

Background

The search for worlds beyond our solar system that could harbor life is one of the main drivers in modern astronomy. To date, over 4000 planets around other stars (exoplanets) have been detected. Most known exoplanets have been discovered only indirectly by observing the effects they have on their host stars. Direct detection of exoplanets is extremely difficult. Planets are very faint compared to their host stars, and typically too close to be separated from the light of the star. Only a handful of exoplanets have been directly observed to date, yet direct detection offers to be the most promising avenue for the possibility of detecting indicators of life. By directly measuring the photons emitted or reflected by a planet, we can more easily study the chemistry of the atmospheres than by indirect methods.

The current state-of-the-art methodology for direct imaging searches and characterization of exoplanets from the ground are conducted on large telescopes with adaptive optics systems. Adaptive optics (AO) correct for the blurring effect of the Earth's atmosphere and approach the sharpest images allowed by physics. The larger the telescope, the easier it becomes to distinguish two point-sources at closer separations.

None of our current direct imaging technology is capable of imaging an Earth analog in the "habitable zone" (where liquid water might exist on the surface) of a G-type star. My research group has just achieved first light on the MagAO-X instrument, an extreme adaptive optics instrument on the Magellan Clay telescope, designed for the purpose of imaging exoplanets in reflected starlight. Reflected light imaging would allow detection of exoplanets regardless of age, and enable characterization of their atmospheres, including habitability markers such as the presence of O₂ or H₂O. To date no exoplanet has been observed in reflected light, however the giant telescopes coming online in the next decade promise a dramatic increase in capability of reflected light direct detection. MagAO-X serves as a precursor to GMagAO-X, the extreme adaptive optics instrument my research group is developing for the Giant Magellan Telescope (GMT), a 25-meter telescope currently being built in Chile. The GMT's advancements in observing power and instrumentation promise to deliver objects 100 million times fainter than their host stars and 6-60 milliarcsecond separations (Weinberger et al. 2018), bringing reflected light imaging of known exoplanets into the realm of possibility. **The 30-meter class ground-based telescopes and their exoplanet science was identified as the top priority for astronomy efforts for the next decade in the recent Astro2020 decadal survey results** (*Pathways*, 2021).

Detection of reflected starlight from a planet's atmosphere is a challenging observation, even with the advancements of the GMT. The PICASO python package (Batalha et al. 2019) was specifically created to enable determination of observing strategy and prediction of signal strength and contrast limits for reflected light exoplanet observations for the next generation of ground- and space-based telescopes. PICASO is an open-source python package developed by Dr. Natasha Batalha at NASA Ames and her collaborators that incorporates decades of radiative transfer models and codes into a robust package for predicting scattering for given exoplanet environments and conditions. It is a vital tool for planning reflected light observations, and for constraining the atmospheres of exoplanets using data obtained from those observations.

Internship Goals and Duties

I propose to complete an internship at NASA Ames, supervised by Natasha Batalha, to learn the intricacies of the PICASO code package and the scientific models and techniques underlying its predictions, and to generate observing strategies for reflected light observations of nearby known exoplanets with GMT and GMagAO-X. Using the PICASO models and parameters and noise models for GMT and GMagAO-X, I will predict observational requirements to yield optimal signal and retrievable information content for known exoplanets around nearby stars. This prediction is vital to being able to use the valuable and competitive telescope time effectively and maximize the information yield from the use of the telescope time. The end goal of the internship will be a well-designed open-source code package that provides users with observing requirements for GMT/GMagAO-X for a planet with given physical parameters and the PICASO modeling suite.

I intend to pursue a career in research, and intend to apply for post-doctoral positions following my PhD. The GMT is a massive undertaking with partner institutions all over the world. In the course of this internship, I will be collaborating with GMT stakeholders and managing the demands of users for predicting observing requirements, integrating complex systems (PICASO, GMagAO-X, physics of exoplanet detection), and leading design work for a vital tool for GMagAO-X and other reflected light imaging programs. This internship will build on and expand my leadership and management experience from my time as an officer in the US Navy, and adapt them to the world of international scientific collaborations.

