Cislunar Explorers Mission Update

Enabling Low Cost Interplanetary SmallSat Missions

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CubeSat
Workshop 2020

Cislunar Explorers Team Organization

- **Cornell University's Space Systems Design Studio (SSDS)**
  - Principal Investigators: Prof. Mason Peck and Dr. Curran Muhlberger
  - Mission Manager: Aaron Zucherman, PhD Student
  - Other members: ~18 Cornell Students
- **National Space Society**
  - NSS Liaison: Dr. Dean Larson

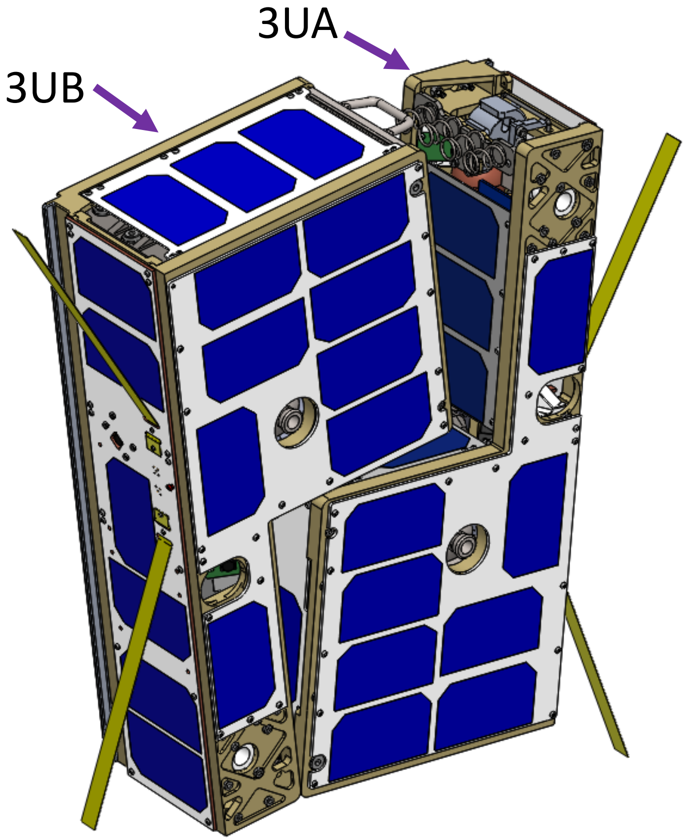
Cislunar Explorers Mission Background

- **NASA's CubeQuest Challenge**
  - 3rd place at Ground Tournament (GT) 1 in 2015
  - 1st place at GT2 in 2016
  - 2nd place at GT3 in 2016
  - 1st place at final GT in 2019
- **CubeQuest Lunar Derby**
  - Achieve Lunar Orbit Prize
  - Spacecraft Longevity Prize
- **1 of 13 6U CubeSats on Artemis-1**
  - Formally EM-1
  - First Lunch of NASA's SLS rocket

Images Curtesy of NASA

Cislunar Explorers Design Overview

- **Technology Demonstrator**
  - No science payload
  - Redundant spacecraft
- **Spin-Stabilized Attitude Control System**
- **Water Electrolysis Propulsion System**
  - Demonstrate potential In Situ Resource Utilization System
- **Optical Navigation System**
  - Low cost position and attitude determination
  - Triangulation using celestial bodies
- **ChipSat**
  - Rideshare on a rideshare
  - Self-contained Satellite



Cislunar Explorers Model

Cislunar Explorers Mission Goals

- **Lower barriers to exploring cislunar and interplanetary space**
  - Test technologies that can be leveraged by future missions
  - Commercial off-the-shelf (COTS) parts wherever possible
  - Open-source design
- **Mission Objectives**
  1. Electrolysis propulsion demo
  2. Optical navigation demo
  3. Reach Lunar Orbit
  4. Femtosatellite operations beyond LEO demo

