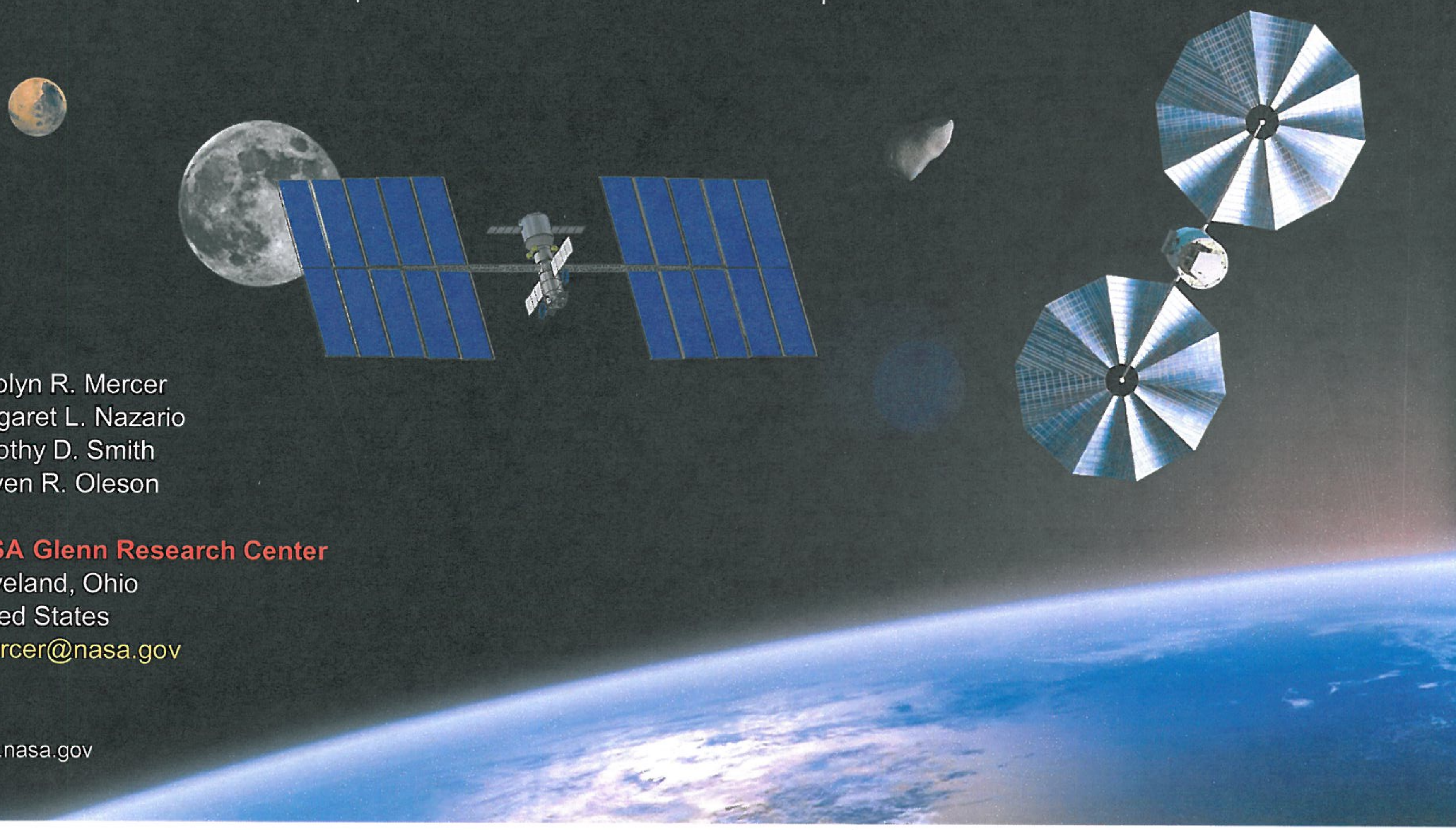
National Aeronautics and Space Administration

# Solar Electric Propulsion Technology Development for NASA Exploration

Space Power Workshop | Huntington Beach, CA | April 24, 2013

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# Solar Electric Propulsion Technology Development Overview

