HASP Student Payload Application for 2019

Payload Title: SORA 3 - Stratopheric Organism and Radiation Analyzer		
Institution: University of Houston		
Payload Class: LARGE		Submit Date: December 14th, 2018

Project Abstract:
By learning from the methodology imposed by the previous SORA missions, the SORA 3 payload will feature improved systems to sample for extremophilic microorganisms and observe the stratospheric radiation environment. An overhauled system to capture microorganisms is being implemented by learning from what did and did not work on the previous SORA missions. Furthermore, the radiation system is expanding to include a container that will closely mimic an ISS module in terms of material structure in hopes of observing the radiation environment to which astronauts are exposed. In addition, the SORA 3 payload will implement a new system featuring organic photovoltaic cells in the interest of observing the change in performance and molecular structure of the cells as a result of prolonged exposure to intense radiation. The first two missions have established a technological foundation from which SORA 3 can expand through exploring more deeply the topics and challenges of the first missions. SORA 3 will continue to use hobby electronics to test the bounds of commerically available technology.

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Abstract

By learning from the methodology imposed by the previous SORA missions, the SORA 3 payload will feature improved systems to sample for extremophilic microorganisms and observe the stratospheric radiation environment. An overhauled system to capture microorganisms is being implemented by learning from what did and did not work on the previous SORA missions. Furthermore, the radiation system is expanding to include a container that will closely mimic an ISS module in terms of material structure in hopes of observing the radiation environment to which astronauts are exposed. In addition, the SORA 3 payload will implement a new system featuring organic photovoltaic cells in the interest of observing the change in performance and molecular structure of the cells as a result of prolonged exposure to intense radiation and a near space environment. The first two missions have established a technological foundation from which SORA 3 can expand through exploring more deeply the topics and challenges of the first missions. SORA 3 will continue to use hobby electronics to test the bounds of commerically available technology.

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1. MISSION STATEMENT AND OBJECTIVES

The 2019 University of Houston (UH) HASP team has set out to expand upon the previous missions [1][2] from the UH team by applying the knowledge and technology that has accrued. The methodology of the first two missions has provided a proof of concept for handling tools, such as the MiniPIX particle detector, in extreme environments. This will serve as the platform for the 2019 mission.

The main objectives of the 2019 mission is to study the exposure to ionizing radiation that organisms face in the upper atmosphere and sample these organisms and bring them to the surface. The organisms in question are microbial extremophiles that naturally reside in this region of the atmosphere. As such, our payload will be a continuation of the work performed by the previous UH HASP teams and will be called the Stratospheric Organism and Radiation Analyzer (SORA) 3.

However, we are also interested in the humans that reside in such harsh environments. We will construct a thermally-controlled, pressurized mock-up International Space Station (ISS) module containing a scintillated MiniPIX. The pressure will be held constant at 1 atm to replicate conditions aboard the ISS. This allows us to study the particle cascades induced by the materials of the module, which will give information regarding the dose that astronauts are exposed to while in space. The payload will also contain a second, unscintillated MiniPIX that will reside outside of the ISS module, recording the outside radiation exposure. This second MiniPIX will act as a control for the ISS module, but also allows us to study the environment that extremophiles are exposed to. In addition to the MiniPIX, we will test the performance of organic photovoltaic cells in stratospheric conditions. Organic photovoltaic cells have promising applications for space-based missions due to their inexpensive, lightweight, and flexible nature relative to their non-organic counterparts. In tandem to the radiation study, we will collect samples of the microbial life through the use of a passive collection system. This system will consist of a T-shaped arm covered with filters that will only be exposed to the outside while at float altitude. We will then bring the uncontaminated, collected samples down to the surface for analysis.

The upcoming mission has the following scientific objectives:

Primary Scientific Objectives:

1. Capture microorganisms in the upper atmosphere at altitudes of approximately 30 km to 41 km using a method not previously used by the UH HASP team.
2. Study the cosmic and terrestrial radiation that extremophiles and astronauts are exposed to.
3. Observe the preformance of organic solar cells in a near space environment

Secondary Scientific Objectives:

1. Testing the newly developed astrobiology hardware in flight and establish a more reliable method for collecting microbes in extreme environments at high-altitude.
2. Implement a redundant storage system for all data recorded.
3. Establish a methodology which allows two or more MiniPIX devices to be used in conjunction.
4. Study and test the effect of different fabrication methods of organic photovoltaic solar cells for use in a highly irradiated environment.

Engineering Objectives:

1. Develop a new astrobiology collection mechanism that is favorable at high altitude.
2. Construct a structure resembling an ISS module as accurately as possible.
3. Use a scintillator to detect thermal neutrons using a MiniPIX.
4. Analyze MiniPIX data in real time and downlink relevant information.
5. Develop novel active layers for organic solar cells which can withstand the strataspheric environment

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1.1. Hypothesis and Objectives

1. By comparing our flight sample to previous missions [1][2], the newly developed passive astrobiology system can be quantitively and qualitatively be compated to previous methods.

   (a) Objective: Sample a comparatively larger volume of air using passive design elements rather than an active pump design at float altitude.

   (b) Objective: Compare the effectiveness in rotation of the sampling filters to those that are stationary.

2. Background sampling and rigorous sterilization procedures will help rule out contamination as a possible source of error.

   (a) Minimize outside contamination of the entire astrobiology system.

   (b) Objective: Retain a sterile environment for the entirety of the balloon flight.

   (c) Objective: Sample a minimum volumetric amount of air at target altitude for the duration of the float phase (approximately 15 to 18 hours).

   (d) Objective: Take background samples using Fluropore Membrane filters at the various locations where the payload will be.

3. The radiation environment within the ISS module will be noticeably different than that outside the module in terms of particle type and concentration.

   (a) Objective: Characterize the radiation environment within the ISS module by particle types and dose.

   (b) Objective: Successfully identify neutron interaction with the scintillated MiniPIX.

   (c) Objective: After capturing samples, analyze data and compare biological effects to similar genotypes found on Earth's surface.

4. The organic photovoltaic cells exposed to stratospheric conditions will under perform cells which have remained on Earth.

   (a) Objective: Compare quantitative and qualitative properties of the cells such as fill factor, efficiency, and physical structure of post-flight cells to cells that have remained on Earth.

   (b) Objective: Using microscopy techniques, analyze the influence of stratospheric radiation on the structure of the cells.

2. BACKGROUND

2.1. Astrobiology

Extremophiles are microorganisms that thrive in physically and/or chemically extreme conditions, which are detrimental to most of life on Earth as we know it. These organisms and microbes have been found everywhere, from deep underwater volcano vents to buried ice lakes in Antarctica [5].

Fungi and bacterial spores have also been found in the stratosphere. Today, the most common altitudes for organism and microbe collection in the atmosphere are in the range of approximately 10 km to 20 km above Earth's surface. As illustrated in the table below, very little data exists on microbiological samples captured in the stratosphere [5]. Conditions at altitudes of 30km to 40km are extreme in temperature, pressure and radiation exposure. Arguably, each successful collection expedition, of at least 30 km into the upper atmosphere, provides information that can be useful in determining what life forms can exist inside and outside of Earth's biosphere. Additionally, RNA analysis of the organisms and microbes can provide useful insight pertaining to their ability to survive in an environment with elevated levels of radiation.

Our experiment focuses on designing a more energy efficient compact collection apparatus that refining our sanitization procedures for preflight assembly, post flight disassembly, and RNA sequencing preparation.

We also want to test the effectiveness of rotating filters to stationary ones. The samples we will collect play an important role in expanding our knowledge about Earth's biosphere. Future studies could produce meaningful contributions to the fields of gene therapy, RNA interface, and cosmic shielding; and provide valuable insight about how life can be distributed on Earth, and ultimately, through outer-space.

