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New Gravities for Old Stars

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Abstract. We present results of calibrating our non-LTE iron model atom with metal-poor HIPPARCOS targets. On the Balmer profile temperature scale, the efficiency of collisions with hydrogen atoms is found to be close to the theoretical prediction, thus not being able to compensate for overionization in Fe I due to strong photo-ionization. While non-LTE effects are quite small in the Sun (0.04 dex), the iron abundance and gravity of the metal-poor subgiant HD 140283 are affected by 0.11 dex and 0.29 dex, respectively. Among other consequences, isochrone ages of metal-poor stars will require a systematic revision.

1. Non-LTE of Iron in Cool Stars

The concept of LTE, most often assumed to be valid throughout the atmospheres of Solar-like stars, heavily relies on the sufficient strength of collisions to counterbalance radiative processes. While collisions with hydrogen atoms do not scale with metallicity, photo-ionization will be significantly enhanced in the UV-transparent atmospheres of metal-poor stars making it difficult to avoid departures from LTE for minority species like Fe I.

Building on the compilation of energy levels and f values by Nave et al. (1994) and the calculated photo-ionization cross-sections by Bautista (1997), we put together a comprehensive model atom consisting of 236 terms of Fe I and 267 of Fe II (see Gehren et al. 2001a). On the one hand, it was found that Fe II could safely be synthesized under the assumption of LTE, on the other, the occupation of Fe I levels turned out to be dictated by the strong (100 times larger than hydrogenic) photo-ionization rates. As a consequence, the following plasma-diagnostic tools based on Fe I are systematically affected:

- temperatures derived from the Fe I excitation equilibrium
- abundances and microturbulences derived from Fe I
- gravities derived from the ionization equilibrium of Fe I/Fe II

In the subsequent sections, we will present results for individual calibration stars. It will be shown that our non-LTE calculations are capable of resolving the discrepancies in gravity found by Fuhrmann (1998a/b, 2000).

The analysis of the Sun is based on the KPNO flux atlas (Kurucz et al. 1984), the stellar analyses rest on FOCES spectra with R = 60 000 and S/N > 300 at Hα. Typically 70 Fe I and 15 Fe II lines can be measured in the optical spectra of the stars under investigation ($[m/\mathrm{H}] < -2$).

We note that FOCES échelle spectra can be rectified *across* Balmer profiles to an accuracy of 0.5 %, a prerequisite for utilizing these lines as a reliable temperature indicator. $H\alpha$ and the higher Balmer profiles yield identical temperatues, if the efficiency of convection α ($=l/H_p$) is lowered to 0.5 (in the framework of the Böhm-Vitense formulation of convection).

2. The Sun as a Star

The first and foremost test any cool-star plasma-diagnostic tool has to pass is the reproduction of the Solar spectrum. To be able to analyse the most metal-poor stars, we have to synthesize the strongest Solar lines. Therefore the correct choice of damping parameters ($\log C_6$, "van-der Waals") is of central importance. We initially implemented the new C_6 values for Fe I by Anstee & O'Mara (1995, hereafter AOM), but had to realize that they lead to a clear trend of abundance with line strength. To minimize this trend, the microturbulence was increased to 1 km/s and $\log C_6$ lowered by 0.4 dex resulting in damping constants in between those of AOM and Unsöld (1968).
The choice of damping constants also leaves its imprint on the *absolute* iron abundance one derives for the Sun: While "$\log C_6$(AOM)" leads to an Fe I abundance close to meteoritic, "$\log C_6$(AOM)$-$0.4 dex" results in ε(Fe I)$\sim$7.6, some 0.05 dex above the value determined from the 35 strongest lines of Fe II using classical $\log C_6$.
There are two lessons to learn from the Sun: *a)* different sources of *f* values are incompatible with one another resulting in substantial scatter of $\sim$0.1 dex (1σ) and *b)* even the *internal* consistency within a given source is far from satisfactory (for more details see Gehren et al. 2001a/b).

