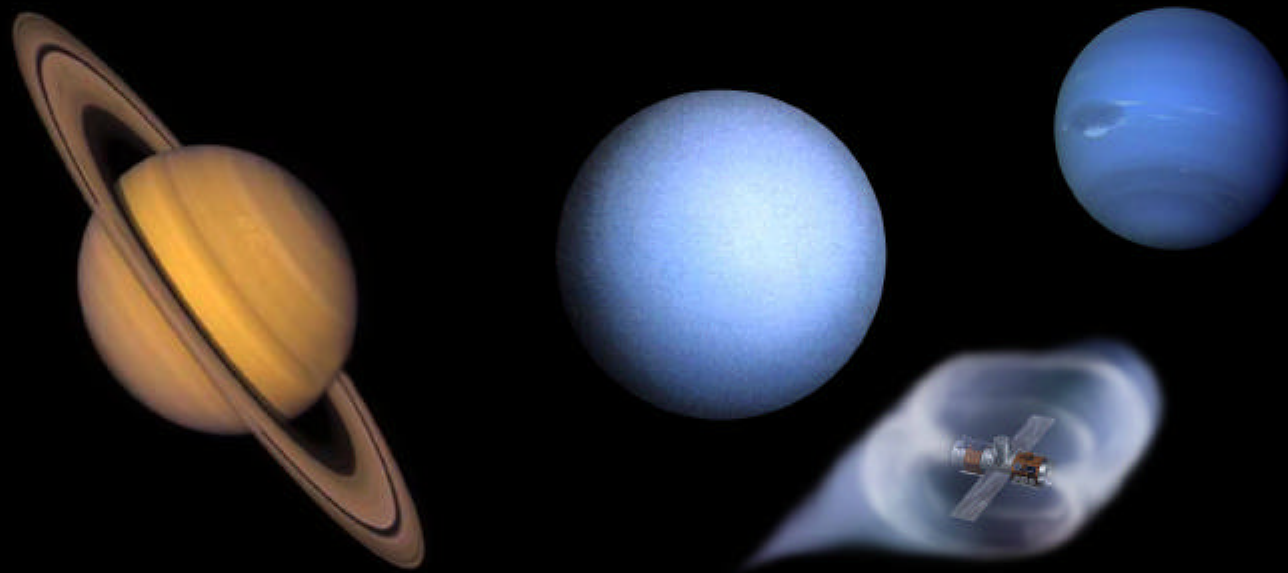
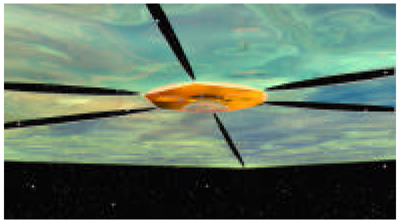


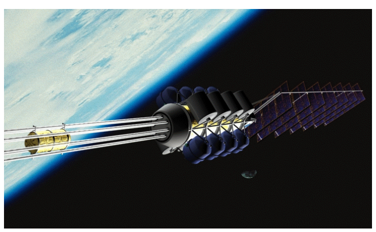
An Overview of NASA's In-Space Propulsion Program