To date my only research experience has been in university settings. This internship will also provide me with experience in a national science organization at NASA Ames, an environment I am intending to pursue as a career path. Experience at NASA is highly valuable for experiencing how science is done at a government agency, and how expectations and goals differ in the culture of the institution. I will foster professional relationships with a new network at NASA Ames and in the GMT community, and broaden my professional skills into a new subdiscipline (atmosphere modeling).

Broader Impacts

The tools I develop and skills I gain in this internship will be invaluable to the GMagAO-X instrument team and other astronomers attempting to perform these types of observations on GMT or other telescopes. **I will contribute a new observing tool to the community and gain a vital skill for the next several decades of exoplanet observing.**

Finally, I will incorporate this experience into community outreach I am involved with at home. I am the lead organizer of Astronomy on Tap (AoT) Tucson, which hosts monthly public astronomy talks at a local brewery. I intend to not only present this work at the Tucson show, but also volunteer to give a talk at the AoT San Francisco and AoT San Jose shows and assist with putting on those shows while I am at Ames. I also teach research at the University of Arizona Warrior Scholar Program, which offers two-week intensive college-prep "boot camps" for veterans. I have already begun planning for creating a research project around exoplanet atmospheres for future WSP workshops. Finally, **I am the founder of the Student Veterans Research Network**, a peer-network community of student veterans pursuing careers in research and graduate education. My participation in the INTERN program will enable me to mentor other student veterans in applying for and obtaining non-academic research internships. I currently actively distribute advice

and mentorship for the academic programs I have participated in (GRFP, NSF REUs, Goldwater and Astronaut Scholarships, etc), and I am eager to be able to help student veterans pursue non-academic internships as well.

References

Batalha, N. E., Marley, M. S., Lewis, N. K., Fortney, J. J. (2019). *ApJ* 878, 70

Pathways to Discovery in Astronomy and Astrophysics for the 2020s, 2021, National Academies of Sciences, <https://www.nap.edu/resource/26141/interactive/>

Weinberger, A., Birkby, J., Bowler, B., López-Morales, M., Males, J., Morzinski, K., Wang, S. (2018). *Giant Magellan Telescope Science Book*, Ch 2, <https://www.gmto.org/wp-content/uploads/GMTScienceBook2018.pdf>

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION University of Arizona				FOR NSF USE ONLY		
				PROPOSAL NO.	DURATION (months)	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Andrew Carnie				AWARD NO.	Proposed	Granted
				NSF Funded Person-months		Funds Requested By proposer
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)		CAL	ACAD	SUMR		
1.		0.00	0.00	0.00		
2.						
3.						
4.						
5.						
6.	(0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00		0
7.	(1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00		0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1.	(0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00		0
2.	(0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00		0
3.	(0) GRADUATE STUDENTS				17,000	
4.	(0) UNDERGRADUATE STUDENTS				0	
5.	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6.	(0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)					17,000	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					17,000	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)						
TOTAL EQUIPMENT					0	
E. TRAVEL						
1. DOMESTIC (INCL. U.S. POSSESSIONS)					21,397	
2. INTERNATIONAL					0	
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS \$ _____				0		
2. TRAVEL _____				0		
3. SUBSISTENCE _____				0		
4. OTHER _____				0		
TOTAL NUMBER OF PARTICIPANTS (0)					TOTAL PARTICIPANT COSTS	0
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES					0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					0	
3. CONSULTANT SERVICES					0	
4. COMPUTER SERVICES					0	
5. SUBAWARDS					0	
6. OTHER					2,686	
TOTAL OTHER DIRECT COSTS					2,686	
H. TOTAL DIRECT COSTS (A THROUGH G)					41,083	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
Total Direct Costs minus tuition charges (Rate: 26.0000, Base: 38815)						
TOTAL INDIRECT COSTS (F&A)					10,092	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					51,175	
K. FEE					0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)					51,175	
M. COST SHARING PROPOSED LEVEL \$				0	AGREED LEVEL IF DIFFERENT \$	
PI/PD NAME Andrew Carnie				FOR NSF USE ONLY		
				INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*				Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET Cumulative

