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SPECTROPHOTOMETRIC STUDY OF THE CEPHEIDS DT CYG AND SZ TAU

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Abstract. The effective temperatures of the cepheids DT Cyg and SZ Tau have been determined from a comparison of their spectral scans with appropriate stellar model atmospheres. Using these temperatures and an independent Wesselink radius determination, the luminosities of the stars have been determined. The pulsation masses and the evolutionary masses of the stars have been discussed.

1. Introduction

Earth-based scanner measurements provide a convenient method for studying the energy distribution in different kinds of stars especially in the wavelength range 300 nm to 1 micron. Scanner measurements have the advantage of speed, linear response, high quantum efficiency, and a moderate but precisely known resolution. The measured magnitudes are nearly monochromatic and after calibration represent a discrete point of the energy distribution curve. This observed energy distribution curve is matched with the computed energy distribution curve from model stellar atmospheres to derive effective temperatures. Scanner observations of the cepheids DT Cyg and SZ Tau at several phases have been used in this study. The radius, luminosity, and mass of the stars have also been derived.

2. Observations

The cepheids DT Cyg and SZ Tau were observed spectrophotometrically on several nights during 1979–1985 with the 104 cm reflector of the Uttar Pradesh State Observatory. The spectrum scanner and other associated equipments were the same as described by Rautela and Joshi (1976). Both the cepheids were observed by using an exit window admitting 5 nm wide spectrum at 14 line-free wavelengths in the wavelength range 403.6–710.0 nm (Oke, 1965). ξ^2 Cet and γ Cam were also observed as standard stars at the same line-free wavelengths at several zenith distances almost every night. The standard stars were used to transform the extinction corrected instrumental magnitudes of the stars to absolute values. These absolute values conform to the calibration of α Lyr as given by Taylor (1984).

The phases were calculated with the help (Moffett and Barnes, 1984) of the ephemerides:

$$\text{Phase (DT Cyg)} = \frac{\text{J.D.} - 2441\,737.793}{2.499082}\,,$$

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TABLE I

Blanketing and reddening corrected magnitudes normalized to λ555.6 nm for DT Cyg and SZ Tau at various phases

	μm^{-1} Phase	2.48	2.40	2.35	2.24	2.19	2.09	2.00	1.90	1.81	1.71	1.65	1.55	1.47	1.41
DT Cyg	0.042	0.36	0.31	0.28	0.19	0.20	0.13	0.10	0.05	0.00	−0.03	−0.03	−0.09	−0.09	−0.10
	0.157	0.34	0.33	0.26	0.20	0.19	0.14	0.10	0.05	0.00	−0.06	−0.06	−0.11	−0.14	−0.14
	0.292	0.40	0.32	0.33	0.25	0.22	0.17	0.11	0.05	0.00	−0.06	−0.07	−0.16	−0.18	−0.18
	0.448	0.45	0.39	0.34	0.27	0.26	0.22	0.10	0.06	0.00	−0.05	−0.09	−0.12	−0.16	−0.17
	0.508	0.51	0.42	0.40	0.28	0.28	0.20	0.16	0.08	0.00	−0.01	−0.07	−0.11	−0.15	−0.16
	0.594	0.43	0.38	0.35	0.29	0.25	0.20	0.12	0.07	0.00	−0.05	−0.07	−0.10	−0.13	−0.14
	0.742	0.39	0.32	0.32	0.23	0.22	0.15	0.11	0.05	0.00	−0.06	−0.06	−0.12	−0.15	−0.16
	0.851	0.29	0.27	0.21	0.16	0.17	0.12	0.03	0.01	0.00	−0.05	−0.12	−0.12	−0.18	−0.18
SZ Tau	0.036	0.40	0.30	0.33	0.25	0.23	0.22	0.12	0.09	0.00	−0.03	−0.08	−0.12	−0.16	−0.19
	0.101	0.41	0.37	0.31	0.24	0.26	0.19	0.14	0.05	0.00	−0.06	−0.10	−0.15	−0.23	−0.23
	0.236	0.45	0.36	0.33	0.27	0.19	0.23	0.12	0.05	0.00	−0.09	−0.11	−0.17	−0.22	−0.24
	0.417	0.48	0.41	0.41	0.28	0.30	0.25	0.14	0.05	0.00	−0.08	−0.11	−0.19	−0.22	−0.26
	0.539	0.46	0.38	0.36	0.28	0.26	0.17	0.14	0.06	0.00	−0.06	−0.12	−0.17	−0.23	−0.28
	0.664	0.39	0.30	0.29	0.22	0.33	0.15	0.12	0.02	0.00	−0.07	−0.13	−0.18	−0.22	−0.23
	0.744	0.35	0.28	0.28	0.19	0.18	0.16	0.11	0.04	0.00	−0.07	−0.10	−0.15	−0.19	−0.20
	0.835	0.33	0.28	0.26	0.22	0.20	0.12	0.11	0.07	0.00	−0.04	−0.11	−0.12	−0.16	−0.17
	0.947	0.30	0.31	0.31	0.23	0.22	0.18	0.12	0.03	0.00	−0.04	−0.05	−0.10	−0.13	−0.14

