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# *UBVR* polarimetry of the peculiar R CrB star V 854 Centauri

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**Abstract.** We present *UBVR* polarimetry V 854 Cen obtained on four nights during February 1991–March 1992. Two sets of measurements are close to two nearby light maxima and the other two during the declines when the star was around 4 mag below the two light maxima. Both the amount and position angle of polarization obtained during one light maximum differ significantly from that obtained during the other and on all four occasions the position angles are nearly independent of wavelength. The wavelength dependence of polarization during the light minimum is much steeper than that during the light maximum and the corresponding position angles differ by $\sim 75°$. During the decline phases the polarized flux is also attenuated by the same factor as the starlight implying that the cloud which obscures the photosphere causing the light fading obscures the scattering region also. This restricts the extent of the scattering region which contributes to the observed polarization at light maximum and early decline phases close to the photosphere. The polarization observed at light minimum, most likely, arises from scattering by dust particles distributed more extensively about the star.

**Key words:** polarization – circumstellar matter – V 854 Cen – R CrB type variables

## 1. Introduction

V 854 Cen (= NSV 6708) is one of the brightest known R CrB stars and has a visual magnitude in the range 7.1–7.4 at light maximum. R CrB stars well known for their declines in brightness by a few tenths of a magnitude to dramatic fadings of 5–8 mag at irregular intervals. V 854 Cen appears to undergo more frequent fadings of large amplitudes than the other R CrB objects identified and probably, it is this fact that has led to its identification only recently in spite of its large visual brightness at light maximum. The star has undergone deep declines every year since 1987 when regular observations were begun (Lawson et al. 1992). Its spectra show strong Balmer lines of hydrogen (Kilkenny & Marang 1989); this is quite unusual for an R CrB star which presumably has a hydrogen-deficient, carbon-rich atmosphere. Like other members of its class V 854 Cen possesses strong infrared excess indicating the presence of an extended dust envelope.

According to the generally accepted model, the light fadings in R CrB stars arise due to the occultation of the star by dense dust clouds ejected by the star (Feast 1987; Fadeyev 1988); partial occultations of the star lead to declines of lower amplitudes. The exact location of dust formation and the geometry of cloud obscuration are quite uncertain. In addition to the sudden and unpredictable fadings, R CrB objects exhibit low amplitude pulsations and the resulting light curves usually appear very irregular in shape and amplitude. Polarimetry of R CrB stars might provide important information on the nature and distribution of dust grains in the envelope, and probably on the ejection of gas and subsequent dust condensation. At light minimum, when the direct unpolarized starlight is obscured by dust along the line of sight, the scattered light becomes relatively more dominant. In the case of the prototype R CrB, Coyne & Shawl (1973) have found the percentage of polarization in *B* band to increase by more than a factor of 10 during a decline of about 7 mag. Unfortunately, these objects have received little attention polarimetrically. Only the prototype R CrB has been observed on a few occasions, that too spread over several years.

The standard model for the fadings in brightness of R CrB stars assumes that dust clouds are ejected from all parts of stellar surface and a fading will occur when the ejection happens to be in the line of sight. However, from an analysis of the polarimetric data available for the prototype, Stanford et al. (1988) have suggested that ejection of dust clouds occur in a preferred plane about the star.

Whitney et al. (1992) obtained spectropolarimetry of V 854 Cen in the 4200–6500 Å region during a deep minimum ($V \sim 15$ mag) and found that the continuum is highly polarized whereas the emission lines which are prominent are unpolarized. We observed V 854 Cen polarimetrically in *UBVR* bands on four different occasions, during two maxima and two decline phases, close to the

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*Send offprint requests to*: A.V. Raveendran epoch of the observations by Whitney et al. (1992). In this paper we present the new *UBVR* polarimetry and discuss the results in the light of the standard cloud eclipse model.

