Stellar Atmosphere and Accretion Disk Models for the Hot Component in Symbiotic Stars

Klaus Werner\textsuperscript{1}, Jochen L. Deetjen\textsuperscript{1}, Stefan Dreizler\textsuperscript{1}, Thorsten Nagel\textsuperscript{1}, Thomas Rauch\textsuperscript{2,1}

\begin{itemize}
  \item \textsuperscript{1}Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, 72076 Tübingen, Germany
  \item \textsuperscript{2}Dr. Remeis-Sternwarte, Universität Erlangen-Nürnberg, Sternwartstr. 7, 96049 Bamberg, Germany
\end{itemize}

Abstract. We describe our NLTE codes which allow the computation of synthetic spectra of hot stars and accretion disks. They can be combined to compute ionizing fluxes from the hot component in symbiotic stars.

1. Introduction

Symbiotic stars are interacting binaries with a relatively large separation when compared to cataclysmic variables. Their orbital periods are of the order of months up to many decades. Symbiotic binaries consist of a cool giant star and a hot ionizing radiation source (see e.g. Kenyon 2001). The giant looses mass by a wind and not by Roche-lobe overflow (Müser & Schmid 1999) at a rate of typically $10^{-6}$ M$_\odot$yr$^{-1}$. Only a few percent of this amount is accreted by the companion. The hot component (in quiescent symbiotics) is in most cases a hot white dwarf. Two known systems are hard X-ray sources and contain accreting neutron stars (Chakrabarty & Roche 1997, Masetti et al. 2002). It is not clear if an accretion disk is present in all systems. The possible formation of stable disks is supported by hydrodynamic simulations (Mastrodemos & Morris 1998, Dumm et al. 2000).

The observed high luminosity of the hot component is generated by mass accretion from the giant wind. An accretion rate of $\dot{M} \approx 10^{-7}$ M$_\odot$yr$^{-1}$ onto a white dwarf yields a luminosity of 100 L$_\odot$. It is believed that hydrogen shell burning of the accreted material can be sustained above the white dwarf core and in this case $\dot{M} \approx 10^{-8}$ M$_\odot$yr$^{-1}$ is sufficient to generate that amount of luminosity.

The white dwarf is dominating the hot component in those symbiotics where steep UV continua are observed. The derived white dwarf parameters are $R \approx 0.1$ R$_\odot$, $M = 0.5$–1 M$_\odot$, and the effective temperatures range between $T_{\text{eff}} = 30\,000$ up to 200\,000 K (see e.g. Müser et al. 1991). The accretion disk is probably dominant in about 10\% of the systems with flat UV continua (Kenyon 2001). The disk temperature reaches 100\,000 K at the inner boundary layer and decreases outwards.

It is obvious that the analysis of emission line spectra from symbiotic stars requires a realistic modeling of the white dwarf and the disk. Occasionally, the collision of winds from the white dwarf and the disk as well as jets can contribute
significantly to the ionizing radiation. In the following we present our approach to calculate synthetic spectra of the hot component. In Sect. 2, we describe the construction of white dwarf and neutron star NLTE model atmospheres, assuming planar geometry and hydrostatic equilibrium. Then we present our method to compute NLTE disk models, which assume a radial Keplerian \( \alpha \)-disk structure and a detailed vertical structure (Sect. 3.). Up to now we are neglecting stellar winds and disk winds. We also disregard jets which are observed in some symbiotics and which could result from outbursts, disk instabilities, or very high accretion rates.

