ANALYSIS OF SEVEN NEARBY OPEN CLUSTERS USING HIPPARCOS DATA

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ABSTRACT

From Hipparcos data in seven open cluster fields (Praesepe, IC 4756, NGC 2516, NGC 3532, NGC 6475, NGC 6633 and Stock 2) we have computed the membership of stars. The mean cluster distances have been derived from intermediate Hipparcos data.

Cluster sequences in the HR diagram have been deduced from their distances, the photometry coming from the 'Base des Amas' (Mermilliod 1988). Comparison between the relative sequence positions shows that metallicity is probably not the only parameter which influences the position of the ZAMS.

Key words: open clusters; Hipparcos; Hertzsprung-Russell diagram; distances; chemical composition.

1. INTRODUCTION

Open clusters have been used for a long time to calibrate the main sequences in the Hertzsprung-Russell diagram as a function of age and metallicity. They also define one of the first steps in the distance scaling of the Universe. The advent of the Hipparcos Catalogue allows, for the first time, to determine, without any physical assumption, the locations of cluster sequences in the HR diagram.

The comparison of the cluster sequences presented here and in Mermilliod et al. (1997) leads to amazing results. The positions of cluster sequences are not correlated with metallicity as one could have thought before.

2. MEMBER SELECTION

The selection of members in an open cluster is always a critical issue. The selection was done with the assumption that all stars belonging to the cluster have the same space velocity and that they lie in a 10 parsec radius sphere centred on the cluster centre.

The selection is iterative (but converges after 2 or 3 iterations): with a set of well known members, we calculate the cluster mean distance with Hipparcos parallaxes as well as the mean space velocity using Hipparcos data and ground based radial velocities.

A field star is considered as a member if its Hipparcos parallax and proper motion are consistent with the mean cluster values at a 3σ level. Stars for which the position in the observational colour-magnitude diagram was not in agreement with the cluster sequence were also rejected. Hipparcos double stars were rejected when their duplicity could bias the mean proper motion and parallax values, i.e. when the field H59 of the Hipparcos Catalogue was equal to G, O, V or X (see ESA 1997).

The number of stars selected in each cluster is given in Table 1. It varies between 6 and 24.

3. CLUSTER MEAN PARALLAXES

3.1. Hipparcos Intermediate Data

The mean cluster parallaxes cannot be computed without caution. As was predicted before the satellite launch (Lindegren 1988), the estimation of the mean parallax or proper motion of a cluster observed by Hipparcos must take into account the observation mode of the satellite. This is due to the fact that stars within a small area in the sky have frequently been observed in the same field of view of the satellite. Consequently, one may expect correlations between measurements done on stars separated by a few degrees, or with a separation being a multiple of the basic angle between the two fields of view.

This means that, when averaging the parallaxes or proper motions for these n stars, the improvement factor does not follow the expected $1/\sqrt{n}$ law and will not be asymptotically better than $\sqrt{\rho}$ if ρ is the mean positive correlation between data. In the case of clusters, the improvement is about $n^{-0.35}$ (Lindegren 1988). The straight average of individual parallaxes would not be an optimal estimate of the mean cluster parallax, and moreover its standard error would be seriously underestimated.

The proper way to take these correlations into account is to come back to the reference great circle

Table 1. New cluster distances.

cluster	N	$\bar{\pi}$ [mas]	$\sigma_{\bar{\pi}}$ [mas]	d [pc]	− [pc]	+ [pc]	m–M [mag]	− [mag]	+ [mag]	m–M [mag]	E$(B-V)$ [mag]	[Fe/H] [dex]	age [Myr]
										Lyngå			
Praesepe	24	5.65	0.31	177.0	9.2	10.3	6.24	0.12	0.12	5.99	0.00	0.07	830
IC 4756	9	3.46	0.30	289.0	23.1	27.4	7.30	0.18	0.20	8.58	0.20	0.04	830
NGC 6475	21	3.43	0.30	291.5	23.4	27.9	7.32	0.18	0.20	7.08	0.06	0.03[1]	130
NGC 6633	6	3.43	0.53	291.5	39.0	53.3	7.32	0.31	0.36	8.01	0.17	-0.11	630
Stock 02	8	3.16	0.47	316.5	41.0	55.3	7.50	0.30	0.35	8.62	0.38	-0.14[2]	170
NGC 2516	15	2.87	0.20	348.4	22.7	26.1	7.71	0.15	0.16	8.49	0.13	-0.23	70
NGC 3532	7	2.40	0.40	416.7	59.5	83.3	8.10	0.33	0.40	8.53	0.04	-0.10[1]	290

