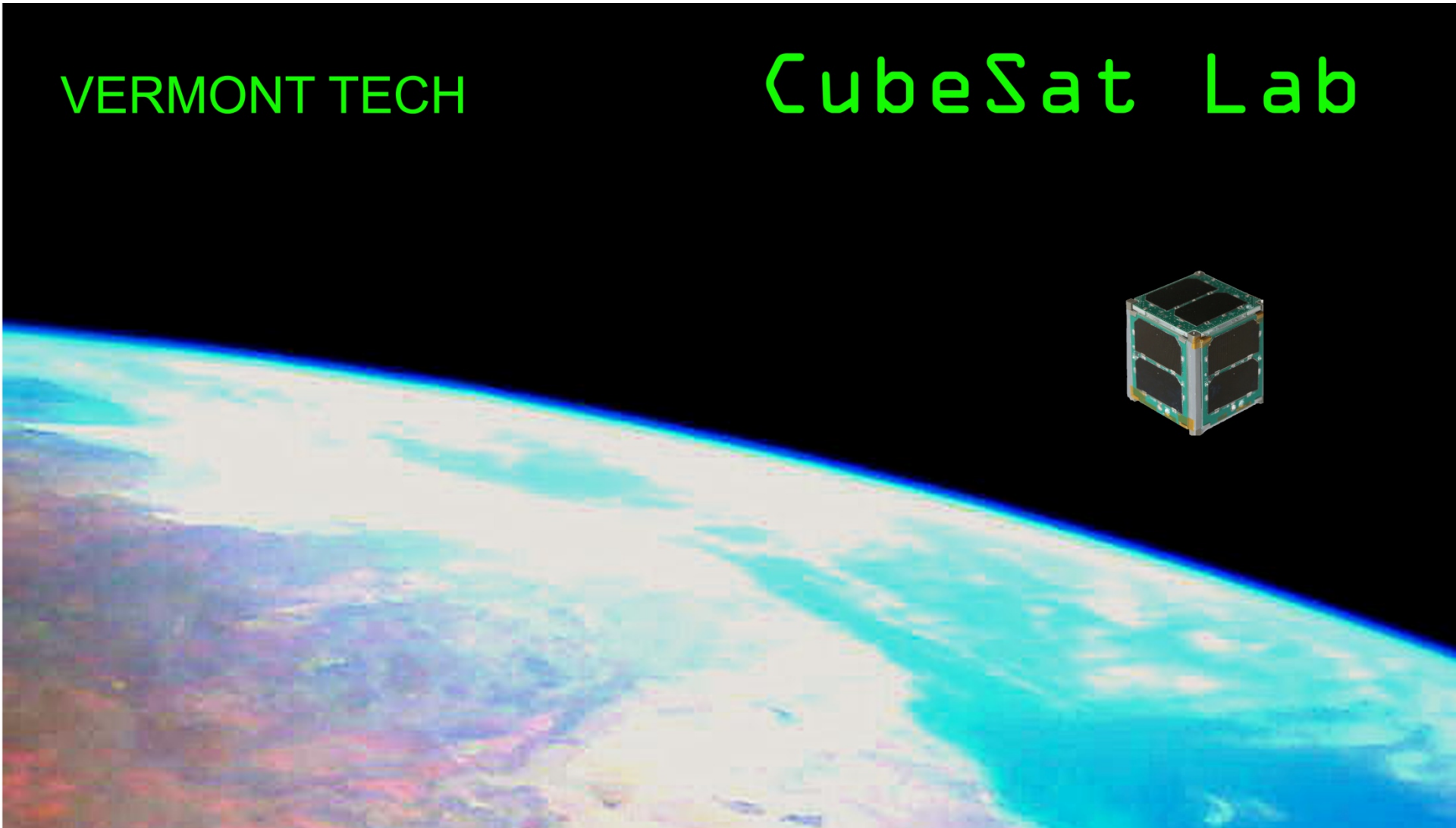
Reliability for Interplanetary CubeSats

Dr. Carl Brandon
Vermont Technical College
Randolph Center, VT 05061 USA

carl.brandon@vtc.edu
+1-802-356-2822 (Voice)
http://www.cubesatlab.org



NASA ELaNa IV Launch

ELaNa IV lessons for interplanetary CubeSats:

- NASA's 2010 CubeSat Launch Initiative (ELaNa)
- Our project was in the first group selected for launch
- Our single-unit CubeSat was launched as part of NASA's ELaNa IV on an Air Force ORS-3 Minotaur 1 flight November 19, 2013 to a 500 km altitude, 40.5^{o} inclination orbit and will remain in orbit about 3 years
- The Vermont Lunar CubeSat will test the Lunar navigation system in Low Earth Orbit
- Follow our project at www.cubesatlab.org

ELaNa IV Results

- 14 University / NASA CubeSats launched
- Only six were heard from at all
- One only lasted one week
- One lasted four months
- One only works in sunlight
- One took five weeks for first contact
- Ours, as many Vermonters do, took a 2 ½ month winter vacation

