J. Astrophys. Astr. (1980) **1,** 71–78

XX Cam—The Inactive R CrB Star

N. Kameswara Rao *Indian Institute of Astrophysics, Bangalore* 560034
N. M. Ashok and P. V. Kulkarni *Physical Research Laboratory, Ahmedabad* 380009

Received 1980 May 8; accepted 1980 May 29

Abstract. Infrared observations obtained six years apart of the R CrB type star XX Cam do not show any infrared excess, unlike all the other members of the class. The observed colours match a 7000 K black body energy distribution quite well. From the year 1898 till todate, apparently XX Cam has undergone only one visual light minimum in 1940. The lack of infrared excess, the abundance peculiarities and further lack of small amplitude light variations with periods of few tens of days, which are characteristic of R CrB type stars, are discussed in terms of theoretical pulsation models of helium stars.

Key words: R CrB star—infrared excess

1. Introduction

XX Cam is one of the brighter members of R CrB class of variable stars which characteristically shows under-abundance of hydrogen, overabundance of carbon and undergoes at irregular intervals, sudden decreases in visual light from 2 to 7 mag. Bidelman (1948) was the first to point out the similarities of the spectrum of XX Cam and R CrB. A search for light variability on Harvard plates by Yuin (1948) from 1898 to 1948 showed only one light minimum of 1·7 mag depth during 1939-40. Until today, it is the only recorded minimum of the star reported in the literature, quite in contrast to the other R CrB type stars which it resembles spectroscopically like R CrB and RY Sgr. On the average R CrB shows a visual light minimum once in 750 days and RY Sgr once in 1000 days (Table 1). Even though the occurrence of light minima in this class of star is very irregular, and sometimes an interval of about ten years exists between the minima of R CrB (Mayall 1960), XX Cam has so far the longest duration in between minima.

The visual light minima of R CrB stars are thought to be caused by a circumstellar cloud or shell of dust particles (probably formed at the time of the minimum) coming in the line of sight between the star and the observer (O'Keefe 1939, Feast 1975). The dust (probably carbon dust) around the star absorbs a fraction of the stellar radiation and reradiates it at a lower temperature (800–900 K) giving rise to the infrared excess. After the initial discoveries of infrared excess in R CrB and RY Sgr (Stein *et al.* 1969; Lee and Feast 1969) it is now known that almost all the bonafide R CrB stars show infrared excesses (Feast and Glass 1973; Glass 1978; Gaustad 1972; Rao 1980b). However, Humphreys and Ney (1974) suggested that the infrared excess of R CrB is due to the presence of a cool companion which mainly radiates in IR. Their suggestion was based on the following results. (1) The energy distribution in the infrared of R CrB seems to resemble that of CIT 6 (a carbon star). (2) The variation of flux at 3·5μ of about 1·5 mag was not accompanied by any visual light variations and also it seems to follow a period of 3·5 years. Particularly there was no change of the infrared flux at the time of the 1972 visual light minimum. Simultaneous visual and infrared observations of RY Sgr by Feast *et al.* (1977) show that this binary model is not applicable to RY Sgr. They observed that the infrared light curve (L mag) mimics the Cepheid-like visual light variations of 38·6 day period synchronously, thus showing the infrared excess to be due to the circumstellar dust.

If infrared excesses are due to dust formed around the star from the ejected gas, some correlation between visual light minima and infrared excess is to be expected in the average properties. A parameter e is defined as the product of the average frequency of the occurrence of visual light minima (*i.e.* $1000/\bar{P}$ days) and the average visual extinction ($\overline{\Delta V}$ in mag). This parameter is given in Table 1 along with the average amount of infrared excess (ΔL) in the 3·5μ L band, for four stars R CrB, RY Sgr, GU Sgr and S Aps. The amount of infrared excess ΔL is obtained as the difference of the average $\bar{L}_{obs}$ and L_{BB} magnitudes; L_{BB} is estimated for a black body from the $(V–J)_0$ index observed at light maximum after correction for interstellar extinction. As can be seen from Table 1, ϵ and ΔL both increase together showing a qualitative relation between visual extinction and the infrared excess. Further support for this relation comes from the IR observations for hydrogen-poor carbon-rich non-variable stars (HdC) HD 182040 and HD 173409,