## 2. Observations

V 854 Cen was observed on four nights – 10 February 1991 (*UBVR* bands), 17 May 1991 (*BVR* bands), 13 February 1992 (*UBVR* bands) and 26 March 1992 (*VR* bands) – with the 2.34 m telescope of Vainu Bappu Observatory, Kavalur. A 16″ diaphragm was used throughout for the observations. The polarimeter used consists of an achromatic half-wave retarder rotated at 10.41 Hz acting as the polarizer and a Wollaston prism acting as the analyzer. A detailed description of the polarimeter is given in Deshpande et al. (1985). The microcomputer system built around a Z-80 microprocessor for the data acquisition and on-line reduction has since been replaced by an IBM compatible personal computer.

**Table 1.** *UBVR* polarimetry of V 854 Cen

| JD 2448000+ | Band | P (%) | θ (°) | Visual magnitude | Source |
|---|---|---|---|---|---|
| 299.00 | U | 2.82±0.10 | 44±1 | 7.2 | 1 |
| | B | 1.59±0.04 | 80±1 | | |
| | V | 0.94±0.04 | 66±1 | | |
| | R | 1.27±0.04 | 83±1 | | |
| 394.75 | B | 0.51±0.22 | 71±12 | 11.2–11.4 | 1 |
| | V | 0.73±0.07 | 80±3 | | |
| | R | 0.69±0.10 | 85±4 | | |
| 666.92 | U | 1.03±0.25 | 69±7 | 7.6–8.0 | 2 |
| | B | 0.44±0.09 | 46±6 | | |
| | V | 0.39±0.07 | 65±5 | | |
| | R | 0.32±0.11 | 55±10 | | |
| 708.84 | V | 0.76±0.31 | 47±12 | 11.3–11.7 | 3 |
| | R | 1.07±0.19 | 46±5 | | |

*Sources*: 1. Lawson et al. 1992. 2. RAS New Zealand Circ. 3. Present study.

In Table 1, the linear polarization $P$ (%), position angle $\theta$ (°) and the corresponding errors in their measurements are given along with the Julian day of observation. Apart from the errors due to photon statistics, the errors quoted in the table include the uncertainty in the determination of instrumental polarization. The instrumental polarization was determined during each observing run by observing a sample of nearby unpolarized objects (HD 18803, HD 24238, HD 42807, HD 65583, HD 90508, HD 98281, HD 102438, HD 103095, HD 106116 and HD 144287) from the list given by Serkowski (1974). The zero point of position angle was also determined during each observing run by observing several highly polarized standard stars (9 Gem, HD 14433, HD 160529, HD 183143 and HD 204827), again from the list of Serkowski (1974). The approximate visual magnitudes at the times of polarimetric observations and the corresponding references are also given in Table 1.

## 3. Results

The values of $P$ (%) and $\theta$ (°) given in Table 1 are plotted in Fig. 1 which also contains the Julian days of observation.

