Personal Statement

My experiences in research and teaching as a graduate student have reinforced my drive to obtain a career as a professor of astrophysics at a university. Over the course of my graduate education, I have served on multiple commitees comprised of fellow graduate students and faculty members. My duties have included evaluating faculty and graduate student candidates as well as assisting in the creation of questions which are fair assessments for our department's comprehensive exam 1 test. Furthermore, I have gained a great deal of teaching experience, and have learned that becoming a great teacher takes *effort*. I am pleased at the improvements I have seen in my teaching through my experience as an instructor of record for a summer course on Python programming in astrophysics, my four semesters as a teaching assistant, and other experiences such as the Institute for Scientist and Engineering Educators Professional Development Program. Please refer to my CV for an idea of my service, teaching, and outreach experience.

I am now half way through my fourth year as a graduate student at CU Boulder; I completed all department qualifiers and advanced to Ph.D. candidacy at the beginning of 2017. The research that I pursued for my master's-level comprehensive exam II has since been improved and published (Anders & Brown 2017, Phys. Rev. Fluids), I have submitted a second paper, and I have a third in the works which will be submitted before the end of the summer (see research statement for more information on these projects and how they tie into my proposed work). Still, my time in graduate school has humbled me. The scientific process is difficult, and contrary to what I believed as a starry-eyed first year graduate student, I *do not* like all aspects of astro- and heliophysics research. A short stint analyzing spectral data of a flare in the spring of 2017 taught me how it feels to come into work unexcited to think about a science problem. I can genuinely say that the paper I published last year, my two forthcoming papers, and the projects I am proposing here for NESSF funding are projects that I passionately enjoy thinking about and working on. A friend and mentor has told me repeatedly that the scientific problems I apply myself to should distract me and capture my attention to such a degree that I am in danger of stepping out in front of moving busses. The projects I propose here, and the related projects on which I am currently working, occupy my attention fully (although, I'll try to keep an eye out for those busses).

Studying fluids is hard. Experimental systems must be set up in a meaningful way such that the experimenter understands the control parameters and how they modify the dynamics of the solution. Further, meaningful metrics must be created to compare the evolved state at different parameters. Fortunately, through my published work (Anders & Brown 2017) and through my current work, I already have experience creating and carrying out careful studies in fluid dynamics to test clear hypotheses. I have experience using open-source, benchmarked numerical tools – specifically the Dedalus pseudospectral framework – such that my research remains transparent, comprehensible, and *reproduceable* to other researchers. I am proficient in software development and the use of collaborative coding tools through my experience in computer science as an undergraduate and my subsequent graduate work.

Thank you for taking the time to consider my application. I hope you agree that the Solar Convective Conundrum (see my proposal) is a problem that *begs* for further studies, and that the work that I am proposing to do here is fundamentally important for our understanding of future studies in solar convection.

Does the Sun drive giant cells?

Evan H. Anders

Advisor: Benjamin P. Brown

Laboratory for Atmospheric and Space Physics (LASP) & University of Colorado – Boulder

1 Background & Motivation

The Sun exhibits a 22-year active magnetic cycle. An organized dynamo seated in the turbulent plasma motions of the solar convection zone drives this magnetism. Solar magnetism manifests itself in the collection of phenomena generally referred to as solar activity, including magnetic storms and coronal mass ejections. Energetic particles ejected by this activity propagate towards Earth, threatening to disrupt power grids and aircraft operations in addition to endangering astronauts and satellites. Understanding the nature of the dynamo that generates the Sun's magnetic fields is a critical step to protecting our society from the threats of solar activity (Charbonneau, 2014).

The solar dynamo is powered by convection, and an understanding of that convection is essential to comprehending how solar magnetism is generated. The early work of Graham (1975), Hurlburt et al. (1984), and others who studied convection in plane-parallel atmospheres provided rich insight into the nature of solar-like stratified convection. From this basis, the field has blossomed into one which now regularly creates complex, 3D global models of convectively-driven dynamos (e.g., Brown et al. (2010) and Guerrero et al. (2016)) and smaller scale local area models with more complex physics (e.g., Stein & Nordlund (2012) and Rempel (2014)). These efforts have taught us a great deal about the nature of convection, and beautiful modern simulations even visually resemble the convection observed on the solar surface.

Unfortunately, the great advances made in computational prowess within the solar convection community have surpassed our fundamental knowledge in the field. This is clear in the "Solar Convective Conundrum," in which observations and theory starkly disagree. The helioseismic measurements of Hanasoge et al. (2012) and Greer et al. (2015) (Fig. 1a) showed an absence of power in the solar velocity spectrum at large length scales. Simulations hypothesized that large-scale "giant cells" should be driven by deep convective motions and visible throughout the solar convective zone, but we do not see these giant cells. Even simpler doppler measurements of the velocity fields at the solar surface, which are not muddied by complex helioseismic inversions, lack giant cells (Hathaway et al. 2015 & Fig. 1b). The motions of surface granules and the slightly deeper supergranules are clearly present, but no larger length scale is distinct. These combined observational inferences clearly show that the lack of giant cells remains a conundrum and deserves further exploration.

