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# SIMULATING GAIA OBSERVATIONS USING A "UNIVERSE MODEL"

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**Abstract.**
Preparing the Gaia mission requires large efforts dedicated to simulations of the observations. Several simulators have been constructed, generating telemetry, images, or the final database. All these tools use a "Universe Model" containing essentially the astronomical objects seen by Gaia and their characteristics, as well as a Relativity model and a radiation model for estimating the potential dammage to the CCDs. The construction of the Universe Model will be described, together with the computation of the astronomical sources characteristics, and the applications and limitations of such a model.

## 1 Introduction

The Gaia DPAC (Data Processing and Analysis Consortium) has decided to put a big effort on the simulation of the mission in order that all softwares prepared for the mission be sufficiently and extensively tested prior to launch. The simulation effort consists in doing several simulators. The GIBIS simulates the images at the output of the CCDs, GASS simulates the telemetry sent to the ground from the satellite after selecting objects and windows around the objects on board. GOG is dedicated to generating intermediate and final data in the data base, including estimations of measuring errors. These 3 simulators make use of two models : the Instrument Model, and the Universe Model (hereafter UM).

This UM is a set of algorithms for computing the positions at any time, and observational properties of any objects expected to be observed by the Gaia instruments. The distributions of these objects and the statistics of observables have to be as realistic as possible for simulations to be usable for estimating telemetry, testing software, simulating images, etc. The algorithms have also to be optimised in order that the simulations can be performed in reasonable time and can be redone when necessary. The complexity of the model is expected to increase during the preparation of Gaia.

Objects which will be, in fine, simulated are: solar system objects (planets, satellites, asteroids, comets), galactic objects (stars, nebulae, stellar clusters, diffuse light), extragalactic objects (galaxies resolved in stars, unresolved but extended galaxies, quasars and active galactic nuclei, supernovae). On top of these objects, a relativity model has to be implemented. The interstellar extinction has to be taken into account. Backgrounds have to be simulated, like the zodiacal light, or extended nebulae. The radiation environment of the satellite and its variation with time is also an element of the UM. For each of these simulated objects one needs to have their full 3D spatial distribution together with their spectral characteristics (to be able to compute photometry and spectroscopy, stable or variable in time), and their motions (for astrometric computations and for spectral corrections). Gravitational lensing for stars and galaxies are also to be simulated.

We here describe the main UM assumptions, the characteristics of the simulated objects, the spectral libraries, and we present the global statistics of the objects as computed from the UM.

## 2 Astrosources

For each "astrosource", the UM defines its characteristics in order to compute the observables. This includes: the photometry and variability with time, the astrometry (position at a given time, 3D velocities to compute radial velocity and proper motion, distance to the observer to compute the trigonometric parallax) and the

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physical parameters which define the spectrum (effective temperature, gravity and metallicity for stars, Hubble type for galaxies, equivalent width and slope of the spectrum for quasars, taxonomical type for asteroids, etc.). The spectra are taken from spectral libraries, interpolated for the astrophysical parameters of the astrosource, and corrected for interstellar extinction, rotation and radial velocity.

Exoplanets are simulated orbiting single stars and creating transits. Multiple stars are generated and eclipses simulated when necessary. The proportion of multiple stars and the distribution in mass ratio and semi-major axis and statistically generated according to Arenou and Soderhjelm (2005). Multiple star simulations are of course not static. Beyond the Galactic properties of multiple stars, the astrometric, spectroscopic (radial velocity) and photometric (eclipses) effects of these objects have to be taken into account: in the course of the simulations of Gaia transits, the orbits are thus computed, the positions of both components are modified, though crudely in the case of eclipse. For extended objects (comets, asteroids, nebulae, etc.) shapes have to be modelled to allow the computation of the image. Figure 1 shows the main classes which allow to describe an astrosource.

