Synthetic spectra of A supergiants

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Stellar winds of A supergiants can have a significant influence on their spectra. Here we present the hydrogen line profiles of a model based on the stellar parameters of HD 12953. 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.

Introduction

A supergiants are slowly rotating stars (usually less then 50 $\mathrm{km}\cdot\mathrm{s}^{-1}$) 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 synthetic spectra of these objects were calculated by a number of different authors using the simplified assumption of a plane parallel atmosphere (e.g. Przybilla at al., 2000). Since A supergiants have stellar winds with a very low velocity gradient, the condition for Sobolev approximation is not valid. 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 $9100K$, a radius of $145R_\odot$ and a mass of about $9.7M_\odot$.

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 by J. Kubát (2003). These parameters serve as the input data to the 2D radiative transfer code (Korčáková, 2003), which solves the equation of radiative transfer.

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.

solution of the radiative transfer equation

We assume axial symmetry. The transfer problem is solved independently in longitudinal planes, which intersect the star (Fig. 1).

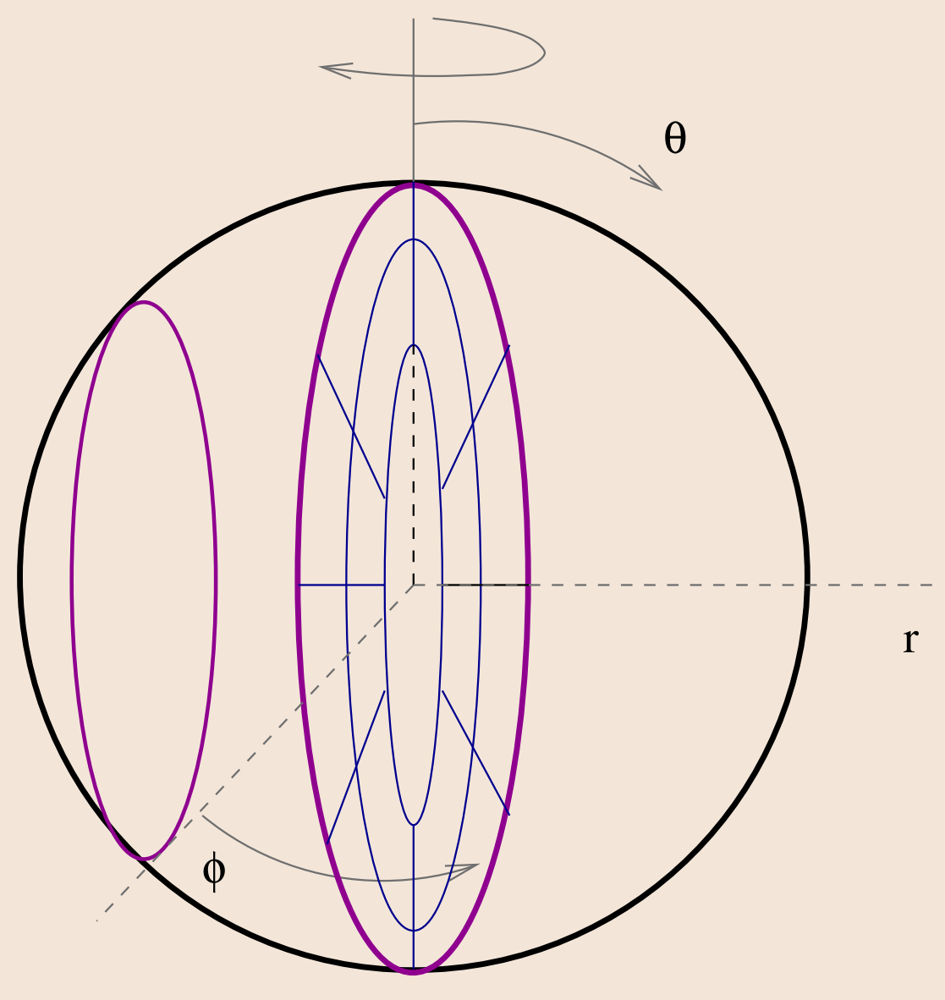

Figure 1: The scheme of the set of longitudinal planes.

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, so it's possible to intersect more cells. This allows us to include the global character of the radiative field better.

