Standard for Modular Autonomous Repair and Refuel Technology

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Mission Objectives

Primary Mission:

- Repair Satellites
- Refuel Satellites
- Create Universal Set of Repairable Subsystems

Mission Objectives

Secondary Mission:

- Expand Space Mission Lifetime Expectancy
- Reduce Space Debris
- Save Money for Future Space Missions
- Increase Mission Reliability

3

Scientific Objectives & Past Efforts

A

Decadal Survey

Alignment of Decadal Goals

- Unknown lifespan of materials in space environment
- Research is needed to improve servicing in space
- Unknowns involving joining of materials

B

OSAM-1

Past Efforts

- On-orbit servicing, assembly and manufacturing in space
- Only located in LEO
- Focus on autonomous rendezvous and refueling

C

TANKER-001 TENZING

Past Efforts

- Technology demonstration of a Rapidly Attachable Fluid Transfer Interface (“RAFTI”)
- Stores 35-kilograms of green propellant

Scientific Objectives & Past Efforts

Space Debris

- 5,900 tons of space debris, 42% from China, 27.5 % from US, 25.5% from Russia, 5 % from other country combined
- Chemical reactions will weaken ozone
- Collision threat to satellite and spacecraft
- More challenge for future satellite launch

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Sustainability

- Space sustainability means maintaining the safety and health of Space
- The current end-of-life protocol for spacecraft emphasizes the need for sustainability
- Space sustainability addresses orbits and their high amounts of orbital debris

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Research

- Researching how refueling/servicing impacts the creation of space debris
- Creating degradable materials
- Tracking of debris/ soon to be inactive satellites
- Aiming to always create an even more sustainable future

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Future-Proofing

- Kessler Syndrome: space collisions and debris become so numerous that launches become impossible
- Creation of guidelines for space debris/servicing
- Servicing leads to greater mission life and less decommissioning

January 2 0 3 4

Standards Development

Standards Development

Solar Array Replacement

Constraints

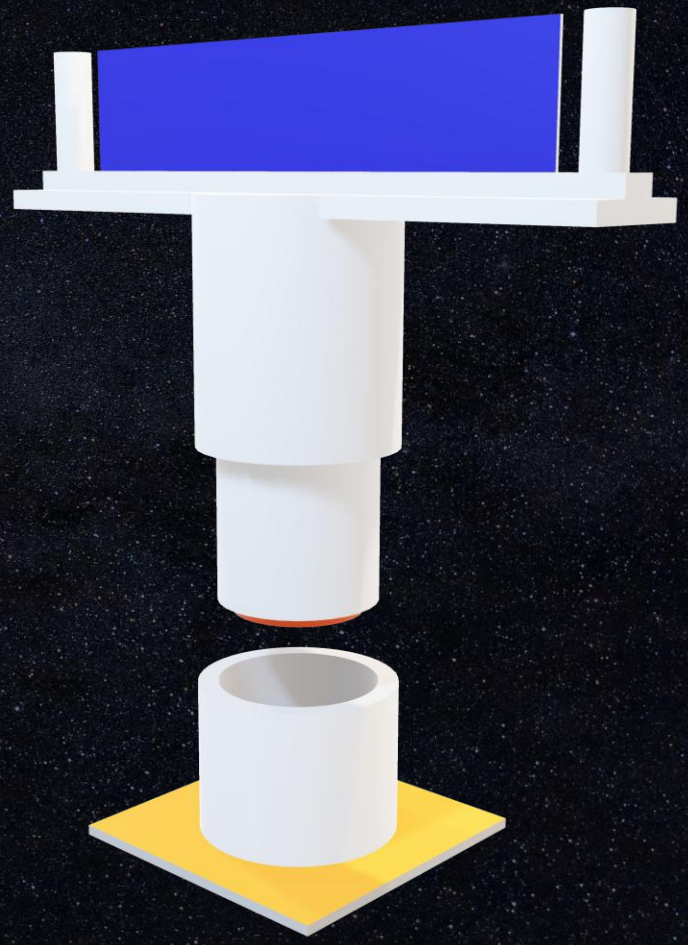
- Sizing
- Mount hardware

Roll Out Solar Array (ROSA):

- Scalable, Compact and Lightweight Solar Arrays

Screw in Roll Out Solar Array (SI - ROSA):

- In stem solution
- Allows for the replacement of solar arrays



Standards Development

SRA (Satellite Refueling Apparatus)
SRB (Satellite Refueling Bay)

Challenges

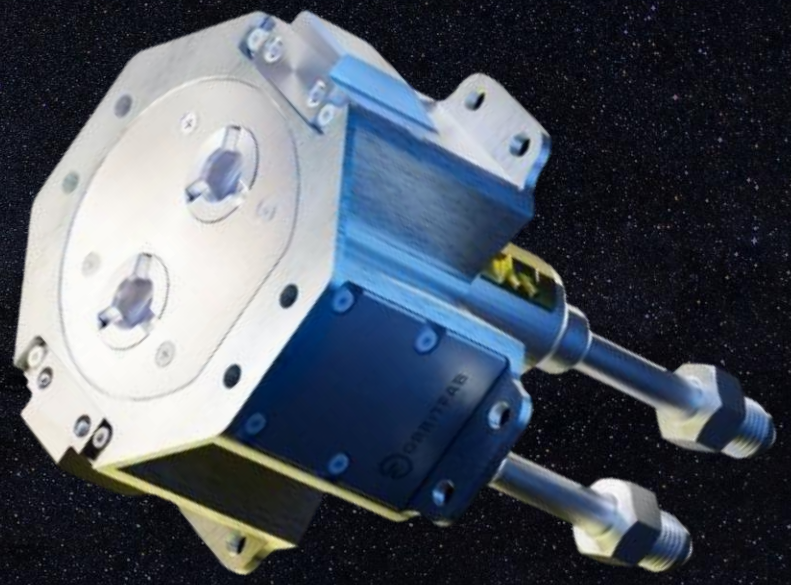
- Dedicated Servicing Area
- Docking method

Satellite Refueling Apparatus:

- Enables Refueling

Satellite Refueling Bay:

- Standardizes Location and Ports



RAFTI Fuel Transfer System

Standards Development

Client Satellite Docking Ring And SRB

Challenges

- Structural Connection

Marman Clamp:

- Currently used to Secure satellites into the payload
- Capable of holding the satellite structure

Improving upon through SRB:

- Utilize internal area of circular ring to house our SRB system

Standards Development

Electrolysis Powered Propulsion

Cheaper:

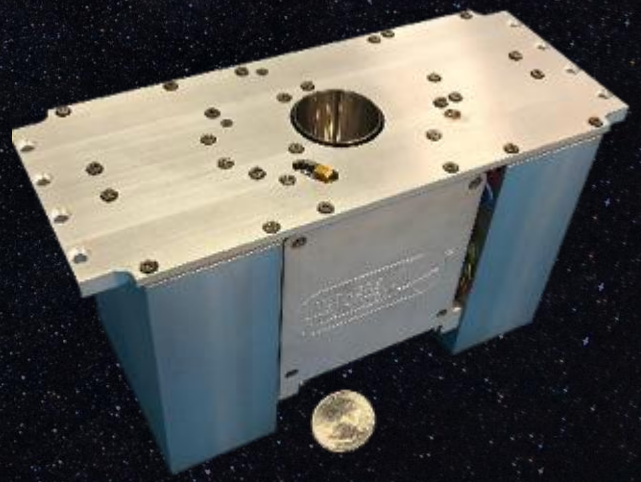
- Transastra Estimated $2.4 Billion in annual savings from asteroid obtained fuel.

Safer:

- Water is safe to be dispersed into atmosphere and handled by humans when initially fueling

Improvements:

- Hydrogen has the highest thrust
- Main limitation is lack of development



HYDROS-M thruster for small satellites

Standards Development

International Docking System Standard

Background

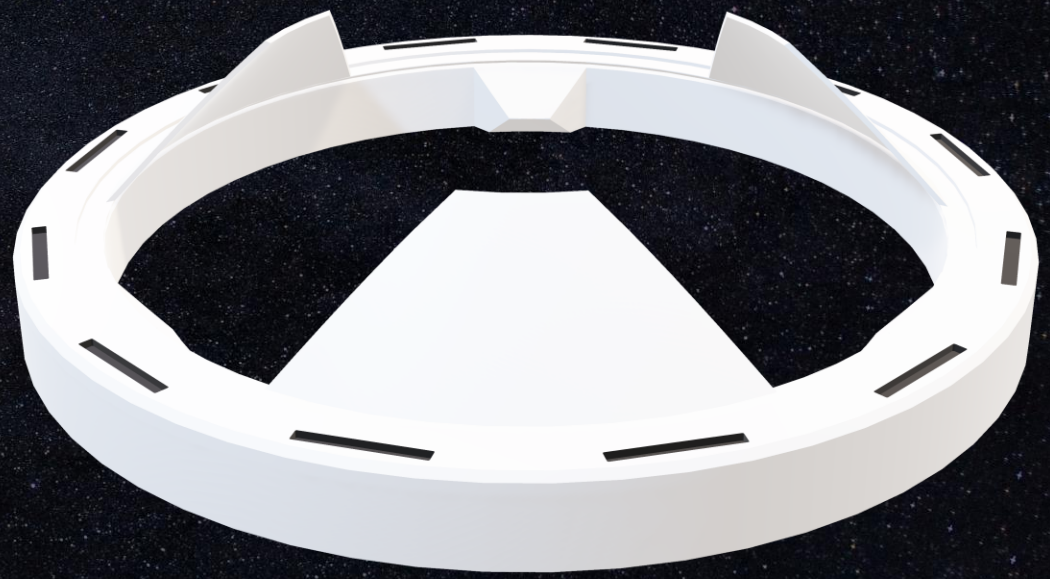
Collaborative effort of ISS international partners to develop a standardized docking ring

Docking System

- Guide Petal System
- Soft Capture System
- Hard Capture System

CSS Implementation

- Hard Dock
- Transfer



January 2035

Standards Development

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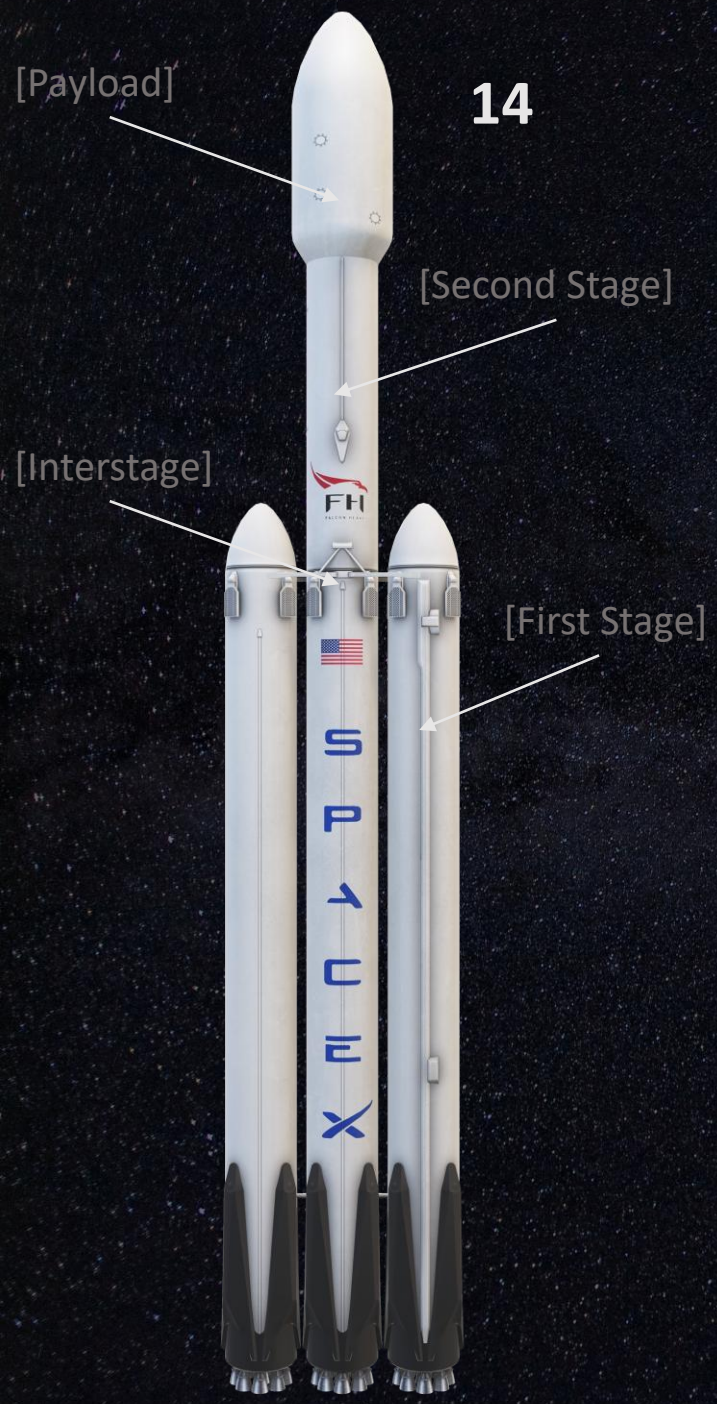
OSV and FSM Launch

Launch Vehicle



Falcon Line:

Standard Payment Plan:

- $67 Million up to 5.5 mT to GTO
- $97 Million estimate

Heritage:

- 8 Total Launches
- 15 Total Landings
- 12 Total Reflights

Overview:

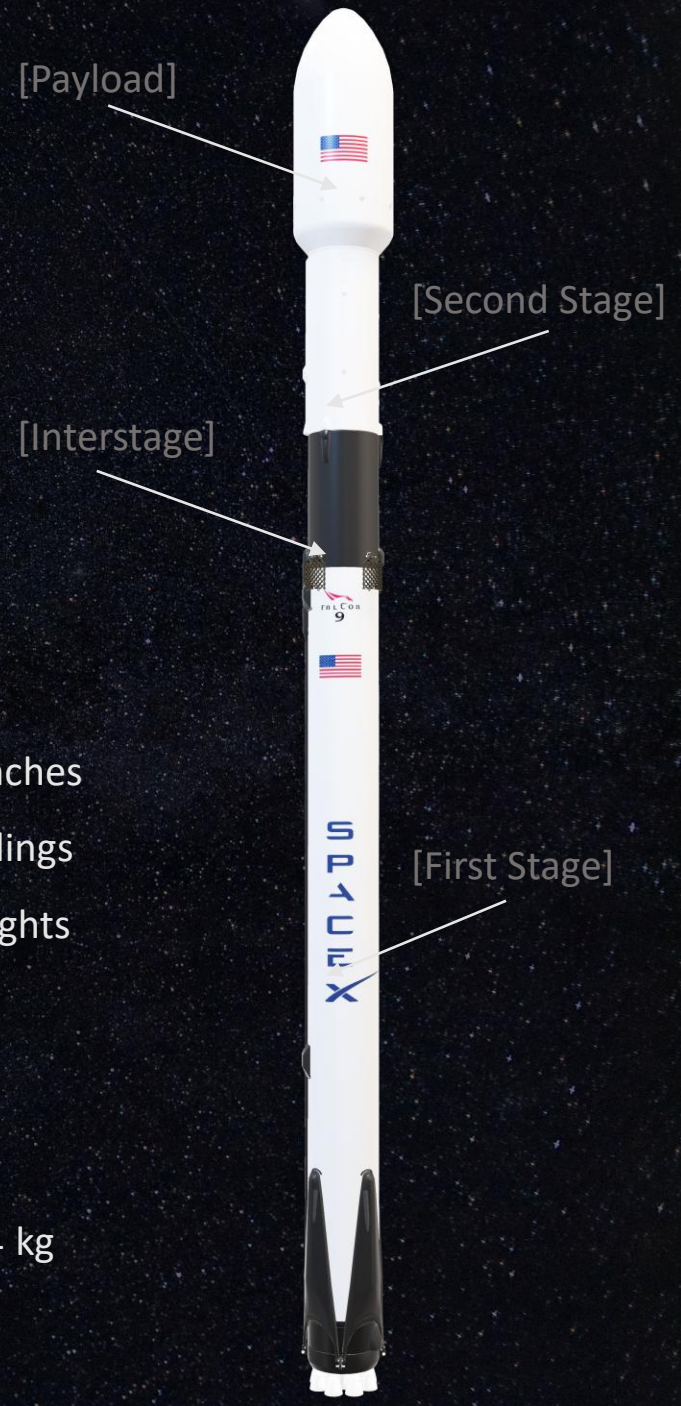
- Height: 70 m
- Width: 12.2 m
- Mass: 1,420,788 kg

Heritage:

- 276 Total Launches
- 234 Total Landings
- 209 Total Reflights

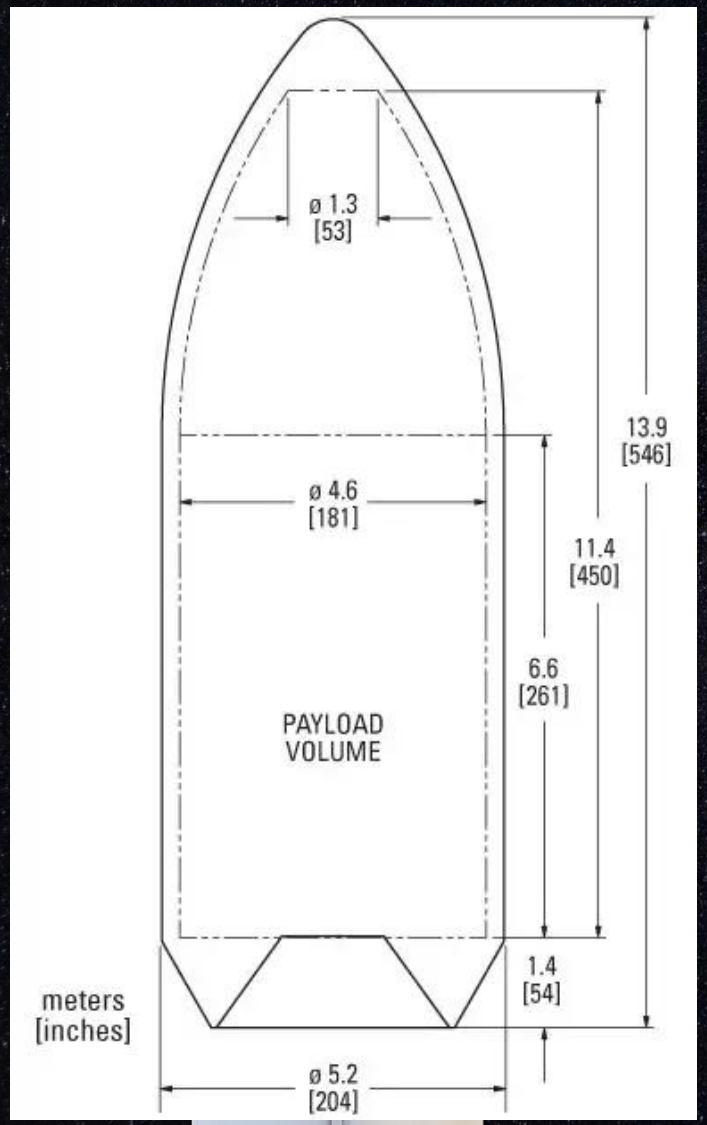
Overview:

- Height: 70 m
- Width: 3.7 m
- Mass: 549,054 kg



Launch Vehicle

Payload Volume:

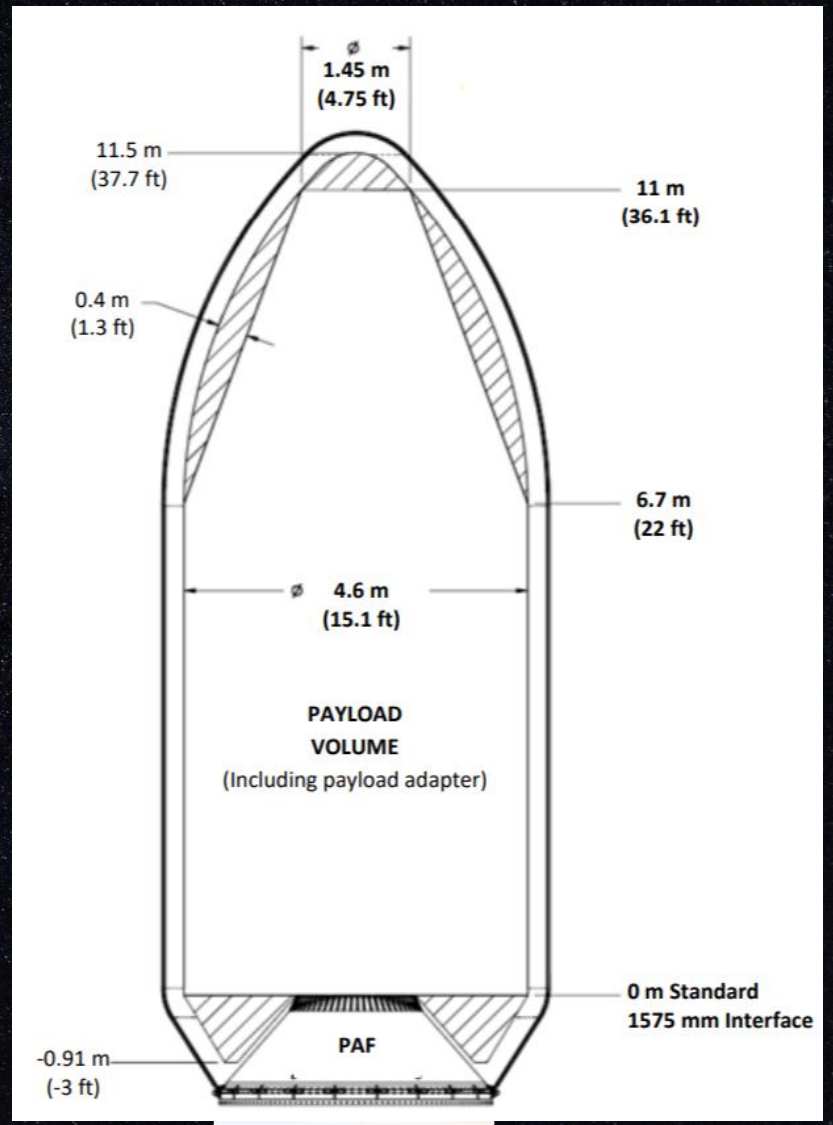


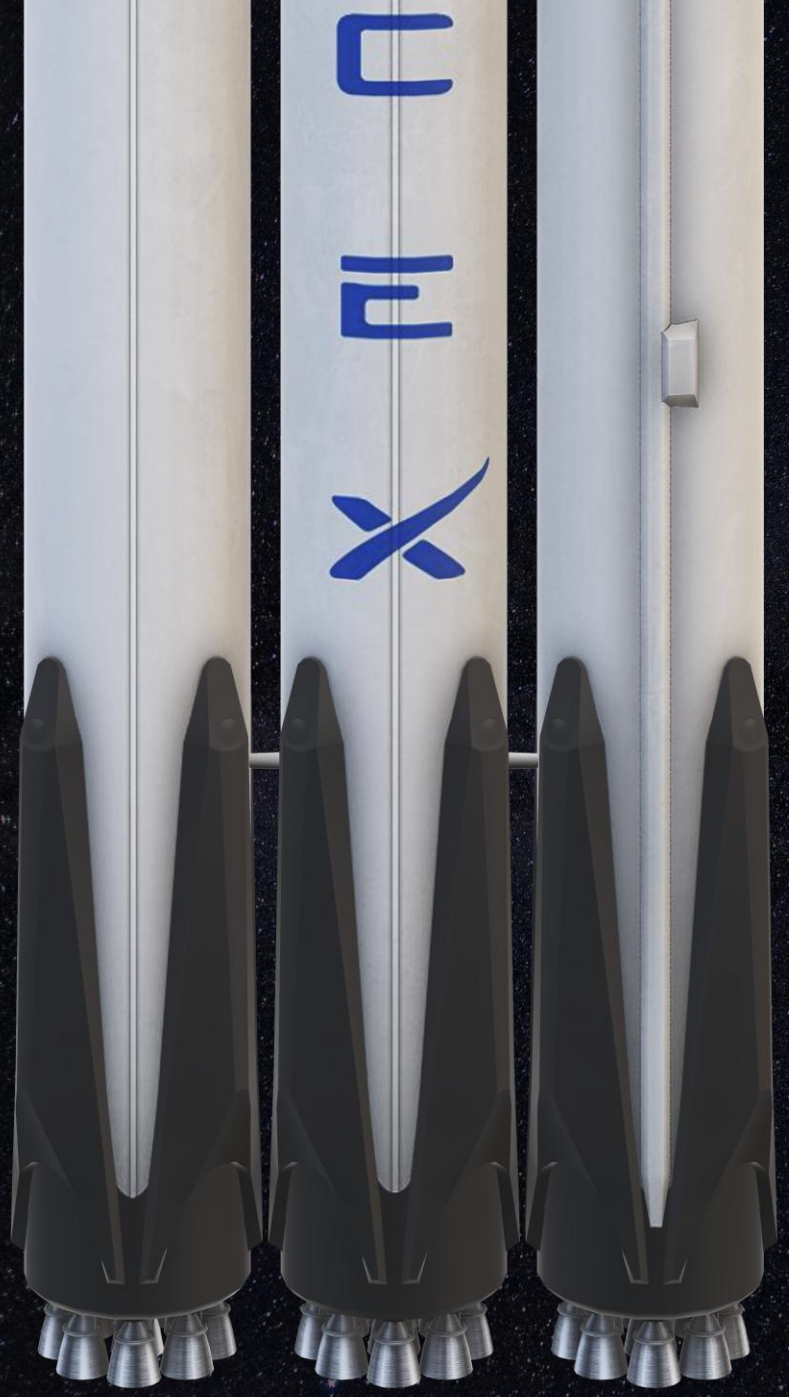
Falcon Heavy:

Standard Fairing:
4.577 m x 6.680 m

Falcon 9:

Standard Fairing:
4.577 m x 6.680





Launch Vehicle

Falcon Heavy Mass Capacity:

Thrusters: 3 Reuseable Falcon 9 nine-engine cores

- 27 Merlin Engines: more than 5,000,000 lbs of thrust at liftoff

Low Earth Orbit (LEO):

- 63,800 kg (140,660 lbs)

Geosynchronous Transfer Orbit (GTO):

- 26,700 kg (58,860 lbs)

Launch Vehicle

Falcon 9 Mass Capacity:

Thrusters: Falcon 9 nine-engine cores

- 9 Merlin Engines: more than 1,700,000 lbs of thrust at liftoff

Low Earth Orbit (LEO):

- 22,800 kg (50,265 lbs)

Geosynchronous Transfer Orbit (GTO):

- 8,300 kg (18,300 lbs)

Launch Vehicles

Launch Provider Name	Launch Vehicle Name	Payload to LEO (kg)	Payload to GTO (kg)	Payload to GEO (kg)	Launch Cost ($ millions)
SpaceX	Falcon 9	22,800	8,300	4,150	$67.00
SpaceX	Falcon Heavy	63,800	26,700	13,350	$97.00
SpaceX	Starship	150,000	150,000	21,000	$200.00
Blue Origin	New Glenn	45,000	13,000	6,500	$200.00
Ariannespace	Arianne 5	20,000	10,000	5,000	$175.00
Ariannespace	Arianne 6	21,600	11,500	5,750	$126.00
United Launch Alliance	Vulcan	24,900	15,300	7,000	$110.00

Note: Launch cost estimate of Starship and New Glenn is rough because they are in development

Vehicle Masses at Launch

Vehicle:	Total Mass (kg)	Dry Mass (kg)	H2O Mass (kg)	Xe Mass (kg)	Isp (s)
OSV	3,071	2,000	1,071	0	450
CSS	4,200	4,000	n/a	200	3,400
FSM	16,134	1,700	14,434	n/a	n/a
PSM	8,880	3,000	n/a	5,880	n/a
KB1	8,903	1,000	7,903	n/a	450
KB2	10,485	1,000	9,485	n/a	450

Launch:	Launch Vehicle	Max Lift to GTO (kg)	Total Lift Mass (kg)	Vehicles to Lift
1	Falcon 9	8,300	3,071	OSV
2	Falcon Heavy	26,700	21,983	PSM, CSS, KB1
3	Falcon Heavy	26,700	26,619	FSM, KB2

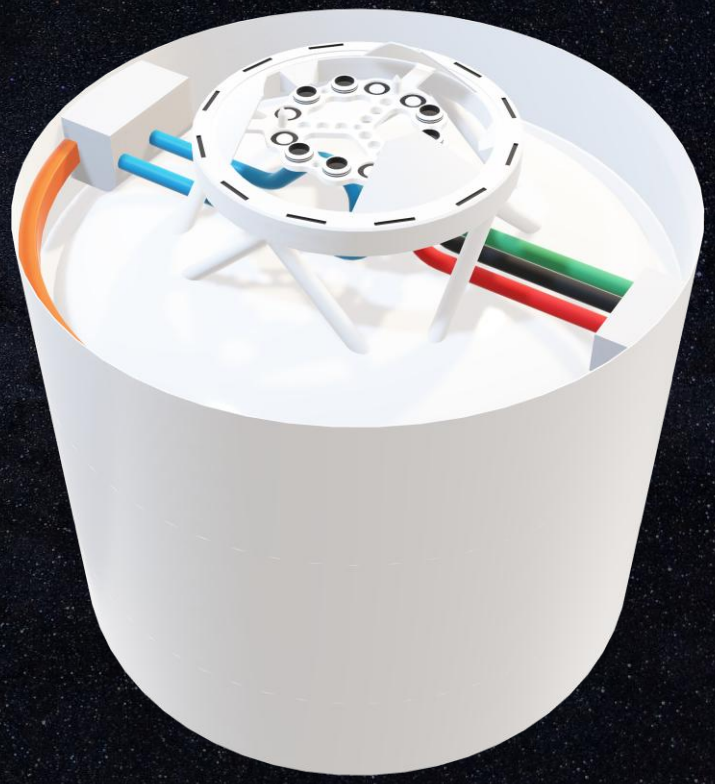
Fuel Supply Module

Specifications:

- Internal volume: 14.5 m^3
- 3-meter OD
- 2.7-meter overall length
- 16,200 kg full

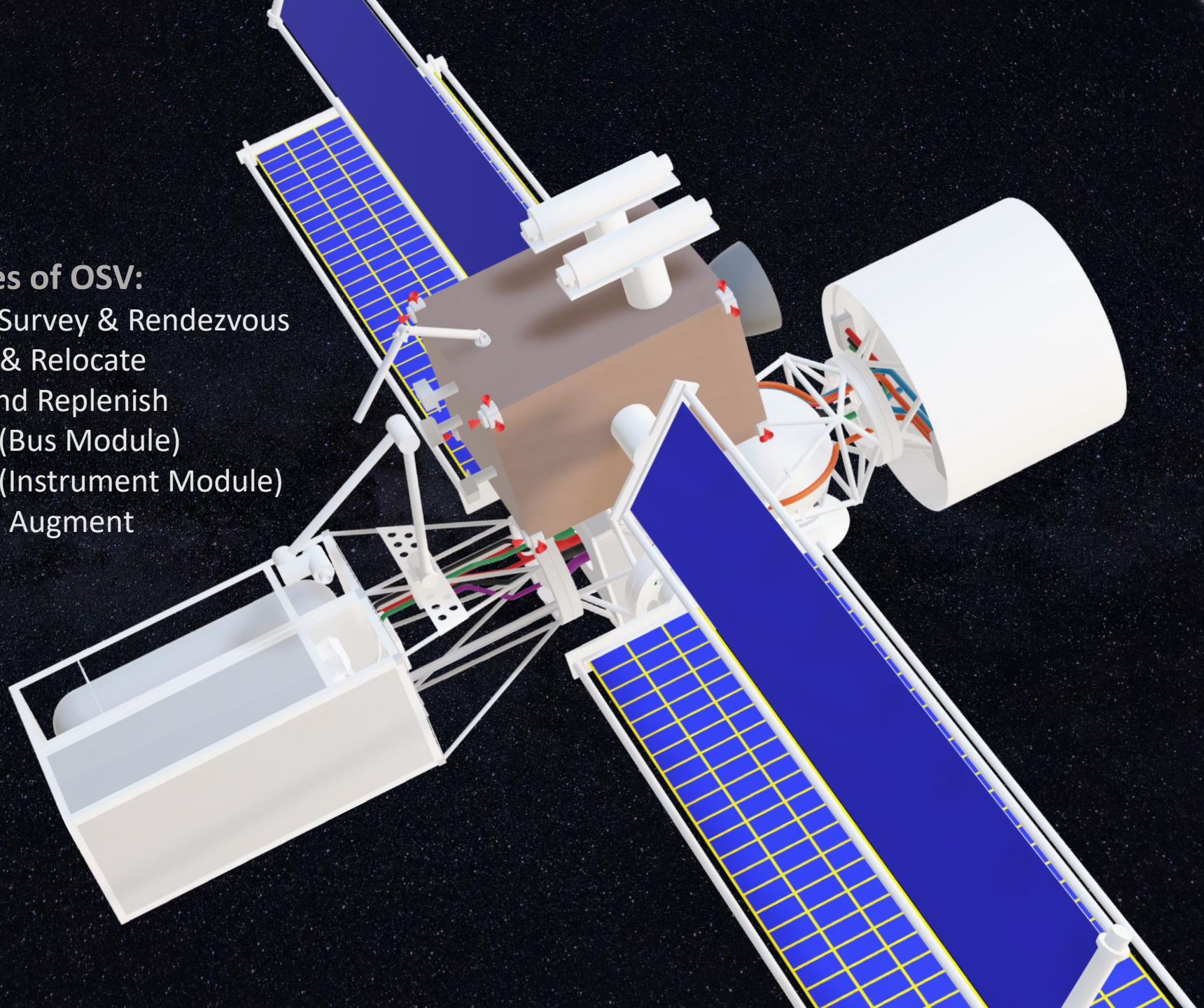
Payload:

- 14.5 tons of water

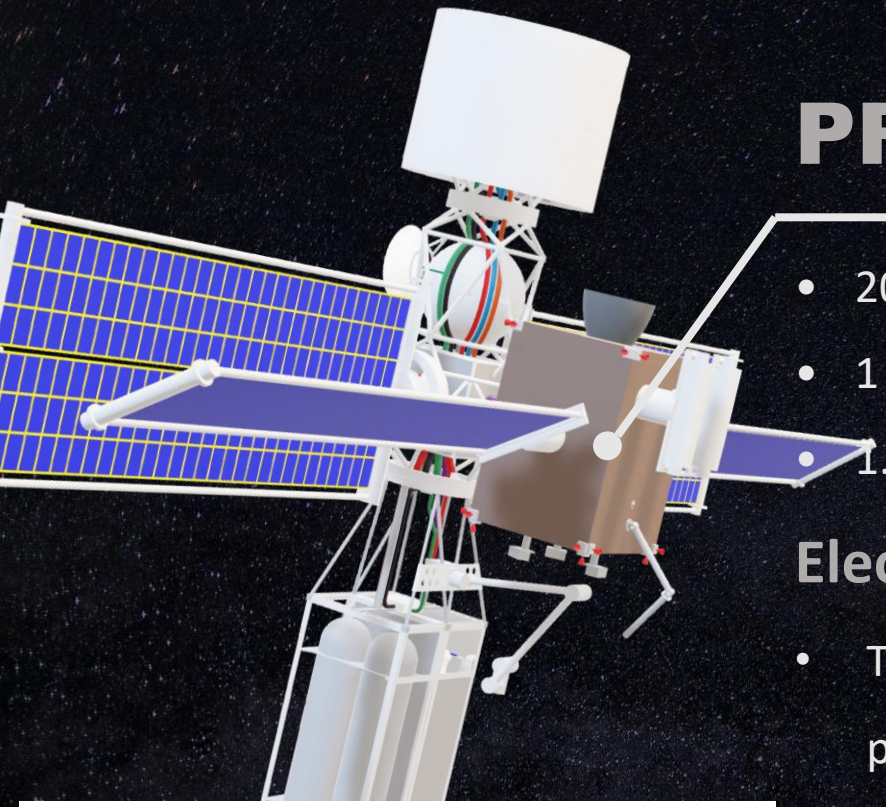


Capabilities of OSV:

- Remote Survey & Rendezvous
- Capture & Relocate
- Refuel and Replenish
- Replace (Bus Module)
- Replace (Instrument Module)
- Repair & Augment



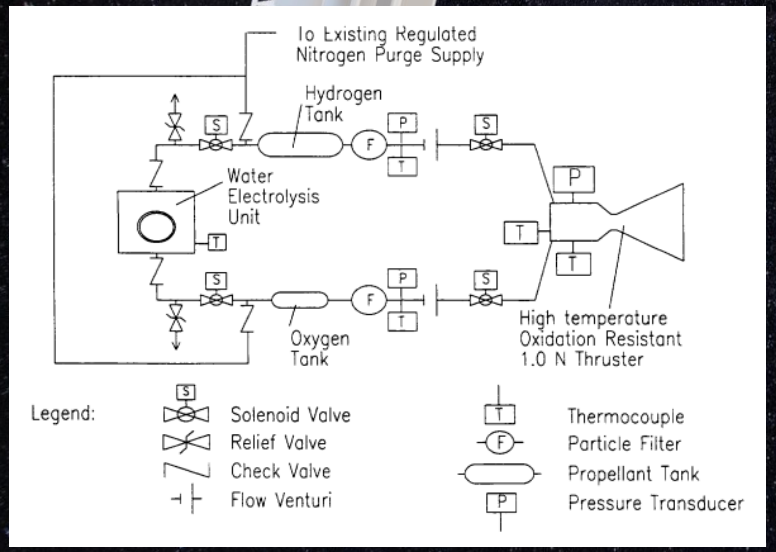
PROPULSION



- 20 Cold Gas Thrusters: **RPO**
- 1 Main Electrolysis Thruster: **Apogee Burns/ Rendezvous**
- 1.5 m^3 Propellant Bay

Electrolysis Propulsion:

- The electrolyzer consumes electrical energy to decompose the water into pressurized hydrogen and oxygen

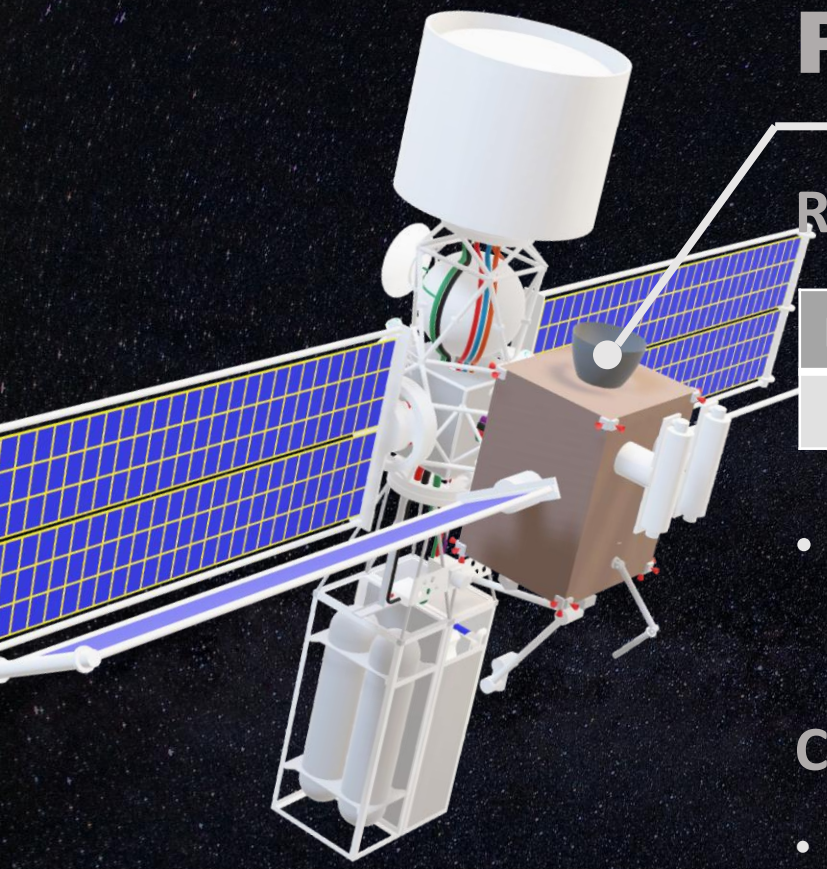


Electrolysis of Water:

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH_{(aq)}$$
$$2H_2O_{(l)} \rightarrow O_{2(g)} + 4H^+{}_{(aq)} + 4e^-$$

- 166.79 kg of Hydrogen ; 1333.17 kg of Oxygen
- The remaining oxygen can be diverted to cold gas thrusters for proximity operations
- Desired I_{sp}= 450 s; Current I_{sp}= 355 s for NanoSAT applications

PROPULSION



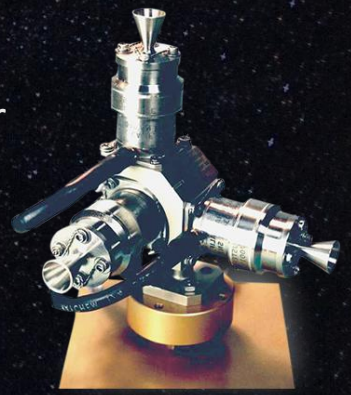
RL10A-4-1: Ideal Characteristics

First Flight	Dry Mass(kg)	Thrust(kN)	I_{sp}(s)(vac)	Length(m)	Diameter(m)
2002	168	99.1	451	1.78	1.17

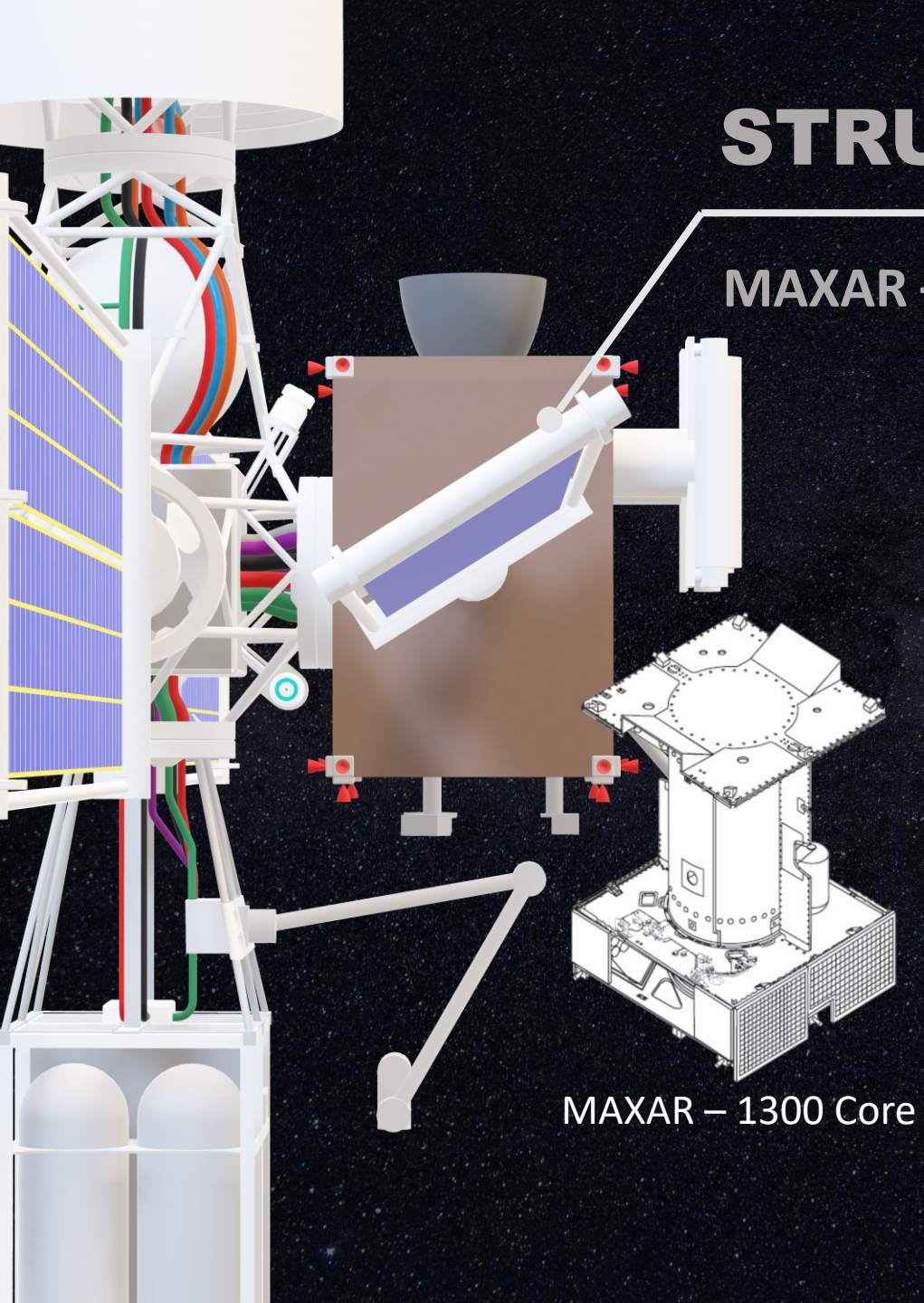
- Main thruster will incorporate an electro-mechanical gimbal for reduced weight and increased reliability

Cold Gas Thrusters:

- OSV has a triple-axis cold gas thrusters (gaseous oxygen) at each corner of the spacecraft
- Allows for redundancy as well as maximum degrees of freedom for maneuverability



