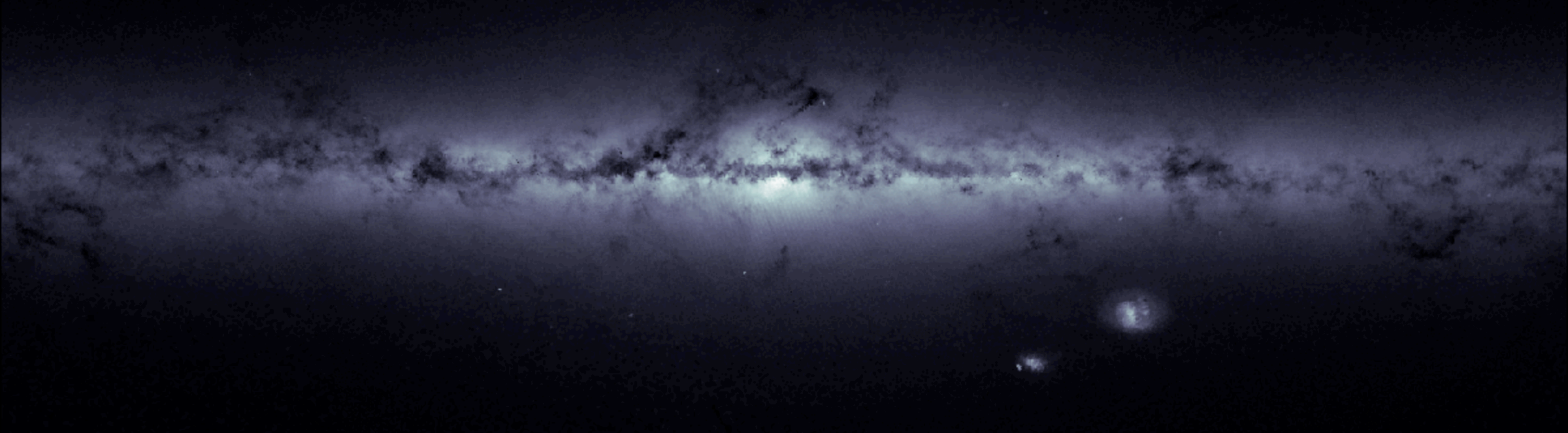
Gaia, an all-sky astrometric and photometric survey

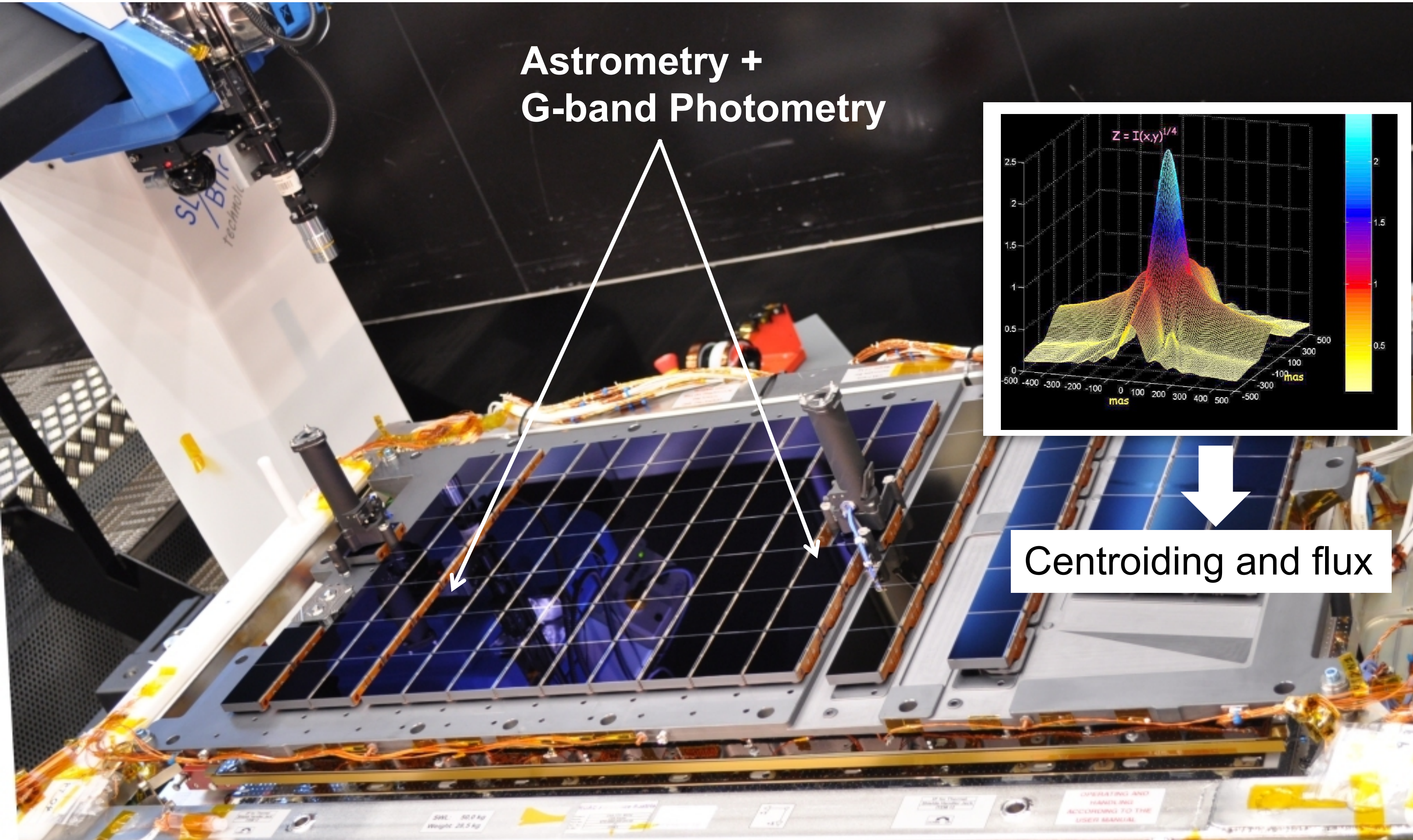
C. Jordi, JM. Carrasco, M. Weiler
on behalf of Gaia-photometry group
University of Barcelona, ICCUB-IEEC



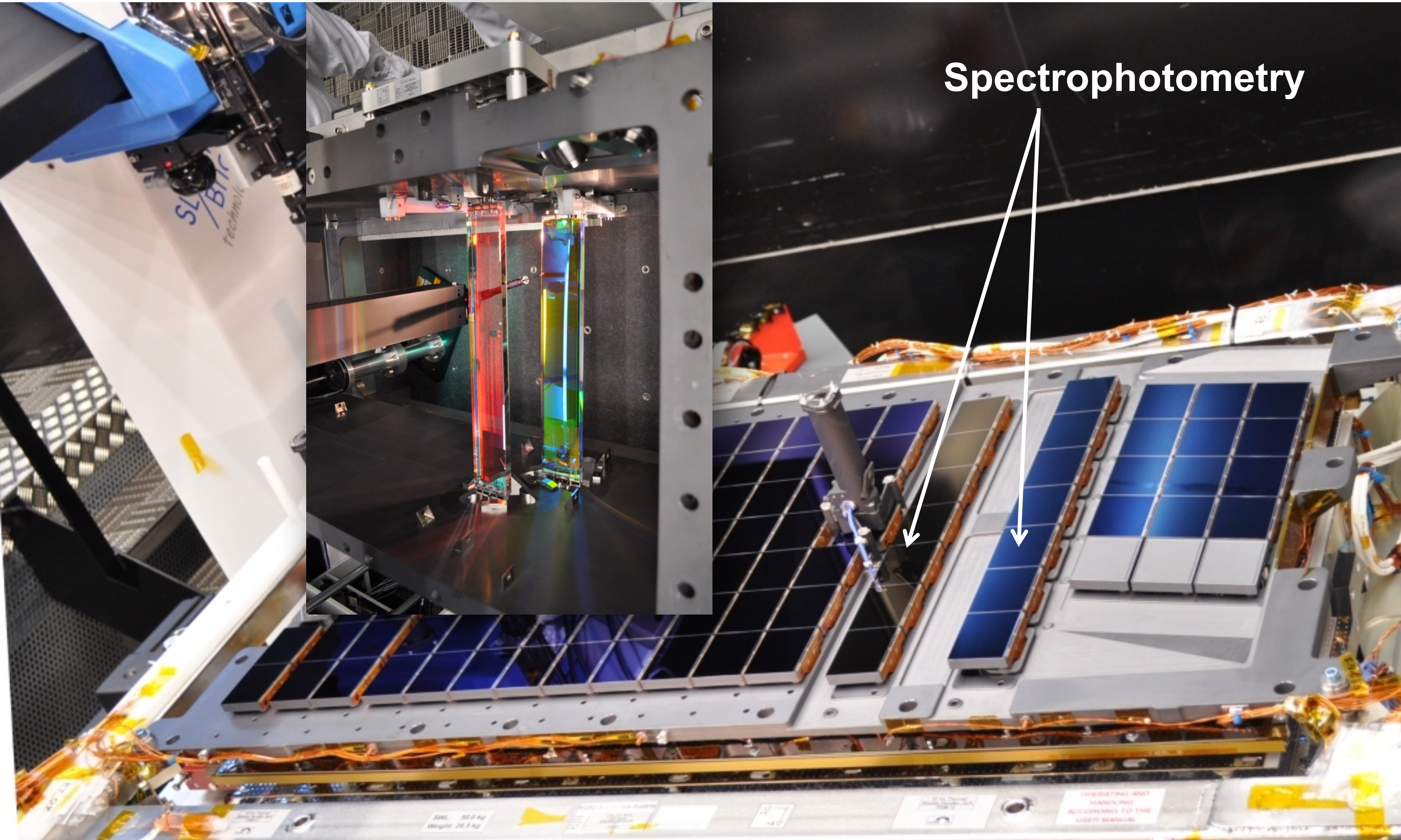
2016 Euclid Photometric Calibration Workshop, 20-23 Sep

The photometric instruments

Photometric instruments



Photometric instruments



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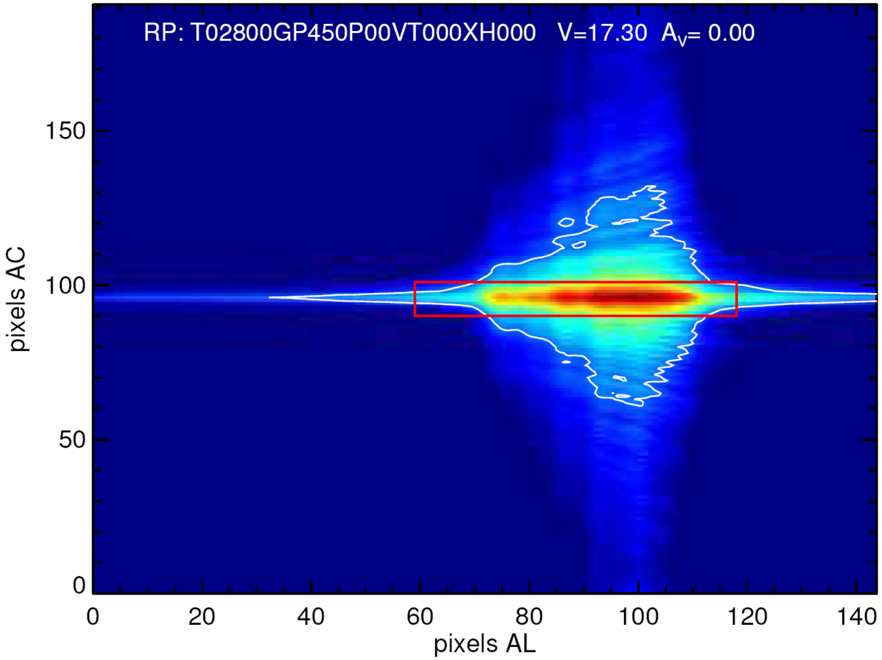
Spectrophotometry: instrument

