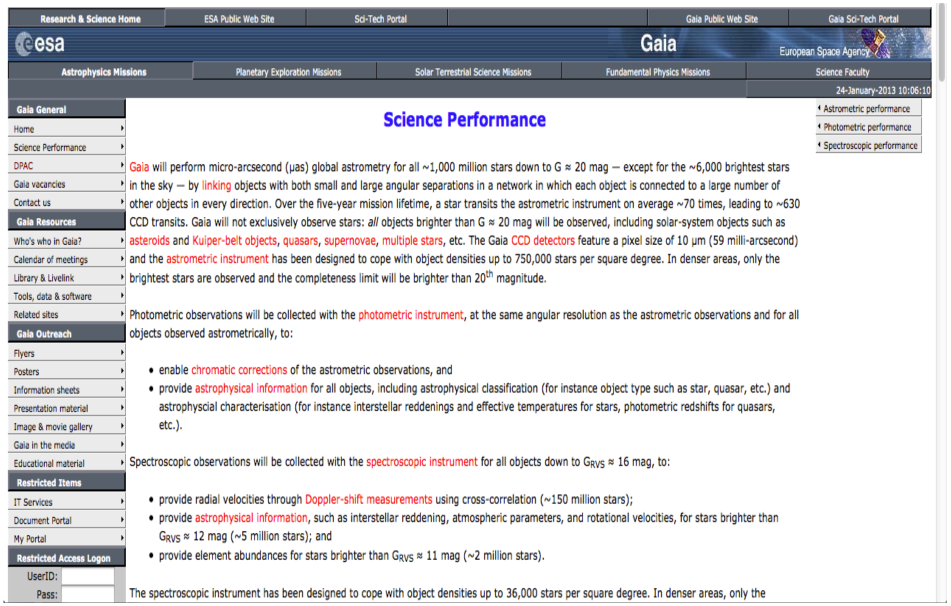
Los modelos de precisión en los datos astrométricos y RVS

M. Romero-Gómez

Gaia errors

Gaia Science Performance website

End-of-mission model errors



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Astrometric performance | Photometric performance | Spectroscopic performance

Science Performance

Gaia will perform micro-arcsecond (μas) global astrometry for all ~1,000 million stars down to G ≈ 20 mag – except for the ~6,000 brightest stars in the sky – by linking objects with both small and large angular separations in a network in which each object is connected to a large number of other objects in every direction. Over the five-year mission lifetime, a star transits the astrometric instrument on average ~70 times, leading to ~630 CCD transits. Gaia will not exclusively observe stars: *all* objects brighter than G ≈ 20 mag will be observed, including solar-system objects such as asteroids and Kuiper-belt objects, quasars, supernovae, multiple stars, etc. The Gaia CCD detectors feature a pixel size of 10 μm (59 milli-arcsecond) and the astrometric instrument has been designed to cope with object densities up to 750,000 stars per square degree. In denser areas, only the brightest stars are observed and the completeness limit will be brighter than 20th magnitude.

Photometric observations will be collected with the photometric instrument, at the same angular resolution as the astrometric observations and for all objects observed astrometrically, to:

- enable chromatic corrections of the astrometric observations, and
- provide astrophysical information for all objects, including astrophysical classification (for instance object type such as star, quasar, etc.) and astrophyscial characterisation (for instance interstellar reddenings and effective temperatures for stars, photometric redshifts for quasars, etc.).

Spectroscopic observations will be collected with the spectroscopic instrument for all objects down to G_{RVS} ≈ 16 mag, to:

- provide radial velocities through Doppler-shift measurements using cross-correlation (~150 million stars);
- provide astrophysical information, such as interstellar reddening, atmospheric parameters, and rotational velocities, for stars brighter than G_{RVS} ≈ 12 mag (~5 million stars); and
- provide element abundances for stars brighter than G_{RVS} ≈ 11 mag (~2 million stars).

