What can we learn from ζ Aur binary systems?

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Abstract. ζ Aur binaries are wide eclipsing systems (P ≃ 1...10 yrs), containing a late supergiant primary (G to M type) and an early dwarf companion (A0 V ... B3 V). Some recent studies of wind phenomena (mass loss rates), chromospheric properties and wind acceleration (of the supergiant) as well as wind accretion phenomena introduced by the gravitational interaction with the companion are presented, summarizing previous work of the Hamburg 'binary wind team'(mainly D. Reimers, R. Baade, A. Che-Bohnenstengel, K. Hempe, K.-P. Schröder).

I) Introduction

In recent years it has been recognized that mass loss in red giants is decisive for the final evolution and fate of low and intermediate mass stars. IUE observations of ζ Aur systems offered a new possibility to obtain accurate mass loss rates (Reimers, 1987).
Unlike common symbiotic stars, ζ Aur systems are well detached binaries (fig. 1), not resolved optically but spectroscopically. While the giant (G - M type) dominates the visual flux, the hot companion outshines him in the UV, though comparably pointlike. Three aspects are offered to the observer of ζ Aur systems:
First, IUE spectra show a wealth of resonance lines, formed in the supergiant wind upon the B star spectrum. Applying a non-sperical radiative transfer scheme (in the two level approximation, Hempe, 1982) Che et al (1983) where able to fit the line profiles by chosing adequate mass loss, wind velocity and turbulence parameters.
Second, the B star companion interacts locally with the supergiant wind. Complex CIV and SiIV features are observed, originating from a shock front and wind accretion onto the hot companion. Thinking in terms of mass loss determination, these phenomena are an unwanted disturbance of the wind, which is approximated to be continuous and sperically symmetric. Studies were made by A. Che-Bohnenstengel and D. Reimers (1986) as well as by Ahmad et al (1983) and Ahmad (1986).

J. Mikolajewska et al. (eds.), The Symbiotic Phenomenon, 339–346.

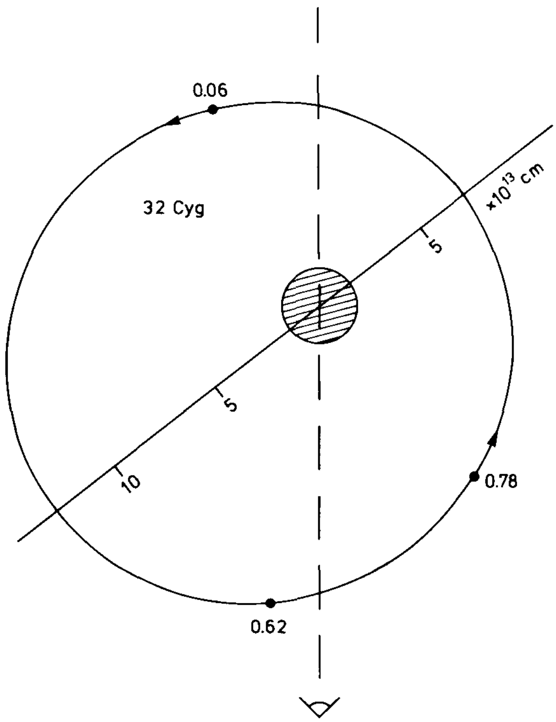

fig. 1: The orbit of the B star relative to the K supergiant 32 Cyg with some observed phases indicated, the B star not drawn to scale.

Third, during eclipse of the companion by the supergiant chromosphere, numerous absorption lines occur upon the B star spectrum. By means of curves of growth, columndensities as a function of height can be determined. Integrating over a simple parameterized density model, Schröder (1985) was able to derive the density distribution of the chromospheres of three K supergiants. Assuming pure rayleigh scattering, these kind of density models are also able to explain the wavelength dependence of the eclipse light curves (Schröder, 1986). Fe I /Fe II ionization ratios give us information about the electron densities of these chromospheres. The steep density gradient (steeper than $\sim r^{-2}$) proves the acceleration of the wind and we are able to fix the location of the so far not well understood wind acceleration region in the upper chromosphere.
Thus, ζ Aur stars are the only stars besides the sun, where winds and chromospheres an be studied in spatial (height) resolution, the B star serving as an ideal probing light sourge.

There is only one disadvantage with ζ Aur systems: there are only very few of them because of their special character. Very well known are ζ Aur, 31 Cyg and 32 Cyg (see Wright, 1970). New discoveries are 22 Vul (Parsons and Ake, 1983) and HR6902 (Griffin & Griffin, 1986). A related but more complex problem is VV Cep. δ Sge undergoes chromospheric eclipses only.(Reimers and Schröder, 1983).

