Gaia errors tutorial

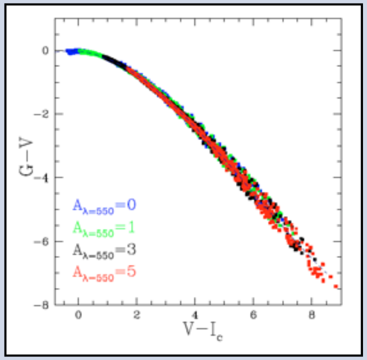
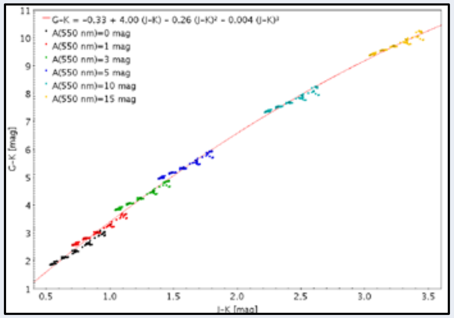
UB team

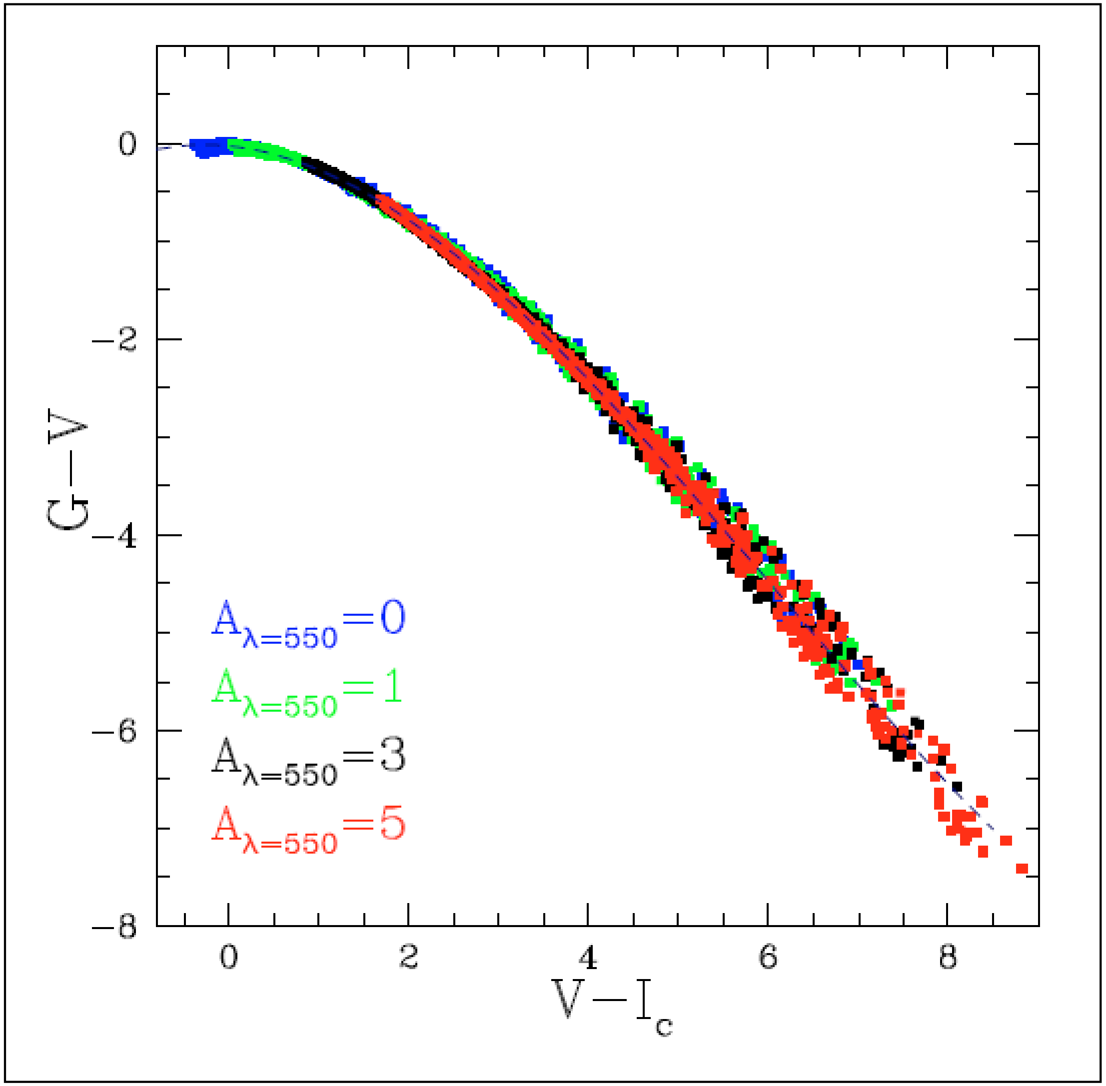
August 31st, Gaia Challenge III

Gaia Errors

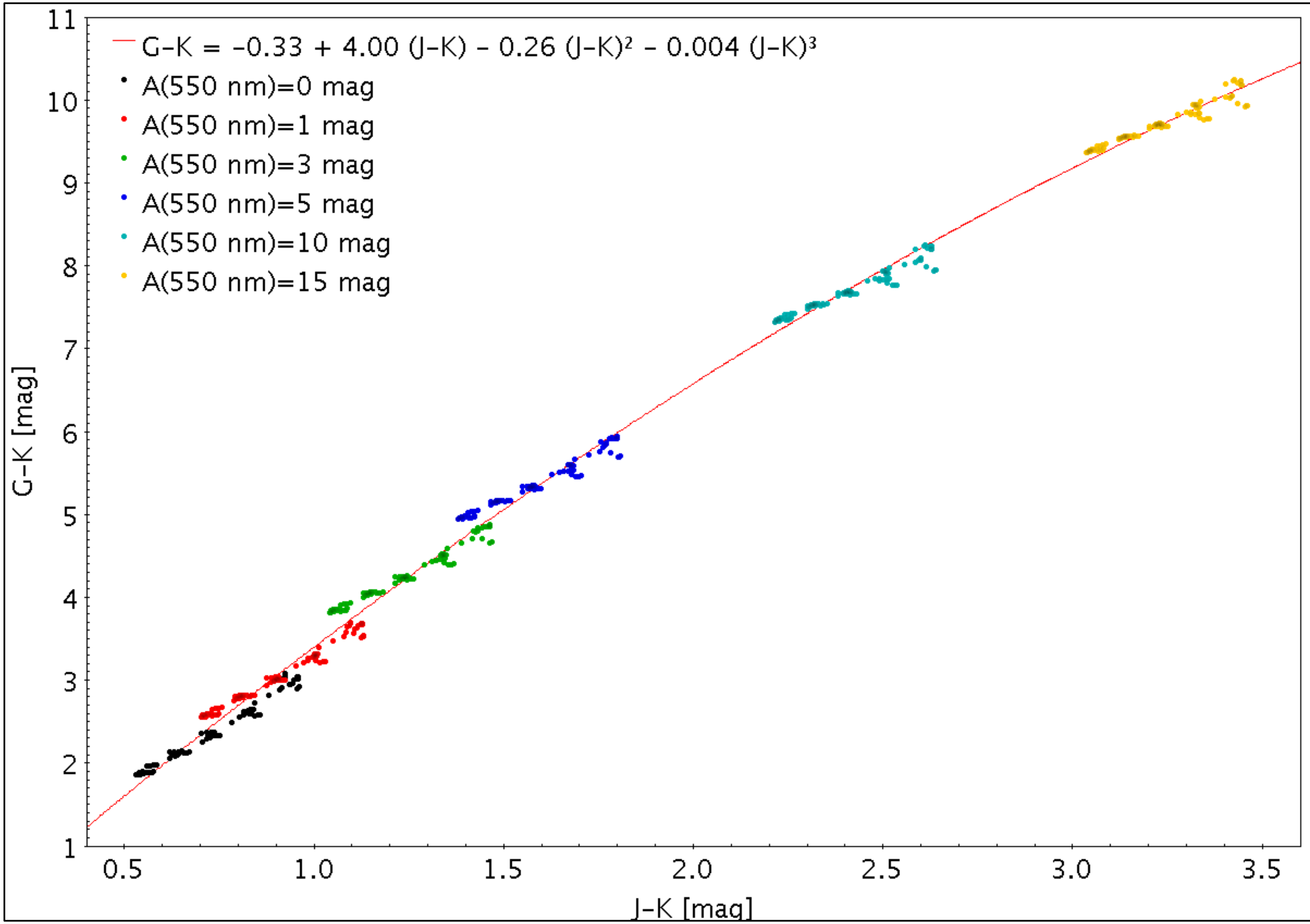
1. **Gaia Error Model (astrometry, photometry, spectroscopy)**
2. **Code to simulate Gaia errors: public in github**
3. Simulating Gaia data: GOG (Gaia Object Generation)
4. Gaia intermediate releases and TGAS solution:
    - Errors expected
    - Simulated catalogue (BGM)
5. Tutorial example:
    - Young Local Association (YLA)

