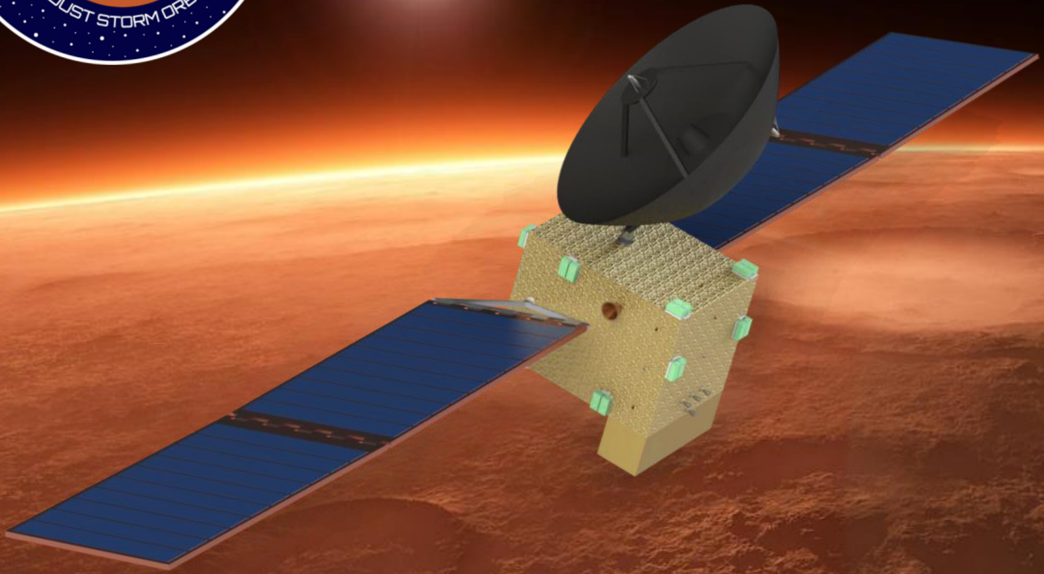
Mars MEDUSA Orbiter

AE 4342 Team 6



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Georgia Institute of Technology

Georgia Tech College of Engineering
Daniel Guggenheim School
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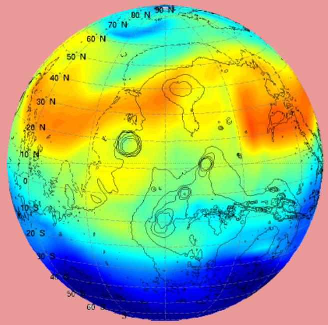
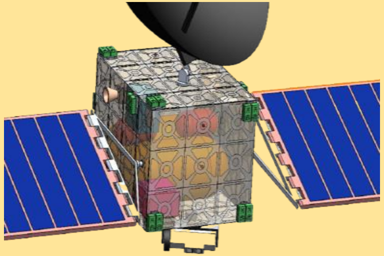
Overview

MEDUSA: **M**ars **E**xploration of **Du**st **S**torms and **A**tmosphere

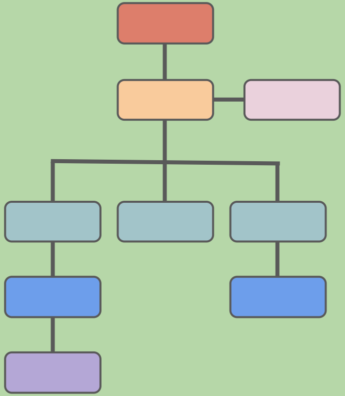
1. Science Investigation



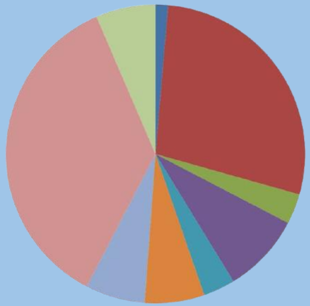
2. Mission Implementation



3. Project Management



4. Cost & Scheduling



Mars MEDUSA Orbiter

Science Investigation

Mission Statement

MEDUSA will investigate the mechanisms of formation, composition, and seasonal changes of dust storms on Mars; this will be achieved through Radiometers and Multi-angle Imaging SpectroRadiometers.

Science Background

The Significance of studying Martian Dust Storms

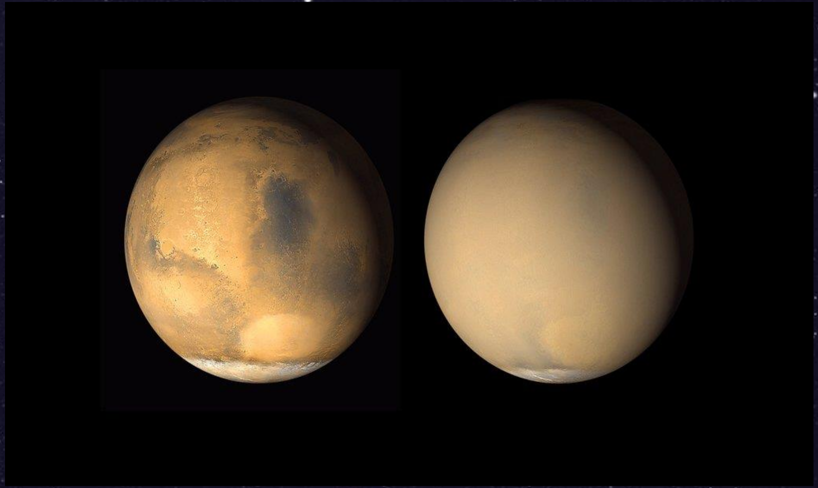
- Better understanding of Martian Climate
- Better understanding of the mechanisms of climate change for Earth applications

Mars Exploration Program Analysis Group interests

- Locations and times of interest for the creation of dust storms
- Analysis of aerosol type, concentration, and movement through dust storms
- How dust storms carry dust and water through the atmosphere and across the surface

Leading Theory

- Atmospheric Factors (heat, pressure) cause dust storms to form
- These dust storms transfer water ice



Credit: NASA / JPL / MSSS

MEDUSA Science

Goal: Explore the formation and impact of dust storms on Mars

Objectives:

- Determine how and under what conditions Martian dust storms form and propagate using MCS and MISR
- Determine how particles move within the dust storm using MISR
- Determine the composition of Martian dust storms using MISR
- Determine if and how H2O is transferred via dust storms on Mars using MISR

Credit: NASA / JPL / MSSS / Justin Cowart / Emily Lakdawalla

Science Traceability

NASA Science Goals	Investigation Science Objectives	Science Measurement Requirements		Instrument Performance				Mission Requirements (Science Driven)
		Physical Parameters	Observable	Parameters		Requirement	Projected	
1) MEPAG Ref: Goal IV, Investigation B3.1: Globally monitor the dust and aerosol activity continuously and simultaneously at multiple locations across the globe, especially during large dust events, to create a long-term dust activity climatology (>10 Mars years) capturing the frequency of all events (including small ones) and defining the duration, horizontal extent, and evolution of extreme events. (High Priority)	1) Determine the topographic and atmospheric conditions that create dust storms	Topographic Features	Morphological Feature	Vertical Resolution	Horizontal Resolution	measure topographical feature size, longitude, and latitude with at least 5 km size	topographic map of mars	Satellite with an orbital inclination angle of 75 degrees
		Temperature	Wavelength: Infrared	Temperature		-153 C to 35 C	-161 C to 37 C	
		Humidity	Wavelength: Visible, Infrared	Humidity		0-10 g*m^-3	0-20 g*m^-3	Establish Link with DSN
		Pressure	Wavelength: Visible, Infrared	Pressure		0-1200 Pa	0-1500 Pa	
		Wind Speed and Direction	Wavelength: Visible, Infrared	Position	Velocity	0-70 km/hr	0-150 km/hr	Handle data rate 9.0 Mbps
	2) Characterize the motion and evolution of dust storms	Movement of Dust Storms	Movement of storm center of mass along surface of mars	Change in position	Time			
		Growth of Dust Storm	Surface area coverage change	Vertical Resolution	Horizontal Resolution	diameter and surface area data over time	diameter and surface area data over time	Global Coverage every 6-7 days
	3) Determine the regularity of dust storms	Frequency of dust storms	Visual, temporal	Vertical Resolution	Horizontal Resolution	Identify dust storms as they're created	Identify dust storms as they're created	
	4) Determine whether the characteristics of Mars' orbit around the sun affect the development of dust storms.	Angular velocity of Mars with respect to the Sun,	Location of Mars on it's orbit	Instrument and Telemetry Communications Data		Mars orbital conditions with respect to the Sun	There have been predictions that as Mars approaches perigee of orbit the dust storms increase	Mission lifespan of >10 years

