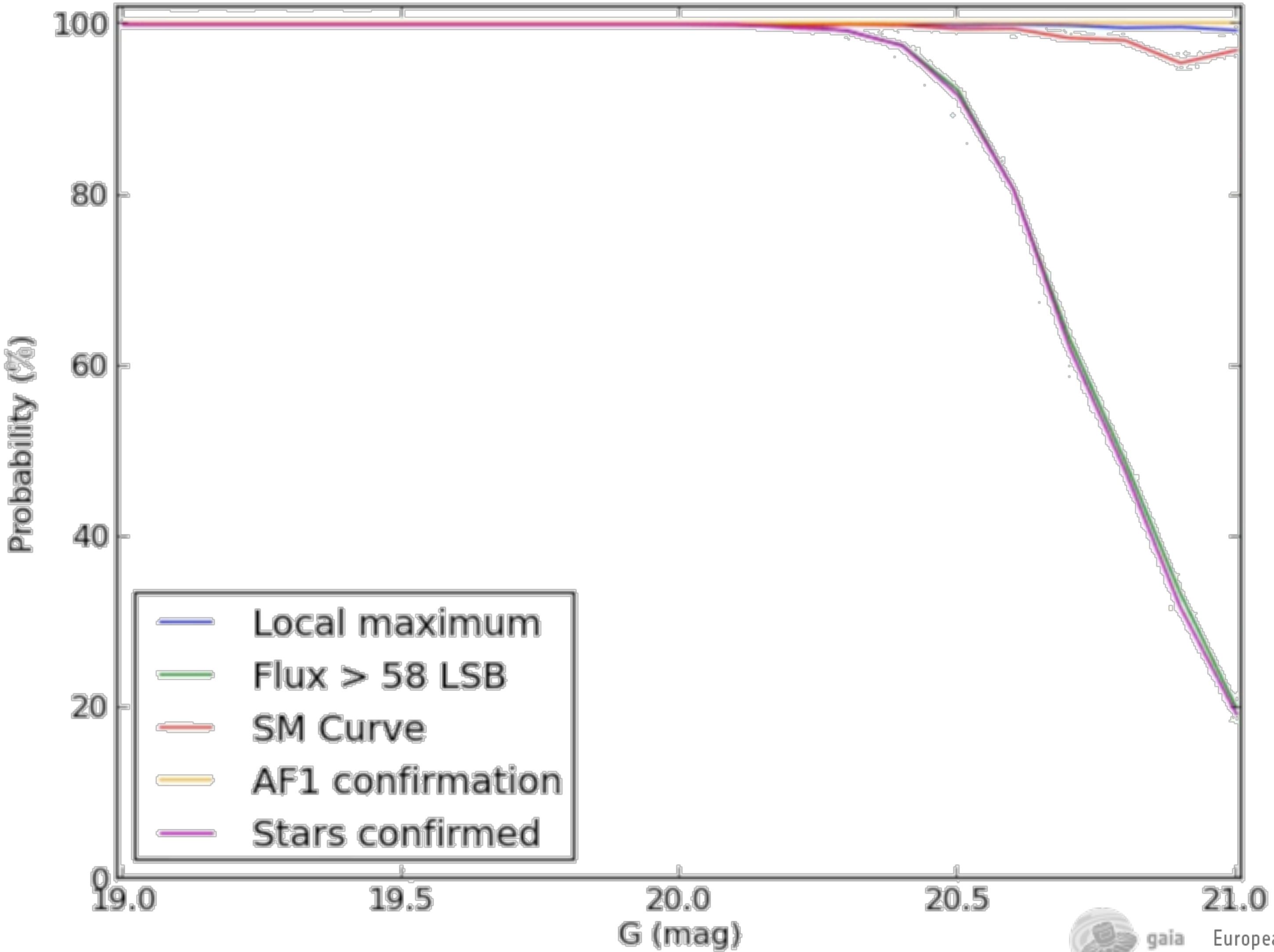
Results resolved double stars



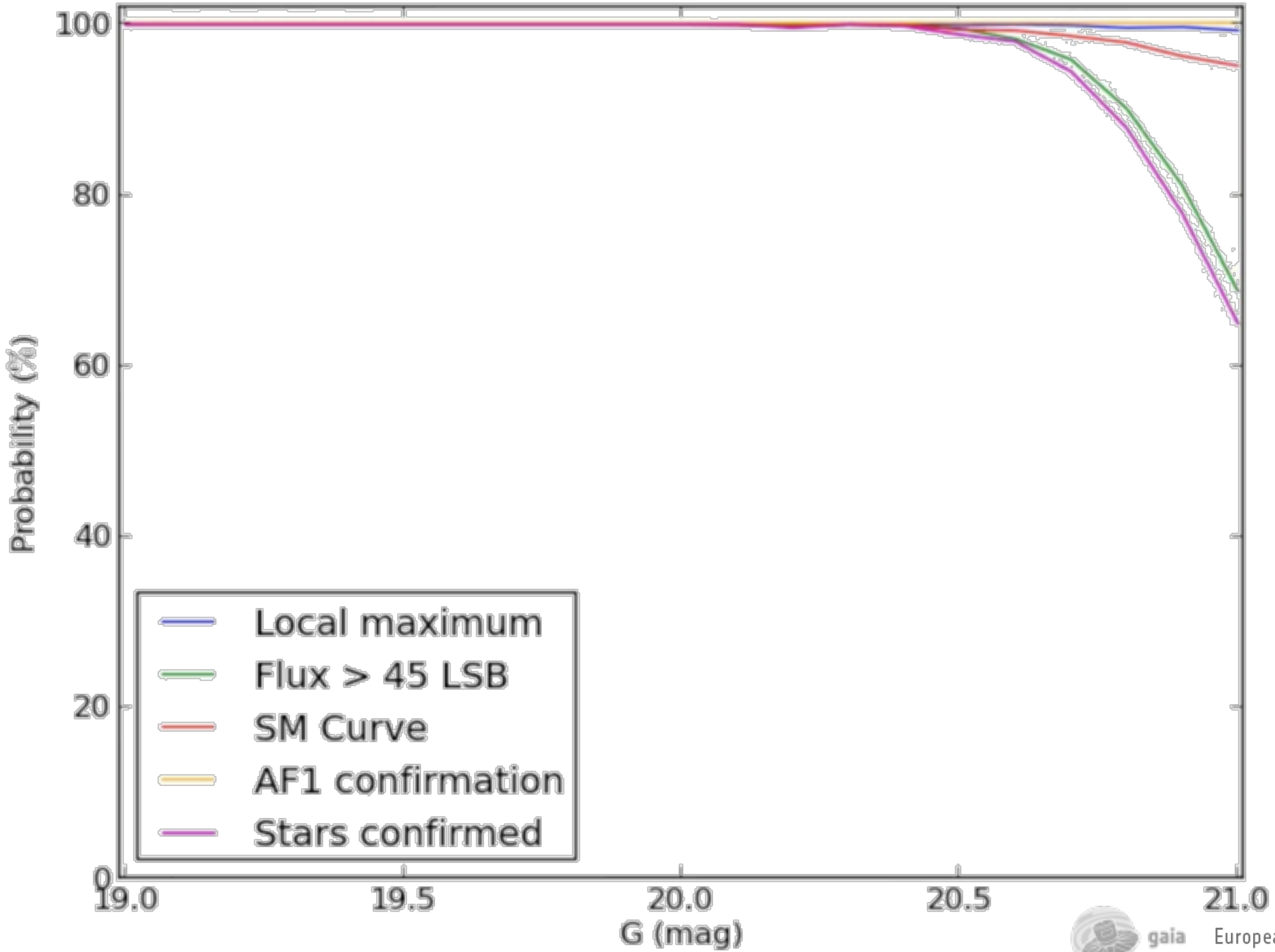
Results for single stars (threshold at 20.3 mag)