Table 1. Photometric parameters of R CrB stars

Star	Sp. Type	$\bar{P}$ (days)*	$\overline{\Delta V}$ (mag)*	ϵ	$\bar{L}_{obs}$ mag.**	L_{BB} mag	$\Delta L=\bar{L}_{obs}-L_{BB}$ mag	T_{BB}† K
R CrB	F81b	750	5·8	7·6	2·2	4·64	2·4	7200
RY Sgr	GoIb	999	5·4	5·4	2·62 – 3·0	4·85	2·23 – 1·85	7000
GU Sgr		1493	2·3	1·45	6·08 – 5·86	7·68	1·82 – 1·6	6000
S Aps	R3	1761	3·4	1·95	5·07	6·25	1·18	4265
XX Cam		>14832	1·7	~0				

*The light curve data are taken from the following sources: R CrB–Mayall (1960) and AAVSO Publications, RY Sgr–Mayall (1972), GU Sgr–Bateson and Jones (1973) and S Aps–Waters (1966).

***L* and (*V–J*) for GU Sgr, S Aps are obtained from Glass (1978); for RY Sgr–from Glass (1978) and Feast et al. (1977); for R CrB from Humphreys and Ney (1974) and Stecker (1975) and Glass (1978). The interstellar reddening is from Glass (1978).

†T_{BB} *is* the black body temperature.

which are spectroscopically similar to R CrB stars. Feast and Glass (1973) show that these non-variable HdC stars do not possess any infrared excesses. For XX Cam the e value obtained is close to zero and from the above relation very little or no infrared excess is to be expected. To check this, the following infrared observations were obtained.

2. IR observations

Observations of XX Cam in the *J*, *K* bands were obtained by B. J. McNamara in December 1973 at NKR's request, with the 127-cm telescope at Kitt Peak. M. Cohen has also kindly obtained observations of XX Cam at 2·2μ, 3·6μ and I0μ, with the 152-cm telescope at Mt. Lemmon in February 1974 at NKR's request. Further observations in *J*, *H, K* bands were obtained by us after six years, on 17 February 1980 with the 102-cm telescope at Kavalur using a liquid nitrogen cooled In Sb detector. These three sets of observations seem to agree with each other within the observational errors (±0·07 mag). The observed magnitudes and fluxes are given in Table 2, along with the mean *UBV* magnitudes given by Fernie, Sherwood and DuPuy (1972).

The interstellar reddening of XX Cam is estimated by Pugach (1977) as *E* (*B–V*) of 0·5 to 0·6 mag based on the distribution of the colour excess in the galactic plane given by Fitzgerald (1968). If a value of *E*(*B–V*) of 0·5 is adopted, the colours of XX Cam become too blue when compared with R CrB. Since the spectra of both R CrB and XX Cam look very similar (see Plate 12 of Yamashita, Nariai and Narimoto 1977), we assume that XX Cam has the same intrinsic (*B–V*) as that of R CrB (*B* – *V*= 0·52 mag) and thus obtain *E*(*B–V*) = 0·30 mag. The energy distribution is shown in Fig. 1 after correcting for the interstellar reddening of *E*(*B* – *V*) = 0·30 mag and using the reddening relations corresponding to van de Hulst's curve No. 15 (Johnson 1968). Also shown in Fig. 1 is the black body energy distribution for temperature of 7000 K. As can be seen from the figure, the energy distribution of XX Cam follows closely that of a black body at 7000 K and does not show any appreciable infrared excess, thus confirming the earlier expectation. Observations obtained six years apart do not show any variations greater

Table 2. Energy distribution of XX Cam.

Filter	λ (μ)	mag	F (watts/cm² μ)	Date
U	0·36	8·48	1·76 × 10^{-15}	
B	0·44	8·20	3·78 × 10^{-15}	
V	0·55	7·35	4·50 × 10^{-15}	
J	1·25	5·63	1·90 × 10^{-15}	Dec. 1973
K	2·2	5·36	2·80 × 10^{-16}	
	2·2	5·5	2·47 × 10^{-16}	
	3·6	5·38	4·16 × 10^{-17}	Feb. 1974
	10	4·5*	2·06 × 10^{-18}*	
J		5·80	1·627 × 10^{-15}	
H		5·70	5·972 × 10^{-16}	Feb. 1980
K		5·55	2·350 × 10^{-16}	

*10 micron measurement is an upper limit to the flux.

than that which can be attributed to observational errors. In this respect XX Cam is more like the non-variable HdC stars.