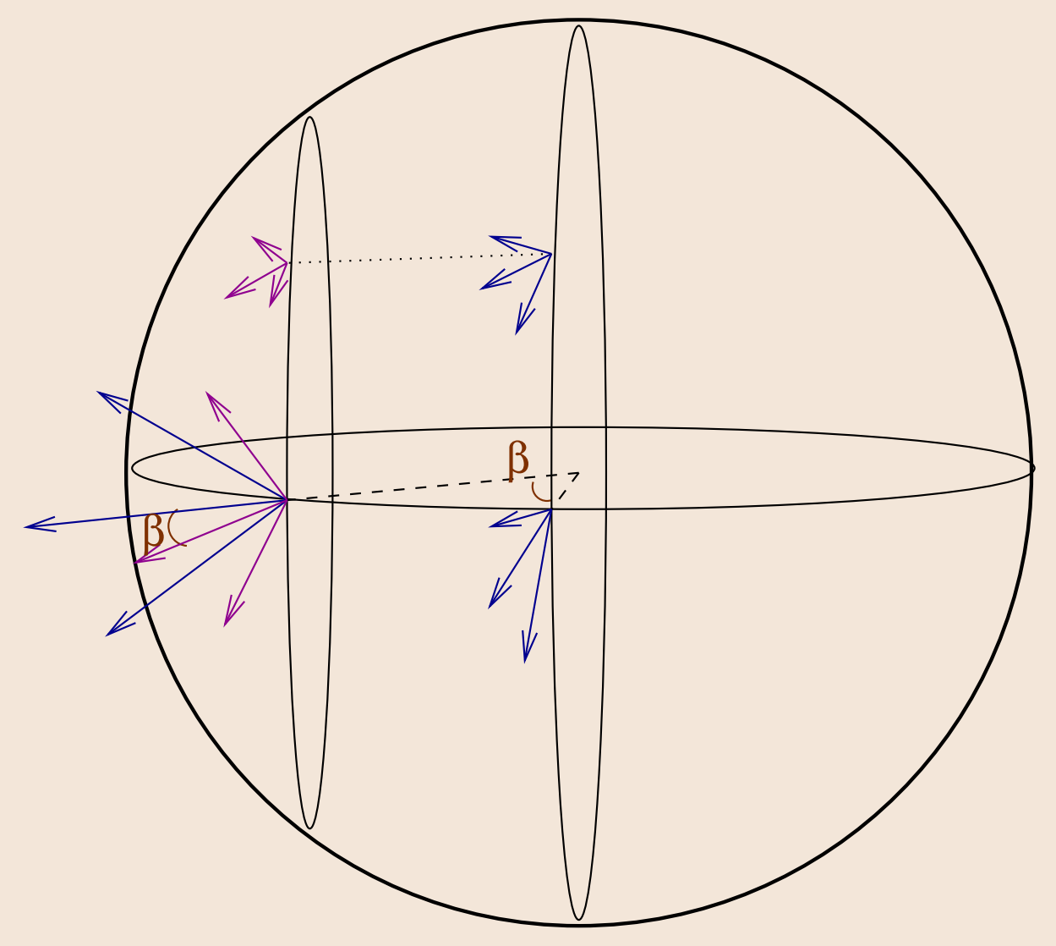

Figure 2: The scheme for calculating the whole radiation field.

