Gaia's astrometric science performance

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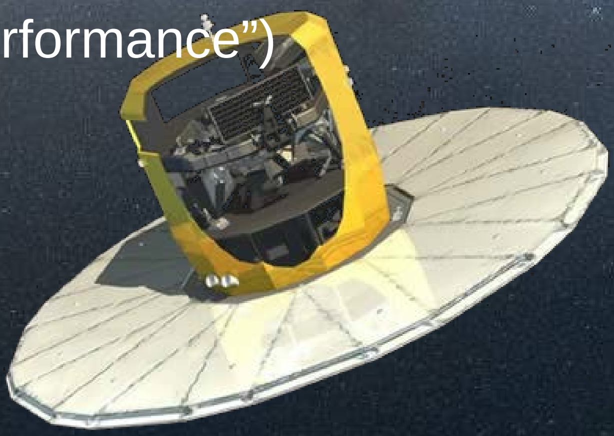
Gaia Project
European Space Agency

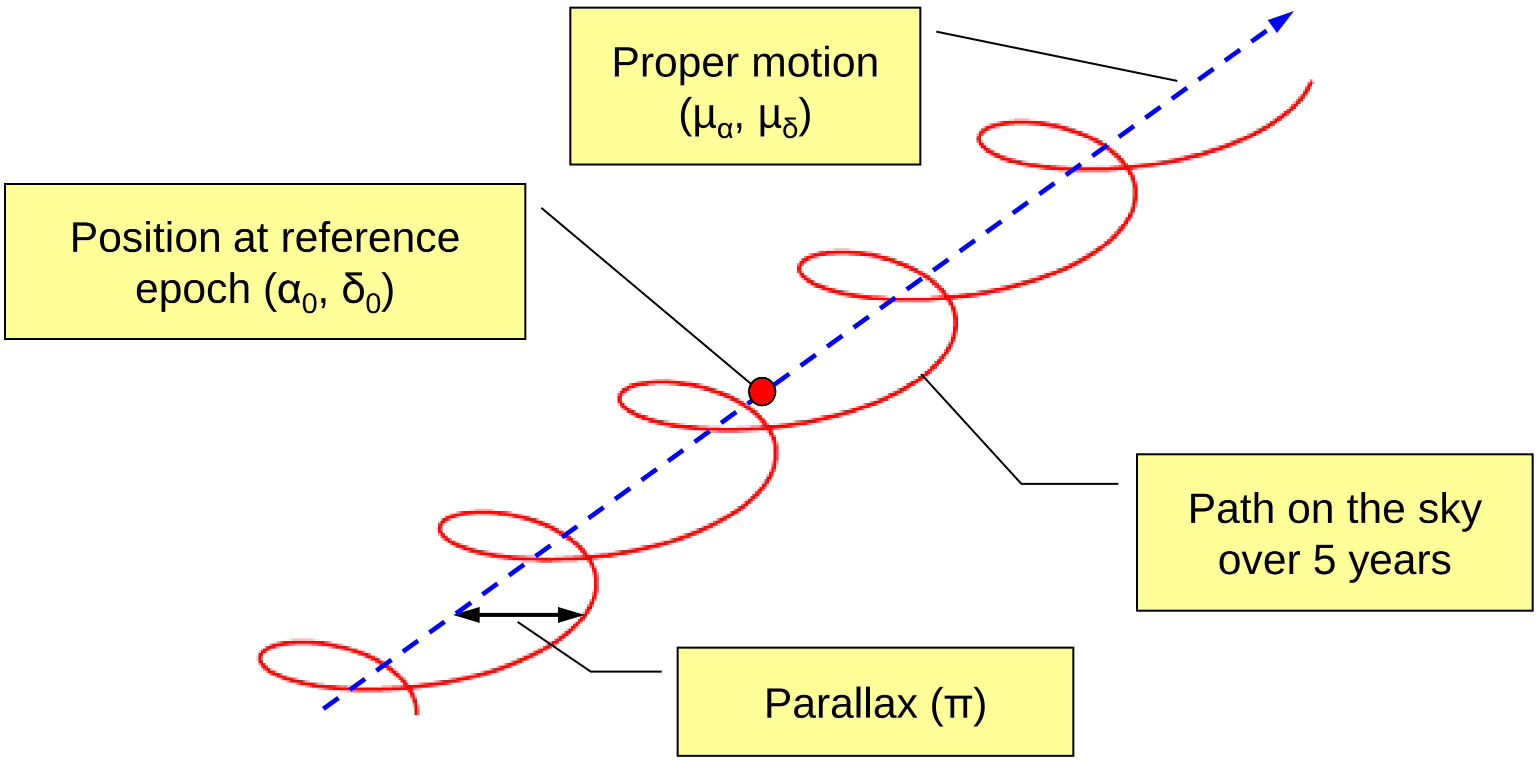
http://www.rssd.esa.int/gaia
(click "Science Performance"
or simply Google for "Gaia science performance")



