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HIGH RESOLUTION SPECTROSCOPY OF THE R CORONAE BOREALIS STAR, V854 CENTAURI, DURING A DEEP MINIMUM

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ABSTRACT

The R Coronae Borealis star V854 Cen was observed at minimum light ($V\sim15$) at high spectral resolution ($\Delta\lambda=0.3$ Å) from 5480 to 7070 Å. The spectrum consists of three components: a continuum devoid of photospheric lines, a collection of sharp emission lines of Sc II, Ti II, Y II, and Ba II, and broad emission lines of [O I], [N II], [S II], Hα, Na D, and C_2 Swan bands. A low resolution spectrum reveals additional lines of Ca II, [C I], and other species. The sharp emission lines are considered to be chromospheric lines. The broad lines with a full width of 400–500 km s^{-1} come from an extended region with a temperature of about 7000 K, but an electron density of 50 cm^{-3} or less. It is suggested that V854 Cen may be a bipolar nebula.

1. INTRODUCTION

V854 Cen, previously known as NSV 6708, is one of the more unusual members of that class of very peculiar stars, the R Coronae Borealis (RCB) stars. V854 Cen, a recent addition to the small number of known RCB stars, was discovered by McNaught & Dawes (1986). It is especially distinguished by the strong photospheric Balmer lines that accompany the characteristic lines of a RCB spectrum at maximum light, e.g., the C I, N I lines, and C_2 bands. Balmer lines are either weak or not present in spectra of other RCBs. By sharp contrast, Hα in V854 Cen shows a deep core and the broad shallow wings characteristic of normal supergiants of the same effective temperature. A second distinguishing mark of V854 Cen is the currently high frequency of the declines from maximum light ($V\sim7$) to minima that may be as faint as $V\sim15$ (Kilkenny & Marang 1989). The fact that the star is often in a deep decline accounts apparently for the delay in discovering what is the third brightest RCB star at maximum light. Fading of RCB stars is due to obscuration of the star by a circumstellar cloud of carbon grains most probably formed during the period of the decline. V854 Cen has a strong infrared excess (Kilkenny & Marang 1989) indicating the presence of circumstellar dust.

The spectrum of V854 Cen during the declines is also unusual for its class, as judged by the limited number of spectra acquired of this and other RCB stars (primarily RCrB and RY Sgr) below maximum light. Ultraviolet spectroscopy of V854 Cen is discussed by Clayton *et al.* (1992b) who note that "V854 Cen at minimum light does not seem to have an analogue in any known emission-line object" and report the presence of the emission lines C II 2326 Å, Mg I 2852 Å, and C I 2965–67 Å not seen in the other RCBs. Low resolution optical spectra of V854 Cen in decline were reported by Kilkenny & Marang (1989) and Whitney *et al.* (1992). The strongest emission lines are the Na D lines followed by the Balmer Hα and Hβ lines and lines of singly-ionized metals (Sc I, Ti II, etc.). At the deep ($V\sim15$) 1991 minimum, Whitney *et al.* found the C_2 Swan bands strongly in emission, but at an earlier less deep minimum ($V\sim11$), Kilkenny and Marang found the bands strongly in absorption. A key finding by Whitney *et al.* is that the emission lines are unpolarized at a time when the continuum is significantly polarized (14% at 4200 Å to 4% at 6500 Å). Hence, the emission lines come from regions not obscured by dust.

In this paper, we describe high resolution ($\Delta\lambda=0.32$ Å) spectra of the interval 5480–7070 Å obtained when V854 Cen was at $V\sim15$. In Sec. 2, we describe and identify the sharp and broad emission lines present on the spectra. It is noteworthy that our spectrum is the first high resolution spectrum of any RCB star during such a deep minimum. Low resolution spectra were obtained in the intervals 3700–7100 Å and 8200–10000 Å. An attempt is made to define the nature of the emitting regions and their relation to the dust clouds which began to obscure the star about 140 days before our observations.

2. OBSERVATIONS

2.1 The 1992 Spectra

High resolution spectra of V854 Cen were obtained on 1992 May 21 and 22 (JD 24487 63.5 and 64.5) with the Cerro Tololo Inter-American Observatory's 4 m telescope and the cassegrain echelle spectrograph equipped with a Tektronix 1024×1024 CCD. Complete spectral coverage was obtained from 5480 to 7070 Å. A total of 4 spectra of

[1]Visiting Observer, Cerro Tololo Inter-American Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1. The sharp emission lines.

Species	$\lambda(\text{Å})^a$	V_r (km s^{-1})	W_λ (Å)	Flux[b]	log gf[c]
Sc II (28)	6245.660	-28.1	0.66	14.5	-0.98
	6279.765	-26.2	0.38	8.3	-1.21
	6309.916	-26.2	0.19	4.6	-1.57
	6320.867	-25.6	0.10	2.5	-1.77
Sc II (29)	5640.988	-24.6	0.55	10.2	-1.13
	5657.874	-26.9	---	---	-0.60
	5658.342	-27.2	---	---	-1.21
	5667.146	-24.6	0.40	7.4	-1.31
	5669.042	-28.5	0.38	7.1	-1.20
	5684.189	-26.9	0.52	9.6	-1.07
Sc II (31)	5526.815	-24.5	1.71	31.6	0.02
Sc II (19)	6604.588	---	0.75	18.8	-1.31
Ti II (91)	6491.607	-27.9	0.09	2.3	---
Y II (19)	5509.900	-28.7	0.11	2.1	-1.01
(27)	5497.410	-28.1	---	---	---
(38)	5662.940	-28.3	0.49	9.0	0.20
	6795.410	-24.5	0.03	0.9	-1.55
Ba II (2)	5853.668	-24.5	0.08	1.6	-1.00
	6141.713	-23.3	0.61	13.4	-0.08
	6496.897	-24.6	0.40	10.1	-0.38

NOTES TO TABLE 1

[a] Kurucz and Peytremann (1975).

[b] Flux given in units of 10^{-16} erg cm^{-2} s^{-1}.

[c] gf-values from the following sources:
Sc II - Wiese and Fuhr (1975); Martin, Fuhr, and Wiese (1988), and Lawler and Dakin (1989)
Y II - Hannaford *et al.* (1982), Pitts and Newsom (1985), Tomkin and Lambert (1983)
Ba II - R. E. Luck (private communication)

1 h duration were obtained and combined to increase the signal-to-noise ratio. The spectra were calibrated using exposures of a ThAr hollow cathode lamp. These exposures were obtained immediately before and/or after the stellar exposures. Flat fielding was accomplished using exposures of a halogen lamp. The wavelength calibration is accurate to about ±0.05 Å as checked by measurements of the OH night sky emission lines. The resolution (FWHM) of the co-added spectrum is 0.34 Å, as determined from the OH lines. The signal-to-noise (S/N) ratio in the continuum at the mid-point of an order runs from about 30 at 5540 Å to a maximum of 50 at 6800 Å.

Inspection at the telescope showed that the spectrum of V854 Cen at minimum light is dominated by two classes of emission lines: sharp and broad. The coexistence of broad and sharp emission lines has been seen in RCrB and RY Sgr at minimum: Clayton *et al.* (1992a) summarize the published discussions of the spectral evolution of RGB, RY Sgr, and V854 Cen from maximum light through deep declines and recovery to maximum. It was also apparent that the rich photospheric absorption spectrum was very weak or absent. Interpretation of the spectrum at minimum light is facilitated by comparisons with a spectra obtained by us on 1989 July 15 and 17 (JD 24477 22.5 and 24.5) with the same telescope and spectrograph, but a different camera–CCD combination. The 1989 spectra at a resolution of 0.32 Å cover the intervals 4220–4880 Å and 5465–6846 Å. V854 Cen was then at $V \simeq 8$ in a shallow decline of depth $\Delta V = 0.9$ mag and 120 day duration (Lawson *et al.* 1992).

