Understanding Space:

Utilizing CubeSats to Analyze Upper Atmospheric Weather Phenomena

Caltech CubeSat Club

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Leadership Information

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The Club Treasurer will be responsible for submitting progress reports to the Amateur Radio Digital Communications Foundation at regular intervals as determined by the organization. Additionally, they will control the deposit/usage of funds.

Project Description

The Caltech CubeSat Club is a professional organization of scientists, engineers, and space-enthusiasts who share a passion for scientific discovery. Established during the COVID-19 pandemic, our organization enables students to design, build, and launch their own satellite through NASA's CubeSat Launch Initiative. Our organization's hands-on projects provide students with a unique end-to-end experience from mission development to mission operations. We request support from the Amateur Radio Digital Communications (ARDC) Foundation to support our research efforts.

Our team has decided to pursue a planetary science mission investigating the effects of upper atmospheric lightning (also known as transient luminous events or TLEs) on the ionosphere. While upper atmospheric lightning is a common phenomenon, it is still not well understood. It is currently estimated that there are up to seven million TLEs each year. Although the effects of upper atmospheric lightning may seem benign, it commonly causes disruptions to aviation and space operations. Furthermore, there have been documented cases of TLEs causing communication loss and component damage. By improving our understanding of upper atmospheric lightning, our club may advance predictions of lightning storms and mitigate the risks upper atmospheric lightning poses to commercial space operations.

We are interested in investigating the following scientific questions during our mission.

> **Question 1:** How does electron ionization affect the development of TLEs
>
> First and foremost, our team wants to investigate how atomic ionization changes during upper atmospheric lightning. According to a 2013 study published by Kuo et. al, TLEs have been associated with emission characteristics in the N2 1P, N2 2P, and N2+ 1N bands.[1] By utilizing a spectrometer, we would be able to record the wavelength emissions of the ionized gases, and thus decode the atomic ionization during upper atmospheric lightning events. Understanding the atomic state of the atmosphere would give researchers a better understanding of the mechanisms that occur during upper atmospheric lightning and how to predict the phenomenon.

Question 2: How does the electric field strength affect the development of TLEs

Next, we would like to investigate how the electric field strength changes in proximity to upper atmospheric lightning. A 2005 study published by Shoory et. al modeled upper atmospheric lightning as a wire antenna with distributed resistance.[2] Using this model, his team was able to predict how the electric field would behave in proximity to a simulated lightning strike. Our team would like to verify his analysis by recording the electromagnetic field strength near upper atmospheric lightning events. We would then be able to determine whether Dr. Shoory's theoretical representation accurately represent the experimental results.

Another research group led by Dr. Luque and Ebert was able to create a simulation that modeled the electric field strength induced by upper atmospheric lightning with spatial and temporal resolution.[3] The figure below visualizes this simulation with the vertical axis representing the altitude (in km) and the horizontal axis representing the temporal progression of the lightning strike (in ms). In this visualization, each curve represents a snapshot of the electric field strength in relation to altitude at an instant in time. As can be seen, after the upper atmospheric lightning event occurs the electric field strength spikes and forms two sperate wavefronts (colored in red). These wavefronts propagate up and down the atmosphere and form sharp electromagnetic gradients. By utilizing a magnetometer, our team would be able to record the magnetic field strength surrounding TLEs and thus determine whether the propagating wavefront phenomena is indeed observable.

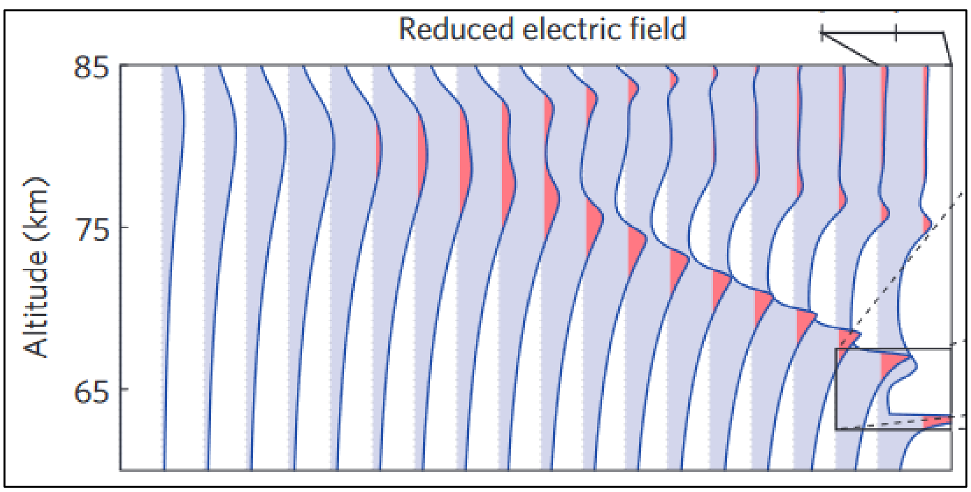

Figure 1: Visualization of Electric Field Strength after Upper Atmospheric Lightning Event