Figures courtesy EADS Astrium and Axel Mellinger

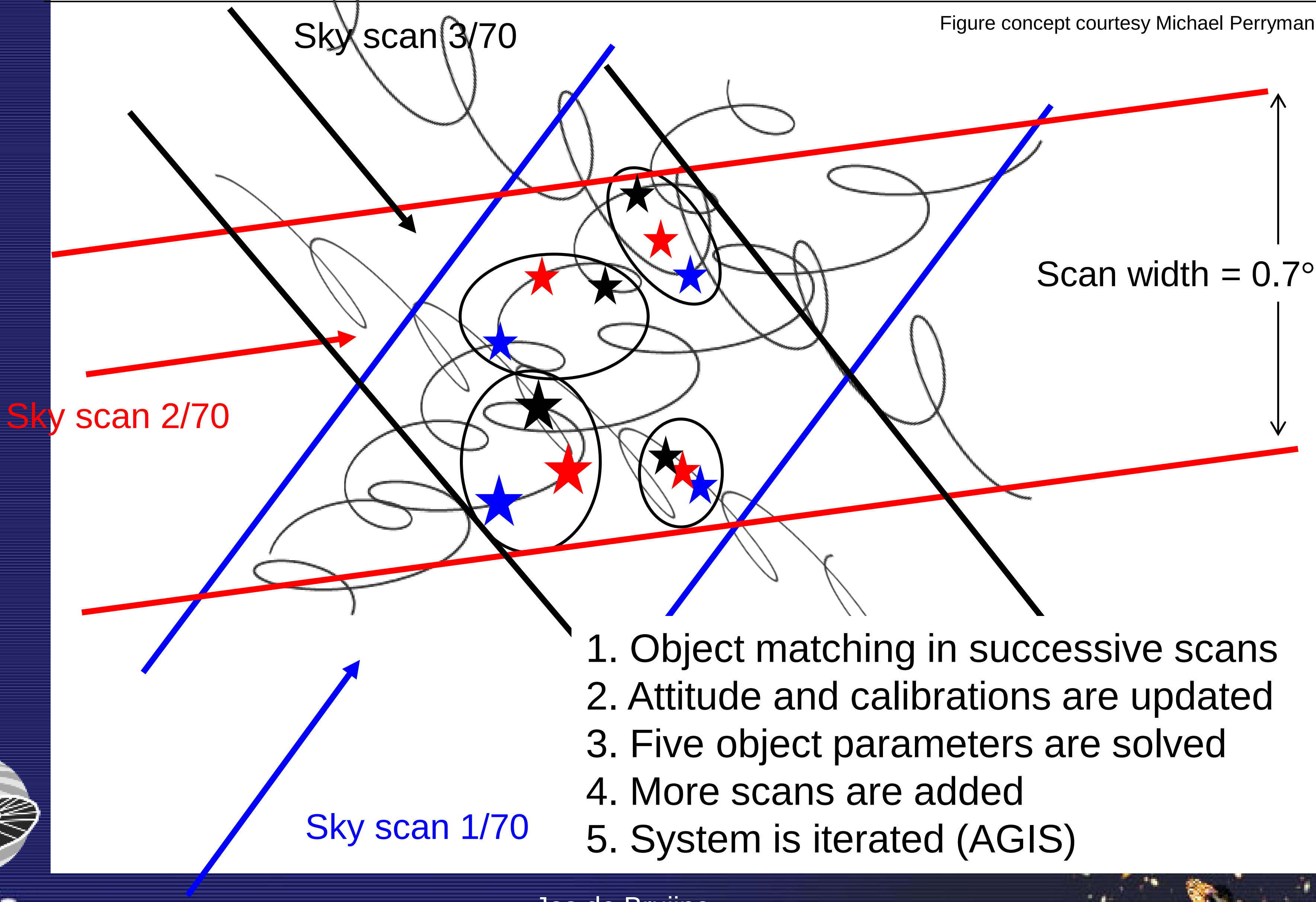
Gaia astrometry in one viewgraph

Figure courtesy Lennart Lindegren



Monitor this path for 10^9 stars during 5 years and fit, for each star, a five-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)

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

g_π = geometrical parallax factor

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*

- All estimates are for “perfect stars” (single, non-variable, non-crowded region, no background peculiarities, …)
- Residual “scientific calibration errors” (e.g., mismatch of the model PSF, sky-background-estimation errors, etc.) are covered by a 20% science margin (m = 1.2) which has been added to all calculations

