# Luminosity calibration in the LMC with Gaia

## Mean parameter determination with many Gaia parallaxes

M. Palmer[1], X. Luri[1], F. Arenou[2], E. Masana[1], G. Clementini[3]

[1]Universitat de Barcelona (ICC-UB), [2]Observatoire de Paris - Meudon, [3]INAF-Osservatorio Astronomico di Bologna

[1]mpalmer@am.ub.es

## Abstract

Determining the mean distance to compact objects such as the Magallanic clouds and open or globular clusters is a vital part of Gaia's role in the field of luminosity calibration. For the LMC, the distances involved mean that most of Gaia's parallax measurements will have a formal error several times larger than the value being measured. However, combining data from the more than seven million stars which are expected to be observed can lead to an unbiased estimate of the mean distance to the LMC though the use of statistical methods. Due to the possibility of error correlations when dealing with mean parameters for many stars with small angular separation, the extent of error correlations in Gaia is discussed below.

## Simulation

Gaia final catalogue data for LMC stars has been simulated using the Gaia Object Generator (A&A 566, A119 (2014)), including the effect of observational errors. The simulated catalogue contains 7.5 million stars, and is based on a real photometric catalogue down to Gaia's limiting magnitude. The distribution of the relative error in parallax is shown below. There are 700 stars with a relative parallax error better than 25%, and 10000 stars better than 50%.

