Gaia photometry

Methods, performances and problems

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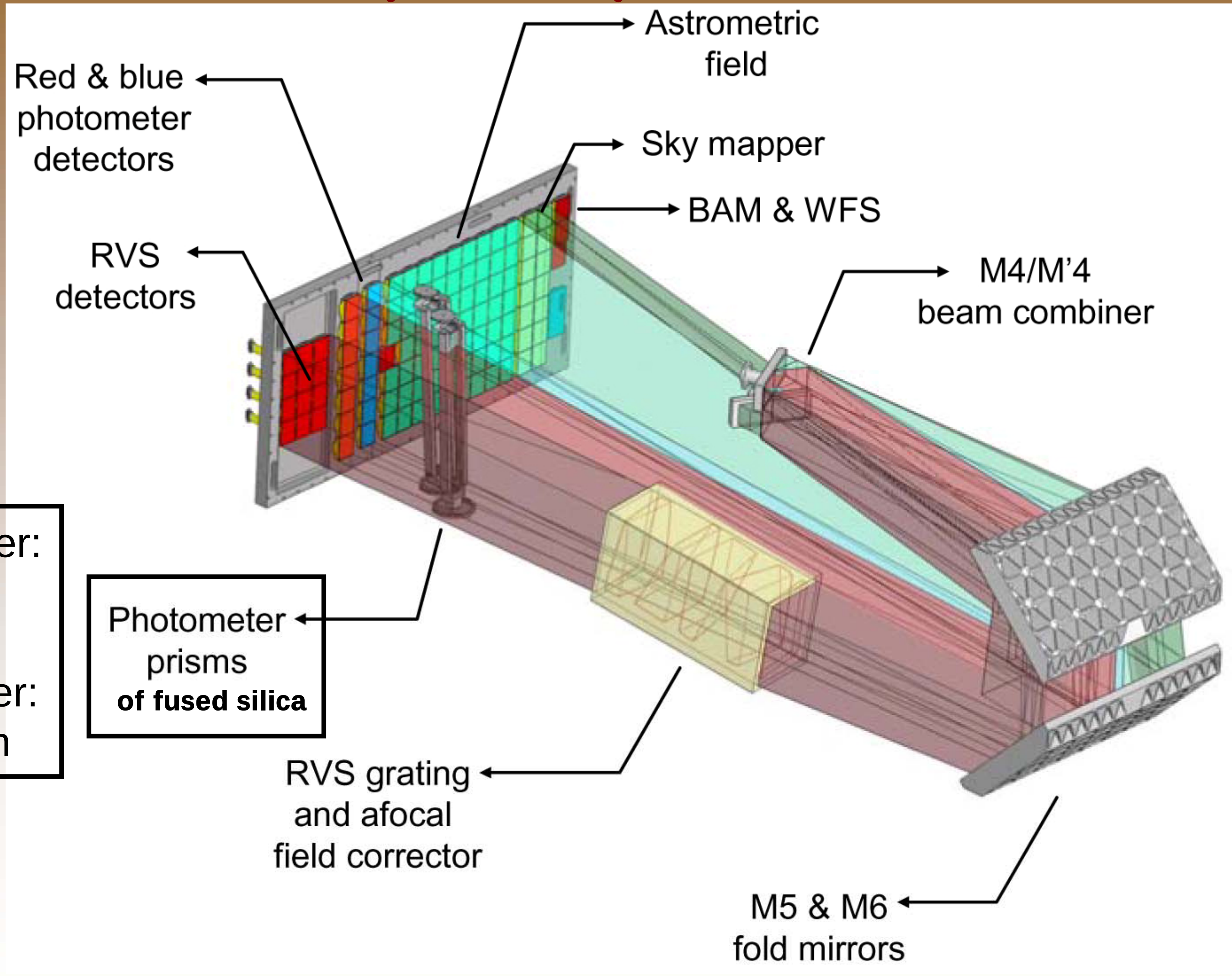
Why Photometry ?

Photometry is necessary to account for the **chromatic aberrations in the astrometric focal plane** to achieve microarcsec accuracy level

The scientific goals of Gaia require complementary astrometry, photometry and radial velocity data, being **the characterization of the observed objects in terms of astrophysical parameters the main goal of the photometry**

Blue and red spectrophotometers



Blue photometer:
330–680 nm

Red photometer:
640–1000 nm

Figures courtesy EADS-Astrium

Focal plane

106 CCDs , 938 million pixels, 2800 cm^2
pixel size= 59 mas, angular resolution=0.12”

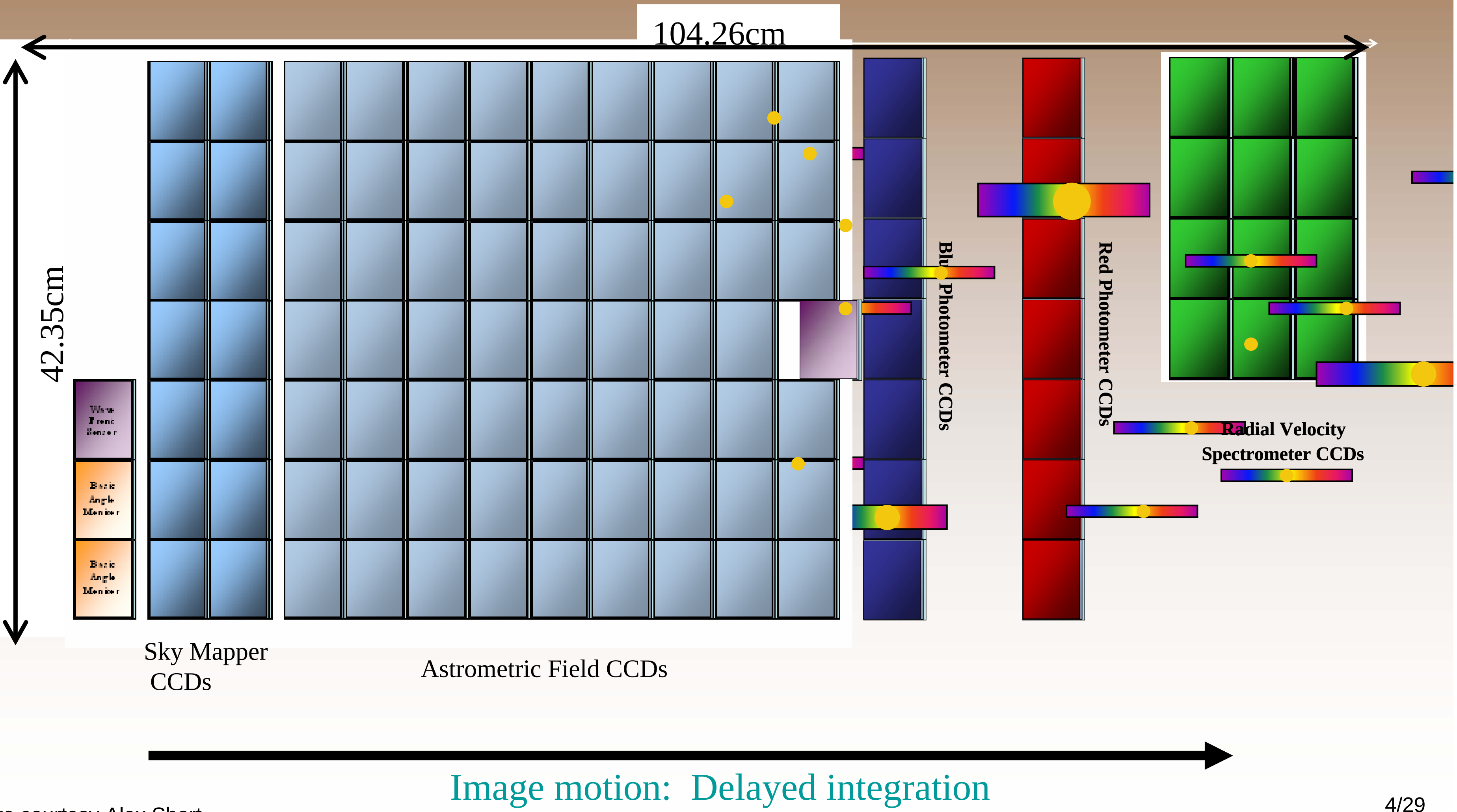
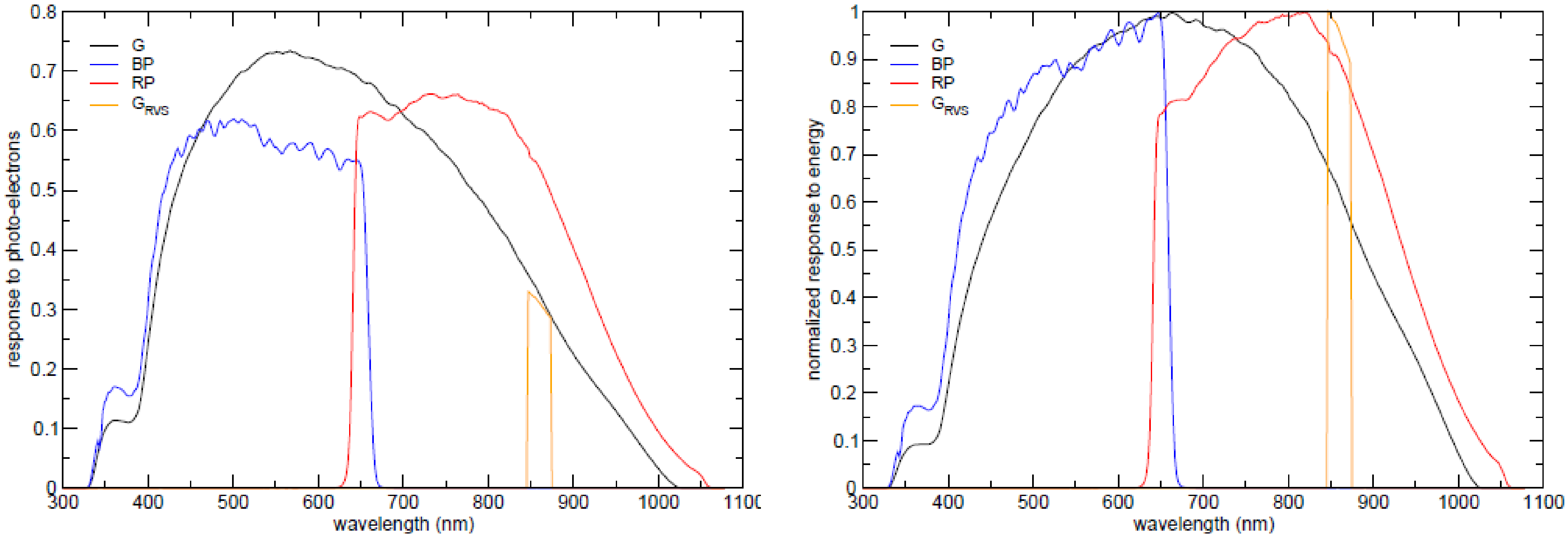


