Atmosphere and Plume Explorer (APEX) CubeSat Study

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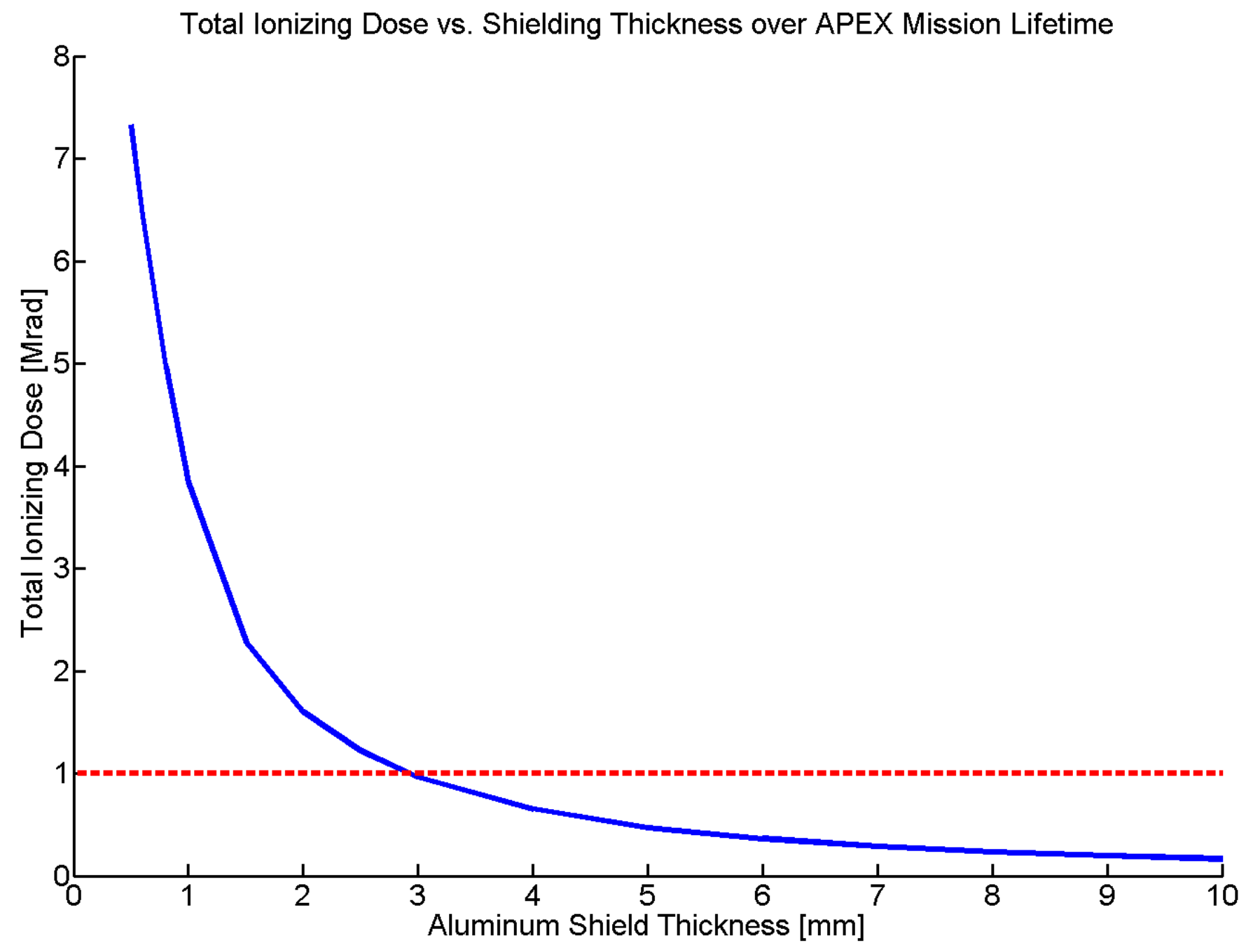
Introduction

This study was performed by a group of largely undergraduate students to determine the utility and viability of placing a nano-satellite (CubeSat) onboard the Europa Clipper spacecraft proposed to be launched by NASA in 2021. The main Clipper craft will perform 45 flybys of Europa over a 3 year period, performing several kinds of scientific experiments (mass spectrometry, magnetic mapping, imaging and more). By including onboard a separate small spacecraft additional science goals can be achieved. The spacecraft proposed here will perform both atmospheric science using a mass spectrometer and radiation dosimetry using a set of modified SRAM chips.

