Creative Education, 2023, 14, 607-636
https://www.scirp.org/journal/ce
ISSN Online: 2151-4771
ISSN Print: 2151-4755

Student Space Missions—Facilitating Pathways to Success for Next Generation Professionals in Space

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How to cite this paper: Bering III, E. A., Khan, S., Jacobs, L. T., Hampton, D., Mölders, N., Thorsen, D., Gamblin, R. B., Greer, M., Greer, P., Gunawan, B., Hernandez, E., Humble, E., Lehnen, J., Nguyencuu, A., Piña, M., Porat, I., Prince, J. R., Pessoa, A. G., Salas, C., Simmons, J., Tovar, C., & Ulinski, A. (2023). Student Space Missions—Facilitating Pathways to Success for Next Generation Professionals in Space. *Creative Education, 14,* 607-636.
https://doi.org/10.4236/ce.2023.143041

Received: February 7, 2023
Accepted: March 28, 2023
Published: March 31, 2023

Abstract

The Undergraduate Student Instrumentation Project (USIP) was a NASA program created to engage undergraduates in rigorous scientific research for the purpose of developing the next generation of professionals in space research. It is now run by the University of Houston using local resources. The development of next generation space professionals is addressed by using inquiry-based learning. Students are guided through the process of selecting a question of interest to them from disciplines such as heliophysics; atmospheric physics, chemistry, and biology; and geoscience. The students are then guided through the process of developing an experimental investigation to address their question. This student-led project is executed by the students from initial ideation of research objectives to the design, testing, and deployment of scientific payloads. The 5E Instructional model places the student at the center of knowledge building, while instructors facilitate interaction with content and guide the inquiry process. The project is designed to integrate engineering, technology, physics, material science, and earth and atmospheric sciences as an important opportunity for the students to gain access to cross-disciplinary experiential research. In addition to classroom engagement, the students build their own payloads and ground instruments. This project increases students' command of essential skills such as teamwork, problem solving, communication, innovation, and leadership. For the students, this formative experience continues to encourage the development of a broader range of technical skills than is typically offered within an undergraduate degree. These skills include project management, systems engineering, balloon payload design, and balloon flight operations. More specifically, we teach sensor and instrument design, avionics, circuit, and power systems design, payload mechanical and thermal design, and telemetry and navigation. The students are also taught to prepare and present standard NASA project review materials, such as Preliminary Design Review, Critical Design Review and Mission Readiness Review presentations. Furthermore, the time and energy that students commit to this project promotes professional responsibility and emphasizes the necessity of coherent teamwork. Not only do students make connections with each other during this process, but also to the broader space science community. They often work with professionals from outside of the USIP structure, and regularly attend and present at conferences and student competitions throughout the project. Student projects included subjects ranging from atmospheric trace gas chemistry, ground penetrating radar and thermal infrared imaging coupled with multiwavelength *LiDAR* study of surface topography and chemistry, auroral electron precipitation, quantitative multi-wavelength airglow studies, search for stratospheric microplastics, monitoring auroral radio emissions, and stratospheric conductivity. This program is a for-credit course of two to three years duration.

Keywords

Curriculum Development, Project-Based Learning, Spacecraft Design

1. Introduction

1.1. Overview

The Undergraduate Student Instrumentation Project (USIP) was a NASA program created to engage undergraduate students in rigorous scientific research for the purposes of innovation and developing the next generation of professionals in space research. It is now run by the University of Houston using local resources. Students lead and execute this project, based on the Engage, Explore, Explain, Elaborate, Evaluate (5E) instructional model, from the initial ideation of research objectives to the design, testing, and deployment of scientific payloads. The 5E Instructional model places the student at the centre of knowledge building, while instructors facilitate interaction with content and guide the inquiry process. Since 2013, this project has been not only an effective vehicle for delivering STEM education, but also has effectively increased classroom engagement and interest in space science. Space research is inherently interdisciplinary and crosscuts Geoscience, Engineering, and Technology. The design of the project integrates engineering, technology, physics, material science, and earth and atmospheric sciences as an important opportunity for the students to gain access to cross-disciplinary experiential research. In addition to classroom engagement, the students build their own payloads and ground instruments. This project increases students' command of essential skills, such as teamwork, collaboration, problem solving, technology, communication, innovation, and leadership. This formative experience encourages the development of a much broader range of technical skills than is typically offered within an undergraduate degree. Furthermore, the extensive time and energy that students commit to this project promotes a strong sense of personal and professional responsibility and emphasizes the necessity of coherent teamwork. Not only do students make valuable connections with each other during this process, but also to the broader space science community. They often work with professionals from outside of the USIP structure, and regularly attend and present at conferences and student competitions throughout their tenure in the project. For the faculty, the project extends their exercise in professional development, learning how to implement project level inquiry-based education on this scale. This paper presents a web-based scaffolding used to simulate the traditional face-to-face 5E experience during COVID. Student projects have included subjects ranging from atmospheric trace gas chemistry, Light Detection and Ranging (*LiDAR*) study of snow and sand avalanche dynamics, auroral electron precipitation, gravity-wave modulation of the hydroxyl layer, search for stratospheric microplastics, and monitoring auroral radio emissions, among others. This program is a three credits/semester course of two to three years duration.

1.2. Motivation

The need to develop new, modern, low cost, ultralight instruments for use on small hand-launched balloons stems from the huge amount of open science questions on transient, ephemeral phenomena such as the aurora borealis and the Arctic ozone hole. For example, to make simultaneous observations of an ephemeral event with either a satellite or a sounding rocket and a simultaneous balloon flight, the 2-hour time delay between launch of a balloon and its arrival at float altitude often requires several launches to obtain the desired observations. The students' payloads will reduce the per launch cost for these observations by 1 - 2 orders of magnitude, thus allowing for many more precursor balloon launches in each campaign. The development and successful proof-of-concept test flights of new instruments that address active science questions will allow future investigators to document that the feasibility of their planned methodology has already been established.

Pedagogically, the development of this course was motivated by the growing realization that undergraduate education still needs more inquiry and project-based learning. Today's entering students (**Figure 1** and **Figure 2**) have been the beneficiaries of science classes that used the 5E model of instruction (Bybee & Landes, 1990), the Next Generation Science Standards (NGSS) (Bybee, 2014; Council, 2012), or equivalent for their entire lives. They are comfortable with inquiry-based instruction and have grown to expect it. 5E lesson plans are impractical in large college lecture classes. Furthermore, at the college level, effective inquiry-based teaching appears to require projects of greater scope than a single class or even semester allows. Finally, working scientists and engineers often

Figure 1. USIP I team. Front row (L-R) Daniel Canales, Megan Pina, Rachel Gamblin, Michelle Nowling, Daniel Hermosillo, Erika Marrero, John Cao. Back Row: Sikender Shahid, Edgar Bering, Hamza Ahmed, Chris Bias. (Missing Arian Ehtashami, Diego Guala). Photo: D. Canales.

Figure 2. First week USIP II (2017) team on the roof of the Davis Observatory. (L-R) Edgar Bering, Itay Porat, Brett Velasquez, Samar Mathur, Christian Behrend, Alexis Fenton, Michael Greer, John Prince. Kneeling: Megan Pina and Rachel Gamblin. Photo: D. Hampton.

spend much of their careers working with system engineers and formally trained project managers. However, most undergraduate science curricula never address these subjects. The course described in this paper tries to address these gaps between undergraduate education and graduates' career-field challenges and professional requirements.

