LINE FORMATION IN WINDS WITH ENHANCED EQUATORIAL MASS-LOSS RATES AND ITS APPLICATION TO THE WOLF-RAYET STAR HD 50896

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Ultraviolet spectra from the "Copernicus" satellite of the Wolf-Rayet star HD 50896 (Johnson, 1978; Cassinelli and Rumpl, 1982) show several P-Cygni profiles whose emission component has a larger equivalent width than the absorption component (see Figure 1). For lines with saturated absorption components, such as the N V ($\lambda\lambda$1239-1243) line, the excess emission is due to thermal emission from the wind. However, for unsaturated lines which are due to scattering, such as the P V ($\lambda\lambda$1118-1128) and O VI ($\lambda\lambda$1032-1038) lines, the excess emission suggests that the scattering is not spherically symmetric.

Based on this premise, a simple model was developed of a stellar wind whose material is concentrated toward the star's equatorial plane (see Figure 2). This model was used to investigate the effect on line formation of the distribution of material in the wind and the orientation of the star-wind system with respect to an observer. In addition, the influence of the wind's velocity structure was investigated for two velocity laws, which are schematically depicted in Figure 3. The first distribution has the asymptotic behavior expected for a radiatively accelerated wind (Castor, Abbott and Klein, 1975). The second one has a similar form in the outer region of the wind, but has a velocity plateau at the inner region, as suggested by ultraviolet to infrared continuum fits of Hartmann and Cassinelli (1977). To simplify calculations, the Sobolev escape probability method was used, and the velocity structure was assumed to be spherically symmetric.

A sample of profiles generated from this model for the N V line is shown in Figure 4. Referring to this figure, note that:

a) The sphericity of the matter distribution in the wind is represented by ξ, where a value of 1 would indicate a spherically symmetric

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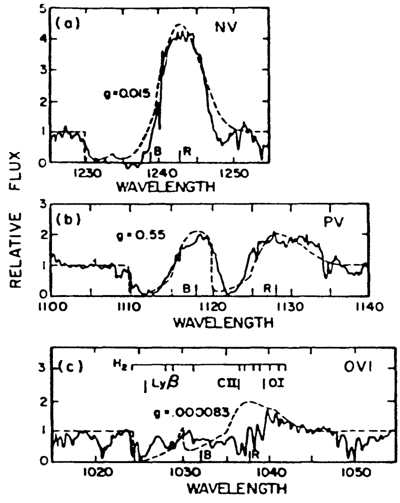

Fig. 1. Line profiles from "Copernicus": (a) N V λλ1239-1243; (b) P V λλ1118-1128; (c) O VI λλ1032-1038. Line centers are indicated by the marks R and B. Several interstellar lines are indicated in (c). The dashed lines show results of profile fits using the nonlocal radiative coupling method of Rumpl (1978) for a spherically symmetric wind. The derived values of the relative ionization fractions, g, are also indicated for model parameters $\dot{M}=1.2\times10^{-5}M_{\odot}/yr$, $R_*=2.5R_{\odot}$, and $v_\infty=2200$ km/s.

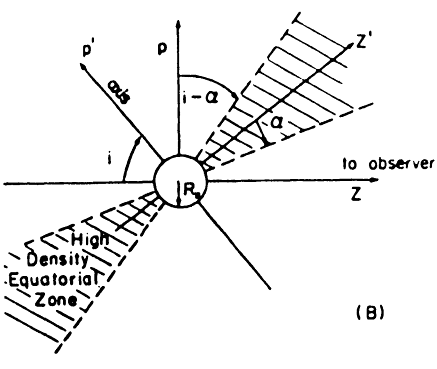

Fig. 2. Schematic of proposed star-wind system. i is the inclination of the system with respect to an observer, and α is the extent of the enhanced mass-loss region about the equatorial plane.

case, and a value of 0 would indicate that all the material is confined to the equatorial region.

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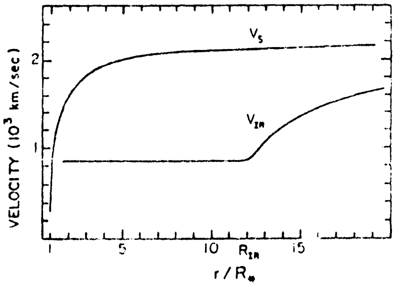

Fig. 3. The two types of velocity laws used in the calculations. The curve V_S shows the "standard" velocity law. The curve V_{IR} shows the two-component velocity structure that seems to be required to explain the large infrared excess of HD 50896.

