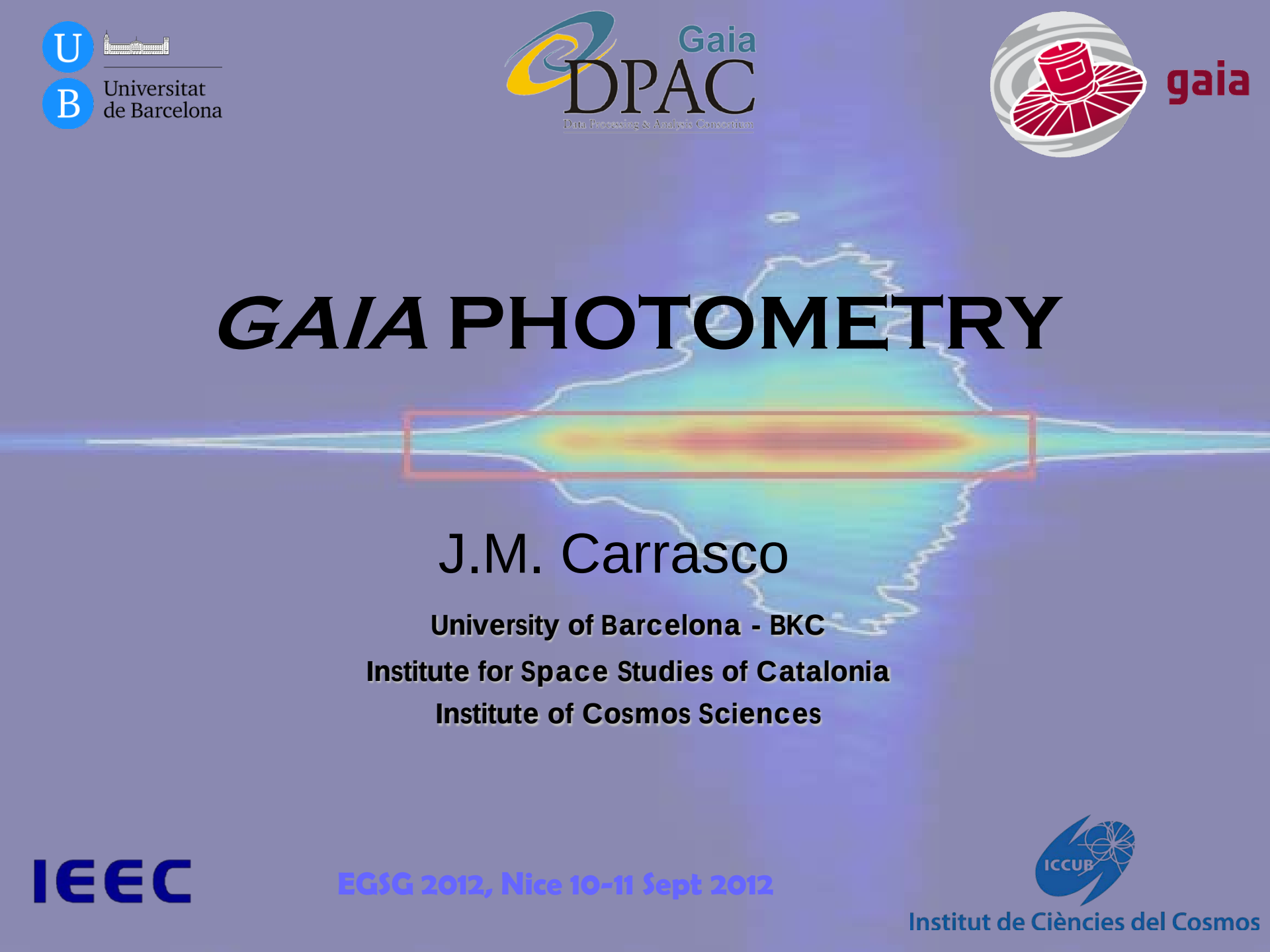


GAIA PHOTOMETRY

J.M. Carrasco

University of Barcelona - BKC

Institute for Space Studies of Catalonia

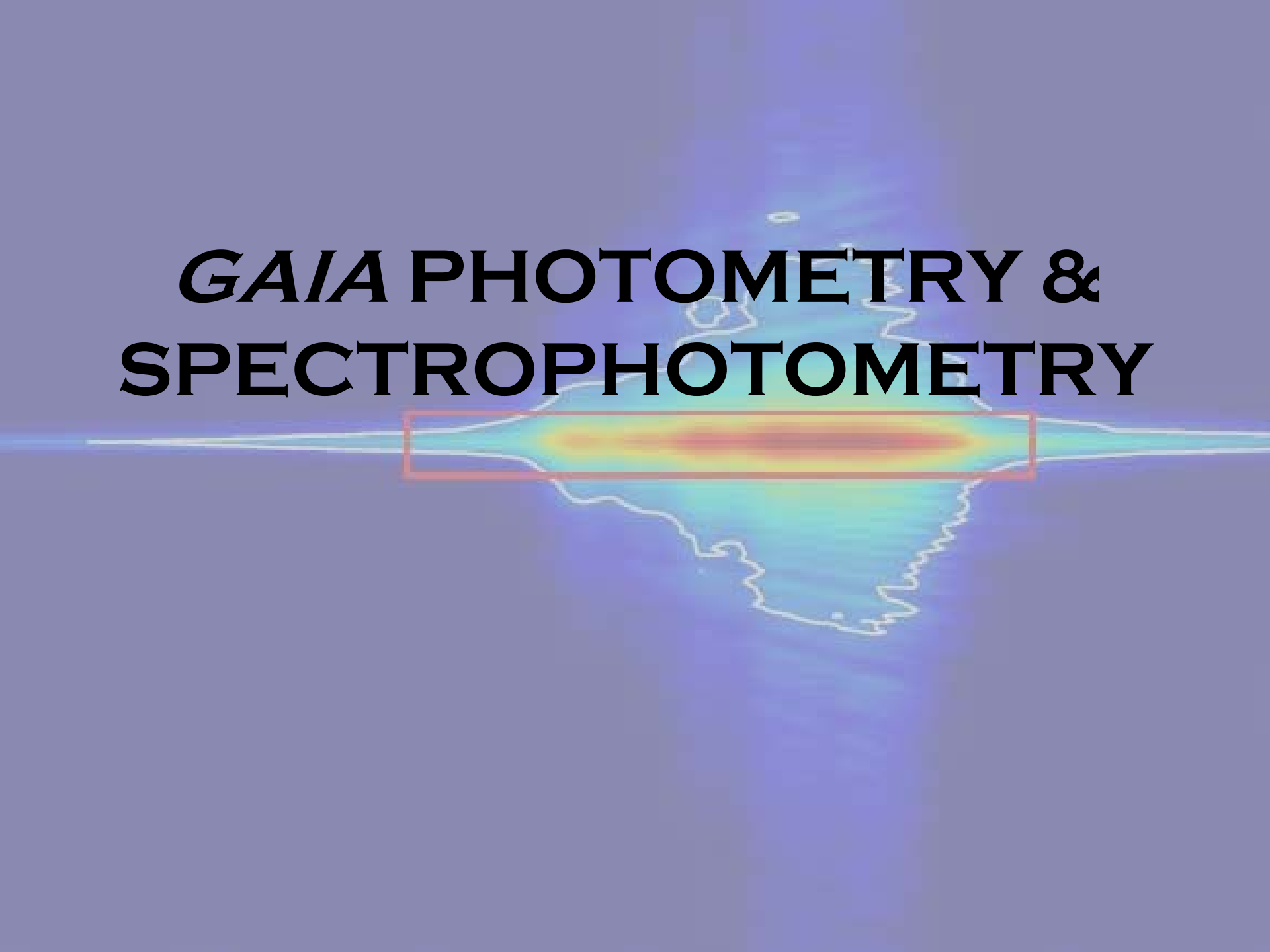
Institute of Cosmos Sciences

EGSG 2012, Nice 10-11 Sept 2012

Outline

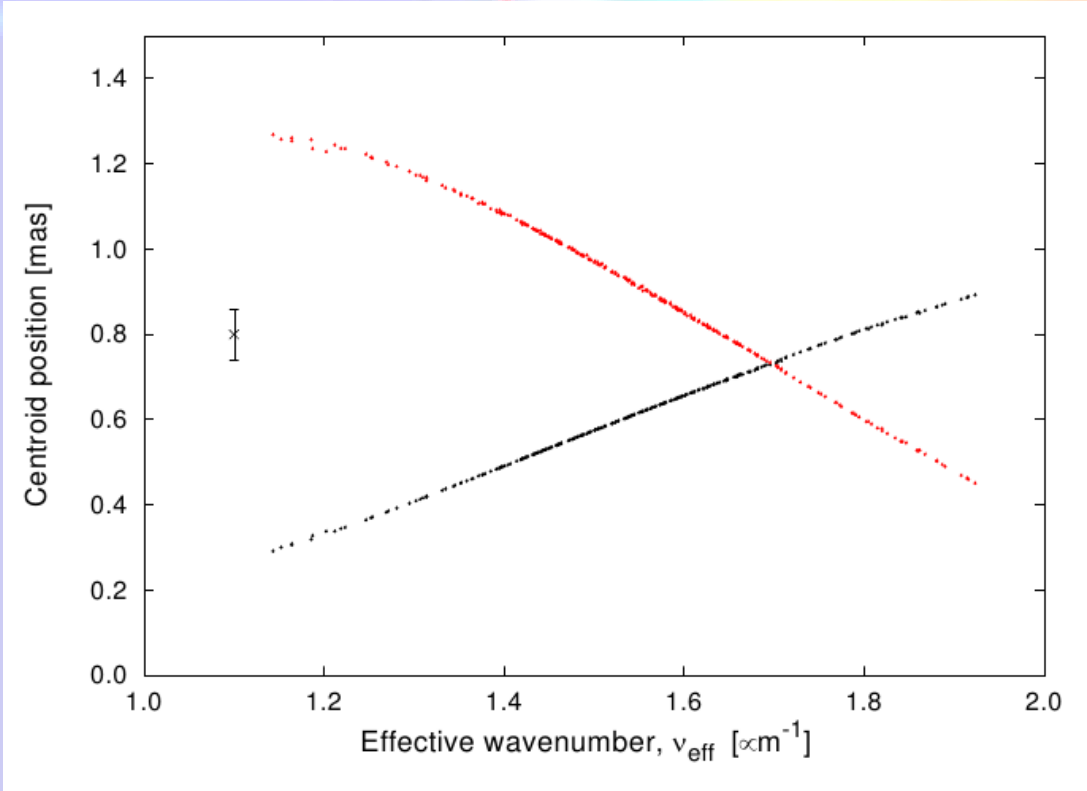
- *Gaia* photometry & spectrophotometry
- Calibration Strategy
  - Pre-processing
  - Internal Calibration
  - External Calibration
- Extragalactic spectrophotometry
  - BP/RP spectra for Galaxies and QSO
- Extended objects
  - 2D image reconstruction
- Photometric capabilities
  - Transformations
  - Performances
- Variability with Gaia
  - Variability capabilities & SNR
  - Photometric alerts
- Conclusions

GAIA PHOTOMETRY & SPECTROPHOTOMETRY



Why photometry?

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



GAIA-CA-TN-ESA-JDB-028

Centroid positions for the polychromatic diffraction images of different spectra versus effective wavenumber, for two representative WFE maps. Stellar spectra from the Pickles library (A_{550} = 0 and 2 mag). The error bar shows the photon-statistical centroiding error σ_ξ for a single-CCD transit of a bright star (G < 13 mag).

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

Focal plane

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

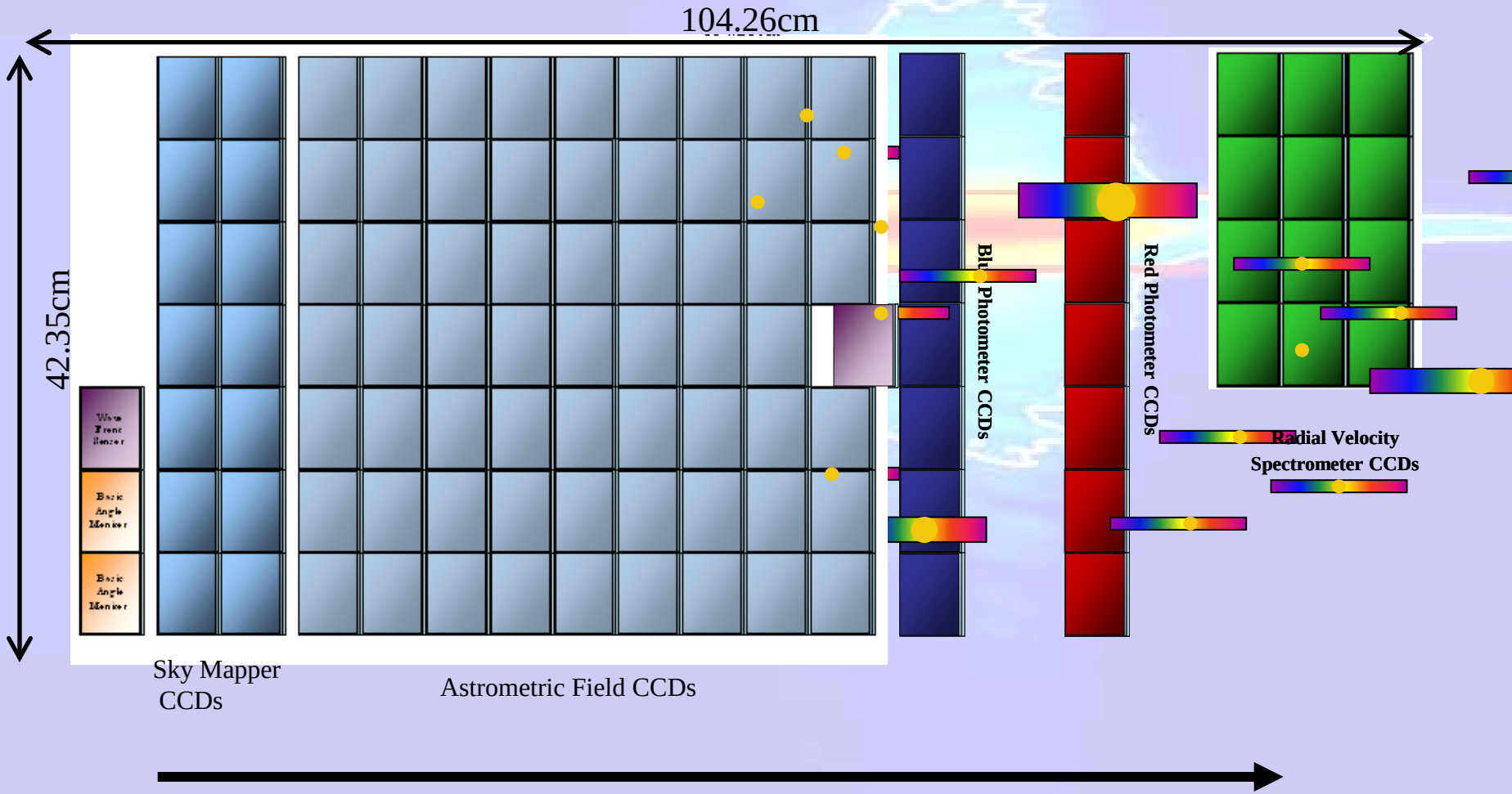
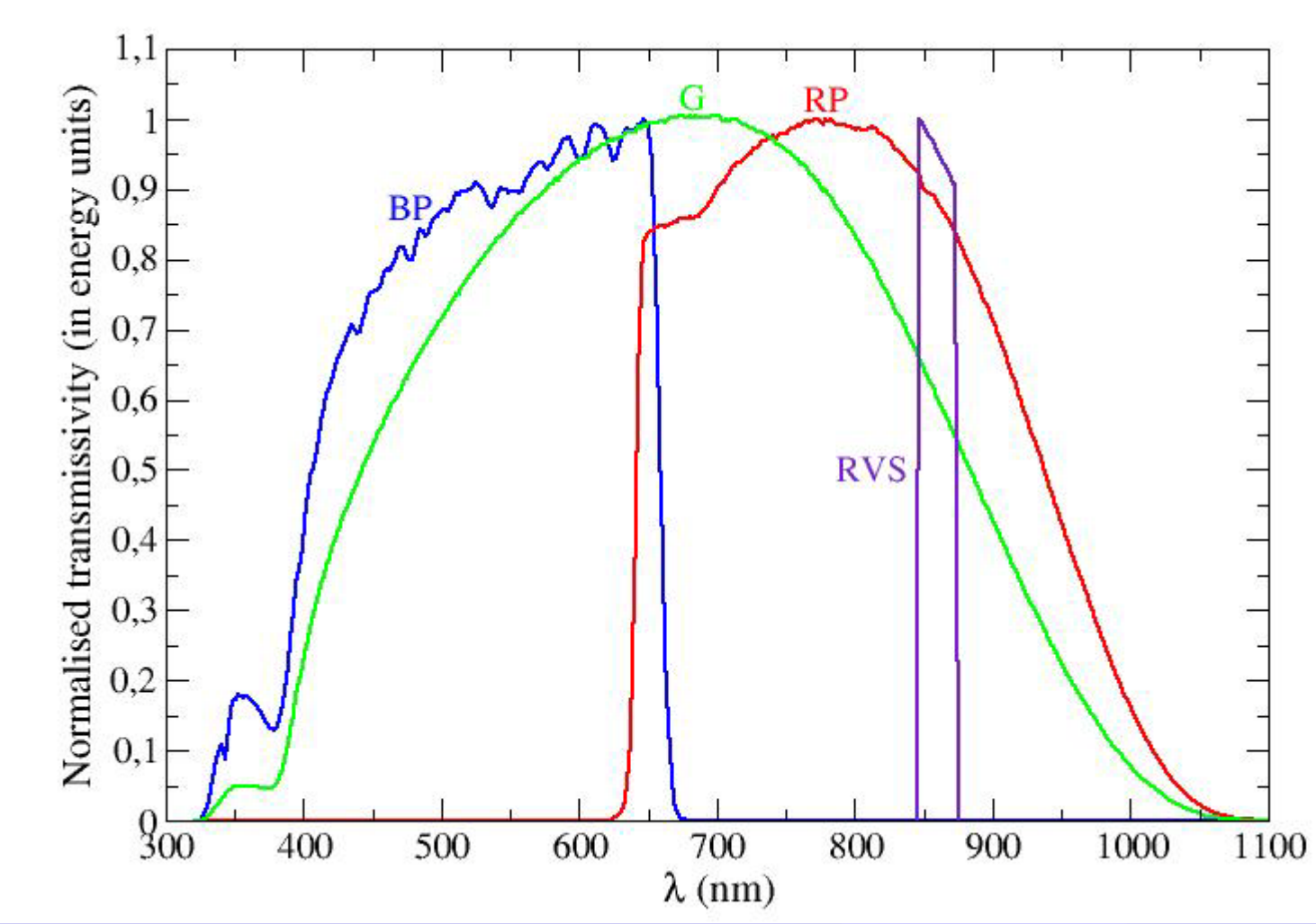
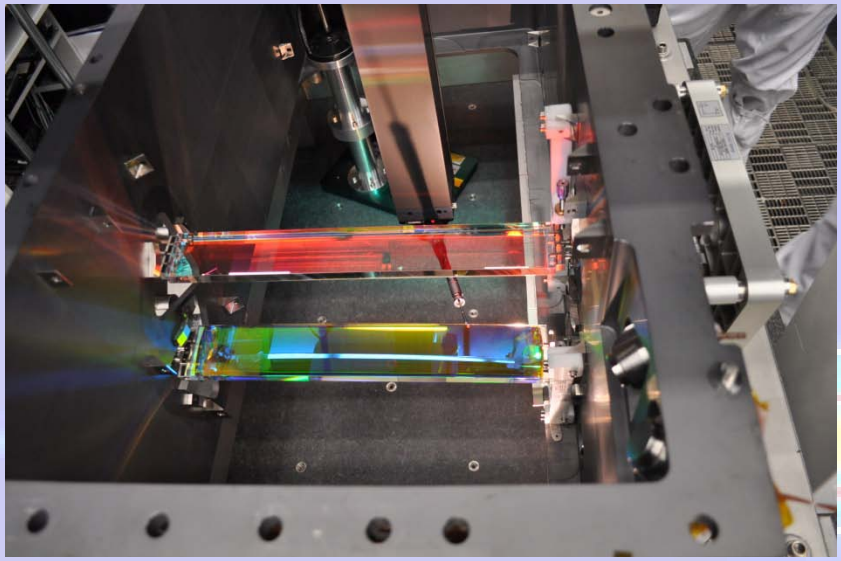