ELaNa IV Results January 29

Position	Payload Name	Beacon Heard?	Commanding and Telemetry	Ground System Status	Overall Status	Identified by JSpOC?	Notes
1.1-A	Prometheus 1.1					No	Prometheus is all green.
1.1-B	Prometheus 1.2					No	
1.2-A	Prometheus 2.1					No	
1.2-B	Prometheus 2.2					No	
1.3	Horus					No	No updates.
1.4	ORSES					No	No uplink/downlink established since 25Nov13.
1.5	ORS Tech 1					Yes	No change for ORS Tech 1 – Full communications (uplink and downlink) . Object 39387.
1.6	ORS Tech 2					Yes	No change for ORS Tech 2 – Full communications (uplink and downlink) . Object 39396.
1.7-A	Prometheus 3.1					No	Prometheus is all green.
1.7-B	Prometheus 3.2					No	
1.8-A	Prometheus 4.1					No	
1.8-B	Prometheus 4.2					No	
2.1	SENSE SV 1					Yes	No contact with SV since 21 Jan 2014. Red, 1 of 2 solar panels deployed, currently experiencing a low-power anomaly. No contact with SV in 7 days, working through fishbone anaylsis.
2.2	H2					No	No change since last report
2.3-A	Vermont Lunar					No	No change for Vermont Lunar.
2.3-B	TJ3Sat					No	No change since last report
2.3-C	Black Knight 1					No	No change for Black Knight 1. We have MIT Lincoln Labs testing our ground station radio and LNA right now. Anticipate renewed contact efforts in two weeks.
2.4	Firefly					No	Firefly continues to be GREEN (spacecraft). Ground station is YELLOW (cold weather issues, next expected contact Thursday). We are commissioning the spacecraft, preparing to enter science mode in February.
2.5-A	KYSat II					No	No changes from last week, using 39384 to track. Still no reliable uplink haven't been able to use 21 meter dish at Morehead State University due to snow and ice in the area. Ground stations and spacecraft are currently green.
2.5-B	NPS-SCAT					No	Still no contact with NPS-SCAT since last contact reported. No other updates but we are currently using the new 39389 object allocation in our attempts.
2.5-C	CAPE 2					No	No change since last report
2.6-a	DragonSat-1					No	No satellite contact; good ground station.
2.6-B	PhoneSat					No	No change. The information provided by JSpOC has helped PhoneSat ops team to eliminate objects that are near the 39381 object that has been used by the team.
2.6-C	SPA-1 Trailblazer					No	Trailblazer still not heard from. We are now continuing to look at those two TLEs and are hopeful. Satellite Red, Ground Station Green.
2.7-A	COPPER					No	No changes to COPPER.
2.7-B	SwampSat					No	There is no update from SwampSat. We have been using the information from JSpOC to track, however, we are unable to communicate with SwampSat. Also, our ground station is fully functional.
2.7-C	ChargerSat					No	No change in SV status. We are currently repairing wind damage on our antenna mount, and as such, have not been able to utilize the information provided by JSpOC.
2.8	SENSE SV 2					Yes	Averaging 5 contacts per day. Yellow, 0 of 2 solar panels deployed, shedding loads to regain positive power balance. Beginning payload checkout as power balance allows.

ELaNa IV Results May 8

Last updated	5/7/2014	by Carl Brandon					
Position	**Payload Name**	**Beacon Heard?**	**Commanding and Telemetry**	**Ground System Status**	**Overall Status**	**Identified by JSpOC?**	**Notes**
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1.1-B	Prometheus 1.2					Yes	
1.2-A	Prometheus 2.1					Yes	
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1.8-B	Prometheus 4.2					Yes	
2.1	SENSE SV 1					Yes	1 of 2 solar panels deployed, currently experiencing a low-power anomaly. No contact with SV for 7 days in January, working through fishbone anaylsis.
2.2	H2					No	No change since last report
2.3-A	Vermont Lunar					Yes	Working
2.3-B	TJ3Sat					No	No change since last report
2.3-C	Black Knight 1					No	No change for Black Knight 1. We have MIT Lincoln Labs testing our ground station radio and LNA right now. Anticipate renewed contact efforts in two weeks.
2.4	Firefly					Yes	Firefly continues to be GREEN (spacecraft). Ground station is YELLOW (cold weather issues, next expected contact Thursday). We are commissioning the spacecraft, preparing to enter science mode in February.
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2.5-B	NPS-SCAT					Maybe	Still no contact with NPS-SCAT since last contact reported. No other updates but we are currently using the new 39389 object allocation in our attempts.
2.5-C	CAPE 2					Yes	Only works in sunlight. Batteries dead.
2.6-a	DragonSat-1					No	No satellite contact; good ground station.
2.6-B	PhoneSat					Yes	Tracked and working.
2.6-C	SPA-1 Trailblazer					No	Trailblazer still not heard from. We are now continuing to look at those two TLEs and are hopeful. Satellite Red, Ground Station Green.
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Lessons Learned from ELaNa IV

- Hardware reliability issues
- Software reliability issues
- Design issues
- Procedural issues
- Communication issues

Reliability issues from ELaNa IV

Hardware reliability issues:

- Radiation hardening – CPU shielding
- Electrical power system - batteries
- Mechanical structure - separation
- Bus communication – pull ups
- Radio issues – beam width
- Temperature range of components
- Vibration test – check list & Engineering Model

Reliability issues from ELaNa IV

Software reliability issues:

- Design reviews
- Language selection (SPARK/Ada)
- Static analysis tools (SPARK 2014)
- Repository
- ISIS antenna electrical model testing

Reliability issues from ELaNa IV

Design issues:

- Multiple busses
- Protuberances
- Power budgets
- Realistic testing – PV solar intensity
- Problems and solutions from previous missions
- Be able to test all systems via USB

Reliability issues from ELaNa IV

Procedural issues:

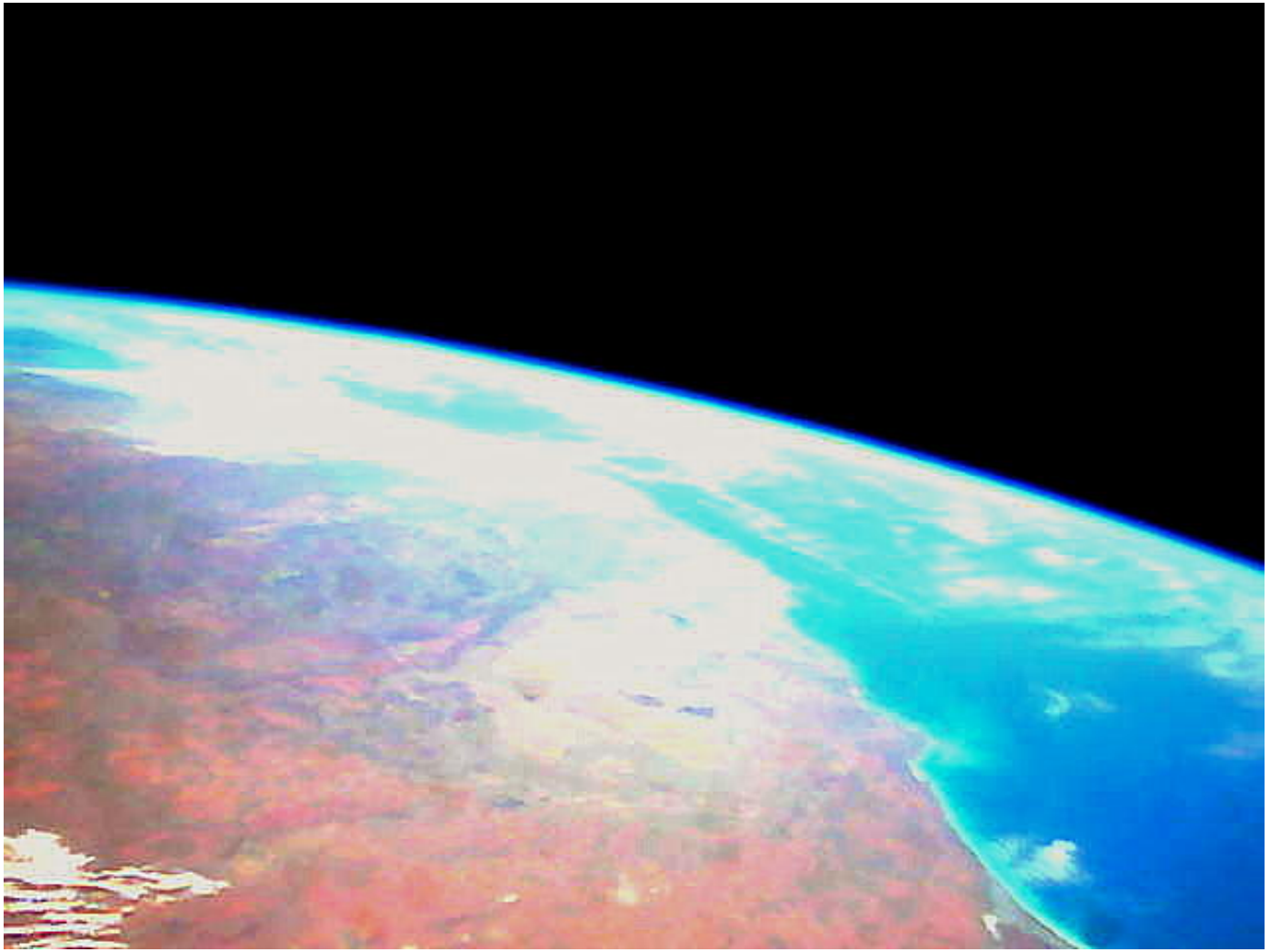
- Nobody has any space experience
- NOAA camera license
- IARU frequency coordination
- FCC/NTIA transmitter license
- FCC launch permission
- Airline transportation of CubeSats

Reliability issues from ELaNa IV

Communication issues:

- Test plans
- MPP Schedules
- ODAR
- Verifications Users Guide
- AMSAT IARU link budget
- Ground activities (integration)
- CubeSat “Cookbook” needed
- Talk to hardware vendors

