THEORETICAL LINE PROFILES FROM A SYMBIOTIC SYSTEM

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Abstract

A model for a symbiotic system is presented which is not spherically symmetrical. The system consists of a cool, mass losing giant and a hot star. The stellar wind from the cool star is radiatively ionized by the hot companion, and the resulting nebular lines are emitted mainly close to the cool star. Due to the elliptical orbit, the line fluxes change with time because of the varying separation of the stars. The line profiles vary from symmetrical to asymmetrical, depending on the angle between the line of sight and the axis of symmetry. The calculated line profiles are compared with observed UV lines of the symbiotic star HBV 475.

1. Introduction

The observed line profiles of some symbiotic stars such as HBV 475, V1016 Cyg or HM Sge cannot be explained with spherically symmetrical models. The line widths measured for these systems are too narrow to be formed in a hot stellar wind or in the inner regions of an accretion disk. The same holds for the UV lines of some other symbiotics (Friedjung et al. 1983). To explain the observed line profiles, Wallerstein et al. (1984) proposed a model for V1016 Cyg and HM Sge on the basis of a binary system, where a low velocity Mira wind collides with a fast wind from a white dwarf. In this work we present a qualitatively different model for HBV 475 with the goal of reproducing the periodically changing asymmetry in the profiles of the recombination and the collisionally excited lines reported by Nussbaumer et al. (1986).

Paper presented at the IAU Colloquium No. 93 on 'Cataclysmic Variables. Recent Multi-Frequency Observations and Theoretical Developments', held at Dr. Remeis-Sternwarte Bamberg, F.R.G., 16–19 June, 1986.

Astrophysics and Space Science **131** (1987) 707–712.

https://doi.org/10.1017/S0252921100105585 Published online by Cambridge University Press

2. The two–dimensional model

For our model we assume a black–body radiation source with effective temperature $T^* = 1.5 \cdot 10^5$ K and radius $R^* = 9 \cdot 10^8$ cm. At a distance p from this hot star, a cool giant is losing mass through a stellar wind. For the wind velocity at the distance r from the cool star, we choose the usual expression

$$v(r) = v_\infty \left(1 - \frac{R}{r}\right)^\beta \quad , \tag{1}$$

$R = 3.5 \cdot 10^{12}$ cm being the radius of the cool star. The terminal wind velocity $v_\infty =$ 80 km/s is chosen to fit the observed line width. The adopted value for v_∞ is typical for a K star (Reimers 1977). The classification of the cool component in HBV 475 is controversial. Dean and van Citters (1970) claim a spectral type no later than K5 whereas Andrillat (1982) specifies the spectral type as M4 III. For lack of a reasonable wind driving mechanism, the extension parameter β is set equal to 1 . With a constant mass loss rate $\dot{M} = 1.4 \cdot 10^{-7} M_\odot/\mathrm{yr}$, the number density $N(r)$ of the atoms in the wind is

$$N(r) = \frac{\dot{M}}{4\pi r^2 \ \mu \ m_H \ v_\infty \ (1 - \frac{R}{r})^\beta} \quad , \tag{2}$$

where m_H is the mass of a hydrogen atom and $\mu = 1.44$ is the mean atomic weight, determined by the elemental abundances.

In Figure 1 we show isocontours of line emissivities in the orbital plane. Such plots are very helpful to obtain a feeling for the shape of the ionized part of the wind. Nevertheless, they are somewhat misleading in connection with the total line fluxes because of the volume scaling effect. To obtain these two–dimensional emissivities, we calculate the ionization structure for a suitable set of radiation directions with their origin in the hot star. For the final model, the ionization structures and the line and continuum emissivities are calculated along 26 radiation paths (see Fig. 1.a), with an improved and faster version of the procedure described by Nussbaumer and Schild (1981). For every direction, the emissivities are determined for $\approx 100 \div 200$ radial points, depending on the density profile along the path. For the remaining points in the plane, the emissivities are determined by interpolation.

The shape of the ionized wind is essentially dictated by the rate and spectral distribution of the ionizing photons from the hot source, the binary separation and the density structure. Nussbaumer and Vogel (1986) show a sample of possible geometries for such models of symbiotic systems. Seaquist et al.(1984) and Taylor and Seaquist (1984) calculated the emergent radio spectrum and the resulting spectral indices for similar models by representing the ionized portion of a pure hydrogen wind with a one parametric function.

