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Snappy and to the point.

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ABSTRACT

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1. INTRODUCTION

What is the solar convective conundrum, why is it a problem, and what are people doing to combat it?

Studies of Kramer's opacities and entropy rain are one path that people are using to figure out what's happening. Some pioneering work on that has been done recently, and they've found blah.

In this paper, we study hydrodynamic convection in the optically thick limit such that a Newton-like conductivity law with a radiative conductivity is valid. For our opacity, we use a Kramer's-like opacity law of the form

Which has been used recently by Käpylä et al. (2017, 2018). We are particularly interested in studying the effects of this fully nonlinear condcutivity and its feedback on convective flows. In this work, we fix $a = 1$ and vary $b = (0, -3.5]$, where in the limit of $b = -3.5$, this radiative conductivity takes the same form as that for free-free interactions (Weiss et al. 2004). We take this approach, as we find that b naturally controls the Mach number when the initial conditions are an adiabatic, hydrostatic polytrope. Regardless of the value of b, the radiative conductivity is highly nonlinear in both T and ρ, and so we can study the importance of its nonlinear nature when the flows are high and low Mach number. The transition from $b = 0$ to $b = -3.5$ is also interesting in that it provides a gradual transition from classic polytropic convective systems (Hurlburt et al. 1984; Brandenburg et al. 2005; Anders & Brown 2017), in which there is a large condition background conductive flux in the system, to systems in which the radiative flux becomes extremely inefficient in the interior and convection is required for nearly all energy transportation in the system.

The importance of nonlinear conductive feedback has previously been studied in the context of mantle convection in the infinite Prandtl number limit (Dubuffet et al. 2000), but there the conductivity is weakly inversely proportional to the temperature, whereas here it is strongly proportional to. Thus, we anticipate the negative feedback effects seen there to not be seen here. Blahblah.

2. EXPERIMENT

2.1. *Equations of Motion*

$$\frac{D \ln \rho}{Dt} + \nabla \cdot (\boldsymbol{u}) = 0 \tag{1}$$

$$\frac{D\boldsymbol{u}}{Dt} = -\nabla T - T\nabla \ln \rho + \boldsymbol{g} + \frac{1}{\rho}\nabla \cdot \left(\bar{\bar{\boldsymbol{\Pi}}}\right), \tag{2}$$

$$\frac{DT}{Dt} + T(\gamma - 1)\nabla \cdot (\boldsymbol{u}) + \nabla \cdot (-\kappa \nabla T) = (\bar{\bar{\boldsymbol{\Pi}}} \cdot \nabla) \cdot \boldsymbol{u} \tag{3}$$

where $D/Dt \equiv \partial/\partial t + \boldsymbol{u} \cdot \nabla$. The viscous stress tensor is defined as

$$\Pi_{ij} \equiv -\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\nabla \cdot \boldsymbol{u} \right), \tag{4}$$

Here's our conductivity profile, diffusivities, control knobs:

2.2. *Reference atmosphere*

We study atmospheres whose initial conditions are polytropic, as we did previously in Anders & Brown (2017). For all studies in this work, we study an adiabatic polytrope where the initial temperature and density stratification are

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Here's the nondimensionalization of our atmosphere:

2.3. *Numerical Methods*

Here's our numerical methods:

2.4. *Initial conditions*

3. RESULTS

Here's a figure that shows how Reynolds number and Mach number scale with b / Ra:

Here's a figure of pretty dynamics at high and low Mach number. Probably a few panels: entropy deviations, kappa deviations, and vertical velocity.

Here's a figure that shows the evolved stratification (where is BZ/DZ .../oz?) at high and low Mach number (and high and low b). Shows the progression towards more nonlinearity in κ and the evolved stratification we get out. This is part of the "deviating away from polytropic convection" storyline.

Here's a figure that shows the importance of nonlinearities in the conductivity at both high and low Ma. Basically, time-averaged scalar values of $\kappa / \langle\kappa\rangle - 1$, and probably a time averaged absv profile of that. Can we say why we see the scaling we see with b?

4. CONCLUSIONS

What have we learned about opacity? Where are nonlinearities important? Where are they unimportant?

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