University of Washington
Astrobiology Program

2011–2022 Academic Program Review
Self-Study Document

Natural Sciences Division, College of Arts and Sciences, in collaboration with the College of the Environment, the College of Engineering and the School of Medicine.

Date Submitted: March 27, 2023
Date Revised: April 24, 2023

Degrees / Certificates:	Graduate Certificate in Astrobiology Dual-Title PhD in Home Dept. & Astrobiology
Year of Last Review:	2010-2011
Program Director:	Victoria Meadows
Program Administrator:	Liza Young

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Part A: Required Background Information

Section I: Overview of Organization

I.1 The UW Astrobiology Program: Training the Next Generation of Astrobiologists.

The mission of the UW Astrobiology Graduate Program is to provide world-class graduate training in the interdisciplinary field of Astrobiology. Broadly, we support and train a community of interdisciplinary researchers and scholars who are interested in the search for life beyond the Earth. To do this, we offer a Graduate Certificate in Astrobiology and we manage a Dual-Title PhD in a Home Discipline and Astrobiology. The Graduate Certificate is offered in parallel with a student's graduate degree in their home department, and the Dual-title PhD is implemented as coordinated program tracks with the collaboration of 11 participating departments that span the Colleges of Arts and Sciences, The Environment, and Engineering—and the School of Medicine. More detailed descriptions of the Graduate Certificate and Dual-Title PhD programs can be found in Sections I.2.1 and II.1.1.

The Astrobiology Program is overseen by the Director---who is supported by the Astrobiology Program Administrator and the Astrobiology Steering Committee (Figure 1). The Steering Committee contains a representative subset of the graduate faculty, as well as representatives from the graduate student and postdoctoral scholar/research scientist community. The Director and Program Administrator manage student admissions, the student database, and coordinate and schedule undergraduate and graduate courses and seminars, student advising, and management, recording and notification of student milestones. The AB Steering Committee provides guidance on key aspects of the program management that include assessment and discussion of student research relevancy, curriculum changes, reporting requirements, and admission of new faculty. The student and postdoc representatives join Steering Committee meetings for discussions of general program issues that do not involve individual faculty or students. An Admissions Committee, which includes a subset of members of the Steering Committee, as well as additional Astrobiology faculty members, reviews applications to the Astrobiology Program from those students that have been admitted to their home departments. Figure 1 shows the organizational chart for the current program.

Current members of the Astrobiology Program include grad students, postdocs, faculty and staff. Today the program has 28 participating faculty from 9 departments and adjunct in a tenth, 34 graduate students from 7 departments, and 3 postdocs from one department (Figure 1). The five key departments in terms of active faculty and two or more students/postdocs are Astronomy, Earth and Space Sciences (ESS), Oceanography, Atmospheric Sciences and Psychology. Four of our faculty serve as astrobiology teaching faculty (Meadows (Astronomy), Barnes (Astronomy), Buick (ESS) and Catling (ESS)) and have a fraction of their teaching responsibilities dedicated to teaching astrobiology (ASTBIO) classes, in addition to mentoring astrobiology graduate students and serving on program committees. The remainder of our faculty serve on a voluntary basis are active in the program as grad student mentors, and they also volunteer to guest teach in our interdisciplinary graduate classes with our astrobiology teaching faculty, and to lead workshops and supervise research rotation students, and serve on program committees. Given the interdisciplinary training approach in our program, there is a considerable amount of faculty-student cross-mentoring that takes place, and a lot of it voluntarily, via interactions on doctoral committees, research rotations, workshops and courses.

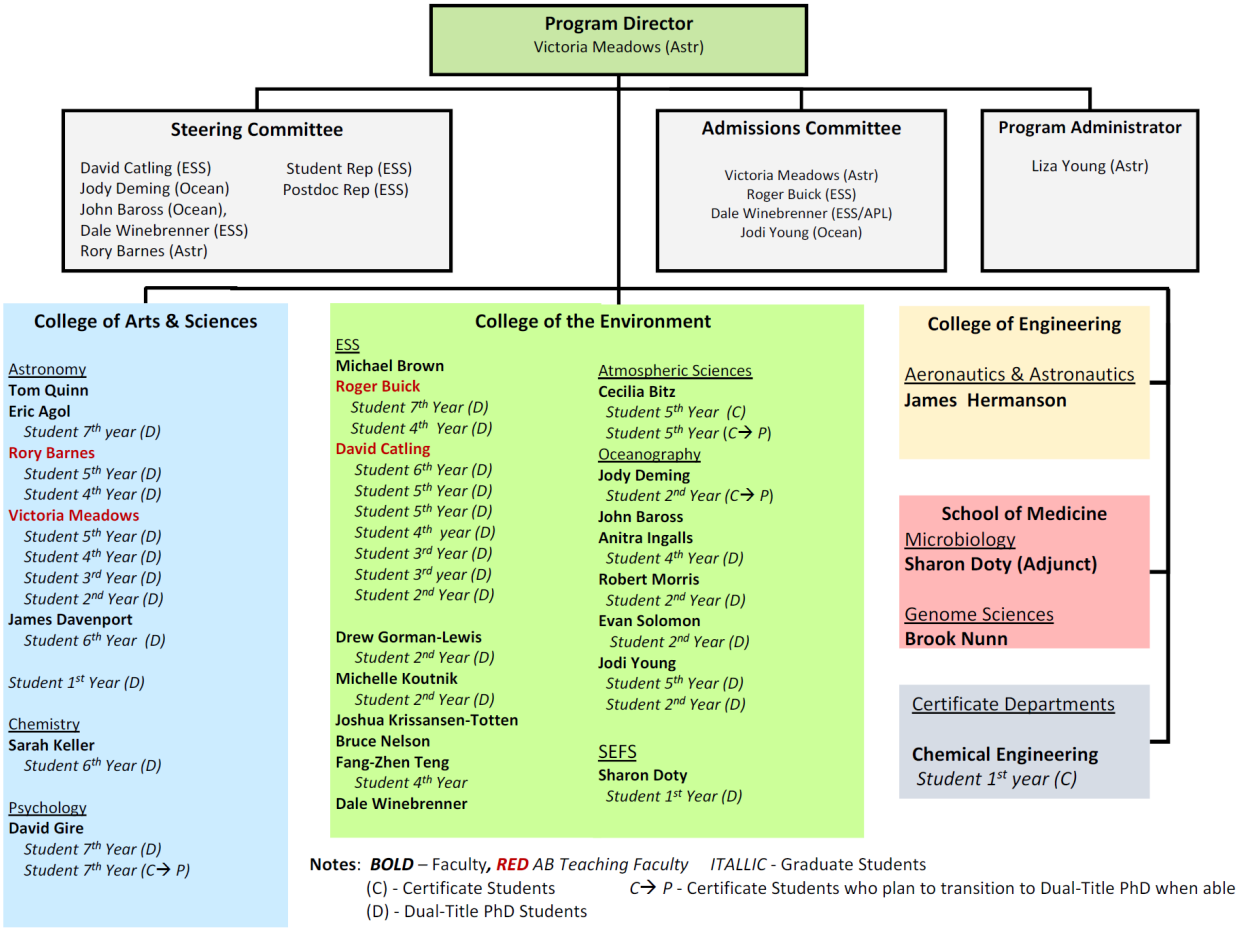


Figure 1: Redacted Organizational Chart for the UW Astrobiology Program

I.1.1 What is Astrobiology?

Astrobiology encompasses the study of life in the Universe, its origin, evolution, distribution and future. The term astrobiology was adopted by NASA, which kickstarted this field in 1995 after the discovery of the first exoplanet (Mayor & Queloz, 1995) and what appeared to be a fossilized microbe in a martian meteorite (McKay et al., 1996). Astrobiology's search for life elsewhere now provides an overarching theme for a large fraction of NASA's research, where it inspires interdisciplinary efforts that combine astrophysics, planetary science, Earth science and heliophysics. Life exists on Earth under and amazingly wide range of conditions that may also be possible on other planetary bodies, including on the surface and subsurface of Mars, in the icy-covered oceans of Europa and Enceladus, and on planets orbiting other stars. Astrobiology is now also a popular topic of research amongst the broader academic and international scientific community, and excites the interest and imagination of the public. Astrobiology research lays the scientific foundation that drives and guides the design of current and future missions to search for life elsewhere in the Solar System, and on extrasolar planets. Astrobiology and its key scientific goals featured prominently in four recent National Academy of Sciences committee reports, including both the Astronomy 2020 Decadal Review, and the Planetary Sciences Decadal (NASEM, 2018a,b;NASEM 2022a,b).

I.1.2 An Overview of The University of Washington's Astrobiology Credentials

Founded in 1998 under an NSF Interdisciplinary Graduate Education, Research and Training award, the now 24-year old UW Astrobiology Program offers a coursework-only Graduate Certificate, and manages a Dual-Title PhD degree in the Home Department and Astrobiology. The Graduate Certificate is available to students enrolled in master- and doctoral-level studies, primarily in STEM and Education Departments, while the Dual-Title PhD curriculum is available

only to students enrolled in 11 specific UWAB-affiliated doctoral programs. Training interdisciplinary scientists under the typically restrictive, department-dominated academic structure is a challenge, but we have worked to develop a structure that can bridge the barriers separating disciplines. The Astrobiology Program has evolved from an academic experiment in interdisciplinary training, with its first student enrollment in1999, into an international educational leader in a young but expanding and impactful scientific discipline. Although many universities offer undergraduate astrobiology courses, the UW Astrobiology Program is one of few to offer structured, interdisciplinary training at the graduate level. With 20 credits of coursework, as well as field workshops and a research rotation, our program is arguably the most comprehensive, coherent, and rigorous. Almost all of the 71 Astrobiology Program graduates have remained in STEM either in academia as professors and postdocs, or at NASA and national labs where they study natural phenomena and help lead missions to Mars, Europa and Venus.

I.1.2.1 The Astrobiology Graduate Certificate

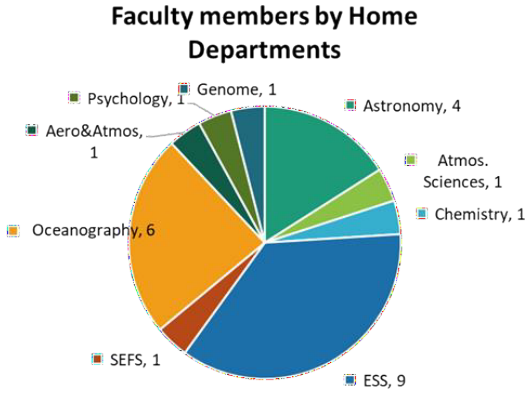
The Astrobiology Graduate Certificate is not standalone, and is awarded to Certificate Students by the program upon graduation from their home department's Masters or PhD graduate program. Prior to 2012, all students enrolled in the Astrobiology Program were only able to earn the Graduate Certificate in Astrobiology, regardless of their home department or the graduate program they were pursuing. At that time the Graduate Certificate requirements looked more like those of today's Dual-Title PhD, albeit without the requirement that the PhD research be astrobiology relevant. When the Dual-Title PhD program was initiated in 2012, we retained the Graduate Certificate option, but modified it to reduce its requirements to coursework only. We also reduced the required number of credits to 15 and modified the requirements so that it could be completed in the two years typical of a Masters program. This made the Astrobiology Certificate a viable option for Masters students, and PhD students enrolled in Departments that do not participate in the Dual-Title PhD option. The Astrobiology Program currently has 4 Certificate students in the Atmospheric Sciences, Psychology and Chemical Engineering Departments (although one of the Atmospheric Science students is applying to transfer into the Dual-Title PhD). In the past, we have graduated post-2012 Certificate Students in a diversity of departments including Earth and Space Sciences, Museology and Physics.

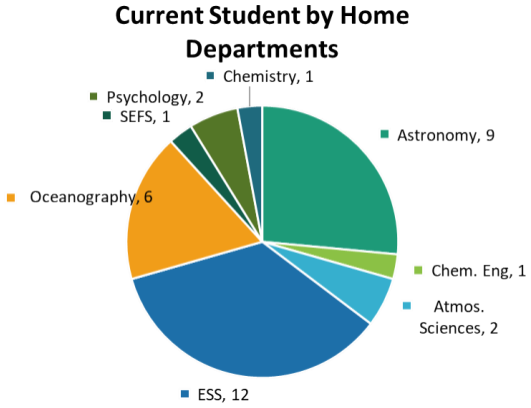
I.1.2.2 The Astrobiology Dual-Title PhD

The Astrobiology Dual-Title PhD was initiated by our Program in 2012 to more appropriately recognize the considerable work that had been done by graduate students in our Astrobiology Program under the former (pre-2012) Graduate Certificate, which is well above that of a typical coursework-only Graduate Certificate. At the time, we discussed creating a new Astrobiology PhD, but given the relatively newness of the field, we felt that might reduce the post-graduation options available to our students. Instead we opted to create an academic degree program that strongly grounded our students in their home discipline, with the same requirements as a "regular PhD" in their home fields, but that also expanded their interdisciplinary training into Astrobiology. Our desire to offer this type of credential was endorsed by the review committee in our last Astrobiology Program review, and since its initiation the Dual-Title PhD has been by far the most popular option for students admitted to our Program. Almost all students enrolled in our original graduate certificate prior to 2012 also opted to transfer into the Dual-Title PhD.

The Dual-Title PhD is not a Dual PhD Degree, supported by two departments, but is instead implemented as coordinated degree program tracks in 11 collaborating departmental programs (Astronomy, Atmospheric Sciences, Aeronautics & Astronautics, Biology, Chemistry, Earth and Space Sciences, Environmental and Forest Sciences, Genome Sciences, Microbiology, Oceanography, Psychology). These collaborating "home departments" span the Colleges of

Arts and Sciences, Environment, and Engineering---and the School of Medicine, and all participating units agree to a common set of requirements for their students in these degree tracks. In the Dual-Title PhD Degree, students complete all the requirements of their standard home department PhD track, but with an additional research rotation, and 20 additional credits of interdisciplinary coursework, colloquia, professional development and field trips---taught and led by Astrobiology Program Faculty. The Astrobiology Dual-Title PhD requirements are specified in the Astrobiology Program's Proposal which was submitted to the Grad School to initiate the Dual-Title PhD credential. On meeting all academic requirements from the home department and the Astrobiology Program, the home department awards the student a Dual-Title PhD, with is issued as a "Doctor of Philosophy in <Home Department> and Astrobiology".



