National Aeronautics and Space Administration

MSFC Advanced Concepts Office Defining the future of space exploration

www.nasa.gov

Advanced Concepts Overview

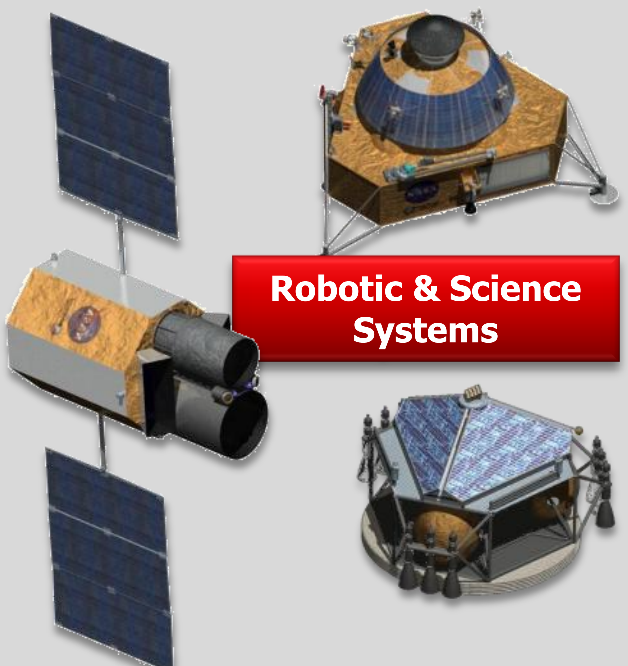
We answer the questions:

Will it work?

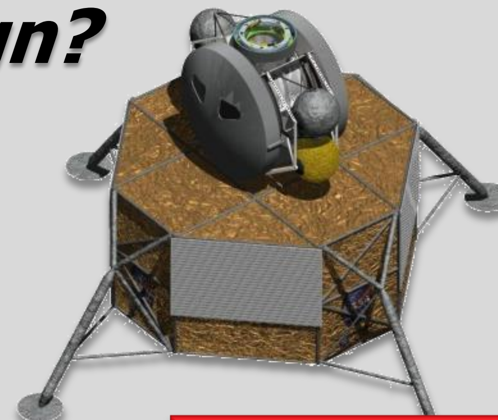
What will it look like?

What is the preliminary design?

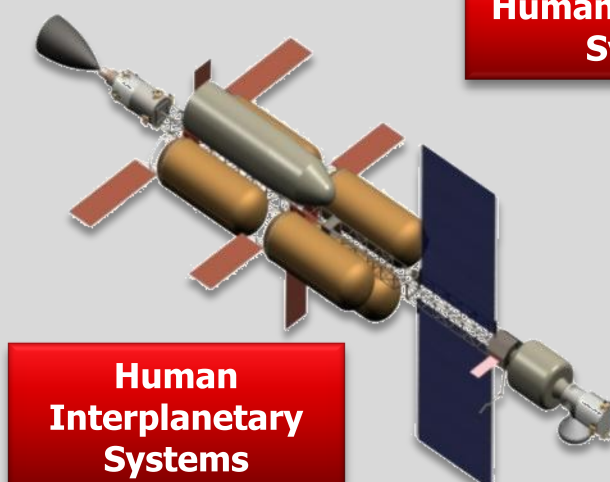
Launch Vehicle Systems



Robotic & Science Systems



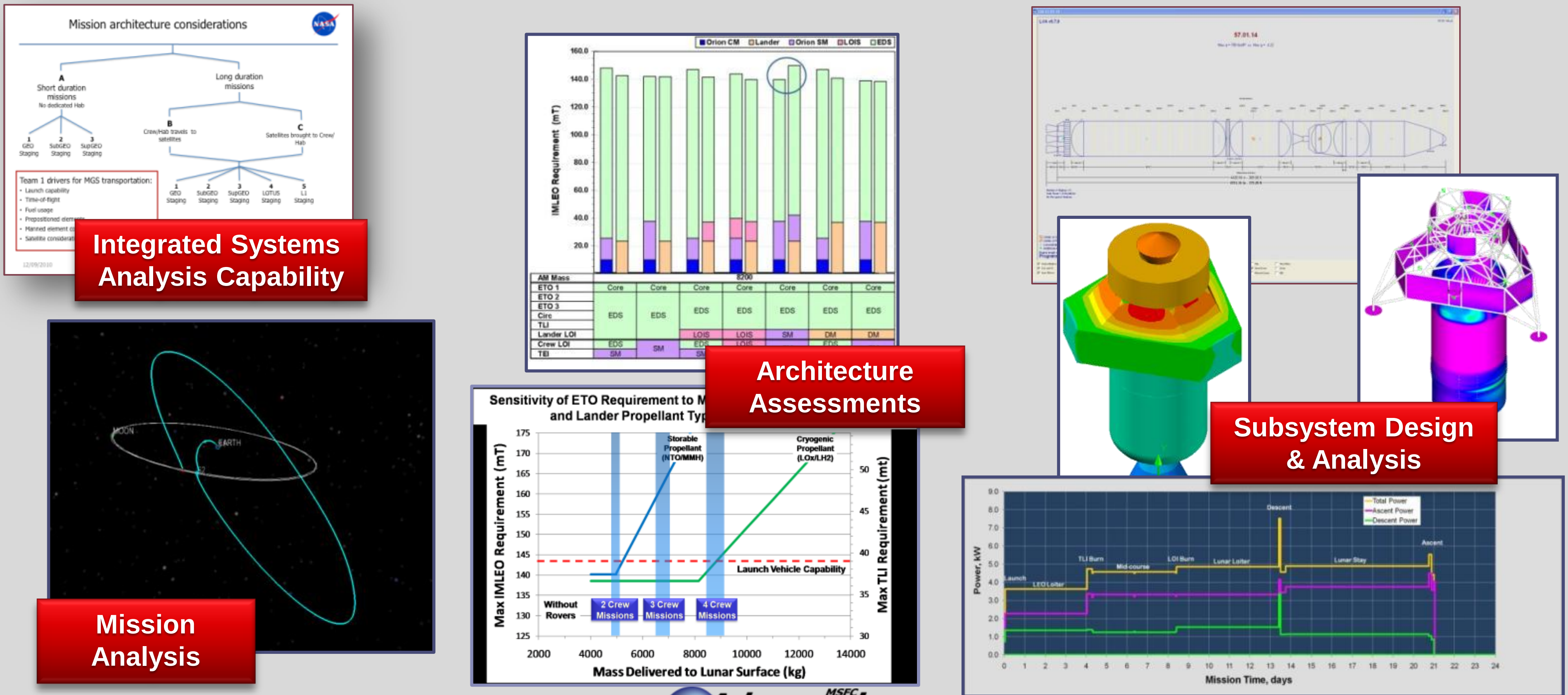
Human Exploration Systems



Human Interplanetary Systems

Advanced Concepts Overview

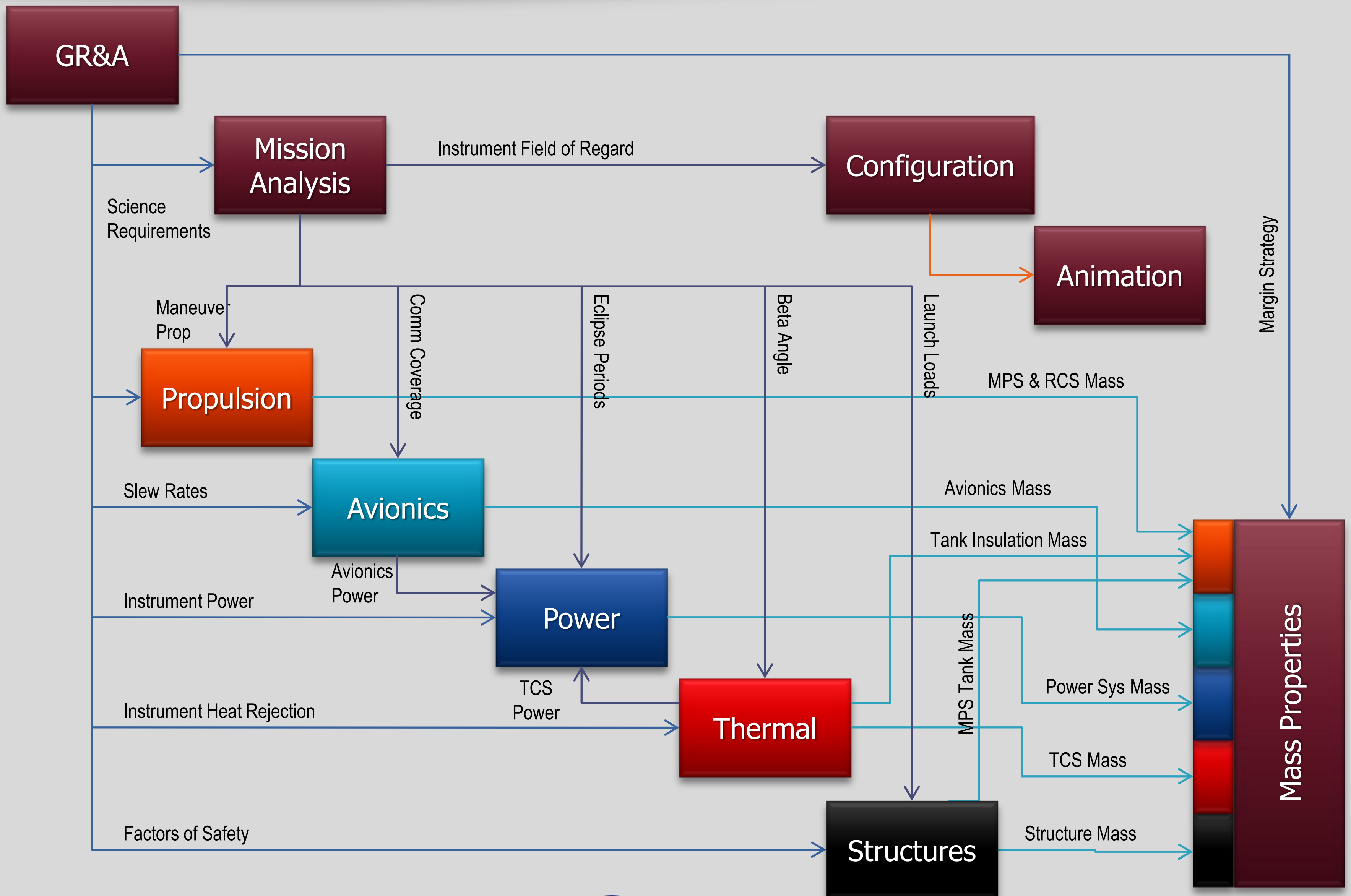
We Utilize Multi-Disciplined Teams Within the Office to Provide Fully Integrated Assessments of Missions and Their Elements



Collaborative Design Team

- The ACO Design Teams are established, co-located teams of systems and design engineers
- Other disciplines or specific expertise are matrixed into the team as necessary
  - Scientific Areas of Interest
  - Programmatic Support
  - Additional Discipline Support