Rae Ann Meyer
NASA/MSFC

November 6, 2002

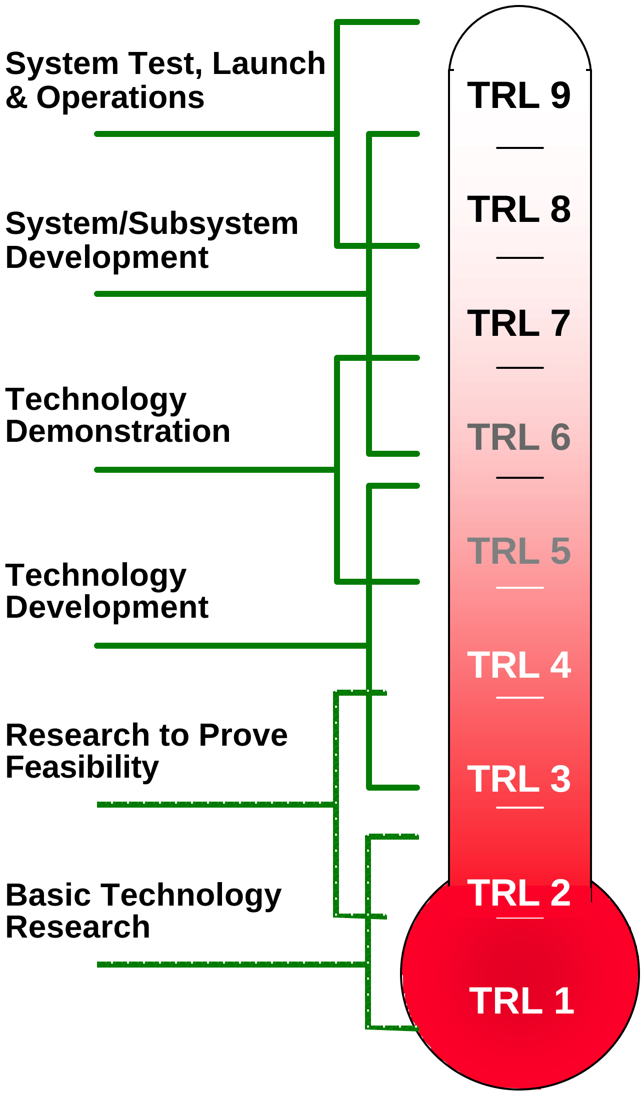
In-Space Propulsion Program Overview

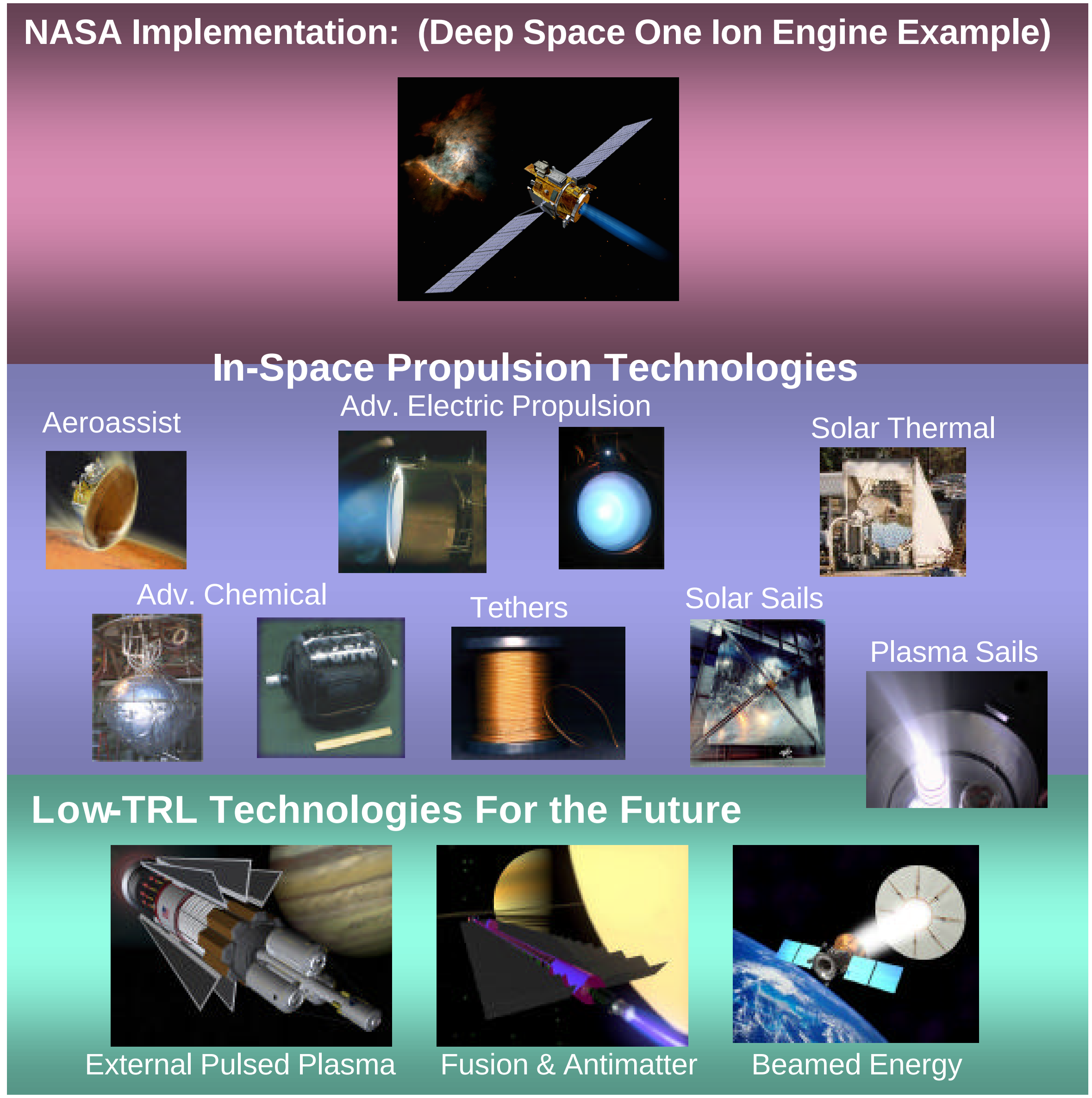




- **Objective**
  - Develop in-space propulsion technologies that can enable and/or benefit near and mid-term NASA science missions by significantly reducing cost, mass, and/or travel times. Technology areas include:
    - Solar Electric Propulsion (nuclear electric is now part of Nuclear Systems Initiative)
    - 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



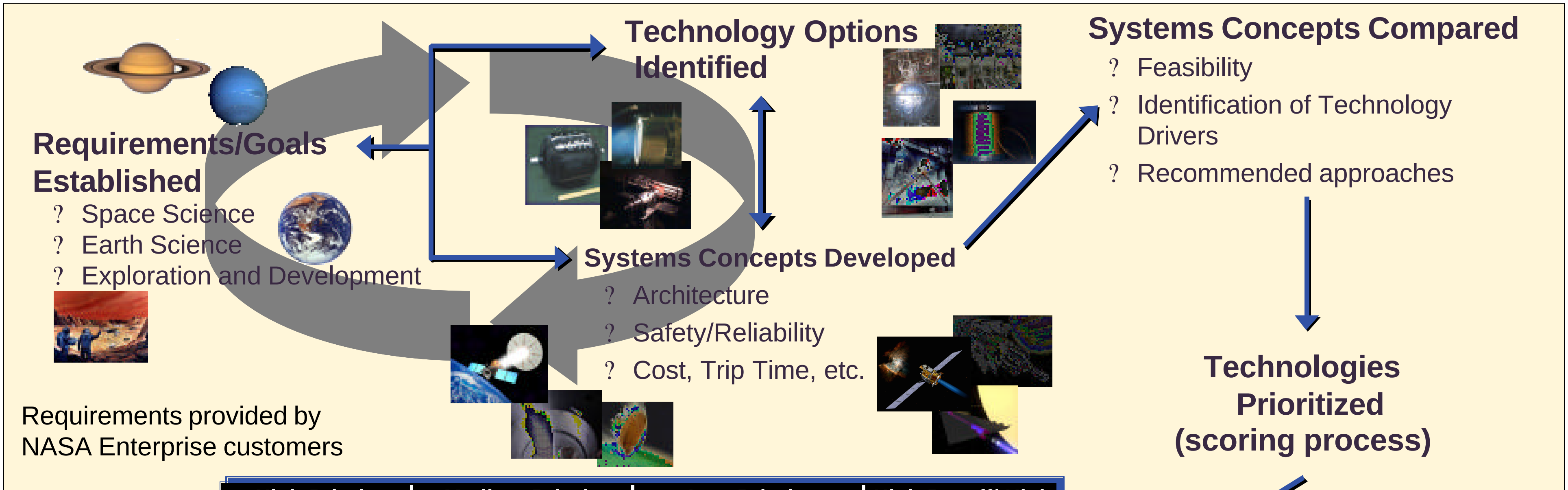


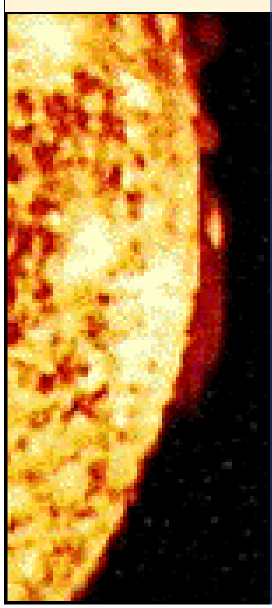
In-Space Propulsion Program Status

- **Status**
  - In Space Propulsion is a HQ, Space Science, managed program
    - Dr. Colleen Hartman, Program Manager
    - MSFC is the implementing organization for ISP
  - Competed efforts
    - Two awards made under an NRA specific to the Next Generation of Ion Electric Propulsion technologies.
    - Released In Space Propulsion Technologies, Cycle 1 solicitation (Aerocapture, Solar Sails, Electric Propulsion for NEP and Power Conversion) under the Research Opportunities in Space Sciences (ROSS) NRA. Selections announced in late August, 2002.
    - In Space Propulsion Technologies NRA, Cycle 2 (Aerocapture, Advanced Chemical, kW Solar Electric Propulsion, Momentum Exchange Tethers, Plasma Sails and Solar Sails) amendment to the ROSS NRA currently open - http://research.hq.nasa.gov/code_s/nra/current/NRA-02-OSS-01/appendA4_4.html.
  - 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**

