DEFINITION OF THE PLEIADES MAIN SEQUENCE IN THE HERTZSPRUNG-RUSSELL DIAGRAM

C.S. Hansen-Ruiz[1], **F. van Leeuwen**[2]

[1]Instituto de Astrofísica de Canarias, La Laguna 38205, Tenerife, Spain
[2]Royal Greenwich Observatory, Madingley Road, Cambridge CB3 0EZ, United Kingdom

ABSTRACT

The Pleiades main sequence is intrinsically of very small width. Disturbances to this width come primarily from three sources: local interstellar reddening (related to the reflection nebulae), multiplicity and variations in the distance moduli related to the size of the cluster ($\sim$ 20 pc diameter). Walraven 5-channel photometry can be used to remove most of the reddening related effects. A full literature survey was made concerning multiplicity to provide information needed to correct for multiplicity effects. The locus of the resulting corrected main sequence can be determined using Hipparcos parallaxes (van Leeuwen & Hansen-Ruiz 1997), providing a well defined observational isochrone for the study of stellar evolution and stellar structure. Preliminary results are presented.

Key words: Pleiades; reddening; main sequence.

1. INTRODUCTION

The Pleiades is an open cluster of about 600 stars (down to V = 17 mag), and an age of 100 million years, located in the Taurus constellation ($\alpha = 3^{\rm h}\ 45^{\rm m}$, $\delta = 24°$). The Pleiades has frequently been used as a reference locus in the Hertzsprung-Russell diagram for the determination of distances to other clusters and the Magellanic Clouds by comparing the zero age main sequences. Having a very narrow main sequence which, moreover, expands from early type stars (B6) to late type stars makes it very suitable for this purpose. It is then of critical importance, with the aid of Hipparcos data, to redefine the main sequence of this open cluster so that it can serve as a reference point in the Hertzsprung-Russell diagram in age, and metallicity, as well as helping to constrain stellar evolution and structure model theories through the use of isochrones.

This contribution is divided in three sections. First we present the photometric sample which is used in our analysis. Then we describe how the data were de-reddened. Finally we present a summary of what is known about multiplicity in the cluster up to now.

2. THE PHOTOMETRIC SAMPLE

We are using a photometric sample of 152 stars measured in the 5-channel Walraven photometric system (van Leeuwen et al. 1986), with photometric errors of the order of a millimagnitude. They cover the spectral types B6 to K0 at the very faint end. The original survey, measured with the Dutch 90 cm telescope on La Silla, ESO, 1979, comprised two samples: the ‘Hertzsprung sample’ of 197 stars (Hertzsprung 1947), centred near Alcyone and covering an area of $3° \times 3°$; and the ‘Pels sample’ of 193 stars outside the previous region and covering an area of $9° \times 9°$. These samples have been reduced and analyzed by van Leeuwen 1983, who found that 67 of these stars were not members. Further selection criteria on the original sample will be explained in van Leeuwen & Hansen-Ruiz (1998). Figure 1 shows the sample transformed to the Johnson photometric system. Already we can see the narrowness of the main sequence, its brightness and how it covers almost the whole range of spectral types. Superimposed we show the Hipparcos measured stars from the Pleiades as selected by us (van Leeuwen & Hansen-Ruiz 1997).

3. DE-REDDENING

The Pleiades cluster is situated in an area of the sky populated with dust clouds, shown by the reflection of light emitted by the brightest members. This interstellar medium is not homogeneous within the cluster, i.e. its influence on the light emitted by the cluster members is different from star to star. Thus the problem of reddening becomes complex. Differential reddening in the Pleiades has been tackled by several authors, using several methods (van Leeuwen 1983, Breger 1986 and references therein). New information about the Pleiades cluster in different wavelengths, and the current understanding of stellar structure and evolution makes it worth to reinvestigate the differential reddening in the cluster as part of the definition of the main sequence of the Pleiades. The intermediate bandwidths of the Walraven system photometric channels make it particularly suitable for reddening determinations, as reddening directions are linear and effectively independent of spectral type (Lub & Pel 1977).

