PURM
Perspectives on Undergraduate Research & Mentoring

13 Years of Undergraduate Heliophysics Research at The University of Alabama in Huntsville and NASA Marshall Space Flight Center

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Introduction

For the past 13 years, the Center for Space Plasma and Aeronomic Research (CSPAR) and the Department of Space Science (SPA) at the University of Alabama in Huntsville (UAH) have partnered with the NASA Marshall Space Flight Center (MSFC) to run a solar and heliospheric physics REU program. The unique co-location of UAH faculty, scientists, and graduate students, with MSFC scientists in the National Space Science and Technology Center (NSSTC) building on the UAH campus generates a vibrant research environment with a "critical mass" of solar and heliospheric researchers. We offer a wide range of projects covering topics in theory/modeling, data analysis, simulations, and hardware development.

The primary goal of the program is to improve the retention of students in STEM majors. To achieve this goal, in previous programs, we targeted recruitment of freshman and sophomore students, along with students from non-research-intensive colleges and universities including community colleges (Yalim et al., 2023). We attribute the success of our students partly to our rigorous selection process, but mainly to our ability to both train them using workshops and tutorials and, perhaps most importantly, enthuse them in the excitement of original research while also providing them with milestones such as presenting their research at the American Geophysical Union (AGU) Fall Meetings as well as participating in an end-of-program poster competition.

A second goal motivating our program is to form cohorts from geographically well-dispersed groups of students. The vast majority of heliophysicists and heliophysics-related college departments and research centers are from outside the southeast region. The heliophysics group in Huntsville is a notable exception and is therefore ideally situated to host an REU program in heliophysics to bring outstanding students from across the nation to increase awareness about the research activities/opportunities in our region and provide our participants with a memorable experience from both academic and cultural-exchange points of view.

In this paper, we present an overview of our program, as an academically and culturally enriching research experience representing the southeast region, focusing mainly on our mentoring strategy to provide our students with the necessary skillset for them to grow into independent researchers. We present a case study that emphasizes the unique and/or impactful elements of our program.

REU Program Overview

Research Theme of Our Program: Heliophysics

The research focus of our program is centered around solar and heliospheric physics (i.e., heliophysics), and some magnetospheric/ionospheric physics. The Sun, the star at the center of our solar system, is the primary source of light and warmth to the Earth and the solar system. As our closest star, it provides an astrophysical laboratory accessible to humans, both via remote space or ground-based observations and now in situ with the Parker Solar Probe. Much of what we know about other stars and galaxies in the universe comes from the Sun. Our star, however, is more than just a harmless benefactor and astrophysical oddity - the Sun can also erupt and release tremendous amounts of mass, energy, and magnetic field into the solar system. These solar storms propagate through the solar system, or heliosphere, until they reach the edge of our local boundary, the heliopause, where they are transmitted into the very local interstellar medium. The storms directed at Earth can create hazardous conditions for humans in space and damage or destroy Earth orbiting satellites. It is important, then, that the Sun, the surrounding heliosphere, and the magnetosphere and ionosphere be studied and understood, both because of its significance to humanity as well as its importance to astrophysics (Turner & Hesse, 2010). The ability to predict solar storms is vitally important to makers of GPS systems, cell phones, electrical providers, and most modern technologies.

It requires a large number of physicists with expertise across many fields to address any one of the above topics adequately. The best research environments for answering these questions tend to involve a judicious mixture of university faculty, research scientists, post-docs, and graduate and undergraduate students. This is precisely the environment within which the REU program is held – SPA, CSPAR, and the NASA MSFC solar and gamma ray groups are all collocated contiguously in the UAH NSSTC Building with offices mixed together and next door to one another. The students are in an office pod in the center of the offices occupied by faculty, researchers, graduate students, and other undergraduate students doing summer research.

