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Gaia Photometric Data: DR1 results and DR2 expectations

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Abstract. Gaia DR1 was released in September 2016 and contained a photometric catalogue of over 1 billion sources. At this stage, this only included mean G-band photometry and an estimate of the error. Even though this may sound limited in nature, interesting science can still be achieved with this data thanks to its quality. A high level overview of the photometric processing and some validation results will be presented. Additionally, epoch photometry in the G-band was released in Gaia DR1 for a small number of variable sources in the South Ecliptic Pole which covers the LMC. The second data release (Gaia DR2) is currently being prepared and, if available, some preliminary validation results will be presented. It is planned that this release will contain colour information in the form of integrated BP and RP photometry in addition to the latest G-band photometry.

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1. Introduction

The main photometric content of Gaia DR1 consists of mean fluxes and errors for over a billion sources in the G passband. The magnitude range over which the catalogue is likely to be complete is $6 < G < 20$. An overview of the photometry can be found in van Leeuwen *et al.* (2017). Figure 1 shows the magnitude distribution of the main catalogue along with its Tycho 2 and Hipparcos subsets.

In addition to the mean photometry, there is also epoch G-band photometry for a selected number of variable stars. This includes 599 Cepheids (43 new identifications) and 2595 RR Lyrae (343 new). Eyer *et al.* (2017) describes the general variability processing that was carried out and Clementini *et al.* (2016) the special RR Lyrae and Cepheid processing.

2. General principles of the calibration

The calibration of the photometry is carried out using internal standards. Initially, the reference fluxes for the standards are generated from the raw, uncalibrated, fluxes.

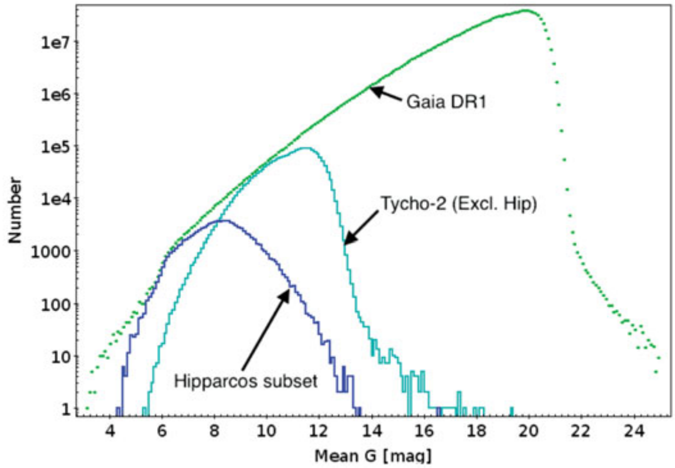

Figure 1. The magnitude distribution of Gaia DR1 along with its Tycho 2 and Hipparcos subsets.

Following a first calibration using these raw fluxes, a new set of reference fluxes is generated using these calibrations. This process is iterated until a stable photometric system is obtained. Care must be taken with this procedure since it will only work if sources are observed under many different conditions. In general, this is easily the case, but when this does not occur, special calibrations must be made.

Currently, the main part of the internal calibration consists of a large-scale and small-scale calibration. The large-scale calibration has a model with colour and across-scan position dependencies. Calibrations are carried out for each combination of the observing configurations (CCD, field-of-view, gate and window class) and approximately every day. The small-scale calibration is effectively a 1d flat field and is averaged out over 4 pixel columns. The model used for Gaia DR1 for the small-scale calibration was a zero point only one, but this is configurable for future processing cycles.

Following the launch of Gaia, a number of unexpected features were found which have an effect on the photometry and required new or improved calibrations. The largest two such complexities are:

(*a*) Contamination of the mirrors and CCDs by water originating from the spacecraft. This is mitigated by periodic heating (decontamination). This varying amount of contamination stresses the photometric initialization and requires special calibration procedures. Following a number of decontamination events, most of the contamination has now gone.

(*b*) A higher background level has been found on the CCDs. This is mainly caused by more straylight from the Sun finding its way to the focal plane. This has meant that the background-subtraction algorithms had to be improved. Even so, this has caused a loss of performance at the faint end due to the data now being sky limited.

Finally, in order to bring the photometry onto a more physical system, a small set of 94 spectrophotometric standard stars are used to provide an external calibration. These standard stars are described in Pancino *et al.* (2012). From this calibration, Vega and AB magnitude zeropoints are generated. While no specific passband information was provided in Gaia DR1, various colour-colour relationships are given in van Leeuwen *et al.* (2017).

For more details about the internal and external calibration, see Carrasco *et al.* (2016).