Science Traceability

NASA Science Goals	Investigation Science Objectives	Science Measurement Requirements		Instrument Performance				Mission Requirements (Science Driven)
		Physical Parameters	Observable	Parameters		Requirement	Projected	
2) MEPAG Ref: Goal II, Investigation A1.2: Measure water and carbon dioxide (clouds and vapor) and dust distributions in the lower atmosphere and determine their fluxes between polar, low-latitude, and atmospheric reservoirs. (Higher Priority)	5) Determine composition and distribution of particles in the lower atmosphere	Dust Particle Composition	Light absorbtion: spectroscopy	Concentration of water	Concentration of dust	Percent composition makeup (. 01%)	Percent chemical composition about 0.001 %	MISR: 400-900 nm MCS: 0.3-45 um
	6) Characterize the vertical and horizontal movement of dust, water, and carbon dioxide through the Martian atmosphere	Verticle movement of particles	Wavelength: Visible, Infrared	Optical		0-30 m/s	0-50 m/s	Vertical Resoulution: <5 km Horizontal Resolution: <300km
3) MEPAG Ref: Goal IV, Investigation A1.2: At all local times, make long-term (>5 Mars years) global measurements of the vertical profile of aerosols (dust and water ice) between the surface >60 km with a vertical resolution <=5 km and a horizontal resolution of <300 km. These obeservations should include the optical properties, particle sizes, and number densities. (High Priority)		Horizontal movement of particles	Visual Movement of dust clouds	Optical		0-30 m/s	0-50 m/s	Mission lifespan >5 years

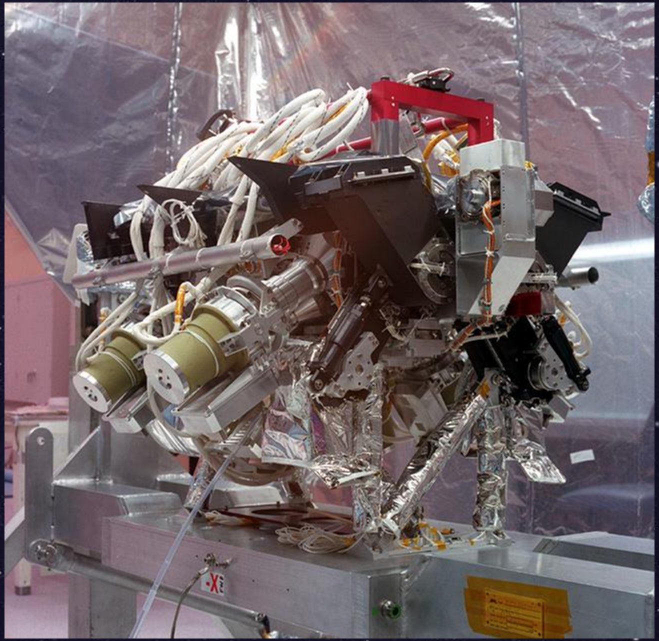
Mars MEDUSA Orbiter

Mission Implementation

Science Instruments

Multi-angle Imaging SpectroRadiometer

- 9 angled pushbroom spectroradiometers
- Captures images in 4 spectral bands from infrared to visible
- Allows analysis of aerosols, winds, and clouds



Credit: NASA / Caltech / JPL

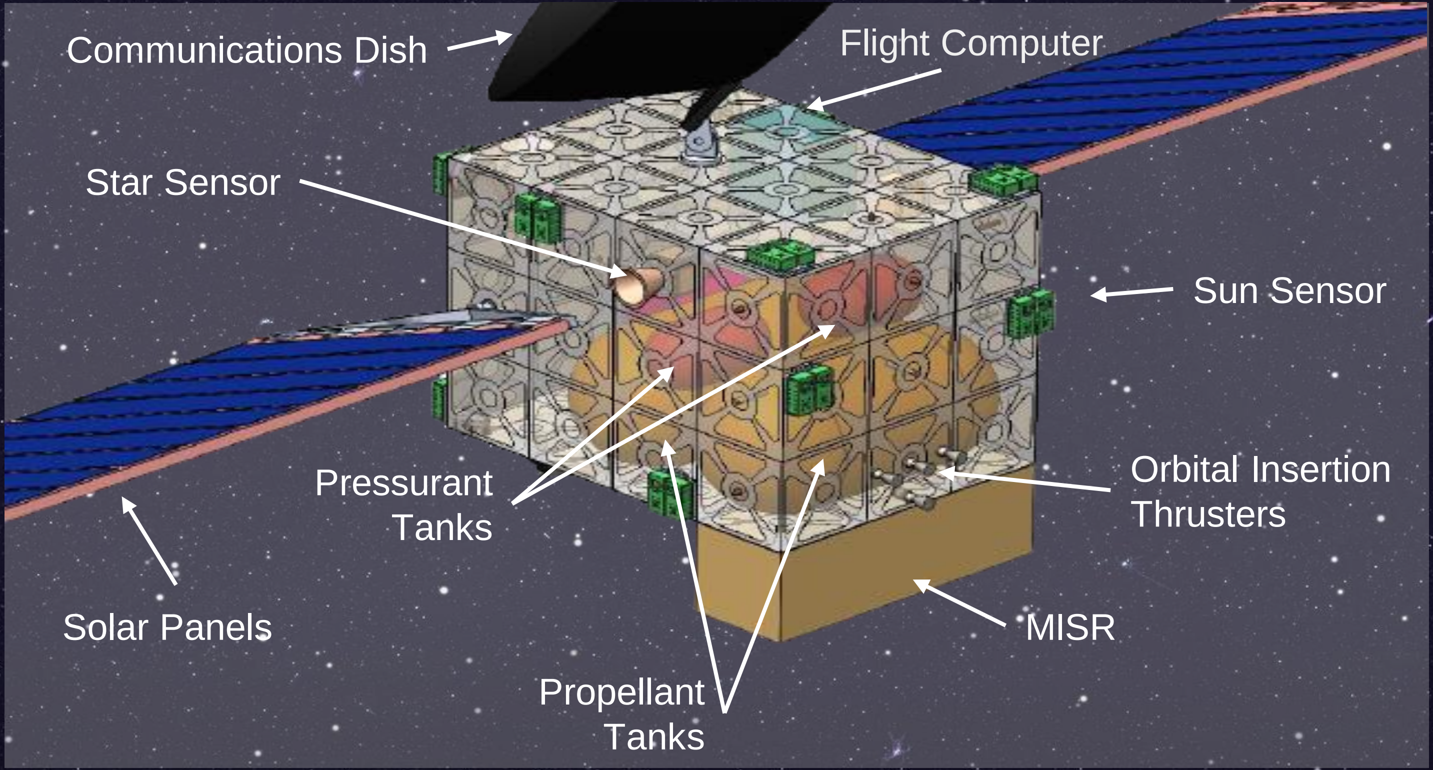
Science Instruments

Mars Climate Sounder (MCS)

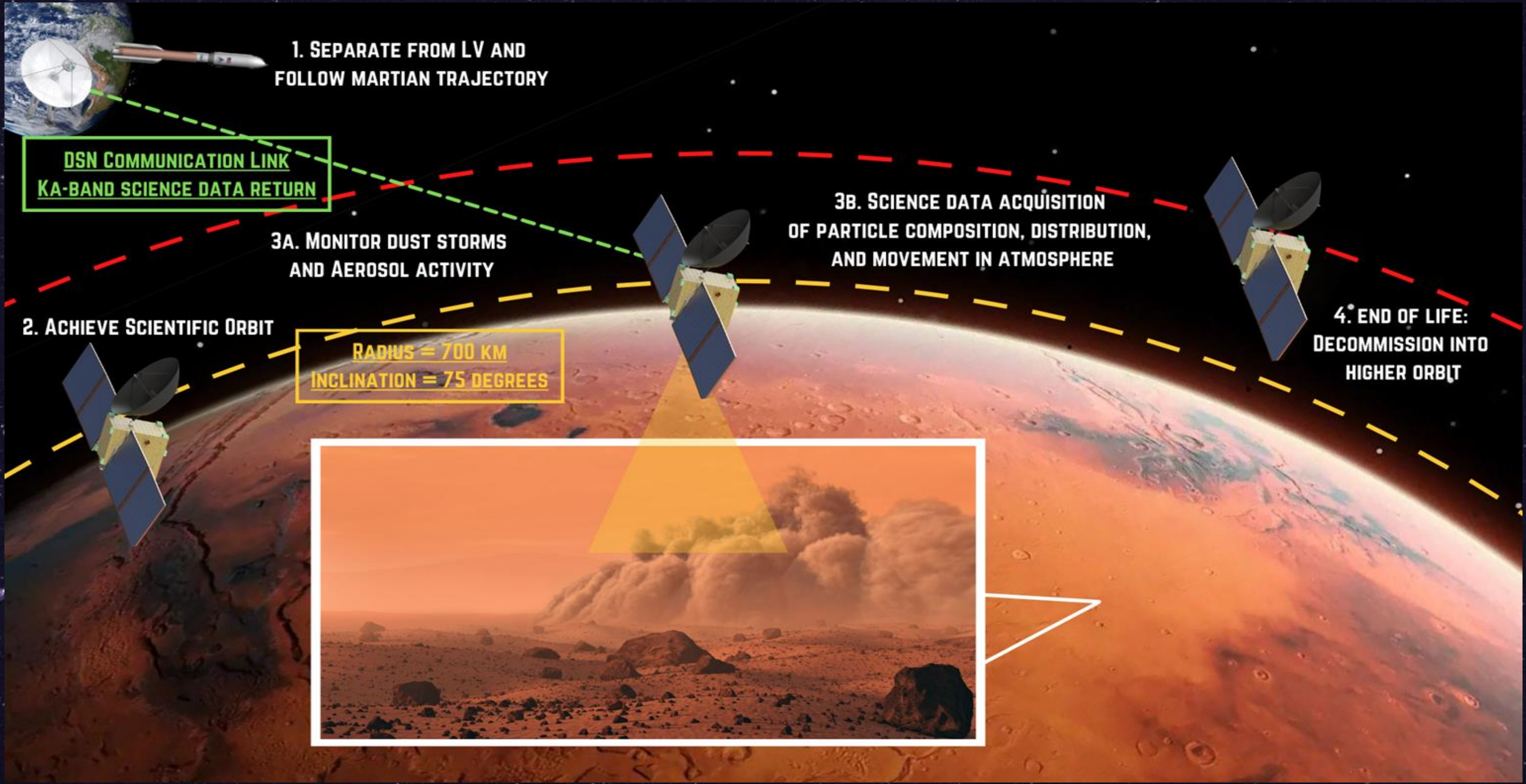
- Captures images in 9 spectral bands from infrared to visible
- Measures temperature, pressure, water vapor, and dust in layers of the atmosphere