This paper begins with the section we are in, the introduction. The second major section presents the details of the 5E methods we use in constructing and teaching the course. The third major section presents the process of implementation of the program, giving an overview of the early campaigns and extensive details of the 2020-2022 program. The fourth section lists the publications that have resulted from the project and summarizes graduation results. The paper ends with conclusions.

2. Outline of the Methodology

We detail the major three components of the methodology: the formal pedagogy, the structure of the virtual classroom, and the organization of the students in the project.

2.1. Pedagogy

Grounded in Constructivist theory, the 5E Instructional model places the student at the centre of knowledge building, while instructors facilitate interaction with content and guide the inquiry process (Bybee et al., 2006). Offering a research-based, sequential framework that provides a conceptual-change model of learning (Bybee & Landes, 1990; Sengul & Schwartz, 2020), empirical studies have shown that the 5E instructional model significantly impacts student engagement and instructional effectiveness (Sengul & Schwartz, 2020; Tanner, 2010; Wheat et al., 2018). Research also indicates that active learning experiences are a very significant contributor to college student achievement and retention (Sengul & Schwartz, 2020).

2.1.1. Engage

The goal of the engage phase is to elicit student interest and gauge prior knowledge through the examination of a particular event or problem, sparking inquiry that directly connects to the desired learning objectives (Bybee, 2014; Bybee & Landes, 1990). The activities conducted in this phase expose prior misconceptions and serve to alleviate cognitive disequilibrium (Sengul & Schwartz, 2020). The course begins with lectures and guided reading on the general areas of ionospheric and atmospheric physics and geoscience. The main objective of the first semester is to engage the students in the Earth and sky around us.

2.1.2. Explore

During the explore phase learners assess the validity of their prior thoughts on the topic and engage in hands-on activities where they can advance their understanding and further investigate problems of interest. Instruction provides concrete descriptions, counters misconceptions, but most importantly, facilitates guided student inquiry (Bybee, 2014; Bybee & Landes, 1990). The second objective of the first semester is to have the students explore the aforementioned areas of science and engineering to choose a question or problem of particular interest to them.

2.1.3. Explain

The explain phase presents full explanations of the scientific content, where students connect concepts through the acquisition of associated vocabulary and science and engineering practices (Bybee, 2014; Bybee et al., 2006). During the first summer and the second semester of this course, the students develop a plan to understand, answer and explain their question or problem. They will design a balloon payload or ground experiment for making observations that will address their question, or a new balloon system that will enable new observations. They will also learn to use systems engineering and planning tools such as GANTT charts to organize their work.

2.1.4. Elaborate

In the elaboration phase students apply concepts learned to new or unique scientific problems. Instruction focuses on presenting students with a novel challenge that requires them to apply and extend the concepts mastered in prior phases (Sengul & Schwartz, 2020; Wheat et al., 2018). In the third semester of this course, the students test and calibrate their experiments. Once tested, it is time to fly. In early March, we extend the world of these young Texans by taking them to Fairbanks, Alaska in March (**Figure 3**) to launch or deploy their experiments.

2.1.5. Evaluate

Although the instructor provides formative assessment throughout the learning process, in the evaluation phase the instructor assesses student-provided evidence of learning and project work product. Instructor feedback guides students

Figure 3. Geophysical institute, university of Alaska, Fairbanks. Photo: e. bering.

to provide clear justification for their findings through open-ended questioning and self-assessment (Sengul & Schwartz, 2020). The evaluate portion of this program consists of data analysis and publication. Students are required to submit to the AIAA Regional Student Paper competition. They are also encouraged and funded to present their results at the Fall AGU meeting, AIAA SciTech, or other national conferences

2.2. Virtual Classroom

2.2.1. Project Overview

The virtual classroom that we designed provides tools for ongoing collaboration, revisions, storage, project planning, systems engineering, and requesting immediate feedback from faculty and fellow researchers. Additionally, the classroom provides an ongoing place to store data from different students and project cohorts for many years. New students can use this continuity in a consistent and secure way. We also provided tools for conferencing and communication. We customized a combination of several tools to meet this need. These tools include Google Classroom, Microsoft Teams, Slack, Git, GroupMe, and Zoom.

2.2.2. USIP Google Classroom

A customized Google Classroom is the access point for all the tools used in the classroom. The goal for the USIP project was to have an organized collection of links that the students could visit and access all the project tools easily. The classroom has four top-level tabs: Stream, Classwork, People, and Grades. There are also links to Google Meet, Microsoft Teams, the Class Drive, and the Class Calendar.

2.2.3. USIP Classwork

The Classwork Tab (**Figure 4**) is the most important and widely used. It includes links to the Class Lectures and Recordings, Announcements, Assignments, and the Wiki.

1) Class Lectures and Recordings.

The goal was to establish a virtual lecture platform that is well suited to simulcasting and thus can be used to connect with students both within the University and at home. In the past, the tool used was Adobe Connect. One of the reasons for this selection is that the recording tool was one of the easiest to use. In addition to a link to Adobe Connect, there is a link to the accumulated lecture recordings. Adobe Connect has been discontinued by Adobe. We have replaced it with Microsoft Teams.

The Microsoft Teams tool serves to hold research group meetings for the separate USIP science and system teams. Microsoft Teams will be used for lectures instead of Adobe Connect going forward. The students selected Slack and GroupMe for private, faculty-free discussions.

2) Announcements and Assignments.

These two links are lists of posts. The Assignments have due dates, the Announcements do not. Announcements are the main tool for posting special

