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On the visual binary υ Carinae

C. H. Mandrini★ and V. S. Niemela† ‡ *Instituto de Astronomía y Física del Espacio, C.C. 67, Suc. 28, 1428 Buenos Aires, Argentina*

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Summary. A spectral- and radial-velocity study of the components of the close visual binary system υ Carinae is presented. Our data show that the fainter star of this system is an early B star of spectral type B3–4IV, and that both components are located at a common distance of 400 pc, having a common age of 1.2×10^7 yr. Slightly different radial-velocity values are determined for the members of the system, indicating an eccentric orbit. We also find evidence that the supergiant A8Ib component has an outward expanding atmosphere.

1 Introduction

Observations from the *International Ultraviolet Explorer (IUE)* satellite have revealed many spectroscopic binaries consisting of an early-type star and a later type giant or supergiant companion (*cf.* Parsons 1981a, b, 1982). However, few such visual binaries are known (see e.g. Corbally 1984). The study of systems with these types of components, mainly visual binaries, is very important since they set valuable observational constraints to our current ideas about the evolution of massive stars.

Many visual binaries still lack accurate spectral classifications for each component, especially when their angular separations are small and the difference in magnitude between members is large. υ Carinae is a visual binary system whose components, υ Car A = HR 3890 and υ Car B = HR 3891, appear in *The Bright Star Catalogue* (Hoffleit & Jaschek 1982, hereafter the Catalogue) both classified as A8Ib. The angular separation between the components of this system is only 5 arcsec. To form a physical pair, as most commonly is the case for stars with such a small angular distance, the 3 mag difference between their apparent visual brightness suggested the need to revise the spectral type of the fainter component (υ Car B). Hurly & Warner (1983) found quite different colours for the components of υ Car, the fainter star being bluer than the brighter one. Subsequently, Corbally (1984) classified υ Car B as a B7III star from 120 Å mm^{-1} spectra on IIa–O emulsion, noting that slight contamination from the brighter component was present in the spectrum of the fainter one.

★Fellow of the CONICET, Argentina.
†Visiting Astronomer, Cerro Tololo Inter-American Observatory NOAO, operated by AURA Inc., under contract with the US National Science Foundation.
‡Member of the Carrera del Investigador Científico, CIC, Provincia de Buenos Aires, Argentina.

In this paper we present new spectral data that show v Car B to be an early B star of spectral type B3–4IV instead of B7III. We determine a common distance of 400 pc for both components of the visual binary. A comparison of their spectral types with numerical evolutionary tracks also indicates a common age of 1.2×10^7 yr. A radial-velocity study reveals slightly different values for both members of the system indicating an eccentric orbit. From our data, we also find evidence of an expanding atmosphere around the supergiant component of v Car.

2 The observations and results

As the components of v Car are very close together and their difference in magnitude is large, it is very difficult to record a spectrum of the fainter component without the contamination of the brighter one. That is why, we have obtained nine blue spectrograms of v Car B leaving v Car A behind the sky suppressor of the image-tube spectrograph of the 1-m telescope at the Cerro Tololo Inter-American Observatory, Chile. We have also obtained five blue spectrograms of v Car A. The spectrograms were recorded on IIIa–J emulsion, baked in forming gas, their dispersion is 45 Å mm^{-1} and they were widened to 1 mm. The plates were developed in D-19 together with the corresponding spot sensitometer intensity calibration plates.

On our spectrograms we find that the spectrum of v Car B is typical of an early B type star. We have compared our spectra with standard stars obtained with the same spectrograph, kindly loaned to us by Dr N. Morrell. From this comparison, we estimate the spectral type of v Car B as B3–4. Fig. 1 shows a tracing of its spectrum. The appearance of the Balmer lines is more similar to a main-sequence object than to a giant star, but since we observe the presence of a rather strong Mg II λ4481 line (see Fig. 1), we estimate that the luminosity class for v Car B may be IV.

