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Instrument calibration and data processing systems of Gaia

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Abstract

The Gaia mission will provide unprecedented positional and velocity measurements of about one billion stars in our Galaxy and throughout the local group. The data processing system is an integral and critical part of the mission. We are developing the Initial Data Treatment system, which will process the raw data arriving from the satellite in near-real-time. It will provide a first estimation of the satellite attitude, the image parameters, and a first cross-match with the Gaia catalogue. We are also developing the Intermediate Data Updating system, which calibrates the instrument response and refines image parameters and cross-match by running on the complete set of raw data, once or twice a year during the mission. Such massive re-processing needs a super-computer such as MareNostrum, where it is planned to run the system. In this paper we describe these data processing systems and the preliminary tests and results obtained with simulated data.

1 Introduction

Gaia is one of the most ambitious astrometric space missions envisaged [1]. Adopted within the scientific programme of the European Space Agency (ESA) in October 2000, it is expected to be launched at the end of 2013. Gaia aims to measure with very high accuracy the positions and velocities of a large number of stars and galactic objects. Consequently, a detailed three-dimensional map of more than 1 billion stars of our Galaxy will be obtained, including most of the objects up to the 20$^{\rm th}$ magnitude. The precision of the final angular coordinates will be of about 20 μas at 15$^{\rm th}$ magnitude.

This work is organized as follows. In Sect. 2 we provide an overview of the Gaia instrument, explaining its main features. In Sect. 3 we describe the several calibration processes involved in the Gaia data reduction system which will be explained in more detail in Sect. 4.

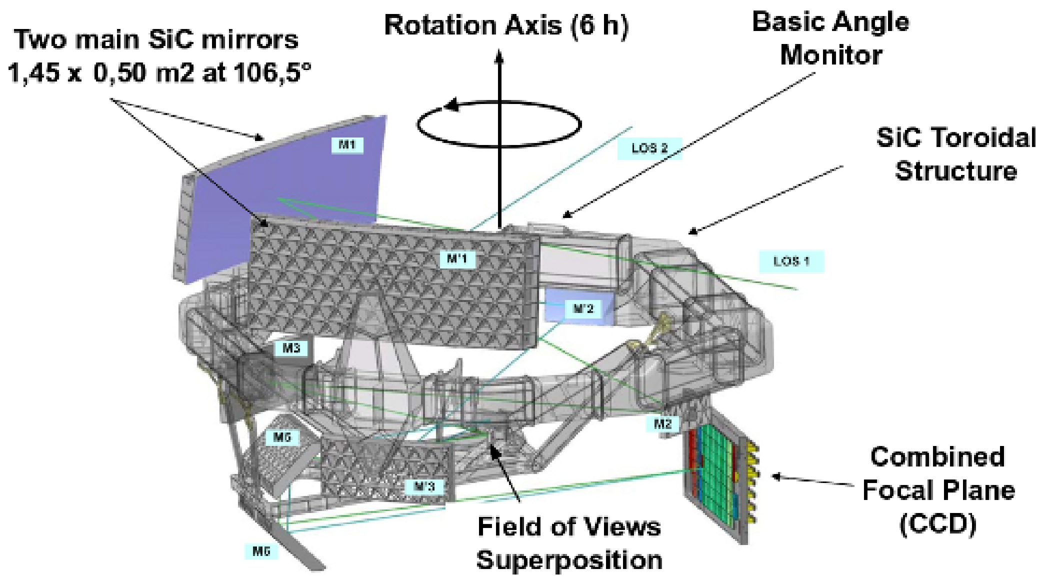

Figure 1: Gaia instrument combining two Lines Of Sight (LOS) at a single focal plane

Finally, Sect. 5 is devoted to summarize the latest testing campaigns carried out to practise and prepare the data processing system for operations.

2 Gaia instrument overview

Gaia combines the information from two space telescopes in several instruments as shown in Fig. 1. These two telescopes involve a total of ten mirrors of various sizes and surface shapes to collect, focus and direct light to a single focal plane composed of 103 state-of-the-art Charge Coupled Devices (CCDs), allowing each observation to be composed of 12 CCD transits.

Table 1 summarizes the most important physical parameters of the focal plane of Gaia. In this table AL stands for along scan, whereas AC stands for across scan.

The data obtained by these CCDs include astrometric, photometric, and radial velocity measurements.

- The astrometric measurements provide transit times at each CCD. When combining all observations and the five years of mission, the stellar positions on the sky, proper motions and parallaxes can be derived.

