An Overview of NASA’s In-Space Propulsion Program

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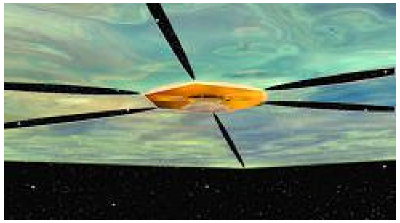
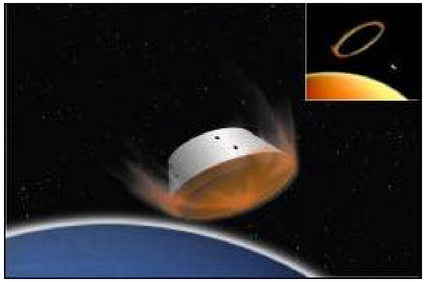
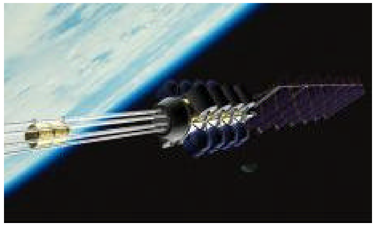
In-Space Propulsion Program Overview

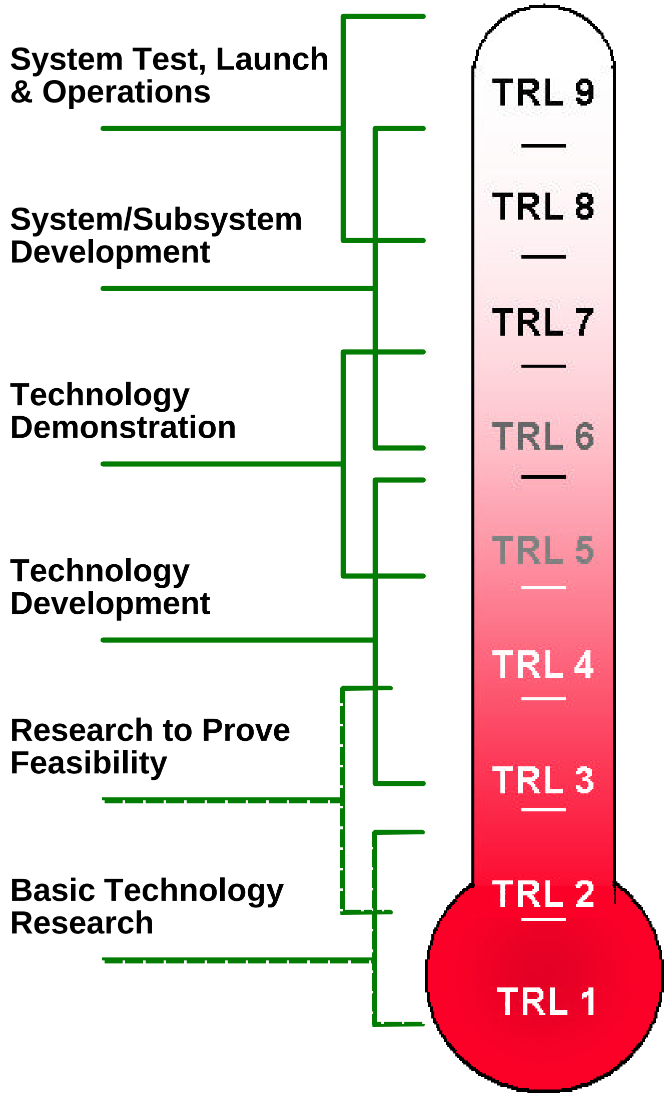






- **Objective**
  - Develop in-space propulsion technologies that can enable and/or benefit near and mid-term NASA science missions by significantly reducing cost, mass, and/or travel times. Technology areas include:
    - Solar Electric Propulsion (nuclear electric is now part of Nuclear Systems Initiative)
    - Propellantless Propulsion (aerocapture, solar sails, tethers, etc.)
    - Advanced Chemical Propulsion
- **Approach:**
  - Identify and prioritize the most promising technologies using systems analysis and peer review.
  - Develop mid-TRL technologies to TRL 6 for incorporation into mission planning within 3-5 years of initiation.
    - Maximize use of open competition to seek best solutions

In-Space Propulsion Program Will Advance Mid-TRL Technologies to Support NASA Mission Applications



NASA Implementation: (Deep Space One Ion Engine Example)

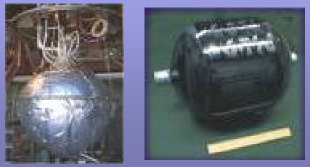
In-Space Propulsion Technologies

Aeroassist

Adv. Electric Propulsion

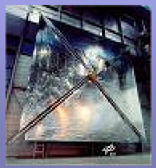
Solar Thermal

Adv. Chemical



Tethers

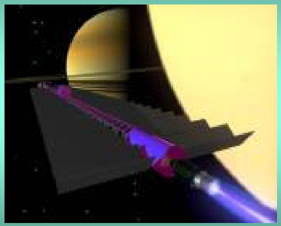
Solar Sails



Plasma Sails

Low-TRL Technologies For the Future

External Pulsed Plasma



Fusion & Antimatter

Beamed Energy

In-Space Propulsion Program Status

♦ Status

- In Space Propulsion Program is managed by NASA HQ, Office of Space Science
  - Dr. Colleen Hartman, Director, Solar System Exploration Division (HQ)
  - Paul Wercinski, Program Executive, In-Space Propulsion Program (HQ)
  - NASA MSFC is the implementing organization for ISP
  - NASA Centers support systems analysis and technology evaluation efforts
- Competed efforts
  - ISP Program goal to have 75% of available funds used for competitive procurements
  - NASA Research Announcements used within Code S
  - Solicitations open to Industry, NASA and other government agencies, and Academia
- Directed efforts
  - FY02 directed tasks included Systems Analysis and continuation of NSTAR life test.
  - Eight directed tasks underway for FY03.
- All Nuclear technologies moved under the Nuclear Systems Initiative