2.2 The Sharp Emission Lines

The sharp emission lines are listed in Table 1 and several examples are shown in Fig. 1. All detected lines were

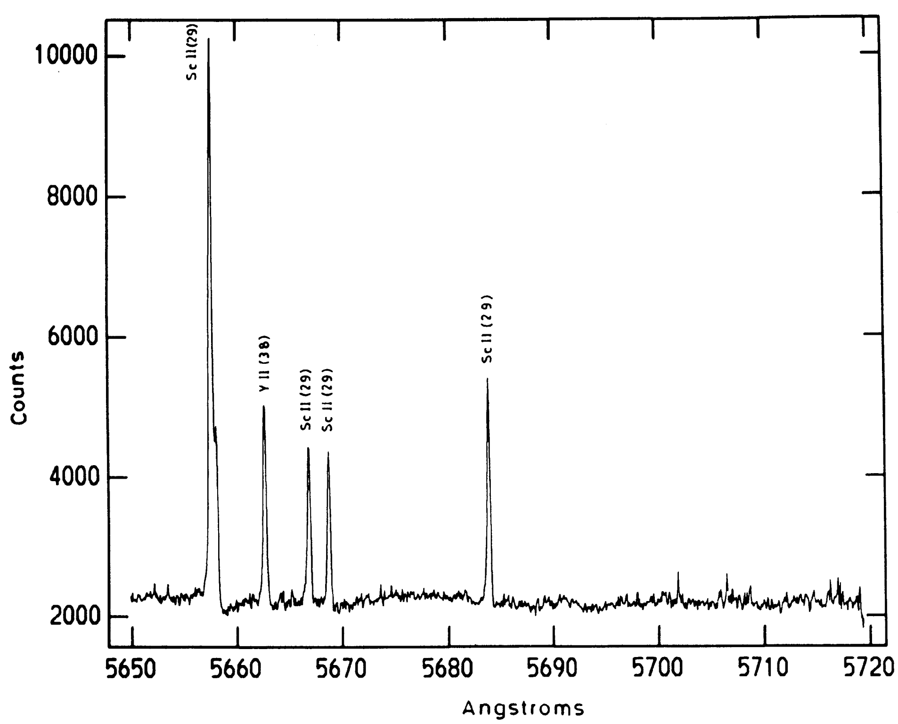

FIG. 1. Spectrum of V854 Cen in the region of 5680 Å showing several sharp emission lines due to Sc II and Y II.

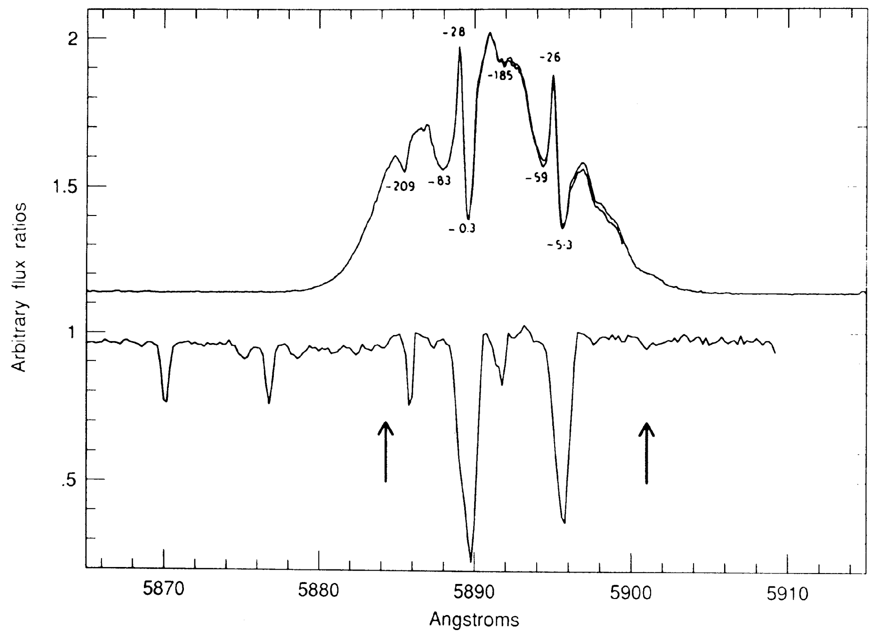

FIG. 2. (top) The blended profile of the two Na I D lines at minimum. The radial velocity (heliocentric) of the components are marked. (bottom) The same region obtained in the 1989 July near-maximum spectrum. Note the broad emission whose outer limits are marked by the arrows. A high velocity (-209 km s^{-1}) absorption component is present in the near-maximum and the minimum spectrum.

identified with Sc II, Ti II, Y II, or Ba II transitions with lower excitation potentials of less than 2 eV. These sharp lines are unresolved at our resolution: the mean FWHM of 0.34 ± 0.03 Å is the same as that of the intrinsically very sharp OH night sky lines. The sharp lines have a mean radial velocity of -26.3 ± 1.7 km s^{-1}. Sharp emission components at -27 km s^{-1} are seen in the Na D lines that we discuss in the next section. The photospheric radial velocity at maximum is -25.2 ± 0.8 km s^{-1} from 9 measurements (Lawson & Cottrell 1989). Our 1989 spectrum obtained just below maximum light gives the photospheric radial velocity as -25.8 ± 1.5 km s^{-1}. Clearly, the centroid of the gas emitting the sharp lines is approximately stationary with respect to the photosphere.

2.3 Broad Emission Lines

Several broad emission lines were obvious by inspection of the spectrum at telescope. Such lines are attributable to Na D, Hα, [O I], [N II], [S II], and C_2. A few lines remain unidentified.

Na D. The 5890 Å D_2 and 5896 Å D_1 lines are the most prominent feature in the entire visible spectrum. The broad emission was incompletely recorded in two adjacent spectral orders. Overlapping segments agree very well in the composite profile shown in Fig. 2 where we compare the 1992 emission and the 1989 absorption profiles. The broad emission at minimum extends at the base to ±470 km s^{-1} either side of the assumed photospheric velocity (-25 km s^{-1}). Broad emission was seen weakly in 1989 when the star had faded by about 1 mag. The limits of the emission are marked by the arrows in Fig. 2. Relative intensities of the emission in 1989 and 1992 are approximately consistent with the idea that broad emission is a more-or-less permanent feature whose visibility depends on the photospheric brightness. The blended emission feature of the two lines is crossed by several absorption components.

An absorption component at -209 km s^{-1} in 1992 was present in 1989 where it is seen accompanying both D_1 and D_2. The equivalent width appears to be unchanged: the less blended line (D_2) had an equivalent width $W_\lambda=110\pm5$ mÅ in 1989 and 94 ± 10 mÅ at minimum in 1992. Since the "continuum" in 1992 is the sharply sloping wing of the emission feature, there is a possibility of a systematic error affecting the measurement of 94 mÅ and, hence, we do not regard the difference between the 1989 and 1992 W_λ's as significant. The ratio of D_1/D_2 in 1989 shows this component to be approximately optically thin and, then, the column density of the component is $N(\text{Na I})\simeq6\times10^{11}$ cm^{-2}.

A broader absorption component at -83 km s^{-1} (D_2) in 1992 was not present in 1989 and, hence, is considered to be a transient associated with minimum light. The same component appears, as it must at D_1, but the velocity of -59 km s^{-1} is presumably distorted by the sharp emission components and the possibly unresolved structure within the -59 to -83 km s^{-1} feature.

