**INTRODUCTION**

**Motivation**
- Stellar radiation zones are typically supposed to be moltenks in standard models of stellar structure and evolution.
- However, increasingly detailed evidence is emerging of dynamical processes such as differential rotation, meridional circulation, turbulence, and internal waves in radiative zones.

**Goals**
- Formulate an elemental model of stellar radiation zones.
- Simulate fluid motions and dynamo action.
- Investigate flow morphology.
- Investigate possibility of dynamo action.

**MODEL FORMULATION**

**Model equations**

**Setting**
- Electrically conducting, self-gravitating (gravite $\sim 1/r^2$), perfect gas confined to a rotating (Ek) spherical shell.

**Background state**
- A hydrostatic polytropic reference state $\rho \propto r^{-\gamma}$, $T \propto r^{-\gamma/2}$, $\ln\psi \propto r^{-\gamma/2}$.

**Model equations**

\[ \nabla \cdot \mathbf{u} = 0, \quad \nabla \times \mathbf{B} = 0, \quad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}, \quad \nabla \cdot \mathbf{E} = 0, \quad \nabla \times \mathbf{E} = -\frac{\mathbf{B}}{\partial t}, \]

where $\mathbf{u}$, $\mathbf{B}$, and $\mathbf{E}$ are the velocity, magnetic field, and electric field, respectively.

**Entropy BC - Dirichlet BC at $r = r_s$**
- This guarantees that the apparent gravity does not point outward so that the flow is convectively stable.

**Scales**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$a$</td>
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<tr>
<td>$b$</td>
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<tr>
<td>$h$</td>
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**Parameter values and initial conditions**

- $R$ is limited from above
- $Z < (1 - \eta)^{3/2}/Pr$

This guarantees that the apparent gravity does not point outward so that familiar thermal convection instabilities are excluded.

**SEQUENCE OF BAROCLINIC FLOWS INSTABILITIES**

- **Symmetry breaking**
  - The problem is invariant under several symmetries including (a) rotations about the polar axis, $x \to y \to z$, (b) reflections in the equatorial plane $x \to y \to z$, and (c) translations in time $t \to t + \omega$. As baroclinicity $Z$ is increased these are broken resulting in a sequence of instabilities.

**CONCLUSION**

- The first non-asymmetric and time-dependent simulations of flows in an elemental model of stellar radiation zones are reported.
- With increasing baroclinicity the bifurcations from simple to more complex flows is found where available symmetries are broken in turn. The flows appear rather different from familiar thermal convection instabilities.
- The poloidal flow component grows relative to the dominant toroidal flow component with increasing baroclinicity. A possibility for dynamo action arises.
- Examples of self-sustained dynamo action in baroclinically-driven flows are reported.
- Magnetic fields in stably stratified stellar interiors are thus not necessarily of fossil origin as often assumed.

**REFERENCES**

- Simões and Busse (2009) Bistability and hysteresis of dipole dynamos generated by turbulent convection in rotating spherical shells, EPL, 85,19001.