The Gaia simulator: current status and scientific exploitation

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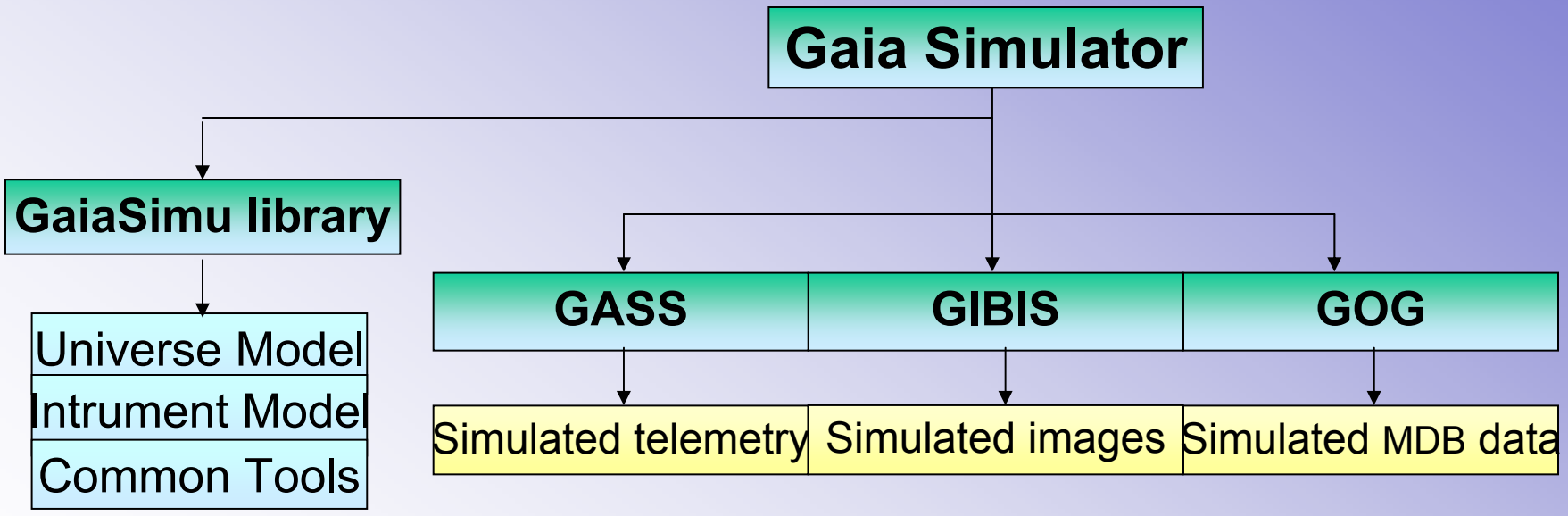
Introduction

Gaia DPAC (Data Processing and Analysis Consortium) has developed 3 data generators to provide realistic simulated data for the development and validation of the different stages of the data processing:



Status

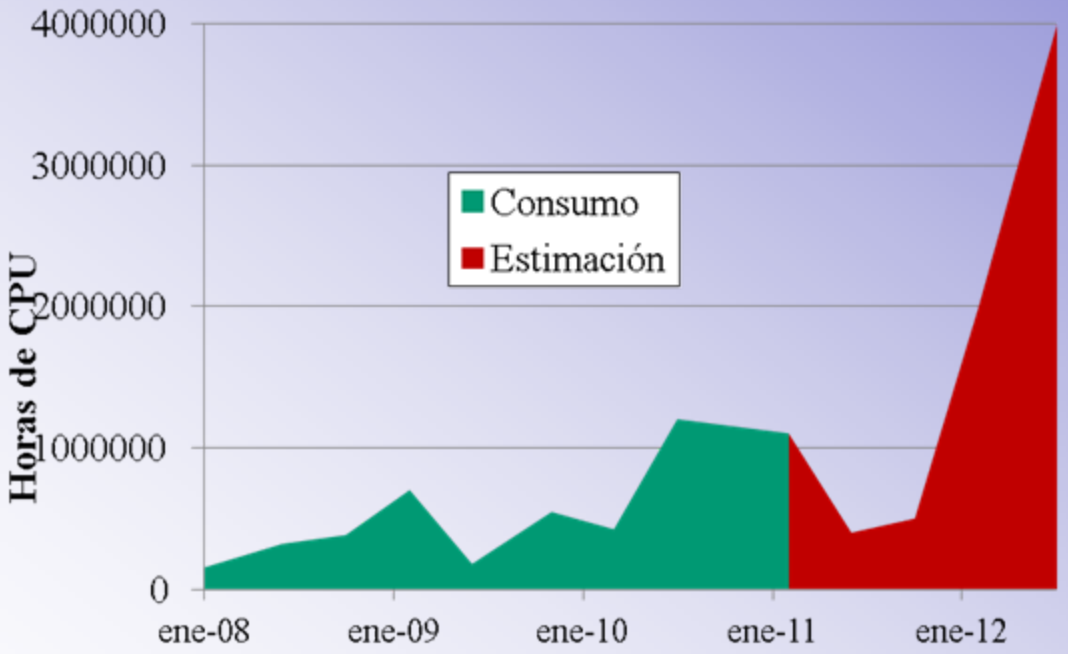
The simulation work must be almost finished for the launch.

- Code stable (end 2011)
- Later optimisation
- Generation of a 1:10 scale simulation of the mission (end 2012)

The Gaia simulator code has currently more than 100.000 lines. In the last years around 30 TB of data have been generated and used in the mission design and development and test of the initial version of the data reduction algorithms.

Status

In the period 2009-2011 more than 50 dataset have been generated; as example, the simulation of the End-to-End test of the system, run at MareNostrum in 2010, covers 18 months of the mission and required 1.300.000 CPU hours.



GASS: GAia System Simulator

The goal of GASS is to simulate the Gaia telemetry from simplified instrument and universe models, allowing the generation of huge amount of simulated data.

- Generation of:
  - solar system objects.
  - single stars.
  - variable stars.
  - multiple systems and exoplanets.
  - supernovae.
  - unresolved galaxies (point-like sources).
  - quasars.

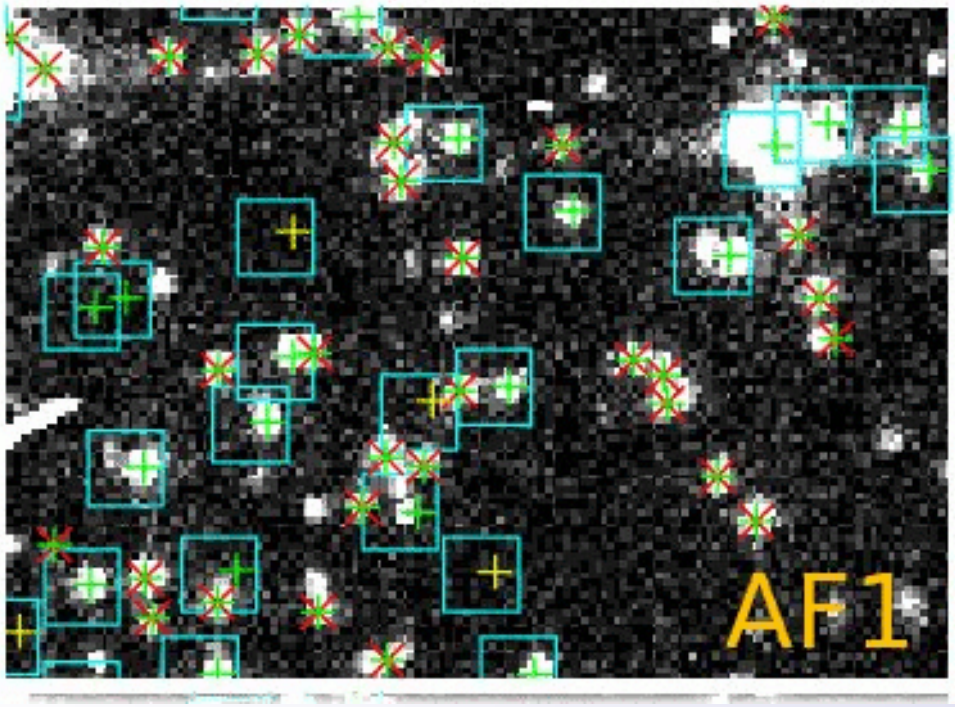
- Other:
  - Extinction model.
  - Zodiacal light.
  - Cosmic rays.
  - Virtual objects.

