COMPARISON BETWEEN OBSERVATIONAL AND THEORETICAL (log T_{eff}, M_{bol}) DIAGRAMS

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In a paper by Perrin et al. (1977), we have constructed an empirical HR diagram for 138 nearby F, G and K stars, for which we had: i) an effective temperature and a metal content derived from a detailed analysis; ii) a reliable bolometric magnitude obtained from an absolute magnitude M_V, based on a large parallax and a rather small bolometric correction.

The main purpose of this paper was to see if one obtains a "cleaner" HR diagram when grouping stars of same metal/hydrogen ratio, and if this "cleaner" HR diagram was evolving with the value of the metal/hydrogen ratio as expected from theoretical grids of evolutionary tracks or isochrones. This was indeed the case, when comparing strongly metal poor stars (halo stars) with disk stars having a solar chemical composition.

But a puzzling result was that in our observational ZAMS, stars of

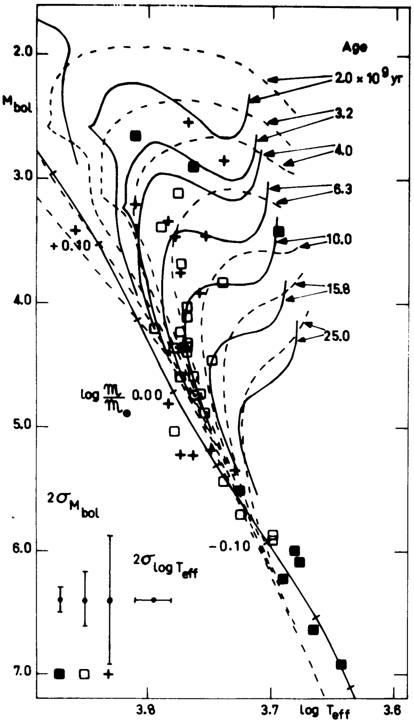

Fig. 1. Observational and theoretical (log T_{eff}, M_{bol}) diagrams for normal metal content stars.

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Table I : Comparison of age determinations from two grids of isochrones (Hejlesen 1975, Demarque 1977) for stars in the lane between 0.5 and 2.0 mag above the main sequence and in the T_{eff} interval : 5500 - 6500 K.

		Hejlesen			Demarque		
HD	$[Fe/H]^*_\odot$	Y	Z	Age(10^9yr)	Y	Z	Age(10^9yr)
121370	+0.50	0.26	0.04	2.5	0.30	0.04	2.5
102870	+0.27	"	"	4.5	"	0.04	2.0
"	"	"	"	4.5	"	0.01	6.0
34411	+0.22	"	"	6.3	"	0.04	2.5
"	"	"	"	6.3	"	0.01	7.5
161797	+0.15	0.28	0.02	10.0	"	0.01	11.0
19373	+0.05	"	"	7.9	"	"	7.0
158614	+0.02	"	"	15.9	"	"	12.5
136064	-0.03	"	"	6.3	"	"	6.0
84737	-0.04	"	"	10.0	"	"	7.0
61421	-0.06	"	"	2.8	"	"	3.5
38393	-0.07	"	"	10.0	"	"	7.5
142860	-0.09	"	"	5.6	"	"	5.0
210027	-0.10	"	"	4.5	"	"	5.5
9826	-0.16	0.29	0.01	5.0	"	"	5.0
22484	-0.16	0.29	0.01	5.6	0.30	0.01	5.5
16895	-0.26	"	"	7.9	"	"	6.0
2151	-0.31	"	"	10.0	"	0.01	8.5
"	"	"	"	10.0	"	0.004	12.0
142373	-0.35	"	"	6.3	"	0.01	6.5
"	"	"	"	6.3	"	0.004	8.5
165908	-0.40	"	"	11.2	"	0.004	12.0
157214	-0.43	"	"	22.4	"	"	20.0
136352	-0.50	"	"	22.4	"	"	22.0
222368	-0.51	"	"	7.1	"	"	8.0
69897	-0.52	"	"	10.0	"	"	8.5
203608	-0.68	0.30	0.004	25	"	0.004	16
"	"	"	"	25	"	0.001	25+
63077	-0.80	"	"	25	"	0.004	18
"	"	"	"	25	"	0.001	25+

solar composition, metal-rich stars and moderately metal-poor disk stars are well mixed and do not segregate on different ZAMS as extreme metal-poor stars do.

We have interpreted this result by suggesting that in these stars there is a concomitant variation of Y and Z, tending to cancel the displacement of the ZAMS that one should observe if Z was varying alone. Based on Hejlesen's evolutionary models (Hejlesen, 1975), that would be the case with a related variation of Y with Z: $\Delta Y \simeq 5\Delta Z$.