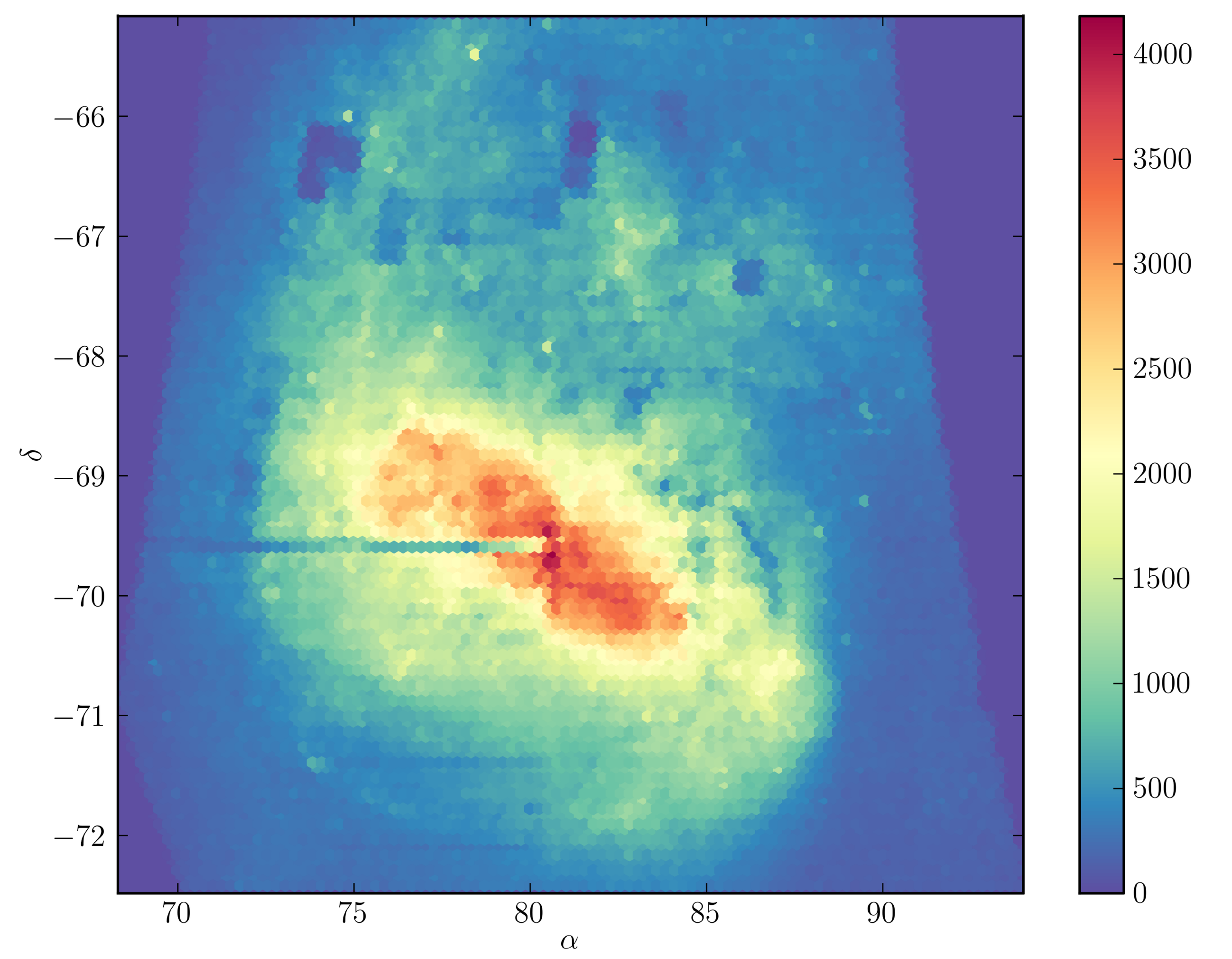


Figure: Sky density map for the simulated Gaia data for the 7.5 million stars expected to be observed in the LMC.

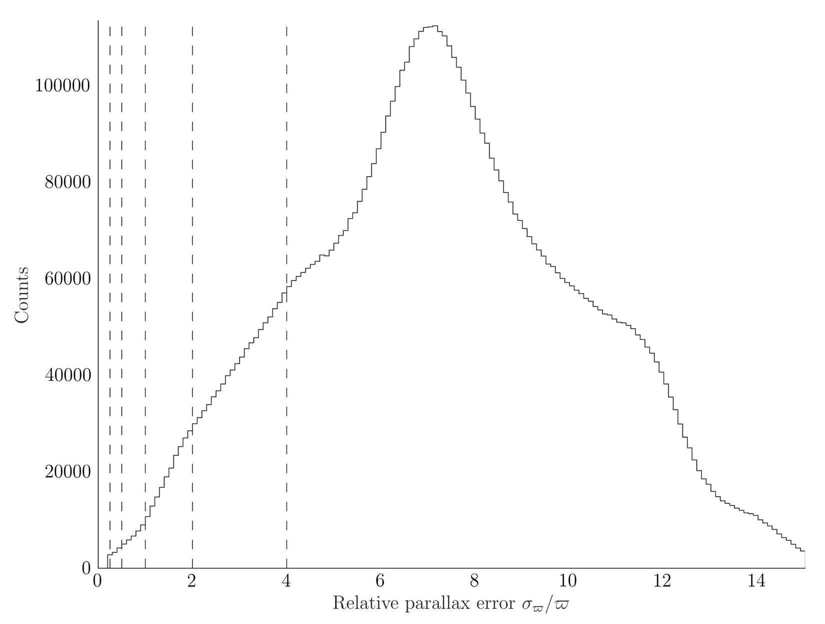


Figure (above): Histogram of relative parallax error for the simulated LMC Gaia data