STRUCTURES



MAXAR – 1300 Core

MAXAR – 1300 Bus:

Parameter	Maxar 1300
Maximum Payload Mass (kg)	500, up to 1200
Bus Dry mass (kg) (w/o Payload)	939, up to 3000
Mission Design Life (yr)	15
Types of Orbits Available	HEO(GEO), MEO, LEO
Structure	Al Honeycomb/Graphite Epoxy composite
Heritage Mission (s)	MTSAT-1/1R
External Payload Volume	2 m x 2 m x 4 m
Internal Payload Volume	4 sections, each approx. 3.0 x 1.2 x 0.3 m
Tank Capacity (kg)	2,272 kg

Rapid Spacecraft Development Office (RSDO) Data Sheet

Key Features:

- 273 Satellites placed in GEO & LEO since 1958
- 91 GEO communication satellites currently in orbit
- 24 LEO Satellites in currently orbit

Structure

General Mass Definition

Mass Limit: 5,000 kg

Mass Reserve: 1,000 kg

Allowable Mass: 4,000 kg

Mass Margin: 1,700 kg

Predicted Mass: 2,300 kg

Mass Growth Allowance (MGA 15%): 300 kg

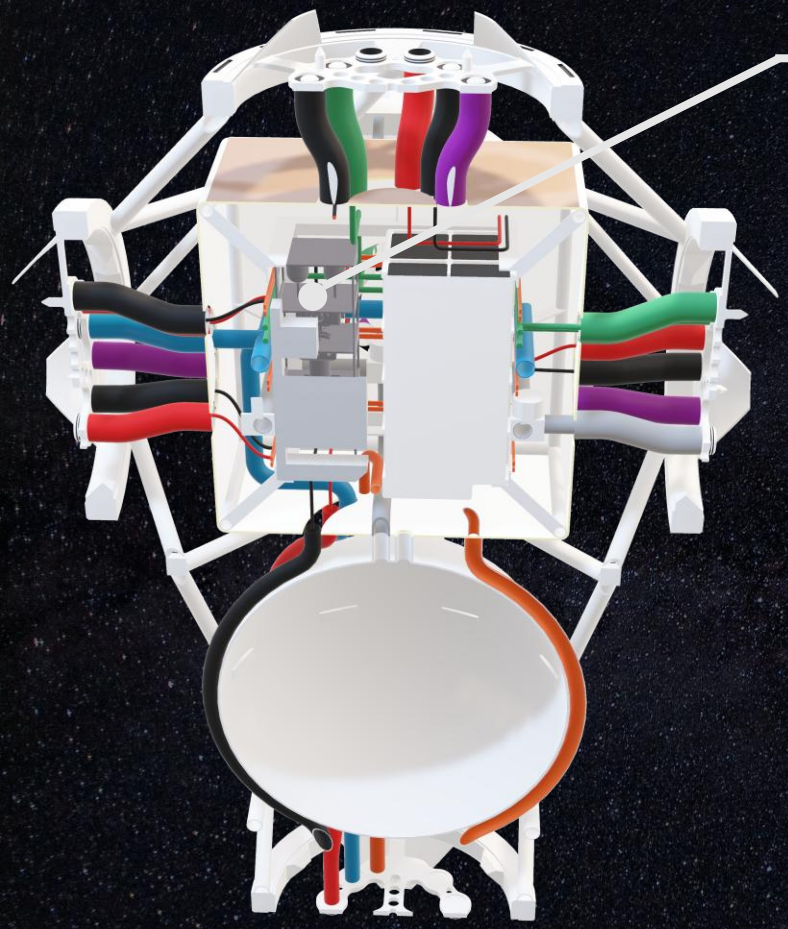
Basic Mass: 2,000 kg

Maturity Code		Design Maturity (Basis for Mass Determination)	Mass Growth allowance (%)
			Structure
E	1	***Estimated***	18-25
	2	***Layout***	10-20
C	3	***Preliminary Design***	4-15
	4	***Released Design***	2-6
A	5	***Existing Hardware***	1-3
	6	***Actual Mass***	NO MGA Use appropriate measurement
S	7	***CFE or Specification Value***	NO MGA Values Provided

Mass Growth Allowance by Design Maturity

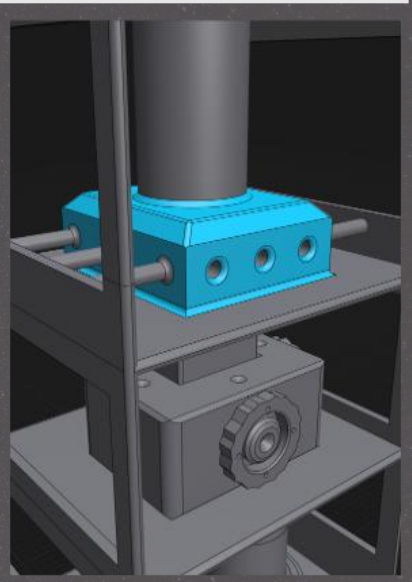
- **Mass Limit:** Maximum mass that can satisfy all mission requirements.
- **Mass Reserve:** Mass allowance defined by the program for potential unforeseen mass changes.
- **Mass Margin:** Difference between the allowable mass and the predicted mass.
- **Predicted Mass:** Sum of the basic mass and the MGA. Used to estimate final mass.
- **Mass Growth Allowance (MGA):** The predicted change to the basic mass based on the assessment on several factor such as the maturity of the technology.

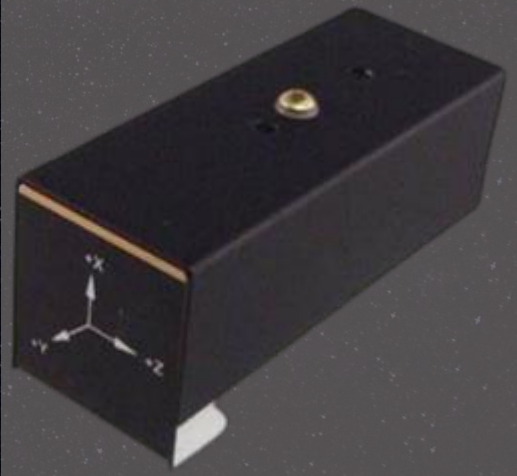
GNC & ADACS



AAC CLYDE SPACE (MM200):

- OSV & CSS Magnetometers provide a measurement of the local magnetic field in order to estimate 3-axis information about the attitude

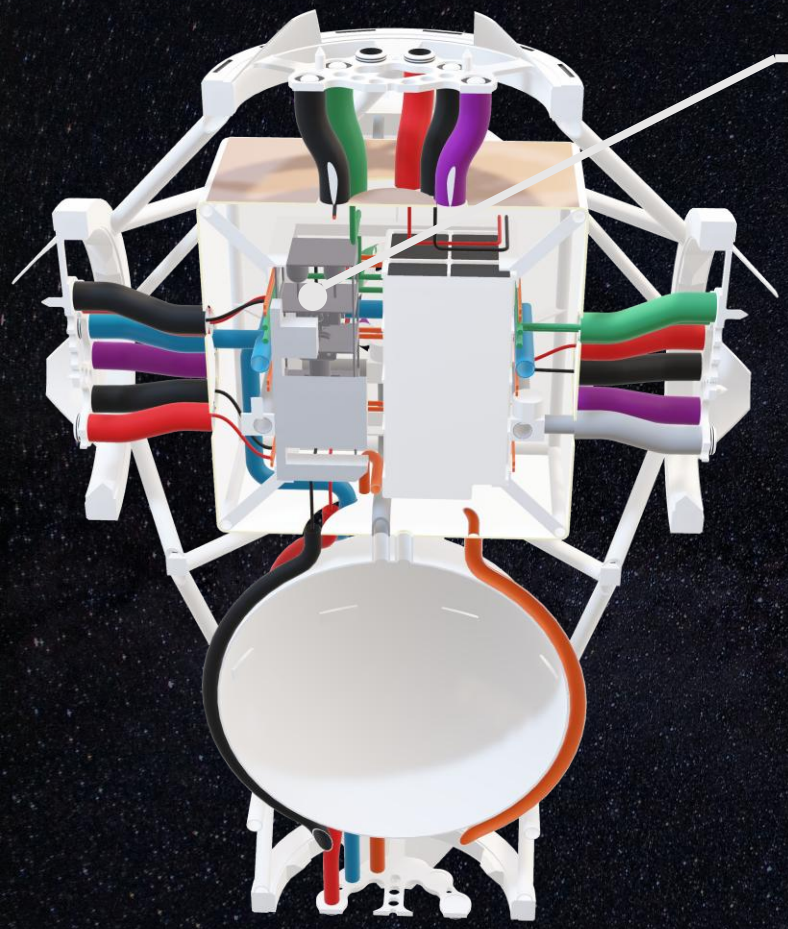




AAC CLYDE SPACE (MM200)

Model	Mass(kg)	Power(W)	Accuracy(m)	Radiation Tol.(krad)
MM200	0.012	0.01	Unknown	30

GNC & ADACS

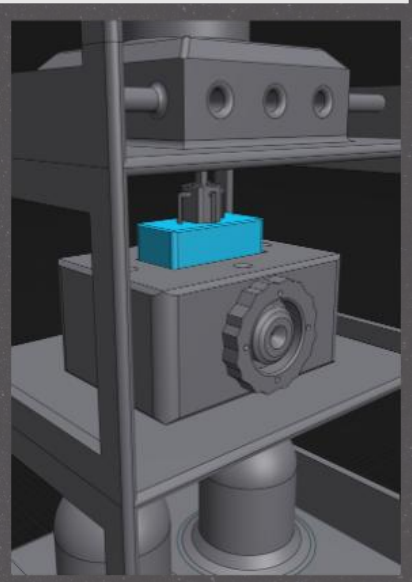


SYRLINKS (GALILEO):

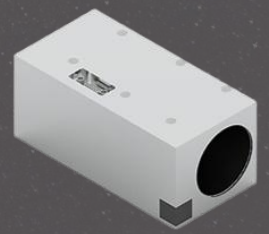
- The receivers measure changes in the distance of the OSV satellites to the constellation of GPS satellites orbiting Earth

KULST:

- Image of star taken while recording the direction in which the image was taken by OSV & CSS to determine where the craft is pointing



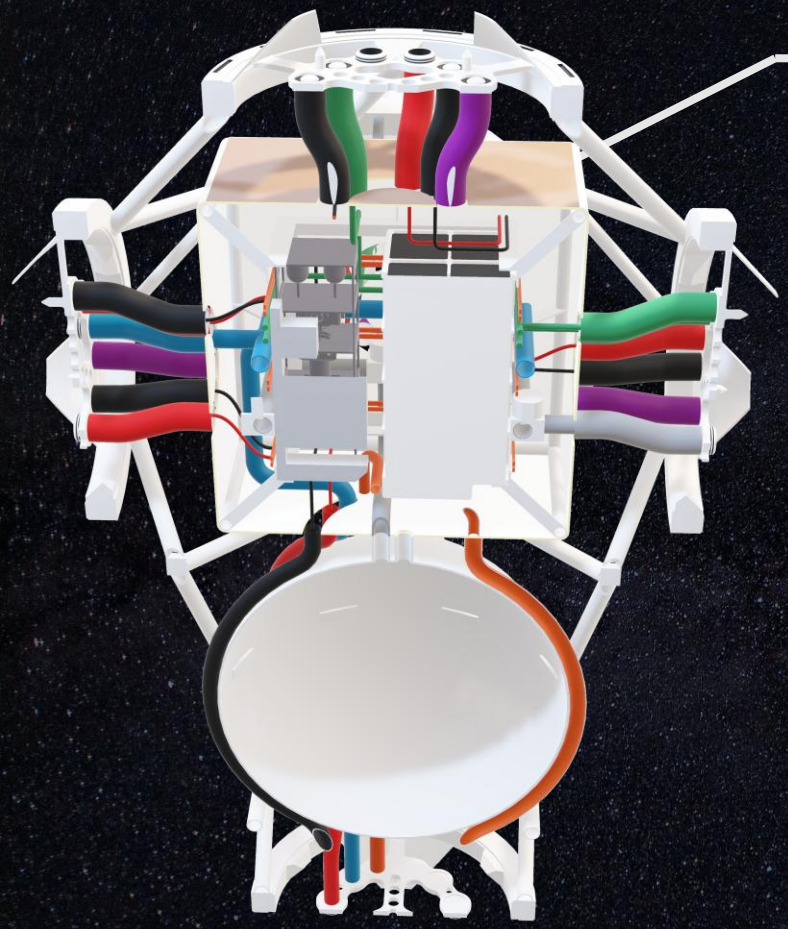
SYRLINKS (GALILEO)



KULST

Model	Mass(kg)	Power(W)	Accuracy(m)	Radiation Tol.(krad)
GALILEO (E1/E5/E6)	0.435	0.5	<0.1	15

GNC & ADACS



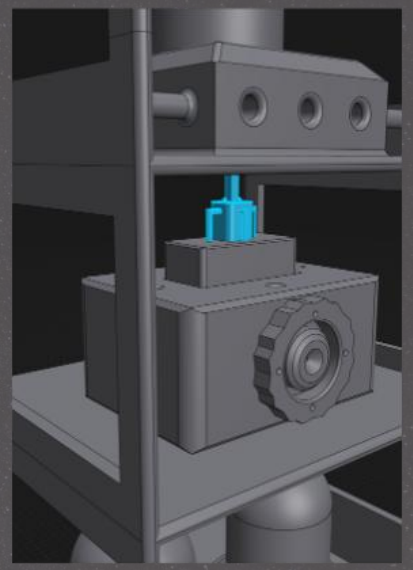
LN-200s:

- Inertial sensors include Gyroscopes for measuring OSV & CSS angular change & accelerometer for measuring velocity change in OSV and & CSS

Magnetic Torquers:

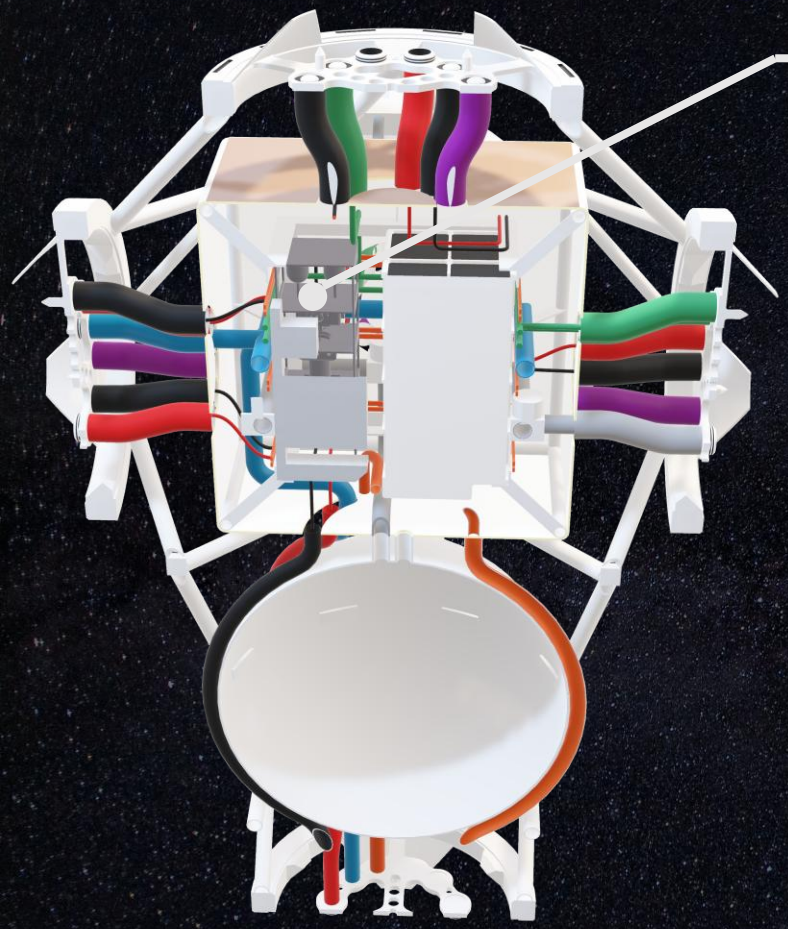
- Magnetic Torquers provide control torques for OSV & CSS for attitude adjustment as well as remove excess momentum from reaction wheels

Model	Mass(kg)	Power(W)	Sensor Type	Axes
LN-200S	0.748	12	IMU	3



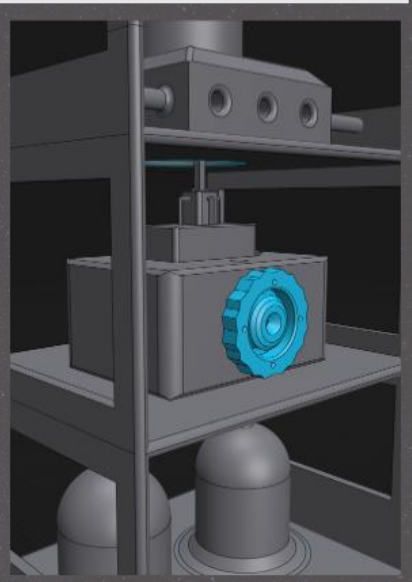
Northrop Grumman (LN-200S)

GNC & ADACS



CubeWheel (Large)

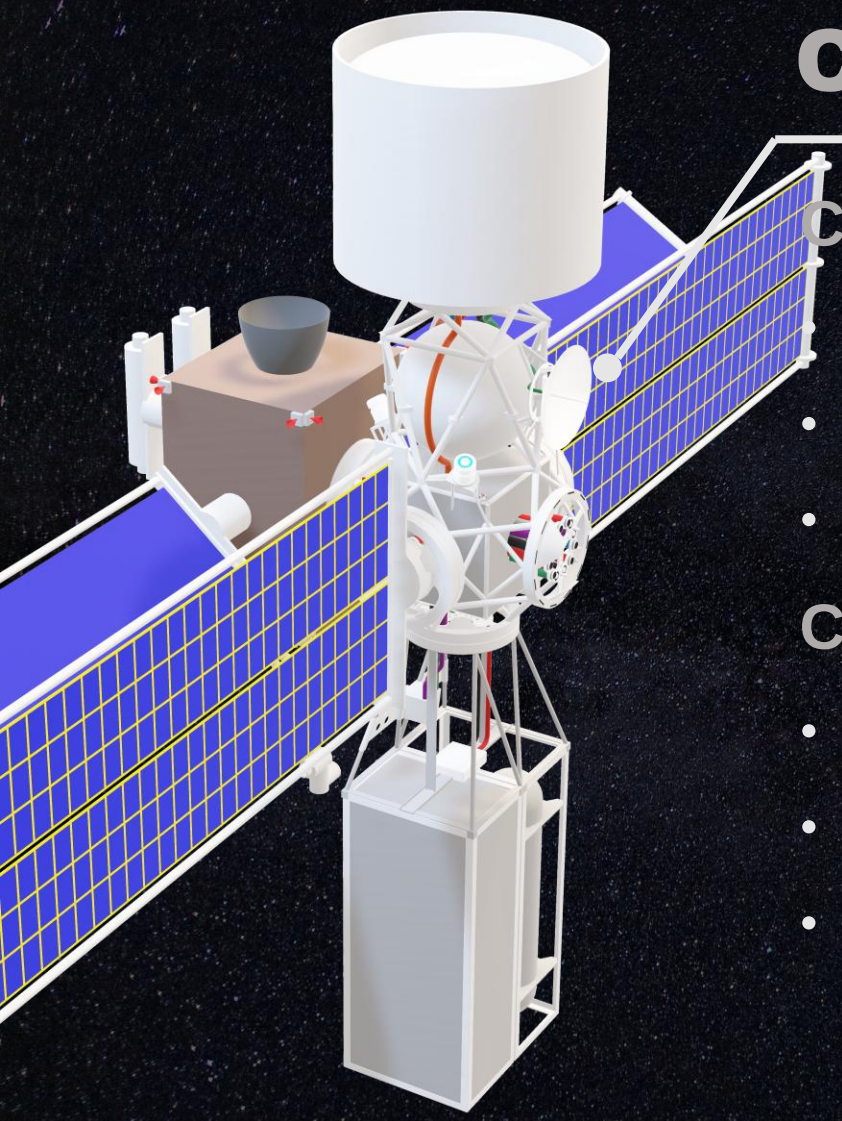
- OSV & CSS reaction wheels provide torque and momentum storage along the wheel axis as well as for full three-axis attitude control



CubeWheel (Large)

Model	Mass(kg)	Power(W)	Momentum Capacity	Radiation Tol.(krad)
CubeWheel Large	0.225	4.5	0.03061	24

COMMUNICATIONS

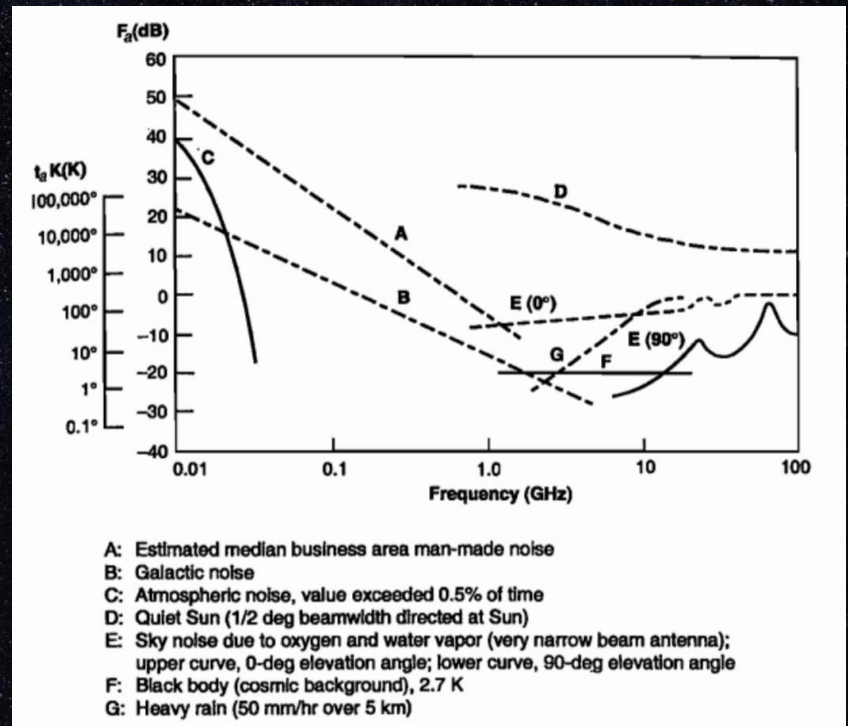


CTECH Transmitter (top):

