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EFFECTIVE TEMPERATURES, RADII AND BOLOMETRIC MAGNITUDES OF Ap AND Am STARS

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Abstract. The effective temperatures, radii and bolometric magnitudes of Ap, Am and normal A stars have been estimated from their energy distribution curves between 478 nm and 680 nm. All the Am stars and one Ap star (i.e. β CrB) were found to be affected by line blanketing, a rough estimation of which in the respective $(B-V)$ colours has been found out in each case.

The range in effective temperature is 0.45–0.60 in terms of θ_e $(=5040/T_e)$, while it is 1.8–4.8 $R_\odot$ in the case of radius, that in bolometric magnitude being from $-0^m.67$ to $+1^m.61$. An approximate estimate of the masses shows that they are between 1.5 and 3.0 $M_\odot$. All these estimates are in agreement with those of the normal A stars. The Ap and Am stars are found to be slightly evolved and, therefore, are probably in the hydrogen shell-burning phase.

1. Introduction

In this extension of our earlier work (Babu, 1976, 1977), we have determined the effective temperatures, radii and bolometric magnitudes of twenty-one A stars (including Ap, Am and normal A stars) from their energy distribution curves obtained by the same instrumentation and observational techniques employed earlier. The basic data of these stars are given in the first six columns of Table I.

It has already been shown (Babu, 1976, 1977; Wolff, 1967a, b) that, in the visible region, the physical parameters of Ap and Am stars are not significantly different from those of normal A stars. On the other hand, since the abnormal abundances of certain elements in Ap and Am stars constitute the main differences between them and the normal A stars, one expects the respective energy distribution curves to show various amounts of blanketing effects, particularly towards the shorter wavelengths. On this basis an attempt has also been made to estimate the blanketing effects, if any, in the colours of these stars.

Finally, the evolutionary aspects of these stars are discussed and their masses estimated.

2. Results

2.1. Effective temperatures

The standard magnitudes of the program stars normalized to 555.5 nm are plotted in Figures 1(a) and 1(b), where the probable errors in the observed magnitudes are less than $\pm 0^m.02$. The reduction techniques are the same as those described earlier (Babu,

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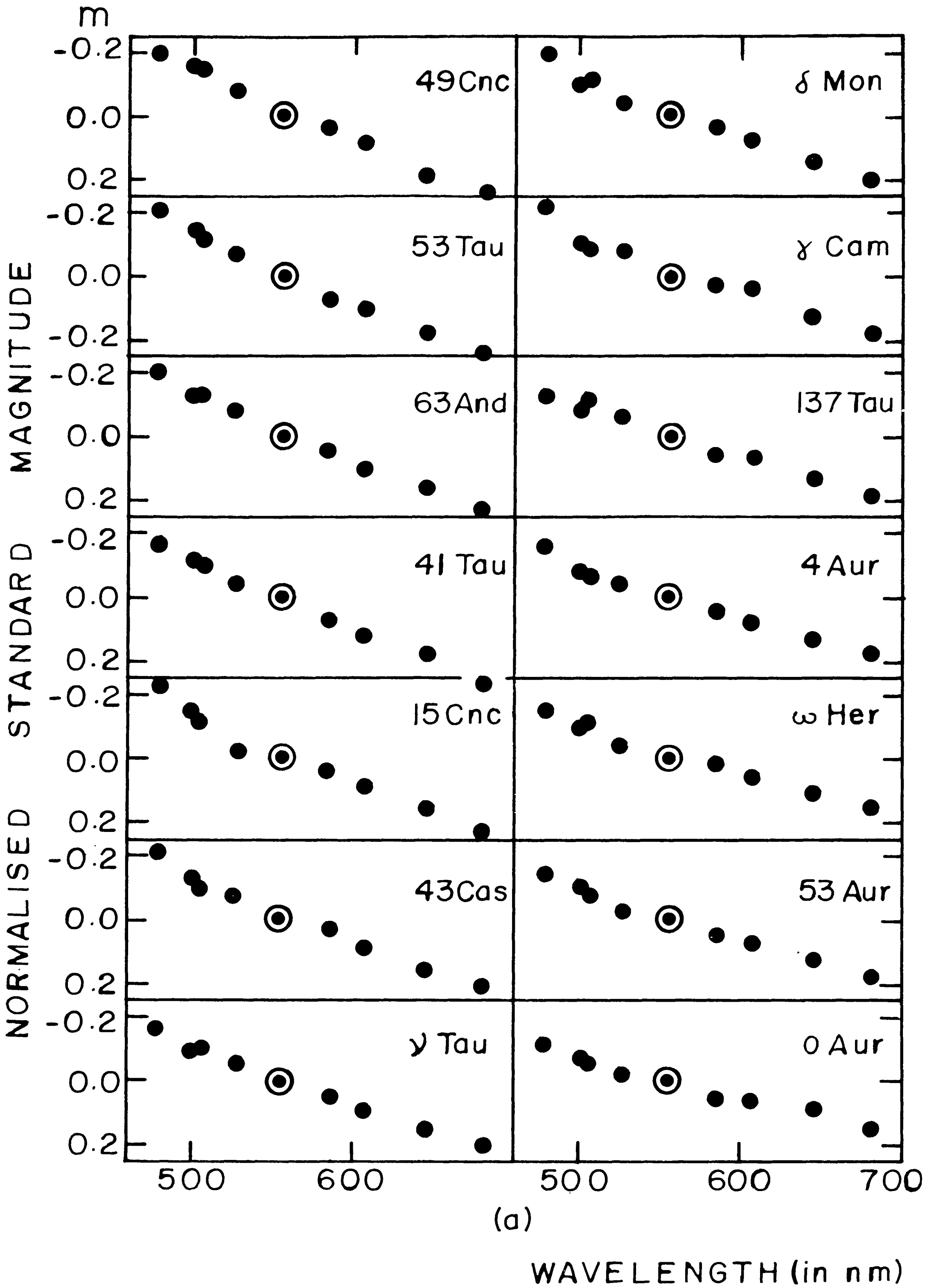