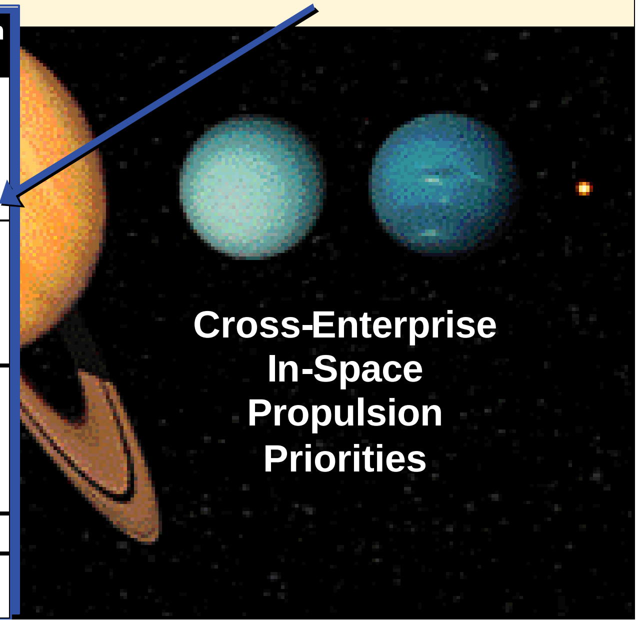
FY02	FY03	FY04	FY05	FY06	FY07
$19.6M	$61.4M	$65.7M	$64.7M	$66.7M	$66.7M

FY02 In Space Propulsion Technology Prioritization Process

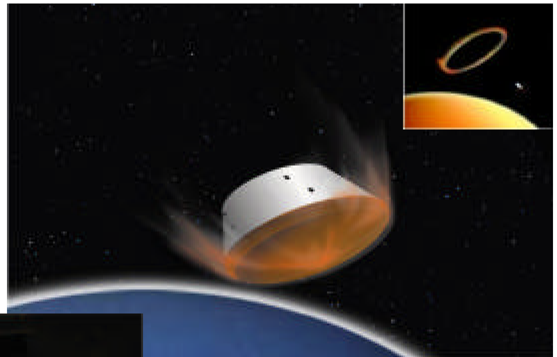


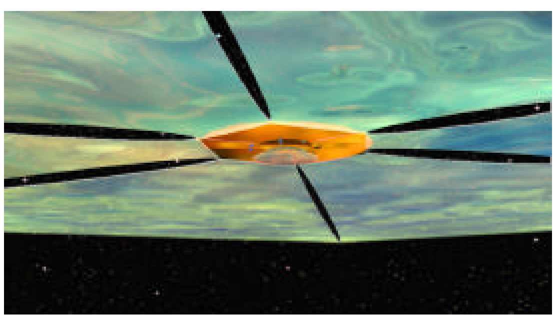


High Priority	Medium Priority	Low Priority	High Payoff/ High Risk (Low TRL)
Aerocapture (robotic to human mission evolvable)	Advanced Chemical (cryogenic + TBD)	Bimodal Nuclear Thermal Propulsion (Low to High Power Evolvable) Moved To NSI	1 g/m2 Solar Sails
Next Generation Ion Propulsion (5/10 kW)	Class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



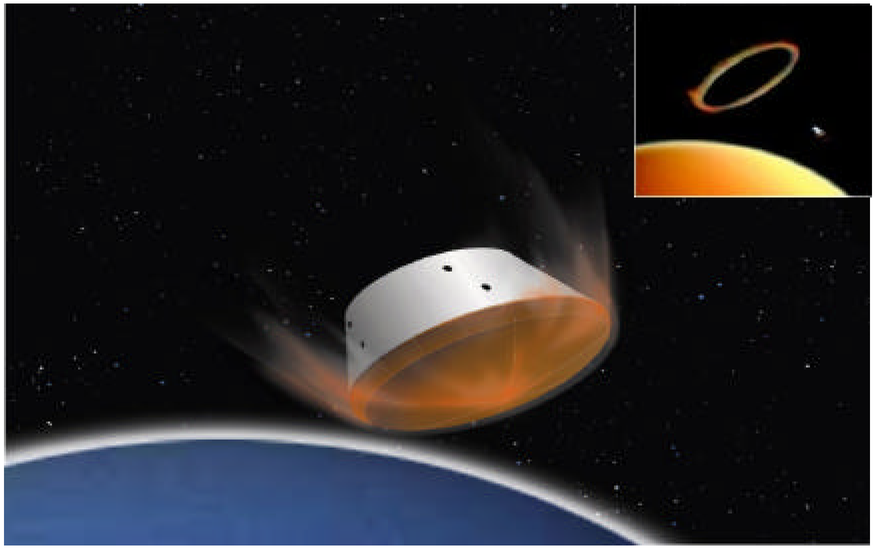
In-Space Transportation Technology Products
High Priority Technologies





