The effects of convection on the colours of A and F stars

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Abstract. We present a discussion on the effects of convection on the *uvby* colours of A and F stars. The mixing-length theory used in ATLAS9 is compared to the turbulent convection theory of Canuto & Mazzitelli (1991, 1992). Comparison with fundamental stars reveals that colours calculated using the Canuto & Mazzitelli convection theory are generally in better agreement than those obtained using mixing-length theory.

Key words: Convection – stars: atmospheres – stars: general – stars: fundamental parameters

1. Introduction

The colours calculated for stars later than mid A-type are affected by treatment of convection. Small systematic errors were found in the colours calculated using ATLAS6 (Kurucz, 1979), which could be due to convection or missing opacity in the models (Relyea & Kurucz, 1978). Recent improvements in opacity in ATLAS9 models (Kurucz, 1991) ought to ensure that opacity is now a less dominant source of the discrepancies. This leaves convection as a possible source of the discrepancies.

We have compared mixing length theory (see Castelli et al., 1997) with the turbulent convection model of Canuto & Mazzitelli (1991, 1992). The ATLAS9 code was used to calculate *uvby* colours. The computations were identical, except for treatment of convection. We considered three cases:

1. mixing-length theory with approximate overshooting (MLT_OV),

2. mixing-length theory without approximate overshooting (MLT_noOV),

3. the Kupka (1996) implementation of the Canuto & Mazzitelli theory (CM).

Here we present a summary of the main findings from the comparisons between the three treatments of convection outlined above. Full details can be found in Smalley & Kupka (1997).

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2. Comparison with Fundamental Stars

The ultimate test of any model colours is to compare them to the colours of stars whose atmospheric parameters have been obtained from direct, model-independent methods. The fundamental stars presented by Smalley & Dworetsky (1995) were used to test the colours obtained from the three grids.

We adopted the following methodology in the testing procedure: The observed *uvby* photometry of the fundamental star was de-reddened using Moon's (1985) UVBYBETA programme. For each grid in turn, values of $T_{\rm eff}$ and $\log g$ were obtained by interpolation within the $(b-y,\, c_0)$ colour grid. We then compared either $T_{\rm eff}$ or $\log g$ with the corresponding fundamental value. This way we could compare $T_{\rm eff}$ and $\log g$ independently, since very few stars have fundamental values for both parameters.

Figure 1 shows the comparison between the fundamental $T_{\rm eff}$ values and those obtained from the 3 grids. The CM model gives the best agreement. The MLT_noOV grid is somewhat discrepant, but still within the error bars. The MLT_OV grid is widely discrepant.

Figure 2 shows the comparison between the fundamental $\log g$ values and those obtained from the 3 grids. There is little difference between CM and MLT_noOV grids, but MLT_OV grid is clearly discrepant. However, the CM models give less scatter and no hint of a possible systematic trend at low $T_{\rm eff}$ observed in the MLT_noOV models.

From the comparisons with fundamental stars we find that the CM grids give the best agreement. The MLT_noOV grids are only marginally less successful in recovering the fundamental values. The MLT_OV grids are however significantly discrepant.

Since there are very few stars with fundamental values of $T_{\rm eff}$ or $\log g$, the comparisons were also performed using non-fundamental stars. Whilst this allows for significantly more stars in the comparisons, there is a very real danger that model-dependent systematic errors could bias any result. However, similar results were found using stars which have values of $T_{\rm eff}$ obtained using the Infrared Flux Method (Blackwell & Lynas-Gray 1994), once known spectroscopic binaries had been excluded. Open cluster stars can be used as surface gravity standards by fitting evolutionary models to the cluster photometry. In this case the stellar interior calculations can be influenced by the treatment of convection (e.g. Stothers & Chin 1995, Canuto et al. 1996). Nevertheless, similar results were found for Hyades stars with $\log g$ obtained from evolutionary models.

Overall, the CM model has the greatest success in recovering the $T_{\rm eff}$ and $\log g$ obtained from both fundamental and non-fundamental methods. However, the MLT_noOV grids are only marginally less successful than the CM grids. The MLT_OV grids are clearly discrepant.