Credit: NASA / Caltech / JPL

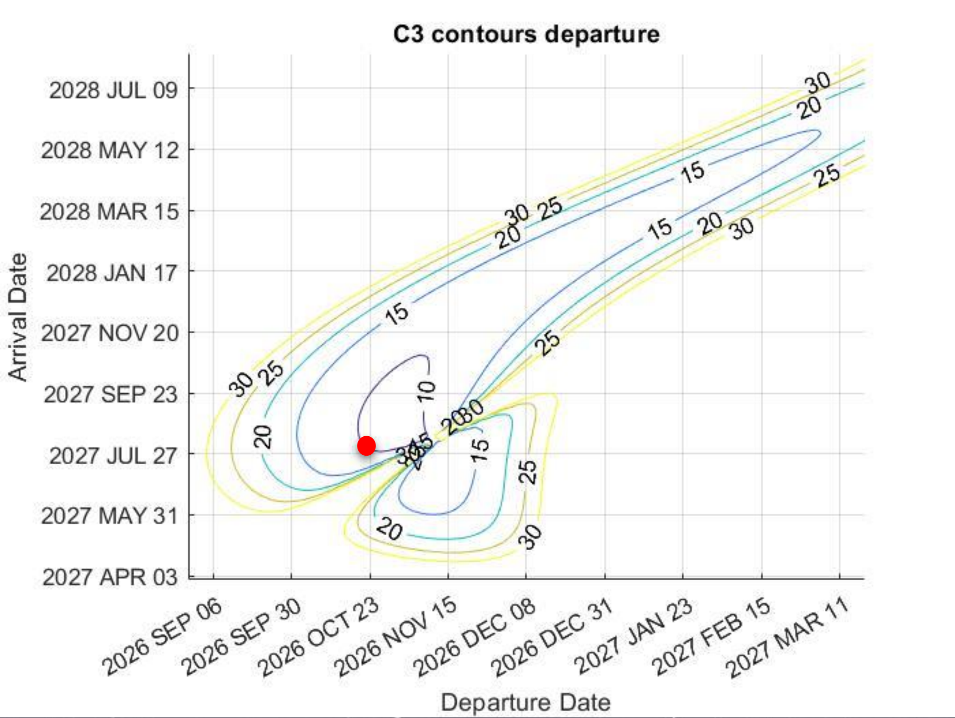
Spacecraft Overview



Concept of Operations



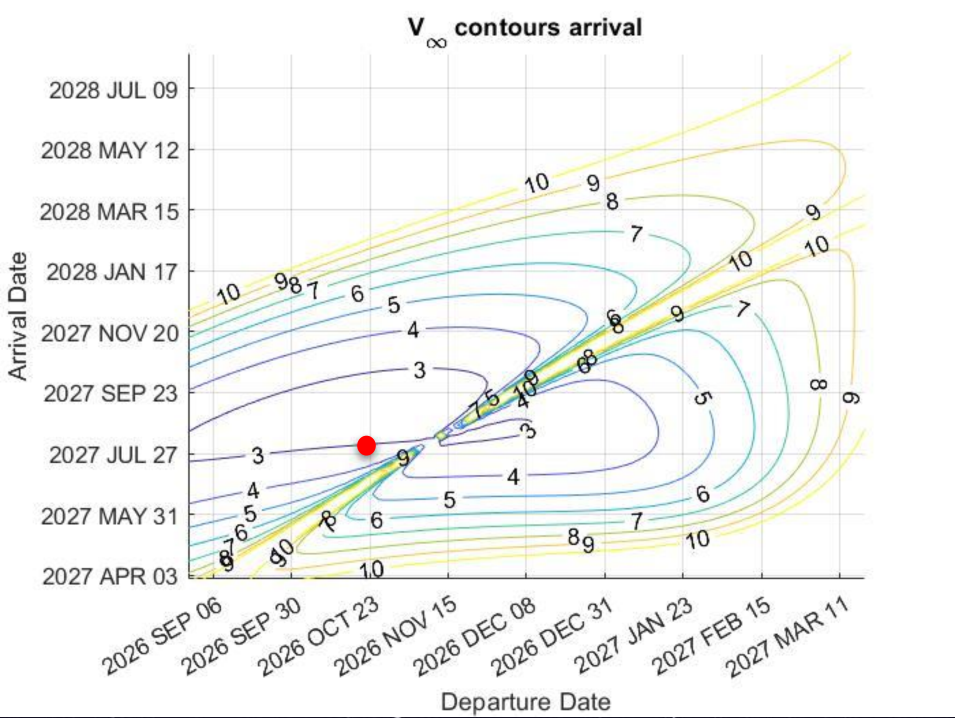
Trajectory



Launch Window:
October 22nd, 2026 to November 7th, 2026

Arrival Window:
August 4th, 2027 to September 4th, 2027

Trajectory

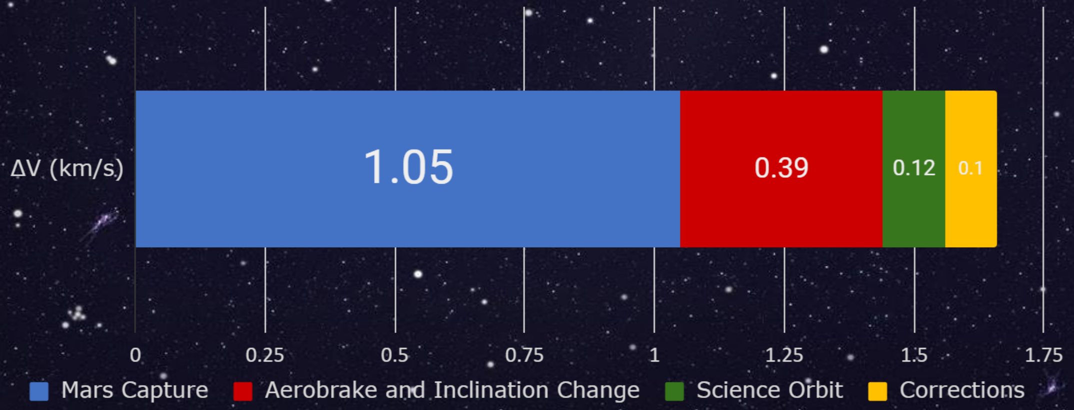


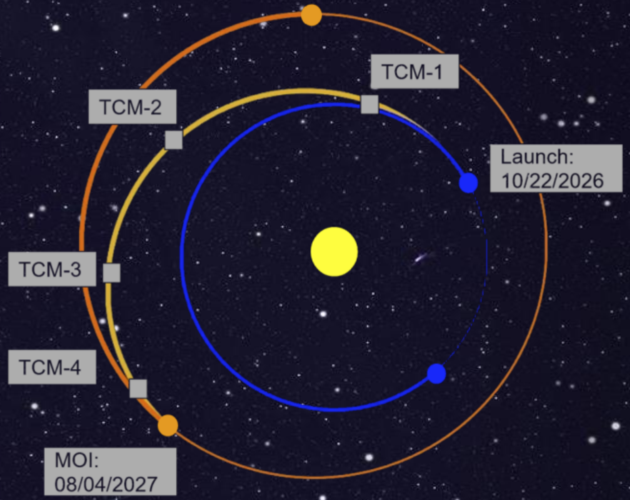
Launch Window:
October 22nd, 2026 to November 7th, 2026

Arrival Window:
August 4th, 2027 to September 4th, 2027

Trajectory

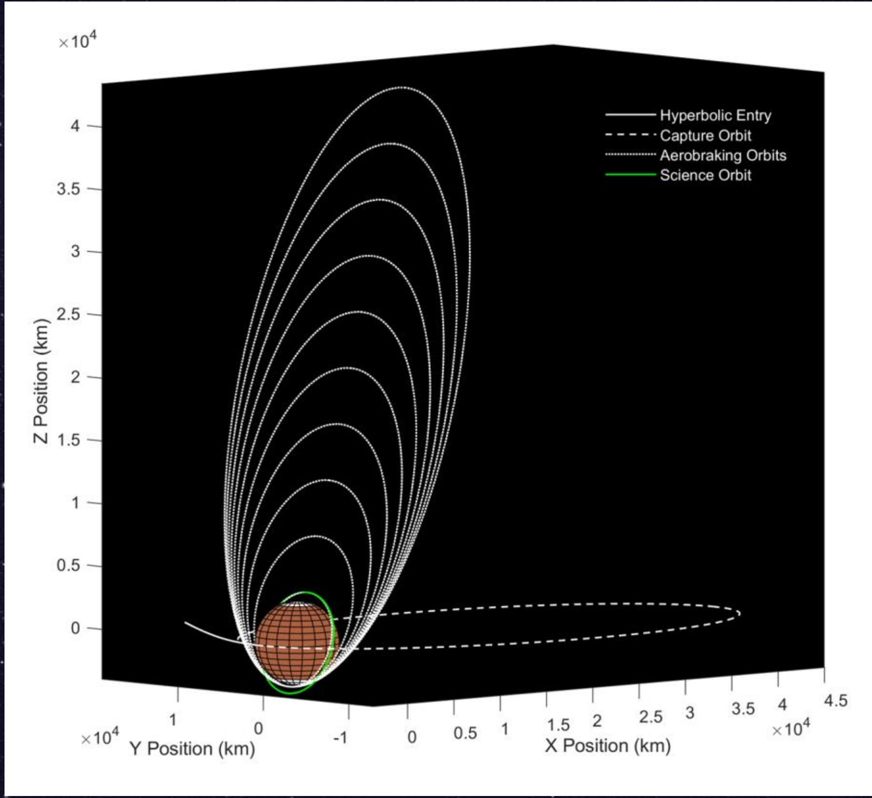
- Type II heliocentric transfer orbit
- Estimated TOF: 287 days
- 3 Main Burns
  - Total Δv of major burns ~ 1.6 km/s
- Additional 0.1 km/s added for corrections





