National Aeronautics and Space Administration

MSFC Advanced Concepts Office

Defining the future of space exploration

Advanced Concepts Overview

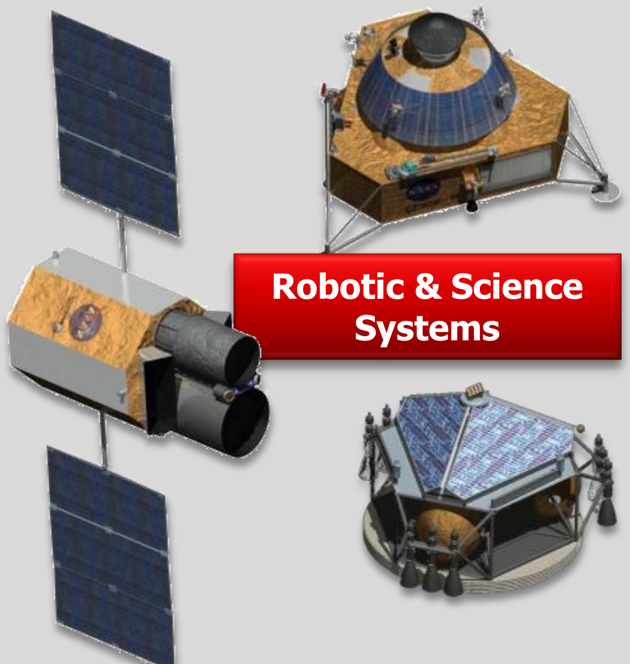
We answer the questions:

Will it work?

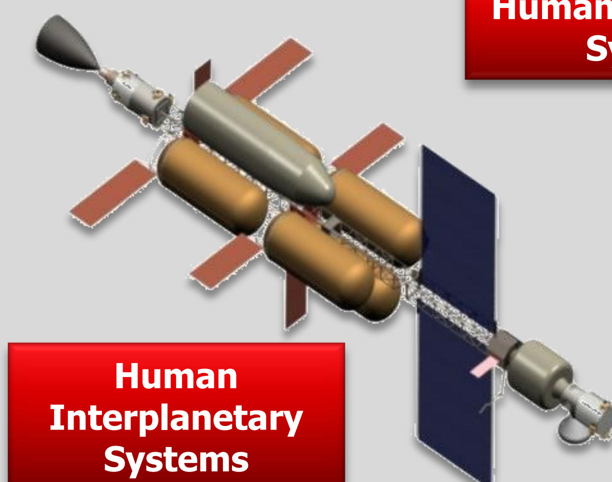
What will it look like?

What is the preliminary design?

Launch Vehicle Systems



Robotic & Science Systems

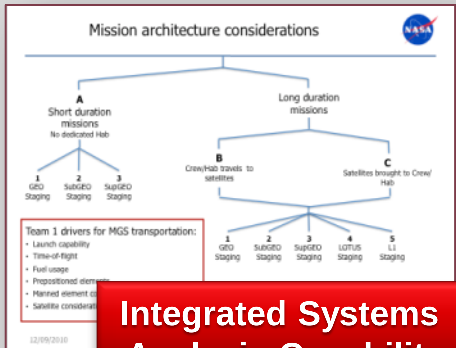


Human Interplanetary Systems

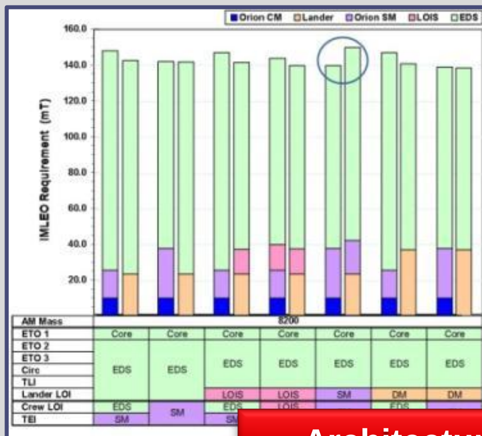
Human Exploration Systems

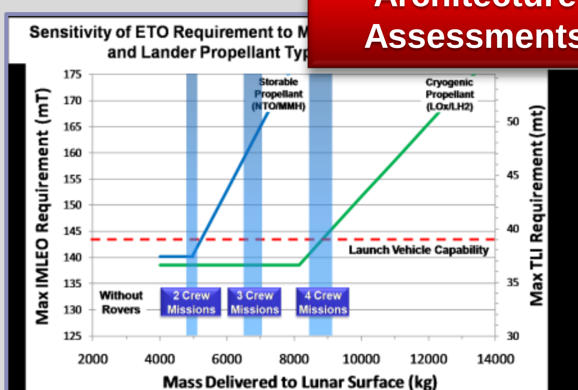
Advanced Concepts Overview

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



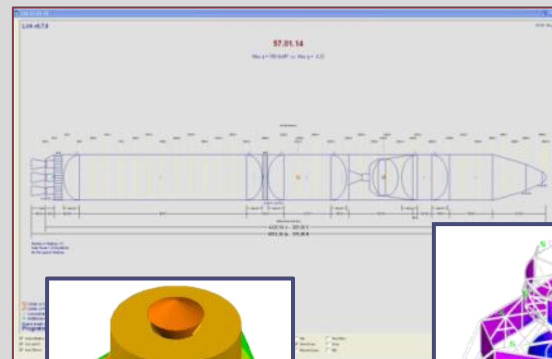
Integrated Systems Analysis Capability

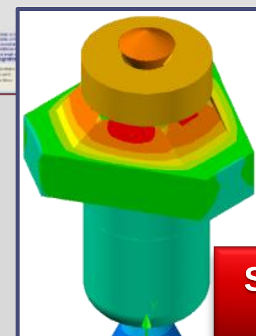


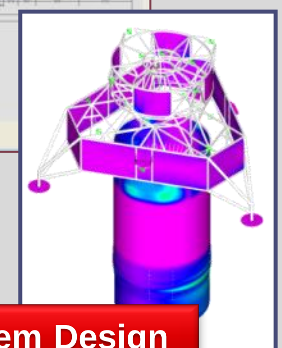


Architecture Assessments

Mission Analysis



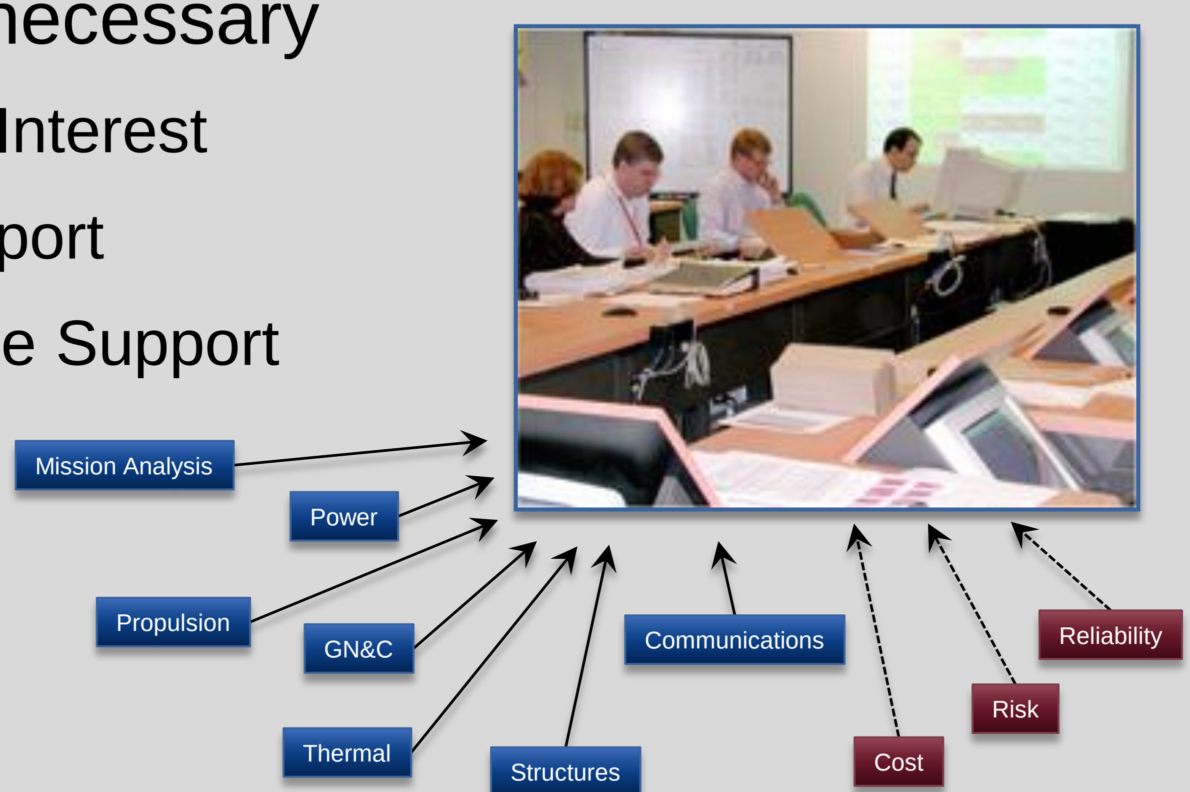




Subsystem Design & Analysis

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



ACO Contributions to the Agency

New Rockets

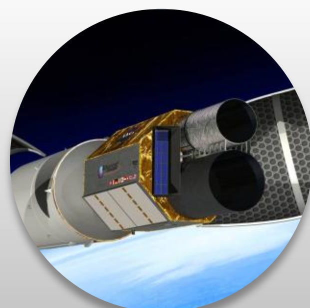
Science Mission Concepts

Sustained Exploration Campaigns

New Technologies

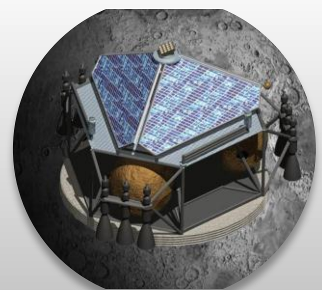
Human Exploration Systems

Earth-to-Orbit Transportation System Definition



Earth & Planetary Science Concept Definition

Human Exploration Architecture Definition



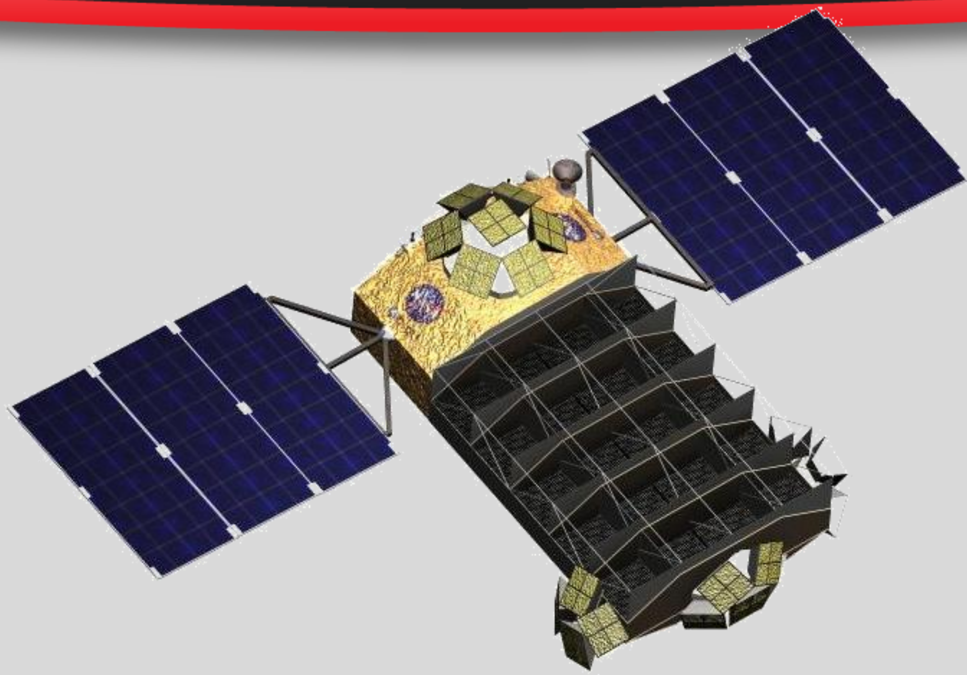
Scientific & Robotic Exploration

In Space Element Definition

Advanced Concepts Products Influence NASA Programs

SCIENCE MISSION CONCEPTS

AXTAR: Introduction



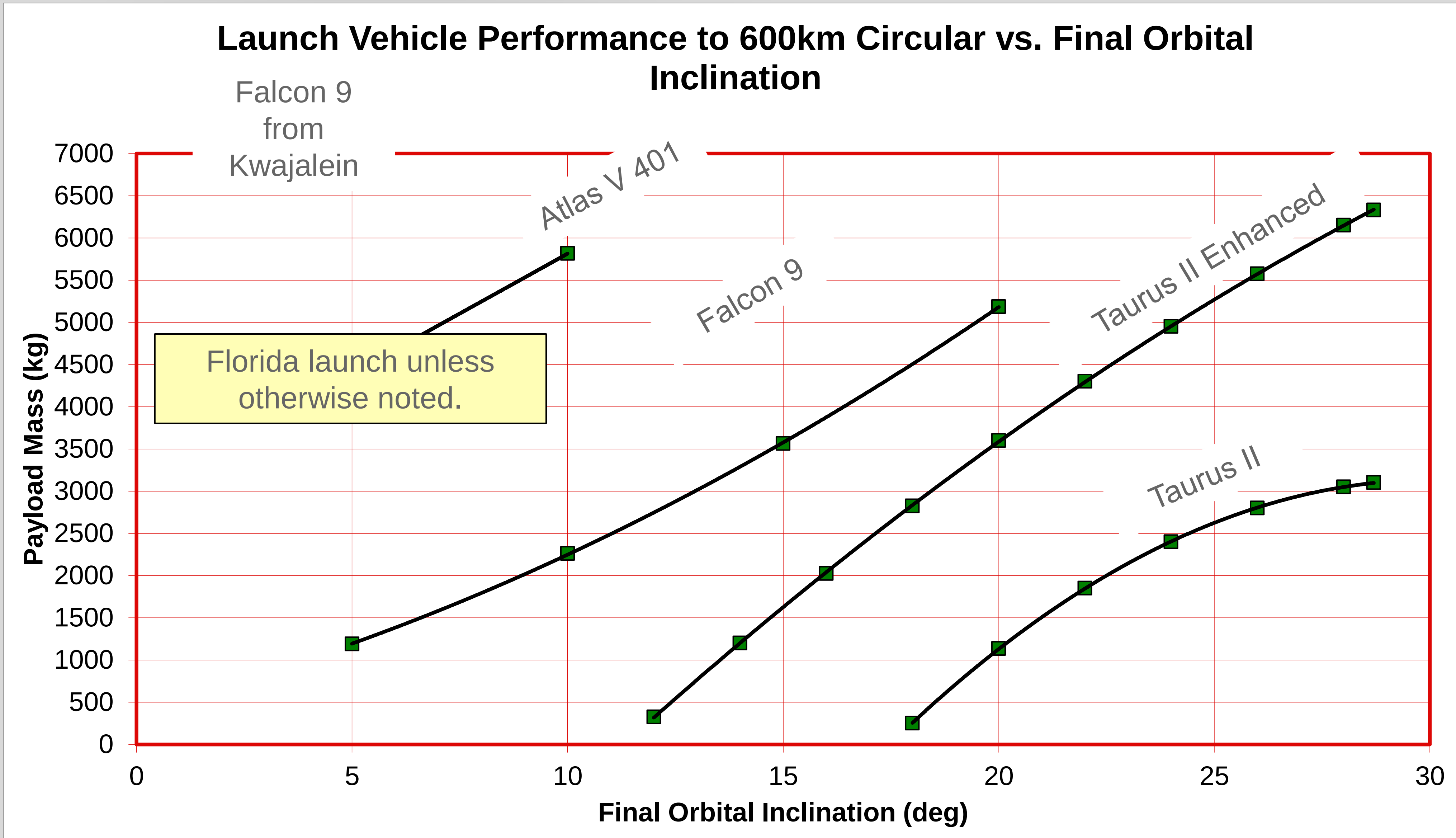
- The Advanced X-ray Timing Array (AXTAR) is an X-ray observatory concept combining very large collecting area, broadband spectral coverage, high time resolution, highly flexible scheduling, and an ability to respond promptly to time-critical targets of opportunity.