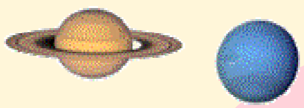
♦ Planned In-Space Propulsion Program Budget

FY02	FY03	FY04	FY05	FY06	FY07
$19.6M	$61.4M	$65.7M	$64.7M	$66.7M	$66.7M

In-Space Propulsion Program Status

- **NRAs used for Competitive Technology Development Selection:**
  - NRA-01-OSS-01 Next Generation Ion Engine Technology (~$21M over FY02-FY04)
    - Awards(2): - NEXT Ion Engine (NASA GRC)
      - Carbon-based grid development (Boeing)
  - NRA-02-OSS-01 ISP Technologies Cycle 1 (~$38M over FY02-FY04)
    - Technologies: Aerocapture, Solar Sails, Power Conversion, and High Power Electric Propulsion (EP)
    - Awards(15):
      - High temperature composite structures (Aerocapture, NASA Langley)
      - Light-weight Thermal Protection System ablators (Aerocapture, ARA Inc)
      - Characterization of Advanced Thermal Protection Systems (Aerocapture, NASA Ames)
      - Ballute analysis and development (Aerocapture, Ball Aerospace)
      - Advanced TPS Instrumentation (Aerocapture, ELORET Corp)
      - Aeroshell System Development and Integration (Aerocapture, Lockheed Martin Astronautics)
      - Development of a Two-Stage Bismuth Hall thruster (High Power EP, Stanford University)
      - Development of a 65 cm, 20 kW, Xenon ion thruster (High Power EP, NASA JPL)
      - Development of a 50 cm, 25 kW Xenon ion thruster (High Power EP, NASA Glenn)
      - Segmented thermoelectric multicouple Space Reactor Power System (Power Conversion, NASA JPL)
      - Brayton Power Conversion System (Power Conversion, Boeing Rocketdyne)
      - Potassium Rankine cycle Power Conversion System (Power Conversion, Oak Ridge National Lab)
      - Development of a Striped-Net sail and Inflatable boom model' (Solar Sail, L'Garde Inc)
      - Development of a CP1 sail and Coilable boom model (Solar Sail, Able Engineering)
      - Development of an integrated set of solar sail simulation tools (Solar Sail, NASA JPL)
  - NRA-02-OSS-01 ISP Technologies Cycle 2 (~$25M over FY03-FY04)
    - Technologies: Aerocapture, Advanced Chem, Alternative Electric Propulsion, Tethers, Plasma Sail, Solar Sail
    - Award announcements anticipated in 2nd Qtr. FY03

FY02 In Space Propulsion Technology Prioritization Process

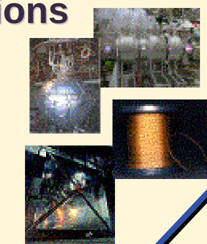


Requirements/Goals Established

- Space Science
- Earth Science
- Exploration and Development

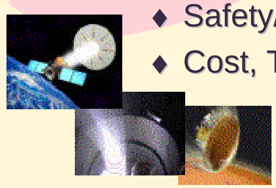
Requirements provided by NASA Enterprise customers

Technology Options Identified



Systems Concepts Developed

- Architecture
- Safety/Reliability
- Cost, Trip Time, etc.

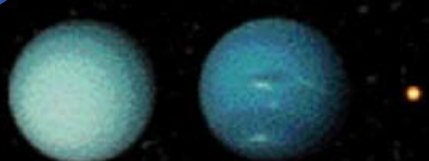


Systems Concepts Compared

- Feasibility
- Identification of Technology Drivers
- Recommended approaches

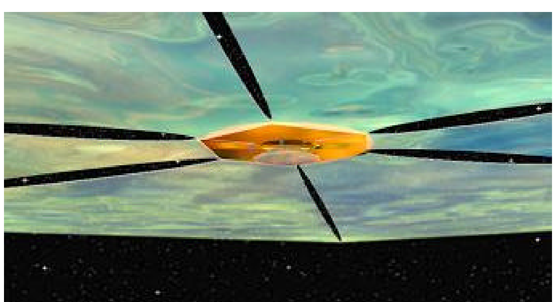
Technologies Prioritized (scoring process)

High Priority	Medium Priority	Low Priority	High Payoff/ High Risk (Low TRL)
Aerocapture (robotic to human mission evolvable)	Advanced Chemical (cryogenic + TBD)	Bimodal Nuclear Thermal Propulsion (Low to High Power Evolvable) Moved To NSI	1 g/m2 Solar Sails
Next Generation Ion Propulsion (5/10 kW)	Class 1 Electric Propulsion (30 kW – 100 kW 3000 – 10,000 sec >50% efficiency)	Solar Thermal Propulsion	Momentum Exchange Tethers
Nuclear Electric Propulsion (Low to High Power Evolvable) Moved To NSI	Class 2 Electric Propulsion (>500 kW) >3000 sec >50% efficiency) Moved To NSI		Plasma Sails
	SEP Hall (100 kw)		
	Solar Sails		



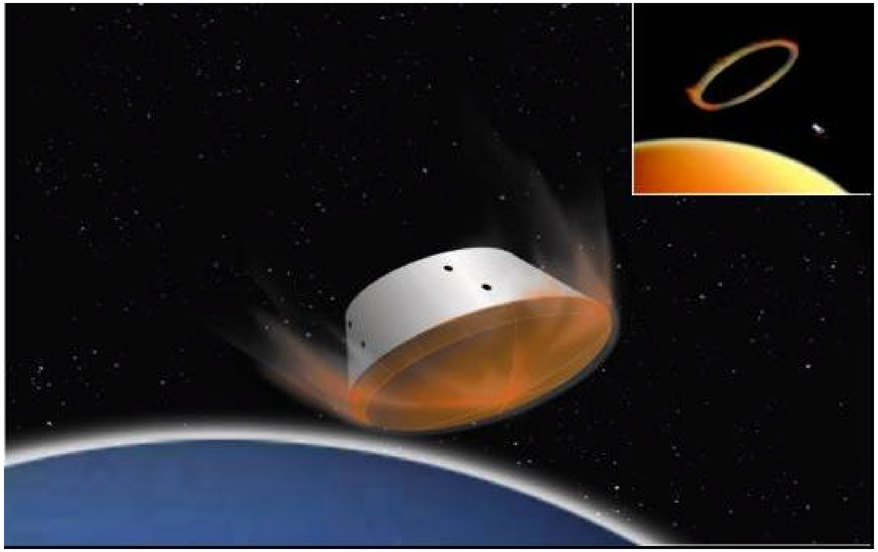
Cross-Enterprise In-Space Propulsion Priorities

