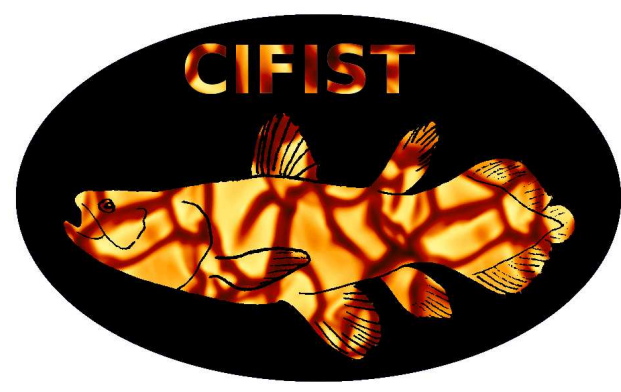


Effective temperatures of cool metal-poor stars derived from the analysis of 3D Balmer lines

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Summary

Balmer lines are recognized as accurate indicators of the effective temperature of late-type stars. The influence of convection on the shape of Balmer line profiles has been investigated using LTE 3D hydrodynamical model atmospheres and 'classical' LTE 1D stellar atmospheres, where convection is modeled within the simplistic picture of mixing-length theory. Models and line profiles computed with the CO⁵BOLD and Linfor3D codes have been used to determine the effective temperatures of three well known metal-poor stars HD84937, HD74000, and HD140283. Expected (3D-1D) Teff biases related to the different treatment of convection in the 1D and 3D models are presented.