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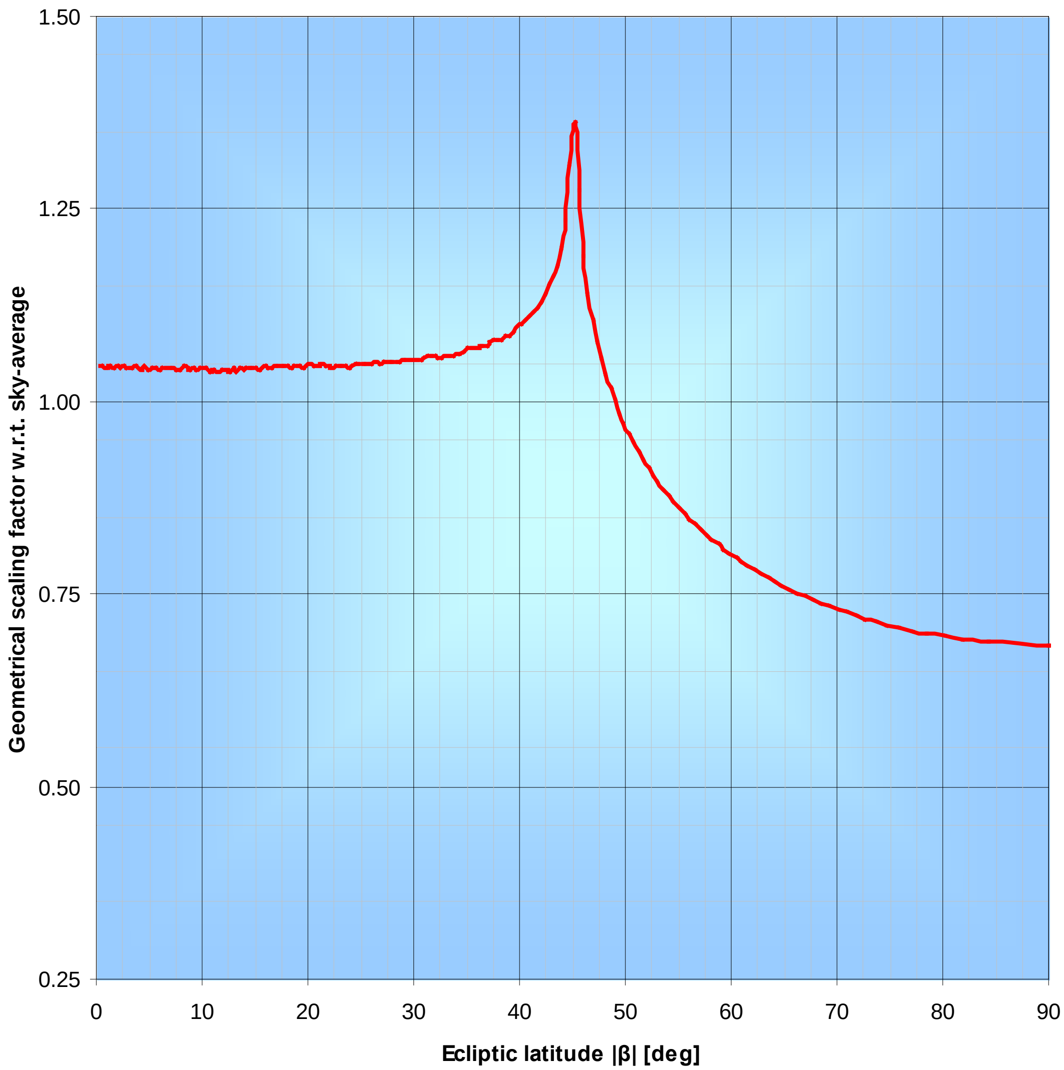
Geometric parallax factor g_π



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)

Dedicated scanning-law simulations yield $g_\pi = 1.47 / \sin \xi = 2.08$ for the sky-average factor

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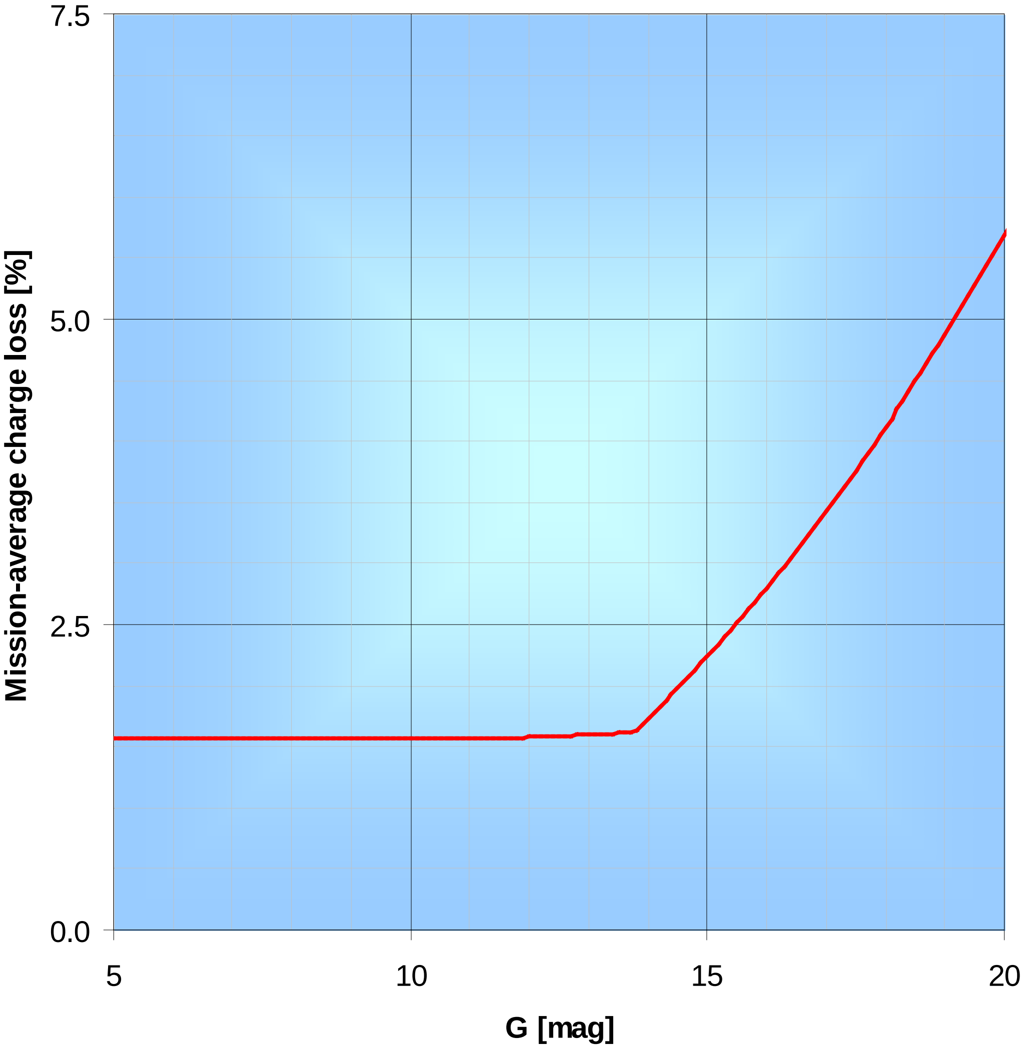
Single-CCD centroiding error σ_ξ