Simplified Vehicle Definition Process



ACO Contributions to the Agency

HEOMD

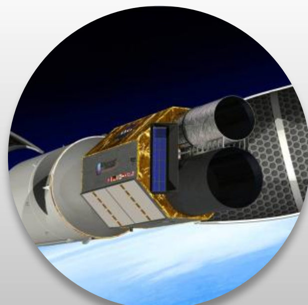
HAT

MSFC Center Development

MSFC Engineering Directorate

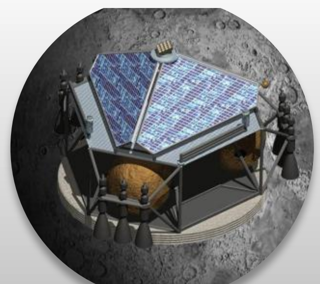
MSFC Science & Mission Systems

Earth-to-Orbit Transportation System Definition



Earth & Planetary Science Concept Definition

Human Exploration Architecture Definition



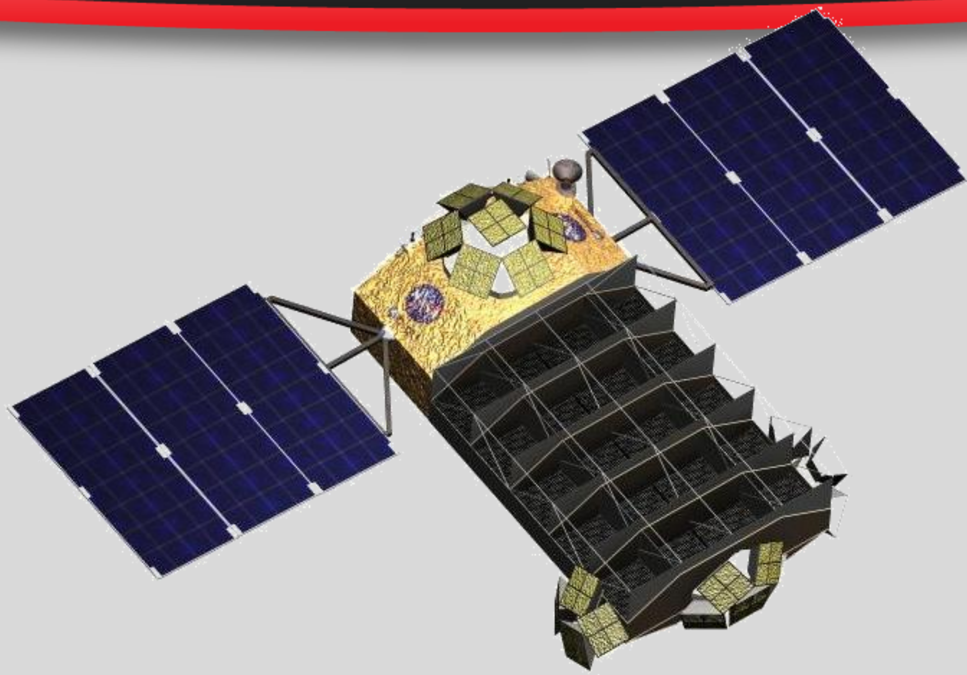
Scientific & Robotic Exploration

In Space Element Definition

Advanced Concepts Products Influence NASA Programs

STUDY EXAMPLES

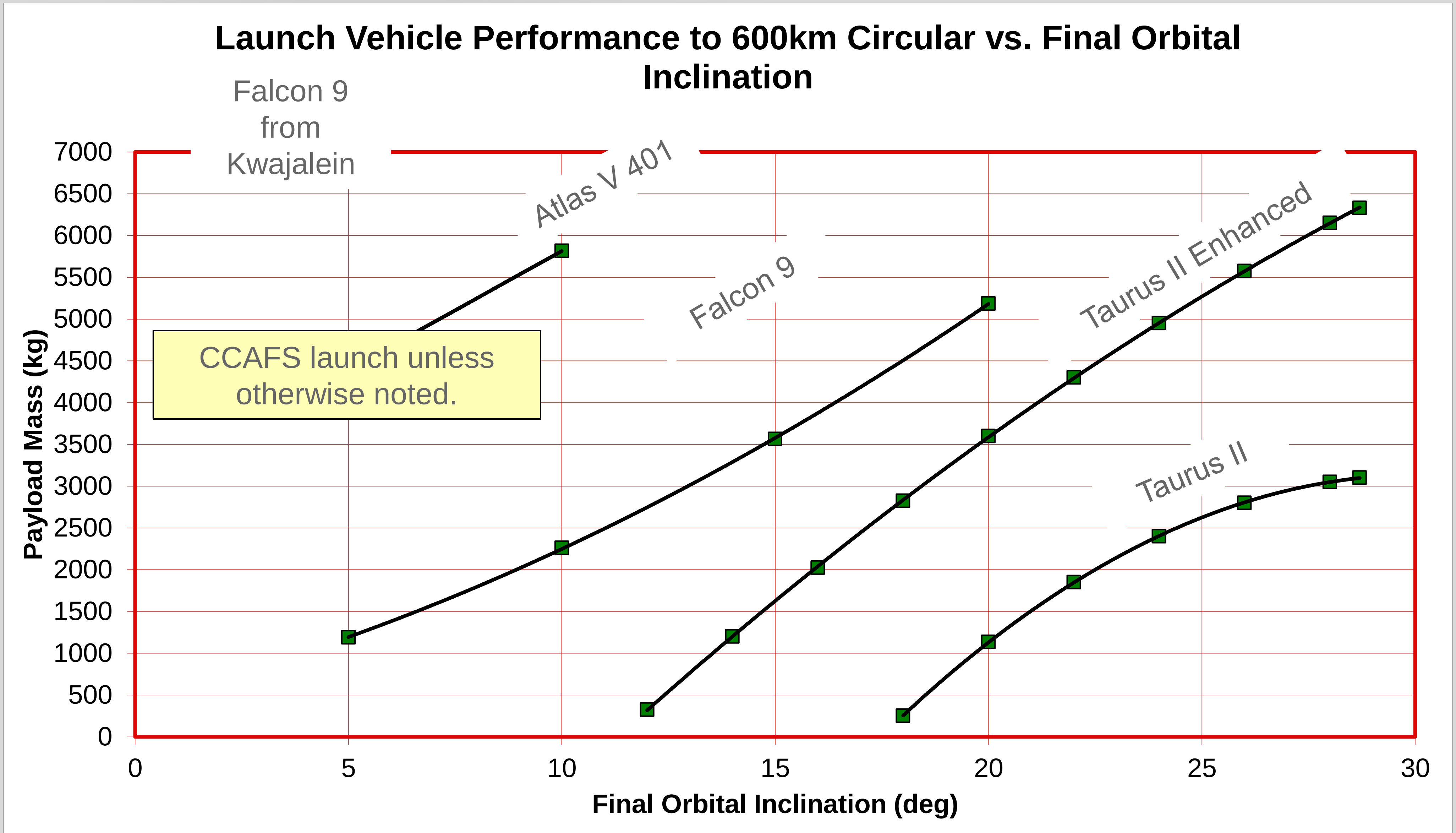
AXTAR: Introduction



- The Advanced X-ray Timing Array (AXTAR) is an X-ray observatory concept combining very large collecting area, broadband spectral coverage, high time resolution, highly flexible scheduling, and an ability to respond promptly to time-critical targets of opportunity.
- It’s mission is to probe the physics of ultra-dense matter, strongly curved space-times, and intense magnetic fields.
- Instruments: (1) the Large Area Timing Array (LATA) is for timing observations of accreting neutron stars and black holes; (2) the sensitive Sky Monitor (SM) acts as a trigger for pointed observations of X-ray transients and also provides sensitive monitoring of the X-ray sky.

Mission Analysis

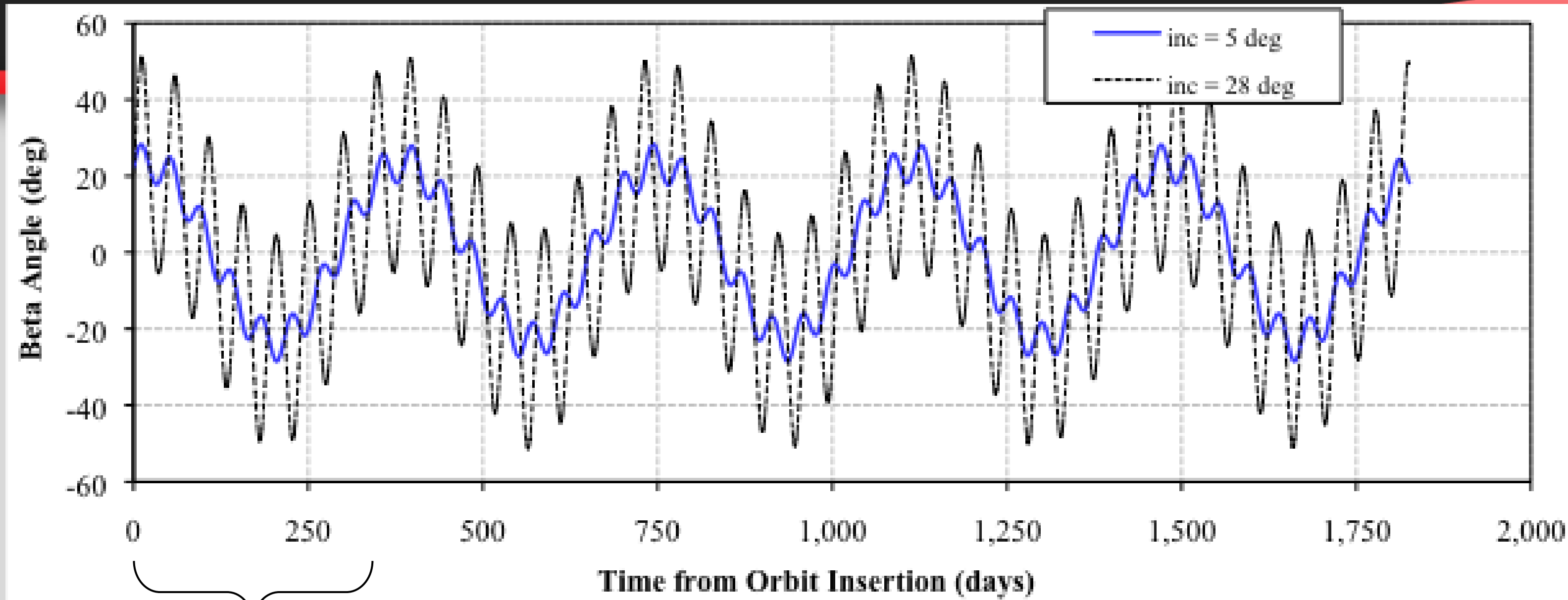
Launch Vehicle Performance (2/2)

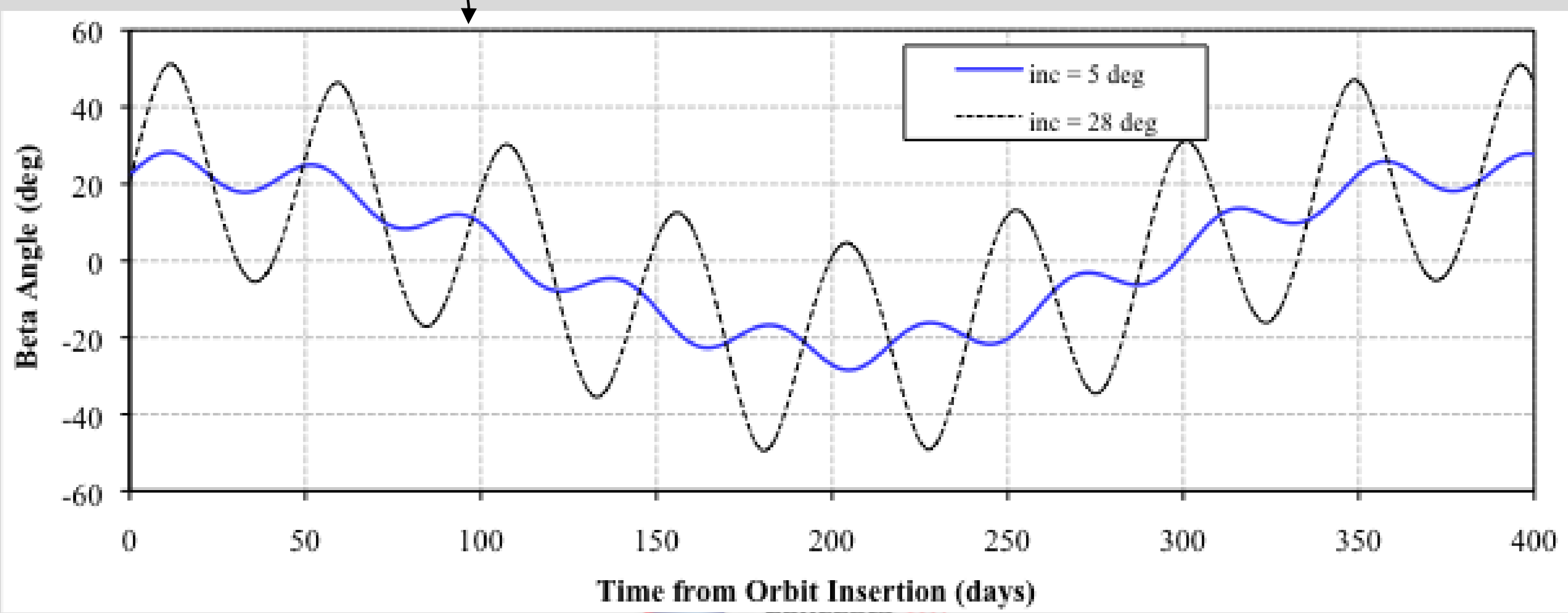


Spacecraft mass will determine final inclination.

Mission Analysis

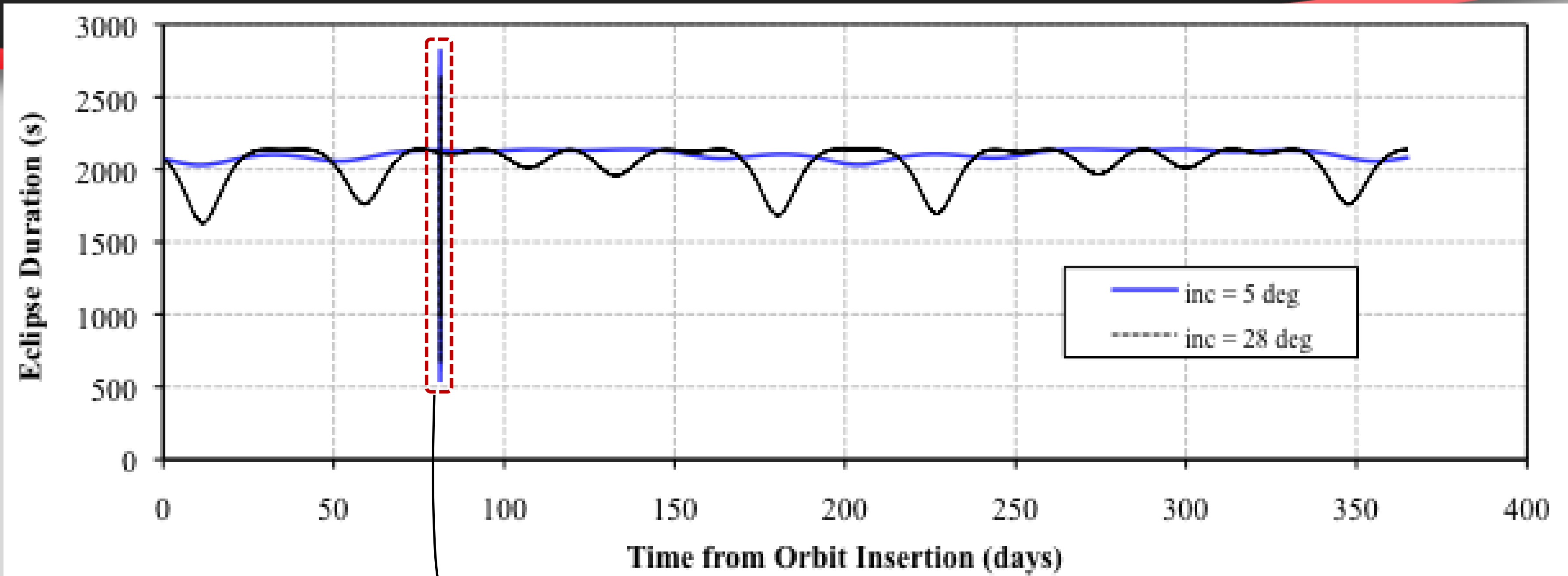
Beta Angle Histories





Mission Analysis

Eclipse Durations



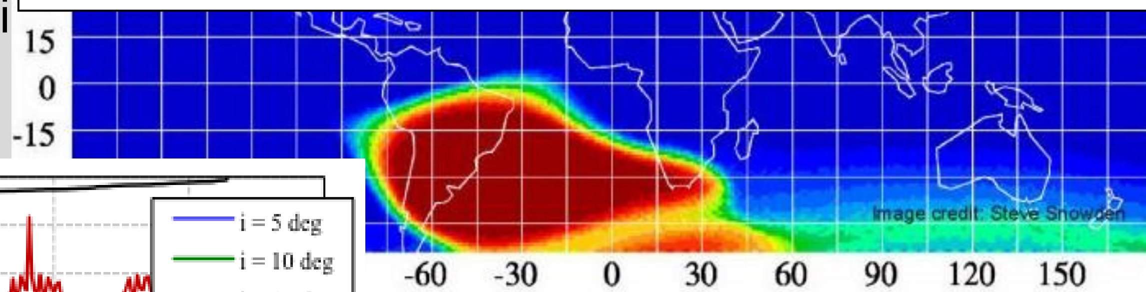
Eclipses by Moon			
Time from Insertion *(days)*	Duration *(s)*	Time from Insertion *(days)*	Duration *(s)*
(i = 5°)		*(i = 28°)*	
81.20	533	81.20	674
81.26	708	81.30	2636
81.30	611	81.40	998
81.31	1199		
81.37	655		