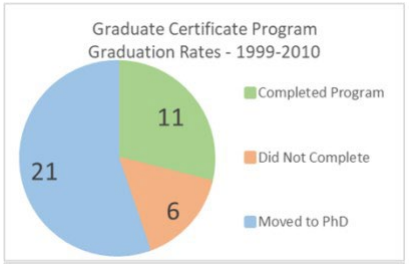


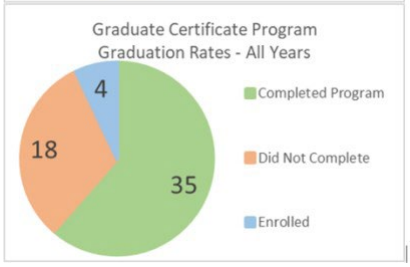
I.1.3 Enrollment and Graduation Patterns

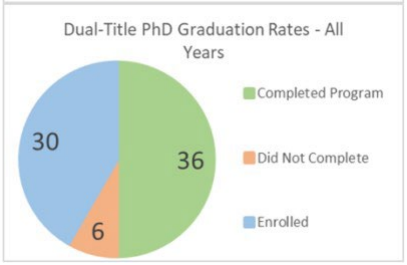
Since its inception in 2012, we have admitted 65 students to our program, and the majority of our students have enrolled in the Dual-Title PhD. We currently have 36 students in the program. Below we describe the enrollment and graduation patterns for the post-2012 Graduate Certificate students and the Dual-Title PhD students. For comparison, we also provide the statistics for the pre-2012 Graduate Certificate.

For the post-2012 Graduate Certificate we have admitted 14 students total, and 8 of them graduated with the Certificate, 2 did not complete it, and 4 are still enrolled today (in Chemical Engineering, Oceanography and Atmospheric Sciences). Since its inception in 2012, we have enrolled 51 students in the Dual-Title PhD, and 18 students have now graduated with the Dual-Title PhD, 3 did not complete the Dual-Title PhD and 30 are still enrolled in the program today. For comparison, 64 students were initially enrolled as Graduate Certificate students from 1998 until 2011. Of those, 24 students graduated with the Certificate, 19 students did not complete the program, and 21 students transferred to the Dual-Title PhD in 2012. Of those transferred students, 18 graduated with the Dual-Title PhD, and 3 did not complete the program.

These statistics show an increase in retention/completion rates in the Dual-Title PhD with a 56% graduation rate for the pre-2012 Certificate (excluding students who transferred into the PhD), an 80% graduation rate for the post-2012 Certificate, and a current 86% graduation rate for the Dual-Title PhD. We note also that over the life of the program, there is no statistical difference between the retention rates for male and female students, which are 69%/67% for graduation of men/women, and 32%/33% men/women for withdrawal from the program. For minorities, 3 out of 16 students withdrew from the program over the last 10 years (81% retention), an improvement over 3 out of 12 in the previous decade (75% retention), but not as high a







retention rate of the 46/48 (96% retention) for white students in the last 10 years. As alumni, our 71 Program graduates have almost all remained in STEM, in a variety of fields, where their training in interdisciplinary science is directly relevant to their career trajectories (See Appendix E for a list of our graduate alumni and their current positions).

I.1.3 Program Administrative Support

The UWAB program employs a 0.5 FTE Program Administrator to support the Program Director and program participants with the numerous administrative tasks related to the program. Because the Astrobiology Program, rather than the home department, is the office-of-record for student records pertaining to astrobiology coursework and astrobiology requirements, the Astrobiology Program Administrator is responsible for tracking student academic progress, maintaining accurate student records according to campus retention policies, providing timely reminders and notifications to students for academic requirements, and liaising with counterparts in the Program's participating departments to share information and facilitate accurate, timely advising for all students. The role also supports curriculum implementation and coordination (e.g. class listings, scheduling, TA recruitment, add codes, videoconferencing support and travel logistics for colloquium speakers) for the seven ASTBIO courses, helps manage the admissions process, and provides academic advising of students in the Graduate Certificate and Dual-Title PhD options. The program administrator position is responsible for fiscal tracking and budget projections for the Astrobiology State, matching/RCR and donor budgets, travel reimbursements and payment of invoices, and weekly updates, announcements, biannual newsletters and other forms of community communication and social interaction.

I.1.3 Shared Governance

The Astrobiology Program is managed by a faculty Director (currently, Professor Meadows in the Astronomy Department) who was appointed by the Divisional Dean of Natural Sciences in the College of Arts and Sciences in 2011, and she will serve three 5-year terms. She is advised by a Steering Committee of astrobiology faculty, research scientists, postdocs and students from participating departments. The Steering Committee is engaged 12 times a year on average, either via meetings, or via asynchronous e-mail discussion. On the Steering Committee, Prof. John Baross is now Emeritus, and will be replaced by Dr. Jodi Young (Oceanography), who has also agreed to trial serving as an Associate Director, starting in Autumn 2024. Though UWAB is officially "housed" with the College of Arts & Sciences, the leadership and faculty of this program routinely work in consultation with the leadership of our collaborating colleges and departments—most notably the College of the Environment. The Astrobiology Program also holds faculty meetings during the Spring and Fall quarters, which are open to all Astrobiology faculty. These meetings are used to discuss and gather input and feedback of plans for the program's annual workshop, other upcoming activities and conferences in the community, as well as changes to the program and the curriculum (such as

new departments joining the program). Reports on admissions, graduations, and other details of the general status and performance of the program are also provided to the faculty during these meetings. New faculty joining the Program are also given a 2 page information sheet outlining expectations for participation for Astrobiology Faculty, and key requirements and milestones they should know to help guide their students through the program (Appendix H).

The students are engaged primarily through annual progress reviews and other less formal opportunities to interact with program management. The students fill out an annual evaluation form and discuss this with their advisor, and are given opportunities to provide feedback on what is and isn't working for them in the program. The program leadership then meets with each advisor to discuss student progress and any clarification or assistance needed in meeting the program academic goals. To further engage students and the remainder of the community, the program has also solicited feedback using climate surveys, and for the last 10 years (with a break for COVID) informal interactions with the Director, faculty, students and postdocs has been encouraged at tea and coffee prior to our colloquium talks. In the 2021 ASTBIO575 Winter Seminar, the Director led a group of students in examining several aspects of how the field of astrobiology, and our program in particular, could be made more inclusive. Class discussions were further expanded on by the students in a series of journal club spillover sessions. A document of recommendations for the program was developed, and we are in the process of implementing these. As a result of a recent call for feedback, we have also initiated a monthly Fireside Chats with the Director meeting between the Director, and students and postdocs, to for professional development and program feedback discussions.

I.2 Budget & Resources

The Astrobiology Program currently requires a minimum of $250K-$270K/yr to fund administrative and instructional costs for its 34 graduate students and the ASTBIO115 undergraduate class. This funding covers 1.5 months of the Director's salary, 0.5 FTE of the Program Administrators salary, 3 Teaching Assistantships to support instruction for ASTBIO115, travel costs for the AB workshop for students and faculty, travel costs for invited speakers for the two ASTBIO 576 colloquia, funding for RA stipends and travel for 4-6 student research rotations a year, and 4-5 final write-up quarters, as well as a small amount of support for public talks, journal club, social events, and teaching lab and office supplies. Salaries for astrobiology teaching faculty were covered under the University Initiative Fund (UIF), but have reverted to the home departments to support, and they are not part of the Astrobiology Program budget.

At its inception, the Astrobiology Program was funded by two near-consecutive NSF IGERT awards for interdisciplinary training, but these expired in 2011. Over the last 12 years, funding for the Astrobiology Program has come from several sources: State provided funds from the College of Arts and Sciences (24% of our current revenue) and the College of the Environment (5%); Research Cost Recovery funds (RCR) and grant matching funds, from CoE, CoEnv and Provost, tied to the Director's Virtual Planetary Laboratory NASA Astrobiology Institute grants (currently 75%); and Gift and Donor Funds (1%). In the past, the fraction of the Astrobiology Program supported by VPL-related RCR and matching was significantly higher, approaching 80% of the total AB Program budget, and it also included the use of matching funding to support TA positions for our ASTBIO115 undergraduate Introduction to Astrobiology class.

State Budget: Over the past 12 years the Director has been able to negotiate with the College of Arts and Sciences (CAS) for improved support of essential components of the program via State Funds (See Appendix B). State funding committed in the Director's appointment agreement is now ~$75K/yr. The State budget now provides 0.5 FTE for an administrative

support professional staff position, and funding for three TAs for ASTBIO115 (2 from CAS, 1 from CoEnv), in addition to the initial fixed support of 1.5 months of the Director's salary and $11.5K/yr of workshop support. The Director's current tenure ends in 3 years.

VPL matching/RCR: Over the last 12 years, by far the largest source of support for this academic program has been from university matching fund agreements tied to two successful NASA awards for Director Meadows' NASA Astrobiology Institute (NAI) Virtual Planetary Laboratory research team. In the NAI competition, to be successful, teams required significant institutional partnership in the form of matching funds or other support offered in kind. Under this model, we were able to obtain a commitment to significant matching funds from the Deans Offices of College of Arts and Sciences Dean's Office, College of the Environment Dean's Office, the Earth & Space Sciences Department, and the School of Oceanography. These were then matched 2:1 by the Provost's Office. Under this agreement, all of the portion of RCR that would have gone to the Astronomy department from this award is instead provided to the Astrobiology Program, along with a portion of funding that would have gone to the Dean's office. These funds go towards RA positions for the Research Rotation requirement for the Dual-Title PhD, and to support research rotation and Colloquium speaker travel costs.

Gift/Donor funds: The program receives the donations to the discretionary Friends of Astrobiology fund, or the more restricted Graduate Student Support fund. Donations to these funds are primarily provided by current faculty members and alumni of the program, but we have also received donations, both one-time and reoccurring, from members of the public who are unaffiliated with the program. In a very noteworthy instance, in 2015 a private donor coordinated and held an audiovisual symphony on astrobiology themes at Benaroya Hall, and gifted the Astrobiology Program $10K for providing scientific consultation and discussion in collaboration with the composers, and we were able to solicit $2K of public donations at the concert itself. While the Graduate Student Support funds help our students with conference attendance, and field and laboratory work, the Friends of AB funds are used at the discretion of the Program Director to support community activities, such as the student Journal Club meetings, the New Student Orientation, and several social events throughout the year.

Although students engaging in research in the first twelve years of the program (1999-2011) were supported for two years each by IGERT traineeships, in the last 12 years students have been supported primarily by their advisor's research grants and instructional funding from their home department. Therefore, the majority of funding within the program goes to supporting students in attaining the program's academic requirements for workshops and research rotations. Our TA positions can also supplement advisor grant funding, and enable our students to gain experience in teaching interdisciplinary undergraduate courses. However, the program has also worked with the UW Advancement Office on several occasions to pursue additional funding from philanthropic sources, but these have not been successful to date. Our most successful donor event, the Origins Symphony, was initiated via direct contact from the donor to our then Director, Dr. Woody Sullivan. Additional funding strategies are given in Section IV.

I.3 Academic Unit Equity, Inclusion and Justice.

As both the Astrobiology Graduate Certificate and the Dual-Title PhD require that a student be enrolled in a home department before being admitted to the Astrobiology Program, the pool of applicants we select from for our program relies heavily on the diversity practices of the students' home departments. However, we actively participant in creating an equitable and inclusive environment for our students and Faculty, that is welcoming and supportive to all participants. Although we do not have a formal diversity committee, all members of the

program are responsible for participating in efforts to improve and ensure a welcoming environment, which is facilitated and led by the Director and Program Administrator. As an example, a recent initiative to explore and suggest ways we could improve the climate and support provided by the program to promote a diverse and safe community was undertaken by the students and led by the director as part of the Winter 2020 ASTBIO575 course.

Our faculty include research faculty, early/mid-career tenure track professors and tenured full professors, from the Astronomy, Atmospheric Sciences, Aeronautics & Astronautics, Earth & Space Sciences, Genome Sciences, Oceanography, Chemistry, Psychology and Environmental and Forest Sciences departments. Of these 25 STEM faculty members, 18 (64%) are male and 10(36%) are female, and 2 are racial minorities. Over the past 12 years, we have recruited 15 professors within the UW and improved the number of our female professors, evolving from 2 female faculty and no minority representation in 2012, to 10 female faculty and two minority professors (Black, Asian), today. Additionally the current Director is female and the current AB Program Administrator is an Asian female. In our student cohort, the current group is split 50/50 male/female, which is an improvement over the historical numbers of 63%/37% male/female. Since 2012 we have enrolled 48 white and 16 minority students (75%/25%).

To ensure we stay at the forefront of DEIA initiatives, the Director, faculty and and Program Administrator actively participate in training offered by the University. The Program Administrator most recently participated in the Neurodiverse Students in STEM activity, and the Equity & Justice in Graduate Programs Summit on Equity in Graduate Education. We engage with the University's Disability Resources for our students and although our GO-MAP (now GSEE) scholars are affiliated with their home departments, we have provided additional support by attending events for the students. Astrobiology Faculty have also led DEI initiatives in their home departments that we incorporate into the AB Program. For example, ESS's Prof., Roger Buick, co-authored UW's "Preventing Harassment in Fieldwork Situations" (2018), which was highlighted by the American Geophysical Union (AGU). The goal is to nurture a mutually respectful, inclusive and equal-opportunity community in field-work situations that involve our graduate students. We adopted these recommendations in our astrobiology field workshop in Clinton, B.C. and ensured there was a contact in the field to help with issues if they arose.

In 2021 via our ASTBIO575 Winter Seminar we began significant discussions on how to improve the climate and the sense of belonging for all members of the Astrobiology Program. In this seminar, in lieu of a science topic, we broadly explored aspects of Astrobiology as a discipline and a community. The intent was to learn about and discuss multiple areas that could address the question "How do we improve the field of astrobiology?" We included topics that affected both how we perform and promote our science, and how we build and support our community. With guidance from our climate surveys and student feedback, as well as the discussions and report from this class, several initiatives have been created with plans to implement more. These include more regular climate surveys, all-grad get togethers, a Slack channel for AB students, AB Coffee/Zoom meetings to get to know all members of our community, dedicated, regular discussions with the Director, and the facilitation of faculty, postdoc and/or peer mentorship of students and postdocs, and especially for new students.