Based on Monte Carlo simulations, including 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, …

Intermezzo: bias calibration

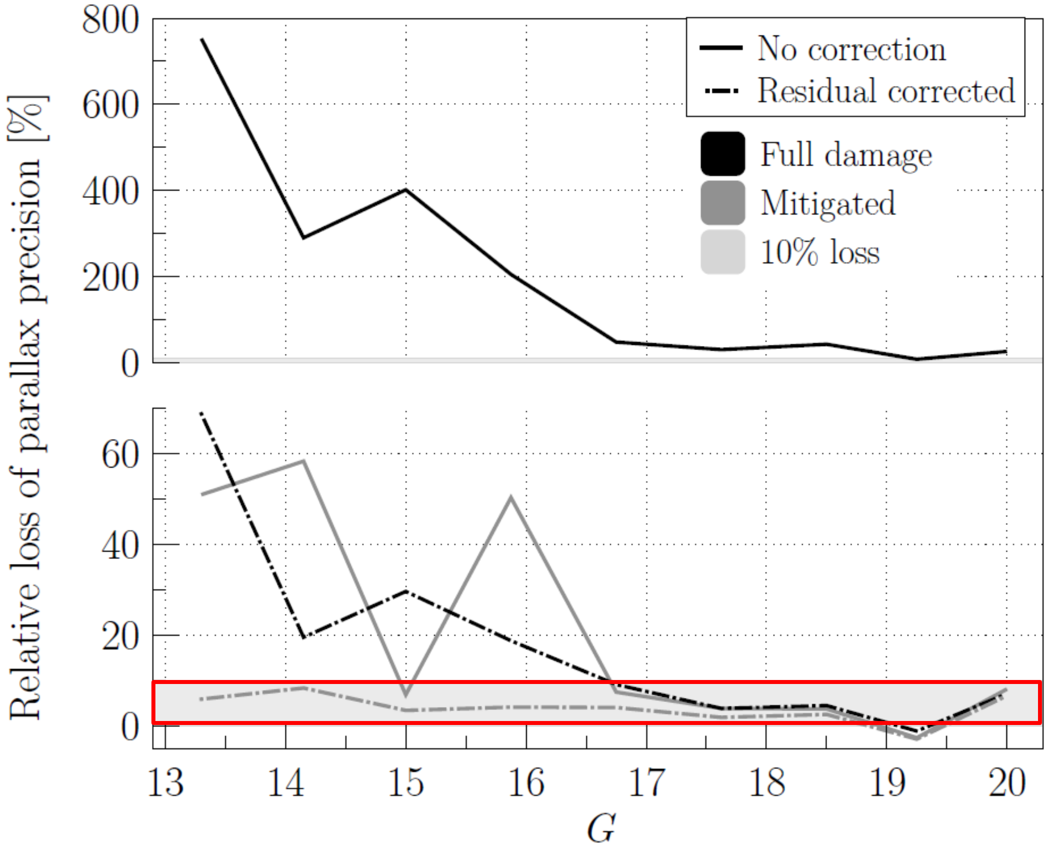


Figure from Prod'homme et al. (2012, MNRAS, submitted); see also 2011PhDT.........9P

Bias calibration was extensively studied by Thibaut Prod'homme and Berry Holl (2012, MNRAS, submitted)

Iterative on-ground software mitigation with a Charge Distortion Model ("CDM in IDU") removes the bias, degrading the end-of-mission parallax errors by less than 10%: effect is covered by the *m* = 20% scientific margin

Astrometry in one equation

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Residual calibration error σ_{cal}

