Spectroscopic Equilibrium of Iron in Metal-Rich Dwarfs

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**Abstract.** We analyze twenty five nearby metal-rich G and late-F dwarfs in order to verify whether the spectroscopic equilibrium (LTE) of iron lines satisfy the observational constraints imposed by the Infrared Flux Method (angular diameters) and Hipparcos parallaxes. The atmospheric parameters derived from iron lines (assuming LTE and employing 1D Kurucz model atmospheres) do not satisfy simultaneously both observational constraints, probably because classical modeling fails to reproduce the detailed line formation of FeI lines.

1. **Introduction**

Until a few years ago, it was not possible to directly determine the fundamental properties of even the closest dwarf stars. The advent of *Hipparcos* has greatly improved the situation, allowing to accurately determine the surface gravities of nearby dwarfs. The situation is much worse for the effective temperatures ($T_{eff}$) of unevolved stars, due to sub-milli-arcsec level angular diameters (a few mas for the closest dwarfs). Fortunately, the stellar diameters of about a dozen dwarfs are now available, mostly from VLTI interferometric measurements (Kervella et al. 2004).

Ramírez & Meléndez (2004, 205a) have shown that the Infrared Flux Method (IRFM) $T_{eff}$ scale is in excellent agreement with measured stellar diameters of 10 FGK dwarfs in the metallicity range $-0.5 < [\text{Fe/H}] < +0.3$ dex. However, the temperatures obtained from spectroscopic equilibrium of iron lines seem to be in conflict with the ones derived from the IRFM. The temperatures of metal-rich dwarfs with planets may be being overestimated by about 110 K when the temperatures are determined from excitation equilibrium of FeI lines (see Ramírez & Meléndez 2004 and references therein). This is not restricted to star with planets, since analysis of other samples results in similar discrepancies. For example, the FeI temperatures of thin- and thick-disk dwarf stars analyzed by Bensby et al. (2003) are also about 110 K hotter than IRFM temperatures (Ramírez & Meléndez 2005a).

The source of the problem is still not clear. The culprit is probably the neglect of NLTE effects, but errors in atomic data are not discarded, as well as granulation effects. In this work we analyze a sample of nearby metal-rich dwarfs from the S$^4$N database (Allende Prieto et al. 2004), which are closer...
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than 15 pc, therefore with extremely small errors in their Hipparcos parallaxes, imposing stringent constraint on their surface gravities (< 0.01 dex), allowing thus to check the validity of spectroscopic gravities. Furthermore, the IRFM temperature scale is used to check the excitation temperatures determined from a 1D LTE analysis.

2. Analysis

The sample stars were selected from the S4N database, and they cover the atmospheric parameters space 5000 K < T_{eff} < 6600 K, 4.0 < log g < 4.6, −0.8 < [Fe/H] < +0.5. Twenty five stars with relatively clean line profiles were selected.

The temperature was determined employing the IRFM T_{eff} scale (Ramírez & Meléndez 2005a,b) and surface gravities are from Hipparcos parallaxes. We will refer to these atmospheric parameters as “physical” parameters.

The choice of atomic data is critical, since systematic errors in the gf-values could lead to wrongly-determined atmospheric parameters. For FeI lines, the gf-values were taken from the Oxford (Blackwell et al. 1995a and references therein) and Hannover (Bard et al. 1991, Bard & Kock 1994) groups. The collisional broadening constants were taken from Barklem et al. (2000).

It has been discussed in the literature the lack of accurate experimental gf-values for FeII lines, and the importance of improving laboratory measurements for accurate stellar abundance work (e.g. Lambert et al. 1996, Gehren et al. 2001). The bulk of laboratory measurements are probably correct in an absolute scale, but there are large uncertainties in a line-by-line basis. On the other hand, theoretical relative line intensities within a given multiplet are highly reliable, but the absolute scale is not. Meléndez & Barbuy (2002) have taken advantage of both methods, with relative gf-values obtained from theoretical calculations and the absolute transition probabilities for each multiplet were normalized with laboratory measurements. Meléndez & Barbuy (2005, in preparation) have updated their previous work with new laboratory and theoretical works. This improved list of FeII lines is used in the present work.

