Growing up, I had an intense passion for astronomy. Unfortunately, in a rural area like my home of mid-coast Maine, most educators through high school believe in a more classically practical application of knowledge. This meant that my dreams of unraveling the mysteries of the Cosmos were abandoned amongst rhetoric that there was no future in being an astronomer, and instead to apply my skill with mathematics to a more marketable career like engineering. With this in mind, my core studies while pursuing my Bachelors degree at Bowdoin College did not include physics or astronomy, but instead mathematics, computer science, economics, and German. In the eleventh hour of my senior year at Bowdoin, I made a simple, yet life-altering decision: I took an internship as a geospatial analyst in the Earth science division at NASA Langley Research Center and abandoned what was shaping up to be a career as a consultant. Being an effective NSF Fellow means stepping boldly into the unknown regions of your chosen field, where you will have by definition little to no prior knowledge to work with, and nevertheless making significant contributions and becoming a world expert. **This ability to start from scratch and quickly become accomplished in a research topic is one that I demonstrate repeatedly throughout the career I detail below, and one that I will apply relentlessly if honored with an NSF Fellowship.**

Relevant Experience: My research topic as part of a team in the NASA National DEVELOP Program was analyzing air quality in Houston, TX and correlating MODIS satellite data with new NASA High Spectral Resolution Lidar (HSRL-2) measurements to determine the effectiveness of HSRL-2 at assessing small ($<2.5\mu m$) particulate matter levels at the ground. Despite having no knowledge of remote sensing and only my math and computer science skills, I quickly became proficient with Matlab and was invaluable as the data and statistical analyst on the team. At the end of the project, the team and center leads requested that I travel to NASA Headquarters due to my expertise, and present the results of the analysis in both a talk and a poster, which gave me valuable presentation experience.

After completing my research project at NASA Langley, speaking to numerous scientists, and gaining the experience of working at a NASA center, I finally understood that a career in space science research was plausible and exactly what I wanted with my future. With this in mind, I moved to NASA's Goddard Space Flight Center and became the research team lead for a programming intensive Earth science research project. Once again, despite my lack of experience with the programming language Python, I learned quickly and became the head developer for a remote-sensing powered, automated landslide detection software package for Nepal written entirely in Python. During this project, in addition to gaining additional experience presenting the results of my research at NASA headquarters for the second time, I learned to both lead and work effectively within a group of researchers. Furthermore, the automated landslide detection product was handed off directly to end-users in Nepal, and as the research team lead I was the main contact tasked with ensuring the product satisfied the needs of the end-users. The culmination of this position at NASA Goddard included making the product open-source in hopes that it could be adjusted to other regions of the world, and a publication that is currently under review in *Earth Interactions*.

During the same time period, I also worked for NASA's Applied Remote Sensing Education and Training (ARSET) program, where I wrote research-oriented python programs and gained experience training NGOs and government organizations in the use of NASA software and remote sensing data. Meanwhile, I attended every planetary science, astronomy, astrophysics, and heliophysics talk I could and spoke to as many scientists as possible in an attempt to pinpoint my interests, and possibly attain a research assistant position in one of those divisions. Eventually I met a planetary scientist, Dr. Conor Nixon, who was working on the Cassini CIRS instrument team at Goddard. Despite my complete inexperience with planetary science and atmospheric modeling, Dr. Nixon recognized my passion, motivation, and intelligence and hired me as a planetary science research assistant for the CIRS team.

After deciding at the end of my first NASA internship that I would to pursue a future in space science, **it had taken me less than a year to go from an Earth science intern with little research experience to a fully-fledged research assistant in the planetary science division at NASA Goddard.** Again I found myself in a position requiring programming languages that I had no experience with, and knowledge of atmospheric modeling and infrared spectroscopy that I lacked. Nevertheless, I committed myself to becoming an expert in my research topic: using the Cassini CIRS far-infrared interferometer to determine the D/H abundance on Saturn and Jupiter. By asking endless questions of my advisor, reading a litany of papers for background information, and immersing myself in the atmospheric modeling software, I swiftly was up to speed and contributing to the CIRS research team at Goddard. Over the next year, I worked and problem solved primarily on my own, but with overall guidance from my advisor and other members of the CIRS team. I gained invaluable experience working through issues in my research independently, as well as added Fortran and IDL to my list of proficient programming languages. **As the lead author on a publication in the Astronomical Journal with 9 other co-authors** that resulted from this work (Pierel et al., 2017), I became skilled at technical writing, compromising with co-authors around the world, and the publication process as a whole. This measurement of D/H had never been made with the high spectral resolution CIRS data, and the results showed definitively for the first time that the deuterium abundance on Saturn is lower than that of Jupiter. This is contrary to current model predictions, which suggests that our understanding of planetary formation and evolution is incomplete, a result that will spur much research in the future to discover the cause of this discrepancy.

