

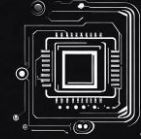
MISSION TO MERCURY

LOCKHEED MARTIN



INTRODUCTIONS

Jacob Lewis – Computing



Siam Altman – Payload/Mission Design



Cameron Alcorn – Attitude/Orbit Control



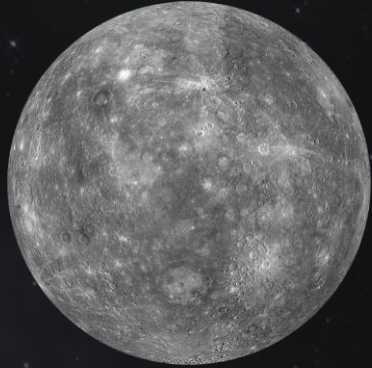
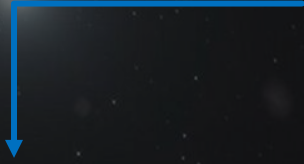
Sophia Sills – Mechanical



Brennan Long – Telecommunications



NORTH POLE



THE MISSION:

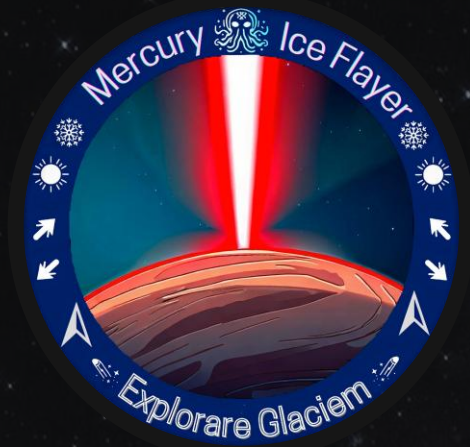
- The Mercury Ice Flyer- a Mercury Orbiter, to collect data on North Pole of Mercury.
- Create a 3x3x4 ft smallsat to carry all components and to be able to send data back to Earth.



Aim to explore the unique properties of Mercury's ice caps

Uncover Composition

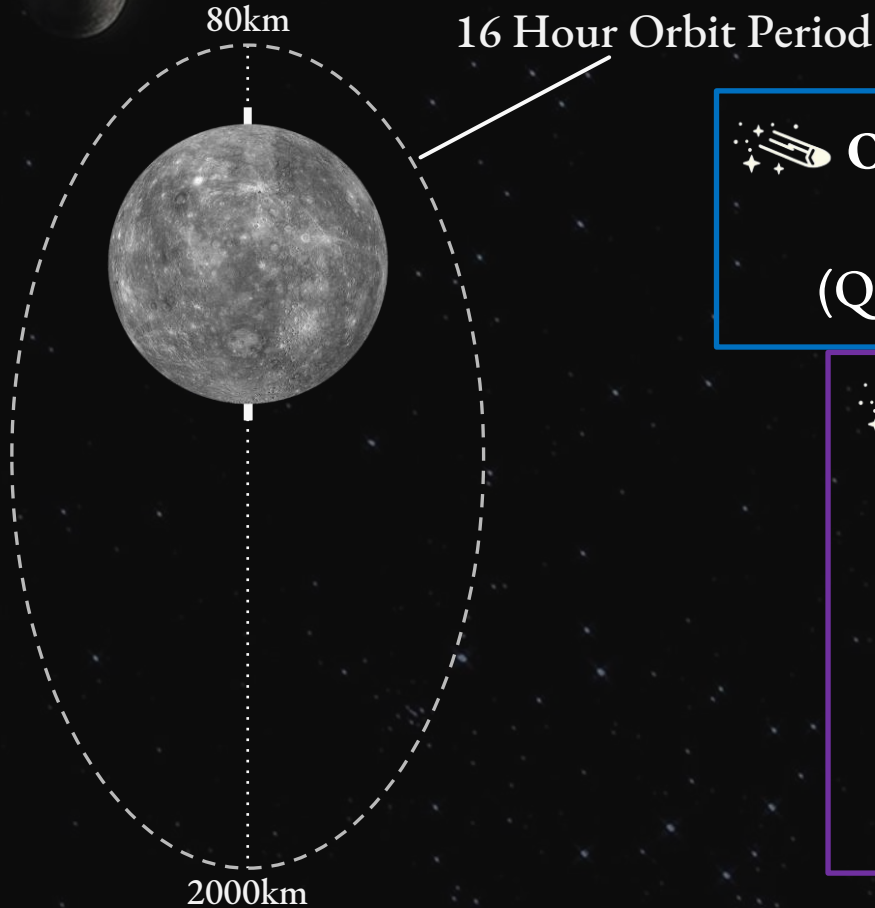
Amount Present



Latin for:

To Explore the Ice

MERCURY POLAR ORBIT:



One Pole: Consolidate resources for better analysis
(Qualitative Data > Quantitative Data)






Elliptical orbit Design:

Thermal: Reduced exposure to radiation reflected by Mercury.

Fuel: Elliptical orbit requires less fuel to maintain orbit compared to circular orbit.

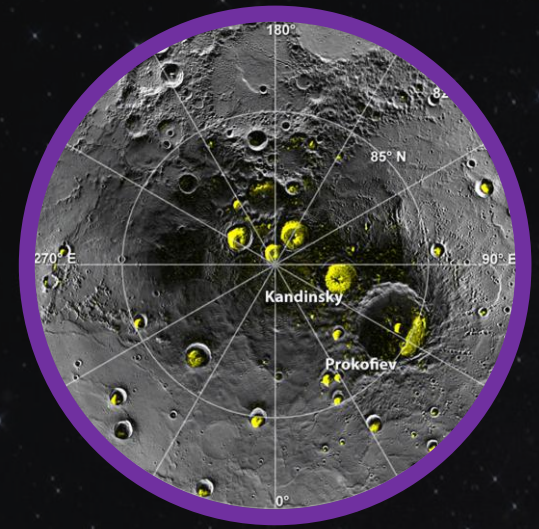
WHY MERCURY?

Scientific Goals

-  Provide better insights to Mercury's Geologic History
-  Offer clues towards early solar system formation
-  Help us understand processes for terrestrial planets

↓
Planetary Science

↓
Astronomy







↓
Evidence of Water
Ice in craters from
MESSENGER



Least Explored Inner-Planet

THE SECONDARY OBJECTIVES:

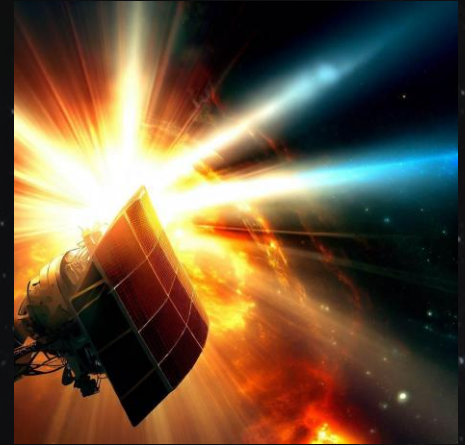
-  Demonstrate the Capabilities and Limitations of Smallsats in deep space exploration
-  Contributes toward Curio Architecture
-  Builds towards the Small Satellite Revolution
-  Pushes Lockheed Martin as Leader and Pioneer in the small satellite industry



HIGH LEVEL REQUIREMENTS:

THE SPACECRAFT SHALL...

- Tolerate constant temperatures at an upward of 370°C on the sunward side of the spacecraft
- Withstand Mercury Occultation (eclipsing) for an upwards of 90 minutes at a time within its elliptical polar orbit
- Maintain an elliptical orbit with a periapsis of 80 km, and an apoapsis of roughly 2000 km
- Withstand 7 Year Journey + 1 Year of Operations



Design

2 Years

➤ Preliminary Design:

- Concept Design
- Feasibility Studies
- Mission Analysis
- Define System Requirements
- Rough Cost Estimations

➤ Detailed Design:

- Subsystem Design
- Science Instrument Design
- Thermal and Structural Design/Analysis
- Design Review and Adjustments
- Design Review Finalization

Assembly

5 Years

➤ Component Manufacturing/Procurement

- Structure and Subsystems
- Science Instruments
- Communication And Power Systems

➤ Assembly and Testing:

- Subsystem and Instrument Integration
- Environmental Testing (Thermal, Vacuum, Vibration, Acoustic)
- Functional + Performance Testing
- Flight Readiness Review
- Transport to Launch Site

Launch

7 Years

- Launch Integration
- Cruise Phase
 - Spacecraft Health Monitoring
 - Planned Gravity Assists and Planned Orbit Burns
 - Mercury Orbit Insertion

Operations

1 Year

- Science Operations
 - Instrument Calibration
 - Initial Spacecraft Health Monitoring
 - Routine Data Collection + Transmission

End of Life

TIMELINE: END OF LIFE



- ✓ Final Planned Science Observations
- ✓ Ensure Data is Backed Up
- ✓ Orbital Maneuver Planning
- ✓ Propellant Conservation
- ✓ Execute Final Maneuver

INSTRUMENTS: SPECTROMETER

Spectrometer Type: Infrared

Wavelength: 0.9 – 6 Microns (900 – 6000 nm)

Power Usage: 70 watts

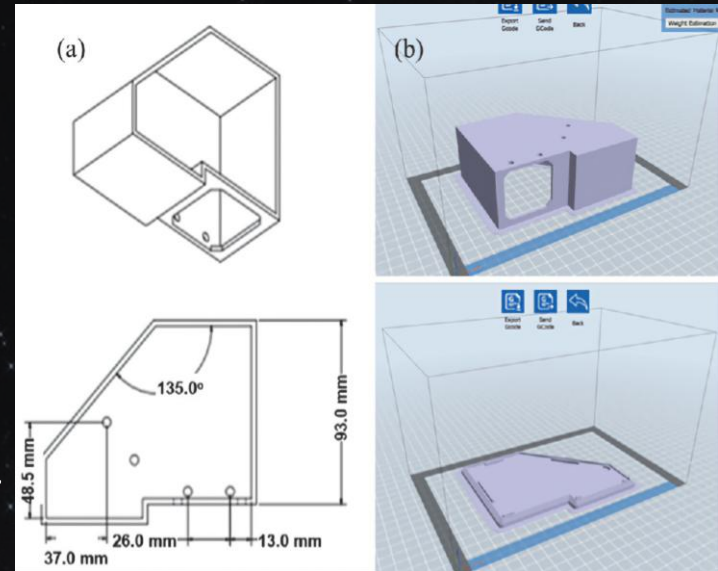
NIMI

➤ Specially designed for:

- Near-Infrared
- Mid-Infrared

❖ **Perfect wavelength to detect water**

- Water ice absorbs light strongly in the infrared
- Water ice reflects differently compared to other materials, allowing it to be distinguishable.



