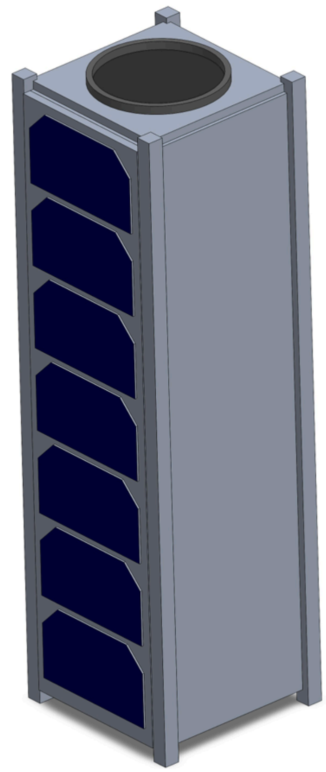
NASA CSLI Application

In Response to Solicitation NNH24ZCF001

November 15, 2024

MEEPsat (Methane Emissions from Permafrost Satellite Tracker)



Submission by:

AIAA, ARC, and SPS at The University of Texas at San Antonio

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CubeSat Mission Parameters		
CubeSat Mission Name	MEEPsat	
Mass (kg)	4.625 kg	
Cube Size (ex., 1U, 2U, 3U, 4U, 6U)	3U	
Rail/Tab Length (mm) (ex., 340.5 mm, 366 mm)	340.5 mm	
Readiness Date for Integration to Dispenser	August 2026	
Desired Orbital Lifetime after Deployment (years)	1 year	
Designated Operational Lifetime (years)	1-2 years	
Is an ISS deployment acceptable (~400 km @ 51.6 degree inclination)? Yes or No	No	
Is a Sun Synchronous Orbit (SSO) acceptable? Yes or No	No	
Sun Synchronous Orbit (SSO) required? Yes or No	No	
Is the proposed mission compliant with the limitations in Section 5.1, or is an exception requested for consideration?	In Compliance	
Orbital Parameters	**Desired/Preferred Range**	**Acceptable Range**
Altitude (km)	325-375 km	300-400 km
Inclination (degrees)	70° - 80°	60° - 85°
Mean Local Time of the Ascending Node (MLTAN) N/A if SSO is not acceptable.	N/A	N/A

<table>
<tr><th colspan="6">CubeSat Project Details</th></tr>
<tr><td rowspan="2">Focus Area(s)
Note: Select as applicable per requirements for Appendix A or B.</td><td colspan="2">NASA Funding</td><td rowspan="2">Sponsoring Organization(s)</td><td colspan="2">Collaborating Organization(s)</td></tr>
<tr><td>Yes or No</td><td>Organization</td><td>List</td><td>International*
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<tr><td>Education</td><td>No</td><td>N/A</td><td>UTSA</td><td>AIAA, ARC, SPS</td><td>No</td></tr>
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1. Abstract

Methane in the atmosphere is one of the largest contributors to climate change, second only to carbon dioxide. However, compared to carbon dioxide, it is 80 times more effective at trapping heat, meaning it does much more harm with a smaller amount. Methane emissions are seen all over the world, but recent data has shown there is a large amount being produced in the polar regions, which had previously gone unmeasured as they were not considered in current models.

Permafrost from the polar regions contains a large amount of frozen organic matter, which contributes to the production of greenhouse gasses such as methane when the permafrost thaws and the organic matter decomposes. In addition, permafrost traps significant amounts of natural gas (thermogenic methane) that is released when it thaws. The Arctic region alone is expected to hold nearly one third of the Earth's frozen carbon, and around half of the methane emissions from these polar regions have been observed to reach the atmosphere and contribute to rising temperatures. While climate change factors have caused permafrost to thaw gradually over time, there have also been regions that experience abrupt thaw, which is the rapid thawing of permafrost over a small area. This increases local greenhouse gas emissions by 125–190%, trapping much more heat in the atmosphere in these regions, rendering more permafrost at risk of abrupt thaw (1). The excess heat would also contribute to this abrupt thaw phenomenon to become more prominent across the polar regions, further expediting methane emissions and raising temperatures at a much faster rate.

This proposal describes the mission objectives of the Methane Emissions from Permafrost Satellite Tracker (MEEPsat), which include tracking these large methane emissions from the abrupt thawing of permafrost in the polar regions. MEEPsat will accomplish this by using an infrared camera to detect these methane emissions and by flagging emissions found over a certain threshold for analysis. These data files will be time-stamped and logged with coordinates, since tracking the geographical location of these emissions will be necessary to further analyze the correlation between the concentration of high methane emissions and their locations. This can be done by ground or air based measurements that focus on the regions with a high concentration of flagged methane emissions. By having MEEPsat collect data from the entirety of the polar regions, ground-based climate researchers will have a better idea of where to focus their resources, which will allow them to ensure the effective measurement of quantitative data.

Understanding high-methane-emission locations in the polar regions, researchers will be able to create new climate models that incorporate our new data to improve their prediction accuracies, which aligns with Strategic Objectives 1.1, 1.3, 3.1, 4.1, and 4.3 from NASA's 2022 Strategic Plan. These improved models will enable researchers to better understand one of the currently poorly-understood, but significant processes that affect the rate of climate change, and to inform the general public about the far-reaching implications due to these climate change factors.

2. Proposal Detail

2.1 Introduction

2.1.1 Background

While climate change has driven widely-documented rising temperatures across the globe, the polar regions of Earth have been disproportionately affected. In recent years, the Arctic region has seen record increases in temperature that are 4 times faster than the global average (Figure 1), and the temperature in the Antarctic region has been increasing twice as fast. While some of this increase is due to global factors that affect climate change (rising CO_2 emissions), it does not fully explain why there has been such rapid temperature increases across the polar regions. Recent research has shown that large methane emissions in these regions could be a significant contributing factor to accelerating processes brought about by climate change, and current climate models that did not account for this excess methane production were severely underestimating how the degree to which temperatures have been increasing in these polar regions. Figure 2 shows how the atmospheric methane emissions are expected to increase, but they can also significantly decrease if actions are taken to mitigate these factors (2). It also shows how including the methane emissions from permafrost can drastically increase the expected atmospheric methane concentration which directly contributes to rising temperatures.

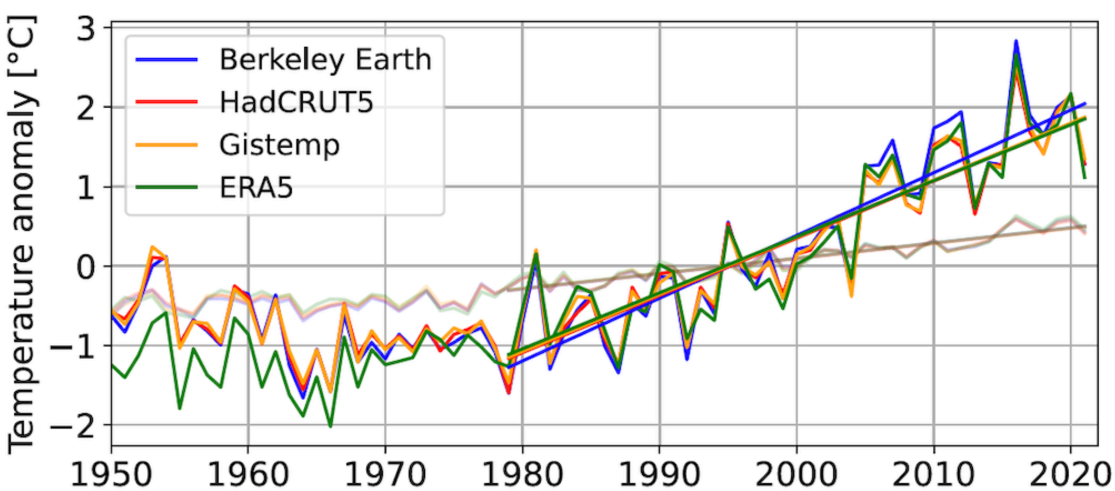

Figure 1: Change in temperature with respect to the temperature in 1981 for the arctic regions (brightly colored lines) and global average (neutral colored lines) as collected by 4 research labs (3). Each dataset is consistent in showing that temperatures in the arctic are rising 3.8 times faster than global temperatures.

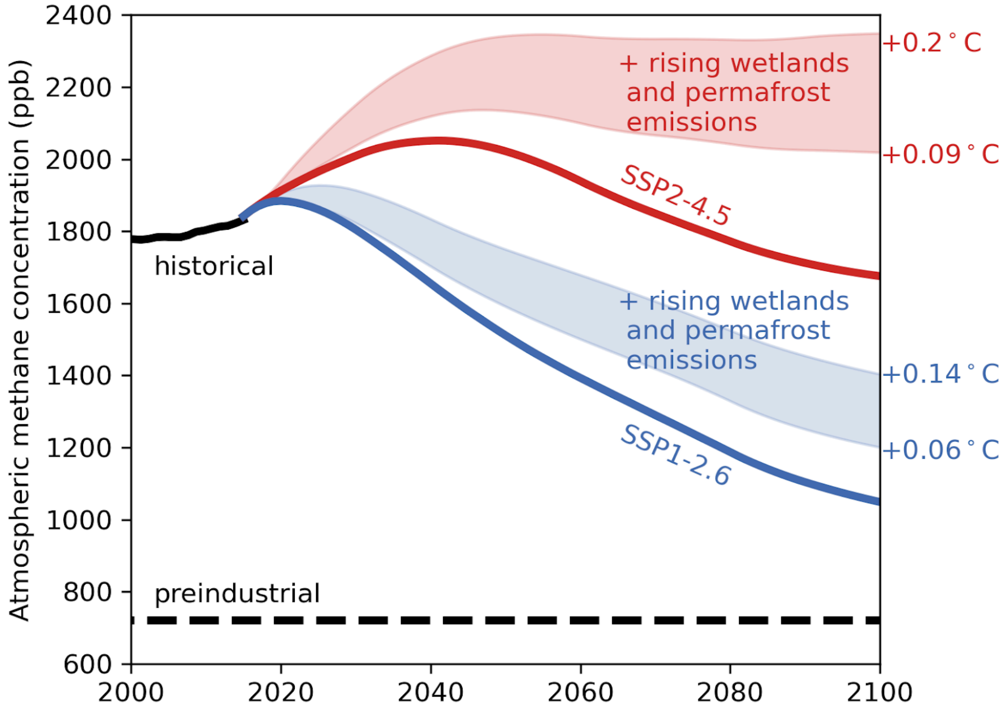

Figure 2: Prediction of atmospheric concentration of methane over time (red) compared to the prediction if immediate action is taken to limit methane emissions (blue). Both cases account for emissions from wetlands and permafrost, which dramatically increase the predicted baseline levels (solid lines) in both cases.

