PROJECT SUMMARY

OVERVIEW:

White dwarf stars (WDs) are incredible laboratories for exoplanet science. Their strong gravities cause elements to stratify leaving pure hydrogen and/or helium photospheres. Any metals observed in their photosphere spectra (called pollution) must have been deposited recently from the planetary regime, providing one of the only probes of exoplanetary material refractory composition. The mechanism for deposition of material onto the WD surface is not well understood. While there is some research on influence of a wide stellar companion on the formation of exoplanets, a population study of the pollution rates of SLS will probe the influence of a wide stellar companion of the planetary regime for mature systems following the AGB phase of the host. While there is some research on influence of a wide stellar companion on the formation of exoplanets, a population study of the pollution rates of SLS will probe the influence of a wide stellar companion of the planetary regime for mature systems following the AGB phase of the host. Understanding of the dynamical influence of a wide stellar companion on the planetary regime is hampered however by low population statistics, particularly for WDs with AFGK stars (called "Sirius-Like Systems", SLS) where the WD's contribution to the spectral energy distribution is drowned out by the brighter main sequence star.

The latest generation of extreme high-contrast adaptive optics (ExAO) instruments are exceptionally well suited for this science case. Extending her previous work with the ExAO instrument MagAO-X, Logan Pearce, the proposer, has designed an extensive observational survey to detect new SLS and examine the WD for pollution called The ExAO Pup Search [1]. The Pup Search will use the ExAO instruments MagAO-X and SCExAO to detect new systems, astrometric and RV monitoring to constrain orbits, and spectroscopy from HST and Keck/HIRES to look for pollution. This program will be carried out at Steward Observatory at the University of Arizona, which provides unparalleled access to the resources required for the program, with the sponsoring scientist Dr. Olivier Guyon.

INTELLECTUAL MERIT:

The data-set produced by the Pup Search will be invaluable to both the exoplanet and white dwarf communities. It will produce a new population of SLS and (un)polluted white dwarfs which will grow the sample size of these systems to enable population-level studies of pollution rates and orbital characteristics. It will provide more pollution measurements of the refractory compositions of exoplanetary material, and probe the influence of a wide stellar companion post-AGB phase. It will also provide observations for comparison to theoretical predictions of the orbital parameters for which the wide companion would be contributing to driving material onto the WD surface.

BROADER IMPACTS:

Veterans are a statistically underrepresented group in higher education, and their retention lags peers, particularly in STEM fields. Student veterans face a unique set of challenges to completing undergraduate STEM degrees, but getting them involved in STEM research in labs and research groups can help mitigate some of these challenges. Building on the success of student veteran research programs at the University of Arizona, Pearce will produce the Student Veterans Research Symposium to showcase the science being conducted by undergrad, graduate, and post-doctoral veterans to promote community, increase visibility, promote professional development, and showcase achievements. The Symposium will begin with local area universities and grow to a national event. Pearce will work with Dr. Jared Males, NSF, and UA stakeholders to organize and fund the Symposium.

[1] The name is a reference to the first known wide White Dwarf – Main Sequence system, Sirius AB. Since Sirius A is the "Dog Star", Sirius B was nicknamed "The Pup"

PROJECT DESCRIPTION

The ExAO Pup Search:
Probing planets in wide binaries by leveraging the power of extreme adaptive optics towards White Dwarf + Main Sequence star systems

The ExAO Pup Search
The search for non-interacting white dwarf - main sequence binaries with MagAO-X and SCExAO

OBJECTIVE: **The study of the pollution and orbital characteristics of non-interacting white dwarf/main sequence star systems provides a direct probe of the influence of the wide companion on the planetary region.**

ASTRONOMICAL CONTEXT: Multiple star systems are an extremely common outcome of the star formation process, especially for higher-mass stars [14]. I am interested in the formation and dynamical evolution of planetary systems around one star in a wide binary — “S-type", as opposed to “P-type" (circumbinary) planets — under the gravitational influence of the wide stellar companion. It is becoming clear that S-type planets are not uncommon [8, 5, 6], and companions will exert gravitational influence on the planetary regime throughout the star’s lifetime impacting the formation and survival of S-type planets. **Observational tests are critical for theoretical predictions of how and to what degree companions influence planetary systems throughout the star’s lifetime.**

White Dwarf - Main Sequence polluted binaries are crucial to exoplanet research:
- *WD pollution is the only method of probing the non-volatile composition of exoplanetary material*
- *Polluted WDMS systems probe the formation and survival of exoplanetary material in wide binary systems*
- *Small population statistics currently hinder studies*
- *High-contrast imaging instruments and techniques are ideal for addressing this problem*

White dwarfs (WD) with (non-interacting) main sequence star companions (WDMS) are an excellent laboratory for probing the influence of a wide companion at late stages of planetary system evolution. Due to their extreme gravity, elements stratify on short timescales (minutes – years) leaving pure H and He photospheres. Any metals observed in the spectra of WDs, called pollution, were deposited recently from the planetary regime [29]. **WD pollution is the only method of probing the refractory compositions of exoplanetary material** [e.g. 31, 26, 33, 23]. WDs show pollution independent of cooling age [27], requiring a mechanism(s) to deposit material that is independent of age [22]. **A wide stellar companion is one such possible mechanism** [32, 22]. The role of the companion in driving material onto the WD is unknown, but may impact the planetary regime through: 1. pushing previously stable planet orbits into regions of chaotic orbits as the primary loses mass and the companion’s orbit expands [32, 11], 2. evolving onto high-eccentricity orbits through external perturbations [4, 9, 28] inducing regions of chaos [2], 3. driving von-Zeipel-Kozai-Lidov oscillations [9, 15], 4. driving secular resonances [2], 5. pushing surviving planets onto close orbits [13], 6. inducing a 2nd or 3rd generation of planet formation [21].

Many of these scenarios produce observationally testable predictions. Stephan et al. [25] determined the distribution of orbital parameters for a WD polluted by the Eccentric Kozai-Lidov (EKL) mechanism to which the orbits of a population of polluted WDMS systems can be compared. Veras et al. [28, Fig 3] made predictions of companion semi-major axis and eccentricity combinations for which the primary's planetary regime is (un)stable at various stellar evolutionary phases which can be compared to (non-)polluted WDMS system architecture.

As one star evolves off the main sequence, they can either evolve into interacting or non-interacting systems [30]; non-interacting WDMS orbits expand as primary loses mass into a regime amenable to direct imaging instrumentation. Additionally, the number of known nearby white dwarfs is fewer than expected from stellar evolution — the "missing white dwarf" problem [12, 10]. For so-called 'Sirius-Like Systems" (SLS), a multiple system containing a white dwarf with a more-luminous K-type or earlier companion(s), the white dwarf contribution to the SED is drowned out by the more luminous MS star, and can't be easily detected. **This motivates probing this population via high-contrast imaging detection methods**.

