THE HYDROGEN/HELIUM RATIO ON THE SURFACE OF WOLF-RAYET STARS

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As yet there have been few detailed analyses of Wolf-Rayet (WR) emission line spectra. Such analyses must certainly take account of line transfer in a spherically extended, expanding medium, a problem not yet completely addressed in the complexity of WR envelopes. However, visual examination of optical spectra suggests real differences in line strengths among the Balmer and Pickering series lines in WN stars. If hydrogen is present, the Balmer lines will be stronger than the adjacent Pickering lines of ionized helium; if hydrogen is weak or absent, then there will be a smooth transition in intensities along the Pickering series with no additional contribution from the Balmer lines at alternatively blending wavelengths (Underhill 1967).

Smith (1973) demonstrated a substantial difference in behavior between the "late" WN stars, those of types WN7 and WN8, and those of types WN5 and WN6, in this Balmer/Pickering alternation. In the former groups, a Balmer contribution is easily seen; in the latter, no substantial amount of hydrogen seems to be present. Smith concluded this was due to real abundance differences. However, Underhill (1973) claimed that the observed behavior could as well be due to a difference in ionization state between WN5, WN6 types and late WN stars, and abundance anomalies could not be deduced from such data. Model calculations supporting either claim have not yet appeared, but it should be noted that already Smith showed that in at least one WN star of even more advanced ionization state, type WN4, a Balmer contribution was readily apparent. This makes claims of an ionization effect in WN5 and WN6 stars more difficult to support. The matter has thus rested until now.

Before proceeding further we wish to state categorically that we believe the spectral sub-classes among the WN (and probably WC) types certainly represent a sequence of ionization but that they may not represent a similar sequence of effective temperatures, nor of evolution. What we will show here is that among WN stars of the same ionization, there exist substantial differences in the Balmer/Pickering decrement.

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C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 311–314.

https://doi.org/10.1017/S0252921100094951 Published online by Cambridge University Press

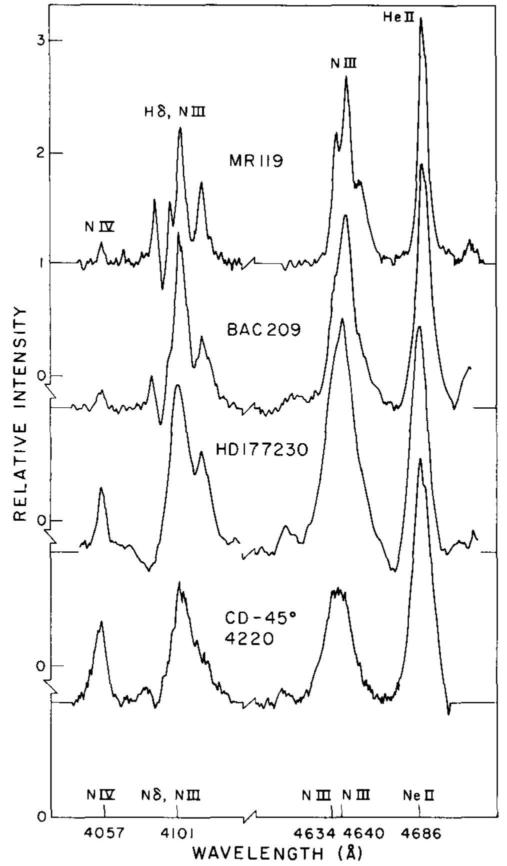

Fig. 1. Montage of spectra of four WN stars showing the nitrogen ions. There is a smooth, but small, progression in increasing ionization from top to bottom. The star CD-45° 4220 is type WN7; the others are classified as WN8.

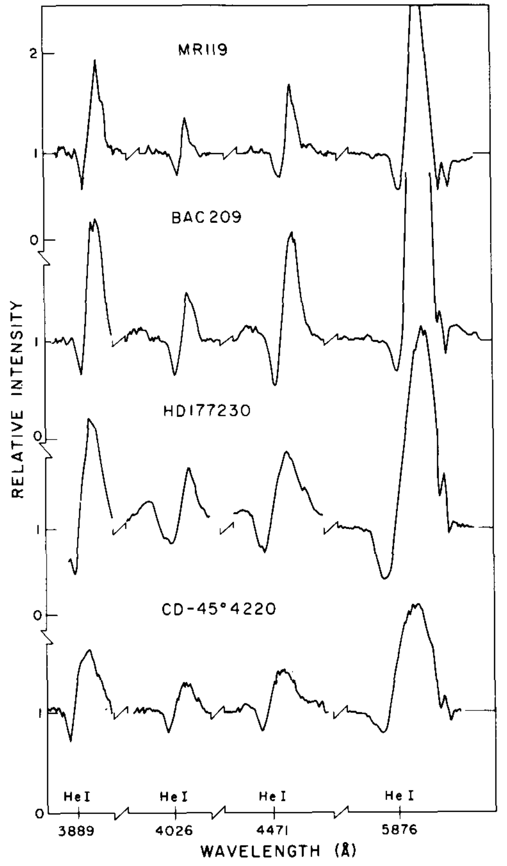

Fig. 2. Montage of spectra of the same four stars as Fig. 1 showing the He I sequence, there is a smooth, but small, progression in line strengths and widths.