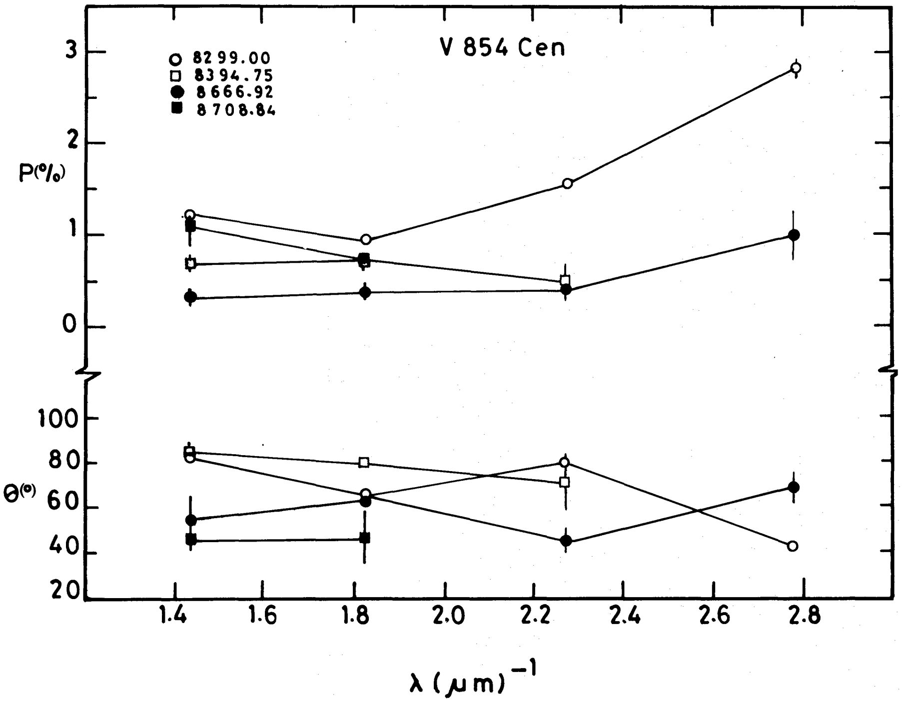

**Fig. 1.** Plots of polarization and position angle against the corresponding inverse of the effective wavelength of filter band

The light curve, a major portion of which was obtained by Lawson et al. (1992), during the period of polarimetric observations is given in Fig. 2. The upward pointing arrows show the times when we made observations and the downward pointing arrow shows when Whitney et al. (1992) obtained spectropolarimetry. The four sets of present observations fall respectively at a maximum, a decline phase around 4 mag below the same maximum, a decline phase close to the next maximum and a decline phase around 4 mag below the same maximum. The spectropolarimetric observations of Whitney et al. (1992) fall at a deep minimum phase, between the phases of the second and third sets of present observations.

It is clear from Fig. 1 that both the amount and wavelength dependence of polarization are variable. The position angle of polarization is nearly independent of wavelength. Apparently, the mean position angle changes from one decline to another. The position angles observed during the first two occasions (open symbols) are well within the uncertainties. Similarly, the position angles obtained during the last two occasions (filled symbols), corresponding to the next decline, also agree within errors. But there is a systematic difference between the two groups of observations with the position angles obtained during the first decline lying systematically above (mean ~15°) that obtained during the next decline. It is clear from Figs. 1 and 2 that there is a significant difference in the amount of polarization from one maximum to another. V 854 Cen was close to maxima on JD 2448299.0 and 8666.92 (visual mag ~7.5), but the amount of polarization at all wavelength bands on the latter occasion is much lower than that during the former occasion. We could not observe the star in all bands on both the occasions when it was ~4 mag below the maximum. The amount of polarization in *V* and *R* bands in which we could observe the object on both the occasions agree mutually within the uncertainties. From Fig. 1 we find that the polarizations in *V* and *R* bands observed during the first decline lie significantly below that observed during the light maximum preceding it while during the second decline they lie significantly above that obtained during the maximum preceding it.

## 4. Discussion

The observations by Serkowski & Kruszewski (1969) and Stanford et al. (1988) show that the polarized flux in R CrB increases early in the decline and drops drastically (by more than a factor of 10) late in the decline. Since no polarimetric data during an early decline was available to them, Whitney et al. (1992) assumed that V 854 Cen also shows a similar behaviour and suggested that, most likely, the obscuring cloud, asymmetrically shaped, contributes to the polarization early in a decline. If we consider the relatively more accurate *V* band polarization measurements given in Table 1, we find that the change in the polarization observed at a light maximum is very small as the star declined in brightness by about 4 mag. This implies that the obscuring cloud instead of contributing attenuates the scattered light which produces the polarization at light maximum. The interstellar component of polarization in the direction of V 854 Cen is probably negligible when compared to the observed values (Whitney et al. 1992). The presence of a significant component would be reflected in the observed values during early decline only if the intrinsic polarization varies appreciably.

There are two basic scenarios by which an evolving dust cloud could cause the declines in R CrB stars (Goldsmith & Evans 1986). In the first case the dust cloud is initially seen as an optically thick disc projected over the sky, with angular size much less than the star's, that grows and eventually occults the entire star, the lateral expansion causing the light fading. In the second scenario the dust