Permafrost is permanently frozen soil in polar regions that naturally thaws over time and releases microbial methane and thermogenic methane, or natural gas (4). Microbial methane is generated from previously frozen organic matter in the soil that becomes exposed to microbes that decompose the material in an anaerobic process known as methanogenesis. However, as temperatures rise, this gradual process occurs on a much faster timescale due to geological features known as thermokarst lakes. They form when a spike in temperatures causes a large amount of permafrost to melt, making the soil above sink in and create a well that fills with precipitation. The cycle of thawing and freezing happens much faster for these thermokarst lakes since more surface area of the soil and permafrost come into contact with water, which increases the thawing rate. As a greenhouse gas, methane aids in trapping heat within our atmosphere, which in turn causes more of these thermokarst lakes to form, causing a series of positive feedback loops that will keep worsening unless something is done to break the cycle (Figure 3). Monitoring the methane in these regions is thus critical to updating our predictive models of climate change in the Arctic polar regions.

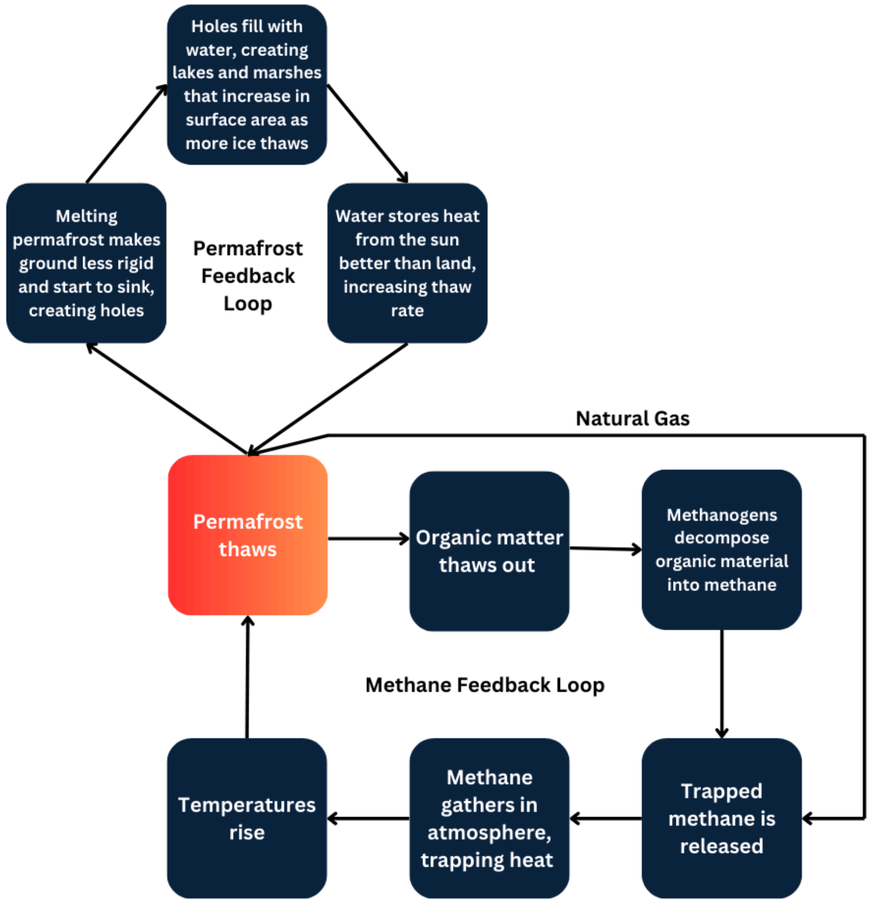

Figure 3: Flow chart of the Permafrost and Methane Feedback Loop Processes.

2.1.2 Current Missions

ABoVE

ABoVE (Arctic-Boreal Vulnerability Experiment) is a terrestrial exploration of how the ecosystems in the Arctic region were affected by climate change in an effort to investigate how these changing ecosystems could have long reaching impacts for societies around the world (5). This experiment began in 2015, and is projected to conclude in 2025. It covered a broad range of studies undertaken to understand why climate factors were having a larger effect in the Arctic region when compared to the rest of the world, and one component that was employed was the AVIRIS-NG (Airborne Visible/Infrared Imaging Spectrometer), which remotely sensed the concentration of methane emissions from specified arctic regions. It consisted of manned planes using infrared images to highlight locations with high methane concentrations. The results from this phase revealed that there were over 1.7 million methane emission sources greater than 3,000 parts per million (ppm) within 255 m of the nearest water surface in a small region of the north coast of Canada. This led to the conclusion that there was an underlying power law connecting the frequency of large methane emissions with proximity to the nearest standing water source, which was then validated by in situ measurements. It was noted that the contributors to these large methane emissions were from the vegetation surrounding these water sources, and not from the water sources themselves, which were not able to be measured. This provides a basis for understanding why the Arctic might be warming at such an alarming rate, and provides background for what still needs to be observed in order to get a more complete picture of the amount of methane produced in the Arctic region.

However, there were several limitations to the ABoVE project. ABoVE was only able to survey a region of 30,000 square kilometers in Alaska and Canada, ignoring the permafrost in Siberia that is predicted to increase carbon-based emissions (threefold with respect to Representative Concentration Pathway 4.5 and twelve-fold with respect to Representative Concentration Pathway 8.5 by 2100) if Siberian permafrost and thermokarst activity are not addressed (6). MEEPsat would autonomously survey the entire polar region, providing more data with less upkeep so that manned ground and air based measurements can be reserved for locations with confirmed large methane emissions and conduct further research.

PREFIRE

PREFIRE (Polar Radiant Energy in the Far-InfraRed Experiment) is a pair of Cubesat satellites that will be measuring the amount of heat emitted in the far-infrared from both the Arctic and Antarctic poles, in an effort to understand the capacity for elements in the atmosphere to keep heat from radiating into space. It was scheduled for launch in early 2024, and is projected to stay in orbit for one year. This mission will help researchers understand how heat exchange between Earth and space occurs and how it might change in the future, which allows them to observe how it would impact factors that can affect climate change, such as permafrost thawing. Since there are two satellites being deployed, it allows for short-period changes to be marked as the two satellites will go over the same region at different times. However the data collected will be general, showing regions where more heat is trapped compared to regions that emit more heat into space, while MEEPsat's mission will be to specifically target methane emissions, since methane has a much larger impact on the atmosphere compared to other greenhouse gasses. In a report from the Intergovernmental Panel of Climate Change, one ton of methane was found to trap 28 times more heat than one ton of carbon dioxide over a 100 year timeframe, even after accounting for methane's short lifespan (7).

By collecting data that can be analyzed over short and long time scales, PREFIRE will be able to show varying trends that can provide useful background for the data received from MEEPsat. Combining the data will allow for more accurate climate models that represent permafrost thawing along with other general climate change factors.

2.2 Objective

This proposal outlines the goals of MEEPsat, an autonomous CubeSat mission designed to detect large methane emission events resulting from the abrupt thawing of permafrost in polar regions. This project aims to supplement data provided by previous missions, such as ABoVE and PREFIRE, to deepen our understanding of the unique impacts of climate change on polar regions and how these changes influence the rest of the planet.

MEEPsat will be equipped with a forward-looking infrared camera to autonomously collect data from polar regions. This camera will pinpoint where significant methane emission events occur, identifying the location and frequency of these large methane emission events. Such information could be key to understanding why the polar regions are warming at rates faster than the global average.

With ABoVE scheduled to conclude in 2025 and PREFIRE launched in early 2024, a unique opportunity is presented when the launch window opens for MEEPsat around 2026. By cross-referencing MEEPsat's methane emission data with findings from ABoVE and PREFIRE, we aim to provide data that will help develop accurate climate models capable of tracking and predicting methane emissions from polar regions, along with identifying contributing factors.

These diagnostic models will support future research efforts to mitigate and, ultimately, either prevent or at least better understand abrupt methane emission events. This initiative will also help educate the public about the significant impacts of climate change, promoting widespread action to reduce its effects and mitigate its risk to humanity.

2.3 CubeSat Overview

2.3.1 Navigation

As seen in Figure 4, the majority of endangered permafrost is found between the latitudes of ±60° – 70°. MEEPsat will operate in a circular orbit with an altitude of 350 km (±50 km). At this altitude, the camera will have a swath width of 53.76 km. Assuming 5 data collection orbits each day, MEEPsat will capture the entirety of both polar regions every 75 days, allowing it to collect almost 5 complete datasets of the arctic during its operation. As most endangered permafrost is found in the latitudes between ± 60° – 70°, using these inclination angles will allow MEEPsat to have a better focus on the regions that are at the most risk while still receiving data from the entirety of the polar regions to provide enough information to update climate models.

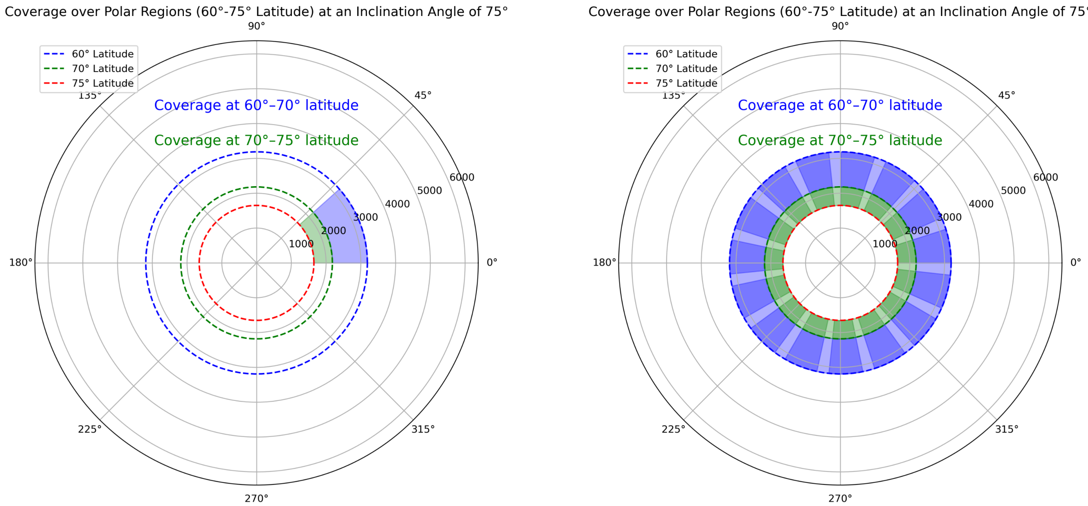

Figure 4: The left figure depicts the satellite's single-pass coverage at 60° (23.1%) and 75° (45.6%) latitudes. The right figure illustrates cumulative coverage over 15 orbits in one day, achieving ~90–100% coverage at 70° latitude. This is taken with an inclination angle of 75°.

As satellites and other spacecraft become more accessible, orbital debris mitigation has become increasingly urgent. Even pieces so small that they cannot be tracked can cause catastrophic collisions (8). In addition, orbital lifetime increases exponentially with respect to altitude, so spacecraft are entering orbit at a faster rate than vehicles can deorbit. This is especially true for LEO, as NASA estimates that it contains 85% of Earth's total orbital debris.

