Miniature Lunar Volatiles (MiLuV) Mission: Using a LIDAR Spectrometer to Map Lunar Volatiles

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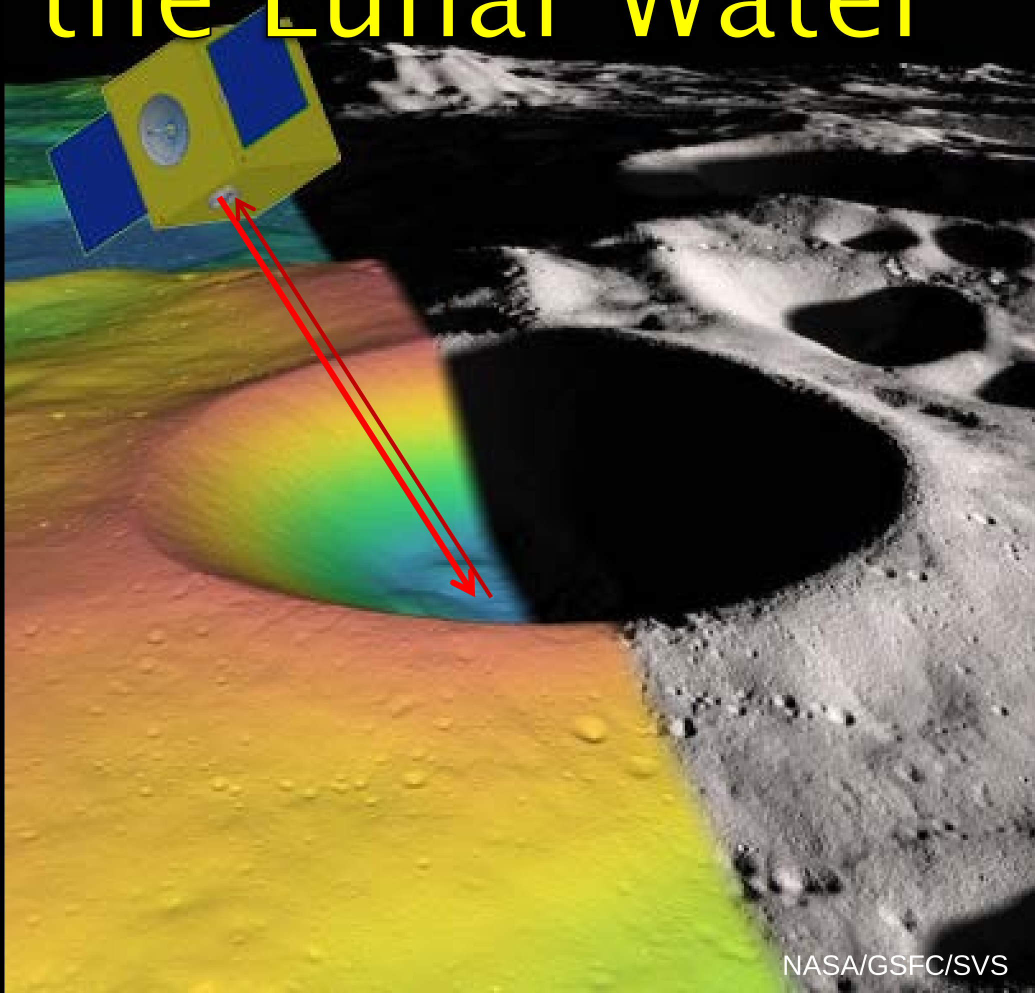
March 18, 2018

ISS024E013418

MiLuV: “Follow the Lunar Water”

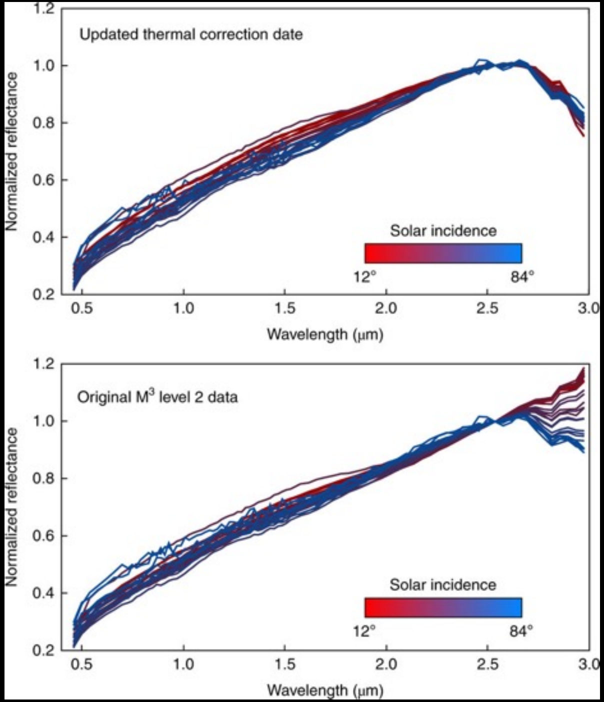
- Science Objectives : Focus on Volatiles
- Spacecraft Concept : Follow LRO/GRAIL
- Mission Architecture : KISS
- Concept of Operations : Map the Moon for 1 year (12 lunations)
- New Technologies : Active 3µm lidar spectrometer, support a return to the Moon as a communications relay