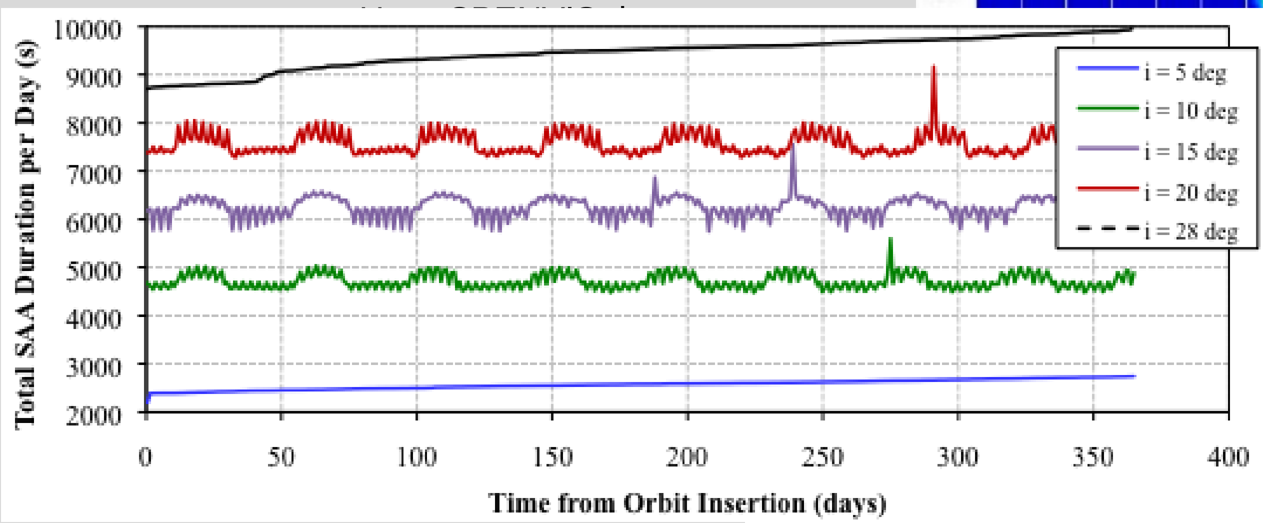
Upon further investigation, shadowing due to lunar eclipses are only partial (i.e. penumbra) and, therefore, can most-likely be neglected.

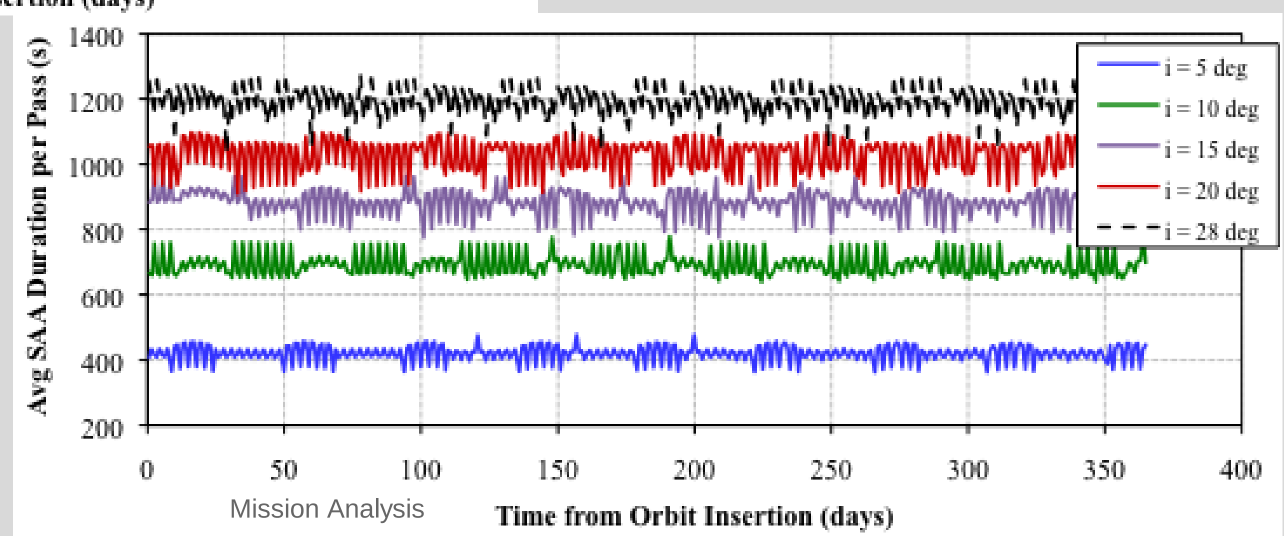
Mission Analysis
South Atlantic Anomaly Passes

- Used script provided by Jens Rar
  AXTAR through the South Atlanti
  - Version: 17-June-09

SAA at ~ 560 km
(http://heasarc.gsfc.nasa.gov/docs/rosat/gallery/display/saa.html)







Mission Analysis
Initial List of Ground Stations

- Initial list of ground stations:
  - ACN (Ascension Island)
  - *AGO (Santiago, Chile)**
  - *CAN (Canberra, Australia)**
  - GWM (Guam)
  - *HAW (Kauai, Hawaii)**
  - *MILA (Merrit Island, Florida)**
  - *PDL (Ponce*
  - South Point (
  - *WGS (Wallo*
  - Kourou (Fre

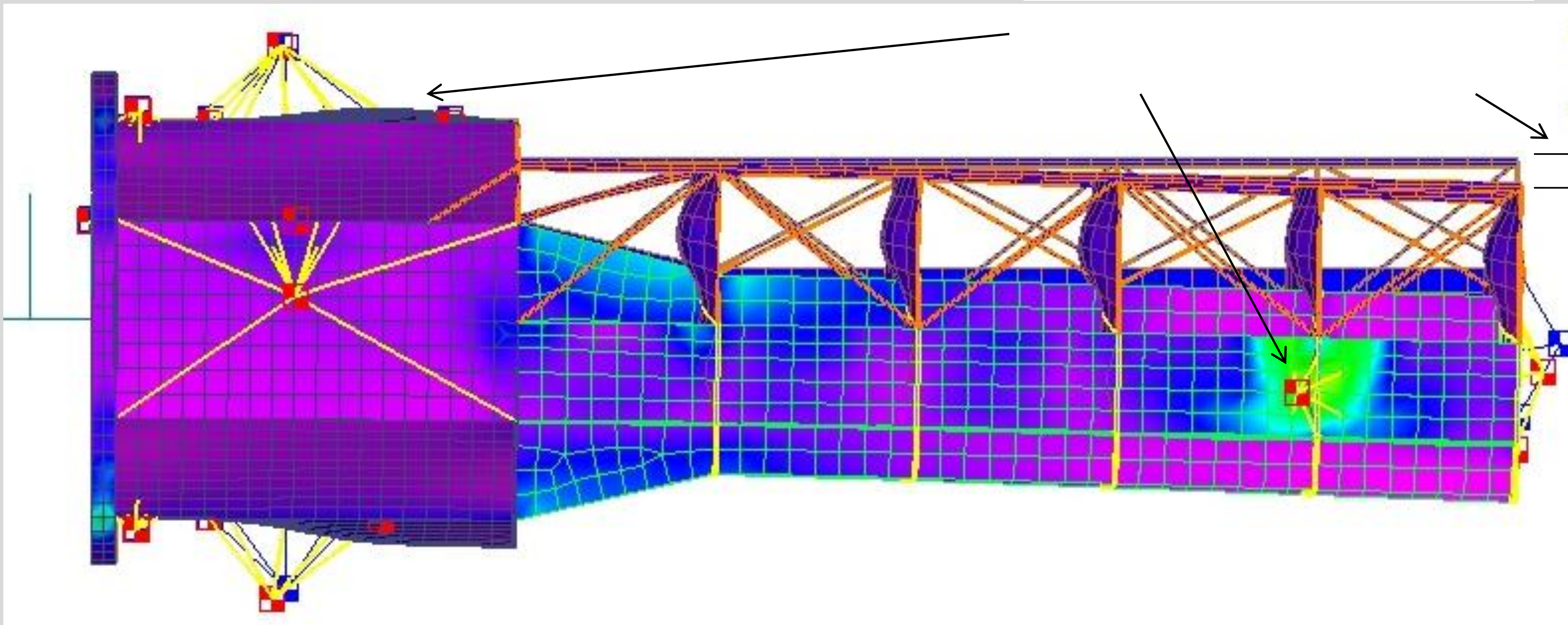
** denotes options that are included in 28.5° orbital inclination case (not 5° case)*

Other ground stations are valid for both 5° and 28.5° orbital inclinations

Minimum allowed contact time = 300 s
Minimum dish elevation = 5°

AXTAR: Structures

Bending displacements < 3 cm

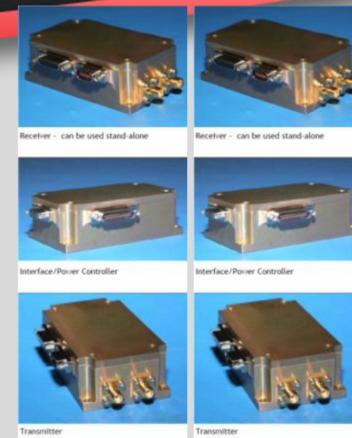


AXTAR: Avionics

Major Components

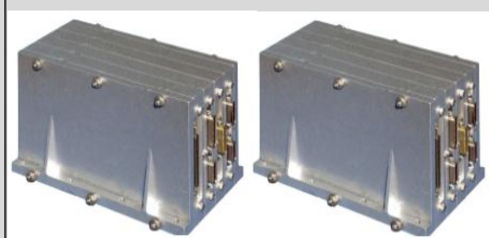
Northrop Grumman
Inertial Measurement Unit LN200
0.15 deg/sqrHr,
sufficient for maneuvers

Ball Aerospace
Star Tracker CT - 602
4 arc sec accuracy, 5” required



AeroAstro
S-band Transceiver
5 W transmitter, able to link TDRSS
Data rate, 60 kbps

Rockwell Collins Telix
Reaction Wheel RSI 68-170
Provides fast slew torque



SpaceMicro Inc.
Proton 200 Computer
4 kg each
Customizable

L3 X-band Transmitter T-728
20 W, provides high data rate 64 Mbps
Can download with two links per day
providing greater ops flexibility

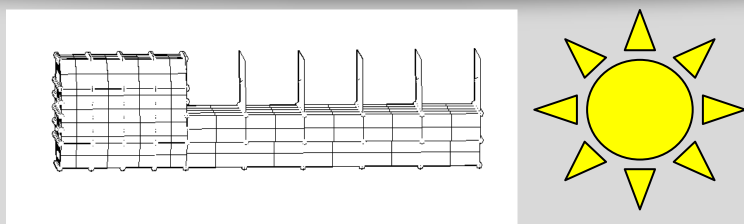
Microcosm MT400-2
To provide attitude torque authority
for long observation times

Surrey Satellite Technology.
High speed Data Recorders
256 Gbits, 150Mbps

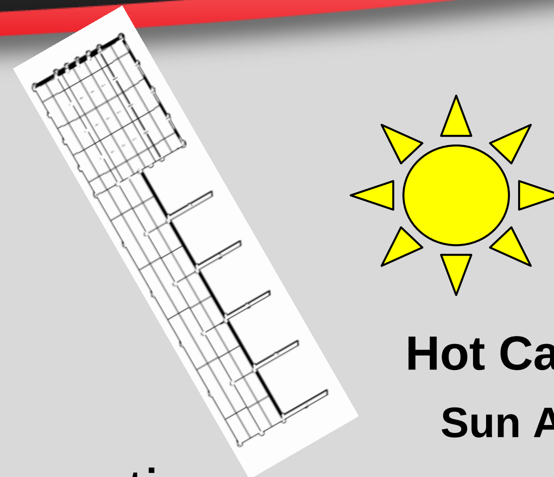
L3 Data Acquisition Unit DTP-503
32 drivers and 32 inputs, 1553 data interface

