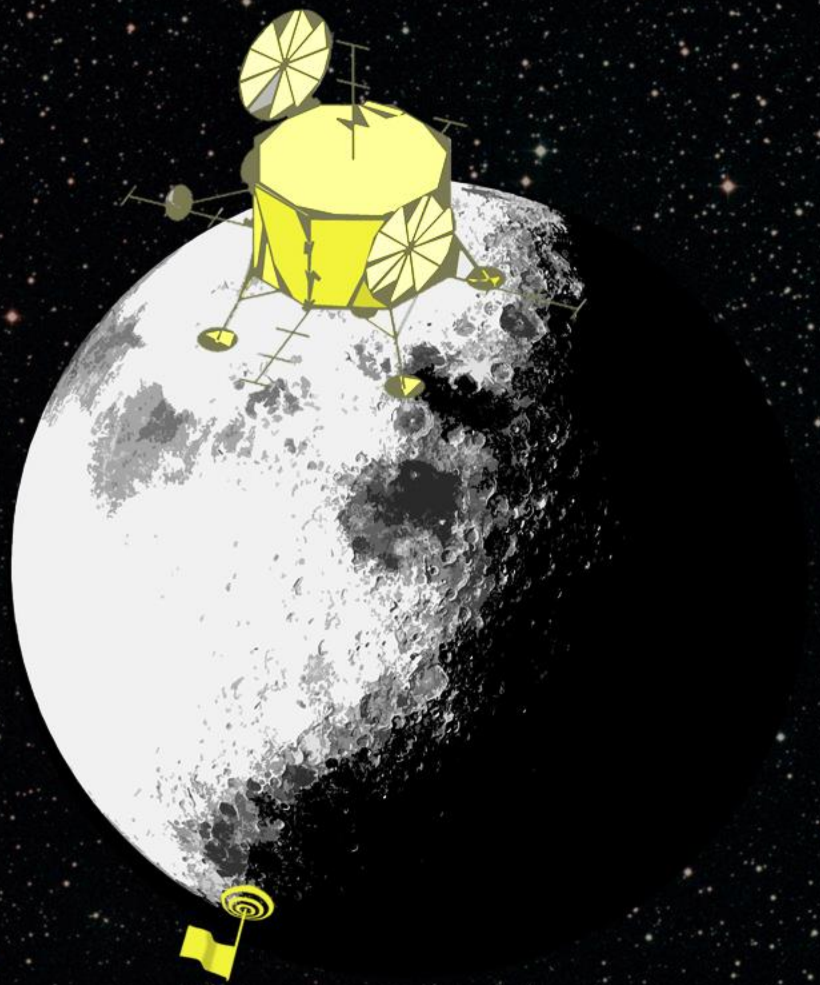
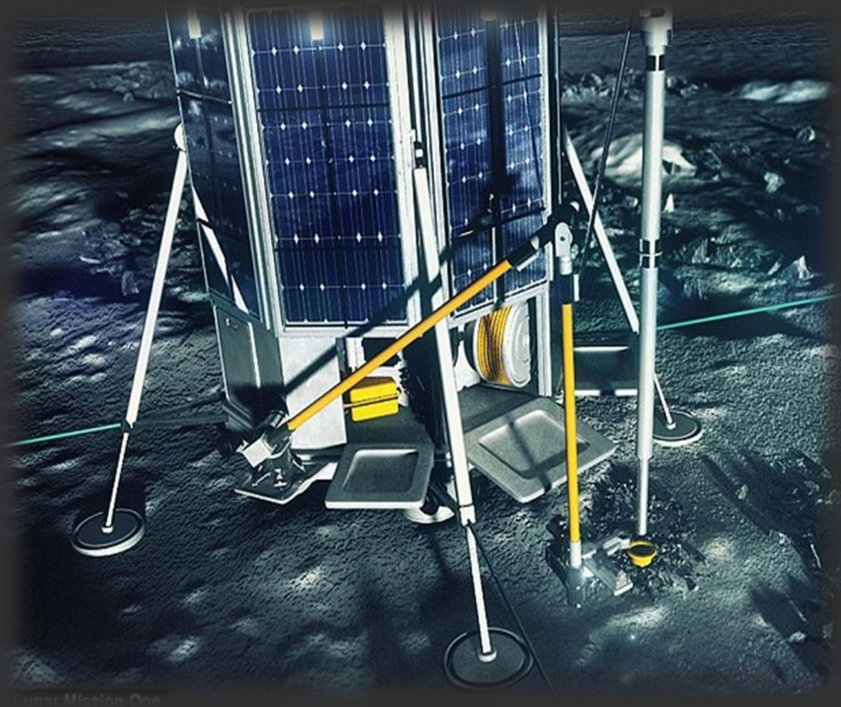
LUNAR MISSION ONE

Cranfield University
MSc Astronautics & Space Engineering 2015-2016
Group Design Project



NASA



Lunar Mission One

Lunar Mission One

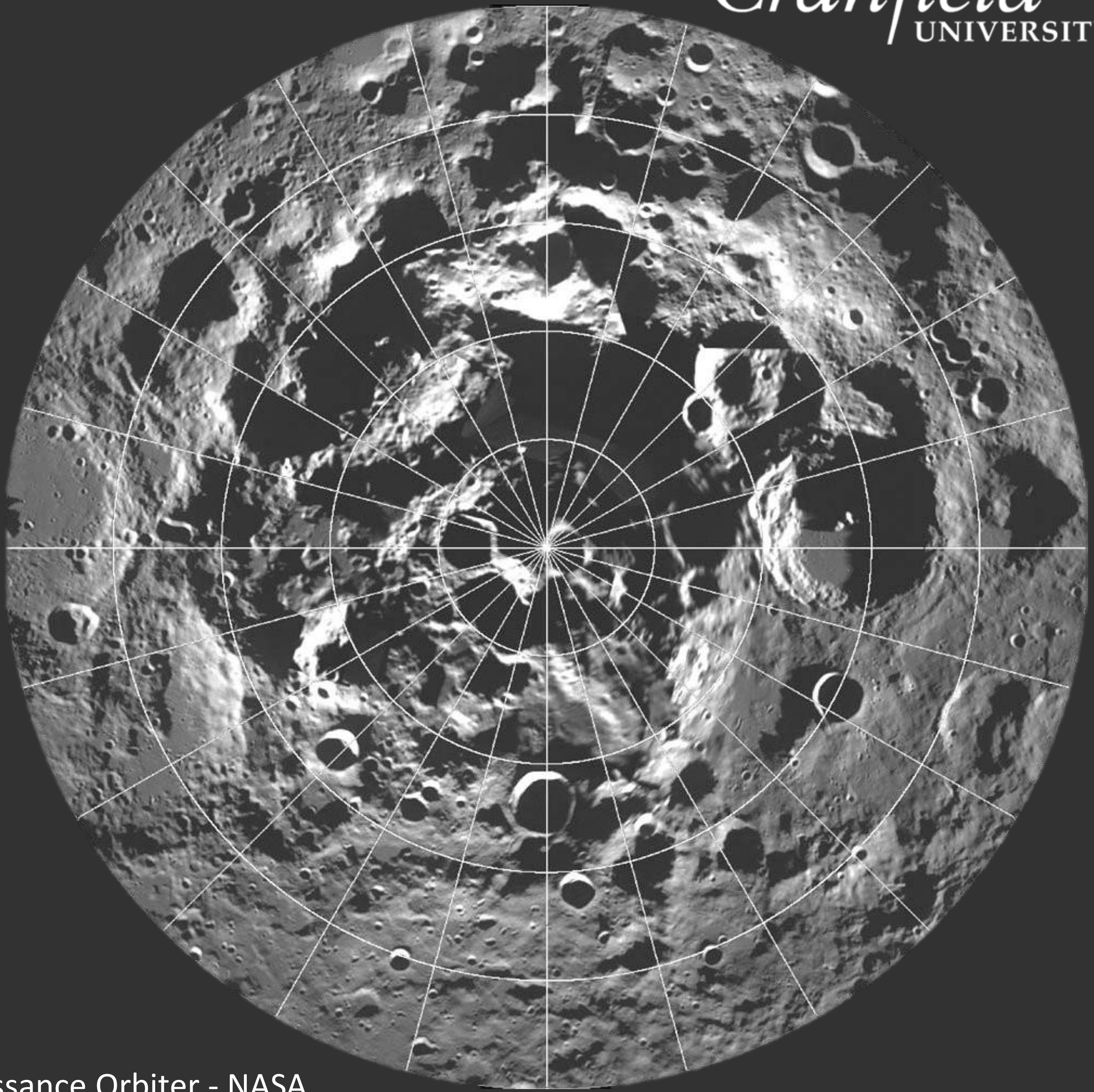
ESA/Foster + Partners

The Objectives

- To land an autonomous spacecraft on the lunar South Pole before the end of 2024.
- To drill to a minimum depth between 20 and 100 metres.
- To perform in-situ science to provide a clearer understanding of the Moon’s creation and to assess the suitability of a manned habitat.
- To examine the South Pole’s potential for radio astronomy.
- To deposit a publicly acquired archive of human DNA and digital memories within the borehole.

The South Pole

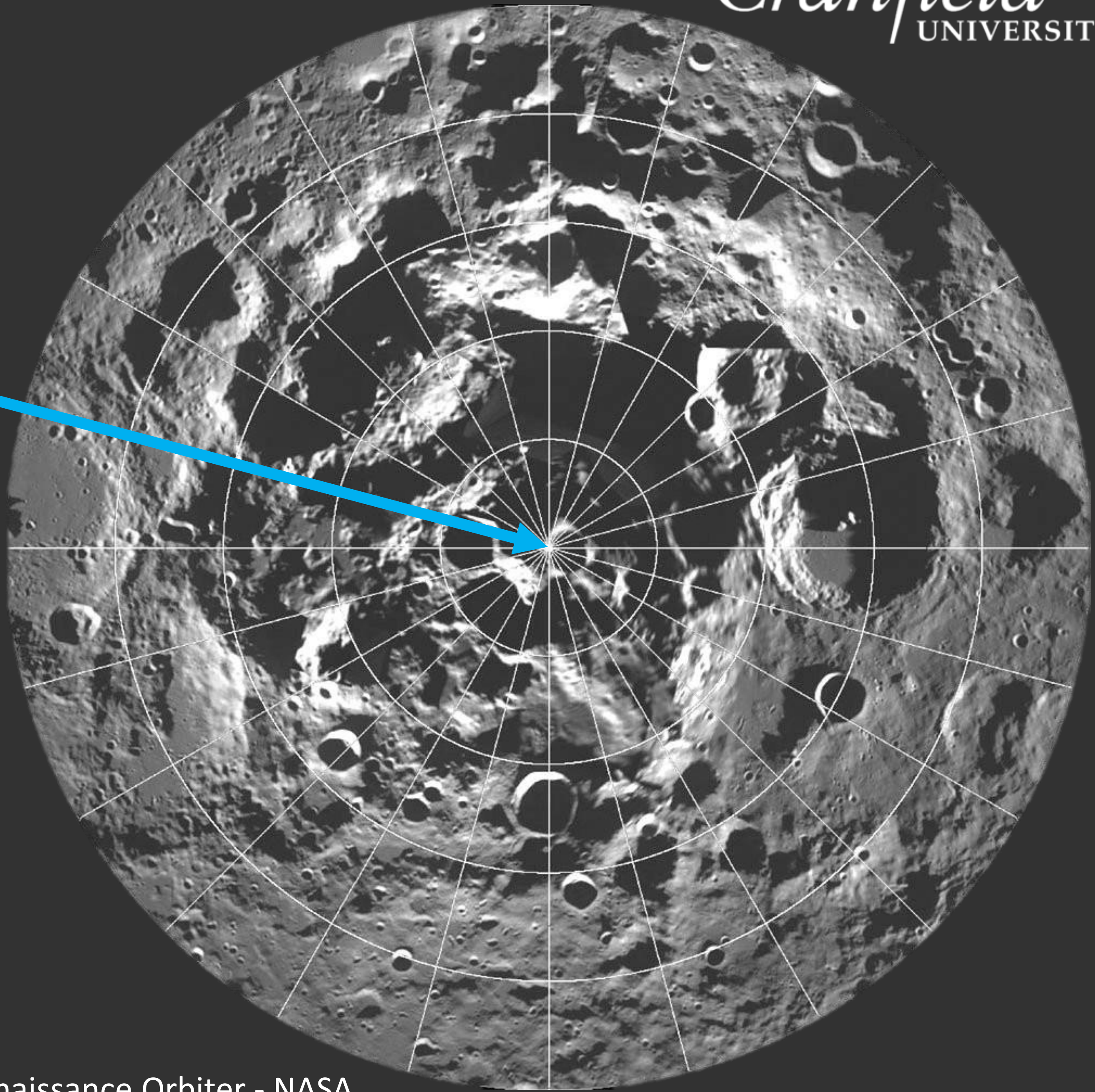
- Previously unexplored
- Longer periods of illumination
- Large quantities of stable volatiles
- Communication blackouts



Lunar Reconnaissance Orbiter - NASA

Shackleton Crater

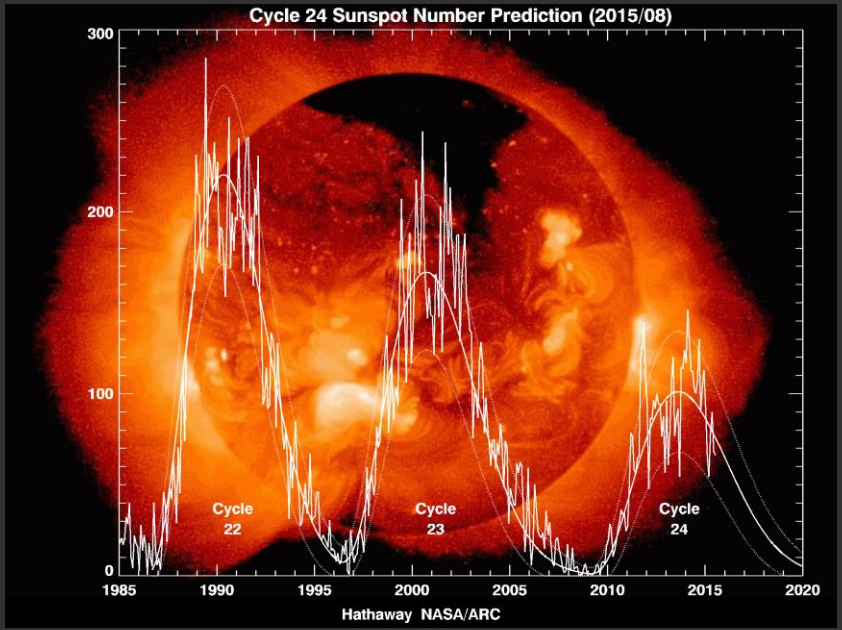
- Shackleton crater ridge high elevation
- Slopes of 15 degrees
- Surface roughness of 3.5m
- 21 km diameter



Lunar Reconnaissance Orbiter - NASA

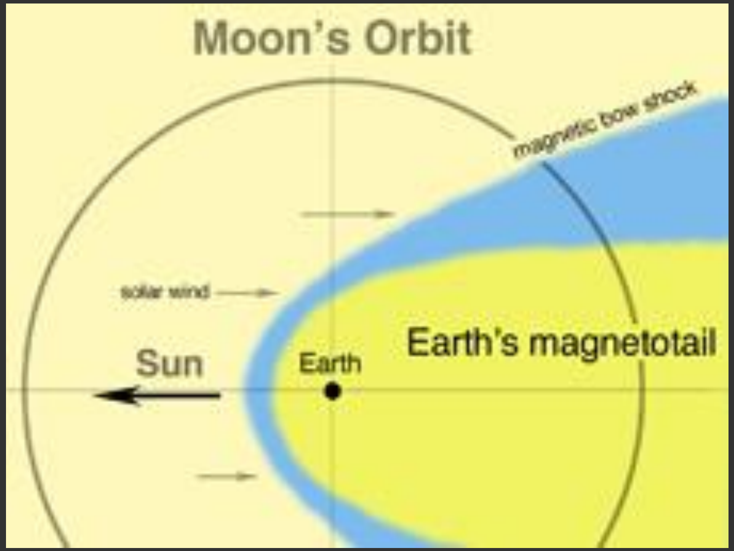
Lunar Environment

- Dust
- Radiation
- Plasma
- Illumination

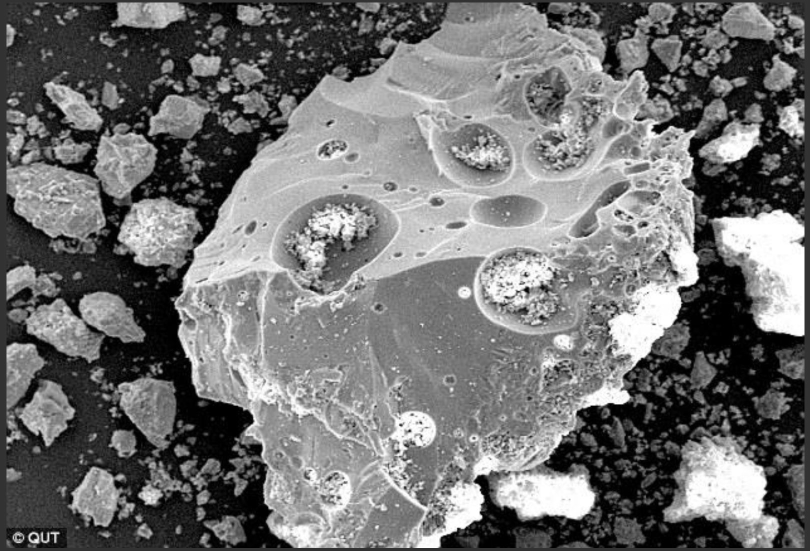


NASA

NASA



Tim Stubbs/University of Maryland/GSFC

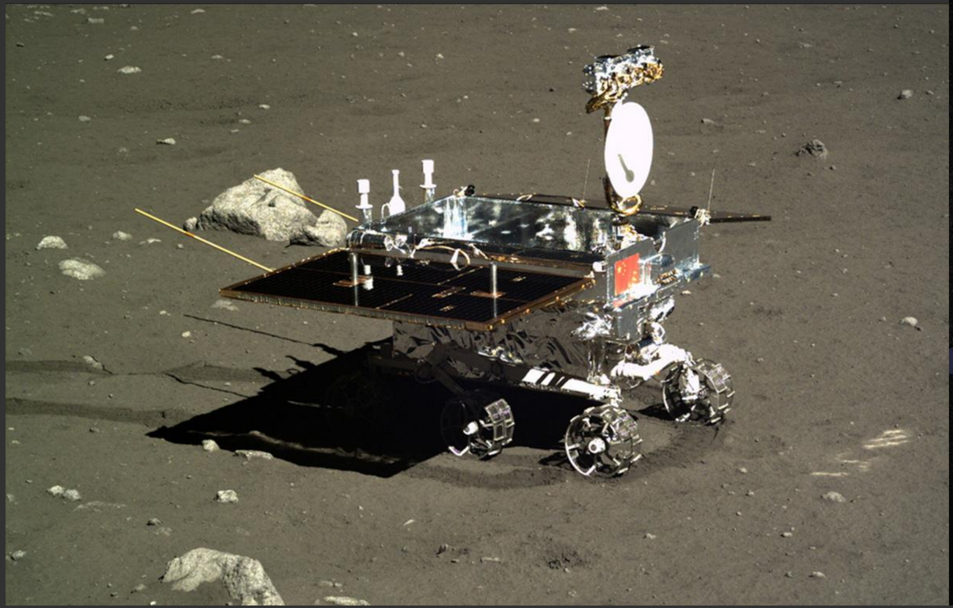


Dr. Zbik

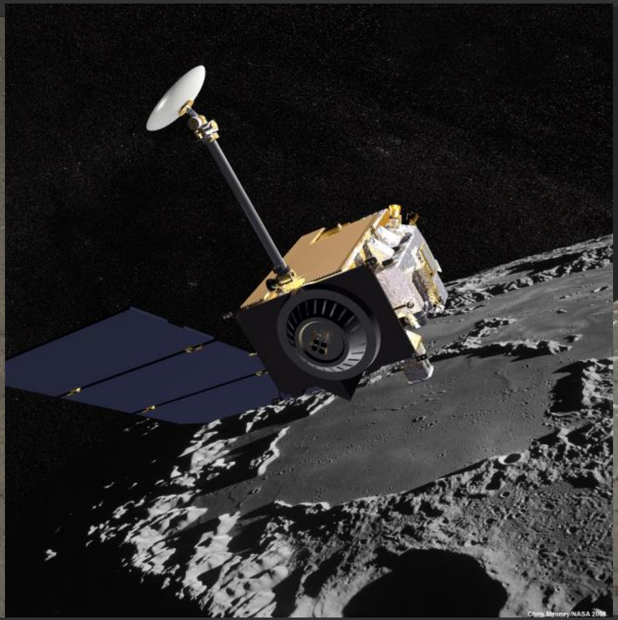
Derived Requirements

- Shall complete all mission objectives before nightfall
- Shall be able to land precisely in a 200 x 200m
- Shall be able to land on slopes of 15 degrees
- TRL of components must allow a 2024 launch readiness date
- Shall withstand the lunar and space environment for the minimum mission duration 177 days
- Must be able to autonomously perform during communication blackouts

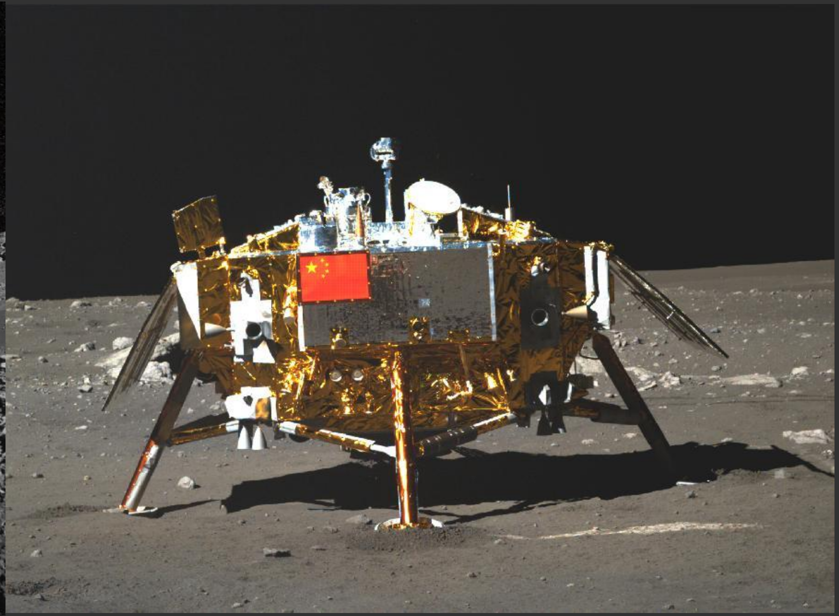
Trade-Off



Yutu rover - Chang’e-3



Lunar Reconnaissance Orbiter - NASA



Lander - Chang’e-3 -Shanghai Aerospace System Engineering Institute

Configuration Driver

Communication blackouts acceptable

More resources can be dedicated to a single design

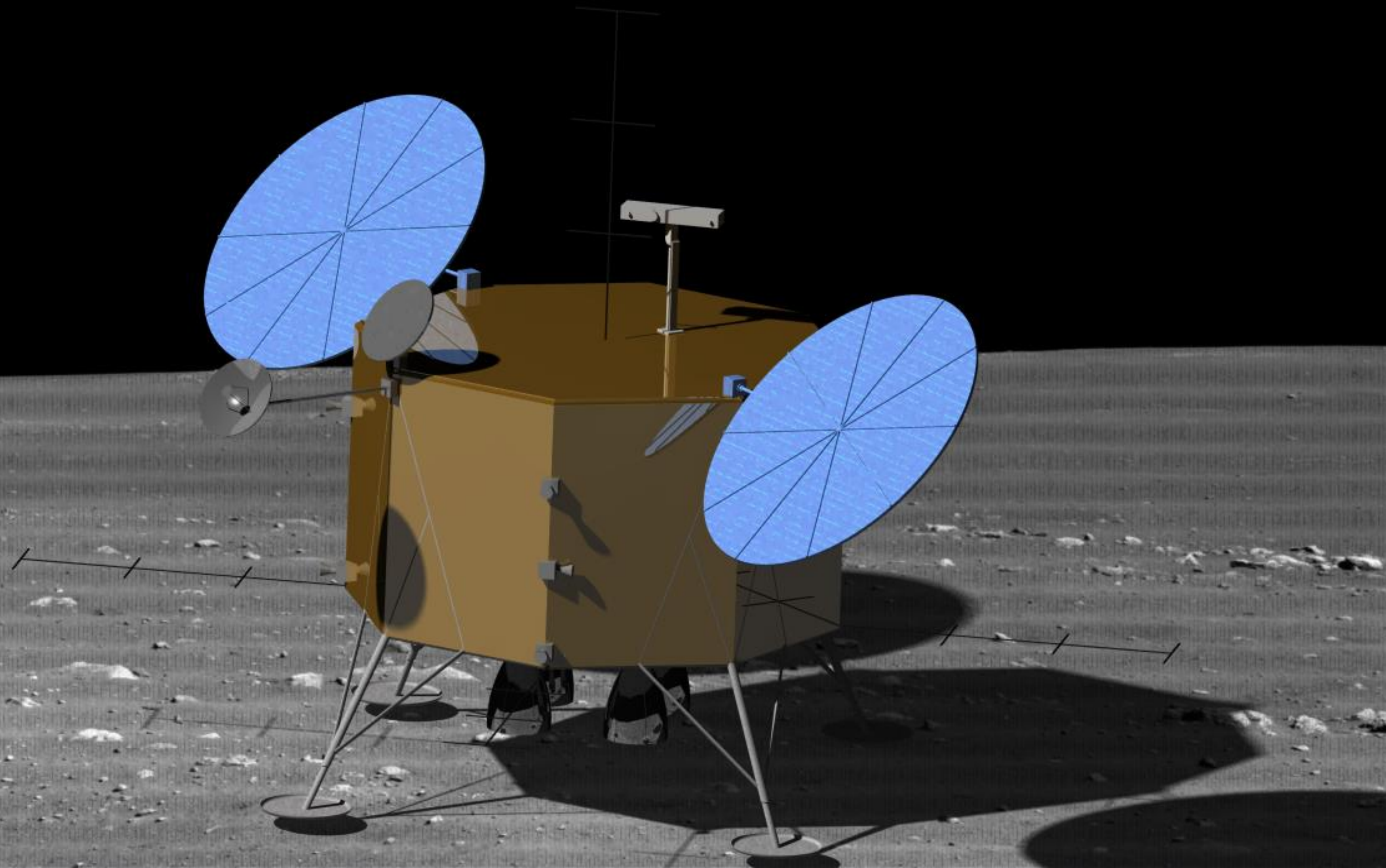
Less ground testing

Less implementation risks

D.U.M.B.O.