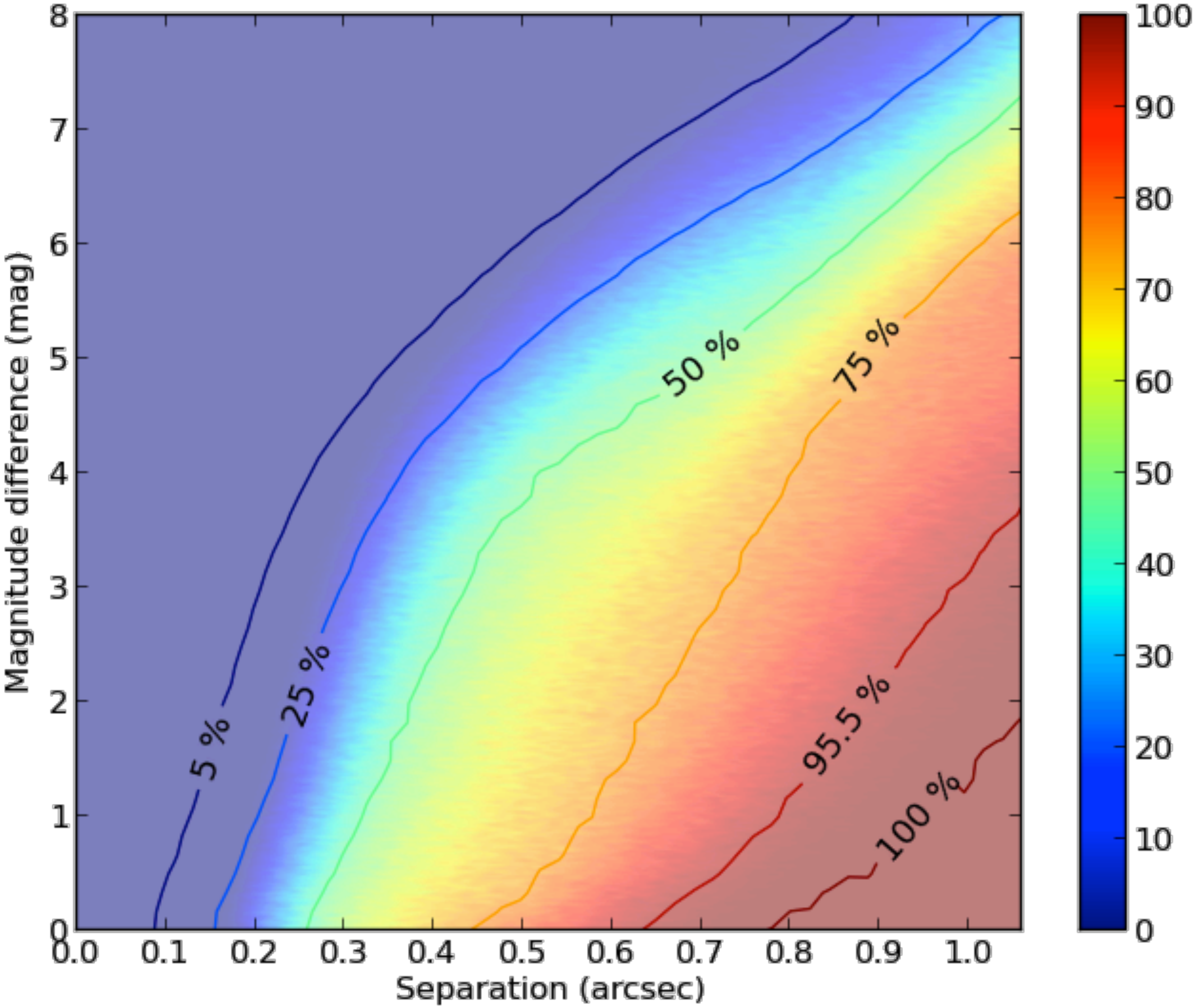
Results for single stars (threshold at 20.7 mag)



Results for single stars (threshold at 21.0 mag)



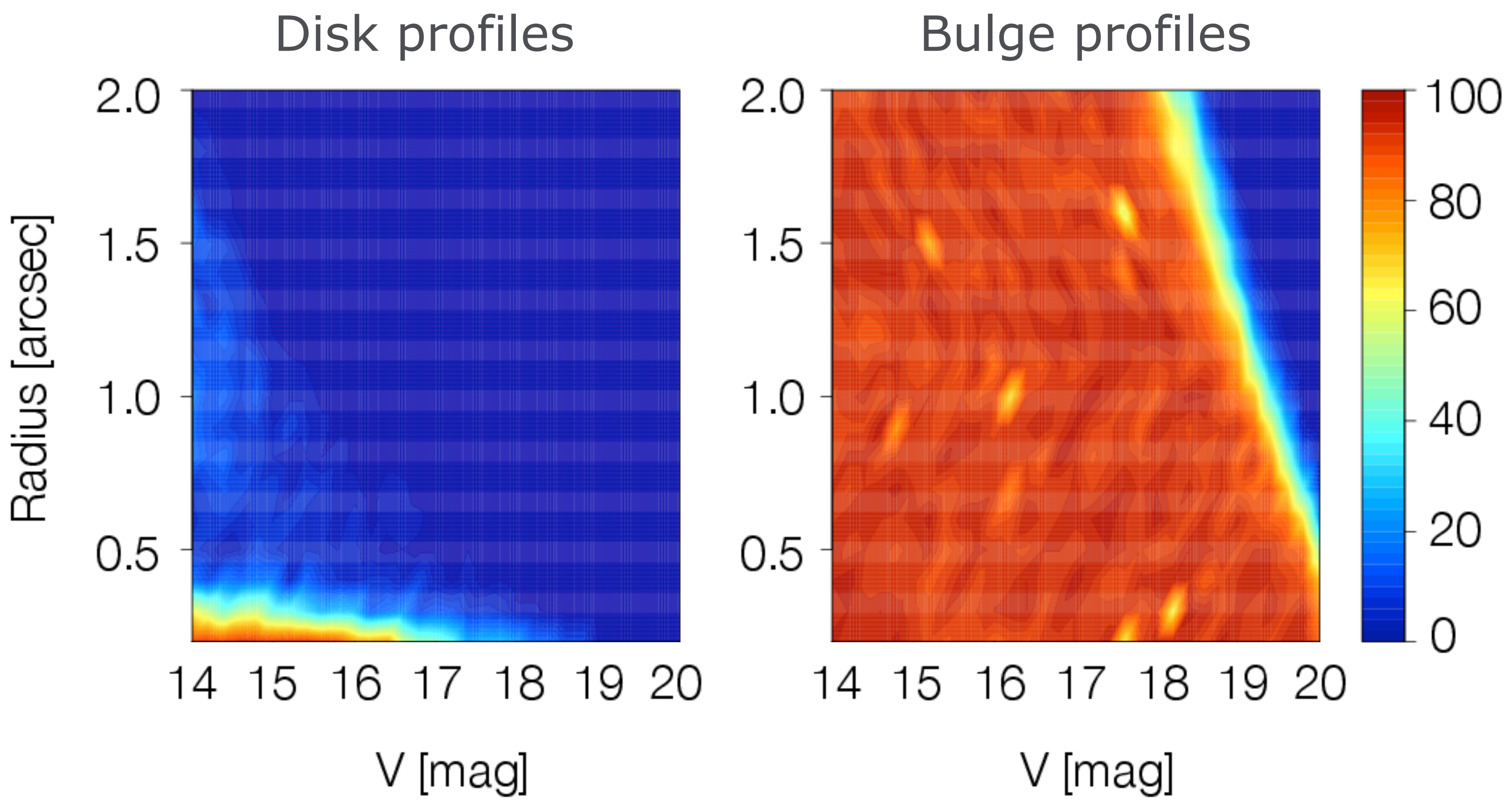
Probability to resolve a double star



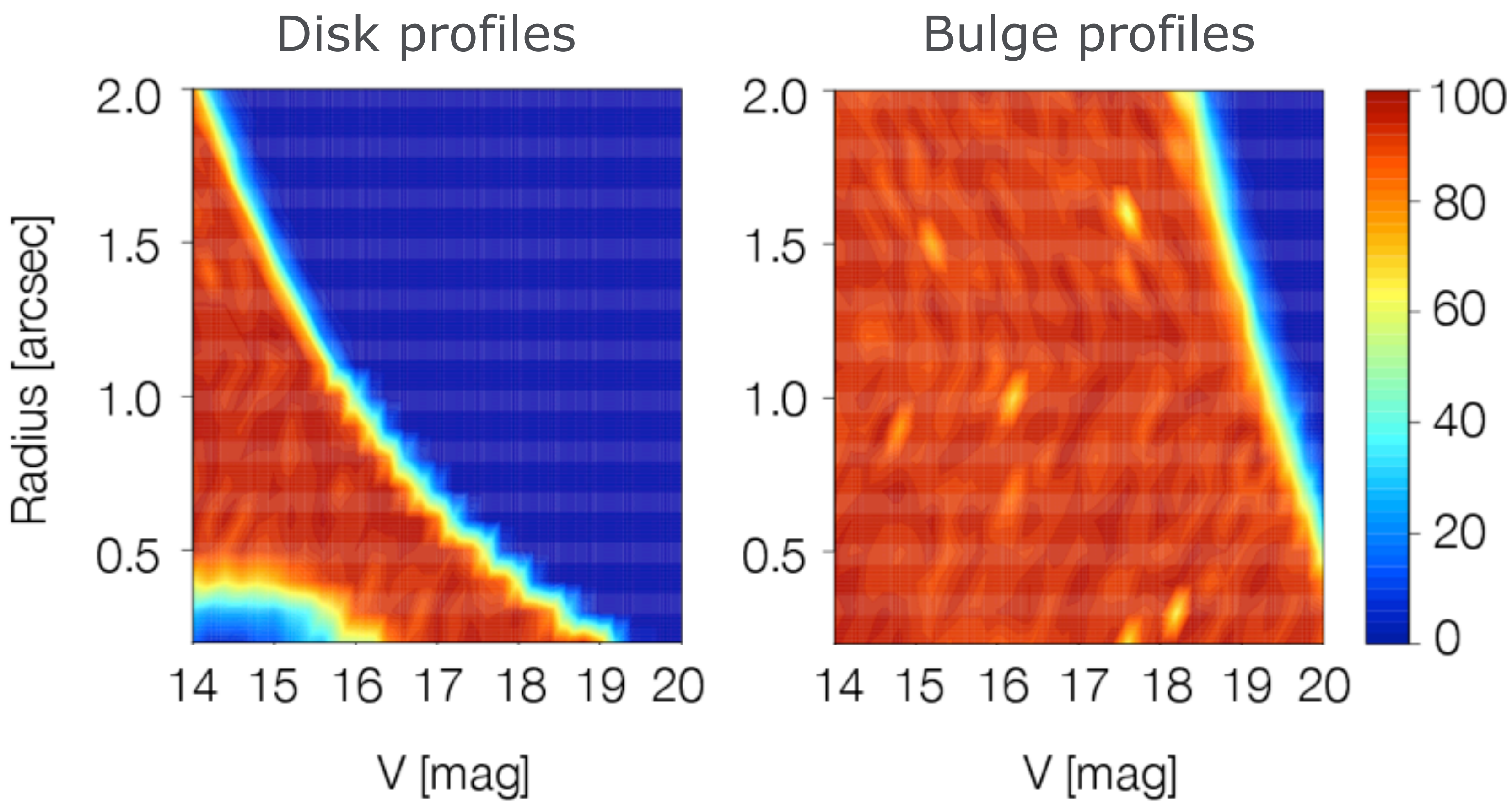
This is independent of the magnitude of the primary