AXTAR: Thermal

- Cold and Hot Case AXTAR to Sun Orientation



Cold Case,
Beta=0°



Hot Case, Beta=50°

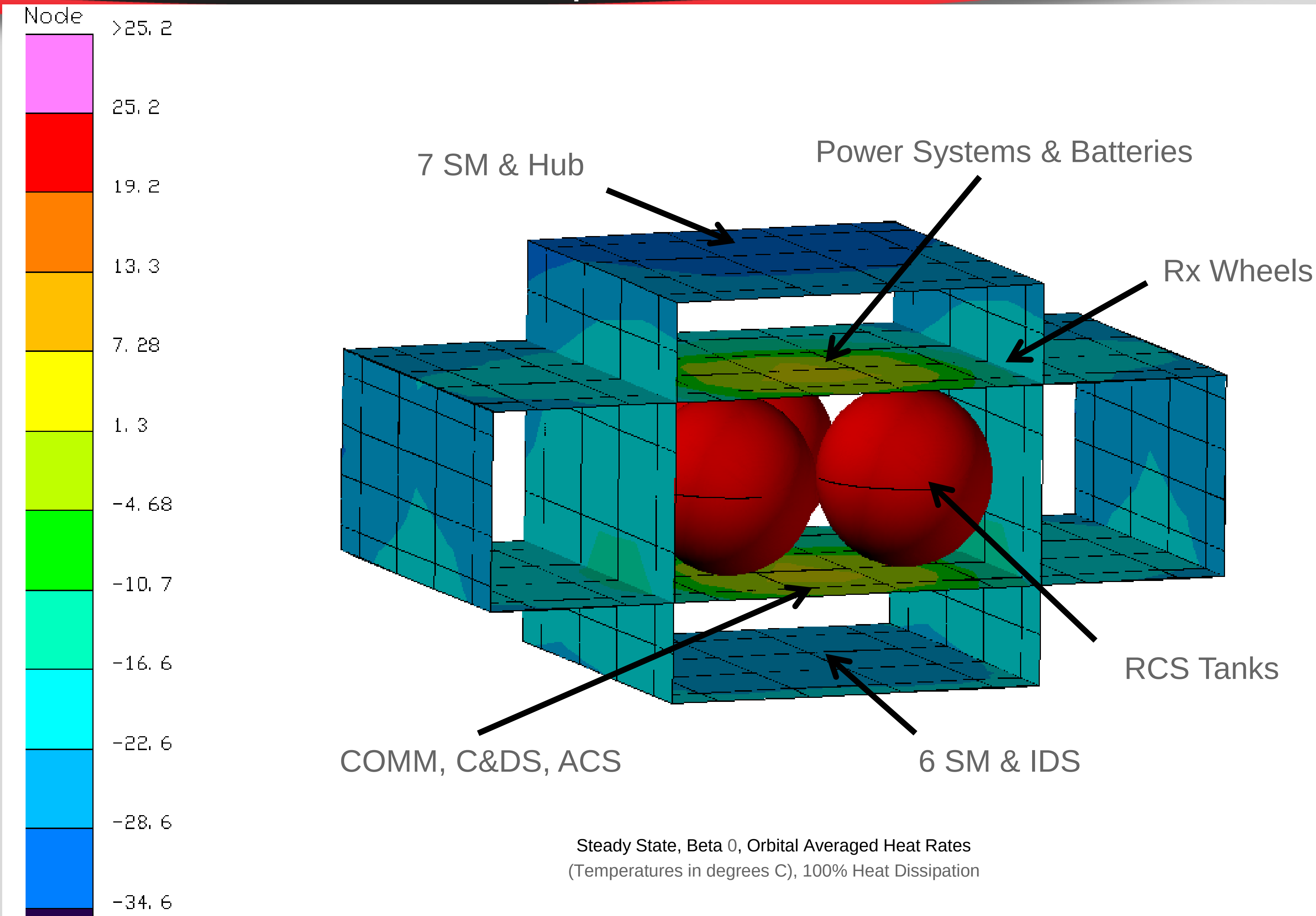
Sun Angle = 30°

◆ Thermal model surface optical properties

	Material	Absorptivity	Emissivity
Spacecraft Bus Internal Surfaces	Black Annodized	.9	.9
Spacecraft Bus External Surfaces	White Paint	.25	.87
Spacecraft Bus Closeouts	White Paint on Beta Cloth Inner Layer, Black Kapton (MLI=5 Layers) ε*=.02	.17 .92	.92 .88
LATA Support Structure	White Paint on Beta Cloth (12 Layers) ε*= .004	.17	.92
LATA Supports	White Paint	.25	.87
LATA Sunshades	White Paint	.25	.87
RCS Tanks	MLI (5 Layers, AlK), ε*=.02	.6	.09

AXTAR: Thermal

- Results - Taurus II – Spacecraft Bus - Cold Case



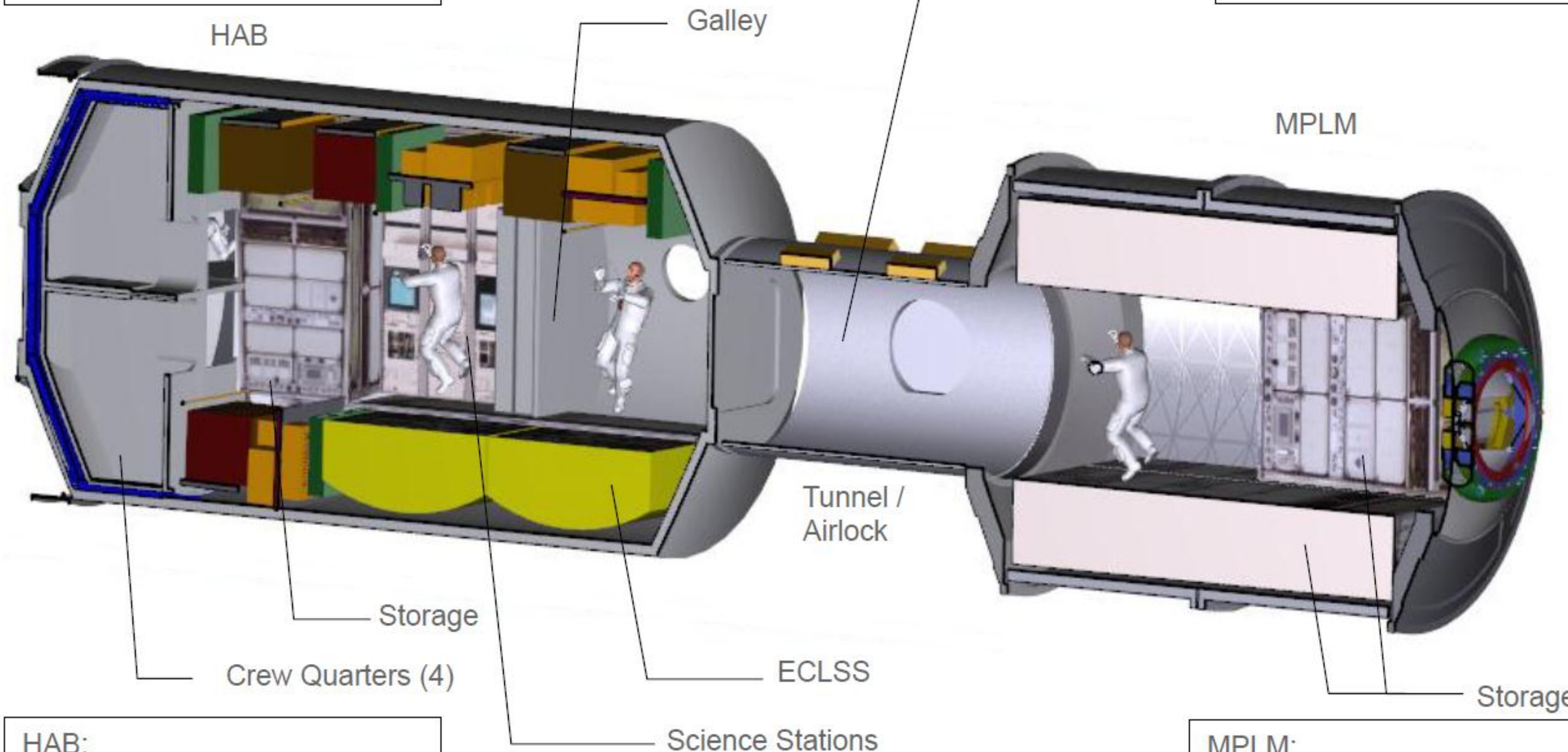
Steady State, Beta 0, Orbital Averaged Heat Rates
(Temperatures in degrees C), 100% Heat Dissipation

Deep Space Habitat

ACO_Border1-02.png

500-day DSH:
Pressurized volume = ~ 193 m^3
Habitable volume = ~ 90 m^3

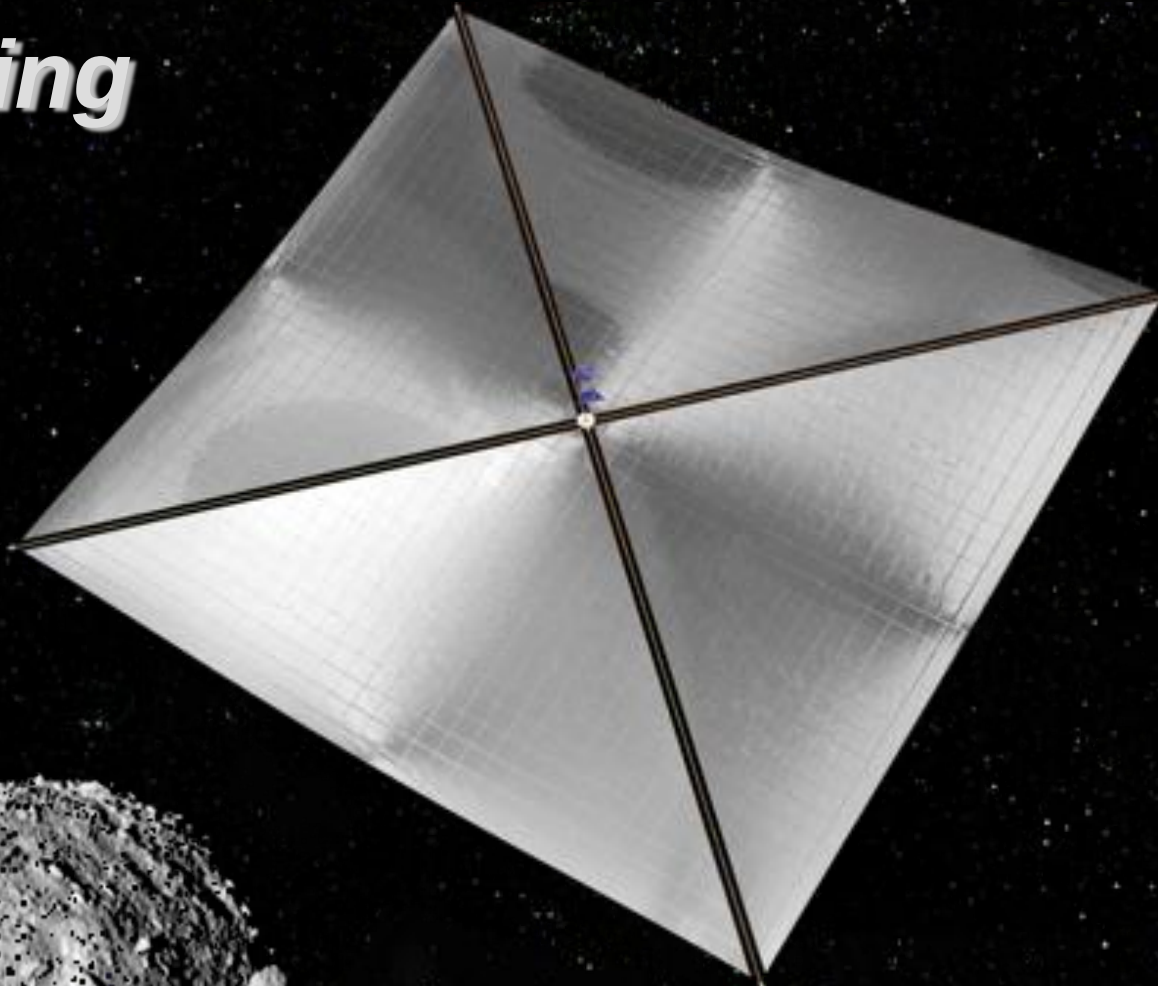
Service Tunnel / Airlock:
Pressurized volume = ~ 10 m^3
Habitable volume = ~ 9 m^3



HAB:
Pressurized volume = ~ 107 m^3
Habitable volume = ~ 56 m^3
Stowage volume = ~ 16 m^3

MPLM:
Pressurized volume = ~76 m^3
Habitable volume = ~ 25 m^3
Stowage volume = ~ 33 m^3

Multiple NEO Rendezvous Using Solar Sails



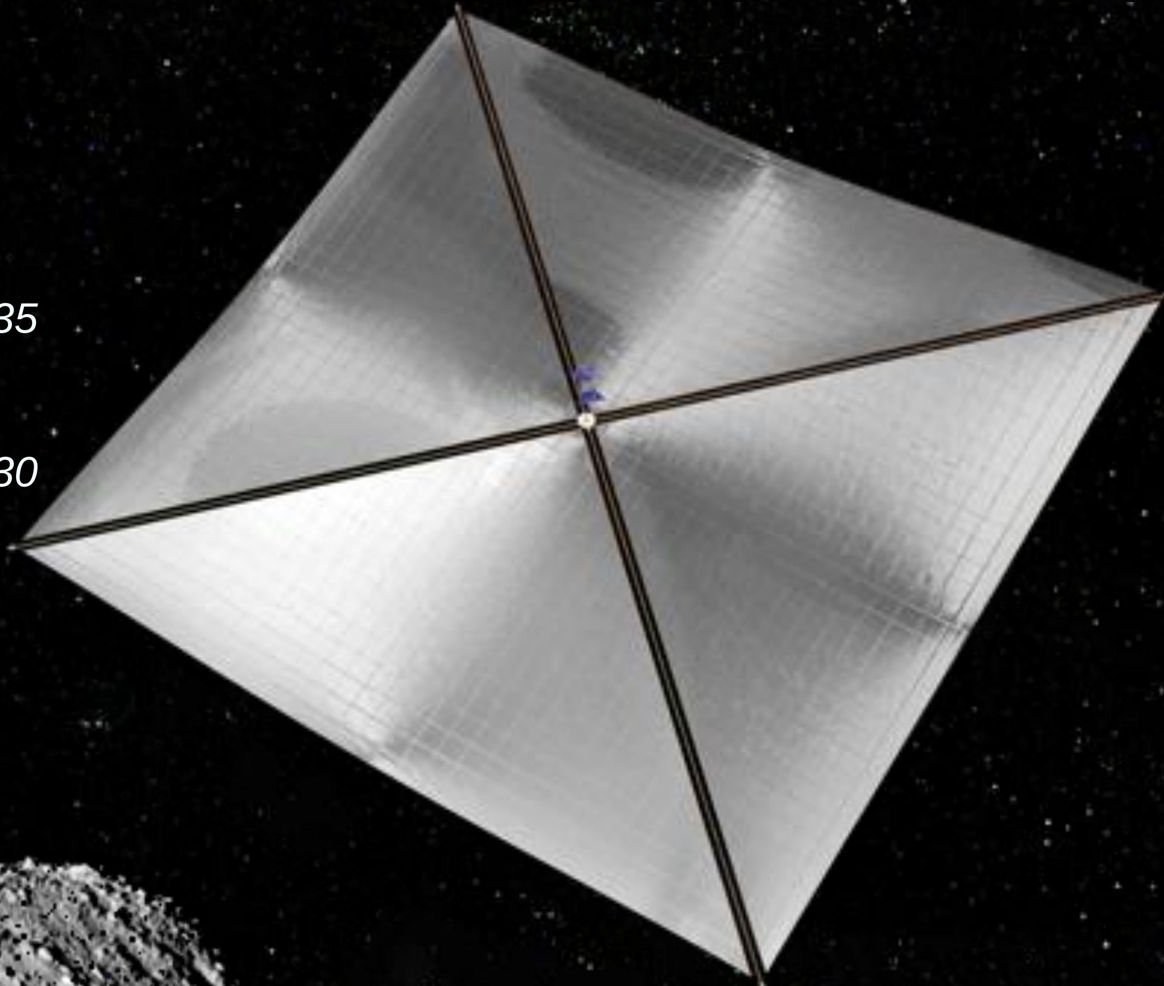
Assess the feasibility of using solar sail propulsion to enable a robotic precursor that would survey multiple Near Earth Objects (NEOs) for potential future human visits

Solar Sail Asteroid Rendezvous Mission:

Departure: *Aug 2017*

Candidate asteroids visited:

NEO	Date	Observation Period
1999 A010	Mar 2019	35 days
Apophis	Dec 2021	30 days
2001 QJ142	July 2023	30 days

