GOLDWATER SCHOLARSHIP

PHYSICS & MATHEMATICS GOLDWATER RECIPIENT:

2022-2023 APPLICATION

TABLE OF CONTENTS

PROFILE INFORMATION

PERSONAL DETAILS

First Name	Ella
Last Name	Giddens

CAREER/PROFESSIONAL ASPIRATIONS

What is the highest degree you plan to obtain?	Ph.D.
In 1-2 sentences, describe your career goals and professional aspirations. It will be used in publications if you are selected as a scholar	Ph.D. in theoretical astrophysics. Using innovative computational and analytical techniques to better understand the dynamical processes at play on all scales of the cosmos

What are your career goals and aspirtations? Indicate which area(s) of mathematics, science, or engineering, you are considering pursuing and specify how your current academic program and your overall educational plans will assist you in achieving your career goals and professional aspirations

My primary career goal is to obtain a position as a researcher and instructor in theoretical astrophysics. I intend to utilize innovative techniques in computation and mathematics to model the dynamical processes that drive the evolution of structure in the universe on a multitude scales. By combining my skills as a physicist and mathematician with the cross disciplinary skills and open mindset I have gained through research outside of my chosen field, I hope to bring novel and innovative ideas to this area of astrophysics, which is in great need of an impetus for a change in perspective and approach. The continued emergence of observational inconsistencies in our theories regarding the formation and evolution of large-scale structure, the nature of dark matter, and the interactions between dark and baryonic matter illustrate the importance of innovative work in this field.

In pursuing an education which will prepare me for this career path, I have been both fortunate and purposeful in my approach. As a student in the honors college, I have been able supplement my core education in physics and mathematics with additional course work which offers diverse perspectives and peer groups. I believe that sufficient exposure to ideas outside of my field is essential for building creativity and strong communication skills and I have therefore made considerable effort to seek out those opportunities. Additionally, by pursuing a double major in physics and mathematics, I have been able to maintain both the physical understanding, and the mathematical prowess necessary for a career in theoretics.

To complement my learning, I have been fortunate to be able to pursue several research opportunities, both in my specialty and in other disciplines. In all of these research experiences, I was lucky to be granted the responsibility of leading my own projects, which has given me significant experience solving problems, pursuing collaboration, and applying for funding. My research in astrophysics is focused in the sub-field which I am most interested in pursuing, and has allowed me some freedom to explore interesting and non-traditional ideas while also reinforcing and building upon the core skillset I have obtained through my studies. In my biological research, I have also been fortunate to have the freedom and latitude to pursue innovative techniques at the intersection of my area of expertise and the expertise of my advisor. Doing so has forced me to become comfortable with ideas and methods from areas outside my area of study, and also forced me to considerably improve my ability to communicate ideas about my work to people who do not share my background. This combination of career focused physics research, and cross disciplinary experiences has significantly improved my overall versatility and capability in my work and stands to place me on the correct trajectory to accomplish my goals.

Describe an activity or experience that has been important in helping shape or reinforce your desire to pursue a research career in STEM.

Throughout my childhood, I was always fascinated by science of any kind, but it wasn't until I was finishing elementary school that I truly began to love physics. While visiting family in California for Christmas in 2012, I was dragged to a flea market by my mom and elder sister, both of whom loved that sort of thing. With no interest in buying clothes or art, I perused the books and found a set of four illustrated books on physics, whimsically titled things like Gravity's Fatal Attraction and A Short History of the Universe. In the following few months, I read each of the books cover to cover and fell in love with the subject and the elegance if its ideas.

Like many neurodivergent children, I had (and still have) a tendency to develop "special interests" or intense fascinations with very specific things. Those books, and the ensuing development of such an interest in astrophysics have remained an immensely important aspect of my life ever since. Physics has become my source of refuge and comfort in trying times, and learning physics remains one of the greatest sources of joy in my life. The opportunity to make physics my career as well as my passion has been the core impetus behind every decision I have made as a student and continues to be the driving force behind my career ambitions even now.

In what way did COVID-19 or other hardships over the past couple years affect your research career plans and did those events alter your ability to pursue those plans? If you have had to make changes, in what way(s) did you adapt to the situation? If COVID-19 did not influence your plans, simply state there was no impact.

