R Coronae Borealis Stars at Minimum Light – UW Cen

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ABSTRACT

Two high-resolution optical spectra of the R Coronae Borealis star UW Cen in decline are discussed. A spectrum from mid-1992 when the star had faded by three magnitudes shows just a few differences with the spectrum at maximum light. The ubiquitous sharp emission lines seen in R CrB at a similar drop below maximum light are absent. In contrast, a spectrum from mid-2002 when the star was five magnitudes below maximum light shows an array of sharp emission lines and a collection of broad emission lines. Comparisons are made with spectra of R CrB obtained during the deep 1995-1996 minimum. The many common features are discussed in terms of a torus-jet geometry.

Key words: Star: individual: UW Cen: variables: other

1 INTRODUCTION

R Coronae Borealis stars (here, RCBs) are H-poor supergiants that decline in brightness unpredictably and rapidly by up to 8 magnitudes to remain at or near minimum light for several weeks to months, and even years in some cases. It is generally accepted that the declines are due to the formation of a cloud of carbon soot that obscures the stellar photosphere (O’Keefe 1939). At present, spectroscopic coverage of RCBs in decline is quite limited but common signatures seem to exist.

In decline, two kinds of emission lines dominate the optical spectrum of a RCB (Herbig 1949; Payne-Gaposchkin 1963): a rich set of sharp lines (FWHM ~ 12 km s⁻¹), and a sparse set of broad lines (FWHM ~ 300 km s⁻¹). Sharp lines first appear very early in a decline and persist through deep minima into the recovery to maximum light. Initially and for a few days, the emission lines are dominated by high-excitation transitions of abundant species (e.g., C I and O I - Rao et al. 1999). After a few days and through the minimum to recovery, the sharp lines are of low excitation with singly-ionized metals well represented. Broad lines, which are seen only when the star has faded by several magnitudes and do not have a common profile, may include the following carriers: He I triplet series, Na I D, and [N II] lines, i.e., a mix of high and low excitation lines. Broad blue-shifted absorption lines have been seen to accompany Na D, Ca II H and K, and the He I lines at 10830 and 3889 Å, especially at and following minimum light. In deep minima, the photospheric absorption lines are ‘veiled’, i.e., the lines become very shallow and broad.

These spectral features may be common to all RCBs. Their discovery and definition rested largely on well observed declines of the two brightest RCBs – R CrB (Payne-Gaposchkin 1963) and RY Sgr (Alexander et al. 1972). Evidence that the features may be ubiquitous is found in the valuable contributions to the spectroscopic literature of RCBs observed through a decline by Cottrell, Lawson, & Buchorn (1990) for R CrB, Skuljan & Cottrell (1999) for S Aps and RZ Nor, and Skuljan & Cottrell (2002a) for V854 Cen. Observations of a few stars in deep declines have also shown that a RCB in such a decline has common spectroscopic features, as we indicate in Section 7. Our reference point will be the extensive coverage at high-spectral resolution of R CrB in the 1995-1996 decline (Rao et al. 1999).

In this paper, we discuss high-resolution spectra of the southern RCB UW Cen taken in mid-1992 and mid-2002 when the star was in a deep decline. We comment also on low resolution spectra of UW Cen obtained prior to 2002 when UW Cen was in the same long decline (Skuljan & Cottrell 2002b). UW Cen with R CrB and RY Sgr is a ‘majority’ member of the RCB class in the terminology introduced by Lambert & Rao (1994). UW Cen’s effective temperature (T eff = 7500 K) and surface gravity (log g = 1.0) are representative of the majority stars (Asplund et al. 2000).

UW Cen is one of the very few RCBs with a visible circumstellar reflection nebula (Pollacco et al. 1991). The nebula varies in appearance, possibly due to the formation and dissipation of dust clouds affecting the illumination of the nebula (Clayton et al. 1999). At maximum light, UW Cen shows light (amplitude less than 0.2 mag in V) and ra-
dial velocity variations typical of RCBs (Lawson & Cottrell 1997).

2 OBSERVATIONS

High-resolution optical spectra were obtained in 1991, 1992, and 2002 at CTIO, using the 4 meter Blanco telescope and Cassegrain echelle spectrometer. The star was at maximum light in 1991, but in decline in 1992 and 2002. The 1991 July 15 (JD 2448453) spectrum covered the spectral range 5540 to 6780 Å at a resolving power of 12,500. A spectrum obtained on 1992 May 22 (JD 2448764) at a resolving power of 30,000 covered the spectral region from 5480 to 7090 Å. The AAVSO database of variable star observations (http://www.aavso.org/data/lcg/) shows that the star was observed in 1992 at about 12th magnitude, or about 3 magnitudes below maximum light. In this decline, which began 90 days before our observation, the star faded to 15th - 16th magnitude by about JD 2448730 before brightening slightly to 12th magnitude and then fading again. Maximum light was not attained until about one year after our observation.