The work of Lord et al. (2014) exemplifies why the absence of giant cells is disturbing. By performing radiative magnetohydrodynamic simulations of the solar photosphere and convective zone using the MURaM code, the authors showed that the length scale of convective motions is determined by the depth in the atmosphere at which they are driven. In general, motions which are driven deeper in the atmosphere should have larger length scales. Due to mass conservation in upflows, these deep motions which are driven at high density should imprint strongly on the surface motions. Thus, the lack of giant cells in observations implies

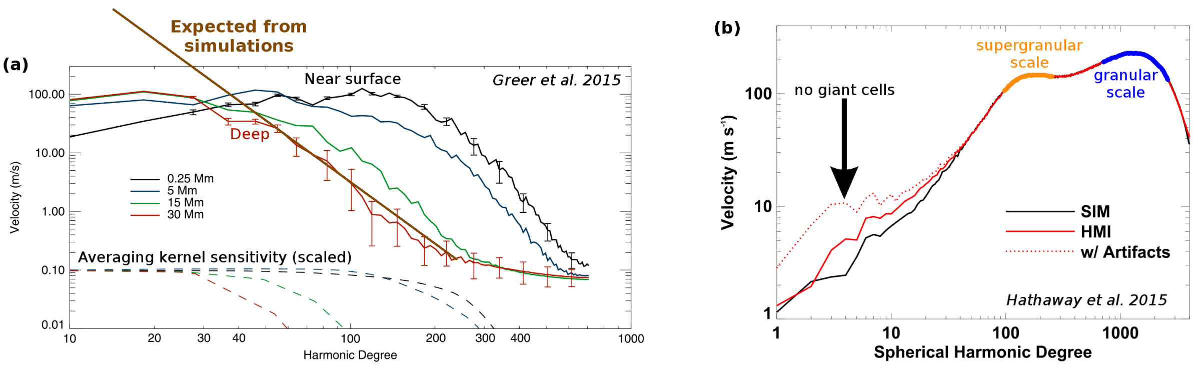

Figure 1: (a) Ring-diagram helioseismic observations of the solar velocity power spectrum at various depths. Here, velocity power decreases toward larger scales, unlike what is expected from simulations (Greer et al., 2015). (b) A spectrum of horizontal velocities at the solar surface, obtained using line-of-sight Doppler velocities (Hathaway et al., 2015). The length scales of surface granules and deeper supergranules appear as distinct features, but the hypothesized giant cells are not observed at low wavenumber.

that current models are missing a piece of physics. Either processes in the solar convection zone mask the deeper motions, or *they are never driven in the first place.*

In order to determine the fate of giant cells, we must return to simple models of convection to understand how nonlinear convective dynamics influence the underlying atmospheric stratification. As convection is only driven where the atmosphere is unstably stratified, processes which stabilize the lower convective zone should prevent the generation of giant cells and affect surface observations. Here I present two simple, small experiments which aim to elucidate fundamental aspects of solar convection. I propose to determine whether either of these mechanisms is the reason that we do not see giant cells at the solar surface. I will use methods similar to those employed in my recently published work (Anders & Brown, 2017) to create simple, controlled experiments studying turbulent compressible convection in stratified atmospheres to gain a deep understanding of the underlying convective physics. Furthermore, the knowledge gained in forthcoming work (Anders, Brown, & Oishi 2018, submitted to PRFluids), in which we discovered a mechanism for self-consistently converging convective simulations on short timescales, will be used to allow us to probe highly turbulent flows which more closely approximate solar convection on manageable human timescales.

2 Proposed Project

In simulations of convection, motions are often driven by enforced boundary conditions on the thermodynamic state. Boundary layers at the top and bottom of the atmosphere naturally arise, and convection is strongly driven within those boundary layers. Convective driving in the Sun is more complex. A positive radial gradient of opacity within the Sun decreases how efficiently radiation carries the solar luminosity with increasing height in the convection zone. This results in a divergence of radiative flux which deposits energy in the convective layers, and this energy must in turn be carried by convective motions. In other words, the convection in the Sun is not driven by a sharp lower boundary but rather through naturally occuring internal heating. Further, the upper boundary layer of the solar convective zone does not arise because of a hard, imposed wall, but rather because of radiative losses at the photosphere, paired with the ionization and recombination of hydrogen. These two effects – the internal driving of solar convection by opacity effects and the driving of convection at the solar surface by hydrogen ioniziation – have not been fully explored in recent literature.

The exciting work of Käpylä et al. (2017) exhibited atmospheres in which deep layers of the convection zone are stable, a setup in which giant cells would not be driven. The authors attribute these deep, stable layers to their inclusion of Kramers' opacity effects which drive convection internally in a manner similar to that in the Sun. However, forthcoming work by my advisor and collaborators (Brown et al. 2018 in prep, Oishi et al. 2018 in prep) shows that stable lower-layers of convective zones naturally arise where stable regions lie below convection zones and convective motions are at low Mach number. Further, first results from work that I am conducting on stratified, internally heated convection (modeled after simpler studes, e.g., Goluskin & Spiegel (2012)), show that these stable convecting layers arise naturally when internal heating is the mechanism which drives convection, even when realistic opacities are not used.

Since the process of internal heating – not the complex form of a Kramers' opacity – appears to be the fundamental cause of the stratification effects seen recently by Käpylä et al. (2017), the first project that I propose in year 1 is a careful study of the effects of Kramers' opacity on convection. The second project I propose in year 2 is a careful study of the effects of hydrogen ionization near the surface of the Sun, building on the previous work of e.g., Rast & Toomre (1993).

2.1 Project 1: Effect of Kramers' opacity on solar convection

The transport of heat within an optically thick atmosphere, in the absence of convective transport, is often quantified by Fourier's law of conduction (Lecoanet et al., 2014), in which the radiative flux is proportional to the conductivity and the temperature gradient. Many careful studies of convection employ a constant radiative conductivity. While a constant conductivity in time and space allows for the creation of simple measurements of the heat transport in the evolved atmosphere, such an assumption about the conductivity is coupled with unrealistic assumptions regarding the functional form of the opacity.