- **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

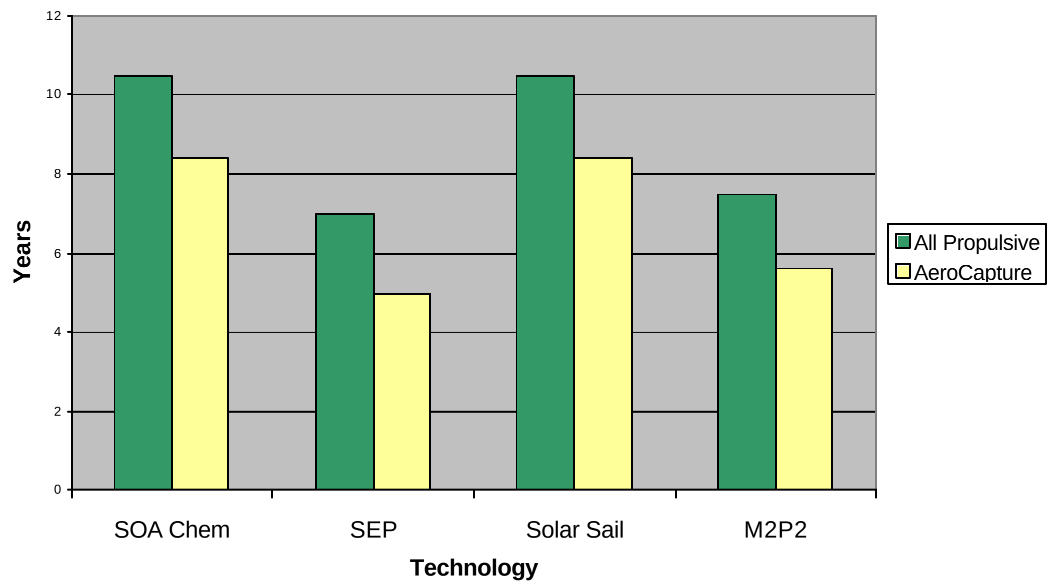


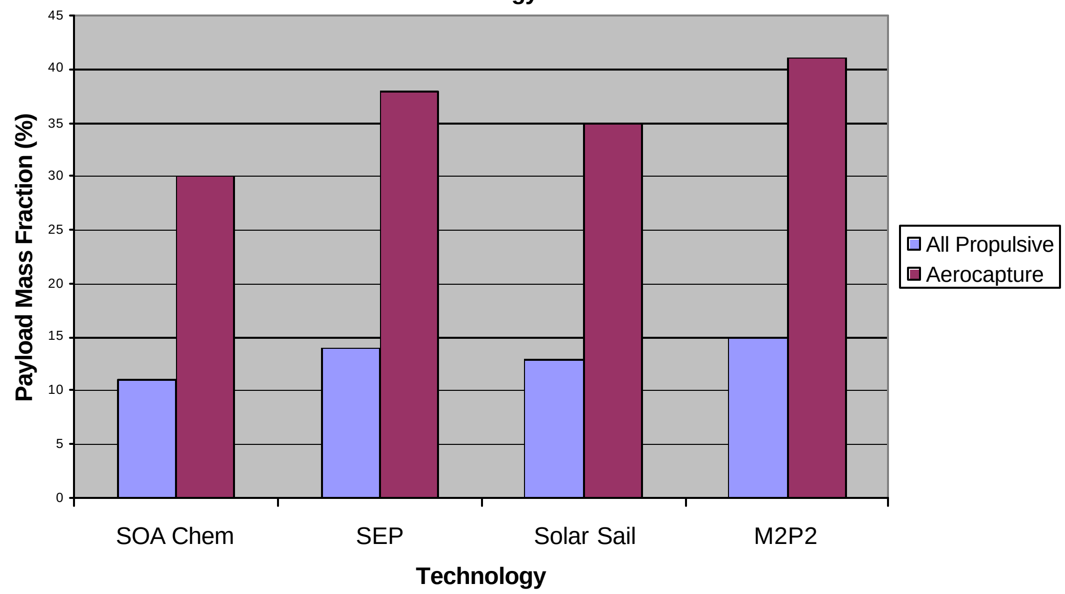
- **Benefits:**
  - No or very little propellant required for orbit insertion/entry
  - Lower transportation system mass
    - Aerocapture saves almost all orbit capture fuel mass and can quickly achieve a scientifically useful orbit (aeroshell and guidance and control system necessary)
  - Capable of 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)

- **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

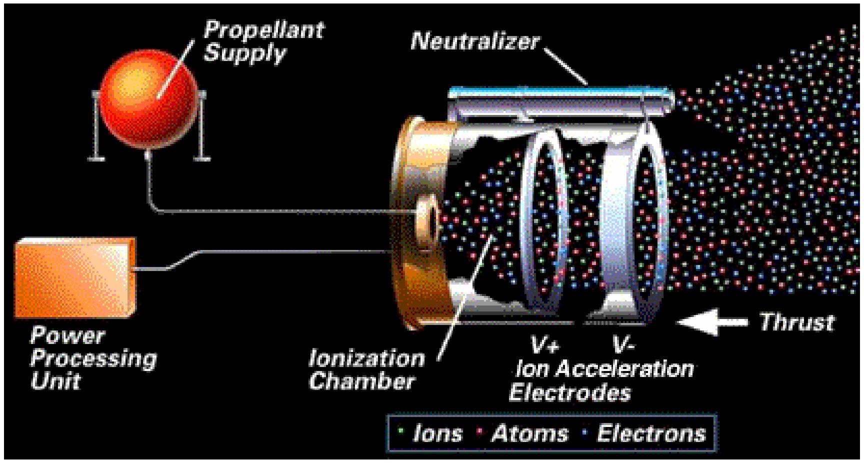
Benefits of Aerocapture Example: Titan Explorer





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

Next Generation Ion Electric Propulsion

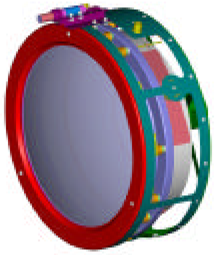


Ion Engine

- **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

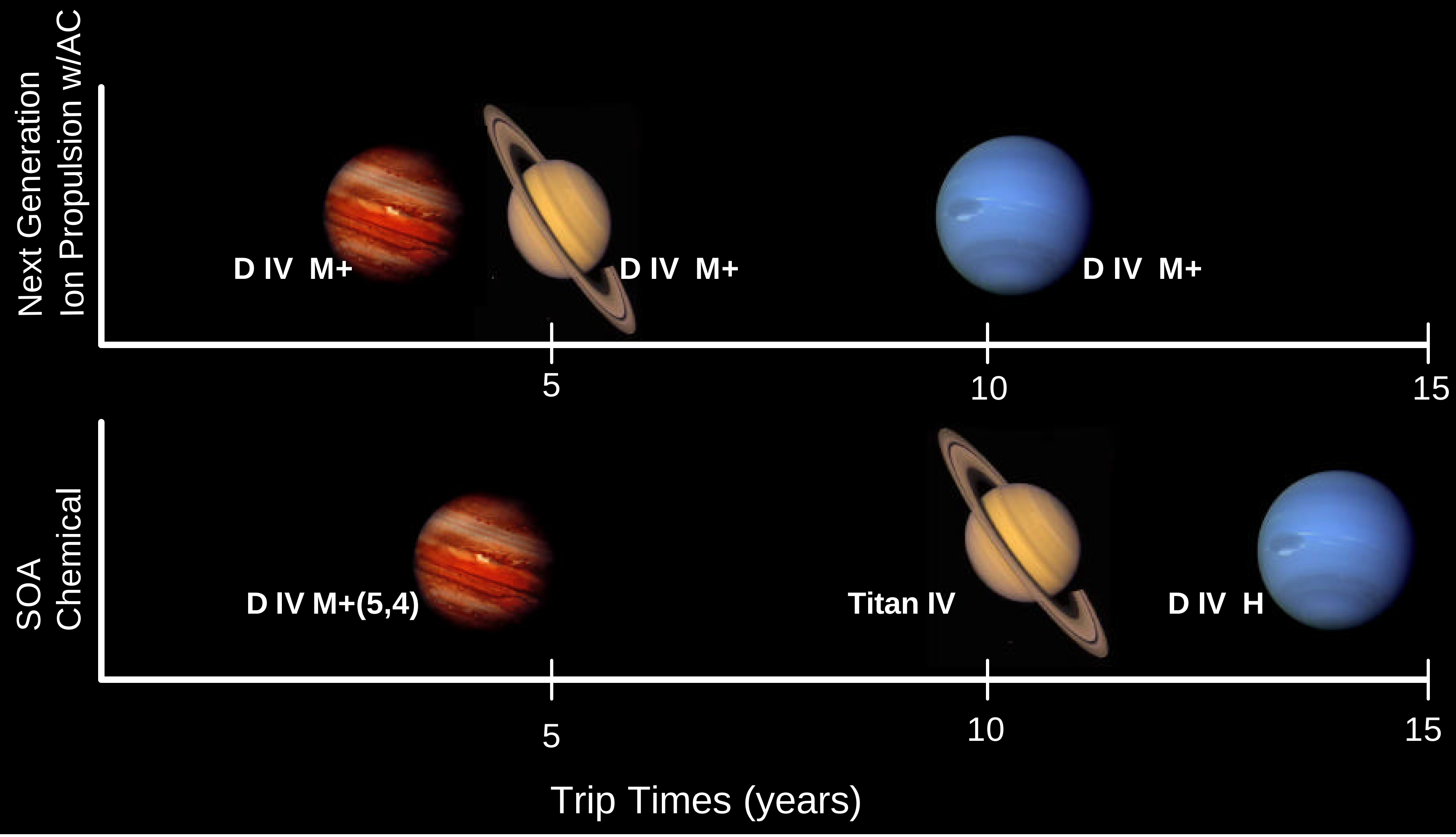
- **Benefits:**
  - Low propellant consumption (high delta V, high performance)
  - High Isp
  - High TRL; SEP Ion in use today
  - Uses smaller LV, lower launch costs
  - No environmental issues
  - Quick access to most of the solar system with 2 to 10 times the payload capability of chemical rockets



