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ASTROMETRIC INSTRUMENT MODEL SOFTWARE TOOL FOR GAIA REAL-TIME INSTRUMENT HEALTH MONITORING AND DIAGNOSTIC

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RESUMEN

Los objetivos de la misión espacial de microarcosegundo dependen de las limitaciones de desempeño asociadas a la configuración instrumental seleccionada y a las condiciones de observación. En particular, la variación de la respuesta instrumental sobre el campo, con respecto a la longitud de onda y el tiempo, son potencialmente críticos. Discutimos el impacto sobre la calidad de los datos y cómo los datos científicos pueden ser utilizados para rastrear directamente y en tiempo real la respuesta astrométrica instrumental de Gaia. Esta es una de las filosofías que impulsan el Modelo de Instrumento Astrométrico (AIM, por sus siglas en inglés). Mostramos los resultados de las campañas de prueba llevadas a cabo en 2013.

ABSTRACT

The goals of micro-arcsecond space mission rely on the limiting performance associated to the selected instrumental configuration and observing conditions. In particular, variation of the instrumental response over the field, with wavelength and in time, are potentially critical. We discuss the impact on the data quality and how the science data can be used to trace directly and in real time the astrometric instrument response of Gaia. This is one of the driver philosophies behind the Astrometric Instrument Model (AIM) concept. We show results from the test campaigns carried on throughout the 2013.

Key Words: astrometry — methods: data analysis — space vehicles: instruments — techniques: image processing

1. INTRODUCTION

Gaia is the ESA next-generation space mission aimed at Global Astrometry at few μas level (Perryman (2005)), producing an all-sky catalogue of position, proper motion and parallax, complete to the limiting magnitude V=20mag. The Gaia concept relies on self-consistency of the astrometric information of celestial objects throughout operation, factoring out the instrument parameters and their evolution by calibration of the overall data set. The final catalogue is foreseen for 2021. The launch happened on 19 December 2013. At the moment of writing paper the satellite was just entering its first part of the commissioning phase.

Gaia astrometry, complemented by on-board spectrophotometry and (partial) radial velocity information (see de Bruijne et al. (2010)), will have the precision necessary to quantify the early formation, and subsequent dynamical, chemical and star formation evolution of the Milky Way Galaxy. The broad range of crucial issues in astrophysics that can be addressed by the wealth of the Gaia data is summarized in de Bruijne 2012.

The Gaia data processing is organized and conducted by one Data Processing and Analysis Consortium (DPAC), i.e., the consortium in charge of the scientific part of the Gaia ground system, with no independent treatment duplicating the entire data analysis, as was in Hypparcos. The DPAC is organized in Coordination Units (CUs) (Figure 1), each of which is in charge of some parts of the whole reduction chain. CU3, in particular, takes care of the so-called core processing, i.e. it will consider a subset of well-behaved stars (e.g. single stars, photometrically and astrometrically stable, not too faint, etc.) and will reconstruct very precisely their five astrometric parameters. The Core Processing is a complex procedure that includes several steps. To translate this information into positional and physical parameters expected by scientists a large and complex data analysis must be implemented. How huge and how complex it is, is briefly addressed in Mignard et al. 2008. In this context, validation of the Gaia astrometric data processing must be a well-structured effort, focused on those data processing areas critical to mission success, and capable of gauging the degree of success throughout the mission. For these critical areas, independent procedures/models are designed and implemented, and results compared to baseline processing. The verification counterpart operating independently from the baseline data reduction

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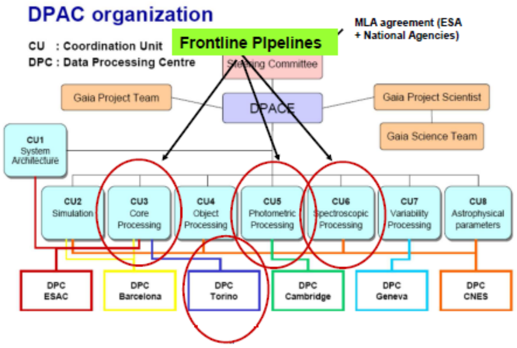

Fig. 1. DPAC organization scheme

chain is called Astrometric Verification Unit (AVU). AVU comprises three systems: the Base Angle Monitoring (BAM) (Gai et al. (2013)), the Global Sphere Reconstruction (GSR) (Vecchiato et al. (2012)) and the Astrometric Instrument Model (AIM). AVU has its own dedicated Data Processing Center located at ALTEC (Torino). A crucial component of AVU is the AIM SW system devoted to the monitoring, diagnostic, and calibration of the Gaia astrometric instrument response. Starting from the AIM concept in § 2, going through a short description of the SW system in § 3, we will arrive to show in § 4 the results obtained during the DPAC test campaigns carried on before launch.

