Testing instrument capabilities from simulations

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OVERVIEW

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- Simulation of the Instrument

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- Simulated Instrument vs. Real Instrument

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- Methods for testing capabilities

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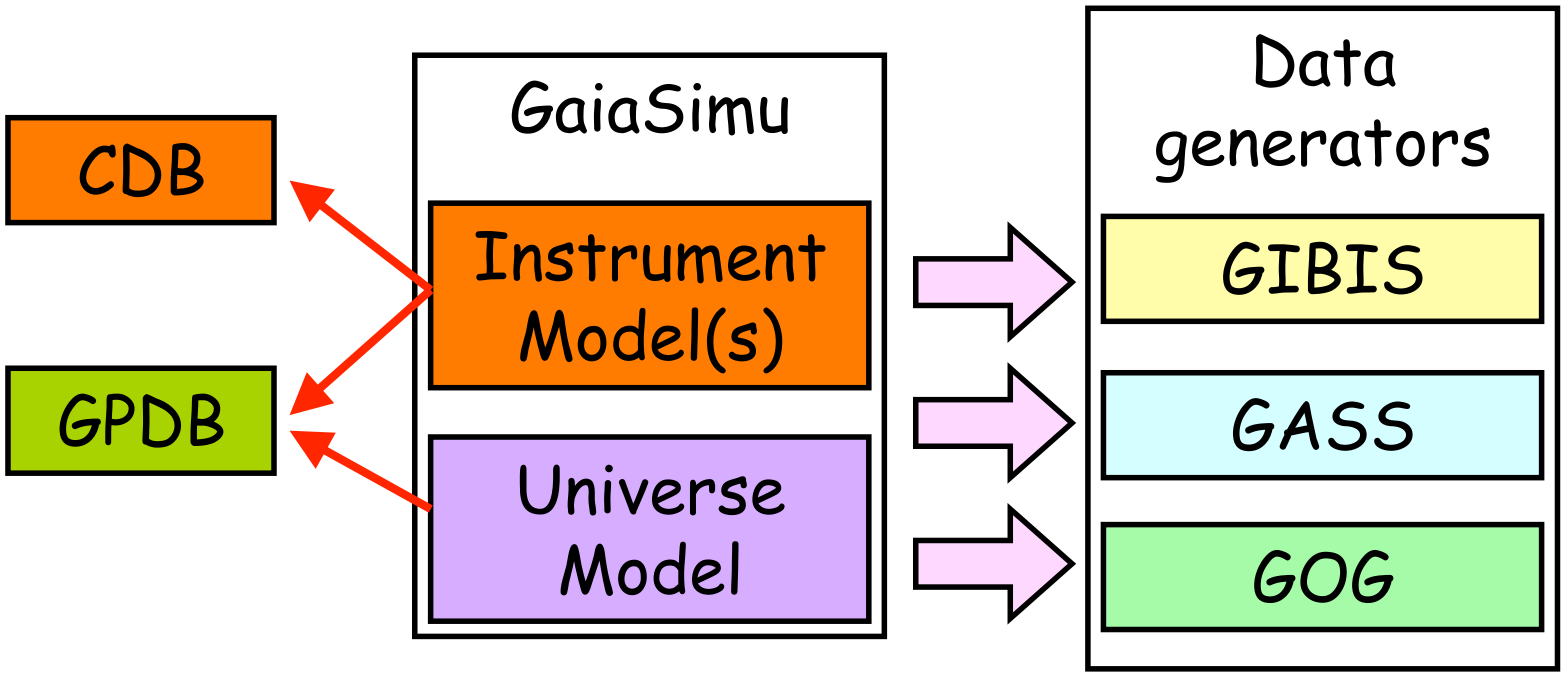
- Simulated Instrument vs. Real Instrument
- Methods for testing capabilities
- example: astrometry