Mission Drivers

Radiation

Space around Jupiter features an intense radiation environment, which would kill a human in a matter of seconds if openly exposed. The maximum Total Ionizing Dose (TID) for this mission was set to 1 Mrad, as most radiation hardened components are rated to this level. To enable the spacecraft electronics to survive this environment, about 2.5 mm of aluminum shielding will cover all critical spacecraft areas.



Plot showing the thickness of aluminum shielding required to keep the APEX CubeSat alive in the Jovian radiation environment. The 1 Mrad TID cutoff dosage is shown as a red horizontal line.

Communications

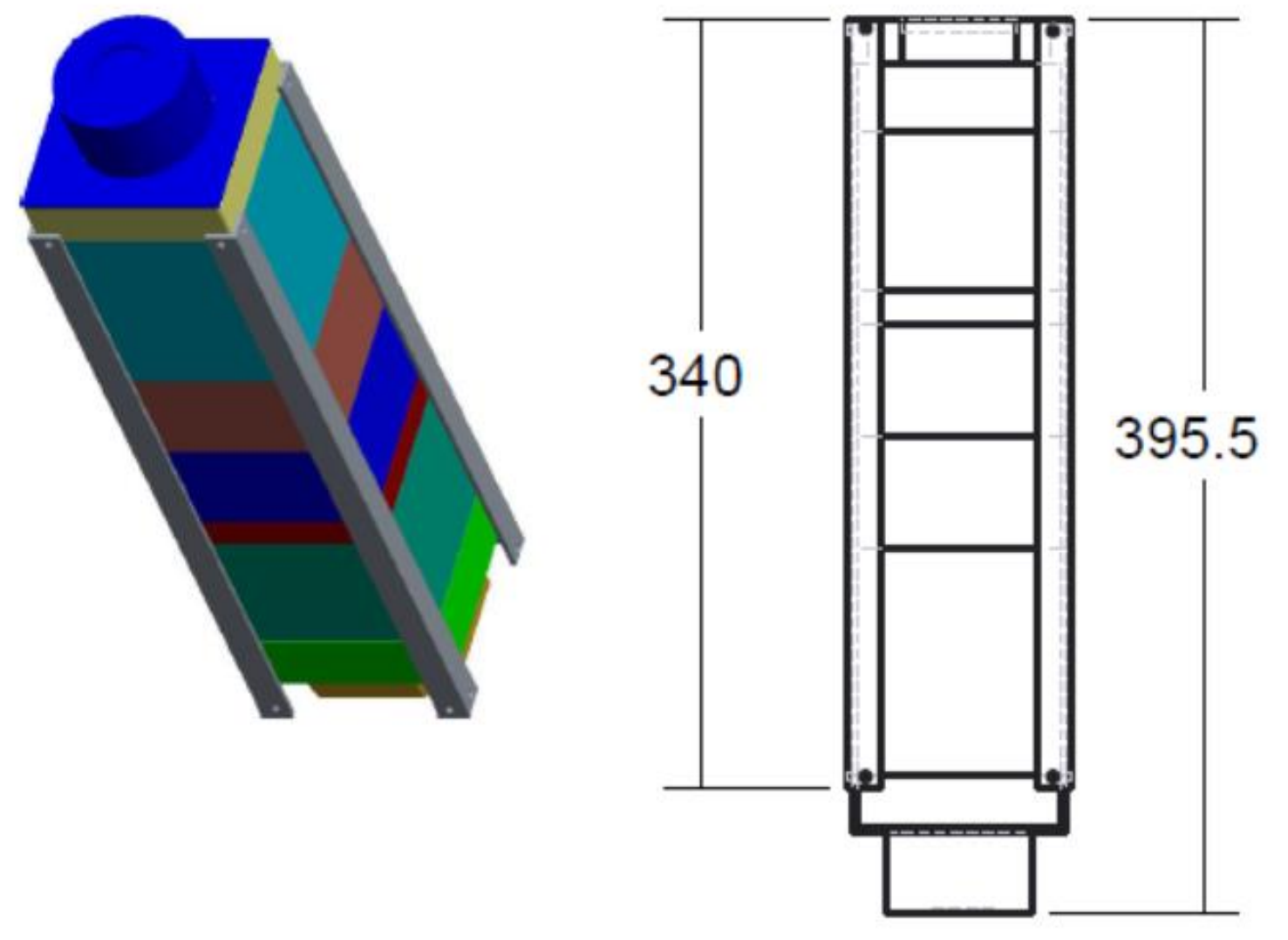
Due to the small size of the spacecraft and the distance form Earth, direct communication back to the surface is impossible. The large antennas and high power levels required simply do not fit inside a satellite smaller than a briefcase. Instead, data will be relayed back to Earth through the Europa Clipper spacecraft.

