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Emergent line profiles from rapidly rotating stars

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Abstract. We present theoretical line profiles emerging from rapidly rotating stars calculated using our multidimensional radiative transfer code. The radiative transfer equation is solved in axial symmetry and the velocity field in the whole photosphere is taken into account.

Key words. Radiative transfer – Methods: numerical – Stars: rotation – Lines: profiles

1. Introduction

Emergent line profiles from stars are significantly affected by macroscopic motions. One of the most important motions is stellar rotation. Although rotation is present in every star, it is usually taken into account only in a very approximate manner. The fast rotation significantly affects the shape of the stellar surface as well as the surface temperature distribution.

2. Description of models

Our calculations are based on a combination of two stellar atmosphere models.

hydrostatic model: The state parameters along the axis of symmetry, electron density and temperature, are obtained using the hydrostatic spherically symmetric model atmosphere code ATA (see Kubát 2003) assuming LTE. The structure at other points is obtained using our "rotation model" described below.

rotation model: We included both gravity darkening coupled with the temperature and density distributions and the differential rotation into our calculations. No longitudinal motions are considered. The equatorial rotational velocity is radius dependent $\mathrm{v}_{\mathrm{rot}}(r) = \mathrm{v}_{\mathrm{rot}}(R)\,(r/R)^{-j}$. R is the polar radius of the star and we use $j = 1$. The rotation velocity $\mathrm{v}_{\mathrm{rot}}(R)$ is chosen to be 0.8 of the critical rotational velocity. For differential rotation we adopt a law derived from solar observations, which can be used for other stars as well (see e.g. Reiners 2003): $\omega(\theta) = \omega_{\mathrm{equator}}\,(1 - \alpha\cos^2\theta)$ (in the spherical coordinate system). Here, ω is the angular velocity, which is constant for every plane parallel to the equator and the parameter α determines the differential rotation. We adopt $\alpha = 0.6$. We obtain the temperature distribution using the von Zeipel (1924) theorem $T_{\mathrm{eff}} \sim g^{\beta}$. We chose $\beta = 1/4$, since this value describes hot stars well enough. The gravitational acceleration is obtained from the gradient of the gravitational potential, $g = |-\nabla\phi|$. For differentially rotating stars

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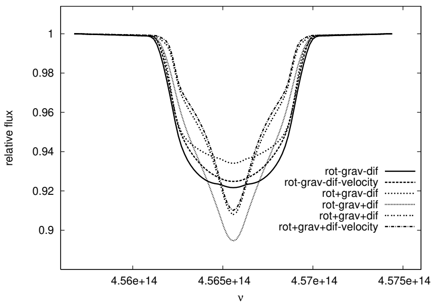

Fig. 2. The Hα line profiles for an extended stellar atmosphere.

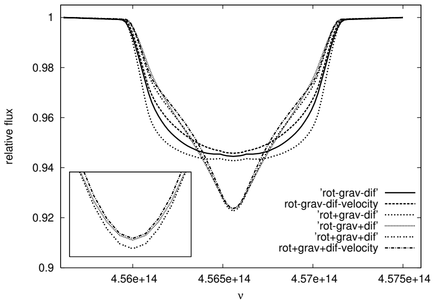

Fig. 1. The Hα line profiles for a thin stellar atmosphere.

$$\phi = \frac{GM}{r} + \frac{1}{2}\,\omega^2_{\mathrm{equator}}(\,1 - \,\alpha\,\cos^2\theta)^2\,r^2\sin^2\theta.$$

The radius dependence is obtained from the condition of constant gravitational potential (Collins 1963)

$$\frac{GM}{r} + \frac{1}{2}\omega^2_{\mathrm{equator}}(1 - \alpha\cos^2\theta)^2 r^2\sin^2\theta = \frac{GM}{r_{\mathrm{pol}}}.$$

We determine the electron density from the condition of the constant electron number in a space volume between equipotentials (this volume is larger for equatorial rotating parts). The distribution of density and temperature obtained serves as input to the 2D radiative transfer code (Korčáková & Kubát 2005), which solves the equation of radiative transfer.

3. Results

We adopt the input stellar parameters T_{eff}=12500 K, $\log g = 4.11$, $M = 3.2 M_\odot$ as an example of a star with a thin atmosphere and T_{eff}=14500 K, $\log g = 3.49$, $M = 4.1 M_\odot$ as an example of a moderately extended atmosphere.

In the Figs. 1 and 2 we plot the Hα line profiles of our model stars. The line profiles are calculated with gravity darkening (+*grav*), differential rotation (+*dif*) included, or excluded ($-$*grav,* $-$*dif*). The lines indicated by "$-$*velocity*" are obtained by neglecting the velocity field in the solution of the RTE. The velocity field is present only in the flux calculation in this case.

4. Conclusion

Using our models we tested the influence of various effects on the line profiles emerging from rapidly rotating stars. The differential rotation changes the line profile similarly in thin as well as in extended atmospheres. This simple statement is not valid for gravity darkening. The latter effect changes the density and temperature structure, and it is impossible to predict its influence on the line profile without any calculations. The difference between the solutions of the RTE with or without a velocity field becomes important for an extended atmosphere where the velocity gradient is larger.

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