Over the last several years, I have been both fortunate and lucky to not be significantly impacted by COVID-19. My education was altered, but not impinged; my research was slowed, but not prevented. In fact, COVID-19 and the advent of virtual schooling finally allowed me the opportunity to begin transitioning my gender, which has been a far more impactful event in both good ways and bad. The past several years have been some of the hardest of my life, and also the most rewarding. Being a trans woman in STEM, particularly in physics, brings with it a litany of problems with discrimination and prejudice, which I have been forced to contend with every day. While this has impacted my research both directly, and by proxy through its impacts on my mental health, it has also strengthened my resolve to succeed in this field. I have been forced to improve my academic skills in order to gain the respect and consideration of peers which previously would have been unconditionally given. In other ways, being transgender in STEM places me in a unique position to provide diverse insight and ideas to an area of academia which has historically struggled with diversity.

Optional Question: Goldwater Scholars will be representative of the diverse economic, ethnic and occupational backgrounds of families in the United States. Describe any social and/or economic impacts you have encountered that influenced your education - either positively or negatively - and how you have dealt with them.

As a transgender woman, particularly as a neurodivergent one, I have been faced with innumerable difficulties of both direct and indirect consequence to my education. The impacts of concealing my gender, and by extension my true self, for the vast majority of my life have presented significant road blocks to obtaining the social inclusion and acceptance that are typically considered a necessary prerequisite for successful education. Throughout much of my time in school, I was bullied and excluded; however, the adversity I have faced has been a constant push towards excellence in my studies and research. Unlike many of my peers, I have come to see my studies and my research as a comfort; as an escape from these and other issues outside of my control. Even now, having transitioned, I face constant adversity with my mental health and with issues of social acceptance. Nonetheless, I am fortunate to be where I am, with the opportunities I receive. Most like me have not been so lucky. Now, as the only openly transgender student (to my knowledge) in the physics department at the University of Utah, I am comforted by the legacy I hope to help build for more people like me to succeed in this field. Being trans has taken me to very dark places in my life, but the ever-present goal of my academic pursuits has equally been a source of reassurance and purpose; with each balancing the other to allow me to persevere despite adversity.

RESEARCH PROJECTS AND SKILLS

RESEARCH PROJECT #1

Modeling COVID-19 Deposition in the Human Lung

Dates	01/2021-12/2021
Average Hrs/Wk	20 (academic year & summer)
Name of Project Mentor	Dr. Fred Adler
Position and Affliation of Project Mentor	Director, School of Biological Sciences, University of Utah
Where the research was performed	University of Utah
Do you have paper/publications/presentations related to this project?	No

Description of research, including your involvement in AND contribution to the project

The goal of this research was to study the deposition mechanics of COVID-19 contaminated aerosols in the human lungs. Our goal was to produce a simplified model of the highly chaotic fluid dynamics in the lung to find qualitative information about where COVID-19 particles were landing and inducing infection. We were interested in understanding how some of the known comorbidities for COVID-19 (asthma, CF, etc.) might change the physiology of the airway and therefore potentially be a factor in the increased risk of infection. I produced a computational model which used advection-diffusion models on a fractalized version of the branching lung geometry to study the qualitative deposition. By treating the lungs as fractal-like, I was able to derive an analytic model for the deposition. I subsequently made several more complex models which introduced important aspects of the underlying fluid dynamics and turbulence.

Research Skills: Briefly describe any research skill(s) you developed while working on this project that will be important going forward in your research

During this project, I gained significant skills in computational physics and code management. I was given several opportunities to create presentations for our working group. I gained critical experience in creating sufficiently detailed models of more complex systems which couldn't be modeled.

RESEARCH PROJECT #2

The Harmony Project

Dates	03/2022-ongoing
Average Hrs/Wk	25 (academic year); 30 (summer)
Name of Project Mentor	Dr. Melodie Weller
Position and Affliation of Project Mentor	Adjunct Assistant Professor of Microbiology and Assistant Professor of Dentistry, University of Utah
Where the research was performed	University of Utah
Do you have paper/publications/presentations related to this project?	**Regional Poster Presenter** Eliza D, and Weller M. Constructing International Trade Networks to Predict the Origin of Trade Mediated Pathogens. Poster session presented at Research on Capitol Hill; 2023 January 20; Salt Lake City, UT.

