Astron. Astrophys. 327, 640–647 (1997)

ASTRONOMY
AND
ASTROPHYSICS

Spectroscopic observations of the interacting binary BY Crucis*

K. Daems and C. Waelkens**

Instituut voor Sterrenkunde, K.U. Leuven, Celestijnenlaan 200B, B-3001 Heverlee, Belgium

Received 15 April 1997 / Accepted 17 June 1997

Abstract. We present multi-wavelength spectroscopic data of the 106 day period interacting binary BY Crucis (Daems et al. 1997). The system consist of an early F-type supergiant that fills its Roche lobe and a more massive companion, hidden in a thick accretion disc.

In the far-UV spectra (from 1200 Å to 1950 Å), strong emission lines of highly ionised elements are observed, superposed on a continuum. Both components of the UV flux originate from the accretion disc around the companion. In the UV range from 1950 Å to 3150 Å the radiation of the F-type mass donor is dominant.

In the visual and the red range we focused our interest on the Balmer lines (H_α, H_β and H_δ), He I 5876 Å, Na I 5890-5896 Å, and the forbidden line [O I] 6300 Å. We also obtained spectra in various other regions, ranging from 3900 Å to 6700 Å. Evidence of mass transfer is observed in the He I-line, the Na I-lines, H_β and some Fe-lines. The H_α-line shows no variability, and its double peaked profile implies that it is formed in a circumbinary disc or envelope. The [O I] line confirms the presence of matter around the binary system. By analysing the line profile variability of He I, we construct a tentative image of the gas flow in the accretion disc around the unseen companion. The Balmer lines are used to probe the outer, cooler gas, flowing through the outer Lagrangian point into a circumstellar disc or envelope.

Key words: binaries: close – circumstellar matter – stars: evolution – stars: individual: BY Cru

1. Introduction

BY Crucis (HD 104901B) is the second brightest star of the physical triple system HD 104901 (Daems et al. 1997 and references therein; hereafter called Paper I). The A component is usually classified as a B8/9Iab/b star (Houk & Cowley 1975). Component C is an early-B main sequence star. BY Cru, the B component, consists of an early F-type supergiant and an unseen companion, with an orbital period of 106.4 ± 0.1 days. The companion star is hidden in a geometrically and optically thick accretion disc.

In our previous paper it was shown that the inclination of the binary must lie between 64° and 76°, the higher value being more probable. At these inclinations no real deep eclipses occur. The masses of the components were found to be between 1.7 and $1.9 M_\odot$ for the F-type mass donor, and 9 to $11 M_\odot$ for the unseen mass gainer (depending on the adopted inclination and the total mass lost from the system). We classify BY Cru as a *W Serpentis* type binary (Plavec 1980).

Since HD 104901A is crossing the Hertzsprung gap, we can determine its age relatively accurately, and hence that of BY Cru, which is 30 ± 4 Myr. Using HD 104901C, being a B type main sequence star, we find that the distance to the stars is about 1.6 kpc, assuming a reddening of 0.38 in the Geneva photometric system.

The shape of the visual light curve of BY Cru (Paper I) reflects mainly the ellipsoidal distortion of the F-type supergiant. There is, however, a small contribution from what is believed to be the accretion disc.

To confirm the presence of the accretion disc, and to study the flow of gas in the system, we have been gathering spectra of BY Cru during the past three years. Due to the long period of over 100 days, we did not obtain complete phase coverage in the spectra. Most spectra were taken around the orbital phases 0.0 (supergiant in front of accretion disc) and 0.5 (accretion disc in front of supergiant).

2. The IUE Spectra

In general, the best place to study (hot) accretion phenomena is in the ultraviolet wavelength range. In total we obtained three sets of low resolution SWP-LWP (short and long wavelength prime cameras) spectra with the, now de-commissioned, International Ultraviolet Explorer (IUE). The observations were guided and monitored by the Vilspa IUE Tracking Station, Spain. One SWP-LWP pair was taken at orbital phase ϕ = 0.0 (supergiant obscures the accretion disc), one pair in the other

Send offprint requests to: K. Daems, Leuven

* Based on observations obtained with the IUE satellite; and at the European Southern Observatory, La Silla, Chile.