The altitude of 350 km was strategically selected with debris mitigation in mind, as its debris density is less than a tenth of the density at 800 km. This LEO minimizes the risk of collision with the higher densities of orbital debris typically found at higher altitudes, ensuring MEEPsat operates within a safer, less congested region of space. Moreover, this altitude complies with both the 25-year rule and the 5-year rule as outlined by the Orbital Debris Second Report and Order (ODSRO) for debris mitigation. MEEPsat's orbital lifetime is estimated to be 2.75 years, allowing for a natural orbital decay and re-entry over time and further minimizing long-term debris accumulation.

At an altitude of 350 km, MEEPsat will complete one orbit in approximately 91.6 minutes, a period calculated using Kepler's Third Law based on its distance from Earth's center. This orbital period allows MEEPsat to complete around 15.72 orbits per day, providing frequent revisits over target regions (Figure 5). Each day, MEEPsat will spend about 14.38 hours per day in sunlight, with the remaining 9.62 hours in Earth's shadow, which allows for 7.7 Wh of power generated per orbit. This balance supports monitoring and data collection throughout the day, aligning with the mission's requirements while meeting the satellite's power and thermal constraints.

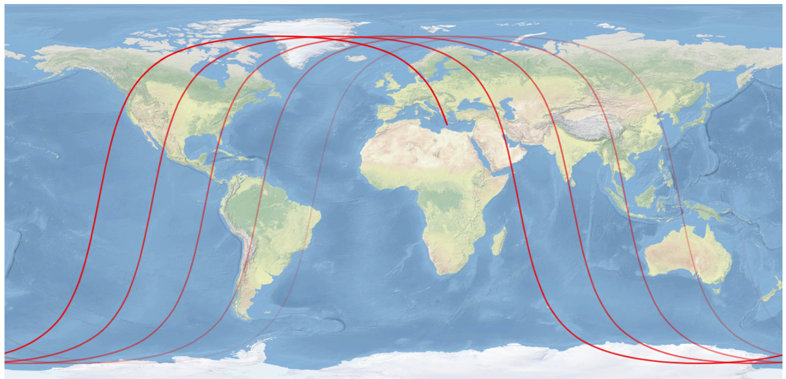

Figure 5: 2D Visualization of MEEPsat's Orbital Path.

The satellite's exposure to sunlight and Earth's shadow is an important factor in managing power and thermal conditions. Given the chosen LEO configuration and inclination, the satellite is expected to spend approximately 60% of its orbit in sunlight and 40% in Earth's shadow. This exposure ratio allows for efficient use of solar power, as the satellite will have regular sunlight exposure to recharge its batteries. The periods spent in Earth's shadow will provide an opportunity for the vehicle to passively cool and ensure that the satellite's systems remain within safe temperature ranges.

Furthermore, the satellite's attitude control system utilizes magnetorquers to align with Earth's geomagnetic field, enabling precise positioning without the need for additional onboard power or mass. Magnetorquers are particularly well-suited for LEO like 350 km, as the geomagnetic field strength at this altitude provides reliable reference points for attitude adjustments. This configuration ensures MEEPsat maintains optimal orientation for monitoring methane emissions in polar regions, enhancing mission efficiency while contributing to sustainable orbital practices by reducing reliance on high-power or high-mass control systems.

2.3.2 Payload

To quickly obtain preliminary data on the locations of abrupt methane emissions, MEEPsat will be utilizing infrared spectroscopy with spectral filtering to detect concentration of methane in the polar regions. To optimize permafrost coverage, MEEPsat will only record data from the latitude ranges of 60°-70°, providing the coverage in Figure 6 below.

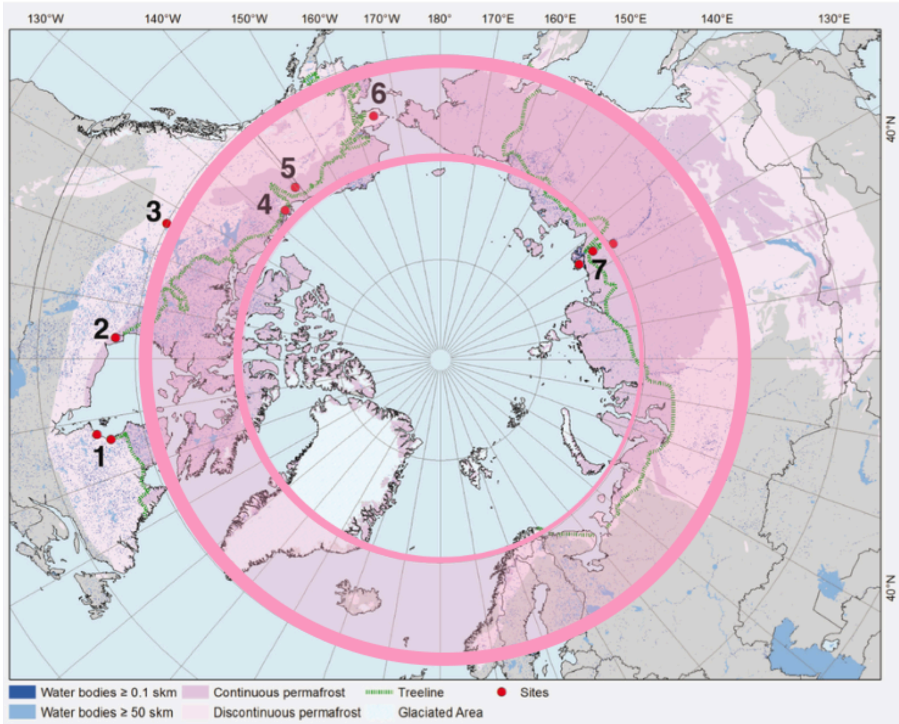

Figure 6: Surface area captured by MEEPsat's camera overlayed on a permafrost map from a study on thermokarst lakes, which are shown by the red site dots on the map (9) . The majority of continuous permafrost resides within 60°–70° of latitude, so it was decided that the cost of data collection beyond this range was not worth the gain.

The payload contains a forward-looking infrared camera assembly oriented directly toward Earth's surface with a spectral filter tuned to observe the peak in methane's absorption spectra at 2.2755 ±0.0005 µm and block all other absorption features due to other molecules in the atmosphere. When methane is present between the camera and a source of light at 2.2755 µm (in this case, reflected and blackbody radiation from Earth), it will appear as a dark void in the image that will allow for detection based on pixel intensity (Figure 7). Further data analysis will tabulate the locations of high methane emission regions and can correlate whether there is an underlying power law based on the separation distance between them and the nearest standing water sources. Images will be stored locally until they can be downlinked to the ground station for data processing. When absorbance associated with concentration above the threshold for a rapid methane emission (2,000 ppm of excess methane when compared to relative background levels) is detected, the image will be flagged for human verification. This concentration threshold also represents a signal-to-noise ratio of around 3–4 as used by ABoVE (10).

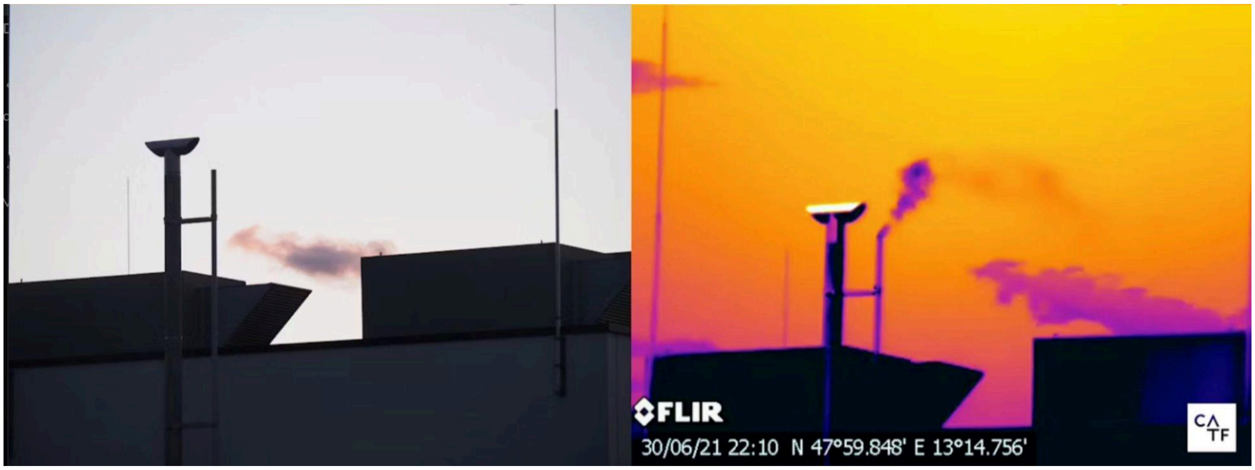

Figure 7: Example of methane emissions captured by Teledyne FLIR's infrared camera through absorption of light. The dark cloud's pixel intensity will be analyzed to determine concentration.

Each image will contain a timestamp and coordinates of the imaged location so that the data can be clearly mapped across the polar regions to better understand the correlation between concentrations of large methane emissions and geographical position. The power law associated with proximity to water sources was found in the ABoVE study on a smaller scale, but MEEPsat will be able to provide that data on a much larger scale, allowing researchers to study any correlations found across larger distances.

2.3.3 Airframe and Structure

The satellite structure will house all communication, data collection, and electronic components internally. External components, such as solar panels and the antenna, will be positioned to maximize mission efficiency. Protecting internal components is crucial due to thermal operational limitations and the need to maintain component integrity. Securing the IR camera and data collection components is a priority, as the stability of these systems is essential for accurate and consistent data collection during orbit. The IR Camera will be placed in the lower half of the MEEPsat with a view point on the bottom face pointing towards the Earth.

The frame structure will be similar in measurements to the EnduroSat 3U CubeSat Structure which was chosen due to its CubeSat Standard Compliant material composition and structural testing considerations. The structure dimensions can be viewed in Figure 15, in Appendix section A.4. The frame structure will serve as the main support frame, housing both the internal components and external elements. This design allows for a lightweight solution and accommodates the recommended deployment switches and separation spring locations specified by the CubeSat Design Specification.

The structure includes thermal protective systems in place to ensure that the internal components are not exposed to extreme temperatures that could hinder the data collection. During manufacturing, the MEEPsat frame will undergo stringent testing at UTSA to ensure it is space qualified, including random sinusoidal vibrations, pyroshock tests, thermal cycling, and thermal vacuum tests.

MEEPsat's internal supports and paneling will be manufactured in-house at The University of Texas at San Antonio (UTSA) using the UTSA Makerspace, a student-led facility that houses a full machine shop, Renishaw metal 3D-printer, and high-temperature thermoplastic 3D printers. In house manufacturing will be utilized for the frame structure and the internal shelving and securement components of the MEEPsat. During the manufacturing phase, the use of 3D-printed parts will be essential for optimizing dimensions, as well as reducing costs and manufacturing timelines. Student-manufactured parts will also showcase the unique capabilities of UTSA and the extensive technical skills students are able to develop. With the use of UTSA's in house testing facilities as well as utilizing SwRI's testing facilities, the structural components will be able to go through vibration, thermal, and off gassing testing.

