NSF GRFP Personal Statement Logan Pearce

I plan to pursue a doctoral degree in astronomy with the goal of conducting original research in extra-solar planet discovery and characterization. My path to astronomy is non-traditional and non-linear, but it is precisely because of this winding path I now know for certain that a career as a **researcher in exoplanetary astronomy** is the ideal path for my future. Every choice I have made as a student, every opportunity I have had, has been with this goal in mind.

Although I have always had an interest in astronomy, I obtained a bachelor's degree in chemistry from Purdue University as a traditional college student in 2003, and earned a commission as an **officer in the US Navy** upon completion. I sought appointment in the Navy's nuclear power program because of the degree of academic challenge it afforded. I was not disappointed. The academic rigor in the schooling and subsequent work in the fleet is unparalleled by anything in the civilian world, in my experience. I served in many roles during my 5 years in the Navy, but the most impactful for me was as a nuclear power plant operator and maintenance division supervisor aboard the aircraft carrier USS John C. Stennis (CVN-74) for over 2 years in both war-time and maintenance conditions. In that capacity, I was continually challenged as a learner, a decision-maker under pressure, and a leader of personnel. The skills and experience I gained from that short intense time are too numerous to recount in detail here, but are an essential part of who I am and a factor in all my successes going forward.

Following separation from the Navy in 2008, I obtained a teaching certification and served as a **middle school science teacher** in Texas for 6 years. I taught in an advanced magnet program, and I focused my classes on teaching physics and engineering. I believe strongly in the power of engineering projects to drive student intellectual development, and so in 2014 I completed a Master's degree in engineering education in which I conducted original research on the effects of a well-designed engineering lesson on student development, while working as an in-service teacher. I also designed a popular elective course at my school in which students designed a crewed mission to Mars. The students' excitement in studying space rekindled my own long-forgotten love of astronomy, and I decided to leave teaching to pursue a career as an astronomer. It had been so long since I had studied math and physics that I quickly realized I needed to re-learn the basics to be successful as a researcher, and I am glad I did. I found the truth of the saying "I didn't know what I didn't know".

Intellectual merit. I began a **second bachelor's degree in astronomy and physics** at the University of Texas at Austin in 2015. Because I entered with the goal of becoming an astronomy researcher, I immediately set about the process of obtaining as many skills and diverse set of experiences as possible. I did not know what area of astronomy I wanted to focus on, but I knew I wanted to get involved in research right away. I began with a job in the Hobby-Eberly Telescope Dark Energy Experiment instrumentation laboratory, assembling the units of the VIRUS instrument for UT's ambitious research project to measure the expansion rate of the universe. During my first year back in school, I obtained essential skills in **programming and research methodology**, and exposure to the instrumentation field of astronomy, in addition to maintaining a 4.0 GPA in my coursework in math, astronomy, and physics.

During my first summer I participated in a Research Experience for Undergraduates (REU) at Northern Arizona University (NAU) in the field of planetary science. Working with Dr. Jennifer Hanley in NAU's Astrophysical Ices Laboratory, I carried out a laboratory experiment to measure the freezing points of various liquid mixtures which could compose the lakes on the moon Titan, to determine if it is possible for the lakes to freeze during Titan's seasonal variations. Whether ice can form in the lakes affects how past and future measurements from spacecraft are interpreted, and impacts planning for future science missions to Titan and other icy bodies in the solar system. The work is still on-going, and publications incorporating my work are still in-progress. I enjoyed the freedom I had at NAU to control the course of my study and determine how best to conduct the experiment, both the big picture design and the day-to-day. I loved the time I had to focus solely on research, and deepened my coding skills. I also found I really enjoyed research involving planets.