The spectroscopic instrument has been designed to cope with object densities up to 36,000 stars per square degree. In denser areas, only the

Implemented in Fortran (twiki REG) (J.M. Carrasco & M. Romero-Gomez)

Implemented in GOG

Epoch and end-of-mission errors

Gaia DPAC

In the Virtual Machine

Astrometric errors

Gaia Science Performance

Astrometric standard errors

Gaia Science Performance website

The mean end-of-mission standard error for parallax includes:

- all known instrumental effects
- an appropriate calibration error
- 20 % margin (results from the on-ground data processing are not included)

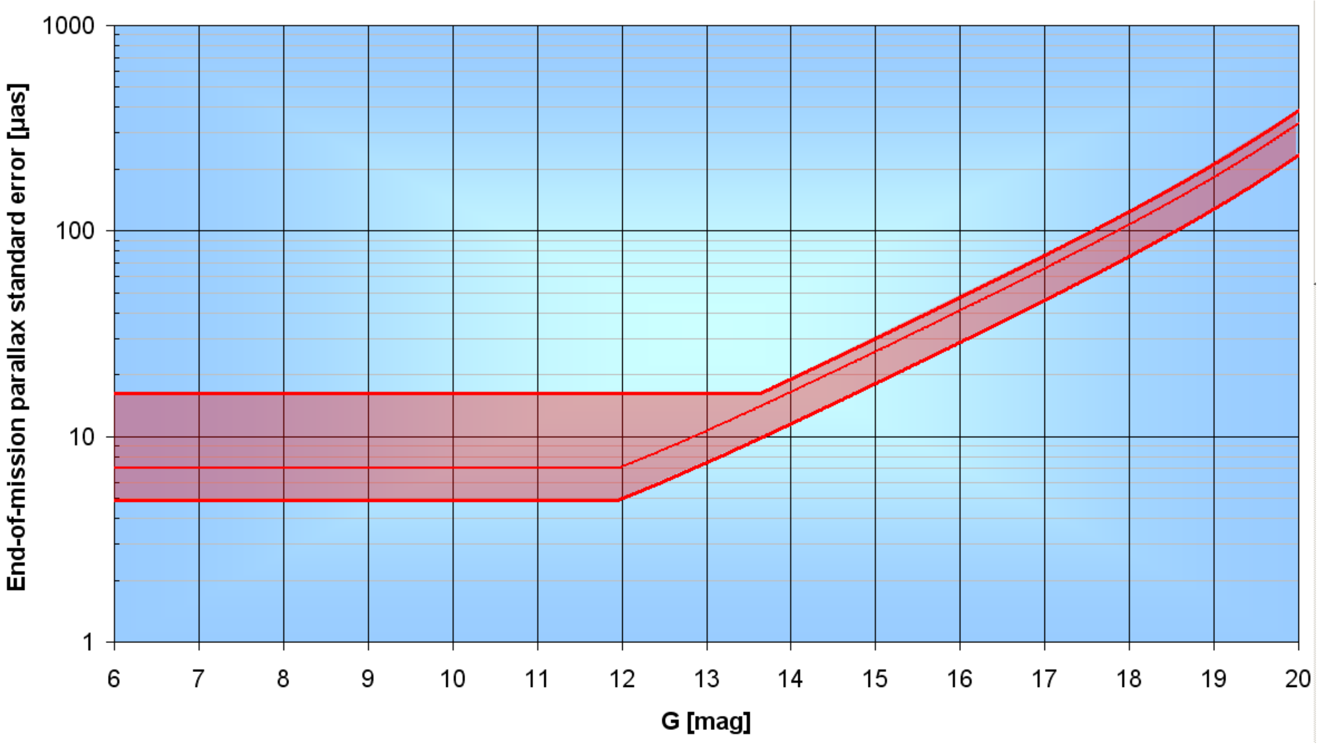
$$\sigma_\pi \, [\mu as] = (9.3 + 658.1 \cdot z + 4.568 \cdot z^2)^{1/2} \cdot [0.986 + (1 - 0.986) \cdot (V-I_C)],$$

where

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

It depends sensitively on the adopted TDI-gate scheme (G < 12 mag)
(The decrease of the CCD exposure time to avoid saturation of the pixels)

End-of-mission parallax standard error



For bright stars (G<12 mag) the standard error is dominated by calibration errors, not by the photon noise