In particular, our post-docs requested a larger role in instruction and mentoring within the program. This will also help the postdocs feel more integrated with the program, which has historically been a challenge. For the 2021 Biosignature Virtual Workshop led by Brook Nunn, postdoc Ardith Bravenac was instrumental in the setup and success of that workshop and participated in all aspects. Similarly, the most recent field workshop in Clinton, B.C in 2022 was co-led by postdoc Sebastian Haas, with Prof. Catling. Haas taught students directly in one-on-

one and group settings, and led the data collection demonstrations. We also created an expertise/internal directory in Slack for the Community to share our backgrounds and expertise which will allow postdocs (and students) to learn more about community expertise and potential mentors for their projects. We also emphasize that AB Faculty members are a secondary mentor for astrobiology students and postdocs and postdocs will be included in opt-in opportunities for more faculty interaction and professional development. The sense of belonging was a key factor shown in the UW Climate survey to enhance retention and student satisfaction. The Astrobiology program gives students a community where they feel they belong and that is shown not only in our increasing retention numbers but our students responses. This is something we are committed to fostering and continually improving.

Our faculty and students are active in sharing their love of science and recruiting potential students from diverse populations from middle school through undergraduate. Prof. Rory Barnes has led numerous Astrobiology lessons with the Mobile Planetarium (ABMP) for K-12 audiences throughout the state, including predominantly Hispanic and indigenous communities. Since February 2022, astrobiology graduate students founded and have been facilitating a program called Raising eSTEAM to provide tutoring to incarcerated middle and high school aged students at Echo Glen Children's Center, a juvenile detention center in Snoqualmie WA. Over the last 10 years both Astrobiology faculty and graduate students have expanded and supported the Astronomy Department's Pre-Major in Astronomy and Physics Program to add and supervise first year minority undergraduate students in astrobiology relevant research.

Section II: Teaching & Learning

II.1 Student Learning Goals and Outcomes

With the Astrobiology Program our goal is to provide world-class education in the interdisciplinary field of Astrobiology, and in interdisciplinary science in general. We also believe that we are responsible for teaching our students not only the science of astrobiology, but in also fostering their professional development and the broader skills needed as future scientists, technologists and team leaders, with practical experience in surveying the field, identifying gaps, writing and giving clear scientific presentations that can be understood by an interdisciplinary audience, and working on scientific proposals in a team setting. We strongly encourage our students to stray outside of their disciplinary comfort zones, to ask questions and learn from their professors and each other, and we encourage them to work in teams to bring their personal expertise to solve interdisciplinary problems. To contribute to an interdisciplinary team it is also absolutely critical that the student be firmly grounded in a home discipline. To that end we have developed the following curriculum, which is completed *in addition to all of the PhD or Master's Degree requirements of the student's home department.*

II.1.1 Requirements for the Graduate Certificate

The Astrobiology Graduate Certificate requires 15 credits of coursework (ASTBIO501, 502, 575, 576, 550, Cognate Course), which are described in more detail below. Although the requirements for this degree are coursework only, where space and funding permits, Certificate students will also be invited to join the annual workshops, which are a requirement for the Dual-Title PhD students (see Section II.1.2 below).

ASTBIO 501: Astrobiology Disciplines (4 credits). This course provides an introduction and concise background to core concepts and essential terminology of the relevant disciplines contributing to Astrobiology. Each week a faculty expert in one area (either the principal instructor or guest faculty) is teamed with a student. The pair prepare and deliver two lectures,

and lead a discussion of a recent paper. The students complete a term paper on an astrobiology topic of their choice. This format emphasizes literature exploration and active, peer teaching, and enhances faculty-student interactions.

ASTBIO 502: Astrobiology Topics (4 credits). This course examines a key topic in astrobiology from an interdisciplinary perspective. The course structure is developed by the principal instructor, who may provide an overview of the topic for 1-3 lectures, and then, depending on the size of the class AB faculty experts or visiting guest lecturers lead subsequent weeks, with student participation presenting relevant papers and/or preparing and delivering lectures. If the class is particularly large (e.g. 15+ students) students may have a larger role in peer teaching. Example ASTBIO502 topics have included “Life on Mars?”, “Extrasolar planets and habitability.”, “The rise of oxygen” and “Biosignatures”.

ASTBIO575: Winter Seminar (1 credit). During Winter Quarter we hold an “in-house” seminar series that either pairs faculty and students across disciplines, or has larger numbers of students work in groups to give presentations on a particular AB topic. In the past 12 years, this seminar has been taught 60% of the time by AB faculty other than the four teaching faculty, expanding our teaching expertise into more biological areas. However, for these faculty the class is taught either as a teaching overage, or in combination with a class the faculty member is teaching in their own department. Topics for the Winter series are flexible, and the class can foster close student interaction with faculty from other fields. Topics have included "The Origin of Life" (taught four times), “Computational Astrobiology”, “Origins and Evolution of Planetary Systems”, “Astrobiology Ethics”, “In Situ and Remote Sensing Biosignatures”, “Venus as an Astrobiology Target”, and “Improving Astrobiology”. Highlights include the Origin of Life classes, which in one case so engaged the students that they continued regular discussions on the topic years afterwards, and eventually wrote a review paper that was published in Geobiology (Stüeken et al., 2013). Similarly the 2020 Improving Astrobiology class led to the students discussing how to improve both our science and diversify the community doing it and similarly engaged the students in student-led follow-on discussions and a white-paper style report.

ASTBIO 576: Astrobiology Colloquium (1 credit). During Autumn and Spring Quarters we present a broad range of talks from at least six outside speakers, combined with research rotation presentations, new community member science introduction talks (faculty and postdocs), faculty science tutorial talks, and “Science Magazine” sessions that feature 10 minute science update talks from 4 members of our community (grad students, postdocs, faculty). All speakers are instructed to be mindful of the interdisciplinary audience and keep their talks as jargon free as possible, with a longer introductory session to give adequate background for a non-specialist to understand the science results that follow. These colloquia are well attended, and have also been webcast and recorded. Until the NAI was disbanded, these talks were broadcast and archived on the NASA Astrobiology website and can still be found there. After 2018 we recorded them in house and archive them on the UW Astrobiology website and on our YouTube channel: https://www.youtube.com/@uwastrobiology8451/videos

ASTBIO550: Professional Development (2 credits). A seminar providing preparation for non-research aspects of being a scientist, including finding and applying for jobs, writing and reviewing grant proposals, building and managing science research teams, understanding the multiple career paths available to someone trained in astrobiology, and how to be an effective interdisciplinary researcher and teacher. Guest lecturers have included the NASA Astrobiology Senior Scientist, experts from the UW Job Center, and the Center for Teaching and Learning, and panels of our alumni now working in diverse jobs outside of typical R1 Academia. The course is split into two strands, one seminar per week on professional development topic with

the instructor and guest lecturers, and a second strand of group activities to develop, submit and mock NASA review interdisciplinary research proposals. Prior to 2018 our proposal efforts created mock (and sometimes real!) NAI Director's Discretionary Fund Proposals, but more recently we have worked on joint interdisciplinary NASA proposals or on NASA FINESST grad student scholarships proposals, with feedback from the instructor and class.

Cognate Course (3 credits): All students in our program are required to take a graduate or upper level undergraduate "Cognate Course" in a department different from their home department. The selection of this course is guided by a list of example courses which is kept on our website, and discussions with the student's advisor**.** These courses can be on complementary science topics for a student's research (e.g. Astronomy students take courses in ESS, Atmospheric Sciences and Oceanography) or topics that focus on excellence in communicating science to the public, or ethics in STEM (see our website for examples). These courses allow our students to expand their disciplinary repertoire, and gain instruction from experts in a broader range of subject areas than those covered by our Astrobiology Faculty.

II.1.2 Requirements for the Dual-Title PhD

The Dual-Title PhD is undertaken in an Astrobiology Program participating department and includes all the requirements of the home department's PhD. In addition, Dual-Title PhD students complete the same 15 credits of coursework as the Astrobiology Certificate, as well as 5 additional credits of coursework which includes additional ASTBIO575 and ASTBIO576 classes, and a quarter-long research rotation and final rotation presentation (ASTBIO600). Additional requirements for the Dual-Title also include 3 annual field workshops, and a PhD thesis whose research must be judged to be astrobiology relevant. The core courses ASTBIO501, ASTBIO502, ASTBIO575, ASTBIO576 and ASTBIO550 are typically let by the Astrobiology Teaching Faculty, although opportunities to lead ASTBIO575 and ASTBIO576 are open to all the astrobiology faculty, and our postdocs often help or lead the selection and hosting of speakers for ASTBIO576.

ASTBIO600: Research Rotation (3 credits): The research rotation is an astrobiology-relevant research experience undertaken for one quarter in an environment that is not the student's home department. Research rotations can be undertaken at UW in another faculty members lab, or can be held at other hosting labs nationally or internationally. The research rotation is initiated with a proposed project and budget, which is approved by the Research Rotation Faculty Coordinator and the Director. Students are encouraged to have a Research Rotation plan in place by their 2nd year, and to have completed their rotation by their 3rd year. In recent years with the pandemic though, we have seen significant and unavoidable delays in research rotation planning and execution. To complete the research rotation, the student either prepares a presentation and gives it to the entire UW Astrobiology community during an ASTBIO576 Astrobiology Colloquium slot (preferred) or submits a written report to the Steering Committee (in special circumstances). The research rotations not only expand a student's research horizons, but if done well, can also lead to future employment opportunities. For example, one of our students did their rotation at the Goddard Space Flight Center to learn more about astrobiology-relevant spacecraft mission concept design, and they were later hired by GSFC on graduation, and now have a leadership role on a spaceflight mission. More information on Research Rotations can be found in Appendix G.

Annual Field Workshops (3 required): Each year (except during the pandemic years 2020 and 2021) we hold a 3-5 day field workshop led by a volunteer faculty member, and/or postdoc. In some cases we have also leveraged research connections through VPL or other Astrobiology

research groups to have guest workshop leaders, as was the case for the Yellowstone workshop that was led by Niki Parenteau and David Des Marais from NASA Ames. These field workshops allow our students to explore different components of the disciplines that make up astrobiology, and also provide an excellent opportunity for interaction between faculty, students and postdocs outside of the classroom. Field workshop locations and the core discipline taught have included Hell's Creek Montana (paleontology), Death Valley (extremophiles) and the Jet Propulsion Laboratory (spaceflight mission design). In 2022 we also held a COVID-safe virtual workshop on designing a spacecraft mission to an icy moon and analyzing data for signs of life. More workshops and workshop details can be found in Section II.3 and Appendix F.

Astrobiology Relevant Research: To earn the dual-title PhD, each student must select an astrobiology-relevant research topic, and justify the astrobiology relevance of their thesis work. Their advisor must also be an Astrobiology Faculty member. Applications for astrobiology relevance are sent to the Steering Committee for review prior to both the general and the final exam, and consist of a cover letter from the student's astrobiology advisor, and supporting information in the form of a General research proposal, or abstract and table of contents for the final exam. The student is then notified in writing of the outcome. Additionally, each student's doctoral committee must include an Astrobiology Faculty member from outside the student's home department serves as an additional mentor for astrobiology research, and who is responsible, along with the student's advisor, for ensuring astrobiology relevancy of research.

II.1.3 Evaluation of Graduate Student Learning

Our graduate courses include a balance of learning from experts in the field with active learning from the students, guided by the principal instructor. These active learning tasks include literature searches and lecture preparation and delivery; scientific paper reading, presentation and discussion; term papers presented in review paper format; press release writing; proposal writing and reviewing, laboratory research, field work and data gathering and analysis. Many of these activities are also done in interdisciplinary groups, which helps to train the students in communicating across disciplines, and in examples of scientific teamwork.

II.1.4 ASTBIO115: An Undergraduate Introduction to Astrobiology

In this undergraduate class designed for non-science majors we introduce the new science of astrobiology, the study of the origin and evolution of life on Earth, and the search for microbial and intelligent life elsewhere in the Universe. This class can also be used to satisfy the UW's "Natural World" Requirement, and ASTBIO115 is also cross-listed as ASTR115, BIOL115, ESS115 and Ocean114. Our learning goals for this course include appreciating the transition from historical to modern views of astrobiology, understanding the origin and evolution of life, and the principles of searching for life in the Solar System and on planets orbiting other stars, and also grasping the key concepts illustrated by the scientific method and scientific debates. Evaulation is assessed using homework, a mid-term and a final. Our textbook is pitched at non-majors, and to enhance understanding we attempt to remove jargon or explain jargon when first introduced. We also include historical background and ongoing debates to engage and appeal to those from non-major disciplines. Student evaluations and homework/exam results are used to identify which concepts may be the most difficult to understand or have insufficient background for a non-specialist to follow, and additional work is done to provide needed background, and clarify explanations in lectures and labs.

II.1.5 Assessing Student Satisfaction and Student Progress

Student satisfaction with the Astrobiology Program experience is sought via course evaluation forms, annual student report feedback, student liaisons with the Steering Committee, climate

surveys, and opportunities for informal discussions with the Program Administrator and Director. Course evaluation forms are requested and completed for all ASTBIO classes, with the exception of the Autumn and Spring Colloquium series and the ASTBIO600 research rotation. All students in the program (Certificate and Dual-Title) in consultation with their advisors, fill out an annual progress report Google form providing a summary of that year's research, academic courses and program requirements completed, outreach activities, anticipated dates for significant degree milestones (e.g. General Exam), goals for the coming year, and are given an opportunity to leave feedback on things they would like to tell us or to see addressed. This yearly summary form is discussed between the advisor, the Director and one other member of the Steering Committee, when available. This annual meeting helps keep program leadership up to date on student progress, and helps us anticipate issues where the program can help. It provides feedback from the students, and helps us remind the advisor of Astrobiology program requirements. This review is in addition to any periodic reviews that may be required by a student's home department. The student representative on the Steering Committee also reports student questions, concerns and feedback on programmatic decisions during Steering Committee meetings. We have also administered Climate Surveys for the students, and the results were overwhelmingly positive (agree or strongly agree) for the program climate, with comparable results for male/female and those who identified as white/minority students. Finally, the orientation, seasonal socials, and the astrobiology tea and coffee held prior to our in person colloquia (which was paused during the early stages of the pandemic) are an opportunity for students, postdocs, faculty and the Director to informally interact and share feedback.

