THE FORMATION OF NITROGEN AND CARBON LINES IN HD 50896(WN5)

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1. INTRODUCTION

Although considerable progress has been made in understanding Wolf-Rayet (WR) stars, the basic mechanisms for producing the nitrogen and carbon emission lines, which characterize a WR's spectrum, are unknown. To determine the mechanisms giving rise to these lines we are currently studying the formation of N and C emission lines in the WN5 star HD 50896. As a basis for our investigation we use a model with -

R_c(core radius)=2.5$R_\odot$
$\dot{M}$(mass loss rate)=5.0x10^{-5} $M_\odot$/yr
L=1.0x10^5 $L_\odot$
T_{wind}=30000K
Wind Velocity(HeII emitting region) < 1800 kms^{-1}

These parameters were previously found to reproduce both the continuous energy distribution of HD 50896, and the HeII emission lines, seen in its spectrum (Hillier 1983). The bulk of the continuous flux is emitted in the region 228Å < λ < 912Å, and is characterized by a very high effective temperature (> 60000 K).

Simplifying assumptions used in the N and C models include -

(i) Radiation field determined from He and H model.
(ii) No Auger ionizations, or dielectronic recombinations.
(iii) Multiplets are treated as a single line in computing the source function but the multiplet structure is taken into account when computing the line profiles. Individual fine structure states within each term are assumed to be populated according to their statistical weights.
(iv) Sobolev approximation (found to be adequate).

2. CIV LINE FORMATION

In WN stars the CIV spectrum is primarily represented by the CIV(2p-2s) resonance doublet at 1549Å and the CIV(3p-3s) doublet at 5805Å. To

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interpret the CIV spectrum we used a nine level CIV atom ($n \leq 4$). We find the following :

(i) The C ionization structure changes rapidly with radius (Figure 1) with the ionization balance primarily maintained by photoionizations from the 3p level in equilibrium with recombinations to all levels.

(ii) The CIV(3p–3s) doublet is produced by continuum fluorescence via the 3p–2s doublet at 312Å. Fluorescence from the 2p state to the 4d level followed by decay to the 3p level is also important. This latter process becomes more significant as the density increases, and as the C abundance increases. Eaton, Cherepashchuk, and Khaliullin (1984), have also recently recognized the importance of continuum fluorescence in the winds of Wolf-Rayet stars.

For a C/He abundance of 4.0×10^{-5} the theoretical CIV(3p–3s) doublet (Figure 2) is in fair agreement with observation. The line strength is sensitive to C abundance but a change in stellar luminosity from 1.0×10^5 to 5.0×10^4 caused less than a 30% decrease in line strength. This is due to the reduction in luminosity causing the ionization structure to change so that $N_{CIV}/N_{CV} = 1$ at larger electron densities where scattering from the 3p–2s, and in particular, the 4d–2p transitions are more efficient.

(iii) The resonance doublet at 1549Å is primarily produced by collisional pumping from the ground state and consequently is sensitive to the local electron temperature. The strength of the line is dependent on both the C abundance and the star's luminosity. For a C/He abundance of 4.0×10^{-5} the emission component (Figure 3) is a factor of 2 too strong.

3. NITROGEN LINE FORMATION

To interpret the N emission line spectrum in HD 50896 we used a 31 level NIV atom ($2snl$, $n \leq 4$; $2pnl$, $n \leq 3$) and a 9 level NV atom ($n \leq 4$). We find the following:

(i) As for C, the N ionization structure changes rapidly with radius. Again the ionization is maintained by photoionizations from excited levels.

(ii) Little or no emission, like that observed, is produced in the NIV(3p $^1P°$–3s ^1S) transition at 6381Å. Although the 3p level is coupled directly to the ground state by a transition at 247Å, it is effectively drained by a strong transition to the $2p^2$ ^1D level.

(iii) Emission due to NIV(3d ^1D–3p $^1P°$) at 4058Å is produced by continuum fluorescence from the 2s2p $^1P°$ level and indirect fluorescence from the $2p^2$ ^1D level (e.g. 2p3d $^1F°$–$2p^2$ ^1D). For a N/He abundance of 7.5×10^{-4} the predicted strength of the line is a factor of 2 too small, although the line strength is proportional to the N abundance.

(iv) The 3d ^3D–3p $^3P°$ multiplet at 7117Å is produced by fluorescence from the 2s2p $^3P°$ state although indirect fluorescence from the $2p^2$ ^3P level can also be important. The line strength is approximately proportional to the square root of the N abundance. The different behaviour of this line compared to the corresponding singlet

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transition is related to the larger optical depth in the triplet fluorescing transition. At a temperature of 30000K, the triplet 2s2p state has roughly 60 times the population of the singlet 2s2p level (assuming the same departure coefficients).

(v) 3p $^3P°$-3s ^3S multiplet at 3481Å is produced by indirect fluorescence from the 2s2p $^3P°$ level. Of these, decay from the 3d ^3D level is singularly the most important. This line is insensitive to N abundance. For a N/He abundance of 7.5×10^{-4} this line, and NIV(λ7117Å) have theoretical equivalent widths a factor of 2 to 2.5 times smaller than observed.