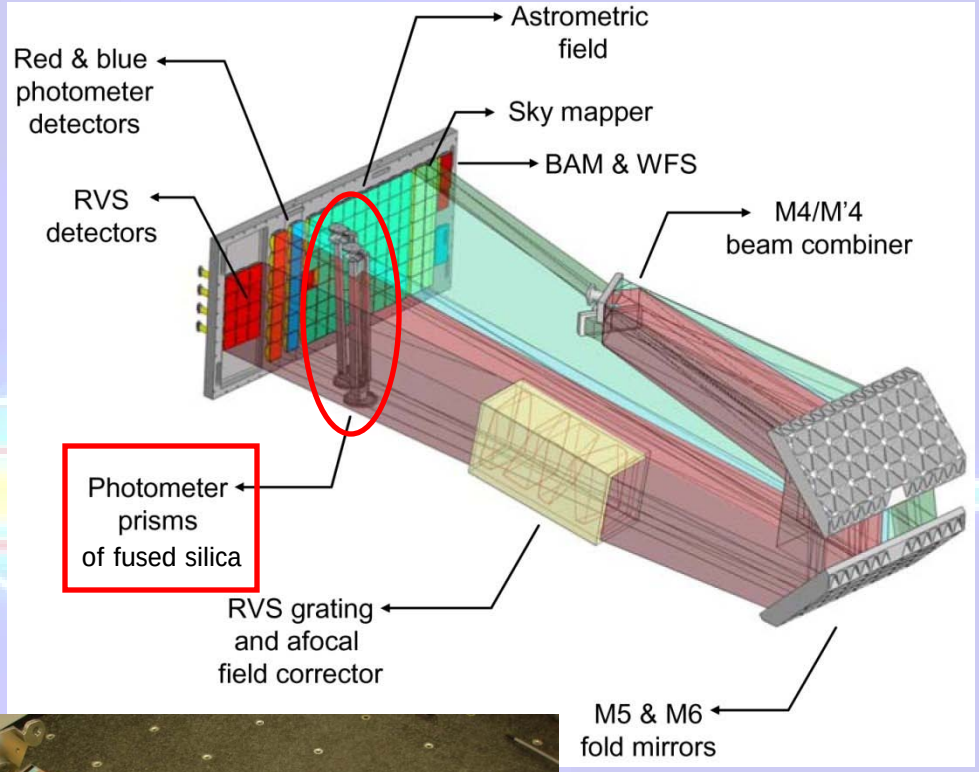
Figure courtesy Alex Short

Gaia passbands



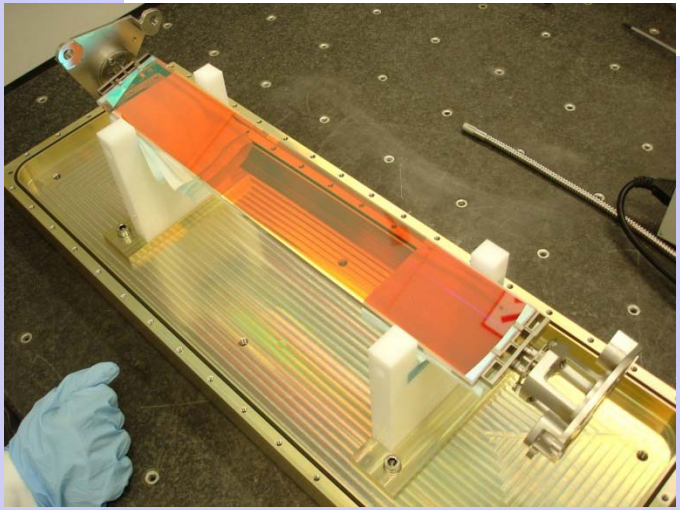
BP/RP spectrophotometers





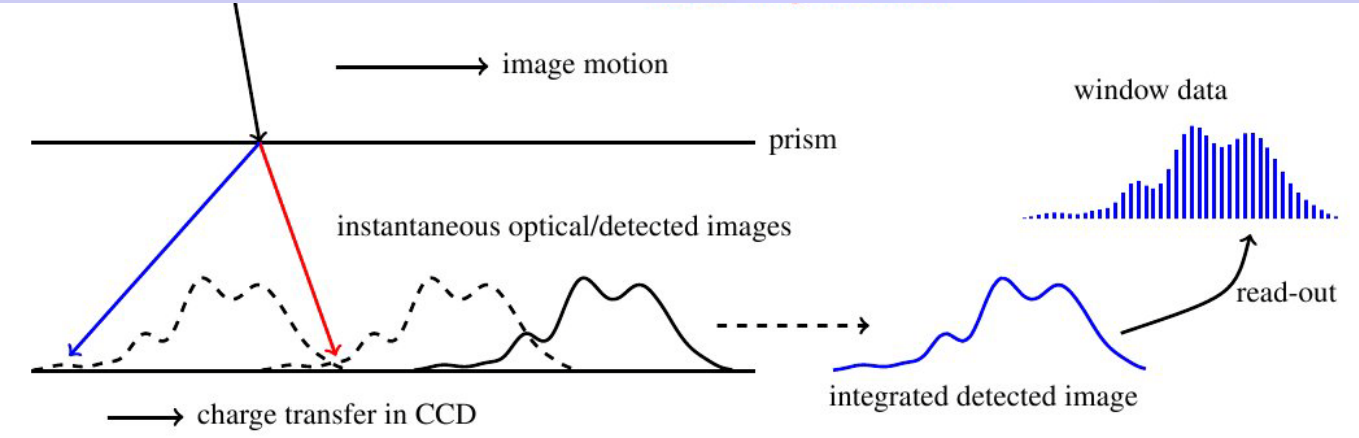
Blue photometer:
330–680 nm

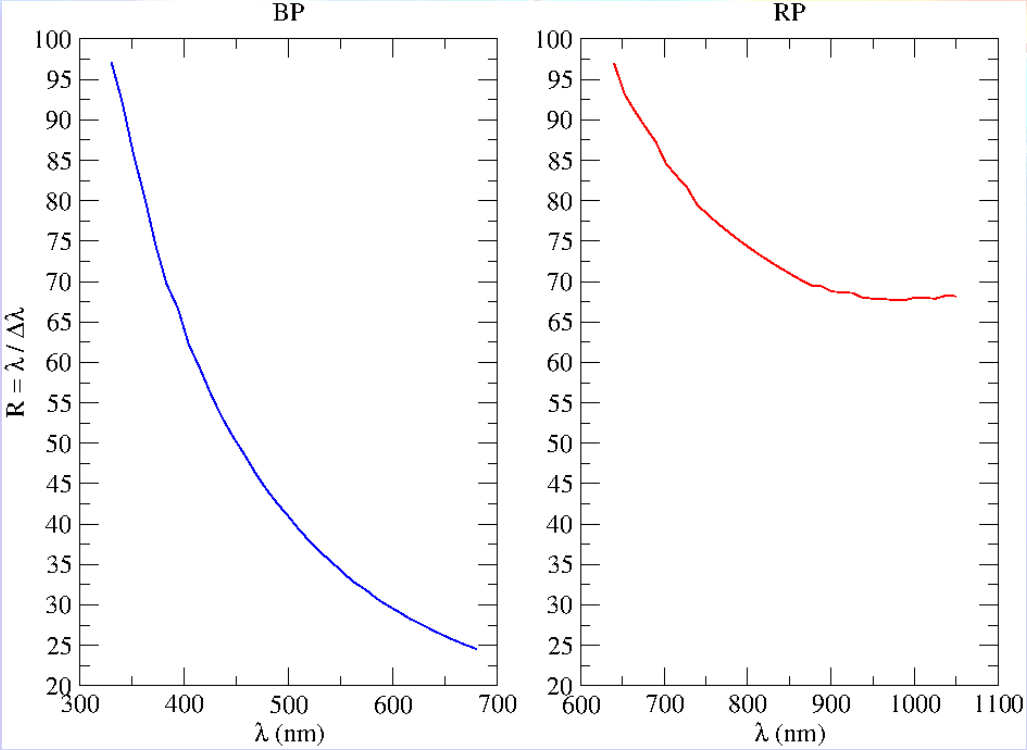
Red photometer:
640–1000 nm



Figures courtesy EADS-Astrium

BP/RP spectrophotometry



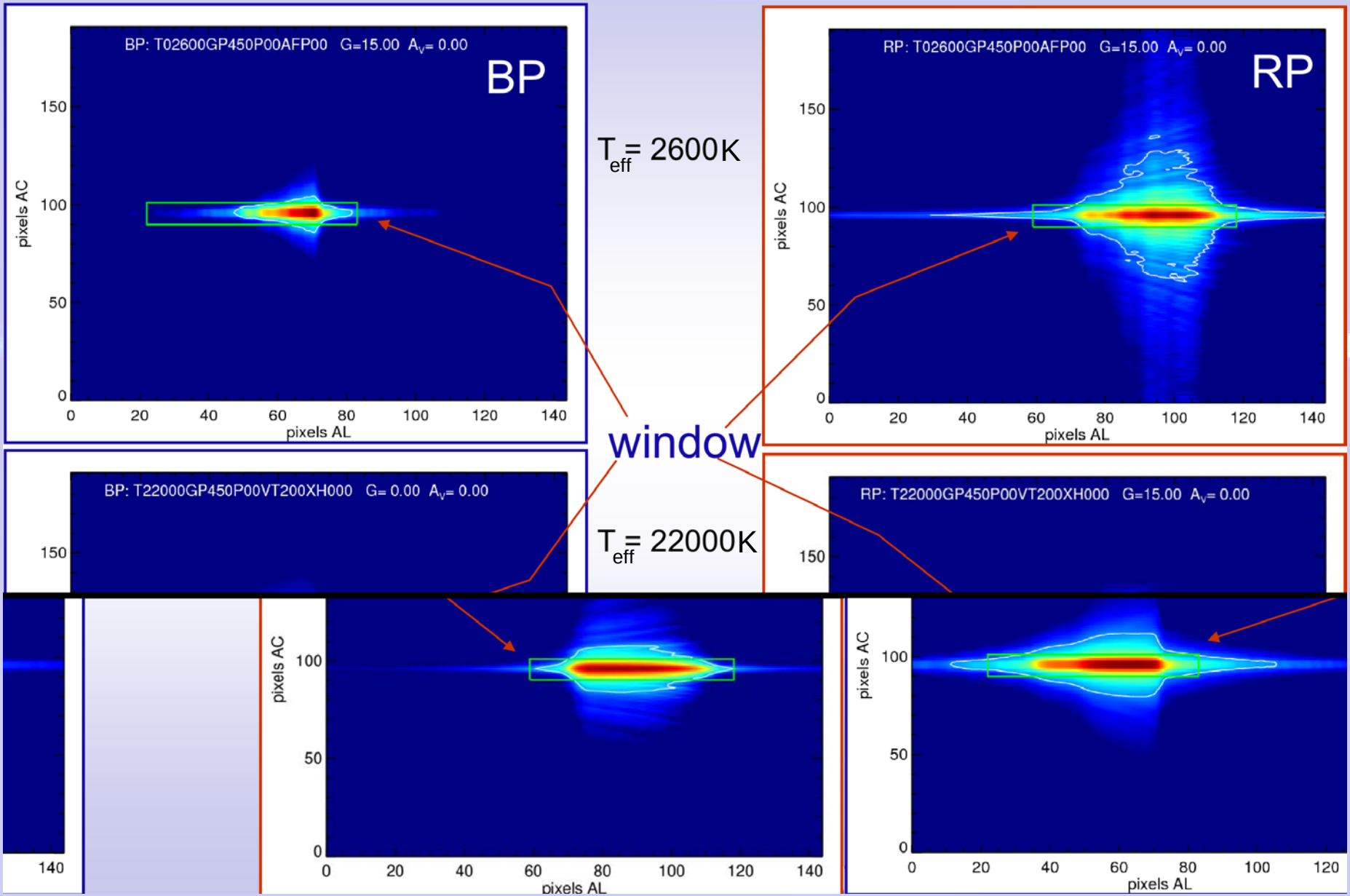


Resolution < 100

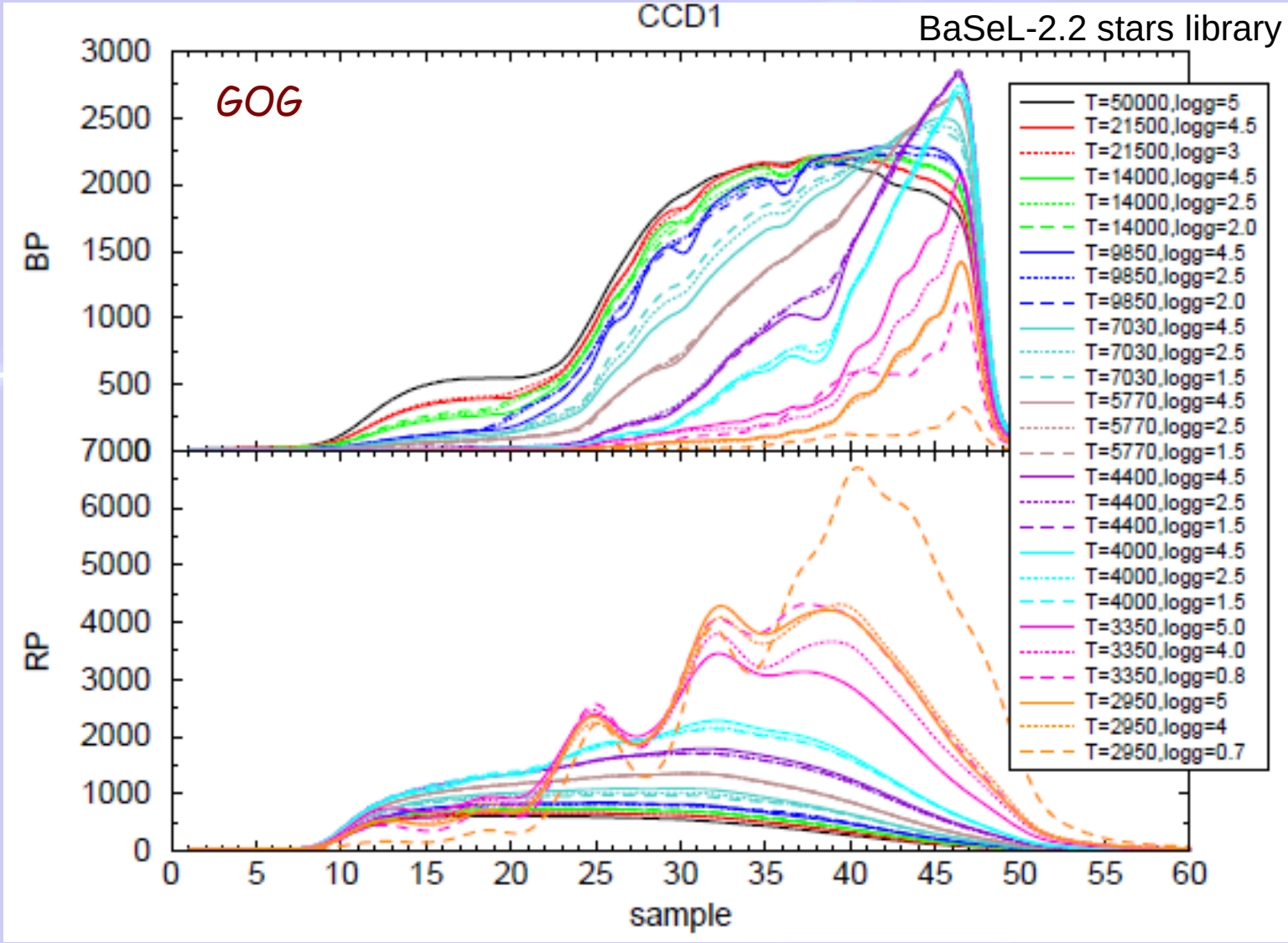
BP: 4-35 nm/pixel
RP: 7-15 nm/pixel

PSF effect is not included here
→ Half resolution is expected

BP/RP spectrophotometry



BP/RP spectrophotometry



CALIBRATION STRATEGY





CU5M11 meeting
Bologna, 17-19 April 2012

Tasks in CU5

DU10: AF, LSF/PSF calibration, bias, sky background, CTI, … (Edimburgh, Leicester)

DU11: Data "pre-processing": bias, sky background, CTI, deblending, LSF/PSF for BP/RP (Leiden, Rome, Teramo)

DU12: internal calibration models (Barcelona)

DU13: ground-based observations (Bologna, Barcelona, Groningen)

DU14: absolute calibration (flux & wavelength) (Bologna)

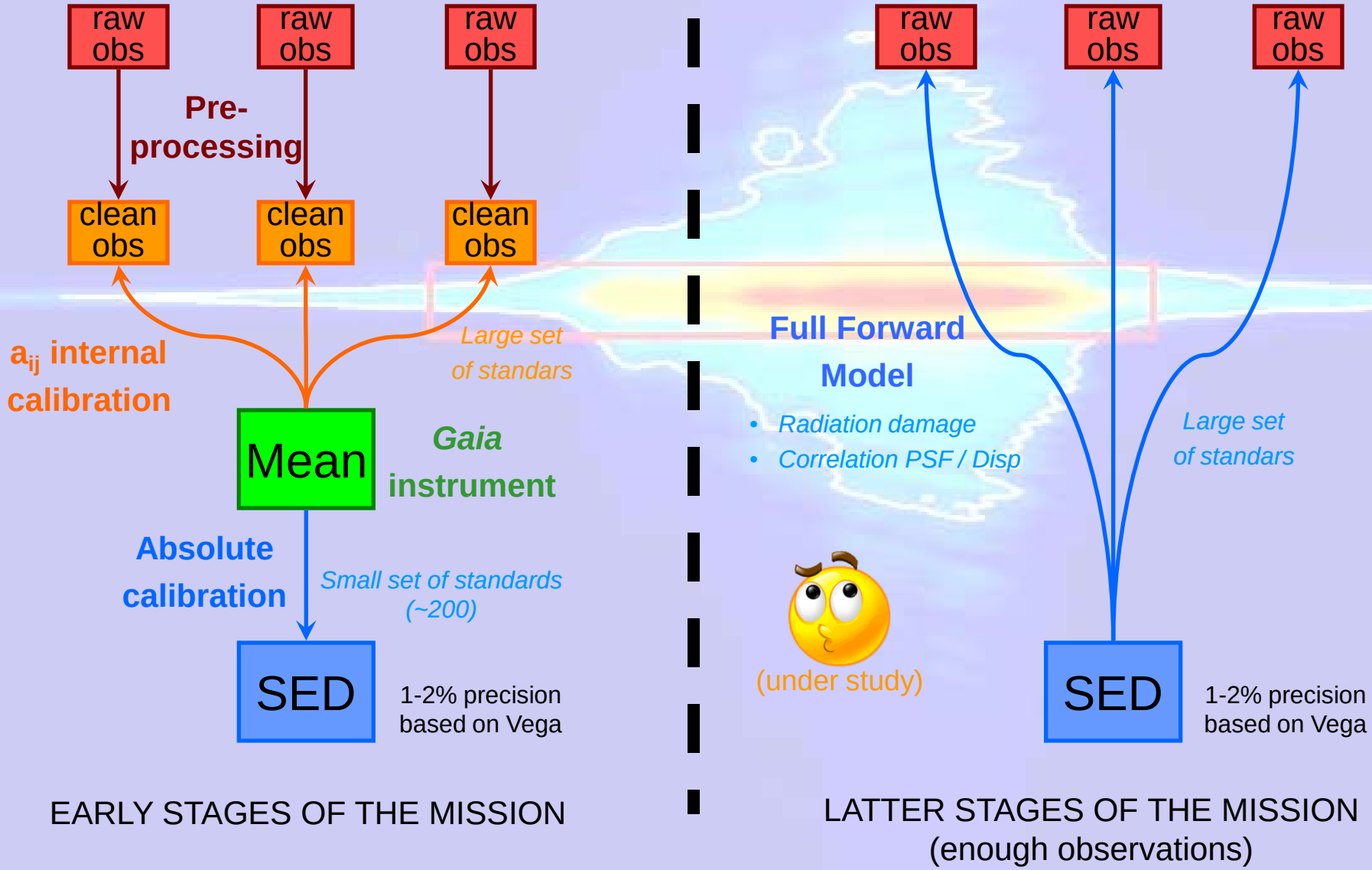
DU15: implementation of models for AF+BP/RP (Cambridge)

DU16: internal reference sources (Barcelona)

DU17: science alerts (Cambridge)

DU18: image analysis in SM (Cambridge)

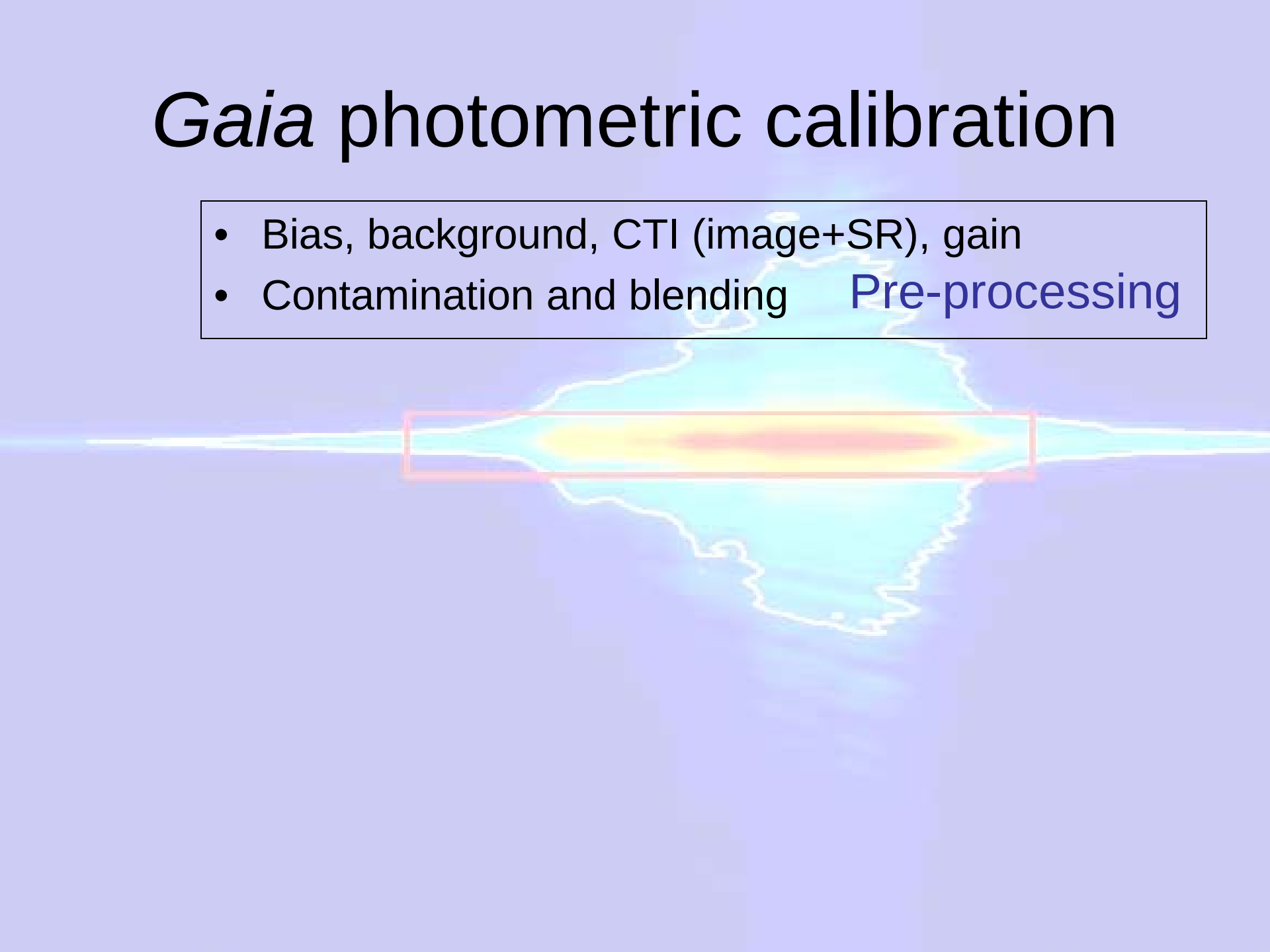
Gaia photometric calibration



Gaia photometric calibration

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

Pre-processing



Crowding

Crowding evaluation classifies BP/RP **transits** as “isolated”, “contaminated” or “blended” and produces a mask indicating which samples can be used for background modelling.