The resolving capability is ~3 times better along- than across-scan

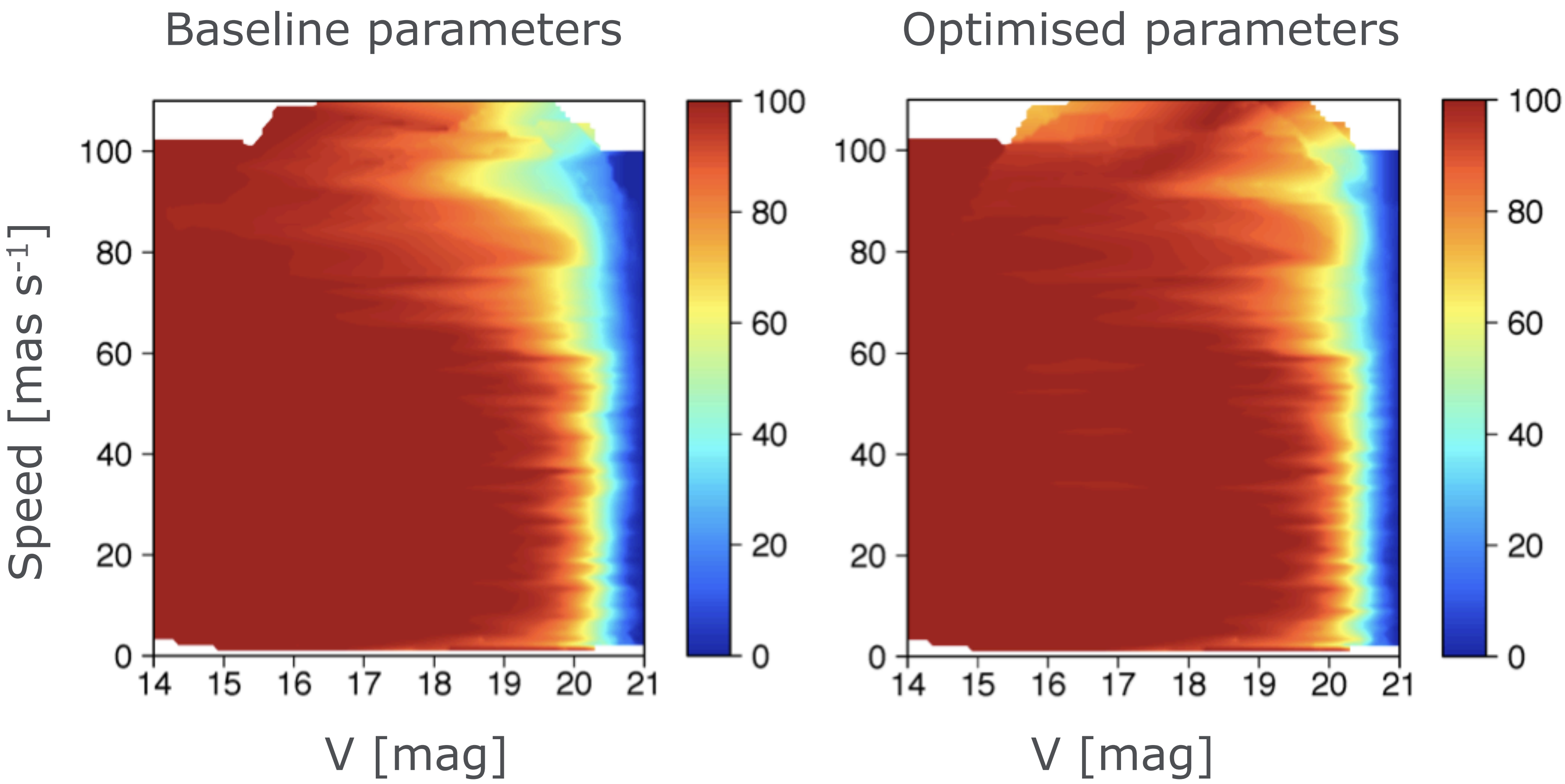
Unresolved galaxies: baseline parameters



