ATMOSPHERIC MODELS FOR LBV'S AT MINIMUM AND MAXIMUM STATES

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We study the relation between photospheric and wind parameters of LBV's on the basis of self-consistent atmospheric models. Our theoretical model consists of a spherically extended, dynamical NLTE atmosphere for the radiative transfer and a modified CAK code for the hydrodynamics. These codes are combined in an iterative scheme to achieve self-consistency.

The observed photometric variability is generally interpreted in terms of a variable photospheric temperature $T_{2/3}$ and radius $R_{2/3}$ with constant luminosity $L = 4\pi\ R^2(2/3)\ \sigma\ T^4(2/3)$. During maximum phase (when $T_{2/3}$ is around 8000 K), we find from our radiatively driven wind models that $\dot{M}$ increases strongly relative to the minimum phase. The increase in $\dot{M}$ is generated by a recombination of doubly to singly ionized iron-group elements. Our models predict mass-loss rates a factor of ~30 higher in the maximum than in the minimum and wind terminal velocities of about 200 km/sec for both states.

The derived mass-loss variations refer to the region of the atmosphere which is optically thin to continuum radiation. On the other hand, the observed photometric variations originate in photospheric regions where $\tau \approx 1$. We investigate the possibility that the higher densities in the atmosphere due to higher $\dot{M}$ produce higher opacities and thus a larger photospheric radius. In such a scenario, the photospheric and wind variability could be accounted for self-consistently if this mechanism were self-initiating due to some instability mechanism (Appenzeller 1986).

T_{eff} is defined by the luminosity and the stellar radius $L = 4\pi\ R_*^2\ \sigma\ T_{eff}^4$ where R_* is chosen small enough to ensure sufficient Rosseland optical depth. According to this definition, T_{eff} and R_* are constant and remain unaffected by different mass-loss rates. Models with high $\dot{M}$ have $T_{2/3} > T_{eff}$ and $R_{2/3} > R_*$. Figure 1 illustrates the effect of increasing $\dot{M}$ on the energy distribution of R71. The models use $T_{eff} = 16000$ K, $R_* = 81\ R_\odot$ (from the observed energy distribution at minimum), a velocity law with $\beta = 1$ (derived from the hydrogen line profiles), and $\log \dot{M} = -6.2, -5.2, -4.2$. Part of the UV flux is redistributed to longer wavelengths. However, the increase in UBV is $\lesssim 0.3$ mag. Even using vastly different velocity laws, the

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observed variability could not be reproduced. The increase of $R_{2/3}$ cannot be explained by opacity effects with constant R_*.

Davidson (1987) derived a relation between $\dot{M}$, the characteristic temperature of the photosphere T_0, and the velocity of the photosphere v_0. Our results imply that his diagnostic diagram can not be used to model an LBV at both maximum and minimum with one fixed index n of his velocity law $v(r) \sim r^n$. This is basically due to the enormous variation of v_0 associated with a variation of $\dot{M}$. If $\log \dot{M} = -6.2$, continuum formation occurs deep in the subsonic region whereas v_0 is of the order of the sound velocity for $\log \dot{M} = -4.2$. As a consequence, $R_{2/3}$ increases rather weakly even at high mass-loss rates if R_* is constant.

We assume the core radius R_* itself is variable between minimum and maximum. A converged model for R71 is derived from a fit to the observed energy distributions and the line profiles in minimum and maximum states. The results are summarized in the table below.

	Log L	M	T_{eff}	R_*	$T_{2/3}$	$R_{2/3}$	log g_{eff}	log $\dot{M}$	v_∞	β
Minimum	5.5	12	16000	84	15500	88	1.3	-6.2	170	1.0
Maximum	5.5	12	10000	230	8100	332	0.0	-4.7	110	1.0

Notice the low gravity both in minimum and in maximum and the low mass. According to evolutionary tracks by Maeder and Meynet (1987), R71 is a post-RSG with an initial mass of ~25 $M_\odot$. The stellar wind properties derived from the line-profile analysis are in agreement with the prediction of the radiatively driven wind theory. However, we cannot self-consistently account for the observed radius variability. The mechanism responsible for the variable photospheric radius appears to have its origin in deeper, sub-photospheric layers.

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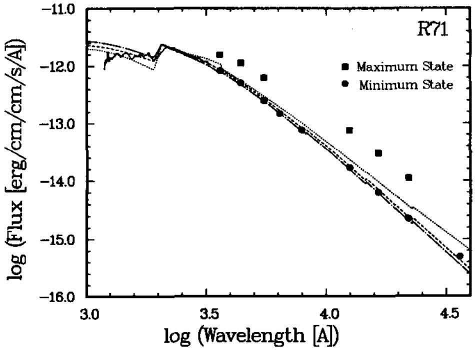

Fig. 1. Observed and calculated energy distributions of R71 at minimum and maximum. The IUE spectrum (solid line) refers to the minimum. The three calculated models have $\log \dot{M} = -6.2$ (dash-dotted), -5.2 (dashed), and -4.2 (dotted) assuming a constant core radius.

Appenzeller, I. (1986) in IAU Symp. 116, "Luminous Stars and Associations in Galaxies," Dordrecht: Reidel, p. 139.
Davidson, K (1987) Ap. J., 317, 760.
Maeder, A., and Meynet, G. (1987) Astr. Ap., 182, 243.