INTELLECTUAL MERIT

My plan as an NSF fellow is to execute an observational survey to leverage the power of the new extreme adaptive optics (ExAO) instruments MagAO-X and SCExAO towards detection and characterization of SLS with a survey called The ExAO Pup Search: The extreme AO non-interacting white dwarf-main sequence binary system survey[1]. The Pup Search has three main objectives:

1. Detect new non-interacting WDMS binary systems with MagAO-X and SCExAO and observe new systems for pollution with VIS-X, HST, and Keck/HIRES
2. Monitor orbits of new and previously known resolved WDMS systems with imaging and radial velocity to determine prevalence of high-eccentricity orbits of MS companions for polluted WDs and compare to estimated orbital parameters for the binary to be influencing pollution, such as those in Stephan et al. 25 and Veras et al. 28 Fig 3.
3. Determine pollution rates for WDMS systems with VIS-X, HST, and Keck/HIRES, compare to single WDs and as a function of cooling age, and compare to estimates such as Veras et al. [29]

There is a demonstrated need in both exoplanet and WD communities for a dataset of this kind. We will grow the sample size of non-interacting white dwarf-main sequence binaries and produce observational tests of the role of wide companions on the planetary regime; as a byproduct we will also be contributing to the missing WD problem by identifying new WDMS systems in the local region and testing the wide companion influence on pollution. This proposed research addresses several gaps identified in the NASA/JPL Exoplanet Exploration Program Science Gap List (Stapelfeld & Mamajek, 2023, JPL Document No: 1792073-2) including SCI-14: Exoplanet interior structure and material properties and SCI-04: Planetary system architectures and occurrence rates.

We observed 5 Pup Search systems with MagAO-X in 2022 and detected at least one new WD companion (Figure 1), which demonstrates the effectiveness of this survey. Zuckerman [32] compiled 38 polluted WDMS and found that the companion suppresses the formation and/or long term stability of planets; they acknowledge that these are small-number statistics and call for further observational surveys with this goal in mind. It is possible that polluted WDMS may be rare, however a larger population size is required, which this survey will provide. It will also be challenging to detect pollution lines with VIS-X as optical metal lines are typically rare and weak; spectra in the 0.3-0.4 μm range with HST and Keck/HIRES is optimal for line detection. The smaller mirror of HST is not a challenge to spatial resolution moving to UV wavelengths as for both HST at 0.3μm and MagAO-X at 0.8μm, $1\lambda/D \approx 25$ mas, so new systems detected by MagAO-X should be accessible to HST in UV.

[1] The name is a reference to the first known wide White Dwarf- Main Sequence system, Sirius AB discovered in 1844 by Friedrich Bessel when he observed changes in the proper motion of Sirius [3], first observed by Alvin Graham Clark [7], and confirmed as the second ever known WD via its spectrum obtained by Walter Adams [1]. Since Sirius A is the "Dog Star", Sirius B was nicknamed "The Pup"

The Keck/HIRES instrument offers high-resolution spectra from 0.3-0.9 μm, offering a broad spectral range covering multiple regimes with pollution lines. Additionally, orbital periods for SLS can be long making orbital parameter determination difficult. Non-interacting orbital periods from 3–300,000 years are common [30]. The Pup Search is targeting objects close to the inner working angle of nearby stars, where periods are shorter and radial velocity will yield better orbit constraints. Astrometric and RV measurements made during this fellowship will contribute to long-term orbit monitoring of these systems for future orbit constraints beyond the fellowship period.

Applicant Qualification. As a member of the MagAO-X team during my PhD I have had 24 hours MagAO-X observing time as PI awarded over 2 semesters, 18 of which were for preliminary Pup Search observations. The remaining 6 hours resulted in publication of a new binary system HIP 67506 AC [20]. I have extensive experience with long-period orbit monitoring [16, 17, 18] and with high-contrast image processing and data analysis [19, 20].

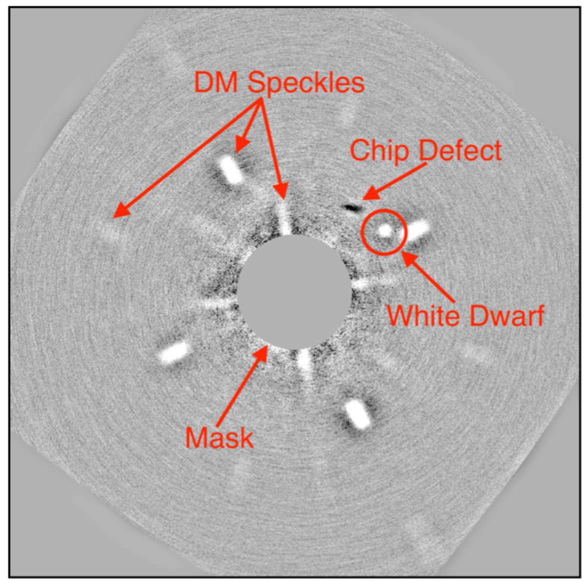

Figure 1: *A new WD companion (red circle) to a main sequence star discovered in i' band with MagAO-X in 2022 as part of the Pup Search program. Host star PSF was removed by unsharp mask and radial profile subtraction; mask, chip defect, and speckles caused by the deformable mirror are labeled. The new WD companion is indicated by the red circle.*

TIMELINE

Figure 2 displays a plan for the organization of this project. In year one my focus will be on detecting previously unknown WDMS systems with MagAO-X and SCExAO (Objective 1). As this process has already begun during my PhD, I already have a robust target list of MS stars highly likely to contain a hidden WD as selected by UV excess in Ren et al. [24], from which I have discovered at least one new WDMS (Figure 2). I will also compile a target list for orbit monitoring of known SLS and begin observations with other telescope resources (Objective 2). I expect publication of new WDMS detections at the end of year one. In year two I will continue Objective 1 and 2 observations and begin to shift focus to Objective 3 by applying for HST, Keck, and VIS-X time, with a second publication of new detections and preliminary orbit monitoring results expected near the end of year two. In year three my focus will primarily be on HST, Keck, and VIS-X spectroscopic observations, with publication of (un)polluted WDs and pollution rates expected near the end of year three.