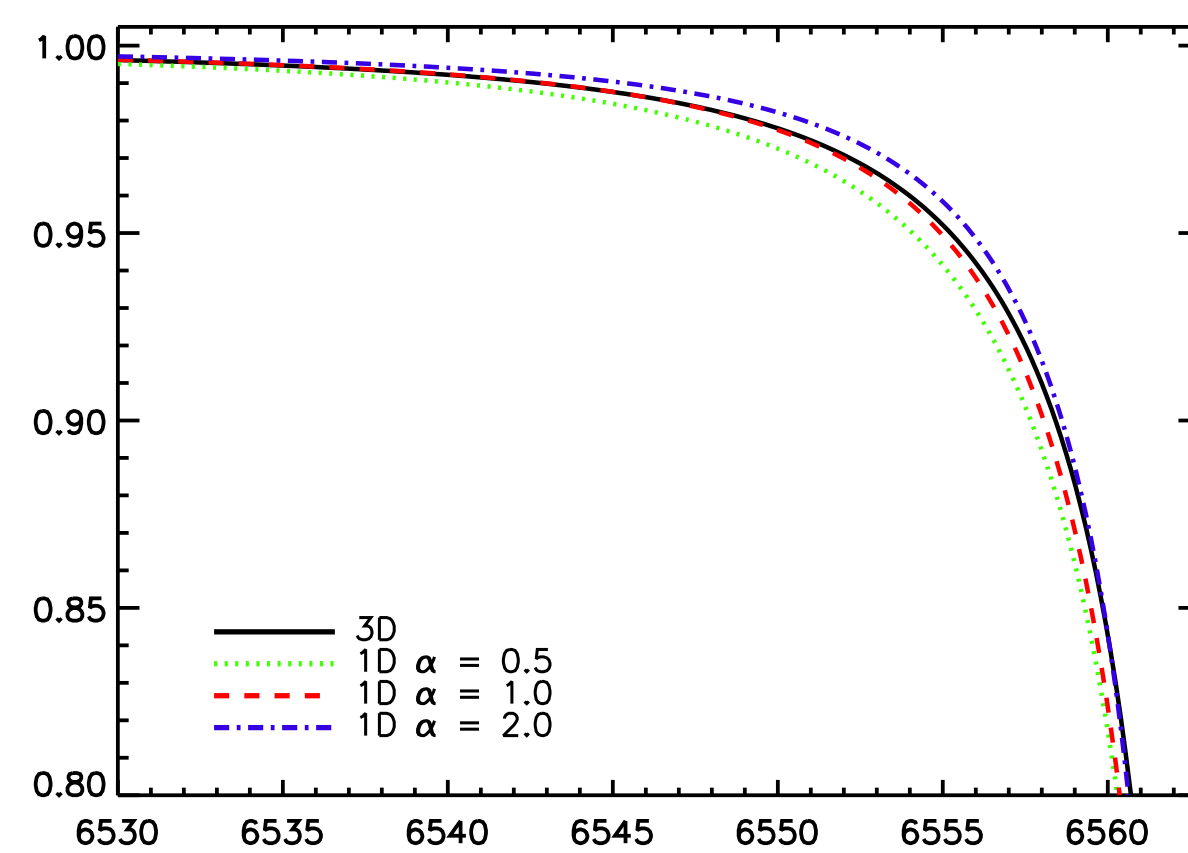


Figure 1. H α Balmer line profile computed using a 3D model, and 1D models with varying mixing length, α .

Model atmospheres & spectral synthesis

The grid of 3D model atmospheres used in the analysis were computed with CO⁵BOLD, a 3D radiation hydrodynamics code designed to model stellar convection (see Freytag et al. 2002 or Wedemeyer et al. 2004 for details). The 1D LHD atmospheres are homogeneous hydrostatic models, and assume plane-parallel geometry. The same equation of state, opacities, and radiation transport routines as in CO⁵BOLD are employed, allowing a direct comparison with the 3D models with the exception of free parameters, such as the mixing-length, α .

The Balmer line profiles were computed using Linfor3D. Self-broadening of the hydrogen lines was calculated according to the Barklem et al. (2000) formula (hereafter BPO), as well as the Ali & Griem (1966) theory (hereafter AG). A grid of ATLAS/BALMER9 profiles (hereafter B9) was computed for comparison purposes, using both recipes, BPO and AG, for resonance broadening. Stark broadening was calculated following Griem's (1960) theories with corrections to approximate the Vidal, Cooper & Smith (1973) profiles. The grid of models spans from 4000 K to 6500 K in effective temperature, $\log g = 3.5$ to 4.5 in surface gravity, and -2.00 to 0.00 in [Fe/H]. The LHD models were calculated using $\alpha=0.5$ throughout the investigation.

Table 1. Measured H α effective temperatures of the three metal-poor stars and the Sun. EE denotes excitation equilibrium.

Method	T _{eff}	log g	[Fe/H]	Reference
SUN - Kurucz flux				
3D H α -BPO	5759.9	4.44	0.00	This work
LHD H α -BPO	5697.5	4.44	0.00	This work
B9 H α -BPO	5643.5	4.44	0.00	This work
NLTE H α -BPO	5720.0	4.44	0.00	Mashonkina et al. (2008)
3D H α -AG	5865.0	4.44	0.00	This work
LHD H α -AG	5773.5	4.44	0.00	This work
B9 H α -AG	5707.5	4.44	0.00	This work
NLTE H α -AG	5780.0	4.44	0.00	Mashonkina et al. (2008)
HD84937 - UVES				
3D H α -BPO	6400.0	4.00	-2.00	This work
LHD H α -BPO	6293.5	4.00	-2.00	This work
B9 H α -BPO	6236.4	4.00	-2.00	This work
NLTE H α -BPO	6300.0	4.00	-2.15	Mashonkina et al. (2008)
B9 H α -AG	6331.9	4.00	-2.00	This work
NLTE H α -AG	6380.0	4.00	-2.15	Mashonkina et al. (2008)
LTE H α -AG	6346.0	4.00	-2.16	Korn et al. (2003)
IRFM	6271.0	4.00	-2.00	González Hernández et al., <i>in prep.</i>
IRFM	6330.0	4.50	-2.49	Alonso et al. (1996)
EE Fe I	6222.0	4.27	-1.86	Thevenin & Idiart (1999)
EE Fe I	6375.0	4.10	-2.00	Fulbright (2000)
HD140283 - UVES				
3D H α -BPO	5877.9	3.50	-2.00	This work
LHD H α -BPO	5796.9	3.50	-2.00	This work
B9 H α -BPO	5803.9	3.50	-2.00	This work
B9 H α -AG	5836.5	3.50	-2.00	This work
H α -AG	5806.0	3.68	-2.43	Korn et al. 2003
IRFM	5696.0	3.50	-2.00	González Hernández et al., <i>in prep.</i>
IRFM	5691.0	4.00	-2.37	Alonso et al. 1996
EE Fe I	5600.0	3.74	-2.21	Thevenin & Idiart 1999
EE Fe I	5650.0	3.40	-2.40	Fulbright (2000)
HD74000 - HARPS				
3D H α -BPO	6346.3	4.00	-2.00	This work
LHD H α -BPO	6182.9	4.00	-2.00	This work
B9 H α -BPO	6124.9	4.00	-2.00	This work
B9 H α -AG	6241.9	4.00	-2.00	This work
IRFM	6247.0	4.00	-2.00	González Hernández et al., <i>in prep.</i>
IRFM	6224.0	4.50	-2.00	Alonso et al. 1996
EE Fe I	6146.3	4.25	-1.83	Thevenin & Idiart 1999
EE Fe I	6025.0	4.10	-2.00	Fulbright (2000)