From input parameters to Gaia errors

Input parameters	Extinction map	Observable values	Gaia magnitudes	Errors
Mv $(V\text{-}I)_o$ (r,l,b)	Av(r,l,b) Extinction law: Ai	V V-I	Jordi et al (2010)  	σ_π=f(G,V-I) σ_α, σ_δ, μ_α, μ_δ=f(σ_π) σ_G=f(G) σ_{BP}=f(G,V-I) σ_{RP}=f(G,V-I) σ_{Vr}=f(V,V-I)
Mk $(J\text{-}K)_o$ (r,l,b)	Av(r,l,b) Extinction law: Aj, Ak	K (J-K)	Carrasco et al (2014)  	A relation between (J-K) -> (V-I) needed σ_π=f(G,V-I) σ_α, σ_δ, μ_α, μ_δ=f(σ_π) σ_G=f(G) σ_{BP}=f(G,V-I) σ_{RP}=f(G,V-I) σ_{Vr}=f(V,V-I)



0
−2
−4
−6
−8
0
2
4
6
8
G−V
V−I_c
A_{λ=550}=0
A_{λ=550}=1
A_{λ=550}=3
A_{λ=550}=5



G-K = -0.33 + 4.00 (J-K) - 0.26 (J-K)² - 0.004 (J-K)³
A(550 nm)=0 mag
A(550 nm)=1 mag
A(550 nm)=3 mag
A(550 nm)=5 mag
A(550 nm)=10 mag
A(550 nm)=15 mag
G-K [mag]
J-K [mag]
1
2
3
4
5
6
7
8
9
10
11
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Astrometry

Astrometric standard errors

Gaia Science Performance website (Des 2014)

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

- all known instrumental effects, including the straylight levels as measured during the commissioning phase
- an appropriate calibration error
- 20 % margin (results from the on-ground data processing are not included)

$$\sigma_\pi \,[\mu as] = (-1.631 + 680.766 \cdot z + 32.732 \cdot z^2)^{1/2} \cdot [0.986 + (1 - 0.986) \cdot (V\text{-}I_C)],$$

where

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

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)