$$\text{Phase (SZ Tau)} = \frac{\text{J.D.} - 2434628.57}{3.14873} .$$

The observations were corrected for interstellar reddening. For this purpose the colour excesses were taken from Ivanov *et al.* (1983). Colour excess of $E(B - V) = 0.05$ for DT Cyg and $E(B - V) = 0.31$ for SZ Tau were adopted. We used a single value of the colour excess in all the phases, since the changes in the energy distribution curves with pahse are small.

Using Schild's (1977) reddening curves and $A_v = 3.25E(B - V)$, the corrections due to reddening for each observed wavelength were determined. The energy distribution curves for the cepheids were also corrected for line-blanketing effects. We adopted the blanketing corrections from Ardeberg and Virdefors (1975) for luminosity class I as these stars are well within the range of luminosity class I. Blanketing and reddening corrected magnitudes for DT Cyg and SZ Tau at various phases are given in Table I.

3. Effective Temperature

The corrected absolute energy distribution curves obtained as described in the last section were then compared with the model atmospheres given by Kurucz (1979). For temperature estimation we plotted the slopes between the inverse wavelength $\lambda^{-1} = 1.41$ μm to $\lambda^{-1} = 2.48$ μm of the models given by Kurucz (1979) against the effective temperatures for $\log g = 2$. Similar slopes were obtained from the observed absolute energy distribution curves. The position of these slopes were then marked on the slope-T_e curve for the models and effective temperatures were read off at different observed phases. The value of $\log g = 2$ given by Parsons (1970), Parsons and Bouw (1971) based upon six-colour photometry was adopted. The temperature values determined at different phases are given in Table II and are plotted in Figures 1 and 2. The effective temperature shows a variation from 6420 to 6115 K during a pulsation cycle

TABLE II

Effective temperature, displacement, and radius of DT Cyg and SZ Tau according to the phase of light variation

Phase (DT Cyg)	T_e (K)	$(\gamma - \bar{R})$ (10^{10} cm)	$R/R_\odot$	Phase (SZ Tau)	T_e (K)	$(\gamma - \bar{R})$ (10^{10} cm)	$R/R_\odot$
0.042	6420	−0.50	28.9	0.036	6250	−8.15	36.6
0.157	6370	−2.75	28.6	0.101	6140	−7.83	36.7
0.292	6240	−4.26	28.4	0.236	6015	−4.90	37.1
0.448	6135	−3.38	28.5	0.417	6020	3.05	38.2
0.508	6115	−2.42	28.7	0.539	6100	6.08	38.7
0.584	6155	−0.37	28.9	0.664	6235	3.64	38.3
0.742	6315	2.30	29.3	0.744	6330	0.34	37.8
0.851	6420	3.00	29.4	0.835	6420	−3.80	37.2
				0.947	6400	−7.16	36.8