2.3.4 Project Organization

MEEPsat is a collaboration between three student organizations (Aeronautics and Rocketry Club, American Institute of Aeronautics and Astronautics, and the Society of Physics Students) located at The University of Texas at San Antonio. All participating students are undergraduates mainly majoring in mechanical engineering and physics. The project is co-led by Smruthi Shashidhar and Grace Zimmer, who are both mechanical engineering majors, and oversee the various sub-teams. The sub-teams are as follows: External Structure, led by Andrew Cervantes; Navigation Systems, which was split into Guidance and Attitude Control teams, led by Manuel Candanoza and Reggie Delaney respectively; Avionics Systems, split into Power and Communications teams, led by Adam Castro and Lizette Rodriguez respectively; and Payload System, led by Grace Zimmer (Figure 8).

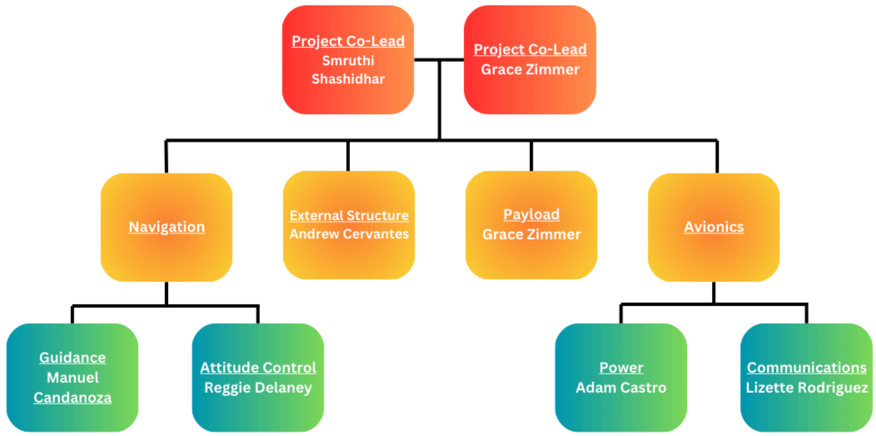

Figure 8: Organizational Structure of MEEPsat Project Team.

As this is UTSA's first experience with a CubeSat project, each team is in charge of researching and developing their respective components. Weekly research discussions, meetings, and presentations have been held to streamline learning and development as a team. This structure will continue throughout the project with weekly tag-ups to monitor progress. This project also includes two UTSA faculty advisors, Dr. Christopher Combs and Dr. Daniel I. Pineda, who provided background knowledge from their respective research areas in order to aid the project.

Dr. Christopher Combs is a tenured professor and holder of the Dee Howard Memorial Endowed Faculty Fellowship in Mechanical Engineering. Under his leadership, the UTSA Mach 7 Ludwieg Tube wind tunnel was developed and completed in 2021, providing a state of the art facility for hypersonics research. He also serves as the director of UTSA's Center for Advanced Measurements in Extreme Environments (CAMEE), a program established at UTSA in 2019 through a $5 million grant from NASA's MIRO program, which supports research and development at minority-serving institutions. Our objective of tracking methane emissions from thawing permafrost directly supports CAMEE's mission, as it integrates remote sensing technologies to address critical environmental challenges. Dr. Combs is also the faculty advisor for the AIAA student chapter at UTSA, one of the student organizations supporting this project.

Given the large learning curve faced by many of the undergraduate students, Katherine Kim, a graduate student in Dr. Combs' UTSA's hypersonics laboratory, has also joined the team to offer guidance through her prior experience with the Texas Spacecraft Laboratory at The University of Texas at Austin. During her undergraduate career, she oversaw multiple small satellite missions including projects funded by the CSLI and the University Nanosatellite Program (UNP).

Dr. Pineda is an Assistant Professor in Mechanical Engineering and Principal Investigator of the UTSA Laser Spectroscopy and Chemical Propulsion Laboratory (LSCPL), and has extensive experience with the development of sensing techniques and spectral models based on absorption spectroscopy (including the development of collisional line mixing models for methane (11,12)), a field which underlies the proposed mission of MEEPsat. Dr. Pineda is also a co-developer of spectraplot.com, a web-based tool used by thousands of spectroscopists and researchers around the world to predict the absorption and emission spectra of gas mixtures, and is faculty advisor to ARC, one of the organizations supporting this project. Through the guidance of these mentors, UTSA students are gaining the technical and scientific expertise essential for future engineers and scientists in the aerospace and space exploration fields.

Lastly, it is important to note that UTSA is classified as a Minority Serving Institution (MSI), containing many populations underrepresented in STEM fields associated with Space Science and Technology: Nearly 70% of UTSA undergraduate students identify as Black or Latinx, and nearly 45% of UTSA undergraduate students are first-generation college students. Moreover, roughly 16% of UTSA students are military-affiliated, including veterans, active duty service members, reserves/guards, and their families, providing numerous pathways for upward economic mobility in an urban-serving environment.

The proposed team is co-led by two female students and includes multiple students who are first-generation students, first-generation Americans, veterans, students with disabilities, and other underrepresented and historically-excluded minorities in STEM, representing multiple opportunities to engage a diverse group of students into the space science and technology workforce upon graduation.

3. Budget and Timeline

Promised contribution commitments for MEEPset to-date include $22,000 in direct monetary funding from the UTSA Office of Research, Klesse College of Engineering and Integrated Design, and the UTSA Department of Mechanical, Aerospace, and Industrial Engineering as well as the UTSA Department of Physics and Astronomy. Additionally, an estimated $15,000 in donated (in-kind) UTSA assets have also been committed to the project in the form of the IR camera hardware. As a result, MEEPsat will be developed on a budget of $37,000 until further financial assistance is secured, which is shown in Table 1. While this budget is modest, by utilizing resources such as UTSA's machining shop and shock testing facilities, as well as numerous testing facilities at SwRI (Southwest Research Institute), it was possible to stay within the budget. Any additional financial assistance is anticipated to help with reducing the time required for the building and testing processes, and improving overall quality of the final product, but is not immediately needed at the project outset to begin work.

Table 1: Cubesat Budget

Part	**Cost**	**Manufacturer**
Transceiver	$5,200	ISISPACE
Antenna	$5,300	ISISPACE
On-Board Processor	$700	Satsearch
Power Modules	$3,300	Endurosat
Solar Panels	$4,500	Endurosat
Camera Assembly	$16,500	Teledyne FLIR, Spectrogon
Magnetorquer	$1,000	ISISPACE
Structure	$500	UTSA
Testing and Facilities	$0	UTSA
TOTAL	$37,000	

The development schedule shown below in Table 2, shows the timeline for designing, building, and launching MEEPsat. The timing of the tasks were structured around events such as the proposal deadline, submission notification, and the launch date.

Table 2: MEEPsat Development Schedule

Start Date	End Date	Task
Sep. 2024	Nov. 2024	Project development and proposal
Nov. 2024	Mar. 2025	Continuation of student skill and workforce development
Mar. 2025		Announcement
Mar. 2025		Second Preliminary Design Review
Mar. 2025	May 2025	Procurement of materials and components
Mar. 2025	July 2025	Manufacturing structure
April 2025	Oct. 2026	Individual component testing
Oct. 2026		Third Design Review
Oct. 2026	Jan. 2026	Assembly and integration
Jan. 2026	June 2026	Full-scale testing
June 2026		Critical Design Review
June 2026	Aug. 2026	Last adjustments/flight preparations and readiness
Aug. 2026		Launch

4. Preliminary Design Reviews

To assess MEEPsat's merit and feasibility, a detailed discussion on the proposal was held with the panel members, along with supporting questionnaires. This was a non-competitive review, and after surveying the panel members, the project received a rating of 4.0 out of 5.

4.1 Merit Review

The merit review panel provided feedback focused on how the project aligned with the goals and objectives of the NASA and CSLI guidelines. The panel members consisted of professionals from UTSA, SwRI (Southwest Research Institute), and JPL (Jet Propulsion Laboratory) who all had experience with reviewing NASA proposals. Considerations included how the project showcased student leadership, the potential for scientific advancement, and how MEEPsat would benefit NASA's Strategic Plan. Specifically, Merit Reviewers agreed that the proposal is relevant to and seeks to meet objectives 1.1, 1.3, 3.1, 4.1, and 4.3 of the 2022 NASA Strategic Plan. Overall, the merit review panel members rated the project a 3.8 out of 5.

Feedback from the merit review panel mainly touched upon making sure the data included was quantitative and ensuring statements were sufficiently supported with evidence. While they all agreed that this was a project that would be beneficial for students and for NASA, having those pieces of evidence and data included allowed for a more thorough presentation of what the project is attempting to accomplish and how exactly it will do that. In response, many diagrams, referenced studies, and specific calculations were added to clarify the project's methodology and lend further credibility.

Reviewers noted that in addition to MEEPsat having the potential to make an impact on climate change, it would also represent an important opportunity to bring educational benefits to students, increase awareness of UTSA's wide range of student facilities and capabilities, and open the door for diverse minority and underrepresented groups in space-related careers.

4.2 Feasibility Review

To conduct the feasibility review, panel members reviewed the proposal with a focus on likely points of failure, technical risk, project structure, budget expectations, and similar considerations to determine project feasibility. The panel members consisted of professionals from UTSA, NASA, and SwRI. Most of the specific critiques concerned the spectroscopy, power system, and testing, with comments on the project not having much room for error or redundancy. On average, the reviewers agreed that MEEPsat had an 80% chance of succeeding on the tight budget given and rated the feasibility at 4.33 out of 5 overall.

The most critical piece of feedback received in the feasibility panel concerned the selected wavelength for the experiment due to water's role in atmospheric infrared absorption. Previously, MEEPsat was set to target the 7.565 μm wavelength due to it being methane's strongest transition, with preliminary simulations showing the absorption of methane being higher than the absorption of water. However, after receiving feedback from the feasibility and merit reviewers, it was noted that the simulations did not accurately depict a water-dense atmosphere, and that the absorption of water at the target wavelength would be significant.

Instead, MEEPsat pivoted to the 2.2755 μm wavelength and included Spectraplot simulations that accounted for the concentrations of water and carbon dioxide in the atmosphere. While methane did not absorb as much light at this wavelength, it resided in an atmospheric window with no water or carbon dioxide absorption, ensuring complete isolation of methane emissions. The camera assembly components were appropriately switched out for equipment that would be able to detect within the 1.5–5 μm spectral range with a higher resolution.

In response to power concerns and the lack of margin for error, MEEPsat's collection ranges were re-evaluated. While the mission originally intended to monitor both polar regions, there is exponentially less permafrost in the southern hemisphere due to Antarctica being 99.5% glacial ice, as shown in Figure 9. As a result, there is very little data for MEEPsat to collect, and the only Antarctic permafrost resides along its shores, where it naturally thaws out. The original collection ranges resulted in 5.2 Gb of data per orbit at the ideal rate of 60 Hz, which was a significant amount of data for the cubesat to transmit. When combined with Antarctica not containing the features MEEPsat focuses on, this meant that half of the data would not be usable. It was determined that the southern pole does not contribute to MEEPsat's mission of investigating abrupt methane emissions.