** Research Assistant of the Fund for Scientific Research - Flanders

Table 1. List of the UV spectra of BY Cru. Shown are the 3 pairs of SWP-LWP low resolution spectra, obtained at the two minima, and at full light. For each observation we give the date, the corresponding orbital phase and the total exposure time (in seconds)

spectrum	date of observation	orbital phase	exposure time
SWP 50521	11/04/94	0.00	3600s
LWP 27874	11/04/94	0.00	600s
SWP 50718	07/05/94	0.25	3000s
LWP 28079	08/05/94	0.26	600s
SWP 44704	18/05/92	0.49	2400s
LWP 23121	18/05/92	0.49	180s

Table 2. The main emission lines identified in the short wavelength UV spectra (SWP) obtained with IUE. Different ions of one species are present (e.g. C II, C IV), indicating different temperature regions in BY Crucis. The lines are present at all orbital phases. It is believed that they are formed by collisions in the accretion disc or in a sort of halo around it

element	wavelength	element	wavelength
N V	1240 Å	C IV	1550 Å
Si II	1297 Å	He II	1640 Å
Si III	1304 Å	Al II	1671 Å
C II	1336 Å	Al III	1855-1863 Å
Si IV	1394-1403 Å	Si III	1892 Å
Si II	1533 Å	Fe III	1895 Å

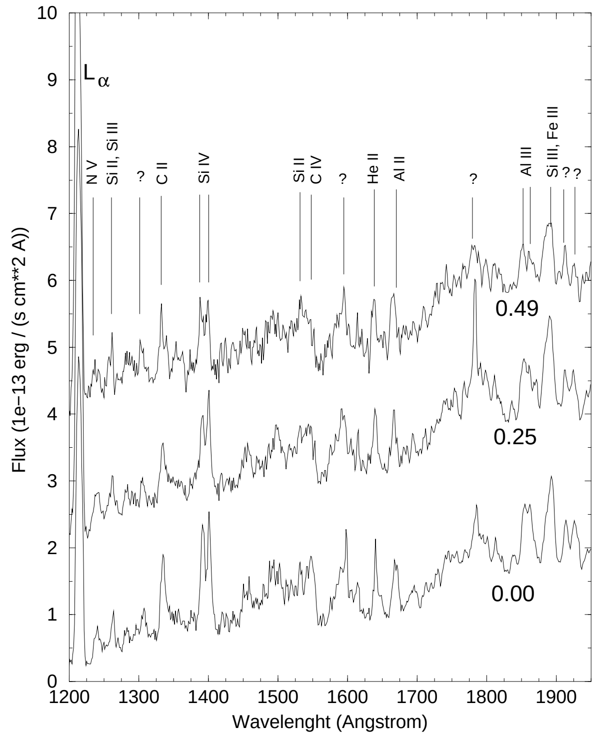

Fig. 1. SWP-spectra of BY Crucis. The spectra have not been normalised. For clarity the SWP-spectrum taken at $\phi = 0.25$ has been shifted upward by 2 units, and the spectrum at $\phi = 0.49$ by 4 units. No significant change in the strength of the UV-continuum is present. As is the case with other *W Serpentis* binaries the emission lines are visible at all orbital phases. The emission lines indicated with a question mark have not been identified. The spike at 1783 Å (at $\phi = 0.25$) results from a bad instrument reading

eclipse ($\phi = 0.5$) and one at full light. In Table 1 the dates, orbital phases and exposure times are shown.

As already published in Paper I, we detect a UV-continuum that is too high to originate from the F-supergiant (Fig. 3 in Paper I). The excess cannot simply be fitted by a stellar atmosphere or a single black body. We believe the excess originates in some (central) part of the accretion disc around the companion star. It is not possible to state whether or not there is a contribution of the central star. But since the central star is not detected in the optical range either (see Sect. 3), we believe it does not contribute.

The measured UV-continuum excess turned out to be quasi phase independent: the excess does not get weaker when the supergiant is closest to the observer. This is contrary to other known (edge-on) *W Serpentis* stars, such as W Crucis or W Serpentis itself, where the continuum does diminish significantly when the accretion disc is hidden behind the supergiant. The persistence of the UV-flux confirms the result of Paper I, that BY Crucis is not an edge-on binary.

Superposed on the continuum UV excess we observe emission lines of ionised C, N, Si, Al, Fe, He (see Table 2) and other not yet identified lines. All these lines are found in the short wavelength range of IUE (SWP-spectra, see Fig. 1). Since the highly ionised elements form only at high energies, the F-type supergiant cannot be the origin of the lines (the supergiant is the dominant source at the longer wavelengths). Unfortunately, because of the low inclination of BY Cru it is difficult to locate this line-forming region: it can be in the accretion disc and/or in a hot spot and/or above the accretion disc.

In other *W Serpentis* stars (most of them are observed edge-on) the emission lines are also observed. When the accretion disc disappears behind the mass donor, the UV-continuum diminishes, but the emission lines remain unweakened. According to Plavec (Plavec 1985) the emission lines are formed by collisions, out of the orbital plane of the binary in a sort of halo around the accretion disc. Because of the analogy with edge-on *W Serpentis* binaries, the UV-emission lines in BY Cru are probably formed in a similar halo around the accretion disc.