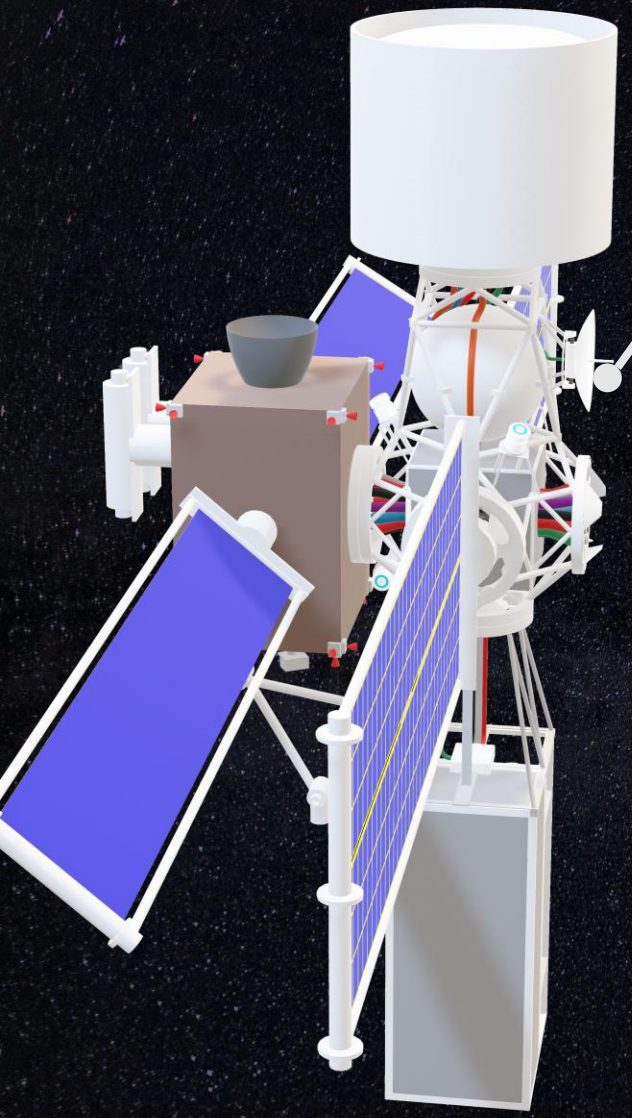
- 11.1-11.8 GHz for telemetry and telecommands
- 30 dBm output
- < 17 W Power Consumption

CTECH Receiver (bottom):

- 12.75-14.50 GHz operating range
- Up to 1000 kbps
- 20W Power Consumption



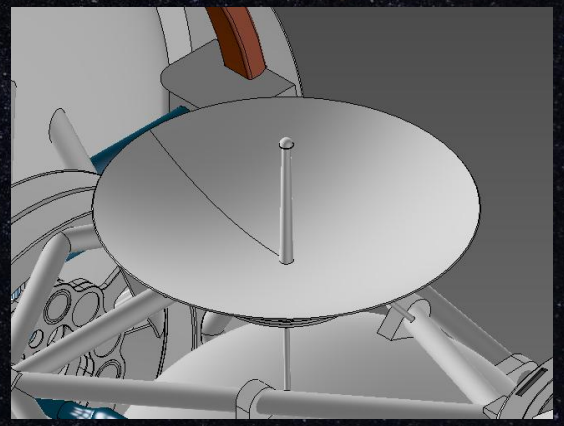
A: Estimated median business area man-made noise
B: Galactic noise
C: Atmospheric noise, value exceeded 0.5% of time
D: Quiet Sun (1/2 deg beamwidth directed at Sun)
E: Sky noise due to oxygen and water vapor (very narrow beam antenna); upper curve, 0-deg elevation angle; lower curve, 90-deg elevation angle
F: Black body (cosmic background), 2.7 K
G: Heavy rain (50 mm/hr over 5 km)



COMMUNICATIONS

CSS Dish Specifications:

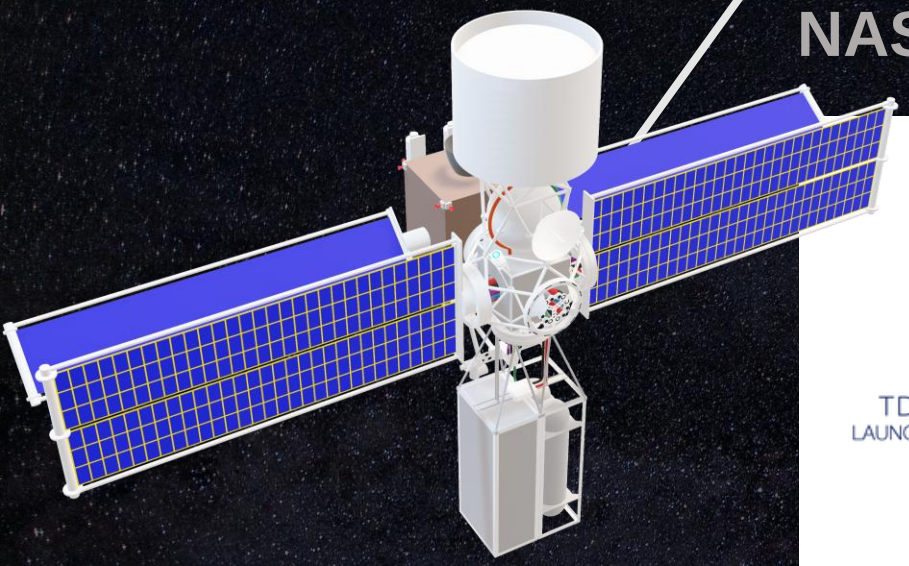
- 1.2-meter diameter,
- Focal Length: 450mm
- Expected gain of 42.4 dBi, with a beamwidth of 1.30 degrees



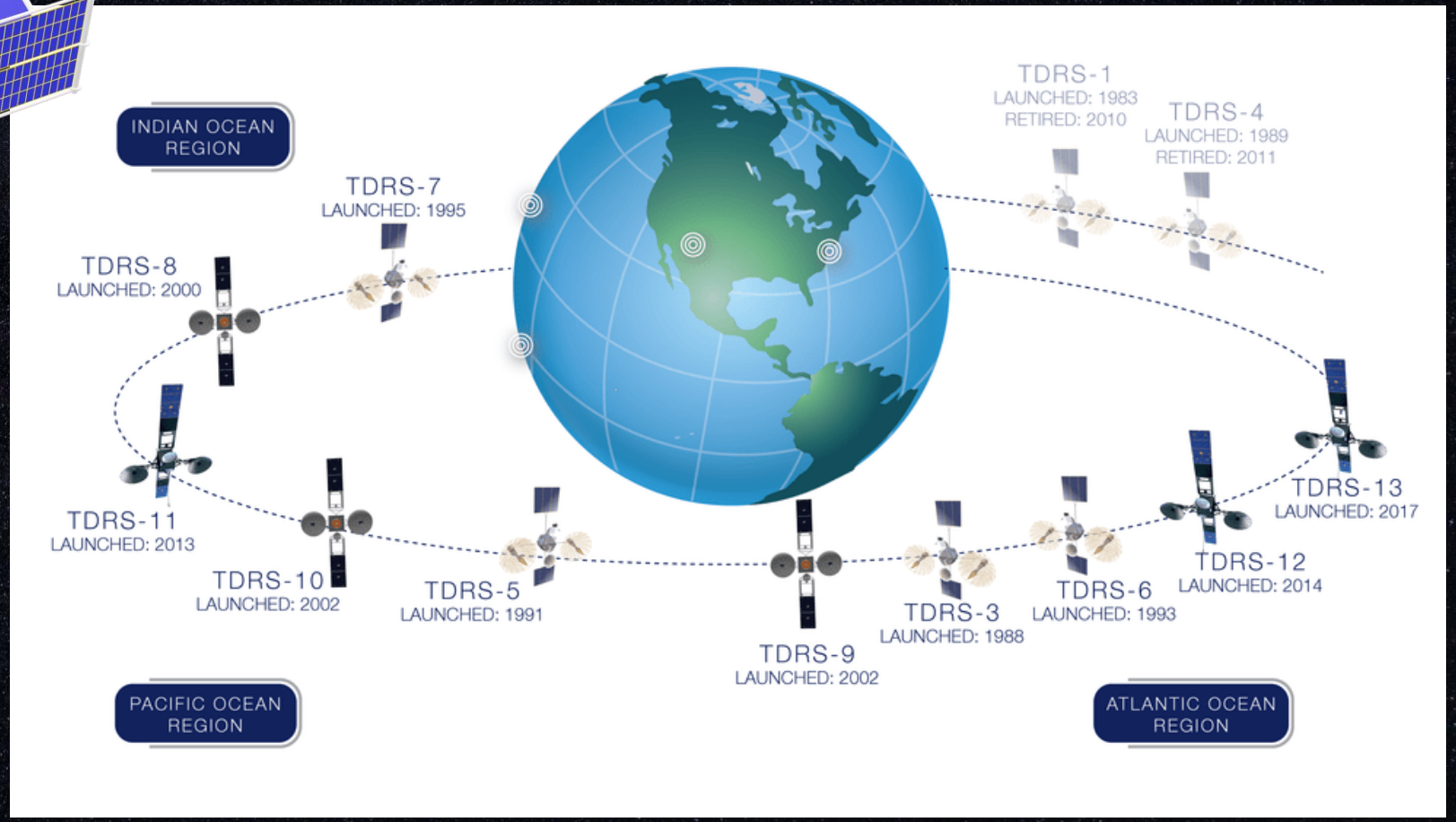
OSV Dish Specifications:

- 1-meter diameter,
- Focal Length: 450mm
- Expected gain of 40.8 dBi, with a beamwidth of 1.55 degrees

COMMUNICATIONS



NASA Tracking and Data Relay Satellites:



ELECTRICAL POWER SYSTEM

Redwire Roll Out Solar Array (ROSA):

iROSA (ISS Roll Out Solar Array):

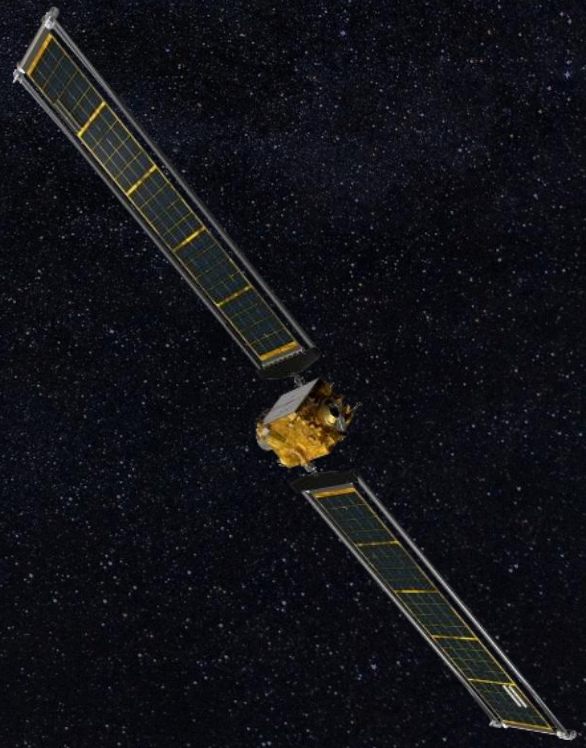
Width: 6 m, Length: 18.2 m

DART (Double Asteroid Redirection Test) Mission ROSA:

- Width: Unknown, Length: 8.53 m

SROSA (SMARRT Roll Out Solar Array):

- CSS
  - Width: 3.6 m, Length: 8.9 m
- OSV
  - Width: 1.8 m, Length: 8.9 m



Solar Cells:

Boeing Spectrolab: XTJ Prime Solar Cells

- 30.7% Efficient

ELECTRICAL POWER SYSTEM

Power Generation:

- Each iROSA provides more than 28 kW of power
- Maintaining the same efficiency, and scaling down:

$$\frac{A_{SROSA}}{A_{iROSA}} = \frac{(3.6m)(8.9m)}{(6m)(18.2m)} = 0.293$$

$$Power_{OSV} = (0.293)(28kW) = 8.22\ kW$$

Batteries:

- Heritage Lithium-Ion Battery Cells
- Capacity of 110 Ah and 4 kWh
- Battery measured 102 x 91 x 46 cm and weighed 170 kg

COMMAND AND DATA HANDLING

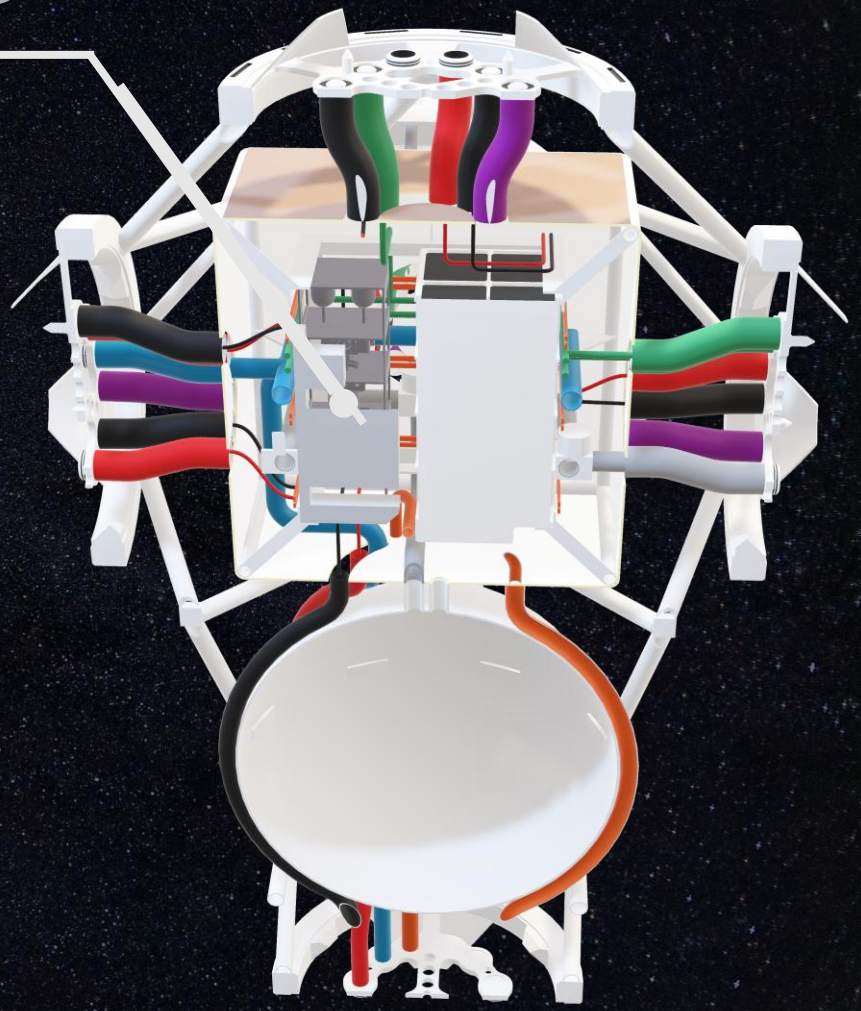
RAD-750 Processor:

Technology Charateristic :

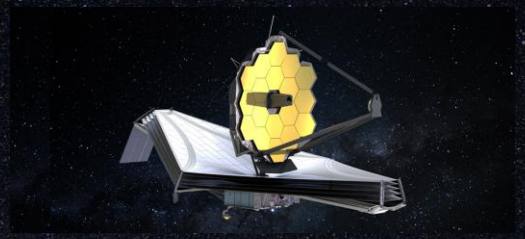
- Anti-radiation: 2000 to 10000 grays
- Operation temperature: -55 °C to 125 °C
- Die area: 130 mm²
- Core clock: 110 to 200 MHz
- Downlink Formats: CCSDS, STDN
- Downlink Band: Ku band
- Data Storage: Up to 5.6 Tb
- Downlink rate: Up to 350 Mbps

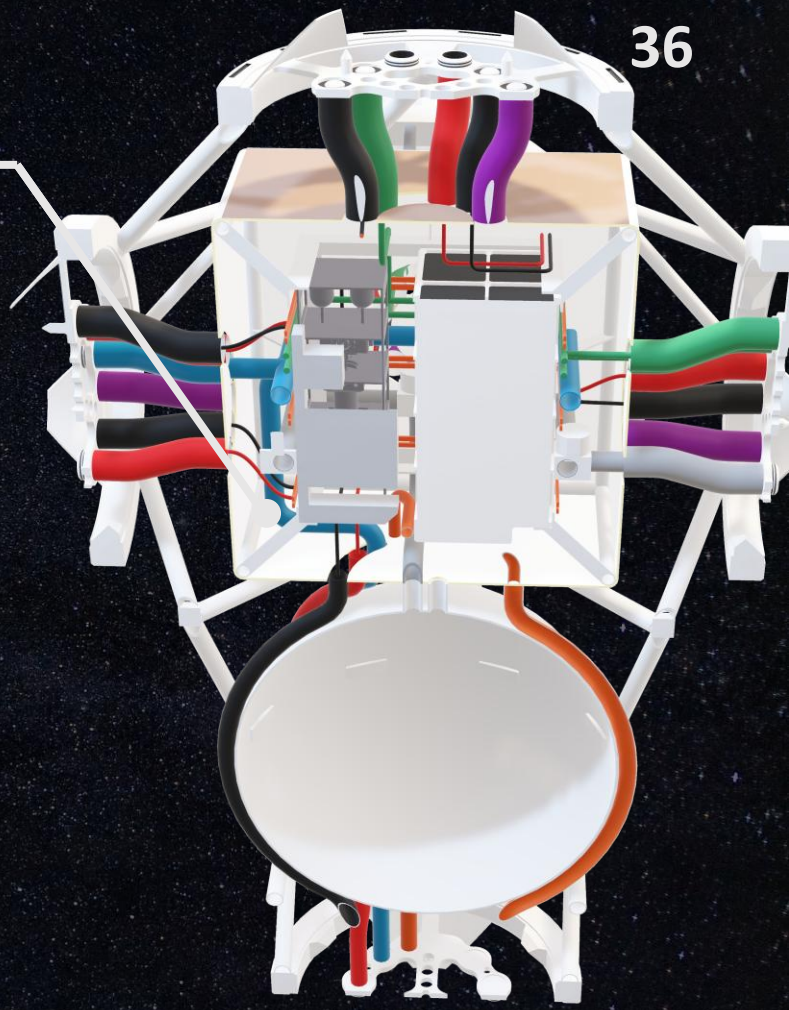
Power requirement:

- 5 watts for CPU
- 10 watts for the standard single-board system



COMMAND AND DATA HANDLING





MIL-STD-1553B:

Characteristic:

- Manchester code for data and clock transmission
- With 1 Mbit per second speed
- Output voltage 18-27 V for the transmitter

Bus Protocol:

- Involves a bus controller and multiple remote terminals
- Messages consist of one or more 16-bits words
- 20 bits word structure: 3-bit synchronization, 16-bits payload, 1-bit odd parity
- Inter-message gap: 4 µs

COMMAND AND DATA HANDLING

MIL-STD-1553B:

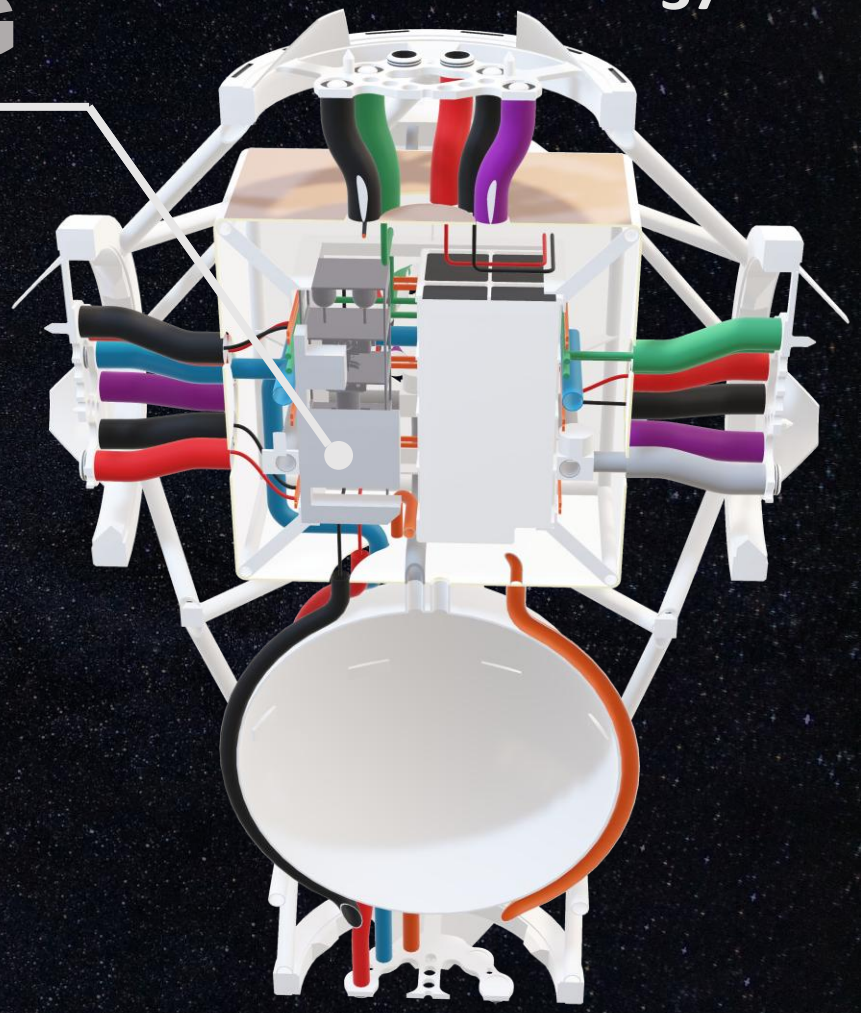
Cable Length and Propagation Delay:

- Propagation delay- 1.6 nanoseconds per foot

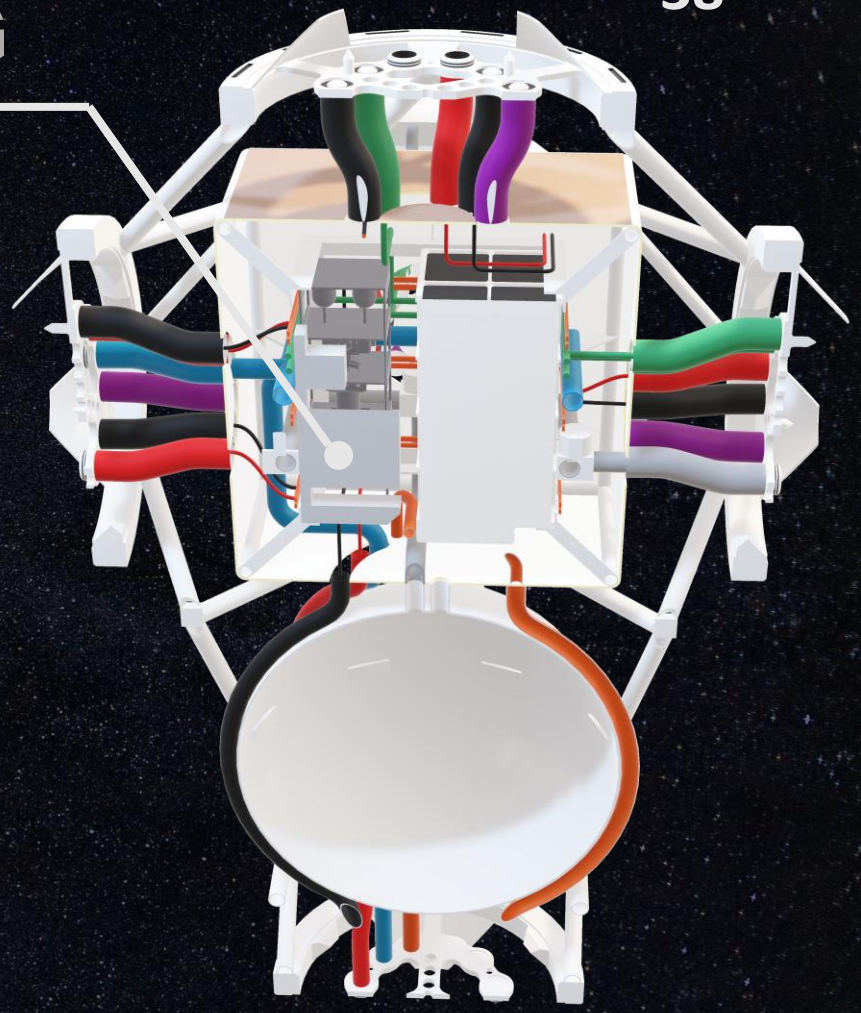
$$D=L/v$$

Where:

- D is the propagation delay.
- L is the distance between the sender and receiver.
- v is the propagation speed of the signal in the medium.