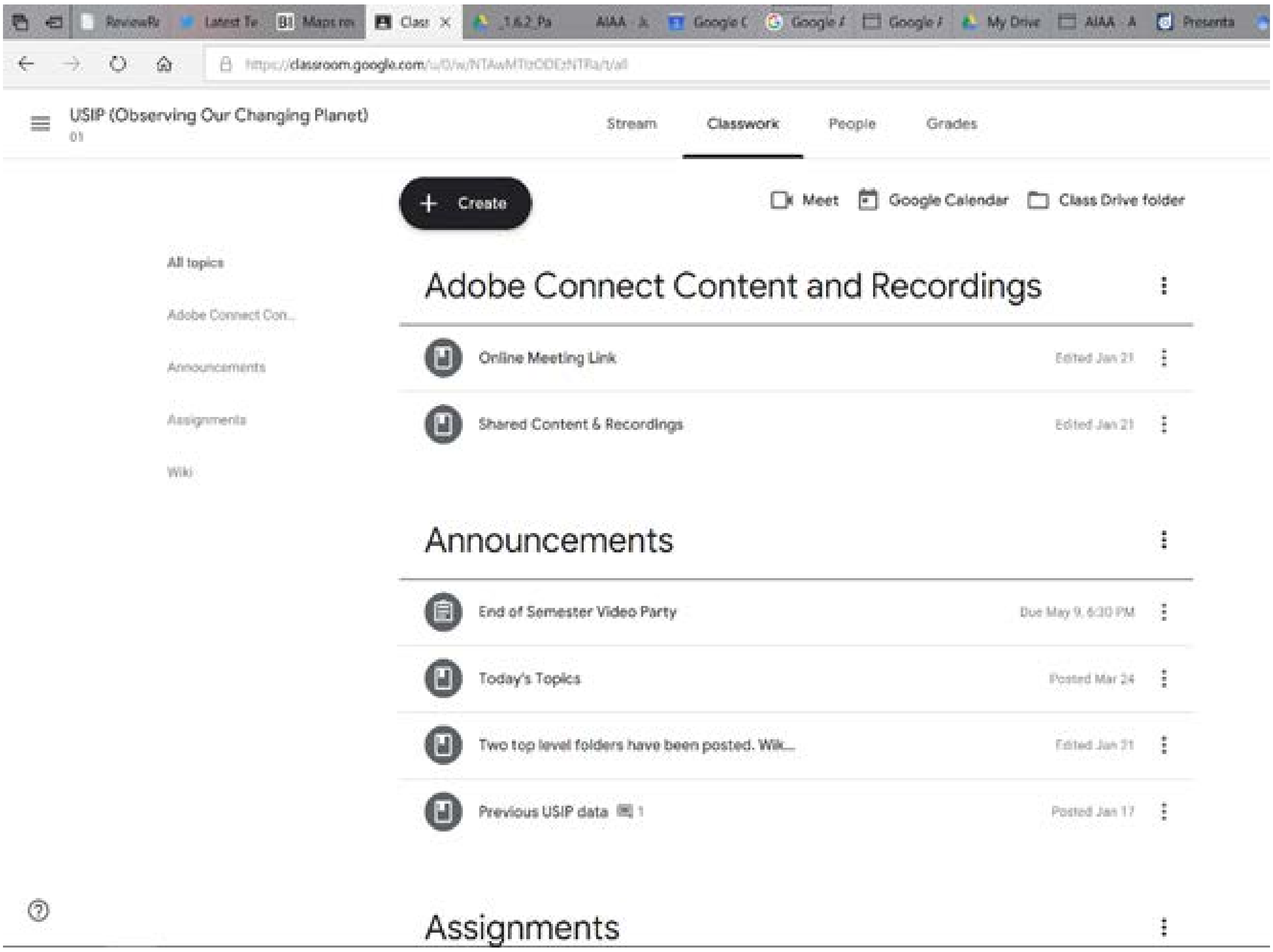


Figure 4. Screenshot of the Classwork Tab.

purpose links that we need from time to time. We add Class Materials with the "Create" button in the Classwork section of the classroom. For easy organization, users can post results of group tasks, materials, and assignments in related topics.

2.2.4. Wiki

The Wiki is the main collaboration space for the USIP project. It holds several things: Work Breakdown Structure (WBS) and File Naming Convention specifications, Microblog, Project and Personal GANTT charts, and Project and Personal File Storage.

1) Wiki—Work Breakdown Structure (WBS) and File Naming Convention Specifications

One of the global objectives of the project is teaching systems engineering and project management. The top level of the Wiki contains two documents that are critical to achieving these objectives. The first document is a detailed WBS for the entire project. The WBS is used in three places, the Project GANTT chart task lists, the Folder structure of the Class Drives, and the line items of the budget. The second document describes a uniform file naming convention based on the WBS. Using uniform file names is not only essential in keeping track of ~15 - 30 students' work products, but also a skill they need in their future careers.

2) Wiki—Microblog

The most important feature of this toolset is the class Microblog. The first goal was to have a space that the students would use daily to document any research they had done. The second goal was to have a tool that students could use easily to ask for immediate feedback from anyone of their research leaders. We encouraged students to post daily updates on research done and use the @mention feature of Google Docs to ask questions or post comments. The assignment reads

"*Make an entry every day you work. Answer the following*:

What do I plan to do today?

What did I do today and how did it work out?

What do I plan to do next?"

The assignment also encourages students to ask questions of the faculty as soon as they arise.

3) Wiki—Project and Personal GANTT Charts

Keeping 15 - 30 students on track and on schedule while designing 5+ experiments is a challenge. We use GANTT charts as the primary long-term scheduling and planning tool. This choice stems from the fact that formal project management processes are a learning objective of the class. The major goals were to have a set of charts where the parent GANTT chart encompassed the project as a whole and each individual student could have a connected child GANTT chart, with each child chart showing an identical subset of the parent chart. The tasks and subtask structure are based as much as possible on the WBS. The faculty mentors review the charts regularly. The GANTT charts are created using Smartsheet and are accessible via links in the Wiki. The Smartsheet app is also accessible from the Microsoft Teams application.

2.2.5. Wiki Files and Other Class Drives

1) Wiki Files

We created a primary storage folder (named Wiki Files) for all class materials on the lead instructor's myNSM Google Drive account. This folder represents unlimited storage for all electronic project materials. The names and subfolder structure follow the WBS as much as possible. All stored materials are supposed to use the project file naming convention. There is a link to the Wiki Files folder in the Classwork tab. There is a subfolder not listed in the WBS that holds the files from previous USIP I - III teams. This combined setup provides a single access point for all USIP data from any year.

2) Personal Drives

Students have access to substantial storage space through their myNSM Google Drive. Currently, this feature is available to all enrolled students at the university. There is a personal link to a student's personal drive from the Classwork tab in the Classroom.

3) USIP Account

A separate myNSM Google account was created specifically for the USIP team to enable them to consolidate all current and future storage requirements in one space. This account also provides a logically and formally distinct copy of everything. The USIP myNSM Drive root folder acts as backup to the Classroom Wiki Files folder and is called USIP IV Storage Backup. The Wiki Files folder is copied regularly and automatically to the USIP IV Storage Backup. Also, the USIP myNSM Drive is one of the two repositories of very large data files that will not be stored in the Wiki Files, which means that the data coupling between folders is a one-way backup.

4) Other Servers

The project has an external physical server, SPACE 1, for storage and processing, located in the same building as the USIP labs. SPACE1 has several Tbytes of hard drive storage. There is a folder on SPACE1 that mirrors USIP IV Storage Backup, via a periodic bidirectional sync. SPACE1 is in the same building as the USIP labs. This structure permits much faster upload speeds from the labs than the myNSM Google Drives do, owing to campus inter-building bandwidth chokes. Therefore, we will upload our very largest data files to SPACE1 alone. SPACE1 offers the students IDL, Matlab, Mathematica, and Python. If real disaster strikes the UH facilities, the myNSM Google Vault acts as a last resort backup to the entire system. Lost data can be found through a simple search.

2.2.6. Class Calendar

The classroom calendar is the main short-term time management tool. The calendar links the students' calendars to the specific class calendar. Instructors can subscribe their own calendars to the class calendar as well if desired. Students and instructors can access the class calendar from inside the Classwork tab (**Figure 4**). The calendar link at the top of the classwork tab is a personal calendar for each student, while the calendar in the pulldown menu on the left side is the class master calendar.

2.3. Project Organization

The undergraduates form teams of 4 - 6 students to develop and build one or two identical payloads per team for launch using 1200 - 2000 gm latex weather balloons and related ground and geoscience instruments. They learn problem solving by addressing the design problems presented by these payloads and instruments. The requirement that they work in teams teaches teamwork through mentored experience. Most of the payloads are launched twice each from Fairbanks, Alaska, in March, as shown in **Figures 5-7**. Other possible launch sites include Palestine, TX, Ft. Sumner, NM and Kiruna, Sweden. Related ground experiments have been developed, deployed, and operated. Each payload contains one or two of the individual science and engineering experiments built by the undergraduate teams. The engineering problems common to all the experiments

Figure 5. Inflating Flight 1 of the USIP I Alaska Campaign. Photo: Bonnie J. Dunbar.

Figure 6. Launch 1 flight team. L-R Erika Marrero, Rachel Gamblin, Michelle Nowling, Megan Pina, Daniel Canales. Photo: Bonnie J. Dunbar.