RISK MITIGATION

This ambitious survey relies on the availability of primarily ground-based instruments, MagAO-X, SCExAO, and Keck, which are subject to observing and maintenance schedules, travel restrictions, and weather. MagAO-X's observing schedule was significantly impacted by COVID and related travel restrictions, and our 2022A observing run was hampered by weather, both of which would impact Objective 1. I will mitigate this risk by applying for time over multiple observing seasons on all instruments/telescopes. Objective 2 can be supplemented with other telescope resources, and HST observations of Objective 3 are not impacted by ground-based restrictions. Objective 3 relies on the availability of HST and Keck spectroscopy, with the main risk being continued availability of HST and

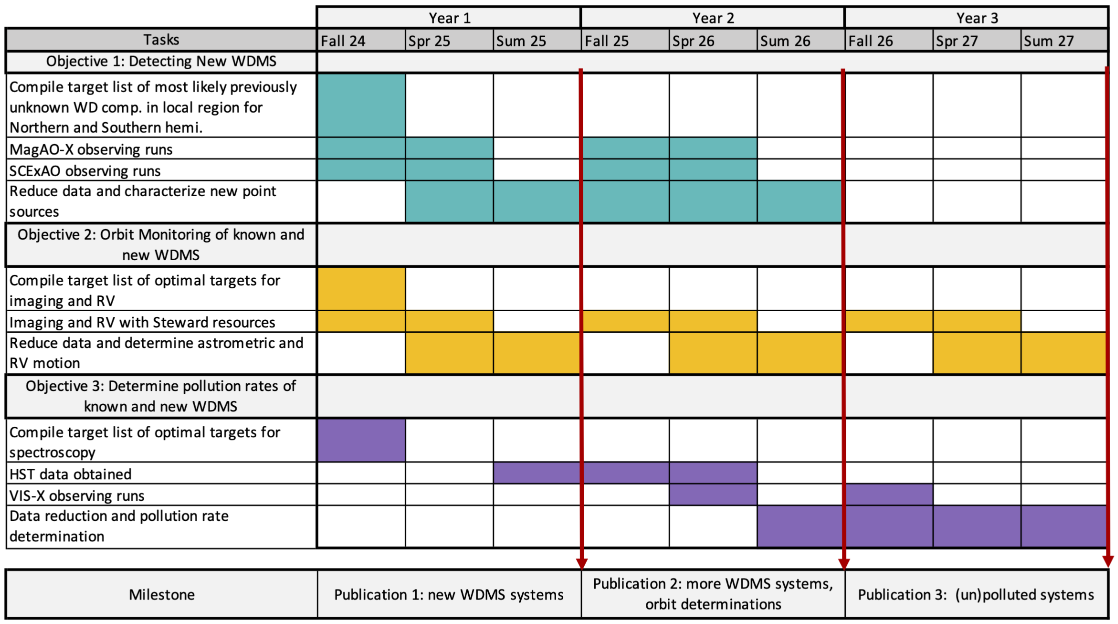

Figure 2: *Project plan and timeline*

being awarded HST and Keck observing hours for this program.

Outcomes

Short term outcomes of the fellowship include providing the **exoplanet community** with a robust investigation of S-type planets in binaries at the end of the star's lifetime, with new WD pollution data providing more evidence of refractory compositions of exoplanets, and providing the **white dwarf community** with an expanded population of SLS. These data produced by this fellowship will be invaluable to both fields. This program builds upon all the strengths developed during my PhD while also pushing me into the new regimes of UV spectroscopy, radial velocity observations, and space-based observations. It enables me to build new professional relationships within the exoplanet community as well as forge new collaborations in the polluted white dwarf community.

Broader Impacts

When I separated from the US Navy in 2008 after a 5 year career as an officer, I found it much more difficult to transition to civilian life than I had expected, both socially and professionally. I struggled to translate my experiences into a civilian-friendly resume, and to find a group of people who understood where I was coming from. When I decided to return to university for a bachelors degree in astronomy and physics in 2015, I connected with the Student Veterans Association at the University of Texas (UT), and found the kind of personally and professionally supportive community I wish I had had 7 years earlier.

Veterans are a statistically underrepresented group in higher education despite the numerous education benefits accompanying veteran status. Veterans are 7% of the US population over 18, yet they make up 3.7% of undergraduate students at the University of Arizona (UA), and 3.6% of STEM majors. At UA, veteran retention also lags compared to all students, with 31% of veteran STEM majors graduating after 6 years compared to 63% of all undergraduates[2]. The veteran population disproportionately comes from other underrepresented groups as well, such as racial minorities and first-generation col-

[2] Source: UA Analytics as of 2020

lege students. Veterans are significantly more likely to have dependents, military reserve obligations, and specific requirements related to education benefits (e.g. needing to take a full course load in order to receive a housing stipend), all of which can limit access to the kinds of opportunities that make graduate school applications stand out.

Veterans often don't realize how their military experience can be applied to STEM academics and careers. In addition to technical skills, veterans tend to underestimate the "soft skills" they've attained in the service, such as leadership and management, and how they can be leveraged for academic and research success. Many student veterans I've known were nervous about how their age and life experience makes them different from their college peers, something which actually is a major strength.

	Year 1			Year 2			Year 3		
	Fall 24	Spr 25	Sum 25	Fall 25	Spr 26	Sum 26	Fall 26	Spr 27	Sum 27
Local symposium for host institution and local community colleges		X							
Regional symposium including school from neighboring states					X				
National symposium								X	

Figure 3: *Symposium timeline*

Getting STEM-inclined veterans involved in STEM research in undergrad can increase retention by (1) helping them see past barriers such as difficult classes, (2) fostering community in academia by becoming contributing members of a research group, mitigating perceptions of otherness due to age and life-stage differences with peers, (3) fostering a sense of purpose by contributing meaningfully to active research, and (4) utilizing skills from service in a new way or uncovering new skills.

It's for these reasons that I have been motivated to help my student veteran peers make the most of the opportunities available in undergraduate and graduate programs. As a PhD student at the University of Arizona I worked for three summers as a Research Project Leader for the Warrior Scholar Program (WSP), conducting week-long projects introducing scientific research and coding as part of WSP's two week "boot camp" for veterans transitioning into undergraduate programs. I worked for an academic year as a consultant for WSP's Diana Davis Spencer Scholars program in which I gave workshops, shared resources, and gave application material feedback for a cohort of 25 WSP alumni who were applying for graduate school. I intend to continue serving my veteran community as a postdoctoral researcher at the University of Arizona.