COMMAND AND DATA HANDLING



RS485:

Characteristics :

- Balanced electrical signaling and multipoint systems supported
- Effective over long distances and in noisy environments
- Differential signaling over twisted pair
- Three-state logic for driver circuits

Power:

- Differential output: minimum 1.5 V across a 54-Ω load
- Receivers detect differential input down to 200 mV

Technical Specifications :

- Supports data rates is 10 Mbit/s

THERMAL CONTROL SYSTEM

Anhydrous Ammonia:

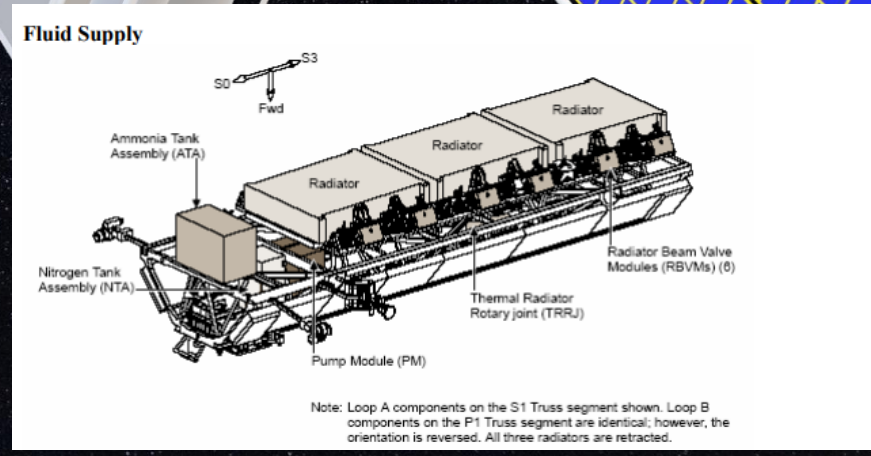
- With extremely low freezing point of -107° F, Capable of moderating temperatures, Anhydrous Ammonia refringent will be used throughout the TCS.

Internal Active Thermal Control Systems (IATCS):

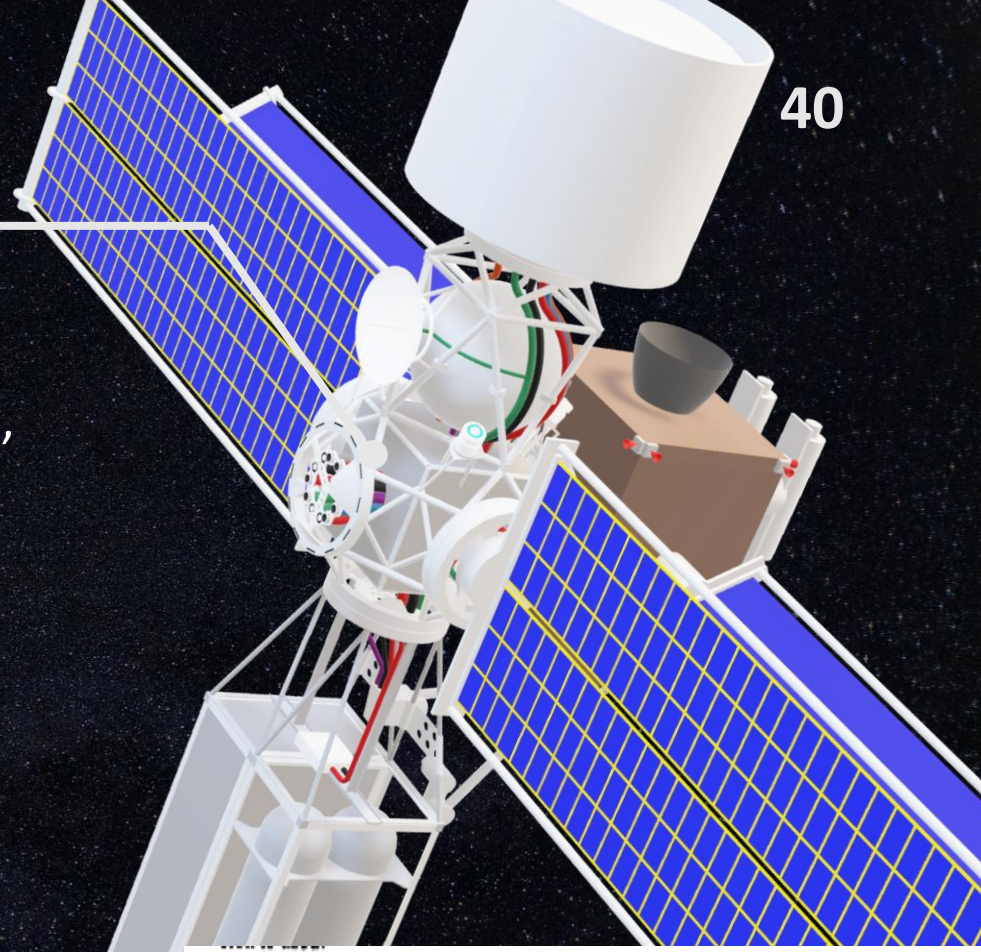
- IATCS provides a constant coolant supply to equipment

Photovoltaic Thermal Control System (PVTCS):

- The Photovoltaic Thermal Control System (PVTCS) consists of ammonia loops that collect excess heat from the Electrical Power System
- Consists of ammonia coolant, 11 coldplates, 2 Pump Flow Control Subassemblies (PFCS) and will be able to dissipate 6,000 Watts.



THERMAL CONTROL SYSTEM



Pump & Flow Control System (PFCS):

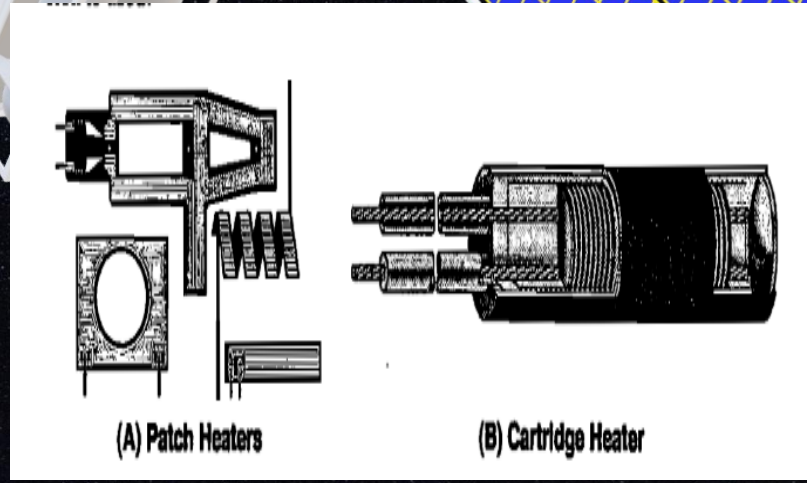
- Pumps the heat transfer fluid to the heat exchanger via valves, pumps, and controls.
- Each PFCS consumes 275 Watts during 3 normal operation
- 40 inches (101.6 cm) by 29 inches (73.7 cm) by 19 inches (48.3 cm)
- 235 pounds (106.7 kilograms)

Interface Heat Exchanger (IFHX):

- Circulates the working fluid, anhydrous ammonia

Heaters:

- The two heaters, producing 1.8 kW of power, will split the total heat to heat the ammonia fluid from freezing in scenarios such as eclipses



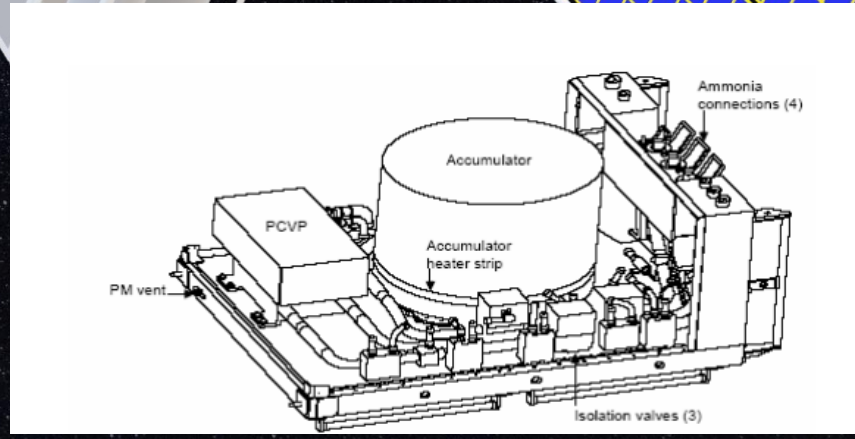
THERMAL CONTROL SYSTEM

Pump Module (PM)

- Circulation, loop pressurization, and temperature control of the ammonia is provided by the Pump Module
- Nominally, loop A will operate at 8,200 lb/hr and loop B at 8,900 lb/hr at 14,000 and 14,700 revolutions per minute
- 69 inches (175.26 cm) by 50 inches (127 cm) by 36 inches (.91 cm) inches
- Weighs about 780 pounds (353.8 kilograms)

Software:

- Thermal Control System (TCS) software is used to control and monitor the system.



THERMAL CONTROL SYSTEM

Surface Finish	α	ε
Optical Solar Reflectors		
8 mil Quartz Mirrors	0.05 to 0.08	0.80
2 mH Slivered Teflon	0.05 to 0.09	0.66
5 mil Silvered Teflon	0.05 to 0.09	0.78
2 mH Aluminized Teflon	0.10toO.16	0.66
5 mil Aluminized Teflon	0.10toO.16	0.78
White Paints		
S13G-LO	0.20 to 0.25	0.85
Z93	0.17 to 0.20	0.92
ZOT	0.18 to 0.20	0.91
Chemglaze A276	0.22 to 0.28	0.88
Black Paints		
Chemglaze Z306	0.92 to 0.98	0.89
3M Black Velvet	-0.97	0.84
Aluminized Kapton		
112 mil	0.34	0.55
1 mil	0.38	0.67
2 mil	0.41	0.75
5 mil	0.46	0.86
Metallic		
Vapor Deposited Aluminum (VDP)	0.08 to 0.17	0.04
Bare Aluminum	0.09 to 0.17	0.03 to 0.10
Vaporized Deposited Gold	0.19 to 0.30	0.03
Anodized Aluminum	0.25 to 0.86*	0.04 to 0.88
Aluminized Polyimide	0.4	0.6
Miscellaneous		
1/4 mil Aluminized Mylar, Mylar Side	(Degrades in sunlight)	0.34
Beta Cloth	0.32	0.66
Astra Quartz	-0.22	0.80
MAXORB	0.9	0.1

November 2 0 4 0

OSV and FSM Launch

November 2040

CSS and PSM Launch

Launch Vehicle

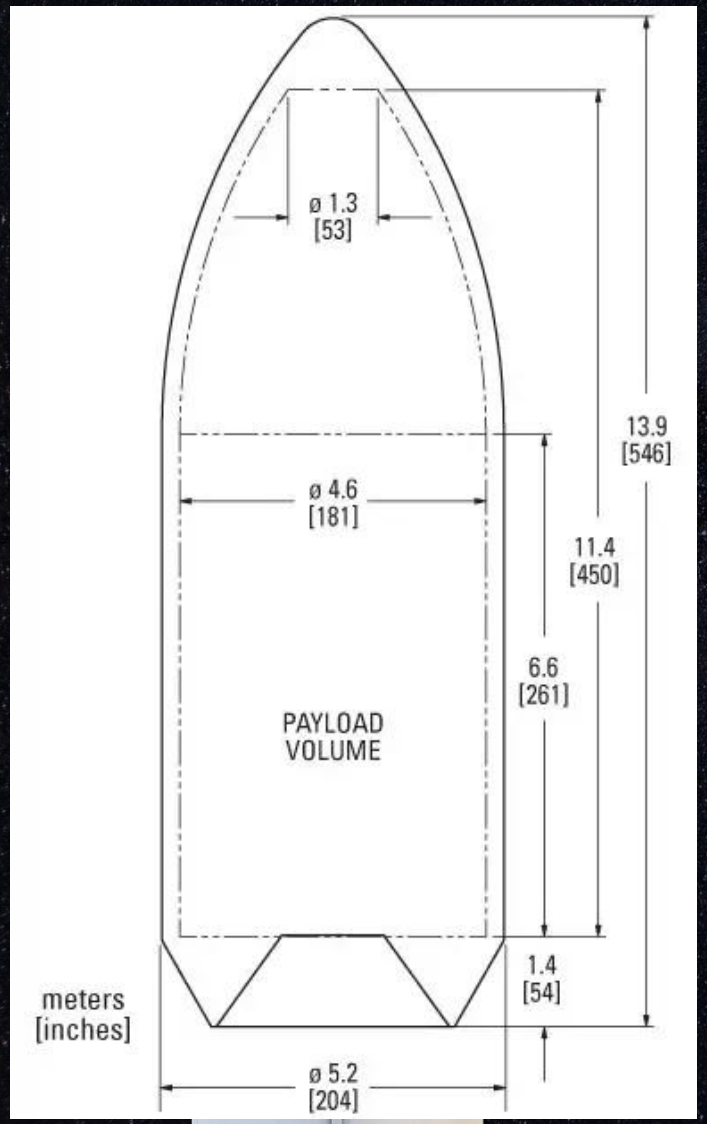
Payload Volume: Falcon Heavy

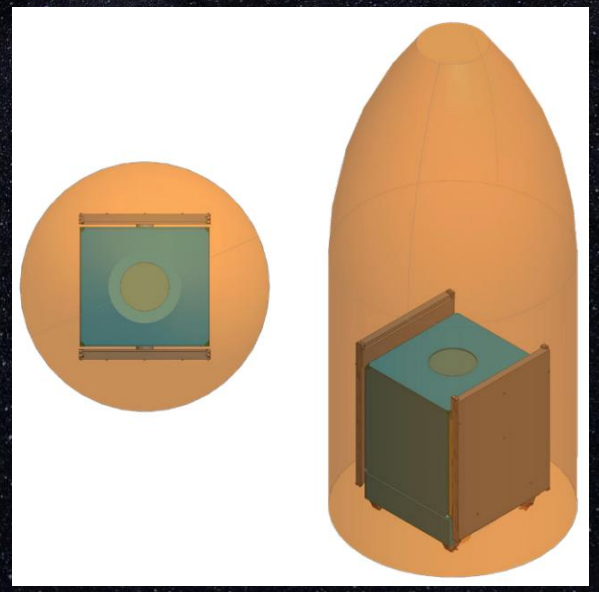
Standard Fairing:

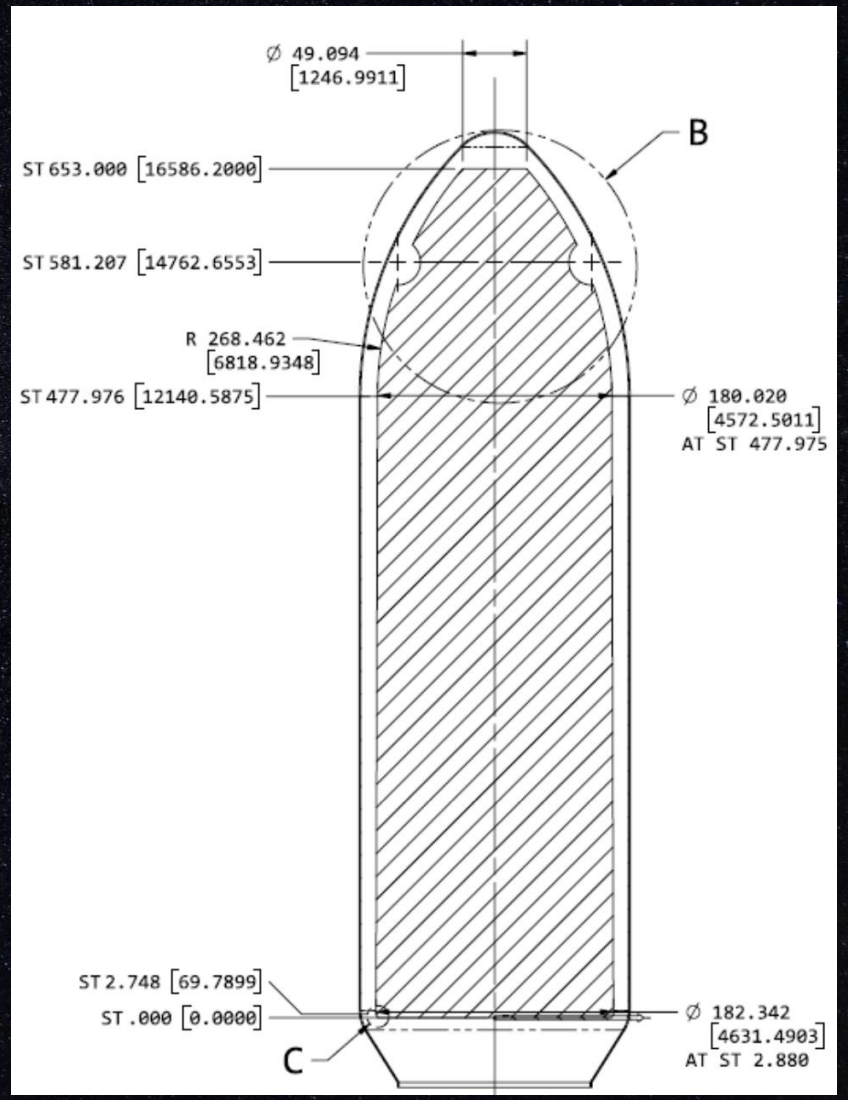
4.577 m x 6.680 m

Extended Fairing:

4.577 m x 12.141 m

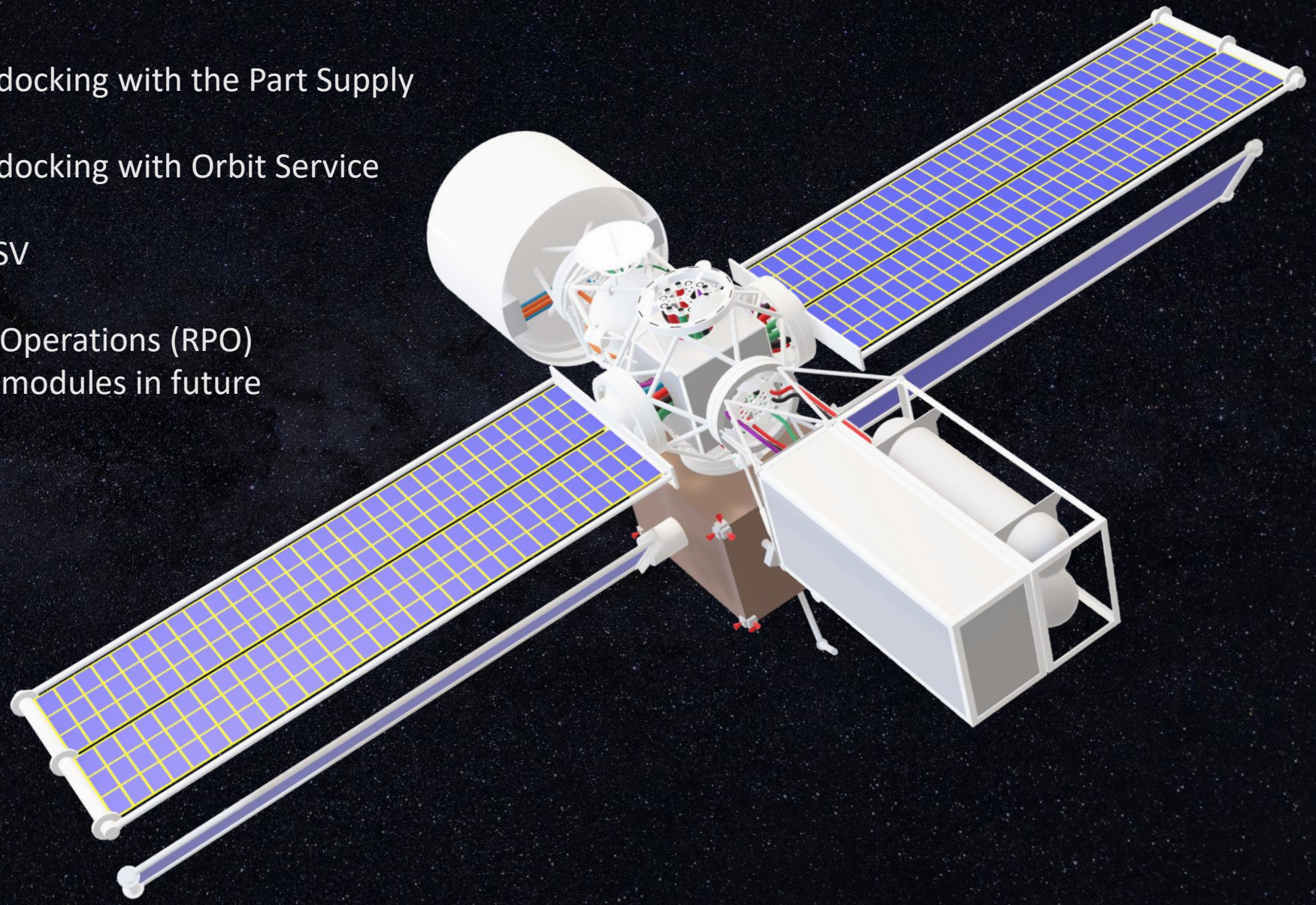






Capabilities of CSS:

- Allow docking and un-docking with the Part Supply Module (PSM)
- Allow docking and un-docking with Orbit Service Vehicle (OSV)
- Resupply and refuel OSV
- Robotic Operations
- Rendezvous Proximity Operations (RPO)
- Expand operation and modules in future



Parts Supply Module

Specifications:

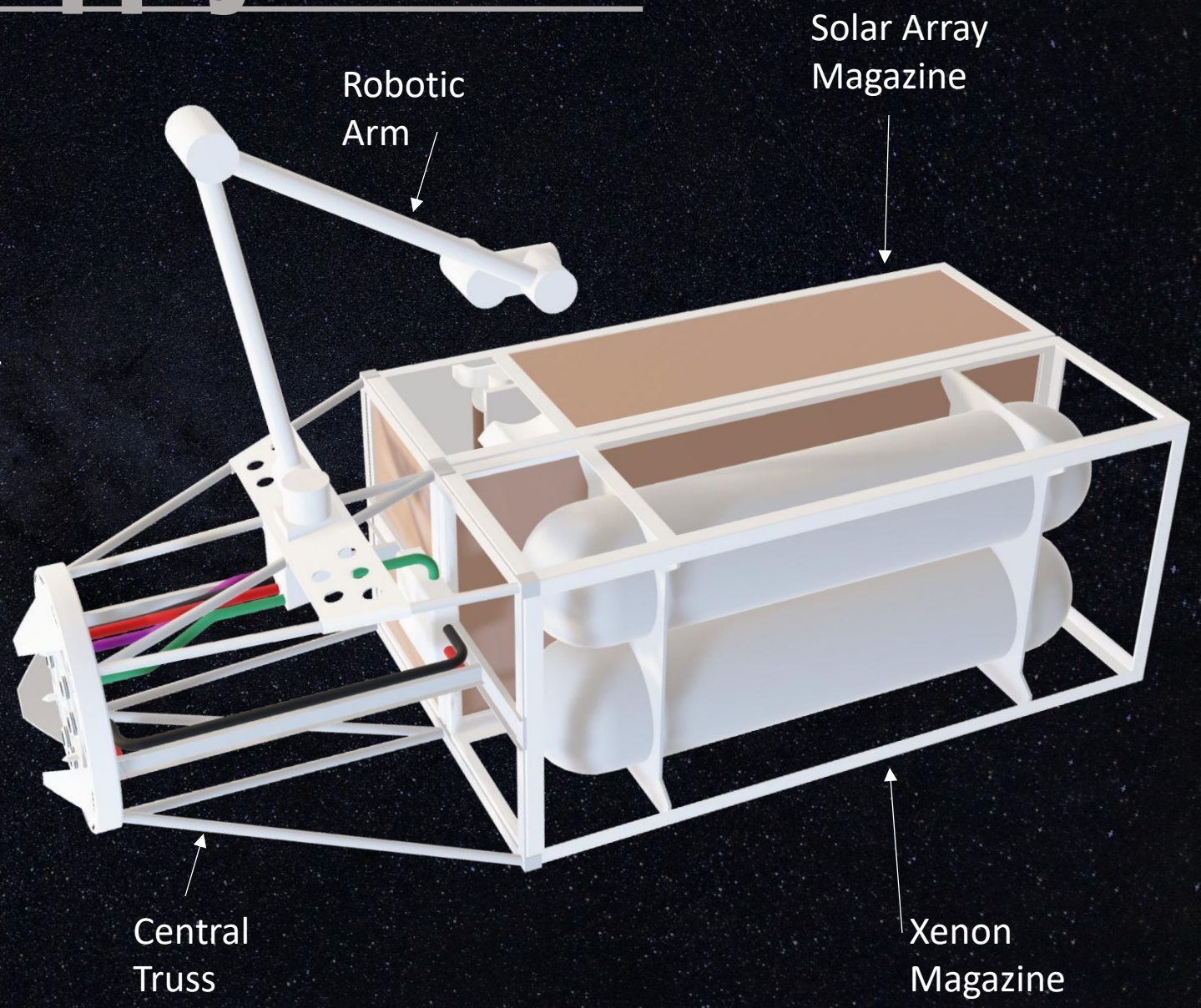
- 6.2m x 2.5m x 1.8m
- 11,500 kg
  - 9,300 kg Xe
  - 2,200 kg dry weight

Payload:

- Replaceable magazines for xenon and solar array replacements
- Xenon magazine with 3 m^3 internal volume

Robotic Arm:

- Interacts with OSV arm to facilitate component transfer



Parts Supply Module

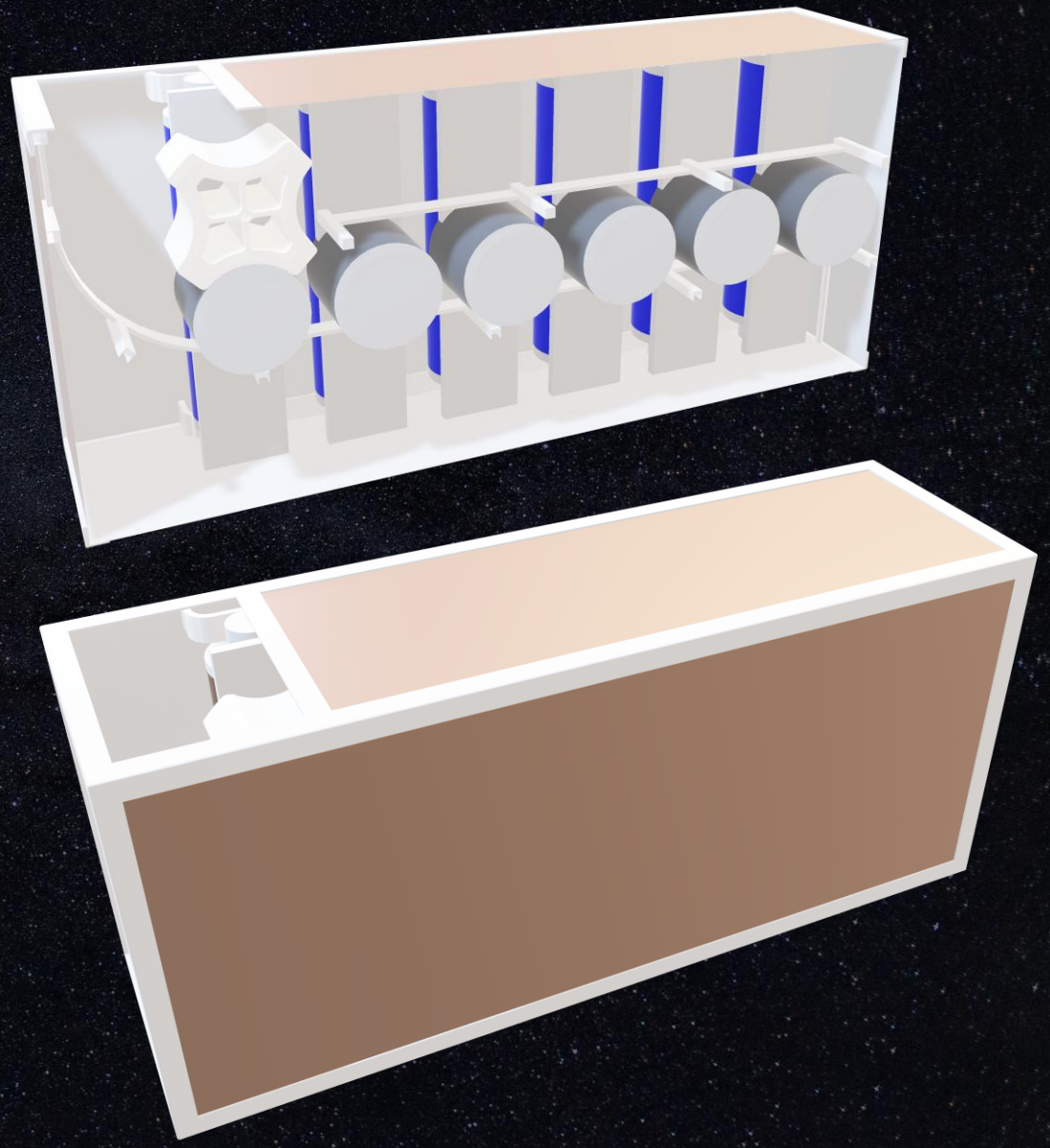
Solar Array Magazine:

Specifications:

- 4.1m x 1.8m x 1.2m
- 1,400 kg

Payload:

- 6x standardized solar arrays
- Advancement mechanism to release arrays one-by-one
- Arrays taken from magazine using robotic arm



Module Sizing

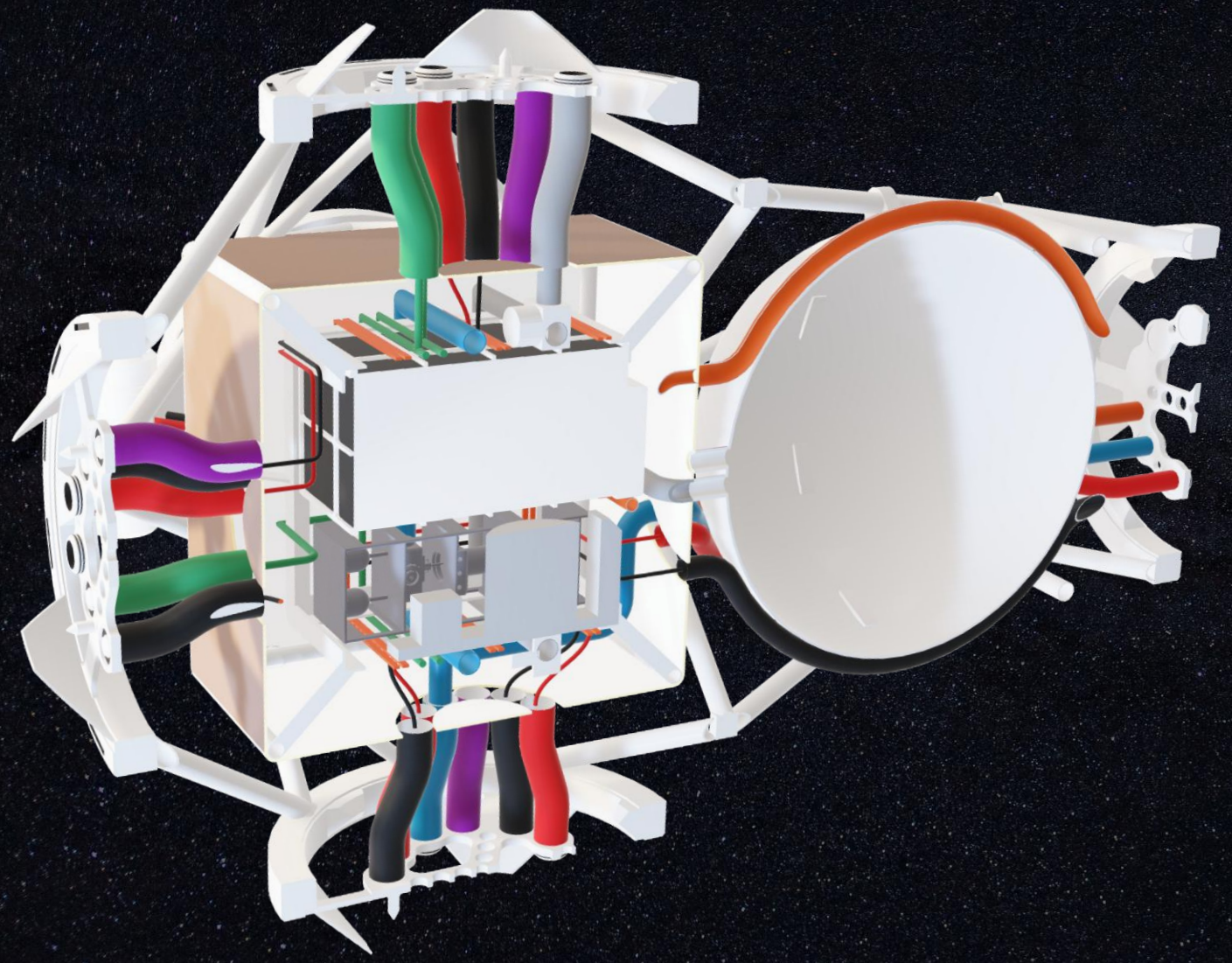
Assumptions

- 12 satellites per year, 15 year lifespan
- GEO satellite uses 105.4 kg MMH per year, 33 kg Xe

- **Results**
  - Specific impulse ratio $\frac{MMH}{H_2O} = 0.75$
  - Equivalent H_2O usage: 1,186 kg per satellite, 14,231 kg CSS requirement
  - Xe usage: 490 kg per satellite, 5,880 kg CSS requirement
  - Calculated Volume: $14.2\ m^3\ H_2O, 1.9\ m^3\ Xe$
- **Design Volumes**
  - FSM: $V = 14.5\ m^3$
  - Core Xe tank: $V = 2.0\ m^3$

Fuel Type	Specific Impulse $\left[\frac{N * s}{kg}\right]$	Bulk Density $\left[\frac{kg}{m^3}\right]$
$LOx + H_2$	4462	320
$MON + MMH$	3347	1200
Xe	-	3100

Core Module



Services Legend	
Red	Electrical Bus Positive
Black	Electrical Bus Negative
Gray	Xenon Passthrough
Blue	Water Passthrough
Green	Data Harness
Orange	FSM Thermal Loop
Purple	Reserved for future expansion

Core Module

Specifications:

- 4x identical docking nodes
- 2 m^3 xenon tank
- 1 m^3 internal volume
- 3,000 kg dry weight

Payload:

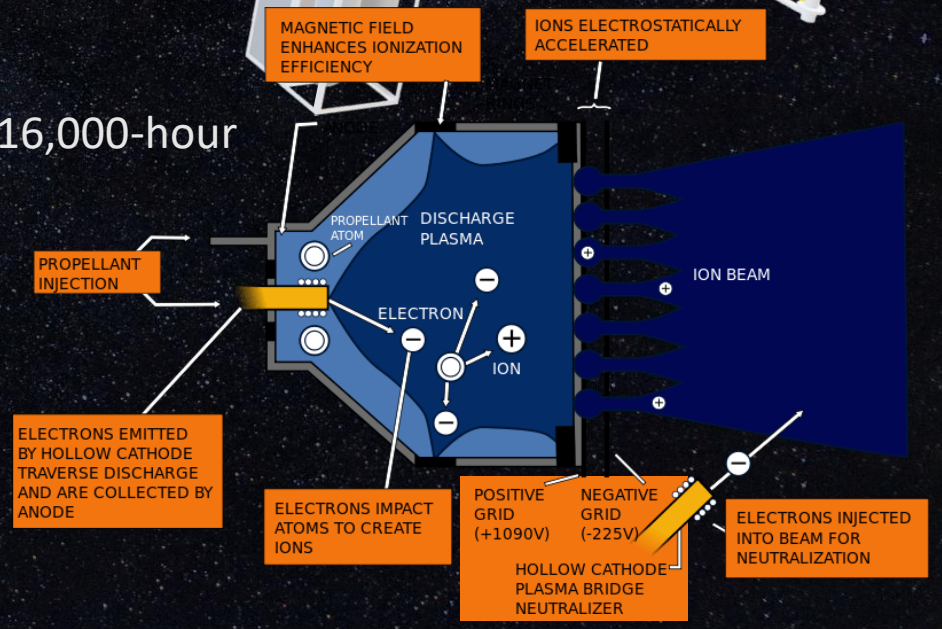
- Includes service connections for docking nodes
- Houses and protects sensitive electronic components
- 5 XIPS thrusters for station keeping
- Steerable communication antenna

PROPULSION

- 5 XIPS-25: **Station Keeping, Orbit Raising**
- 2 m^3 Xenon tank Propellant Bay

XIPS Propulsion: **Xenon Ion Propulsion System**

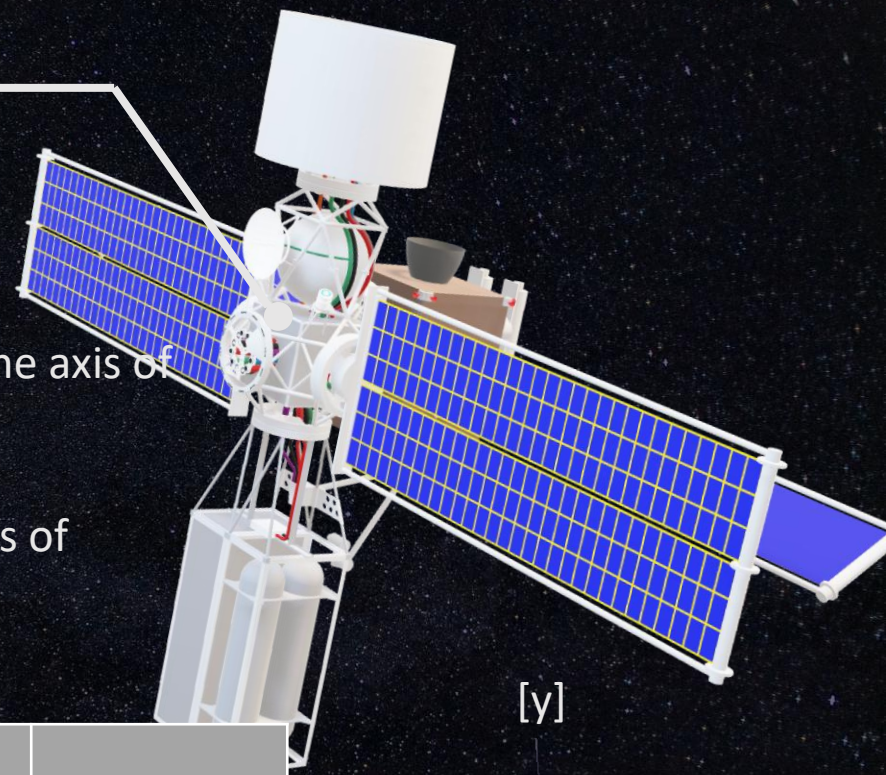
- XIPS-25 (25 cm) engine is used on Boeing 702 class satellites
- The 25-cm life-test completed a 16,250-hour life test with 14,134 On-Off cycles distributed over 2 power levels with a total throughput of about 170 kg of Xenon Propellant
- A 25-cm flight discharge cathode assembly successfully completed a 16,000-hour wear test at JPL at three different current levels



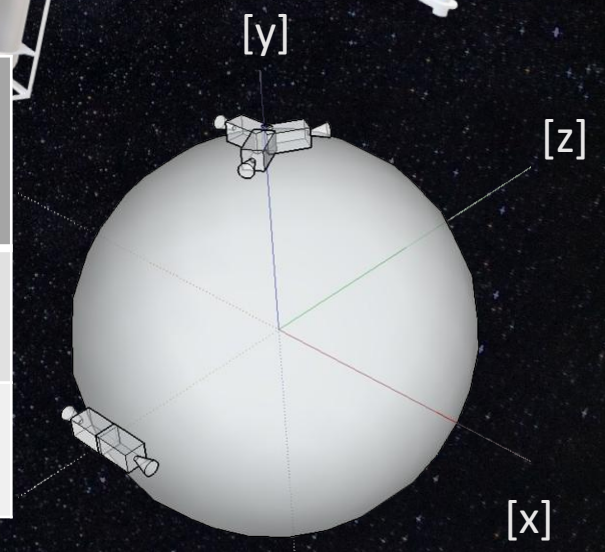
PROPULSION

XIPS-25 Axis:

- Without gimballed thrusters:
  - 3 degrees of freedom to stop any tumble except one going through the axis of symmetry(y) of the spacecraft
  - 2 extra thrusters will be able to negate any movement around the axis of symmetry, and account for redundancy



	Total Input Power(W)	Thrust (mN)	I_{sp}(s) (vac)	Electrical Efficiency (%)	Mass Utilization Efficiency(%)	Beam Voltage(V)	Beam Current(A)
Low Power	2067	79	3400	87	82	1215	1.43
High Power	4215	165	3500	87	84	1215	3.01