II.2 Instructional Effectiveness

All Astrobiology courses use the University's IAW system to provide standard course evaluation forms to enrolled students at the end of each quarter. These forms are also provided to the ASTBIO 115 quiz sections to provide graduate student TA's feedback separate from the feedback provided for the professor in charge of the main lecture section of the course. As described in detail above, we also solicit student feedback on their degree coursework in a variety of ways, and this feedback includes comments on instructional effectiveness. In addition, faculty obtain collegial teaching assessments from their home department, which may include teaching during astrobiology classes. Faculty and students may obtain training in instructional methods from their home departments via the Teaching Assistant Conference and instructional workshops held by the University. Teaching and Mentoring Outside of the Classroom. In the past feedback has included comments on expanding the type of proposals students can work on in the Professional Development class, and that was accommodated. Students have also been concerned about the challenge of learning about a completely new topic alone, to present in class, and so classes were restructured to include more faculty mentoring and the opportunity to work with peers in groups.

II.3 Teaching and Mentoring Outside the Classroom

One of the key differences between the Astrobiology Certificate and the Dual-Title PhD, and perhaps what distinguishes the Astrobiology Program from the home department degree programs, is the large extent to which teaching and mentoring occurs outside the classroom. Non-classroom activities in the Astrobiology Program include our field workshops and research rotations, our seminar and colloquia, and the scientific research of our graduate students. Our Astrobiology Faculty have numerous responsibilities in mentoring our students, both in the classroom and as Chairs and Astrobiology Faculty members of our students' doctoral committees. Faculty in the Steering Committee also play a major role in reviewing and approving the research relevancy of astrobiology students, and in monitoring their overall research and academic progress on an annual basis as described in Section II.1.5 above.

Faculty are also responsible for leading students on field expeditions pertaining to their own research, such as on ocean-going or polar research vessels, and on astronomical observing runs. Our faculty also volunteer to teach and mentor non-UW students interested in astrobiology and John Baross, David Catling, Victoria Meadows, Rory Barnes and others have all either taught at and/or organized summer or winter schools in astrobiology, including Meadows and Barnes who co-organized with Spanish astrobiologists, the International Summer School in Astrobiology in Santander, Spain from 2013-2019.

For the Dual-Title degree, as described in Section II.1.2 above, two significant educational experiences, the research rotation and the annual field workshop are held outside the classroom. Every AB Dual-Title PhD student must spend at least one quarter working in a lab outside their area of expertise. The location for the research rotation may be at UW or with experts at other universities and institutions, and NASA labs have been a popular destination that has also resulted in job offers for our graduating students. Because research rotations pair a student with a working lab for what is primarily an educational experience, the UW Astrobiology Program pays for the RA stipend and travel costs for the student to reduce any monetary burden on the hosting laboratory. However, there is still a considerable investment from the lab in training the students in new techniques, and helping them get to the stage that they are performing productive science. Many, although certainly not all, of our rotations are therefore supported by UW faculty volunteers, and UWAB alumni at other institutions.

Our research rotations have provided remarkably diverse and rewarding experiences. On campus, students have worked on projects including: “Designing and Developing an Octopus-Inspired Soft Robotic Limb”, “Diversity-generating retro-elements in hydrothermal vent archaea metagenomes of Lost City and the Hulk Vent”, “Growing transgenic and hyperaccumulator planets in Mars and lunar simulant soils”. Off campus, examples include lab work at JPL on “Serpentinizing systems on Enceladus and Europa”, and at GSFC on “Detecting Earth-like exoplanets via direct imaging” and “Modeling exo-zodiacal noise for exoplanet observations”.

Our annual field workshops are the most popular component of our Astrobiology program and provide additional and diverse opportunities in which to mentor and train our students. These immersive workshops are essential components to our program that allow students to collaborate across disciplines, learn about each other’s role in Astrobiology field, network for future collaborations, and build community. Our Dual-Title PhD students are required to participate in 3 of these annual workshops. These workshops are not required for Certificate students but we include these students when time and funding permit. Each year one of our faculty members organizes and leads a team of ~15 graduate students in hands-on activities such as field sample collections (ranging from geological to oceanographic seawater sampling), instrumentation (e.g., handheld nanopore devices, or GC-mass spectrometers), and data analysis, integration, or interpretation. Our most recent field-based workshops included trips on a research vessel in Puget Sound and a biogeochemical field expedition to Last Chance Lake Canada to collect water and microbiome samples from an early-Earth Analog site.

Due to safety concerns during the pandemic, we had to became creative with our research rotations, and instead of a field exercise, led by Brook Nunn (Genome Sciences) we developed an innovative, weeklong virtual workshop focused on a simulated mission to an icy moon of Jupiter, entitled “Simulated Mission to Detect Life 2022”. Although lacking in scenery, this workshop packed a punch on networking, with 15 students, and 5 faculty and postdocs participating, along with staff support and 15 outside experts who made themselves available on Zoom to answer student questions. Goals of the workshop included (but were not limited to) learning instrument capabilities & limitations, experimental design, sample management on site,

data types and structure, data analysis/interpretation, the importance of replication, how environmental context shapes interpretation, how to discriminate between life and non-life processes, and how to critically think about the Life Detection Ladder and assessing claims of life detection. The students were engaged 4 hours per day on Zoom, with 2-4 hours of outside learning and networking. Students "developed" scientific packages for both an Orbiter and a Lander, and analyzed and interpreted 90 (faculty and postdoc generated) datasets from the scientific packages they sent on their mission. We also held 5 in-person tours across campus to meet instrument-operators and see analog instruments. The workshop culminated in an evidence and science-based 3 hr public debate on Zoom: Team Life detection vs Team False Positive. The debate was well attended and audience members included the NASA Senior Scientist for Astrobiology (Mary Voytek), the co-Lead for the Network for Life Detection (Heather Graham), the president of Impossible Sensing (Pablo Sabron) and several outside professors.

II.4 Professional Development

In 2013, we developed and started teaching ASTBIO550 Professional Development for Astrobiologists which is required and taught ever 2-3 years. This course focuses on non-research aspects of being a scientist, to complement the more formal research training our graduate students receive from their advisors. Both the Certificate and the Dual-Title PhD place an emphasis on learning key skills for proposal preparation, peer review, scientific paper writing, science administration, writing faculty teaching statements, applying for jobs and negotiating. A feature of this course is a class on Astrobiology Careers Outside Academia, where we discuss options available for graduates, and which features several of our non-academic UWAB alumni. Other forms of professional development and career development include strategic research rotations in institutions that may hire the grad student, and support to attend professional conferences and workshops, including AbSciCon where we try to support every grad student who wishes to attend. Additionally, graduate students supervision of undergrads, benefits both with experience doing and supervising research and this is implemented through participation in programs like Pre-MAP, and in an advisor's research group.

Section III: Scholarly Impacts

Members of the UW Astrobiology Community are extremely productive and impactful, with many leading the field in their research areas. Below we describe highlights of that work and impact over the last 12 years. Faculty CVs are also provided in Appendix C.

III.1 Faculty Scholarly Impact

UW Astrobiology faculty have been instrumental in shaping the astrobiology community, yielding fundamental advances in several fields with research that highlights the broad interdisciplinary nature of our program. As one of our two largest research efforts, Astrobiology faculty housed in the astronomy department have systematically worked to lay the scientific foundation for the astronomical search for life on exoplanets, and their research has strongly influenced future science directions for the field of astronomy. Prof. Victoria Meadows has led the Virtual Planetary Laboratory for the last 22 years, with 70 researchers at 23 institutions exploring how to search for habitable worlds, and how to identify and ultimately confirm the presence of life. Her VPL team includes UWAB professors Barnes, Quinn and Agol (Astronomy), Bitz (Atmos), Baross (Ocean), Buick, Catling and Krissansen-Totton(ESS), Keller and Black (Chemistry), and publishes on average 80 papers a year. Major research themes for the VPL include using Earth as an exoplanet analog, understanding the life and environments of the Earth through time, exploring how interactions between a planet, its star, and planetary system affect habitability, understanding how life impacts its environment in observable ways, and simulating the

observability of signs of habitability and life for current and upcoming NASA telescopes. Our other major research effort is led by Prof. David Catling (ESS), who was awarded a $1.2 million from the Simons Foundation to study the early Earth environment conducive to the origin of life, and spread of life on the early Earth. Like VPL, this grant embodies the interdisciplinarity of the Astrobiology Program, and also includes several collaborators within UWAB faculty including Prof. Roger Buick (ESS), Prof. Sarah Keller (Chemistry), and Prof. Roy Black (Chemistry).

III.1.1 Research Highlights

Highlights from VPL researchers at UW in the last 10 years include research led by Professors Barnes, Agol and Meadows to understand the evolution and potential habitability of Earth-sized planets orbiting small, red M dwarf stars, the most common type of star in the Galaxy. These planets are the best targets for near-term observations from JWST and the next generation of extremely large ground-based telescopes. With a UWAB student, Prof. Barnes led a seminal theoretical paper on the early loss of M dwarf planetary oceans and habitability, and the potential for O_2 buildup (Luger & Barnes, 2015) that has now garnered nearly 500 citations. Prof. Agol helped discover the TRAPPIST-1 M dwarf planetary system, which is the most observationally promising for studying terrestrial exoplanet atmospheres (Gillon et al., 207). Prof. Agol also refined the Transit Timing Variation technique that he pioneered, to measure the masses of planets in the TRAPPIST-1 system, including three in the habitable zone, with exquisite 3% precision (Agol et al., 2021) showing they were indeed likely to be rocky, and potentially water-rich, although other compositions are possible. This paper is barely 2 years old and already has 130 citations. Prof. Meadows and her UW Astrobiology students used theoretical models to better understand the evolution and final state of several plausible types of atmospheres for the TRAPPIST-1 planets (Lincowski et al. 2018; 128 citations), the detectability of these states to JWST (Lustig-Yaeger et al., 2019; 175 citations) and the feasibility of detecting signs of life on these worlds (Meadows et al., 2023). Profs. Agol and Meadows are collaborators on JWST proposals to observe TRAPPIST-1 planets, and their work has been used to interpret the results from these data. They have also led and submitted numerous proposals to JWST to observe the TRAPPIST-1 system. Prof. Quinn and UWAB student Dr. Nate Kaib changed our view of the early Earth's Galactic with simulations that suggest that the Sun formed closer to the Galaxy's core and then migrated vast distances (Kaib & Quinn, 2011).

UWAB faculty in the Earth and Space Sciences (ESS) department are also field leaders in understanding geological evolution of planets and origin of life research. Prof. Josh Krissansen-Totton (ESS) – a previous 2019 Dual Title PhD student, now a recently-hired UWAB faculty member – has conducted several studies that have received wide media attention including work on disequilibrium biosignatures across Earth's history (Krissansen-Totton et al., 2016) that was covered by Scientific American and the LA Times, and work on constraining climate and ocean pH in the early Earth (Krissansen-Totton et al., 2018) covered by space.com; both of these studies also included UWAB alumna Dr. Giada Arney (NASA GSFC) and UWAB faculty Prof. David Catling (ESS). Other paradigm changing work from Dr. Catling's group on the environmental conditions on the Earth at the time of life's origin showed that impacts can generate atmospheres that are more conducive to producing organic molecules (Zahnle et al., 2020) and that carbonate-rich lakes can concentrate phosphate to the high levels needed for prebiotic chemistry, thereby solving an apparent bottleneck to the origin of life (Toner & Catling, 2020). Prof. Buick and then UWAB ESS students Eva Stüeken, Michael Kipp, Owen Lehmer, Matt Koehler and Eddie Schwieterman (Astronomy) published papers that illuminate the nature and processes that governed the composition of the early Earth atmosphere, including the development of nitrogen fixating metabolisms and the implication for atmospheric biosignatures (Stüeken et al., 2015; 2016), and the rise of oxygen (Krissansen-Totton et al., 2015; Kipp et al.,

2017). In an innovative piece of interdisciplinary work, UWAB student Sanjoy Som, with Buick and colleagues, combined engineering and geology expertise to use fossilized raindrop imprints to constrain the atmospheric pressure 2.7 billion years ago (Som et al., 2012; Som et al., 2016).

On exploring the possibility of life on icy worlds like the Jovian satellites, by studying similar environments here on Earth highlights include the discovery of dense bacterial communities in geologically isolated brine (Cooper et al, 2019) and exploration of the frozen Lake Vostok (Winebrenner et al., 2019). The unexpected discovery by Prof. Deming and then grad student Zach Cooper of very dense microbial life in a sub zero, yet liquid, habitat impacted the field of polar marine science, and revealed food security issues for Inuit ice cellars as well. In the Lake Vostok study, led by Prof. Dale Winebrenner with then UWAB grad student Paul Kintner, estimates of ice and oxygen fluxes across the lid of the frozen lake were obtained using radio waves, to better understand this terrestrial analog for world with ice-covered oceans.

On the origin of life, research spans Chemistry, ESS, Biology and Oceanography, and it has been significantly strengthened by the addition of Prof. Sarah Keller's lab and students in Chemistry. A paper led by students in Oceanography and Biology, who started their scientific discussion in an ASTBIO575 class let by John Baross, argued that the origin of life occurred due to combined actions in multiple environments (Stüeken et al., 2013; 120 citations). John Baross also led a review paper on the environmental roots of the Origin of Life with UWAB Alumni Stüeken and Anderson. Prof. Keller's lab showed how amino acids can stabilize fatty acid membranes in the presence of the salts required to catalyze RNA, solving the apparent paradox of how conditions that favor membranes and RNA work against each other, improving our understanding of how the first protocells might have arisen. This paper was promoted in a most-viewed article in the Atlantic, a SciShow video and a Discovery Magazine article.

III.1.2 Astrobiology Community Leadership

UWAB faculty have also led numerous community initiatives that shape the direction and scope of the field on a national and international level. The VPL and Prof. Meadows made the initial discoveries that showed the importance of interpreting biosignatures (signs of life in a planetary environment) in the context of that environment. This work focused on both false positives and false negatives for life mediated by the environment, and led to a 2016 focused workshop on Exoplanet Biosignatures organized by VPL personnel, and resulting in 6 papers, including three led by Prof. Meadows, Prof. Catling and UWAB alum Prof. Schwieterman, that have since obtained over 900 citations. Prof. Meadows was also Lead Editor for an Arizona Press Space Science Series book on Planetary Astrobiology, along with UW Alumna Dr. Giada Arney.