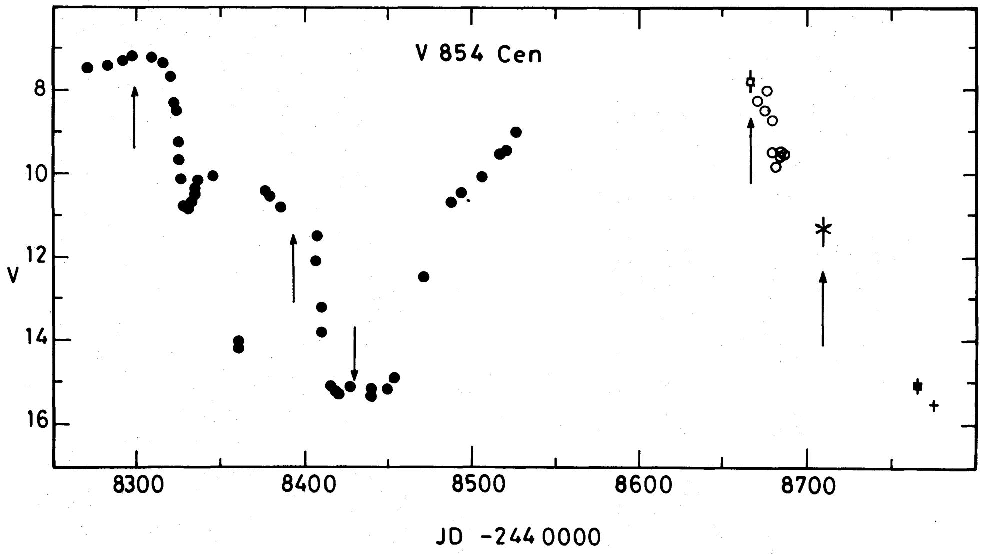

**Fig. 2.** Light curve during the period of polarization measurements. The upward pointing arrows indicate the epochs of present observations and the downward pointing arrow the epoch when Whitney et al. (1992) obtained spectropolarimetry. Filled circles represent the observations taken from Lawson et al. (1992); open square, RAS New Zealand Circ.; open circles, IAU Circ. No. 5468; cross, present study; filled square, Rao & Lambert (1992); plus, AAVSO Circ. No. 260. The error bars indicate the maximum possible uncertainties in the values. Note that some errors are smaller than the symbols

condensation is first seen as a large optically thin disc, with angular size comparable to that of the star, which becomes optically thick as grain growth proceeds and causes the fading. If the direct starlight alone were blocked as the decline progresses, as would be the case according to the first scenario, we would expect a large increase in the percentage of polarization, contrary to what is observed. If dust condensation occurs over a large region over the stellar surface in the beginning itself as in the second scenario, during the early decline it is quite reasonable to expect an attenuation of scattered light along with the photospheric light, consistent with the present observations.

The scattered flux observed depends on the flux from the star incident on the scatterers. Hence, a reduction in the incident flux will result in a proportionate reduction in the scattered flux and the corresponding polarized flux. In this case the new obscuring cloud should have a larger angular extension as seen from the star and its effect should be seen in the infrared emission which arises from the re-radiation of starlight by the dust. From the IRAS observations and *UBVRIJKLM* data at light maximum Rao & Lambert (1992) find that the ratio of IR excess flux to total flux (visual + IR) is 0.48, indicating that the dust cloud which gives rise to IR excess occupies an effective solid angle around $2\pi$. The *L* band magnitudes obtained at light maximum (Whitelock & Feast 1988) and minimum (Harrison & Stringfellow 1991) do not show any increase in the infrared flux at light minimum. This indicates that the new obscuring cloud does not contribute significantly to the infrared flux at light minimum and hence, occupies a small fractional solid angle as seen from the star (Whitney et al. 1992). So the possibility that the reduction in polarized flux almost at the same rate as the drop in brightness is as a result of a reduction in the flux from the star incident on the scatterers, is less likely. It is more likely that the new obscuring cloud has a small angular extent as seen from the star but has a projected disc large enough to eclipse the scattering region along with the photosphere, thereby attenuating scattered light along with the photospheric light. However, the projected disc of the cloud cannot be very large, otherwise the emission line regions also would be occulted. Since the emission lines are unpolarized, they are not occulted, and are probably seen directly (Whitney et al. 1992). This places the scattering region responsible for the polarization at light maximum close to the photosphere.