While a constant radiative conductivity is the go-to choice for many in the physics community who study incompressible Rayleigh-Bénard convection, it is often not the choice for those in the heliophysics or astrophysics communities. Instead, these communities generally employ a radiative conductivity which is a function of the temperature, density, and the Kramers' opacity (Barekat & Brandenburg, 2014; Brandenburg, 2016; Käpylä et al., 2017). As a result, the conductivity varies greatly throughout the depth of the atmosphere, which more carefully models natural physics but also makes the solution harder to interpret.

In order to study the importance of Kramers' opacity, a frame of reference must be constructed in which to study this varying opacity. For example, what atmospheric parameter determines the Mach number of evolved flows? At what value of the Rayleigh number does convection turn on (and thus, at what *supercriticality* are other studies being run)? What are the parameters of the initial state that determine key quantities of the evolved convection, and what can we learn about the evolved dynamics from them? Only by answering these simple questions can a careful study of Kramers' opacity be carried out. Through answering these questions about basic polytropic systems, I was able to determine that regardless of

Mach number, basic stratified compressible convection *transports heat in the same manner as unstratified, incompressible Rayleigh-Bénard convection* (Anders & Brown, 2017).

After determining how to carry out controlled experiments studying the role of Kramers' opacity, I will study the importance of the nonlinear nature of this opacity on convection. In downflows (where density is high and temperature is low), the radiative conductivity should be low compared to upflows. However, at low Mach number, where fluctuations in temperature and density are small, we anticipate that this effect will be unimportant. In the Sun, the Mach number of convection ranges from nearly Mach 1 at the surface to $O(10^{-5})$ in the deep interior. Thus, it is important to understand how this complex form of opacity interacts with convection at both high and low Mach number in order to understand how it influences solar convection.

In summary, my goal in year 1 is to quantify the importance of the varying opacity felt by solar convection. I aim to understand the importance of nonlinearities in the opacity on nonlocal convective transport and atmospheric stratification. If comparatively high opacity in the downflows enhances the importance of nonlocal transport at all Mach numbers, then the "entropy rain" addition to convective theory expanded by Brandenburg (2016) and explored by Käpylä et al. (2017) could be an essential element of solar convection. Nonlocal transport mechanisms of this nature could drastically change the stratification of deep convection. If marginal stability in the deep convection zone is achieved because of nonlocal transport effects associated with this opacity, it would imply that the nature of Kramers' opacity helps lead to the lack of observed giant cells.

2.2 Project 2: Solar convection influenced by hydrogen ionization and recombination

Convection is strongly driven at the solar surface in part by the ionization and recombination of hydrogen. This piece of physics is absent from many studies of solar convection. Instead, surface convection is often driven by either an imposed entropy draining layer at the upper boundary (Käpylä et al., 2017), or the natural thermal boundary layer that forms near the upper surface (Anders & Brown, 2017). These methods have a considerable problem in that the size of low entropy convective elements which form at the surface are determined either by the pre-imposed size of the entropy draining region or the natural size of the thermal boundary layer (which depends on the opacity).

The convective boundary layer near the solar photosphere is much larger than the local thermal diffusion length scale, in part because of the depth at which hydrogen ionizes. This large boundary layer drives large convective elements (granules), and the length scale of those elements likely significantly influences the convective dynamics. If the size of these convective elements allows them to persist deep in the atmosphere, they could drastically alter the mean stratification deep in the convective zone. We aim to study the difference in the nature of convection – especially in the surface power spectrum (as in Fig. 1) – when hydrogen recombination is the driver of convection near the upper boundary, rather than the other more common methods.

I will implement the basic nature of hydrogen ionization and recombination through the use of a nonlinear equation of state built around a single-atomic level model of particles, similar to that used in Rast & Toomre (1993). This work in year 2 will further be guided by prior studies on moist convection (Leconte et al., 2017), in which phase changes resulting in cloud formation are studied. We will examine the effects of hydrogen ionization on atmospheric stratification in two ways. First, we will determine the effects of the *location* of the ionizing layer in order to determine if we can naturally make transitions from stable regions (above) to convecting regions (below) occur, as occurs at the solar photosphere. We will also determine the effects of the *extent* of the ionizing layer, to determine if this changes the average length scale of convective elements, and to determine if there is any correlation between the length scale of convective elements driven at the surface, the atmospheric stratification, and the average power spectrum of motions near the surface. If large elements descend to the bottom of the convective zone and stay there, they could very well restratify the atmosphere and prevent the generation of giant cells.

3 Timeline of proposed work

Year 1 (Fall 2018 - Summer 2019):

- *Project 1:* Conduct literature review on convection with Kramers' opacity early fall 2018. Understand past work done, and implement fully compressible equations with Kramers' opacity in simple atmospheres. Understand how to control the Mach number in these atmospheres by end of year 2018. Run simulations, analyze data, and submit a paper to The Astrophysical Journal on the nature of convection with Kramers' opacity at both low and high Mach number by end of spring 2019.
- *Project 2:* Conduct literature review on past work done on ionizing convection and moist convection. Construct appropriate atmospheres for studying ionizing convection, and learn what properties of these atmospheres control different aspects of the evolved solutions.

Year 2 (Fall 2019 - Spring 2020):

- *Project 2:* Run simulations of ionizing convection, analyze data, and submit a paper to The Astrophysical Journal by the end of year 2019.
- *Academic progression:* Combine work from five published (or submitted) papers into a thesis, to be defended at the end of Spring 2020.