[1] from Piatti et al. (1995)
[2] from Claria & Piatti (1996)

level, to calibrate the correlation between the reference great circle abscissae, so that the full covariance matrix between observations allows to find the optimal astrometric parameters. As part of the least-squares procedure, the final covariance matrix between astrometric parameters is also found. The adopted method is similar to that of van Leeuwen & Evans (1997) with the exception that the calibration of correlation coefficients has been done on each reference great circle. This has been done using the theoretical formulae by Lindegren (1988) to which harmonics were added through the use of cosine transform (Press et al. 1992).

For a given cluster, either the mean parallax or the proper motion or both may be considered to be the same unknown(s) for the cluster, the other astrometric parameters of cluster stars remaining determined individually. In our case, only the parallax has been considered constant, the resulting values being given Table 1. From these mean parallaxes $\bar{\pi}$, and associated standard errors, the distance and distance moduli are also indicated, together with a $\pm 1\sigma$ variation. In the right part of Table 1, the distance moduli, colour excesses, and ages, quoted by Lyngå (1987), and metallicities from Lyngå (1987), Piatti et al. (1995) or Claria & Piatti (1996) are also indicated.

3.2. Accuracy of the Results

The distances and the distance moduli given in Table 1 deserve some more comments. Since the transformation from parallax to distance is not linear, a bias in the quoted distances could be expected. However, the relative error σ_{π}/π is small (between 6 and 17 per cent) so the effect is probably negligible (see Brown et al. 1997).

When computing the mean cluster parallax, one implicitly assumes that the dispersion in individual parallaxes is only due to the measurements errors. The depth of the cluster should be taken into account; however, except perhaps for Praesepe, it is small compared to the quoted error on distance and may be neglected.

Finally one may ask whether there could be a magnitude or colour effect in the Hipparcos parallaxes which could bias the mean parallax estimation. The variations of the normalised differences $(\pi - \bar{\pi})/\sigma_{\pi}$ as a function of apparent magnitude V (bottom) and colour index $(B-V)$ (top) are represented in Figure 1. The independence between these normalised differences and apparent magnitudes or colour indices was not rejected by a Pearson or Kendall statistical test.

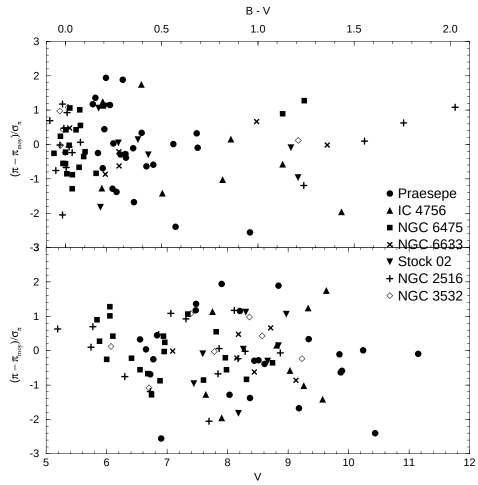

Figure 1. Normalised differences of the 94 cluster members versus (B-V) (top) and V (bottom).