Two 30 minute exposures of UW Cen were obtained on 2002 June 20 (JD 2452446.54). The spectrograph was set to record the wavelength interval 4900 to 8250 Å in 45 orders. Spectral coverage was complete between these limits. A resolving power of 35,000 was achieved. The light curve from the AAVSO database shows that the star went into decline in late-1998. As typical of RCBs, the decline was rapid. The star was fainter than \( V \approx 13 \) from mid-1997 (\( V = 9.1 \) at maximum), and, in particular, at minimum light with \( V \approx 15 \) or possibly fainter from early-1999 to the beginning of 2001 when it brightened gradually reaching 13th magnitude by early 2002. At the time of our observation, UW Cen had faded again and was at \( V \approx 14 \) or about 5 magnitudes below maximum brightness. In the following months and through the 2003 observing season, it remained very faint.

3 UW CEN’S 1991 SPECTRUM

The maximum-light spectrum obtained in 1991 shows a good match to the 1992 spectrum when the star was about three magnitudes below maximum light. The photospheric absorption lines are broad enough not to be affected by the difference in resolving power of the spectra. Figure 1 shows the superposition of the 1991 (full line) and 1992 (dashed line) spectra in the region of H\( \alpha \). It is clear that a majority of the lines have similar profiles in 1991 and 1992. The 1992 spectrum was used by Asplund et al (2000) for their abundance analysis. Analysis of the 1991 spectrum would confirm that analysis.

The radial velocity in 1991 from 32 unblended lines across the interval 5800 - 6750 Å is \(-31.8 \pm 2.6 \) km \( s^{-1} \) with two strong Ba\( \text{II} \) lines indicating a velocity of about \(-20 \) km \( s^{-1} \). Lawson & Cottrell (1997) obtained radial velocities on 10 occasions between 1991 May and 1991 September from spectra of the 6540 - 6640 Å interval with a resolving power of 10,000. Their two observations close to the time of our observation give a velocity of about \(-21 \) km \( s^{-1} \), a value differing by 12 km \( s^{-1} \) from our measurement.

4 UW CEN’S 1992 SPECTRUM

When observed in 1992, UW Cen was about 3 magnitudes below maximum light yet the 1992 spectrum closely resembles the 1991 maximum light spectrum. The prominent difference is that certain strong low excitation lines are strengthened in the 1992 spectrum, notably strong lines of Sc\( \text{II} \) and Ba\( \text{II} \). Figure 2 shows the interval 6095 – 6160 Å where strengthening of the Ba\( \text{II} \) 6141 Å line in the 1992 spectrum is conspicuous. Strengthened lines are slightly red-shifted (\( 7 \) km
Figure 3. Comparison of UW Cen spectra around the Na I D lines for the 1992 and 2002 minima. Note the presence of sharp emission in the core of a D line in the 1992 (indicated by arrows) at the same velocity as the prominent emission in the 2002 spectrum. Blue-shifted shell absorption components are present in the 1992 spectrum at -157 and -194 km s\(^{-1}\).

Figure 4. Profiles of sharp emission lines showing red-shifted absorption. The peak radial velocity of the emission is at -34 km s\(^{-1}\) and the weak absorption component is at about 6 km s\(^{-1}\).

5.1 The sharp emission lines

Permitted and forbidden atomic lines are present as sharp emission lines. The list of atomic lines is dominated by low excitation lines of singly ionized metals, e.g., Sc ii (RMT 19, 28, 29, 31, 26, 27), Ti ii (RMT 101, 92, 91, 69, 103, 70, 86, 71), Fe ii (RMT 74, 40, 48, 49, 42), Y ii (RMT 26, 20), and Ba ii (RMT 1, 2). Except for the Na I D lines and K I (RMT 1), sharp emission lines of neutral atoms are not present. Li i at 6707 Å, a strong absorption line at maximum light, is not present either in absorption or in emission. Molecular emissions (C2 and CN) are not present. The sharp lines are slightly broader than the instrumental width (as assessed from the [O i] night sky emissions): the sharp lines’ FWHM, after correcting for the instrumental width is 11.4 km s\(^{-1}\).

