SPECTROPHOTOMETRIC DETERMINATION OF THE TEMPERATURE OF THE CEPHEID ζ GEMINORUM

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Abstract. The absolute energy distributions of the cepheid ζ Gem at several phases of the light cycle have been given. By matching these with suitable model atmospheres, the effective temperatures of the star at these phases have been determined. The radius and effective gravity variations as well as the mass have been derived.

1. Introduction

Various techniques have been applied to determine the temperatures of cepheids. Oke (1961a, b) determined the temperatures by energy distribution studies, Parsons (1971) by six colour wide-band photometry and Schmidt (1972) by Hα line profile studies. Oke's method has been applied to determine the temperatures of ζ Gem using blanketed models for supergiant stars given by Parsons (1969) and the latest calibration of α Lyr given by Hayes and Latham (1974).

2. Observations

Photoelectric spectrophotometric scans of ζ Gem were made on several nights during 1970–71 on the 52-cm reflector of the Uttar Pradesh State Observatory. The scanner consists of a Hilger and Watts monochromator with a 600 lines mm^{-1} grating, used in the first order, and an exit slit 1 mm wide admitting 70 Å of the spectrum. An unrefrigerated EMI 9558B photomultiplier and standard recording d.c. techniques were employed. Measurements have been made in the wavelength interval λλ 4036–5840 Å, at ten line-free wavelengths suggested by Oke (1965). γ Gem was used as the comparison star for converting the extinction corrected instrumental magnitudes to absolute values. The corrections arising out of the calibration of α Lyr by Hayes and Latham (1974) were applied to the observations of γ Gem. The *R* magnitudes of the star taken from the eight-colour photometry by Wisniewski and Johnson (1968) have been used to give a long base line for determining the temperatures. Using the effective wavelength of the *R* filter and the magnitude of α Lyr (Johnson *et al.*, 1966), it was found that a correction of $0\overset{m}{.}22$ for *R* magnitude gives the absolute energy distribution of the continuum of α Lyr based on the above referred calibration of that star.

The observations have been grouped according to the phases of the star calculated from the ephemeris (Kukarkin *et al.*, 1969)

$$\mathrm{Phase} = \frac{\mathrm{JD}\text{-}2\,434\,416\overset{d}{.}780}{10\overset{d}{.}150\,82}.$$

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TABLE I

Magnitudes of ζ Gem per unit frequency interval ($m_{r,b}$) corrected for line blanketing and reddening

λ (μm)	$1/\lambda$ (μm)$^{-1}$	Phase 0.0		Phase 0.08		Phase 0.18		Phase 0.31		Phase 0.45		Phase 0.62		Phase 0.70		Phase 0.80		R.C.
		$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	$m_{r,b}$	B.C.	
0.4464	2.24	3.19	0.33	3.21	0.38	3.28	0.46	3.52	0.54	3.73	0.56	3.57	0.50	3.54	0.43	3.32	0.33	0.60
0.4566	2.19	3.19	0.27	3.19	0.31	3.25	0.38	3.50	0.44	3.73	0.46	3.57	0.40	3.48	0.37	3.32	0.27	0.59
0.4785	2.09	3.18	0.15	3.17	0.16	3.26	0.19	3.45	0.21	3.66	0.23	3.55	0.20	3.49	0.18	3.25	0.15	0.56
0.5000	2.00	3.14	0.18	3.16	0.20	3.24	0.23	3.41	0.27	3.57	0.31	3.50	0.24	3.46	0.22	3.23	0.18	0.52
0.5263	1.90	3.14	0.19	3.10	0.22	3.22	0.26	3.40	0.30	3.56	0.31	3.44	0.27	3.40	0.24	3.20	0.19	0.48
0.5556	1.80	3.07	0.10	3.10	0.11	3.20	0.13	3.35	0.15	3.54	0.16	3.43	0.14	3.35	0.13	3.20	0.10	0.45
0.5840	1.71	3.08	0.05	3.09	0.05	3.16	0.06	3.33	0.07	3.46	0.07	3.38	0.06	3.36	0.06	3.14	0.05	0.42
0.7000	1.43	3.03	0.03	3.02	0.03	3.07	0.04	3.24	0.04	3.38	0.04	3.28	0.04	3.28	0.04	3.10	0.03	0.33

B.C. = Blanketing correction.
R.C. = Reddening correction.