Prof. Meadows and Prof. Nunn also serve as Co-Leads for two of the five NASA Research Coordination Networks, the Nexus for Exoplanet Systems Science (NExSS) and the Network for Life Detection (NfoLD). As a NExSS Co-lead, in 2021, Prof. Meadows co-led the Biosignatures Standards of Evidence workshop with Dr. Heather Graham of GSFC (an NfoLD co-lead), an innovative virtual workshop to develop a community assessment framework for claims of biosignature detection and to start a community discussion on issues relating to a reporting protocol for biosignature discoveries. The workshop produced a community framework for biosignature assessment and an extensive community report (Meadows, Graham et al., 2022; https://arxiv.org/abs/2210.14293) and is the first of a series of biosignature workshops.

Prof. Meadows also co-leads, with TRAPPIST-1 discoverer Dr. Michaël Gillon (U. Liège), the JWST TRAPPIST-1 Community Initiative, a group of over 100 researchers working together to support each other in submitting JWST proposals on the TRAPPIST-1 system and analyzing the

data. As part of this initiative, Prof. Agol released up-to-date parameters of the TRAPPIST-1 system for community use. Prof. Rory Barnes has also hosted 2 public workshops on the open source virtual planet simulator, VPLanet; at the 2022 workshop collaborators from numerous institutions simulated facets of the evolution of the LP 890-9 system (Barnes et al., 2022).

Prof. Meadows has been extremely active in advocating for astrobiology research and defining the future vision for astrobiology on the national and international stage. She was lead editor for *Planetary Astrobiology*, an introductory review book targeted at graduate students and newcomers to the field (Meadows et al. 2020). In the last 5 years she also served as a member on the NAS panels on Exoplanet Strategy and Astrobiology Strategy (simultaneously), and a Science Panel Chair for the Science Panel on Exoplanets, Astrobiology and the Solar System for the NAS Astro2020 Decadal Report. The searching for life on exoplanets "Discovery Area" from her panel's report wasthe science driver for the next astrophysics flagship mission recommendation. The work of her former UWAB students featured prominently in the Astro2020 Decadal and she also testified to the NAS Planetary Sciences Decadal on Venus astrobiology.

III.1.3 Community Recognition

The scientific excellence of our faculty and their leadership in astrobiology has been widely recognized on the regional, national and international stage. Prof. Victoria Meadows (Astronomy), Prof. Sarah Keller (Chemistry), and Prof. Cecilia Bitz (Atmospheric Sciences) were all named to the Washington State Academy of Sciences. Prof. Bitz was named an American Meteorological Society fellow in 2015, and became an AGU Fellow in 2018, joining fellow UWAB Faculty AGU Fellows, Prof. Steve Warren and Prof. Deborah Kelley. Prof. Meadows became a fellow of the American Astronomical Society in 2022. Prof. John Baross (Oceanography) is a Fellow of the American Academy of Microbiology, and was awarded the 2022 NASA Exceptional Scientific Achievement award, and also featured as a leading NASA scientis in the 2021 NASA calendar. Prof. Jody Deming (Oceanography) was featured in the National Academy of Sciences outreach initiative DASER experiments in 2020. Prof. Evan Soloman (Oceanography) was named the U.S. Science Support Program's 2018 distinguished lecturer. Prof. Sarah Keller was named a 2021 Biophysical Society Fellow. Prof. Eric Agol (Astronomy) became a 2017 Guggenheim fellow. Prof. Cecilia Bitz held the position of chair of the Department of Atmospheric Sciences at UW and Prof. Tom Quinn (Astronomy) has served as interim chair of the Department of Astronomy at UW since 2021. Prof. J Michael Brown (ESS) served as chair of the Vashon Groundwater Committee on the King County Council in 2016 and on the Senate Committee on Planning and Budget in 2017. Prof. Sharon Doty's (Environmental and Forest Sciences) research group developed technology that is now being used by the Arbor Day Foundation to fight pollution; Doty was additionally awarded the 2020 UW College of the Environments Exceptional Mentoring of Undergraduates award. Although it is not possible to encompass all of the many accomplishments of the UWAB faculty in the limited space of this report, it is clear that the faculty that makes the UWAB program possible are leaders in their home fields and in the astrobiology community.

III.2 Postdoctoral Scholars, Research Impacts, Recognition and Teaching.

Our postdoctoral scholars and other early career researchers, although not the primary focus of the Astrobiology Graduate Program, are valuable members of the program both as mentees still requiring professional experiences and advice, and as mentors and teachers for our graduate and undergraduate students. Many of our postdocs have guest lectured in our core courses, but while a postdoc with us in 2020, Dr. Michael Wong also led a capstone undergraduate class on Astrobiology for Science Majors. As a postdoc and early career scientist Dr. Baptiste Journaux (Dept. of Earth and Space Sciences) has been working on the properties of water ice polymorphs and, especially, ices with salt impurities, at pressures and temperatures

characteristic of the interiors of icy moons. His work has recently resulted in a paper in PNAS reporting the discovery of new NaCl hydrates that must form in the interiors of Europa and Ganymede (ref), one of which may also appear on the surface of Europa and could explain puzzling visible near-infrared light spectroscopic observations. Dr. Ardith Bravenec (Dept. of Earth & Space Sciences) has been working on the properties of salty solutions at low temperatures, applicable to Mars, and their possible habitability. Dr. Sebastian Haas (Dept. of Earth & Space Sciences) works on saline lakes in British Columbia that are possible analogs to origin of life environments. He organized and co-led a UW Astrobiology Workshop to the most phosphate rich lake in the world in Sept 2022, teaching our graduate students in the field. Dr. Zoe Todd (Dept. of Earth & Space Sciences) is a Sagan Fellow working on astrochemistry and origin of life, and she will become tenured faculty at U. Wisconsin, Madison, in Sept 2023, joining their Center For Origins Research.

III.3 Graduate Students: Research Impacts, Leadership and Recognition.

Our current graduate students are high achievers who have garnered significant amounts of external recognition for their scientific and educational innovation and initiative in the form of awards and scholarships. Although we are not permitted to mention the names of current students in this report, five of our students currently hold NSF GRFP awards, and two have NASA FINESST awards. Three have Washington Space Grant awards.

Graduates of the UWAB program have achieved exceptional success, and displayed a remarkable rate of retention in STEM careers. Twenty-three of our cumulative 42 alumni from 2017 (assuming spending six years of postdoc before eligible for a faculty position) now hold tenure-track professorships in major academic institutions such as the University of Washington, the University of California, the University of St. Andrews, McGill University, the University of Arizona, and the University of Maryland. UWAB alumni also have broad representation in prestigious NASA positions and NASA postdoctoral fellowships at the Jet Propulsion Laboratory, Ames Research Center, and the Goddard Space Flight Center, and at non-NASA research institutions such as the Scripps Institute of Oceanography, the Woods Hole Oceanographic Institute and the Flatiron Institute for Computational Astrophysics. Others have careers as data scientists, programmers, directors and scientific entrepreuners. Notably, graduate Sanjoy Som founded the Blue Marble Space Institute of Science, a non-profit that supports both astrobiology research and significant efforts for outreach to the public.

UWAB alumni have gone on to play pivotal roles in the astrobiology community at universities, NASA centers and other research institutions, and/or lead key aspects of the field of astrobiology. Many have embraced Astrobiology not only as an influential component of their research, but also as a captivating and challenging subject for teaching, since it embraces and incorporates so many disciplines. Of particular note, representation of UWAB program graduates in both the mission concept development required for the Astro2020 Decadal Review, and on the Astro2020 Decadal Review and Planetary Science and Astrobiology Decadal Review was extensive. Two of the key telescope concepts under consideration that could potentially search for life, LUVOIR and HabEx had Dr. Giada Arney (Dual-Title 2016, astronomy) and Dr. Shawn Domagal Goldman (UWAB Postdoc, 2012) working in the mission concept study office, while Dr. Nick Cowen (Certificate 2009, astronomy) served as an international ex-officio non-voting member on the LUVOIR Science and Technology Definition Team for this mission concept (Prof. Meadows was also a member of this STDT Team). Dr. Tyler Robinson (Dual-Title 2012, astronomy) served on the HabEx Science and Technology Definition mission team. In the final Astro2020 Decadal Report 1.1 and 2.9 were reproduced from work done by UWAB Alumni Dr. Giada Arney and Dr. Tyler Robinson, respectively. Figure

2.17 was reproduced from the HabEx mission report, which was coauthored by Dr. Tyler Robinson. Furthermore, in the Planetary Science and Astrobiology 2023 official decadal report UWAB Alumna Dr. Giada Arney served on the panel on Venus, and past post-doc Dr. Michael Wong served on the panel on giant planet systems.

III.4 Influence of external research advances, changing paradigms and changing funding.

Remarkable advances in the discovery and characterization of exoplanets, driven both by advances in technique and, especially, new space telescopes, have opened of new avenues of investigation for atmospheric characterization and biosignature definition for exoplanets. In particular, the discovery of the TRAPPIST-1 planetary system, which is amenable to atmospheric study with JWST has become a huge focus for our exoplanetary astrobiology research. Similarly the selection of the Habitable Worlds Observatory as NASA next Astrophysics Flagship telescope has also focused our efforts at Virtual Planetary Laboratory on understanding how we can support these direct imaging observations of more Earth-like exoplanets orbiting more Sun-like stars. This became the major new focus of our most recent funding proposal. Similarly, results from the Cassini spacecraft have provided the first direct information on which terrestrial analogs, including subglacial analogs, can most directly address questions concerning whether or not life is possible in the subglacial ocean of Enceladus, sharpening our focus on analog targets. Other faculty members cite the links that have been made between the possibility of the origin of life in hydrothermal vent environments and the chemistry measured in the Enceladus plume which mimics the chemistry of Earth's ocean serpentinization environments (where water runs over volcanic rock). Enabled by increasing computational capability at progressively lower costs, higher fidelity geophysical and biogeochemical modeling has become possible. UWAB has led in modeling disciplined by observations to understand key events in early Earth history, as well as atmospheric biosignatures and the coupled evolution of planetary bodies and their atmospheres.
At the same time, methods and instruments for sequencing genomes, environmental DNA, environmental proteins (i.e., proteomics), and metabolites in environments have been developed widely, for widely varying applications, but have enabled groundbreaking new studies of extreme environments on Earth. UWAB has led in studies of cold, briny environments.

III.5 Collaborative and Interdisciplinary Efforts

We hope that we have already demonstrated that the UW Astrobiology program is highly collaborative and massively interdisciplinary. We would not be able to manage and coordinate this program without the buy-in and support of the 11 disciplines that collaborate on the UW Astrobiology Graduate Program. Our students also make connections across departments by spending time in research rotation projects outside of their home department. Similarly our research is also highly interdisciplinary between units, with the most common collaborations on joint research occurring between Astronomy, ESS and Chemistry, largely focused around the early Earth as an analog for exoplanetary systems, and environmental constraints and prebiotic chemistry relevant to the origin of life on Earth. The Virtual Planetary Laboratory incorporates the largest number of UW Astrobiology Faculty in different departments, and connects those departments to 19 other external institutions. The larger VPL collaboration between Astronomy, ESS, Atmospheric Sciences and other institutions has produced a productive, massively interdisciplinary team whose research raises the profile and standing of UW Astrobiology while supporting NASA efforts to develop telescopes to search for life on exoplanets. This being said, as we discuss in Future Directions, we feel that the Astrobiology Program research community could be even further integrated, and we look forward to moving towards that goal.

Section IV: Future Directions

The 2005 Astrobiology Program review panel described the Astrobiology Program at the University of Washington as the "the leading program in this discipline both nationally and internationally. It provides the broadest educational training, has the largest student enrollment and has faculty participation from the widest variety of departments and colleges compared to programs at any other institution worldwide….the UW Astrobiology Program is currently at the very top of its field, and is a recognized leader in astrobiology graduate education and astrobiology research at the national and international levels". In the intervening 15+ years we have worked to solidify this lead, expand our interdisciplinary breadth, and increase the size of the cohort of students that we train and support. In the last 10 years we have initiated the Dual-Title PhD, and reworked the Graduate Certificate into a credential accessible to a broader population of graduate students. We have expanded the number of participating departments from the original 6 to the current 11, spanning the expertise and scholarship of four Colleges and Schools. We have recruited new faculty to the program, expanded our disciplinary breadth and improved the number of earlier career faculty, and women and minorities, available to train, mentor and inspire our students. The number in our student cohort has almost doubled, and we now train and support 34 graduate students, similar to that of a small department.

Our goal now is to maintain the level of excellence and pre-eminence of the UW Astrobiology Program, while we deepen its interconnectedness, broaden the interdisciplinary range of its teaching faculty, and strengthen its financial basis. We note that the faculty are in agreement that the graduate program does not need to grow. The number of graduate students and faculty we have now provides ample disciplinary breadth for the activities of the program, although there is a clear need to identify, recruit and support an astrobiology teaching faculty member who can lead classes with a strong biology theme, including on the origin of life. Our focus then for the next 10 years is to maintain the program at or near its current size, and invest in developing and supporting the interconnectedness needed to enhance the interdisciplinarity of our teaching and research. However, to maintain the program we will need stable funding, especially given the anticipated shortfall in funding for the program over the next five years.

IV.1 Current Challenges

The Astrobiology Program has identified two major near-term challenges that we will need to address. One is the upcoming retirement of one of our teaching faculty, and the recent retirement of one of our most generous volunteer faculty, and the second is the reduction in future program funding that is anticipated due to changes in the larger funding programs that have been used to garner matching support, and the larger, ongoing issue of the lack of long-term, stable funding for the program.

IV.1.1 Disciplinary Balance in Teaching Faculty

We currently have four Astrobiology Teaching Faculty, who have some fraction of their time committed to teaching ASTBIO courses. Prof. Roger Buick (ESS - 1 Qtr/yr), Prof. David Catling (ESS - 1Qtr/yr), Prof. Rory Barnes (Astronomy - 1.5 Qtrs/yr) and Prof. Victoria Meadows (Astronomy - 1.5 Qtrs per year, but effectively 1Qtr/yr due to Director's teaching release). Given the expertise of our four teaching faculty, it is no surprise that our core courses and course topics are strongly focused on early Earth, planetary science and exoplanets. However, Prof. Buick, who is a geochemist with a biology background has taught Origins of Life classes, along with Prof. John Baross, who is now Prof. Emeritus. However, within the next 2-5 years, Prof. Buick will also retire. While the Origins of Life ASTBIO575 was taught frequently in the first half

of the last decade (once every two years) by Buick and Baross, it has not been taught more recently. In our recent climate survey, students have noted that our classes are somewhat planetary and astronomy focused, given the heavy concentration of expertise in our teaching faculty in those areas. This requires more effort from our biology and chemistry trained students to learn material that is often not at all familiar to them in the majority of our classes.