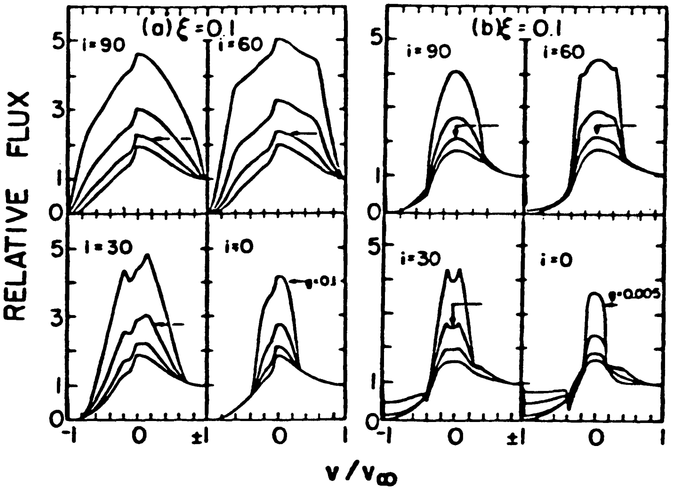

Fig. 4. A sample of line profiles generated from the model corresponding to the N V line for the case ξ=0.1. The group on the left (a) corresponds to the velocity law V_S in Figure 3; while the group on the right (b) corresponds to the velocity law V_{IR}. Values for the inclination of the star-wind system, i (in degrees), are given. Also, a particular value of the relative ionization fraction of N V, g, is indicated. Adjacent profiles within a set differ in g by a factor of $10^{0.5}$. The other model parameters are the same as those given for Figure 1.

b) The orientation of the wind is indicated by i, where a value of 90° corresponds to an equator-on view, and a value of 0° corresponds to a pole-on view.

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c) Profiles generated for the first velocity law (Figure 3: V_S) are shown by the group on the left side (Figure 4a). Profiles generated for the other velocity law with the plateau velocity being 0.4 of the terminal velocity (Figure 3: V_{IR}) are shown by the group on the right side (Figure 4b).

Comparison of these profiles to the N V line of HD 50896 indicates that the best fits correspond to the pole-on case for the first velocity law and the 60° inclination case for the other velocity law for values of low to moderate sphericity ($0.01 \lesssim \xi \lesssim 0.1$). The fit for the first velocity law is rejected because this star is known to exhibit intrinsic polarization (Serkowski, 1970) which could not arise if the star-wind system is viewed pole-on. Therefore, for the velocity distributions investigated, the second is favored. Application to the observed P V and O VI profiles support this conclusion.

To summarize:

a) As expected, the distribution of matter in a stellar wind, the orientation of the star-wind system, and the form of the velocity distribution can significantly affect line formation in a stellar wind.

b) Application of the proposed model to interpret the stellar wind lines of HD 50896 indicates that:

i) the wind is non-spherically symmetric;
ii) the inclination of the star-wind system is approximately 60°;
iii) the velocity structure could consist of an inner constant velocity plateau beyond which the wind rapidly accelerates to its terminal velocity;
iv) the plateau velocity is about 0.4 times the terminal velocity.

For a more detailed discussion of the above work, see Rumpl (1980).

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DISCUSSION

Hellings: How important for your results is the second acceleration in the wind ? It occurs at about 10 stellar radii in a region where the optical depth is very low because the density is very low (10^{-15}).

Rumpl: The second acceleration is necessary to achieve the terminal velocity of 2200 km/s which is indicated by the shortward edge of the absorption component in the profiles, just as the plateau velocity is necessary in determining the central width of the emission feature. In a private communication, Hartmann has told me that the point at which the second acceleration occurs is somewhat arbitrary.
I would like to point out that the model is incapable of determining certain parameters, such as the stellar radius, the mass loss rate and the point at which the second acceleration begins in the wind. The model is capable of giving information regarding the distribition of material in the wind, the orientation of the star-wind system, and the wind's velocity structure.

Stenholm: Do you have any indications that the non-spherical appearance of the stellar wind depends on the presence of the compact companion which is suggested for HD 50896 ?

Rumpl: No. If prior to this meeting you would have asked me what mechanism caused the non-spherical nature of the wind, I might have answered rotation or possibly magnetic fields. However, the presence of the compact companion could be responsible.

Heap: I would like to ask IUE observers whether observed profiles of strong resonance lines look like Bill Rumpl's predictions in the sense of having an emission component bordered by some plateau velocity significantly smaller than the terminal velocity?

Underhill: It is extraordinarily difficult to determine accurately the longward edge of a WR emission line in the UV because of uncertainty about where to draw the continuum and because of blending. The displacement longward of the steep descent of a strong emission line is often less that the displacement shortwards of the steep edge of the absorption.

Massey: Are there any differences in the line profiles between the Johnson and Cassinelli observations for HD 50896?

Cassinelli: The observations by Johnson and me are about identical.

Rumpl: The spectra were taken about 3 years apart, and you are probably interested is possible shorter term variations which are due to the compact companion.

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