Personal Statement

My hometown of Depew, New York, is a blue-collared collection of people who work hard to earn what we have. Living in this area posed numerous challenges in my life, especially in regards to academics; my high school was small, and while offering some advanced courses, classes often had low enrollment and limited student engagement. This made transitioning to a challenging university physics program difficult, as many of my peers had far more resources previously available to them. Overcoming these struggles at university has helped me realize that I can rely on the blue-collared work ethic that was instilled in me to succeed in academia. It was this work ethic that I was consistently able to lean on when I felt overwhelmed or discouraged, and has also fortified my desire to pursue a career in astrophysics. **I am pursuing a Ph.D. in physics, with the intention of entering a career in research and education at a university.** Alongside my career, I will continue to be involved in scientific outreach and education, with the goal of inspiring the next generation of scientists and reforming physics education.

Intellectual Merit

Entering university, my interests were scattered, and I felt uncertain about my ability to do graduate-level research. Even with this uncertainty, I knew that if I jumped into a project, I could rely on my work ethic to see me through. I was fascinated by astronomy, and it was to that end that I began work with Dr. Brenda Frye in the fall of my first year. Our group studied early universe objects using gravitational lensing, as the magnification of background images provided by lensing allows for detection of distant objects. I was assigned with measuring the dynamical masses of six new galaxy cluster lensing fields using the virial method. To accomplish this, I reduced spectroscopy data using a combination of IRAF and IDL code, and measured the spectroscopic redshift of objects in our fields. I had no prior experience in coding up until that point, and I vividly remember countless nights being tormented by error messages. After what seemed like an eternity, I finally got the first step to work. The success snowballed, and before long the data were reduced, and I measured the redshift of each object in our data set. The redshifts I measured allowed us to determine cluster membership and calculate the recessional velocities of cluster members. However, we could not immediately determine the virial mass; the limited resolution of our ground-based observations led to our data being undersampled. I was able to further expand on my computational abilities by implementing the Gapper algorithm, a robust statistical technique specifically designed for small number statistics, which allowed for a more accurate measurement of the velocity dispersion. **This work culminated in the coauthorship of a paper that has been accepted into *The Astrophysical Journal*** [4].

In my junior year, **I earned a fully funded position as an undergraduate University of Arizona (UA)/NASA Space Grant Intern**, where I continued to characterize cluster lenses. I reduced and analyzed deep optical imaging in the g and i-bands of one massive galaxy cluster, G165.7+67.0. This goal has allowed me to showcase my coding abilities by using a novel reduction software, *THELI*. **I have further applied the expertise I have developed in *THELI* by writing an open source users manual for the software** [2]. This manual contains information on both using *THELI* as well as the theory behind it, with the ultimate goal of providing amateur astronomers with a more approachable resource on the software. **My results will be combined with other imaging results to measure the photometric redshift of all objects in the field, which will be published in an upcoming paper**.

That same year, I decided to also explore my interest in mathematical astrophysics research. This prompted me to initiate research with Dr. Paul Carter studying nonlinear dynamical systems. I studied problems that could be approached using geometric singular perturbation theory (GSPT), which are characterized by a system of first-order ordinary differential equations and a small parameter, $0 < \varepsilon \ll 1$. This approach enables the construction of solutions in the singular limit $\varepsilon \to 0$; one can then study if solutions persist through perturbation for $0 < \varepsilon \ll 1$. This approach has a direct connection to astrophysics; it can be shown that the Navier-Stokes equations, which govern the dynamics of the gas surrounding stars, have this structure [3].

The following summer, **I worked on an NSF-funded REU project with Dr. Carter, where I proved the existence of steady spherically symmetric transonic stellar wind solutions to the Navier-Stokes equations including viscosity and heat conduction.** The rigorous construction of solutions including the effects of viscosity and heat conduction is novel. I was able to construct transonic solutions in the singular limit ($\varepsilon \to 0$) by analyzing the level sets of the dynamics (i.e., trajectories with constant energy) and utilizing results from stability and canard theory. Proving that these solutions persist requires an extra level of analysis, as previous results have only been proven in generality for systems with three dimensional phase space, whereas the phase space in our system is four dimensional. I remedied this problem by performing a center manifold reduction at the sonic point (the point at which trajectories transition from sub- to super-sonic) which guaranteed the existence of a three dimensional center manifold on which previous results hold. This result, along with other results from GSPT, enables the construction of a one-dimensional trajectory that is $\mathcal{O}(\varepsilon^{1/2})$-close to the singular transonic solution for $0 < \varepsilon \ll 1$. **I have carried out this proof in full detail in a manuscript that will be submitted later this year** [1]. I especially enjoyed the mathematical perspective on astrophysics research gained through this project; this experience, along with my background in observational astronomy, has given me a well-rounded view of astrophysical research and solidified my interest in the subject. Additionally, it trained me to be exceptionally precise in my thinking, and sharpened my skill of considering limiting cases and functional analysis far beyond the scope of undergraduate courses.