3. Spectrum

The spectrum of XX Cam has been analysed by Orlov and Rodriguez (1974) in some detail, and further reanalysis of Orlov and Rodriguez's data was done by

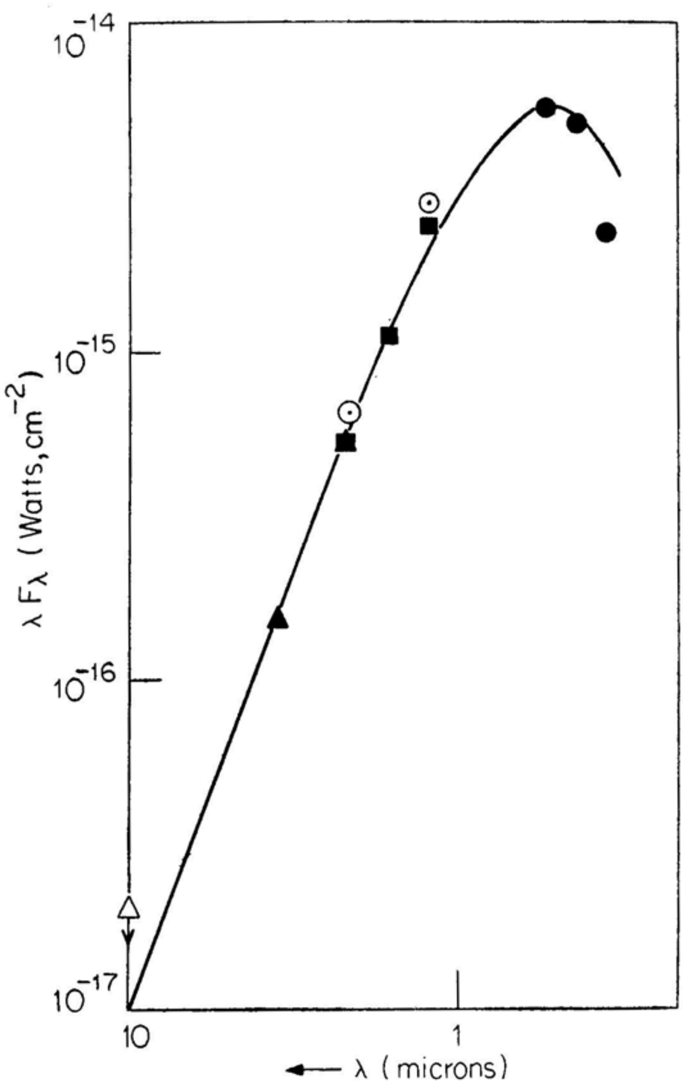

Figure 1. Energy distribution of XX Cam (Table 2) corrected for $E(B - V) = 0.30$. The curve represents a black body energy distribution (full line) for 7000 K which is made to agree with the observations at 0.55 microns.

● –Mean *UBV* observations given by Fernie, Sherwood and DuPuy (1972).

⊙–Observations in Dec. 1973.

▲–Observations in Feb. 1974. Open triangle denotes the upper limit.

■–Observations in Feb. 1980.

Schönberner(1975) with the help of model atmospheres. The effective temperature obtained by Schönberner of 7200 ± 600 K is in good agreement with the black body temperature of 7000 K estimated from the colours earlier. He also derives a mean micro-turbulent velocity of 9·5 km S^{-1}. Within the uncertainties of the analysis, all the three stars R CrB, RY Sgr and XX Cam have the same effective temperature of 7000 K and log g = 0·15. Although no observations of hydrogen lines were available in XX Cam, Schönberner estimated that hydrogen is more deficient in XX Cam than in RY Sgr and R CrB.

It is of importance to establish the C/H ratio in R CrB stars for an understanding of the stage of evolution and the process of mixing of surface and interior material. Moreover, it was noticed earlier that there might be a relation between C/H ratio and the Li abundance (Rao 1975). To estimate these parameters in XX Cam, a coudé spectrogram of 16Å mm^{-1} dispersion centred at λ 6600 was obtained on 1972 September 11, using the cooled Varo-image intensifier and the 61-cm coudé auxiliary telescope of Lick Observatory. The following equivalent widths are obtained; Hα λ 6562·8 = 0·52Å, CI λ 6587·7 = 0·70Å, the feature at λ 6707·8 of Li = 0·112Å. These could be compared with the value of RY Sgr obtained by Danziger (1965): Hα = 0·72Å, CI λ 6587·75= 0·354 Å and Li λ 6707 = 0·124Å. From a differential curve of growth analysis done with respect to RY Sgr, similar to that by Danziger, we obtained from the CI λ 6587·7 and Hα lines the (C/H) ratio Log $[(C/H)_{RY\ Sgr} / (C/H)_{XX\ Cam}] \simeq -$ 1·16. This value roughly agrees with the value of – 0·9 estimated by Schönberner. Thus we see that in XX Cam, carbon is a little more abundant and hydrogen more deficient than in RY Sgr.