Our experiment is an attempt to further develop our technique for capturing microorganisms in the upper atmosphere, as demonstrated during our 2017 [1] flight; which was inspired by the LSU HASP 2011, 2012, 2013 flights [4] and from research by D.R. Canales [16]. This flight will help confirm the results from our first and second flights[2]. We will use a rotating arm mechanism to sample the air for microorganisms through the use of fluropore membrane filters. The samples we hope to collect are an important part to expanding our understanding of Earth's biosphere. Further studies could provide more insight on how life can be distributed on Earth, and ultimately, through outer-space.

TABLE I. History of Microbiological Sampling of the stratosphere [1].

Date	**Altitude (km)**	**Sample Method**	**Biology Measured**	**Volume**
1936	11 - 12	Balloon	5 Bacillus sp., 1 Penicillium sp., 1 Macrosporium sp., 2 Aspergillus sp.	*Unknown*
1978	48 - 77	Meteorological rocket	Mycobacterium sp., Mircococcus sp.	*Unknown*
2003	30 - 41	Balloon, liquid neon cryopump	Isolated S. pastuerii, B. simplex, the fungus, Egnydontium album	57
2004	20	Airplane, impactor surfaces	Bacillus luciferins, Bacillus sphaericus	*Unknown*
2006	19 - 41	Balloon, liquid neon cryopump	7 cells L-1 (counting clumps), Bacillus sp., Staphylococcus sp., Engyodontium sp.	19 – 81
2007	20	Airplane, impactor surfaces	Micrococci, Microbacteria, Staphylococcus sp., Brevibacterium sp.	*Unknown*
2010	20	Airplane, impactor surfaces	Isolated Bacillus sp.	*Unknown*
2017	32	Balloon, liquid medium w/ vacuum pump	Multiple findings [1]	*Unknown*
2018	32	Balloon, liquid medium w/ vacuum pump	Inconclusive [2]	*Unknown*

2.2. Cosmic Radiation

Understanding the biological effect of radiation on humans is crucial for successful space flight. By observing the environment in which astronauts reside, information regarding the conditions which induce the biological changes can be gathered. Among this information is dosage of various particles. In the upper atmosphere, primary particles, which consist largely of protons (p^+) and ionized atomic nuclei [6], collide with the nuclei of air molecules and can induce air showers. These air showers produce secondary particles, which consist of positrons/electrons ($e^\pm$), neutrons(n), muons($\mu^\pm$), pions ($\pi^\pm$), and various other hadrons. The primary particles of interest are Galactic Cosmic Rays (GCRs), which originate outside of the solar system but within the Milky Way Galaxy and typically have been accelerated to nearly the speed of light [7].

The results from the previous missions have confirmed the successful application of the MiniPIX as a dosimeter through the idenification of the Regener-Pfotzer Maximum. This maximum is the altitude at which ionizing radiation reaches its peak [3]. The value of this altitude depends on various environmental factors, but it is around 18 km. With this confirmation, the MiniPIX will remain the primary tool we will use to measure radiation.

Primary particles can induce an air shower by colliding with the nucleus of any atom or particle. This poses a potential threat to astronauts residing in spacecrafts, as the materials in the spacecraft's structure can induce an air shower and thus bombard astronauts with radiation. By using a MiniPIX to measure the radiation outside of as well as within a structure emulating a module from the Internation Space Station, we can observe the environment that current astronauts live in and how the structure changes the radiation field. Additionaly, the measurements outside of the structure will give information as to the conditions in which atmospheric extremophiles reside.

2.3. Organic Solar Cells

2.3.1. Introduction

Photovoltaic devices have been a staple in space energy harvesting since the launch of Vangaurd 1 in 1958. Since then, silicon, gallium arsenide, indium phosphide, cadmium telluride, and other III-IV systems have played the key roles. When choosing a system to gather solar energy, the only economic factors are the initial cost of the arrays, and the cost of transporting the system to orbit. To reduce this cost, we want solar cells with the highest specific power, which is defined as the W/kg. Recent studies have shown organic solar cells (OSC) with a specific powers of 10 W/g, which is why OSCs are an active area of research for space energy generation. Organic solar cells are thin film, light weight, flexible, and can be produced using roll to roll printing, making it ideal for space applications.[23] In this experiment we are exploring the effects of stratospheric conditions on organic solar cells, with a particular focus on the effects of cosmic ray bombardment in conjunction with the MiniPIX system. Additionally, we would like to to investigate the radiation hardness of different types of organic solar cells and demonstrate their reliability upon entry and exit of the stratosphere. In the following sections we will explain the basic workings of an OSC and explain some of the benifits and hinderences of a space like environment on the OSC, then explain the methodology of our experiment.

2.3.2. Working principals

OSCs use earth abundant, carbon based semiconductors, such as conjugated polymers(as donors) and fullerene derivatives(as acceptors). Where as in mono-crystalline solar cells the valance and conduction bands are used to determine the energy band gap, OSCs model the difference between the highest occupied molecular orbit(HOMO) and the lowest unoccupied molecular orbit(LUMO) as equivalent to this energy band gap. When donor(D) and acceptor(A) layers meet, their Fermi levels match up and band bending occurs, which creates a small electric field, or built in potential (Vbi). Charge generation occurs when excitons, an electron/hole pair bound together by the Coulomb force, are generated in the donor material. This exciton will travel towards to D-A interface, where the aforementioned Vbi will seperate the exciton into free charges given sufficient conditions. Exciton transportation inside of the bulk is hindered to 5-50nm before recombination occurs depending on material and structure, while the average thickness of an OSC is 50-100nm, thus the architecture of the active layer is of much importance. Instead of using a bi-layer of n-type and p-type semiconductors, OSCs use the bulk hetero-junction (BHJ), which is a blend with A-D regions that are within the estimated diffusion length. [26]

A newer type of organic-inorganic blend solar cell which has gained a lot attention is the perovskite solar cell (PSC). This solar cell has a novel active layer comprised of organometallic molecules which exhibit the perovskite crystal structure ABX3. The most commonly used perovskite material is methylamoniumm lead trihalide (CH3NH3PbX3, MAPX), where lead can be swapped for tin, and halides such as boron, iodine, and chlorine are employed. Fabrication of the perovskite solar cell is highly attractive as it can be accomplished with wet chemistry, roll to roll printing, or vapor deposition. Some key features of the perovskite structure is that the bandgap of the material is tunable via the halide content and that the diffusion length of holes and electrons is 1 micron, making them perfect for roll to roll thin film printing. The Shockley–Queisser limit is about 31 percent under an AM1.5G solar spectrum at 1000W/m2, for a Perovskite bandgap of 1.55 eV, which is near the theoretical maximum of 33.7 percent, and reports of perovskite cells with PCE as high as 22 percent have already been fabricated. As a newer material there is still much unknown about the physics of the perovskite solar cell, such as if charges occur as bound excitons or free charges. [27]

Space transport involves high doses of radiation, large fluctuations of temperatures, and extreme vacuum conditions. The need to study the effects of a space like environment on organic electronic devices is paramount as advances in the organic semiconductor field continue and space exploration becomes more standard. [21] In this study, we propose to mount four different types of solar cells onto our payload and monitor their performance. We will be using prefabricated small molecule based OSCs, self fabricated polymer based OSCs, self fabricated PSCs, and prefabricated amorphous silicon solar cells. Each of these is a lightweight, flexible, and thin solar cell ideal for space use. Additionaly, effect to the crystal structure of the perovskite based cell is of particular interest, as cosmic ray bombardments and fluxtuations of temperature can be determental.

3. PAYLOAD SYSTEMS AND OPERATION

SORA 3 will implement an overhauled astrobiology system that will collect larger samples of stratospheric organisms as well as require less amperage, allowing us to expand the radiation system and reduce the chance of electrical failure. The radiation system will apply the techniques developed over the previous missions by consisting of a scintillated MiniPIX within a pressurized module modelled after an ISS module. Additionally, various types of organic photovolatic cells will be flown in order to study their performance in harsh stratospheric conditions.

