H/He RATIOS FOR WN STARS IN THE LMC AND THE GALAXY

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The chemical abundances of hydrogen, helium, carbon, nitrogen, and oxygen in the winds of W-R stars bears directly on the problem of their evolutionary stage. The commonly held view that W-R stars are highly evolved objects has been based upon the apparent deficiencies of H in their envelopes and the enhanced strengths of CNO lines in the two sequences WN and WC (e.g. Gamow 1943). The picture that emerges is one in which many W-R stars are in the helium burning phase with the WC types more evolved than the WN stars. For this reason it is important to estimate the H content of as many WR stars as possible.

In the visible, most of the He II lines are due to the Pickering series (n-4). Due to intrinsic broadening, members of this series with even principal quantum number are blended with the H I Balmer lines (n-2). Qualitatively, the presence of hydrogen is shown by the enhanced fluxes measured for the even Pickering series over those for the odd series. Castor and Van Blerkom (1970) and Smith (1973) have applied this method quantitatively to a few galactic W-R stars using an optically thin approach, while Willis (1980) and coworkers have extended it to six stars in the Large Magellanic Cloud (LMC). The results invariably show that H is well below the cosmic abundance in many cases; H/He ratios vary from about 1-2 down to 0 compared to a normal value of 10. Though there are significant problems with using this Pickering decrement we have utilized it to find H/He ratios for 21 WN stars in the LMC, and 38 stars in the Galaxy. We have additionally extended the analysis to include the derivation of the H/He ratio if the lines are optically thick.

Figure 1 shows representative profiles for both stars that appear to have H (left) and those that do not (right). It is clear that the n=8 line is stronger in some stars thus indicating the contribution of H to their spectra. This figure also shows that stars of similar spectral type can have apparently differing quantities of H, and further that some early WN types have hydrogen while some later types do not.

Equations (1) and (2) relate the fluxes of the H+He lines to the fluxes of the pure He lines (at a particular wavelength) for the

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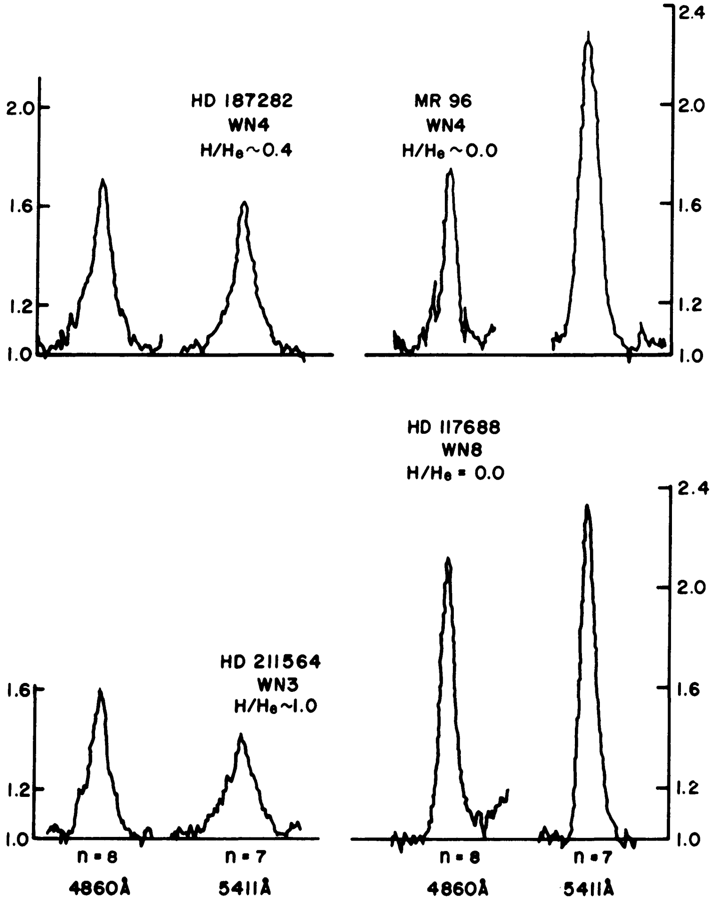

Figure 1. Sample line profiles comparing odd and even Pickering series members in some WN stars with and without H.

optically thin and optically thick cases respectively. Equation (1) results from arguments presented by Castor and Van Blerkom (1970), while the derivation of Equation (2) comes from Massey (1980):

$$\frac{F(H+He)}{F(He)} = \left[\frac{N(H^+)}{N(He^{++})} + 1\right] \quad \text{(thin)} \tag{1}$$

$$\frac{F(H+He)}{F(He)} = \left[\frac{N(H^+)}{N(He^{++})} + 1\right]^{2/3} \quad \text{(thick)} \tag{2}$$

where we have made the usual assumptions including: (1) spherical symmetry, (2) the ratio of atomic parameters ≈ 1, (3) the departure coefficients ≈ 1, and (4) the ionization potentials out of the upper levels are small compared to kT_e.

