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Absolute energy distribution in Rho Cassiopeiae

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Summary. The continuous energy distribution of ρ Cas obtained in the wavelength range 340–710 nm has been compared with the energy distribution of δ CMa in the same wavelength range. The circumstellar shell associated with ρ Cas seems to modify the continuum of the star appreciably. Variations in the Balmer emission of ρ Cas taking place within a day are noticed.

1 Introduction

The supergiant star ρ Cas (HD 224014) has been known to be surrounded by a circumstellar envelope. Although originally classified as F8 Ia in the MK classification (Morgan, Keenan & Kellman 1943) the spectrum and the luminosity of the star show large variations. During 1946–47 the star went through a deep light minimum when the visual magnitude dropped by about two magnitudes and the spectrum assumed characteristics of an M-type star, including bands of TiO. Beardsley (1961) suggested that the star, initially an F supergiant, expanded and ejected a cool circumstellar cloud which in turn was responsible for the M characteristics. Greenstein (1948) found evidence of matter falling back on to the star within a period of one day after a sudden expansion. Sargent (1961) on the basis of spectral comparison with another supergiant star δ CMa (HD 54605; F8 Ia) inferred that ρ Cas has the same photospheric spectrum as δ CMa but for the circumstellar features. We have observed ρ Cas along with δ CMa with the help of a spectrum scanner to compare their continuous-energy distributions.

2 Observations

The observations covering the wavelength interval 340–710 nm were secured at the Uttar Pradesh State Observatory. In 1970, ρ Cas alone was observed through the 52-cm reflector, but in 1974 both ρ Cas and δ CMa were observed through the 104-cm Sampurnanand reflector. An exit window of 7 nm has been used throughout. γ Gem, ξ^2 CrB and α Lyr have been observed as standard stars.

The calibration of α Lyr by Hayes & Latham (1975) has been used to convert the observed energy distribution to absolute units. The standard deviations of the comparison stars do not exceed 0.03 mag in the entire observed range of wavelengths.

Table 1. Reddening corrected monochromatic magnitudes of ρ Cas and δ CMa normalized to wavelength 550 nm.

λ (nm)	1/λ (μm)$^{-1}$	ρ Cas 1970 October 31 (mag)	1970 November 19 (mag)	1974 October 2 (mag)	1974 October 3 (mag)	Reddening correction for ρ Cas (mag)	δ CMa Mean (mag)	Reddening correction for δ CMa (mag)
340	2.94	–	–	0.44	0.83	2.37	1.81	0.53
350	2.86	1.01	0.63	0.51	0.91	2.32	1.76	0.49
360	2.78	0.99	0.75	0.55	1.03	2.26	1.53	0.48
370	2.70	0.98	0.79	0.57	0.84	2.20	1.39	0.47
380	2.63	0.73	0.66	0.32	0.76	2.16	1.01	0.46
390	2.56	0.40	0.24	0.23	0.62	2.12	0.91	0.46
400	2.50	0.29	0.16	0.11	0.27	2.08	0.55	0.45
410	2.44	0.09	0.23	0.05	0.22	2.05	0.43	0.43
420	2.38	0.12	0.27	0.12	0.29	2.01	0.43	0.42
430	2.33	0.35	0.33	0.13	0.22	1.97	0.27	0.42
440	2.27	0.20	0.22	0.23	0.30	1.93	0.30	0.41
450	2.22	0.18	0.18	0.20	0.22	1.89	0.22	0.40
460	2.17	0.07	0.10	0.10	0.13	1.85	0.16	0.39
470	2.13	0.02	0.04	−0.03	0.05	1.80	0.07	0.38
480	2.08	0.07	0.04	−0.03	0.08	1.74	0.07	0.37
490	2.04	0.06	0.08	0.09	0.10	1.70	0.10	0.36
500	2.00	0.03	0.07	0.08	0.10	1.65	0.08	0.35
510	1.96	0.02	−0.01	−0.01	0.03	1.61	0.02	0.34
520	1.92	0.05	0.08	0.06	−0.02	1.57	0.06	0.34
530	1.89	0.01	0.05	0.04	0.03	1.53	0.03	0.33
540	1.85	0.00	0.03	−0.01	0.02	1.49	0.01	0.31
550	1.82	0.00	0.00	0.00	0.00	1.46	0.00	0.30
560	1.79	−0.04	−0.03	−0.08	−0.07	1.43	−0.06	0.30
570	1.75	−0.10	−0.02	−0.14	−0.09	1.39	−0.10	0.29
580	1.72	−0.15	−0.09	−0.23	−0.14	1.36	−0.18	0.29
590	1.70	−0.16	−0.07	−0.21	−0.14	1.34	−0.18	0.28
600	1.68	−0.04	0.00	−0.10	−0.05	1.31	−0.10	0.28
610	1.64	0.05	0.06	0.05	0.03	1.27	0.01	0.27
620	1.61	0.15	0.09	0.11	0.07	1.23	0.05	0.26
630	1.59	0.10	0.22	0.13	0.08	1.20	0.07	0.26
640	1.56	0.09	0.17	0.07	0.01	1.17	0.00	0.25
650	1.54	0.05	0.03	0.08	0.02	1.14	0.01	0.25
660	1.52	0.07	0.09	0.05	−0.00	1.12	−0.01	0.24
670	1.49	0.08	0.12	0.07	−0.06	1.09	−0.03	0.24
680	1.47	0.09	0.17	0.11	−0.05	1.07	0.01	0.23
690	1.45	0.10	0.35	0.10	0.06	1.04	0.14	0.23
700	1.43	0.16	0.31	0.22	0.03	1.02	0.13	0.23
710	1.41	0.27	0.33	0.25	0.11	1.00	0.17	0.22

