Background: From a young age, my immigrant mother instilled a general quest for knowledge in me through attending local planetarium and library events. She also taught me the ways in which my Japanese culture tells stories about the significance of the moon, stars, and Milky Way compared to American folklore. Reflecting upon my experience participating on the audience side of outreach, I realized the profound effect they have on retaining people from marginalized communities in STEM fields, however, I saw room for improvement in creating more diverse outreach events. Participating in those outreach events was the primary reason I chose to pursue a career in astronomy and began to focus all of my curiosity on astronomy-related books. My undergraduate career at the University of Arizona further supported my ambitions of becoming an astronomer due to the resources provided to minoritized students seeking a career in astronomy which decreased my imposter syndrome and aided my confidence as a woman in a male-dominated field. This led to me holding multiple leadership positions in the university's Astronomy Club, focusing on the expansion of local outreach and diversity, equity, and inclusion (DEI). Also, my years of undergraduate research experience in both galaxies and exoplanets prepared me to study in a PhD program, pursue my own inquiries about the Milky Way, and appreciate the art of formulating the right questions. **My goals as an astronomer are to investigate the mysteries of galaxy evolution and increase accessibility to higher education for students in marginalized communities through outreach and mentorship.**

Intellectual Merit: In lectures and recreational reading, my primary curiosity was always galaxies, and I was determined to find a research project at the University of Arizona where I could investigate the unanswered questions pertaining to these massive structures. Without any prior computer science experience, I taught myself the basics of Python to strengthen my research skills, and during my second year of undergraduate studies, I secured a research role with Dr. Dennis Zaritsky to study ultra-diffuse galaxies (UDGs) which are large yet low surface brightness galaxies. Due to their extreme mass-to-light ratio, UDGs are important probes in galaxy evolution and dark matter's influence on galaxies. Over the course of the project, **I developed analysis software in Python to systematically measure the frequency of nuclear star clusters** (NSCs) in UDG candidates in the Systematically Measuring Ultra-Diffuse Galaxies (SMUDGes) catalog using images from the Sloan Digital Sky Survey (SDSS). **I constructed multi-component models of the galaxies using a package called "GALFIT" on the university's high-performance supercomputer** to detect any potential NSCs. I created masks and point source function (PSF) profiles to increase the precision of our results and made simulated point sources to determine the magnitude limit of detecting a potential NSC in UDG candidates. I identified 297 candidate galaxies with potential NSCs with 85% confidence, and from that, 32 UDGs with potential NSCs met the defined criteria for UDGs. I accomplished my goal of creating a pure sample with little contamination of objects that are not true NSCs to define a lower limit of this population. I analyzed the relation between the brightness of the NSC, the brightness of the galaxy, the color, and the radial offset between the point source and the center of the galaxy. I learned how to make a Monte Carlo Markov Chain to model the distribution of radial offsets. Exploring the radial offset opens up a future discussion of how astronomers define the term "nuclear" and will aid simulations of NSC formation. I concluded that there also is a weak dependence on the environment when identifying UDGs with NSCs aligning with previous research in the field. This work probed a large yet shallow sample of candidate UDGs compared to other works and contributes to a larger ongoing hunt for the reason behind NSCs forming in low surface brightness galaxies. I presented my preliminary findings via iPoster at the 241st American Astronomical Society (AAS) conference, and my **first-author paper was submitted to the Astrophysical Journal** for review in August 2023.