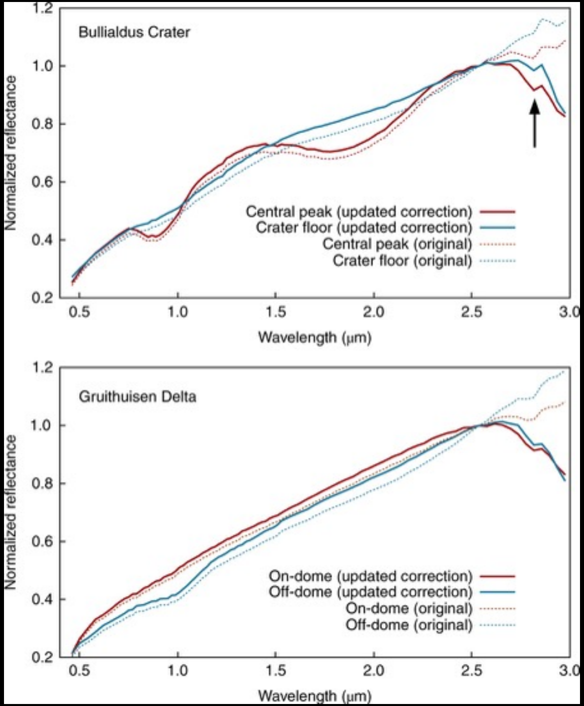


Science Objectives

- Mapping lunar volatiles at the 3.0 and 1.5 μm spectral absorption bands from pole to pole in nadir direction in day and night and in permanent darkness
  - Detecting water ice on surface above 100 parts per million concentration
  - Measuring distribution of surface volatiles in areas of permanent shadow
  - Mapping the global distribution of H_2O/OH from pole to pole
  - Monitoring diurnal cycle of surface H_2O/OH frost

Mobile Volatiles?



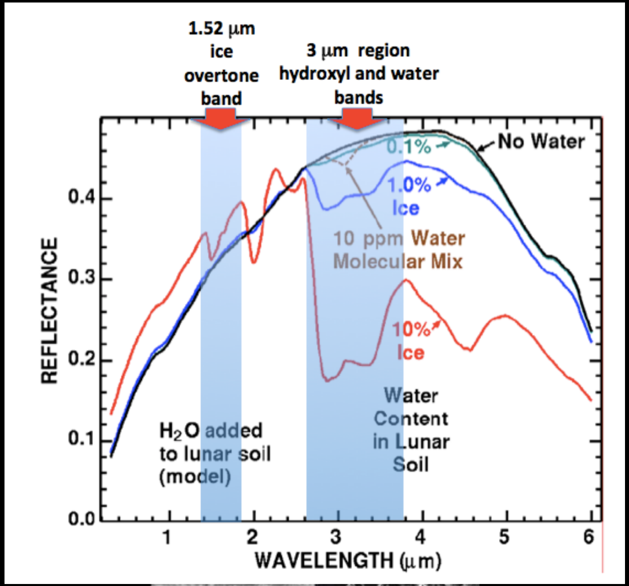


The thermal correction (solid spectra above), highlights the 3.0μm feature in areas thought to be "dry" (top spectra). The spectra of Gruithuisen Delta dome and nearby mare surfaces (bottom spectra) show similar 3 μm absorptions despite differences in composition and albedo.

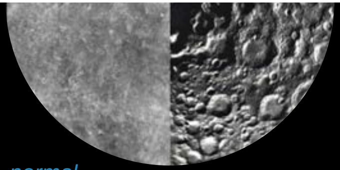
Bandfield, J. L., M. J. Poston, R. L. Klima, and C. S. Edwards (2018), Widespread distribution of OH/H2O on the lunar surface inferred from spectral data, *Nature Geoscience*, *11*(3), 173-177.