Blue photometer:	330–680 nm	3-27 nm/pixel
Red photometer:	640–1050 nm	7-15 nm/pixel



Figures courtesy of DPAC

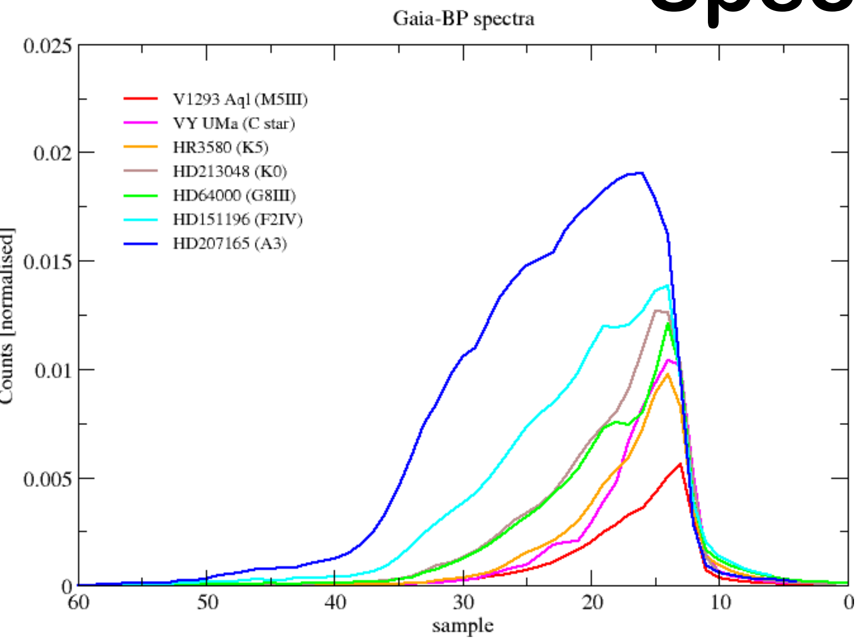
Red spectra of a M-dwarf (V=17.3)

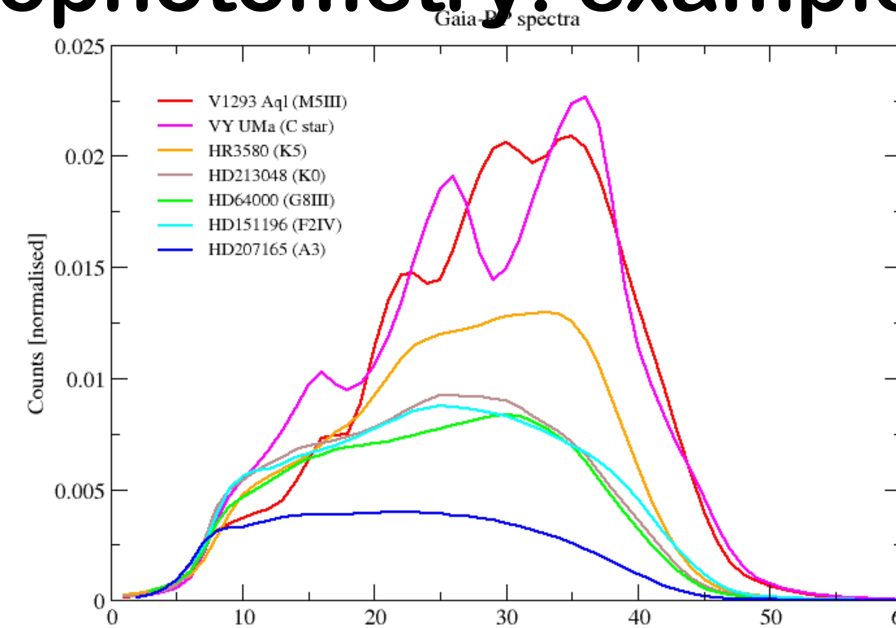
Red box: extracted window sent to the Earth

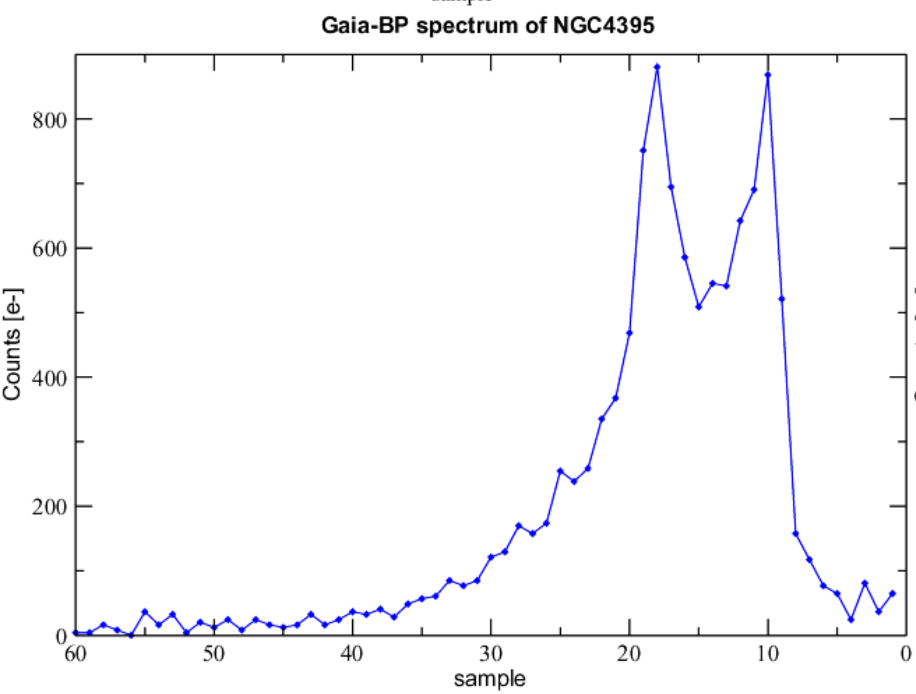
Window size: 60x12 = 3.54” x 2.12”

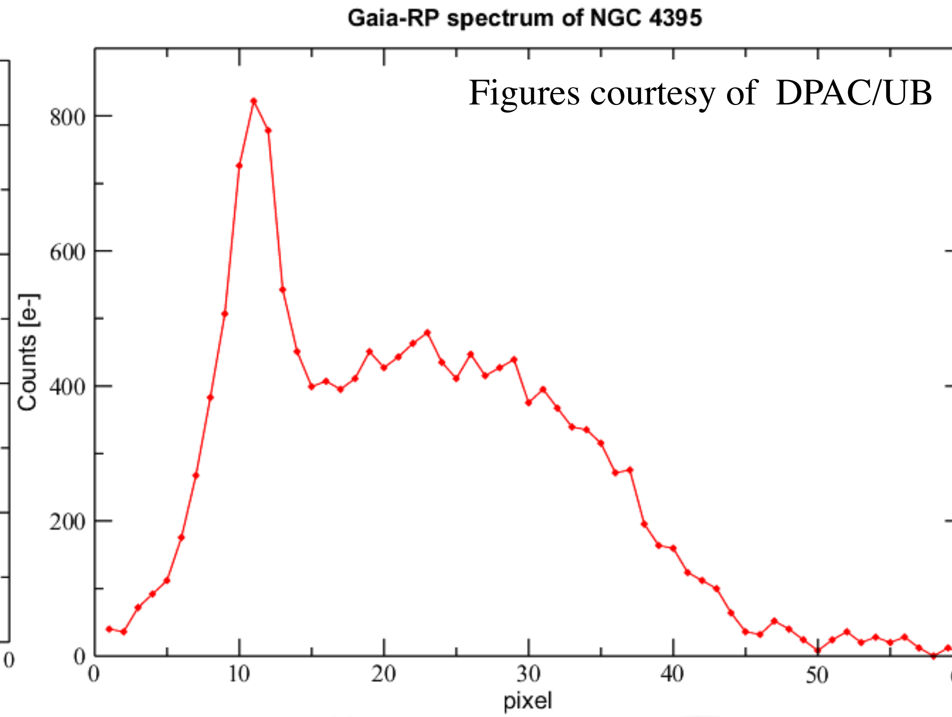
2D and 1D windows

Spectrophotometry: examples









Figures courtesy of DPAC/UB

Photometry processing: PhotPipe

Instrumental effects and calibration

UNITS OF CALIBRATION = “instrument”

- FoV
- Gate
- Window class
- AC position
- Time

INSTRUMENTAL EFFECTS

- Sensitivity (optics+CCDs)
- Aperture
- Background & straylight
- Gain, bias, CTI
- PSF/LSF (saturation)
- Contamination
- BP/RP blending
- Geometry
- Dispersion

It is unfeasible to have enough standard sources available

Principles of processing: self-calibration

Variety of “instruments”:

CCDs, columns, telescopes, with time variation

Variety of configurations:

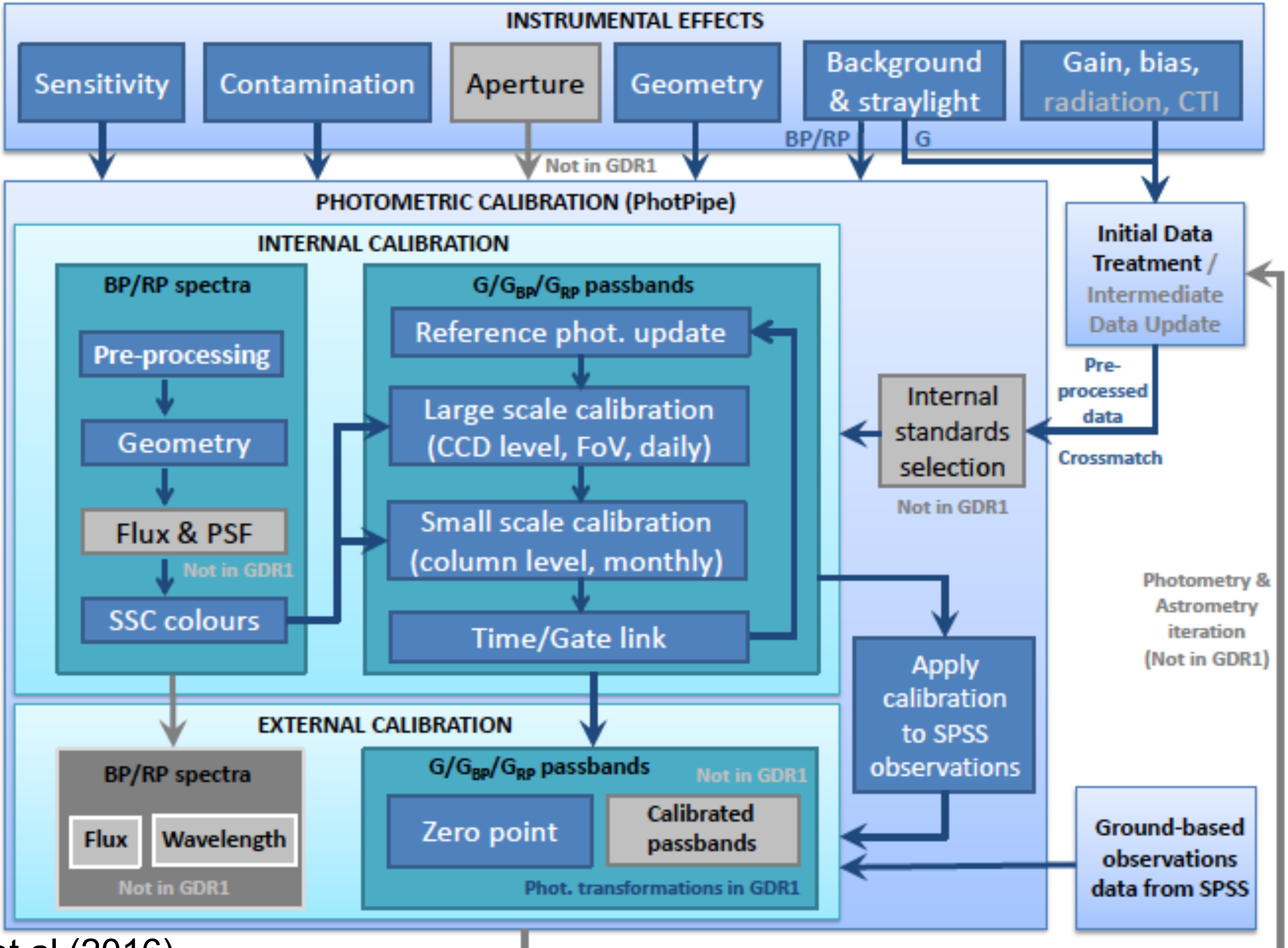
1D, 2D, narrow & large windows, gates, …

Variety of sources (stars, galaxies, QSO, …)
Observed by the different instruments
Some sources are observed with different configurations
All sources are observed through the mission (monitor the time variation)

Calibration of differences among instruments and configurations
All “well-behaved” sources can be used as internal standards

1 billion sources → if only 10% are “well-behaved”
→ 100 million sources as standards

PhotPipe structure



Carrasco et al (2016)

Internal calibration model in GDR1

Initialization: $$\overline{I_s} = \sum_k I_{sk} \frac{w_k}{\sum_k w_k}$$

Selection of internal standard sources:
constant sources (all sky, all colours, all types, full range of magnitudes)

Calibration:

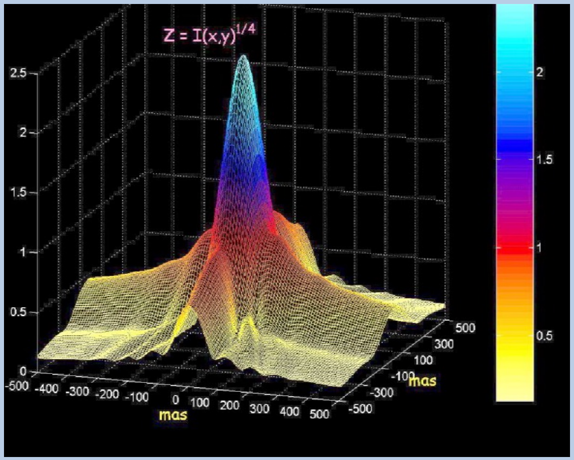
$$\frac{I_{skll'}}{\overline{I_s}} = \mathrm{LS}_{skl} \cdot \mathrm{SS}_{skl'} \quad \begin{cases} \mathrm{LS}_{skl} = \sum_{m=1}^{M} \sum_{r=0}^{R} A_{rml} \cdot (C_{sm})^r + \sum_{j=0}^{J} B_{jl} \cdot (\mu_k)^j \\ \mathrm{SS}_{skl'} = \sum_{m'=1}^{M'} \sum_{r'=0}^{R'} a_{r'm'l'} \cdot (C_{sm'})^{r'} \end{cases}$$

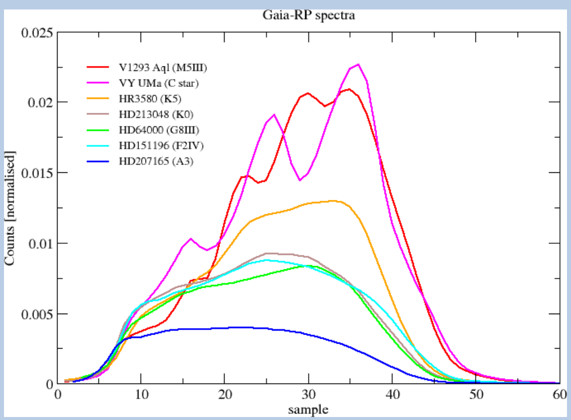
Source update: $$\overline{I_s} = \sum_k I_{sk} \frac{w_k}{\sum_k w_k} \Big/ \mathrm{LS}_{skl} \cdot \mathrm{SS}_{skl'}$$

Carrasco et al (2016)

PhotPipe:

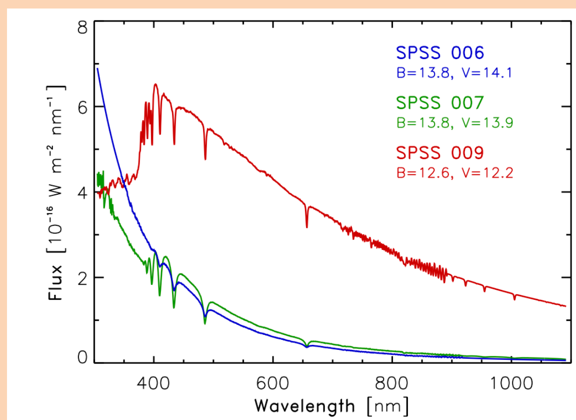
Observations



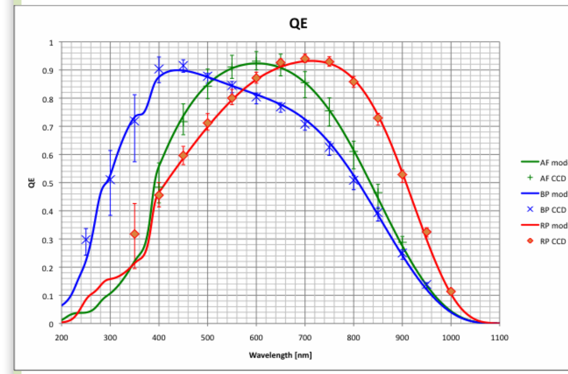


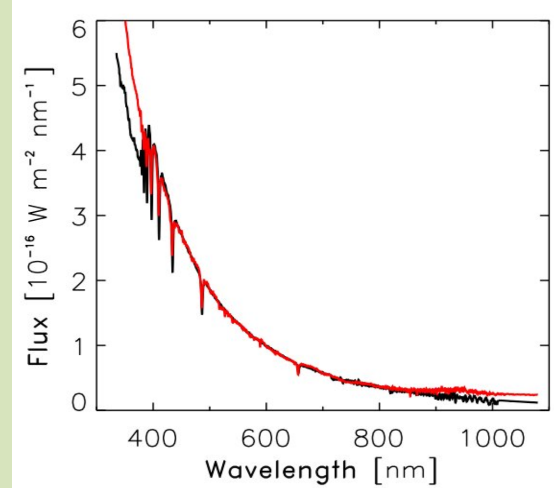
Calibration

- Internal calibrators
  millions of sources
- External calibrators
  ~ 200 SPSS
  (Pancino et al 2012)



Output





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Calibration units

Number of calibration units (CU) in DR1 (14 months)

Instrum.	Scale	N_{rows}	N_{strips}	$N_{gate/WC}$	N_{FoV}	N_{AC}	N_{time}	N_{CU}
AF	LS	7	8/9	10	2	-	420	520 000
AF	SS	7	8/9	10	-	492	1	305 000
BP/RP	LS	7	1	6	2	-	420	35 000
BP/RP	SS	7	1	6	-	492	1	21 000

- AF

Large scale (LS): 1240 CU / unit-time (unit-time = day)
Small scale (SS): 305,000 CU / unit-time (unit-time = 14 months in DR1)

- BP/RP

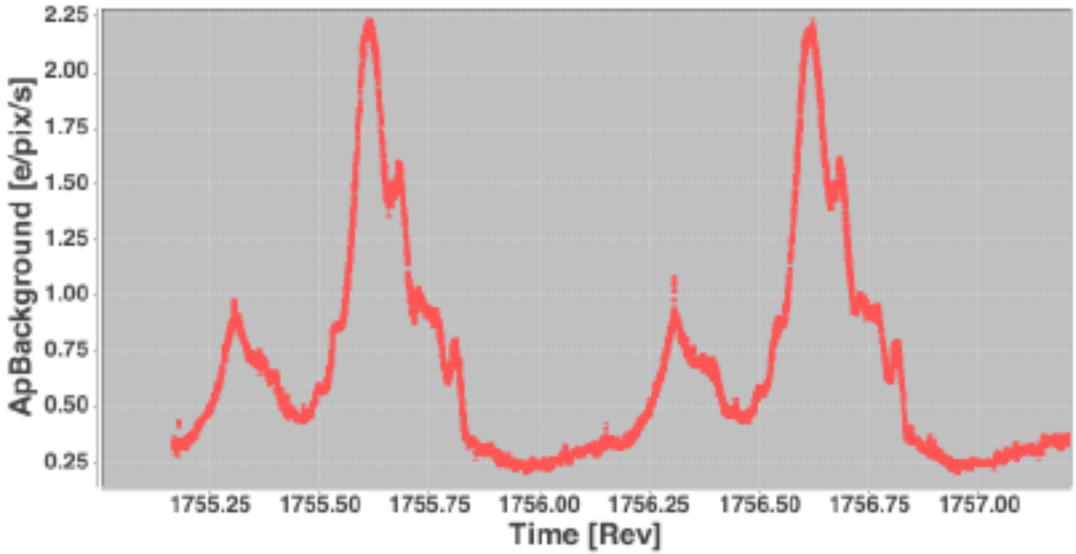
Large scale (LS): 84 CU / unit-time (unit-time = day)
Small scale (SS): 21,000 CU / unit-time (unit-time = 14 months in DR1)

Carrasco et al (2016)