Age determinations have been obtained for subgiants lying 0.5 to 2.0 magnitudes above the ZAMS. Needless to say, the knowledge of the proper ZAMS to be used in age determinations is quite important, especially for the subgiants close to the lower limit $(0\overset{m}{.}5)$. Therefore we have decided to see how our results were affected by using a different theoretical grid.

We seized the opportunity to check our results with the publication of the tables of isochrones by Ciardullo and Demarque (1977).

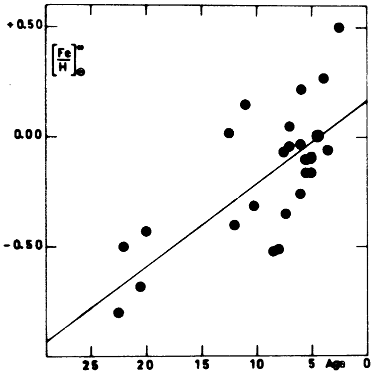

Fig. 2a. $[Fe/H]^*_\odot$ versus Age diagram (Demarque).

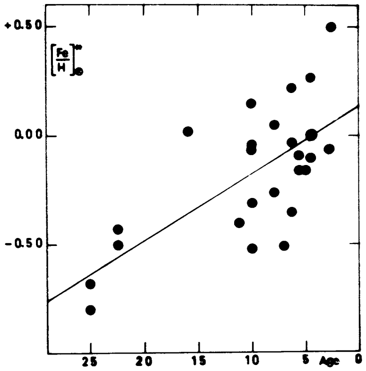

Fig. 2b. $[Fe/H]^*_\odot$ versus Age diagram (Hejlesen).

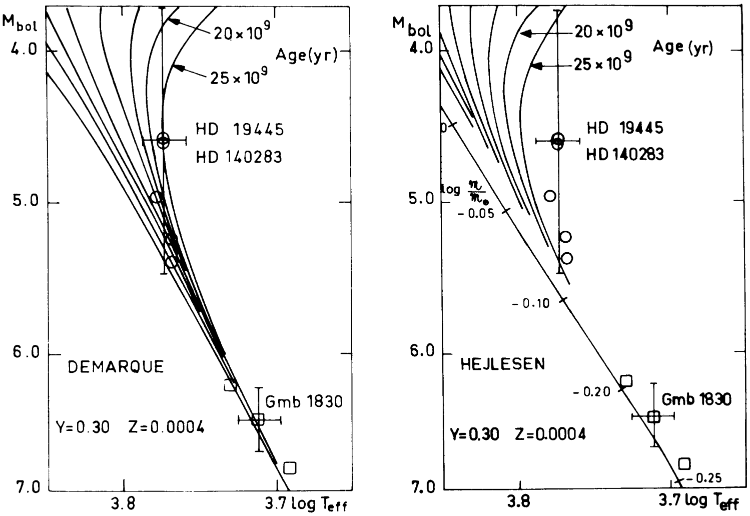

Fig. 3a and 3 b. Observational and theoretical (log T_{eff}, M_{bol}) diagrams for halo stars.

In Fig. 1, a comparison is made between the grid of isochrones computed by Hejlesen with that by Demarque. The full lines represent the isochrones of Hejlesen, the broken lines those of Demarque. The ages for which these grids of models have been computed are given in units of 10^9 years. In Demarque's grid we took the 200 million year isochrone to be equivalent to a zero-age main sequence. The two grids of isochrones have not been computed with exactly the same values of Y and Z in Hejlesen and Demarque, ($Y = 0.28$, $Z = 0.02$), ($Y = 0.30$, $Z = 0.01$), respectively, because for the models of Demarque we had at our disposal only the grid ($Y = 0.30$, $Z = 0.01$) which sets the Sun at an acceptable place. The two sets of isochrones have been drawn showing the beginning of the giant branches. The differences between the two grids should be studied by specialists of internal structure.

We have studied them in an empirical way with the help of an observational HR diagram, containing stars of normal metal abundance falling in the interval: $-0.15 < [Fe/H] < +0.15$ and in the effective temperature interval: 5500 - 6500 K. The representative points of the stars have different symbols corresponding to the errors of their absolute bolometric magnitude. At the lower left side of the diagram the $2\sigma_{M_{bol}}$ bars and the average $2\sigma_{\log T_{eff}}$ bar are drawn.

We can see on the diagram that the slope of the observational ZAMS agrees somewhat better with the slope of the theoretical ZAMS of Hejlesen.

We have constructed more such composite diagrams for different chemical compositions. We have stimated the ages for stars falling in the strip $0^m\!.5$-2^m above the main sequence, and in a metal abundance interval: $-0.80 < [Fe/H] < +0.50$, 6 times less and 3 times more abundant than the normal solar metal abundance. These age estimations have been made once on the grids of Hejlesen and once on those of Demarque. In Table I these estimations are given in columns 5 and 8; column 2 contains the [Fe/H] values for the stars.

