REVISED WOLF-RAYET BINARY ORBITS AND NEW BINARIES

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Abstract. Revised orbits are presented for the double-lined binary WR+O systems HD 63099 (WR9) and HDE 320102 (WR97). The orbit derived for WR9 from OVI emission and HeII absorptions is considerably different from that previously published based on the CIVλ4658 emission line velocities. WR97 is found to have a period of 12.6 days and small minimum masses, probably due to a low orbital inclination. Two stars in our Galaxy, WR30a and WR70, and two in the Magellanic Clouds, Brey44 and AB7, show radial velocity variations of emission and absorption lines in opposite sense. Although no periods are yet available, preliminary values of the mass ratios can be estimated from the velocity variations.

Key words: stars: binaries – stars: Wolf-Rayet

1. Introduction and observations.

Binary stars with WR components provide us with fundamental information regarding the stellar masses. However, it has long been known (*cf. e.g.*, Smith 1967) that the emission line spectra of WR stars present many peculiarities, *e.g.*, variable line profiles, phase shifts between the velocity curves obtained from different lines, widely different velocity amplitudes for lines of different ions, etc. All this complicates the interpretation of the radial velocity curves, and obviously introduces large uncertainties in the values obtained for masses of stars in WR+OB binary systems. The fraction of known binaries among the stars with WR spectra is steadily increasing, but still most WR stars lack the necessary radial velocity information for the establishment of their binary status.

In this paper I will present new radial velocity data for two WR+O binaries with previous data, and stars with WR+O spectra which have no previous radial velocity determinations. The radial velocity determinations are mainly based on spectra obtained at *CTIO* with the Cassegrain spectrograph attached to the 1-m telescope, with some additional data obtained with the 2.1-m telescope at the *CASLEO* Observatory in San Juan, Argentina.

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2. Results and discussion

In the following each WR+O system is discussed individually.

2.1 HD 63099 (= WR9)

With the spectral types of the components as WC5+O7, HD 63099 is the WR+O binary system with the earliest WC type component in our galaxy which has a published orbit. A low mass ratio for the binary components was derived from the radial velocity curves of the broad CIII-IV λ4652 emission blend, and the mean values of the H and He absorption lines (Niemela *et al.* 1984). Because the emission lines of different ions may show radial velocity curves of different amplitudes, a new orbital analysis was performed based on the radial velocities of the OVI $\lambda\lambda$3811-34 emissions of the WC5 component and the mean of the HeII absorption lines for the O7 component (Niemela *et al.* 1994). The previously determined period of 14.305 days was adopted. In this period, the radial velocity curves of OVI emission and HeII absorptions suggest a circular orbit, as was the case for previous radial velocity curves (Niemela *et al.* 1984). A sine fit to the observations gives the orbital elements listed in Table I. Figure 1 presents the observed and calculated radial velocities of the OVI emission and HeII absorption lines.

The orbital elements listed in Table I are significantly different from those determined previously, mainly because the radial velocity curve of the OVI emission has much lower amplitude than that of CIII-IV emission. This is also the case for the WO+O4 binary AB8 in the SMC (Moffat *et al.* 1985). The mass ratio resulting from the present analysis, M(WC5)/M(O)= 0.63 for the components of WR9 is rather higher than the previous value 0.28.

TABLE I
Orbital Elements of WR9

parameter	HeII abs.	OVI em.
V_0 (km/s)	+31	-371
K (km/s)	77	123
T_0 (2440000+)	3519.4	3518.9
σ (km/s)	17	45
$a \sin i$ ($R_\odot$)	22	35
$M \sin^3 i$ ($M_\odot$)	7	5

2.2 WR30A

WR30a is a faint star, whose spectrum has been classified as WC4+O4, but no radial velocity information is available. We have obtained spectra of