4 Numerical Tools and Feasibility

I will use the open-source Dedalus[1] pseudospectral framework (Burns et al., 2016) to carry out my simulations. Dedalus is a flexible solver of partial differential equations, making it extremely easy to study diverse sets of equations under many different atmospheric constraints. I have already published one paper using this tool (Anders & Brown, 2017) and am now adept at using it to create suites of simulations in short time frames. Our run scripts for using Dedalus to study stratified atmospheres are themselves publically available[2]. By using an open-source code base and opening our run scripts to the community, we hope to make our results reproduceable and decrease barriers for future users in *extending* our studies towards a more complete understanding of convection.

[1] http://dedalus-project.org/

[2] https://bitbucket.org/exoweather/polytrope

I will primarily study 2D convective solutions in plane-parallel atmospheres in order to gain intuition about the mean behavior of vertical profiles within the atmosphere. Once I have a grasp on how my measurements vary in 2D across parameter space, I will run select 3D simulations to verify whether or not that behavior holds in 3D, as I did in my previous paper (Anders & Brown, 2017). In cases where 2D and 3D diverge, I will quantify how and why they do so. By primarily studying in 2D, and by carefully selecting my 3D runs once I know which parameters I must examine more carefully, I can complete a full suite of simulations, such as those in my previous paper (Anders & Brown, 2017), using roughly 10 million CPU-hours. Through my advisor, I have access to an allocation on NASA Pleiades of roughly 20 million CPU-hours/year, so the proposed projects are feasible.

5 Relevance to NASA

The proposed work fits with NASA's 2014 Strategic Plan objective 1.4: "Understand the Sun and its interactions with Earth and the solar system, including space weather." Specifically, I aim to help answer the fundamental question, "What causes the Sun to vary?" by understanding the nature of stratified convection present at the solar photosphere and in the deep interior. This work also aims to answer one of the three overarching science goals in chapter 4.1 of NASA's 2014 Science Plan: "Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond earth." In order to understand how to predict space weather appropriately, we need to understand the processes that cause this weather. Recent work shows that our fundamental understanding of solar convection is flawed, and our theory needs clarification.

This work has been motivated by data from the Helioseismic and Magnetic Imager (HMI) onboard the NASA Solar Dynamics Observtory (SDO) spacecraft (Hanasoge et al., 2012; Greer et al., 2015; Hathaway et al., 2015), and will continue to be informed by new helioiseismic measurements made from SDO data. This work will additionally be informed by the new measurements which will be made possible by the upcoming joint NASA-ESA Solar Orbiter's Polarimetric and Helioseismic Imager (PHI), and will help explain conundrums arising from those observations.

6 Summary

Recent observations call into question our fundamental understanding of solar convection (Hanasoge et al., 2012; Greer et al., 2015; Hathaway et al., 2015). We propose two focused, scoped studies of the mechanisms which drive the Sun's convection at the solar photosphere and deep in the interior. These studies will carefully probe the effects of hydrogen ionization and Kramers' opacity, comparing convective simulations with these elements to simpler studies without them. Due to the developed nature of our computational tool, Dedalus, and extensive experience using that tool (Anders & Brown, 2017), the simulations for these projects can be implemented and carried out on short time scales, and the body of work proposed here will be finished within two years.

References

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Käpylä, P. J., Rheinhardt, M., Brandenburg, A., et al. 2017, Astrophys J. Lett., 845, L23

Lecoanet, D., Brown, B. P., Zweibel, E. G., et al. 2014, The Astrophysical Journal, 797, 94

Leconte, J., Selsis, F., Hersant, F., & Guillot, T. 2017, Astronomy & Astrophysics, 598, A98

Lord, J. W., Cameron, R. H., Rast, M. P., Rempel, M., & Roudier, T. 2014, The Astrophysical Journal, 793, 24

Rast, M. P., & Toomre, J. 1993, The Astrophysical Journal, 419, 240

Rempel, M. 2014, The Astrophysical Journal, 789, 132

Stein, R. F., & Nordlund, Å. 2012, Astrophys J. Lett., 753, L13

Timeline of Graduate Studies

Evan Anders
Department of Astrophysical and Planetary Sciences
University of Colorado at Boulder

Fall 2014 - Spring 2015: Began graduate studies, and worked as a Teaching Assistant.

Summer 2015: Began work as a graduate Research Assistant with Dr. Benjamin P. Brown. *Awarded CU Boulder's 3-year George Ellery Hale Graduate Student Fellowship.*

Fall 2015: Hale fellowship funding began.

January 2016: Completed department qualifier Comprehensive Exam I with highest marks in cohort.

Spring-Summer 2016: Studied fundamental compressible, stratified convection simulations.

Fall 2016: Passed second and final departmental Ph.D. qualifier, Comprehensive Exam II. This exam was essentially a master's thesis defense.

Spring 2017: Improved work from comprehensive exam II and submitted it to Physical Review Fluids (published in Summer 2017). Worked on a side project analyzing stellar flares on flare star YZ CMi, but decided to return to convection work for thesis. Finished graduate coursework.

Summer - Fall 2017: Started two projects in convection: one studying internally heated, stratified convection, and another studying how to use boundary value problems (BVPs) to fast-forward convective solutions in order to save computational time.

Spring 2018: Submit paper on BVPs to referees (February 2018). Continue work on internally heated convection. Getting married April 2018.

Summer 2018: Finalize work on internally heated convection, submitting results to the Astrophysical Journal by end of summer. *End of funding of Hale fellowship.*

Fall 2018: *Start of proposed funding from NESSF.* Determine proper atmospheric setup for simulations with realistic opacity and determine how to control Mach number of these simulations. Run first simulations with realistic opacities.