(a)

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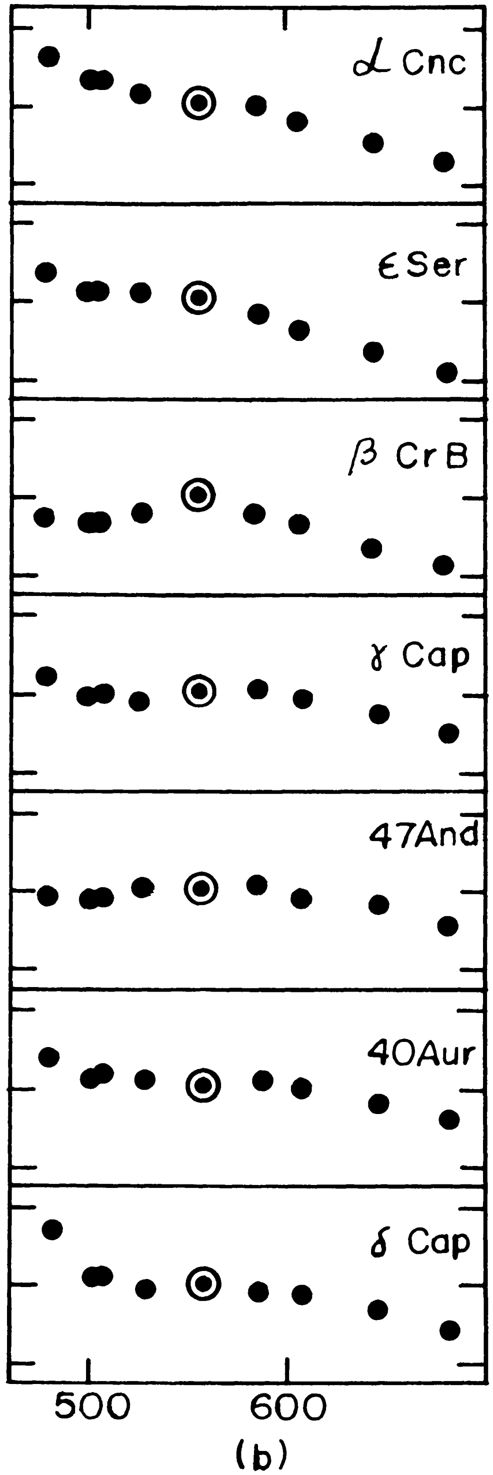

Fig. 1. (a) The energy distribution curves of those program stars which have no apparent blanketing effects. The ordinate represents the standard magnitudes, the normalization having been done at 555.5 nm, which is denoted by a dot in a circle. (b) The energy distribution curves of those program stars, which show blanketing effects.