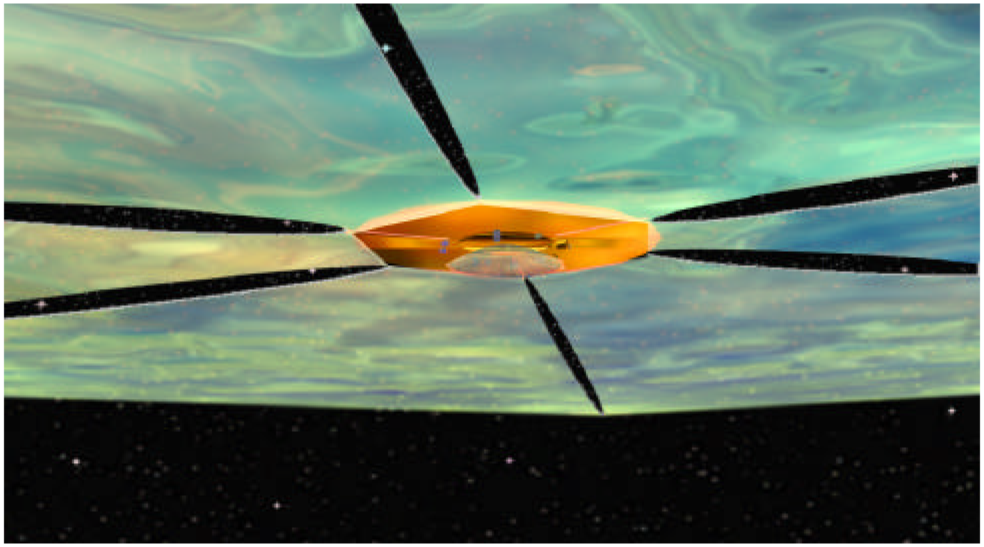
Technologies developed under this effort will increase Isp by greater than 30% over today's SOA ion engine, while significantly increasing power and thrust and reducing system alpha.

Next Generation Ion Electric Propulsion

Trip Time and Launch Vehicle Benefits For Potential Destinations



Solar Sails



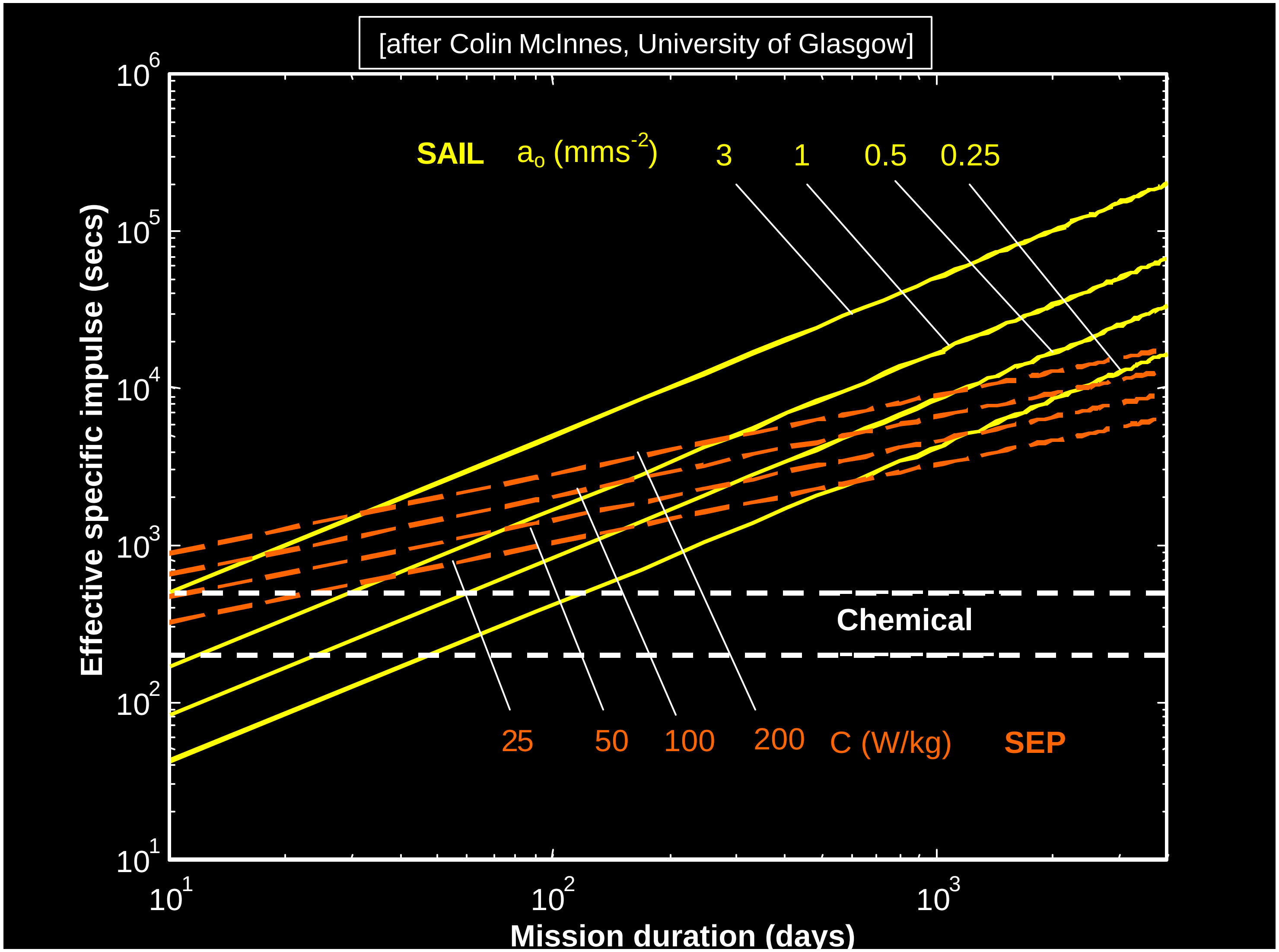
? **General Description:**
Solar sails use photon "pressure" or force on thin, lightweight reflective sheet to produce thrust;

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

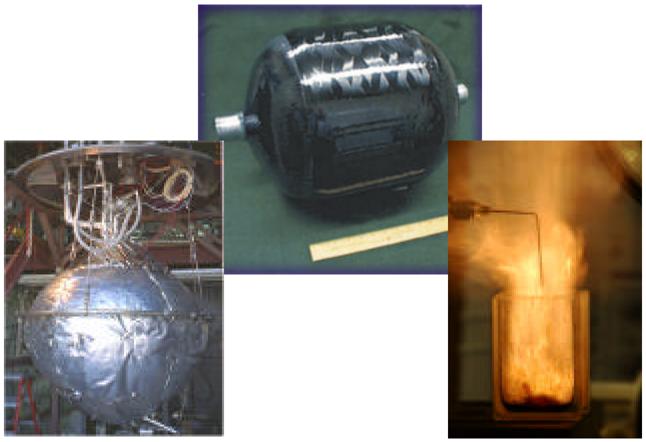
? **Benefits:**
- ? No propellants required
- ? As technology advances (lighter sail material) more ambitious missions are possible – missions closer to the sun and reduced trip time for outer planets
- ? Very simple design (engineering challenge is large area and low mass)
- ? No environmental issues
- ? 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

