Calibration model for *Gaia* photometry and spectrophotometry

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Abstract From the astrometric measurements of unfiltered (white) light, *Gaia* will produce broad band G magnitudes, while the spectral energy distribution of each source will be sampled by a dedicated spectrophotometric instrument providing low resolution spectra in the blue (BP, 330–680 nm) and the red (RP, 650–1050 nm). We present the data reduction scheme for this data. It is foreseen as an iterative process updating the mean spectra and the calibration parameters. Uncertainties from a prototype of the data reduction chain are also evaluated.

1 Introduction

The *Gaia* science case has been fully described several times (see [1, 3, 4, 5]).

The spectrophotometric instrument consists on two low-resolution slitless spectrographs, BP (330–680 nm) and RP (650–1050 nm). The total flux of these BP and RP spectra will yield $G_{\rm BP}$- and $G_{\rm RP}$-magnitudes as two broad passbands. On the other side, the white light observations in the astrometric field will yield the so called G band photometry in the wavelength range of 350–1000 nm.

The scientific aim of these *Gaia* low resolution spectra is fully described in [2]. Here we present the detailed description of the calibration process, which includes dispersion, LSF, wavelength and flux sensitivity calibrations, as well as time dependence on these variables.

It is not feasible to design a calibration procedure exclusively based on thousands of standard stars with on-ground observations. Instead, calibration will rely on millions of 'internal standard sources' complemented with 'few' (hundreds) of on-ground standard stars. The process has been thought as two separate tasks: the internal calibration to transform all the observations in a common and comparable

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instrumental system, and the absolute calibration in order to transform from instrumental units to absolute and physical ones (both wavelength and fluxes). This latter step is done supported by ground-based observations.

The proposed calibration is an iterative process where the predicted observations (according to the best known instrument and source parameters) are compared with the true observations to update consecutively the parameters of the source and the parameters describing the instrument.

2 G, $G_{\rm BP}$ and $G_{\rm RP}$ calibration model

The basic approach for the calibration of the CCD sensitivity can be seen in eq. 1:

$$f_l = \sum_{m=0}^{M} (A_{km} + a_{\kappa m}) g_{im} \tag{1}$$

being f_l the flux of the observation l for the source i and g_{im} the standard flux for band m used to predict f_l. A_{km} and $a_{\kappa m}$ are the large and small scale calibration coefficients, respectively, for calibration unit k. $a_{\kappa m}$ describe variations of the sensitivity from column to column of the CCDs. A_{km} represents variations in the response of a CCD and the optical system at large spacial scale and can be monitored at short intervals of time catching rapid variations of the instrument.

Calibration models using different combinations of fluxes directly derivable from *Gaia* data are being tested with simulated noise-free data (see an example in Fig. 1 using G, $G_{\rm BP}$ and $G_{\rm RP}$), and also noisy data, to identify suitable models. The first tests show that the systematics are below 0.5 mmag.

The photometric signal will be extracted with predefined windows of limited size. Thus, a fraction of the light from the source will fall outside of this window. The fraction of measured flux will vary depending on the location of the transit in the focal plane and FoV, the colour of the source, the centering error of the extraction window and the actual scan motion of *Gaia* during the observation. In the calibration process this variation

of flux loss will have to be corrected. Our simulations show that the flux loss due to these effect for AF CCDs was found to be $\sim 10\%$ of the total flux with variations of $\sim 3\%$ depending on the colour of the source, the centering errors and the AC scan motion. We checked that a linear model and least square fitting can properly correct for these effects.

3 BP/RP spectrophotometry calibration model

To produce the mean spectra for each source observed by Gaia, the combination of the several observations obtained along the mission is needed. This task is not trivial,