Unresolved galaxies: optimised parameters



Detection probability of near-Earth objects



For main-belt asteroids, there is no difference

INTERMEZZO – END

Astrometry in one equation

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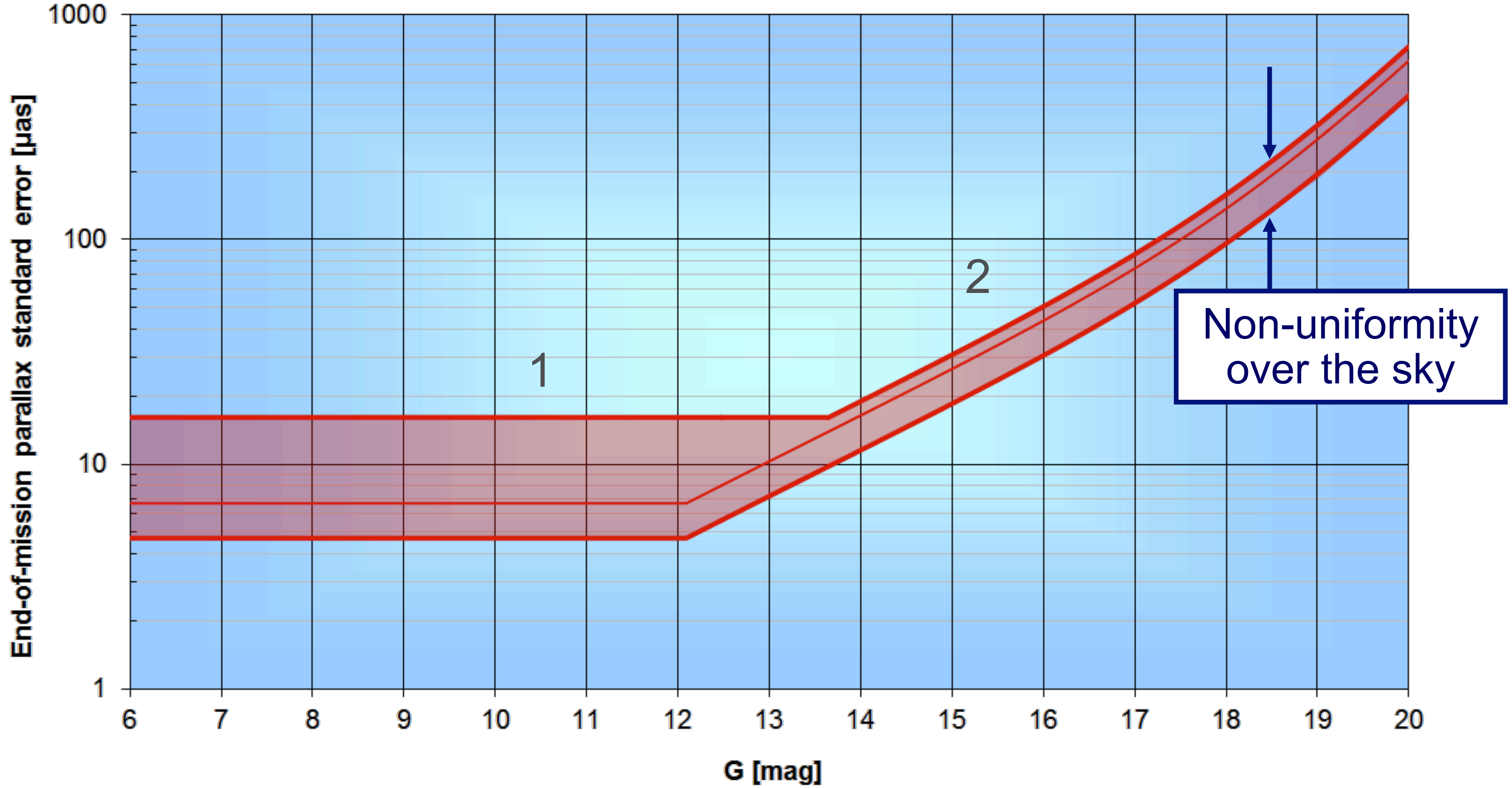
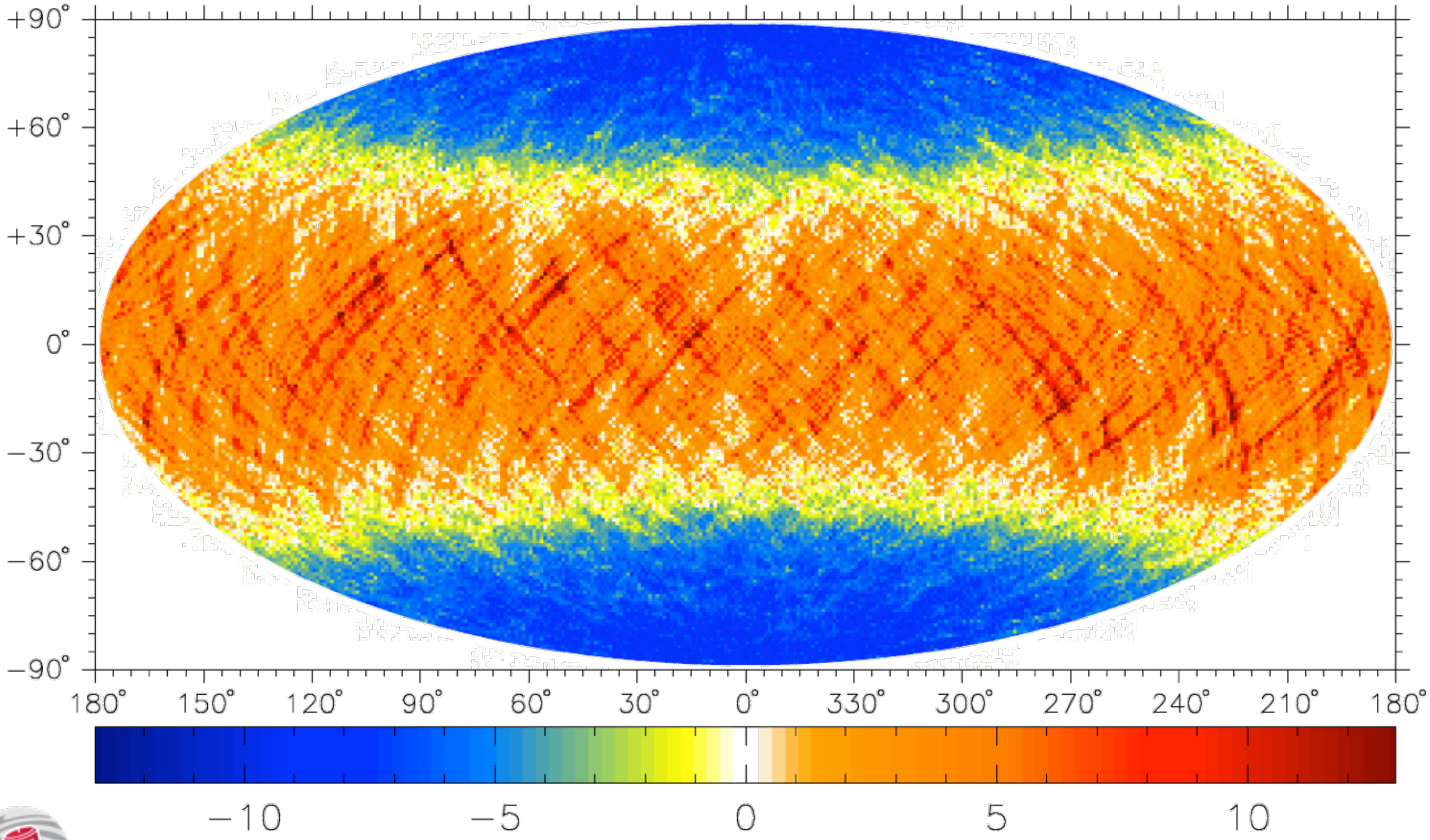
End-of-mission parallax standard errors



1. 3 < G < 12: bright-star regime (calibration errors + CCD saturation)
2. 12 < G < 20: photon-noise regime, with sky-background, straylight, and electronic noise setting in around G ~ 17 mag

Figure from http://www.cosmos.esa.int/web/gaia/science-performance

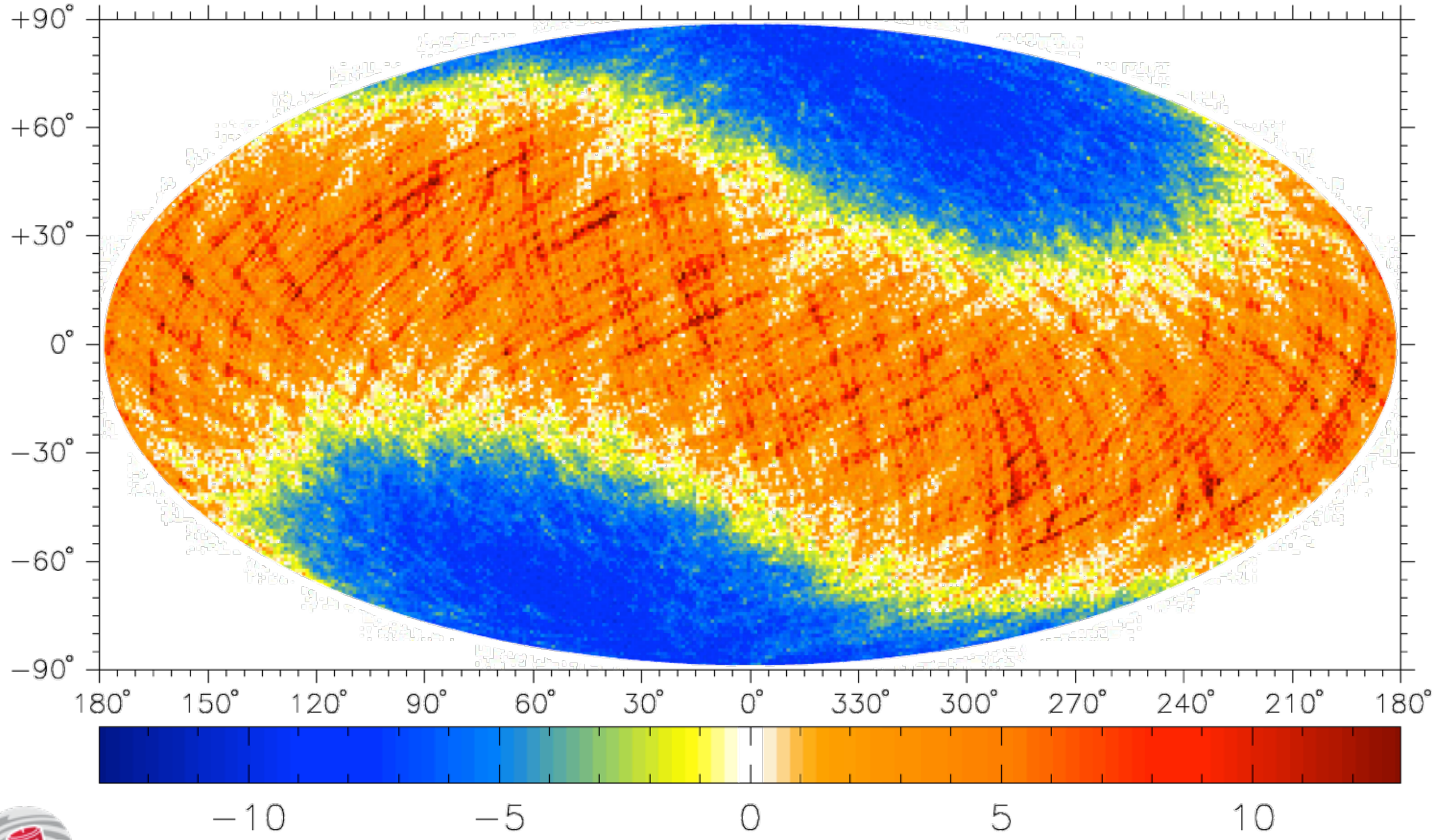
Parallax-error-variation map @ G=15 mag



Sky-average: σ_π = 27 μas

Figure from http://www.cosmos.esa.int/web/gaia/science-performance – ecliptic coordinates