The radial velocity as determined from 53 sharp lines is -34.6 ± 1.9 km s\(^{-1}\). Our spectrum was not flux-calibrated, but the similarity between UW Cen’s and R CrB’s lines suggests that the excitation temperature of UW Cen’s emitting region is similar to that derived for R CrB, i.e., \(T_{\text{exc}} \approx 4000\) K.

Some strong emission lines are accompanied by red-shifted absorption (see Figure 4). The absorption appears at velocities between -4 to -11 km s\(^{-1}\). It is unlikely that the absorption component is simply the result of emission superposed on the photospheric line. Since the absorption-free unblended sharp emission lines are symmetrical about the emission peak, it is unlikely that the absorption component has eaten into the sharp emission line.

A few forbidden transitions are seen as sharp emission lines: [Ca ii] at 7291 Å and 7323 Å, and [Fe ii] at 7155 Å. The sharp [Ca ii] lines are superposed on broader components (Figure 5). The sharp forbidden components are at a velocity of -33 km s\(^{-1}\), a value consistent with sharp permitted emissions. The line width (FWHM), after correcting for
Figure 5. The [Ca II] lines in the 2002 minimum spectrum of UW Cen.

Figure 6. He I lines at 5876 Å and 7065 Å in the 2002 minimum spectrum. In contrast to the parabolic He I profiles, the [N II] line shows a double-peaked emission profile.

Figure 7. Lines of [N II] and [S II] in the spectrum of the 2002 minimum of UW Cen.

5.2 The broad emission lines

Broad emission lines include He I at 5876 Å, 7065 Å, the Na D lines, and lines of [N II], [S II], and [Ca II]. The He I lines have a roughly parabolic line profile. The [N II] profiles are double-peaked, but the weaker [S II] lines are single-peaked.

The instrumental width is about 13 km s⁻¹, also consistent with other sharp emission lines.

5.2.1 He I lines

The He I lines at 5876 Å and 7065 Å are seen as broad emission lines with a P- Cygni profile (Figure 6). The rest wavelengths (5875.652 Å, and 7065.277 Å) are taken from laboratory wavelengths with the unresolved components weighted by their theoretical intensities for optically thin emission. The 7065 Å line may have a P Cygni profile with weak absorption to -460 km s⁻¹ and maximum absorption at -305 km s⁻¹. The broad emission is centered at -66 km s⁻¹, extending on the redside to about 112 km s⁻¹. It also may be noted that there is no sharp emission superposed on these broad lines.

5.2.2 Na D lines

The Na D lines show a broad emission profile with superposed sharp emission (Figure 3). The blue edge of broad emission of D2 extends to -273 km s⁻¹. The red edge of D1 extends to +128 km s⁻¹. The profile (after removing the sharp emission) can be fit by a double peaked profile consisting of two Gaussians, each with a FWHM of 127 km s⁻¹, a separation of 144.0 km s⁻¹, and of roughly equal flux. The flux ratio of the D2 to D1 broad emission lines is about 1.8, close to ratio of 2.0 for optically thin emission lines.

5.2.3 Forbidden lines

[Ca II]: The Ca²⁺ ion is expected to contribute broad emission lines at 3968 Å and 3933 Å (the H and K lines), the infrared triplet lines at 8542 Å, 8662 Å, and 8498 Å, and the forbidden lines at 7291 Å and 7323 Å. Our spectrum does not cover the wavelength regions of the permitted lines. The broad component of the forbidden lines is of approximately the same strength for the two lines (Figure 5). The velocity range at the base of the broad emission extends from about
Figure 8. Absorption lines in spectra of UW Cen at the 2002 and 1992 minima. Note the shallow Si\(\text{II}\) 6347 Å line in the 2002 minimum spectrum.

\[-250 \text{ km s}^{-1} \text{ to } +103 \text{ km s}^{-1}\] with a centre at about \(-61 \text{ km s}^{-1}\), and FWHM of about 222 km s\(^{-1}\).

[NII]: The lines 6583 Å and 6548 Å lines are present as broad emissions. The 5754 Å line is not detected. Figure 7 shows the 6583 Å [NII] line as double-peaked. Rest wavelengths of 6583.454 Å and 6548.08 Å have been adopted (Dopita et al. 1997). The velocity range at the base extends from \(-245 \text{ km s}^{-1}\) to \(+135 \text{ km s}^{-1}\). The red and blue peak are separated by 145 km s\(^{-1}\) with the blue peak at \(-128 \text{ km s}^{-1}\) and the red peak at \(+17 \text{ km s}^{-1}\) for the 6583 Å line, the stronger line of the pair. The peaks are about equal strength, and of similar width (FWHM of 120 km s\(^{-1}\)). The mean velocity is about \(-56 \text{ km s}^{-1}\).

