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 Stratified, Compressible Convection

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Dear Members of the Selection Committee,

Having just read over 100 graduate applications as a member of my department's graduate admissions committee, I understand how mind-numbingly bland these statements get. I'll try to keep this to the point.

I am now half way through my fourth year as a graduate student at CU Boulder, and while my research has only really taken off in the past year in large part due to our department's comprehensive exam structure (see academic timeline), I have gained much experience in all aspects of the process of academia. I was a co-instructor of record for our department's introductory Python programming course last summer, have spent 4 semesters TAing different aspects of our departments Introductory Astronomy class on The Solar System, and participated in and completed the Institute for Scientist and Engineering Educator's Professional Develop Program (ISEE PDP) last year, during the course of which I invested 100 hours alongside my team of 4 to develop a day-long class on discovering exoplanets through the transit method to be taught to incoming first generation or underrepresented college freshmen at CU as part of the MASP PEAC program. I was also my department's "Lead Graduate Teacher" during the '16-'17 school year, interfacing between my department and CU's Graduate Teacher Program and leading videotape consulatations with other teaching assistants in the department to help them improve their teaching. I love teaching, and I love becoming a better teacher by examining the wealth of physics education research that is now present. I want to teach at the collegiate level, and in order to reach this long term goal I must get a faculty position at college. COLLAGE letter?

I have also invested a large amount of time to service within my department and community outreach. I have served on three separate faculty hiring committees – two for positions within the National Solar Observatory (NSO), which recently relocated to Boulder, and one for the director of CU's famed Fiske Planetarium. I am currently serving on our department's Graduate admissions committee and helping determine who will be admitted into the entering graduate class of 2018. Beyond this, I served on our department's Exam committee last academic year, helping to modify and ensure that the questions asked of the students during our Comprehensive Exam I are fair. In the broader community, I have been an administrator of CU Boulder's CU STARs group, in which I mentor undergraduate students and lead outreach trips to underserved high schools across Colorado. I also make a habit of helping to lead one public open house at our observatory every semester, and I volunteer to staff Astronomy Day once a year.

I have developed myself professionally to the best of an extent that I can as a graduate student here at CU, and now I am turning my sights towards buckling down for my final two years in graduate school and getting research done. I recently had my first paper published, and have just submitted my second paper. As laid out in my proposal, I have three specific projects which I am genuinely *excited* to explore, and which will lay the ground work for many careful future studies in solar, stellar, and atmospheric convection. Astronomy is turning towards open source, comprehensible, collaborative tools, and I have developed a great deal of experience using the Dedalus pseudospectral framework, which can flexibly solve diverse systems of partial differential equations and which is fully open source. I have a strong background in computer science, and am becoming adept at using collaborative, version control tools such as git and mercurial. Through the use of these tools, we hope to make our science completely transparent and reproduceable.

Oh, and I'm not an observer. I'm a simulator, but I think that simulations should be *experiments*, not just boxes o' physics.

Towards a more complete understanding of Stratified, Compressible Convection

Evan H. Anders

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

Blah blah blah. This project supports objective 1.4 of NASA's 2014 Strategic Plan and will assist in developing "the knowledge and capability to detect and predict extreme conditions in space" in accordance with NASA's overarching Heliophysics science goals.

I. 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 [1, 2].

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 [3] and [4] and others in simple domains 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., [5], [6], and many others) and smaller scale local area models with more complex physics (e.g., [7], [8]). 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. Recent observations by [9] (Fig. 1a) show that deep velocities in the solar convection zone are much lower than we would anticipate from our knowledge of simulations. While the more recent observations of [10] (Fig. 1b) argue that the problem is perhaps not so bad as it appeared a few years before, observations do not line up with simulations. The standard picture of convection from simulations is that deeper motions are driven more intensely, and thus, through mass conservation, should imprint as the strongest motions at the solar surface. This is what is seen in simulations, and which was verified by the work of [11]. However, this is precisely not what we see at the solar surface. The horizontal velocity power spectrum at the solar surface shows excess of power in granular and supergranular scales, but the "giant cells" which are theorized to be driven at the base of the 14-density-scale-height-deep convection zone are not observed [12].