2. Stellar Atmosphere Models

Our computer code calculates plane-parallel, hydrostatic NLTE models in radiative equilibrium. It uses an Accelerated Lambda Iteration (ALI) technique and it is described in detail by Werner & Dreizler (1999) and Werner et al. (2002). The code solves self-consistently the equations of radiation transfer, hydrostatic and radiative equilibrium, particle conservation, and the NLTE rate equations for the atomic levels populations. Full NLTE line blanketing is possible. Iron group elements are included by a statistical approach (superlevels and -lines) and an opacity sampling method. Basic input parameters are \( T_{\text{eff}} \), \( \log g \), and the chemical composition. The code computes the atmospheric structure and an emergent spectrum. It is routinely used for the spectral analysis in the X-ray to IR spectral regions of many objects: Central stars of planetary nebulae, white dwarfs, and subdwarfs. For white dwarfs element diffusion strongly affects the (E)UV flux, however, this is unimportant for accreting white dwarfs because of the short diffusion time scales. This process could only play a role when accretion were shut off over a period of many years. We have successfully computed and applied such models (Dreizler & Wolff 1999, Schuh et al. 2002). Some symbiotic systems harbor a magnetic white dwarf. In these cases as well as in the systems with neutron star components the magnetic field affects the emergent stellar spectrum. A polarized radiation transfer calculation is possible with an extension of our code (Deetjen et al. 2002). We already applied our code to the analysis of UV and X-ray data from symbiotic stars (Jordan et al. 1994, 1996).

An extensive grid of stellar fluxes, also relevant for white dwarfs in symbiotic systems, is available from \texttt{http://astro.uni-tuebingen.de/~rauch/} (Rauch 2002). The data have been calculated for photoionization modeling, in particular with the CLOUDY code (Ferland et al. 1998).

3. NLTE Accretion Disk Models

A new computer code, that has been developed from the stellar atmosphere code described above, calculates disk spectra under the following assumptions (for more details see Nagel et al. (2002) and in this volume). The radial disk structure is computed assuming a stationary, Keplerian, geometrically thin \( \alpha \)-disk (Shakura & Sunyaev 1973). This model is fixed by four global input parameters: Stellar mass \( M_\star \), and radius \( R_\star \) of the accretor, mass accretion rate \( \dot{M} \), and the viscosity parameter \( \alpha \). For numerical treatment the disk is divided into a
number of concentric rings. For each ring with radius $R$ our code calculates the
detailed vertical structure, assuming a plane-parallel radiating slab (in analogy
to a stellar atmosphere).

In contrast to a (planar) stellar atmosphere, which is characterized by $T_{\text{eff}}$
and $\log g$, a particular disk ring with radius $R$ is characterized by the following
two parameters, which follow from the global disk parameters introduced above.
The first parameter measures the dissipated and then radiated energy. It can be
expressed in terms of an effective temperature $T_{\text{eff}}$:

$$T_{\text{eff}}^4(R) = \frac{3GM\dot{M}}{8\sigma \pi R^3} \cdot (1 - R_*/R)^{1/2}. $$

The second parameter is the surface mass density $M$ of the disk ring:

$$M(R) = [1 - (R_*/R)^{1/2}] \frac{\dot{M}}{3\pi \bar{w}}. $$

$\sigma$ and $G$ are the Stefan-Boltzmann and gravitational constants, respectively. $\bar{w}$
is the depth mean of viscosity $w(z)$, where $z$ is the height above the disk mid-
plane. The viscosity is given by the standard $\alpha$-parametrization as a function of
the total (i.e. gas plus radiation) pressure, but numerous other modified versions
are used in the literature. We use a formulation involving the Reynolds number,
as proposed by Kriz & Hubeny (1986) and Hubeny & Hubeny (1998).

The radiation transfer equations plus vertical structure equations are then
solved like in the stellar atmosphere case, but accounting for two basic differ-
ences. First, the gravitational acceleration (entering the hydrostatic equation)
is not constant with depth, but increases with $z$. This is simply the vertical
component of the gravitational acceleration exerted by the central object (self-
gravitation of the disk is negligible):

$$g = z \frac{GM_*}{R^3}. $$

Second, the energy equation for radiative equilibrium balances the dissipated
mechanical energy and the net radiative losses:

$$\frac{9}{4} \rho w \frac{GM}{R^3} = 4\pi \int_0^{\infty} (\eta_{\nu} - \kappa_{\nu} J_{\nu}) d\nu,$$

where $\rho$, $\eta$, $\kappa$, $J$ denote mass density, opacity, emissivity and mean intensity,
respectively. In the case of a stellar atmosphere the left-hand side of this equation
vanishes and we get the usual radiative equilibrium equation.