Science Approach and Benefits

- Optimized for high spatial resolution measurements of surface spectral reflectance/absorption
- Two bands to maximize water detection and discriminate multiple phases of water.
  - 3 μm, sampling a sensitive water band
  - 1.5 μm, sampling the 1.52 μm ice band
  - Reference band at 1.064 μm already measured by LRO/LOLA
  - Addresses the NASA 2014 Science Plan goal to "Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve"

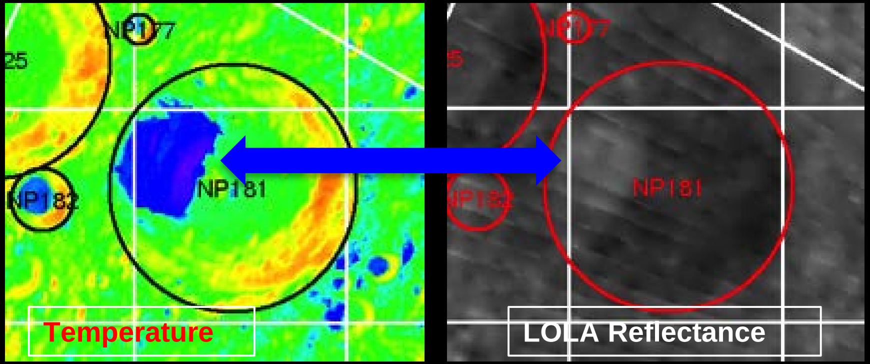


- Benefits of active spectral reflectance measurements
  - Immune to solar background and lunar thermal emission
  - Uniform illumination and observation conditions (normal albedo) around the globe, no need for photometric calibration.
  - Definitive measurements of water abundance variations during lunar day and night
  - Sensitive to 100 ppm water ice concentration

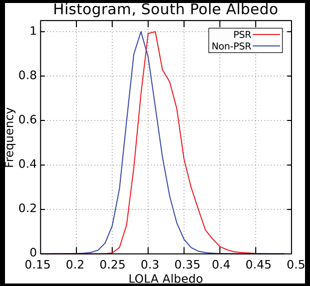


Measurements from previous and planned missions

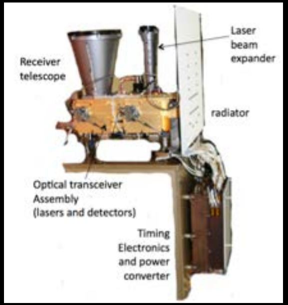
- The Lunar Orbital Laser Altimeter (LOLA) on the Lunar Reconnaissance Orbiter (LRO) has shown the value of active laser measurements at the Moon
  - PSRs are brighter than areas that receive sunlight
  - Bright areas occur only at temperatures supporting surface water ice
- Passive spectrometer measurements near 3 μm show possible water ice on surface in polar regions and possible movement ice frost on lunar surface
- The Lunar Flashlight mission will measure surface reflectance to laser light from 1 to 2 μm



North Polar Crater Lovelace
Permanent Shadow:
Brighter Than Surroundings



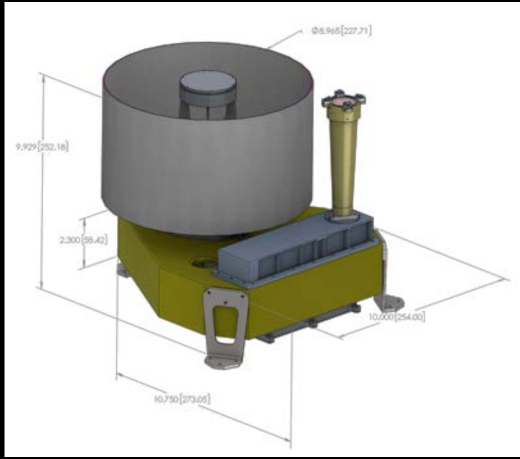
PSR Brighter than surroundings

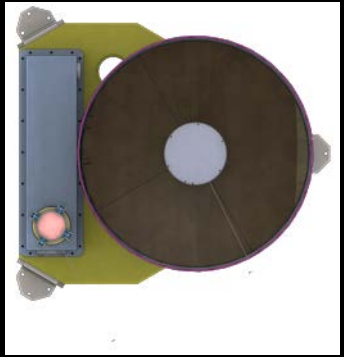


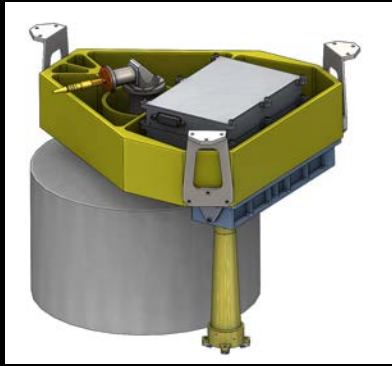
LOLA on LRO

Lunar Ice LIDaR Spectrometer (LILIS) concept

Optical Transceiver Assembly (OTA)