In our spectrum of V854 Cen at minimum, the sharp emission lines could be mistaken for structure within the broad emission lines. By contrast, spectra of RY Sgr (Spite & Spite 1979) and RCrB (Lambert *et al.* 1990) at minimum show intense sharp emission lines superimposed on weaker broad lines. Our spectrum is also remarkable because the two Na D lines are blended into a single emission

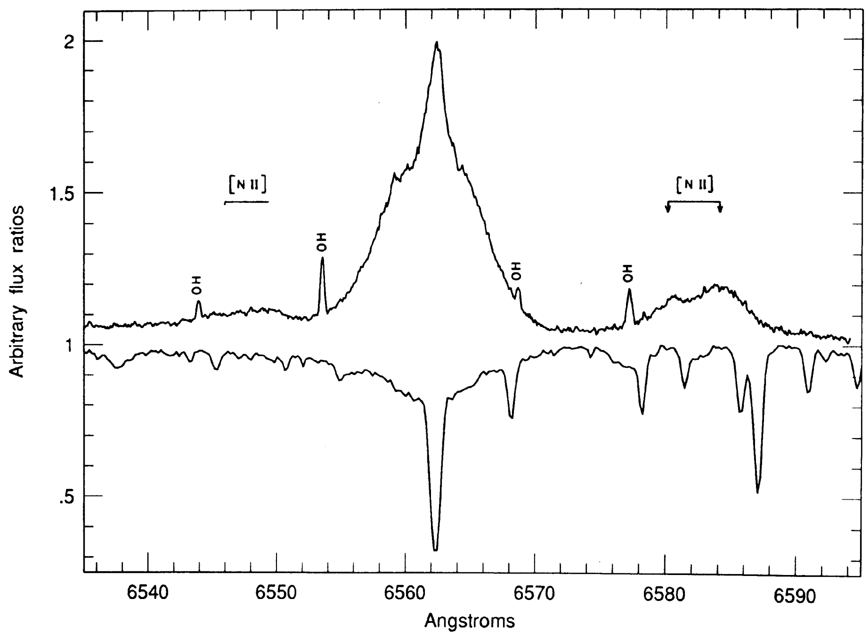

FIG. 3. (top) Hα profile at minimum along with [N II] 6548,84 Å profiles. The double peak in [N II] 6584 Å is prominent. (bottom) The absorption profile of Hα observed in 1989 July. Note that the extent of the absorption wings in this profile is the same as that of the emission profile at minimum light.

feature but, in the published spectra of RY Sgr and RCrB, the broad components of the Na D_1 and D_2 lines are well resolved.

The prominent absorption components in 1989 were at -12 km s^{-1} and presumed to be a blend of photospheric and interstellar absorption lines. This component is present at minimum light where the velocities of the narrow absorption core (0 and 5 km s^{-1} for D_2 and D_1, respectively) are presumably biased by the adjacent sharp emission lines at -26 km s^{-1}. It is certainly possible that the emission lines fill in what would otherwise be a broad absorption feature. If this strong absorption line were entirely interstellar in origin, the absorption in the 1992 spectrum would extend to the same low fractional intensity of the local continuum as the lines did in 1989. This condition is obviously not met, and probably this failure cannot be attributed to the presence of the sharp emission lines. Hence, we conclude that the principal contributor to this strong component is the star and not intervening interstellar or remote circumstellar gas.

Whitney *et al.* (1992) suggest that their low-resolution ($\Delta\lambda = 14$ Å) spectrum of the 1991 minimum shows a "broad-emission bump (>200 Å) lying under the Na I D lines." It is impossible to isolate such a broad and weak feature from our echelle spectra in which a 65 Å piece of an order is isolated and adjacent orders overlap only minimally. Unfortunately, the low resolution 1992 spectrum is of too low a S/N to confirm the ultrabroad feature at its 1991 strength (relative to the Hα and C_2 emission).

Hα. Emission at Hα is of a similar width to the much stronger emission at the Na D lines: the Hα line at its base extends ± 435 km s^{-1} from line center. In Fig. 3, we compare the 1992 emission and 1989 absorption profiles. These profiles are remarkably near perfect mirror images: both have a sharp core superposed on broad wings and are of a similar width. Close examination of the 1989 profile shows that the core is asymmetric as though the red part of the core may be filled in by emission. The 1992 emission profile is fairly symmetrical. Note that we have made no attempt to correct for overlying sharp telluric (H_2O) lines in either the 1989 or the 1992 profiles.

Forbidden Lines. A most interesting aspect of the 1992 spectrum is the presence of *broad* nebular lines of [O I], [N II], and [S II]. To our knowledge, the *only* previous report of forbidden emission lines in the spectrum of a RCB star is by Herbig (1949, 1968) who noted [O II] 3727 Å emission in RCrB at a faint minimum: $V \sim 13$ or a decline of about 7 mag. Herbig was unable to determine that the [O II] line's width differed from that of the Sc II *et al.* lines. [Lawson (1992) shows a spectrum of V854 Cen taken at $V \sim 14.5$ in 1991 June in which a broad [N II] 6584 Å line was present but unrecognized.] Although Whitney *et al.* (1992) detected the [O I] lines in their low resolution spectrum, they did not unequivocally attribute these forbidden lines to the star and left open the possibility that the lines' appearance in the stellar spectrum was due to imperfect removal of the strong [O I] emission from the night sky. Identification of the 6300 Å line with Sc II was suggested.

Examples of line profiles for the forbidden lines are shown in Figs. 3 ([N II]) and 4 ([O I]). Equivalent widths and radial velocities (v_r) are given in Table 2. The profiles appear to be double peaked, but with line center at about the velocity (-26 km s^{-1}) of the sharp lines. The blue peak is displaced about -110 km s^{-1} from line center and

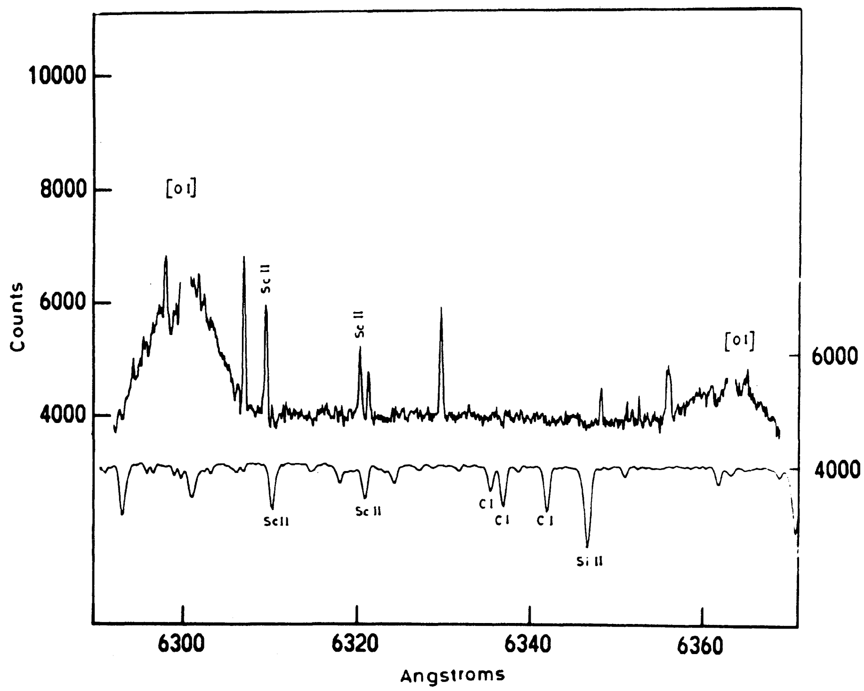

FIG. 4. (top) The region [O I] λ6300 and λ6363 Å lines. (The terrestrial [O I] lines are not shown and where they occur is left as a gap.) The sharp emission lines of Sc II 6310, 6320 Å are shown—the emissions without identifications are all due to terrestrial OH. The lower figure is the near-maximum spectrum showing the strong absorption lines. The continuum is scaled to the same level of counts as the continuum at the minimum shown on top. Note the very indistinct nature of the absorption lines during the minimum.

the red is shifted by $+25$ km s^{-1} ([S II]) to $+44$ km s^{-1} ([N II]). The [O I] lines are probably also double peaked. The sharp core to the [O I] lines is presumed to be entirely overlying night sky emission because other forbidden lines do not show this core. The [S II] lines are distinctly sharper than either the [O I] or [N II] lines.

Additional forbidden lines are present on the low resolution spectrum of which the most prominent are [C I] 9850 and 9823 Å with tentative identifications of [C I] 8727 Å and [O II] 3727 Å.

TABLE 2. The broad emission lines.

Species	λ(Å)	V_r (km s^{-1})	W_λ (Å)	Flux[a]	Width[b] (km s^{-1})
[O I]	6300	-26	4.81	10.6	380
	6363	---	1.56	3.4	300
[N II]	5755	---	0.02	0.05	---
	6548	---	0.98	2.25	260
	6584	-33	3.18	7.31	310
[S II]	6717	---	0.48	1.10	220
	6731	-27	0.25	0.58	170
Hα	6563	-37[c]	19.7	45.2	435
Na I D_2	5890	---	---	---	470
D_1	5896	---	---	---	---

NOTES TO TABLE 2

[a] Flux given in units of 10^{-15} erg cm^{-2} s^{-1}.

[b] Half width of the line at its base.