Our program provides undergraduate students with first-hand experience working on world-class research projects related to the Sun and the heliosphere covering a range of topics, from theory/modeling, to simulations, data analysis, and instrument development. This range of topics is well-suited to the broad spectrum of abilities we encounter. About half our projects involve data analysis, with the other half being made up roughly equally of projects involving simulation, theory/modeling, and instrument development. We tailor our projects to a wide range of abilities, so that we generally have a mix of freshman, sophomore and junior participants.

Our Philosophy Towards Undergraduate Research and Training

REUs have become highly competitive, making it increasingly difficult for students from small universities and those without much exposure to undergraduate research to be accepted into REU programs. About half the students accepted into our program have only 1 or 2 years of college training. This requires us so first bring them up to a standard suitable to manage the projects they have been assigned. We achieve this by, firstly, providing computer skills training and solar and heliospheric physics lectures at an introductory and mid-level range. Most importantly, we select a mix of students with, on average, ~50% having prior research or computational skills and 50% being completely or largely inexperienced. This ensures that students have peers with some prior knowledge and skills that can be shared communally. Since the students share a common workplace, they assist each other, an approach that works surprisingly well. Finally, we select faculty/researcher mentors willing to spend more time with less experienced students. We regard careful student-mentor pairing as key to ensuring that both obtain the maximum return from the program. In addition, our REU Management Team serve as “shared” or “group” mentors, and they check on the student group daily during the first several weeks and are available to support students throughout the summer.

Growing from Dependent to Independent Researchers

Student-Mentor Placement

To ensure student success, our first step is a carefully considered and proactive placement of a faculty/researcher mentor with a student based on the research project, the skills required, and the mentor's personality and experience working with students. As we have done before successfully, at the beginning of each calendar year, the Management Team develops a list of potential scientists from UAH and MSFC to serve as REU mentors (on a 50%-50% basis). Each scientist mentor submits a project description, required programming skills, and statement of willingness to work with inexperienced students. Each mentor is encouraged to provide at least one co-mentor to assist during the summer, these possibly being a colleague, a post-doc, or graduate student. The co-mentors are available to assist the student if the advisor is on travel, and they may have different skills and more time that the student can draw on. We encourage the co-mentor to work with the scientific advisor from the outset so as to be familiar with the student's project. Once the students have been selected, the Management Team pairs students with projects that best match their skill level and interests while also considering the personality of the mentors.

Table 1. *Example quotes about student/mentor relations from past REU programs*

> "*I enjoyed the passion that my mentor had about my project. In general, he was an engaging person to talk with and kept things interesting, I look forward to continuing my research with him.*" (REU student from Palomar College, CA).
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> "*My interactions with my advisors were very good. All of them were nice and patient regarding me and my work. I was also able to ask them personal questions about my future and receive advice that made me think hard about my future.*" (REU student from Whitman College, WA).

The UAH-MSFC REU program has been fortunate in that we have always had more potential mentors and research projects than students. This has allowed us to find good matches for each student. With the addition of new faculty, a larger number of post docs, and a growing graduate student body, the number of mentors, co-mentors, and research projects continue to grow each year. The Management Team notify both the selected students and mentors and ensure that the mentors provide introductory reading material and answer questions prior to the students' arrival. We have found this placement process to be extremely successful, resulting in our students doing some excellent research, and publishing a number of papers in prestigious research journals. The effectiveness of the student/mentor partnering can be gleaned from the example quotes from past REU programs (see e.g., Box 1). These examples are typical and reflect that the care taken in identifying suitable student-mentor pairing generally works well.

Introductory Workshops

We anticipate that most students accepted into our program will have very little research experience and almost certainly no previous experience with solar or heliospheric physics. To address this, each year, we hold a series of introductory solar and heliospheric physics lectures given by UAH and NASA scientists. The goal of the lectures is the students to learn fundamental concepts of solar, heliospheric, magnetospheric, and ionospheric physics. The science lectures discuss heliophysics from the interior of the Sun, the interaction of the solar wind with the Earth, and out to the heliopause. The students are encouraged to ask questions and participate in exercises.

