Improving 1D Stellar Models with 3D Atmospheres

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Introduction

Many of today's stellar models share common issues; amongst these are the use of an artificial Eddington-grey atmosphere (or another simplified $T(\tau)$ relation) and the mixing-length formulation to describe convection.

The aim of our work is to implement the results from sophisticated 3D radiation-coupled hydrodynamics (RHD) simulations of stellar atmospheres into the 1D stellar evolutionary models.

3D RHD Simulations

Trampedach et al. (2013) have computed a grid of stellar atmospheres at solar metallicity; the range of $T_{\rm eff}$ and $\log(g)$ can be seen in **Figure 1**. Using this grid, Trampedach et al. (2014a, 2014b) extracted $T(\tau)$-relations and described how the mixing-length parameter, $\alpha_{\rm MLT}$, varies across the HR-diagram (see the figure).

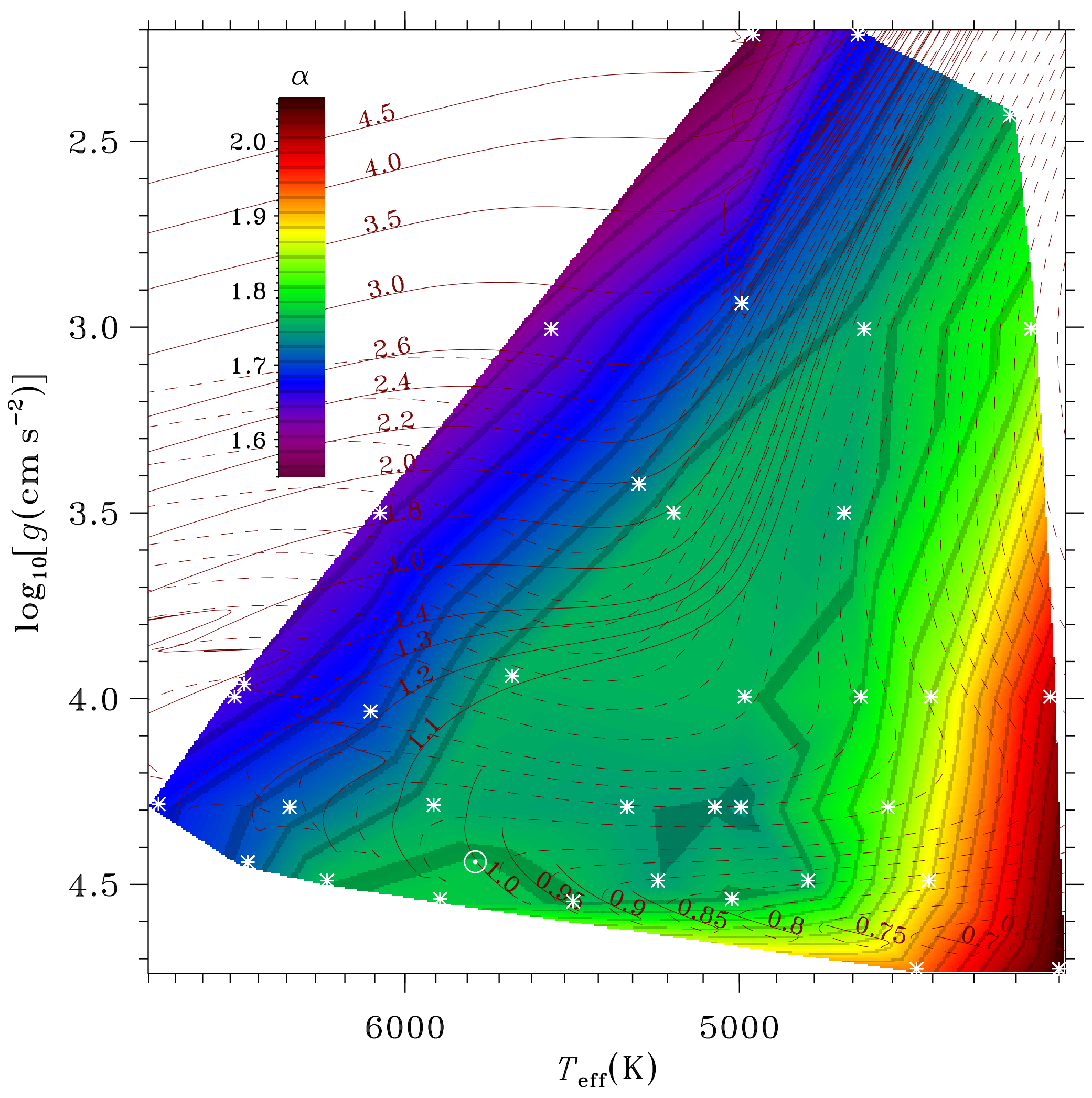


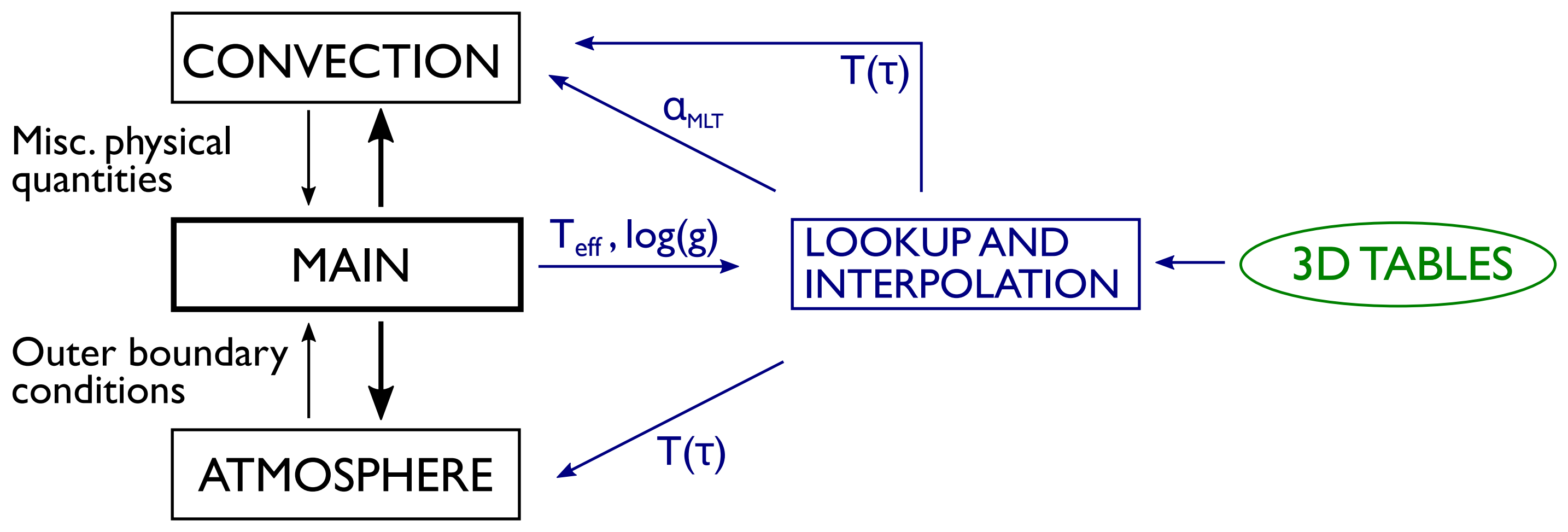
Figure 1 The behaviour of $\alpha_{\rm MLT}$ as a function of $T_{\rm eff}$ and $\log(g)$ at solar metallicity. The figure is reproduced from Trampedach et al. (2014b).

Implementation

We have implemented the results from Trampedach et al. (2014a, 2014b) – in the form of a table with $\alpha_{\rm MLT}$ and $T(\tau)$-relations (more specifically, the Hopf-function $q[\tau]$) – into the GARching STellar Evolution Code (GARSTEC, see Weiss & Schlattl 2008). The advantage of this approach is, that it that the resulting models can be evolved in time; they are not just static envelope models.

Figure 2 shows a schematic overview of the full implementation and the interaction between the different parts of the stellar evolution code. In **Figure 3** it is shown, how our implementation changes the calculations in different regions of the structure model.

Furthermore, to be fully consistent with the atmospheric calculations, we have produced new opacity tables to match those used in the 3D simulations.