3.1. Astrobiology System

3.1.1. Design and Operation

The collection assembly will be designed as a single mechanized enclosure as shown below. The rotating arm will be raised out of the collection container and began rotating once float altitude has been reached. The raising of the rotating arms will be done by a L-16 linear servo motor. The rotation of the filter arm will be provided by the rotational motor mounted onto the filter arm. The lid on the top of the linear servo will seal the clean box during ascent and descent. The Fluropore Membrane filters will be mounted on the ends of the rotating arm. The arms will spin at 80 RPM for the duration of float conditions. In theory, the sampled volume will be the cross-sectional area of each filter multiplied by the distance the payload travels. Which results in a far greater sampled volume than the 0.03 liters per minute sampling of the pumps from the previous flight.[2] When it is time for the payload to descend, a command will be sent to retract the rotating mechanism back into the clean box. The fluropore filters on the rotation arm will be compared to the ones on mounted on the linear servo as shown in the figure below. Background samples will be taken using the same fluropore membrane filters and will sample the various places the payload will be, such as the UH lab room, the clean room used for sterilization and the Fort Sumner launch site.

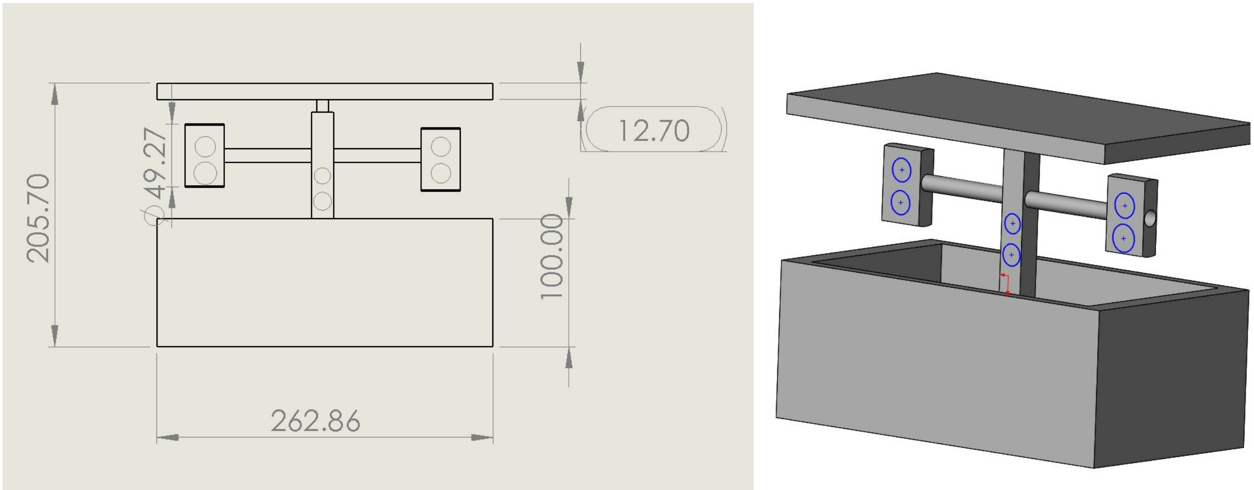

FIG. 1. Cross-section view of the clean box with the extended rotating arm. **All numbers are in millimeters**

3.1.2. Pre-Flight Preparation

The rotating arm mechanism will be tested in low pressure and in various mounting positions. Once it is certain that the arm functions in the intended conditions during flight. We will take it to the clean room to be sterilized.

The clean box that houses the arm will autoclaved. All tools used in the assembly of the clean box will either be autoclaved or soaked in a 70 % ethanol solution inside of a clean room. Each person who enters the clean room will be garbed in a lab coat, goggles, hair net and latex gloves after thoroughly washing their hands in a 70 % ethanol solution.All wires within in the box will be soaked in the 70 % ethanol solution and the rotating arm mechanics will be powered on and retracted the box. The box will then be integrated into the payload.

3.1.3. Post-Flight Procedures

Once the payload is retrieved, the intact clean box needs to be removed and placed inside of a cooler with ice to be then transported to The University of Houston and placed in cold storage at 4 °C. All equipment used in the filtration process will be either autoclaved or taken from previously unopened sanitized packaging. The autoclaved, pre-sanitized items and the clean box will then be washed in a 70 % ethanol solution before they are placed inside a SterilGARD e3 Class II Biological Safety Cabinet (the Cabinet). The cabinet has a laminar flow air barrier and UV lights built into the ceiling for decontaminating the workspace prior to use.The Fluropore Membrane filters from the clean box and the backgeound samples will be processed through a DNA extraction kit and the remaining sample fluid will be stored in the cold storage for in-house 16S ribosomal RNA sequencing through the University of Houston sequencing team.

3.2. Radiation Monitoring System

3.2.1. MiniPIX Detector

The MiniPIX detector is a silicon-based hyrbid pixel detector founded on Timepix technology. The device is built by ADVACAM [17] and utilizes technology developed by the Medipix Collaboration at CERN [18]. The sensor consists of a 256x256 array of pixels and a pitch of 55 µm. A USB 2.0 connection is used to interface with the device, which provides power and data output. The primary use of the detector will be to characterize cosmic radiation by the type of particle and its incident energy.

FIG. 2. Picture of a MiniPIX particle detector [17].

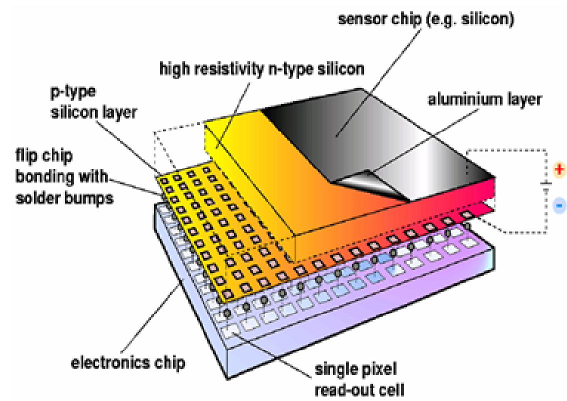

FIG. 3. Layers that makeup the MiniPIX sensor.

When an ionizing particle hits the sensor, electron-hole pairs accumulate within the semiconducting material. The electronics reads-out the pairs by depleting the silicon with a bias voltage. If a charge is above the set threshold, the charge is counted. The energy deposited in a pixel can be determined from the back-plane pulse amplitude. Particles incident on the sensor appear as pixel clusters, which is defined as a continuous area of activated pixels. By analyzing these clusters, the incident particle can be identified. The morphology of the cluster gives information regarding the type of particle as well as the angle at which the particle was incident upon the detector.

Detectors using Timepix technology are used to measure radiation aboard the ISS. Since the University of Houston is a member of the Medipix Collaboration, scientists at the University of Houston work with preparing Medpix devices to be used aboard the ISS. As a result, the UH HASP team may be able to work with these scientists and compare data gathered from the mockup ISS module to data from the ISS.

Due to the SORA 3 mission being a continuation of previous missions, we have the opportunity to compare data from previous flights. For example, this will allow us to observe how data regarding particle counts and dose changes with the solar cycle. Hathaway [8] has shown that a direct relationship exists between the development of the solar cycle and neutron counts.

3.2.2. Calibration

It is necessary to calibrate the sensor. The calibration procedure is rather sophisticated, so the calibration will be applied by Dr. Stuart P. George at the University of Houston. Dr. George is a member of the Medipix Collaboration. The general outline of the calibration is as follows. A source calibration is applied by using a 60 keV ^{241}Am decary line, Sn Flourescence and ^{55}Fe gamma rays. The pixel detector consists of 65 536 silicon p-n dioded, each containing its own individual processing circuit. The response of each pixel can never to identical to one another, so a calibration mut be performed on each pixel. Dr. George will calibrate each pixel energy threshold from DAC counts to energy [19]. The threshold of the sensor will be set to 4 keV, which sufficiently filters out background noise. The bias voltage of the sensor will be set to 200 V, which guarantees that the silicon is completely depleted while reading out the charge.