Almost as important, at least in terms of obtaining practical hands-on skills for their projects, the students attend introductory programming lectures and work through a series of self-guided programming tutorials in Python, MATLAB or IDL SolarSoft. Each mentor determines which programming tutorial(s) their student should complete. Typically, this introductory workshop lasts 3 days. The first part of the program includes two daily "science" lectures, one in the morning and one

after lunch. The remaining time is spent working through tutorials. The Management Team is on hand during this time to answer questions and assist students with the tutorials, which they have developed. They also update the tutorials each summer based on the anticipated student projects. Although all students are expected to complete the tasks independently, we encourage them to help each other. Students with more programming experience assist those with less experience and relationships build quickly. In addition to the introductory workshops, the students attend the heliophysics science lecture program, two lectures per day during the first week, one lecture per day in the morning during the second week and one lecture per week during weeks 3-10 of the program. The students also attend weekly science talks that are part of the weekly UAH and MSFC colloquium series. We have found that a front-loaded science and workshop program ensures that the students, both those without and with some research experience, develop sufficient skills to make early meaningful progress on their projects with some reasonable understanding of the scientific rationale behind the project.

By thoroughly mixing the students from the outset, the students begin to develop a sense of community and bond with one another.

Cohort Activities
Besides research activities, our REU students participate in a variety of cohort and enrichment activities. These include visits to the Saturday night planetarium show at the Von Braun Astronomical Society, a tour of the NASA Marshall Space Flight Center, a hike to Green Mountain in the south Huntsville area, and outreach activities including a summer bridge program organized by UAH for incoming and prospective students from the high schools in the Huntsville area to learn about their research activities. We are fortunate in that the summer at CSPAR/SPA and NASA MSFC is alive with numerous other undergraduate and graduate student activities. The students are neighbors and share workspace with other NASA and NSF Established Program to Stimulate Competitive Research (EPSCoR) Future Technologies and enabling Plasma Processes (FTPP) project summer students – this includes an FTPP international summer space weather camp that has students from Germany, South Africa, and the USA, an FTPP plasma physics program that draws students from the Southeast, and NASA interns from all over North and Central America. Our REU students are encouraged to participate in the additional group activities organized by these other groups. Additionally, 1-2 students supported by the Solar wind with Hydrogen Ion charge Exchange and Large-Scale Dynamics (SHIELD) NASA Drive Center REU program join our REU cohort activities. An interesting point that we have learned about our REU students is that they enjoyed participating in outreach activities in which they shared their knowledge with younger people, such as high school students (see, e.g., the summer bridge program at UAH above).

Career Development Workshops
One obstacle for students from disadvantaged backgrounds is early engagement in professional and career development opportunities. We find that students from non-research-intensive universities and first-generation students are often unaware of the requirements (and opportunities) to attend graduate school. This includes not knowing about the graduate student lifestyle, the requirements for admission to graduate school, or alternative career options. To address this need, we engage our REU students in the UAH Professional Development Program, organized by the Director of Undergraduate Research. This is offered to all summer internship programs at UAH. The REU students follow a series of professional development lectures that includes preparing for graduate school, the application process, GRE preparation, and graduate student funding. Additionally, a UAH career counselor hosts a “resume and CV writing” workshop and provides each student with one-on-one resume guidance and interview tips. The career guidance program is augmented by a “graduate student panel” to talk about their experiences as graduate students. The panel includes past REU students that have since followed a science career - we have several “success” stories, including

former REU students that entered the SPA graduate program and either have or are close to obtaining their PhD degrees in Space Science. Of course, the REU students have significant interactions with their scientist/engineer mentors and co-mentors, and we encourage the mentors to talk to the students about what propelled their academic or research paths.