The Sun

Barklem et al. (2002) obtained a solar temperature of 5733 K for H α and 5723 K for H β . Using a NLTE-BPO analysis, Mashonkina et al. (2008) obtain 5720 K for H α . The 3D BPO fit gives 5760 K, and provides the best fit thus far for the solar H α temperature using the Barklem theory.

Table 2. H α , H β and H γ T_{eff}.

3D T _{eff}	1D T _{eff}	3D-1D	line
HD84937			
6401.8	6293.5	108.3	H α
6398.1	6318.4	79.7	H β
6393.1	6295.2	97.9	H γ
Sun			
5759.9	5697.5	62.4	H α
5753.7	5670.3	83.4	H β
5755.0	5657.5	97.5	H γ

Hotter temperature scale

Effects of convection on the determination of stellar effective temperatures from Balmer lines show a rather complex dependence on the atmospheric parameters. However, whereas the actual magnitude of the 3D-1D temperature bias is difficult to estimate based on stellar parameters, overall the 3D temperatures are consistently hotter than the 1D temperatures.

Introduction

One of the primary methods used in determining the effective temperature of a cool star involves the comparison of synthetic to observed Balmer line profiles. Temperature determinations are based mostly on the H α line, since the wings of the line are strongly temperature sensitive, and are nearly insensitive to the model mixing-length parameter (Fuhrmann et al. 1993). However, in the case of metal-poor stars, where the convective zone reaches further out in the atmosphere, the H α line may be affected, and as a consequence, may not be completely insensitive to the mixing-length.

Synthetic spectra computed using 3D hydrodynamical model atmospheres and 3D line formation have the property that they are independent of such free parameters inherent to 1D models. In general, however, a profile computed from a 3D model has a different shape from that computed from a 1D model, as shown in Figure 1. To characterize the influence of convection on the shape of the Balmer line profiles, we have fitted observed spectra of metal-poor stars to grids of 3D and 1D model profiles, solving for the effective temperature by minimizing the RMS deviation.