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TABLE I

HR No.	Name	Sp. Type[4]	$\pi^{(1)}$	$m_v^{(2)}$	$(B-V)^{(5)}$	θ_e	$R/R_\odot$	M_{bol}	B.C.	$(B-V)_{\theta_e}$
395	47 And	A1m	0″.016	5^m.49	0^m.26	0.60	2.3	1^m.31	−0^m.20	−0^m.14
478	43 Cas	A0p	0.011	5.59	−0.06	0.51	2.6	0.34	−0.46	
682	63 And	B9p	0.011	5.58	−0.13	0.47	2.3	0.25	−0.54	
1148	γ Cam	A2IV	0.010	4.62	0.02	0.55	4.8	−0.67	−0.29	
1251	ν Tau	A1V	0.076	3.90	0.03	0.54	2.5	0.67	−0.30	
1268	41 Tau	B9p	0.910	5.19	−0.12	0.47	2.8	−0.18	−0.58	
1339	53 Tau	B8p[3]	0.008	5.28	−0.05	0.49	3.8	−0.66	−0.46	
1592	4 Aur	A1V	0.016	4.93	0.05	0.56	2.7	0.66	−0.20	
1971	o Aur	A0p	0.014	5.47	0.04	0.60	2.6	1.04	−0.16	
2033	137 Tau	B9p	0.007	5.54	−0.04	0.55	4.5	−0.53	−0.30	
2143	40 Aur	A4m	0.017	5.27	0.23	0.60	2.4	1.22	−0.20	0.14
2425	53 Aur	B9p	0.009	5.51	0.03	0.57	3.7	0.05	−0.23	
2714	δ Mon	A2V	0.018	4.14	−0.01	0.54	3.2	0.13	−0.29	
3215	15 Cnc	B9p	0.010	5.63	−0.07	0.48	2.6	0.07	−0.56	
3465	49 Cnc	A1p	0.011	5.66	−0.10	0.45	2.2	0.16	−0.71	
3572	α Cnc	A5m	0.033	4.25	0.17	0.56	1.8	1.54	−0.30	0.06
5747	β CrB	F0p[3]	0.032	3.66	0.27	0.54	2.3	0.85	−0.34	0.02
5892	ε Ser	A2m	0.038	3.73	0.14	0.54	1.8	1.38	−0.25	0.02
6117	ω Her	B9p	0.028	4.56	0.01	0.56	1.8	1.54	−0.26	
8278	γ Cap	Am[3]	0.030	3.66	0.32	0.58	2.7	0.81	−0.24	0.10
8322	δ Cap	Am	0.063	2.83	0.23	0.60	2.0	1.61	−0.22	0.14

References; Except where indicated against individual stars, the data are taken from the reference indicated in the column heading: (1) Bečvář (1964); (2) Hoffleit (1964); (3) Osawa (1965); (4) Cowley *et al.* (1969); (5) Blanco *et al.* (1970).

1976), the standard stars being α Lyr, γ Gem and α Leo. The calibration of α Lyr given by Hayes and Latham (1975) has been used. In order to estimate the effective temperatures (T_e) of the program stars, the slopes of these energy curves were then compared with those of the theoretical models for the case $\log g = 4.0$ given by Mihalas (1966). The results are given in Table I under the heading θ_e ($= 5040/T_e$). To obtain these slopes, the complete range of the observed energy distribution curves have been used for all the four normal A and ten Ap stars (Figure 1(a)), while for the remainder (one Ap and six Am, Figure 1(b)), the abnormal depression of the energy distribution curves shortward of 555.5 nm forced us to consider only the remaining available range of about 125 nm on the longer wavelength side. The error in temperature determination is about ± 0.02 in θ_e for the former category, while it is expected to be slightly larger for the latter.

