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 in research and teaching 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. Teaching well takes *effort*, and I am pleased at the improvements I have seen in my teaching through my experience as an instructor of record for a summer course, 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. 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), and I have two more papers in the works which will be submitted to journals 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 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 published last year, the papers I am working on writing over the upcoming months, and the projects I am proposing here for NESSF funding are projects that I 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 the point that I am in danger of stepping out in front of moving busses. The projects I propose here, and the related work that on which I am currently working, occupy my attention to this degree, but I solemly swear to not let myself be hit by a bus if funded by NASA.

Studying fluids is hard. Experimental 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 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 experienced in software development and the use of collaborative code 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.

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 a 22-year active magnetic cycle. An organized dynamo seated in the turbulent plasma motions of the solar convective 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. Our increasingly technological society provides great motivation to understand the Sun's magnetism. 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).

An understanding of the convection which powers the Sun's dynamo is essential to understanding 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 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)). 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 seem to have surpassed our fundamental knowledge in the field. There is currently a so-called "Solar Convective Conundrum," in which observations and theory are starkly disagreeing. This conundrum has two components, both of which are present in recent observations by Hanasoge et al. (2012) (Fig. 1a). First, the convective flows they observed are too slow – their observations find solar convective velocities which are *two orders of magnitude* smaller than theory predicts. Second, their observations showed that there was less power in the solar velocity spectrum at large length scales than at short length scales – exactly the opposite of what theory predicts. This 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 observations by Greer et al. (2015) (Fig. 1b) display a lack of giant cells but high velocity amplitudes that are in line with theory, verifying that at least half of the conundrum deserves further exploration. 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 is distinct.

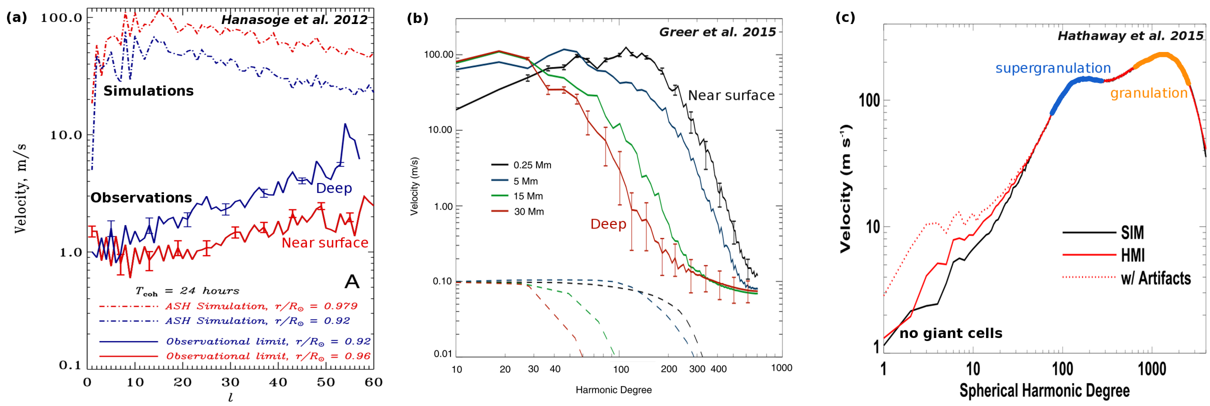

Figure 1: (a) Power spectra of solar convective velocities are shown for both observations and simulations, and both near the surface and deeper Hanasoge et al. (2012). Observations are obtained using time-distance helioseismology, and show velocities roughly two orders of magnitude lower than those 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.

The lack of giant cells is disturbing, as is exemplified by the work of Lord et al. (2014). They showed that the length scale of convective motions is determined by the depth in the atmosphere at which they are driven. Deep convection drives larger scale motions due to the increasing nature of the local density scale height with depth. These deep motions which are driven at high density should imprint hugely on the surface motions. The lack of their presence in our observations implies that our 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, there is a need to return to simple convective models to understand how the presence of convection modifies the underlying atmospheric stratification, and how this stratification in turn affects the observable convection at the surface of the atmosphere. Here I present two simple, small experiments which aim to understand two fundamental aspects of solar convection and to determine whether either of them is the reason that we do not see giant cells at the solar surface. I will use methods similar to those I employed in my recently published work (Anders & Brown, 2017) to create simple, controlled experiments in comprehensible atmospheres in order to gain a deep understanding of the underlying convective physics.

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 the efficiency with which radiation can carry the solar luminosity with increasing height in the convective 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 upper boundary, but rather because of the ionization and recombination of hydrogen. These two effects – the internal driving of solar convection and also the driving of convection at the solar surface by hydrogen ioniziation – have not been studied carefully in at least two decades.

Recent exciting work by Käpylä et al. (2017) exhibited convection zones 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 drives convection internally in a manner similar to that in the Sun. However, forthcoming work by my advisor (Brown et al. 2018 in prep) shows that stable lower-layers of convective zones naturally arise where convective zones overly stable regions 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 in the presence of a constant opacity throughout the depth of the atmosphere.

Since the process of internal heating – not the complex form of a Kramers' opacity – is the fundamental cause of the stratification effects seen recently by Käpylä et al. (2017), the first project that I propose is a careful study of the effects of Kramers' opacity on convection. The second project I propose 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 Mini Project 1: Kramers' Opacity

Many careful studies of convection employ a constant opacity and thus, a constant conductivity. The transport of heat within an atmosphere, in the absence of convective transport, is often quantified by 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, 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 using modern computing resources.

In order to study the importance of Kramers' opacity, a frame of reference must be constructed in which to study this varyin 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 convection 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). When examined in a similar manner under a proper framework, I am excited to gain a more fundamental understanding of Kramer's opacity.

After determining how to systematically study 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), opacity will be high compared to upflows. However, at low Mach number, where variations in T and ρ are small in upflows and downflows, 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 very low Mach number deep in the interior, where Mach number is $\mathrm{O}(10^{-5})$. 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 is to quantify the importance of nonlinearities in the opacity felt by solar convection. My motivation is to understand the importance of these nonlinearities 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, and this nonlocal transport could drastically change the stratification of deep convection where low-entropy fluid falls and then resides.

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 (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 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. If large convective elements are driven by this effect at the surface and persist deep in the atmosphere, they could hugely 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 – 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 built around a single-atmoic level model of particles, similar to that used in Rast & Toomre (1993). This work will further be guided by prior studies on moist convection (e.g., Leconte et al. (2017)), in which phase changes resulting in cloud formation are studied. We will study 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 in the Sun. 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.

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.

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

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.
- 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.

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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.

#Evan H. **Anders**

GRADUATE STUDENT — 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.

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.

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.

Name: Anders, Evan H | Soc-Sec-Nbr: | Birthdate: | Date Printed: 05/27/14 |

ID: 1399038

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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

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

ID: 1399038

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

Continued on next Column/Page

	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 GRADUATE TRANSCRIPT

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. 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				
--------- 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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