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HIGH S/N Na I D LINE PROFILES IN LATE-TYPE MS STARS AND THEIR IMPORTANCE FOR STELLAR MODELLING [1]

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1 Introduction

Progress in observational techniques (i.e. high S/N spectroscopy) and modelling (e.g. RE models including convection, nonLTE codes, accurate atomic data) make significant to carry to extremes the numerical fit of a portion of the stellar spectrum and try to interpret the residual differences between calculations and observations in terms of stellar characteristics *new* respect to the employed model.

We have started to apply this synthesis method to a set of high resolution, high S/N spectra of late-type dwarfs in the region of the Na I D lines, obtained at ESO with the 1.4m CAT on May 1989 (Franchini et al. 1992). The dwarf stars are modelled in radiative equilibrium (RE), and the Na I D line synthesis accounts for nonLTE and blend effects.

We aim to interpret the residual differences between observations and calculations in terms of non-radiative heating in the stellar chromosphere. There we present our first results for the star 70 Oph A and, as a comparison, for the Sun as a star.

2 Method

As a standard atmosphere we assume a 1-dimensional radiative equilibrium (RE) model. Linsky (1985) lists a number of approximations inherent in RE models: (1) description of line blanketing (including molecules and nonLTE effects), (2) theory of convection (including overshoot), (3) treatment of atmospheric (magnetic) inhomogeneity, and (4) account for the CO cooling in non-magnetic regions. However the only alternative to 1-d RE model is 1-d semiempirical model but the latter already includes a temperature - rise in the chromosphere that is what we want specifically to study by the use of the synthesis technique. The RE models are built with the code MARCS which has been developed by Bengt

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Gustafsson and Åke Nordlund. The models account for: (i) convection (Nordlund 1974), (ii) line blanketing by means of opacity distribution functions for metals and (iii) molecular opacities (see also Gustafsson et al. 1975).

Our main line formation parameters are the sodium abundance A_{Na} and the instrumental + macroturbulence + rotation broadening profile. We fit the stellar sodium abundance to the outer wings of the Na I D lines. This procedure yields $A^{\star}_{Na} = 2.35 \;\; 10^{-6}$, which is substantally equal to the solar value. Furthermore, we assume that instrumental + macro (granulation) + rotation broadening is accounted for by a normalized gaussian profile. So, we have only the halfwidth at half maximum of the gaussian profile, $\Delta\lambda$, as a free parameter. We estimate $\Delta\lambda$ "empirically", from the line widths of the weakest lines in the spectrum, and from the fit to the observed profiles of Fe I 5905 line. Both these procedures yield $\Delta\lambda_{\star} \sim 75$ mÅand $\Delta\lambda_{\odot} \sim 40$ mÅ.

Neutral sodium energy levels do not follow the Saha-Boltzmann law in the high photosphere and low chromosphere (e.g. Caccin et al. 1980). We solve the Na I statistical equilibrium equations coupled to the radiation transfer equation with the nonLTE code MULTI (Carlsson 1986). The sodium atomic model is similar to the one used by Caccin et al. but the Van der Waals damping constants are fixed after Andretta et al. (1991).

The departure from LTE of the line bound levels and continuum are the input for a successive program which accomplishes the spectral line synthesis accounting for the blend of the Na I D_1 and D_2 resonance lines.

3 Results and conclusion

For the comparison with the observations, we convolve the synthetic Na I D line profiles with a gaussian broadening normalized function whose HWHM is set to 40 mÅ for the Sun and 75 mÅ for 70 Oph A, as discussed above. Hence, we compute the ratio between observed and computed NaI D line profiles for both 70 Oph and the Sun; the FeI 5905 is also included in the calculation, as a matter of comparison . We find that while the calculations fit rather well the observations of both the iron line and the Na I D line wings (ratio ~ 1), the Na I D line cores are brighter than those predicted on the basis of the RE models both for 70 Oph A and the Sun (ratio ~ 1.5). In fact, the value of the ratio in the Na I D cores is roughly the same for 70 Oph A and the Sun. This result is indeed misleading and it is an artifact due to the different broadening functions pertaining to the two dwarf stars. When we deconvolve the observations with the broadening gaussian profiles discussed above , and then compute the ratio to the unconvolved RE synthetic line profiles, we obtain the results shown in Fig. 1, in which the maximum value of the ratio for 70 Oph A is roughly twice the solar one.

We think that differences between observed and computed Na I D line profiles, such as those reported in Fig. 1, contain evidence for non-radiatively heating in stellar chromospheres.

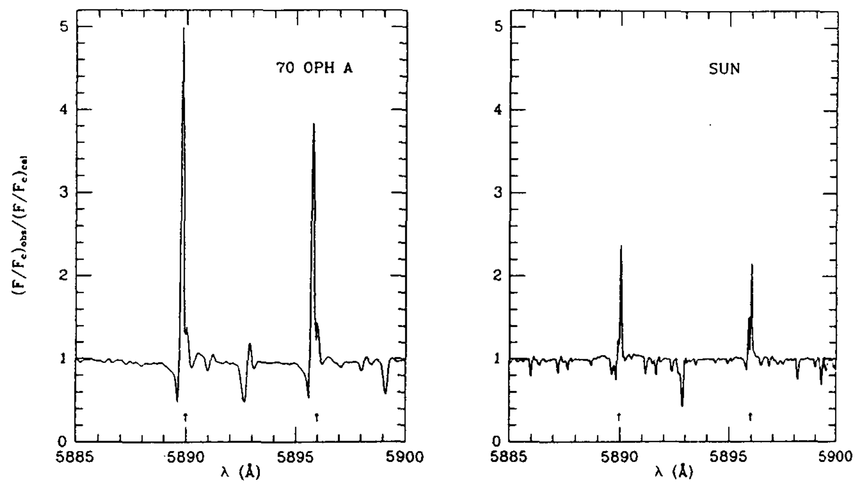

Figure 1. The observed to computed spectrum ratios for 70 Oph (left panel) and the Sun (right panel). The Na I D line cores are marked with arrows whilst the other negative peaks in the ratio correspond to absorption lines not included in the synthetic spectrum.

We plan to continue the work sketched in this poster expanding over the present stage in three respects: (i) processing the whole data set of late-type main sequence stars; (ii) improving the procedure, e.g. by the use of a radial-tangential model for macroturbulence broadening; (iii) calibrating different observed/computed Na I D line ratios in terms of non-radiative heated chromospheres.

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