Drilling & Utility Moon Base Operations

- Dry Mass: 740kg
- Total Mass: 2016kg
- Height: 2.6m
- Width: 2.8m



Mission Timeline

30 days — 18 mins — 122 days — 54 days

28 Aug. 2024	28 Sep. 2024	28 Sep. 2024	29 Jan. 2025	24 Mar. 2025
LAUNCH	ENTERING LANDING PHASE	00:28 S/C LANDED	100M DEPTH REACHED	END OF MISSION

Systems Architecture

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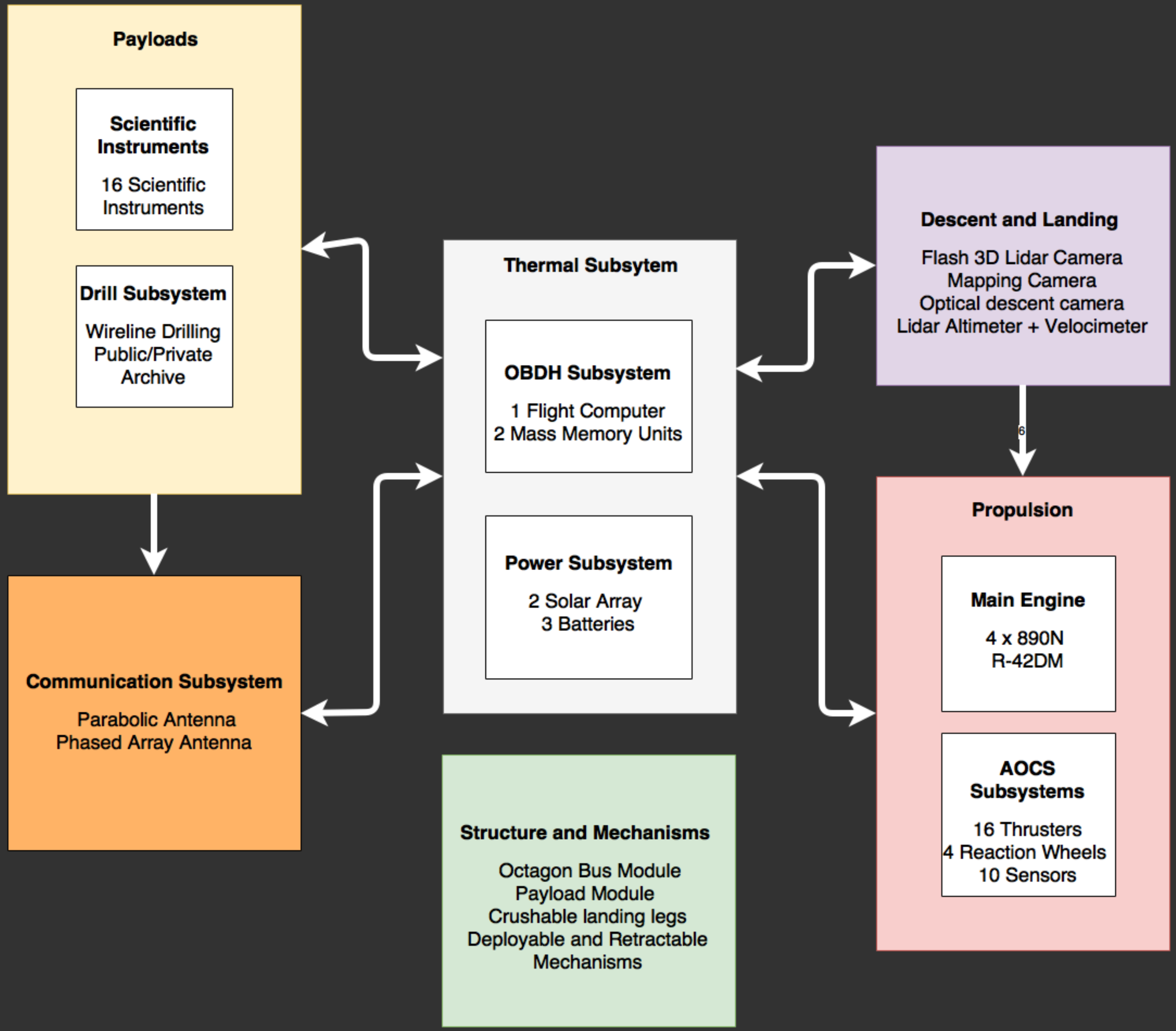
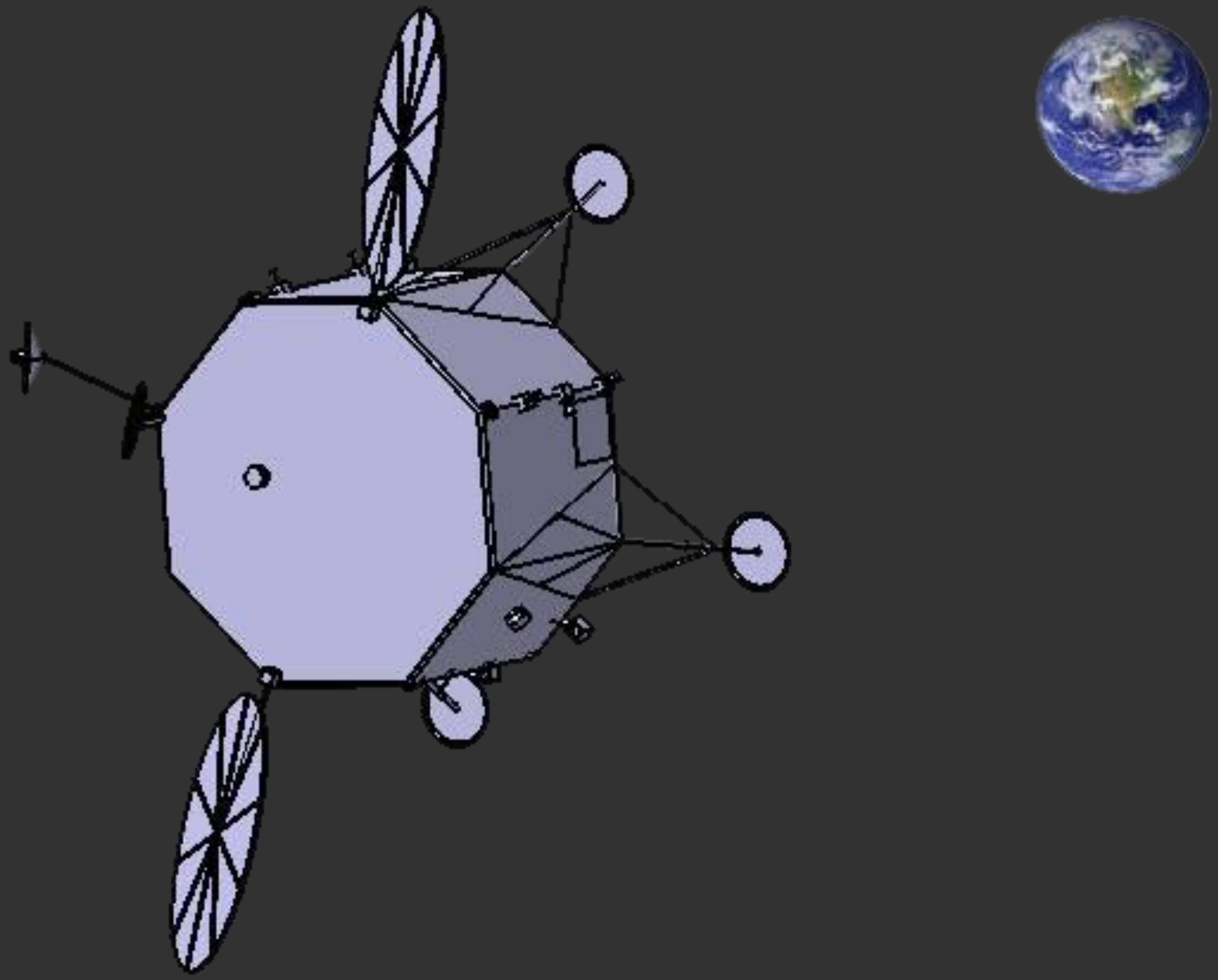
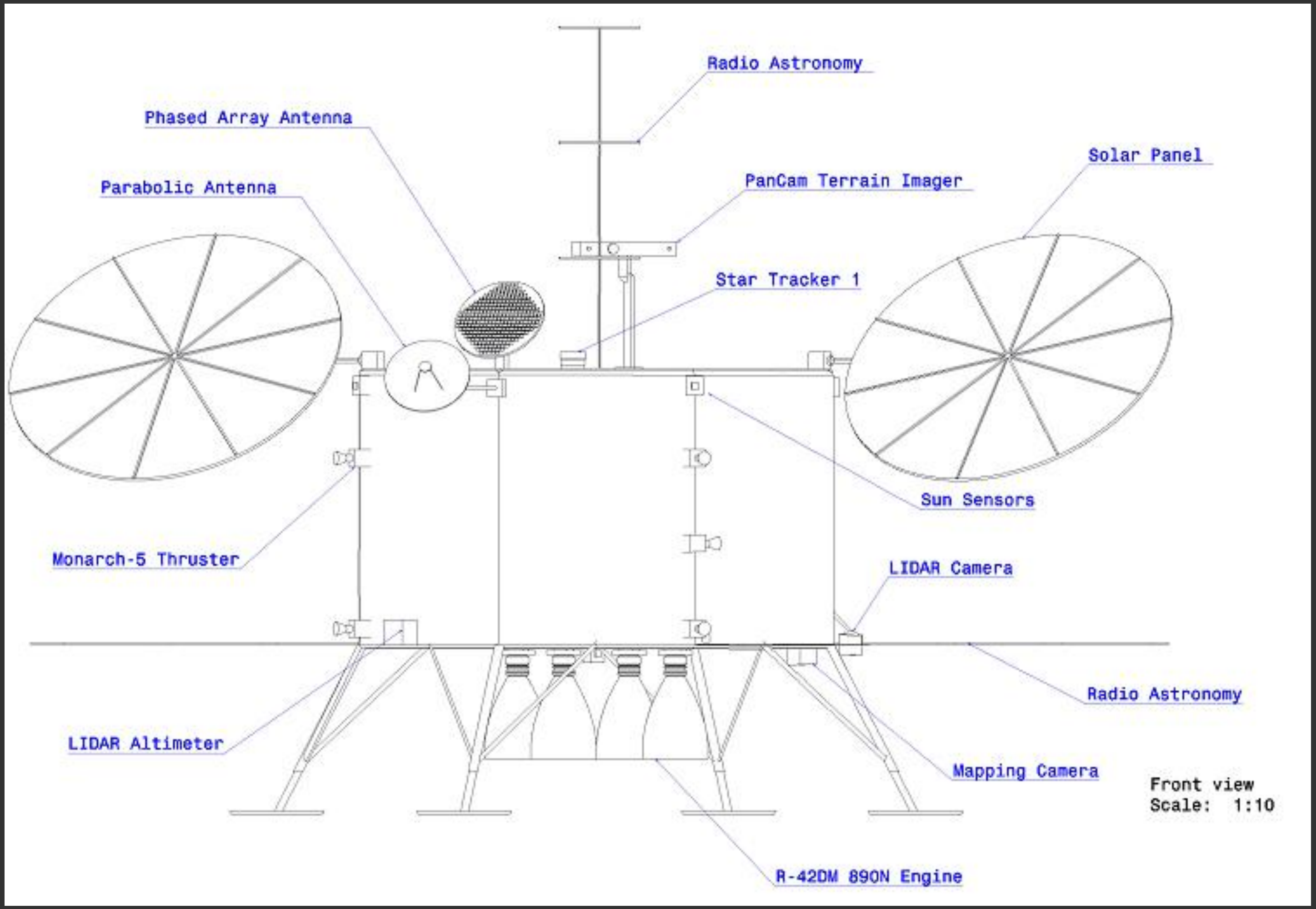
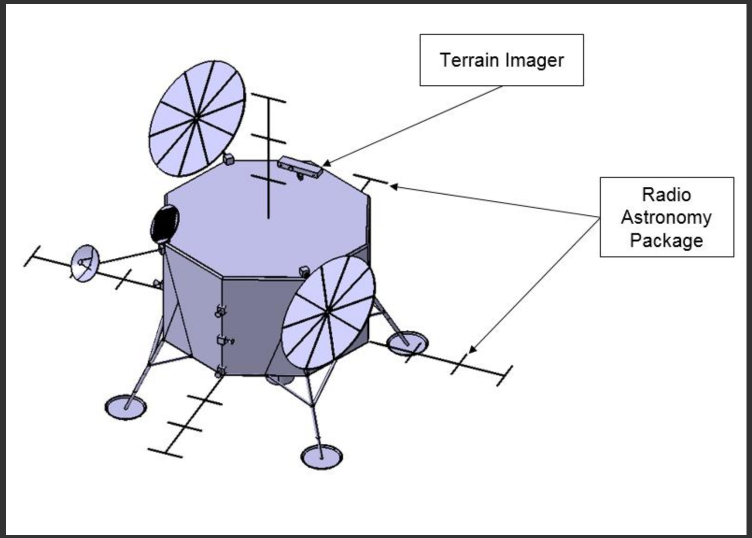


Configuration



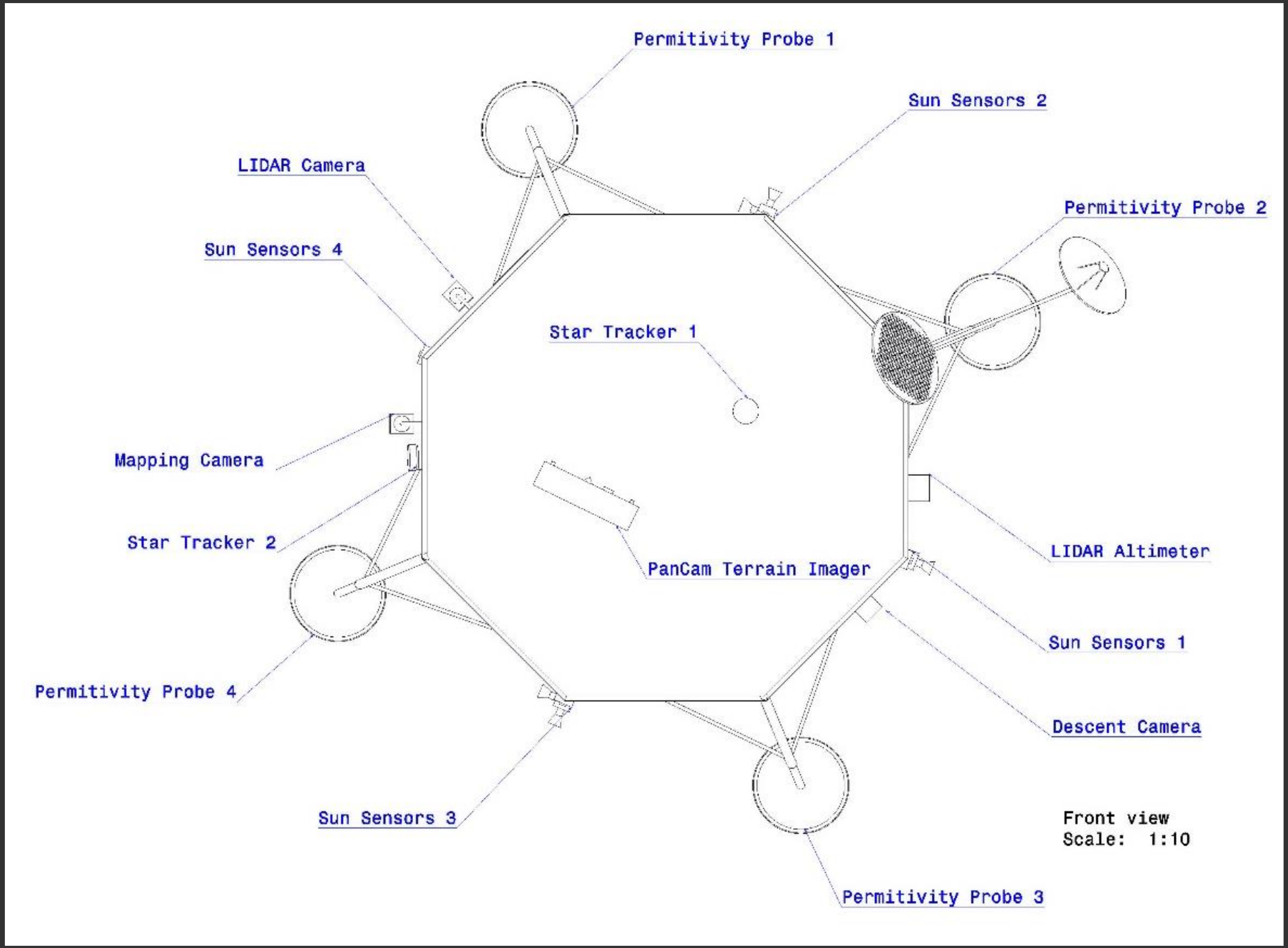
Front View





Opportunity - PanCam - JPL

Top View



Permitivity Probe 1
Sun Sensors 2
LIDAR Camera
Permitivity Probe 2
Sun Sensors 4
Star Tracker 1
Mapping Camera
Star Tracker 2
LIDAR Altimeter
PanCam Terrain Imager
Sun Sensors 1
Permitivity Probe 4
Descent Camera
Sun Sensors 3
Front view
Scale: 1:10
Permitivity Probe 3

Internal Configuration

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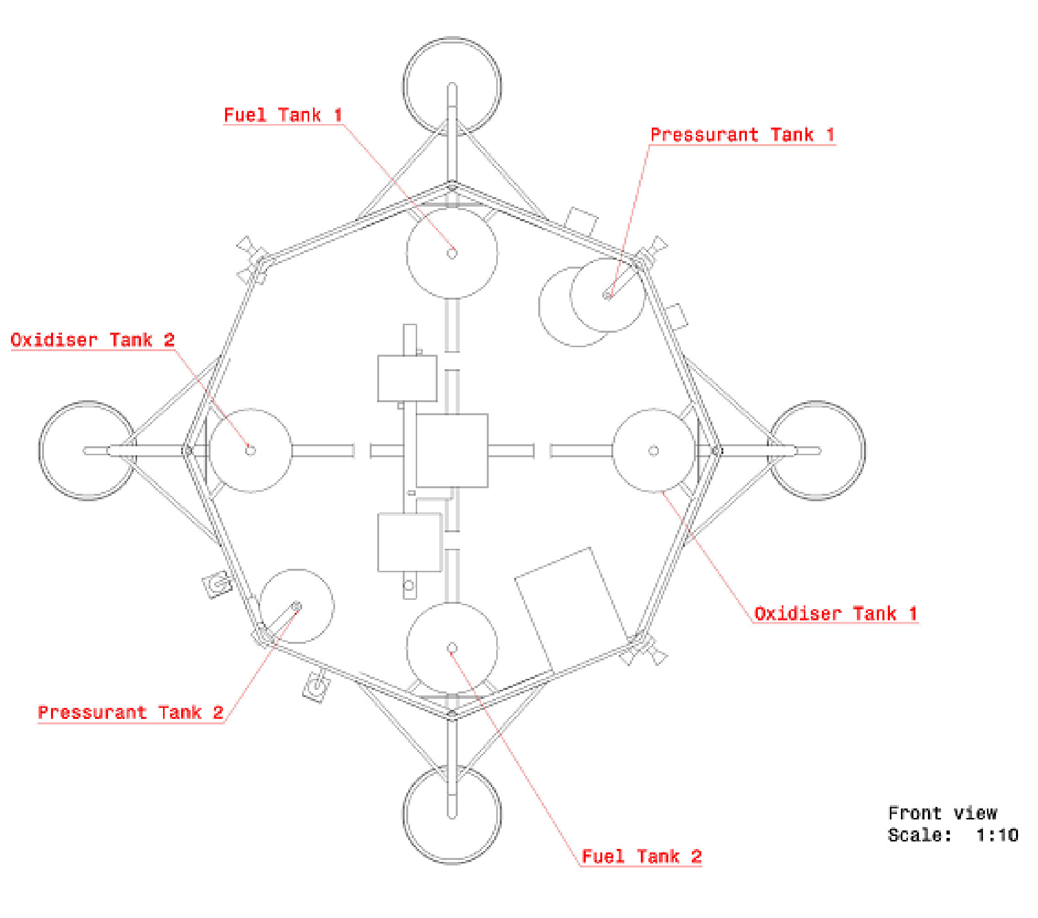

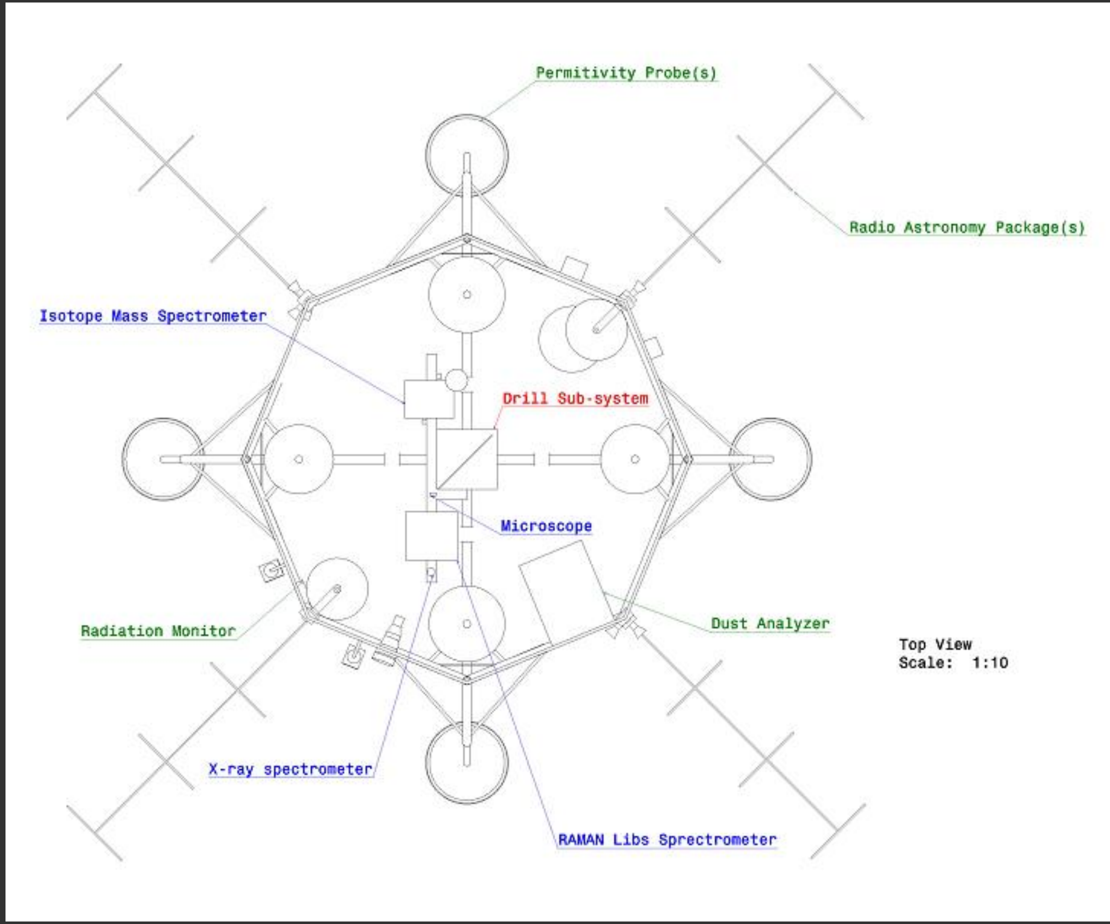

Mass Budget

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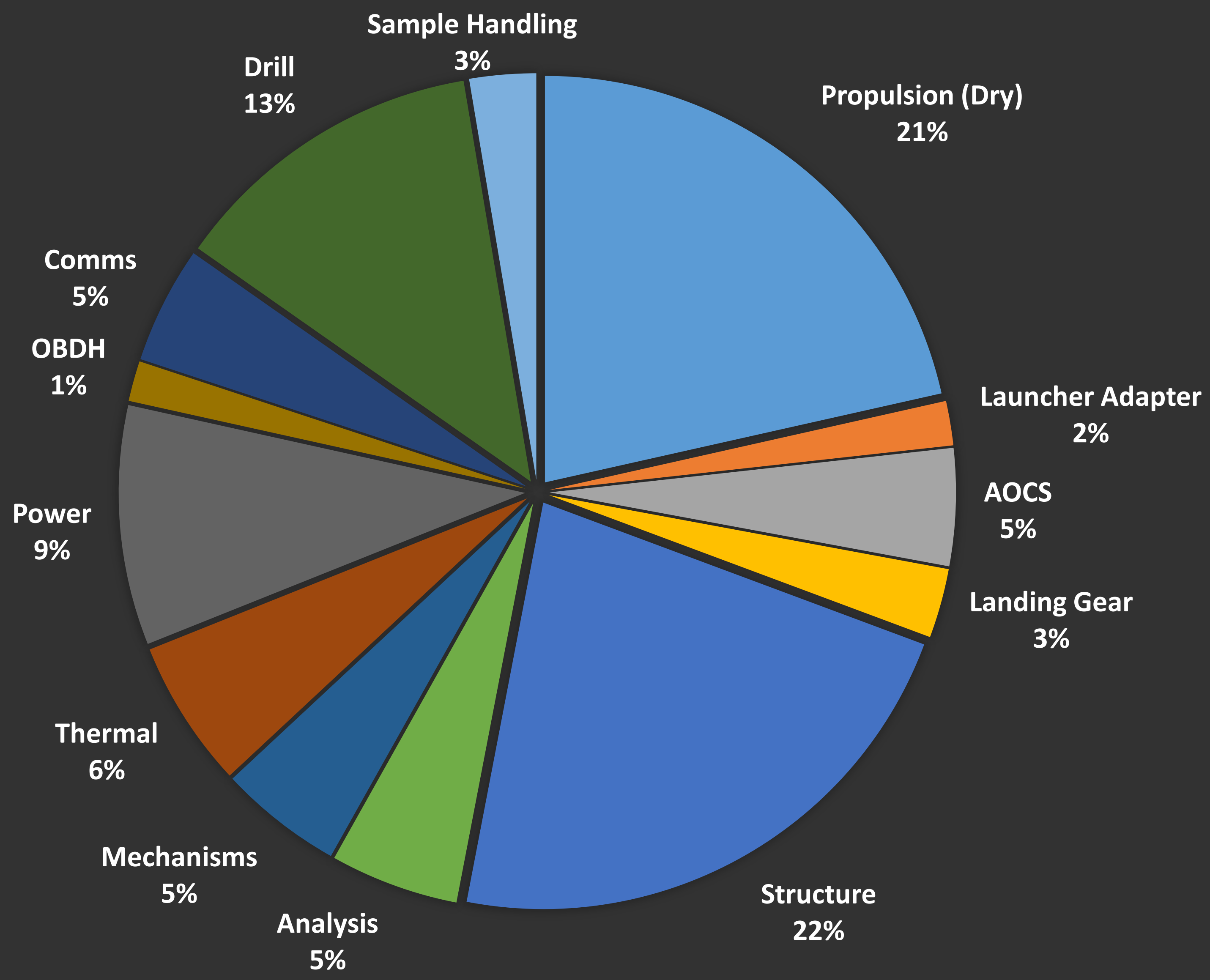
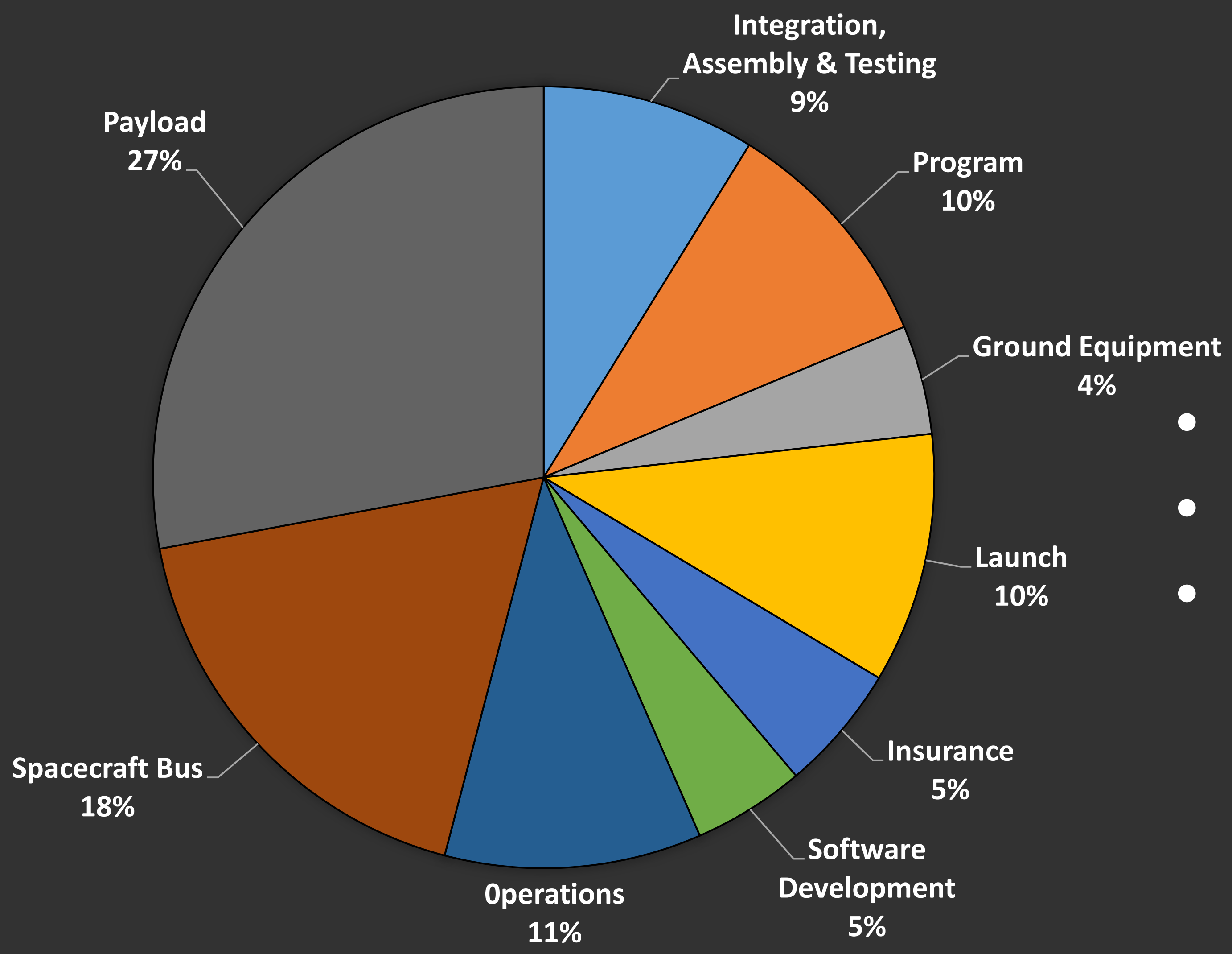


- Dry Mass:
  740 kg
- Propellant Mass:
  1276 kg
- Total Mass:
  2016 kg

Margins included

Cost



- Cost Estimation: USD$754M
- **Uncertainty: $ ± 188M**
- **Quoted Costs: FY$10**

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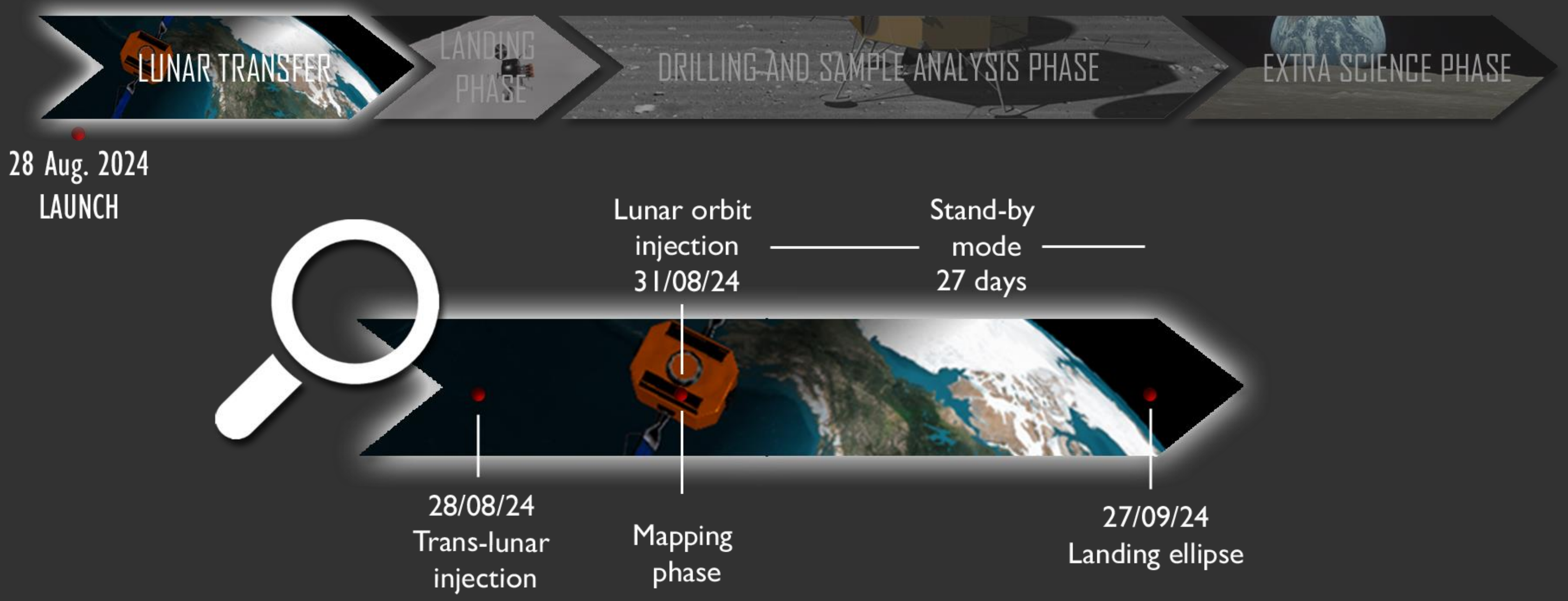