Figure courtesy Alex Short

Photometry

1. Photometry: broad bands
2. Spectrophotometry: BP & RP spectra

Gaia passbands

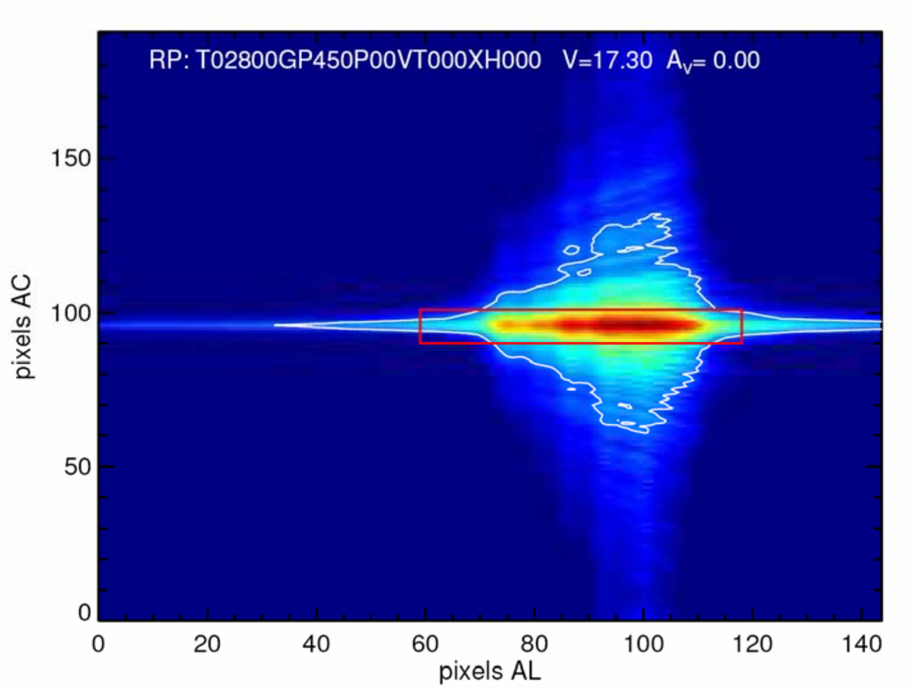


CJ-041 with updates EADS-Astrium (CDR), RK, AM

Spectrophotometry
Blue and red spectrophotometers

Resolution ~100

BP: 4-35 nm/pixel
RP: 7-15 nm/pixel



Red spectra of a M-dwarf (V=17.3)

Red box: extracted window sent to the Earth

Figures courtesy Anthony Brown

Calibration approach
& deliverable products

Data processing has to account for:

non-linearity & saturation

Pre-processing

- Bias, background, CTI (image+SR), gain
- Contamination and blending

Internal calibration

- Overall sensitivity variation (optics, CCDs)
- Flux out of the window (AC & AL flux loss)
- PSF/LSF variation
- Dispersion variation
- Geometry variation (AL & AC); tilts