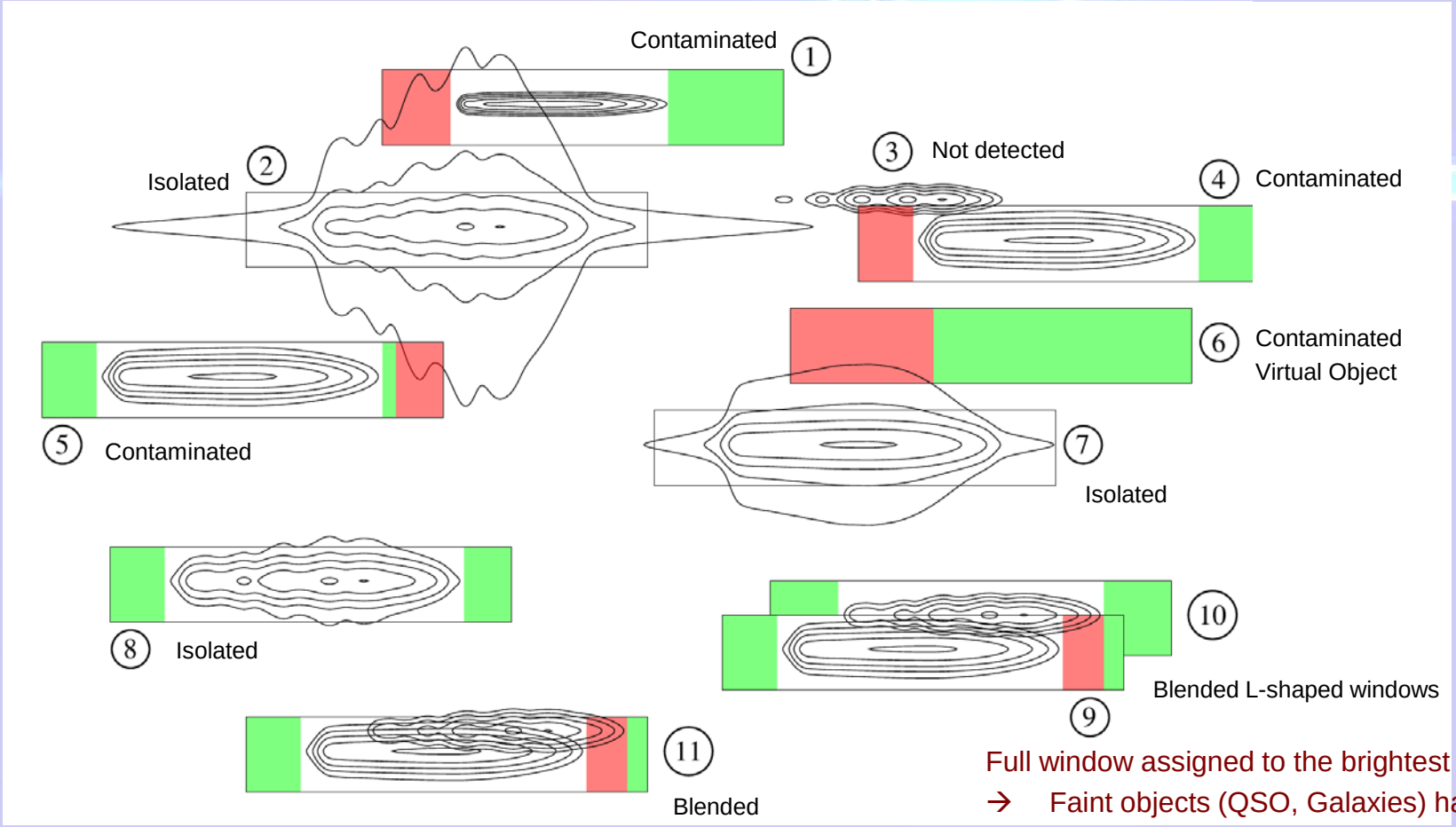
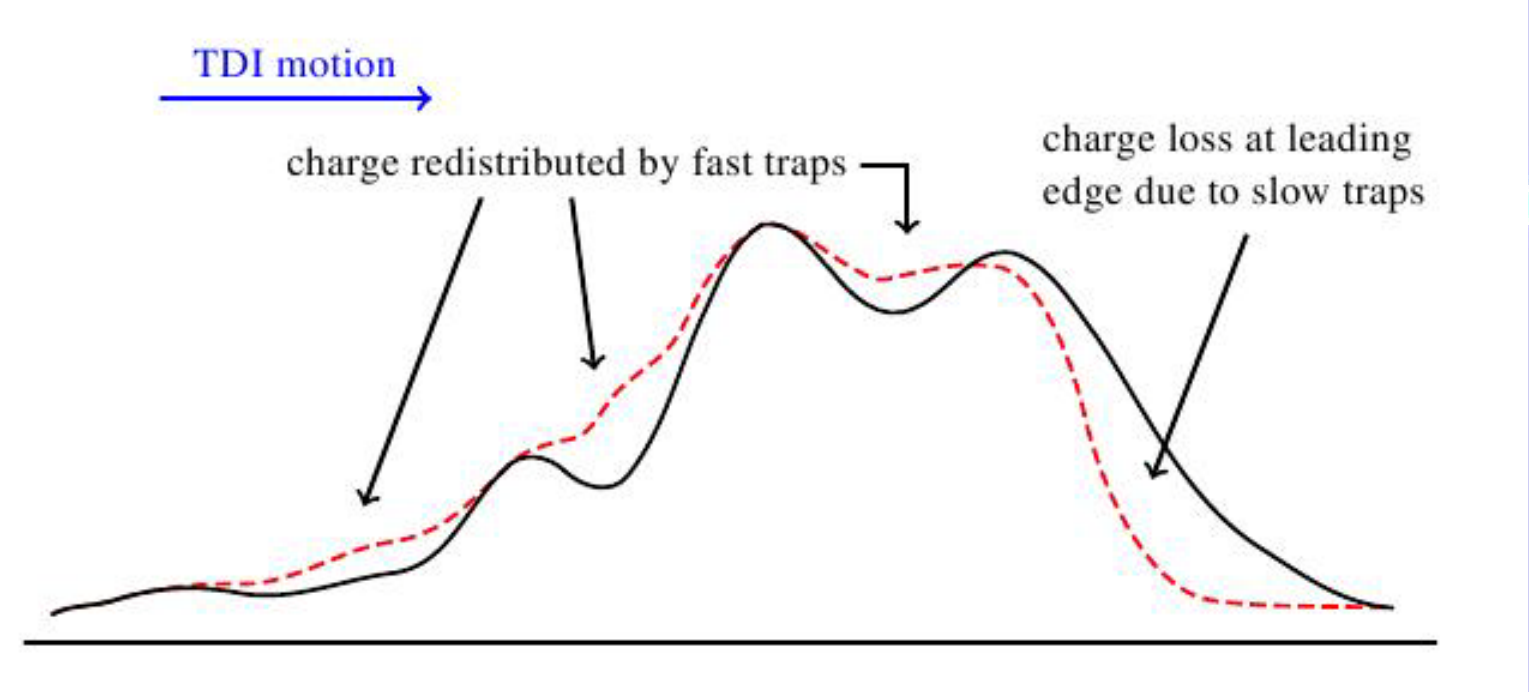


Figure courtesy Anthony Brown

Full window assigned to the brightest object

→ Faint objects (QSO, Galaxies) have more complicated reduction

CTI effect on BP/RP spectra



CTI distorts the shape of the spectra → Worse redshifts

2 methods to face the problem: Reconstruction vs Prediction

Figure courtesy Anthony Brown

Gaia photometric calibration

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

Pre-processing

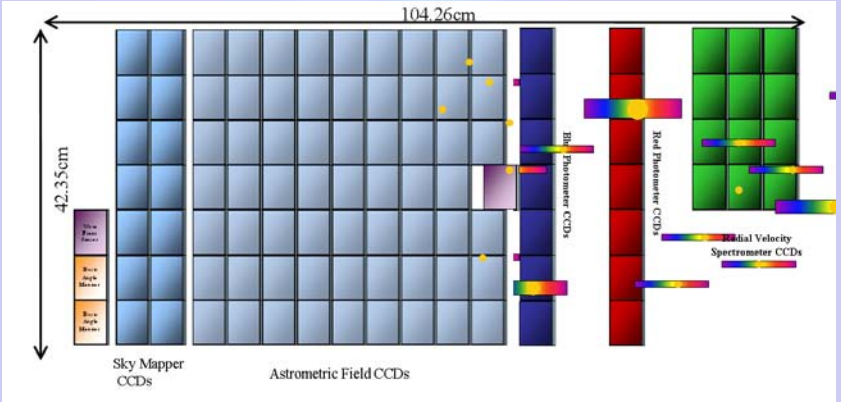
- Overall sensitivity variation (optics, CCDs)
- Flux out of the window (AC & AL flux loss)
- PSF/LSF variation
- Dispersion variation
- Geometry variation (AL & AC); tilts

Internal calibration

106 CCDs , 938 million pixels, 2800 cm^2

→ STRONG DIFFERENCES IN DIFFERENT OBSERVATIONS OF THE SAME SOURCE

NEED TO BE HOMOGENEIZED



Sensitivity

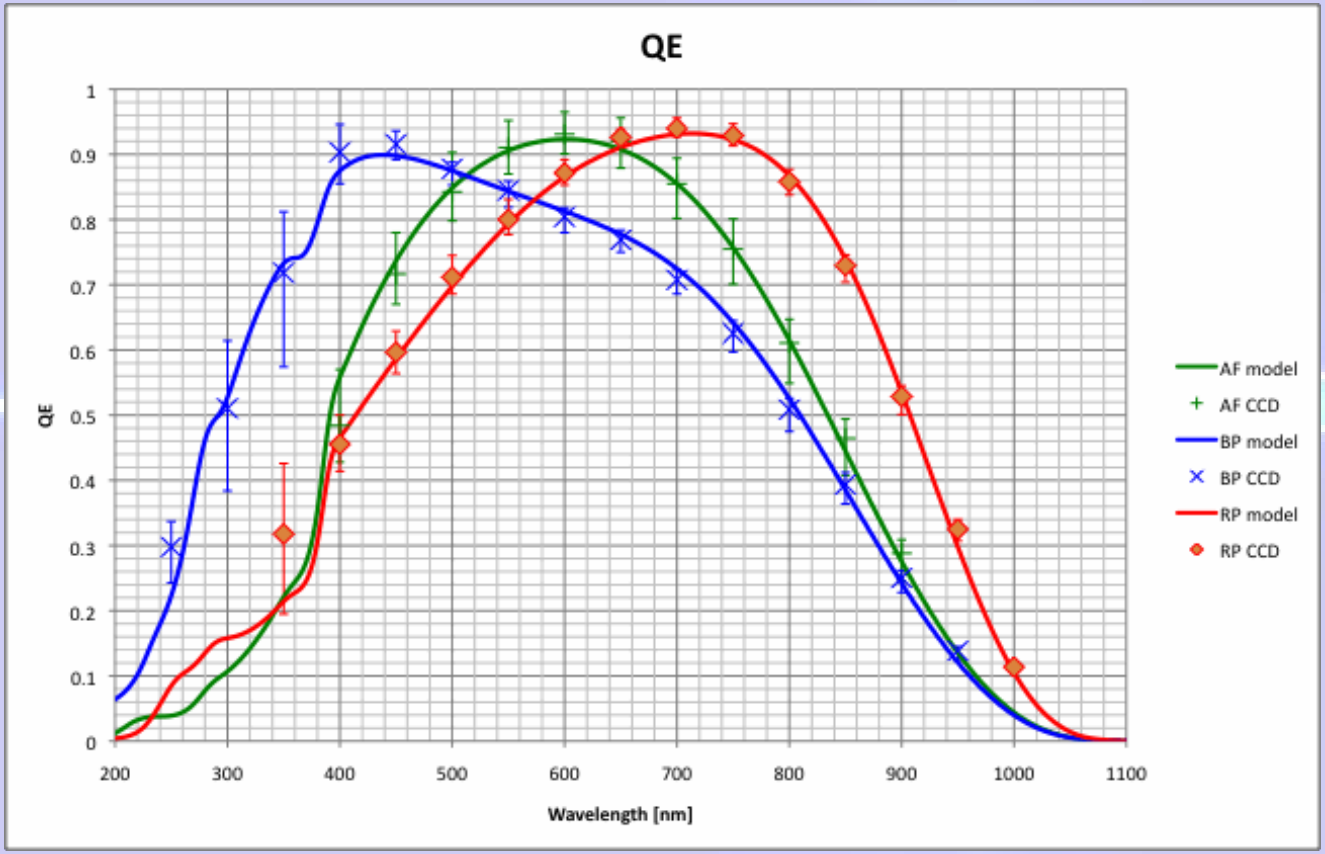
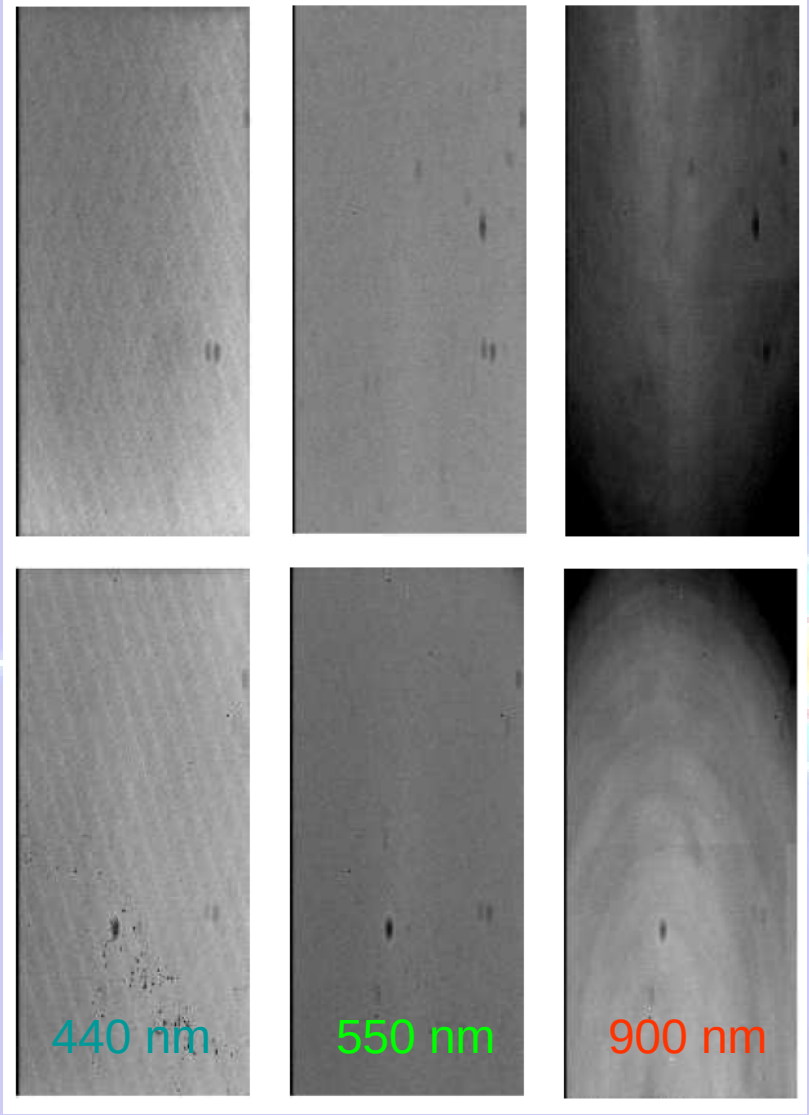