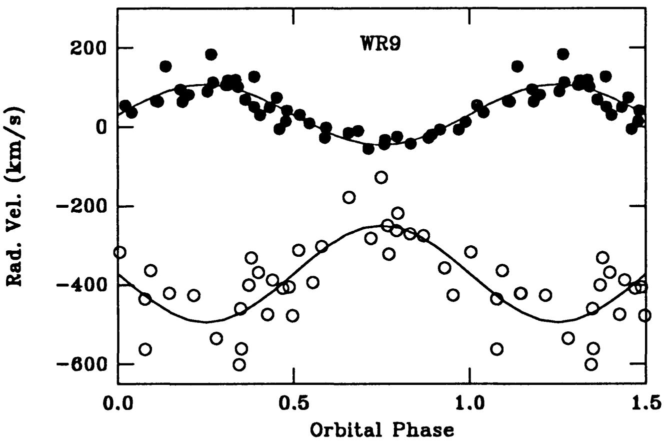

Fig. 1. Radial velocity variations of the HeII absorptions (filled cirles) and OVI emission (open cirles) in the spectrum of WR9. The curves represent the orbital fit from Table I.

WR30a in February 1992 and February 1994. The radial velocities of the CIV λ4658 emission show large variations between spectra obtained during consecutive nights. Therefore WR30a may be a short-period binary. However, our data are too few for a period determination. The absorption lines of the O4 component show a Balmer progression, indicative of a strong stellar wind. A plot of the CIV emission line velocities versus the HeII absorption

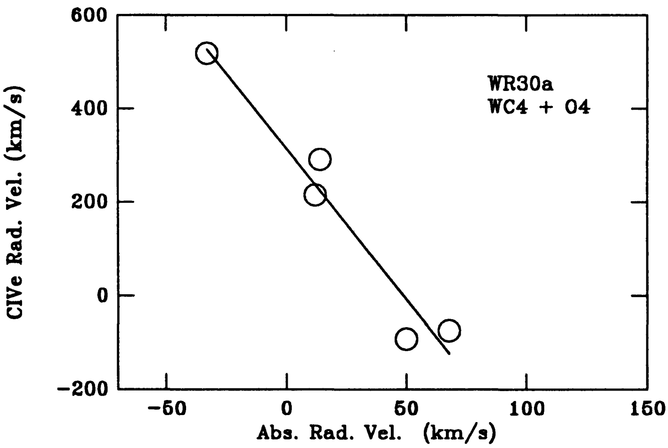

Fig. 2. The radial velocity of the CIV λ4658 emission plotted against the radial velocity of the HeII absorptions for WR30a. The line is a linear fit to the data.

line velocities from the available spectra is presented in Figure 2. It is clear

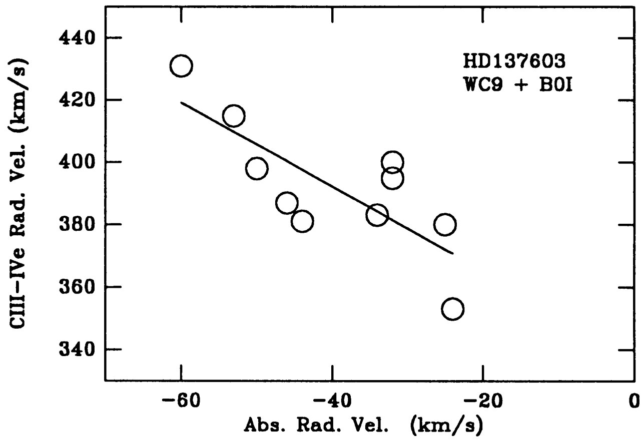

Fig. 3. The mean radial velocity, for each observing run, of CIII-IV λ4652 emission plotted against the radial velocity of the absorption lines for HD 137603. The line is a linear fit to the data.

from this figure that the emission and absorption lines follow opposite binary motion. A linear fit to the data shown in Figure 2 indicates a very low mass ratio, namely $M(\mathrm{WC4})/M(\mathrm{O}) = 0.15$. This may be a result of a spuriously enlarged radial velocity amplitude for the C IV emission due to line profile variations.

2.3 HD 137603 (= WR70)

HD 137603 has a spectrum of type WC9+B0I, thus being the latest type WC star in a binary. This star has shown variable IR emission (Williams *et al.* 1991), probably originating in colliding stellar winds of the binary components. No radial velocity orbit is available for this star, however. We have collected radial velocity data for HD 137603 from 1979 to 1984. The mean radial velocity for each epoch of observation of the C III-IV λ4652 emission is plotted against the velocity of the absorption lines in Figure 3. This figure shows that the absorptions and emission follow opposite binary motion. A linear fit to the data in Figure 3 indicates a mass ratio $M(\mathrm{WC9})/M(\mathrm{B0}) = 0.45$. The radial velocities for each observing run appear to be approximately constant, but differ from one run to another, suggesting that HD 137603 is a long-period binary (Niemela *et al.* 1994). Our radial velocity data would be compatible with a period of the order of 1200 days.