2. AIM CONCEPT AND GOALS

Science data can be used to trace directly the instrument response, taking advantage of the repeated measurements of stars over the field. This is one of the driving philosophies behind the AIM concept.

One of the main tasks of the AIM project is to implement and perform instrument response monitoring and diagnostics independent of the baseline processing, so to compare the two results, and to report on possible alerts. This part of AIM is devoted to assessing the astrometric instrument response during in-flight operations, starting from the commissioning phase, including the possibility of accomplishing complete calibration procedures (like that of the effective PSF) following the signal profile fitting model described in Gai et al. 2013. Therefore the AIM Software System is devoted to the processing of the Gaia astrometric raw data in order to monitor and analyze the astrometric instrument response over the mission lifetime.

The variation of instrumental response over the field of view with wavelength and in time is often unavoidable and potentially so critical that a proper knowledge of the Payload behavior has coming to be a key ingredient for optimal definition of data reduction and calibration procedures. Data calibration presents exciting challenges, particularly during commissioning and early phase science operations for which the calibrations are crucial.

3. AIM SW TOOL

AIM is an object oriented software tool coded using the Java language and counts more than 50,000 code lines of scientific algorithms and about 20,000 infrastructure code lines. The high level subsystems decomposition are shown in Figure 2.

AIM processing strategy is based on time, i.e. each AIM run is defined on 24 hours of observed data for astrometric observation having magnitude ≤ 16. Its modularity allows dedicated runs for commissioning phase making it easy-fitting on needs. The AIM pipeline is operated at the DPCT (Data Processing Center of Torino). The software is composed of six scientific modules devoted to the daily processing (RDP, Monitoring, Daily Calibration, Calibration Diagnostics, Fine Selection and Daily Report), called in sequence by the infrastructure software, which provides the overall workflow and the DB interaction functionalities.

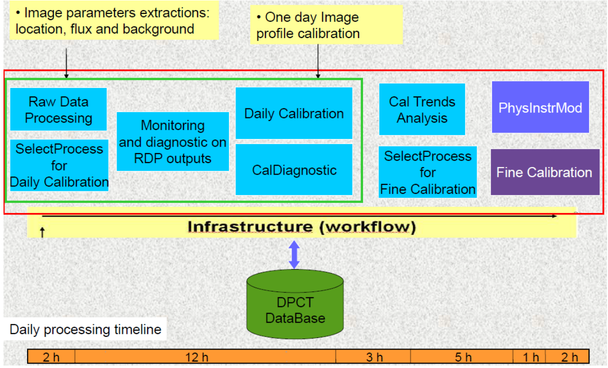

Fig. 2. High level subsystems decomposition of AIM project. The modules within the green box are devoted to the daily data processing whereas outside there are the modules devoted to weekly/monthly processing.

The RDP module is in charge of the basic processing to convert the raw data into the actual measurement and estimate the image parameters. This process includes modules devoted to the right handling of the reference image profile through the AIM models Libraries and the calibration/knowledge of the Astro instrument (i.e. the astrometric instrument model recovery module and the parameters extraction module).

The Calibration module is devoted to the Gaia signal profile reconstruction on daily basis: the PSF/LSF calibration, and related diagnostics included