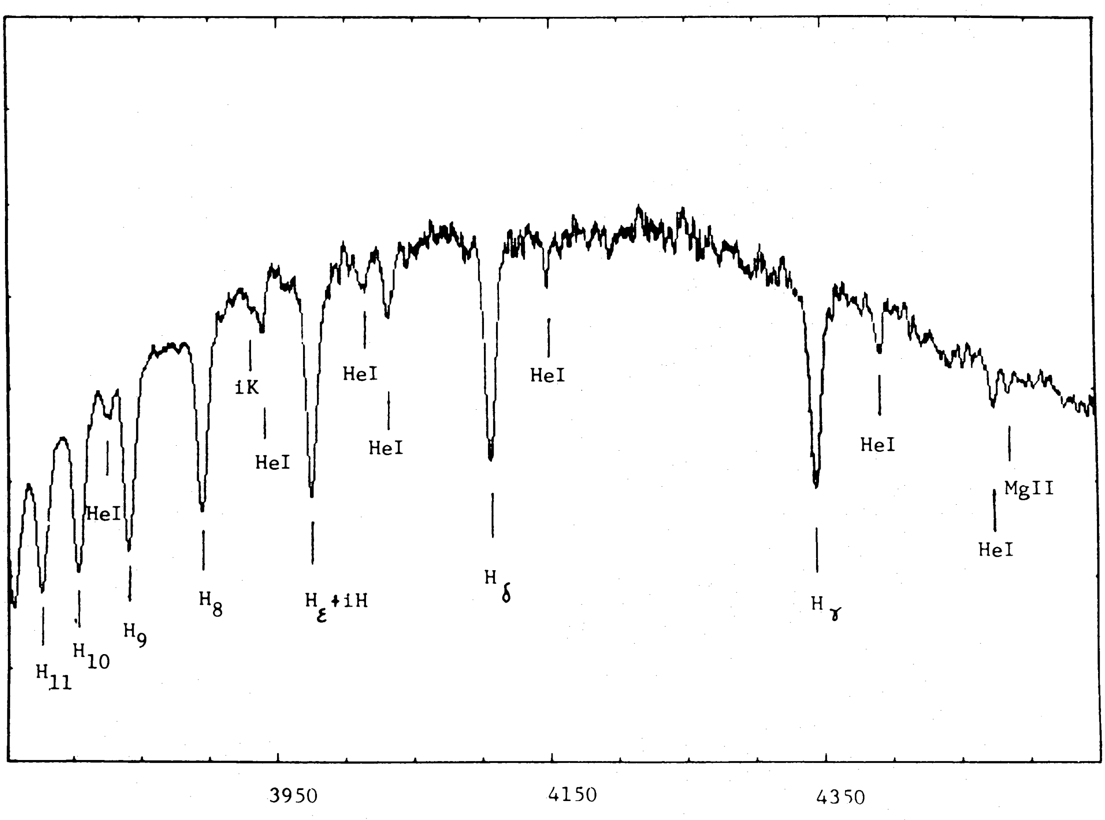

Figure 1. Intensity tracing of the spectrum of v Car B corresponding to plate E-4041.