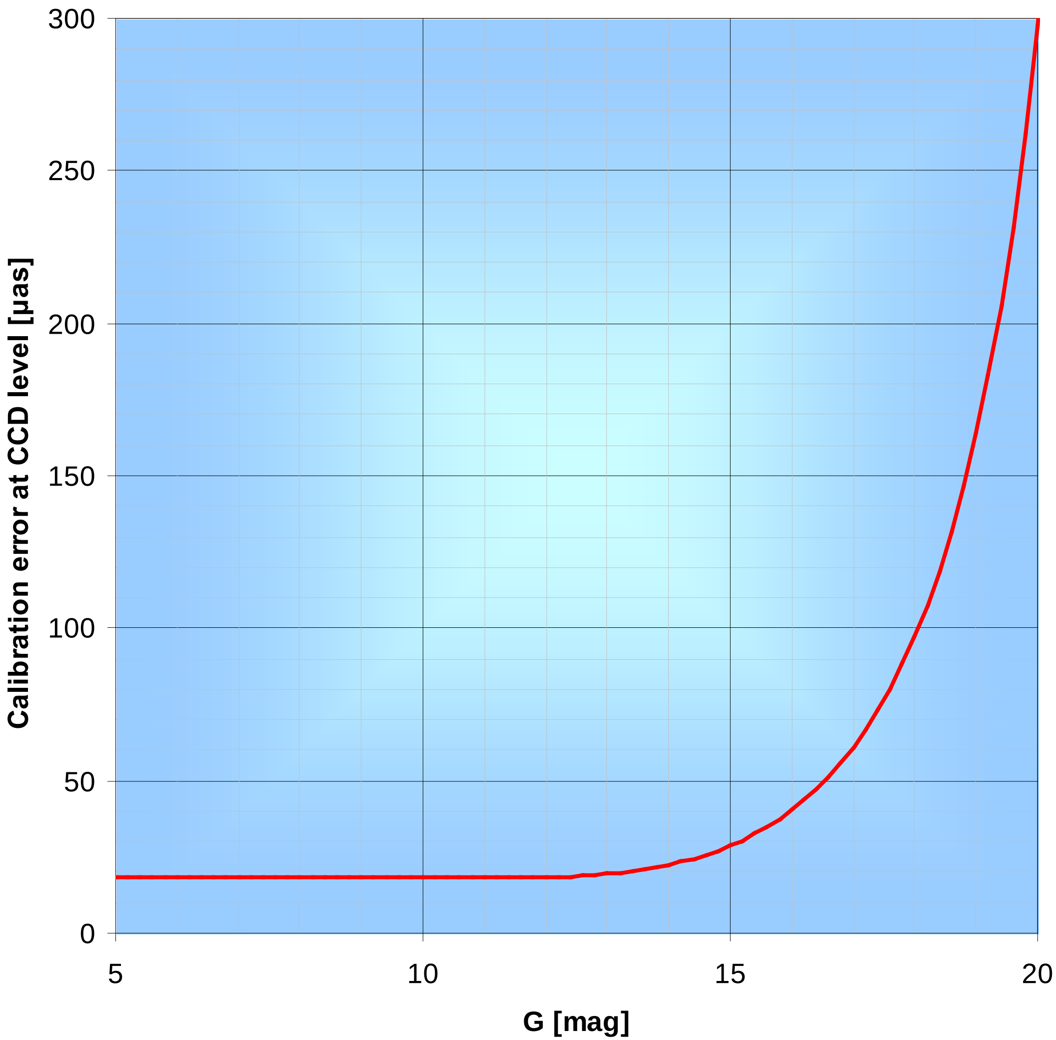

Figure based on data from GAIA.ASF.RP.SAT.00005 (Science performance budget report)

Residual errors include chromaticity calibration, geometrical transformat-ion from focal plane to field coordinates, satellite attitude model, thermo-mechanical stability of the telescope and focal plane, metrology errors associated with basic-angle monitoring, etc.

Value is small compared to random errors and relevant only for bright-star noise floor

