The Gaia simulator: possible use for NEAT

May 2013

X. Luri, ICCUB/IEEC
On behalf of the DPAC CU2

The mission

A (mainly) astrometric mission

- >10^9 objects (~1% Milky Way)
- Complete up to 20th magnitude
- Positions, velocities and parallaxes
  - Nominal precision (15th mag): ~25μas
- Spectrophotometry
- Spectroscopy and radial velocities (G<16)
- No input catalogue → unbiased survey

Multiple pairs of instantaneous observations provide an all-sky grid of angular measurements. A global reduction process converts them into global astrometry: positions, parallaxes and proper motions.

Spectrophotometric measurements provide photometric magnitudes and physical parameters for all the observed objects.

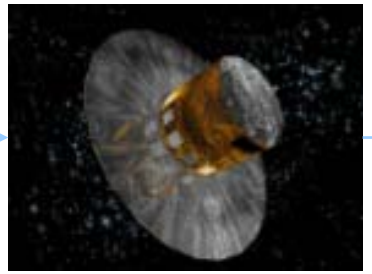
Spectroscopic measurements provide radial velocities.

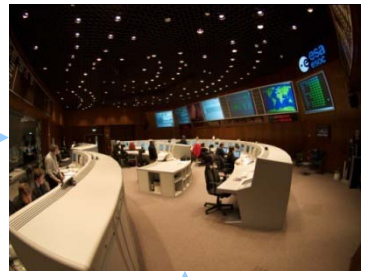
Organizing it: the DPAC

The Gaia simulator

Industry/ESA CSG/ESOC

(2013)





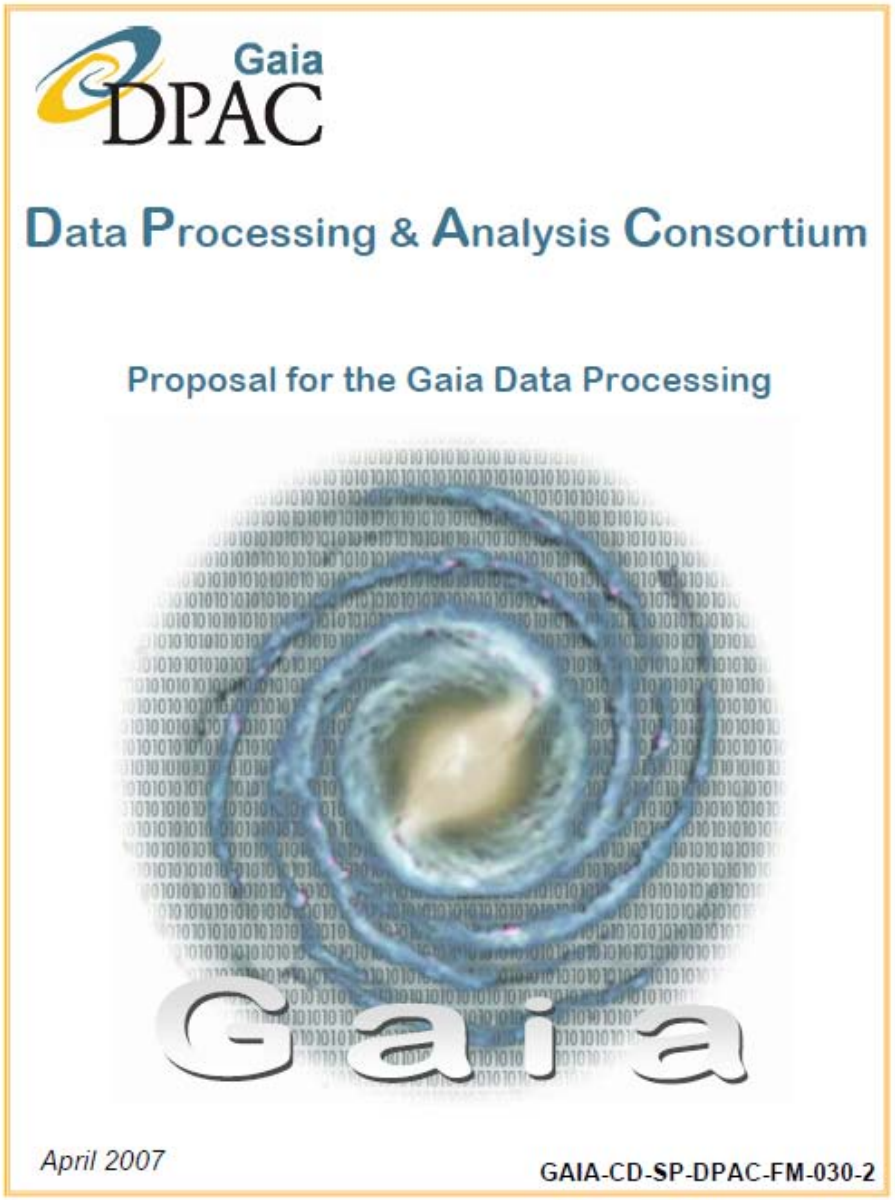
One consortium: the DPAC

The final responsibility of the Mission is in the hands of ESA

Data reduction is a responsibility of the scientific community, funded by the member states