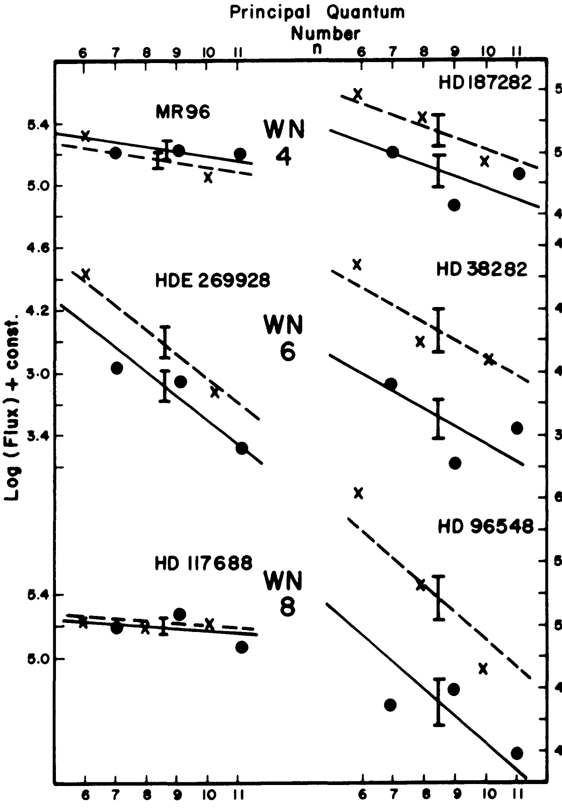

Figure 2. Fluxes of He II Pickering lines vs. n. The presence of H is suggested by the enhancement of even numbered lines.

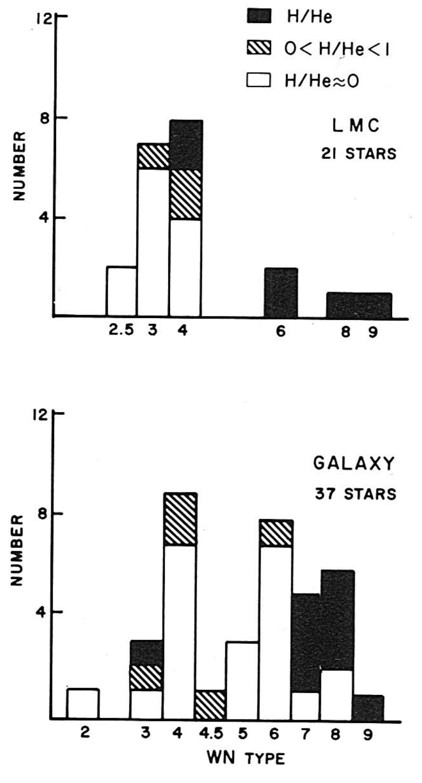

Figure 3. Correlation of H/He ratio with spectral subtype for WN stars in the LMC and the Galaxy.

Microphotometer tracings of spectra taken by PSC at Kitt Peak and Cerro Tololo Observatories were used to determine the equivalent widths for our sample of stars. The continuous energy distribution for each is necessary to convert the widths to line fluxes; at the moment this information is not available. For some of the stars in the LMC we used the photometric colors of Smith (1968a,b) to approximate the continua. For the other stars in the LMC and the Galaxy we chose representative continua from those given by Smith and Kuhi (1981). Once the fluxes were determined, we calculated the decrement by fitting straight lines through the even and odd members of the Pickering series separately. Sample fits are shown in Figure 2 where the dashed lines represent the fits for the even members (crosses), and the solid lines represent the fits for the odd members (dots). Most of the fits were found using data from the lines n=6 to n=11. For some (in the LMC) we used data for lines n=9 and higher.

We further adjusted the ratio of H/He thus determined by attempting to account for some of the problems inherent in this approach (e.g. the problem of further blending of some of the lines with other species, particularly N III at λ4097). Our tentative results are shown in Figure 3 in the form of a bar graph grouping the stars by limits on the hydrogen content. Contrary to previous works we have found a few stars which appear to have H/He > 2.0; we would not be surprised at all to find that for some it may approach a significant fraction of the cosmic H/He abundance. As a whole the later types appear to have more cases showing some hydrogen than the earlier types, though for WN8 and WN9 stars the fact that the major form of He might be He^{+} rather than He^{++} may change the results for them somewhat. We have estimated the effects of this lower ionization in these late types and feel that for stars where the He I line λ4471 is of roughly the same strength as He II λ4542 then our derived value is probably correct to better than 50%. The fact that a significant number of earlier WN types show some hydrogen also argues against an ionization effect. There must, therefore, be some real differences in hydrogen content among the WN stars.

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