(vi) The strong UV emission lines due to NV(2p-2s)(λ1240Å), NIV(2s2p $^3P°$-$2s^2$ ^1S)(λ1486Å) and NIV($2p^2$ ^1D-2s2p $^1P°$)(λ1719Å) are all formed by collisional pumping. The present model, with N/He = 7.5×10^{-4}, yields line strengths within a factor of two of that observed. The most discrepant line, NIV(1486Å), is a factor of two stronger than that observed. As this line is formed at smaller electron densities than other emission lines (Figure 4) its strength relative to the other N lines can be reduced by changing the electron temperature in its formation region. All lines are sensitive to abundance, but it should be noted that the N abundance is so large that it can influence the atmospheric structure. In particular, at electron densities $< 10^{12}$, collisional processes between the lowest energy levels of N can be important wind coolants. This cooling process may act to limit the strength of the NIV 1486Å line.

(v) The large strength of the NV(3p-3s) transition at 4609Å is not reproduced in the present models. As there is still a large parameter space to be explored, and numerous model assumptions which may need to be relaxed, we don't consider that it invalidates our model.

4. CONCLUSION

An ongoing investigation into the formation of nitrogen and carbon lines in WN stars has indicated that the optical CIV and NIV lines in the WN5 star HD 50896 are formed by continuum fluorescence. The strong CIV(3p-3s) doublet at 5805Å is pumped by continuum radiation at 312Å through the CIV(3p-2s) transition. This mechanism, together with the requirement that the pumping transition occur longward of the HeII Lyman limit at 228Å, explains the absence of other optical CIV lines in the spectra of HD 50896. Optical NIV lines cannot be fluoresced from the ground state - instead they are fluoresced from the 2s2p singlet and triplet states. Preliminary results suggest C/He=3×10^{-5} (by number) and a N/He abundance of around 10^{-3}.

4. REFERENCES

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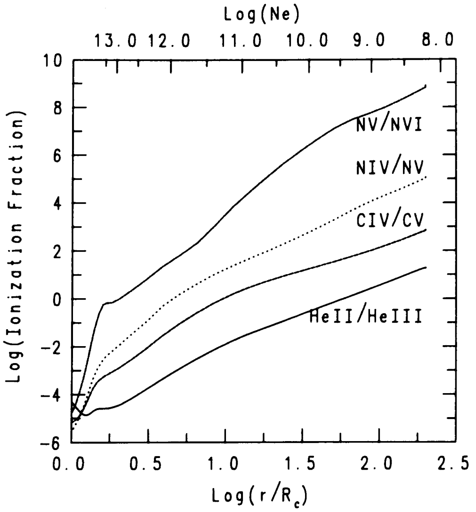

FIG. 1 – The theoretical ionization structure of the stellar wind for a stellar luminosity of 10^5 $L_\odot$.

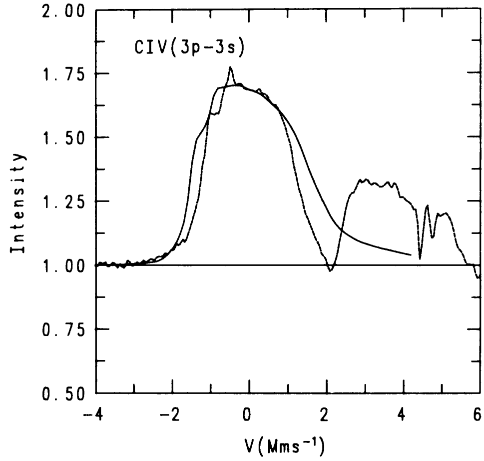

FIG. 2 – The observed CIV(λ5805Å) doublet profile (dashed line) in HD 50896 and a theoretical profile for a C/He abundance of $4.0\text{x}10^{-5}$.

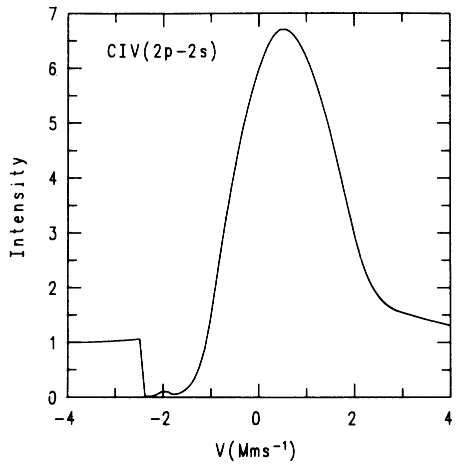

FIG. 3 – The theoretical profile for the CIV resonance doublet at 1549Å. For a C/He abundance of $4.0\text{x}10^{-5}$ the emission component is a factor of two stronger than that observed although the profile is of similar shape.

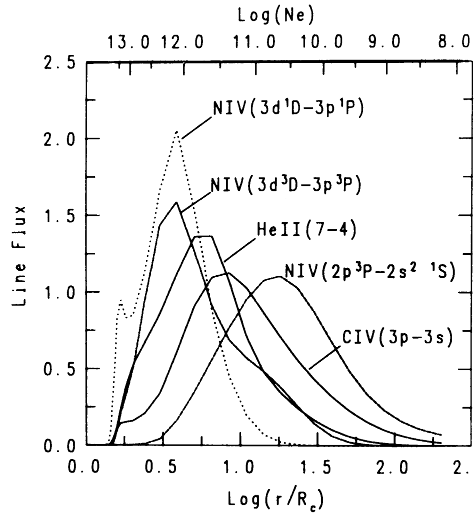

FIG. 4 – Illustration of where the emission lines HeII(7–4), CIV(3p–3s), NIV($2s^2$ ^{1}S–2s2p ^{3}P°), NIV(3d ^{1}D –3p ^{1}P^0) and NIV(3d ^{3}D –3p ^{3}P°) originate in the stellar wind. The curves have been normalized to have unit area.

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