MODELLING THE INSTRUMENTS AND SIMULATING THE DATA STREAM

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ABSTRACT

The simulation of the Gaia observations is a key tool for the preparation of the mission. Simulations have been, and continue to be, used to test and optimise the mission design. They allowed the development of a prototype of the Gaia Data Access and Analysis System, to start the development of the reduction and analysis algorithms and to develop prototypes of the on-board data handling algorithms. They are used to assess the final accuracy and finally prepare the scientific exploitation. Such a mission simulator is a long term project which has led to the development of a modular tool allowing progressive enhancement of the simulated data quality towards representative Gaia data. It combines models of the different astrophysical sources that Gaia will observe, providing spatial distribution, photometry, kinematics, spectra, etc, with a model of the satellite and its instruments. The development of those models is made within the Gaia Simulation Working Group which organises this development and provides access to the resulting simulations to the Gaia community. In this presentation we will describe this simulation effort, its organisation, development status, current applications and future enhancements.

Key words: Gaia; Simulations; Instrument modelling; Sky modelling; Galaxy model; Software design.

1. THE GAIA SIMULATION WORKING GROUP

Simulations of the Gaia observations and of the behaviour of the spacecraft itself are needed for many aspects of the mission. For instance:

- Overall predictions for mission concept & goals
- Realistic data to be used for industrial design (spacecraft & instruments)
- Simulated telemetry to fill test data bases (e.g., the GDAAS data base)
- Simulated scientific data for development and testing of algorithms and reduction software
- Predictions for evaluation of mission performances, in particular for some peculiar objects
- Realistic data to develop and test the on-board algorithms

The need to develop a system to provide simulations covering these needs in a consistent way was identified early in the mission development. Furthermore, the development of such a system requires contributions from many different scientific and technological areas and therefore a good coordination of the efforts.

The *Gaia Simulation Working Group* (SWG) was thus created in 2001 to coordinate this development effort and its mandate is to create a **Gaia Simulator** able to *simulate the data stream generated by the astrometric (ASM, AF, BBP) and Spectro (MBP, RV) fields to support investigations of accuracy, sampling strategy, data compression, data analysis, scientific performance, etc.* The simulator is being developed in a cooperative effort by many European teams organised around the SWG.

The SWG is coordinated by X. Luri and C. Babusiaux and currently is composed of 19 core members and 40 associate members. The SWG web page can be found at `http://gaia.am.ub.es/SWG/`

2. OVERALL STRUCTURE OF THE GAIA SIMULATOR

The Gaia Simulator is a large software development project (its core already contains more than 60 000 lines of code). As such it is being developed using modern software development tools, the main ones being:

- UML (Unified Modeling Language) a design tool to build software systems `http://www.uml.org/`
- Java, an object oriented language, that ensures high portability of the system `http://java.sun.com`
- CVS (Concurrent Versions System), a development tool for maintenance of source code in a distributed team of developers `https://www.cvshome.org/`

- The Gaia Parameter Database, a tool developed by ESA to ensure coherence in the values of constants and parameters used throughout the mission development activities `http://www.rssd.esa.int/Gaia/paramdb/` (password required). See de Bruijne et al. (2005) for more details.

The overall structure of the system is described in Figure 1. Several common packages are defined containing common tools used for all the development aspects:

Universe: the classes of this package implement models of the different celestial objects to be observed by Gaia. These models are then used to simulate the physical properties of these objects at the observation dates (Figure 3).

Instruments: given the physical characteristics of celestial objects provided by the previous packages (position, magnitudes, velocities) the classes of the *Instrument* package are used to simulate Gaia observations. They implement models of the satellite and of Astro and Spectro instruments, including the scanning law, the optics, the CCDs and the on-board data handling (Figure 2).

Utilities: this package contains miscellaneous utilities used throughout the simulator. They include among others numerical methods and astronomical tools.