Power

Due to the low level of solar intensity at Jupiter, a large solar array is required to power the spacecraft. Options featuring small nuclear power sources were ruled out due to the current political environment.

Concepts

A number of notional mission profiles were developed to satisfy the mission constraints. First a set of 3 CubeSat Units (10 cm x 10 cm x 30 cm) sized spacecraft were considered. Due to the large volume of components required to keep the satellite alive in the Jovian environment, this option was found to be infeasible.



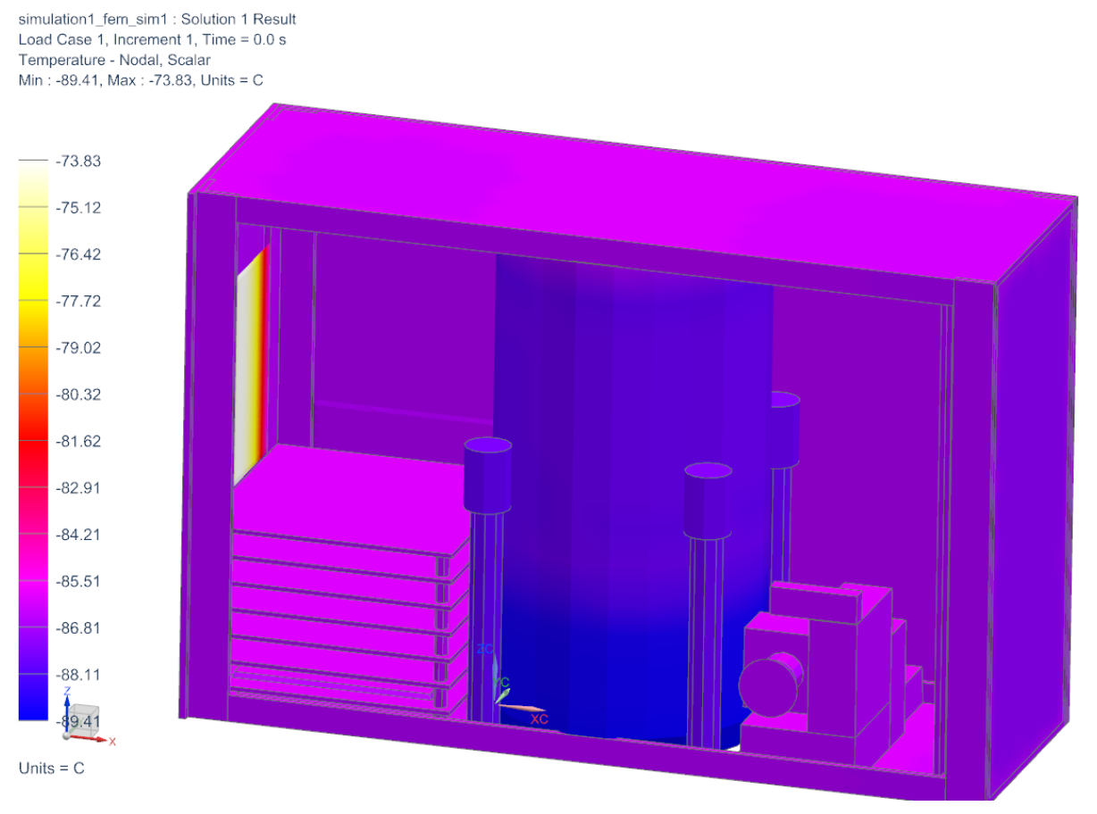
A notional APEX spacecraft design showing the extension of the components outside of the maximum volume.