Budget	
Keynote speaker travel and accomodation	$1,000
Coffee, lunch, snacks throughout day	$1,000
Conference dinner/reception	$2,000
Total	$4,000

Figure 4: *Example Symposium budget for the first local Symposium.*

Building on the success of research conferences aimed at diversity and specific student groups, such as The Conference for Undergradute Women in Phyiscs (CUWiP) and the Society for Advancement of Chicanos/Hispanics & Native Americans in Science conference (SACNAS), **I propose to start the annual Veterans Research Symposium** at UA, a student veteran focused scientific research conference showcasing the research produced by veterans across disciplines at undergraduate, graduate, and post-doc levels. Together with my PhD advisor, Dr. Jared Males (also a US Navy veteran), we have already begun the work of refining this idea and taking the first steps at the University of Arizona. The goal of the conference is to **promote community** among student veterans across disciplines, **increase visibility** of veteran researchers and encourage recruitment into research, **enable connection** for graduate programs looking to recruit student veterans, and **showcase the skills and achievements of veterans in STEM** research to encourage recruitment and retention of veterans. Taking place over two days, the conference will consist of multiple poster and/or talk sessions, workshops, and a keynote speaker. We plan to begin with local area universities initially, building eventually to a national conference. Figure 1 displays a proposed timeline; Figure 2 displays an example budget for the first local

Symposium. I anticipate spending approximately 10% of my time on developing the conference, ramping up to 25% as the conference approaches. We will work closely with UA and NSF to fund the initial Symposium, and build on its success to expand funding for the larger events. We will track participation rates by veteran researchers, as well as attendance by non-veterans to assess the utility of this symposium. **The support of this fellowship at UA will enable me to continue this work and see the Symposium through to success.**

JUSTIFICATION OF HOST INSTITUTION

Host Institution: University of Arizona
Faculty Mentor: Olivier Guyon
The University of Arizona's Steward Observatory (hereafter UA) is the ideal institution to host the survey I am proposing. MagAO-X on the Magellan Clay Telescope, of which UA is a partner, is especially well suited to this science. It is built for extreme high contrast imaging on the order of 10^{-7}, so the contrasts involved in Sirius-Like Systems (SLS) [$\mathcal{O}(10^{-2}-10^{-4})$] are easily achieved in short observation times. MagAO-X is optimized for optical wavelengths where WDMS star contrasts are much lower and inner working angles are smaller compared to IR-optimized high-contrast instruments. MagAO-X achieves exceedingly high Strehl ratio ($\sim$ 70% in z$'$) in optical wavelengths compared to other adaptive optics instruments. We also plan to use its high-resolution spectrograph, VIS-X, for spatially resolved spectra. While optical pollution features in white dwarfs are less common and harder to detect than UV, VIS-X will complement our planned UV HST and Keck/HIRES spectra (Objective 3). As a current member of the MagAO-X team I have already begun initial Pup Search observations with new white dwarf companion discoveries. Steward Observatory additionally offers a wealth of telescope resources for Pup Search Objective 2 - orbit monitoring of SLS. In addition to the astrometry provided by MagAO-X, Steward offers access to several radial velocity instruments including the MIKE spectrograph at Magellan, NEID, and the Habitable Planet Finder (HPF) to complement the astrometry and provide better orbit constraints. Astrometry can also be supplemented with additional Steward resources like MMT/MAPS and LBT/SHARK-NIR or SHARK-VIS.

Due to the joint appointment of Olivier Guyon to Steward and NAOJ, hosting my fellowship at Arizona offers access to SCExAO, the extreme AO instrument on Subaru Telescope of which Olivier is the PI. This opens up the Pup Search survey to both northern and southern hemisphere targets. SCExAO/VAMPIRES offers a newly-commissioned four color imaging mode which enables fast color characterization of candidates to vet white dwarf status.

In addition to the expertise that Dr. Jared Males (MagAO-X PI) and Dr. Olivier Guyon (SCExAO PI) will lend to the success of this survey, there are a number of other faculty at Arizona that can provide additional support. Dr. Chad Bender (NEID PI and HPF team member) will be invaluable for the RV objective of this survey, as students and post-docs in Daniel Apai's and other exoplanet groups in Steward and Lunar Planetary Laboratory also on UA campus.

Additionally, while a grad student I have done work contributing to the science goals of GMagAO-X, the ExAO instrument our group is building for the GMT. GMT/GMagAO-X will be invaluable tools for WDMS characterization, in addition to detection and characterization of hundreds of exoplanets in reflected light. I am excited by the mission of GMagAO-X, and hosting my fellowship at Arizona will allow me to continue to collaborate on this vital instrument for the future of exoplanet direct imaging.

Finally, hosting my fellowship at Arizona is ideal for my diversity, equity, and inclusion efforts. Below, in my Broader Impacts section, I detail a proposal for a veteran-specific research symposium. Dr. Jared Males and I have begun the work of initiating this symposium at UA, including formulating a plan and beginning discussions with relevant University parties. This is an effort I care deeply about seeing through, and hosting my fellowship at UA will allow me to continue to build on work already begun.

After serving 5 years on active duty in the Navy and teaching 6 years in middle school, I have learned what it takes to thrive in my professional life. Given my previous professional experiences, and my already well established world-wide collaborator network, continuing my research program by hosting my fellowship at UA is the best match for me both personally and professionally.

Long Term Career Goals

I intend to pursue a career in astronomical research in exoplanet direct imaging. I will pursue research scientist positions at observatories, research facilities, or universities, however I will also consider faculty positions. As an NSF fellow at the University of Arizona, I will pursue my proposed and related research as well as continue my service to the student veteran community. In my postdoctoral career and beyond I will strive to meaningfully contribute to the exoplanet and white dwarf communities and provide a welcoming and supportive community for student veterans and non-traditional students.

References

[1] W. S. Adams. The Spectrum of the Companion of Sirius. , 27(161):236, Dec. 1915. doi: 10.1086/122440.

[2] Á. Bazsó and E. Pilat-Lohinger. Fear the Shadows of the Giants: On Secular Perturbations in Circumstellar Habitable Zones of Double Stars. *Astronom. J.*, 160(1):2, July 2020. doi: 10.3847/1538-3881/ab9104.

[3] F. W. Bessel. On the variations of the proper motions of Procyon and Sirius. *Mon. Not. R. Astron. Soc.*, 6:136–141, Dec. 1844. doi: 10.1093/mnras/6.11.136.

[4] A. Bonsor and D. Veras. A wide binary trigger for white dwarf pollution. *Mon. Not. R. Astron. Soc.*, 454:53–63, Nov. 2015. ISSN 0035-8711. doi: 10.1093/mnras/stv1913.

