THE PARALLAX OF THE PLEIADES CLUSTER

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ABSTRACT

Using 54 well defined members of the Pleiades cluster, a common proper motion and mean parallax of these stars is determined. The solution made use of the Hipparcos intermediate astrometric data in order to eliminate correlations that occur between astrometric parameter determinations for stars in a small area on the sky. This method also made it possible to incorporate ground-based relative proper motions with 10 times higher precision than the Hipparcos proper motions as additional constraints. The parallax result for the cluster is in considerable disagreement with previous (mainly photometric) determinations, putting the cluster some 15 per cent nearer to the Sun than was expected. At this moment there are no spectral or photometric indications that explain this difference between the photometric and the astrometric distance modulus for the cluster. This then creates a considerable uncertainty in other photometric distance calibration, which may contain similar discrepancies at the level of 0.1 to 0.4 mag.

Key words: space astrometry; Pleiades; luminosity calibrations.

1. INTRODUCTION

There have been many different estimates of the distance to the Pleiades cluster over the past 85 years. One of the earliest attempts was by Hayn (1914), determining a dynamical parallax of 13 mas. Most of the methods following used comparisons between the Pleiades main sequence and measured or modelled properties for nearby stars. Some examples are:

- comparisons with the Hyades main sequence (Blaauw 1963, Turner 1979), giving 7.8 mas;
- other photometric comparisons (Mitchel & Johnson 1957, van Leeuwen 1983, Eggen 1986, Vandenberg & Poll 1989) giving values ranging from 7.4 to 7.7 mas;
- ground-based parallaxes for 5 stars by Gatewood et al. (1990), producing a parallax of 6.7 mas;
- parameters of rotational modulation stars by O'Dell et al. (1994), producing a parallax of 7.5 mas;
- parameters of a binary system by Gianuzzi (1995) producing a parallax of 7.5 mas;

All these methods, with the exception of the the determinations by Hayn (1914) and Gatewood et al. (1990) relied on the compatibility between 'average' solar neighbourhood stars and stars in the Pleiades cluster. There seemed to be a good reason to assume such compatibility, as the metallicity of the cluster stars (Fe/H) is assumed to be similar to the Sun and average stars in the solar neighbourhood (Vykhrestyuk & Karetnikov 1973).

The Pleiades has played an important part in the galactic and near extra galactic distance scale determinations, in particular for distances of young open clusters containing Cepheids, and for distance determinations of the Magellanic Clouds. A Hipparcos based distance for the Pleiades is not necessarily going to upset all those connected distance determinations, but is rather going to show the uncertainties in photometric distance determinations. There is a need for additional observational parameters required to understand the various quantities that may affect the luminosities of stars, so that in the future such luminosity based calibrations can become more reliable.

The Hipparcos data for stars concentrated in a small area of the sky have some limitations, caused by the reduction procedures. All astrometric data have been derived from the fundamental measurements of abscissae, one-dimensional positional measurements with respect to a reference great circle. For stars measured on the same great circle, these abscissae tend to have errors that are correlated. When considering stars in a small area of the sky, such correlations can accumulate and reflect in the astrometric parameter determinations. Using methods described by van Leeuwen & Evans (1997) and van Leeuwen (1997) we used these original abscissae data, after correcting them for the correlations, to derive an uncorrelated result for the astrometric parameters of the cluster.

The use of the abscissae data made it also possible to incorporate ground based relative proper motion determinations in the solution. This was, however,

