A&A 500, 505–506 (2009)
DOI: 10.1051/0004-6361/200912202

Astronomy & Astrophysics
Special issue

COMMENTARY ON: PERRYMAN M. A. C., LINDEGREN L., KOVALEVSKY J., ET AL., 1997, A&A, 323, L49

The Hipparcos catalog

F. van Leeuwen

Institute of Astronomy, Madingley Road, Cambridge, UK
e-mail: fvl@ast.cam.ac.uk

In July 1997 four letters were presented on the occasion of the publication of the Hipparcos catalog (Perryman et al. 1997; Lindegren et al. 1997; Høg et al. 1997; van Leeuwen et al. 1997), covering the astrometric data, the double stars, the Tycho catalog, and the photometric data. The first of these papers received about 10 times more references than the other three together, an indication of where the main impact of the Hipparcos catalog has been, namely in the parallax and proper motion data for the nearly 118 000 stars it contained.

The history of the Hipparcos mission covers approximately the same time span as the journal A&A, starting at the submission of the first modest proposals in France in 1967 (Lacroute 1982). Studies for a European Space Agency (ESA) led mission started in the mid-1970s. The mission was approved by ESA at the end of 1981, and in 1982 the preparations for the input catalog (Turon et al. 1992) and the data processing software started, uniquely divided between two consortia processing the same data in parallel (Lindegren et al. 1992; Kovalevsky et al. 1992). The Tycho mission was early on established as a unique opportunity to scientifically utilize the star mapper detectors onboard the satellite (Høg et al. 1992). The launch took place in August 1989. The failure of the Apogee Boost Motor left the satellite trapped in its geostationary transfer orbit. After increasing the perigee height of the orbit to around 450 km, the observations were started in November 1989. In 1992, part 1 of Vol. 253 of A&A was dedicated to our first experiences with the actual mission data, as well as the exploration possibilities for the Hipparcos data. In 1995 a large part of Vol. 304 was dedicated to the first preliminary results for the mission, based on 3 years of accumulated and processed data. This provided the first glimpse at the wealth of data being produced and the accuracies that had now been realized. The catalog was finally made public in 1997, and the paper reviewed here with the three papers mentioned above formed part of the official presentation of the catalog in the refereed literature. A fifth, more extensive paper published in the same Vol. 323, established the Hipparcos catalog as the optical realization of the International Celestial Reference System (ICRS) (Kovalevsky et al. 1997).

But this was not the end of the data processing. Over the years that followed it became clear that other significant improvements to the astrometric data were still possible. Subsequent studies (van Leeuwen 2005; van Leeuwen & Fantino 2005) culminated in the complete re-reduction of the astrometric data and the presentation of a new, and significantly improved for the brighter stars, catalog in October 2007 (van Leeuwen 2007a,b). However, the paper by the Hipparcos Project Scientist at ESA, Michael Perryman, the Hipparcos Science Team of 1997, and a couple of other names closely associated with the Hipparcos data reductions, marked what can be seen as the most important milestone in the history of the Hipparcos project, as well as an important milestone for astronomy in general (see also Perryman 2008, online). For the first time accurate absolute parallax measurements became available, and for relatively large numbers of stars. In the latest version of the Hipparcos catalog there are nearly 30 000 stars with parallax accuracies better than 10 per cent, allowing for a wide range of studies to take place. Since 1996 there have been over 1600 refereed papers (and a further 2000 non-refereed publications) relying at least partly on the Hipparcos data.