[5] S. Christian, A. Vanderburg, J. Becker, D. A. Yahalomi, L. Pearce, G. Zhou, K. A. Collins, A. L. Kraus, K. G. Stassun, Z. de Beurs, G. R. Ricker, R. K. Vanderspek, D. W. Latham, J. N. Winn, S. Seager, J. M. Jenkins, L. Abe, K. Agabi, P. J. Amado, D. Baker, K. Barkaoui, Z. Benkhaldoun, P. Benni, J. Berberian, P. Berlind, A. Bieryla, E. Esparza-Borges, M. Bowen, P. Brown, L. A. Buchhave, C. J. Burke, M. Buttu, C. Cadieux, D. A. Caldwell, D. Charbonneau, N. Chazov, S. Chimaladinne, K. I. Collins, D. Combs, D. M. Conti, N. Crouzet, J. P. de Leon, S. Deljookorani, B. Diamond, R. Doyon, D. Dragomir, G. Dransfield, Z. Essack, P. Evans, A. Fukui, T. Gan, G. A. Esquerdo, M. Gillon, E. Girardin, P. Guerra, T. Guillot, E. K. K. Habich, A. Henriksen, N. Hoch, K. I. Isogai, E. Jehin, E. L. N. Jensen, M. C. Johnson, J. H. Livingston, J. F. Kielkopf, K. Kim, K. Kawauchi, V. Krushinsky, V. Kunzle, D. Laloum, D. Leger, P. Lewin, F. Mallia, B. Massey, M. Mori, K. K. McLeod, D. Mékarnia, I. Mireles, N. Mishevskiy, M. Tamura, F. Murgas, N. Narita, R. Naves, P. Nelson, H. P. Osborn, E. Palle, H. Parviainen, P. Plavchan, F. J. Pozuelos, M. Rabus, H. M. Relles, C. Rodríguez López, S. N. Quinn, F.-X. Schmider, J. E. Schlieder, R. P. Schwarz, A. Shporer, L. Sibbald, G. Srdoc, C. Stibbards, H. Stickler, O. Suarez, C. Stockdale, T.-G. Tan, Y. Terada, A. Triaud, R. Tronsgaard, W. C. Waalkes, G. Wang, N. Watanabe, M.-S. Wenceslas, G. Wingham, J. Wittrock, and C. Ziegler. A Possible Alignment Between the Orbits of Planetary Systems and their Visual Binary Companions. *Astronom. J.*, 163(5):207, May 2022. doi: 10.3847/1538-3881/ac517f.

[6] A. Eggenberger, S. Udry, and M. Mayor. Statistical properties of exoplanets. III. Planet properties and stellar multiplicity. *Astronomy & Astrophysics*, 417:353–360, Apr. 2004. doi: 10.1051/0004-6361:20034164.

[7] C. Flammarion. The Companion of Sirius. *Astronomical register*, 15:186–189, Jan. 1877.

[8] C. Fontanive and D. Bardalez Gagliuffi. The Census of Exoplanets in Visual Binaries: population trends from a volume-limited Gaia DR2 and literature search. *Frontiers in Astronomy and Space Sciences*, 8:16, Mar. 2021. doi: 10.3389/fspas.2021.625250.

[9] A. S. Hamers and S. F. Portegies Zwart. White dwarf pollution by planets in stellar binaries. *Mon. Not. R. Astron. Soc.*, 462:L84–L87, Oct. 2016. ISSN 0035-8711. doi: 10.1093/mnrasl/slw134.

[10] J. B. Holberg, T. D. Oswalt, E. M. Sion, M. A. Barstow, and M. R. Burleigh. Where are all the Sirius-like binary systems? *Mon. Not. R. Astron. Soc.*, 435(3):2077–2091, Nov. 2013. doi: 10.1093/mnras/stt1433.

[11] N. A. Kaib, S. N. Raymond, and M. Duncan. Planetary system disruption by Galactic perturbations to wide binary stars. *Nat.*, 493(7432):381–384, Jan. 2013. doi: 10.1038/nature11780.

[12] B. Katz, S. Dong, and D. Kushnir. Luminosity function suggests up to 100 white dwarfs within 20 pc may be hiding in multiple systems. *arXiv e-prints*, art. arXiv:1402.7083, Feb. 2014. doi: 10.48550/arXiv.1402.7083.

[13] K. M. Kratter and H. B. Perets. Star Hoppers: Planet Instability and Capture in Evolving Binary Systems. *Astrophys. J.*, 753(1):91, July 2012. doi: 10.1088/0004-637X/753/1/91.

[14] M. Moe and R. Di Stefano. Mind Your Ps and Qs: The Interrelation between Period (P) and Mass-ratio (Q) Distributions of Binary Stars. *Astrophys J., Sup.*, 230(2):15, June 2017. doi: 10.3847/1538-4365/aa6fb6.

[15] A. J. Mustill, M. B. Davies, S. Blunt, and A. Howard. Dynamical orbital evolution scenarios of the wide-orbit eccentric planet HR 5183b. *Mon. Not. R. Astron. Soc.*, 509(3):3616–3625, Jan. 2022. doi: 10.1093/mnras/stab3174.

[16] L. A. Pearce, A. L. Kraus, T. J. Dupuy, M. J. Ireland, A. C. Rizzuto, B. P. Bowler, E. K. Birchall, and A. L. Wallace. Orbital Motion of the Wide Planetary-mass Companion GSC 6214-210 b: No Evidence for Dynamical Scattering. *Astronom. J.*, 157(2):71, Feb. 2019. doi: 10.3847/1538-3881/aafacb.

[17] L. A. Pearce, A. L. Kraus, T. J. Dupuy, A. W. Mann, E. R. Newton, B. M. Tofflemire, and A. Vanderburg. Orbital Parameter Determination for Wide Stellar Binary Systems in the Age of Gaia. *Astrophys. J.*, 894(2):115, May 2020. doi: 10.3847/1538-4357/ab8389.

[18] L. A. Pearce, A. L. Kraus, T. J. Dupuy, A. W. Mann, and D. Huber. Boyajian's Star B: The Co-moving Companion to KIC 8462852 A. *Astrophys. J.*, 909(2):216, Mar. 2021. doi: 10.3847/1538-4357/abdd33.

[19] L. A. Pearce, J. R. Males, A. J. Weinberger, J. D. Long, K. M. Morzinski, L. M. Close, and P. M. Hinz. Companion mass limits for 17 binary systems obtained with binary differential imaging and MagAO/Clio. *Mon. Not. R. Astron. Soc.*, 515(3):4487–4504, Sept. 2022. doi: 10.1093/mnras/stac2056.

[20] L. A. Pearce, J. R. Males, S. Y. Haffert, L. M. Close, J. D. Long, A. L. McLeod, J. M. Knight, A. D. Hedglen, A. J. Weinberger, O. Guyon, M. Kautz, K. Van Gorkom, J. Lumbres, L. Schatz, A. Rodack, V. Gasho, J. Kueny, W. Foster, K. M. Morzinski, and P. M. Hinz. HIP 67506 C: MagAO-X confirmation of a new low-mass stellar companion to HIP 67506 A. *Mon. Not. R. Astron. Soc.*, 521(3):4775–4784, May 2023. doi: 10.1093/mnras/stad859.