To increase my breadth of experience in research I wanted to investigate a completely different field in astronomy, exoplanets. There are many ways of discovering exoplanets, but I wanted to focus on the most popular approach using transiting photometric data. In my third year, I joined Dr. Chad Bender at the University of Arizona and his collaborators at Penn State on **Transiting Exoplanet Satellite Survey (TESS) exoplanet follow-up characterization**. I specifically worked on a system, labeled TOI-5375, with an early M-type host star and a companion initially identified to be a planet candidate. I used followup observations of radial velocity (RV) data procured from the Habitable-zone Planet Finder (HPF) and ground-based transit data from the Red Buttes Observatory (RBO) to investigate the orbital and physical parameters of the companion. I analyzed the data using a specific Hamiltonian Monte Carlo Markov Chain called “exoplanet” to find the best fit model for the data, and I used multiple dynamic functions to model the transit and RV data. I concluded that the host star has a companion too big to be an exoplanet, but rather, is a very low mass star (VLMS) near the hydrogen burning mass limit (0.08 M_sun) with an orbital period of 1.72 days and an estimated age of 400 Myrs. Objects near the hydrogen burning mass limit, like TOI-5375 B, are able to measure the mass and radius mostly independent of models, and estimating its age makes this a benchmark VLMS due to the scarcity of data in this population. This binary pair shows the necessity of following up on satellite data with ground-based observations because it is otherwise nearly impossible to accurately characterize the companions with TESS alone. I presented my findings to a general audience of about 50 people at the University of Arizona Astronomy Club, and **I published my first-author paper in the Astronomical Journal in April 2023.**

I am now navigating my first month of the astronomy and astrophysics PhD program at the University of California-Santa Cruz (UCSC) working on mapping the disequilibrium of the Milky Way’s disk using the Dark Energy Spectroscopic Instrument (DESI). The knowledge I gained as an undergraduate researcher was crucial for my preparedness for graduate school, and I now have a unique perspective on my current research because of my skills in simulations, modeling, observational data reduction, and high-performance computing. Although my experience working on exoplanet detection was fruitful, my true curiosity has always been directed towards galaxies. Their sheer size, beauty, and scientific potential invoke a sense of awe that begs to be explored.

Broader Impacts: I have been greatly involved in the University of Arizona Astronomy Club since joining in 2019. I was elected the Vice President in 2021, and President in 2022, leading the club of over 100 active members. I increased the annual funding for the club from $100 to $600 to create more outreach opportunities, worked with the department administrators to organize an out-of-state summer trip to San Diego, and conducted telescope training events for members. I also led the DEI initiatives of the Astronomy Club. I am a queer woman of Japanese descent, and I viewed myself as a role model for the incoming members to show that there can be someone similar to them in a leadership position. While President, the officers and I implemented a Code of Conduct as well as increased the amount of DEI presentations during our weekly meetings. I believe this aided the retention of minority students in the field and in turn, grew the number of curious minds in the program. In addition, the club created an inclusive and supportive environment for members to present their research in an informal setting with the purpose of preparing them for future talks. Furthermore, most outreach in which the club participated was volunteer telescope observation events at public elementary and middle schools in the Tucson area where students normally do not have the opportunity to explore space through a telescope. **Listening to the students’ questions and imaginative explanations for astronomical phenomena will always reinforce that spark in me to pursue teaching and science communication through outreach which I plan to continue to do at my graduate program**. I will make science more accessible to non-experts of all ages in the Santa Cruz area through creating more outreach opportunities at primary schools for a younger audience and at Astronomy on Tap to share astronomy education for older audience members. I will focus on making these events multi-cultural to increase representation in the field.

Being mixed race, I navigate life with a unique lens of trying to preserve my cultural heritage while presenting white. I am aware of the privilege my identity holds and that not all minorities are treated equally. In the U.S., only 1% of physics PhDs were awarded to Black scientists between 2018 and 2019 [1], and in 2022, only 21% of the members of the International Astronomical Union (IAU) were women [2]. I intend to use my experiences to further improve accessibility in astronomy and uplift the voices of astronomers in intersectional minority communities. **I plan to continue to make astronomy more accessible through local observation nights and by investing time in programs similar to the Tucson Initiative for Minoritized student Engagement in Science and TEchnology Program (TIMESTEP).** As an undergraduate leader for TIMESTEP, I was a panelist for a discussion on navigating the first two years of the astronomy degree, participated in discussions about accessibility in astronomy, and provided the knowledge I acquired during the graduate school application process.

