Lunar IceCube and Vermont's Contribution to Space Research

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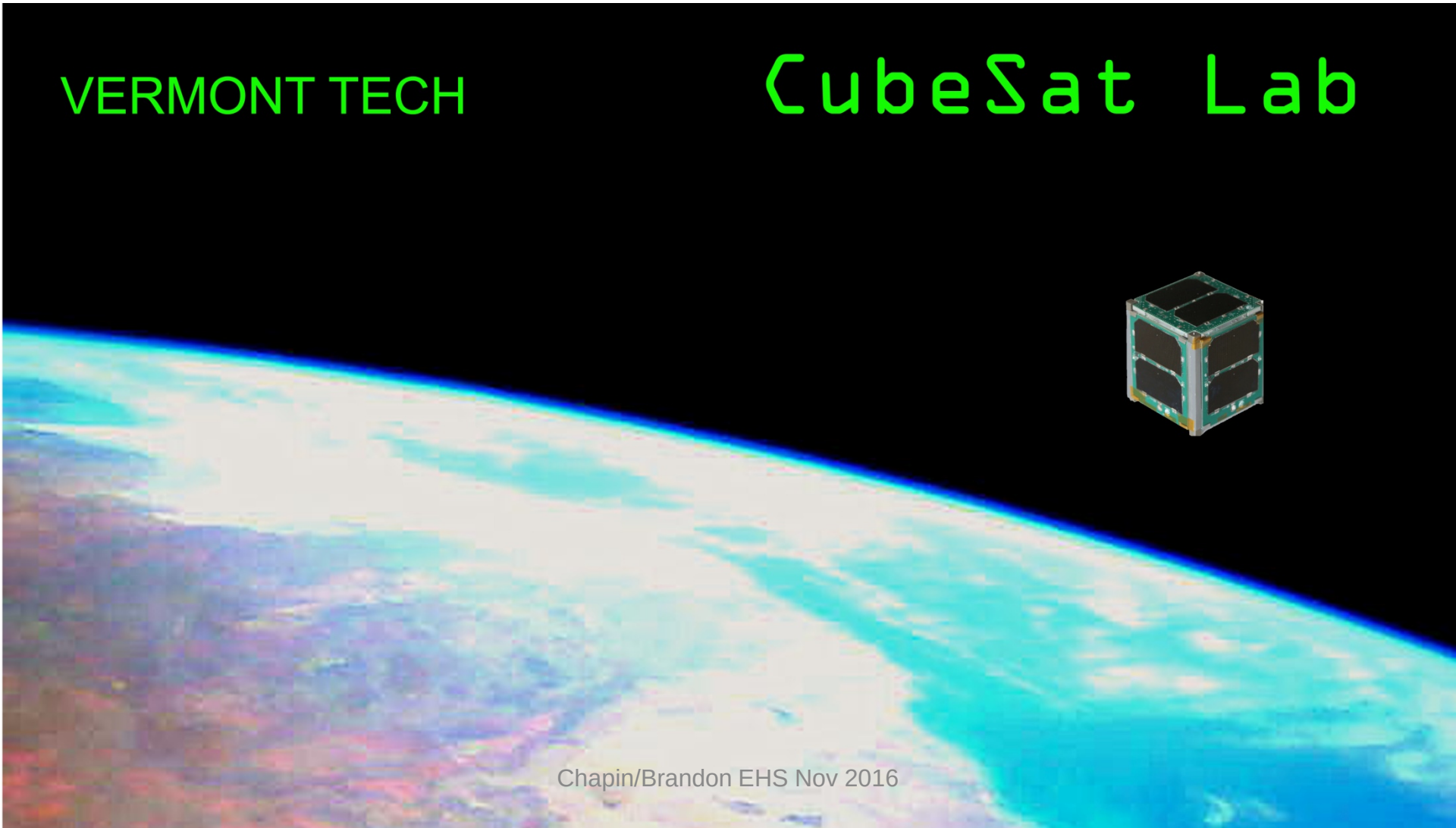
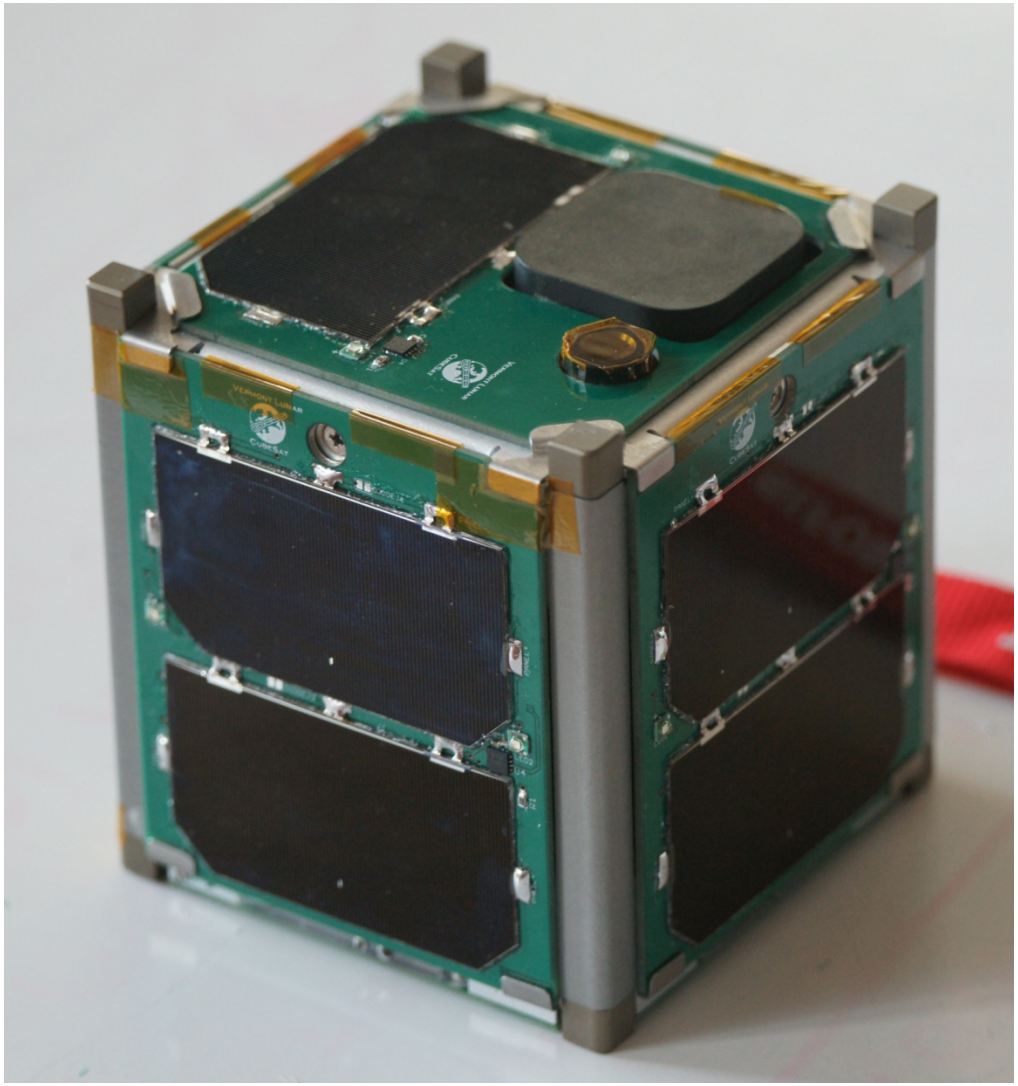