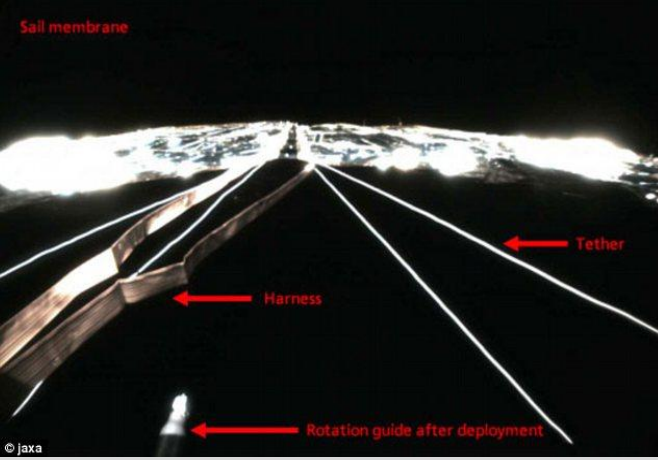


Solar Sail Spacecraft Launch Mass:
328.6 kg

Mass at destination:
228.4 kg

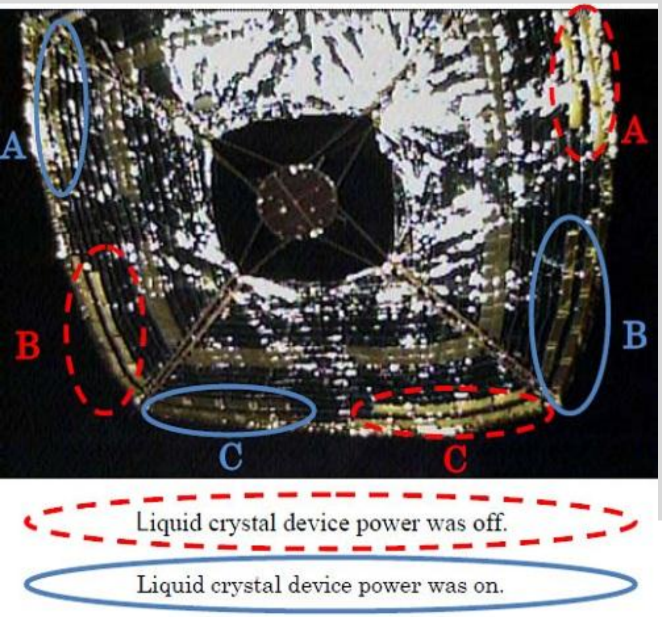
Cost:
$175M, plus launch vehicle and ops

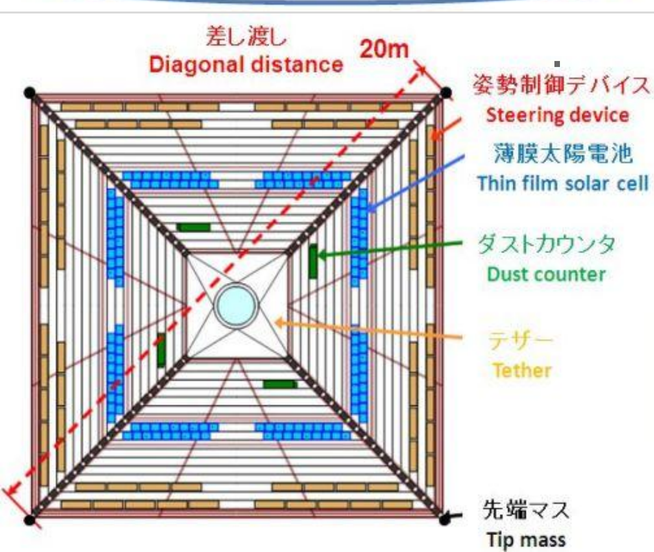
Interplanetary Kite-craft Accelerated by Radiation Of the Sun (IKAROS)

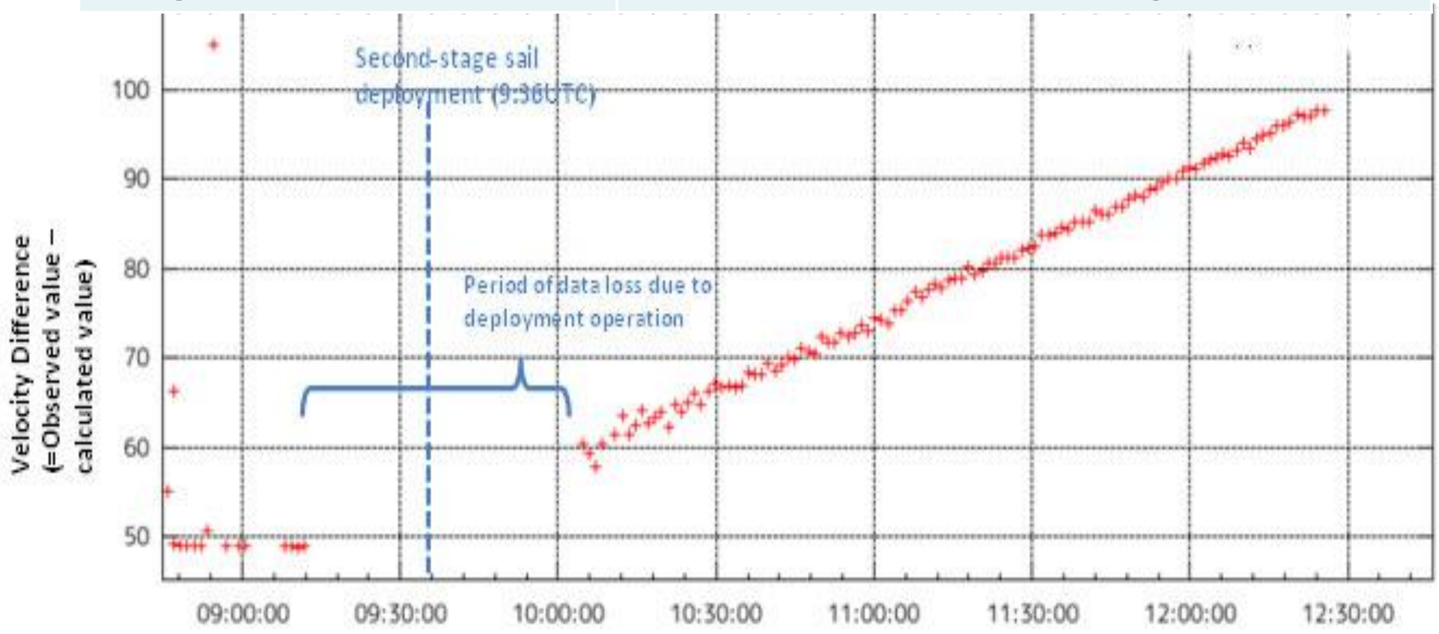


- IKAROS was launched on May 21, 2010
- The Japan Aerospace Exploration Agency (JAXA) began to deploy the solar sail on June 3.
- IKAROS has demonstrated deployment of a solar sailcraft, acceleration by photon pressure and attitude control
  - Deployment was by centrifugal force
  - Sail membrane is 7.5 mm thick

Configuration / Body Diam.	1.6 m x Height 0.8 m (Cylinder shape)
Configuration / Membrane	Square 14 m and diagonal 20 m
Weight	Mass at liftoff: about 310 kg



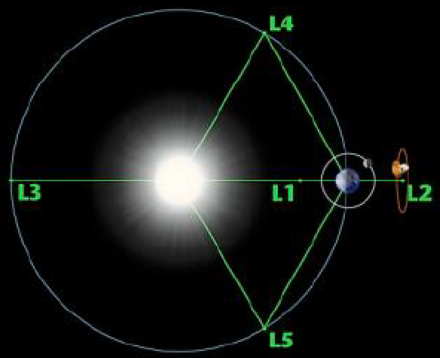




Space Launch: Advancing the Legacy of Human Exploration

SLS is a National Asset

SLS Will Open Up the Inner Solar System for Human Exploration



High-Earth Orbit (HEO)/Geosynchronous-Earth Orbit (GEO)/Lagrange Points:
- Microgravity destinations beyond LEO
- Opportunities for construction, fueling, and repair of complex in-space systems
- Excellent locations for advanced space telescopes and Earth observatories

Mars and Its Moons, Phobos and Deimos:
- A premier destination for discovery: Is there life beyond Earth? How did Mars evolve?
- True possibility for extended, even permanent, stays
- Significant opportunities for international collaboration
- Technological driver for space systems

Earth's Moon:
- Witness to the birth of the Earth and inner planets
- Has critical resources to sustain humans
- Significant opportunities for commercial and international collaboration

Near-Earth Asteroids:
- Compelling science questions: How did the Solar System form? Where did Earth's water and organics come from?
- Planetary defense: Understanding and mitigating the threat of impact
- Potential for valuable space resources
- Excellent stepping stone for Mars

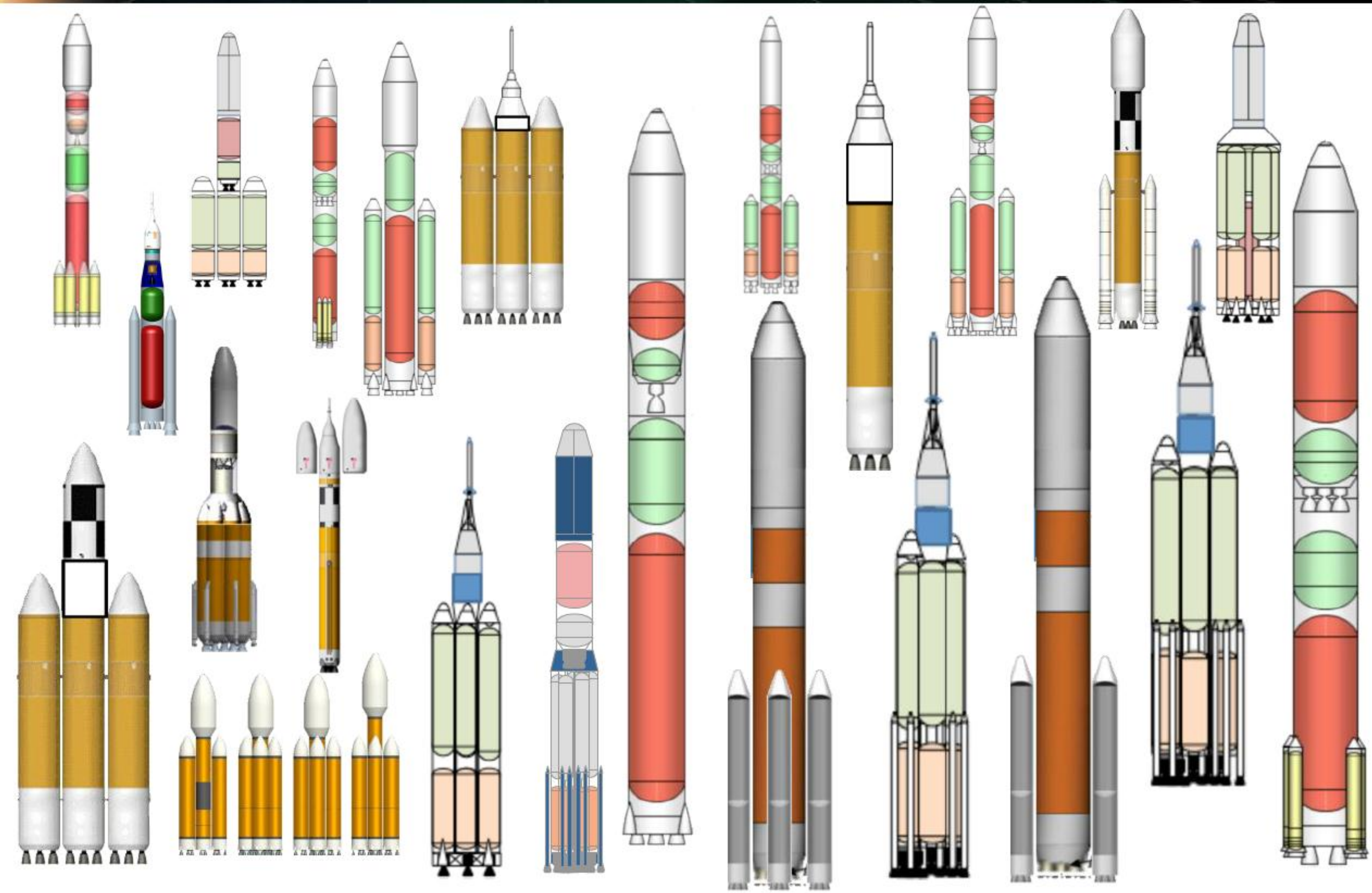
Increasing Our Reach and Expanding Our Boundaries

The Space Launch System Objectives

- **Safe: Human-Rated**
  - Loss of Crew/Loss of Mission: TBR
- **Affordable**
  - Constrained budget environment, with no planned escalation
  - Maximum use of common elements and existing assets, infrastructure, and workforce
- **Initial capability: 70 tonnes (t), 2017–2021**
  - Serves as primary transportation for Orion and exploration missions
  - Provides back-up capability for crew/cargo to ISS
- **Evolved capability: 130 t, post–2022**
  - Offers large volume for science missions and payloads
  - Modular and flexible, sized to mission requirements

SLS First Flight in 2017

Many Solutions: One Affordable Answer

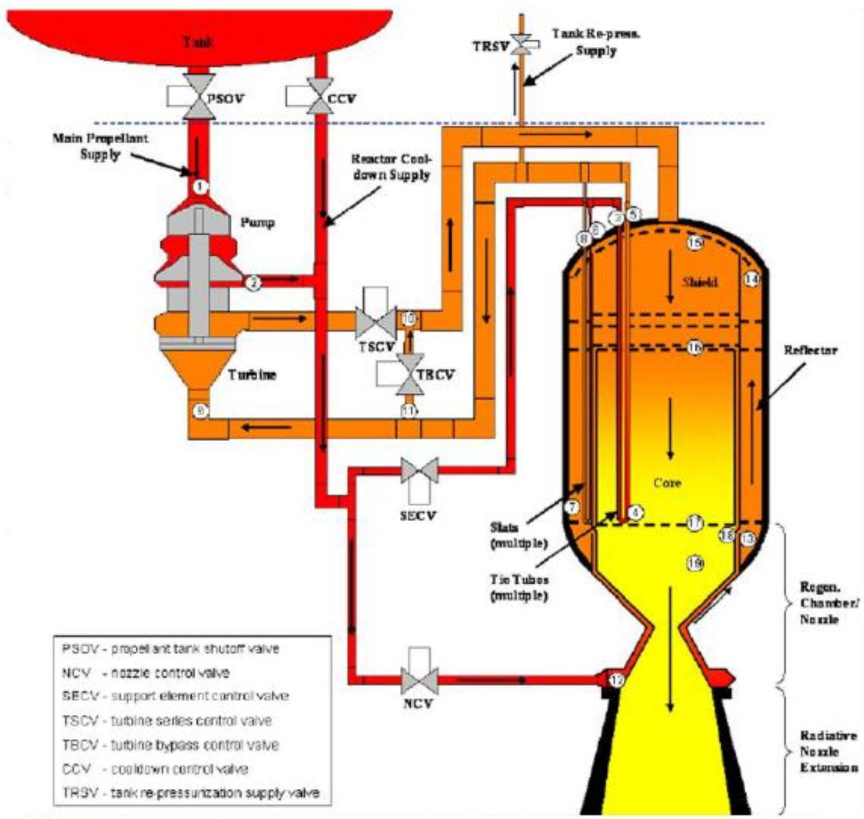


"This enterprise is not for the faint of heart."