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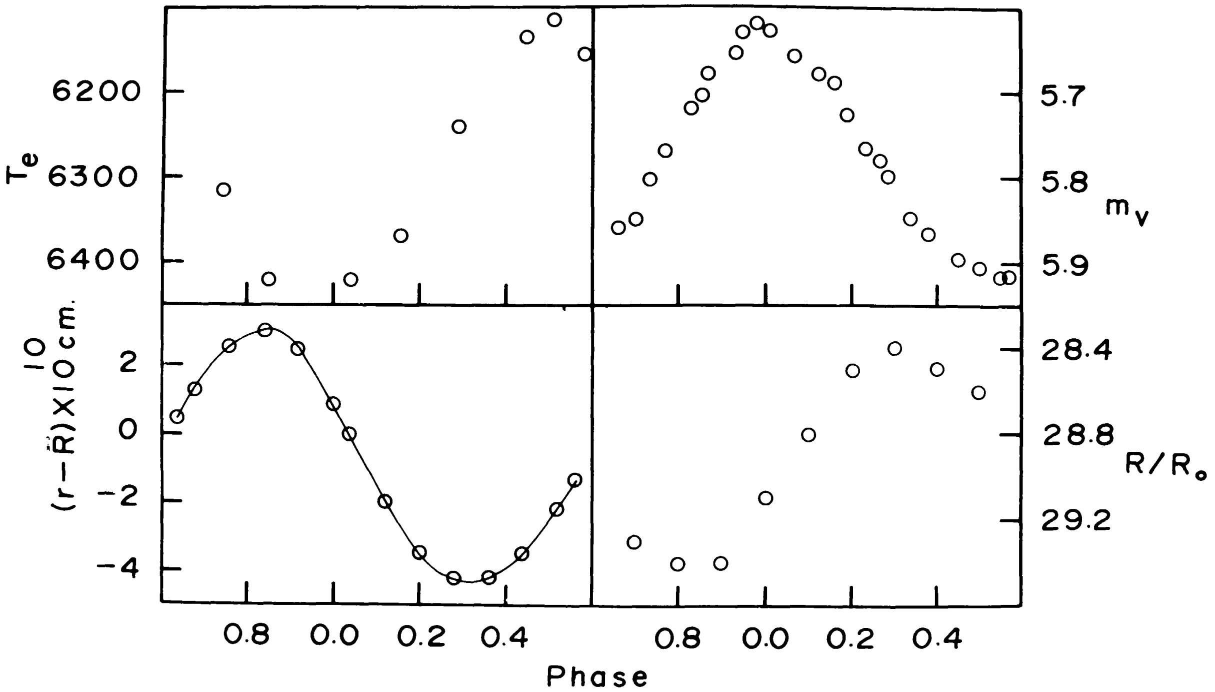

Fig. 1. Variation with phase in the parameters of DT Cyg.

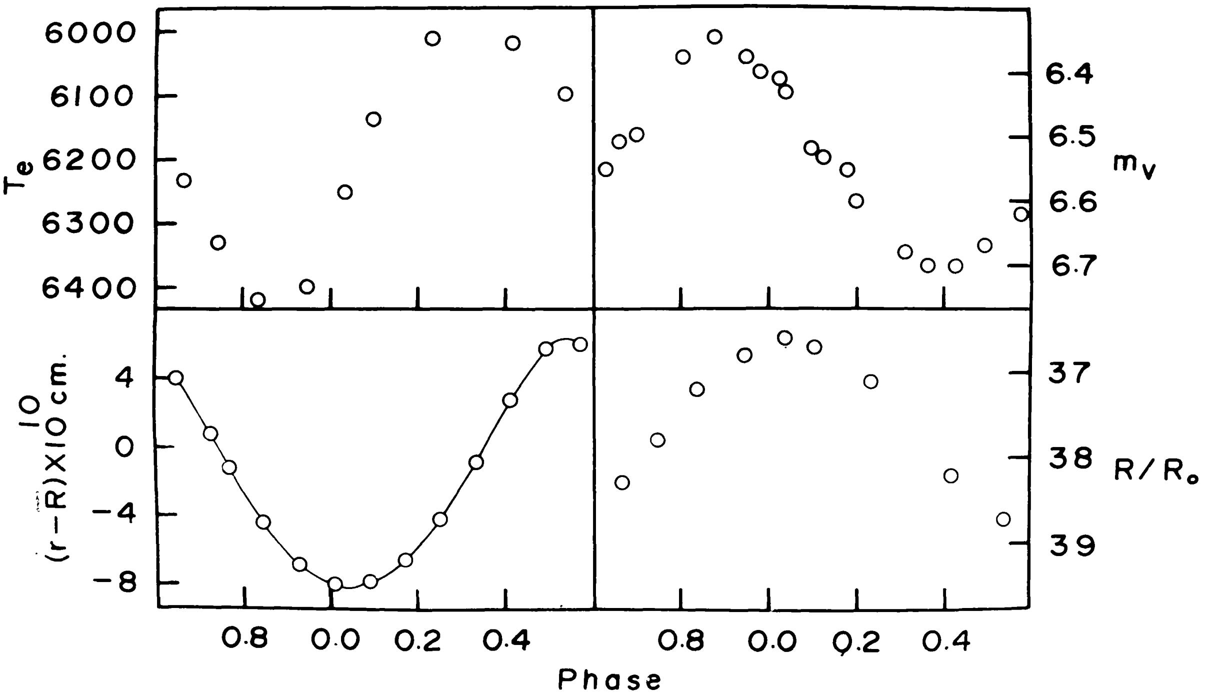

Fig. 2. Variation with phase in the parameters of SZ Tau.

and a mean temperature of 6294 K is obtained for DT Cyg. Parsons (1970) temperatures, based on six-colour photometry show variation from 6450 to 6125 K with a mean temperature of 6296 K, which is in agreement with our results. The effective temperature obtained by us for SZ Tau varies from 6420 to 6015 K, with a mean temperature of 6178 K. This mean value is lower than the mean effective temperature of 6268 K derived by Schmidt (1972) through Hα profile studies. The mean temperature of 6171 K obtained by Parsons (1970) is in agreement to our result. The error in the temperature estimates on account of the deviations in the slopes determined by least-squares fitting does not exceed ± 60 K. The $\log g$ values given for these stars by Parsons (1970) range between 2 and 2.5. The error in the temperature estimates on this account can reach a maximum of 100 K, in the range of temperature found for the stars.