- 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

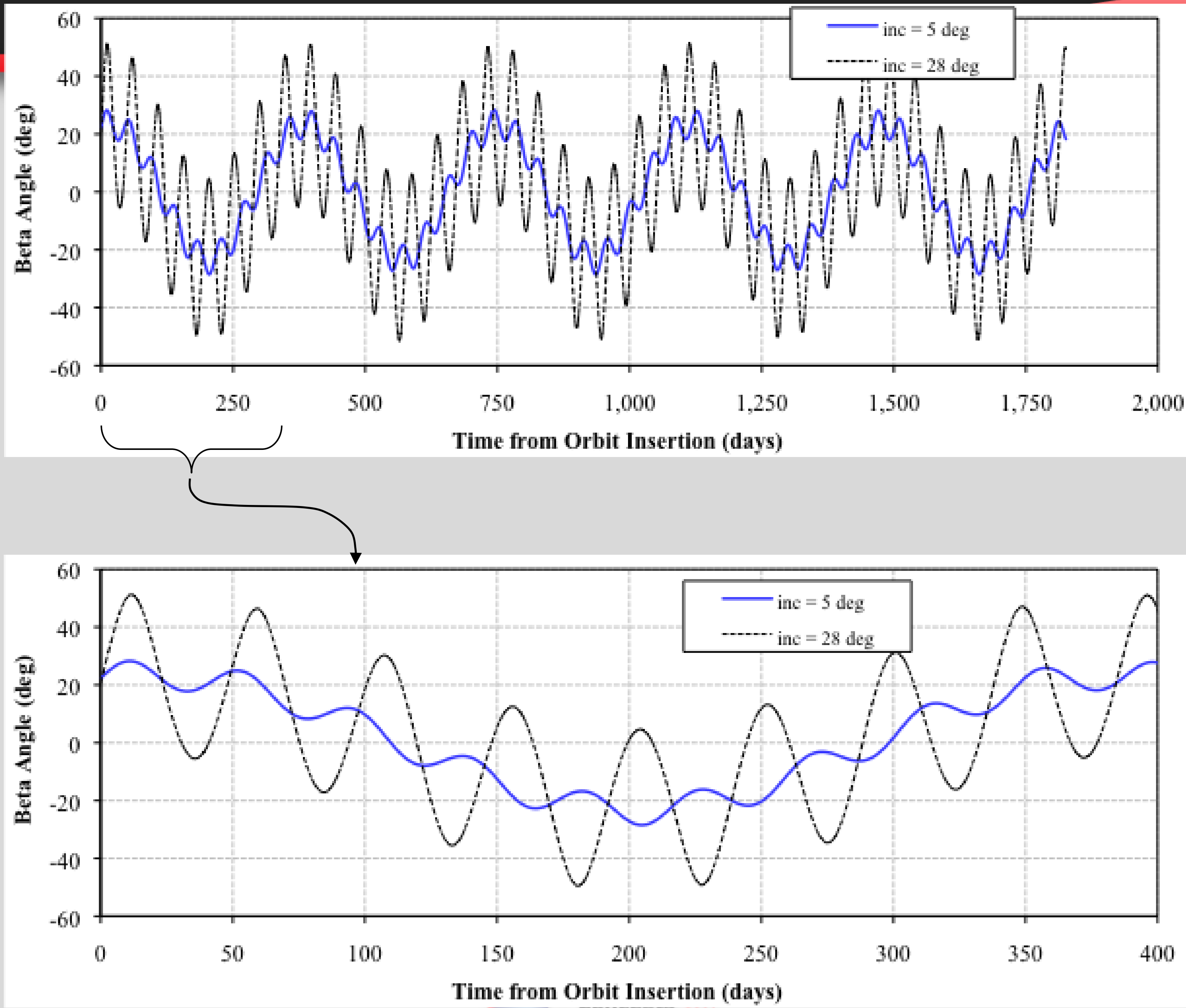
Launch Vehicle Options



Spacecraft mass will determine final inclination.

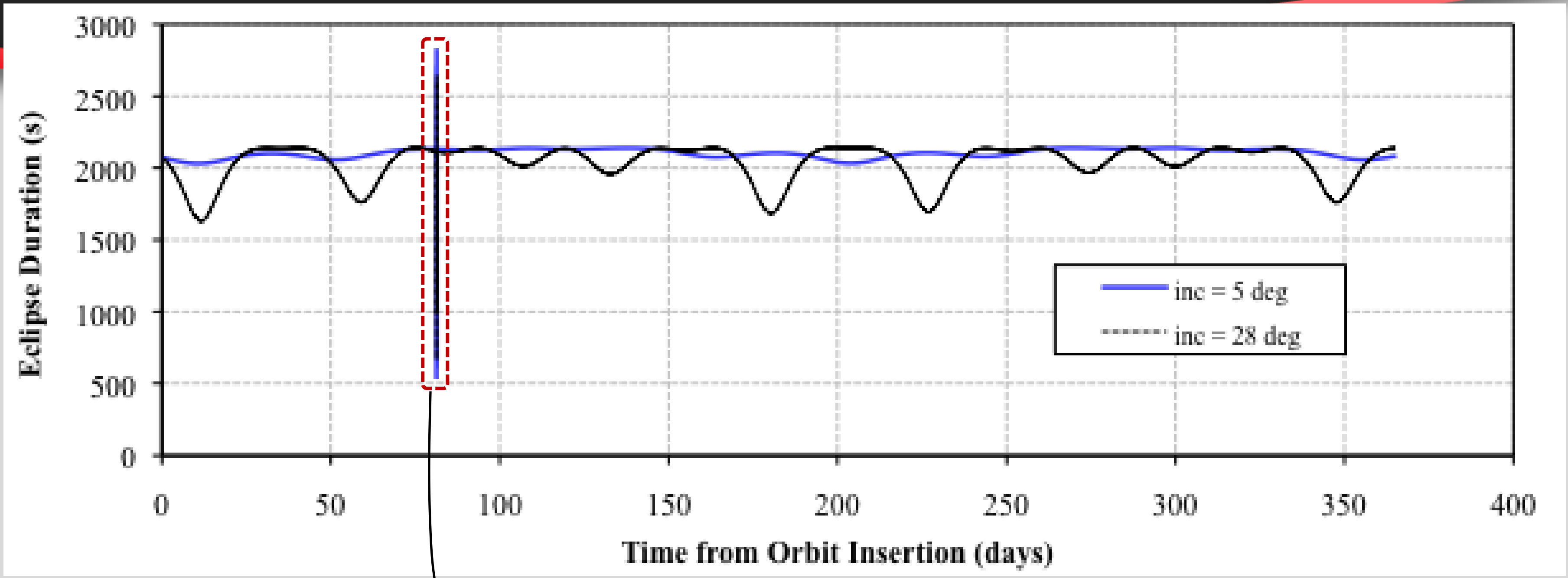
Mission Analysis

Sun Angle Determines Power Generated



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		

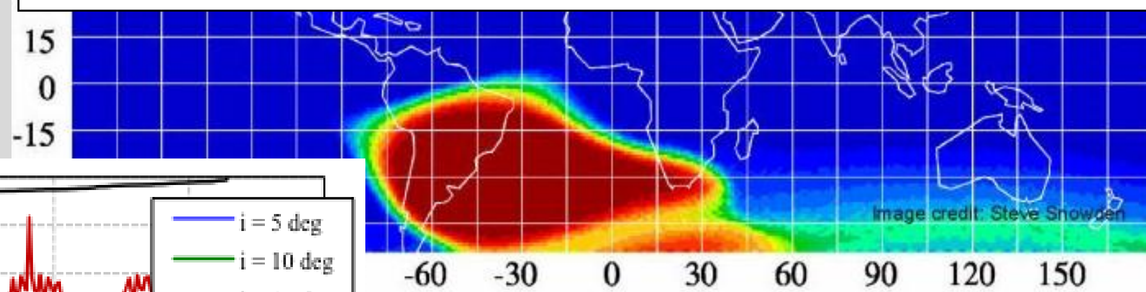
Upon further investigation, shadowing due to lunar eclipses are only partial (i.e. penumbra) and, therefore, can most-likely be neglected.

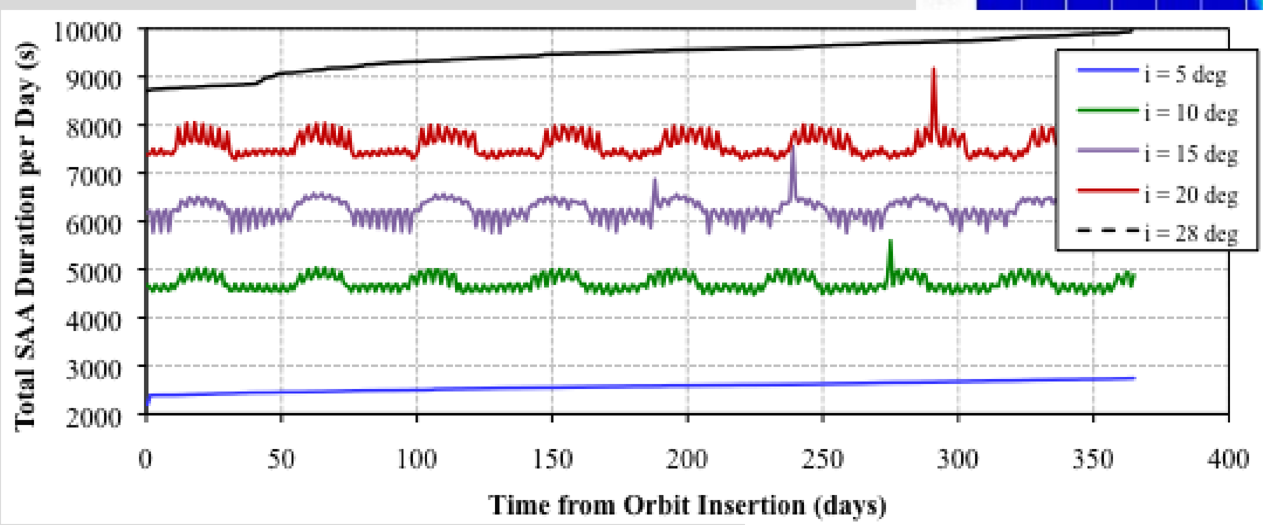
Mission Analysis

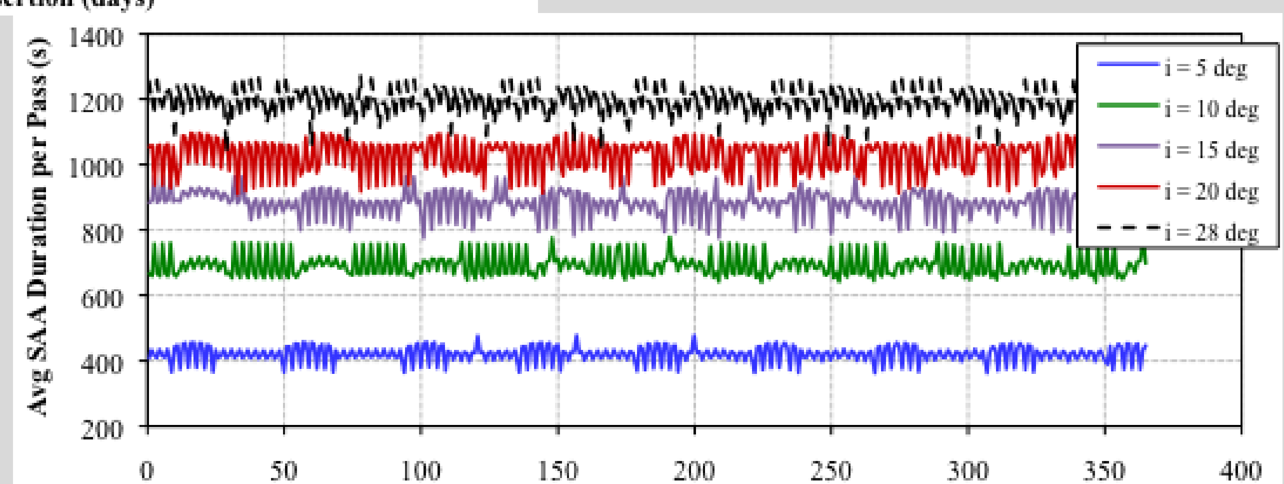
South Atlantic Anomaly passes increase radiation dose

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 de Leon Ground Stati*
- South Point (Hawaii)
- *WGS (Wallops Ground Station, Vi*
- Kourou (Frech Guiana)

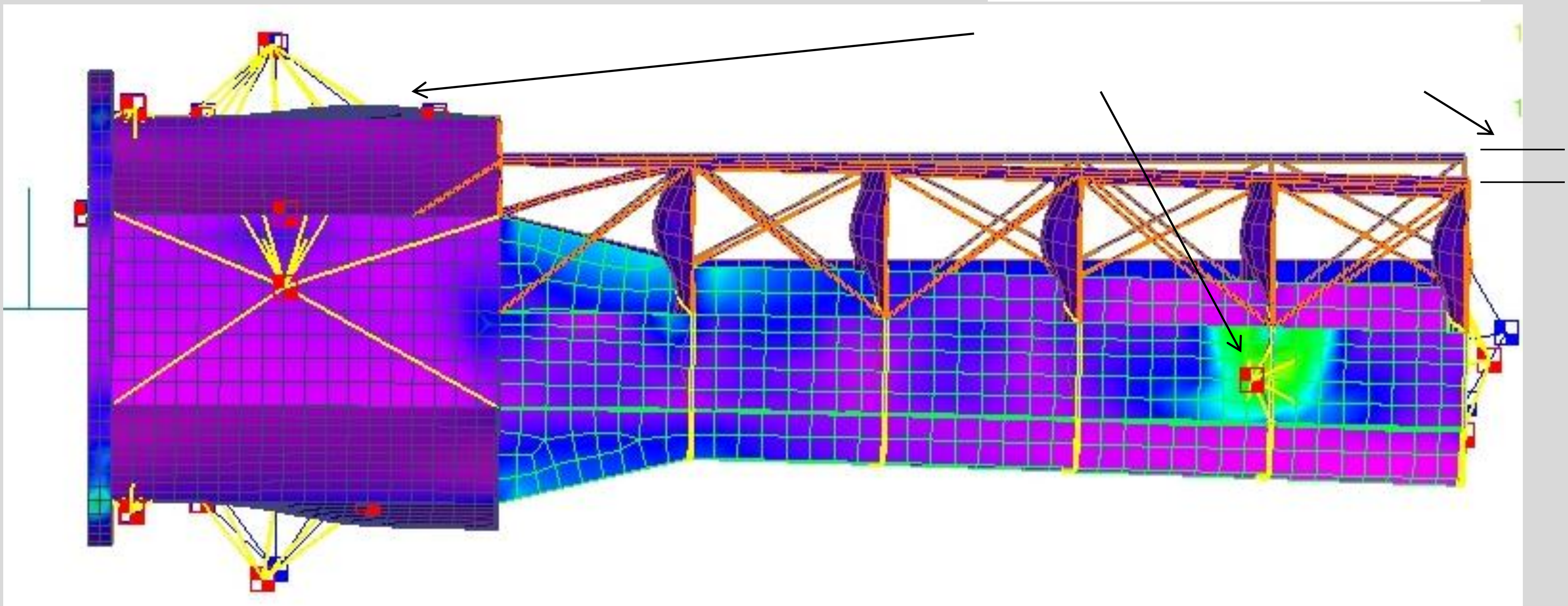
** denotes options that are included in 28.5° orbital inclination case (not 5° case)*

