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Gaia photometric calibration

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Abstract

The Gaia instrument is planned for launch in 2013, observing the whole sky between magnitudes 6 and 20 during 5 years. It will give high accuracy astrometry, including parallaxes and proper motions, photometry in three broad bands (unfiltered, blue, and red), and red and blue spectrophotometry. In addition, it will measure radial velocities for stars brighter than 17. The final results are expected three years after the end of mission, but a number of early releases are planned. The spectrophotometry is obtained from many individual, slit-less spectra, and we describe the strategy adopted for obtaining a combined spectrum for each source, and epoch spectra for variable sources. We finally address more advanced data treatments that may be applied in the late mission to better separate spectra of double stars and in crowded areas, and to get the full benefit for the brighter sources.

1 Introduction

Gaia is an ESA mission which will make a complete and unbiased astrometric and photometric survey of the sky between magnitudes 6 and 20, in order to improve our understanding of the Galaxy. The launch is scheduled for the autumn of 2013, and Gaia will continuously scan the sky during five years.

The data reduction for the 10^{11} observations of 10^9 sources is a highly demanding task in terms of human as well as computational resources. The photometric part is in the hands of some 80 people from more than a dozen universities and research centres around Europe.

The Gaia project is presented in more detail in [3], and the photometric expectations and scientific performance are discussed in [1]. Up to date information can be found on the ESA web.

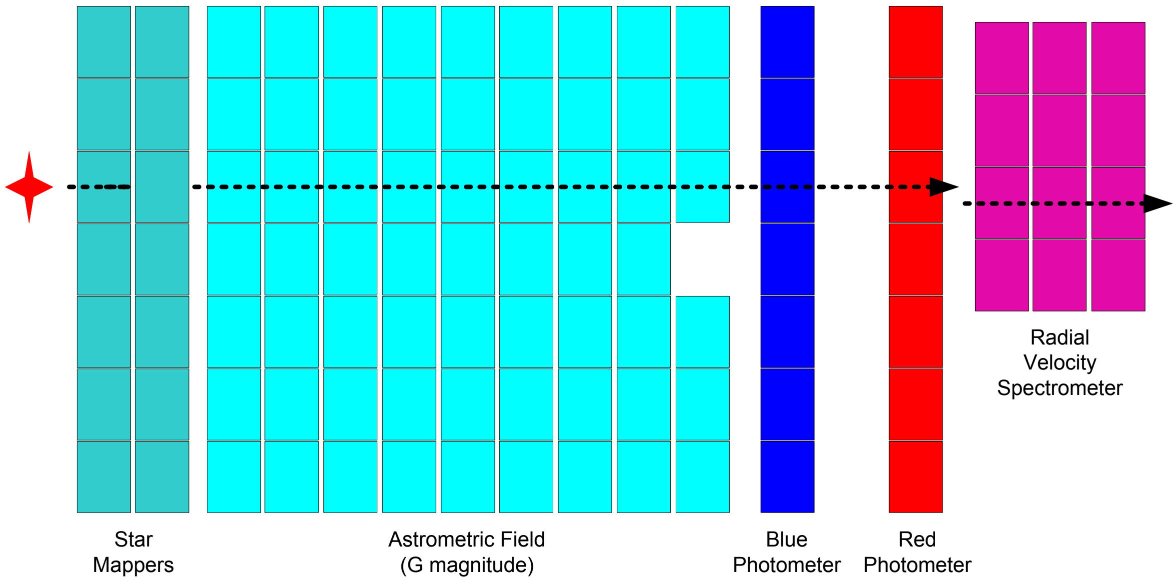

Figure 1: Gaia focal plane. Incoming images are detected by the star mapper, with separate CCDs for the two telescopes, while the rest of the focal plane is common.

2 The Gaia instrument

The Gaia instrument has two telescopes, and thereby two fields of view, which are scanning the same great circle as the instrument rotates on its axis. Due to a carefully designed precession of the axis, the whole sky is covered many times, and in many different scan directions, during the mission. This scanning pattern has been optimised for the astrometric part of the project.