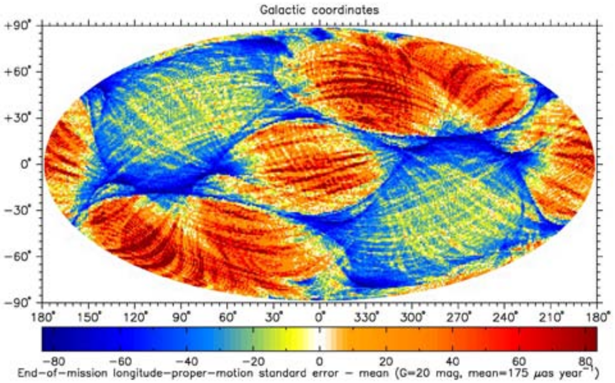
Astrometric End-of-mission errors

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)

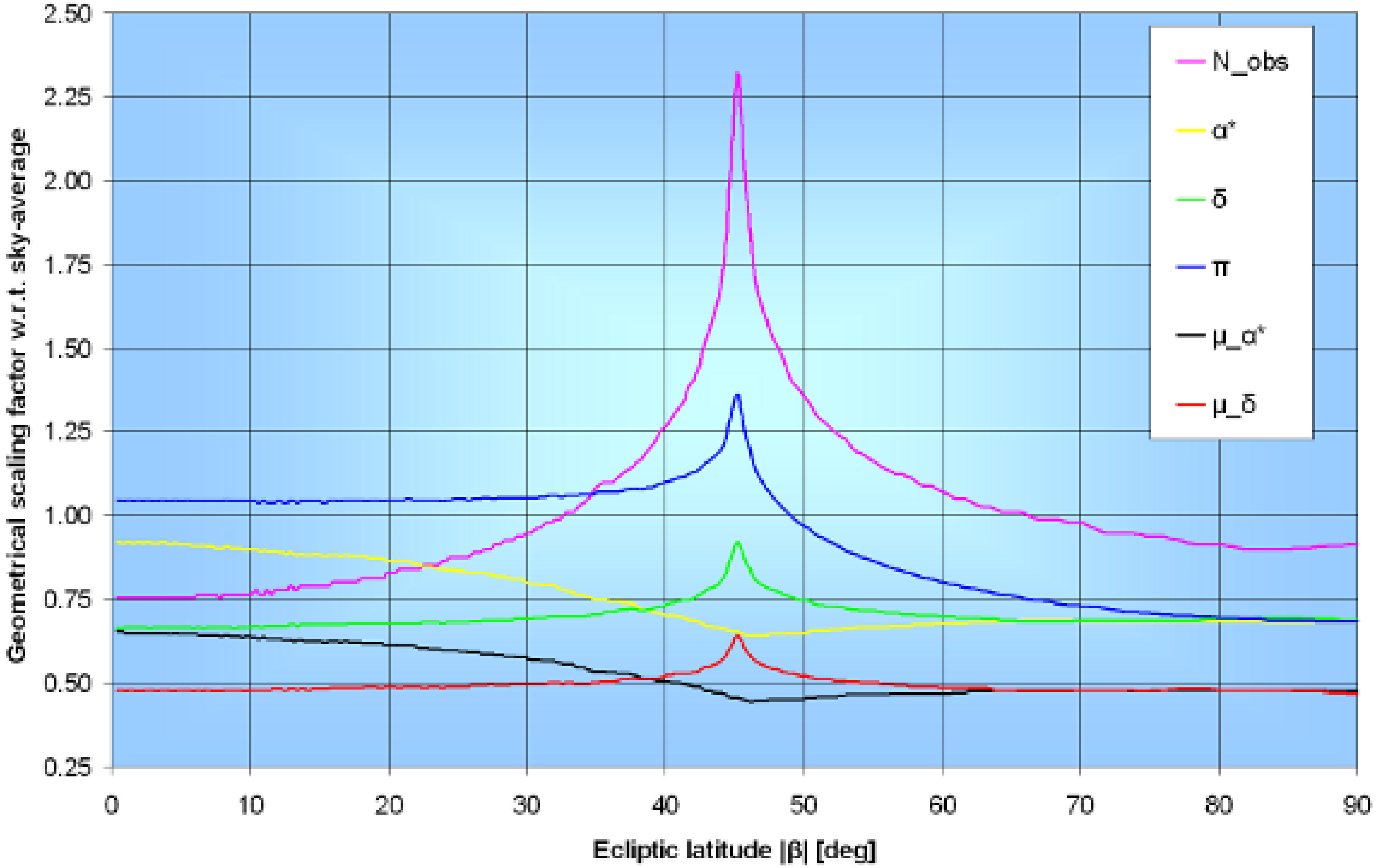


Geometrical scaling factor:

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)

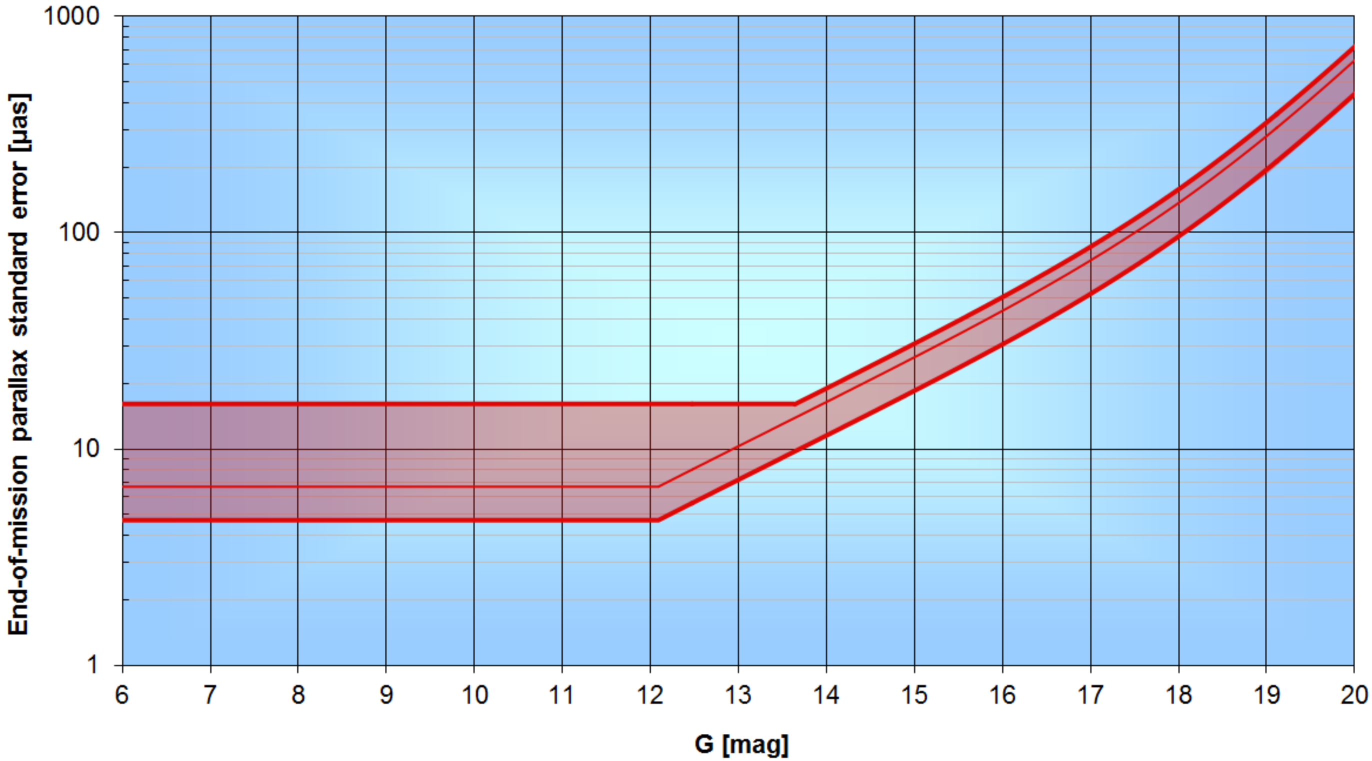
Geometric factor (g) to be applied to the sky-averaged astrometric errors for the five astrometric parameters as function of ecliptic latitude β.

