RADII OF SOME Ap, Am AND A STARS

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Abstract. Based on the observed energy curves of nine Ap stars, three Am stars, four normal A stars and one F0 V magnetic star, their radii have been estimated.

Thence, the bolometric magnitudes M_{bol} have been obtained and a plot between log T_e and M_{bol} of these stars shows that a majority of Ap and Am stars are a little above the zero-age Main-Sequence, suggesting that they are slightly more evolved as compared to the normal A stars.

The bolometric corrections derived from the above M_{bol} are much closer to those computed by Mihalas than to the ones given by Davis and Webb, the latter being about $0^{m}.1$ more negative than the former.

1. Introduction

The direct determination of stellar radii with intensity interferometric techniques, pioneered and developed by Hanbury Brown and his collaborators (1967) is restricted only to stars brighter than $m_{vis} = +2^{m}.0$. An alternative, though less precise, method developed by Gray (1967) can be applied to much fainter stars, the only requirements being their energy distribution curves and parallaxes. This involves the comparison of the observed energy curve of a star with those predicted from model atmosphere computations. This method has the advantages that it uses only the visual region of the spectrum and does not depend on bolometric corrections. In fact, one can estimate the bolometric corrections if the radii are known independently.

Using Gray's method, the radii of nine Ap stars, three Am stars, four normal A stars and one F0 V magnetic star have been estimated. These stars are listed in Table I.

2. Procedure

The radius of a star is given (Gray, 1967) by the relation

$$R/R_{\odot} = 44.33 \times 10^{6}(F_{\nu}/\mathscr{F}_{\nu})^{1/2}p^{-1} \tag{1}$$

where p is the parallax of the star, while F_{ν} and $\mathscr{F}_{\nu}$ are its observed and computed monochromatic fluxes (in erg s^{-1} cm^{-2} Hz^{-1}). In terms of observable quantities,

$$\log F_{\nu} = -0.4[\{(\Delta m_{\nu})_{obs}\}_{star} + \{(\Delta m_{\nu})_{obs} - (\Delta m_{\nu})_{cal}\}_{stand} + m_{vis} - 48.6098] \tag{2}$$

and

$$\log \mathscr{F}_{\nu} = -0.4[M_{\nu} - 1.2429], \tag{3}$$

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TABLE I

Bolometric corrections, absolute bolometric magnitudes and radii of the program stars. Spectral types are from Blanco *et al.* (1970) and the parallaxes are from Bečvář (1964).

HR	Star	Sp. type	Parallax	B.C.	M_{bol}	$R/R_{\odot}$	
						Others	Present
15	α And	B 9p (III)	0.031	$-0\overset{m}{.}685$	$-1\overset{m}{.}075$	4.0[c]	3.6
707	ι Cas	Ap	0.018	−0.183	+0.667	2.1[c]	2.9
1389	68 Tau	A2 IVm	0.025	−0.301	+0.929	1.67[b]	2.1
1458	88 Tau	Am	0.028	−0.121	+1.499		2.2
1570	π^1 Ori	A0p	0.017	−0.175	+0.715		2.7
1672	16 Ori	Am	0.018	−0.118	+1.582	1.89[a]	2.2
2029	ξ Aur	A2p	0.015	−0.267	+0.533		2.6
2095	θ Aur	B9.5pv	0.028	−0.614	−0.664		3.3
2148	17 Lep	A2p	0.031	−0.137	+2.363		1.5
4752	17 ComA	A si	0.014	−0.493	+0.617	2.2[c]	2.0
4915	α^2 CVn	B9.5pv	0.025	−0.745	−0.855	2.3[c]	3.1
5105	78 Vir	Ap	0.016	−0.310	+0.640	2.1[c]	2.4
1544	π^2 Ori	A0 V	0.025	−0.336	+1.004	2.00[b]	2.0
2088	β Aur	A2 V	0.050	−0.324	+0.066		3.0
2155	θ Lep	A1 V	0.017	−0.359	+0.461		2.4
2763	λ Gem	A3 V	0.043	−0.217	+1.603	1.54[b]	1.7
4825	γ Vir N	F0 V	0.092	−0.100	+2.630	1.67[a]	1.5