Additionally, in the last decade our three Microbiology faculty have left the program due to retirements or changing priorities. We have largely compensated for these losses by strongly recruiting origin of life chemists, microbial oceanographers and genome scientists into the program (six in total over the last decade), and our colleagues in this area have been invaluable in bringing a life sciences perspective and expertise as guest lecturers in our core courses. Indeed, in our last 10 year review, we felt that faculty with research experience in origin of life science were particularly lacking. The addition of Chemistry and the recruitment of Prof. Sarah Keller and her group has greatly helped redress that balance. However, none of our life sciences faculty are identified or supported as Astrobiology Teaching Faculty, and although they can volunteer to lead workshops that are life sciences based, or perform teaching overages by taking on an ASTBIO575 Winter Seminar, they do not lead any of our core courses. Consequently our existing life sciences faculty can't lead our core courses, and balance out the disciplinary expertise provided by our Astronomy/Earth and Space Sciences teaching faculty.

IV.1.2 Near-term Funding Shortfall, and Long Term Funding Instability

As discussed in Section I.2 and shown in Appendix B, over the last decade, support for the Astrobiology Program budget has come primarily (~70% of total budget) from matching funds associated with NASA Astrobiology Institute Cooperative Agreement that supports the Director's Virtual Planetary Laboratory research group. These NASA funds are highly competitive, and must be reapplied for every five years. The matching funds must also be reapplied for, and are tied to competition for the funding being successful and the research grant being awarded. Consequently they do not constitute a stable funding source for the program.

This precarity is now in sharp relief, because in 2018, the NASA Astrobiology Institute was dissolved, and support for large astrobiology research groups was replaced by the NASA Interdisciplinary Consortia for Astrobiology Research (ICAR) program. The Director's NAI grant ends in June, 2023, and an ICAR proposal was submitted on January 10, 2023 to continue the Virtual Planetary Laboratory research group. However, the ICAR program differs from the NAI in having a smaller overall budget, and the funding is implemented via a grants program, rather than a cooperative agreement---so there is no requirement for institutional support that can be used to justify matching at the Provost's level. Consequently the total funding that can be requested, and the corresponding RCR from which matching can be negotiated, is now less than it has been in the past by nearly a factor of two, and because of the lack of required institutional support, the Provost does not have to provide a match. However, the Provost has graciously agreed to provide a match, given the massively cross-college nature of the program, but this amount is less than would have been available if matching had been required. Due to both of these factors, even if the proposal to refund the Virtual Planetary Laboratory is successful, the matching funding coming to the AB Program will be significantly less than in the past. This is balanced in part by CAS paying for our ASTBIO115 TAs, rather than requiring that we do that from our RCR, as tuition is now covered. However, this will not cover the entire shortfall in matching funding, and we are looking at 7% shortfall in Program funding even if successful with the ICAR, and a 49% shortfall in funding if the ICAR proposal is not successful.

IV.2 Opportunities for the Program over the next 10 years

Given the challenges facing us, the Astrobiology Program intends to pursue several opportunities to consolidate our position in the next few years in the areas of interdisciplinary research and education, and the funding sustainability for both our research and the academic program that is needed to support that position.

New Funding: The interdisciplinary breadth of the program is sufficiently large, that our research cannot be funded under a single program, and so multiple sources of support will need to be sought. However, although competitively acquired funding for student RAs or to leverage matching will allow the program to continue, it still will not address the desire for funding stability for the program. Although the VPL NAI funding and the associated matching that has supported the program for the last decade is not longer available, there are still opportunities for large astrobiology research consortia funding through the NASA ICAR program.

New Faculty: With the possible retirement of Prof. Buick from the teaching faculty, we have an opportunity to acquire a new teaching faculty member, and in fact there is a good case for acquiring a new teaching faculty member before Prof. Buick's retirement, especially if that faculty member is based in the life sciences and so can increase our disciplinary diversity.

New Connections: In both our climate surveys and focus group discussions, students, postdocs and faculty all expressed a strong desire to connect more with each other and explore closer partnerships in teaching and research. This would enhance not only the excellence of our interdisciplinarity, but also build a closer knit community where participants have a stronger sense that they belong. As the UW Climate Survey emphasized, a sense of belonging is a strong indicator of student retention in a degree program. The program does not need to be significantly bigger to fulfill its purpose, but the degree to which we interact with each other could be enhanced. The remote experience at the outset of the pandemic, while isolating, and perhaps a driver of the current desire to connect, also highlighted a different array of tools that augment our "before times" connections, particularly for our campus-dispersed community.

IV.3 Implementation Plan

Funding: We have just submitted another proposal to continue VPL funding for the next 5 years, this time to the NASA ICAR program. Additionally, we have created a faculty Funding Committee that meets quarterly to explore potentially appropriate funding opportunities available across multiple disciplines and sponsors. This may take the form of coordinated proposal efforts from multiple faculty to NASA astrobiology programs. This would help to fund a small cohort of graduate students and may bring in some matching as well. In initial discussions we also have plans to reach out to specific philanthropic entities to establish support for the program and in particular for our very popular, training mechanisms (workshops and research rotations). We would also like to continue the dialog with participating colleges who have a significant fraction of the students in the program, but who contribute a disproportionately small amount to support their required research activities. Coordinating matching contributions from multiple grants, and/or requesting some portion of the $130K per year in ABB generated by teaching ASTBIO115 are other options we could pursue. For research rotations, our students could pursue additional scholarship funding on the national level. We will try again to work with UW Advancement to search for private funding opportunities, although our experiences there have been frustrating, as Advancement expects us to identify and cultivate our own donors.

Faculty: To increase the disciplinary and other forms of diversity of our faculty we can continue to identify and recruit existing UW faculty into the program, and encourage departments to make

new hiring decisions while keeping astrobiology relevant in mind, so as to replace astrobiology active faculty on retirement. We have recruited 15 excellent faculty over the last decade using these processes. However, since these faculty are not teaching faculty, and all our teaching faculty are in Astronomy or ESS, it is not possible to significantly diversify our teaching in this way, as "non-teaching" faculty cannot lead ASTBIO classes without getting a reduction in departmental teaching responsibilities to compensate, or teaching the ASTBIO class as an overage. So to solve this problem, we need to explore three options: 1. Hire a new faculty member in a life sciences department (e.g. Oceanography, Microbiology, Biology, Genome Sciences or Chemistry) who has 1-1.5 quarters a year responsibility to astrobiology teaching, 2. Explore any mechanisms available to "convert" the teaching responsibilities of an existing life sciences astrobiology faculty member by negotiating a fraction of their teaching for astrobiology, so that the become a dedicated teaching faculty member or 3. Develop some system or agreement that allows existing life sciences astrobiology faculty to be credited for teaching an Astrobiology class so that it does not have to be as a teaching overage. This could potentially allow all of our non-teaching faculty to contribute in more significant ways to our teaching.

Connectivity: Our Program Climate Surveys and ASTBIO575 have resulted in a wealth of suggestions for improving connections among all members of the program. A major theme for faculty has been the desire to obtain more collaborative interdisciplinary funding, which could be enabled in part by more interdepartmental research collaboration. Suggestions for more mechanisms for faculty interaction, and to generate collaborations, included a monthly lunch with chalk talks on our science and/or our own journal club discussion, as well as more regular intellectual events, such as 2 hr Program workshops once a quarter on different subjects, and an in-house conference once a year (we used to hold such an event pre-pandemic). We have a renewed commitment to involving early career members of our community in appropriate fora and committees across campus and nationally. The students have also requested more social events and interactions with faculty, which could be supported by our new coffee mixer which pairs members of the community for a half hour once a week, Fireside Chats with the Director, and the development of an Astrobiology Connection Committee, with participation from all levels of the program, to plan intellectual and social events that bring our community together.

IV.4 The UW Astrobiology Program's Benefit and Impact.

The Astrobiology Program brings to Washington's leading research university a cohort of superior interdisciplinary graduate students (that may not have chosen to attend UW otherwise) that enrich the intellectual environments of their departments, a considerable amount of research and educational grant money, and strong positive publicity. The program sponsors public lectures and seminars that have been very well attended, and performs educational outreach at local schools and institutions. The UW has arguably the top program nationally in astrobiology, and it has a proven track record of both its faculty and alumni taking significant leadership in astrobiology research, national science strategy, and NASA missions that search for life in our Solar System and beyond. The prestige to the University from our program in turn enriches our regional profile in aeronautical and astronautical engineering and research. If financial sustainability can be achieved and the program enhanced in the ways outlined here, then the high national and international reputation of the program will be maintained, and its benefits to the region, state and nation will be sustained into the future.

Part B: Unit-Defined Questions

How do we maintain and grow this academic program over the longer term given that it is currently primarily supported by matching funds from the Director's research grant?

As described in some detail in Sections I.2 and IV.1.2 above permanent funding for this program from the University represents a very small fraction of the program's operating costs. Over the last decade, typically about 70% of our operating costs have been supported by matching at the departmental, College and Provost level, tied to the success of two NASA Astrobiology Institute Cooperative Agreements led by the current Director, Victoria Meadows. Although the Director has negotiated larger fractions of State support, such that the salary for the UW Astrobiology Director and Administrator, as well as funding for TAs and workshops will be supported even if no additional funding is obtained, this still leaves large fractions of the operating budget, specifically for research rotations and colloquia, supported by relatively unstable funding. Should the next ICAR proposal attempt be unsuccessful, the program will have only half the funding needed to operate. Similarly, the current Director is serving her third term, and has no desire to continue in this role after her current term is up in 2026, and may even step down before then if a suitable replacement can be found. Given these circumstances, how does the program continue, and how can we obtain stable funding for the program going forward?

What actions will help improve the way that teaching of interdisciplinary Astrobiology courses are fostered and accredited among participating departments and faculty?
The majority of Astrobiology Courses are led by the Astrobiology Teaching Faculty, who have 1/3 to 1/2 of their teaching responsibilities to Astrobiology. However, because of the massively interdisciplinary nature of the topics that we teach, significant input in our core courses, and even leading of a 575 Winter Seminar is required of our non-teaching faculty, who are not credited for co-teaching these courses, or teaching 575 as a teaching overload. Although the University strongly supports and encourages interdisciplinarity in teaching and research, there seems to be no formal way for non-teaching astrobiology faculty to be credited for the work that they contribute to the program, and to also have it count towards their merit reports and tenure. Is there a process by which we can raise the profile of these contributions, and ideally negotiate a lessening of departmental responsibilities so that the "non-teaching" Astrobiology faculty who teach are not supporting the program by teaching overages?

How has our Dual-Title PhD program been successful since implementation, and how can we improve it to better serve the needs of our students and the broader Astrobiology community?
Although we have outlined how we perceive the program to have been successful, we are very interested in seeing an external perspective on the program. Similarly, we are interested in diverse views on how the program can improve its training of our students, and its relevancy to the broader Astrobiology community.

What are the optimal methods for attracting the best students to our program, and retaining them?
While our students are exceptional, and the UW Astrobiology Program has been a world leader in Astrobiology education, we are very aware that we have growing competition. In the previous decade the Astrobiology Program was one of perhaps three programs in the world focused on astrobiology graduate education. Now many other universities in the US and internationally are developing Astrobiology Programs. How do we remain competitive in recruitment of students with interdisciplinary aptitude and strong Astrobiology interests, that now have many more options? In the second part of the question we are very interested in developing new ways to increase student retention, especially for minorities, and to make the Astrobiology Program a more cohesive and supportive community.

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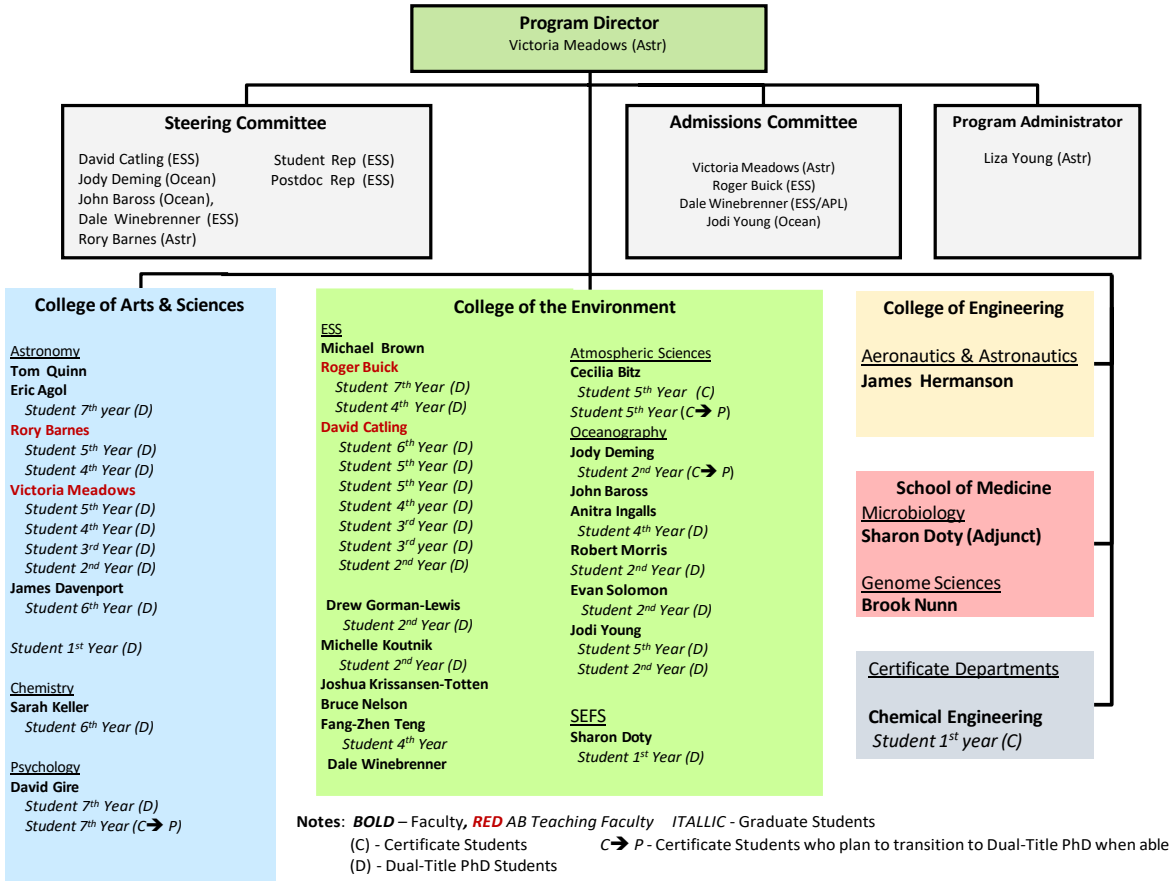
Part C: Appendices

