Stellar Atmosphere Modeling
ASP Conference Series, Vol. 288, 2003
I. Hubeny, D. Mihalas, & K. Werner, eds.

Computation of Element Diffusion in Non-LTE Stellar Atmosphere Models

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Abstract. We present a model grid of chemically stratified stellar atmospheres for hot DA white dwarfs. The presence of traces of metals in their hydrogen rich atmospheres strongly affects the emergent flux. The abundances and depth dependent stratification patterns of these metals are predicted self-consistently by the models, using an equilibrium condition for the interplay between gravitational settling and radiative levitation.

1. White Dwarf Atmospheres

The atmospheres of white dwarfs exhibit a quasi-monoelemental composition: A large fraction of all heavy elements in these stars has disappeared from the outer layers due to gravitational sedimentation (Schatzman 1949). Traces of metals may however be sustained by radiative levitation provided the radiation field is intense enough to supply substantial momentum transfer. This is the case in most objects hotter that $T_{\rm eff} \approx 40\,000\,$K. The radiative acceleration is exerted on trace elements by a non-LTE radiation field through the element's local opacity and therefore can vary strongly with depth, which results in a chemically stratified atmospheric structure.

2. Modelling Stratified Atmospheres

The Tübingen model atmosphere program PRO2 in its standard form approximates stellar atmospheres as plane parallel, chemically homogeneous atmospheres in radiative and hydrostatic equilibrium. Together with the solution of rate equations in full non-LTE for sophisticated atomic data this makes PRO2 especially suitable for application to hot compact stars. Several extensions to this concept have recently been, or are currently being, implemented (see contributions by Werner, Rauch, Nagel, Dreizler, and Deetjen, these proceedings.) To correctly describe the chemically stratified atmospheres of hot white dwarfs and possibly sdB stars, modifications that allow the self-consistent prediction of depth dependent abundance profiles have been implemented (Dreizler 1999).

Balancing the radiative acceleration and the effective gravitational acceleration (including the effects of the electrical field that builds up through diffusion of electrons) yields an equilibrium condition for each atomic species (see e.g. Chayer et al. 1995). Its solutions yields equilibrium abundances, but as these