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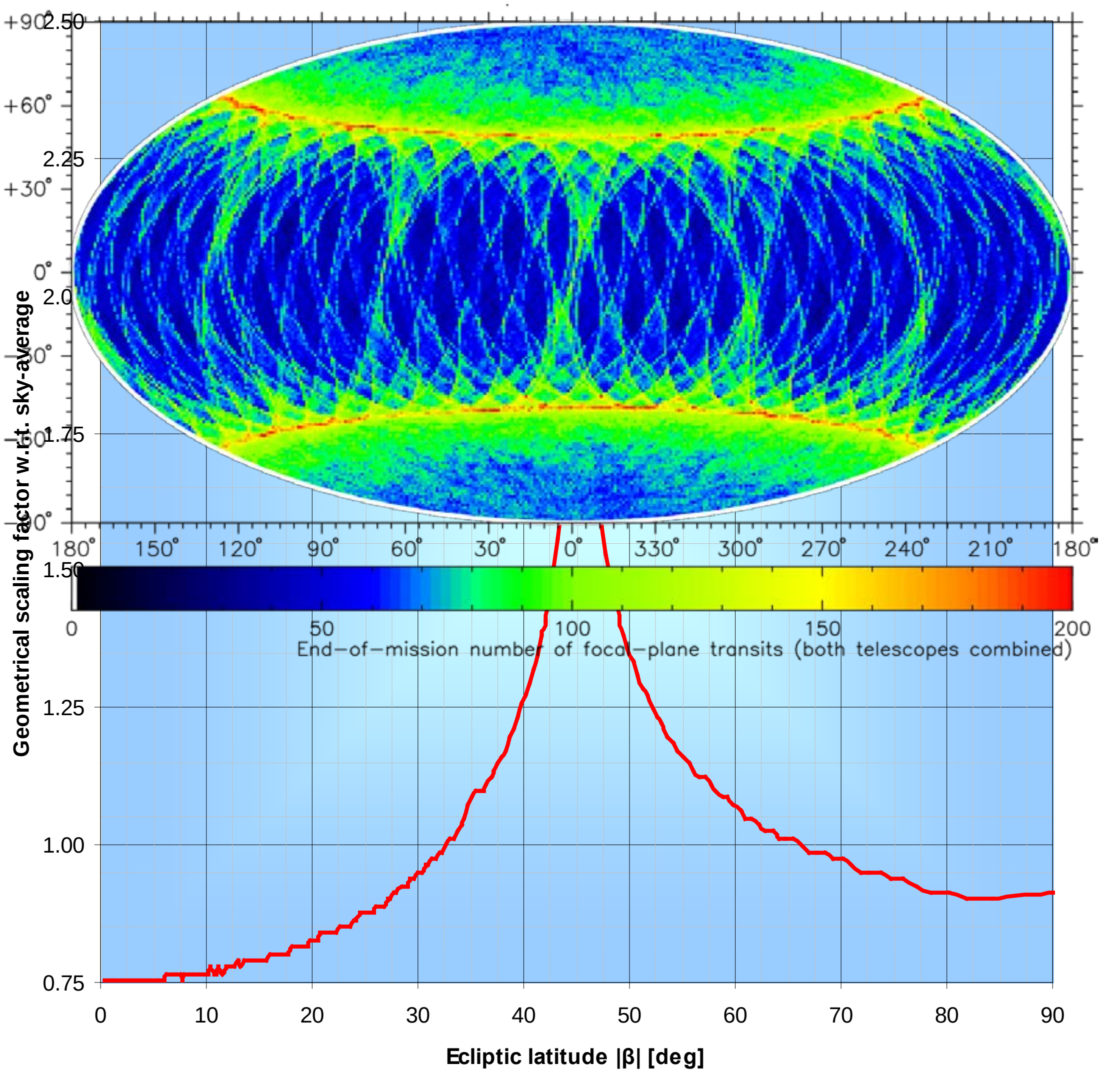
Number of CCD transits N_{eff} (1/3)



1: Number of focal-plane transits

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

The sky-average number of transits is 86.2 (with 0% dead time) and varies strongly as function of ecliptic latitude

Figures from http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance – Ecliptic coordinates