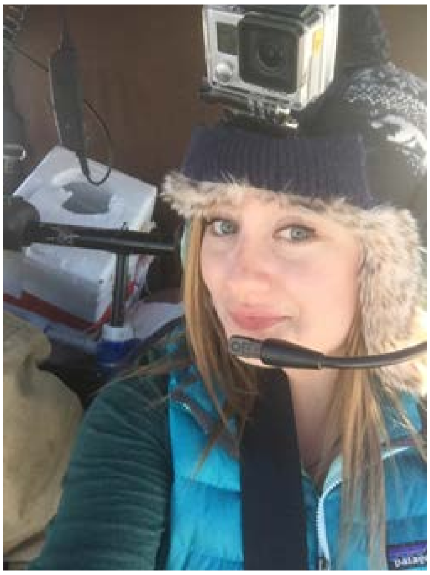


Figure 7. Michelle Nowling about to take off on a helicopter recovery mission.

are solved by systems teams comprised of a mix of members from the instrument teams. Success requires effective communication skills. A cadre of three student Managers manages these teams. Faculty mentors work directly with the students throughout the process to ensure learning and project success. The development and successful proof-of-concept test flights of new instruments that address active science questions will allow future investigators to document that the feasibility of their planned methodology has already been established.

3. Implementation

This program has been offered 5 times to date at UH. Roman numerals are used to label the different classes. The class dates were/are:

- USIP I: Jan. 2014-Dec. 2015
- USIP II: Jan. 2016-Dec. 2017
- USIP III: Jan. 2017-Dec. 2018
- USIP IV: Jan. 2020-Dec. 2022
- USIP V: Aug. 2021-Dec. 2023

3.1. Experiments

The cumulative student-selected set of experiments includes All-Sky Camera (ground based), Trace Gas Profiles, Microplastic Aerosol Profiles, Astrobiology Sampling, VLF Induction Magnetic Receiver, HF Receiver, Total Electron Content (ground based), Star Tracker attitude sensor, Ozone Profile, Auroral Imaging, Auroral Spectroscopy (both ground-based, and balloon-borne), Multiwavelength *LiDAR* (drone-borne), and Meteorology. All the balloon payloads included at least one camera.

Some of the USIP IV experiments were:

3.1.1. Conductivity

The conductivity project aimed to broaden the scarce collection of global atmospheric conductivity data and investigate unexplained short-term conductivity variations. Atmospheric conductivity is a measure of how easily ions can move through the atmosphere, and it increases proportionally to the product of ion concentration and ion mobility. Many existing model profiles of the conductivity rely heavily on measurements of ion production rates, rather than actual conductivity measurements. Performing direct atmospheric conductivity measurements would help scientists gain better understanding of the conductivity of the stratosphere (Baumgaertner et al., 2013).

The project produced a high-altitude balloon payload diagrammed in **Figure 8** to perform the conductivity measurements using the relaxation time method (Byrne et al., 1990). At intervals determined as a function of altitude, two spherical probes were charged alternatingly to opposite potentials. Once the charges are released, the potentials decay exponentially by conduction into the atmosphere surrounding the probes, relaxing to the ambient potential.

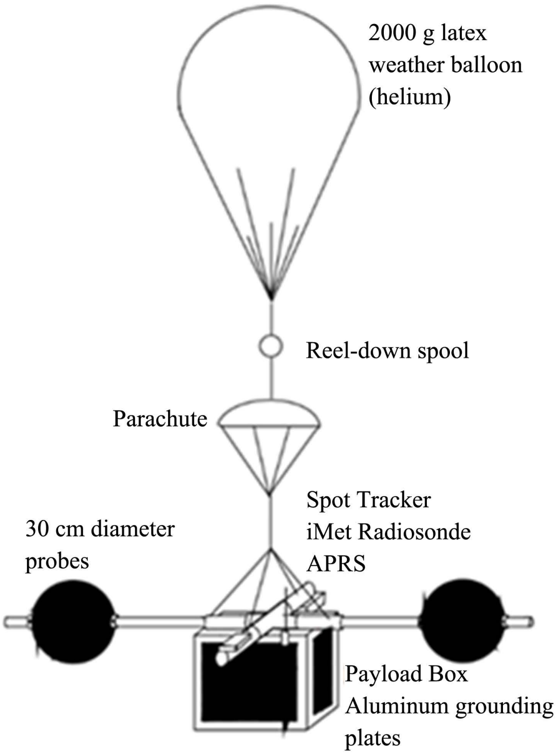


Figure 8. USIP IV conductivity measurement.

3.1.2. High Energy Particles

The High Energy Particles team (HEP) seeks to find an explicit correlation between the presence of VLF waves and precipitation of high energy particles from the Aurora. The theory behind wave-particle interactions in space weather is well understood. The pitch angle scattering of electrons by VLF waves generated in the Aurora will increase the flux of electrons entering the atmosphere. These electrons then undergo Bremsstrahlung interactions as they enter the atmosphere and produce X-rays. Confirmation of a positive correlation between VLF waves and X-rays in an active aurora would serve as evidence to this theory, which is currently supported by correlations that are not so clear.

An air-core loop antenna will be used to receive VLF signals recorded between 3 - 22 kHz, covering the frequency within the VLF band. The VLF antenna will be connected to the receiver via coax cable. The information will be passed through a preamplifier, which will strengthen the signal enough to be digitized. An output filter cleans the signal of noise contamination. The waveform data were then digitized by a high speed A-D card and stored on a 1-TB SD card. The combined information from the modulator circuit will also be sent to the Arduino on board where it will be processed and transmitted via XDATA to the ground station. **Figure 9** shows a data sample from this experiment.

ADVACAM's USB MiniPix camera served to detect and capture images of incident high energy particles. Each captured image is represented as a data frame consisting of a 256 × 256 array of numerical energy values. Each nonzero array value in a retrieved data frame represents a location where a single sensor cell

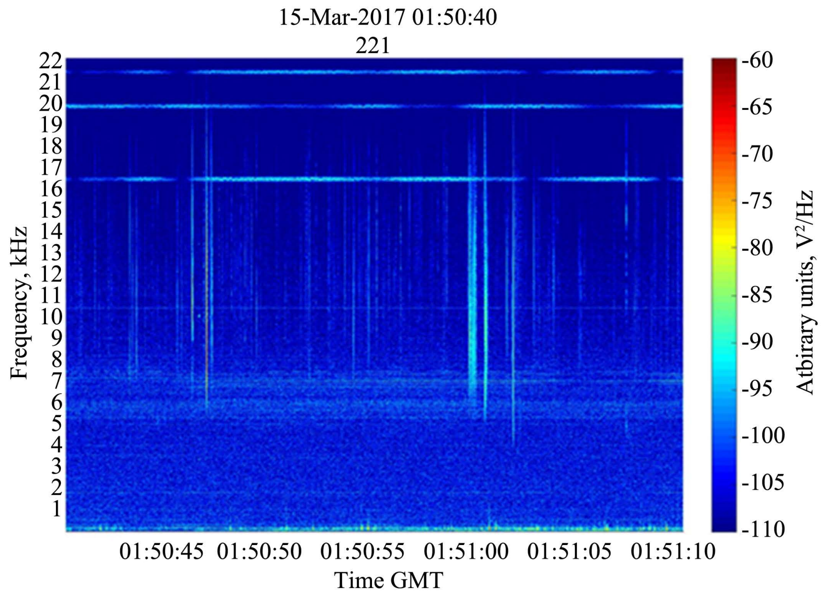


Figure 9. Snippet of VLF data from a 2017 flight. Time is AkDT.

had contact with a particle. A cluster of energy values will characterize a single incident particle and a LSM9DS0 magnetometer will provide its angle of incidence. Using ADVACAM's PIXET PRO software, as well as internally and externally integrated code, these clusters' can be analysed post-flight providing information such as the total energy per cluster and shape of each cluster which along with the angle of incidence, will be used to determine the identity of particles (protons, neutrons, and X-rays) that contacted the MiniPIX's sensor. Further data processing and binning of data, based on energy per particle and particle direction, will be utilized when looking for significant findings. A correlation between VLF waves and high energy particles is of special interest.