Trajectory

- Capture in highly elliptical insertion orbit
- Lower periapsis, raise inclination
- Raise periapsis, circularize orbit
  - 700 km, i = 75°
  - 10 year lifespan
  - EOL: relay satellite



GNC & ADCS

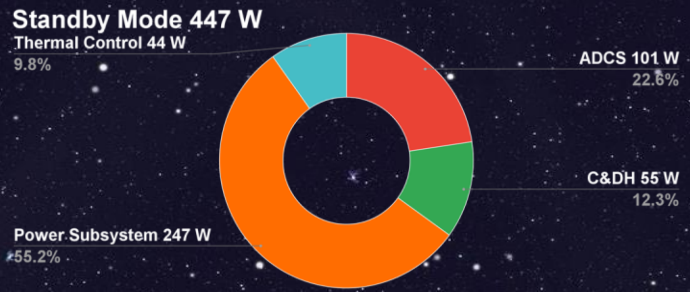
- Attitude Control
    - 4x Reaction Wheels
        - Slew rate: 0.045 deg/s
- Sensors
    - 2x Inertial Measurement Unit (IMU)
    - 2x Star tracker
    - 12x Sun Sensor

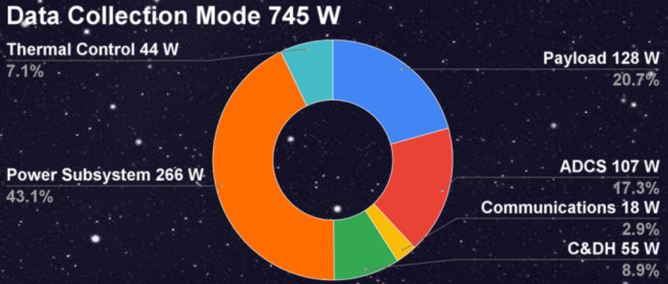
Reaction Wheel
Credit: SpaceTeq

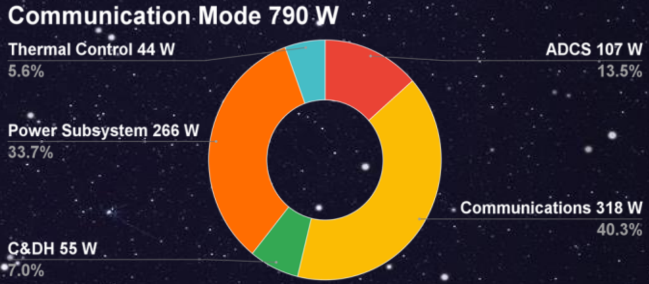
Star tracker
Credit: Leonardo Company

Power

- Orbit
    - Period: 133 minutes
    - 11 orbits per day
    - Time per Eclipse: 41 minutes
- Three Power Modes:
    - Standby/Eclipse
    - Communications
    - Data Collection





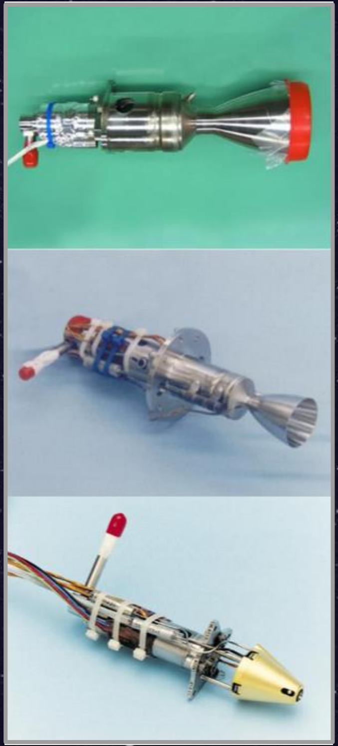


Power

- Triple Junction Solar Cells
  - Area: 20 m^2
  - Mass: 17 kg
  - Power Generated: 1200 W
- Lithium Ion Batteries
  - 10 years: ~40,000 Cycles
  - Depth of Discharge: 30%
  - Number of Cells: 99 cells
  - Mass: 11 kg
- Power Management and Distribution System
  - Regulated Direct-Energy Transfer
    - Higher Efficiency
    - Large power variation
  - Power: 160 W
  - Mass: 54 kg
- Wiring
  - Power: 60 W
  - Mass: 33 kg

Propulsion

- Propellant - Hydrazine
- Pressurizer - Helium
- Thrusters:
  - Four MR-107S @ 270 N used for Complete insertion burn in 24 min
  - Four MR-106E @ 22 N used for Trajectory corrections
  - Eight MR-103D @ 0.9 N used for Attitude control redundancy
- Tanks:
  - 2 Propellant Tanks with mass of 20 kg each
  - 2 Pressure Tanks with mass of 13 kg each



Credit: Aerojet Rocketdyne

Propulsion

Valve diagram

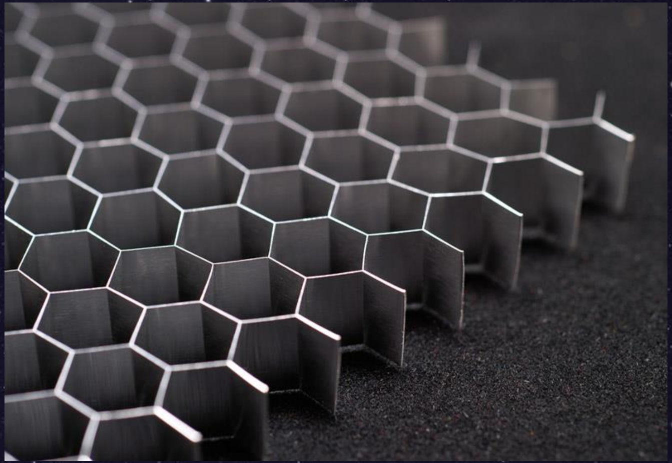
Thermal

- Ideal operating temperature = 10 °C
- Pre trimmed thermal balance temperature = 367 K = 94 °C
- Radiators used to trim temperature to permissible component range
- 15 layer MLI blanket used on outside of spacecraft
- Heaters applied to solar panels, propulsion tanks, antennas, gimbals, IMU, star tracker

Credit: John Rossie of AerospaceEd.org

Structural Properties

- Potential loads: Launch, gravity, radiation pressure, aerobraking
- Aluminum alloy honeycomb structure
- Carbon composites such as graphite epoxy applied for additional support
- Titanium alloys used for fuel tank and smaller components



Credit: Argosy International

Mass Breakdown

Dry Mass Range: 500-1000kg

Dry Mass: 801 kg

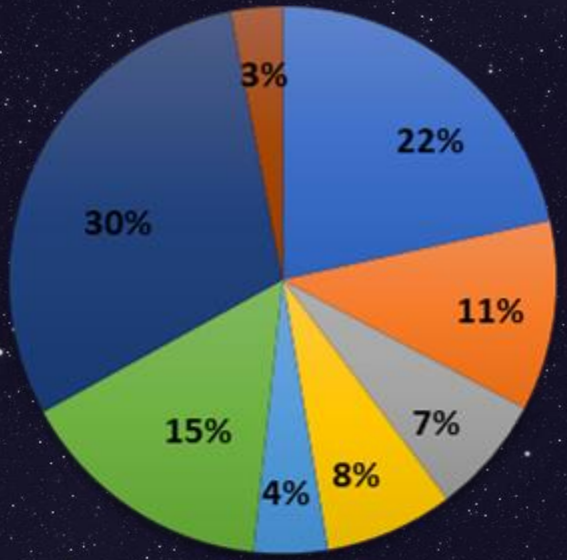
Propellant Mass: 1000 kg

LV Adapter: 166.5 kg

LV Capacity: 3000 kg

	Allocated (kg)	Level 1
1.0 Payload	172.7	172.7
2.0 Spacecraft Bus (dry)		628.49
2.1 Propulsion	90.19	
2.2 ADCS	56.17	
2.3 Communications	60.72	
2.4 C&DH	35.2	
2.5 Power	121.73	
2.6 Structure	240.44	
2.7 Thermal Control	24.04	
3.0 Spacecraft Dry Mass		801.19
4.0 Consumables		0
5.0 Propellant		1000
6.0 Loaded Mass		1801.19
7.0 Kick Stage		0
8.0 Injected Mass		1801.19
9.0 Lauch Vehicle Adapter		166.5
10.0 Boosted Mass		1967.69
11.0 Margin		1032.31
12.0 Total LV Capacity		3000

