EMPIRICAL WIND MODELS FROM DETAILED UV-LINE FITS: TAU SCORPII

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The main-sequence BO star Tau Sco has been studied previously by Lamers and Rogerson (1978). However, their line fit was restricted to the blue wings of the UV resonance lines because the line formation was calculated in Sobolev approximation. We now repeat this investigation by means of the comoving-frame (CMF) method, which we have extended to the treatment of overlapping doublets. From a systematic comparison (Hamann 1980b) we know that the results may deviate considerably from those of the Sobolev method. Our method has been applied previously to the other "prototype" of mass loosing early-type stars, the Of star Zeta Puppis (Hamann 1980a).

In Tau Sco, two different types of line profiles can be distinguished: The doublets of NV and OVI have only slightly blue shifted flux minima. The absorption do not extend to velocities above 1000 km/s. The other group consists of the N III, Si IV and C IV doublets. These profiles have their deepest depressions at the laboratory wavelengths, and all these "photospheric components" reach the same depression of 20% continuum flux, which points to a strange saturation effect. Additionally, the profiles of the second group exhibit faint blue wings which extend to velocities of 1600 km/s.

The above description of the observed profiles suggests to distinguish three zones in the wind of Tau Sco (see Table 1).

The line formation calculations provide the following free parameters: a) The velocity law v(r) holds for all lines: b) The opacity law $\varkappa_i(r)$ is written

$$\varkappa_i(r) = \frac{\varkappa_i^0}{r^2\, v(r)/v_s}\; q_i(r)$$

in order to separate the geometrical dilution factor (r in stellar radii). $\varkappa_i^0$ is an individual fit parameter for each line, as well as the function q_i (r) which describes the run of the ion's population fraction with radius. c) The Doppler-broadening velocity v_D (microturbulence).

For simplicity we assume that the radius-dependent parameters: $\frac{dv}{dr}$ and q_i (r) remain constant in each of the three zones.

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 161–165.

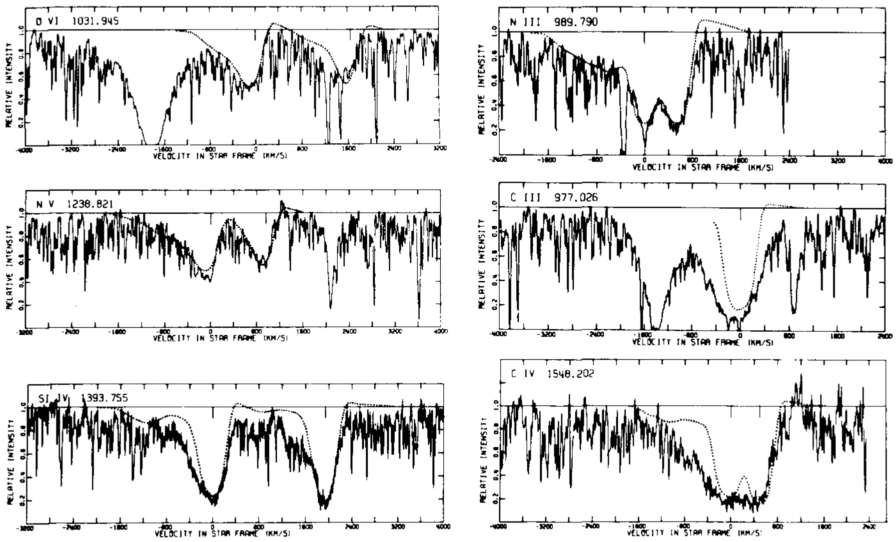

Fig. 1: COPERNICUS-tracing of the Tau Sco resonance lines (taken from LAMERS and ROGERSON 1978) and theoretical profiles (dotted) which have been calculated with the parameters compiled in Tables 1 and 2.

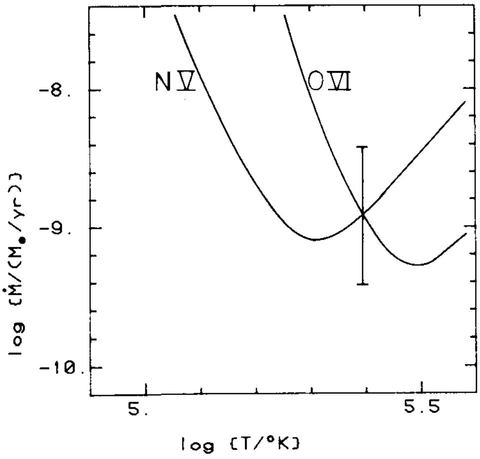

Fig. 2: Fit lines for NV and OV I on the base of the"warm wind"-model. From this diagram we derive the temperature in Zone II and the mass-loss rate.

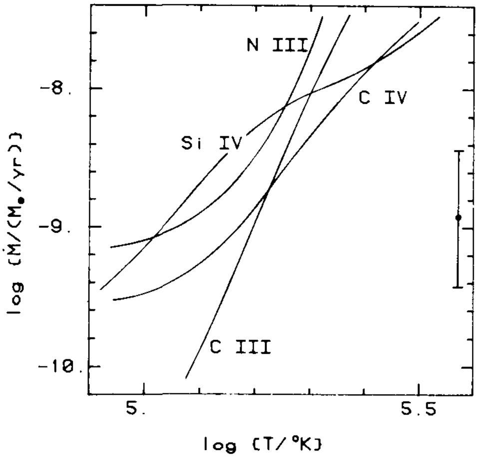

Fig. 3: Fit lines for N III, Si IV, C III and C IV. Using the previously derived mass loss rate, we derive the temperature in zone III.