2.4 HD 37248 (= Brey 44)

HD 37248 is a WR star in the LMC with a spectrum of type WC4+O9. I have obtained spectra of this star during three different epochs. Here also

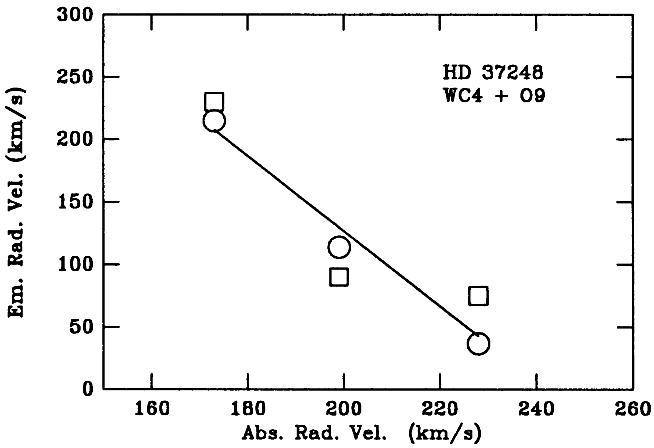

Fig. 4. Mean velocities of the emission lines of CIV λ4658 (squares) and OVI λ3811-34 (circles) plotted against the radial velocities of the absorption lines for HD 37248. The line is a linear fit to the data.

the radial velocity of the different spectral features seem to be constant during each observing run (typically about one week), but differ from one epoch to another. Therefore HD 37248 is probably also a long-period binary. The mean radial velocities, for each epoch, of the CIV and OVI emissions are plotted against the absorption line velocities in Figure 4. As can be seen from Figure 4, in the spectrum of HD 37248 the CIV and OVI emission velocity data seem to match well, following an orbital motion opposite to the absorption lines. A linear fit to the radial velocity data shown in Figure 4 indicates a mass ratio M(WC4)/M(O)= 0.33.

2.5 HDE 320102 (= WR97)

HDE 320102 is the only known binary in our galaxy with a WN type component classified as WN3. Our new spectral observations indicate a period of about 12.6 days for this binary (Niemela *et al.* 1994). The orbit appears to be approximately circular, a sine fit to the radial velocities of the absorption and emission lines of NV λ4603-19 and HeII λ4686 gives the orbital elements listed in Table II. Figure 5 shows the observed radial velocities and a preliminary orbital fit. The values of the minimum masses appear rather low, probably indicating a low orbital inclination. The mass ratio M(WN)/M(O)= 0.5 is similar to the WN4+O binaries. Indeed, in our spectra, the NIV λ4058 emission appears almost as strong as the NV λ4603-19 emissions, as can be seen in Figure 6. Therefore the spectral type of the WN component in HDE 320102 probably would be better classified as WN4.

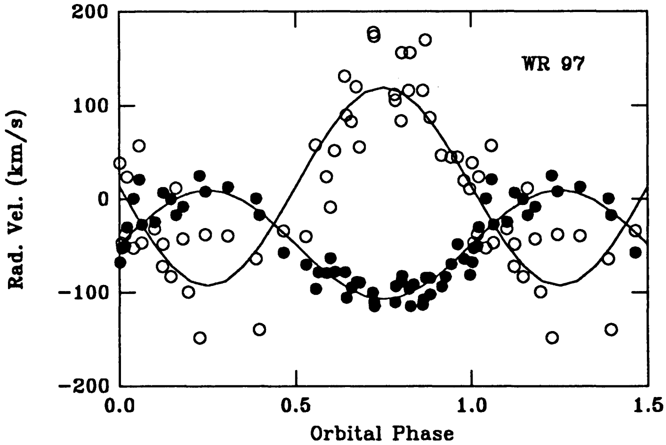

Fig. 5. Observed radial velocities of the absorption lines (filled circles) and NV λ4603-19 emissions (open cirles) folded in the period of 12.6 days. The curve represents the orbital fit from Table II.