Spring 2019: Run final realistic opacity simulations, analyze and finalize results on the effects of Mach number on these simulations. Submit to The Astrophysical Journal.

Summer-Fall 2019: Determine proper atmospheric setup for simulations with hydrogen ionization and recombination. Run simulations and analyze data. Submit results to the Astrophysical Journal.

Spring 2020: Write thesis, which will cover the work of the five published papers above. Defend thesis and graduate with Ph. D. in Astrophysical & Planetary Sciences.

Benjamin Brown

Biographical Sketch
Department of Astrophysical and Planetary Sciences
University of Colorado, Boulder
bpbrown@colorado.edu

Professional Preparation

Harvey Mudd College	Physics	BS May 2003
University of Colorado, Boulder	Astrophysics	PhD August 2009
University of Wisconsin, Madison	Astronomy	Postdoc September 2009 – August 2013
University of California, Santa Barbara	KITP	Postdoc September 2013 – July 2014

Appointments

Assistant Professor	University of Colorado, Boulder	August 2014 –
Research Associate	Kavli Institute for Theoretical Physics	September 2013 – July 2014
Postdoctoral Fellow	University of Wisconsin, Madison	September 2009 – August 2013
NSF AAPF	University of Wisconsin, Madison	September 2009 – August 2013

Five Publications Most Relevant to Proposed Work (out of 34 total)

- Bordwell, B., **Brown**, B. P., & Oishi, J. S., “Convective dynamics and disequilibrium chemistry in the atmospheres of giant planets and brown dwarfs”, 2018, *The Astrophysical Journal*, in press
- Lecoanet, D., Schwab, J., Quataert, E., Bildsten, L., Timmes, F. X., Burns, K. J., Vasil, G. M., Oishi, J. S., & **Brown**, B. P., “Turbulent chemical diffusion in convectively bounded carbon flames”, 2016, *The Astrophysical Journal*, 832, 71:1–8
- Lecoanet, D., **Brown**, B. P., Zweibel, E. G., Burns, K., Oishi, J. S, & Vasil, G. M., “Conduction in low-Mach number flows: part I linear & weakly nonlinear regimes”, 2014, *The Astrophysical Journal*, 797, 94:1–16
- Vasil, G. M., Lecoanet, D., **Brown**, B. P., Wood, T. S., & Zweibel, E. G., “Energy conservation and gravity waves in sound-proof treatments of stellar interiors: Part II Lagrangian constrained analysis”, 2013, *The Astrophysical Journal* 773, 169:1–23
- **Brown**, B. P., Vasil, G. M., & Zweibel, E. G., “Energy conservation and gravity waves in sound-proof treatments of stellar interiors: Part I anelastic approximations”, 2012, *The Astrophysical Journal* 756, 109:1–20

Synergistic activities

Brown is an expert in the stratified fluid dynamics of stars and planetary atmospheres. Brown has been involved in modelling stellar convection since 2003, when he began using the anelastic spherical harmonic (ASH) code to study the coupling of convection, rotation and magnetic dynamo action in the Sun and in other solar-type stars. He has published results on magnetohydrodynamic processes in stellar interiors, on convective wave generation and transport, and on fundamental properties of stratified fluid dynamics. He is a core member of the development team for the open-source Dedalus framework. He has extensive HPC experience and a history of success in obtaining large computing allocations. At University of Colorado, he leads a research group of four graduate students, two postdocs and two undergraduate students, working on topics in solar, stellar and exoplanetary dynamics. He has mentored two students through Masters level (Anders & Bordwell); both recieved highest honors in their research.

Evan H. **Anders**

PH.D. CANDIDATE — ASTROPHYSICAL AND PLANETARY SCIENCES

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Education

University of Colorado – Boulder (CU Boulder) *Boulder, CO*

PH.D IN ASTROPHYSICAL AND PLANETARY SCIENCES · EXPECTED MAY 2020 *Aug. 2014 - Present*

M.S. IN ASTROPHYSICAL AND PLANETARY SCIENCES · DECEMBER 2016

Whitworth University *Spokane, WA*

B.S. IN PHYSICS; MINORS IN COMPUTER SCIENCE & MATH · CUMULATIVE GPA 4.0/4.0 *Aug. 2010 - May 2014*

Research Experience

CU Boulder & Laboratory for Atmospheric and Space Physics (LASP) *Boulder, CO*

GRADUATE RESEARCH ASSISTANT *May 2015 - Present*

- Working to understand the fundamental heat transport properties of stratified convection.
- Performing large-scale numerical simulations on NASA Pleiades.

Laser Interferometer Gravitational-Wave Observatory (LIGO) *Hanford, WA*

NSF SURF FELLOW *Summer 2013*

- Developed a tool in Python to analyze calibration lines in LIGO's power spectrum.
- Analyzed the consistency between input and output channels in LIGO's photon calibration system.

Pacific Northwest National Laboratory (PNNL) *Richland, WA*

DOE SULI INTERN *Summer 2012*

- Optimized functions in GAiN, a Python module which applies PNNL's Global Arrays parallel programming toolkit to the NumPy Python module.
- Designed new parallel algorithms for the GAiN 'reduce' function and developed the foundation of the GAiN 'master-slave' interface.

Relevant Publications

Anders, E.H., Brown, B.P, and Oishi, J. S. "Accelerated convergence of convective simulations...". 2018. Submitted to Phys. Rev. Fluids.

Anders, E.H. and Brown, B.P. "Convective heat transport in startified atmospheres...". 2017. Phys. Rev. Fluids 2, 083501.