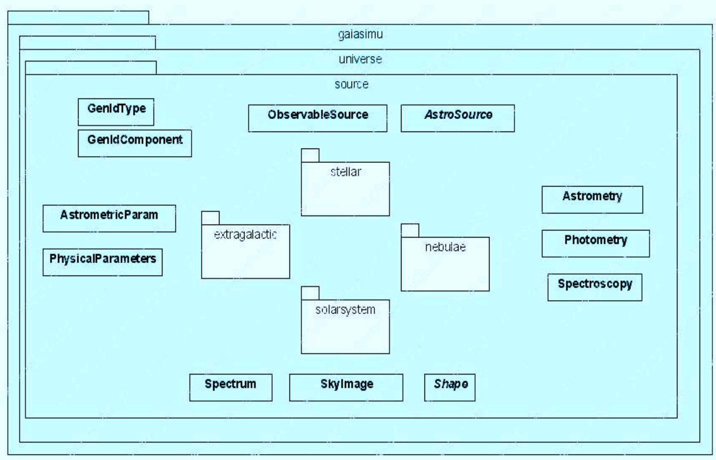


**Fig. 1.** Main classes describing an AstroSource.

## 3 Object generators

The "astrosources" have to be built from a set of generators which generate in any given direction of observations the objects which are present in the field of view of the instrument and their characteristics. Details on the various object generators can be found in Robin et al. (2009). The main aspects are described below.

Most of the objects in Gaia instruments are stars. To generate the stars in the Milky Way we use a version of the Besançon Galaxy Model which have been rewritten is Java. This version possess several improvements with regards to the standard model (Robin, et al, 2003). They are : full simulation of stellar multiplicity, inclusion of several stellar variability (delta Scuti, ACV, cepheids, RRab, RRc, roAp, semi-regular, dwarf novae), rare objects (Wolf Rayet, planetary nebulae). It also includes the computation of the microlensing towards the Galactic bulge, and uses the Drimmel & Spergel (2001) model as 3D extinction map for computing the extinction along any line of sight.

At present no stellar populations in local group galaxies have been implemented in the UM. Plans are done to simulate at least the stars in the Magellanic Clouds. Unresolved galaxies are generated using the Stuff (catalogue generation) and Skymaker (shape/image simulation) codes from E. Bertin, adapted in Java for the DPAC purpose. The galaxy simulator generates a mock catalog of galaxies with a 2D uniform distribution and a distribution in each Hubble type sampled from Schechter's luminosity function. Each galaxy is assembled as a sum of a disc and a spheroid and is put at its redshift and luminosity and K corrections are applied. The algorithm returns for each galaxy its position, magnitude, bulge to disc ratio, disk size, bulge size, bulge flatness, redshift, position angles, and V-I. A corresponding spectrum is extracted from a spectral library established from PEGASE2 software (www.iap.fr/pegase and Livanou et al, 2009). A shape image can be associated to the galaxy through library of images taken from the HST, rescaled and resampled at the correct distance.

Quasars are simulated from the scheme proposed in Slézak and Mignard (2007). To summarize, lists of sources have been generated with similar statistical properties as the SDSS, but extrapolated to G = 20.5 (the SDSS sample being complete to i = 19.1) and taking into account the flatter slope expected at the faint-end of the QSO luminosity distribution. Since bright quasars are saturated in the SDSS, the catalogue is complemented by the Véron-Cety & Veron (2006) catalogue of nearby QSOs.

The Solar System objects (SSOs) are only a little sample of the total number of objects expected to be observed by Gaia, but their peculiarities strongly condition the design of this part of the Universe Model. The semi-empirical statistical approach (constrained by observations) considered in the other parts of the Universe Model is no longer valid (in this first version of the Solar System Module) due to the high apparent motions of the SSOs. The reason is quite simple: it is not possible to generate a catalogue of objects (along with their physical information) for a certain (static) sky region, since the observed objects in that direction depends on time. Therefore, to generate a catalogue of SSOs we would need to specify both the sky region and observation time. However, if the simulations are required to be done in a reasonable computational time, the computation of the ephemerides along the mission of a set of ($\sim 10^5$) SSOs is not feasible in this first approach.