In his study of Li abundances, Zappala (1972) found that the equivalent widths obtained for the Li feature on Varo-spectrograms (the same equipment used here) are systematically larger by 0·08 in log W_λ/λ, when compared to conventional spectrograms of the same dispersion (16 Å mm^{-1}). If this correction is applied to the equivalent width of Li feature in XX Cam, the corrected equivalent width is obtained as 93 mÅ; this may be compared with 124 mÅ in RY Sgr (Danziger 1965) and 220 mÅ in R CrB (Keenan and Greenstein 1963). Thus the Li abundance in XX Cam seems to be less than in RY Sgr. In both the stars the equivalent widths fall on the linear part of the curve of growth and differences in continuous opacity and excitation temperatures are small.

From the equivalent widths of four neutral oxygen lines observed by Danziger in RY Sgr, Schönberner (1975) found oxygen to be under-abundant by a factor of 2·5 relative to the oxygen abundance in normal B stars. For R CrB, Keenan and Greenstein (1963) show that the neutral oxygen lines are much stronger than in the normal F5 Ib super-giant star α Per, and thus oxygen might even be over-abundant when compared with solar abundance. The equivalent widths for two O I lines are as follows for R CrB measured on a 16Å mm^{-1} coudé spectrogram obtained by Herbig with the 3 meter telescope: λ 6454 = 210 m Å and λ 6453 = 135 mÅ as compared to 80 mÅ for both the lines obtained by Danziger for RY Sgr. (The equivalent widths of nearby Ca I lines λ 6437, λ 6462 and λ 6432 of Fe II are roughly equal to the equivalent widths of the same lines obtained in RY Sgr by Danziger within ± 0·02 in log W_λ/λ. The other two O I lines used by Danziger in RY Sgr λ 6154 and λ 6156 are very badly blended in the spectrogram of R CrB.) An order of magnitude estimate of the oxygen abundance for R CrB from the equivalent widths, thus shows that it is the same as in normal B stars. In XX Cam, the neutral oxygen line λ 7774 is much stronger than in R CrB. The equivalent width of this feature obtained from the Varo-spectrograms obtained at 33Å mm^{-1} dispersions are 2·40 and 1·90Å for XX Cam and R CrB respectively (Rao and Mallik 1978). It is well known that the λ 7774 feature is sensitive to luminosity of the star. Since Schönberner's analysis gives roughly the same effective gravity for both XX Cam ($\log g$ = 0·20) and R CrB (log g = 0·15), the difference in the equivalent widths might thus reflect differences in the oxygen abundance. In any case the oxygen abundance in XX Cam is the same as or even more than that of R CrB. (Although the O I lines λλ 6453, 6454 are present on the Varo-spectrogram of XX Cam mentioned earlier, they are very much blended.) Thus the qualitative study of the red spectrograms of XX Cam shows that it has less hydrogen, less lithium, more carbon and normal or more oxygen abundances when compared to RY Sgr and R CrB.

4. Light variability

There is another characteristic which seems to distinguish XX Cam from other R CrB stars, namely the variability in the visual light even at the time of normal light maximum. Most of the R CrB stars seem to show a cepheid type (?) light variability of 0·2 to 0·5 mag in a period of a few tens of days (Feast 1975). RY Sgr, the best studied star in this respect, shows pulsations with a period of 38·6 days (Alexander *et al.* 1972). Both R CrB itself (Fernie, Sherwood and DuPuy 1972) and UW Cen (Bateson 1972) have been reported to have periods around 40 days. GU Sgr also seems to show a periodicity of 38 days with amplitude of 0·3 mag (Bateson and Jones 1973; Rao 1980a). Sherwood (1975) has shown that there is a variability in light of 0·2 to 0·4 mag in *V* for all the other confirmed members of R CrB class, with periods of few tens of days. However, the two non-variable HdC stars HD 137613 and BD–10° 2179 which were specifically looked for light variability, do not show any light variations greater than 0·1 mag in *V*, with a period of a few tens of days (Rao 1980a). *UBV* observations of XX Cam have been obtained by Fernie, Sherwood and DuPuy (1972), Landolt (1968, 1973) and Rao (1980a), extending from 1967 to 1972. These observations, although scattered in time do not reveal any light variations greater than 0·1 mag in *V.* Even the Harvard photographic observations reported by Yuin (1948) do not show any prominent periodic variations of few tens of days. Except for the 1·7 mag drop in 1939-40, the only other light variability that has been reported of XX Cam, is the irregular light variation of about 0·1 mag or less in timescales of about 10 minutes on some nights by Totochava (1973, 1975). Apparently on some other nights such, rapid light variations are not present (Robinson 1974, personal communication; Totochava 1975). Our own observations of continuous monitoring of the star, for 3 hours on two nights through a *B* filter with the 102-cm reflector, do not show any variability greater than 0.03 mag. The significance of these short period irregular light variations is not clear at present; in any case these are small in amplitude. Thus XX Cam again shows characteristics similar to that of non-variable HdC stars.