Launch

- Falcon 9 Full Thrust
  - 3 Tonnes capability to TLI

- Launch site: Cape Canaveral, SLC-40

- Launch time/date: 12:47 GMT, 28-08-2024

Falcon 9 - SpaceX

Launch Configuration

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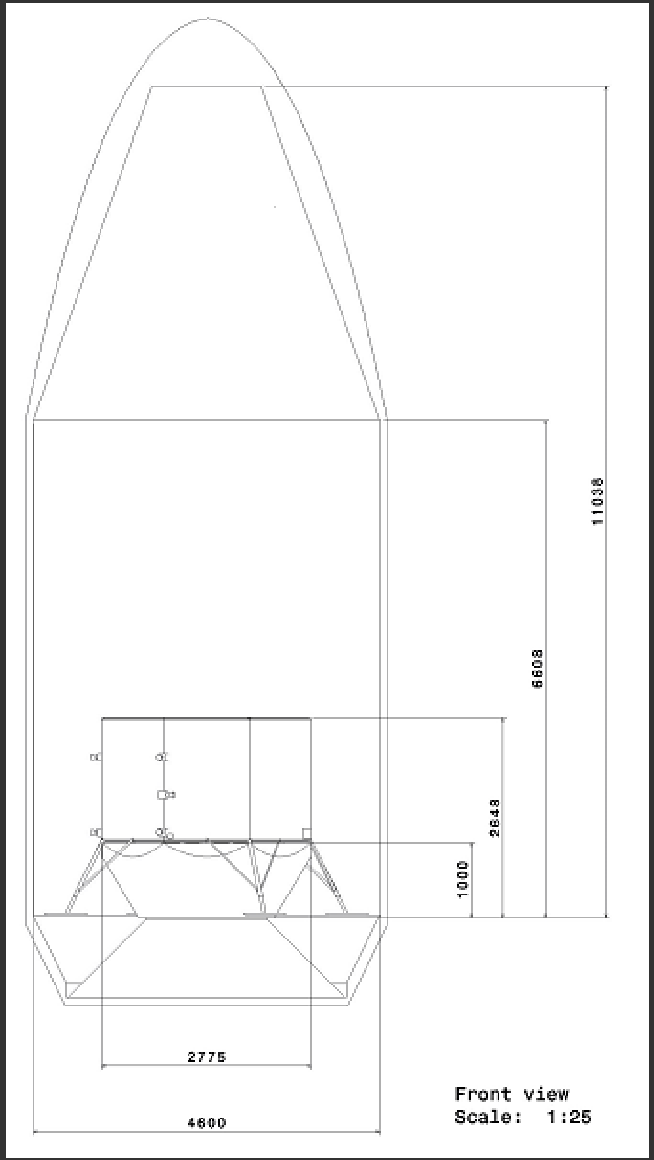
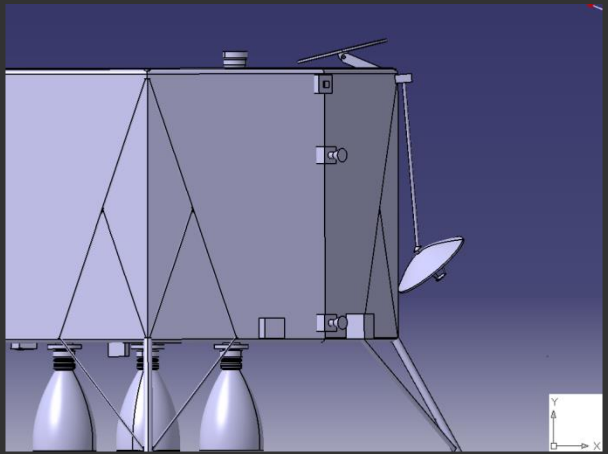
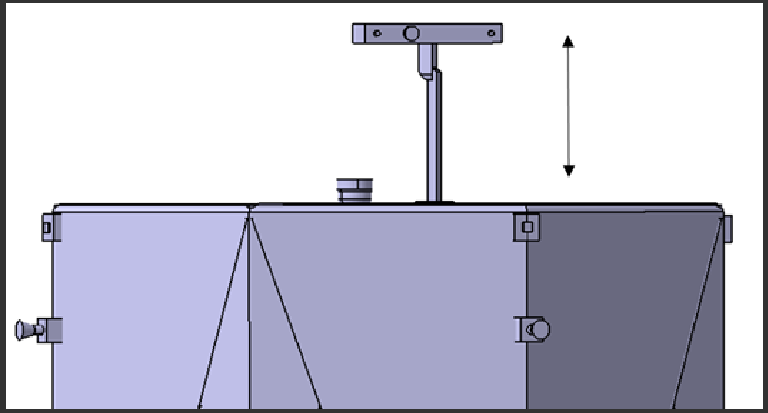
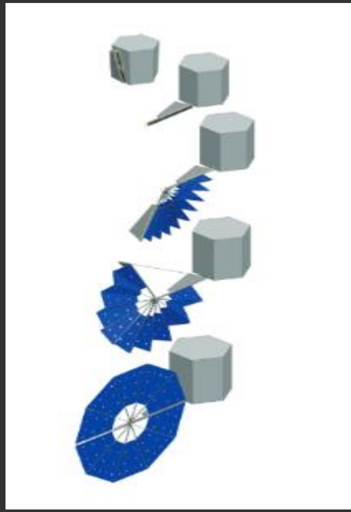








Orbital ATK (2015)

Trajectory Phases

Phase 1 – Launch

Phase 2 – Parking Orbit (Earth)

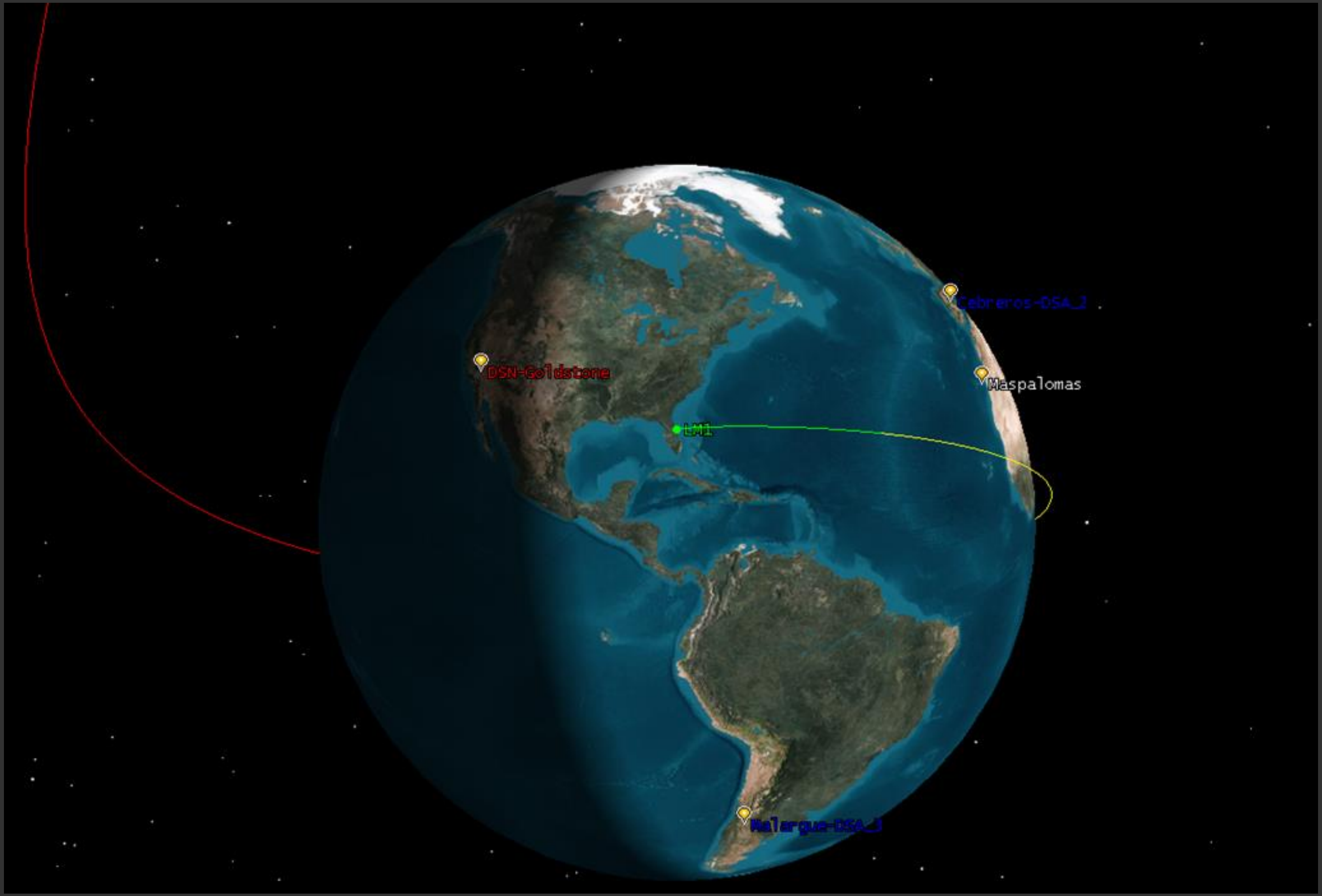
Phase 3 – Cruise to Moon

Phase 4 – Mapping Ellipse

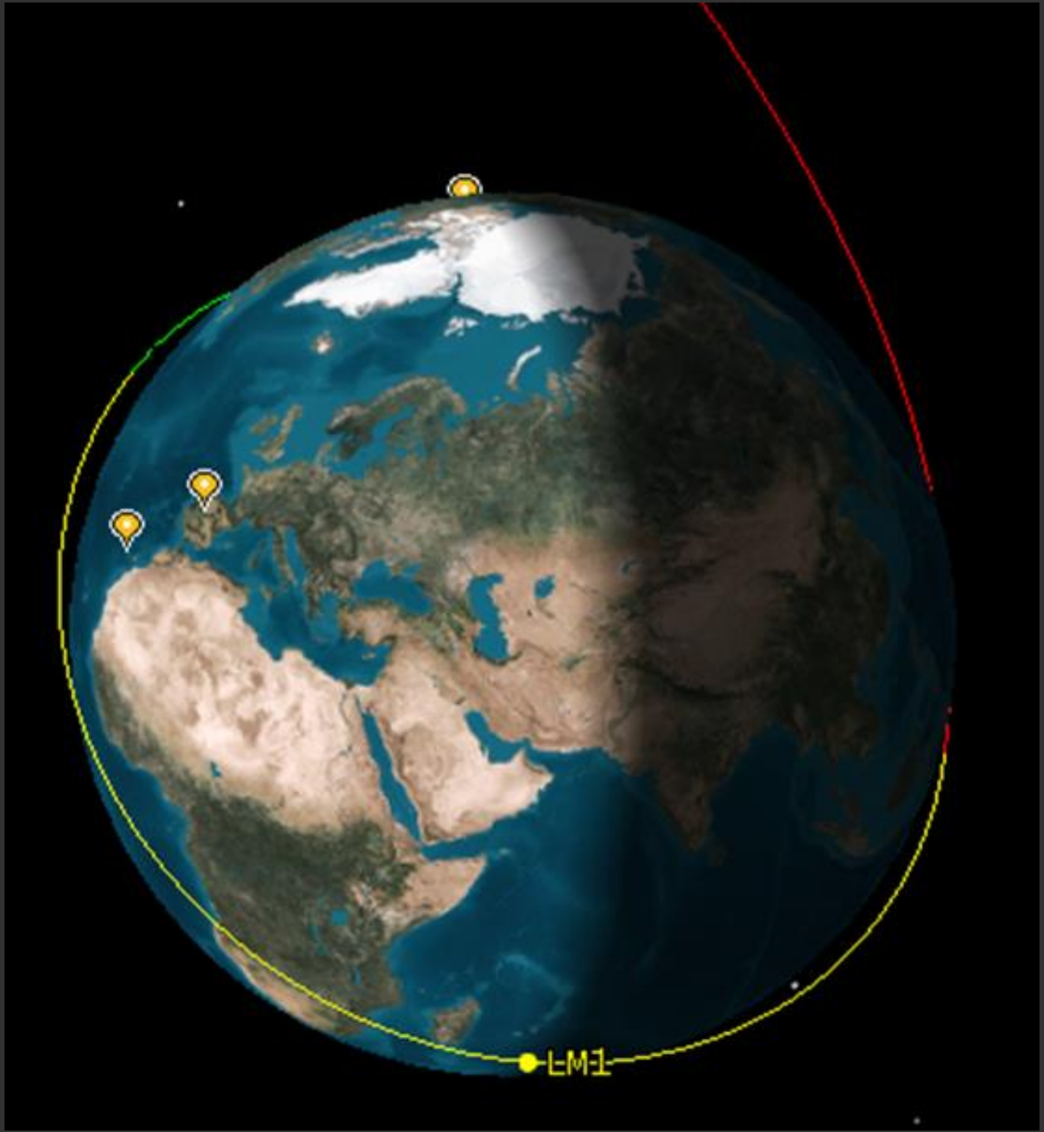
Phase 5 – Parking Orbit (Moon)

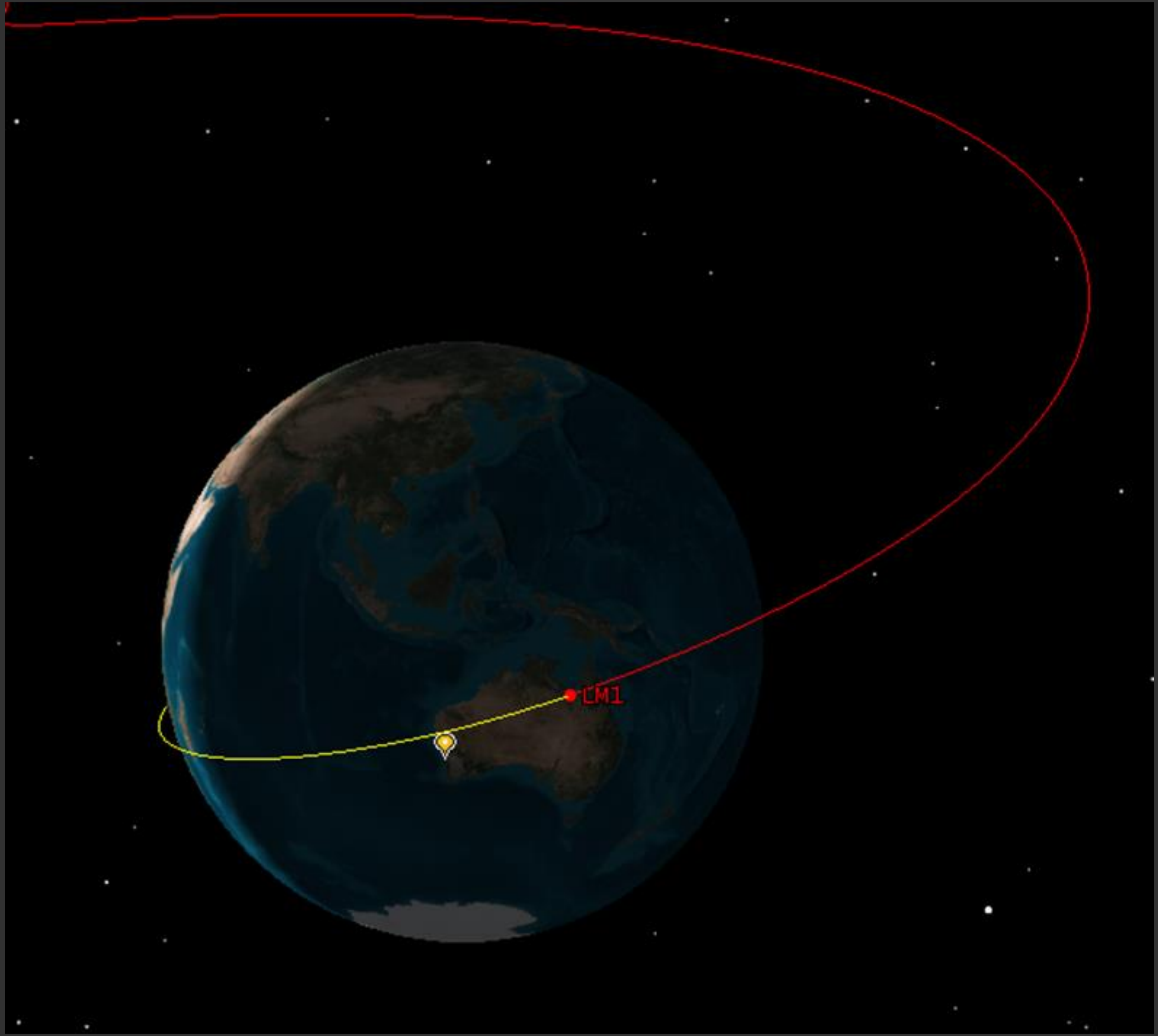
Phase 6 – Landing Ellipse

Phase 1 – Launch (Green)



Phase 2 – Parking Orbit (Yellow)





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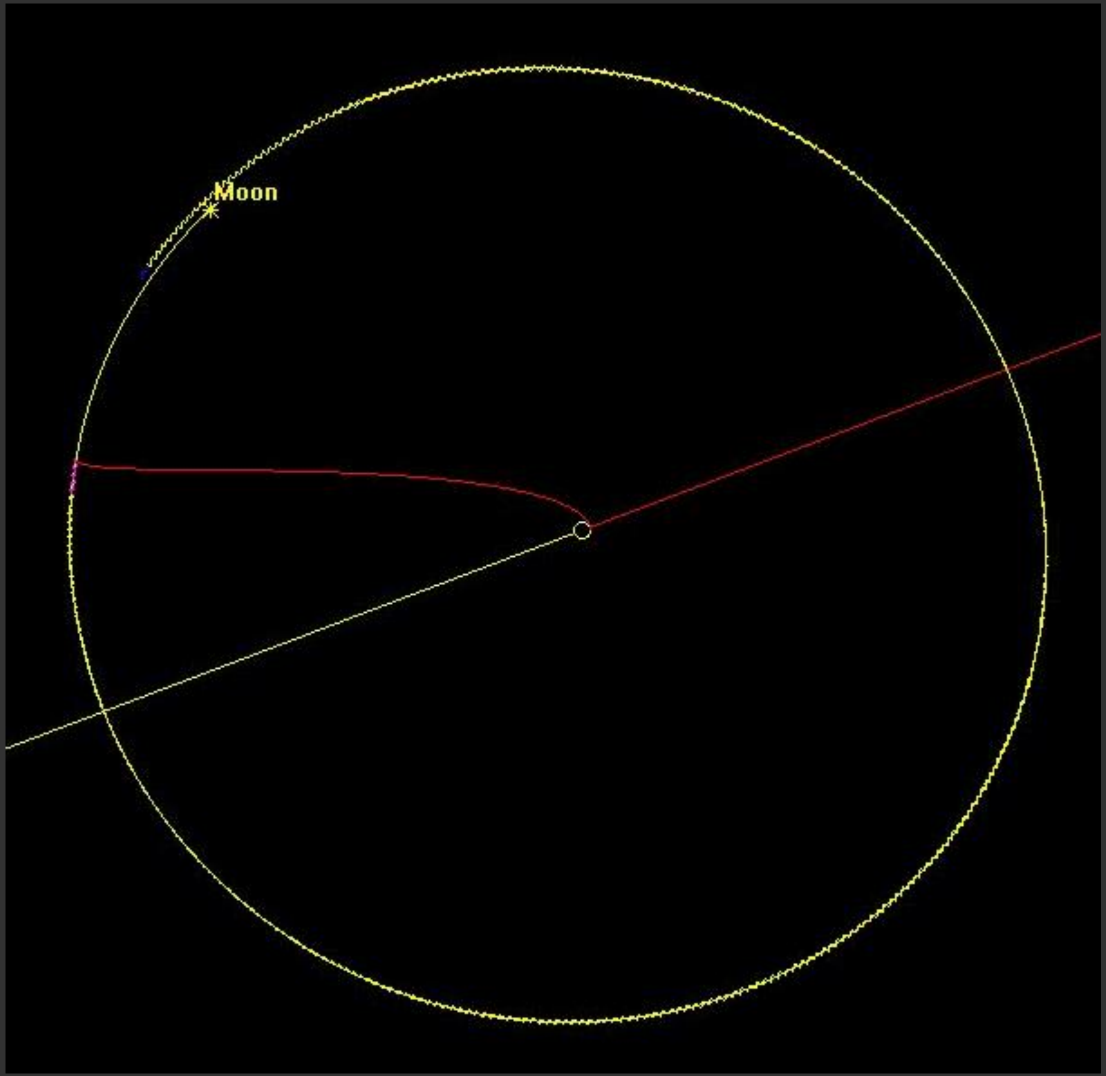
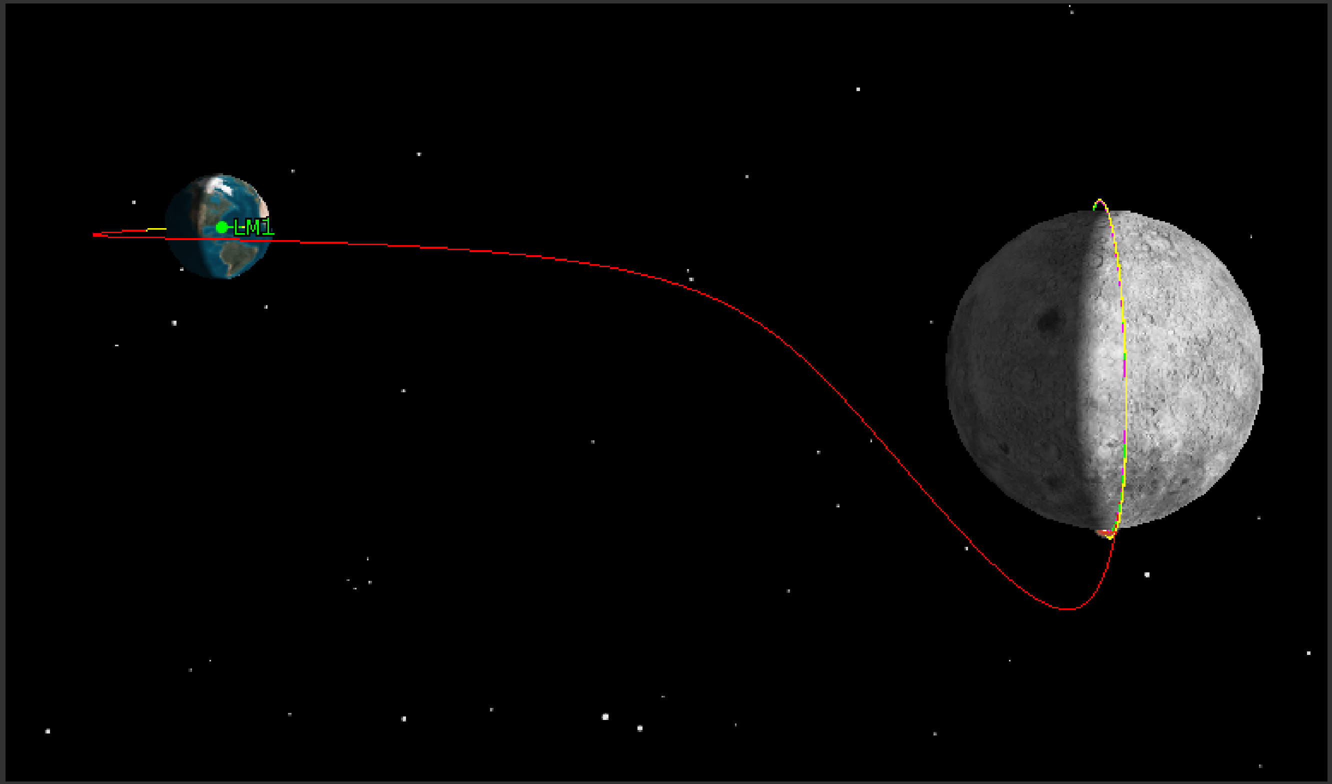
Phase 3 – Cruise to Moon (Red)





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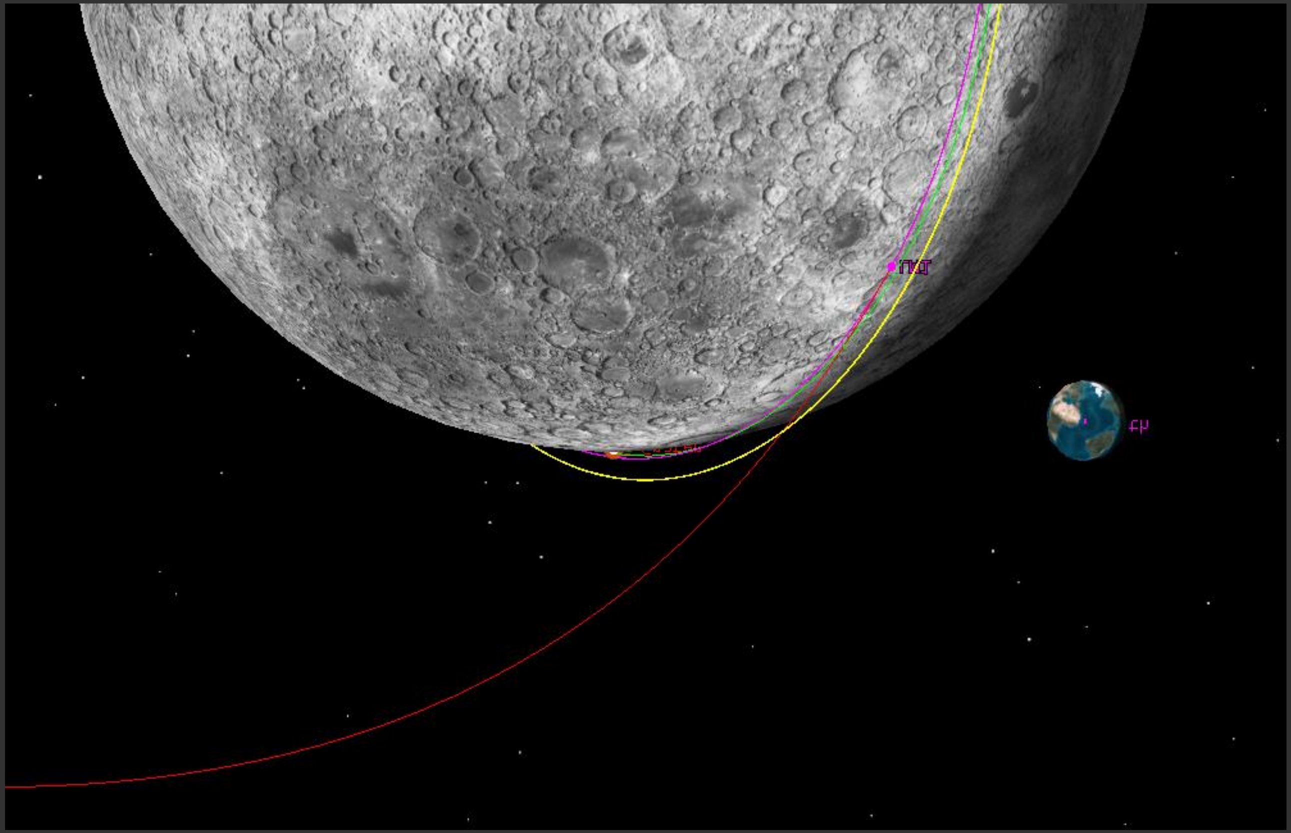
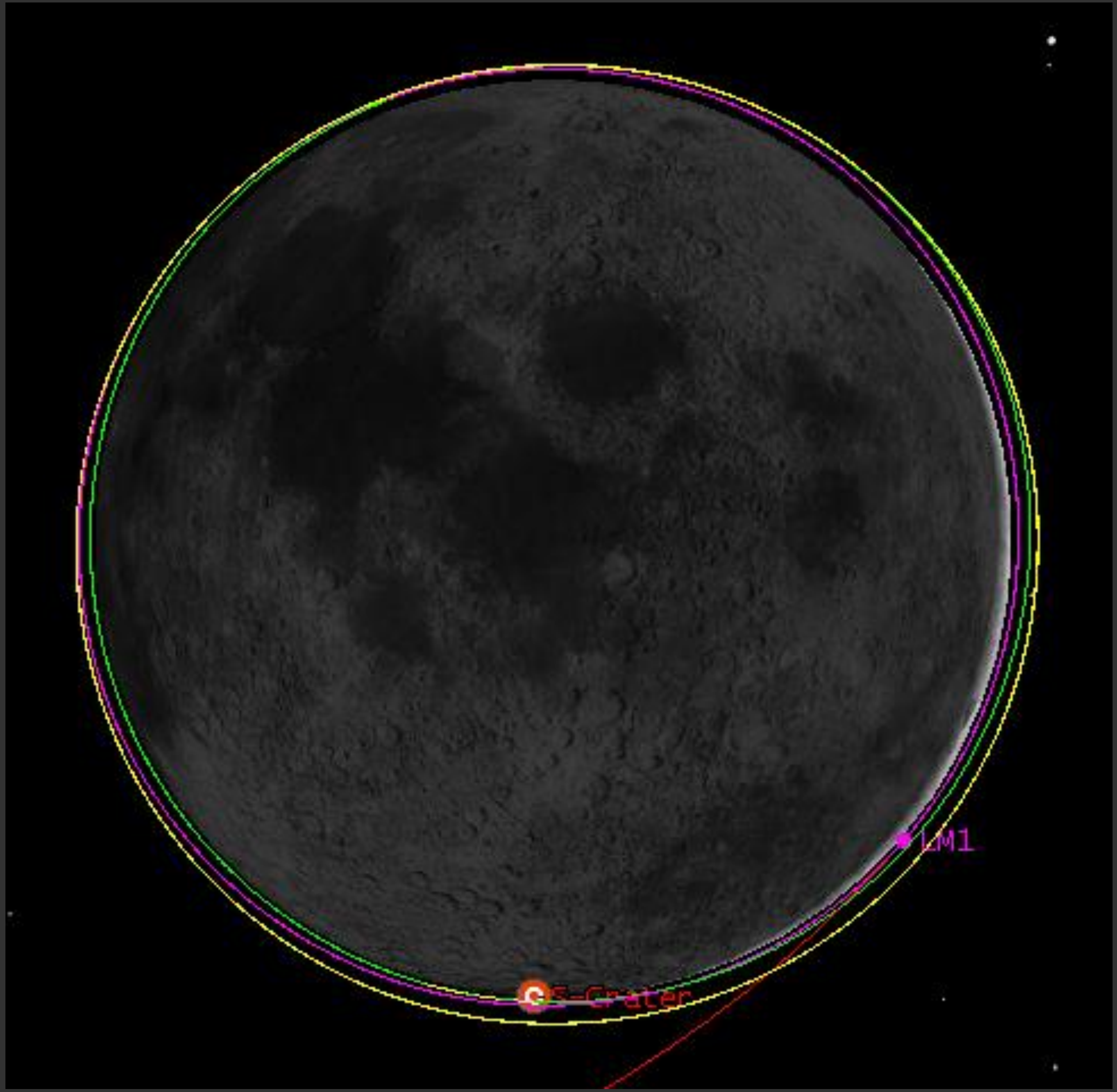
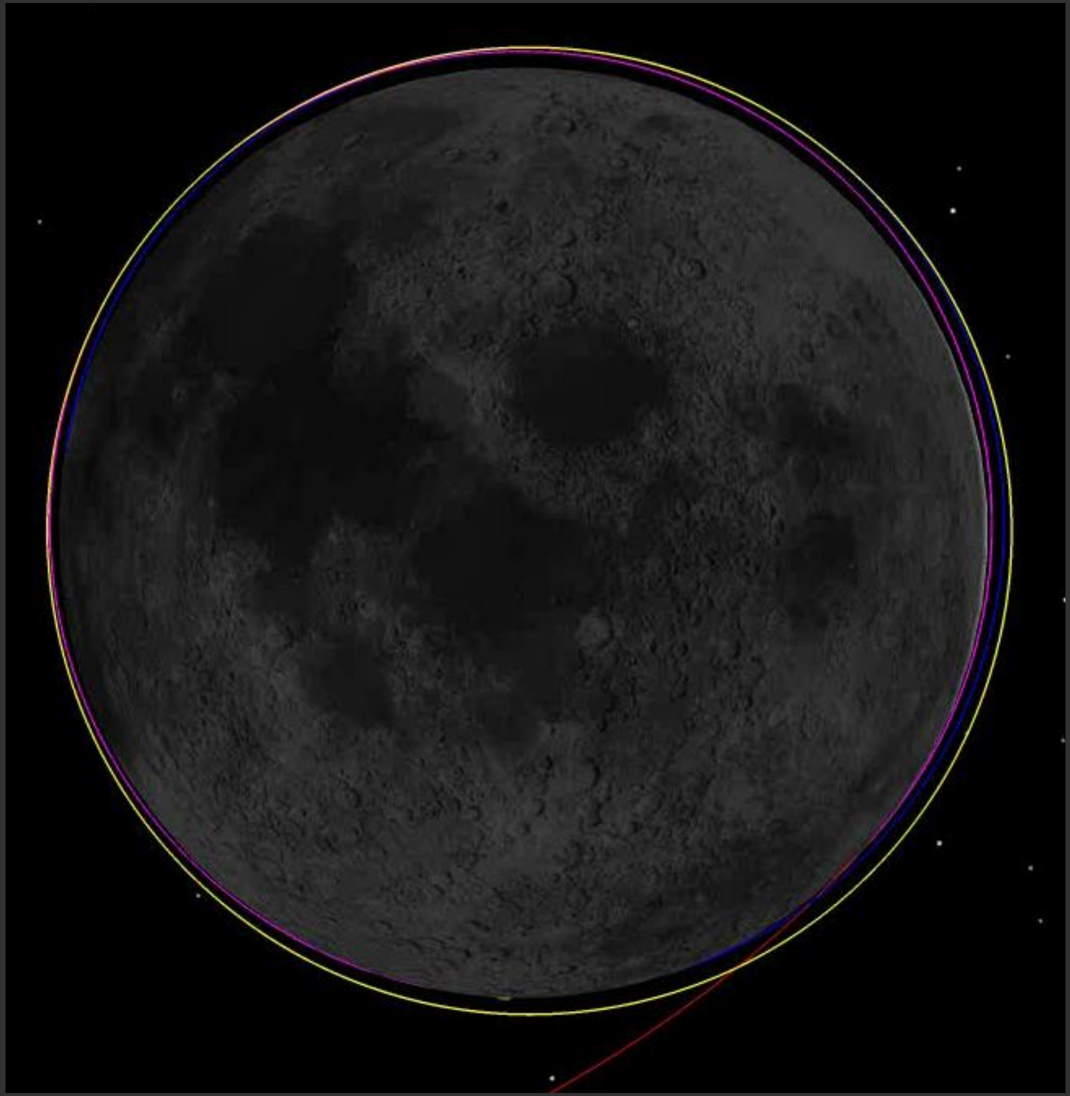
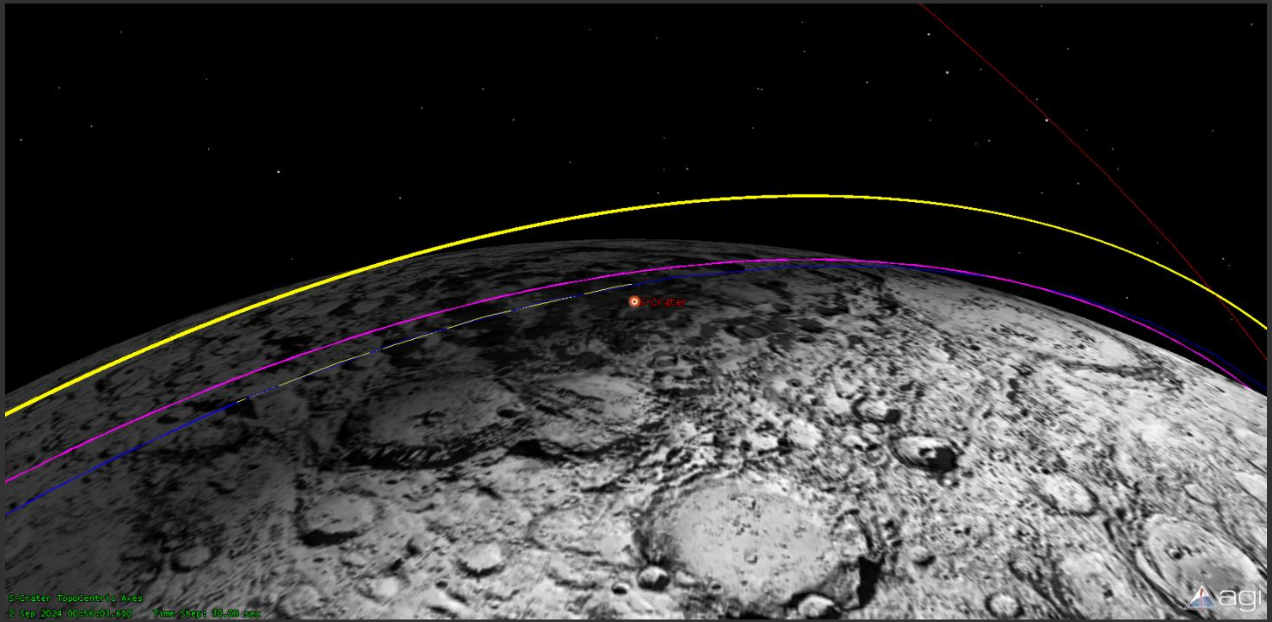
Phase 3 – Cruise to Moon (Red)