The total observed disk spectrum, which depends on the inclination angle,
is finally obtained by intensity integration over all rings accounting for rotational
Doppler effects.

4. Summary and Outlook

We have modeling tools at hand which can be used to calculate ionizing spectra
of the hot component in symbiotic stars. We can compute synthetic spectra
emerging from the white dwarf (or neutron star) and from the accretion disk.
Our immediate aim for the near future is the inclusion of irradiation effects of the
stellar spectrum onto the disk. We also want to include effects of a disk wind
onto the emergent spectrum. Wind models for the compact star are already
available (see e.g. Jordan et al. 1996) and must be utilized at least for analyses
of those symbiotic systems where hot stellar winds are observed (Schmid 2000).
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References

Chakrabarty, D., & Roche, P. 1997, ApJ, 489, 254
Deetjen, J. L., Dreizler, S., Jordan, S., & Werner, K. 2002, in Stellar Atmosphere Modeling, ed. I. Hubeny, D. Mihalas, & K. Werner, The ASP Conference Series, in press
Dreizler, S., & Wolff, B. 1999, A&A, 348, 189
Dumm, T., Folini, D., Nussbaumer, H., Schild, H., Schmutz, W., & Walder, R. 2000, A&A, 354, 1014
Ferland, G. J., Korista, K. T., Verner, D. A., & Ferguson, J. W., Kingdon, J. B., & Verner, E. M. 1998, PASP, 110, 761
Hubeny, I., & Hubeny, V. 1998, ApJ, 505, 558
Jordan, S., Mürset, U., & Werner, K. 1994, A&A, 283, 475
Jordan, S., Schmutz, W., Wolff, B., Werner, K., & Mürset, U. 1996, A&A, 312, 897
Kenyon, S. 2001, in Encyclopedia of Astronomy and Astrophysics, IOP Publishing Ltd. and Nature Publishing Group, 3262
Kriz, S., & Hubeny, I. 1986, Bull. Astron. Inst. Czechoslovakia, 37, 129
Mastodemos, N., & Morris, M. 1998, ApJ, 497, 303
Mürset, U., & Schmid, H. M. 1999, A&AS, 137, 473
Mürset, U., Nussbaumer, H., Schmid, H. M., & Vogel, M. 1991, A&A, 248, 458
Nagel, T., Dreizler, S., & Werner, K., 2002 in Stellar Atmosphere Modeling, ed. I. Hubeny, D. Mihalas, & K. Werner, The ASP Conference Series, in press
Rauch, T. 2002, in Ionized Gaseous Nebulae, ed. W. J. Henney, J. Franco, M. Martos, & M. Peña, RevMexAA Conf. Series, 12, 150
Schmid, H.M. 2000, in Thermal and Ionization Aspects of Flows from Hot Stars, ed. H. Lamers & A. Sapar, ASP Conference Series, 204, 303
Schuh, S. L., Dreizler, S., & Wolff, B. 2002, A&A, 382, 164
Shakura N. I., & Sunyaev R. A. 1973, A&A, 24, 337
Werner, K., & Dreizler, S. 1999, in Computational Astrophysics, ed. H. Riffert, & K. Werner, Journal of Computational and Applied Mathematics, 109, 65
Werner, K., Deetjen, J. L., Dreizler, S., Nagel, T., Rauch, T., & Schuh, S.L. 2002, in Stellar Atmosphere Modeling, ed. I. Hubeny, D. Mihalas, & K. Werner, The ASP Conference Series, in press