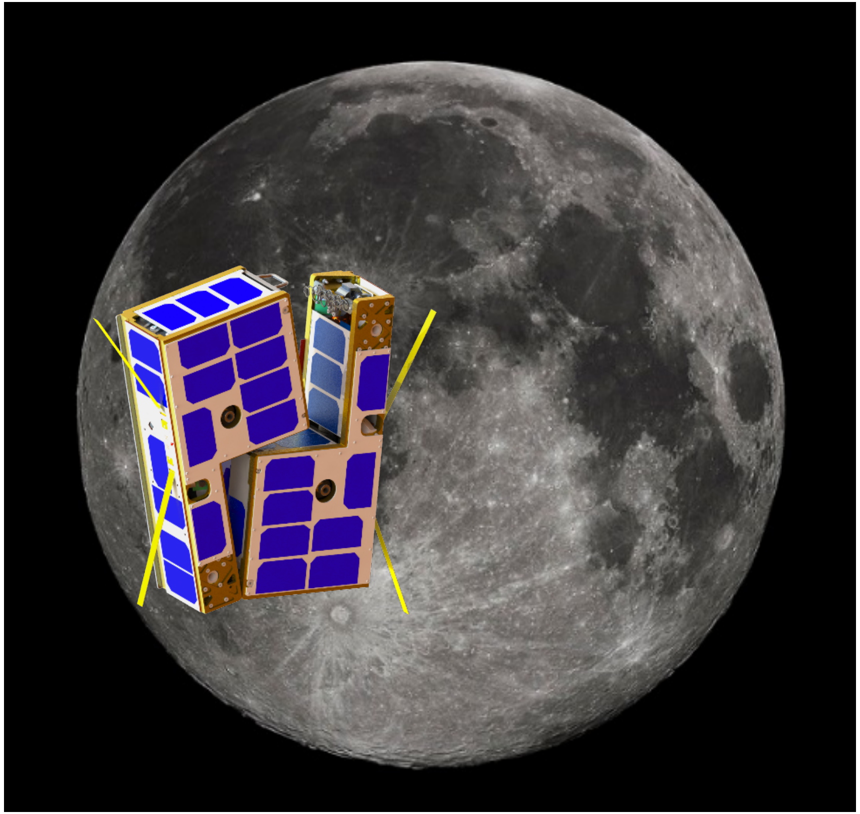
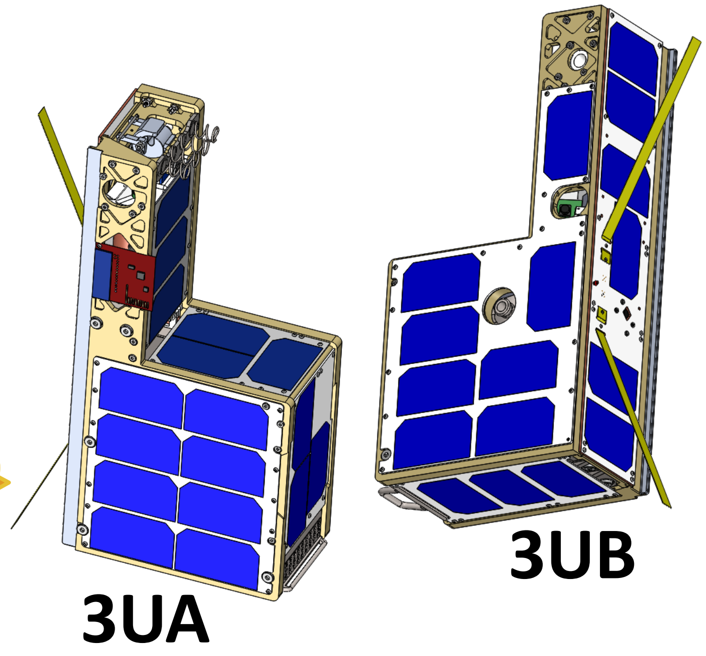
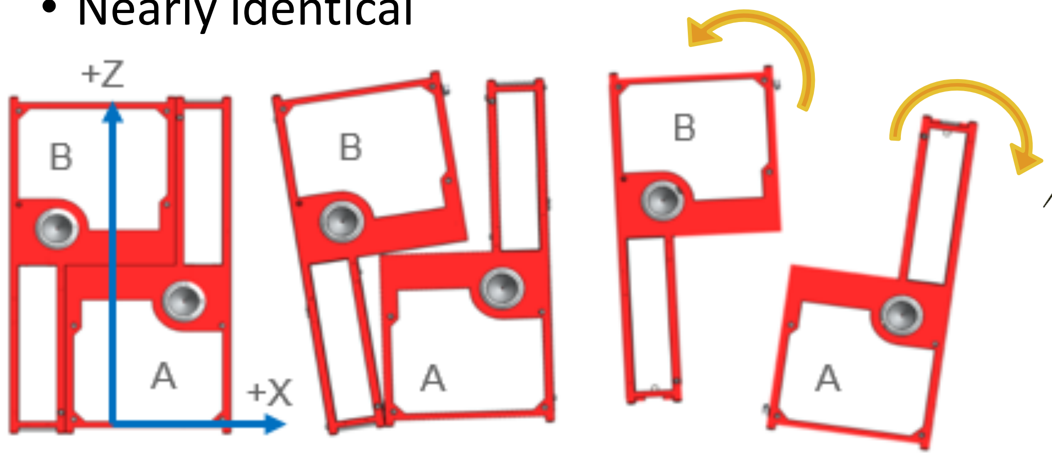


Image Curtesy of NASA

Cislunar Explorers Deployment

- **Spring-loaded separation releases both into opposite spins providing passive spin stabilization**
- **Redundant Spacecraft**
  - Stowed: 6U CubeSat
  - Deployed: 2x 3U volume L-shaped NanoSats
  - Nearly identical