Conference Talks & Posters

Foreign Conferences

Compressible Convection Conference 2017, 25-minute talk. "Convective heat transport...". *Lyon, France*

Domestic Conferences

APS Division of Fluid Dynamics 2017, 10-minute talk. "The effects of Mach number...". *Denver, Colorado*
APS Division of Fluid Dynamics 2016, 10-minute talk. "Sustained shear flows...". *Portland, Oregon*
AAS Solar Physics Division 2016, Poster. "The structure and evolution of boundary layers...". *Boulder, Colorado*

Awards & Honors

2015-18	**George Ellery Hale Graduate Fellowship**, providing funding for three years of graduate research	*CU Boulder / NSO*
2016	**High Pass**, for defense of publication-ready research on CU APS Comprehensive Exam II	*CU Boulder*
2016	**Carl Hansen Graduate Fellowship**, awarded to a graduate student studying stellar interiors	*CU Boulder*
2014	**President's Award for Outstanding Academic Achievement**, for graduating with a 4.0 GPA	*Whitworth U.*
2013	**Johnston-Hansen Foundation Scholarship**, awarded to a Physics student	*Whitworth U.*
2012	**Carl Hansen Pre-Engineering Scholarship**, awarded to an Engineering student	*Whitworth U.*
2012	**Math / Comp. Sci. Departmental Scholarship**, awarded to a student in the Math / Comp. Sci. department	*Whitworth U.*
2011	**Carl Hansen Pre-Engeering Scholarship**, awarded to an Engineering student	*Whitworth U.*
2010	**Mind & Heart Scholarship**, awarded to an entering undergraduate to assist with four years of tuition	*Whitworth U.*

Service

- 2017-18 **Member**, Graduate admissions committee — *CU Boulder*
- 2016-17 **Member**, Hiring committee for director of Fiske Planetarium — *CU Boulder*
- 2016 **Graduate Student Member**, Exam committee for CU APS Comprehensive Exam 1 — *CU Boulder*
- 2016 **Chair**, Graduate student committee for NSO/CU faculty appointment — *CU Boulder*
- 2015 **Member**, Graduate student committee for three-year NSO/CU appointment — *CU Boulder*

Teaching Experience

CU Boulder — *Boulder, CO*

GRADUATE PART-TIME INSTRUCTOR FOR ASTR 2600 — *Summer 2017*

- Co-instructor of record for an introductory course in Python programming
- Developed curriculum including lectures, tutorials, homework, and the final exam.

GRADUATE TEACHING ASSISTANT FOR ASTR 1010 — *Fall 2014, Fall & Spring 2015, Fall 2017*

- Delivered mini-lectures to familiarize students with lab material.
- Held office hours and helped staff the Astronomy Help Room (AHR).

LEAD GRADUATE TEACHER — *Fall 2016 - Spring 2017*

- Led video consultations with Graduate Teaching Assistants
- Coordinated and ran orientation for new Teaching Assistants in the department.

Whitworth University — *Spokane, WA*

COMPUTATIONAL PHYSICS TEACHING ASSISTANT — *January 2014*

- Guided students in designing computational models of physical phenomena.
- Assisted students in translating mathematical operations into numerical algorithms.

PHYSICS TUTOR — *Fall 2012 - May 2014*

- Reviewed basic concepts with students to help improve problem-solving skills.
- Provided supplemental instruction to clarify course material for students.

PHYSICS LAB TEACHING ASSISTANT — *Fall 2011 - Spring 2012*

- Instructed students through the completion of laboratory activites.

Outreach

(CU STARs) CU Boulder Science, Technology, and Astronomy RecruitS — *Boulder, CO*

GRADUATE COORDINATOR — *August 2016 - Present*

- Guided undergraduate students in designing hands-on high school-level lessons to teach basic concepts in astronomy and astrophysics.
- Ensured middle/high school visits across Colorado ran smoothly.

University of Colorado
Boulder

Department of Astrophysical and Planetary Sciences
Duane E226, CB391
Boulder, Colorado 80309-0391
(303) 492-8915 http://aps.colorado.edu

January 26, 2018

Dear Colleagues,

It is a pleasure to recommend Evan Anders for the NASA Earth and Space Science Fellowship (NESSF) program. Evan is a fourth year graduate student in the Department of Astrophysical and Planetary Sciences (APS) at the University of Colorado, Boulder. Evan is an extremely gifted graduate student; Evan has performed well in his course work within the APS department (including classes that I have taught), and in his research. Evan has been working with me since May 2015, studying convection and dynamics in the solar interior and in particular the transport of heat by turbulent, stratified convection. Evan is a gifted numericist and solar theorist, with strong skills in supercomputing, data analysis, and analytic approaches to problems. Evan has extensive experience using the Dedalus pseudospectral framework in his research. Evan has completed all of his graduate coursework and comprehensive exams, achieving highest honors on his Masters level research project (Anders & Brown 2017, PhysRevFluids). Evan is well-poised to begin the research proposed here.

Evan has proposed a novel project for his NESSF supported research "Towards a more complete understanding of solar convection". His proposed work will help directly resolve a significant conundrum in solar theory. Namely, why don't we see giant cells of convection at the solar surface, or beneath it with helioseismology? His work will help answer which mechanisms are selecting the scale of convection, and his work will help explain why motion on the scales of giant cells is either hidden, or never driven in the first place. This is a crucial issue for the solar dynamo and builds on Anders & Brown (2017). Evan came up with this project on his own and wrote this proposal single-handedly.

In summary, Evan has proposed a novel and interesting project which will answer important questions about the nature of deep solar convection which powers the solar dynamo. Evan has significant computational and mathematical skills, which make him very well suited for successfully achieving the proposed research. I strongly recommend Evan Anders for the NASA NESSF and very much look forward to working with him on this research.

