NLTE Model Atmospheres for OB Stars

Thierry Lanz

Department of Astronomy, University of Maryland, College Park MD
and NASA Goddard Space Flight Center, Greenbelt MD

Ivan Hubeny

AURA/NOAO, NASA Goddard Space Flight Center, Greenbelt MD

Abstract. We briefly describe various improvements that we have recently implemented in our non-LTE model atmosphere code, TLUSTY. This includes opacity sampling, improved Fe collisional strengths, and resonance-averaged photoionization cross-sections. We have calculated a grid of NLTE, fully-blanketed, model atmospheres covering the range of O to early B-type stars (20,000 \( \leq T_{\text{eff}} \leq 55,000 \)K, 3.0 \( \leq \log g \leq 4.75 \)) with the solar and 1/5 solar metallicity. The models incorporate over 70,000 NLTE atomic levels of about 30 ions of H, He, C, N, O, Ne, Mg, Si, S, Fe and Ni, which are grouped into about 700 superlevels. We compare our predicted EUV fluxes to other existing grids of model atmospheres (Atlas9, CoStar models).

1. Introduction

The extreme-ultraviolet (EUV) flux of hot, O and B-type stars cannot be observed at Earth (apart of the exceptional case of the two early B stars, \( \epsilon \) and \( \beta \) CMa) due to interstellar extinction. Therefore, we have to rely on model atmospheres to predict the EUV flux that is responsible for the photoionization of circumstellar gas. We present in this paper predicted EUV fluxes for a grid of NLTE, line-blanketed model atmospheres calculated with our model atmosphere code, TLUSTY.

2. TLUSTY’s recent upgrades

TLUSTY is based on the hybrid Complete Linearization/Accelerated Lambda Iteration method to calculate NLTE model atmospheres assuming plane-parallel geometry, hydrostatic and radiative equilibria, and including the opacity of millions of atomic lines (Hubeny & Lanz 1995). The code has been improved in numerous ways since then to make it faster and more robust. A full description will be published soon. Here, we describe three recent improvements.
Figure 1. The top two panels illustrate a level of detail with which the radiation field can be represented and the number of atomic lines included in the model atmosphere calculations. The bottom panel shows the flux ratios between model spectra computed with ODF and OS with different steps.

2.1. Opacity Sampling

The opacity of millions of iron lines was described earlier by means of the Opacity Distribution Function (ODF) formalism. This had the marked advantage of a relatively “low” (about 30,000) number of frequencies required to describe the radiation field. On the other hand, treatment of line blends is correct only statistically. We have implemented a second approach, opacity sampling (OS), to improve the description of the line opacity and check the ODF approach. OS is implemented in a flexible manner: the user can define the spectral range and frequency step used to model iron-peak lines. We present an example for a model atmosphere with $T_{\text{eff}} = 35,000$K, log $g = 4.0$ and the solar composition. Fig. 1 shows the model spectrum computed with TLUSTY and OS mode: about 180,000 frequencies are included in the model calculation with a step of 0.75 fiducial Doppler width for iron. The bottom panel compares the predicted emergent UV flux using the two different samplings and the Opacity Distribution Function method. At low resolution, the three model UV spectra agree within few percents; large differences in line strengths (up to 10%) are however found.
2.2. Fe collisional strengths

Collisional strengths between Fe superlevels were estimated using the Van Regemorter (VR) approximation. In an improved version, the collisional strength between two superlevels is estimated by the sum of all contributing transitions between all levels included in these superlevels (VR formula for allowed transitions, Eissner-Seaton formula with $\gamma(T)=0.05$ for forbidden transitions). The improved description results in stronger iron lines, and yields systematically lower iron abundances (up to 0.3 dex).

2.3. RAP cross-sections

The photoionization cross-sections are extracted from the Opacity Project database (Cuoto et al. 1993). We smoothed the cross-sections with a Gaussian ($\delta E = 0.03E$), following Bautista et al. (1998), in order to keep the global effect of the autoionization resonances.

3. A Grid of NLTE Model Atmospheres

We have computed a grid of NLTE, line-blanketed model atmospheres, covering a range in effective temperature and surface gravity typical of O and early B stars. The effective temperature spans a range from 20,000 K up to 55,000 K, with a 5,000 K step. We calculated model atmospheres with $\log g$ between 3.0 and 4.75, although models with high $T_{\text{eff}}$ and low gravity were not calculated because the atmospheres are too close or beyond the Eddington limit.

The model atmospheres include about 700 NLTE (super)levels, representing about 70,000 individual atomic levels. (A superlevel groups several levels close enough in energy so that Boltzmann statistics can be assumed between those individual levels). The following ions are included: H I, He I, He II, C II, C III, C IV, N II, N III, N IV, N V, O II, O III, O IV, O V, O VI, Ne I, Ne II, Ne III, Ne IV, Mg II, Si II, Si III, Si IV, S II, S III, S IV, S V, S VI, Fe III, Fe IV, Fe V, Fe VI, Ni III, Ni IV, Ni V, Ni VI.

These models are currently used to analyze high-resolution, high-quality STIS UV spectra of O stars in the Small Magellanic Cloud. We found a very good agreement between the observed spectra and our model photospheric spectra (excluding obviously wind lines).

Fig. 2 shows the predicted ionizing fluxes from NLTE and LTE line-blanketed model atmospheres. The differences remain mostly within a factor of 2. Our ionizing fluxes agree also within a factor of 2 with the predictions of models incorporating the stellar winds (Schaefer & de Koter 1997, Pauldrach et al. 2000).

References

Figure 2. Predicted ionizing photon fluxes in the hydrogen Lyman continuum for TLUSTY line-blanketed models (line), simple NLTE H-He models (squares), and Kurucz models (diamonds). The bottom panel compares the ionizing photon fluxes of TLUSTY models with NLTE stellar wind models. Lower gravity models have larger ionizing fluxes.