[21] H. B. Perets. Planets in Evolved Binary Systems. In S. Schuh, H. Drechsel, and U. Heber, editors, *Planetary Systems Beyond the Main Sequence*, volume 1331 of *American Institute of Physics Conference Series*, pages 56–75, Mar. 2011. doi: 10.1063/1.3556185.

[22] C. Petrovich and D. J. Muñoz. Planetary Engulfment as a Trigger for White Dwarf Pollution. *Astrophys. J.*, 834:116, Jan. 2017. ISSN 0004-637X. doi: 10.3847/1538-4357/834/2/116.

[23] K. D. Putirka and S. Xu. Polluted white dwarfs reveal exotic mantle rock types on exoplanets in our solar neighborhood. *Nat. Commun.*, 12:6168, Nov. 2021. ISSN 2041-1723. doi: 10.1038/s41467-021-26403-8.

[24] J. J. Ren, R. Raddi, A. Rebassa-Mansergas, M. S. Hernandez, S. G. Parsons, P. Irawati, P. Rittipruk, M. R. Schreiber, B. T. Gänsicke, S. Torres, H. J. Wang, J. B. Zhang, Y. Zhao, Y. T. Zhou, Z. W. Han, B. Wang, C. Liu, X. W. Liu, Y. Wang, J. Zheng, J. F. Wang, F. Zhao, K. M. Cui, J. R. Shi, and H. Tian. The White Dwarf Binary Pathways Survey. V. The Gaia White Dwarf Plus AFGK Binary Sample and the Identification of 23 Close Binaries. *Astrophys. J.*, 905(1):38, Dec. 2020. doi: 10.3847/1538-4357/abc017.

[25] A. P. Stephan, S. Naoz, and B. Zuckerman. Throwing Icebergs at White Dwarfs. *Astrophys. J. Let.*, 844(2):L16, Aug. 2017. doi: 10.3847/2041-8213/aa7cf3.

[26] D. Veras. Post-main-sequence planetary system evolution. *Royal Society Open Science*, 3:150571, Feb. 2016. doi: 10.1098/rsos.150571.

[27] D. Veras, A. J. Mustill, B. T. Gänsicke, S. Redfield, N. Georgakarakos, A. B. Bowler, and M. J. S. Lloyd. Full-lifetime simulations of multiple unequal-mass planets across all phases of stellar evolution. *Mon. Not. R. Astron. Soc.*, 458(4):3942–3967, June 2016. doi: 10.1093/mnras/stw476.

[28] D. Veras, N. Georgakarakos, I. Dobbs-Dixon, and B. T. Gänsicke. Binary star influence on post-main-sequence multi-planet stability. *Mon. Not. R. Astron. Soc.*, 465:2053–2059, Feb. 2017. ISSN 0035-8711. doi: 10.1093/mnras/stw2699.

[29] D. Veras, S. Xu, and A. Rebassa-Mansergas. The critical binary star separation for a planetary system origin of white dwarf pollution. *Mon. Not. R. Astron. Soc.*, 473:2871–2880, Jan. 2018. ISSN 0035-8711. doi: 10.1093/mnras/stx2141.

[30] B. Willems and U. Kolb. Detached white dwarf main-sequence star binaries. *Astronomy & Astrophysics*, 419:1057–1076, June 2004. doi: 10.1051/0004-6361:20040085.

[31] S. Xu and A. Bonsor. Exogeology from Polluted White Dwarfs. *Elements*, 17(4):241, Aug. 2021. doi: 10.48550/arXiv.2108.08384.

[32] B. Zuckerman. The Occurrence of Wide-orbit Planets in Binary Star Systems. *Astrophys. J.*, 791: L27, Aug. 2014. ISSN 0004-637X. doi: 10.1088/2041-8205/791/2/L27.

[33] B. Zuckerman, D. Koester, C. Melis, B. M. Hansen, and M. Jura. The Chemical Composition of an Extrasolar Minor Planet. *Astrophys. J.*, 671(1):872–877, Dec. 2007. doi: 10.1086/522223.

References

[1] W. S. Adams. The Spectrum of the Companion of Sirius. , 27(161):236, Dec. 1915. doi: 10.1086/122440.

[2] Á. Bazsó and E. Pilat-Lohinger. Fear the Shadows of the Giants: On Secular Perturbations in Circumstellar Habitable Zones of Double Stars. *Astronom. J.*, 160(1):2, July 2020. doi: 10.3847/1538-3881/ab9104.

[3] F. W. Bessel. On the variations of the proper motions of Procyon and Sirius. *Mon. Not. R. Astron. Soc.*, 6:136–141, Dec. 1844. doi: 10.1093/mnras/6.11.136.

[4] A. Bonsor and D. Veras. A wide binary trigger for white dwarf pollution. *Mon. Not. R. Astron. Soc.*, 454:53–63, Nov. 2015. ISSN 0035-8711. doi: 10.1093/mnras/stv1913.

[5] S. Christian, A. Vanderburg, J. Becker, D. A. Yahalomi, L. Pearce, G. Zhou, K. A. Collins, A. L. Kraus, K. G. Stassun, Z. de Beurs, G. R. Ricker, R. K. Vanderspek, D. W. Latham, J. N. Winn, S. Seager, J. M. Jenkins, L. Abe, K. Agabi, P. J. Amado, D. Baker, K. Barkaoui, Z. Benkhaldoun, P. Benni, J. Berberian, P. Berlind, A. Bieryla, E. Esparza-Borges, M. Bowen, P. Brown, L. A. Buchhave, C. J. Burke, M. Buttu, C. Cadieux, D. A. Caldwell, D. Charbonneau, N. Chazov, S. Chimaladinne, K. I. Collins, D. Combs, D. M. Conti, N. Crouzet, J. P. de Leon, S. Deljookorani, B. Diamond, R. Doyon, D. Dragomir, G. Dransfield, Z. Essack, P. Evans, A. Fukui, T. Gan, G. A. Esquerdo, M. Gillon, E. Girardin, P. Guerra, T. Guillot, E. K. K. Habich, A. Henriksen, N. Hoch, K. I. Isogai, E. Jehin, E. L. N. Jensen, M. C. Johnson, J. H. Livingston, J. F. Kielkopf, K. Kim, K. Kawauchi, V. Krushinsky, V. Kunzle, D. Laloum, D. Leger, P. Lewin, F. Mallia, B. Massey, M. Mori, K. K. McLeod, D. Mékarnia, I. Mireles, N. Mishevskiy, M. Tamura, F. Murgas, N. Narita, R. Naves, P. Nelson, H. P. Osborn, E. Palle, H. Parviainen, P. Plavchan, F. J. Pozuelos, M. Rabus, H. M. Relles, C. Rodríguez López, S. N. Quinn, F.-X. Schmider, J. E. Schlieder, R. P. Schwarz, A. Shporer, L. Sibbald, G. Srdoc, C. Stibbards, H. Stickler, O. Suarez, C. Stockdale, T.-G. Tan, Y. Terada, A. Triaud, R. Tronsgaard, W. C. Waalkes, G. Wang, N. Watanabe, M.-S. Wenceslas, G. Wingham, J. Wittrock, and C. Ziegler. A Possible Alignment Between the Orbits of Planetary Systems and their Visual Binary Companions. *Astronom. J.*, 163(5):207, May 2022. doi: 10.3847/1538-3881/ac517f.