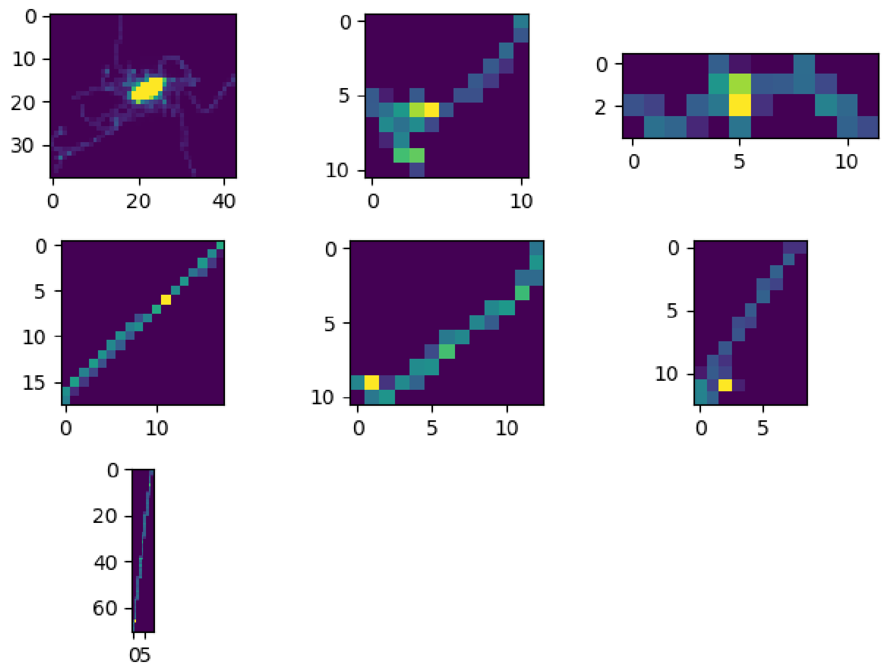

FIG. 4. Examples of different track types from data collected by a MiniPIX.

3.2.3. Collection Parameters

ADVACAM has developed a Python API to configure the device and its acquisition parameters. The shutter speed of the device controls the rate at which data is output from the device. The shutter speed controls the exposure time of the sensor before saving the data to a frame. Once the data is saved, the device enters manufacturer-set dormant period, which lasts for approximately two seconds. This time will be utilized as a cool-down period for the device. The value of the shutter speed is highly dependent on the application of the sensor. Within the context of HASP, we expect high radiation exposure which will require a quicker shutter speed. This is to the fact that if the shutter speed is too long, the sensor become overcrowded and clusters become difficult or impossible to analyze. However, if the shutter speed is too short, there will be many frames with little to no data, which will use a large amount of storage space. Based off of previous SORA missions, a shutter speed of a few seconds is sufficient for our application. The exact shutter speed will be determined through testing and may be different for each device we use.

3.2.4. Data Format

The data frames are stored as plain text values where each value corresponds to a value from a pixel on the pixel array. In a separate file, metadata such as acquisition type, shutter speed, bias voltage, and other parameters are recorded for each frame. Both the data file and the metadata file will be stored on the RP3 and the various redundant storage systems we implement. The MiniPIX data from previous missions used about 1 GB to 2 GB. For the 2019 mission, we expect about double that value due to our use of two MiniPIX devices.

3.2.5. Structure

The MiniPIX outside of the ISS module will be contained within a small case plastic case to protect the device from atmospheric moisture. Thermal paste will be used to fix the MiniPIX on a small block of aluminum, which will behave as a heat sink. This simple setup has proven to work on previous missions and is shown in Figure 5.

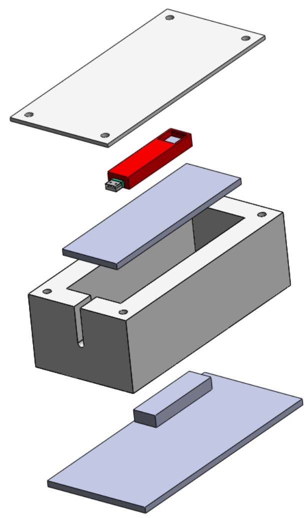

FIG. 5. Exploded view of the MiniPIX case assembly. Shown in white is the plastic construction, red is the MiniPIX device, and the grey represents the aluminum heatsink.

3.2.6. ISS Module

As part of the radiation subsystem, the payload will include a capsule intended to mimic the structure of one of NASA's modules on the ISS. The method deployed by NASA and other agencies is called "Stuffed Whipple" shielding and is deployed in ISS modules that are at highest risk of impact [9]. This module will remain at atmospheric pressure throughout the entire flight in attempt to model the environment as closely as possible. Inside the capsule will be a scintillated MiniPIX that will record the radiation environment within the module. The scintillated MiniPIX will measure the neutrons within the ISS structure in attempt to determine the exposure within the structure.

The materials that make-up the module will be those used in the outer walls on the ISS and will have the same thickness. The main differences in structure will be the omission of standoffs and a multi-layer insulator (MLI) in our module. The walls of the ISS have standoffs between layers of materials, which increases the total wall thickness to about one foot, and the MLI used by NASA is not available commercially. In the interest of saving space, we will not include the standoffs, and all materials will be layered on one another in the same order as they are used on the ISS.

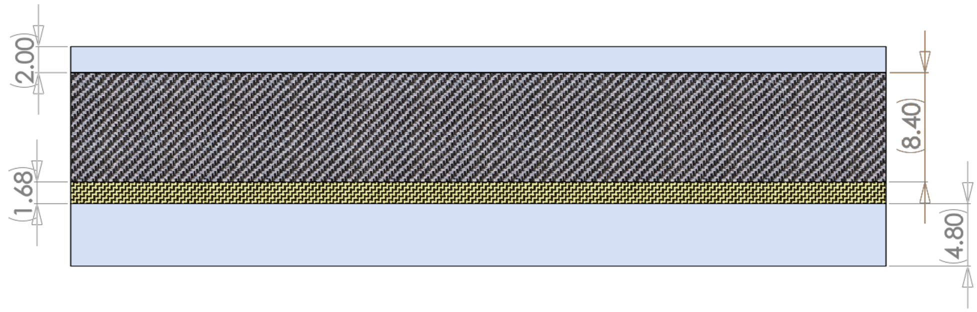

FIG. 6. Layers and thicknesses of the materials that will be used to construct the ISS module. From top to bottom: aluminum 6061-T6, six layers of Nextel AF62, six layers of Kevlar fabric, and aluminum 2219-T87. The atmosphere is contained by the 4.8 mm layer of aluminum [10]. All measurements are in mm.

3.2.7. Scintillated MiniPIX

The MiniPIX's sensor can only interact with charged particles. In order to measure neutrons with the MiniPIX, a scintillator is rerquired. The scintillator will interact with the neutrons and produce a specific signature of particles which can be measured by the MiniPIX. Uher et al. [13] used a similar method, but with a lithium-based scintillator. We will use a boron-loaded plastic scintillator [14] to cover exactly half of the MiniPIX sensor. The reation between the Boron-10 nucleus and a thermal neutron is

$$^{10}\mathrm{B} + \mathrm{n} \longrightarrow {}^{7}\mathrm{Li} + {}^{4}\mathrm{He} + \gamma(480\,\mathrm{keV})$$

according to Pawelczak et al [15]. This scintillator was chosen due to its large reaction cross-section for thermal neutron capture and its emission of light charged particles. This larger rwaction cross-section increases the probability that the neutron will produce particles that can be measured by the MiniPIX.

By covering half of the sensor, we can compare the uncovered half with the data recorded by the MiniPIX outside of the ISS module.