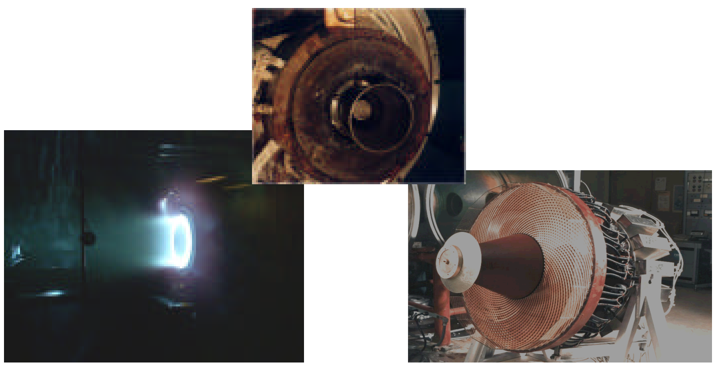
SAIL Propulsion Performance – Constant Thrust

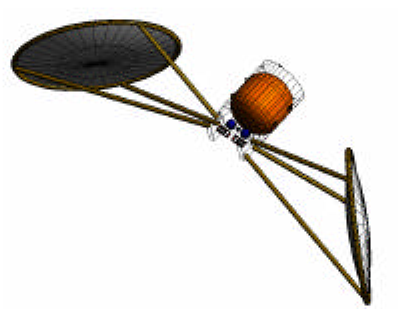
Note: "Effective Isp" means dry mass is included as well as propellant



In-Space Transportation Technology Products
Medium / Low Priority Technologies

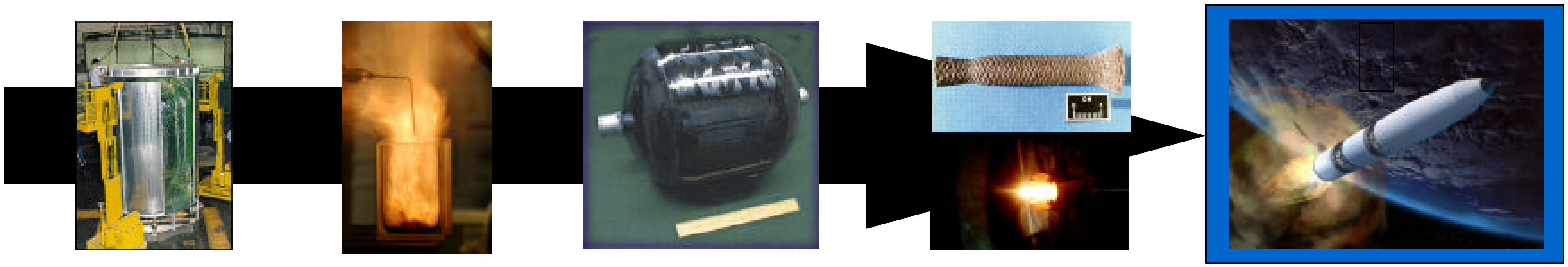






- **Advanced Chemical**
  - Fuels development
  - Cryogenic Fluid Management
  - Lightweight components
- **kW Solar Electric Propulsion**
  - Laboratory demonstration of 50kW Hall thrusters
  - Competitively select thruster technology advancement based on application
- **Solar Thermal Propulsion**
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

Advanced Chemical Propulsion



Cryogenic Fluid Management

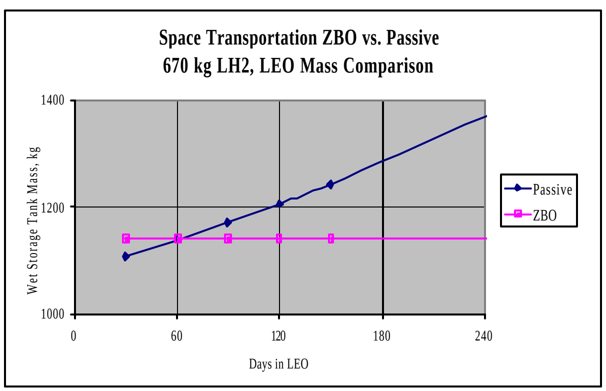
Propulsion supporting technology that may enable long-term storage of cryogens in low g, including propellant transfer and mass gauging

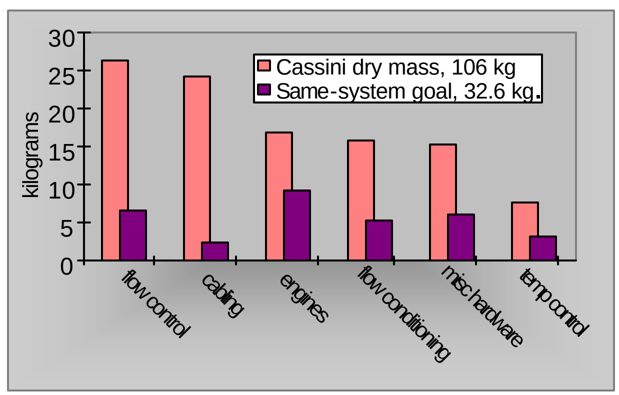
Lightweight Components

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



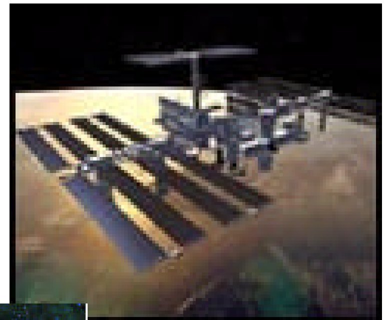


Propellant	Isp(lbf-s/lbm)
O_2/CH_4	365
ClF_5/N_2H_4	350
OF_2/C_2H_4	415
N_2F_4/N_2H_4	395
F_2/N_2H_4	415
OF_2/C_2H_6	410
OF_2/B_2H_6	420

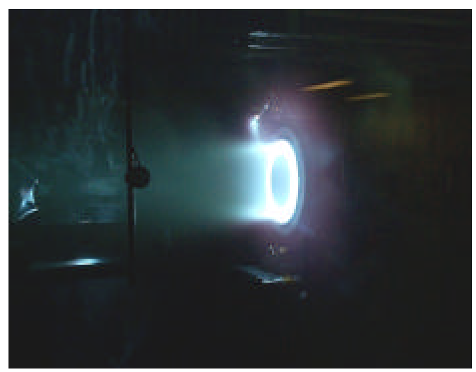
Isp for a variety of Bipropellant Systems