Figure courtesy Ralf Kohley & Alcione Mora, Feb 2010



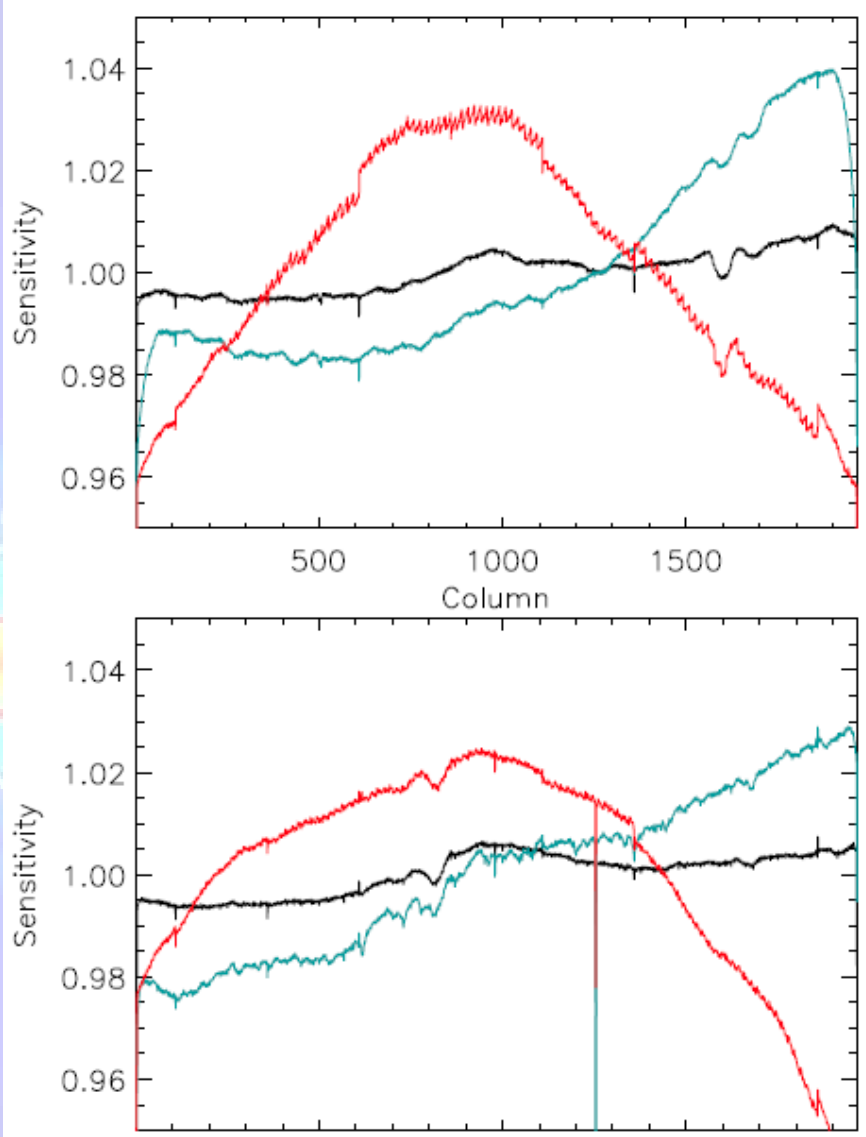
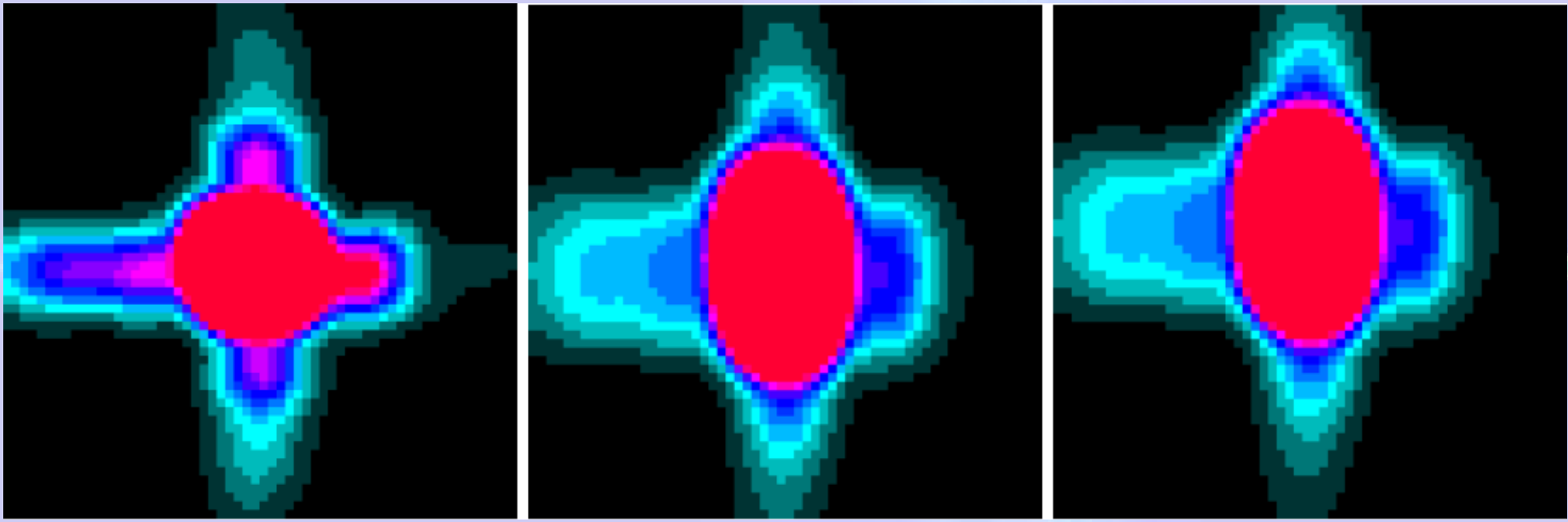


Figure 9: Flat field images for CCD 05486-15-2 for 400 nm, 550 nm and 900 nm (upper row, from left to right) and for CCD 06036-11-1 (lower row). CCD columns are aligned vertical (AL scan direction) in this figure. Oval dark patterns are believed to origin from particles in the optical path. Note, that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

Flux losses outside the window

AF S5R4T1 V-I=2.0



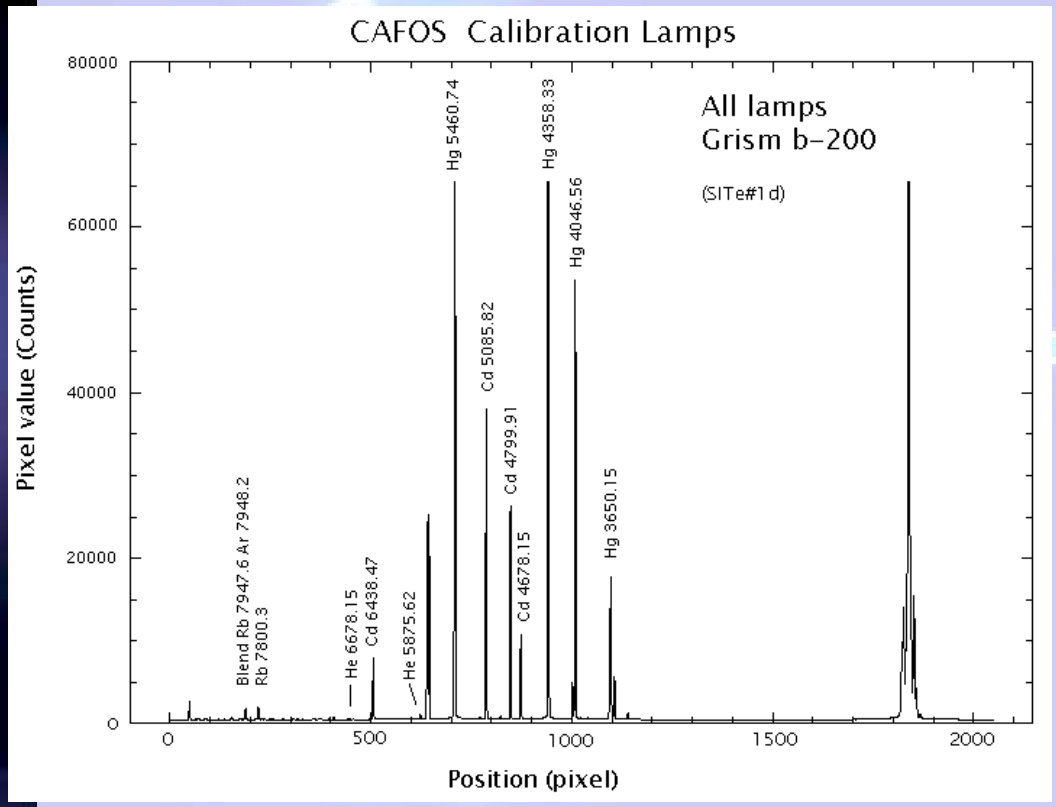
No AC motion | Nominal AC motion | window +1 pixel

1-2% variation

- Window strategy will cut the total flux detected for bright / extended sources.
- Different scan directions will change the flux detected for extended objects (shape)

Where is the calibration lamp?





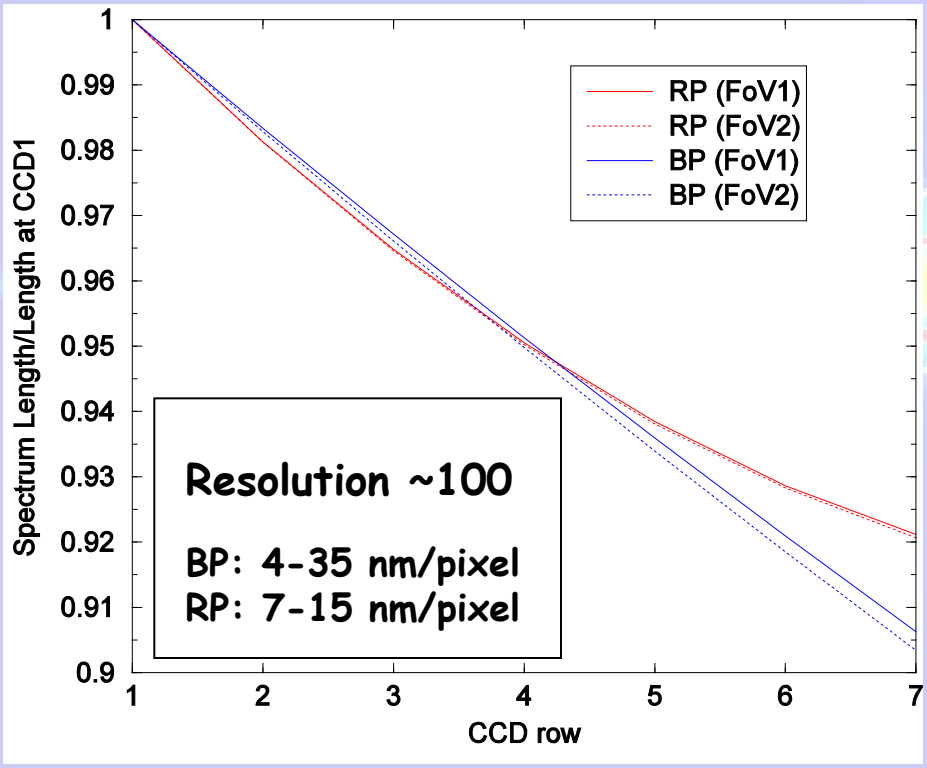
The BP/RP spectra is moving with the star.

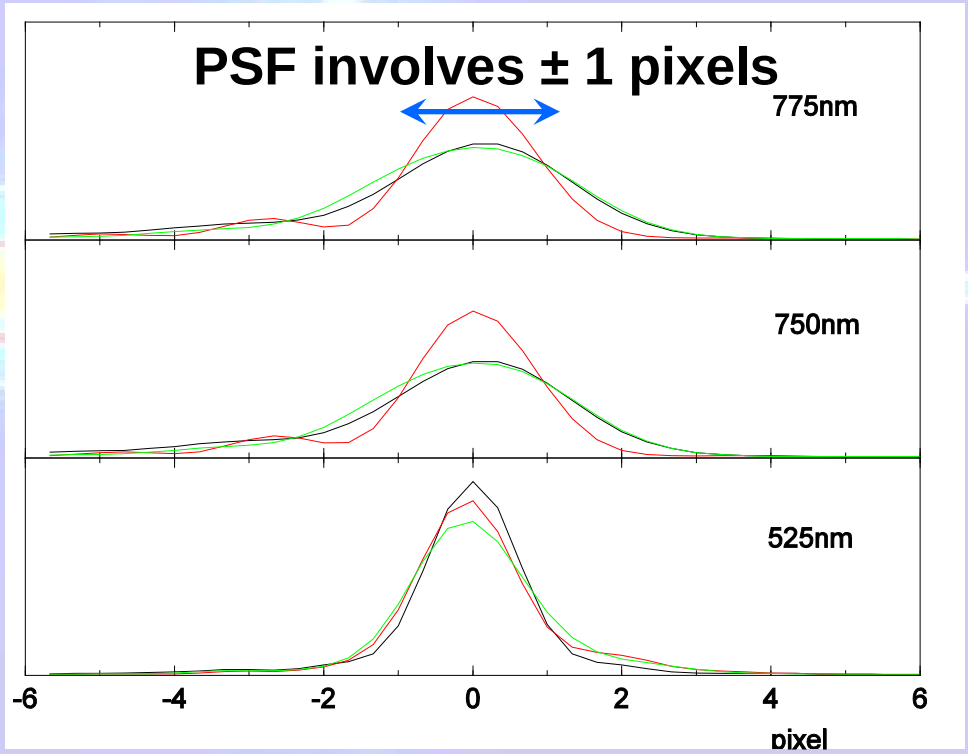
We cannot easily associate pixels and wavelengths.

→

The *Gaia* observations themselves will be the calibrators

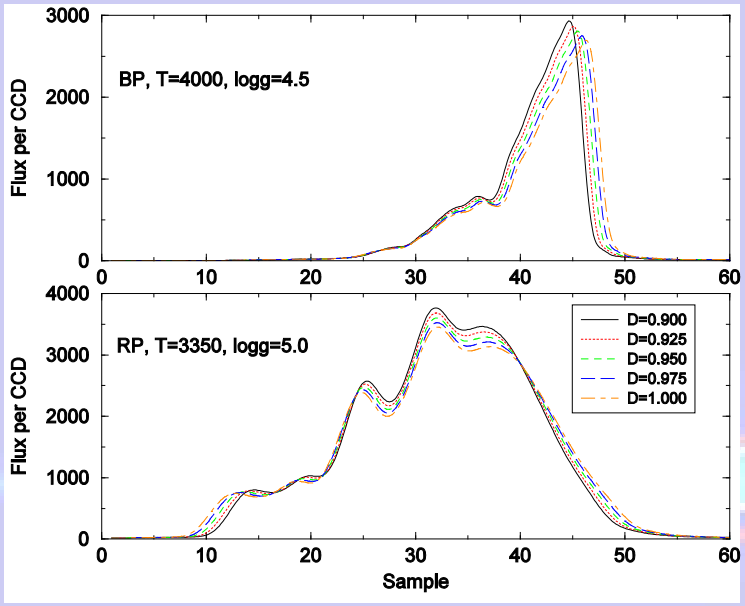
Dispersion and LSF



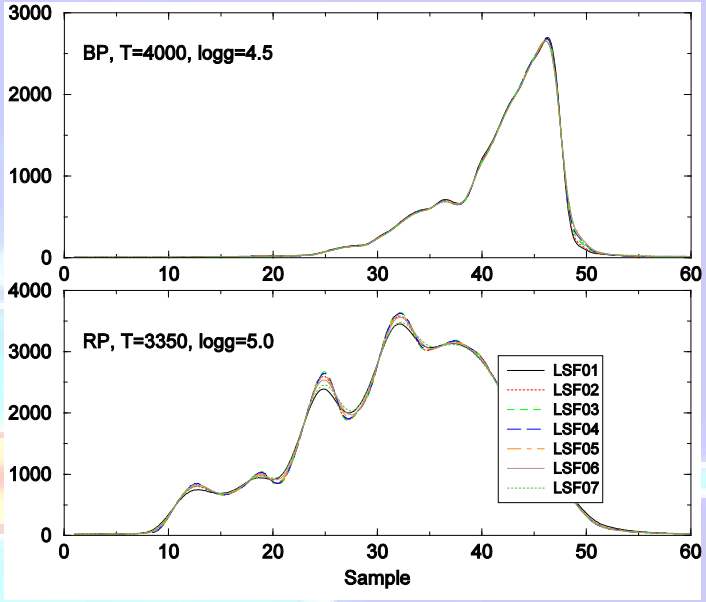


Geometrical shift (up to 3 pixels) to be added!!