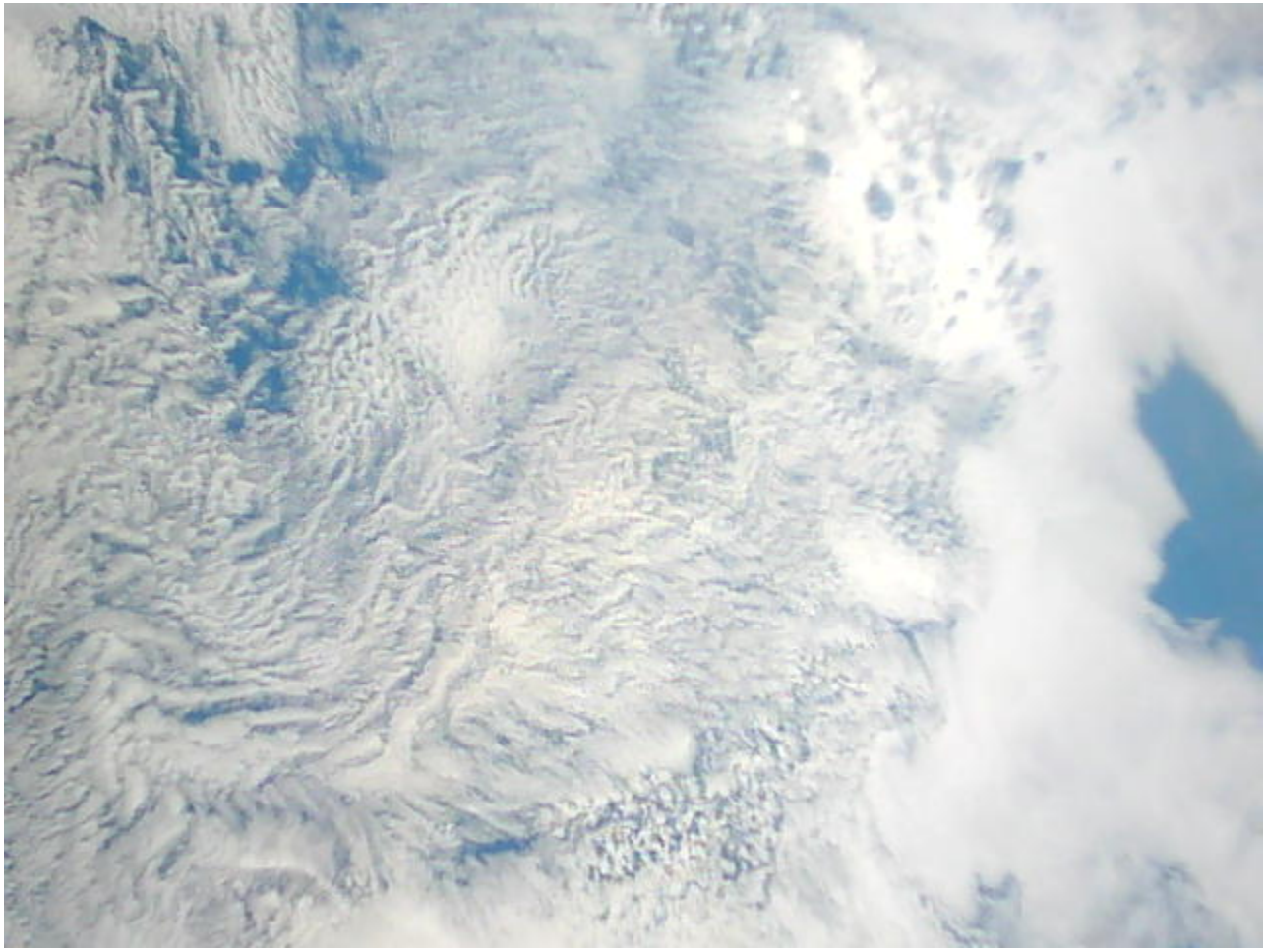
Lessons Learned from ELaNa IV



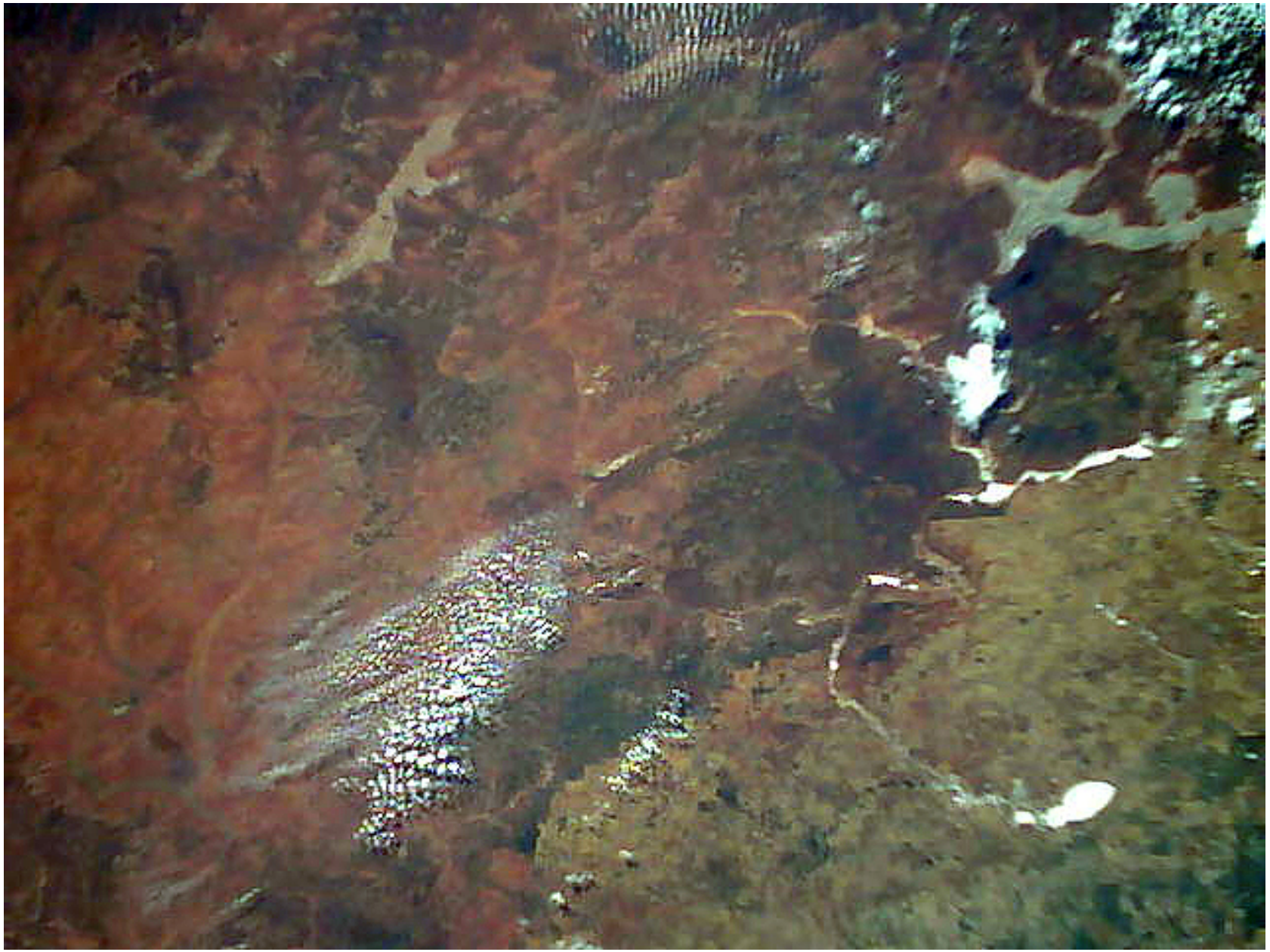
Our first picture of Earth

The North coast of Western Australia near Port Hedland