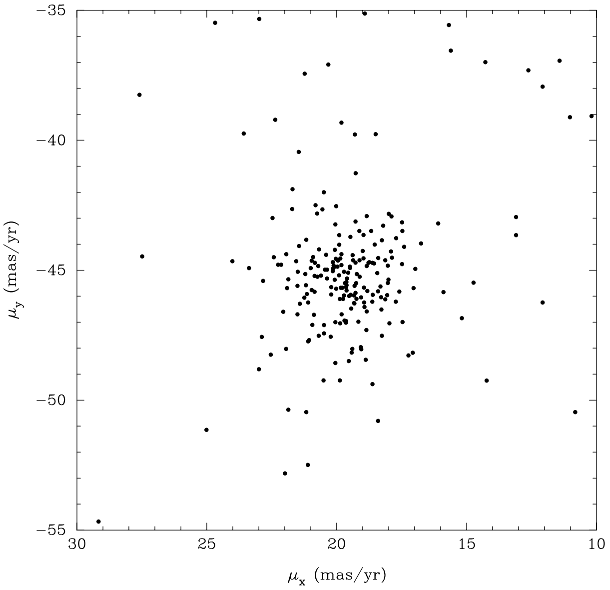

Figure 1. Ground based proper motion determinations in the Pleiades cluster. Errors are mostly at a level of 0.2 to 0.4 mas/yr.

far from straightforward due to the distortions often found in such determinations (see Tian et al. 1996).

The next two sections of the present paper show the available ground-based and Hipparcos astrometric data respectively, and the selecting of stars used in the final solution. This is followed by comparisons with various ground-based determinations and a discussion of some of the problems in photometric luminosity calibrations that are exposed by this comparison.

2. GROUND BASED ASTROMETRIC DATA

Comparisons between available ground based determinations of relative proper motions and positions in the region of the Pleiades cluster (Jones 1970, Vasilevskis et al. 1979, Wang et al. 1996), all showed the same problems as were encountered in a similar comparison for studies in the Orion area (see Tian et al. 1996). It was therefore decided to re-reduce a large quantity of plate measurements using the Tycho positional reference frame and the Hipparcos proper motion reference frame. These reductions will be reported elsewhere in the near future. The current (preliminary) result is a catalogue of around 2200 stars down to $m_{pg} = 14.5$, in an area of 1.7 degr around the center of the cluster. The proper motion precision for stars brighter than $m_{pg} = 13$ is in general better than 0.25 mas/yr, about 8 times better than the Hipparcos accuracy. This is due to the much larger epoch difference in the ground based data, using plates spanning over 80 years. The proper motion and position reference system for the ground based data fits within the expected accuracy with the Tycho positions for 1991.25, and with the Hipparcos proper motions. Figure 1 shows the vector point diagram for the Pleiades cluster stars as derived from the ground-based proper motions.

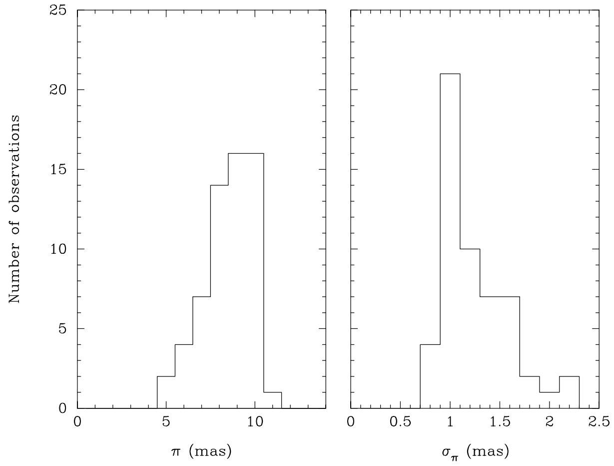

Figure 2. Distributions of the parallaxes and their accuracies for 54 Hipparcos Pleiades members.

3. HIPPARCOS ASTROMETRIC DATA

An area within 5.5 degrees from the center of the cluster was searched for members contained in the Hipparcos Catalogue, using primarily proper motions as selection criterion. In this area 264 stars are contained in the Hipparcos catalogue, three quarters of which can be discarded as possible cluster members beyond any doubt. Of these stars, 60 are probable cluster members on the basis of their proper motion, parallax and photometric properties. Among these 60 stars 26 cluster members given by Hertzsprung (1947). The total sample of 264 stars also contains 3 stars known from this catalogue not to be cluster members. Among the 26 members from the Hertzsprung catalogue, two are visual double stars and two are indicated in the Hipparcos catalogue as showing orbital motion. The remaining 34 probable members are outside the central area. Of these one is a visual double star and one was solved in a stochastic solution (possibly indicating orbital motion). This left 54 'clean' Pleiades members for the determination of the cluster parallax and proper motion. Figure 2 shows a histogram of the parallax values and accuracies for these 54 stars, as well as for 6 stars with disturbed individual solutions. Figure 3 shows the photometric data, clearly confirming every star in the selection as a member.