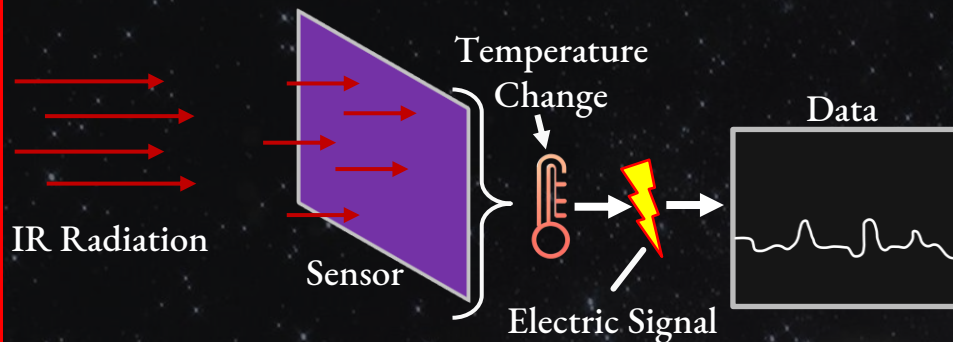
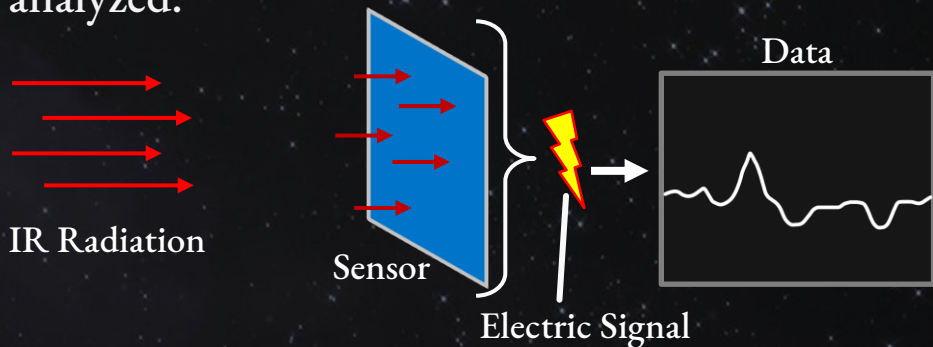
INFRARED SENSORS

Indium Gallium Arsenide
(InGaAs) Detector (NI)

Lithium Tantalate (LiTaO_3)
Pyroelectric Detector (MI)

Operating Principle: Infrared radiation hits sensor, generating electrical signal that can be analyzed.

Operating Principle: Infrared radiation contacts sensor creating heat. Heat on sensor causes voltage to be generated and measured.



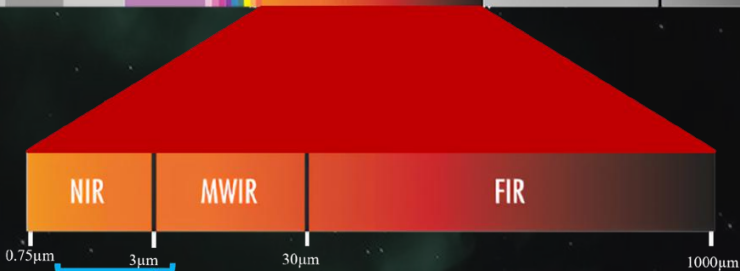
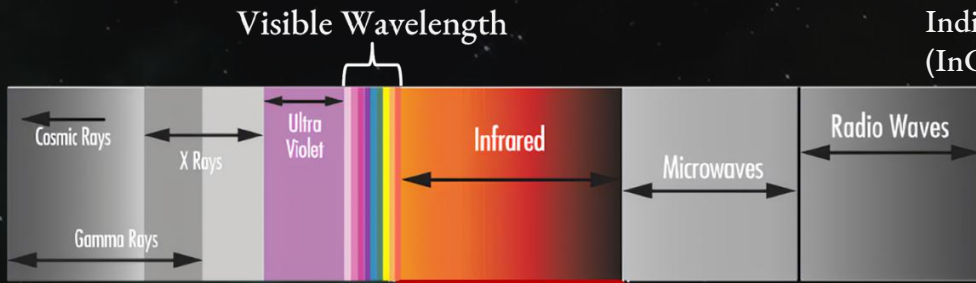
Wavelength: 0.9–2.6 Microns

Wavelength: 2–6 Microns

Operating Temperature: -40 to 60°C

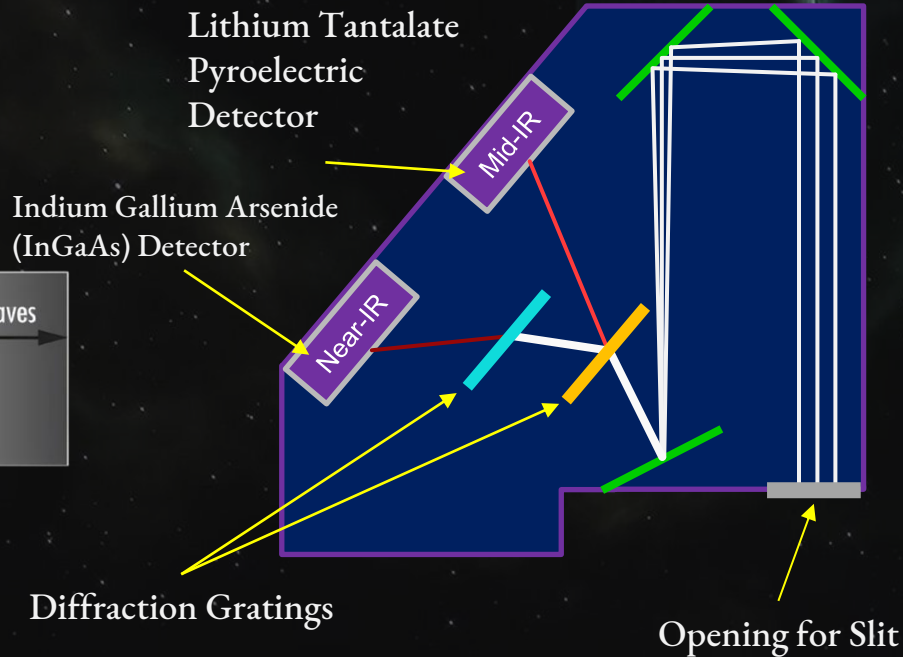
Operating Temperature: 0 to 50°C

SPECTROMETER SPECIFICS:



Spectrometer Wavelength

Wavelength range water strongly absorbs infrared radiation



Lithium Tantalate
Pyroelectric
Detector

Indium Gallium Arsenide
(InGaAs) Detector

Diffraction Gratings

Opening for Slit

MID-INFRARED ISSUE

Mercury Cadmium Telluride (HgCdTe)
Detector

Lithium Tantalate (LiTaO₃)
Pyroelectric Detector

-196 to -40 °C (Requires Cryogenic Cooling)	Operating Temperature	0 to 50 °C (Room Temperature Tolerable)
1-14 Microns (μm)	Spectral Range	1-14 Microns (μm)
N/A	Sensitivity	N/A
0.5-5 A/W	Responsivity	0.01-10 ⁴ V/W



❖ Sensor Size

❖ Dark Current + Background Noise (Johnson Noise, Shot Noise, 1/f Noise)