This paints a troubling picture. Years of simulation results – and the Mixing Length Theory of convection that they inform – seem to be wrong. One fundamental problem is that we, as a community, are so focused on ensuring that the physics in our simulations are as "correct" as we can make them that we ignore the fact that we do not understand the effects of each piece of physics on the nature of convection. When running large, 3D, complex simulations, computational cost often limits the number of simulations which can be run, and parameter space studies are often out of the question.

Drawing on the knowledge and expertise of those in the physics community who study incompressible, unstratified Rayleigh-Bénard convection, we have recently examined hydrodynamic, compressible convection in simple stratified domains [13]. We discovered that these somewhat complicated systems *transport heat in the same way as incompressible systems*, and that the Mach number of convection can be easily specified *a priori*. By setting up a simple experiment, we were able to learn something concrete about the fundamental nature of convection.

Here we propose a trio of similar, small experiments. In each experiment, we test the effects of one new piece of physics in order to gain an understanding of how they influence the convective motions and in order to gain a frame of reference for how to understand these effects in simulations with more complicated, "more realistic" physics.

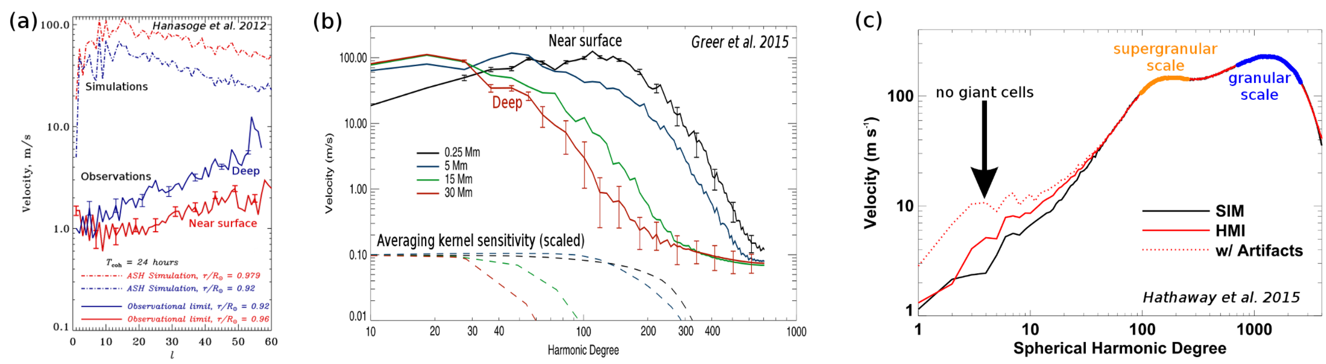

FIG. 1. (a) Power spectra of solar convective velocities are shown for both observations and simulations, and both near the surface and deeper [9]. Observations are obtained using time-distance helioseismology, and show velocities roughly two orders of magnitude lower than those predicted by simulations, 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 [10]. A simple spectrum of horizontal velocities at the solar surface, obtained using line-of-sight Doppler velocities [12]. The length scales of surface granules and deeper supergranules appear as distinct features, but the hypothesized giant cells are not observed at low wavenumber.

II. NUMERICAL TOOLS AND FEASIBILITY

I will use the open-source Dedalus[1] pseudospectral framework [14] 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 [13], have submitted 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 [13]. 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 most of the systems I propose to study here have not been studied 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 [13], 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 completed each year.

Furthermore, my recent work (Anders, Brown, & Oishi 2018, submitted to PRFluids) has shown that properly constructed boundary value problems, coupled with initial 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 (while attaining converged atmospheres) that we are able to solve.

III. PROPOSED PROJECT

I propose a series of small projects which will probe and quantify the effects of key elements of solar convection on the dynamics of the evolved flows. Each of these pieces of physics is often included in the more complex global simulations or local area models.