[a] Gray (1968).
[b] Fracassini *et al.* (1973).
[c] Stift (1974).

where $(\Delta m_v)_{obs}$ = the observed monochromatic magnitude of a star normalized to $\lambda = 555.5$ nm;

$(\Delta m_v)_{cal}$ = the calibrated magnitude of the standard star with a similar normalization;

m_{vis} = the apparent visual magnitude of the program star; and

M_v = the computed monochromatic magnitude taken from the model energy curve, the slope of the Paschen continuum of which matches with that of the program star.

In our work, the hydrogen line blanketed models computed by Mihalas (1966) have been chosen for comparison purposes. We have adopted the case $\log g = 4.0$ for all stars except for α And, whose luminosity class having been given as III (Hogg, 1958), the models with $\log g = 3.0$ have been used. The m_{vis} values have been taken from Bečvář (1964). Also, α Lyr has been adopted as the standard star and its latest calibration given by Hayes and Latham (1975) has been used.

3. Results

The radius of each of the program stars has been calculated using F_ν and $\mathscr{F}_\nu$ at ten different wavelengths viz., $\lambda=478.5$, 500.0, 505.0, 526.0, 555.5, 584.0, 605.5, 625.0, 643.5 and 680.0 nm and the average of these ten estimates is adopted as its radius. The results are given in Table I. The standard deviation related to these averages is less than 1%, indicating that the radii are effectively uniform at different wavelengths.

It is well known that the uncertainty in the parallax of a given star is the major contributor for the error in the radius calculated on the basis of that parallax. As the individual errors in parallaxes have not been quoted by Bečvář (1964) for the program stars, it is not possible for us to give the corresponding individual errors in the determination of radii. Therefore, an attempt was made to obtain an approximate value of the average uncertainty in these radii by following a procedure used by Gray (1968) which involves a linear relationship between $(B-V)$ and $\log (R/R_\odot)$ of the program stars.

For these stars a least squares solution yields the relation

$$\log (R/R_\odot) = 0.412 - 0.614(B - V). \tag{4}$$

The average of the deviations of the individual values from this relation in terms of $R_\odot$ turns out to be about 20%, which includes the uncertainties related to all the parameters and the assumptions employed up to this stage.

4. Comparison with other Works

A few of the stars discussed here are in common with similar work done by others, viz., (a) Gray (1968): 16 Ori and γ Vir N; (b) Fracassini *et al.* (1973): 68 Tau, π^2 Ori and λ Gem; (c) Stift (1974): α And, ι Cas, 17 Com A, α^2 CVn and 78 Vir. For comparison, the results of these authors also are included in Table I.

The agreement of the present results with those obtained by all the above authors is within 0.4 $R_\odot$ which, in its turn, is within the uncertainty quoted by us, the only exceptions being ι Cas and α^2 CVn, for which these are both greater by 0.8 $R_\odot$ than those obtained by Stift (1974). A possible explanation for these descrepancies, at least for a part of them, could be that the method used by Stift implies that the radius of a star depends on the chosen effective temperature and the bolometric magnitude, thus becoming rather sensitive to any errors in these parameters. In addition, these two stars are known to be variables also.

5. Discussion

5.1. Evolutionary Aspects

Substituting the radii obtained in the present work, in the relation (Heintze, 1973)

$$M_{\text{bol}} = 42.414 - 10 \log T_e - 5 \log (R/R_\odot), \tag{5}$$

we have calculated the absolute bolometric magnitudes of all the program stars, where T_e, in terms of $\theta_e(=5040/T_e)$, has been taken from Babu (1976), while the constant includes the solar values of T_e and M_{bol} adopted from Heintze (1973). The results are given in Table I.