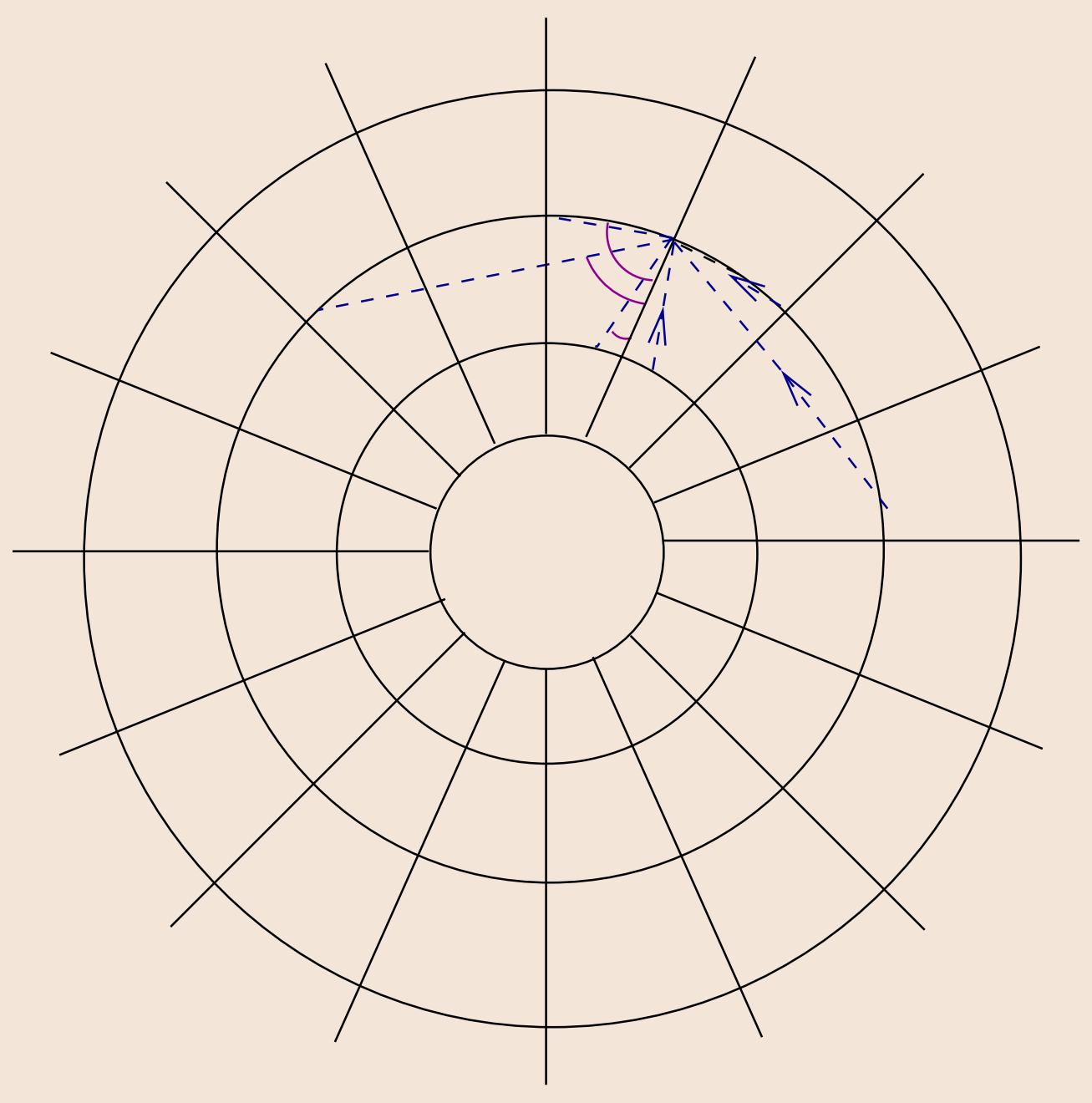

Figure 3: The scheme for solving the radiative transfer in the longitudinal plane.

The transfer equation is then calculated along the selected rays

$$I_{(B)} = I_{(A)}e^{-\Delta\tau_{(AB)}} + \int_0^{\Delta\tau_{(AB)}} S(t)e^{[-(\Delta\tau_{(AB)}-t)]}dt. \qquad (1)$$

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).

Results

The aim of this poster is to show the ability of calculating synthetic spectra of an expanding A supergiant atmosphere. 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 $r^{new}(d) = d^{1.16}r^{old}(d)$, to obtain the observable P Cygni profile. 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 Hα 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, a purely formal solution in the 2D case with velocity fields is very time consuming. Thus for demonstration purposes we preferred the faster LTE variant to save some computing time.

