Highlights of Astronomy, Vol. 12
International Astronomical Union, 2002
H. Rickman, ed.

OB Associations, Open Clusters, and the Luminosity Calibration of the Nearer Stars

Anthony Brown

European Southern Observatory, Karl-Schwarzschildstraße 2, 85748 Garching bei München, Germany

Abstract. In the context of the luminosity calibration of the nearer stars I discuss the Hipparcos results on distances to nearby OB associations and open clusters. The shortcomings and assumptions in the analyses used to derive these results are pointed out and for the open clusters a comparison is made with results obtained from main sequence fitting. I conclude that given the considerable uncertainties in the latter technique there is no convincing evidence that the Hipparcos based distances to open clusters beyond the Hyades should not be trusted.

1. Introduction

Every method of distance determination that relies on knowing the brightness of some group of standard candles ultimately depends on establishing accurately the luminosity calibration of the stars in the Solar vicinity. Historically, this was accomplished as follows. Starting from the Hyades, for which an accurate geometrical distance was available, the main sequences of several well-studied clusters were patched together in order to obtain a luminosity calibration extending from late G to O5 stars. This calibration was then cross-checked for the early type stars with the distance of Sco OB2, which was also established geometrically albeit less accurately than for the Hyades. Subsequent calibrations of, e.g., O-stars and Cepheids were based on an extension of this main sequence fitting technique to more distant clusters containing these types of stars.

The major weakness in this method of constructing the distance ladder is the assumption that age differences for clusters with lifetimes up to that of the Hyades (~ 600 Myr) do not matter and that reliable corrections for differences in the chemical compositions of clusters can be made. Hence, an important driver for the Hipparcos mission was to determine by geometrical means (trigonometric parallaxes and proper motions) accurate distances to the nearby OB associations and open clusters in order to establish a fundamental luminosity calibration.

However, apart from the distances to the Hyades and Sco OB2 the Hipparcos results have not remained unchallenged. They have been especially disputed in the case of the Pleiades and other open clusters beyond the Hyades, for which recent main sequence fitting distances apparently cannot be reconciled with those of Hipparcos. In the following I review the Hipparcos results for the nearby OB associations and open clusters beyond the Hyades. In each case the weaknesses and assumptions implicit in the analysis of the Hipparcos data are discussed and for the open clusters a discussion on the uncertainties in the main sequence fitting technique is included.

2. The Nearby OB Associations

Based on the Hipparcos Catalogue (ESA 1997) a comprehensive survey of the stellar content of nearby ($\lesssim 1$ kpc) OB associations in 22 fields on the sky was undertaken by de Zeeuw et al. (1999). Using a combination of proper motions and parallaxes the members of OB associations were searched for on the assumption that those belonging to the same association share a common space motion apart from a small velocity dispersion. This led to the successful identification of physical groups in 12 out of the 22 fields for which subsequently distances were determined based on the mean Hipparcos parallax. These distance are all systematically smaller, by about 0.2 magnitudes in the distance modulus, than the previously established photometric ones.

The sources of uncertainty are: (1) deviations from the kinematical model of uniform motion plus a small and isotropic dispersion, (2) biases occuring when converting the parallaxes of the association members into a mean distance (see e.g., Arenou & Luri 1999), (3) selection biases in the Hipparcos data, (4) erroneous sky-boundaries for the associations, and (5) the presence of interloper field stars masquerading as association members. All these points were addressed by de Zeeuw et al. (1999) through extensive Monte Carlo simulations and their results show that it is mainly the last item which is a cause for concern. The number of interlopers may be 10–35% of the number of association members and if they are primarily foreground stars one will underestimate the distances to the associations. Nevertheless, assuming that the distances are not biased, de Zeeuw et al. concluded that the calibration of the HR-diagram for early type stars may have to be revised. This was further studied by de Bruijne (1999) using the following analysis.

From basic astrometry it follows that if the tangential velocity of a cluster is known, the proper motions give information on the parallaxes. For Sco OB2 the relative precision of the measured proper motion ($\mu/\sigma_\mu \sim 25$) is superior to the relative precision of the parallax ($\pi/\sigma_\pi \sim 7$). Hence, parallaxes derived from velocities are more precise estimates of the true parallaxes than the observed ones. Collecting all the Hipparcos data for a particular cluster one can simultaneously determine the cluster centroid space motion, the internal velocity dispersion, and the individual 'kinematically improved' parallaxes for all member stars. This kinematical modeling technique is described in detail in Lindegren, Madsen, & Dravins (2000) and was applied through a slightly different implementation by de Bruijne (1999) to Sco OB2. From the results he derived a more accurate HR-diagram for this association which shows that indeed the previously widely used Schmidt-Kaler (1982) calibration of the main sequence for B-stars is too bright. The main sequence as derived by de Bruijne (1999) corresponds more closely to the calibration presented by Mermilliod (1981). The main uncertainties are: (1) the accuracy of the membership list and (2) the assumption of a uniform motion plus a small, unique and isotropic velocity dispersion. These error sources are extensively discussed in Lindegren et al. (2000) and de Bruijne (1999) who both show that their analyses are robust.

3. Open Clusters beyond the Hyades

Because of the closeness of the Hyades cluster, its extent on the sky, and the large number of members in the Hipparcos Catalogue, there is little doubt about the accuracy of the Hipparcos distance as derived by Perryman et al. (1998). Thus I will turn promptly to a discussion of the open clusters beyond the Hyades.