- The photometric instrument provides colour information for celestial objects by generating two low-resolution spectra, one in the blue and one in the red range of the optical spectrum; 330–680 nm and 640–1000 nm respectively.

Table 1: Gaia focal plane parameters.

Parameter	Value
Focal Plane Width	104.26 cm, 1.58°
Focal Plane height	42.35 cm, 0.69°
Image motion	60 arcsec $\cdot$ s^{-1}
CCD Dimensions (AL×AC)	4500×1966 pixels
Pixel Dimensions (AL×AC)	10×30 10^{-6} m
Typical Window Size (AL×AC)	12×12 pixels
Detection Window Size (AL×AC)	80×12 pixels
Field of View basic angle	106.5°
TDI Period (AL pixel size)	0.9828 ms

- The third instrument is a Radial Velocity Spectrometer, which reveals the velocity of the star by measuring the Ca triplet in a high-resolution spectrum covering a narrow wavelength range from 847 to 874 nm.

3 Instrument calibration

To fulfil its objectives Gaia needs to be calibrated, starting from the spacecraft attitude to the response of the several instruments.

The attitude of Gaia will be initially obtained from the Attitude and Orbit Control System (AOCS) installed onboard and will be refined from the observations and the Gaia catalogue itself. A precise determination of the attitude is required to obtain accurate astrometry of the sources observed by Gaia.

After the attitude, the projection through the several mirrors of the images to the focal plane must be calibrated with high accuracy, including the possible deviations in the geometry and the assembly of the mirrors and detectors.

Finally, the response of each CCD and their corresponding electronics modules must be calibrated. The characterization of the CCD response is very complex and includes the calibration of:

- Line/Point Spread Function of the observed photon counts for each type of source.

- The charge transfer inefficiency appearing in the Time Delayed Integration (TDI) operation mode used by Gaia, which is based on a continuous charge shift from one pixel row to the next, synchronized with the satellite spin motion.

- The CCD biases and CCD video signal digitization.

- Other cosmetics effects such us dead pixels, signal saturation, etc.

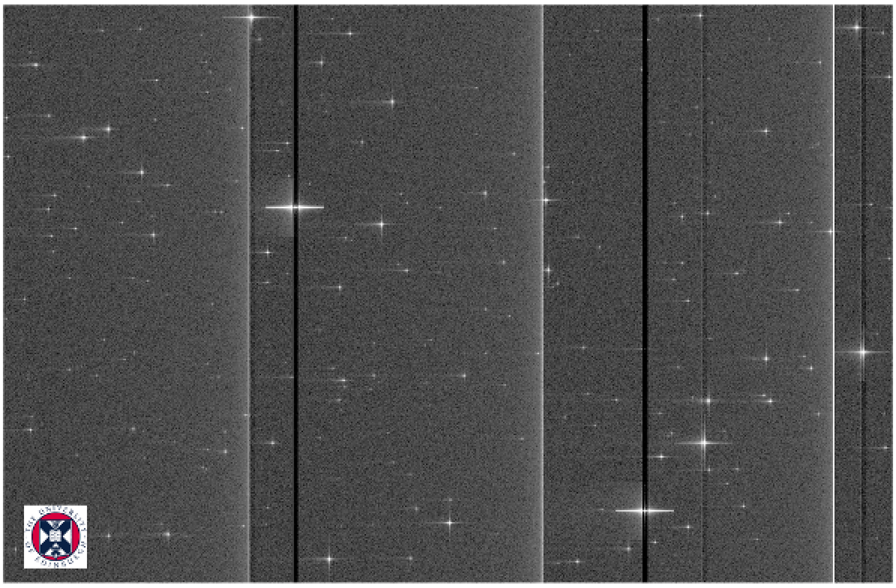

Figure 2: Simulation of the observed scene of a single CCD of the astrometric instrument (Courtesy of M.Davidson, University of Edinburgh)

Figure 2 presents a simulated image of one of the astrometric CCDs including all the CCD effects above mentioned. The image motion is from left to right and we can clearly observe:

- Bright vertical lines: due to the regular injection of charge to improve the charge transfer.
- Dark vertical bands: narrow zones when the integration time has been greatly reduced to allow the observation of bright sources.

4 Data processing system

The Gaia mission requires the construction of a Ground Segment that shall be operative for the duration of the mission until the achievement of the expected quality before the publication and distribution of the results to the international scientific community. The Ground Segment is formed by six Data Processing Centers (DPCs), managed by the Data Processing and Analysis Consortium (DPAC), responsible towards ESA for the reduction of data of the mission. DPAC includes more than 400 specialists astronomers, engineers, programmers, etc.