Results

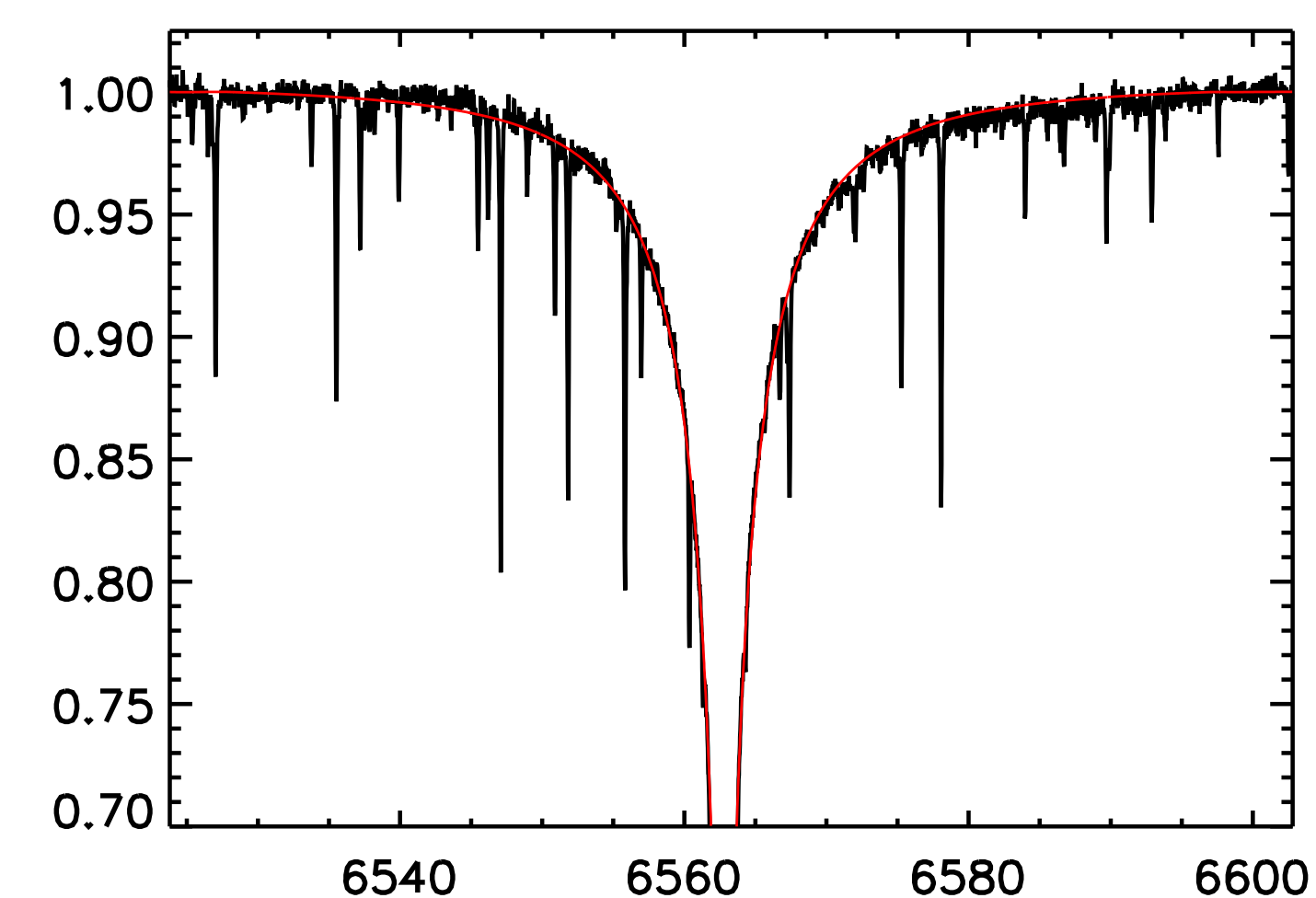


Figure 2. H α fit of HD140283 using 3D models. The best fit gives T_{eff} = 5877.9 K, using log g = 3.50, and [Fe/H] = -2.00.

Consistency between T_{eff} derived from H α , H β and H γ

We had sufficient spectral range coverage of HD84937 and the Sun (Kurucz flux) to measure the effective temperature from the first three Balmer lines. We find that the 3D H α , H β and H γ give temperatures consistent to within 9 K for HD84937, and to within 6 K for the Sun. In comparison, the spread in the 1D temperatures calculated using a mixing-length parameter of $\alpha = 0.5$ is much more significant: 25 K for HD84937 and 40 K for the Sun.