5. Discussion

The lack of infrared excess in XX Cam implies lack of the presence of (or production of) circumstellar dust, and this behaviour is similar to that of non-variable HdC stars like HD 182040. Such an inference also derives support from the polarisation observations. The polarisation observations of XX Cam obtained at different times do not seem to show any changes in either the percentage of polarization or position angle of the electric vector or wavelength dependence (Kolotilov, Orlov and Rodriguez 1974). Moreover, these observations can be explained as due to the interstellar extinction. Although XX Cam has the same $T_{\rm eff}$ and log g as R CrB and RY Sgr the lack of production (or very infrequent production) of dust is puzzling.

The R CrB type variation of large drops in visual light and the pulsations (light variations) with periods of few tens of days seem to be related phenomena. All stars which show R CrB type variations also seem to show some sort of periodic variations in light (pulsations?). It might even be that the pulsations cause the R CrB type activity. The absence of such pulsations or periodic variations light in XX Cam and in the non-variable HdC stars might indicate that they lie just outside the instability strip. The presence of such an instability strip has been postulated by Trimble (1972) from her theoretical studies of pulsations in helium stars. However, non-variable and variable (R CrB stars) HdC stars seem to have the same M_v of – 4·0 mag (Feast 1972; Richer 1975) $T_{\rm eff}$ and thus occupy the same position in the HR diagram. This might be related to the fact that XX Cam and even all the cool non-variable HdC stars (Warner 1967) have hydrogen much more deficient (except HD 148839) and carbon enhanced in abundance than R CrB and RY Sgr. The theoretical pulsation calculations of Trimble (1972) show that increasing the carbon content is like increasing Z, the metallicity parameter and the effect of this on the pulsational properties of helium stars is such that for a given $T_{\rm eff}$ a star with large Z will be less likely to pulsate than one with smaller Z. Thus XX Cam with a higher carbon content (also oxygen) and less hydrogen might be more stable than R CrB and RY Sgr. However, more observational studies regarding the chemical composition of HdC stars coupled with better theoretical pulsation models are needed, before the above conjecture can be properly justified.

Although at present the evolutionary phase of R CrB stars is not clear (see Bond, Luck and Newman 1979; Paczynski 1971; Sackman, Smith and Despain 1974; Schönberner 1975; Wheeler 1978), the deficiency of hydrogen and lithium and enhancement of carbon (probably oxygen too) in XX Cam as well as the non-variable HdC stars might indicate in a stage of evolution later than of R CrB and RY Sgr.

Acknowledgements

We would like to express our thanks to M. K. V. Bappu, M. Cohen, G. Herbig, E. Harlan, B. McNamara and Sushma Mallik, for their help and advice.

References

Alexander, J. B., Andrews, P. J., Catchpole, R. M., Feast, M. W., Lloyd Evans, T., Menzies, J. W., Wisse, P. N. I., Wisse, M. 1972, *Mon. Not. R. astr. Soc.,* **158,** 305.

Bateson, F. W. 1972, *Inf. Bull. Var. Stars,* No. 661.

Bateson, F. W., Jones, A. F. 1973, *R. astr. Soc. New Zealand, Var. Stars Sec. Circ.,* No. 193.

Bidelman, W. P. 1948, *Astrophys. J.,* **107,** 413.

Bond, H. E., Luck, E. R., Newman, M. J. 1979, *Astrophys. J.* **233,** 295.

Danziger, I. J. 1965, *Mon. Not. R. astr. Soc.,* **130,** 199.