External calibration

- Absolute flux scale
- Wavelength scale

Mean, minimum and maximum QE

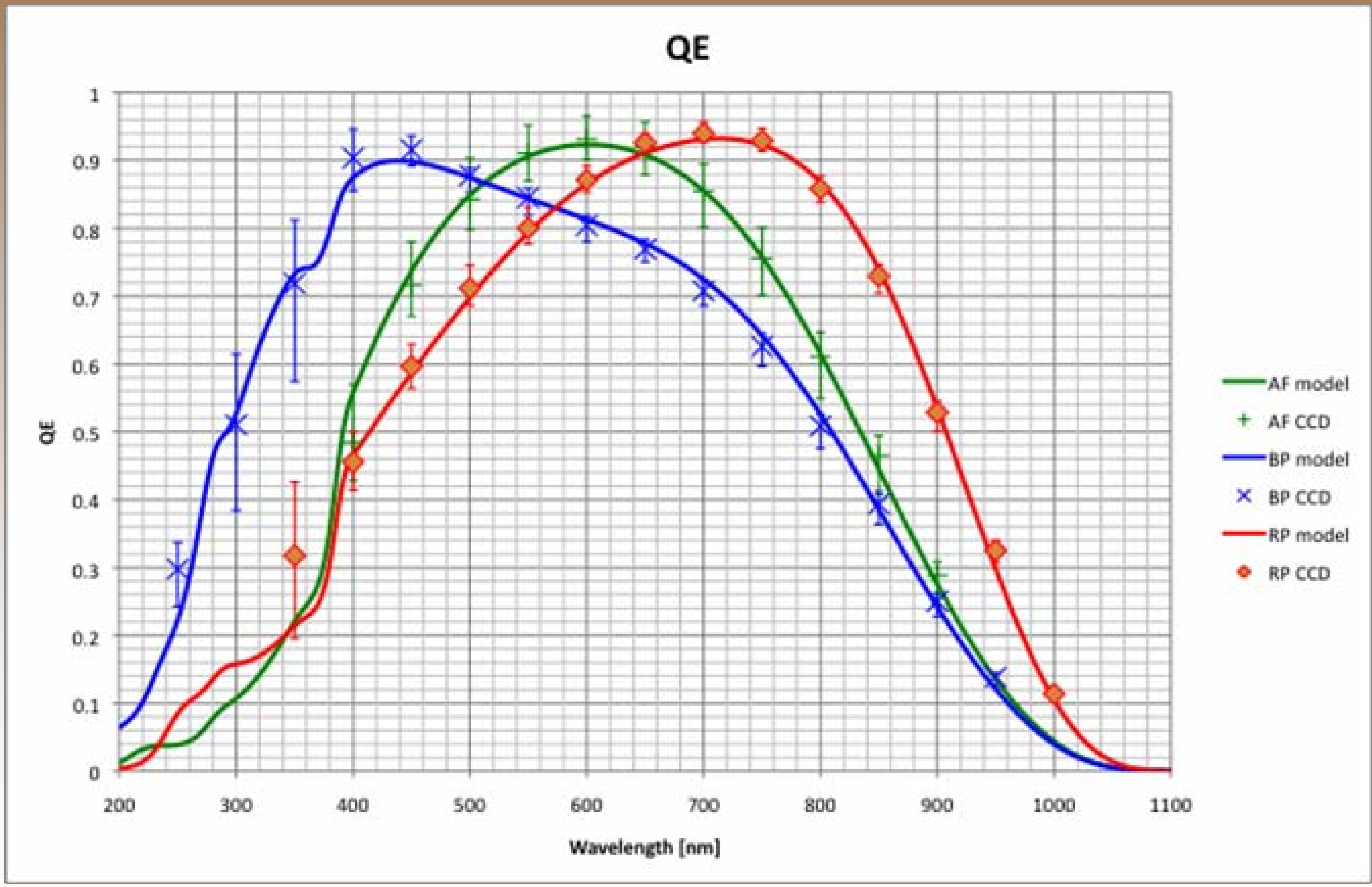


Figure courtesy Ralf Kohley & Alcione Mora

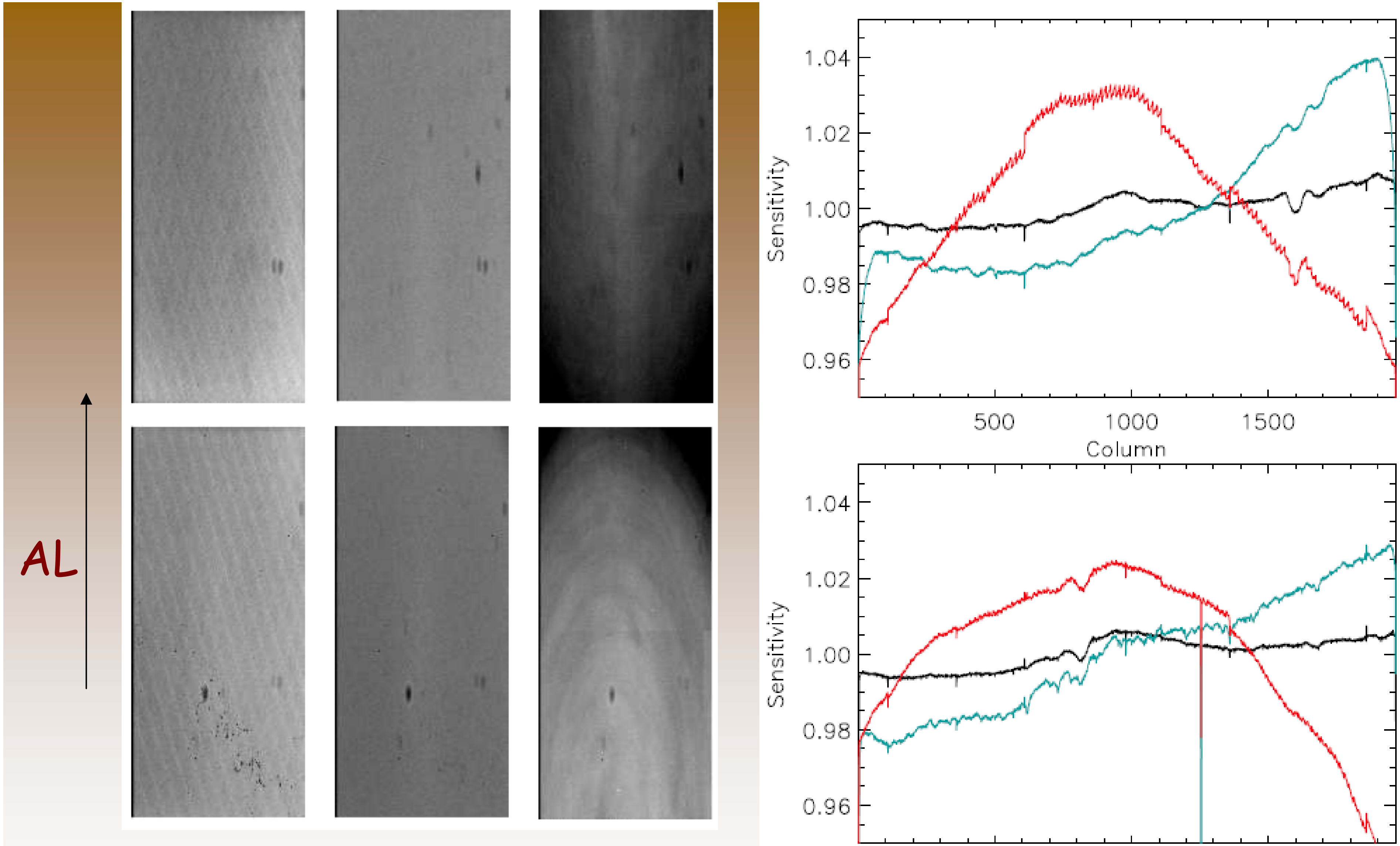
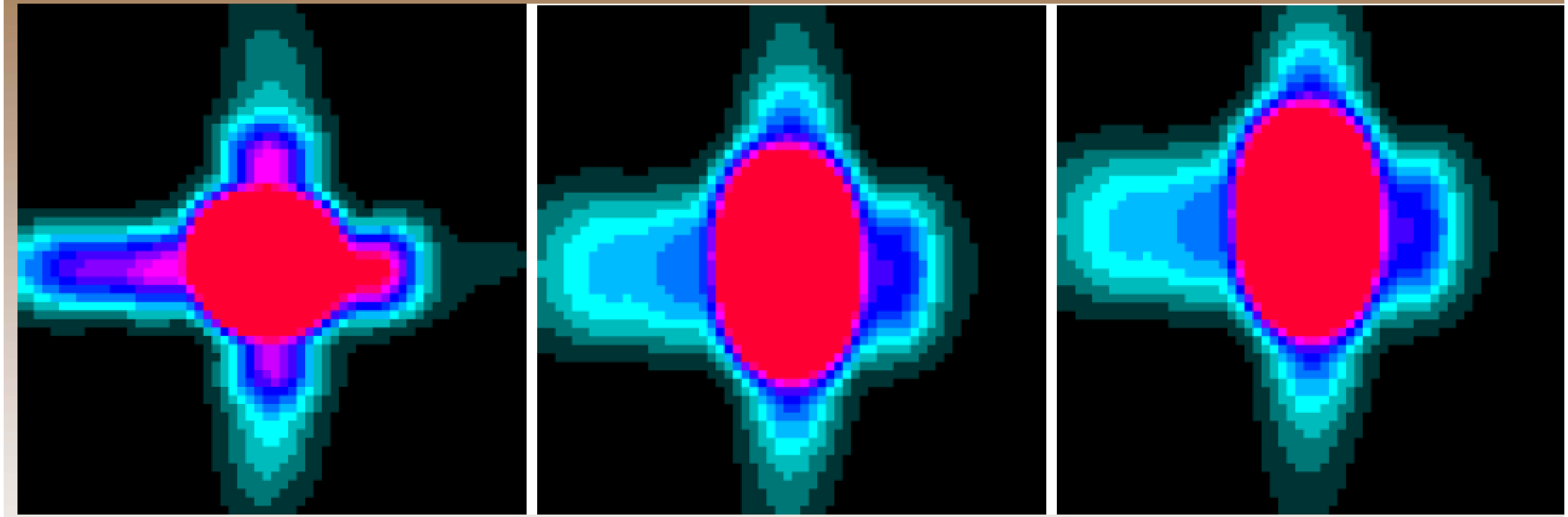


Figure 9: Flat field images for CCD 05486-15-2 for 400 nm, 550 nm and 900 nm (upper row, from left to right) and for CCD 06036-11-1 (lower row). CCD columns are aligned vertical (AL scan direction) in this figure. Oval dark patterns are believed to origin from particles in the optical path. Note, that the pixels with 3:1 length scale are displayed at 1:1 scale here.