To solve this problem, the simulation must not be based on a reliable statistical model, but on catalogues containing orbital elements of SSOs, stored on disk. By computing SSOs ephemerides in time, and crossing the obtained positions with the Gaia Scanning Law, only the transiting ones (i.e. the SSOs inside one of the FoVs) at any time along the mission are selected. This transits list contains all the candidates expected to be observed, and obviously, it contains also the transit time in the corresponding FoV, the astrometric data and the apparent magnitude of these objects. This is the basic input for the simulation of the Solar System.

## 4 Universe Model output and tests

The Universe Model produces output catalogues of astrosources with their astrophysical parameters and all necessary parameters allowing to compute their contribution to Gaia observations (positions, velocities, rotation, light curve, shape, low and high resolution spectra, etc.) to be used by the simulators GASS, GIBIS and GOG. The output can be given either as an ascii file or directly ingested in the Main Data Base for processing.

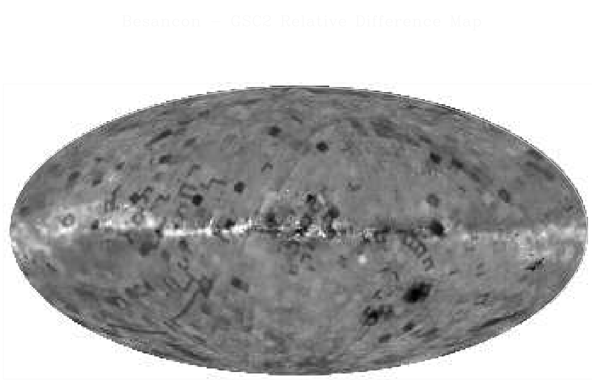

**Fig. 2.** Difference between GSC2 catalogue star counts at G=17 and galaxy model. Out of the Galactic plane the agreement is better than 10%. Significant excesses in the modelled star counts are found in the Galactic plane, that could be due to incompleteness in the data due to crowding, or to inappropriate model of extinction. Lack of counts in the model are found in the Magellanic cloud region (not included in the model) and in a few squared regions, most probably due to defects in the GSC2 photometric calibration.

In order to ensure that the model is reliable and realistic enough three level of tests are performed: unit tests on individual classes, integration tests on packages, and finally validation tests by comparison with real data. Concerning the third type, the validation of the stellar density has been done by comparing UM outputs with GSC-II catalogue over all sky (Drimmel et al, 2005). An example is given in fig 2. Moreover the Besançon Galaxy Model is extensively tested by comparison with many different data sets at various wavelengths (Robin et al, 2003). More tests are planned, for example on the number and separation of binaries, and by comparison of the model with the Hipparcos catalogue. We are also doing extensive kinematical tests by comparison of the simulations with Tycho-2 catalogue.

Figure 3 shows the predicted number of stars as a function of Galactic coordinates from the Gaia UM.

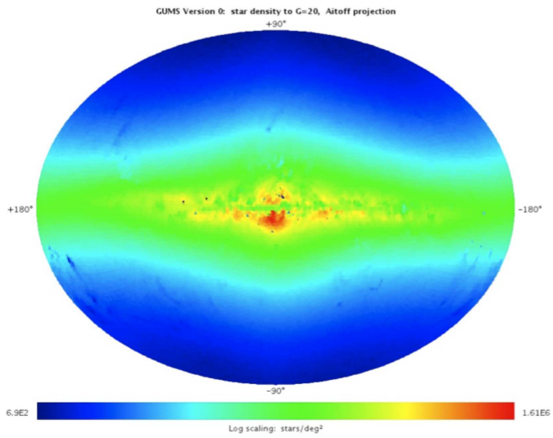


**Fig. 3.** Expected number of stars at magnitude G=20 from the Gaia DPAC Universe Model simulations GUMS.

## 5 Perspectives

The Gaia UM serves as providing simulations for testing purposes inside the DPAC. In the future and specially after launch the model will be maintained and will be further used for testing the analysis softwares. When waiting for real data, one will prepare the data interpretation using simulations in order to establish efficient methods for multivariate data analysis. Another application under study consists in doing a bayesian classifier based on prior probabilities computed from the simulations.

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