Instrument simulation in CU2 - overview



Data generators characteristics vs. Instrument model

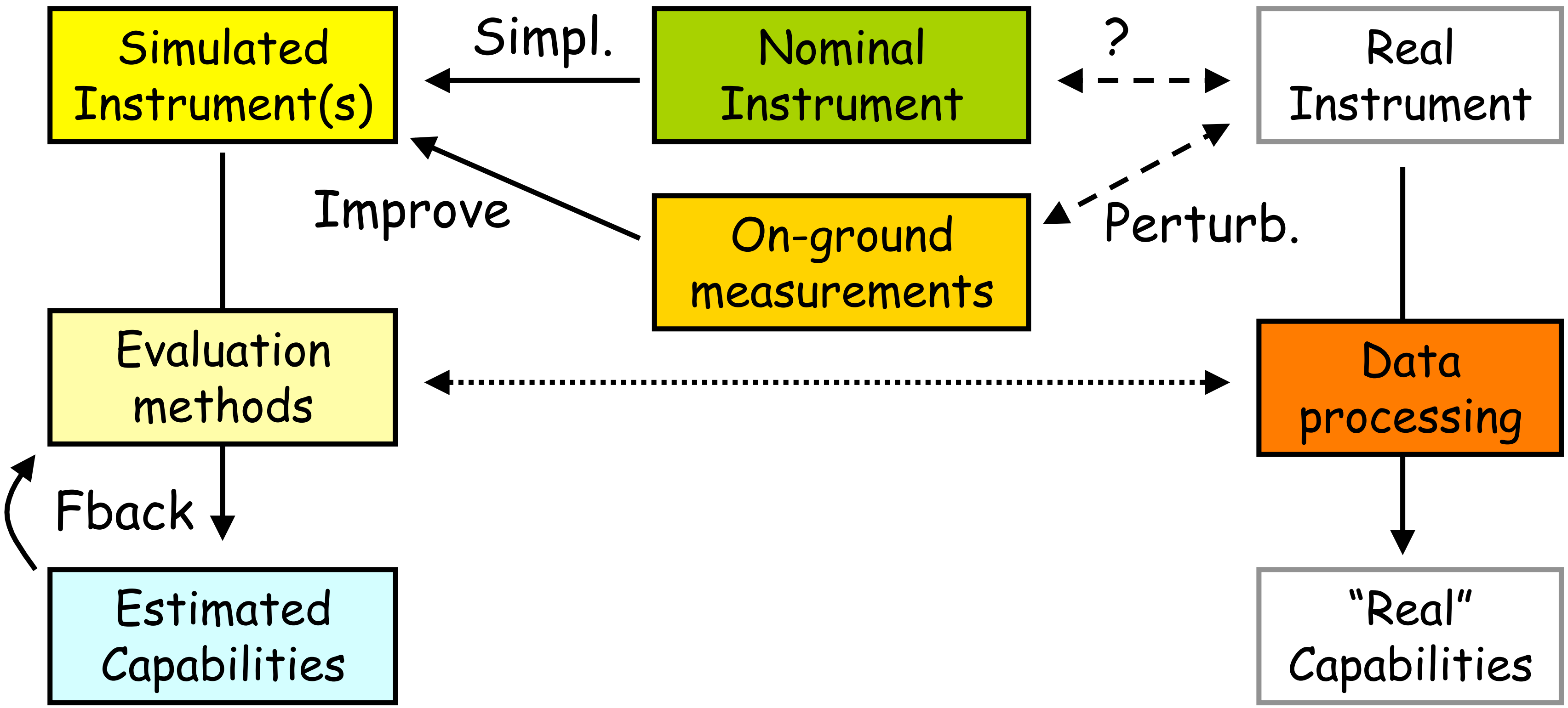
- GIBIS: simulation of data at pixel level. As realistic as possible for limited regions of the sky and over short periods of time.
- GASS: simulation of telemetry stream. Use simplified models of the instrument. Large amount of data over a significant part of the planned Gaia mission duration
- GOG: simulation of observed object lists + intermediate/end of mission Gaia data for given source. Use error models.

-> Need different models of the same subsystems/effects (problems: duplication and consistency)

Simulated vs. Real Instrument

- instrument is not completely built yet
- many subsystems already tested or being tested now
- In any case, knowledge of the real instrument can/will be only partial:
    - Many relevant instrument parameters not measured (or non-measurable) on-ground
    - In-flight configuration and environmental conditions different from nominal / predicted ones.