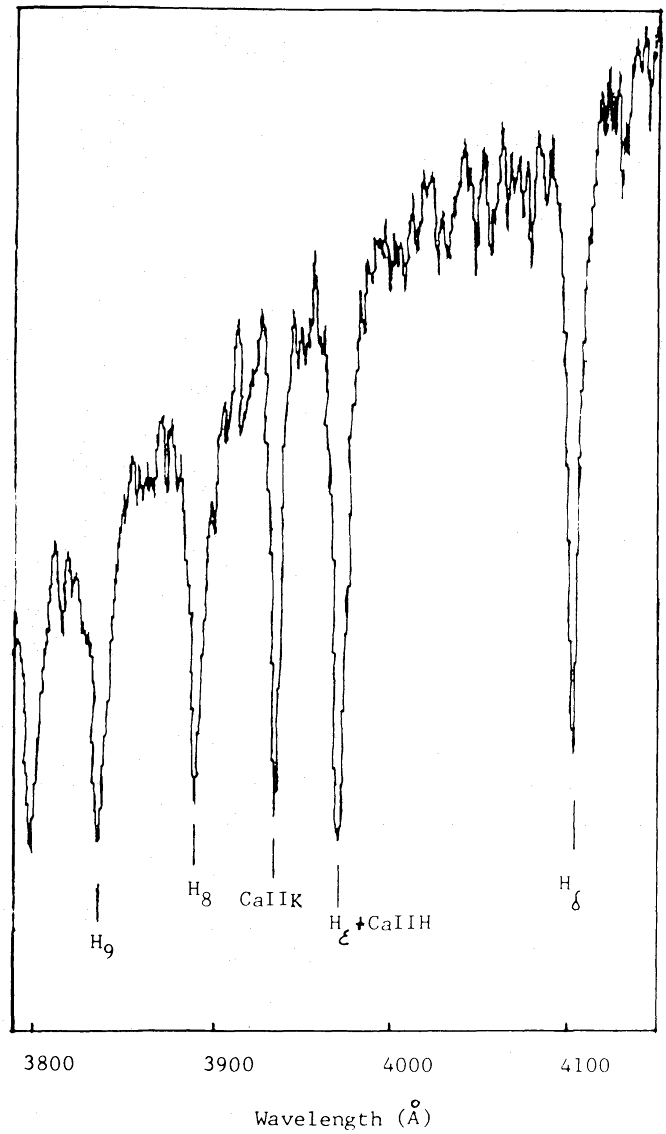

Figure 2. Intensity tracing of the spectrum of υ Car A corresponding to plate E-4968.

Regarding υ Car A, which Corbally (1984) classified as an A6Ib star, we observe that the intensity ratio between Ca II λ3933 and H I λ3970 corresponds well to that of an A8 star (see Fig. 2). Therefore, we consider that the classification given in the Catalogue, which agrees with our spectrograms, should be preferred.

With the value of absolute visual magnitude for a star of spectral type A8Ib (M_V(A8Ib) $= -5.1$) from Schmidt-Kaler (1982) and an apparent visual magnitude $M_V = 2.96$ from the Catalogue, we find a spectroscopic parallax of 409 pc for υ Car A. Considering that υ Car B is located at this same distance, from its $m_V = 6.03$ we obtain for this star $M_V = -2.03$. This value is in excellent agreement with the mean absolute visual magnitude corresponding to spectral types B3–4IV (Schmidt-Kaler 1982). Thus, undoubtedly the components of this visual binary are located at a common distance of about 400 pc from the Sun. Moreover, the distance that we have found from the spectral type shows that the trigonometric parallax of υ Car ($\pi = 0.027$ arcsec) in the Catalogue must be in error, since this would imply a distance to the system of only 37 pc.

In order to determine the radial velocities of the components of υ Car, the lines in the spectrograms were measured with the Grant oscilloscope comparator-microphotometer at the

Table 1. Herliocentric radial velocities (km s^{-1}) for υ Car A.

PLATE NUMBER	HELIOCENTRIC JULIAN DATE (2440000 +)	H I (*)	METALLIC LINES (*)	Sr II 4077
E-4036	4742.475	9 ± 2 (5)	16 ± 4 (10)	-20
E-4036	4742.477	19 ± 3 (4)	22 ± 4 (10)	-23
E-4968	5121.475	2 ± 5 (5)	9 ± 6 (8)	
E-4968	5121.478	1 ± 3 (5)	3 ± 4 (9)	-36
E-6254	5840.464	4 ± 5 (5)	12 ± 3 (2)	-40
MEAN RAD. VEL. VALUE		7 ± 3	13 ± 3	-30 ± 5

(*) The number between brackets indicates how many lines were included in each mean.

Instituto de Astronomía y Física del Espacio (IAFE), Buenos Aires. These data are shown in Tables 1 and 2 for the components A and B of the system, respectively.

Table 1 lists the radial velocities of υ Car A for each plate in the following way: the average radial velocity of the lines from the Balmer series (H9, H8, Hδ, Hγ and Hβ); the average radial

Table 2. Herliocentric radial velocities (km s^{-1}) for υ Car B.

PLATE NUMBER	HELIOCENTRIC JULIAN DATE (2440000 +)	HI + HeI (*)	He I 4471
E-4036	4742.481	4 ± 5 (4)	-37
E-4037	4742.485	-5 ± 4 (5)	-61
E-4041	4743.455	9 ± 12 (5)	-49
E-4045	4744.444	0 ± 8 (5)	-98
E-4045	4744.448	10 ± 4 (5)	-73
E-4051	4745.458	10 ± 4 (5)	-33
E-4051	4745.460	6 ± 9 (5)	-15
E-5970	5773.750	3 ± 6 (5)	-25
E-6254	5840.460	13 ± 8 (5)	-14
MEAN RAD. VEL. VALUE		5 ± 2	-45 ± 9

(*) The number between brackets indicates how many lines were included in each mean.

Table 3. Wavelengths used in the determination of radial velocities.