Ranging Electronics Box (REM)

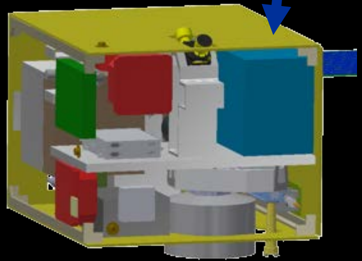
Integrated detector cooler assembly (IDCA)

Total Mass	**10 kg**	
Volume: OTA REB	25x30x28 cm 10x15x20 cm	*Optical Transceiver Assembly* *Receiver Electronics Box (including detector)*
Power	**28W**	
Data Rate	200 kbps	

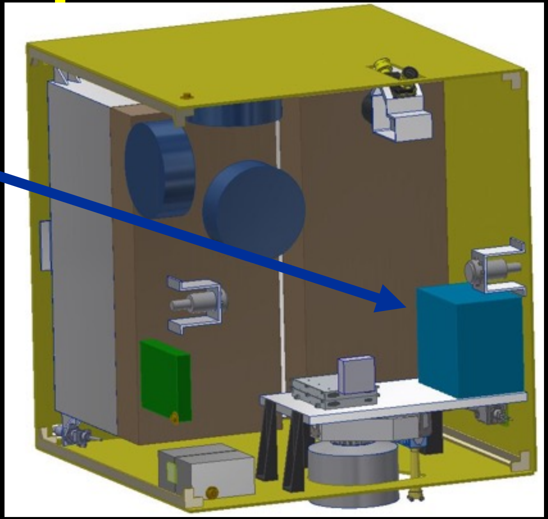
MiLuV

Maximum Spacecraft Envelopes

MUSTANG
Power System

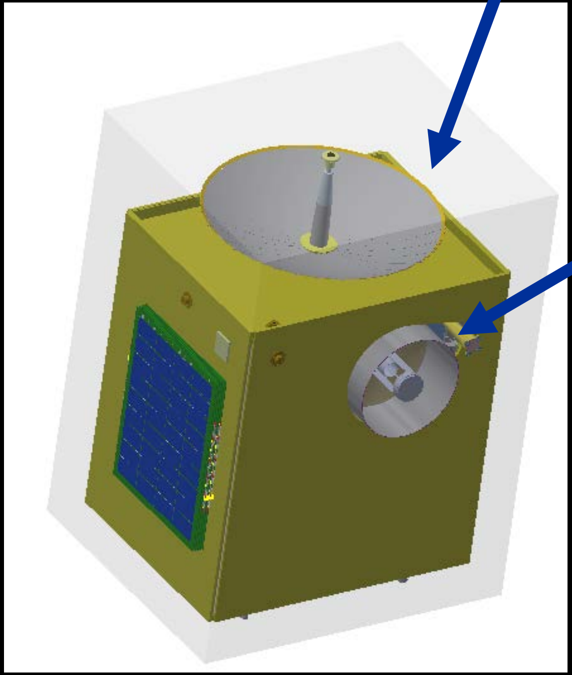


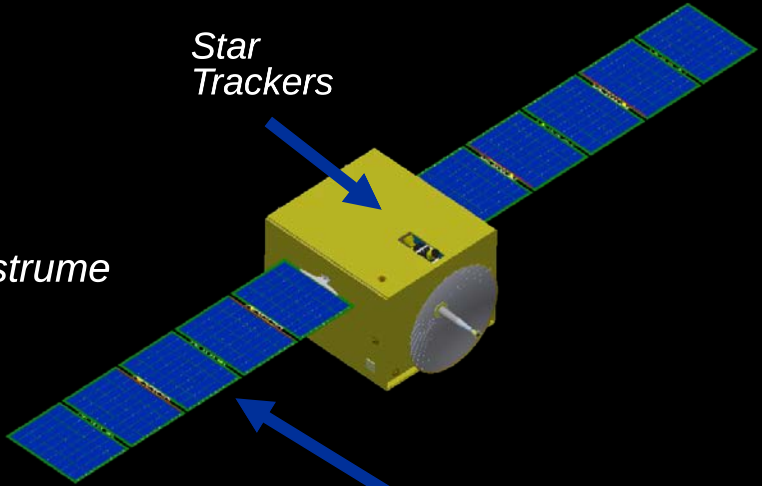
ESPA



ESPA Grande

MiLUV ESPA Spacecraft