Description of research, including your involvement in AND contribution to the project

The Harmony Project (H1.0) was predicated on experimental findings that detected Hepatitis delta virus (HDV) like RNA signatures in human salivary glands. We hypothesize that these HDV like viruses are present in the food supply. My research is focused on using mathematical modeling on global trade networks to locate potential source countries and commodities using a global epidemiological dataset and on quantifying the general threat of emergent trade mediated pathogens to public health. The H1.0 identified several potential source commodities and our findings are currently undergoing internal review while lab specimen are tested. The new H2.0 project builds on H1.0 by incorporating climate data to understand how increasing drought might induce susceptibility and drive the emergence of such a pathogen. I recently submitted a $20,000 seed grant for this project, and we intend to apply for a much larger NSF, DOD, or NIH grant in the coming year.

Research Skills: Briefly describe any research skill(s) you developed while working on this project that will be important going forward in your research

I improved my computational skills and managed a code project of industrial scale and complexity. I learned important communication skills in areas outside of my specialty and have been able to apply them to grant and paper preparation. I have been able to present my work to state legislators.

RESEARCH PROJECT #3

Modeling Gravity in Galaxy Clusters

Dates	04/2022-ongoing
Average Hrs/Wk	20 (academic year); 25 (summer)
Name of Project Mentor	Dr. Daniel Wik
Position and Affliation of Project Mentor	Assistant Professor, University of Utah
Where the research was performed	University of Utah
Do you have paper/publications/presentations related to this project?	No

Description of research, including your involvement in AND contribution to the project

In this project, I am probing the viability of Modified Newtonian Dynamics (MOND) as a possible alternative to dark matter. MOND is known to perform well on galaxy scales; however, it fails to compete with the presiding ΛCDM model on galaxy cluster and cosmological scales. To better understand, test, and constrain these weaknesses, I use supercomputer N-body /hydrodynamics simulations of galaxy clusters and their mergers in both Newtonian gravity and MOND to better understand the predictive differences between the two theories. Using this approach, we intend to better understand the weaknesses of both models and hopefully elucidate solutions to many open problems in both MOND and ΛCDM. By studying the dynamics of x-ray emitting galaxy clusters, we hope to make use of emerging observationaltechnologies like the XRISM observatory by proposing phenomenological tests of each of the theories.

Research Skills: Briefly describe any research skill(s) you developed while working on this project that will be important going forward in your research

I have developed skills in supercomputing and distributed mainframe usage, including development utilizing massive parallelization architectures. I have improved my theoretical skills and derived several novel results in my research. I have been awarded a 50,000 hours/quarter computing grant.

MENTOR RECOGNITION

LETTER WRITER INFORMATION

OTHER ACTIVITIES/ ACCOMPLISHMENTS

Activity/ Accomplishment	ESL Tutor
Organization/Scope of Activity	Guadalupe School/International
Role/ Involvement	I teach tutor a group of ~5 adult students in English each week at Guadalupe Schools. I have been doing so for 3.5 years. Tutors are provided lesson plans by ESL specialists and are given training on good pedagogical techniques.
Length of Involvement	More than 1 academic year

Activity/ Accomplishment	Science Research Initiative
Organization/Scope of Activity	University of Utah/College/University
Role/ Involvement	Science Research Initiative (SRI) is a program at the University of Utah aimed at getting undergraduates into research early in their careers. I was a member of the inaugural class of students in 2020.
Length of Involvement	More than 1 academic year

RECOGNITIONS

Recognition/Type	University of Utah UROP Scholar
Year	2022
Description	(2x) Awarded to competitive applicants to fund their research goals for up to two semesters of research with an advisor. I am currently in my first of two semesters under this grant.

Recognition/Type	Ltd. Governor's Award for Exceptional Service
Year	2021
Description	Awarded to members of the Utah community for outstanding service to the public. I was awarded this honor on my 2 year anniversary as an English as a second language tutor for Guadalupe Schools.

