Effects of granulation on Cu I 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 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.

1 Introduction

Copper is an element which can be produced through multiple nucleosynthetic channels and there is no general consensus on the interplay and relative importance of the various channels. Observations of copper abundances in Galactic stars show a decrease in the Cu/Fe ratio at low metallicities. At higher metallicities copper abundances are traced by the lines of Mult. 2 at 510.5 nm and 587.2 nm with excitation potentials of 1.4 and 1.6 eV respectively. However at very low metallicities these lines become vanishingly weak, even in cool giants. On the other hand the resonance lines of Mult. 1 324.7 nm and 327.3 nm remain measurable down to the lowest metallicities, as has been shown by the investigations of Bihain et al. (2004) and Cohen et al. (2008).

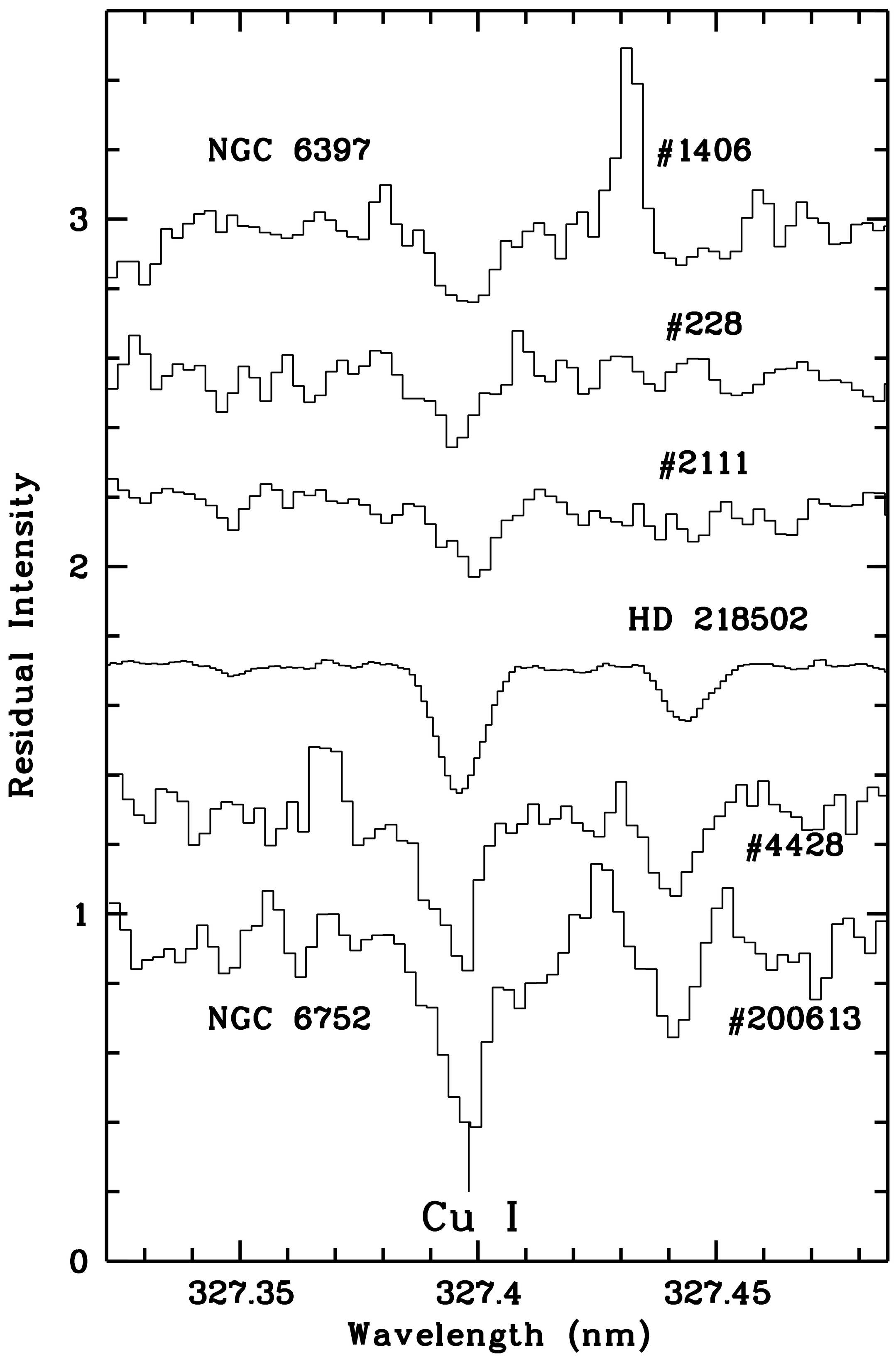

