HYADES DISTANCE AND CHEMICAL COMPOSITION FROM THE COMPETITIVE USE OF ASTROMETRY, PHOTOMETRY, SPECTROSCOPY, AND INTERNAL STRUCTURE COMPUTATION

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SUMMARY

An analysis of observational astrometric, photometric, spectroscopic data for the Hyades cluster is performed in order to compare Hyades G dwarfs to the sun. Internal structure computations are also used to compare the solar ZAMS with the Hyades ZAMS and to discuss the constraints existing between distance and chemical composition for the cluster.

1. INTRODUCTION

The paramount importance of the Hyades cluster for the zero point of the galactic and extragalactic distance scale has already been stressed in some former papers of this symposium. This moderately young cluster, 0.6 billion years old (Patenaude 1978), is also a very important milestone in the study of the law of the enrichment of heavy elements in the galaxy. For many years I have been interested in an accurate determination of the chemical composition, which was fairly controversial, of stars in this cluster.

Now my approach to the study of the Hyades is evolving: the still existing disagreement between photometric and spectroscopic abundances, the still uncertain distance-modulus of the cluster, the discrepancy between the masses of some of its binaries on the mass-luminosity diagram (Eggen 1967), have forced me to use in a competitive way astrometry, photometry, spectroscopy and internal structure computation in trying to make a step forward in the physical understanding of this cluster. I improved the written version of my contribution to the IAU Symposium N. 85 with results coming from the papers by Hanson (1979), Nissen (1979), and Flower (1979) presented at this symposium.

In what follows I shall first speak of the chemical abundance of some stars of the cluster as obtained from high dispersion spectroscopic analyses. Second, I shall compare spectroscopic and photometric abundance results. Third, I shall show different possibilities for the

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positions of three Hyades dwarfs on theoretical grids of ZAMS's computed with different Y and Z. I shall compare their position on empirical log (T_{eff}, M_{bol}) diagrams composed of solar neighborhood stars of solar mass, or smaller, having well-determined parallaxes. I shall finish by discussing the constraints existing between distance and chemical composition.

2. CHEMICAL COMPOSITION OF SOME STARS OF THE CLUSTER FROM DETAILED ANALYSES

Since the publication of the first papers on high dispersion analyses of some solar type dwarfs and of the four K-type giants of the Hyades by Wallerstein and Helfer (1959), Helfer *et al* (1960), Parker *et al* (1961), Wallerstein (1961), Helfer and Wallerstein (1964), I became interested in their chemical composition. I remember that we have shown (Cayrel *et al* 1970) that not only the abundance of sodium in respect to iron was enhanced in the four Hyades giants--γ, δ, ε, θ_1, Tauri--but also in two G-type dwarfs, HD 28068 (Van Bueren 63) and HD 28344 (Van Bueren 73). This result supports the statement that sodium was already enhanced in the interstellar matter from which the Hyades were formed and not endogenic. In the same paper (Cayrel *et al* 1970) we found that the iron abundance was normal with respect to the sun.

Very recently we again did (Cayrel-Bentolila 1979) an iron abundance determination of the Hyades G dwarf Van Bueren N. 64 (VB 64). This star as well as VB 63 and VB 73 analyzed by Foy (1974, 1976) is too faint to be observed with a classical high dispersion spectrograph, coudé camera. We decided, therefore, to observe them with a high dispersion echelle electronographic camera at the 1.5 meter telescope of the Haute Provence Observatory.

Figure 1 shows a composite curve of growth of the three Hyades dwarfs; VB 63, VB 64, VB 73, and of Vesta taken as comparison object for eliminating possible systematic instrumental effects. Vesta was, of course, taken with the same electronographic equipment as the Hyades dwarfs. The best populated curve of growth, VB 64, is the one for which we had the richest observational material. The abscissa of the curve of growth contains the necessary correction for the slight difference in effective temperature between the four objects. The log $X_{\odot}$ have been read on the branched solar curve of growth of Foy (1972) taking into account damping differences between different lines. Our normalisation is such that for the comparison object (in our case Vesta) ordinates and abscissae are equal on the linear part of the curve of growth. If the three Hyades stars in Figure 1 have a different iron abundance, it would be necessary to shift the three curves of growth by the logarithmic abundance difference between them and Vesta to obtain the fit with the Hyades stars. No such shift seems necessary since all the points cluster around the same curve of growth. If we claim that the Hyades have an over-abundance of iron by, for instance, 0.3 dex, we must be prepared to say that the shifted curve of growth (dotted line in fig. 1) is actually the best fit through the data points and one will have a hard

