Statement of Purpose

Astronomy can be a daunting field to work in. There's an overwhelming amount of effort that needs to be put in to study it. The days get long, and the nights longer still, hours spent trying to understand physical concepts to their minutest detail. It is, however, also perhaps the most fascinating. It's one of the most well known scientific fields, and it's the sort of subject that catches everyone's eye; the magnificence of stars and galaxies, the colorful spectacle of nebulae and the innate awe at even the mention of black holes.

With it, this subject carries questions, questions which make us reconsider our place in this universe, make us think about what we really know about ourselves. Through my undergraduate research experience, I have gotten a chance to be someone who can find the answers to those questions, which I think is the most rewarding aspect of studying astrophysics. I believe that by pursuing an ASTRONOMY/ASTROPHYSICS PhD at X UNIVERSITY, I can carry out research which can answer more of these questions and through the teaching aspect, inspire others to get excited by such questions as well.

My first stint at carrying out research was a summer position with Dr Kevin Luhman, and I worked on two separate projects. The two projects were trying to determine the kinematic age of the *Scorpius-Centaurus* complex and to test whether clustering algorithms were a good method to identify known members of the star association *32 Ori*. I undertook this research remotely, while at home in India. For the Sco-Cen project, I used two separate methods to try to find the age, namely an expansion age method and a traceback age method. From this project, I learnt how to utilize three dimensional radial velocities of stars and their time-dependent behaviors to determine their motion in the past. I was also able to teach myself the **R** programming language to carry out this analysis of stellar kinematics. I would say the most important skill I learnt from this project however, was how to communicate efficiently with an advisor/collaborator while being under the constraint of being in vastly different time zones, yet being able to maintain a coherent thread of questions and responses.

From my second project, I carried out density-based clustering algorithms on the U/V/W velocities of stars present in the field of the star association *32 Ori* to try to identify known members, by which I was able to test how well the various clustering algorithms were able to identify members. From this project, I was able to learn how to apply statistical methods like clustering algorithms to analyze data and then draw confident conclusions based on it. I also gained a lot of experience in understanding code written by others and how to refactor and reorganize it in a way that made sense to me, even if that meant changing what language it was written in, and I understood that coding, which till that point had seemed like a chore to me, can be a really fun and interesting way to understand difficult concepts by seeing them in practice.

From my junior year of college to present, I have worked with Dr Gautam Nagaraj (at that point a graduate student), Dr Robin Ciardullo and Dr Howard Bond through the **Students Together for Astronomy Research (STAR)** initiative organized by the astronomy department at Penn State. This project consisted of trying to identify blue, post-horizontal branch stars present in a data set containing *uBVI* photometric data for over 100 Galactic and Large Magellanic Cloud globular clusters. These stars have low scatter in their bolometric flux as they move across the HR diagram, and as such are theorized to be standard candles. My responsibilities in this project were to find a way to "clean" the dataset by removing foreground and background stars. For this, I applied the clustering algorithms I worked with for the projects with Dr Luhman. As such, I was able to create a pipeline to identify blue stars that would filter through the raw data first, ensuring any bad photometric data was thrown out, de-redden the stars based on their respective distances, find matches in *Gaia* DR3 based on *G* magnitudes and parallaxes, obtain proper motions for those matches, and then use the clustering algorithm DBSCAN to ensure cluster membership of any field stars present in the photometric data. Through this, we were able to work on creating a comprehensive census of blue stars present in these clusters, which will be used for further analysis by Dr Bond to further his theory of their use as standard candles. I learned a lot from this project, and have enjoyed every single moment of it. I have had the chance to use **python,** the **sklearn** library, as well as various **astropy** modules to create a single program which can carry out all the necessary steps for this process, and that has made me a significantly better programmer. I worked exhaustively with Dr Nagaraj in weekly meetings to write and optimize this program, which incorporates a lot of the elements I learned from my work over the summer with Dr Luhman in the use of clustering algorithms for proper motion analysis. From my experience working with *Gaia* I understood how to use the **Astronomical Data Query Langauge (ADQL)** to search for matches from a given dataset, as well as to select which data products I needed. This also led to a lot of time using **SIMBAD** and **Vizier** to verify some of the candidate blue stars and to perform literature reviews on the stars we found.

Through this project, I also had the opportunity to work with multiple advisors and mentors, and I believe that being able to work with them for a longer-term project such as this has surely benefitted my communication and teamwork skills. As part of this project, I have created literature reviews and presented my results on two occasions. I first presented at the end of the STAR project, where I showcased the results to an audience of Penn State astronomy department faculty and students, and then at the end of 2022, I presented a poster at the Mid-Atlantic Section Meeting of the American Physical Society held at Penn State, where the audience more broadly consisted of astronomers and physicists, as well as undergraduate students from both disciplines. This was a thrilling experience as I had the chance to describe my research in a way that was understandable to those who were not as deeply involved in it as I was, and that helped me understand a lot of the key concepts, such as stellar evolution, a lot better. This project will conclude with the publishing of two papers in the spring of 2024, one being a data release of the entire dataset, and the other being the catalogue of the blue stars along with their characteristics.

From the start of my senior year, I have been working with Dr Robin Ciardullo and Dr Howard Bond on characterizing the parameters of the planetary nebula *Abell 57 (PN A66 57)*. For this project, I used the photoionization simulation program **Cloudy** to create model nebulae whose emission line ratios (relative to H-β) I then matched to the observed, and de-reddened, line ratios obtained using the Hobby-Eberly Telescope. Part of my responsibilities for this project was to find an ideal way to identify the parameters, and I was able to utilize the **Cloudy** optimizer to do so in an efficient way. This project has pushed me outside of the comfort zone that I had carved out working with stellar populations and has made me think differently about the data that I work with. I have gotten the chance to see how various parameters, such as effective temperature, observed geometry, the radius of the nebula, and the modelled atmosphere influence the emitted spectra in practice, and understand how to properly optimize models to fit the given data. This project will conclude with the publishing of a paper in

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November 2023 which will describe the characteristics of the central star of Abell 57 as well as the nebula as a whole.

Program Specific Stuff will go here