The effective temperatures for seven of the program stars (41 Tau, 53 Tau, o Aur, 15 Cnc, β CrB, ω Her and γ Cap) have been estimated previously by several authors (Searle and Sargent, 1964; Baschek and Oke, 1965; Auer *et al.*, 1966; Mihalas and Henshaw, 1966; Wolff, 1967a, b; Jugaku and Sargent, 1968; Durrant, 1970; Babu, 1971; Mégessier, 1971; Stift, 1973). For the remainder of the stars, we believe that effective temperatures have been estimated for the first time.

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2.2. Radii

Following the procedure adopted earlier (Babu, 1977), we have estimated the radius of each star as the mean of those calculated at five different wavelengths, namely $\lambda =$ 555.5, 584.0, 605.5, 643.5 and 680.0 nm. The standard deviation of these averages, in each case, is found to be less than 2%, indicating that the radii are essentially uniform at the wavelengths considered. The results are given under $R/R_\odot$ in Table I

The average uncertainty in these radii is estimated to be about 25% from a study of the relationship between $B-V$ and $\log(R/R_\odot)$, a major portion of which is due to the uncertainties in the respective parallax measurements. However, for five stars (viz. γ Cam, 53 Tau, 137 Tau, 53 Aur and ω Her) the uncertainty is of the order of 50%, caused by the still larger uncertainty in their parallaxes. The estimated radii are within the range of 1.4–4.9 $R_\odot$ mentioned by Catalano and Strazzulla (1975).

2.3. Bolometric magnitudes and bolometric corrections

Using the derived effective temperatures and radii, we have calculated the absolute bolometric magnitudes M_{bol} based (see Allen, 1973) on the relation

$$M_{\text{bol}} = 42.36 - 10 \log T_e - 5 \log \frac{R}{R_\odot}$$

TABLE II

Revised absolute bolometric magnitudes and bolometric corrections for stars studied earlier (Babu, 1977).

HR No.	Star	Sp. Type	M_{bol}	B.C.
15	α And	B9p(III)	$-1^{\text{m}}.13$	$-0^{\text{m}}.74$
707	ι Cas	Ap	0.61	−0.24
1389	68 Tau	A2mIV	0.88	−0.36
1458	88 Tau	Am	1.45	−0.18
1544	π^2 Ori	A0V	0.95	−0.39
1570	π^1 Ori	A0p	0.66	−0.23
1672	16 Ori	Am	1.53	−0.17
2029	ξ Aur	A2p	0.48	−0.32
2088	β Aur	A2V	0.01	−0.38
2095	θ Aur	B9.5pV	−0.72	−0.67
2148	17 Lep	A2p	2.31	−0.19
2155	θ Lep	A1V	0.41	−0.41
2763	λ Gem	A3V	1.55	−0.27
4752	17 Com A	Asi	0.56	−0.55
4825	γ Vir N	F0V	2.58	−0.15
4915	α^2 CVn	B9.5pV	−0.91	−0.80
5105	78 Vir	Ap	0.59	−0.36