—Wayne Hale

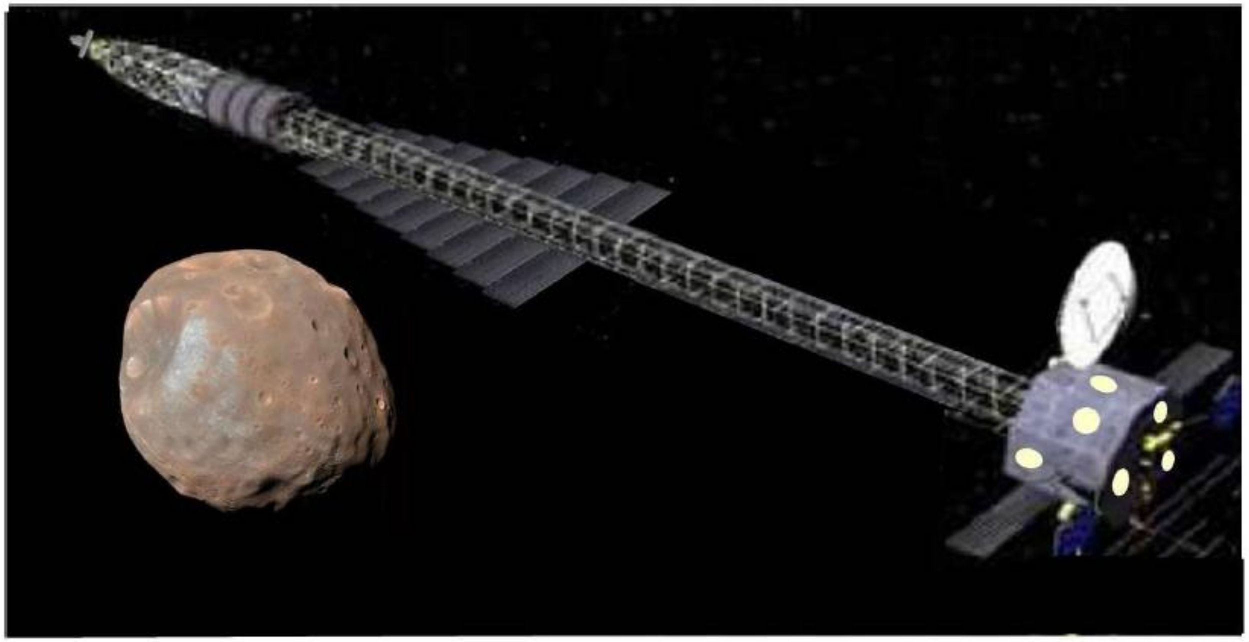
AES Nuclear Cryogenic Propulsion Stage

- MSFC led activity to establish viability of Nuclear Thermal Propulsion for future NASA exploration missions
- ED04 is supporting mission architecture analysis and vehicle concept performance trade studies



Fission Fragment Rocket Engine Mission Concept

- MSFC (EV) led NIAC study to define technology characteristics and evaluate mission concepts for dusty plasma Fission Fragment propulsion technology
- ED04 is performing mission analysis and spacecraft concept design



Example: Cryostat

CRYOSTAT Mission Overview

DESCRIPTION

- This project will demonstrate the technologies needed to store, monitor, access, pre-position and transfer cryogenic propellants for large cryogenic propellant storage and transfer systems that will support future space mission and commercial market opportunities

APPROACH

- Critical technologies are demonstrated in one mission utilizing one vehicle

APPLICATIONS

- Human exploration missions beyond LEO utilizing:
  - Large cryogenic stages w/ long duration space exposures
  - Propellant transfer for the earth departure stages (EDS)
- Supporting infrastructure for commercial space options (e.g., for satellite servicing, propellant transfer, refueling depots, tourism, etc.)

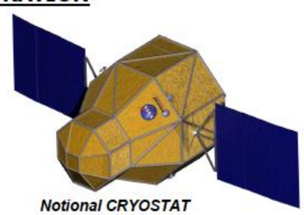
BENEFITS

- Enabling large cryogenic propulsion stages for Human exploration
- Options for use of commercial operations to support explorations missions (through use of multiple propellant transfers)

TECHNOLOGY ELEMENTS

- Tank Thermal Control
- Tank Pressure Control
- Cryogenic Propellant Transfer
- Liquid Acquisition
- Mass Gauging
- Leak Detection

CONFIGURATION



Notional CRYOSTAT Configuration

YOSTYAT Concepts

Lite Maximum Size
on Falcon 9 Capability)

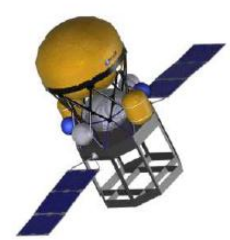
:	4.6 m
	4 m
ass:	316 kg
ass:	2000 kg
CFM System	3816 kg
Bus	3020 kg
Total Mass:	**6836 kg**

CFM System

Spacecraft Bus

CPS-Lite Minimum Size
(Based on 2 Month Mission)

Length:	4.2 m
Dia.:	2 m
LH2 Mass:	250 kg
LOX Mass:	580 kg
CFM System	2350 kg
Bus	1300 kg
Total Mass:	**3650 kg**



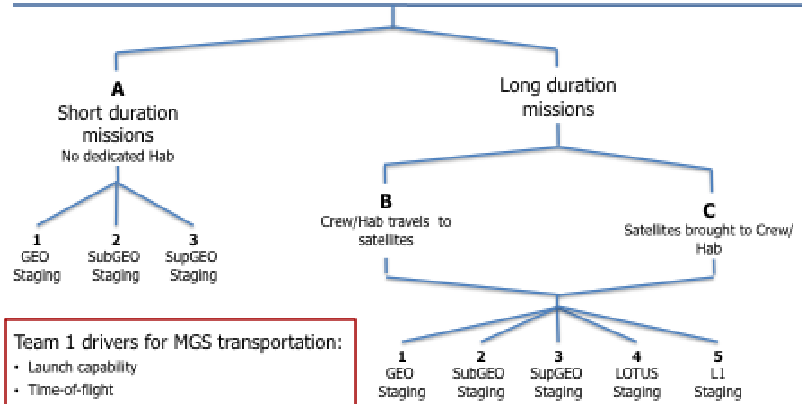
CPS-Pathfinder
(2 Month Mission)

Element	Mass
LH2	250 kg
Total CFM Payload	791 kg
Spacecraft Bus	471 kg
Launch Mass	**1262 kg**

Spacecraft Size
Length = 2.4 m
Dia. = 1.9 m

Example: Manned GEO Servicing

Mission architecture considerations

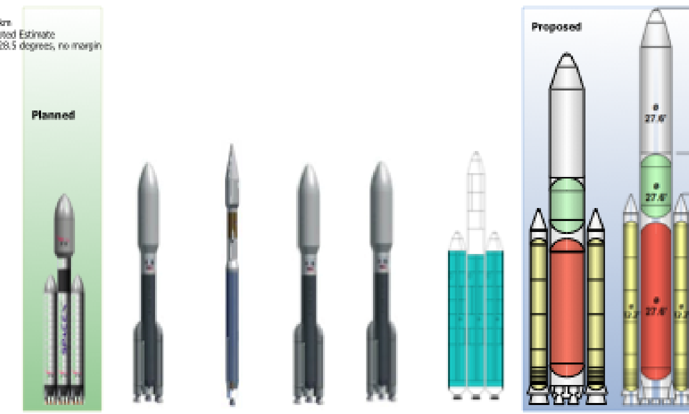


Team 1 drivers for MGS transportation:

- Launch capability
- Time-of-flight
- Fuel usage
- Prepositioned elements
- Manned element considerations
- Satellite considerations

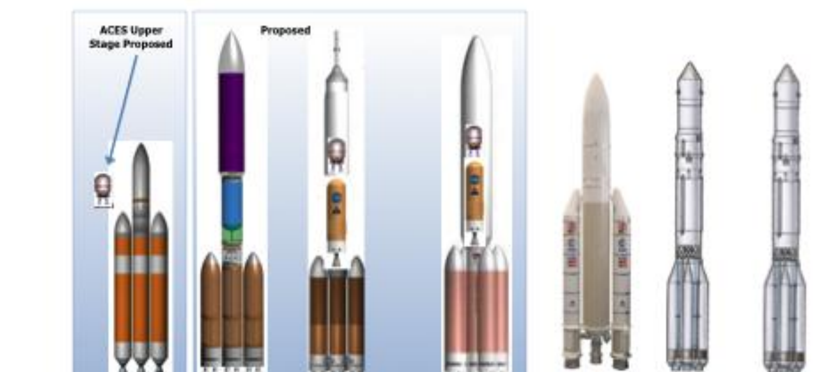
Potential launch vehicles for MGS missions (1 of 2)

1 – KSC ELV performance, 200 km
2 – SpaceEx Falcon9 Heavy Quoted Estimate
3- 30 nmi X 130 nmi insertion, 28.5 degrees, no margin



Launch Vehicle	Falcon 91	Falcon 9 Heavy2	Atlas 5011	Atlas 4011	Atlas 5411	Atlas 5511	Delta IV Heavy1	In-line Shuttle C3	HEFT SDV3
LEO pyld (kg)	9,115	32,000	8,140	9,695	15,930	17,415	23,060	79,900	108,600
GTO pyld (kg)	3,475	19,500	3,860	4,740	7,850	8,540	12,575	~37,800	51,395
GEO pyld (kg)	~1,750	~9,750	~1,930	~2,375	~3,925	~4,270	6,160	~21,735	29,556

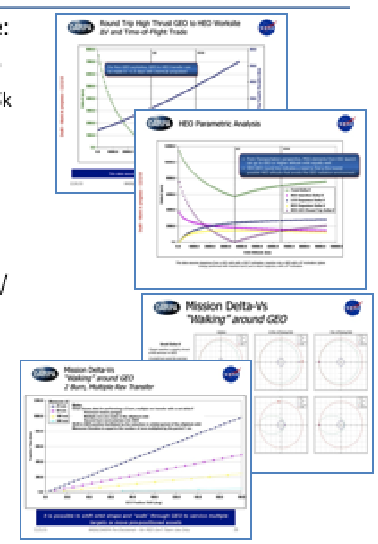
Potential launch vehicles for MGS missions (2 of 2)



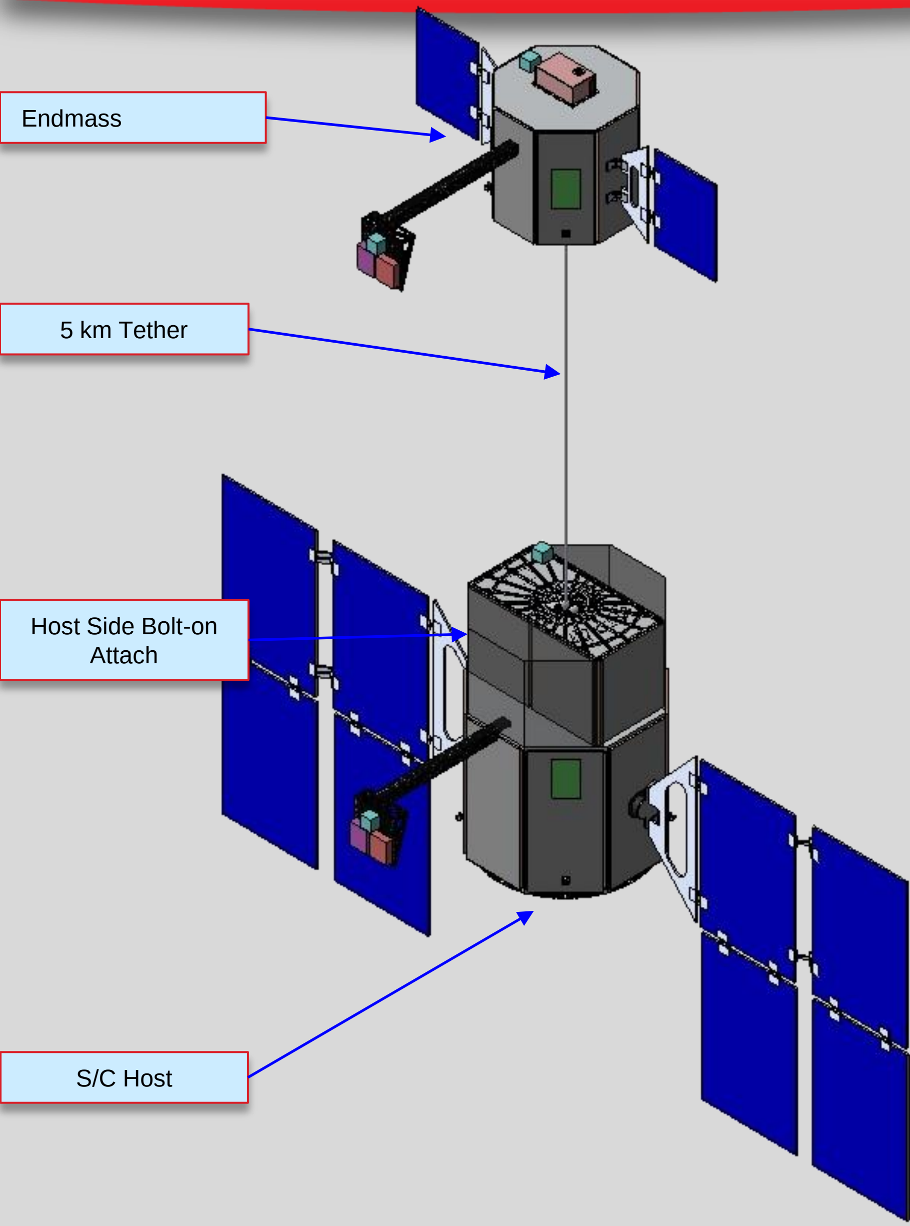
Launch Vehicle	DIVH w/ACES US	Atlas V Phase 2	Atlas V Phase 2 w/Ares 1 2nd stage ACES 3rd	Atlas V Phase 3 w/Ares 1 2nd stage/ACES 3rd	Ariane 5 ECA (A5 w/blkII cryo US)	Proton K	Proton M
LEO pyld (kg)	35,000	77,900	80,000	120,000	20,000	20,800	22,000
GTO pyld (kg)	19,500	43,200	~40,000	~60,000	10,500 (12,000 with SECB upgrade)	5,100	6,000
GEO pyld (kg)	~9,750	24,100	~23,000	~34,500	~5,250	2,600	3,500

