THE HYADES CLUSTER — TOO DISTANT?

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1. THEORETICAL AND OBSERVATIONAL ZERO AGE MAIN SEQUENCE

Theoretical zero age main sequences (TZAMS) from Flower (1976) are compared with two observed zero age main sequences (ZAMS) in Fig. 1.: ZAMS40, based on a distance of 40 pc (Sandage 1957) and ZAMS46 on a distance of 46 pc (see Flower 1977 for T_{eff}: (B-V): BC scales). Although ZAMS46 lies above any TZAMS, the TZAMS can be shifted in luminosity by changing the chemical composition. An equation giving the effects of Y (helium) and Z (metals) on the TZAMS was found by Flower (1976) to be

$$\Delta \log L/L_{\odot} = 0.432\ (\log Z_R - \log Z) - 0.838\ (Y_R - Y) \qquad (1)$$

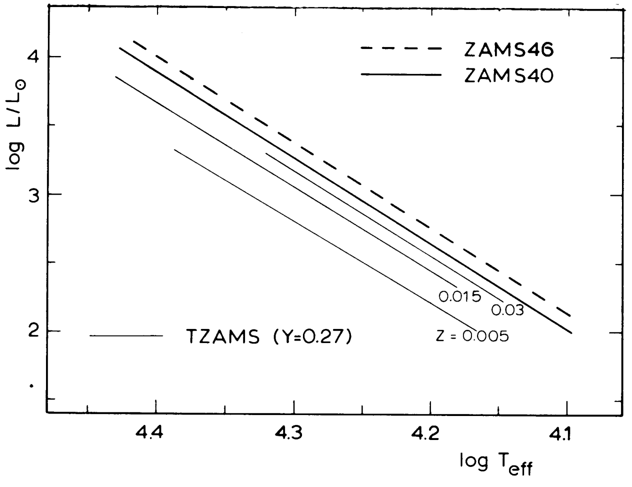

Fig. 1. Theoretical and Observational Zero Age Main Sequences.

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where $\Delta \log L/L_\odot \equiv \log(L/L_\odot)_R - \log(L/L_\odot)$ and R indicates values for a reference composition. Using eq. (1), one finds that metal abundances in the range of $0.03 \leq Z \leq 0.05$ for Y between 0.22 and 0.32 give coincidence with ZAMS40. However, for ZAMS46 the required metal abundances are $0.06 \leq Z \leq 0.10$ for the same range in Y. Before assigning any significance to these high metallicities, the uncertainties inherent in such comparisons must first be evaluated; i.e., three other factors, besides variations in Y and Z, may have a significant influence on such comparisons: 1) uncertainties in stellar opacities; 2) evolutionary effects; and 3) effects of stellar rotation. These will now be evaluated.

2. THE "EVOLUTIONARY DISTANCE" TO THE HYADES CLUSTER

Although the luminosity of the ZAMS is quite sensitive to Z, a change in Y or Z has very little effect on the slope of the ZAMS (Flower 1976). Therefore, a ZAMS constructed by MS (main sequence) fitting, starting with the Hyades, represents MS stars with the same chemical composition as the Hyades stars. Consequently, the distance estimation from comparisons between the TZAMS and the upper part of the observed ZAMS refers to the distance to the Hyades cluster itself.

Fricke et al. (1971) found that the location of the TZAMS is very sensitive to changes in opacity at temperatures $\geq 10^6$ K. Using their results and the L-T_{eff} relation for upper MS models (Flower 1976), one finds that to eliminate the difference in luminosity between ZAMS46 and the TZAMS, opacities must be increased by factors of 3 and 2 for $Z = 0.03$ and $Z = 0.04$ respectively. However, at temperatures $\geq 10^6$ K opacities are not expected to increase in the near future by more than 20% (Mertz 1977, private communication). This increase in opacity corresponds to an increase of 0.042 in $\log L/L_\odot$ of the TZAMS.

Any brightening of the Hyades stars due to evolution off the MS will shift the zero point of the observed ZAMS. The models of Demarque and Gisler (1975) show that Hyades stars three magnitudes fainter than the brightest Hyades stars have increased their luminosities by no more than 0.008 in $\log L/L_\odot$; for stars fainter than this, the luminosity increase is smaller.