Vermont Lunar CubeSat

VERMONT TECH

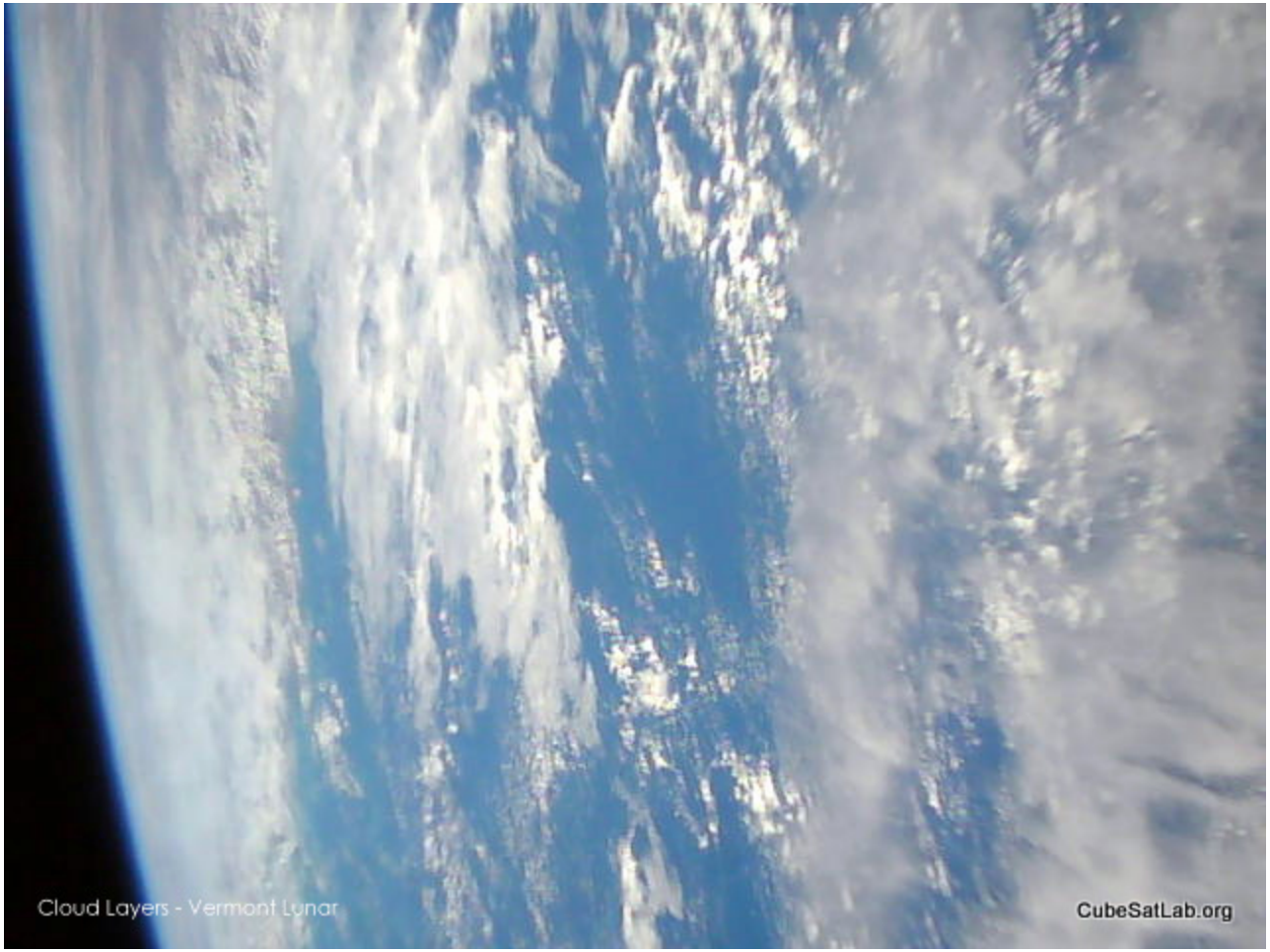


Vermont Lunar CubeSat (10 cm cube, 1 kg)

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

Vermont Lunar CubeSat



Clouds over the ocean, June 2015.