Data Processing and Analysis Consortium

- Formed to answer the Announcement of Opportunity (AO) for Gaia data processing
- Involves large number of European institutes and observatories (>400 people, >20 institutes)
- The science community must fund the majority of the Gaia processing (not ESA)

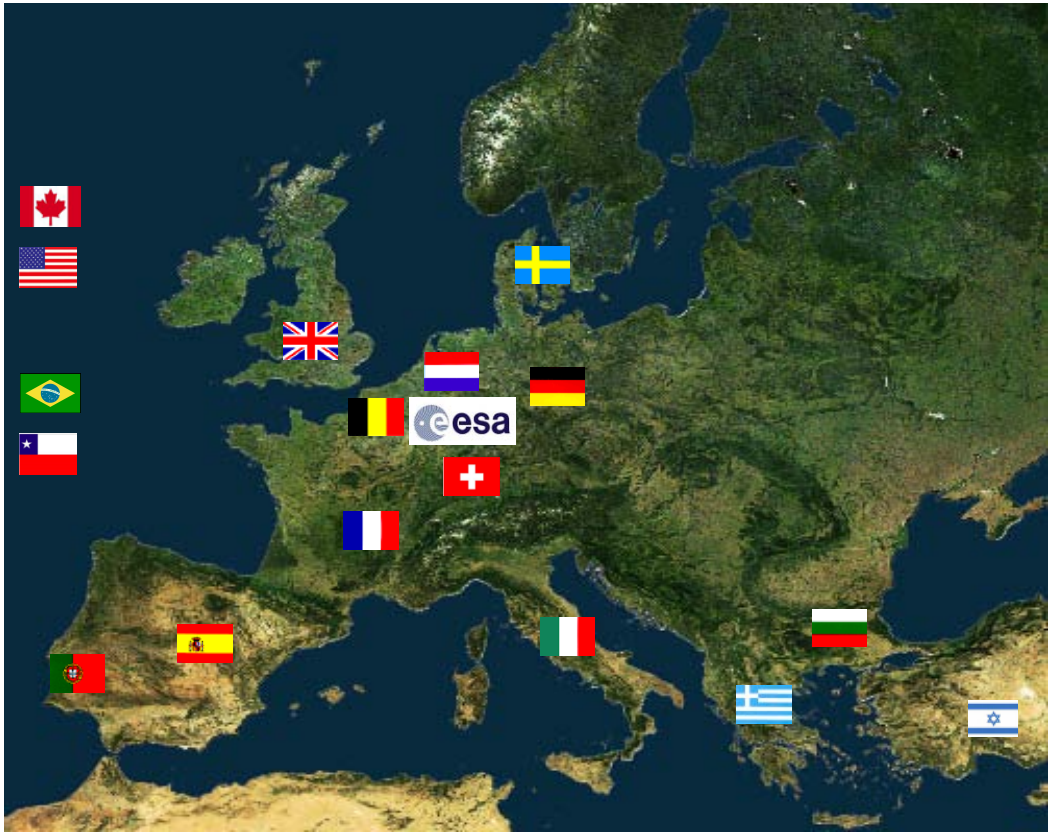


AO response (2006)

- 711 pages
- Presents the initial design for the processing of the Gaia data
- Also defines the structure of DPAC
- Concepts have evolved since then

The Gaia simulator

- 459 members
- 24 Funding Agencies
- 93% in the 10 largest



- With a 5 years mission, ~33% of DPAC cost will be dedicated to Operations

MLA duration: 2007-2022
FTEs/year up to 2011: 270
Average yearly cost: ~30Meuros
Global cost: ~500M€

DPAC coordination units

- CU1: System Architecture
- CU2: Data Simulations
- CU3: Core Processing
- CU4: Object Processing
- CU5: Photometric Processing
- CU6: Spectroscopic Processing
- CU7: Variability Processing
- CU8: Astrophysical Parameters
- CU9: Catalogue Access

This talk

DPAC coordination units

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Expertise in astrometriy processing (Paris, BCN)