II) The supergiant wind

The wind is visible at all phases in P Cyg type profiles (during total eclipse of b star: pure emission lines) of ions like Fe II, Si II, S II, Mg II, C II, Al II and O I. These lines are formed by scattering of B star photons in the wind of the red giant. A few lines like Fe II UV mult. 9 (at 1270 Å) are seen in pure absorption due to the branching ratios of the upper levels which favour reemission as Fe II UV mult. 191 photons (Hempe and Reimers, 1982; Baade, 1986).
Theoretical modelling of wind line profiles and of their phase dependency has yielded accurate mass loss rates and wind velocities for a number of systems (Table 1). It has turned out, that a good mass loss determination requires both phases with the B star in front (showing wind material at about terminal velocity only, which yields wind turbulence v_{tur} from the width of the profiles) and phases with the B star behind the red supergiant (which yields the windvelocity v_w from the profiles, whose widths are about $2v_w + v_{tur}$ then). Typically, $v_w \simeq 2v_{tur}$ is obtained. Further details can be found in Che, Hempe and Reimers (1983). It turned out that it was possible to match the circumstellar line profiles at all phases with <u>one</u> set of parameters v_w, v_{tur} and - within a factor of 2 - one mass loss rate $\dot{M}$ (c.f. fig. 2). That means, at least in the orbital plane the envelope asymmetries (in density) are within a factor of 2 on a scale of several K giant radii. Table 1 gives a summary of the final parameters chosen by the work of Che et al, 1983.

Table 1. Summary of wind and turbulent velocities, and mass loss rates for ζ Aur, 32 Cyg and 31 Cyg

	v_{wind}	$v_{turbul.}$	final model v_w	v_{tur}	$\dot{M}$
	{km/s}		{km/s}		$\{M_\odot/yr\}$
ζ Aur	20...45	20...40	40	30	0.63 10^{-8}
32 Cyg	30...60	15...30	60	25	2.80 10^{-8}
31 Cyg	30...80	10...30	80	20	≧1.0 10^{-8}

From the observed population of excited Fe II levels from 32 Cygni at distances of ≧ 5 K giant radii, Che-Bohnenstengel (1984) found T_e = 4800 K for $n_e/n_H \simeq 0.01$ and $T_e \simeq 10^4$ K for smaller electron densities. The LTE value would be 4200 K.
In 31 Cyg, the more extended strömgren sphere (the companion is the earliest of these three systems) complicates the quantitative interpretation of the wind line profiles in terms of mass loss.

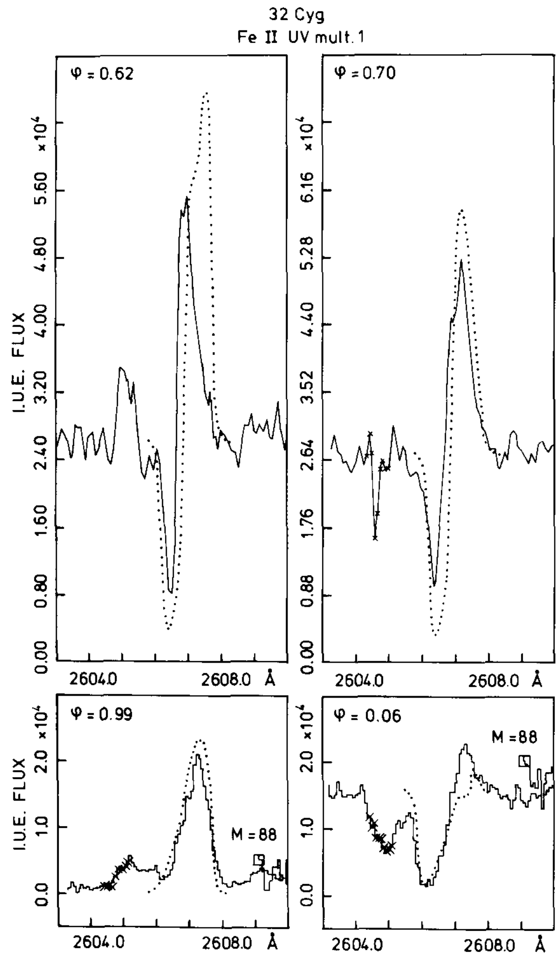

fig.2: Comparison of theoretical (.....) Fe II UV mult. 1 wind lines with the observation for 32 Cygni at various phases.

