C I E R A
Center for Interdisciplinary Exploration and Research in Astrophysics

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Northwestern University
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Northwestern University

September 17, 2022

Dr. Angela Dyson & Faculty Search Committee
School of Mathematics, Statistics and Physics
Newcastle University

Dear Committee:

I am applying for the position of Lecturer in Astrophysics at the Newcastle University School of Mathematics, Statistics and Physics. With this letter, please find my curriculum vitae.

Observable stellar phenomena like magnetic dynamos and waves are generated by turbulent convection which is poorly understood despite decades of study. Stellar convection is fast compared to stellar evolution, occurs in highly turbulent magnetized plasmas, is subject to rotational Coriolis forces, and involves flows which must traverse extreme stratification. In my research, I use 3D numerical simulations to investigate these convective complications and to improve 1D stellar evolution models. I have found that convection in density-stratified atmospheres exhibits the same fundamental heat transport scaling laws as incompressible Rayleigh-Bénard convection. I have learned how to disentangle the scaling of turbulence and rotational constraint in the complicated parameter space of rotating convection. I have extensively studied how fast convective flows interact with the slowly evolving background atmosphere. More recently, I have learned which processes determine the location of the interface between a convective region and a stably-stratified region, with huge implications for massive star evolution and remnant formation.

My top five research outputs, ranked in order of importance, are the following papers:

1. Anders et al. 2022a, ApJ 926, 169 ("Convective Penetration Paper")
2. Anders et al. 2022b, ApJL 928, L10 ("Schwarzschild-Ledoux Paper")
3. Anders et al. 2019, ApJ 884, 65 ("Entropy Rain Paper")
4. Jermyn, Anders, et al. 2022, ApJ 929, 182 ("Convective Penetration in stars")
5. Anders et al. 2018, PRF 3, 083501 ("Accelerated Evolution Paper")

My most influential work focuses on penetrative convection. Observations suggest that stellar structure models and 1D prescriptions of convection underestimate the size of convection zones. To match these observations, boundary mixing processes implemented in 1D stellar structure models have to be finely tuned and varied from one type of star to another. I have developed the first *a-priori* theory which can explain these observations (paper # 1), and follow-up work by Dr. Adam Jermyn (paper #4) suggests that this theory takes a step towards solving this decades-old problem. I discovered this process because I consistently observed expanding convection zones in simulations where I expected very little mixing beyond the convective boundary. Using my previous work (e.g., #5) on the long-term secular evolution of convection zones, I realized that I was witnessing a long-timescale relaxation process. Zahn and Roxburgh's work on penetrative convection in the 1970s-90s provided me with analytical descriptions of this process. I modified their theory to account for the effects of viscous dissipation, which cannot be neglected even in astrophysical plasmas with miniscule viscosities (per the zeroth law of turbulence). This theory agreed well with laminar and turbulent three-dimensional simulations using the *Dedalus* code. I parameterized this theory for inclusion in 1D stellar structure models. I am now collaborating with Dr. Cole Johnston to implement my theoretical prescription self-consistently into the 1D *MESA* software instrument to understand how penetrative convection affects massive star evolution. Our forthcoming evolutionary tracks will also take into account the results of paper #2, in which I demonstrated for the first time using 3D numerical simulations that convective flows ignore the stabilizing effects of composition gradients when they establish the radiative-convective boundary location. Upon arriving at Newcastle, I hope to submit an off-cycle STFC grant proposal to perform state-of-the-art, 3D simulations of massive star core convection to continue to unravel the mystery of penetrative stellar core convection.

Earlier in my career, I studied the "solar convective conundrum." This convective conundrum focuses on deep, large-scale "giant cells" in the Sun's convection zone, which are predicted by theory but are not robustly observed. In paper #3, I tested the "entropy rain" hypothesis, which posits that the Sun's luminosity is not carried by giant cells but rather by cold downflowing "raindrops" launched from the solar surface. I developed a theory for the transport of luminosity by a single raindrop by expanding the theory of "thermals" (cold blobs which evolve into buoyant vortex rings) to account for atmospheric density stratification. Surprisingly, I found that cold downflows can carry the full solar luminosity in the deep convection zone. Furthermore, since thermals are a model of atmospheric convection frequently used in the geophysical community, this paper has attracted cross-disciplinary attention and discussions.

Finally, in my Accelerated Evolution Paper (#5), I created a tool which circumvents the discrepancy between evolutionary and dynamical timescales. I demonstrated that convective flows significantly change as the background stratification evolves. I developed an alternative numerical evolution scheme to traditional timestepping which used up to factor of ten fewer computational resources than traditional methods in our tests. This study created foundational numerical tools that enabled the science in papers #1 and #2.

Together, these works demonstrate the breadth of my research and my approach to science. I decompose complex problems into manageable research questions. I study those questions using direct numerical simulations, which I perform using the flexible *Dedalus* pseudospectral framework. I use my simulation results to learn lessons about stellar interiors. When possible, I synthesize my findings into useful products for e.g., the 1D stellar modeling and observing communities, which are much larger than the hydrodynamical modeling community. I develop numerical tools and schemes to push the limits of state-of-the-art simulations.