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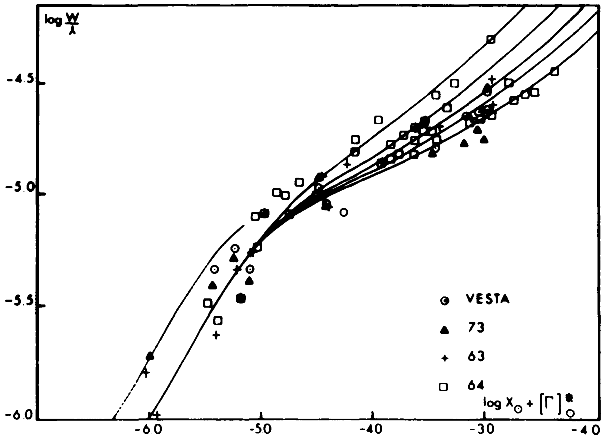

Figure 1. Composite curve of growth of the three Hyades dwarfs; VB 63, VB 64, VB 73, and Vesta taken as comparison object

time convincing me that this is the case.

3. COMPARISON BETWEEN PHOTOMETRIC AND SPECTROSCOPIC ABUNDANCES

We are following also with great interest the evolution of the discrepancy between the abundances of the heavy elements in the Hyades as found from photometric analyses and from spectroscopic detailed analyses of their atmospheres. Figure 2 shows this evolution. The central line is the zero-difference-abundance-line with respect to the sun expressed by the usual heavy element parameter [Fe/H]. On the upper side of the diagram the open squares are photometric abundance determinations as found by different authors versus the year in which these determinations have been published. On the lower side of the diagram the filled circles are spectroscopic abundance determinations as found by different authors versus the year in which they have been published. Please note that these determinations are quoted in the References. The unique filled square is an abundance value from Barry *et al* (1978) and comes from his spectral quantification method.

From Figure 2 we can see that with the exception of the spectroscopic value of Alexander (1967) the photometric [Fe/H] values are always higher than the spectroscopic ones. But, the difference between photometric and spectroscopic abundances tends to become smaller in time. If we consider Barry as photometric [Fe/H] and compare it with Cayrel-Bentolila, then we could think that there is no more difference between photometry and spectroscopy. On the contrary, if we consider Nissen's last photometric value and take Tomkin and Lambert's spectroscopic [Fe/H] value as granted, we have to admit that there is still a difference by at least 0.25 dex between the Hyades heavy element abundance as obtained by photometry and as obtained by spectroscopy.

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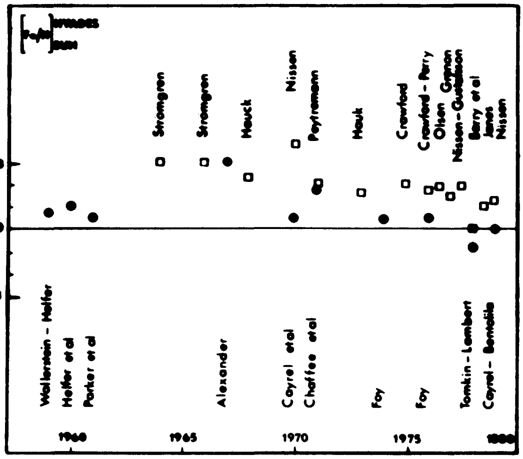

Figure 2. Comparison between photometric (open squares) and spectroscopic (filled circles) abundance determinations as a function of time.

4. COMPARISON BETWEEN OBSERVATIONAL ZAMS OF THE HYADES AND THEORETICAL ZAMS

One way to test the chemical composition of the three Hyades dwarfs and, at the same time, their distance and internal structure is to compare their position on the (log T_{eff}, M_{bol}) diagram with the position of grids of ZAMS's computed with different Y (He per unit mass) and Z (heavy elements per unit mass) values. Indeed, theoretical computations of internal structure have shown that the locus of the Theoretical Zero Age Main Sequence (ZAMS) does depend upon its initial chemical composition. They show also that a He-poor but metal normal ZAMS occupies almost the same position as a He-normal but metal rich ZAMS in the theoretical HR diagram. For more details see Cayrel de Strobel (1978).