[c] The broad profile is at -37 km s^{-1}, but the core of the sharper emission is at -18 km s^{-1}.

C_2 Bands. C_2 Swan bands were noted by Whitney *et al.* (1992) to be strongly in emission at the 1991 minimum. On our higher resolution spectrum, the $\Delta v = -1$ sequence is in emission: Figure 5 compares the 0–1 band at the 1992 minimum, the 1989 near-maximum spectrum and a spectrum of enhanced C_2 absorption derived by ratioing spectra of RCrB taken at maximum and in decline (Lambert *et al.* 1990). Although C_2 is weak in V854 Cen near maximum, the bandhead Å is clearly present as, on close inspection, are several unblended rotational triplets. The C_2 emission differs in two striking ways from its photospheric absorption counterpart. First, rotational structure is *not* resolved; the C_2 lines evidently belong to the family of broad emission lines and not to that of the sharp emission lines. Second, the peak emission intensity does not occur at the *P* branch bandhead, but at 5630 Å. The shift is equivalent to a radial velocity of -230 km s^{-1}. Since all other broad emission lines are at -26 km s^{-1}, we are disinclined to attribute such a high velocity to the C_2 molecules. However, the molecules and the atoms and ions may not be colocated.

Inspection of Fig. 5 suggests that the apparent shift of the peak emission may result from superposition of a broad "line" at 5630 Å on weak emission by the C_2 band. We were unable to find a convincing identification for the 5630 Å except with those C_2 lines emitted from the very lowest

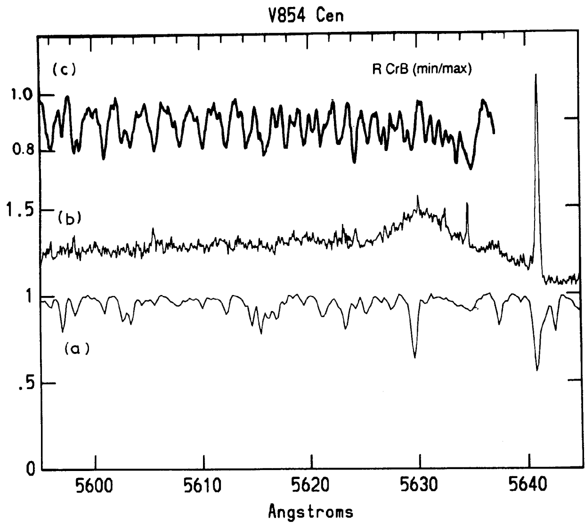

FIG. 5. The region of C_2 (0–1) Swan band. (a) The absorption spectrum at near-maximum, (b) the same region during the deep minimum—strongly in emission, (c) the ratio spectrum of RCrB at minimum-to-maximum light (Lambert *et al.* 1990) showing the enhanced C_2 band in absorption.

rotational level of each of the three substates of the $d\,^3\Pi_g$ upper level of the Swan system. Apart from the two satellite lines that are well displaced from the clump of lines near 5630 Å, the lines from the lowest levels are $Q_1(2)$ at 5628.39 Å, $Q_2(1)$ at 5628.96 Å, $P_3(1)$ at 5630.43 Å, $P_2(2)$ at 5630.85 Å, and $P_1(3)$ at 5631.17 Å, where the wavelengths are from Curtis & Sarre (1985). Lines from the next to lowest levels in the upper level [e.g., $R_3(0)$, $R_2(1)$, and $R_1(2)$] are much less prominent. It appears that the 5630 Å "line" may be emitted by cold C_2 molecules excited by very dilute radiation. An unidentified feature at about 5159.7 Å in the low resolution spectrum obtained by Kilkenny & Marang (1989) is likely to be due to the same set of P and Q lines from the 0–0 band. Excitation of these lines from the lowest levels of the $d\,^3\Pi_g$ substates provides an interesting problem. We note, for example, that the Swan system's lower state ($a\,^3\Pi_u$) is not the C_2 molecule's ground state ($X\,^1\Sigma_g^+$). It will be of interest to search for the C_2 singlet systems: the Phillips system in the near-infrared and the Mulliken system in the ultraviolet.

The wavelength extent of the C_2 band profile shows that a second population of warmer C_2 molecules must exist. It is difficult to derive an accurate band profile for a band that extends over almost an entire echelle order. Nonetheless, the excitation temperature of the second component is probably less than the photospheric temperature. A cool environment for the majority of the C_2 molecules is confirmed by the weakness of all but the leading bands of each Δv sequence. On the low resolution spectrum (Fig. 6), the $\Delta v=0$ sequence shows only the 0–0 bandhead. This is also true for the higher quality spectra shown by Whitney *et al.* (1992). At high resolution, the 0–2 band at 6191 Å is weakly present. The 1–2 band at 5585 Å is just detectable, but sharp telluric and probably broad stellar [O I] emission make it impossible to determine the C_2 band's emission profile.

Unidentified broad lines. A few prominent broad emission lines could not be identified—see Table 3. We note

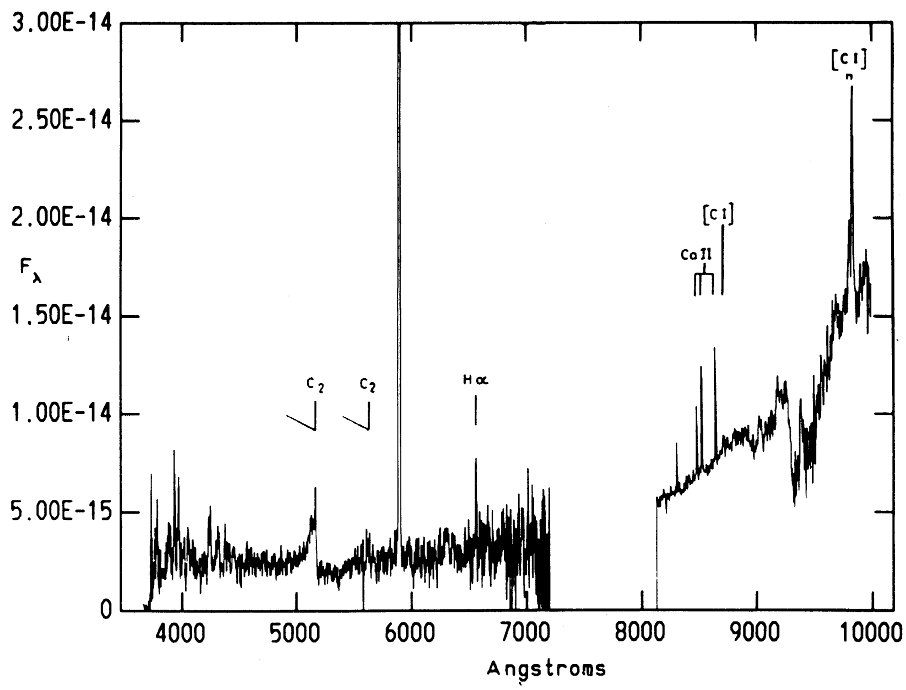

FIG. 6. The low resolution flux calibrated spectrum of V854 Cen at minimum and taken on the same night as the high resolution observations: F_λ is given in ergs cm^{-2} s^{-1} Å^{-1}. Note the flatness of the continuum shortward of 6000 Å. Some prominent lines are labeled. The strongest line at 5893 Å is due to Na D.

TABLE 3. Unidentified broad emission lines.

λ(Å)	W_λ (Å)	Width[a] (Å)
5777	0.95	14
5800.4	0.65	10.4[b]
5829.8	1.54	18[b]
5855.7	0.50	14[b]
6618	---	---[b,c]
6772	?	15.4[d]

NOTES TO TABLE 3

[a] Width of the line at its base.

[b] Possibly the same line is seen in HD 44179 (Schmidt *et al.* (1986).

[c] Exceptionally broad, but ill-defined.

[d] Possibly double peaked, but three weak sharp emission lines may provide a false blue peak.

that several of these lines may be the same features that were reported for HD 44179 ("The Red Rectangle") by Schmidt *et al.* (1980). The very broad spectral features of The Red Rectangle attributed by Witt & Schild (1988) to hydrogenated carbon grains are not seen. In the low resolution spectrum, a prominent line at 8329 Å lacks an identification; we do not know if it is sharp or a broad emission line.