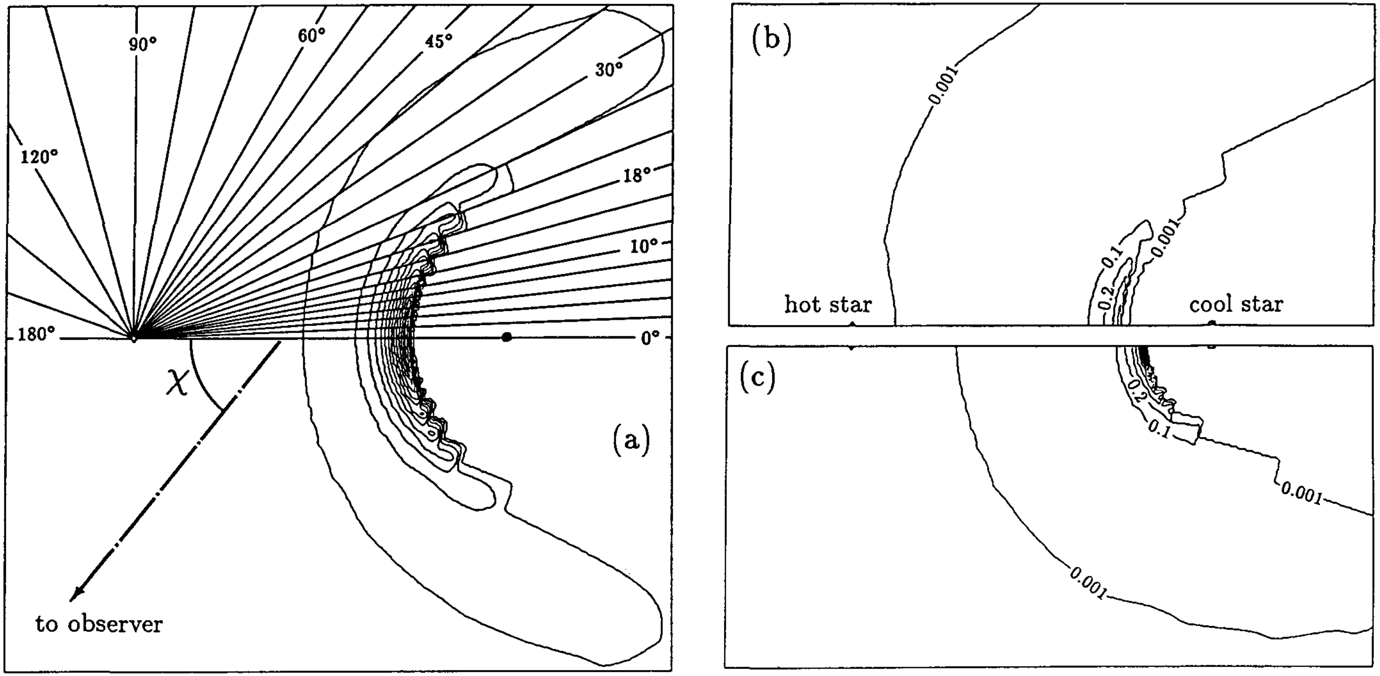

Figure 1. Contours of equal emissivity for N V $\lambda1239$ (a), He II $\lambda1640$ (b) and $H\beta$ (c). The selected set of radiation–paths and the definition of the viewing angle χ are also indicated in (a). The binary separation is $p = 4 \cdot 10^{13}$ cm. The emissivities are normalized, such that the maximum values is 1 for $H\beta$, which results in a maximum value of 0.45 for He II $\lambda1640$.

https://doi.org/10.1017/S0252921100105585 Published online by Cambridge University Press