4. Radius

The radii of the stars were determined with the help of the Wesselink (1946) method. The method assumes that the phases of equal temperature are phases of equal surface brightness. Any difference in the measured brightness is caused by different size of the star at such phase pairs. The integration of radial velocity curve, converted to photospheric pulsation velocity curve by using the factor 24/17, gives the displacement $\gamma - \bar{R}$ at several phases of the star, where $\bar{R}$ is the mean radius and γ is the instantaneous value of the radius at the corresponding phase. Some pairs of equal temperature phases were marked and the corresponding difference in magnitude were read off from the V light curve. The mean radius of the star was determined with the help of each of the pairs using the relation

$$\left[\frac{\bar{R} + \Delta\gamma_1}{\bar{R} + \Delta\gamma_2}\right]^2 = 10^{0.4(\Delta m)},$$

where $\Delta\gamma_1$ and $\Delta\gamma_2$ are obtained from the displacement curve and Δm is the V magnitude difference at the two phases of equal effective temperature. We used the radial velocity curve given by Sanford (1930) for DT Cyg and by the Barnes and Moffett (1985) curve for SZ Tau. The visual light curves given by Moffett and Barnes (1984) were used. The variation of effective temperature, visual magnitude, displacement, and radius are given in Figures 1 and 2, respectively, for DT Cyg and SZ Tau. The average value for the mean radius comes out at $29\,R_\odot \pm 1.8\,R_\odot$ for DT Cyg and $37.8\,R_\odot \pm 1.2\,R_\odot$ for SZ Tau.

5. Luminosity

By use of the radius and effective temperature determined above, the luminosity was determined. We obtained the mean bolometric magnitudes for DT Cyg and SZ Tau equal to -2.94 and -3.44, respectively. The bolometric magnitudes converted to luminosities give $\log L/L_\odot$ equal to 3.08 and 3.28, respectively, for DT Cyg and SZ Tau.

5. Mass

The Wesselink radius-mass of the star was determined using the radius determined in this paper and the relation

$$Q_i = \pi[\langle \rho \rangle / \langle \rho_\odot \rangle]^{1/2}$$

and

$$\log Q_i - g_i(m) = a_i \exp\{-b_i[\log(M/R) - C_i]^2\} + d_i ,$$

where $g_0(m) = A_0 m$.

The values of A_0, a_i, b_i, c_i, d_i were taken from the table of Cox *et al.* (1972) for fundamental mode pulsation of the star. By use of assumed values of M/R, Q_0 was calculated and a period of pulsation (π) determined. The process was repeated until a period equal to the period of the star was obtained, Wesselink radius-mass equal to 5.31 $m_\odot$ and 7.50 $m_\odot$ were obtained for DT Cyg and SZ Tau, respectively.

The evolutionary mass for the stars were estimated using Becker *et al.* (1977) evolutionary tracks and their mass luminosity relation given by

$$\log L = j + k \log M ,$$

where

$$j = 0.46 - 41 \Delta Z + 6.6 \Delta Y - 5(\Delta y)^2$$

and

$$k = 3.68 + 21 \Delta Z - 4.5 \Delta y + 11(\Delta y)^2 ;$$

in which ΔZ and ΔY are assumed to be zero corresponding to $Y = 0.28$ and $Z = 0.02$ using the luminosity of the stars as determined above, we get evolutionary mass equal to 5.04 $m_\odot$ and 5.72 $m_\odot$, respectively, for DT Cyg and SE Tau.

Cox (1979) estimated the evolutionary and pulsation masses for a large number of cepheids and found that the ratio of pulsation to evolutionary masses ont he average is 0.97 ± 0.025. Our estimate for DT Cyg is nearly equal to unity but in case of SZ Tau the pulsation mass is larger than the evolutionary mass. The evolutionary masses are very sensitive to chemical composition. Iben and Tuggle (1975) showed that the galactic cepheids have a chemical composition of $Y \simeq 0.28$ and $Z \simeq 0.02$. We suspect that SZ Tau may be a metal-rich cepheid.

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