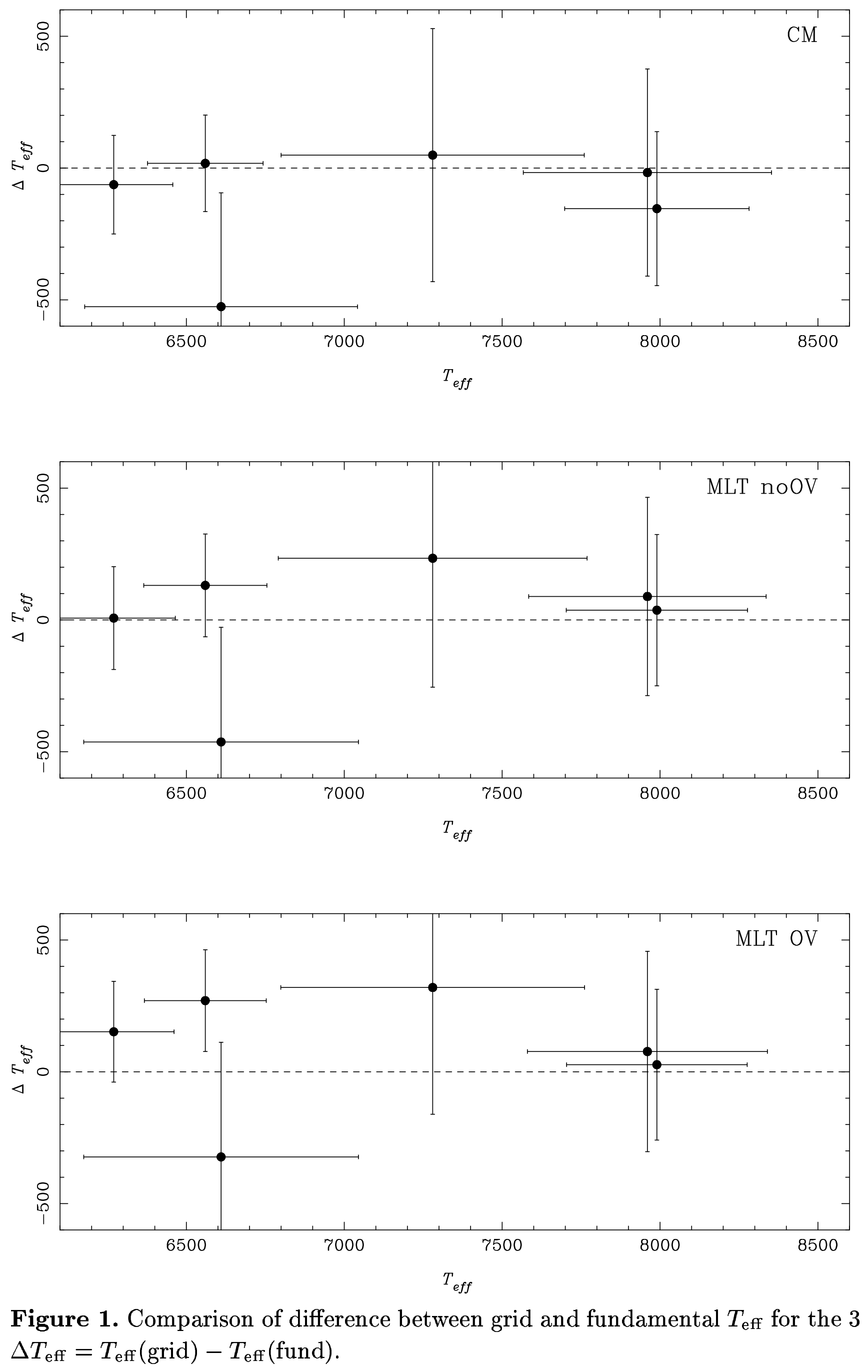

Figure 1. Comparison of difference between grid and fundamental $T_{\rm eff}$ for the 3 grids. $\Delta T_{\rm eff} = T_{\rm eff}(\text{grid}) - T_{\rm eff}(\text{fund})$.