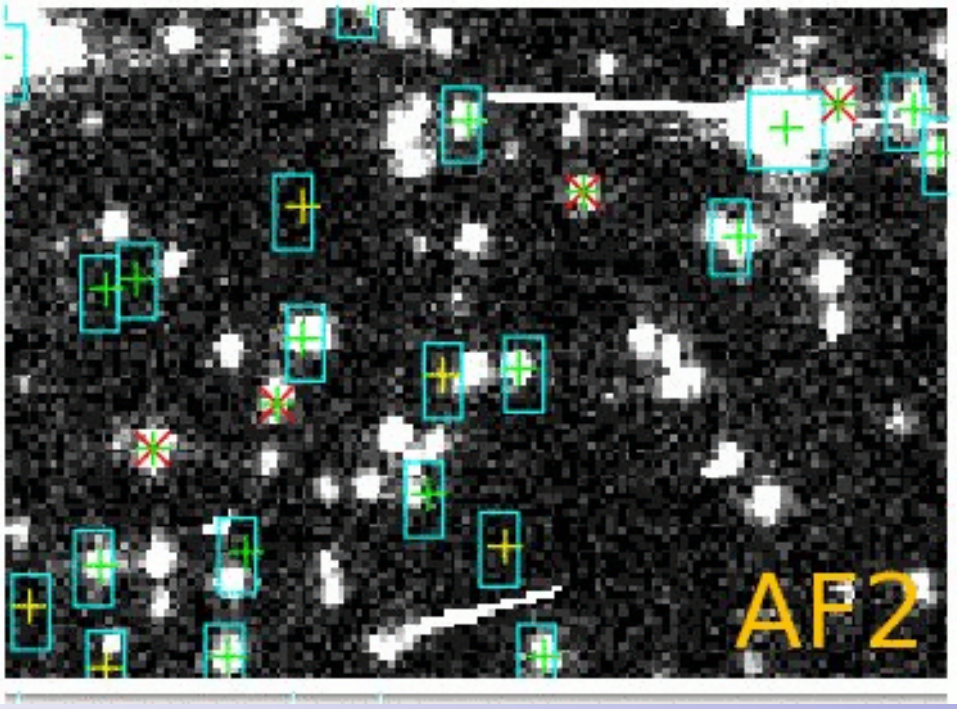
GASS

- Instrumental effects:
  - attitude with/without noise.
  - PSF/LSF function of FoV, CCD, and λ.
  - LSF (for SM and AF) lineal combination 11 monochromatic LSF.
  - charge injection and CDM model.
  - CCD non linearity.
  - basic angle variation.
  - QE variation.
  - pixel saturation.
  - conflicts in windows: truncation, gate conflicts…
  - blended sources.
  - …
- Others:
  - TM output format according Astrium specifications.
  - pre-scan observations.

GIBIS: Gaia Instrument and Basic Image Simulator

The goal of GIBIS is to simulated the Gaia observations at pixel level, using detailed models of the instruments and astronomical objects. The Gibis output is a high realistic images.


AF1


AF2

Gog: Gaia Object Generator

Gog is a tool designed to simulate catalogue data and main database data (including mission final data) for the Gaia satellite

Gog uses a model of the Gaia instruments to generate the data:

- Optical model (PSFs, transmitivity,…)
- Focal plane model (CCDs, electronics, …)
- **Instrumental errors** (radiation damage, read-out-noise,…)
- **Calibration errors**
- …

Gog: Gaia Object Generator

Parallax final accuracy:

$$\sigma_\pi = m \cdot g_\pi \cdot \sqrt{\frac{\sigma_\eta^2}{N_{eff}} + \frac{\sigma_{cal}^2}{N_{transit}}}$$

m: contingency margin

g_π = 1.47 / sin ξ a geometrical factor (ξ solar aspect angle)

σ_η : centroid error (function of G)

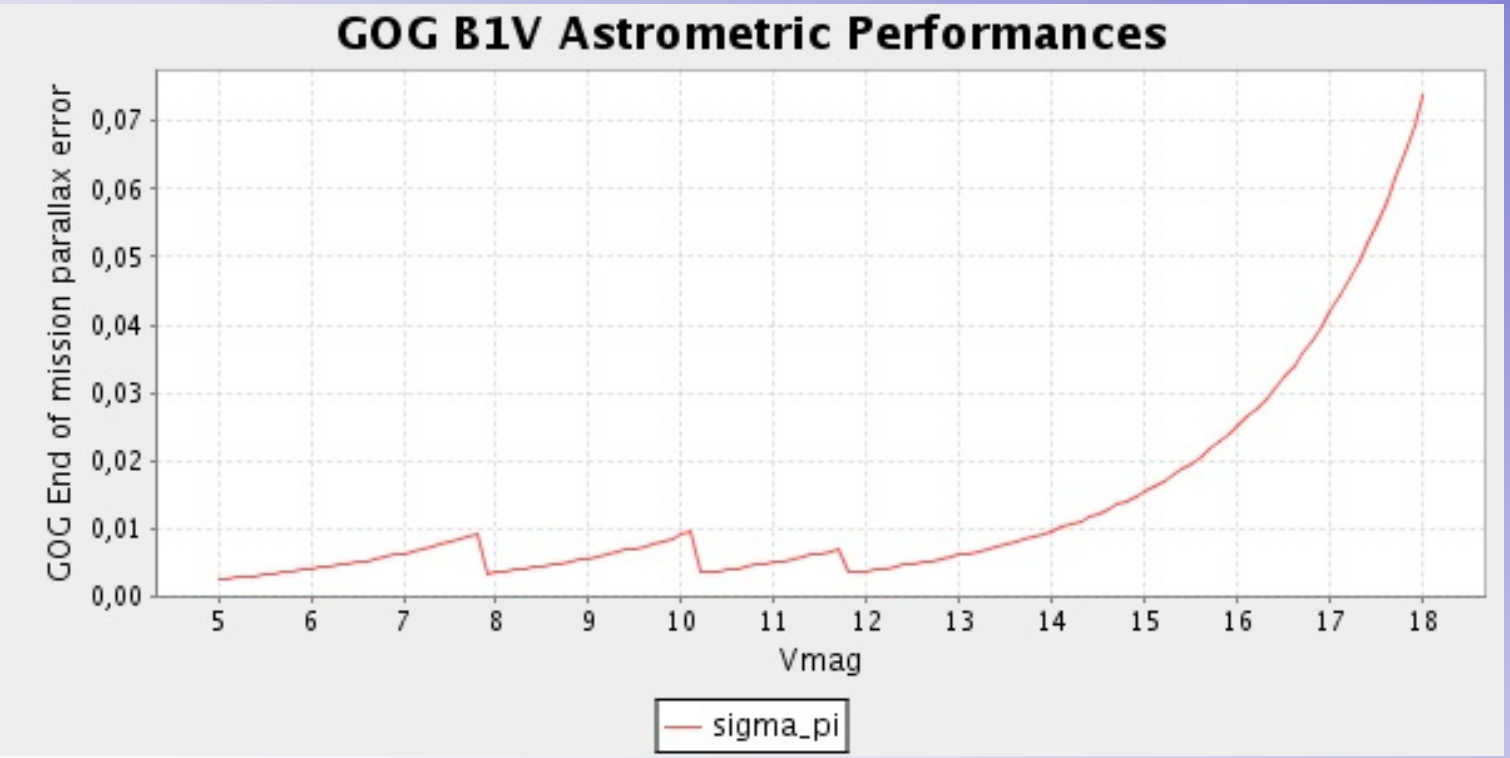
σ_{cal} : calibration error

N_{eff} : number of elementary CCD transits

$N_{transits}$: number of field of view transits

Gog: Gaia Object Generator

Example of parallax final accuracy (mas)



Gog: Gaia Object Generator

Photometry final accuracy:

$$\sigma_{Gj} = m \cdot \sqrt{\frac{\sigma_{pj}^2 + \sigma_{cal}^2}{N_{eff}}}$$

m: contingency margin

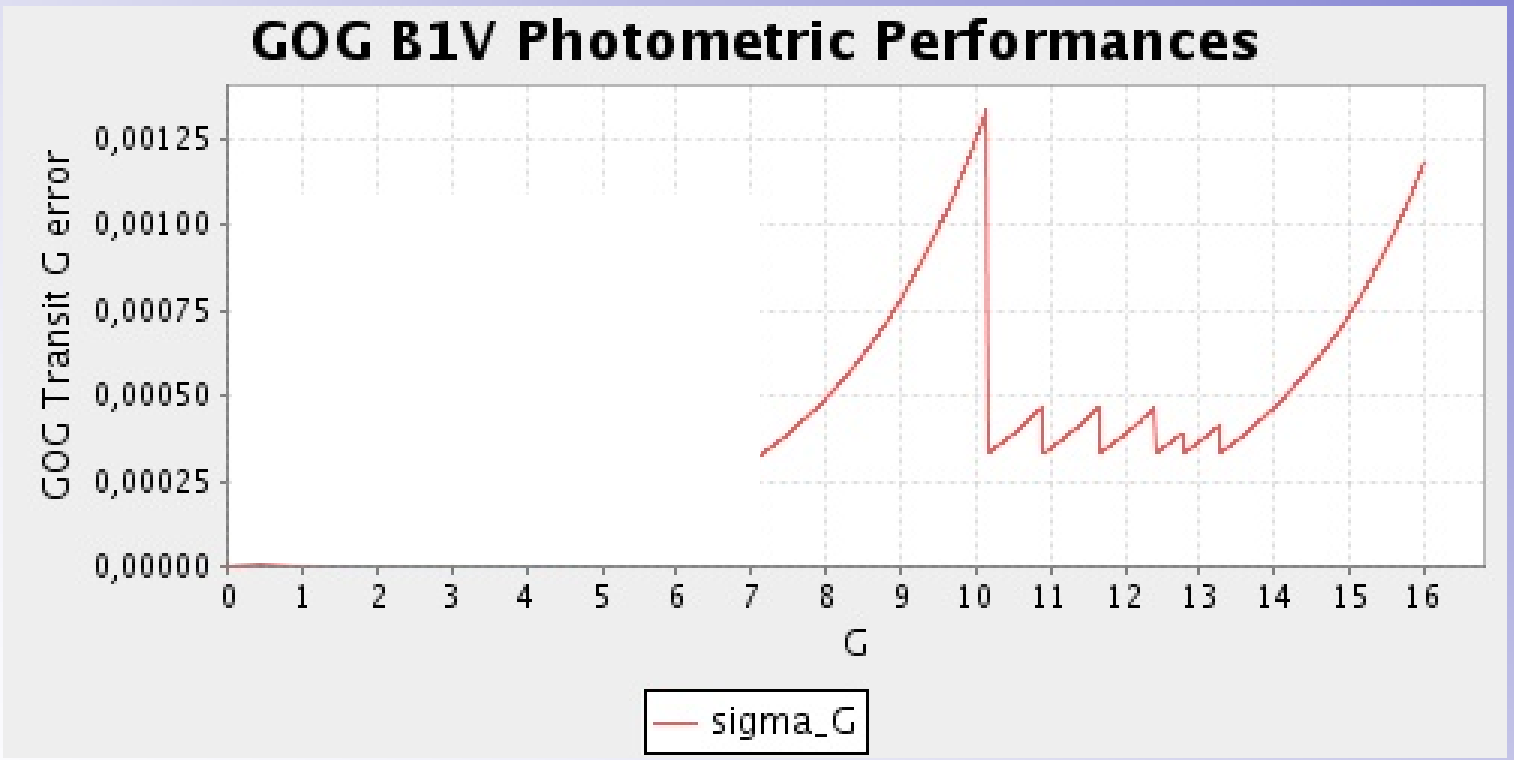
σ_{pj} : single CCD transit photometry error (function of G)