In-Space Transportation Technology Products
High Priority Technologies



- **Aerocapture**
  - Low-mass aeroshell with integrated TPS
  - Aerocapture flight-like instrumentation
  - Advanced Aerodynamic Decelerators (trailing ballutes, attached ballutes and inflatable aeroshells)
- **Next Generation Ion Thruster**
  - Next generation integrated ion engine thruster technology
    - NASA's Evolutionary Xenon Thruster
    - Carbon Based Ion Optics
- **Solar Sails**
  - Sail subsystem design and fabrication and ground demonstration
  - Structural testing of sail booms
  - Long term environmental evaluation of ultra-thin sail material

Aeroassist / Aerocapture



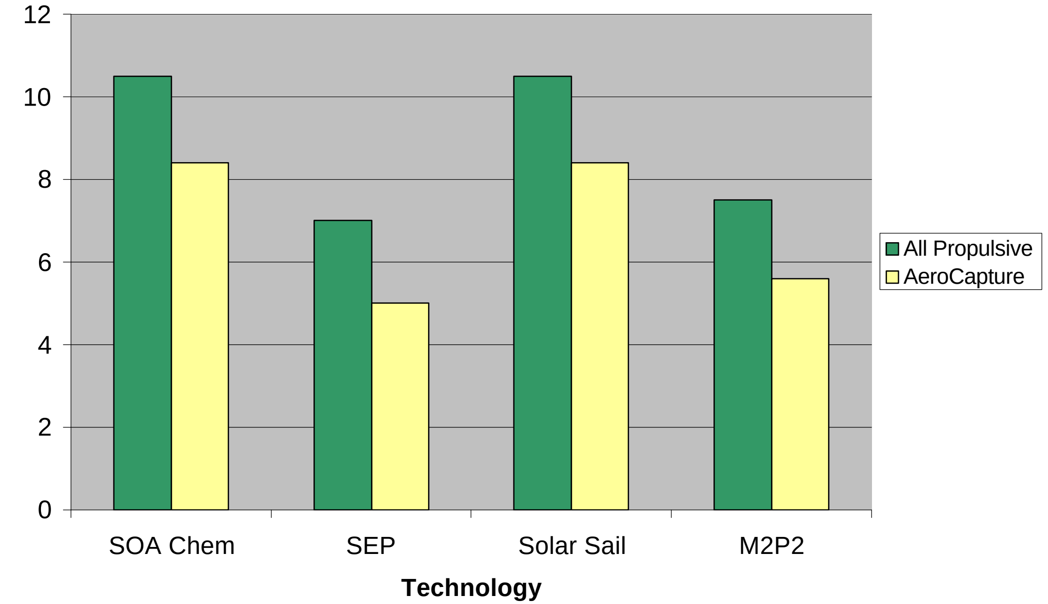
♦ **General Description: Aeroassist is the use of aerodynamic forces during atmospheric flight to accomplish transportation function**

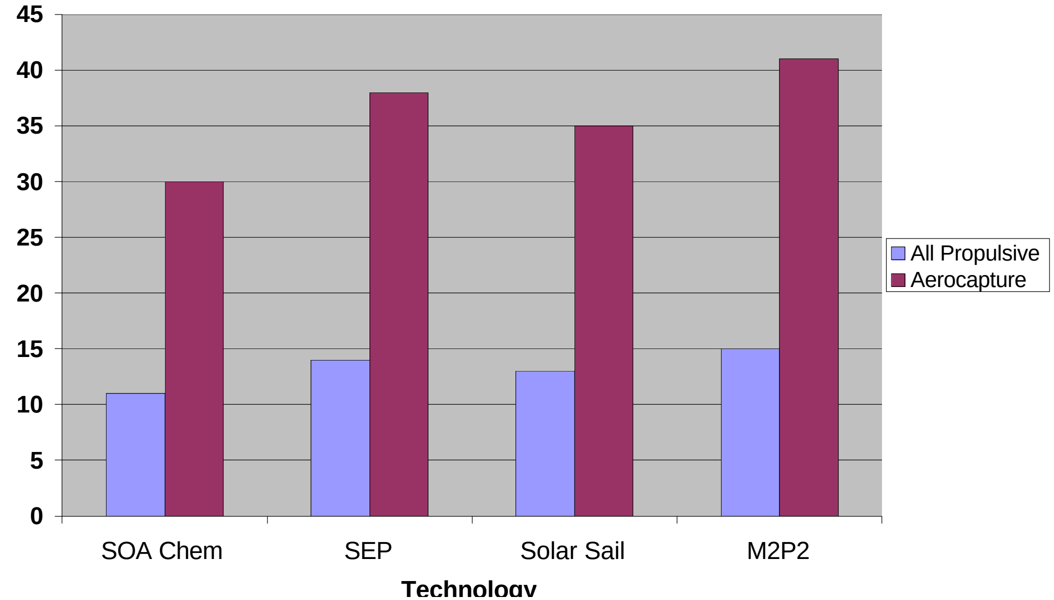
Aeroentry - a vehicle enters an atmosphere, either from hyperbolic or elliptical orbit, and lands/impacts
Aerocapture - a vehicle uses an atmosphere to insert into an elliptical orbit from a hyperbolic orbit
Aerobraking - a vehicle uses an atmosphere to modify an already-established elliptical orbit
Aerogravity Assist - a vehicle uses a combination of atmosphere and propulsion to modify a hyperbolic orbit; an aerodynamically-assisted swingby
Precision Landing - a vehicle uses systems during aeroentry and terminal descent to achieve a landing at a specified site