The complexity of the data reduction system implies the development of different modules or Processing Systems in charge of specific parts of the processing. These processing systems are managed by 8 Coordination Units (CU), each responsible for a particular aspect of data processing.

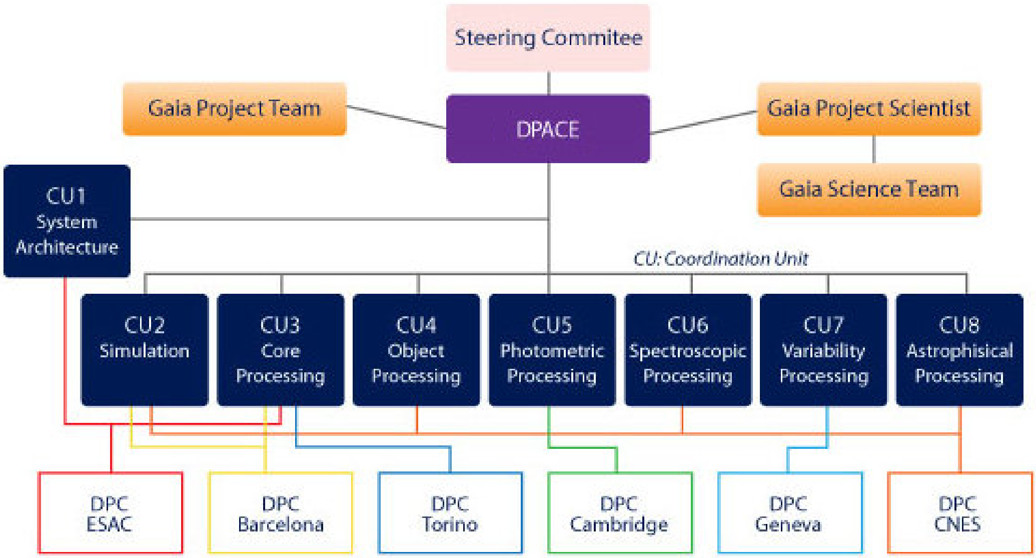

Figure 3: Coordination Units and Data Processing Centers within DPAC

CU3 is in charge of the core processing of Gaia data and among the several modules developed by this CU, we are developing the Initial Data Treatment system (IDT) and Intermediate Data Updating (IDU).

IDT is in charge of processing the raw data arriving from the satellite in near-real-time. It will provide a first estimation of the satellite attitude, the image parameters, and a first cross-match with the Gaia catalogue. On the other hand, IDU will calibrate the instrument response and will refine such image parameters and cross-match by running on the complete set of raw data including improved and more specific calibrations coming from other CUs. IDU is the system in charge of unifying all the results, closing the iterative reduction process. Without IDU, Gaia would not be able to provide the envisaged accuracies and its presence is key to get the optimum convergence of the iterative process on which all the data processing of the spacecraft is based.

Figure 3 depicts the structure of the DPAC, including the relation of the different DPCs and the Coordination Units.

5 Testing campaigns

To assure the readiness of all the data processing system before the launch, DPAC has started to define and exercise several testing campaigns.

The first test campaign, called End-To-End Test or E2E, was addressed to assure the correct integration of the several data processing systems, starting from IDT and finishing the iteration cycle in IDU. This test was mainly focused in the system interfaces and the demonstration of the iterative processing chain.

In this test campaign, a reduced scale sky density dataset was simulated. This dataset contained a total amount of 30 millions of sources with the corresponding 400 million observations for 580 mission days, ending in a test data volume of approximately 1 TByte.

The latest test or Operation Rehearsal, aimed to test the Daily Processing Chain in the real environment at DPCE. This test was focused in the execution of IDT over a realistic dataset in a realistic time scale and environment. The dataset, of 300 GBytes, consisted in 3 mission days with 90 million observations and 97 million sources.

Finally, future test campaigns are already scheduled before the launch and they will increase in both; the dataset volume and in the system features to be tested.

6 Conclusions

Gaia is an ambitious space mission with a very complex instrument. Gaia requires a demanding data processing system which has been designed as an iterative process where different systems are in charge of specific parts of the processing and calibration.

The integration and coordination of all the systems and the processing power involved is also a big challenge but recent test campaigns have demonstrated its reliability.

Acknowledgments

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References

[1] Perryman, M. A. C., et al. 2001, A&A, 369, 339