RESEARCH CAREER INTEREST/DIRECTION

Major Field of Study	Physics & Astronomy
Physics & Astronomy Areas of Specialization	2021
Is the research you intend to do in a multidisciplinary area?	No

CURRENT COLLEGE/UNIVERSITY

GPA	4.00
Graduation Year	Spring 2024

COURSEWORK

RESEARCH ESSAY

MOND Phenomenology in Galaxy Clusters

University of Utah

January 15, 2023

1 Introduction

It has been well established that Newtonian gravity, as a weak field limit of General Relativity, fails to correctly explain some astronomical and cosmological observations beyond the galaxy scale. The observed discrepancies between galaxy rotation curves and our predictions thereof[10], as well as the missing mass problem in galaxy clusters[16], have led theorists to the broadly accepted ΛCDM model of cosmology as an explanation of these phenomena. While ΛCDM is, without credible dispute, currently the best explanation for these observations, it is not the only possible explanation, nor is it without flaw. For a recent review of tensions with ΛCDM, see Perivolaropoulos et. al[9]. Of particular interest are emergent observations of extremely high redshift galaxies from JWST[2] and the persistent failure of particle physicists to directly observe dark matter, both of which suggest weaknesses in ΛCDM which should be explored. Modified Newtonian Dynamics (MOND) provides a possible alternative to ΛCDM by introducing a change to the theory of gravitation in regions of low acceleration[6], instead of using particulate dark matter.

MOND makes an alteration to the form of the gravitational field in acceleration regimes below a characteristic $a_0 \approx 1.2 \times 10^{-10}$ m s^{-2}. The original work on MOND was largely *ad hoc*[6, 7], but more modern formulations have made considerable progress in bringing the theory[8, 1] onto the same footing as ΛCDM. It is well known that MOND is extremely successful in galaxies, and that it has correctly predicted, *a priori*, several phenomena which have later been confirmed and which are not predicted by ΛCDM[5]. Unfortunately, MOND is inconsistent with observation at the scale of galaxy clusters, and predicts gravitational masses which are still too large to be entirely explained by visible matter (baryonic matter), despite recent attempts to fix the tension[4]. My research is focused on exploring the extent of these tensions in galaxy clusters and on exploring further alterations or refutations by which to test MOND's explanatory capabilities. In exploring this particular area, I hope to bring an open-minded and cross-disciplinary perspective to dark matter research in an effort to challenge the status quo and instigate positive disruption in this largely stagnant area of physics research.

2 Research Pursuits

The intent with this project has been to probe the extent to which MOND fails in galaxy clusters and to explore possible avenues for reconciliation. To this end, I use the super-computing resources provided by my university to run high resolution N-body / magnetohydrodynamics simulations of galaxy clusters and their mergers in both the MOND and Newtonian paradigms. Because galaxy clusters bridge the gap between low and high acceleration regimes, phenomenological changes in the structure and evolution of galaxy clusters may illustrate further challenges to both ΛCDM and to

MOND, hopefully driving further examination of both theories. Furthermore, recent research in the morphology of binary cluster collisions has illustrated the extremely complex dynamics of such events[13, 12] and provides a litany of observable tests of MOND based upon merger phenomenology.

To conduct this work, I use the N-body and magnetohydrodynamics software RAMSES[11] and the associated MOND gravity patch RAyMOND[3] to perform our simulations. While there have been hydrodynamic simulations of individual galaxies in MOND gravity, my simulations will be the first galaxy cluster simulations to be performed in MOND gravity. The versatility of my approach will allow me to perform a comprehensive parameter space exploration of cluster phenomenology in MOND including the exploration of further modified versions of MOND including MOND + sterile neutrinos and MOND theories with different or variable values of the a_0 acceleration constant. There are many interesting questions which can be explored in these simulations. Galaxy cluster mergers are of significant interest to researchers because they exhibit extremely complex gas dynamics, which produce a litany of observable phenomena from cold fronts to AGN fueled bubbles and more[14, 15]. By performing these simulations, I will be able to produce a litany of differential observational expectations between ΛCDM and MOND which could be observed in upcoming observation missions. One particularly exciting prospect is the dynamics of gas turbulence during cluster mergers in MOND and ΛCDM, which will be observable with the upcoming XRISM mission.

3 Outcomes and Implications

MOND phenomenology in galaxy clusters is a grossly understudied area of astrophysics. Because MOND is known to fail in galaxy clusters, very little attention has been paid to investigating its dynamics on that scale; however, I believe that there are things to learn about both MOND and ΛCDM by studying the specifics of MOND's weaknesses. Furthermore, MOND shows considerable promise on smaller scales, and so there is a real impetus to find a theoretical extension which does work in galaxy clusters. Due to the lack of sufficiently successful alternatives, ΛCDM has also been widely accepted, and its weaknesses have been explained away by a series of immunizing strategems which significantly weaken the foundations of the theory. By pursuing this work, I will endeavor to play a part in resolving these issues; I will contribute to our understanding of MOND, either by strengthening it or providing further refutations, and I will use these studies to illustrate creative solutions to presistent issues in ΛCDM.