Simulated vs. Real Instrument

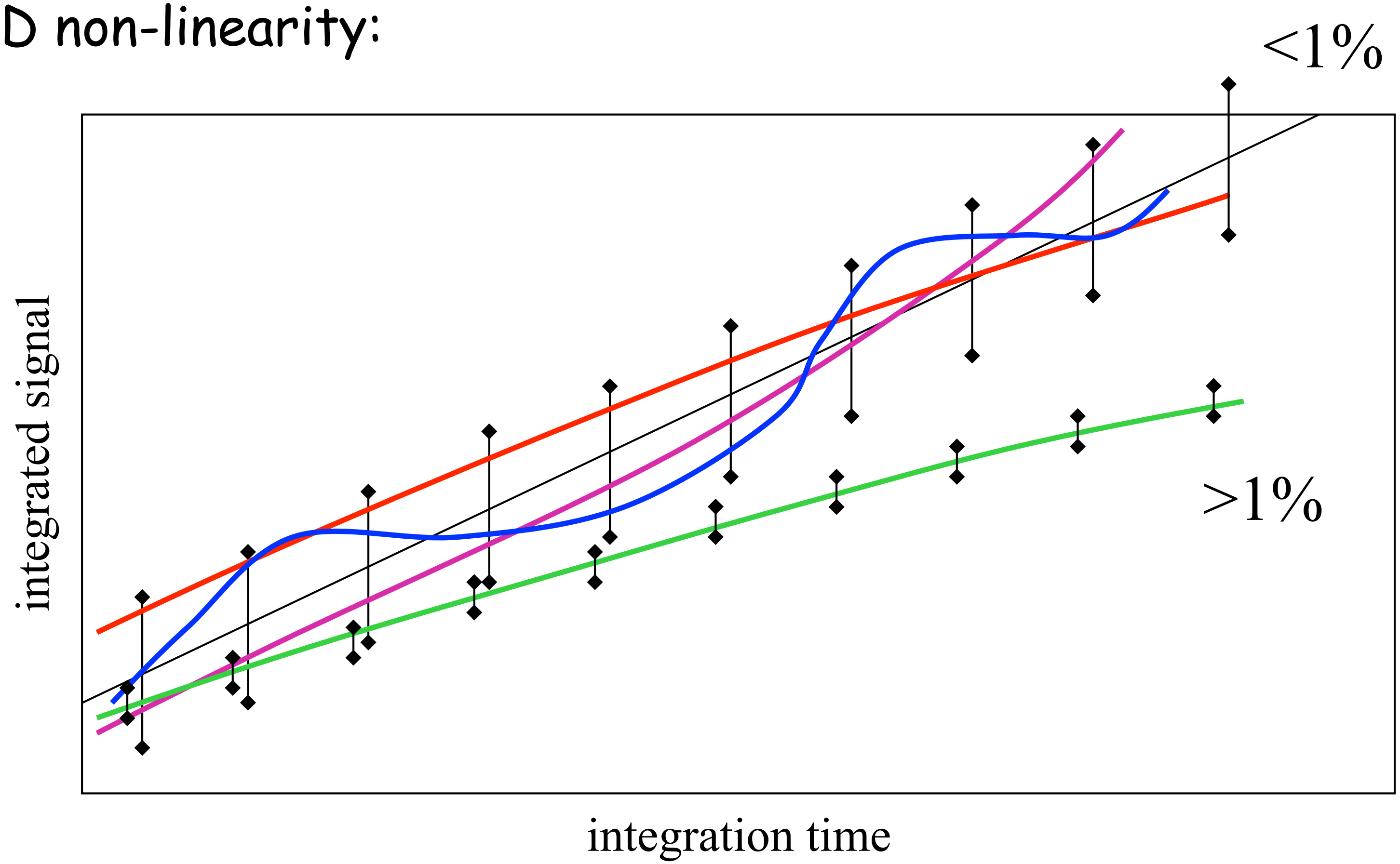


Further note on on-ground measurements

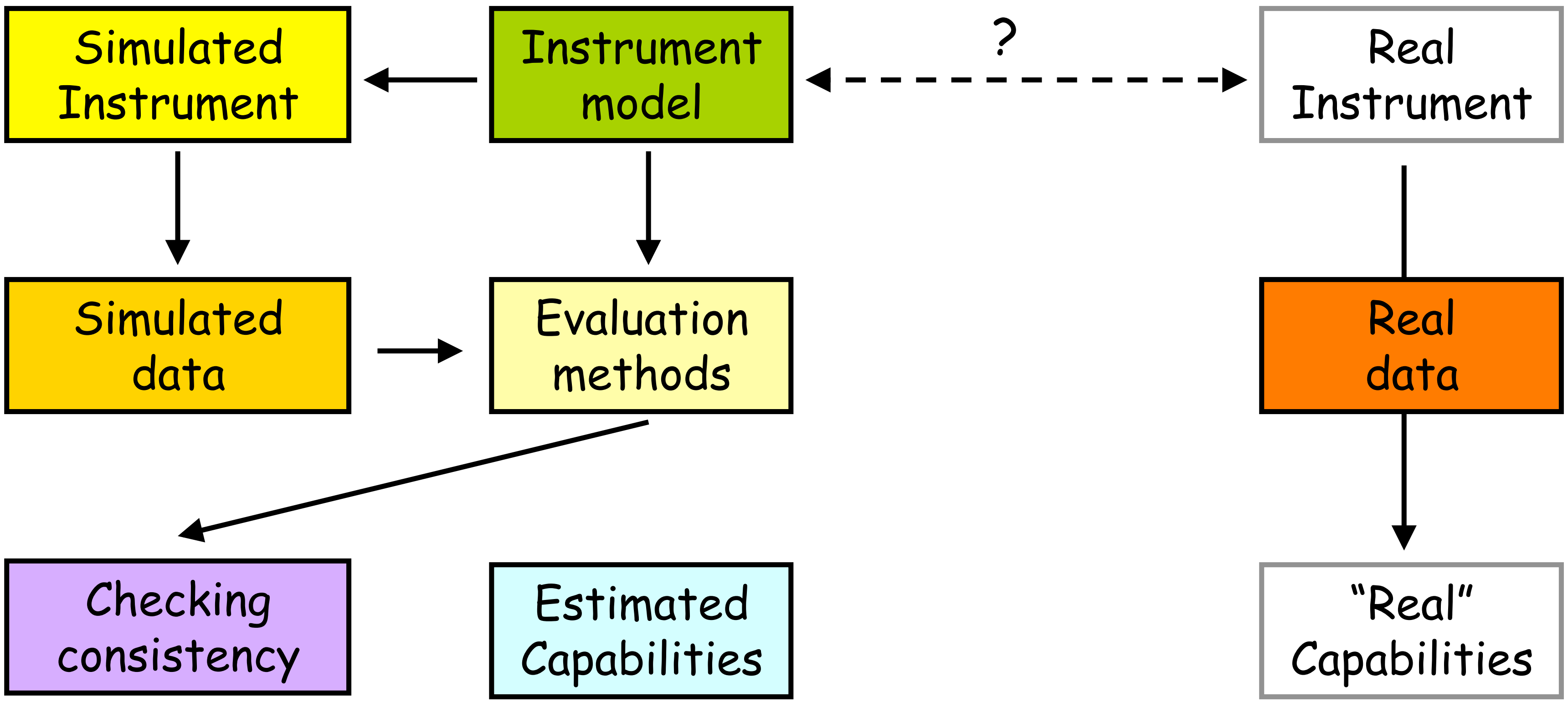
- Usually made by industry to convince ESA that requirements are fulfilled
- Requirement fulfilled doesn't mean "proper" knowledge of the instrument
- Example: CCD non-linearity