Flux in the window

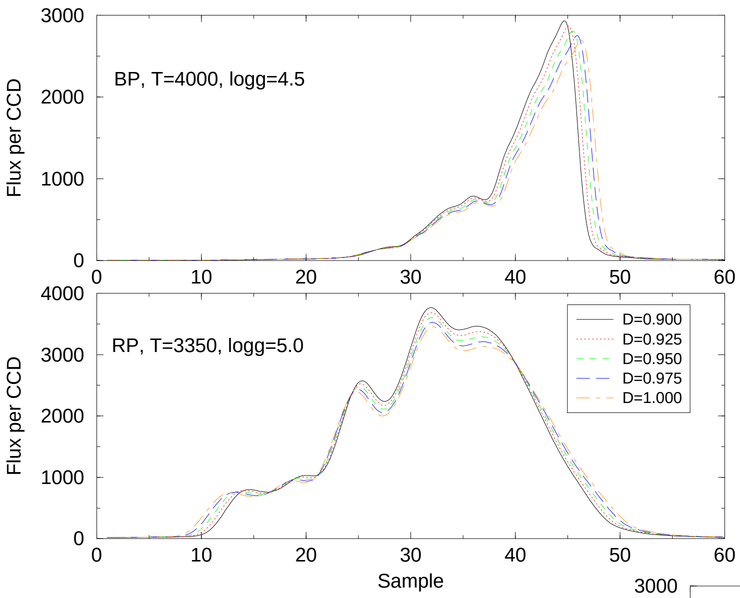
AF S5R4T1 V-I=2.0

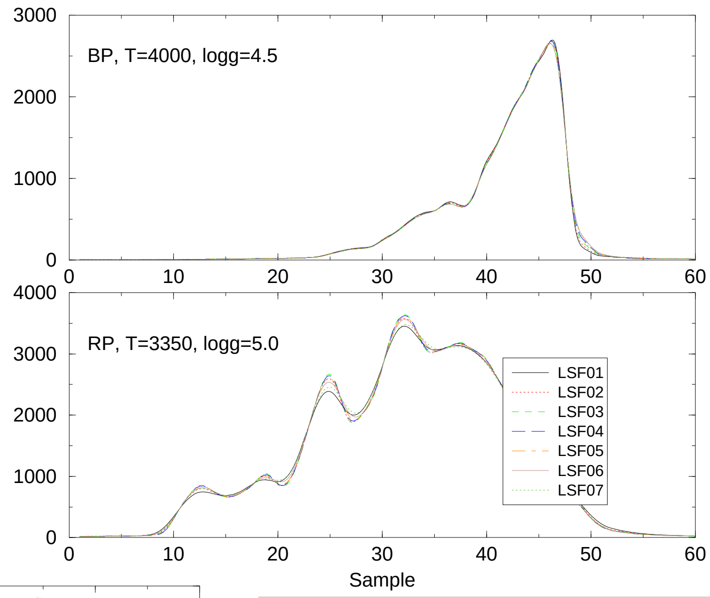


No AC motion | Nominal AC motion | window +1 pixel

1-2% variation

Dispersion and LSF

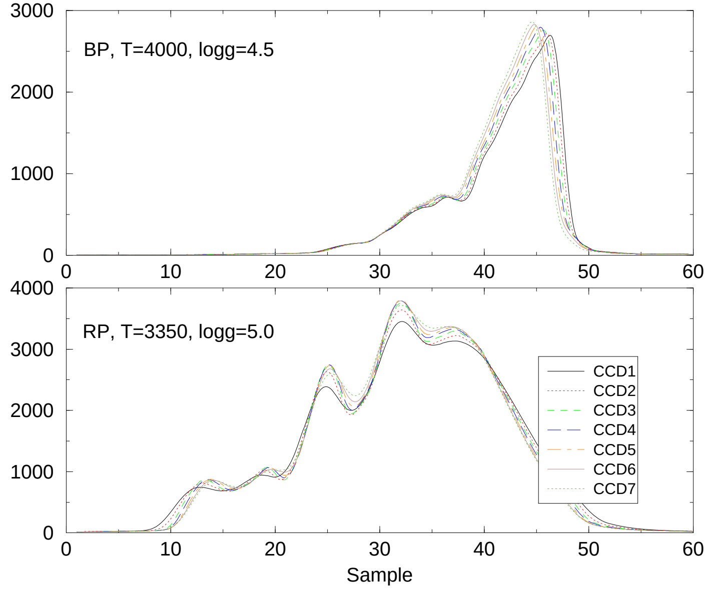




Disp effect

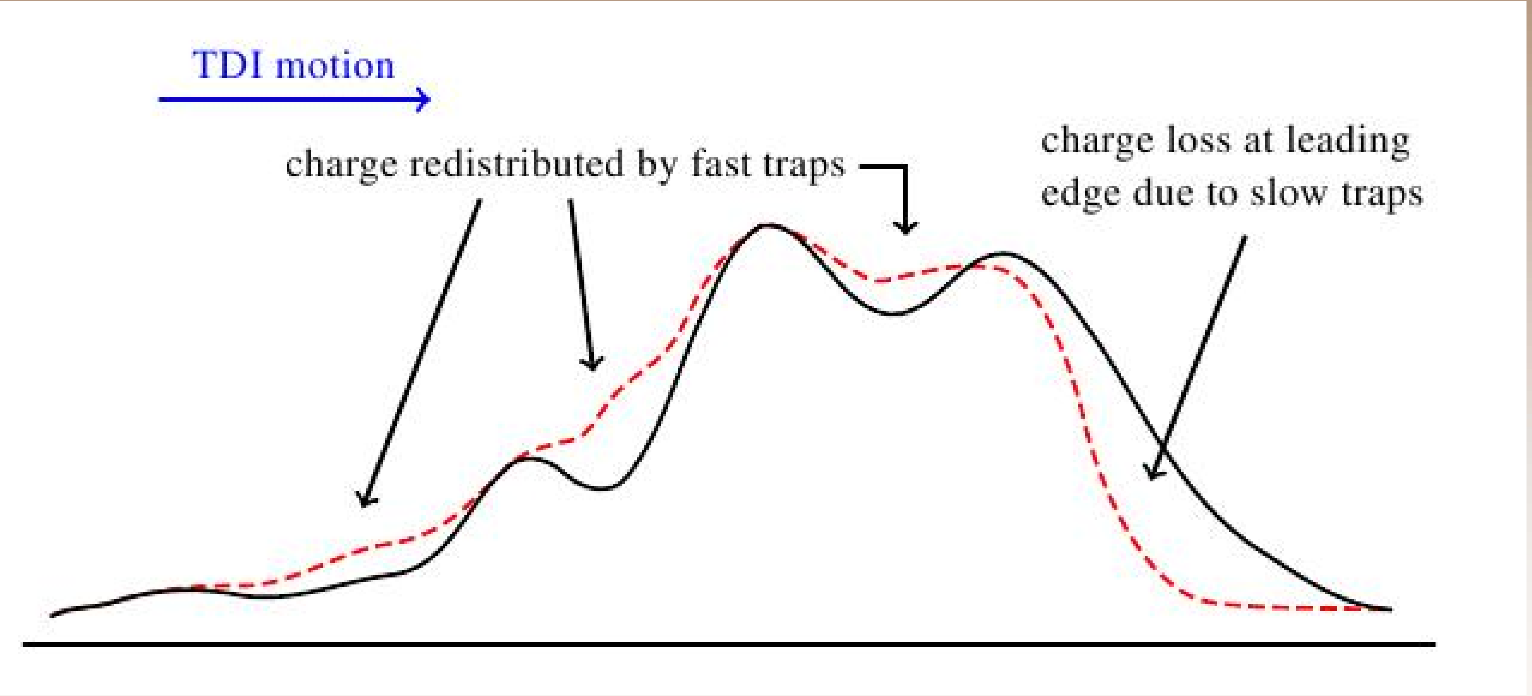
$D_7 \sim 0.9 D_1 \rightarrow \Delta\lambda_7 \sim 1.1 \Delta\lambda_1$

