A SPECTROSCOPIC SEARCH FOR DUPLICITY AMONG A COMPLETE SAMPLE OF NORTHERN GALACTIC WOLF-RAYET STARS

R. Lamontagne* and A.F.J. Moffat*
Département de physique, Université de Montréal and
Observatoire astronomique du mont Mégantic

ABSTRACT. We have analysed new spectroscopic observations of 22 population I WR stars in a sample defined by b<12.5 mag, $18^h<\alpha<6^h$, $\delta>-30^o$. This completes the search for orbital duplicity among all of the 30 pop I WR stars contained within these limits. We thus have an unbiased data base in a volume segment bounded by a distance of 3-4 kpc for WNE and WC stars ($\overline{M}_V \simeq -4.5$), and 4-5 kpc for WNL stars ($\overline{M}_V \simeq -6.5$). Although more observations are still needed in some cases, we have found several new binary systems. Some of these are low-amplitude, single-line binaries, often with runaway velocities and/or large separations from the galactic plane. We consider them to be candidates for a WR + collapsar stage, as originally predicted by Tutukov and Yungelson (1973) and de Loore and De Grève (1975).

I. INTRODUCTION

Since their discovery in 1867, the problem of duplicity among Wolf-Rayet stars has been a major one. Several years ago all WR stars were believed to be components of close binary systems. This belief has now been put into considerable doubt with well-observed, constant velocity stars like HD 93162 and HD 93131 (Moffat 1978; Moffat and Seggewiss 1978; Conti et al. 1979). In a recent series of papers, Massey has analysed a number of spectroscopic observations and estimated the frequency of binary WR systems to be less than 50% (Massey 1980b; 1981). Unfortunately, this estimate is not based on a complete sample but rather on an extrapolation of some selected objects (WR stars with absorption lines).

II. BINARY FREQUENCY

In 1978, we initiated a survey of 30 galactic WR stars. The limits imposed for practical reasons to the sample were $18^h<\alpha<6^h$, $\delta>-30^o$ and b<12.5 magnitude. More than 450 spectra were obtained by the authors at Kitt Peak National Observatory, Dominion Astrophysical Observatory and l'Observatoire astronomique du mont Mégantic. All the spec-

* Visiting Astronomer, Kitt Peak National Observatory, which is operated by AURA Inc., under contract with the National Science Foundation.

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 283–287.

tra were taken at moderate dispersion (43 - 78 Å mm^{-1}) on III a-J or IIa-0 plates, some with an image-tube. They were analysed using a PDS machine in the photographic density mode. Among the 30 stars of the survey, 8 were WC, 15 were WNE (WN 2-6) and 7 were WNL (WN 7-9). Seven stars have previously well-studied orbits; we have no new data for these.

The maximum binary frequency that one might expect in such a sample can be estimated following a few simple hypotheses:

1. All O-stars become WR-stars after mass loss via either a stellar wind or Roche lobe overflow (RLOF).
2. There are two stages of WR binary: WR + OB and WR + compact star (WR + c) (Tutukov and Yungelson 1973; de Loore and De Grève 1975). The WR component was the original primary in the first case, secondary in the latter.
3. All WR + OB systems become WR + c systems.
4. The two WR-stages last equally long (de Loore 1981).
5. The O + c stage is relatively short-lived (de Loore 1982) and we neglect it here.

If one knows the fraction, x, of binary O-stars then one can evaluate the maximum fraction, y, of binary WR-stars to be $y = 2x/(1 + x)$. Garmany, Conti and Massey (1980) have found, after an exhaustive study, that the fraction of binary O-stars is 36%. With this value for x we get a maximum binary frequency of WR-stars of 53%.

In our sample of 30 stars, there are eight WR + OB systems, five WR + compact star candidates and ten probably single WR-stars. For the remaining seven stars we still need more observations. We can assume that among our sample all the WR + OB systems have been found because they are easier to detect, usually exhibiting large velocity amplitudes in the emission lines. We also assume, to be consistent with our hypothesis concerning the relative fraction of WR + OB and WR + c stars expected, that among the stars for which more spectra are required, there will be ∿ three WR + compact star candidates to give us a total of eight WR + compact systems. Our observations would thus give 16 binary systems out of 30 stars, or a maximum frequency of 53%. A similar calculation for WR stars of similar magnitude in the remaining part of the sky in the southern hemisphere (using the catalogue of van der Hucht et al. 1981), gives 22 binaries out of 40 WR stars (frequency of 55%), but seventeen stars still remain to be studied in the present magnitude range.

