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The BP/RP low resolution spectra calibration

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Abstract

For every source, Gaia will provide low resolution spectra in blue (BP) and in red (RP), acquired several times along the 5 years mission. Each of the spectra will be obtained with slightly different instrumental configurations (different PSF, spectral dispersion, geometry, overall response, tilts, windowing, gating, . . .). The purpose of the BP/RP calibration process is to yield final spectra to the users calibrated in both flux and wavelength. For this, CU5 implements two steps: (1) to refer all observed spectra to a common/mean instrumental system by using a large amount of reference stars, and (2) to absolutely calibrate the common/mean system in fluxes and wavelength with a smaller set of standard stars with on-ground observations. These steps are called internal and external calibration, respectively. The characteristics of the standard sources are slightly different for wavelength and flux calibration. To calibrate fluxes we require constant sources with very well known absolute fluxes. To calibrate wavelength scale, sources with strong spectral features, as Wolf-Rayet and late-type giants, are the most suitable.

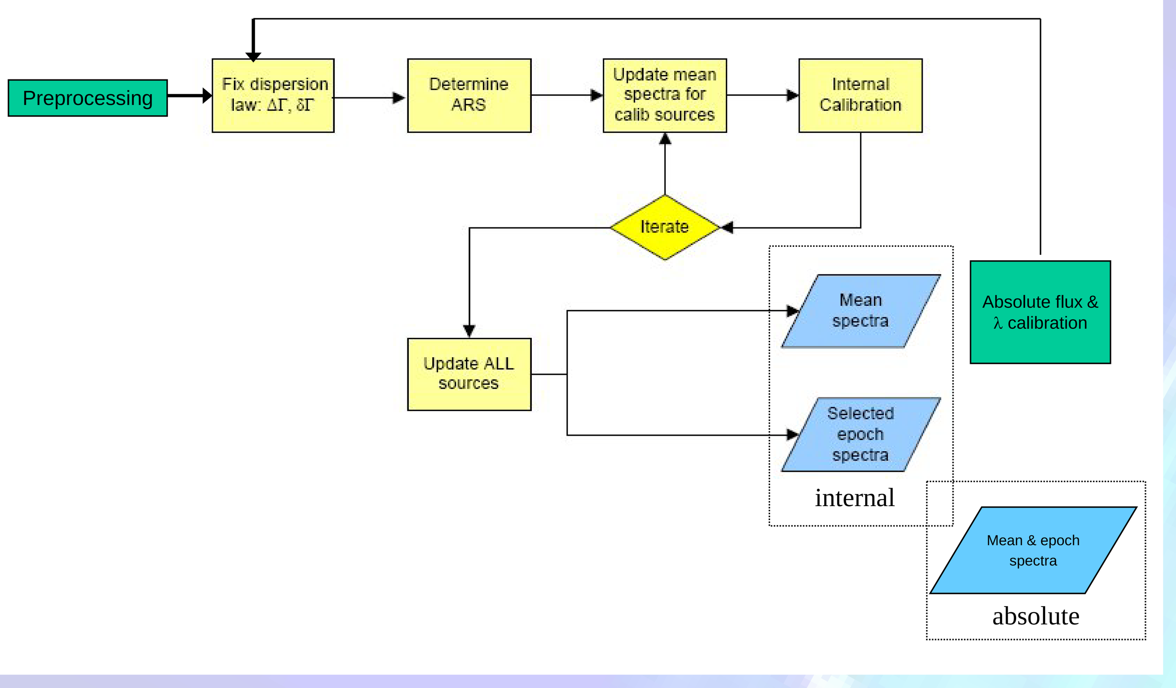
The BP/RP processing is a collaborative effort of the whole DPAC-CU5 (Photometry). In particular, the University of Barcelona team is elaborating and testing the internal calibration model, the absolute wavelength calibration and the selection of the calibration sources for both processes in a tight relationship with Cambridge (responsible of implementation and the data processing center), Leiden (responsible of pre-processing) and Bologna (responsible of absolute flux calibration) teams.

This poster explains the currently planned BP/RP calibration scheme and the expected outputs. It also points out the other effects not accounted for yet in the reduction process that could produce extra uncertainties to the final calibrated spectra.

Calibration Scheme

The calibration process is complex and the very large volume of data is a true challenge. The whole process is an iterative one. The main parts are:

- The ***pre-processing*** accounts for instrument properties like bias, bias instability, gain, non linearity, charge distortion, etc, based on knowledge from industry and tuned with true observations
- The ***internal calibration*** (it works entirely in the instrument system, and the spectra include the response and resolution of the instrument) is modeling the relation between different observations of a given source.
- The ***absolute calibration*** will transform the internally calibrated spectra to an absolute scale (flux and wavelength).
- The selection of the ***calibration sources***, according to variability, type of object, etc.