Spectropolarimetry of V 854 Cen obtained by Whitney et al. (1992) during the deep minimum following the first two sets of observations listed in Table 1 shows that the emission lines are unpolarized whereas the continuum is strongly polarized. It is well known that in R CrB stars the photospheric absorption lines become weaker and emission lines become stronger as the decline in brightness progresses (Herbig 1949; Gaposchkin 1963; Alexander et al. 1972; Kilkenny & Marang 1989). Usually, the emission lines start appearing in the spectrum when the star fades around 2–3 mag below the maximum. But the spectra of V 854 Cen taken when it was only about 1 mag below the light maximum during the 1989 decline show broad emission around Na I *D* lines (Rao & Lambert 1992). Since the observed flux through broadbands always includes the contribution from the unpolarized emission line flux, we would expect a decrease in the polarization, especially at shorter wavelengths, as a result of increased contribution from unpolarized emission flux as the star declines in brightness (assuming that the cloud which occults the star obscures the scattering region also, the possibility discussed above). The position angle of polarization is independent of the specific scattering mechanism and is determined by the density distribution of the scatterers alone (Simmons 1982). Hence, we also would expect the change in the polarization to occur without a change in the position angle as a result of dilution by the unpolarized emission flux. The observations obtained during the first decline (i.e. 1991) are qualitatively consistent with this picture while that obtained during the next decline (i.e. 1992) are not. It is possible that during the initial decline phases of the 1992 minimum the scattering region was not completely occulted, thereby causing the observing marginal increase in polarization in *V* and *R* bands.

The polarized flux in the *V* band during the 1991 maximum is $9\,10^{-3}$ F, where *F* is the *V* band flux. At the following light minimum when Whitney et al. (1992) observed V 854 Cen the drop in brightness was $\sim 8.2$ mag. The polarization observed then ($\sim 10\%$ in *V* band) corresponds to a polarized flux $\mathrm{PF} = 5\,10^{-5}\,F$, a drop by only 5.6 mag. This is 2.6 mag less than the drop in brightness, contrary to what is seen during the decline phases when both the starlight and polarized flux drop at the same rate. The position angle of polarization observed during the maximum is $\sim 75^{\circ}$ whereas that observed during the deep minimum is $\sim 0^{\circ}$. Hence the polarized flux seen at the light minimum is not the attenuated polarized flux seen at light maximum and has its origin in some part of the envelope different from where the polarized flux observed at light maximum originates. It is less likely that the polarization at light minimum arises from scattering by dust grains in the new obscuring cloud since the light scattered by the cloud has to come at a low average angle and thus resulting in a low polarization (Whitney et al. 1992). Most likely, the polarization observed at light minimum arises from scattering by dust particles distributed asymmetrically and more extensively about the star. Whitney et al. (1992) have suggested that the polarization late in the decline arises from clouds ejected at earlier epochs and present off to the side of the obscuring cloud. The dust grains which produce the polarization at light minimum have a spatial distribution significantly different from that of the particles which contribute to the polarization at light maximum as indicated by the large difference in the corresponding position angles ($\sim 75^{\circ}$). If the polarization at light minimum arises from an asymmetrically shaped new obscuring cloud, a scenario suggested by Whitney et al. (1992), then we would expect the position angle to be different from minimum to minimum. On the other hand if the continuum polarization comes from an extended region about the star which is not affected by the obscuring cloud then the position angle should not change drastically from minimum to minimum. The geometry, which decides the position angle of polarization (Simmons 1982), of an extended envelope is expected to vary slowly when compared to changes in the geometry of an obscuring cloud with a smaller spatial extension. This can be checked by further observations during deep minima. The position angle of polarization observed during the maximum as well as during early declines lie within 65° ± 15°, implying a preferred plane about the star. This, probably, corresponds to the plane of dust ejection as suggested by Stanford et al. (1988) in the case of the prototype R CrB.

The possibility of a photospheric origin for polarization at light maximum is also consistent with the observed reduction in polarized flux almost at the same rate as the brightness during decline phases. Further continuum polarization observations close to light maximum over extended period of time are needed.

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