3.1.3. Microplastics and Extremeophiles

The USIP IV Microplastics and Extremophiles team were hoping to measure the concentration and composition of both microplastics and extremophiles in the Stratosphere. The instrument currently under development evolved as a successor to the repeating bellows system designed by the Extremophiles Team of USIP II. The current team has also made several design modifications to allow the instrument a greater chance of success. The new bellows will slide along a guiding structural rail to ensure the chamber expands and contracts smoothly. Additionally, a reversible system of pulleys will pull the bottom deck of the chamber along the guide rail, allowing control over both expansion and contraction. An overview of the new system can be seen in Figure 10.

The new instrument will be constructed of the same material as the previous version. To avoid compromising the samples with potential plastic fragments from the bag, the filters will be sealed between two controlled valves that only open during the expansion phase. Because this project is concerned only with the overall quantity and diversity of samples rather than altitude profiles, two

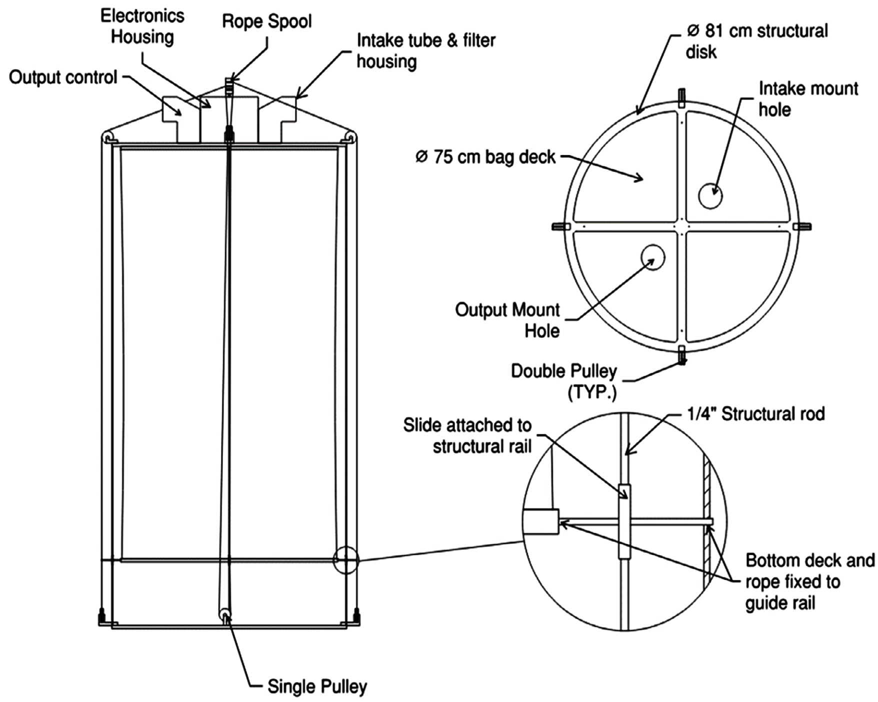


Figure 10. Drawing of microplastics sampler.

static filters will be used instead of a rotating filter wheel. After recovery, one filter will undergo analysis for microplastics, the other for extremophiles. A sealed pair of control filters will also be flown but not exposed to outside air.

The sample intended for analysis of microplastics was planned to be sent to the Raman and Infrared Research Laboratory at UH. There it will first be inspected visually under magnification to identify particles of interest. All plastics less than 5 mm in size will be considered microplastics. A selection of particles will then be analysed via Raman spectroscopy to determine the compositions of plastics present. The sample intended for extremophiles will be analysed via PCR and 16s rRNA sequencing to catalogue the diversity of organisms present.

Fabrication of the experiment was unfortunately delayed owing to supply chain issues and illness among the machine shop staff. We expect to fly it in 2023.

3.1.4. Remote Sensing: Multiwavelength LiDAR

The USIP Remote Sensing team is currently working on designing and building a 905 nm and 532 nm dual wavelength time-of-flight based *LiDAR* that is to be attached and flown using a Matrice 600 Pro Drone. The wavelength selected will serve both topographic and bathymetric mapping. The 905 nm wavelength will be used for topographic mapping while the 532 nm wavelength will be used for bathymetric mapping as well as snow depth analysis. This choice was made because 905 nm has generally high reflectance values in nature so it won't be difficult to receive a return signal and 532 nm is capable of penetrating through water and snow which will allow for mapping the floor of riverbeds as well as conducting snow depth analysis. The *LiDAR* is expected to fly over Tanana related to the possibilities of landslides in that area. The produced maps will have a 0.3 - 1 m spatial resolution.

Data will be collected using the transmitter, receiver, and Data Acquisition and Control System (DACS). In the transmitter, both lasers will be pulsed and use a palmer scan pattern with a scan distance of 100 m. A Galilean beam expander will be used to control the laser's beam divergence. The receiver objective will focus the returning light onto a photodarlington. The voltage produced by the photodarlington will feed into an amplifier to increase the gain further. From there, a comparator will filter out the noise which will be kept low due to a bandpass filter on the receiver lens. All laser pulses and received data will be time stamped. The change in time from the laser pulse to the return signal is measured in the detector and will be used to determine the distance from the *LiDAR* to the ground. The motor used for the palmer scanner will also have positional time stamps so that the direction that each laser pulse went in can be determined. The DACS will contain an Inertial Measurement Unit (IMU) and Real Time Kinematic (RTK) GPS system along with an Arduino uno. The IMU and GPS data will be time stamped to correlate the *LiDAR*s position and orientation with the times of the laser pulses. The RTK GPS has a 2 cm horizontal accuracy. The data collected from the GPS and IMU will be stored on an SD card. All data accumulated will be processed into a .las file for map generating on ENVI and/or ArcGIS.

The pulse rate is 40 kHz which will result in a high-density point cloud of the underlying terrain. Factoring in the scan direction from the time stamped mirror motor mount as well as the IMU and RTK GPS data will facilitate the generation of GPS coordinates for each laser pulse. This will be used to develop digital elevation models (DEM's) as well as 3D models of the terrain. Dry ground, snow, and bodies of water can be distinguished as well. The *LiDAR* will further be tested in Texas before being operated in Alaska. This means that the team will have to take into consideration and design the *LiDAR* at both extremes of temperature. Therefore, the *LiDAR* produced will be versatile and could benefit the scientific community and/or *LiDAR* industry. Owing to issues with the comparator, the *LiDAR* has not been completed yet. Work is still being done on it to finish the build.