The paper by Perryman et al. (1997) is little more than a rather dry summary of achievements by the Hipparcos mission and products from it. How remarkable those achievements were is by now almost hidden in the mist of time. Concentrating on the most crucial of all measurements, those of the absolute parallaxes, it is worth noting that the original aim of the mission was to reach a mean error of 2 mas. The value presented in 1997 was just below 1.0 mas, with best values at 0.4 mas, while in the latest 2007 reductions the mean value is about 0.7 to 0.8 mas and the best values have accuracies of 0.09 mas, more than 20 times the goal of the mission (Fig. 1). This was achieved despite the mission operating in the wrong, 10.6 h geostationary transfer orbit. The latter subjected the satellite to strongly varying torques, which created difficulties in the reconstruction of the satellite attitude. The reconstructed attitude provided the reference system with all positional measurements. To achieve the accuracies that were obtained were, to say the least, remarkable under these conditions. The anomalous orbit also caused frequent exposure to strong radiation at the crossings of the Van Allen belts, which gradually and thoroughly destroyed the electronic equipment onboard and reduced the power that could be extracted from the solar panels, forcing an end to the mission in May 1993. The improvements in the final results were made possible by both a better performance of the instrument than expected (leading to a higher gain factor) and a very detailed understanding of the dynamics of the satellite, significantly reducing calibration noise.

Considering the limited space available for a Letter, the paper could not cover the extensive tests that had taken place at earlier stages in the preparation of the catalog on the reliability of the data and the errors assigned to it (Lindegren 1995; Arenou et al. 1995). In many ways these tests, which showed that the

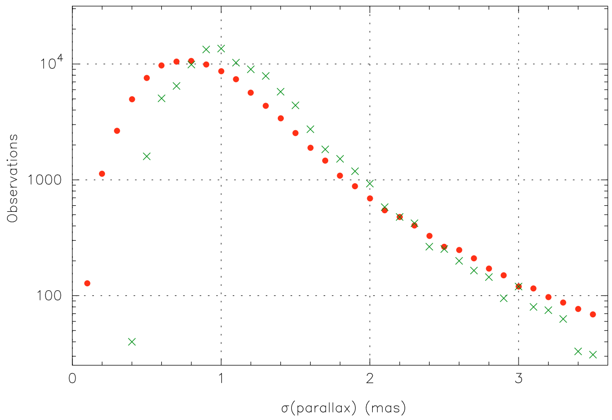

Fig. 1. Histogram of the number of single stars for intervals of width 0.1 mas in parallax error. The dots show the results for the new solution, the crosses for the 1997 solution. The original aim of the mission was to reach parallax accuracies of 2 mas. (From van Leeuwen 2007b, online).

parallaxes and their standard errors as presented in the catalog are fully reliable on an individual basis, are an essential part of the publication and an important reference in the use of the catalog. For the same reasons, similar tests have been performed on the new catalog as published 10 years later (van Leeuwen 2007b). These tests ultimately define the value and reliability of the catalog for individual entries and can identify any error correlations that may still exist in the data.

Not all papers using the 1997 Hipparcos catalog were equally complementary about the data; in particular, the Hipparcos parallax as determined for the Pleiades cluster caused an upset and, for some, a feeling of overall uncertainty about the Hipparcos results (Soderblom et al. 2005). This uncertainty was partly justified by the correlated errors in the underlying abscissa data for those measurements that were obtained within an interval of typically 30 to 60 s of time. Locally, these correlated errors could accumulate into correlated errors for the astrometric parameters of stars at a small (less than 2 degrees) separation on the sky. This did not affect the results when interpreted on an individual basis, as was referred to above, but became a problem when combining data from several stars to obtain a cluster parallax (van Leeuwen & Evans 1998). The new 2007 reduction (van Leeuwen 2007a,b) has identified and removed the main sources behind the error correlations, reducing them by more than a factor ten to an insignificant level. However, the discrepancy remains for the Pleiades parallax (van Leeuwen 2009). This was not a huge surprise, as the cluster spans a much larger area (about 8 to 10 degrees diameter) than the typical scale for the accumulation of error correlations (1.5 to 2 degrees). Data in the 1997 catalog could have been locally "wrong", but not easily so over the whole cluster.