- Req may sound like "CCD non-linearity calculated in someway shall not exceed 1%"
- For calibration purposes, you may prefer a non-linearity > 1%, but a well known non-linearity profile vs. integration time

Further note on on-ground measurements

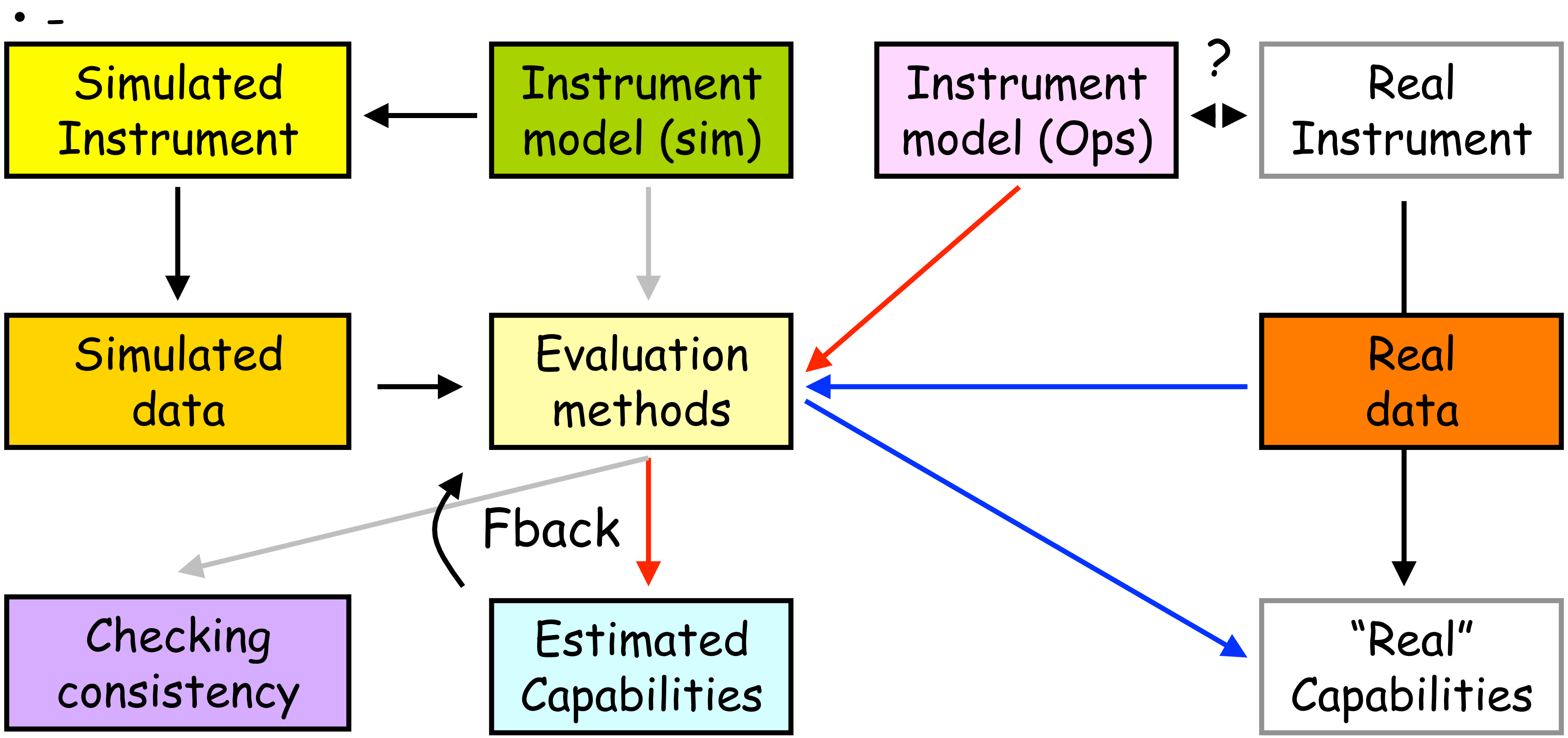
CCD non-linearity:



Evaluation methods



Evaluation methods



Example: astrometric performance

PSF/LSF model for simulations

The model is based on a dual representation:

- numerical library for GIBIS. The starting point is a numerical library where the elements are generated from the optical design of the instrument (CodeV generated WFEs, 1 per CCD) plus some ad-hoc effects (TDI, pixel, etc).
- analytical library for GASS/GOG. The elements of the library are generated from bi-quartic B-spline fittings of the numerical library. Interpolation for any point in the coefficients grid available.
- Both the analytical and the numerical representations provide the integrated flux over one pixel, normalised to the total integrated flux

Note that:

- many effects can be introduced at the level of the numerical library and they will automatically be present in the analytical representation with no need to develope specific models for GASS/GOG
- the analytical representation requires a minimised number of computations in GASS/GOG
- nonetheless, many effects are not usefully described by means of precomputed libraries (CTI, noise, magnitude, non-linearity/saturation, …) and are treated separately

PSF Numerical (discrete sampling) Library

Generated as follows (starting from nominal WFEs, PS-010):

- monochromatic PSFs (250-1050 nm) with steps of 1 nm
- 11 quasi-monochromatic PSF (using triangular bands, LL-080)
- pixel, TDI, attitude errors, optical distortion, charge diffusion (effqmPSF)
- source motion and gates are treated separately
- Polychromatic PSF can be computed by linear combination of effqmPSF + source spectrum
- Polychromatic PSF library for colour index V-I also available.

Analytical library

Analytical library:

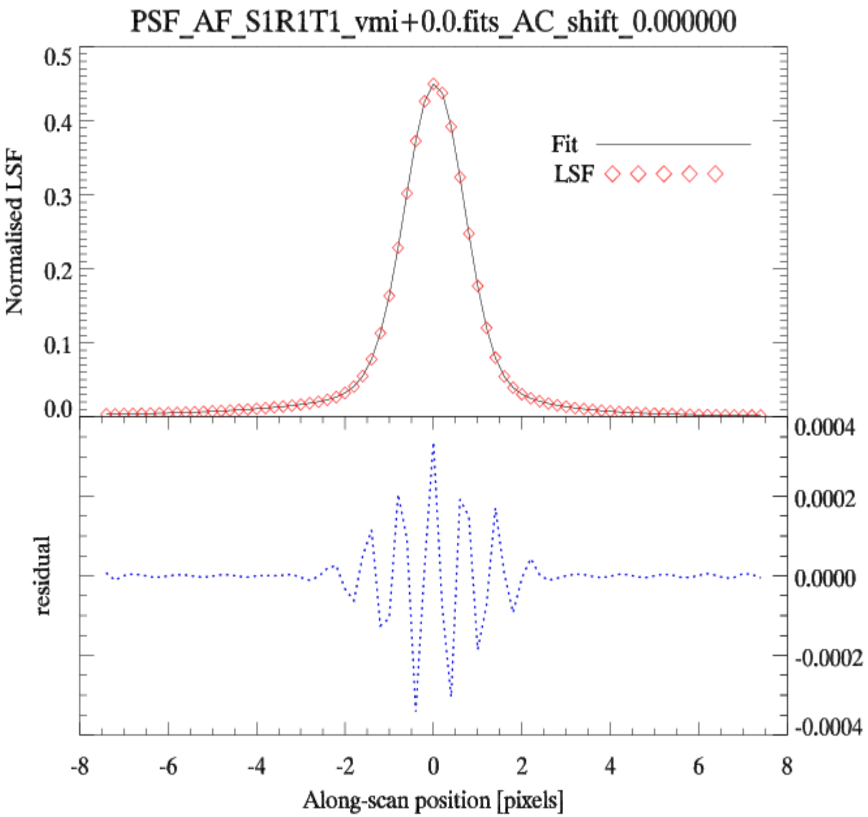
- Fitting functs: Bi-quartic B-Spline + wings (LL-066). Result: Analytical function giving pixel readout for any (continuous) AL position (33 params)
- Details of the analytical library coeffs calculation in DB-009
- Interpolation in coefficients space domain (DG-014)

