

**Mission Feasibility Study for a Venus Orbiting CubeSat.** M. Regina A. Moreno (mapodaca@mit.edu)<sup>1</sup> and Cadence Payne (cbpayne@mit.edu)<sup>1</sup>, <sup>1</sup> Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139

**Introduction:** A recent Nature publication by Greaves et. al (2021) outlines the unusual detection of traces of Phosphine gas in the venusian atmosphere, a signature that is typically a strong indicator of life in Earth-like conditions. This discovery has spiked interest in further and more detailed studies of the venusian atmosphere. Despite fascinating atmospheric profiles, Venus remains largely under-surveyed and under-visited, particularly in comparison with Mars. Nonetheless, NASA has recently demonstrated increased interest in Venus, approving two new missions to the planet expected to launch between 2028 and 2030. Unfortunately, medium-to-large scale missions (e.g., 300 - 5000 kg), due to their long development timelines and high costs, tend to prioritize scientific goals that are not high-risk or require special mission constraints. This slows the development of the field, limits creativity, and raises the financial bar to inaccessible levels, removing the competitive edge for smaller research institutions for grant applications. The game changer for Earth Observation missions becoming more accessible was the development of CubeSats. A new CubeSat mission to Venus would not only help further our understanding of this planet, but will challenge the interplanetary compatibility of the CubeSat form factor, a boundary crossed only once before by the Mars Cube One mission. We propose an investigation of a mission concept, including an analysis of mission feasibility and survivability, for a Venus orbiting CubeSat.

**Mission Concept:** The representative mission concept involves a student-led 12U (20 x 20 x 30 cm<sup>3</sup>) CubeSat that will be the first small satellite to orbit and survey the venusian atmosphere. This CubeSat would take advantage of a rideshare opportunity as a secondary payload to NASA Goddard's DAVINCI Mission to Venus in the year 2029 or NASA JPL's VERITAS Mission to Venus in the year 2028. The proposed concept has three main objectives. The first is to serve as a technology demonstration for addressing the feasibility of using the CubeSat form factor for Venus and other interplanetary missions. The second is to demonstrate an interplanetary CubeSat communications relay for transmitting science data from deep space to Earth ground stations. Lastly, the proposed CubeSat's science payload will provide complementary data products to those being gathered by the primary mission.

Our study will determine which spacecraft subsystems will be suitable for use of commercial-off-the-shelf components, and which will require modifications for interplanetary compatibility. Operations of the CubeSat will consider collaboration possibilities that are being explored with both of the NASA Venus teams.

Further, we intend to investigate compatibility with NASA's Deep Space Network to demonstrate the CubeSat's communication relay.

#### **Interplanetary CubeSat Qualification:**

With the exception of NASA JPL's Mars Cube One (MarCO) and the lunar CubeSat payloads onboard Artemis 1, few opportunities have taken advantage of the CubeSat form factor for interplanetary applications [1]. This work will consider the unique challenges and design requirements for interplanetary CubeSat missions such as use of a propulsion system, radiation hardened components, and powerful communication systems that aren't necessarily pertinent for traditional placement in Low-Earth Orbit [1]. To investigate the proposed mission concept, we will perform a set of studies and analyses to both inform the CubeSat design and prove feasible use of this form for an interplanetary mission. Steps include forming a set of requirements for satisfying mission and science operations informed by legacy interplanetary CubeSat missions, identifying mission compatibility with use of Commercial-off-the-shelf hardware for cost reduction, power analysis and power system sizing, orbital trajectory analysis for informing propulsion requirements, developing communications link budgets for commercially available radios and ground systems, and initiating data volume estimates given our intended science payload. Lastly, we will initiate the risk mitigation and analysis process to further inform design constraints for ensuring CubeSat survival in the harsh interplanetary, Venus, and solar radiation field environments.

**Utility of Miniaturized Payloads.** Full scale missions to Venus are costly (e.g. Mariner 2 cost \$554 million USD) since they require dedicated launches. Thus, large-scale, dedicated missions to Venus have been scarce and continuous sampling of the planet has only been enabled by flybys from other missions. By comparison, the launch and development of small satellites are significantly less expensive (~\$4 to \$10 million USD including launch costs). Additionally, small satellites are resource constrained, and thus drive the miniaturization of payloads that are small in Size, Weight, and Power (SWAP). These payloads have only been made possible by the miniaturization of technology that continues to enable high-fidelity measurements. Our proposed work will demonstrate CubeSat interface compatibility (power, data volume/storage, mechanical, etc.) with a miniaturized mass

spectrometer capable of sampling and surviving the venusian atmospheric environment.

**Preliminary Science Targets:** The science payload will survey the venusian atmosphere via a mass-spectrometer, preliminarily targeting measurements of abundant and trace gas composition in the stratosphere (50 - 70 km). This instrument will help better characterize the diverse set of atmospheric gasses across varying geographical regions and potentially seasonal or other short-scale (days to months) time variations. Larger missions, such as NASA's DAVINCI are limiting observations to characterize a target region, where a CubeSat orbiter could both supply supplementary data for their mission's target, as well as provide context for gas composition in the venusian atmospheric system more broadly. The science objective of this mission addresses the need to further understand the chemical makeup of the atmosphere and how it varies with time [4]. Given our proposed orbiter concept, the CubeSat can study the upper atmosphere to help inform understanding on solar contributions to Venusian atmospheric loss.

#### **Communications Relay Demonstration:**

As a secondary mission objective, we propose demonstration of use of a CubeSat communications relay for future Venus probes and landers. Enabling a dedicated relay that provides a link from the Venus sampling instruments (during descent and/or landing), to the Venus orbit, and back to Earth provides a buffer between the surveying mission and Earth ground stations. The thickness of the venusian atmosphere demands high-powered communication links that are difficult to close from within the atmosphere to NASA's deep space network. Enabling a low-cost, CubeSat-based relay established in-orbit around Venus can potentially reduce power requirements, latency, and data blackouts from the sampling instruments.

**Potential Impact:** This CubeSat mission has three main fields of impact: planetary science and demonstration of a Venus-orbiting CubeSat, climate change awareness, and social impact. In-situ techniques are the future of atmospheric science since they can supplement the data captured by remote sensing efforts. By proposing a low-cost platform to host a dedicated planetary surveying instrument, such as a CubeSat, this project opens the doors for academic and smaller budget research institutions to enter the field of planetary science. Additionally, the scientific impact of further studying Phosphine to determine its validity as a life indicator will address a controversial hot topic using a low-cost, low-risk mission.

The climate change awareness component of the mission will be done via integration of a traditionally excluded field in space exploration: art. The concept involves organizing a nationwide competition where people will be asked to create an art piece that does not interfere with the other mission objectives, but most importantly, inspires people on Earth to take action towards undoing the damage we have done to our home planet. This art piece will be an engraving on the CubeSat to minimize space and weight added.

The third objective is to demonstrate social impact by purposely building collaboration opportunities with faculty and students from Historically Black Colleges and Universities (HBCU). As we push the boundaries of our knowledge and technology, it is important to make sure that everyone is represented in these efforts. It is the belief of this mission that actively collaborating with minority serving institutions is crucial for increasing representation in the field, and we intend to build our team with these efforts in mind.

#### **References**

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