[6] A. Eggenberger, S. Udry, and M. Mayor. Statistical properties of exoplanets. III. Planet properties and stellar multiplicity. *Astronomy & Astrophysics*, 417:353–360, Apr. 2004. doi: 10.1051/0004-6361:20034164.

[7] C. Flammarion. The Companion of Sirius. *Astronomical register*, 15:186–189, Jan. 1877.

[8] C. Fontanive and D. Bardalez Gagliuffi. The Census of Exoplanets in Visual Binaries: population trends from a volume-limited Gaia DR2 and literature search. *Frontiers in Astronomy and Space Sciences*, 8:16, Mar. 2021. doi: 10.3389/fspas.2021.625250.

[9] A. S. Hamers and S. F. Portegies Zwart. White dwarf pollution by planets in stellar binaries. *Mon. Not. R. Astron. Soc.*, 462:L84–L87, Oct. 2016. ISSN 0035-8711. doi: 10.1093/mnrasl/slw134.

[10] J. B. Holberg, T. D. Oswalt, E. M. Sion, M. A. Barstow, and M. R. Burleigh. Where are all the Sirius-like binary systems? *Mon. Not. R. Astron. Soc.*, 435(3):2077–2091, Nov. 2013. doi: 10.1093/mnras/stt1433.

[11] N. A. Kaib, S. N. Raymond, and M. Duncan. Planetary system disruption by Galactic perturbations to wide binary stars. *Nat.*, 493(7432):381–384, Jan. 2013. doi: 10.1038/nature11780.

[12] B. Katz, S. Dong, and D. Kushnir. Luminosity function suggests up to 100 white dwarfs within 20 pc may be hiding in multiple systems. *arXiv e-prints*, art. arXiv:1402.7083, Feb. 2014. doi: 10.48550/arXiv.1402.7083.

[13] K. M. Kratter and H. B. Perets. Star Hoppers: Planet Instability and Capture in Evolving Binary Systems. *Astrophys. J.*, 753(1):91, July 2012. doi: 10.1088/0004-637X/753/1/91.

[14] M. Moe and R. Di Stefano. Mind Your Ps and Qs: The Interrelation between Period (P) and Mass-ratio (Q) Distributions of Binary Stars. *Astrophys J., Sup.*, 230(2):15, June 2017. doi: 10.3847/1538-4365/aa6fb6.

[15] A. J. Mustill, M. B. Davies, S. Blunt, and A. Howard. Dynamical orbital evolution scenarios of the wide-orbit eccentric planet HR 5183b. *Mon. Not. R. Astron. Soc.*, 509(3):3616–3625, Jan. 2022. doi: 10.1093/mnras/stab3174.

[16] L. A. Pearce, A. L. Kraus, T. J. Dupuy, M. J. Ireland, A. C. Rizzuto, B. P. Bowler, E. K. Birchall, and A. L. Wallace. Orbital Motion of the Wide Planetary-mass Companion GSC 6214-210 b: No Evidence for Dynamical Scattering. *Astronom. J.*, 157(2):71, Feb. 2019. doi: 10.3847/1538-3881/aafacb.

[17] L. A. Pearce, A. L. Kraus, T. J. Dupuy, A. W. Mann, E. R. Newton, B. M. Tofflemire, and A. Vanderburg. Orbital Parameter Determination for Wide Stellar Binary Systems in the Age of Gaia. *Astrophys. J.*, 894(2):115, May 2020. doi: 10.3847/1538-4357/ab8389.

[18] L. A. Pearce, A. L. Kraus, T. J. Dupuy, A. W. Mann, and D. Huber. Boyajian's Star B: The Co-moving Companion to KIC 8462852 A. *Astrophys. J.*, 909(2):216, Mar. 2021. doi: 10.3847/1538-4357/abdd33.

[19] L. A. Pearce, J. R. Males, A. J. Weinberger, J. D. Long, K. M. Morzinski, L. M. Close, and P. M. Hinz. Companion mass limits for 17 binary systems obtained with binary differential imaging and MagAO/Clio. *Mon. Not. R. Astron. Soc.*, 515(3):4487–4504, Sept. 2022. doi: 10.1093/mnras/stac2056.

[20] L. A. Pearce, J. R. Males, S. Y. Haffert, L. M. Close, J. D. Long, A. L. McLeod, J. M. Knight, A. D. Hedglen, A. J. Weinberger, O. Guyon, M. Kautz, K. Van Gorkom, J. Lumbres, L. Schatz, A. Rodack, V. Gasho, J. Kueny, W. Foster, K. M. Morzinski, and P. M. Hinz. HIP 67506 C: MagAO-X confirmation of a new low-mass stellar companion to HIP 67506 A. *Mon. Not. R. Astron. Soc.*, 521(3):4775–4784, May 2023. doi: 10.1093/mnras/stad859.

[21] H. B. Perets. Planets in Evolved Binary Systems. In S. Schuh, H. Drechsel, and U. Heber, editors, *Planetary Systems Beyond the Main Sequence*, volume 1331 of *American Institute of Physics Conference Series*, pages 56–75, Mar. 2011. doi: 10.1063/1.3556185.

[22] C. Petrovich and D. J. Muñoz. Planetary Engulfment as a Trigger for White Dwarf Pollution. *Astrophys. J.*, 834:116, Jan. 2017. ISSN 0004-637X. doi: 10.3847/1538-4357/834/2/116.

[23] K. D. Putirka and S. Xu. Polluted white dwarfs reveal exotic mantle rock types on exoplanets in our solar neighborhood. *Nat. Commun.*, 12:6168, Nov. 2021. ISSN 2041-1723. doi: 10.1038/s41467-021-26403-8.