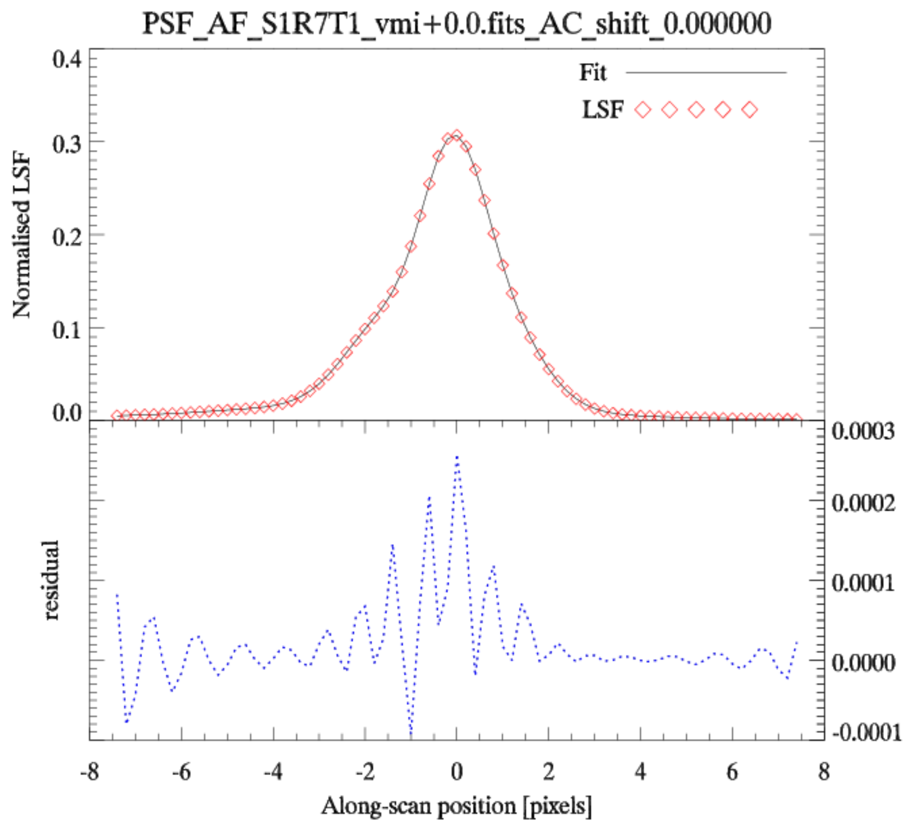
Parameter	SM	AF
Telescopes	2	2
FoVs	7	62
Triang. bands (wavelength)	11	11
(V-I)	12	12
	154	1364

<- Size of Parameter space domain

Analytical model – AF (example)

- S1R1T1 vs. S1R7T1 (V-I = 0.0)





Other talks related to instrument modeling

- F. van Leeuwen – Modeling the attitude: lessons learnt from Hipparcos
- D. Risquez – Modeling the attitude of the Gaia Satellite
- M. Weiler – Implementation of CTI models in GIBIS
- T. Prod'homme – Radiation effects on Gaia CCDs

LSF - Signal profile modeling

- Problem treated in LL-084, MG-009
- The LSF model can be written as a linear combination of basis functions

$$\tilde{L}(u) = \sum_{m=0}^{N} c_m B_m(u)$$

- How many parameters N do we need to properly model the signal profile?
- Which are the basis functions that provides the most accurate approximation of the LSF?
- How good this approximation is (as a function of N)?