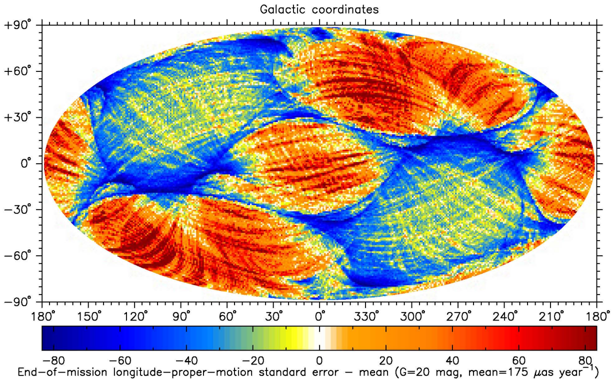
Astrometric End-of-mission errors

Gaia Science Performance website

The end-of-mission performance depends on the scanning law. A more accurate standard error can be computed by:

1) Multiplying the mean value by a geometrical scaling factor (g), different for each of the five parameters (see figure and table)
2) Taking into account the individual number of transits the star will have by multiplying the mean value by $\sqrt{\bar{N}/N_{transit}}$

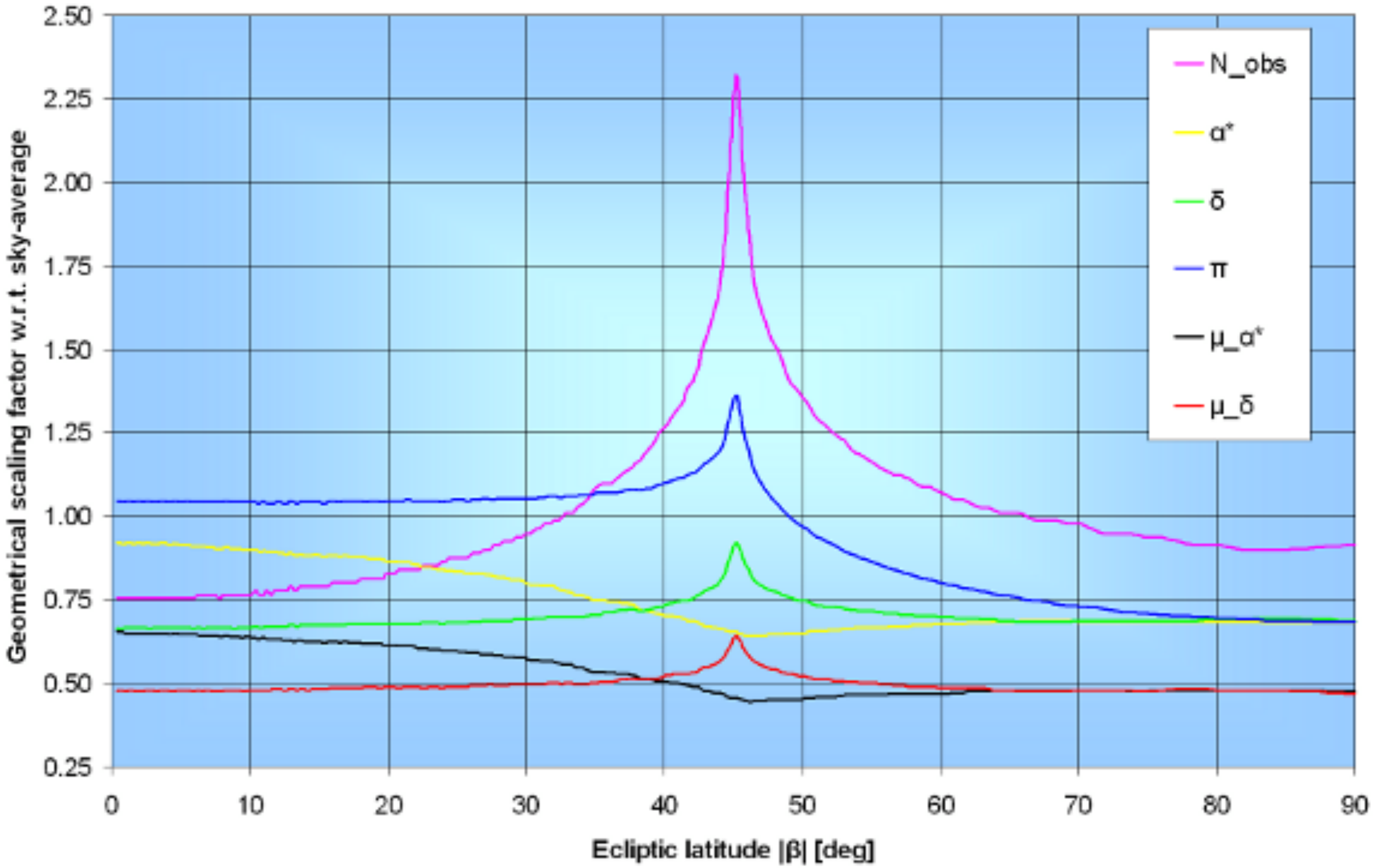
Both corrections depend on the mean ecliptic latitude β (ecliptic-longitude-averaged)



