# THE GAIA INSTRUMENT AND BASIC IMAGE SIMULATOR

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## ABSTRACT

Detailed and accurate simulations are needed to be able to test and optimize the design according to the scientific needs, develop the on-board algorithms, prepare the reduction studies and assess the final performances and challenges. To this aim, a pixel-level simulator of the Gaia observations has been developed. It is part of the Gaia Simulator, sharing a common structure with the telemetry simulator GASS. It combines a model of the astrophysical sources that Gaia will observe with a model of the instruments, in order to simulate Gaia observations of given regions of the sky with a high level of precision. I will present here this pixel-level simulator with its current applications.

Key words: Gaia; Simulations.

## 1. INTRODUCTION

Gaia is in its design consolidation phase, the final design being frozen in 2005. Precise studies are underway to optimize them. Such studies are crucial in order to retrieve the most information possible with the most valuable scientific information content. Indeed a clear estimation of the scientific needs and the instrument limitations is crucial for optimizing the final accuracy of the mission, and an early appreciation of the difficulties that will show up during the reduction can reduce the complexity of the analysis by huge factors. Moreover the scientific questions of interest to the community will evolve within ten years, so we must try to optimize the instrument in order to retrieve the most information possible without imposing scientific biases. The only practical way to achieve this optimization is through simulations. In this context, a pixel level simulator of the Gaia instruments, the Gaia Instrument and Basic Image Simulator GIBIS has been built.

GIBIS is part of the Gaia Simulator (Luri et al. 2005). It shares a common structure with the GAia System level Simulator GASS (Masana et al. 2005). 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, down to the pixel-level.

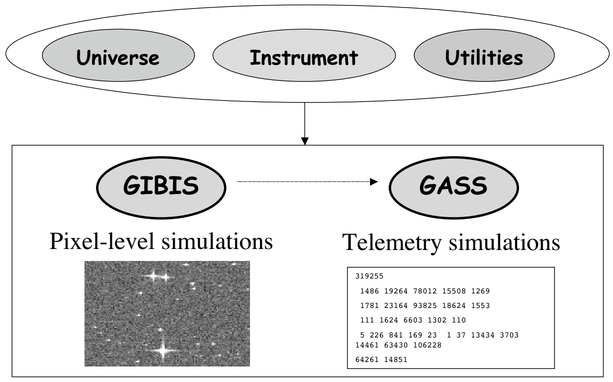


*Figure 1. GIBIS within the Gaia Simulator.*

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 combines a sky model with the response of the Gaia instruments and the on-board data handling, to produce realistic Gaia raw data. I will present here its structure, how it is developed and used by the Gaia community, the current status of its universe and instrument models and finally its main current applications.

## 2. HOW DOES IT WORK?

GIBIS is a long term project. It has been developed, as the overall Gaia Simulator, to allow a progressive enhancement of the simulations towards representative Gaia data. Its development is made within the GIBIS team of the Simulation Working Group.

The design of GIBIS has been made in UML (Unified Modelling Language). The core of GIBIS is developed in Java. This core shares a common structure with GASS (Figure 1), allowing a common development and use of the common toolbox, which contains a universe model, an instrument model and a utility box developed by the Gaia Simulation Working Group (Luri et al. 2005). Indi-

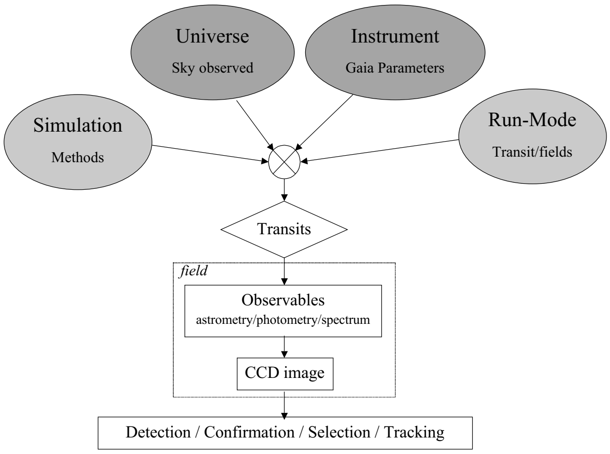


*Figure 2. GIBIS main structure.*

vidual simulations can be written in any other language and are called from the Java core. This allows a quick integration of the programs provided by the astronomical community which uses a wide range of programming languages. Currently GIBIS uses codes in C, Fortran, IRAF and IDL.

The resulting GIBIS simulated data are provided back 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 detail versus the CPU time. As illustrated in Figure 2, GIBIS then transforms the astrophysical characteristics of the sources into observables in the fields requested, creates the CCD image and runs the on-board algorithm prototypes to deliver to the user the resulting Gaia observations.