The flowchart shows the steps in the calibration. The Barcelona team is involved in the internal calibration and the external absolute wavelength calibration.

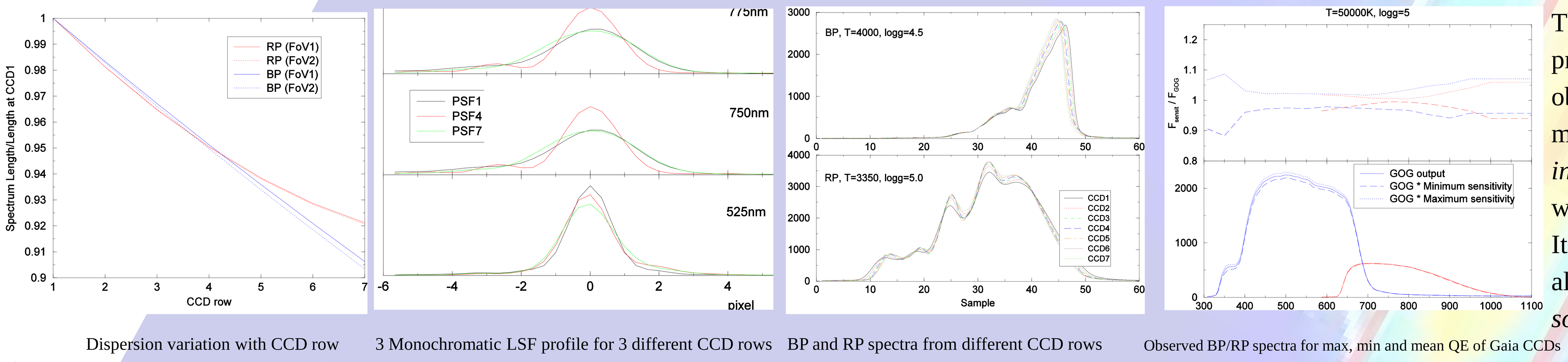
The steps are the following:

1. extract transits of calibration sources (large amount of sources for internal calibration);
2. assume instrumental parameters, including wavelength scale;
3. compute/update mean spectra for calibration sources;
4. run internal calibration, i.e. update instrumental parameters (overall response, geometry, flux loss, …); normalize coefficients
5. iterate steps 2-3-4, if needed;
6. revise geometry and differential dispersion and repeat the internal calibration if needed;
7. update mean spectra for all sources.

The process is complemented with the initial step of the pre-processing and the final step of the absolute flux and wavelength calibration

Internal calibration: Epoch and Mean spectra

The final Gaia BP/RP product is desired to be one single spectrum per source combining all observations from that source and epoch spectra for the sources showing variability. All these observations will be observed in different places of the focal plane, with different instrumental properties (different sensitivity, dispersion law, PSF, non-linearity in the response, tilts, windowing, gating, the high frequency of blending, charge distortion, …)[1]. Then, all observations need to be referred to a same "mean" instrument. Once the mean spectrum of a source is built, this can be used to obtain a prediction for any BP/RP observation of this particular source, using the expected instrumental values the observation is supposed to have.



Dispersion variation with CCD row — 3 Monochromatic LSF profile for 3 different CCD rows — BP and RP spectra from different CCD rows — Observed BP/RP spectra for max, min and mean QE of Gaia CCDs

