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Convective overshooting in stellar interiors

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Abstract. The region of turbulent convective motions in stellar envelopes provides for both energy transport and the redistribution of chemical elements by mixing processes. Penetration or overshooting of these convective motions into the surrounding stable layers extends the unstable region thereby influencing the mixing and hence the structure and evolution of stars. We review here different approaches to the study of convective overshooting with special emphasis on numerical simulations. Overshooting from convective cores is also discussed.

Key words: convection, hydrodynamics, turbulence

1. Introduction

The existence of convective overshooting into surrounding stable regions in stellar interiors is generally accepted, but there is a considerable uncertainty about its exact nature and extent. By nature we mean the manner in which the overshooting affects the energy transport and the mixing of material in the neighbouring stable regions. While there is a general consensus amongst various studies on the extent of overshoot from stellar convective cores and from stellar envelopes upwards, the situation is not so good for estimates of overshooting below the stellar convective envelopes.

In this paper, we review some of the approaches for studying overshooting from stellar convective cores and envelopes and present some new results from three-dimensional numerical simulations of turbulent compressible convection penetrating into stable layers below stellar-type convective envelopes.

2. Overshooting from convective cores

The inclusion of overshooting from stellar convective cores produces appreciable changes in the evolutionary tracks of medium and large mass stars on the H-R diagram. This is because even a small to moderate amount of overshooting of 0.1 – 0.2 Hp,Hp being the pressure scale height, influences the duration of the central hydrogoen burning phase thereby lengthening the main-sequence lifetimes and increasing the mass of the fiinal hydrogen exhausted core.

The treatment of convective overshooting from a core requires modelling of thermal convection in a fluid sphere with uniformly distributed heat sources. Since such calculations are not forthcoming, attempts have been made to estimate overshooting by resorting to empirical determinations. Since an enhanced size of the convective core due to overshooting leaves its signatures on the evolutionary tracks, it should also affect the shape of the isochrone (locus of constant age). A convenient way to estimate overshoot would thus be to look for a best fit to both the H-R diagram of individual clusters and the width of the main sequence band (Stothers 1991, Napiwotzki et al 1991, Maeder & Mermilliod 1992, Dowler & Vandenbergh 1995). These studies have indicated an overshoot extent of 0.2 – 0.3H_p. Fitting the two stars in a binary system with known masses and the same age and initial composition with a common isochrone also gives a test of the extent of overshooting (Roxburgh 1998).

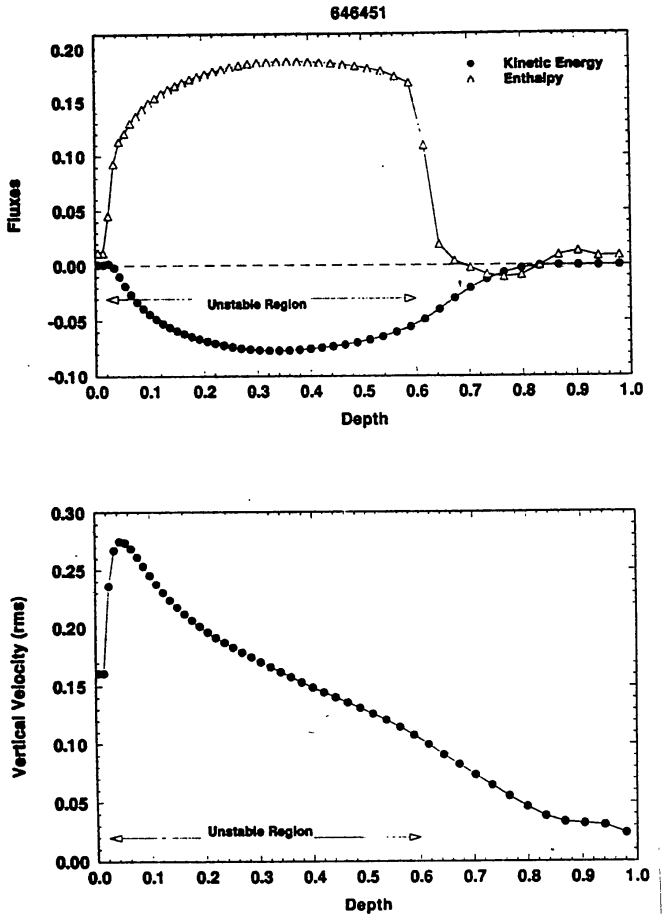

Figure 1. Penetration distance from Numerical simulations can be computed from the kinetic energy flux, the enthalpy flux or the e-folding distance of vertical velocity. The temperature, pressure, density and the total depth of the domain is normalized to unity at the top. The velocities are scaled to $(ptop/ptop)^{1/2}$ and various fluxes are scaled to $(ptopVtop)$. In the figures, the top of the domain is donated by depth zero.