3. Line Profiles

Since our model is axially symmetric in respect to the line connecting the two stars, we can calculate the resulting line profiles with the help of the above described emissivities. We assume that every point in the system contributes a velocity–shifted Doppler profile. The velocity–shifts depend on the velocity field of the stellar wind and the viewing angle. Due to the axisymmetry of the problem, the observers position can be defined with a single angle χ (see Fig. 1.a). In Figure 2 we show calculated line profiles of Hβ for two values of the separation p and three viewing angles χ. For $\chi = 0°$ the main emitting region moves towards the observer, yielding an asymmetric blue–shifted line, whereas the profiles are symmetric for $\chi = 90°$ because of the axisymmetry of the system. To fit the observed line profiles, we should find a consistent orientation of the system relative to the observer, such that the time dependent angle $\chi(t)$ accounts for the varying asymmetry of the line profiles, whereas the binary separation $p(t)$ causes the flux variation. With an orbit excentricity of $\epsilon = 0.3$ (Nussbaümer et al. 1986), we have not yet found a way for reproducing the desired relative flux variation (e.g. a factor 4 for the He II λ1640 line flux) . In Figure 3 we compare observed IUE high resolution spectra with calculated He II λ1640 line profiles. We can always reproduce the observed strength and profile for epochs near maximum brightness (phase 0.5). Near minimum, the calculated line fluxes of He II λ1640 are too strong by about a factor 2 and the line profiles are shifted to the red compared with observations.

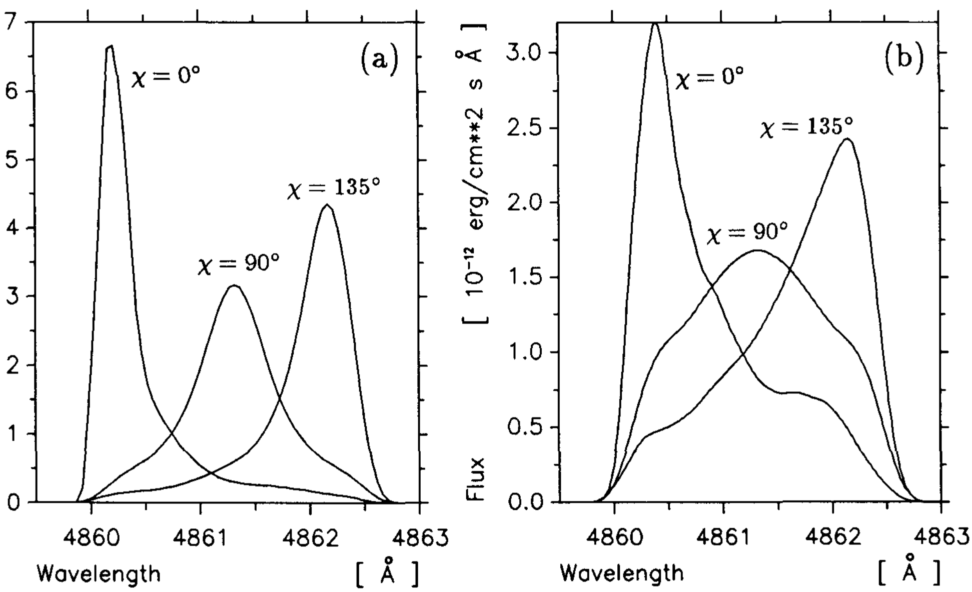

Figure 2. Calculated Hβ profiles for viewing angle $\chi = 0°, 90°$ and $135°$ and two binary separations $p = 4 \cdot 10^{13}$ cm (a) and $p = 6 \cdot 10^{13}$ cm (b).