Figure 3 shows six theoretical ZAMS in the (log T_{eff}, M_{bol}) plane computed by Hejlesen (Perrin *et al* 1977). The full lines are three ZAMS computed with different Z values, keeping constant Y; the broken lines are three ZAMS computed with different Y values, keeping constant Z. On this diagram we have also drawn 6 different possibilities for the locations in ordinates of each of the three Hyades dwarfs. The bolometric magnitude values come from six distance moduli determinations by Van Bueren (1952), Heckmann and Lübeck (1956), Hanson (1975), Klemola *et al* (1975), Hanson (1979). As we can see on Figure 3 the effective temperatures of the three dwarfs have not been varied and come from Cayrel and Bentolila (1979). On the left side of the diagram the 2 σ error bar on the logarithm of the effective temperature has been drawn. On the right side of the diagram we have given two 2 σ error bars concerning the bolometric magnitudes of the stars. One is the error bar on the bolometric magnitude as determined by Hanson (1979) from the

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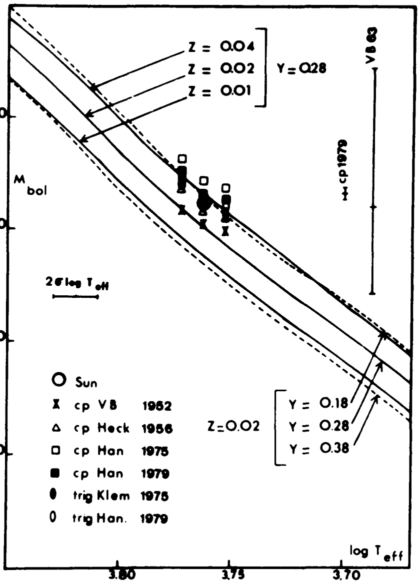

Figure 3. Comparison between theoretical ZAMS's and actual locations of three Hyades members.

converging point method, and one is the error bar as found from the individual trigonometric parallax of the dwarf VB 63. The difference between these two error bars is very high--more than by a factor of 20. Figure 3 is complemented by Table 1 which in its upper part contains some useful photometric, spectroscopic, and kinematic data for the sun and the Hyades and in its lower part the distance moduli determinations. Since the spectral type, the (B-V), and the (U-B) colors of the sun are still controversial (Hardorp 1978, Chmielewski 1979), we substituted them with question marks in Table 1.

The comparison of the observational locations of the three Hyades on the (log T_{eff}, M_{bol}) diagram with the grid of theoretical ZAMS shows that they fall either on the metal enhanced and helium normal ZAMS (Y=0.28, Z=0.04) or on the helium poor and metal normal ZAMS (Y=0.18, Z=0.02). Only the observational Van Bueren points satisfy the helium normal and metal normal ZAMS.

We have also compared the six different locations with the locations on a (log T_{eff}, M_{bol}) diagram of nearby stars having well determined parallaxes better than $\rho \geq 0.060''$ and a determination of the heavy elements abundances as represented by the logarithmic [Fe/H] ratio from detailed analyses. Figure 4 shows this comparison, together with the 6 theoretical ZAMS's of Hejlesen. On this diagram the open circles represent metal deficient stars by no more than 0.6 dex, the crosses metal normal stars, the filled circles metal enhanced stars. The sun is represented with its actual symbol. The Hyades seem to occupy the region of the already slightly evolved metal poor and metal normal stars. The Hyades being about 10 times younger than the intermediate and old disk stars are surely not evolved because following, for instance, Iben (1967), the life time on the ZAMS for stars having about one solar mass is higher than 6 billion years.

Having at our disposal theoretical grids of ZAMS's computed by Hejlesen (1977), we have been interested in establishing for a range of masses around the solar type Hyades dwarfs, the differences in M_{bol} and in effective temperature between a metal enhanced ZAMS (by 0.17 dex) and a solar ZAMS, and between a He-poor ZAMS (by -0.17 dex) and a solar ZAMS. The upper part of Table 2 contains these differences in columns 6 and 7, and 10 and 11, respectively. For instance, for a 1 solar mass model the