3. Overshooting from convective envelopes

The mixing length theory, which is frequently used for modelling convection zones in stellar models has the superadiabatic temperature gradient $\Delta\nabla = 0$, and the fluid velocity $V = 0$ at the stable-unstable interface and there is no penetration of eddies into the surrounding stable region. The model is not self-consistent as the eddy is accelerated in the convection zone and thus should have a velocity $V_0 \simeq (F/\rho)^{1/3}$ at the boundary of the stable-unstable regions, F being the energy density flux and ρ the local mass density. Moreover, a self-consistent model must incorporate feedback of the overshoot on the energy transport in the penetrative region.

A number of non-local models have been studied by various authors which incorporate some element of feedback (Shaviv & Salpeter 1973, Maeder 1975, Roxburgh 1978, 1985, van Ballegooijen 1982). All these studies predicted an overshooting extent of a pressure scale height or more above the solar convection zone and few tenths of a pressure scale height below the unstable zone. Schmitt et al. solved the equations for buoyant plumes and obtained a relationship $d = f^{1/2} V_0^{3/2}$ between the amount of overshoot (*d*) and the vertical velocity at the bottom of the convection zone (V_0); f being a filling factor. Zahn (1991) studied the problem analytically based on scaling arguments and obtained a similar relationship. According to the helioseismic inversion of the recent solar oscillation data, an upper limit of $0.05H_p$ on the downward penetration has been suggested (See Roxburgh, 1998 for a review).

Attempts have been made recently to study the overshoot by directly solving the governing fluid equations in two and three dimensions in which the convective region is sandwiched between two stable layers (Roxburgh & Simmons 1993, Hurlburt et al. 1994, Singh et al. 1994, 1995, 1998, Freytag et al. 1996, Nordlund & Stein 1996).

Since the speed and memory of the presently available computers restrict the calculations to resolve all scales, some sort of scaling relationships relating the overshoot distance to the flow variables like the vertical velocity and the input flux need to be examined which can then be applied to the stellar cases. Keeping this in mind, we simulated several models by varying the input flux (F), the horizontal and vertical resolution, and aspect ratio (width / depth) of the box. The penetration distances below the covection zone were computed by using the temporal and horizontal averaged kinetic energy flux, the enthalpy flux and the vertical velocity. The input physics and details of the simulation parameters are described in Singh et al. (1998). Fig. 1 shows the distributions of these three quantities for a particular case of a grid of 64 × 64 × 51. It was found that $d \propto F^{1/2}$ and $d \propto V_0^{3/2}$ for four models in which only the input flux and hence the efficiency of convection has changed. The penetration was found to proceed sub-adiabatically for a mesh of 35 × 35 × 51. We also find that while the vertical resolution and the aspect ratio influence the penetration distance, there is little effect of increasing the horizontal resolution on *d* for the range of parameters presently considered.

We find that more models need to be studied, especially with a continuous rather than a piece-wise conductivity profile and by varying the stability of the lower stable layer. Such computations are underway.

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References

Dowler P., Vandenbergh D., 1995 (private communication)

Freytag B., Ludwing H. G., Steffen M., 1996, A&A, 313, 563

Hurlburt N. E., Toomre J., Massaguer J. M., Zahn J. -P., 1994, ApJ, 421, 245

Maeder A., Mermilliod J. -C., 1992, A&AS, Suppl. 98, 477

Napiwotzki R., Schoenberner D., and Weidemann V., 1991, A&A, 243, L5

Nordlund A., Stein R. F., 1996, in Stellar Evolution : What Should be Done? 32nd Liege Colloquium. Eds. Noels, A., et al. P., 75

Roxburgh I. W.,1978, A&A, 65, 281

Roxburgh I. W., 1985, Solar Phys. 100,21

Roxburgh I. W., Simmons J. 1993, A&A , 277, 93

Roxburgh I. W., 1998, in ASP Conf. 138, Proc. 1997 Pacific Rim Conf. on Stellar Astrophysics, ed. K. L. Chan, K. S. Cheng, H. P. Singh (San Francisco : ASP), 411

Singh H. P., Roxburgh I. W., Chan K. L., 1994, A&A, 281, L73

Singh H. P., Roxburgh I. W., Chan K. L., 1995, A&A, 295, 703

Singh H. P., Roxburgh I. W., Chan K. L., 1998, A&A, 340, 178

Stothers R. B., 1991, ApJ, 383, 820

van Ballegooijen A. A., 1982, A&A., 113, 99