σ_{cal} : calibration error

N_{eff} : number of elementary CCD transits

Gog: Gaia Object Generator

Example of photometry final accuracy:



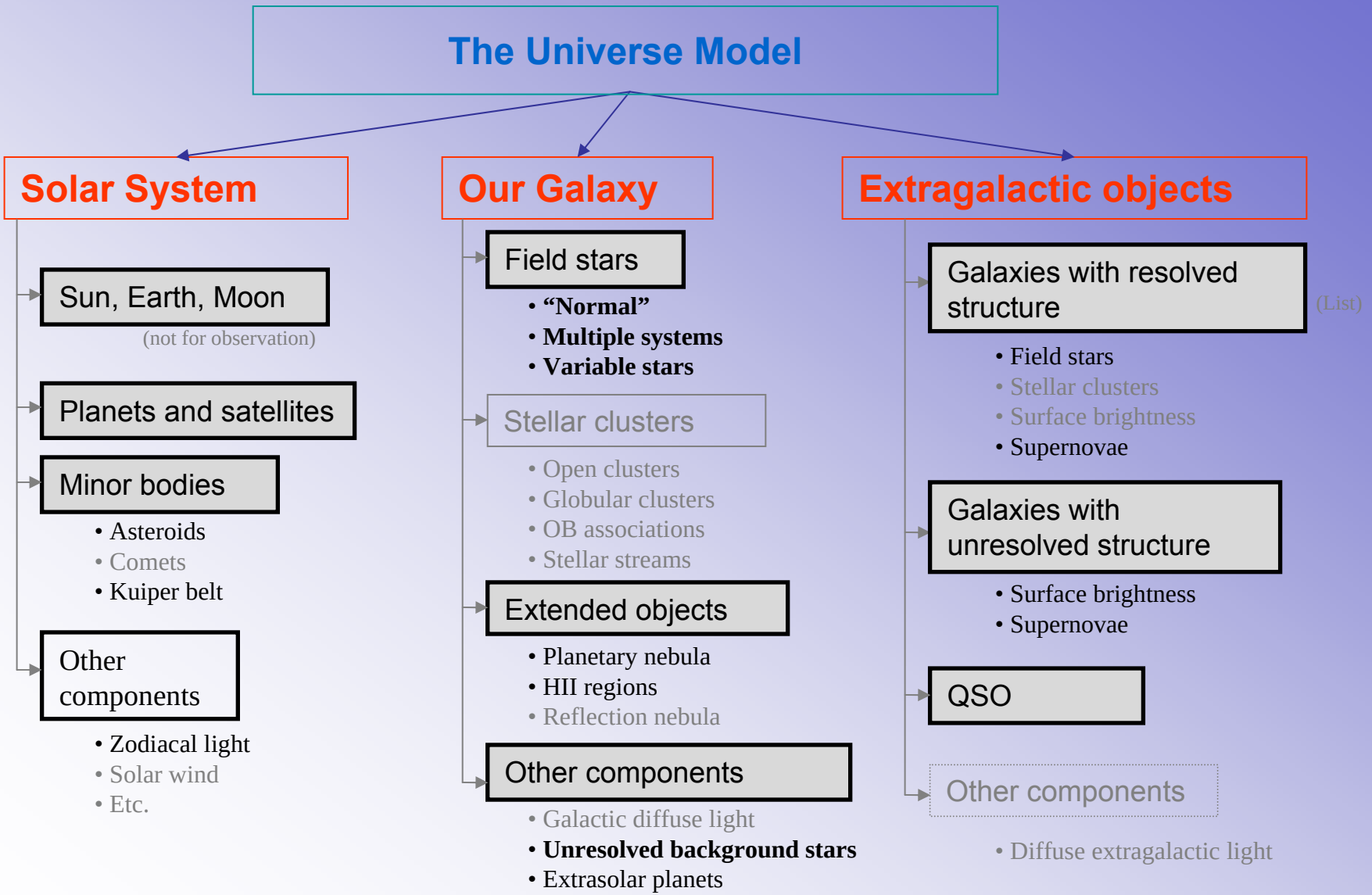
The Universe Model

All the data generated by Gass, Gibis and Gog is based on an Universe Model that provides the astronomical sources to be observed by Gaia (position, velocity, magnitude and physical parameters)

It has different components:

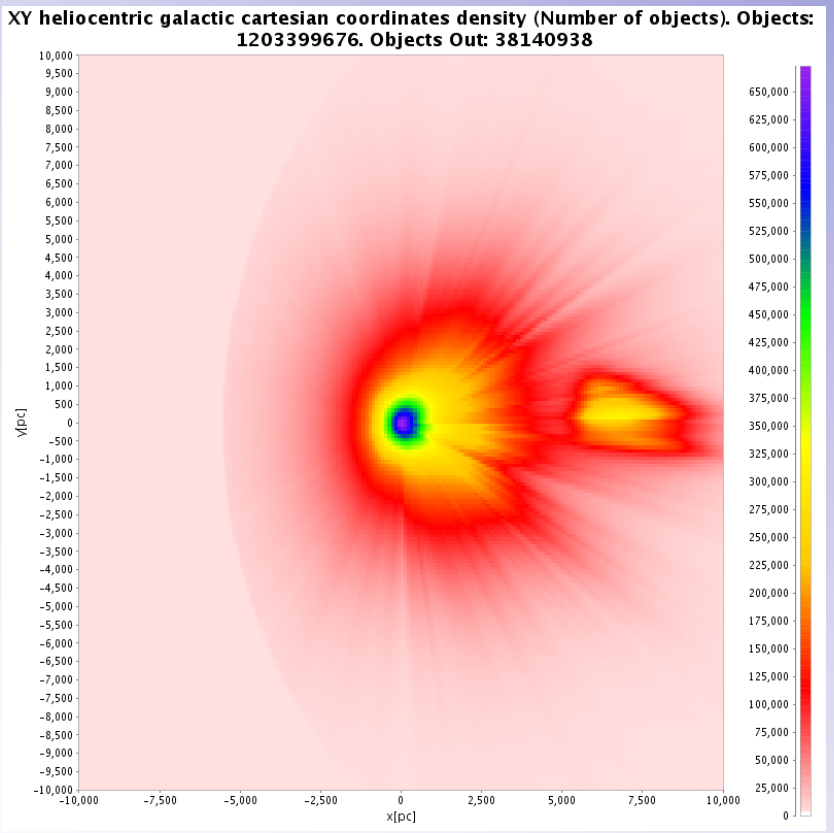
- Stars in the Milky Way, including multiple systems and variables
    - Based on Besançon Galaxy Model (Robin et al. 2003) + 3D extinction model (Drimmel 2002)
    - several populations: thin/thick disk, spheroid and bulge
- LMC/SMC
- Extragalactic objects (QSO, unresolved galaxies)
- Solar System Objects
- Exoplanets
- …