♦ **Benefits:**

- No or very little propellant required for orbit insertion/entry
- Lower transportation system mass
  - – Aerocapture saves almost all orbit capture fuel mass and can quickly achieve a scientifically useful orbit (aeroshell and guidance and control system necessary)
- Capable of high ?V impulsively at target arrival (multi-g deceleration)
- Shortens trip times to outer planets (by using aerogravity assist or allowing higher Earth departure energies)

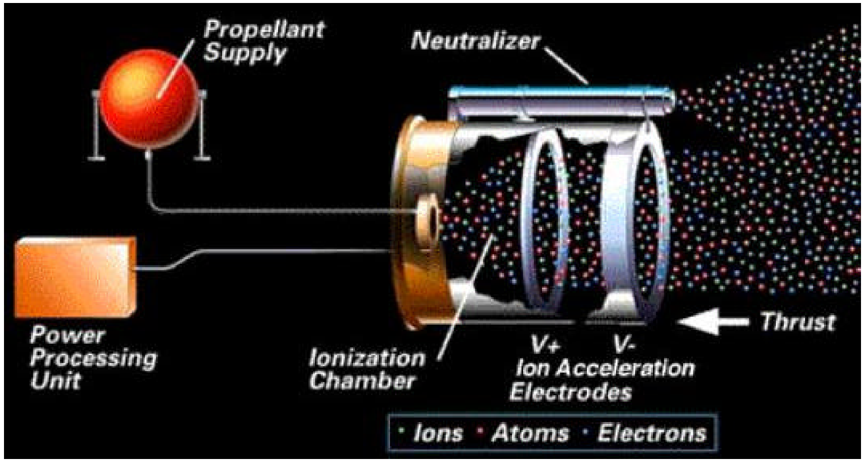
Benefits of Aerocapture Example: Titan Explorer





Aerocapture provides <u>significant</u> benefits in Trip Times & Payload Mass Fraction to all mission designs

Next Generation Ion Electric Propulsion



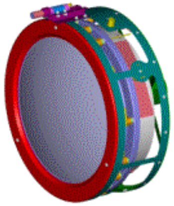
Ion Engine

♦ General Description:

In Space propulsion technology that utilizes electrical energy to produce an electrostatic reaction (with a propellant) to obtain thrust.
May utilize Solar or Nuclear generated power
Applications: Primary propulsion – earth orbit and planetary, orbit insertion, station-keeping, precision control, maneuvering

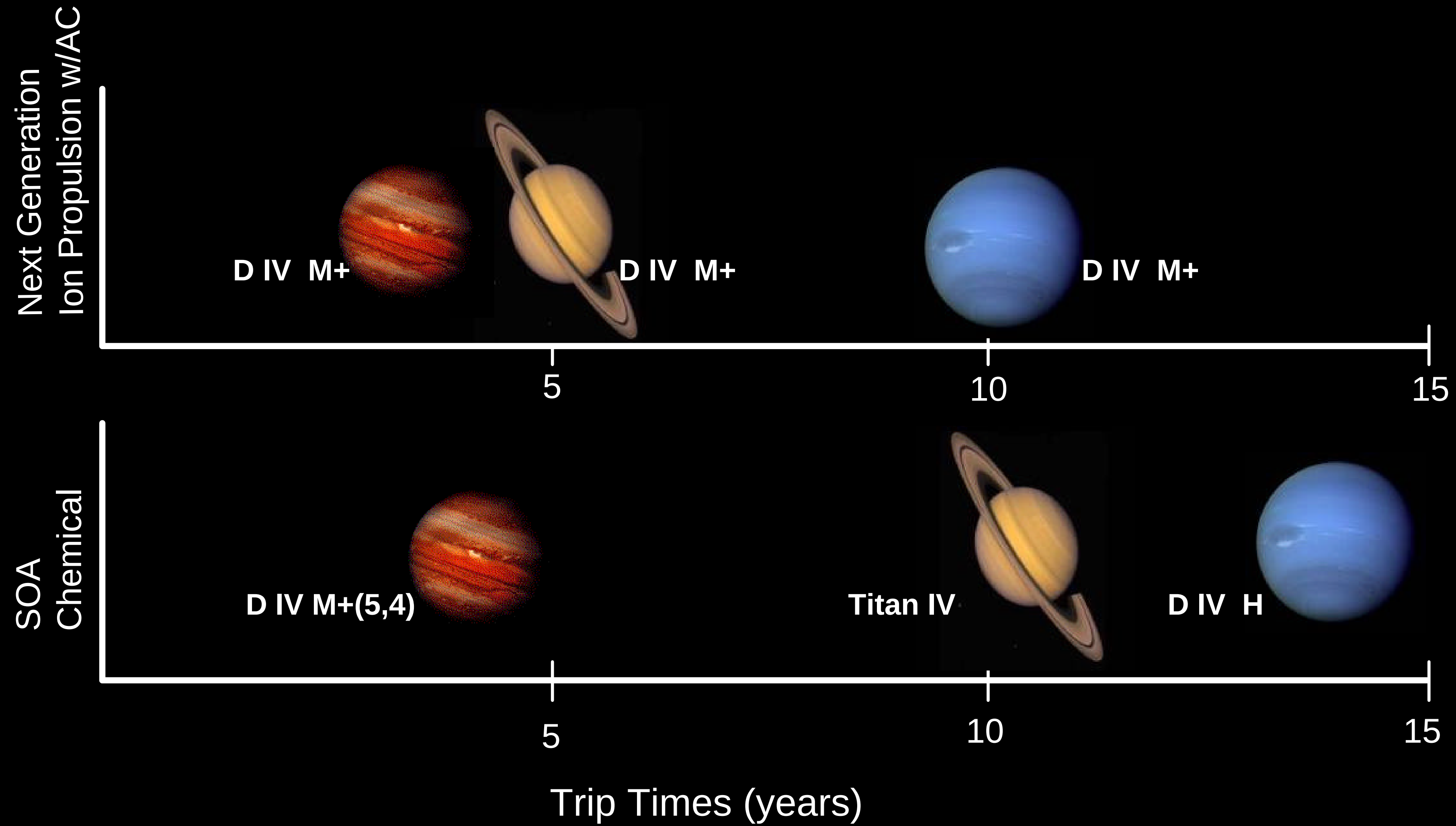
♦ Benefits:

- Low propellant consumption (high delta V, high performance)
- High Isp
- High TRL; SEP Ion in use today
- Uses smaller LV, lower launch costs
- No environmental issues
- Quick access to most of the solar system with 2 to 10 times the payload capability of chemical rockets

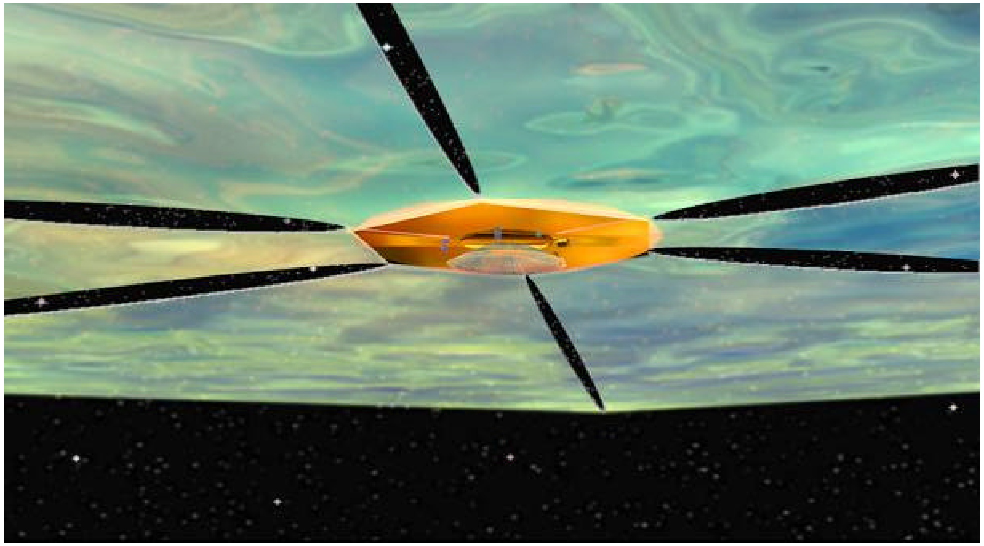


Technologies developed under this effort will increase Isp by greater than 30% over today's SOA ion engine, while significantly increasing power and thrust and reducing system alpha.

Trip Time and Launch Vehicle Benefits For Potential Destinations



Solar Sails



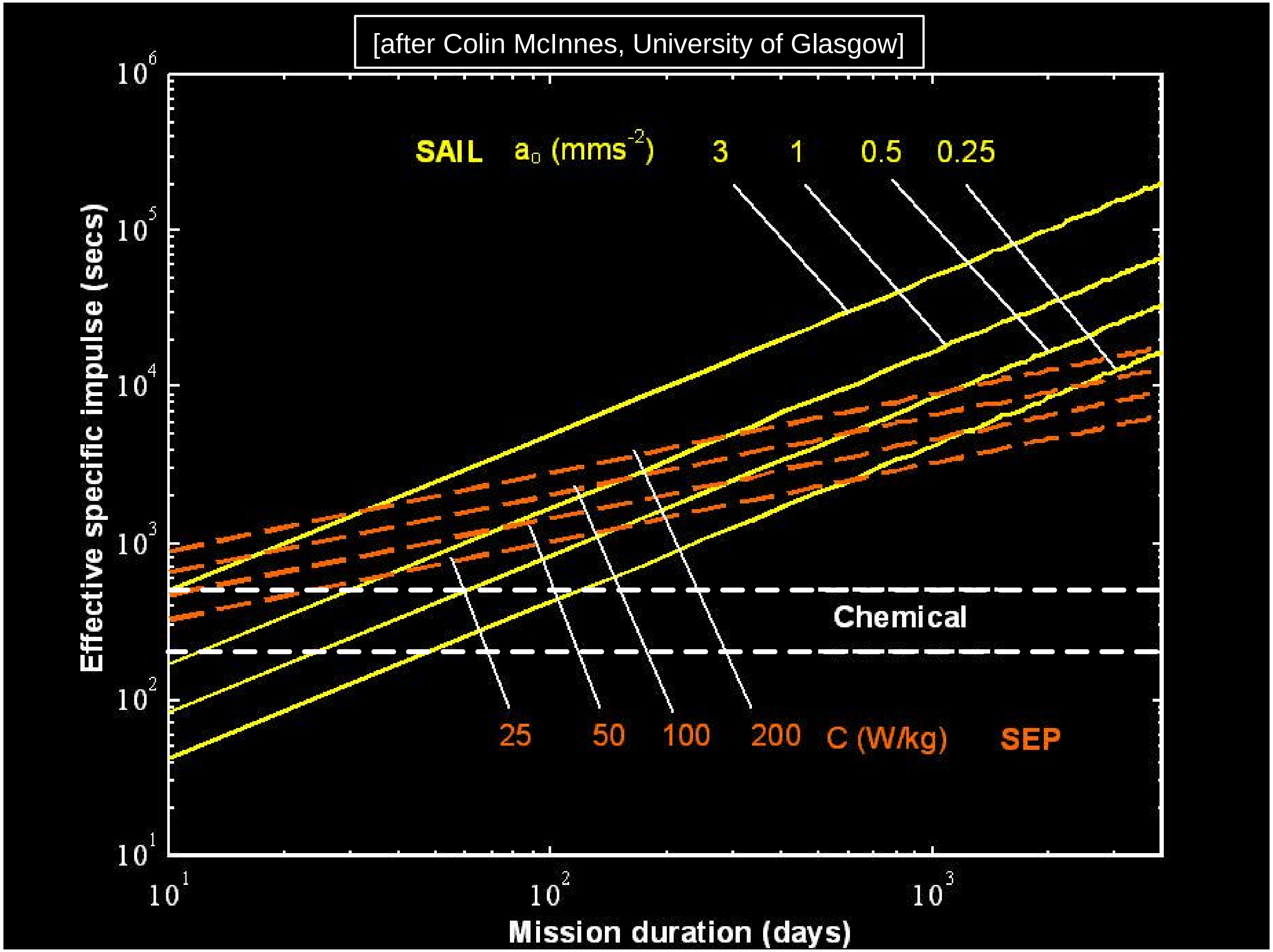
♦ **General Description:**
Solar sails use photon "pressure" or force on thin, lightweight reflective sheet to produce thrust;