Since rotational effects do not change the slope of the MS (Meyer-Hofmeister 1972), no correction is required for moderately massive rotating stars. Corrections for the Hyades rotating stars will be small because the Hyades MS stars are slow rotators, rotating at less than a tenth of their breakup velocity. Using the models of Faulkner et al. (1968) for a 1 $M_\odot$ uniformly rotating star, one finds an increase of ≤ 0.02 in $\log L/L_\odot$. This probably represents an upper limit because effects of rotation are minimized

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since the lower envelope of the MS band is emphasized when determining the ZAMS.

These factors give a 0.07 increase in log $L/L_{\odot}$ of the TZAMS. Adding this to the TZAMS for (Y,Z) = (0.25,0.04), log $L/L_{\odot}$ = 3.25 at log T_{eff} = 4.3, results in the TZAMS being 0.15 mag brighter than ZAMS40 or in a Hyades distance modulus of (m-M) = $3^{m}.18$. If the range in Z of the Hyades stars is between 1.5 and 2.5 times solar Z, then the minimum and maximum moduli are $3^{m}.05$ and $3^{m}.29$.

The modulus, (m-M) = $3^{m}.18$, agrees quite well with that from "secondary indicators," (van Altena 1974) and from the convergent-point results of Corbin et al. (1975), but disagrees with Hanson (1976) and Anthony-Twarog and Demarque (1977). However, McAlister (1977) has reanalyzed Hanson's solution for possible systematic magnitude effects and finds (m-M) = $3^{m}.18$. Unfortunately, the models used by Anthony-Twarog and Demarque were not calibrated to reproduce the T_{eff} of the Sun; this would require a larger mixing length. Because a larger mixing length would result in a smaller modulus and because the masses derived for the Hyades binaries depend on the adopted modulus, the consistency between the CM diagram and the ML relation for the Hyades binaries they found for a modulus of $3^{m}.34$ would be wiped out. Hence, if the mixing length chosen for the models must be the same for both the Sun and the Hyades stars, then a smaller modulus is required from comparisons with the Hyades CM diagram.

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DISCUSSION

HANSON: The Hyades distance modulus $3^m\!.42 \pm 0^m\!.20$ (m.e.) (Hanson 1975 Astron. J. 80, 379) was determined from Lick absolute proper motions in the central $6^\circ \times 6^\circ$ region of the cluster. In more recent work I have extended my proper motion measurements to 4 additional regions, North, South, East and West of the cluster center; the resulting 16° extent on the sky gives a much better hold in the convergent point. The resulting distance modulus is $3^m\!.31 \pm 0^m\!.06$ (m.e.). This value is in excellent agreement with recent Hyades trigonometric parallax determinations at Van Vleck and Lick observatories.

SEARS: Did you consider the mass-luminosity relation of the Hyades binaries?

FLOWER: It seems that I forgot to mention the mass range of my models. Since I have only computed models for moderately massive stars, $3 \leq M/M_\odot \leq 10$, it was impossible for me to consider the Hyades mass-luminosity relation.

SEARS: The preceding paper by Garrison assumed that clusters overlap, down to the Hyades, in the HR diagram. Perhaps your work indicates that this assumption may not be correct. Is that a possible interpretation of your results?

FLOWER: This is a very interesting point. If clusters are overlapped, starting with the Hyades to form a ZAMS, then, because the slope of the ZAMS is independent of chemical composition, the resulting ZAMS is just an extension of the Hyades main sequence. This means that comparisons between this observed ZAMS and main sequences of clusters will give a correct distance to the clusters only if the clusters have the same composition as the Hyades. If the composition differs from the Hyades, then the intrinsic luminosity of the cluster main sequence will be different from that of the observed ZAMS, and, hence, a wrong distance to the clusters will result.

ABT: I think that there is a fourth effect that you should consider. If I understand correctly, you are comparing models computed for single stars with real stars, many of which are double. Because of duplicity the real ZAMS should be about $0^m\!.2$ above the computed ZAMS.

FLOWER: It is true that unresolved double stars will be above the single stars of a cluster (as in the Hyades and Pleiades clusters), but the single stars should still define a lower envelope, which is the cluster main sequence unaffected by duplicity.

CAYREL de STROBEL: We used the main sequences calculated by Hejlesen for normal metal abundance ($Z = 0.02$), and three solar-type Hyades stars fitted perfectly.

FLOWER: If you reduce the metal abundance of the Hyades, you bring them closer. You could pick a metal abundance, and I can tell you which theoretical ZAMS will fit.

CAYREL de STROBEL: Why concentrate only on Z? What about Y?

FLOWER: Yes, if you change Y by 0.05, you change log L by

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