Lessons Learned from ELaNa IV



Clouds over the ocean.

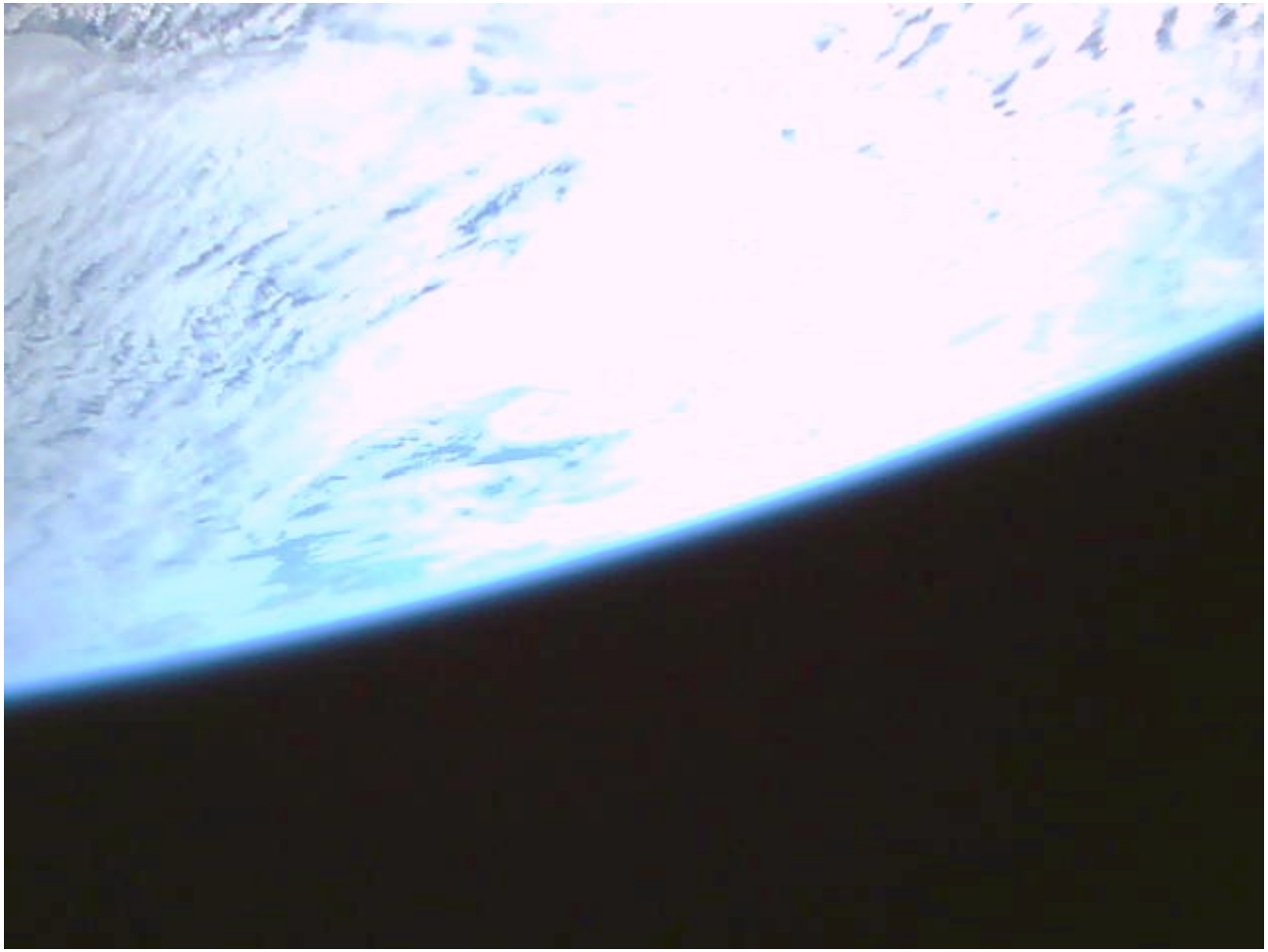


Western Australia north of Perth

Lessons Learned from ELaNa IV

Clouds over the ocean.