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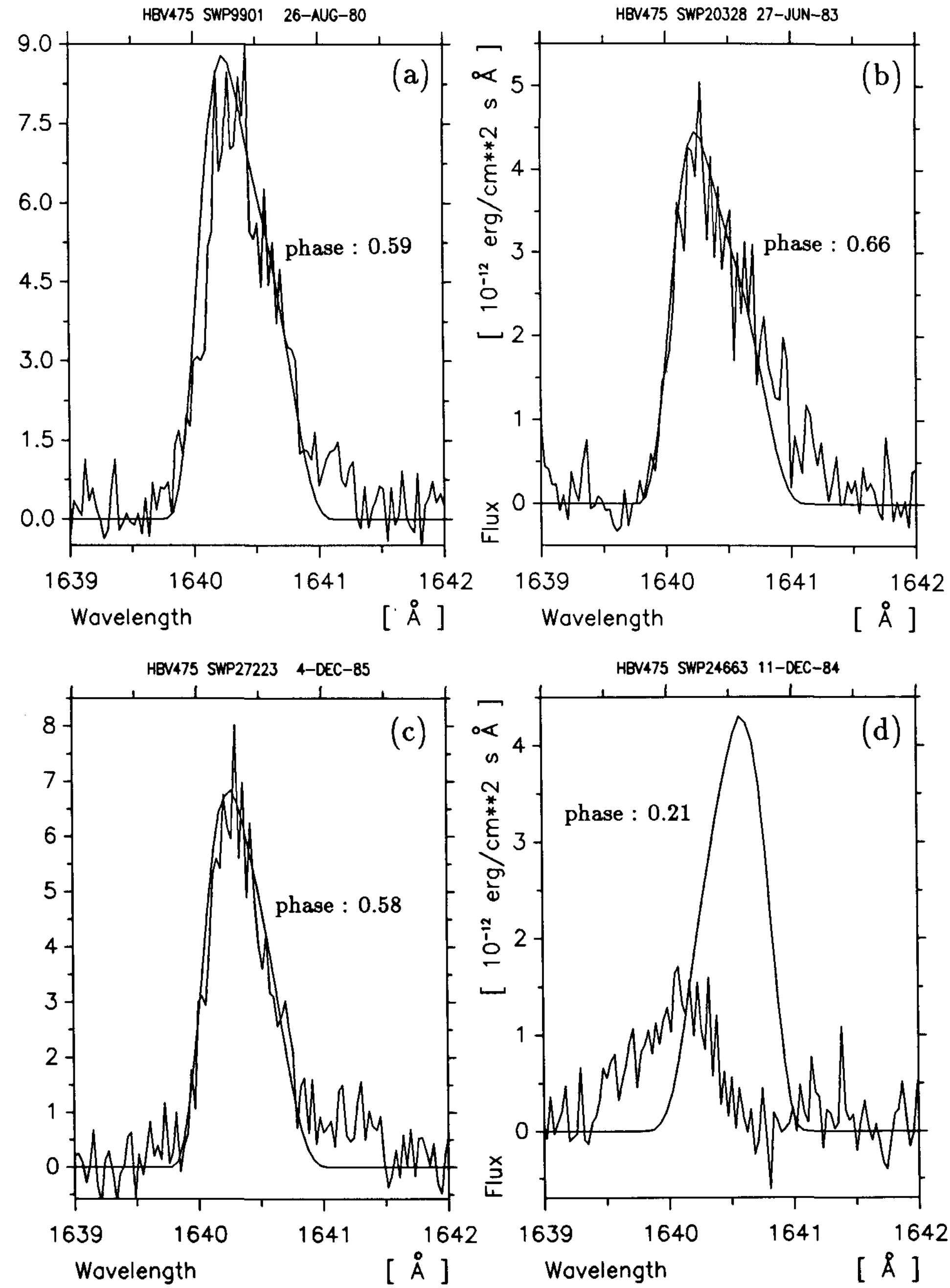

Figure 3. Comparison of calculated and observed line profiles for He II $\lambda1640$ around maximum epoch (a),(b),(c) and minimum epoch (d).

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4. Conclusions

In this brief description we have not followed up all the implications of our model. For instance, during one period the ionized portion of the wind travels around the mass losing star. Since a typical recombination time is $\tau = \frac{1}{N_e \cdot \alpha}$ (recombination coefficients α are of the order $5 \cdot 10^{-13}$ cm^3 s^{-1}) and N_e varies approximately as r^{-2}, there is a distance, where the recombination time exceeds the orbital period of 964 days. Hence, there might be an ionized bubble surrounding HBV 475, where part of the line flux could be absorbed. Our model is a good alternative to the more popular models for symbiotic stars, since it can explain :

(i) the observed spectrum of HBV 475 from the UV to the radio region

(ii) the asymmetric line profiles near maximum phase

(iii) the outbreak of symbiotic systems by a sudden increase of the mass loss rate.

The main weakness of our model for HBV 475 is, that we cannot yet reproduce, together with (i), a sufficiently high line flux variation.

Acknowledgements: We thank H.Nussbaumer for stimulating discussions and the *Schweizerische Gesellschaft für Astrophysik und Astronomie* for financial support which enabled us to attend this colloquium.

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