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# Effects of granulation on neutral copper resonance lines in metal-poor stars

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**Abstract.** We make use of three dimensional hydrodynamical simulations to investigate the effects of granulation on the Cu I lines of Mult. 1 in the near UV, at 324.7 nm and 327.3 nm. These lines remain strong even at very low metallicity and provide the opportunity to study the chemical evolution of Cu in the metal-poor populations. We find very strong granulation effects on these lines. In terms of abundances the neglect of such effects can lead to an overestimate of the A(Cu) by as much as 0.8 dex in dwarf stars. Comparison of our computations with stars in the metal-poor Globular Clusters NGC 6752 and NGC 6397, show that there is a systematic discrepancy between the copper abundances derived from Mult. 2 in TO stars and those derived in giant stars of the same cluster from the lines of Mult. 2 at at 510.5 nm and 587.2 nm. We conclude that the Cu I resonance lines are not reliable indicators of Cu abundance and we believe that an investigations of departures from LTE is mandatory to make use of these lines.

**Key words.** Hydrodynamics – Line: formation – Stars: abundances – Galaxy: globular clusters – NGC 6397, NGC 6752

## 1. Introduction

In our quest to understand how the Universe evolved from the primordial chemical composition, consisting of H, He, and traces of Li, to the present day complexity, we strive to uncover all the nucleosynthetic channels. This requires to measure the evolution of as many chemical species as possible. For some species this becomes difficult at low metallicities, when all the observable lines become very weak. This is the case for Cu, the measurements of Cu abundances are mainly based on the lines of Mult. 2 at 510.5 nm and 578.2 nm (Sneden et al. 1991; Mishenina et al. 2002). However, such lines become very weak at low metallicities, even in cool giants. The strongest line, at 510.5 nm, has an equivalent with of a few tenths of picometer for a K giant of metallicity –2.5 and becomes very difficult to measure. This induced several groups (Bihain et al. 2004; Cohen et al. 2008) to push the observations in the near UV, where the Cu I resonance lines at 324.7 nm and 327.3 nm are stronger by a factor of ten and can be measured at the lowest metallicities. These lines are formed in the cool outer layers of the stellar atmo-

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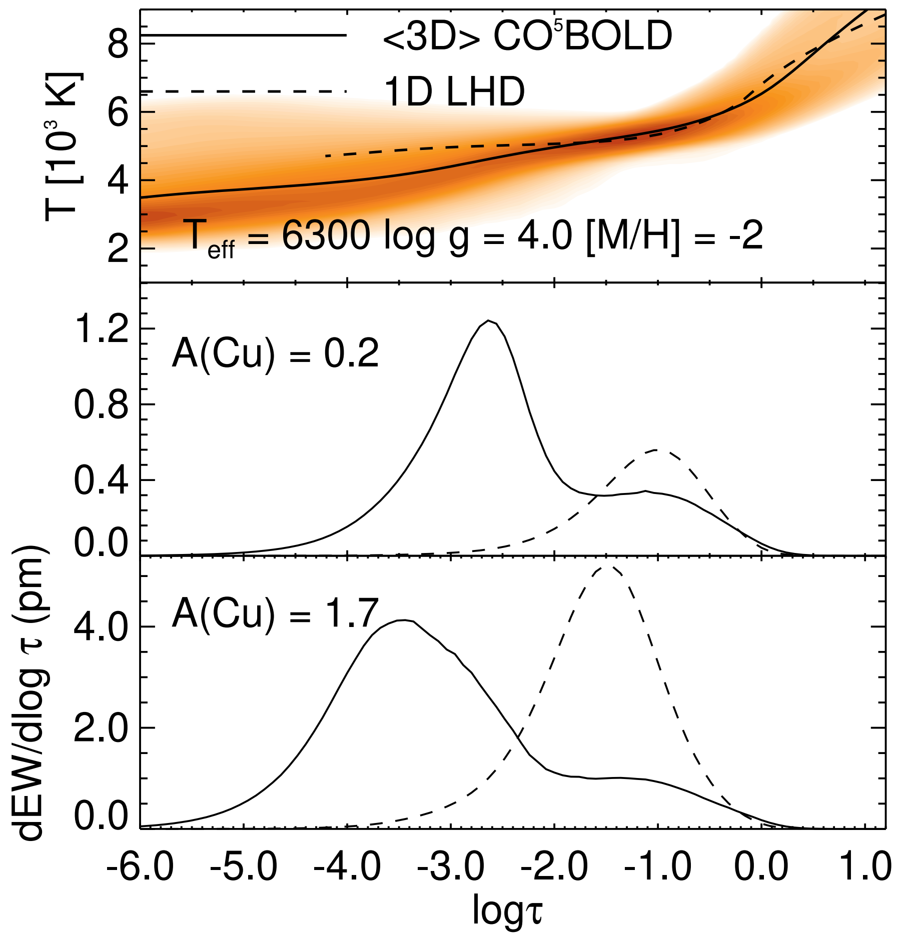


**Fig. 1.** The top panel shows the temperature distribution for the hydrodynamical model d3t63g40mm20n01. The shading allows to visualise the temperature histogram of the model (over space and time), for any given optical depth. A darker colour indicates a larger number of cells in the given temperature bin. In the two lower panels we show the contribution functions of the EW at disc-centre, defined such that their integral over $\log \tau_\lambda$ gives the EW (Magain 1986), for the Cu I 324.7 nm line and the model d3t63g40mm20n01 for two different values of Cu abundance. In the upper panel A(Cu)=0.2, in the lower panel A(Cu)=1.7. The solid lines refer to the 3D model, the dashed lines to the corresponding $1D_{LHD}$ model.