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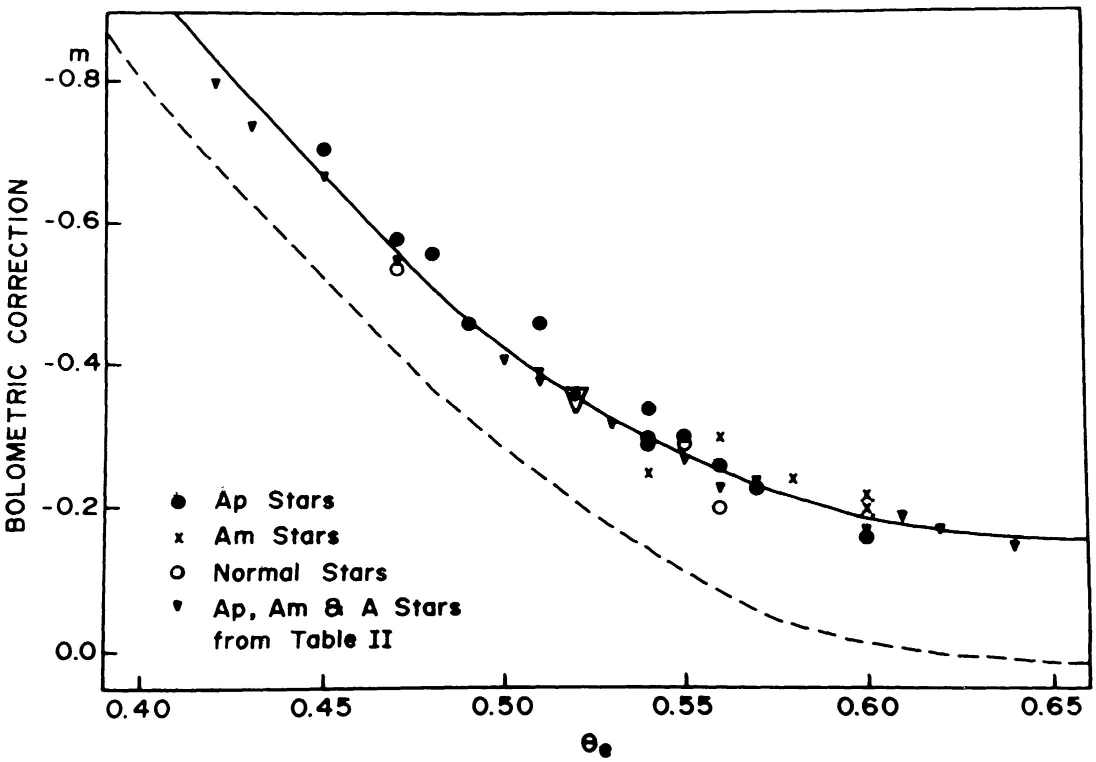

Fig. 2. Relationship between θ_e and bolometric corrections. The dashed line represents the relationship given by Code *et al.* (1976) for Main Sequence stars and the solid line represents the relationship obtained by us.

and, thence, the bolometric corrections for all the program stars have been obtained. These are listed under M_{bol} and B.C. in Table I.

However, in an earlier paper (Babu, 1977) the expression used for bolometric magnitudes was that given by Heintze (1973), where the constant term in the above formulation was taken as 41.414. The change is due to the revised values of effective temperature and bolometric magnitude of the Sun (Allen, 1973). Because of this change, and for the sake of uniformity, the bolometric magnitudes and bolometric corrections for 17 stars discussed in Babu (1977) have been recomputed by application of the resulting correction of $-0\overset{m}{.}054$, and are listed in Table II.

In Figure 2, we have plotted θ_e against the bolometric correction (B.C.), in which the curve given by Code *et al.* (1976), shown by a dashed line, is also included for comparison. Our data have been found to fit the following expression which has been generated by a least-squares solution

$$\text{B.C.} = -12.98\theta_e^2 + 16.77\theta_e - 5.58,$$

shown in the figure by a solid line.

It may be noted that this curve lies systematically by about $0\overset{m}{.}15$ above the curve given by Code *et al.* (1976), which indicates that the constant chosen by us in estimating B.C., or that chosen by Code *et al.* (1976), needs some modification.

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3. Discussion

3.1. Blanketing Effects

Figure 3 shows a plot between B–V and θ_e for the program stars. Even though β CrB and γ Cap have been assigned the spectral type of F0p (Osawa, 1965), we have denoted them as Ap and Am, respectively, based on their abundance peculiarities.