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

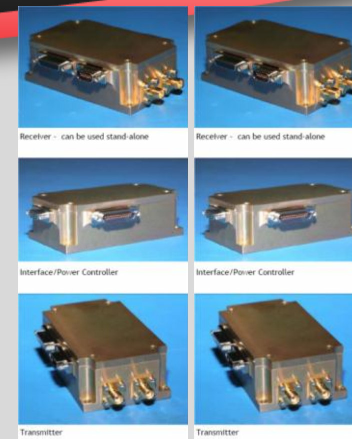
Bending displacements < 3 cm



AXTAR: Avionics

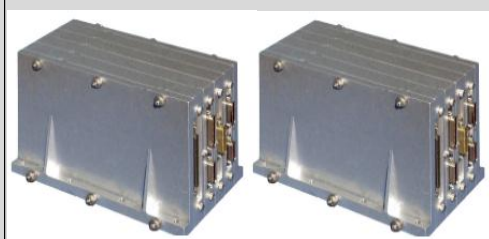
Northrop Grumman
Inertial Measurement Unit LN200
0.15 deg/sqrHr,
sufficient for maneuvers

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

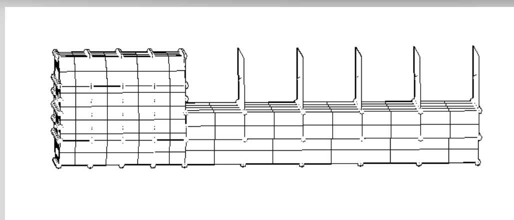
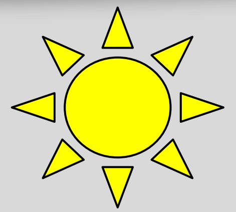
Microcosm MT400-2
To provide attitude torque authority
for long observation times

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

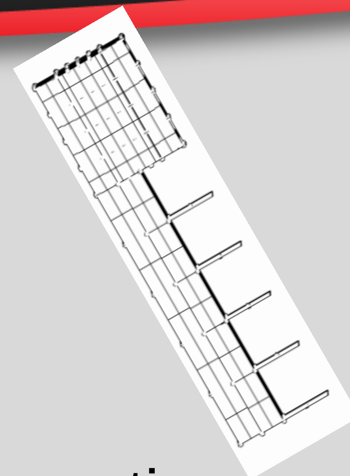
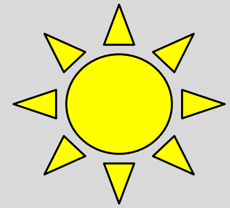
L3 Data Acquisition Unit DTP-503
32 drivers and 32 inputs, 1553 data interface

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

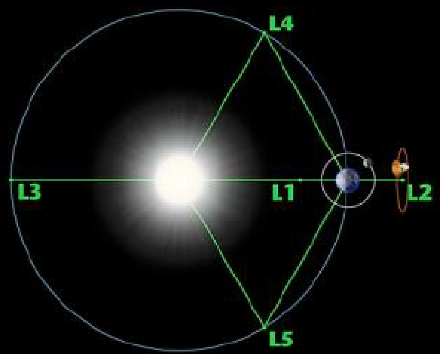
	Material	Absorptivity	Emissivity
Spacecraft Bus Internal Surfaces	Black Annodized	.9	.9
Spacecraft Bus External Surfaces	White Paint	.25	.87
Spacecraft Bus Closeouts	White Paint on Beta Cloth Inner Layer, Black Kapton (MLI=5 Layers) ε*=.02	.17 .92	.92 .88
LATA Support Structure	White Paint on Beta Cloth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

SPACE LAUNCH SYSTEM

Space Launch: Advancing the Legacy of Human Exploration

SLS is a National Asset

SLS Will Open Up the Inner Solar System for Human Exploration



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

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

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

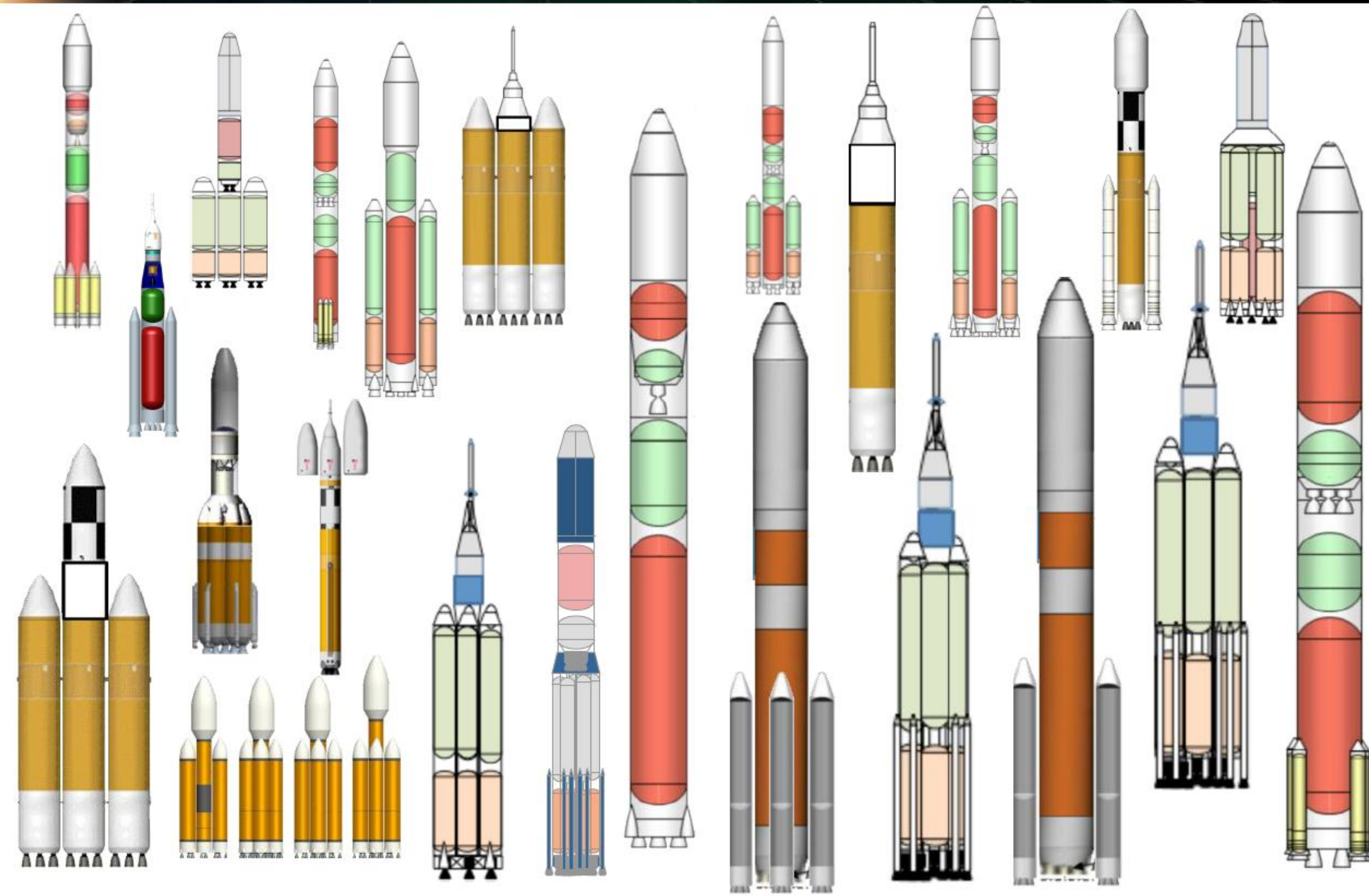
The Space Launch System Objectives

- **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 Possible Solutions



"This enterprise is not for the faint of heart."
—Wayne Hale

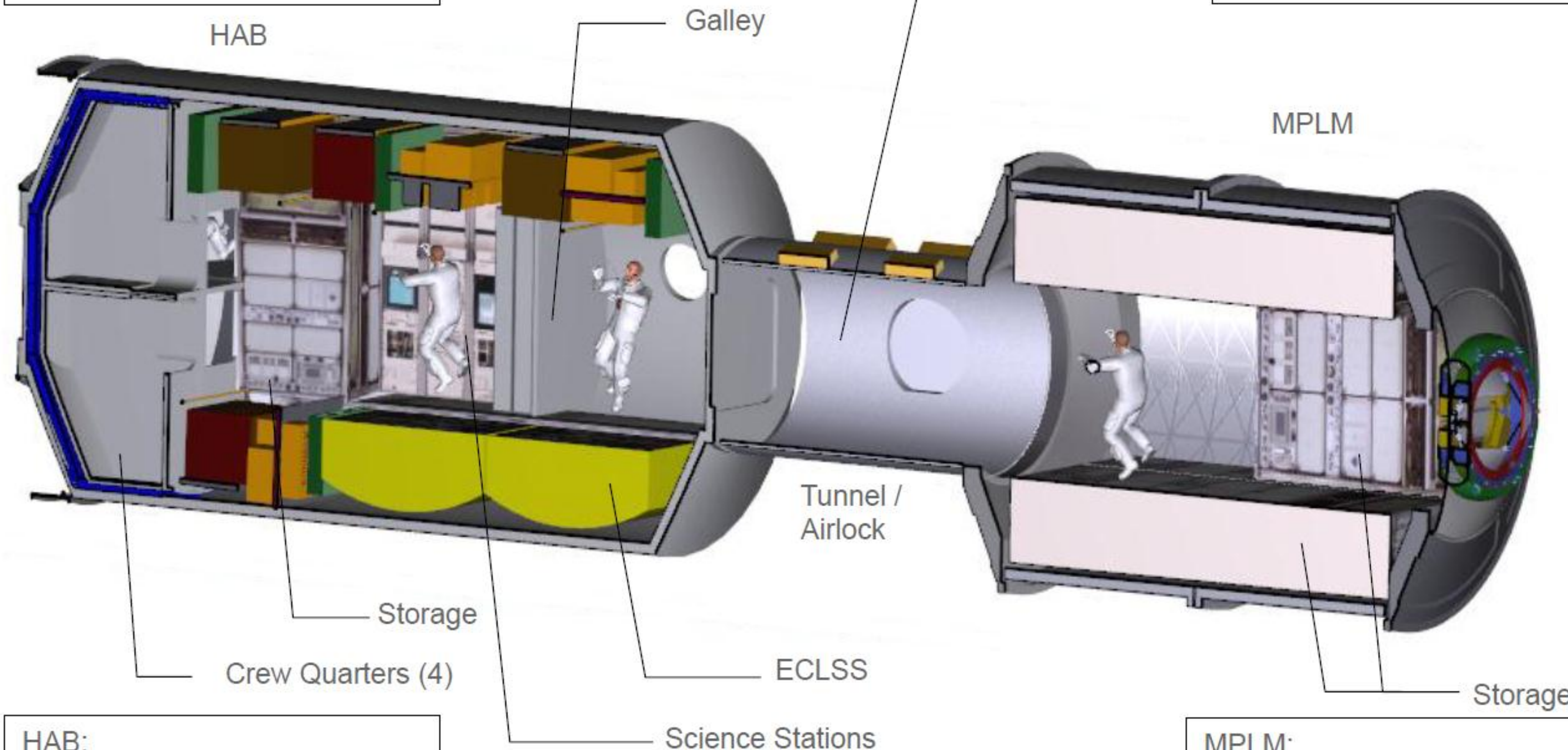
HUMAN EXPLORATION SYSTEMS

Deep Space Habitat

ACO_Border1-02.png

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

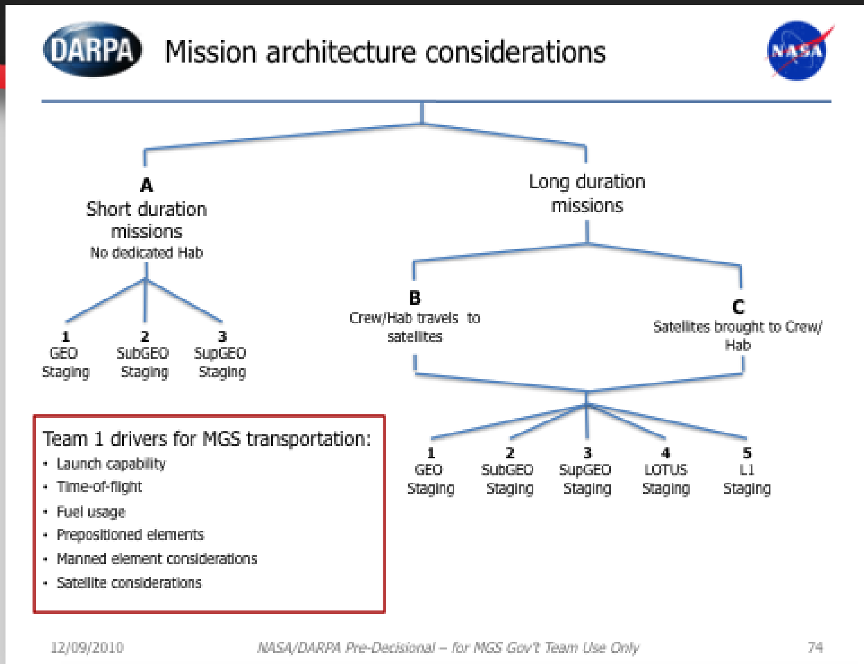
Service Tunnel / Airlock:
Pressurized volume = ~ 10 m^3
Habitable volume = ~ 9 m^3



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

Example: Manned GEO Servicing

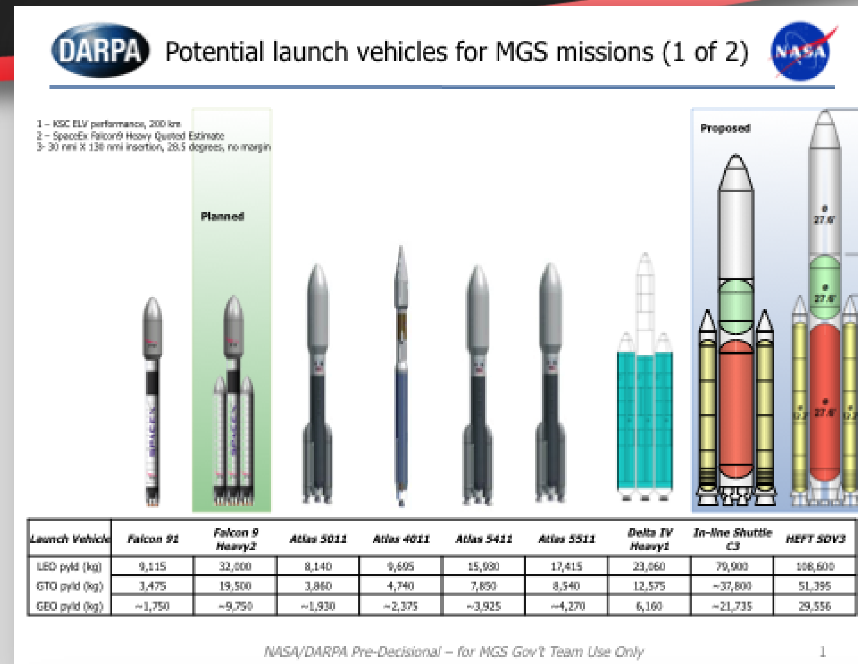


Mission architecture considerations

Team 1 drivers for MGS transportation:

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

12/09/2010 NASA/DARPA Pre-Decisional – for MGS Gov't Team Use Only 74

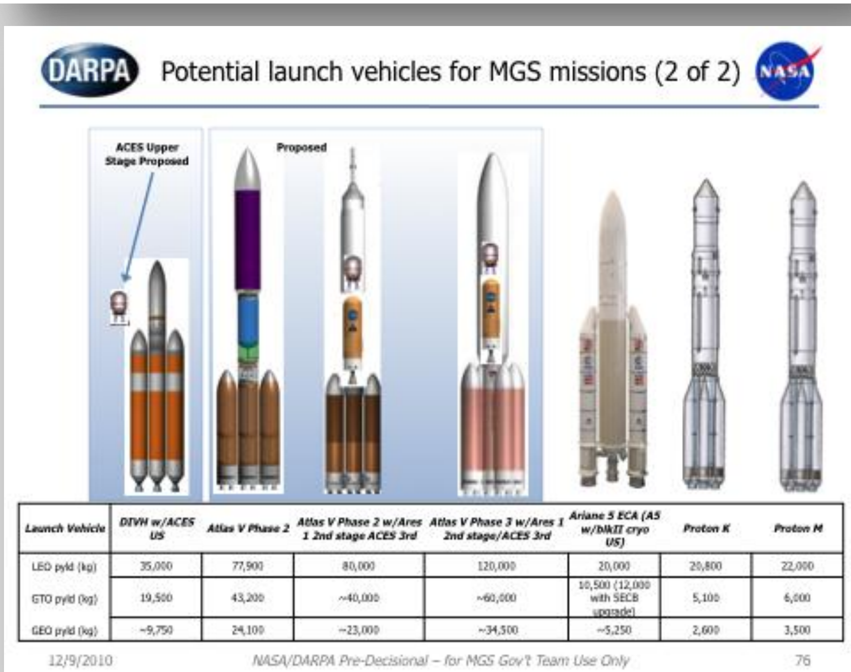


Potential launch vehicles for MGS missions (1 of 2)

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

NASA/DARPA Pre-Decisional – for MGS Gov't Team Use Only 1



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

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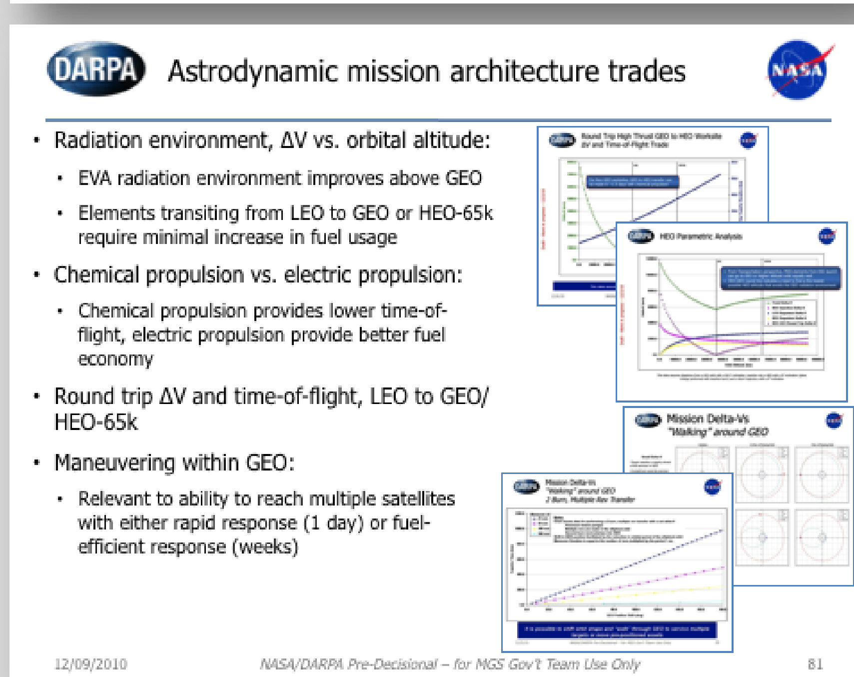


Astrodynamic mission architecture trades

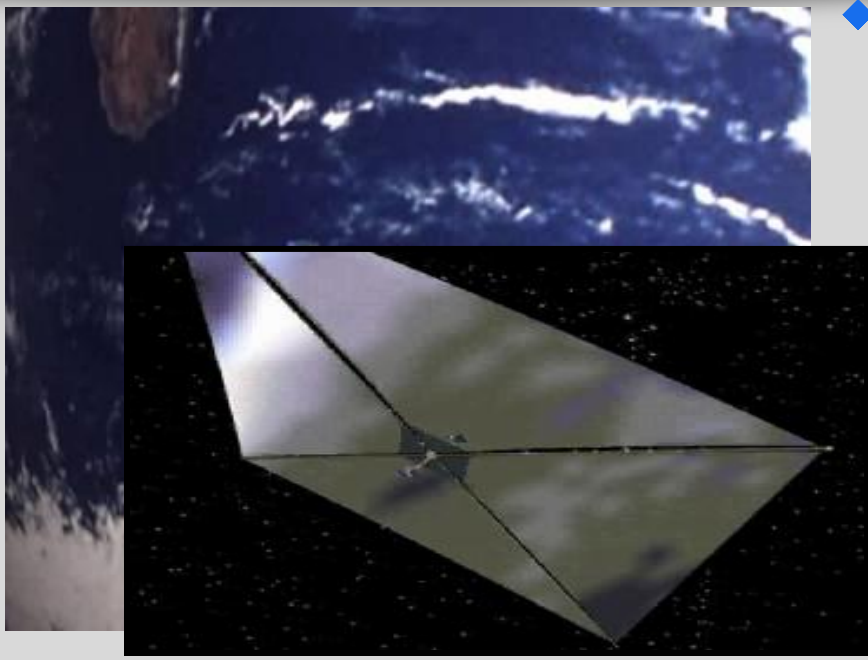
- Radiation environment, ΔV vs. orbital altitude:
  - EVA radiation environment improves above GEO
  - Elements transiting from LEO to GEO or HEO-65k require minimal increase in fuel usage
- Chemical propulsion vs. electric propulsion:
  - Chemical propulsion provides lower time-of-flight, electric propulsion 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)

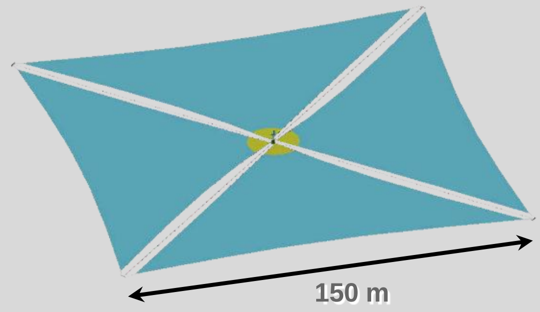
12/09/2010 NASA/DARPA Pre-Decisional – for MGS Gov't Team Use Only 81

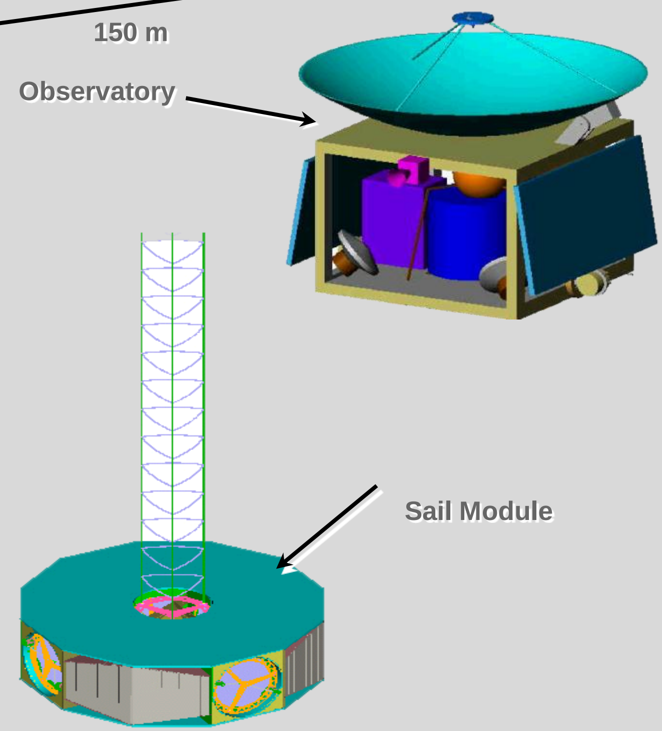
TECHNOLOGY ASSESSMENTS AND MISSIONS ENABLED

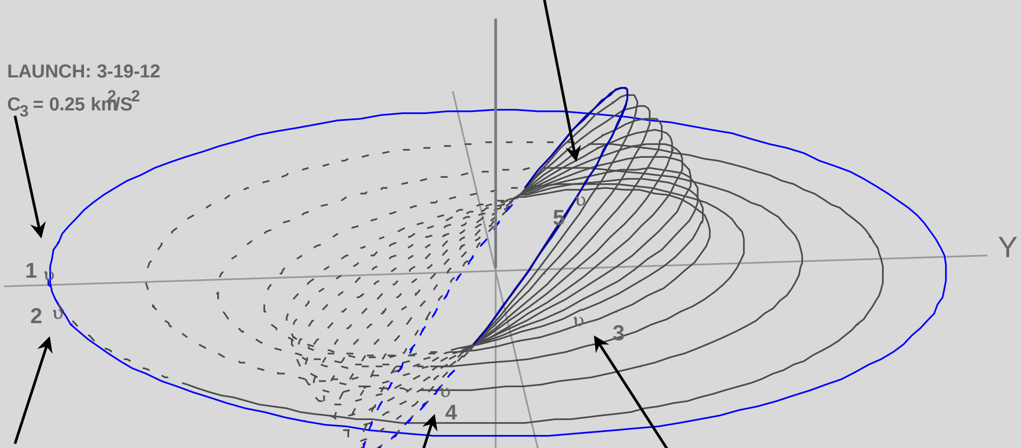
Solar Sails

- Solar sails use photon “pressure” or force on thin, lightweight reflective sheet to produce thrust. Sails can open up new regions of the solar system to accessibility for important science missions, with no propellants required.





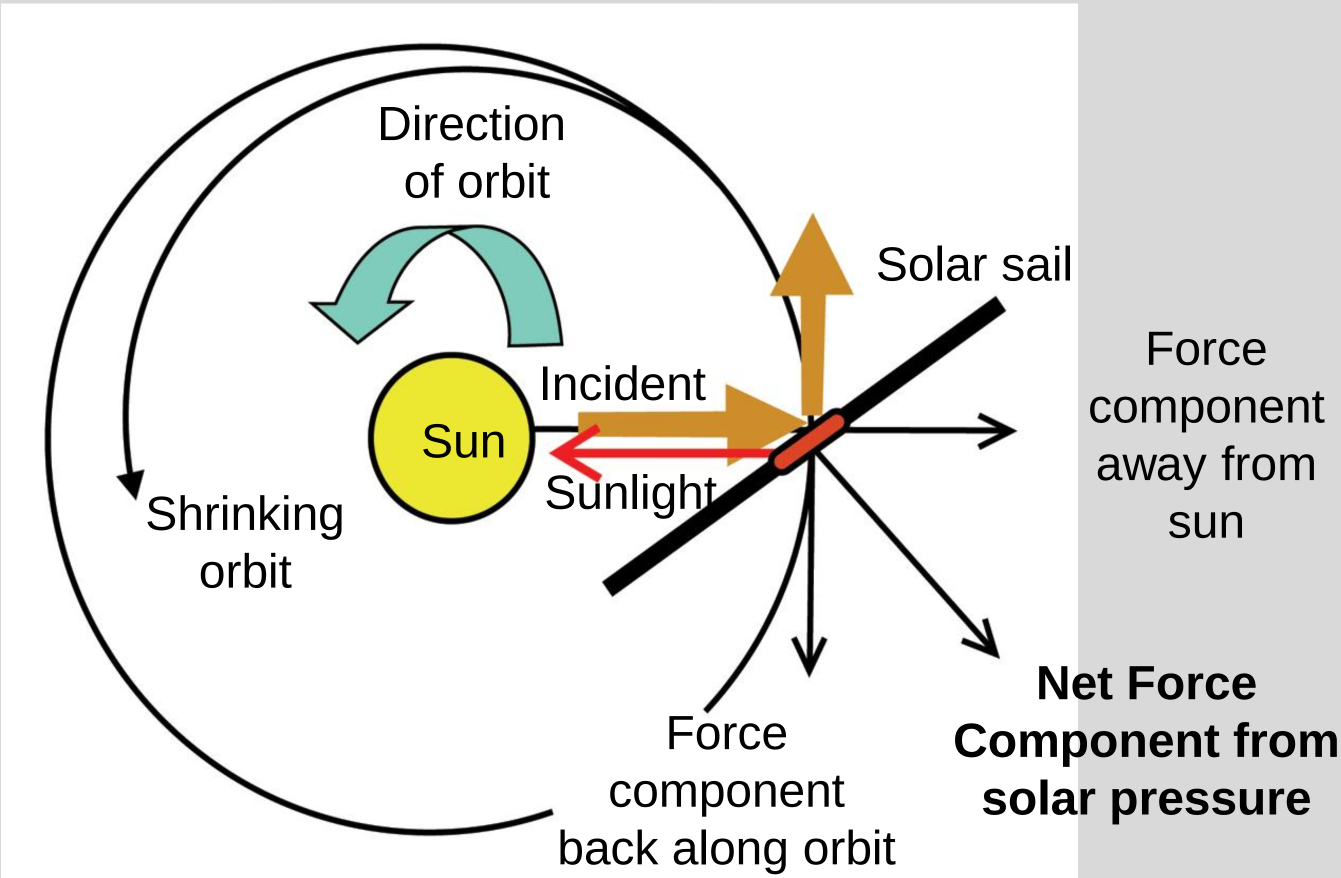




MSFC Advanced Concepts

Solar Sails

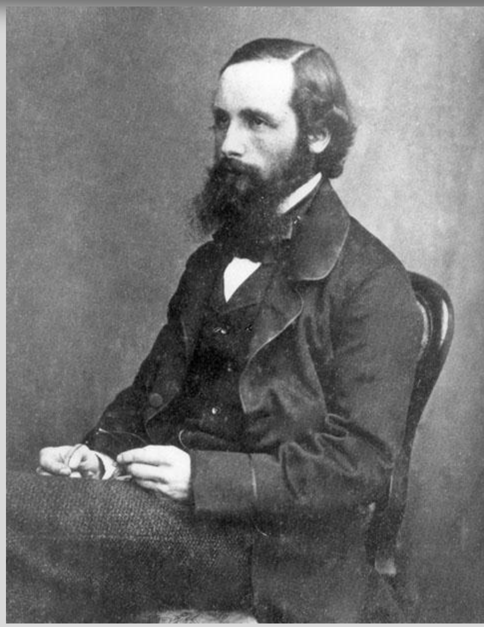
Propulsion from Photon Momentum Exchange



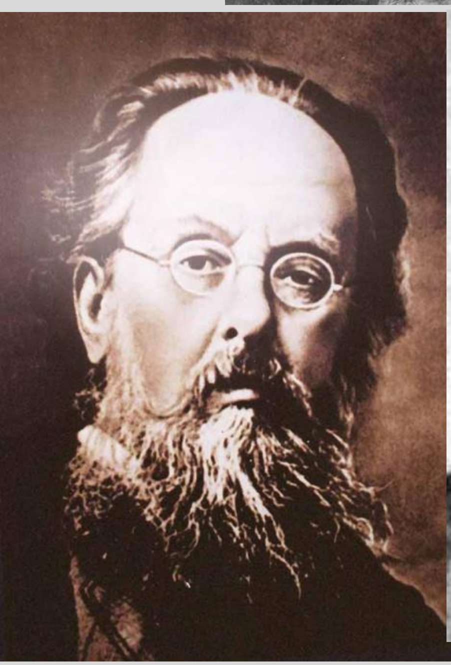
Reflecting the photons forward along the direction of motion slows the spacecraft down.