Benjamin Brown *Benjamin Brown*

Assistant Professor in Solar Physics
Department of Astrophysical and Planetary Sciences

University of Colorado
Boulder

Department of Astrophysical and Planetary Sciences
Duane E226, CB391
Boulder, Colorado 80309-0391
(303) 492-8915 http://aps.colorado.edu

January 26, 2018

Dear Colleagues,

We attest that this NESSF proposal, “Towards a more complete understanding of solar convection” is the sole work of the student, Evan Anders.

Evan conducted the background research on this proposal, has done the preliminary research to assess feasibility, and wrote the proposal document single-handedly. This proposal builds on their successful master’s level research project at University of Colorado and the published work out of that (Anders & Brown, 2017, Phys Rev Fluids).

This proposal is the work of Evan Anders and is to support their research.

Benjamin Brown
Assistant Professor
Department of Astrophysical and Planetary Sciences

Evan Anders
Graduate Student
Department of Astrophysical and Planetary Sciences

ID: 1399038

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* AND/OR LEAD TO STUDENT DISCIPLINARY SANCTIONS. *
****

SUMMARY OF ADVANCED PLACEMENT CREDIT:

- Art 2D Design 3.00
- US History 3.00
- Biology 2.00
- Biology (Cont) 2.00
- Chemistry 3.00
- Chemistry (Cont) 3.00
- US History (Cont) 3.00
- Calculus AB 4.00
- Physics B 3.00
- Physics B (Cont) 4.00

Course	Title	Credits	Grade	QualPts
	2010 Fall Semester			
EL126	Women Writers	3.00	A	12.00
PE153	American Ballroom Dance	1.00	A	4.00
PE152	Swing and Lindy Hop	1.00	A	4.00
EL110	Writing I: Writing/Naturl Wrld	3.00	A	12.00
EN110	Engineering Orientation	1.00	S	0.00
GE125	First Year Seminar	1.00	P	0.00
MA172	Calculus II	4.00	A	16.00
SN201	Intermediate Spanish	4.00	A	16.00

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	18.00	16.00	64.00	4.00
WHITWORTH CUMULATIVE DATA:	18.00	16.00	64.00	4.00

Total credits earned: 48.00

Course	Title	Credits	Grade	QualPts
	2011 Jan Term			
TH241	New Testament	3.00	A	12.00

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	3.00	3.00	12.00	4.00
WHITWORTH CUMULATIVE DATA:	21.00	19.00	76.00	4.00

Total credits earned: 51.00

Course	Title	Credits	Grade	QualPts
	2011 Spring Semester			
EN171	Engineering Graphics & CAD	3.00	A	12.00
CS171	Computer Science I	3.00	A	12.00
MA273	Calculus III	4.00	A	16.00
PS153	General Physics II	4.00	A	16.00
SN202	Intermediate Spanish II	4.00	A	16.00

Course   Title   Credits Grade QualPts

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	18.00	18.00	72.00	4.00
WHITWORTH CUMULATIVE DATA:	39.00	37.00	148.00	4.00

Total credits earned: 69.00

Course	Title	Credits	Grade	QualPts
	2011 Fall Semester			
TH382	Campus Ministry	2.00	A	8.00
CH161L	General Chemistry I Lab	1.00	A	4.00
CS172	Computer Science II	3.00	A	12.00
EN211	Statics	3.00	A	12.00
MA281	Differential Equations	3.00	A	12.00
MA278	Discrete Mathematics	3.00	A	12.00
PS251W	General Physics III	4.00	A	16.00

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	19.00	19.00	76.00	4.00
WHITWORTH CUMULATIVE DATA:	58.00	56.00	224.00	4.00

Total credits earned: 88.00

Course	Title	Credits	Grade	QualPts
	2012 Jan Term			
CS371	Windows Applications Dev	3.00	A	12.00

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	3.00	3.00	12.00	4.00
WHITWORTH CUMULATIVE DATA:	61.00	59.00	236.00	4.00

Total credits earned: 91.00

Course	Title	Credits	Grade	QualPts
	2012 Spring Semester			
TH382	Campus Ministry	1.00	A	4.00
CS274	Ethic, Soc & Leg Issues in CS	3.00	A	12.00
PS373	Electronics	4.00	A	16.00
CS273	Data Structures	3.00	A	12.00
PS357	Math Meth for Engnrs/Scntsts	4.00	A	16.00

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	15.00	15.00	60.00	4.00
WHITWORTH CUMULATIVE DATA:	76.00	74.00	296.00	4.00

Total credits earned: 106.00

Continued on next Column/Page

Evan H. Anders
PO Box 725
Colbert WA 99005-0725

2012 Fall Semester

CS320	Qual Assurance Software Develp	3.00	A	12.00
EN390	INTERN: Parallel Computing	1.00	S	0.00
CO250	Western Civ II	4.00	A	16.00
CS278	Comp Organiztn & Assemblr Prog	3.00	A	12.00
CS374W	Database Management	3.00	P	0.00
PS451	Electricty and Magnetism I	4.00	A	16.00

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	18.00	14.00	56.00	4.00
WHITWORTH CUMULATIVE DATA:	94.00	88.00	352.00	4.00

Total credits earned: 124.00

2013 Jan Term

PS271	Computational Physics	3.00	A	12.00
FW149	Swimming for Fitness	1.00	A	4.00

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	4.00	4.00	16.00	4.00
WHITWORTH CUMULATIVE DATA:	98.00	92.00	368.00	4.00