LSF - Signal profile modeling

Principal Component Analysis provide a solution to this problem (LL-084)

- The model of the signal profile is obtained starting from a large sample of LSFs, generated with many different WFEs and SEDs over M points
- Any LSF can be written as linear combination of basis vectors

$$\vec{L} = c_0 \vec{B}_0 + \sum_{m=1}^{M} c_m \vec{B}_m$$

where B_0 is the mean LSF and B_m are obtained from the covariance matrix (deviations wrt the mean profile)

The truncated expansion $$LSF' = c_0 B_0 + \sum_{m=1}^{N<M} c_m B_m$$ has minimum expected RMS error among all linear models with N free parameters (under proper hypothesis)

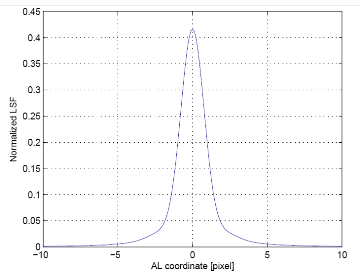
LSF - Signal profile modeling

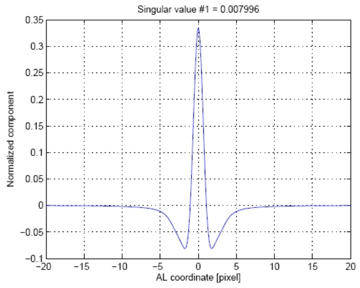
Another approach is also proposed (MG-009):

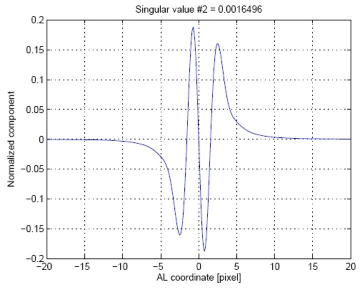
signals are expected to be reasonably close to the ideal case -> they fit a context of small perturbations/aberrations

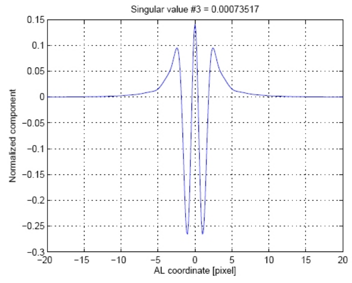
- ideal instrument -> $$F_0(u;\lambda) = \left(\frac{\sin\rho}{\rho}\right)^2, \quad \rho = \frac{\pi D}{\lambda f} u$$
- perturbations -> $$F_n(u;\lambda) = \frac{d}{du} F_{n-1}(u;\lambda) = \frac{d^n}{du^n} F_0(u;\lambda)$$
- polychromatic LSF -> $$F_0(u) = \int S(\lambda) F_0(u;\lambda) d\lambda$$
- ortho-normalisation -> $$\sum_k F_p(u_k) F_q(u_k) = \delta_{pq}$$