Also explored was the possibility of having the APEX spacecraft perform a full insertion burn into Europa orbit to perform larger amounts of science around Europa. This option was deemed infeasible after significant study due to a lack of powerful propulsive options for CubeSats. Any hardware that would accomplish this proposed task would require more than 50% of the complete spacecraft volume.

Continuing Hurdles

Cold Temperatures

The Jovian environment is significantly colder than those encountered by a typical CubeSat. Most electronic components are rated to approximately -40ºC, and the current APEX model shows temperatures in the range of -70 to -90ºC.



A representative model of spacecraft heating performed in NX Space Systems Thermal showing the temperature extremes seen by spacecraft around Jupiter.

Future work will focus on spot heating critical components of the APEX craft, and rearranging the spacecraft to better utilize all waste heat created to meet the temperature constraints.

Proposed Architecture

The final proposed option for the APEX architecture features the 6U spacecraft detaching from the Europa Clipper spacecraft upon arrival in the Jovian system. The APEX craft will then perform a number of flybys in conjunction with Clipper performing relative science. At the end of the mission lifetime, the CubeSat will dive to Jupiter's first moon, Io, and sample its volcanic plumes. A final swing by the Europa Clipper craft will allow APEX to fully transmit all of the data obtained from this flyby.

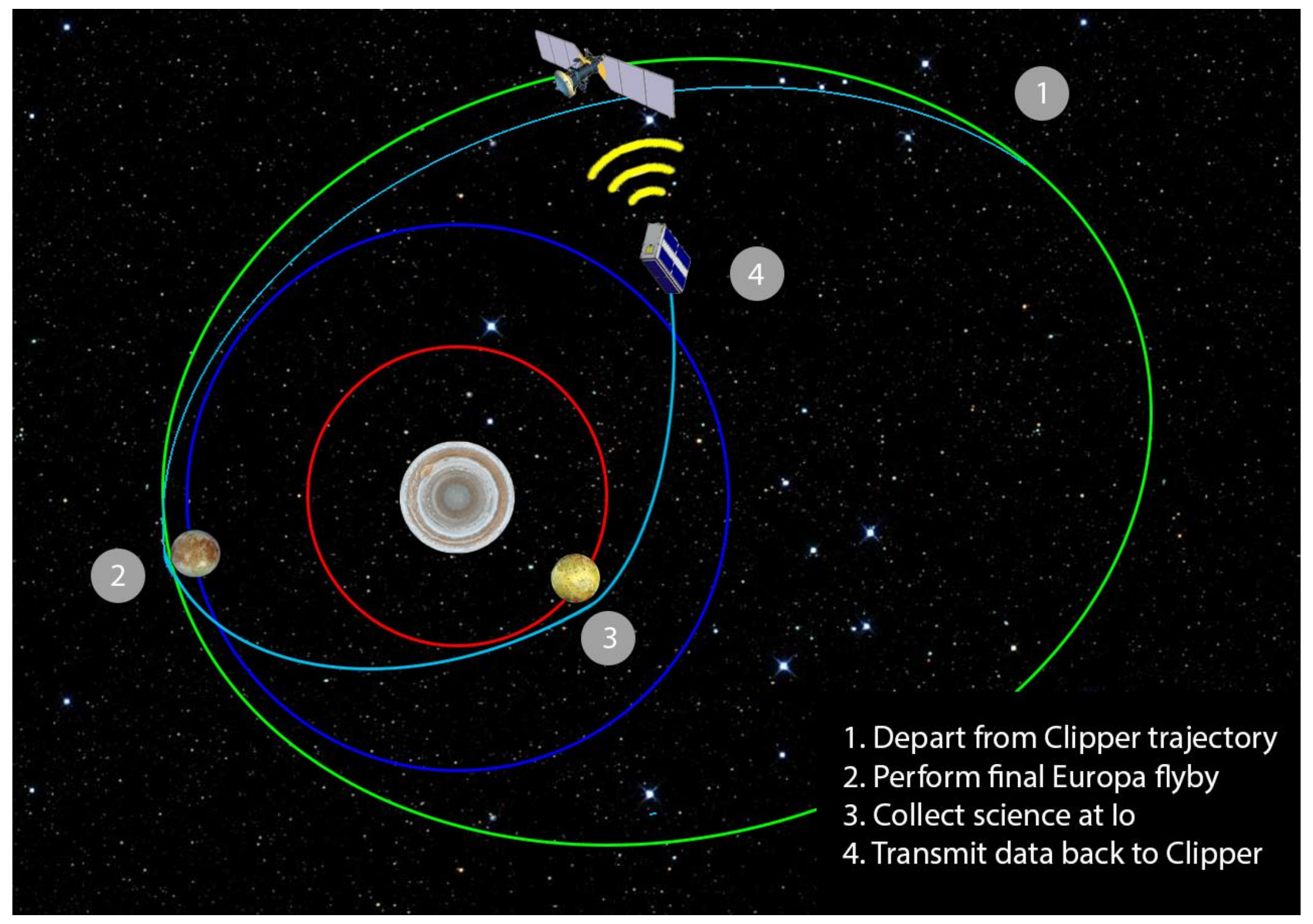
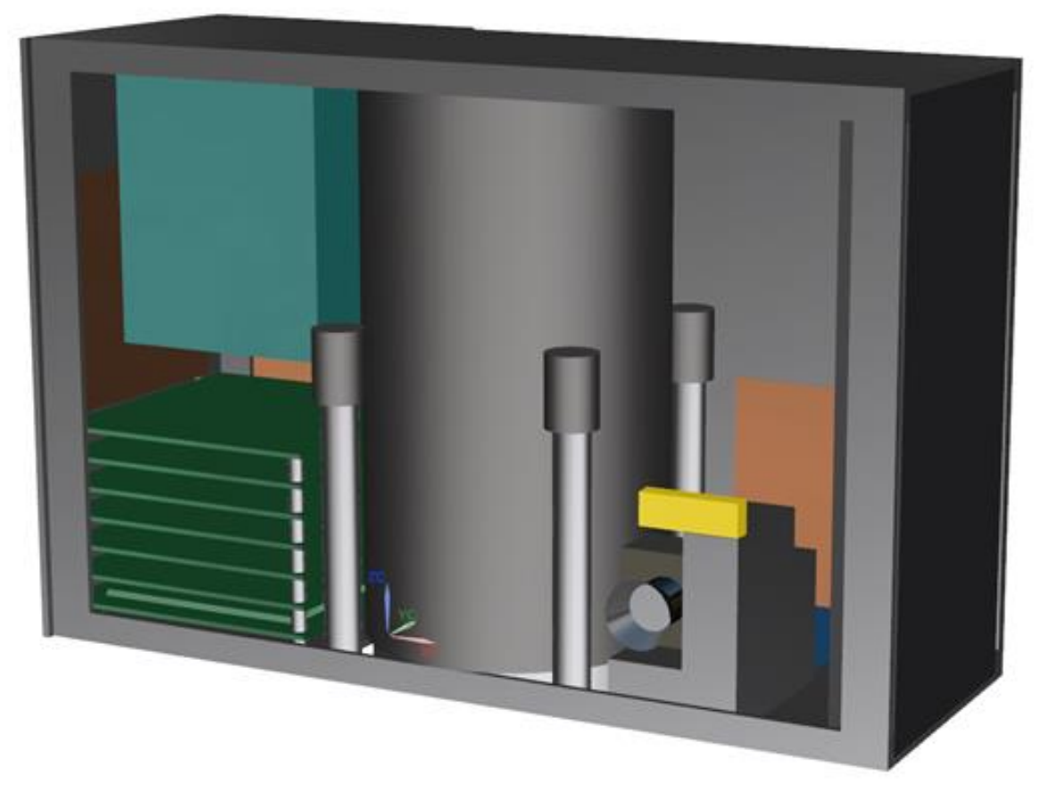


Diagram showing the proposed mission profile of the APEX spacecraft (trajectory shown in light blue) away from the Europa Clipper spacecraft (light green).

The spacecraft features a propulsion system encompassing 2 out of 6 total CubeSat units. The spacecraft has a set of deployable solar arrays, which will provide the power to all spacecraft systems, as well as the heaters that keep the critical components functioning.



