THE BOUNDARIES OF A CONVECTIVE ZONE

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It is worth noting that various definitions for the boundaries of a convective zone may be considered. Their importance for stellar evolution is very unequal.

1. A level r_N is defined at the place where the Nusselt number N = 1, the Nusselt number being the ratio fo the total heat transfer in the turbulent state to that in absence of turbulence (Spiegel, 1966). Thus, r_N is the level reached when the contribution of convection to the energy transport changes of sign. If there is a negligible transport by sound waves, the usual equation of energy transport in stellar structure may be written :

$$\frac{\partial T}{\partial M_r} = - \frac{G\,Mr}{4\pi r^4} \; \frac{T}{P} \; \frac{1}{N} \; \nabla_{rad}$$

where N may be determined by an iterative process in a non-local form of the mixing-length theory. For example, at the edge of a convective core, there are usually 2 levels r_{N1} and r_{N2}, the first one marks the transition from the convective zone to the overshooting zone (convective motions with $N < 1$), while the second one marks the transition from the overshooting zone to the radiative zone ($N \equiv 1$). A frequent but unsatisfactory treatment in stellar models is to consider $r_{N1} = r_{N2}$.

2. The level r_T is defined at the place where the mean temperature excess ΔT of a fluid element vanishes. Thus, at r_T, the forces acting on the elements also vanish and this level may be called the dynamical edge of the core. For subsonic convection, the levels r_T and r_N are evidently equal.

3. Following Shaviv and Salpeter (1973), a level r_δ may be defined at the place where $\delta = 0$, where δ is

$$\delta = \frac{(\partial T \;/\; \partial r\;)}{(dT \;/\; dr\;)} - 1 \quad ,$$

https://doi.org/10.1017/S025292110001245X Published online by Cambridge University Press

$\partial T/\partial r$ is the gradient in the surrounding medium, in the non-local formalism adopted (Maeder and Bouvier, 1976) it is a non-local quantity. It was shown that the temperature fluctuations of the turbulent medium are able to make $\delta \equiv 0$ at many places in convective cores. So, this boundary r_δ has no true meaning.

4. The level r_ε is defined at the place given by Schwarzschild's criterion, i.e., at the place where $\varepsilon = 0$, with

$$\varepsilon = \frac{(dT / dr)_{rad}}{(dT / dr)_{ad}} - 1 .$$

Formally, r_ε and r_{N1} do not coincide. ε may be written

$$\varepsilon = N \frac{(dT / dr)_{eff}}{(dT / dr)_{ad}} - 1 ,$$

where $(dT/dr)_{eff}$ is the fictious gradient, necessary if all the energy was carried by radiation in the convective zone. In the calculated models, this gradient is slightly subadiabatic for $r \to r_{N1}$. Thus, r_ε lies slightly below r_{N1}, but due to the very small deviations from adiabaticity, these 2 levels are essentially undiscernible at the edge of a convective core.

5. A kinematical edge r_v may be defined at the level, where the velocity of a mean fluid element becomes zero. This level evidently coincides with the level r_{N2} defined before. It is this level which determines the extention of the zone of convective mixing.

In a convective core, the significant levels are, in order of increasing distance from the centre, $r_\varepsilon < r_{N1} = r_T < r_v = r_{N2}$. This order will be reversed at the bottom of a convective zone, provided the convection is adiabatic there.

Numerical models show that the distance of overshooting $(r_{N2} - r_{N1}) / \ell$ expressed in terms of the mixing length is very insensitive of the various efficiency parameters of convection. Comparisons with observations of open star clusters show that an overshooting amounting to about 7 % of pressure scale height is likely to occur in upper MS stars.

Bibliography

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