TIMESTEP provides a safe space for students to share their experiences, and I learned the value of mentoring students with different perspectives. Additionally, in the summer of 2021, I worked as a camp counselor for Arizona's longest-running science camp: the Astronomy Camp based in Tucson. Although the camp was conducted remotely that year, I led breakout room discussions about different topics in astronomy including galaxy classification and stellar evolution. Students learned how astronomers remotely observe using the 32" and 24" telescopes on Mt. Bigelow, and they would conduct their own research project with help from camp counselors. I taught 20 to 30 students how to use the image processing software AstroImageJ to analyze the images from the telescope. Regardless of the remote method of the camp that year, the experience demonstrated the resilience of current and future scientists to uncover the mysteries of the cosmos. I plan to use my experience to create more mentorship roles to support undergraduates seeking higher education and between senior and junior graduate students, as well as increase the networking opportunities between women, people of color, and disabled graduate students across different programs to promote community growth and increase camaraderie. **I am participating in the Women in Science and Engineering (WiSE) mentorship program to aid students in navigating their final years as undergraduates.** We will meet for three, one-hour long sessions throughout the quarter to share advice on applying to graduate school and finding research opportunities at UCSC. Having a supportive network of peer mentors is one way to increase the retention of minority communities in STEM and build camaraderie between undergraduate and graduate students.

In my third year as an undergraduate, I applied for and accepted a preceptor position for the introductory physics mechanics class. **As a preceptor, a graduate student and I led two discussion sections per week of about 30 students.** This was an important opportunity for me because this was a way to develop my teaching and science communication skills. The graduate student and I would give a short explanation of the topic, the students then worked together to complete a tutorial on the current lecture material, and we answered any questions in an open-ended manner to give students a deeper understanding of the topic. Being a preceptor for this introductory class instilled a new-found appreciation for the foundation introductory physics classes laid for me. This experience reassured me that I love to teach science, and I want to continue to do so in my career. **In Santa Cruz, I am participating in the Project for Inmate Education, a program where graduate students and faculty teach 10-week college-level pre-algebra, algebra, and introductory astronomy courses at the county jail.** As volunteers, we rotate between lecturing and grading the students' assessments. The impact of removing socioeconomic barriers to education using resources such as this project will be felt throughout the community because education is a tool to increase economic development, science literacy, and self-advocacy, and it is important that everyone receives the opportunity to educate themselves.

<u>Future Goals</u>: I am pursuing a PhD in astronomy and astrophysics at UCSC with the goal of becoming a professor studying galaxy evolution. I believe being an astronomy professor, pioneering frontier science and creating a welcoming environment for marginalized communities in the classroom, will be a fulfilling role in the science community. Due to my undergraduate experience, I am well-equipped to excel in a PhD program as well as promote accessible methods of outreach to the public in the Santa Cruz area. With the guidance of my advisor Dr. Constance Rockosi, I am excited to study the inhomogeneities of the Milky Way, decipher how it evolved to its present state, and contribute to the understanding of spiral galaxy evolution. I am currently participating in outreach opportunities such as Project for Inmate Education and Astronomy on Tap and will promote intersectional identities in all my outreach endeavors. If I am awarded the NSF GRFP, I will use the support to create high-impact astronomical research and advance the field of galaxy evolution along with uplifting students from underrepresented communities. I will continue to make the field more accessible for students through mentorship programs at UCSC to encourage the pursuit of higher education, and I plan to mentor undergraduate researchers to show them the exhilarating feeling of being on the forefront of scientific discovery.

[1] *Mulvey, P., Nicholson, S., & Pold, J. (2021). Trends in Physics PhDs. https://files.eric.ed.gov/fulltext/ED611388.pdf*

[2] *International Astronomical Union | IAU. (n.d.). Www.iau.org. Retrieved September 15, 2023, from https://www.iau.org/public/themes/member_statistics/*

Mapping the Disequilibrium of the Milky Way Galaxy in the Disk and Halo using DESI