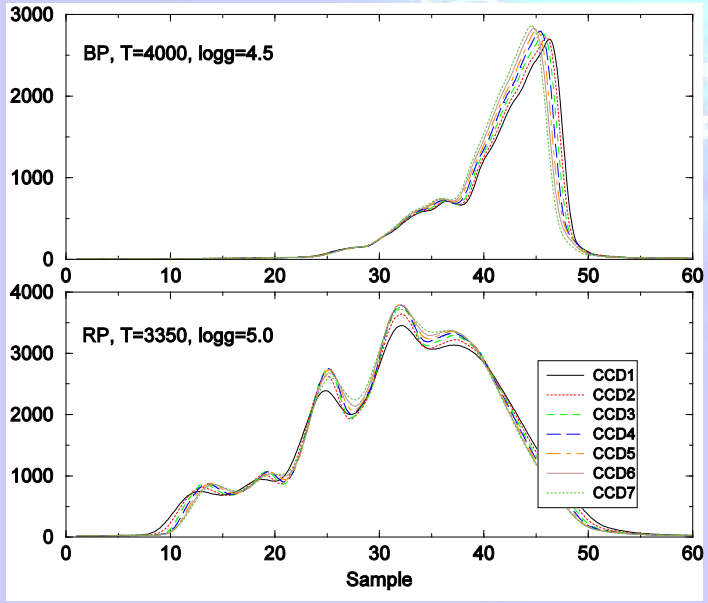
Dispersion and LSF



D effect

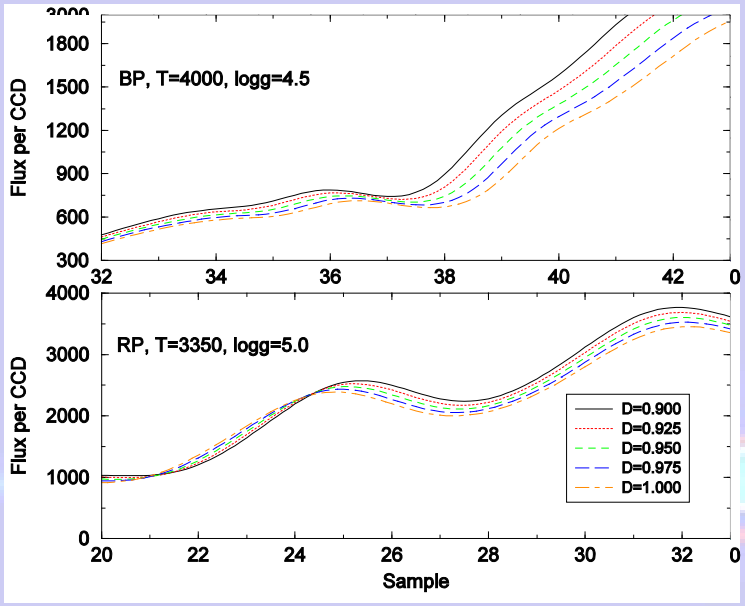


LSF effect

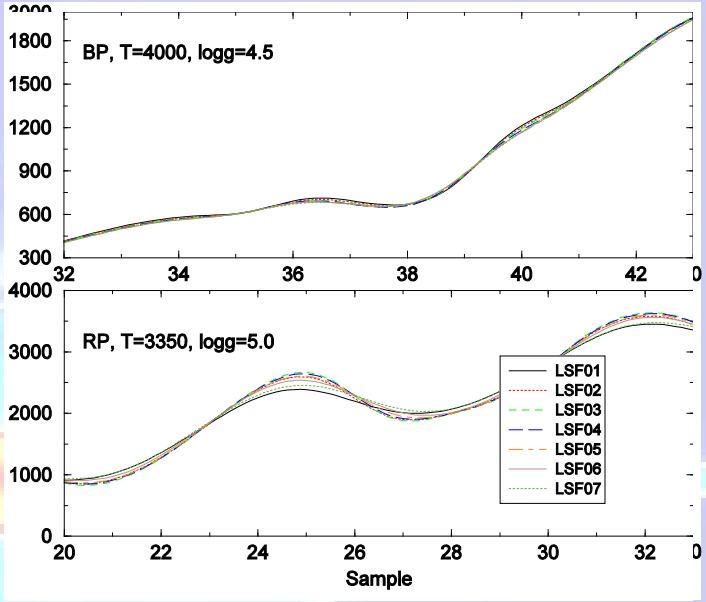


CCD effect

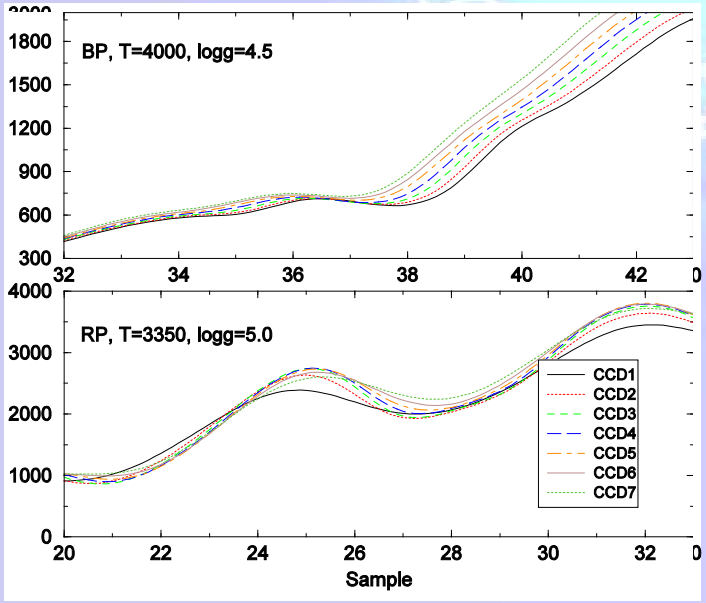
Dispersion and LSF



D effect

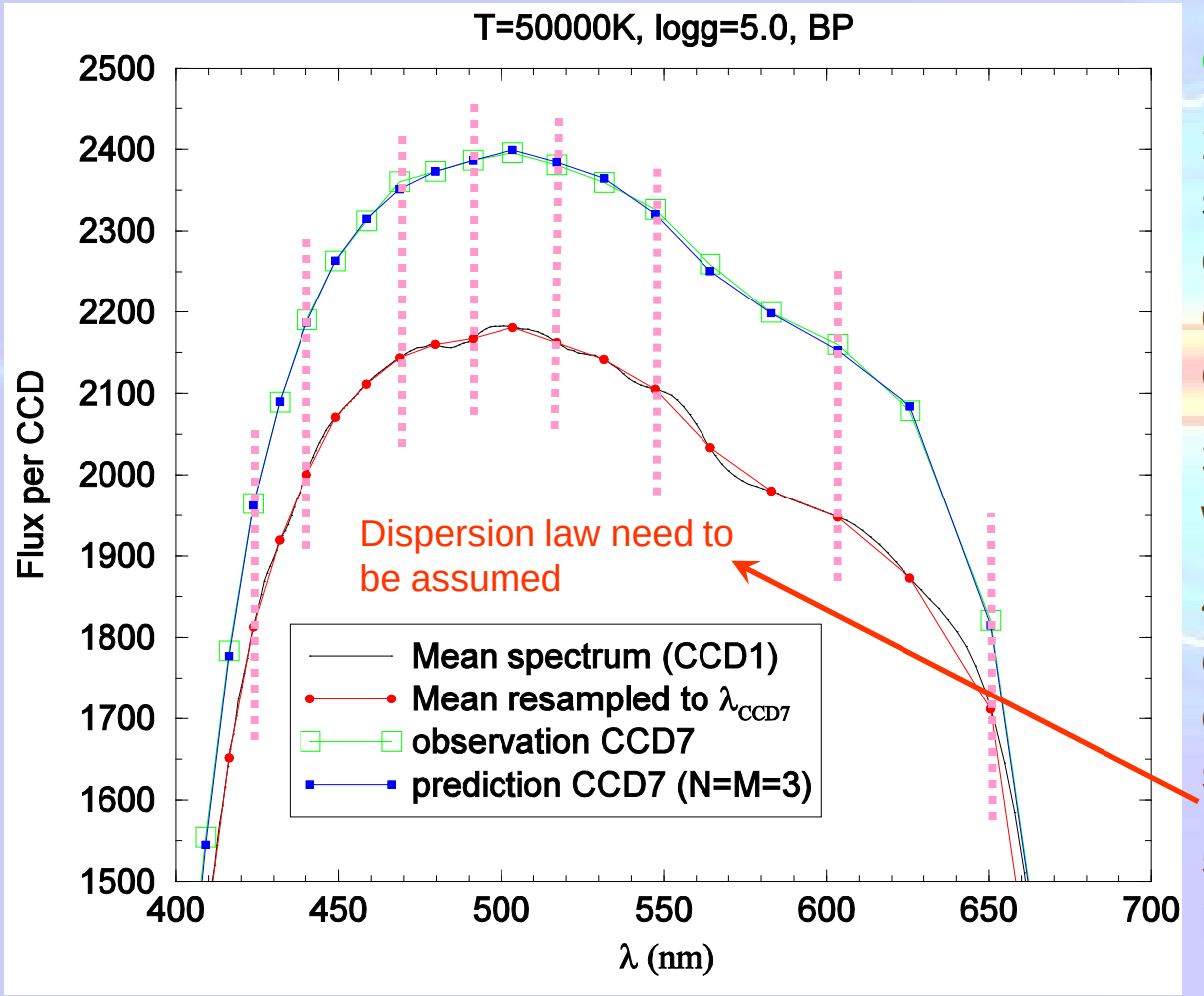


LSF effect



CCD effect

Procedure to obtain the prediction



1. We want to predict an **observation, f_i**.

2. We have a **mean spectrum, g(u)**, of the same observed source but with a different instrumental configuration.

3. Mean spectrum has its own wavelength scale.

4. It must be resampled to observation λ scale. We obtain a **resampled mean spectrum, h_i.**

5. Through a_{ij} model a **prediction** can be derived.

Procedure to obtain the prediction

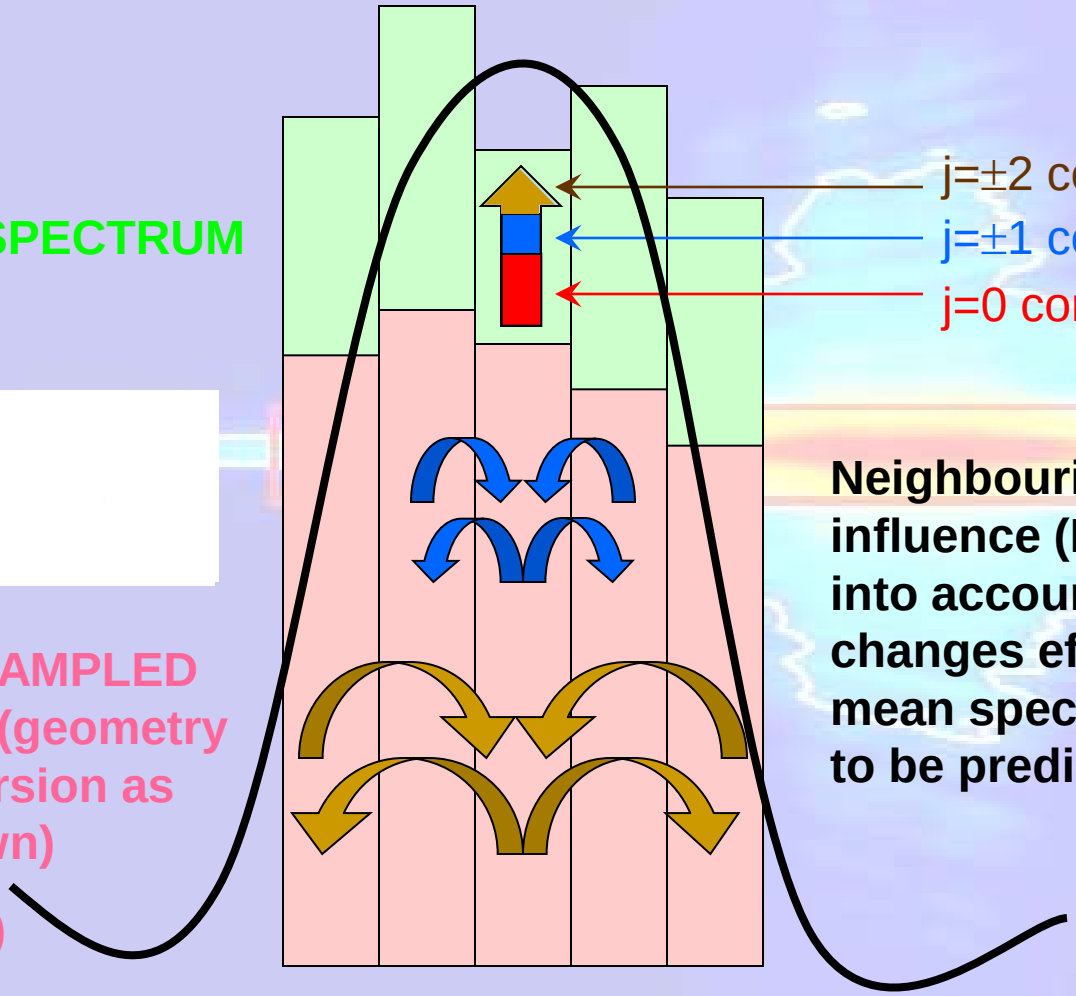
OBSERVED SPECTRUM

(f_i)

f_i

MEAN RESAMPLED SPECTRUM (geometry and dispersion as known)

(h_i)



Neighbouring samples influence (M=2 case) to take into account instrumental changes effects from reference mean spectrum to observation to be predicted.

LSF smearing, D change, …

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

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

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

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

Instrument calibration

Source update

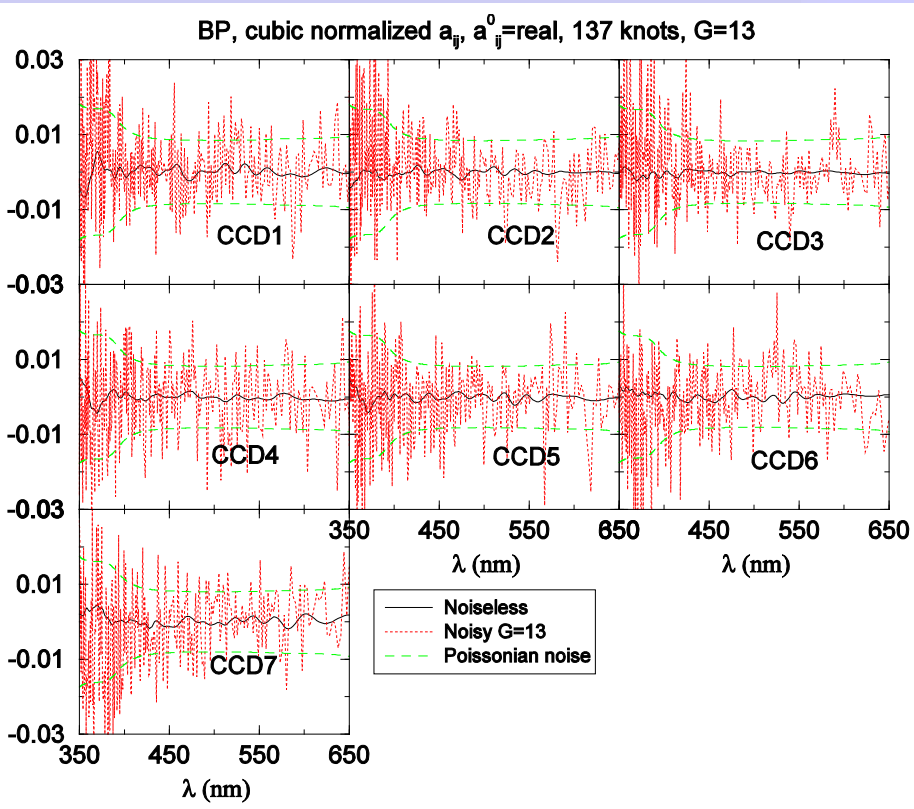
Assumptions when calibrating the instrument:

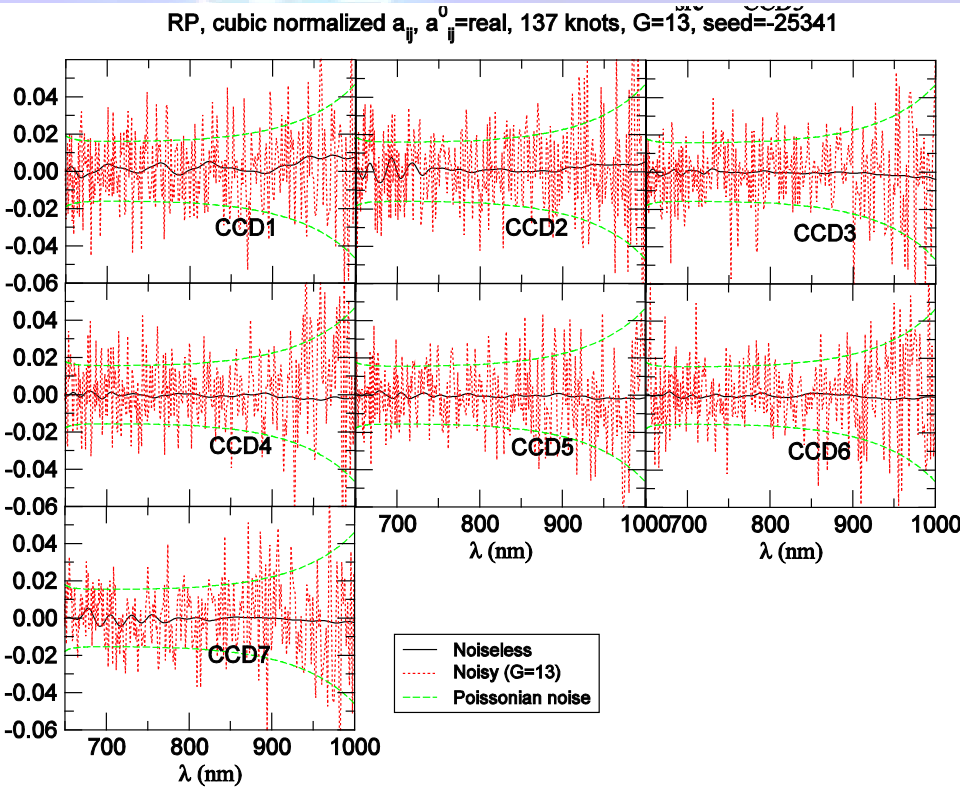
- Only performed using calibration sources.
- The equations system consist on all observations of all calibration sources performed using the same instrumental configuration (same CCD, FoV, column, gate, dispersion, LSF, geometry, ...) and fitting parameters for a given pixel i.
- The unknowns are c_{jl}.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





Hot star: T=50000K, logg=5

Tilts

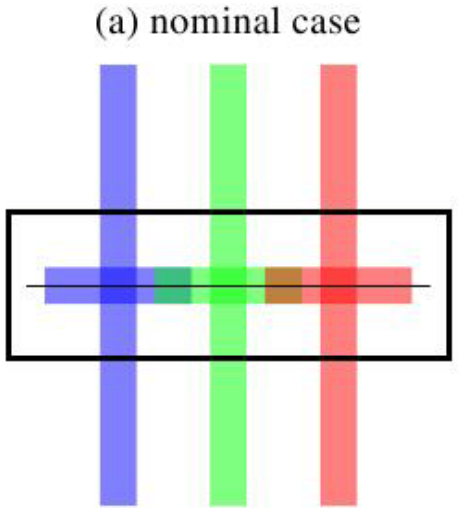


Figure courtesy Anthony Brown

Gaia photometric calibration

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

Pre-processing

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

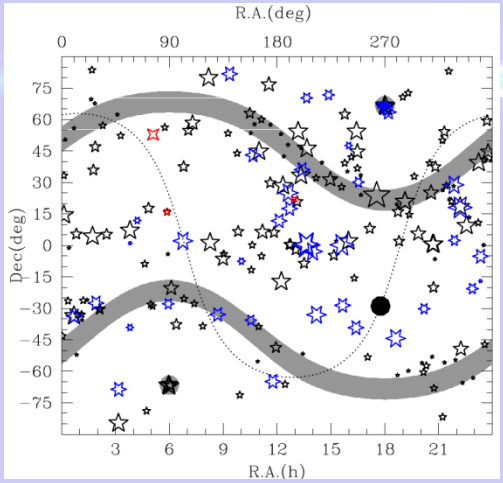
Internal calibration

- Absolute flux scale
- Wavelength scale

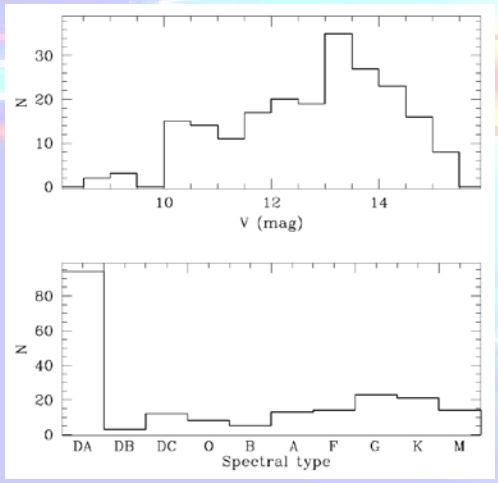
External calibration

SpectroPhotometric Standard Stars (SPSS)

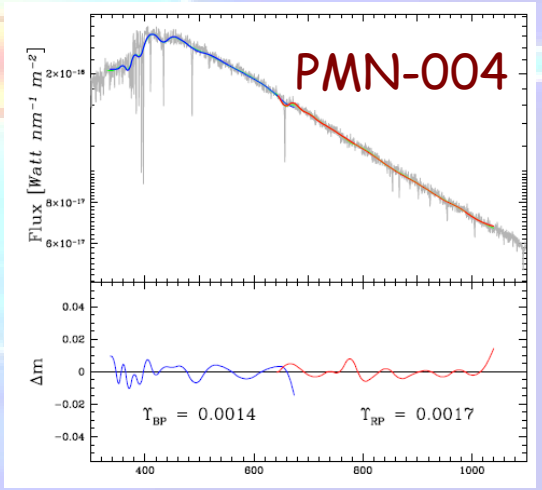
The link between Vega and our SPSS will be ensured by 3 *Pillars*; used to calibrate the *Primaries* (50), our ground-based calibrators spread over the whole sky. They will in turn enable to calibrate our *Secondaries* (200), the actual *Gaia* grid.



Sky position distribution



V and SpT distribution



Absolute BP/RP calibrated spectra

Pancino et al 2012, MNRAS (in press), arXiv:1207.6042v1

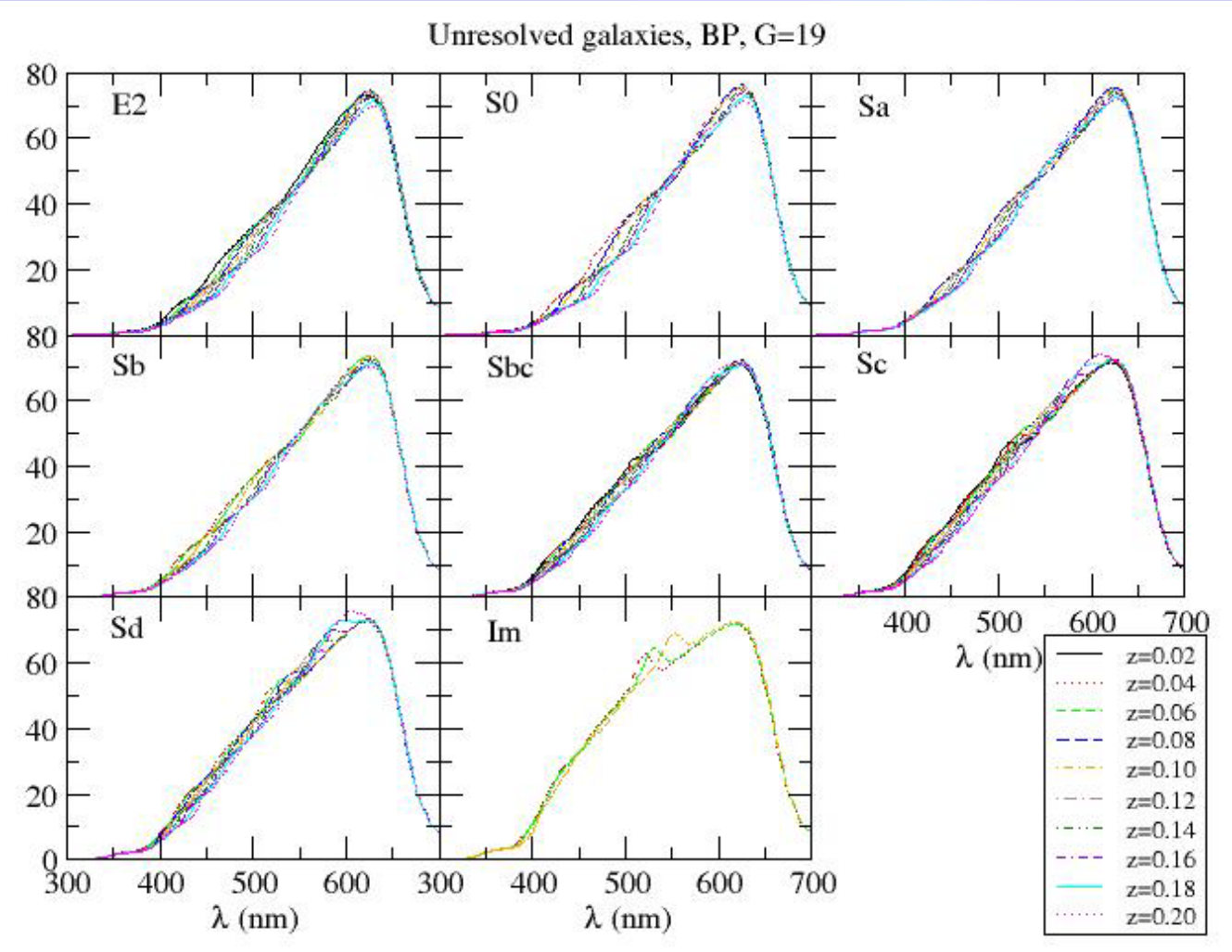
Data release scenario

First release: launch + 22 Months Sept-2013 →July-2015	• Positions (α,δ) and G-mag for single-like stars (90% of the sky) • the Hundred Thousand Proper Motions (HTPM) catalogue based on the Hipparcos stars
Second release: launch + 28 Months Jan-2016	• Updates of above + • **Mean radial velocities for stars** with non-variable radial velocity (90% of the sky)
Third release: launch + 40 Months Jan-2017	• **Positions (α,δ), proper motions, and parallaxes** and G-mag for single stars (90% of the sky) • Orbital solution for period between 2 months and 75% of the observation duration • Integrated photometry RP/BP • Spectrophotometry from RP/BP for sources for which astrophysical parameters are simultaneously released • **Source classification based on BP/RP and astrometry** for stars with sufficiently high quality data • Mean RVS spectra for sources where single epoch spectra are usable and APs are simultaneously released
Fourth release: launch + 65 Months Feb-2019	Updates of all above + • Source classification plus **multiple stellar astrophysical parameters** derived from BP/RP, RVS and astrometry for the majority of stars • **Variable star classifications and parameters** as available, and the epoch photometry • **Solar system results** with preliminary orbital solutions and individual epoch observations • Non-single star catalogue
Final release: End Mission + 3 years (36 months) **Sept-2021/2022**	Full astrometric, photometric, radial velocity catalogue • All available variables and non-single stars solutions • Source classifications (probabilities) plus multiple astrophysical parameters derived from BP/RP, RVS and astrometry for stars, unresolved binaries, galaxies and quasars. Precision improved with respect to 4th release. Some parameters may not be available for fainter stars. • Non Single Stars solutions and exo-planet list • All epoch and transit data for all sources • All Ground Based Observations made for data processing purposes (or links to it)

