Astron. & Astrophys. 29, 155–157 (1973)

Research Note

Absolute Energy Distribution of Two δ Scuti Variables

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Received June 28, 1973

Summary. The absolute energy distributions of two δ Sct stars β Cas (HR 21) and υ UMa (HR 3888) have been given. By matching these with model atmospheres their effective temperatures, gravities, radii and masses have been estimated.

Key words: δ Scuti stars – absolute energy distribution

Introduction

There has been considerable interest in the spectrophotometric studies of the δ Sct stars with a view to ascertain their evolutionary status in the HR diagram. Earlier workers (Danziger and Kuhi, 1966; Danziger and Oke, 1966; Danziger and Dickens, 1967) have spectrophotometrically obtained estimates of their masses and luminosities that are low as compared to those obtained from their evolutionary tracks and parallaxes. Bessell (1967, 1969), however, obtained masses of about 1.9 $M_\odot$ for the stars ϱ Pup, δ Del and δ Sct which are consistent with a normal left to right evolution in the HR diagram. Breger and Kuhi (1970) also obtain values of $\sim 2 M_\odot$ for stars in the δ Sct region. Dickens and Penny (1971) find masses of about 3.5 $M_\odot$ for the variables and 1.6 $M_\odot$ for the non-variable stars in the same region. In this paper we discuss the absolute energy distribution curves for two δ Sct stars, based on Oke and Schild's (1970) calibration of α Lyr and derive their effective temperatures, gravities, radii and masses.

Observations

The observations were made on several nights during 1969-70 through the 20-inch reflector of the Uttar Pradesh State Observatory. The scanner consists of a Hilger and Watts monochromator with a 600 lines/mm grating used in the first order. The system gives a dispersion of 70 Å/mm at the exit slit. An unrefrigerated EMI 9558 B photomultiplier and standard dc techniques were employed. The measurements were made at intervals of 100 Å in the range λλ 3500 – 6000 Å with a bandwidth of 70 Å. γ Gem, α Lyr and η UMa were observed as standard stars. Extinction coefficients were determined by observing the standard stars at several zenith angles every night. The absolute energy distribution curves of the standard stars were taken from Wolff *et al.* (1968) to which necessary corrections arising out of Oke and Schild's (1970) calibration of Vega were applied. The measured fluxes have been corrected for line blanketing effects, taking the blanketing data for a F 2 V star from Melbourne (1960). To correct the observed fluxes of the stars for the effect of absorption lines, the appropriate way would have been to planimeter the high dispersion spectra of the stars to find out the blanketing corrections. Since the required spectra were not available to us, we applied the blanketing corrections from the literature for a star of the same spectral class. The absolute fluxes of β Cas and υ UMa expressed as magnitudes per unit frequency interval are given in Table 1. Each entry in the table is a mean of several (between 3 and 7) observations. The standard deviation of a single measurement does not exceed $\pm 0\overset{m}{.}03$.

Temperature and Gravity

To determine the effective temperature and the gravity of any star, we obtained the Balmer jump (D) at $\frac{1}{\lambda} = 2.74$ and the slope (m) between $\frac{1}{\lambda} = 1.7$ and $\frac{1}{\lambda} = 2.3$ from the mean energy distribution curve. Similar slope and Balmer jump were determined for the models (Carbon and Gingerich, 1969) in the appropriate temperature and gravity range. The quantity D for the models was plotted against m for various values of T_e and $\log g$. The positions of the observational stars were marked on this

Table 1. Monochromatic fluxes of β Cas and υ UMa, expressed in magnitudes per unit frequency interval, corrected for line blanketing

$1/\lambda$	β Cas		υ UMa		Line blanketing corrections used
	Maximum of brightness	Minimum of brightness	Maximum of brightness	Minimum of brightness	
2.857	3.409	3.378	4.787	4.812	$0^m.228$
2.777	3.362	3.335	4.695	4.778	.228
2.702	3.280	3.309	4.730	4.664	.208
2.631	2.901	3.024	4.360	4.225	.165
2.560	2.500	2.485	3.775	3.764	:133
2.500	2.250	2.245	3.624	3.619	.120
2.440	2.324	2.340	3.765	3.831	.100
2.380	2.256	–	–	–	.078
2.330	2.248	2.340	–	–	.078
2.270	2.260	2.282	3.746	3.754	.073
2.220	2.241	2.299	3.680	3.745	.070
2.170	2.273	2.320	3.665	3.676	.068
2.130	2.253	2.323	3.735	3.685	.052
2.080	2.270	2.358	3.720	3.740	.043
2.040	2.236	2.332	3.737	3.746	.027
2.000	2.262	2.340	3.732	3.731	.013
1.960	2.304	2.346	3.716	3.733	.013
1.920	2.300	2.370	3.732	3.754	.013
1.890	2.283	2.339	3.725	3.750	.013
1.850	2.270	2.334	3.728	3.750	.013
1.820	2.263	2.333	3.740	3.765	.013
1.785	2.273	2.318	3.750	3.753	.013
1.754	2.290	2.302	3.731	3.749	.013
1.724	2.268	2.318	3.738	3.715	.013
1.695	2.256	2.300	3.706	3.743	.013
1.666	–	2.340	3.750	3.750	.013