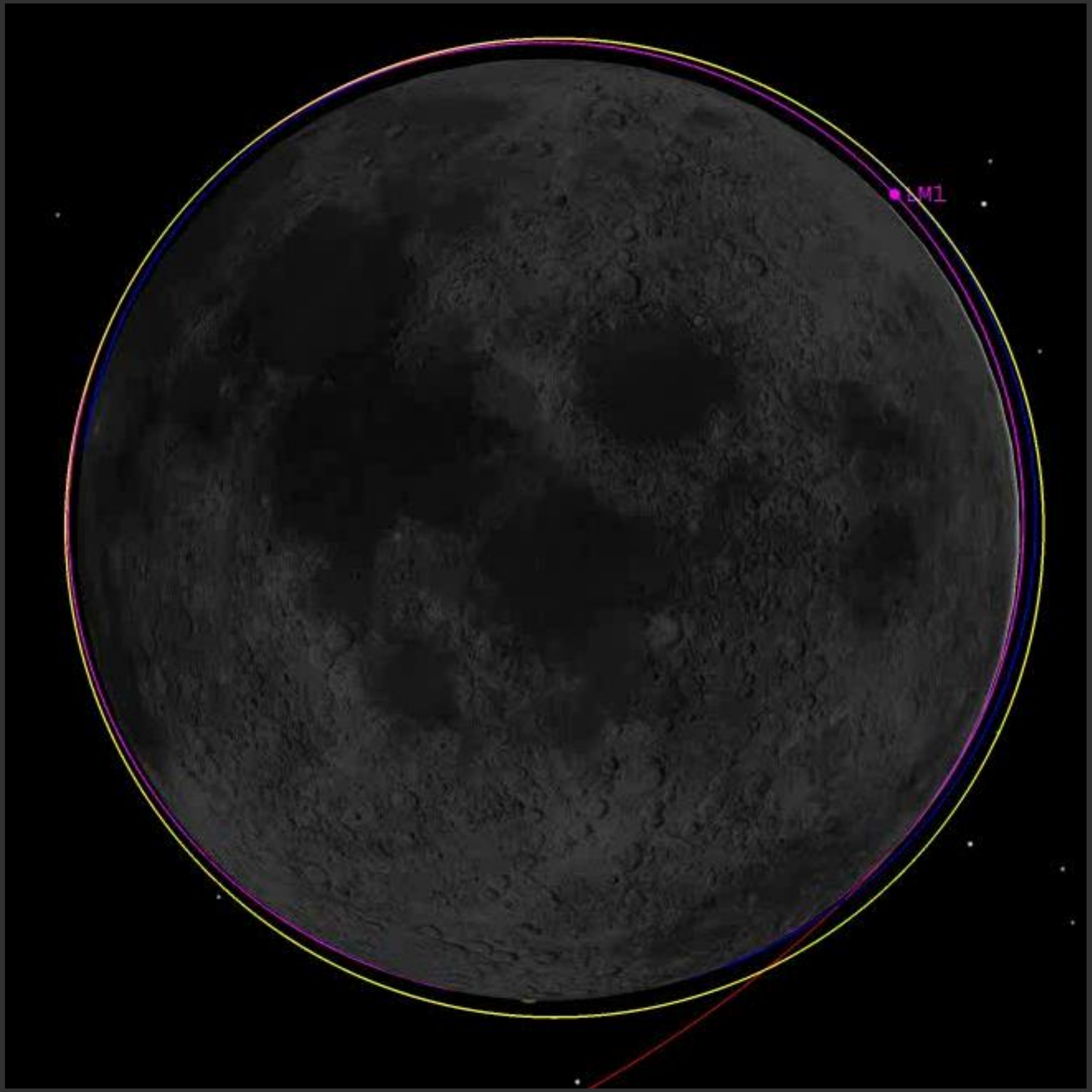


Phase 4 – Mapping (Pink)

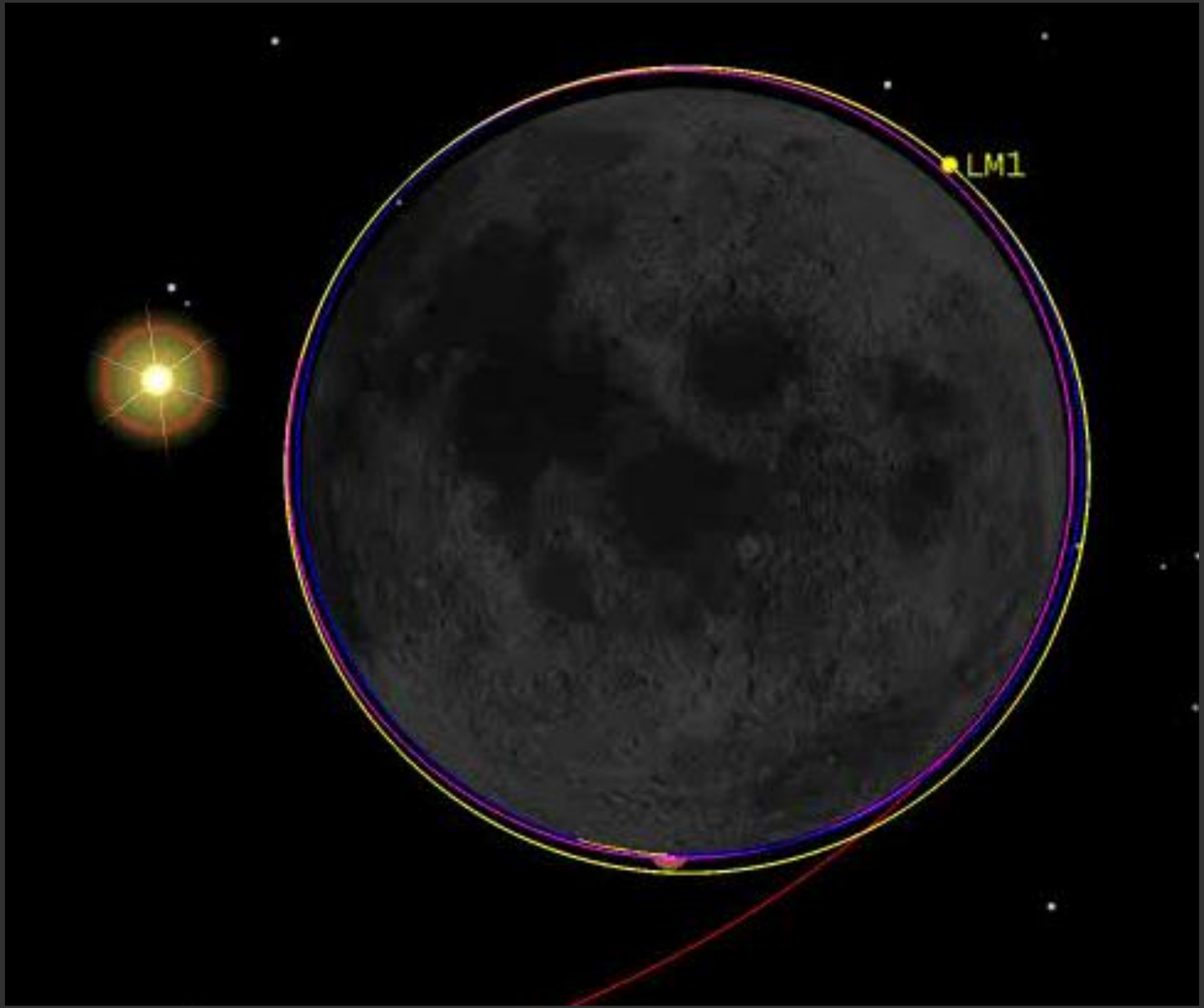


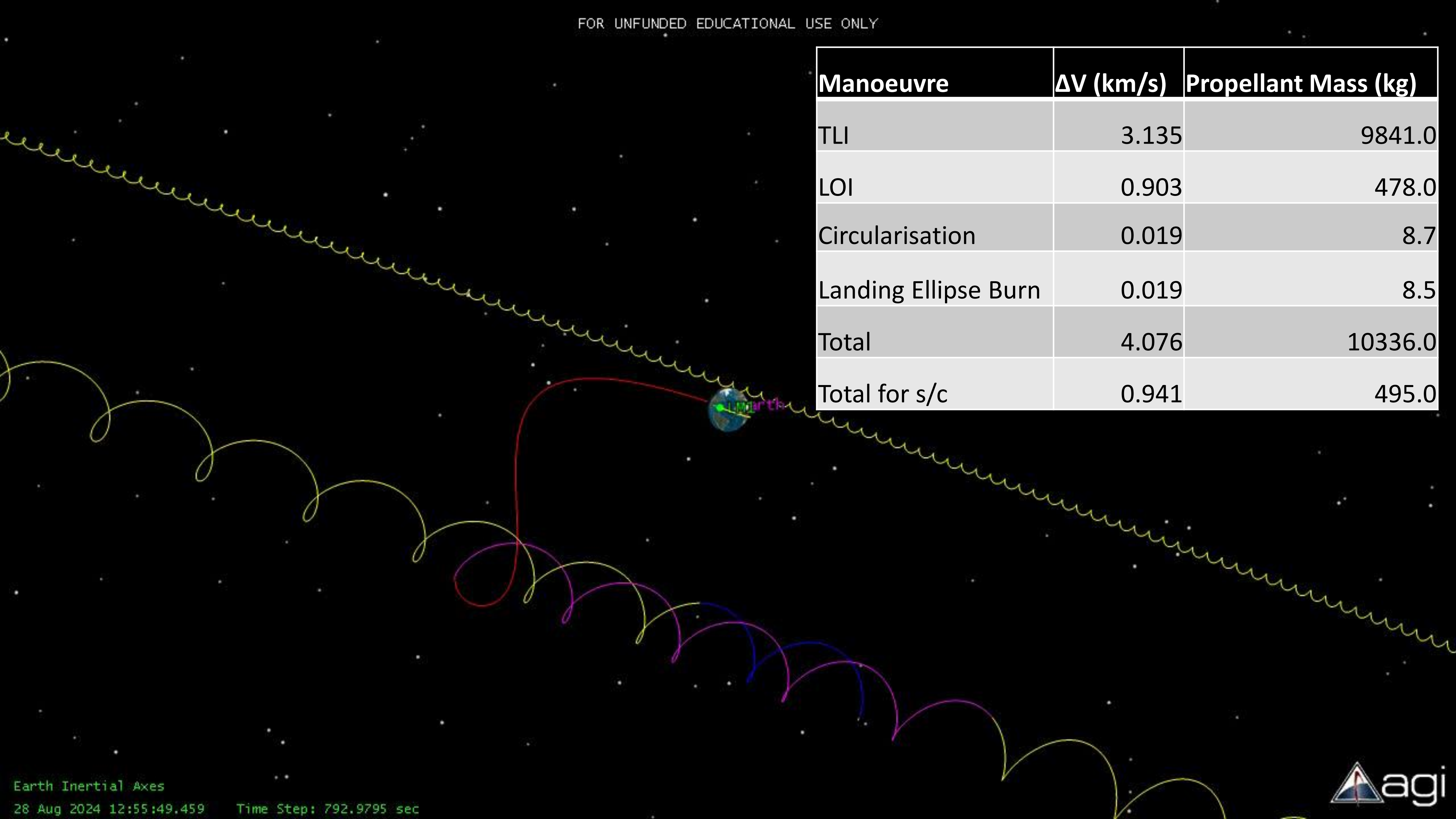


Phase 5 – Parking Orbit (Yellow)



Phase 6 – Landing Ellipse (Blue)





Manoeuvre	ΔV (km/s)	Propellant Mass (kg)
TLI	3.135	9841.0
LOI	0.903	478.0
Circularisation	0.019	8.7
Landing Ellipse Burn	0.019	8.5
Total	4.076	10336.0
Total for s/c	0.941	495.0

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AOCS

- AOCS provided by Falcon 9 up to TLI orbit
- Employed immediately
  - For detumbling, calibration and orbit determination
- 3-axis stabilisation provided by:
  - Eight 4.5N thrusters (plus eight for redundancy)
- Momentum storage provided by:
  - Three 4Nms reaction wheels (plus one for redundancy)

MONARC 5 Thruster - AMPAC-ISP

AOCS

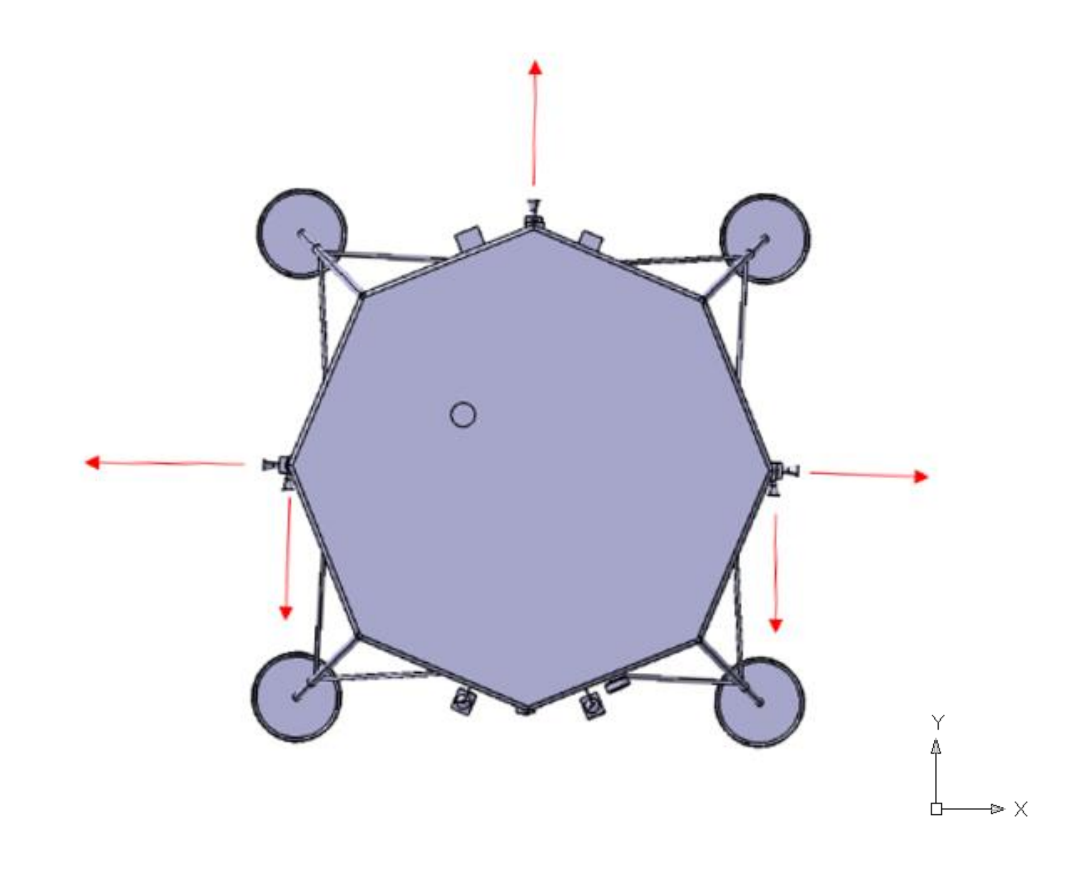
- Orbit determination provided by:
  - Rigel-L star trackers – position
  - LN-200S IMU's inbuilt accelerometers – velocity
  - MOOG Bradford Coarse sun sensors – sun tracking
  - Various DSA & DSN ground stations – ranging

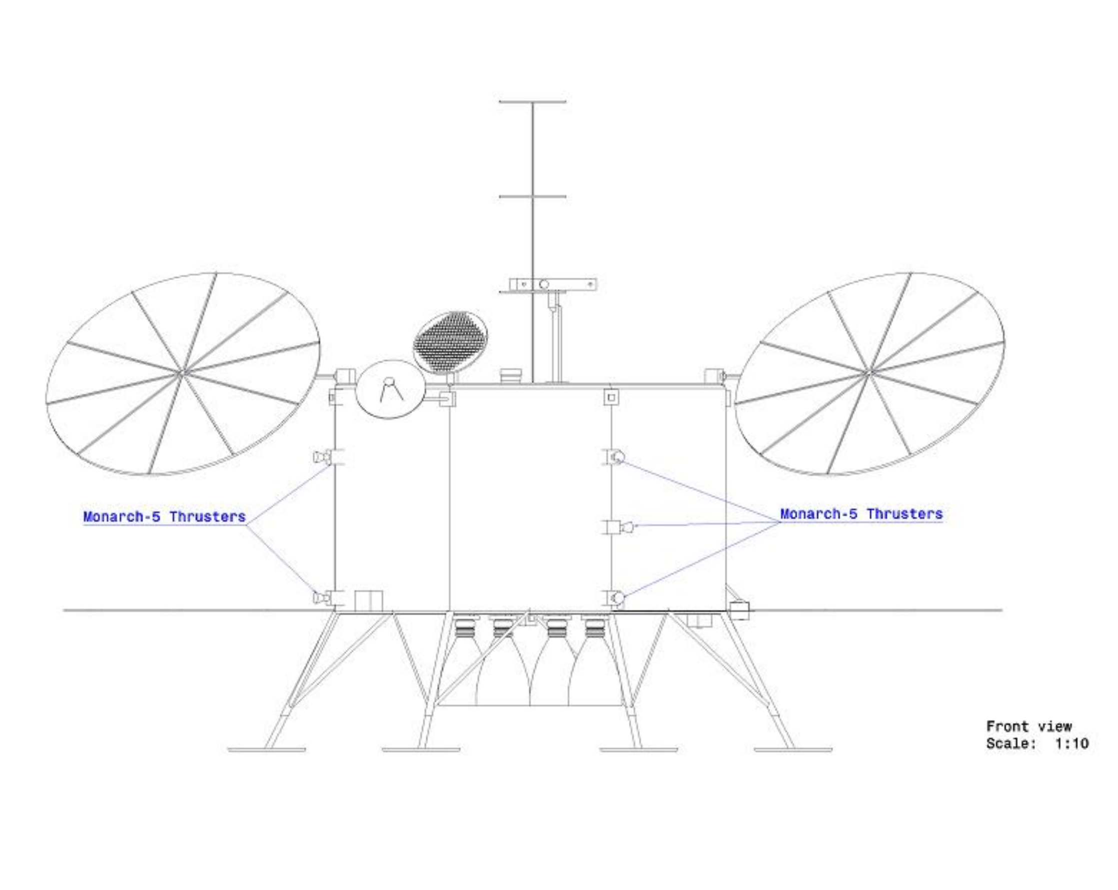
- Highest pointing accuracy – 0.11 deg (from lunar mapping)