3. HD 19445, HD 84937 & HD 140283

With a temperature from Balmer profiles and a mass estimate from evolutionary tracks, one can iteratively determine the gravity which best reproduces the parallax measured by HIPPARCOS. Since the volume density of halo stars is low, we have to consider targets out to about 100 pc. In this volume, the programme stars are among the most metal-poor and cover stellar evolution from the main sequence to the subgaint branch.
The main free parameter of our non-LTE model (the poorly known efficiency of collisions with hydrogen atoms) has to be calibrated to achieve concordance between the abundances derived from Fe II in LTE and Fe I in non-LTE *at the* HIPPARCOS *gravity.* As long as H collisions are present at all (parameterized by S_H times the formula of Drawin 1968) the levels are thermalized *relative to one another*, yet heavily underpopulated *relative to* Fe II due to overionization. Thus the abundances scale with S_H enabling us to finetune the model.
The efficiency of hydrogen collisions needed turns out to scatter around 0.7. Our model is able the resolve the discrepancy between gravities from pressure-broadened wings of Mg I*b* lines (in excellent agreement with HIPPARCOS, cf. Fuhrmann 1998b, 2000) and from Fe I/II assuming LTE (see Figure 1). This is particularly noteworthy, as the size of the non-LTE effect (clearly a function of evolutionary stage, metallicity, ...) is correctly predicted for all three targets.

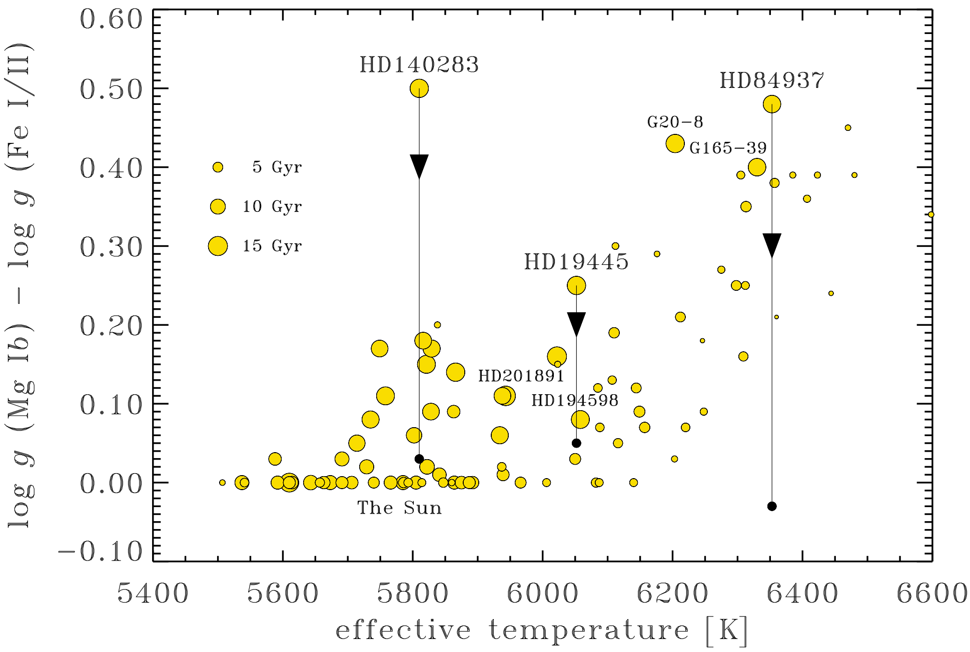

Figure 1. LTE gravities from Fe I/II vs. Mg I*b* in the sample of Fuhrmann (1998b, 2000). Some additional stars from Korn & Gehren (2001) are labelled. As can be seen, iron in LTE yields gravities systematically too low, in particular for hot and metal-poor stars. The black bullets indicate the revised positions of the programme stars using our S_H=0.7 iron non-LTE model. 0.01 dex in gravity corresponds to 1 % deviation with respect to HIPPARCOS.

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