CONVECTION

$T(\tau)$

$\alpha_{\rm MLT}$

Misc. physical quantities

MAIN

$T_{\rm eff}$, $\log(g)$

LOOKUP AND INTERPOLATION

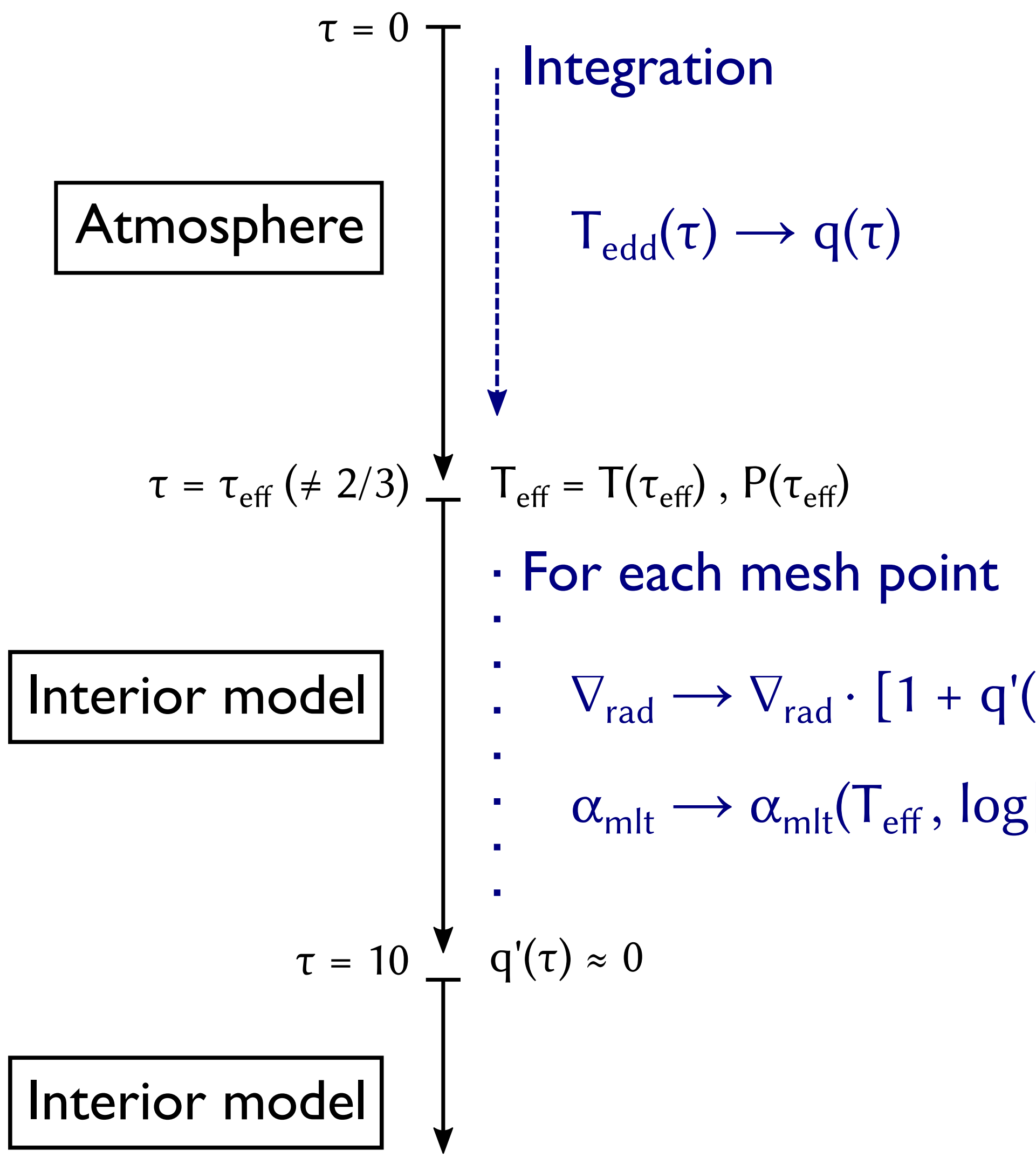
3D TABLES

Outer boundary conditions

ATMOSPHERE

$T(\tau)$

Figure 2 Overview of the full implementation. The modules in GARSTEC are drawn in black, our implementation in blue and the tables from Trampedach et al. (2014a) in green.



$\tau = 0$

Integration

Atmosphere

$T_{\rm edd}(\tau) \longrightarrow q(\tau)$

$\tau = \tau_{\rm eff}$ ($\neq 2/3$)

$T_{\rm eff} = T(\tau_{\rm eff})$, $P(\tau_{\rm eff})$

For each mesh point

Interior model

$\nabla_{\rm rad} \longrightarrow \nabla_{\rm rad} \cdot [1 + q'(\tau)]$

$\alpha_{\rm mlt} \longrightarrow \alpha_{\rm mlt}(T_{\rm eff}, \log[g])$

$\tau = 10$

$q'(\tau) \approx 0$

Interior model

Figure 3 Overview of the different regions – the atmospheric integration above the photosphere and the interior model just below the photosphere – in a stellar structure model changed by our implementation. Everything deeper are calculated as usual.