One of the surprising results to come out of the analysis of the Hipparcos data was the distance to the Pleiades cluster based on the parallaxes of its members. Analyses by van Leeuwen (1999) and Robichon et al. (1999a) lead to a distance modulus of 5.37 ± 0.07, significantly different from the value of 5.60 ± 0.04 derived from the most recent main sequence fitting analysis by Pinsonneault et al. (1998). A similar discrepancy was found for the Coma cluster. However the most serious concern was that the differences between the various clusters studied with Hipparcos could not easily be reconciled with the standard picture of main sequence locus as a function of metallicity and helium content.

This prompted Pinsonneault et al. (1998) to undertake a detailed investigation of the main sequence fitting method from which they concluded that the discrepancy between the Hipparcos and main sequence fitting distances to the Pleiades is too large to be explained as due to errors in the main sequence fitting method. Instead they propose that at least in the area on the sky close to the cluster centre there are systematic errors in the Hipparcos parallaxes at the ~ 1 mas level. Pinsonneault et al. (1998) ascribe the cause of these systematic errors to the asymmetric distribution of the Hipparcos observations over the parallax ellipse of the Pleiades members. Narayanan & Gould (1998) suggested that a systematic error in the Pleiades distance may arise due to the correlated errors in the observations of different stars in small ($\sim 1^\circ$) regions on the sky.

The explanation for the source of systematic errors suggested by Pinsonneault et al. (1998) was shown by Robichon et al. (1999a) to be incorrect. Furthermore, the presence of correlations in the observations between different stars was anticipated before the launch of the Hipparcos mission and they can be taken into account. This was done by both van Leeuwen (1999) and Robichon et al. (1999a) and in principle there should be no systematic errors left. However, the assumptions are that the correlations are well understood and calibrated, that the cluster membership list is clean, that the cluster kinematics correspond to a single velocity vector and a small isotropic dispersion, and that the correlations are the sole cause of the errors. In this context it is worth noting that Lindegren et al. (2000) find evidence for a log-normal distribution of the velocity dispersion in the Hyades and that the Pleiades are known to have an elliptical halo. Hence, the cluster kinematics might be more complicated.

On the other hand one can investigate the error sources for main sequence fitting and there the situation is rather murkier than in the conclusions reached by Pinsonneault et al. (1998). There are five important sources of *external* error for this technique: (1) the choice of stellar models, (2) the choice of atmosphere models, (3) the calibration from $(L, T_{\rm eff})$ to, e.g., $(M_V, (B-V))$, (4) the cluster metallicity and helium abundance, and (5) the quality and homogeneity of photometric data. Notwithstanding their extensive analysis, what Pinsonneault et al. (1998) have mainly shown is that when one settles on a particular choice for each of these five ingredients small *internal* errors on the main sequence fitting distances can be achieved.

https://doi.org/10.1017/S1539299600014611 Published online by Cambridge University Press

Robichon et al. (1999b) point out that the choice of calibrations from the theoretical to the observational HR-diagram alone can lead to up to 0.2 magnitude effects on the main sequence. In addition, as described in both Pinsonneault et al. (1998) and Robichon et al. (1999a), the metallicities of open clusters in the Solar neighbourhood are still not accurately known. The measurements differ from author to author and between the photometric and spectroscopic determinations. The best precision one can obtain within a single homogeneous study is 0.1 dex, which already translates to a 0.1 magnitude effect on the main sequence locus when using Johnson B, V photometry. Finally, studies by Dravins et al. (1997) and de Bruijne (2000), employing the kinematic modeling technique, have succeeded in deriving a very high precision main sequence locus for the Hyades in the M_V–$(B-V)$ plane. The latter has been compared to stellar models by Castellani, Degl'Innocenti, & Prada Moroni (2000) and they show that even in the 'safe' colour range of 0.5–1.0 in $(B-V)$ the fitting of theoretical isochrones to the main sequence is affected by significant uncertainties.

In the light of all these uncertainties one must conclude that from main sequence fitting there certainly is no evidence that the Hipparcos distances to open clusters should not be trusted.

References

Arenou, F., & Luri, X. 1999, in ASP Conf. Ser. Vol. 167, Harmonizing Cosmic Distance Scales in a Post-Hipparcos Era, ed. D. Egret & A. Heck (San Francisco: ASP), 13

de Bruijne, J.H.J. 1999, MNRAS, 310, 585

de Bruijne, J.H.J. 2000, PhD Thesis, Leiden University

Castellani, V., Degl'Innocenti, S., & Prada Moroni, P.G. 2000, MNRAS, in press

Dravins, D., Lindegren, L., Madsen, S., & Holmberg, J. 1997, ESA SP–402, 733

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

van Leeuwen, F. 1999, A&A, 341, L71

Lindegren, L., Madsen, S., & Dravins, D. 2000, A&A, 356, 1119

Mermilliod, J.C. 1981, A&A, 97, 235

Narayanan, V.K., & Gould, A. 1999, ApJ, 532, 328

Perryman, M.A.C., et al. 1998, A&A, 331, 81

Pinsonneault, M.H., Stauffer, J., Soderblom, D.R., King, J.R., & Hanson, R.B. 1998, ApJ, 504, 170

Robichon, N., Arenou, F., Mermilliod, J.-C., & Turon, C. 1999a, A&A, 345, 471

Robichon, N., Arenou, F., Lebreton, Y., Turon, C., & Mermilliod, J.-C. 1999b, in ASP Conf. Ser. Vol. 167, Harmonizing Cosmic Distance Scales in a Post-Hipparcos Era, ed. D. Egret & A. Heck (San Francisco: ASP), 72

Schmidt–Kaler, Th. 1982, in Landolt–Börnstein New Series, Group VI, Vol. 2b, 1, ed. K. Schaifers & H.H. Voigt (Springer–Verlag)

de Zeeuw, P.T., Hoogerwerf, R., de Bruijne, J.H.J., Brown, A.G.A., & Blaauw, A. 1999, AJ, 117, 354