Figure 9: Permafrost map of Antarctica demonstrating that there are no unusual or abrupt methane emissions that MEEPsat can utilize in its mission (13).

Appendix A - Technical Documentation

A.1 Payload

All of the hardware for MEEPsat's camera assembly will be commercial off-the-shelf products to ensure high-quality data collection and minimal disruption associated with technology and firmware development (Table 3).

Table 3: Main Camera Assembly Components

Component	**Manufacturer**
MWIR Camera	Teledyne FLIR
Lens	Teledyne FLIR
Spectral Filter	Spectrogon

The thermal imaging will be captured with a midwave forward-looking infrared (FLIR) camera and lens manufactured by Teledyne FLIR (Figure 10), and the specifications are listed in Table 4. It includes time stamped images, a spectral filter mount, and factory-calibrated ambient drift compensation that will be verified upon reception. The camera will be oriented with the aperture directly pointed towards Earth's surface with the assistance of the attitude control system. Since the area of interest is the most permafrost-dense region of the arctic pole, the camera will only collect data from the latitudes 60° to 70° during the data collection orbit. With a calculated orbital velocity of about 7,600 m/s and an orbital period of 91.6 minutes, MEEPsat's camera will collect data 144.68 seconds per orbit, generating a power usage of 0.362 Watt-hours when collecting data. The ideal refresh rate is 60 Hz to ensure complete capture of the polar regions at the simulated velocity, but if the ground station is not able to accommodate for the estimated 2.65 Gb of data generated, a refresh rate of 30 Hz and data size of 1.33 Gb will be utilized instead. In the event that MEEPsat is not able to transmit data, it will have 500 Gb of local storage so that data will be kept for over a week while the connection is repaired, assuming 5 data collection orbits per day.

Figure 10: A6753 MWIR Camera and respective 50mm lens from Teledyne FLIR.

Table 4: Camera Specifications

FLIR A6753 MWIR Camera (1–5 broadband option)	
Size (without lens)	226 × 102 × 109 mm
Weight	3.2 kg
Power Consumption	24V/9W
Operating Temperature Range	-20°C to 350°C
Resolution	640 × 512
Spectral Range	1.5 – 5.0 µm

The camera will use a 50 mm manual bayonet lens from FLIR that will be focused to infinity and calibrated before launch (Table 5). The camera assembly will undergo extensive thermal testing using UTSA's available crucible and freezing facilities to verify that the camera's internal thermal regulation system will be sufficient in preventing a drift in focus. It will also undergo shock testing using both UTSA and SwRI facilities to ensure all factors are accounted for. If necessary, a simple remote focus system will be implemented consisting of a servo and an arduino that will receive commands from the ground station during repositioning orbits.

Table 5: FLIR Lens Specifications

50 mm, 1-5 µm, f/2.5 Broadband FPO Manual Bayonet Lens (4218539)	
Diameter	68 mm
Weight	0.3 kg
Operating Temperature Range	–20°C to 50°C
Focal lens	50 mm

To calculate the swath of the camera, the Ground-Resolved Distance (GRD) and Ground-Sampling Distances (GSD) were calculated using Equations 1 and 2 listed below, where A is camera altitude, λ is target wavelength, D is diameter of the camera's aperture, P_x is the pixel size, and f is the focal length of the camera. The GRD, used to determine the resolution of the camera with respect to optical limitations, was found to be 48.58 m at 350 km of altitude. The GSD, which refers to the geographical distance between each pixel, was found to be 105 m per pixel at 350 km. The swath width, with an image width of 512 pixels, is 53.76 km.

$$GRD = \frac{1.22 \times A \times \lambda}{D} \tag{1}$$

$$GSD = \frac{A \times P_x}{f} \tag{2}$$

While this resolution is lower than its more expensive predecessors, it is still sufficient for methane detection. The selected lens was the only FLIR lens capable of detecting the 1.5–3 µm spectral range, which is the only range that can be used for methane detection at the atmospheric level. However, the camera does not need to capture the size or detail of the entire emission accurately to classify a hotspot as concentration is an intensive property. Methane is also lighter than air, so it will rise rather than disperse across the ground and become too diluted for detection. In addition, the camera's GRD is similar in resolution to ABoVE and PREFIRE, so while the pixel intensity may be averaged slightly, the emission absorption data will still be captured by the camera. This means MEEPsat will be able to determine the locations of smaller emissions even with a lower resolution. As a precaution, the concentration threshold was shifted to 2,000 ppm to mitigate chances of data becoming overlooked. Figure 11 demonstrates the emission data MEEPsat would pick up from an example 4.5 km methane emission.

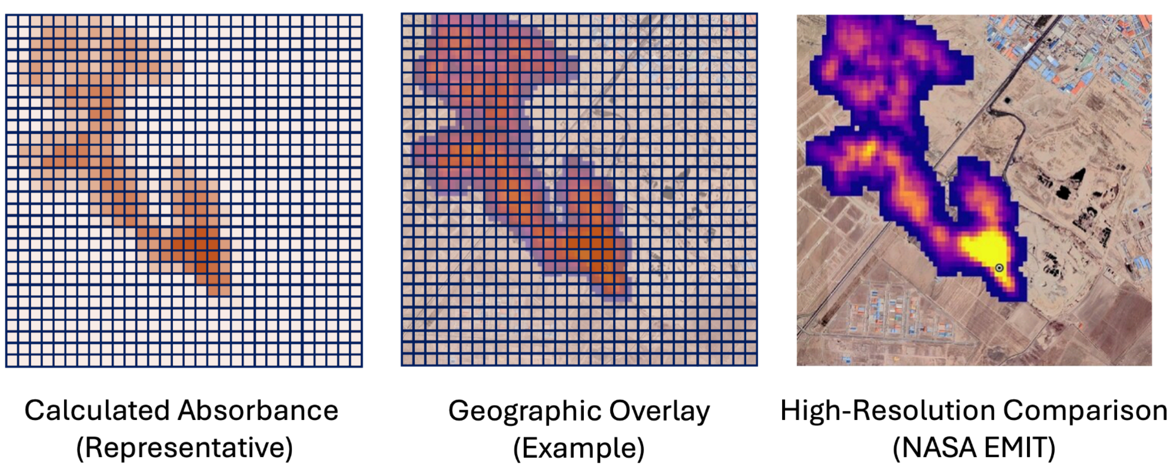

Figure 11: Sample image from NASA's EMIT satellite compared to a simulation of MEEPsat's camera detection. While EMIT's GSD is 3/5 that of MEEPsat's, MEEPsat still successfully captures the emission with little loss of information.

The spectral filter will be a bandpass filter selected for the 2.2755 (± 0.0005 µm) wavelength. It is crucial to this experiment in order to block out other emissions and isolate methane. Methane has distinct peaks in its absorption spectra at approximately 2.2755 and 2.2757 µm (Figure 12) that reside in an atmospheric infrared window, which is a small wavelength opening where terrestrial infrared emissions are not absorbed by gasses in the atmosphere. Infrared imaging also allows for data collection at any time of day since ultraviolet and visible light are outside of the camera's spectral range and have no impact on collected data.

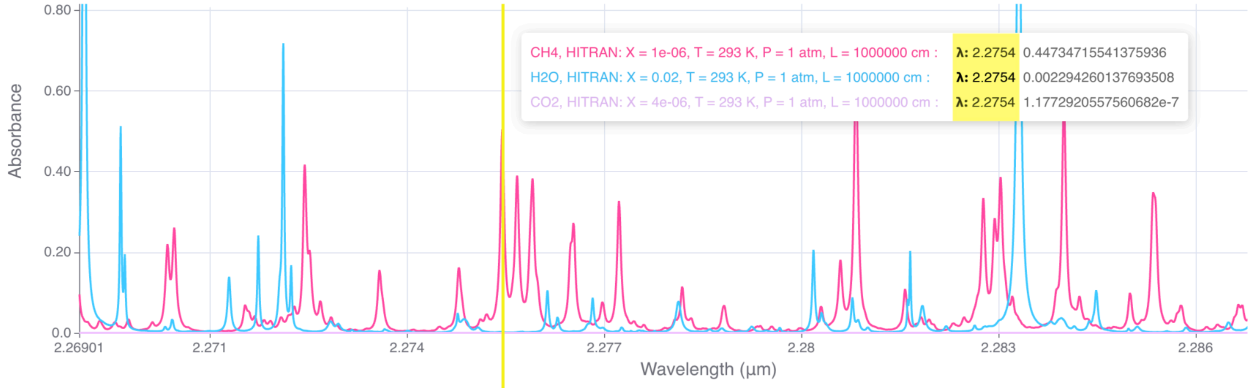

Figure 12: Atmospheric absorption spectra for CH_4, H_2O, and CO_2 for λ=2.27–2.29 µm from Spectraplot. The figure demonstrates that the target CH_4 transition wavelength at 2.2754 µm (yellow) is not absorbed by H_2O or CO_2 at all with respect to their atmospheric concentrations and distances.

The camera assembly connects to the onboard computer via GigE Vision 2.0 ethernet cable for local data storage between transmissions and downlinking. Once the images are transmitted to the ground station, a preliminary Python script will search for images containing any pixels with an intensity below its overall average. The script will then use a derivation of the Beer-Lambert equation (Equation 3) to compare the pixel intensity to the average surrounding intensity and obtain the absorption coefficient, which is directly proportional to the concentration.

$$I_1 = I_0^{-\mu x} \tag{3}$$

In this equation, I_1 represents the pixel intensity with methane, I_0 represents the pixel intensity without methane, μ is the absorption coefficient, and x is the altitude of the camera on the satellite above ground level.

If an abrupt methane emission is found, the image's timestamp can be referenced to find the estimated coordinates as simulated in the orbital path model. This data can then be analyzed at the ground station by utilizing the data from ABoVE and PREFIRE to better understand the correlation between high methane emissions and geographical position and potentially confirmed using ground or air based measurements.

A.2 Attitude Control System

In order to maintain a polar orbit, attitude control is extremely important. This will be established by the use of a magnetorquer system. A magnetorquer creates a magnetic dipole when a current runs through its structure, which then interfaces with the Earth's magnetic field and generates a torque that is used to keep the satellite position fixed.

The magnetorquer allows for the satellite to freely pivot around the local gradient of the magnetic field, and the only factors it is dependent upon is the strength of the ambient magnetic field and the current supplied to the system. Since MEEPsat will be in low earth orbit, the ambient magnetic field corresponds to the geomagnetic field, which is strong enough to generate sufficient torque for the magnetorquer system to work properly. This system will operate as long as the current is constantly supplied, which will not be an issue as there will be an on board battery pack as well as solar panels that can deliver a sufficient amount of electrical energy for the magnetorquer (Appendix A.3).