Whitney *et al.* claimed identifications for bands of the CN Red system: "broad CN bands at 5730 and 5878 Å" and also at 5255 and 6631 Å. These bands are not apparent on our high resolution spectrum. On the low resolution spectrum, the CN Violet 0–0 band is absent, and it would normally be much stronger than the CN Red bands in the 5500–6000 Å interval. Whitney *et al.*'s spectrum did not extend to 3883 Å.

2.4 The Absorption Spectrum

The outstanding characteristic of the absorption spectrum is its absence. Even prominent lines of the 1989 spectrum such as C I 6337 Å, Si II 6347, and 6371 Å are most probably absent—see Fig. 4, where the Si II lines may just be discernible. Although the S/N in the continuum of the 1992 spectrum is modest, the photospheric lines are quite obviously either "veiled" (i.e., diluted by overlying continuum) and/or rendered undetectable by a broadening of the line profiles. A weakening of photospheric absorption lines attributed to veiling has been reported for other RCBs in decline from Herbig (1949) to Cottrell *et al.*'s (1990) extensive coverage of RCrB in 1988. We are unaware of a previous report of the complete disappearance of even the strongest absorption lines at minimum light.

2.5 Low Resolution Spectroscopy

Low resolution spectra were kindly obtained at our request by T. Storchi-Bergmann, C. Winge, and P. Challis on the CTIO 1.5 and 1.0 m reflectors on 1992 May 21. A composite spectrum is shown in Fig. 6 with the prominent features listed in Table 4. The weak continuum is almost flat shortward of 6000 Å, but rises steeply to longer wavelengths. The spectrum from 4000 to 7000 Å closely resembles the higher quality spectrum obtained by Whitney *et al.* (1992) at the 1991 minimum. In the newly observed near-infrared region, the prominent lines are the [C I] transitions near 9850 Å and the Ca II infrared triplet which are optically thick: the observed flux ratios are 8497 Å: 8541 Å: 8661 Å = 1:1.8:1.8 rather than the optically thin ratios of 1:9:5. The Ca II H and K lines are also optically thick. Despite the low S/N, emission lines are evident in the blue and may be identified as Ca I (4226 Å), Sc II, Ti II, Fe I, Fe II, and Ba II transitions. C_3 4050 Å is possibly present. CH may be present [Kilkenny & Marang (1989)]. CN 3889 Å is not present.

TABLE 4. Emission lines from the low resolution spectrum.

λ(Å)	Species	Flux[a]
3727.2	[O II}	4.4:
3930.6	Ca II K	6.6
3965.8	Ca II H	5.8
4859.3	Hβ	1.5
5891.3	Na I $D_1 + D_2$	109
8320.9	??	1.6
8496.6	Ca II	2.7
8540.9	Ca II	4.7
8660.6	Ca II	4.9
8727.9:	[C I]	1.1:
9823.2	[C I]	5.1
9848.1	[C I]	15.4
5165	C_2 0-0	25.0
5635	C_2 0-1	11.7
4737	C_2 1-0	5.5

NOTES TO TABLE 4

[a] Flux given in units of 10^{-14} erg cm^{-2} s^{-1}

3. DISCUSSION

At minimum light, the spectrum of a RCB has three components: broad emission lines, sharp emission lines, and a continuum with "veiled" or indistinct absorption lines. These components are so different that we may suppose that they arise from three distinct regions: the nebula (broad emission lines), the chromosphere (the sharp emission lines), and the dust-shrouded photosphere (the veiled absorption lines). Although the basic character of a RCB's minimum spectrum was noted long ago (Joy & Humason 1923; Herbig 1949, 1958; Payne-Gaposchkin 1963), little is known of the physical conditions in the three regions because of a dearth of spectra taken at minimum light. Our spectra of V854 Cen at the 1992 minimum permit new estimates to be made of the conditions in its nebula.

An important piece of evidence about the relative locations of the circumstellar dust and the gas responsible for the emission lines was provided by Whitney *et al.* (1992) who observed that the emission lines at the 1991 minimum were unpolarized and, hence, the emitting gas lies primarily outside regions of high dust concentration. Their polarization observations made at low spectral resolution refer to the strong emissions at Hα, Na D, and the C_2 Swan bands. Since the broad or nebular component dominates these features, the nebular gas must extend over a greater volume than the dust. We confirm below what has been found for RCrB at minimum (Rao 1974, 1975) that the sharp or chromospheric lines are also only lightly reddened and, hence, the visible chromospheric regions are also unobscured by dust. Chromospheric emission in the cores of strong photospheric lines of RCrB at maximum light (Keenan & Greenstein 1963; Lambert *et al.* 1990) suggest the chromosphere is also a more-or-less permanent feature for the prototype. Perhaps this is also the case for other RCBs like V854 Cen.

3.1 The Nebula

"Nebula" is here synonymous with the region providing the broad emission lines and the high-velocity absorption lines seen in the Na D lines. Prior to spectroscopy of V854 Cen, the short list of broad emission lines included the Ca II H and K, the Na D, and the He I 3889 Å lines seen in probably all (the few) spectra at minimum of RCrB, RY Sgr, U Aqr, and SU Tau (Rao 1975). Broad Na D emission is present in our 1989 spectrum of VCrA. Herbig (1949) reported the CN violet system in emission at 3883 Å from RCrB. The emission linewidths generally correspond to ± 200 to ± 300 km s^{-1} which is taken to mean that the nebula is expanding at this velocity along the line of sight. High velocity absorption seen in the Na D lines is identified as arising from nebular gas on the line of sight to the dust cloud. High velocity blue-shifted absorption components to the Ca II H and K lines have been seen in RCrB at minimum (Payne-Gaposchkin 1963). [O II] emission from RCrB (Herbig 1949) is plausibly attributed to the nebula. Our spectrum of V854 Cen provides much new information on the broad emission lines, especially firm detections of [O I], [N II], and [S II] lines. Of course, some emission lines seen on the low resolution spectra may also be broad; e.g., the Ca II lines. Our array of forbidden lines provides estimates of the nebula's temperature (T) and electron density (n_e).

Whitney *et al.*'s (1992) discovery that the broad lines (here, C_2, Hα, and Na D) are not polarized shows that these lines are outside the layers of high dust concentration and, hence, the lines are not reddened significantly by the circumstellar dust. Interstellar reddening is slight because the V854 Cen is at a galactic latitude of $+19°$. Observations of nearby globular clusters shows $E(B-V) \lesssim 0.1$ mag is probably appropriate (Kilkenny & Marang 1989). An estimate of the electron temperature in the nebula is provided from the [N II] ratio 5755 Å/(6584 Å+6548 Å). If the reddening suffered by the nebula is $E(B-V)=0.1$, the corrected flux ratio gives $T=7000\pm500$ K. (The flux ratios [O I] 6300 Å/6363 Å, [N II] 6584 Å/6548 Å, and [C I] 9850 Å/9823 Å are each predicted to be equal to 3 for optically thin lines. The observed flux ratios of 3.1, 3.2, and 3.0 match the prediction to within the errors of measurement.)

The electron density may be estimated from the [S II] line ratio 6716 to 6731 Å. The flux ratio of 1.9 is equal within the errors of measurement to the predicted ratio of 1.5 for the low density ($n_e \to 0$) limit. Therefore, at $T\sim 5000$ to 8000 K: $n_e < 100$ cm^{-3} is suggested. Unfortunately, the flux of the [C I] 8727 Å line is too uncertain to yield a useful second estimate of n_e ($\lesssim 8000$ cm^{-3}) from the 8727 Å/(9823+9848 Å) ratio.

The ionic ratios computed from the line fluxes for $T\simeq 7000$ K and $n_e \sim 50$ cm^{-3} are log $(N^+/O^+) \sim -1.4$ and log $S^+/O^+ \sim -2.9$ and log $(C^0/O^0) \sim 0.2$. The Hα-to-Hβ flux ratio is close to that expected from case B recombination at $T\sim 7000$ K. Then, if the H lines are due to recombination, log $(N^+/H^+) \sim -4.6$, log $(O^+/H^+) \sim -3.2$, and log $(S^+/H^+) \sim -6.1$. By comparison, we note that solar photospheric composition corresponds to log $(N/H) = -4.0$, log $(O/H) = -3.1$, and log $S/H = -4.8$.