Astrodynamic mission architecture trades

- Radiation environment, ΔV vs. orbital altitude:
  - EVA radiation environment improves above GEO
  - Elements transiting from LEO to GEO or HEO-65k require minimal increase in fuel usage
- Chemical propulsion vs. electric propulsion:
  - Chemical propulsion provides lower time-of-flight, electric propulsion provide better fuel economy
- Round trip ΔV and time-of-flight, LEO to GEO/HEO-65k
- Maneuvering within GEO:
  - Relevant to ability to reach multiple satellites with either rapid response (1 day) or fuel-efficient response (weeks)



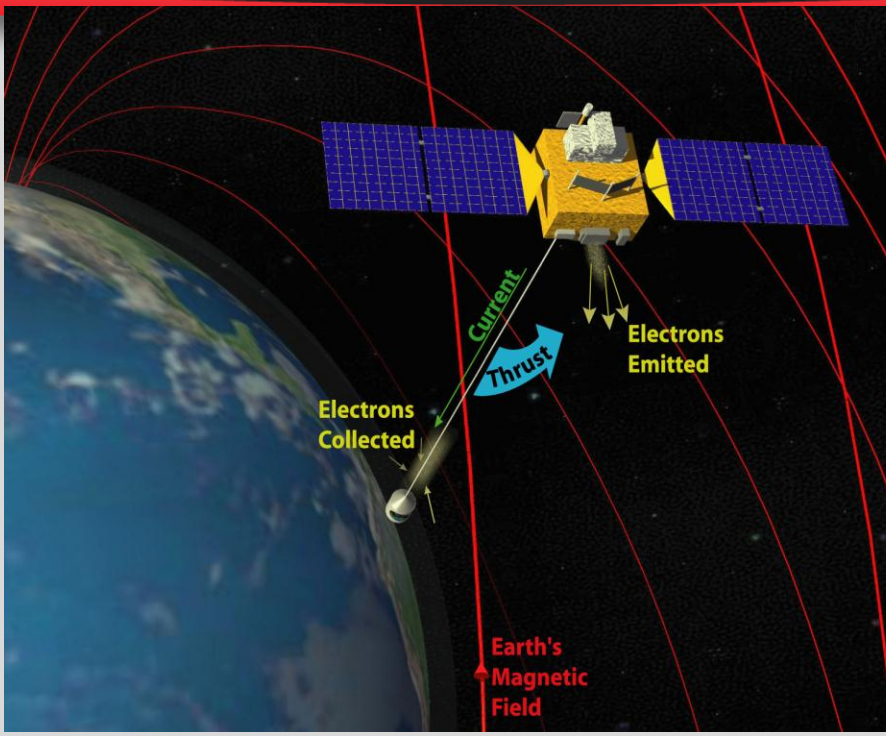
Propel: Propulsion using Electrodynamics



PropEl will demonstrate robust and safe electrodynamic tether propulsion in Low Earth Orbit to enable multiple Space Science, Exploration and Space Utilization Missions for a variety of users

- LEO propulsion and station-keeping without the use of fuel
- Multipoint *in situ* LEO plasma measurements
- Enabling technology for more ambitious reusable tether upper stages
- Critical demonstration for MW power generation and propulsion at Gas Giants

How Does Propel Work?



An **Electrodynamic Tether (EDT)** is essentially a long conducting wire extended from a spacecraft. Gravity will tend to orient the tether in a vertical position. If the tether is orbiting around the Earth, it will be crossing the Earth's magnetic field lines at orbital velocity (7-8 km/s!). The motion of the conductor across the magnetic field induces a voltage along the length of the tether.

- An EDT can produce thrust by collecting electrons from the local plasma at one end of the tether and expelling them back into the plasma at the other end; the voltage drives a current along the tether
- This current interacts with the Earth's magnetic field to cause a Lorentz force (**J x B**) either parallel or antiparallel to the spacecraft's velocity
- The resulting electrodynamic force is controlled and used for station-keeping, boost, deboost and to change a spacecraft's inclination

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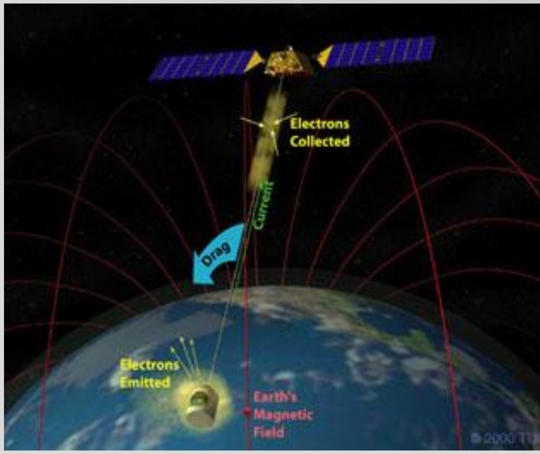
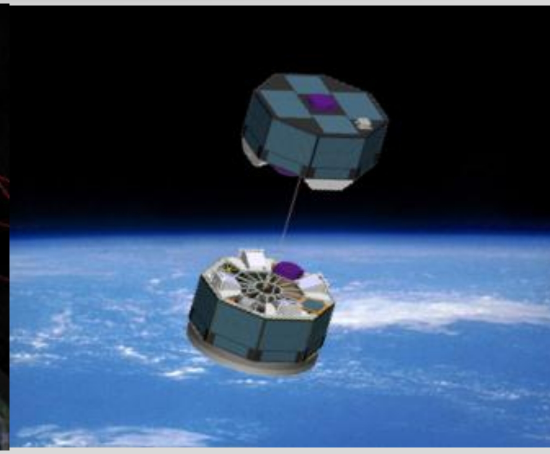
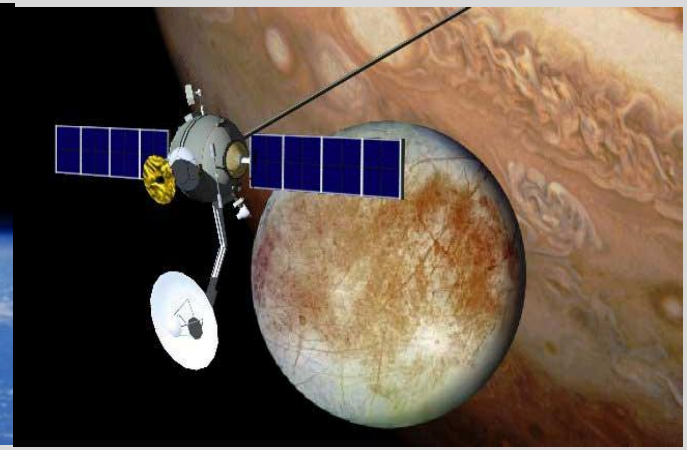
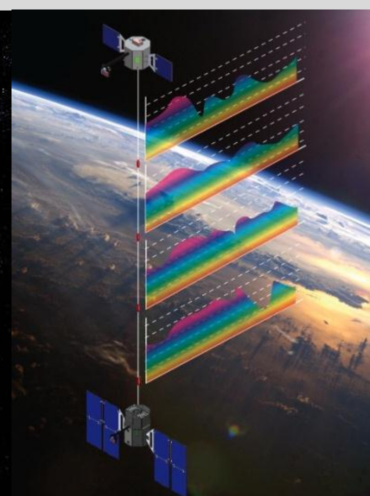
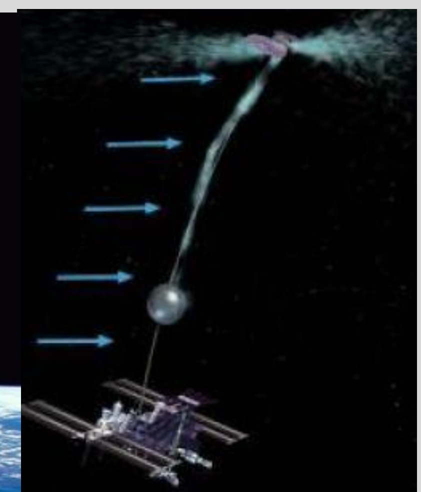




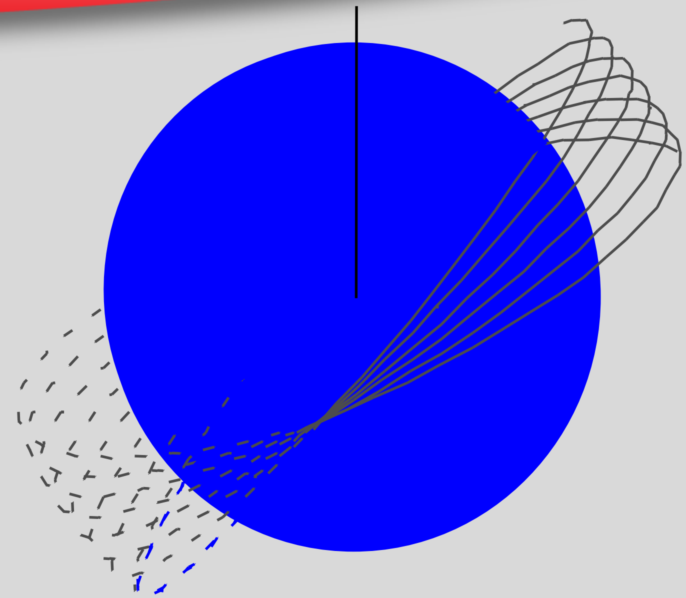


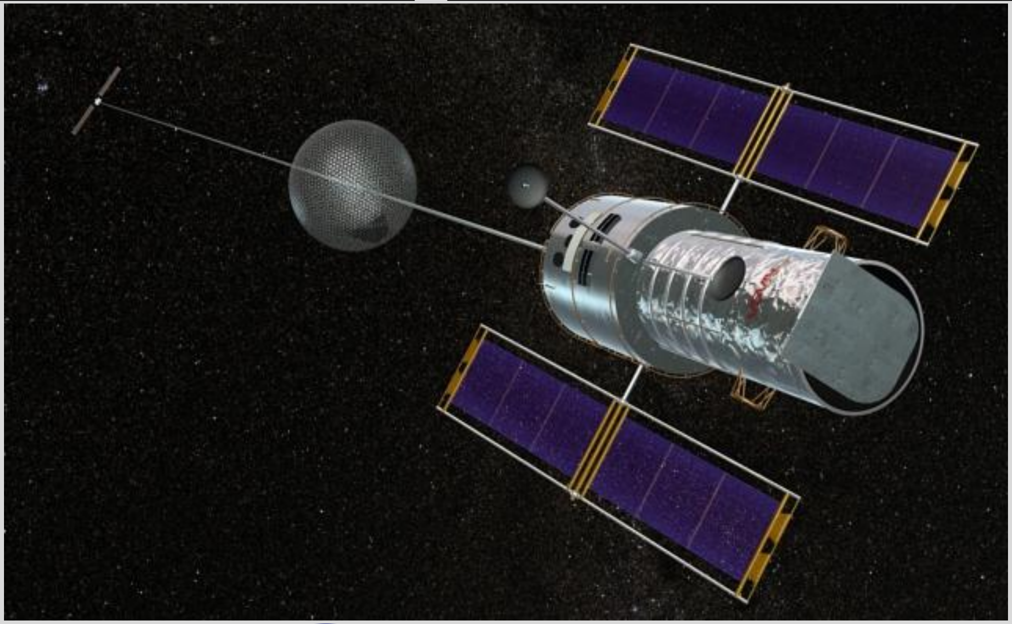




Inclination and Altitude Change

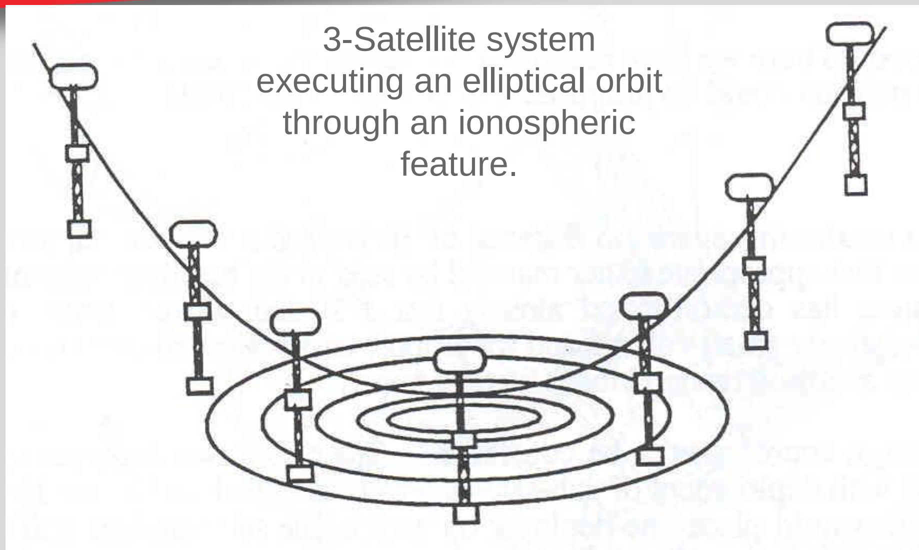
- Cape Canaveral launch sites and Vandenberg launch sites cannot reach the same orbital inclinations due to launch azimuth constraints.
- With an electrodynamic tether tug in LEO, satellites could be launched into another inclination and then "towed" to the proper inclination.
- LEO tether tug could also reboost or change multiple spacecrafts' orbital elements
- Important capability for high-value national assets.