Astrometric errors = geometrical factor * σ_π



These values are given in a Table (gfactor-Jun2013.dat).

End-of-mission parallax standard error



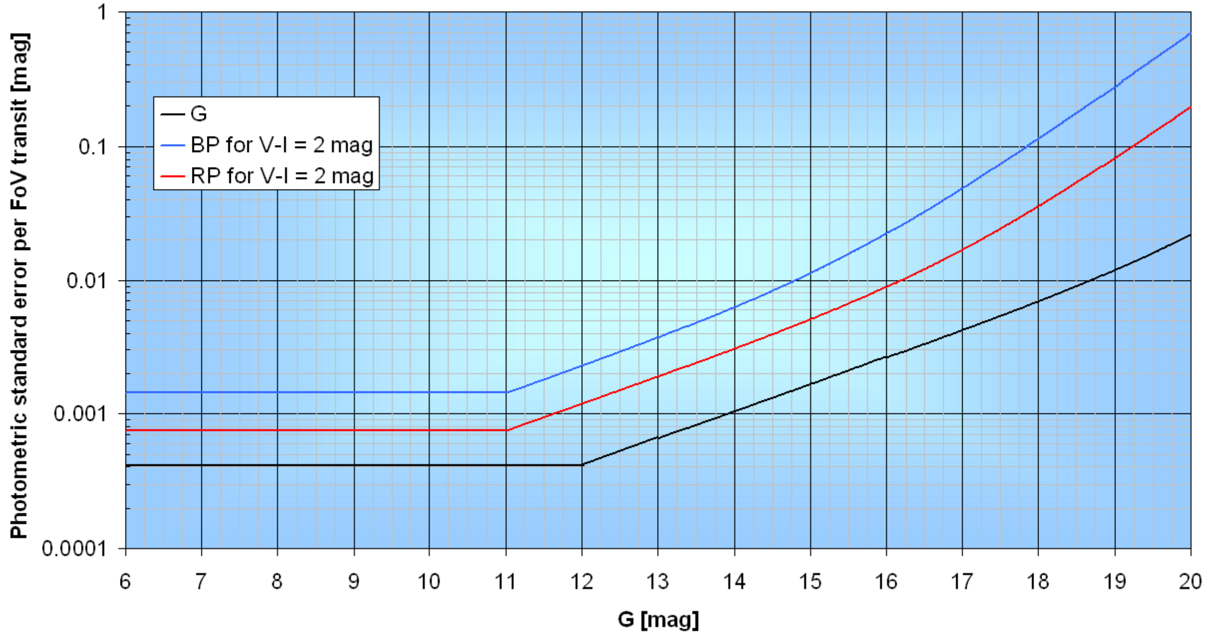
For bright stars (G<12 mag) the standard error is dominated by calibration errors, not by the photon noise

Photometry

Photometric standard errors per transit

Gaia Science Performance website (Sep 2015)

σ_G [mag] = $10^{-3} \cdot (0.04895 \cdot z^2 + 1.8633 \cdot z + 0.0001985)^{1/2}$,
where $z = \mathrm{MAX}[10^{0.4 \cdot (12 - 15)}, 10^{0.4 \cdot (G - 15)}]$.



Includes all known instrumental effects + 20% science margin
This is the single-field-of-view transit, taking into account all CCDs along scan

End-of-mission photometric standard errors

Gaia Science Performance website

- division of the single-field-of-view-transit photometric standard errors by the square root of the number of observations (~70 in average).
- all known instrumental effects, including straylight as measured during the in-orbit commissioning phase, as well as a 20% science margin
- with an assumed calibration error of 30 mmag at CCD-level