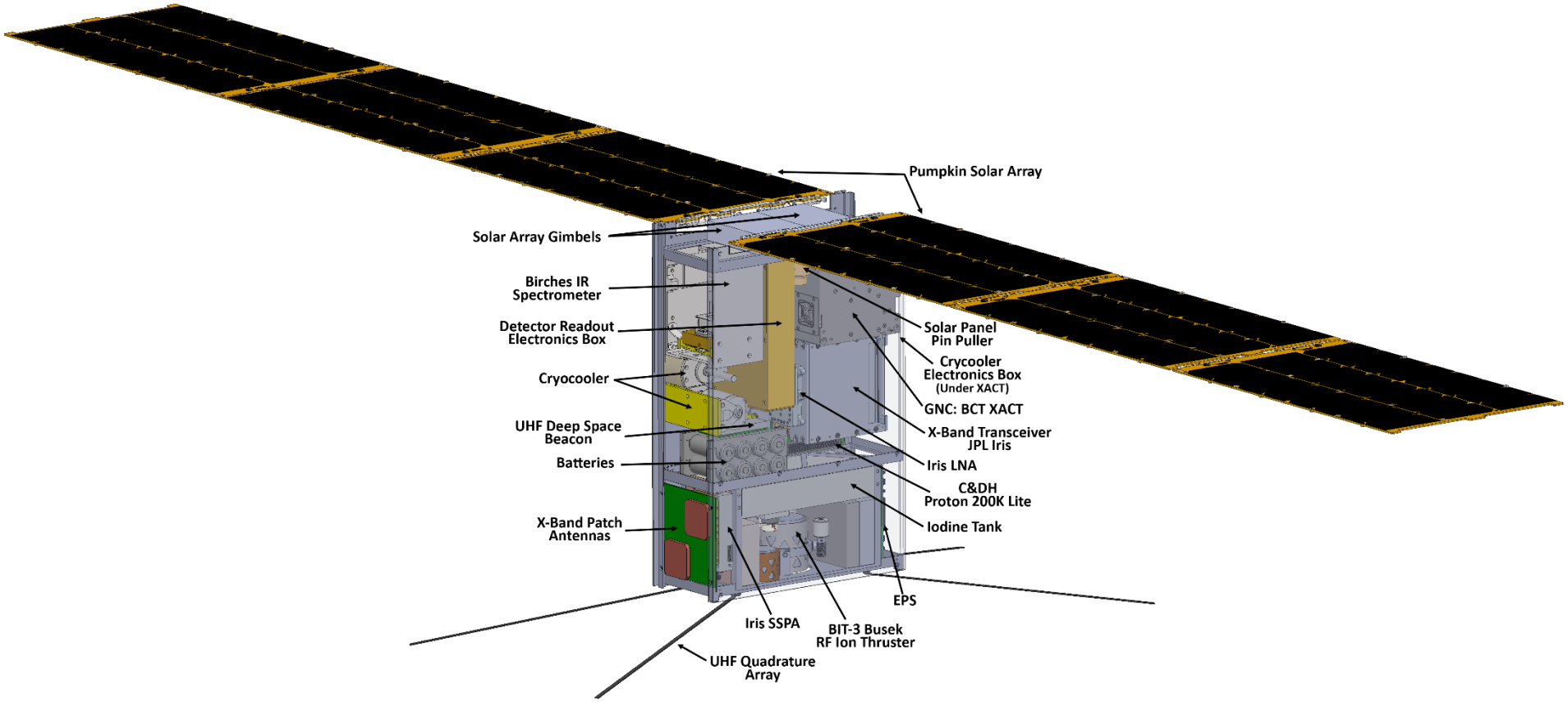
VERMONT TECH

Vermont Lunar CubeSat

It worked until our reentry on November 21, 2015:

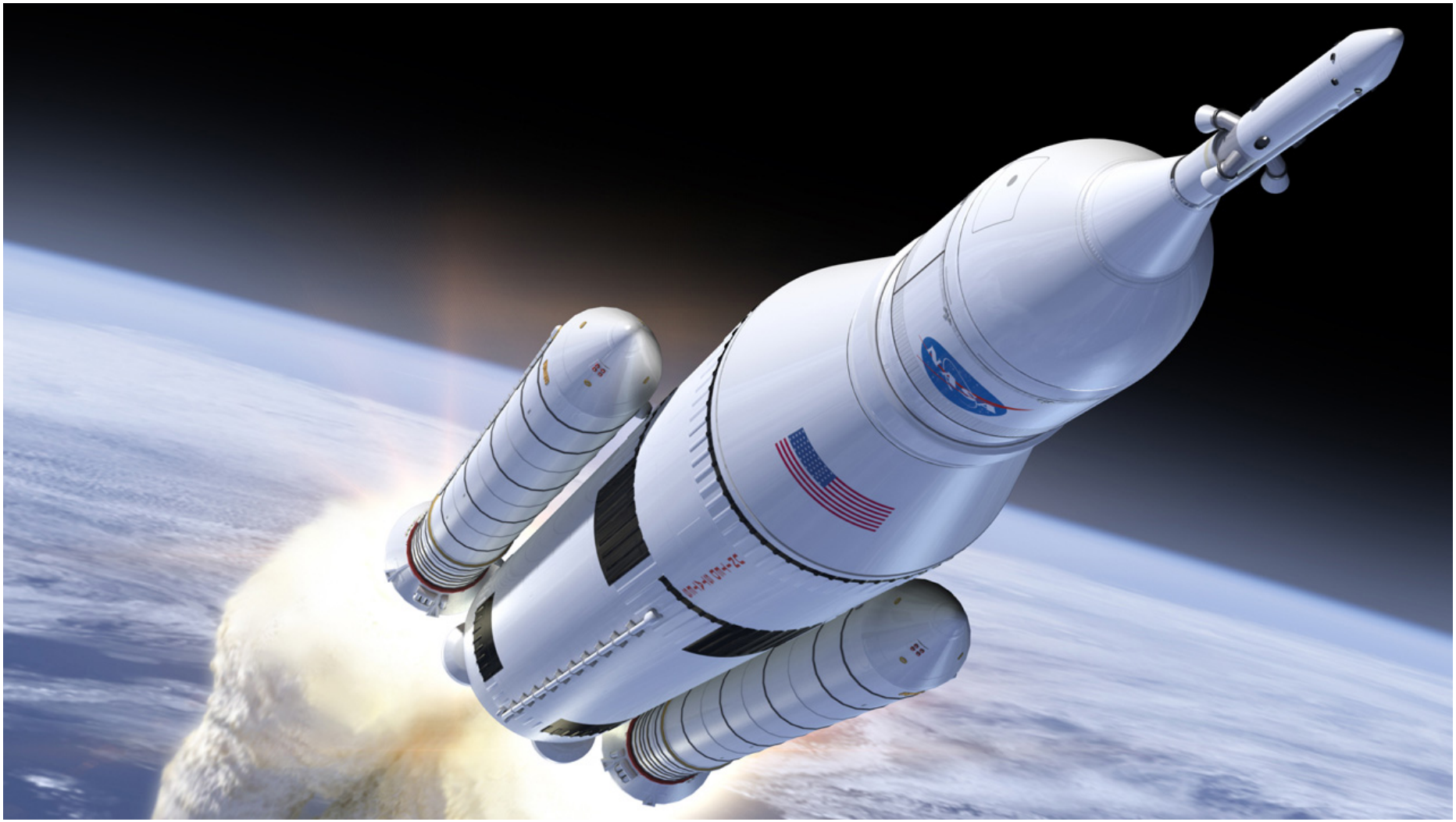
- We completed **11,071 orbits**.
- We travelled about **293,000,000 miles**, equivalent to over 3/4 the distance to Jupiter.
- Our single-unit CubeSat was launched as part of NASA's ELaNa IV on an Air Force ORS-3 Minotaur 1 flight November 19, 2013 to a 500 km altitude, 40.5^{o} inclination orbit and remained in orbit until November 21, 2016. **It is the only one of the 12 ELaNa IV university CubeSats that operated until reentry.**
- We communicated with it the day before reentry.
- We are the only successful university satellite on the east coast.
- **Follow our project at http://www.cubesatlab.org/**

Lunar IceCube (10cm x 20cm x 30cm)