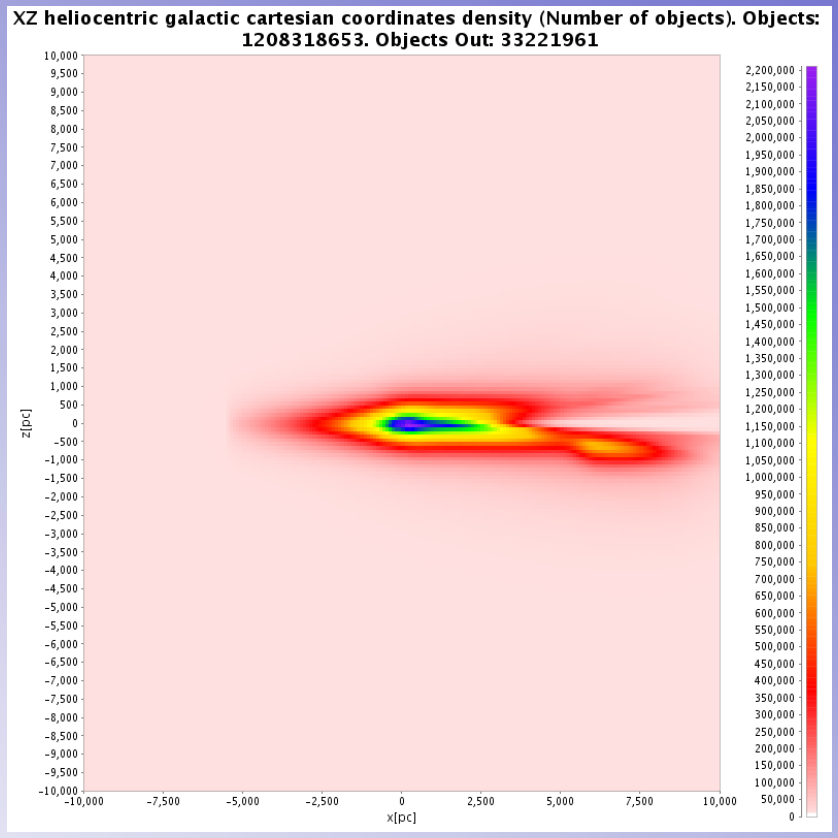
The Universe Model



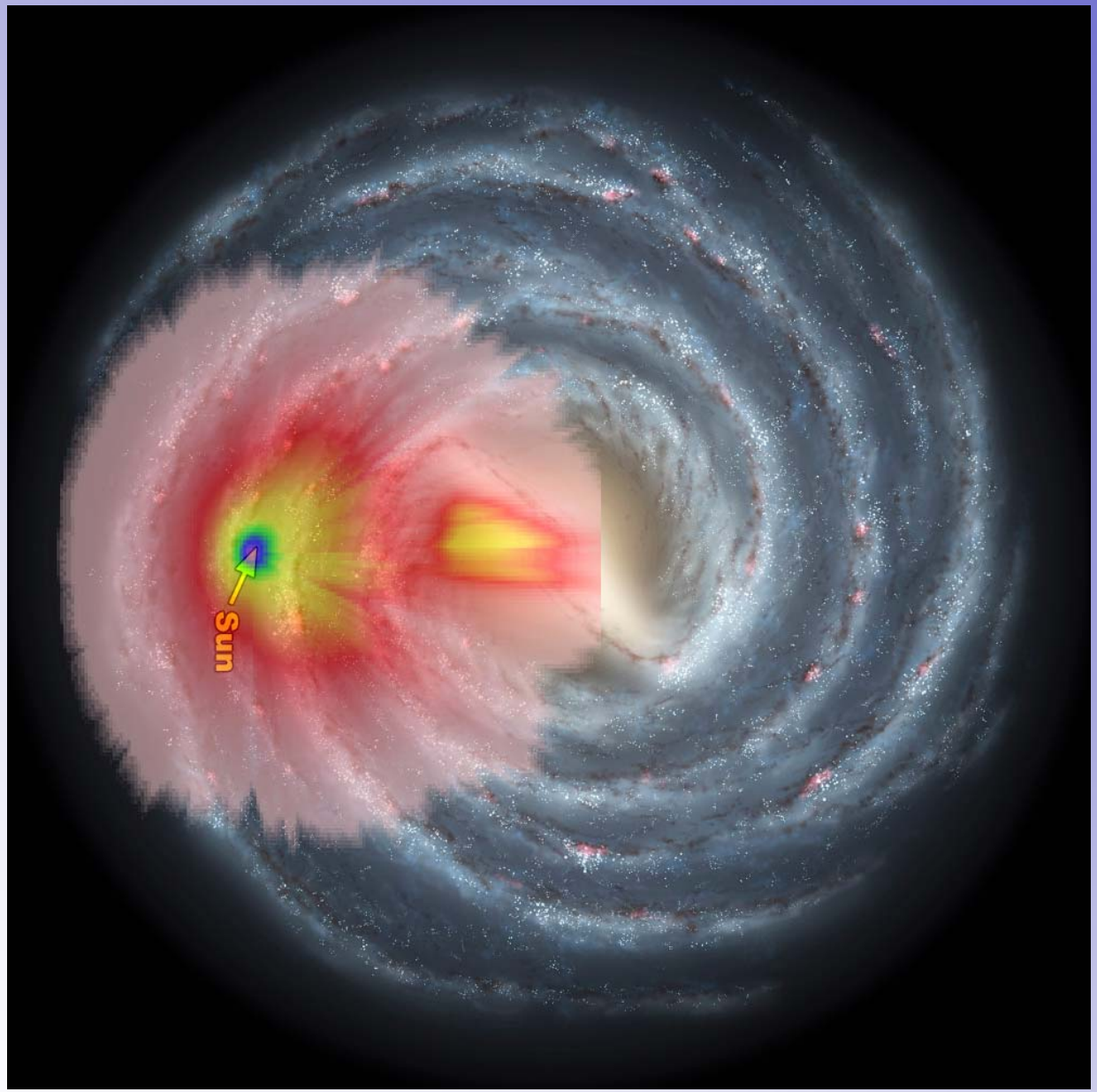
The Universe Model: Milky Way

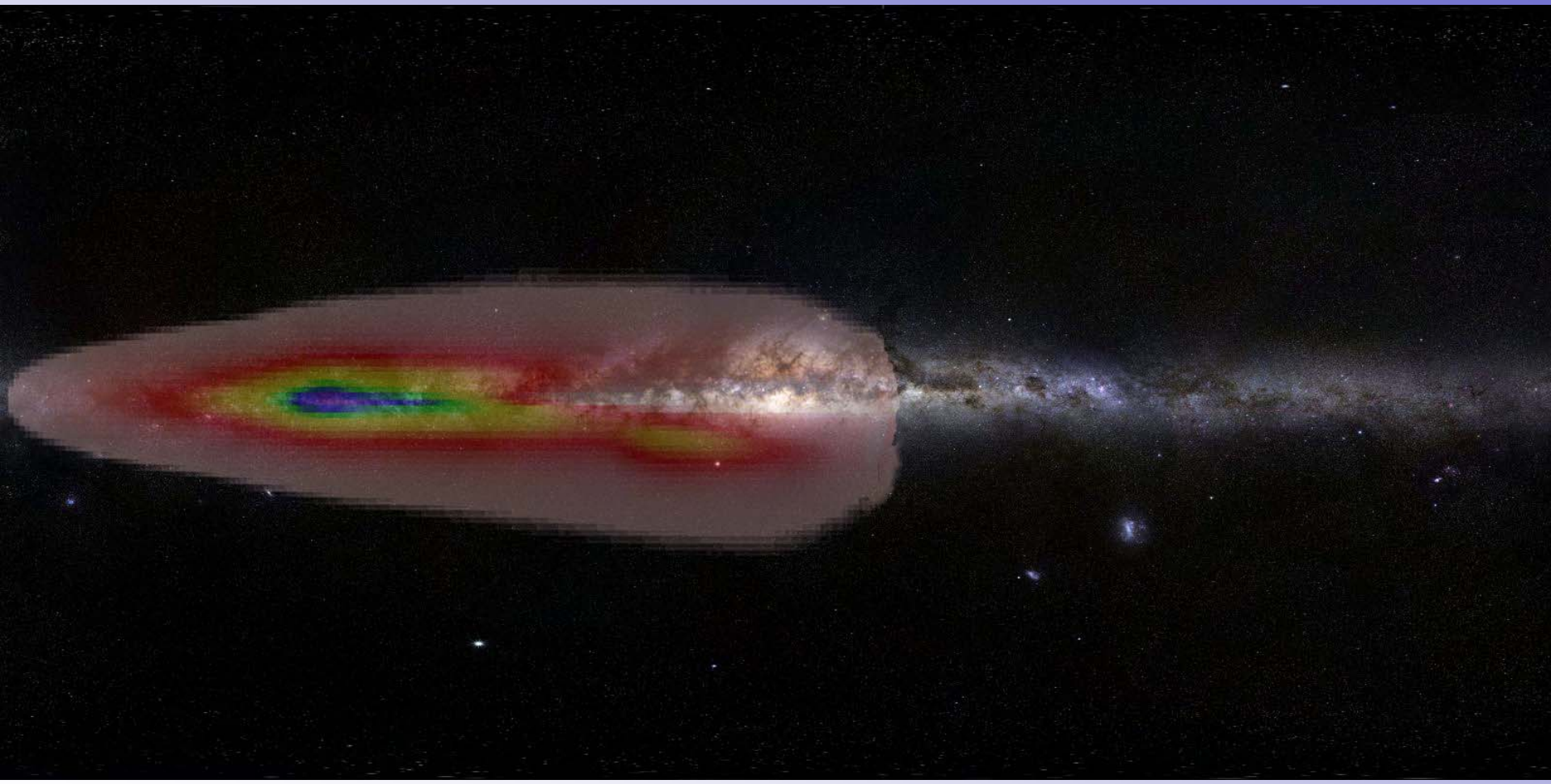
Beçanson Galaxy Model (Robin et al.)