[SII]: The red lines at 6717 Å and 6731 Å are present in emission. Rest wavelengths are adopted from Dopita et al. (1997), namely, 6716.472 and 6730.841 Å. The [SII] line profiles differ in a surprising way from the profiles of the [NII] lines: both [SII] lines show the red but not the blue peak of the [NII] profiles (Figure 7). The red peaks of the [SII] and [NII] lines have approximately the same width. The equivalent width of the 6731 Å line is about twice that of the 6717 Å line. This ratio for gas at a temperature of about 10000 K (or less) corresponds to an electron density \(n_e \simeq 10^{3.7} \text{ cm}^{-3}\) (Aller 1984).

5.3 Absorption lines
The normal photospheric spectrum is absent. Figure 8 shows the region of the strong photospheric line of Si\(\text{II}\) at 6347 Å from the 2002 and 1992 spectra. Clearly, photospheric lines are ‘veiled’ in the 2002 spectrum. The radial velocity estimated from some 15 lines is \(-4.3\pm5.7 \text{ km s}^{-1}\) where the large standard deviation reflects the difficulty of measuring these weak broad lines.

A few narrow absorption lines do appear in the 2002 spectrum but these are not photospheric lines. Figure 9 shows several low excitation lines of Fe\(\text{I}\) in absorption without any accompanying emission. They provide a radial velocity of \(-9.7\pm4.3 \text{ km s}^{-1}\) from six lines, a velocity similar to that of the red-shifted absorption components associated with the sharp emission lines.

6 UW CEN AND R CRB IN DECLINE
The components of UW Cen’s spectrum in the 2002 deep minimum are similar to those seen during the 1995 - 96 minimum of R CrB (Rao et al. 1999). These components include the veiled photospheric spectrum, low excitation sharp emission lines, broad emission lines, and high velocity blue-shifted absorption lines seen in the Na D lines. Other minima of R CrB show the same components, as do the limited observations of other R CrB stars in decline. In this section, we compare spectroscopic properties of UW Cen and R CrB at minimum light.

6.1 Sharp emission lines
Sharp high excitation emission lines were seen in R CrB for a short period beginning just after the onset of the decline. Since our UW Cen spectrum was taken long after the decline’s onset it is not suprising that the equivalent lines are absent.

Lower excitation lines of singly-ionized metals and neutral atoms are seen in R CrB following disappearance of the high excitation lines. These lines show a similar level of excitation for the two stars. The line widths are also similar for the two stars. The sharp emissions made their initial appearance in the cores of R CrB’s absorption lines when the star had faded by about 3 magnitudes. At the time of our 1992 observation, when UW Cen was about 2.7 magnitudes fainter than at maximum, sharp emission lines are
detected only in the Na D line cores, suggesting that the emitting region was weaker or more obscured than in the case of R CrB. Sharp emission lines are prominent in the 2002 spectrum when UW Cen was about five magnitudes below maximum light.

That the sharp Na D line emission for UW Cen occurs at the same velocity (−35 km s⁻¹) in 1992 and 2002 minimum suggests that the emitting gas may be a semi-permanent feature detached from the stellar photosphere. This is consistent with observations of R CrB showing a constant velocity for sharp emission lines and a variable velocity for photospheric lines.

Red-shifted absorption associated with sharp emission lines seen in UW Cen and was seen in the early stages of the R CrB decline, and also in a decline of V854 Cen (Rao & Lambert 2000). UW Cen’s 2002 spectrum also shows this absorption component in low excitation Fe I lines without accompanying emission. Comparison of the 1991 maximum and 1992 minimum spectra shows strong absorption lines of Ba II redshifted relative to other absorption lines. The redshifted absorption suggests that cool gas is falling toward the star – from the detached region responsible for the sharp emission lines?