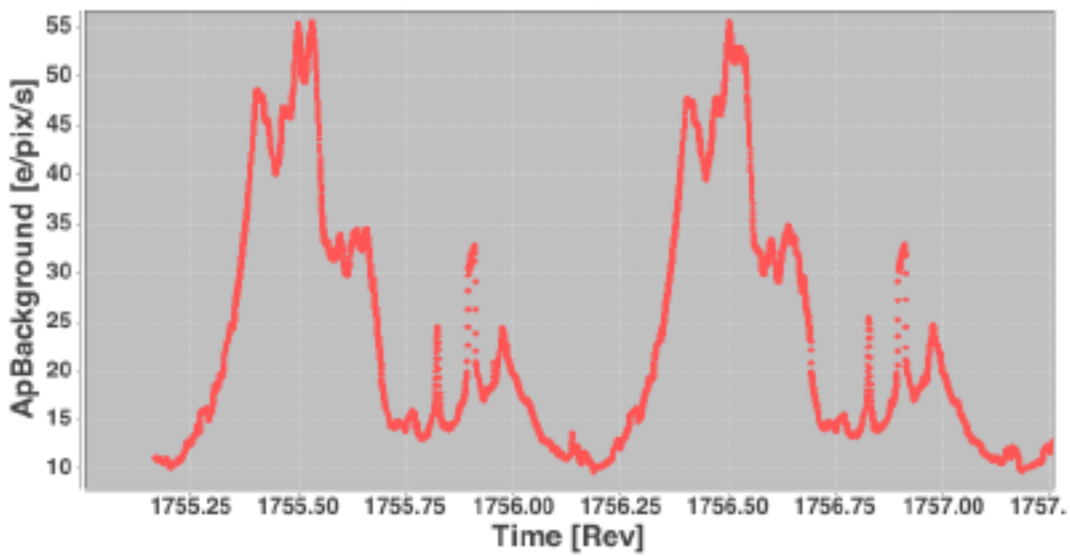
Instrumental effects

Background

Variation due to straylight



BP row 1

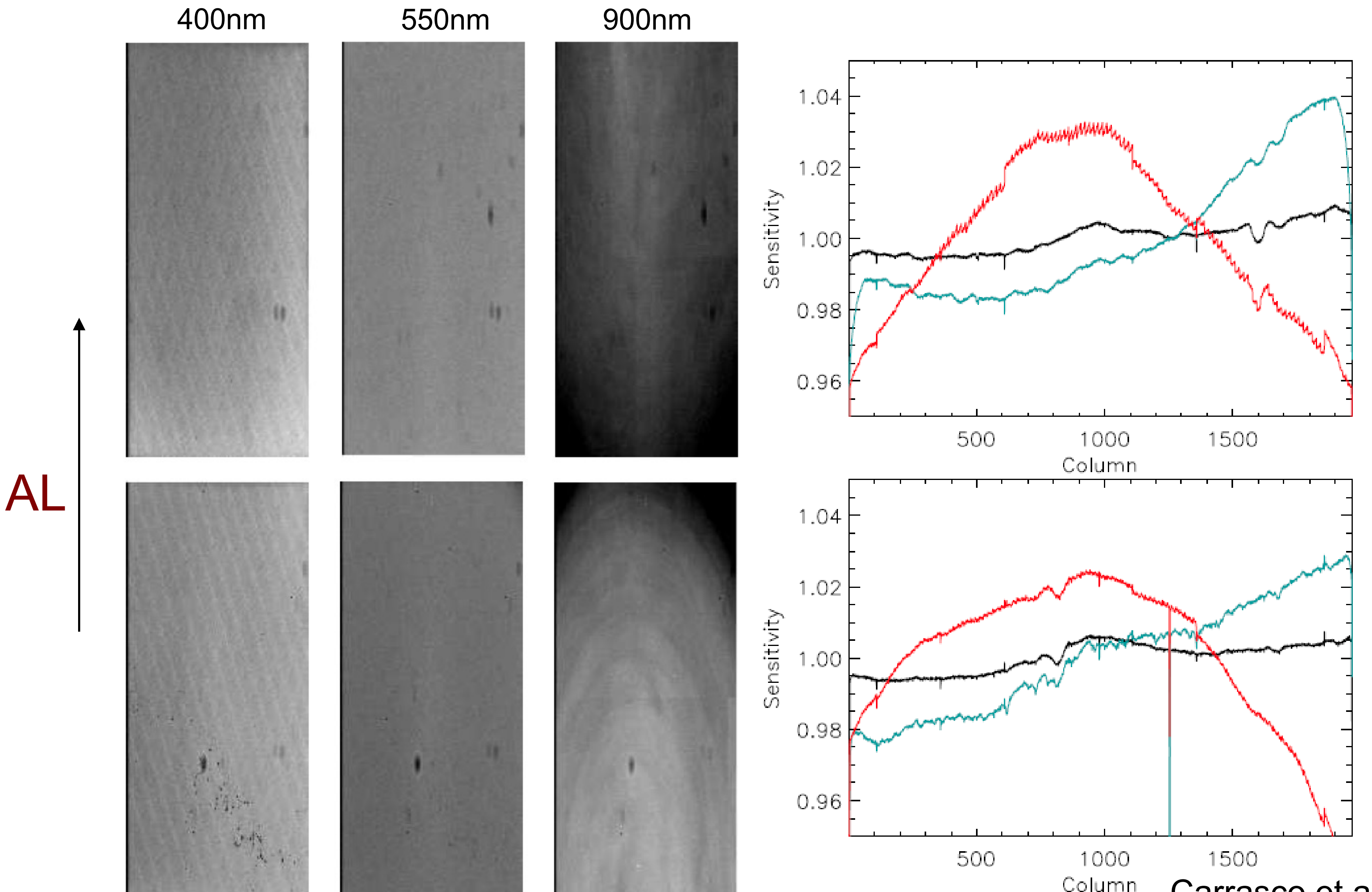


AF row 7

Fabricius et al (2016)

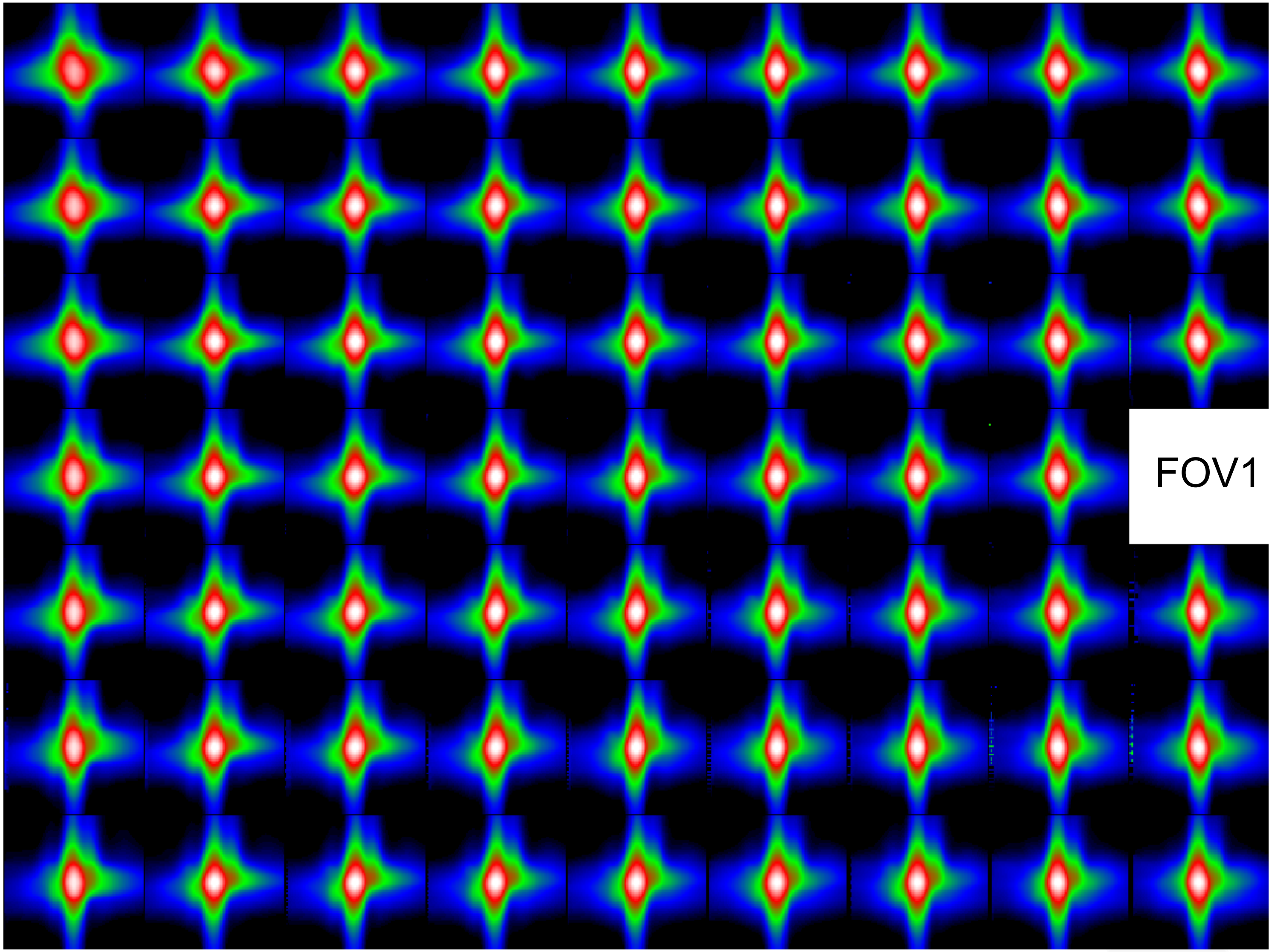
CCD flatfields

Examples

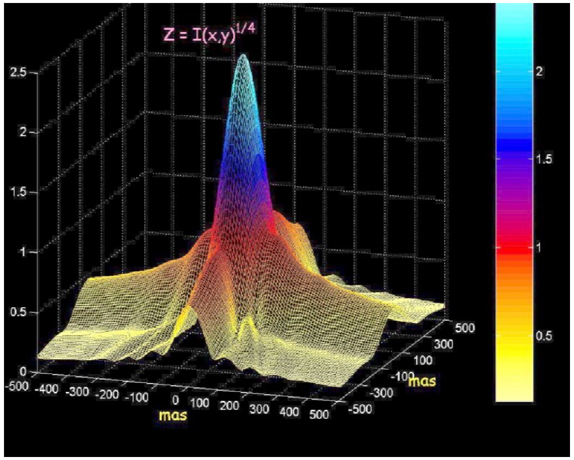


Carrasco et al (2016)