November 2040

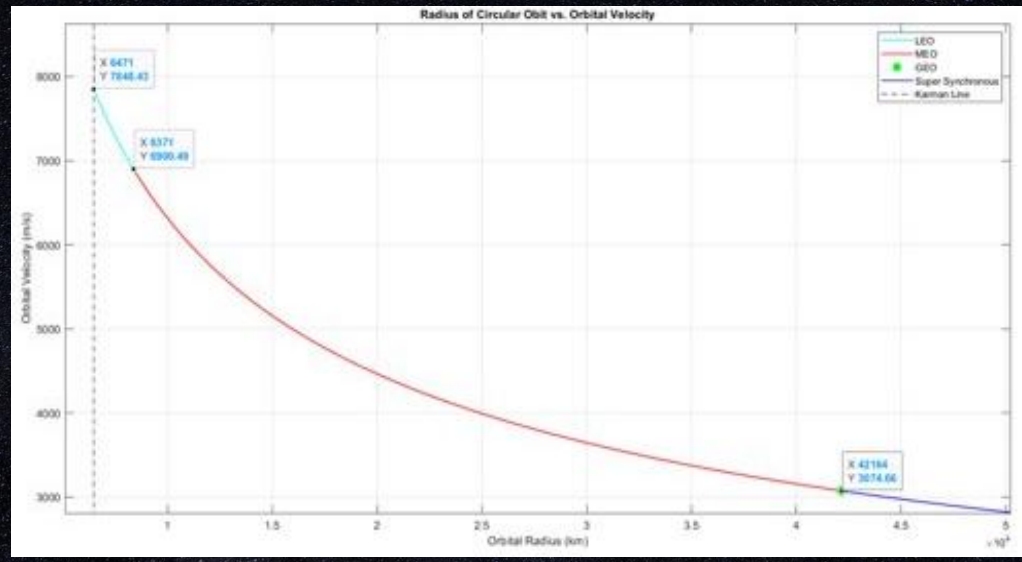
CSS and PSM Launch

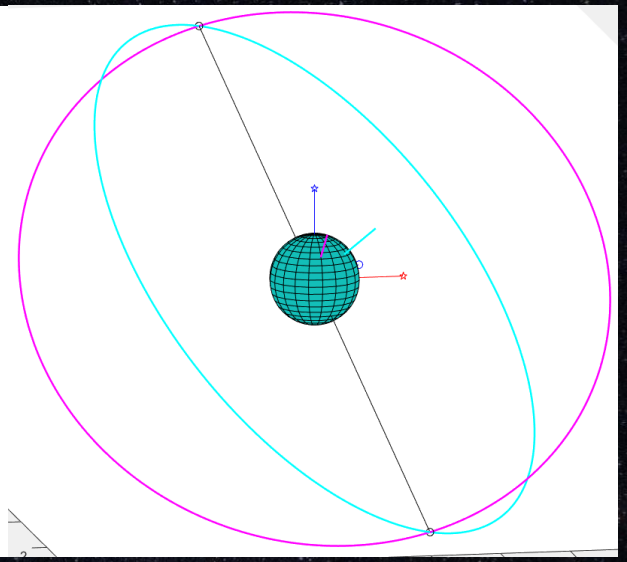
January 2 0 4 1

Rendezvous and Begin Operations

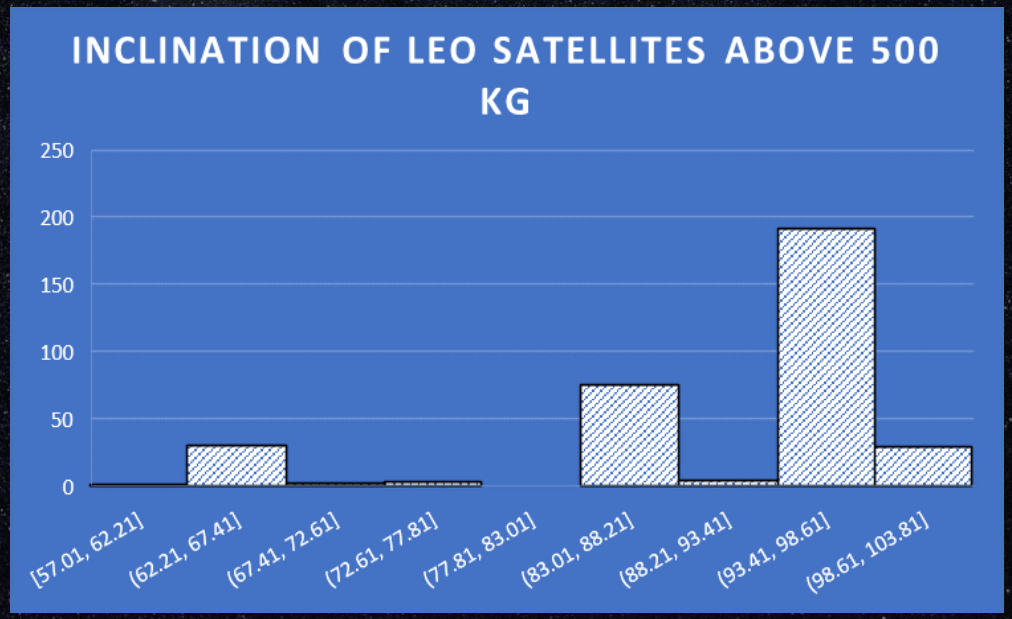
LEO vs. GEO

Row Labels	# Satellites in Each Orbit Type
Elliptical	59
GEO	580
LEO	5936
MEO	142
Grand Total	6717

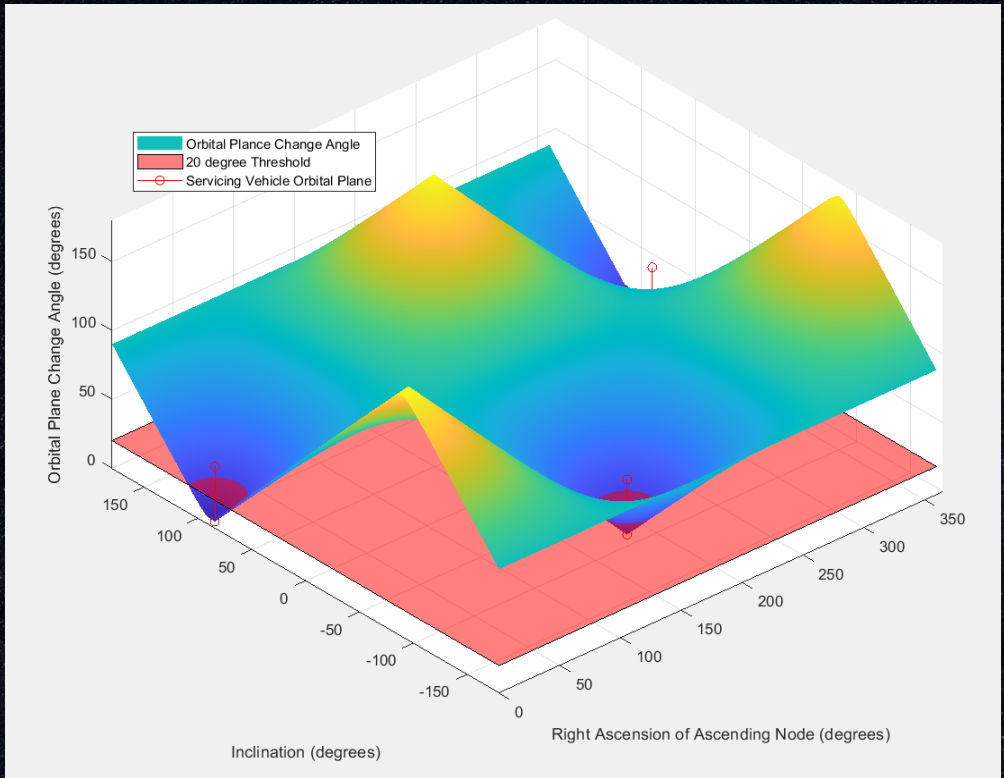


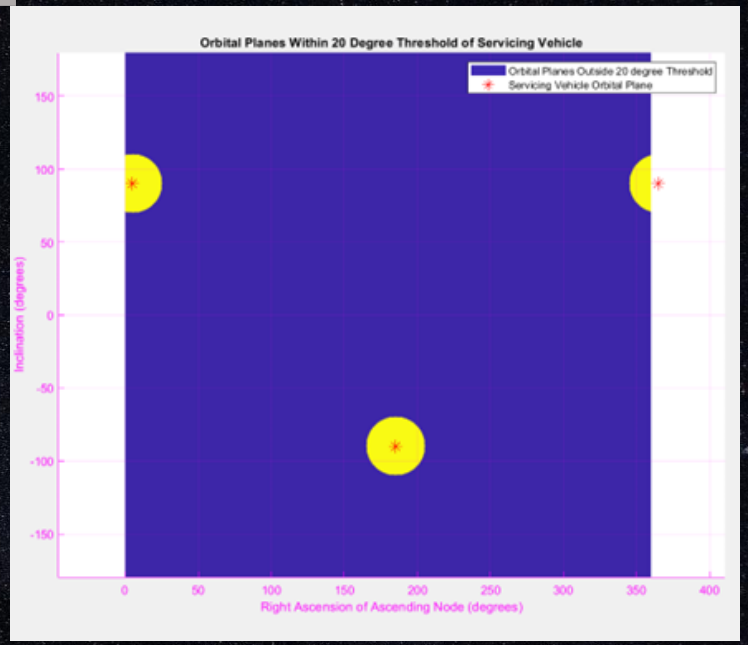


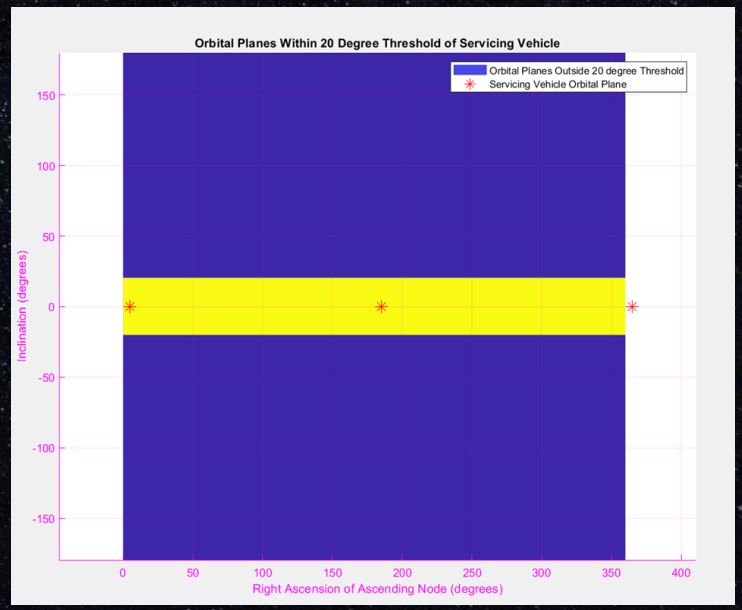
Row Labels	# Satellites Above 500 kg in Each Orbit Type
Elliptical	37
GEO	544
LEO	378
MEO	141
Grand Total	1100



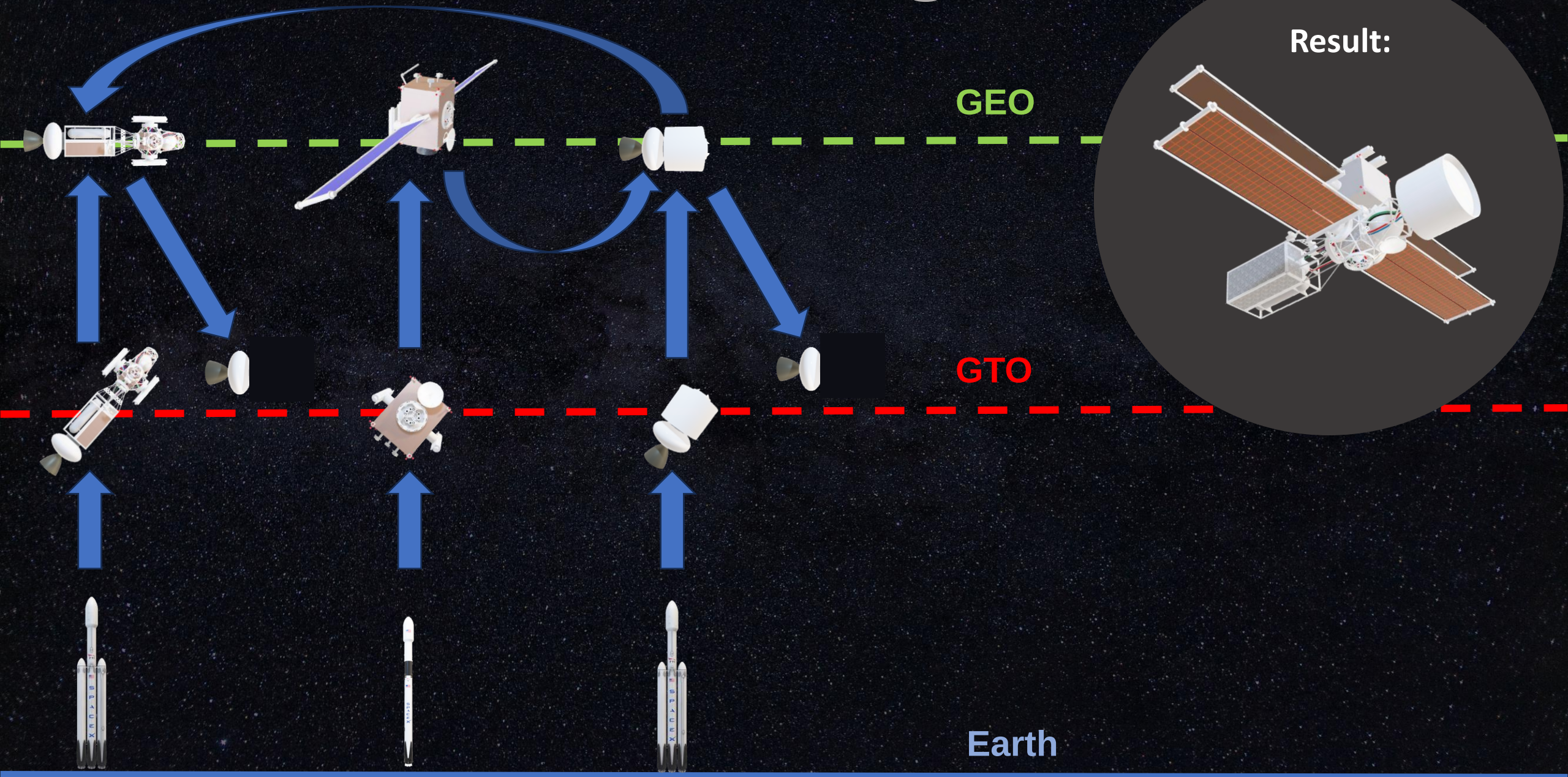
LEO vs. GEO


Orbital Plance Change Angle
20 degree Threshold
Servicing Vehicle Orbital Plane
Orbital Plane Change Angle (degrees)
150
100
50
0
150
100
50
0
-50
-100
-150
Inclination (degrees)
0
50
100
150
200
250
300
350
Right Ascension of Ascending Node (degrees)


Orbital Planes Within 20 Degree Threshold of Servicing Vehicle
Orbital Planes Outside 20 degree Threshold
Servicing Vehicle Orbital Plane
Inclination (degrees)
150
100
50
0
-50
-100
-150
0
50
100
150
200
250
300
350
400
Right Ascension of Ascending Node (degrees)


Orbital Planes Within 20 Degree Threshold of Servicing Vehicle
Orbital Planes Outside 20 degree Threshold
Servicing Vehicle Orbital Plane
Inclination (degrees)
150
100
50
0
-50
-100
-150
0
50
100
150
200
250
300
350
400
Right Ascension of Ascending Node (degrees)

Station Building Phase



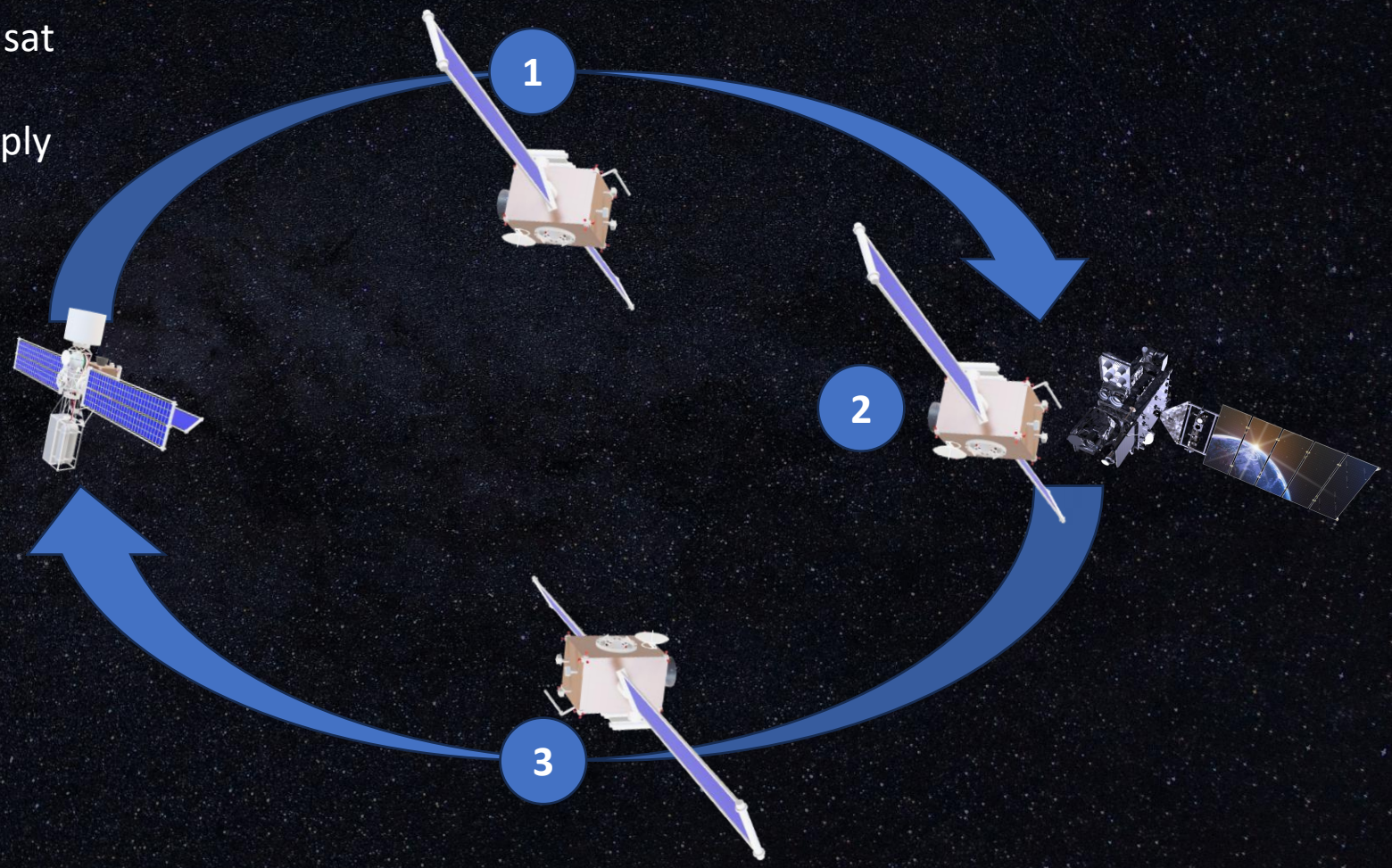
Station Building Phase

Interaction #	OSV	CSS	FSM	PSM	KB1	KB2	ΔMass (kg)	ΔV (m/s)
1	Burns						- 1,047	1842.8
2		Carried		Carried	Burns		- 7,502	1842.8
3					Burns		- 401	1487.8
4			Carried			Burns	- 9,084	1842.8
5						Burns	- 401	1487.8
6	Burns						- 23	50
7	Receives Fuel		Sends Fuel				+ 204	0
8	Burns		Carried				- 204	50

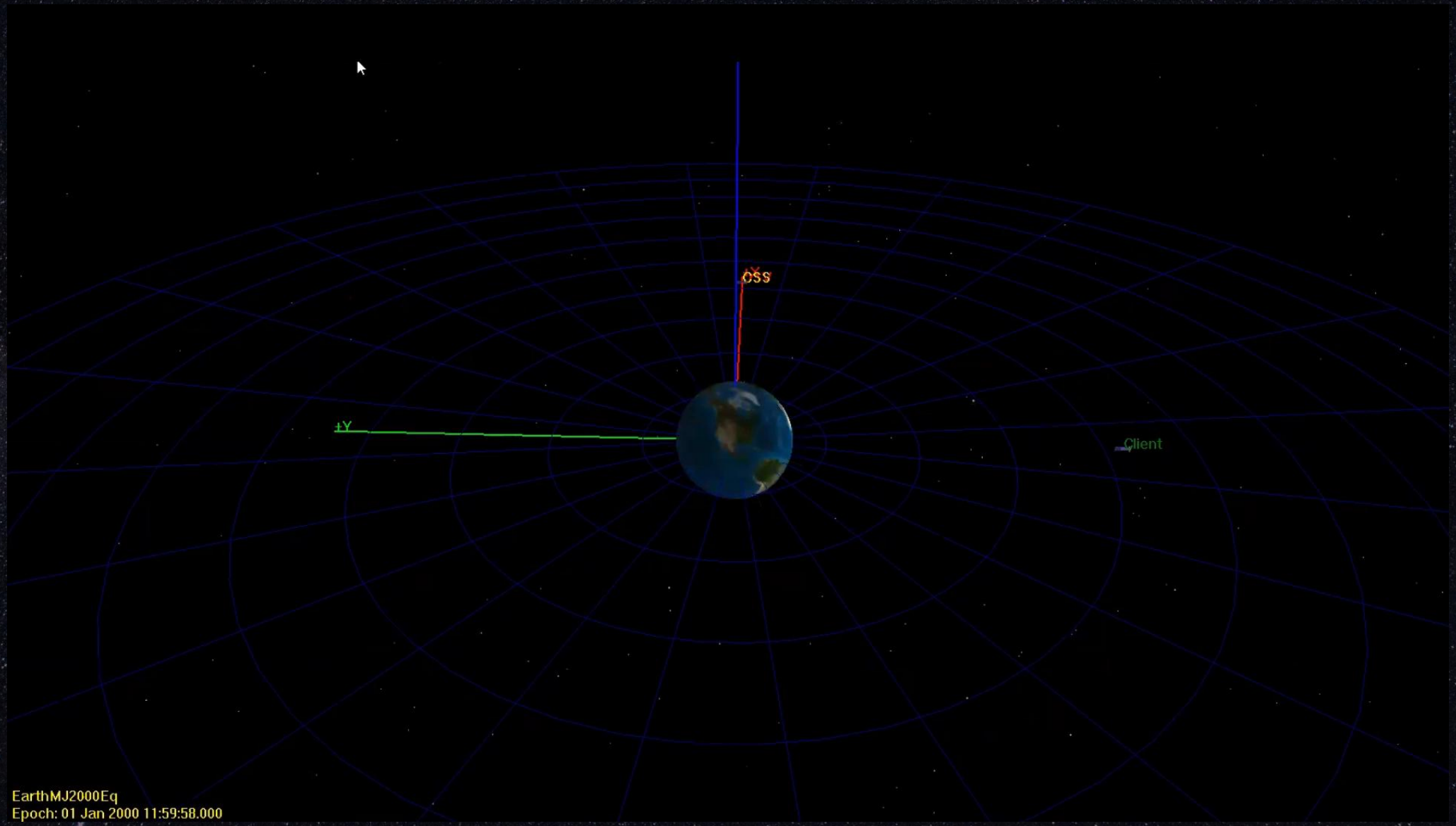
Servicing Operations

Action Summary:

1. Rendezvous and dock to client sat
2. Perform servicing on client sat
3. Rendezvous with CSS for resupply

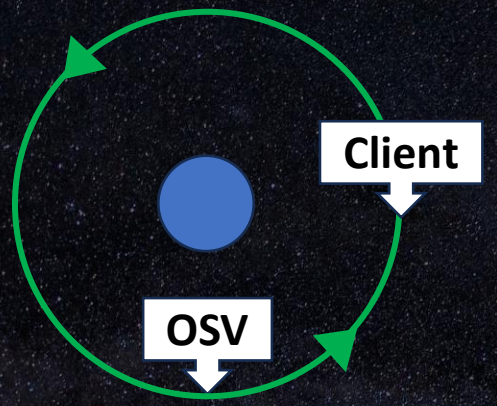


Servicing Operations

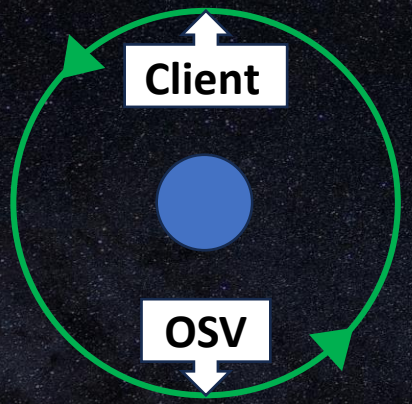


Phasing Rendezvous Cost

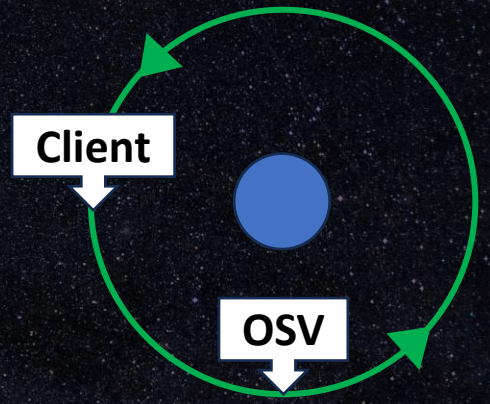
+90° Phase Angle
Client Is Ahead

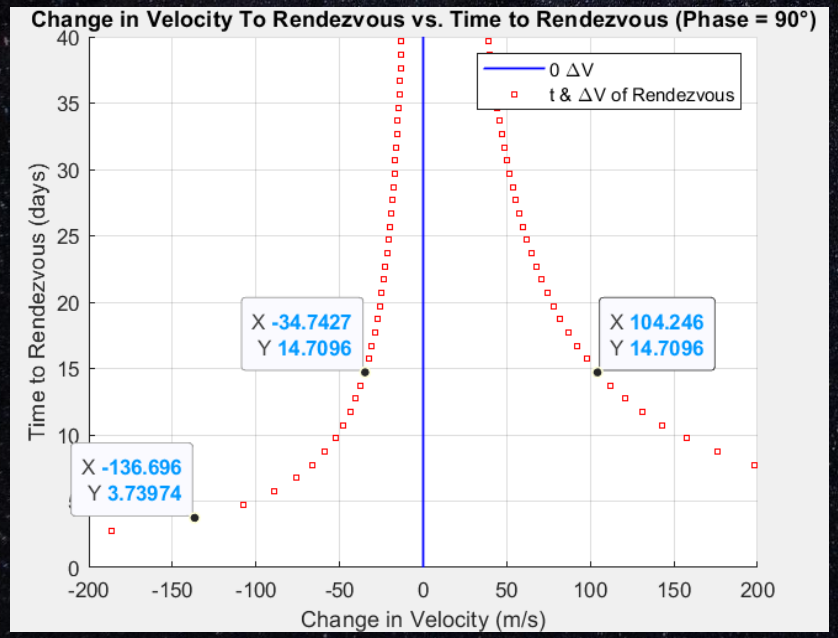


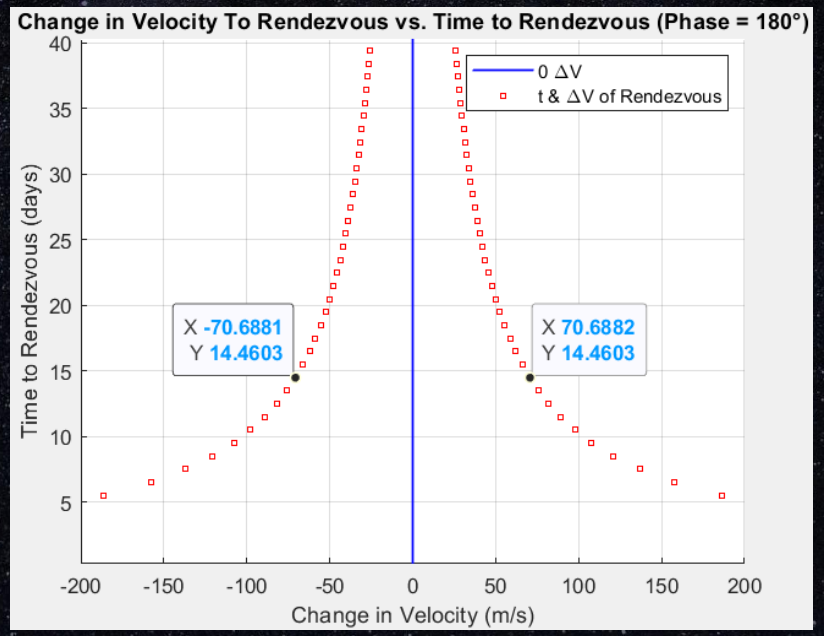
180° Phase Angle
Client Is Neither

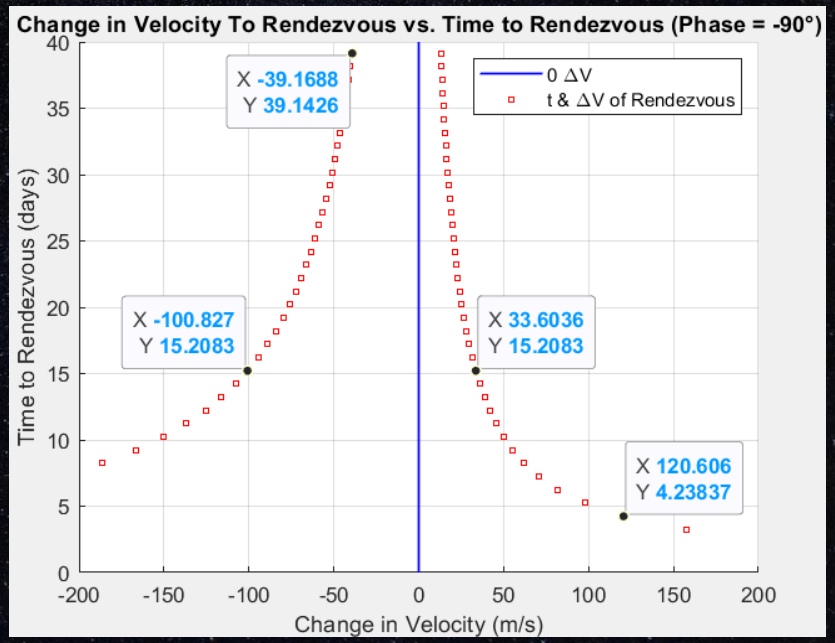


-90° Phase Angle
Client Is Behind



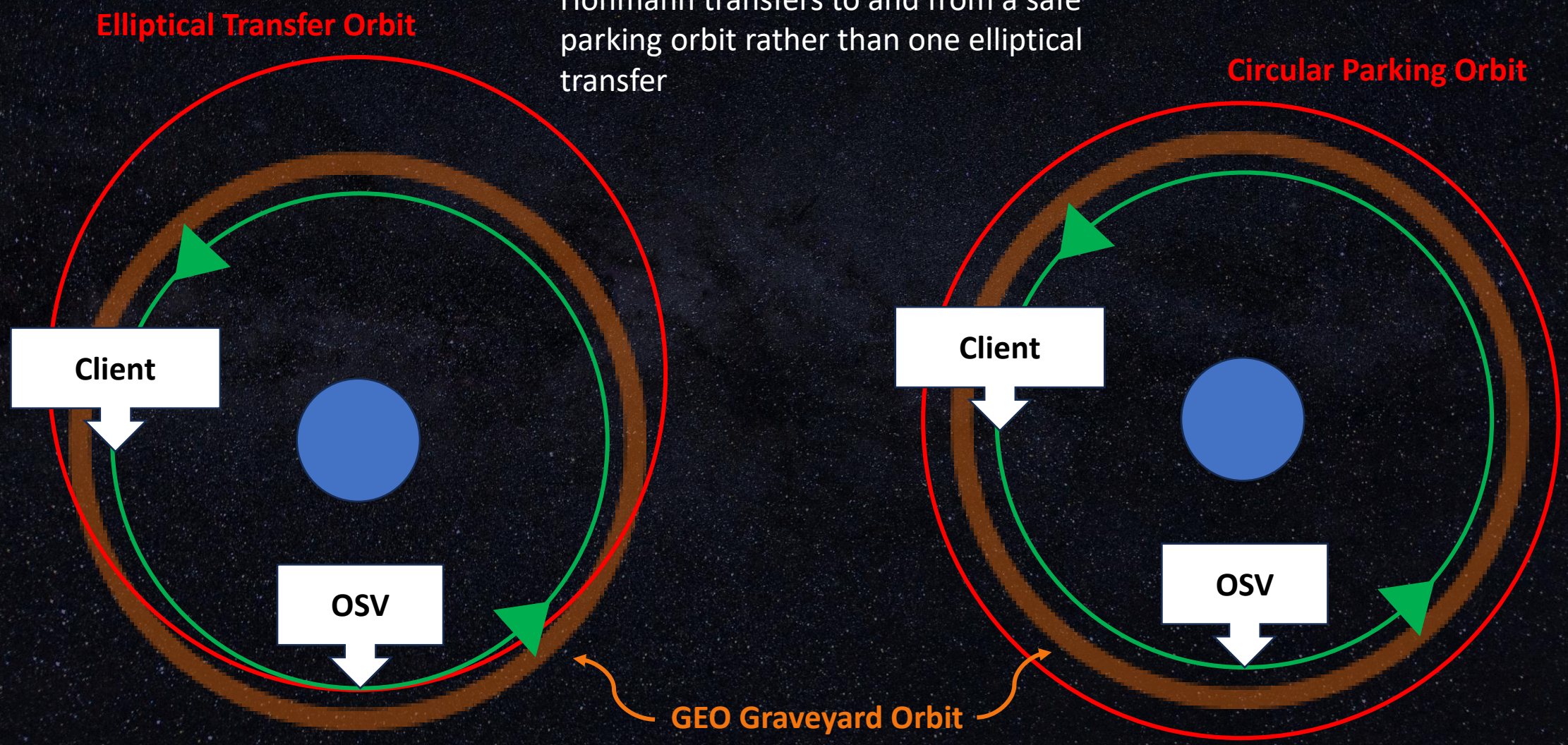




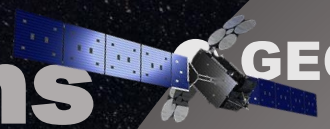


Minimizing Collision Risk

For negative phase angles use two Hohmann transfers to and from a safe parking orbit rather than one elliptical transfer



Servicing Operations



GEOSTAR-3

TEMPO

Target Satellites:

Mission Description:

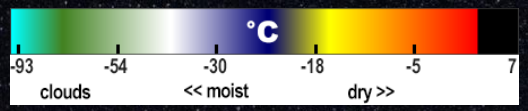
Geostationary Operational Environmental Satellites (GOES)

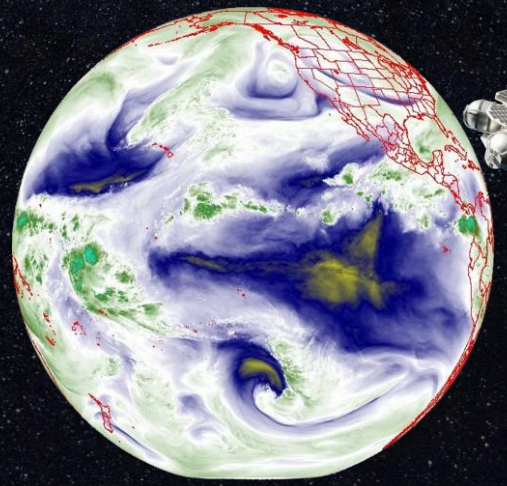
- Provides enhanced imagery and atmospheric readings for NOAA
- GOES 13-15 focus on climate variability and weather patterns
- GOES-R series: GOES-R(16), GOES-S(17), GOES-T(18), and GOES-U(19)
- Advanced Baseline Imager (ABI)
- Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)
- Geostationary Lightning Mapper (GLM)
- Magnetometer (MAG)
- Space Environment In-Situ Suite (SEISS)
- Solar Ultraviolet Imager (SUVI)

GOES

TANKER-002

Orbital Characteristics: Geostationary (35786 km)





GLIMR

Servicing Operations

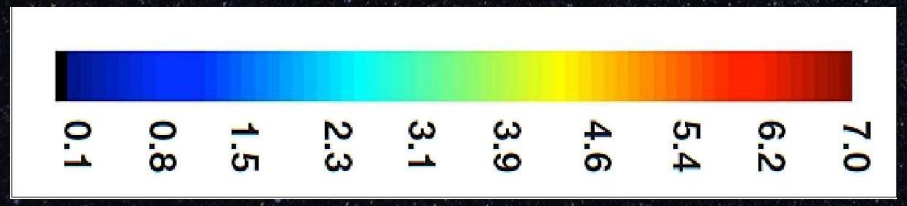
Target Satellites:

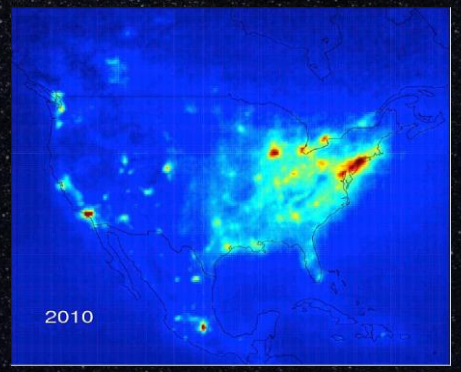
Mission Description:

Tropospheric Emissions: Monitoring of Pollution (TEMPO)

- Launched 2023 on a commercial satellite to GSO
- TEMPO is an imaging Offner grating spectrometer that measures solar backscattered Earth radiance
- Improve emission inventories, population exposure, allow for effective emission control strategies

Orbital Characteristics: **Geostationary (100° W longitude)**





GLIMR

GEOSTAR-3

• TEMPO

GOES

TANKER-002

Servicing Operations

TANKER-002

Target Satellites:

Mission Description:

Northrop Grumman Innovation Systems (NGIS): GEOStar-3

- Communications satellite spacecraft bus, based of GEOStar-2 line
- GEOStar-3 bus provides increased battery capacity and solar array power
- Compatibility with all commercially available launch vehicles and the option to launch with another spacecraft
- Can accommodate payloads of up to 800 kilograms and 8,000 watts

Orbital Characteristics: **Geosynchronous (35786 km)**

Satellite Orders: **Galaxy 33, Galaxy 34, MEV 1, MEV 2, MRV**

GLIMR

GEOSTAR-3

TEMPO

GOES

Servicing Operations

GOES

TANKER-002

GLIMR

GEOSTAR-3

TEMPO

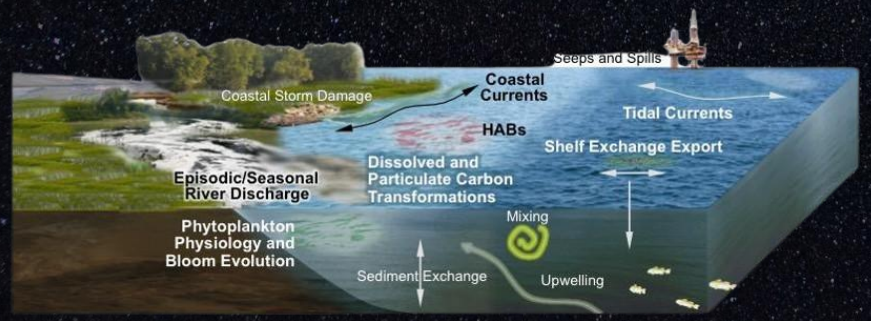
Target Satellites:

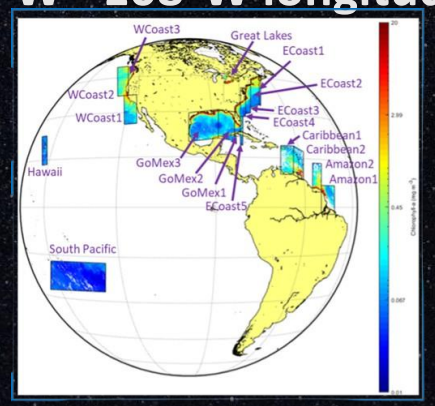
Mission Description:

Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR)

- Monitors coastal ecosystems in the Gulf of Mexico, Southeastern United States coastline, and the Amazon River plume
- Water quality, ecological processes and biogeochemical factors
- Lifecycle of coastal phytoplankton blooms and oil spills
- Main Instrumentation: Hyperspectral Imager (HSI), Landmark Imager (LMI)

Orbital Characteristics: Geostationary (88°W - 108°W longitude)





Servicing Operations

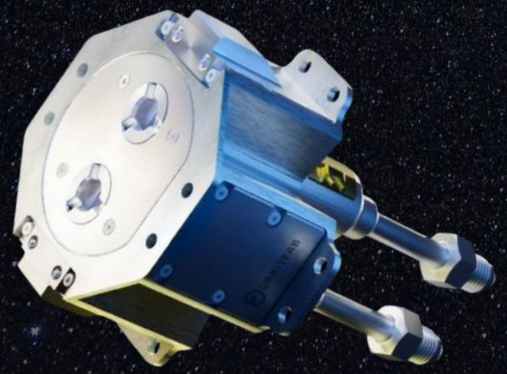
Target Satellites:

Mission Description:

Orbit Fab: Tanker 002

- Tanker-002 will have the capability to store propellant for up to 15 years
- Tanker-001 Tenzing : 35-kilogram small satellite tanker designed to store high-test peroxide
- Tenzing was launched on 30th June 2021 via a SpaceX Falcon 9
- Orbit Fab are also behind RAFTI (Rapidly Attachable Fluid Transfer Interface)

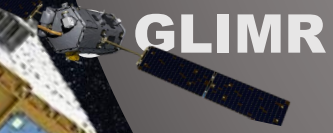
Orbital Characteristics: Slightly off Geostationary Orbit



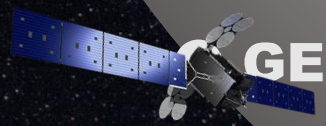
TEMPO

GOES

TANKER-002



GLIMR



GEOSTAR-3

January 2 0 4 1

Rendezvous and Begin Operations

October 2 0 5 0

Expand Operations

Expand Operations

Additional Modules:

3D Printing Module:

- Z-Peek has been successful tested in space environment on LEO and beyond

Create Network of OSVs:

- Expanding operations to LEO will broaden the client base and increase the number of compatible satellites

Kick Stage Refuel:

- It will become space debris after fulfilling its mission
- Reuse for multiple mission

Decommissioning Module:

- Less space debris
- Safe space Environment

Expand Operations

Asteroid Mining

- Improving understanding of the compositional elements of asteroids
- Asteroids hold substantial amounts of Platinum Group Metals
- Feature multiple flexible legs, enabling them to anchor to the asteroid
- Attaching ISRU-produced regolith tiles, provide protection from radiation

Challenge:

- High cost for robot development and launching
- Microgravity and extensive distances complicate asteroid retrieval

Expand Operations

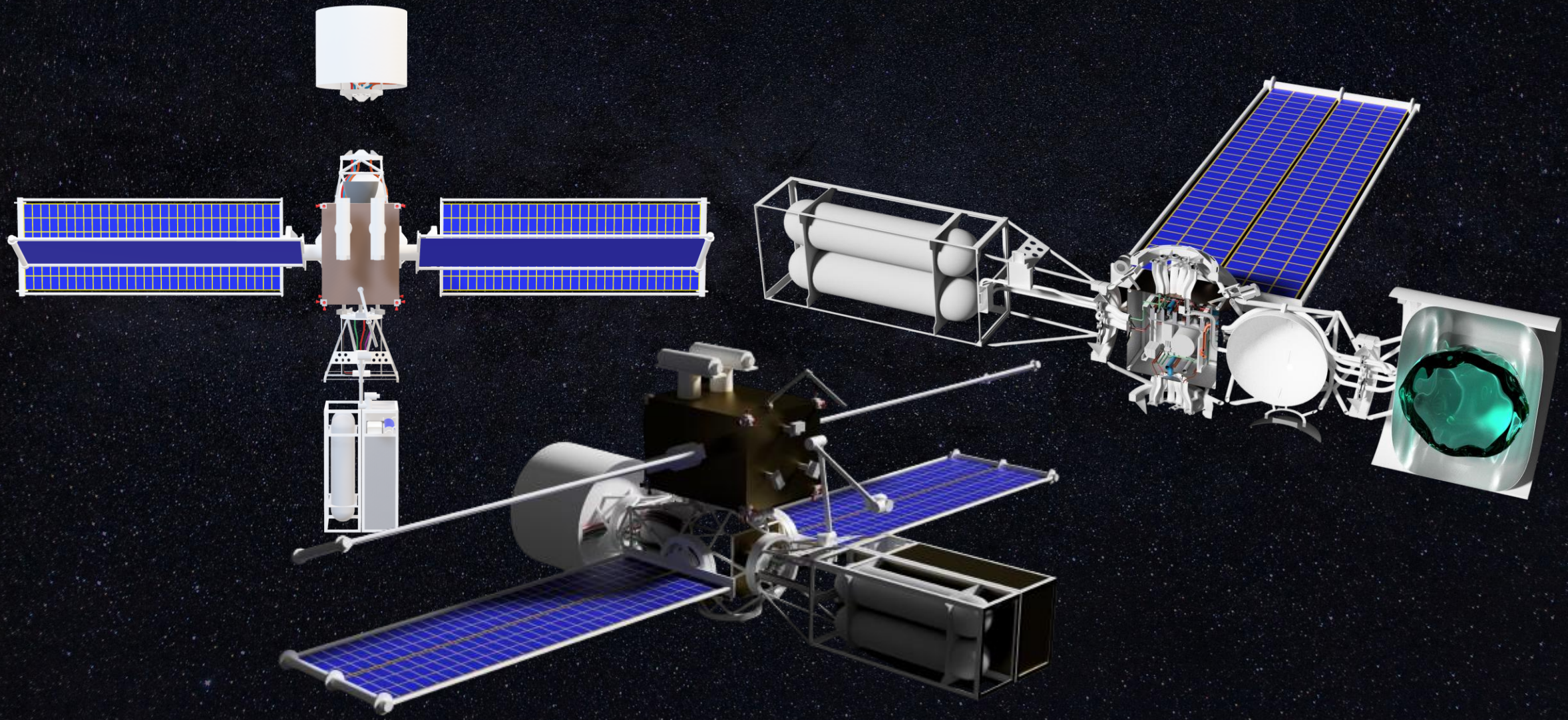
Pharmaceutical Delivery:

International Space Station (ISS) U.S. National Laboratory:

- 453 medication uses were reported per crewmember during space mission
- 4 medications per crewmember per week
- Remote-controlled drug delivery devices
- Improve understanding into drug absorption and metabolism influenced by microgravity condition
- Extent space missions, including Mars exploration and journeys to distant planets

Overview

Questions



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- Author links open overlay panelJiabao Feng a, a, c, b, AbstractAluminized colorless transparent polyimide (CPI/Al) film has a medium absorptivity emissivity ratio, Li, R., Sharma, A. K., Mi, Z., Hu, X., Li, F., Tao, L., Bos, H. L., Longun, J., Rieger, J., Stark, W., Lv, M., Rusu, R.-. D., Mai, A. T. M., Dao, A. T., … Plis, E. A. (2022, March 26). *Property evolution and molecular mechanisms of aluminized colorless transparent polyimide under space ultraviolet irradiation*. Polymer Degradation and Stability. https://www.sciencedirect.com/science/article/abs/pii/S014139102200101X#:~:text=Aluminized%20colorless%20transparent%20polyimide%20(CPI,Al%20films%20are%20rarely%20reported.
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