–**Perfect absorber:** 4.5 microNewton/m^2
–**Perfect reflector:** 9.0 microNewton/m^2

♦ **Benefits:**

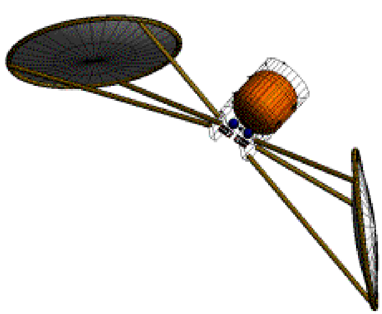
- No propellants required
- As technology advances (lighter sail material) more ambitious missions are possible – missions closer to the sun and reduced trip time for outer planets
- Very simple design (engineering challenge is large area and low mass)
- No environmental issues
- Sails can open up new regions of the solar system to accessibility for important science missions
  - High DV for:
    - –Inner solar system sample return missions
    - –Reaching high inclination orbits around the sun
    - –Getting to the outer planets quickly
    - –Interstellar precursor missions
  - Non-Keplarian orbits:
    - –Levitated orbits, e.g. geostationary satellite not on the equator
    - –Pole sitters, e.g. hovering above the Earth's north pole
    - –Hovering at a point closer to the sun than L_1

SAIL Propulsion Performance – Constant Thrust



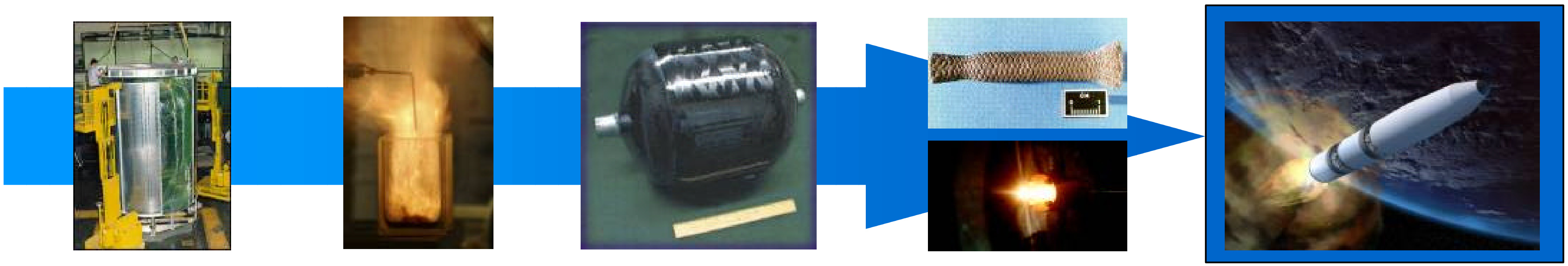
Note: "Effective Isp" means dry mass is included as well as propellant

In-Space Transportation Technology Products
Medium / Low Priority Technologies



- **Advanced Chemical**
  - Fuels development
  - Cryogenic Fluid Management
  - Lightweight components
- **kW Solar Electric Propulsion**
  - Laboratory demonstration of 50kW Hall thrusters
  - Competitively select thruster technology advancement based on application
- **Solar Thermal Propulsion**
  - Technology investments under further study
  - Directed tasks focused toward fundamental performance questions

Advanced Chemical Propulsion



Cryogenic Fluid Management

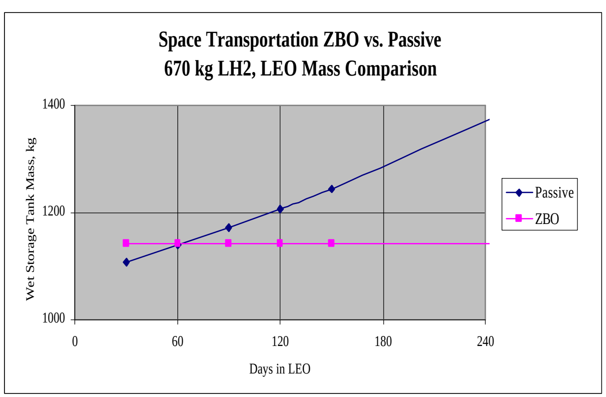
Propulsion supporting technology that may enable long-term storage of cryogens in low g, including propellant transfer and mass gauging

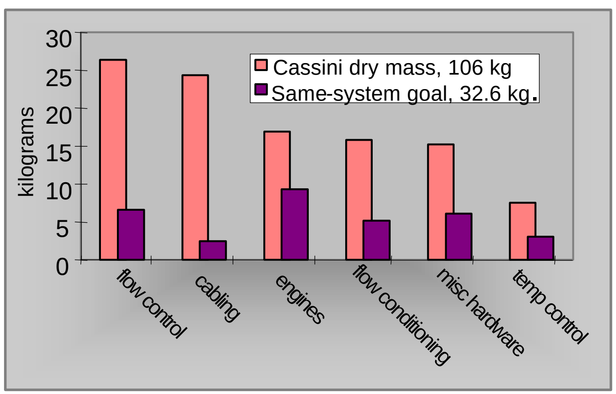
Lightweight Components

Optimized component, material and manufacturing technology to reduce the mass of cross-cutting propulsion components: feed system components, tanks, etc.

