VARIABILITY IN ATMOSPHERE FROM SOLAR ENERGETIC ELECTRONS STUDY (VIA-SEES)

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Abstract

Variability In Atmosphere from Solar Energetic Electron Study (VIA-SEES) is a hybrid science mission and technology development campaign from the Earth and Planetary Exploration Technologies (EPET) program at the University of Hawai'i. It is oriented around establishing a direct correlation between Solar Radiation Events (SREs) and Variability in Atmospheric gases, specifically Nitric and Nitrous Oxide, as well as Ozone. The mission is intended to fly on a 3U CubeSat and will collect a data set which is multimodal. To achieve robust performance, a variety of techniques are employed to make the science data set easier to interpret by an analyst. It is important to consider the format of the data sets, which is generally given by the instrument collecting the data. To allow for a better establishment of an anticoincidence, meaning that there is a precise correlation between 2 readings on the same index, a systems engineering approach is taken. This is as the science mission requirements should drive the design of the mission. A comprehensive approach is taken in the design of the VIA-SEES spacecraft, to maximize the scientific value of the mission.

EPET Student Experience

VIA-SEES is a student-initiated research and engineering project that emerged as part of a recently established University of Hawai'i certificate program in Earth and Planetary Exploration Technology (EPET). The VIA-SEES team consists of nine students who are currently designing and building the mission payload through supported extracurricular research projects while continuing their formal education in space mission design. The extracurricular research will flow into the final EPET course where mission design and payload are combined to produce a small deployable spacecraft as a capstone project.

EPET 201 – Space Exploration
The EPET sequence begins with an introductory course that exposes students to the science and engineering of space exploration. The course consists of research projects and papers based on faculty-led colloquia and extensive trade studies. Topics covered include:

- Scientific instrumentation
- Mission trajectories, design, and planning
- Science and engineering constraints imposed on spacecraft design

EPET 301 – Space Science and Instrumentation
Building on this foundation, the second installment EPET 301 provides students the knowledge to formulate science objectives, develop preliminary instrument/payload designs, and create a science traceability matrix. Topics covered in this course include:

- Design of space flight instrumentation
- Essential techniques for remote sensing. Spectroscopy as a tool for investigating the mineralogy and geochemistry of planetary surfaces

EPET 400 – Space Mission Design
The capstone project begins with the EPET 400 course which covers all aspects of spacecraft design. Here, students use their creativity as they design their mission within science, engineering and budget constraints. For demonstration purposes, students work with a university-made 1U CubeSat kit, part of which can be seen in Figure 1. Topics in this course include:

- Science payload and instrument selection
- Systems and subsystems engineering
- Project management (schedule, budget, etc.)

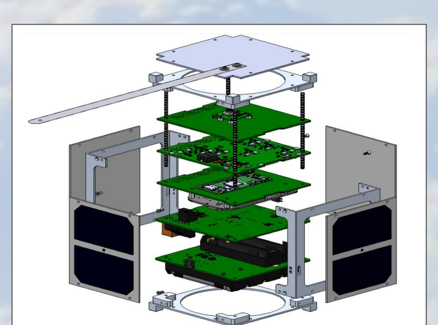

Figure 1. Exploded view of the Artemis CubeSat

EPET 401 – Capstone Project: Producing a Science Satellite
EPET 401 is the culmination of the EPET student experience. In this course, students construct the spacecraft for a mission designed in the preceding courses and in parallel extracurricular activities (see Fig. 2). The primary objectives of this course are to:

- Develop a space mission consisting of a multidisciplinary team of engineers and scientists
- Build a small spacecraft and payload using concurrent science and engineering methodologies