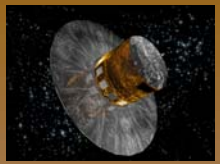
LSF effect



joint effect

CTI effect on BP/RP spectra





Telemetry

IDT

Raw images

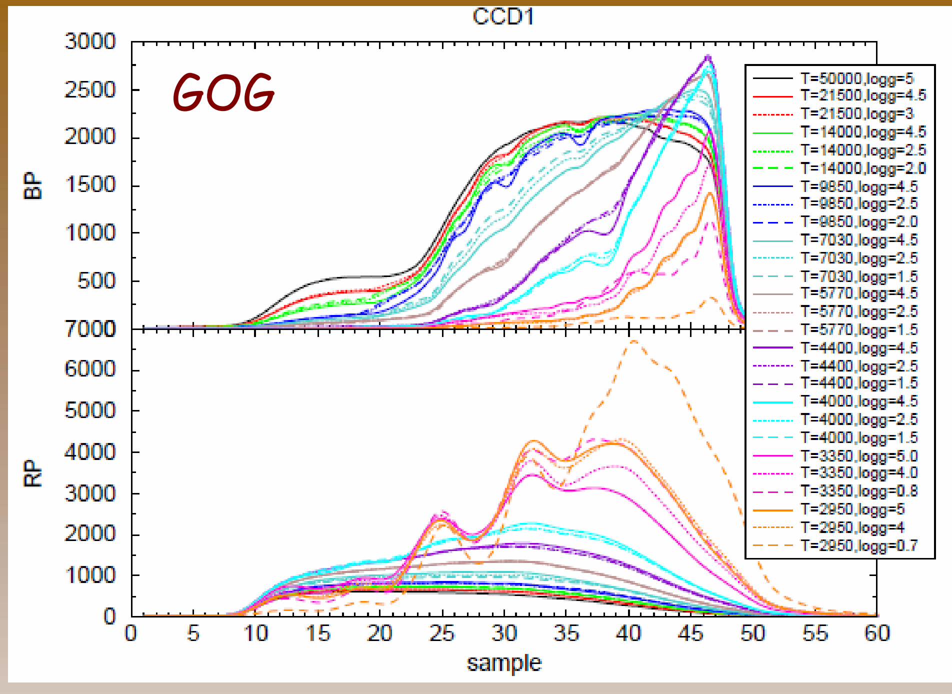
Pre-processing

Clean images

Internal calibration
"forwarding model"
- Source update
- Instrument update

Internal fluxes
Internal XP spectra

MDB

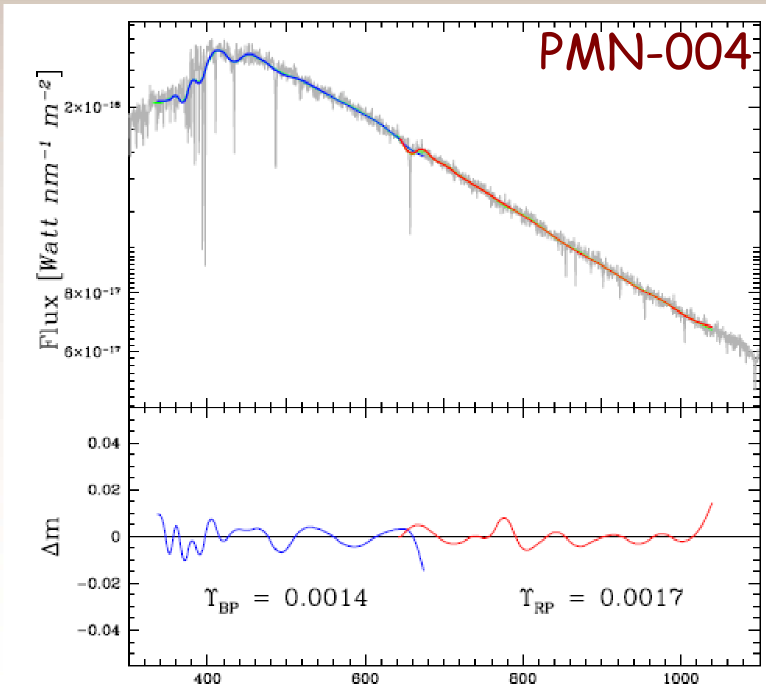


External calibration

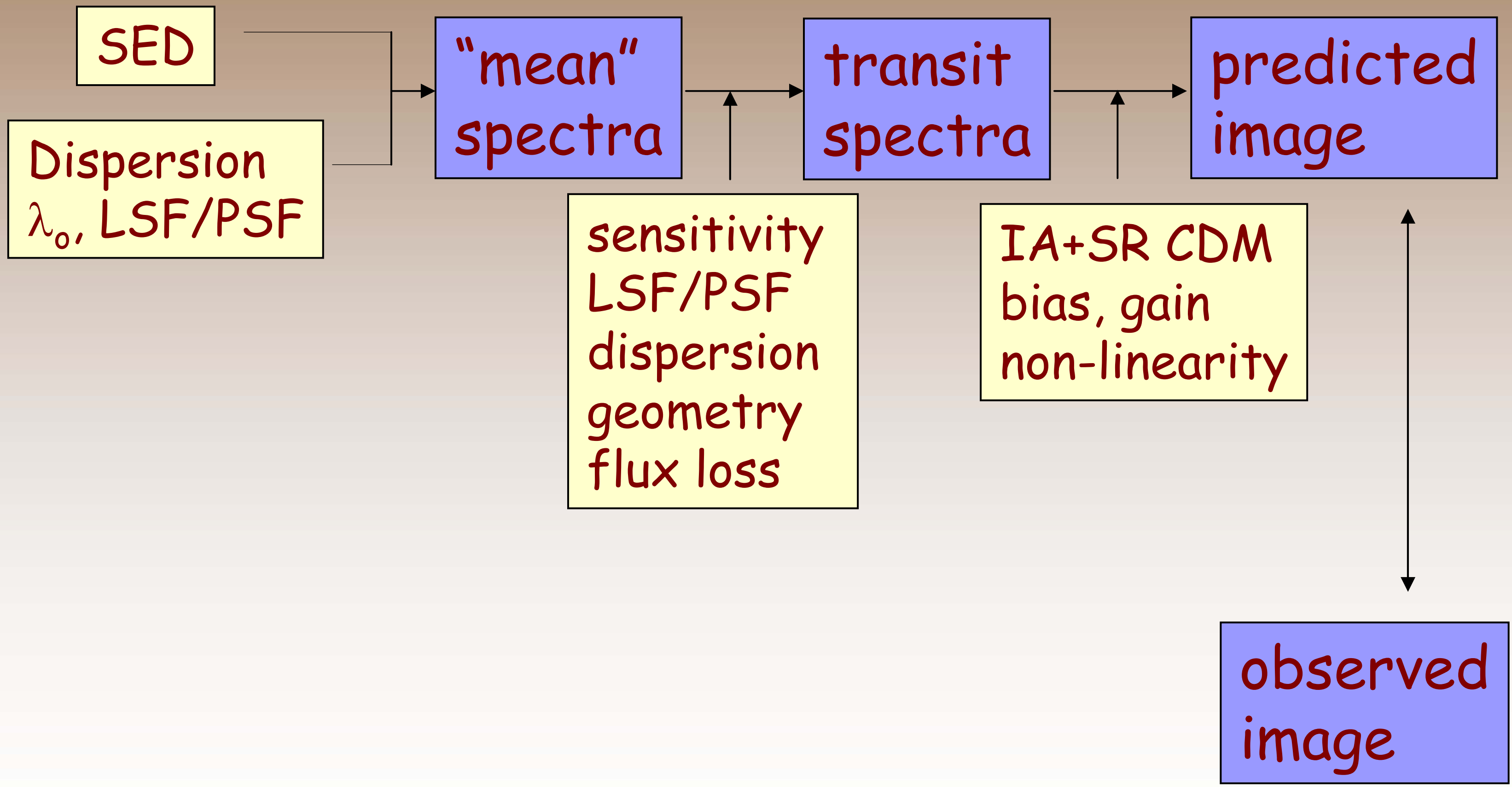
Flux, LSF, disp, λ_o

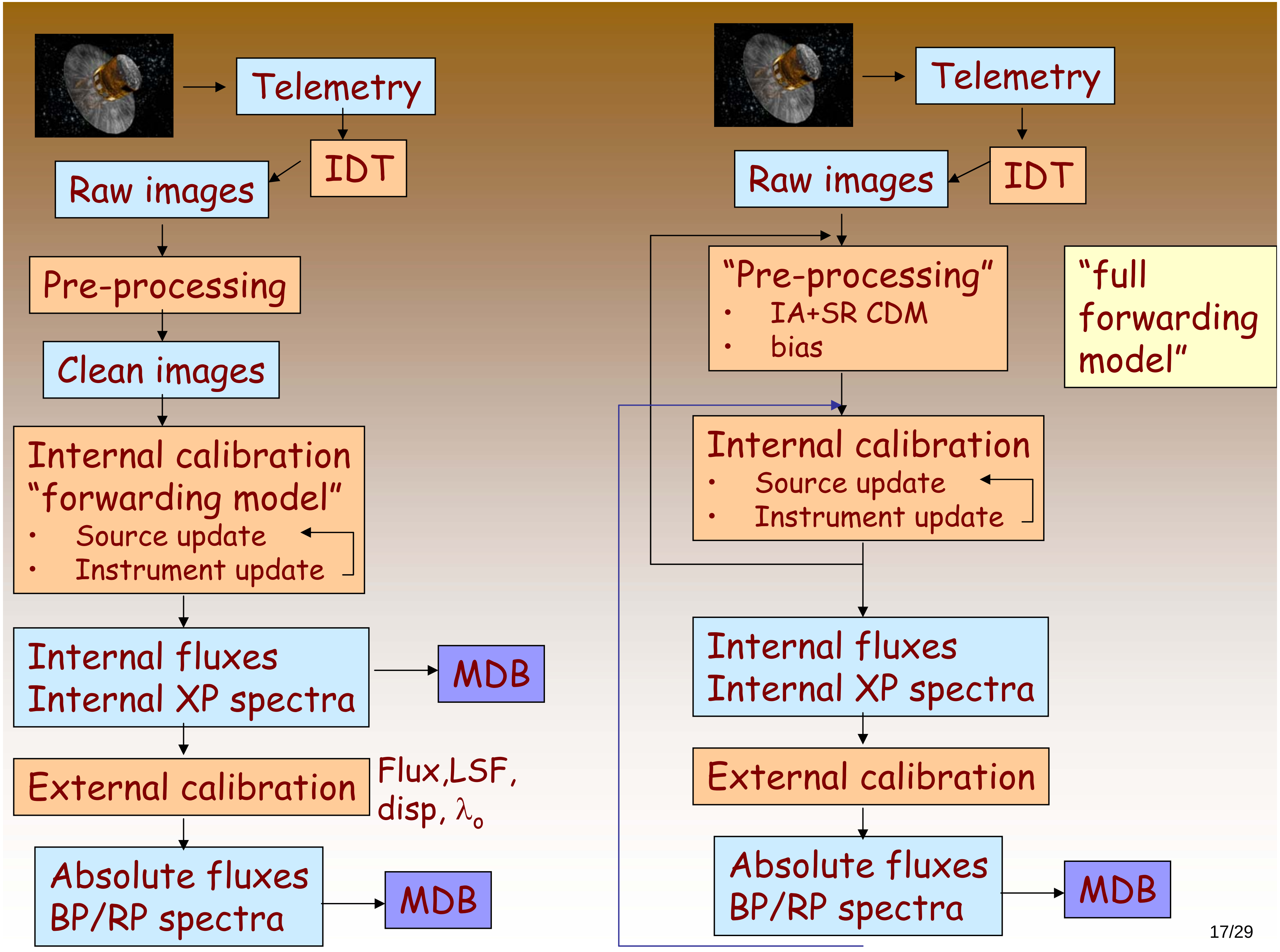
Absolute fluxes
BP/RP spectra

MDB



Full forwarding model

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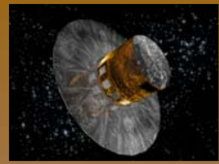