An example of how a solar sail propulsion can change orbits

Solar Sailing Is Not A New Idea



- James Clerk Maxwell (England), who developed the modern theory of electromagnetism in the 1860’s, proved that light could exert pressure.



- Konstantin Tsiolkovsky (Russia) first discussed solar sailing; Fridrickh Tsander (Russia) wrote in 1924, “For flight in interplanetary space I am working on the idea of flying, using tremendous mirrors of very thin sheets, capable of achieving favorable results.”

Echo II 1964

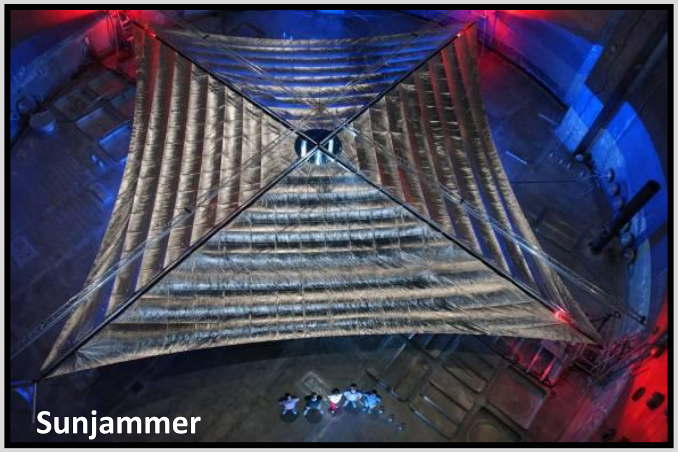
solar thrust affect on spacecraft orbit

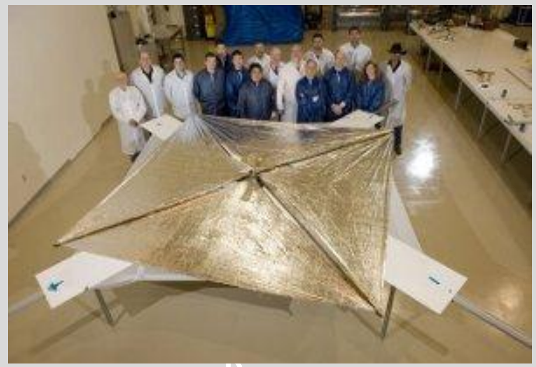
- 135-foot rigidized inflatable balloon satellite
- laminated Mylar plastic and aluminum
- placed in near-polar Orbit
- passive communications experiment by NASA on January 25, 1964.

When folded satellite is packed into the 41-inch diameter canister shown in the foreground

Spherical shape has no solar pressure torques – enabling direct observation of thrust effects without regard to spacecraft attitude

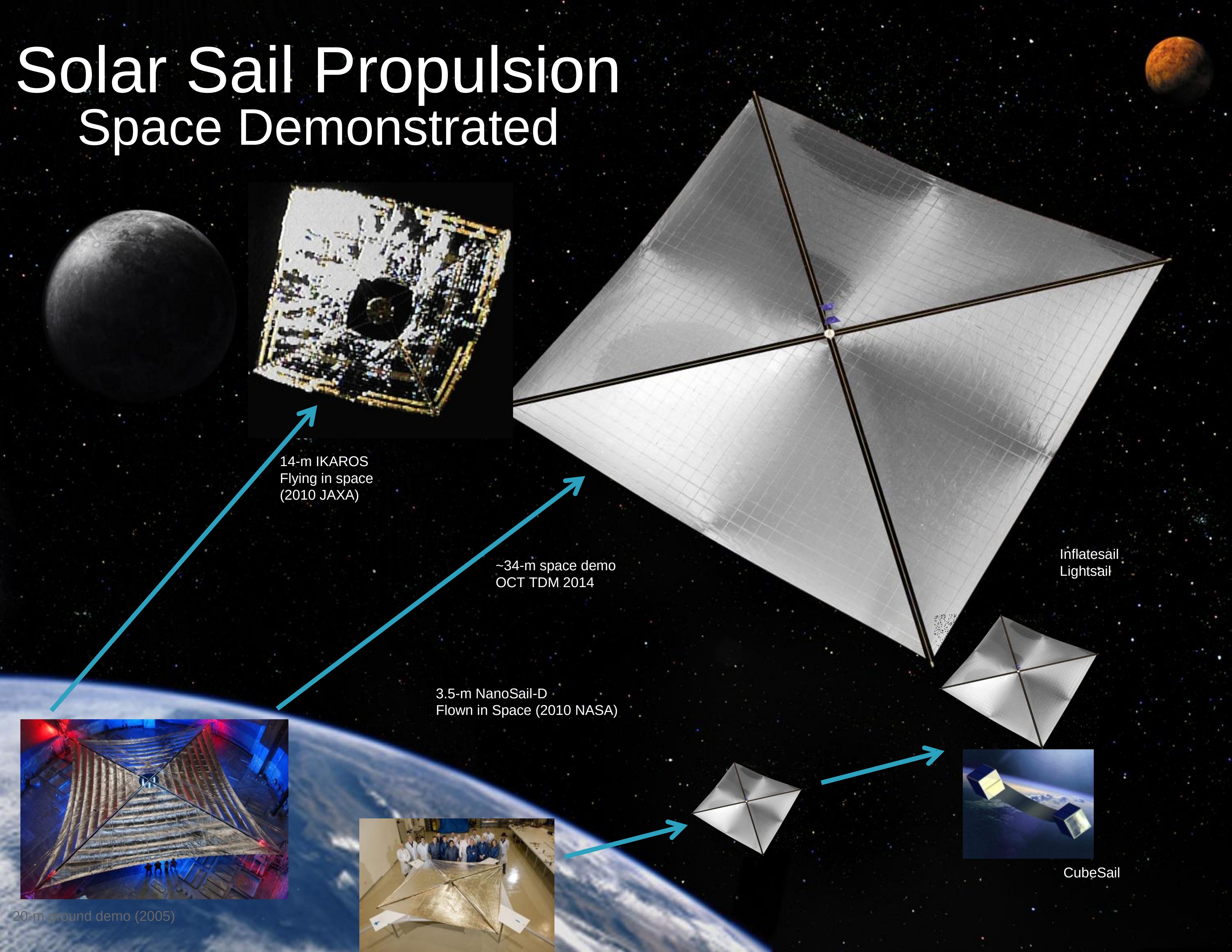
Solar Sail Propulsion Technology Status



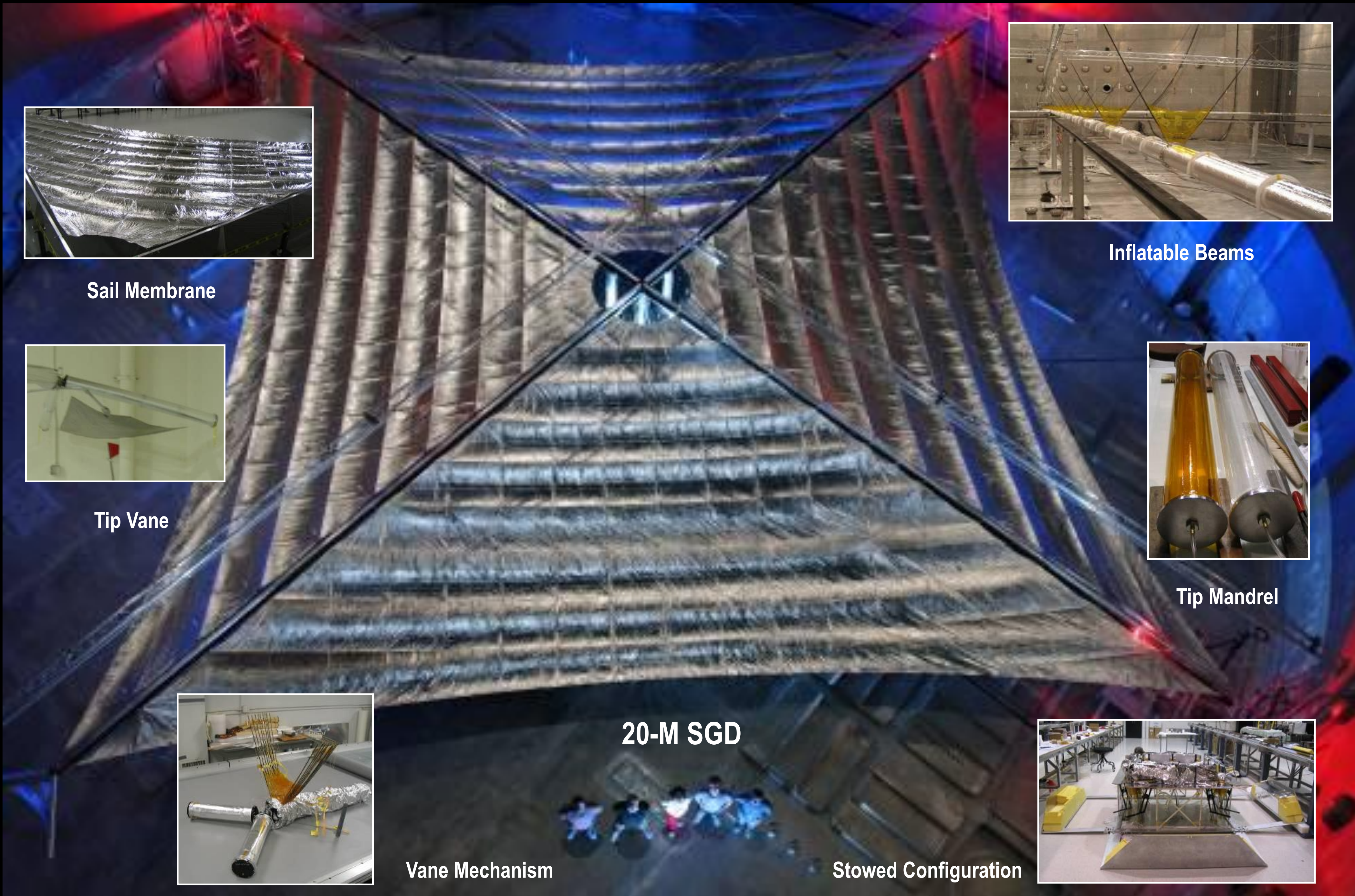


NanoS
ail-D

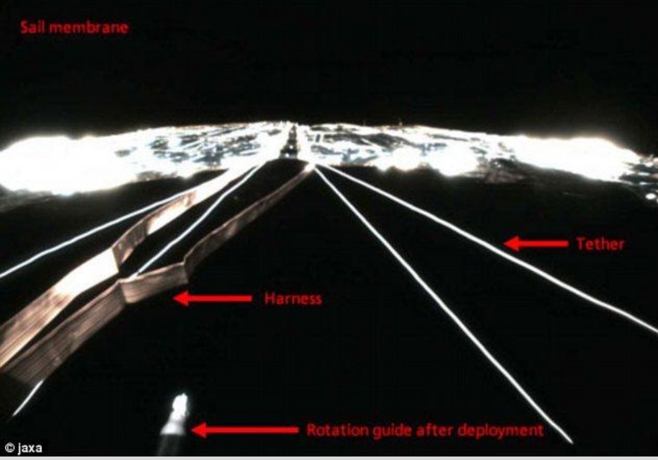
- Two 20-m system ground demonstrations (ATK and L'Garde) designed, fabricated, and tested under thermal vacuum and flight-like conditions - 2005
- IKAROS (JAXA) successfully flying in deep space – 2010
- NanoSail-D flew in orbit (NASA MSFC) - 2010
- L'Garde funded by NASA OCT to demonstrate deep space solar sail propulsion (*Sunjammer*) as a Technology Demonstration Mission in ~2014

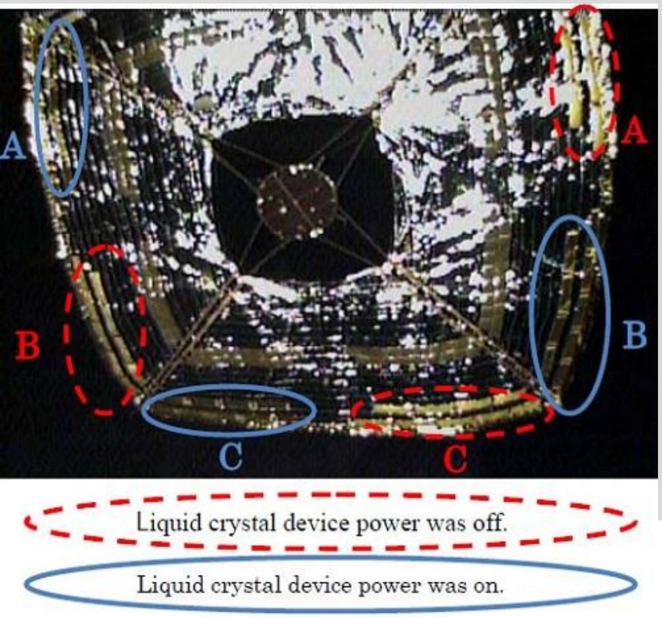

Solar Sail Propulsion
Space Demonstrated
14-m IKAROS
Flying in space
(2010 JAXA)
~34-m space demo
OCT TDM 2014
Inflatesail
Lightsail
3.5-m NanoSail-D
Flown in Space (2010 NASA)
CubeSail
20-m ground demo (2005)