REMOTE SENSING PERIOD

3 Hour Data Window

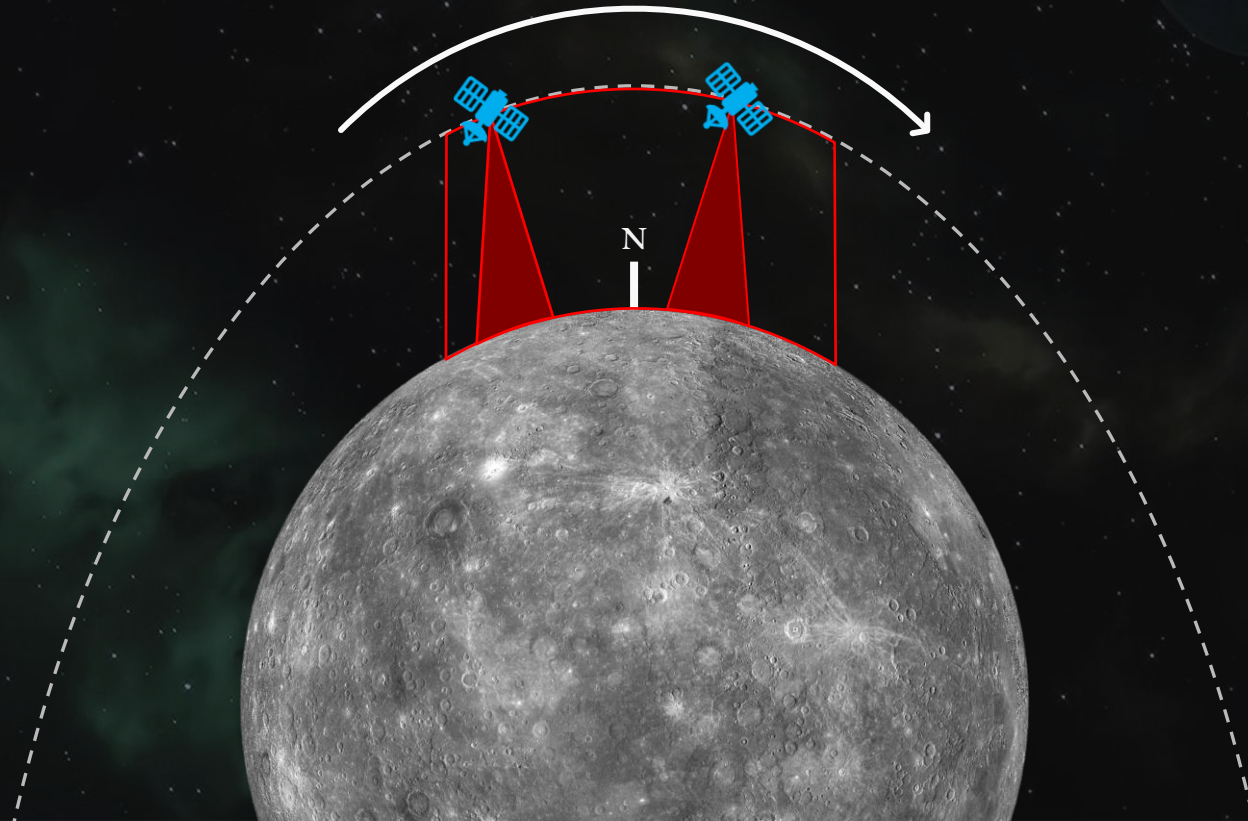
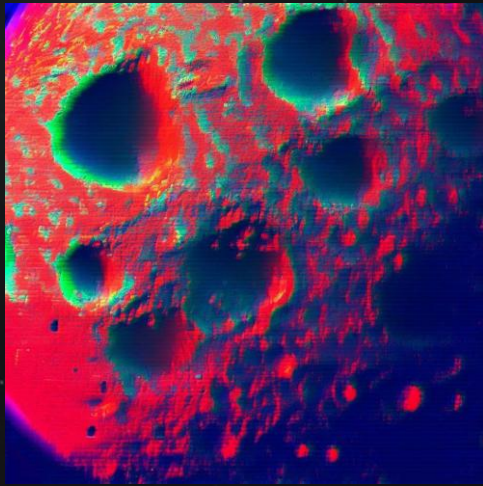
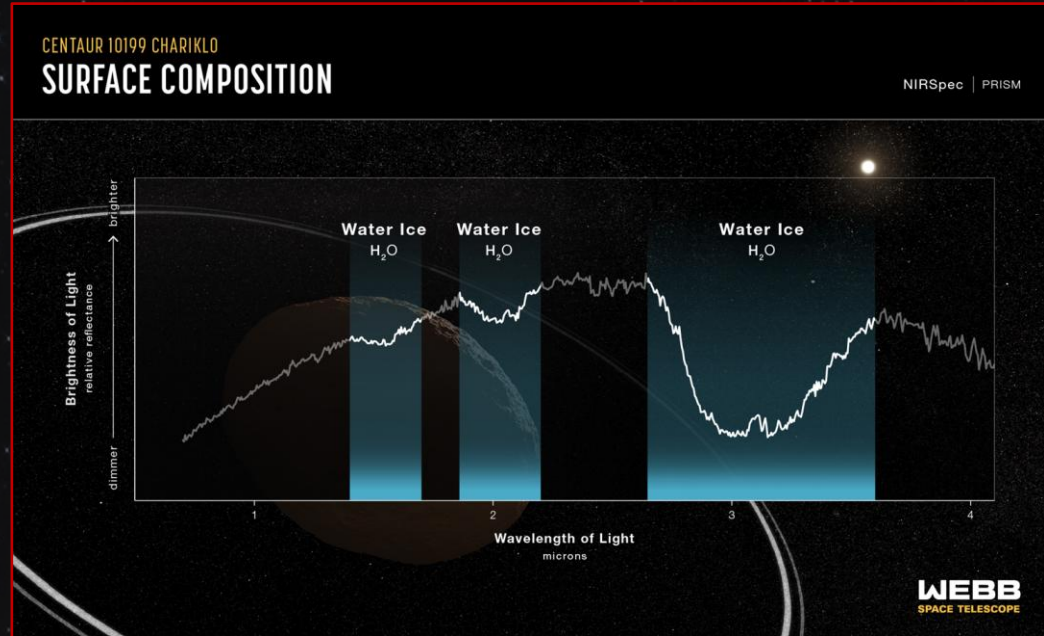
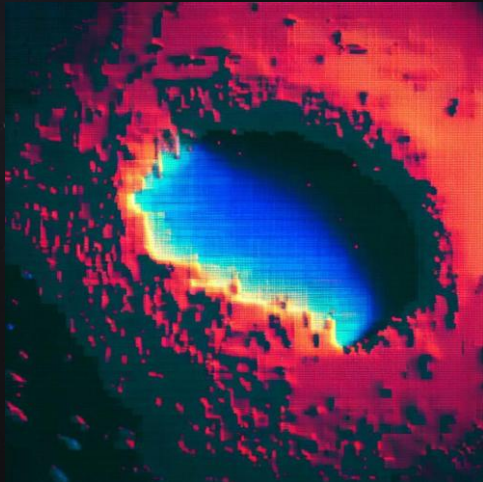


ILLUSTRATION:

Example of envisioned Infrared Data
(Absorption Data)



Imaging Spectroscopy



Credit: James Webb Space Telescope

FALCON 9 – ELECTRON:

Max Rideshare
Capacity of
Separation Port

831 kg	Payload to LEO Orbit	350 kg
Rideshare: 5–6 Million	Cost Per Launch	7.5 Million
221/224 (99% Success Rate)	Reliability	32/35 (91% Success Rate)
First Flight: June 4, 2010 Iterations: Falcon 9 V1.0 V1.1 V1.2 (Full Thrust) ★ <u>Block 5</u>	Heritage	First Flight: May 25, 2017 Iterations: Block 1 Block 1.1 ★ <u>Block 1.2</u> HASTE (Suborbital)



ROCKET LAB PHOTON BUS

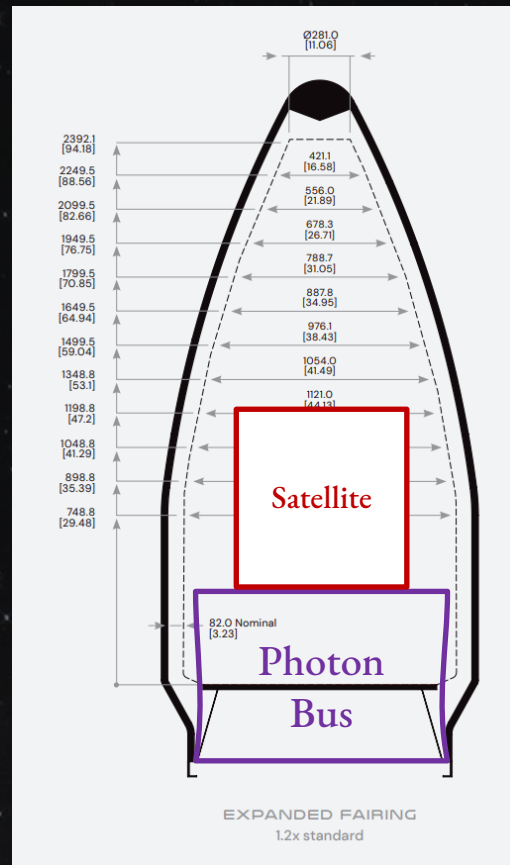


Capstone aboard Photon

Characteristics:

- Configurable/Modular Design
- Solves needed Δv Requirements
(Delivers roughly 4km/s)
- Accommodate payload range from
5–190 kg

★ **Purpose:** Solely propel satellite to reach escape velocity



TRAJECTORY TO MERCURY

Estimated Δv Hohmann Transfer: 7–8 km/s

Estimated Δv Gravity Assists:

3–3.5 km/s

DSM-1
Earth Pass

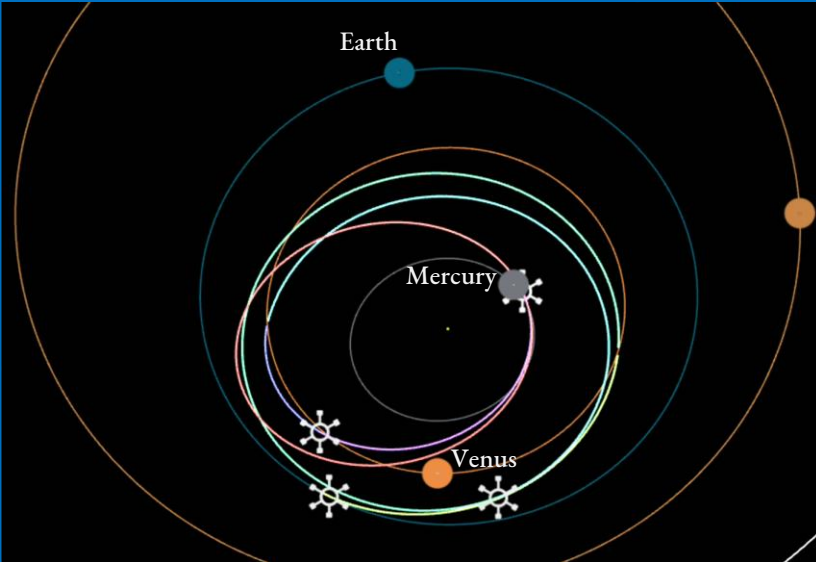
DSM-2
Venus Pass

DSM-3
Venus Pass

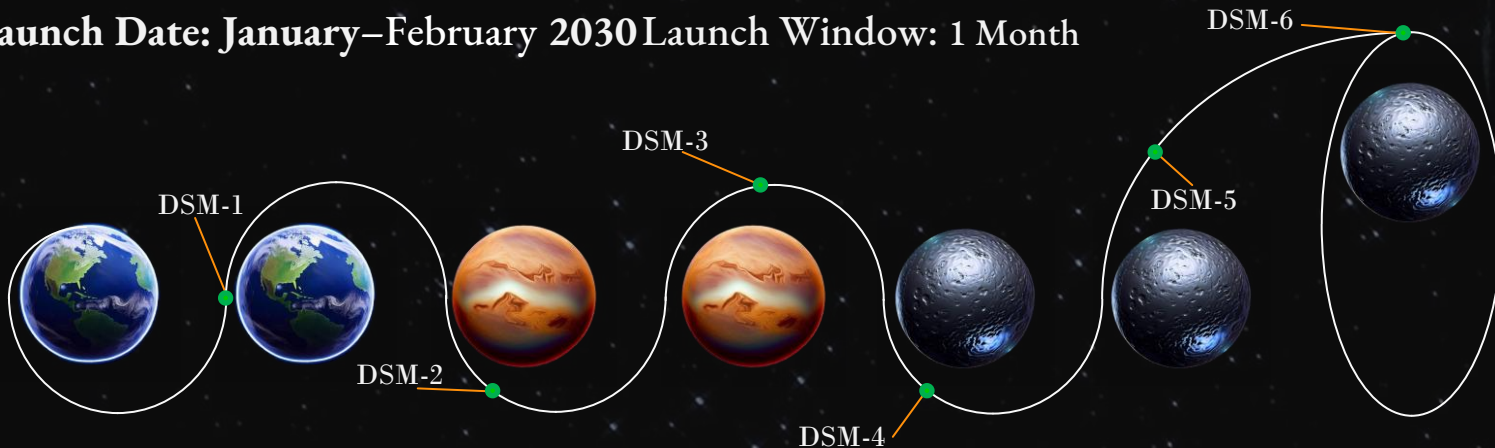
DSM-4
Mercury Pass

DSM-5
Mercury Pass

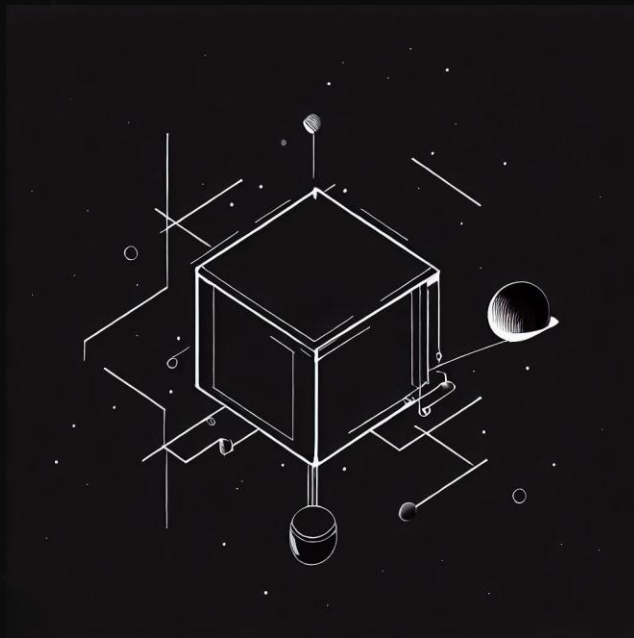
DSM-6
Mercury Orbit
Insertion



Launch Date: January–February 2030 Launch Window: 1 Month



MASS ESTIMATES



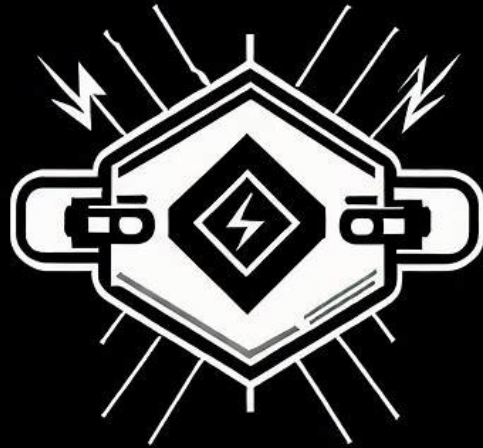
MASS ESTIMATES

COMMUNICATIONS	<u>ANTENNA</u> 53 KG <u>TRANSCEIVER AND AMPLIFIER</u> 7.2 KG <u>MODEM</u> 1.3 KG	PAYLOAD	<u>LOW DEF CAMERA</u> 1.6 KG <u>LIDAR</u> 5 KG <u>GAMMA SPECTROMETER</u> 25 KG
ON BOARD COMPUTING	<u>SPACE FLIGHT COMPUTING AND DATA STORAGE</u> 0.5 KG	ATTITUDE & ORBIT CONTROL	<u>REACTION WHEEL X3</u> 15 KG <u>STAR TRACKERS</u> 0.5 KG <u>SUN SENSOR</u> 0.3 KG
PROPULSIONS	<u>5 LB MONO-PROPELLANT X2</u> 1.5 KG <u>FUEL</u> 65 KG	MATERIAL AND STRUCTURE	<u>ALUMINUM T-4</u> 10 KG <u>HEAT SHIELD</u> 60 KG

TOTAL MASS ESTIMATE

~190 KG

POWER SYSTEMS



* INDICATES ALWAYS ON

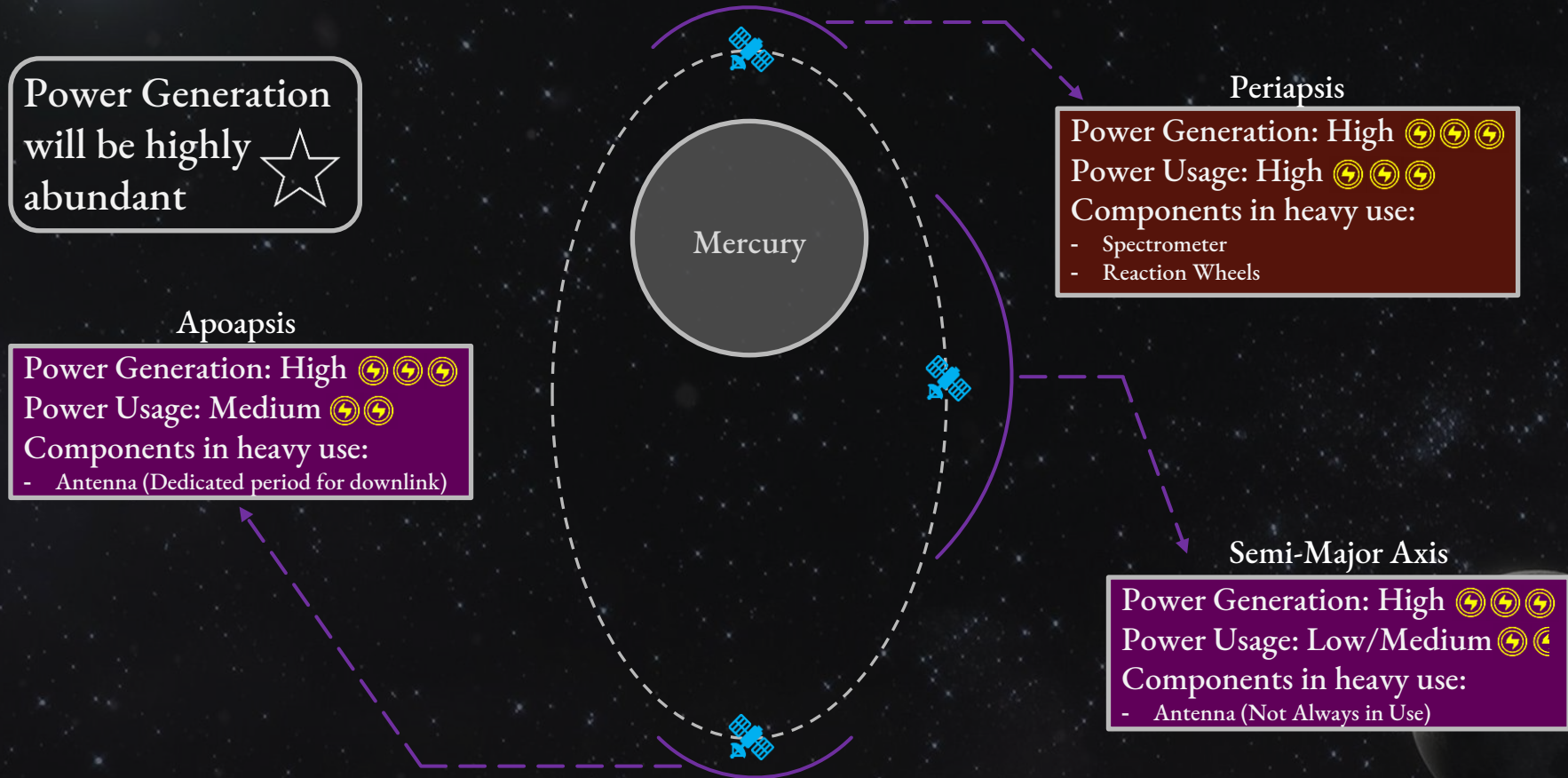
POWER ESTIMATES


COMMUNICATIONS	<u>TRANSPONDER/RECEIVER</u> 110 W <u>AMPLIFIER</u> 100 W <u>MODEM</u> 5 W	PAYLOAD	<u>LOW DEF CAMERA</u> 10 W <u>LIDAR</u> 50 W <u>GAMMA SPECTROMETER</u> 70 W
ON BOARD COMPUTING	<u>SPACE FLIGHT COMPUTER*</u> 25 W <u>SOLID STATE RECORDER</u> 15 W	ATTITUDE & ORBIT CONTROL	<u>REACTION WHEEL X3</u> 120 W <u>STAR TRACKER*</u> 1 W
PROPULSION	<u>5 LB MONO- PROPELLANT X2</u> 72 W		<u>SUN SENSOR*</u> .74 W

POWER ESTIMATES



- Worst Case Scenario Power Requirement: **534 W**
- Average power consumption without transmissions: **28 W**
- Power Required for transmissions: **170 W**
- Power Required for data Collection: **125 W**
- Power Required for attitude and orbit control: **123 W**

POWER MANAGEMENT IN ORBIT:





Power Generation
will be highly
abundant 

Apoapsis



Power Generation: High 
Power Usage: Medium 
Components in heavy use:
- Antenna (Dedicated period for downlink)

Mercury

Periapsis

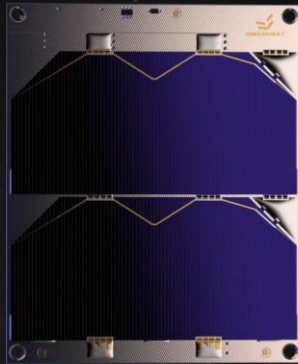
Power Generation: High 
Power Usage: High 
Components in heavy use:
- Spectrometer
- Reaction Wheels

Semi-Major Axis

Power Generation: High 
Power Usage: Low/Medium 
Components in heavy use:
- Antenna (Not Always in Use)