ELEMENT	WAVELENGTH (Å)	SOURCE
FeII	3814.121	2
H9	3835.386	2
H8	3889.051	2
CaIIK	3933.664	1–2
SrII	4077.714	2
HeI	4026.14	1
H_δ	4101.737	1–2
FeII	4178.855	2
FeII	4233.167	2
H_γ	4340.468	1–2
FeII	4351.764	2
TiII	4395.031	2
TiII	4443.802	2
HeI	4471.477	1
MgII	4481.228	1
FeII	4549.467	2
FeII	4583.829	2
H_β	4861.416	1

1) Petrie, 1953.
2) Moore, 1945.

velocity of: Ca II λ3933, Mg II λ4481, Fe II λ3814, λ4178, λ4233, λ4549, λ4583 and Ti II λ4395, λ4443 (this value appears in the second column under the title of Metallic Lines) and finally, the radial velocity for Sr II λ4077.

The radial velocity values of υ Car B are shown in Table 2 for each plate. Here the first column lists the average radial velocity of the lines from the Balmer series (H9, Hδ, Hγ and Hβ) and He I λ4026, while the second column corresponds to He I λ4471. We have not included H8 and Hε among the H I lines because, due to blends, they appear to have systematically more negative velocities in all the plates (H8 is blended with He I λ3888 and Hε with Ca II λ3968). The He I λ4009, λ4143 and λ4387 lines have not been included because they are too weak and therefore, their radial velocity values are not reliable. In all cases the errors listed are the mean errors. Table 3 shows the wavelengths used for the determination of the radial velocities.

3 Discussion

In our spectral analysis of the components of the visual binary system υ Car, we find that a classification of the fainter member (υ Car B) as a B3–4IV star describes better its spectrum; while we confirm the classification of A8Ib given in the Catalogue for υ Car A.

From the radial velocities of υ Car A given in Table 1, we note that Sr II λ4077 shows the most negative values; while the velocities corresponding to the H I absorptions are more negative than those from the metallic lines. Since Sr II λ4077 is a resonance line, and therefore it is probably formed in the outer part of the stellar atmosphere, its negative radial velocity (-30 ± 3) km s^{-1} points to the existence of an outward expanding atmosphere in the supergiant star. This is also consistent with the Balmer lines mostly arising in the envelope of the star (*cf*. Hutchings 1971); while the metallic lines seem to better represent the stellar radial velocity. It should be noted that the average radial velocity for the metallic lines $(+13\pm3)$ km s^{-1} is in excellent agreement with the value published in the Catalogue, namely +14 km s^{-1}.

We note from Table 2 that the radial velocities for υ Car B turn out to be somewhat more negative than those determined for υ Car A. At the above derived distance of 409 pc, the angular separation of 5 arcsec between the components of υ Car equals 2000 AU. If we assume that this corresponds to the maximum separation of the stars; and that both stars have normal masses, that is to say M(B3–4IV)$\sim 8\,M_\odot$ and M(A8Ib)$\sim 13\,M_\odot$ (Schmidt-Kaler 1982), we can estimate a circular orbital period of about 19.5×10^3 yr. With such a long period, we do not expect to see an appreciable difference in the radial velocities of the components due to orbital motion. Assuming an orbital inclination $i=90°$, we can estimate the semi-amplitudes of the radial velocity variations (K) of both components to be K(B3–4)=1.9 km s^{-1} and K(A8)=1.2 km s^{-1}. Then, from the observed radial-velocity difference of about 8 km s^{-1} (see Tables 1 and 2) between the components of υ Car, we must conclude that the orbit of this binary is eccentric.

As was first recognized by Struve (1929), the lines from the He I diffuse series in the spectra of B stars show marked asymmetries and the presence of strong 'forbidden' components due to the Stark effect. In the case of He I λ4471 this 'forbidden' component lies blueward the normal stellar component, and its presence in the spectrum of υ Car B can be inferred from the more negative radial velocities of He I λ4471 in Table 2.

Two stars at a distance of about 2000 AU certainly follow individual evolutionary paths. Therefore, if we use the log $T_{\rm eff}$ and log $L/L_\odot$ data corresponding to the individual spectral types of the components of υ Car (Schmidt-Kaler 1982) and compare them with numerical evolutionary tracks (e.g. Maeder 1981, figs 2 and 3); we find that the brighter component falls on a track corresponding to a star which left the main sequence as an O9–B0 object with an initial mass between 15–20 $M_\odot$. This is consistent with an evolutionary age of 1.2×10^7 yr for the system, and also with the fact that υ Car A (which is bolometrically 1 mag brighter than υ Car B) is the more evolved component.

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