The monochromatic magnitudes of both ρ Cas and δ CMa have been corrected for interstellar reddening. The choice of an accurate value of the colour excess $E(B-V)$ for ρ Cas is, however, difficult, because of different values of the observed and the intrinsic colours of the star obtained on different occasions (Sargent 1961; Schmidt-Kaler 1961a). Although a value based on an estimate of the distance of the star may be expected to give a more accurate value of the interstellar reddening, the uncertainties in the parameters involved make it still less reliable. We have for this work, adopted a value of $E(B-V)$ equal to 0.48 mag derived on the basis of the observed colour of the star (Landolt 1973) and the intrinsic colour of an F8 Ia star (Schmidt-Kaler 1961b; FitzGerald 1970), assuming that the spectral type of the star during the interval of our observations had remained at F8 Ia. This gives us $A_v = 1.44$ mag.

The observed $(B-V)$ colour of δ CMa, is more consistent. The mean of the several values of the $B-V$ colour of the star listed by Blanco *et al.* (1968) is 0.67 ± 0.013 mag. These data yield $E(B-V) = 0.10$ mag, whence $A_v = 0.30$ mag for δ CMa.

With the above values of A_v and the reddening curve given by Whitford (1958), the monochromatic magnitudes of the stars have been corrected for interstellar reddening. No blanketing corrections have been applied since under normal conditions these corrections for both the stars would be the same. The reddening corrected monochromatic magnitudes of both the stars, normalized to wavelength 550 nm along with the respective reddening corrections have been given in Table 1.

3 Discussions

Fig. 1 shows the energy distribution of ρ Cas on the four nights of observations. For comparison we have also plotted the energy distribution of δ CMa with each of these curves. From these it appears that (1) the Paschen slope in ρ Cas is different from that in δ CMa and