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Exoplanet processing

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Gaia archive

Simulated data: CU2

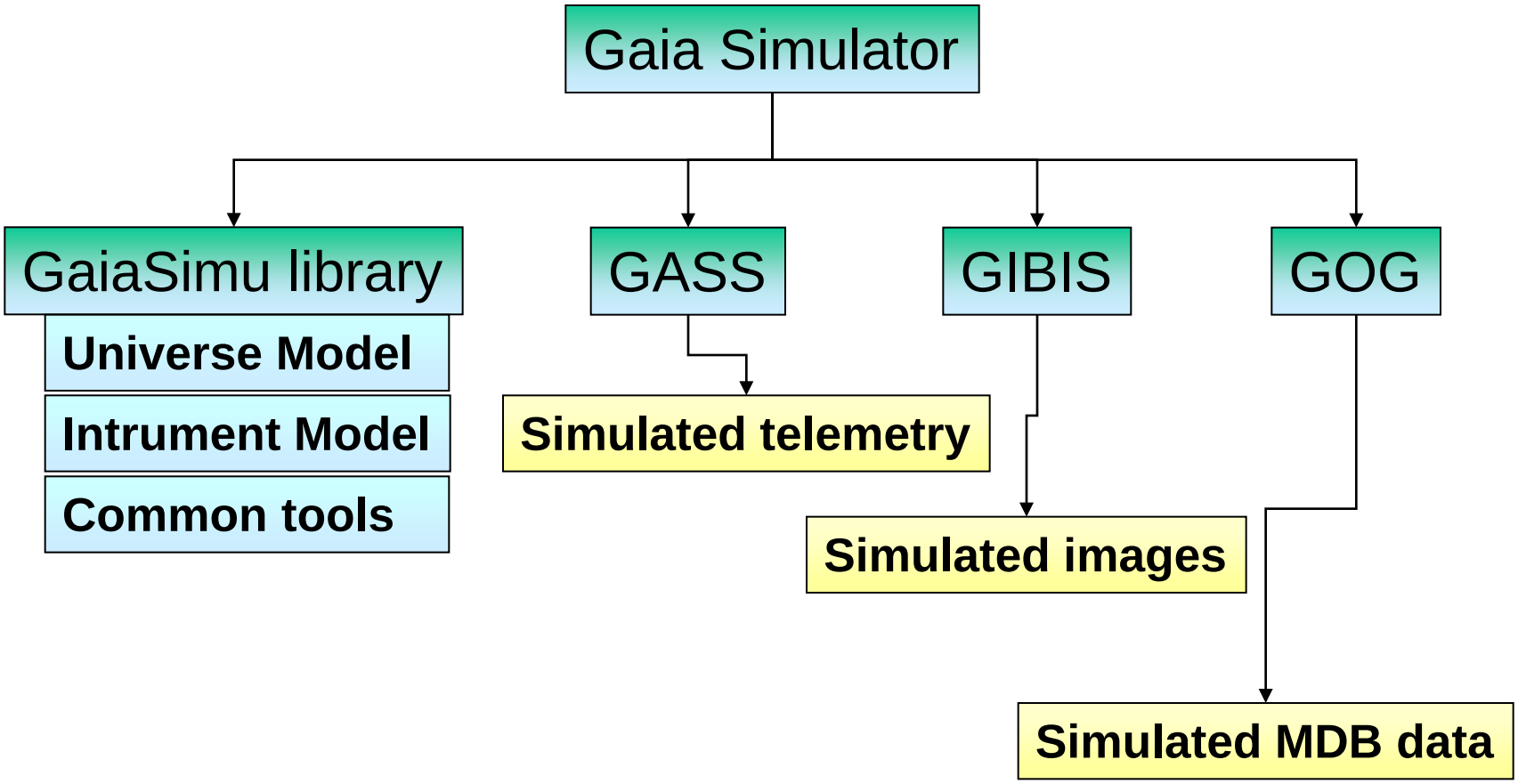
The CU2 role

The CU2 task is to cover the simulation needs for the work of other CUs, ensuring that reliable data simulations are available for the development and testing of the various stages of the data processing development.

The CU2 operates in close coordination with the rest of the DPAC:

- Requests for simulated data are sent in each cycle by the different CUs in DPAC
- The development of the different modules of the simulator is jointly agreed, taking into account each CU's needs, their global priorities within the overall consortium, the availability of the simulation models (which can depend on industrial tests or other CU accuracy models) and the available CU2 manpower.