Mass by Subsystem



Communications

	Uplink Frequency	Downlink Frequency	Transmitter Gain	Receiver Gain	Free Path Space Loss	Earth Atmospheric Loss	Bandwidth	Uplink C/N	Downlink C/N	Data-Rate	Link Margin
Ka-Band (HGA)	N/A	31.1 GHz	57.9 dBi	79.014 dBi	282.3-290.2 dB	2 dB	500 MHz	N/A	14.3-28.79 dB	.005-6 Mbs	6.1 dB
X-Band (HGA)	7.1 GHz	8.4 GHz	49 dBi	67.64 dBi	269-276.6 dB	<1 dB	20 Hz	18.79 dB	28.84 dB	.001-4Mbs	18.6 dB

Link Budget

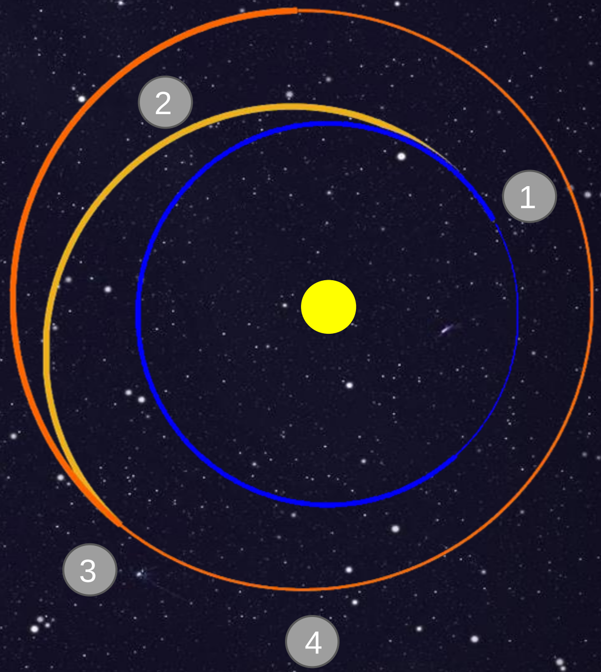
Link Schedule

1 Launch:
- Downlink lifeline communication begins ~ 1 hr after launch, ~5 minutes prior to launch vehicle separation on LGA
- When signal is received, DSN uplink is confirmed, doppler/turnaround ranging is defined, and commandability is confirmed.

2 Transit:
- Downlink lifeline communication continues including trajectory data and spacecraft health on HGA
- Command uplink for trajectory correction and anomaly adjustment by DSN

3 Mars Orbit Insertion:
- Downlink insertion progress, health, and anomaly data by the LGA
- Command uplink to perform insertion maneuvers and anomaly adjustment by DSN

4 Mars Orbit
- Spacecraft downlink health data (X-Band) and and collected instrument data (Ka-Band) when line of sight is visible on HGA (LGA if in low power mode).
- Command uplinked for trajectory correction, anomaly adjustment, and to transition between mission phases by DSN



Communication Subsystems

High-gain Antenna
- Ka Band and X band

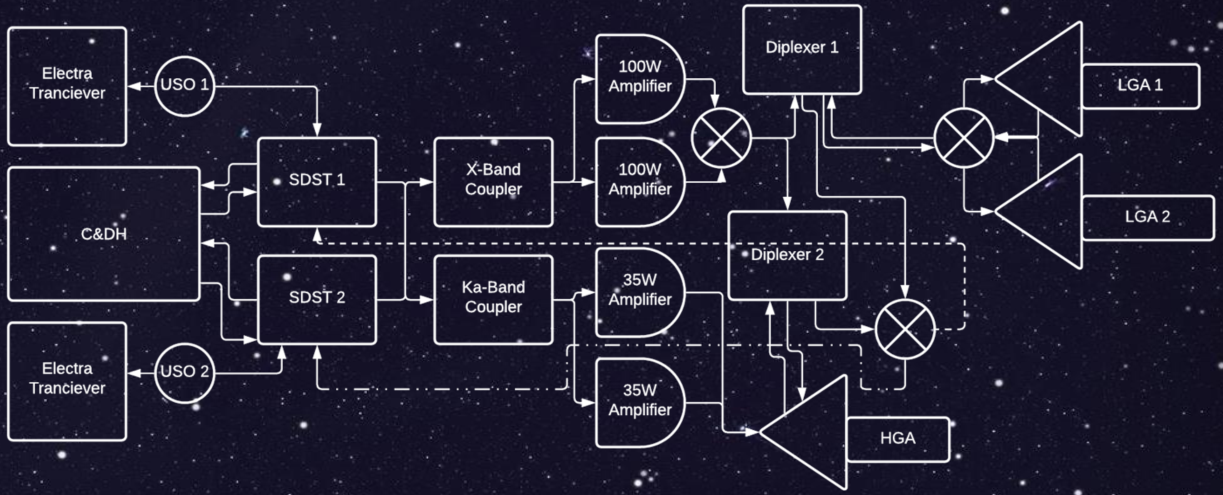
2x Low-Gain Antenna
- X-Band
- Only used for insertion and emergencies

4x Amplifiers
- Traveling Wave Tube Amplifiers
- Two for Ka-band (35W)
- Two for X-Band (100)

2x Transponders
- General Dynamics Small Deep Space Transponder

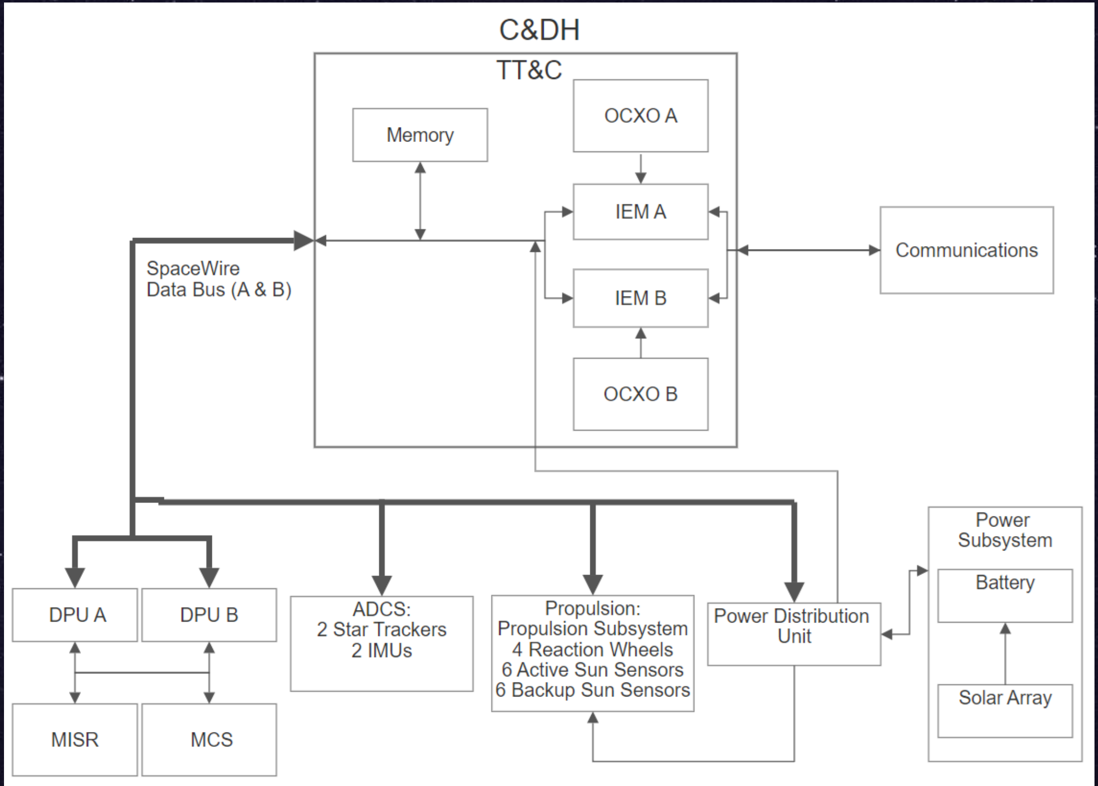
Ultra Stable Oscillators
- Take on causes for frequency instability in circuits
- High stability vs. temperature