Advanced Fuels

Storable chemical propulsion concepts that offer performance improvements through attributes such as higher density or increased Isp or operating temperature

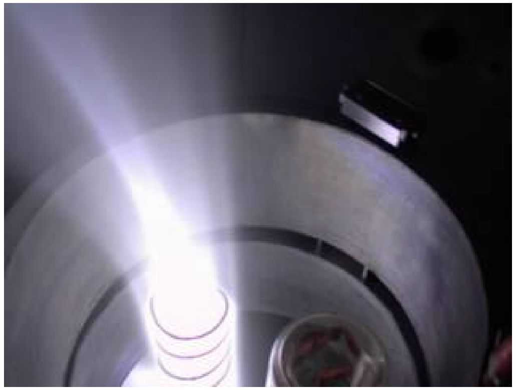




Propellant	Isp(lbf-s/lbm)
O_2/CH_4	365
ClF_5/N_2H_4	350
OF_2/C_2H_4	415
N_2F_4/N_2H_4	395
F_2/N_2H_4	415
OF_2/C_2H_6	410
OF_2/B_2H_6	420

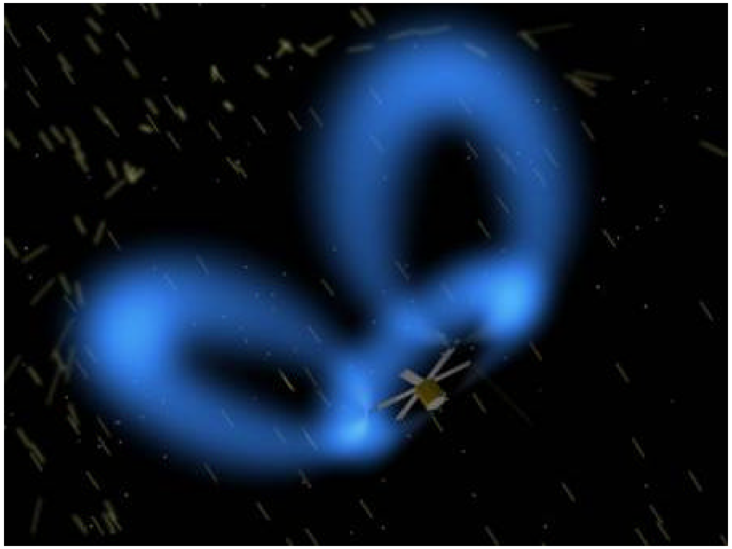
Isp for a variety of Bipropellant Systems

In-Space Transportation Technology Products
High Risk/High Payoff & Lower Priority Technologies



- **Plasma Sails**
  - Thrust measurement and validation
  - Compare analytical model results vs. Laboratory test data
- **Momentum Exchange Tethers**
  - Model development and evaluation
  - Catch Mechanism concept
  - High strength tether
- **Solar Sails < 1g/m2**
  - Ultra-lightweight sail materials
  - Large area lightweight structures and mechanisms

Plasma Sails



- **General Description:**

This technology is based on the transfer of momentum from the solar wind to an artificial magnet field structure similar to what naturally occurs at all magnetized Planets in the solar system, called a planetary Magnetosphere. A plasma sail differs from a solar sail in that electromagnetic / electrostatic fields are used to create and stabilize an area that exchanges momentum with solar wind, solar photons, or both.

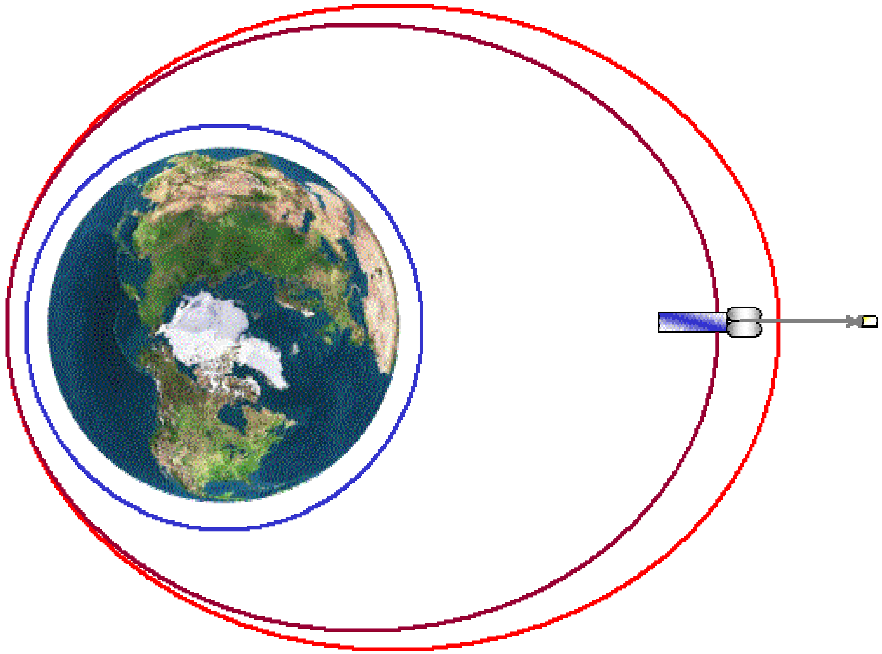
♦ Benefits

- Dramatic reduction in trip times to Outer Planets and beyond.
  - Pluto fly by – 6 years
  - Saturn magnetosphere insertion – 5.6 years
  - Jovian magnetospheric insertion – 1.2 years
  - Heliosphere – 10 years
- May provide spacecraft radiation shielding
- Basic concepts utilize low cost component technology