PSF map

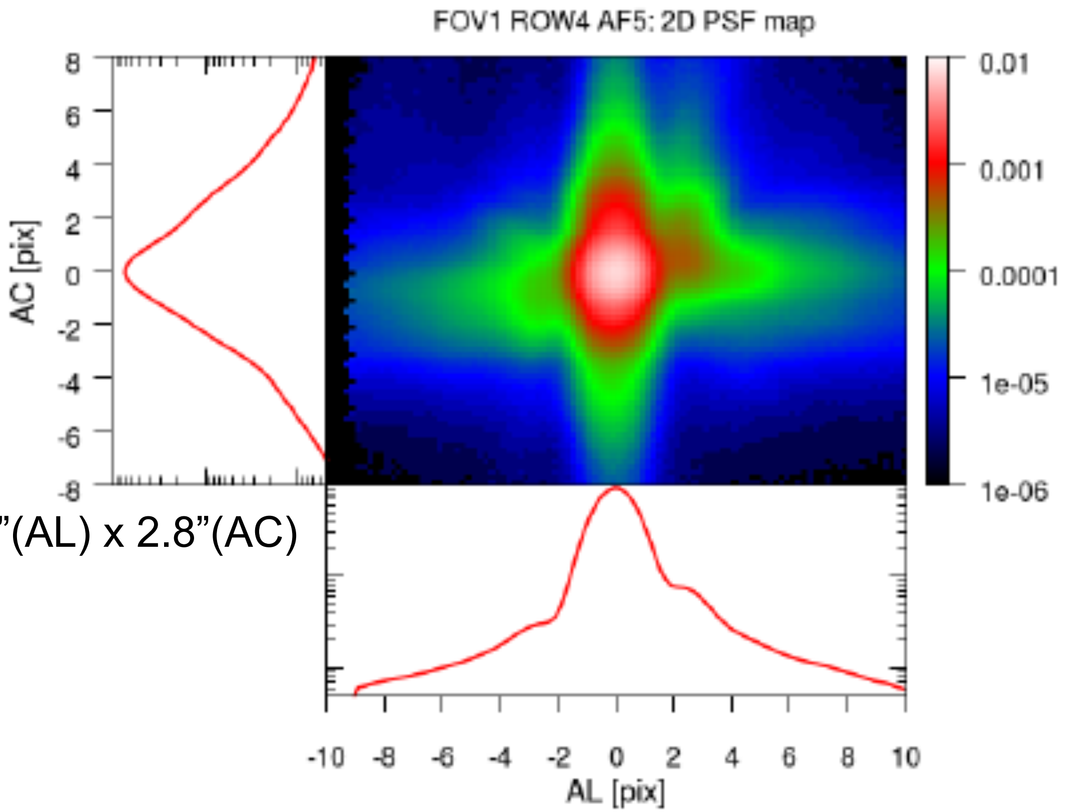


Aperture correction



Bright stars: 2D window, PSF fitting

Faint stars: 1D window, LSF fitting



Median AL FWHM = 103 mas

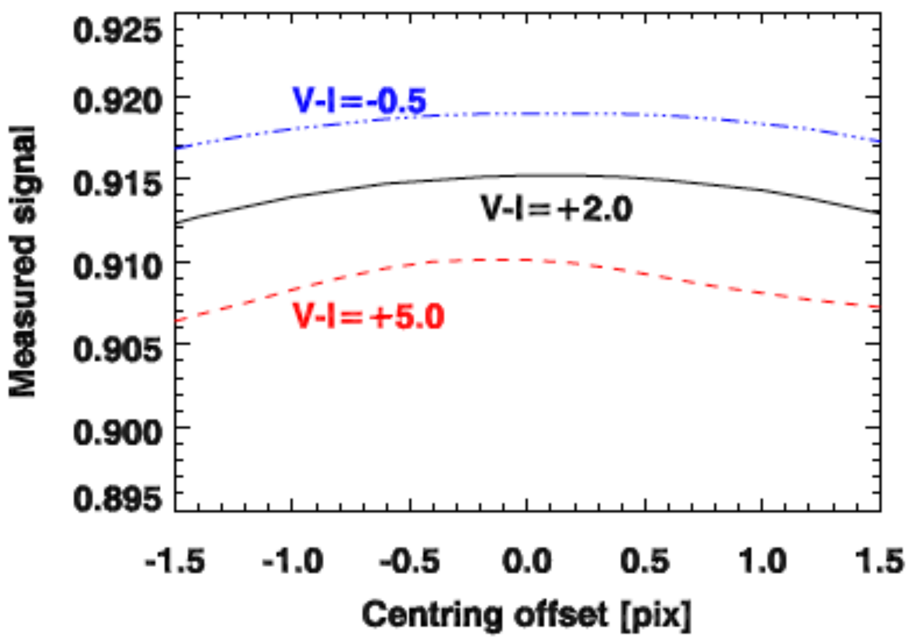
1.2"(AL) x 2.8"(AC)

Fabricius et al (2016)

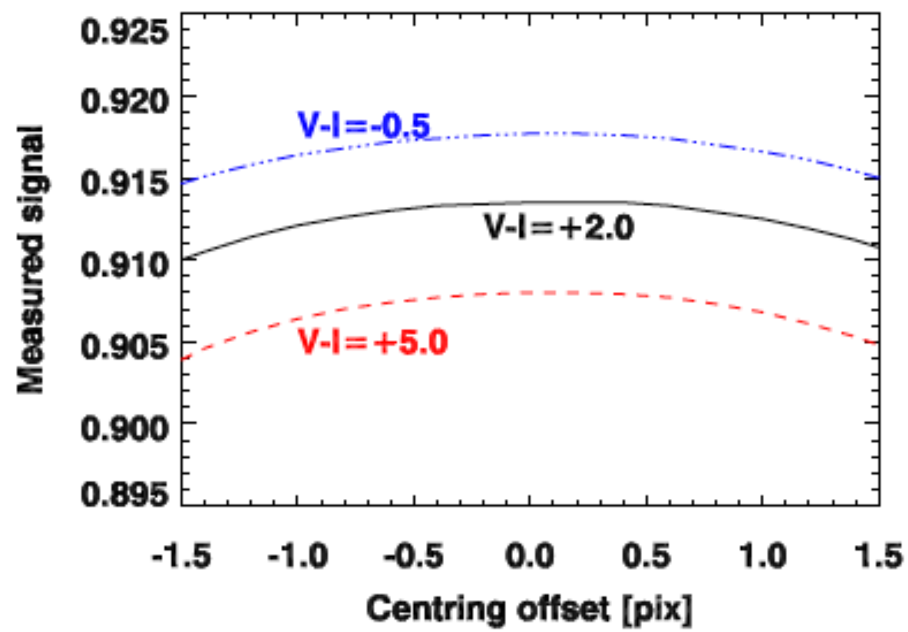
Aperture correction

1-2% variation

AF S9R1T2



No AC motion



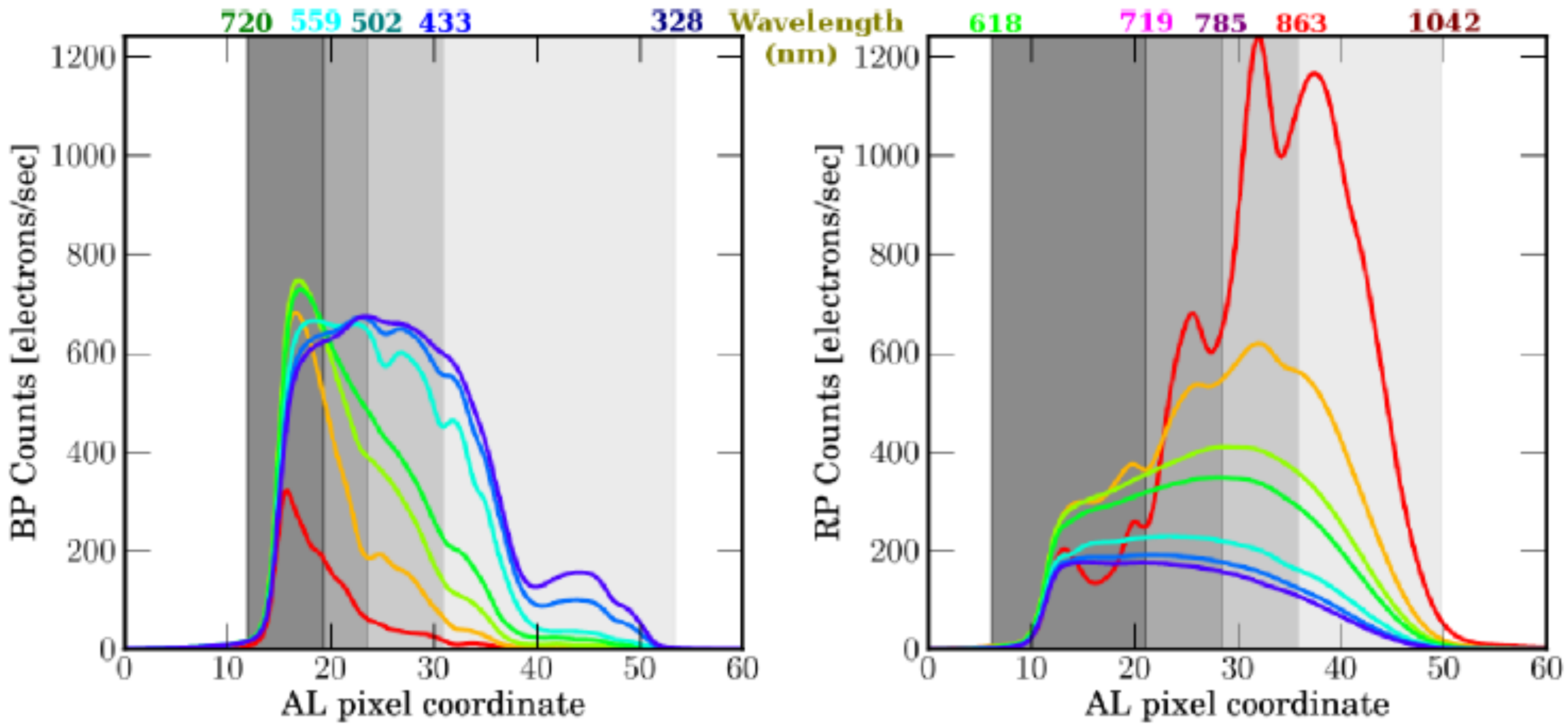
Maximum AC motion

Calibration as function of colour, centring offset and AC motion

Carrasco et al (2016)

Colour dependence

Colour dependence calibrated with Spectral Shape Coefficients
Linear terms for dependences



Steps not foreseen

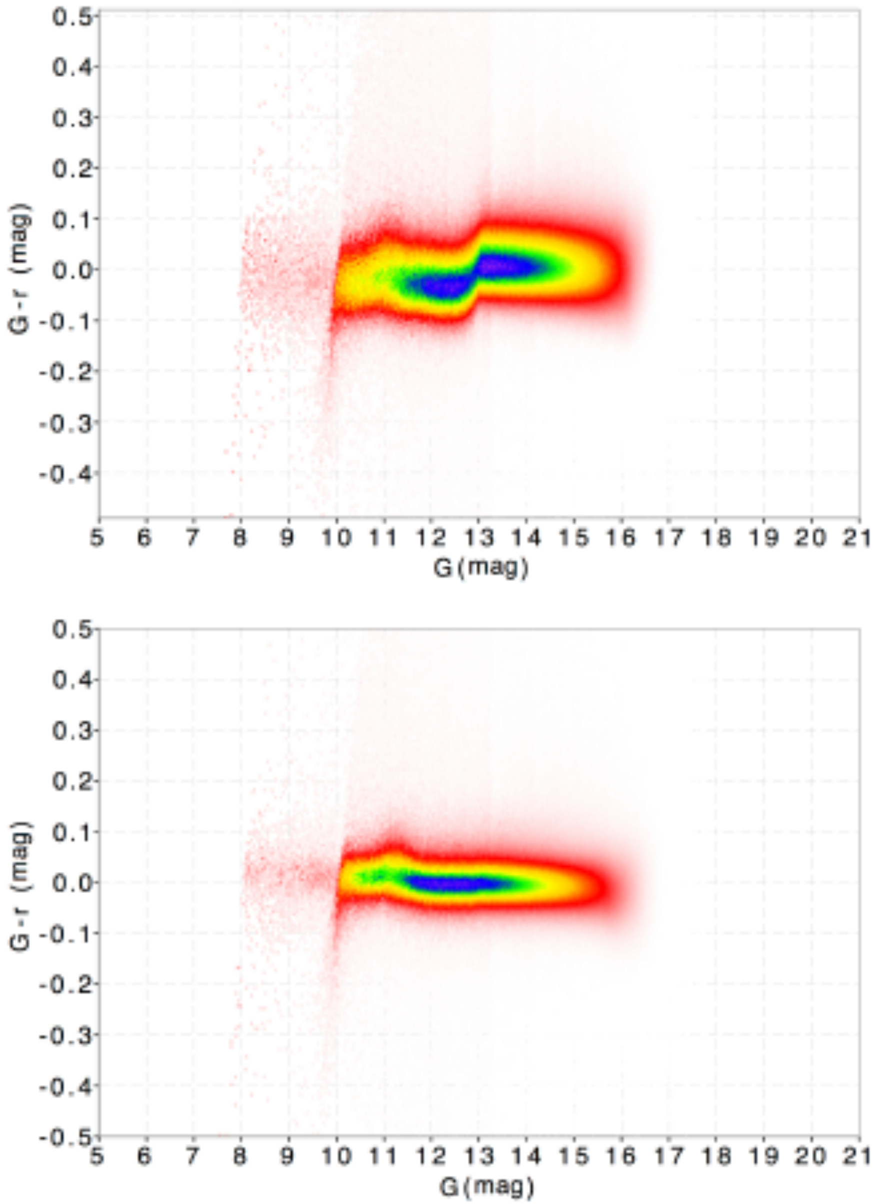
Mixing

- The several calibration units (CUs) are treated separately
- Every CU potentially defines a photometric instrument/system
- To converge to a unique ”mean” instrument, one needs a large amount of sources observed with different CUs
- If there is poor mixing, there will be differences among the several CUs