POWER PRODUCTION AND BATTERY

ARRAY



82 solar cells

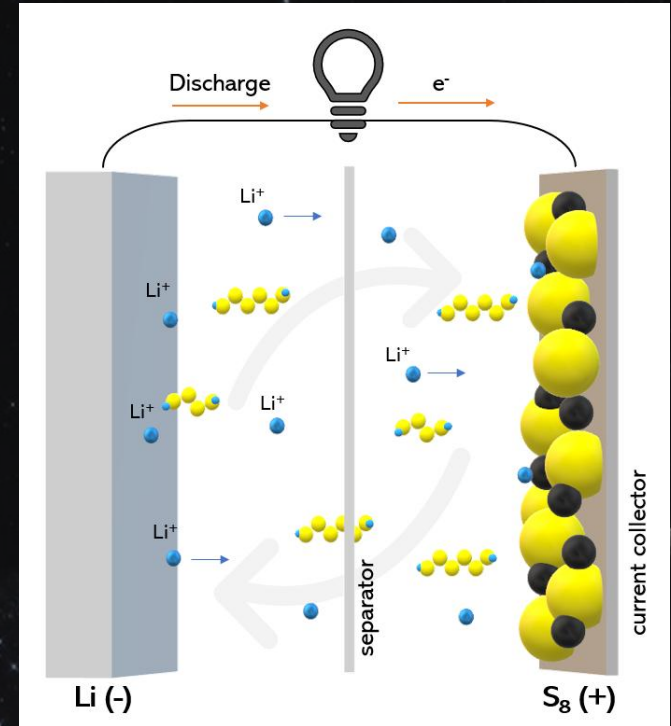
$$F_{sun} = \frac{\text{Total Solar Luminosity}}{\text{Surface Area of Sphere}} = \frac{L_{sun}}{4\pi r^2}$$

Theoretical Max Power
Output = 776.25 W

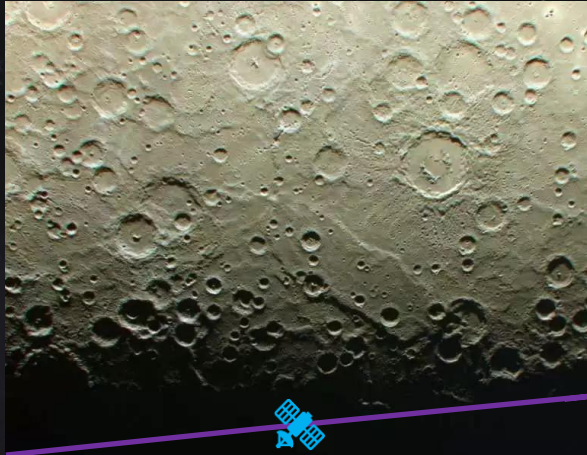


Lithium Sulfur Dioxide Battery
Array

- 10 year storage life
- Operation temp -50 - 75°C



MERCURY OCCULTATION (ECLIPSING)

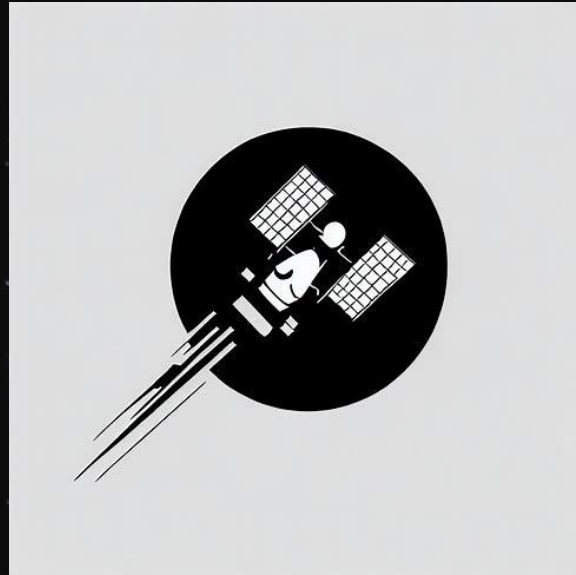


Power Generation: None
Power Usage: High ⚡⚡⚡
Components in heavy use:
- Spectrometer if at North Pole
- Reaction Wheels

➤ Planned Procedure:

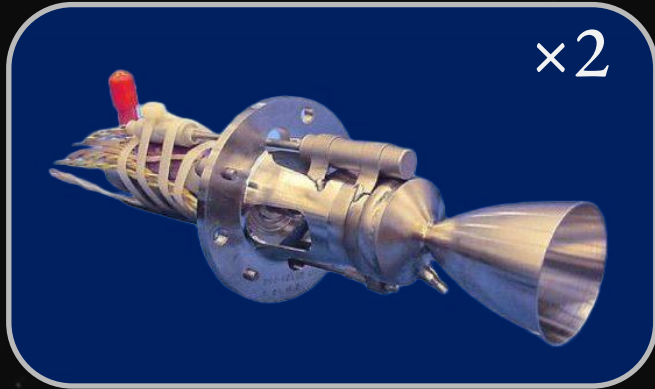
1. Assess spacecraft health & power status
2. Adjust power consumption accordingly
3. Adjust thermal system to account for temperature change
4. Maintain telemetry
5. **After Occultation: Verify Spacecraft Health**

PROPULSION



PROPULSION:

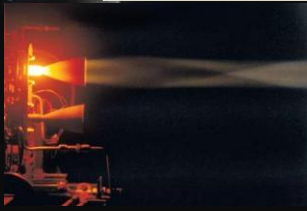
MR-106L 22N (5.0 lbf) REA



- ❖ Simplicity
- ❖ Fast Response
- ❖ High Thrust-to-Weight Ratio
- ❖ Established Technology: Proven Heritage

- × Lower Specific-Impulse compared to Electric
- × Limited Lifetime

HYDRAZINE THRUSTER V.S. ELECTRIC:



MR-106L 22N (5.0 lb) REA



XR-5 Hall Thruster

	235 Sec.	Specific Impulse	1920 Sec.	
	15,275 N–Sec.	Total Impulse (Lifetime)	282,744 N–Sec.	
❖ Simplicity	44.5 N.	Thrust	0.17 N.	❖ Long Operational Lifetime
❖ Fast Response	72 W.	Power Consumption	3.0 kW	❖ Low Thrust
❖ High Thrust-to-Weight Ratio	0.26	Thrust-to-Weight Ratio	0.00133	❖ Highly Efficient
❖ Established Technology: Proven Heritage	In Production since 2005 (20 Years)	Heritage	In Production since 2015 (8 Years)	× Increased Complexity
× Lower Specific-Impulse compared to Electric				× Slow Response
× Limited Lifetime				× Increased Power Consumption
				× Developing Technology

COMPUTING SYSTEMS



ON-BOARD COMPUTING SYSTEMS:

PROCESSOR



EDGE 3U CubeSat Processor

- 25 W
- 2 GB DDR3
- Non-Volatile MRAM- system commands will not be lost in the event of losing power

SOLID STATE RECORDER



Kryten M3

4 GB flash storage

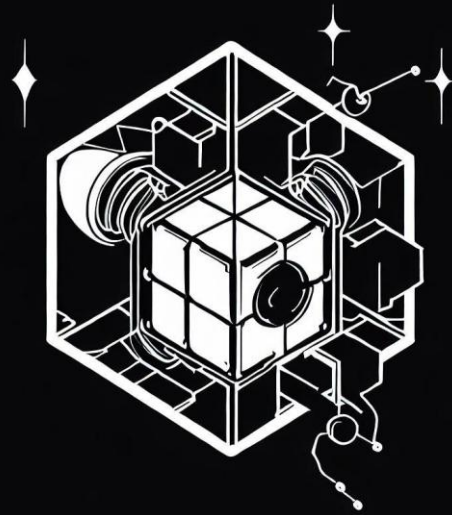
Utilizing data trimming, storage can be conserved

- Transmit the data
- Ensure the data is collected on the ground
- Data is deleted off of the SSR

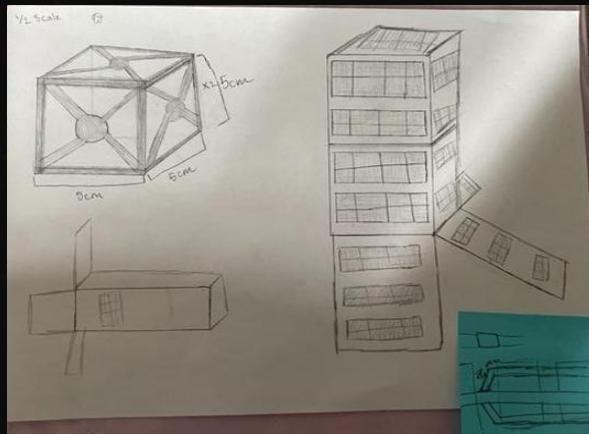
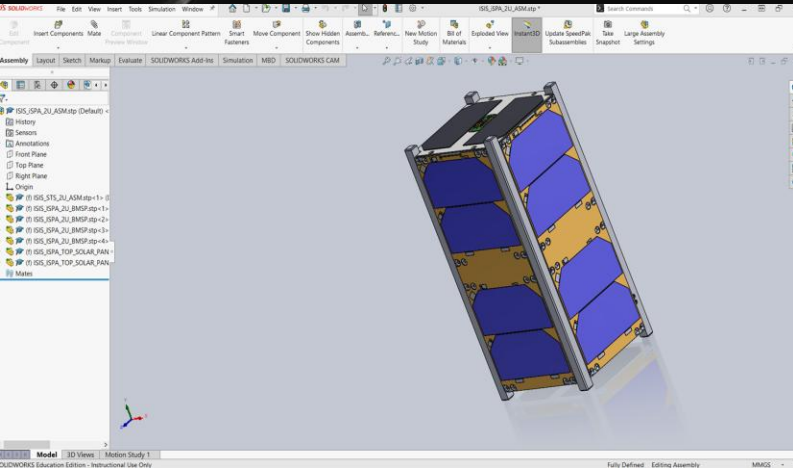
TOTAL STORAGE ESTIMATES

DATA COLLECTION TOOL	DATA COLLECTED PER ORBIT	DATA COLLECTED PER DAY	DATA COLLECTED OVER ONE YEAR
SPECTROMETER	1.75 GB	7.7 GB	2.81 TB
CAMERA	1 GB	4.4 GB	1.61 TB
LIDAR	0.435 GB	1.9 GB	696.75 GB
ALL COMBINED	3.185 GB	14.0 GB	5.12 TB