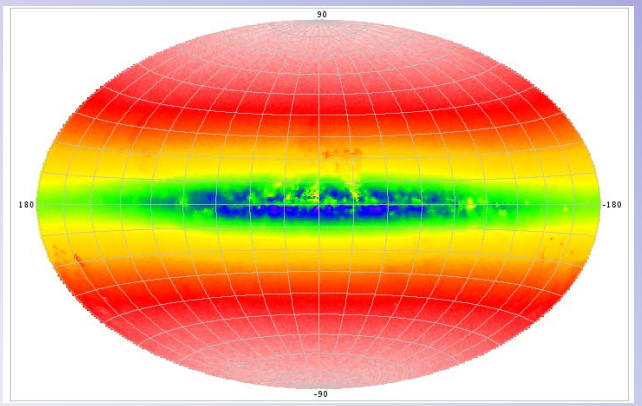
Simulation of the galactic distribution of the contents of the Gaia Catalogue G<20 (DPAC-CU2)


Sun

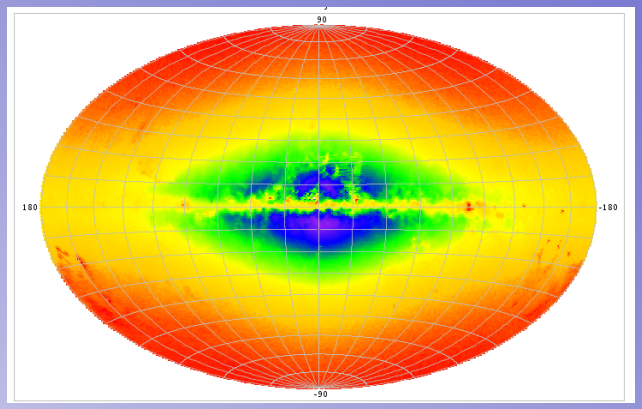


The Universe Model: Milky Way

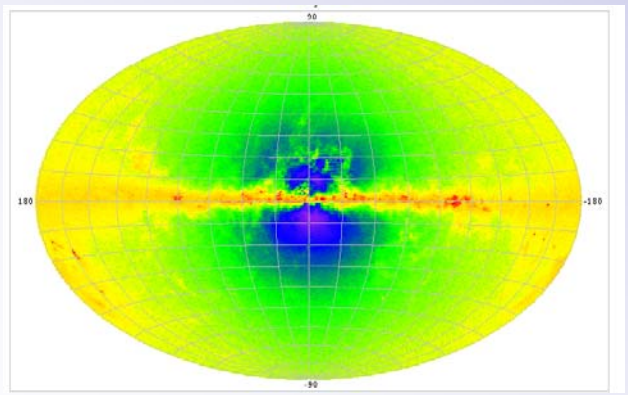
Sky density distribution: Milky Way stars + LMC + SMC (G<20)