3.2.8. Organic Photovoltaic Cells

We will be using four different types of solar cells with a total of 12 arrays on board our payload. There will be one type of cell on each of three sides of the payload, leaving one face free for any unique cells we may develop during our research. Half of our panels will be prefabricated and purcahsed from a supplier, and will be regarded as a control against which we will evaluate our in house fabricated cells. For the in house fabrication, we will be focusing on polymer:fullerne BHJ and perovskite active layer cells. We intend to investigate a variety of polymer:fullerene blends and develop a procedue for fabrication which yields the greatest PCE and MPP in the stratospheric environment, and to investigate the possibility of transpatent conductive oxide(TCO) layers besides the traditional indium tin oxide (ITO) glass and polyethylene terephthalate (PET) plastic. [24]

Solar cells are characterized by their current vs voltage (IV) curve, which tells you the maximum power point (MPP), V_{max} and I_{max}, open-circuit voltage (V_{oc}) and short circuit current (I_{sc}), leading to the fill factor (FF) and efficiency (PCE). This curve will be generated using a variable resistor in series with two multimeters, one acting as voltmeter and the other an ammeter, and the solar cell in question, which will follow Ohm's Law. From the plot, V_{oc} is seen when $I = 0$, I_{sc} is when $V = 0$, and the MPP is where V_{max} and I_{max} meet. The MPP can then tell us the efficiency (η), which is defined as

$$\eta = \frac{MPP}{P_{in}}. \tag{1}$$

The fill factor gives information on the "squareness" of the IV curve and is defined as

$$FF = \frac{MPP}{V_{oc} I_{sc}}, \quad (2)$$

and it is optimal to maximize the fill factor. [20]

Before flight, every cell will be characterized with IV curves using AMG 0 simulated sun light to generate a characteristic profile, as expected in the space environment, for the each new cell, and microscopy will be preformed to understand the topology and interfacial details of the new cells. Currently our plan is to have one of each cell type remaining on ground as a control, and we will have each panel onboard the payload wired to an arduino unit where IV curves will be recorded during flight, with a characteristic profile generated every 30 s. This data will be stored on the arduino with backup stored to a raspberry pi. On board our payload we will be measuring the tempreature and pressure of the environment to deteremaine any effects on the preformance due to temperature and pressure changes. Finally after recovery, the IV data will be extracted from the arduino/raspberry pi and plotted, and each cell will be re characterized and once again viewed under the microscope to look for any physical defects. From spin coating and vapor deposition, to annealing and solvent choice, each step in the fabrication process alters the morphology of the active layer. Due to the importance of the bulk heterojunction, transmission electron microscopy (TEM) will be used to investigate how the BHJ morphology is altered through different fabrication methods and due to cosmic ray exposure. We will use TEM to observe the sizes and position on the donor and acceptor domains throughout the active layer, and look for voids in the structure of the perovskite active layer after flight. Our interst in microscopy lies in observing the structure of the active layer and investigate how it is effected by different fabrication techniques and due to the near space environment. [25] With the HASP mission, we are going to compare fabricated organic polymer and perovskite solar cells against purchased prefabricated organic solar cells. Each of these cells will be analyzed before, during, and after exposure to the stratosphere. In analyzing our cells, we will measure the open circuit voltage, short circuit current, and maiximum power point, then fill factor will be determined along with efficieny. We are interested in investigating novel active layer materials for both polymer:fullerene blends and perovskite structures, along with different substrate, transport, and conducting layers, thus our exact methodology for fabrication is yet to be determined. In conjunction with our MiniPIX detector, we will be analyzing the effect that cosmic ray bombardment has on our solar cells. By analyzing the times at which cosmic rays are recorded, we can look at our IV data and determine if there was any effect on the cells preformance. Additionally, we will watch for problems which arise due to UV-A, B, and C rays with photodiodes. These photodiodes will serve the additional purpose of monitoring the solar power spectrum that our cells are exposed to.

3.3. SOCRATES Design

3.3.1. Overview

For this mission, we will use SOCRATES (System fOr Computing, Radiation, Astrobiology, Temperature, Environment and Solar), our flight computer, to manage flight operations and send and receive commands from the ground. SOCRATES is composed of two components: a Raspberry Pi 3 (RP3) and an Arduino Mega (Arduino) which interface via USB. SOCRATES' primary purposes during the flight will be to monitor environmental conditions inside the payload structure and inside the ISS module and to control the astrobiology system. It will also monitor temperature of the various subsystems including the solar cells, astrobiology collection system, MiniPIX, and air pressure throughout the flight. The temperature of each the 12 solar cells will be individually monitored with a thermistor. The voltage produced by each cell will also be monitored and recorded by SOCRATES via the Arduino. SOCRATES will use an accelerometer to monitor the activated state of the astrobiology system. All recorded data will be continuously written to an SD card mounted on a shield on top of the Arduino and to a removable USB flash drive connected to the RP3. SOCRATES will be programmed to deploy the astrobiology system at the appropriate altitude as sensed by the atmospheric pressure sensor. SOCRATES will also accept discrete commands from the HASP systems to turn the astrobiology collection system on and off.

In order to maintain data integrity we will save the data recorded by SOCRATES to both the SD card of the Arduino and to the USB drive connected to the Raspberry Pi. Data will be written to a discrete data file for a given period of time and then the file name will be incremented and the following data will be written to a new file. In case the data collection process is corrupted for a given period of time, this period of corruption will not interfere with the collection of all previous data.

3.3.2. The Sensors

Our payload will utilize 14 thermistors to measure temperature at various points in our payload. The decision to use thermistors was based primarily on the performance of the analog temperature sensors during our 2017 flight, during which several of those sensors had slight malfunctions, and the success of thermistors in our 2018 flight. Thermistors are able to accurately measure temperature in the range −55 °C to 125 °C and should therefore be adequate for the conditions in the stratosphere. Pressure will be recorded from two digital pressure sensors, one low pressure sensor in the main payload structure which will record pressure in the 0 kPa to 3.44 kPa range, and the second pressure sensor will be located inside the ISS module and record pressure in the 20 kPa to 110 kPa range. All sensor data will be UTC timestamped via the onboard real time clock and recorded to the SD card on the Arduino and USB drive attached to the RP3. To confirm the activated status of the astrobiology collection system, an accelerometer will be used to detect whether the collection arm is spinning or parked as is appropriate for the altitude of the payload. Each solar cell will also be monitored for temperature to aid in the calculation of efficiency of each cell in addition to being monitored for voltage directly through the analog ports of the arduino. Current of each solar cell will also be measured using a shunt resistor and IV curve and fill factor will be calculated after the payload has landed from the values that were collected for voltage and current of each cell. In order to accomodate all analog pins required to measure temperature, current, voltage and pressure, several analog multiplexes will be wired together in series for the arduino. One MiniPIX will be located inside the ISS module and an additional MiniPIX will be located inside the main structure of the payload.

TABLE II. Sensors that compose SOCRATES

Sensor	Quantity	Platform	Purpose
Thermistor	4	Arduino	Record temperature measurements
Pressure (0 kPa to 3.44 kPa)	1	Arduino	Record lower pressure measurements
Pressure (20 kPa to 110 kPa)	1	Arduino	Record higher pressure measurements
Photodiodes	3	Arduino	Record intensity of visible light
Accelerometer	1	RP3	Report the current state of astrobiology system
Real Time Clock	2	Arduino/RP3	Record timestamps in UTC
MiniPIX	2	RP3	Cosmic ray detector

3.3.3. Space Constraints

Since half of the space inside the payload will be used by the astrobiology systems, we need to design our electronics to be relatively compact yet accessible for necessary modifications or repairs after testing. We will use one RP3 to both interface with two MiniPIX and store sensor and voltage data from the Arduino. Also, in order to reduce the space required for the interface between the Arduino and all of the payload's sensors, we will use two layers of proto-shields to more effectively utilize vertical space. The RTC pressure sensors will be mounted directly on the first shield while the thermistors will be mounted on the top most shield.