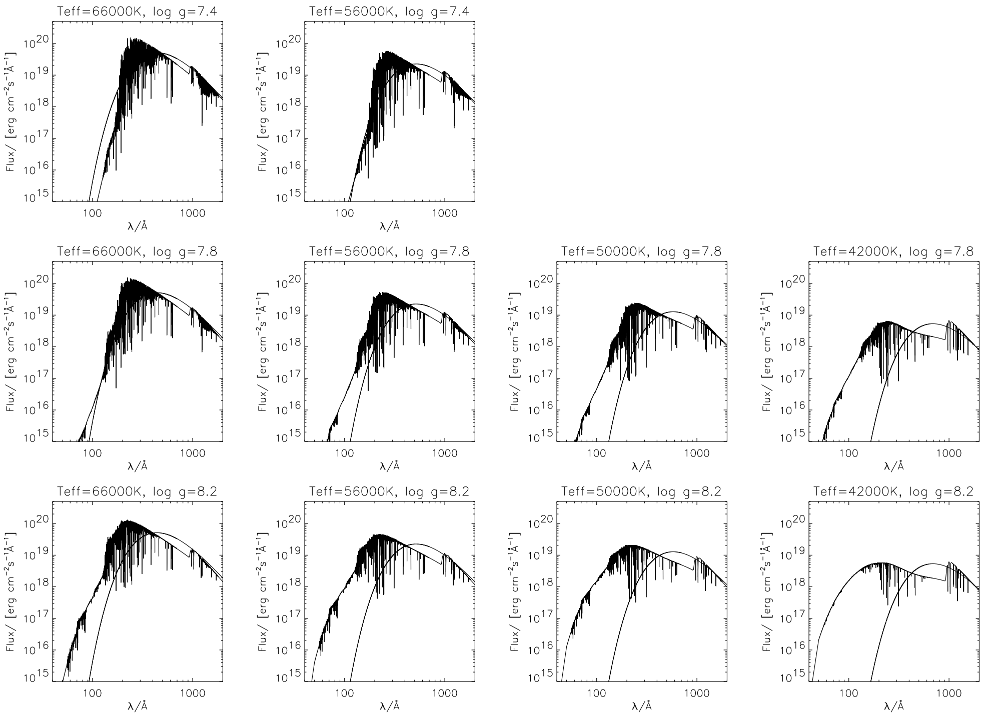

Figure 1. Emergent fluxes for different parameters; see the text.

also determine the opacity, there exists an intimate coupling to the radiative acceleration. Therefore, the whole system has to be solved self-consistently, which is done here by iteration (Dreizler 1999).

3. The Model Grid

We present such diffusion calculations for the elements He, C, N, O, Si, Fe and Ni in a hydrogen plasma within model atmosphere solutions in the effective temperature range of $T_{\rm eff} = 30\,000$ K to 72 000 K and for surface gravities from $\log g = 7.2$ to 8.4.

Fig. 1 shows the emergent fluxes for a few of these self-consistently solved, chemically stratified stellar atmosphere models at different parameter combinations: The emergent spectra result from the full non-LTE solution while the overplotted spectral distributions represent the black body flux for the given effective temperature. Obvious effects are the decrease of the overall flux level and the strengthening of the Lyman jump with decreasing temperature, and the shift of the maximum flux towards longer wavelengths for the black body radiation. This last effect is not seen in the non-LTE models.

The peculiarities mostly come from the fact that the metal abundances in all these models are not free parameters but are a function of the effective temperature and the surface gravity. The decrease of the total absorber content with decreasing effective temperature and increasing surface gravity becomes obvious through the number of lines visible in the individual spectra. For stars at parameter combinations where a high effective temperature yields a strong radiative acceleration and a low surface gravity yields a comparatively weak gravitational acceleration, the absorber content is so high that any flux at the shortest wavelengths is totally blocked. For lower effective temperatures or increased surface gravities, this blocking is more and more lifted as more absorbers are being drawn into deeper layers, resulting in a flux redistribution.

Using the example of iron, Fig. 2 illustrates the structural properties of the models underlying the effect just described. Iron and nickel dominate the opacity in the EUV, where the flux of hot white dwarfs peaks. The figures show that the iron abundance varies with the atmospheric parameters as expected.

The first panel shows the decrease of the iron abundance at $\tau_{\mathrm{ross}} = 2/3$ with decreasing effective temperature at a fixed surface gravity of $\log g = 8.0$. The inset figure shows depth-dependent iron abundance profiles for the different models; the shaded area marks the approximate line formation region between $\tau_{\mathrm{ross}} = 0.5$ and 1.0. The effect of abundance variations in that area is translated to "error bars" in the main graph. The second panel shows a decrease of the iron abundance at $\tau_{\mathrm{ross}} = 2/3$ with increasing surface gravity at a fixed effective temperature of $T_{\mathrm{eff}} = 56\,000\,\mathrm{K}$; the inset figure is similar to the one in the first panel.

4. Reality Check: Comparison to Observations

The model grid presented here has been calculated for an analysis of a sample of hot DA (= hydrogen rich) white dwarfs. When comparing the predicted spectra to spectroscopic EUVE observations, the fits turn out to be of good quality for most of the sample stars, and in particular mostly better than with chemically homogeneous stellar model atmospheres. The present implementation of diffusion theory therefore seems to be able to quantitatively describe the processes that take place in moderately hot white dwarf atmospheres, and these calculations have been successfully used to reproduce observed EUV spectra (Dreizler & Wolff 1999; Schuh, Dreizler & Wolff 2002).

Acknowledgments. We would like to thank Burkhard Wolff, Klaus Werner, Ivan Hubeny and Detlev Koester for input and helpful discussions. This work is funded through DFG grant DR 281/13-1.

