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Student: Evan H. Anders
Advisor: Benjamin P. Brown

University of Colorado at Boulder, Laboratory for Atmospheric and Space Physics (LASP)

NASA Earth and Space Science Fellowship (NESSF) 2018
Application

Towards a more complete understanding of solar convection

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My experiences as a graduate student have reinforced my drive to become a professor of physics and astrophysics at a university. Over the past four years, I have served on multiple commitees with duties including evaluating faculty and graduate student candidates and helping craft questions for our department's comprehensive exam 1 test to ensure that those questions are fair assessments. I have gained a great deal of experience teaching, and have learned that great teachers are made, not born. It takes work and effort to learn how to teach, and I have gained a great deal of experience in this through my experience as an instructor of record for a summer course, through my four semesters as a teaching assistant, and through 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. The research that I pursued for my master's-level comprehensive exam II has since been improved and has since been published (Anders & Brown 2017, Phys. Rev. Fluids), and I have two more papers in the works which will be submitted to journals before the end of the year (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 what it feels like to not come into work excited about the science problem I'm working on. I can genuinely say that the paper I've published, the papers I hope to publish by the end of 2018, and the projects I am proposing here for NESSF funding are projects that I have enjoy working on, and that I will enjoy working on. A mentor has told me repeatedly that the problems I'm working on should distract me to the point where I'm walking across the street thinking about them and almost being hit by busses. These problems have my attention in this way (but I promise not to get hit by a bus if funded by NASA).

Studying fluids is hard. Studying highly nonlinear, stratified flows is even harder. The systems must be set up in a meaningful way such that the experimenter understands what the control parameters are, and how those controls 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 forthcoming work on internally heated convection, I already know how to determine what the control parameters are on fluid systems, how to modify them to test a specific hypothesis, and how to create a measurement to measure that hypothesis. I further have experience using open-source, tested numerical tools – specifically the Dedalus pseudospectral framework – which has been benchmarked and which allows me to easily set up new experiments (either by changing the atmosphere against which equations evolve or by changing the equations themselves). Within my research group all of our code is created using version control software, and we release the code that we use in part to encourage scientific transparency and in part to help the community by allowing others to build on our own scientific tools to conduct experiments of their own.

Thank you for taking the time to consider my application. I hope you agree that the scientific problem in the community being addressed and the approach I propose for addressing it are as fundamentally interesting as I do. (Need to fix this).

Towards a more complete understanding of solar convection

Evan H. Anders

Advisor: Benjamin P. Brown
Laboratory for Atmospheric and Space Physics (LASP) & University of Colorado at Boulder

1 Background & Motivation

The Sun exhibits active magnetism which cycles in magnitude every 11 years. This magnetism arises from an organized dynamo seated in the turbulent plasma motions of the solar convective zone, which occupies roughly the outer 30% of the Sun's radius. This activity manifests itself in the collection of phenomena generally referred to as solar activity, including magnetic storms and coronal mass ejections. Such activity propagates towards Earth, threatening disruption of power grids and aircraft operations as well as endangering astronauts and satellites. The motivation to understand the Sun's magnetism in our increasingly technological society is great. A critical step in protecting our society from the Sun's magnetism is to gain an understanding of the nature of the dynamo that generates the Sun's magnetic fields (Charbonneau, 2014).

To understand the dynamo that drives the Sun's magnetism, we must understand the convection which powers that dynamo. Numerical studies of convection in stratified domain have a rich history in the past decade. The early work of Graham (1975), Hurlburt et al. (1984), and others in simple, plane-parallel atmospheres provided rich insight into the nature of stratified convection and provided a basis in a field which now regularly creates both complex, 3D global models of convection (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)). From these efforts we have learned a great deal about the nature of convection, and have even created beautiful simulations which even *look* like the convection we see on the surface of the Sun.

Unfortunately, the great advances made in computational prowess within the solar physics community seem to have surpassed our fundamental knowledge in the field. There is currently a so-called "Solar Convective Conundrum" which has two components. Both components of this conundrum are present in the recent observations by Hanasoge et al. (2012) (Fig. 1a). First, they observed solar convective velocities two orders of magnitude smaller than theory predicts. Second, their observations showed that there was less power at large length scales than short length scales – exactly the opposite of what we expect. The two-part convective conundrum – the presence of low convective amplitudes and the lack of "giant cells" at large length scales – has baffled the community since it came to light.