Preliminary Results

In **Figure 4**, calculated evolutionary sequences of a $1.0\,\mathrm{M}_\odot$ star at solar metallicity from the PMS until $\log(g) = 2.4$ are shown. Two different tracks are calculated; both with EOS and opacities to match the atmospheric simulations. Firstly, a "standard evolution", i.e. using a constant $\alpha_{\rm MLT} = 1.739$ (solar calibrated value) and Eddington-grey atmosphere. Secondly, using our implementation of $\alpha_{\rm MLT}$ and $T(\tau)$ from the 3D simulations.

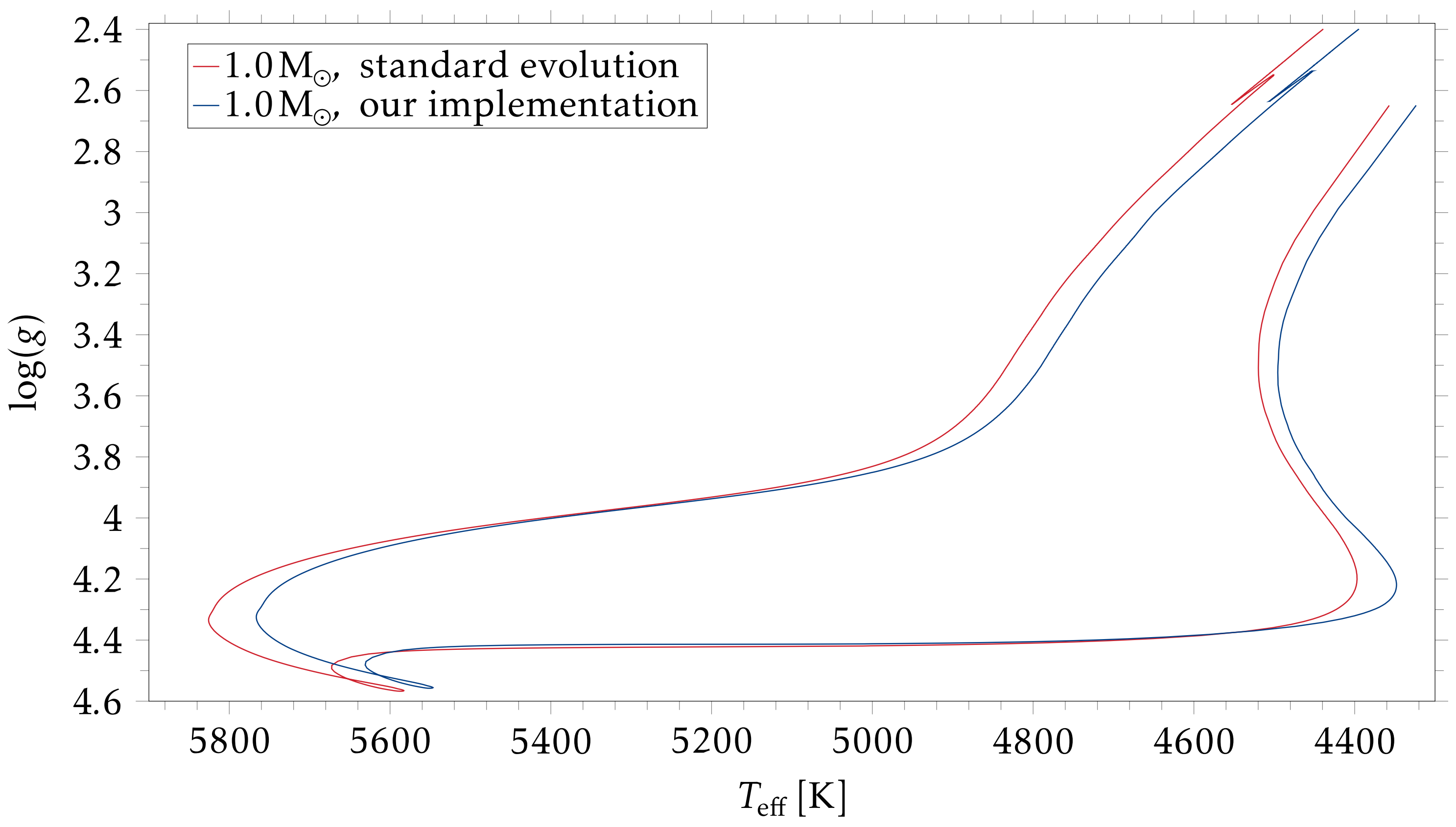


Figure 4 Evolutionary tracks of a $1.0\,\mathrm{M}_\odot$ calculated with different microphysics (details in the text above). The final difference between the tracks is about 44 K and at the turn-off about 59 K.

References

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