Geometrical scaling factor:

Each particular transit does not carry the same astrometric weight. The weight depends on the angle between the along-scan direction (where we make the measurement) and the circle from the star to the sun (the parallax shift is directed along this circle). Therefore, a large number of transits does not guarantee a small parallax error (Jos de Bruijne)

Geometric factor (g) to be applied to the sky-averaged astrometric errors for the five astrometric parameters as function of ecliptic latitude β.



Geometric factor (g) to be applied to the sky-averaged astrometric errors for the five astrometric parameters as function of ecliptic latitude β.

$\|\sin(\beta)\|$	β_{min} [°]	β_{max} [°]	N_{obs}	α^*	δ	π	μ_{α^*}	μ_δ
0.025	0.0	2.9	61	0.920	0.666	1.045	0.651	0.478
0.075	2.9	5.7	61	0.916	0.667	1.044	0.648	0.478
0.125	5.7	8.6	62	0.907	0.667	1.043	0.642	0.478
0.175	8.6	11.5	62	0.898	0.668	1.041	0.636	0.479
0.225	11.5	14.5	63	0.887	0.672	1.042	0.628	0.482
0.275	14.5	17.5	65	0.881	0.675	1.044	0.624	0.485
0.325	17.5	20.5	66	0.871	0.678	1.046	0.618	0.488
0.375	20.5	23.6	68	0.853	0.679	1.046	0.607	0.489
0.425	23.6	26.7	71	0.833	0.682	1.048	0.594	0.490
0.475	26.7	30.0	75	0.814	0.689	1.053	0.581	0.495
0.525	30.0	33.4	80	0.786	0.697	1.058	0.563	0.498
0.575	33.4	36.9	87	0.751	0.708	1.067	0.536	0.502
0.625	36.9	40.5	98	0.717	0.725	1.088	0.513	0.515
0.675	40.5	44.4	122	0.679	0.774	1.154	0.484	0.545
0.725	44.4	48.6	144	0.646	0.822	1.156	0.451	0.573
0.775	48.6	53.1	106	0.656	0.738	0.943	0.457	0.515
0.825	53.1	58.2	93	0.668	0.711	0.852	0.467	0.496
0.875	58.2	64.2	85	0.679	0.695	0.789	0.473	0.486
0.925	64.2	71.8	80	0.686	0.686	0.741	0.479	0.478
0.975	71.8	90.0	75	0.684	0.690	0.700	0.479	0.479
Mean	**0.0**	**90.0**	**81**	**0.787**	**0.699**	**1.000**	**0.556**	**0.496**

Astrometric errors

GOG

GOG: astrometric Epoch Data

For each transit GOG provides:

-Local plane coordinates (ω, z)

-Observing time (t), that is mean time per transit

-Angle from local plane coordinates to equatorial coordinates (θ)

-Precision in the local plane coordinates (σ_ω, σ_z)

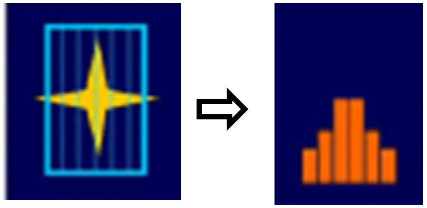
$$\sigma_w = \frac{\sigma_\eta}{\sqrt{n}}$$

$$\sigma_z = p_r \frac{\sigma_\eta}{\sqrt{n}}$$

n : along scan AF number of CCDs

p_r : relation between AC and AL pixel size (=3)