## NASA Human Exploration – capability driven architecture

## Concept studies using Solar Electric Propulsion (SEP)

- Mars
- Near Earth Asteroids

## Technology needs derived from those studies

- Parameterized assessments on "reasonable vehicle" configurations
- System-level impacts of power and propulsion technologies

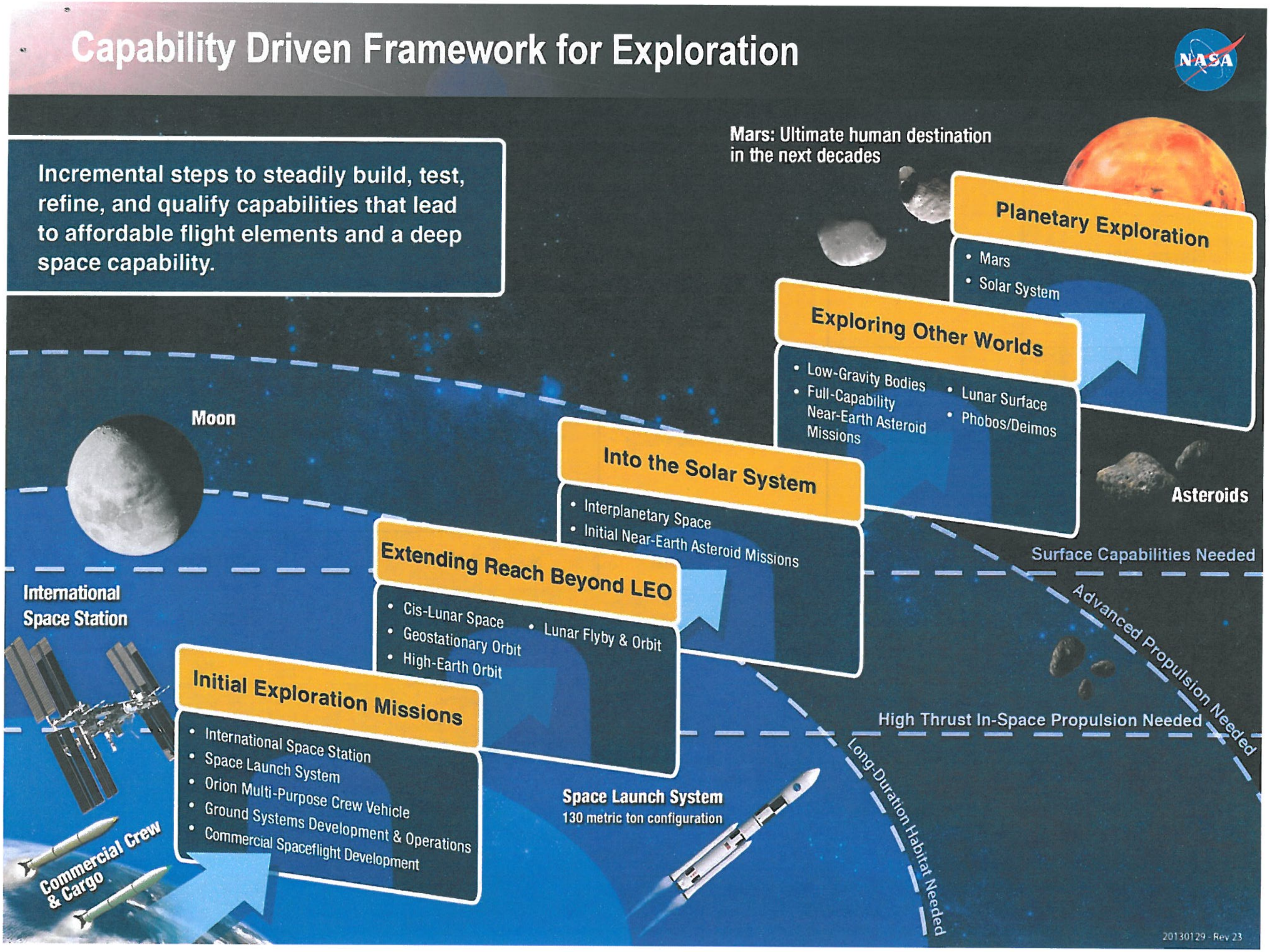
## Technologies under development

- Solar arrays
- High voltage electronic parts
- Electric thrusters and power processing