Background and Motivation

Astronomers are able to examine the Milky Way (MW) in more detail than any other galaxy due to the Earth's location inside it. We can use our unique position to observe ongoing interactions with satellite galaxies, such as the Large Magellanic Cloud (LMC) and Sagittarius dwarf galaxy (Sgr), which is an important process for the growth and evolution of all galaxies. However, our residency in the MW also poses challenges when investigating different aspects of its structure, and the solution is to use all-sky surveys. All-sky surveys have mapped the disk and halo of the Galaxy and uncovered inhomogeneity in the spatial and kinematic distribution of the stars in stellar streams in the disk and the wake of major mergers in the halo. A large gravitational perturbation in the past has resulted in observational evidence that the MW is in the stages of returning to equilibrium. Researchers have hypothesized that the best current explanation for the perturbation in the disk is the disturbances originate from the MW's interaction with Sgr [1] or the last major merger event, Gaia-Sausage-Enceladus (GSE) [2]. Yet, previous work has not confirmed any direct observational evidence or produced N-body simulations that yields the precise current state of the MW. This raises concern as to whether previous investigations have incorrectly estimated the mass and gravitational potential of Sgr or GSE, or they misunderstood the dynamic interaction, therefore it is imperative for this disequilibrium to be studied. This phenomenon was first observationally discovered by Antoja et al. 2018 [3]. Since then, multiple other investigations into this phenomenon studied the vertical structure using data from the Gaia survey [4, 5, 6]. Although Gaia maps proper motion out to 21st magnitude, the survey is limited at 14th magnitude for measuring radial velocities (RVs) which are required to map the 3D velocities of the MW; this can be compared to the Dark Energy Spectroscopic Instrument (DESI) survey which maps RVs and metallicities out to 19th magnitude. **I propose investigating the disequilibrium in the disk and stellar halo of the MW using DESI spectroscopy combined with Gaia astrometry to map the disk out to 19th magnitude and trace stellar streams in the stellar halo relating to the merger events.** The depth that DESI provides will increase our knowledge of the kinematic interactions closer to the edges of the disk and halo of the MW.

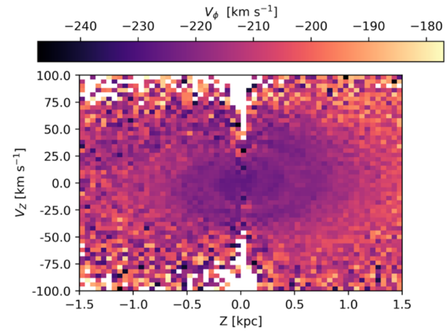

Figure 1: Exploratory phase diagram using the DESI radial velocity and Gaia distances plotting velocity in the vertical direction versus the vertical location at 8 kpc. This shows the phase spiral which can be compared to Figure 1 in Antoja et al. 2018 [3].

Intellectual Merit

DESI is an all-sky survey that collects spectroscopic data providing 3D kinematics and chemical abundances of millions of stars in our Galaxy. One way of identifying the inhomogeneity in the vertical structure uses phase space in Galactocentric coordinates. The disturbance appears as "phase spirals" or "ridges" in the diagram as seen in Figure 1. The phase spiral is caused by the entire distribution of the disk being offset in the Z direction due to the gravitational forces from another object [3]. The disk then begins the process of equilibrizing and we see the spiral form as a result of quasi-sinusoidal motion in the vertical direction. With DESI, I will use Main Sequence (MS), Red Giant Branch (RGB), and Red Clump (RC) stars to map this perturbation which will allow me to observe 10 times further than Gaia spectroscopy. Previous studies have also mapped small regions of the halo out to 40 kpc [2] however, DESI provides an all-sky sample to probe any disequilibrium caused by past and current mergers. The ridges in the (R, $V\varphi$) phase plane will also need to be explored, as seen in previous literature [6], because they correlate to regions of constant energy or constant angular momentum and follow the path of stellar streams in the MW disk. It is essential to conduct research in both the disk and stellar halo of the MW because the components shed light on the different kinematics at play during major merger events. The "feathers" of overdensities in the disk [7] are related to the stellar streams in the halo in that they are both signatures of satellite galaxy interactions. To fully examine all avenues of this proposed project, I have devised a three-part plan consisting of the following:

Part I: Using the observational data from DESI, I will map the vertical structure specifically in the disk of the MW and produce phase diagrams in the (Z, V_Z) plane at different radii from the center of the Galaxy. I will determine where the spiral dissipates and map the density and metallicity of the spiral. I will also measure the winding angle to determine the time since the perturbation of the disk.