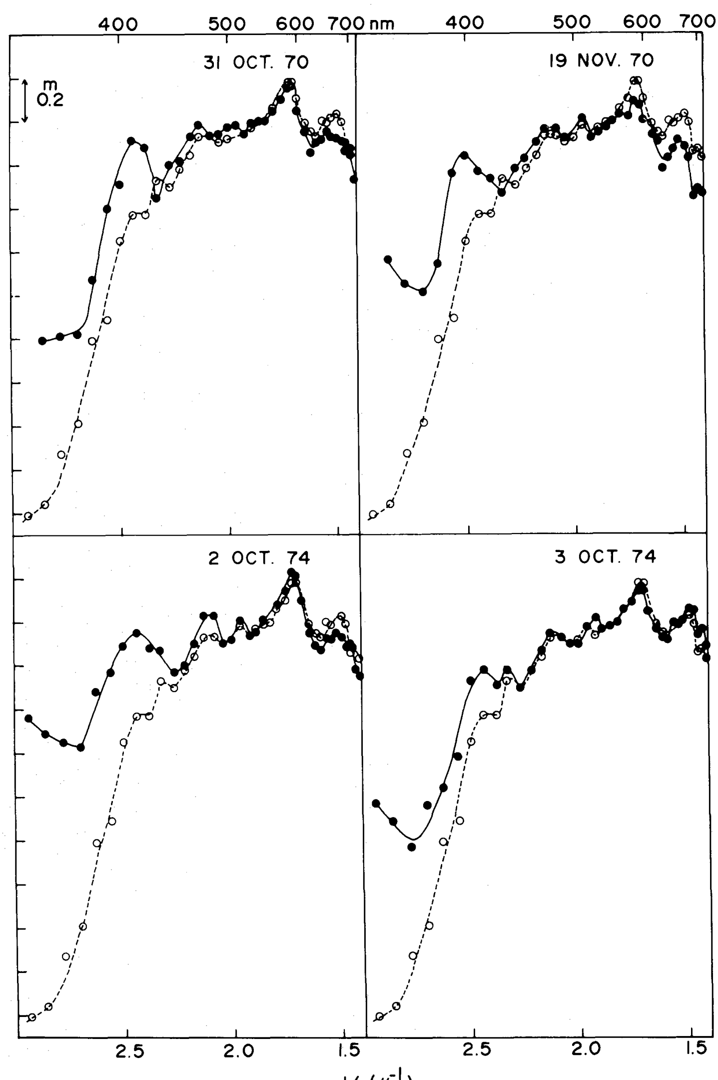

Figure 1. Energy distribution curves of ρ Cas and δ CMa. Filled circles – ρ Cas. Open circles – δ CMa.

(2) the Balmer jump in ρ Cas is smaller than that in δ CMa on all the four nights and that it is different on each night.

3.1 ENERGY DISTRIBUTION IN THE PASCHEN CONTINUUM

To assess the difference in the slopes of the Paschen continua of the two stars we have plotted in Fig. 2 the monochromatic magnitude differences between δ CMa and ρ Cas against inverse wavelength. Similar magnitude differences were also plotted for δ CMa and α Lyr.

The relative gradients $G_{\delta \mathrm{CMa}, \rho \mathrm{Cas}}$ and $G_{\delta \mathrm{CMa}, \alpha \mathrm{Lyr}}$ at 500 nm ($1/\lambda = 2.0$) were then obtained from the relation $G_{\mathrm{A,B}} = 0.921\, S_{\mathrm{A,B}}$ (Kienle 1941), where $S_{\mathrm{A,B}} = d(\Delta m_{\mathrm{A,B}})/d(1/\lambda)$ is the slope of the least-square best-fitting straight line among the points of the corresponding magnitude differences between stars A and B, within the limits $1.8 < 1/\lambda < 2.2$.

Next, using the known absolute gradient (ϕ) of α Lyr at wavelength 500 nm to be 1.10 (Code 1960; Lamla 1965) we obtained the absolute gradient of δ CMa to be 2.25 and that of ρ Cas to be 2.05 and 2.21 for the epochs 1970 and 1974 respectively. The colour temperatures corresponding to these ϕ values were then read from a T_c–ϕ curve for black bodies (Lamla 1965). The colour temperature for ρ Cas came out to be higher than that for δ CMa by about 650 K in 1970 and 100 K in 1974.

It appears reasonable to assume that the modifications in the energy distribution curves of ρ Cas are brought about by the circumstellar cloud surrounding it. One can then explain the apparent decrease in the colour temperature of the star in 1974 compared to that in 1970 as being due to an increase in the density of the circumstellar cloud resulting in enhanced circumstellar reddening.