3.1.5. VLF and HF Receivers

The purpose of this experiment is to study the effects of the sudden change in electromagnetic radiation from multiple terrestrial sources such as solar radiation, the magnetosphere, and the aurora borealis on the D-region of the ionosphere. VLF and HF waves were chosen for measurement because naturally occurring waves propagate through the Earth-ionosphere waveguide, which can be used to remote sense the ionosphere. The D-region reduces the energy in propagating waves due to absorption. This means that any fluctuations in the D-region are inversely correlated to the strength of frequency waves being received. Although there is a good understanding of space climate, there is not of space weather. Therefore, this project aims to use a SDR receiver, and a copy of the flight proven VLF receiver created by the USIP II team. The goal is to get data that will serve to find abnormalities that can help discern the negative effects these emissions have on our infrastructure, technology, and weather phenomena.

We have refined and expanded our current concept from a preceding team who focused only on the VLF band (**Figure 11**). Even though the designs were based on previous iterations, owing to the inclusion of the HF band, we also have redesigned many aspects. Much of the payload received an overhaul. Data handling was optimized throughout the payload.

These measurements will be recorded by using both a ground station and a high-altitude weather balloon filled with helium. Our payload consists of receiver antennas that tuned to their respective frequency receiver and microcontrollers to store the data immediately. One receiver is attuned to VLF, and the second receives both MF and HF signals. The VLF receiver is described above. The SDR will collect HF signals.

Electromagnetic signals and time stamping will be recorded and stored in separate electronic storages for each drive respectively. We will also include a triply redundant set of GPS devices to properly track and recover the payload. The payload box itself is insulated to protect the components from the low temperatures. The Lithium-ion batteries are used to obtain hours of flight time. After recovery, the data will be stored in a server that is routinely synched with back-up servers as described above.

3.1.6. Project DAGGER

Project DAGGER was developed to compare all-sky camera images of the Aurora Borealis with computational models. NOAA/NASA empirical models, as well as a first principles approach, will be evaluated against data collected in March 2022 campaign. The data were taken by the USIP II airglow camera, which was upgraded to allow remote operation of the camera and the filter wheel. Sample data are shown in **Figure 12** and **Figure 13**.

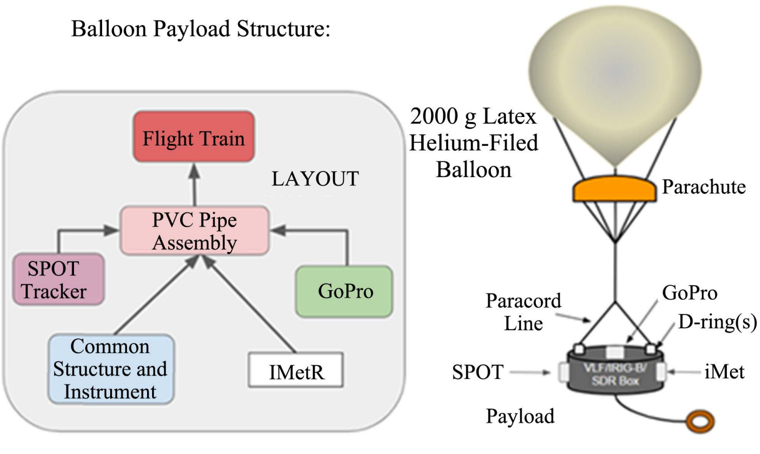


Figure 11. Cartoon of the VLF/HF payload.

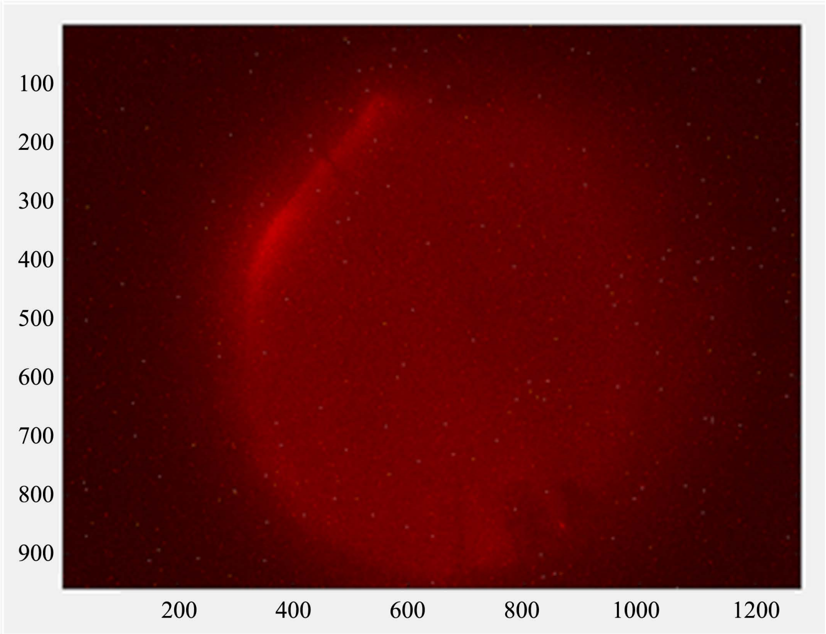


Figure 12. Image of near-IR (N2) auroral activity on March 22, 2017.

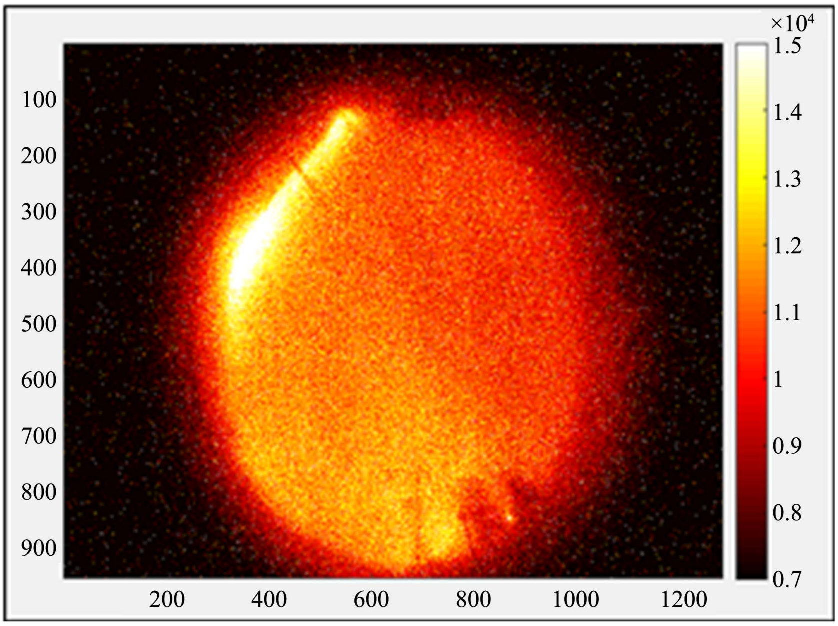


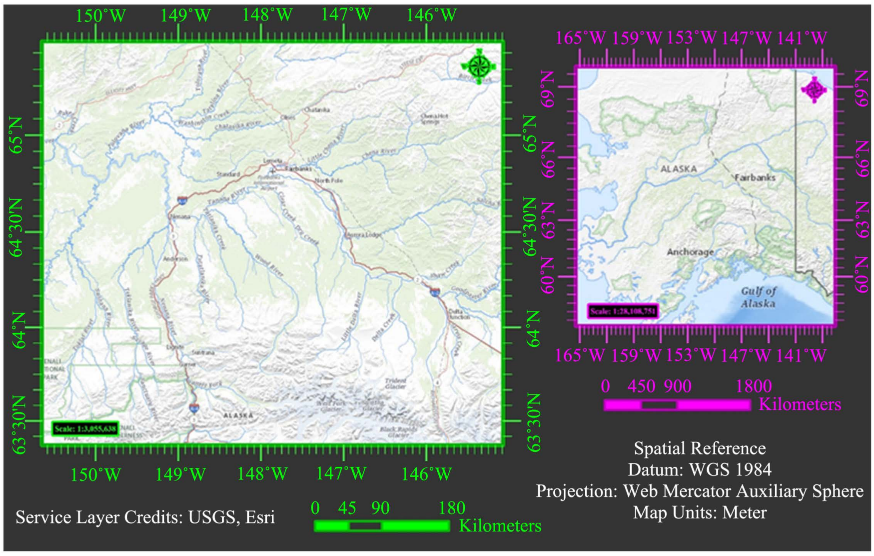
Figure 13. Enhanced Image of near-IR (N2) auroral activity on March 22, 2017.

