

Improved 3D model atmospheres for cool DA white dwarfs: Long-standing problem of the surface gravity distribution solved

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The high-log g problem

As first shown by Bergeron et al. (1990), the surface gravity, $\log g$, determined from the Balmer lines of cool DA white dwarfs ($T_{\text{eff}} < 13000$ K), is significantly higher than the expected canonical value of $\log g \sim 8$, which is about the mean value determined later for hotter DA stars. This discrepancy is now observed in all large spectroscopic surveys of DA white dwarfs; Fig. 1 shows the current status of this long-standing high-log g problem. Since white dwarf stars are expected to cool at constant mass and almost constant radius, the sudden increase in $\log g$ cannot be explained in terms of simple astrophysical arguments, and no satisfactory solution has been reported until now.

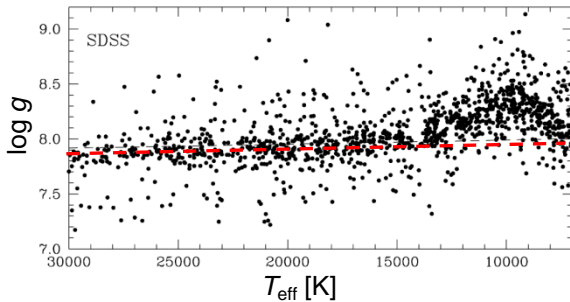


Fig. 1. Surface gravity distribution as a function of T_{eff} for the SDSS sample of DA white dwarfs (see Tremblay et al. 2011 for details). An evolutionary model from Fontaine et al. (2001) at the median mass of the sample ($0.59 M_{\odot}$) is shown as a red dashed line.

The non-detection of He I lines in high-resolution Keck observations of cool DA stars ruled out the possibility that helium in their atmospheres would mimic systematically higher spectroscopic surface gravities. This led to the conclusion that the only viable explanation for the high-log g problem is an inadequate treatment of the convective energy transport in models of the atmospheric structure, which so far is based on the mixing-length theory (MLT).

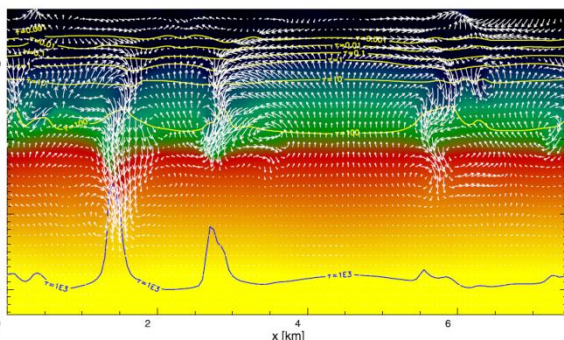


Fig. 2. Temperature structure of the 3D white dwarf model at $T_{\text{eff}} = 11975$ K and $\log g = 8$, for a slice in the x - z plane through a box with coordinates x , y , z (in km). The temperature is color coded from 8000 K (dark blue) to 60000 K (yellow). The arrows represent convective velocities, thick lines correspond to contours of constant Rosseland optical depth. [CO5BOLD model computed at AIP]

3D hydrodynamical convection models

Based on first physical principles, a fully three dimensional radiation-hydrodynamics (RHD) treatment of the convective flows in the atmospheres of DA white dwarfs can overcome the limitations of the mixing-length approach. Fig. 2 shows a snapshot from a CO5BOLD simulation used for the present investigation. The averaged temperature structures of the 3D simulations differ significantly from the $T(\tau)$ relations of the classical 1D models, as illustrated in Fig. 3.

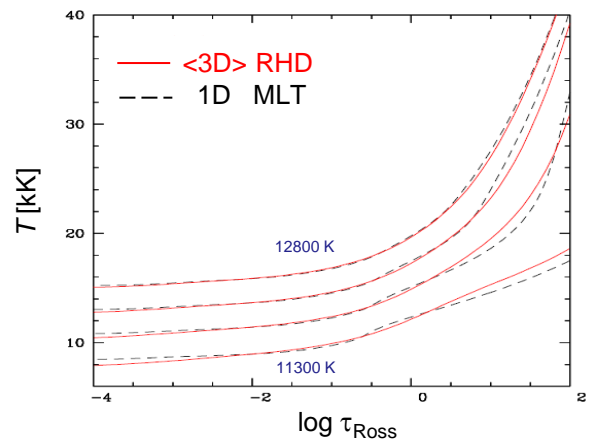


Fig. 3. Temperatures versus Rosseland optical depth for 3D (solid) non-gray simulations at $T_{\text{eff}} = 11300, 11975, 12390$ and 12800 K (shifted vertically by 0, 2, 4 and 6 kK, respectively, for clarity), compared with corresponding 1D MLT models (dashed lines).

Surface gravity corrections from 3D models

The gravity correction $\Delta \log g$ (3D-1D) is the difference between the $\log g$ values obtained from fitting a given Balmer line with synthetic profiles from 3D hydrodynamic and 1D classical model atmospheres, respectively.

T_{eff} [K]	$\Delta \log g$ 3D - 1D	$\Delta \log g$ SDSS
11300	-0.23	-0.25
11975	-0.17	-0.19
12390	-0.12	-0.13
12800	-0.08	-0.09

Table 1 demonstrates

that, for the considered range of effective temperatures, these theoretical differential 3D-1D corrections (col. 2) closely coincide with the empirical corrections (col. 3) that are necessary to bring the $\log g$ determinations shown in Fig. 1 into agreement with astrophysical expectations.

Conclusions

A long-standing puzzle concerning the cooling sequence of DA white dwarfs has been resolved by using realistic 3D hydrodynamic simulations of radiative convection in the surface layers of these compact objects. We have shown that the atmospheric temperature structure predicted by classical 1D mixing-length models is inaccurate and leads to spuriously high spectroscopic gravity determinations.