[24] J. J. Ren, R. Raddi, A. Rebassa-Mansergas, M. S. Hernandez, S. G. Parsons, P. Irawati, P. Rittipruk, M. R. Schreiber, B. T. Gänsicke, S. Torres, H. J. Wang, J. B. Zhang, Y. Zhao, Y. T. Zhou, Z. W. Han, B. Wang, C. Liu, X. W. Liu, Y. Wang, J. Zheng, J. F. Wang, F. Zhao, K. M. Cui, J. R. Shi, and H. Tian. The White Dwarf Binary Pathways Survey. V. The Gaia White Dwarf Plus AFGK Binary Sample and the Identification of 23 Close Binaries. *Astrophys. J.*, 905(1):38, Dec. 2020. doi: 10.3847/1538-4357/abc017.

[25] A. P. Stephan, S. Naoz, and B. Zuckerman. Throwing Icebergs at White Dwarfs. *Astrophys. J. Let.*, 844(2):L16, Aug. 2017. doi: 10.3847/2041-8213/aa7cf3.

[26] D. Veras. Post-main-sequence planetary system evolution. *Royal Society Open Science*, 3:150571, Feb. 2016. doi: 10.1098/rsos.150571.

[27] D. Veras, A. J. Mustill, B. T. Gänsicke, S. Redfield, N. Georgakarakos, A. B. Bowler, and M. J. S. Lloyd. Full-lifetime simulations of multiple unequal-mass planets across all phases of stellar evolution. *Mon. Not. R. Astron. Soc.*, 458(4):3942–3967, June 2016. doi: 10.1093/mnras/stw476.

[28] D. Veras, N. Georgakarakos, I. Dobbs-Dixon, and B. T. Gänsicke. Binary star influence on post-main-sequence multi-planet stability. *Mon. Not. R. Astron. Soc.*, 465:2053–2059, Feb. 2017. ISSN 0035-8711. doi: 10.1093/mnras/stw2699.

[29] D. Veras, S. Xu, and A. Rebassa-Mansergas. The critical binary star separation for a planetary system origin of white dwarf pollution. *Mon. Not. R. Astron. Soc.*, 473:2871–2880, Jan. 2018. ISSN 0035-8711. doi: 10.1093/mnras/stx2141.

[30] B. Willems and U. Kolb. Detached white dwarf main-sequence star binaries. *Astronomy & Astrophysics*, 419:1057–1076, June 2004. doi: 10.1051/0004-6361:20040085.

[31] S. Xu and A. Bonsor. Exogeology from Polluted White Dwarfs. *Elements*, 17(4):241, Aug. 2021. doi: 10.48550/arXiv.2108.08384.

[32] B. Zuckerman. The Occurrence of Wide-orbit Planets in Binary Star Systems. *Astrophys. J.*, 791: L27, Aug. 2014. ISSN 0004-637X. doi: 10.1088/2041-8205/791/2/L27.

[33] B. Zuckerman, D. Koester, C. Melis, B. M. Hansen, and M. Jura. The Chemical Composition of an Extrasolar Minor Planet. *Astrophys. J.*, 671(1):872–877, Dec. 2007. doi: 10.1086/522223.

Data Management Plan

Data Products: Data associated with this project will include imaging and spectroscopic data obtained from astronomical instrumentation (fits files) and code used to reduce and analyze the data.

Data Storage and Computation: I anticipate that 4 TB of storage will be necessary to manage the instrument data, which I will store locally on an external hard drive. Some instruments may also maintain an archive for data storage, but not all. I will maintain local copies of all instrument data files used in this survey. The data analysis code will be maintained on my local machine, on Dropbox, and on my personal GitHub.

Data and Research Product Dissemination: I will make all data reduction and analysis code publicly available on my GitHub account. I will share my methods and results with the scientific community via peer reviewed publications, with my GitHub repositories clearly associated with each paper. I anticipate that my research will result in three publications over the course of the three year fellowship. I also maintain a robust research website in which I will summarize my work in public-friendly language and provide links to resources I generate for the community.

Broader Impacts: I will produce a website for the Student Veterans Research Symposium with all public-facing information and products relating to the symposium. Internal documentation will be hosted on a Google drive and enable collaboration while producing the symposium. Data collected on participation and demographic information will be privately maintained and not accessible to the public. The event will also be documented on my personal website.

FACILITIES, EQUIPMENT, AND OTHER RESOURCES

Data collection for my research will be conducted at the Magellan Clay Telescope at Las Campanas Observatory in Chile using the MagAO-X instrument, at the Subaru Telescope in Hawai'i using the SCExAO instrument, at the Keck II Telescope in Hawai'i using the HIRES instrument, and at local telescopes at Kitt Peak in Arizona. Magellan and the Arizona telescopes are maintained by Steward Observatory and accessed via Steward's time allocation committee (TAC), Keck is maintained by the Keck Observatory and accessed via their TAC, and Subaru is maintained by NOAJ and access via their TAC.

My proposed research analysis will primarily be completed on a laptop or desktop, as stated in the Data Management Plan. Large or long analysis computations can be completed using the high-performance computing facilities at Steward Observatory. I will require a 4TB hard drive to store the data.

The Student Veteran Research Symposium will make use of the University of Arizona room facilities and catering services. We will work with UA to reserve adequate rooms for the seminar, keynote speaker, poster hall, and conference dinner.

THE UNIVERSITY OF ARIZONA
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October 11, 2023

National Science Foundation
Astronomy and Astrophysics Postdoctoral Fellowship Office

To Whom it May Concern:

We are writing in regard to Logan Pearce's application for a NSF AAPF. Her proposed scientific mentor, Olivier Guyon, has reviewed her research proposal. The University of Arizona (UA) will welcome her here and offer her full support and access to facilities if a Fellowship is awarded. Fellows and postdocs are fully integrated into the educational and research activities at UArizona, including teaching courses if they express an interest in gaining teaching experience, participating in research activities and seminars, and have access to all telescopes, observatory labs, and computing facilities under the operation of the UArizona. The proposed Student Veteran Research Symposium aligns with the UA's mission to serve veteran student population, especially in STEM, and complements UA's ASEMS-V program, a partnership between Arizona's Science, Engineering, and Math Scholars (ASEMS) Program to get veterans into STEM research experiences.

Professor Olivier Guyon has agreed to collaborate with and mentor Logan Pearce in the research aspect of this project. Logan will be able to interact and collaborate with an excellent group of faculty and researchers in our department, and her past collaboration with campus veteran services provides a foundation for the success of the proposed educational program. Logan has demonstrated high levels of engagement in the educational, outreach and research activities of Steward Observatory throughout her PhD experience, and we are confident she will continue to do so as a postdoctoral researcher.

Sincerely,

Dr. Buell T. Jannuzi
Head, Department of Astronomy &
Director, Steward Observatory

Dr. Olivier Guyon
Astronomer
Steward Observatory