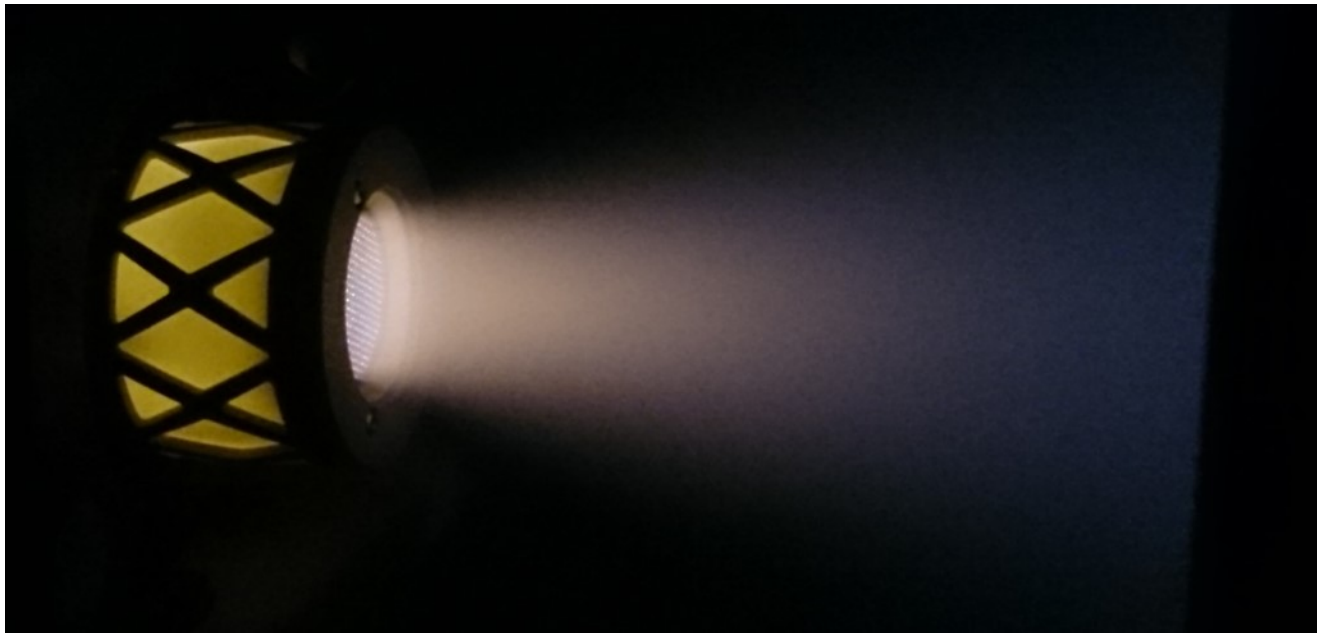
Lunar IceCube 6U CubeSat, Morehead State University, PI., Goddard (BIRCHES IR Spectrometer), JPL (Iris 2 data & navigation radio) & **Vermont Tech (Flight software).** Busek ion drive with 1.5 kg Iodine propellant, Pumpkin photovoltaic array (120 W).