Total credits earned: 128.00

2013 Spring Semester

EN396	Robotics	1.00	S	0.00
PS200	Physics Outreach	1.00	S	0.00
PS363	Thermodynamics	4.00	A	16.00
PS453	Electricity and Magnetism II	3.00	A	12.00
SP113	Interpersonal Communication	3.00	A	12.00

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	12.00	10.00	40.00	4.00
WHITWORTH CUMULATIVE DATA:	110.00	102.00	408.00	4.00

Total credits earned: 140.00

2013 Fall Semester

EN351	Dynamics	3.00	A	12.00
MA330	Linear Algebra	3.00	A	12.00
PH201	Logic	3.00	A	12.00
PS455	Quantum Mechanics	4.00	A	16.00
PS471	Research in Physics	1.00	S	0.00

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

Continued on next Column/Page

Course   Title   Credits Grade QualPts

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	14.00	13.00	52.00	4.00
WHITWORTH CUMULATIVE DATA:	124.00	115.00	460.00	4.00

Total credits earned: 154.00

2014 Jan Term

PS495	TA:PS-271 Computational Phys	2.00	S	0.00

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	2.00	0.00	0.00	0.00
WHITWORTH CUMULATIVE DATA:	126.00	115.00	460.00	4.00

Total credits earned: 156.00

2014 Spring Semester

CO350	Western Civ III: Capitalism	4.00	A	16.00
CS472	Software Engineering	3.00	A	12.00
PS371	Optics	4.00	A	16.00
PS353	Advanced Dynamics	4.00	A	16.00

PROVOST'S HONOR ROLL   MEMBER LAUREATE SOCIETY

	Earned	CredCalc	QualPts	GPA
WHITWORTH SEMESTER/TERM DATA:	15.00	15.00	60.00	4.00
WHITWORTH CUMULATIVE DATA:	141.00	130.00	520.00	4.00

Total credits earned: 171.00

-------------- Degree Earned 05/14 --------------

Bachelor of Science
  Major: Physics
  Minor: Mathematics
      Computer Science
  Graduation Honors: Summa Cum Laude

End of official record.

Evan H. Anders
PO Box 725
Colbert WA 99005-0725

UNOFFICIAL TRANSCRIPT

NAME: Anders, Evan Henry
STUDENT NR:
BIRTHDATE :
PRINT DATE: 01/29/2018

Degrees, Certi cates and Licensure

Master of Science DEC 15, 2016
CU Boulder
College Arts & Sciences GRAD
Major : Astrophysical & Planetary Sci

Other Institutions Attended:

HIGHER EDUC. INSTITUTIONS: Whitworth University
DEGREE: BAC 05/2014
Spokane WA 09/10 - 05/14

COURSE TITLE	CRSE NR	UNITS	GRADE	PNTS
--------- Fall 2014 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Atomic and Molecular Processes	ASTR 5110	4.0	A-	14.8
Cosmochemistry	ASTR 5330	3.0	A	12.0
Mathematical Methods	ASTR 5540	3.0	A	12.0
Seminar in Astrophysics Dark Matter	ASTR 6000	1.0	B+	3.3
ATT 11.0 EARNED 11.0 GPAHRS 11.0 GPAPTS 42.10 GPA 3.827				
--------- Spring 2015 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Intro Plasma Physics	ASTR 5150	3.0	A	12.0
Intro to Fluid Dynamics	ASTR 5400	3.0	A	12.0
Observations & Statistic	ASTR 5550	3.0	A	12.0
Seminar in Planetary Science Mars Science Lab	ASTR 5835	1.0	A-	3.7
ATT 10.0 EARNED 10.0 GPAHRS 10.0 GPAPTS 39.70 GPA 3.970				
--------- Fall 2015 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Radiatve/Dynamic Process	ASTR 5120	4.0	A	16.0
Astro/Space Plasmas	ASTR 5140	3.0	A	12.0
Seminar in Planetary Science Venus after Venus Express	ASTR 5835	1.0	A	4.0
ATT 8.0 EARNED 8.0 GPAHRS 8.0 GPAPTS 32.00 GPA 4.000				

COURSE TITLE	CRSE NR	UNITS	GRADE	PNTS
--------- Spring 2016 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Stellar Structure & Evol	ASTR 5700	3.0	A	12.0
Seminar in Astrophysics Space/GB Detector	ASTR 6000	1.0	A	4.0
Special Topics in APAS	ASTR 7500	3.0	A	12.0
Doctoral Dissertation	ASTR 8990	5.0	IP	0.0
ATT 12.0 EARNED 7.0 GPAHRS 7.0 GPAPTS 28.00 GPA 4.000				
--------- Fall 2016 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Doctoral Dissertation	ASTR 8990	5.0	IP	0.0
ATT 5.0 EARNED 0.0 GPAHRS 0.0 GPAPTS 0.00 GPA 0.000				
--------- Spring 2017 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Special Topics in APAS	ASTR 7500	3.0	A	12.0
Doctoral Dissertation	ASTR 8990	6.0	IP	0.0
ATT 9.0 EARNED 3.0 GPAHRS 3.0 GPAPTS 12.00 GPA 4.000				
--------- Fall 2017 UC Boulder ------				
College Arts & Sciences GRAD	Astrophysical & Planetary Sci			
Doctoral Dissertation	ASTR 8990	5.0	IP	0.0
ATT 5.0 EARNED 0.0 GPAHRS 0.0 GPAPTS 0.00 GPA 0.000				

CUMULATIVE CREDITS :

	TR UNITS	CU UNITS	TOT UNITS	QUAL UNITS	QUAL PTS	GPA
GRAD	0.0	39.0	39.0	39.0	153.80	3.944

***** END OF ACADEMIC RECORD ****

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