Question 3: How does electron density affect the development of TLEs

Lastly, we would like to investigate how the electron density changes after the development of TLEs. Based on the study by Dr. Luque and Ebert, their research team was able to simulate electron density after upper atmospheric lightning events. Their results are visualized in Figure 2. Similar to their previous figure, the vertical axis represents the altitude (in km) and the horizontal axis horizontal axis representing the temporal progression of the lightning strike (in ms). In this visualization, each curve represents a snapshot of the electric density in relation to altitude at an instant in time. Their results indicate that after the lightning strike the electron density forms a sharp gradient which propagates towards the ground. Using our CubeSat, we would be able to measure the electron density in the vicinity of the satellite in order to validate these results.

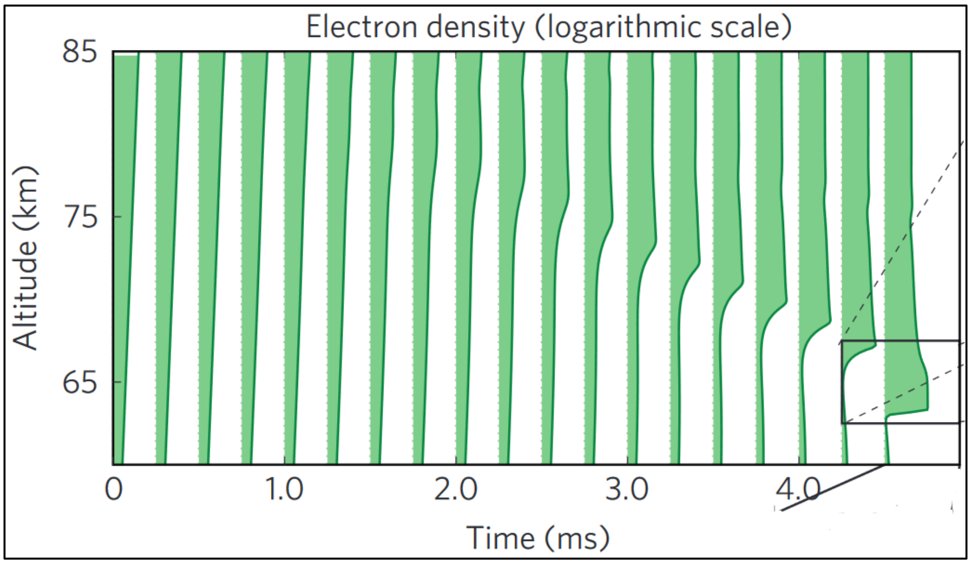

Figure 2: Visualization of Electron Density after Upper Atmospheric Lightning Event

Scientific Contribution

To date, only one planetary mission has been developed to explore upper atmospheric lightning. ROCSAT-2 was launched by the Taiwanese National Space Program Office in 2004. The satellite carried the ISUAL Imager, which was a spectrophotometer used to measure the N2 LBH band.[4] Our mission is unique because it is the first to bring upper atmospheric observation to the CubeSat platform. Furthermore, our use of a newer CCD photospectrometer enables our team to observe atomic ionization across a larger spectral range, to take measurements at higher frequencies, and to lower the minimum detectable photon energy. All in all, these advancements mean our sensor will enable our team to capture a more wholistic snapshot of the atmospheric ionization than the ROCSAT-2 satellite. Furthermore, our satellite would be the first to study how our atmosphere's electromagnetic properties respond to upper atmospheric lightning. By improving our understanding of upper atmospheric lightning, we may be able to forecast lightning strikes before they occur and increase reliability of future space systems.

Our team's main priority is making our research accessible to the rest of the scientific and academic community. Therefore, we have decided release all raw data and images to the public under the Creative Commons CC-BY license. The goal is to allow future scientists/researchers to extend our work. Our engineering/technical schematics will be released to the public for non-commercial purposes under the CC-BY-NC license. Our organization strongly believes in the ARDC's open access goals, and therefore we will be working closely with Caltech on their educational outreach programs. Some potential opportunities include Caltech's annual technology symposium which attracts local students and their summer high school student programs. We look forward to sharing our findings with students and researchers alike.