III) Shock front and accretion phenomena

There are several broad, complex high excitation lines observed in N^{4+}, C^{3+}, Si^{3+}, Al^{2+} and Fe^{2+} ions, which cannot be explained by resonance scattering of B star photons in the wind, since the wind temperature is far too low to produce sufficient of such ions. The special phase dependence of the emission and absorption features also excludes an origin in a hot transition region of the red supergiant. Che-Bohnenstengel and Reimers (1986) studied the cIV and SiIV resonance doublets in detail and proposed the following configuration (fig.3):
Formed by the supersonoc motion of the B star in the wind of the supergiant, there is a shock cone. The B star is located near to its apex.

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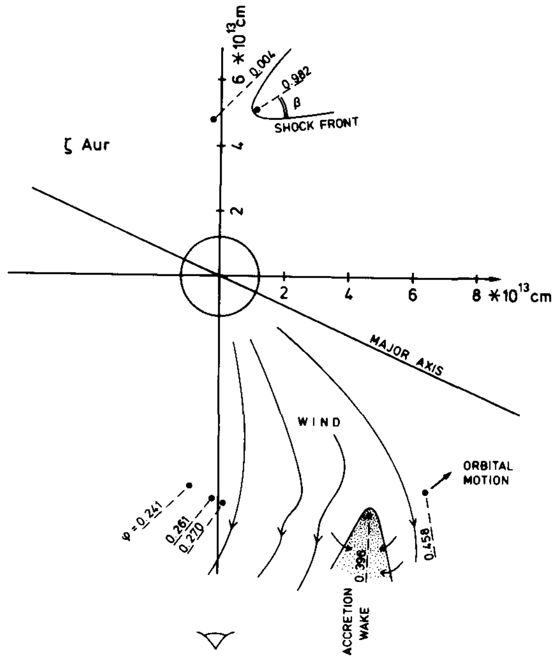

fig. 3: A roughly to scale presentation of shock front and accretion phenomena of ζ Aur at various observed phases. The disturbances in the wind at phase ϕ = 0.396 are shown qualitatively. Broken lines indicate the aberration of the shock cone axis (arctan v_{orbit}/v_{wind}) at each phase.

The emission region has an extension comparable to the supergiant diameter, since the (asymmetric) emission remains visible during total eclipse of the companion, but its intensity has decreased considerable. In the back of the cone, there is a clumpy accretion wake, causing complex absorption features (observed in CIV and SiIV)shortly after primary eclipse (with the cone then opened to the observer, semi angles beeing about 25°...45°). Comparing the emission measures of CIV and SiIV, Che-Bohnenstengel and Reimers (1986) estimated the temperature in the shock cone region to be about 50000...80000 K. The density is enhanced there by about 3 orders of magnitude (compared to the wind), n_e is of the order of $10^8...10^9/cm^3$ ($10^7....10^8/cm^3$ in the accretion wake).

Applying the Theory of Livio and Warner (1984), they found ζ Aur and δ Sge beeing candidates for an accretion disk, formed inside of the shock cone. Actually, only these two systems have broad symmetric emission features, observed in the SiIV and CIV lines (except during ζ Aur eclipse since the ζ Aur accretion disk is small enough to be totally eclipsed by the giant) and at δ Sge Fe II UV mult. 78 lines and others, emitted from the edge of the disk.

IV) Chromospheric eclipses

The extended chromosphere - where the wind already starts to expand - could be studied by means of curves of growth, applied first by O.C. Wilson, H.G. Groth, K.O. Wright and others in the 1950's. Today, we benefit from much better atomic data and the IUE data are a major advance in several aspects: the comparably pointlike b star provides a smoth continuum (whereas at ≥ 400 nm the K giant contributes to the flux with his complex spectrum). On it, one can observe numerous absorption lines of Fe II, Ti II, V II, Fe I and more, up to heights h' (projected binary separation) of partly more than one supergiantradius above the photosphere. The resultant height depending columndensities N(h') can well be reproduced by a numerical integration of a simple density model (along the relevant lines of sight), as shown by fig. 4. The density $\rho(h)$ is represented by a power law of the form

$$\rho(h) \sim r^{-2} * h^{-a}$$

with 'a' of the order of 2.5 ... 3.5 (Schröder, 1985).