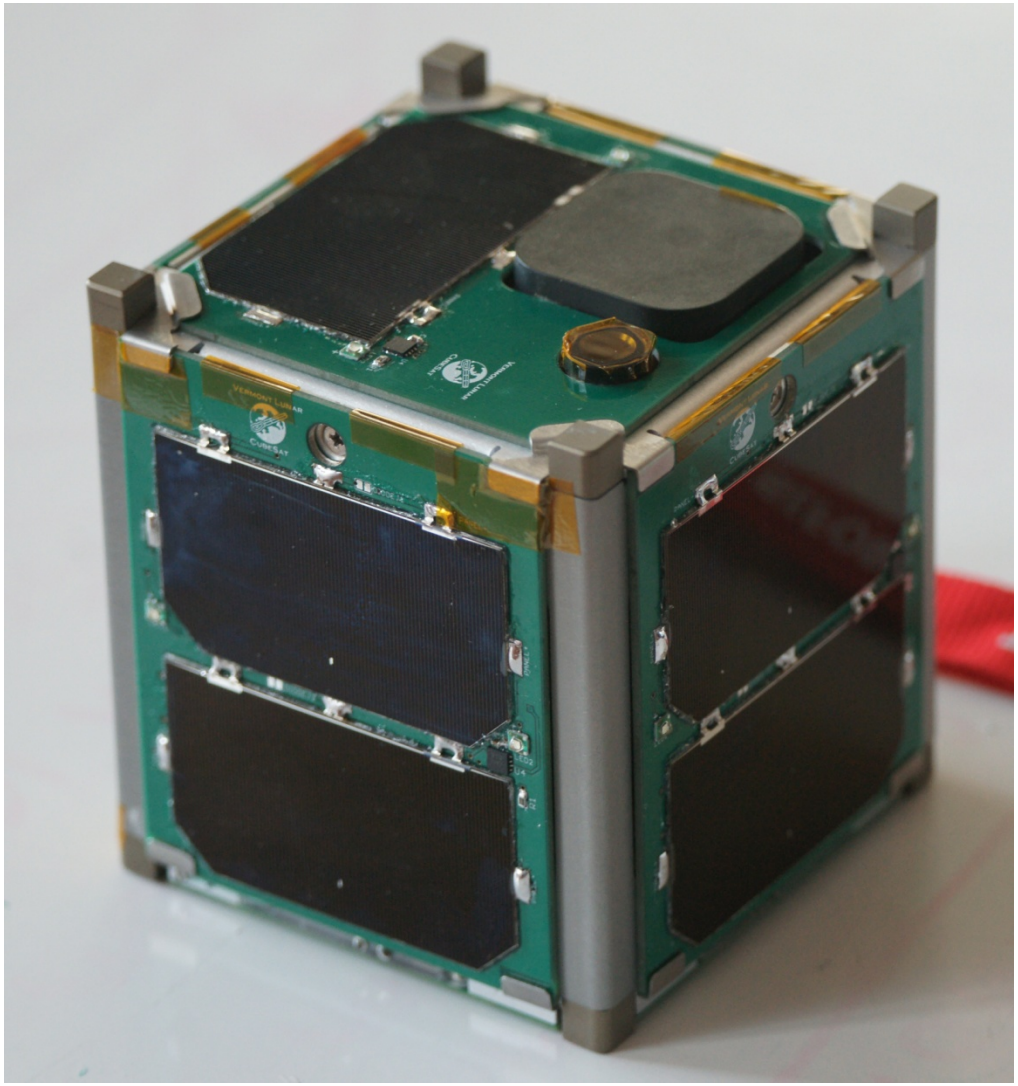
Lessons Learned from ELaNa IV



More clouds.