In Figure 1, we have plotted log T_e against M_{bol} to study the evolutionary aspects of these stars. The zero-age Main-Sequence (ZAMS) given by Eggen (1963) and the evolutionary tracks given by Iben (1967a, b) have been chosen for comparison pur-

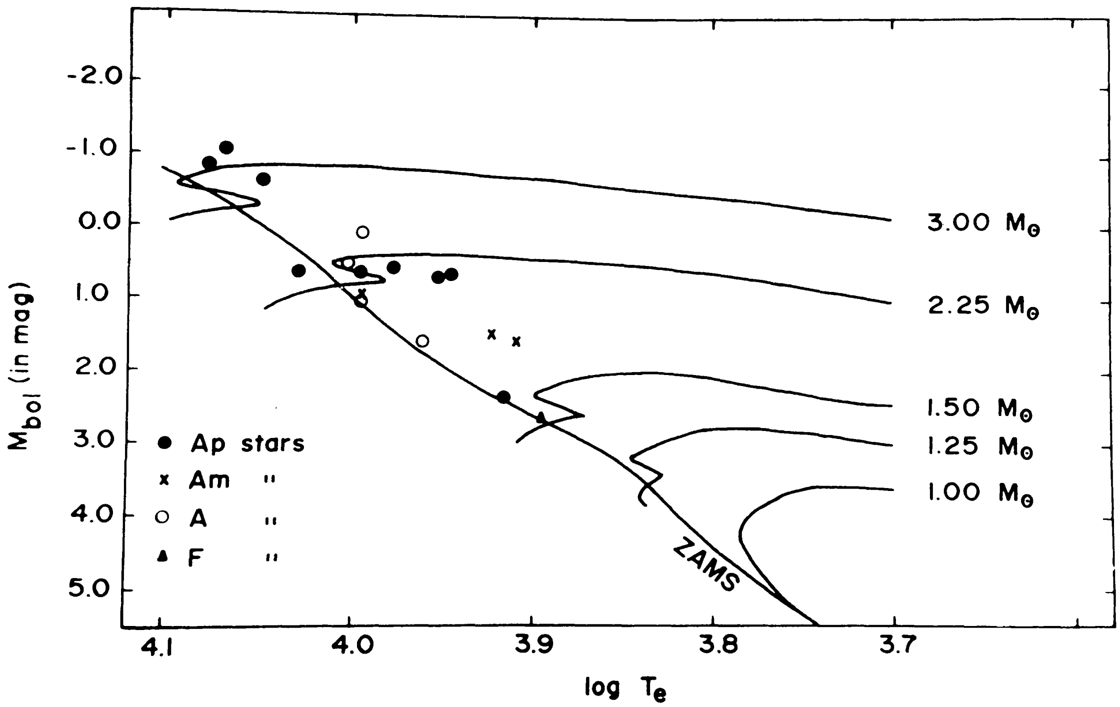

Fig. 1. Relationship between log T_e and M_{bol}. The ZAMS has been taken from Eggen (1963) while the evolutionary tracks are from Iben (1967a, b). The values of T_e are from Babu (1976).

poses. While eight of the program stars (68 Tau, 17 Lep, 17 Com A, 78 Vir, π^2 Ori, θ Lep, λ Gem and γ Vir N) are on or near the ZAMS, the other nine (α And, ι Cas, 88 Tau, π^1 Ori, 16 Ori, ξ Aur, θ Aur, α^2 CVn and β Aur) are definitely above the ZAMS. It is interesting to note that the majority of the stars which appear to be slightly evolved, are of Ap and Am types, while three of the four normal A stars (π^2 Ori, θ Lep and λ Gem) and the one F0 V non-peculiar magnetic star (γ Vir N) are very close to ZAMS. This position of Ap and Am stars above the main sequence may represent transitional phases in the evolution of dwarfs as suggested by Eggen (1957).