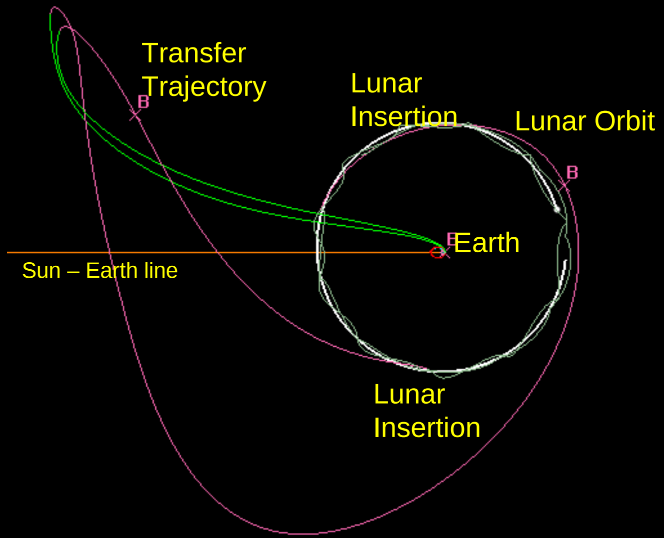
MiLuV ESPA

MiLuV Flight Dynamics

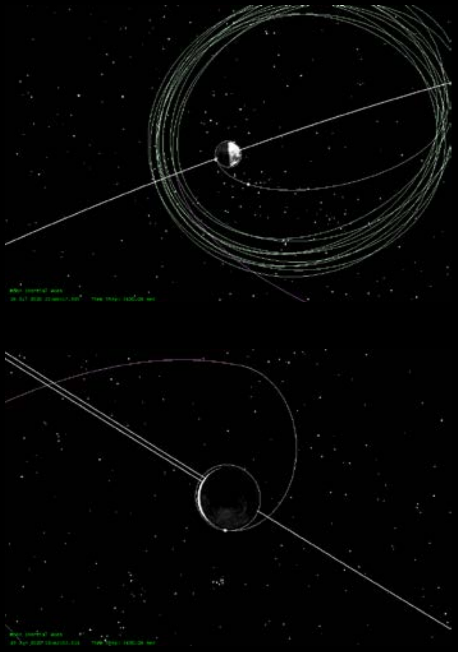
- Translunar Transfer Designs
  - PACE (LEO orbit deployment, 2022 launch)
  - IMAP (Sun-Earth L1 Transfer deployment, 2024 launch)
  - GTO (GTO deployment into long duration transfers, 2020 launch that applies to any launch opportunity)

MiLuV Transfer to Moon – GTO Deployment

Maneuvers: GTO Periapssis Raise, 196 m/s
Injection from GTO, 833 m/s
Lunar Insertion, 1079 m/s,
Total DV = 2108 m/s
Transfer duration: ~ 169 days