2x Electra Proximity Payload
- Government provided telecommunications platform



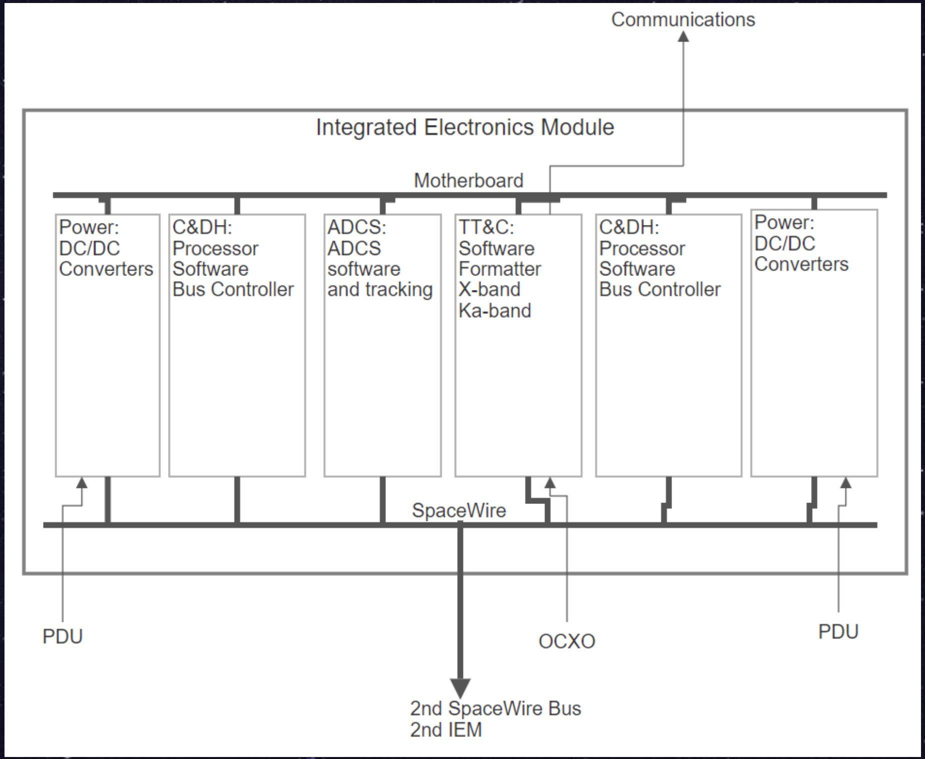
C&DH Schematic

- Oven Controlled Crystal Oscillator (OCXO)
- Data Processing Unit (DPU)
- Integrated Electronics Module (IEM)
- SpaceWire



Computing

- Processor: RAD5500
- Power Distribution Unit (PDU)
- Oven Controlled Crystal Oscillator (OCXO)



Spacecraft Integration

System Testing & Assembly Order:

1. Power
2. ACDS
3. Science Instruments
4. Structure
5. Solar Array
6. Communication
7. Propulsion

MRO Science Instrument Integration
Credit: NASA

Structural Assembly:

Gimbals

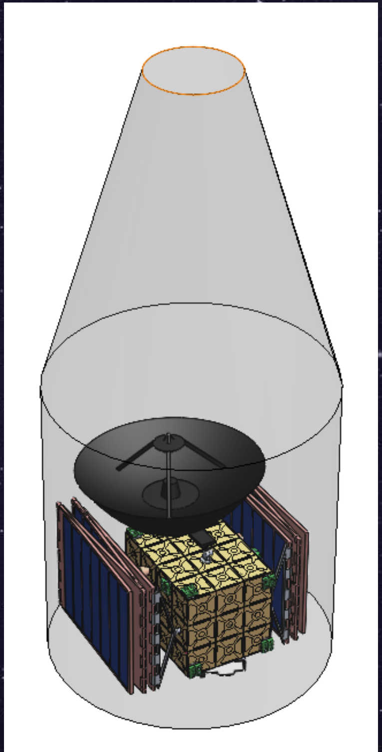
1. Solar arrays
2. HGA

Type 22 High Gain Antenna Pointing Assembly
Credit: MOOG

Type 1 Solar Array Drive Assembly
Credit: MOOG

Launch Vehicle

- Medium Class Launch Vehicle
- Employ 5m Fairing
- Potential Option: Atlas V 5xx
- Two stage expendable rocket system
- Flexible with SRB usage, engine configurations, and payload fairing selection



Atlas V
Credit: ULA

Ground Systems & Operations

Goddard Space Flight Center Operations Room
Credit: NASA Goddard/Pat Izzo

Ground Station (ie. Goddard Space Flight Center)

1. sending commands
2. anomaly resolution
3. spacecraft health monitor
4. data processing

❖ Eleven 90-minute passes per day

Distributed Active Archive Center (NASA's DAAC)

1. data storage

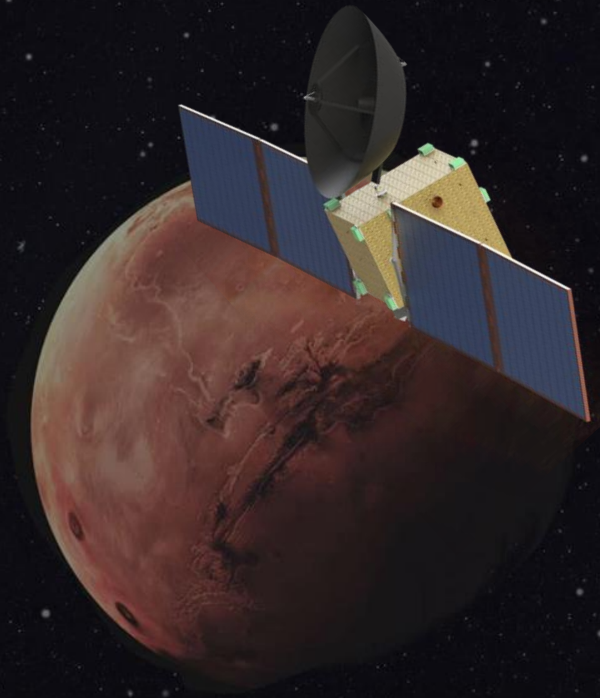
Spacecraft Testing

Category	System/Structure Tested	Test Type
Functional	Solar Panels	Solar Energy Absorption
		Folding/Unfolding/ Maneuverability
	Antennas/Communication	Data Uplink/Downlink
		Enxtending/Retracting/ Maneuverability
		External Radio Signal Sheilding
	Thrusters	Thrust Stand
		Exhaust Duct
	Batteries	Life/Fatigue
		Power Output
	Electrical	Wiring Checks
	Cameras	Resolution
	Structural Material	Tensile
		Torsional
Environmental	Entire Spacecraft	Space
		Thermal
		Space Dust Management
		Solar Radiation
Launch		Pyroshock
		Accoustics