3.3.4. Powering It Up

In order to stay within the power constraints, a robust power supply will need to handle all the components of the payload. The power supply we will be using is the PCM-DC-AT500 by WinSystems INC. It offers one +5 V needed to power the payload's electronics. This power supply could effectively take +30 V and step it up to the +12 V and +6 V outputs as needed. The power supply will also be able to step down to the +3.6 V output as needed for sensors. One of the +12 V outputs goes to the Arduino since it can step down to the appropriate voltages internally while the other goes to a linear actuator for the astrobiology collection arm. Thermistors and pressure sensors will also receive power through the Arduino. A remaining +5 V output is converted to a USB power cable for the RP3.

4. HASP INTERFACE

4.1. Interfacing with HASP: Serial Uplink

The SORA 3 payload will not utilize any serial commands. Everything will be configured such that the payload is autonomous.

4.2. Interfacing with HASP: Serial Downlink

For the duration of the flight, the serial downlink will be used to downlink the temperature and other various statistics that will be computed directly on the RP3 as data is collected. It will also be used to downlink messages regarding the status of the payload, the command uplink status and error messages. The data packets will be human readable so they can be analyzed as they are received from HASP. The packets will be delimited by keywords `begin_packet` and `end_packet`, and we will use a simple one character header to differentiate between data packets and message packets. The format of the packets is potentially subject to change but the current design is outlined in Listing 1.

Listing 1 is a sample of our proposed downlink data packet format. Included is a format sample to enhance readability in this application which will not be included in the actual downlink data stream.

Listing 1. Sample of proposed downlink data packets ID: 15667 - 15669

```
<Format Sample>
begin_packet
|ID Number|Raspberry Pi Temp|MiniPix 0 Temp|MiniPix 1 Temp|ISS Temp|ISS Pressure
|Accelerometer val x|Acc val y|Acc val z
|Solar Cell Index 00:Temp,Voltage,Current|Solar Cell Index 01:Temp,Voltage,Current
...
|Timestamp|Date|
end_packet
<End Format Sample>
```

The first integer represents the ID of the packet. Following the packet ID are temperature readings of the Raspberry Pi and both MiniPix, temperature and pressure within the ISS Module, astrobiology collection arm accelerometer x, y, z values. Then follows the set of values for each of the twelve solar cells, which include the index, temperature, voltage and current of the cell. Included before the closing delimiter is the timestamp in $HH{:}MM{:}SS\ MM/DD/YY$ at which the packet was written. During our previous flights, these data packets were crucial status updates to the state of our payload. We will once again use them for the same purpose to keep a close eye on our payload.

4.3. Interfacing with HASP: EDAC and DB9 Connections

The power supply unit (PSU) will use a +30V and ground line from the EDAC connection. The linear actuator of the collection system will use +12V and the collection arm servo motor will take a +6V connection. Other sensors will be powered through the Arduino taking +5V through the previously described USB connection.

We will use discrete commands in this mission. Two of the commands will be used to deploy and retract the astrobiology system. This is only in case of emergency if we notice that the system has not already deployed at the planned altitude as designed. The other two discrete channels will be used to turn on and off SOCRATES in case that we notice an issue.

TABLE III. Table of all discrete commands to be used during flight

Command	Purpose	EDAC Pin	Description
Discrete 1	Astro. System ON	f	Extends collection arm and activates rotation
Discrete 2	Astro. System OFF	n	Stops collection arm rotation and retracts arm
Discrete 3	SOCRATES ON	h	Powers up SOCRATES
Discrete 4	SOCRATES OFF	p	Shuts down SOCRATES

5. THERMAL CONTROL PLAN

Based on our previous missions [1][2], we have designed a thermal control plan centered around the high-performance devices. The devices that are at highest risk of thermal failure are the RP3 and the two MiniPIX devices. The data from the previous SORA missions strongly suggest that all devices will remain above their lower temperature limit. If a device were to experience thermal failure, it would be by overheating.

The temperature of all high-performance devices will be downlinked and monitored by the mission control team. In the case of a device overheating, said device will be shut down until it is safe to resume operations. The RP3 will be considered overheating if the temperature exceeds 85 °C. A MiniPIX will be considered overheating if the device temperature exceeds 80 °C.

In attempt to prevent overheating, each device will be configured with an individual metal heat sink. The RP3's processor will be equipped with a heat sink designed specifically for that device. Using the same technique used on the previous mission, each of the MiniPIX devices will be fixed to a plate of aluminum. For the MiniPIX contained in the pressurized environment, an aluminum heat pipe will be used to distribute heat from the device to the outer aluminum shell.

6. POWER AND WEIGHT BUDGET

TABLE IV. Power and weight budget for SORA 3

Component	Voltage (VDC)	Current (mA)	Duty Cycle (%)	Power (mW)	Mass (g)
30 to 5 V DC/DC Converter	30	1500	100	45000	10
RP3 + (2)MiniPIX	5	1210	100	6050	92.4
Linear Actuator	12	650	20	7800	84
Servo Motor	6	550	100	3300	39
Accelerometer	5	3.9	100	19.5	10
(14)Thermistors	5	3.5	100	17.5	80
Altitude/Pressure Sensor	3.6	1.4	100	5.04	10
Low Pressure Pressure Sensor	5	7	100	35	10
Structure w/ bolts	N/A	N/A	N/A	N/A	5000
Total	**N/A**	**2427.6 peak**	**N/A**	**17234**	**5215**

7. PROCEDURES

7.1. Decontamination

7.1.1. Objectives

The Sanitization procedures of the previous flight were rigorous and we will conduct this year's flight within the same SterilGARD e3 Class II Biological Safety Cabinet.

7.1.2. Sterilization Preflight

The payload will be built within the confines of a class 100 clean hood that is located inside of a class 10,000 clean room. Any tools that are used to construct the sampling box will be heat sterilized at 120 °C for 20 min. This will be followed by exposing each side of the container to germicidal UV-C (254 nm) light for 20 min and then soaked overnight in 91% isopropyl alcohol to denature proteins in any possible sources of contaminating bacteria. This sterilization method destroys close to 100% of all organisms and their endospores. To sterilize parts that would otherwise be damaged by the autoclave method they will be cleaned by hand with 91% isopropyl alcohol to kill microorganisms by denaturing proteins and dissolving the lipid membrane. Following this, the materials will be rinsed with a 95% ethanol (v/v) solution as an extra precautionary step to ensure complete decontamination. After all parts have dried, the sampling box will be constructed and placed in a gas-porous sterilization pouch and exposed to ethylene oxide (EO) at a concentration of 0.45-0.65 0.45 mg/m^3 to 0.65 mg/m^3 at 55 °C and 30-50 % RH for 4 hours to annihilate any spores and to provide another form of anti-bacterial treatment. Once the final HASP integration is ready for sampling clean box are produced, the chambers will be sterilized and sealed. After the containers are integrated into the rest of the payload, the entire device will be placed in an autoclave bag for transportation.

7.1.3. Sterilization Post flight

Before payload descent, we will shut off all of our systesms. By powering down all the systems, the arm will retract into the sterile container and be sealed by the rubber O-ring on the lid. Each team member involved in the recovery process will wear new latex gloves; cleaned with 91 % isopropyl alcohol and will extract the clean box from the SORA 3 payload and placed into a sterile cold cotnainer to perserve any organisms captured. The clean box will remain sealed until decontamination procedures are complete and the cold bo has reached the University of Houston clean room. The payload will be disassembled under class 100 conditions and all tools used during this procedure will be either heat or 91 % isopropyl alcohol sterilized. Once in the clean room, the same procedures that were performed preflight will be performed post flight.The fluropore membrane filters will be carefully extracted from the clean box and the low sample DNA extraction will be performed on each individual filter. The remaining DNA fluid will be stored within the $-4\,^{\circ}\mathrm{C}$ sample storage.

