Synthetic spectra of A supergiants

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Abstract. Stellar winds of A supergiants can have a significant influence on their emergent spectra. Here we present the hydrogen line profiles of a model based on the stellar parameters of HD12953. The radiative transfer equation is solved in two dimensions in axial symmetry. We don't include the velocity field by the Sobolev approximation, but in detail using the Lorentz transformation. This allows us to correctly include the stellar wind, since the velocity gradient in A supergiants is too small for the Sobolev approximation to be valid.

1. Introduction

A supergiants are slowly rotating stars (usually less then 50 km s\textsuperscript{-1}) with stellar winds. Due to the stellar wind the strong lines show P Cygni profiles and the weak lines are asymmetric. The stellar spectra as well as the photometry show variability. The first synthetic spectra of A supergiants were calculated by Wolf (1971, 1972) and Parsons \\& Peytremann (1973). They assumed plane-parallel geometry and the atmosphere in hydrostatic equilibrium and in LTE. They did not include line blanketing. Later the Kurucz (1993) models, which include this effect (e.g. Verdugo et al., 1999), were used. A better approximation was made by Przybilla (2002), who used the LTE model atmosphere, but he calculated the emergent spectra from the solution of the equations of statistical equilibrium. The first attempt to solve the wind of A supergiant together with photospheric layers has been done by Aufdenberg et al. (2002). Since A supergiants have stellar winds with a very low velocity gradient, the condition for Sobolev approximation is not fulfilled there. We present here a method for solving the radiative transfer equation that is appropriate for this case.

We present the results where the influence of the velocity field on the spectral lines of the star is modeled, with the parameters corresponding to HD 12953. This star is an A supergiant with an effective temperature of 9100 K, a radius of 145R\textsubscript{\odot} and a mass of about 9.7M\textsubscript{\odot} (Kudritzki et al., 1999).

2. Description of models

Our calculations are based on two numerical models. The state parameters, electron density and temperature, are obtained using the hydrostatic spherically symmetric model atmosphere code ATA (see Kubát 2003). These parameters serve as the input data to the 2D radiative transfer code (Korčáková, 2003), which solves the equation of radiative transfer.
2.1. **Hydrostatic code**

The code calculates spherically symmetric static NLTE model atmospheres. It solves the equations of hydrostatic, radiative, and statistical equilibrium. The radiation field is accounted for using the method of approximate lambda operators. During the formal solution step the static spherically symmetric radiative transfer equation is solved using Feautrier variables. The temperature structure is calculated with the help of the electron thermal balance method (Kubát et al., 1999). Although the code is able to include an arbitrary number of chemical elements, for simplicity, we used a pure hydrogen model here.

2.2. **Solution of the radiative transfer equation**

We assume axial symmetry for the solution of the radiative transfer equation. The transfer problem is solved independently in longitudinal planes, which intersect the star (Fig. 1). The whole radiation field is obtained by rotating these planes around the axis of symmetry (Fig. 2). In each plane the transfer problem is solved using a combination of the short and long characteristic method (Fig. 3).

The ray starts and ends at the grid circle (Fig. 3), so it is possible to intersect more cells. This allows us to include the global character of the radiation field better. The
The scheme for calculating the whole radiation field.

Transfer equation is then calculated along the selected rays

$$I_{(B)} = I_{(A)} e^{-\Delta \tau_{(AB)}} + \int_0^{\Delta \tau_{(AB)}} S(t) e^{-\Delta \tau_{(AB)} t} dt.$$  \hspace{1cm} (2.1)

The interval $AB$ is a section of the ray, which is in one cell. We assume the source function as well as the opacity to change linearly within this interval.

In every cell we assume a constant velocity and its change is permitted only at the boundary of cells. This approximation allows us to solve the static equation of radiative transfer in the cells. At the cell boundaries we perform the transformation of frequency (it is possible to neglect the transformation of intensity in this case due to the small velocity gradient). A more detailed description of the method will be published elsewhere (Korcáková & Kubat, 2004).

3. Results

The aim of this paper is to show the ability to calculate synthetic spectra of an expanding A supergiant atmosphere. We consider the spherical symmetry, although it is not necessary for the radiative transfer code. Since we do not have a consistent radiative hydrodynamics model of the wind, we used as input a model derived from the hydrostatic code by multiplying the radius scaled by

$$r_{new} = d^{16} r_{old}(d),$$

where $d = 1 \ldots ND$ is the index of the depth point, to obtain an observable P Cygni profile. We adopt the beta
velocity law (see, e.g., Cassinelli & Lamers, 1999)

\[ v(r) = v_\infty \left\{ 1 - \left[ 1 - \left( \frac{v_R}{v_\infty} \right)^\beta \right] \frac{R}{r} \right\}^\beta, \]  

(3.1)

with parameter \( \beta = 1 \) and the terminal velocity \( v_\infty = 280 \text{ km} \cdot \text{s}^{-1} \) for the velocity field. We choose the velocity in the photosphere \( v_R = 0.2 \text{ km} \cdot \text{s}^{-1} \). This is not a physically consistent model, however, we want to present the new method for solving radiative transfer. Currently we are working on coupling this code with the hydrodynamic one described in Krtička & Kubát (2004).

In Fig. 4 the H\( \alpha \) line profile obtained from our code is plotted. This line shows the P Cygni profile, which is observed in HD 12953. Since we don’t take the input data from the hydrodynamic model, and we don’t include NLTE effects, our line is weaker than in the observed spectrum (where the relative intensity in emission is 1.62). Note that the system of equations of the statistical equilibrium is included in our code. However, even
4. Conclusion

We present here a new method for solving the radiative transfer equation in axial symmetry, which includes the velocity field.

Our method considers a constant value of velocity in the cells and permits the change of velocity only at the cell boundaries. This approximation allows us to include the small velocity gradients as well as the high ones (but not relativistic) in stellar wind of hot stars. The calculated Hα line profile of the P Cygni type is plotted in Fig. 4.

Our code is appropriate for calculating of flux in lines formed in rotating winds. Since these stars have extended atmospheres, the emission region is too large for the approximation of radiative transfer using the plane-parallel model, however a full 3D calculation is not necessary. This code is also applicable to a solution of the radiative transfer equation in accretion discs (Korcáková et al., 2004). In this case, it is possible to include not only the radiation from the central object and the discs itself, but also from the hot corona and wind from the inner parts of the disc.
**Figure 5.** Limb darkening in the H\(\alpha\) line.

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**References**


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