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

A. Mini Project 1: Internally heated convection

Our first experiment involves the study of atmospheres where a constant internal heating term is included in the energy equation. This is the simplest form of internal heating, and is similar to that which has been studied in Rayleigh-Bénard convection, just with compressibility and stratification included (e.g., [15]). We have found that these systems can be constructed so as to naturally include stable layers underlying unstable, convection regions. These systems are important to study, because the changing opacities in the interior of the solar convective zone effectively act like an internal heating term, depositing energy and driving convection.

We find that these systems essentially have the same input control parameters as simple polytropic convection [13], which include the Rayleigh number (Ra, the strength of convective driving and amount of turbulence), the Prandtl number (Pr, the ratio of the thermal to viscous diffusivity), the characteristic superadiabaticity of the atmosphere (which sets the Mach number of the flows), and the depth of the atmosphere. In the internally heated systems, we find that the magnitude of the internal heating directly relates to the superadiabaticity of the atmosphere, and thus Ma, but we must split up the depth into two parameters: the depth of the *unstable* region, and the depth of the new *stable* region. In [13], we explored the effects of the magnitude of the superadiabaticity on the resulting convection, and found that – except where the Mach number is very high – it has almost no effect on the other properties of the convective flows.

In this project, we will focus on understanding how the depth of the atmosphere, and the amount of stratification felt by the flows, affects the resultant convection. We will set the depth of the convection zone (to 1, 3, and then 5 density scale heights), and for each of these depths we will run simulations for shallow and deep radiative zones. We will examine the evolved stratification of these atmospheres in order to determine where convection is driven and where it is not. Preliminary results show that the so-called "Deardorff zones" present in the simulations of [16] are also present in these simple simulations of internally heated convection and do not require complex forms of the conductivity to be achieved. We expect that the extent of these subadiabatic zones in which convection carries the flux can be determined *a priori* in these simple simulations, but further work must be done.

We're looking for the motions at the surface and also the stratification.

IV. MINI PROJECT 2: HYDROGEN RECOMBINATION

Most studies of convection are driven either by the choice of fixed boundary conditions (hot at bottom, cold at top) or through the volumetric depoisition of energy throughout the domain (internal heating). Here we propose a project in which we utilize a nonlinear equation of state to represent the ionization / reionization of hydrogen near the surface of the Sun. We examine the effects that this has on the driving boundary layer region near the top of the simulation, and we do blahblahblah.

In order to carefully study the effects of the ionization of hydrogen, or other similar phase changes, we must first understand the reference state for such an atmosphere. It will no longer simply be polytropic, as the nonlinear EOS rules out the simple polytropic assumption. Once the appropriate state which is in hydrostatic and thermal equilibrium despite this phase change is discovered, we will then carefully study the effects of the temperature of ionization (which will in turn determine its depth), and also the ionization energy of the transition. In standard simulations of convection, the interactions of the flows with a hard boundary forms a thin boundary layer, which scales downwards as the diffusivities shrink, and this boundary generally drives convection. We suspect that we can create atmospheres with larger or smaller boundary layers than the natural thermal boundary length scale, which will nominally drive convection on different length scales than the natural one. We are interested in seeing how these "too large" convective flows interact with their surroundings, and in seeing how the atmosphere naturally evolves in the presence of these flows.

Things we can study: stratification of evolved solution. Stable layers? filling factors. Power spectrum.

V. MINI PROJECT 3: KRAMER'S OPACITY

While it is convenient to use a constant conductivity (and thus opacity) in the energy equation, as this makes the interpretation of results very simple, this greatly over-simplifies the form of radiative conductivity in natural systems like the Sun. In this project, we will carefully implement a kramer's opacity of the form $\kappa \propto T^3/\rho$. We will run experiments at low and high Mach number, some in which κ is constant with time and some in which κ is allowed to evolved with time. We anticipate that at low Mach number, the deviations from the initial state will be small, and the fully nonlinear effects of this term will not be important. At high Mach number, however, like the solar surface, we expect this term to vary significantly from the high temperature, low density upflows to the low temperature, high density downflows.

We are curious to see if this more realistic form of the conductivity significantly changes the transport properties of the overall convection: does it affect the heat transport (Nu)? How does the change in the adiabatic temperature gradient under this formulation change our intuition? We can likely naturally have heavily driven regions and lightly driven regions of naturally-occuring, internally heated convection. Our studies from project 1 will help inform how to interpret the divergence of this flux term as an internal heating source.