3. The CAT/CES Spectra

The 1.4m Coudé Auxiliary Telescope at La Silla, Chile, equipped with the Coudé Echelle Spectrometer was used to obtain high resolution spectra of BY Cru from the blue to the red wavelength range. Since the apparent visual magnitude of BY Cru is about 7.7 (in the Geneva photometric system),

Table 3. List of the spectra taken during our three years observation campaign. Given are identification of the prominent line(s), the central wavelength of the spectra, and the total number of spectra obtained at that wavelength

major spectral line(s)	central wavelength of spectrum (Å)	total number of spectra
Ca II (K)	3933	2
H_δ	4101	3
Si II, Fe II	4130	2
Fe II, Ti II	4175	2
He I, Fe II, Ti II	4473	2
Si III, Ti II, Mg I	4563	3
H_β	4862	6
He I, Fe II	4925	7
Fe I	5050	3
[Fe II], Mg I, Fe II	5169	4
He I, Na I	5885	27
[O I]	6300	4
H_α	6563	11
He I	6678	5

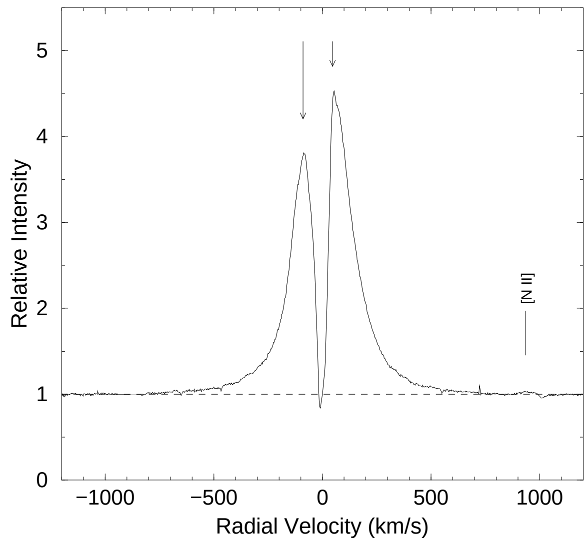

Fig. 2. High resolution spectrum of the H_α-region, as observed in BY Cru at orbital phase 0.73 (full light). The profile is independent of the orbital phase, indicating that it is formed in a circumbinary shell or disc. Given the high radial velocities, however, it can not be excluded that the emission wings are formed in the rapidly rotating accretion disc around the unseen companion. Also marked is the forbidden [N II]-line (6583.6Å). The horizontal dashed line represents the normalized continuum. The two arrows indicate the location of the blue and red edge of the absorption component

it takes some 30 to 60 minutes to obtain a good spectrum (S/N > 100). One spectrum covers 40 to 50 Å.

A total of 81 high resolution spectra were obtained with the CAT/CES, spread over three years, which corresponds to about ten orbital cycles. Cycle-to-cycle variations are observed in most spectral lines. This long term variation is probably due to a non-constant mass transfer rate. The spectra are listed in Table 3.

High-rate mass transfer from the supergiant to the companion cannot have been conservative, given the huge IR-excess originating in cool dust around the system (Fig. 3 in Paper I). At a certain stage in the mass transfer process, and possibly still at present, the Roche lobe of the mass gainer may have been saturated by mass coming from the supergiant through the inner Lagrangian point. This results in mass loss, mainly through the exterior Lagrangian point, creating a circumbinary disc.

In the next sections we use our time series of the different optical lines to probe the location, geometry and dynamics of the line forming regions in the complex system. We start with a detailed line-by-line analysis before incorporating our findings in a global picture.

3.1. H_α 6563 Å

Shown in Fig. 2 is a typical H_α-line profile (orbital phase ϕ = 0.73) as observed in the BY Cru system. A variation in the emission line intensity was observed: a difference of about 2 (relative intensity units) occurs between times of eclipse and times of total light. This variation however is not caused by changes in the line itself, but by the varying background continuum originating in the revolving binary.

The H_α-line profile is quasi independent of the orbital phase, indicating that the line formation region is not one of the two stellar components, nor located very close to one of them. The line consists of a strong broad emission component and a blueshifted absorption. The blue edge of the absorption component corresponds to the average radial velocity of -83 ± 5 km s^{-1}, while the red edge shows a radial velocity of 61 ± 8 km s^{-1}. The positions of these blue and red absorption edges do not seem to depend on the orbital phase, although more observations of H_α at different phases would be useful to confirm this. A photosperic absorption component is not observed.

The H_α-profile is characteristic for a rotating excretion shell or disc: matter is revolving about the binary system in a slowly expanding structure.

The broad base of the emission, indicating velocities of over 500 km s^{-1}, suggests that part of the emission might be formed in the rapidly rotating accretion disc. The orbital motion of the center of mass of the disc, which should then be reflected in the emission component, has however not been detected so far.