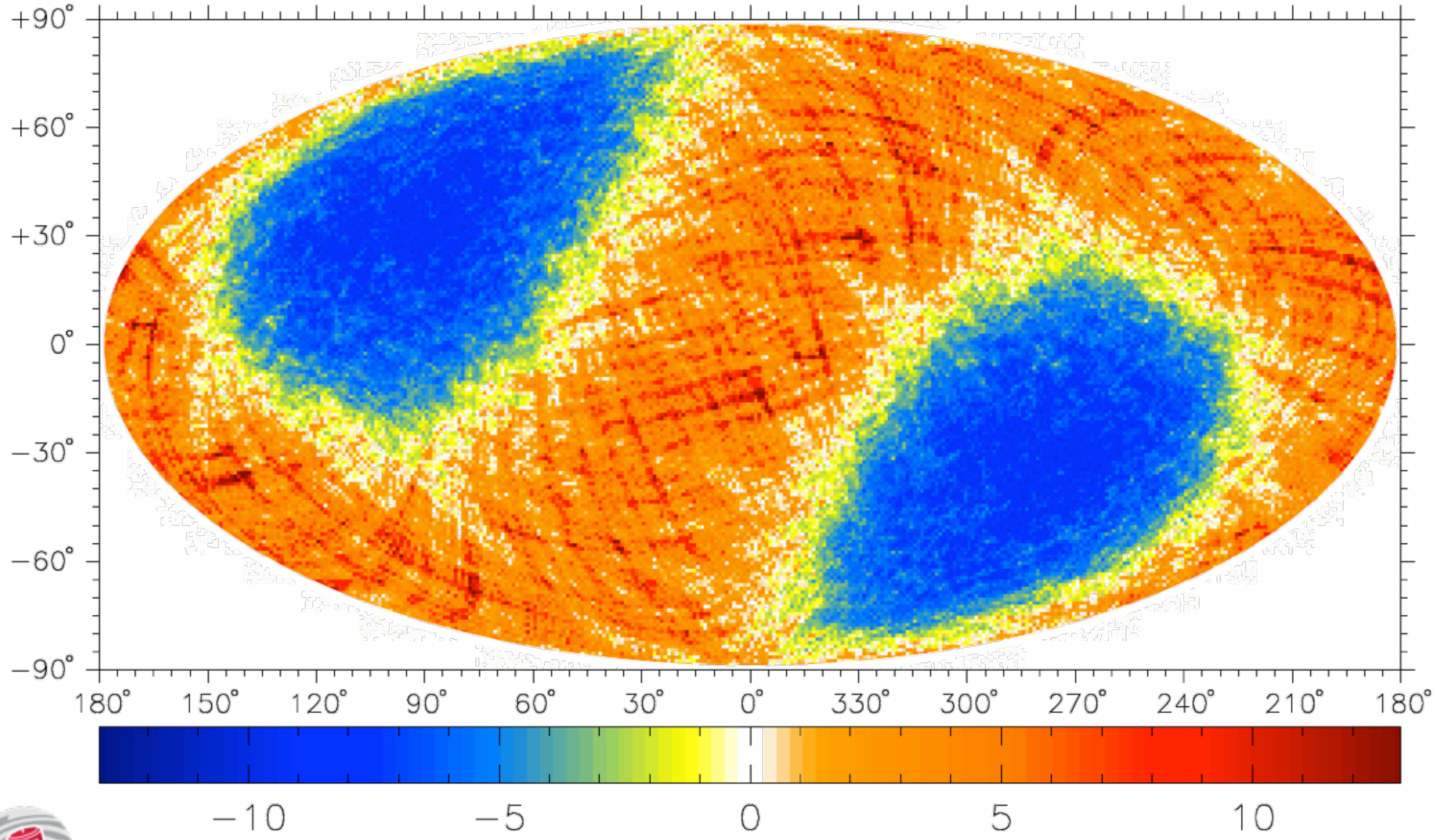
Parallax-error-variation map @ G=15 mag



Sky-average: σ_π = 27 µas

Figure from http://www.cosmos.esa.int/web/gaia/science-performance – equatorial coordinates

Parallax-error-variation map @ G=15 mag



Sky-average: σ_π = 27 µas

Figure from http://www.cosmos.esa.int/web/gaia/science-performance – galactic coordinates

End-of-mission astrometry

For a 5-year Gaia mission, sky-averaged position and proper-motion standard errors, σ_0 [µas] and σ_μ [µas yr^{-1}], are:

$$\sigma_0 = 0.743 \cdot \sigma_\pi$$

$$\sigma_\mu = 0.526 \cdot \sigma_\pi$$

For any given V magnitude and V-I colour index, the end-of-mission parallax standard error, σ_π [µas], averaged over the sky, is:

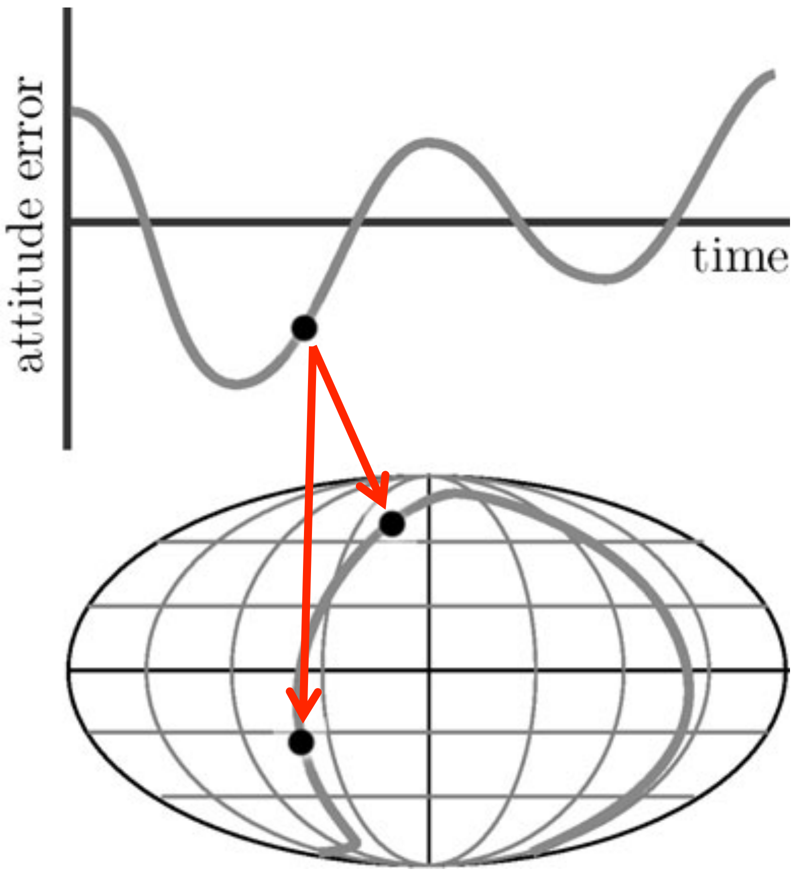
$$\sigma_\pi \text{ [µas]} = \sqrt{(-1.631 + 680.766 \cdot z + 32.732 \cdot z^2)}\ [0.986 + (1 - 0.986)(V-I)]$$

$$z = \mathrm{MAX}[10^{0.4\,(12.09 - 15)}, 10^{0.4\,(G - 15)}]$$

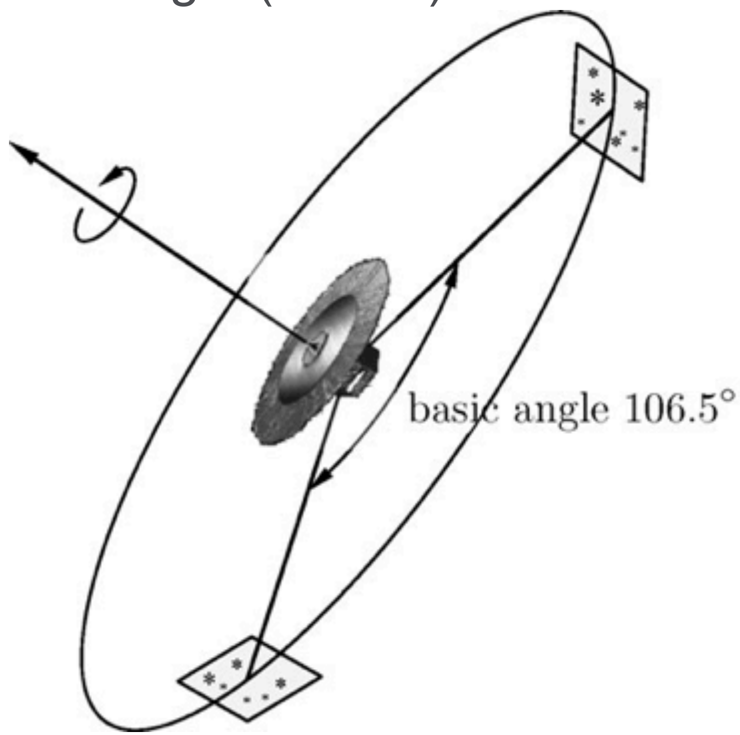
$$G = V - 0.0107 - 0.0879 \cdot (V-I) - 0.1630 \cdot (V-I)^2 + 0.0086 \cdot (V-I)^3$$

Equations and variations over the sky available on http://www.cosmos.esa.int/web/gaia/science-performance

What about correlations?