Presentations, Poster Competition, and AGU Attendance
A cornerstone of our program is that each REU student is expected to present their research in a public setting and that the work should be of sufficient significance that it can be presented at a major domestic international conference, namely AGU Fall Meetings or American Astronomical Society (AAS) Winter Meetings. Each student is asked to make two presentations during the summer: The first occurs at the end of the first three weeks of the program. The students are asked to prepare slides and give a 15-minute talk to the Management Team and mentors, describing the problem they have been assigned. The purpose of this presentation is to ensure that each student has a good understanding of their project and to determine if there are problems with their understanding and/or advisor. At the end of summer, each student prepares a poster and presents this to the rest of the participants, as well as interested graduate students, mentors, and other NSSTC staff.

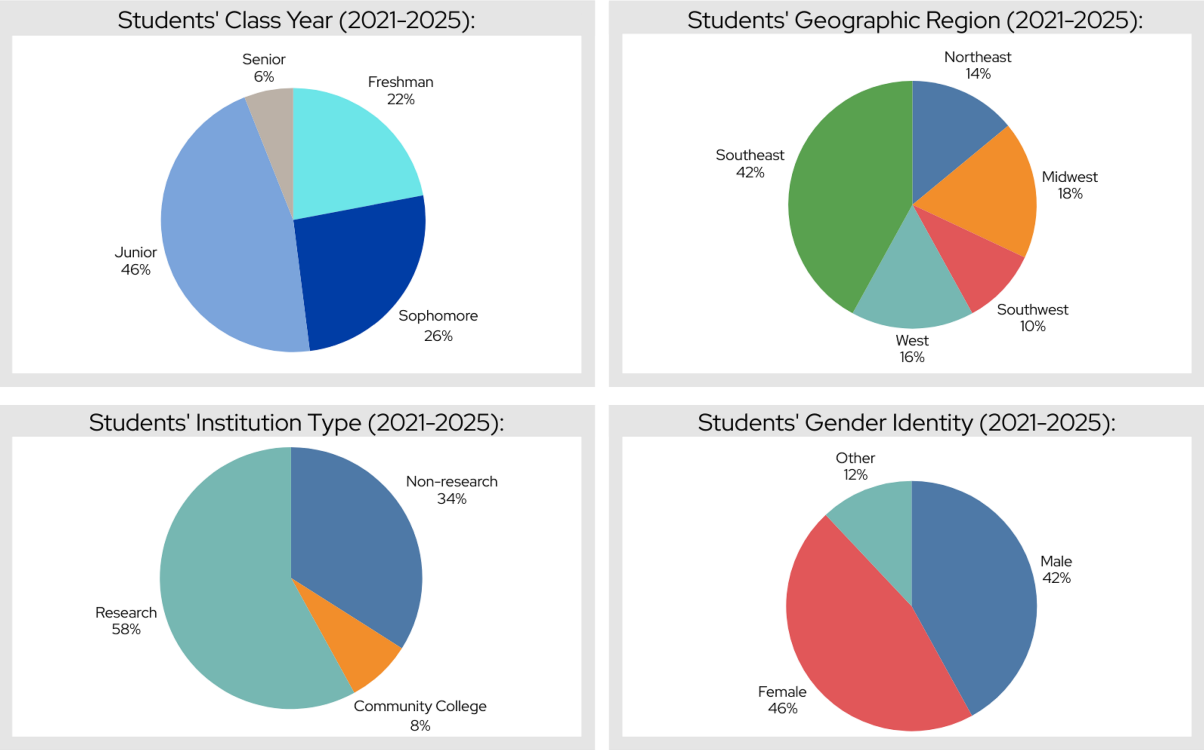
In view of the enthusiasm with which the REU students tackled their poster presentations, we have been organizing a final poster competition since summer 2021 where a jury of 2-3 scientists from UAH and MSFC that are not mentors/co-mentors in any project judge the online student poster submissions according to rubrics based on appearance, content, and narrative. The first three winners of the poster competition are announced at the end of the REU final presentations and are acknowledged with certificates. Additionally, the first-place winner is awarded a trip to an international conference outside the US which gives the student another opportunity to present their work as well as provides the student with a cultural enrichment experience. Since its inception, this competition became one of the highlights of the program and increased the quality of the posters significantly. **In particular, three of the first-place winners were from non-research/community college students which shows the effectiveness and quality of mentorship in our program**.