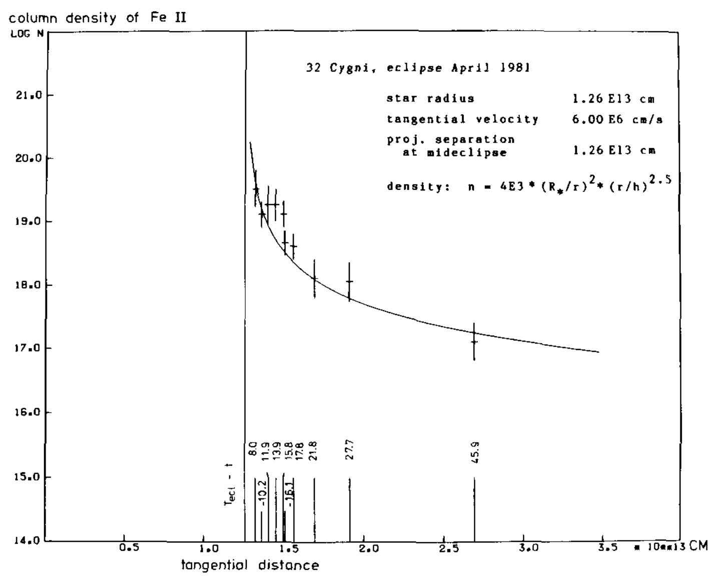

fig. 4: Observed columndensities obtained by means of curves of growth of Fe II UV lines from 32 cyg chromospheric eclipse versus tangential distance, compared to a track of theoretical columndensities, calculated by numerical integration over the density model specified in the plot.

In addition to absorption lines, the wavelength dependence of eclipse continuum light curves can be reproduced by such density models for the

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lower chromosphere. The parameters are slightly different but the density fits to the absorption line density in the overlapping height range. (Schröder, 1986). When continuum fluxes from IUE high resolution spectra are obtained (from line free sections only), pure rayleigh scattering turns out to explain the (line absorption cleaned) continuum opacity very well (fig. 5).

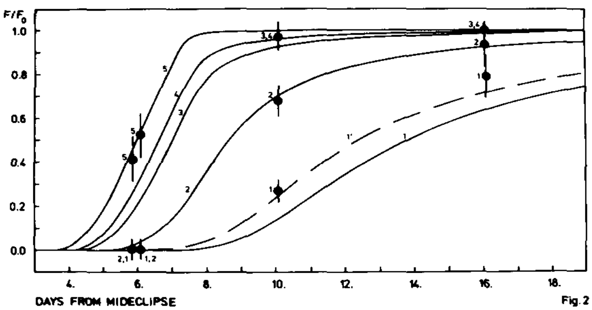

fig. 5: Measured 32 Cyg normalized continuum fluxes (cleaned from line absorption) are indicated by dots at 1350Å (1), 1513Å (2), 1783Å (3), 1960Å (4) and 2992Å (5). Solid lines: fluxes from the best fitting model of a rayleigh scattering chromosphere at these wavelengths.

Observation of the iron ionization ratio Fe I /Fe II $\simeq 10^{-3.5}$ and iron ionization equilibrium calculation yield electron densities of $n_e \leq 10^{-4} ... 10^{-2}$, increasing with height. While the metals are mainly in the first ionization stage (due to the radiation field of the B star, radiative ionization dominates), hydrogen has to be regarded as beeing nearly neutral (the strömgrenspheres of the B stars do not reach down into the chromospheres). Making a simple hydrogen ionization calculation, Schröder (1986) found Te ≦ 8000 K ... 11000 K, slightly increasing with height ($h \leq 0.5\ R_*$). Therefor , no dust formation is possible and radiative pressure on dust grains can be ruled out as a wind acceleration mechanism in these K supergiants.
Applying the equation of continuity to $\rho(h)$ and knowing the mass loss rate $\dot{M}$, v(r) can be derived. For 32 Cyg and 31 Cyg, the observed velocity is consistent with the thus derived terminal velocity. The density gradient is showing actually the acceleration of the wind. The ζ Aur density gradient is steeper than it should be from acceleration only. At that 1979 eclipse, we certainly observed a local mass loss deficiency.

On scales less than about one giant radius, the chromospheric matter is not as homogeneous as we, for simplicity, assume it to be. At egress of 1981 eclipse of 32 Cyg, Schröder (1983) found a very compact cloud of a diameter of about 1/6 giant radius close to the limb of the giant. It was about ten times denser than the surrounding matter and by rayleigh scattering, it produced a second dip in the shorter wavelength light curves. From old Ca II K observations, additional line absorptions at radial velocities up to ±100 km/s are known near eclipse (Wright, 1970).

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These timedepending features are intrinsic problems, when studying wind acceleration. But in prinziple, ζ Aur systems for the first time enable us to determine location and fundamental physical parameters of the wind acceleration region, giving important constrains to every theory on wind acceleration mechanisms.
In conclusion, by their special character ζ Aur systems teach us a lot about the fundamental parameters of red supergiant winds and chromospheres. The interactions of the companion with the wind are restricted to the local environment and do not dominate the processes in the circumstellar matter further.

Acknowledgement: The Deutsche Forschungsgemeinschaft supported the binary project with several grants to the author and his collegues.

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