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First Cycle Processing of Gaia data

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Abstract

The data reduction is an integral and critical part of the Gaia mission to provide the unprecedented positional and velocity measurements of more than 1 billion stars of our Galaxy. After developing the Initial Data Treatment system, currently processing the raw data arriving from the satellite in near-real-time, we are now focused on the development of the Intermediate Data Updating system, which is in charge of the recalibration of the instrument response and the refinement of the 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 outline the iterative data reduction approach adopted in Gaia, describing the main systems involved and their roles in the cyclic data processing required for the first Gaia Catalogue release.

1 Introduction

Gaia is one of the most ambitious astrometric space missions ever envisaged [1]. Adopted within the scientific programme of the European Space Agency (ESA) in October 2000, it was launched on 19th of December 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 is going to be obtained, including most of the objects up to the 20$^{\rm th}$ magnitude. The precision of the final angular coordinates is of about 20 μas at 15$^{\rm th}$ magnitude.

This work is organized as follows. In Section 2 we provide an overview of the Gaia Ground Segment, explaining its main goals and players. In Section 3 we identify the main calibration tasks that are linked to the main processing systems that compose the core of the data reduction approach adopted for Gaia. Finally, Section 5 is devoted to summarize the current status of the first Cycle Processing of Gaia data, including the testing campaigns carried out to proof the concept and test the interfaces between all systems.

2 Gaia ground segment

The Gaia mission has required the construction of a Ground Segment that will 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. This Ground Segment is managed by the Data Processing and Analysis Consortium (DPAC).

The complexity of the data reduction system has implied 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.

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

The processing demand of all these systems has also implied the setting-up of 6 Data Processing Centers (DPCs), responsible towards ESA for the reduction of data of the mission.

The Data Processing Centre of Barcelona (DPCB), plays an important role within the overall Gaia Ground Segment, since it is the place where IDU will run. IDU is one of the most demanding systems in data volume and processing power which requires a super-computer such as MareNostrum for its proper operation.

Figure 1 depicts the structure of the DPAC, including the relation of the different DPCs and the Coordination Units.

3 Main calibration systems

Gaia, as a survey satellite reaching accuracy and completeness levels never obtained before, must be fully self-calibrating, solving the attitude, the instrumental responses and the star positions (and much more) from the transit data.

The attitude of Gaia is initially obtained from the Attitude and Orbit Control System (AOCS) installed on-board and then is refined on-ground 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 on the focal plane of the two Fields Of View through the several mirrors 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:

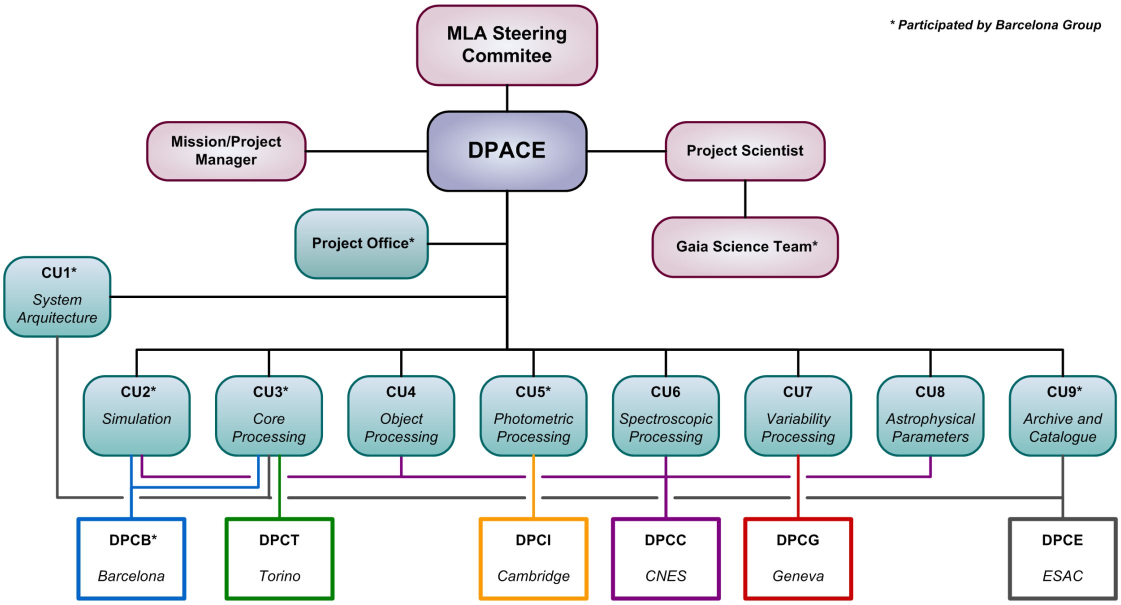

Figure 1: Coordination Units and Data Processing Centers within DPAC

- Line/Point Spread Function (LSF/PSF) 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 presents a real image of one of the Gaia Sky Mapper CCDs acquired in a special mode to image the sky scene close to the Galactic plane. In this figure, we also shown how Gaia analyses the image on the fly to detect the point sources which are then downlinked as small images.

4 Gaia data reduction

The goal of the data reduction system is to transform the raw data into the final science data, consisting of an astrometric and spectrophotometric catalogue based on all the observations made of each source, meeting the final accuracies of mission goals.

The Gaia data processing consists of several iterative processes dealing with astrometry, photometry and spectrometry provided in the raw data. Each iterative process is reprocessing all the accumulated data again in each iteration of Data Reduction Cycle (DRC).