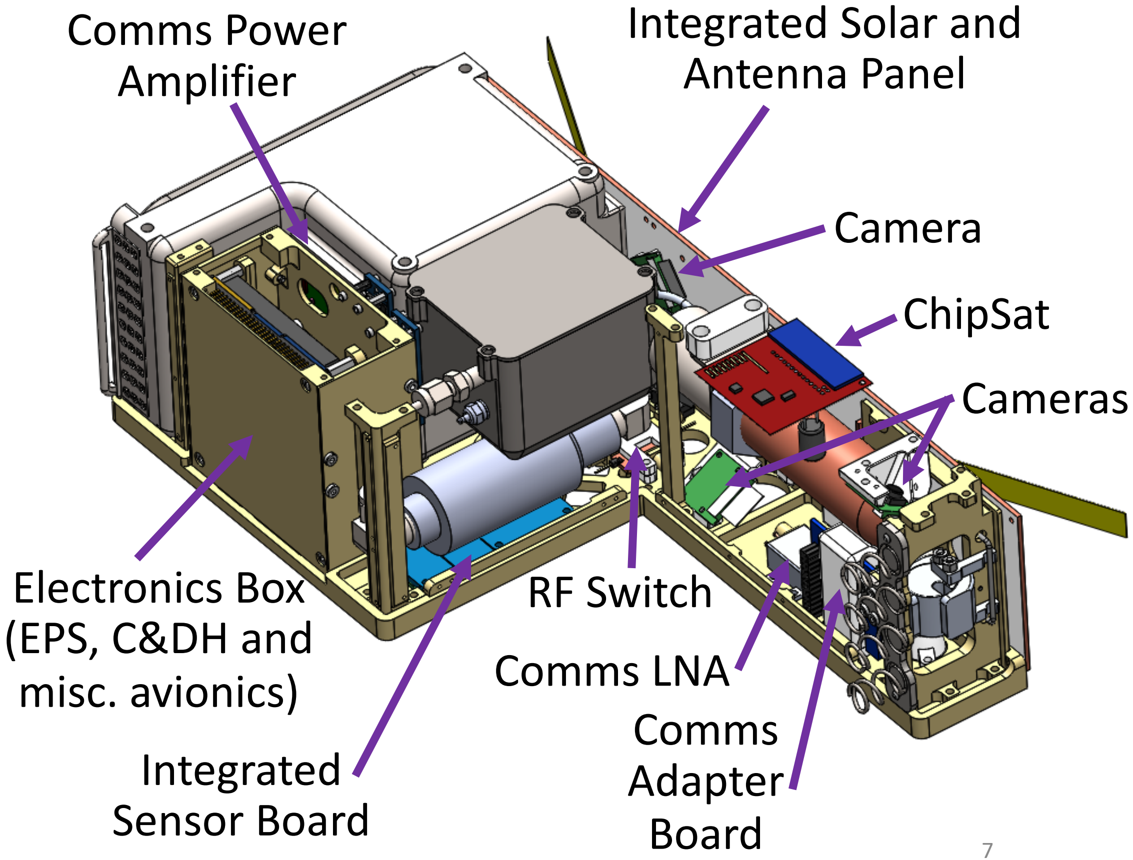




Cislunar Explorers Separation

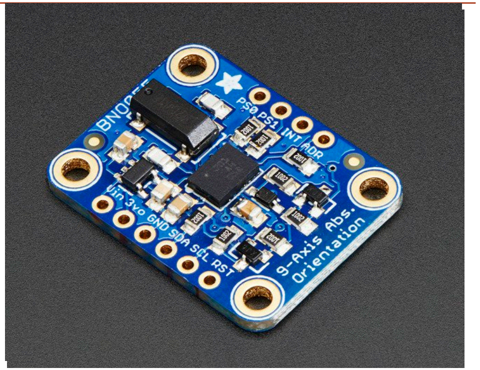
Cislunar Explorers Subsystems

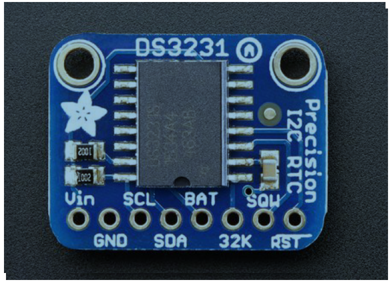
- **Command and Data Handling (C&DH)**
  - Raspberry Pi Model A+
- **Electrical Power System (EPS)**
  - ZTJ Photovoltaic Cells
  - GomSpace Nanopower p31us
  - Integrated 18650 lithium-ion batteries
- **Communications**
  - RX/TX: Amateur radio UHF 70 cm band
  - Spring tape deployable antennas
- **Flight Software**
  - F-Prime open source software
  - Developed at JPL

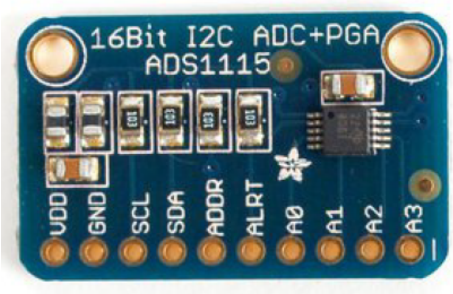


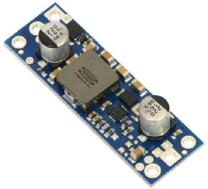
COTS Sensors and Avionics

- **Switch**: Jameco Subminiature E Series Switches
- **Pressure Sensor**: Cynergy3 IPSU Industrial Pressure Transducer
- **Inertial Measurement Unit**: Adafruit 9-DOF IMU BNO055 Breakout
- **Real Time Clock:** Adafruit DS3231 Precision RTC Breakout
- **Analog to Digital Converter:** Adafruit ADS1115
- **Voltage regulator:** U3V50AHV