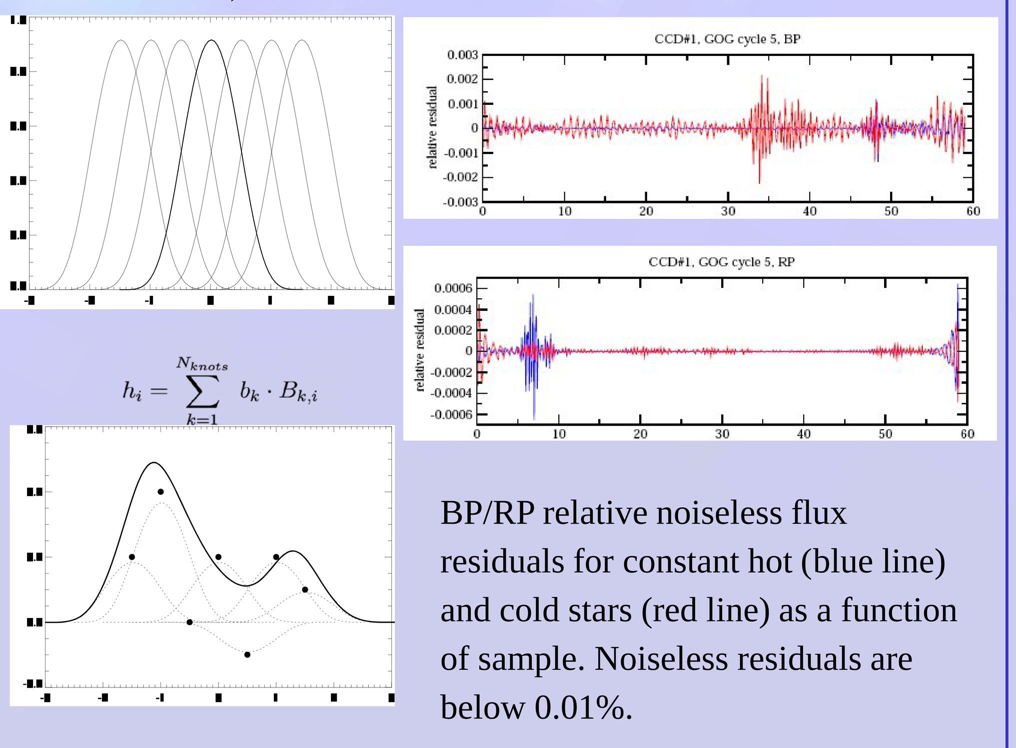
[1] see for instance the poster of Voss et al. on the aspects of the photometric G band calibration and the expected photometric precision

The comparison of this prediction with the real observation can be used to monitor changes in the *instrument* with respect to what is expected. Iteratively this process is also used to refine the *source* spectrum.

Source update:

We wish to produce mean spectra, combining the many individual observations of a source into a single spectrum in the mean instrument. We should use the same representation for all sources, and it should not change between data processing cycles.

We aim to represent the mean spectra as a combination of some basis functions (B_{ki}) with their corresponding weights (b_k). Several tests with basis functions of different shape have been performed. The example below shows the case of bi-quartic B-splines with equidistant nodes.



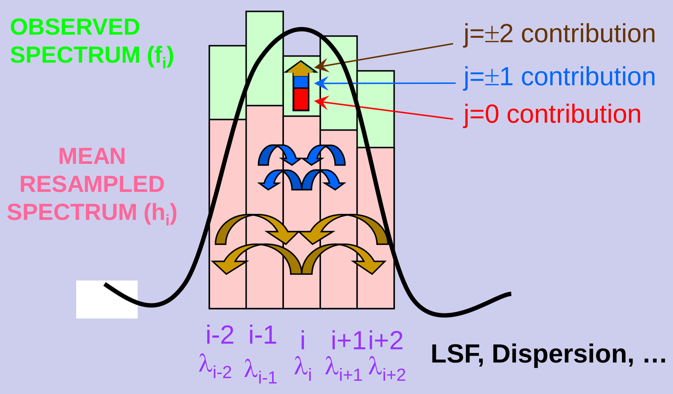
$$h_i = \sum_{k=1}^{N_{knots}} b_k \cdot B_{k,i}$$

BP/RP relative noiseless flux residuals for constant hot (blue line) and cold stars (red line) as a function of sample. Noiseless residuals are below 0.01%.

Mean spectra make good sense for constant sources, but are not well defined for variable sources, for which epoch calibrated spectra are necessary. Experiments in a near future are planned.

Instrument calibration:

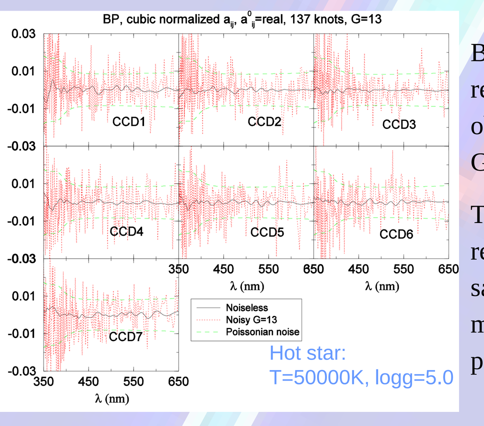
The current model accounts for changes in sensitivity, PSF and wavelength scale, both zero point and dispersion law. The accumulated charge in a given pixel (f_i) is the contribution of fluxes at several wavelengths and the combination varies from observation to observation due to changes of PSF and dispersion law. This means, then, that the relationship to relate fluxes in different observed spectra needs a colour (wavelength) dependence.