Rigel-L Star Tracker – SSTL

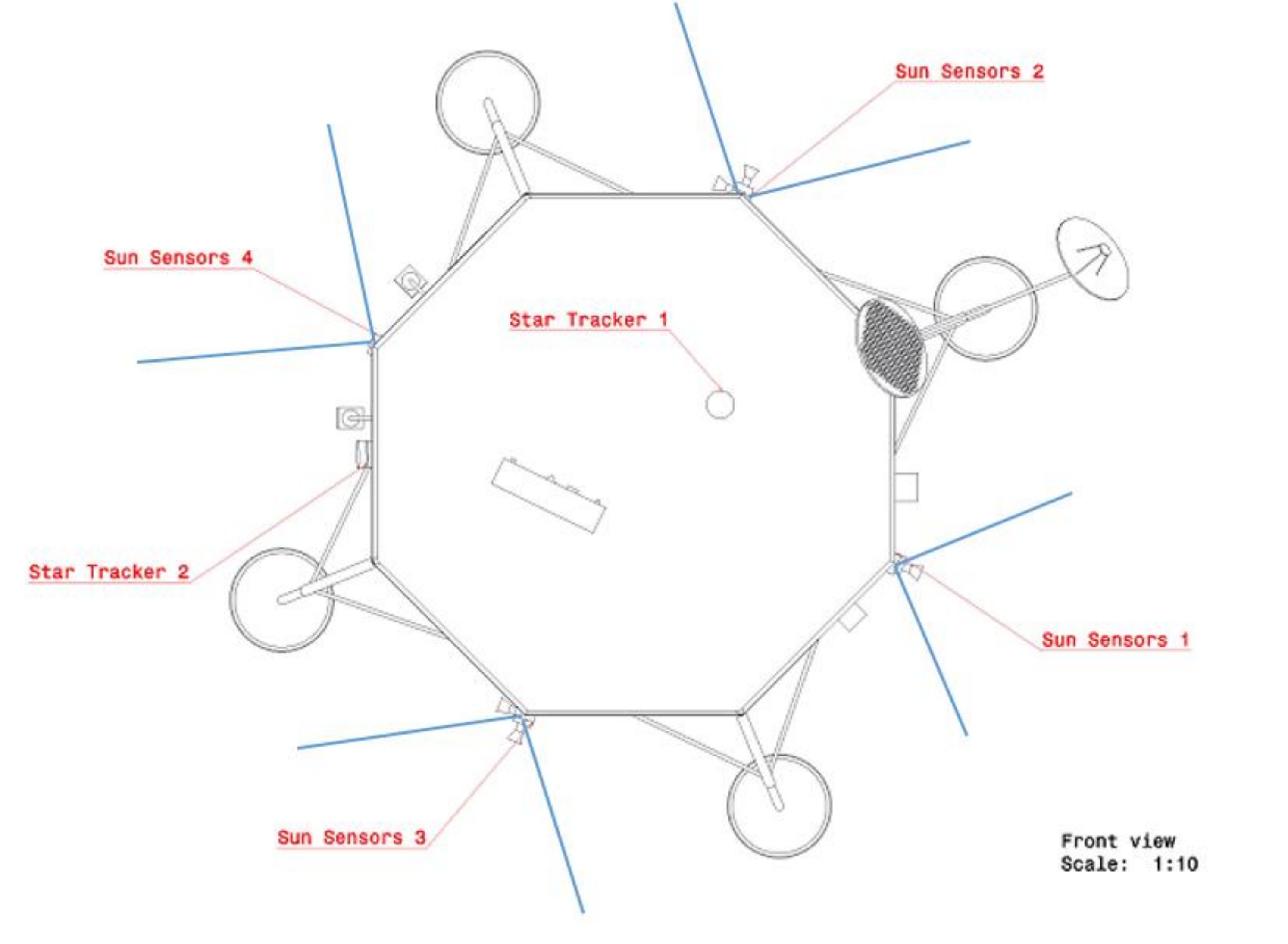
LN-200S IMU – Northrop Grumman

AOCS Thrusters

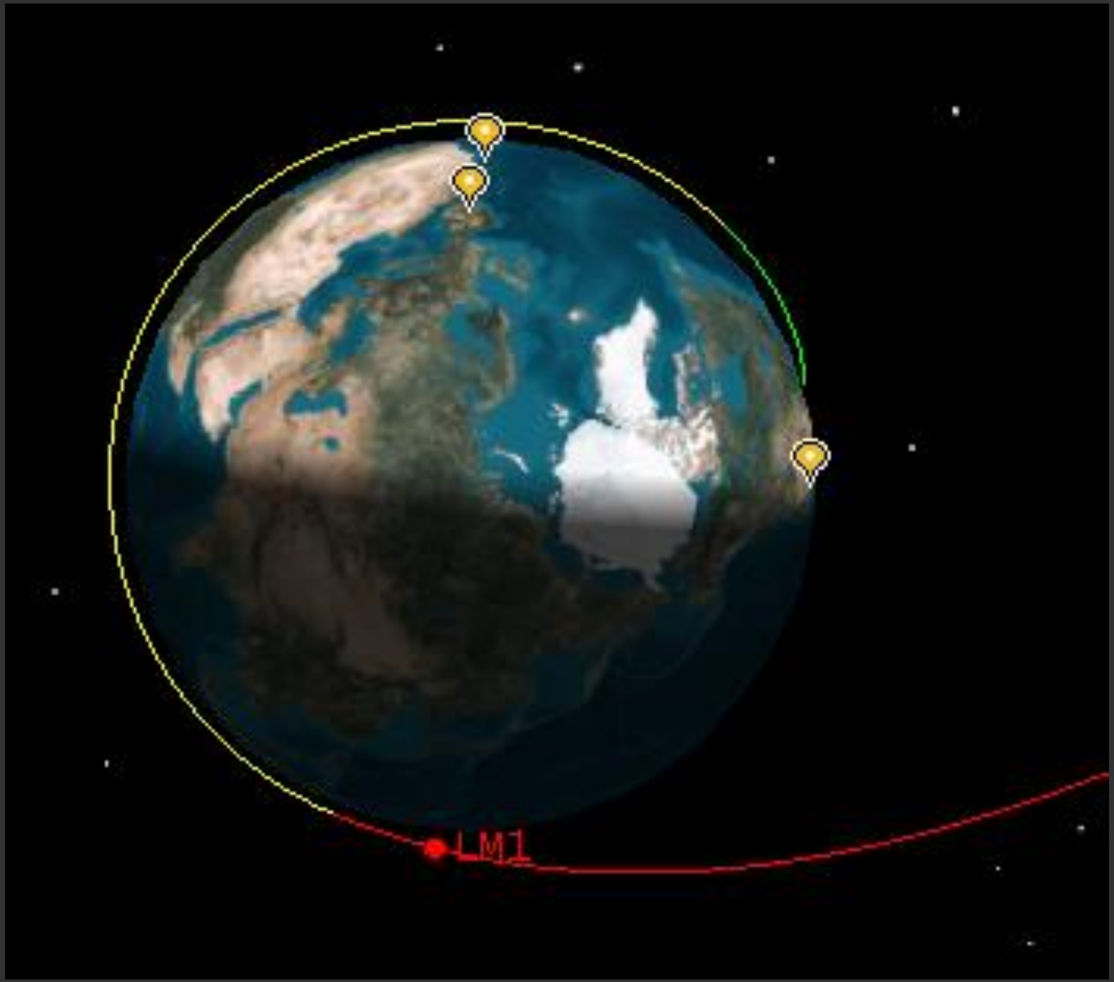




AOCS Sensors



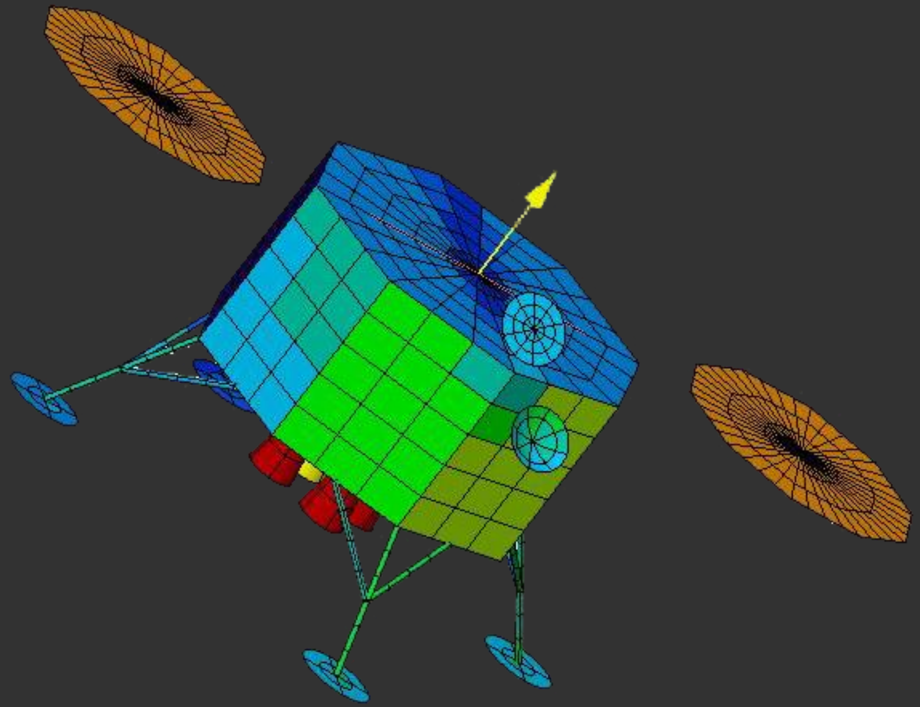
Power



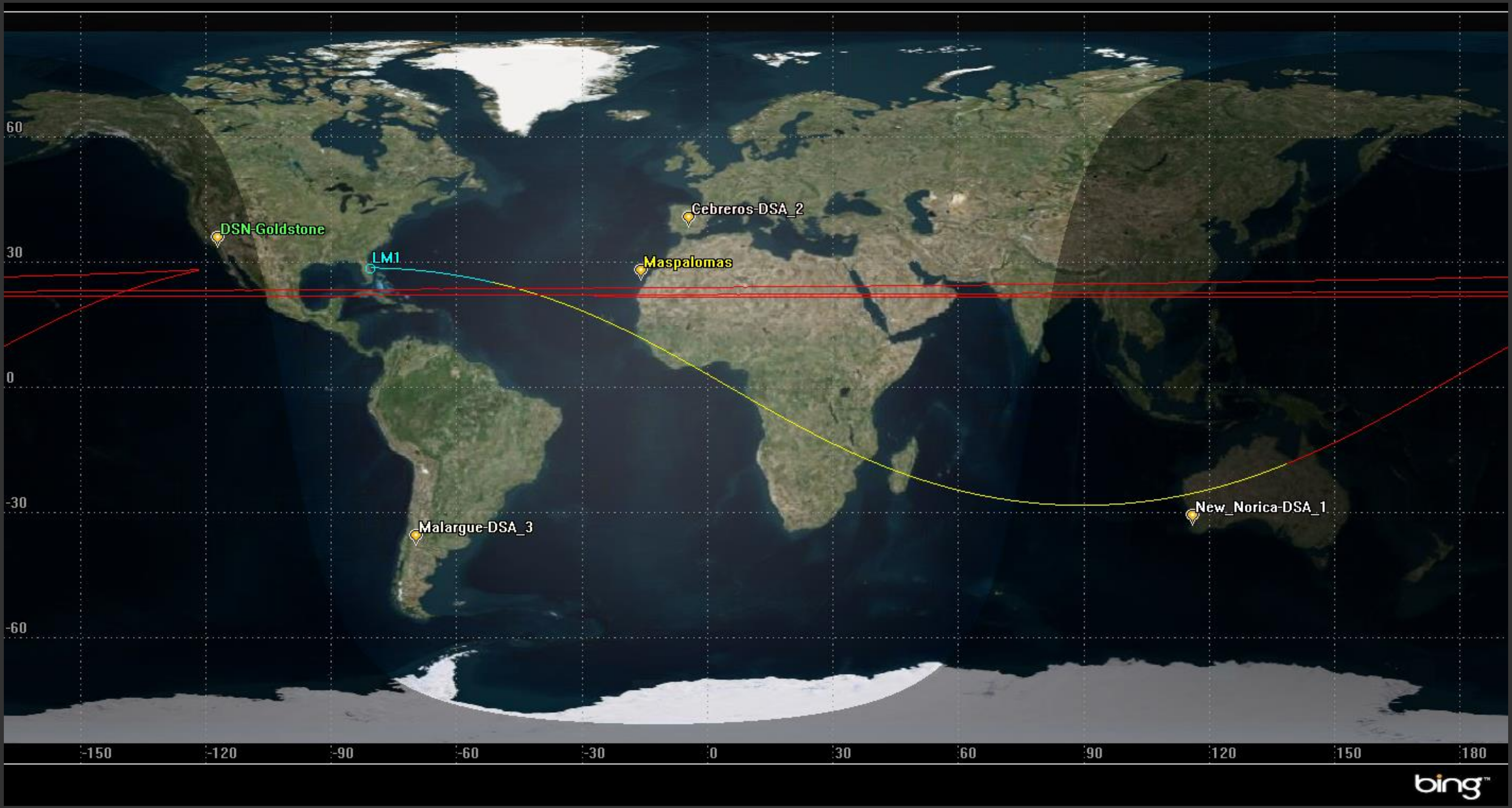
Thermal

- Modelled with two cases: hot & cold
- Passive thermal control

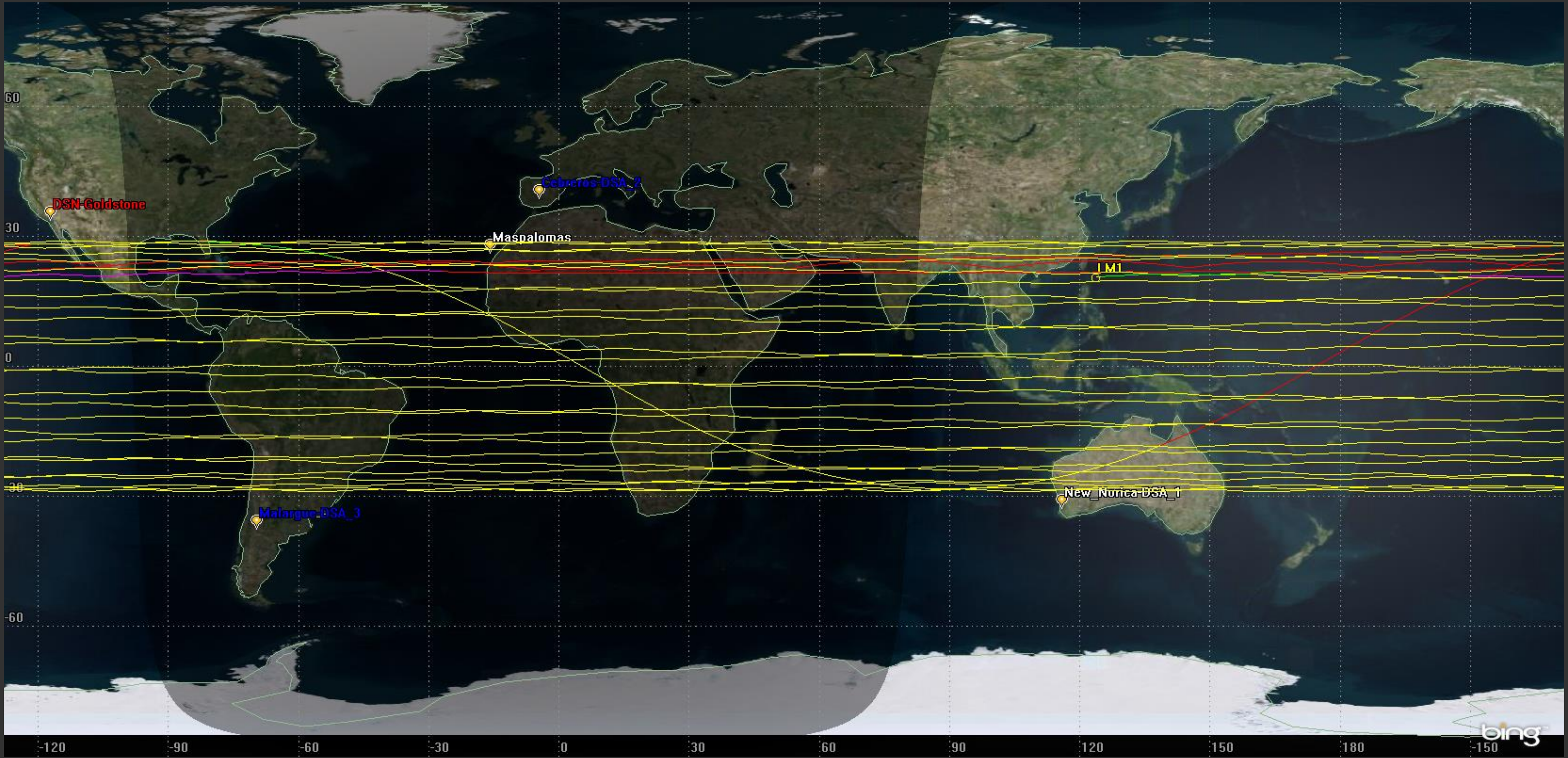
	Exterior	Interior	Antenna
Material	Teflon	Kapton	White paint
Emissivity	0.4	0.5	0.7
Absorptivity	0.12	0.31	0.1



Communications



Communications



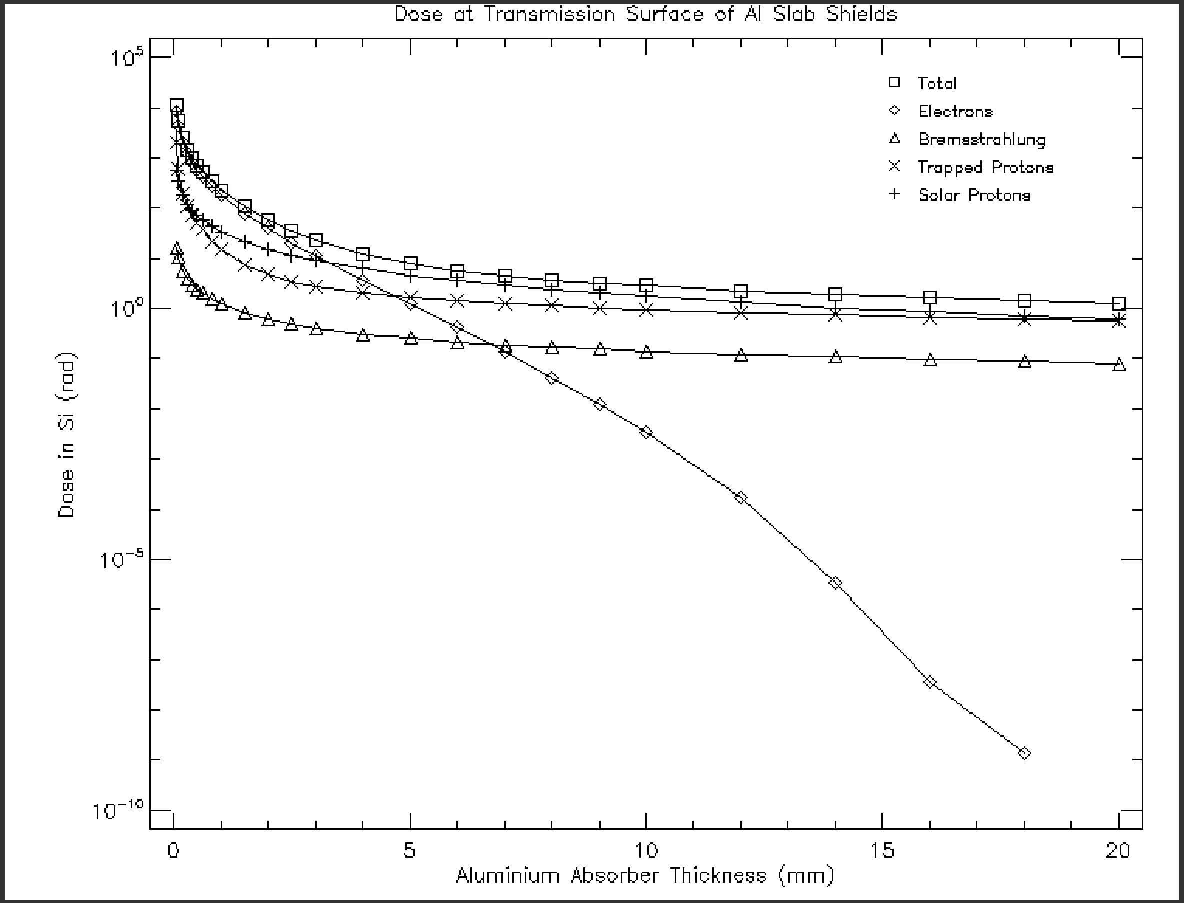
Scientific Instruments

- Dust analyser – ELDA
- Radiation monitor – NGRM
- Turned on until end of mission

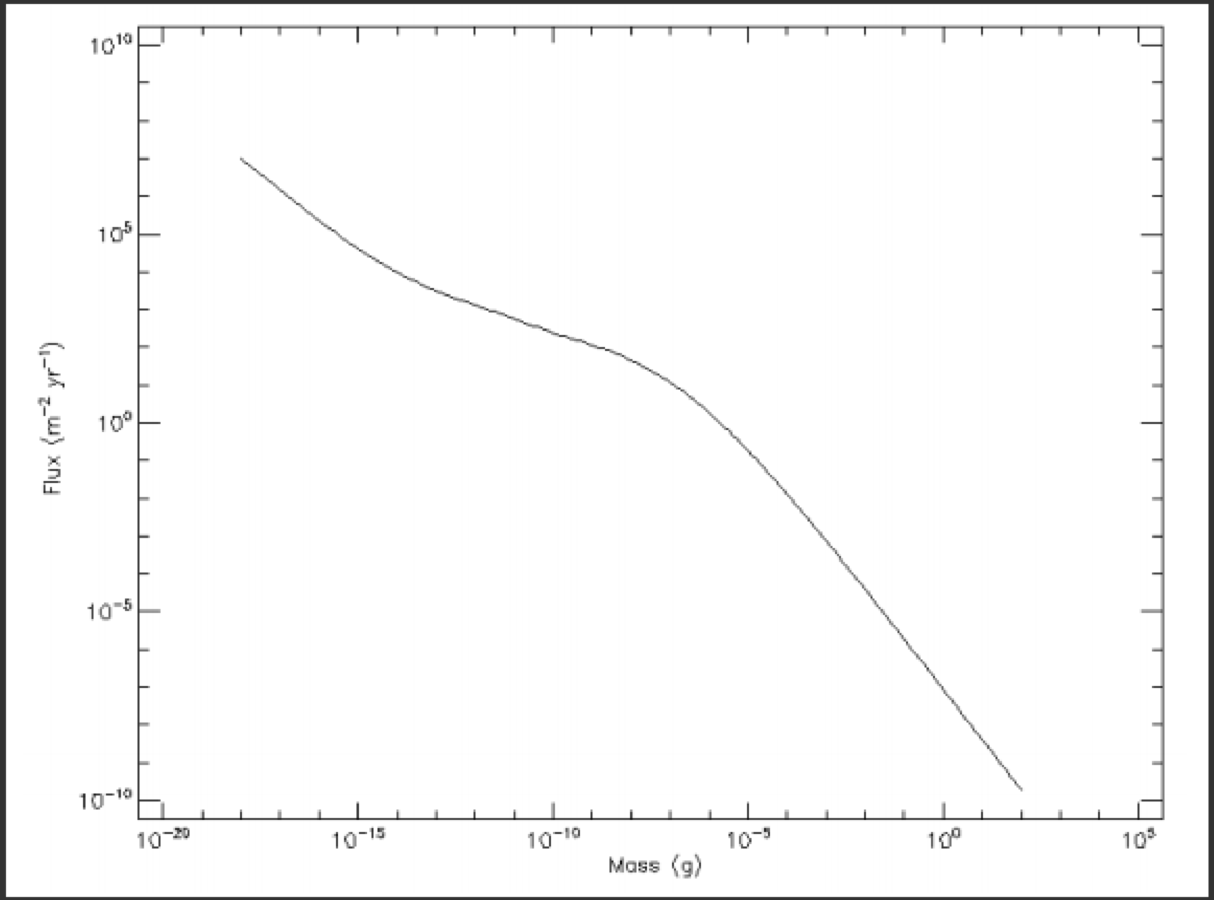
ELDA – University of Colorado (Xie et al. n.d.)

NGRM developed by RUAG.(RUAG n.d.)

Risks



Dose at Transmission Surface of Al Slab Shields
Total
Electrons
Bremsstrahlung
Trapped Protons
Solar Protons
Dose in Si (rad)
Aluminium Absorber Thickness (mm)



Flux (m^{-2} yr^{-1})
Mass (g)

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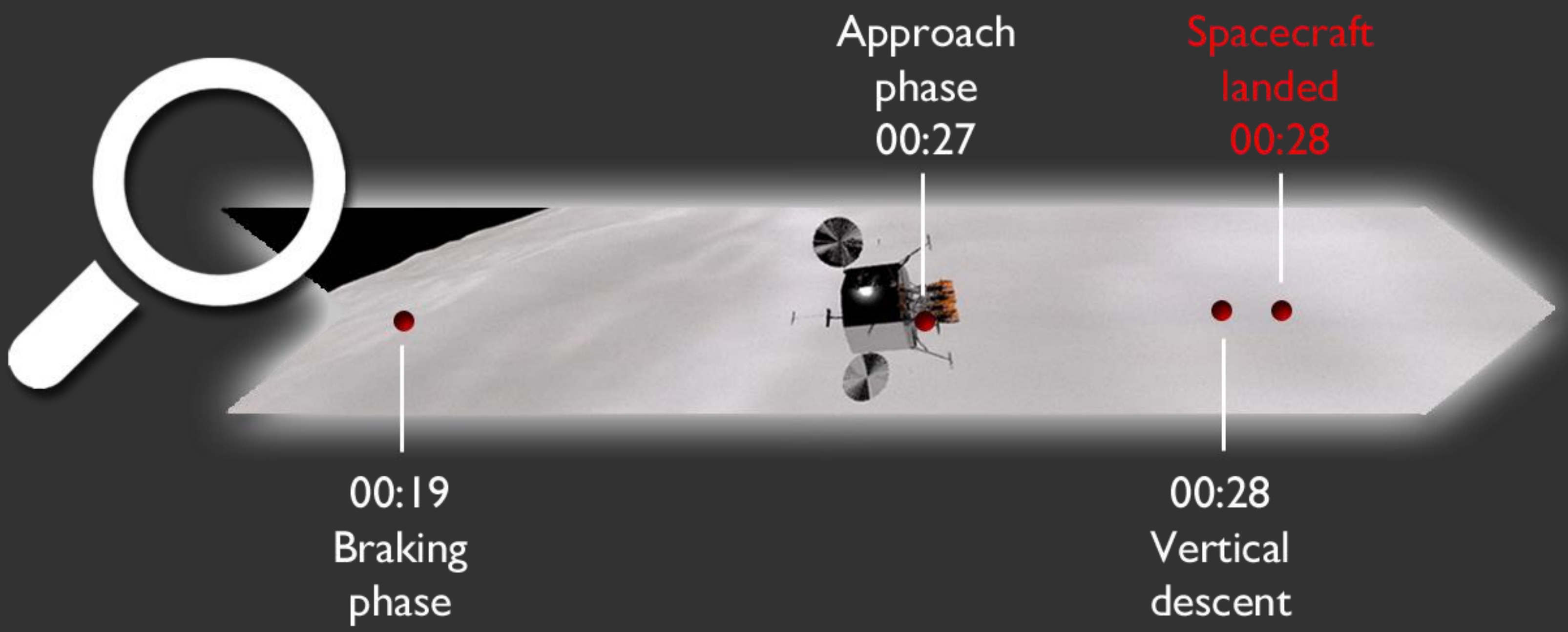
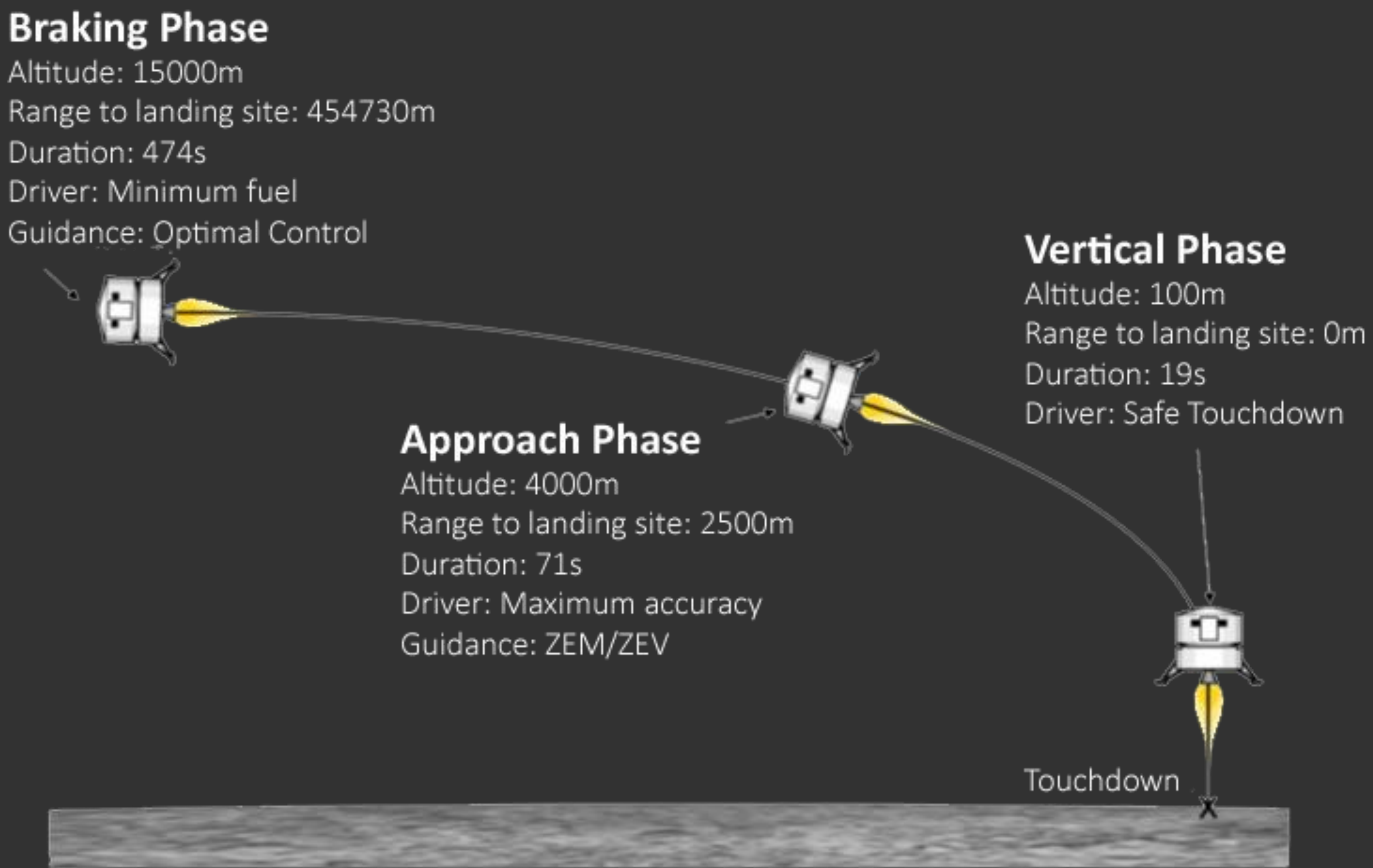
28 Sep. 2024
LANDING SEQUENCE



Sequence



Braking Phase
Altitude: 15000m
Range to landing site: 454730m
Duration: 474s
Driver: Minimum fuel
Guidance: Optimal Control
Approach Phase
Altitude: 4000m
Range to landing site: 2500m
Duration: 71s
Driver: Maximum accuracy
Guidance: ZEM/ZEV
Vertical Phase
Altitude: 100m
Range to landing site: 0m
Duration: 19s
Driver: Safe Touchdown
Touchdown

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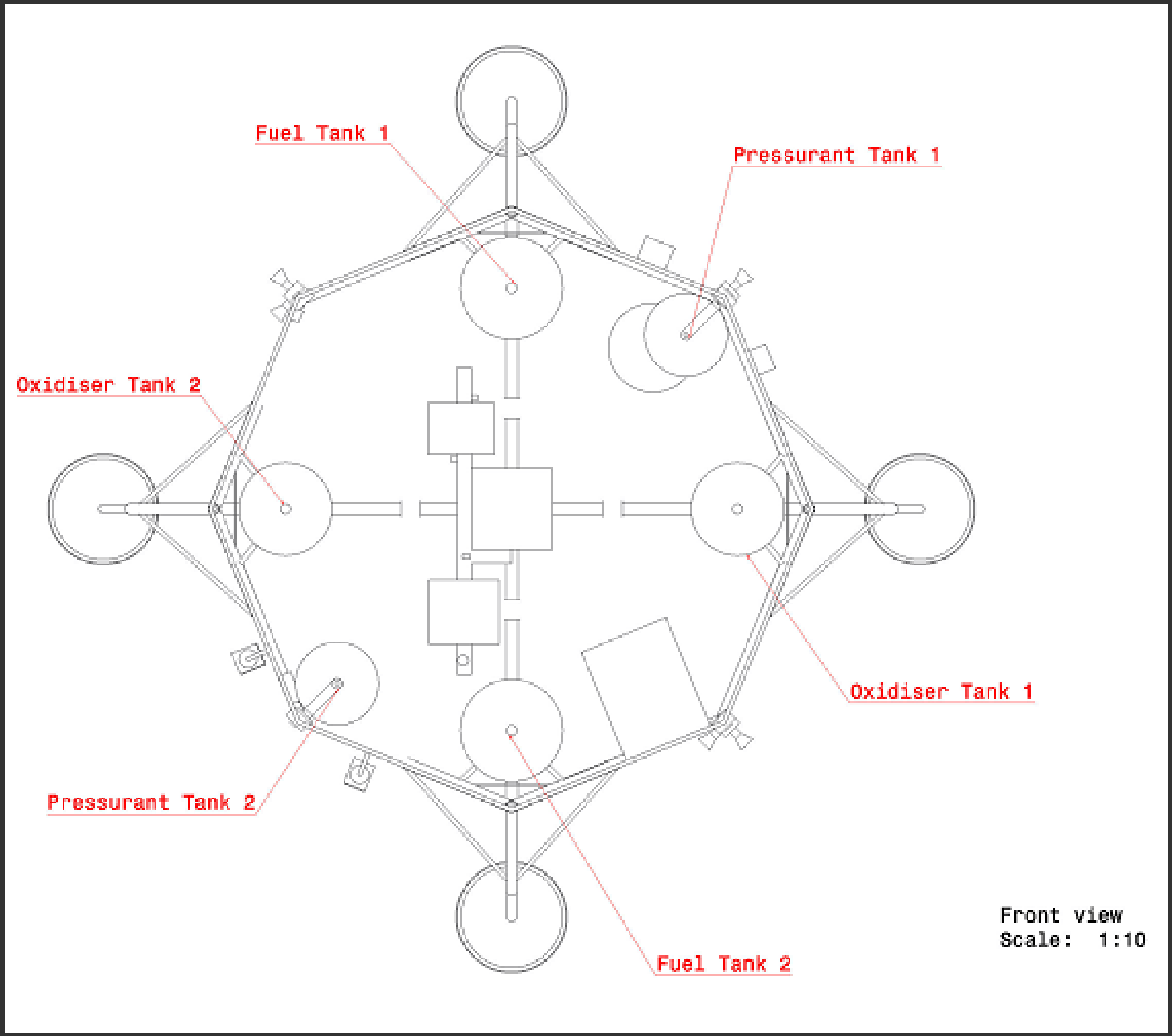
Key Hardware: Propulsion

- 890N nominal thrust
- 327s Isp
- Maximum Thrust of ~1300N

Aerojet
R-42DM
(C. Stechman 2010)