Planetary science does differ from astronomy, however, so in my second year, I decided to explore **exoplanet research**, the field within astronomy devoted to discovering and characterizing planets around other stars. I began a project with Dr. Adam Kraus studying the motion of a large companion that is far enough from the host star to be resolved in images. Dr. Kraus' program has been monitoring several of these type of companions for many years with images from the Keck Telescope in Hawai'i, enough time to measure orbital motion. These companions are too large to be formed through models of planet formation, but too small to be well understood in models of star formation, so they represent a poorly understood parameter space of star and planet formation. I measured the astrometric relative motion of one of these companions, GSC 6214-210 b, fit Keplerian orbital parameters to the motion, and studied the fit for clues which could point to formation mechanism. To measure the astrometry, I built my own Markov Chain Monte Carlo (MCMC) Point Spread Function fitting algorithm. To fit orbital parameters to the astrometry, I built my own rejection sampling fitting algorithm. To say this was challenging is an understatement. I undertook extensive study on Keplerian orbits, MCMC and rejection sampling statistical theory, and extensive upgrades to my coding skills, while maintaining a nearly-4.0 GPA in math, physics, and astronomy coursework. I found that planet formation pathways are unlikely to explain my system's origin, and star formation is more likely. I have presented this work via poster at several conferences including the American Astronomical Society 231^{st} and 233^{rd} meetings, and the Star and Planet Formation in the Southwest 2 meeting. I am proud to say that after almost two years of work, **publication of my results in a first-author paper is expected in fall of 2018.**

In this project I fell in love with exoplanet research, particularly the subfield of high-contrast imaging. In the summer of 2017, I traveled to the Keck Telescope in Hawai'i to collect another epoch of data for my project, and assist Dr. Kraus in obtaining images of other objects for his program. That was when I firmly decided that **observational astronomy research** was all I wanted to do. I love the infrared and optical observing I had done, but in the interest of diversifying my experience, I spent this past summer with the Berkeley SETI Research Center at the University of California Berkeley, on the Breakthrough Listen (BL) project to search for technosignatures in primarily radio wavelengths. Working with Howard Isaacson, I developed the "1 Million Star" target list for BL's upcoming observing campaign with the MeerKAT telescope in South Africa, which will be the largest Search for Extraterrestrial Intelligence (SETI) search in history. I used the latest *Gaia* data release to find the nearest 1 million stars with good astrometric solutions that BL will be able to observe with MeerKAT, and developed a tool for querying the list to make observing scripts. I selected this internship because I had no previous experience in radio astronomy, the internship was heavily focused on coding skills, which I am always seeking to grow, and also because the project involved **planning a large-scale observing campaign.** I expect to contribute to the upcoming **publication of the target list this fall.**

Broader Impact. As a teacher, I most enjoyed enabling my students' growth through engineering projects, in which they experienced frustrations and failures and iterations to make their idea into the best version they could. As a second-time student, I experienced this same growth through my astronomy research projects. The skills, drive, and motivation I gained from my own summer REU and internship experiences was invaluable. As a graduate student, I want to continue to improve students' educational experiences through **Research Experiences for Teachers.**

Most secondary science teachers have little to no experience with actually carrying out a scientific investigation, because it is not their professional expertise. Yet they are tasked with teaching science literacy, including science methodology and patterns of thinking, to the nation's youth. It can be difficult for teachers, with many other professional demands, to develop an intuitive sense of how the scientific community generates and evaluates new knowledge. Yet teaching this in schools is vital, as teachers can be front-line actors in improving the nation's science literacy. Giving secondary science teachers direct experience in carrying out a science project, then, represents an invaluable opportunity for the scientific community to help shape the scientific literacy of the nation.

I became aware of the NSF's Research Experiences for Teachers (RET) after I had already left the teaching profession, but immediately recognized its potential power. I had attended numerous teacher workshops, which were excellent, but I would have leaped on the opportunity to actually do real science. I found that there were not many RET programs available, and those were mostly engineering and computer science focused. **I want to begin an astronomy RET program at my graduate institution.**

Astronomy is a science elective course at most high schools, and astronomy research could be incorporated easily into a physics class, which is typically required. I envision the teachers participating in research alongside the undergraduate students, presenting their projects at the end, and being on publications. Teachers could also be requested to develop lessons related to their projects which they can distribute to their professional communities. In addition to improving student science literacy, they would also be modeling life-long learning, showing students that someone who is "just a teacher" is making meaningful impacts in professional science.