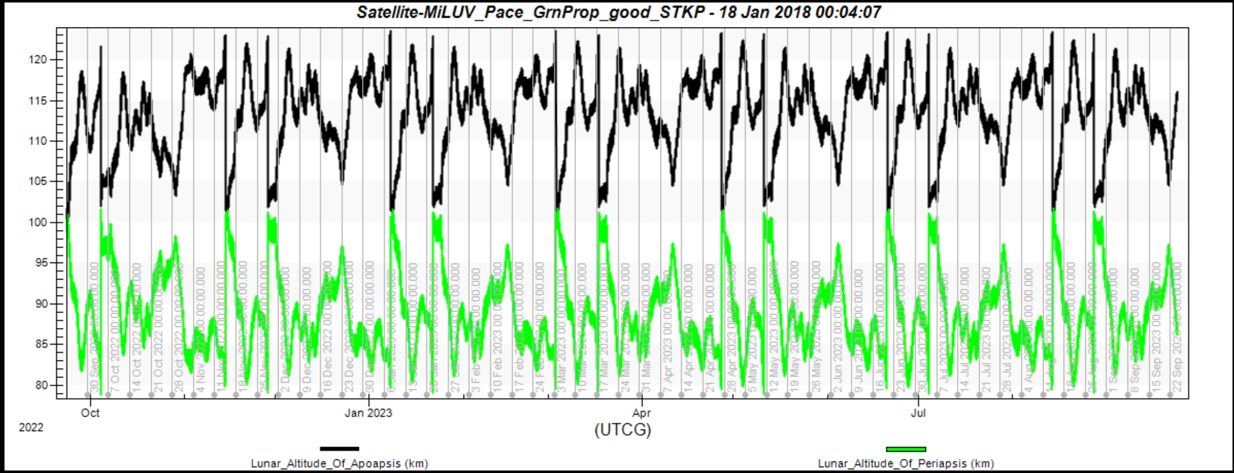


Maneuvers: GTO Periapssis Raise, 196 m/s
Injection from GTO, 831 m/s
Lunar Insertion, 891m/s,
Total DV = 1918 m/s
Transfer duration: ~ 86 days



MiLuV Concept

- One year in a polar, ~100 km circular orbit
- ~100% duty cycle
- Ride-share and GTO orbit options were evaluated
- Orbit allows for dense coverage of the poles
- LILIS has a 100m surface spatial resolution from 100km
- Can we act as a com relay (yes!)

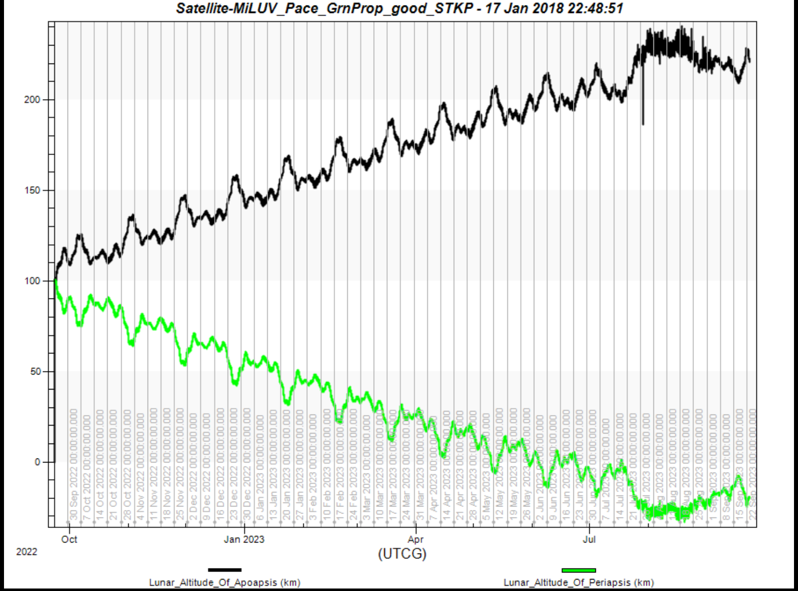


Two maneuvers of ~ 4.6 m/s each to recircularize orbit
~ 13 maneuver per year
Total 1-year DV of 117 m/s
Not optimized

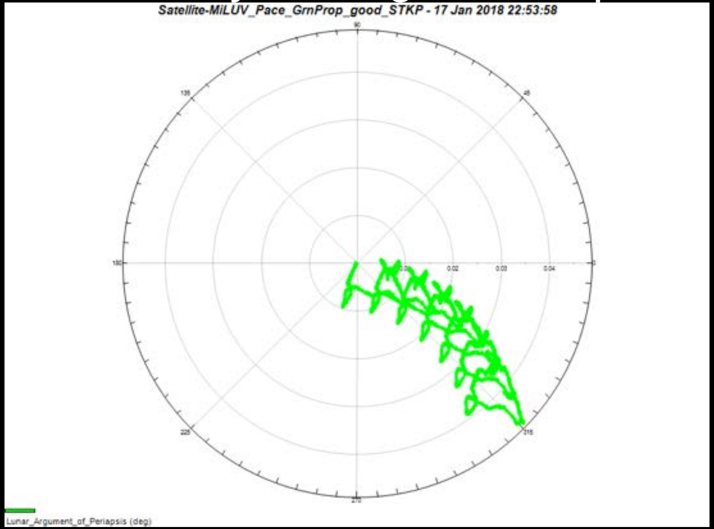
Orbit Evolution for 1-year – SK’s are needed

- Initial state at 100 km circular
- No maneuvers
- Lunar gravity set to 100x100 deg and order

- Apoapsis and Periapsis Altitude (km)



- Eccentricity vs. Arg of Periapsis Evolution)