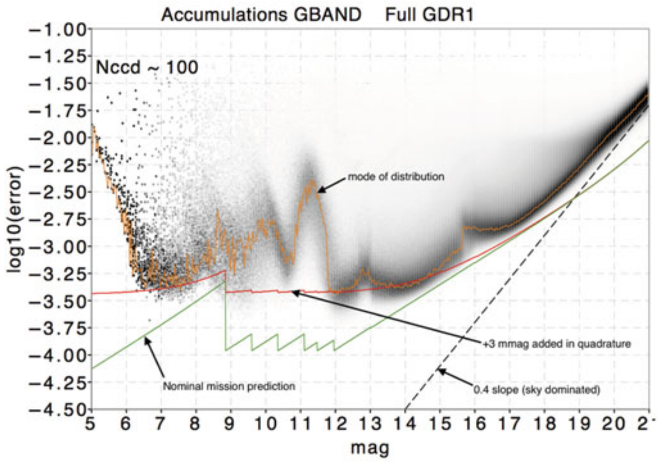

Figure 2. The error on the mean G flux as a function of magnitude for sources with about 100 CCD observations. The nominal mission prediction is shown along with a version with 3 mmag added in quadrature. Also shown is a line with a 0.4 slope indicating the effect of sky domination.

3. Validation of Gaia DR1

Figure 2 shows the distribution of the error on the mean flux as a function of magnitude. By restricting this plot to sources with the same number of observations (about 100 in this case), comparisons can be made with the expectations from the nominal mission. Various features can be seen:

- At the faint end, the error expectation is not achieved due to the data being sky limited. This is a consequence of the higher than expected sky background.
- At G=13 and 16, the higher errors seen are a consequence of changing configurations (window class) at these magnitudes. These performances will be improved with changes to the calibration models.
- The various bumps seen brighter than G=12, are caused by saturation effects which were not accounted for in Gaia DR1.

By adding 3 mmag in quadrature to the nominal error prediction it can be seen that for these calibrations a calibration floor of 3 mmag has been reached. This represents the order of magnitude of systematic errors remaining to be calibrated.

Comparisons with external catalogues can be made to validate the data, but great care must be taken since it will be uncertain as to the source of any differences seen. Additional information is usually needed to identify the source of the differences. Analysis shows that possible systematic effects as a function of magnitude of around 10 mmag exists in the photometric data of Gaia DR1. This is confirmed by an internal consistency check that was carried out (see Fig. 40 of Arenou *et al.*, 2017).

Further details on the photometric validation can be found in Evans *et al.* (2017).

4. Gaia DR2: contents and expectations

For the second data release, in addition to the mean G fluxes and errors, mean BP and RP fluxes (and their errors) will be available giving colour information for more than a billion sources. Additionally, epoch photometry and colours (G, BP and RP) will be released for tens of thousands of variable sources. Full passband information will also be available along with the Vega/AB zeropoints.

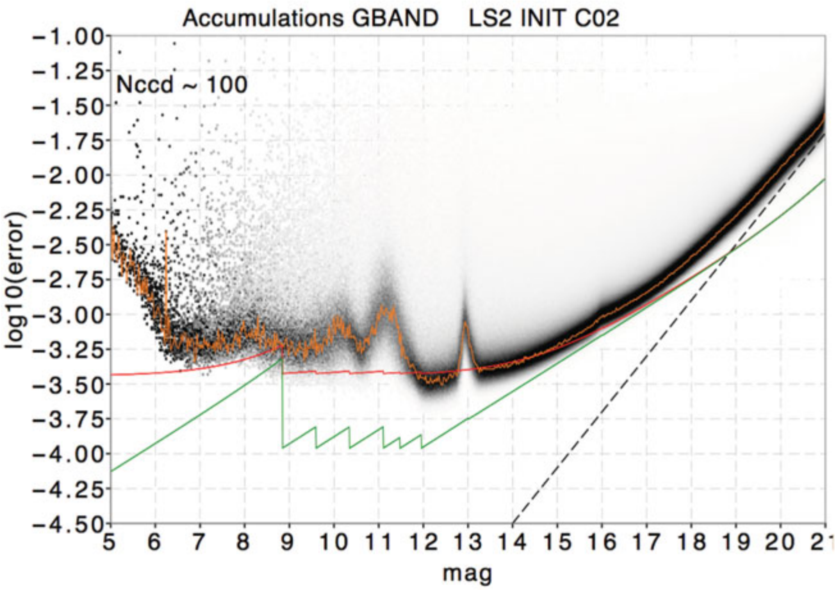

Figure 3. As for Figure 2, but for an early stage of the Cycle 2 reductions.

A number of improvements have been carried out to the calibration procedures:

• The Image Parameter Determination used for the fluxes has been improved due to the use of more sophisticated LSF/PSF models. Saturation is also partially taken into account.

• The cross match has been improved leading to fewer outlier observations.

• By using data from a low contamination period, the initialization of the photometric system has been improved.

• The handling of outliers has been improved leading to fewer anomalous magnitudes.

• More extreme-colour and bright sources will be included in the photometric catalogue.

Figure 3 shows the error on the mean, cf. Fig. 2, at an early stage of the reductions for Gaia DR2. Already the calibration floor of 3 mmag has been surpassed and it is expected that further improvements will be made. Also note that many of the bumps seen in Fig.2 have been reduced.

As a consequence of the changes to the processing of the data, two differences with respect to Gaia DR1 exist. The new photometric initialization implies a (slightly) different passband. This is due to using less contaminated data for the initialization. Also a new cross-match procedure means that some Source Identifiers will have changed. This is not a simple one-to-one relationship. The moral of these differences is that the user should treat Gaia DR2 as a totally new catalogue.

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