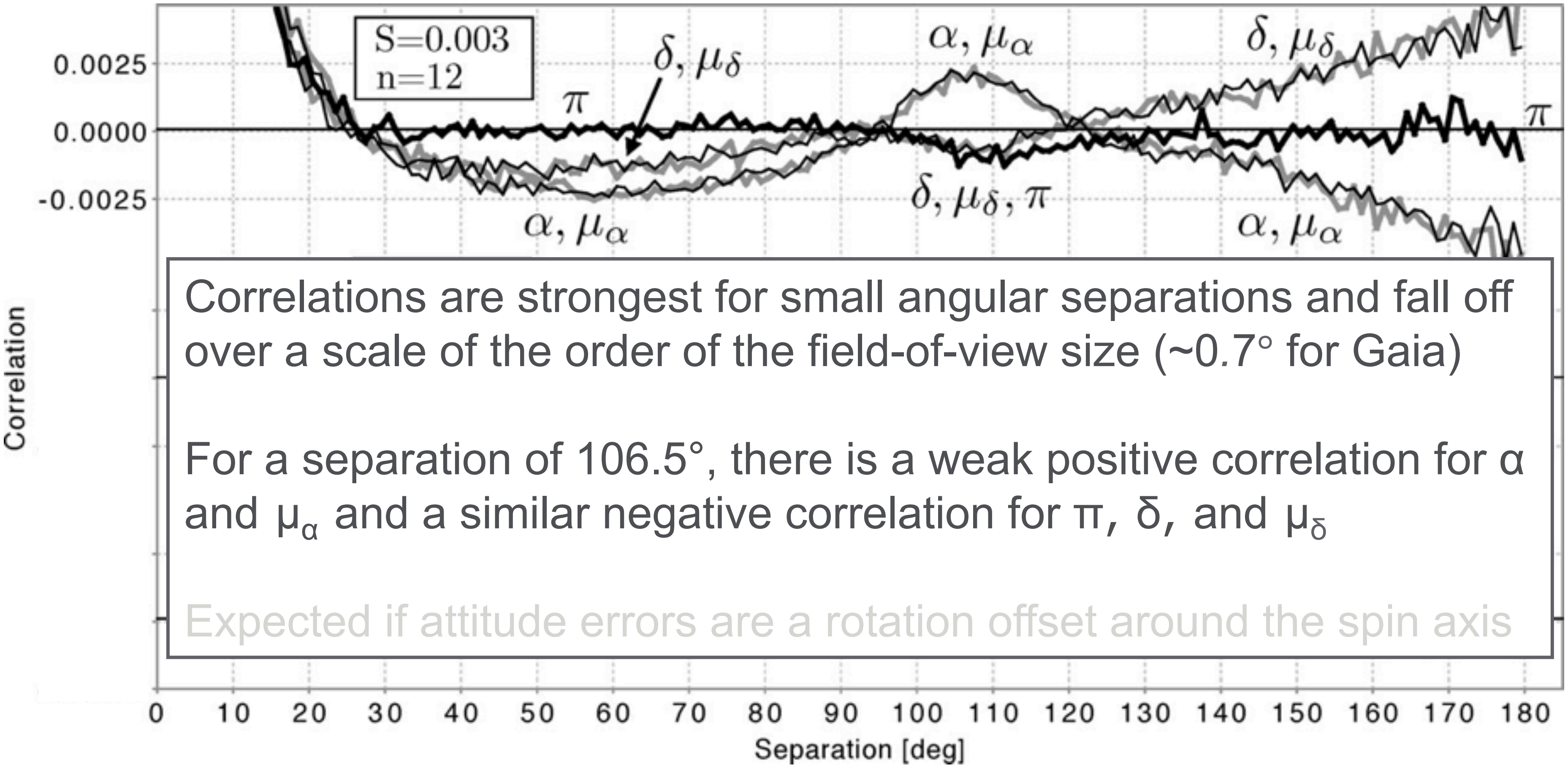


An error in the attitude at a particular time ‘biases’ all observations made at that time, in both fields → correlations between stars within each field as well as stars separated by the basic angle (106.5°)



Figures from Holl et al. (2010)

AGIS-Lab simulations of correlations



Correlations are strongest for small angular separations and fall off over a scale of the order of the field-of-view size (~0.7° for Gaia)

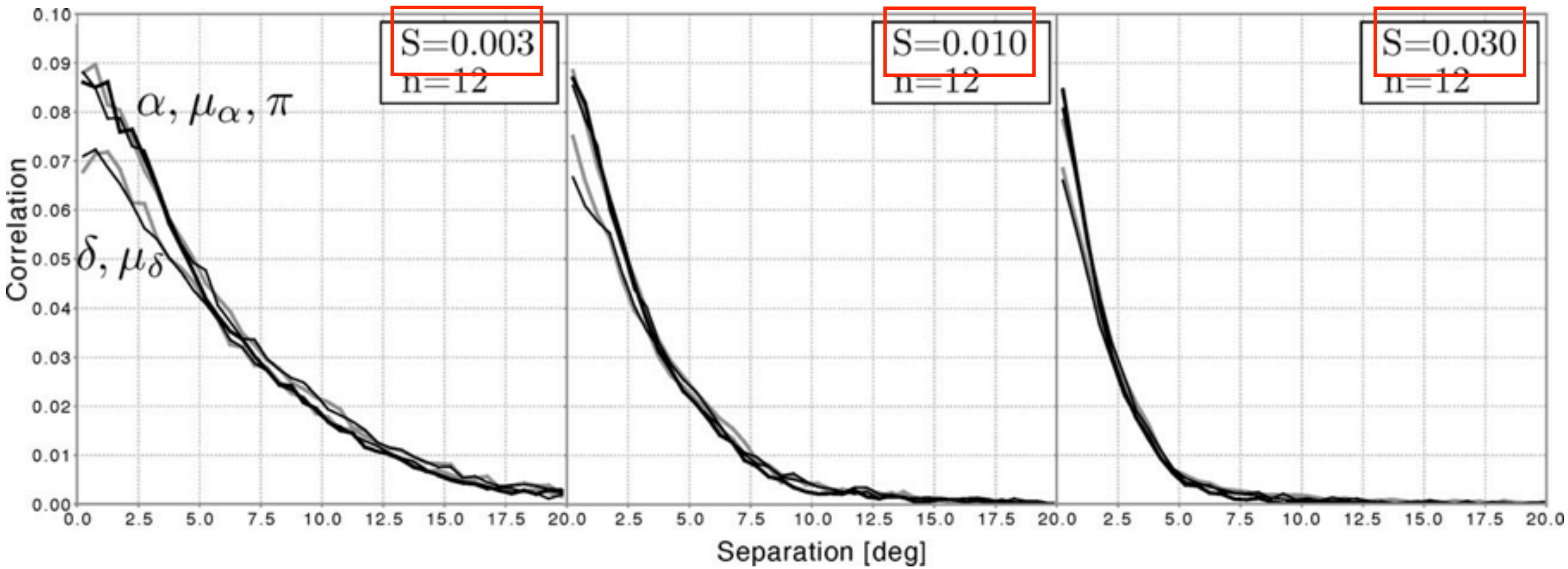
For a separation of 106.5°, there is a weak positive correlation for α and μ_α and a similar negative correlation for π, δ, and μ_δ

Expected if attitude errors are a rotation offset around the spin axis

Warning: the plot does not correspond to Gaia but a scaled version (S is an AGIS-Lab scaling parameter of the field-of-view size with S = 1 for Gaia)

Figures from Holl et al. (2010)