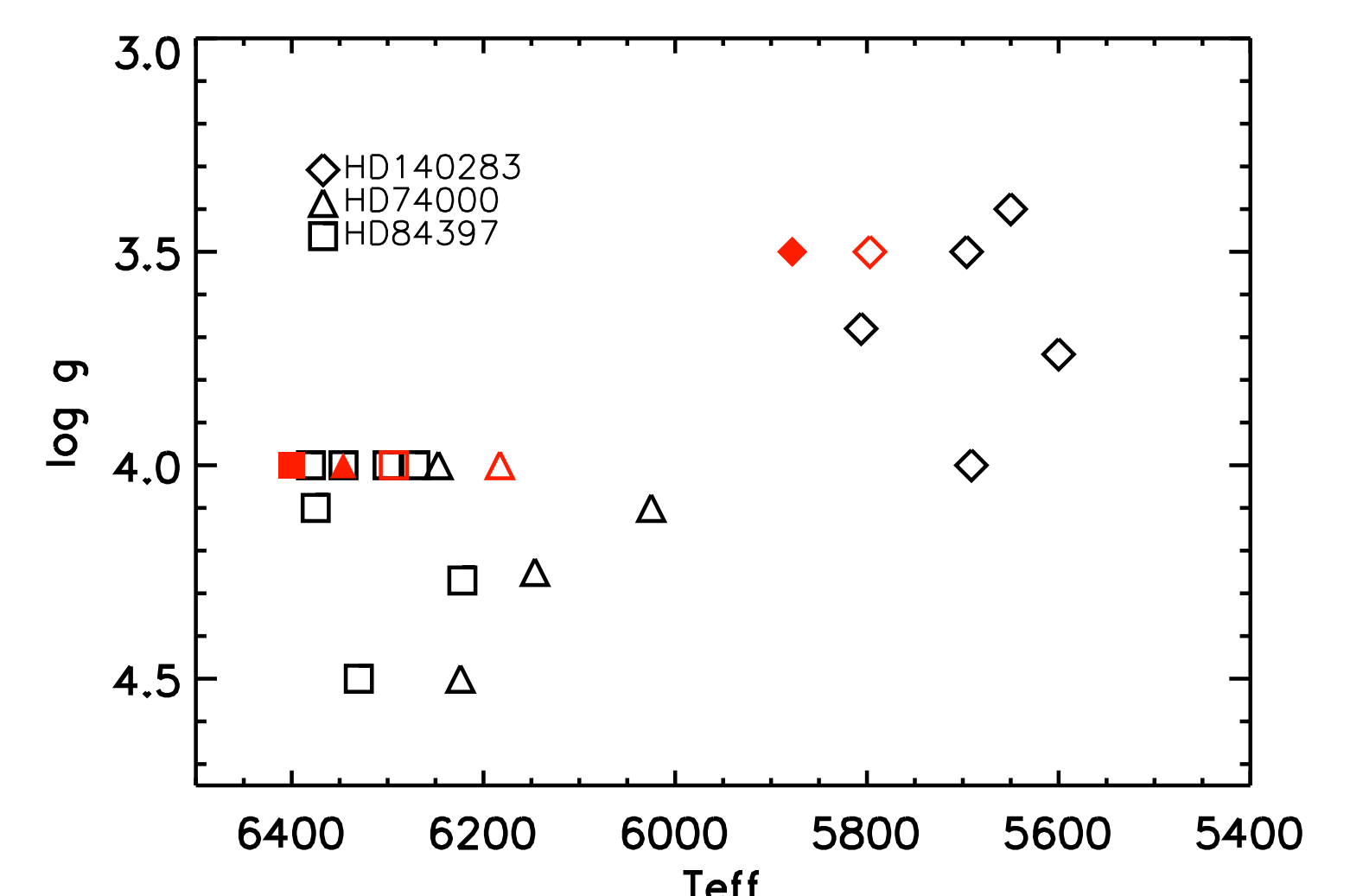


Figure 3. Values from Table 1, where 3D values are marked with filled red symbols, and 1D LHD with open red symbols.

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