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A Summary of Processes in Convective Boundary Mixing

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ABSTRACT

Convection zones have motions which extend beyond the nominal boundary of the convection zone. The mechanisms which lead to these motions are collectively known as “convective boundary mixing” (CBM). However, the terminology of this field is muddled in stellar astrophysics; terms like convective “overshoot” and “penetration” are often used interchangeably even though they refer to specific processes. Here we briefly recall the fluid dynamical processes of convective overshoot, entrainment, and convective penetration.

Keywords: Stellar convection zones (301), Stellar physics (1621); Stellar evolutionary models (2046)

1. INTRODUCTION

1. Observations tell us we don’t understand the mixing at convective boundaries.

2. In order to resolve this problem, we need to build a community understanding of CBM processes.

3. The literature of stellar astrophysics often uses the terms “convective overshoot” and “convective penetration” interchangeably. However, these terms refer to separate and distinct fluid dynamical processes.

4. We will briefly describe three fluid dynamical processes which may be important at the boundaries of convective regions: convective overshoot, entrainment, and convective penetration.

2. CBM PROCESSES

In the following discussion, we will assume that the edge of the convection zone is the place where a stability criterion (Ledoux or Schwarzschild) crosses through zero.

2.1. *Convective Overshoot*

Convective overshoot is a phenomenon that occurs because the boundary of a convection zone, as determined by a discriminant’s root, defines the location where the acceleration due to buoyancy changes sign. However, it does not correspond to the place where the convective velocity is zero. Flows buoyantly decelerate beyond the nominal convective boundary, leading to an extended region where velocities are appreciably. This extended region is a convective overshoot.

A simple estimate of the size of an overshoot region can come from a simple $\Delta x = u\Delta t$ argument. Here Δx is the size of the OZ, u is the convective velocity, and $\Delta t \sim N^{-1}$ is the inverse of the Brunt-Väisälä frequency in the RZ. Overshoot is a process which occurs on the dynamical timescale and is ever-present, but is generally small in stellar environments.

2.2. *Entrainment*

Return flows from overshooting convection carry material with the chemical and entropic composition of the RZ. This material is quickly mixed by turbulence in the

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convection zone. As a result, convective motions which overshoot and entrain materials can cause convective boundaries to gradually advance.

Entrainment is a process which occurs over many dynamical times, and is generally much faster than nuclear timescales.

2.3. *Convective penetration*

In some cases, convection zones can grow by entrainment beyond the place where $\nabla_{\rm rad} = \nabla_{\rm ad}$. This can create an extended, well-mixed nearly-adiabatic "penetration zone" beyond the convective boundary. The process of convective penetration is therefore a process by which convection zones can potentially mix far beyond the convective boundary.

2.4. *Some points of confusion*

We note that the expansion of convective boundaries by entrainment is often referred to as conective penetration. However, the growth of convection zones by entrainment generally involves movement of the convective boundary criterion. These are distinct proceses, although entrainment can also lead to convective penetration.

3. CONCLUSIONS & DISCUSSION

1. There is confusion about terminology of convective boundary mixing.

2. It is important for us to distinguish between these three proceses and separately parameterize them.

3. This will allow us to make testable predictions and hopefully unify observations and models better.

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