More recent work by Greer et al. (2015) (Fig. 1b) argue that the convective velocity amplitude is perhaps not so low as previously reported, but there is still a distinct lack of giant cells imprinting on the near-surface flows in this work. Even simpler doppler measurements of the velocity fields at the solar surface which are not muddied by complex helioseismic inversions lack giant cells (e.g., Hathaway et al. (2015) & Fig. 1c). The motions of surface granules and the slightly deeper supergranules are clearly present, but no larger length scale
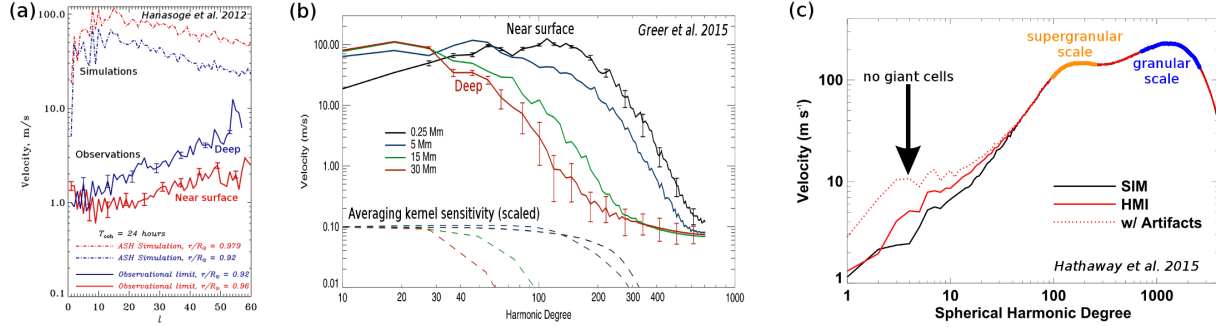
Figure 1: (a) Power spectra of solar convective velocities are shown for both observations and simulations, and both near the surface and deeper Hanasoge et al. (2012). Observations are obtained using time-distance helioseismology, and show velocities roughly two orders of magnitude lower than those predicted by simulations, and a decrease in power approaching larger length scales rather than the opposite. (b) Further observations of solar velocity power using ring-diagram helioseismology. Here, velocity magnitudes are roughly in line with those predicted by simulations, but show decreasing power as larger scales are approached, unlike what is expected from simulations Greer et al. (2015). A simple 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.

is distinct.

The difficulty in the lack of giant cells is exemplified by the work of Lord et al. (2014), who showed that the length scale of convective motions is determined by the depth in the atmosphere at which they are driven. Unstable, convecting layers drive motions whose scale is proportionate to the local density scale height. Deep in the atmosphere, the density scale height is large, and so we expect the bottom of the convection zone to drive large, giant cells which imprint through to the surface. The lack of their presence shows either a lack of our fundamental understanding of convection or a systematic problem with our observational methods – and the former is more likely.

Our inability to observe giant cells hints at the possibility that giant cells are never driven in the first place, which would mean that the deep convection zone is not stably stratified. Some recent work (Brandenburg (2016), Käpylä et al. (2017)) has sought to understand the nature of convection – and explain the lack of giant cells – when nonlocal effects are included and observed. These efforts are, however, often extensions of already complex theory (Mixing Length Theory) or simulations which include a large amount of physics, but not a careful study of how those physics determine the solution.

Drawing on the knowledge and expertise of those in the physics community who study incompressible, unstratified Rayleigh-Bénard convection, I have recently examined hydrodynamic, compressible convection in simple stratified domains Anders & Brown (2017). I discovered that these somewhat complicated systems *transport heat largely in the same way as simple incompressible systems.* This was accomplished by setting up a simple experiment, understanding the different control parameters on the experiment and how they affected the convective states, and then setting up a controlled parameter space study.

Here I present two simple, small experiments which aim to understand the nature of con-

vection in which giant cells are not driven. I will use methods similar to that in my recently published work to create simple, controlled experiments on comprehensible atmospheres in order to gain a deep understanding of the underlying convective physics.

2 Proposed Project

In simple simulations of convection, motions are often driven by enforced boundary conditions on the thermodynamic state. This creates boundary layers at the top and bottom of the atmosphere, and convection is strongly driven within those boundary layers. The situation in the Sun is less black-and-white. There is a positive radial gradient of opacity within the Sun, such that at radii near the solar surface, radiative flux is inefficient and convection is required to carry the solar luminosity outwards. This divergence of radiative flux acts like an internal heating term which drives the convection weakly at the base of the solar convective zone and more strongly near the top of the solar convection zone. Further, the upper boundary layer of the Sun is not determined by the local thermal diffusivity (which is very small), but rather by the ionization and recombination of hydrogen.

We propose two simple experiments to test these two aspects of solar convective driving. In the first, we will study the nature of Kramers' opacity, which decreases with depth, and the internally heated convection which this drives. In the second, we will carefully study the effects of hydrogen ionization on convection in order to determine the nature of convection when new physics determines a different length scale for the driving region than the natural physics of the thermal boundary layer.