Fig. 1. The Cu I 324.7 nm line in three TO stars of NGC 6397 and two TO stars in NGC 6752. In the middle the template star HD 218502, with atmospheric parameters close to that of the GC stars. The spectra have been displayed vertically by 0.4 units, with respect to each other, for display purposes.

In this contribution we wish to asses the reliability of the Cu I resonance lines as copper abundance estimators, by using Globular Clusters, for which Cu abundance can be measured both for giants and dwarf stars and study the consistency of the Cu abundances in the two classes of stars.

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$\sim$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. In Fig. 1 we show the spectra in the region of the 327.4 nm line, showing the good quality of the data. 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.

Table 1: Atmospheric parameters of the programme stars.

Star	$T_{\rm eff}$ K	$\log g$ [cgs]	[Fe/H] dex	ξ km s^{-1}
Cl* NGC 6752 GVS 4428	6226	4.28	-1.52	0.70
Cl* NGC 6752 GVS 200613	6226	4.28	-1.56	0.70
Cl* NGC 6397 ALA 1406	6345	4.10	-2.05	1.32
Cl* NGC 6397 ALA 228	6274	4.10	-2.05	1.32
Cl* NGC 6397 ALA 2111	6207	4.10	-2.01	1.32
HD 218502	6296	4.13	-1.85	1.00