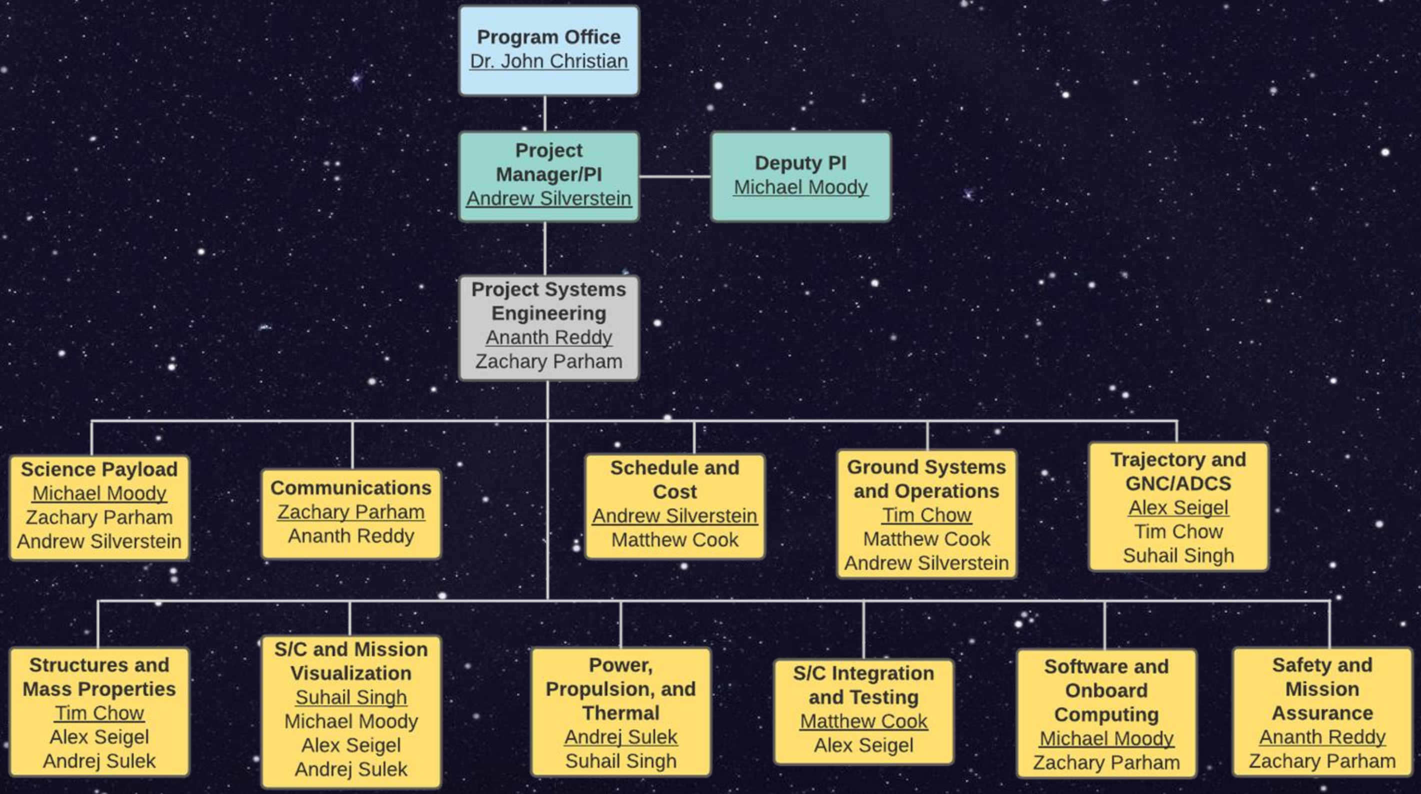
Credit: National Technical Systems

Mars MEDUSA Orbiter

Project Management

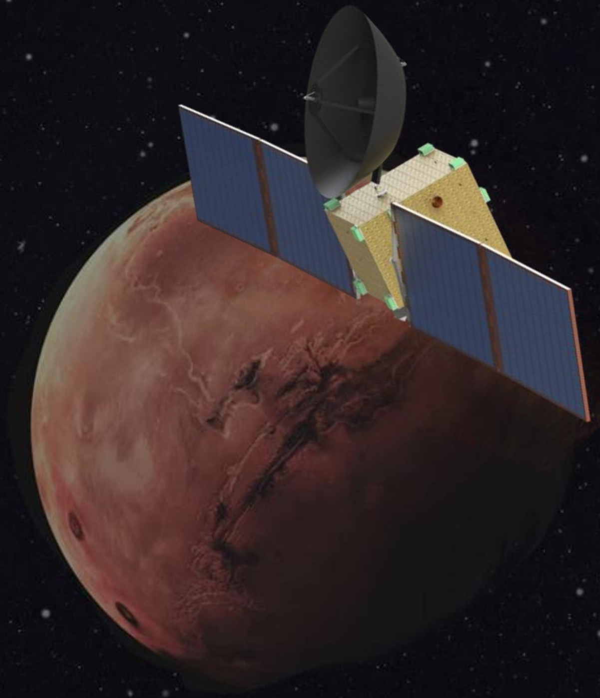


Organizational Structure



Mars MEDUSA Orbiter

Cost & Scheduling



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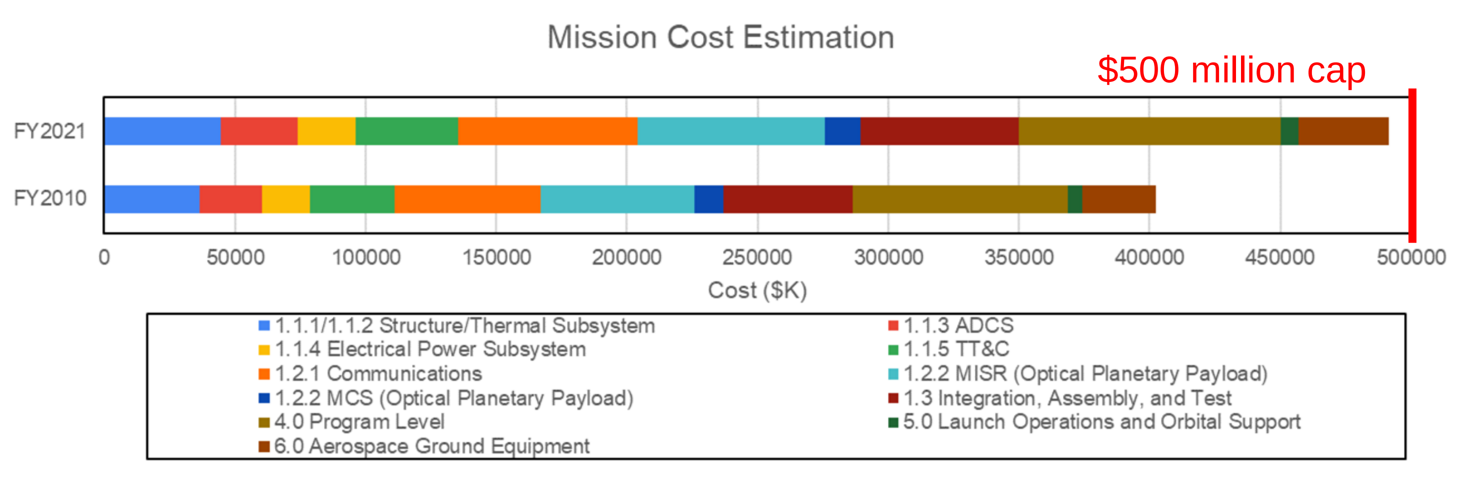
Cost

- Unmanned Space Vehicle Cost Model (USCM8) parametric estimation
- NASA Instrument Cost Model (NICM) for science instruments
- FY2021 Estimated Cost:
  - $491,425,375.1



Risk Matrix

SEVERITY	Almost Impossible	Unlikely	Could Occur	Known to Occur	Common
Catastrophic	5	10 **Risk 4**	15 **Risk 2** **Risk 3**	20 **Risk 1**	25
Major	4	8	12	16	20
Moderate	3	6 **Risk 6**	9	12	15
Minor	2	4	6	8	10 **Risk 5**
Insignificant	1 **Risk 7**	2	3	4	5

PROBABILITY

Mitigation: High Risks

- Risk 1 - ADCS Failure (Risk Value: 20)
  - Redundancy in system components
  - Testing to simulate operational environment
- Risk 2 - Transponder Failure (15)
  - MEDUSA contains a backup transponder cross linked into the system should one fail
- Risk 3 - Failure to Deploy Solar Arrays (Risk Value: 15)
  - More accurate environmental testing
  - While in orbit:
    - Move mechanism up and down to “unsnag”
    - Fire thrusters to shake orbiter

	Almost Impossible	Unlikely	Could Occur	Known to Occur	Common
Catastrophic	5	10 **Risk 4**	15 **Risk 2** **Risk 3**	20 **Risk 1**	25
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Insignificant	1 **Risk 7**	2	3	4	5

Mitigation: Medium Risks

- Risk 4 - Failure of Science Instrumentation (Risk Value: 10)
  - One fails:
    - Continue mission using remaining payload
  - Both fail:
    - Revert to relay satellite
- Risk 5 - Unrealistic Budget (Risk Value: 10)
  - Mission descope - threshold science mission

	Almost Impossible	Unlikely	Could Occur	Known to Occur	Common
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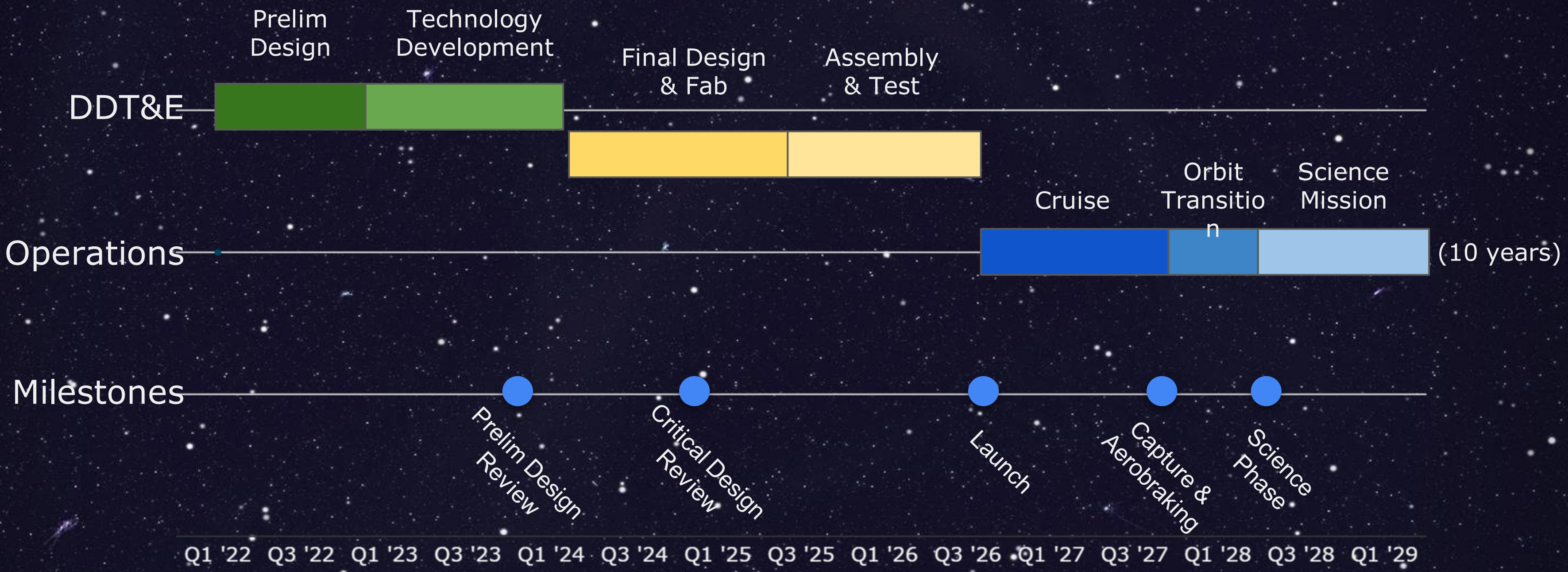
Schedule


Prelim Design
Technology Development
Final Design & Fab
Assembly & Test
DDT&E
Cruise
Orbit Transition
Science Mission
Operations
(10 years)
Milestones
Prelim Design Review
Critical Design Review
Launch
Capture & Aerobraking
Science Phase
Q1 '22 Q3 '22 Q1 '23 Q3 '23 Q1 '24 Q3 '24 Q1 '25 Q3 '25 Q1 '26 Q3 '26 Q1 '27 Q3 '27 Q1 '28 Q3 '28 Q1 '29