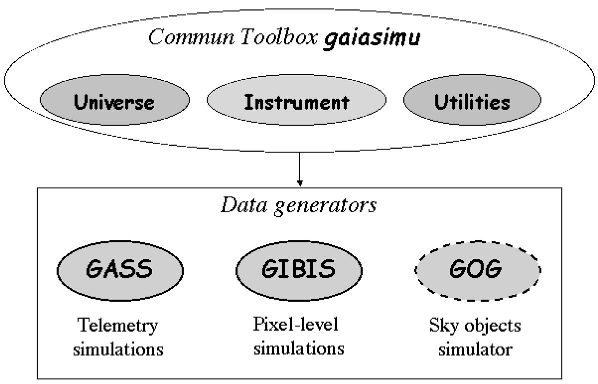

Figure 1. Structure of the Gaia Simulator.

Using the above packages several *Data Generators* have been built. A Data Generator is a module that, using the models implemented by the common packages, generates specific simulated data. There are currently three Data Generators in the Gaia simulator:

GIBIS, designed to generate detailed simulations at pixel level (see Section 3).

GASS, designed to generate large amounts of realistic telemetry (see Section 4).

GOG (planned), designed to generate lists of objects with detailed physical characteristics (see Section 5).

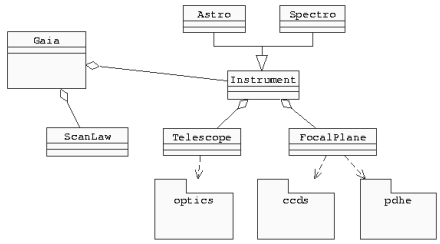

Figure 2. UML description of the structure of the Instruments package.

3. GIBIS

The Gaia Instrument and Basic Image Simulator, GIBIS, is a pixel-level simulator of the Gaia observations. While GASS simulates a huge amount of realistic raw telemetry stream, GIBIS simulates a smaller amount of Gaia observations but to a greater level of detail.

GIBIS has been developed to be able to test and optimize the mission design, develop the on-board algorithms, prepare the reduction studies, in particular the image capabilities ones, and provide statistical results to the telemetry simulator GASS.

GIBIS aims to be able to simulate all the different sources and kinds of sky configurations that Gaia will observe. The objects can be point-like (stars, quasars), extended (unresolved galaxies), moving within the integration time (asteroid) or a combination of those. Not only average sky properties are simulated but also extreme cases such as high crowding and high background variations. Statistical distributions are available (for stars and galaxies only for the moment), but also pre-defined sky configurations such as globular and open clusters, Baade's Window,.... Each user can specify their own sky configuration by adding background images, stars, galaxies, asteroids, etc.

The main characteristics of the instruments are to be simulated, using variable parameters to test different design options, and including possible defaults to access the final accuracies and design the calibration procedure. This includes realistic Point Spread Functions, CCD response models including realistic noise, defaults and cosmic ray impacts and satellite attitude modelling. The actual on-board algorithm prototypes (detection, confirmation, selection, tracking), provided by the Gaia On-Board Detection working group, are implemented within GIBIS.

GIBIS is available to the Gaia Community through a web page[1]. The user specifies the portion of the sky to be observed, including his own favorite sources, and the characteristics of the instruments for design tests, until this latter is frozen. Both statistical mean configurations and extreme cases (crowded fields, high background, worst case noise, distortions,...) can be simulated. The user can also choose between different simulation methods to account for the different needs regarding the level of de-