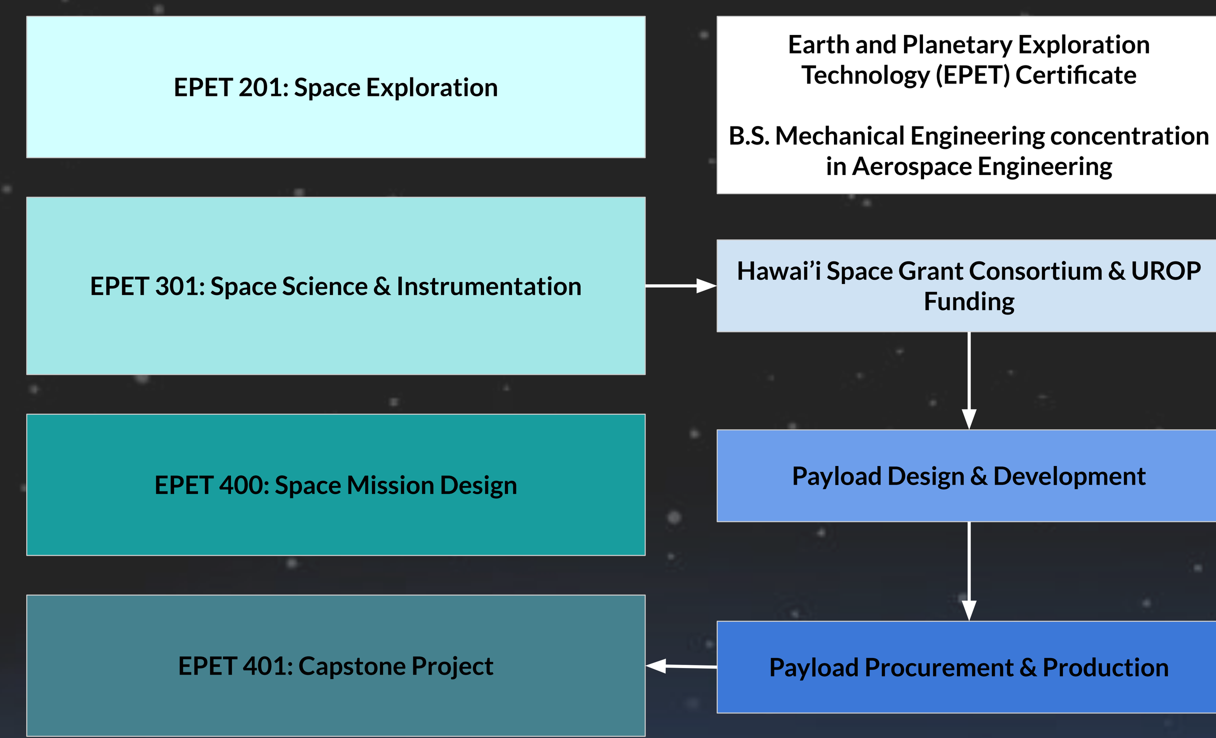

Figure 2. EPET Course Sequence over 4 semesters

Mission Concept

Student research and discussion during EPET 301 led to a mission concept with science objectives that addresses knowledge gaps laid out in some of NASA's most recent strategic plans and decadal surveys. In particular, the VIA-SEES mission will aid in understanding Earth's atmospheric response to auroral, radiation belt, and solar energetic particles and the associated effect on ozone and nitrous oxides in the ozone layer (see Fig. 3 for more details). Slow solar wind travels at speeds between 300 to 800 km/s, with particles arriving at Earth in about 2-3 days. In a solar flare, particles are accelerated to relativistic velocities, arriving at Earth in about 10 minutes. Electrons traveling at these energy levels will cause Energetic Electron Precipitation (EEP), a phenomenon which causes the dissociation of molecules in our atmosphere. Over time, these dissociations can catalyze the destruction of the ozone layer and have impactful effects on the Earth's climate. The dissociation energies of some of these molecules are listed in Table 1.

Molecule / Bond Type	Energy (kcal/mol)	Energy (eV/Bond)
C-Cl (Single)	330	14.32
Cl-O (Single)	200	8.68
N-O (Single)	200	8.68
C=C (Double)	611	26.52
C=O (Double)	732	31.77
O=O (Double)	498	21.61
N=N (Triple)	945	41.01
O3 (Resonant)	364	15.80