Kraft (1961) has tabulated the values of the colour excess $E(B-V)$ for a number of cepheids including ζ Gem, from two sources. A colour excess of $0^m_.12$ is obtained for ζ Gem from Kron and Svolopoulos's (1959) method whereas Kraft's method gives a value of $0^m_.18$ for this excess. Since the two methods lead to the same period-colour relation, we find it difficult to choose between these two values. We have, therefore, used the mean of the above two values for the colour excess of ζ Gem.

Assuming $R=3$, and adopting the reddening curve given by Whitford (1958), the monochromatic magnitudes of the star have been corrected for interstellar reddening. The line blanketing corrections have been adopted from Parsons (1970). The blanketing and reddening corrected magnitudes per unit frequency interval, $(m_{r,b})$ for ζ Gem along with the blanketing and reddening corrections are given in Table I. The standard deviation of an individual measurement does not exceed $0^m_.02$.

3. Effective Temperature

The slopes of the best fitting (in the least-square sense) straight lines in the energy distribution curves for the models given by Parsons (1969), between $1/\lambda=1.43\ (\mu\text{m})^{-1}$ and $1/\lambda=2.24\ (\mu\text{m})^{-1}$, were obtained and were plotted against effective temperatures for values of $\log g=1.2$, 1.8, and 2.4. Corresponding slopes were also obtained for ζ Gem. Assuming an initial value of $\log g=1.8$ (see Parsons, 1971) the estimates of the temperatures of ζ Gem at different phases were read off from this curve corresponding to the observed slopes at the different phases. The values of mass and radius derived by using these temperatures yielded an average value of $\log g=1.6$, which being different from the assumed value of $\log g=1.8$, was now used iteratively and the entire process was gone through again. The process was repeated until a consistent value of $\log g$ was obtained. This was reached at $\log g=1.5$. The final temperatures are given in Table II.

TABLE II

The effective temperatures and radii of ζ Gem at various phases

Phase	θ_e	$R/R_\odot$
0.00	0.806	58.9
0.08	0.809	60.5
0.18	0.819	62.6
0.31	0.836	64.2
0.45	0.866	62.6
0.62	0.847	58.6
0.70	0.829	57.5
0.80	0.822	56.9

A variation of $\log g = \pm 0.3$ around $\log g = 1.5$ in the model atmospheres gives an error of ± 50 K in the estimates of the temperatures. These temperature estimates are in fair agreement with those determined by Schmidt (1972) from Hα line profile studies, if one employs the $(B-V)$ values given by Mitchell *et al.* (1964), but the estimates are too high by about 300 K as compared to those obtained through the relation

$$\theta_e = 0.643 + 0.337(B - V)_0$$

given by Oke (1961b). The corresponding relation obtained by us based on the intrinsic $(B-V)$ colours of the star taken from Mitchell *et al.* (1964) and our values of effective temperatures, yields the relation

$$\theta_e = 0.67 + 0.23(B - V)_0.$$

4. Mass

The mass of the star has been determined from the temperature, luminosity and period relationship given by Iben and Tuggle (1972) and we get

$$\log \frac{M}{M_\odot} = 0.60 \pm 0.04.$$

The mass of the star derived from the $(\log(M/M_\odot), \log(L/L_\odot))$ diagram for the pulsation mass of cepheids by Iben and Tuggle (1972) comes to be $\log(M/M_\odot) = 0.66$. The two values are in fair agreement.

5. Radius and Effective Gravity

The mean radius of ζ Gem has been calculated through the usual luminosity temperature relation. For this we have adopted a mean absolute visual magnitude of $-4\overset{m}{.}22$ and a bolometric correction of $-0\overset{m}{.}04$ (Parsons, 1971, 1972). We thus obtain a mean radius of the star, $\bar{R} = 61\ R_\odot$. The radius variations in a pulsation period have been computed through the displacement curve $(R - \bar{R})$ obtained by integrating the radial velocity curve of the star given by Abt and Levy (1974). These radii are also given in Table II.

The effective gravity g at different phases has been calculated using the relation

$$g = \langle g \rangle \frac{\bar{R}^2}{R^2} + \ddot{R},$$

where R is the radius of the star at a particular phase and $\bar{R}$ is the mean radius. The $\ddot{R}$ values have been derived from the same radial velocity curve (Abt and Levy, 1974). The value of $\langle g \rangle$ corresponding to the above estimates of the mass and mean radius comes out to be 29.5 cm s^{-2}. Figure 1 shows the effective temperature, magnitude, radius, and effective gravity variations as well as the graphical mean radius and effective gravity values of the star over a complete cycle.