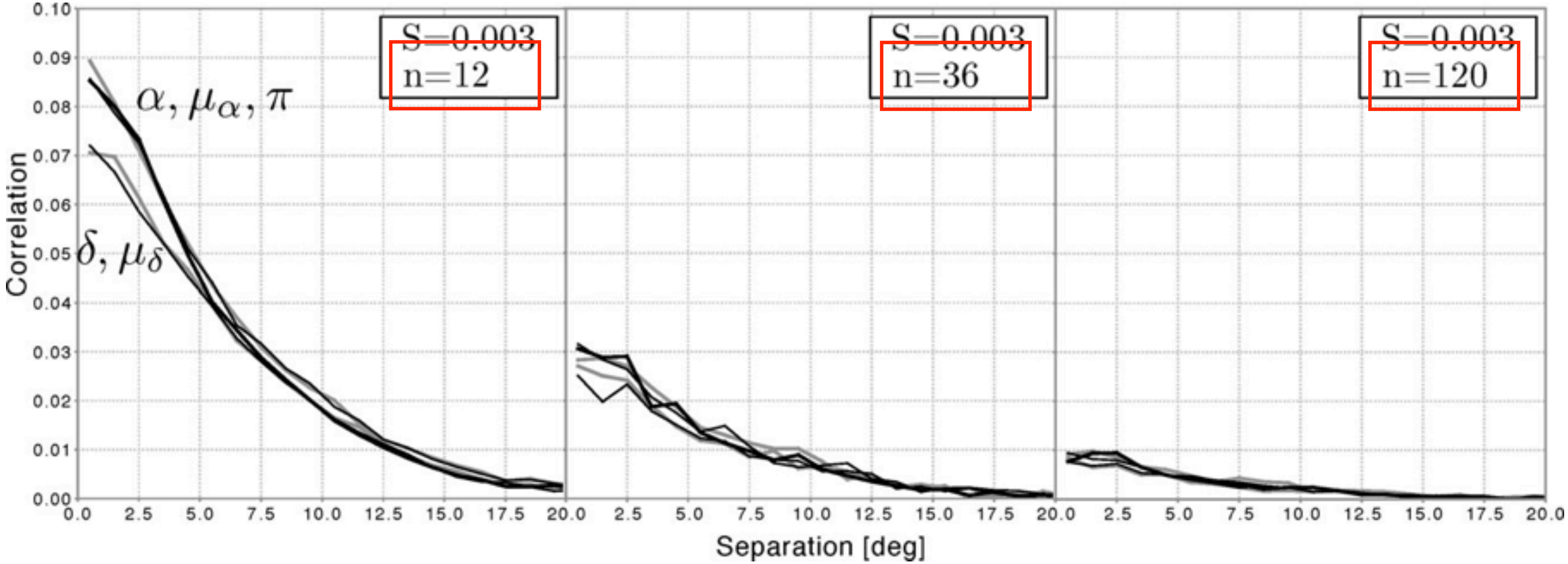
Influence of field-of-view size



The correlation half-length scales with the size of the field-of-view and equals ~0.3° for Gaia (0.4 × 0.7°)

Figures from Holl et al. (2010)

Influence of # stars in global solution



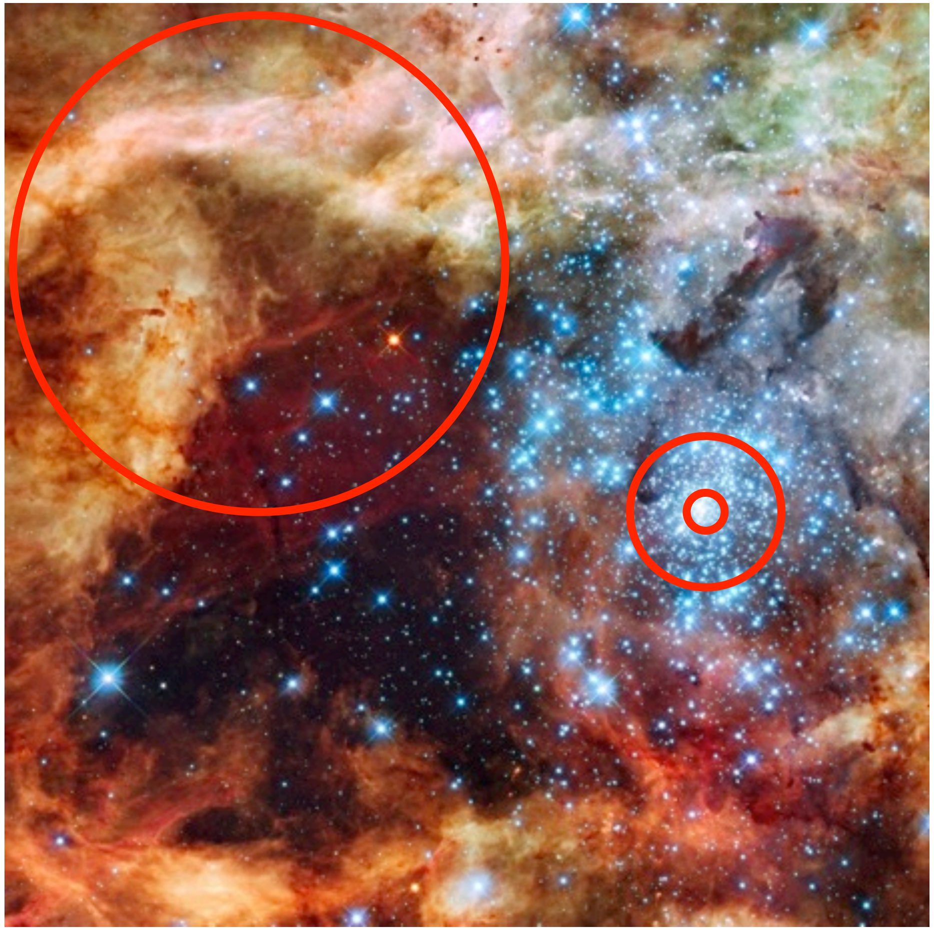
The maximum correlation depends on the number (and magnitude distribution) of stars used in the AGIS global solution

Using 100 million stars suggest that r_{max} ~ 0.005 for bright stars (V < 13 mag) and smaller for fainter stars

Figures from Holl et al. (2010)

How much time is left?

Case study of a dense region (R136)



162 arcsec (0.05°)

Crowding implies incompleteness at high densities and faint magnitudes
- ✓ The astrometric limit is ~1 million stars deg^{-2} over a full CCD (0.7°)

R136 starburst in the LMC with HST:
- ✓ Field density is 350,000 stars deg^{-2} down to G = 20 mag
- ✓ Cluster density is ~10 million stars deg^{-2}
- ✓ Core density is ~40 million stars deg^{-2}