Propulsion Sub-system



Key Hardware: GNCS

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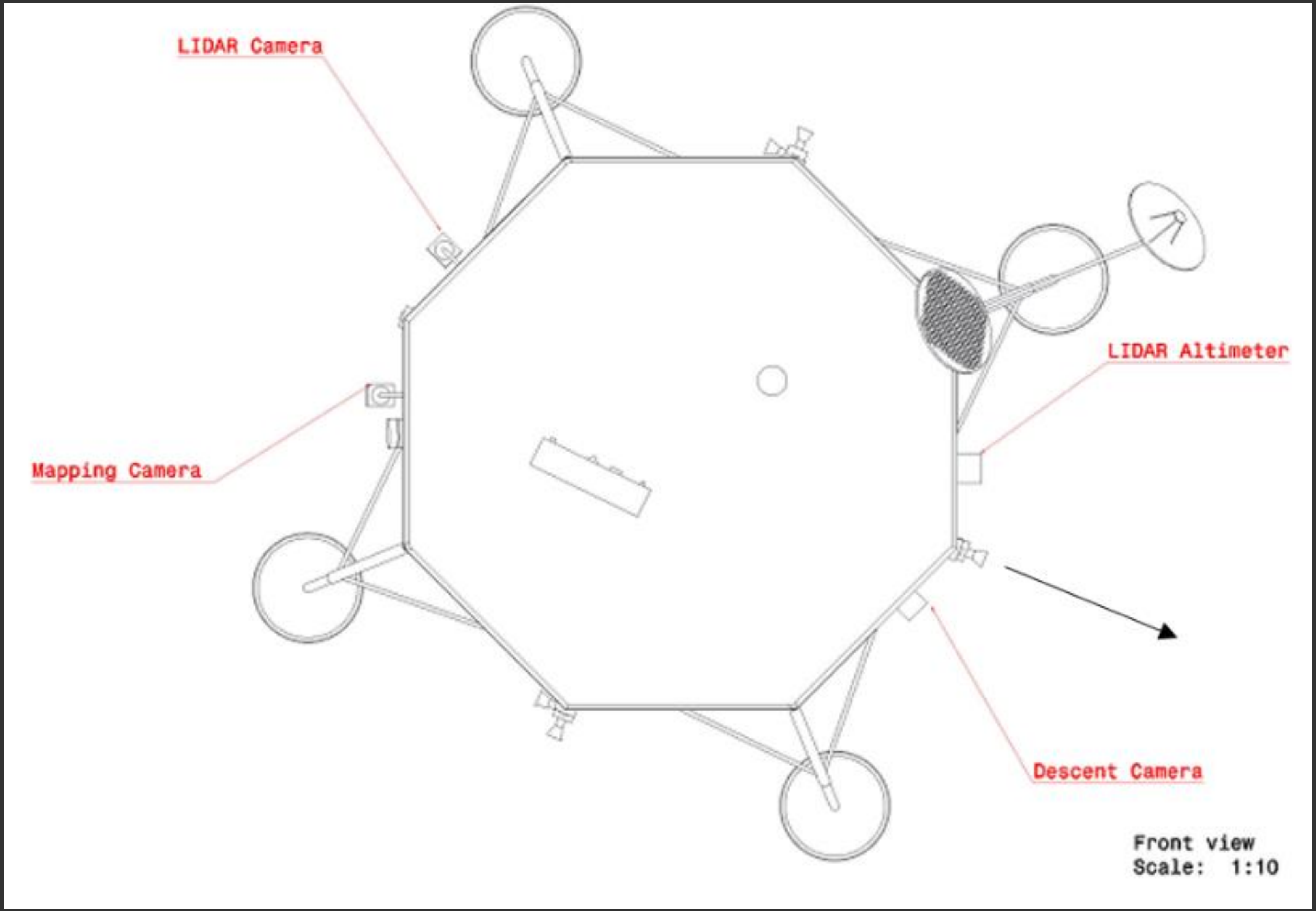
Sensor	Amount	Name	Main Function
IMU	2	Miniature IMU	Inertial Navigation
IMU	1	LN-200S	Inertial Navigation
Optical Camera	1	N/A (Self designed)	Mapping
Flash Lidar	1	DragonEye	Navigation, HDA
Descent Camera	1	MARDI	Navigation, HDA
Lidar Velocimeter	1	N/A	Altimetry, Velocimetry

Descent and Landing



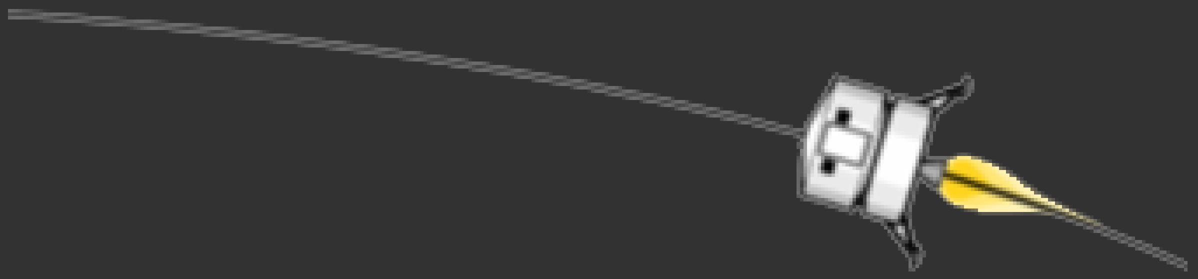
Altitude: 15000m
Range to landing site: 454730m
Duration: 474s
Driver: Minimum fuel
Guidance: Optimal Control

Braking

Approach

Descent

Touchdown



Altitude: 4000m
Range to landing site: 2500m
Duration: 71s
Driver: Maximum accuracy
Guidance: ZEM/ZEV

Braking

Approach

Descent

Touchdown

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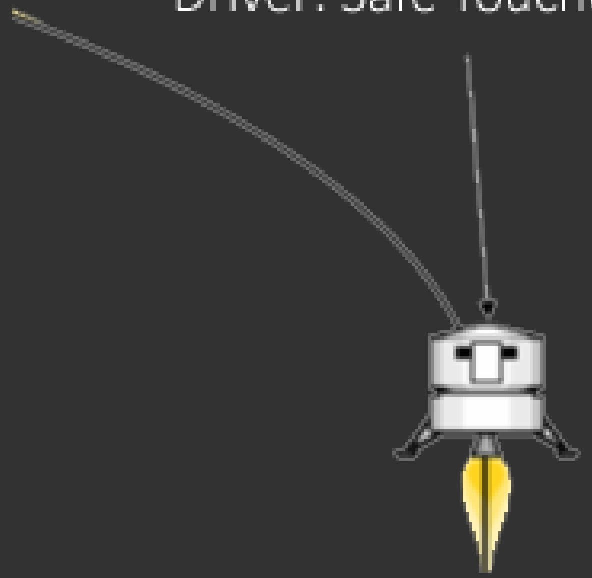
Altitude: 100m
Range to landing site: 0m
Duration: 19s
Driver: Safe Touchdown



Braking

Approach

Descent

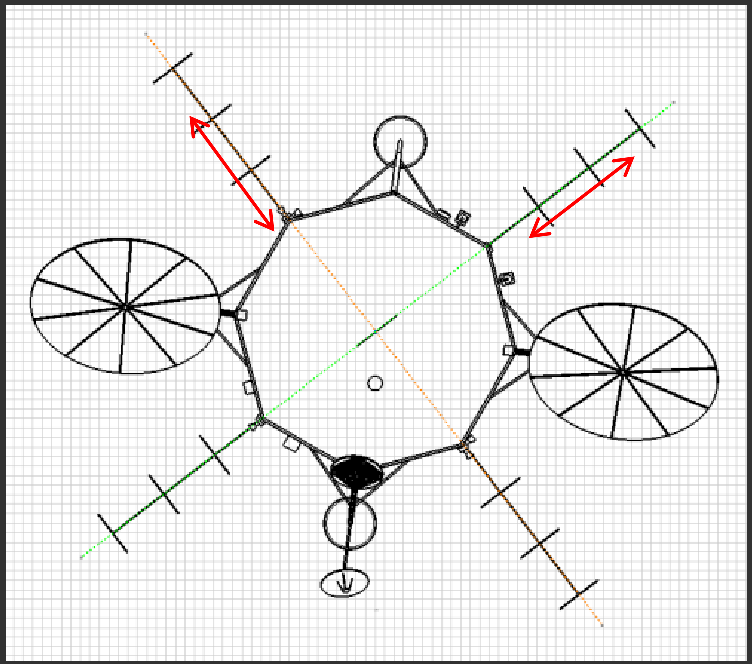
Touchdown

AOCS

- AOCS is used for translation along lateral axes

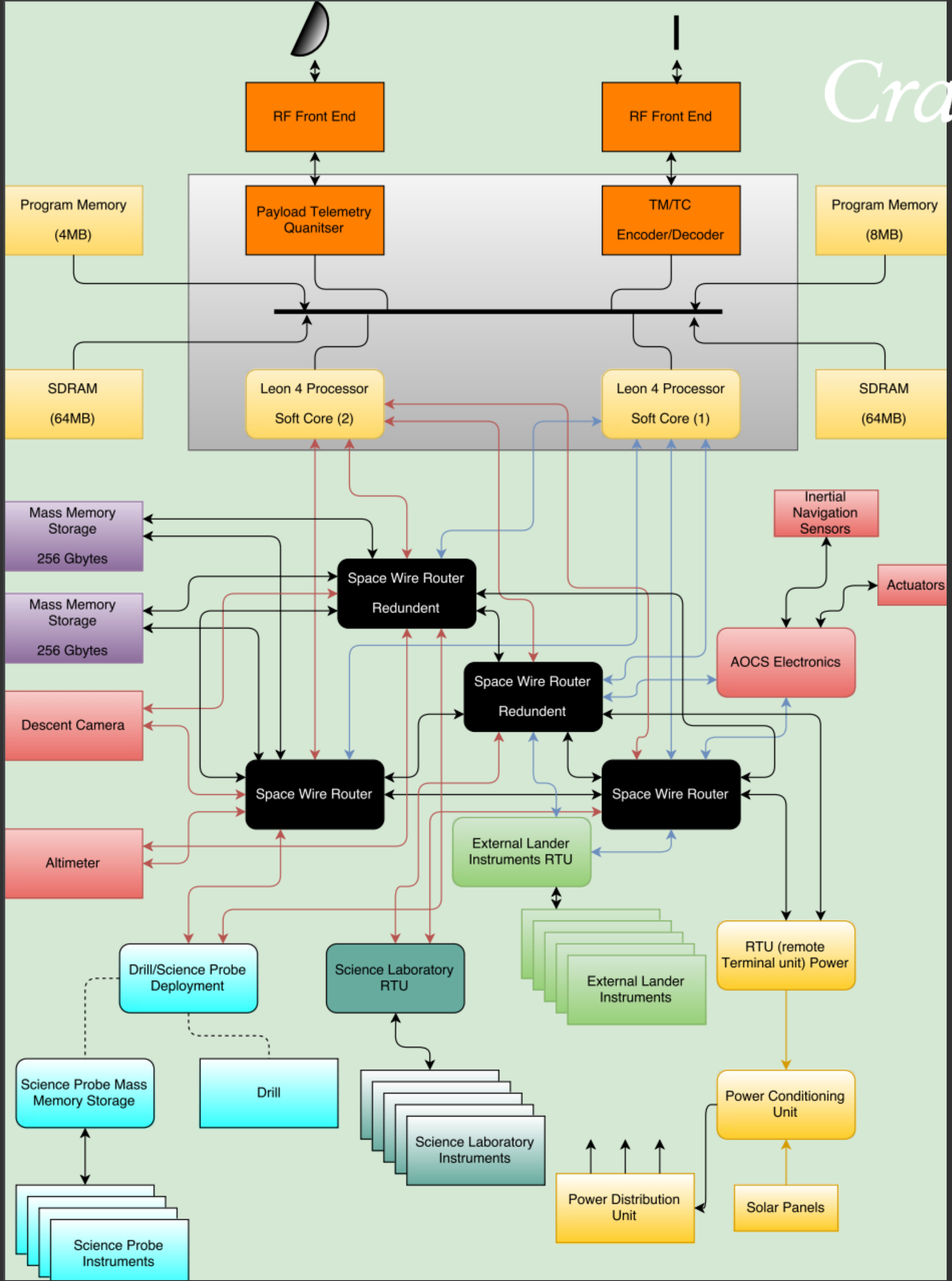
- Enable last minute course correction

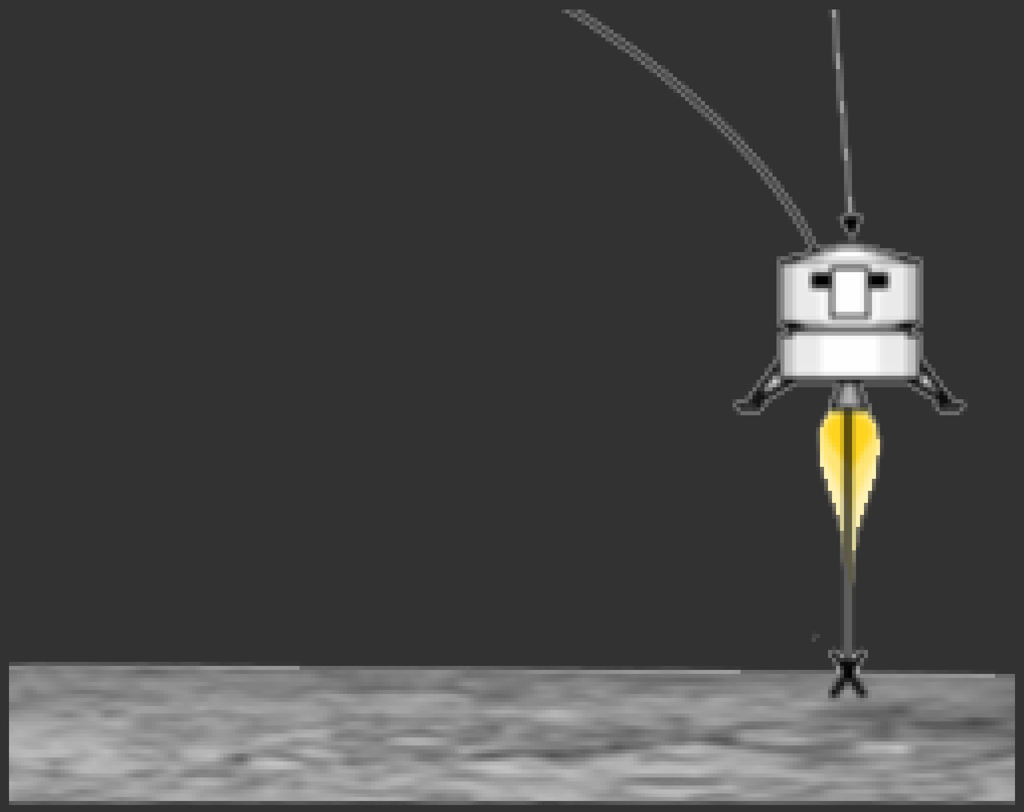
- Increases Landing precision



OBDH

- Dual Leon 4 Processors
  - One analyses environment upon descent
  - One controls AOCS
  - If one fails the other can immediately take over operations
- Dual 250Gbit Mass Storage devices
- Architecture designed for redundancy





Braking

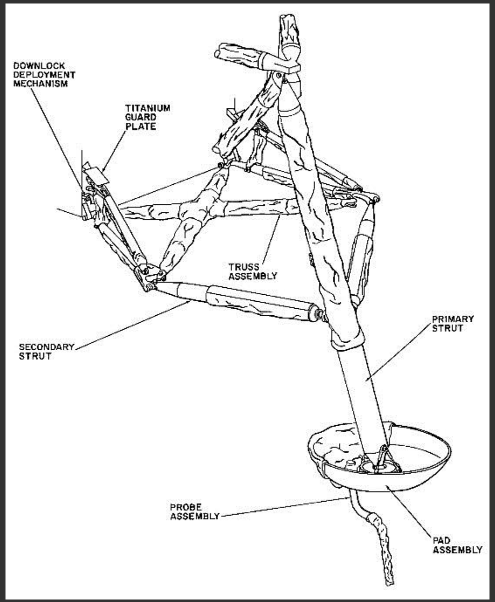
Approach

Descent

Touchdown

Landing Legs

Driving Requirements:
-Wide footprint for stability
-Absorb impact velocity (5m/s)
-Avoid sinking into regolith

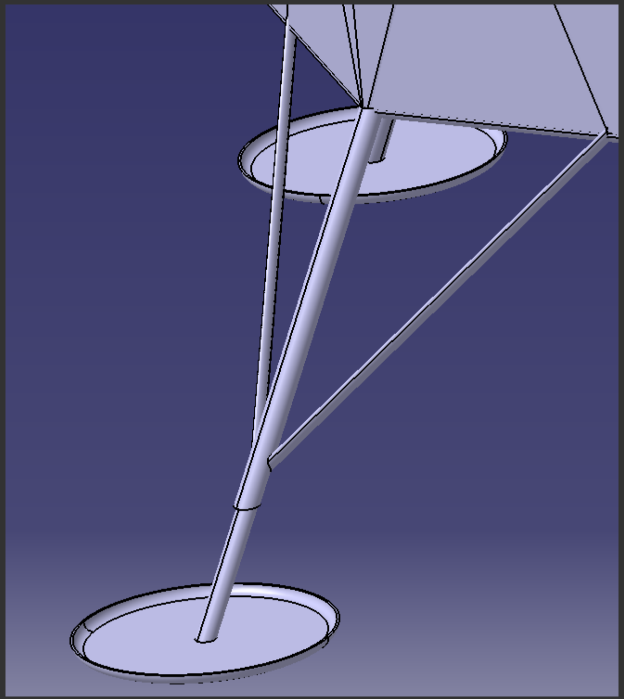


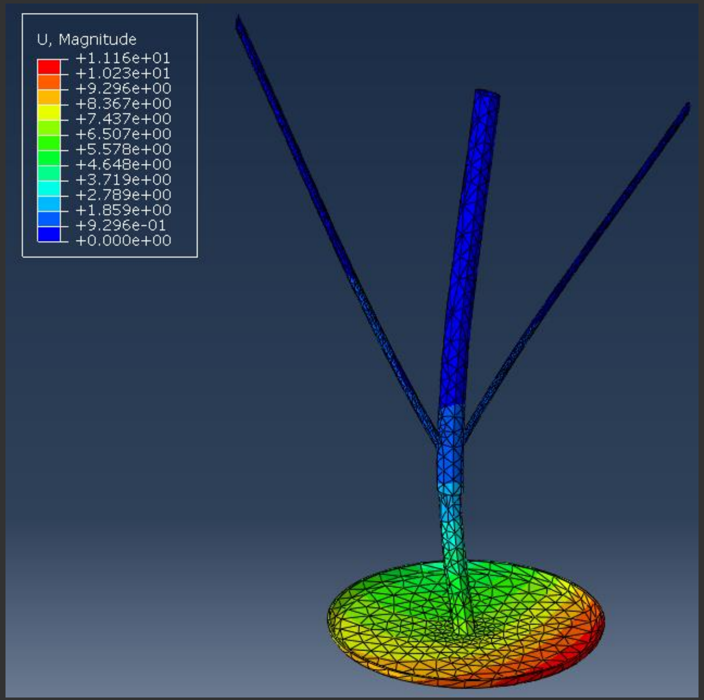
Apollo Lunar Descent Module


Chang'e 3

Main Challenges:
-Difficult to estimate in plane forces
-Calculating compression distance
-Accurate bearing strength of regolith

Landing Legs



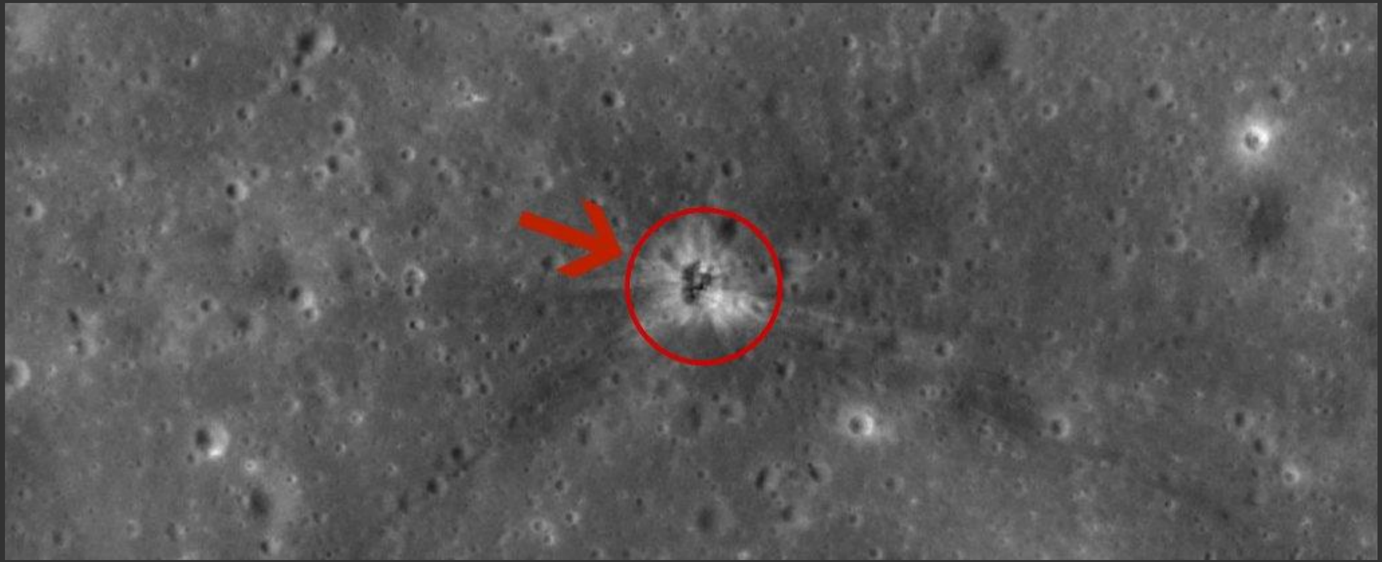


- Crushable Cantilever
- Aluminium Lithium Alloy for struts
- Crushable Aluminium honeycomb inside main strut

Risks

Main issues to be mitigated:

- Instrumentation failure (Sun sensor, Lidar etc.)
- Asymetric thrust (Main engine or thrusters)
- Propellant Depletion



NASA/GSFC/Arizona State University

Post landing checks ensure spacecraft health before proceeding

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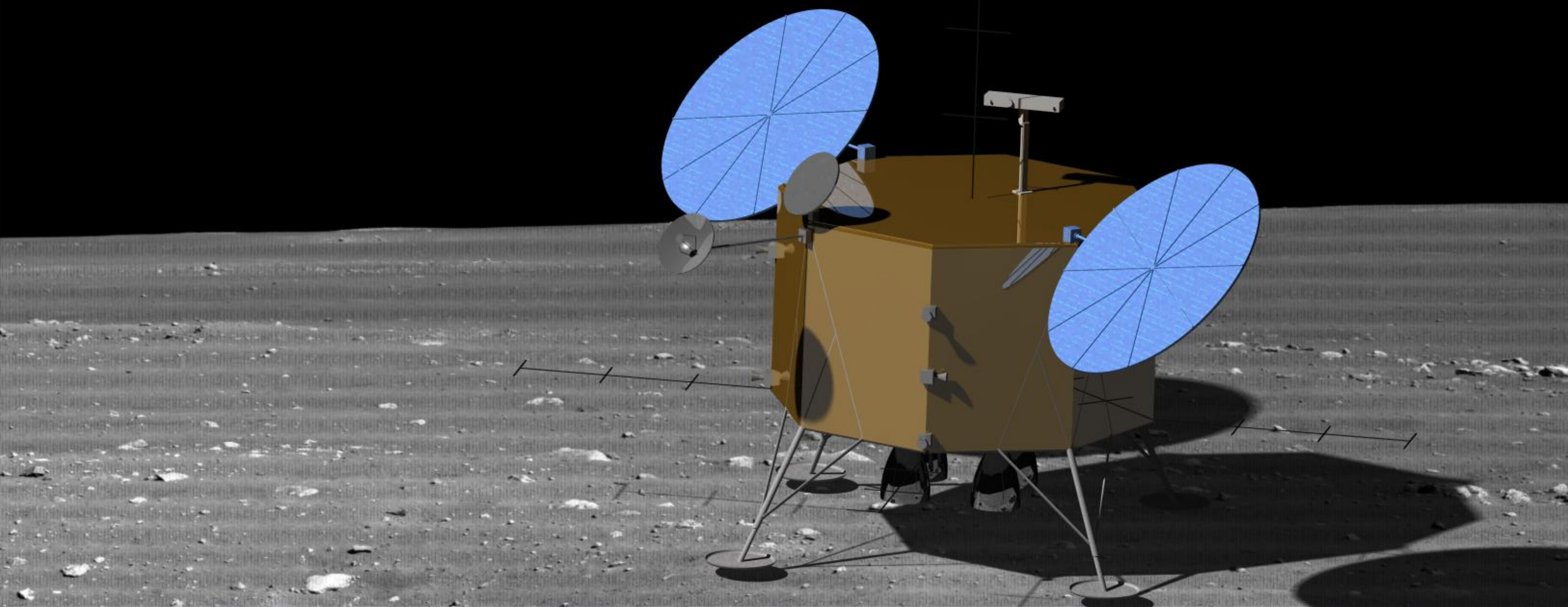
Intermission

30 minutes



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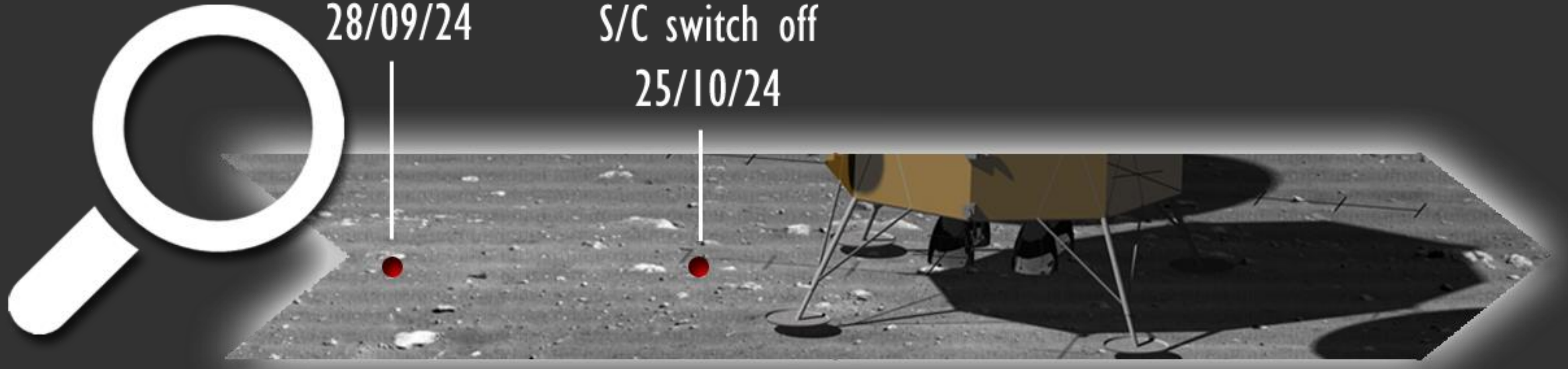
29 Sep. 2024
START OF DRILLING PHASE

Health checks
28/09/24

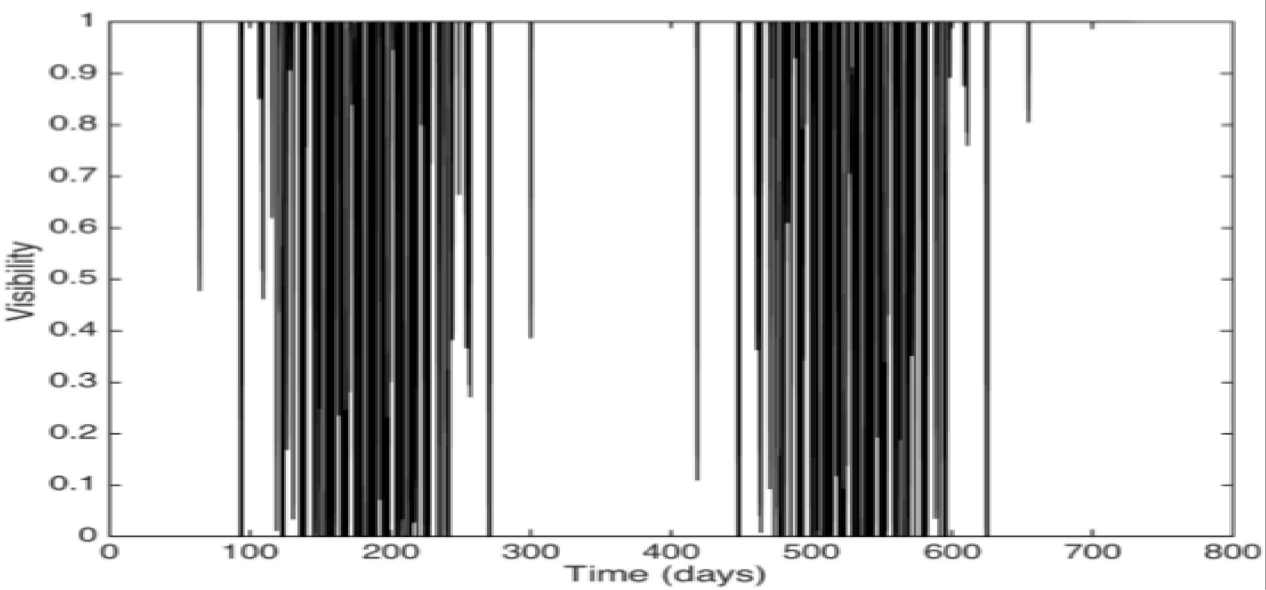
Partial eclipse
S/C switch off
25/10/24



Drilling and sample analysis phase
122 days

Schedule

- 100.8m in 122.34 days.
- 97 sequences/samples
- A sequence involves:
  - Drill descent + drill 1.05 m + retraction
  - Probe descent + analysis + Retraction time
- Sequence duration increases with wire retraction time.