EXTRAGALACTIC SPECTROPHOTOMETRY

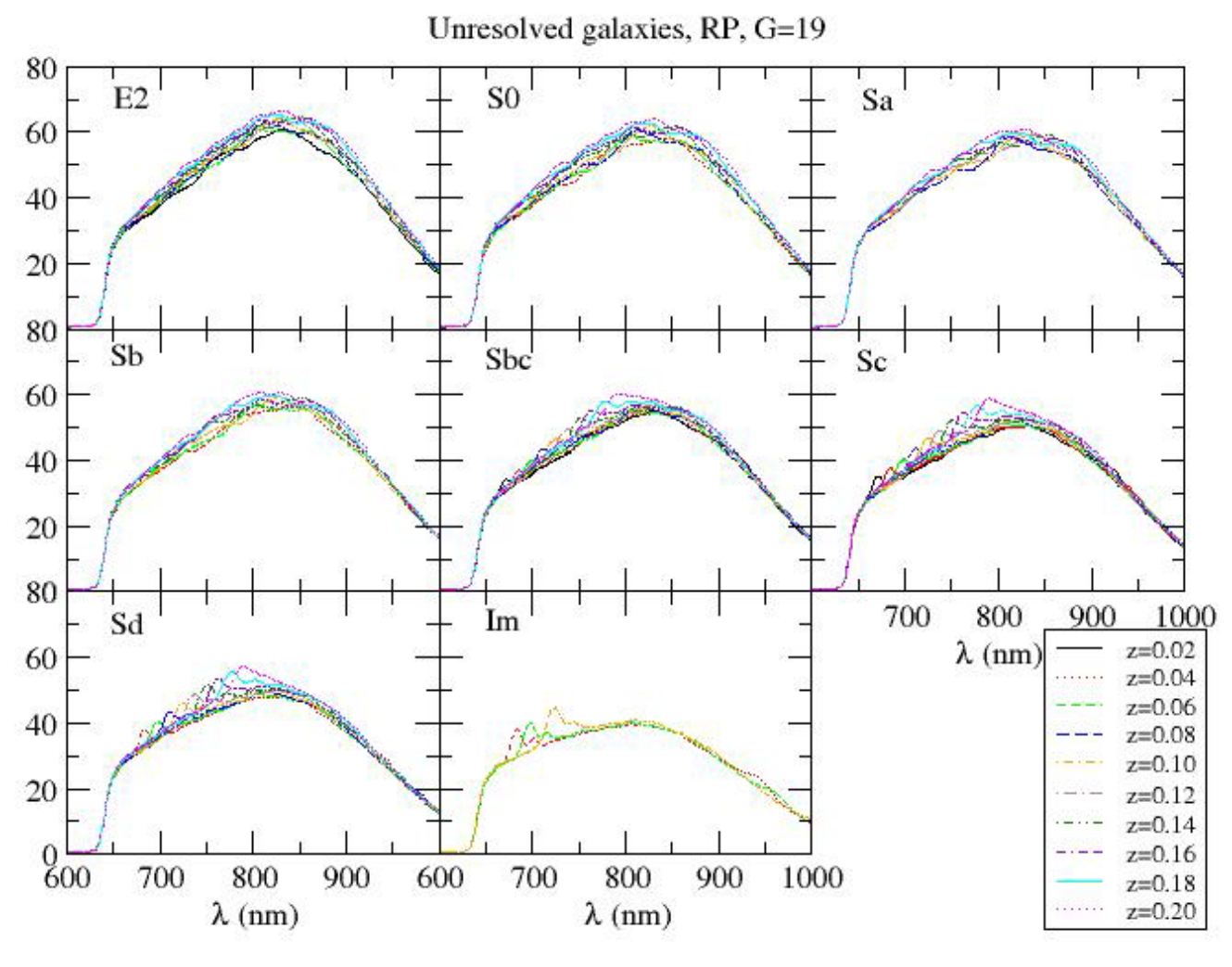


Unresolved Galaxies



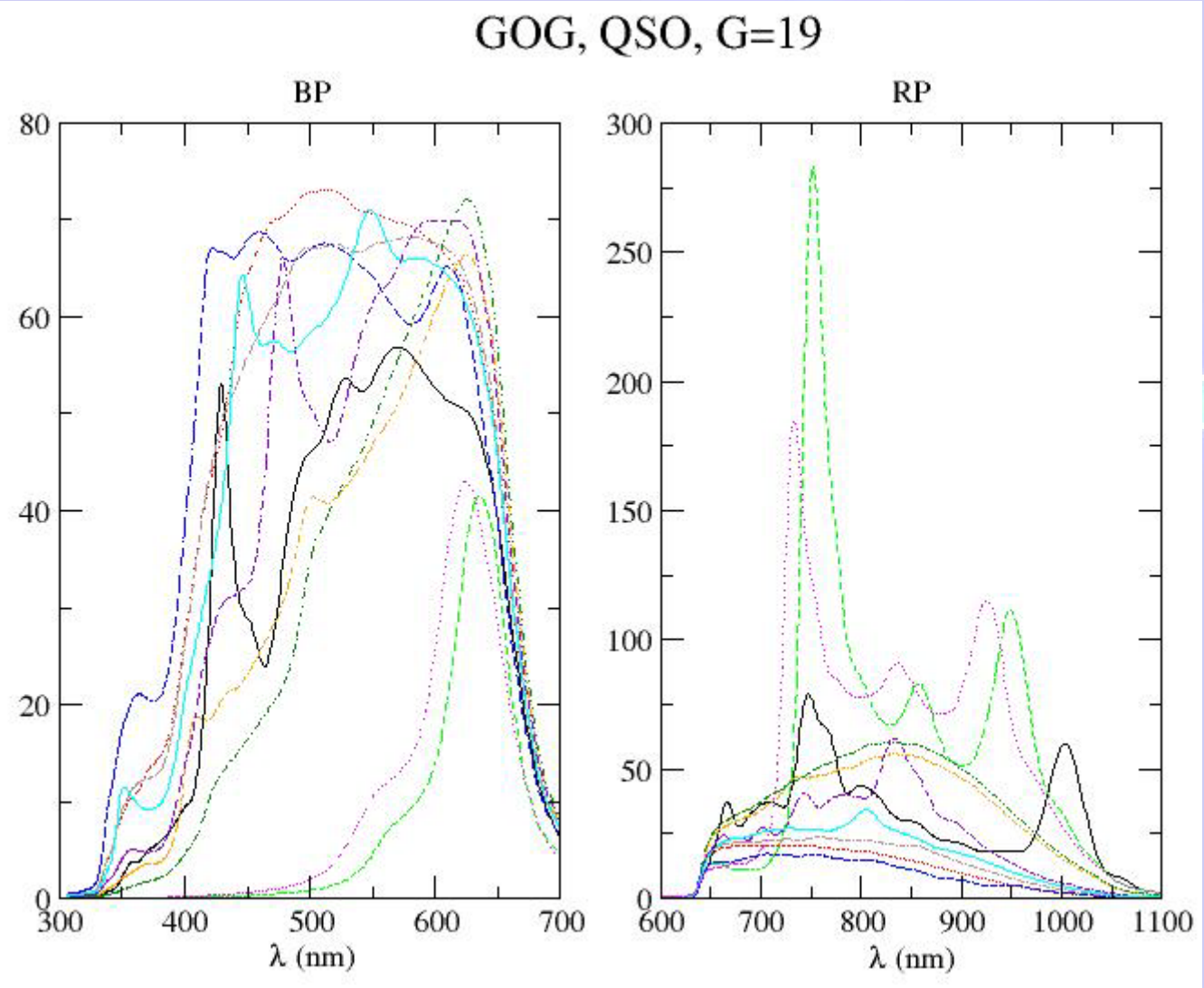
PEGASE.2 library used in GUMS (GAIA-C8-TN-UOA-PAT-001)

Unresolved Galaxies



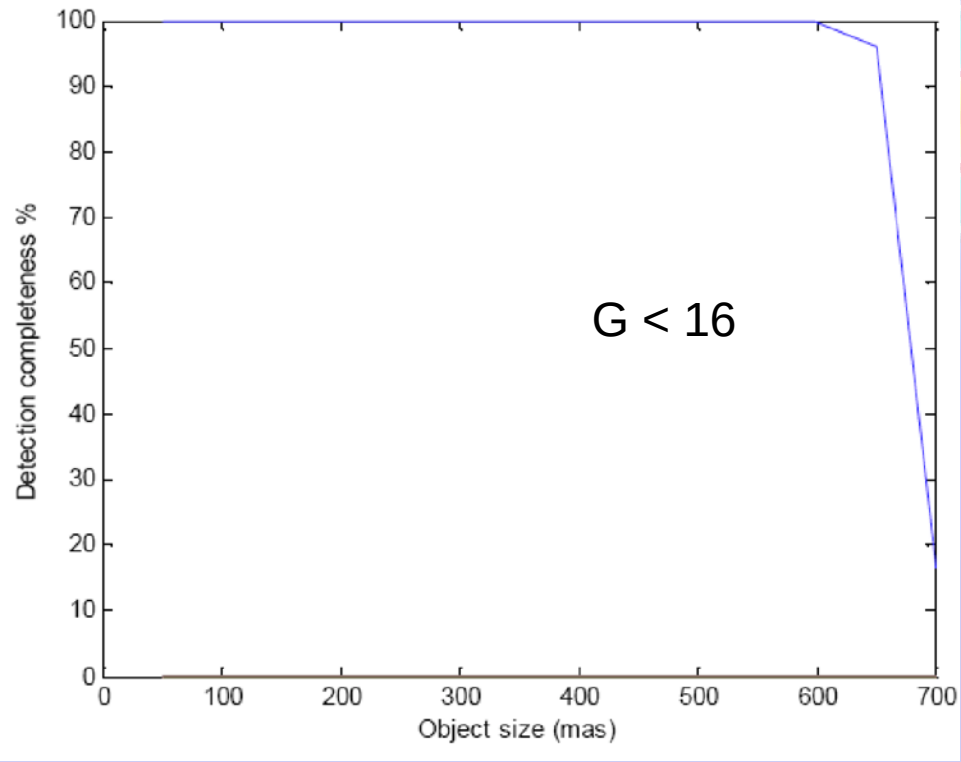
PEGASE.2 library used in GUMS (GAIA-C8-TN-UOA-PAT-001)

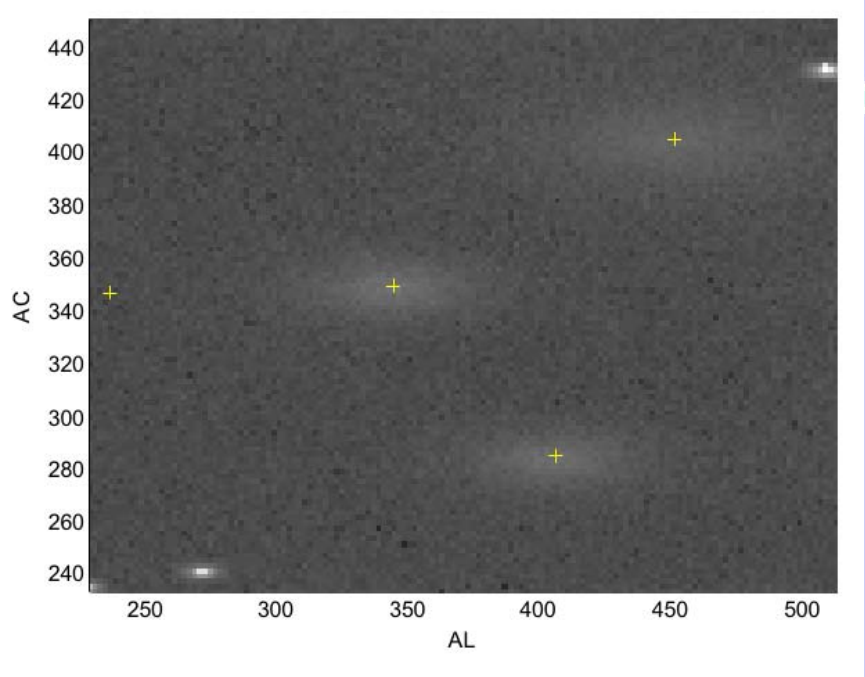
Quasars


GOG, QSO, G=19
BP
RP
80
60
40
20
0
300
400
500
600
700
λ (nm)
300
250
200
150
100
50
0
600
700
800
900
1000
1100
λ (nm)

Extended objects with *Gaia*

Very extended sources are seen as ***background*** by Gaia processing
Detection probability analyzed in GAIA.ASF.BG.PLM.00015.
Up to 600 mas size, all sources can be detected. At 700 mas, only 20% are detected.





Missed detection on galaxies.

EXTENDED OBJECTS WITH *GAIA*

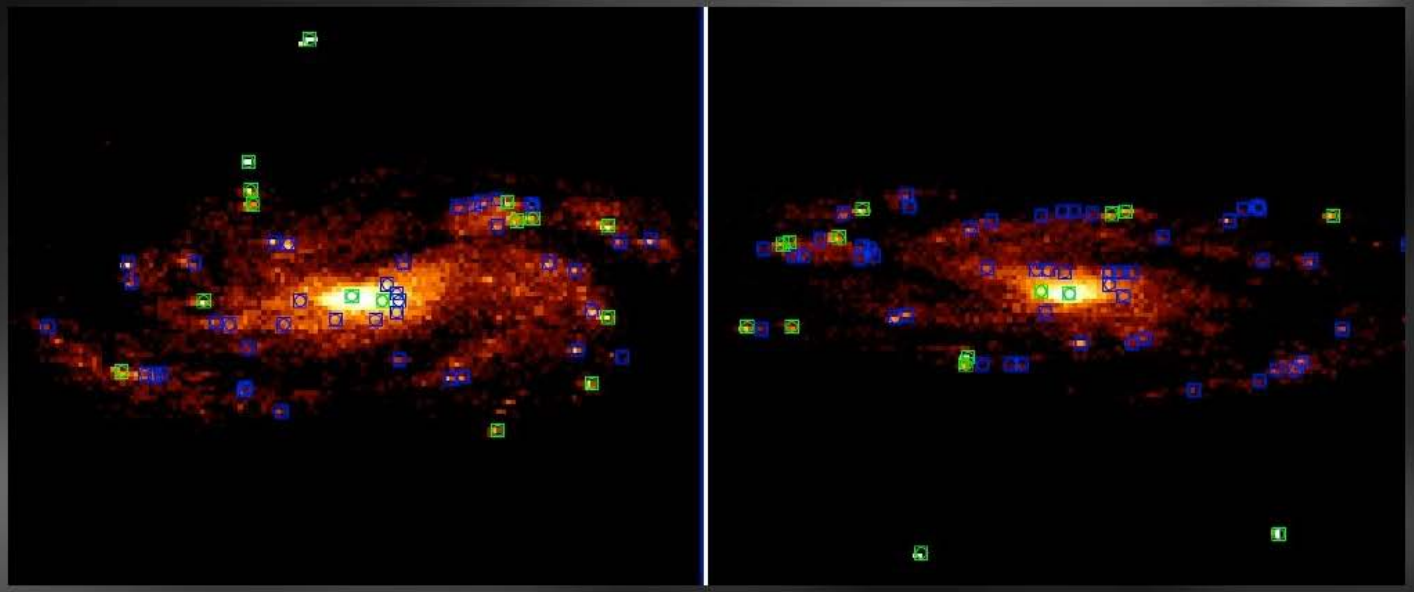


Extended Objects

- CU3 & CU5 will provide astrometry and photometry (respectively), with same methods optimized for stars. Size & tilts will perturb results.
- Morphology and astrometry will be done by CU4 (C. Ducourant, DU70).
- CU8 will provide AP + classification
- CU5-DU18 will do a 2D image reconstruction

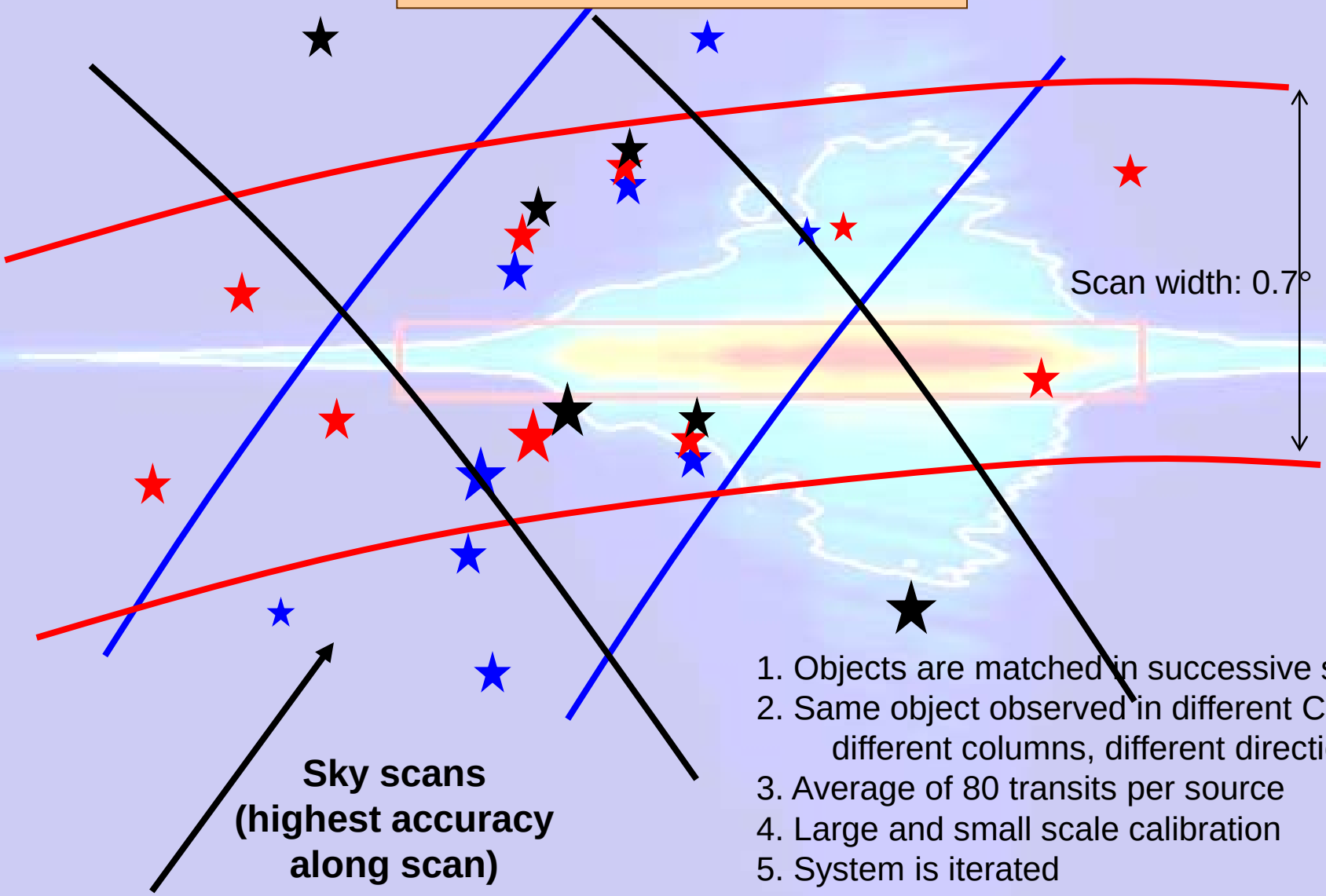
What will Gaia see?

Simulated data for M100, based on the HST image. Each transit gives a different scanning angle of the galaxy, hence might reveal different knots.



blue: all detections from VPA green: detections brighter than 20 mag

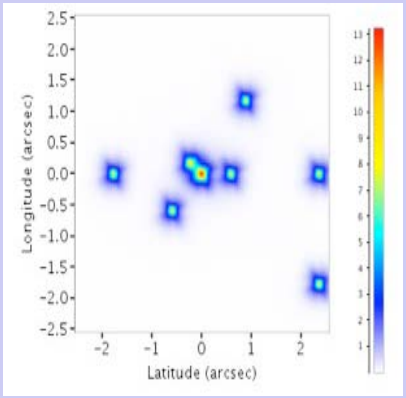
Gaia data treatment principle



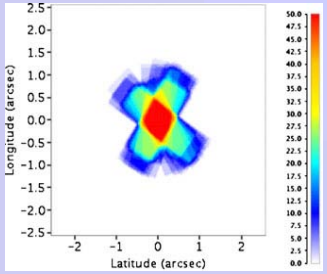
1. Objects are matched in successive scans
2. Same object observed in different CCDs, different columns, different directions
3. Average of 80 transits per source
4. Large and small scale calibration
5. System is iterated

2D image reconstruction

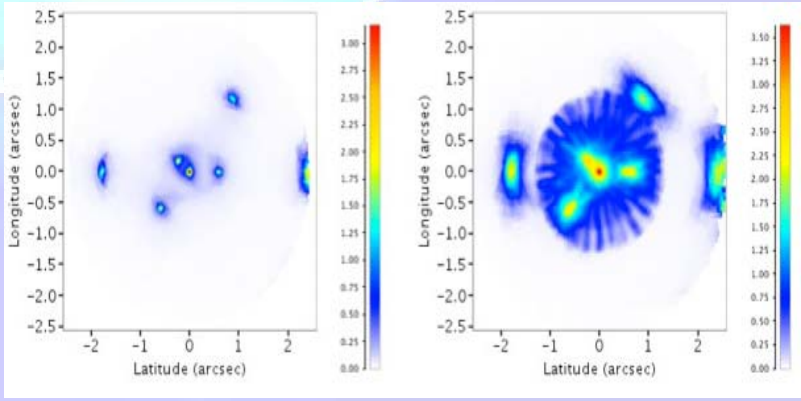
2D image reconstruction from 1D transits can allow background characterization and determine the extended structure.