SIMPLE MODEL

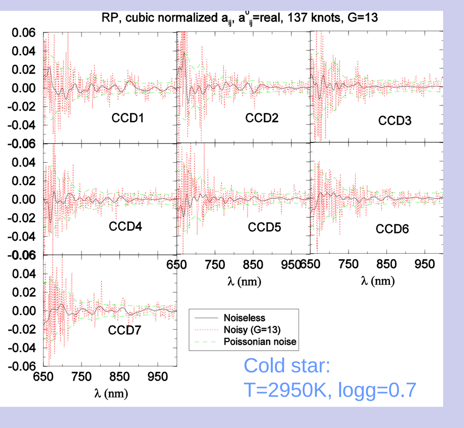
$$f_i = \sum_{j=-M}^{+M} a_{ij} \cdot h_{i+j}$$

The observed flux in a given pixel (f_i) is a weighted combination of several fluxes in the mean spectrum (h_{i+j}). Weigths (a_{ij}) are the instrument parameters to determine.



BP/RP relative flux residuals per observation for G=13 using M=3.

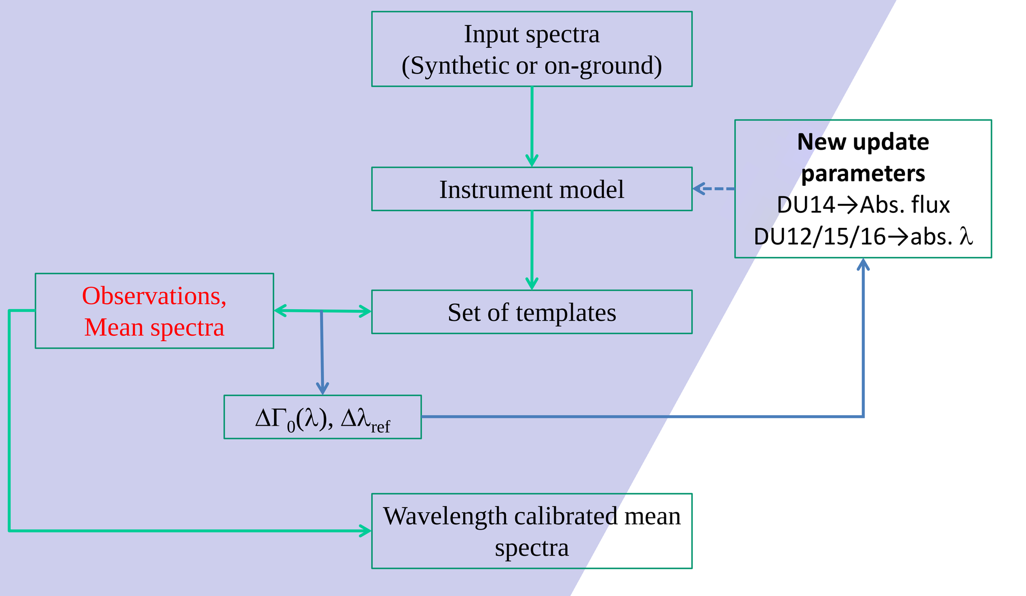
The calibration residuals are of the same order of magnitude that the poissonian noise.



Although the 'simple model' here yields acceptable results, more experiments are needed to rule out the presence of systematics, and to account for instrumental effects like tilts, non-linearity, etc.

External calibration: Absolute wavelength calibration

Absolute wavelength scale calibration will rely on on-ground observations of suitable standard sources. The main goal is to compare Gaia's mean spectra of these sources with on-ground spectra of the same source to derive changes in dispersion, $\Delta\Gamma_0(\lambda)$, and zero point wavelength, $\Delta\lambda_{ref}$, with respect to the assumed ones in the internal calibration. In our experiments to do this comparison, a series of templates are created using the most updated instrument parameters (as the PSF, overall transmission, …). The χ^2 minimization yields the true wavelength scale. The dispersion and the wavelength zero point are then corrected and included in the next iteration. We have evaluated a first set of good calibrators among the large sample of candidate sources. The main conclusions are that **WR stars are good calibrators in BP and can be also used for RP; Be stars can be used for RP** and we have to check the shape of more observed spectra in this band. More work should be devoted to analyze more in detail new observed spectra of Be stars. Finally, **late-type stars are also good candidates for RP** due to the large number of molecular bands and due to the large amount of flux in this band.