The students' final posters are presented primarily at the AGU Fall Meetings held annually in a major city in the US. This is the largest annual national and international meeting held in our field. Each student is required to submit an abstract to the AGU before the end of the summer. Our program partially supports students who wish to travel to the AGU. If a student is unable to attend, their poster is still presented by a Management Team member or their advisor. The AGU is an opportunity to meet numerous solar and heliospheric physics scientists from the US and the rest of the world, to discover the extent and excitement of the field, and interact with other students. Typically, 7-10 REU students participate in the AGU each year.

Long-term Mentoring Relationships with Students
We endeavor to maintain long term relationships with our REU students through Facebook and "annual follow-up" emails. This reminds the students of their time with us, and the connection that they maintain with the program and their mentors. Mentors often write references for their students for graduate schools. Several past participants have indicated that a strong letter from an eminent scientist who speaks highly of their research capabilities has contributed to their acceptance into prestigious schools.

Mentors sometimes continue to work with students beyond the REU program, especially when a student's work is to be used in a publication. **Our program has a remarkable achievement of 12 refereed publications having included our REU students over the past 13 years. We regard this as one of our most satisfying accomplishments with the REU program, and publication of a paper makes an enormous impact on a student's future career.**

Figure 1. *Cumulative pie charts for our NSF REU program during the 2021-2025 period showing a breakdown of the students' class year (top left), the students' geographic region (top right), the students' institution type (bottom left), and the students' gender identity (bottom right)*



Conclusions

In concluding our discussion, we identify some of the important outcomes from our REU program.

Our program has helped increase the number of students, especially from non-research-intensive universities and institutions, entering graduate school in STEM fields. **Although our focus is on heliophysics, students learn important computing and engineering skills that can lead them to either or both non-physics STEM degrees and careers**. Our longitudinal tracking found that 13 REU students (2021-25) went on to graduate school (to 11 different schools, including 3 who attend(ed) UAH). Increasingly, we find that students who were in our more recent cohorts or were part of an earlier REU cohort during their early study years wrote in our exit surveys that they were considering applying for graduate school. Because of this, we anticipate an increase in these final statistics in the coming years.

Our program provided research opportunities to students from universities and colleges that do not have high research activity levels. **It is important to engage these students early in their careers since the educational environment in non-research colleges tends not to link the basic physics/math courses taken by students to discovery-based activities, including research and applications**. We risk early loss of these students from STEM, so our achievement of 22% freshman and 26% sophomore participation is important when combined with attracting 42% of our REU students from low research-level universities and community colleges. Notably, 8% are students from the latter (see Figure 1), and they use their REU experience from our program as leverage to pursue a degree in a four-year college/university (see the next paragraph below).

To provide research opportunities to students from community colleges and explore whether this leads them to more problem-solving/research-oriented careers is another important achievement of our program. Traditionally, community colleges provided vocational training, with subject matter taught from the perspective of direct applications, rather than a broader scientific framework. **Exposing students to a more unstructured problem-solving environment associated with research projects allows them to see the value in understanding science more broadly. The result is an improved retention of students in all scientific fields**. Our longitudinal tracking found that 3 REU students (2021-25) from community colleges went on to pursue undergraduate STEM majors in well-known research universities, 2 in California, and 1 in Florida.

Finally, we provide research opportunities to undergraduate students from a geographically well-dispersed applicant pool around the US who, as a student body, also reflect the city of Huntsville workforce gender demographics (see Figure 1). The Huntsville area, being an oasis of technology in the southeast US, presents research and career opportunities in STEM fields for outstanding students across the nation. **Therefore, a memorable academic and cultural experience helps to build and retain a much-needed highly-skilled potential workforce in STEM**.

Acknowledgments
The authors acknowledge support from the REU grant funded by the National Science Foundation under award number AGS-1950831. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The authors would like to thank Ms. Laura Provenzani for providing the figure.

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