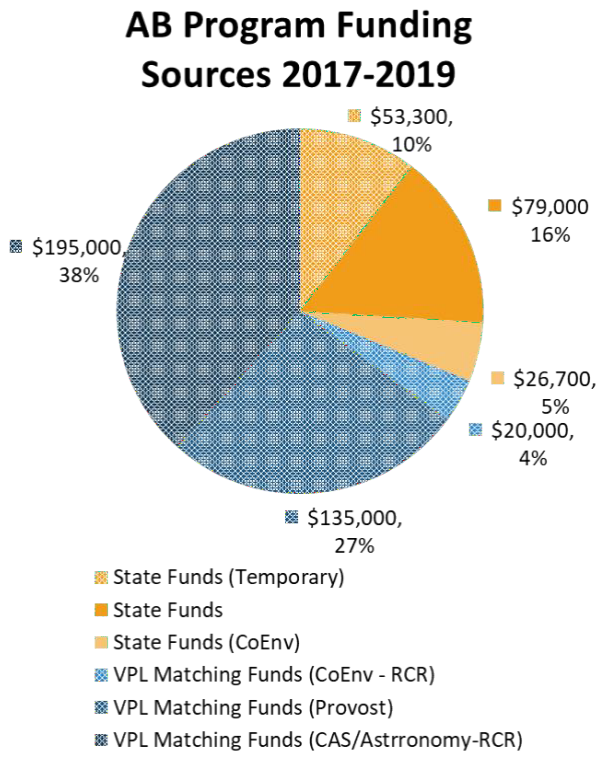
Appendix A: Organizational Chart



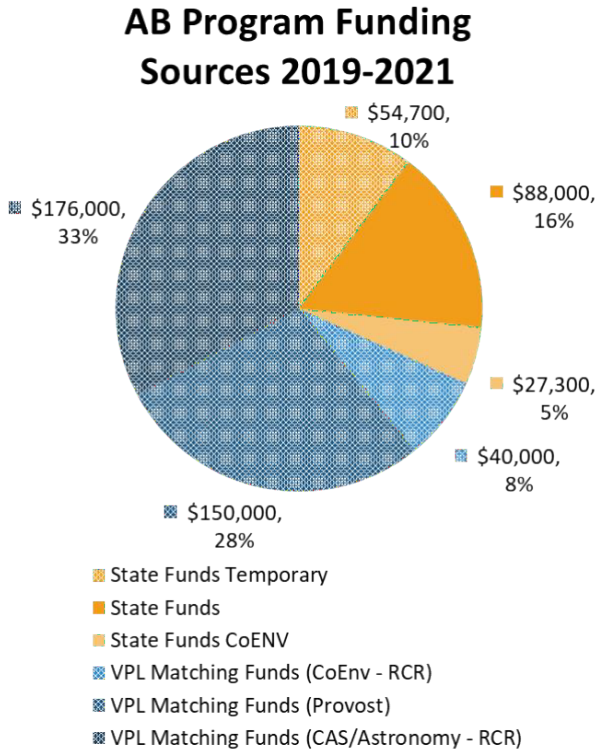
Notes: ***BOLD*** – Faculty, ***RED*** *AB Teaching Faculty* *ITALLIC* - Graduate Students
(C) - Certificate Students *C➔ P* - Certificate Students who plan to transition to Dual-Title PhD when able
(D) - Dual-Title PhD Students

Appendix B: Budget Summary, last 3 Biennia and upcoming Biennium

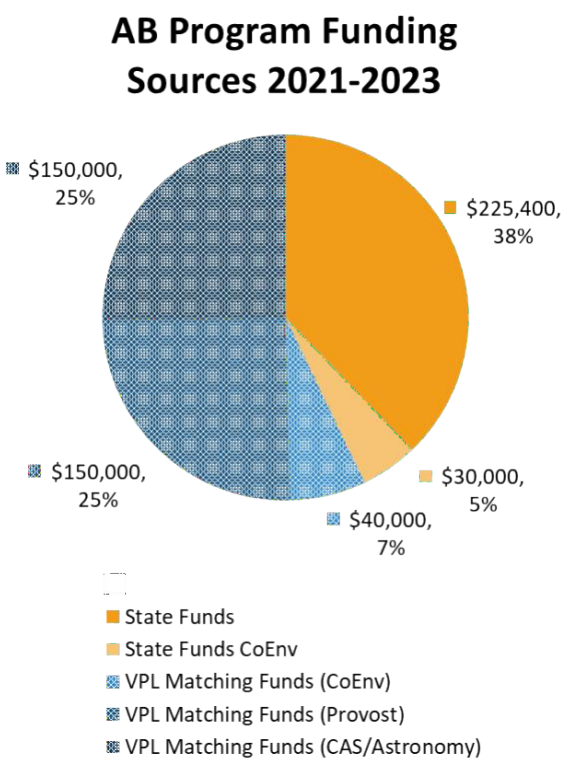
2017-2019	Expenses
Director (ADS & 2 Weeks Summer)	**$56,000**
Administrator	$80,000
Research Rotations & RA Support	$200,000
ASTBIO 115 Teaching Assistants	$88,000
Conferences+Workshops	$10,000
Workshops	**$23,000**
Colloquium	$12,000
Scholarships	$20,000
Supplies & Services	$2,000
Total	**$491,000**



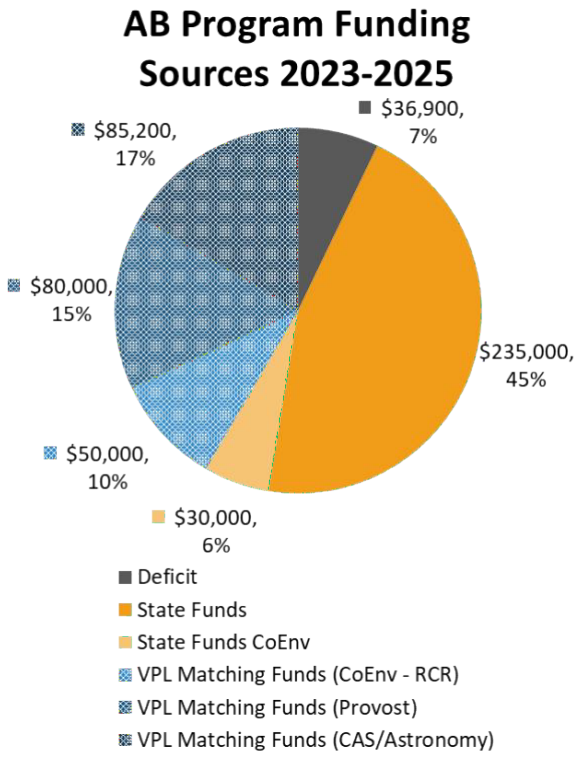
2019-2021	Expenses
Director (ADS & 2 Weeks Summer)	**$65,000**
Administrator	$82,000
Research Rotations & RA Support	$214,000
ASTBIO 115 Teaching Assistants	$92,000
Conferences+Workshops	$10,000
Workshops	**$23,000**
Colloquium	$10,000
Scholarships	$20,000
Supplies & Services	$2,000
Total	**$518,000**



2021-2023	Expenses
Director (ADS & 2 Weeks Summer)	**$72,000**
Administrator (50% FTE)	**$98,000**
Research Rotations & RA Support	$223,000
ASTBIO 115 Teaching Assistants	**$48,600**
Conferences+Workshops	$10,000
Workshops	**$23,000**
Colloquium	$12,000
Scholarships	$20,000
Supplies & Services	$2,000
Total	**$508,600**



2023-2025	Expenses
Director (ADS & 2 Weeks Summer)	**$75,000**
Administrator (50% FTE)	**$104,000**
Research Rotations & RA Support	$226,000
ASTBIO 115 Teaching Assistants	**$49,500**
Conferences+ Workshops	$10,000
Workshops	**$23,000**
Colloquium	$15,000
Scholarships	$20,000
Supplies & Services	$2,000
Total	**$524,500**



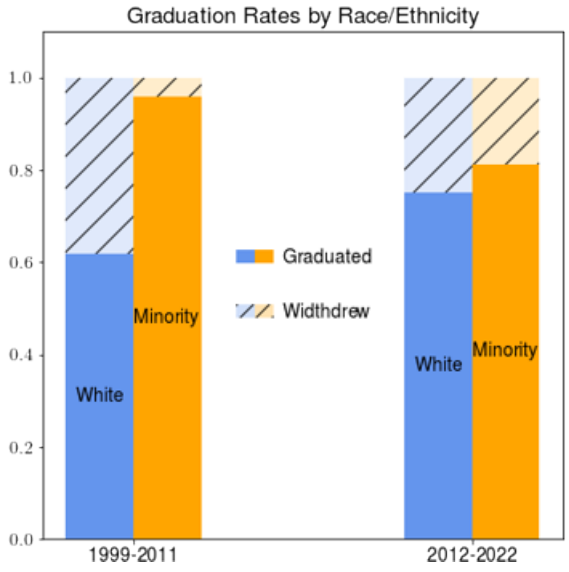
Appendix C: Faculty Information

Please Click on Faculty name for CV

Name	Rank	Affiliation
Eric Agol	Professor	Astronomy
Rory Barnes	Associate Professor	Astronomy
John Baross	Professor	Oceanography
Cecilia Bitz	Professor and Chair	Atmospheric Sciences
J Michael Brown	Professor	Earth and Space Sciences
Roger Buick	Professor	Earth & Space Sciences
David Catling	Professor Adjunct Professor	Earth & Space Sciences Atmospheric Sciences
Jody Deming	Karl M. Banse Endowed Professor	Oceanography
Sharon Doty	Professor	Environmental & Forest Sciences Adjunct Microbiology
David Gire	Professor	Psychology
Drew Gorman-Lewis	Associate Chair Associate Professor	Earth & Space Sciences
James Hermanson	Professor Adjunct Professor	Aeronautics & Astronautics Mechanical Engineering
Anitra Ingalls	Calvin Professorship Professor	Oceanography
Sarah Keller	Duane and Barbara LaViolette Endowed Professor	Oceanography
Josh Krissansen-Totton	Assistant Professor	Earth and Space Sciences
Victoria Meadows	Director, UW Astrobiology Program Professor	Astronomy
Robert Morris	Associate Professor Associate Director	Oceanography
Bruce Nelson	Professor-Emeritus Adjunct Professor	Earth & Space Sciences Oceanography
Brook Nunn	Research Associate Professor	Genome Sciences
Tom Quinn	Chair, Professor Adjunct Professor	Astronomy Physics
Evan Solomon	Associate Professor	Oceanography
Fang–Zhen Teng	Professor	Earth & Space Sciences
Dale Winebrenner	Research Professor Adjunct Research Professor	Earth & Space Sciences Electrical & Computer Eng.
Jodi Young	Assistant Professor	Oceanography

Appendix D: Equity and Inclusion Additional Information

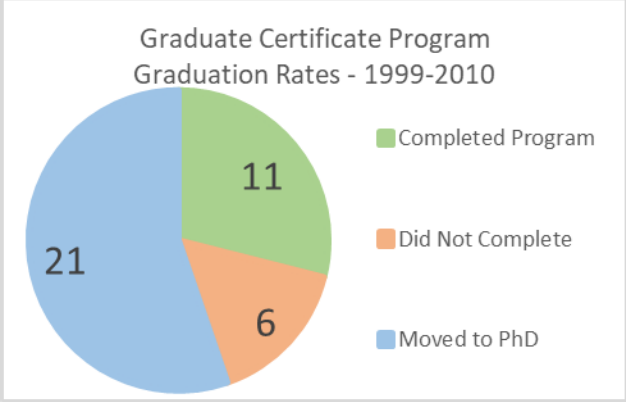
As stated previously the diversity of our student body is controlled both by who is admitted into the University, and who we can recruit and retain, once they are here. Because both the Astrobiology Graduate Certificate and the Dual-Title PhD require that a student be enrolled in a home department before being admitted to the Astrobiology Program, the pool of applicants we select from for our program relies heavily on the diversity practices of the students' home departments. However, we can be an active participant in the environment that we create for our students and Faculty, and we have focused our efforts on developing an equitable and inclusive environment that is welcoming and supportive to all participants.

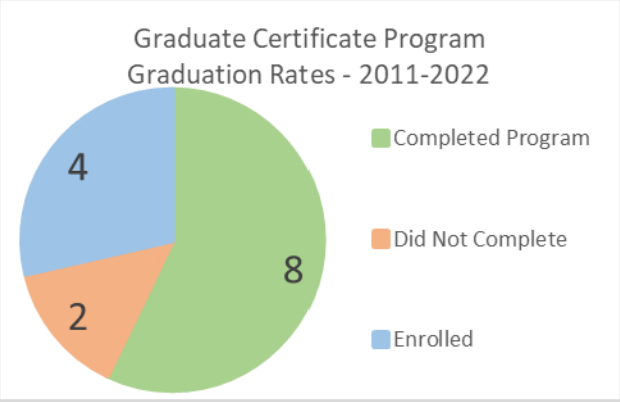


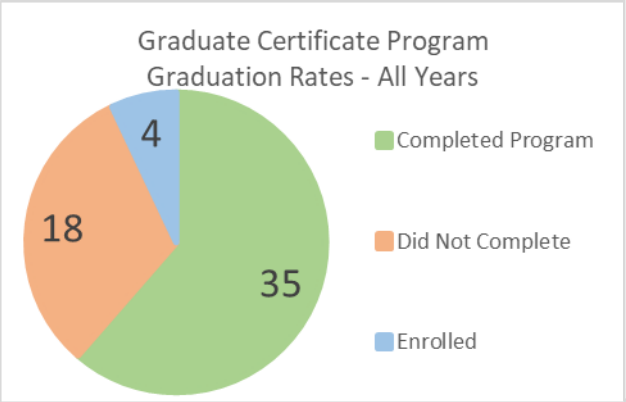
In outreach to the community and future recruitment of students, Prof. Rory Barnes has led Astrobiology with the Mobile Planetarium (ABMP) bringing a mobile planetarium to K-12 audiences throughout the state, including indigenous communities. With our grad students, Prof. Barnes teaches about life on Earth and the search for life in the universe using a customized planetarium show that uses the World Wide Telescope format so that participants "fly" through the Solar System, the Milky Way Galaxy, and the edge of the Universe. In a typical day, the ABMP reaches 7-8 groups of 25-30 students each and Astrobiology personnel both present the show, and describe their diverse experiences as professional scientists, promoting the pursuit of a college education.