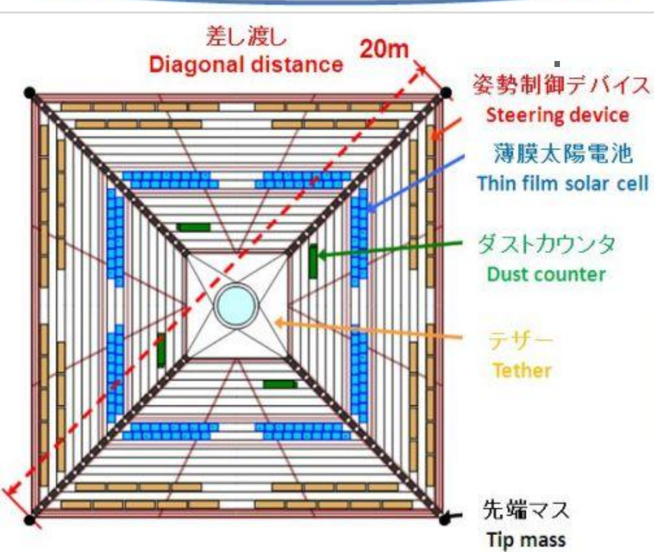
L’Garde 20-m System Ground Demonstrator



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

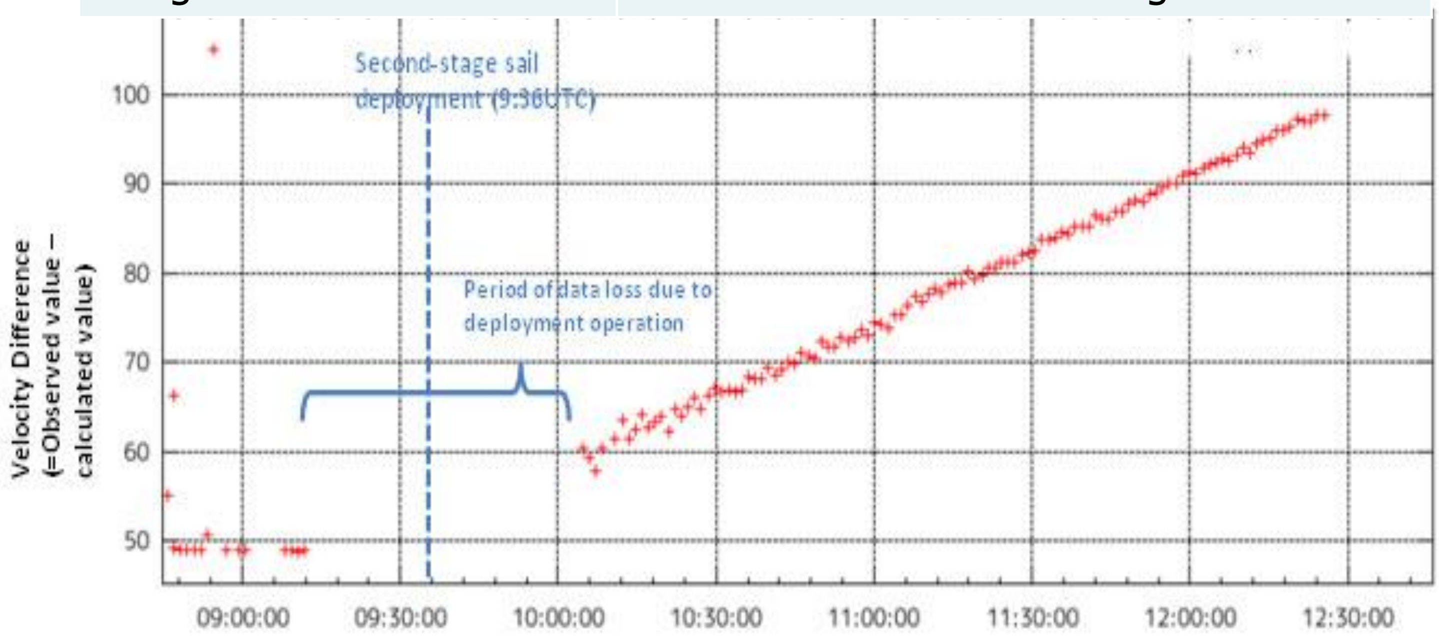






- IKAROS was launched on May 21, 2010
- The Japan Aerospace Exploration Agency (JAXA) began to deploy the solar sail on June 3.
- IKAROS has demonstrated deployment of a solar sailcraft, acceleration by photon pressure and attitude control
  - Deployment was by centrifugal force
  - Sail membrane is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



Multiple NEO Rendezvous Using Solar Sails

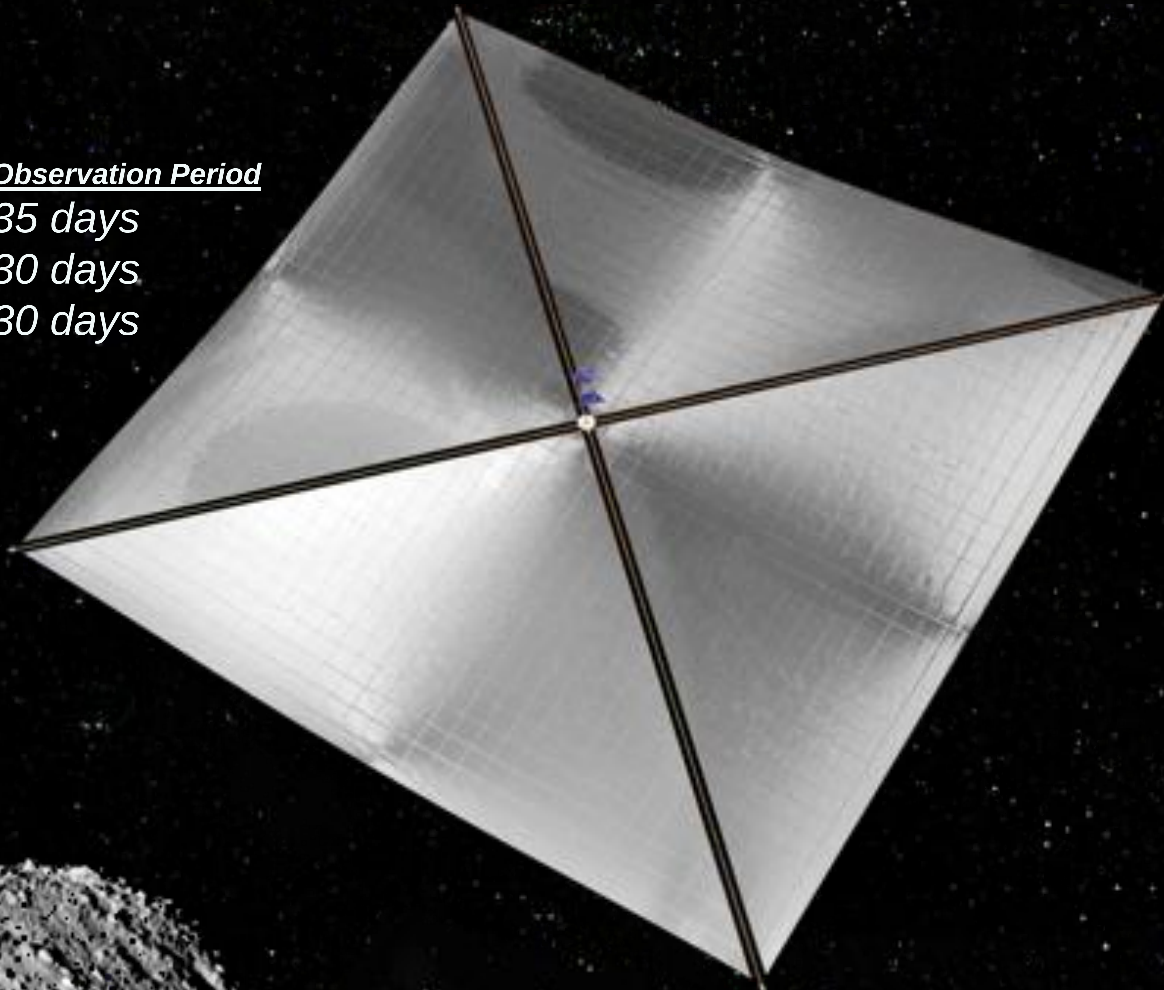
Assess the feasibility of using solar sail propulsion to enable a robotic precursor that would survey multiple Near Earth Objects (NEOs) for potential future human visits

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*



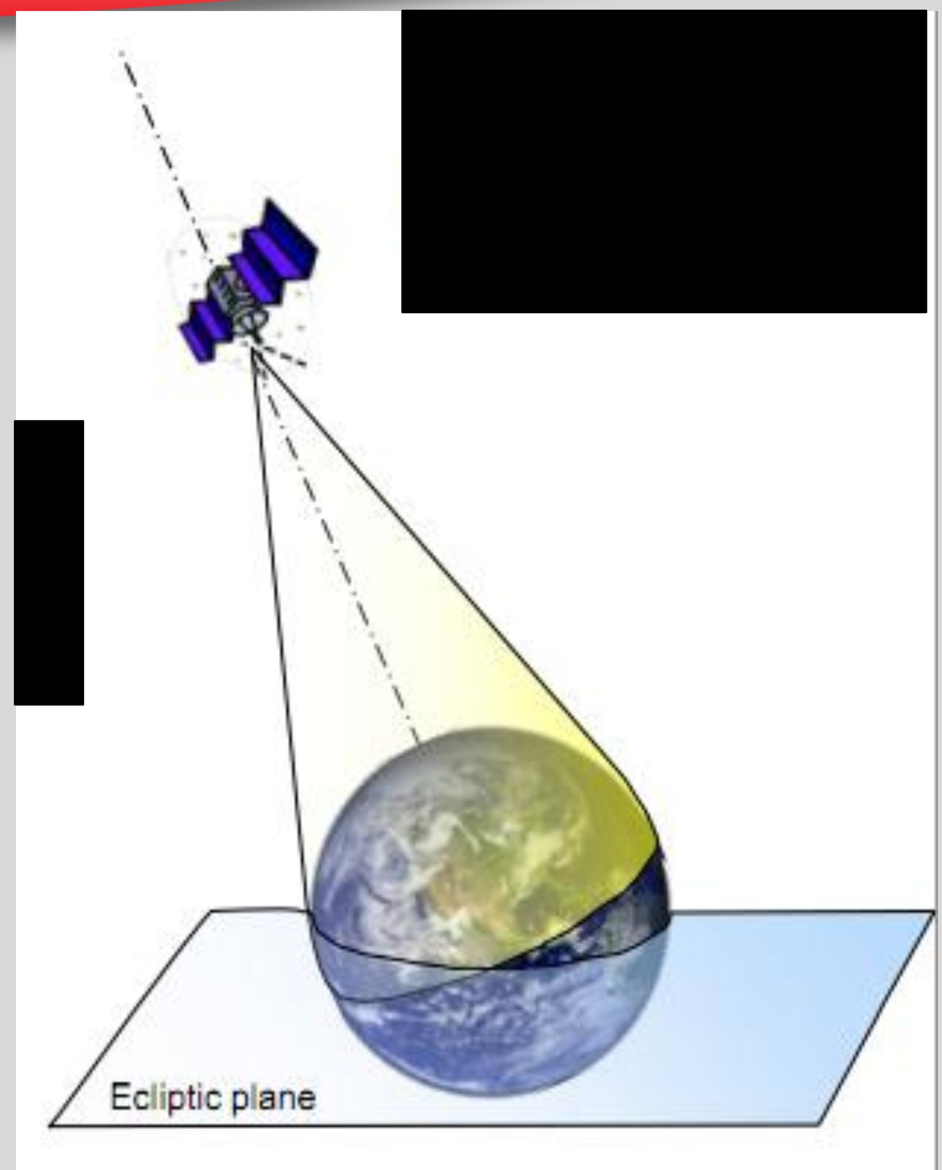
Solar Sail Spacecraft Launch Mass:
328.6 kg

Mass at destination:
228.4 kg

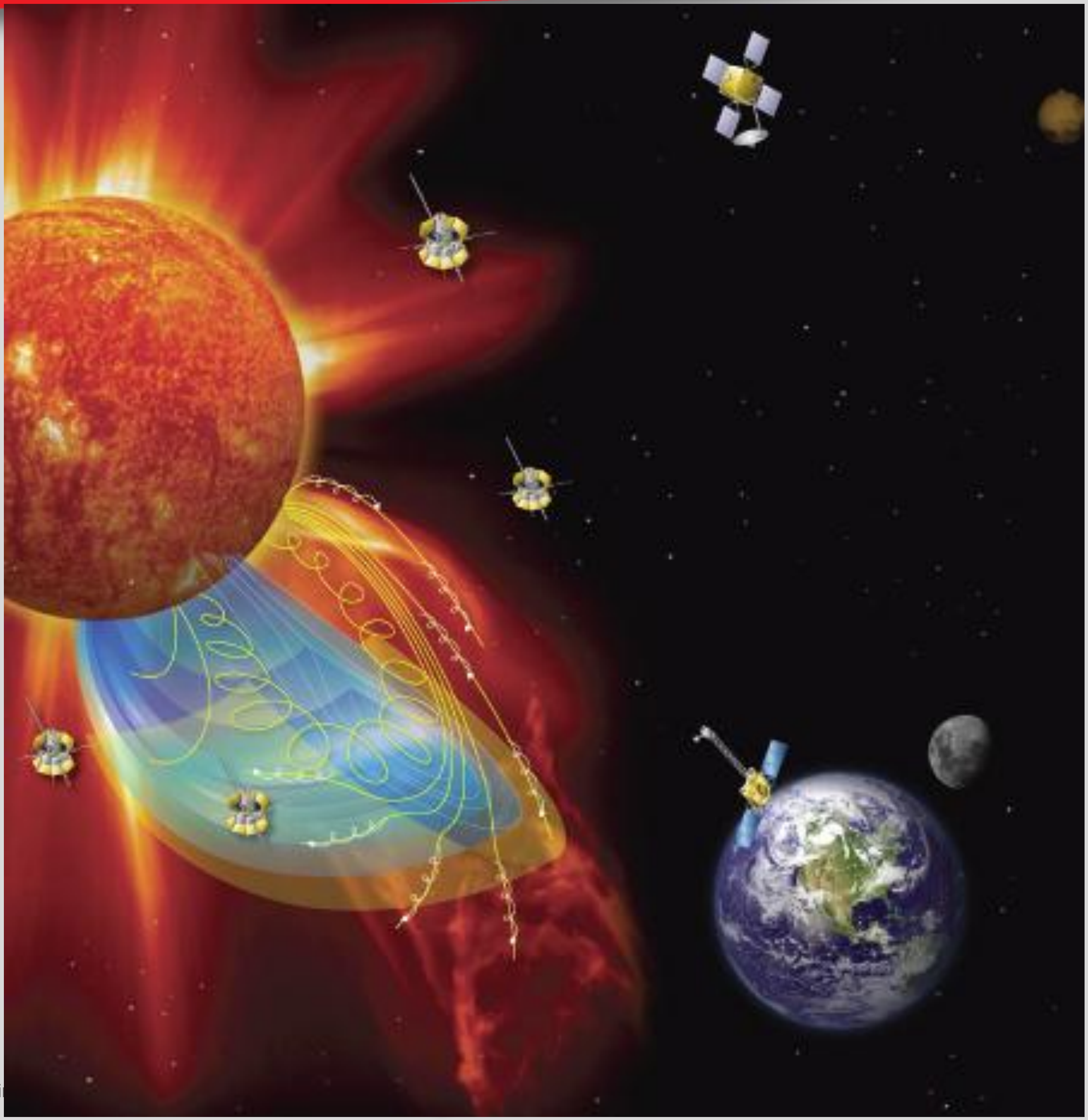
Cost:
$175M, plus launch vehicle and ops

