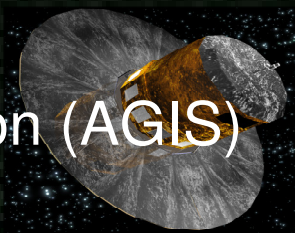


# Implementation of the global parameters determination in Gaia's Astrometric Solution (AGIS)

F. Raison\*, A. Olias\*, D. Hobbs\*\*, L. Lindegren\*\*

\* European Space Astronomy Centre of ESA, Madrid, Spain,  
 \*\* Lund Observatory, Lund, Sweden.



## Abstract

Gaia is ESA's space astrometry mission with a foreseen launch date in early 2012. Its main objective is to perform a stellar census of the 1000 Million brightest objects in our galaxy (completeness to V=20 mag) from which an astrometric catalog of micro-arcsec level accuracy will be constructed. A key element in this endeavor is the Astrometric Global Iterative Solution (AGIS). A core part of AGIS is to determine the accurate spacecraft attitude, geometric instrument calibration and astrometric model parameters for a well-behaved subset of all the objects (the "primary stars"). In addition, a small number of global parameters will be estimated, one of these being PPN  $\gamma$ . We present here the implementation of the algorithms dedicated to the determination of the global parameters.

## A. Motivation

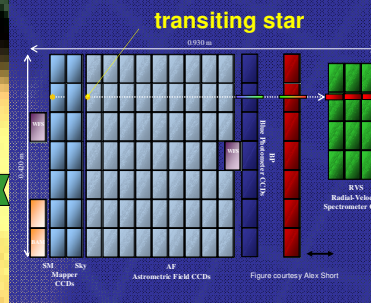
- The global parameters estimation provide a number of stringent tests of general relativity.
- Gaia is expected to constrain 2 parameters of the PPN formalism:
  - PPN  $\gamma$ , measuring the curvature of space-time through gravitational light deflection.
  - PPN  $\beta$ , measuring the degree of nonlinearity in the superposition law of gravity.
- Based on simulations (AGISLab), AGIS could provide a value of PPN  $\gamma$  about  $10^{-6}$ , which is significantly better than today's best estimate from the Cassini mission ( $10^{-5}$ ).

## C. AGIS

- AGIS is the mathematical and numerical scheme that will generate the core astrometric solution, i.e. the standard astrometric parameters (position, parallax, proper motion, radial velocity) for all observed celestial objects brighter than G=20 mag with targeted accuracies (e.g. <10  $\mu$ s [G<10 mag], <25  $\mu$ s [G=15 mag], <300  $\mu$ s [G=20 mag]).
- The best global match between all measurement data and an observational model involving the unknown source, attitude, calibration, and global parameters is sought in a least-square sense using normal equations and a block-iterative solution scheme.
- A Global Update block is used for global parameters determination.

## B. Gaia measurements

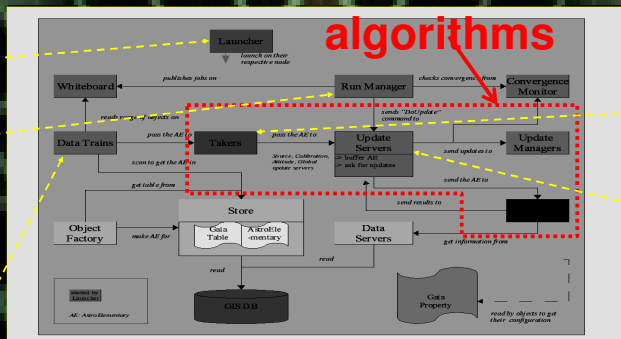
- Gaia is a scanning satellite, hence stars transit through the focal plane continuously in the along-scan direction. CCDs are operated in Time-Delayed Integration (TDI) mode synchronized with the star motion on the focal plane.
- Due to the large amount of CCDs and the limited downlink bandwidth, the amount of data to be gathered has been reduced by defining windows around the selected objects.