Telemetry

IDT

Raw images

“Pre-processing”
- IA+SR CDM
- bias

“full forwarding model”

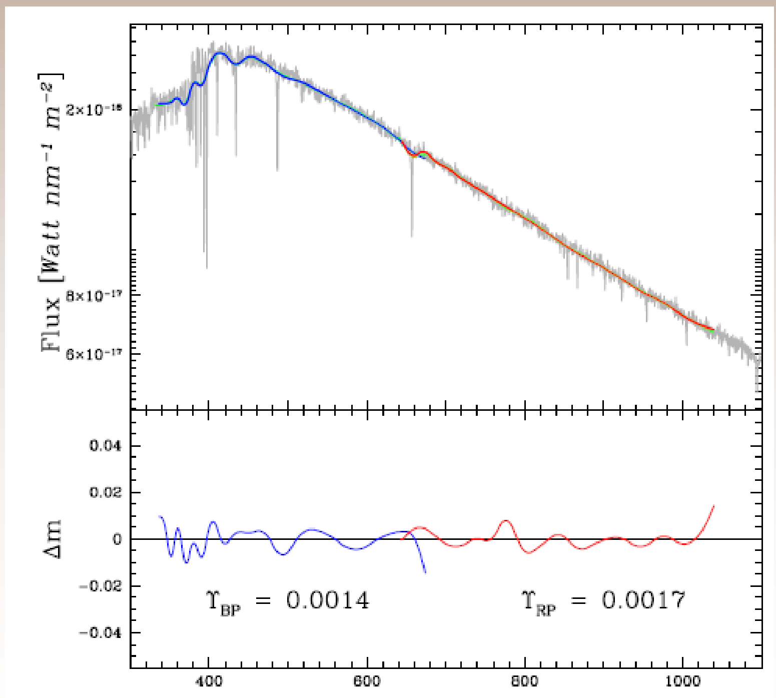
Internal calibration
- Source update
- Instrument update

Internal fluxes
Internal XP spectra

External calibration

Absolute fluxes
BP/RP spectra

MDB



Performances

Simple model for G calibration

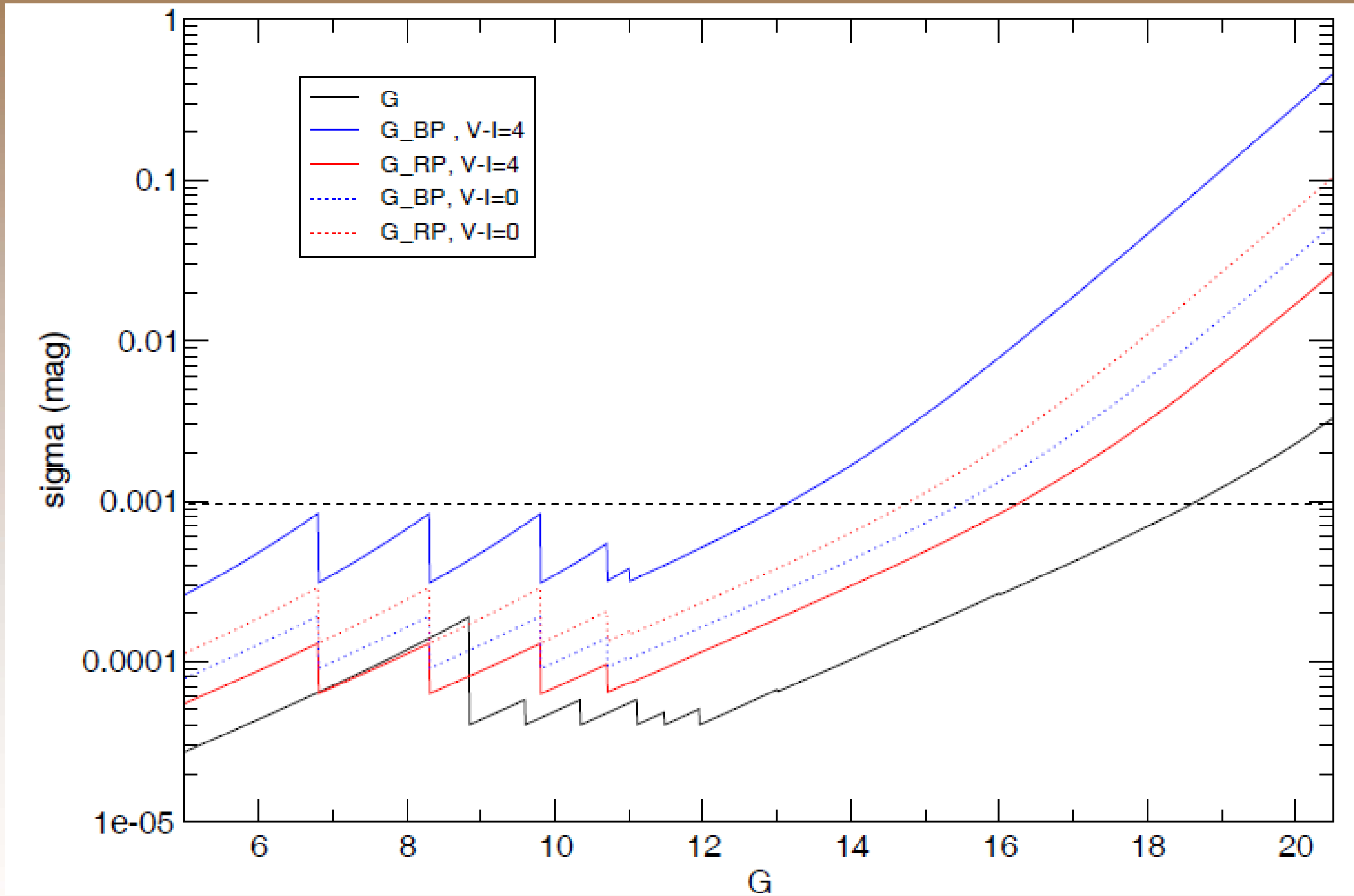
Grey variation

Wavelength dependence

$$
\begin{aligned}
f_i = {} & (A_0 + a_0) \cdot g_i + (A_1 + a_1) \cdot (bp_i - rp_i) + (A_2 + a_2) \cdot (bp_i - rp_i)^2 / g_i + \\
& + (A_3 + a_3) \cdot (bp_i - rp_i)^3 / g_i^2 + (A_4 + a_4) \cdot (bp_i - rp_i)^4 / g_i^3 + \\
& + (A_5 + a_5) \cdot (bp_i - rp_i)^5 / g_i^4 + (B_0 \cdot \Delta x_i + B_1 \cdot \Delta x_i^2 + \\
& + B_2 \cdot \Delta x_i^3) \cdot g_i + (C_0 \cdot v_i + C_1 \cdot v_i^2) \cdot g_i
\end{aligned}
$$