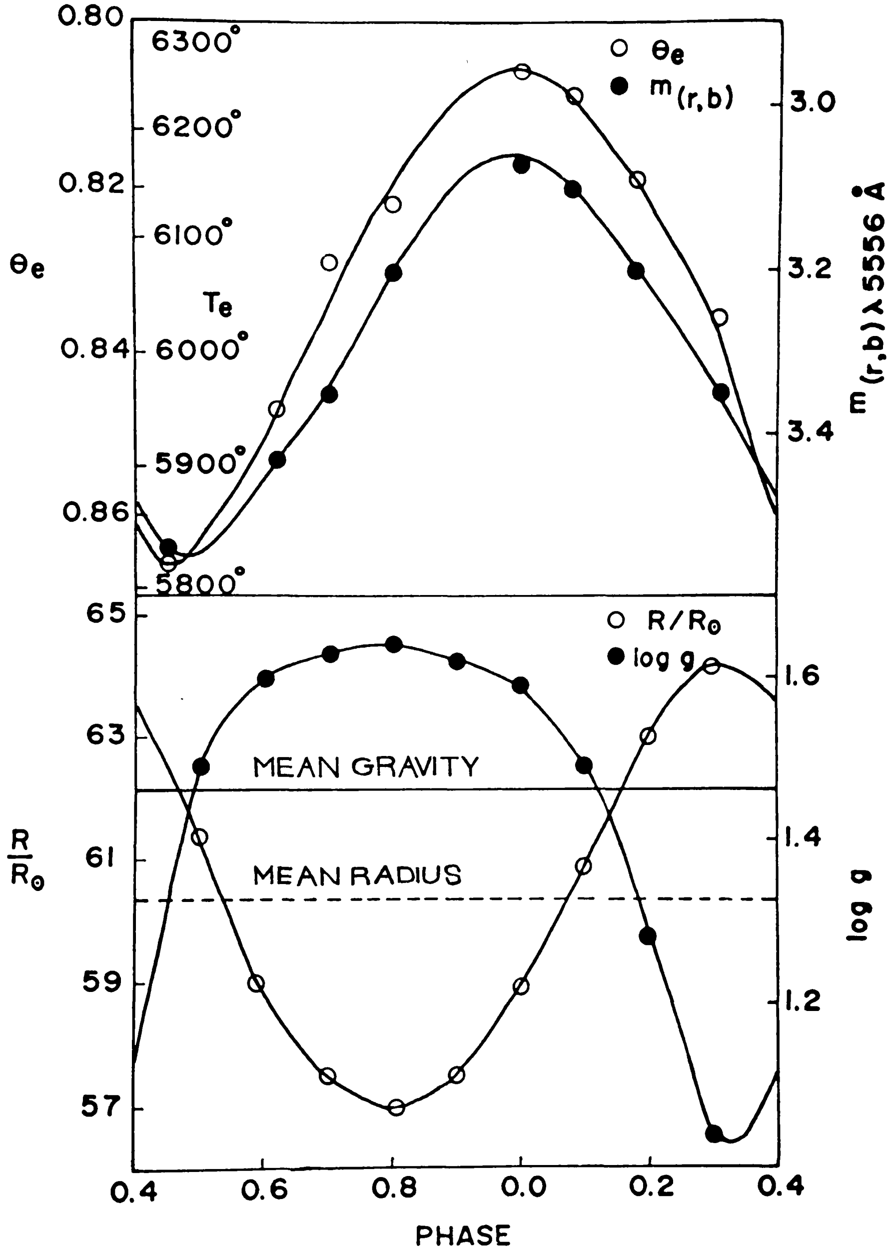

Fig. 1. The effective temperature, magnitude, radius and effective gravity variations of ζ Gem over a cycle.

An attempt to determine $\bar{R}$ from Wesselink's method did not succeed. This may be because of the almost sinusoidal light and temperature curves wherein the difference in the brightness between two phases of equal temperatures could not be ascertained accurately. Also there may be a phase lag between the motions of the continuum-forming layers and the layers forming the lines. In which case the information supplied by the radial velocity about the radius variations would not match with the luminosity and temperature variations. Simultaneous radial velocity and spectrophotometric measures of this star along with the accurate blanketing corrections for each phase would prove useful.

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