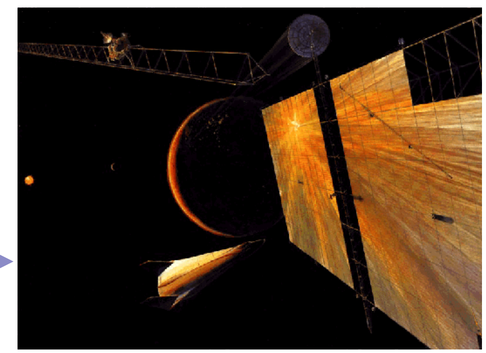
SEP Hall Thrusters

? **ISS Drag Makeup**
- ***Significantly reduces required refueling flights***



? **Lunar/Mars Exploration**
- ***Reduces Launch Vehicle Fleet***



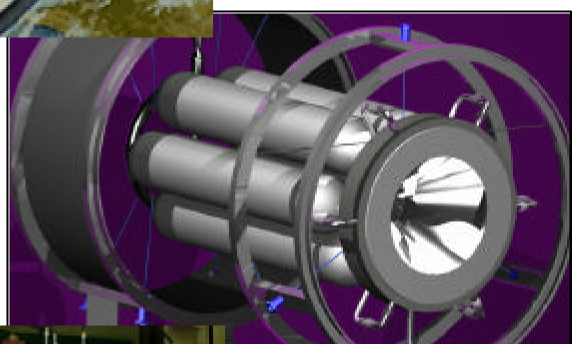


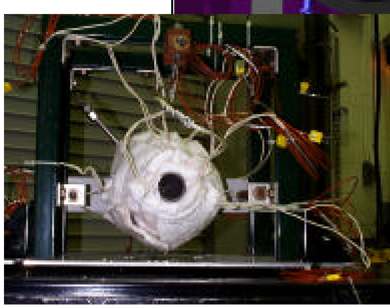
? **LEO to GEO Space Transportation**
- ***Four Times the Payload of Chemical Systems In Four Weeks using next generation power levels***

SEP Hall at power levels greater than 50 kW

? **Space Solar Power**
- ***Reduces number of launch vehicles required by a factor of 5 !*** *Deliveries in few weeks to less than four months.*

Solar Thermal Technologies



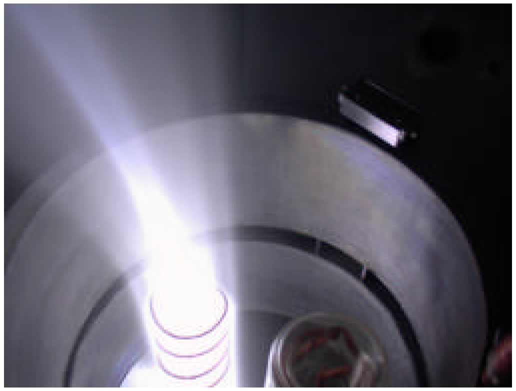


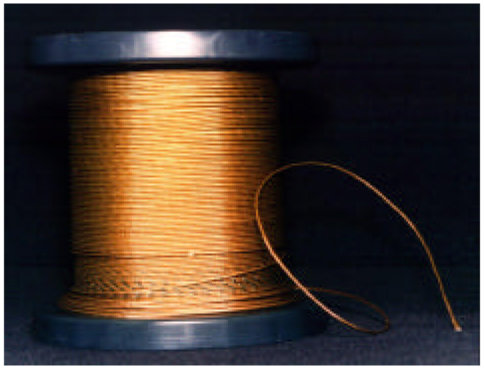
- **General Description**
  - Solar thermal engine serves as a high temperature heat exchanger and nozzle. Concentrated sunlight heats mono-propellant without combustion. Anticipated Specific Impulse approaching 850 seconds with thrust levels up to 50 lbs.

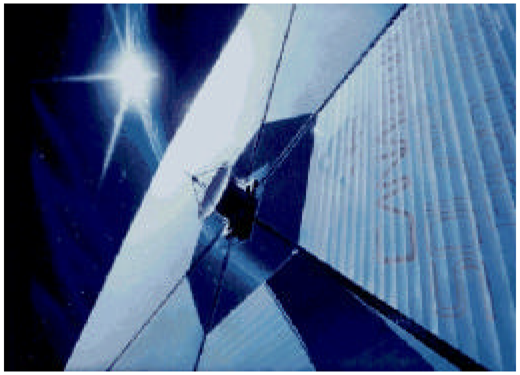
- **Applications**: Orbit transfer, primary propulsion stage

- **Challenges**
  - High temperature materials
  - Hydrogen storage
  - Inflatable concentrator performance
  - Reduction of mass and volume

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

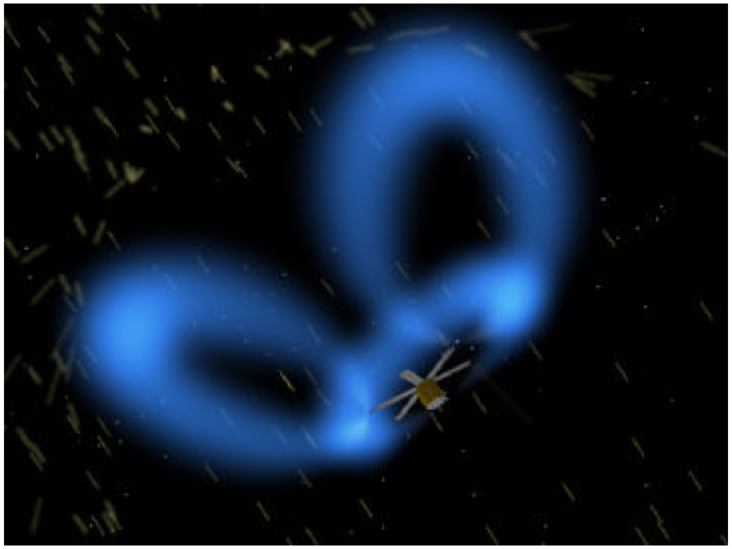






- **Plasma Sails**
  - Thrust measurement and validation
  - Compare analytical model results vs. Laboratory test data
- **Momentum Exchange Tethers**
  - Model development and evaluation
  - Catch Mechanism concept
  - High strength tether
- **Solar Sails < 1g/m2**
  - Ultra-lightweight sail materials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

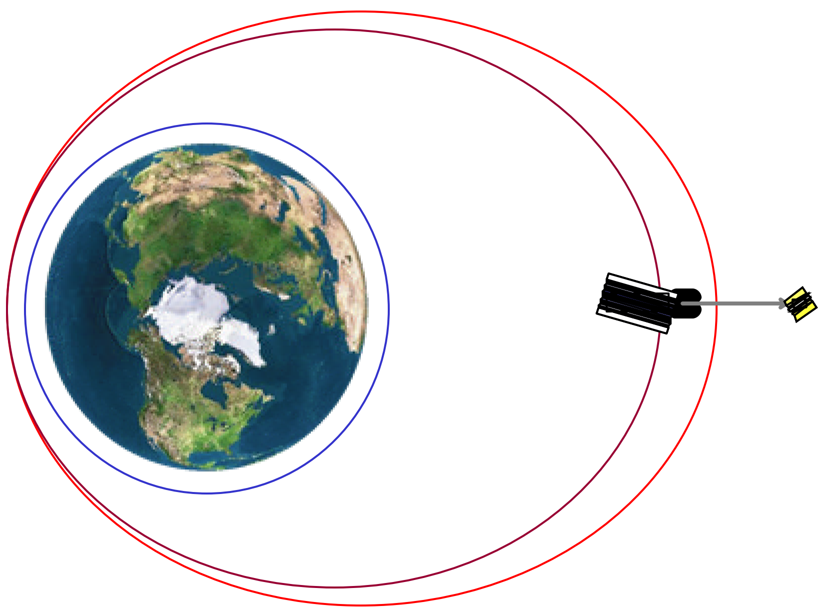
? Benefits

- ? 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 ? V 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

