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Abundance stratification in stellar atmospheres

D. Monin[1], **F. LeBlanc**[2]

[1] Herzberg Institute of Astrophysics, National Research Council Canada, Canada
[2] University of Moncton, Canada

Abstract. There is observational evidence that vertical stratification of chemical elements seems to be present in the atmosphere of some chemically peculiar stars. Diffusion processes acting in their atmospheres are most likely responsible for the stratification. We present atmospheric models with inclusion of self-consistently calculated vertical abundance gradients. These models are based on a modified version of the multi-purpose atmospheric code PHOENIX.

1 Microscopic diffusion

In multicomponent gases, the different atomic species diffuse with respect to each other. It is mainly caused by two competing processes: gravitational settling and radiative levitation. Levitation caused by selective radiative acceleration driven through spectral lines and continua can lead to an accumulation or a depreciation of species in different regions of the atmosphere. The supported abundances are temperature dependant, and thus vertical abundance gradients are built.

2 Stratified models of atmosphere

The atmospheric models are calculated self-consistently while determining the abundance gradients caused by diffusion. Several improvements have been brought to the first generation of such models (Hui-Bon-Hoa, LeBlanc and Hauschildt, 2000) which are based on the PHOENIX code (e.g. Hauschiltd, Allard and Baron, 1999). In our models we calculate the abundances by imposing that the diffusion velocity of each species is zero (i.e. equilibrium abundances) at all depths.

The calculation of radiative accelerations involves direct line opacity calculations and solving the radiative transfer equation at a large number of frequency points. Redistribution of momentum among the ionization stages of an element is taken into account. Thermal diffusion is small and neglected in our calculations. Concentration gradient which was not included in our earlier models is now included.

The atmospheric physical structure has to be adjusted every time the abundances are changed. A set of abundance corrections is followed by a set of temperature iterations. The total of several hundred abundance corrections as well as several hundred temperature iterations are needed in order to bring the diffusion velocities down to the 1% level. Equilibrium abundances are reached when all forces acting on an atom are balanced.

$$\frac{Diffusion}{velocity} = \frac{Diffusion}{coefficient} \times \left\{ \frac{Radiative}{acceleration} + \frac{Pressure}{gradient} + \frac{Concentration}{gradient} + \frac{Thermal}{diffusion} \right\} = 0$$

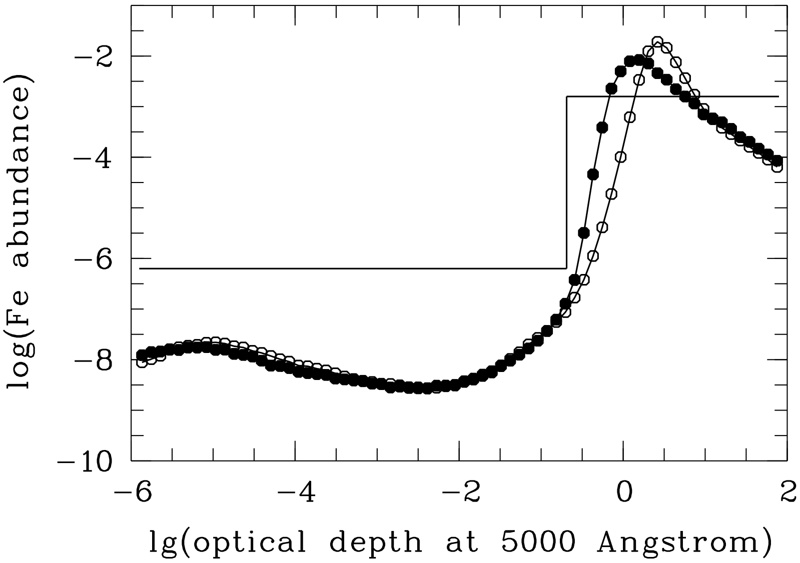

Figure 1: Vertical stratification of Fe in Teff=7700K, logg=4.0 models. *Solid line* — 2-zone empirical model; *open symbols* — self-consistent model, concentration gradient not included; *filled symbols* — new self-consistent model with the concentration gradient included.

3 Abundance profiles

Several studies have shown (for example, Ryabchikova et al. 2005) that lines of several elements in spectra of CP stars are better fitted to observations assuming 2-zone vertical stratification. These two zones have abundances that are different by a few orders of magnitude. In our self-consistent models of a 7700K star elements such as Fe, Cr, Si, and Ca indeed accumulate at large optical depths, while they are dramatically underabundant in the upper atmosphere. The 2-zone empirical and our self-consistent stratification profiles for Fe are shown in Fig. 1. The profiles are generally consistent. Although, the transition zone in our models is located deeper and higher abundances are obtained around optical depth = 1. It should be noted that the empirical abundance profile and the ATLAS model of atmosphere are not consistent. The inclusion of the concentration gradients in the calculation of the diffusion velocity (filled symbols in Fig. 1) brings the transition zone to lower depths, makes it sharper, and reduces the peak abundance. It also changes the Fe abundance in some layers by 2 orders of magnitude. Our new Fe profile is in a better agreement with the empirical one. And our new self-consistent model should now be tested with observational data.

4 Changes in the physical structure of the atmosphere

The abundance stratification may lead to significant changes in the physical structure of the atmosphere. The temperature appears to be higher where accumulation of elements occurs, and it is lower where those elements are underabundant (Fig. 2). We find that the difference in temperature between homogeneous and stratified models can be as high as 10%. Higher temperatures at large optical depths is due to accumulation of several elements in those layers and, therefore, the increase in opacity. Up to now, synthetic spectra of stars with stratification have been obtained using homogenous models of atmosphere. Self-consistent models should be used instead in order for the vertical temperature distribution to be consistent with the vertical abundance distribution.

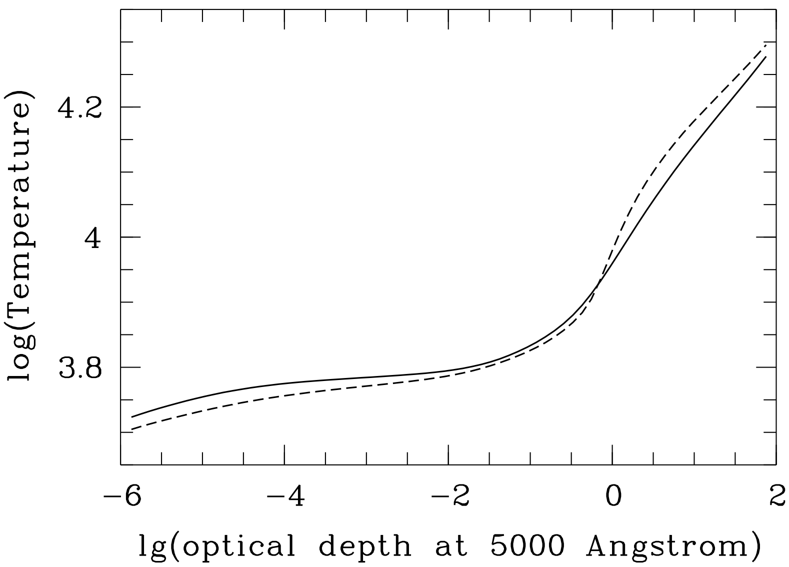

Figure 2: Temperature distribution in Teff=7700K, logg=4.0 models. *Solid line* — solar abundance; *dashed line* — stratified model.

References

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