σ_η: line spread function centroiding error



GOG: astrometric epoch data

Parameters that can be derived from epoch data:

Local plane parallax factors
(ω, z) and the satellite ephemerides

Equatorial parallax factors
(ω, z), the satellite ephemerides and θ

Epoch (α,δ) equatorial coordinates
(ω, z), attitude of the satellite and ephemerids
(if barycentre equatorial coordinates are required)

GOG: astrometric epoch data

Example of GOG products:
Orbital motion for a binary system from GOG epoch data astrometry

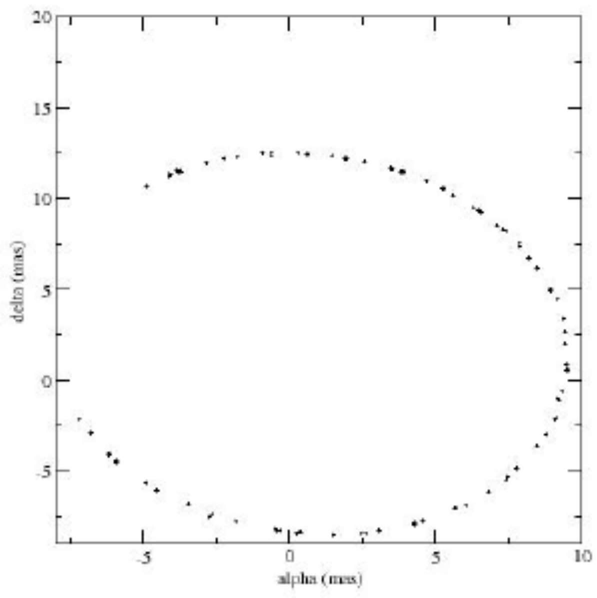


FIGURE 3: Astrometric binary orbit obtained from GOG results.

GOG: astrometric end-of-mission

Parallax accuracy σ_π:

$$\sigma_\pi = m \cdot g_\pi \cdot \sqrt{\frac{\sigma_\eta^2}{N_{eff}} + \frac{\sigma_{cal}^2}{N_{transit}}}$$

σ_η : line spread function centroiding error

σ_{cal} : calibration error, a configurable parameter in GOG (5.7 μas by default)

g_π : parallax geometrical factor, g_π=1.47/sinξ, where ξ is the solar aspect angle (ξ=45° GPDB)

N_{eff} : number of elementary CCD transits (N_{strip} x $N_{transit}$) according to the Gaia scanning law

m : the contingency margin (configurable parameter in GOG)

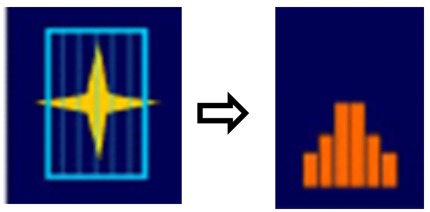
GOG: astrometric end-of-mission

Computation of the line spread function centroiding error:

- The counts per each sample in an standard window (S_i) are computed both from the G magnitude of the star and the LSF. This LSF is computed considering the Teff, logg and [Fe/H] of the star. GOG derives the B-Spline coefficients that describe the LSF using its internal spectral library.
- The Cramér-Rao minimum variance bound (MVB) method is used (it is a simplified implementation of the one used by Astrium). See Bastian et al. (2004)

In practice, one records a set of n discrete samples of the image spot of the star, each of them being the result of the addition of m pixels in the AC direction: $\{ S_k = N * L(k.\Delta\eta - \eta_0) \}_{k=1,n}$ from which one estimates the first derivatives at each point $\{ S'_k = N * L'(k.\Delta\eta - \eta_0) \}_{k=1,n}$. The discrete form of the previous formula (equation 3) can be written as per equation (4) to highlight the main contributors to the final performance:

Equation (3) **Cramér-Rao bound** **(discrete form)**	$$\sigma_\eta = \left[\sum_{k=1}^{n} \frac{(S'_k)^2}{r^2 + b + S_k} \right]^{-1/2}$$
Equation (4)	$$\sigma_\eta = \left[\sum_{k=1}^{n} S_k \cdot \left(\frac{1}{1 + \frac{r^2 + b}{S_k}} \right) \cdot \left(\frac{S'_k}{S_k} \right)^2 \right]^{-1/2}$$