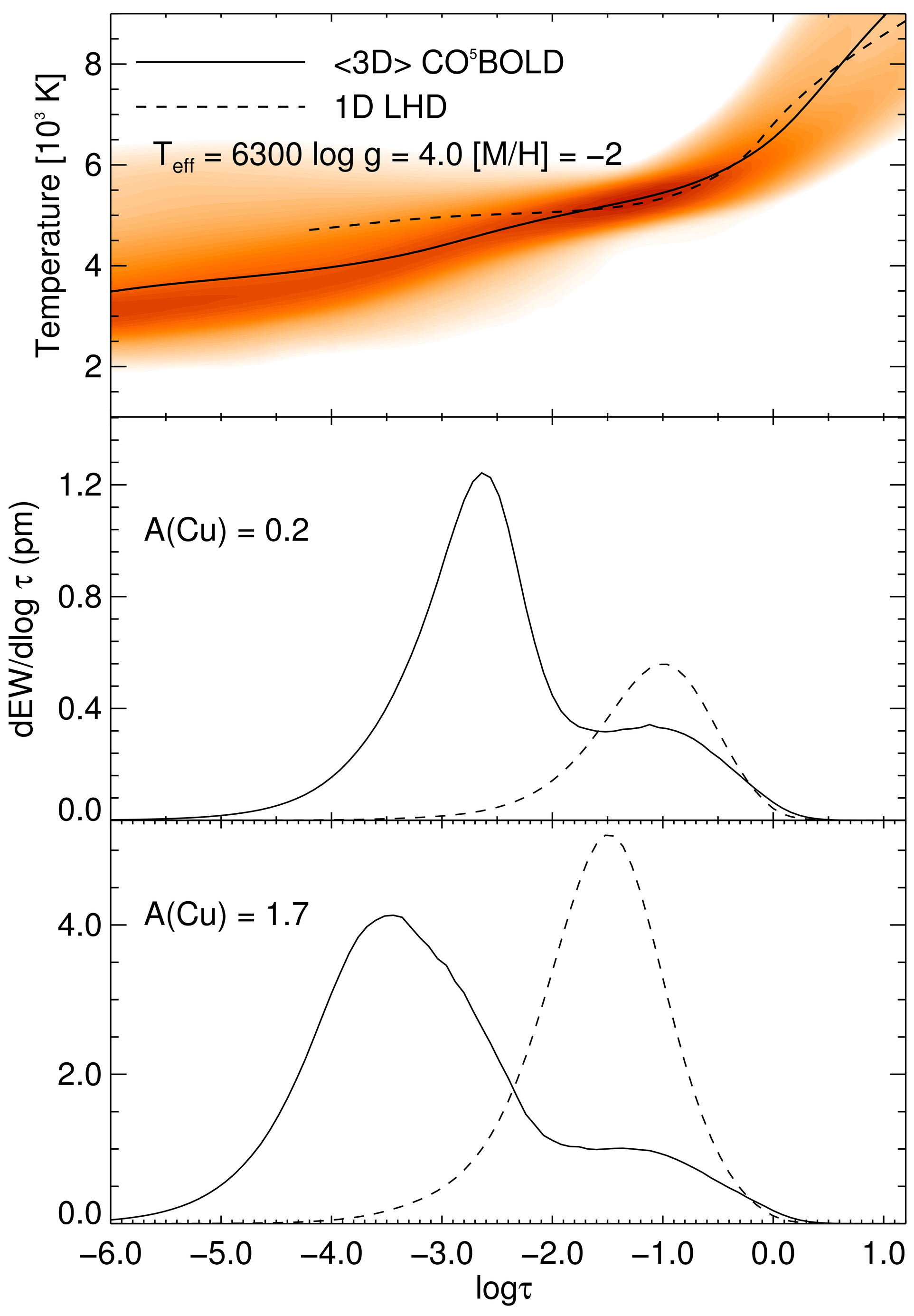

Fig. 2. The top panel shows the temperature distribution for the hydrodynamical model d3t63g40mm20n01. The shading allows to visualise the temperature histogram of the model (over space and time), for any given optical depth. A darker colour indicates a larger number of cells in the given temperature 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 $1D_{\rm LHD}$ model.

The 1D model atmospheres cannot account for the effects of convective motions in formally stable layers. 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. To account for this we used 3D models computed with the code CO^{5}BOLD (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. The abundance results for 1D and 3D is given for each star in Table 2.

Table 2: Copper abundances for the program stars.

Star	A(Cu) 1D	σ	A(Cu) 3D	σ
Cl* NGC 6752 GVS 4428	3.23	0.08	2.56	0.16
Cl* NGC 6752 GVS 200613	3.01	0.05	2.23	0.07
Cl* NGC 6397 ALA 1406	1.33	0.03	0.74	0.05
Cl* NGC 6397 ALA 228	1.30	0.03	0.73	0.05
Cl* NGC 6397 ALA 2111	1.19	0.02	0.60	0.02
HD 218502	1.52	0.09	0.95	0.04

3 Results and conclusions

The first thing which is obvious is 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. The result of this comparison is given in Table 3. The abundance for giants has been derived 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, already studied by Yong et al. (2005). It is clear that neither in 1D nor in 3D giants and dwarfs provide the same abundance. That the problem is with the modelling of the Cu lines is confirmed by the analysis of the giant in NGC 6752 (star Cl* NGC 6752 YGN 30), 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.

Table 3: Mean copper abundances for the two clusters.

Star	A(Cu) 1D	σ	A(Cu) 3D	σ
NGC 6752 dwarfs	3.04	0.07	2.28	0.12
NGC 6752 giants	2.03	0.05	1.98	0.05
NGC 6397 dwarfs	1.25	0.05	0.63	0.04
NGC 6397 giants	1.40	0.17	1.30	0.17

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