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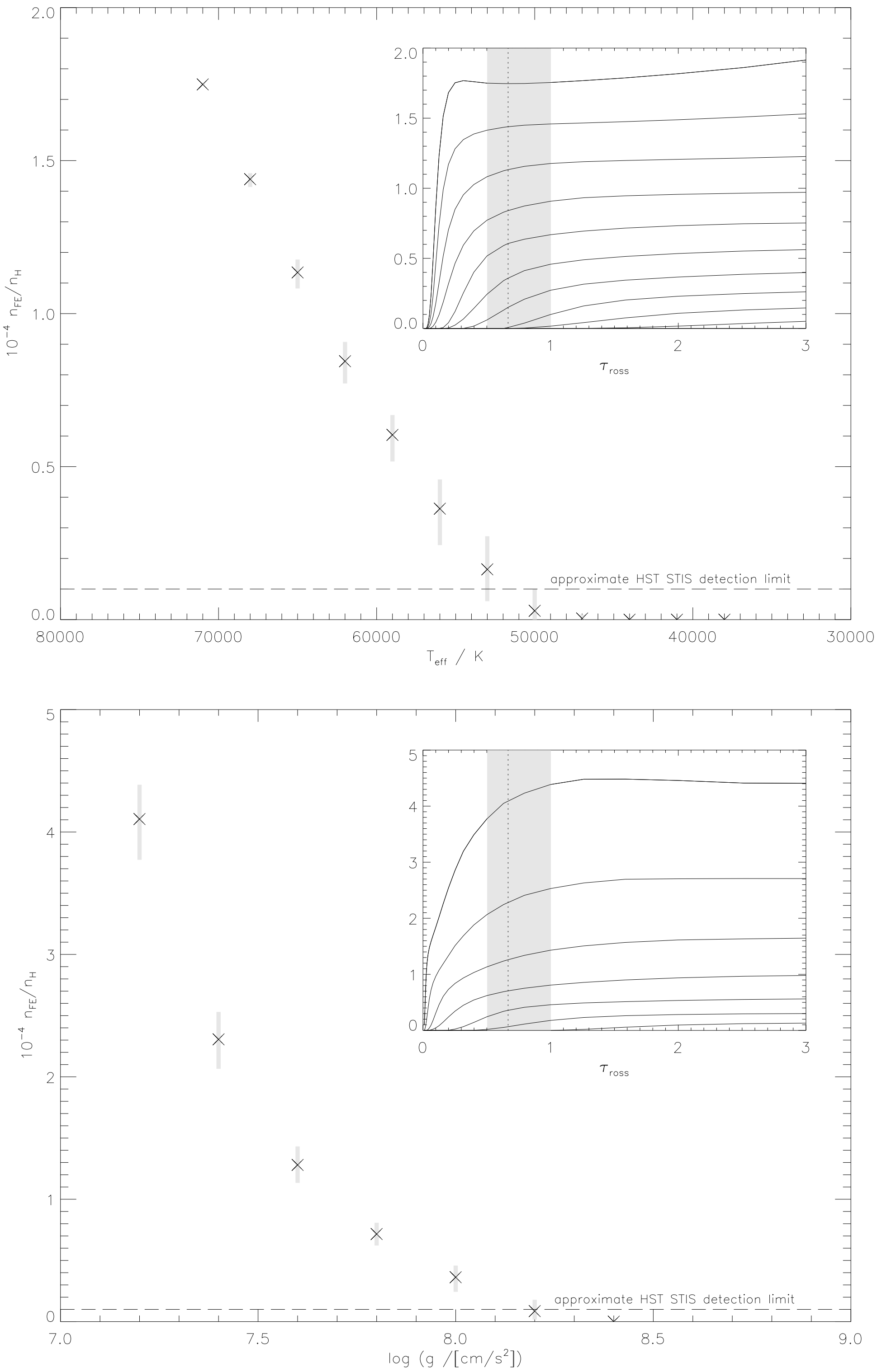

Figure 2. Iron abundances for different parameters; see the text.