	B1V			G2V			M6V		
G [mag]	G	BP	RP	G	BP	RP	G	BP	RP
3 - 13	1	4	4	1	4	4	1	4	4
14	1	4	4	1	4	4	1	5	4
15	1	4	5	1	4	4	1	6	4
16	1	5	5	1	5	5	1	11	4
17	2	5	8	2	6	6	2	26	5
18	2	8	16	2	10	9	2	63	6
19	2	16	37	2	23	20	2	158	9
20	4	37	91	4	56	48	4	395	20

Units: mmag

Radial velocity

End-of-mission radial velocity error

Gaia Science Performance website (June 2015)

$$\sigma_{V_{rad}}\ [\mathrm{km\ s^{-1}}] = 1 + b \cdot e^{a \cdot (V - 12.7)},$$

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

→ TableVr-Jun2015.dat

End-of-mission radial velocity error

Gaia Science Performance website

$$\sigma_{V_{rad}}\ [\mathrm{km\ s^{-1}}] = 1 + b \cdot e^{a \cdot (V - 12.7)},$$

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

Included:

-all known instrumental effects, including straylight as measured during the in-orbit commissioning phase.

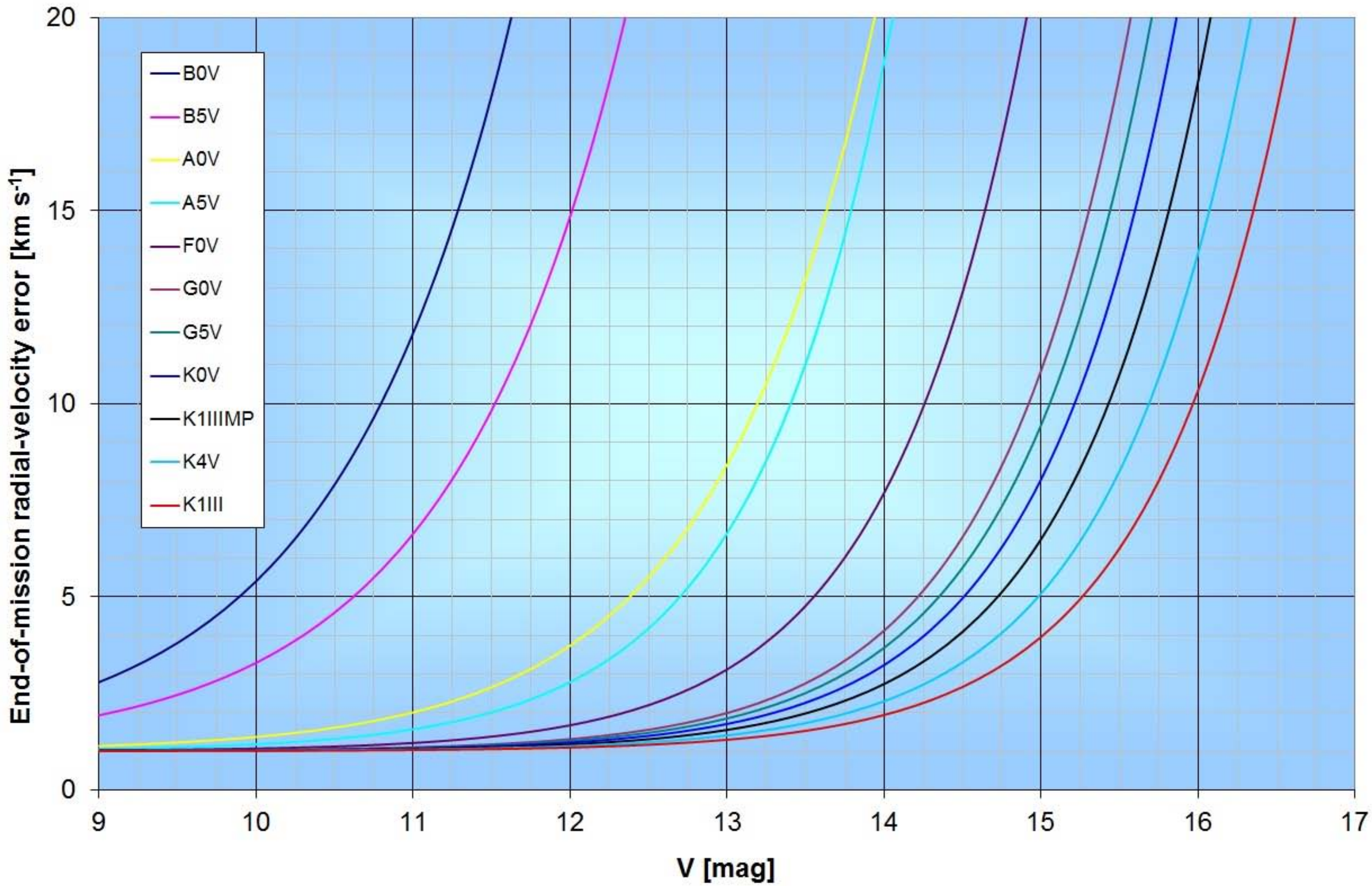
-residual calibration errors at ground-processing (DPAC) level