III - WOLF-RAYET + COMPACT STAR CANDIDATES

Among our sample we have found two new binaries. They are most interesting because they permit us to complete the study of all but one WNL (=WN7-9) star brighter than 12.5 mag in the galaxy. These two systems are: 209 BAC (WR124), a WN8 star with a very high peculiar radial velocity and moderately high distance Z from the galactic plane, and HD 177230 (WR123), also a WN8 star, with very high Z. These two stars are candidates for the WR + c stage. The detection of such systems with low mass companions is very difficult because the radial velocity amplitudes are very low. This problem is less serious for the narrow-line WNL stars. To reduce the noise, we have calculated the mean velocity from several emission lines on each plate. We have then compared the internal and external σ's for several WNL stars. Table 1 summarizes the pertinent information for 5 WNL stars of our sample.

From Table 1, one can see that both 209 BAC and HD 177230 are far from the galactic plane in contrast with the other three stars, whose separations correspond to the mean for extreme population I (∿50-100 pc). Also, the external standard deviations of these two stars are twice their internal deviations. It is tempting to suppose that the recoil of a supernova explosion in a binary system has "kicked" these two stars out of the galactic plane and that they now could be binary systems with a low-mass, probably neutron-star companion. We have looked for binary motion in the radial velocities of those two stars, with the following results:

IV. 209 BAC

An F-test on $(\sigma_{ext}/\sigma_{int})^2$ in Table 1 shows that this star is variable at the 99% level. A period search using a single sine-wave fit has been applied to the mean radial velocities (after subtracting off the mean for each line and each observatory) of 209 BAC. The best period found was 2.3583 ± .0002d. The KPNO photometric data from 1979 also showed a period near $2^d.4$. A circular orbital solution resulted in the following mass function: $f(m) = 5.0 ^{+3.6}_{-2.4} \times 10^{-4}\ m_\odot$. The standard deviation (O-C) after the fit is 8 km s^{-1}, insignificantly larger than the internal deviation. Figure 1 shows the radial velocity data with the orbital solution (a) and photometric data (b). One can see that when the WR star is in front (phase zero) the light curve passes through a minimum, i.e. the WR star (or more likely its envelope) must be occulting the secondary object.

V. HD 177230

An F-test again shows high probability (99.9%) of intrinsic variability of the radial velocities. In contrast, the three remaining stars in Table 1 have low (<60%) probability and are likely stars of constant radial velocity. The same period-search technique was applied to the data of HD 177230 and yielded a period of 1.7616 ± .0002d. A circular orbital solution led to $f(m) = 1.9 ^{+0.9}_{-0.7} \times 10^{-3}\ m_\odot$. Again, the standard deviation (O-C) after the fit was 9 km s^{-1}, similar to the internal deviation. Figure 2 shows the data with the orbital solution. In Figure 2b we have plotted our He II 4686 radial velocities (circles) and those of Massey (1980a), to show that they are also compatible with Fig. 2a, even though Massey in his paper claimed that HD 177230 was probably not a binary system.

V. CONCLUSIONS

Although we have found no new WR + OB binaries in the complete sample, our new data have revealed at least two WR + c candidates, both of type WN8. Unlike three other probably single stars of type WN7, 8 and 9, they are situated far from the galactic plane, probably as a result of the kick from a supernova which resulted in the present compact companion.

The binary frequency in our sample appears to be close to the maximum allowed if all massive O-stars become WR stars.

Table 1: Data for 5 WNL stars

WR	Name	Spectral type	z(pc)	σ_{int} (km s^{-1})	σ_{ext} km s^{-1})	σ(O-C)
108	HDE 313846	WN9	-59	8	10	-
123	HD 177230	WN8	-824	8	16	9
124	209 BAC	WN8	±264	6	11	8
156	MR 119	WN8	+71	5	6	-
158	MR 122	WN7	+9	9	12	-

Notes: Spectral types and distances from galactic plane are from van der Hucht et al. (1981) and Hidayat et al. (1981) except WR 108 for which we have taken the intrinsic parameters for a WN8 star. 209 BAC also has a runaway velocity.

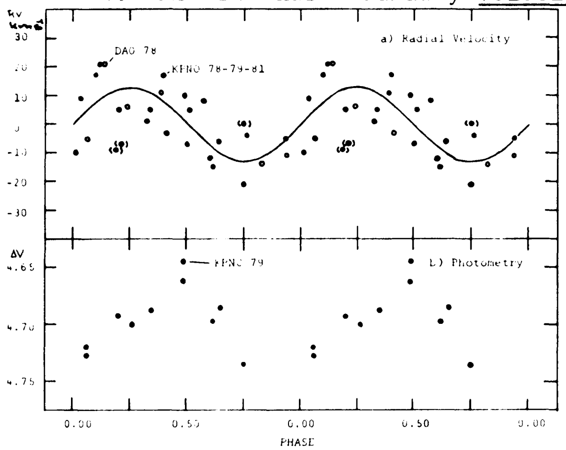

Fig. 1 OBSERVATIONS OF 209 BAC.