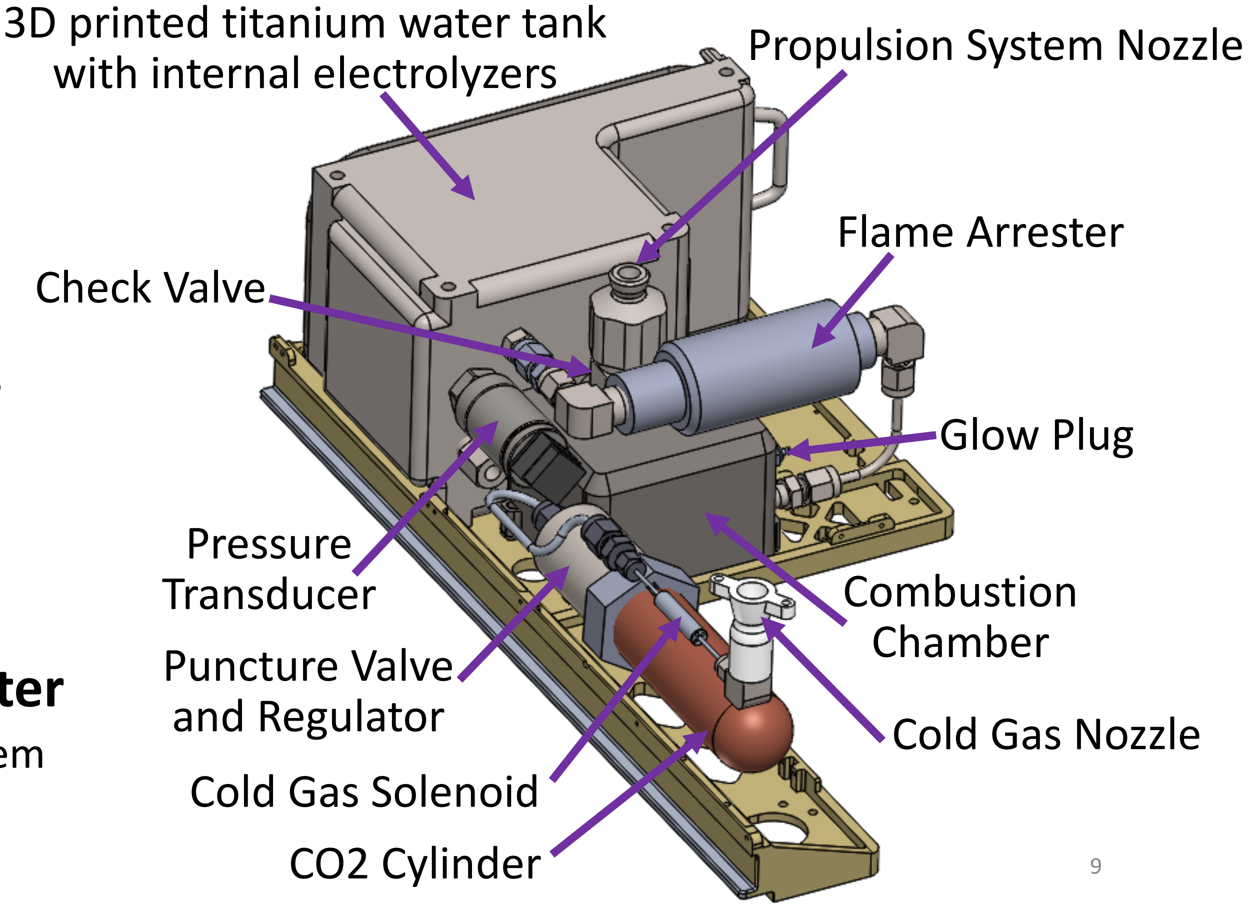




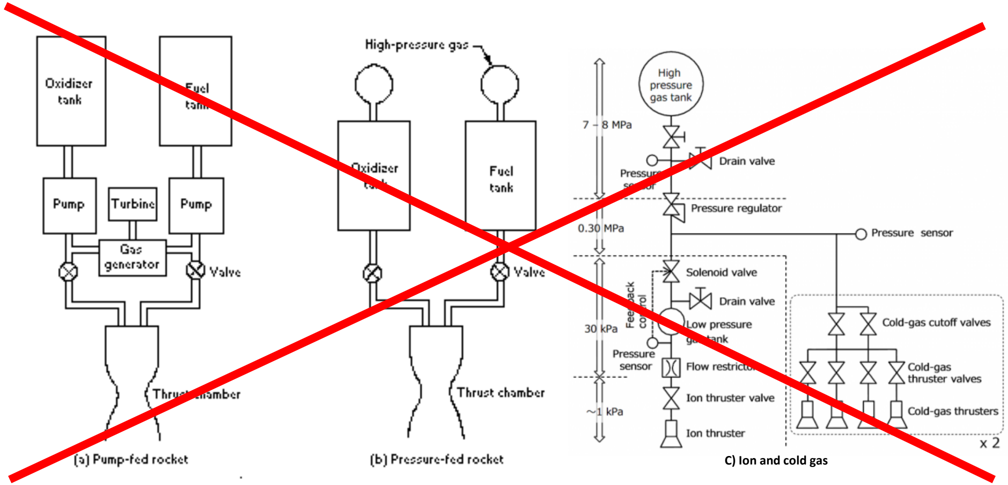


Propulsion and Attitude Control

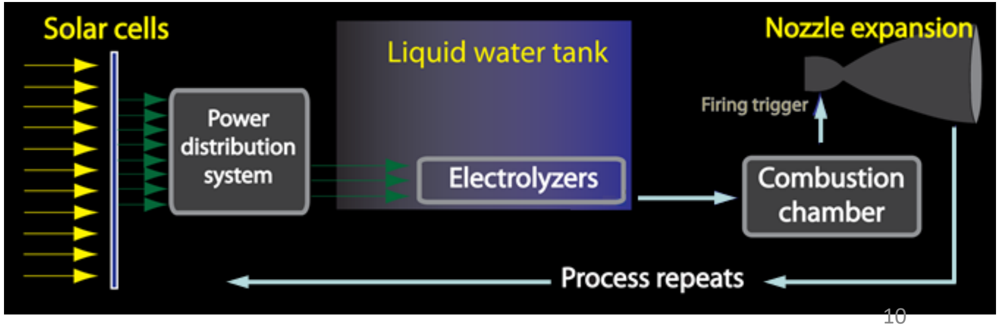
- **Electrolysis Propulsion System**
  - ~1 kg of water propellant
  - > 500 m/s of ΔV
- **Passive Attitude Control**
  - Sloshing of water provides damping for spin-stabilization
  - Spinning separates water from electrolyzed gas
- **Single CO2 cold gas thruster**
  - “Active” attitude control system
  - Simple in-house design