GOG: astrometric end-of-mission

$g_{\alpha} = 0.787 \cdot g_{\pi}$
$g_{\delta} = 0.699 \cdot g_{\pi}$

$g_{\mu\alpha} = 0.556 \cdot g_{\pi}$
$g_{\mu\delta} = 0.496 \cdot g_{\pi}$

$\|\sin(\beta)\|$	β_{min} [°]	β_{max} [°]	N_{obs}	$\alpha*$	δ	π	$\mu_{\alpha*}$	μ_{δ}
0.025	0.0	2.9	61	0.920	0.666	1.045	0.651	0.478
0.075	2.9	5.7	61	0.916	0.667	1.044	0.648	0.478
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0.475	26.7	30.0	75	0.814	0.689	1.053	0.581	0.495
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0.775	48.6	53.1	106	0.656	0.738	0.943	0.457	0.515
0.825	53.1	58.2	93	0.668	0.711	0.852	0.467	0.496
0.875	58.2	64.2	85	0.679	0.695	0.789	0.473	0.486
0.925	64.2	71.8	80	0.686	0.686	0.741	0.479	0.478
0.975	71.8	90.0	75	0.684	0.690	0.700	0.479	0.479
Mean	**0.0**	**90.0**	**81**	**0.787**	**0.699**	**1.000**	**0.556**	**0.496**

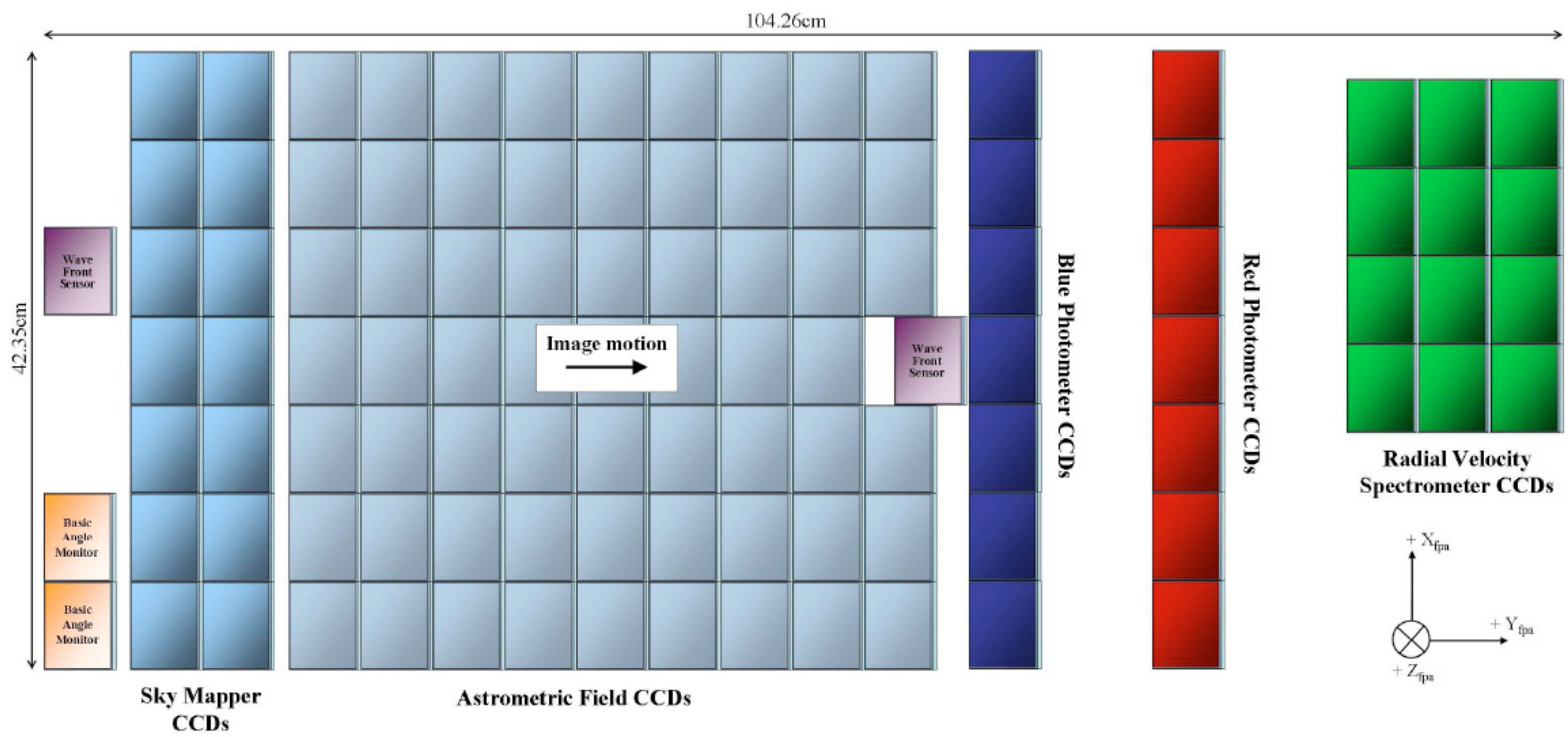
Only mean values for the geometrical factor are being considered (TB improved)