Sequence number	Drilling sequence [hrs]	Total sequence duration [hrs]	Probe analysis time [hrs]	Length drilled [cm]
1	1,01	17,51	16,49	30
2	2,60	19,10	16,46	105
3	3,82	20,32	16,43	210
4	4,03	20,53	16,40	315
5	4,25	20,75	16,37	420
6	4,46	20,96	16,34	525
7	4,67	21,17	16,31	630
8	4,88	21,38	16,28	735
9	5,10	21,60	16,25	840
10	5,31	21,81	16,22	945

The Drill

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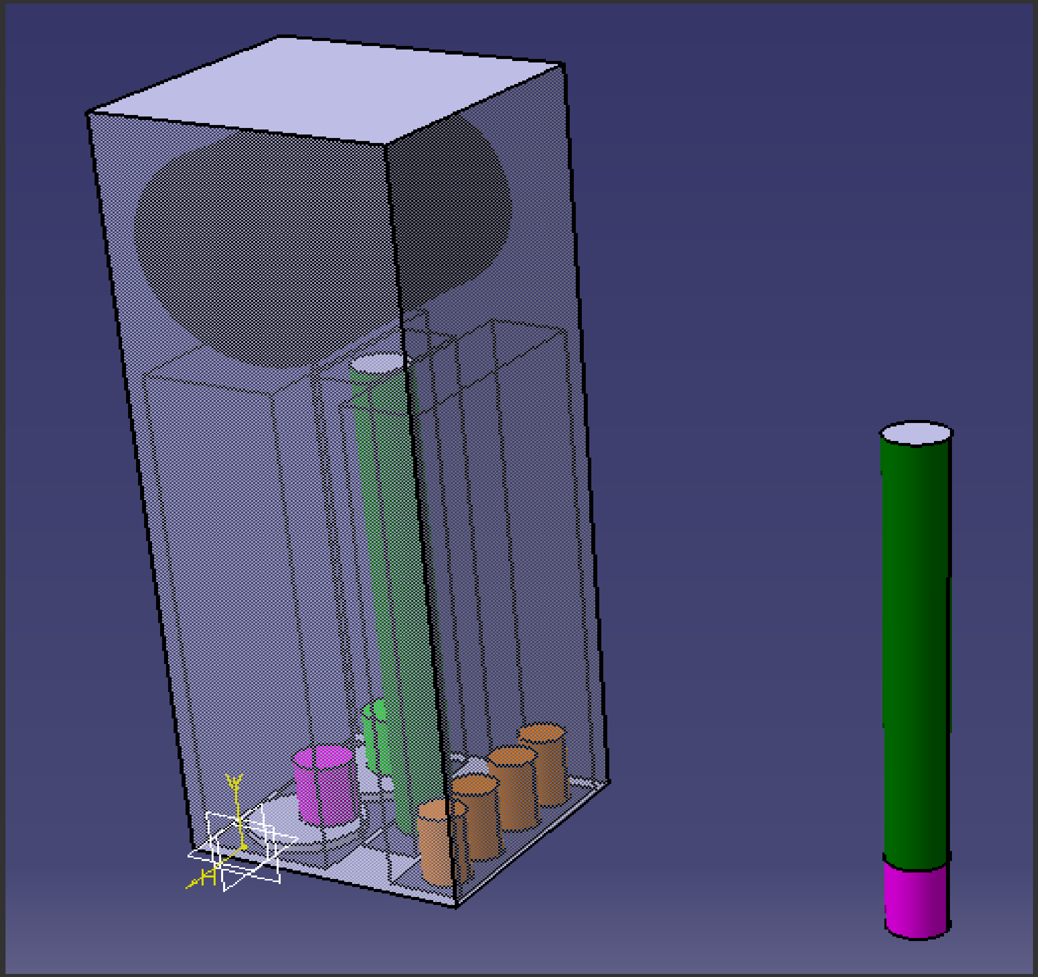
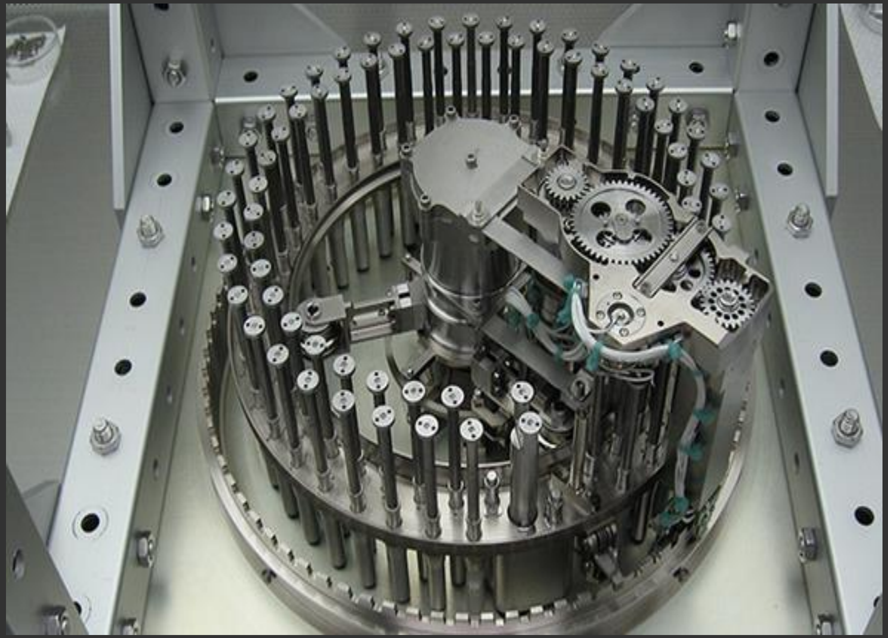
- Dimensions
  - Length: 1m
  - Diameter: 5cm
- Rotary percussive, hollow drill bit.
  - Pink: Drill bits
  - Dark green: Drill Mechanisms
  - Light green: Science probe
  - Black: The wireline
    - Length: 105m
    - Diameter: 2.5mm
  - Orange: Archives



Mechanisms

- Drill bit changing apparatus.
- Scientific instrument/drill bit mechanism interchangeability.
- Wireline spool and motor.
- Archive deployment into the borehole.



Credit: Honeybee robotics

Credit: Honeybee robotics

Science Drivers

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Goal 1	Understand the geochemistry/mineralogy of the lunar crust
Goal 2	Characterise the impact history of the landing site and constrain the age of the south-pole Aitken basin
Goal 3	Understand the diversity and origin of the lunar south polar volatiles
Goal 4	Constrain models of the lunar interior
Goal 5	Characterise the lunar environment for the future scientific exploitation and human exploration
Goal 6	Identify resources for the future human space exploration
Goal 7	Assess the potential of the lunar surface as a platform for the astronomical observations
Goal 8	Science education

Scientific Instruments

Lunar Surface	Sample Analysis	Borehole Science
Gamma-ray Spectrometer	Isotope Mass Spectrometer	Borehole Permittivity Probe
Terrain Camera	Alpha Particle X-Ray Spectrometer	Highly Miniature Radiation Monitor
Dust Analyser	Raman-LIBS Spectrometer	Micro-Seismometer
Radio Astronomy Demo Package	Microscope	IR Imager
Radiation Monitor		Heat Flow Probe
Surface Permittivity Probes		
Surface Seismometer		

Primary Payloads

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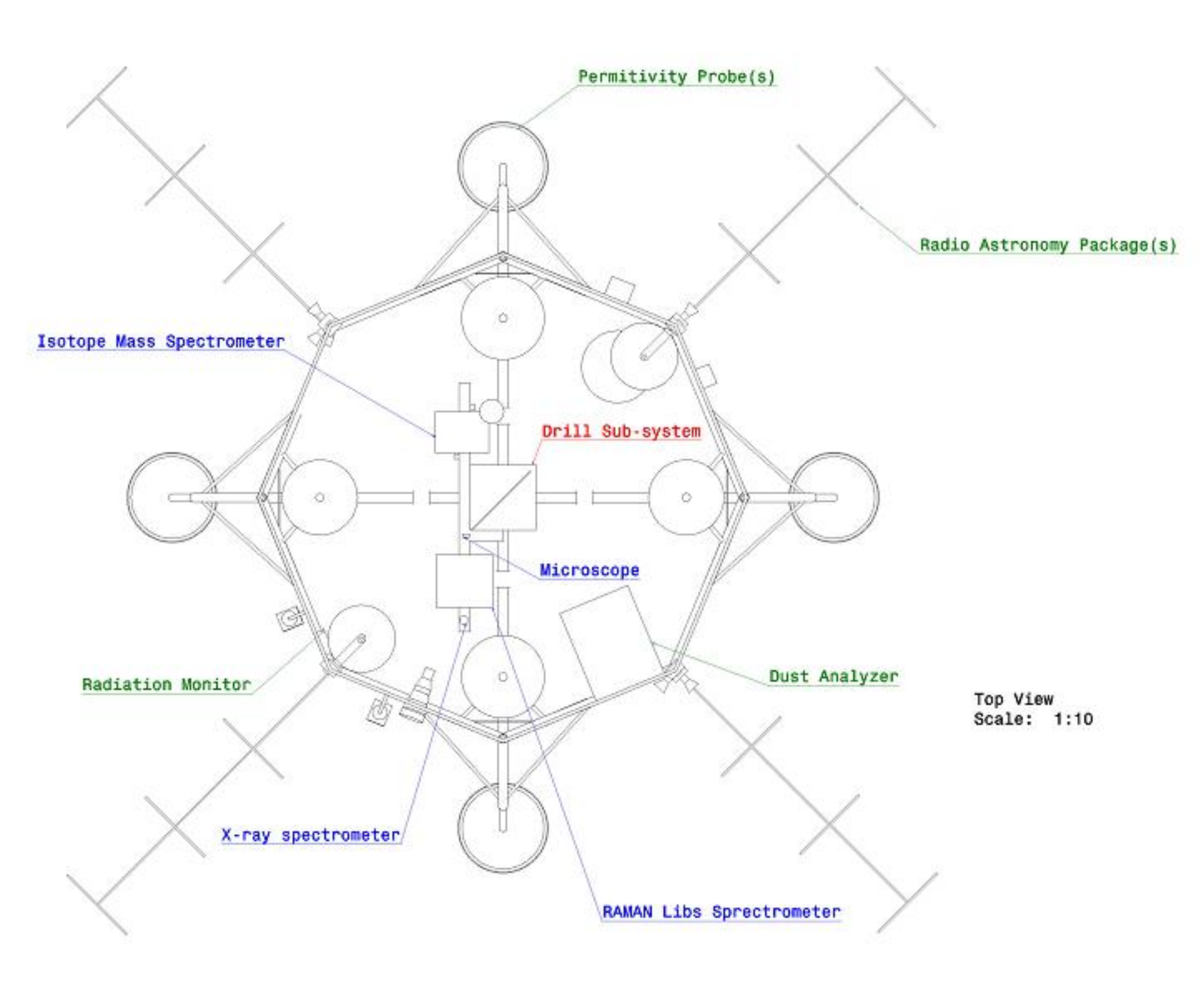

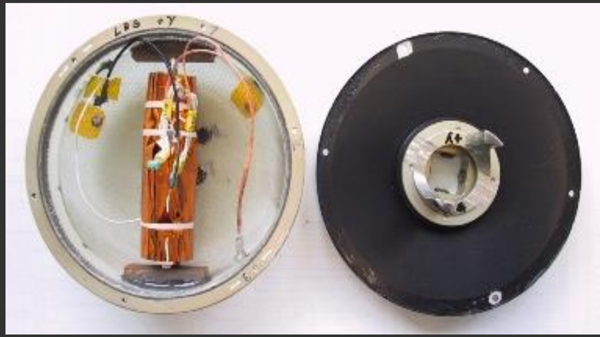

CASSE - Philae

Sample Handling: Instruments and Strategy

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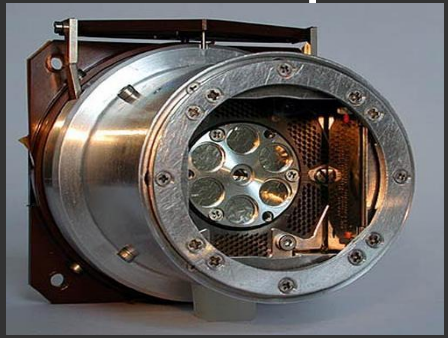
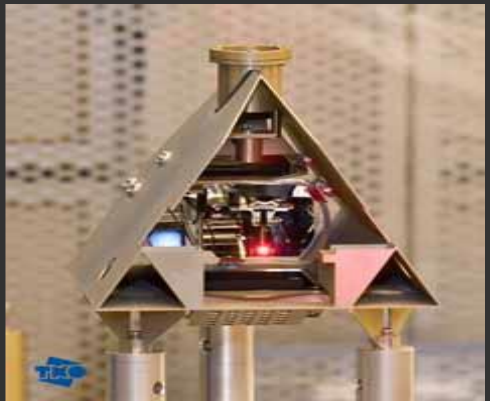
- Alpha Particle X-Ray Spectrometer
- Raman-LIBS Spectrometer
- Isotope Mass Spectrometer



NASA, 2016

TN0, 2009

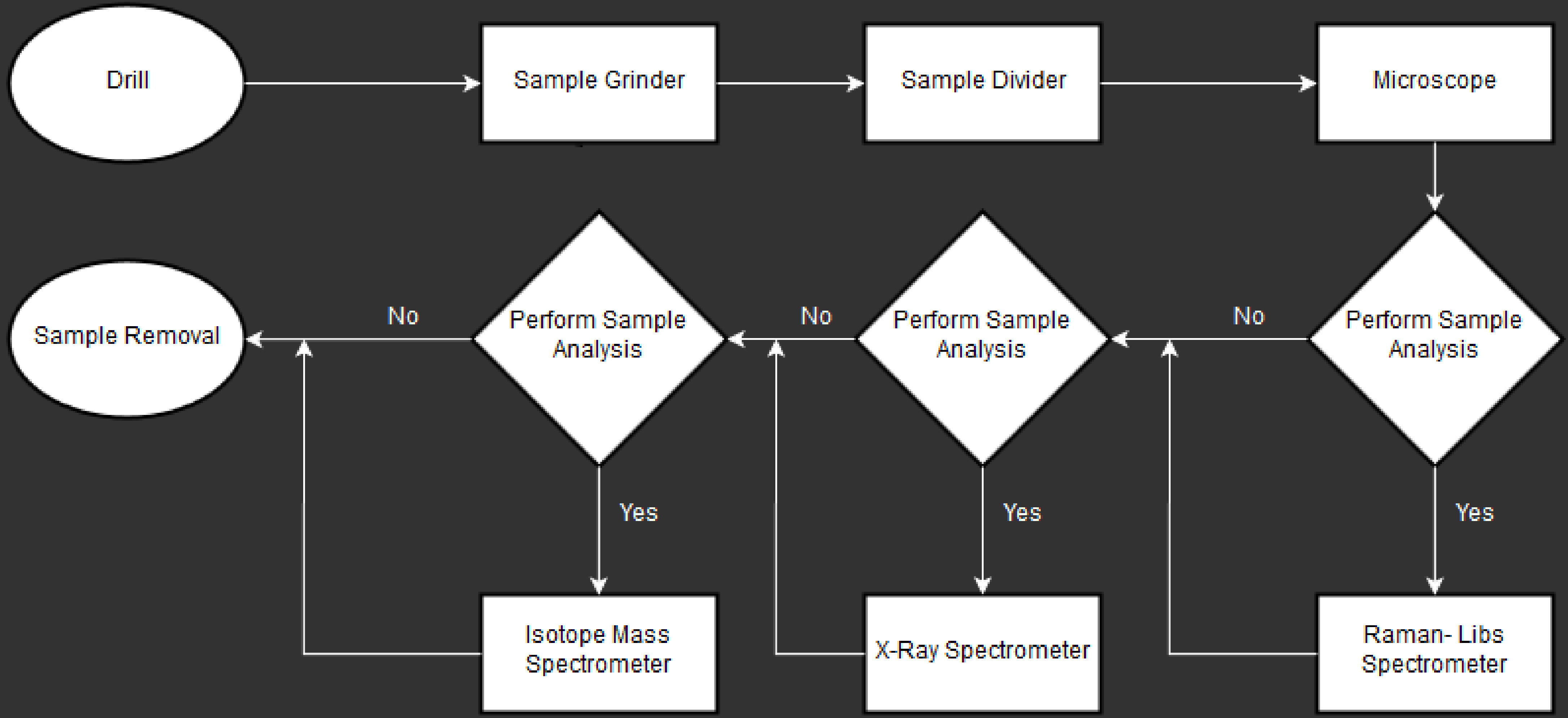
Philae, 2005



The core sample is extracted from the drill and put in a recepticle → The sample is taken out of the drill part → The sample is crushed → The sample is divided into 3 equal parts; the last one will be divided again into 4. → The samples are flattened → The sample is analysed by the microscope → The samples are delivered to the 3 instruments → Once the analysis is performed, samples are ejected out of the spacecraft

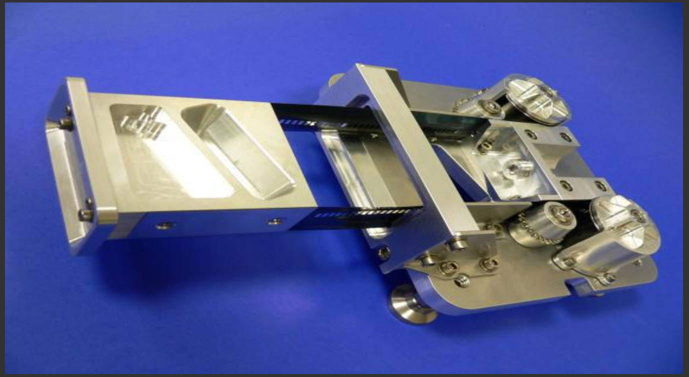
Strategy and path of distribution

Instruments Configuration



Sample Handling: Design and Mechanisms

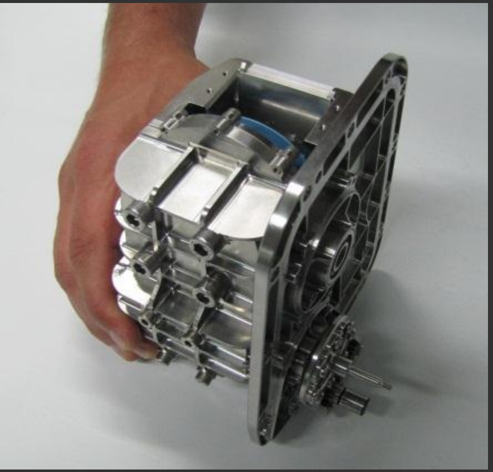
Mechanisms adapted from ExoMars Mission:



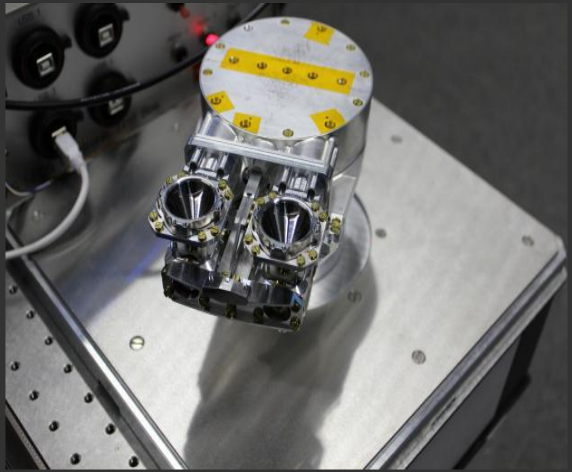
Core Sample Handling Mechanism

ESA, 2013

Crushing station (left) and Dosing station (right)

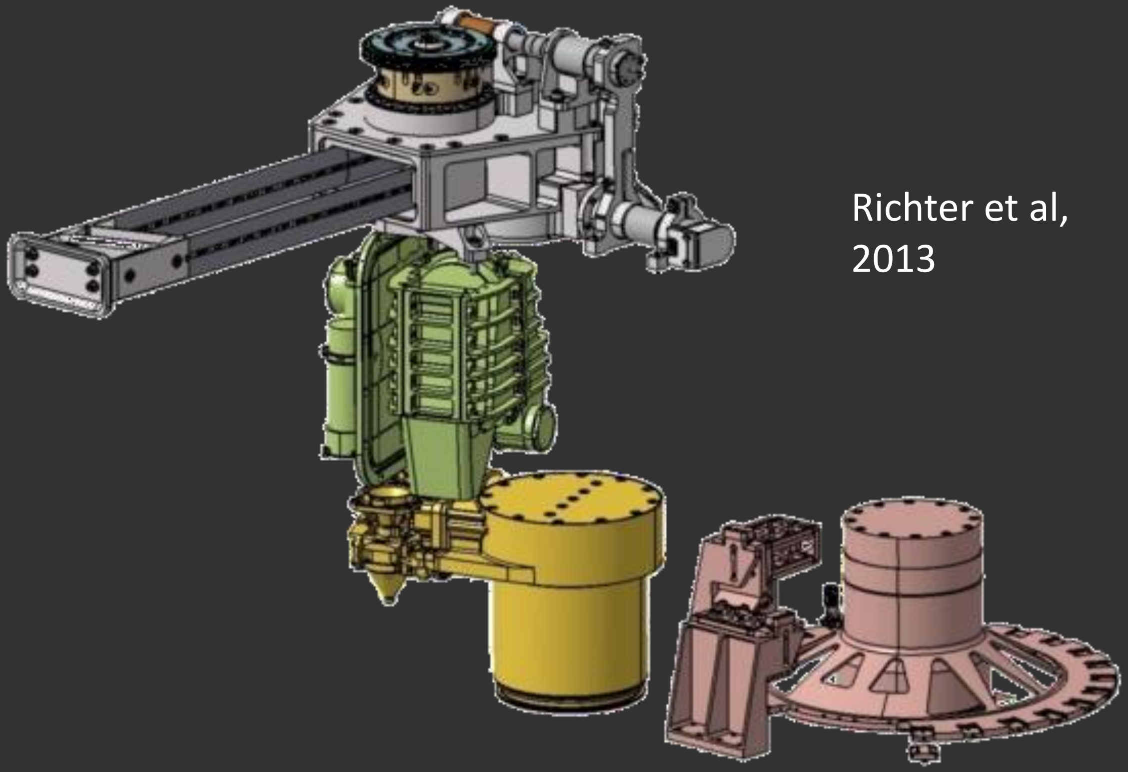


ESA, 2013



ESA, 2013

Assembly:

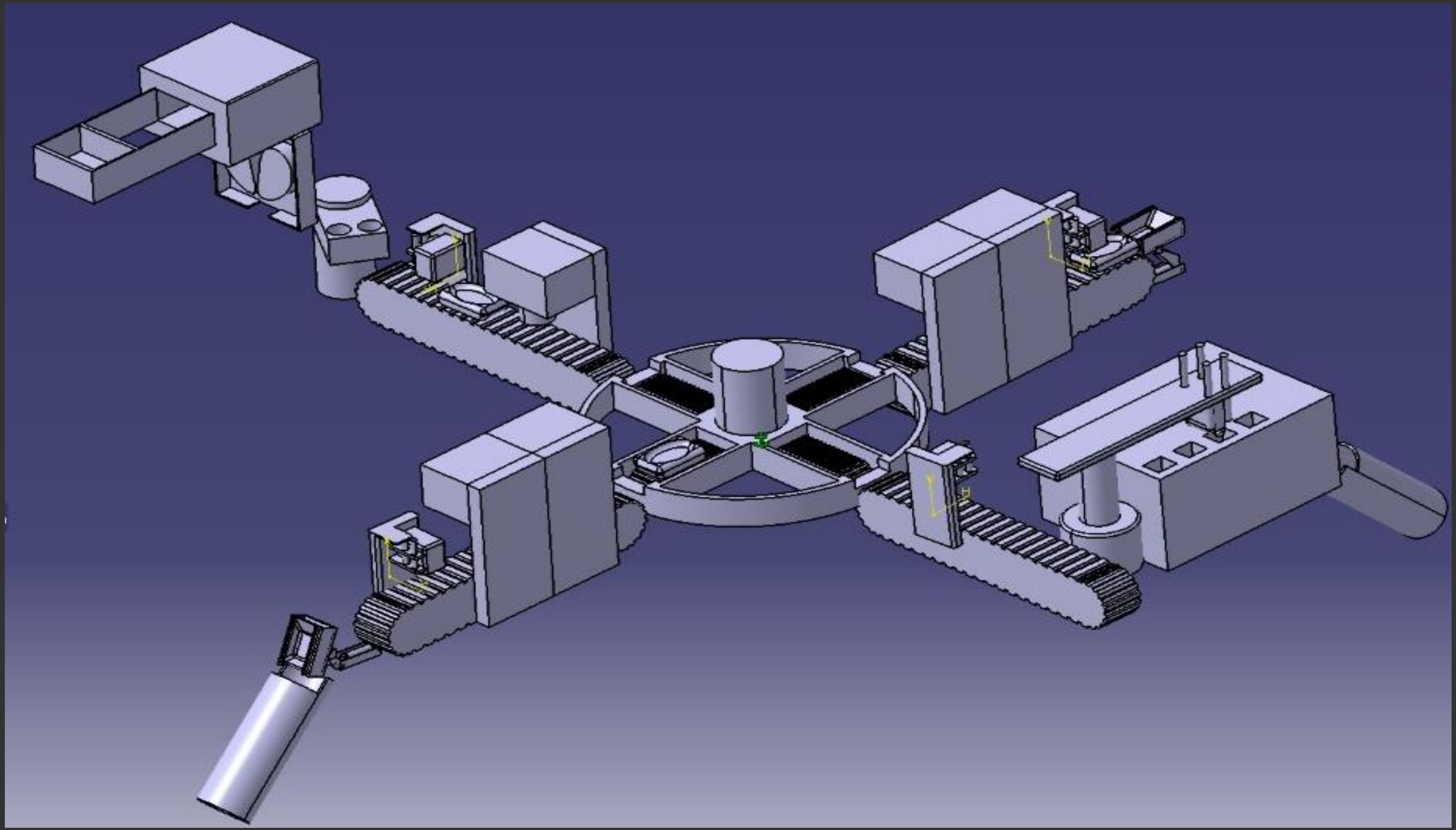


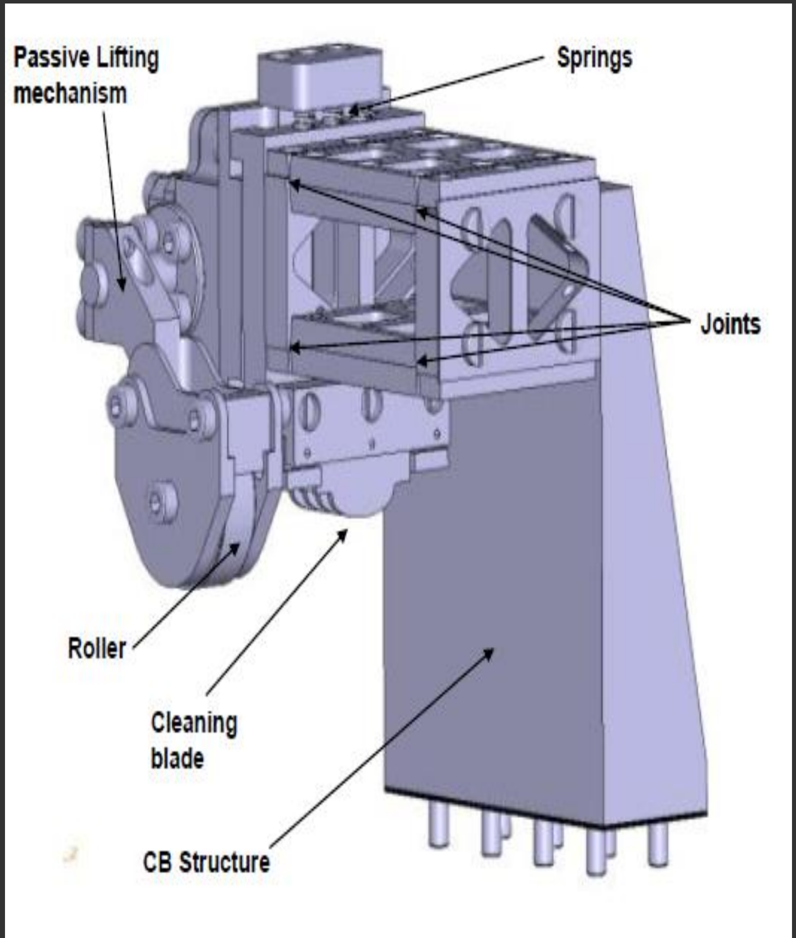
Richter et al, 2013

First part of the SHS consists of the 3 mechanisms

Sample Handling: Design and Mechanisms

Whole assembly of the SHS:

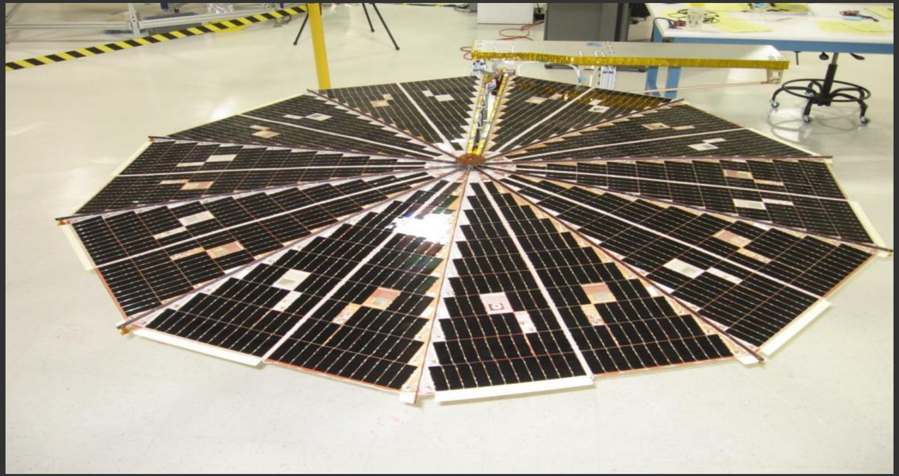




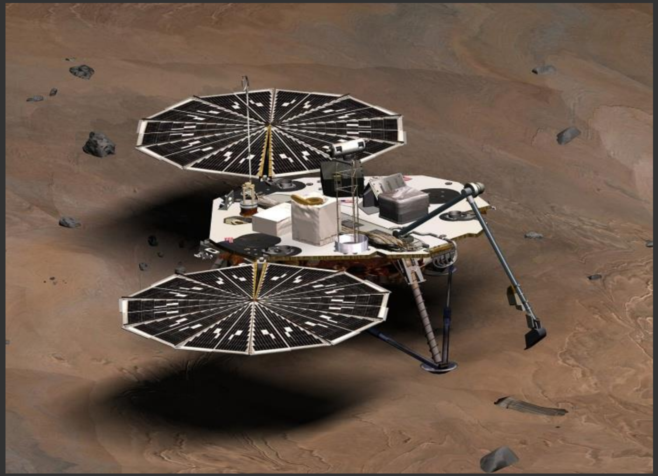
ESA, 2013

Power: Solar Panels

UltraFlex Solar Array (Orbital ATK) is used – cells selected are XTJ Triple Junction (Spectrolab)