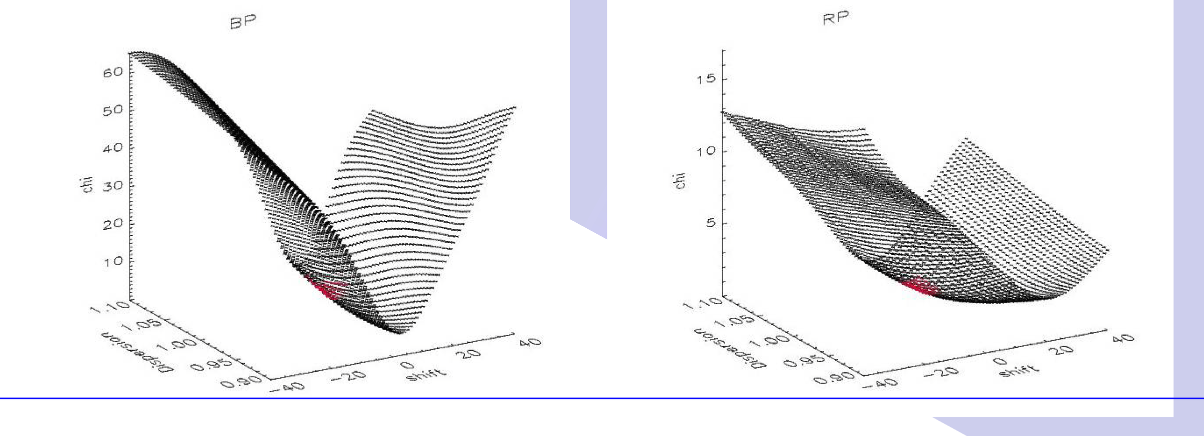


Scheme of the absolute wavelength calibration process using chi-square

Dispersion & wavelength zero point: ($\Delta\Gamma_0(\lambda)$, $\Delta\lambda_{ref}$)

The iso-χ^2 contours:
Smaller surface → minimum better defined
Distance between the successive curves is a good indicator of the localization and the depth of the minimum
The orientations of these curves inform us about the correlations between dispersion and the shift

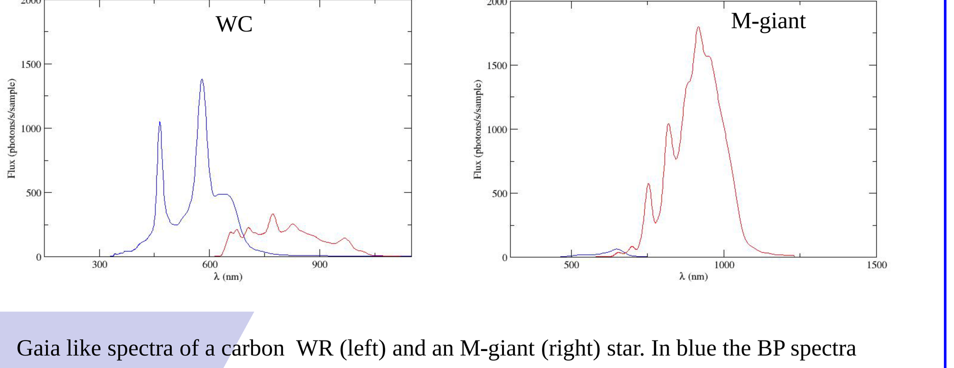
Polynomial fit of the χ^2 :



- We confirm that lines play an important role in the calibration process.
- We confirm that inaccuracies in the absolute flux calibration are not a critical issue.
- The absolute zero point wavelength shifts and dispersions variations are correlated, so the χ^2 method derive them simultaneously.
- WR stars are good calibrators in BP and can be also used for RP.
- Be stars can be used for RP and we have to check the shape of more observed spectra in this band. More work should be devoted to analyze in detail new observed spectra of Be stars.
- Late-type stars are also good candidates for RP due to the large number of molecular bands and due to the large amount of flux in this band.

Preliminary estimation of the errors: the total error on the wavelength in BP, based on one WR star, is in the order of ~0.02-0.50 nm. In case of RP and using one the M-giant star, the error is ~0.06-0.40 nm.

- New test with a mean spectrum represented as sum of a set of basic functions should be done (the actual simulator has been GOG cycle 5)
- The error model for on-ground observed templates will be investigated in more details
- The number of calibrators to be used in the real mission is to be set



Gaia like spectra of a carbon WR (left) and an M-giant (right) star. In blue the BP spectra and in red the RP ones. The strong emission features of the WR star are due to highly ionised carbon and helium lines. In case of the M-giant stars, the strong absorption bands in the red part of the spectrum are due to molecules such as TiO and VO.

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Background BP/RP image courtesy of A. Brown