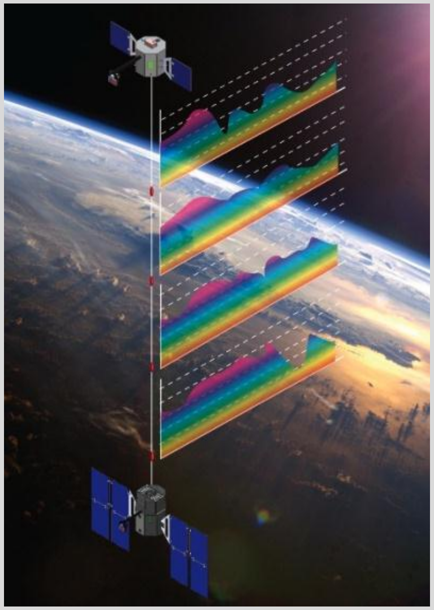




Multipoint Ionospheric Science

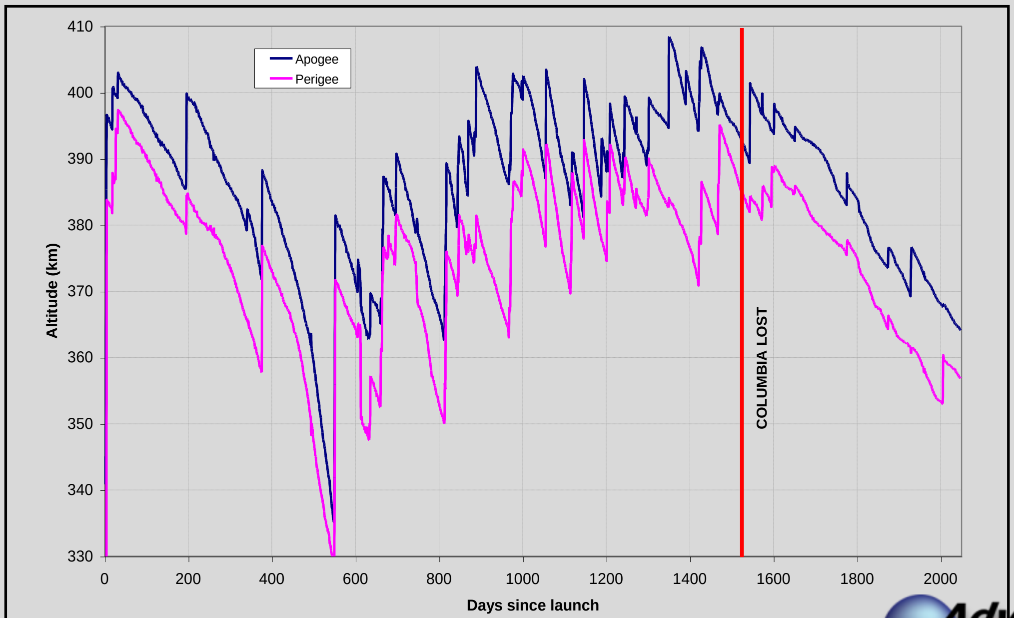
- Three or more instrumented satellites tethered with a separation of 10km.
- Each subsatellite deploys itself from the central spacecraft; one upward and one downward
- Baseline elliptical orbit with <140km perigee and optional electrodynamic reboost for sustained low-altitude flight

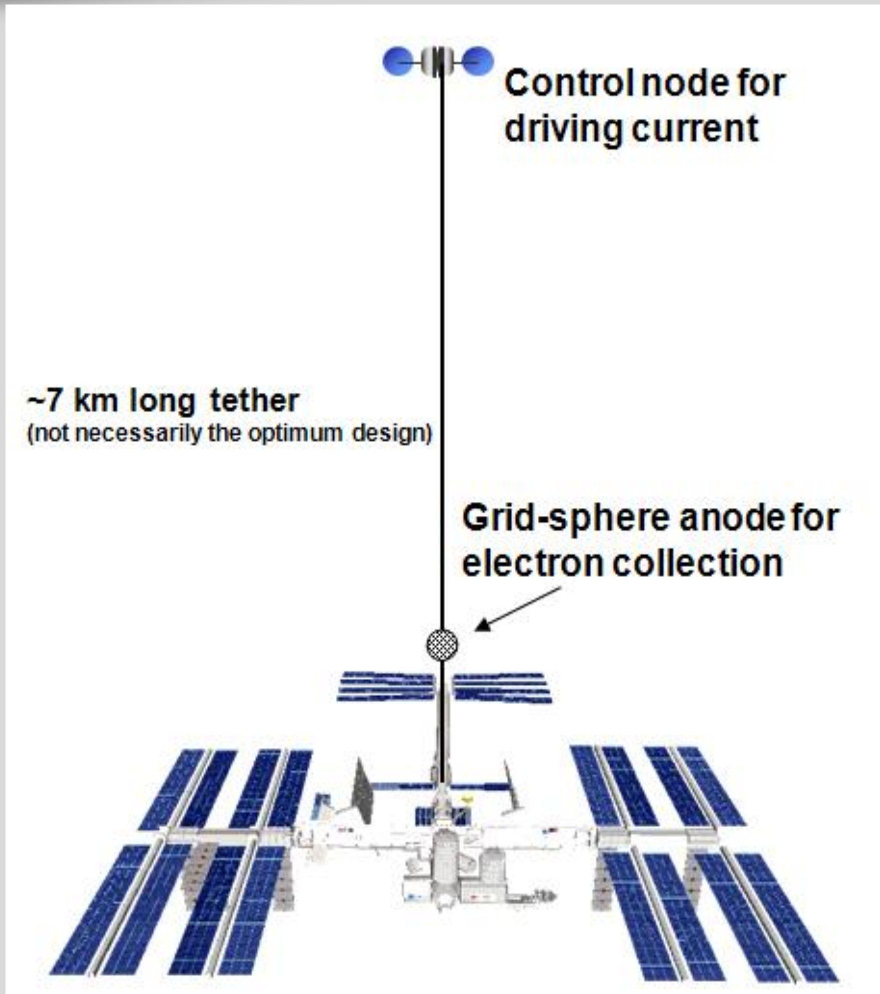




Station Keeping or Reboost of Space Platforms

- Atmospheric drag causes the ISS orbit to continuously decay.
- Russians supply fuel for propulsive reboost.
- An electrodynamic tether could be used to reboost the ISS orbit without consuming propellant.
- The tether would also passively stabilize the station configuration (gravity-gradient).
- Safety and value of ISS would increase.

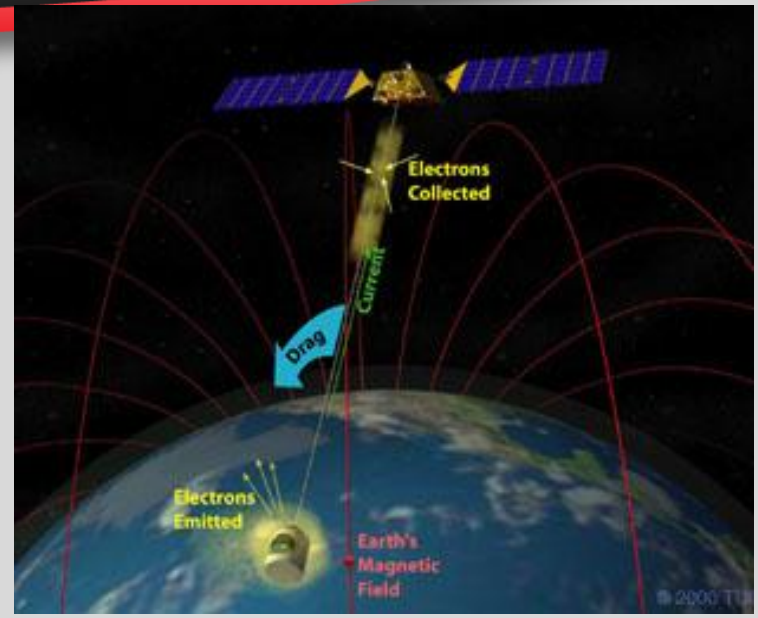




MSFC Advanced Concepts

Orbital Debris Mitigation — ”Terminator Tether”

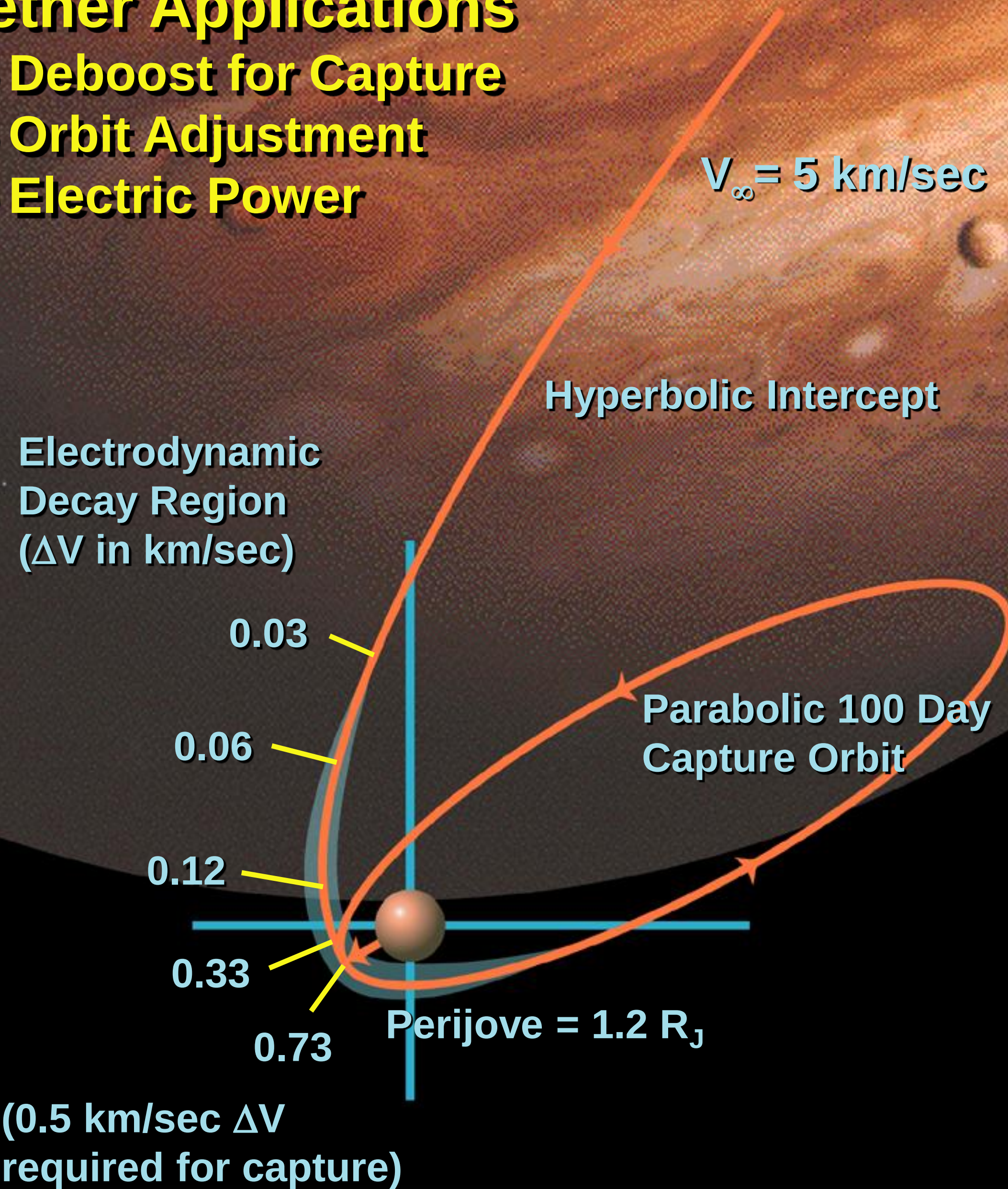
- Dead satellites can remain in orbit for extended periods of time and pose a debris and collision threat.
- An electrodynamic tether can be deployed from the spacecraft after it “dies” and will generate drag forces that will cause the spacecraft to deorbit.
- Unlike propulsive deorbit, the host spacecraft does not need to be operating or have attitude control—the tether generates the power and stability it needs.
- Debris populations can be reduced significantly.

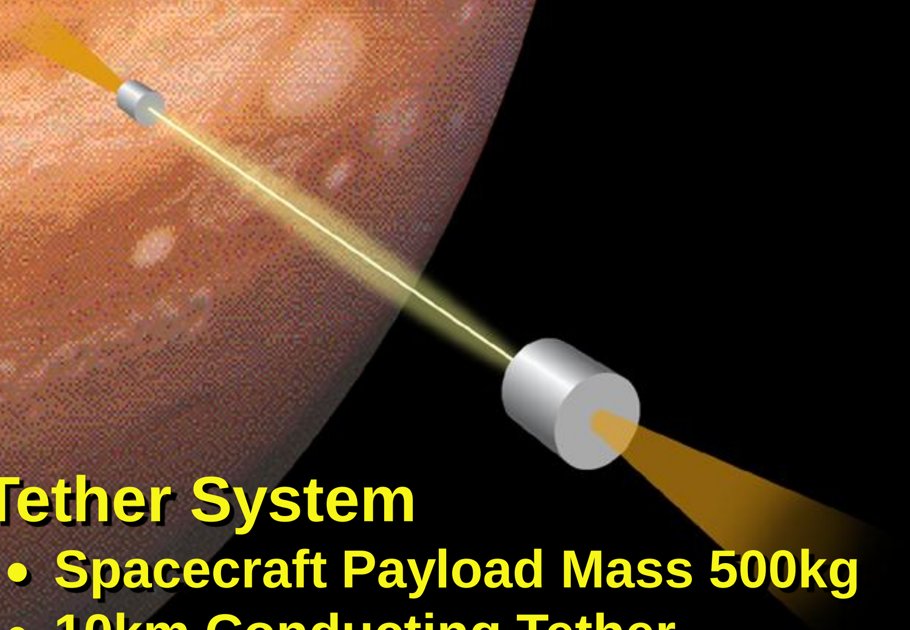


Jovian Electrodynamic Capture

Tether Applications

- Deboost for Capture
- Orbit Adjustment
- Electric Power





Tether System

- Spacecraft Payload Mass 500kg
- 10km Conducting Tether
- Tether Resistance: 96Ω
- Plasma emitter at each end
- Propulsion Mass Budget
  - Tether 98kg
  - Emitter Expellant 22kg
  - Deployer and Controls $\leq$ 128kg
  - Total $\leq$ 240kg