Stars and their variability observed from space
C. Neiner, W. W. Weiss, D. Baade, R. E. Griffin, C. C. Lovekin, A. F. J. Moffat (eds)

BETTER PHYSICS FOR MODELLING STARS AND THEIR OSCILLATIONS

R. Trampedach[1], G. Houdek[2] and W. Däppen[3]

Abstract. Our interpretation of stellar observations can only be as good as our stellar models and the strong constraints provided by asteroseismology demand very good models indeed. We have approached modelling improvements from three angles: Including effects of realistic 3D convection on the structure of stellar surface layers, including non-adiabatic effects of that convection on oscillations, and finally improving and modernising the equation of state for stellar plasmas. We present a review of our progress on all three fronts.

Keywords: Equation of state, Convection, Asteroseismology, Stars: atmospheres, Stars: oscillations

1 Convective Effects on Modes and Stellar Atmosphere Structure

The structure of atmospheres of late-type stars are governed by interactions between turbulent convection and radiative transfer in three dimensions. This has consequences for both the outer boundary conditions of stars (Trampedach et al. 2014a), determining which atmospheric parameters correspond to a given interior model and what will be observed; and also for the acoustic cavity trapping the observed oscillation modes inside the star, affecting their frequencies through the *structural surface effect* (Trampedach et al. 2017). Direct interactions between modes and convection gives rise to coherent mode-damping and frequency shifts (*modal surface effect*) which also manifest as a component of the pressure fluctuations that is out of phase with the density fluctuations (adiabatic modes are in phase) shown in Fig. 1 (Houdek et al. 2018). This modelling effort is in progress.

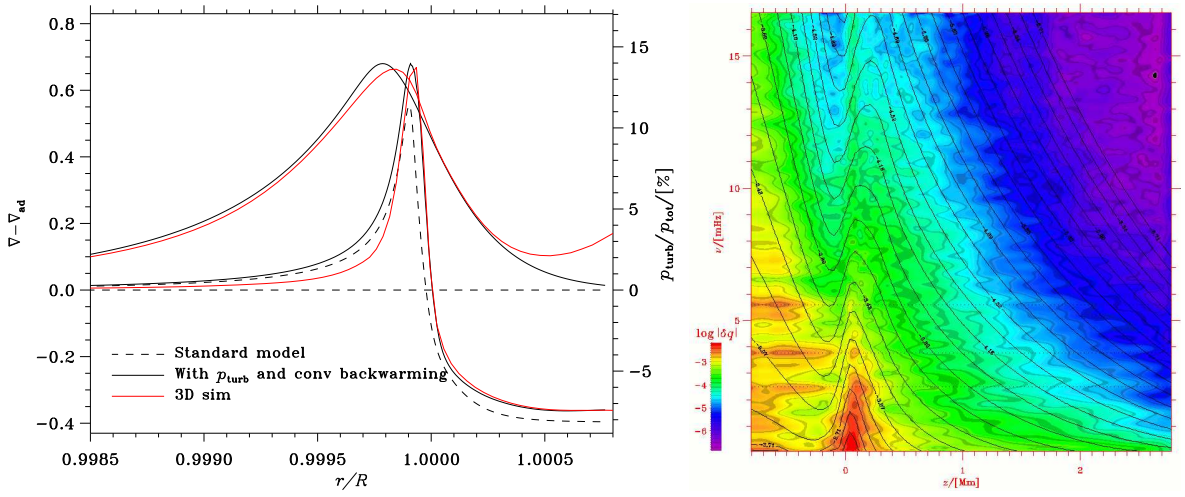

Fig. 1. Left: The turbulent to total pressure ratio (broad peak) in a 3D solar simulation (red) and reproduced in a 1D model (black). Convective backwarming affects the super-adiabatic gradient (narrow peak) A model without those two effects is shown for reference (dashed) (Trampedach et al. 2014b). **Right:** Interactions between modes and convection are quantified through the non-adiabatic pressure fluctuations, shown as function of depth and frequency in a solar sim.

[1] Space Science Institute, 4765 Walnut Street, Boulder, CO 80301, U.S.A.
[2] Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, DK
[3] Department of Physics and Astronomy, University of Southern California, Los Angeles, CA 90089, USA

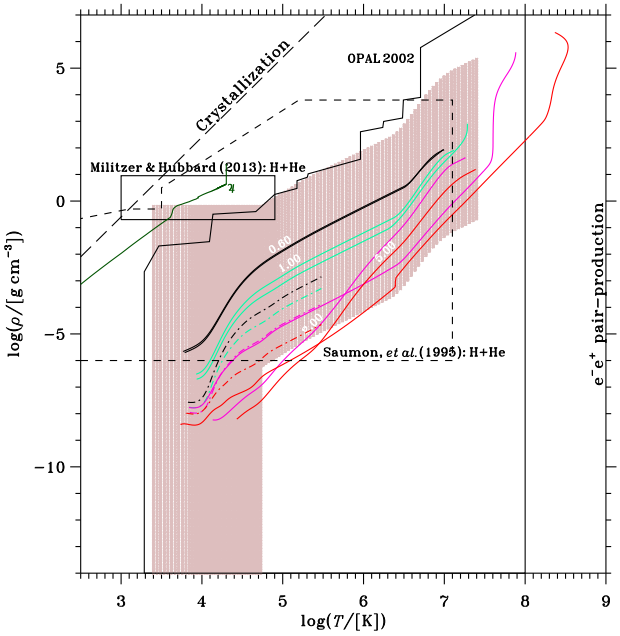

Fig. 2. The extent of various current EOS, compared with constraints on the present work: Lack of crystallisation at high density, lack of electron-positron pair-production at high T and limits to molecular partition functions at low T. The original MHD is shown in grey (Hummer & Mihalas 1988; Mihalas et al. 1988). The black outline shows the extent of the OPAL EOS by Rogers & Nayfonov (2002), and a few high-density EOS that are only evaluated for H+He mixtures are also shown. A few stellar structure tracks are shown for 0.6, 1.0, 2.0 and 5.0 $M_\odot$ (colour coded) and each shown for three stages of their evolution.

2 A New Equation of State

The Mihalas-Hummer-Däppen (MHD) equation of state (EOS) by Hummer & Mihalas (1988); Mihalas et al. (1988) is missing a number of physical processes, only includes six elements and has a fairly limited extent in temperature T and density ϱ. An extensive update addressing those three issues is close to complete. A total of 27 elements are now included (H He Li Be B C N O Ne Na Mg Al Si P S Cl Ar K Ca Ti V Cr Mn Fe Co Ni Zr), making it uniquely suitable as a basis for opacity calculations and addressing some of the opacity issues raised by Lynas-Gray et al. (2018). Out of these 27 elements, 187 molecules form (based on partition functions by Barklem & Collet (2016)), beyond the H_2 and H_2^+ molecules included in the original MHD EOS, making this EOS very relevant for stellar atmosphere modelling.

The update also includes a much improved model of the distribution function of electric fields around atoms and ions in the plasma, which perturbs bound electrons and gives rise to pressure ionization. The hard-sphere approximation of interactions between neutral atoms has been abandoned and substituted for a model where the nuclear charges are screened by their bound electrons. The Debye-Hückel theory for weakly coupled plasmas has been amended with results from plasma simulations making it, if not accurate then at least applicable, all the way to the point of crystallisation (see Fig. 2). Relativistically degenerate electrons are included, as are quantum diffraction and exchange interactions among them.

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