## Demonstration mission concepts

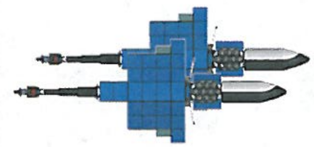
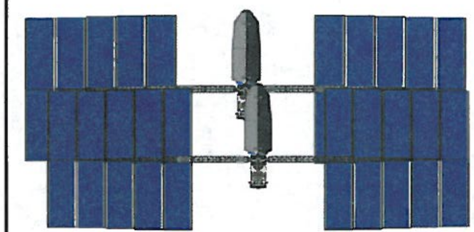
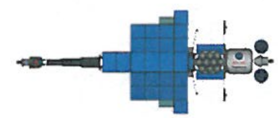
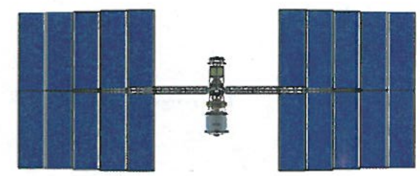
- Reduce risk for future missions
- Provide near-term capability

## Summary


Capability Driven Framework for Exploration
NASA
Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
Mars: Ultimate human destination in the next decades
Planetary Exploration
• Mars
• Solar System
Exploring Other Worlds
• Low-Gravity Bodies
• Full-Capability Near-Earth Asteroid Missions
• Lunar Surface
• Phobos/Deimos
Moon
Into the Solar System
• Interplanetary Space
• Initial Near-Earth Asteroid Missions
Asteroids
Surface Capabilities Needed
Extending Reach Beyond LEO
• Cis-Lunar Space
• Geostationary Orbit
• High-Earth Orbit
• Lunar Flyby & Orbit
International Space Station
Advanced Propulsion Needed
Initial Exploration Missions
• International Space Station
• Space Launch System
• Orion Multi-Purpose Crew Vehicle
• Ground Systems Development & Operations
• Commercial Spaceflight Development
High Thrust In-Space Propulsion Needed
Space Launch System
130 metric ton configuration
Long-Duration Habitat Needed
Commercial Crew & Cargo
20130129 - Rev 23

# Concept Vehicles for Mars Landing

## Solar Electric Propulsion can be used to bring crew and cargo to Mars

| | | | | |
|---|---|---|---|---|
| **Cargo Missions** |  |  |  |  |
| **Crew Mission** |  |  |  |  |
| **2037 Conjunction Class "long stay" mission** | **Chemical Propulsion** | **Nuclear Thermal** | **Nuclear Electric** | **Solar /Chem** |
| **Electric Propulsion Power level** | n/a | n/a | 2.5MW crew/ 1MW cargo | 800kW Solar |
| **Total Mass (t)** | ~1,200 | ~600 | ~550 | ~490 |
| **# Heavy Lift (SLS) Launches** | ~12 | ~9 | ~7 | ~7 |
| **SLS Delivery to LEO (t)** | 105 & 130 | 105 | 105 & 130 | 105 & 130** |
| **SLS Shroud Dia. /Barrel Length** | 10 / 22 | 10/25 | 10/25 | 10/10 |
| **Time on Mars (days)** | 500 | 500 | 400 | 300 |

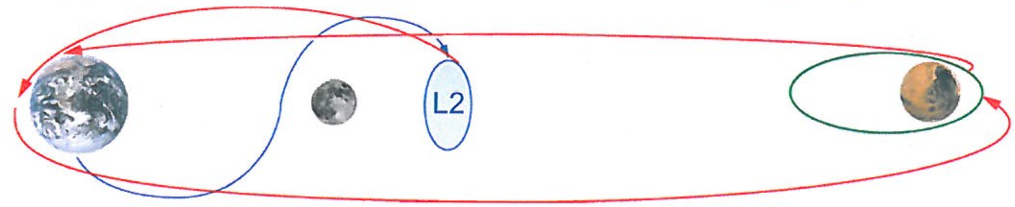
**Depending upon SLS performance 1-2 ATV launches using a Ariane 5 class vehicle are required to provide consumables