3.2. Campaigns

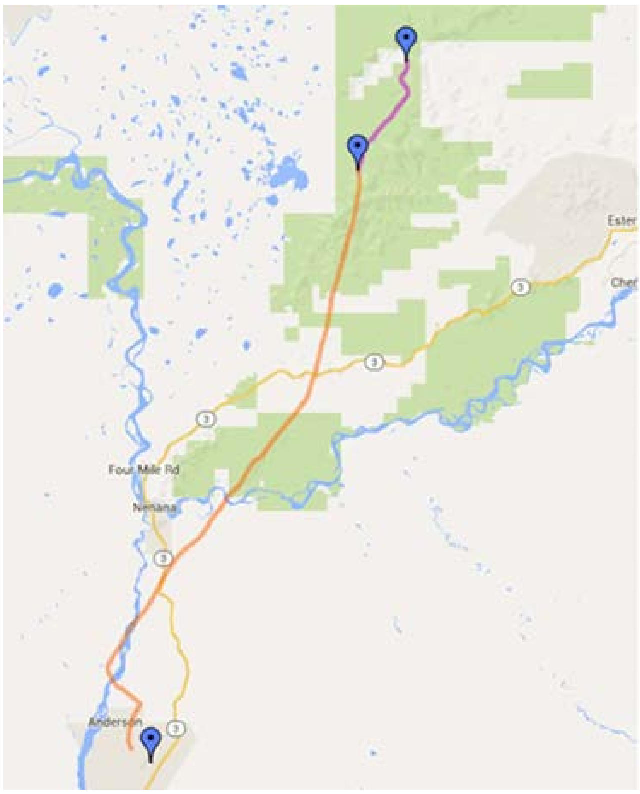
There have been six campaigns run in support of these programs. Since this paper addresses the latest iteration, we will limit ourselves to a brief discussion of the two most recent campaigns. Typical flight paths are shown in Figure 14(a) and Figure 14(b).

3.2.1. USIP II, III Alaska Flight Campaigns

1) 2017 Campaign



(a)



(b)

Figure 14. (a) Right panel: Map of Alaska, Left panel: Detail of Fairbanks and Vicinity; (b) Flight path of 12:53 03/26/15 flight. In (a), Nenana is in the right center of the left panel. In this panel, Fairbanks is just off the right edge where Highway 3 leaves the Figure.

During March 4-26th, 2017, the USIP II UH Ultralight team made 9 launch attempts; of them, eight were successful (**Figure 15**). We recovered 5 out of 8 successful launches. One of the unrecovered payloads (Ozone) had full radio

Figure 15. Launch of USIP II Alaska 2017 Flight 1 from Chatanika Lodge. Launch team from L to R: ItayPorat, John Prince, Alexis Fenton, Christian Behrend and Megan Pina. Woman behind John Prince is Dr. Emily Calandrelli, a prominent science communicator.

telemetry. The other two relied upon onboard recording. The failed launch attempt was the result of a payout-reel failure owing to a fabrication error in the COTS reel. The TEC and airglow experiments took data on the ground throughout the duration of the campaign. TEC has great data. The airglow experiment detected aurora, moonlight, and airglow (Figure 12 and Figure 13). Gravity-wave analysis is still ongoing.

2) 2018 Campaign

During March 10th to 25th, 2018, the USIP III UH Ultralight team encountered a sustained interval of snowfall that sharply curtailed our launch attempts. There were 3 successful launches (one carried two payloads) and two failed launch attempts. We have recovered all the payloads. The failed launch attempts were the result of inexperience and a battery pack failure on the pad. These failures used up two of our four nearly clear nights.

The TEC and airglow experiments took data on the ground throughout the duration of the campaign. TEC has great data (Figure 16 and Figure 17).

3.2.2. USIP IV Alaska Flight Campaign

2022 Campaign

During March 5-27th, 2022, the USIP IV UH Ultralight team made 2 tethered and 4 free flight launch attempts; of them, both tethered and 4 free flights achieved flight. We recovered all the launches; however, only one payload, the VLF and HF Receivers, obtained data, which look excellent. The TEC and airglow experiments took data on the ground throughout the duration of the campaign. TEC has great data. The airglow experiment detected aurora, moonlight, and airglow (Figure 12 and Figure 13).

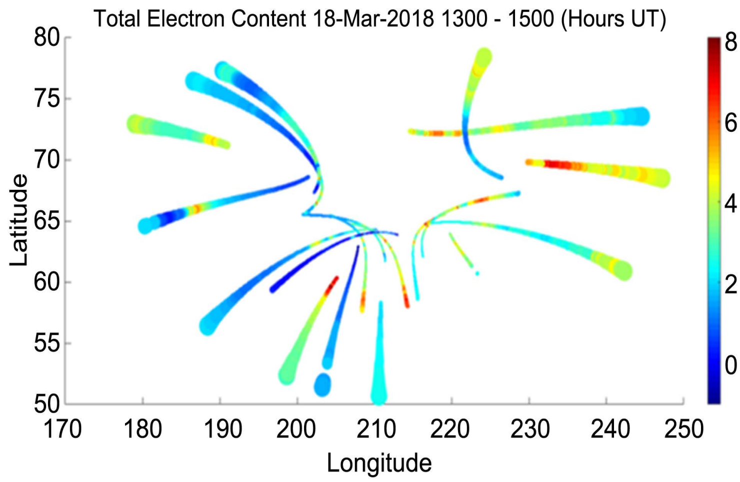


Figure 16. Total electron content observations from Fairbanks during the most active interval of the 2018 campaign.