Two types of solutions were made. Solution (A) in which the proper motions of all members were considered the same (except for a projection effect described by van Leeuwen & Evans 1997), and solution (B) where for the central field the proper motions from the Hipparcos solution were replaced by the proper motions from the ground-based solution. Contrary to the expectations, the second solution is of slightly lower quality than the first, as indicated by the unit weight standard deviation (uwsd), but overall the results are very similar, as can be seen in Table 1. In both cases the distance of the cluster is found to be 116 pc and the accuracy of the parallax about 2.7 per cent. The lower accuracy of the second solution might be the results of the presence of orbital motions in the cluster centre, causing discrepancies between short epoch range and long epoch

Table 1. Summary of the astrometric solutions.

Sol.	π		M-m		$\mu_\alpha \cos\delta$		μ_δ		$\rho^{\pi}_{\mu_\alpha \cos\delta}$	$\rho^{\pi}_{\mu_\delta}$	$\rho^{\mu_\delta}_{\mu_\alpha \cos\delta}$	uwsd
	mas		mag		mas/yr		mas/yr					
(A)	8.61	±0.23	5.32	±0.05	19.67	±0.24	−45.55	±0.19	-0.100	-0.042	0.244	1.058
(B)	8.65	±0.24	5.31	±0.05	20.11	±0.28	−46.16	±0.23	-0.013	-0.016	0.247	1.099

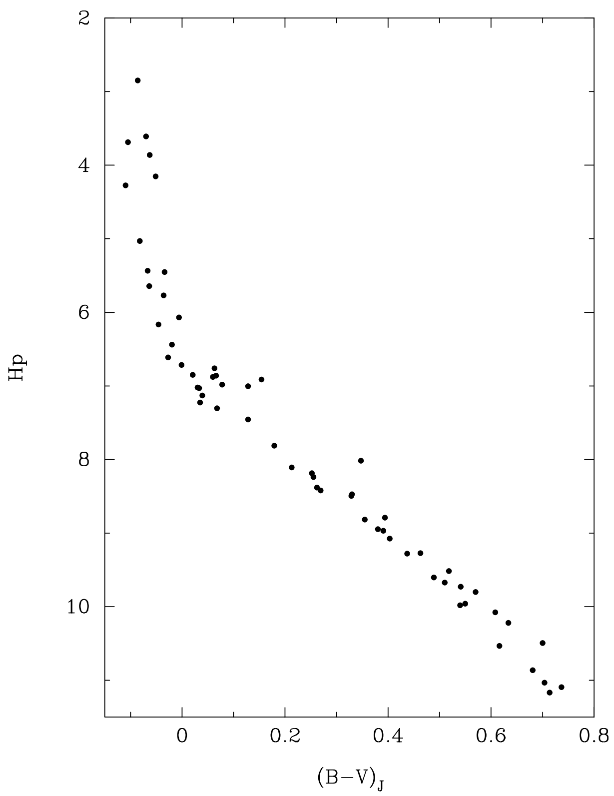

Figure 3. Colour-magnitude diagram for the Hipparcos Pleiades members. Data for 60 stars are shown, 54 as used in the combined solution plus 6 stars with non-single star solutions.

range determinations (see also Wielen et al. 1997).

4. COMPARISON WITH GROUND BASED PARALLAXES

The only compatible ground-based parallaxes are from Gatewood et al. (1990), who give parallax determinations for five members of the Pleiades, for three of which there are also Hipparcos determinations. Their results and the equivalent Hipparcos results are shown in Table 2. The differences are larger than expected given the accuracies of both determinations, but the errors given by Gatewood et al. 1990 do not include the zero-point errors of the reference system. The parallaxes for all Pleiades members as determined by Gatewood et al. (1990) rely on the same zero-point calibration.

Table 2. Comparison between Gatewood and Hipparcos parallax determinations of Pleiades members.