The origin of the absorption line might be absorption of star-light by the circumbinary disc. For this it is necessary that the H_α-region obscures the stars at least partly. But, given the low inclination of at most 76°, it should be more appropriate to talk about a circumbinary envelope or shell (at least close to the stars). Another possibility is self-absorption in the H_α-region. An observation in favour of this interpretation is the fact that the absorption does not reach below the continuum level. In W Crucis, a system which has an inclination close to 90°, the H_α-line profile is very similar to the one observed in BY Crucis. But in W Crucis the absorption does reach below the continuum and it has a larger blueshift. Comparing these two stars, we

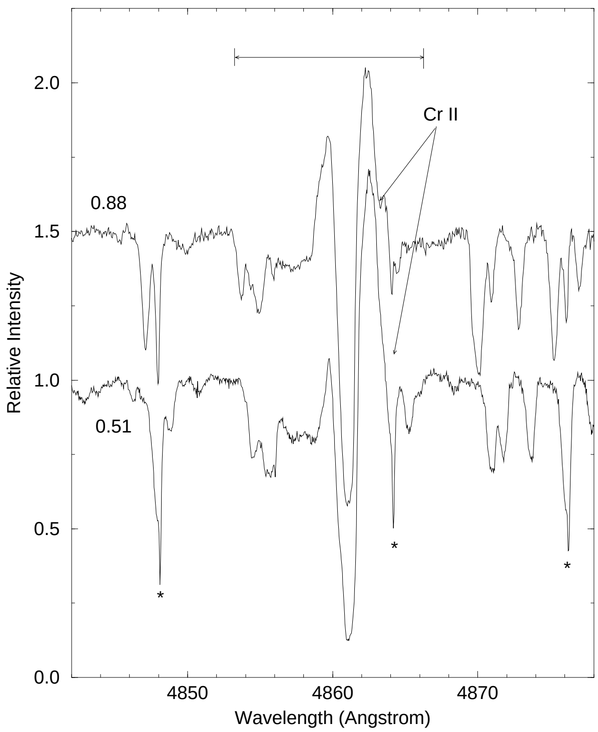

Fig. 3. The spectral region of H_β. Shown are one spectrum taken during eclipse (ϕ = 0.51) and one out of eclipse (ϕ = 0.88). The absorption, best visible on the blue side of the double peak emission line due to the expanding shell ($\lambda < 4859$Å) and somewhat less on the red side, is a part of the wings of the photospheric H_β-line. The horizontal arrow indicates the total extent of the photospheric absorption for the top spectrum. Also clearly visible at ϕ = 0.88 is how the Cr II-line cuts into the right emission component, thereby lowering this peak. During ϕ = 0.51 this Cr II-line is partly blended with an Earth atmosphere water vapor line. These water lines are marked with a *

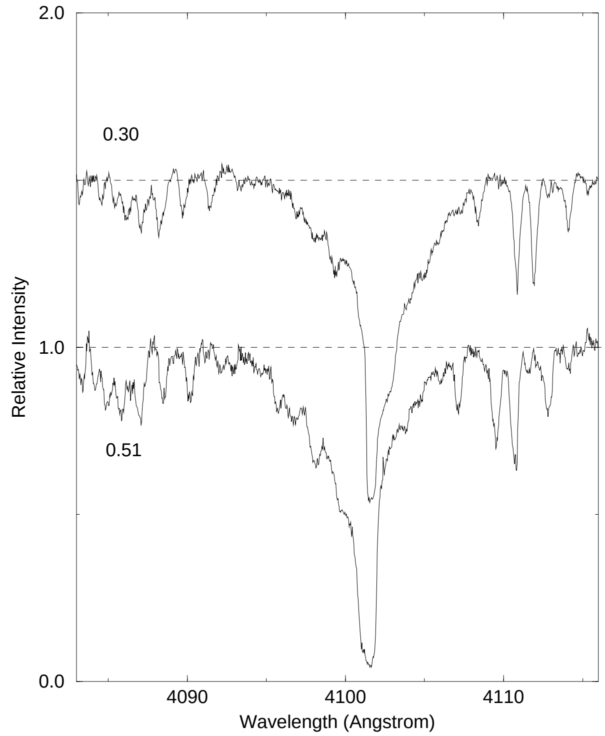

Fig. 4. The spectral region of H_δ. The top spectrum (shifted by 0.5) is taken at ϕ = 0.30, the other spectrum at ϕ = 0.51. Clearly visible are the two separate components: one broad, moving photospheric component associated with the supergiant; and one stationary, narrow component. All the other spectral lines visible originate in the supergiant. The continuum is represented by the dashed lines

expect the absorption in BY Cru to be mainly self-absorption, while in W Cru it is also absorption of star light.

Just barely detectable in the spectrum shown in Fig. 2 is the forbidden line [N II] (6583.6Å). This line is a further indication that an extensive circumbinary structure is present in BY Crucis.

3.2. H_β 4861 Å

Qualitatively, one finds the same profile for the H_β-line as for the H_α-line, indicating that this line, like the previous one, is mainly formed in an expanding shell. However, this second Balmer line does show an orbital phase dependent behaviour. H_β has a much stronger absorption component than the H_α-line, and the emission itself is weaker. Unlike H_α, the H_β-line does show photospheric absorption (Fig. 3).