Input (Sky*PSF)



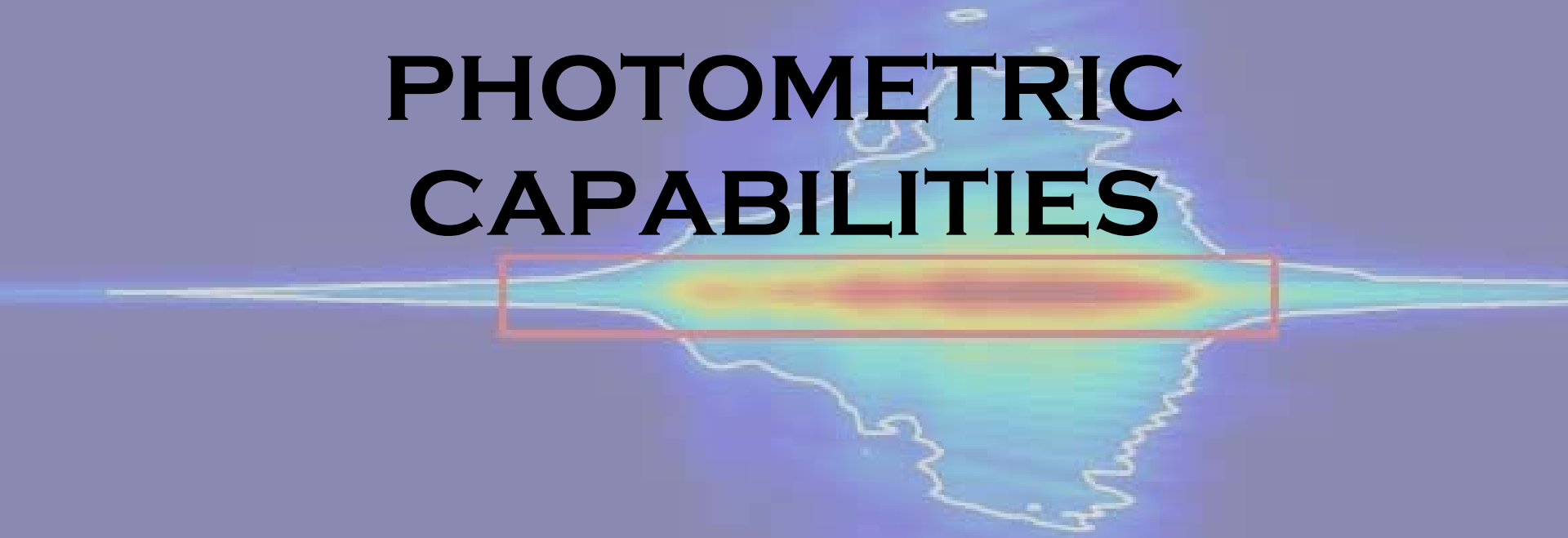
Coverage region



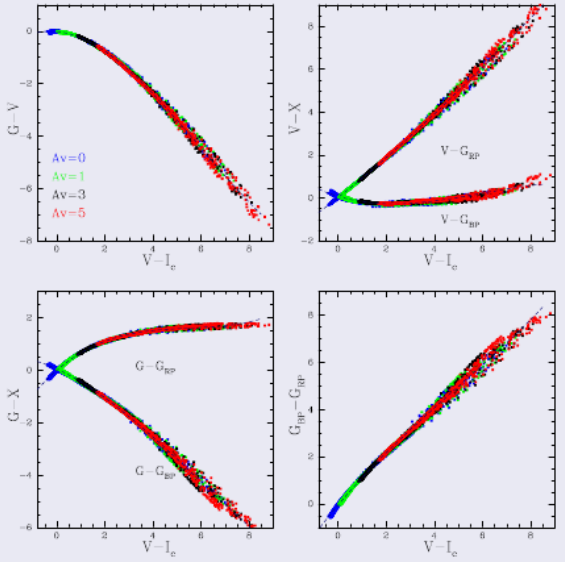
Faststack technique

Drizzle technique

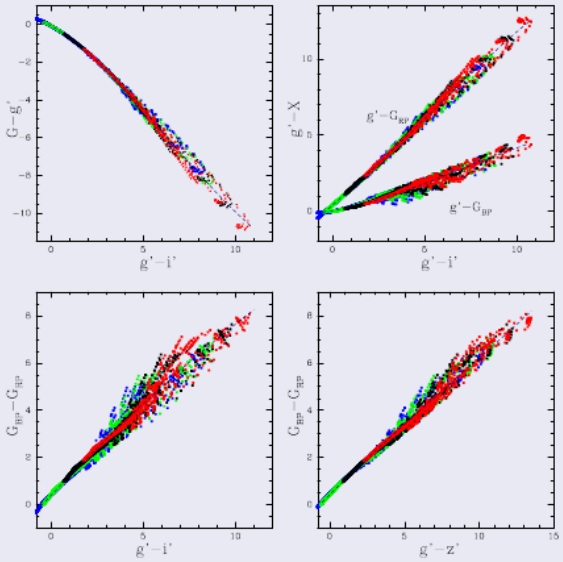
PHOTOMETRIC CAPABILITIES



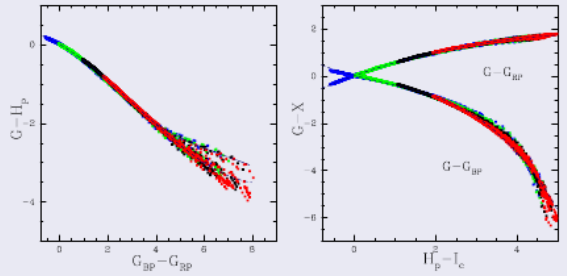
Gaia photometric transformations



Johnson-Cousins: $V - I_c$ relationships have the lowest residuals. $B - V$ show large scatter. The residuals increase for $T_{\rm eff} < 4500$ K in all cases. Among cool stars, scattering exists due to the logg and [M/H].



SDSS: $g' - i'$ relationships more sensitive to reddening than $V - I_C$. $G_{\rm BP} - G_{\rm RP}$ correlates better with $g' - z'$ than with $g' - i'$. Larger residuals than with Johnson passbands. The dispersion increase for $T_{\rm eff} < 4500$ K (more present in $g' - r'$ than in $r' - i'$).



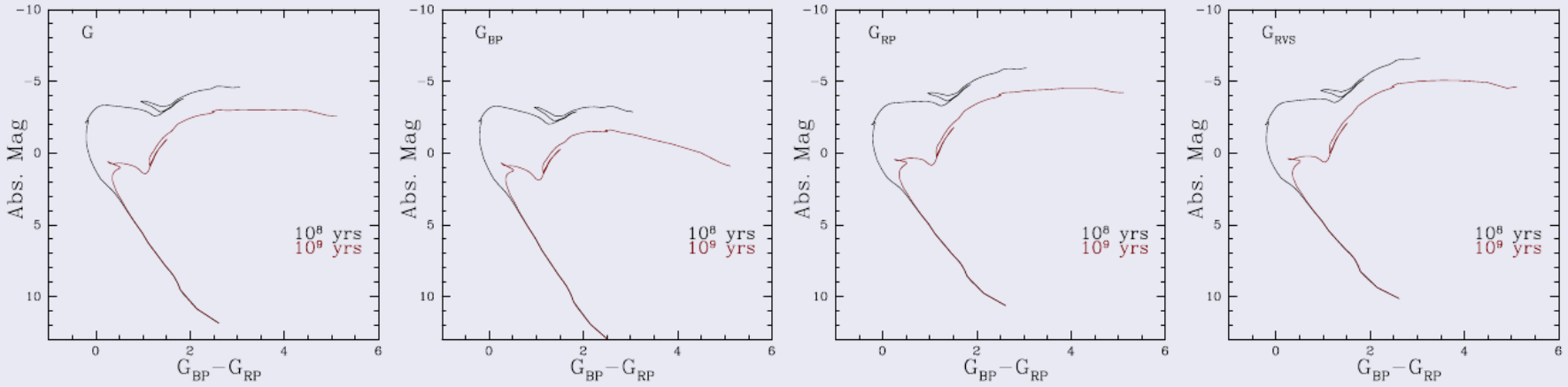
Hipparcos: Small deviation from the main trend for $G_{\rm BP} - G_{\rm RP} \gtrsim 4$ due to cool metal poor stars with $T_{\rm eff} < 2500$ K and [M/H]<-1.5 dex. It is preferable not to use the transformation with $B - V$ or $B_T - V_T$ for the cool stars.

Jordi et al. 2010, A&A 523, 48

BaSeL-3.1 stars

The same work has been expanded to WDs and to ALHAMBRA passbands and can be done for any other spectral libraries (Galaxies, QSO, ...) or photometric systems requested.

Gaia photometric isochrones



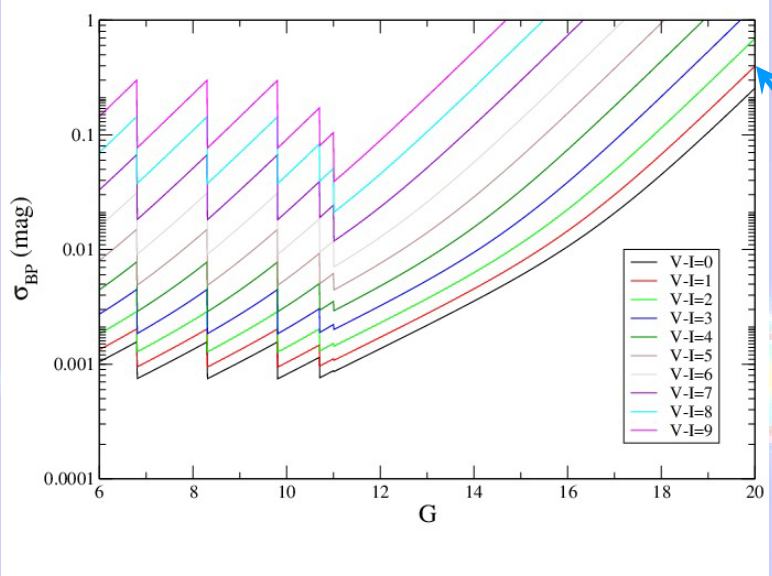
Padova isochrones (Marigo et al. 2008) computed in the *Gaia* passbands for solar metallicity and for different ages. Stellar tracks, isochrone files in the *Gaia* passbands are available as web interface at **(http://stev.oapd.inaf.it)**.

Jordi et al. 2010, A&A 523, 48

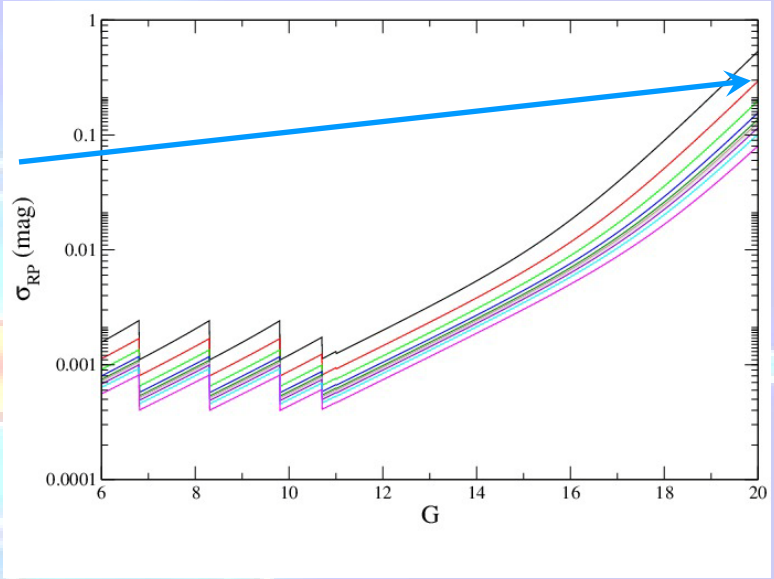
BaSeL-3.1 stars

Gaia photometric performances

(per transit)



σ_{BP-RP}=0.5 at G=20 for V-I=1



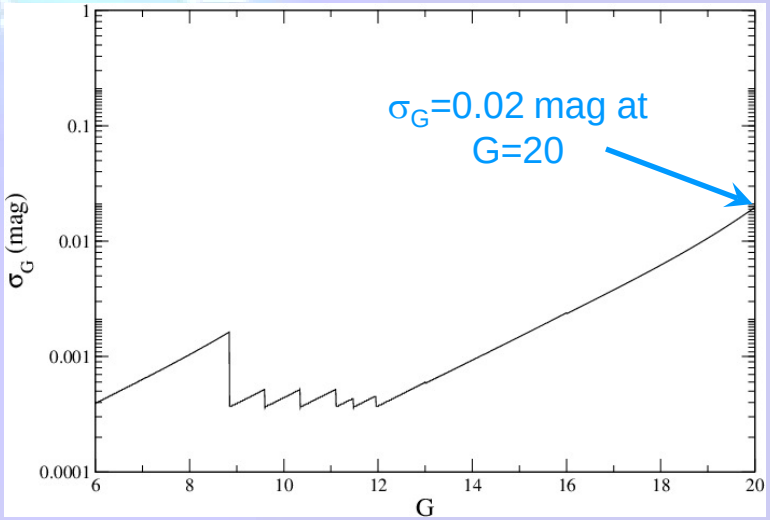
These σ values will determine *Gaia* variability detection capabilities

m=1.2 (20% margin)

σ_{cal} relevant if G↓↓

$$\sigma_X[\mathrm{mag}] = \frac{m}{\sqrt{n_{\mathrm{strips}}}}\left[\sigma_{\mathrm{cal}}^2 + \left(2.5\log_{10}e \times \frac{[g_{\mathrm{aper}} f_X + (b_X + r^2) n_{\mathrm{s}}(1 + n_{\mathrm{s}}/n_b)]^{1/2}}{g_{\mathrm{aper}} f_X}\right)^2\right]^{1/2}$$

=0 in these plots



σ_G=0.02 mag at G=20

Jordi et al. 2010, A&A 523, 48

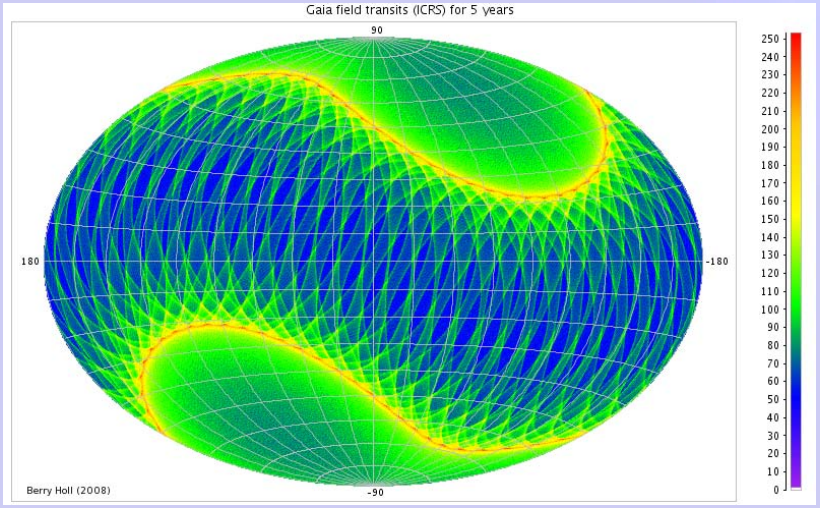
Gaia photometric performances

Single transit uncertainty:

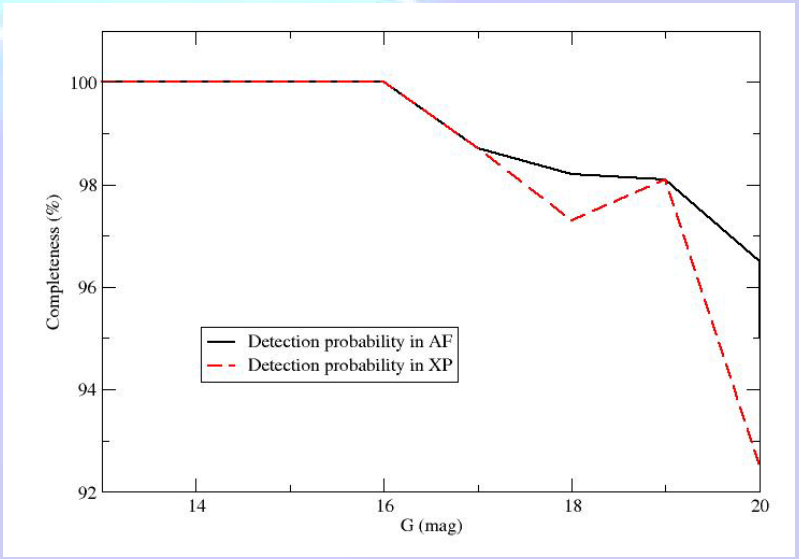
Jordi et al. 2010, A&A 523, 48

$$\sigma_X[\mathrm{mag}] = \frac{m}{\sqrt{n_{\mathrm{strips}}}}\left[\sigma_{\mathrm{cal}}^2 + \left(2.5\log_{10}e \times \frac{[g_{\mathrm{aper}}f_X + (b_X + r^2)n_{\mathrm{s}}(1 + n_{\mathrm{s}}/n_b)]^{1/2}}{g_{\mathrm{aper}}f_X}\right)^2\right]^{1/2}$$

End of mission uncertainties: $\sigma_X^{\mathrm{EOM}} = \sigma_X / \sqrt{N_{\mathrm{obs}} \times DP}$