What ionizes the nebular gas? If it is supposed that H is photoionized, the ionizing flux may be estimated from the luminosity of a Balmer line. We adopt a stellar distance $d\simeq 2.5$ kpc based on the assumption that the absolute visual magnitude is $M_V \simeq -5$ and $E(B-V)=0.05$ for the intervening interstellar medium. Then, the Hβ flux gives a luminosity in the line of 1.3×10^{31} erg s^{-1} and the total luminosity emitted by all recombination lines is 1.1×10^{32} erg s^{-1} for case B. This is a slight overestimate because the Hα profile shows a sharp/chromospheric component blended with the broad/nebular one. At $M_{\rm bol} \sim -5$, the star emits $L\sim 3\times 10^{37}$ erg s^{-1} but, if $T_{\rm eff} \sim 7000$ K (Lawson & Cottrell 1989), the flux in the Lyman continuum is 1.2×10^{31} erg s^{-1} for a blackbody spectrum. Modest departures from a blackbody spectrum (chromospheric emission lines?) or a slight increase of the adopted temperature put the stellar output in the Lyman continuum within the required range which itself is dependent on the adopted distance.

The nebula appears to be very extended. On the assumption that $n_e \simeq n_p \simeq 50$ cm^{-3} throughout a spherical nebula, we find a nebular radius $R_{\rm neb} \sim 2\times 10^5\, R_\odot$. [It is conceivable that n_e exceeds n_p. Our preliminary analysis of the photospheric spectrum gives $C/H \sim 1$, and as the ionization potential of C is less than that of H, the degree of ionization of C may exceed that of H and, hence, $n(C^+) > n(H^+)$ is possible. However, if the nebula gas is mixed with dust, it may be depleted in C relative to H.] If the ionized gas is not uniformly distributed, the estimate of $R_{\rm neb}$ has obviously to be increased: e.g., $R_{\rm neb} \sim 4.5\times 10^5\, R_\odot$ for a filling factor $f\sim 0.1$. At $M_V \sim -5$ and $T_{\rm eff} \sim 7000$ K, the star has a radius $R_* \sim 80\, R_\odot$ giving a nebular radius $R_{\rm neb} \sim 2600\, R_*$ to $5600\, R_*$ for $f=1$ and 0.1, respectively.

The expansion velocity ($v \sim 200$ km s^{-1}) and the nebula radius ($R_{\rm neb} \sim 2\times10^5$ $R_\odot$) give a "crossing time" $t_{\rm neb} \sim R_{\rm neb}/v$ of about 20 yr. If gas is ejected only when a RCB goes into or remains in decline, the nebula will be enormously extended and diluted after 20 yr from the last decline. Since V854 Cen has experienced many declines in recent years, the presence of a large nebula is not surprising.

The size of the dusty region may be estimated from the infrared flux. On the plausible assumption that the region is optically thick in the infrared, the comparison of the peak infrared flux from the dust and the peak visible flux from the unobscured star (at maximum) gives $R_d \sim 50$ R_* for the infrared dust and stellar temperatures of 900 and 7000 K, respectively and fluxes taken from Lawson & Cottrell (1989). This estimate of R_d is consistent with the requirement that the grains be heated by the starlight. On the assumption that the dust grains in a shell of radius R_d are heated by starlight, the grains achieve a temperature T_d where

$$\frac{R_d}{R_*}=0.5\left(\frac{\epsilon_{\rm vis}}{\epsilon_{\rm ir}}\right)^{1/2}\left(\frac{T_*}{T_d}\right)^2,$$

where $\epsilon_{\rm vis}$ and $\epsilon_{\rm ir}$ are the grain emissivities at visual (say 5500 Å) and infrared (say 3.3 μ) wavelengths, respectively. For $T_d \sim 900$ K, and emissivities for amorphous carbon grains from Borghesi *et al.* (1985), we find $R_d \sim 80$ R_*. Cool dust presumably exists to much greater distances from the star, but can be detected only by far-infrared observations.

For those RCB stars for which observations are available, the infrared excess does not change during light minimum (Feast 1986). Few infrared observations have been reported as yet for V854 Cen, but Whitney *et al.* (1992) do note that, at the 1991 deep minimum, the L magnitude was just 0.15 mag fainter than at maximum and, hence, the infrared excess was essentially unchanged. According to the fluxes collated by Lawson & Cottrell (1989), we find that the infrared excess emitted by the dust is approximately half the total (visual plus infrared) flux and, hence, the dust cloud, as seen by the star, subtends a solid angle of about 2π. If the infrared excess is unchanged at a deep minimum, the freshly formed dust cloud should subtend either a solid angle much less than 2π or fall within the angle subtended by existing clouds. Although the infrared excess of a RCB star does not evolve in phase with a decline, there is a longer term evolution of the infrared fluxes that may be identified with the cooling of dust clouds as they move away from the star and the birth of new clouds at a decline (Feast 1986).

3.2 The Chromosphere

Although the spectral coverage is limited, examination of the emission line fluxes reveals no evidence for strong circumstellar reddening. Emission line fluxes in the absence of reddening scale as $S=gf\ 10^{-\chi\theta}/\lambda^3$ where $\theta_{\rm exc}=5040/T_{\rm exc}$ and $T_{\rm exc}$ is an excitation temperature. For the three Y II lines spanning 1100 Å, S with $T_{\rm exc} \sim 7000$ K is constant to within 0.1 dex. The Ba II and Sc II lines covering 600 to 700 Å give a similar result. Since the lines under consideration span a small range in excitation potential ($\chi \sim 1.9$ to 2.2 eV), the conclusion that the lines are little affected by circumstellar reddening is not greatly dependent on the choice of $T_{\rm exc}$. Since the photosphere is dimmed at minimum by $A_V \sim 8$, differential reddening with $R=A_V/E_{B-V}=3$ or an unusually large ratio $R \sim 5$ to 6 would produce very different line ratios even across the 600 to 1100 Å intervals.

The chromospheric lines are unresolved at our resolution: their FWHM of 17 km s^{-1} is identical to that of the spectrometer as measured by the terrestrial OH lines. Our measurements are made from a co-added spectrum, and some broadening must have been introduced in the co-addition. Certainly, the chromospheric lines have intrinsic widths of 10 km s^{-1} or less.

Broad Hα emission at a deep minimum ($V \sim 14.5$) in 1991 was attributed by Lawson (1992) to a turbulent layer at the base of the chromosphere. The similarity between the Hα and [N II] 6584 Å linewidths in 1991 and in our 1992 spectrum suggest to us that the broad Hα emission is formed by recombination in the extended low density nebula responsible for the forbidden line emission.

The He I 3889 Å line was among the earliest set of broad emission lines seen in the spectrum of RCrB at a deep minimum. The low resolution spectrum (Fig. 6) is of too low quality to yield a detection of this He I line. Our high resolution spectrum shows clearly that other He I lines, e.g., 5876, 6678, and 7065 Å are absent. Surendiranath *et al.* (1986) argue that the presence of He I 3889 Å in the absence of lines like 7065 Å requires high densities ($n_e \sim 10^{10}$ cm^{-3} at $T \sim 2\times10^4$ K) characteristic of a chromosphere (Clayton *et al.* 1992b) and not the low density ($n_e < 50$ cm^{-3}) derived for the nebula. Confirmation of the presence and identification of the He I 3889 Å in the spectrum of V854 Cen at minimum would be highly desirable.

3.3 The Photosphere

All previous reports of the appearance of the photospheric absorption lines at a deep minimum like that of V854 Cen in 1992 have been based on low resolution photographic spectra. The lines are referred to as "veiled." At the 1949 minimum of RCrB, only the strongest lines were seen, and then as vague depressions of the continuum (Herbig 1949; see Fig. 2 of Herbig 1968). Before the lines become so heavily veiled, they are redshifted (relative to the usual photospheric velocity) by a few km s^{-1} (Payne-Gaposchkin 1963). In our spectrum of V854 Cen, the photospheric absorption lines are very indistinct, and even the strongest lines can only be described as "possibly present."