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TABLE 1

PHOTOMETRIC SPECTROSCOPIC KINEMATIC ASTROMETRIC DATA FOR SUN AND HYADES

HD	-	28344	28068	28099
star	SUN	VB 73	VB 63	VB 64
m_V	-26.74	7.85	8.06	8.12
sp	?	G1V	G2V	G6V
(B-V)	?	0.60	0.63	0.66
(U-B)	?	0.13	0.17	0.20
T_{eff}	5790 K	5930 K	5800 K	5660 K
log T_{eff}	3.763	3.773	3.763	3.753
μ_α	-	0.131"	0.128"	0.118"
μ_δ	-	-0.010"	-0.014"	-0.024"
R_V	-	41.0 Kms^{-1}	43.5 Kms^{-1}	40.8 Kms^{-1}
M_{bol}	4.75			
$(m-M)_{cp}$ Van Bueren 1952		3.03	3.03	3.03
M_{bol}		4.83	4.96	5.02
$(m-M)_{cp}$ Heckmann 1956		3.14	3.14	3.14
M_{bol}		4.65	4.85	4.91
$(m-M)_{cp}$ Hanson 1975		3.42	3.42	3.42
M_{bol}		4.37	4.57	4.63
$(m-M)_{cp}$ Hanson 1979		3.31	3.31	3.31
M_{bol}		4.48	4.68	4.74
$(m-M)_{trig}$ Klemola 1975		3.19	3.19	3.19
M_{bol}		4.60	4.80	4.86
$(m-M)_{trig}$ Hanson 1979		3.25	3.25	3.25
M_{bol}		4.54	4.74	4.80

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ΔT_{eff} between metal enhanced and solar models is as high as -320 K and for He-poor and a solar model as high as -760 K.

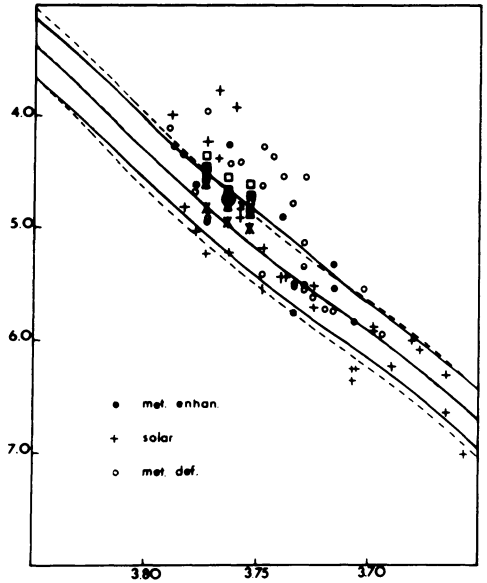

Figure 4. Comparison between an observational ZAMS composed of nearby stars with good parallaxes and well determined [Fe/H] ratios, and the actual location of three Hyades members together with the 6 theoretical ZAMS of Hejlesen.

We have also been interested in establishing the differences ΔM_{bol} and ΔT_{eff} on a grid of ZAMS's computed by Flower (1979). This grid appealed especially to us because one of the ZAMS has been computed with an increased opacity with respect to that of Cox and Stewart (1970a, 1970b).

We see from Table 2 that models by Hejlesen and by Flower corresponding to equal masses differ significantly in effective temperature and M_{bol}. This can be seen also in Figure 5 which compares three ZAMS's of Hejlesen with ZAMS's of Flower and which shows the locations of the three Hyades dwarfs. The slope of the ZAMS's computed by Flower is steeper than that of the ZAMS's of Hejlesen.

Finally we have been interested in establishing with the help of Hejlesen models the mass of the Hyades dwarf VB 63 as a function of (Y, Z) and M_{bol}, or as a function of (Y, Z) and T_{eff}. Table 3 contains in columns 3, 4, 5, 6, 7, 8 the mass results from each of the six previously chosen M_{bol} values. Column 9 contains the masses resulting from the effective temperature found for VB 63. Because of the large uncertainty on the distance modulus several solutions are possible:

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TABLE 2

GRID OF THEORETICAL ZERO AGE MAIN SEQUENCES ACCORDING TO HEJLESEN AND FLOWER

HEJLESEN

$M/M_\odot$	solar ZAMS Y=0.29 Z=0.02 l/Hp=2.0		metal enhanced ZAMS by +0.17 dex Y=0.27 Z=0.03 l/Hp=2.0				He-poor ZAMS by −0.21 dex Y=0.18 Z=0.02 l/Hp=2.0			
	M_{bol}	T_{eff}	M_{bol}	T_{eff}	ΔM_{bol}	ΔT_{eff}	M_{bol}	T_{eff}	ΔM_{bol}	ΔT_{eff}
0.79	5.93	5050 K	6.19	4730 K	+0.26	-320 K	6.58	4415 K	+0.65	-635 K
0.89	5.31	5550	5.58	5200	+0.27	-350	6.00	4775	+0.69	-775
1.00	4.72	6010	4.97	5690	+0.25	-320	5.38	5250	+0.66	-760
1.12	4.13	6440	4.35	6150	+0.22	-290	4.77	5740	+0.64	-700
1.26	3.52	6920	3.74	6580	+0.22	-340	4.16	6210	+0.64	-710