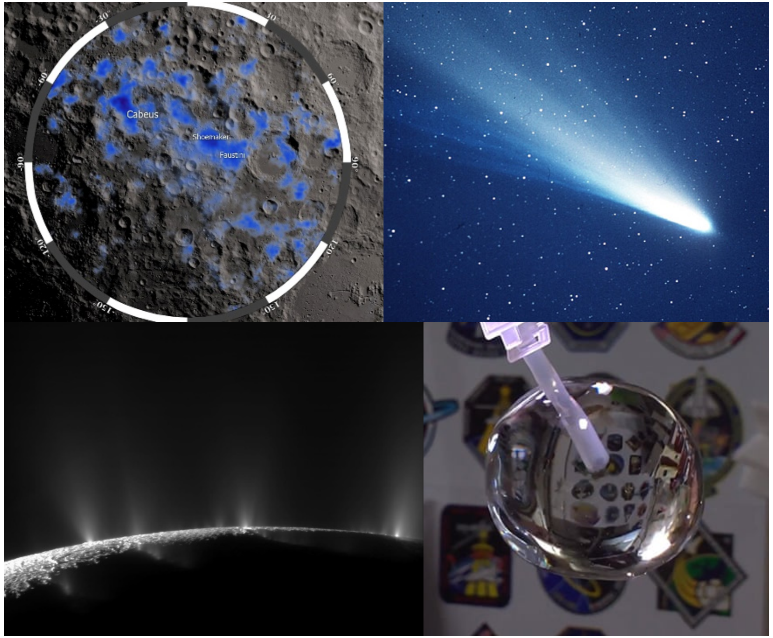
- **Simple construction and operation**
  - No pumps or actuated components
  - No cryogenic systems
  - Low power consumption (~6W)
  - Low pressure
- **Water as a propellent**
  - Non-toxic
  - Inert
- **Subsystem Synergy**
  - Damping for spin-stabilization
  - Propellant tank serves as heat sink
  - Tank is structural element of spacecraft
  - Water is a good radiation shield



Images courtesy of NASA



Electrolysis Propulsion (2 of 2)

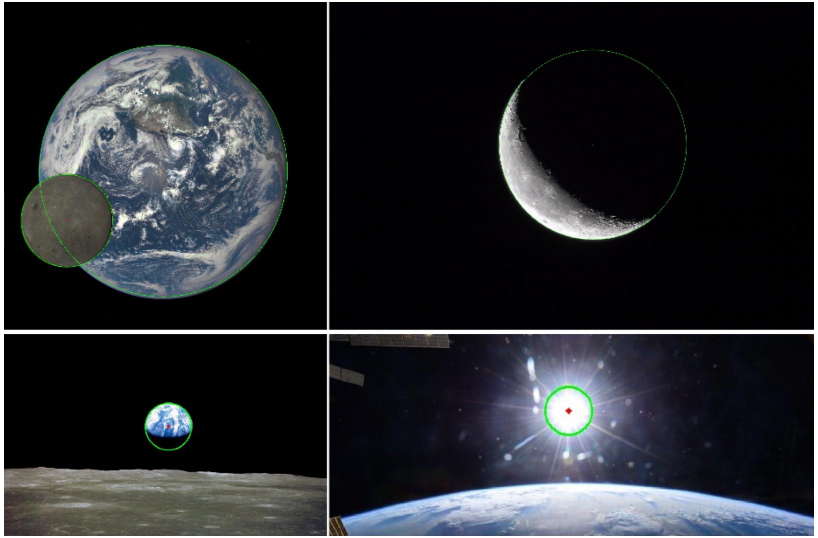


Images Curtesy of NASA

- **Highly Scalable**
- **High thrust-per-unit-power**
- **In Situ Resource Utilization (ISRU):** using available materials to replenish supplies
  - Water is relatively abundant in the solar system
  - Targets with water have scientific/commercial value
  - Additional use for a resource necessary for human activity
  - Greater efficiency and lower infostructure requirements for using water as fuel than liquid oxygen and hydrogen systems
  - Could turn delta-v limits into delta-v increments

Optical Navigation (1 of 2)

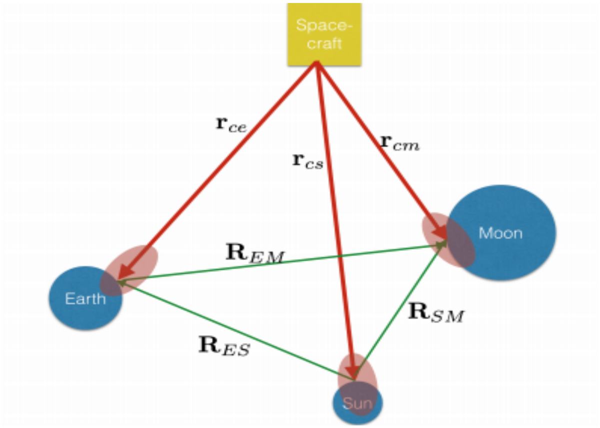
- **Autonomous position and attitude determination**
- **Triangulation using celestial bodies**
  - Captures images of the Sun, Earth, and Moon
  - Compares apparent size and angular separation with a table of ephemerides
- **Apply estimation methods overtime for accuracy**
  - Kalman filter, ext.
  - < 100km expected error by end of mission
- **Applicable to other environments**
  - Gas giant moon systems
- **Robust navigation within planetary systems**
  - Utilize low-cost optics
  - Little to no impact on mission operations