Table 1

The Empirical Three-Zonal Model of Tau Sco

	Zone I	Zone II	Zone III
Observation	"Photospheric Components" of C III, C IV, N III , Si IV	Lines of N V, O VI	faint blue wings of C III, C IV, N III, Si I V
velocity range [km/s]	0.01 ... 0.1	0.1 ... 1000	1000 ... 1600
velocity gradient $\frac{dv}{dr}$ (error range)	?	$2500 \frac{km/s}{R_*}$ (800 ... 8000)	$500 \frac{km/s}{R_*}$ (250 ... 2500)
T_e [°K]	$\lesssim$ 160 000	250 000	125 000 ... 160 000
Microturbulence	100 km/s	100 km/s	?

Mass loss rate: $\log \{ \dot{M} / (M_\odot/yr) \} = -8.9 \pm 0.5$, d.h. $\dot{M} = 1.3\ (0.4\ ...\ 4) \cdot 10^{-9}\ M_\odot/yr$

Table 2

Fit Parameters

Ion	τ_i^{I}	χ_i^{o}	$\log q_i^{II}$	$\log q_i^{III}$
N V	0	.4	0^+	$<-.7$
O VI	0	.4	0^+	$<-1.$
N III	250	.2	$-.3$	0^+
Si IV	250	.15	0 *	0^+
C III	>1000	.1*	0 *	0^+
C IV	>1000	.13	0 *	0^+

The dimensionless opacity is related to the reference velocity v_s = 1600 km/s. For zone I the line center optical depth τ_i^I is given instead of the opacity because this layer is nearly static and of unknown but small spatial extension.

* Parameter unsafe
\+ Arbitrary normalisation

The parameters which lead to the best agreement with the observation are compiled in Table 1 and 2, while the corresponding fits are shown in Fig. 1.

Apart from all uncertainties, the above results confirm quantitatively that the degrees of ionisation decrease from zone II, where the high stages N V and O VI are dominant, to the lower stages (N III etc.) in the outermost zone III.

The "thin corona model" (Cassinelli, Olson and Stalio, 1978) contradicts this ionisation structure (this argument was already used by Lamers and Rogerson, 1978).

On the other hand, it is a very elementary argument in favour of the "warm wind model" that the phenomenological distinction between the two groups of lines corresponds exactly to an entirely different temperature-dependency of the concerning ionsation fractions. For these reasons, we adopt the "warm wind model" for τ Sco and combine the fit parameters (Table 2) with theoretical ionisation fractions (see Fig. 2 and 3). For the conversion of the fit parameters, see Hamann (1980a). All results are summarized in Table 1.

Conclusion

The observed UV resonance lines of Tau Sco are well reproduced by theoretical profiles. The CMF calculations allow for a fit of the whole profile range and a correct treatment of the doublets.

An empirical model was derived which distinguishes three zones. Some uncertainties enter the model via the velocity field: The lines are formed close to the photosphere and do not contain much information about the spherical extension. Nevertheless, the derived ionisation conditions rule out the "thin corona model" in this case. The "warm wind model" allows for a consistent interpretation of the fit parameters and yield an electron temperature which decreases outwards from 250 000 $^{\circ}$K to 140 000 $^{\circ}$K. The derived mass loss rate log $\dot{M}/(M_{\odot}/yr)$ = -8.9 $\pm$ .5 is a factor of 5 smaller than found by LAMERS and ROGERSON, 1978).

The line fits firmly establish the large microturbulence of 100 km/s in zones I and II. It is a striking fact that we found roughly the same large microturbulence in most stellar winds investigated so far, e.g. ζ Pup; α Cam, ϵ Ori, ξ Per (HAMANNand LAMERS, in preparation); or even for the O subdwarf HD 49798 (SIMON et al. 1979).

These supersonic motions bay be important for the energy transfer and heating of stellar winds.

More details of the Tau Sco study will be published in Astronomy and Astrophysics.

References:

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DISCUSSION

HEARN: I understand that in your calculation the velocity distribution on the model is determined just by fitting the line profiles. With the radiative transfer solution you can calculate the radiative forces. Have you done this and are the forces consistent dynamically with the velocity distribution?

HAMANN: The radiation force on all UV resonance lines is sufficient to accelerate the wind (see Lamers and Rogerson, 1978). However, the run of the velocity field cannot be checked this way with reasonable accuracy, because the radiation force is roughly proportional to $v\frac{dv}{dr}$ or only to v in optically thin lines; compare Castor, Abbott and Klein, 1975). Therefore the velocity field itself cancels out in the equation of motion (in first order approximation!).

VIOTTI: With reference to the large turbulent velocity you have found in these early type stars and in particular in the mass loser sd O star HD 49798, I found that in the two other mass loser sd O star BD+37°442 and +37°1977 the line width is larger than in the non mass loser sd O stars BD+48°1777 and BD+75°325. It would be of great importance to derive the turbulence velocity in all these stars to find a possible link with the presence of a stellar wind.