## 3. STATUS OF GIBIS VERSION 2.0

GIBIS, available on-line since September 2002, is in constant development, incrementing step by step toward more realistic data generation, following the needs and priorities of the users. The current version of GIBIS, version 2.0, is described here.

### 3.1. Universe Model

GIBIS aims to be able to simulate all the different 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 (resolved galaxies are both extended and contain point-like stars, near-Earth objects can be both fast moving and extended for the high Gaia angular resolution). Not only average sky properties through statistical distributions are simulated but also extreme cases such as high crowding and high background variations.

- **Stars**
  Currently GIBIS uses star files provided by M. Haywood, generated by a modified version of the Besançon population synthesis model (Robin & Crézé 1986, Haywood et al. 1997). Files have been generated up to $G = 24$ in various galactic directions (Kapteyn's Selected Areas, Lynds 1963) with a field of view equivalent of an Astro CCD. The file the closest to the galactic coordinates queried by the user is used in the simulation. This file system will soon be replaced by a new version of the Besançon model which is currently ported in Java for a direct inclusion into the Gaia Simulator universe model by A. Robin et al.

  In addition to the Galaxy model, some special fields are available in GIBIS. Globular and open clusters have been modelled by N. Robichon. Some other special fields are provided from HST or ground-based observations, for example Baade's Window from HST data, bulge fields from OGLE data and some local group dwarf galaxies from ESO–WFI or HST data. The user should look in the help pages for the description of the size, resolution and completeness of the original observations.

- **Galaxies**
  The simulation of galaxies is done using STUFF and SKYMAKER, originally developed by E. Bertin and adapted to Gaia by C. Dollet. STUFF simulates a catalogue of galaxies which are simulated into pixel data by the SKYMAKER image generator software. The different galaxy types are simulated by combining an exponential profile for the disc and a de Vaucouleurs profile for the bulge. A description of the distribution functions used in STUFF can be found in Erben et al. (2001).

  More realistic profiles can be simulated using observed galaxy images such as the nearby galaxies of the Frei et al. (1996) catalogue, transformed to be as observed from a larger distance. This will be implemented later on in GIBIS.

- **Solar System Objects**
  Asteroids are simulated in GIBIS using a program developed by D. Hestroffer which convolves the Gaia PSF with an asteroid shape and velocity. They are assumed to be of solar spectrum. Ephemeris are not yet included in GIBIS so that asteroids are added manually in the user defined sources.

- **User defined sources**
  The user can provide his own source list to the simulator. This is the option the most commonly used by the GIBIS users as it allows to make specific tests of their on-board or reduction algorithms. The user can currently provide stars, galaxies and asteroids.

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

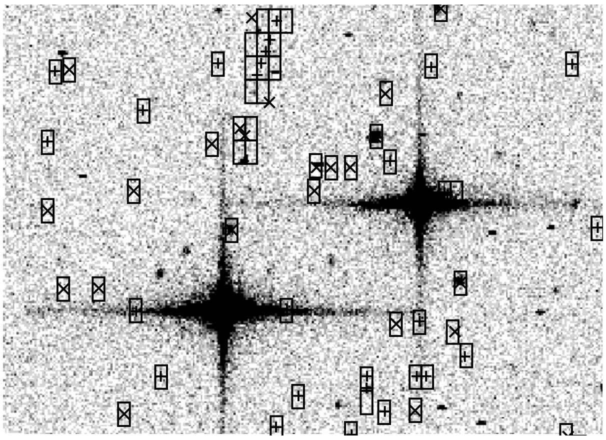

*Figure 3. GIBIS 2.0 simulation of a typical galactic field (l=8°,b=20°) observed in the astrometric field, the second telescope pointing in the (l=262°,b=-26°) direction. Cosmic-ray impacts are included. The detected stars in Astro1 and Astro2 are indicated as + and x respectively. The boxes correspond to the windows selected in this field. The detection/selection has been done using Pyxis 2.0.*

- **Backgrounds**
  The main contributors to the Gaia background will be the faint undetected galactic sources, the zodiacal light and small-scale structures such as nebulae. The faint sources are simulated using the galaxy model and setting fainter magnitude limits than the Gaia ones. The user can chose between adding a constant value for the background, assuming a solar spectrum, or adding an HST-PC image convolved to the Gaia properties. The latter option does not yet include variation of the background with the different Gaia filters.