Table 1. Dissociation energies of common atmospheric molecules

	Science Goals	Science Objectives	Science Measurement Requirements: Physical Parameters	Science Measurement Requirements: Observables	Instrument Performance Requirements		Mission Requirements
Atmospheric Variablity As a Result of SEEs	"To understand our atmosphere's response to auroral, radiation belt, and solar energetic particles, and the associated effects on Nitric Oxide (NO) and ozone" (Heliophysics Roadmap for Science and Technology for 2009-2030, LWS #7).	Determine the baseline levels of atmospheric ozone in non-SEP intervals and the size of ozone depletions before, during, and after solar energetic particle events. (Heliophysics Roadmap for Science and Technology for 2009-2030, LWS #7)	Define the variability in nitric oxide (NO), nitrogen dioxide (NO2), total reactive nitrogen oxides (NOy), and ozone (O3) production and depletion before, during, and after solar energetic particle events.	Observe levels of nitric oxide (NO), nitrogen dioxide (NO2), total reactive nitrogen oxides (NOy), and ozone (O3) in the 250-500 nm wavelength.	Spectral range	250-500 nm	MR.1 - The spacecraft shall successfully enter Low Earth Orbit (LEO) at a TBD eccentricity
					Spectral Resolution (FWHM)	UV-1: 0.63 nm UV-2: 0.42 nm VIS: 0.63 nm	
	Understand the role of the Sun and its variability in driving change in the Earth's atmosphere, the space environment, and planetary objects (Heliophysics Roadmap for Science and Technology for 2009-2030, H2).				Spectral Sampling (FWHM)	UV-1: 1.9 px UV-2: 3.0 px VIS: 3.0 px	MR.2 - The spacecraft shall launch by January 2025 in order to be operational during peak solar maximum in July 2025
					Nominal ground footprint	13 × 24 km2 at nadir	
					Swath	2600 km	MR.3 - The total mass of the spacecraft shall not exceed 12 kg
					FOV	780 × 576 px (spectral × spatial)	
Solar Energetic Electrons (SEEs)	"Understand the Sun, Earth, Solar System, and Universe". (NASA Science Mission Directorate)	Determine the composition of Solar Energetic Particles (SEPs). (Heliophysics Science and Technology Roadmap for 2014-2033)	Define the local energy flux of 10-2000 keV electrons	Observe auroral electrons (10-30 keV), medium-energy electrons (30-300 keV), and relativistic electrons (300-2000 keV).	Range	10-2000 kev	MR.4 - The mass of the electrical and power subsystems shall not exceed 1/4th of the allotted mass or 3 kg
					Resolution (dE/E)	< 30%	
	"STP #6 Solar Energetic Particle Acceleration and Transport (SEPAT): Understand how and where solar eruptions accelerate energetic particles that reach Earth". (Heliophysics Science and Technology Roadmap for 2014-2033)				Measument Cadence	10 ms	MR.5 - The mission shall have a 3 year lifespan
					Histogram Cadence	6 s	
					Swath	TBD	MR.6 - The scientific instruments shall have an accuracy of TBD %
					FOV	52º	

Figure 3. VIA-SEES science traceability matrix

Science Objectives

The primary science objective of the VIA-SEES mission is to determine baseline levels of atmospheric ozone in non-SEP intervals and the size of ozone depletions before, during, and after solar energetic particle events. This will be done by measuring a direct correlation between flux in Solar Energetic Electrons (SEEs) and the variability in total reactive nitrous oxides and ozone concentration in the ozone layer.

To date there has not been an Earth-observing mission that has integrated simultaneous measurements of solar energetic particles (SEPs) and stratospheric nitrous oxide and ozone using one spacecraft. Hence, near real-time correlated measurements of solar radiation and upper atmospheric gases would provide means to discover the existence and extent of gas depletion based on radiation. The VIA-SEES mission will utilize one 3U CubeSat in Low Earth Orbit (LEO) to capture this unique set of data during the next Solar Maximum, in July of 2025.

Preliminary Design Review

EPET 400 culminated with the completion of a Preliminary Design Review in which the technical adequacy of several spacecraft components were assessed and the general system requirements and design were detailed. For instance, Figure 4 below illustrates how the measurements taken by the VIA payload will fulfill the instrument performance requirements laid out in the science traceability matrix. Additionally, further trade studies were carried out to determine the optimal parameters for Attitude Determination and Control System (ADCS).