The emission component seems to change in intensity. But, as is the case with the H_α-line, this change in intensity is, at least partly, the result of the normalization of the spectrum to the variable background continuum radiation originating in the binary. A second reason why the emission apparently changes is the blending with the photospheric H_β and Cr II-lines, moving back and forth with the orbital motion of the supergiant.

All the other lines visible in the spectra shown in Fig. 3, except for the Earth atmosphere water lines, are from the photosphere of the supergiant, as can be deduced from their Doppler shift.

3.3. H_δ 4102 Å

The H_δ spectral line is seen in absorption only, consisting of at least two separate components (Fig. 4). One narrow component is stationary, and must therefore arise in the circumbinary shell or disc. The other, broader component is a photosperic H_δ-line of the F-supergiant.

3.4. He I 5876 Å

The spectral region about 5885 Å is a very interesting domain: In one exposure one obtains a high resolution spectrum of two (actually three) important lines: He I (5876 Å) and Na I (5890 and 5896 Å). The He I-line can be used to probe deep into the accretion disc around the unseen mass gainer. The Na I-line on the other hand is used to investigate the cooler gas and interstellar matter intervening on the line of sight. A disadvantage of these two lines being so close together, is that when they

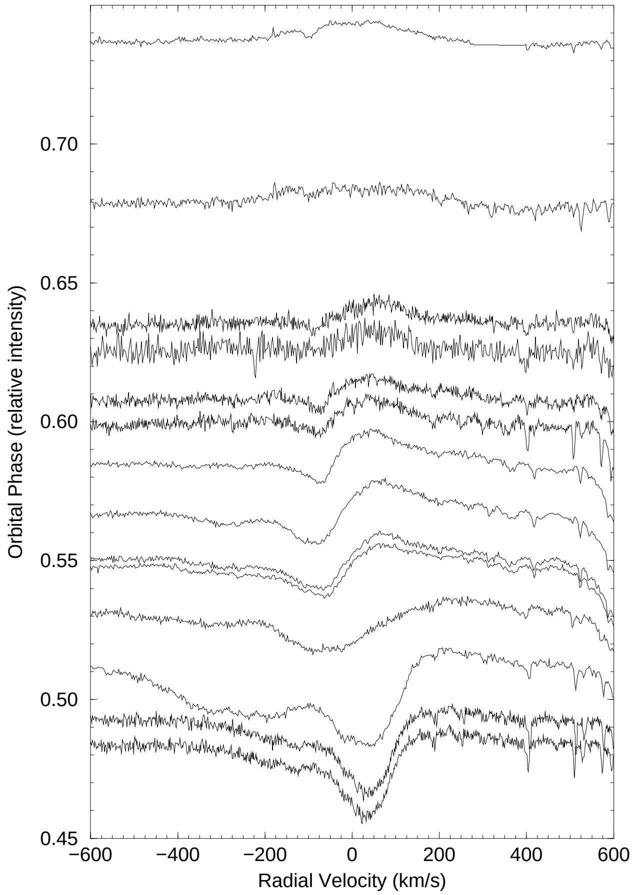

Fig. 5. The transition of the He I-line from absorption (in eclipse) to emission (at full light). The central absorption is believed to originate in the accretion disc or halo. The blueshifted absorption reaching radial velocities of about -500 km s^{-1} is formed in a stream of gas, flowing from the mass donor to the accretor. It is strongest at orbital phase 0.51

become very broad due to Doppler effects they begin to blend, making it difficult to determine the continuum in the spectra.

He I 5876 Å (the same goes for He I 6678 Å) is seen in broad emission, except for the orbital phases in which the mass gainer and accretion disc are in front of the mass losing supergiant. In the latter case, a very broad absorption is seen, especially along the shorter wavelength-side. In order to understand the behaviour of the He I-line and find its place of origin, we have monitored it more closely during its transition from absorption to emission (roughly between phases 0.50 and 0.65). As mentioned before, obtaining good phase coverage is difficult, given the long period of the binary.

During the phases at which the unseen companion and the accretion disc are (partly) in front of the supergiant (ϕ = 0.5), we observe two separate absorption components (Fig. 5). One component is more or less symmetric in shape, and its center lies close to the rest-wavelength of the line in the system. This line must originate in the part of the accretion disc that is in front of the supergiant, or in the halo around this accretion disc. It must be the supergiant, and not the companion, that supplies the background radiation; if not, the absorption line would be present at all orbital phases.

The second absorption component is seen only on the blue side of the rest-wavelength. It shows radial velocities of several hundred kilometers per second. The maximum value measured so far is about -500 km s^{-1}. In order to reach these extremely high velocities, the absorption component must be formed in a supersonic stream of gas, flowing from the supergiant to the companion. At ϕ = 0.51, we look right into this stream (at a certain orbital inclination i).