7.2. Testing and Integration

7.2.1. Vacuum Chamber Testing

Each subsystem will be tested in-house with a vacuum chamber. This testing phase will be used to ensure that each component of each subsystem performs as it should while in near-vacuum conditions, so if any problem arises it can be understood and fixed. The ISS module structure will be tested individually with a pressure sensor to ensure that the module remains pressurized for a full 24 hour period which will ensure that the welded joints and the hermetic seal are sufficient. To ensure the construction is sound and flight-ready, the ISS structure will be repeatedly tested in the vacuum chamber up until the time of flight. The high-performance devices (i.e. the MiniPIXs and the RP3) will be thermally tested by performing and collecting data for a full 24 hour period. Next, the full electronics system will be tested to ensure the astrobiology components correctly respond to the changing pressure. To conclude vacuum testing, all subsytems will be fully integrated into one assembly which will then be tested in near-vacuum conditions for a 24 hour period. The complete system will be considered optimal when both MiniPIX devices are ensured not to overheat, the RP3 is shown not to overheat, the astrobiology system deploys at the proper air pressure, and the astrobiology system seals at the proper air pressure all while remaining below the amperage limit of 2.5 A.

7.2.2. HASP Integration

During HASP integration, the payload will be tested for proper connection to the HASP systems and be thermally testing at least once more. The integration team will verify that the EDAC connection distributes power as necessary as well as sends the correct discrete commands at will. The astrobiology system will be tested without the membrane filters so as to conserve resources. Any necessary tweaks or changes will be made to properly integrate our payload with the HASP systems. The system will be considered integrated once the payload appropriately receives power and commands and completes thermal testing.

As of now, all 17 members of the UH HASP team will attend integration.

7.2.3. Post-Integration Operations

Once integration is complete, the subsystems will undergo one final check, and the astrobiology system will be sterilized and fitted with the membrane filters. If funds can support it, we will send a small team to New Mexico to oversee the flight operations.

7.3. Flight Operations

Each system is autonomous, however, a mission control team will monitor the downlinked data to determine the status of each subsystem. If the astrobiology system fails to automatically respond or the electronics systems needs a reboot, the corresponding discrete command will be sent. The flight operations team will consist of the project leader and the three system coordinators.

7.4. Post-Flight Operations

If a team is onsite in New Mexico, the data storage systems will be collected and safely stored. Otherwise, the payload will be shipped to our facilities.

7.5. Payload Orientation

The SORA 3 payload does not have any preferred orientation or placement on the HASP gondola.

8. IN-FLIGHT FAILURE CONTINGENCY PLAN

If for some reason the sampling system fails, commands can be uplinked to the control system that allow for subsystem resets. If downlinked data shows extreme overheating or any sort of abnormality that could result in damage to HASP or other payloads, we will shut down all systems through the discrete command provided by HASP.

9. PROJECT MANAGEMENT

9.1. Team Structure

Faculty Mentor:

Andrew Renshaw

Physics Department

arenshaw@central.uh.edu

Project Leader:

Reed Masek

Physics B.S., Spring 2020

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Team Coordinators:

Jimish Patel

Physics B.S., Spring 2020

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HASP Payload Application 2019

Michael Butowicz

Computer Science B.S., Fall 2020

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Taylor Hill

Physics B.S., Spring 2019

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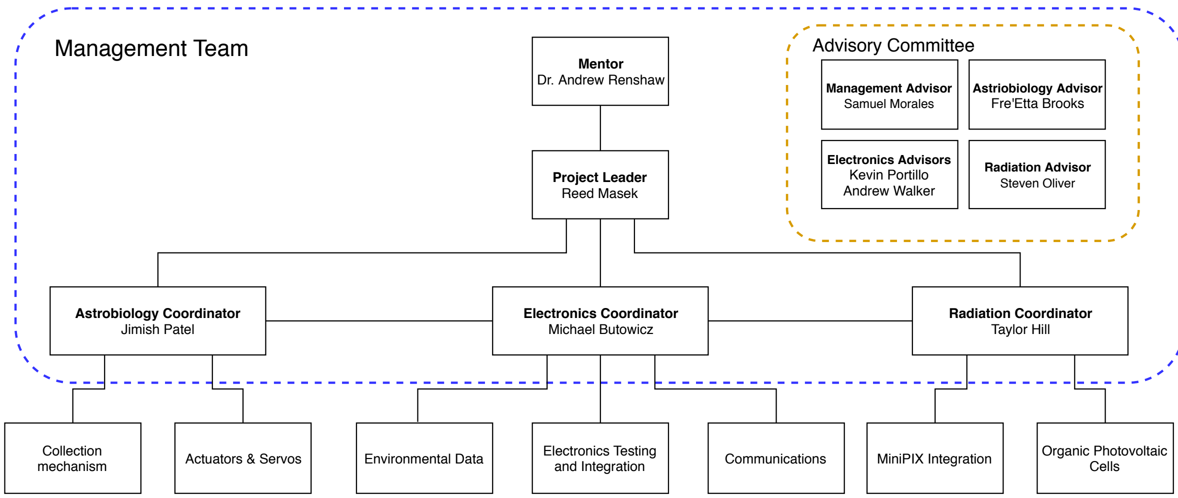


FIG. 7. Team role tree for the current UH HASP team.

9.2. Roles and Responsibilities

- PI – Dr. Andrew Renshaw
  - Attend weekly team meetings and provide general research team guidance
  - Review project design and final products for submission to HASP
  - Attend monthly teleconferences.
  - Equipment procurement

- Project Leader - Reed Masek
  - Interface with HASP Flight Control Team and act as team main point of contact
  - Compile monthly reports and submit to HASP
  - Attend monthly teleconference with HASP
  - Coordinate with PI on administration tasks and internal group business
  - Periodically check-in with team coordinators regarding the team's progress
  - Coordinate meetings and assign tasks with deadlines
  - Approve designs, tests, ideas, and any work related to HASP and payload
  - Final decisions on staffing (staffing decisions will be a group decision overall)
- Electronics and Communications Coordinator - Michael Butowicz
  - Do necessary reserach for finalizing work
  - Coordinate information, tasks, and deadlines with subgroup
  - Approve work done by subsystem team
  - Write bimonthly updates along with detailed reports from subsytem meetings
  - Make detailed presentations, if necessary, for weekly team meetings
  - Report to project leader and PI with any project changes, issues encountered, and any external communications.
  - CC PI and Project Leader in all emails for external communications
  - Perform other such duties as the Project Leader or PI may specify
- Astrobiology Coordinator - Jimish Patel
  - Do necessary reserach for finalizing work
  - Coordinate information, tasks, and deadlines with subgroup
  - Approve work done by subsystem team
  - Write bimonthly updates along with detailed reports from subsytem meetings
  - Make detailed presentations, if necessary, for weekly team meetings
  - Report to project leader and PI with any project changes, issues encountered, and any external communications.
  - CC PI and Project Leader in all emails for external communications
  - Perform other such duties as the Project Leader or PI may specify
- Radiation Coordinator - Taylor Hill
  - Do necessary reserach for finalizing work
  - Coordinate information, tasks, and deadlines with subgroup
  - Approve work done by subsystem team
  - Write bimonthly updates along with detailed reports from subsytem meetings
  - Make detailed presentations, if necessary, for weekly team meetings
  - Report to project leader and PI with any project changes, issues encountered, and any external communications.
  - CC PI and Project Leader in all emails for external communications
  - Perform other such duties as the Project Leader or PI may specify
- Team Member
  - Do necessary reserach for finalizing work

– Coordinate with team and subsystem coordinator

– Make detailed presentations, if necessary, for weekly team meetings

– Report to project leader and PI with any project changes, issues encountered, and any external communications.