The two telescopes have a common focal plane as shown in Fig. 1, measuring 1×0.42 m, with 102 science CCDs arranged in seven rows. As the instrument rotates, stellar images from a 0.7 degree wide band will slowly cross the focal plane, spending about 4.5 s in each CCD. The rotation is kept in step with the clocking of the CCDs, which are read continuously, in order to obtain sharp images.

Incoming images are detected by the star mappers, where each CCD only sees one field of view. Then follows several CCDs which serve the astrometry and broad band G photometry. After the astrometric field we have the blue and red photometers, each with a prism to produce low resolution spectra. Finally, in four of the seven rows, we have the radial velocity instrument observing the Ca triplet around 860 nm.

Only the star mapper CCDs are read out fully. In the remaining CCDs only small segments (or *windows*) are read around the expected position of each image, and in addition pixels in the across scan direction are binned during the readout process, forming *samples*. In this way the number of samples becomes a small fraction of the number of available pixels. This gives us a significant gain in readout noise, as more time can be spend on taking each

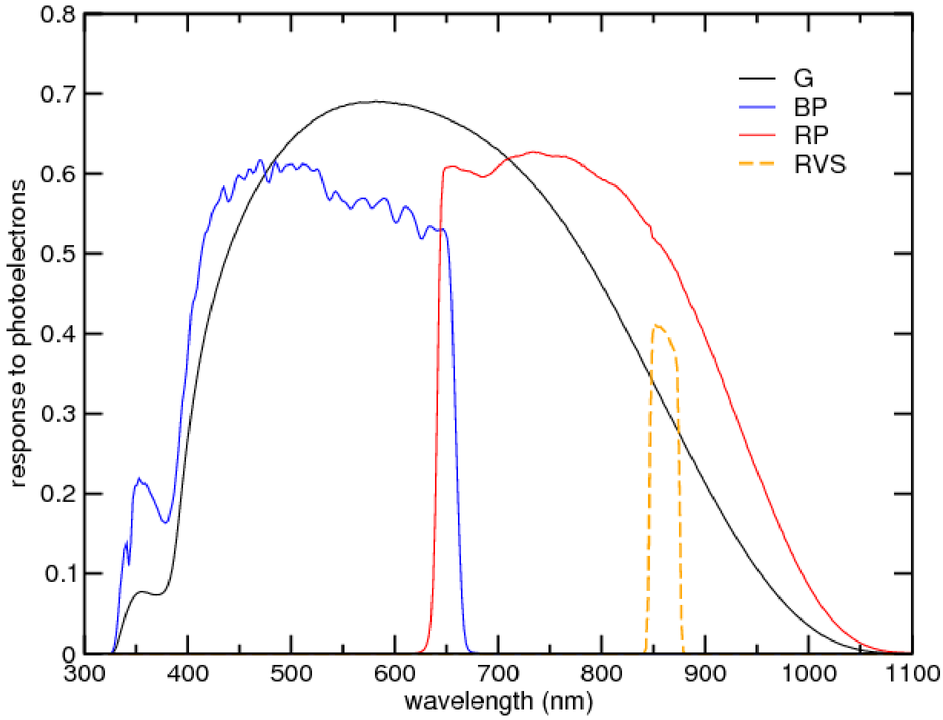

Figure 2: Gaia photometric bands

sample, and in addition a gain in telemetry as there is a much smaller data volume to send to ground. It also means that the images are in fact merely one dimensional profiles, the exception being randomly selected calibration observations and bright images where the full 2D image resolution is maintained.

2.1 The photometric observations

The Gaia passbands are shown in Fig. 2. They include the very wide, unfiltered G band from the astrometric field, the BP band for the blue photometer, and the RP band for the red photometer. The numbers include the QEs of the CCDs, and the optical properties of the mirrors, prisms, and filters.

For the G band, the flux is determined together with the transit time. This is done using a comparison of the observed profile with a predicted image profile, where the latter depends on the colour and various circumstances of the observation.

For the blue and red photometers, the spectra have a length of about 40 pixels in the scanning direction, but windows of 60 samples are extracted in order to allow for image wings, and have some samples for background estimation. The windows measure 3.5×2.1 arcseconds, so spectra from binary sources are not well separated in a single transit.

3 CCD calibration

Gaia can only meet its goals if the CCDs are extremely well calibrated. Apart from the usual sensitivity variations across a CCD, and non-linearities and saturation, two effects require special attention. They are the bias variations, and the charge transfer inefficiency (CTI).