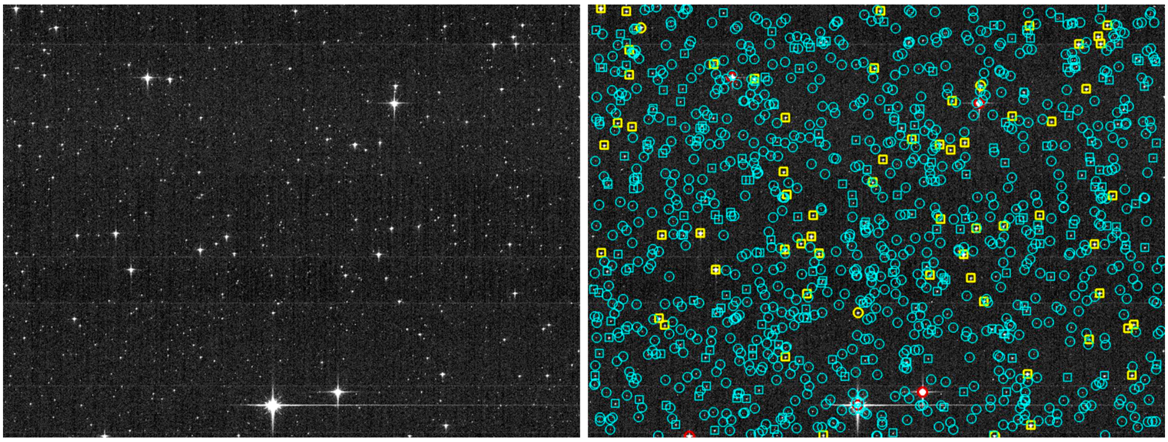

Figure 2: On the left pane, observed scene of a single Gaia Sky Mapper CCDs and on the right pane, an overlay of confirmed sources really downlinked.

Catalogue releases then consists on one or more DRCs exercises according to the accuracy and precision obtained.

The complexity of this data reduction system implies the development of different modules or Processing Systems in charge of specific parts of the processing. In this section we will introduce the most relevant systems:

- The Initial Data Treatment (IDT) transforms the most recently arrived telemetry into a more convenient form; uncompressing, rearranging and reformatting the telemetry to create raw information ready for storage in the main database. IDT also provides an initial determination of basic image parameters, links the new observations with previous observations (sources) in the main data base and derives various auxiliary data.

- Astrometric Global Iterative Solution (AGIS) is the cornerstone of the data processing. It provides the main calibration, the attitude solution and the astrometric solution of about 100 million primary sources including the stellar positions on the sky, proper motions and parallaxes. The results obtained through AGIS are mandatory for the improvement of the iterative solution of the rest of the processing systems.

- Photometric Pipeline (Photpipe) provides calibrated fluxes and colours for the observed sources 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.

- Intermediate Data Updating (IDU) recalibrates the instrument LSF/PSF and refines image parameters and cross-match provided by IDT by running on the complete set of accumulated raw data. IDU is the most demanding instrument calibration and data reduction system in data volume and processing power for Gaia.

IDU is the system in charge of unifying all the results, closing the iterative reduction

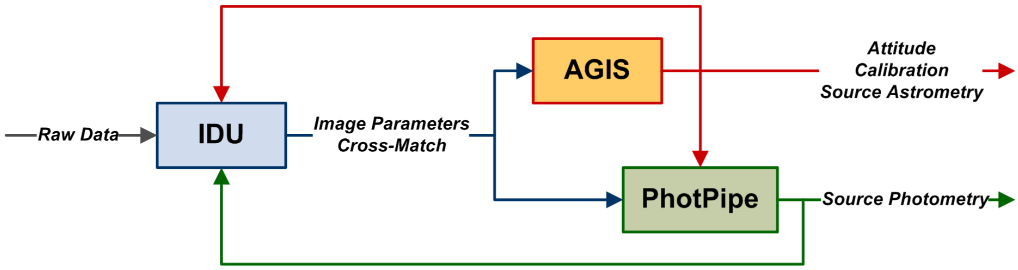

Figure 3: Iterative reduction concept with IDU, AGIS and Photpipe

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.

Iterations between IDU, AGIS and Photpipe shown in Figure 3 is what will give us the high accuracies envisaged for the final Gaia catalogue.

Among the rest of DRC systems, the most relevant processing tasks are:

- Solar System Object processing
- Spectrometric processing
- Variability processing
- Astrophysical parameters determination

Each one of the mentioned systems runs in the different DPCs and their results are distributed among the other DPCs within each DRC, closing in this manner the reduction iterative loop.

5 First cycle processing

To assure the readiness of all the systems involved in the cyclic data processing, DPAC has defined and exercised several testing campaigns during last years.

These tests have been exercised over simulated datasets and currently over the real data from the spacecraft. We can distinguish two kinds of tests:

- Global Operation Rehearsals focused on testing the interfaces and enforcing a common development road map for all systems and DPCs.
- Test campaigns of specific processing concepts and systems.

An special case is the IDU-AGIS test campaign, focused on the proof of the astrometric iterative reduction concept by running several times both systems and analysing the convergence and stability of the resulting astrometric parameters.

All these testing campaigns are essential for the system readiness for the first operational execution currently planned for end of 2015, which is mandatory for the release of the first Gaia catalogue.

6 Conclusions

Gaia is an ambitious space mission with a very complex instrument. Gaia requires a demanding data processing system on both data volume and processing power. This processing has been designed as an iterative process between several modules each one solving different aspects of the data reduction system. IDU is the system in charge of unifying all the results, closing the iterative reduction process.

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. and de Boer, K. S. and Gilmore, G. and Høg, E. and Lattanzi, M. G. and Lindegren, L. and Luri, X. and Mignard, F. and Pace, O. and de Zeeuw, P. T., 2001, A&A, 369, 339-363