This work will be informed by current work which we are performing, in which we are studying simple internally heated convection – similar to work which is done in boussinesq convection (e.g., Goluskin & Spiegel (2012) – in stratified compressible domains. We are discovering how internally heated convection creates stable and unstable layers, and the nature of the evolved stratification compared to the initial stratification set up by the internal heating.

2.1 Mini Project 1: Kramers' Opacity

Many careful studies of convection employ a constant opacity and thus, a constant conductivity. The transport of heat within the atmosphere, in addition to convective transport, is often quantified through Fourier's law of conduction (Lecoanet et al., 2014), in which the radiative (conductive) flux is proportional to the conductivity and the temperature gradient. A constant opacity in time and space allows for the creation of simple measurements of the heat transport in the evolved atmosphere compared to the initial atmosphere.

While a constant 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 Kramers' opacity, in which the opacity is proportional to T^3/ρ, where T is temperature and ρ is density. This means that the conductivity is proportional to ρ/T^3, which changes significantly throughout the depth of the solar convection zone. Unfortunately, there have never been systematic, careful studies of the effects of Kramers' opacity on stratified convection.

What experimental knob determines the Mach number? At what value of the Rayleigh number does convection turn on (and thus, at what *supercriticality* are other studies being run)? What is the appropriate reference state which is in hydrostatic and thermal equilibrium? What are the parameters of that reference state that determine key quantities of the evolved convection, and what can we learn about the evolved convection from them?

After determining what the appropriate reference state is for a simple convective experiment where the Kramer's opacity is operating, and after determining how to systematically compare similar atmospheres at low and high Mach number, we will study the importance of nonlinearities in this opacity term on the resultant convection. In downflows (where density is high and temperature is low), we expect the opacity to be small compared to downflows, and the opposite to be true for upflows. If this is the case, then the "entropy rain" formulation presented in Brandenburg (2016) may be an appropriate adjustment to the Mixing Length theory of convection. However, at low Mach number, where variations in T and ρ are small in upflows compared to downflows, we anticipate that this effect will be unimportant. Near the solar surface, the Mach number is nearly 1, and this is likely significant. However, deep in the convective zone, the Mach number is very small $(\mathrm{O}(10^{-5}))$, and so this effect is likely quite unimportant.

We want to quantify *how important* the nonlinearities in the opacity are for nonlocal transport, and also what effects these might have on the resultant stratification (and thus convective driving) of the solar convection zone.

2.2 Mini Project 2: Hydrogen recombination

Convection is strongly driven at the solar surface 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, or the natural thermal boundary layer that forms near the upper surface and conducts the necessary energy across the upper boundary. 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 scale of convective driving near the photosphere of the Sun is *much* larger than the natural thermal diffusive length scale. It is determined by the depth of hydrogen ionization, and this large thermal boundary layer and the large convective elements it creates likely plays an important role on the convective dynamics. We aim to study the difference in the nature of convection – especially in the surface power spectrum – when hydrogen recombination is the driver of convection near the upper boundary, rather than the other more common methods.

We will implement the basic nature of hydrogen ionization and recombination through the use of a nonlinear equation of state rather than just the standard ideal gas equation of state which is often used in convective studies. By adjusting the power of this recombination (how much energy is released or absorbed), and also the depth of this recombination, we can study the effects of this form of driving on the convection.

This work will be guided by previous studies of ionizing convection (e.g., refs and refs) and also work on moist convection, in which simple convection with a nonlinear equation of

state and cloud formation can be studied (e.g., ref).

3   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 general 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), will soon submit another paper, and am now adept at using it to create suites of simulations in short timeframes.

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, but most questions I am asking are quite basic, and the systems I propose to study here have not been studied carefully in the compressible context, at least not recently. 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 3 million CPU-hours. Through my advisor, I have access to an allocation on NASA Pleiades of roughly 20 million CPU-hours/year, so one- or two- of the following projects of the scope I am proposing can be easily completed each year.

Furthermore, forthcoming work (Anders, Brown, & Oishi 2018, to be submitted to PRFluids in February) has shown that properly constructed boundary value problems can fast-forward the slow thermal evolution of these convective simulations. This work was done in Boussinesq, Rayleigh-Bénard convection but can be easily extended to stratified convection, and will greatly extend both the number of simulations we are able to complete and the level of turbulent driving that we are able to resolve, allowing us to study simulations more like the Sun.

4   Timeline of proposed work

Year 1 (Fall 2018 - Summer 2019):
- 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 short paper to The Astrophysical Journal on the nature of convection with Kramers' opacity at both low and high Mach number by end of spring 2018.

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

- Conduct literature review on past work done on ionizing convection and moist convection. Construct appropriate atmospheres for studying ionizing convection, and learn what aspects of these atmospheres control different aspects of the evolved solutions.

