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Balmer Lines and Effective Temperatures in Cool Stars

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Abstract. Theoretical work on the self-broadening of Balmer lines by us predicts a large impact on model profiles, and therefore effective temperature determinations, particularly in metal-poor stars. We present initial results of the application to observations of a sample of cool dwarf stars. The effective temperatures determined for our sample show much improved agreement with the infra-red flux method results in the literature when compared with analysis using the previously available broadening theory.

1. Introduction

We present some initial results of the application of our theoretical work on the self-broadening of Balmer lines (Barklem *et al* 2000) to determining effective temperatures of cool dwarf stars (F, G and K stars). This work will be described in much more detail in a future journal paper.

2. Observations and Reduction

Observations were taken at Isaac Newton Telescope with the MUSICOS cross-dispersed echelle spectrograph, and have $R \sim 30000$ and typical S/N of 100–300. We have developed a technique for continuum determination by interpolation to those orders where deep lines like the Balmer lines are. We do this by surface fitting continuum points of a 2D array of the extracted orders. The continuum normalised orders are then wavelength calibrated and spliced together to produce a single spectrum.

Figure 1 shows the agreement of spectra reflected from the moon reduced in this manner with the Kitt Peak FTS solar flux atlas (Kurucz *et al* 1984). This indicates an estimate of the observational error as better than 1% which corresponds typically to errors less than approximately 50 K in effective temperature (Fuhrmann *et al* 1993).

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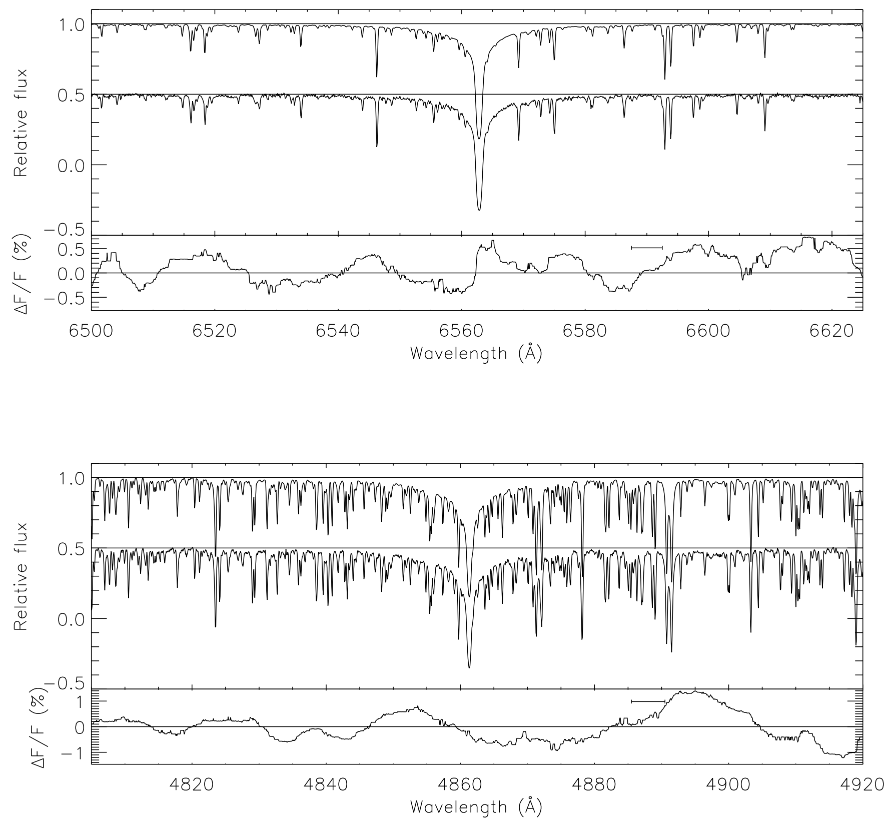

Figure 1. The FTS solar spectrum degraded to $R = 30000$ (upper spectrum) compared with the moon spectrum obtained in this work (lower offset spectrum) for the Hα (upper figure) and Hβ (lower figure) regions. The relative difference between the two spectra $\Delta F/F$ is shown, which has been median filtered with a 5Å width bin (shown as horizontal bar) to show low frequency, i.e. continuum, behaviour.

