Static spherically symmetric NLTE model atmospheres near the Eddington limit

Jiří Kubát
Astronomický ústav, Akademie věd České republiky, CZ-251 65 Ondřejov, Czech Republic

Abstract: Radiative force plays important role in determination the structure of stellar atmospheres. If radiative force overcomes gravity, stellar wind appears. In O and B stars the dominant cored by spectral lines of metals. However, in first stars metals are not present, the radiative force is dominated by continuum hydrogen and helium absorption, and does not overcomes gravity. Since no stellar wind is present in these stars, static model atmospheres are suitable. However, if such star is close to the Eddington limit, the calculation procedure is often unstable.

Introduction

In the course of last 40 years calculation of static model atmospheres became quite usual and almost routine task even for the relatively complicated case of NLTE. Despite the enormous success of these calculations, there are situations, in which codes fail to converge to the correct solution. This may be caused by many reasons, which sometimes even mutually amplify. One of these reasons is a strong radiation field, which even in the static case perturbs the stellar atmosphere close to radiative instability. However, spherically symmetric atmospheres of hot stars are usually unstable even for cases where radiative force calculated for the static case does not overcomes gravity. In the presence of a velocity gradient, radiation, which is absorbed or scattered in spectral lines of metals, adds necessary radiative force thanks to the Doppler effect. Thus static extended spherically symmetric atmospheres of O and B supergiant stars do not correspond to reality. Nevertheless, there exists a class of stars, where metals giving rise to the line force are missing, and neither hydrogen nor helium lines are able to transfer enough momentum to the gas. Since no stellar wind is present in these stars, static model atmospheres are suitable. However, if such star is close to the Eddington limit, the calculation procedure is often unstable.

Calculations

Using our code we calculated a grid of hydrogen-helium spherically symmetric NLTE model atmospheres in hydrostatic and radiative equilibrium. The helium abundance \( Y_H = n_H/n_{\text{tot}} = 0.1 \). We considered 16 level hydrogen atom (15 levels + continuum) and a 50 level helium atom (29 levels of He I + 20 levels of He II + 1 level of He III). Individual hydrogen levels correspond to main quantum numbers \( n = 1, \ldots, 15 \). For He I, all levels up to \( n = 4 \) were taken separately according to the orbital quantum number \( l \), for \( 5 \leq l \leq 9 \) we took 2 averaged levels for each \( n \), one for singlets, one for triplets. The levels of He II were considered similarly as the hydrogen levels, however for \( n = 1, \ldots, 20 \). Details of the model atoms used (oscillator strengths, photodissociation cross sections, collisional excitation and ionization rates, line profiles) can be found in Kubát et al. (1999).

Stellar parameters (radius, luminosity, mass) were taken from two sources. For massive stars (\( M > 100 M_\odot \)) we used parameters from Kudritzki (2002), for less massive stars we calculated models for selected parameters from the evolutionary tracks of Marigo et al. (2001). The basic problem in calculations of static model atmospheres close to the Eddington limit is the fact that during the iteration process radiative force may temporarily exceed gravity. In such case an instability is introduced to the calculation scheme, which results in non-realistic values of density and temperature. To overcome this problem, we started our calculation with models with lower luminosity and after we succeeded to converge such model we were gradually increasing the luminosity until we reached the value which we wanted to model. However, even this procedure sometimes failed, since changes in opacity from iteration to iteration may result in too high values of the radiative force.

The models shown in the Figure 1 are such examples of stars. We succeeded to converge all of them, those ones with highest luminosities using the above described procedure. However, some of them still display susceptible features appearing in the region of formation of the hydrogen Lyman-\( \alpha \) line.

References

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Figure 1: Temperature structure and ratio of radiative force vs. gravitational force of H-He models for parameters from Kudritzki (2002).

Figure 2: Temperature structure and ratio of radiative force vs. gravitational force of H-He model atmospheres of stars for parameters from the evolutionary track \( M = 100 M_\odot \) (Marigo et al., 2001). Stars with lower masses always resulted in a significantly lower radiative force and, consequently, these models converged quickly and without problems. We do not show them here.

Acknowledgements:

This work has been supported by a grant 205/07/0031 (GAČR). The Astronomical Institute Ondřejov is supported by the project AV0Z10030501.

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