I knew once I had decided that I wanted to pursue a career in astronomy that I would need to obtain a PhD if I wanted to conduct my own research and return to NASA as a fully qualified research scientist. During my year as a research assistant for the CIRS team at Goddard, I was accepted to the Physics PhD program in the Department of Physics & Astronomy under advisor Dr. Steven Rodney at the University of South Carolina, where I would finally be conducting astronomical research. With no previous physics education, I was accepted with the understanding that I would need to quickly prove that this would not hinder me academically in any way. I completed my first year of graduate education with a 3.9 GPA and passed my qualification exams on the first of three attempts, solidifying my position as a PhD candidate. **As a PI I was awarded a ~$50,000 NASA HST Archival Research Grant titled "Turning Gravitational Lenses into Cosmological Probes", and as a Co-I I was awarded a $25,000 NASA EPSCoR grant titled "Rare and Peculiar Stellar Explosions with the Next Generation of Space Telescopes".** Under the second grant, I already have a publication in preparation as lead author in which I have extrapolated supernova (SN) spectral energy distribution (SED) templates into the IR and UV, to be used with next generation space telescopes JWST and WFIRST. Under the first grant, I will be developing a standardized software package capable of measuring time delays and lensing properties of strongly gravitationally lensed and multiply imaged SNe.

Future Goals: My first goal, which I am already well on my way toward accomplishing, is to obtain my PhD from the Department of Physics & Astronomy at the University of South Carolina, which will make me the first member of my family to obtain such a degree. I will tailor my research and the software I develop during this time to be relevant for the next generation of space telescopes, namely JWST and WFIRST. After completing my PhD, I plan to return to NASA and become a research scientist analyzing data from one of these telescopes, where the expertise and global connections gained through an NSF Fellowship would make me a valuable and effective researcher.

Summary of Intellectual Merit: Time and time again Ive proven my ability to master a subject effectively and efficiently. I continue to challenge myself by stepping into an area of research I have no experience with, and nevertheless have been extremely successful. After starting my quest to become an astronomer in 2014 with no experience, I have already gained a complex understanding of remote sensing, statistical analysis, atmospheric modeling, technical writing, STEM outreach, SN classification, gravitational lensing, and much more.I am proficient with Matlab and R, I can program in seven languages, and I have shown through my success thus far in my Physics degree that the obstacle of stepping into the unkown is no obstacle at all. In short, I have a plethora of research experiences and technical skills that, in addition my aptitude for mastering new subjects quickly, set me up to become a world expert in analyzing multiply imaged SNe and a successful NSF Fellow.

Broader Impacts: Due to my academic experience at a young age, I am committed to ensuring that no child's love of astronomy will go unfostered in my community. It is crucial that childen who love STEM, and specifically astronomy, are reinforced that this is a valid future career and that a graduate degree is possible for them. Growing up in rural Maine, graduate degrees were few and far between, and even the percentage of high school graduates attending a 2-4 year college was only around 50%. In my current community within Columbia, SC according to City-Data.com, **only** 27% **of people graduated from high school,** 13% **have a bachelor's degree,** 3% **have a master's degree, and** 0% **have a PhD.** I will use my STEM outreach experiences with NASA's ARSET program, as well as the techniques I learned volunteering in elementary school math classrooms in college and tutoring high school students while at Goddard, to help foster excitement for STEM in my community. I have already discussed my plans with the local after-school program leader, who was very excited to implement a framework to encourage astronomy and STEM learning. By taking kids to our local University observatory, and leading them through a series of exciting and educational astronomical exercises throughout the year, I hope to convince these students that **achieving higher degrees is possible and valuable**, and break the viscious cycle of supressed academic opportunities forming in my community.

It has been over half a century since renowned astrophysicist Sjur Refsdal first hypothesized the use of a supernova (SN) resolved into multiple images as a cosmological tool. In recent years, the first multiply-imaged core-collapse (CC) SN Refsdal (Kelly et al., 2015), and subsequently the first Type Ia SN iPTF16geu, have been discovered (Goobar et al., 2016). As the light for each of the multiple images follows a different path through the expanding universe and through the lensing potential, the SN images appear delayed by hours (for galaxy-scale lenses) or years (for cluster-scale lenses). For objects like SN Refsdal, measurement of this time delay can be used as a precise test of cluster lens models (Treu & Ellis, 2015). For a SN like iPTF16geu, the time delay can lead to a **direct constraint on the Hubble constant** H_0, that is completely independent of the local distance ladder. The next decade is expected to yield observations of tens to hundreds of multiply-imaged SNe (Oguri & Marshall, 2010), yet there is no public software package for analyzing multiply-imaged SNe.