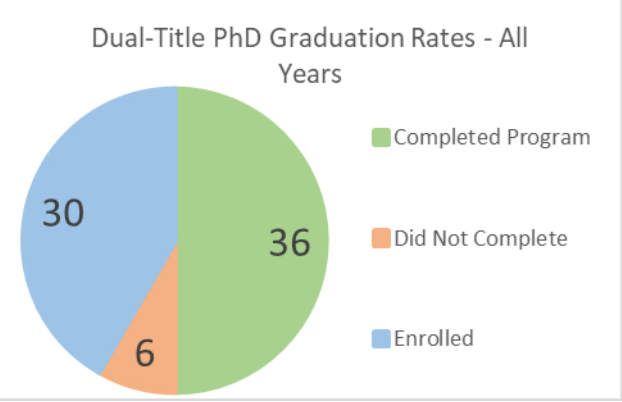
In outreach to the community, our Dual-Title astrobiology graduate students have served as lead organizers and presenters for Astronomy on Tap Seattle (AoT), a free monthly event with 2 half hour public talks. Most recently, since September 2022 AoT has featured 7 astrobiology graduate students as speakers.

These statistics show a trend towards higher retention/completion rates in the Dual-Title PhD with a 56% graduation rate for the pre-2012 Certificate (excluding students who transferred into the PhD), an 80% graduation rate for the post-2012 Certificate, and a current 86% graduation rate for the Dual-Title PhD. As alumni, our 77 Program graduates have almost all remained in STEM, in a variety of fields, where their training in interdisciplinary science is directly relevant to their career trajectories (See Appendix E for a list of our graduates and their current positions).









Appendix E: Workshops

The annual 4-5-day workshop has become an excellent opportunity for informal off-campus interaction and instruction of both students and faculty. Below we provide more details on some examples.

2014 R/V Tommy G. Thompson (TGT)- Led by Jody Deming Oceanography

In 2014, the UW Astrobiology Program hosted a three-day field trip aboard the R/V Thompson that introduced students to experimental oceanography and extremophiles. Participants obtained samples of Puget Sound to tests for increasing acidity levels related to run-off from the urban communities, including preforming preliminary tests in the ship's laboratory. AB program members also performed "box coring" experiments in which samples of the sea floor near the edge of the continental shelf were brought to the surface. The location was chosen to be near a "methane seep" where bubbles of methane emerge from the seafloor. The samples contained communities of extremophiles such as sulfate reducers and methanogens, as well as animals that lived off the microbes. The students thus learned about offshore environments, the impact of technology on that environment, and life that thrives in methane-rich environments.

Yellowstone 2015- Led by Niki Parenteau (NASA AMES) , David DesMarais (MIT), and Victoria Meadows AB Director

The UWAB Workshop at Yellowstone National Park was a unique opportunity for students to study microbial life in extreme environments and gain a first-hand appreciation for the diversity of geothermal systems that exist in planetary settings. Activities involved measuring temperature and pH across/within multiple geothermal systems to probe the conditions suitable for cyanobacterial mats, as well as measuring the in situ reflectance spectra of microbial mats to assess their potential as remotely detectable surface biosignatures. These field measurements and their subsequent analysis provided students with a better understanding of the environmental limits for life, and the challenges associated with remotely detecting photosynthetic pigments across interstellar distances. Additionally, the diverse geothermal systems and complex geology within the Yellowstone Caldera provided many opportunities for astrobiological discussions, including lessons on the potential for biosignature presentation in hydrothermal silica deposits, with potential relevance to target selection for Mars sample return.

Jet Propulsion 2017- Victoria Meadows AB Director
UW Astrobiology students, led by professor Vikki Meadows, visited the NASA Jet Propulsion laboratory to meet researchers, view prototypes for future missions, and participate in faux mission planning.

Death Valley 2018 – Roger Buick Earth and Space Sciences
Characterizing microbial life in Death Valley: Determining the phylogenetic diversity within the topsoil of Death Valley and searching for genes that enable survival in extreme heat, saline, and dry environments.
Purpose is to identify the kinds of microorganisms that have adapted to survive and thrive in the unique environment of Death Valley. Through doing this, we aim to identify genes that enable these adaptations and understand the impact of extreme environments on microbial diversity

Clinton B.C 2022- David Catling Earth and Space Sciences and Sebastian Haas Postdoc Earth and Space Sciences.
UW Astrobiology Workshop at The Salt Lakes of the Cariboo Plateau, BC, Canada
Why the lakes: Prebiotic phosphorylation uses ~0.1-1 M phosphate but natural waters are ~1 μM. Lakes concentrate by evaporation or freezing solving this prebiotic "concentration problem" Last Chance Lake is the most phosphate-rich in the world. Goodenough is also relatively phosphate-rich. Sensor measurements (YSI: salinity, temperature, pH, O2), Sediment sampling (pushcores, subsampling by slicing) for quantitative chemical analyses (ICP-MS). Water sampling and filtering (for nutrient concentrations, IC, ICP, PON/POC, d13C, d15N, chlorophyll, DIC). Collect evaporites (mineral composition, e.g. XRD). DNA or RNA extraction from water, sediment or microbial mats. Sample mats, brine flies and shrimp, surrounding vegetation for potential food web level analysis. Sample the surrounding (basalt) rock and minerals

Appendix F: Research Rotations

Every AB student must spend at least one quarter working in a lab outside his/her area of expertise (usually on campus with an AB faculty member, but some are off campus); upon completion, an oral presentation is also given. Here are some past examples.

Designing and Developing an Octopus-Inspired Soft Robotic Limb for Planetary Exploration was a rotation done here on the UW campus. This student was advised by **Josh Smith** from Computer Science. Please see movie link Movie

Another student working with AB alum **Dr. Rika Anderson and AB Faculty Dr. John Baross** of Oceanography, explored the presence and diversity of reverse transcriptase, as well as the presence of retroviral integrase and diversity-generating retro-elements, in hydrothermal vent metagenomes of Lost City and Hulk Vent (both cellular and viral) and in the genomes of thermophilic archaea.

In Death Valley they looked at the carbon isotopes to help discern the possible glaciations that lead to the Noonday's deposition. Specifically, they indicate the size of the glaciation and whether it was a Snowball event or something smaller. **Advisor Roger Buick**

Another on campus rotation included UW Observations of transgenic and hyperaccumulator plants in Mars and lunar simulant soils. This student was **advised by Sharon Doty** Professor, Environmental & Forest Sciences and adjunct in Microbiology

The Jet Propulsion Laboratory was another site visited by a student to work with AB program alum, **Dr. Steve Vance**. The rotation was “Hydrothermal systems on Earth are often environmental niches highly favorable to microbial life. In particular, hydrothermal systems driven by exothermic serpentinization reactions are able to sustain themselves via predominantly geochemical drivers, even in the absence of magmatic or other heat sources from below.

A student traveled to the UK for their rotation on “Spectral analysis of a cross section of pigmented microorganisms to explore the parameter space of possible reflectance biosignatures.” **Advisor Charles Cockell.**

Reconstructing an organic biomarker record of increasing eukaryotic diversity in the late Proterozoic. **Advisor Jochen Brocks** Australian National University

Investigating nickel (Ni) isotopes in Archean sedimentary rocks as a potential proxy for ancient methane cycling, **Advised by Prof. Derek Vance** at ETH Zürich

NASA Goddard is a popular destination and one student’s work was mission planning for an upcoming exoplanet direct imaging mission (either EXO-S, EXO-C, or AT LAST). Advisor **Shawn Domagal-Goldman**. A few years later this same student **Giada Arney** an alumnus of the AB program was a research advisor two additional students’ rotation to work with NASA scientists and engineers at the Goddard Space Flight Center (GSFC) on the LUVOIR mission concept study.

Here are some examples of various rotations here at the University of Washington

Multi-Flare Efects on the Atmospheric Evolution of an Earth-like Planet Orbiting an M-Dwarf With and Without a Global Planetary Magnetic Field **Advisor Victoria Meadows**

The Many Hats of Methanogens: Partners in Syntrophy & a Key to Ancient Nitrogen Fixation **Advisor John Leigh**

Growth of Cold-Adapted Bacteria Under Different Pressures and Temperatures" **Jody Deming**

“Quantify the genetic controls of virus-bacteria advised by **Fangzhen Teng**

Micrometeorite work with **Don Brownlee and Roger Buick**

Tom Quinn advised Modeling the distribution of parameters such as mass, period, and eccentricity using data from known exoplanets

David Catling advised the rotation of Analytic climate models for different worlds within the solar system

Growing iron oxidizing bacteria and collecting Fe oxides for chemical and isotope analysis was co-advised by **Jim Staley / Bruce Nelson**

Appendix G: AB Faculty Responsibilities

A very brief guide to several things that your students (and the Program) are expecting you to do….

Teaching

Astrobiology Faculty are responsible for teaching, or helping to co-teach Astrobiology Courses. The larger core classes are strongly interdisciplinary and typically require participation from professors from multiple disciplines to provide the breadth required. A typical load for a faculty member participating in a core course (who is not the Principal Instructor) will be the preparation and delivery of one lecture, and guiding a student to prepare a lecture of their own. For our Colloquia, AB Faculty may be asked to select, invite and host (introduce the speaker's talk, and take to dinner) one speaker in the series. This will typically be only once per year. AB Faculty are also strongly encouraged to lead and/or participate in relevant Astrobiology Field Workshops, which are held once a year.

Cognate Courses

All AB Students must complete 3 credits of a "Cognate Course" which is a course outside the student's home department that provides complementary training in an area relevant to their research work. Student choices of cognate courses should be approved by their advisors, so please make a point of discussing options for cognate courses with your grad student(s).

Research Rotations

Faculty should encourage their students to plan their rotation and submit a description of what they would like to do to David Catling for **approval before the end of their second year**. Students are strongly encouraged to **complete their rotation by the end of their third year**. Funding for AB Rotations is available through the Astrobiology Program. Please ask the AB Program Director or Administrator if your student needs funding for a rotation. More information on rotations can be found at:
http://depts.washington.edu/astrobio/drupal/content/astrobiology-research-rotation

Significant Milestones

Please let the AB Program Director or Administrator know about significant student milestones (General/Final scheduling etc.) and any awards that your students win. Students are often quite shy about notifying us when they achieve significant recognition or accomplishments, so we are relying on you to let us know!

Dual-Title PhD Research

To ensure that all Dual-Title PhD students receive appropriate guidance and supervision, a student's doctoral advisor (Committee Chair) must be an Astrobiology Faculty member. Dual-

Title PhD candidates must also have a second Astrobiology Faculty member from outside his/her home discipline serving on his/her dissertation committee.

It is the AB advisor's responsibility to ensure, at all points during a student's graduate tenure, that a student's research is appropriately relevant to the field of astrobiology. This includes closely monitoring the approved astrobiology content of a student's doctoral research and final dissertation, and ensuring that there is a description/justification of the relevance of the research to astrobiology in the introduction to the dissertation.

To ensure the research is astrobiology relevant, students will be required to present their proposed research to the Steering Group (1) **before completing the General Exam** and (2) **prior to scheduling a Final Exam**.

(1) At least six weeks prior to the PhD Candidacy (General) Exam the student should submit an application for astrobiology relevance to the AB Steering Group (via Tina). The application includes a cover page, a written description of the proposed research (may be thesis proposal), and a letter of support from the student's advisor. This Advisor letter need not exceed one page, but must contain a brief summary of the proposed research with respect to astrobiology, and a clear recommendation that the research has overall astrobiology relevance.

(2) No later than the end of the first week of the quarter before the quarter in which the student intends to schedule the Final Exam, he/she must submit a research update to the Steering Group (via Tina). (e.g., If a student plans to schedule a Final Exam in the Spring quarter, the research update must be submitted no later than the first week of the preceding Winter quarter.) The research update must include a cover letter from the student's astrobiology advisor as well as relevant supporting materials (e.g., abstract, outline, etc.) sufficient to demonstrate that the astrobiology relevance has been maintained at the level approved prior to the General Exam.

Alumni

We'd also like to encourage the AB Faculty to keep track of alumni and send updates on their current employment and notable achievements to the Program Director. Being able to promote our Alumni achievements in the Newsletter and on the UWAB website helps to raise the profile and prestige of the program. So if your graduates are out there exceling and exceeding expectations, then let us know about it!

Appendix H: Committee Questions Prior to the Site Visit

1. **How do postdocs officially become part of Astrobiology? Is this a formal process?**

There is no formal process for postdocs to become part of the Astrobiology Program. All postdocs of Astrobiology Faculty who engage in astrobiology relevant research are welcomed. It is up to the Astrobiology Faculty member to request that the postdoc be added to our e-mail lists and website.

2. **Who teaches ASTBIO115? The Astrobiology teaching faculty?**

Yes, the Astrobiology teaching faculty are responsible for teaching ASTBIO115.

3. **Is the Astrobiology Steering Committee involved in any way with graduate admissions in the home department of students applying to the Dual Title PhD program? If so, how are they involved and what does that evaluation look like?**

No, the Astrobiology Steering Committee is not formally involved in graduate admission in the home departments. The Astrobiology Admissions Committee considers only those students who have been admitted to their home departments, after the home department's admissions process is completed. That being said, sometimes members of the Astrobiology Teaching Faculty, the Astrobiology Steering Committee and/or the Astrobiology Admissions Committee serve on the Admissions Committees of their home departments. As part of their service to their home department, these faculty can help identify and promote students interested in Astrobiology for consideration by their home departments' committees.

4. **Some future looming budget issues were identified in the self-reflection. Is there a potential solution that is being considered by the program so far?**

The first paragraph of section IV.3 (pg. 26) describes several potential solutions to the funding shortfall that have been discussed with faculty. We have not attempted to implement any of these solutions yet, as we are perhaps a month away from learning the outcome of the VPL ICAR proposal. This will determine whether or not we must look for funding in the order of 7% or 50% of the program costs over the next few years.