In my senior year, I have undertaken a new research project which synthesizes my mathematical acumen and my coursework in general relativity. The goal of my project is to classify the stability of the Cauchy horizon of a Reissner-Nordström black hole using a Penrose limit. Penrose limits allow us to "zoom in" on a null geodesic and classify the spacetime in the neighborhood of the null ray. Selecting the null geodesics near of the Cauchy horizon for analysis by this method could lead to interesting results and insights on the instability at this "inner horizon" of the black hole. I aim to publish the results from this project in a refereed journal.

Broader Impacts

Entering academia, I was unsure of how to succeed. Thankfully, I had mentors in my life that helped me adjust to the challenges of university and research. It was through these experiences that I came to realize how important mentorship was in young peoples' lives, and how **we in the science community have a duty to usher in the next generation of scientists.** With this goal in mind, I have been involved in numerous outreach programs with the intention of **helping young scientists enter the field** and **bringing science to underrepresented groups**.

During my junior year, I volunteered as a peer mentor in the Astronomy Department. I was assigned a group of freshman astronomy majors; my job was to help these students transition smoothly into the program and direct them to resources that would best equip them for success. I directly witnessed the impact that mentorship can have when I was able to help one of my students earn a research position with astronomy faculty that was later funded by the UA/NASA Space Grant program. **This experience has fueled my passion for mentorship and makes me eager to continue mentoring undergraduate students while in graduate school.**

I have also been involved with the Physics Discovery program at Flandrau Planetarium. Members of this program perform weekly scientific demonstrations for local Tucson schools (K-12), many of which have students from underrepresented groups including those from low socioeconomic background, students of color, and refugee families. It was through this program that I have found my passion for scientific outreach. **To help grow this program, I am leading an effort to build a modern physics demonstration that will explore the wave-particle duality of light and radioactivity.** Programs like this are essential to growing the scientific community to include all people, and I hope to continue my involvement in programs like this in the future.

In addition to this outreach work, **I have also been heavily involved in improving physics education.** According to the UA Teacher Course Evaluations in Spring 2019, 73.43% of students rated Introductory Physics II (E&M) as "much more difficult than usual," and 41.26% of students rated the course as "one of the worst." In an effort to assuage this sentiment, **I worked with Dr. Shawn Jackson to become an undergraduate teaching assistant (UTA) for the course.** In this role, I held problem solving sessions where I helped students through exam-level problems and oversaw group work, while also holding an office hour every week. We are confident that providing students with this additional resource will result in an uptick in performance. This experience has prepared me for the teaching responsibilities I will have in graduate school, and has also sparked an enthusiasm for teaching that will drive me to continue improving as an instructor throughout my career. I plan to continue this work with Dr. Jackson in the spring.

I have also been working with Dr. Jackson to reform physics education. According to the American Test Anxieties Association (ATAA), approximately 16% - 20% of students experience high test anxiety, and another 18% experience moderately-high test anxiety. Moreover, the ATAA reports that these students tend to score twelve percentiles lower than their low test anxiety counterparts[1]. It is clear from these studies that measures must be taken to allow students with high test anxiety to showcase their skills in a non-exam environment. **With this goal in mind, I am working with Dr. Jackson to develop a new assignment for upper division physics classes: an Analytic Formal Report (AFR).** An AFR is written in a similar tone as an academic paper, and will be graded on the *validity* and *thoroughness* of a student's solution to a challenging homework problem. Students will be expected to discuss *all* of the intricacies of their arguments, as well as the underlying physics of the problem and limiting cases. We hope that this assignment will allow students with high test anxiety an alternative route to display their abilities, and provide them the opportunity to let their grade in the course reflect their talents in physics, not just their ability to score well on exams.

Future Goals

As I continue in my career, I will further develop my skills as a researcher and become more involved with mentorship and education within the scientific community and abroad. **I plan to attend a top graduate program for physics to continue investigating nonlinear systems and their applications to astrophysics.** My past research experience, along with my blue-collar work ethic, will allow me to quickly adapt and succeed while pursuing a Ph.D. in physics. In addition to my research responsibilities, I will work to fulfill my duty to **usher in the next generation of scientists from all backgrounds.** *It is important to me that I achieve these goals, and the support of the NSF GRFP will provide me with the resources I need to reach them.*

[1] A. Bauer et al. Canards in the Stellar Wind Problem with Viscosity and Heat Conduction. *In preparation*.

[2] A. Bauer et al. THELI Reduction Software: A Write Up For Inexperienced Data Reducers. *THELI Forum*, 2019.

[3] P. Carter et al. *Nonlinearity*, 30:1006–1033, 1 2017.

[4] B. L. Frye, ..., A. Bauer, et al. *The Astrophysical Journal*, 871:51, 2019.

[1] https://amtaa.org/