Table 2. Effective temperatures and gravities of β Cas and υ UMa

Star	B-V	Temperature °K				θ_e	$\log g$
		Morton and Adams (1968)	Danziger and Dickens (1967)	Dickens and Penny (1971)	This paper		
β Cas	$0^m.34$	7360	–	–	7600	0.66	4.1
υ UMa	$0^m.39$	7650	6950	7244	7700	0.65	4.2

grid according to their D and m values and their temperatures and gravities were determined. Table 2 gives the effective temperatures and the gravities of these stars. The accuracy of the temperature determination is ± 0.01 in θ_e and that of gravity is ± 0.15 in $\log g$. The effects of these errors in the determined radii and masses have been taken into account in the respective discussions. Taking into account the uncertainties of the blanketing corrections used by us the above quoted errors in θ_e and $\log g$ might have to be increased by 0.005 in θ_e and 0.1 in $\log g$.

The temperature of υ UMa obtained by us is higher than that given by Danziger and Dickens (1967) or by Dickens and Penny (1971) from energy distribution measurements. Although Dickens and Penny used Oke and Schild's (1970) calibration of α Lyrae, they used the unblanketed models and applied corrections to bring the temperatures and gravities down by 0.03 in θ_e and 0.1 in $\log g$.

Radius

The radii of the stars have been calculated from the relation,

$$R^2 \mathscr{F}_\nu = D^2 F_\nu \quad (1)$$

where R and D are the radius and the distance of the star, and $\mathscr{F}_\nu$ and F_ν are the true and the measured fluxes. $\mathscr{F}_\nu$ is obtained from the fitted model atmosphere. To obtain F_ν, we converted the mean monochromatic magnitude of a star to the flux value using the relation,

$$\log F_\nu = -19.442 - 0.4\,\mathrm{m}, \quad (2)$$

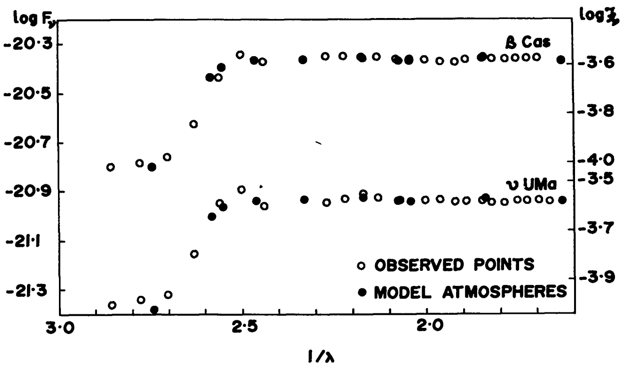

Fig. 1. The curves showing the fit between the observed fluxes (F_ν) of β Cas and υ UMa and the theoretical fluxes ($\mathcal{F}_\nu$) obtained by interpolation from the grid of model atmospheres (Carbon and Gingerich, 1969) for the effective temperatures and gravities of these stars

the constant having been evaluated by adopting a value of 3.5×10^{-20} ergs s^{-1} cm^{-2} Hz^{-1} for α Lyr at λ 5556Å (Oke and Schild, 1970). These curves were fitted to appropriate curves obtained by interpolation for the T_e and log g of the stars from the grid of model atmospheres given by Carbon and Gingerich (1969). The fit is shown in Fig. 1.

Transforming relation (1) to obtain the radius, in solar units, we get,

$$R_\nu = \frac{44.33}{\pi} \times 10^6 \left(\frac{F_\nu}{\mathcal{F}_\nu}\right)^{\frac{1}{2}} \tag{3}$$

where π is the parallax of the star in seconds of arc. The value of the parallax is read from Jenkins (1952).

The radii determined with the help of the above come out to be $R = 2.50\,R_\odot$ for β Cas; and $R = 2.53\,R_\odot$ for υ UMa. The probable errors of these determinations on account of the errors in parallaxes, measured fluxes and the computed fluxes come out to be 10.3% for β Cas and 14.2% for υ UMa. The largest contribution to these errors is by the parallaxes. Gray (1967) obtained a value $R = 2.86\,R_\odot$ for β Cas by matching the energy distribution of the star to a scaled solar model.

Mass

Because of their low amplitudes of variation, we can assume that there are no large accelerations in the atmospheres of these stars, and therefore one can take the values of log g obtained above to represent the effective surface gravities of the stars. This enables us to estimate the masses of these stars through the relation,

$$g_{\mathrm{eff}} = \frac{GM}{R^2} \,. \tag{4}$$

The masses thus calculated come out to be $M = 2.86\,M_\odot$ for β Cas and $3.68\,M_\odot$ for υ UMa. The percentage errors in these masses, due to errors in radii and the effective gravities have been estimated to be 21% for β Cas and 29% for υ UMa. Dickens and Penny (1971) obtain a mass of $3.3\,M_\odot$ for υ UMa by using $\log g = 4.1$, $T_e = 7244$°K and $M_v = 1^m\!.6$. The Q values calculated for the stars with the above determined masses and radii come out to be 0.045 for β Cas and 0.062 for υ UMa. From the above masses and the Q values it appears that these stars are not low-mass stars and that they are pulsating in the fundamental mode.

Acknowledgements. The authors wish to express their thanks to Dr. S. D. Sinvhal for helpful discussions.

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