The system that is planned for use on MEEPsat is the iMTQ Magnetorquer Board provided by ISISPACE as seen in Figure 13. This consists of a board containing two torque rods and one air core torque rod, to bring the total to three actuators in the system. Three actuators allow for control over all three axes, so the satellite is able to maintain its position relative to Earth along the orbital path. Each torque rod is equipped with current sensors, and the system is equipped to detumble for up to 12U Cubesats. Since MEEPsat is only 3U, this system will be more than enough to ensure the camera is directed in such a way to enhance its observable region over the polar regions.

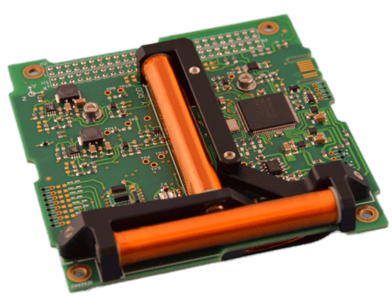

Figure 13: The iMTQ Magnetorquer Board is an off-the shelf product that will provide attitude control for MEEPsat.

A.3 Avionics

A.3.1 Power

The power subsystem consists of a triple junction 3U solar panel configuration and a six output-channel electrical power system (EPS), both manufactured by EnduroSat.

The EPS contains a battery with a storage limit of 10.2 watt-hours (Wh) and an input voltage compatible with the solar panel. The EPS contains output power buses that match the voltage requirements of all components in the payload excluding the camera and the transmitter. The camera requires 24V and will therefore require the use of a DC-DC step up converter. The transmitter can operate in a voltage range between 7V (minimum) and 20V (maximum), therefore, a DC-DC step up converter set to 12V will be utilized to ensure reliability and long-term performance. Table 6 shows the required power budget for the proposed mission.

Table 6: Power Budget

Component	Power Requirements	
	W	**V**
On-Board Processor (OBP)	0.1	5
Camera	9	24
Transmitter (reduced power state)	0.1	12
Transmitter (standby mode)	1.6	12
Transmitter (transmitting)	14	12
Attitude Determination and Control System (ADCS)	1.2	5
GPS	0.9	3.3

The solar panel is equipped with sun and temperature sensors and will be connected to the attitude determination and control system (ADCS) to orient the panels at the ideal incidence angle. Assuming a perpendicular sunlight incidence angle, the solar panel can generate 8.4 W in low earth atmosphere. In the 91.6-minute orbit, 54.96 minutes will be sun facing and 36.64 minutes will be eclipsed, allowing for a power generation of 7.7 Wh. Due to the relatively low power generation and relatively high-power consumption, different operational modes will be implemented during the mission. Table 7 shows the different modes of operation and the on-time (min) per orbit, and Table 8 shows the power consumption per mode. The power consumption for each mode includes the power used to reposition the satellite for the respective mode of operation.

Table 7: Payload On-Time (min) per Mode of Operation

Mode	**Payload Component**						
	OBP	EPS	Antenna (receiving)	Transmitting	GPS	Camera	ADCS
Power Save	36.64	36.64	36.64	5	2	0	0
Charging (sunlight)	54.96	54.96	54.96	5	2	0	54.96
Imaging	10	10	10	5	10	4.82	10
Data Transfer	10	10	10	10	5	0	10

Table 8: Energy Consumption of Operational Modes

Mode	**Energy Consumption (Wh)**
Power Save	1.25
Charging	2.38
Imaging	2.25
Data Transfer	2.625

The Power Save mode will occur only when MEEPsat is in the eclipsed portion of its orbit and power will only be supplied to essential components. The charging mode of operation will occur during the sunlit portion of orbit with power being supplied to essential components as well as the ADCS to ensure maximum power generation from the solar panels. During the imaging mode, the camera will be oriented to the point of interest and the imaging process will occur. The final mode of operation is the data transfer mode and will require the most amount of power consumption.

After MEEPsat's deployment, the first modes of operation will be the Power Save and Charging modes. Taking into consideration the energy generated and consumed during these modes, MEEPsat will launch with the battery charged to 6.13 Wh (60%) to ensure the battery is fully charged after the initial orbit. MEEPsat will then cycle through different modes of operation, allowing for the batteries to be charged between imaging and data transfers.

This exposure ratio provides a balance between power generation and cooling opportunities, ensuring the satellite remains operational and efficient throughout its mission. By maintaining a balance between sunlight exposure and shadow periods, the proposed orbital configuration supports the satellite's energy needs while preventing thermal overload. Since there is no onboard cooling system, MEEPsat relies on sinking the heat in the chassis to passively cool through radiation with the help of high-emissivity coatings, MLI blankets (Multi-Layer Insulation), and aluminum spreaders.

The power consumption of the magnetorquers should be relatively low with EXA MT01. The minimum amount of power that will be needed for this exchange in retargeting is around 0.2 watts. Although magnetorquers require constant power because they change the orientation of the satellite due to changes in Earth's magnetic field, in a LEO this issue will be less of a factor. In addition to orienting the satellite to face the regions of Earth we want to observe, we will also be able to orient the satellite towards the Sun for charging purposes to account for the energy used in this maneuver.

A.3.2 Communications

For this project, the bandwidth chosen is considered to be a commercialized satellite bandwidth. For the uplink and downlink, MEEPsat will communicate in the S-Band. This is highly beneficial owing to the open-source and versatile nature of the communication band. This bandwidth will allow the satellite to communicate with the ground station for low-earth orbit and will reduce interference because of this bandwidth's ability to communicate at very long ranges and versatility when it comes to data processing.

ISISPACE is a well-known company that, among many other things, manufactures electronics and telecommunication systems for Cubesats. This company manufactures not only antennas but also transmitters that can primarily be used in amateur satellite systems as illustrated in Figure 14.

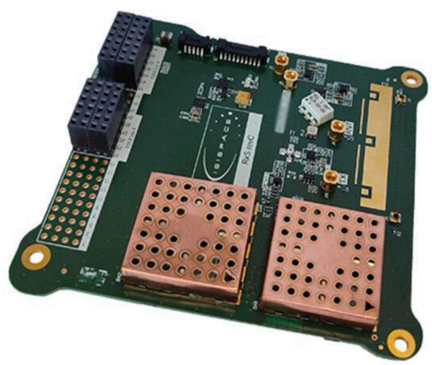

Figure 14: S-Band High Data Rate Transmitter from ISISPACE. This transmitter will provide the MEEPsat with a downlink signal communication of up to 4.3 Mbps.

The S-band patch antenna system is formally named "ISIS-QMS-TPL-0045." This antenna system is not only made for the desired uplink and downlink bandwidth, but is also lightweight, power efficient, and open source.

During the research phase of the communications section, it was decided that a patch antenna in the s-band would best benefit our satellite system since AWS (Amazon Web Services) ground station only provides its services in the s-band. Not only is this antenna system just beneficial to the telecommunications networking system on the ground, but it's highly beneficial instrumentally to MEEPsat. Antenna characteristics such as: circular polarization and high power beam width give the Cubesat wider communication beams and because of the circular polarization the CubeSats orientation is completely independent of the ground antenna's orientation. This means that in comparison to all the other offered systems by ISISPACE this system has less of a probability of inducing interference during the uplink/downlink transfer communication process phase of this project.

The transmitter is a curtail part of the satellite because it is the component of the telecommunications system that processes the signals from MEEPsat to the ground station. In this sense, the transmitter would do the job of downlinking signals. The transmitter chosen for this project was the S-Band High Data Rate Transmitter. It is not only in the desired bandwidth but has CCSDS (Consultative Committee for Space Data Systems) capabilities, which allows for this transmitter to be compatible with a wide range of ground station networking systems.

The proposed primary plan for ground station communication is the AWS ground station in Ohio. This company is a commercial company with a variety of networks not only within the United States but across the world. This ground station primarily works within the S bandwidth (sometimes X-bandwidth for downlinks) and will suffice as a communications system locations where the collected data from MEEPsat will be communicated from MEEPsat to the ground station using a SDR company that is compatible with AWS's networking services to allow not only faster transmission rates but little to no interference. From this downlink communication the data from MEEPsat's raw data will be uploaded into an iCloud storage system provided by AWS. From this iCloud storage system the raw data can be uploaded into a personal computer. The AWS ground station hugely benefits this project because of the fast data transfer rates, budget, and wide bandwidth.

If the primary plan for the ground station communication is not viable, the secondary proposed plan will be a student-led communications team. This communications team will be the first established University of Texas at San Antonio ground station. This will consist of a software-compatible SDR (software-defined radio) communication system on a personal computer, a low-noise amplifier, and one more antenna on the ground. This is a cheaper method of ground communication, but it will also require satellite tracking system software and a decoding software of personal choice.

A.4 Structure and Mass Budget

Table 9 presents the mass budget for the 3U MEEPsat mission. Of the 6.0 kg mass goal for a 3U design, 4.625 kg is allocated to the main systems, leaving 1.375 kg available for miscellaneous components, such as electronic connections and structural fasteners, as well as room for error with the component dimensions.

Table 9: Mass Budget

Component	**Mass**
IR Camera	3.200 kg
Camera Lens	0.3 kg
Transceiver	0.094 kg
Antenna	0.085 kg
Onboard Computer	0.130 kg
Batteries (X2)	0.230 kg
Solar Panels	0.146 kg
Structure	0.340 kg
External Structure Plates (X3)	0.100 kg
TOTAL	4.625 kg

The satellite structure will house all communication, data collection, and electronic components internally. External components, such as solar panels and the antenna, will be positioned in designated locations to maximize mission efficiency. Protecting internal components is crucial due to thermal operational limitations and the need to maintain component efficiency. Securing the IR camera and data collection components is a priority, as the stability of these systems is essential for accurate and consistent data collection during orbit.

To maintain structural stability against temperature effects, vibrations, and corrosion, material selection is crucial based on the parameters of the MEEPsat environment during both orbit and launch. The primary environmental condition considered was thermal expansion due to fluctuating temperatures in orbit. An expected temperature change of 250°C was used as a baseline for material selection. In alignment with the CubeSat Design Specification, Aluminum 6082 will be used as the main structural material for MEEPsat. To address corrosion due to radiation exposure, the material will be anodized in accordance with rail connection standards. Anodizing process will be optimized to mitigate fitting issues that could occur from the addition of aluminum oxide coating

Following the material selection, transportation and deployment parameters for MEEPsat were considered. The dimensions for the 3U design are 10 x 10 x 34.05 cm, which fit within the Orbital Deployers. A rail deployment system was chosen as it allows MEEPsat to be moved into the desired orbital altitude. The design of MEEPsat will feature anodized Aluminum 6082 rails as the contact points between the satellite and the deployer. To maintain volume restrictions, the orientation of internal components is a top priority. This preliminary design is subject to modifications during the physical implementation of components. With this approach, the center of gravity will fall within the required range: as specified by the CubeSat Design Specification, the center of gravity for a 3U design must be within the axis range: for the X and Y axes, it is within ±2 cm, and for the Z axis, it is within ±7 cm of the geometric center.