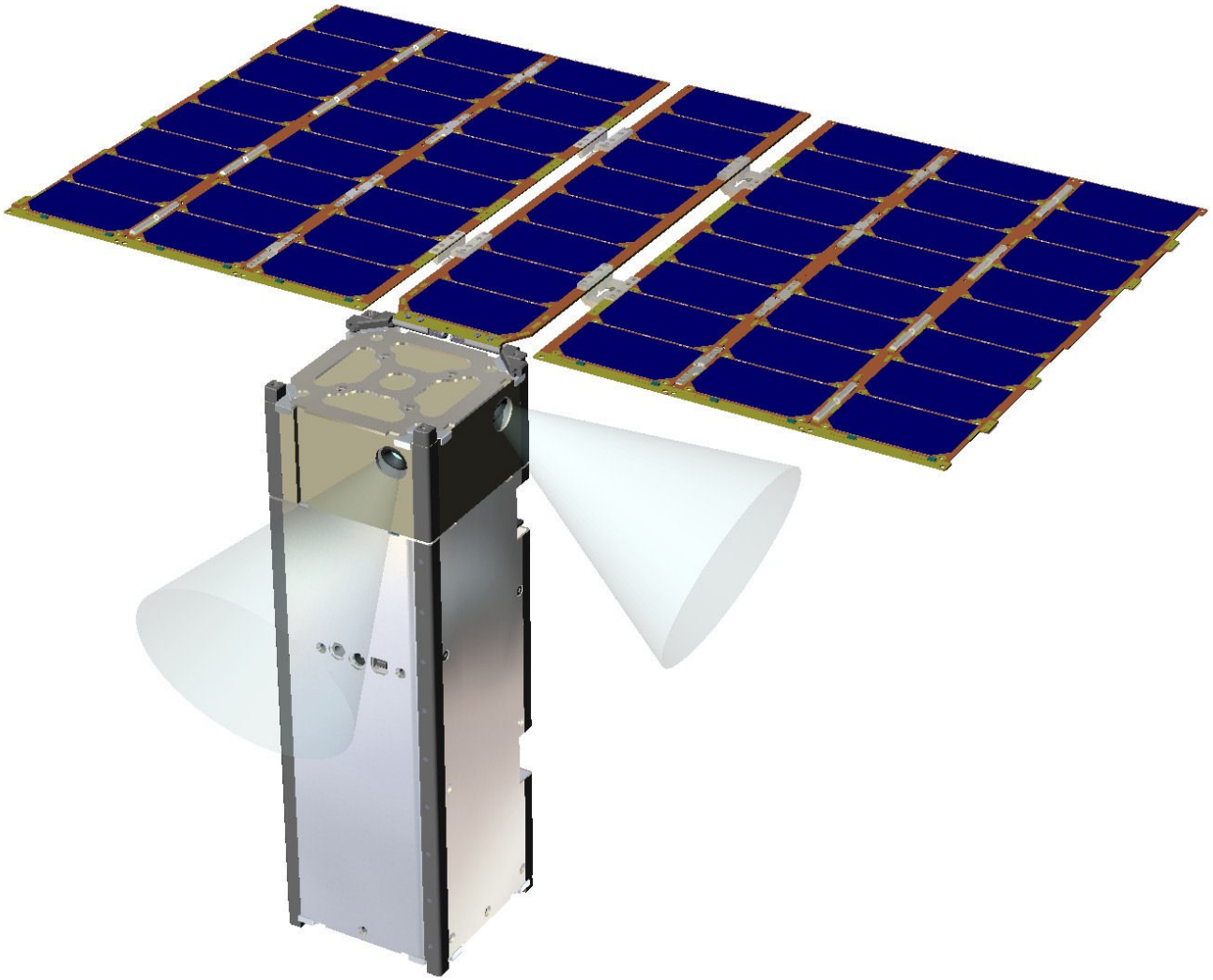
Our ELaNa IV CubeSat

VERMONT TECH



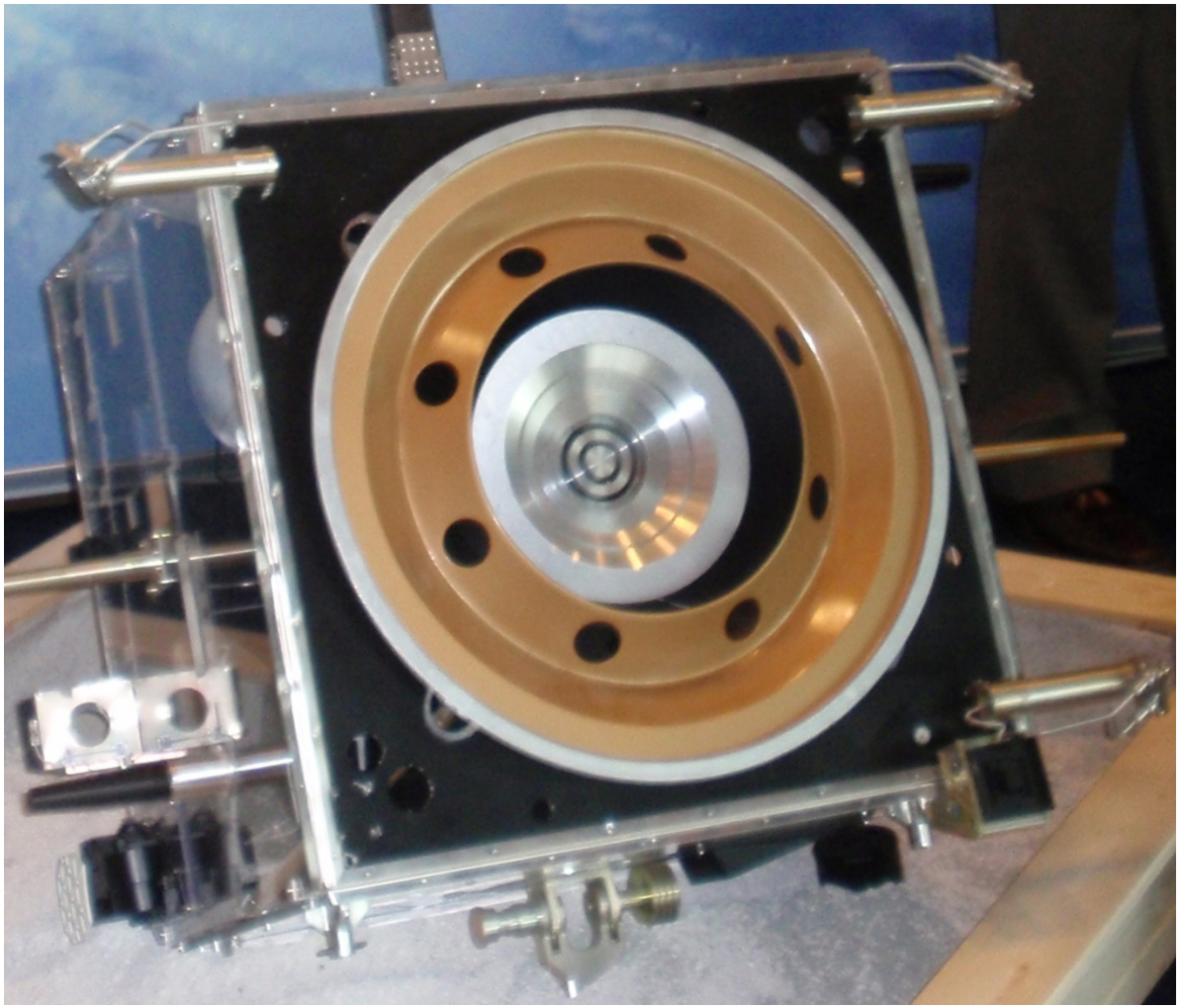
Vermont Lunar CubeSat

Follow on Ion Drive CubeSat



Triple CubeSat with CubeSat Kit 56 W fold out PV panel.
Ion drive with 0.5 kg – 0.75 kg Xenon or Iodine.