MECHANICAL



LOW FIDELITY SOLIDWORKS



MATERIALS/THERMAL CONTROL

6061
Aluminum
T-4

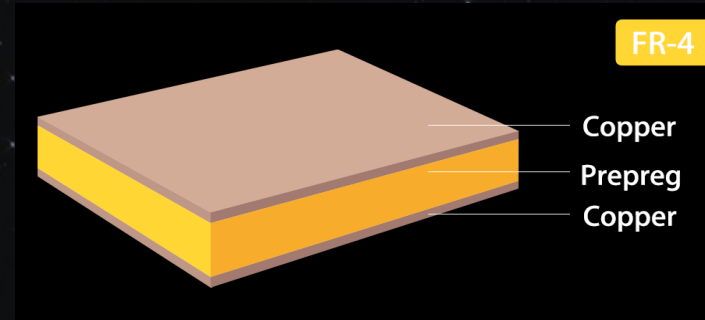
PROPERTY	VARIABLE	VALUE
Initial Mass Density	ρ_o	2.70 g/cm^3
Yield Stress	σ_y	30.05 MPa
Young's Modulus	E	70.6 GPa
Shear Modulus	μ	27.9 GPa
Poisson Ratio	ν	0.279
Resistivity @ 25°C	ρ_{ro}	3.2396 $\mu\Omega\text{-cm}$
Resistivity Temp. Coeff.	α	0.0033 K
Specific Heat Temp. Coeff.	β_1	4.94 $J/Kg K$
Specific Heat Temp. Coeff.	β_2	2.96 $J/Kg K$
Molecular Wt.	M_w	26.982 $gm/mole$
Steinberg Strength Coeff.	β	100.0
Steinberg Strength Exponent	N	0.27



Material Properties

- Typical outside surface α / ϵ value: 0.70
- Typical inside surface α / ϵ value: 0.34
- Operating Temperature: $\geq 1,093$ °C
- Thickness: 250 μm

Flame retardant Epoxy/FR4



Heat Shield Formula

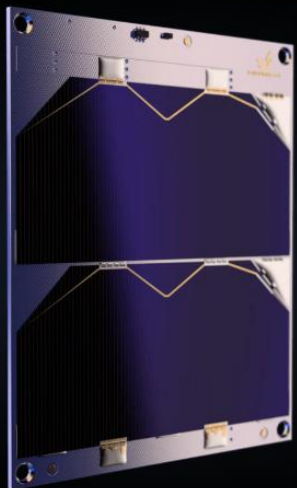
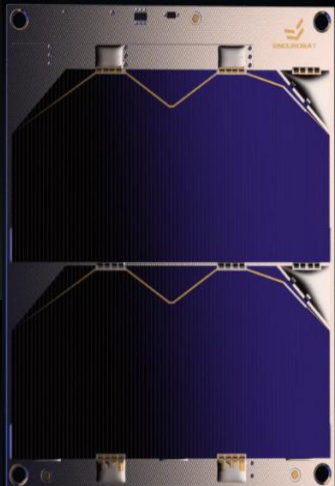
$$\frac{M_{load}}{M_{FC}} = 1 \propto \frac{L^3}{(m \omega^2 \sin(\theta) L \cdot \cos(\theta) L)}$$

$$N_{m_\sigma} \omega^2 \sin(\theta) N_L / N_d^2 \propto 1$$

SOLAR PANEL X/Y

FEATURES

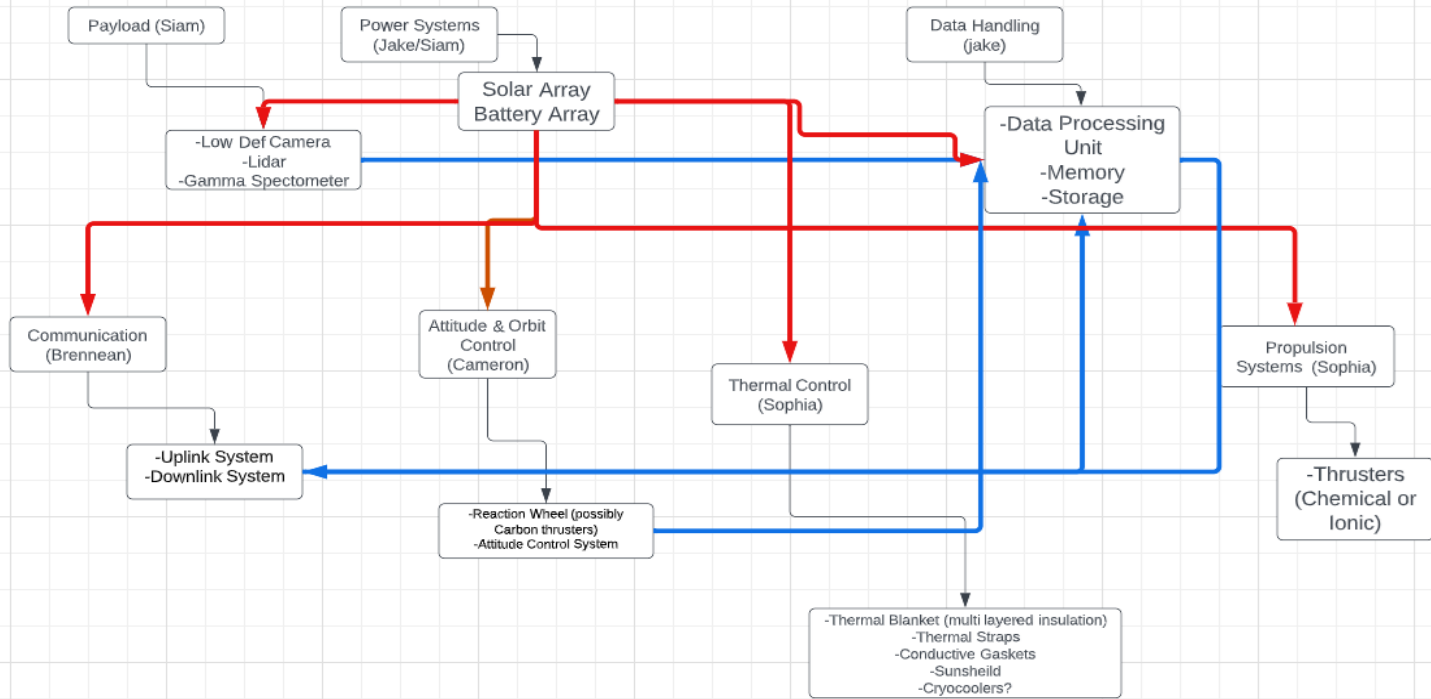
Power Efficiency At EOL	29+%
Max Power	Up to 2.4 W in LEO
Internal By-Pass Diode	reverse bias protection
Solar Cells Thickness	150 μm \pm 20 μm
Sensors	Temperature and Sun, optional Gyroscope
MTQ	Available with integrated magnetorquer
RBF	Available with Remove Before Flight pin
Mass	44 g (53 g with MTQ)
Customisation	Multiple panels can be connected in series or parallel
Max Voltage	4.8 V (for 2 cells)
Max Current	504 mA
PCB Thickness	1.6 mm



BOX DIAGRAM

○ SubSystems Chart ○

— = Power
— = Data



TELECOMMUNICATIONS

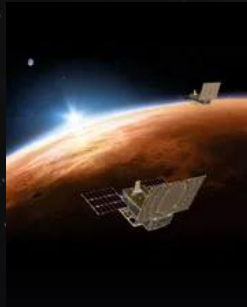


FREQUENCY BANDS



EXOCUBE

- ❖ Frequency: S-Band
- ❖ Antenna Gain: 2.2 dBi
- ❖ Output Power: 0.5 W
- ❖ Data Rate: 9600 bps



MARCO

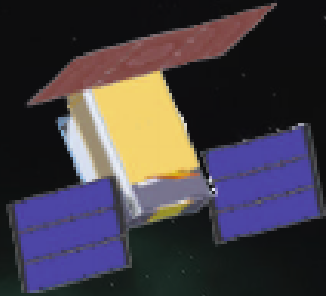
- ❖ Frequency: X-Band
- ❖ Antenna Gain: 14 dBi
- ❖ Output Power: 25 W
- ❖ Data Rate: 8 Mbps

WHY X-BAND?

- Lower Interference from Sun
- Ability to Penetrate through Dust and Gas
- Small Antenna Size
- High Data Rates Possible
- Well-established ground infrastructure

REFLECTARRAY V.S.

PATCH ARRAYS



Size: 5 kg with 1.2m Arrays
Gain: 22 dBi

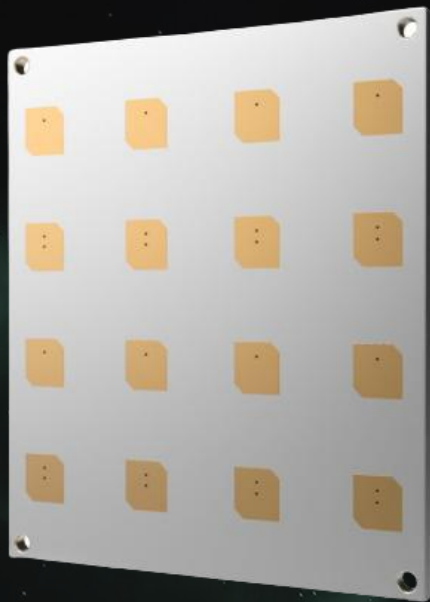
- Made of a grid of small patches
- Uses a surface to reflect and redirect radio waves
- Utilizes a deployment mechanism



Size: 52.8g with .4m Arrays
Gain: 25 dBi

- Made of individual radiating elements
- Uses a grid to transmit and receive radio waves

4X4 X-BAND PATCH ARRAY



SPECIFICATIONS:

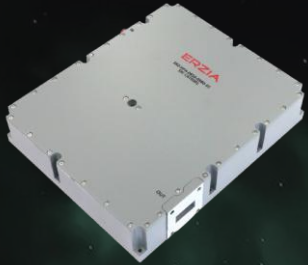
- RF Power Handling up to 15 W
- 53g Mass
- 25+ dBi over operational bandwidth

4X4 Grid Pattern

- 16 Patch Antenna Systems
- Higher Gain
- Higher Transmission Power Output
- Small in Size

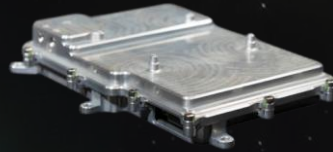
COMMUNICATION COMPONENTS

HIGH POWER AMPLIFIER



- Boosts power of the signal
- Allows for communication with weaker signals
- Provides reliable and consistent power output