FLOWER

	solar ZAMS Y=0.20 Z=0.018 l/Hp=1.36		metal enhanced ZAMS by +0.30 dex Y=0.20 Z=0.036 l/Hp=1.36				solar ZAMS with opacities increased by 20% Y=0.20 Z=0.018 l/Hp=1.36			
0.80	6.33	4930 K	6.61	4620 K	+0.28	-310 K	6.54	4730 K	+0.21	-200 K
0.90	5.75	5320	6.04	4980	+0.29	-340	5.97	5105	+0.22	-215
1.00	5.22	5660	5.51	5320	+0.29	-340	5.44	5445	+0.22	-215
1.10	4.73	5960	5.02	5625	+0.29	-335	4.96	5740	+0.23	-220
1.25	4.06	6380	4.34	6010	+0.28	-370	4.30	6125	+0.24	-255

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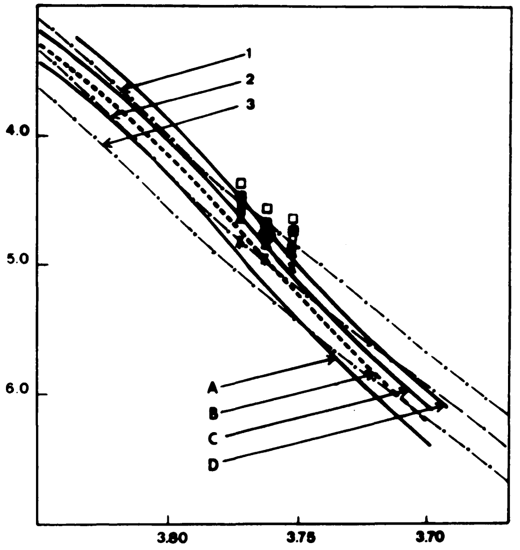

Figure 5. Comparison between ZAMS's of Hejlesen (numbered lines) and ZAMS's by Flower (lettered lines). The corresponding values of (Y, Z) are: (0.26, 0.04) for curve 1, (0.28, 0.02) for curve 2, (0.29, 0.01) for curve 3, (0.252, 0.018) for curve A, (0.202, 0.018) for curve B, (0.202, 0.018) for curve C, (0.202, 0.036) for curve D.

(Y, Z)=(0.28, 0.02) with $M/M_{\odot}$=0.95, or (Y, Z)=(0.27, 0.03) with $M/M_{\odot}$=1.03, or (Y, Z)=(0.26, 0.04) with $M/M_{\odot}$=1.08, or (Y, Z)=(0.18, 0.02) with $M/M_{\odot}$=1.14. However, solutions with Z=0.04 are only marginally acceptable in view of the most recent determination of [Fe/H].

TABLE 3

MASS OF VB 63 AS A FUNCTION OF (Y, Z) AND M_{bol} OR T_{eff}

		M_{bol}						T_{eff}
Y	Z	VB 1952 4.96	Heck 1956 4.85	Klem 1975 4.80	Han 1979 4.74	Han 1979 4.68	Han 1975 4.57	5800 K
0.38	0.02	0.83	0.85	0.86	0.87	0.88	0.89	0.78
0.28	0.02	0.95	0.97	0.98	0.99	1.01	1.03	0.95
0.27	0.03	1.00	1.03	1.04	1.05	1.06	1.08	1.03
0.26	0.04	1.04	1.06	1.07	1.08	1.11	1.12	1.08
0.18	0.02	1.08	1.10	1.12	1.14	1.16	1.17	1.14

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CONCLUSION

The differential detailed analyses carried out very recently of three Hyades solar type dwarfs confirm previous spectroscopic analyses which attributed to the Hyades the same iron content as to the sun. However, the comparison between photometric and spectroscopic abundance determinations still shows a slight difference, but by no more than +0.15 dex. One way to arbitrate between photometry and spectroscopy is to study the location of these dwarfs on a theoretical (log T_{eff}, M_{bol}) diagram. In this paper such an attempt has been done, but it was made difficult by the imprecision on the distance modulus of the Hyades.