For DR1 (only 14 months with some gaps), we introduced additional steps:

- Gate/window link (to account for poor mixing)
- Time link (to account for decontamination events)

Gate/window link



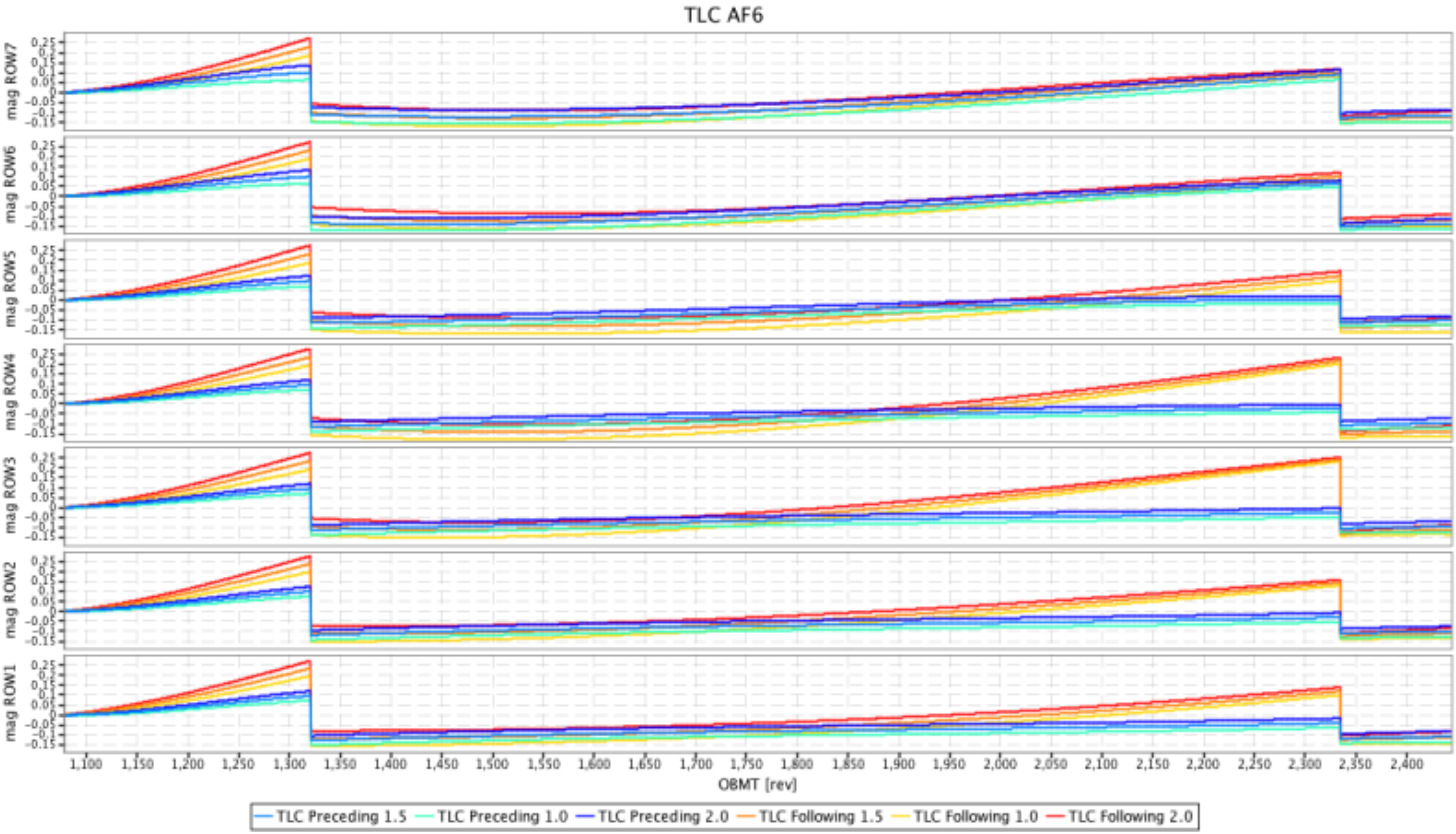
At G=13, acquisition windows change from 2D (PSF fitting) to 1D (LSF fitting)

Before calibration

After calibration

Carrasco et al (2016)

Time link (contamination)

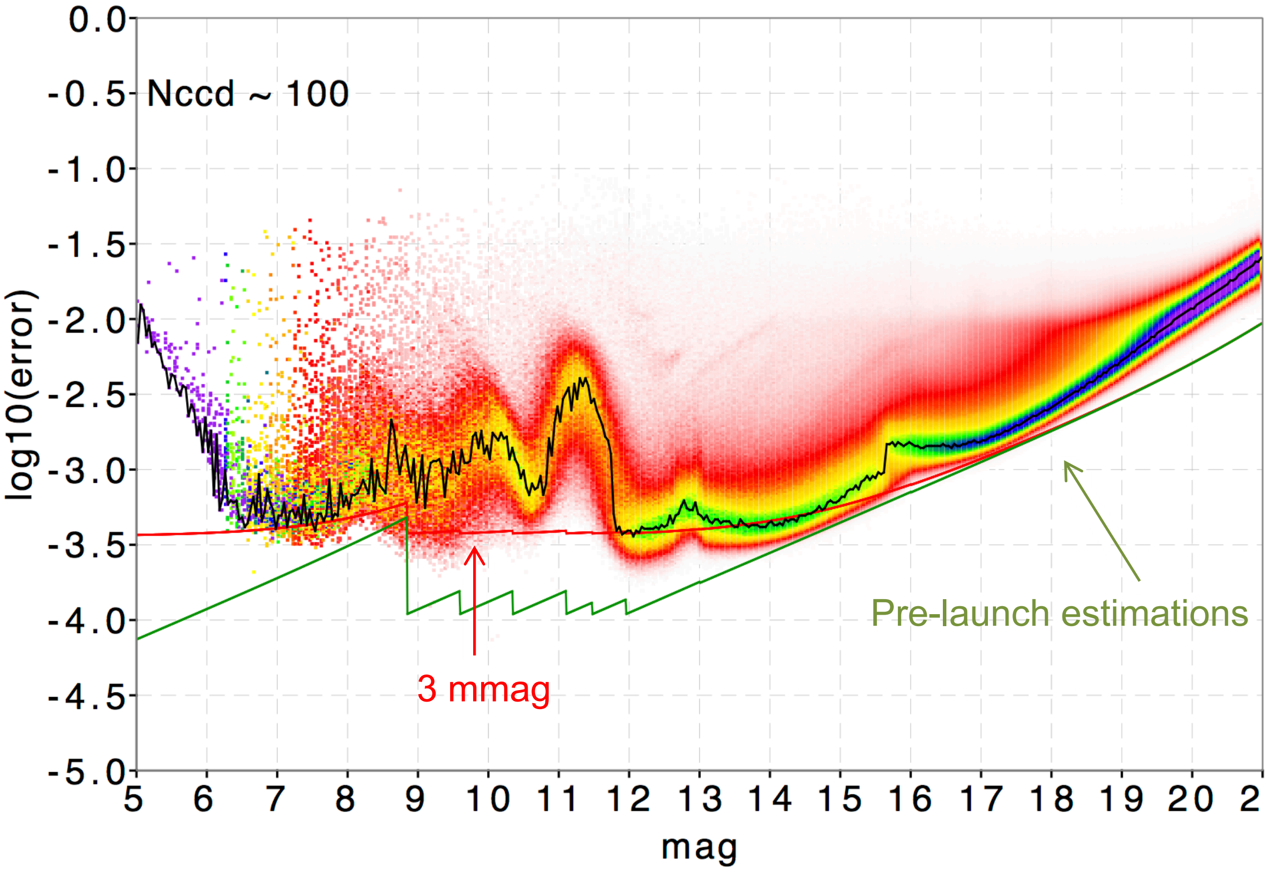


Riello et al (in prep)

Results

Gaia-DR1: photometry

Error on the weighted mean G value for source with ~100 CCD transits

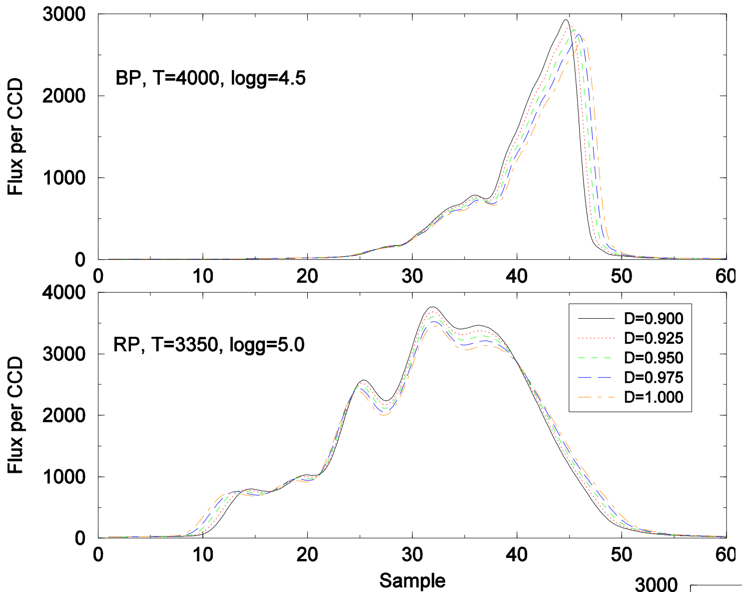


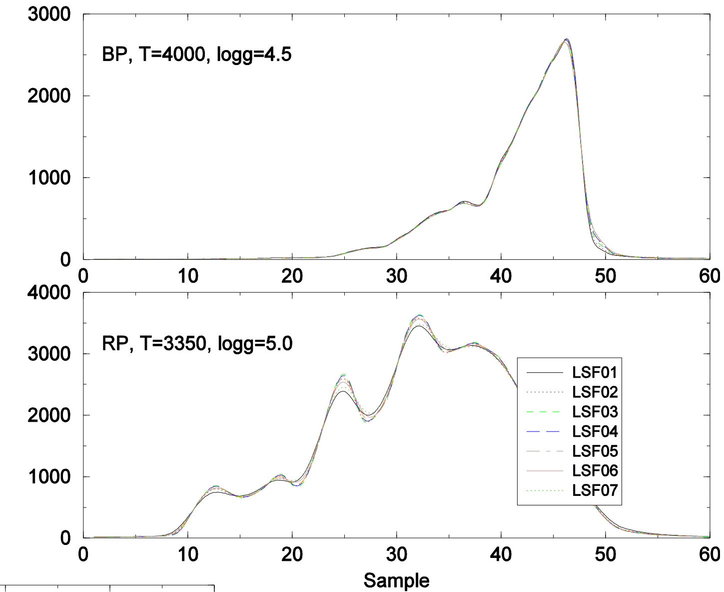
- Systhematics of ~10 mmag
- Science performances: Gaia webpage