When the binary revolves out of eclipse, the following behaviour is observed. First the highly blueshifted absorption disappears, as a consequence of the flow of gas turning out of the line of sight of the observer, thereby decreasing the visual column density of the flow. Secondly, the absorption, centered about the rest-wavelength, turns to emission. This transition is first detected in the red part of the spectral line, because it is the part of the accretion disc that recedes from the observer that first clears the surface of the supergiant. As the binary revolves further, also the blue side turns to emission, as the approaching side of the disc no longer obscures the supergiant. The symmetric emission line persists for the rest of the binary period, until the mass gainer and accretion disc start again to obscure the mass losing star.

We can use the moment of transition from helium absorption to emission to estimate the outer radius of the accretion disc. From the spectra (Fig. 5) we learn that the transition occurs between orbital phase 0.60 and 0.65. We assume an orbital inclination of 76°, a supergiant mass of 1.7 $M_\odot$ and the mass of the companion 9.1 $M_\odot$ (Table 3 in Paper I). For this configuration we find that, using a geometrical model, the outer radius of the accretion disc must be in the range of 86 to 117 $R_\odot$, i.e. the radius is about 78 to 106% of the mean Roche lobe radius of the unseen star.

The absorption does not disappear completely (Fig. 6). At all orbital phases when the broad emission line is observed, we also detect a small, relatively narrow absorption line, superposed on the emission. The origin of this line is not yet certain. Doppler-shift indicates the absorption line is Fe I or possibly even He I. In any case, the line must be formed in or close to the atmosphere of the mass losing supergiant.

If we assume that the broadening of the He I emission line is mainly due to the rotation of the accretion disc, it is possible to estimate the inner (visible) boundary of the disc. Radial velocity measurements show a maximum displacement of about 250 to 300 km s^{-1}. If we assume Keplerian rotation in the accretion disc, and a central star of 9.1 $M_\odot$, we find an inner distance of 20 $R_\odot$ to 28 $R_\odot$.

3.5. Na I 5890-5896 Å

The Na I spectral line is even more complicated than the He I-line. The line profile probably consists of five different components: two interstellar components, one circumbinary, one circumstellar (around the

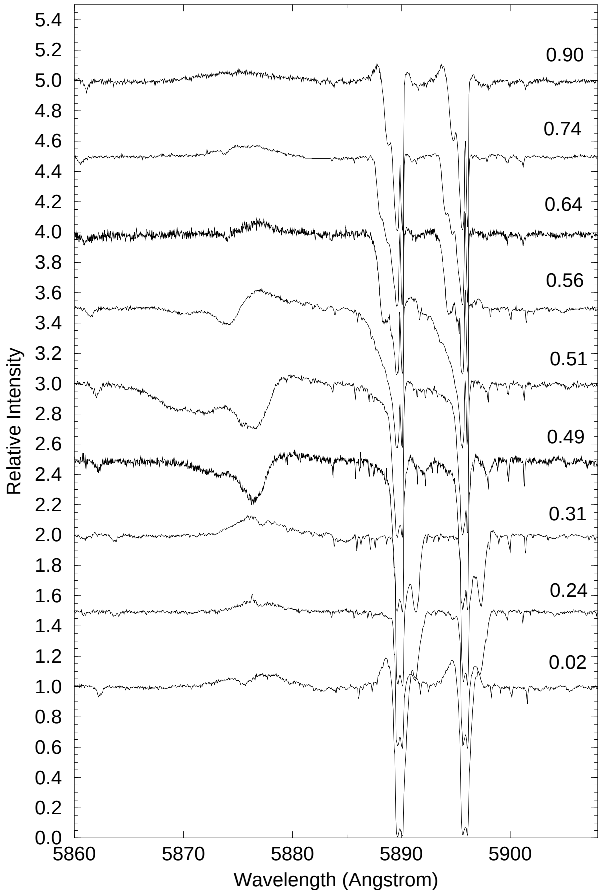

Fig. 6. Spectral region of He I and Na I. Shown are the major variations in the line profiles during one orbital cycle. The spectra are displaced upwards by 0.5 units for clarity. To the right of each spectrum is the corresponding orbital phase. For the interpretation of the different components of the lines, see the text

unseen companion) and one photospheric.

The two interstellar absorption components are easiest to recognize, since they are very narrow and stationary, and they are also present in high resolution spectra of HD 104901 A and C. The blue component is formed in an interstellar region moving at a radial velocity of -15.1 ± 0.6 km s^{-1}, while the red component has a radial velocity of 6.0 ± 0.7 km s^{-1}. Since BY Cru lies in the plane of our Galaxy, the Na I interstellar lines are very strong, going all the way down to almost zero intensity. The presence of these deep interstellar components makes it very difficult to interpret the other line components.