sphere. Such layers are formally stable against convection and 1D model atmospheres cannot account for the effects of convective motions ("granulation") here. The use of 3D hydrodynamical simulations has shown that one effect of this is a steeper temperature gradient in the outer layers than what predicted by 1D models (Asplund et al. 1999; Asplund 2005). This effect is often referred to as "overcooling" and is more pronounced for metal-poor stars. In this contribution we wish to investigate the effects of granulation on the formation of the Cu I resonance lines in metal-poor stars. To do so we analyse the lines in the turn-off stars of

**Table 1.** Atmospheric parameters and copper abundances for the program stars.

| Star | $T_{\rm eff}$ K | $\log g$ [cgs] | [Fe/H] dex | $\xi$ $\rm kms^{-1}$ | A(Cu) 1D | $\sigma$ | A(Cu) 3D | $\sigma$ |
|---|---|---|---|---|---|---|---|---|
| Cl* NGC 6752 GVS 4428 | 6226 | 4.28 | -1.52 | 0.70 | 3.23 | 0.08 | 2.56 | 0.16 |
| Cl* NGC 6752 GVS 200613 | 6226 | 4.28 | -1.56 | 0.70 | 3.01 | 0.05 | 2.23 | 0.07 |
| Cl* NGC 6397 ALA 1406 | 6345 | 4.10 | -2.05 | 1.32 | 1.33 | 0.03 | 0.74 | 0.05 |
| Cl* NGC 6397 ALA 228 | 6274 | 4.10 | -2.05 | 1.32 | 1.30 | 0.03 | 0.73 | 0.05 |
| Cl* NGC 6397 ALA 2111 | 6207 | 4.10 | -2.01 | 1.32 | 1.19 | 0.02 | 0.60 | 0.02 |
| HD 218502 | 6296 | 4.13 | -1.85 | 1.00 | 1.52 | 0.09 | 0.95 | 0.04 |

two metal-poor Globular Clusters (NGC 6752 and NGC 6397) and compare the derived abundances, both in 1D and 3D, with those derived for giants, making use of the lines of Mult.2

## 2. Observational data and analysis

Our data consists of spectra acquired with UVES at the ESO Kueyen 8.2m telescope, at a resolution of R∼45 000. We have 3 TO stars in the NGC 6397, 2 TO stars in NGC 6752 and the field TO star HD 218502. For each cluster star the total integration time is of the order of 10 hours for each star. The data has already been described in Pasquini et al. (2004) and Pasquini et al. (2007). The reduced spectra were downloaded from the ESO archive, thanks to the improved strategies for optimal extraction (Ballester et al. 2006), the S/N ratios are greatly improved with respect to what was previously available. We measured the EWs of the Cu I lines by fitting a gaussian with the IRAF task `splot`. For each star we computed a 1D LTE model atmosphere with the atmospheric parameters given in Pasquini et al. (2004) and Pasquini et al. (2007) and summarised in Table 1. We used the ATLAS 9 code (Kurucz 1993a, 2005) in its Linux version (Sbordone et al. 2004; Sbordone 2005). From this we computed for each line a curve of growth with the SYNTHE code (Kurucz 1993b, 2005; Sbordone et al. 2004; Sbordone 2005) taking into account the hyperfine structure of the lines. The abundance was determined by interpolation in these curves of growth. For the hydrodynamical models we used the $\mathrm{CO}^5\mathrm{BOLD}$ code (Freytag et al. 2002, 2003; Wedemeyer et al. 2004) and used spectrum synthesis on these models to compute curves of growth and "3D corrections", as defined by Caffau & Ludwig (2007), with respect to the 1D LHD models. The appropriate 3D correction was found for each star by interpolating in the 3D grid.

## 3. Results and conclusions

From Table 1 it is immediately clear that the 3D corrections are large. The reasons for this can be understood by looking at Fig. 1 where the temperature distribution of one of our 3D models is depicted, together with the mean temperature distribution and that of a corresponding LHD model. The overcooling is obvious from the top panel and the contribution functions in the two bottom panels reflect the fact that in these cool outer layers the Cu atoms populate mainly the ground layer, thus contributing for the bulk of the absorption of the line, at variance with what happens in the 1D model (dashed line). The two bottom panels correspond to two different Cu abundances, illustrating how the tendency to prefer the outer layers increases with the increasing number of absorbers. As expected this results in larger 3D corrections for more metal-rich stars. However, one should be always cautious when facing contribution functions like the ones shown in Fig. 1. In fact all the computations have been performed in LTE, it is likely that photons coming from the warm streams may produce overionisation in these low density outer layers. If NLTE effects are important a considerable resizing of the outer peak of the contribution function can be expected. A way to check indications of possible NLTE effects is to compare the abundances in the cluster, derived from the resonance lines in TO, with those of giants, derived from the lines of Mult. 2. We derived abundance in NGC 6397 using the EWs for two giants measured by Gratton (1982), for NGC 6752 we used a UVES spectrum of a giant star (star Cl* NGC 6752 YGN 30), already studied by Yong et al. (2005). Neither in 1D nor in 3D giants and dwarfs provide the same abundance. In NGC 6752 the dwarf stars imply a higher abundance, both in 1D and 3D, the reverse is true in NGC 6397. That the problem is with the modelling of the Cu lines is confirmed by the analysis of the giant in NGC 6752, for which we were able to measure both the Cu I resonance line at 327.3 nm and the 510.5 nm line. Both in 1D and 3D the two lines provide abundances which differ by about 0.5 dex. We conclude that the Cu I resonance lines are not good abundance indicators, a full 3D-NLTE study should be undertaken for these lines. At the same time one may suspect that also the lines of Mult. 2 may be affected by deviations from LTE. The Galactic evolution of copper must be placed on solid grounds with a better modelling of the line formation.

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