Pole Sitter Spacecraft

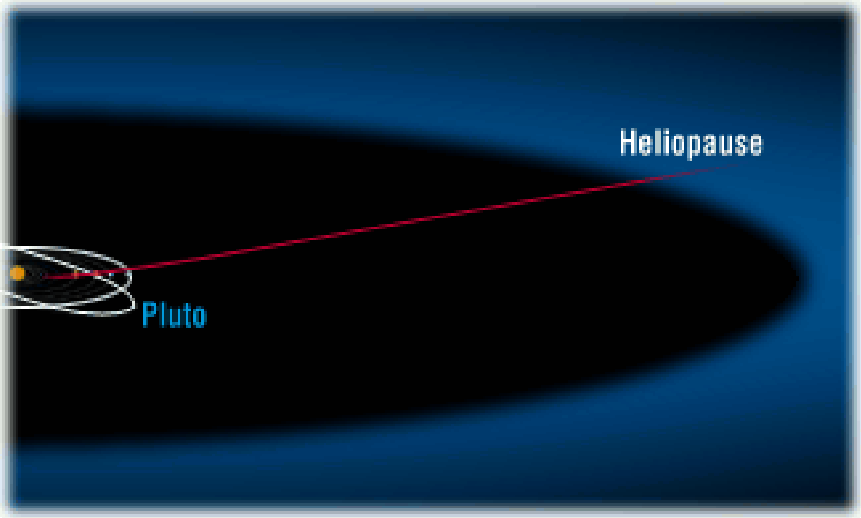
- Constantly above an Earth pole
- Continuous hemispheric view of the pole
- New vantage point for telecommunications satellites and Earth observing satellites



Solar Far-Side Sentinel



Solar Sail Propulsion for the Interstellar Probe Mission



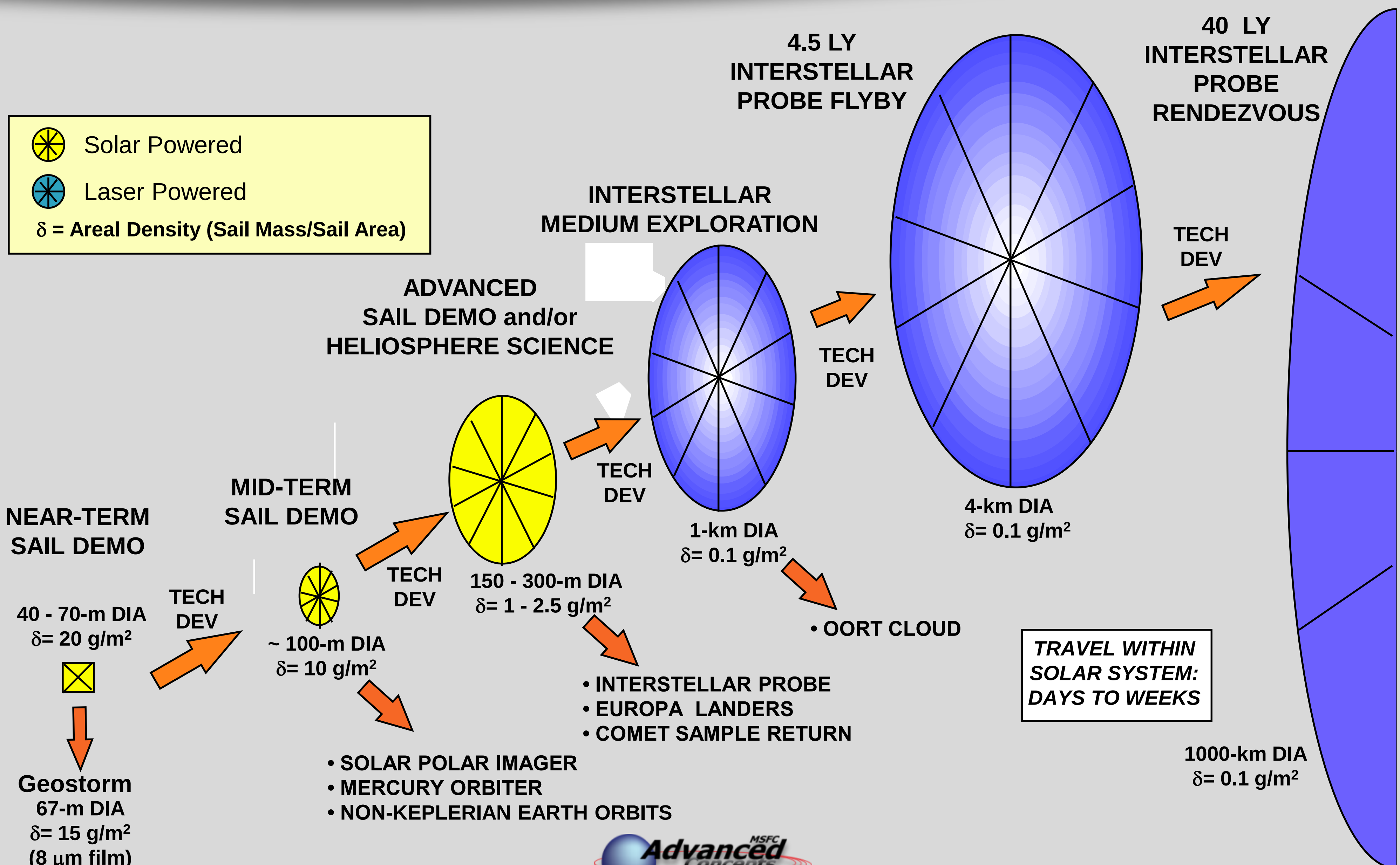
The Heliopause is a barrier where charged particles from the sun cannot go beyond because cosmic rays from deep space force them back.

- **Sail Requirements**
  - 500 - 800 meters diameter
  - 1 g/m^2 density
  - Survivable to T= 3000K for close solar approach

- The first mission to beyond the Heliopause
  - 250 AU minimum
  - Reach 250 AU within 20 years from launch
  - 15-20 AU/year target velocity

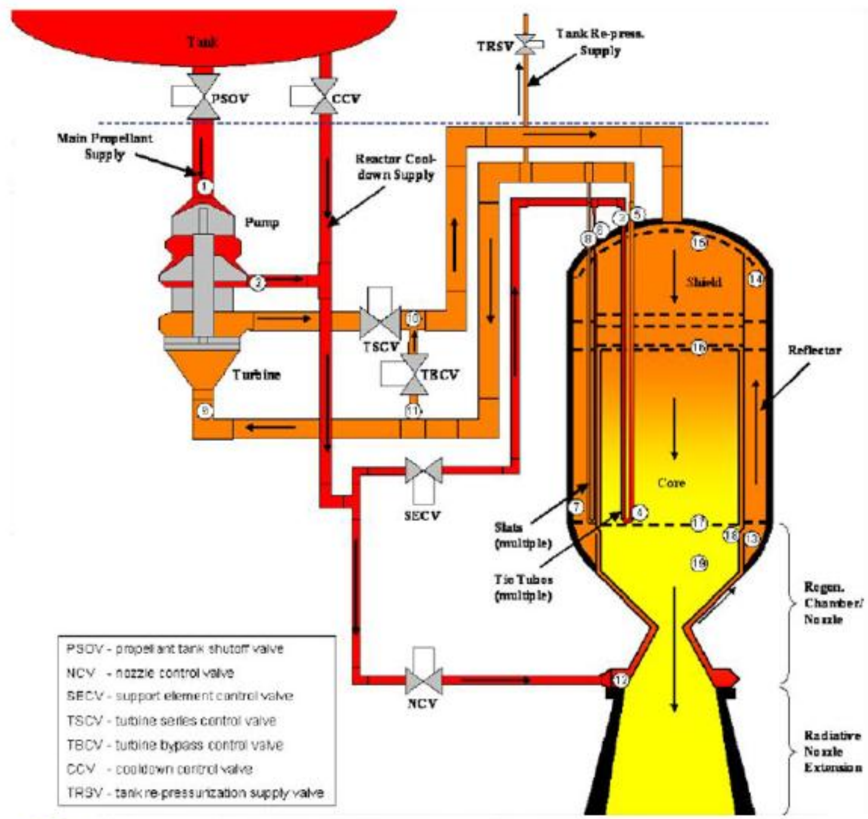
Carbon fiber μ-truss fabric (1 gm/m^2, 2 mm thick)

Near-Term Solar Sail Applications Lead to Interstellar Capability with Laser Sails



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



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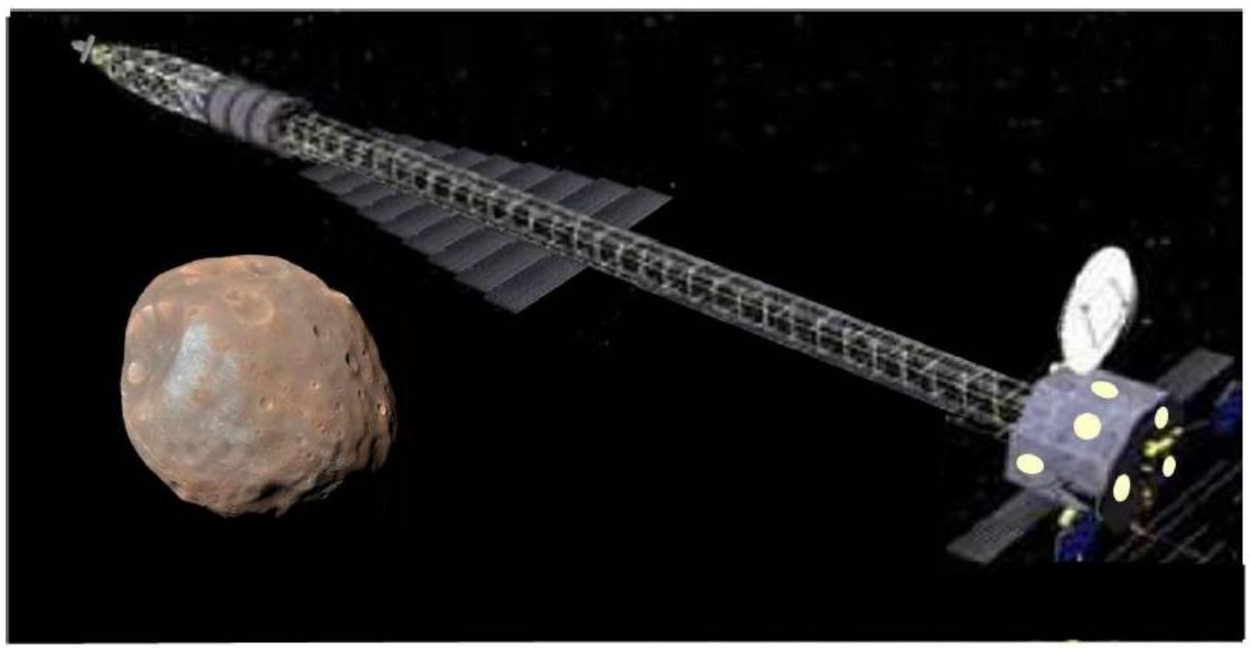
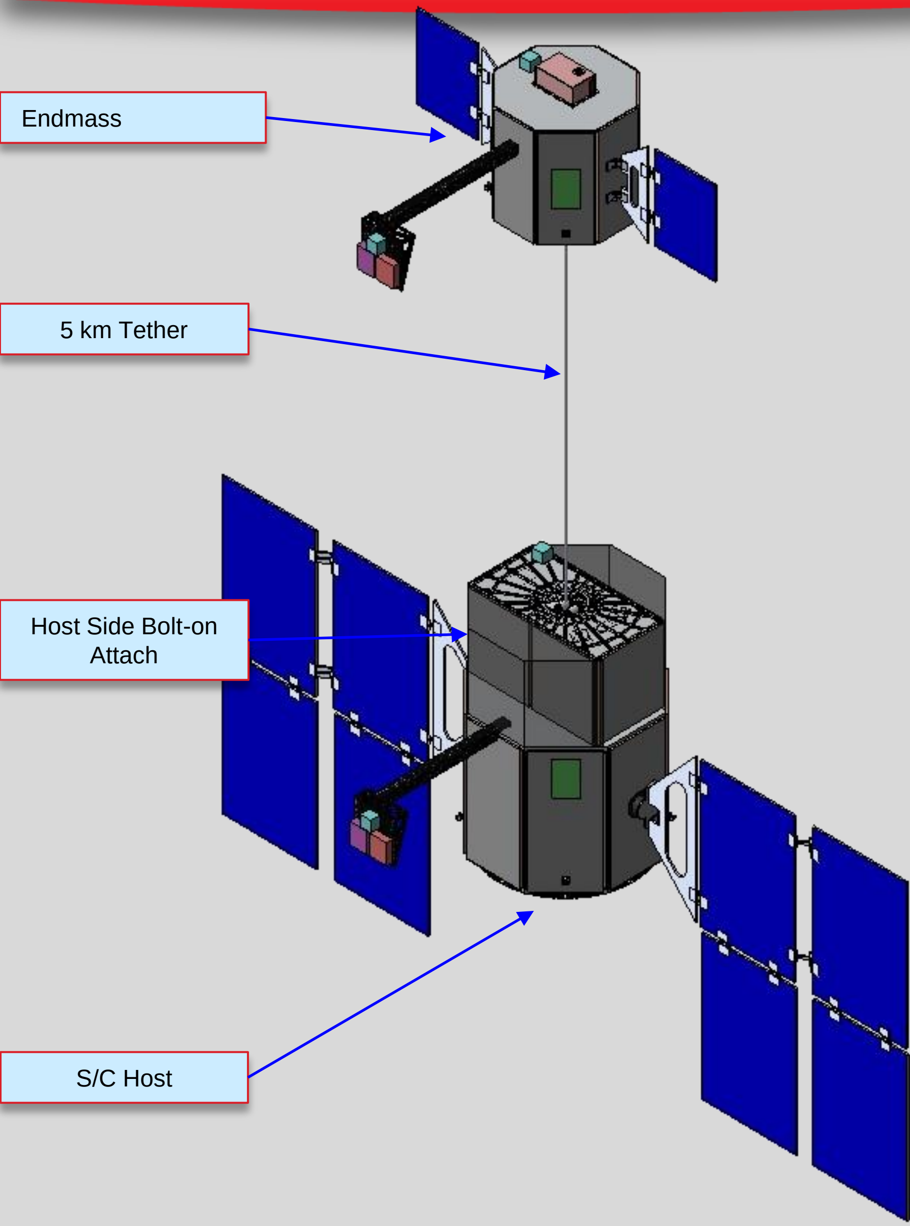
Fission Fragment Rocket Engine Mission Concept

- **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**



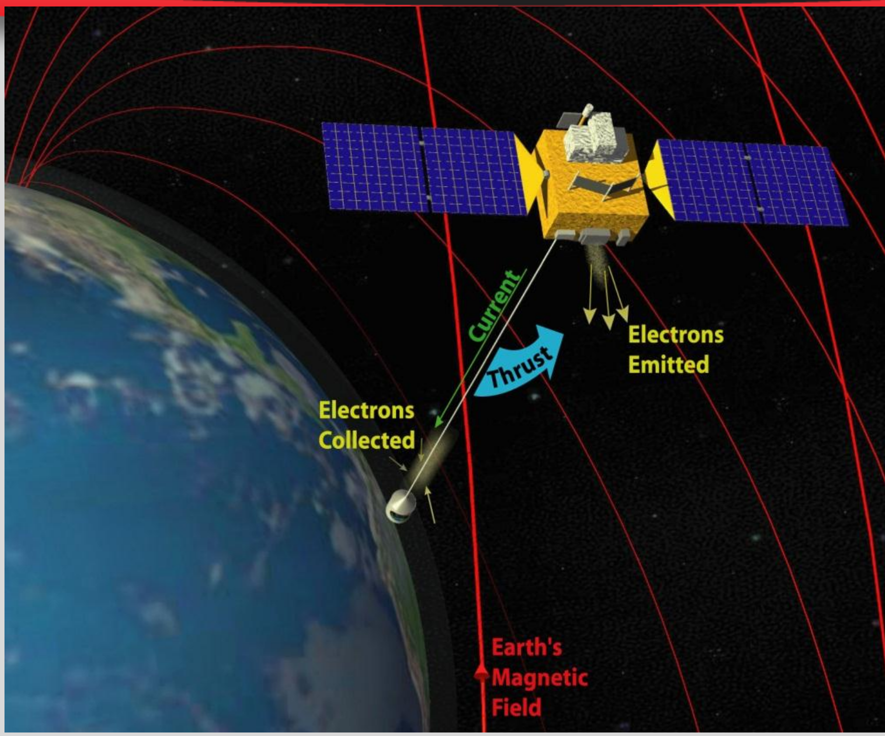
Propel: Propulsion using Electrodynamics



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

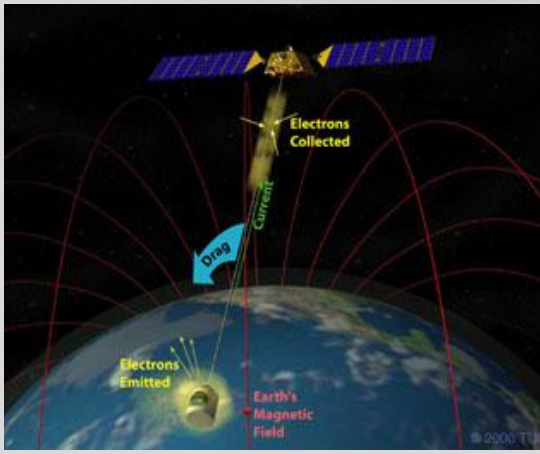
How Does Propel Work?

