NLTE MODELS OF EXTREMELY METAL POOR STARS

C. I. Short\textsuperscript{1} and P. H. Hauschildt\textsuperscript{2}

\textsuperscript{1}Institute for Computational Astrophysics and Department of Astronomy and Physics, Saint Mary’s University, Halifax, Canada
\textsuperscript{2}Hamburger Sternwarte, Hamburg, Deutschland

Abstract

We present atmospheric models and synthetic spectra for red giant stars of $-5 < \frac{\text{[A/H]}}{} < 0$ with spherical geometry and tens of thousands of atomic and ionic transitions, including those of Fe\textsubscript{I} and Fe\textsubscript{II}, in self-consistent non-LTE using the PHOENIX code. We pay special attention to how well-known non-LTE effects vary with metallicity down to XMP values. Preliminary results show that the effect of non-LTE over-ionization of Fe\textsubscript{I} on the $F_{\lambda}$ distribution is reduced at lower $\frac{\text{[A/H]}}{}$ values, as expected. However, the strengths of many individual lines are significantly affected by departure from LTE at all $\frac{\text{[A/H]}}{}$ values. We find that the classical “back-warming” effect of line opacity on the atmospheric temperature structure is reduced at low $\frac{\text{[A/H]}}{}$ values, as expected. As expected, the effect of non-LTE is to further reduce back-warming, but, somewhat surprisingly, this effect is strongest at the lowest $\frac{\text{[A/H]}}{}$ values.

Key words: Stars: red giants, atmospheres, spectra, abundances

1. Introduction

Recently a class of red giant stars, known, variously, as extremely metal poor (XMP), ultra metal poor (UMP), or very metal poor (VMP) stars, has been discovered in the halo of the Milky Way with metallicities in the range of $-6 < \frac{\text{[A/H]}}{} < -3$. The chemical composition of these stars holds clues to the origin of the chemical elements heavier than He in the galaxy, and the nature of the first supernovae. However, accurate abundance determinations rely on realistic modeling of the atmosphere and spectrum, including the effects of departures from local thermodynamic equilibrium (LTE).

2. The Red Giant Model

We have calculated theoretical atmospheric models with stellar parameters approximately equal to those determined for the XMP stars CD -38:245 and CS 22949-037 Cayrel, et al. 2004: $T_{\text{eff}} = 4800$ K and $\log g = 1.5$. The RMS microturbulent velocity for line broadening, $\xi_T$, was set to 2.0 km s$^{-1}$, and the mixing length parameter for the approximate treatment of convection, $\alpha$, was set to twice the pressure scale height. Both of these choices are typical of red giant models.

3. PHOENIX Modelling

The multi-purpose PHOENIX atmospheric modeling and spectrum synthesis code uses efficient numerical methods and large scale parallelism to perform a direct solution of the coupled multi-level non-LTE radiative transfer and statistical equilibrium equations with spherical geometry Short, et al. 2001. We computed models with 39887 $b - b$ transitions among 4636 energy levels among 27 chemical species, including Fe\textsubscript{I} and Fe\textsubscript{II}. Additionally, the model includes $\sim 10^7 b - b$ atomic and molecular transitions in the approximation of LTE. Fig. 1 and Table 1 show the chemical species included in the non-LTE rate equations and the number of ionizations stages, excitation levels, and $b - b$ transitions included. Fig. 2 shows the Grotrian diagram of the model Fe\textsubscript{I} atom used in the rate equations.
Species Treated in NLTE by PHOENIX

Figure 1. The chemical elements included in the non-LTE statistical equilibrium computed by PHOENIX. Elements are annotated with the number of ionization stages, E levels, and b−b transitions included in non-LTE.

Figure 2. Grotrian diagram of model Fe I atom used in the PHOENIX non-LTE statistical equilibrium calculation.

4. Discussion and Conclusions

4.1. Flux distribution

Fig. 3 shows the expected reduction of line blanketing as [A/H] decreases to XMP values. Fig. 4 shows that for relatively metal rich stars, non-LTE effects brighten the violet and near UV band $F_{\lambda}$ level with respect to that of LTE models. This is due to the non-LTE over-ionization of Fe I, which partially lifts the veil of Fe I lines that blan-
Figure 4. The visible band flux distribution, $F_{\lambda}$, for non-LTE and LTE models of abundance, $[\text{A/H}]$, from 0.0 to -5.0. The spectra are displayed at a spectral resolution, $R$, of 100. Solid line: non-LTE calculation; dashed line: LTE calculation.

The effect of non-LTE on the overall $F_{\lambda}$ distribution diminishes with decreasing $[\text{A/H}]$, as expected due to the reduced role of Fe I line opacity at low metallicity.

4.2. ATMOSPHERIC STRUCTURE

Figure 5. The dependence of kinetic temperature, $T_{\text{kin}}$, on continuum optical depth at 1200 nm, $\tau_{1200}$ for models of abundance, $[\text{A/H}]$, from 0.0 to -5.0. Solid line: non-LTE calculation; dashed line: LTE calculation.

Fig. 5 demonstrates the expected flattening of the atmospheric $T_{\text{kin}}(\tau)$ structure with decreasing metallicity; surface cooling and bottom heating are both reduced at decreased $[\text{A/H}]$ values. This effect is presumably due to a decrease in the classical “back-warming” effect of line blocking with decreased metal line opacity. For the most metal poor models ($[\text{A/H}] = -3.0$ to $-5.0$) this flattening of the $T_{\text{kin}}$ structure is enhanced in non-LTE models as compared to LTE models. This result is consistent with the expectation that the effect of scattering in non-LTE spectral line formation should decrease the cooling role of the lines (see, for example, Anderson 1989). The understanding of why the non-LTE reduction of backwarming is larger at reduced metallicities requires detailed examination of the non-LTE line formation.

4.3. FUTURE WORK

As can be seen from the non-LTE effects on the $F_{\lambda}$ distribution, even at XMP metallicities individual spectral lines of astrophysically important elements that may suffer from non-LTE effects. Therefore, non-LTE modelling will be required to derive accurate abundances from the fitting of such lines. We plan to examine our high resolution LTE and non-LTE spectra carefully to identify abundance diagnostics for which non-LTE modelling is necessary.

REFERENCES