1 m Wide, 367kg ESA SMART-1



82 kg xenon @ 150 atmospheres, 1,200W

Busek Ion Thrusters

BRFIT-1

10 W 0.067 mN

BRFIT-3

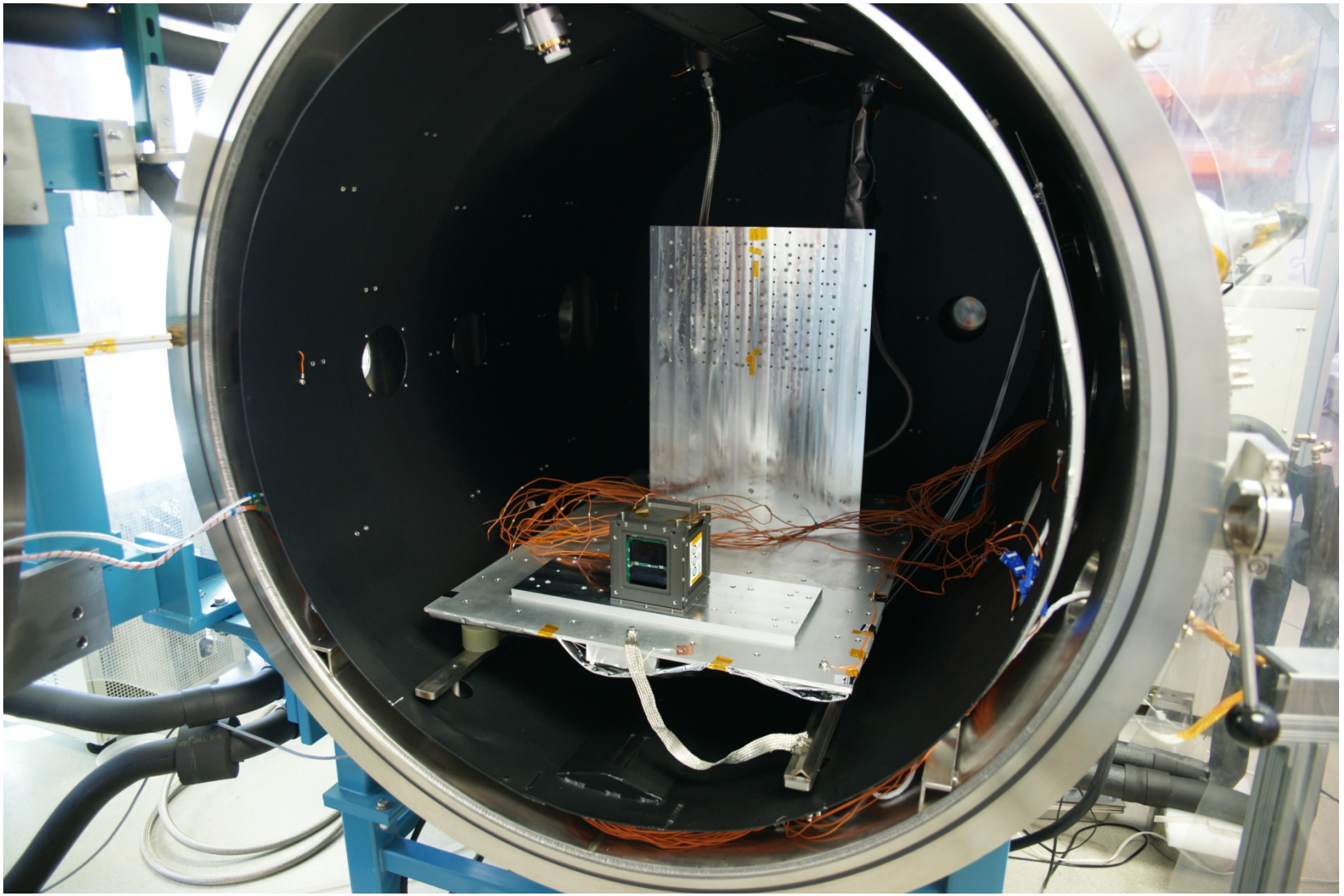
80W 1.6 mN

Software Development Comments

- SPARK caught errors as we refactored the software as we developed greater understanding of the hardware
- SPARK helped the discipline of the software during turnover as some students graduated and were replaced
- Although we did not have a formal development process, without SPARK we probably would not have completed the project with the limited personnel resources and tight time constraint
- Although the CubeSat is limited to 1.3kg, the paperwork might be 130 kg ;)

X and Y axis Vibration Test

Vacuum Thermal Bakeout



ELaNa IV Launch Minotaur 1 – Wallops Island November 19, 2013, 8:15 PM

First two stages are Minuteman II first two stages, third and fourth stages are Pegasus second and third stages

Acknowledgements

- NASA Vermont Space Grant Consortium
- NASA
- Vermont Technical College
- AdaCore, Inc. (GNAT Pro)
- Altran Praxis (SPARK)
- SofCheck (AdaMagic)
- Applied Graphics, Inc. (STK)
- LED Dynamics (PV boards)
- Microstrain (IMU)

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