The spectra we will show have been obtained at the cassegrain foci of the 4m telescopes either at KPNO or CTIO. These representative spectra were drawn from a much larger body of data on galactic WR stars which will be discussed elsewhere. For this paper we have deliberately picked four stars with very similar spectra classes.

In Figure 1 we show a montage of spectra of the nitrogen ions. The type is given primarily by the ratio of N III λλ4634,4640 to N IV λ4557. The line widths are slightly different from star to star but within a spectrum similar from ion to ion, thus indicating that the lines are formed throughout a similar region of the stellar envelope in each case. In Figure 2 we show a similarly arranged montage of He I spectra. These lines show a smooth progression from narrower to

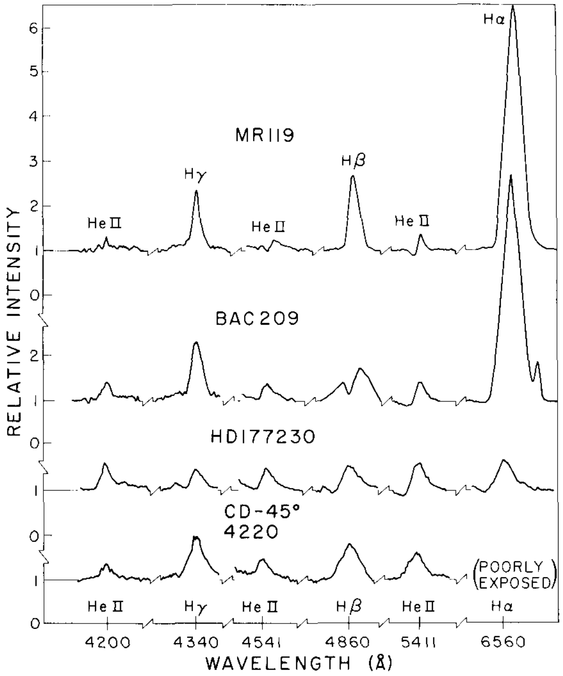

Fig. 3. Montage of spectra of the same four stars as in Figs. 1 and 2, showing the Balmer/Pickering sequences. HD 177230 shows no evidence of a Balmer contribution whereas the other stars do so. By inspection this cannot be an ionization effect and must represent a real hydrogen abundance difference.

wider width but in a given star have similar widths to each other and to the nitrogen ions. The P Cygni appearance of these lines is also a spectral type indicator among WN7 and WN8 stars. Finally, in Figure 3 we show a similarly arranged montage of the Balmer/Pickering lines. We now see that in HD 177230, in contrast to the other three stars there is a smooth progression along the Pickering sequence with no contribution by the Balmer lines.

The interpretation of these results in terms of a real difference in the hydrogen content is straightforward and unambiguous. The result that WN stars have different amounts of hydrogen present has interesting consequences for massive star evolution. We believe that mass loss by a stellar wind must play a major role, so as to produce stars with different degrees of "stripping." This is further support of the stellar wind evolutionary "scenario" outlined by Conti (1976).

This work was supported by National Science Foundation Grant AST79-18388.

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DISCUSSION

SAHADE: I was glad to hear that now you say that the spectra of WR stars display a spectrum that describes the stellar wind. Now if that is so and if the extended envelopes of WR stars is stratified and each layer is characterized by different physical parameters, I wonder how could you talk about abundances before you are able to describe the physical conditions of each layer of the extended envelope.

CONTI: The point of showing these spectra was to indicate that stars with otherwise similar nitrogen spectra, and HeI spectra, have different Balmer/Pickering decrements. The fact that the line widths of all these lines are similar suggest they are formed throughout appreciable, and similar, region in the stellar wind (envelope). I don't see how this can be explained by ionization or stratification effects. An interpretation in terms of different H/He is straightforward and un ambiguous.

MOFFAT: The evidence for a larger-than-usual H/He ratio in the hotter WN-stars is, based on the presence of upper Balmer absorption lines, claimed to arise in, or close to, the WR photosphere, which is visible below a relatively thin expanding envelope. In the case of HD 193077, it now seems that the narrow, moderately strong emission line of NIV 4058 shows periodic behaviour in radial velocity, indipendently from three sources, including Massey (1980), with P = 2.3240 days. Assuming this to be due to a circular orbit, the semi-amplitude is $K = 16$ Km s^{-1}. In addition, the emission lines NIV 4058 and HeII 4686 show long-term trends in radial velocity, possibly in antiphase with the absorption lines. Thus there appears no reason to suppose HD 193077 to have anomalous H/He: we may be seeing a triple system in which the absorption lines come from a widely separated OB-star. The close object may be compact like that conjectured for the single-line binary HD 50896.

CONTI: I would like to say that I don't believe that you have established an orbit for HD 193077. The scatter in the data is very large; a constant velocity is consistent with the errors. In any case, the emission spectrum of HD 193077 indicates a presence of hydrogen, since there is a Balmer - Pickering decrement.

MONTMERLE: What further steps are needed to obtain an actual number for the H/He ratio on the outer parts of WR star?

CONTI: These lines are optically thick, hence one has to use an envelope model. The physical conditions in the WR envelopes are not understood. The numbers need to come from a self-consistent treatment of line transfer in a spherically extending, expanding envelope.