♦ Challenges

- Computational/experimental simulation and verification

Momentum Exchange Tethers



♦ General Description

- Momentum-exchange/electrodynamic reboost (MXER) tether facility in Earth orbit boosts spacecraft to high-energy, pre-escape trajectories
- High-thrust propulsion conducts ΔV at perigee to target hyperbolic C3
- Low-thrust propulsion (SEP, NEP, sails) uses lunar swingby to achieve low-C3 heliocentric orbit

♦ MXER Tether Concept

- Operational Orbit: 400 x 13,000 km
- Tether Length: 140 km
- Tether Station Mass: 8-10X design payload mass

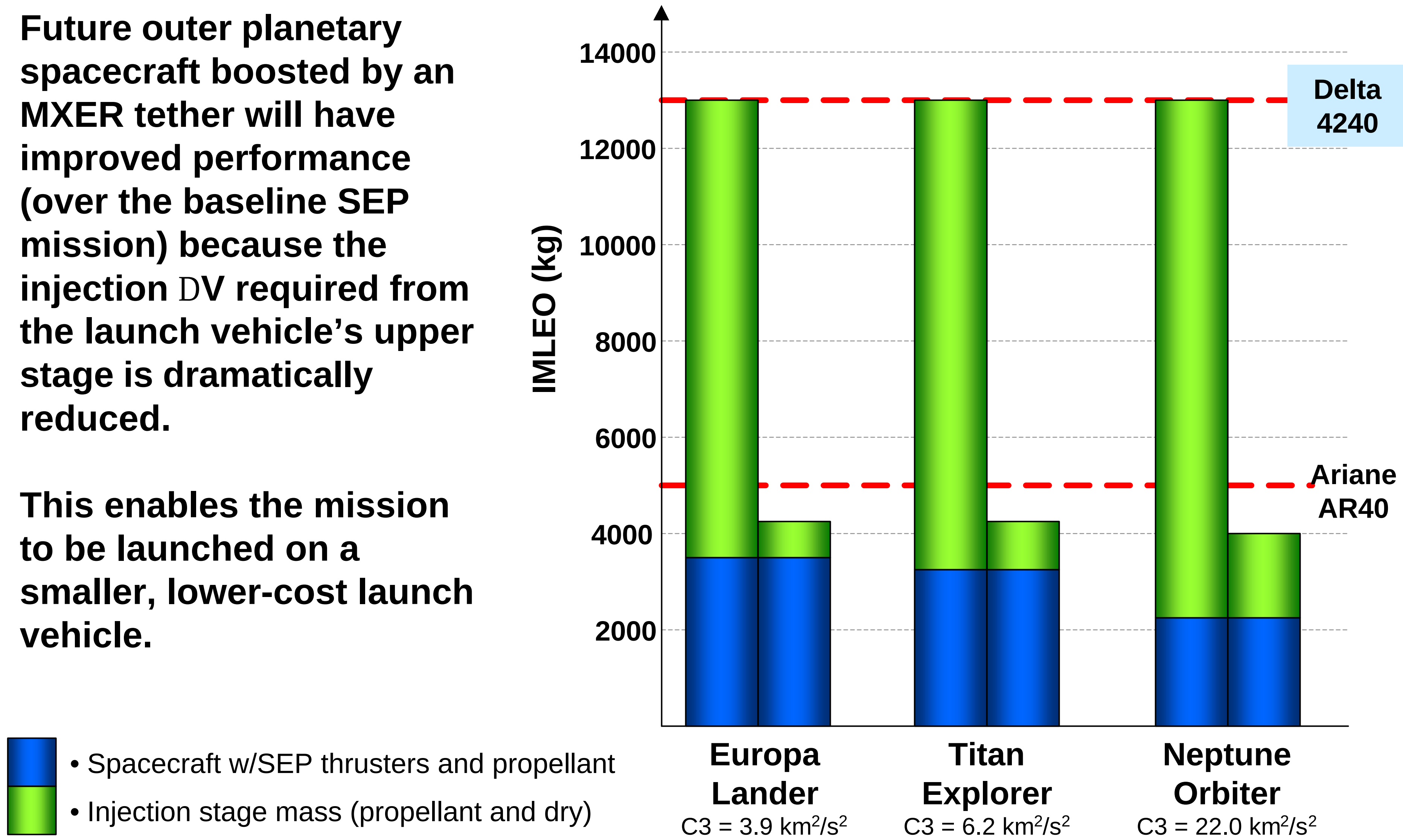
♦ Benefits

- ~90% of Earth escape ΔV provided by tether
- Electrodynamic propulsion can reboost tether without propellant
- MXER tether facility supports commercial GEO missions as well as interplanetary spacecraft

Momentum Exchange Tethers Dramatically Reduce Launch Vehicle Size

Future outer planetary spacecraft boosted by an MXER tether will have improved performance (over the baseline SEP mission) because the injection DV required from the launch vehicle's upper stage is dramatically reduced.

This enables the mission to be launched on a smaller, lower-cost launch vehicle.



In-Space Propulsion Program Summary

- **Program Overview**
  - New Initiative in Code S in FY02
  - Develop in-space propulsion technologies that can enable and/or benefit near and mid-term NASA science missions by significantly reducing cost, mass, and/or travel times. Technology areas include:
    - Solar Electric Propulsion, Aerocapture, Solar sails, Plasma sails, Tethers, Advanced Chemical Propulsion
  - Identify and prioritize the most promising technologies using systems analysis and peer review.
  - Develop mid-TRL technologies to TRL 6 for incorporation into mission planning within 3-5 years of initiation.
  - Maximize use of open competition to seek best solutions
  - Support Code S exploration missions primarily, but also look for 'spin-off' technology to other NASA Enterprise customers, e.g. Human Exploration and Development
  - Technology repriortization activity operating in 3 year cycle
    - Responsive to technology developments and mission priorities
    - Next activity will take place in FY04.