[1] http://gibispc.obspm.fr:8080/gibis

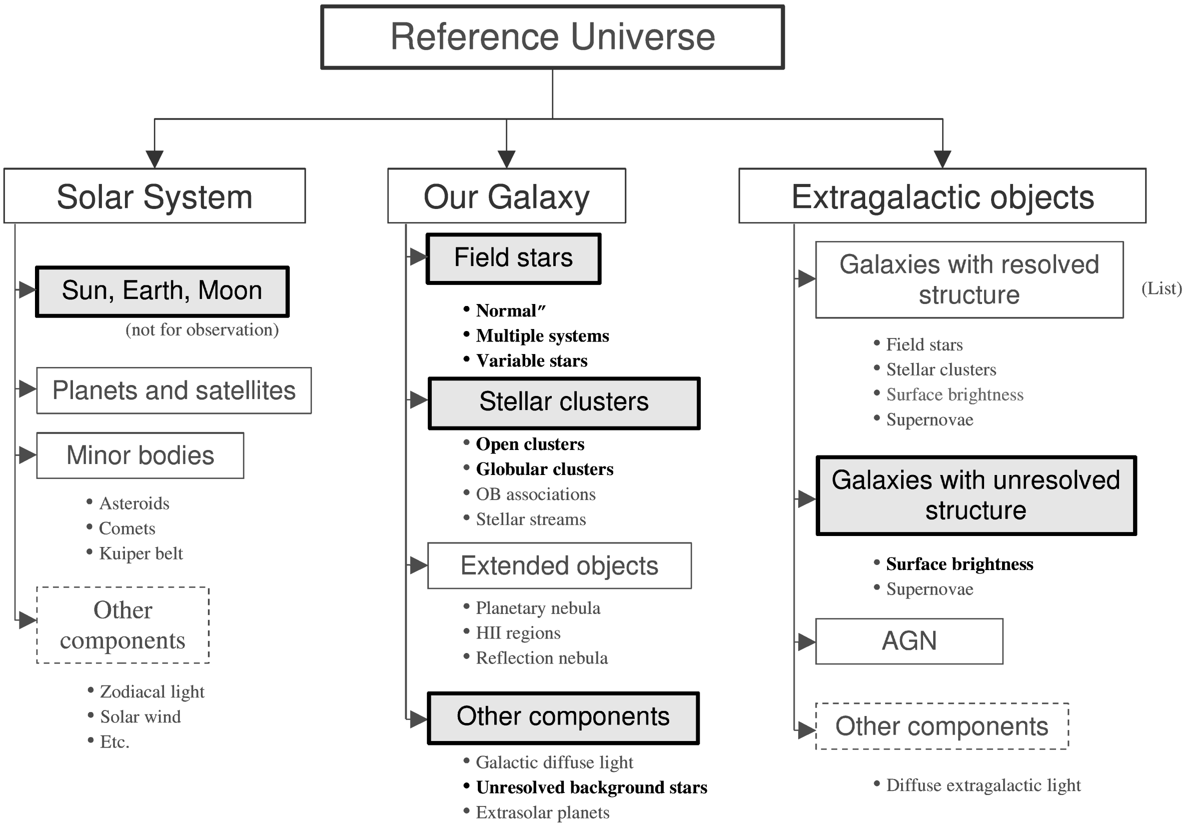

Figure 3. Breakdown of the components of the 'gaiasimu' universe model

tail versus the CPU time. GIBIS then combines the sky model requested with the response of the Gaia instruments into observables in the field requested, creates the CCD image and then applies the on-board data handling algorithm prototypes, to produce realistic Gaia raw data.

GIBIS in now in version 2.0. Available on-line since 2002, it has already been used in a number of applications by the Gaia community. It has been widely used to develop, test and evaluate the on-board algorithms. Tests and optimisation of the design have been made with GIBIS, in particular studies of the different windowing strategies. Imaging capabilities, in particular of binary stars have been studied. Crowded field on-board performances and on-ground reduction studies have also been developed. Estimations of the achievable accuracies for various objects such as Solar System objects have been undertaken.

More details about GIBIS and its current status can be found in Babusiaux (2005) and on its web page[2].

[2]http://gibispc.obspm.fr/∼gibis

4. GASS

The Gaia System Simulator (GASS) is designed to simulate the telemetry stream of the Gaia mission according to the GDAAS (Gaia Data Access and Analysis Study) specifications, modelling the astronomical objects and instruments. This telemetry stream provides realistic data for several purposes, such as filling the test data base of GDAAS, test of algorithms (e.g., cross-matching, telemetry compression,…) and reduction software, or evaluation of the mission performances.