Orbital ATK, 2013



ESA, 2011

Orbital ATK, 2013

ESA, 2011

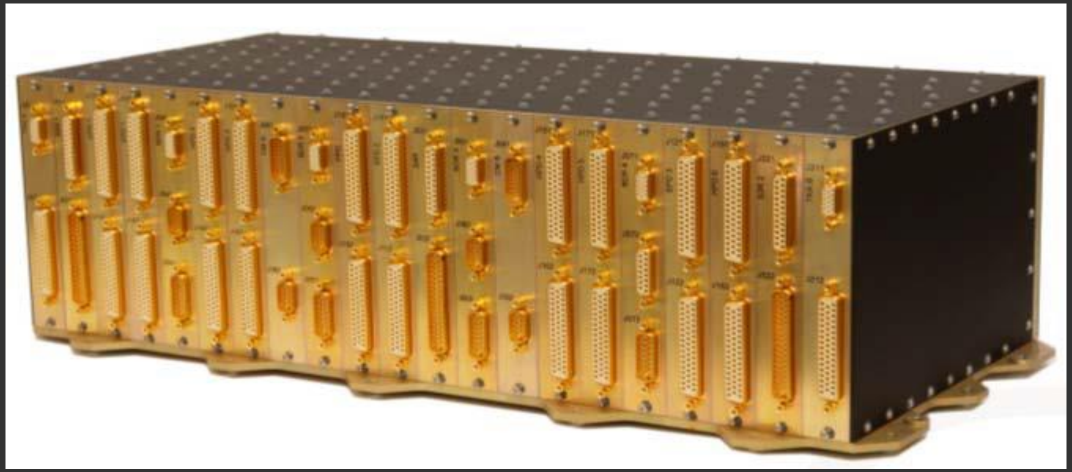
Solar Array Main Features	
Manufacturer	Orbital ATK
XTJ Triple Junction efficiency	29,5%
Power provided	1367 W
Wings	2
Sun angle	15°
Cell degradation per year	2%
Efficiency after degradation	0,9868
Specific energy	112 W/kg
Inherent degradation	0,77
Battery efficiency charge	0,7
Array output efficiency	0,9
Diameter of the wing	2 m
Specific cost	400 $/W
Area per wing	3,142 m²
Total area	6,283 m²
Total mass	12,21 kg
Cost	546800 $

Power: Batteries and PCDU

Batteries:
Selected batteries are Li-Ion VES 180 from SAFT
- 2 batteries and 1 redundant
- Energy provided: 3500 Wh
- Night time withstood: 28 hours
- Minimal charging time: 36 hours

Terma Space, 2012

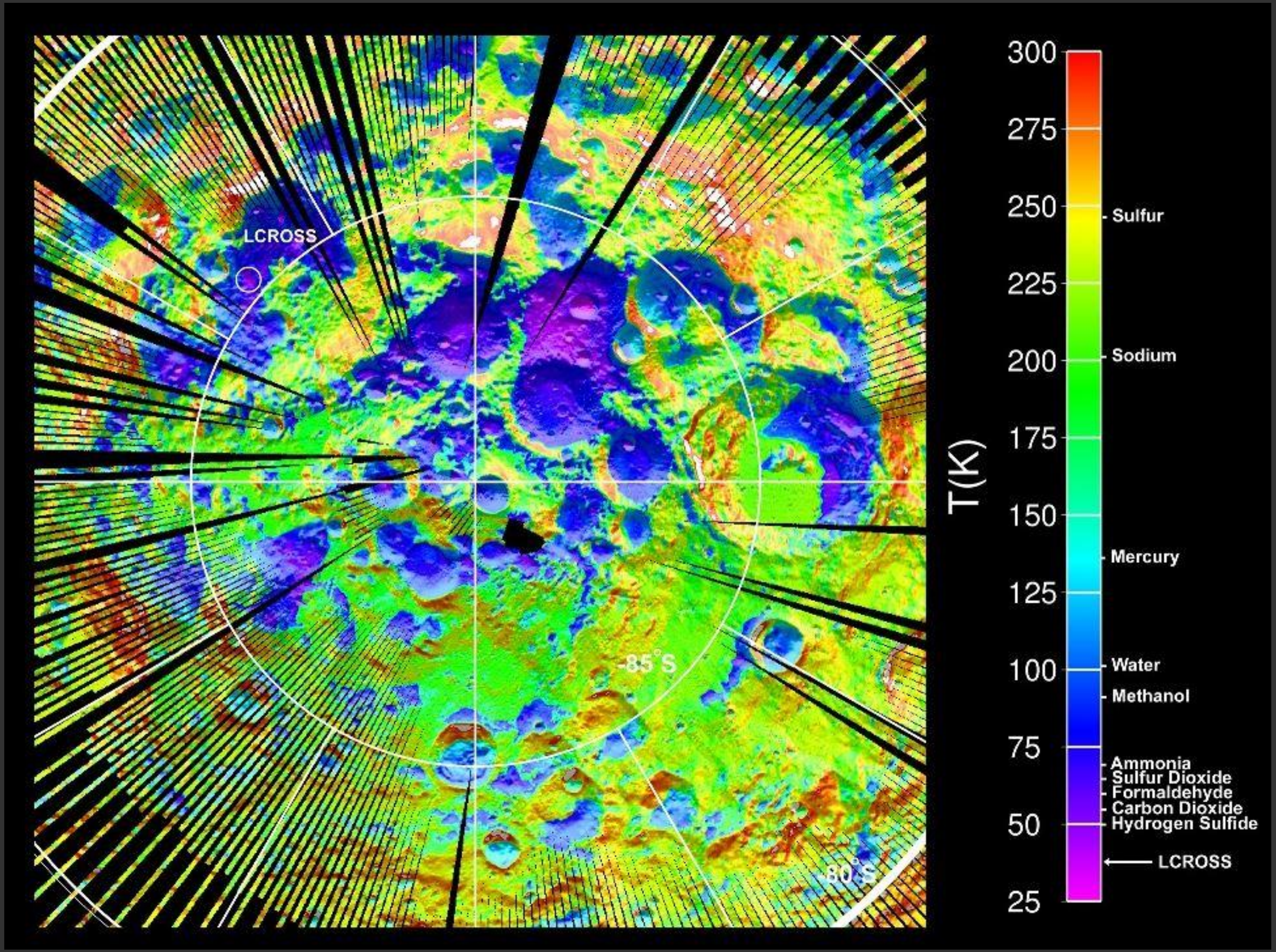
Architecture, Control and Regulation:
- 28V fully regulated bus
- MPPT Architecture (Max Peak Point Tracking)
- PCDU from Terma Aerospace is designed to control and distribute the power to all the loads



Terma Space, 2012

Thermal (Over Moon's surface)

- Two cases studied, hot case (T=250K) and cold case (T=223K)
- The same passive control design is able to stand both scenarios (over the moon's surface and parking orbits)



NASA/Jet Propulsion Laboratory

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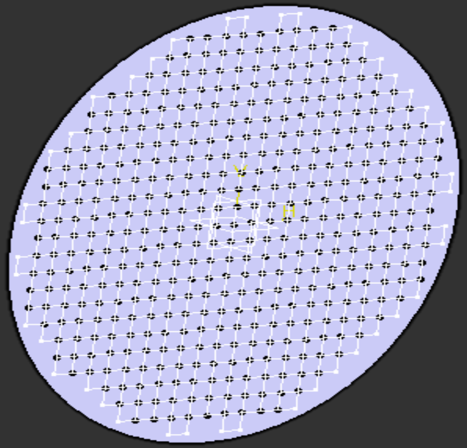
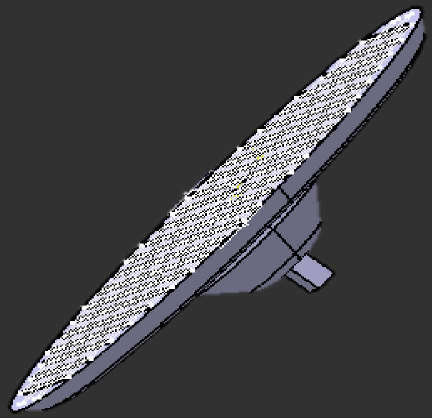
Communications & OBDH

- Phased Array Antenna
- Data Rate: 7.5Mbps



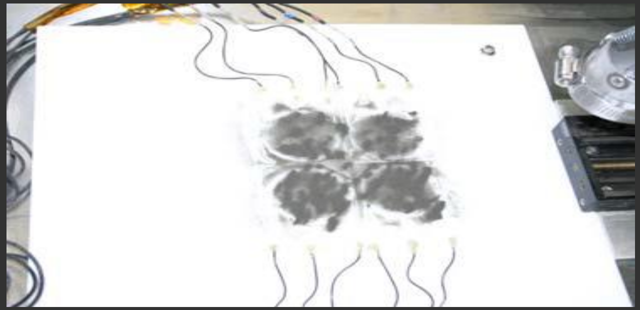


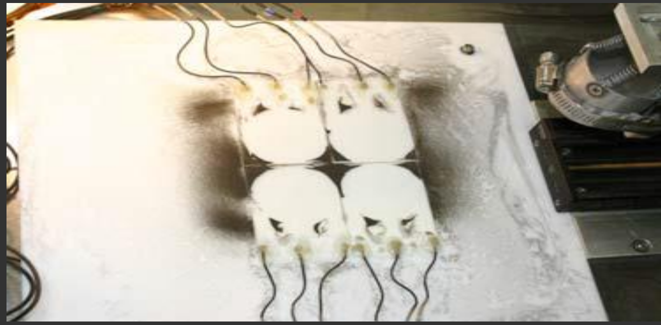
Total Data Collected Over The Drilling Phase

Instrument Groups	Data Rate (Mbits/s)	Drilling Phase (Mbits)
Surface Instruments	0.036	372
Science Probe Instruments	2.902	39
Sample Instruments	0.029	5
Total With 70% Code Inc (Mbits)	5.044	709

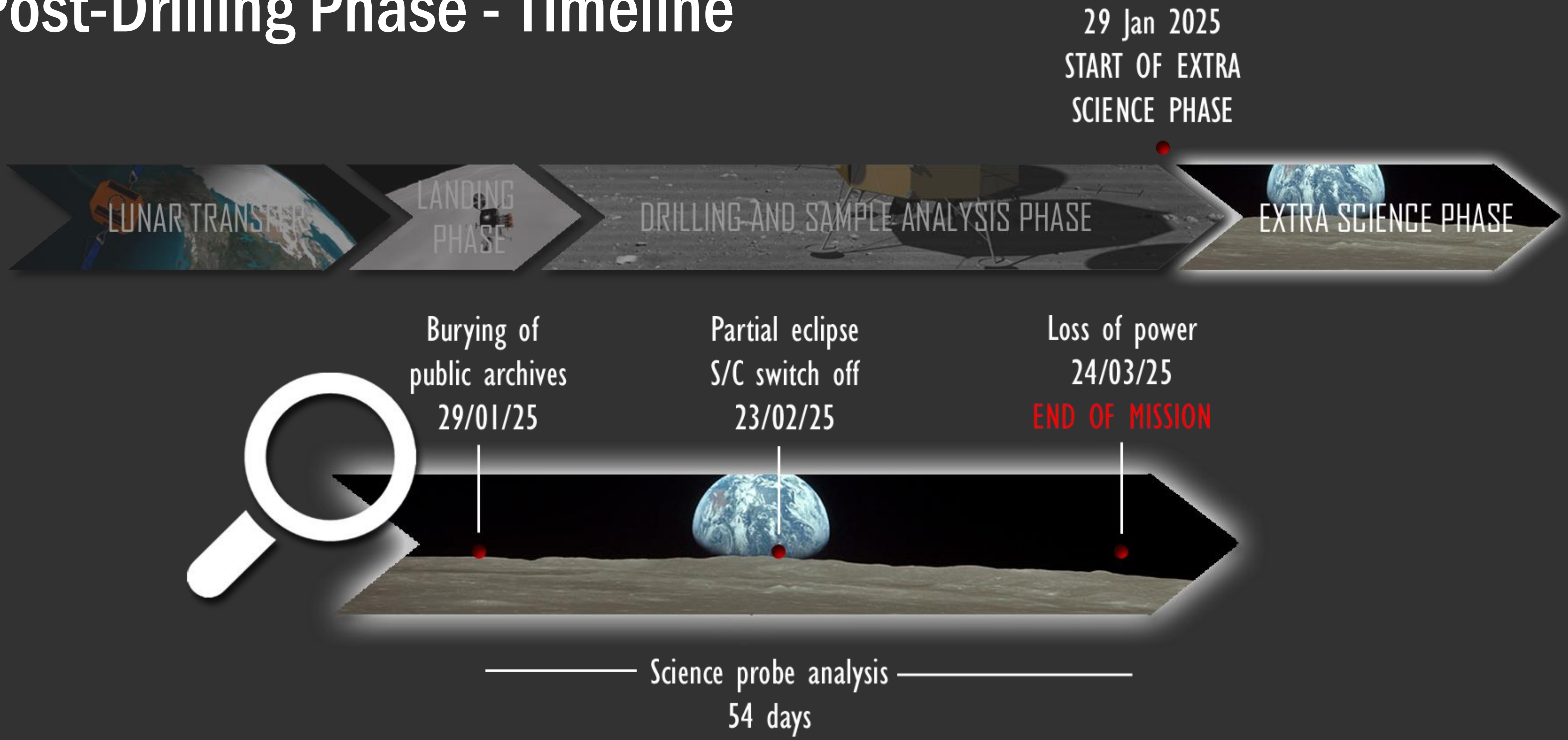
Risks

- Drill
  - Wireline drill and spud tube reduces the probability of borehole collapse
  - Qualification of components in direct contact with lunar dust or within borehole
  - Before detachment, wireline cleaned with EM-field and bristles – unknown ferrous content of deep samples



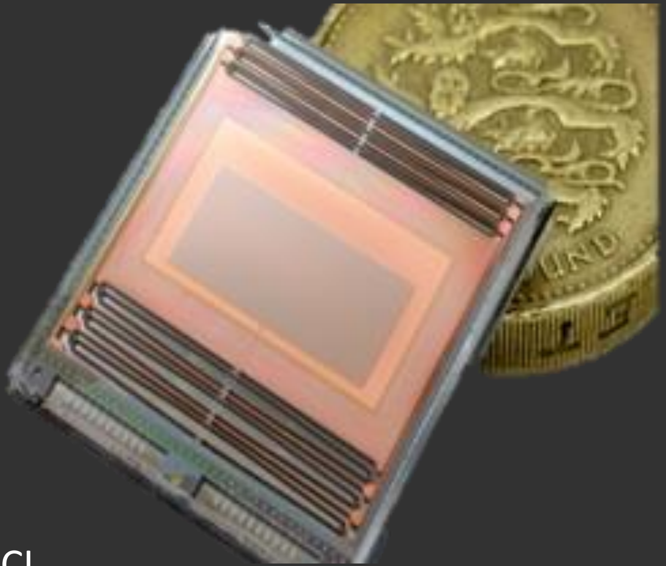


Post-Drilling Phase - Timeline

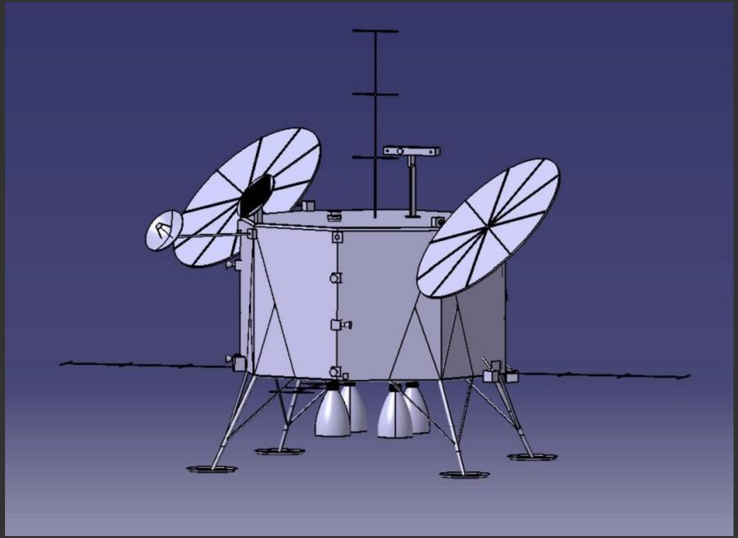


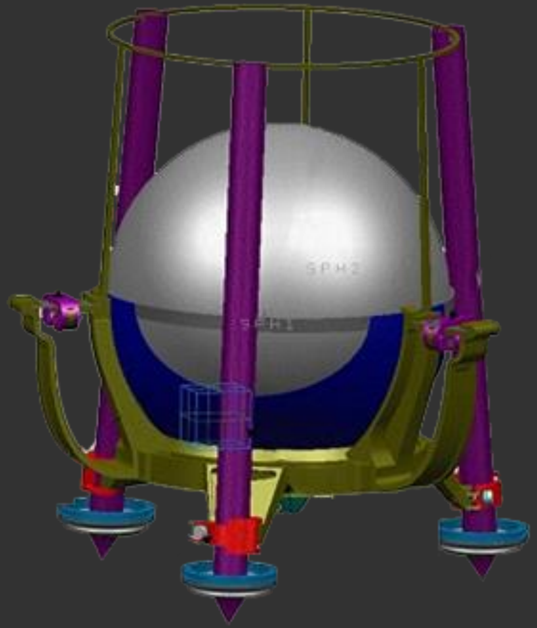
Long Term Science Investigations

- 54 days of extra science
- 11 Instruments capable of extra science
- Notable Instruments
  - Micro-Seismometer
  - Surface Seismometer
  - Radio Astronomy Demonstration Package – OSS



UCL





CNES

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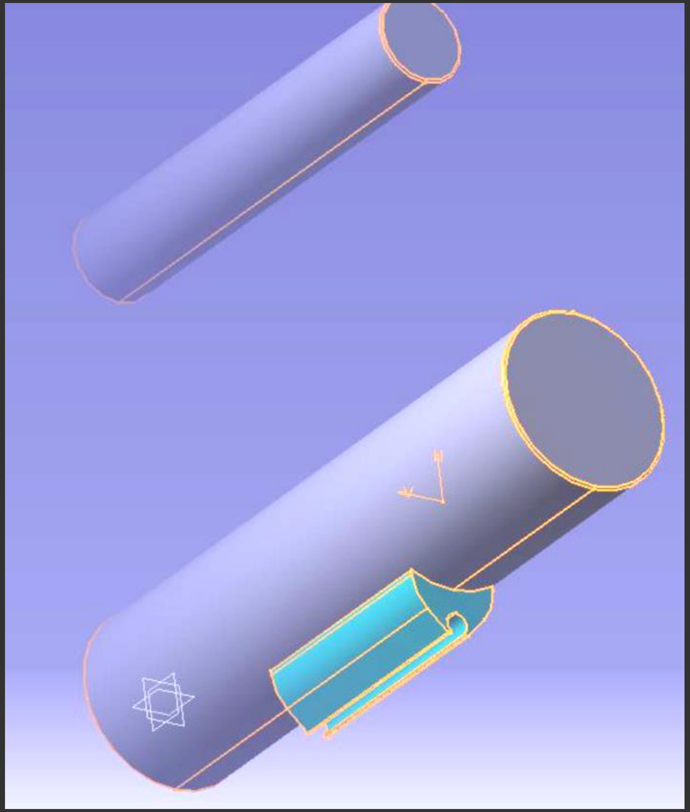
Archives

- Storage of digital data and DNA given by the project backers
- 10 archive capsules
  - 5 into the borehole
  - 5 into the lander
- Volume = $200 cm^3$
- Archive protected for millions of years
- Protection of the archive against radiation and shocks



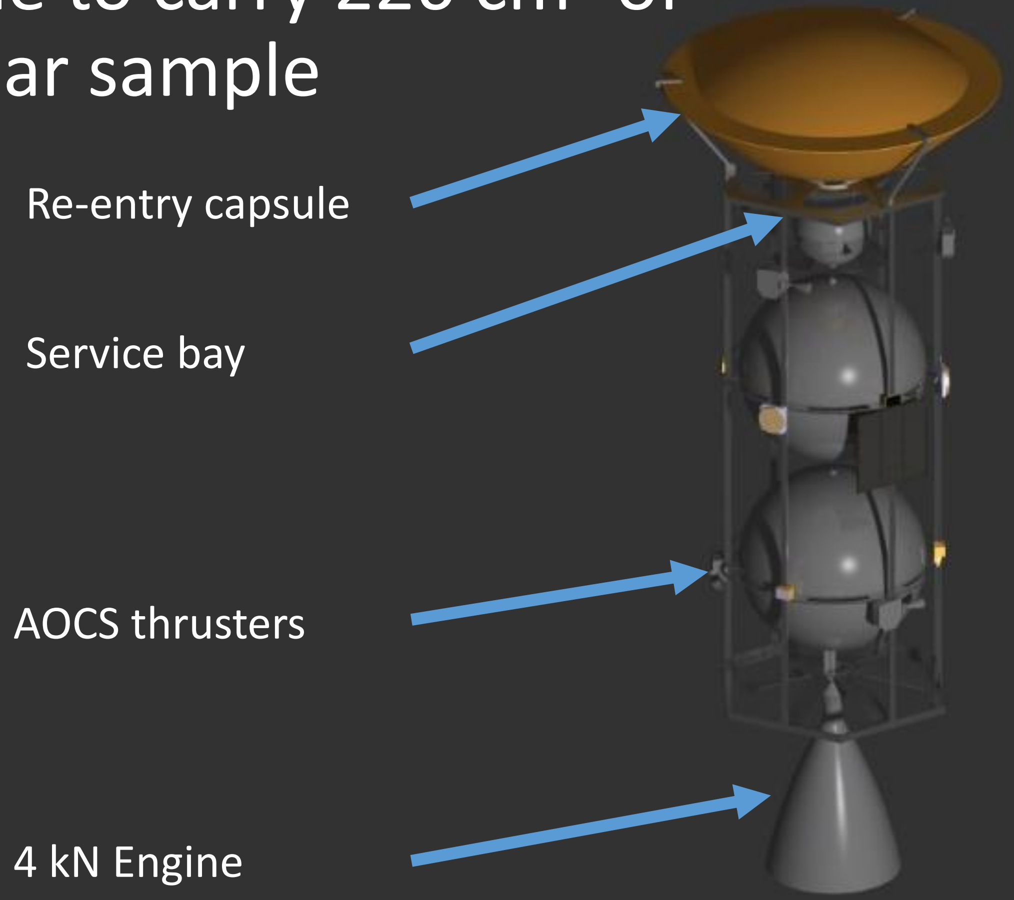
Sample Return

- Objective: provide lunar sample for Earth scientists
- A nice-to-have for the project
  - Studied and designed
  - Cut due to risk and budget considerations

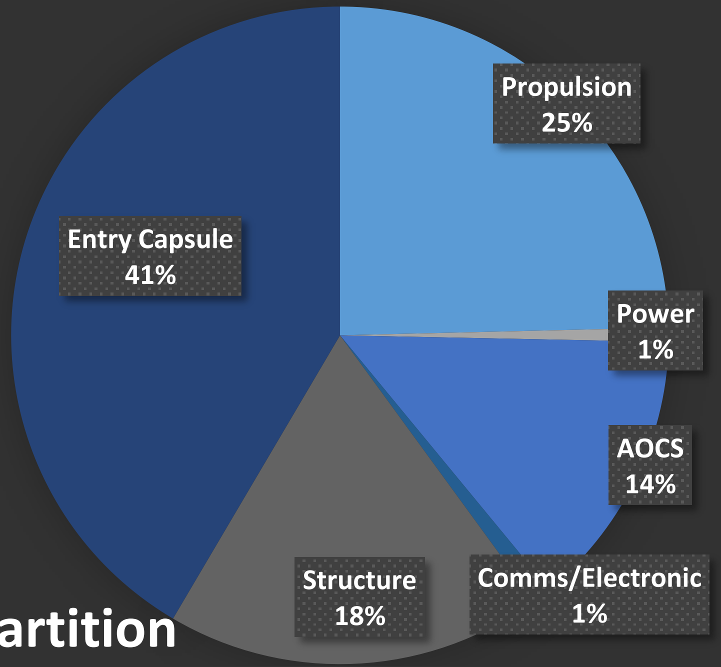
- Trajectory via Earth-Sun Lagrange Point
  - 100 days to come back
  - Low DeltaV

Sample Return

- Able to carry 226 cm^3 of lunar sample



- Budget
  - Dry mass 95 kg
  - Launch mass 236 kg
  - Cost $13M



Dry Mass repartition

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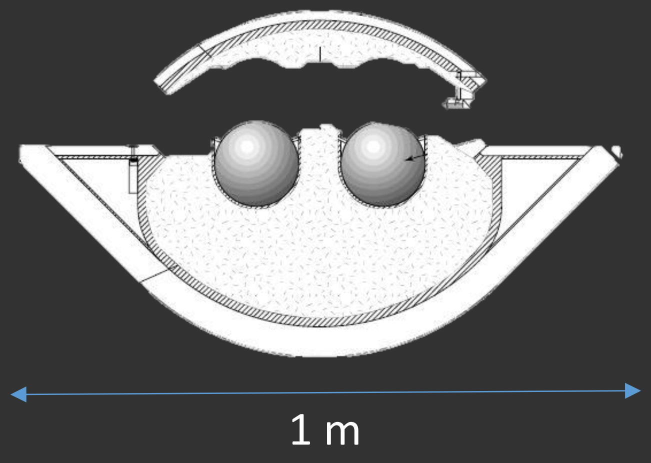
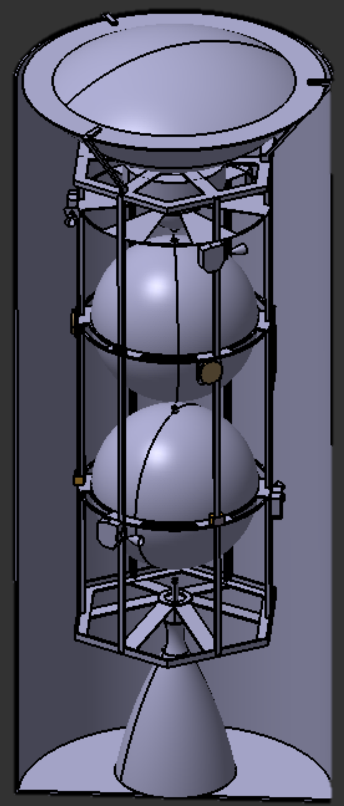
Sample Return

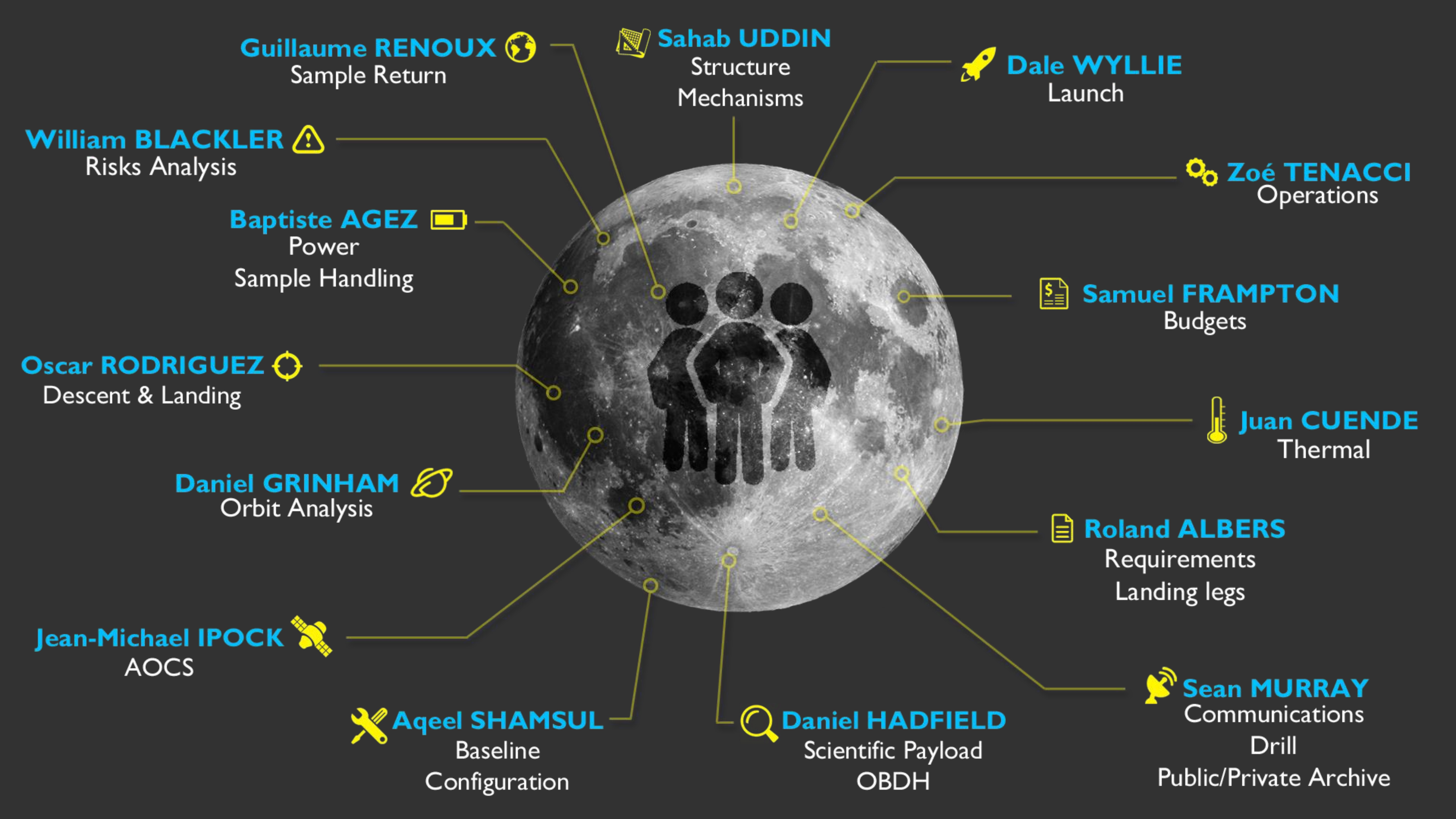
- Passive re-entry capsule
  - Interplanetary rated
  - 45-degree sphere cone
  - High velocity landing



- Integration into the lander
  - Launched like a missile from a submarine
  - Thermal protection of the lander by a Teflon layer



	2012 RAL LMO STUDY	CRANFIELD LMO STUDY
Mass	835.7 kg	740 kg
Delta-V (S/C Only)	3 km/s	2.88 km/s
Cost	USD $751M	USD $754M
Scientific Instruments	13	16
Initial Lunar Orbit	100x100 km	15x100 km
Configuration	• Single lander • body mounted solar arrays • 4 Main engines • Side mounted drill	• Single lander • Sun tracking solar arrays • 4 Main engines • Centre placed drill
Drilling Time	6-9 months	4 months


Guillaume RENOUX
Sample Return
Sahab UDDIN
Structure
Mechanisms
Dale WYLLIE
Launch
William BLACKLER
Risks Analysis
Zoé TENACCI
Operations
Baptiste AGEZ
Power
Sample Handling
Samuel FRAMPTON
Budgets
Oscar RODRIGUEZ
Descent & Landing
Juan CUENDE
Thermal
Daniel GRINHAM
Orbit Analysis
Roland ALBERS
Requirements
Landing legs
Jean-Michael IPOCK
AOCS
Sean MURRAY
Communications
Drill
Public/Private Archive
Aqeel SHAMSUL
Baseline
Configuration
Daniel HADFIELD
Scientific Payload
OBDH