3.1 Bias

The electronic bias when reading a CCD sample has a variation along the pixel rows, which is easily calibrated for normal CCDs, where all pixels are read. When reading a Gaia CCD, we consider only the selected windows, where the pixels are binned just before reading, while the remaining pixels are flushed. This process gives rise to complex bias variations that must be calibrated using a detailed model of the reading process and therefore a detailed reconstruction in the data processing of the readout. Each flush, each binning, and each sampling must be known to the precise 100 ns of time.

3.2 CTI: charge transfer inefficiency

The Gaia CCDs are operated in drift scan mode, or time delayed integration, where the image motion is kept close to the clocking of the charge down the pixel columns. It is therefore essential, that the charge transfer works to near perfection and with the same efficiency for faint and bright signals. This is unfortunately not fully the case, and the performance is expected to degrade during the mission. Our biggest enemy here is radiation damage showing up as imperfections in the CCD lattice where the moving charges may get delayed. As a result, especially the fainter images are distorted and the image parameters get biased, a bias that depends in a non-linear way on the brightness and several observational circumstances. The more active the Sun is during the mission, the more radiation damage, and the more difficult it will be to calibrate the image shape.

3.2.1 CTI mitigation

An important way to mitigate the CTI is through regular charge injections on the leading edges of the CCDs. The injected charge will travel down the columns together with the images and will engage the imperfections for a while, allowing the immediately following images to travel almost unscathed. The injections will have to be repeated every couple of seconds or so and will of course lead to the loss of the CCD transits coinciding with the injections.

4 Photometric calibration

In the photometric calibration, the observations are first brought to a common mean instrument system, and later to an absolute system defined from ground based observations, where a campaign is on-going [2].

4.1 Broad band photometry

For the G band, fluxes are determined fitting a calibrated image profile to the actual observation, where the image profile depends primarily on the colour, the flux, and the background level. For binary sources, things become much more complex and a physical modelling may be needed.

The observed fluxes for the integrated BP and RP bands are simply the sum of the samples in the windows. This will not be useful for binary sources, where a detailed modelling will be required.

The calibration to bring the broad band photometry to a common instrument system, must take a long list of effects into account, primarily wavelength dependent sensitivity variations across the CCDs, and corrections for de-centring of the images in the observed windows.

4.2 Low dispersion spectra

The calibration of the spectra is the most complex part of the Gaia photometry. The passband varies slightly across the field due to variations in the filters coated on the prisms, and these variations are difficult to disentangle from variations in the PSF. In addition, the dispersion varies ±5% across the field, and we have of course the same variations in sensitivity, decentring, and charge transfer as for the broad band photometry.

Two rather different ways have been proposed for calibrating the spectra. One is to establish an empirical transformation between a kind of mean spectrum and the individual observations, and the other involves a full forward model where the whole transformation from a SED to an observation is established.

The first approach, the empirical transformation, is relatively simple and robust, but it is difficult to find a model that work fully satisfactory for all spectral types. Due to its simplicity and to the modest requirements for getting it going, this is very likely the model we will use in the early phases of the mission.

The second approach, the full forward model, requires the PSF to be known. We therefore need a significant number of observations of well established calibration sources with good ground based spectra. It is therefore not easy to use in the early mission phases. It is however more versatile, and therefore our preferred option for the end of mission. It can in principle be applied also in crowded areas, and may include any instrument effect that is well modelled.

4.2.1 Epoch spectra

For variable sources, the spectra from individual transits may be of interest. The idea is correct the observations to compensate sensitivity variations, but that the published epoch spectra will have the same phasing and dispersion as the observation. Each epoch spectrum will therefore have its own (known) wavelength scale.

5 Data releases

The final Gaia catalogue will be published 2-3 years after the end of mission, i.e. in the early 2020's. However, a few preliminary releases are envisaged. For photometry this may mean G band data in mid 2015, the integrated BP and RP bands in early 2016, and the first spectro- photometry in early 2017. The spectro-photometry comes late, partly because more observations are needed, and partly because the idea is to have a first astrophysical classification ready at the same time.

Acknowledgments

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