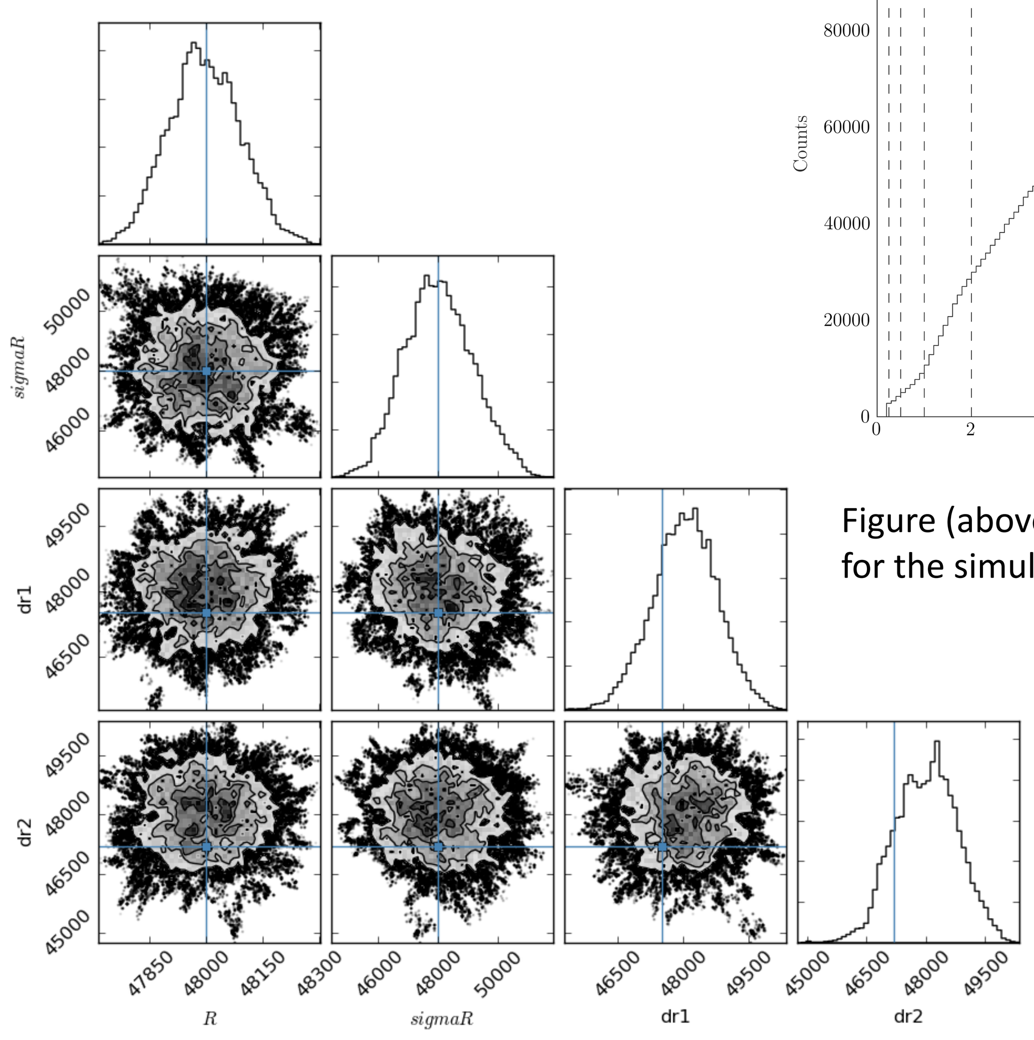


Figure: Triangle plot of the results of the MCMC sampling of the likelihood function. Histograms are the posterior PDF of: the mean LMC distance (R), the depth of the LMC ($\sigma_R$, ×64 to give same magnitude to each parameter in the minimisation), and the posterior distance to the first two stars in the catalogue (only two are shown for illustration). Also shown is the correlation between each pair of parameters. The blue lines represent the true value, included in the initial simulation.

## Method

To find the mean distance to the LMC, we use a Bayesian method which fits the mean distance and depth of the LMC using all of the available stars. The method is formulated so that it is independent of any external assumptions (reddening etc.), and relies on trigonometric parallax alone. The method relies on adaptive MCMC sampling to construct the posterior PDF for the mean distance, the depth, and the posteriori distance to each individual star.

$$ln P(D|\theta) = ln\left(\frac{1}{2\pi\sigma_d\epsilon}\right) - 0.5\left(\left(\frac{d_r - d_{mean}}{\sigma_d}\right)^2 + \left(\frac{\varpi - 1/d_r}{\epsilon}\right)^2\right)$$

The log-likelihood function as defined above has several advantages: observational errors are explicitly taken into account; the explicit inclusion of a distance distribution and non-truncation of the observed parallax avoids the Lutz-Kelker bias; the observed parallax is used directly so there are no non-linear transformations in the equations which can bias the result. The posterior distance to each star can be marginalised out of the likelihood function to save computing time. The use of this method on the simulated LMC data results in a estimate of the mean distance of better than 0.5% (without the inclusion of error correlation effects as discussed below..

# Correlated errors in the Gaia catalogue

## Background

Stars which are located close to each other on the sky will have a common component in their error. This can be due to, for example, inaccuracy in the attitude calibration or basic-angle calibration, which will affect all stars within the same field of view equally. The presence of this common error between stars in compact regions of the sky can mean that the precision on the mean parallax will not scale with 1/√N. This provides a lower limit in the possible precision when averaging the properties of many stars, if they are within a small region of the sky.

## Method

To test this effect we use simulated Gaia transit data (Gaia Object Generator, A&A 566, A119 (2014)) for an open cluster, and include a component of the observational error which is common to all stars within a transit. This error is made up of basic-angle calibration and attitude calibration errors, which are common to all stars within a field of view, and geometric calibration errors, which are common to stars within each CCD. The expected size of each error is obtained from the Gaia Parameter Database.

We then recreate the Gaia AGIS solution from the simulated transit data using least squares fitting for the five astrometric parameters.