CU2 product tree



The CU2 has provided to DPAC and Gaia in general many sets of simulated data (amounting to many terabytes) for various purposes:

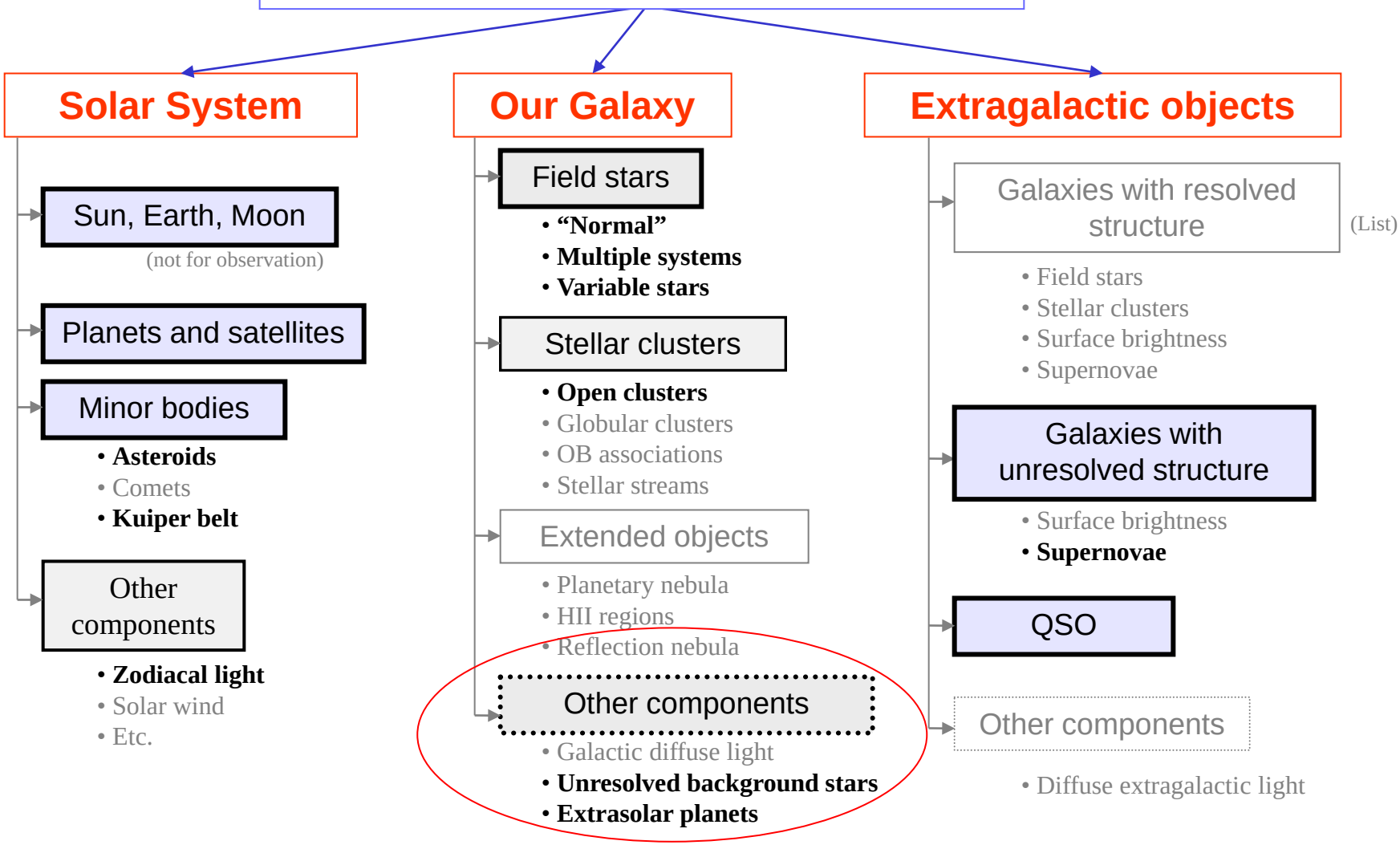
- Mission design
- Instrument design
- Data reduction testing and validation
- Scientific preparation

The GaiaSimu library

GaiaSimu library: this library is the basis for the development of the Gaia simulator. It contains the common models used by the data generators to produce simulations of the Gaia observations. It is composed of three parts:

1. The instrument model: models of the Gaia instruments and elements of the spacecraft
2. The universe model: model of the objects in the sky that Gaia will observe, with all its physical characteristics
3. Common tools: a toolbox for use throughout the simulator