The Pleiades anomaly and the way this was approached by different researchers exposed some of the current trends in this area of astronomy. Questions that could be asked are, for example: do we use theoretical isochrones to calibrate data or do we use data to calibrate theoretical isochrones; what is the accuracy of differential small-field (ground-based or HST) parallaxes; has there been any systematic comparison between absolute parallaxes for binary stars as derived by Hipparcos and parallax determinations for the same objects as derived from radial velocities and astrometric data? Concerning the first question, the answer should be obvious. However, the calibration used for the theoretical isochrones that were deployed to determine the Pleiades distance (An et al. 2007) and which led to conclusions that the Hipparcos parallax for the Pleiades is wrong, is based on the Hyades, and any age-related variations are defined by the theoretical tracks alone. The calibration errors for small-field differential parallaxes were determined by van Leeuwen (2009) and shown to be about 2.0 to 2.5 mas, much larger than the internal precision of those data, which is often used as their accuracy (Soderblom et al. 2005). The answer to the last question is still open, but should be given before using these results in drawing more extensive conclusions. In general, it should be the quality of the data and the data reduction methods that determines the value of a result and not its level of confirmation of the currently accepted values or theories.

Above all, the experience gained with the Hipparcos mission has opened the door to a still more ambitious mission, the Gaia satellite currently being built (O'Mullane et al. 2007; Lindegren et al. 2008). Gaia will extend the range of significant parallax measurements from about 300 pc to 30 kpc and the number of sources studied from 118 000 to 10^9. As at the start of the Hipparcos mission, the data processing challenges look formidable, but with the experience and commitment of the people working on these projects, in industry, at ESA, and in the scientific community, one should be confident about a good outcome and a spectacular catalog to be presented in the early 2020s.

References

An, D., Terndrup, D. M., Pinsonneault, M. H., et al. 2007, ApJ, 655, 233
Arenou, F., Lindegren, L., Frœschlé, M., et al. 1995, A&A, 304, 52
Høg, E., Bastian, U., Egret, D., et al. 1992, A&A, 258, 177
Høg, E., Bassgen, G., Bastian, U., et al. 1997, A&A, 323, L57
Kovalevsky, J., Falin, J. L., Pieplu, J. L., et al. 1992, A&A, 258, 7
Kovalevsky, J., Lindegren, L., Perryman, M. A. C., et al. 1997, A&A, 323, 620
Lacroute, P. 1982, in Scientific aspects of the Hipparcos space astrometry mission, ed. M. Perryman, & T. Guyenne, ESA-SP, 177, 3
Lindegren, L. 1995, A&A, 304, 61
Lindegren, L., Hoeg, E., van Leeuwen, F., et al. 1992, A&A, 258, 18
Lindegren, L., Mignard, F., Söderhjelm, S., et al. 1997, A&A, 323, L53
Lindegren, L., Babusiaux, C., Bailer-Jones, C., et al. 2008, in IAU Symp., 248, 217
O'Mullane, W., Lammers, U., Bailer-Jones, C., et al. 2007, in Astronomical Data Analysis Software and Systems XVI, ed. R. A. Shaw, F. Hill, & D. J. Bell, ASP Conf. Ser., 376, 99
Perryman, M. A. C. 2008, in IAU Symp., 248, 8
Perryman, M. A. C., Lindegren, L., Kovalevsky, J., et al. 1997, A&A, 323, L49
Soderblom, D. R., Nelan, E., Benedict, G. F., et al. 2005, AJ, 129, 1616
Turon, C., Gomez, A., Crifo, F., et al. 1992, A&A, 258, 74
van Leeuwen, F. 2005, A&A, 439, 805
van Leeuwen, F. 2007a, Hipparcos, the new reduction of the raw data (Dordrecht: Springer)
van Leeuwen, F. 2007b, A&A, 474, 653
van Leeuwen, F. 2009, A&A, 497, 209
van Leeuwen, F., & Evans, D. W. 1998, A&A, 323, 157
van Leeuwen, F., & Fantino, E. 2005, A&A, 439, 791
van Leeuwen, F., Evans, D. W., Grenon, M., et al. 1997, A&A, 323, L61