Radial Velocities

Gaia Science Performance

Radial velocities

- a star transits the spectroscopic instrument on average ~40 times, leading to ~120 CCD transits



End-of-mission radial velocity error

Gaia Science Performance website

$$\sigma_{vrad}\,[\mathrm{km\ s^{-1}}] = 1 + b \cdot e^{a \cdot (V - 14)},$$

Errors are magnitude (V= Johnson Visual) and colour dependent (V-I)

	B0V	B5V	A0V	A5V	F0V	G0V	G5V	K0V	K1III-MP	K4V	K1III
$V-I_C$ [mag]	-0.31	-0.08	0.01	0.16	0.38	0.67	0.74	0.87	0.99	1.23	1.04
a	0.90	0.90	1.00	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
b	50.00	26.00	5.50	4.00	1.50	0.70	0.60	0.50	0.39	0.29	0.21

Receipts outlined by JdB-022 (2005)
At the time of the Gaia Mission Critical Design Review (April 2011)

End-of-mission radial velocity error

Gaia Science Performance website

$$\sigma_{vrad}\,[\mathrm{km\ s^{-1}}] = 1 + b \cdot e^{a \cdot (V - 14)},$$

Included:

- -all known instrumental effects
- -residual calibration errors at ground-processing (DPAC) level

Not included:

-the residual "scientific calibration errors“: e.g., template-mismatch errors, residual errors in the derivation of the locations of the centroids of the reference spectral lines used for the wavelength calibration, etc. (result from the on-ground data processing) . They are assumed to be covered by the 20% science margin.

Radial Velocities

GOG

GOG: End-of-mission radial velocity error

From Sartoretti et al. (2007):

- -Monte Carlo simulations
- -A margin (factor 1.6) added to account for calibration errors and other instrumental errors not included previously
- -lower and upper limit fixed to 1 and 35 km/s
- -Errors depending on **Teff FeH logg vsini Vmag**

GOG interpolates looking for the closest combination given priority to Teff and V
All the tables provided up to now have [Fe/H]=0, vsini=0 and Av=0. with 8.5 < V < 17.5

SPType	Teff	[Fe/H]	logg	vsini	V	comments
A0V	9800	0.0	4.0	0.0	8.5-17.5	Useful to
B5V	15200	0.0	4.0	0.0	8.5-17.5	study Teff
B0V	30000	0.0	4.0	0.0	8.5-17.5	variations
K0V	5150	0.0	4.5	0.0	8.5-17.5	Useful
G5V	5500	0.0	4.5	0.0	8.5-17.5	to
G0V	6000	0.0	4.5	0.0	8.5-17.5	study
F0V	7300	0.0	4.5	0.0	8.5-17.5	Teff
A5V	8200	0.0	4.5	0.0	8.5-17.5	variations
K1III	4500	0.0	2.5	0.0	8.5-17.5	logg
K4V	4500	0.0	4.5	0.0	8.5-17.5	variations

GOG: End-of-mission radial velocity error

To take into account [Fe/H] effects, GOG apply (empirical law):

$$V_{eff} = V + \delta_{Fe/H} = V - 0.5/1.5 \cdot [Fe/H]$$

GOG provides errors for:

- -single CCD transit RVS spectra,
- -single transit 3-CCD combined spectra
- -40 transits 3-CCDs combined spectra.