4. CLUSTER COLOUR–MAGNITUDE DIAGRAMS

In each cluster, Johnson BV photoelectric photometry compiled in the 'Base des Amas' was used to build well defined cluster sequences in the observational Hertzsprung-Russell diagram. For IC 4756 and Stock 2, not enough photoelectric photometry was available to obtain a clean sequence. Reddening of each cluster (from Lyngå 1987) and Hipparcos mean cluster parallaxes were used to obtain the absolute magnitude M_V and the dereddened colour indices $(B-V)_0$. The higher part of the Figure 2 shows the superposition of the 5 cluster sequences in the $(M_V, (B-V)_0)$ diagram. The lower part reproduces the sequences of Praesepe and NGC 2516 with the error bars on absolute magnitudes derived from Hipparcos data (see Table 1). The cluster sequences separate into two groups: Praesepe and NGC 6475

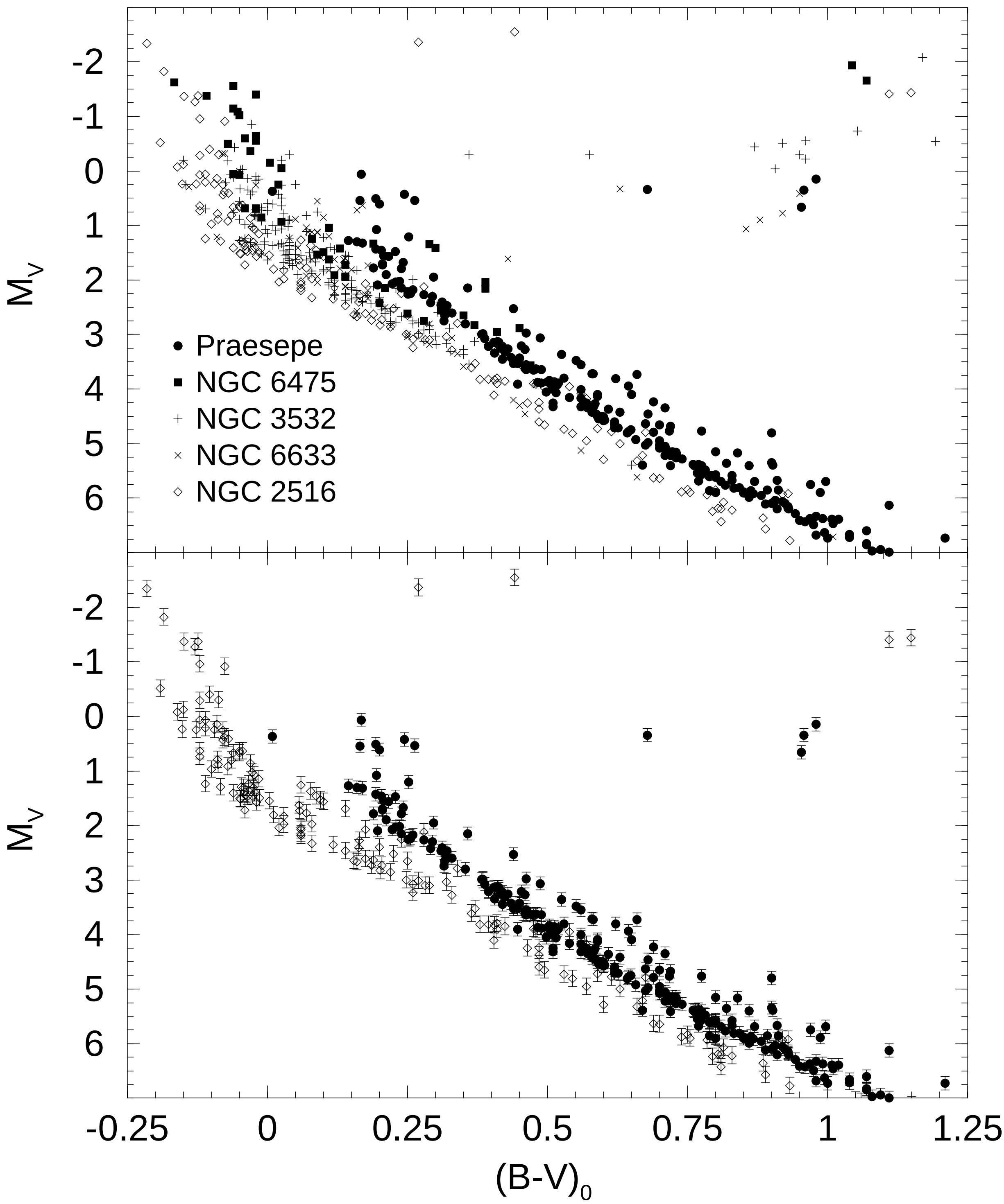

Figure 2. Colour-Magnitude diagram of five open clusters using Hipparcos mean parallaxes.