FRONTIER-X MODEM



- Encodes and decodes data for transmission
- Provides error correction
- Enables higher data rates

X-BAND TRANSCEIVER



- Enables two-way communication
- Sending data and commands to the ground station

MXBT X-BAND TRANSPONDER



- Transmits and Receives Signals
- Receives and retransmits signals from the ground station

ATTITUDE/ORBIT CONTROL



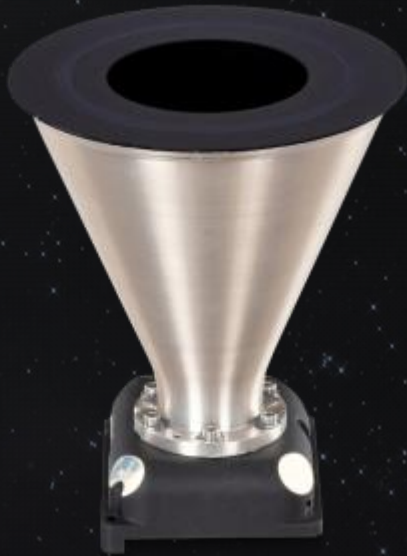
SUN SENSOR



NSS FINE SUN SENSOR FROM NEWSPACE SYSTEMS

- Most basic attitude sensor
- Used to help position solar panels and provide data in tumbling scenarios

STAR TRACKER

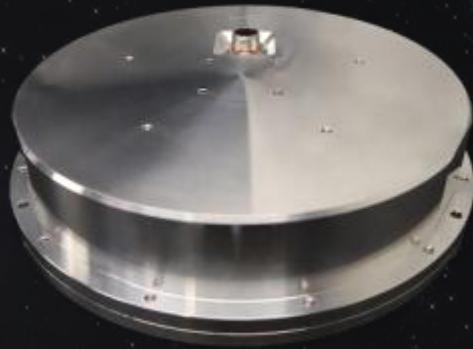


ST-16RT2 LARGE BAFFLE VARIANT FROM ROCKET LAB

- Maximum Slew Rate of 3° /second
- 90+ currently in orbit
- Maximum Power Draw of 1W
- 235 g
- \$140,000

REACTION WHEELS

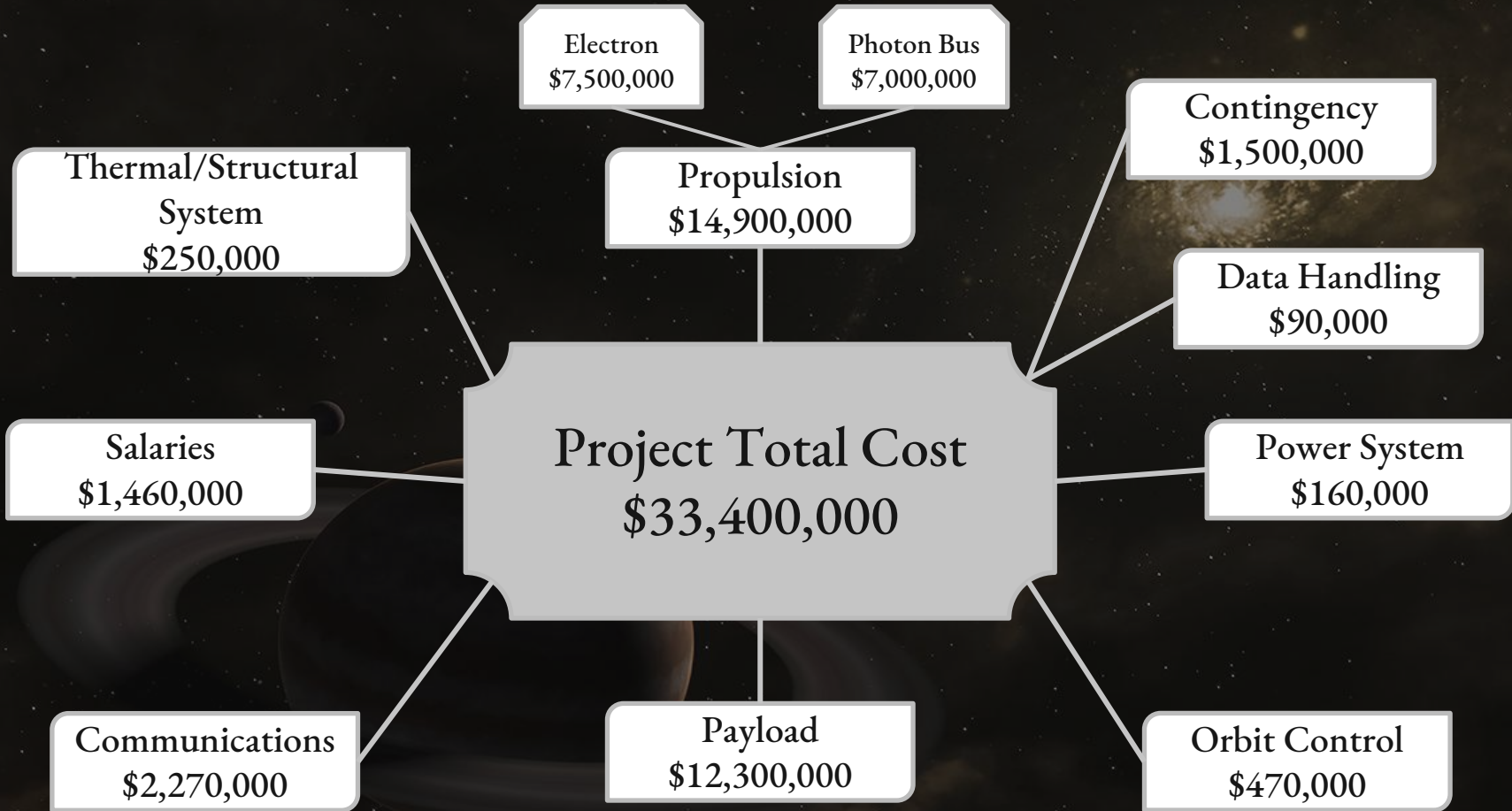
RW5-12.0 FROM ROCKET LAB



- 3 on the satellite
- 12 Nms Momentum
- 0.2 Nm Torque
- 257 mm diameter x 68 mm height
- 5 Kg
- 40 W Maximum Power Draw
- \$100,000 each