– CC PI and Project Leader in all emails for external communications

– Perform other such duties as the Project Leader or PI may specify

9.3. Timeline

TABLE V. Timeline for the 2019 SORA 3 Mission

Month of 2019	Description of Work
January	* Secure funding * Create and finish budget for mission * Make inventory of hardware * Procure hardware/software * Start designs of SORA 3 * Update SOCRATES *Determine cell types * Upgrade vacuum chamber * Recruit new members
February	* Continue with work from January in terms of design development and funding procurement. * Have finished list of inventory * Continue recruitment if necessary and finalize by end of month.
March	Obtain funding by the end of this month. Finish all tasks from the previous two months and transition into building phase. * Have all hardware/software orders in by the end of the month * Begin fabrication of polymer and perovskite based solar cells * Begin PSIP, have draft by end of the month
April	* Order remaining items if needed * Submit a NASA On-site Security Clearance Document by April 15th. * Finish PSIP by April 26th * SOCRATES and MiniPIX integration and testing *In house solar cell fabrication continued * Prepare for astrobiology work
May	* PSIP and FLOP development * Finalize integration of SOCRATES and hardware * Finalized fabrication of cells and begin profiling * Continue working on astrobiology upgrades
June	Final PSIP due June 28th *Finalize astrobiology and cell upgrades and ready for integration * Testing in lab
July	Final FLOP due July 19th * Make changes from testing and continue tests
August	Payload Integration during July 15th - July 19th *Have all payload work done and ready for flight
September	* Launch SORA 3 on September 2nd * Recovery TBD.
October	Debrief and analyze all data from flight
November	Have final report by end of November
December	Final Report due on the 6th

9.4. Funding

Funding sources will be local contributions - applying for funding through the Physics Department, the College of Natural Science and Mathematics, The University of Houston Division of Research, and local organizations and companies willing to support this endeavor. Additionally, the University of Houston Department of Biology has promised long-term support for development of the astrobiology system and analysis of the astrobiology data.

10. APPENDIX A

10.1. Payload Dimensions

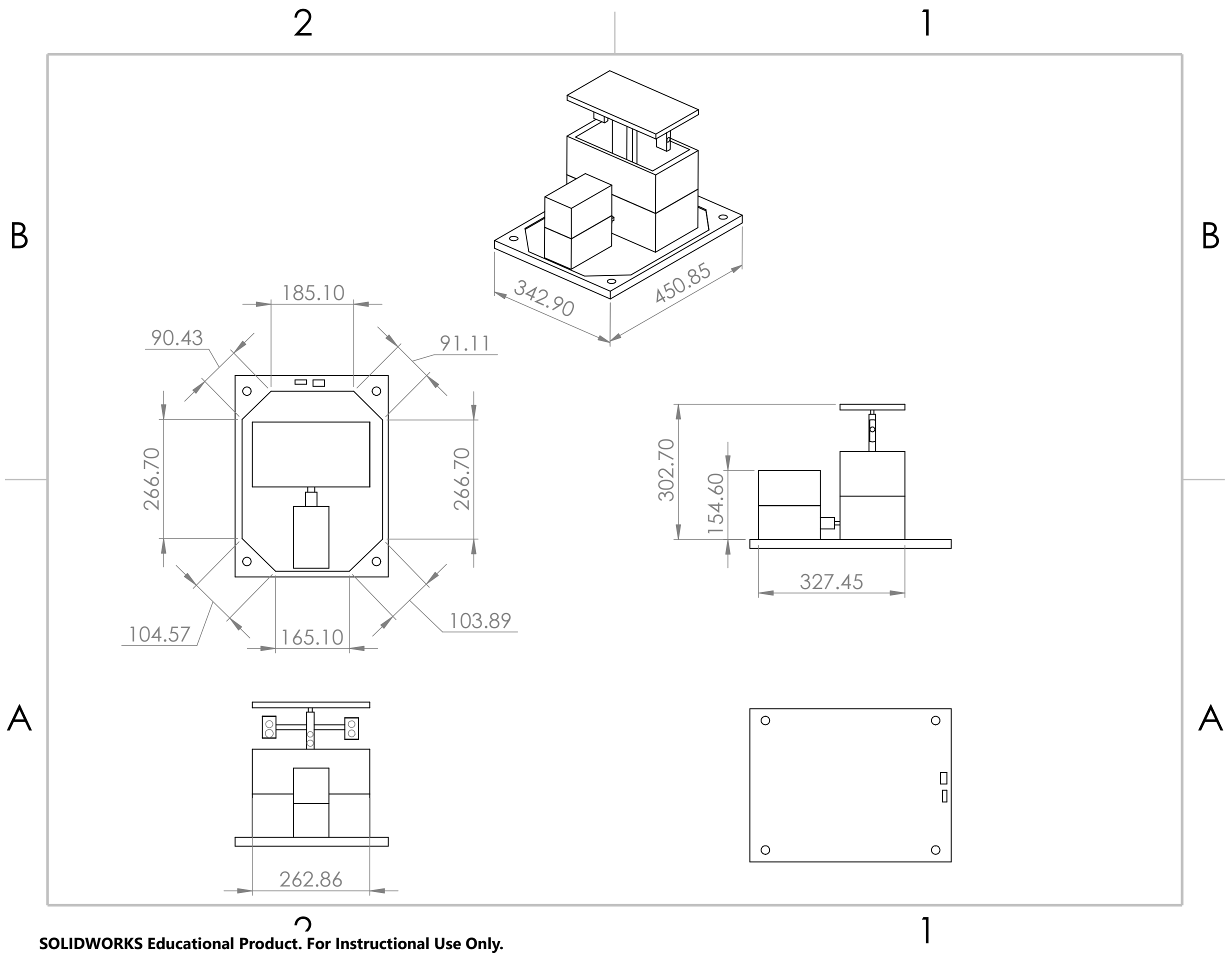
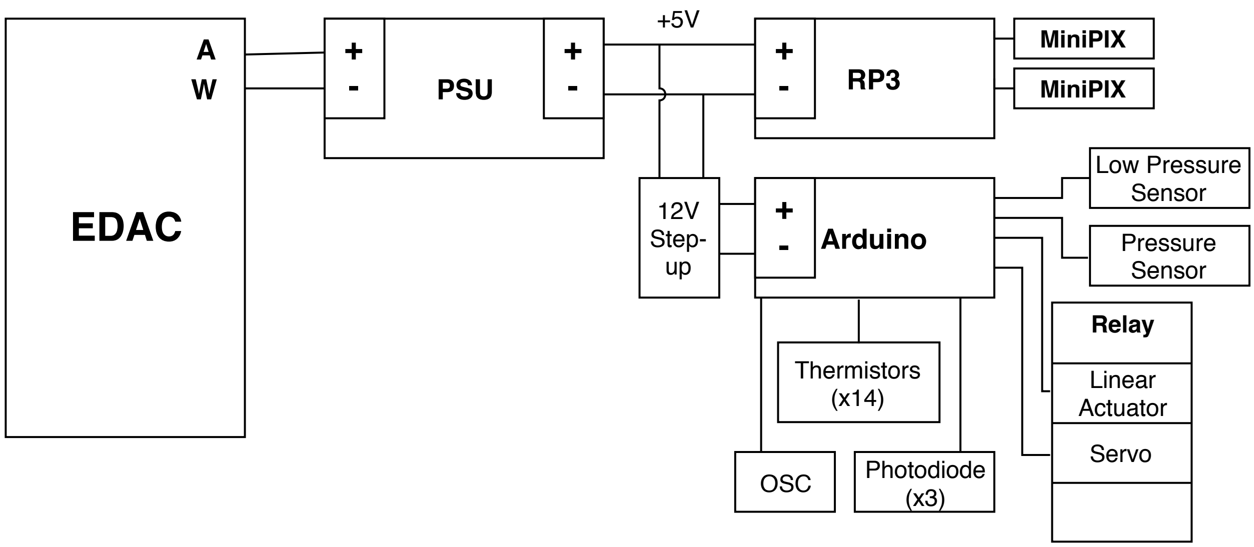


FIG. 8. Drawing for the preliminary payload design. All dimensions are in millimeters.

10.2. Electronics Wiring Diagram



Legend	
EDAC	EDAC 516 Connector
RP3	Raspberry Pi 3
PSU	PCM-DC-AT500
Arduino	Arduino ATMega
Relay	2 Relay Module
Thermistor	Precision Epoxy Thermistor
OSC	Organic Solar Cells

FIG. 9. Preliminary wiring configuration of the flight computer, electronics, and sensors.

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