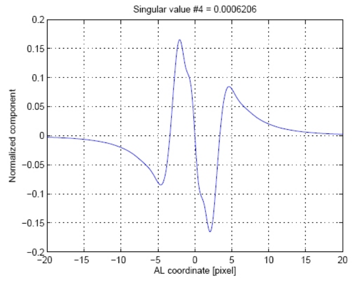
LSF - basis functions

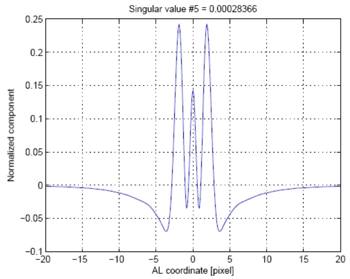


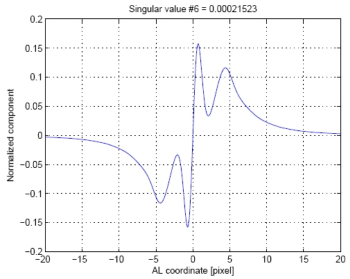


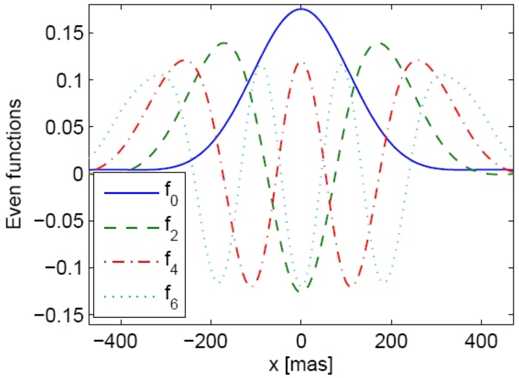


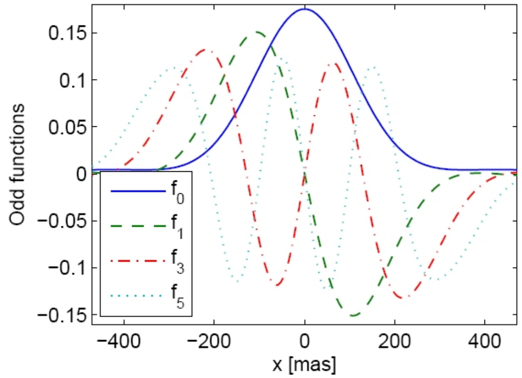










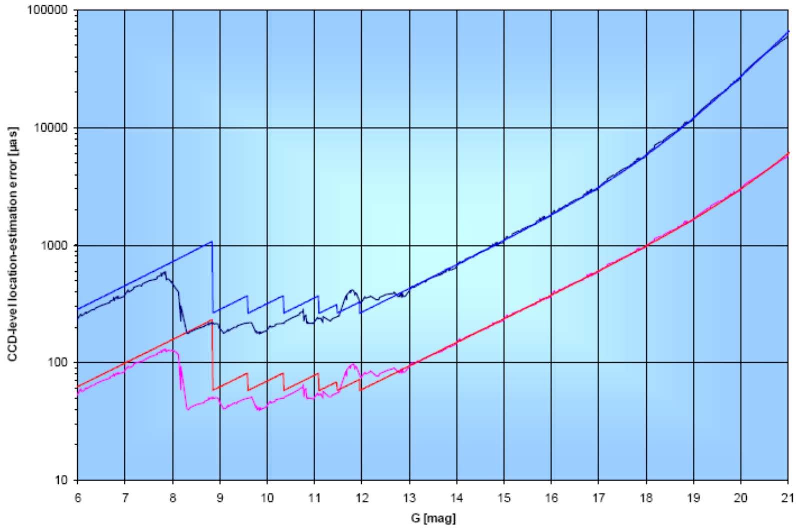


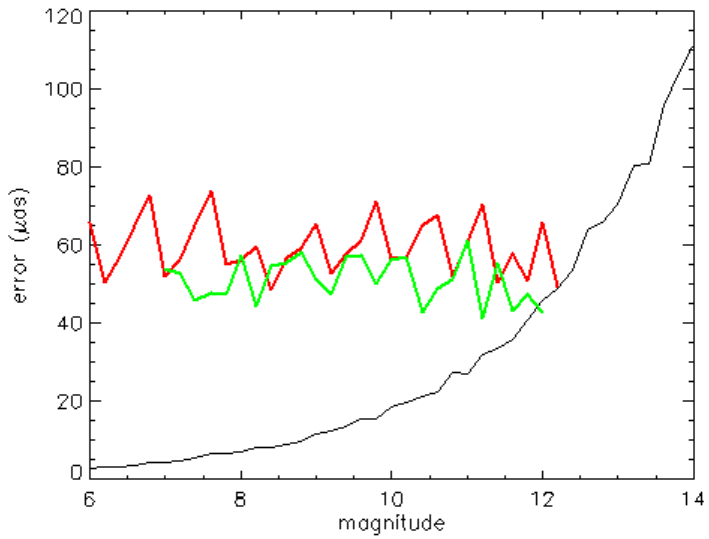
Signal profile modeling - summary

LL-084	Model	MG-009
~ 10 - 11	Number of params	~ 10 - 11
PCA (mean LSF + cov. + interpolation)	Basis functions	$(\sin x/x)^2$ + derivatives
10^{-3}	RMS residual (5 pars)	
10^{-4}	RMS residual (10 pars)	10^{-4}
	astrom. residual (μ,rms)	(7 μas ; < 1 μas)
Tukey's biweight (LL-068)	Localisation process	COG
simulated + real (camp. #3)	Data	simulated

Astrometric accuracy

- First tests with this models (Analytical LSF + PCA) in IDT 8.0
- Other independent astrometric accuracy analysis:
- GAAT (JDB-053, JDB-055) Bright Stars (DG-001, ML-025)





- Similar results in the magnitude range [6,14]

Summary

• Simulation of the instrument must take into account all major effects

• Effects introduced with rather simple models may already provide a satisfactory first order description

• Further refinements using more complex/sophisticated models fight with:

- "distance" between the nominal and the real instrument
- Computing time, data storage, et cetera

• Requirements satisfied does not mean you are able to properly model/simulate your instrument

• Tests of instrument capabilities using simulations are reliable only up to a certain level (they provide anyway a first approximation of what you can expect)

• Gaia astrometric performances will probably be limited by poor knowledge of the real signal profile

Thank you