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

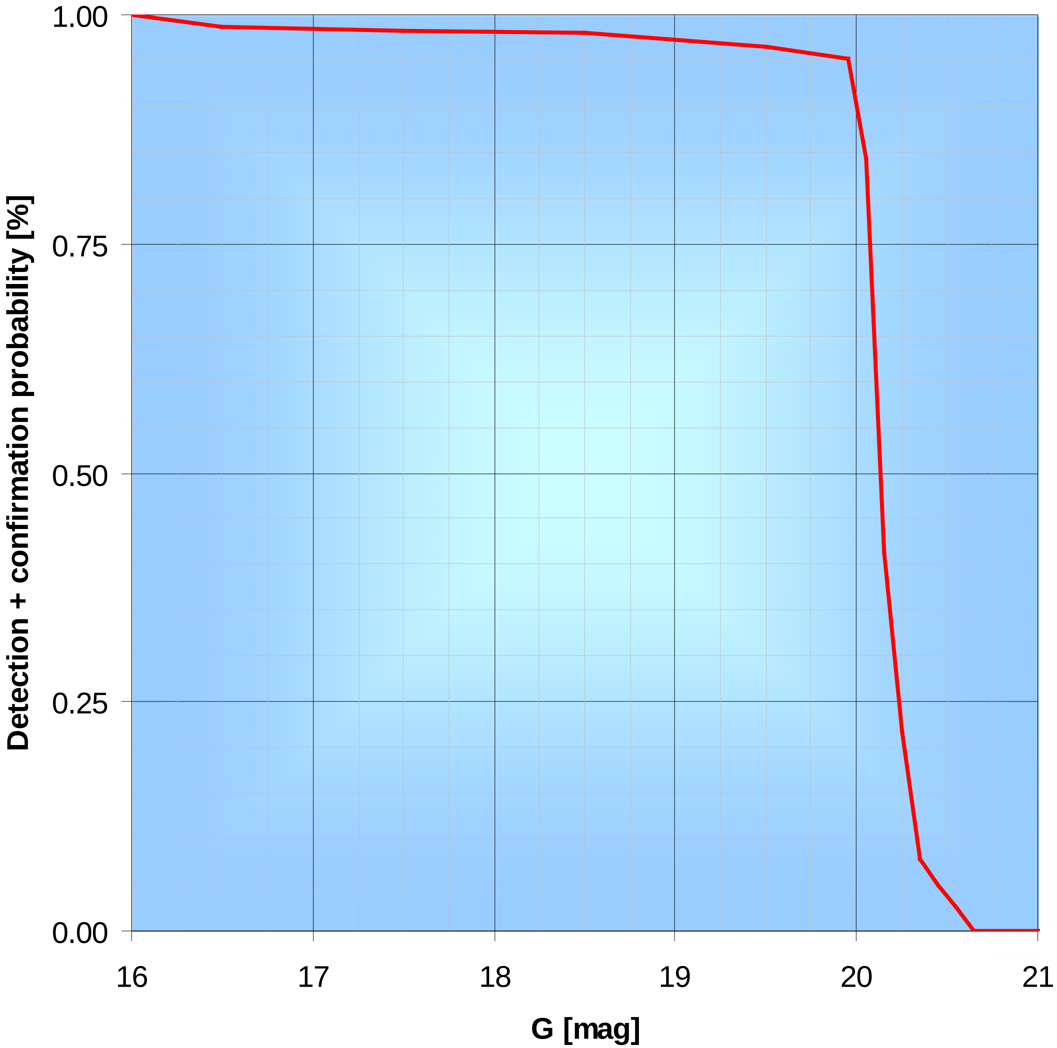


Figure based on data from GAIA.ASF.BG.PLM.00015 (VPU software validation report)

2: 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

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

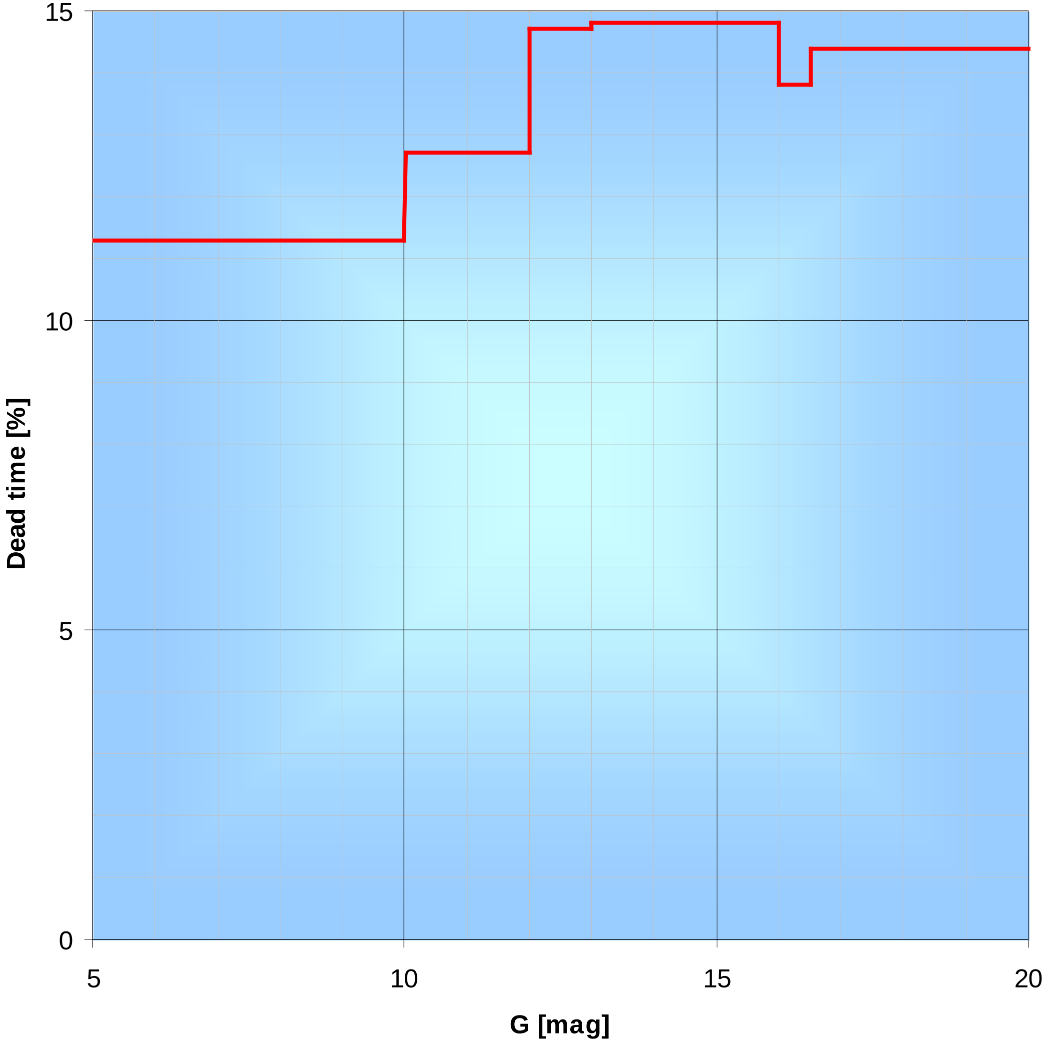


Figure based on data from GAIA.ASF.TCN.SAT.00133 (Dead-time report)

3: Dead time

Numerous effects are accounted for, for instance 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, etc.