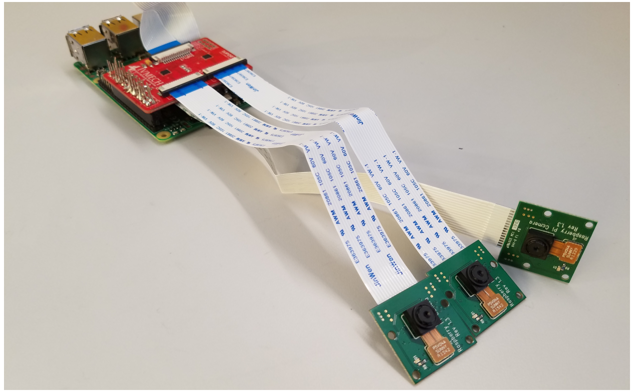


Apparent Size of Earth Chart

Distance to Earth at Burn	Apparent Diameter of Earth	Computed Diameter of Earth
1,100,017 km	30 pixels	30 pixels
594,600 km	55 pixels	54 pixels
368,982 km	88 pixels	86 pixels
28,034 km	1161 pixels	1158 pixels

Optical Navigation (2 of 2)

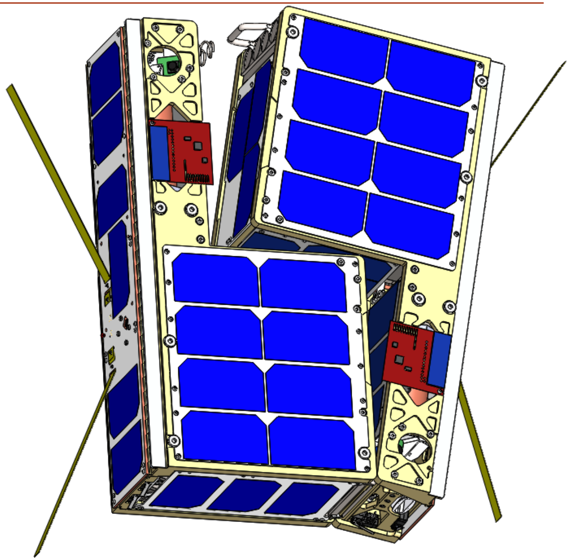




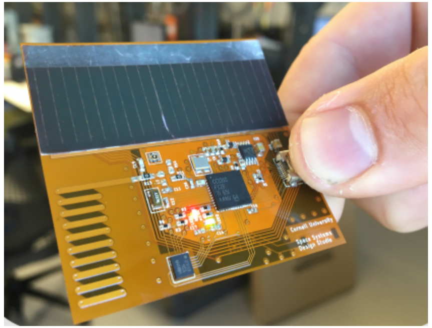
- **Position and attitude from the same sensors**
- **Use of only hobbyist electronics**
  - 3x Raspberry Pi Camera v2 (8 megapixels)
  - Raspberry Pi Camera Multiplexer
  - Real Time Clock
  - Inertial Measurement Unit
- **Does not require constant comms link for tracking**
  - Spacecraft can check in with position
  - Saves power, useful for SmallSats
  - Ground tracking may be impractical for deep space SmallSats
- **Final lunar orbit verified by doppler tracking from multiple ground stations**

ChipSats

- **ChipSats:**
  - Femtosatellites developed at Cornell University's Space Systems Design Studio
  - Includes power, C&DH, sensors, and comms systems on a printed circuit board
  - 22mm x 50.5mm x 1mm
  - Flight heritage on ISS and on KickSat 1 and 2
  - Future Beyond LEO missions:
    - Interplanetary Exploration (see CAESAR)
    - Interstellar Exploration (see Breakthrough Starshot)



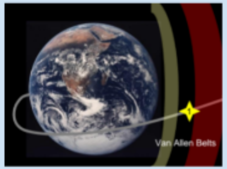
- **Secondary Payload on a Secondary Payload**
  - Fastened to outer surface of each spacecraft
  - "Monarch" - latest iteration of ChipSat design
  - Electrical connections to spacecraft for radio activation and shut-off.
  - Flexible printed circuit board (Kapton)



Mission Operations (1 of 3)

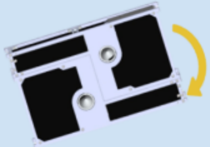
Initialization

CubeSat Deployment (T+0)



Establish Comms (T+5m)

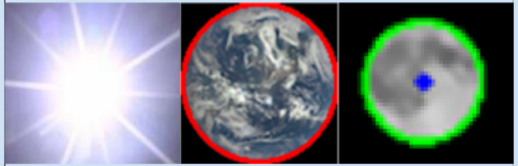
6U Spin-Up (T+1H)



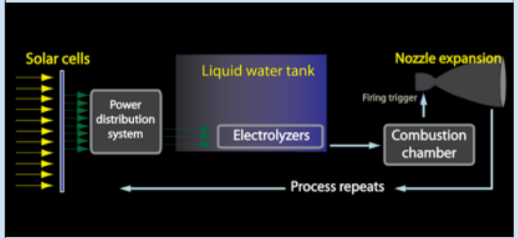
3U Separation (T+2H)