The photosperic component is also easily identified, especially out of eclipse. It is best visible at ϕ = 0.31 (in Fig. 6) on the red side of the rest wavelength of Na I. Also in the orbital phases ϕ = 0.64 and 0.74 it is clearly visible, but on the short wavelength side.

During eclipse of the accretion disc, a broad Na I emission line appears. At phases when the supergiant is closest to the observer (ϕ = 0.0), it is seen as two emission peaks to the short and the long-ward wavelength side of the absorption line. At phase 0.5 it is only seen on the red side of the line. It is not yet clear whether this emission is present at all times, and just seems to be gone because of blending with other line components, or whether it really disappears out of eclipse. The origin of this emission is very likely to be the circumbinary disc or envelope.

Finally there is a component which is only visible when the accretion disc is in front of the supergiant. During these phases a blueshifted absorption is observed, similar to the one observed in the He I-line. The absorption is never visible on the red side of the spectrum. Again, this behaviour can be explained as a gas flow streaming in the line of sight, and towards the observer (at an inclination i) about ϕ = 0.5. The maximum radial velocity observed is about -200 km s^{-1}.

3.6. [O I] 6300 Å

The presence of an extensive disc and/or envelope of diffuse matter is also observed in the stationary forbidden [O I] emission line. The line is some 20% stronger than the continuum radiation and it seems slightly double peaked, suggesting a rotating circumbinary shell or disc. The center of the emission peak has a radial velocity of -9.5 $\pm$ 1.5 km s^{-1} with respect to the system velocity.

4. Discussion

BY Crucis is a semi-detached interacting binary, best described as a *W Serpentis* star. The companion star is never observed. This is mainly because it is hidden in a huge accretion disc, but also because of the difference in luminosity between the two stars: it can be expected that the supergiant is about ten times as bright as the companion. Another factor is that the mass transfer process must have spun up the companion, thus broadening its spectral lines enormously. This broadening makes identification of spectral lines of the companion, if present at all, very difficult. In order to hide a complete main sequence star, the amount of mass transferred from the supergiant donor to the companion must be large. The mass transfer rate is not only large, but also varying in time, as is observed in the long term variations in the lines at different epochs.

4.1. Mass loss: circumbinary matter

The Balmer lines, the forbidden [O I] line and the presence of dust leave no doubt that circumbinary matter is present. The two peaks in the emission profiles suggest that the gas is concentrated in a disc in the equatorial plane. However, considering the low inclination (Paper I), it is strange that extra absorption of a non-stellar nature is present in the first Balmer lines. Close to the stars, the circumbinary matter must therefore assume a more shell-like shape. According to Doppler shift measurements this shell is expanding slowly.

The gas around the binary BY Cru is an indication for high mass loss as a consequence of high rate mass transfer. Using simple, approximative evolutionary scenarios we estimate in Paper I that about 1 to 2 $M_\odot$ left the binary during the mass transfer process. Clearly then, this mass, orbiting the binary, is responsible for the double peaked line profiles.

4.2. Mass transfer: accretion disc

The flow of gas close to the stars proves to be difficult to analyse. Although it is hard to obtain good orbital phase coverage in the observations, some important things can already be learned from our spectral series.

A first important observation is that the broad He I emission line, originating in the rapidly rotating accretion disc, does not disappear at orbital phase $\phi = 0.0$ (supergiant closest to the observer). The only way to obtain such a situation is by having a relatively low orbital inclination. The He I emission therefore confirms the result published in our previous article, where we found an inclination of only 76°. We have constructed a simple geometrical model with masses of 1.7 $M_{\odot}$ for the Roche lobe filling supergiant and 9.1 $M_{\odot}$ for the companion. This model reveals that the major part of the accretion disc, including the central part, never disappears behind the supergiant for an inclination of 76°. This again is in perfect agreement with the observation that the UV-continuum, originating in the hot accretion disc, is constant throughout the whole orbital period (Paper I).

Secondly, an extremely blueshifted absorption component is clearly visible when the accretion disc eclipses the supergiant. A similar red absorption has never been detected. The maximum blueshift, detected to date, corresponds to a radial velocity of about -500 km s^{-1}. It is not easy to find a mechanism in the binary that produces such high velocities. The origin can not be the gas in orbit in the accretion disc about the companion, because a redshifted absorption would be seen at some orbital phases. The same argument excludes the possibility that the observed line is a photospheric line of the companion. A wind mechanism or some sort of jet perpendicular to the orbital plane is also very improbable, since the blueshifted absorption would be visible at almost every phase, except the phases when the companion might be (partially) obscured by the supergiant. In reality the absorption is only seen roughly between phases 0.4 to 0.6.