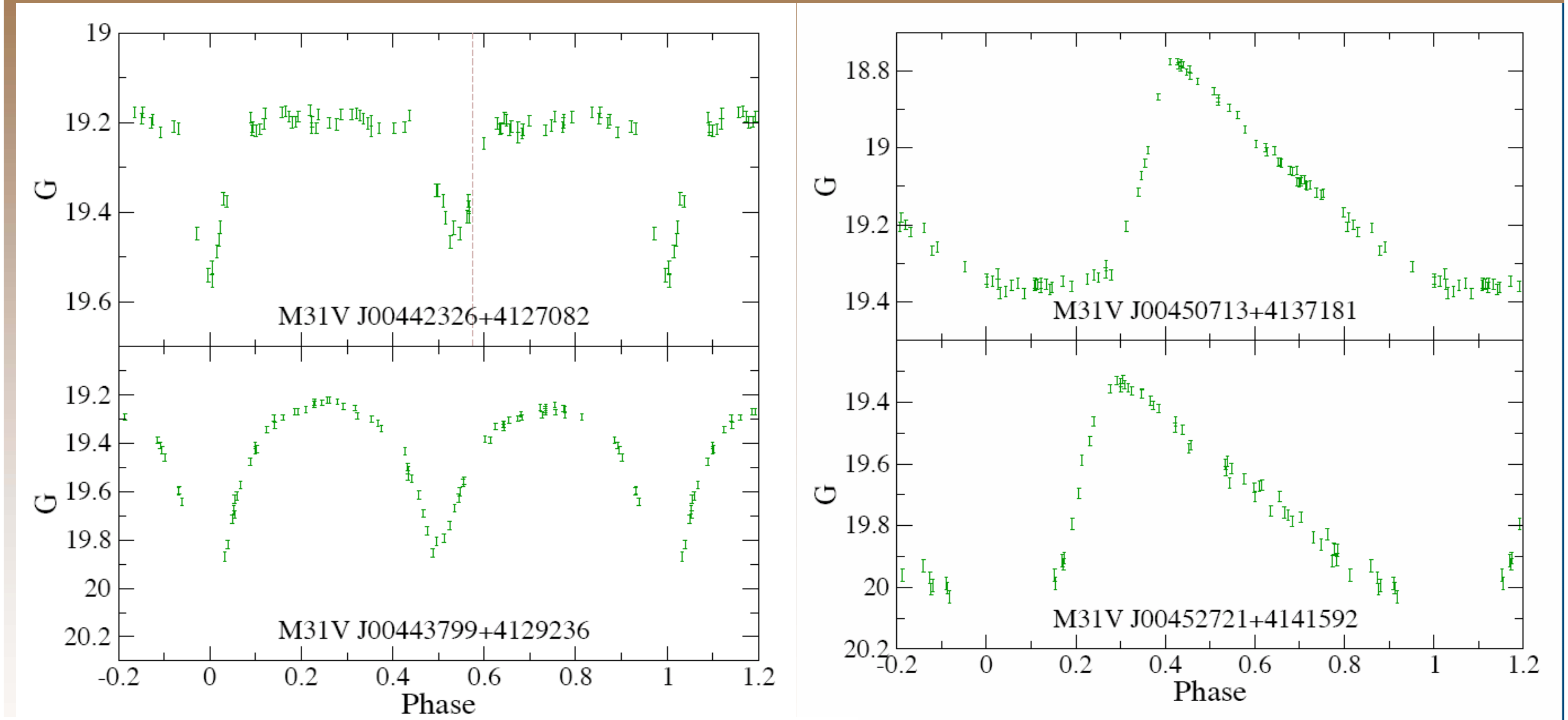
Flux in the window

end-of-mission σ_G



Aperture photometry

Variability



Light curves of stars in M31 Vilardell et al (2007)

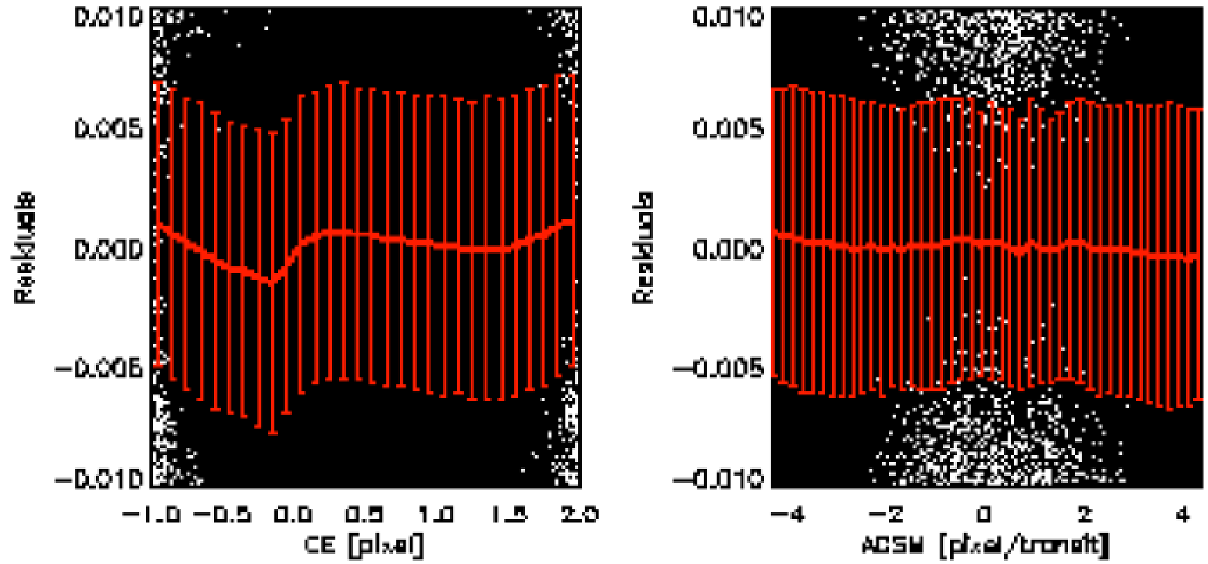
G magnitude

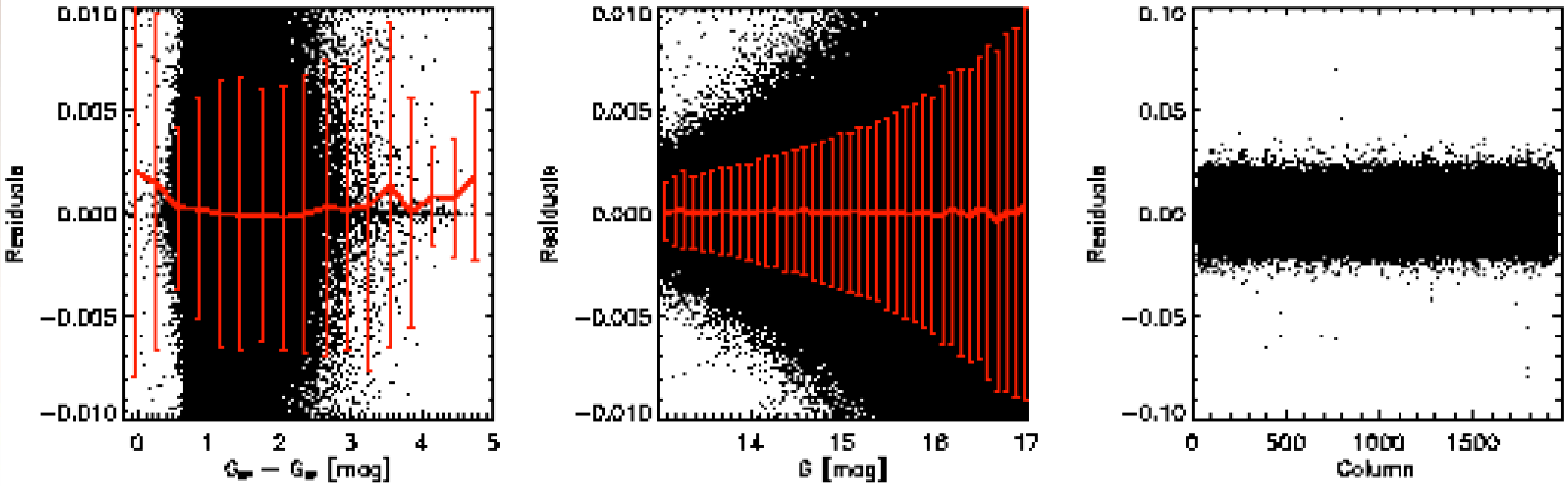
HV-005

GASS: 1 day

13<G<17

350,000 transits





Conclusions (I)

G calibration

- calibration errors at the level of mmag
- CTI in IA & SR not accounted for
- bias and background uncertainties
- non-linearity & saturation under study
- bright stars performances to be assessed

- limited by performance of extraction image parameters

Simple model for BP/RP calibration

$$f_i = \sum_{j=-M}^{+M} a_{ij} \cdot h_{i+j}$$

$$a_{ij} = \sum_{l=0}^{L} c_{jl} \cdot (i - i_{ref})^l$$

$$h_i = \sum_{k=1}^{N_{knots}} b_k \cdot B_{k,i}$$

$$f_i = \sum_{j=-M}^{+M} \sum_{k=1}^{N_{knots}} \sum_{l=0}^{L} c_{jl} \cdot b_k \cdot (i - i_{ref})^l \cdot B_{k,i+j}$$

Instrument calibration

Source update

Assumptions when calibrating the instrument:

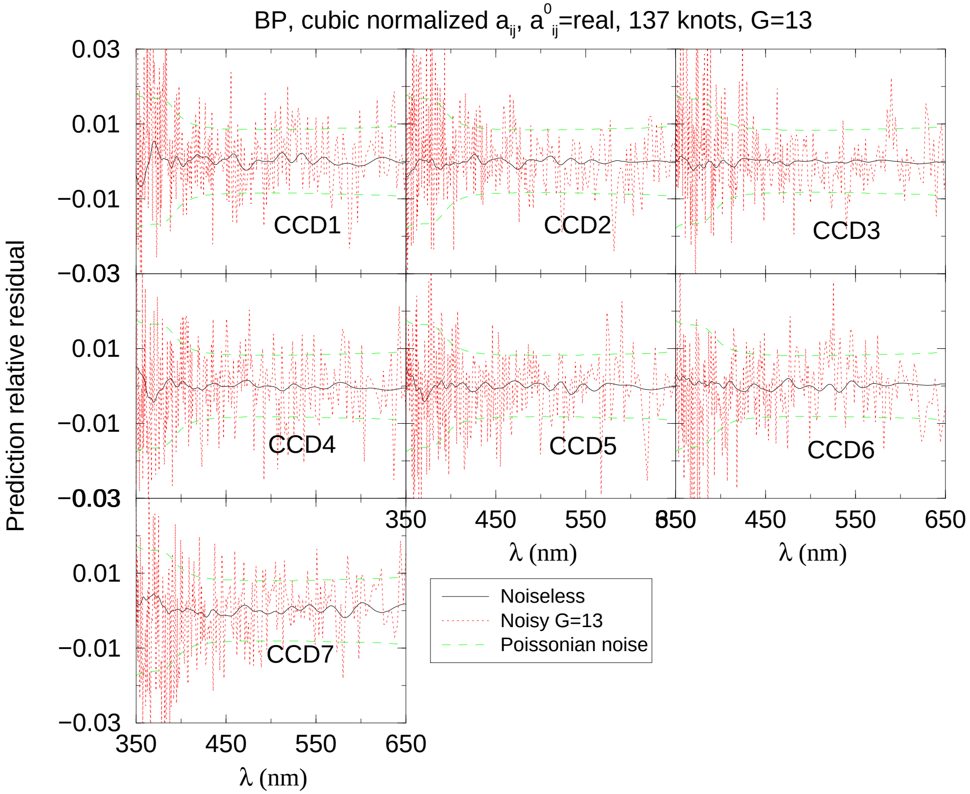
- Only performed using calibration sources.
- The equations system consist on all observations of all calibration sources performed using the same instrumental configuration (same CCD, FoV, column, gate, dispersion, LSF, geometry, ...) and fitting parameters for a given pixel i.
- The unknowns are c_{jl}.
- b_k (different for each calibration source) are considered as known.

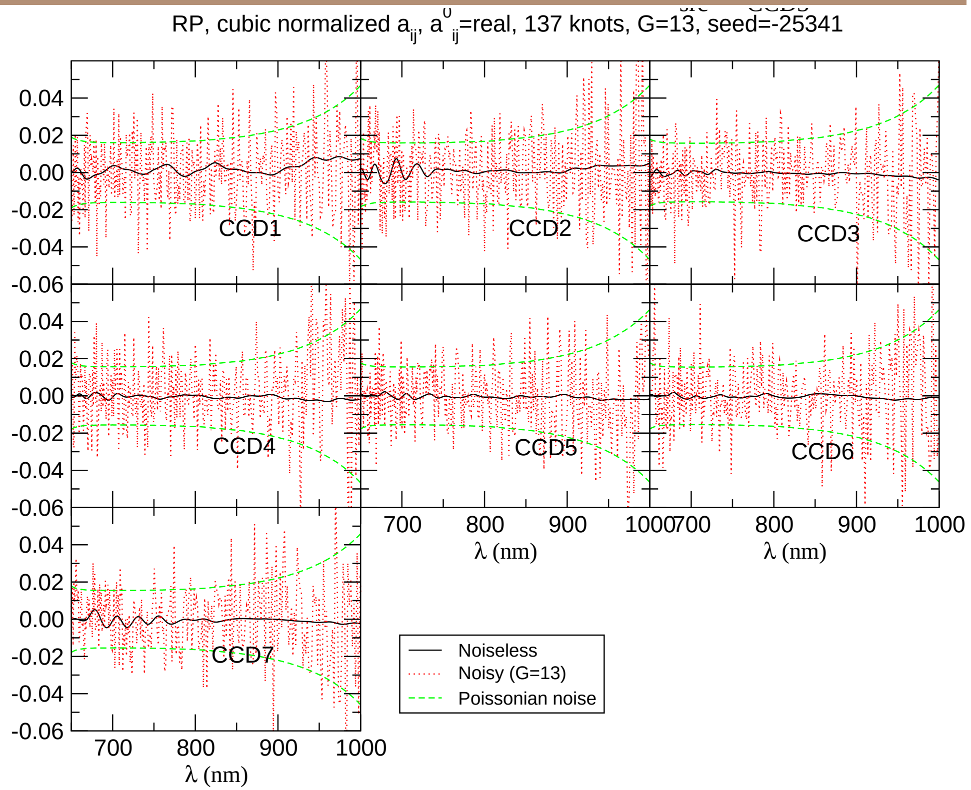
Assumptions when producing mean spectrum:

- To be done for every source, not only calibration sources (but for the iterative loop perhaps only calibration sources are needed).
- The equations system is formed by all observations at the same source, independently of the instrumental configuration. used, and using all observed pixels in a single equations system.
- The unknowns are b_k.
- c_{jl} (different for each instrumental configuration) are considered as known.

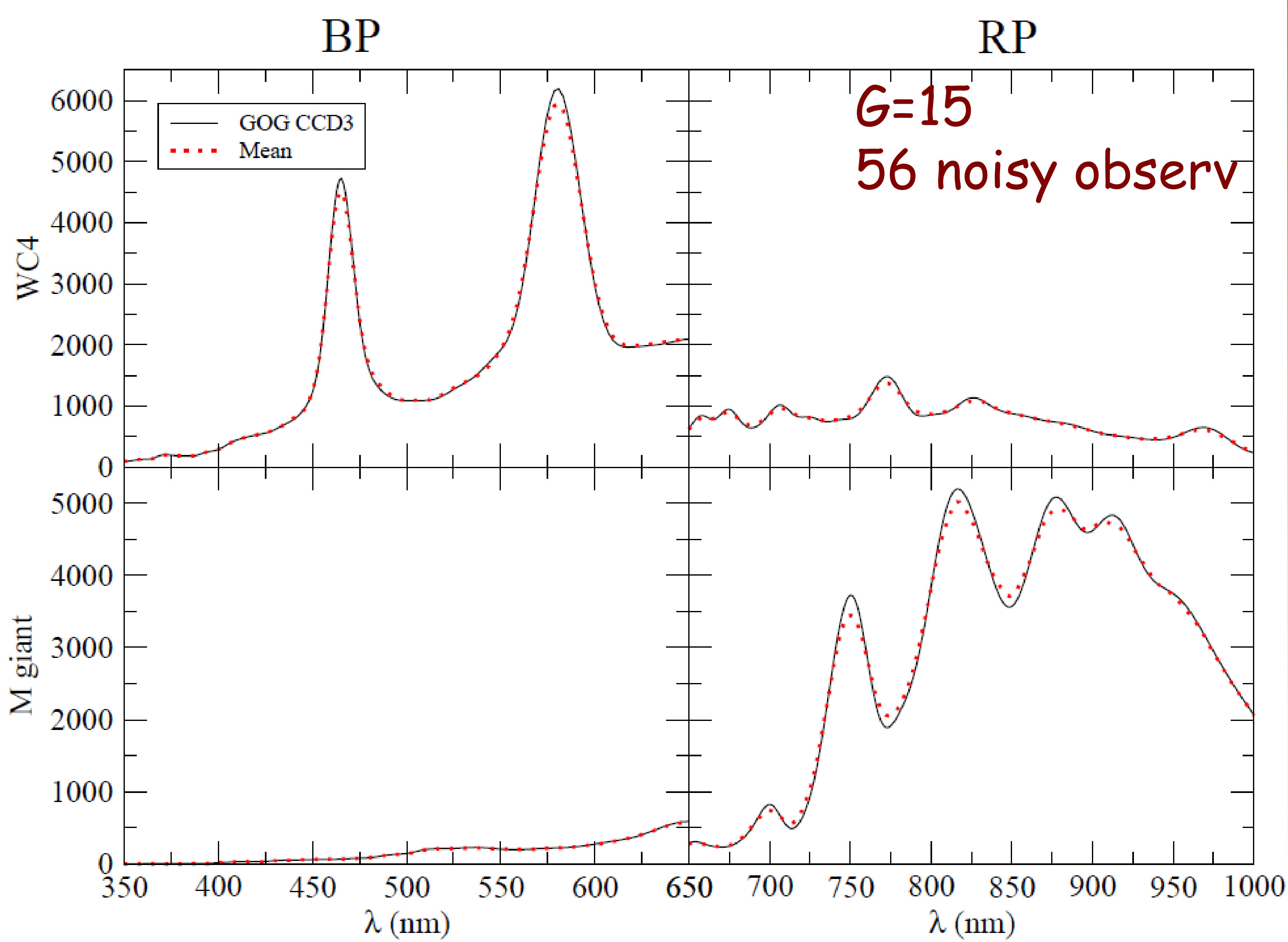
Relative residuals in prediction

T=50000K, logg=5.0, 56 obs, $\lambda_{src}=\lambda_{CCD3}$





Hot star: T=50000K, logg=5



BP
RP
G=15
56 noisy observ
GOG CCD3
Mean
WC4
M giant
λ (nm)
λ (nm)

Conclusions (II)

BP/RP spectra calibration

- calibration errors below observational noise

- CTI in IA & SR not accounted for
- bias and background uncertainties
- non-linearity & saturation

- improvement of the simple model by the full forwarding model → to assess feasibility

See poster by G. Busso

Thank you

Photometric processing is a collaborative effort:
UK, The Netherlands, Italy, Spain