Part II: I will probe the (R, $V\varphi$) plane to investigate the overdense ridges that correspond to stellar streams in the disk of the MW. I will catalog the age and radial velocities of these stars which hints at how these stars were affected by a major merger event. I will investigate whether the ridges point to specific stellar populations, or "folds" in the density perturbations of the disk. Parts I and II will be completed in the first two years at my graduate program, University of California-Santa Cruz (UCSC), which has many experts in DESI and galaxy evolution.

Part III: I will expand my investigation of inhomogeneities of the MW from the disk to the stellar halo of the Galaxy. Similarly, using DESI, I will track the kinematics of the stars in this region to look for evidence of stellar clumps associated with satellite galaxy remnants and observe orbital tracks of stars that may follow the paths of previous merging events. I will also research stellar shells produced by the last major merger event, Gaia-Sausage-Enceladus (GSE). I will follow up on several peculiar overdense regions in the disk and halo of the Galaxy using the Keck telescope's spectrograph, DEIMOS, to retrieve precise stellar abundances. I will be well equipped with resources at UCSC to carry out all these parts because of the expertise of the faculty and access to world-renowned telescopes.

The importance of studying the disequilibrium of the disk and stellar halo of the MW is because the stellar streams and vertical asymmetry can be used to trace the past merger history of the MW and the dark matter gravitational potential of the Galaxy. These gravitational detectors of dark matter fluctuations will increase the field's understanding of the effect of major mergers on the potential well [7]. Because the MW is an average spiral-type galaxy, the results deduced from this project can be applied to the disks of similar galaxies in the local universe. Furthermore, my years of undergraduate research have prepared me to undertake this project due to the extensive experience I have conducting data analysis with supercomputers, large all-sky surveys, and publishing results in peer-reviewed journals. Organizing a large-scale research project also requires proficient leadership and communication skills which I obtained through conference presentations, multi-institution collaborations, community outreach, and campus involvement in both my undergraduate and early graduate career.

Broader Impacts

My results on this project will further the field of astronomy through increasing our understanding of the MW's dynamics during major galactic disruptions. **With the support of the NSF GRFP I will have the independence to pursue high-impact science that evolves the field of galaxy formation and evolution, as well as mentor undergraduate students who are interested in similar topics.** Mentorship is vital for advancing the field of astronomy because peer-to-peer connection during large research projects can instill confidence in the mentee's abilities, and also provide an opportunity for the mentor to grow their teaching skills. I plan to work with undergraduate students at UCSC to research and identify specific streams in the disk of the Galaxy and compare them to previous literature. My previous experience as a preceptor and astronomy camp counselor has prepared me to excel as a mentor. Along with the outreach I mentioned in my personal statement, when I conduct at least four follow-up spectroscopy observations, I will participate in a program called Shadow the Scientist (StS) which allows high school students across the world to access observatories, in-person and virtually, to follow the astronomers' night as we collect data. StS focuses on serving BIPOC students and making observing more accessible for students who live far from observatories and dark skies. The program pulls back the curtain on the hands-on aspects of astronomy for students who are curious about a career in the field and provides an entryway for early experience in astronomical research.

References: [1] Xu et al. (2020) [2] Chandra et al. (2023) [3] Antoja et al. (2018) [4] Antoja et al. (2023) [5] Bennett et al. (2021) [6] Khanna et al. (2019) [7] Laporte et al. (2019)

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

Strengths: the applicant has built a solid experience of research and demonstrated the potential of being an independent scientist as supported by academic performance and supporting letters. Weaknesses: N/A

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Very Good

Explanation to Applicant

Strengths: the applicant has experience of broader impact and has a specific plan and vision. Weaknesses: N/A

Summary Comments

The application is very well written and provides a convincing evidence of the success of the applicant.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Very Good

Explanation to Applicant

This proposal was very well-organized and well-structured, with clear descriptions of past projects and future plans.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

The broader impacts of this proposal are specific and detailed and have clear actions and plans, as well as a well-demonstrated track record of broader impact contributions already.

Summary Comments

This is a strong application overall. The only way it could have been stronger is to have a more detailed and impactful intellectual merit in the research plan, but overall it is very good.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

2 first author papers as UG, Excellent plan of work on DESI at UCSC

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

Active in Women in Science, Astro outreach and INMATE education

Summary Comments

Excellent proopsal