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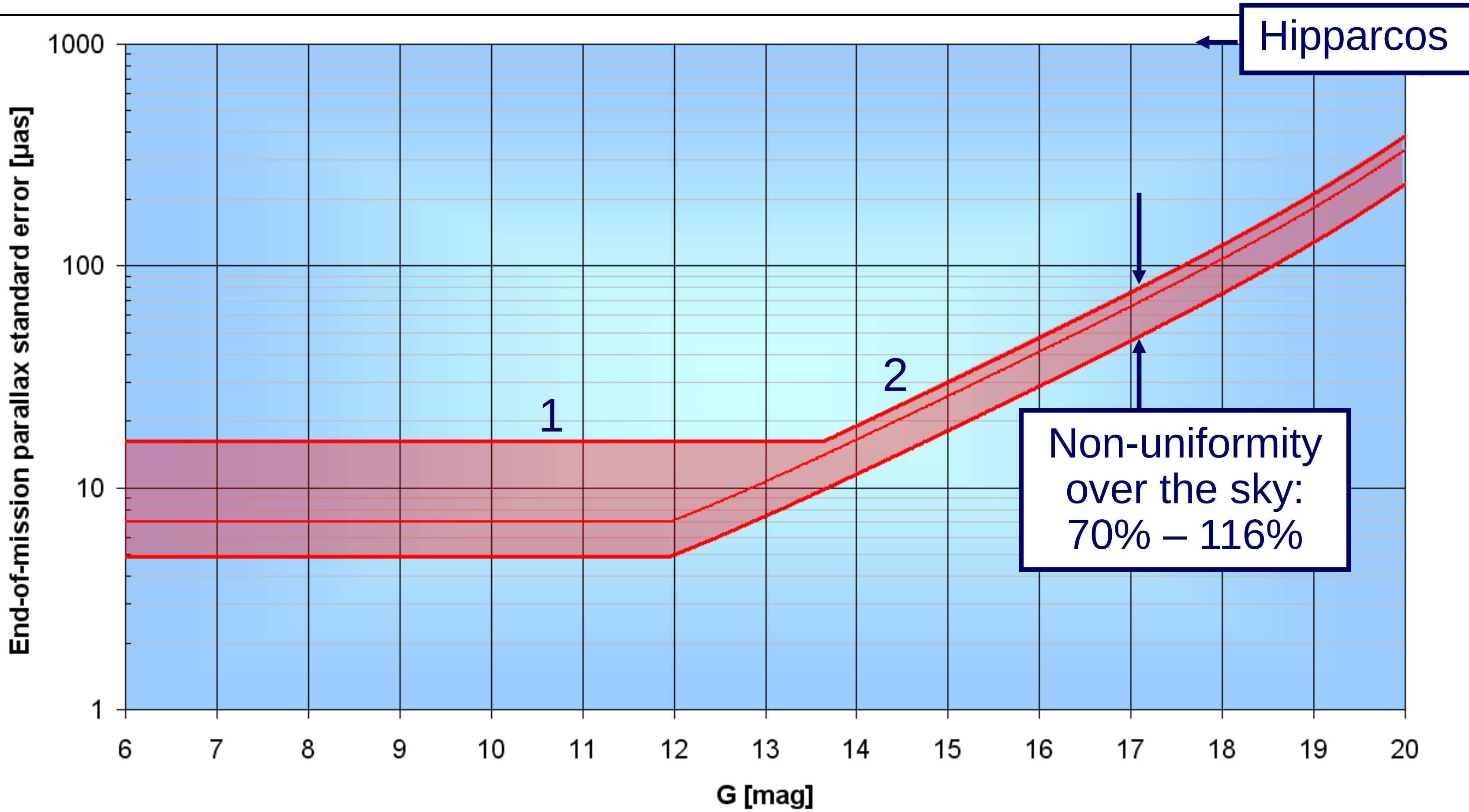
End-of-mission parallax errors



1. 6 < G < 12: bright-star regime (calibration errors, CCD saturation)
2. 12 < G < 20: photon-noise regime, with sky-background noise and electronic noise setting in around G ~ 20 mag

Figure from http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance

End-of-mission astrometry

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:

$$\sigma_\pi\ [\mu as] = \sqrt{(9.3 + 658.1 \cdot z + 4.568 \cdot z^2)}\ [0.986 + (1 - 0.986)\ (V\text{-}I)]$$

$$z = MAX[10^{0.4\ (12 - 15)}, 10^{0.4\ (G - 15)}]$$

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

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

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

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

Equations and variations over the sky available on http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance

I am sorry …

… that I had no time to discuss important "subtleties" like

Crowding and Gaia's dense-area strategy (modified scanning law)

Double and multiple stars

Extended objects (external galaxies, asteroids, comets, …)

Gaia's bright limit

Gaia's bright-star strategy (TDI gates)

BP/RP photometric science performance

RVS spectroscopic science performance

Background information

Gaia science performance pages
http://www.rssd.esa.int/Gaia
(click “Science performance” or simply Google for “Gaia science performance”)

Gaia-performance preprint
2012arXiv1201.3238D
(de Bruijne, Astrophysics and Space Science, in press)

ESA / EADS-Astrium / DPAC reports (Livelink)
GAIA-EST-TN-00539 (= JDB-022)
GAIA-CA-TN-ESA-JDB-053
GAIA-CA-TN-ESA-JDB-055
GAIA.ASF.RP.SAT.00005
GAIA.ASF.TCN.SAT.00133