A Grid of Non-LTE Line-Blanketed Model Atmospheres of O Stars

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Abstract. We have built a grid of over 400 NLTE line-blanketed model atmospheres covering the stellar parameter range of O-type stars at 7 different chemical compositions. The model atmospheres assume plane-parallel geometry, radiative, and hydrostatic equilibria. Departures from LTE are allowed for about 100,000 atomic levels, and the blanketing effect of millions of Fe and Ni lines is included. These model atmospheres are available at our Web site, http://tlusty.gsfc.nasa.gov.

1. The Atmospheres of O-Type Stars

The astrophysical importance of O-type stars has long been emphasized, in the context of topics ranging from the evolution of massive stars and their effect on the galactic environment, to tracing young stellar populations in high-redshift galaxies. Their basic properties, and hence our understanding of their evolution, and of their contribution to galactic evolution, are derived from spectrum analyses. These results therefore hinge on our physical understanding of their atmospheres. Modeling the atmospheres of O stars has been an ongoing effort over the past decades because of the complexity of these atmospheres: departures from LTE are prevalent, and a strong stellar wind structures the outer layers. We refer the reader to several papers in this volume for a description of such models (e.g., see Hubeny & Lanz; Hillier; and Hamann). These models have been used in many detailed NLTE model-atmosphere analyses of hot stars, but limited emphasis has been put in constructing grids of models. In this paper, we limit ourselves to the latter goal. A grid of models covering the whole range of O-star parameters is indeed an essential tool for analyzing large stellar samples, or for constructing composite spectra of unresolved stellar populations in distant galaxies.

Kurucz' (1993) extensive grid ranges from O stars to K stars. While he demonstrated the importance of line blanketing, his assumption of LTE is not appropriate for the hotter models (though quite reasonable for cooler models). The CoStar grid (Schaerer et al. 1996) provides models at 2 metallicities along
evolutionary tracks (about 25 models for 2 metallicities), using a number of approximations (Sobolev approximation, ionization of heavy elements following H and He ionization) and prescribed wind parameters. Pauldrach, Hoffmann, & Lennon (2001) have calculated a small grid of models with solar composition, in which the wind structure is solved consistently with an approximate treatment of NLTE line blanketing. Our approach consists in providing a grid of NLTE line-blanketed photospheric models that covers densely the parameter space \((T_{\text{eff}}, \log g, \text{composition})\). With the exception of the very strongest lines in the UV, most spectral features are insensitive to the properties of a wind; therefore these models can be used to derive the basic photospheric properties, in particular the effective temperature scale and the surface abundances, of O-stars.

2. A Brief Description of the Model Atmosphere Code, TLUSTY

TLUSTY is a NLTE model atmosphere code which assumes a plane-parallel geometry, and radiative and hydrostatic equilibria. Departures from LTE are allowed for an arbitrary number of populations. TLUSTY uses a hybrid Complete Linearization/Accelerated Lambda Iteration Method (Hubeny & Lanz 1995) with which we are able to incorporate consistently the effects of thousands of NLTE levels, and of millions of individual lines, in the model atmospheres. All atomic data and opacities included in the models are specified by the user, making TLUSTY a very flexible tool to model widely different objects. The opacity and the radiation field are represented with an Opacity Sampling technique. For details on the treatment of opacities and the general methodology, see the related papers by us in this volume.

3. The Model Atmosphere Grid

The model atmospheres are calculated assuming a plane-parallel geometry, and radiative and hydrostatic equilibria. The models incorporate about 100,000 NLTE atomic levels of over 40 ions of H, He, C, N, O, Ne, Si, P, S, Fe, and Ni, which are grouped into about 900 superlevels. Individual levels in the same superlevel are assumed to follow the Boltzmann statistics relative to one another (i.e., they have the same NLTE departure factor, \(b_j\)). A total of 8000 lines of the light elements are included, as well as 12 million lines from Fe III-VI and Ni III-VI. To represent accurately all these lines, we have adopted a small sampling step, using about 180,000 frequencies over the whole spectrum (Fig. 1).

We have covered the parameter space of O-type stars, with effective temperature ranging from 30,000 K to 55,000 K in 2,500 K steps, and surface gravity in the range \(3.0 \leq \log g \leq 4.75\) in steps of 0.25 dex (see Table 1). Models at the highest temperatures and lowest surface gravities are nearly unstable, being close to the Eddington limit, and have therefore not been calculated. A total of 60 models are available for each chemical composition. Our grid covers compositions from solar down to 1/100 times solar in seven steps. Abundances are scaled to the solar composition. In all cases, we have, however, assumed a solar helium abundance: \(\text{He}/\text{H}=0.1\) by numbers. Non solar-scaled abundances (resulting, e.g., from CNO-cycle processing) can be readily accomodated with TLUSTY;
Figure 1. Model spectrum ($T_{\text{eff}} = 35000 \text{ K}$, $\log g = 4.0$, solar composition) illustrating how the radiation field is represented with Opacity Sampling, and the number of atomic lines included in the model atmosphere calculations. A short section of the spectrum is enlarged in the bottom panel.

however, this increases very quickly the number of models to be computed by adding additional parameters. We view this grid as a starting point, from which detailed abundance analyses can be performed. Finally, we have always assumed a microturbulent velocity, $V_t = 10 \text{ km/s}$. This mimics the desaturation of lines in the photospheric region. Most lines are formed there, where velocities are subsonic, with the exception of a few very strong resonance lines.

The models (vertical structure, spectrum), as well as the current version of the computer code and the atomic data, are available from our Web site (http://tlucent.gsfc.nasa.gov). A detailed description of the models and their properties will be published elsewhere. This grid supersedes a first grid described by Lanz & Hubeny (2001).

Table 1. Range of stellar parameters ($T_{\text{eff}}$, log $g$) in the model grid.

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Figure 2. Best model fit (thin) to the HST/STIS spectrum (thick) of the SMC O9.5V star, NGC 346-12. The model parameters are $T_{\text{eff}} = 30,000\, \text{K}$; $\log g = 3.5$; one tenth solar metallicity.

4. Comparison to Observed UV Spectra

We have started to apply these new NLTE model atmospheres to the analysis of the UV spectrum of O-stars in the SMC observed with HST/STIS and FUSE. As an example, we present here the case of NGC 346-12, an O9.5V star in the Small Magellanic Cloud; this star has a weak wind. In Fig. 2, the model spectrum has been normalized to the observed $V$ magnitude, and corrected for interstellar extinction. Notice that the two interstellar components (galactic and SMC) of the Si IV and C IV resonance lines are not included in the model. The excellent fit that is achieved here is quite typical of the quality of the fits that we obtain in the whole UV spectrum, as well as for other O stars (obviously, in case of stronger winds, our models cannot reproduce the strong resonance lines formed in the supersonic wind). The results of this NLTE spectrum analysis will be published elsewhere.

References