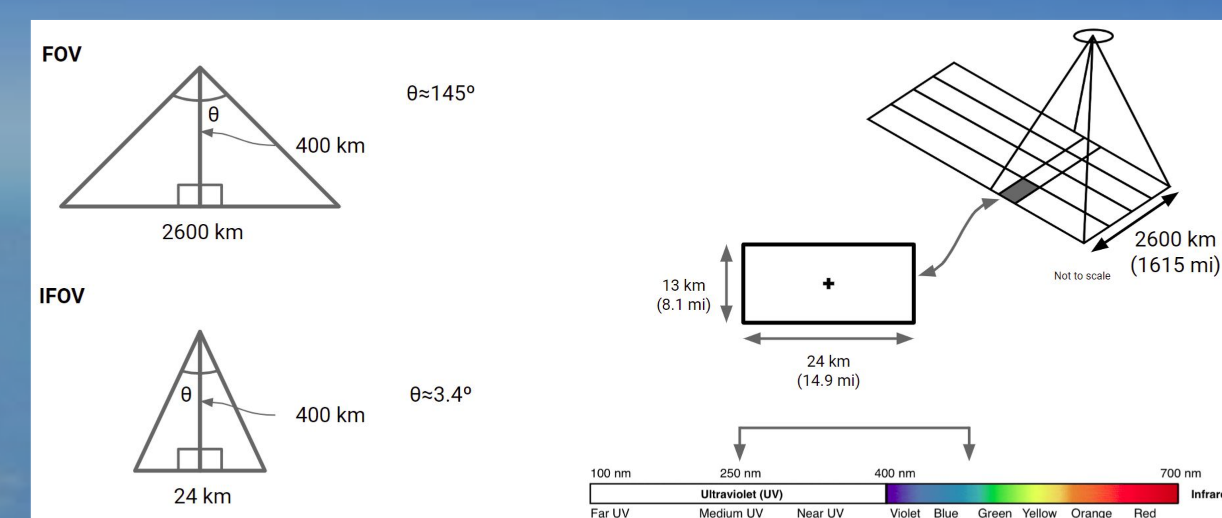

Figure 4. Illustration and breakdown of the VIA sensor specifications

Criteria	Rationale	Percent (%)	Ratings	AvaSpec-Mini2048CL	ARTCAM-2020UV	22mm Cluster Camera
Minimum spectral range of 250-500 nm	STM Performance Requirments	25	0: Outside 1: Within	1	1	1
Spectral Resolution (FWHM)	STM Performance Requirments	25	1: Poor 4: Great	4	3	2
Spectral Sampling (FWHM)	STM Performance Requirments	15	1: Poor 4: Great	3	3	2
Nominal ground footprint	STM Performance Requirments	10	0: Insuffcient 1: Sufficient	1	1	1
Swath	STM Performance Requirments	10	0: Insuffcient 1: Sufficient	1	1	1
FOV	STM Performance Requirments	10	0: Insuffcient 1: Sufficient	1	1	1
Power usage under 3 W	CubeSat Kit Power Budget	5	1: Poor 4: Great	4	3	3
Total Weighted Percent		100		96.25	88.75	78.75

Imager Trade Study

Figure 5. VIA instrument trade study results

Payload Selection & Design

A trade study, part of which is detailed in Figure 5, was performed to select the optimal atmospheric sensor for the mission. Figure 6 shows the AvaSpec-Mini2048CL spectrometer, which was determined to be the optimal choice for the VIA payload.

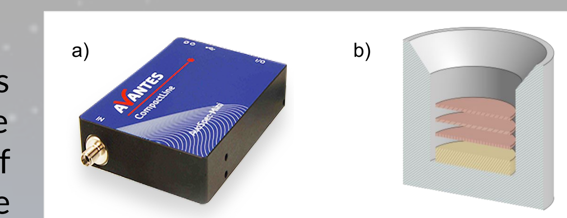

Figure 6. a) AvaSpec-Mini spectrometer b) SEES detector concept design

An additional trade study was performed for the SEES detector. The team concluded that an off-the-shelf detector would not meet the science objectives. Discussions with the Instrument Development Lab (IDL) at the University of Hawai'i as well as graduate students at University of Colorado, Boulder supported the conclusion that constructing an detector would be optimal to meet SEES mission requirements. A SEES concept design can be seen in Figure 6.

Current Status

Current work in progress includes the following tasks:

- Finalization of the SEES detector design which involves simulating particle interactions using Geant4, optimizing detector geometry within science and engineering constraints, and updating the CAD model.
- Calibration of the VIA instrument by testing the Avaspec instrument on various gases in a laboratory setting and comparing to spectral libraries.
- Continuance of trade studies related to different spacecraft subsystems. Various iterations of the spacecraft layout and architecture are being considered, as demonstrated in Figure 7.

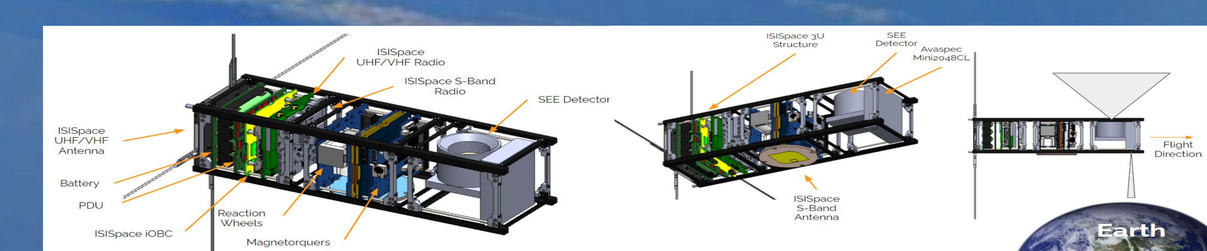

Figure 7. CAD Design and flight orientation

Conclusion

As presented in this poster, the EPET curriculum combines lecture, laboratory, and project-based approaches with effective interdisciplinary cohort/group learning strategies to integrate the nature of planetary materials and landforms with the science and engineering tools to study them. The process leading to the building and testing of the VIA-SEES mission spacecraft by the end of the 2022 calendar year will be the first fully successful completion of the EPET course and certificate cycle.

Acknowledgments

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