Figure from http://hubblesite.org/newscenter/archive/releases/2009/32/

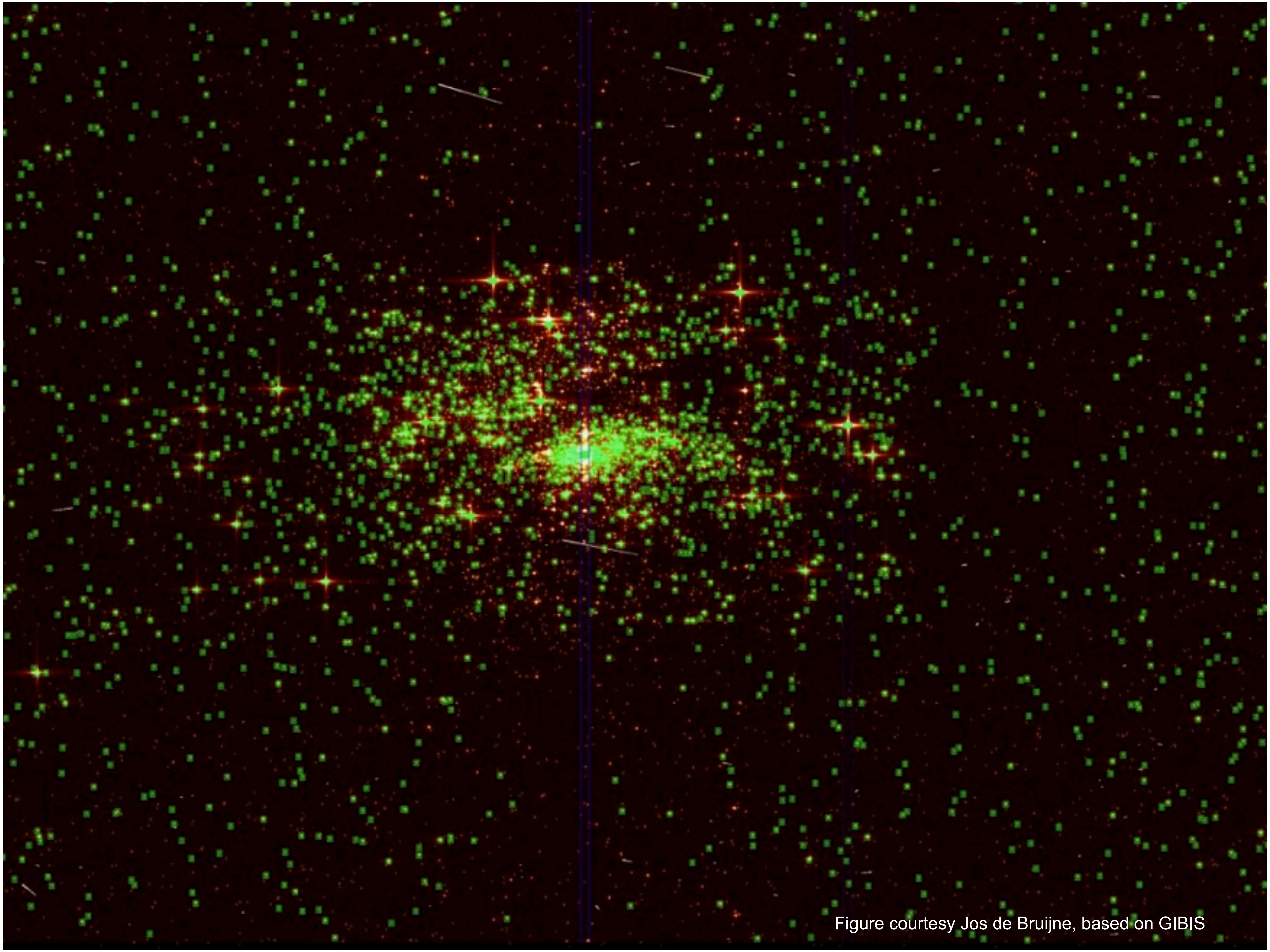


Figure courtesy Jos de Bruijne, based on GIBIS

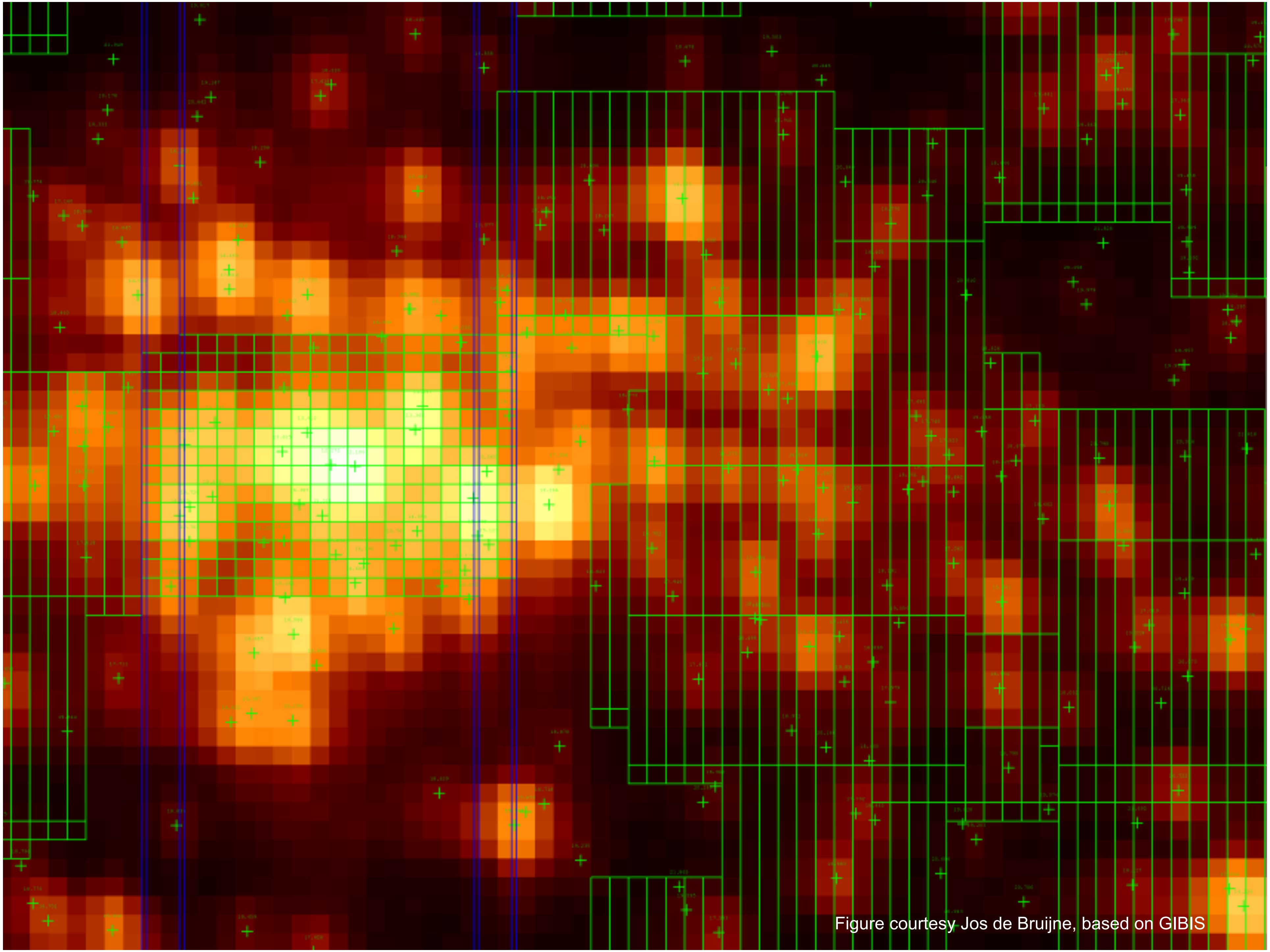


Figure courtesy Jos de Bruijne, based on GIBIS

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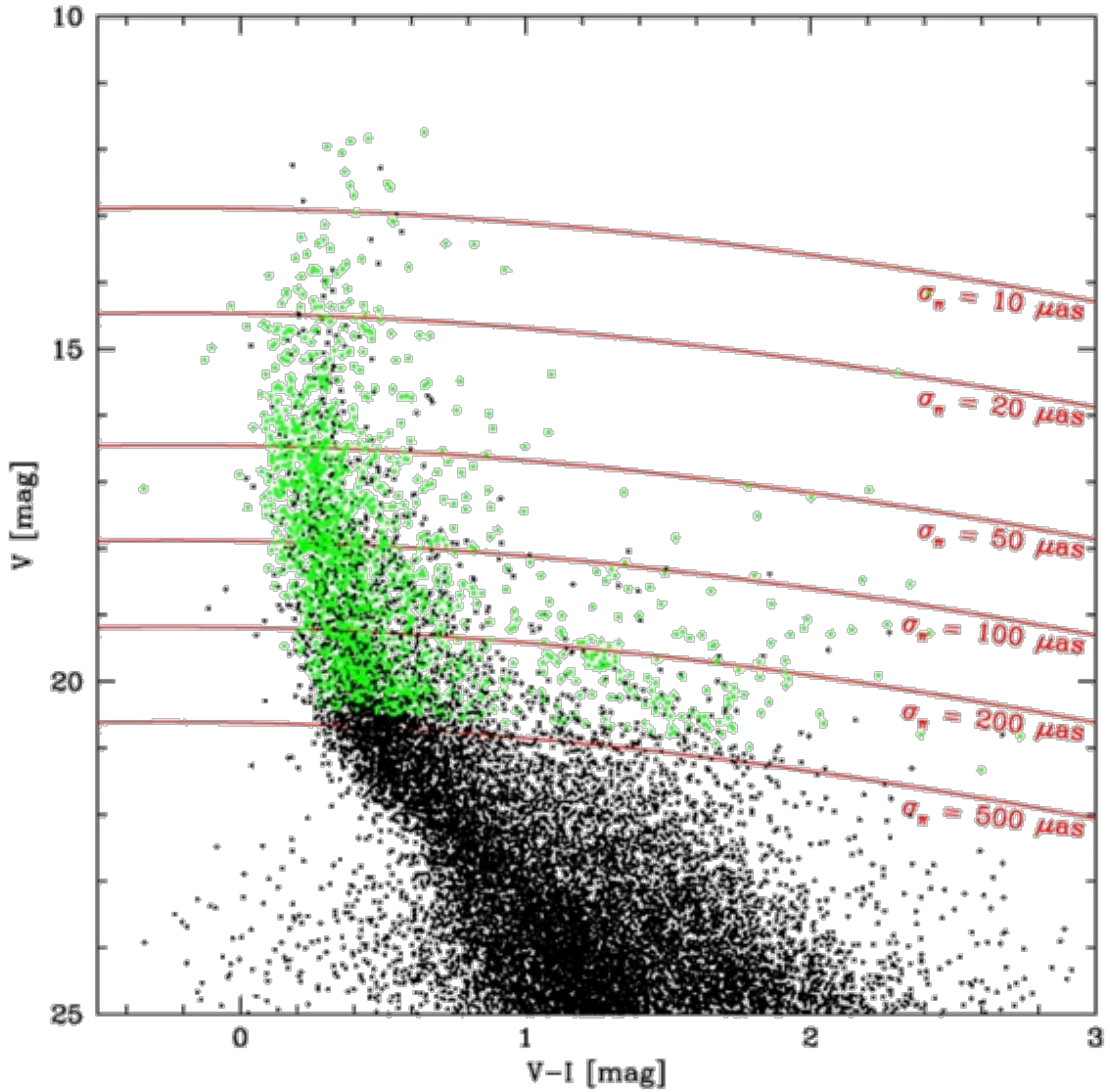

De Bruijne & de Marchi (2011)

The cluster poses “no problems” to Gaia:

- ✓ Stars down to 20 mag are detected and observed (but not all)
- ✓ The window overlap, however, is large and de-blending the data will be a challenge …

Black: HST input

Green: Gaia detection


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