Feast, M. W. 1972, *Mon. Not. R. astr. Soc.,* **158,** 11 p.

Feast, M. W. 1975, *Variable Stars and Stellar Evolution,* Eds V. E. Sherwood and L. Plant, D. Reidel, Dordrecht, p. 129.

Feast, M. W., Glass, I. S. 1973, *Mon. Not. R. astr. Soc.,* **161,** 293.

Feast, M. W., Catchpole, R. M., Lloyd Evans, T., Robertson, B. S. C., Dean, J. F., Bywater, R. A. 1977, *Mon. Not. R. astr. Soc.,* **178,** 415.

Fernie, J. D., Sherwood, V., DuPuy, D. L. 1972, *Astrophys. J.,* **172**, 383.

Fitzgerald, P. M. 1968, *Astr. J.,* **73,** 983.

Gaustad, J. 1972, *Mem. Soc. R. Sci. de Liege 6^{e} Serie,* Tome III, 87.

Glass, I. S. 1978, *Mon. Not. R. astr. Soc.,* **185,** 23.

Humphreys, R. H., Ney, E. P. 1974, *Astrophys. J.,* **190,** 339.

Johnson, H. L. 1968, *Nebulae and Interstellar Matter* Eds. B. M. Middlehurst and L. H. Aller, University of Chicago Press, Chicago, p. 167.

Keenan, P. C., Greenstein, J. L. 1963, *Contr. Perkins. Obs. Ser II,* No. 13, 199.

Kolotilov, E. A., Orlov, M. Ya, Rodriguez, M. H. 1974, *Soviet Astr.,* **17,** 615.

Landolt, A. U. 1968, *Publ. astr. Soc. Pacific,* **80,** 318.

Landolt, A. U. 1973, *Publ. astr. Soc. Pacific,* **85,** 606.

Lee, T. A., Feast, M. W. 1969, *Astrophys. J.,* **157,** L173.

Mayan, M. W. 1960, J. *R. astr. Soc. Can.,* **54,** 193.

Mayall, M. W. 1972, *R. astr. Soc. Can*., **66,** 233.

O'Keefe, J. A. 1939, *Astrophys. J.,* **90,** 294.

Orlov, M. Ya, Rodriguez, M. H. 1974, *Astr. Astrophys*., **31,** 203.

Paczynski, B. 1971, *Acta Astr.,* **21,** 1.

Pugach, A. F. 1977, *Variable Stars* (*Russian*) **20,** 391.

Rao, N. K. 1975, *Bull. astr. Soc. India,* **3,** 50.

Rao, N. K. 1980a, *Astrophys. Sp. Sci.,* **70,** 480.

Rao, N. K. 1980b, *Observatory,* (in press).

Rao, N. K., Mallik, S. G. V. 1978, *Mon. Not. R. astr. Soc.,* **183,** 211.

Richer, H. B. 1975, *Astrophys. J.,* **197,** 611.

Sackman, I. J., Smith, R. L., Despain, K. H. 1974, *Astrophys. J.,* **181,** 555.

Schönberner, D. 1975, *Astr. Astrophys.,* **44,** 383.

Sherwood, V. E. 1975, *in IAU Symp.* 67: *Variable Stars and Stellar Evolution* Eds V. E. Sherwood and L. Plant, D. Reidel, Dordrecht, p. 147.

Stein, W. A,, Gaustad, J. E., Gillet, R C., Kanacke, R. F. 1969, *Astrophys. J.,* **155,** L3.

Totochava, A. G. 1973, *Astr. Circ. USSR* No. 791.

Totochava, A. G. 1975, *IAU Symp.* 67: *Variable Stars and Stellar Evolution* Eds V. E. Sherwood and L. Plaut, D. Reidel, Dordrecht, p. 161.

Trimble, V. 1972, *Mon. Not. R. astr. Soc.* **156,** 411.

Warner, B. 1967, *Mon. Not. R. astr. Soc.* **137,** 119.

Waters, B. H. J. 1966, *R. astr. Soc. New Zealand, Var. Stars Sec. Circ.,* No. 119.

Wheeler, T. C. 1978, *Astrophys. J.,* **225,** 212.

Yamashita, Y., Nariai, K., Narimoto, Y. 1977, *An Atlas of Representative Stellar Spectra,* University of Tokyo Press, Tokyo.

Yuin, E. 1948, *Astrophys. J.,* **107,** 413.

Zappala, R. R. 1972, *Astrophys. J.,* **172,** 51.