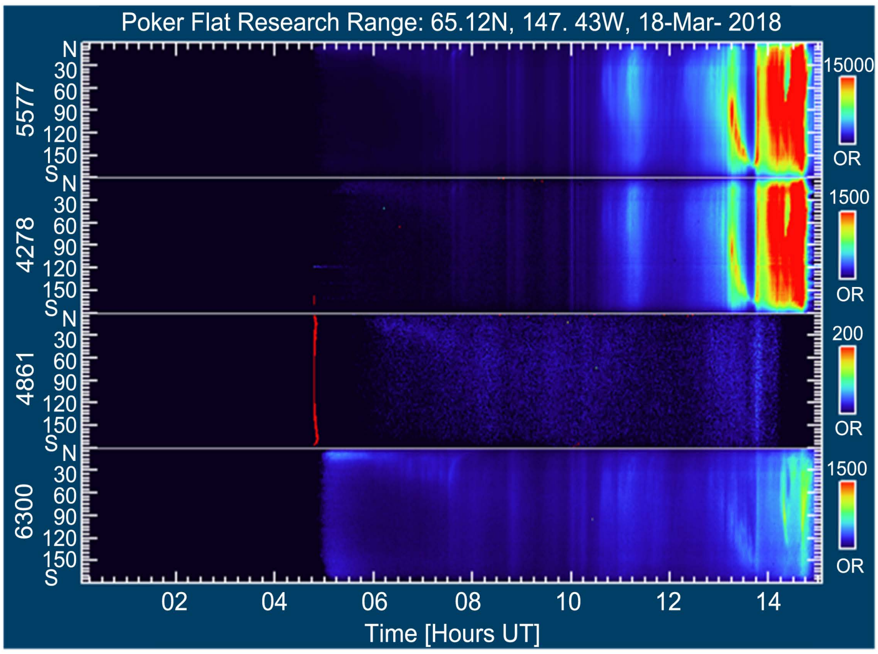


Figure 17. Keogram format presentation of 4 meridian scanning photometer channels at Poker Flat Research Range during the same night.

4. Publications

There have been over 70 publications at several conferences, including:

1) *NSTA STEM Forum, May 2014*: (Labay-Marquez & Bering, 2014)

2) *Fall 2014 AGU meeting*: (Gamblin et al., 2014)

3) 2015 AIAA Region IV Student Paper Competition was held on campus at the University of Houston. Each USIP student submitted an abstract. However, the competition was no paper, no podium. Unfortunately, the papers were due during the Alaska campaign. Therefore, no written papers were submitted. The students gave verbal presentations anyway. Their mistake was not following fa-

culty advice to submit only six abstracts and write the papers in teams. That task would have been much more doable with the time available. However, learning that being a co-author on a citable paper is more than being a single author on an uncitable abstract is an important lesson to teach as well.

4) *2015 AIAA Aviation*: (Bering & Gamblin, 2015)

5) *IUGG 2015 Prague*: (Gamblin et al., 2015)

6) *Fall 2015 AGU meeting*: (Canales et al., 2015; Ehteshami et al., 2015; Nowling et al., 2015)

7) *Lunar and Planetary Science Conference*, *2016*: (Gamblin et al., 2016)

8) *APS National Mentoring Community Conference*, *2016*: (Behrend et al., 2016a; Bias & Bering, 2016; Darlington et al., 2016; Martinez et al., 2016; Medellin et al., 2016; Nowling et al., 2016; Pina & Bering, 2016; Velasquez & Bering, 2016)

9) *Fall 2016 AGU meeting*: (Behrend et al., 2016b; Bering et al., 2016)

10) *AIAA SPACE 2017*: (Greer et al., 2017)

11) *American Association for the Advancement of Science*, *2017*: (Lehnen, 2017a)

12) *AIAA Region IV Student Paper Competition*, *2017*: (Fenton et al., 2017; Lehnen et al., 2017; Mathur et al., 2017; Medellin et al., 2017; Nowling et al., 2017; Perez & Bering, 2017; Piña & Bering, 2017; Porat et al., 2017; Prince & Bering, 2017; Velasquez & Bering, 2017)

13) *IAGA 2017*: (Bering, 2017)

14) *Fall 2017 AGU Meeting*: (Bering III et al., 2017; Gunawan et al., 2017; Hernandez et al., 2017; Lehnen, 2017b; Nguyen et al., 2017)

15) *AIAA Aerospace Sciences Meeting*, *SciTech 2018*: (Gunawan et al., 2018a)

16) *Fall 2018 AGU Meeting*: (Gunawa et al., 2018; Bering et al., 2019; Gunawan et al., 2018b; Hernandez, Bering, Molders, et al., 2019; Hernandez et al., 2018; King et al., 2018; Prince, 2018)

17) *Fall 2019 AGU Meeting* (Bering et al., 2019; Hernandez, Bering, Molders, et al., 2019; Hernandez, Bering, Talbot et al., 2019; Porat et al., 2019)

18) *ASCEND 2020* (Bering et al., 2020)

19) *Fall 2020 AGU Meeting* (Bering III et al., 2020; Greer et al., 2020; Hernandez, Bering III, Pessoa, Manriquez, Frissell et al., 2020; Hernandez, Bering III, Pessoa, Manriquez, Labelle et al., 2020; Ulinski et al., 2020)

20) *AIAA Region IV Student Paper Competition*, *2021* (Hernandez, 2021a; Simmons et al., 2021; Ulinski et al., 2021) + 3

21) *Virtual Conference for Undergraduate Women in Physics, 2021* (Tovar, 2021a)

22) *TSAPS 2021* (Tovar, 2021b)

23) *72nd International Astronautical Congress*, *IAC 2021* (Bering et al., 2021a)

24) *Fall 2021 AGU Meeting* (Bering et al., 2021b; Chitturi et al., 2021; Hernandez et al., 2021b; Humble et al., 2021; Nathan et al., 2021; Tovar et al., 2021)

25) *AIAA SCITECH 2022 Forum 2022* (Bering et al., 2022a; Simmons et al., 2022)

26) *SEG/AAPG International Meeting for Applied Geoscience & Energy 2022*

(Greer et al., 2022)

27) *44th COSPAR Scientific Assembly. Held 16-24 July 2022* (Bering et al., 2022b)

The scale and impact of all this productivity is highlighted by the fact the first author of this paper was identified as the dominant author who contributed the most to the topic of web learning in physics education during 2020-2021 (Prahani et al., 2022).

Student Outcomes

USIP at the University of Houston is now being offered for the 5th time, with 20 enrolled students. 39 students completed the first three iterations, and 14 completed the 2022 iteration. All the eligible alumni graduated, more than half with honours. Of these students, two are in medical school, ten are in graduate programs in various science and engineering disciplines, eight work for NASA or NASA contractors, and all the rest have jobs with various engineering and technology firms, mostly in the Houston area.

The graduation rate of students in this program is 100% so far, higher than the average graduation rate in UH STEM programs. Half of the USIP students have graduated with Honours of some sort, far above the intended 15% honours rate. These rates mean that a side effect of the program is improved time management and learning skills.

The student class evaluation essays show that the students found the challenge and inspiration most helpful in their education.

5. Conclusion

We have presented the structure and results of a four-semester set of courses that teach students "Observing Our Changing Planet" and "How to Build Spacecraft". The course successfully integrates the three dimensions of the NGSS Framework. Students learn Science and Engineering practices through experience doing a mentored spacecraft development project. The projects are all interdisciplinary and the students engaged daily with Crosscutting Concepts. Specifically, the students conduct real world investigations addressing at least one of these Disciplinary Core Ideas: ESS1.B, ESS2.A, ESS2.D, and ETS1. The outcomes include multiple student publications, honours degrees, and success in graduate school applications and job hunts.

Acknowledgements

Funding for the USIP program was provided by NASA Grants NNX13AR57G and NNX16AK65A. Additional funds were provided by several University of Houston offices, including Office of the Provost, Division of Research, Cullen College of Engineering, Department of Physics, College of Natural Sciences and Mathematics, and College of Technology. We also received substantial support from several generous donors. Private donors include Drs. Andrew Askew, Edgar Bering, Carolyn Farb, Ben Longmier, and Phil Inderwiesen; John Guthery, Barbara Clark, Rachel Gamblin, and Pat Tovsen. Thank you, everyone!

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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