Rotational Velocities (Vsini)

GOG

GOG: End-of-mission rotational velocity error

From Sartoretti et al. (2007) :

- -Monte Carlo simulations
- -Single transits for 6 <V<13.5
- -End-of-mission for 6 < V< 16.5
- -Tabulated as a function of **Teff FeH logg vsini Vmag**

SPtype	Teff	[Fe/H]	logg	vsini	V	comments
B5V	15200	0.0	4.0	50.0	9.0-18.0	Vsini
	15200	0.0	4.0	150.0	9.0-18.5	variations
G5V	5500	0.0	4.0	0.0	13-18.5	
K1III	4500	0.0	2.5	0.0	13.0-19.0	[Fe/H]
	4500	-1.5	2.5	0.0	13.018.0	variations

GOG: End-of-mission rotational velocity error

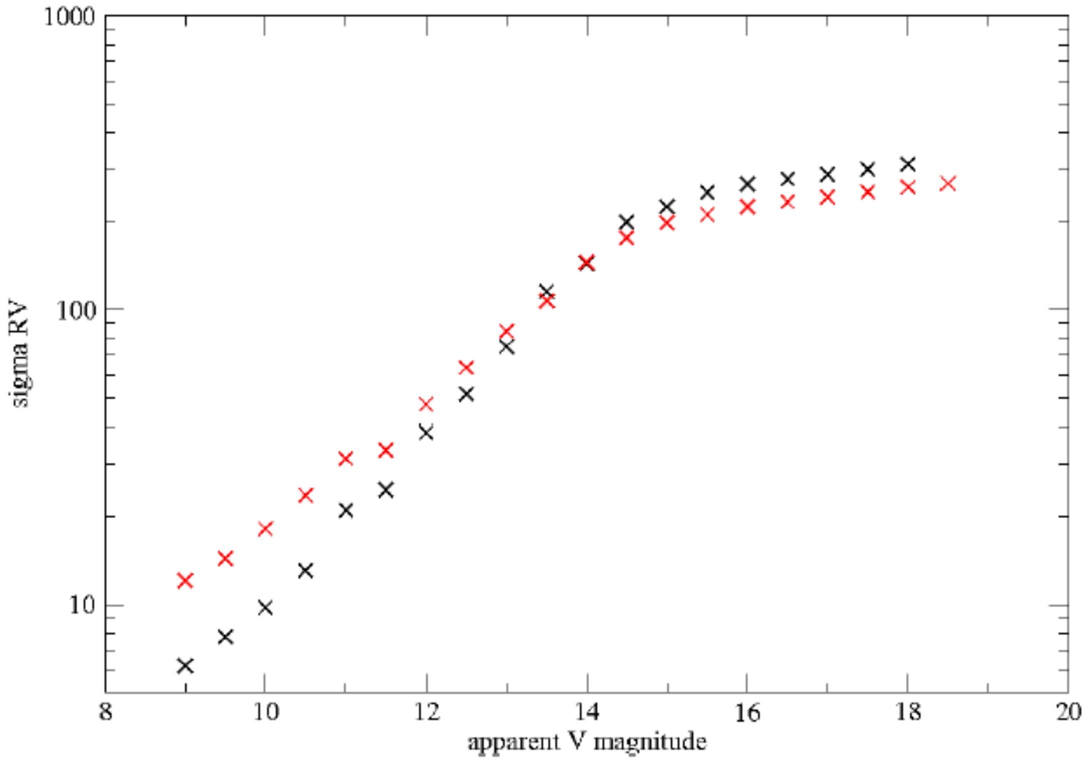


Figure 8: Variation of the precision (one sigma error) in rotacional velocity as a function of apparent magnitude for two stars with Teff=15200K, [Fe/H]=0.0 and logg=4.0 and different rotacional velocity. Vsini=50.0km/s in black, Vsini=150.0km/s in red.