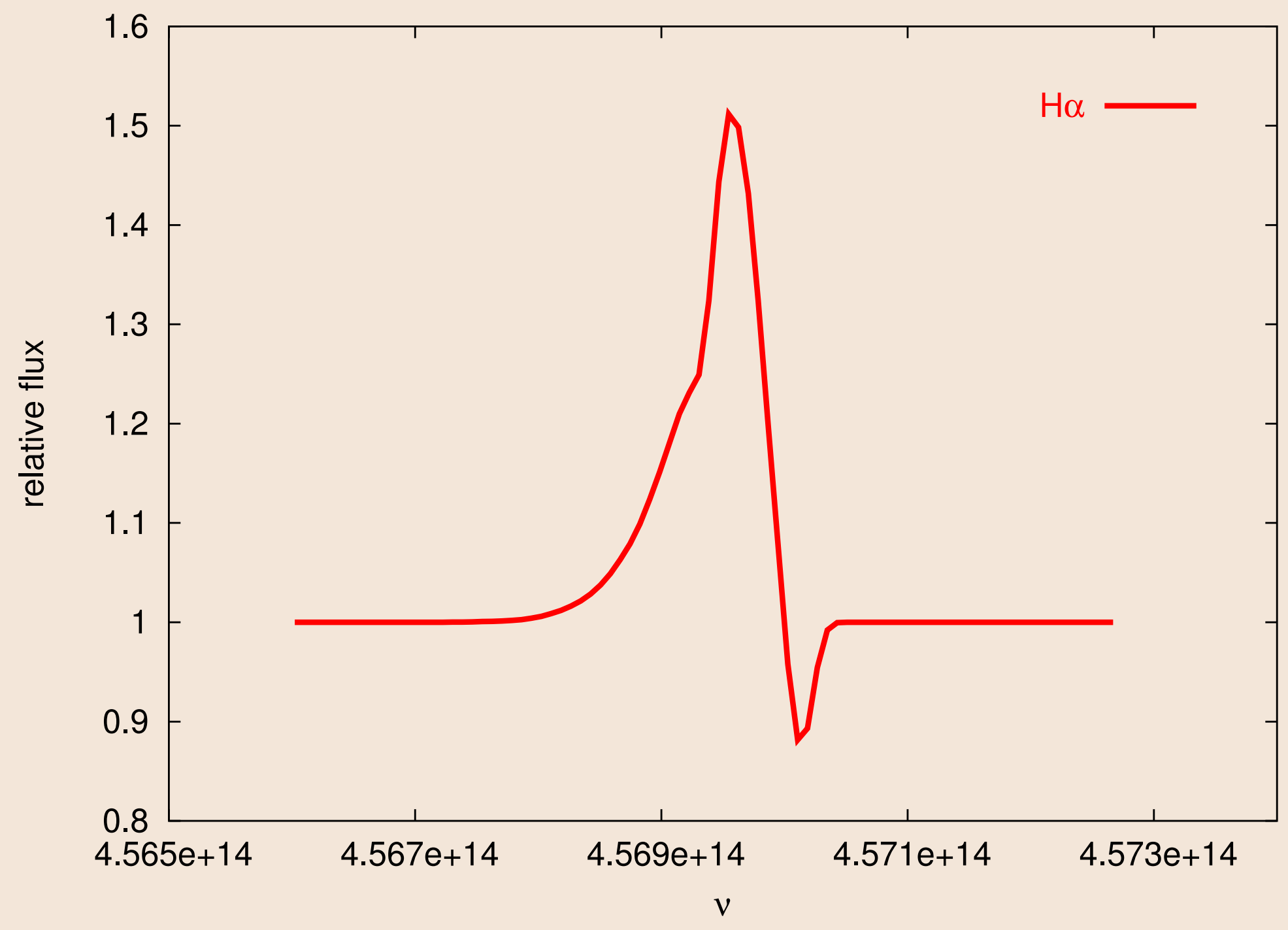

Figure 4: Hα line profile.

In the next Fig. (5) we show the limb darkening. The emission comes from the far extended region. Note, if we want to describe stellar rotation in such an extended atmosphere, we have to use a more accurate method than the simple convolution of static and rotation profiles. Failing to do this we will obtain wrong value of rotation velocity. Our code is able to solve the transfer problem in rapidly rotating stars, too.