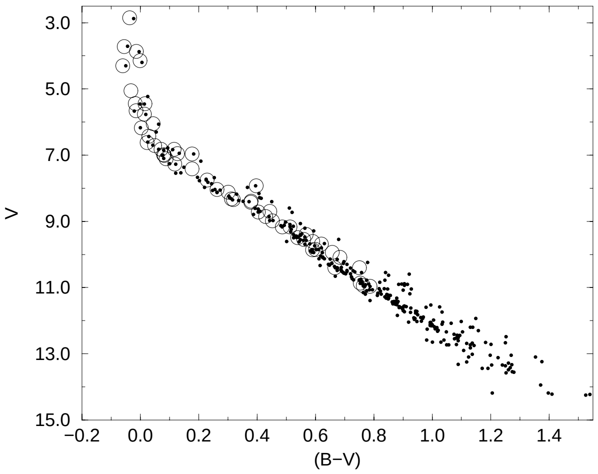

Figure 1. Hertzsprung-Russell diagram of the Pleiades cluster in the Johnson photometric system. The original Walraven sample cleaned from non-members is shown as dots, while stars contained in the Hipparcos sample are indicated by open circles. The Walraven photometry has been converted to the Johnson system through the transforming equations of Rosvick et al. 1992.

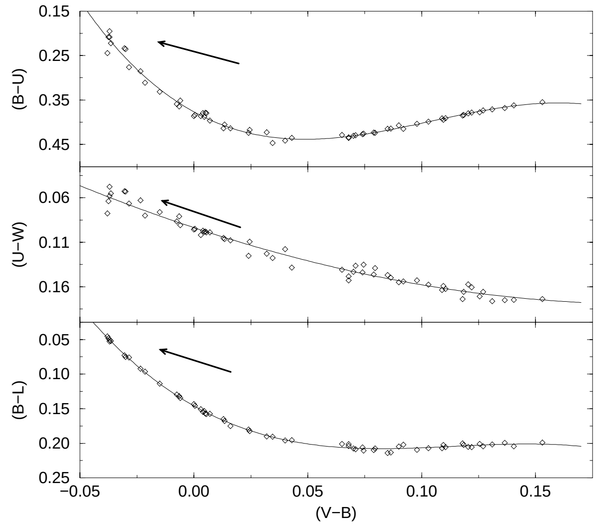

Figure 2. Colour-colour diagrams of the Pleiades cluster in the Walraven photometric system, where colours are expressed in terms of log(I). The diagrams show only a subsample of the data: the upper part of the main sequence. The arrows show the de-reddening directions, which in the case of the (V−B)−(U−W) diagram runs almost parallel to the main sequence. The curves are third-order polynomials, fitted through weighted least squares.

In the present paper we show a determination of the differential reddening through the use of empirical calibration grids. This is an iterative procedure using three colour-colour diagrams (Figure 2). Curve fittings were done over the spectral range B6-F1, using all data in each of the three colour-colour diagrams.

This provided in each colour-colour diagram a reference curve, which was an approximation of the reddening free curve in that diagram for the stars in the Pleiades cluster. Average reddening coefficients for the Walraven system were assumed (see Lub & Pel 1977 and Table 1).

Every star was subsequently moved along the de-reddening directions in all three diagrams by the same amount in the common coefficient $V - B$, until the nearest position to the three fitted curves was found. Weights representing the accuracies of the observations were applied here. The step-size used in shifting the positions of the stars was 0.0005 logI in $V - B$. Only the positive shifts found in this way were applied. The procedure was repeated a few times until corrections became insignificant.

Table 1. The reddening directions used.

Ratio	Coefficient
$A_V = E_V/E_{V-B}$	3.0
E_{B-U}/E_{V-B}	0.61
E_{U-W}/E_{V-B}	0.45
E_{B-L}/E_{V-B}	0.39

4. THE MULTIPLICITY PROBLEM

Another contribution to the width of the main sequence comes from the multiple systems. This problem is of crucial importance in the Pleiades cluster where almost a third of the stars in the central region appears to be part of multiple systems. This is a consequence of the mass segregation in the cluster. The double and multiple systems act as singles stars with a high mass in most dynamical interactions, leading to a loss of energy and an accumulation towards the cluster centre. When the stars of a double system are of the same mass this can lead to the effect of placing the star 0.75 mag above the 'true' main sequence. Depending on the luminosity ratios between components, shifts in colour can also be expected. In order to disentangle between reddening and multiplicity, a survey of data of multiple systems has been made through the literature, as will be shown in van Leeuwen & Hansen-Ruiz (1998).