HIP	HII	AO No.	π_H	σ_{π_H}	π_G	σ_{π_G}
			mas		mas	
17588	859	827	9.21	0.82	7.0	0.8
	1122	829			6.7	1.1
17664	1234	830	6.66	0.86	6.6	0.9
17704	1431	833	9.05	0.88	6.5	1.1
	1762	836			6.5	1.1

5. COMPARSIONS WITH OTHER GROUND-BASED DETERMINATIONS

The difference between the distance as found with the Hipparcos parallax information and as found from ground-based determinations is much larger than expected. It is, however, quite clear from the Hipparcos data that the ground-based value of 7.7 mas or less is not supported. Looking at the way the ground-based distance moduli have been determined, there seems only one way open to explain the discrepancy: in almost all cases a photometric distance was obtained through comparing photometric properties of Pleiades members with those of 'average' nearby stars, for which distances were reasonably well known. The justification for this was the observed metallicity of the Pleiades stars, which is very similar to the solar metallicity. The conclusion from the discrepancy must therefore be, that this compatibility of Pleiades stars and average nearby stars is incorrect. There is only one well known difference between the average solar neighbourhood stars and the stars in the Pleiades: their age. The Pleiades stars are much younger than stars in the immediate solar neighbourhood. However, stellar evolution models do not predict as much of a shift in absolute magnitudes as seems to be observed here: the difference in distance modulus between the Hipparcos and ground-based determinations is 0.3 mag. It should also be noted here that the Pleiades main sequence has a very narrow intrinsic width, implying a very homogeneous chemical composition for all cluster members. Any explanation for the observed discrepancy needs to apply over a wide spectral range, from late B-types to early K-types.

In the Hipparcos HR diagram for stars with parallaxes known to better than 10 per cent, the Pleiades main sequence lies at the blue envelope. This is what may be expected for very young stars.

6. HELIUM

One abundance effect is known from star models to produce a lower luminosity for the same temperature: an increased helium abundance. In fact, in order to explain the observed difference of 0.3 mag the helium abundance would have to be as high as 0.35 to 0.40. This seems highly unlikely, given a helium abundance as measured in HII regions of alway close to 26 per cent. Measurements of He abundances for B-type stars in several young open clusters and associations by Brown et al. (1986) gives a confirmation of this value, again within a very narrow range. It therefore seems very unlikely that the observed luminosity difference in the Pleiades can be attributed to an excessive Helium abundance.

7. FURTHER WORK

With the distance modulus of the Pleiades now well determined, the next step to take is the cleaning-up of the Pleiades photometry (Hansen-Ruiz & van Leeuwen 1997) and to supplement this photometry with spectral information for all known cluster members, as well as for a comparison sample of stars in the solar neighbourhood. A new polarimetric survey could also be very useful. This would then allow the elimination (or at least the recognition) of a range of effects influencing the positions of the Pleiades stars in the HR-diagram and in various colour-colour diagrams, which would provide a set of 'clean' isochrones, ready for comparisons with theoretical and numerical models.

8. CONCLUSIONS

The discrepancy between the photometric and astrometric parallax of the Pleiades introduces a significant uncertainty in the application of photometric distance determinations. The identification and quantification of this discrepancy and similar ones observed in other young clusters (see Mermilliod 1997) with an observable characteristic in the spectra of the stars involved is critical. The possibility that this discrepancy is caused by Helium seems very unlikely. In the presence of such large and unexplained luminosity discrepancy, estimates of the age of the cluster as based on isochrones become uncertain too. Comparisons with isochrones will primarily show the discrepancy, and no longer the physical parameters of the cluster. This would probably also be the case for many other young open clusters, if only we had accurate measures of their parallaxes available.

The implementation of the Pleiades main sequence in earlier galactic distance determinations should not be adjusted until the observed difference is reliably explained and incorporated in the determinations. Using the ground-based distance modulus, the Pleiades provided a well determined reference main sequence roughly in the middle of the Hipparcos HR-diagram for stars in the solar neighbourhood. Thus, photometric distance determinations using the Pleiades main sequence effectively used a main sequence for average solar type stars. The findings for the Pleiades tell us now that such determinations can contain uncertainties of at least 0.3 mag, uncertainties for which the explanation and relevant observational parameters are, for the time being, still missing.

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