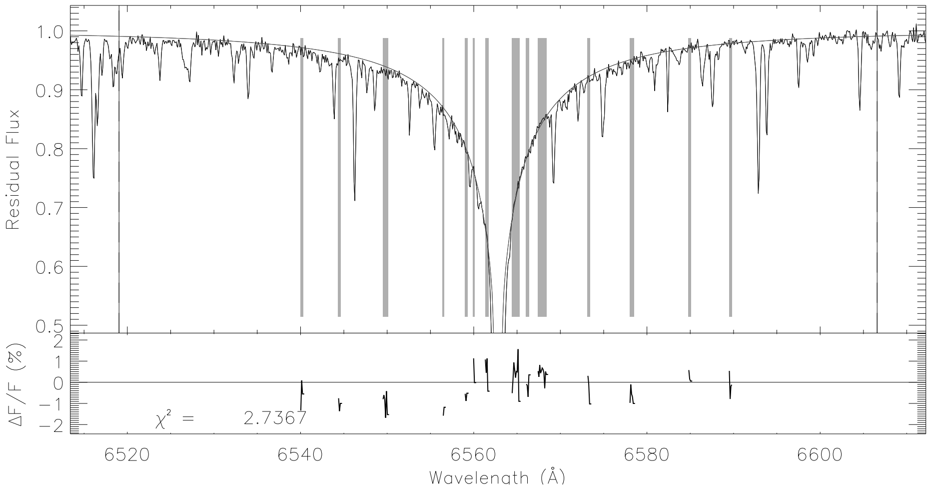

Figure 2. An example of the fitting method for Procyon Hα profile. The shaded regions show the windows used for determining the χ^2 statistic. The full vertical lines show the estimated limit of validity of the impact approximation for self-broadening.

3. Quantitative Fitting of Balmer Lines

In order to remove the subjectiveness of fitting Balmer lines by eye, we introduced a method for automated fitting. We use a reduced χ^2 statistic

$$\chi^2 = \frac{1}{N-M}\sum_{i=1}^{N}\left(\frac{f_i - F_i}{\sigma_i}\right)^2$$

where N is the number of wavelength points, M is the number of free parameters (here one, namely $T_{\rm eff}$), f_i is the synthetic residual flux, F_i the observed residual flux, and $\sigma_i = 1/\mathrm{SNR}$.

In order to avoid problems with blending lines we determined a set of spectral windows believed to be unblended using the Kitt Peak FTS solar atlas, and the best of our spectra of solar metallicity stars of differing temperatures with specific reference to Procyon (F5V-IV) and HR 8832 (K3V). For *every star* we use these same windows, *or a subset* of the windows if there is an obvious blend or atmospheric line (positions of which vary in the stellar rest frame from star to star). This removes the need to judge what is noise, and what is a weak line, particularly in lower SNR spectra of metal-poor stars.

We minimise this statistic in the $T_{\rm eff}$ space. An example of the fitting procedure is shown in figure 2. We derived effective temperatures from Hα, Hβ and Hγ where appropriate, for a sample of 32 F, G and K dwarf stars with a spread in temperature and metallicity.

4. Model Spectra

Synthetic spectra are computed in LTE using MARCS 1D LTE plane-parallel models, Stehle (1994) Stark broadening calculations, and Barklem *et al* (2000) self-broadening theory (hereafter BPO). For metal-poor stars models are computed with α-element abundances enhanced by 0.4 dex. Radiation and approximate helium collisional broadening are included, although comparatively small. For comparison we also derived the results where BPO theory was replaced by Ali & Griem (1966) resonance broadening theory. We also do both comparisons using MARCS models with mixing length theory (MLT) parameters $\alpha = 0.5/y = 0.5$ and $\alpha = 1.5/y = 3/(4\pi^2)$, and use the differences in results to estimate the error due to this representation of convection.

5. Comparison with IRFM

Figure 3 compares the effective temperatures derived in this work for both BPO and Ali & Griem theories, with those stars in common with Alonso et al.'s (1996) results using the Infrared Flux Method (IRFM). Comparisons with other IRFM determinations are similar, however, we note that for a given star different IRFM determinations do show differences. For example the two metal-poor outliers on the first plot were found to be much cooler ($\sim$ 100 K) by Magain (1987), which agrees better with our results.

6. Comparison with other results from Balmer lines

Figure 4 compares the effective temperatures derived in this work for BPO theory, with those stars in common with Fuhrmann's (1998, 2000) results using Balmer lines. The results are plotted with metallicity to demonstrate that the expected differences in metal-poor stars are seen, however, the differences are not as large as predicted in Barklem *et al* (2000). We found that our results using Ali & Griem are typically 50–150 K hotter than Fuhrmann's who uses this same description of resonance broadening. No significant trend of this difference is seen with temperature or metallicity. The reason for this has been found to be the combined effect of different model atmospheres, different Stark broadening calculations and a slightly different interpretation/implementation of Ali & Griem theory. These three differences all happen to act in the same direction with respect to line strength. Different observations and fitting also blur the comparison.