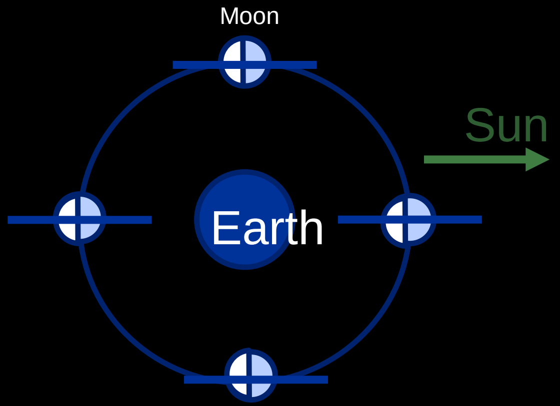


MiLuV

MiLuV Science Operations

Science Orbit:

- Polar orbit, 91 – 91.5 degrees inclination, inertially fixed.
- Orbit altitude of 100km +-10 km, no more than 150km while taking data Instrument continually points within 1 degree of Nadir
- Data is recorded on-board the spacecraft
- Attitude knowledge (reconstruction) is 1mrad, we will use the LILIS altimeter data as a tracking type to both improve orbit determination and pointing knowledge (Mazarico et al., 2017, PSS; Goossens Thursday Poster)

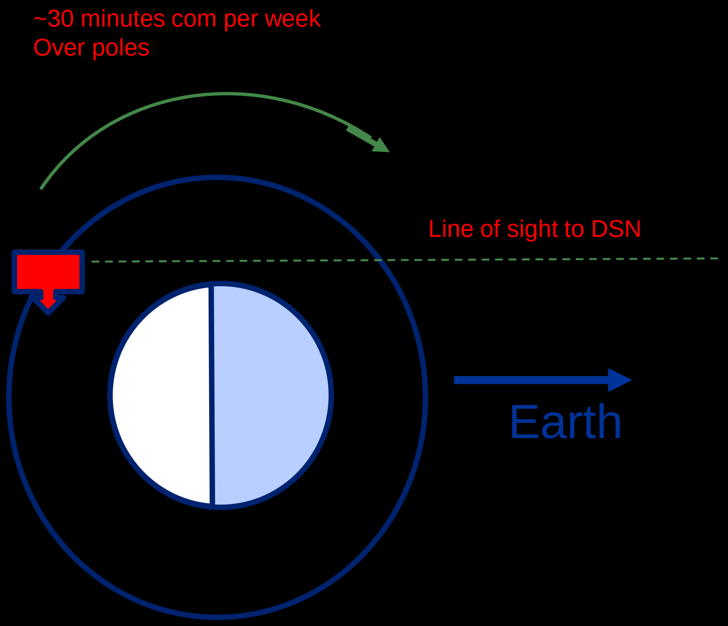


Orbit Maintenance: ~Once per month a command is sent to perform orbital maintenance. Commands are uplinked to perform an orbit circularization maneuver which consists of two burns of approximately 4.6 m/s each.
The science instrument is turned off while the burns are performed, then science mode is resumed

MiLUV Science Operations

Communication Orbit: Occurs once every 84 orbits (7 days)

- Science Instrument powers off
- Spacecraft points antenna toward DSN prior to orbiting the lunar north pole
- Spacecraft downlinks all housekeeping and science data stored from the previous 7 days. This takes approximately 30 minutes (1/4 orbit)
- When data is confirmed received, spacecraft points Nadir, turns instrument on and begins science mode again.
- Use navigation tracking passes, ~every other day. These can accommodated at any time with a +Y or -Y patch antenna (LGA, 120º full-angle), by a yaw flip (180º) maneuvers (also decreases momentum buildup) or by doing 90º yaw maneuvers near the poles to give us 90N/30N (or 90S/30S) visibility of Earth stations.



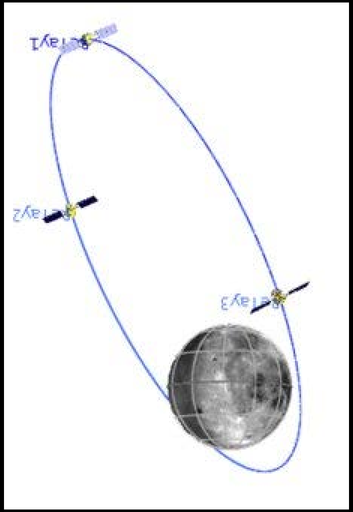
MiLuV End of Mission

2 Possible End of Mission Scenarios:

1. Enter an LRO “Frozen Orbit”

2. Deliberately De-Orbit the Spacecraft such that it will not strike an Apollo site

Both maneuvers need to be analyzed, but they should require approximately the same amount of fuel