Primary Mission

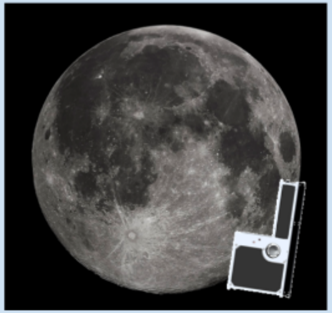
Optical Navigation



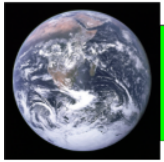
Electrolysis Propulsion



Lunar Orbit

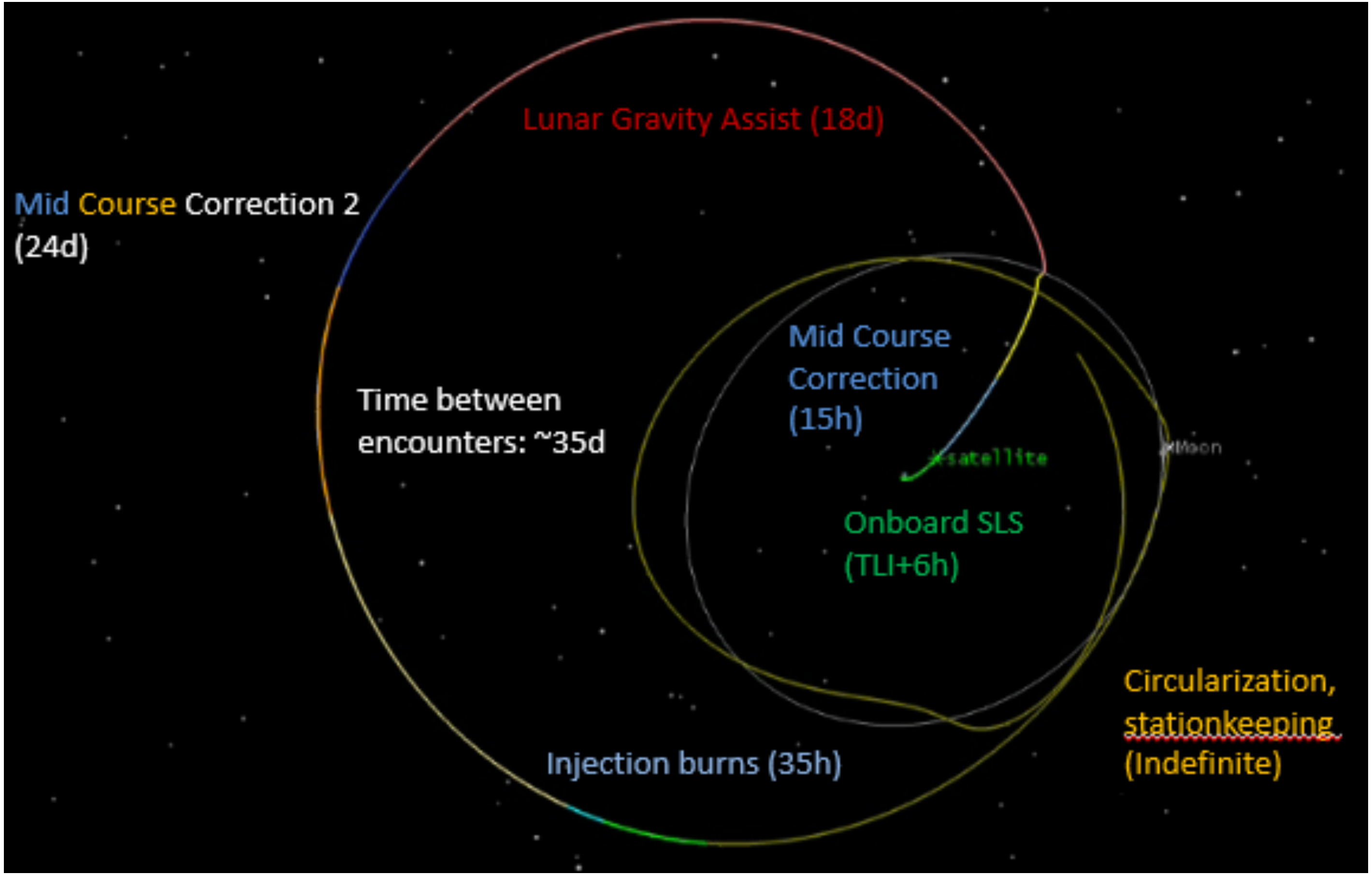


- Apoapsis <10,000 km
- Periapsis >300 km altitude
- Maintain until end-of-life propellant threshold is reached
- Lunar impact disposal with remaining propellant