6.2 Broad emission lines

The inventory of broad emission lines in UW Cen in 2002 does not precisely duplicate that for R CrB at its minimum across the common wavelength interval. The profile of a line in UW Cen and the same line in R CrB are generally similar, most notably the He I lines have a quasi-parabolic profile, and the [S II] lines are double-peaked. The [S II] lines are seen in UW Cen (also, V854 Cen, Rao & Lambert 1993) but not in R CrB. The K i 7664 Å and 7699 Å lines were seen in R CrB but not in UW Cen. The C i Swan bands were in emission in R CrB but not in UW Cen. These differences may reflect differences in composition and physical conditions rather than major structural differences.

The low excitation sharp emission lines in R CrB, UW Cen, and all other stars where they have been seen occur with a small blueshift relative to the photosphere. Broad emission lines share neither the velocity of the sharp lines nor the velocity of the photosphere, and appear not to be constant for a given star. For UW Cen in 2002, the broad emissions are displaced to the blue by 26 km s⁻¹ from the sharp emission lines (mean broad line velocity is −61 km s⁻¹). This mean velocity is outside the range of reported photospheric velocities: -10.1 to -26.8 km s⁻¹ (Lawson and Cottrell 1997), -29.3 km s⁻¹ (Herbig 1994, private communication) and -43.8 km s⁻¹ (this paper). In the case of R CrB in the 1995-1996 minimum, the broad lines were blue shifted by about 20 km s⁻¹. For RY Sgr in separate declines Alexander et al. (1972) and Spite & Spite (1979) reported differing redshifts of the broad lines relative to the sharp lines, but Asplund (1995) found broad and sharp lines at the same velocity. An especially intriguing star is S Aps where the broad Na D lines were blue-shifted by about 100 km s⁻¹ relative to the sharp emission lines with their normal small blueshift with respect to the photosphere (Goswami et al. 1997).

6.3 Blue-shifted Na D absorption

Observations of R CrB in the 1995-1996 minimum showed the blue-shifted high-velocity Na D absorption developing in strength and velocity shortly after minimum light. Such high-velocity gas has been reported for other declines of R CrB and other R CrB stars. It is then not surprising that the 1992 spectrum of UW Cen obtained about two months after the star had reached minimum light should show high-velocity absorption in the Na D lines.

High-velocity absorption with a profile like that of the 1992 components is not present in our 2002 spectrum. Very broad shallow absorption could be difficult to impossible to detect given the presence of the broad emission line. Absorption at velocities less than about −250 km s⁻¹ is definitely absent.

Observations of the Na D lines are reported by Skuljan & Cottrell (2002b) who observed UW Cen at low resolution (Δλ ≳ 3 − 6 Å) during a partial recovery to V ≃ 13 − 14 in the deep extended decline in which our 2002 spectrum was obtained. These Na D observations were obtained between 534 and 622 days from the onset of the decline, and about four years before our observation. The spectra appear to show blue-shifted absorption at a velocity of about -220 to -300 km s⁻¹. Such a component is not present in our spectrum. (Skuljan & Cottrell did not detect broad Na D emission lines but remark that ‘they are probably at or below the noise level in the continuum.’)

7 DUSTY TORUS AND BIPOLAR JETS

In line with contemporary fashion for models of mass-losing luminous low mass stars (Lopez 1999; Rao, Goswami & Lambert 2002) including RCB stars (Rao & Lambert 1993; Clayton et al. 1997), we invoke the geometrical combination of bipolar jets and an equatorial torus of dust and gas.

There are observational hints that there is a preferred plane (i.e., a torus) for dust formation and ejection (Clayton et al. 1997; Rao & Raveendran 1993). Observational evidence, especially measurements of the infrared flux emitted by the circumstellar dust, suggests that the dusty region is comprised of clouds (Feast 1986; Feast et al. 1997) and a decline results when a new cloud forms along the line of sight. If dust formation is restricted to a preferred (equatorial) plane and clouds confined to a torus, dust-forming RCB stars observed at high inclination to the torus will not exhibit declines but will possess an infra-red excess. The stars Y Mus, XX Cam may be such examples (Clayton 1996; Walker 1986). At the other extreme, there may be stars with the torus perpendicular to the plane of the sky and, if the torus is optically thick, these RCBs will be difficult to identify.

We speculate how a torus-jet model may account for the spectroscopic signatures of an RCB in decline, including the sharp emission lines, the broad emission lines, the veiled photospheric lines, and the high-velocity blue-shifted Na D absorption:

- Sharp low-excitation emission lines, we suppose, originate from the base of the jets where the jet velocity is low. Depending on the geometry of the jet and torus, the viewing angle and the size of the new cloud, the base of the jet on the far side may be obscured. In which case, the sharp
lines will always have a net blueshift determined by the jet outflow velocity near its base, the angle of inclination and the volume of the emitting region unobscured by dust. The characteristic velocity of the lines when the star is in decline is \(-10\, \text{km s}^{-1}\) relative to the photosphere.