ORGANIZATION University of Arizona				FOR NSF USE ONLY		
				PROPOSAL NO.	DURATION (months)	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Andrew Carnie				AWARD NO.	Proposed	Granted
				NSF Funded Person-months		Funds Requested By proposer
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)		CAL	ACAD	SUMR		
1.		0.00	0.00	0.00		
2.						
3.						
4.						
5.						
6.	() OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00		0
7.	(0) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00		0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1.	(0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00		0
2.	(0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00		0
3.	(0) GRADUATE STUDENTS				17,000	
4.	(0) UNDERGRADUATE STUDENTS				0	
5.	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6.	(0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)					17,000	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					17,000	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING \$5,000.)						
TOTAL EQUIPMENT					0	
E. TRAVEL						
1. DOMESTIC (INCL. U.S. POSSESSIONS)					21,397	
2. INTERNATIONAL					0	
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS \$ _____				0		
2. TRAVEL _____				0		
3. SUBSISTENCE _____				0		
4. OTHER _____				0		
TOTAL NUMBER OF PARTICIPANTS (0)					TOTAL PARTICIPANT COSTS	0
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES					0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					0	
3. CONSULTANT SERVICES					0	
4. COMPUTER SERVICES					0	
5. SUBAWARDS					0	
6. OTHER					2,686	
TOTAL OTHER DIRECT COSTS					2,686	
H. TOTAL DIRECT COSTS (A THROUGH G)					41,083	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)					10,092	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					51,175	
K. FEE					0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)					51,175	
M. COST SHARING PROPOSED LEVEL \$				0	AGREED LEVEL IF DIFFERENT \$	
PI/PD NAME Andrew Carnie				FOR NSF USE ONLY		
				INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*				Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification -

Budget Impact Statement: The budget has been revised, per the directive of Program Director, Dr. Joel F. Schildbach, to include additional information and justification for temporary relocation costs, while still maintaining a total budget request of \$55,000 or less. There will be no change to the scope of the project.

Personnel (line B.3). A stipend of \$17,000 (\$2,833.33 x 6 months) is being requested, while the GRF is active (on reserve) status. This is the same rate as the GRF stipend.

Travel (line E.1). \$21,397 is requested to cover the following travel and relocation related expenses:

- Cost of driving from Tucson, AZ to Mountain View, CA x2 (850 miles, 13 hours one way; Drive to Mountain View, return to Tucson; based on UA mileage reimbursement rates of \$.445 per mile <https://snre.arizona.edu/sites/snre.arizona.edu/files/5095%20Reimbursement%20Rates%20%20181001.pdf>) at \$378/one-way, for a total of \$757
- Hotel in between Tucson and Mountain View x2 nights at \$120/night, for a total of \$240
- Temporary Relocation Costs for a furnished guest house/studio with kitchen. Furnished studio/guest house with kitchen in Mountain View, CA for 6 months (April 1 - Sep 30, 2023) based on average AirBNB rental rates of \$3,400/mo (including taxes @ 9.13% and Fees). Attached link is an example representative of current listings: https://www.airbnb.com/wishlists/v/1190076276?s=67&unique_share_id=92988da1-6d06-4079-bd6f-0cb4e79d8fb2of
Total budget requested at \$3,400/mo, for 6 months is \$20,400.

Other (line G.6) \$2,686 is requested to cover the following expenses:

- \$2,268 to cover 2 months of Tuition and Fees for 3 credits of enrollment at the University of Arizona in the Fall 2023 semester, based on current FY23 rate of \$5,671.18 per semester.
- \$418 for 2 months of UA Student Health Insurance through UArizona campus health, provided by Aetna, based on current FY23 rate of \$1,045 for Fall

Indirect Costs (line I) \$10,092 is requested to cover the expenses related to Personnel, Travel and Other costs, less tuition and fees, at a rate of 26%

Total Budget Requested: \$51,175