References

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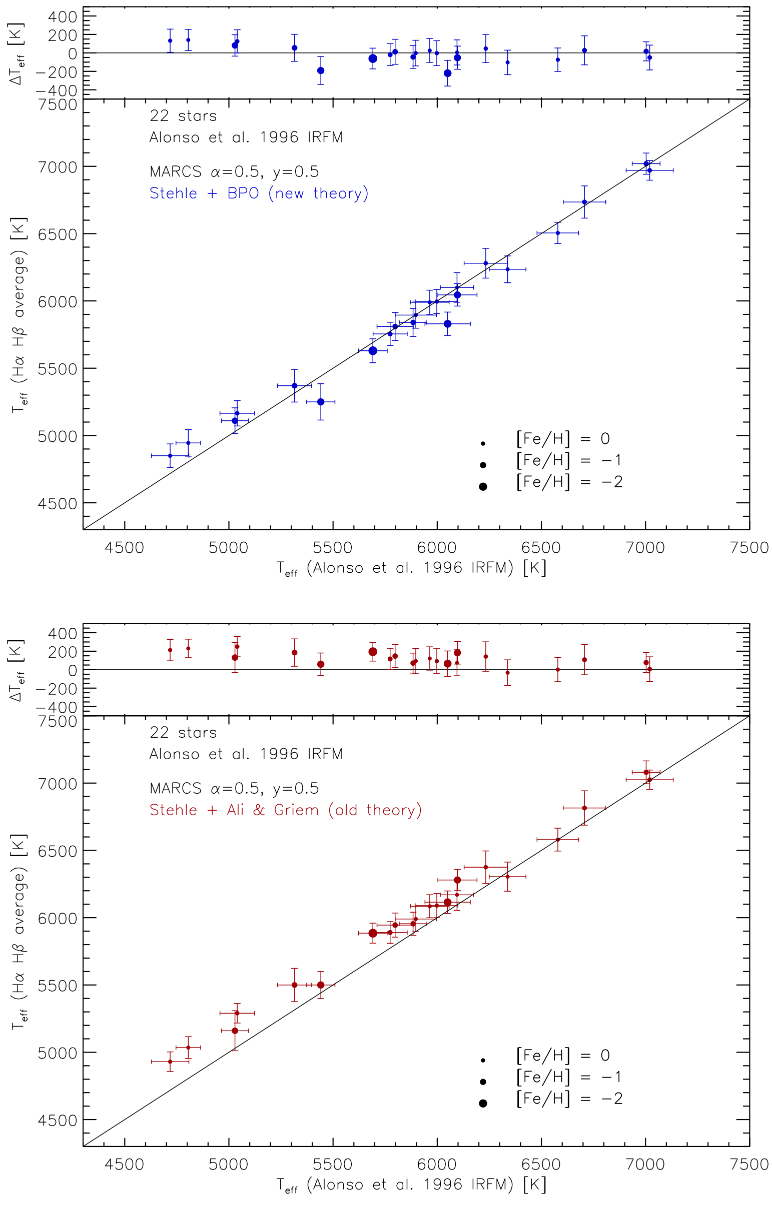

Figure 3. Derived effective temperatures using BPO (upper) and Ali & Griem (lower) theory for the self-broadening compared with the IRFM results of Alonso *et al* (1996).

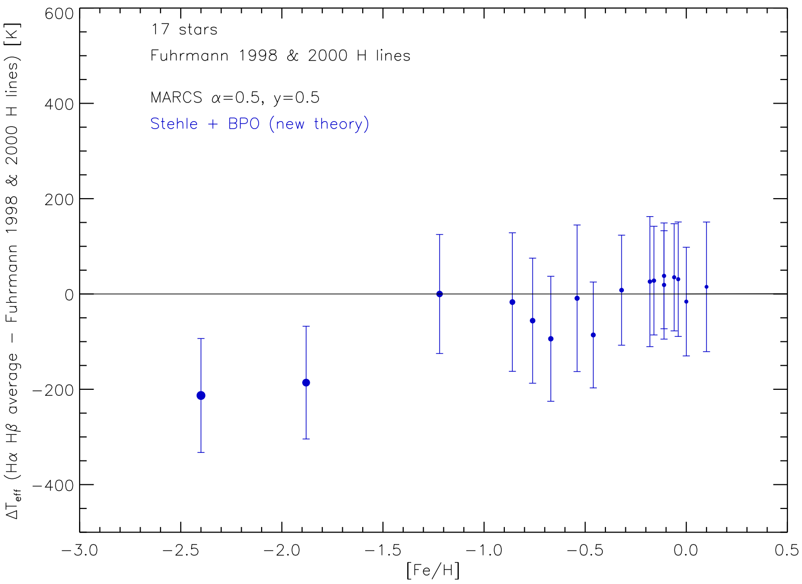

Figure 4. Difference between derived effective temperatures from this work (using BPO) and those of Fuhrmann (1998, 2000) plotted against metallicity.

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