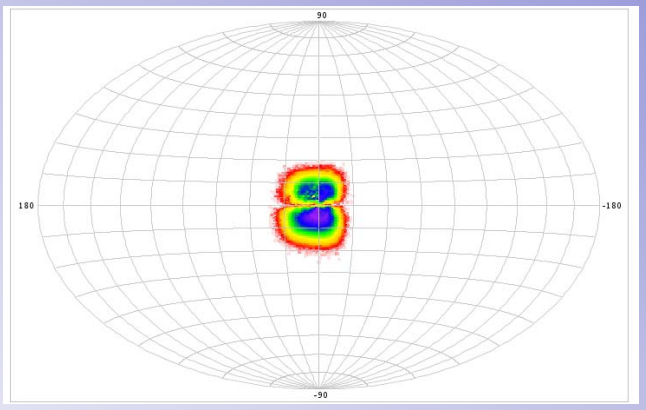
Thin disk



Thick disk



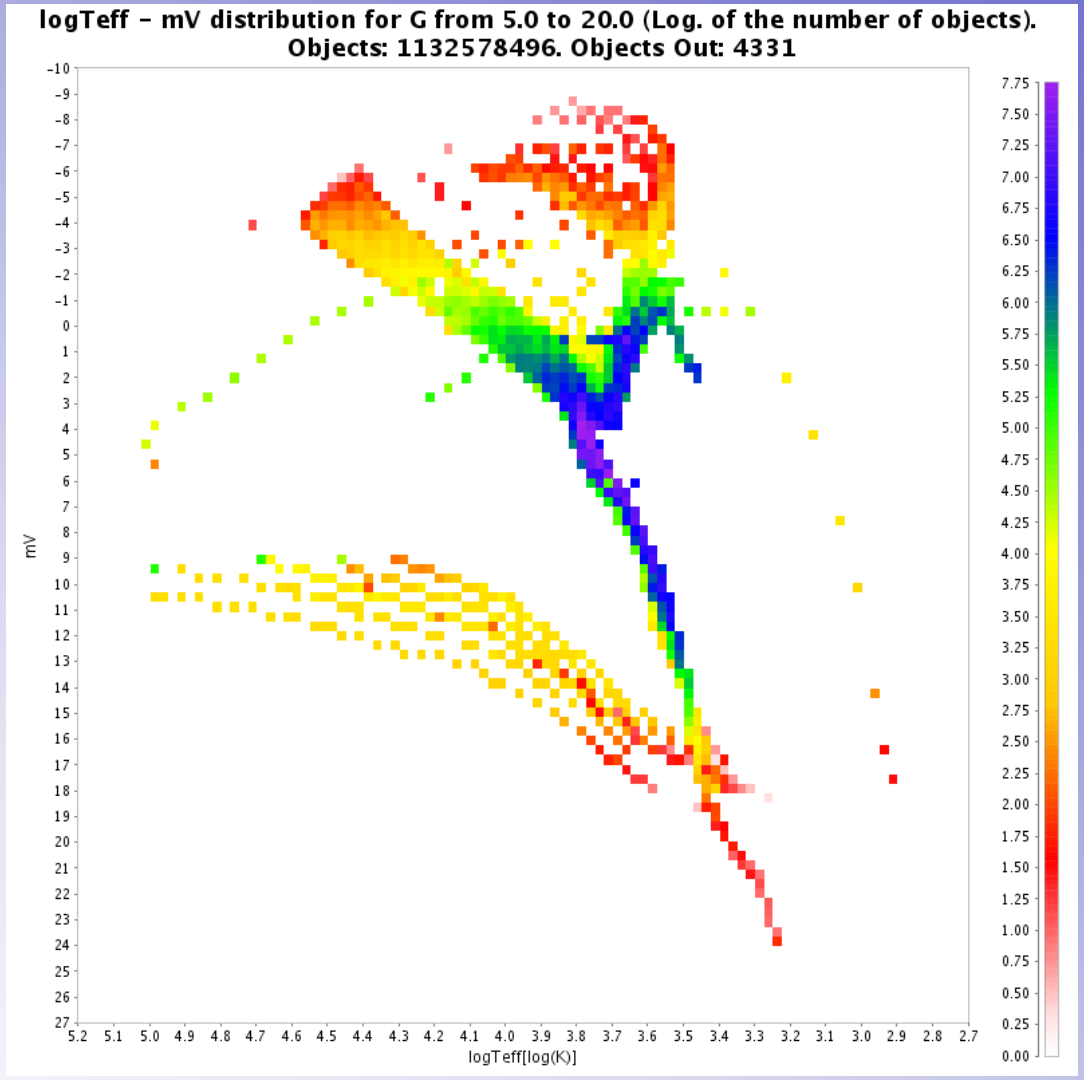
Halo



Bulge

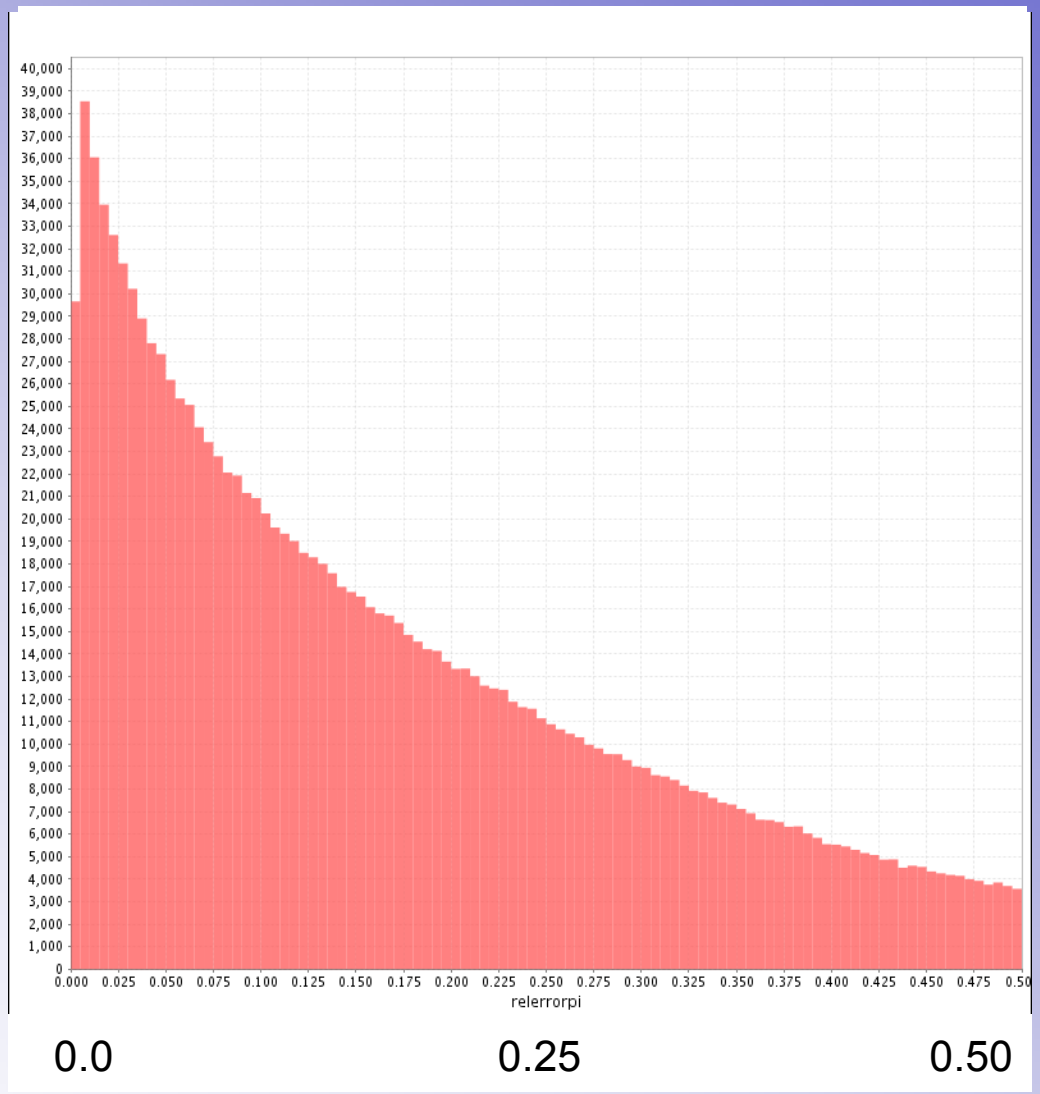
The Universe Model: Milky Way

HR diagram (G<20)



Astrometry: Error distribution

- σ_π/π distribution
- All the stars



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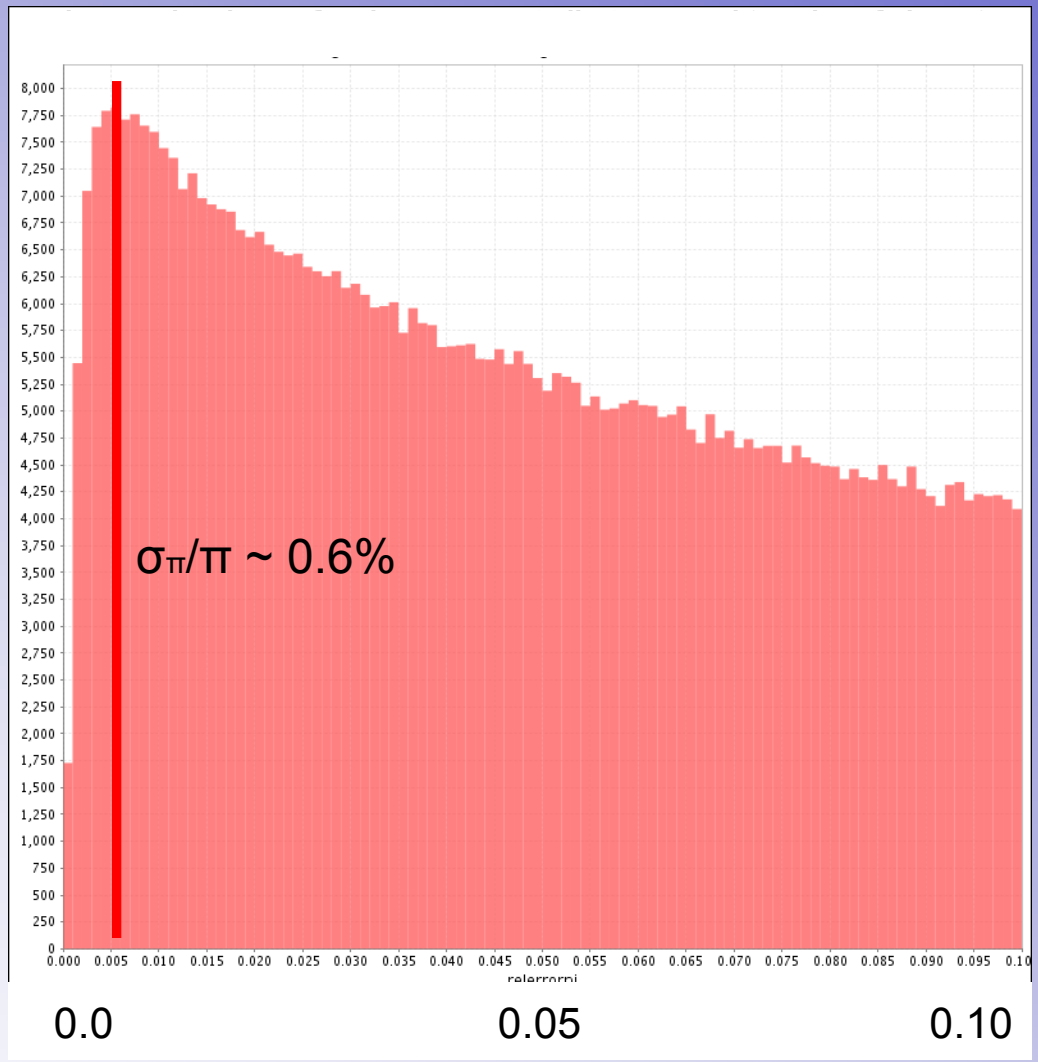
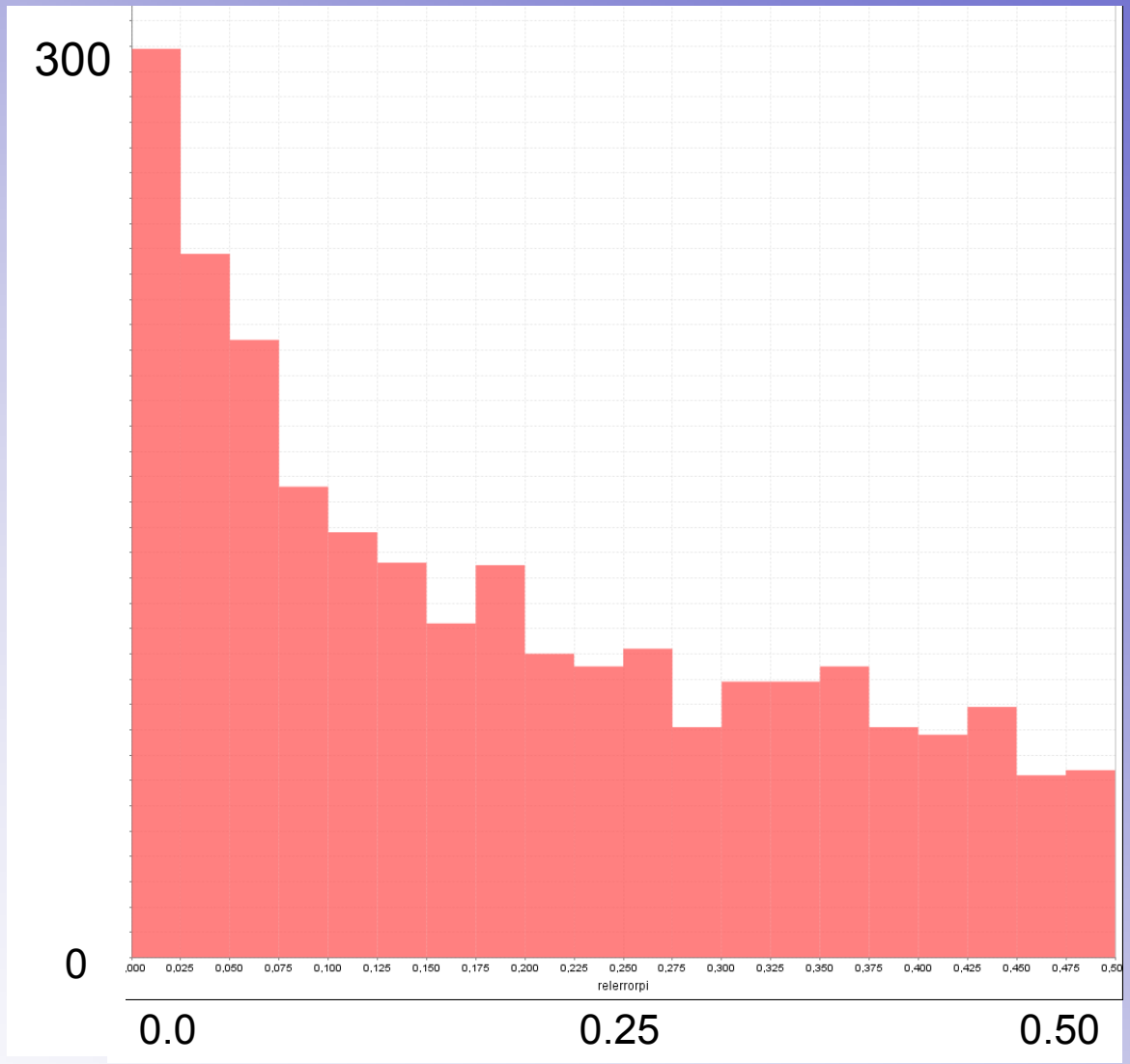