In this figure it can be seen that while all the Ap and normal A stars fall on or below the temperature scale given for Main Sequence stars (Code *et al.*, 1976), the Am stars fall much above the general trend giving distinct indication of a reddening effect in their colours. These latter stars with their high abundances of metals are expected to show effects of line blanketing. The abnormal depression of their energy distribution curves for wavelengths shorter than 555.5 nm, which obviously is the effect of the reddening in their B–V colours, confirms this. The one Ap star which also lies far off the trend and in the vicinity of the Am stars, is β CrB. The fact that this star is heavily blanketed has already been shown by Wolff (1967a). The B–V values based on θ_e of these seven stars, as obtained from the above-mentioned temperature scale, are given in Table I under $(B\text{–}V)_{\theta_e}$. Thus, the difference between $(B\text{–}V)_{\theta_e}$ and the observed B–V would be the approximate blanketing effect in the colour of a given star, which may be checked with the aid of the respective spectrum. Since the other stars do not show this reddening effect, it appears that their line blanketing does not extend to the blue:

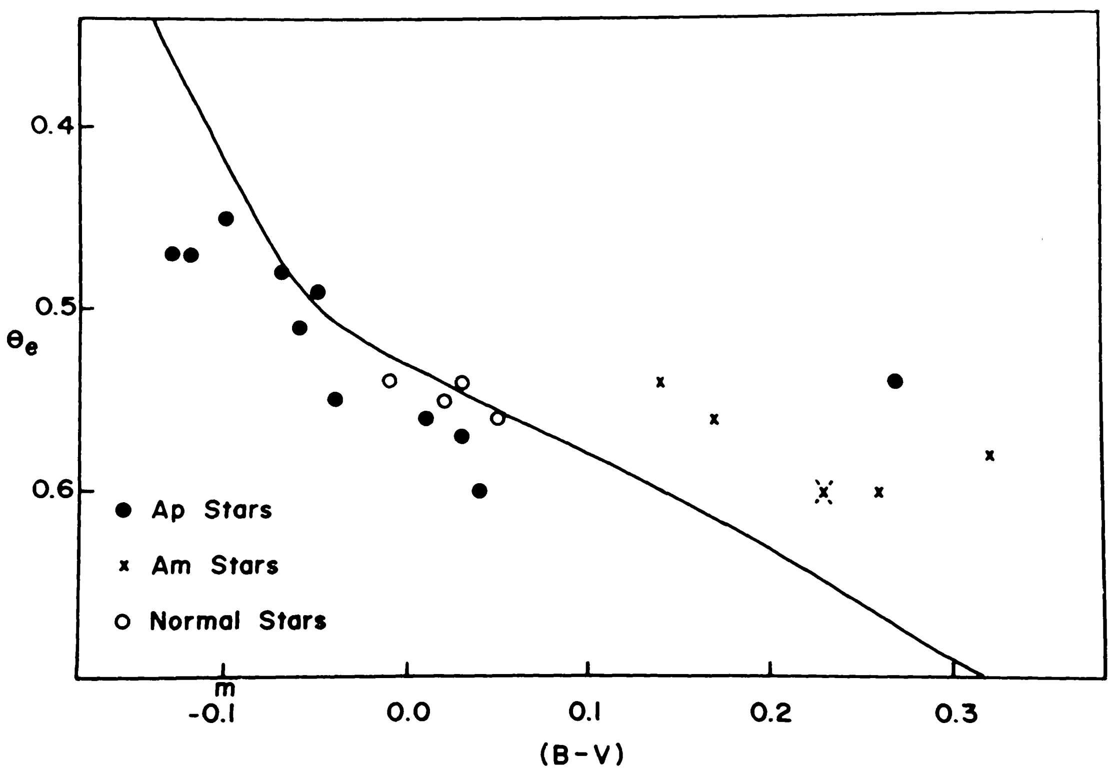

Fig. 3. Relationship between B–V and θ_e. The temperature scale (Code *et al.*, 1976) is shown by the solid line.

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if at all present, it is probably confined to the ultraviolet region; which can only be confirmed from observations of these stars outside the Earth's atmosphere.

However, in a severely blanketed star, the consequent backwarming would raise the continuum in the longer wavelength region, in such a way that the Paschen slope gives a steeper gradient. Thus, the values of θ_e obtained on the basis of such slopes are expected to be only the upper limits, and a complete blanketed model must be computed before the observed data can be used for better estimates of effective temperatures.

In the present study, the interstellar extinction has been assumed to be negligible because of the proximity of the program stars.