- Double-peaked broad emission lines (e.g., [N II] but not He I) are identified with regions of the jets quite distant from the star and visible to us along paths not intersecting the newly formed cloud and the dusty torus. The double-peaked profiles have a ready explanation: the blue-shifted peak comes from the jet nearer to us and the red-shifted peak from the opposing jet. The details of the profile depend on the jet velocity and the opening angle and the angle of inclination to the line of sight. The mean velocity could be, as observed for UW Cen, blue-shifted relative to the photospheric velocity if the receding jet is partially obscured by the dusty torus. However, this construction would likely predict unequal fluxes in the blue and red halves of the line, which is not the case (see also Rao et al. 1999 for R CrB).

If there is a steep transition from subsonic to supersonic flow (i.e., a Parker-type wind), lines with profiles intermediate between the sharp and broad lines will be absent, as observed. This geometry is consistent with Whitney et al.’s (1992) observation that the Na D broad lines from V854 Cen are unpolarized even though the local continuum is significantly polarized. It is also consistent with the indication that the broad line flux is probably constant through a decline, as shown by Skuljan & Cottrell (2002a) for V854 Cen, and by Rao et al. (1999) for R CrB.

- Judged by differences in profile and derived physical conditions, the He I lines cannot be produced by the gas responsible for the [N II] and similar lines. The He I emission is here identified with the dusty equatorial torus. Gas in the clouds causing a decline is accelerated quite quickly to high velocities, as revealed by the blue-shifted Na D absorption. Dust ejection is known to occur in localized regions. Then, the torus will be populated by many high velocity clouds. Collisions in the torus between the high velocity atoms in a high-velocity dust cloud and slowly moving older residents (electrons, He atoms, and dust grains) of the torus, may provide sufficient excitation to cause emission. Since the He I emission may come from regions spread across the torus, expansion (or rotation) of the torus will provide a roughly parabolic emission line profile provided that the number of contributing clouds is not small. A velocity shift from the photospheric velocity will occur if the clouds are asymmetrically around the torus.

Evidence for excited He atoms along the line of sight to RCB stars is provided by Clayton, Geballe, & Bianchi’s (2003) observations of the He I 10830 Å line in a sample of RCB stars. In stars observed near maximum light, the 10830 Å line with the exception of V854 Cen is strongly in absorption with a blueshift of 200–300 km s\(^{-1}\). There is a hint of P Cygni emission with a suggestion that the emission is stronger for stars observed in decline. Although a detailed study of He I excitation is needed, these observations are consistent with our speculation about the origin of the the 7065 Å and other lines, all of which must be much weaker than the 10830 Å line.

- When the star is thoroughly obscured by the dust cloud responsible for the decline, it is seen by starlight scattered multiple times by dust in the torus. These dusty clouds expanding outward will impose a range of Doppler shifts on the scattered starlight. The result is a greatly smeared (veiled) version of the photospheric spectrum is received by the observer.

- In the recovery phase, the sightline to the star is becoming less opaque. Gas along this sightline may be seen in absorption against the reduced photospheric continuum, seen through the new cloud and also be scattering off other dust clouds. Some of this gas is associated with the dust which caused the decline and some may be in the expanding torus as a result of earlier declines. Dust is accelerated by radiation pressure and gas-dust collisions transfer momentum to the gas. This outward moving gas provides the blue-shifted absorption lines in the Na D and other resonance lines of abundant atoms and singly-charged ions (e.g., Ca\(^+\)). In a very deep decline, the starlight is scattered into the line of sight from dust primarily off the line of sight to the star. The absence of Na D absorption at this time implies that the high velocity gas is confined to a plane and is not spherically distributed about the star.

This sketch of the jet-torus model does not address why a RCB star should have a preferred plane for formation and ejection of dust and a pair of polar jets. The key to the preferred plane may possibly be linked to the origin of a RCB star. A favoured model involves the accretion of a He white dwarf by a C-O white dwarf. Accretion may lead to heating and swelling of the merged envelope, i.e., to the observed supergiant. One might suppose that C-O white dwarf is greatly spun up during accretion and, therefore, the RCB retains a memory of the binary orbital plane. Origins of the bipolar jets and the formation of dust clouds in the equatorial plane are left for a future theoretical study.

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