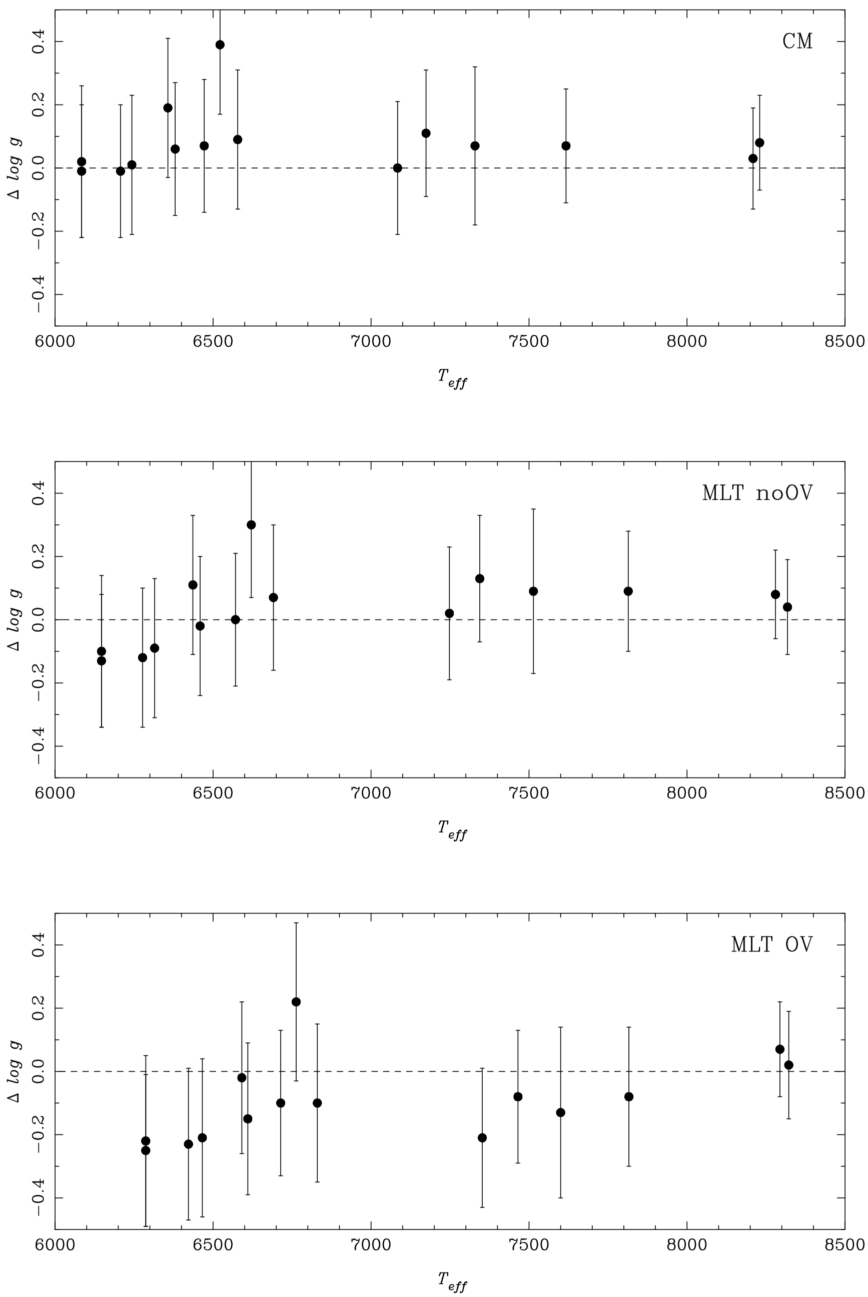

Figure 2. Comparison of difference between grid and fundamental $\log g$ for the 3 grids. $\Delta \log g = \log g(\text{grid}) - \log g(\text{fund})$.

3. Metallicity Effects

The colours of late-A and F stars can be significantly affected by metallicity, due to the vast amount of metal lines. The m_0 metallicity index can be used to estimate [M/H] in late-A and F stars, usually via empirical relations (Smalley 1993).

In all the three cases considered here, the theoretical m_0 values are found to be discrepant. None of the model results based on the different convection treatments agrees completely with the standard main-sequence reference line, and all are discrepant for late-type stars. The problem may not be due to convection alone, but could be related to microturbulence (Smalley & Kupka 1997), because microturbulence is probably closely related to the small-scale part of the photospheric convective flow (Holweger & Stürenburg 1993). Investigations into the causes of this discrepancy are being undertaken.

4. Conclusion

From a comparison with the observed *uvby* colours, we have found that the CM grid gives results that are generally superior to those with MLT theory without overshooting (MLT_noOV). Models with overshooting (MLT_OV) are found to be clearly discrepant.

The metallicity index m_0 is not in agreement. The reason for this is unclear, but could be linked to microturbulence.

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