Evans et al (2016)

BP/RP processing

XP: Dispersion and LSF

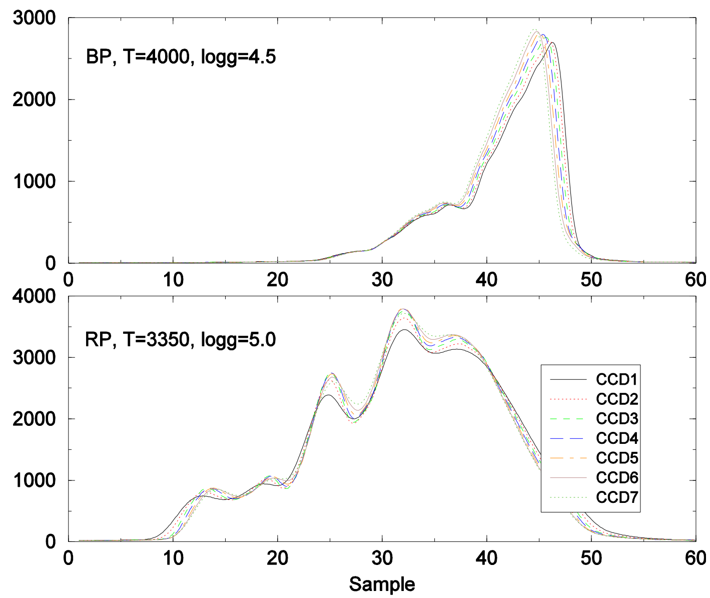




Disp effect

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

LSF effect



joint effect

Functional Analytic Instrument Model: FAIM

Approach:

Observations are an integral transformation of the source spectrum:

observed spectrum (counts per ...) — *instrument* — *source spectrum*

$$f(u,\square) = \int_0^\infty K(\lambda, u, \square) \cdot s(\lambda)\, \mathrm{d}\lambda$$

pixels — wavelength — further instrumental parameters

Develop source spectra and observed spectra in orthonormal basis functions:

Matrix equation: $\boldsymbol{I}\,\mathbf{s} = \mathbf{f}$

"instrument matrix" ($\boldsymbol{I}$); *coefficient vectors for source and observed spectrum* ($\mathbf{s}$, $\mathbf{f}$)

Transformation of a basis function orthogonal to *all* SPSS is unconstrained in calibration process:

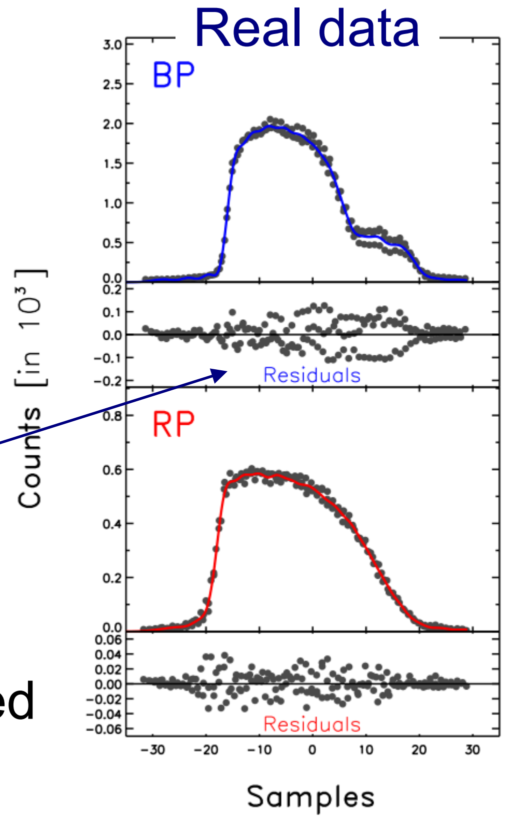
Trim basis functions to SPSS ⟹ *Functional Principal Component Analysis*

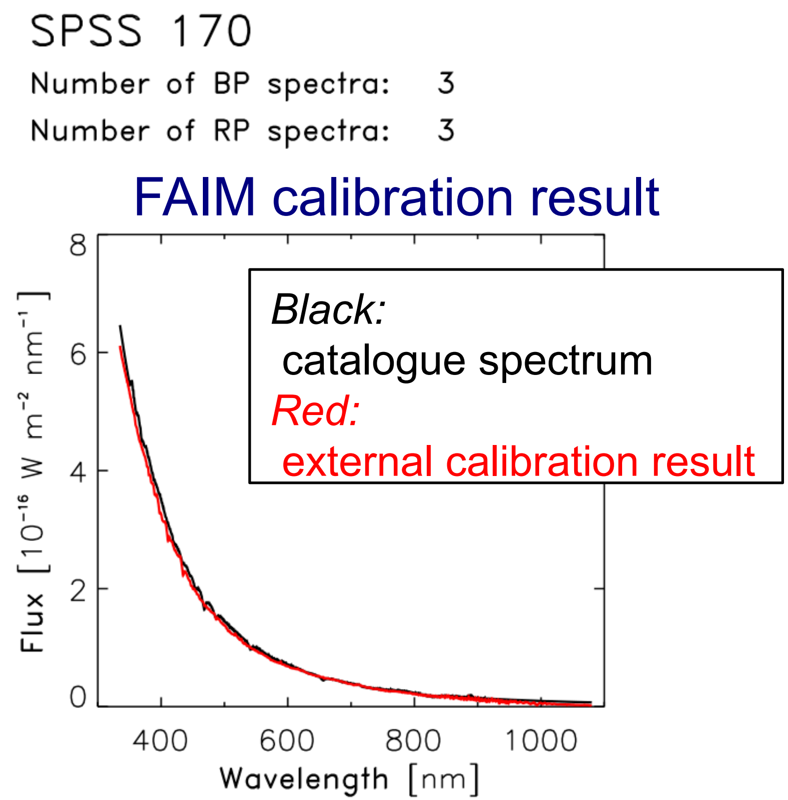
Functional Analytic Instrument Model: FAIM

First tests:

External calibration only
(□ neglected, differences between individual transits in high S/N spectra)

- 15 basis functions
- 15 x 15 inst. matrix
- instr. matrix obtained from 86 SPSS





FAIM advantages:

- Handles degeneracies in the calibration
- Minimum number of free parameters
- Fast and robust implementation

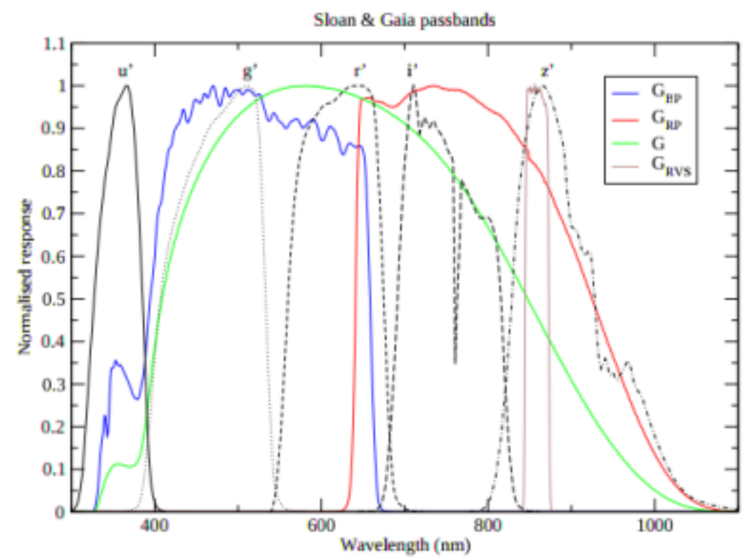
Synthetic photometry

Synthetic photometry

We use FAIM (Functional Analytic Instrument Model) formalism

F: Synthetic flux in the passband **T: Passband transmissivity** **s: Calibrated SED of the source**

$$F = \int_{\lambda_0}^{\lambda_1} T(\lambda) \cdot s(\lambda)\, \mathrm{d}\lambda$$

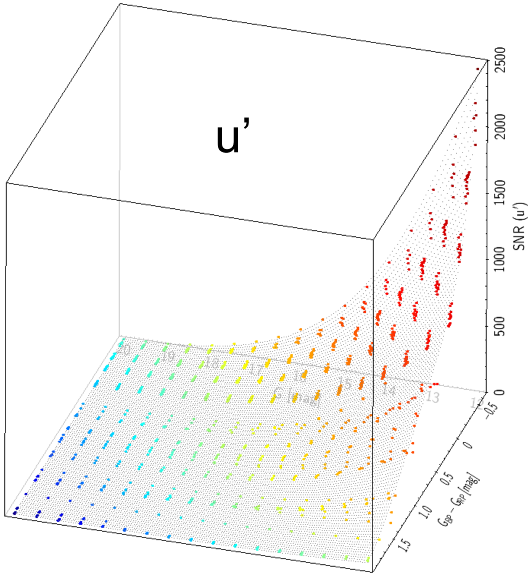


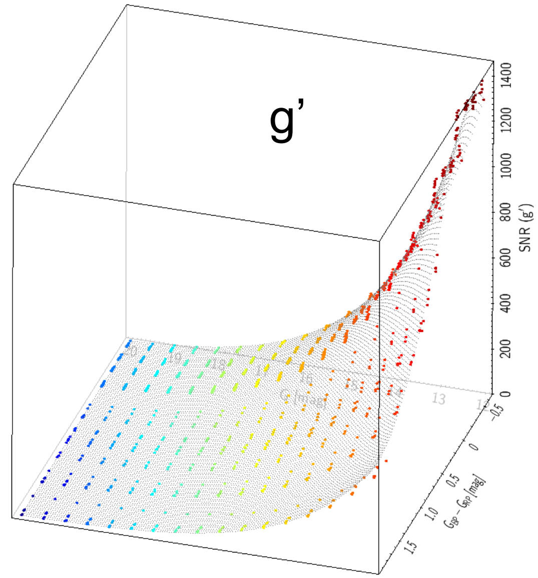
Covariance matrix of the vector s: Σ^{s}