PRICE ESTIMATES

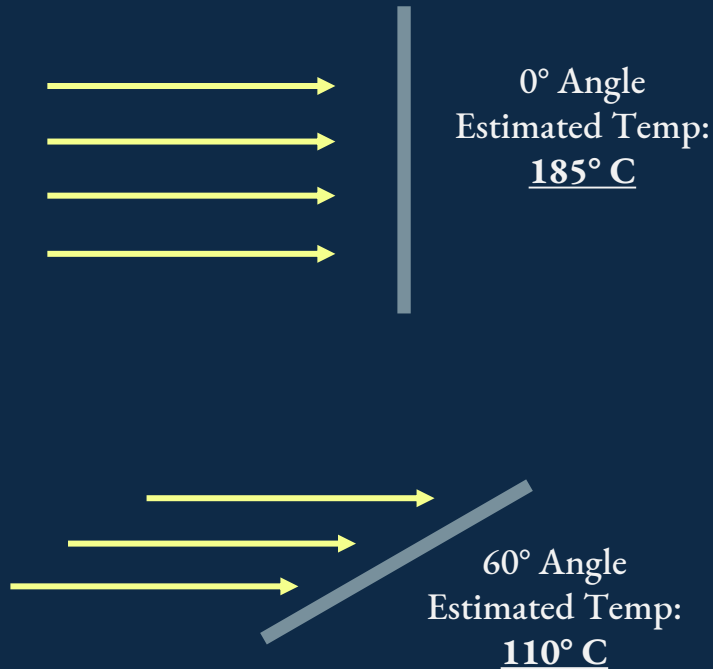




SOLAR PANEL ANGLING + HEAT

Solar Irradiance (Earth) = 1361 W/m^2

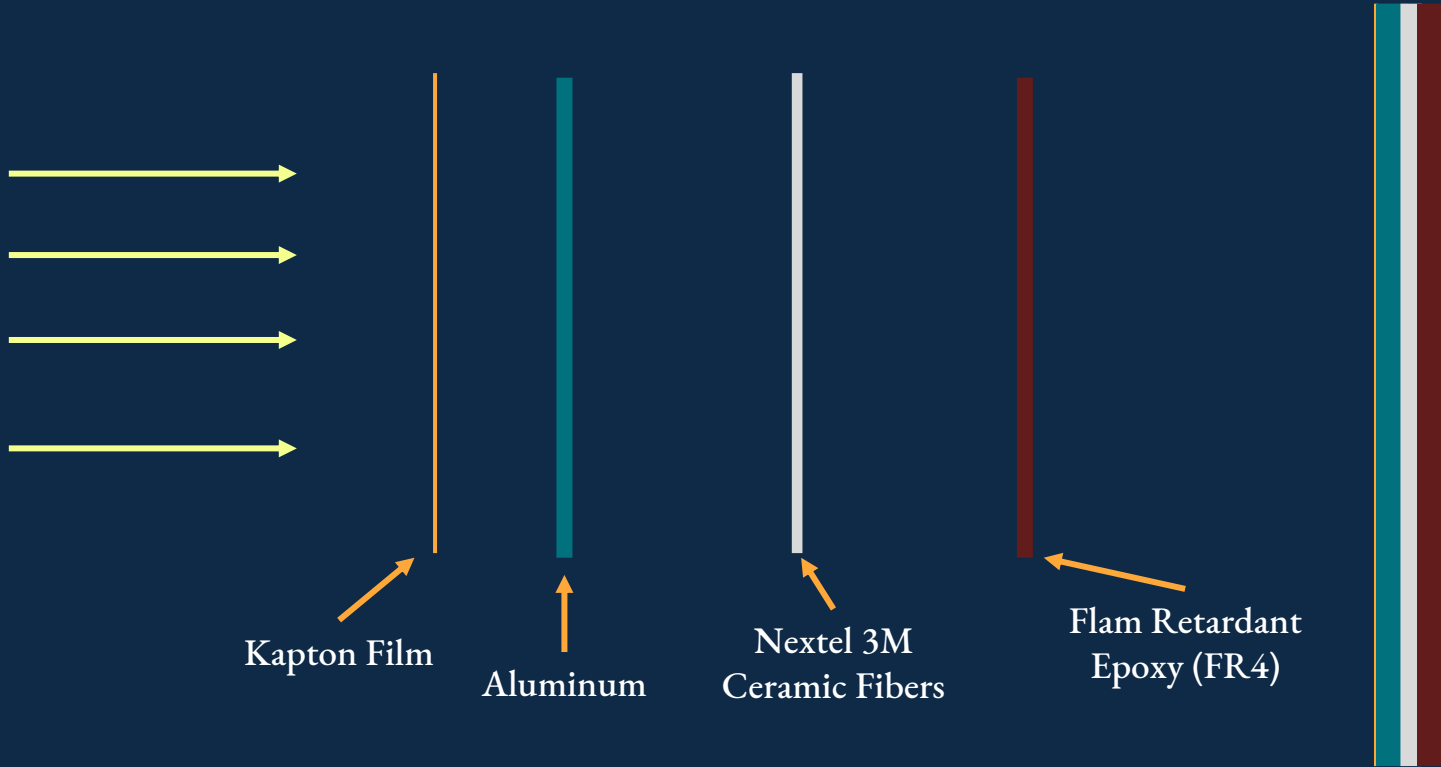
Solar Irradiance (Mercury) = 9100 W/m^2

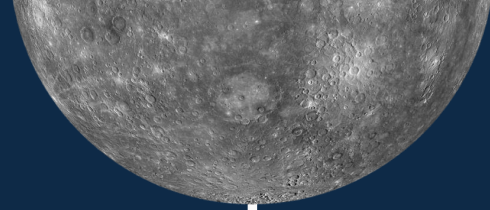


Temperature Reduction: Coatings

- ❖ Anti-Reflective Coatings: Improve efficiency, maximizing absorption, minimizing reflection
- ❖ Infrared Coatings: Reflect largest heat contributor, resulting in lower temperatures, and better solar panel efficiency

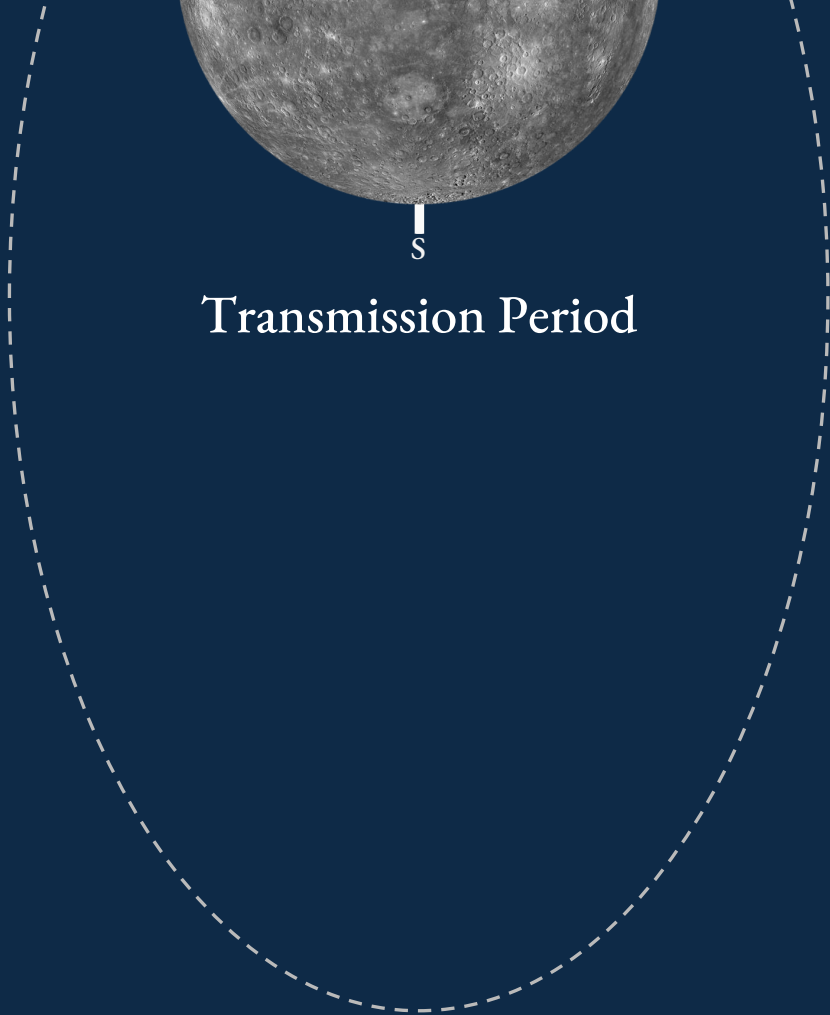
HEAT SHIELDING + DESIGN



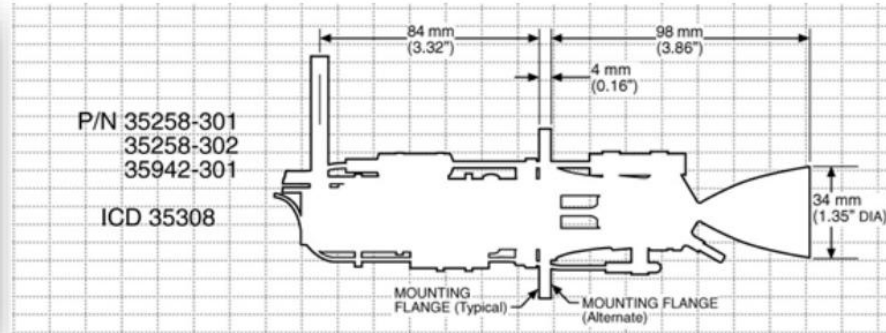


S

Transmission Period



MR-106L 22N (5.0 lbf) Rocket Engine Assembly



Design Characteristics

- Propellant..... Hydrazine
- Catalyst..... S-405/LCH-202
- Thrust/Steady State..... 34 - 10 N (7.7 - 2.3 lbf)*
- Feed Pressure..... 27.6 - 5.9 bar (400 - 85 psia)
- Chamber Pressure..... 13.4 - 3.8 bar (195 - 56 psia)
- Expansion Ratio..... 60:1
- Flow Rate..... 14.0 - 4.1 g/sec (0.031 - 0.009 lbm/sec)
- Valve..... Dual Seat
- Valve Power..... 25.1 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power..... 4.00 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr..... 7.06 Watts Max @ 28 Vdc & 21°C
- Mass..... 0.59 kg (1.14 lbm) Nom

Performance

- Specific Impulse..... 235 - 228 sec (lbf-sec/lbm)
- Total Impulse..... 561,388 N-sec (126,205 lbf-sec)
- Total Pulses..... 120,511
- Min Impulse Bit..... 0.015 N-sec @ 5.9 bar & 16 ms ON
..... (0.034 lbf-sec @ 85 psia & 16 ms ON)
- Steady State Firing..... 4,000 sec Single Firing

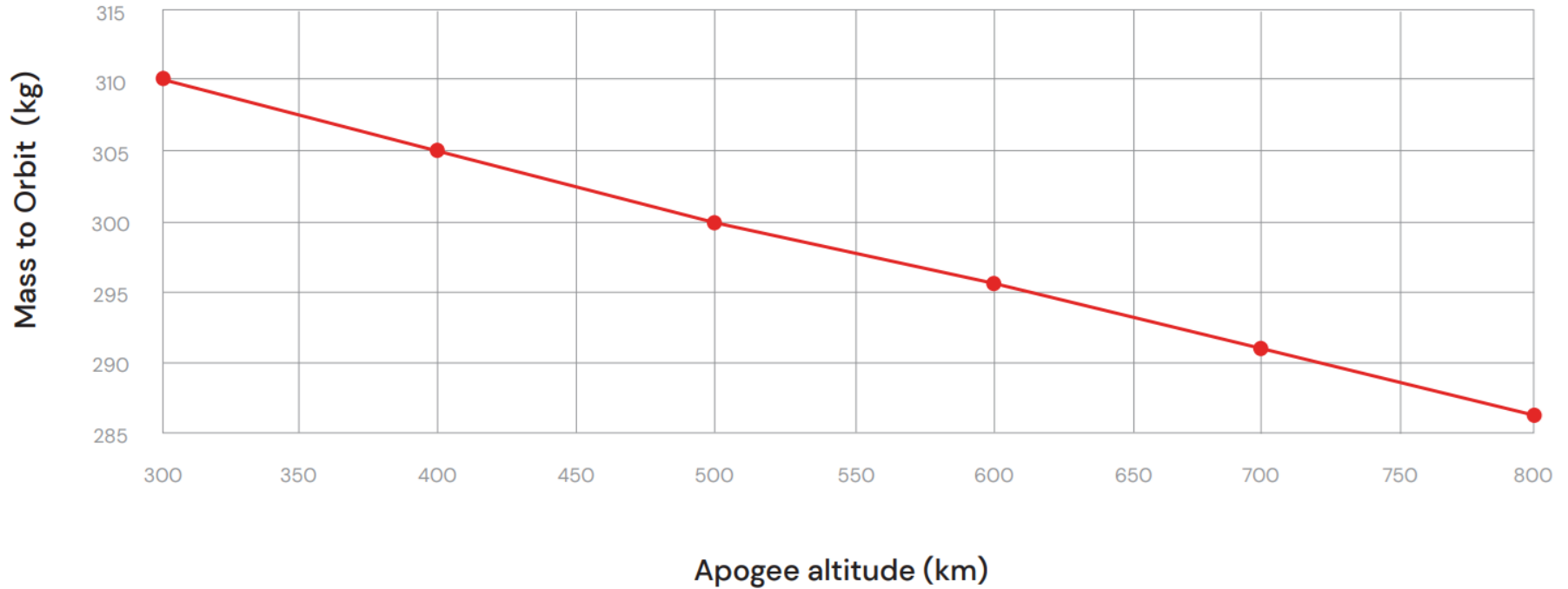
Status

- Flight Proven
- Currently in Production

Reference

- AIAA-2005-3954

ELLIPTICAL ORBIT: PAYLOAD VS APOGEE (Perigee: 180 km, Inclination: 39°)



THANK YOU FOR LISTENING