Astrometry: Error distribution

- σ_π/π distribution
- Cepheids



Astrometry: Error distribution

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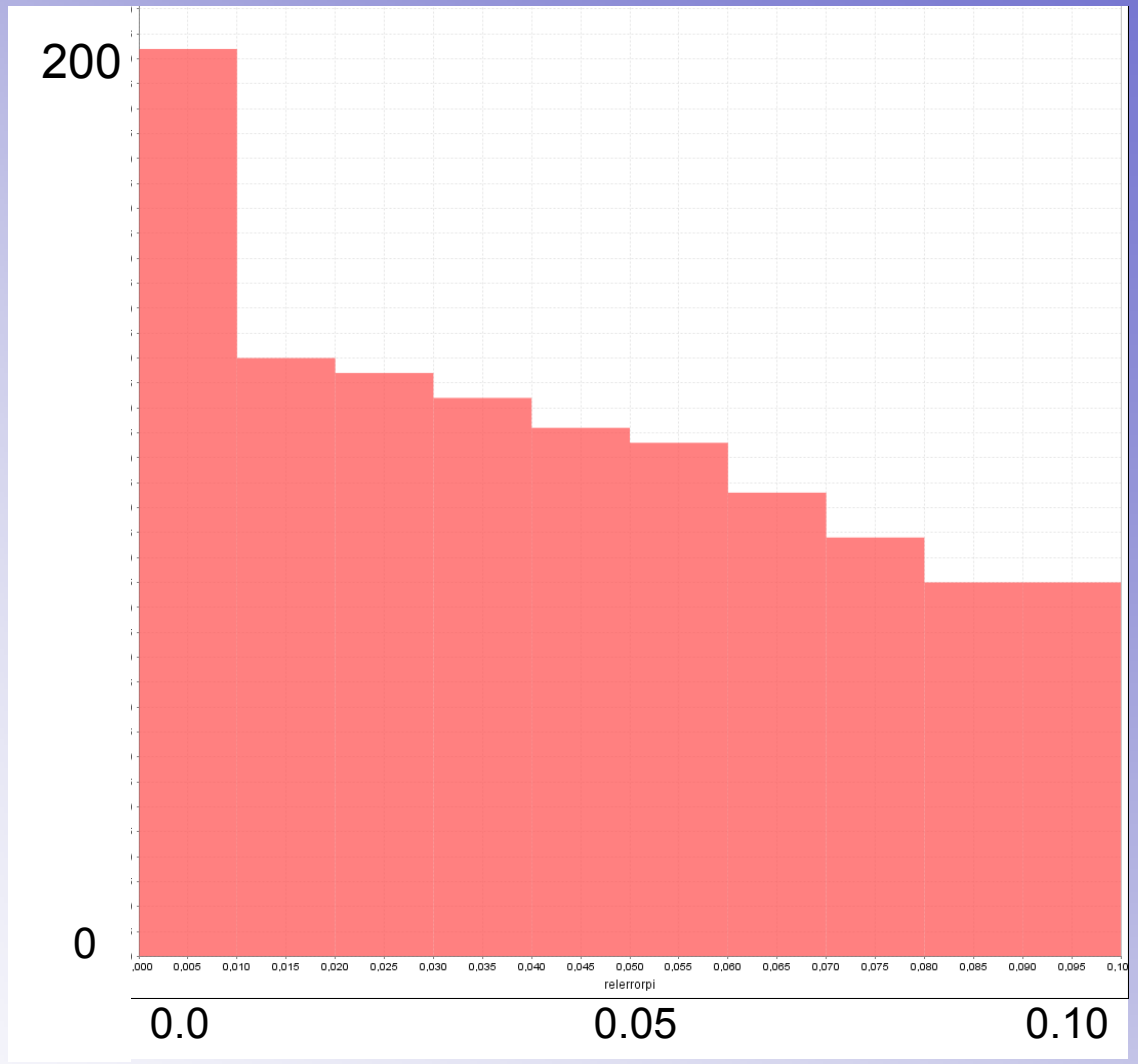


Magellanic Clouds

-Based on catalogues of stars known to be part of the LMC with their characteristics obtained from surveys.:

~ 7 500 000 for LMC
~ 1 500 000 for SMC

- Mostly faint objects, G ~ 19-20 and thus $\sigma\pi$ ~ 300 μas (worst case)

- Mean distance fixed

~ 48 000 pc for LMC $\rightarrow$ π = 20.8 μas
~ 61 000 pc for SMC $\rightarrow$ π = 16.4 μas

-Assuming a depth of 3000 pc (still a large uncertainty on the depths of LMC and SMC)

d = 45 000 – 51 000 pc for LMC $\rightarrow$ π = 22.2 – 19.6 μas
d = 58 000 – 64 000 pc for SMC $\rightarrow$ π = 17.2 – 15.6 μas

Magellanic Clouds

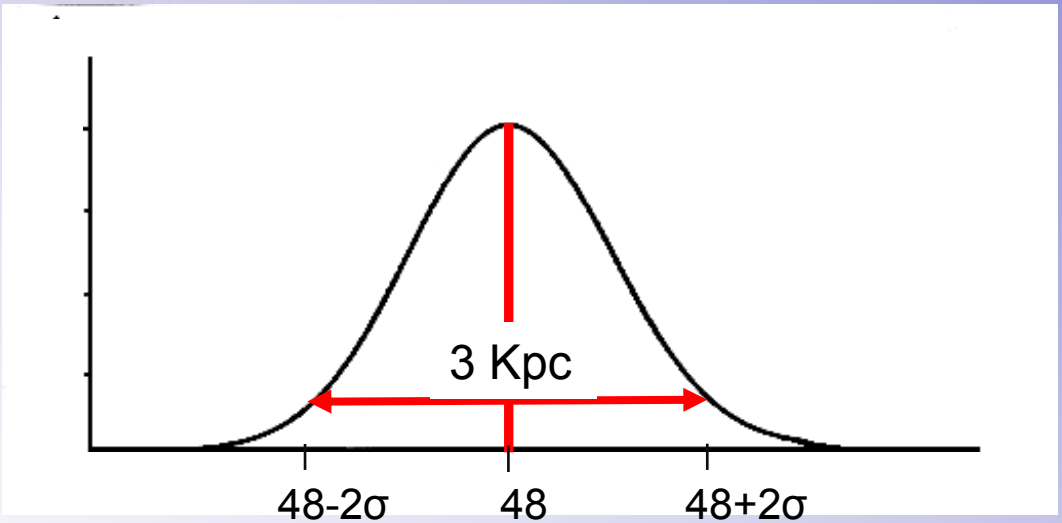
Error in mean parallax
~ 0.12 μas for LMC
~ 0.24 μas for SMC

- at the Gaia precision level 3D structure of the Magellanic Clouds is relevant
(the term “distance to the LMC/SMC” becomes imprecise)

- Simulated using a Gaussian distribution around the mean distance.

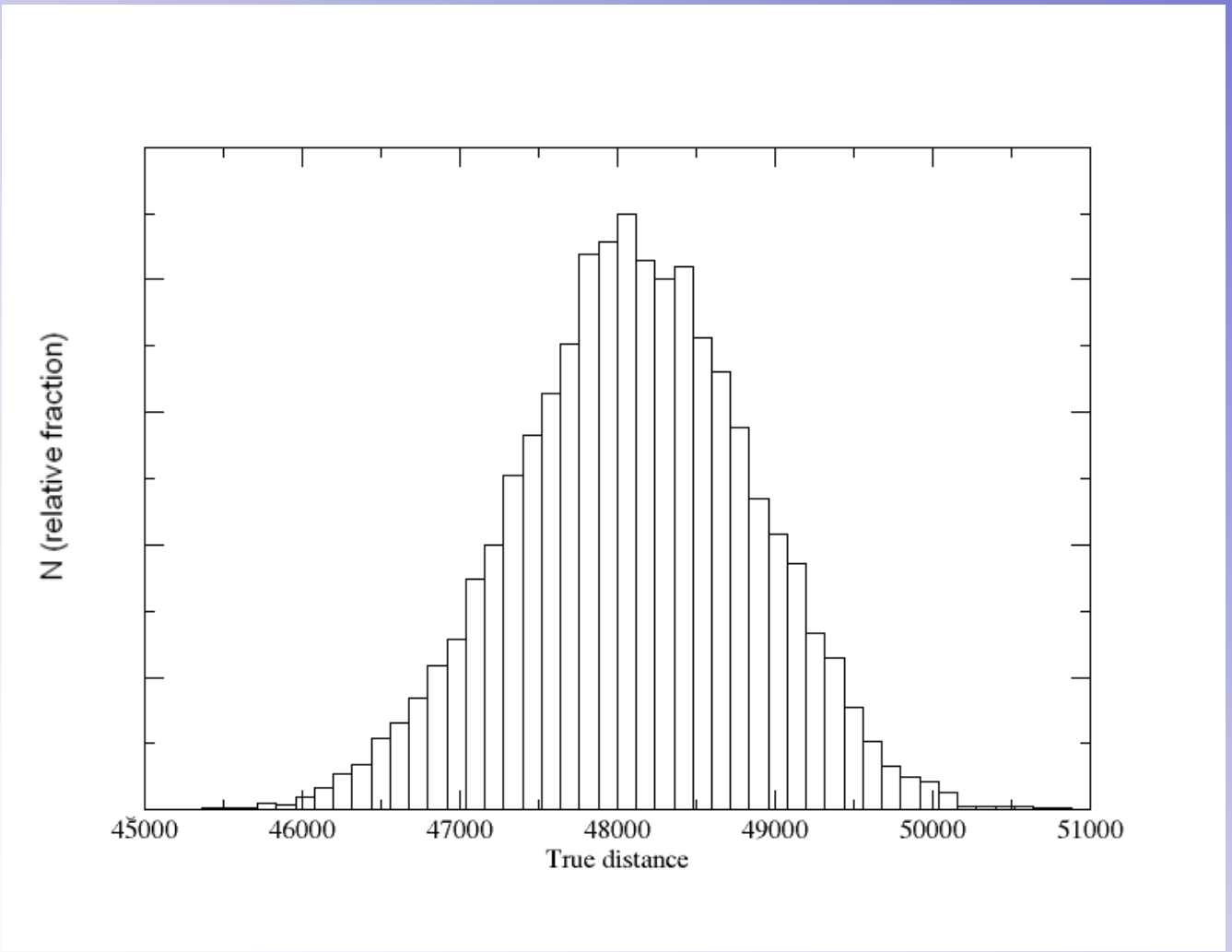
LMC:

σ_{dist} = 0.75 Kpc



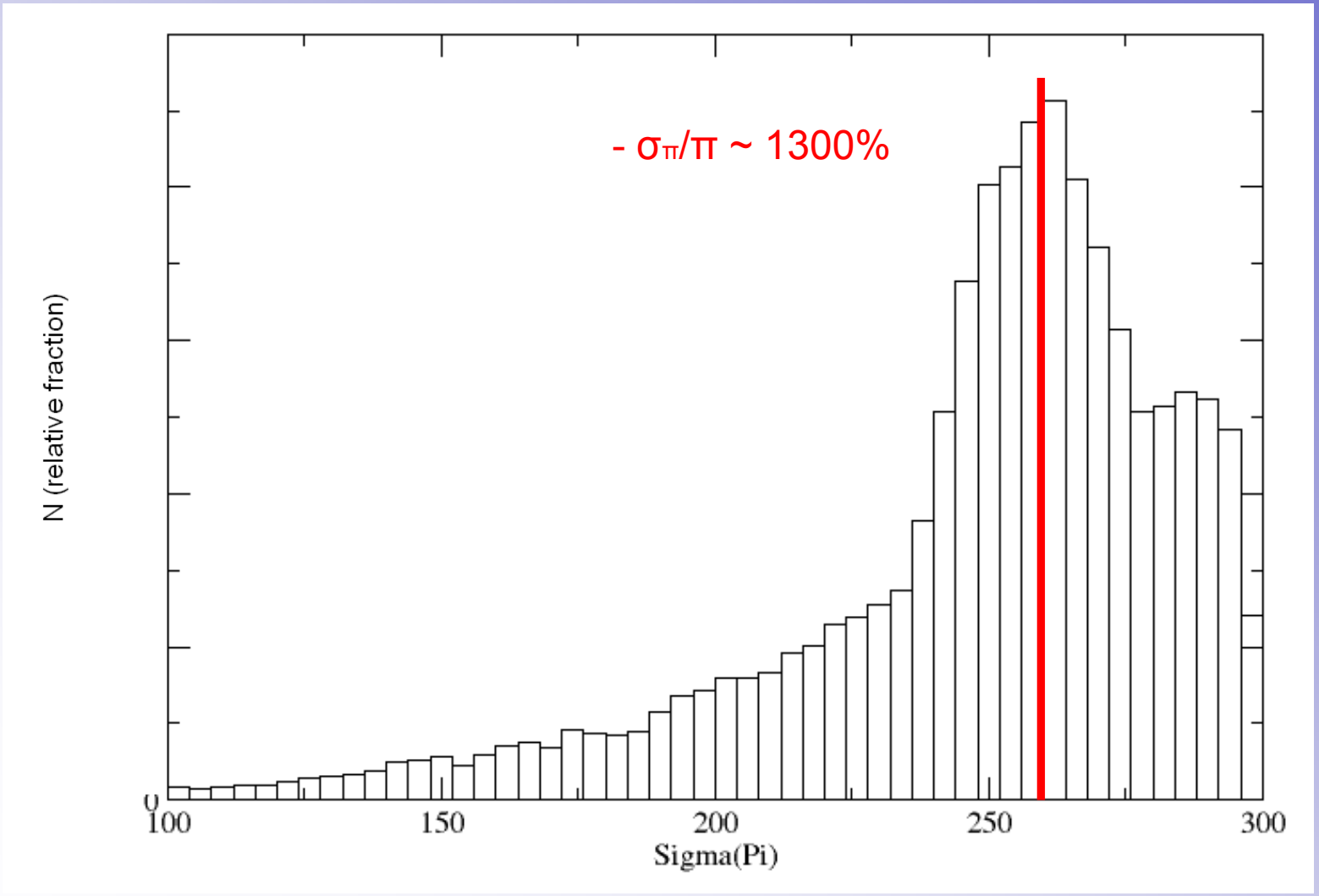
Large Magellanic Cloud

Simulated distances distribution



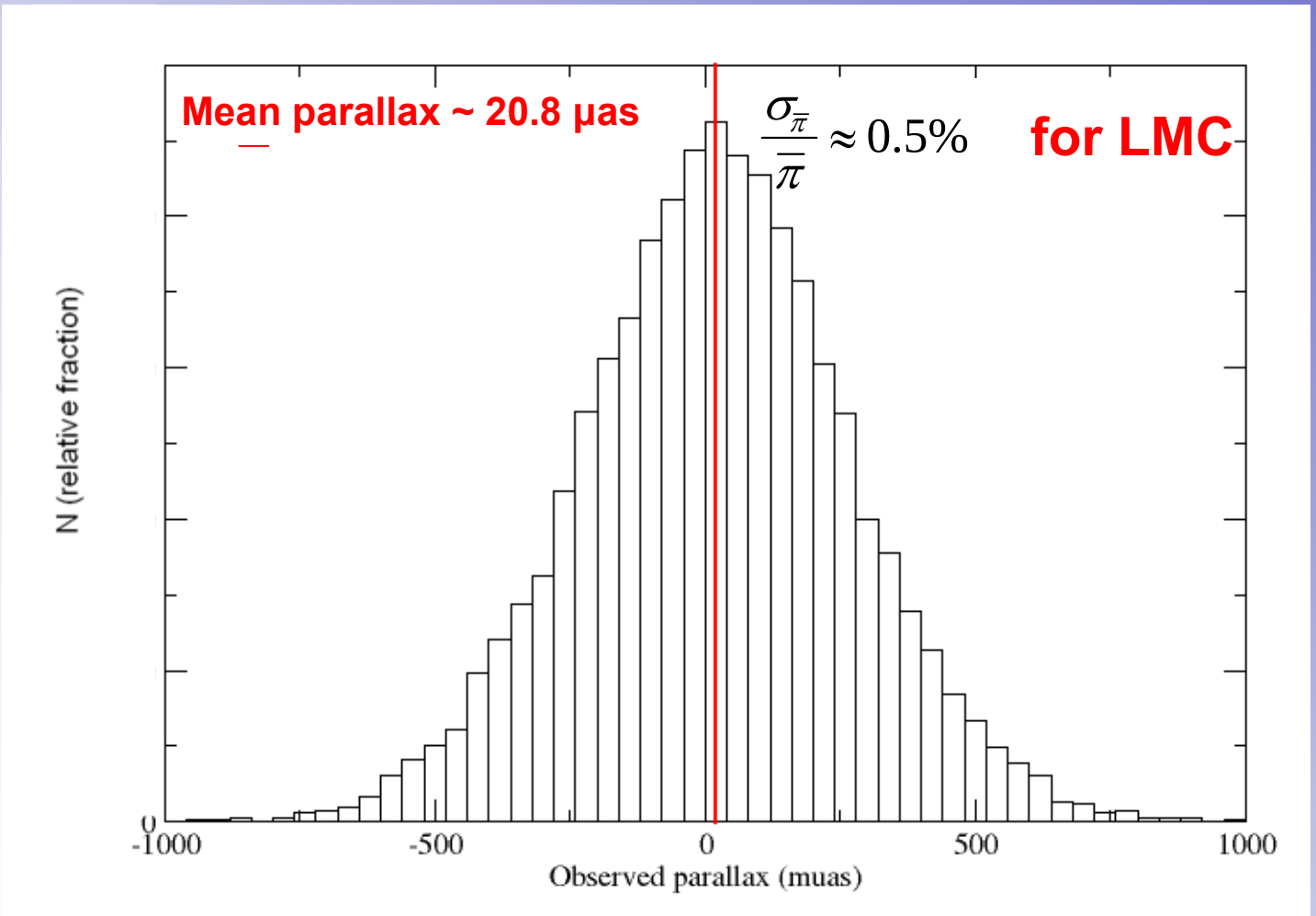
Large Magellanic Cloud

σ_π distribution in μas (GAIA simulated final data)



Large Magellanic Cloud

Observed parallax distribution (GAIA simulated



Summary

- There is 3 data simulators available: Gass (telemetry); Gibis (images) and Gog (catalogue data)

- They use models of the instrument and astronomical obejcts.

- Gog can be used to study the accuracy of the final photometry and distance determination for any subset of stars (stellar populations, LMC, SMC, individual stars, L-P Cepheids relation,…)

- Work is on going to improve the error models.

- We plan to generate a full statistical analysis of the expected contents of the Gaia catalogue based on Gog simulations.

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