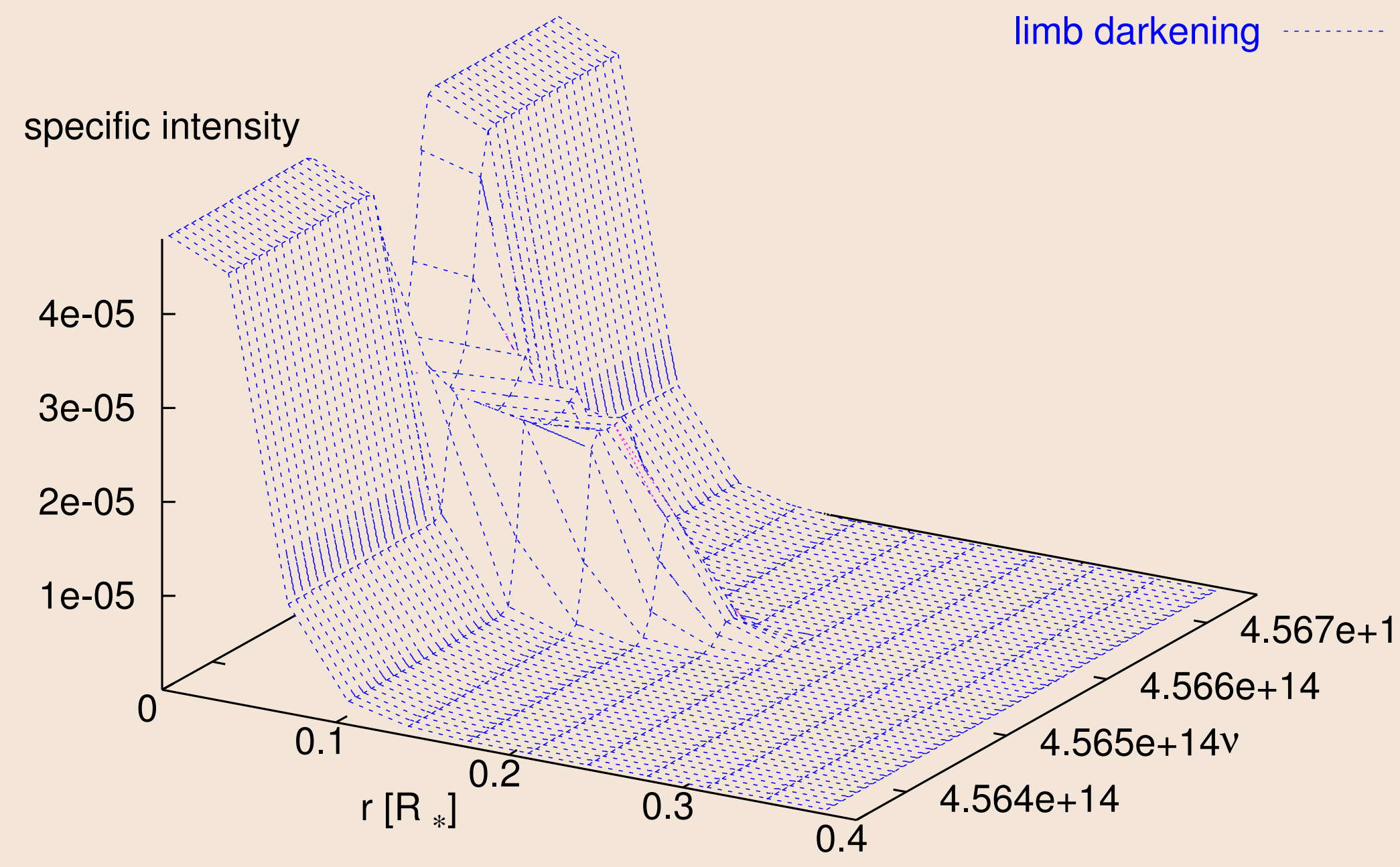

Figure 5: Limb darkening in the Hα line.

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 research was supported by GAČR grants 205/02/0445, 205/04/P224 and 205/04/1267.

References

Korčáková, D., 2003, NLTE Models of Moving Stellar Atmospheres, PhD thesis, Masaryk University, Brno
Krtička, J., & Kubát, J., 2004, A&A 417, 1003
Kubát, J., 2003, in *Modelling of Stellar Atmospheres*, IAU Symp. 210, N. E. Piskunov, W. W. Weiss & D. F. Gray eds., ASP, A8
Kubát, J., Puls, J., Pauldrach, A. W. A., 1999, A&A, 341, 587
Przybilla, N., Butler, K., Becker, S. R., Kudritzki, R. P., Venn, K. A., 2000, A&A, 359, 1085

Poster presented at the IAU Symposium 224 "The A Star Puzzle", 8 – 13 July 2004, Poprad, Slovakia