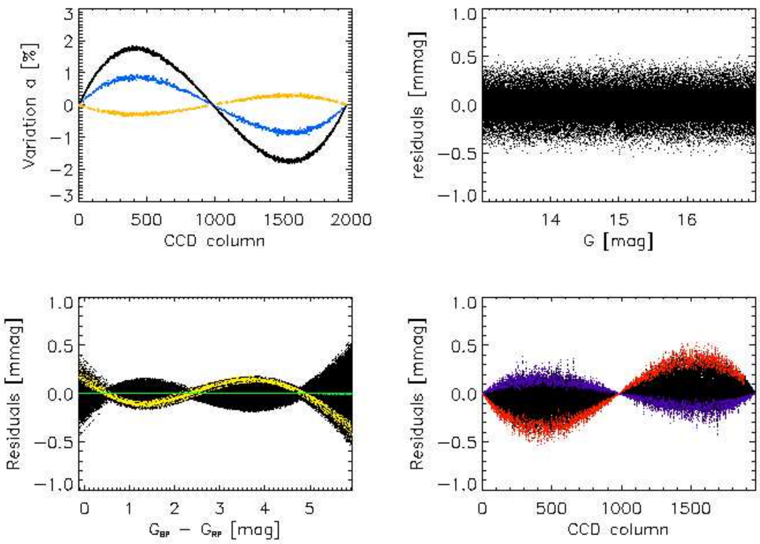

Fig. 1 Results for small scale sensitivity calibration applying G, $G_{\rm BP}$ and $G_{\rm RP}$ standard fluxes. The upper left plot show the derived coefficients, a_G in black line, a_{BP} in blue and a_{RP} in orange. It reproduces the sinusoidal behaviour used for simulations. For the calibrated noise-free data no correlations with magnitude in the residuals from eq. 1 are found (upper right plot). In the lower left plot the residuals are shown vs. $G_{\rm BP}-G_{\rm RP}$ colour. The lower right plot show a clear correlation between the magnitude of $a_{\kappa m}$ in each CCD column and the residuals. All sources with $G_{\rm BP}-G_{\rm RP}>$ 5.8 are overplotted in red, sources with $G_{\rm BP}-G_{\rm RP}<0.0$ are overplotted in dark blue.

as all these observations will be observed in different places of the focal plane, with different instrumental properties (different sensitivities, dispersions, PSF, ...). Once the mean spectrum of a source is built, this can be used to obtain a prediction for any BP/RP observation obtained for this particular source, using the expected instrumental values the observation is supposed to have. The comparison of this prediction with the real observation can be used to monitor changes in the instrument with respect to what is expected.

The simplest calibration model we are exploring (eq. 2) takes into account the contribution of the neighbouring pixels of the spectra, as instrumental effects (PSF for instance) spread the monochromatic light in the adjacent positions in the focal plane, contaminating neighbouring pixels.

$$\frac{f_i - h_i}{h_i} = \sum_{j=-M}^{+M} a_{ij} \cdot \frac{h_{i+j}}{h_i} \tag{2}$$

where M is the number of neighbours to be considered at each side (thus $2M+1$ is the number of coefficients to be fitted); f_i is the observed flux at a pixel with a central wavelength λ_i; h_{i+j} is the internally calibrated mean source flux at a pixel with central wavelength λ_{i+j} and a_{ij} are the transformation coefficients from the mean

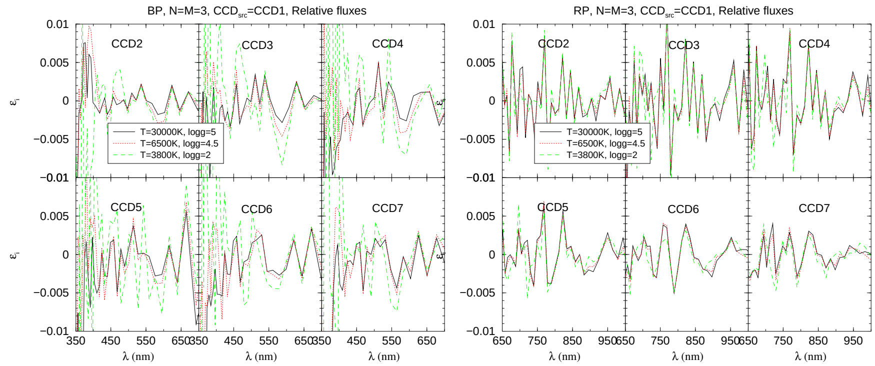

Fig. 2 BP (left) and RP (right) relative differences of prediction computed from the source spectrum, from CCD1, with respect to the real observation with in a different CCD row.

source spectrum to the observed spectrum. The subindices j are used to indicate the neighbour pixels at right and at left ($j = 0$ is for a pixel with central wavelength λ_i, $j = -1$ the pixel at left, $j = +1$ the pixel at right, and so on until $j = \pm M$).

Eq. 2 is iteratively revisited to determine the instrumental coefficients, a_{ij}, or the observation prediction, f_i. In preliminary studies using this method, Fig. 2, observations can be predicted with an uncertainty better than 1% in flux.

χ^2 minimisation method is being explored to recover information about the dispersion law and geometric shifts. The shape of the χ^2 near the minimum show that these two effects are correlated, and that, if fluxes are well known for bright sources, the two effects can be extracted independently of the presence of features in the spectra.

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