The Universe Model



Exoplanet model in the simulator

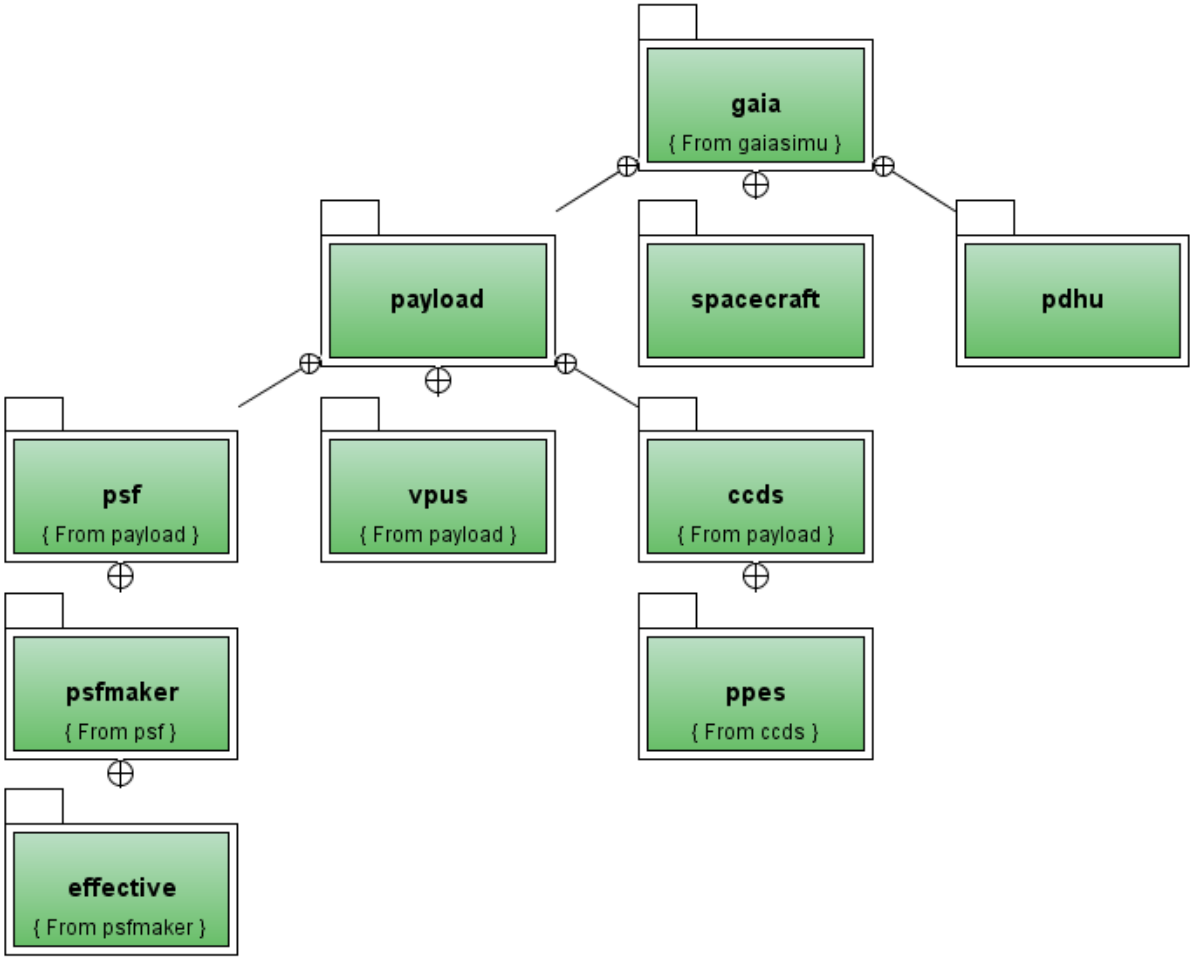
- Model described in Sozetti (2007).
- One or two planets (can be extended) generated with distributions in true mass Mp and orbital period P resembling those of Tabachnik & Tremaine (2002)
- Semi-major axes are derived given the host mass, planet mass, and period. Eccentricities are drawn from a power- law-type distribution.
- Full circularization (e = 0.0) is assumed for periods below 6 days. All orbital angles are drawn from uniform distributions.
- Observed correlations between different parameters (e.g, P and Mp) are reproduced.
- Simple prescriptions for the radius (Baraffe et al. (2003)), effective temperature, phase, and albedo based on the present-day observational evidence.

- For every dwarf star generated of spectral type between F and mid-K, the likelihood that it harbours a planet of given mass and period depends on its metal abundance according to the Fischer & Valenti (2005) and Sozzetti et al. (2009) prescriptions
- M dwarfs, giant stars, white dwarfs, and young stars do not have planets for the time being, as well as double and multiple systems.
- The astrometric displacement, spectroscopic radial velocity amplitude, and photometric dimming (when transiting) induced by a planet on the parent star, and their evolution in time, are computed by the simulator.

