Novel observations of convectively-driven flows in stars constantly prove that our theories of convection are incomplete. For example, observations of massive stars demonstrate unexpectedly high mixing at the core convection boundary (Johnston, 2021), so theories underestimate the sizes of convective regions. A recent observation has claimed the detection of waves driven by massive star core convection (Bowman et al., 2019). Such a wave signal could resolve disagreements about convective excitation mechanisms and the transfer of waves through stellar interiors (Rogers et al., 2013; Lecoanet et al., 2021). Observations of the Sun show a convective conundrum: "giant cells" predicted by theory and simulations are not detected by many observations (Hanasoge et al., 2012; Proxauf, 2021), suggesting that we do not understand the how the Sun's convection is driven. A major problem in applied mathematics is developing theories that explain these observations. In the next five years, **I will conduct research and create community tools to help resolve these and other modern mysteries in applied mathematics.**

Problem 1: Convective boundary mixing As I mentioned in my cover letter, mixing at convective interfaces is a compelling problem in astrophysics. My recent work on penetrative convection may help to resolve discrepancies between observations and theory (Anders et al., 2022). My previous work focused on a minimal model: it employed the incompressible Boussinesq approximation, and it studied a Cartesian domain. There remains a great deal of work to be done in developing a robust theory of penetrative convection that works broadly in stellar evolution. For example, the effects of rotation, composition gradients, magnetic fields, density stratification, and geometry have not yet been studied in detail. Furthermore, use of the fully compressible equations subtly changes the theoretical constraint that I derived, and must be explored. Studying penetrative convection in the presence of any of these complications would be an excellent PhD project. We already know the zeroth order answer of how this process works, so there is a solid foundation for students to build upon, and because the stellar modeling community is invested in this work, it will give students a meaningful and high-impact way to contribute in the field.

Problem 2: Open-source, easily accessible code for multi-D stellar simulations There are no open-source, user-friendly codes for running dynamical simulations of stars. Current stellar dynamics codes require help from an expert to run, are restricted to limited equation sets, or only focus on a portion of the stellar domain. Over the next five years, I will build an easy-to-use Python module that uses the Dedalus pseudospectral framework (Burns et al., 2020) to create dynamical simulations of full stars. It is possible to include the full stellar domain in Dedalus, because flows that pass through the coordinate singularity at $r = 0$ can be resolved (Vasil et al., 2019; Lecoanet et al., 2019), and radial discretization can be fine-tuned so that resolution elements are localized in turbulent regions. Background stellar stratifications will be imported from MESA stellar models (Paxton et al., 2011). Planned evolutionary equation sets will include both hydrodynamic and magnetohydrodynamic formulations of both the anelastic and fully compressible equations. All of these formulations must be verified in the various dynamical regimes occurring in stars. I will need to build a robust scheme for radial discretization that handles arbitrary stars at various stages in stellar evolution. My 7 years of experience using Dedalus has given me the expertise to implement and debug all of these features. Once complete, my proposed open access module will enable researchers and Newcastle students to carry out experiments to understand observations like those discussed in my introduction.

Problem 3: Discrepant timescales Convection includes both short timescales associated with turbulent motions and long timescales associated with, for example, the restratification of the background state. Discrepant timescales such as these occur in a variety of natural contexts, making it difficult to understand the long-term evolution of natural systems. For example, in stars, the rate at which nuclear burning changes is very slow compared to any dynamical process (convection, wave propagation, rotation, magnetic dynamo cycle, etc.). Understanding how short and long timescale processes nonlinearly interact is crucial for minimizing computational cost and ensuring robust results, because simulations of turbulent flows can only compute a few tens or hundreds of dynamical timescales. I have examined how fast and slow processes affect one another in the context of convection, and I would like to create a general framework for understanding how processes operating on discrepant dynamical timescales interact in natural systems. Slowly-evolving phenomena that are influenced by fast dynamics include, for example, latitudinal differential rotation profiles in rotating convection simulations, the evolution of shear flows via Reynolds stresses, and the evolution of large-scale magnetic fields in dynamo simulations. Studying methods for accelerating the evolution of any of these phenomena would make an excellent PhD project.

Beyond Research I love teaching and am excited to teach any of the undergraduate mathematics or physics courses offered by the School. As for graduate education, my research background has best prepared me to lead the Theoretical Physics "Computational Research Skills in Physics" MRes module or to mentor a research component under the "Astrophysics and Geophysics" theme. I currently co-mentor five graduate students, and have co-mentored undergraduate students in the past; I look forward to starting a vibrant research group where PhD, MRes, and undergraduate students all feel welcome, and where individuals whose identities are underrepresented in mathematics, physics and astrophysics can build confidence and identities as people in STEM. When I was a graduate student at the University of Colorado, I created and iterated upon the first rubric used in the graduate admissions process to make it more equitable and I would love to work on similar processes at Newcastle. As a postdoctoral fellow at CIERA, I chaired a public outreach committee for a year and have been actively involved in organizing a climate survey for the 2022-2023 academic year. I enjoy working to make my department a more fair, equitable, and just place, and I will bring this dedication and drive with me to Newcastle.

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