Acknowledgements

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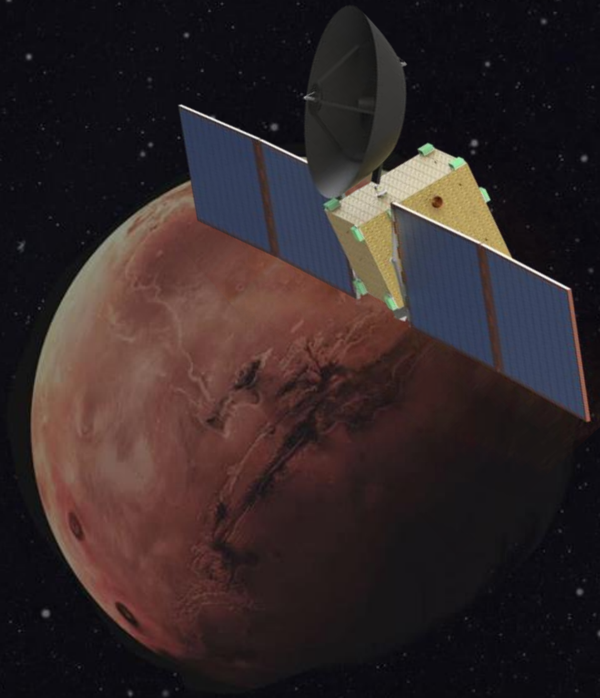
The New SMAD Editors: Wertz, Everett, Puschell

MISR team, MCS team, Mars Reconnaissance Team

Mars Odyssey, TERRA orbiter

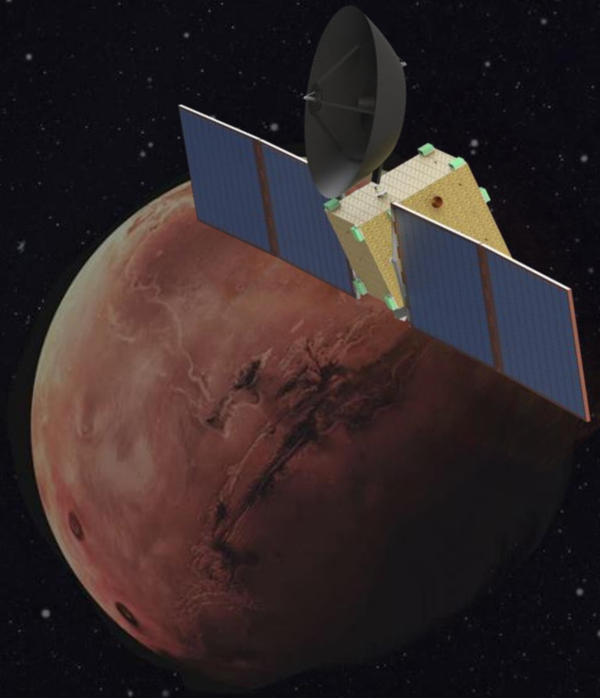
Mars MEDUSA Orbiter

Thank You



Mars MEDUSA Orbiter

Appendix



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Daniel Guggenheim School of Aerospace Engineering

Mass Budget

	CBE (kg)	Level 2 Cont.	Allocated	Level 1
1.0 Payload				172.7
1.1 MISR	148	10%	162.8	
1.2 MCS	9	10%	9.9	
2.0 Spacecraft Bus (dry)				628.49
2.1 Propulsion				90.19
2.1.1 Propellant Tanks (x2)	40.4	10%	44.44	
2.1.2 Pressurized Tanks (x2)	26	10%	28.6	
2.1.3 Insertion Burn Thrusters (x4)	4.04	10%	4.44	
2.1.4 Trajectory Correction Thrusters (x4)	1.92	10%	2.11	
2.1.5 Attitude Adjustment Thrusters (x8)	2.64	10%	2.9	
2.1.6 Pressurizer	7	10%	7.7	
2.2 ADCS				56.17
2.2.1 IMU (x2)	1.5	10%	1.65	
2.2.2 Star Trackers (x2)	5.2	10%	5.72	
2.2.3 Sun Sensors (x12)	24.36	10%	26.8	
2.2.4 Reaction Wheels (x4)	20	10%	22	
2.3 Communications				60.72
2.3.1 X-band Transponder				
2.3.1.1 SDSTs (x2)	5.8	10%	6.38	
2.3.1.2 4x Frequency Multiplier	0.1	10%	0.11	
2.3.1.3 Additional Components	0.5	10%	0.55	
2.3.2 Traveling-wave tube amplifiers				
2.3.2.1 X-band TWTA (x2)	1.9	10%	2.09	
2.3.2.2 Ka-Band TWTA (x2)	1.6	10%	1.76	
2.3.2.3 X-Band Power Converters	3	10%	3.3	
2.3.2.4 Ka-Band Power Converters	1.5	10%	1.65	
2.3.2.5 Diplexers	1.8	10%	1.98	
2.3.2.6 Waveguides	1.5	10%	1.65	
2.3.2.7 Other Microwave Components	1.4	10%	1.54	
2.3.2.8 Misc. TWTA Hardware	0.2	10%	0.22	

Mass Budget cont.

2.3.3 X-band & Ka-band Antennas				
2.3.3.1 HGA Prime Reflector	19.1	10%	21.01	
2.3.3.2 Antenna Feed Assembly	1.6	10%	1.76	
2.3.3.3 LGAs and Polarizers	0.8	10%	0.88	
2.3.3.4 Misc. Antenna Hardware	1.1	10%	1.21	
2.3.4 USOs	1.7	10%	1.87	
2.3.5 UHF				
2.3.5.1 Electra Transceivers (x2)	10.1	10%	11.11	
2.3.5.2 UHF Antenna & Radome	1.4	10%	1.54	
2.3.5.3 String Switch	0.1	10%	0.11	
2.4 C&DH				35.2
2.4.1 DPU (x2)	10	10%	11	
2.4.2 IEM (x2)	18	10%	19.8	
2.4.3 Misc. Computer Components	4	10%	4.4	
2.5 Power				121.73
2.5.1 Batteries	9.2	10%	10.12	
2.5.2 Solar Panels	16.34	10%	17.97	
2.5.3 PMAD	56	10%	61.6	
2.5.4 Wiring	29.13	10%	32.04	
2.6 Structure				240.44
2.6.1 Primary Aluminum Prism	162	10%	178.2	
2.6.2 Gimbals and Secondary Structures	56.58	10%	62.238	
2.7 Thermal Control				24.04
2.7.1 Heaters, Radiators, Insulation	21.85	10%	24.04	
3.0 Spacecraft Dry Mass	728.36			801.19
4.0 Consumables				0
5.0 Propellant				1000
6.0 Loaded Mass				1801.19
7.0 Kick Stage				0
8.0 Injected Mass				1801.19
9.0 Lauch Vehicle Adapter				166.5
10.0 Boosted Mass				1967.69
11.0 Margin				1032.31
12.0 Total LV Capacity				3000

Cost

WBS Element	Non-recurring ($K)	Recurring ($K)	Total Cost ($K)
1.1.1/1.1.2 Structure/Thermal Subsystem	30276.31984	6264.72	36541.03984
1.1.3 ADCS	16038	8040.221469	24078.22147
1.1.4 Electrical Power Subsystem	12094.83	6094.44	18189.27
1.1.5 TT&C	26916	5379.887465	32295.88746
1.2.1 Communications	42827.4	13097.7	55925.1
1.2.2 MISR (Optical Planetary Payload)			**NRE + 1st Unit Cost**
1.2.2.1 Fabrication			40597.98891
1.2.2.2 Management			4048.722626
1.2.2.3 Systems Engineering			4753.211734
1.2.2.4 Product Assurance			3137.306378
1.2.2.5 Integration and Test			6377.999112
1.2.2 MCS (Optical Planetary Payload)			**NRE + 1st Unit Cost**
1.2.2.1 Fabrication			7431.850077
1.2.2.2 Management			702.3193334
1.2.2.3 Systems Engineering			1095.212286
1.2.2.4 Product Assurance			633.5363089
1.2.2.5 Integration and Test			1153.5629
1.3 Integration, Assembly, and Test	30275.0876	19251.85058	49526.93818
4.0 Program Level	66234.90512	15879.50562	82114.41074
5.0 Launch Operations and Orbital Support		5850	5850
6.0 Aerospace Ground Equipment	28040.89308		28040.89308
Total Cost (FY2010)	**402493.4704**	**Total Cost (FY2021)**	**491425.3751**

Risk Mitigation

1. ADCS Failure (Risk Value: 20)
    a. Redundancy in system components
    b. Testing to simulate operational environment
2. Transponder Failure (15)
    a. MEDUSA contains a backup transponder cross linked into the system should one fail
3. Failure to Deploy Solar Arrays (Risk Value: 15)
    a. More accurate environmental testing
    b. While in orbit:
        i. Move mechanism up and down to “unsnag”
        ii. Fire thrusters to shake orbiter
4. Failure of Science Instrumentation (Risk Value: 10)
    a. One fails:
        i. Attempt to continue mission using other payload
    b. Both fail:
        i. Revert to being relay satellite
5. Unrealistic Budget (Risk Value: 10)
    a. Mission descope - fallback to threshold mission
6. Unplanned Loss of Contact (Risk Value: 6)
    a. Extended Data storage
    b. At threshold enter Safe Mode
    c. Comms system to Wideband mode
    d. Emergency use of 70-m DSN
7. Biological Contamination Risk (Risk Value:1)
    a. Assembly in clean room