Combined with the rest of the simulator Universe Model:

- Provides full astrometric and photometric model of the Gaia observations (+ potentially NEAT observations)
- Includes photocenter position noise due to stellar spots
- Includes variability in field stars and host stars. Could add microvariability.
- Includes binaries in field stars

The Instrument Model



The Data Generators

The simulator comprises three *data generators*, software components that use the GaiaSimu library to produce specific types of data for the DPAC. The three data generators are:

- The GAia System Simulator (GASS)
- The Gaia Instrument and Basic Image Simulator (GIBIS)
- The Gaia Object Generator (GOG)

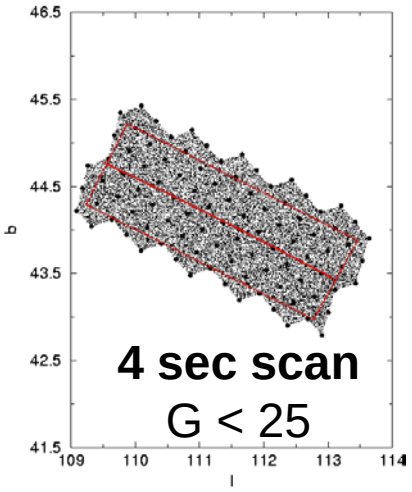
GASS

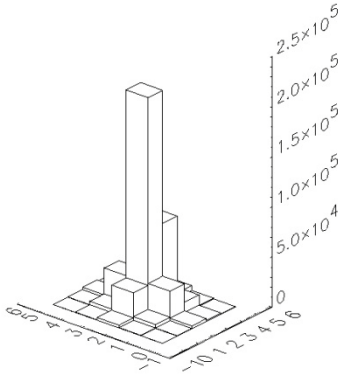
This data generator provides simulations of the telemetry stream of the mission based on some simplications of the instrument and Universe models allowing a large amount of data to be simulated over a signicant period of time.

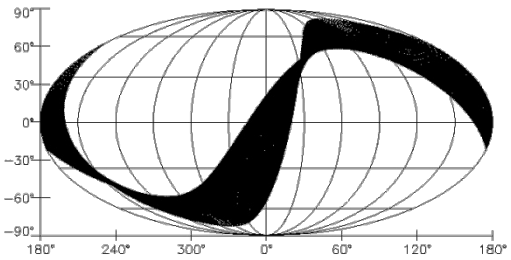
GASS provides realistic data for:

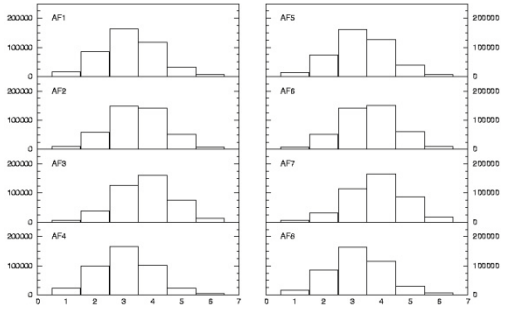
- Predictions to be used for mission design.
- Filling of test databases
- Testing of core reduction algorithms
- Evaluation of mission performances, in particular for peculiar objects (binary stars, NEO's, extrasolar planets,...)

GASS is run in large computer clusters and specially at the **Mare Nostrum supercomputer**.









ASTRO patches

GIBIS

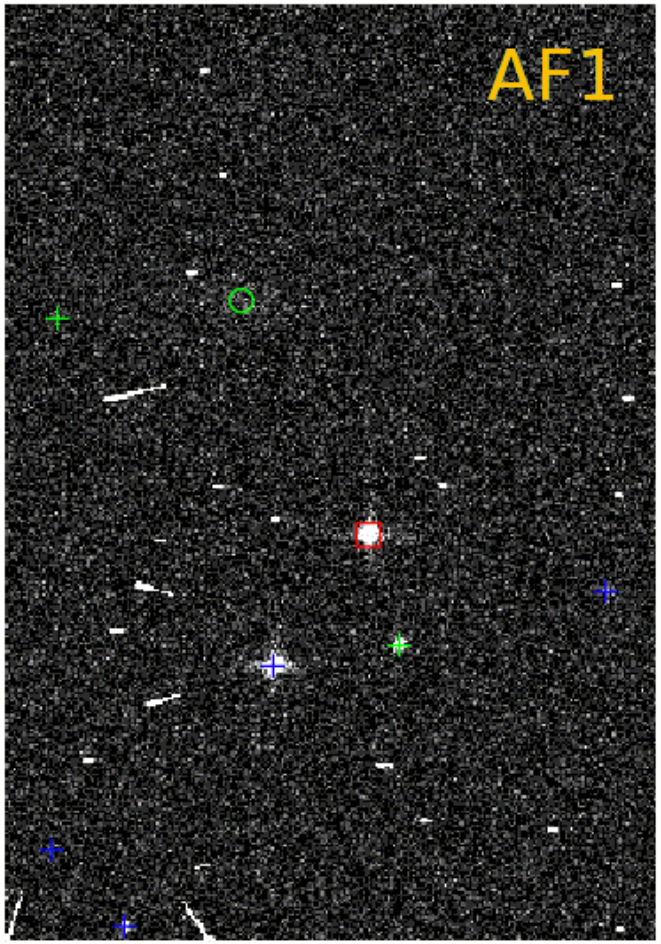
This data generator provides simulations of the data at the pixel level. The resulting simulations are as realistic as possible and restricted, due to computing time limitations, to a region of a sky over a short period of time.