Mass Summary

Spacecraft Dry Mass Total	68.028	MPL MiLUV Design
Mass of Helium Pressurant	6.4	(Helium is proportional to Fuel Mass)
Total Dry Mass	**74.428**	
Mass of Green Propellant	39.7	
Propellant Mass Fraction (Fuel/Dry M)	0.542	
Delta V from available fuel	**1000 m/s**	
Delta V req. for Lunar Orbit Insertion	800 m/s	Upper bound for candidate rideshares polar LEO, L1, Lunar flyby
Delta V for Station Keeping + EOM	130.8 m/s	8.4 m/s/month x 12 months + 30 m/s EOM
Total Delta V req	930.8 m/s	Margins are included in the performance requirements
Mass Fraction for Req. Delta V	**0.48**	
Minimum Mass of Fuel Req.	35.15	
Mass Margin for Fuel	**11.4%**	
Mass Limit of ESPA	320	
Total Launch Mass	**114.128**	Dry Mass + Fuel Mass
Mass Margin for ESPA	**64.3%**	

All masses listed are in units of kg

Note:
Typically, a "Tailored" mass margin is assigned to each component of a CubeSat Spacecraft based on the TRL level and the uncertainty of the physical properties. The sum of the total of the component masses and margins are held up against the total allowed mass for the Spacecraft. Using this technique, a total margin of 0.0 is acceptable. While some mass, has been added to the components, a rigorous margin calculation has not been completed for this study.

MiLuV Cost Estimate

- MiLUV initial cost estimation was completed using two separate techniques: parts cost times rule of thumb and a bottoms up labor estimate
  - Parts cost rule of thumb reduced to 2.5x due to higher TRLs of Proton 400K and MUSTANG
- Neither cost estimate includes science data analysis or reporting

Parts Cost Rule of Thumb x2.5			
	$M		**$M**
Parts ROT	12.23	*2.5*	30.58
DSN Ops	4.31	*1*	4.31
Instrument	40.00	*1*	40.00
Total for Spacecraft			**74.88**
With 30% Margin			**97.35**

- DSN costs could be reduced depending on desired mission ConOps; current costs reflect more of a worst case daily contact usage
- MUSTANG avionics cost could be reduced by an additional $200K depending on options desired and test approach
- Custom MUSTANG board cost could potentially be reduced from $1M depending on complexity and test methodology

Bottoms Up Labor and Parts Cost Estimate			
	FTE	**$M**	**$M**
FTE for S/C Bus @$200K	64.5	12.90	12.90
Parts Cost		12.23	12.23
DSN Ops		4.31	4.31
Instrument		40.00	40.00
Total for Spacecraft			**69.43**
With 30% Margin			**90.26**

MiLuV Findings/Outcomes

- To produce a near-Class D mission, parts selection, processes, and procedures will have to be maintained at a higher level than a normal CubeSat. This will require an especially vigilant QA system, who understands the training and education required.
- Our philosophy was not to go for the cheapest with CubeSat technology but instead use as robust parts as doable for this form factor (e.g., MUSTANG)
- Spacecraft design is “Single String”, meaning the failure of any one subsystem could likely cause a mission failure
- Subsystem power requirements are large for the S/C surface area, the mass of propellant is relatively large compared to the mass of the spacecraft, the bus will be exposed to “soak back” heat from the thrusters for long periods of time, and the telescope is sensitive to thermal gradients. This will require additional thermal analysis and testing.

MiLuV Findings/Outcomes Continued

- An increase of approximately 5 kg in the quantity of fuel required for the mission will exceed the volume of the ESPA standard and require an ESPA Grande rideshare.
- The Propellant tank will likely need to be custom designed for this mission. A slosh analysis will need to be performed, along with design and verification of a propellant management system to ensure that the fluid dynamics of the fuel do not interfere with the ACS maneuvers
- Green Prop systems have been flown on rideshares, however, they are still relatively new and must be designed to the satisfaction of the prime mission. Green propellant systems are still in their developmental stage. The green propellant nozzles have not been used with the propulsion system.
- If an SLS lunar flyby is selected as the rideshare, the high lunar encounter velocities will require the propulsion system to be precise.
- SmallSat Integration teams may require training in contamination control.
- DSN may not be available for every desired Com Orbit, the con Ops will need to be flexible to get data back in a timely manner