The only mechanism we can think of is a stream of gas in the system. The most probable location for a high velocity stream in the binary is between the two stars, carrying matter from the mass donor to the companion. This option would explain why we observe the absorption only at certain orbital phases, namely when the stream coincides with the line of sight of the observer (at an inclination i). However, it remains to be seen if such a stream can indeed reach a velocity of about 500 km s^{-1}. Approximative calculations, including only gravitation, yield velocities of only 100 to 200 km s^{-1}, depending on the masses of the stars and distance to be crossed. This number is consistent with the velocity found in the Na I-line, but is less than half of the velocity indicated by the He I-line.

4.3. The star inside the accretion disc

It might seem problematic that we observe He I-line components that are according to their Doppler shift, formed relatively deep in the accretion disc, i.e. close to the companion star. Then why do we not observe the star itself? Or, is it observed, but not recognized?

If continuum radiation originating from the gainer is observable, it must be in the UV. The fact that we do not observe this stellar UV flux indicates that the star is indeed hidden. Furthermore, the chance of identifying spectral lines of the companion is small. The fast rotating inner part of the accretion disc may have spun up the central star to nearly break-up speed. For a main-sequence star of about 9 $M_{\odot}$ this will be several hundred kilometers per second, thus broadening the spectral lines of the star enormously. The difference in luminosity of the supergiant and the companion also makes detection difficult.

In any case, it is to be expected that the central star is a main-sequence star. If it were a compact object, the high mass would leave no doubt that we are dealing with a (massive) black hole. This would imply a completely different binary evolution: instead of the first mass transfer phase we believe the system is in now, the binary would be in the phase of its second mass transfer. Major problems arise if this scenario is investigated. The main problem is that, assuming a 9 $M_{\odot}$ black hole and a 1.7 $M_{\odot}$ mass donor, it is very difficult, if not impossible, to create this system, without disrupting the progenitor binary. Also, the binary would have lost tens of solar masses during the process. Finally, the age of the system, as deduced by the age of HD 104901A puts strong constraints on the possible scenarios.

5. Conclusion

In *W Serpentis* binaries a common problem always returns: what is the nature of the, often undetected, mass accretor. Also in the studied BY Crucis binary this problem remains unsolved. Detecting the companion star is made very difficult by two things: the fact that it is hidden in an accretion disc, and its rapid rotation.

What can be learned from the spectra we presented is that mass transfer is still going on at present in BY Crucis. Since the accretor is not detected, the rate of accretion needs to be high in order to produce an extensive accretion disc. Mass transfer was non-conservative, as is clear from the fact that circumbinary matter is detected. The CAT/CES spectra, together with the UV-continuum, confirm that BY Crucis is not an edge-on system.

Many spectra we obtained are difficult to interpret, due to several factors. A first factor is the fact that we observe many lines closely packed together. Doppler shifts and broadening causes these lines to blend. If the lines get stacked on one another it is often difficult to determine the position of the continuum. A second factor is that we often observe different components of one line, formed in separate regions inside or outside the binary.

As to the history of the system, and linked to this topic the present nature of the companion, detailed computer simulations are needed to calculate possible progenitor binaries. In these simulations, however, many parameters are quite uncertain: how massive is the core of the star(s) at the onset of mass transfer?, how much mass was lost during the mass transfer?, is mass transfer caused by Roche lobe overflow or rather by a stellar wind?, what were the initial period, separation, eccentricity, etc.

In the light of these computations, BY Crucis is an important object of study. BY Cru is more constrained than many other interacting binaries, and certainly more than the other known *W Serpentis* stars, thanks to the two other stars in the multiple system HD 104901. Independent of observations of BY Crucis itself, which are always difficult to interpret due to its very nature, we are able to constrain distance and age of the system. These constraints limit the possible scenarios of formation significantly.

6. Future research

The next step in our analysis of BY Crucis is the comparison of the observed light curves and radial velocity curve of the supergiant with synthetic curves. The goal is to estimate values for parameters (e.g. dimensions and outer temperature of the accretion disc) that are presently still uncertain. It can then also be checked whether the low inclination is compatible with the light curves. Simultaneously, W Crucis will be analysed with the same light curve program and compared with the results obtained for BY Crucis.

Acknowledgements. Many thanks to H. Van Winckel, C. Aerts and P. Mathias for obtaining some of the CAT/CES spectra.

References

Daems K., Waelkens C., Mayor M., 1997, A&A 317, 823 (Paper I)
Houk N., Cowley A., 1975, Michigan Spectral Survey, Ann Arbor, Dep. Astron., Univ. Michigan, 1
Plavec M.J., 1980, IUE Observations of long period eclipsing binaries: A study of accretion onto non-degenerate stars. In: Plavec M.J, Popper D.M., Ulrich R.K. (eds.) Proc. IAU Symp. 88, Close Binary Stars: Observations and Interpretations. Reidel, Dordrecht, p. 251
Plavec M.J., 1985, From Algol to β Lyrae. In Eggeleton P.P., Pringle J.E. (eds.) Interacting Binaries, Reidel, Dordrecht, p. 155

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.