- Some 700 measurements per object are expected over the 5 year mission ( $10^{12}$  observations)
- The "Time of observation" for image centre relative to CCD is determined to ~200 mas precision (magnitude 15). They are used as input in AGIS.

## D. Implementation

- 1 Launcher:**
  - runs on every node of the cluster.
  - starts the appropriate processes.
- 2 Run Manager:**
  - controls the overall AGIS processing.
  - publishes jobs on the Whiteboard.
  - handles multiple iterations.
  - checks for convergence of the solution by consulting the Convergence monitor.
- 3 Data trains:**
  - pick jobs from the Whiteboard.
  - receive objects from the DB (AstroElementaries with "times of observation").
  - pass the objects to the attached algorithms.



- 4 Algorithms:**
    - Source Update, Attitude Update, Calibration Update, Global Update (optional).
    - Client/Server scheme.
  - 5 Taker:**
    - is a (Global)Collector (client) attached to data train.
    - sends AstroElementaries to the server.
  - 6 Update Server:**
    - buffers the list of AstroElementaries received from Collector.
    - Processes them accumulating the update information.
- (Global)UpdateServer:
- pass the AE to (Global)UpdateWorker (GlobalGIS).
  - one (Global)UpdateServer object is a master and the others are slaves.
  - Master will collect all the intermediate results from the slaves.
  - Master will ask its (Global)UpdateWorker to perform the final calculation.

This architecture was designed to maximize the degree of parallelism in the processing.

## E. Algorithms for Global Update block

Assuming a centered Gaussian observation noise of standard deviation  $\sigma_L$  the astrometric problem is equivalent to a weighted least-square minimization of

$$\min_{\mathbf{x}} J(\mathbf{x}) = \sum_L \left( \frac{f_L(\mathbf{x}) - f_L^{\text{obs}}}{\sigma_L} \right)^2 \frac{W_L}{\sigma_L^2 + \epsilon^2} = \sum_L R_L(\mathbf{x})^2 W_L$$

sum over observations      statistical weight

Observed-Calculated (Residual)

- This scheme performs a special treatment of outliers (involving the down-weighting function  $w_L$  and the fraction  $\epsilon$  of data having a larger standard deviation).
- The solution vector  $\mathbf{x} = (g_1, g_2, \dots, g_n)$  gives the optimal agreement between the observational model  $f$  and the actual observations
- What is really solved in practice is a system of normal equations system for the updates  $\Delta \mathbf{x}$  to the parameters  $\mathbf{x}$ :

$$\sum_L \frac{\partial R_L}{\partial \mathbf{x}} \frac{\partial R_L}{\partial \mathbf{x}^T} W_L \Delta \mathbf{x} = - \sum_L \frac{\partial R_L}{\partial \mathbf{x}} R_L W_L \Leftrightarrow \mathbf{N} \cdot \Delta \mathbf{x} = \mathbf{b}$$

$\mathbf{N}$  is a symmetric  $n \times n$  matrix,  $\mathbf{b}$  is an array of length  $n =$  number of parameters

In the case of PPN  $\gamma$ , the partial derivatives

$$\frac{\partial R_L}{\partial \mathbf{x}} \quad \text{i.e.} \quad \frac{\partial R_L}{\partial \gamma}$$

are obtained through a general relativity model (Gaia Relativistic Model) that provides a single consistent relativistic framework for the whole Gaia processing.

## F. Preliminary Results

- So far, the  $\sim 10^{-5}$  level of accuracy was reached with:
  - PPN  $\gamma$  as first global parameter.
  - <parallax> as a second parameter to reduce the impact of the statistical correlation between PPN  $\gamma$  and the parallax.
  - 167 x 10<sup>6</sup> AstroElementaries (2 x 10<sup>6</sup> simulated sources).
  - Starting value: PPN  $\gamma = 1.1$
  - Simulated true value: PPN  $\gamma = 1.0$
- Improved implementation and a larger set of simulated observations should allow to reach the expected  $10^{-6}$  level of accuracy.