Year 2 (Fall 2019 - Spring 2020):

- Run simulations of ionizing convection, analyze data, and submit a short paper to The Astrophysical Journal by the end of year 2019.

- Combine work from five published (or submitted) papers into a thesis, to be defended at the end of Spring 2020.

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?" 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. It is clear from recent work that our understanding of the fundamentals of convection is not as perfect as we once thought, and now is an exciting time to clarify our theory and determine which parts of it fail and which parts hold true under more examination. Only once we understand the fundamental nature of stratified, compresible convection can we begin to understand how it drives the dynamo in the Sun in the presence of many complications such as differential rotation, shear layers near the base and top of the convection zone, and magnetism.

The 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, and from the new measurements which will be made possible by the upcoming joint NASA-ESA Solar Orbiter's Polarimetric and Helioseismic Imager (PHI).

6 Summary

Recent observations call into question our fundamental understanding of stratified convection in systems such as the solar convection zone (Hanasoge et al., 2012; Greer et al., 2015). We propose two focused, scoped studies of the mechanisms which drive the Sun's convection at the base and top of the solar convection zone. These studies will carefully probe the specific physics of these mechanisms and compare the nature of convection *with* these elements to simpler studies *without* them. Due to the developed nature of our computational tool, Dedalus, the simulations for these projects can be implemented and carried out on short timescales, and the body of work suggested here should be finished within two years, by the end of the spring of 2020.

References

Anders, E. H., & Brown, B. P. 2017, Physical Review Fluids, 2, 083501

Brandenburg, A. 2016, The Astrophysical Journal, 832, 6

Brown, B. P., Browning, M. K., Brun, A. S., Miesch, M. S., & Toomre, J. 2010, The Astrophysical Journal, 711, 424

Burns, K., Vasil, G., Oishi, J., Lecoanet, D., & Brown, B. 2016, Dedalus: Flexible framework for spectrally solving differential equations, Astrophysics Source Code Library, ascl:1603.015

Charbonneau, P. 2014, Annual Review of Astronomy and Astrophysics, 52, 251

Goluskin, D., & Spiegel, E. A. 2012, Physics Letters A, 377, 83

Graham, E. 1975, Journal of Fluid Mechanics, 70, 689

Greer, B. J., Hindman, B. W., Featherstone, N. A., & Toomre, J. 2015, Astrophys J. Lett., 803, L17

Guerrero, G., Smolarkiewicz, P. K., de Gouveia Dal Pino, E. M., Kosovichev, A. G., & Mansour, N. N. 2016, The Astrophysical Journal, 819, 104

Hanasoge, S. M., Duvall, T. L., & Sreenivasan, K. R. 2012, Proceedings of the National Academy of Science, 109, 11928

Hathaway, D. H., Teil, T., Norton, A. A., & Kitiashvili, I. 2015, The Astrophysical Journal, 811, 105

Hurlburt, N. E., Toomre, J., & Massaguer, J. M. 1984, The Astrophysical Journal, 282, 557

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

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

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.

Education

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

PH.D IN ASTROPHYSICAL AND PLANETARY SCIENCES · EXPECTED MAY 2020

M.S. IN ASTROPHYSICAL AND PLANETARY SCIENCES · DECEMBER 2016   *Aug. 2014 - Present*

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.

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   *August 2014 - December 2015, Fall 2017*

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

CU Boulder Graduate Teaching Program   *Boulder, CO*

LEAD GRADUATE TEACHER   *August 2016-May 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   *August 2011 - May 2012*

- Instructed students through the completion of laboratory activites.

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Awards

2016	**Carl Hansen Graduate Fellowship**, awarded to a graduate student studying stellar interiors	*CU Boulder*
2015	**George Ellery Hale Graduate Fellowship**, providing funding for three years of graduate research	*CU Boulder / NSO*
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-Engneering 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*

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.

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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				

2011 Jan Term

Course	Title	Credits	Grade	QualPts
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				

2011 Spring Semester

Course	Title	Credits	Grade	QualPts
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				

2011 Fall Semester

Course	Title	Credits	Grade	QualPts
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				

2012 Jan Term

Course	Title	Credits	Grade	QualPts
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				

2012 Spring Semester

Course	Title	Credits	Grade	QualPts
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				

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

Course	Title	Credits	Grade	QualPts

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

	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

Undergraduate Transcript   14   Evan H. Anders, NASA NESSF 2018

NAME: Anders, Evan Henry
STUDENT NR: 104330960
PRINT DATE: 01/16/2018   BIRTHDATE :

Degrees, Certificates and Licensure

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

Other Institutions Attended:

   HIGHER EDUC.   Whitworth University
   INSTITUTIONS: 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 ****