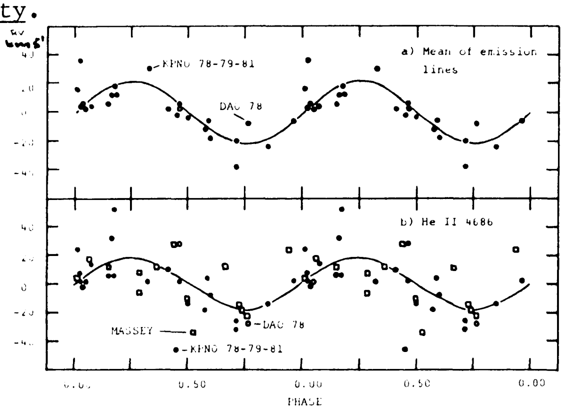

Fig. 2 RADIAL VELOCITIES OF HD 177230.

REFERENCES

Conti, P.S., Niemela, V.S., Walborn, N.R. 1979, Ap. J., 228, 206.
de Loore, C., De Grève, J.P. 1975, Ap. Sp. Sci., 35, 241.
de Loore, C. 1981, IAU Colloq. No. 59, Effects of Mass Loss on Stellar Evolution, eds C. Chiosi & R. Stallio, Reidel, Dordrecht.
de Loore, C. 1982, this symposium.
Garmany, C.D., Conti, P.S., Massey, P. 1980, Ap. J., 242, 1063.
Hidayat, B., Supelli, K., van der Hucht, K.A. 1981, preprint.
Massey, P. 1980a, Ap. J., 242, 638.
Massey, P. 1980b, Doctoral Thesis, Univ. of Colorado.
Massey, P. 1981, Ap. J., 246, 153.
Moffat, A.F.J. 1978, A. & Ap., 68, 41.
Moffat, A.F.J., Seggewiss, W. 1978, A & Ap., 70, 69.
Tutukov, A.V., Yungelson, L.R. 1973, Nauchn. Inform., 27, 3, 58, 70, 86.
van der Hucht, K.A., Conti, P.S., Lundström, I., Stenholm, B. 1981, Space Sci. Rev., 28, 227.

https://doi.org/10.1017/S0074180900028989 Published online by Cambridge University Press

DISCUSSION

Massey: I'm not quite sure I understand the logic of your introductory remark. If you start with a sample of stars for which the binary frequency is 36% (O-type stars) and assume that the sample of WR stars is all descended from these, how do you get 50% ? Is this because you have two WR stars for the binaries ?
The second question concerns HD 177230. At 10 Å/mm we saw no radial velocity variations greater than 15 km/s; the velocities of NIII and HeII were not correlated. Yet you find a very significant value for your f-test from lower dispersion data. Any comment ? At a lower dispersion your systematic (non random) errors will be larger in terms of km/s; possibly this accounts for the discreancy. What do your velocity standards show ?

Lamontagne: 1) This estimate is very sensitive to the lifetime of each stage in the evolution of a massive close binary system (a. OB+OB, b. WR+OB, c. compact+OB, d. compact+WR). Since c. is unlikely to be relatively short (de Loore 1981), we will see proportionally fewer O-binaries.
2) We have reduced the noise in our data by averaging the velocities of the best emission lines available (medium to strong, symmetric lines); those were HeI 3888, 4024, 4471; HeII 4100, 4200, 4338, 4541, 4686, 4859; NIII 4640; and NIV 4058. With this technique we have been able to obtain a plate-to-plate dispersion of the mean velocity of about 6 to 10 km/s for "single" WNL stars, and also for the WNL+compact suspects after fitting an orbit, i.e. O-C's. Taking 4058 alone, your published data show the same periodicity and amplitude as ours. NIII 4640, being wider shows more scatter.

Maeder: The automatic doubling of the observed number of binary WR stars to account for those stars with compact companions is a generous procedure for binary WR stars, but a hazardous one. A fraction of binary systems is disrupted as suggested by the existence of runaway stars. Thus we should try to estimate this fraction and until this is made the doubling procedure should be considered as giving only an upper limit to the frequency of WR stars.

Lamontagne: The existence of runaway stars in general does not necessarily imply the disruption of a large fraction of massive binaries, where one expects the less massive (WR) component to explode as a SN. In our binary statistics of WR stars we have not merely doubled the WR fraction just because there are two WR phases; it is really the probably short duration of the OB+c stage which increases the expected WR binary frequency relative to the O-type binary frequency.