3.2 ENERGY DISTRIBUTION SHORTWARD OF WAVELENGTH 410 NM

The flux in ρ Cas at wavelengths shorter than 410 nm is greater than that in δ CMa on all the four nights of observations, and it is variable. A quantitative estimate of the Balmer jump was not made because the continuum on either side of this discontinuity could not be ascertained with certainty. But a marked change in the Balmer jump is noticed between two

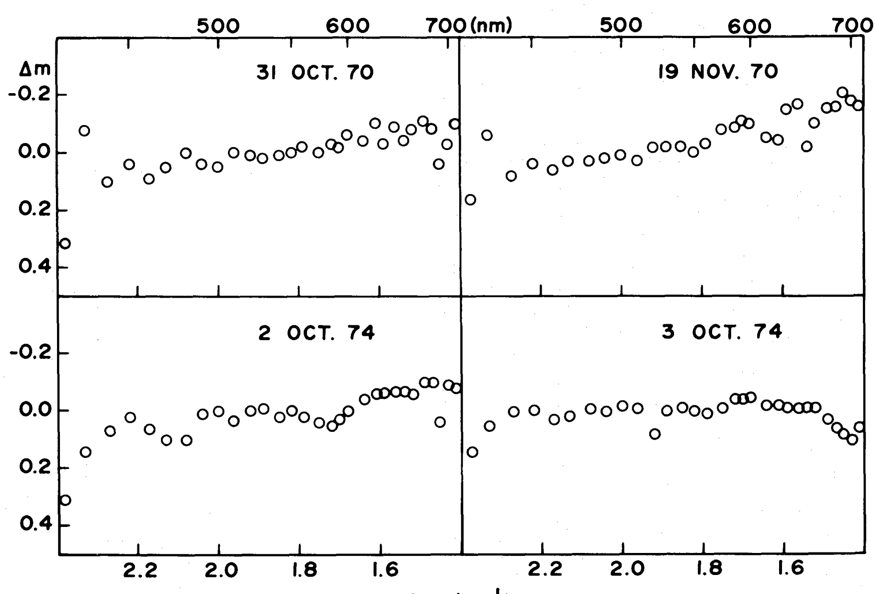

Figure 2. Monochromatic magnitude differences, δ CMa–ρ Cas.

successive nights in 1974. The excess flux shortward of wavelength 410 nm may be attributed to hydrogen emission in the associated chromosphere (Sargent 1961) of the star. However, we have no explanation to offer for the variations in this emission except to suggest that the mechanism responsible for heating up the chromosphere could act in bursts of short duration.

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References

Beardsley, W. R., 1961. *Astrophys. J. Suppl.*, **5**, 381.

Blanco, V. M., Demers, S., Douglass, G. G. & FitzGerald, M. P., 1968. *Publ. US Naval Obs.* (second series), 21.

Code, A. D., 1960. *Stellar atmospheres*, p. 50, ed. Greenstein, J. L., The University of Chicago Press.

FitzGerald, M. P., 1970. *Astr. Astrophys.*, **4**, 234.

Greenstein, J. L., 1948. *Astrophys. J.*, **108**, 78.

Hayes, D. S. & Latham, D. W., 1975. *Astrophys. J.*, **197**, 593.

Kienle, H., 1941. *Z. Astrophys.*, **20**, 239.

Lamla, E., 1965. *Landolt–Börnstein VI band 1*, p. 382, ed. Voigt, H. H., Springer-Verlag, Berlin.

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

Morgan, W. W., Keenan, P. C. & Kellman, E., 1943. *An atlas of stellar spectra*, The University of Chicago Press.

Sargent, W. L. W., 1961. *Astrophys. J.*, **134**, 142.

Schmidt-Kaler, T., 1961a. *Z. Astrophys.*, **53**, 28.

Schmidt-Kaler, T., 1961b. *Astr. Nachr.*, **286**, 113.

Whitford, A. E., 1958. *Astr. J.*, **63**, 201.