A model of the proposed APEX spacecraft showing the intended configuration of components.

The scientific instrument performing the most groundbreaking science onboard (mass spectroscopy) is the Winds Ions Neutrals Composition Suite (WINCS) developed at the Naval Research Laboratory. This instrument will provide additional insight into the speed and composition of the atmospheres of both Europa and Io, which in the case of Io will lead to a completely unique set of scientific discoveries.

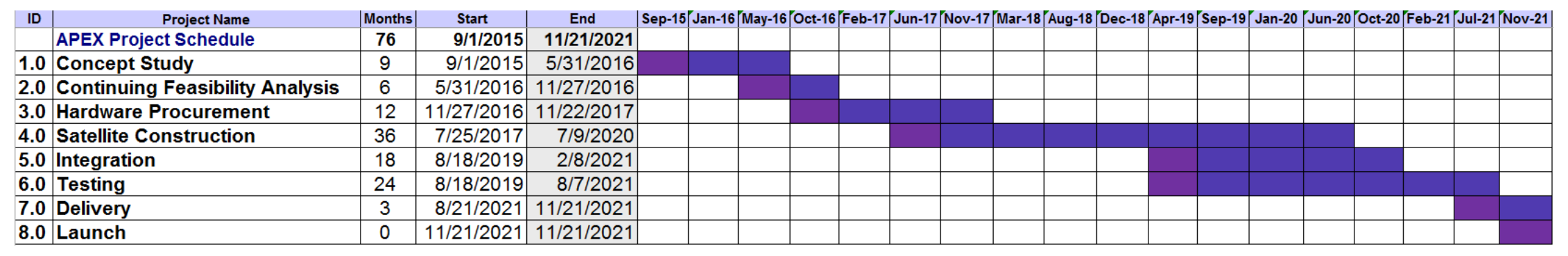
Also included will be a suite of dosimeters giving a variety of radiation measurements to allow for a better understanding of the full radiation environment in the Jovian system.

Conclusions

This study has developed a notional method for extracting additional science from an existing proposed NASA mission. The mission profile developed in this study provides valuable additional science while not adding significant risk or complexity to the main mission.

The proposed addition of an Io flyby allows for the collection of scientific data that will not be obtained by the Io Volcano Observer (IVO) spacecraft (which would not fly if Europa Clipper is funded). This augmentation in capabilities is a large cost save, as IVO had an expected mission cost of $450 million, compared to the $10 Million.

With a launch in 2021 much work still needs to be completed to turn the APEX CubeSat into reality, but as the notional project timeline below suggests, there is still sufficient time to prepare a spacecraft for launch prior to the launch of the Europa Clipper mission.



ID	Project Name	Months	Start	End	Sep-15	Jan-16	May-16	Oct-16	Feb-17	Jun-17	Nov-17	Mar-18	Aug-18	Dec-18	Apr-19	Sep-19	Jan-20	Jun-20	Oct-20	Feb-21	Jul-21	Nov-21
	APEX Project Schedule	76	9/1/2015	11/21/2021																		
1.0	Concept Study	9	9/1/2015	5/31/2016	■	■	■															
2.0	Continuing Feasibility Analysis	6	5/31/2016	11/27/2016			■	■														
3.0	Hardware Procurement	12	11/27/2016	11/22/2017				■	■	■	■											
4.0	Satellite Construction	36	7/25/2017	7/9/2020						■	■	■	■	■	■	■	■	■				
5.0	Integration	18	8/18/2019	2/8/2021											■	■	■	■	■			
6.0	Testing	24	8/18/2019	8/7/2021											■	■	■	■	■	■	■	
7.0	Delivery	3	8/21/2021	11/21/2021																	■	■
8.0	Launch	0	11/21/2021	11/21/2021																		■

A notional timeline of the APEX mission from conception to launch.

Acknowledgments

The study performed would not have been possible without the valuable input and advice of both Dr. Alexander Ghosh and Professor Victoria Coverstone of the Advanced Research for the Exploration of Space (ARES) group in the department of Aerospace Engineering. In addition, the tireless work of the other student members of the team has been instrumental to the continued success of the study.

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