Structural testing requirements were considered when selecting the structure design. As specified by the CubeSat Design Specification, random vibration, thermal vacuum bakeout, and shock testing must be considered. It also accommodates the recommended deployment switches and separation spring locations specified by the CubeSat Design Specification. Figure 15 shows a model of the CAD design for a typical 3U structure, illustrating how it fits within the volume parameters.

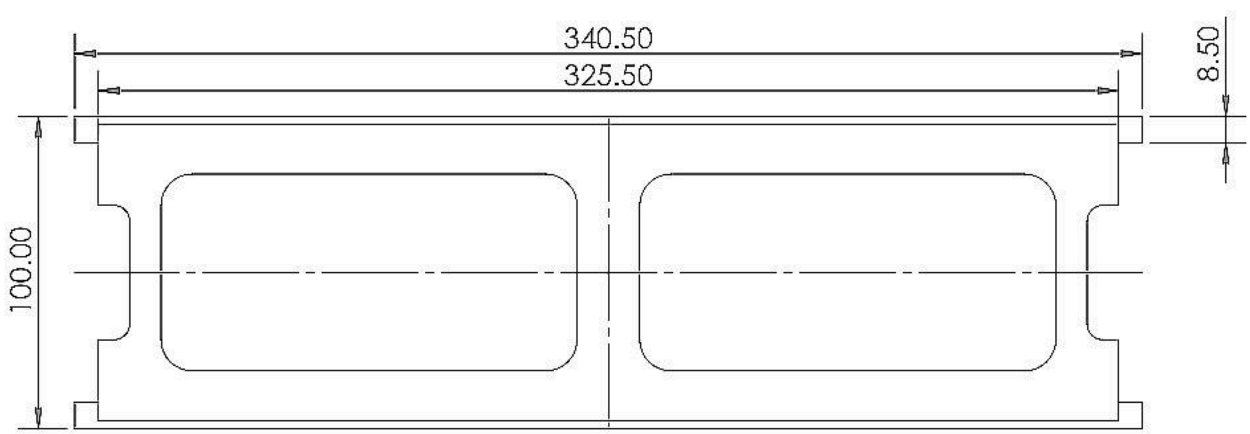

Figure 15: Cubesat Geometry in millimeters

As part of MEEPsat's development schedule, a full complement of thermal, vibration, and vacuum testing will be implemented in accordance with The Launch Services Program Requirements Document (LSP-REQ-317.01B) using UTSA and SwRI's extreme environment testing facilities.

MEEPsat's external frame, internal supports, and paneling will be manufactured in-house at UTSA, as it provides a large amount of in-house facilities and resources that will be leveraged in this project. A summarized list is provided below.

High performance computing: As needed, the students in this project have access to two sources of state-of-the-art research computing resources alongside lab-based desktop systems: "Arc", which is a UTSA supported on-campus High Performance Computer research cluster that is available free to UTSA faculty and students, and "Lonestar", a UT System-supported HPC Cluster located at the Texas Advanced Computer Center (TACC) in Austin, TX.

Additive manufacturing: Multiple additive technologies are available for the fabrication of MEEPsat components and parts. These include Hyrel System 30M 3D printer with multi-material printing capabilities including polymers, ceramics, and hydrogels; FormLabs Form 3+ SLA 3D printers; and a Renishaw AM 400 metal printer. The metal 3D printer can print SS316, titanium, Inconel, and copper.

Dynamic characterization and vibration testing: UTSA has many facilities to conduct vibration tests at controllable frequencies. This equipment includes: high frequency dual purpose shaker 2025E-HF and the power amplifier SmartAmp 2100E21 from The Modal Shop, Agilent 33120A Function / Arbitrary wave generators, accelerometers, NI DAQ systems, and multiple Tektronix digital oscilloscopes. A Polytec Scanning Vibrometer has also recently been acquired to measure the response of the MEEPsat structure to vibration inputs.

Machine Shop: UTSA's machine shops (located within the UTSA Makerspace) are available for fabrication and modification of MEEPsat components as needed. The shops are equipped with manual and CNC milling machines, lathes, saws, grinders, sheet metal fabrication tools, welding/cutting equipment, inspection equipment, and include full-time staff to train and assist students with educational and research projects.

Keeping the manufacturing in-house will allow for better optimization of parts, reduce costs and manufacturing timelines, as well as highlight the capabilities of the technology UTSA has to offer and the skills of the students who will use them to their full potential.

Appendix B - Additional Documentation

B.1 Project Members

Key Project Personnel (Resumes for the following will be attached at end of document):

- Smruthi Shashidhar, Project Co-Lead
- Grace Zimmer, Project Co-Lead, Payload Lead
- Dr. Christopher Combs, Faculty Advisor
- Dr. Daniel I. Pineda, Faculty Advisor

Merit Review Panel Members:

- Chris Packham, Professor of Astronomy at UTSA with a P.h.D. in Astrophysics
- Pippa Molyneux, Lead Planetary scientist at SwRI with a P.h.D. in Space Science
- Kathya Zamora Garcia, Mars Science Laboratory Project Manager at NASA Jet Propulsion Laboratory with a M.S. in Engineering Management/B.S. in Aeronautical Engineering
- Robert W. Ebert, Lead Adjoint Professor of Space Physics at UTSA/Assistant Director of the Space Research Division at SwRI with a P.h.D. in Space Physics
- Kristen E Brown, Assistant Professor of Civil and Environmental Engineering at UTSA with a P.h.D. in Environmental Engineering

Feasibility Review Panel Members:

- Joe Hernandez-McCloskey, NASA Space Technology Graduate Research Opportunity Fellow and P.h.D. Candidate in Mechanical Engineering at UTSA with a B.S. in Aerospace Engineering
- Kyle Fetter, P.h.D. Candidate in Mechanical Engineering at UTSA with a M.S. in Aerospace Engineering/B.S. in Mechanical Engineering
- Jahsiah Toby, Propulsion Design Engineer at Relativity Space with a M.S./B.S. in Mechanical Engineering
- Todd Veach, Manager of Research and Design at SwRI with a P.h.D in Physics
    - Participated in feasibility review discussion, but did not fill out a questionnaire

B.2 Compliance Documentation

B.2.1 International Amateur Radio Union (IARU)

Satellite Frequency Coordination Request will be submitted to IARU once proposal is approved.

B.2.2 Federal Communications Commission (FCC)

Notice of Intent to Operate will be submitted to the FCC with the coordinated frequency and emission designation, after coordination with the International Amatuer Radio Union (IARU) and once proposal is approved.

B.2.3 Launch Services Program Requirements

Cubesat design specifications were made in compliance with this document, and includes factors to account for a full complement of thermal, vibrational, and vacuum testing.

B.3 CSLI Compliance

MEEPsat's mission plan follows NASA's 2022 Strategic Plan and is directly applicable to objectives 1.1, 1.3, 3.1, 4.1, and 4.3. Specifically, MEEPset's mission objectives are aimed at developing a relationship between the locations and severity of methane emissions as it relates to thawing permafrost on Earth, which will provide NASA with important data on greenhouse gas emission factors and contribute to a better understanding of Earth's evolving climate.

NASA's strategic objective 1.1 specifically outlines the need for robust climate observations and research, so as to obtain data that is "necessary to understand, model, monitor, and ultimately predict climate and environmental change." SmallSats and CubeSats are increasingly becoming a larger part of this vision, as they provide a more cost-effective foundation for many modern scientific studies. The proposed data to be collected, focused on methane emissions, will aid in our understanding of greenhouse gases in Earth's atmosphere and how they are related to the ancient geology of Earth's permafrost. We envision that the data collected during the mission of MEEPsat will be shared with both academic as well as government stakeholders through online repositories, conferences, and journal manuscripts, which is relevant to NASA's strategic objective 1.3, which describes the need to ensure that NASA's science data are accessible to all and produce practical benefits to society.

Additionally, NASA's strategic objective 3.1 specifically outlines the need for innovating and advancing transformational space technologies; with the recent development and proliferation of mid-wave infrared photonics and optoelectronics, there are more opportunities than ever to detect and measure a variety of greenhouse gases relevant to energy processes, atmospheric chemistry, and ancient geological activity. With a mid-infrared sensor detecting methane on the Mars Curiosity Rover, and the mid-infrared images presently being collected by the James Webb Space Telescope, scientists have more high-quality spectral information than ever before to better understand the evolution of the universe, our solar system, and Earth. MEEPsat's use of the mid-wave infrared region of the electromagnetic spectrum fits within this transformational sensing technology boom that is increasingly relevant to NASA's space science and technology goals.

Importantly and uniquely, MEEPsat's goals include building up a robust space science and technology research and engineering program at The University of Texas at San Antonio, which directly applies to NASA's strategic objective 4.1. This objective is concerned with attracting and developing a talented and diverse workforce. As more commercial entrants become involved in the development and deployment of CubeSats and SmallSats, they will need a trained workforce to accomplish their goals and grow NASA's capabilities in space science. As mentioned, UTSA is classified as a minority-serving institution (MSI), and its student population comprises multiple students from underrepresented and historically-excluded backgrounds needed to diversify the space science and technology workforce. It is important to note that UTSA's classification as an MSI is defined by its undergraduate student population, with >50% of the student propulsion identifying as Black or Latinx. Furthermore, at least 47% of UTSA's Ph.D. graduates identify as Black or Latinx, representing a unique opportunity to support and promote diversity in STEM as it relates to the space science and technology workforce development in the growing amount of emerging roles that require an M.S. or Ph.D. to successfully advance U.S. research and development in this sector. Moreover, UTSA is in the early years of a focused investment in space science and technology, which includes hiring multiple new tenure-track research faculty, developing new degree programs including M.S, Ph.D., and undergraduate certificates in aerospace engineering, and developing of new courses such as astrodynamics, propulsion, compressible flow, and aerodynamics. Given the nature of the proposed MEEPsat project in relation to this space science and technology initiative, UTSA is uniquely positioned to integrate projects and data collected by MEEPsat into the curricula of UTSA courses and leverage in-house UTSA facilities to enable student participation in the manufacturing and fabrication of MEEPsat components, promoting a sustainable program wherein UTSA students graduate with the knowledge and skills to continue development of satellites and space technology when they enter the workforce.

Lastly, the MEEPsat project team—which includes the participation of three distinct student organizations at UTSA focused on aerospace and space science—is well-positioned to engage K–12, community college transfer, and university students through their existing robust outreach network across the greater San Antonio Metropolitan Area and South Texas, directly relevant to NASA's strategic objective 4.3, Build the Next Generation of Explorers. Independently, AIAA, ARC, and SPS develop their own design-build-test projects (e.g., such as participation in NASA Student Launch and Spaceport America Cup), and have historically engaged with elementary, middle, and high schools as part of their organizational missions. It is envisioned that these networks and project-based activities will be leveraged in the proposed MEEPsat effort to enhance UTSA's capacity to build additional support for K–12 educators working with UTSA, out-of-school learning experiences for students participating in the projects, and for collaborations with nearby institutions such as Southwest Research Institute (SwRI) in space science research initiatives.