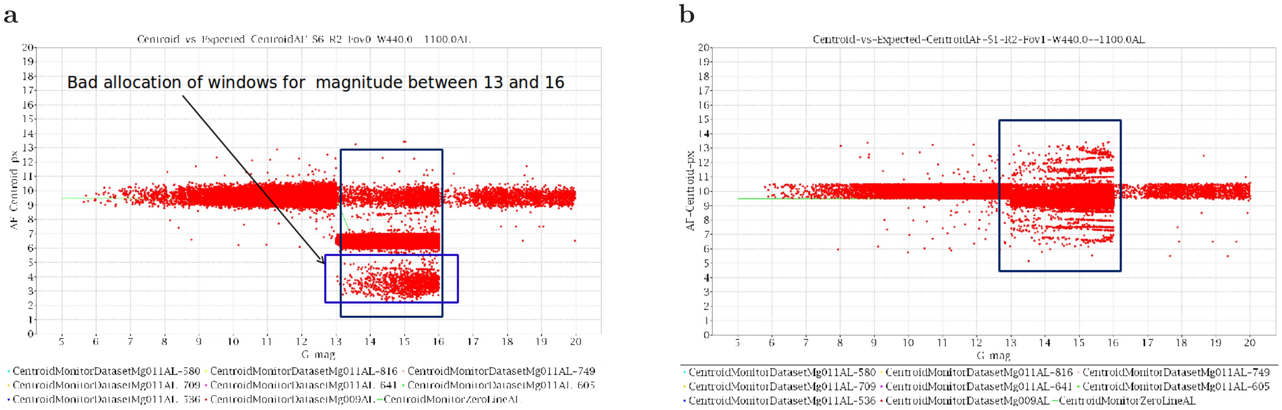

Fig. 3. Both graphs show the centroid distribution for two different CCDs versus magnitude as calculated by RDP. Figure **a** put in evidence an erroneous allocation of the window on the celestial object. Only two kind of window width (18 and 12 pixels with center at 9.5 and 6.5 respectively) should be present for magnitude between 13 and 16 (or gclass =2 in the Gaia nomenclature). The graph shows also gclass=2 stars with 6 pixels window (and center at 3.5 pixels). Figure **b** shows several outliers due to bad simulations.

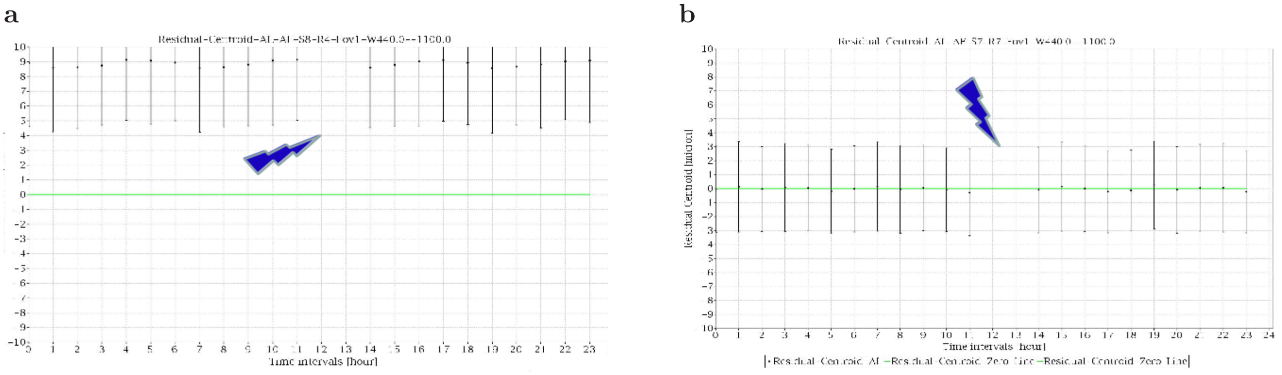

Fig. 4. The two figures show the variation of the residual centroid mean over one hour versus time. The residual centroid weights how much the computed centroid value is away from the expected value. In graphs **a** a centroid offset of about 1 pixel for CCD S8R4 is visible, otherwise any offset for CCD S7R7 in **b**. In both plots we observe a data lack for 3 hrs.

the image moments variations over the whole focal plane.

The Monitoring and Diagnostic packages are a collection of software modules, each dedicated to perform a particular task on selected data sets with the goal to extract information about instrument health, Astro instrument calibration parameters, and image quality during in-flight operations over few transits or much longer time scales.

The weekly-monthly processing collects three SW modules: Calibration Trends Analysis, Fine Calibration, Physical Instrument recovery module. The Calibration trend analysis look at the image moments variations over time; the Fine Calibration run every time it is needed a new LSF/PSF profile calibration and the Instrument recovery package is devoted to the handling of the non-nominal instrument configurations library and the recovering of the instrument configuration in the selected time interval.