Because of my unique background, I can readily see the power and need for this type of outreach to the public. The potential of a few teachers coming to my school for the summer can have a compounding impact on the community and the nation. Get the teachers, you get the students, who get the parents, who get the community. I very much want to see this program expanded to many science disciplines, and plan to pursue outreach to teachers as a graduate student. I want teachers to have the same sort of life-changing research experiences I have been privileged to have.

Additionally, I have worked extensively for Astronomy on Tap (AoT) Austin, which is monthly astronomy talks for the public at a bar, and plan to continue that at my graduate institution. I also served the veteran student community as a peer mentor, and my fellow astronomy undergradute students as the undergraduate representative to the astronomy department. I love serving my peers by helping them take full advantage of the professional and educational opportunities at UT Austin. I plan to look for ways I can continue to serve my peers at my graduate institution, such as through student veteran services or within the astronomy department.

It took me a while to find purpose in my career, but I have no doubt I have found it. **Astronomy is my path**, with a career as a research scientist, ideally at a national laboratory or observatory. Graduate school will prepare me for research as a professional astronomer, refine my skills at conducting and communicating research, and to continue encouraging peers and mentoring younger students. The support of this fellowship will enable me to continue to excel in graduate school, and to pursue competitive opportunities for the future.

Seeing the Unseen in the *Gaia* Era:
Using Multi-Epoch Astrometry to Find Companions to Young Stars

Abstract High-contrast imaging is a powerful method to directly study the atmospheres of self-luminous planets, but the largest barrier to these efforts is the low occurrence of massive planets on wide orbits. Instead of blind surveys, target lists need to be informed by additional evidence indicating the presence of a planet to narrow the search and maximize the likelihood of discoveries. **I propose to conduct a high-contrast imaging survey for new faint companions to young stars, using accelerations detected in multi-epoch astrometry to optimize the target list.** I will select targets by combining astrometry from past satellite missions, including *Hipparcos*, with recent high-precision astrometry from the *Gaia* mission, to find young stars undergoing acceleration due to the presence of an unseen companion of planetary mass, but which cannot be readily characterized from the *Gaia* astrometry alone. I will then follow up these detections with a high-contrast imaging campaign to directly detect the companion, using coronagraphy from the ground and eventually space-based imaging. **The results will increase the number directly imaged exoplanets for characterization and result in a more efficient search campaign paradigm.**

Background and Motivation. Direct imaging surveys of young stars to date have resulted in the discovery of about a dozen exoplanets. These valuable systems are being used to inform planetary evolutionary models, distinguish between planet formation pathways, and determine the dependence of atmospheric clouds on mass and age. However, more giant planets are needed to develop meaningful statistical characterization of this population group and their host stars, and understand them as an ensemble outcome of the planet formation process.

Bowler (2016) determined the occurrence rate of planets (5-13 M_{jup}) at separations observable in imagining (30-300 AU) to be $0.6^{+0.7}_{-0.5}$%, suggesting that giant planets are quite rare at those distances. With such a low occurrence rate, direct imagining survey strategies must be optimized to select targets that maximize the likelihood of finding a giant planet or brown dwarf companion.

An ideal way to narrow the search is to infer the presence of the companion by observing the acceleration of the star in the plane of the sky due to the tug of the companion. The European Space Agency's *Gaia* (Gaia Collaboration 2016) satellite promises to deliver highly accurate astrometric measurements of 1.7 billion nearby stars by the end of the mission in 2022. To date, no extra-solar planet has been discovered astrometrically. With *Gaia*, however, the first detection is likely in the very near future, followed by potentially thousands more by the end of the nominal mission lifetime. *Gaia* astrometry alone will be able to detect planets with complete orbits, and periods on the scale of years, but which are too close to the host to be observed in imaging.

