THE Hα PROFILE IN ZETA PUPPIS

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The Hα profile in the spectrum of Zeta Puppis is shown in Figure 1 (Conti and Frost 1977). It is of the P Cygni type, with a violet displaced absorption component that extends to about 300 km s^{-1} from line center. An unusual feature is the broad wing emission which can be seen out to 1500 km s^{-1} on both sides of the line. Of the roughly 2.5 Å equivalent width of Hα, 1.8 Å is due to velocity displacements $|\Delta v| > 300$ km s^{-1}. The presence of wing emission shortward of the violet absorption edge has been noted before in a Wolf-Rayet star, where it is attributed to non-coherent electron scattering (Castor, Smith and Van Blerkom 1970). In the present case, an optical depth in electrons of nearly 1.5 is required to produce the extensive wings by scattering a normal P Cygni profile. This exceeds by a factor of three the electron scattering optical thickness through the entire envelope, assuming published values of the mass loss rate, terminal velocity of the wind and photospheric radius. Thus an alternative explanation is required.

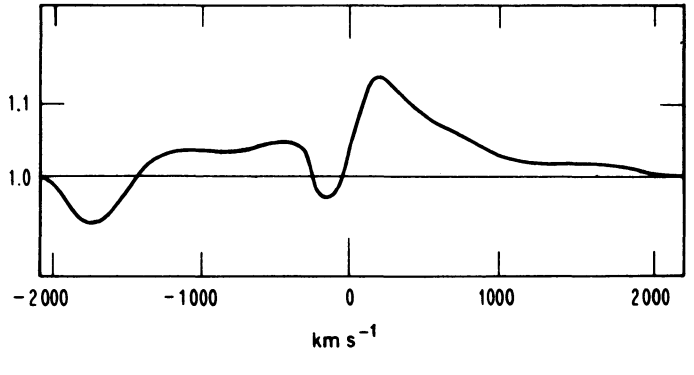

Figure 1

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P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 249–252.

In a rapidly outflowing envelope, the line optical depth directly in front of the continuum emitting core $\tau(r)$ at a radius r is proportional to the line absorption coefficient k(r) and inversely proportional to the velocity gradient dv/dr. If at some radius r^* the velocity gradient becomes very large, $\tau(r)$ will be considerably reduced for $r \geq r^*$. It is possible that $\tau(r) > 1$ for $r < r^*$ but $\tau(r) << 1$ for $r > r^*$. In such a situation, the envelope becomes nearly transparent, and any absorption component will terminate at a velocity displacement $\Delta v \approx -v(r^*)$. The envelope emission is also affected by the change in $\tau(r)$, but calculations show that the wing can revert to emission shortward of the absorption component. This may be the explanation of the Hα profile in ζ Pup.

Recent work by Castor and Barlow in the infrared continuum of ζ Pup finds a velocity distribution

$$v(r) = v_o(r-r_o)$$

which is difficult to reconcile with radiatively driven stellar wind theory. This latter gives a velocity law of the form

$$v(r) = v_\infty(1-1/r)^{1/2} \quad .$$

Since infrared measurements probe the inner part of the wind, it is possible that a transition in velocity field occurs from the first to the second type at some radius r^*. This would produce the large velocity gradient postulated above.

In order to test this hypothesis, a preliminary model of ζ Pup has been constructed with runs of the source function and optical depth given a priori. Future models will solve the statistical equilibrium equations. Figure 2 shows the profile found in one calculation. One observes the broad emission wing extending beyond the violet absorption. There is also an apparent red absorption due rather to a decrease in envelope emission at the transition radius. Possibly, too abrupt a transition from one velocity law to another has been used in these preliminary models.

Further study will show whether a region, or regions, of rapid acceleration can exist in stellar winds, and whether the Hα or other emission lines can be used as a diagnostic of this behavior. At present, we have no other explanation of the Hα profile.