The faint polarized continuum in the red is attributed to scattered photospheric radiation (Whitney *et al.* 1992). Dust grains in the presumably expanding very optically thick dust shell ensure that the photons are scattered and Doppler shifted before exiting the dusty layers. This scattering process necessarily introduces a red shift and a broadening of the absorption lines in the emergent spectrum (Rao 1974, 1975). Rao's observations of RCrB at minimum and his analysis of the scattering of photospheric radiation led to estimates of the expansion velocity of about 45 km s^{-1} at about 5 mag below maximum light. Absence of the lines in our spectrum suggests that the photons defining the visible spectrum have been scattered off particles with velocities (relative to the line of sight) of about ± 70 km s^{-1} or greater. This requirement cannot be met in the picture of a single obscuring cloud moving away from the star unless the cloud also expand internally at the required high velocity. In our picture (see below), the velocities may be a combination of the rotational velocities of a dusty torus and its expansion velocity. (Electron scattering would accomplish the same effect: the rms velocity of an electron in the nebula at $T=7000$ K is 600 km s^{-1}. Electron scattering in an asymmetric nebula would also introduce polarization of the continuum.)

3.4 A Bipolar Nebula

Coexistence of a chromosphere, a nebula, and a large thick dust layer obscuring the photosphere raises an unsolved question of the relative locations and sizes of these three regions of quite different physical conditions. Earlier discussions of the question have generally assumed spherical symmetry: the star is at the center of the large nebula in which the dust is, at minimum light, also roughly symmetrically distributed about the star. The dust may be gathered in clouds, but the clouds are presumed to be numerous, as demanded by observations showing that the infrared flux is unchanged during a decline (Forrest *et al.* 1972). A few of the many clouds contributing infrared radiation lie along the line of sight and are responsible for a decline. Radiation pressure drives the dust grains outward and the gas is dragged along with the dust and, hence, the nebula expands. The chromosphere is not directly incorporated into this picture of the nebula and dust shell. In one scenario, the chromosphere is placed above the innermost and thickest shell of dust, but this raises the awkward questions of how the chromosphere is heated and how the nebular exterior to the chromosphere is accelerated because the dust may be vaporized in transiting the chromosphere. Other scenarios consider the chromosphere to be viewed through tunnels in the dust shell, but these tunnels must be so arranged that the much brighter photosphere is not seen. Discussion of the traditional spherically symmetric model may be found in Feast (1990) and Lambert *et al.* (1990).

As a working hypothesis and an alternative to the spherically symmetric model, we suppose that V854 Cen and other RCBs are bipolar nebulae with a high velocity bipolar wind and a dusty equatorial torus. This bipolar geometry is quite common among luminous evolved mass-losing stars. Examples include the peculiar object V1016 Cyg (Solf 1983), planetary nebulae NGC 6302 (Meaburn & Walsh 1980), NGC 2392 (Gieseking *et al.* 1985), and the Egg Nebula CRL 2688 (Cohen & Kuhi 1977, 1980). The central star of CRL 2688 is a supergiant (spectral type F5 Ia) that has been likened by Cohen and Kuhi to RCrB. The reverse analogy—RCrB is a bipolar nebula—was not drawn. Our geometrical picture does not clarify at all the question of where and why dust forms around the RCB. Indeed, our picture seemingly adds the restriction that dust form in a particular plane perpendicular to the bipolar flows.

The simple geometry of a dusty disk and bipolar flows is not in conflict with observations. The simultaneous presence of the disk (i.e., deep minimum and obscuration of the photosphere) and the chromosphere is more readily explained than with the traditional spherically symmetric model. Imagine that the chromosphere normally extends several stellar radii above the photosphere, and in the polar directions at least, is largely unaffected by the development of the dusty disk. If the disk's thickness is greater than the stellar diameter but less than the chromospheric diameter, the photosphere will be obscured, but portions of the chromosphere will be visible above and/or below the disk. The disk must have a central hole. The diameter of this hole relative to the disk's thickness will for a given photospheric radius determine the maximum tilt of the disk relative to the line of sight that provides for full obscuration of the star. Radial expansion of a torus tilted with respect to the line of sight will eventually result in the return of the star to maximum light. Obviously, a stiff constraint on the tilt would imply that few RCBs experience observable declines, but all have an infrared excess from the warm dust. In our picture, the chromosphere may or may not be quenched at or near the latitudes of the disk. The large radius (relative to the stellar diameter) of the disk makes it unlikely that the chromosphere around the far pole will be visible except through the dust disk. If the chromosphere participates even lightly in the bipolar expansion, the visible "near" chromospheric regions will, as is observed, be blueshifted relative to the photospheric lines. For V854 Cen this blueshift is small and barely discernible, which implies that the bipolar flows may be approximately perpendicular to the line of sight. The chromospheric lines for RCrB are blueshifted by about 10 km s^{-1} (Cottrell *et al.* 1990).

At present, the geometry of the nebula seems poorly constrained except for Whitney *et al.*'s (1992) key observation that the broad emission lines are unpolarized. This shows clearly that the bulk of the nebular gas cannot be viewed through significant amounts of dust. (The Egg Nebula CRL2688 also has an unpolarized emission line and polarized continuum.) We suppose the gas is largely concentrated in the bipolar flows and note that the implied expansion velocities are typical of observed bipolar flows; compare, for example, profiles of our forbidden lines (Fig. 4) with the [N II] 6583 Å profile for V1016 Cyg (Solf 1983). Since the dusty torus has a much smaller diameter ($R_d \sim 50\ R_*$) than the nebula ($R_{\rm neb} \sim 10^3$–$10^5\ R_*$), both arms of the bipolar flow will contribute to the broad emission lines and, hence, the lines will be approximately centered on the photospheric velocity when the bipolar flow is symmetric. The width of the emission line will, in general, increase as the bipolar flow is more nearly aligned with the line of sight. The apparent doubling of the forbidden line profiles may reflect different contributions from the two arms. Emission from the base of the receding arm of the flow may be occulted by the dusty disk, and these emission lines (the C_2 Swan lines?) will be blueshifted by an amount corresponding to the flow velocity on the angle of the inclination to the line of sight.

In the standard spherically symmetric model of a RCB shell, the gas is taken to be accelerated by radiation pressure on the dust and a dust-gas coupling through collisions. Velocities of 200–300 km s^{-1} are attainable by this mechanism (Hartmann & Apruzese 1976). In our model the expansion velocity is attributed to the bipolar flow whose acceleration is an ill-understood process. Lambert *et al.* (1990) suggested that a RCB's chromosphere might be supported by Alfvén waves, as in models of extended expanding chromospheres developed by Hartmann *et al.* (1982). The chromosphere is capable of feeding the nebula. Expansion of the chromosphere at a velocity of a few km s^{-1}, a density of order of 10^9 cm^{-3} (Clayton *et al.* 1992b), and a radius of a few stellar radii provides a mass loss rate that is comparable to that inferred for the nebula with a velocity of about 200 km s^{-1}, a density of about 50 cm^{-3}, and a radius of a few thousand stellar radii. At the edge of the disk gas and dust may be expelled radially by radiation pressure. This expulsion may be responsible for the blueshifted Na D absorption lines.

In our model, as in the standard model, the onset of dust formation is not yet understood. A key question for our model concerns the location of the disk: does the disk reform at each minimum in the same plane? Stanford *et al.* (1988) show from polarization observations of RCrB that for this star there appears to be a preferred plane for the dust cloud. These authors discuss several possible origins for a preferred orientation of the dust cloud; i.e., rapid rotation of RCrB, the orbital plane of a binary system, a magnetic field, and pulsations. They conclude that an ejection mechanism connected with nonradial pulsations' is the most likely explanation. Unfortunately, since comparable series of polarization observations are not yet available for V854 Cen and other RCBs, we do not know if the dust around RCBs commonly forms in a preferred plane.

Imaging of UW Cen, a classical RCB, shows a faint roughly circular reflection nebula with two sets of diagonally opposed "jets" with an angle of about 60° between the jet systems (Pollacco *et al.* 1991). Pollacco *et al.* identify the jets with the dusty regions that, if projected on the line of sight cause UW Cen to decline in brightness. The jets could also be considered to be the bipolar gas flows. Spectra of the jets are needed to determine if they are dust or gas flows. In either case, the existence of two pairs of jets suggests that there is not a preferred plane for the bipolar flow or the dust layer.