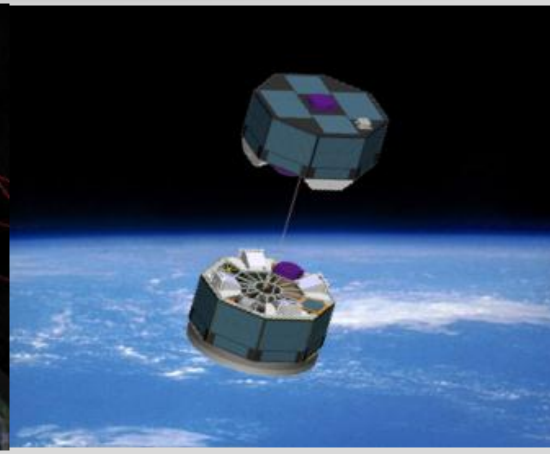


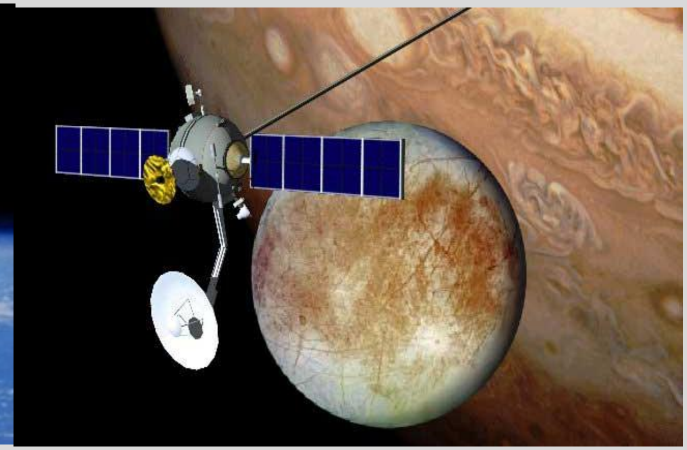
An **Electrodynamic Tether (EDT)** is essentially a long conducting wire extended from a spacecraft. Gravity will tend to orient the tether in a vertical position. If the tether is orbiting around the Earth, it will be crossing the Earth's magnetic field lines at orbital velocity (7-8 km/s!). The motion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

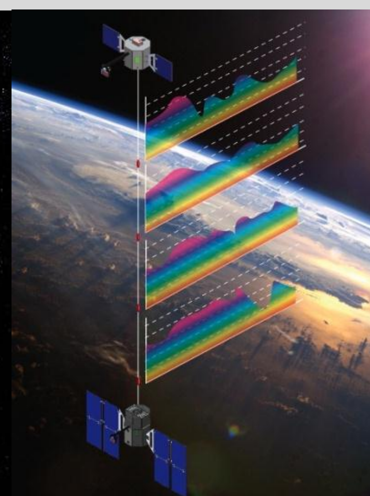
- An EDT can produce thrust by collecting electrons from the local plasma at one end of the tether and expelling them back into the plasma at the other end; the voltage drives a current along the tether
- This current interacts with the Earth's magnetic field to cause a Lorentz force (**J x B**) either 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

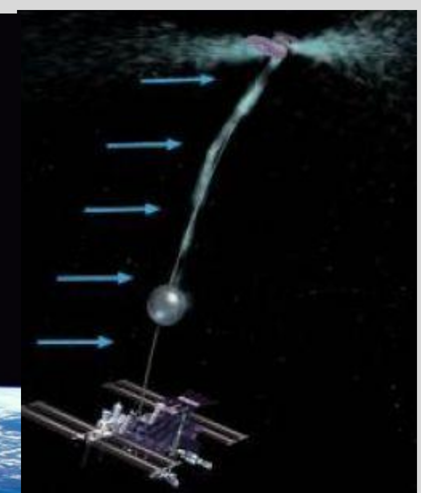
MISSIONS ENABLED BY PROPEL







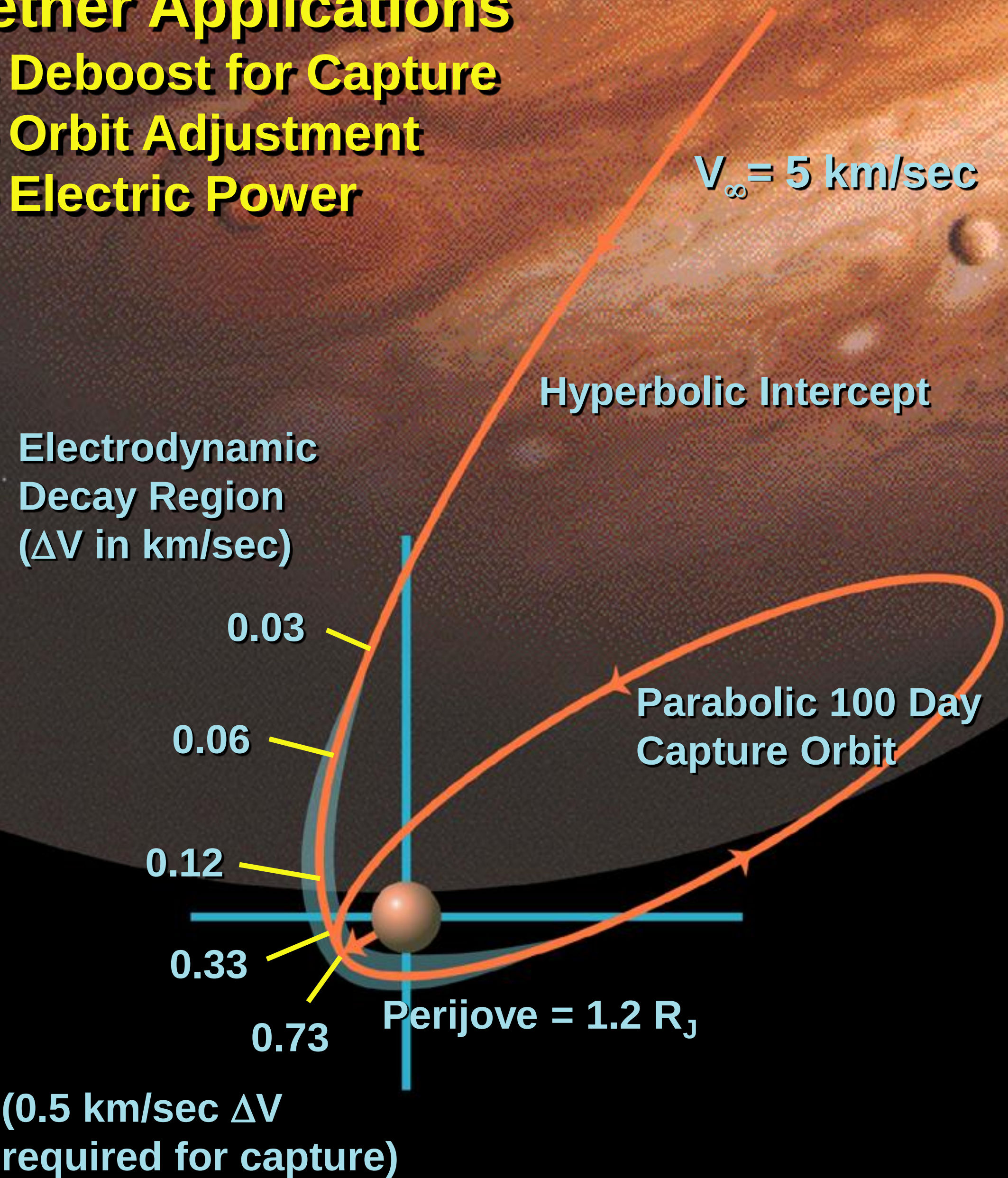


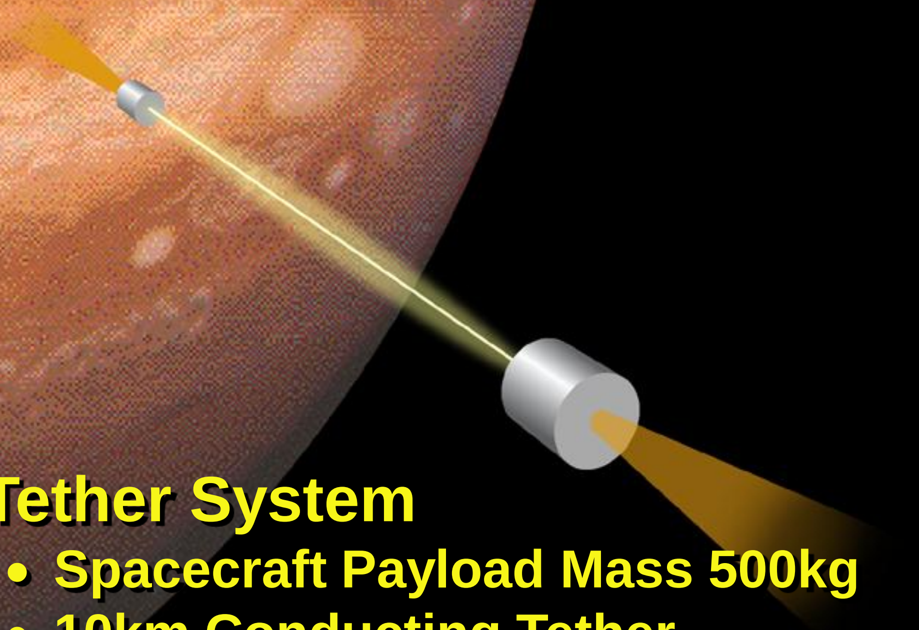


Jovian Electrodynamic Capture

Tether Applications

- Deboost for Capture
- Orbit Adjustment
- Electric Power



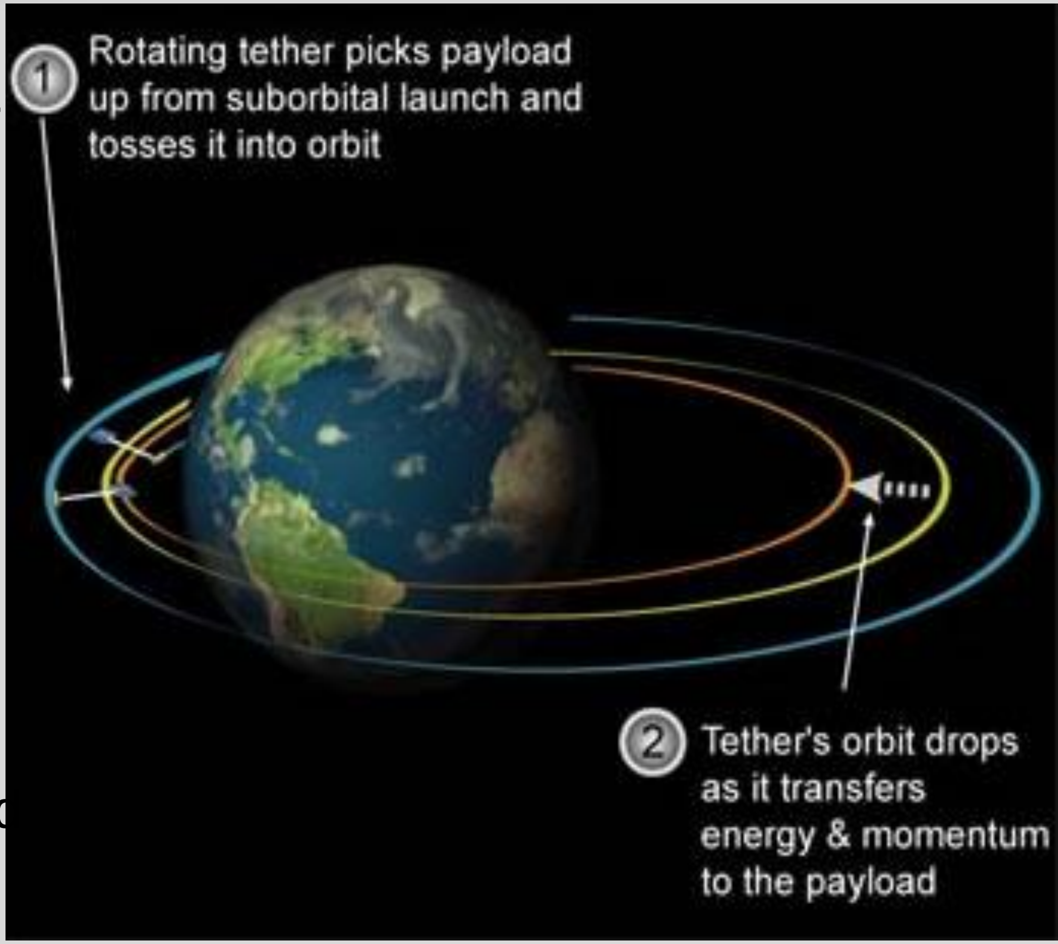


Tether System

- 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 ≤ 128kg
  - Total ≤ 240kg

LEO-GTO Tether Launch Assist

- A momentum-exchange / electrodynamic reboost (MXER) tether facility is a spinning tether in an elliptical Earth orbit.
- The tether's orbit and rotation are designed to allow it to match position and velocity with a payload in a low Earth orbit (LEO).
- The tether tip "catches" the payload, holds it for a half-rotation, and then "throws" it into a higher-energy orbit like geosynchronous transfer orbit (GTO).
- The energy and momentum transferred to the payload by the tether are then restored over weeks through electrodynamic reboost.
- Solar energy is used to drive electrical current through conductive portions of the tether—the magnetic field of the Earth exerts a force on the tether restoring its orbit.



"Catch & Throw" Momentum Exchange