Though it is difficult to pinpoint the individual masses of stars from this diagram, it can be seen that excepting for three stars (α And, θ Aur and α^2 CVn) with about 3 $M_\odot$ each, the rest range between 1.5 and 2.25 $M_\odot$. This is a reasonable estimate for A type stars (Allen, 1963).

5.2. Bolometric Corrections

Using the absolute visual magnitude M_{vis} given in Bečvář's catalogue (1964), we have calculated the bolometric corrections (B.C.) of the program stars with the help of their M_{bol} obtained in the previous section from the formula:

$$\text{B.C.} = M_{bol} - M_{vis} \quad (6)$$

The results are given in Table I.

It is evident from Figure 2, a plot between θ_e and B.C., that our results are much closer to those computed by Mihalas (1966) than to the ones given by Davis and Webb

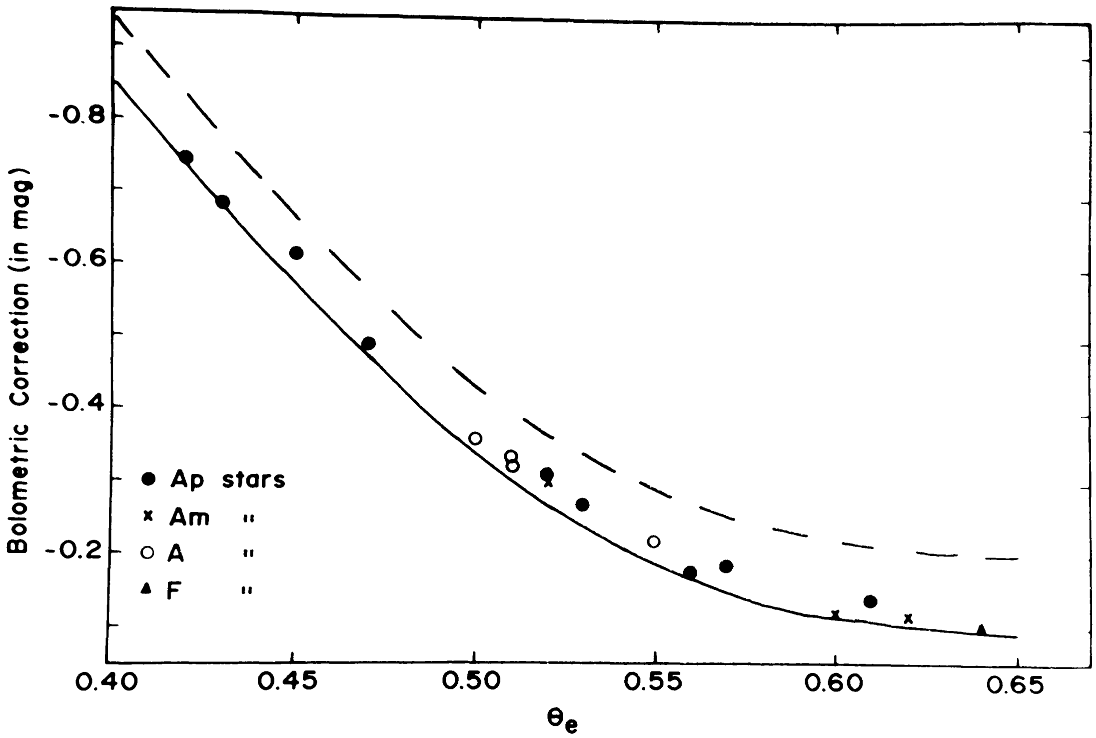

Fig. 2. Relationship between θ_e and bolometric corrections. The solid line represents the theoretical relationship given by Mihalas (1966) for the case $\log g = 4.0$, while the broken line represents that given by Davis and Webb (1970). θ_e is taken from Babu (1976).

(1970), the latter being about $0^m.1$ more negative than the former. Incidentally, Stift (1974) used the B.C.'s given by Davis and Webb. This could possibly explain part of the discrepancy between the values of radii given by him and in this work, as mentioned earlier.

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