The promise of accurate astrometric measurements is beginning to be exploited to characterize known companions' masses and orbits. Bowler et. al. (2018) used radial velocity and relative astrometric measurements to determine the dynamical mass of the companion to GJ 758. They used this independent mass measurement to test several brown dwarf evolutionary models. Calissendorff & Brown (2018) improved on the mass measurement by exploiting multi-epoch astrometry using the differences between *Hipparcos* and *Gaia* astrometric motions spanning a 24 year baseline. Multi-epoch astrometry from *Hipparcos* and *Gaia* thus provides the baseline and accuracy needed to identify young stars experiencing acceleration due a previously unseen companion that is wide enough to be reached by imaging, and significantly increases the likelihood of detection of giant planets in direct imaging surveys.

Study Design and Intellectual Merit. **I propose a study to identify and characterize new substellar companions to young stars by exploiting the promise of multi-epoch astrometry.** I will use astrometric measurements from *Hipparcos* and *Gaia* of young stars over a several-decade time span to search for stars undergoing accelerations due to the presence of an unseen companion. I will develop a ranking scheme to optimally identify planets by incorporating the magnitude of the acceleration (to be consistent with planet masses), stellar multiplicity (to rule out binary systems), distance (closer objects will have larger angular separations), and age of host star (younger planets will be brighter). I will prioritize the target list to find 50 planet host candidate stars, which is the upper end of the number of targets that could reasonably be surveyed during my PhD tenure.

I will then conduct a high-contrast imaging survey to follow up on the targets I identified from the ground (e.g. the vortex coronagraph on the Keck II telescope) and later from space (e.g. James Webb Space Telescope), primarily in the infrared L-band where the planet's spectral energy distribution peaks and thus it will be brightest in imaging.

In years 1-2 of my graduate study, I will develop and publish a target list for the imaging survey based on multi-epoch astrometry. In years 3-4, I will conduct a high-contrast imaging survey of these targets, publishing newly imaged companions. In my final year, I will consider how my observations impact the field of substellar formation and evolution, culminating in the successful completion of my Ph.D.

This study is a natural extension of my previous experience. My current work with Dr. Adam Kraus (Pearce et. al., submitted) on an orbit study of a planetary companion imaged with Keck II NIRC2 camera has given me great familiarity with planet companions imaged with Keck II. That work uses my measurement of the companion's orbit to constrain its formation mechanism. In the course of that work I have built a collaboration with experts in coronagraphy and high-contrast imaging techniques. In addition, my summer internship at UC Berkeley enabled me to work extensively with *Gaia* data and its catalog. Thus, this proposed study is a next step in my scientific undertakings, one that leverages the promise of current cutting-edge technology.

Caltech is ideally suited for me to carry out this work, because there are many scientists involved in high-contrast imaging and exoplanet characterization studies (e.g. D. Mawet, H. Knutson, L. Hillenbrand), and because the access to Keck and Palomar Observatories is unrivaled.

Broader Impact. As I showed in my personal statement, teachers' engagement in science is vital to our communities. Thus, I intend to pursue funding for a Research Experience for Teachers program at my graduate institution. With this project, I can recruit teachers to collaborate with me and other members of our department during the summer. I will recruit secondary school teachers of math, physics, astronomy, or any subject in which they could incorporate their experience into their classroom, from local or regional area schools. Teacher-researchers will make meaningful contributions to the catalog search and the imaging portion of this project. Teacher-researchers would be able to assist with observations at the Keck Telescope or similar observing facility, learn coding skills through data analysis, learn image manipulation, and to learn scientific professional skills. Under the mentorship of my thesis advisor or another research scientist, I would relish the opportunity for a teacher researcher to learn alongside me and contribute to the analysis.

References Bowler, B. P., Dupuy, T. J., Endl, M. et. al. 2018, ApJ, 155, 159; Bowler, B. P. 2016, PASP, 128, 102001; Calissendorff, P. & Janson, M. 2018, AA 615, 5.; Gaia Collaboration G, Prusti T., de Bruijne J., Brown A., Vallenari A., et. al. 2016. A&A, 595, 36.; Pearce, L., Kraus, A., et. al. 2018. ApJ, Submitted