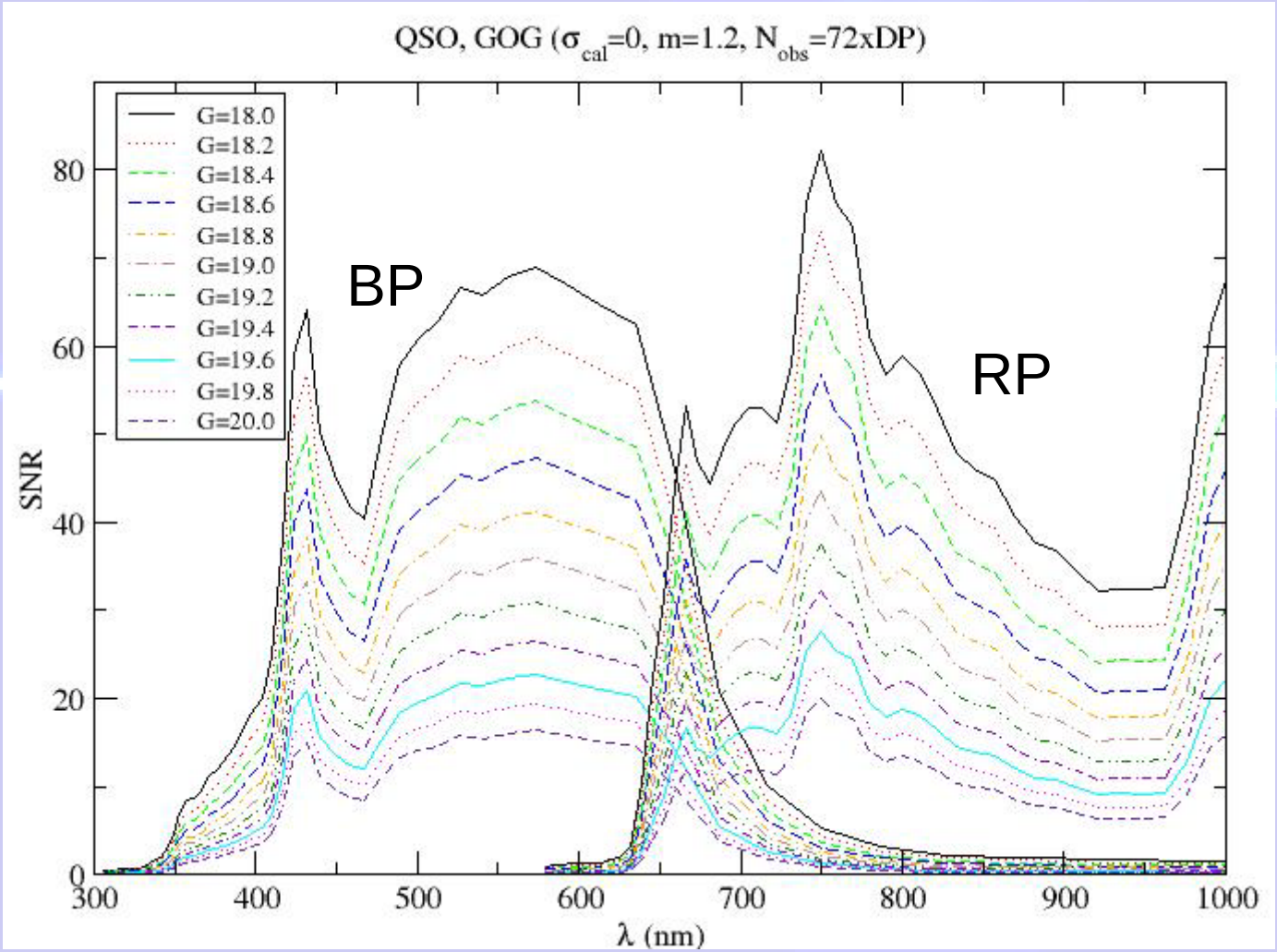


Number of observations (N_{obs}) after 5 years



Detection Probability (DP) in G and XP

Gaia photometric performances

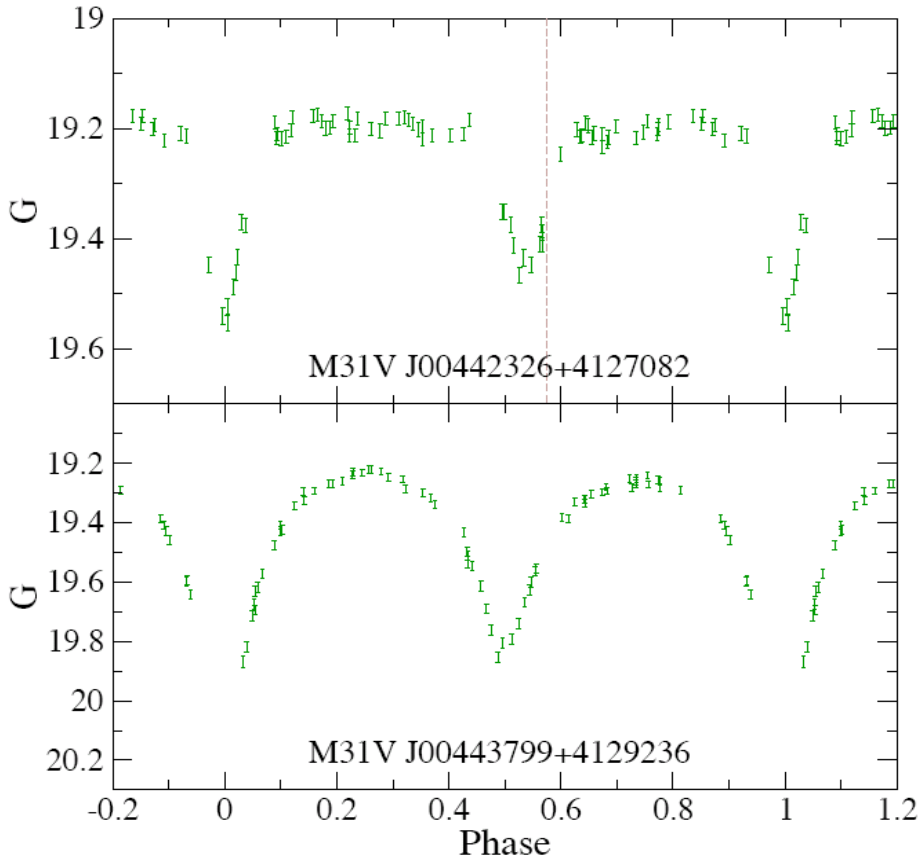


VARIABILITY WITH *GAIA*

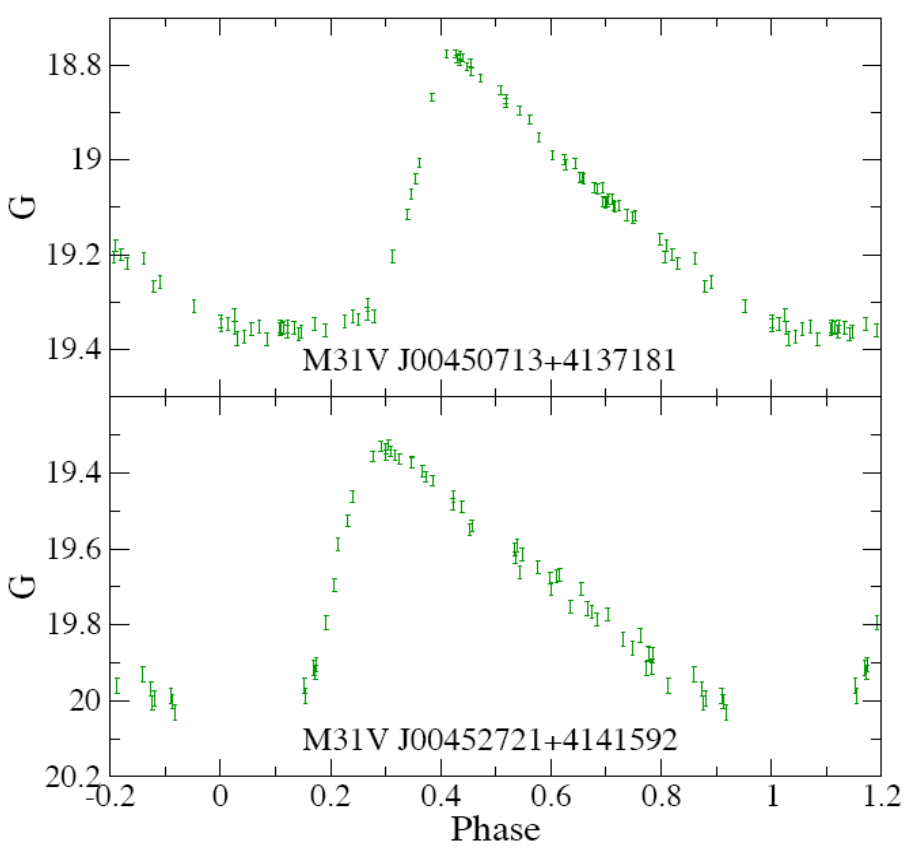


Variability with *Gaia*

Eclipsing binaries



Cepheids

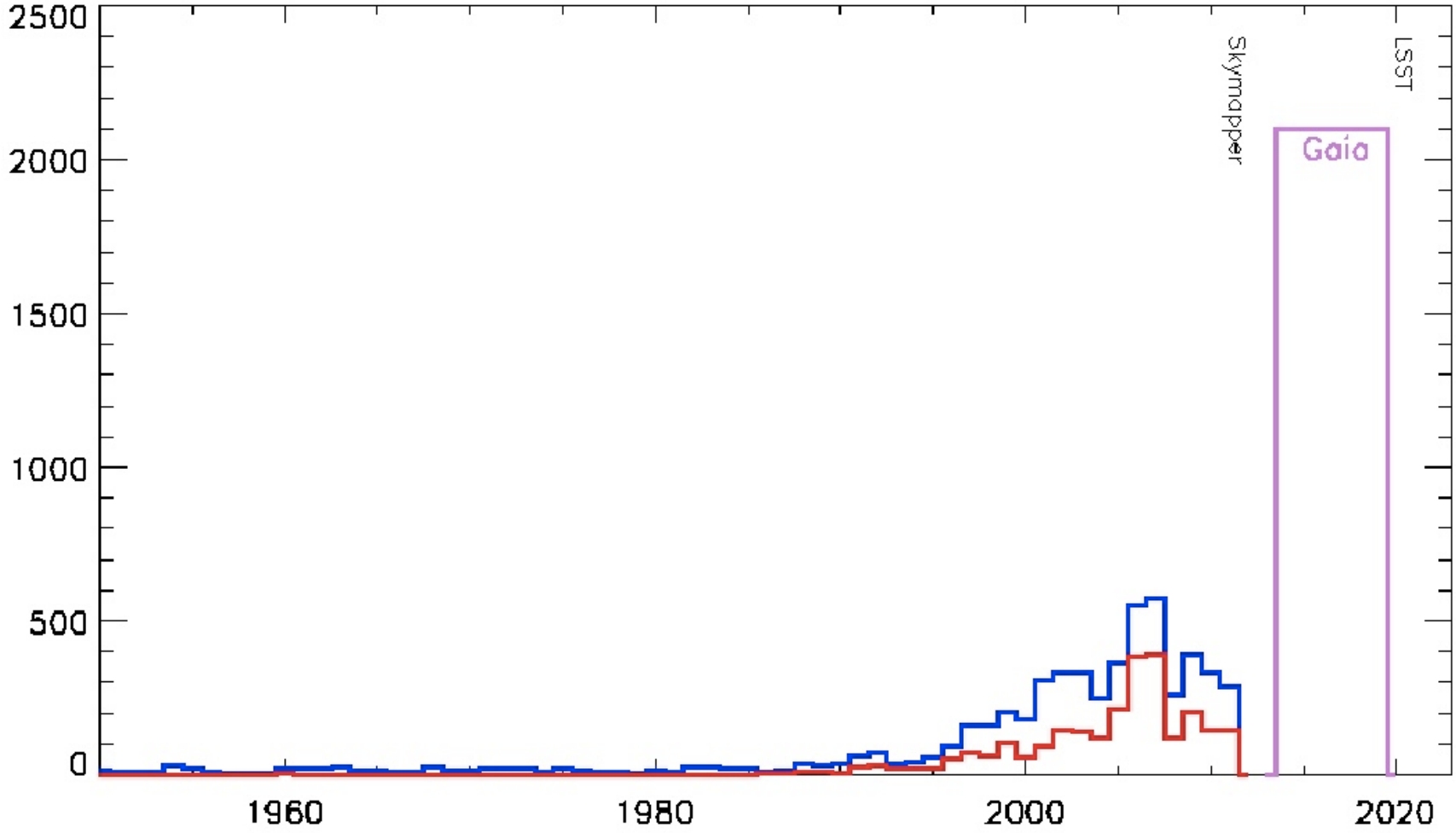


Light curves of stars in M31 (error bars from *Gaia*)

based on ground-based observations by Vilardell et al (2007)

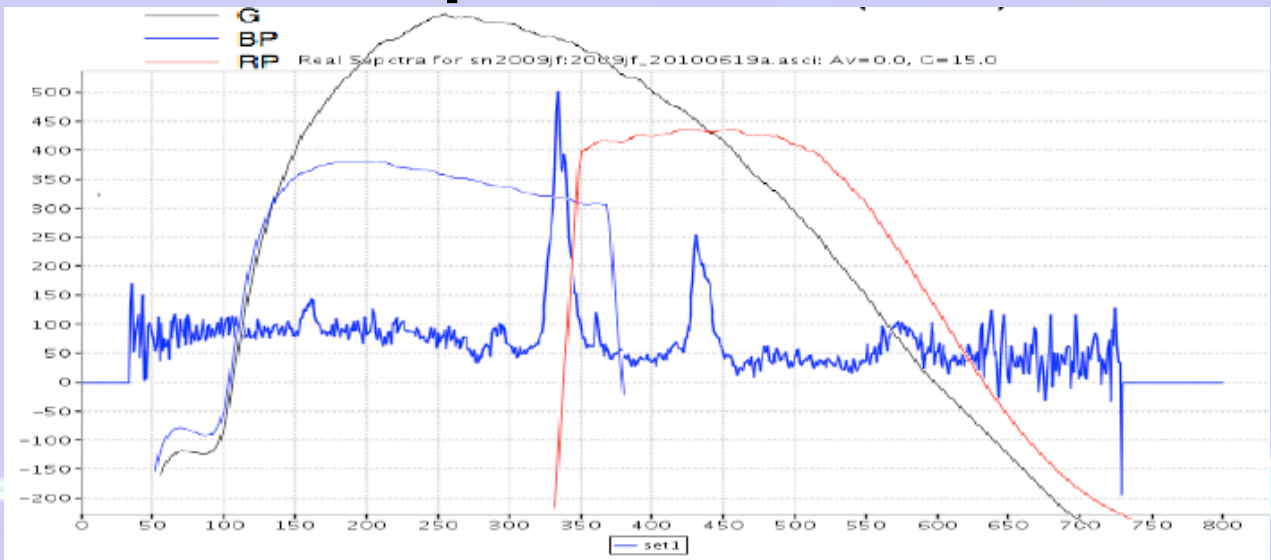
Supernovae

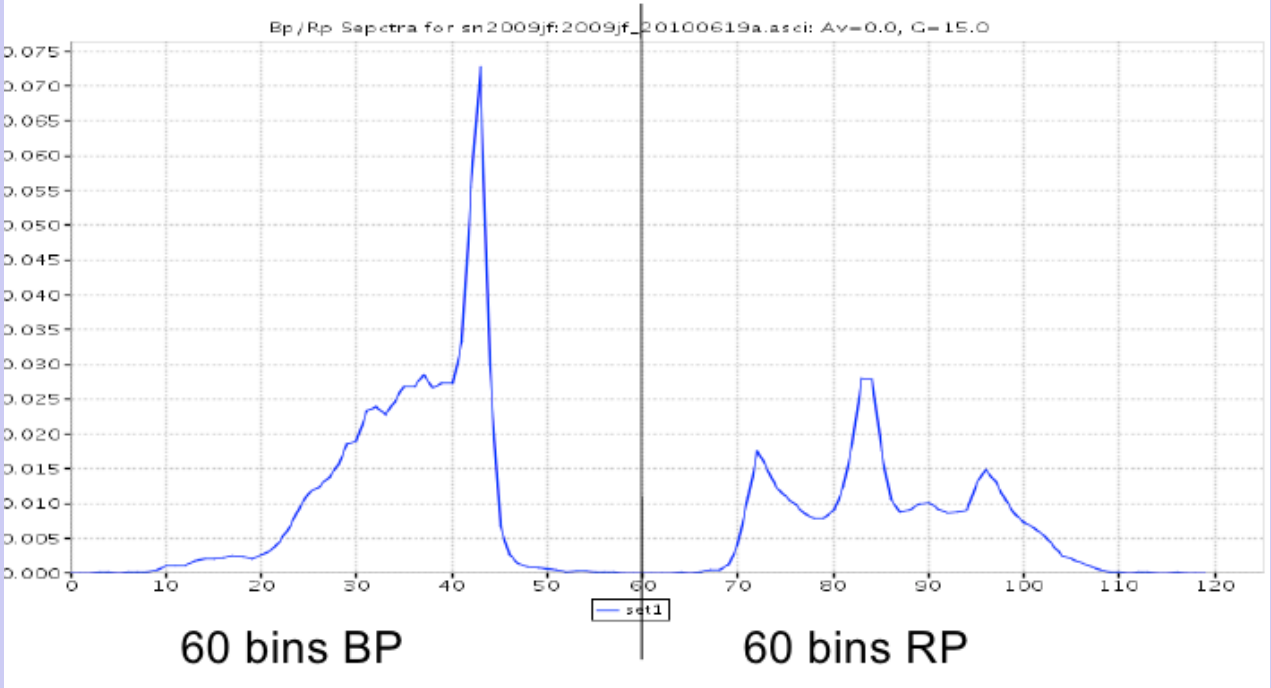
http://www.cbat.eps.harvard.edu/lists/Supernovae.html



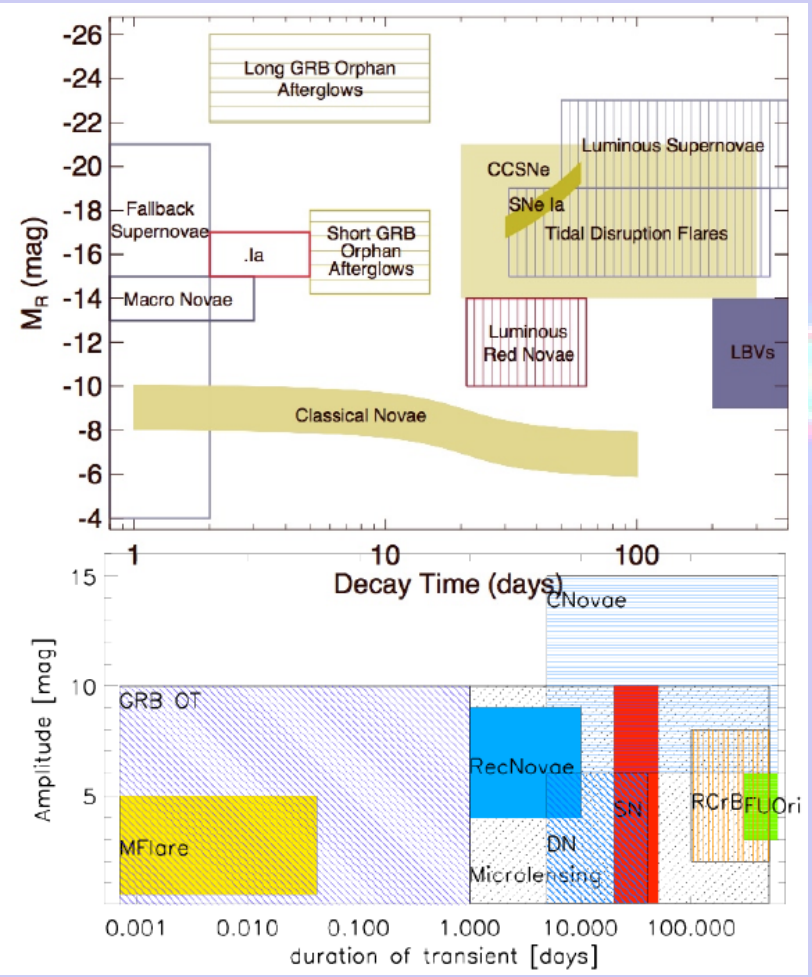
See also nice paper: *Supernovae and Gaia*, Altavilla et al. 2011, 2012Ap&SS.tmp...66A

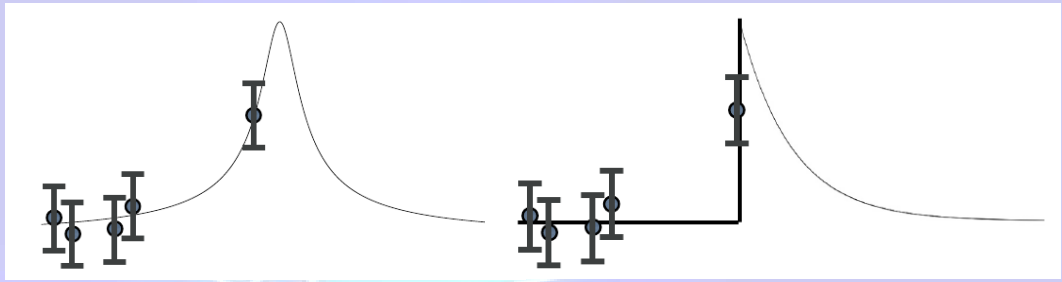
Supernovae


G
BP
RP
Real Spectra for sn2009jf:2009jf_20100619a.asci: Av=0.0, C=15.0
set1


Bp/Rp Spectra for sn2009jf:2009jf_20100619a.asci: Av=0.0, C=15.0
set1
60 bins BP
60 bins RP

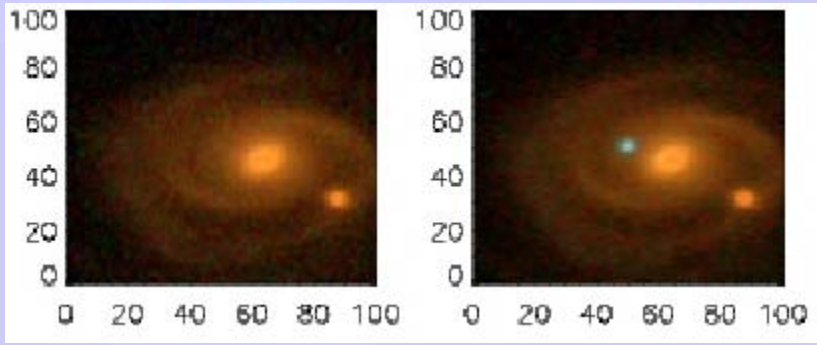
Photometric alerts





Gaia automatic classification methods for transient sources are being tested with real data:

- SDSS Legacy Survey: Stripe 82, 270 deg^2, scanned ~80 times
- 14/29 = 48% SNe correctly classified
- 4 new SNe discovered



Conclusions

• BP/RP low resolution spectrophotometry allows strong features to be identified (redshift determination).

• Internal calibration errors in G at the level of mmag and BP/RP below observational noise. External calibration at 1-2% based on Vega.

• At faint magnitudes (G>18) calibration errors are less relevant (dominated by photon noise, background extraction and CTI).

• Improvement of the simple model by the full forwarding model → to assess feasibility.

• Variability can be detected:

Epoch obs. at G=20: $\sigma_G = 0.02$; $\sigma_{BP-RP} = 0.5$ for V-I=1

• Gaia photometric simulations and transformations are available *(and could be expanded to other libraries and/or photometric systems under request)*

Universitat de Barcelona

Gaia DPAC
Data Processing & Analysis Consortium

gaia

Thanks for your attention

IEEC

EGSG 2012, Nice 10-11 Sept 2012

ICCUB
Institut de Ciències del Cosmos