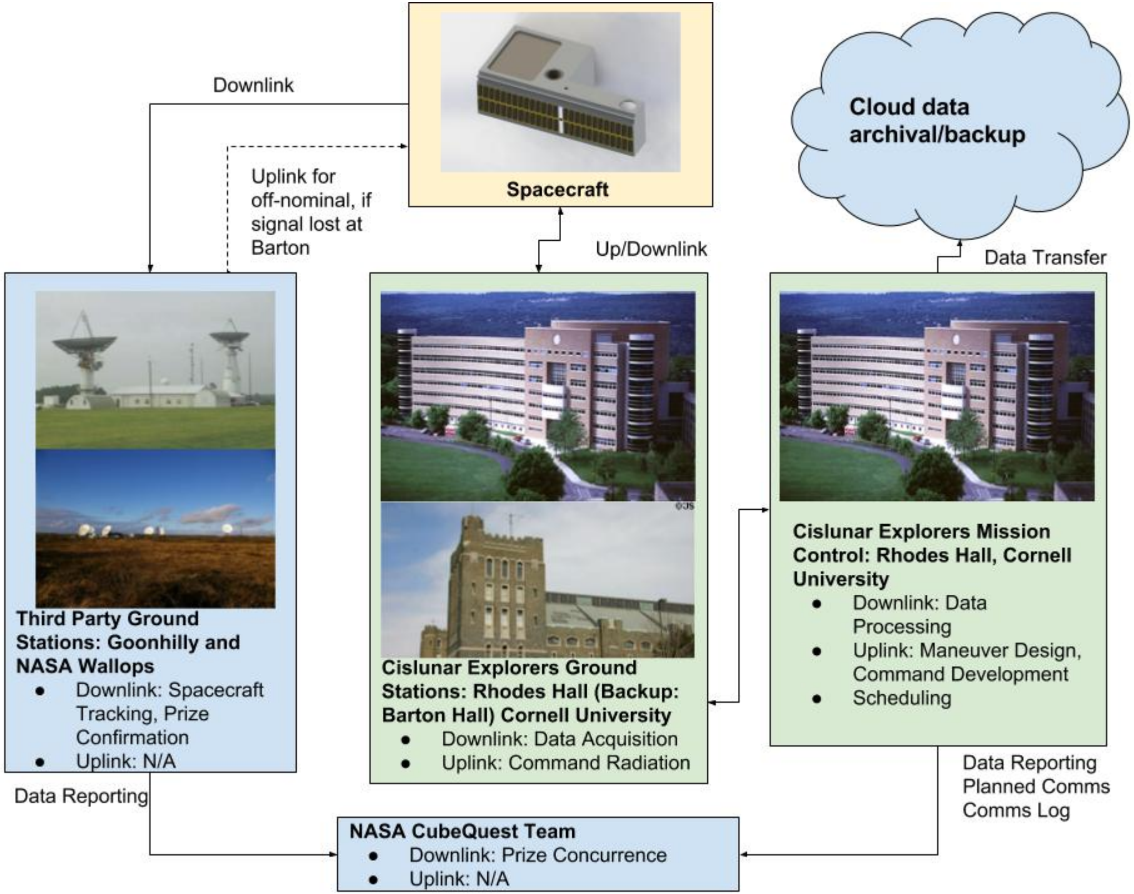


	Initialization (T+0)	Lunar Swingby (T+6.5D)		Ballistic Lunar Trajectory	Lunar Capture (T+~1M)		Station-keeping	End of Life (T+1Y)

Mission Operations (2 of 3)



Mission Operations (3 of 3)



Acknowledgements

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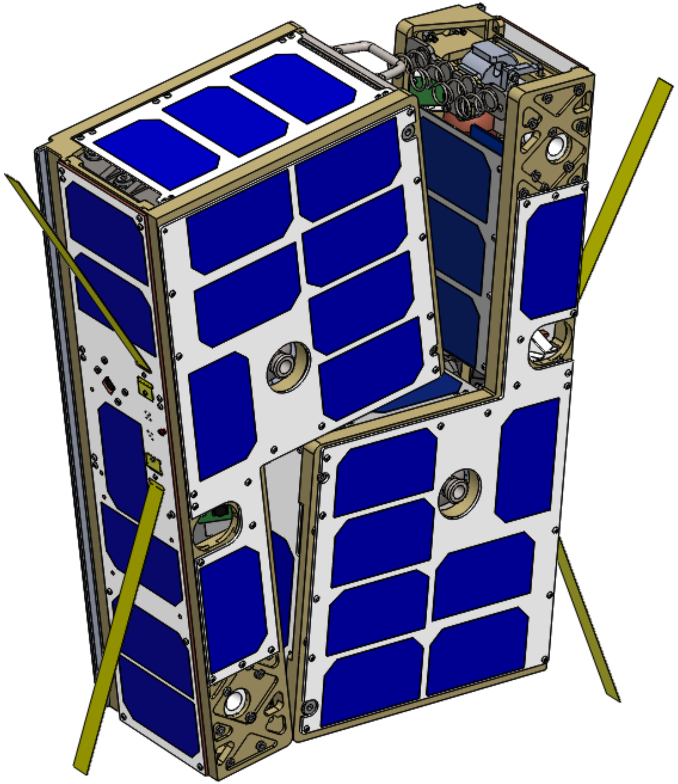
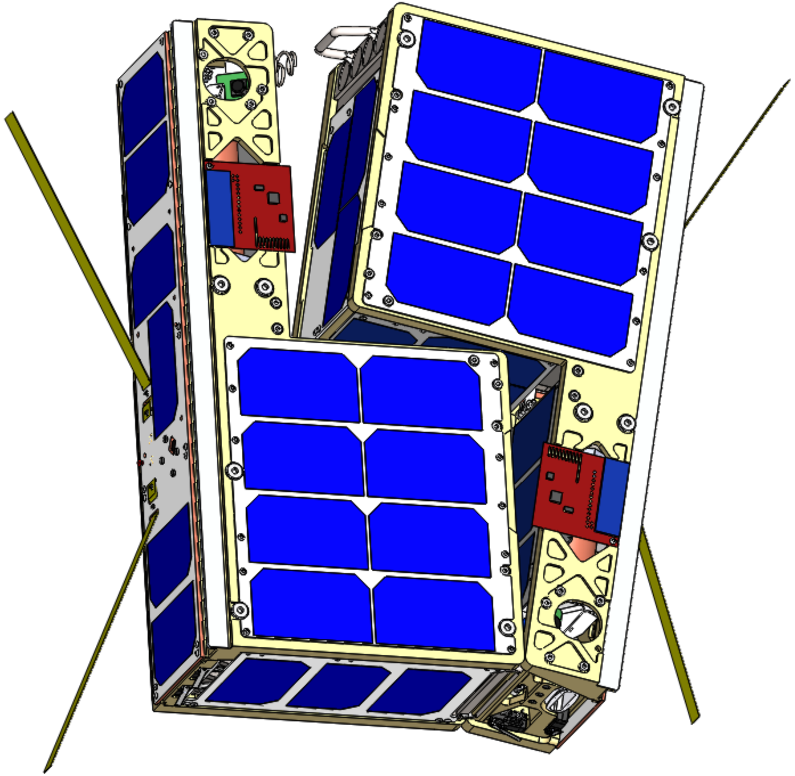
- NASA's Space Technology Mission Directorate for selecting this project for a launch opportunity via their Centennial Challenges CubeQuest program.
- Kyle Doyle for his great contributions to the Cislunar Exporters
- The entire Cornell University student team

Questions?





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