Measurements of continuum polarization should eventually show whether there is a preferred plane for cloud formation and ejection. Tantalizing observations of broadband polarization for V854 Cen were obtained by Rao & Raveendran (1992) in 1991 February (maximum light $V=7.2$), 1991 May (in decline, $V\sim11.3$), 1992 February (near maximum $V=7.6$–8.0), and 1992 March ($V\simeq11.5$). The position angle of polarization (and the degree) changed by about 30° between the two maxima, but the angle in decline was essentially the same as at the preceding maximum. These observations can be interpreted as showing a roughly constant position angle ($65°\pm15°$) and, hence, a preferred plane for dust formation. Alternatively, one might argue that the clouds were ejected in jet-like structures with an angle of about 30° between the 1991 and 1992 jets *A* range in the line-of-sight inclination of the dusty torus may be required to accommodate the fact that the infrared excess does not change greatly in decline. Obviously, additional observations are needed.

If dust around RCBs is concentrated in a disk, one expects some stars to have disks in the plane of the sky and, hence, not to show the deep declines that are taken to be a defining characteristic of the class. (Pollacco *et al.* make a similar comment with respect to their model of dust concentrated in collimated jets.) One RCB, XX Cam, has shown a single decline after almost a century of observations, and this decline was a mild one of just 1.7 mag (Rao *et al.* 1980). Of course, dust shells that do not dim the star will be detectable through their emitted infrared radiation. XX Cam has an infrared excess (Walker 1986). Unfortunately, infrared observations of XX Cam (and most other RCBs) are made so infrequently that fresh dust disks may well escape detection. The frequency of nondeclining RCBs (about 1 in 30) is a measure of the dust layer's thickness and radius relative to the stellar diameter.

4. CONCLUDING REMARKS

The unpredictable declines to minimum light of the R Corona Borealis stars and the structure of the extended atmospheres of these rare peculiar stars have long defied analysis. We have shown that high resolution spectroscopy of one of these stars—V854 Cen—can yield new clues to structure of the extended atmosphere. In particular, we found that a series of forbidden emission lines detected at minimum light for the first time in a RCB spectrum provide estimates of the nebula temperature ($T=7000$ K) and density ($n=n_e<50$ cm^{-3}). Sharp emission lines of singly ionized metals are attributed to unobscured regions of the stellar chromosphere. Published reports of spectra of RCB's at minimum light refer to "veiled" photospheric lines, but in V854 Cen at minimum the photospheric lines are undetectable and are presumed to be washed out by multiple scattering of photospheric radiation in the dusty disk. It is suggested that V854 Cen at minimum may be a bipolar nebula with a dusty disk obscuring the photosphere, but incompletely covering the chromosphere. The broad forbidden and other lines are attributed to the bipolar flow.

Further progress in understanding RCB's will require spectroscopy, photometry, and polarimetry of selected stars through several minima. Since the declines are unpredictable, deep, and often of considerable duration, it will be difficult to obtain these necessary observations. As a final note, we point out the potential of high resolution ultraviolet spectroscopy at maximum and at minimum. Spectral resolution is needed to distinguish chromospheric from nebular lines. At short wavelengths, the photosphere makes a negligible contribution to the spectrum even at maximum. Spectra below about 2000 Å may show broad emission lines and, hence, offer the first look at the nebula when the star is out of decline—at least as viewed from Earth. Ultraviolet emission lines may reveal the as yet undetected or unrecognized transition region between the chromosphere and nebula.

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REFERENCES

Borghesi, A., Bussoletti, E., & Colangeli, L. 1985, A&A, 142, 225
Clayton, G. C., Whitney, B. A., Stanford, S. A., & Drilling, J. S. 1992a, ApJ, 397, 652
Clayton, G. C., Whitney, B. A., Stanford, S. A., Drilling, J. S., & Judge, P. G. 1992b, ApJ, 384, L19
Cohen, M., & Kuhi, L. V. 1977, ApJ, 213, 79
Cohen, M. & Kuhi, L. V. 1980, PASP, 92, 736
Cottrell, P. L., Lawson, W. A., & Buchhorn, M. 1990, MNRAS, 244, 149
Curtis, M. C., and Sarre, P. J. 1985, J. Mol. Spec., 114, 427
Feast, M. W. 1986, in Hydrogen Deficient Stars and Related Objects, edited by K. Hunger, D. Schönberner, and N. K. Rao (Reidel, Dordrecht), p. 151
Feast, M. W. 1990, ASP Conf. Series 11, 538
Forrest, W. J., Gillett, F. C., & Stein, W. A. 1972, ApJ, 178, L129
Gieseking, F., Becker, I., & Solf, J. 1983, ApJ, 295, L17
Hannaford, P., Lowe, R. M., Grevesse, W., Biémont, E., & Whaling, W. 1982, ApJ, 261, 736
Hartmann, L., & Apruzese, J. P. 1976, ApJ, 203, 610
Hartmann, L., Edwards, S., & Avrett, E. 1982, ApJ, 261, 279
Herbig, G. H. 1949, ApJ, 110, 143
Herbig, G. H. 1958, Mém. Soc. Roy. Sci de Liège, 4^e Ser, 20, 251
Herbig, G. H. 1968, Mém. Soc. Roy. Sci de Liège, 5^e Ser, 17, 353
Keenan, P. C., & Greenstein, J. L. 1963, Contr. Perkins Obs. Series 11, 197
Kilkenny, D., & Marang, F. 1989, MNRAS, 238, 1P
Kurucz, R. L., & Peytremann, E. 1979, Smithsonian Ap. Obs. Spec. Rep. 362
Lambert, D. L., Rao, N. K., & Giridhar, S. 1990, JAA, 11, 475
Lawler, J. E., & Dakin, J. T. 1989, JOSA, 136, 1457
Lawson, W. A. 1992, MNRAS, 258, 33P
Lawson, W. A., & Cottrell, P. L. 1989, MNRAS, 240, 689
Lawson, W. A., Cottrell, P. L., Gilmore, A. C., & Kilmartin, P. M. 1992, MNRAS, 256, 339
Martin, G. A., Fuhr J. R., & Wiese, W. L. 1988, J. Phys. Chem. Ref. Data 17, Suppl. 3
McNaught, R. H., & Dawes, G. 1986, IAU Circ. No. 4233
Meaburn, J., & Walsh, J. R. 1980, MNRAS, 191, 5P
Payne-Gaposchkin, C. 1963, ApJ, 138, 320
Pitts, R. E., & Newson, G. H. 1985, JQSRT, 35, 383
Pollacco, D. L., Hill, P. W., Houziaux, L., & Manfroid, J. 1991, MNRAS, 248, 1P
Rao, N. K. 1974, Ph.D. thesis, University of California
Rao, N. K. 1975, Bull. Astron. Soc. India, 3, 50
Rao, N. K., Ashok, N. M., & Kulkarni, P. V. 1988, JAA, 1, 71
Rao, N. K., & Raveendran, A. V. 1992, A&A (in press)
Schmidt, G. D., Cohen, M., & Margon, B. 1980, ApJ, 239, L133
Solf, J. 1983, ApJ, 266, L113
Spite, F., & Spite, M. 1979, A&A, 80, 61
Stanford, S. A., Clayton, G. C., Meade, M. R., Nordsieck, K. H., Whitney, B. A., Murison, M. A., Nook, M. A., & Anderson, C. M. 1988, ApJ, 325, L9
Surendiranath, R., Rangarajan, K. E., & Rao, N. K. 1986, in Hydrogen Deficient Stars and Related Objects, edited by K. Hunger, D. Schönberner, and N. K. Rao (Reidel, Dordrecht), p. 199
Tomkin, J., & Lambert, D. L. 1983, ApJ, 273, 722
Walker, H. J. 1986, in Hydrogen Deficient Stars and Related Objects, edited by K. Hunger, D. Schönberner, and N. K. Rao (Reidel, Dordrecht), p. 407
Whitney, B. A., Clayton, G. C., Schulte-Ladbeck, R. E., & Meade, M. R. 1992, AJ, 103, 1652
Wiese, W. L., & Fuhr, J. R. 1975, J. Phys. Chem. Ref. Data 4, 263
Witt, A. N., & Schild, R. E. 1988, ApJ, 325, 837