<u>*Intellectual Merit*</u> : As the PI on an ongoing HST Archival Research Grant, **I am developing the first open-source software package** in Python that will enable a user to precisely measure lens properties and time delays for the hundreds of multiply imaged SNe expected in the LSST/WFIRST era. Properties of dark energy and dark matter are still poorly understood and inadequately constrained, but measurement of the lensing magnification and time delays can be used to test models for the dark matter distribution in the lensing object (Rodney et al., 2015, 2016) or as a probe to test cosmological models (Suyu et al., 2014). To that end, I will first use the software I am creating to make more precise time delay measurements for the two currently documented multiply imaged SNe. SN iPTF16geu is Type Ia, so by providing a more accurate time delay and luminosity distance measurement, I will be able to accomplish two critical goals. First, directly measuring the source magnification will provide an important milestone in breaking degeneracies in the lens model (Kolatt & Bartelmann, 1998; Oguri & Kawano, 2003). Second, precise determinations of the time delays for a multiply imaged Type Ia SN will provide a constraint on H_0, and the methodology and software I develop will be **essential to future SN surveys** for tightening those constraints. Between SN iPTF16geu and SN Refsdal, I will be able to validate the software package and methodology I am developing for time delay measurements, and provide these tools for the next generation of observations with JWST, WFIRST, and LSST. A standardized, validated, open-source tool will need to be available to quickly and accurately make these measurements in the future, as gaining a sample of 150 time delay measurements can tighten the area of uncertainty for dark energy equation of state parameters w_0 and w_a by a factor of 4.8 (Linder, 2011).

Observations either by way of gravitational lensing, or by the next generation telescope JWST, will provide a sample of extremely high redshift SNe. Of interest in the early universe are pair-instability (PI) and Population III (Pop III) SNe. The progenitors of PISNe are massive stars in low metallicity environments including the early universe, which retain their high mass until their death as a CC SN. POP III stars are hypothesized to form around $z \approx 30$, but have yet to be observed despite models predicting that a POP III star should be visible to current telescopes through a gravitational lens during its death as a CC SN (Marri & Ferrara, 1998). **Understanding these first stars is crucial to a wide range of cosmology, including the formation of primeval galaxies, initial stages of cosmological reionization, and the origin of Supermassive black holes** (Whalen et al., 2013).Therefore, I will collect a sample of current high-z and gravitationally lensed SNe, and begin discerning the properties of these first stars. In addition to searching for, and studying the physics of PI and Pop III SNe, I will include theoretical light curve templates for both objects in the open-source software I am developing, so that future observations can be identified and both lens properties and progenitor physics studied. Not all SNe found and analyzed will be strongly lensed and valuable for identifying lens and dark energy properties or dark matter distribution. Therefore, I will also collect a sample of these weakly lensed SNe, and carefully measure their magnification in order to make small corrections in the Hubble diagram. This will ensure that the full sample of gravitationally lensed SNe are made useful, and that the accuracy of the current H_0 measurement is improved.

Research Outline:

1. Complete the python software package titled *Supernova Time Delays* (SNTD).
2. **Write publication** presenting SNTD capabilities and validation.
3. Improve precision on time delay measurements for SN Refsdal and SN iPTF16geu using SNTD.
4. **Write publication** presenting new time delay measurements, and the methodology required for these analyses and obtaining a constraint for H_0 from iPTF16geu.
5. Use theoretical models to include PISN and POP III SN light curve templates in SNTD.
6. Obtain gravitationally lensed and high-z SN sample to study the physics of PISNe and POP III SNe, as well as make Hubble diagram adjustments with weakly lensed SNe from sample.
7. **Write publication** detailing magnification corrections for Hubble diagram SNe and their affect on H_0.
8. **Write publication** detailing search for, and ideally discovery of, PISNe and POP III SNe and their physical properties.

Broader Impacts Summary: In my personal statement, I described how my time as a PhD candidate at the University of South Carolina will have a strong impact on my community, but it will have a clear effect on the scientific community as well. The SNTD software package will be a crucial tool in years to come, as the next generation of telescopes drastically increases our catalogue of multiply imaged SNe. Improving our understanding of the first stars will be essential to various branches of cosmology such as the origin of supermassive black holes, and I will pave the way for future PISN and POP III SN observations by including their theoretical templates in SNTD, and search for the first POP III SN observation by forming a sample of strongly lensed SNe. Finally, by documenting SNTD and my improved measurement of the Refsdal and iPTF16geu time delays, I will provide a constraint on H_0 and a standardized methodology that will be used for future SN observations to tighten constraints on H_0 and dark energy properties.

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