Improving distances to nearby bright stars:
Combining astrometric data from Hipparcos, Nano-JASMINE and Gaia

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Abstract. Starting in 2013 Gaia will deliver highly accurate astrometry data which eventually
will supersede most other stellar catalogues in accuracy and completeness. It is however limited
to observations from magnitude 20 to 6 and will therefore not include the brightest stars. Nano-
JASMINE, an ultra-small Japanese astrometry satellite, will observe these bright stars, but with
much less accuracy. Hence the Hipparcos catalogue from 1997 will likely remain the main source
of accurate distances to bright nearby stars. We are investigating how this might be improved
by optimally combining data from all three missions in a joint astrometric solution. This would
take advantage of the unique features of each mission: the historic bright-star measurements
of Hipparcos, the updated bright-star observations of Nano-JASMINE, and the very accurate
reference frame of Gaia. The long temporal baseline between the missions provides additional
benefits for the determination of proper motions and binary detection, which indirectly improve
the parallax determination further. We present a quantitative analysis of the expected gains
based on simulated data for all three missions.

Keywords. astrometry, catalogue combination, Gaia, Hipparcos, Nano-JASMINE, bright star,
distance, parallax

1. Introduction

The distance to a star can most directly be deduced from its trigonometric parallax.
From the ground this was only done for a few thousand very close-by stars, but with the
was the first satellite to determine astrometric parameters (stellar positions, parallaxes
and proper motions) from space and gave the distances to about 21000 stars with an
uncertainty less than 10 per cent (ESA 1997). Now, 25 years later, Gaia will improve our
knowledge of stellar astrometry much further and provide millions of stellar parallaxes
with unprecedented accuracy. Gaia is an ESA cornerstone mission and will be launched
for its five year nominal mission at the end of 2013. It will continuously scan the sky in a
well-chosen pattern and observe up to a billion stars down to magnitude 20. However, due
to CCD saturation it will not observe stars brighter than about magnitude 6. Hence the
brightest \(\sim 5000\) stars are not observed by Gaia, and for these Hipparcos will continue
to be a main source of distance information.

In addition to these two astrometry missions there is a third upcoming mission, the
ultra-small Japanese satellite Nano-JASMINE. Just as Gaia this satellite is based on
CCD detections and its scanning principle and observing strategy are derived from the Gaia pendants, however this mission is meant to be a technology demonstrator for larger follow-ups and therefore significantly smaller and less accurate. It is scheduled for launch by the end of 2013 and expected to provide astrometry for about one million stars in the visual magnitude range from about 1 to 10 with an accuracy of about 3 mas for objects of magnitude 7.5. Gaia data will be reduced using the Astrometric Global Iterative Solution (AGIS), developed by ESA and Lund Observatory (Lindegren et al. 2012). Thanks to a collaboration between the Nano-JASMINE Science Team and parts of the AGIS team it is possible to use AGIS also for the core data reduction of Nano-JASMINE.

2. Catalogue combination by joint solution

While Nano-JASMINE’s uncertainties are not better than the uncertainties in the Hipparcos results, significant improvements for bright star astrometry can be made by combining the results of Hipparcos and Nano-JASMINE, thanks to the long time baseline between the missions. The combination is done by incorporating the Hipparcos information directly in the astrometric solution for the Nano-JASMINE data. This is done by using the Hipparcos data and the inverse of its covariances as starting values when accumulating the normal equations for the astrometric solution. In contrast to a posterior catalogue combination scheme this “joint solution” combines the data sets in a statistically optimal way (Michalik et al. 2012), taking into account the correlations between the different astrometric parameters.

In addition to the astrometric improvement coming from the combination described above further improvement can be gained by using (preliminary) results of Gaia during the Nano-JASMINE data processing: Gaia and Nano-JASMINE will both observe stars between magnitude 6 and 10. Since these stars are well determined by Gaia a joint solution can be used to determine the attitude and geometry deviations of Nano-JASMINE with better accuracy and therefore improve all Nano-JASMINE results. This includes calibrating the basic angle (the nominally fixed angle between the two fields of view of the satellite) which may be affected by thermal variations originating from the low earth

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**Figure 1.** The magnitude range plotted against mission time of the three astrometry missions Hipparcos (Hip), Nano-JASMINE (NJ), and Gaia.
orbit of the satellite. The basic angle stability is particularly critical to achieve absolute parallaxes, avoiding zero-point errors. Additionally the Nano-JASMINE results get aligned with the Gaia reference frame. Therefore the optimal results for bright stars are obtained by reducing the Nano-JASMINE data together with preliminary Gaia results and by combining the historical Hipparcos measurements during data analysis, see Fig. 1. We quantify the expected improvements in parallax and proper motion determination by simulating this scenario.