### 3.2. Instrument Model

The main characteristics of the Gaia satellite and payload are simulated in a modular way, allowing a progressive improvement of the detail level of the simulations. Many instrument parameters can be changed by the user to be able to test different design options until the design is frozen. The default parameters are regularly updated by a direct use of the Gaia Parameter Database (de Bruijne et al. 2005). Noise and possible defaults are included to access the final accuracies and design the calibration procedure.

- **Optics**
  The Gaia Point Spread Function is computed using `psfmaker` (Babusiaux et al. 2004). It includes realistic optical aberrations, smearing effects due to pixel integration, TDI smearing, attitude induced motions, attitude rate errors, optical distortions and CCD charge diffusion. It does not yet include the CCD charge transfer inefficiency (CTI). The polychromatic PSFs are computed according to the telescope transmission, CCD quantum efficiency and filters. For non-photometric fields the PSF is given as a function of the source V–I color.

  Vignetting is simulated in the MBP focal plane for the sky mapper. Vignetting at the border of the Astro telescopes fields of view are not yet included.

  Straylight and ghosts are not yet simulated.

- **CCD**
  The main CCD characteristics are present, including realistic read-out noise computed according to the sampling strategy, dark and saturation. However defaults, sensitivity variations, hot pixels, non-linearity, aging and CTI are still to be simulated.

  Cosmic-ray impacts are simulated in GIBIS using particle event morphology and energy provided by A. Short from detailed Monte-carlo simulations of the Gaia CCDs.

  To avoid bright stars saturation, gates can be activated, however this is not yet managed by the on-board data handling so the user has to activate the gates manually in this version.

- **Response**
  The photometry is simulated using formulae provided by C. Jordi from the Photometry Working Group, which provide the transformation from standard V and V–I into the Gaia photometric systems magnitudes.

  A simulation of the RVS spectra has been provided by the RVS Working Group (Katz 2003), but is not yet implemented in GIBIS.

- **Payload data handling**
  The actual on-board algorithm prototypes developed and provided by the On-Board Detection Working Group (Arenou et al. 2005) are implemented directly within GIBIS. The algorithms currently implemented are those of Pyxis version 2.0 and contain the detection, selection, cross-matching and tracking algorithms. The confirmation algorithm for Astro is not yet implemented.

- **Scanning Law**
  The scanning law is not yet implemented in GIBIS. In the mean time the user can define the transit characteristic for his simulation (across-scan position within the focal plane, across-scan star image speed, scan angle relative to the input coordinates) so that several different transits can be manually simulated. The pointing direction of the second telescope can also be set independently.

## 4. MAIN CURRENT APPLICATIONS

GIBIS is used in a number of applications by the Gaia community. The main current ones are summarized.

**On-board algorithms:**
The On-Board Detection Working Group make an intensive use of GIBIS (Arenou et al. 2005). It was used to

test different binning strategies in the Astro and Spectro sky mappers, develop and test the on-board detection, selection and cross-matching algorithms and define the observation strategy in Spectro. The on-board detection performances in the Astro Sky Mappers of the algorithms have been assessed for single and double stars on typical and crowded fields. Performance assessments need also to be done on high and variable sky backgrounds, with cosmic-ray events and CCD defaults, as well as the study of the detection of galaxies. This is underway.

Test images generated by GIBIS have been provided to the Payload Data Handling Electronic contract for the design of the implementation architecture of the Payload Data Handling System.

The performances of the algorithms in Astro, as derived from GIBIS simulations, have been provided in terms of statistical results for GASS telemetry simulations.

**Sampling strategy and Imaging capabilities:**
Nurmi (2005) and Dollet et al. (2005) studied how to combine and optimize the Gaia observations obtained at different transits to restore the object environments and detect faint companions.

**High density fields:**
Babusiaux (2005) determined the main characteristics of the most crowded regions that will be observed with Gaia. Evans (2004) studied how to use the Astro high resolution astrometry and PSF fitting methods to improve the medium band photometry accuracy, which suffers from the low spatial resolution of the Spectro instrument in relatively dense fields of the galactic plane.

**High background fields:**
GIBIS allows simulations of high sky background levels and variations which have been used in Arenou et al. (2003) to study the on-board and on-ground background determination.

**Solar System objects:**
Chéreau (2004) estimated the on-board detection performances of fast moving objects in the Spectro sky mappers. Hestroffer & Berthier (2005) used GIBIS simulations to derive the expected astrometric precision for such extended and moving objects.

## 5. CONCLUSIONS

GIBIS is in constant development. Its steps and priorities are defined within the Simulation Working Group according to the needs and the input simulations or parameters becoming available.

For more information about GIBIS, have a look at the web page `http://gibispc.obspm.fr/~gibis` or contact `carine.babusiaux@obspm.fr`.


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