GIBIS provides realistic CCD images for:

- Instrument design
- PDHE design
- Detection & selection algorithm development
- Scientific mission design (e.g. RVS)
- Detailed analysis of reduction algorithms

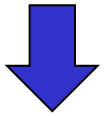
The Gaia simulator

GIBIS is available as a web service and is also run in batch mode in computer clusters.

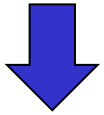


GIBIS possibilities for NEAT

GIBIS provides highly realistic simulation of Gaia CCD images with full detail (astrometry & photometry)



Could be adapted to provide simulations of NEAT CCDs with high realism? (Gaia PSF → NEAT interference fringes)



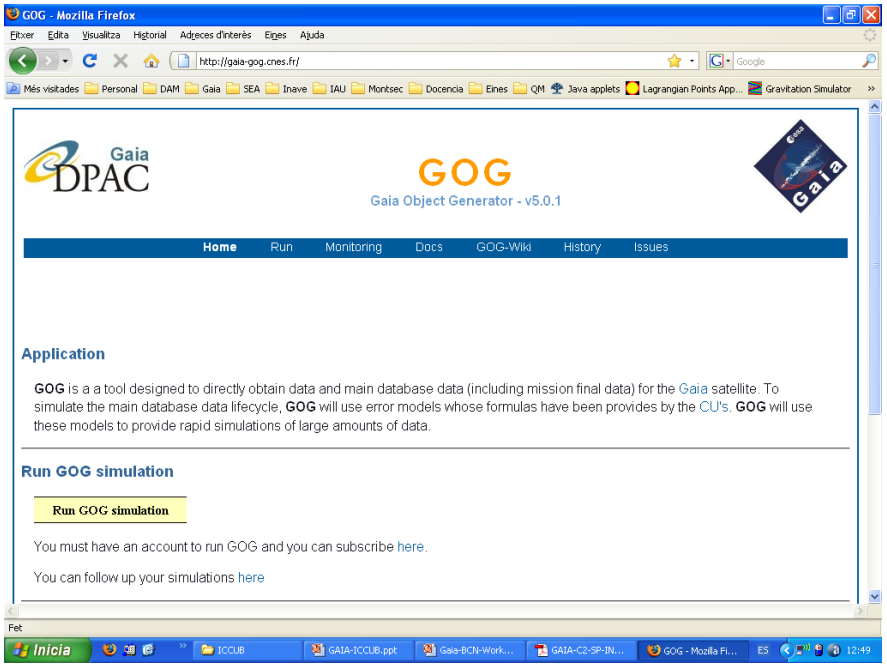
Help in detailed analysis of NEAT performance

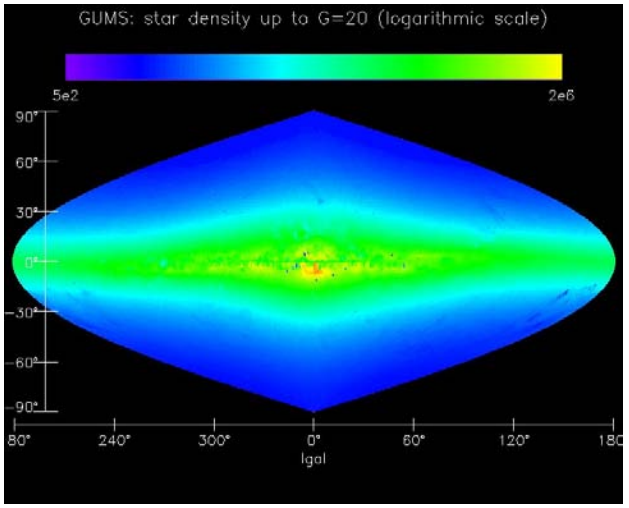
GOG

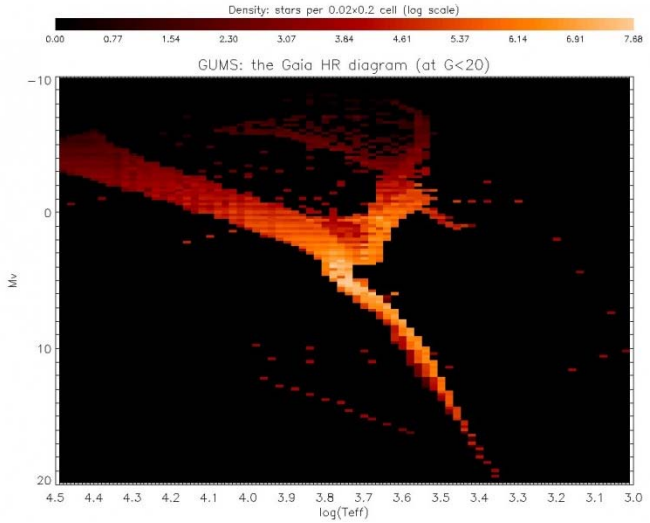
This data generator provides simulations of number counts and lists of observable objects from the Universe model and, for a given source or a collection of sources, simulations of intermediate and end-of-mission Gaia data.