3.2. Evolutionary aspects

In Figure 4 we have plotted $\log T_e$ versus M_{bol} to study the evolutionary aspects of these stars. The evolutionary tracks given by Iben (1967a, b) have been chosen for comparison, while the boundaries of the Main Sequence are shown by the dashed lines (Novotny, 1973).

It can be seen from this figure that while only five (three Ap and two Am) stars are located within the boundaries of the Main Sequence, eleven (five Ap, four Am and two A) are very near or just above the upper boundary, and the remaining five (three

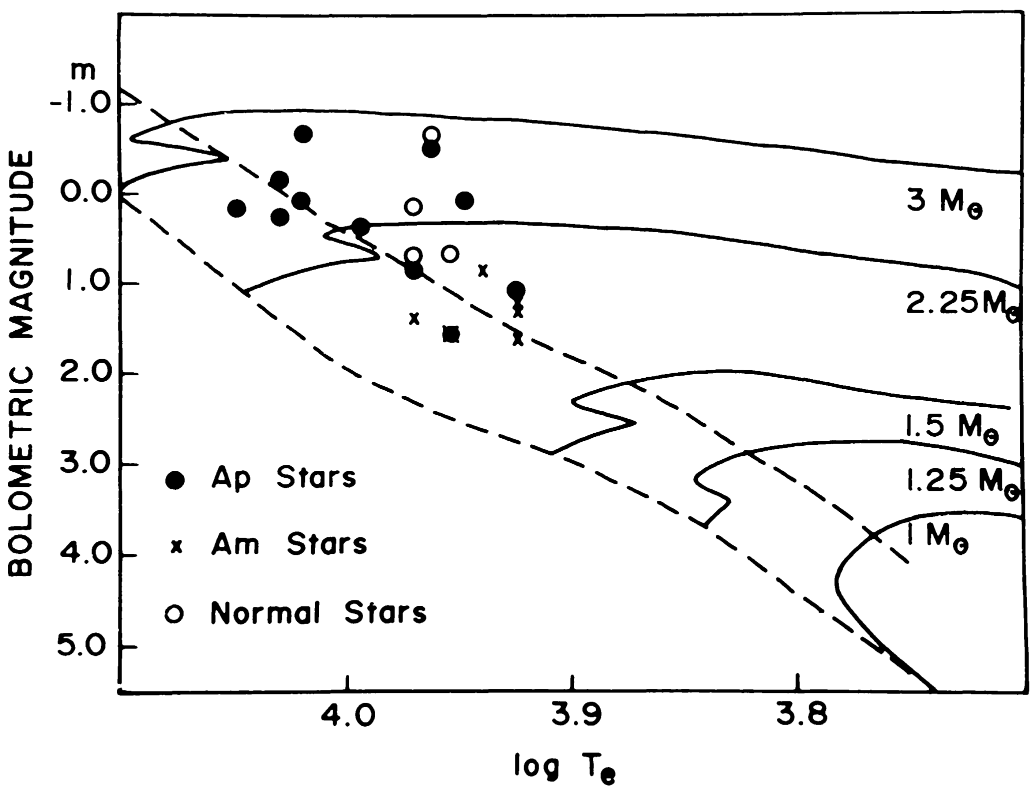

Fig. 4. Relationship between $\log T_e$ and bolometric magnitudes. The evolutionary tracks are from Iben (1967a, b), while the Main Sequence band is shown by the dashed lines (Novotny, 1973).

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Ap and two A) are clearly above the Main Sequence. Thus, the program stars, in general, appear to be slightly evolved or are in the process of just leaving the Main Sequence. This position of Ap and Am stars may represent the transitional phase towards yellow giants as suggested by Eggen (1957).

Although it is difficult to locate the masses of the individual stars from this diagram, it can be seen that most stars are situated from a little above 1.5 $M_\odot$ to about 2.25 $M_\odot$, while four (63 And, 41 Tau, 15 Cnc and 49 Cnc) are about midway between 2.25 $M_\odot$ and 3 $M_\odot$, which is a reasonable estimate for A type stars (Allen, 1973). The three remaining stars (γ Cam, 53 Tau and 137 Tau), with nearly 3 $M_\odot$ each, belong to either late B spectral type or to luminosity class IV.

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