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.

End-of-mission radial velocity error

Gaia Science Performance website



2. The Gaia errors code

The Gaia errors code

- https://github.com/mromerog/Gaia-errors
  - README
  - Gaia-errors.f
  - main_Gaiaerrors.f
  - Makefile + auxiliary files and tables

Gaia errors subroutine

Real equatorial coordinates of the star

α
δ
π
$\mu_{\alpha}*$
μ_{δ}
Vr

Mv, (V-I)o + extinction map

+

Gaia error model

+

Gaussian distribution
(independent variables)

→

Observed equatorial coordinates of the star

α
δ
π
$\mu_{\alpha}*$
μ_{δ}
Vr

Main code schema

Galactocentric coordinates of the star (X,Y,Z,Vx,Vy,Vz)

Coordinate transformation
(Rotation curve, Sun galactocentric position and Vsun)

Heliocentric equatorial coordinates of the star

$(\alpha,\delta,\pi,\mu_{\alpha}*,\mu_{\delta},Vr)$

Mv, (V-I)o + extinction map

+

Gaia errors subroutine

Observed heliocentric equatorial coordinates of the star

$(\alpha,\delta,\pi,\mu_{\alpha}*,\mu_{\delta},Vr)$

Coordinate transformation
(Rotation curve, Sun galactocentric position and Vsun)

Observed galactocentric coordinates of the star (X,Y,Z,Vx,Vy,Vz)

Main code

- Input: ascii file with 9 columns

x,y,z,vx,vy,vz,Mv,(V-I),Av

Galactocentric
Coordinates
Positions in kpc
Velocities in km/s

Absorption in
V (mag)

Intrinsic (V-I)
color (mag)

Absolute magnitude
in V (mag)

Main code

- Output: ascii file with 18 columns

Av,V,V-I,G,Grvs, $\sigma\pi/\pi$,X,Y,Z,Vx,Vy,Vz, Xo,Yo,Zo,Vxo,Vyo,Vzo

Galactocentric
Coordinates
Positions in kpc
Velocities in km/s

Galactocentric
Coordinates
affected by errors
Positions in kpc
Velocities in km/s

Relative error in parallax

Gaia G and Grvs magnitudes (mag)

observed (V-I) color (mag)

Apparent magnitude in V (mag)

Absorption in V (mag)

Example RC stars

- Input: JHK
- From Alves et al (2000): (V-I) and (V-K) ,
- Cardelli et al (1989) extinction law
  - $K=Mk+5*\log10(distpc)-5.+0.114*Av$
  - $(V-K)=(1.-0.114)*Av+(V-K)_{intrinsic}$
  - $\mathbf{V}=K+(V-K)$
  - $\mathbf{V-I}=(1.-0.479)*Av+(V-I)_{intrinsic}$
  - $\mathbf{G}=V-0.0257-0.0924(V-I)-0.1623(V-I)^2+0.0090(V-I)^3$