VI. TIMELINE OF PROPOSED WORK

a. Year 1:

- (Fall '18) Finalize Internally Heated convection work, submit a paper to ApJL.
- (Spring-Summer '19) Run simulations of nonlinear EOS, write paper, submit to ApJ. Begin opacity project.

b. Year 2:

- (Fall '19 - Spring '20) Finalize opacity project, submit ApJ. Write and finalize thesis by end of Spring '20.

VII. 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." This work also fits in with one of the three overarching science goals of the Heliophysics section 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." Furthermore, simulated observables created by this work will be directly comparable to data retrieved by the currently operational Solar Dynamics Observatory and the future NASA-ESA Solar Orbiter mission.

VIII. SUMMARY

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[1] Å. Nordlund, R. F. Stein, and M. Asplund, "Solar Surface Convection," Living Reviews in Solar Physics **6**, 2 (2009).

[2] P. Charbonneau, "Solar Dynamo Theory," Annual Review of Astronomy and Astrophysics **52**, 251–290 (2014).

[3] E. Graham, "Numerical simulation of two-dimensional compressible convection," Journal of Fluid Mechanics **70**, 689–703 (1975).

[4] N. E. Hurlburt, J. Toomre, and J. M. Massaguer, "Two-dimensional compressible convection extending over multiple scale heights," The Astrophysical Journal **282**, 557–573 (1984).

[5] B. P. Brown, M. K. Browning, A. S. Brun, M. S. Miesch, and J. Toomre, "Persistent Magnetic Wreaths in a Rapidly Rotating Sun," The Astrophysical Journal **711**, 424–438 (2010), arXiv:1011.2831 [astro-ph.SR].

[6] G. Guerrero, P. K. Smolarkiewicz, E. M. de Gouveia Dal Pino, A. G. Kosovichev, and N. N. Mansour, "On the Role of Tachoclines in Solar and Stellar Dynamos," The Astrophysical Journal **819**, 104 (2016), arXiv:1507.04434 [astro-ph.SR].

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[8] M. Rempel, "Numerical Simulations of Quiet Sun Magnetism: On the Contribution from a Small-scale Dynamo," The Astrophysical Journal **789**, 132 (2014), arXiv:1405.6814 [astro-ph.SR].

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[10] B. J. Greer, B. W. Hindman, N. A. Featherstone, and J. Toomre, "Helioseismic Imaging of Fast Convective Flows throughout the Near-surface Shear Layer," The Astrophysical Journal Letters **803**, L17 (2015), arXiv:1504.00699 [astro-ph.SR].

[11] J. W. Lord, R. H. Cameron, M. P. Rast, M. Rempel, and T. Roudier, "The Role of Subsurface Flows in Solar Surface Convection: Modeling the Spectrum of Supergranular and Larger Scale Flows," The Astrophysical Journal **793**, 24 (2014), arXiv:1407.2209 [astro-ph.SR].

[12] D. H. Hathaway, T. Teil, A. A. Norton, and I. Kitiashvili, "The Sun's Photospheric Convection Spectrum," The Astrophysical Journal **811**, 105 (2015), arXiv:1508.03022 [astro-ph.SR].

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[14] K. Burns, G. Vasil, J. Oishi, D. Lecoanet, and B. Brown, "Dedalus: Flexible framework for spectrally solving differential equations," Astrophysics Source Code Library (2016), ascl:1603.015.

[15] D. Goluskin and E. A. Spiegel, "Convection driven by internal heating," Physics Letters A **377**, 83–92 (2012), arXiv:1210.8154 [physics.flu-dyn].

[16] P. J. Käpylä, M. Rheinhardt, A. Brandenburg, R. Arlt, M. J. Käpylä, A. Lagg, N. Olspert, and J. Warnecke, "Extended Subadiabatic Layer in Simulations of Overshooting Convection," The Astrophysical Journal Letters **845**, L23 (2017), arXiv:1703.06845 [astro-ph.SR].

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

ID: 1399038

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

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
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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

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	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
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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				

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 ****