GASS divides the simulation process in four steps:

1. *Inputs and initialisations:*

   The input parameters can be introduced using the command line or the Graphical Used Interface.

2. *Modelling of satellite pointing:* the simulations are limited to the area of the sky scanned by Gaia during the selected interval of time. To determine this area, GASS uses the ephemeris of the satellite and the nominal scanning law.

3. *Simulation of sky objects:* a list of objects present in

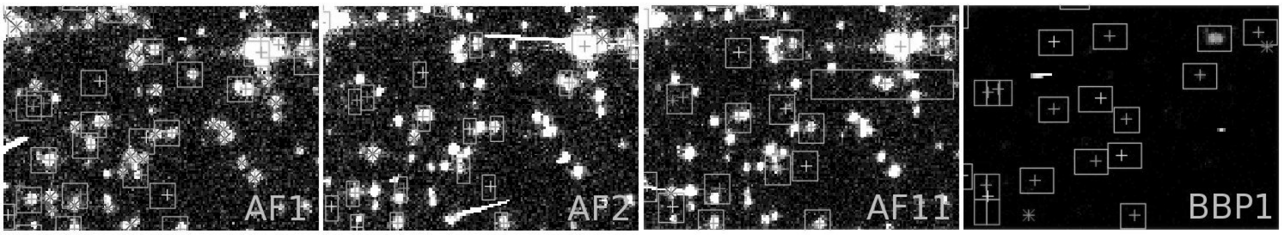

Figure 4. GIBIS 2.0 simulation of an Astro transit through Baade's Window. Each image is of 7″ × 14″. Baade's Window data have been kindly provided by K. Kuijken from HST-PC data. The second telescope is pointing to a typical galactic field at ($l = 262°$,$b = -26°$). Cosmic rays impacts are included. The results of the selection algorithm are overlaid. The crosses indicates the Astro1 and Astro2 detections. The detections not selected further are crossed out. The boxes present the windows selected and extracted.

the given sky area is generated using the *gaiasimu* universe model.

4. *Telemetry generation:* from the list of sky objects the satellite telemetry stream is simulated using the models of the instruments (field of view geometry, PSF, spectral response, ...) and of the on-board algorithms (detection, transit prediction, ...).

GASS output consists of several files:

- *Log File:* control messages generated during the execution of the simulation.
- *Attitude File:* the quaternion representation of the satellite attitude.
- *Sources File:* the *catalogue* of simulated sources, including identifier, astrometry and photometry.
- *Telemetry File:* the simulated telemetry stream.

For test purposes, GASS can generate other files with intermediate data, like field angles and observed time for each transit.

More details about GASS and its current status can be found in Masana et al. (2005).

5. GOG

GOG is the third Data Generator built into the Gaia Simulator. It is now in its design phase, and a first implementation will be available in 2005.

Its purpose is to generate lists of celestial objects using the universe model built into *gaiasimu* so that lists of objects observable by Gaia in a given region of the sky (or the whole sky) can be produced in a stand-alone mode, without needing to run GIBIS or GASS for that purpose.

These lists will be useful for several aspects of mission design and specially for telemetry sizing. GOG will be able to generate object counts up to a given magnitude in a given direction of the sky, so that the amount of telemetry generated by Gaia can be predicted. Furthermore, GOG will be able to generate total counts of objects or counts by object type (stars, galaxies, QSO, etc), allowing to make predictions of the scientific return in the different cases.

The first step of the GOG implementation will use the existing *gaiasimu* Galaxy Models, and it will then be progressively expanded to include more and more types of objects.

6. FUTURE DEVELOPMENTS

The Gaia Simulator and its Data Generators are being intensively used by the Gaia community in many mission design and scientific preparation tasks. In the coming years these needs will become more and more demanding and will require more complex, precise and realistic simulations. The Gaia simulator will evolve with these needs, including more functionalities and modules to cater for the ever growing demands.

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