B.4 Review Panel Responses

B.4.1 Overall Compliance Responses

All panel reviewers were given the same overall compliance questionnaire inspired by the provided rubric to fully assess MEEPsat's relevance to NASA and space technology. Questions and responses are as follows:

1. <u>Does the proposal describe a project with clear, meaningful student leadership in conducting management, design, analysis, development, construction, and operation? The proposal must describe the specific ways in which students are key to project success.</u>
    - yes
    - Yes it does. This proposal describes a great learning opportunity for the students involved. Developing the structure and experimental design of the project will greatly improve their academic understanding of mechanical, electrical, and optical design.
    - Yes, the proposal mentions how this is entirely student managed (outside of advisors) and that students will be in charge / performing all aspects of the operation, even construction.
    - Yes, but I didn't follow the approach for the actual Methane detection well. Some kind of methodology, optical design etc, I think would be very helpful. How will the methane be quantitatively measured, as compared to just background 7.66um emission for example? Some requirements on the filter etc.
    - I suggest that some top level requirements are needed FIRST, that then flow down to the design you made.

- The proposal lists the student leads of each sub-system and of the project as a whole. There is also some discussion of previously weekly meetings that were used to develop the current concept, but it isn't clear if the project leads to a plan to continue with this meeting cadence through the duration of mission design, development and operation. There's no schedule in the version of the proposal I saw, and no information about the number of students involved, if/when more students might be recruited to the project, and whether the leads expect to remain in their positions for the full mission (the proposal doesn't say when they expect to graduate), which makes it difficult to assess student engagement throughout the lifetime of the project. The proposal notes that the project provides opportunities to engage a diverse group of students into the space sector. There's a more detailed discussion of student benefits in Appendix B.4. I suggest moving that to the main text since you are currently under the 15-page limit.
- Yes

2. Does the proposal exhibit potential to advance a scientific measurement, possibly using a new or enabling technology, influenced by the NASA Science Plan?
   - yes
   - I believe it does, yes. Although, I am unfamiliar with the specifics of the NASA Science Plan.
   - Yes, the NASA Science Plan lists Climate Change as a key area for which this proposal targets. Namely focusing on ice change processes.
   - Yes, I think so, but see comments above.
   - Yes, the project has the potential to provide new measurements of localized methane emissions to determine the contribution of thawing permafrost to climate change. The proposal describes how the project addresses specific objectives in the NASA 2022 Strategic Plan. However, this information is currently only in the abstract and appendices. I recommend also including some discussion of relevance to the Strategic Plan in the main proposal body since this is an important aspect of the proposal evaluation.
   - Yes
   - While the measurements are obtained from an off-the-shelf IR camera, its application towards mapping methane emissions in the Earth's polar regions has the potential to advance our understanding of atmospheric heating in that region.
   - The proposal shows a strong plan to fill a gap in the scientific knowledge by taking measurements that are difficult to do from a ground based mission to to travel and geographical issues.

3. Does the proposal demonstrate that the project can enhance future missions, reveal a flaw in a potentially enhancing technology, or otherwise impact the trade space for enhancing technologies?
    - yes
    - For the proposed problem of methane production at the polar regions, this seems like a reasonable and novel idea using an infrared camera and absorption spectroscopy.
    - Yes, the proposal mentions supporting other experiments on a larger scale, namely ABoVE and PREFIRE. This proposal aims to support ABoVE with additional experimental data which can be used to influence where more direct in-situ analyses should be conducted (via PREFIRE or something similar).
    - I think the area of missing science space could be more clearly spelt out.
    - MEEPsat has the potential to enhance future climate missions, such as PREFIRE, by obtaining complementary measurements that allow for more detailed climate models.
    - Yes
    - The proposal could enhance future missions aimed at targeting areas of enhanced methane emissions in the Earth's polar regions.
    - I expect to see continued interest in the data collection and would expect the data collected from this mission to contribute to planning for future projects.

4. Does the proposal demonstrate that the CubeSat investigation provides benefits to NASA by addressing one or more of the goals and objectives of the 2022 NASA Strategic Plan, NASA Strategy for STEM Engagement, NASA Science Plan, and/or Science or Technology Areas of Interest based on the selected focus area(s)?
    - yes
    - I am unfamiliar with these specific focus areas, but judging by the relevant missions section, I would agree that this research topic is justified.
    - Yes, the proposal focuses on further understanding the driving mechanisms behind rapid climate change that have recently been attributed to the melting of permafrost. This is relevant to the 2022 NASA Strategic Plan objective for understanding the Earth system and its climate and NASA Science Plan objective to understand Climate Variability and Change.
    - Yes, I think so.
    - Yes, the proposal describes relevance to objectives 1.1, 1.3, 3.1, 4.1, and 4.3 of the 2022 NASA Strategic Plan, which cover science, technology, and STEM engagement topics. However, this information is almost entirely contained within an appendix. It would be great to highlight this relevance in the main proposal text if possible.
    - Yes

- The proposal states that it is relevant to several strategic objectives of the 2022 NASA Strategic Plan.
- Yes, the proposal explicitly references alignment with Strategic Objectives 1.1, 1.3, 3.1, 4.1, and 4.3

5. Do you believe this satellite will provide the aforementioned benefits to NASA and its objectives?
    - definitely can after a few details worked out--confirm if the effects of ADCS power-off has potential to compromise science mission and move forward with either increased battery capacity or mitigation plan should proper orientation not be achieved for the entire estimated periods of time.
    - Yes I do.
    - Yes
    - Yes.
    - Yes. In particular, UTSA as a minority serving institution has a lot of potential for training a diverse space sector workforce. They also have access to the appropriate facilities and staff to address the science and technology objectives of the project.
    - In conjunction with other data it can provide a benefit.
    - Yes, the science measurements provided by this satellite along with the training of students during this project will greatly benefit NASA and its objectives.
    - Yes, this satellite will help train the future workforce, provide necessary data for many other research projects, and enhance the [response was cut off in the form]

B.4.2 Merit Review Responses

While ratings were requested for each question, not all reviewers included one. As a result, the individual scores may be inaccurate as there were only 1-2 ratings given. The merit review supporting questionnaire and responses are as follows:

1. What factors did you consider in assessing the project's merit?
    - How convinced I was by the proposal. 7
    - Potential educational benefits to students, potential science return of the proposed mission
    - Process and thought description and detail. Did they really think things through?
    - The project's science goal and the technical investigation described in the project to address that goal.
    - feasibility and scientific benefit

2. <u>Do you believe this experiment will be effective for analyzing melting permafrost and the effects of global warming? Average rating: 6.5/10</u>
    - Yes, but it could be shown from start to finish, with requirements and how it will actually be measured. 7
    - Potentially. However, some details of the experiment were unclear to me, which makes it difficult to assess how effective it will be. For example, have you already identified a filter that can provide the sensitivity you need at 7.66 microns? I also wasn't sure if you plan to roll the spacecraft to observe the latitudes from 75 deg to the pole, or if you plan to use a camera with a very wide field of view to observe large regions simultaneously. 6
    - I believe the experiment, if conducted as described in the proposal, can be effective in identifying regions of methane enhancements over wide swaths of Earth's polar region. This would provide data for identifying regions of permafrost melting in that region.
    - yes
    - [the fifth reviewer did not respond]

3. <u>Do you believe this experiment could make an impact on the current understanding of global warming? Average rating: 8/10.</u>
    - Yes. 8
    - Yes, if successful the experiment could lead to a better understanding of the amount of methane being released into the atmosphere, allowing for more accurate climate models. 8
    - Can contribute to the understanding, yes.
    - I believe that this experiment could demonstrate that mapping regions of methane emissions over wide swaths of Earth's polar region is possible. To better understand the effects of global warming, the data and maps generated from these observations would need to be incorporated into models which have been developed outside of this project.
    - yes

B.4.3 Feasibility Review Responses

1. <u>What factors did you consider when assessing feasibility?</u>
    - Does spacecraft stay online? Can it maintain the required orbit and orientation? What spectral line is targeted for methane? Can methane be seen from space without atmospheric interference? How to mitigate other sources of radiation?
    - Overall the project seems actively doable from my perspective and understanding into absorption spectroscopy and real-time concentration measurements. For this

case the feasibility of this project relies greatly on the students involved, the timeline in which the project is due, and the resources at the team's disposal.
- Effectiveness of the measurement technique, considerations for propulsive environment, material compatibility for space environment

2. <u>What are some technical risks you foresee with this project? What are the most likely points of failure?</u>
   - Largest technical risk/likely point of failure at the moment is cutting power to attitude control system during data transfer operation--how can you confirm the spacecraft won't tumble around and take a long time to get back on track, which would affect the charging period and thus the operation of the next cycle and repeating? either further analysis needed to validate this strategy or larger battery needed (latter is erring on safer side). Thermal protection system--thermal analysis (calculation or FEA) needed to prove the method of thermal management is sufficient to keep the electronics within their required operational temps
   - Speaking from my expertise I would say the greatest point of failure in this project is in the avionics and control system. Although, a major focus for this project is the payload for which the scientific rigor is great and should not be underestimated in the work required to finish the project.
   - Power system design and structural/environmental testing. Alignment of the infrared camera will likely shift due to vibrations from the launch vehicle, probable that the camera images a different location than anticipated.

3. <u>What would you estimate is the probability of success for this project?</u>
   - 80% the science part is solid but the spacecraft engineering needs a little more thought in specific areas to make sure the science mission is pulled off always
   - 75% due to the scope of the project and the required expertise of the students needed to complete the project.
   - 85% Would like to see additional support on considerations for launch/deployment outside nominal operations of proposal.

4. <u>How would you rate the organizational structure of the project?</u>
   - 10
   - Good. Fairly well organized.
   - 95% strong advisor team and smart organization of project leads. Schedule estimates should be depicted.

5. Do you believe there is enough financial support for this project?
    - seems fair, but it appears the components are priced on a unit basis--should any system fail in testing, extra for breathing room would be nice, but I am sure this is factored into the unit costs quoted. also don't forget the cost of fasteners.
    - I think that the budget is a good start, however it doesn't allow much slip for unexpected costs in the design, manufacturing, and shipping. Would like to see another 10% added to the budget to allow for this.
    - Yes, I believe there is enough funding to develop the structure, however additional funding for development and redundancies would be a nice safety net.

B.5 Financial Letters of Support

To date, the MEEPsat team has secured commitments of $5,000 from the UTSA Department of Mechanical, Aerospace, and Industrial Engineering, $5,000 from the UTSA Klesse College of Engineering and Integrated Design, $10,000 from the UTSA VP Office of Research, $2,000 from the UTSA Department of Physics & Astronomy, and $15,000 in estimated equipment donations, resulting in a total commitment of $35,000 towards the project. While this commitment meets the project budget for materials, additional resources and in-kind contributions will be sought as needed for fabrication and testing services, backup components and hardware, as well as tooling or manufacturing resources needed to build and assemble MEEPsat. The letters stating these commitments will be attached at the end of the document.

Appendix C - References

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