3. Simulations

Simulations are carried out using AGISLab, a software package developed at Lund Observatory to aid the development of algorithms for the Gaia data processing (Holl et al. 2012). It is used to simulate Nano-JASMINE observations and to process this data in the same manner as in the real mission, i.e., by using the AGIS algorithms. AGIS is an iterative scheme implementing a block-wise least-squares solution on very large data sets, as required to reduce data from large astrometry missions such as Gaia. Nano-JASMINE simulations are based on a realistic scanning law featuring a triangular spin axis precession motion, see Fig. 2. The observation accuracy model assumes a (somewhat optimistic) centroiding uncertainty of 1/300th of a pixel (\(\sim 7\) mas) for stars brighter than magnitude 7, with additional photon noise for fainter stars (\(\sim 30\) mas at magnitude 10).

The simulation dataset consists of two parts: first, the 5026 brightest Hipparcos stars (mag < 6) with astrometric parameters and uncertainties taken from the Hipparcos catalogue. They are used to evaluate the improvement in the uncertainties of the astrometric parameters of the bright stars. To this we add 330 000 randomly distributed stars of magnitude 10 that represent stars observed in the overlapping magnitude range that were not included in the Hipparcos catalogue. They represent the stars that were seen by Gaia as well as by Nano-JASMINE and for which the well-determined Gaia positions help to constrain the solution better.

First we simulate the errors in the Hipparcos Catalogue, providing a reference case for the bright stars and starting values for the solutions (Case B and C below) which incorporate the Hipparcos data. This was followed by three simulations.

Case A: We simulate Nano-JASMINE observations with the two datasets mentioned above and process the data without additional information, i.e. Nano-JASMINE only.
Table 1. Average uncertainties (RSE†) of 5026 Hipparcos stars between magnitude 1 and 6.

<table>
<thead>
<tr>
<th>Reference:</th>
<th>Parallax [µas]</th>
<th>Proper motion [µas yr⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hipparcos only (Hip)</td>
<td>740</td>
<td>673</td>
</tr>
<tr>
<td>Case A: Nano-JASMINE only (NJ)</td>
<td>1282</td>
<td>1844</td>
</tr>
<tr>
<td>Case B: Hip + NJ</td>
<td>595</td>
<td>50</td>
</tr>
<tr>
<td>Case C: Hip + NJ + Gaia</td>
<td>588</td>
<td>43</td>
</tr>
</tbody>
</table>

Case B: In a second run we incorporate the information from Hipparcos into the data processing of Nano-JASMINE, using the method described in Michalik et al. 2012.

Case C: In a third run we simulate the astrometric parameters with Gaia accuracy and fold expected Gaia covariances (de Bruijne 2012) into the Nano-JASMINE data processing. This is done by setting up the covariances of these sources with a sigma according to the expected Gaia uncertainties and using it in a joint solution scheme. Under the optimistic assumption of the parameters being uncorrelated the covariance is set up with zeros in all off-diagonal positions.

4. Results

We compare the three cases and our current knowledge of the bright star astrometric uncertainties, with the results given in Table 1. Our current knowledge is represented by the Hipparcos catalogue. The results of the Nano-JASMINE observations alone are less precise, but combined with Hipparcos they give a significant improvement over our current knowledge. Including provisional Gaia results brings a further improvement thanks to the improved calibration of the geometry and attitude of Nano-JASMINE. This improvement is fairly small, but it needs to be emphasized that there is a second and very important advantage of the Nano-JASMINE joint solution with Gaia results, i.e., the alignment of the Nano-JASMINE results with the Gaia reference frame.

5. Conclusions

Nano-JASMINE offers an opportunity to significantly improve the Hipparcos parallaxes and proper motions of the brightest 5000 stars which will not be observed by Gaia. In addition, a combined solution with Gaia data ensures that the results are on the same reference frame as the Gaia catalogue and that the parallaxes are absolute.

References

ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200

† “The Robust Scatter Estimate (RSE) is defined as 0.390152 times the difference between the 90th and 10th percentiles of the distribution of the variable. For a Gaussian distribution it equals the standard deviation. The RSE is used as a standardized, robust measure of dispersion within the Gaia core processing unit.” (Lindegren et al. 2012)