Regarding contributions: I did the bulk of the creative and scientific work for my first-author papers from above (e.g., I developed the experiment and simulation code, performed simulations, carried out analyses, and wrote the bulk of the manuscripts). I contributed to paper #4 by helping translate my mixing prescription into 1D properly and in helping synthesize the results. These works were primarily funded by personal fellowship awards.

Teaching Statement: Good teachers are not born, they are made through dedicated practice and effort. My teaching philosophy is rooted in having a growth mindset and acknowledging that I will always have room to grow into a better teacher. In addition to practical classroom experience, teachers should understanding modern teaching pedagogy and best educational practices. I regularly seek out pedagogy training through e.g., my participation in UCSC ISEE's Professional Development Program twice and through taking

CIRTL's "Introduction to Evidence-Based STEM Teaching" MOOC course.

Seeking out training in teaching pedagogy has in particular taught me the importance of active learning, scientific inquiry, skill-learning, and the creation of equitable and inclusive learning environments. Active learning techniques (e.g., Think-Pair-Share) increase student exam performance and should be included alongside lecturing in the classroom. Furthermore, as researchers, we regularly participate in self-motivated scientific inquiries, but students rarely authentically experience this process; I hope to include authentic inquiry activities and projects in my courses. In addition to cognitive learning, it is also critical that teachers make their classrooms places where students learn the skills necessary to be a scientist (e.g., communication, collaboration, persistence, organization, and self-reflection), because these skills will help our students succeed as well-rounded individuals in any career path. Finally, teachers must create equitable environments where diverse learners can succeed. This can be done in some rather explicit ways (e.g., a verbal welcome statement to broad identities), and can also be incorporated into assessments by providing multiple pathways for students to productively participate.

Outside of the classroom, a Lecturer must support young scientists through mentorship, and I currently provide research mentorship to five graduate students. I have led or participated as a mentor in projects on topics including magnetoconvection, internally heated convection, and magnetic field instabilities (please refer to my publication list). In addition to being scientifically productive, these mentoring relationships have provided opportunities to practice my mentoring skills like active listening and advocating for my mentees in my professional network. It is exciting to hear that Newcastle has been awarded an STFC Data Intensive Science CDT, and I would be thrilled to work with students who will be hired as a result of the CDT. Fluid dynamical simulations produce large quantities of data, and it is often unclear how to manage, store, or statistically analyze those datasets properly, so my work is topical to this award.

Equity, Diversity, and Inclusion: I am dedicated to providing a just, equitable and inclusive environment in my mentoring relationships, my classrooms, and my host institution. I have committed myself to developing the role of under-represented groups in physics and in developing evidence-based programs to target these groups. When I was as a PhD student, I served on the CU Boulder Astrophysics graduate admissions committee for two years, and I developed the first standardized rubric used in this process. An updated version of this rubric is still in use, and its implementation has measurably reduced bias in the admissions process and improved the diversity of admitted students. As a postdoctoral fellow at Northwestern, I have forged connections between the CIERA astrophysics institute and the Baxter Center for Science Education (BCSE), which has connections to many underserved high schools in the Chicago area. CIERA now facilitates a yearly "Astronomy day" as part of BCSE's Summer Scholars program, whose participants are high schoolers who identify as traditionally underrepresented in STEM. During Astronomy day, we facilitate an authentic exoplanets inquiry activity and talk about possible career paths in astronomy. I chaired the K12 education and public outreach taskforce, served for a year on CIERA's JEDI (Justice, Equity, Diversity, Inclusion) committee, and now serve in the Climate Action Team which is working with an external contractor to implement a sociosystemic organizational development plan (including a departmental climate survey).

As a Lecturer at Newcastle, I will continue my work in JEDI initiatives. I will work to complete the tasks outlined in the action list of the School's Athena Swan bronze award (or a future award application), and I will participate in existing public outreach initiatives. I will also employ evidence-based practices for reducing differential attrition in my classrooms. I am additionally interested in developing (or expanding if it already exists) a Maths, Stats, and Physics mentorship network. Individuals at all levels (undergraduate students, postgraduate students, postdocs, lecturers) can benefit from both peer and vertical mentoring structures, and these structures have been shown to improve retention of underrepresented groups in STEM. CIERA has recently been carefully designing and implementing a mentoring network, and I will use the knowledge and lessons learned in building that network when establishing one at Newcastle.

Summary: I am particularly excited about this Lecturer position in your rapidly-growing Physics group. I envision productive collaboration with current members of the School like Prof. Rogers and Drs. Wood, Guervilly, and Bushby on topics like the interactions between convection and stable regions, rotationally-constrained convection, stratified convection, and magnetoconvection. I further look forward to forming a welcoming community and forging new collaborations as the Physics group expands in the coming years. I bring knowledge of new research areas to the School, e.g., multi-timescale processes, expertise with the open-source *Dedalus* code, and also multi-spatial scale processes like my “entropy rain” research. *Dedalus* has been used in a wide variety of fields, and I hope to use it to form cross-disciplinary collaborations with members of the Applied Maths research group on topics like biological fluid dynamics and with members of the JQC Durham-Newcastle on topics in quantum fluid dynamics. I value teaching and mentorship, and am an engaged member of my department community. For all these reasons, I am an ideal candidate for this post.

In support of my application, please feel free to contact the following individuals:

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If there are any other questions or concerns please do not hesitate to contact me. Thank you for your time and consideration.

Sincerely,

Evan H. Anders