# SEP Options for Mars

800kW EOL/1 AU | 500V power systems | 2400 Direct Drive Nested Hall Thrusters

## Option 1

All Chemical
4 SLS Launchers
~500 day Mars stay

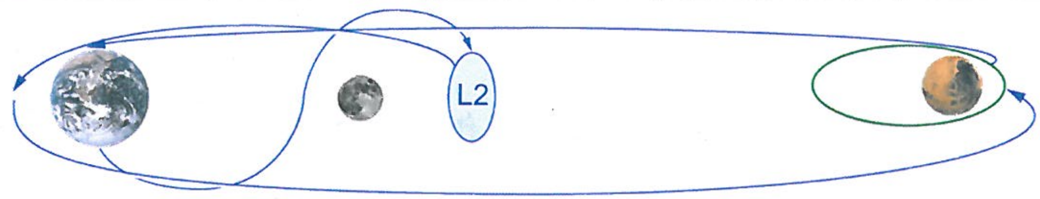



*Chemical Capture and Depart*

SEP Tug stays at L2, does not fly to Mars

## Option 2

SEP/Chem
2 SLS + 3 ATV (15t)

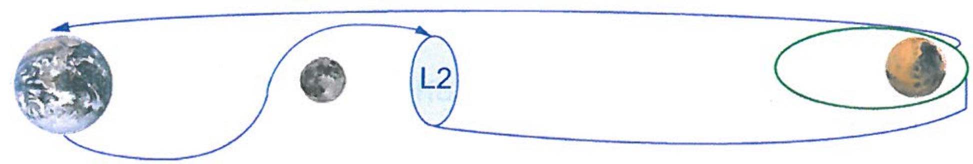



*Partial Chem Capture and Depart*

Earth/Moon Departure Flyby with Chem/SEP

## Option 3

SEP/Chem
2 SLS + 2+ ATV (18t)
300 day Mars stay



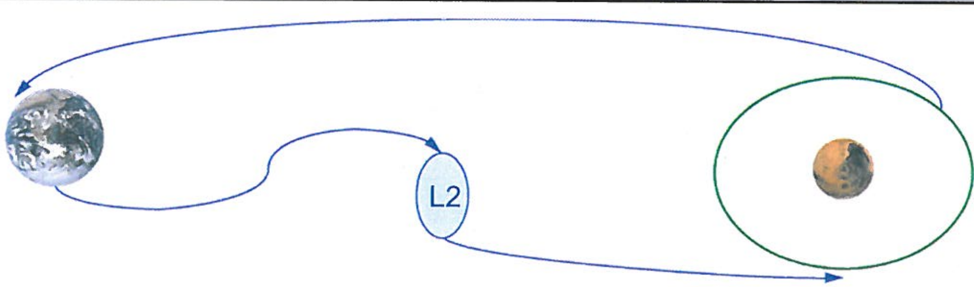

*Partial Chem Capture and Depart*

ATV tankers bring biprops and crew consumables – adds 90 days to stay time

Combination of Solar Electric and Chemical Propulsion provides best mix of stay time, required IMLEO, and simplicity