Iron abundances were obtained from FeI and FeII lines, employing the program MOOG (Sneden 1973) and Kurucz model atmospheres. First, iron abundances were determined from the physical parameters (IRFM + Hipparcos), then LTE spectroscopic equilibrium was imposed to obtain spectroscopic temperatures and gravities, enforcing simultaneously $\Delta A_{FeI}/\Delta \chi_{exc} = 0.000 \pm 0.002$ dex/eV (excitation equilibrium) and $A_{FeI} = A_{FeII}$ (ionization equilibrium).

The results are shown in Figure 1, where the difference between physical and spectroscopic parameters ($\Delta T_{eff}$, $\Delta \log g$) are plotted as a function of $T_{eff}$ and log g. As can be seen, we succeed to bring into rough agreement the temperatures determined from the IRFM and excitation equilibrium of FeI lines. However, ionization equilibrium is not satisfied, and spectroscopic gravities could be off by as much as 0.4 dex, which is much higher than the uncertainties expected from Hipparcos parallaxes (< 0.01 dex) or errors in masses and bolometric corrections (a few 0.01 dex).

In the lower panel we show a plot of $\Delta \log g$ vs. $\Delta T_{eff}$. If spectroscopic equilibrium is fulfilled in a LTE 1D analysis, ($\Delta \log g$, $\Delta T_{eff}$) are expected
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3. Conclusions

Classical LTE 1D modeling may be failing to satisfy spectroscopic equilibrium of iron lines, and the atmospheric parameters estimated from this assumption may be wrong. Since FeII is the main ionization stage in G and F dwarfs and it is expected to be formed in LTE, the problem is probably due to NLTE effects on FeI lines. Considering NLTE on line formation of FeI lines results in a higher iron abundance than that derived from a LTE approach (e.g. Shchukina & Trujillo Bueno 2001), thus lowering the discrepancy observed between spectroscopic and Hipparcos gravities.

A detailed discussion, as well as implications for the metallicity distribution of stars with planets will be presented in a forthcoming article (Meléndez & Ramírez 2005, in preparation).

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References

Allende Prieto, C., Barklem P. S., Lambert, D.L., Cunha K. 2004, A&A, 420, 183
Bard, A., Kock, A. & Kock, M. 1991, A&A, 248, 315
Bard, A. & Kock, M. 1994, A&A, 282, 1014
Barklem, P. S.; Piskunov, N.; O’Mara, B. J. 2000, A&AS, 142, 467
Bensby, T.; Feltzing, S. & Lundström, I. 2003, A&A, 410, 527
Blackwell, D. E.; Lynas-Gray, A. E. & Smith, G. 1995, A&A, 296, 217
Gehren T., Butler K., Mashonkina L., Reetz J. & Shi J. 2001, A&A, 366, 981
Kervella P.; Thevenin, F.; Di Folco, E.; Segransan, D. 2004, A&A, in press
Lambert, D. L. Heath J. E., Lemke M., Drake J. 1996, ApJS, 103, 183
Meléndez, J. & Barbay, B. 2002, ApJ, 575, 474
Ramírez I. & Meléndez J. 2004, ApJ, 609, 417
Ramírez I. & Meléndez J. 2005a, ApJ, submitted
Ramírez I. & Meléndez J. 2005b, ApJ, submitted
Shchukina, N. & Trujillo Bueno, J. 2001, ApJ, 550, 970
Sneden, C. 1973, Ph.D. thesis, University of Texas
Figure 1. Differences between the physical (IRFM + Hipparcos) and spectroscopic atmospheric parameters derived in this work. The size of the circles is proportional to their metallicities. The zone inside the ellipse (lower panel), \((\Delta T_{\text{eff}}/75 \, \text{K})^2 + (\Delta \log g/0.075 \, \text{dex})^2 < 1\), shows the expected region of consistency between physical and spectroscopic parameters.