Amateur Radio Applications

Our communications sub-team leader, Michael Gutierrez, is currently leading an initiative to build a student-operated ground station at Caltech. Our club currently owns a 3-meter yagi antenna, which we are planning to utilize to set up a steerable SatNOGS ground station on the roof of the 10-story Caltech Hall Library. Furthermore, Michael has been working closely with Caltech's Department of Electrical Engineering to refurbish an old 6-meter parabolic dish antenna. Once complete, it will be available for students and faculty to use for radio astronomy projects, satellite communications, and general radio education. There are currently no resources like this available at Caltech – if a student wanted to learn about RF hardware or software defined radio, they would have to either join a lab, take an upper-level class, or build their own antenna. These ground stations we plan to build will remedy that by being available to anyone with proper training and supervision.

This will be instrumental in supporting Caltech's upcoming CubeSat missions, since we plan to use these ground stations as a Mission Operation Center for this mission, as well as potentially for other Caltech-affiliated missions. We are currently in communication with NASA JPL as well as the Caltech Earth Sciences Department about how we can get our members involved in real research projects through the club. The end goal is to provide Caltech students with hands-on experience with operating real spacecraft. More information about this initiative can be found here: https://smallsats.caltech.edu/about

In addition, our CubeSat proposal is only one of the projects we're pursuing that will make use of the RF communications knowledge and equipment we have available. For example, this year we plan to launch a series of high-altitude balloons carrying custom-built science payloads, with the mission objectives planned by our members. Of course, a necessary part of this is retrieving the science payload after landing, so we will need to maintain constant contact with the balloon. Krishna Pochana and Saren Daghlian, our electrical sub-team leads, have taken a year-long course at Caltech which involved several similar balloon launches, so we are familiar with the process and resources required. In fact, the club has already flown a prototype of our own high-altitude science payload earlier this year, and we learned a lot. Here is an article that Michael wrote summarizing the launch: https://caltechadmissions.blog/the-mission/ These projects closely align with the ARDC's goals to educate students and to advance the amateur radio community. Our organization will give students the flexibility to explore amateur radio outside of the academic community, so that they may hone their interests or pursue intriguing topics.

Budget[1]

Component	Name	Quantity	Cost per Unit	Total Cost
Satellite Parts				
Spectrometer	Teledyne CCD42-10 Spectrometer	2	$5,000	$10,000
Magnetometer	Sensys FGM3D/250 Magnetometer	1	$3,000	$3,000
Bus/structure	Cube Sat Bus/Structure Kit	2	$8,750	$17,500
GNSS	Pumpkin GNSS Receiver Module	1	$11,500	$11,500
Flight Computer	ISIS On Board Computer	2	$7,000	$14,000
Battery	EXA BA0x Battery Array	2	$4,500	$9,000
Solar Arrays	EXA Deployable Solar Array	2	$7,000	$14,000
Attitude Control	iMQT Magnetorquer Board	1	$9,750	$9,750
Communications	ISIS VHF Uplink/UHF Downlink Full Duplex Transceiver	2	$8,500	$17,000
Antenna	ISIS Deployable Antenna	1	$8,000	$8,000
Ground Station				
FPGA Dev Board	Xilinx RFSoC Dev Board	1	$2,250	$2,250
RF Transceiver	Ettus B210 Software Defined Radio	2	$2,000	$4,000
CPU	Intel NUC PC	2	$750	$1,500
Amplifier/filter	MiniCircuits LNA/BPF	4	$150	$600
Subtotal				$122,100
Margin (20%)				$24,420
Total				$146,520

Table 1: Detailed Budget

The table above (Table 1) shows a detailed budget of our expected expenditures. Most notably we expect that our CubeSat and amateur radio programs will cost around one hundred and fifty thousand dollars combined. Although our program costs are high, we have sought high-quality components to ensure our CubeSats' operability in space and to source reliable equipment for our amateur radio program. Our treasurer and executive officers would be responsible for

[1] Prices have been adjusted to accommodate 10.25% tax rate and shipping costs

submitting annual reports to the ARDC foundation detailing our progress and use of funds. Furthermore, we will be consulting with Caltech/JPL faculty to ensure that funds are utilized as efficiently as possible.

Thank You

Our team would like to thank the Amateur Radio Digital Communications Foundation and Grant Application Managers for considering our proposal. Your support would contribute to our mission and catalyze opportunities for amateur radio projects at Caltech. For more information about the students and their backgrounds please visit our website:
https://smallsats.caltech.edu/bios

Bibliography

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[3] A. Luque and U. Ebert, “Emergence of sprite streamers from screening-ionization waves in the lower ionosphere,” *Nat. Geosci.*, vol. 2, no. 11, pp. 757–760, Nov. 2009, doi: 10.1038/ngeo662.

[4] J. L. Chern *et al.*, “Global survey of upper atmospheric transient luminous events on the ROCSAT-2 satellite,” *J. Atmospheric Sol.-Terr. Phys.*, vol. 65, no. 5, pp. 647–659, Mar. 2003, doi: 10.1016/S1364-6826(02)00317-6.