4. REAL TIME MONITORING AND DIAGNOSTIC

The main goal of Monitoring module is to provide all the data needed for analyzing the output produced by the RDP. It achieves its goal collecting statistical data and generating a collection of datasets used to plot multiple parameter trends. For that reason the Monitoring natural location within the AIM processing chain is just at the end of the RDP processing and before starting the Calibration module.

Many different elements (java classes, property files, data model objects) interact each others to make sure that the Monitoring module completes its job.

From the Data Model (DM) perspective the Monitoring is made up of 3 main objects:

MonWrapper: a container that associates the DM objects produced by RDP (aimElementaries, Id-

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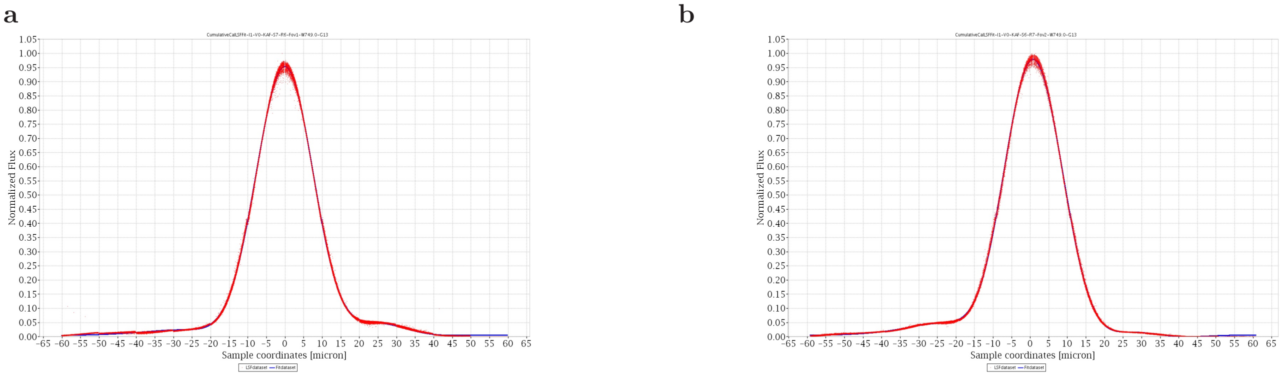

Fig. 5. Two examples of LSFs reconstructed profile from the data. **a** plots the reconstructed profile for Field Of View 2, Row 7 and Strip 6, for a red color star with magnitude between V=13 and 15, while **b** the reconstructed profile for the same color and location on the focal plane but different Field Of View.

tAstroElementary, AstroObservation, InfoMonitoring). The data inside this DM object is the main input of the Monitoring process, but contains almost no information on how to use this data.

MonMetadata: a DM object that defines a specific configuration, containing all the information needed by the Monitoring DataTakers to do their work, such as the DT that will receive a specific dataset, the focal plane information (ccd row, ccd strip, fov), the dataset keys, an so on. It is a way to instruct the Monitoring DTs on how to treat the data received. These objects are produced by a specific class inside the infrastructure software.

MonPacket: a combination of 1 MonMetadata and a list containing all the MonWrapper associated with that specific configuration. The association between a monMetadata and its relative MonWrappers is made inside the infrastructure software according to a set of properties defined by a specific property file named MonMedatada.properties.

From the infrastructure side the Monitoring is made up of:

Reader and Writer: a set of java classes that get the necessary data from the DB and build all the required MonWrappers, associating correctly the RDP outputs.

AimMonMetadataManager: a java class responsible for the creation of all the required MonMetadata objects and their association with the corresponding MonWrappers. The creation is performed according to the properties provided by monmetadata.properties

Actually it counts about twenty different diagnostic tasks, each one devoted to follow the possible variation of a well-defined feature. In the following § 4.1 we describe some results from the DPAC test campaign for a few diagnostic cases.

4.1. *Few examples from Operations Rehearsal*

Three test campaigns called Operations Rehearsal are carried on by DPAC throughout 2013 for testing the readiness of the science critical SW systems. Commissioning and Nominal Operation phases have been mimic. A realistic amount of data was simulated with several no-nominal effects in addition to prove the capability of the different systems to detect anomalies and discover the causes. We show in Figures 3 and 4 a few findings detected by some specific tasks inside the AIM Monitoring module and in Figure 5 two examples of AIM capability to reconstruct the image profile over the astrometric focal plane.

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