In conducting this research, I hope to both utilize and strengthen my cross-disciplinary background. In the study of dark matter, some of the central tenants of scientific epistemology have been lost, and with them much of the impetus for driven, progressive science. My background in cross-disciplinary research will, with any luck, help me to ground my own research on a stronger foundation and to challenge my peers in this field to consider their research more philosophically. It is my belief that the relative stagnation in this field and the echo chamber that exists in the research community is, at least in part, attributable to the lack of diverse thought, approach, and background

represented. As an undergraduate, I am taking advantage of the relative freedom afforded by my position to explore a diverse set of ideas and theories that have been largely overlooked. As my career path begins to narrow onto physics research, I hope that this research experience will be an impetus by which to preserve creative and challenging thought with which to confront the status-quo and push forward our understanding of the universe.

References

[1] Jacob Bekenstein and Mordehai Milgrom. Does the missing mass problem signal the breakdown of newtonian gravity? *The Astrophysical Journal*, 286:7–14, 1984.

[2] Larry D Bradley, Dan Coe, Gabriel Brammer, Lukas J Furtak, Rebecca L Larson, Felipe Andrade-Santos, Rachana Bhatawdekar, Marusa Bradac, Tom Broadhurst, Adam Carnall, et al. High-redshift galaxy candidates at $z = 9 - 13$ as revealed by jwst observations of whl0137-08. *arXiv preprint arXiv:2210.01777*, 2022.

[3] GN Candlish, R Smith, and M Fellhauer. Raymond: an n-body and hydrodynamics code for mond. *Monthly Notices of the Royal Astronomical Society*, 446(1):1060–1070, 2015.

[4] Alistair O Hodson and Hongsheng Zhao. Generalizing mond to explain the missing mass in galaxy clusters. *Astronomy & Astrophysics*, 598:A127, 2017.

[5] David Merritt. *A philosophical approach to MOND: Assessing the Milgromian research program in cosmology*. Cambridge University Press, 2020.

[6] Mordehai Milgrom. A modification of the newtonian dynamics as a possible alternative to the hidden mass hypothesis. *The Astrophysical Journal*, 270:365–370, 1983.

[7] Mordehai Milgrom. A modification of the newtonian dynamics-implications for galaxies. *The Astrophysical Journal*, 270:371–383, 1983.

[8] Mordehai Milgrom. Quasi-linear formulation of mond. *Monthly Notices of the Royal Astronomical Society*, 403(2):886–895, 2010.

[9] Leandros Perivolaropoulos and Foteini Skara. Challenges for λcdm: An update. *New Astronomy Reviews*, page 101659, 2022.

[10] Yoshiaki Sofue and Vera Rubin. Rotation curves of spiral galaxies. *Annual Review of Astronomy and Astrophysics*, 39(1):137–174, 2001.

[11] Romain Teyssier. Cosmological hydrodynamics with adaptive mesh refinement-a new high resolution code called ramses. *Astronomy & Astrophysics*, 385(1):337–364, 2002.

[12] JA ZuHone. A parameter space exploration of galaxy cluster mergers. i. gas mixing and the generation of cluster entropy. *The Astrophysical Journal*, 728(1):54, 2011.

[13] JA ZuHone, M Markevitch, and D Lee. Sloshing of the magnetized cool gas in the cores of galaxy clusters. *The Astrophysical Journal*, 743(1):16, 2011.

[14] JA ZuHone, M Markevitch, M Ruszkowski, and D Lee. Cold fronts and gas sloshing in galaxy clusters with anisotropic thermal conduction. *The Astrophysical Journal*, 762(2):69, 2012.

[15] John A ZuHone, Maxim Markevitch, Rainer Weinberger, Paul Nulsen, and Kristian Ehlert. How merger-driven gas motions in galaxy clusters can turn agn bubbles into radio relics. *The Astrophysical Journal*, 914(1):73, 2021.

[16] Fritz Zwicky. Die rotverschiebung von extragalaktischen nebeln. *Helvetica physica acta*, 6:110–127, 1933.