Lunar IceCube Launch Vehicle



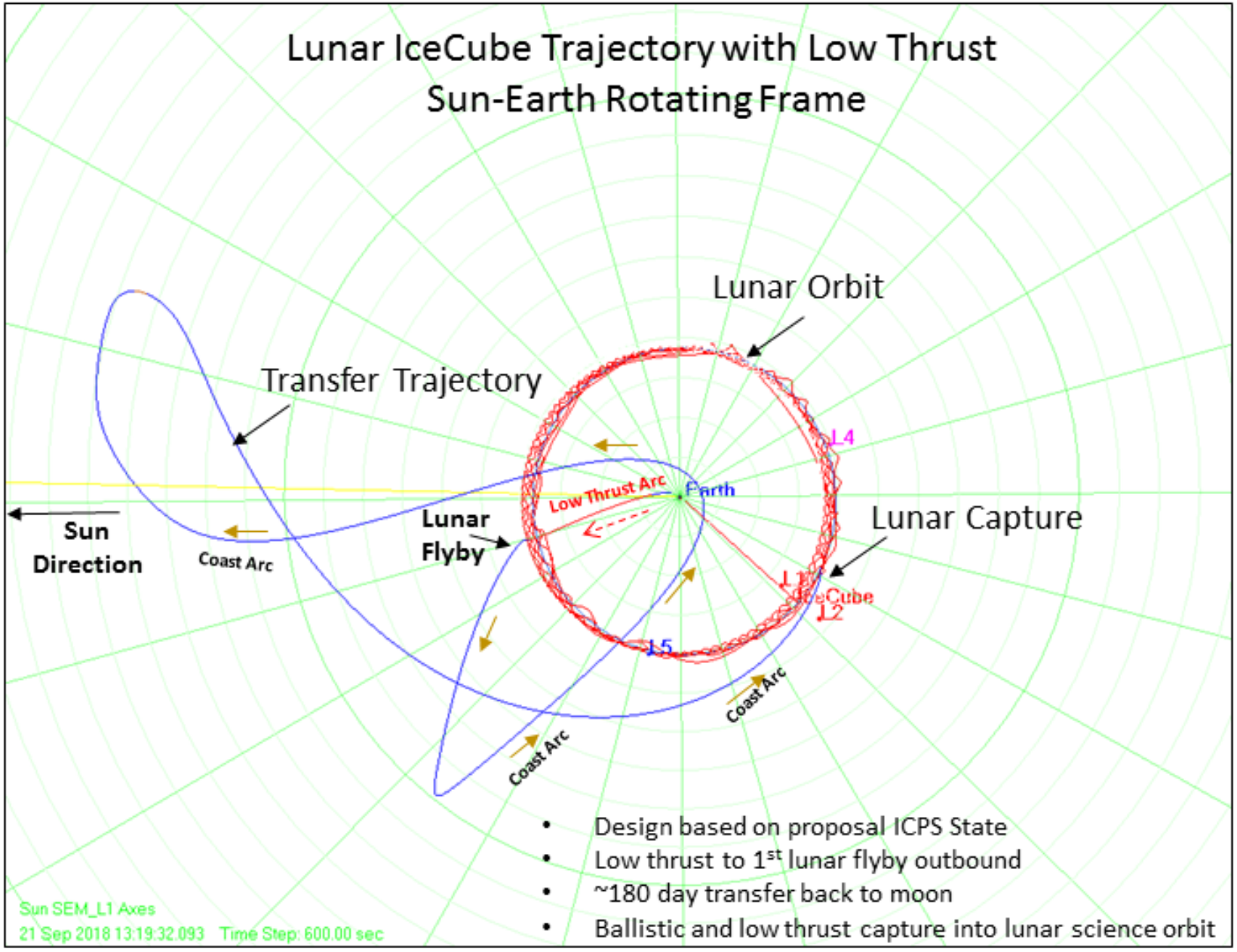
NASA's Space Launch System 2018

Busek Ion Thruster



BIT-3 Iodine Propellant

65W 1.4 mN, 3 cm beam width


Lunar IceCube Trajectory with Low Thrust
Sun-Earth Rotating Frame
Lunar Orbit
Transfer Trajectory
Sun
Direction
Coast Arc
Lunar
Flyby
Low Thrust Arc
Earth
L4
L5
L2
IceCube
Lunar Capture
Coast Arc
Coast Arc
Sun SEM_L1 Axes
21 Sep 2018 13:19:32.093 Time Step: 600.00 sec
• Design based on proposal ICPS State
• Low thrust to 1st lunar flyby outbound
• ~180 day transfer back to moon
• Ballistic and low thrust capture into lunar science orbit

Our Ground Station

The 70m Dish at Goldstone, California

Mars Science Laboratory Sol-200 Memory Anomaly

- Six months after landing on Mars, uncorrectable errors in the NAND flash memory *led to an inability of the Mars Science Laboratory (MSL) prime computer to turn off for its normal recharge session*.

- This potentially fatal error was apparently due to two pieces of its C software having pointers which pointed to the same memory. Curiosity has about 500 kLOC written in C.
- ***SPARK/Ada would have prevented this failure*** (in a 2.5 billion dollar spacecraft).

Ariane 5 initial flight failure:

Good

Bad, 37 seconds later

Ariane 5 initial flight failure:

- Software reused from Ariane 4.
- *The greater horizontal acceleration caused a data conversion from a 64-bit floating point number to a 16-bit signed integer value to overflow and cause a hardware exception.*
- Efficiency considerations had omitted range checks for this particular variable, though conversions of other variables in the code were protected.
- *The exception halted the reference platforms, resulting in the destruction of the flight.*
- Financial loss close to $500,000,000.
- ***SPARK/Ada would have prevented this failure***

Boeing 787

Boeing 787 generator control computer:

- There are two generators for each of two engines, each with its own control computer.
- The computer keeps count of power-on time in centiseconds in a 32 bit register
- *Just after 8 months, the register overflows. Each computer goes into "safe" mode shutting down its generator resulting in a complete power failure, causing loss of control of the aircraft*
- The FAA Airworthiness Directive says to shut off the power before 8 months as the solution
- ***SPARK/Ada would have prevented this failure***

Acknowledgements

- NASA Vermont Space Grant Consortium
- NASA
- Vermont Technical College
- AdaCore, Inc. (GNAT Pro, SPARK Pro)
- Morehead State University
- Applied Graphics, Inc. (STK)
- Busek (BIT-3 Iodine ion drive)

http://www.cubesatlab.org/