If one trusts the 2 σ error bar by the converging point method and if one disregards evolutionary effects, the comparison between the observational and theoretical ZAMS shows that Hyades dwarfs fall either on a metal enhanced and helium normal ZAMS, or on a helium poor and metal normal ZAMS. One solution could also be that the Hyades have normal [Fe/H] ratios, but slightly different C, N, O, Na, Ca, Mg abundances, which could affect their photometric abundance determinations. Yet, if Cox and Stewart opacities must be raised by 20% (as done by Flower), the Hyades could be both metal and helium normal. It seems excluded that the Hyades are helium rich.

The comparison between Hejlesen and Flower grids of ZAMS's shows a significant disagreement. One way to test which grid has a better imput physics is to analyse in detail dwarfs significantly cooler than the three we have discussed. If the new photocounting technique will allow to do high dispersion spectroscopy on such faint stars, the remaining difficulty is the still uncertainty of their distance.

A gain by an order of magnitude or better in the individual trigonometric parallaxes would solve the problem of the distance of the cluster and allow to locate the Hyades on their appropriate ZAMS and to better understand their internal structure.

Such an important increase in accuracy can be obtained with the help of the astrometric satellite Hipparcos.

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DISCUSSION

LYNGA: Does Dr. Nissen wish to make any comments on this?

NISSEN: Yes, I think that most of the difference between the photometric and spectroscopic results can be explained in terms of different temperature scales. I mean a difference of just a hundred degrees can explain most of the difference. And in this connection I wonder how such an uncertainty in the temperatures would affect your conclusions from the log T, M_{bol} diagram?

CAYREL: Of course, the effective temperatures of the three solar-type Hyades stars are affected by an uncertainty of about $60^{o}K$. But the error bar in M_{bol} is infinitely greater. It is this error which prevents any firmer conclusion on the position of these Hyades stars in a Log T_{eff}, M_{bol} diagram. If we could have results from the European astronomical satellite instead of three *miserable* little *etoiles*, this error could be reduced drastically.

DEMARQUE: I have two questions. One, have you looked into the effects of evolution? Have you applied any evolutionary corrections to your composition of these stars, because it might not be negligible?

CAYREL: No. The only data I have, because you are too lazy (laughter), are the data of Iben and his data do not show any evolutionary effects.

DEMARQUE: But we do have! We have had our isochrones published for two years now!

CAYREL: I know, but not tables (laughter).

DEMARQUE: The other question is, have you looked into the mass-luminosity relation, because the real use of stellar interiors is really the combined use of the H-R diagram and the mass-luminosity relation?

CAYREL: Now this is more a classroom study and not a study for the big scientist. (Laughter). Qualitatively we can say that, for stellar models having the same mass and the same heavy element content, the He-rich model is more luminous and hotter than the He-poor model. Quantitatively, we can say that the difference between a He-rich and a He-poor model having the same mass, say $1M_{\odot}$, and differing by a factor of two in the content is:

$$\Delta T_{eff} \approx + 700^{o}K,$$

$$\Delta T_{bol} \approx - 1.34 \text{ mag.}$$

We have just seen that even such a great difference in bolometric magnitude is not sufficient if we want to estimate the He content of the Hyades in this indirect way. This is because of the very high 2σ trigonometric parallax error bars found for the three Hyades dwarfs.

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DEMARQUE: So you don't think there is anything wrong with the models?

CAYREL: No, no.

FLOWER: Let me comment on the use of theoretical main-sequence models to infer a metallicity for the Hyades cluster. Small changes in the assumed temperature scale used to compare models with observations or in the stellar opacities employed result in rather drastic changes in the inferred metallicity. For instance, shifting the zero point of the temperature scale from a solar color index of 0.63 mag to 0.67 mag will decrease the inferred Hyades metallicity by a factor of two; or, a slight increase of just 20% in interior opacities reduces inferred metallicities by a factor of 1.2. Hence, one may find it difficult to emphasize metallicities inferred from theoretical main-sequence models.

CAYREL: No, because I am absolutely sure the *B-V* will go down again, and will not be staying at 0.66. The good value is something like 0.63. Of course, I have my opinions. A paper that is coming out from the Geneva photometry will show you almost exactly that the *B-V* goes down again, and I think that Grenon can comment on this, because I am not a photometrist. (To Grenon). You are also thinking it's 0.62?

GRENON: That's right. I should be very careful.

STRAIZYS: The use of different models does not affect your results?

CAYREL: No. At Symposium 80 in Washington about the H-R diagram we have given our results on this point.

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