sequences are about $0.5 - 0.7$ magnitude above those of NGC 3532, NGC 6633 and NGC 2516.

5. ZAMS

The helium abundance Y is very difficult to measure directly and is only observable in B stars. Thus, Y is usually supposed to vary with the metal abundance Z according to the law: $\mathrm{D}Y/\mathrm{D}Z = (\mathrm{D}Y/\mathrm{D}Z)_\odot$ i.e. $Y = 2.8Z + 0.227$ where 2.8 is derived from the calibration in luminosity of a solar model calculated with updated input physics (Lebreton 1997) and 0.227 is the primordial helium abundance (Balges et al. 1993). Figure 3 shows ZAMS for different values of Z with values of Y following the previous law. For metallicities in the range of those of the 5 clusters presented in this poster ($-0.23 <$ [Fe/H] < 0.07), the shift in magnitude between sequences is smaller than 0.25 magnitude.

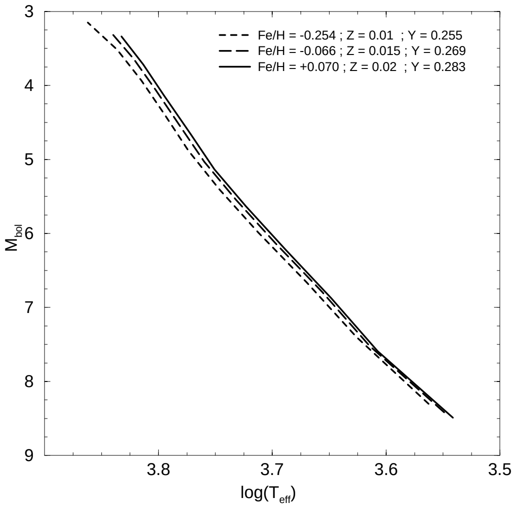

Figure 3. ZAMS computed for different values of Z and Y following Y = 2.8 Z + 0.227.

6. CONCLUSION

Relative position of cluster sequences in the $(M_V, (B-V)_0)$ diagram are qualitatively but not quantitatively in agreement with [Fe/H] variations. Praesepe and NGC 6475, with a metallicity higher than the solar one, have sequences higher than NGC 3532, NGC 6633 and NGC 2516 which are deficient. But the magnitude shift between sequences is larger than expected. The NGC 2516 sequence, for example, is 0.8 magnitude below the Praesepe one. According to the ZAMS presented in the previous paragraph, this cannot be explained only by the metallicity difference between the two clusters ([Fe/H] $= -0.23$ for NGC 2516 and [Fe/H] $= 0.07$ for Praesepe). Assuming a usual helium variation, the metallicity difference required to explain a shift of 0.7 magnitude between two sequences, would be higher than 1.1 dex! Although metallicity determinations are quite uncertain, such a difference between NGC 2516 and Praesepe is probably to be excluded. In the other hand, if the difference between the sequences of NGC 2516 and Praesepe of 0.25 magnitude is due to metallicity difference, the difference of 0.45 magnitudes $(0.7 - 0.25)$ between the two sequences is very unlikely compared with the errors on the distance modulus derived from the Hipparcos mean parallaxes.

This is a confirmation of what has been found for 6 other clusters in Mermilliod et al. (1997). This seems to indicate that helium abundance variations between clusters may be larger than thought before, or, at least, that another parameter added to metallicity, plays an important role in the position of sequences in the HR diagram.

This result is, however, to be confirmed with more photoelectric data, more precise reddenings and homogeneous [Fe/H] determination.

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