TABLE II

Preliminary circular orbital elements of HDE 320102

Parameter	mean abs.	NV em.	HeII em.
V_0 (km/s)	-48	+9	-4
K (km/s)	58	111	107
T_0 (2440000+)	4893.8	4894.2	4893.0
σ (km/s)	10	27	29
$a \sin i$ ($R_\odot$)	14	27	27
$M \sin^3 i$ ($M_\odot$)	4	2	2

2.6 AB7 (= AzVi 336a)

AB7, located inside a hot gas bubble in the SMC, is the earliest WN type star in a binary system, as it has been classified as WN1+O6 (Pakull 1991). Radial velocities from photographic spectra have been published by Moffat (1988). We have observed this star during November 1988 and December 1990. Combining our data with the published values does not allow a consistent determinations of the binary period. A plot of our radial velocities of the absorption lines against the radial velocities of the HeII λ4686 emission, shown in Figure 6, clearly shows that the absorptions and the emission follow opposite orbital motion. A linear fit to the data in Figure 6, indicates a mass ratio M(WN1)/M(O)= 0.5, similar to the galactic WN4+O binaries.

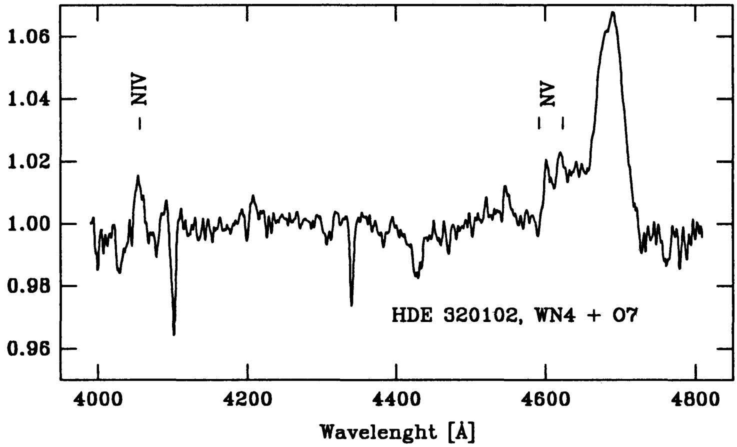

Fig. 6. Spectrum of HDE 320102

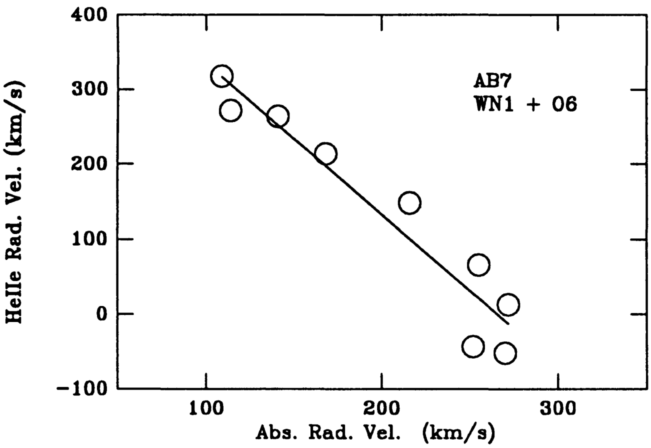

Fig. 7. The radial velocity of the HeII λ4686 emission plotted against the mean radial velocity of the absorptions for AB7. The line is a linear fit to the data.

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DISCUSSION:

Koenigsberger: Of the effects mentioned by Tony Moffat which lead to profile variations, we must be particularly careful with atmospheric eclipses, which will distort the lines which are susceptible to absorption, and lead to fictitious redshifts.

Moffat: A few years ago, Massey et al. published a study of the shallow eclipsing system CX Cep (they had WN5 + 08). They also had only a few data points, and they plotted RV (em) vs RV (abs). This led to a mass ratio, M_{WR}/M_o, that in fact was quite different from the value that was obtained from a more definitive study with many (some 60) CCD spectra by Lewis et al. (ApJ 1993). So caution should be exercised when deriving mass ratios from the slope of RVs based on only a few data points.

Niemela: Certainly, but if we don't know yet the period, the radial velocity plots are the only way to estimate the binary status and a preliminary value of the mass ratio, which depends on the lines used for the radial velocity study.