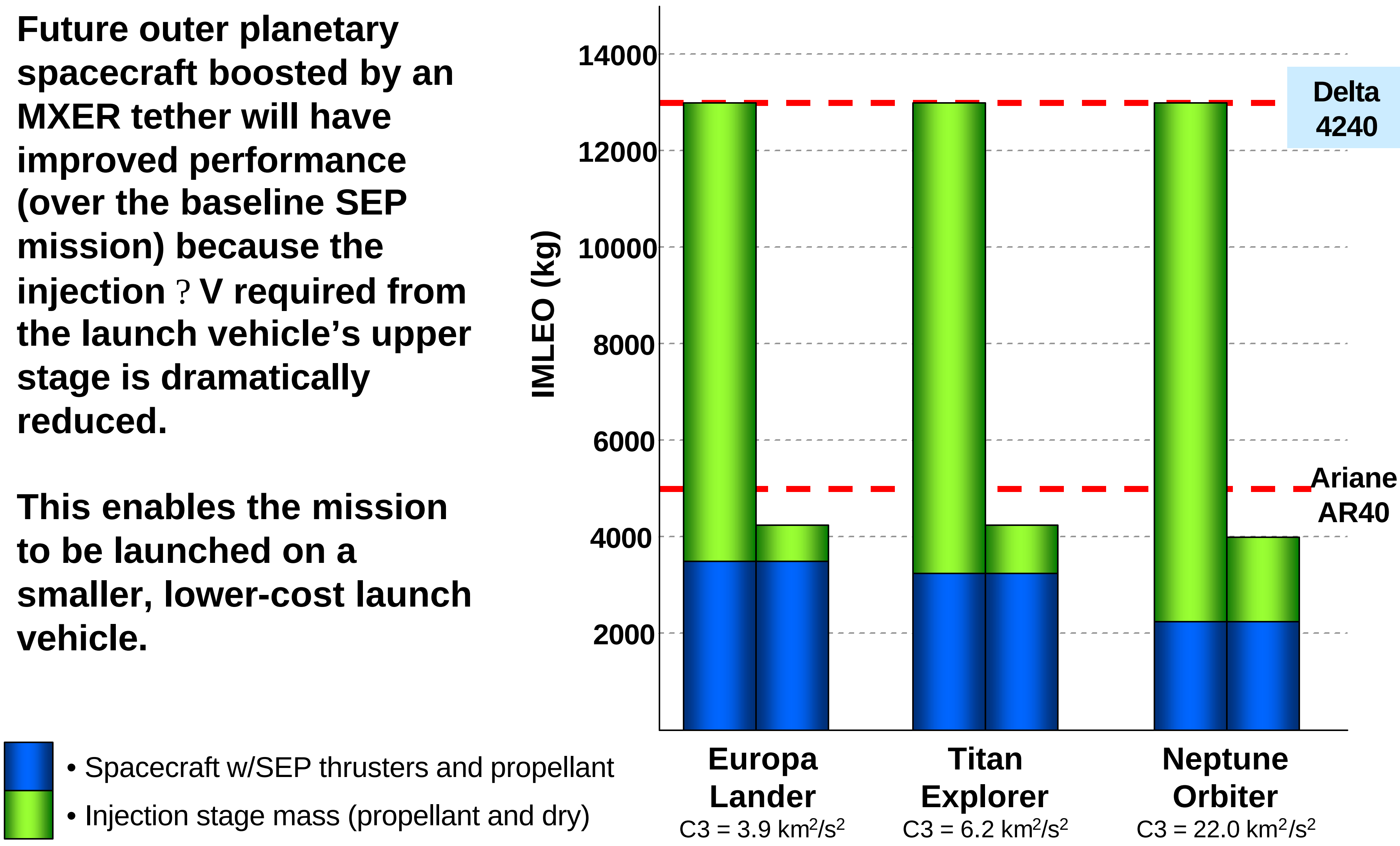
? **Benefits**

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

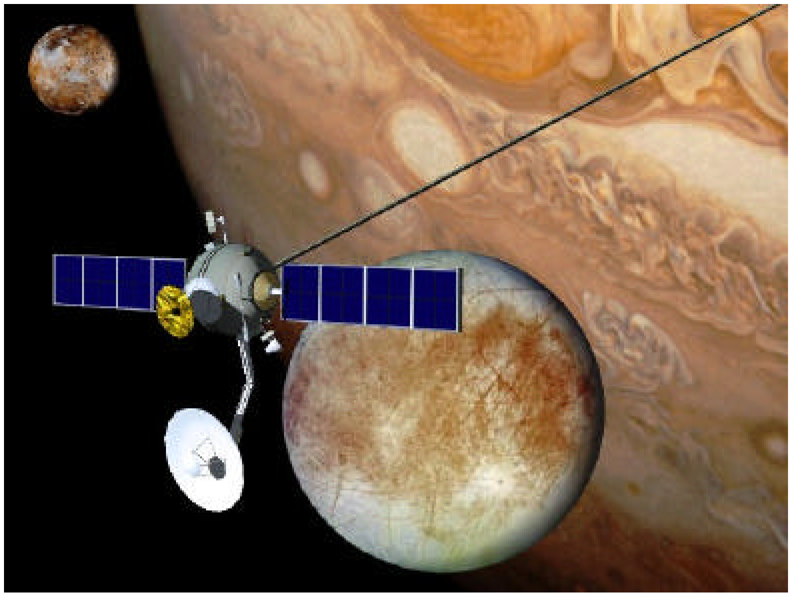
Momentum Exchange Tethers Dramatically Reduce Launch Vehicle Size

Future outer planetary spacecraft boosted by an MXER tether will have improved performance (over the baseline SEP mission) because the injection ?V 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.



Electrodynamic Tethers Offer Propulsion and Power Without Fuel



- **General Description:**
  The conducting Electrodynamic Tether (EDT) produces an inducted Electromagnetic Field (EMF) as it passes through a planetary magnetic field and when the electric circuit is completed through the ionosphere it produces thrust and/or power. The gaseous giants have ideal environments for EDT operations because of their rapid rotation rates and intrinsic magnetic fields.

- **Benefits:**
  - Multiple ?V maneuvers for same mass ratio
  - Provides propulsion without propellant (long-life; requires no resupply)
  - Potential alternative to RTG for power under special circumstances
  - Braking force merely requires resistive dissipation of energy
  - Propellantless propulsion and continuous power (kW to MW) at gas giants (Jupiter, Saturn)
  - No need to preserve onboard fuel for deorbit at end of life
  - Allows all rocket fuel to be used for orbit insertion; results in higher efficiency system
  - Increases efficiency of upper stages and the stationkeeping lifetime of orbiting spacecraft
- **Comment**
  - Enabling technology for MXR tethers