5. PRELIMINARY RESULTS AND DISCUSSION

The de-reddening procedure above mentioned leads to the 'cleaned' main sequence shown in Figure 3.

We can compare our new reddening corrections to other data on the Pleiades, for example, polarization data from Breger (1986) (Figure 4). The result is roughly the same as obtained by him, comparing polarization to other reddening estimations (Figure 4 in Breger 1986). There seems to be a correlation in terms of higher polarization corresponding

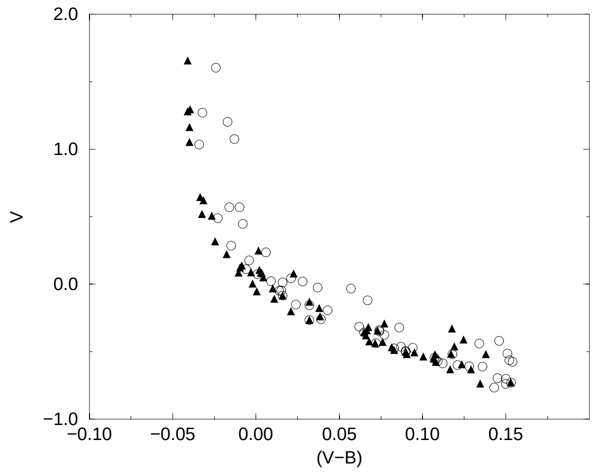

Figure 3. Hertzsprung-Russell diagram of the Pleiades cluster upper main sequence in the Walraven photometric system. Open circles represent the observed data, while filled triangles correspond to the results of the dereddening procedure.

to higher reddening corrections, but the noise in the data makes it difficult to establish it straightaway.

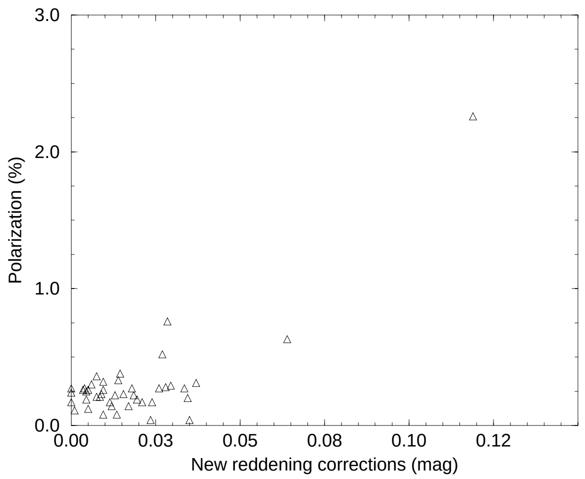

Figure 4. Correlation between polarization in the Pleiades cluster stars (Breger 1986) and the current reddening estimates.

The main uncertainty in the way we estimate the reddening corrections is due to the fact that we are not using an independent blue envelope, but an 'average' fit to the main sequence, which will have an offset from the blue envelope. The overall reddening of the cluster stars, through the medium between the Sun and the cluster, remains undetermined. Further analysis of the data (using blue envelopes, theoretical atmosphere grids) may provide better constrains on these estimates.

ACKNOWLEDGMENTS

To Erik Stengler for helping me (CSHR) not to hate LaTeX too much.

REFERENCES

Breger, M. 1986, ApJ, 309, 311

Hertzsprung, E., 1947, Annalen Leiden, XIX, part A

van Leeuwen, F., 1983, PhD thesis, Leiden University

van Leeuwen, F., Alphenaar, P., Brand, J., 1986, A&AS, 65, 309

van Leeuwen, F., Hansen-Ruiz, C.S., 1997, ESA SP–402, this volume

van Leeuwen, F., Hansen-Ruiz, C.S., 1998, in preparation

Lub, J., Pel, J.-W., 1977, A&A, 54, 137

Rosvick, J.M., Mermilliod, J.-C., Mayor, M., 1992, A&A, 255, 130