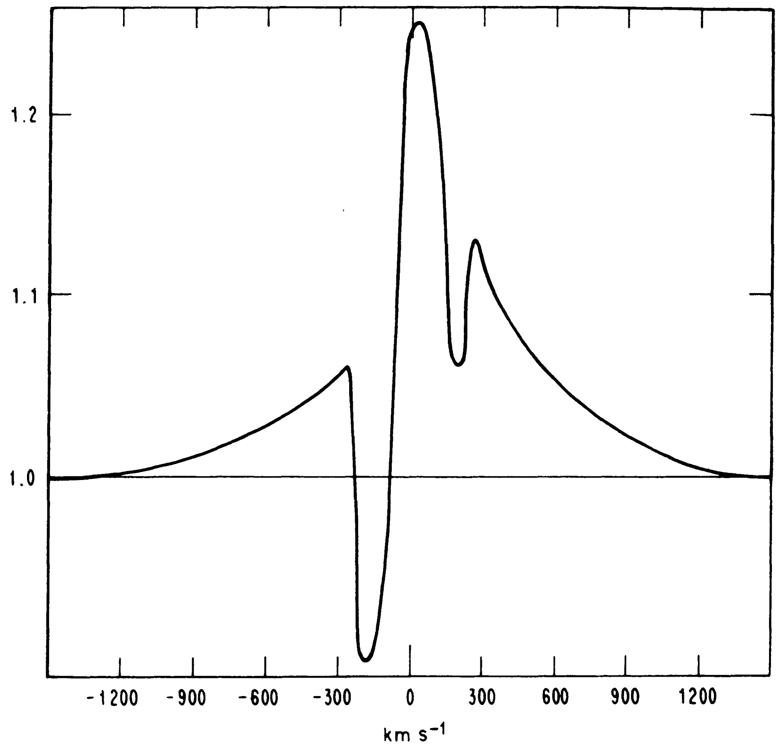

Figure 2

REFERENCES

Castor, J.I., Smith, L.F. and Van Blerkom, D.: 1970, Ap. J., 159, p. 1119.

Conti, P.S. and Frost, S.A.: 1977, Ap. J., 212, p. 728.

DISCUSSION FOLLOWING VAN BLERKOM

Underhill: You show a rapid acceleration in flow velocity rather close to the photosphere. What causes the abrupt change in the applied outward force at this point in the atmosphere? If the dominant force is radiation pressure, an abrupt change in the integral of $F_\nu K_\nu$ over the whole spectrum is implied to occur at the indicated radius. Here K_ν is the total monochromatic opacity due to all sources, lines, continua and electrons. What is the cause of this change? What happens to the state parameters of the atmosphere to cause such an abrupt change?

Van Blerkom: I have not calculated the hydrodynamic state of the envelope including radiation pressure, but can only refer you to calculations which have been done by others. In particular, John Castor has shown that when overlapping of spectral lines is properly treated, a region of slow velocity rise exists close to the photosphere and is followed by a region of much more rapid acceleration. The infrared analysis presented earlier by Castor also indicates a region near the photosphere in which the velocity rise is approximately linear with radius.

Conti: The Hα line profile of ζ Pup shown here is, interestingly, not very typical of most Of stars. The line is similar to λ Cep, another Of star with relatively large rapid rotation. I suspect that this rotation, possibly including shear energy input, has something to do with this absorption feature. This is the first time I have seen a theoretical explanation for this kind of emission line.

Hearn: How certain are you of the continuum level in this line profile?

Conti: I am quite confident that the continuum is drawn correctly. The absorption feature on the left handside of the figure is λ6527 of the He II (5-n) series. Leftward of that is a very nice continuum. The Hα absorption is not absolutely certain to go below the continuum but may by a few percent as shown.

Hutchings: The profiles with emission on both sides of the absorption are found in Be stars and you should seriously consider rotation as an important contribution to them.

Van Blerkom: The scale of the drawing, which extends to 1500 km s^{-1} on both sides of line center may be misleading. The absorption component is not at line center, but extends roughly 300 km s^{-1} to the violet. While rotation is no doubt important, I believe the violet displacement of this component is suggestive of absorption in an expanding envelope.

Cassinelli: What did you do about the underlying photospheric line?

Van Blerkom: A photospheric absorption profile was taken from a T_{eff} = 50,000 K, log g = 4 non LTE stellar atmosphere model of Mihalas and used as the boundary condition for the incident radiation field.

Cassinelli to Conti: There could not be a 4Å shift of the underlying photospheric line could there?