## Results

We calculate the mean parallax of the stars in the simulated open cluster, for two cases: one including a common component of the random error, and one with a completely random error of the same magnitude. We find that the inclusion of correlated errors results in a error on the mean parallax which can not be removed though the inclusion of more stars. The error on the mean due to the correlated errors is a random value with mean zero and standard deviation of 0.7 µas, confirming the expectation that correlation effects in Gaia will be less than 1 µas. This effect is only important for observations of small regions (around 1 square degree or less), and will average out over larger areas. This is also true for the case of the LMC, which is extended over several degrees, and it is expected that the size of the effect will be reduced much below 0.7 µas.

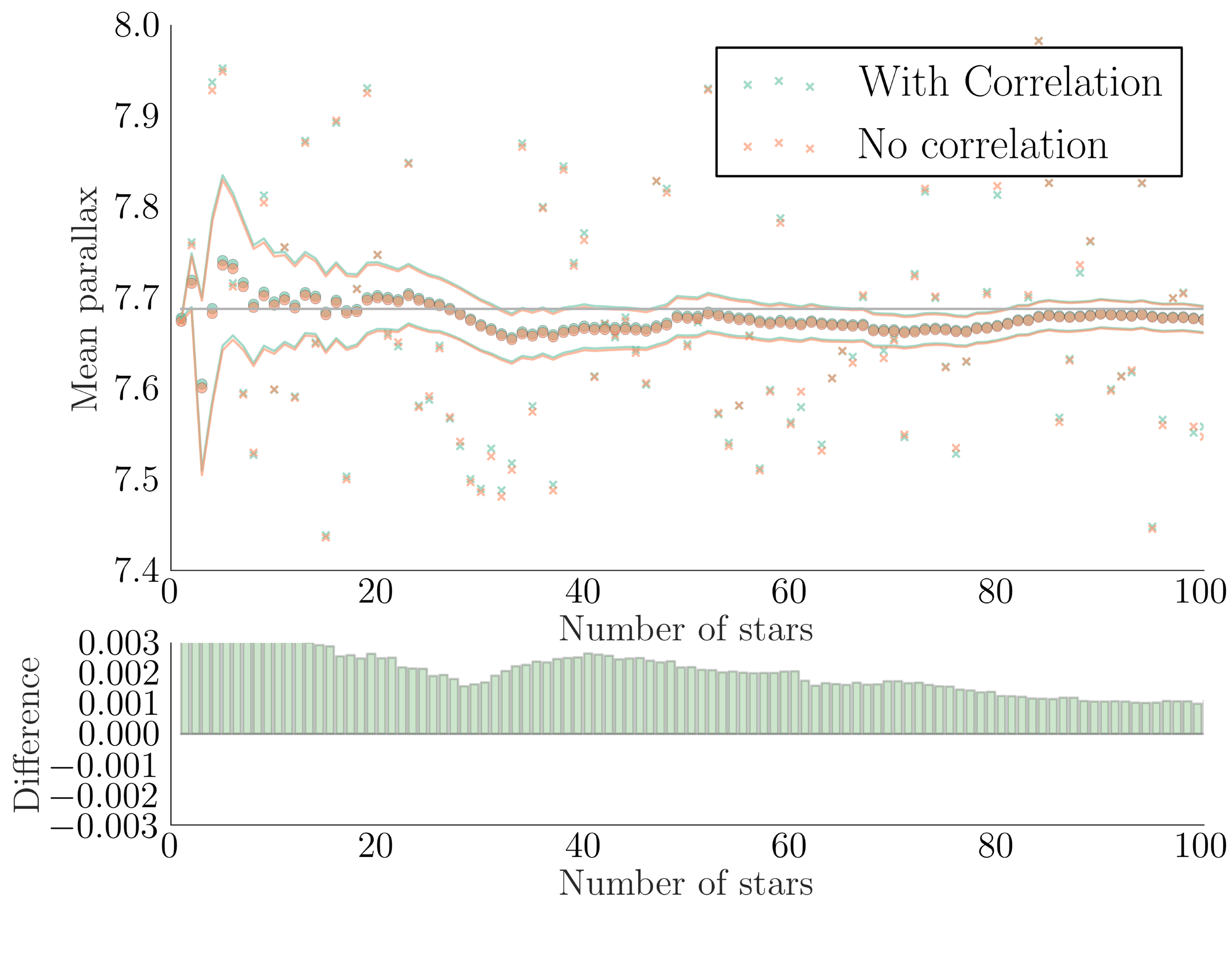


Figure: Observed parallax (crosses) in mas, and mean parallax (circles) for a simulated open cluser, increasing the number of stars from left to right. By including more stars in the calculation of the mean parallax, the precision is increased, but there is an error on the mean parallax of the order of 1 µas which can not be removed even through the inclusion of thousands of stars.