The [Fe/H] versus age relation of Demarque (left) and of Hejlesen (right) are shown in Figs. 2a and 2b. Both the diagrams are rather well populated by stars having ages between 5 and 10 billion years. For these stars the dispersion in heavy-element content is as high as a factor of 5. Even though the spread in [Fe/H] is great, an attempt has been made to derive the average enrichment of stars in the solar neighborhood from a least squares fit. The enrichment relation we obtained is very similar for Demarque and Hejlesen: The metal content grows roughly by a factor of 2 per 10 billion years. Here is is interesting to point out that the ages of the oldest disk stars with Demarque's estimation are not very much smaller than the ages with Hejlesen's.

The same can be said for the ages of the two halo subgiants HD 19445 and HD 140283: Demarque's models attribute to them a very large age, both the stars fall on the 25 billion year isochrone, as we can see in Fig. 3a (left). These two stars fall outside of this isochrone on Hejlesen's models (Fig. 3b, right), but their parallaxes are not very good.

Using the Demarque models it seems also necessary to assume the existence in the disk stars of a simultaneous variation of the helium content with the metal content, roughly: $\Delta Y \simeq 5\Delta Z$.

In conclusion, we can assert that all the results given in Perrin _et al._ (1977) based on the theoretical grid of evolutionary models of Hejlesen remain valid if we study the observational ($\log T_{eff}$, M_{bol}) diagram with Demarque's evolutionary models.

REFERENCES

Ciardullo, R.B. and Demarque, P. (1977). _Transactions of the Astronomical Observatory of Yale University_, Vol. **33**.
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DISCUSSION

DEMARQUE: I think the discrepancy you find between the main sequences can be understood in terms of the choice of mixing lengths.

CAYREL de STROBEL: Yes.

DEMARQUE: I still believe that the oldest disk clusters, such as NGC 188, appear to be much younger than the globular clusters. If you correct our evolutionary tracks to a mixing length of about 1.5 scale heights, you get excellent agreement and you find an age which is only about 5 billion years.

CAYREL de STROBEL: I don't believe that. I can get the age down by 20 to 30%, but to not less than 12 billion years. Reeves also finds an age of greater than 12 billion years for the old disk stars.

SEARS: With regard to the difference in the oldest age of clusters (Demarque), the clusters are fitted to the Hyades and the field stars have directly determined parallaxes. Perhaps that is part of the discrepancy.

McNAMARA: How do you reconcile your results, which show a dependence of metal content on age, with those of Dr. McClure, whose study of galactic clusters does not show such a correlation?

CAYREL de STROBEL: I reconciled my results (1) when I showed the great dispersion of metal content in stars having ages between ~ 5 to 10 billion years; and (2) when I showed immediately after, the age versus [Fe/H] relation between these stars and the very much older disk stars. Between these two samples there is a significant metal content enriched relationship.

TAYLER: If we really take your ages literally, even Sandage and Tammann would have to reduce their Hubble constant. Are you willing to admit that your ages may be sufficiently over-estimated to be consistent with present estimates of the Hubble constant and an open universe?

With reference to main sequences of stars with different chemical composition, if we use a mixing length theory of convection (which we know is only an approximation) can we be sure that the mixing length does not depend on chemical composition?

CAYREL de STROBEL: In answer to your first question, surely my error bars for the oldest stars are so great that I wouldn't dare touch the actual value of the Hubble constant.

With respect to your second question, I would be happy to try again to estimate the ages of the oldest disk stars and the halo stars using isochrones computed with several values of the mixing length. But they are very difficult to acquire.

BELL: The question of the mixing length for metal deficient main sequence stars could be checked using Groombridge 1830, which is known to be metal poor.

KRAFT: Is it possible that any galactic clusters which might have ages > 6 x 10^9 yr. would have been dissolved? After all, very old galactic clusters such as NGC 188 are rare. Perhaps there are field disk stars much older than the oldest known galactic cluster.

CAYREL de STROBEL: I agree with you that certainly there are very old disk stars with ages about the same as those of halo stars. But Dr. Buscombe has pointed out that we are probably wrong about the scarcity of old galactic clusters, because we can't see them very far away.

FOY: I'd like to mention that I have analyzed two stars in M67, and I have found that they are marginally metal deficient relative to the Sun. I remember that in Lausanne Mayor said that, from the point of view of dynamics, old open clusters could be peculiar, because normal ones must already have evaporated. Consequently, it would be better not to use them to determine the metal-enrichment law of the galactic disk.