GOG aims to simulating the contents of the MDB at any stage of the data processing.

GOG is available as a web service and is also run in batch mode in computer clusters.

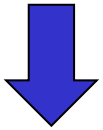






GOG possibilities for NEAT

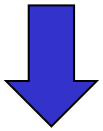
Simulation of Gaia catalogues, including realistic astrometry and associated errors



Can simulate Gaia reference stars for NEAT with high realism

The Gaia simulator

Simulation of epoch data: realistic astrometry & photometry of field stars and stars with exoplanets at any given epoch



Can simulate series of Gaia or NEAT reduced observations at arbitrary epochs.

(cross-validation with NEAT simulator?)

Summary

The Gaia Simulator has produced **several terabytes of simulated data** in the last years that have been used for Gaia mission design and development and testing of the reduction algorithms.

- Well tested and in production
- Realistic Gaia simulations at several levels
- **Provides detailed astrometric & photometric simulations**
- **Includes exoplanet model**
- Modular design, can be expanded and adapted for NEAT

Appendix: the final archive, CU9

CU9 role

The CU9 will be in charge of designing, implementing and operating the Gaia archive. It will be responsible of actually making the Gaia data available to the scientific community.

The CU9 will be oficially started next June.

Proposed data releases

- **First release: launch + 22 months (~90% of the sky)**
  - Positions (α,δ) and G magnitudes for all stars where the formal errors on the position are acceptable. The catalogue will be for the mean epoch 1 of observation and only for sources exhibiting single star behaviour
  - The Hundred Thousand Proper Motions (HTPM) catalogue based on the Hipparcos stars

- **Second release: launch + 28 months (~90% of the sky)**

  - Positions (α,δ) with five-parameter solution where available, and G magnitudes for all stars where the formal errors on the position are acceptable. The catalogue will be for the mean epoch 1 of observation and only for sources exhibiting single star behaviour
  - Integrated photometry BP/RP, with appropriate error estimates for sources where basic astrophysical parameter estimation has been verified (such parameters would also be released).
  - Mean radial velocities for stars in the catalogue which do not exhibit any deviation from a constant radial velocity, and for which, in the absence of atmospheric parameter estimates, an appropriate synthetic template could be selected. These will be based on single epoch radial velocity determination hence probably only bright stars.

- **Third release: launch + 40 months (~90% of the sky)**

  - Five parameter astrometric solution with appropriate error estimates for at least 90% of the sky for bona fide single stars.
  - Orbital solutions (including the 5-parameter astrometric term) for periods between 2 months and 75% of the observation duration
  - Integrated photometry BP/RP with appropriate errors
  - Spectrophotometry from BP/RP for sources for which astrophysical parameters aresimultaneously released
  - Source classifications (probabilities) plus stellar effective temperatures and line-of-sight extinctions based on BP/RP and astrometry for stars with sufficiently high quality data (expected to be most stars).
  - Mean RVS spectra for sources where single epoch spectra are usable and astrophysical parameters are simultaneously released.
  - Mean radial velocities for those stars in the catalogue that do not exhibit any deviation from a constant radial velocity and for which astrophysical parameter estimates are available.

- **Fourth lease: launch + 65 months**
  - Updates of astrometry with appropriate error estimates.
  - Spectrophotometry from BP/RP for sources for which astrophysical parameters are simultaneously released.
  - Mean RVS spectra for sources where single epoch spectra are usable.
  - Source classifications (probabilities) plus multiple stellar astrophysical parameters derived from BP/RP, RVS and astrometry for the majority of stars.
  - Orbital solution (including the 5-parameter astrometric term) for periods between 2 months and 75% of the observation duration
  - Variable star classifications and parameters as available, and the epoch photometry with appropriate error estimates, on which these results are based, are simultaneously released
  - Solar system results with preliminary orbital solutions and individual epoch observations
  - Non-single star catalogue

- **Final release: end of mission + 3 years (2022-2023)**

  - Full astrometric, photometric, radial velocity catalogue
  - All available variables and non-single Star solutions
  - Source classifications (probabilities) plus multiple astrophysical parameters derived from BP/RP, RVS and astrometry for stars, unresolved binaries, galaxies and quasars.
  - Precision improved with respect to 4th release. Some parameters may not be available for fainter stars.
  - Non-single Star solutions and exo-planet lists
  - All epoch and transit data for all sources
  - All Ground Based Observations made for data processing purposes (or links to it)