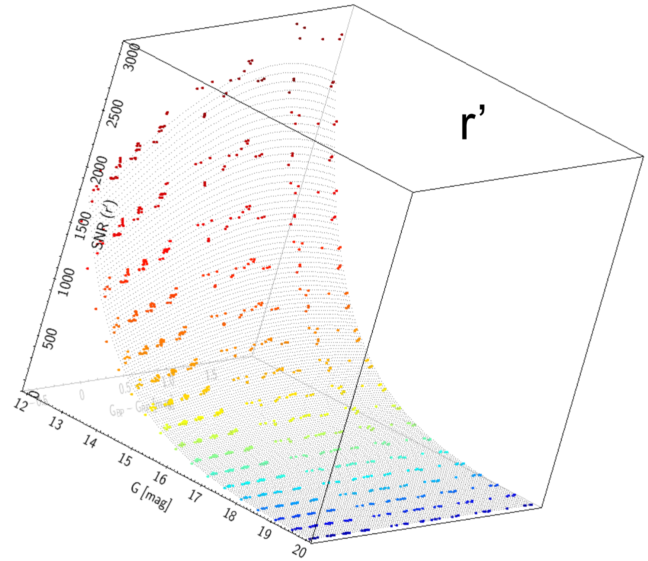
↓

Variance of the flux in the passband : Σ^{F} → SNR = F / Σ^{F}

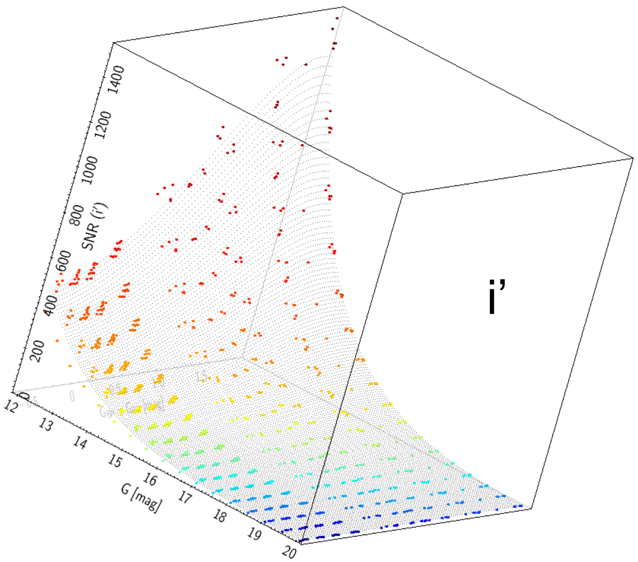
Example of Synthetic photometry: SDSS

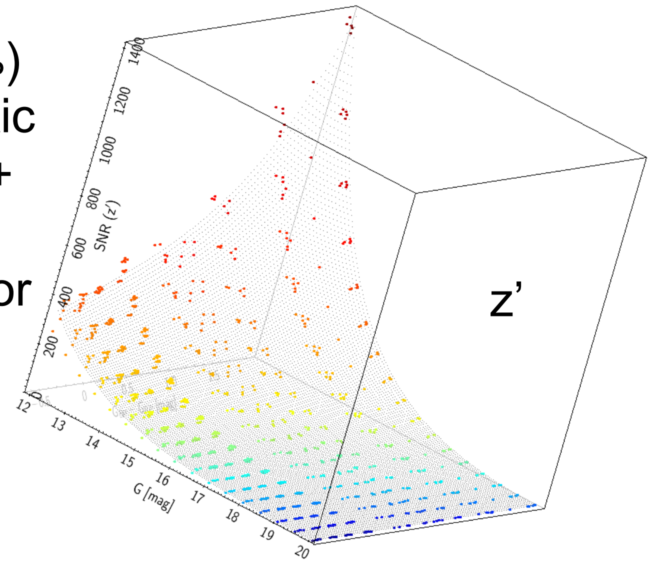






Fitted $SNR_x=f(G,G_{BP}-G_{RP})$ relationships from synthetic photometry (BaSeL-3.1 + WDs) will be made available in GOG simulator (SDSS, Johnson, Hipparcos/Tycho, …)





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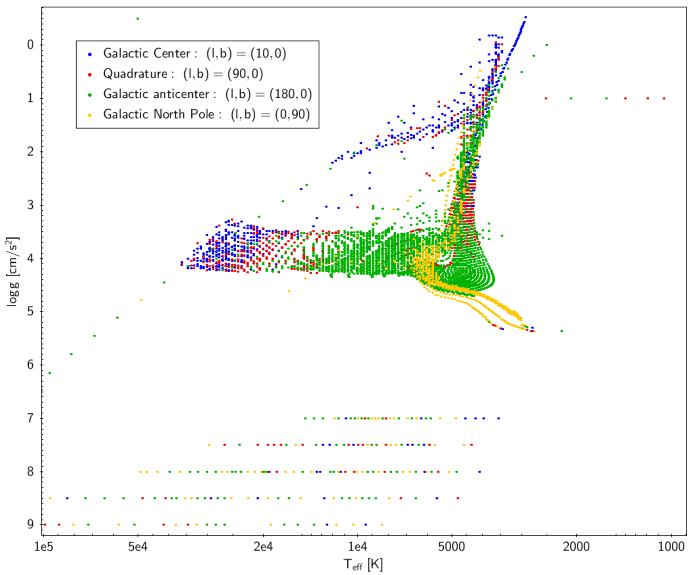
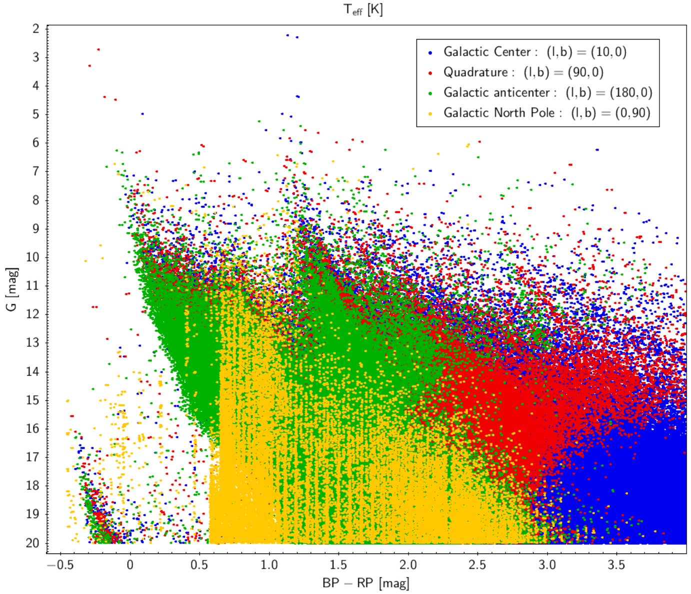
Gaia Universe Model Snapshot

Robin et al (2012)





Stars with G<20 for a FoV=4°

- Galactic center: *l*=10° *b*= 0°
- Quadrature: l=90°, b=0°
- Anticenter: l=180°, b=0°
- Galactic North Pole: l=0°, b=90°

G	ρ_{center} (star/deg^2)	$\rho_{quadrature}$ (star/deg^2)	$\rho_{anticenter}$ (star/deg^2)	ρ_{pole} (star/deg^2)
<16	15766	17256	9052	454
16-17	15231	17167	6857	271
17-18	27295	28527	10921	407
18-19	48206	46642	15676	607
19-20	81088	76598	20832	868
All	187586	186204	63338	2607

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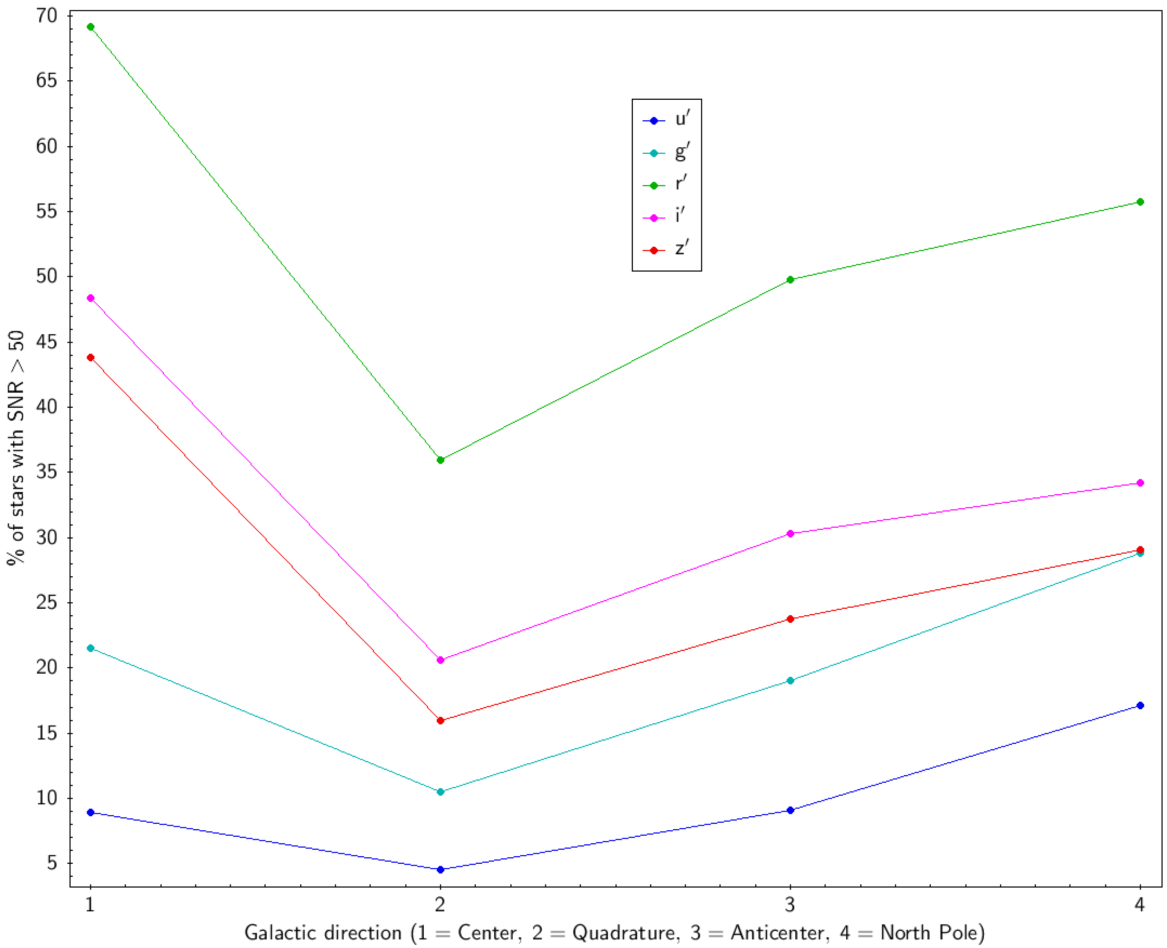
SNR for the simulated sample

12<G<20,
$-0.63<G_{BP}-G_{RP}<1.95$

Galactic North Pole:
l=0º, b=90º

Filter	%	Stars/deg²
u'	17	443
g'	29	756
r'	56	1460
i'	34	886
z'	29	756

Stars with SNR>50



Conclusions

Conclusions: Gaia photometry is unique

- Homogeneous all-sky coverage with G_{lim} ~ 20.7
- Integrated photometry (G, G_{BP} and G_{RP} passbands)
  End-of-mission uncertainty at mmag level
  Systhematics at same level
- BP/RP spectrophotometry down to G_{lim}
  Data processing is being redesigned
- Synthetic photometry on BP/RP spectra
  Error model will be implemented in GOG for simulations
- Absolute calibration at 1% level accuracy
  constrained by the SPSS on-ground observations

Thanks