## Option 4

All SEP
45 day Mars stay




SEP spiral down to 24 hour circular orbit

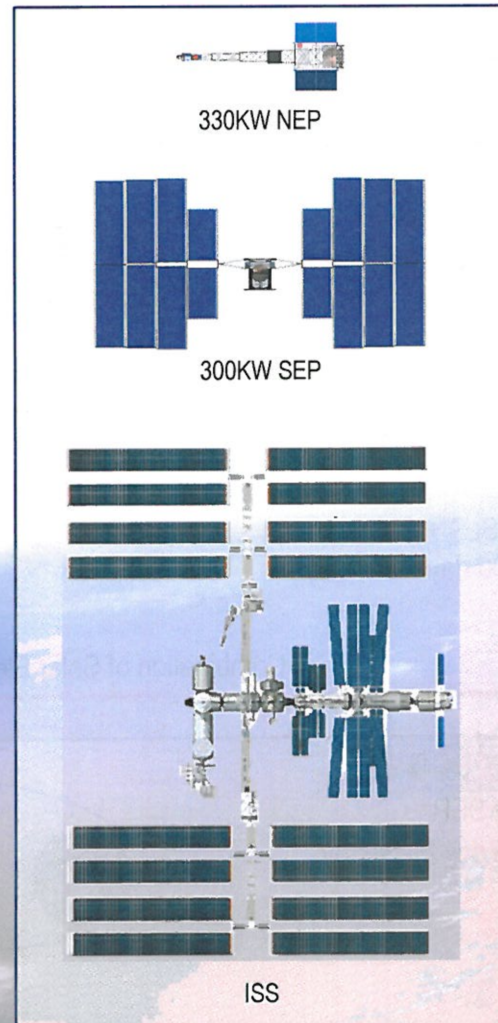
SEP trajectories in BLUE
Chemical trajectories in RED

# Concept Vehicles for Piloted Near Earth Asteroid Missions

## Solar Electric Propulsion can be used to bring crew and cargo to NEAs

### Design Constraints

- Un-piloted low Earth orbit spiral to E-M L1, crew rendezvous and transfer to 2008-EV5 NEO
- 2023 Launch date; Nominal mission duration of 800 days (piloted portion NTE 400 days)
- Single fault tolerant
- 100 metric ton launch vehicle : 8.5 m diameter dynamic envelope, no more than 44.5 mt mass at liftoff
- Target 300 kW power to propulsion system, 15kW power to payload except during eclipse, 5kW power for housekeeping loads
- Withstand cryogenic kick stage propulsive maneuvers up to 0.1 g steady state acceleration




NEP and SEP vehicles shown to scale with the International Space Station

# Parametric Assessments for SEP

## 300kW-Class

### Power
- 300V and 120V Spacecraft Bus Voltage
- Planar and 2X Concentrator Solar Array
- 29%, 33%, 35%, and 37% solar cells

### Propulsion
- Direct Drive and Conventional Power Processor Unit 30 kW and 50 kW Hall Thrusters
- Single Xe tank and smaller tanks;
- passive and active cooling

### Configuration
- SEP and NEP

## MW-Class

### Power
- 500V and 300V Spacecraft Bus Voltage
- MegaFlex and MegaROSA
- 33% IMM cells

### Propulsion
- Direct Drive and Conventional Power Processor Unit
- 50 kW Hall, 75 kW Hall and 200kW Nested Hall Thrusters
- 2000 s, 2400 s and 3000/2140 s Isp
- Xe and Kr propellant

### Configuration
- SEP, SEP/Chem and Chemical
- SEP, NEP, NTP and Chemical

# Parametric Assessments for SEP: Conclusions

### 300kW-Class

Large mass benefits from:

- High voltage (~300V) spacecraft bus
- Direct Drive architecture
- Single, large Xenon tank

### MW-Class

Large mass benefits from:

- High voltage (300V – 500V) spacecraft bus
- Direct Drive architecture with Nested Hall thrusters
- Single, large Xenon tank

### Solar Arrays:

- Reliably deployable arrays with flexible blankets and highly compact stowed volume are required. Credible ideas exist that could meet mission needs.
- Missions close for 29% efficient cells with planar arrays. Higher efficiency and concentration will reduce the number of cells and size of the array; cost is the overriding consideration.

Notes:

These results are mission dependent, and do not account for abort scenarios.

Key power technologies are highlighted in red.

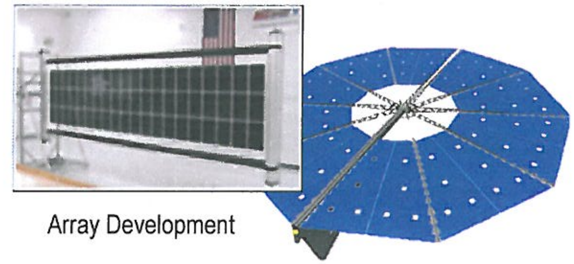
# Solar Power Technology Development

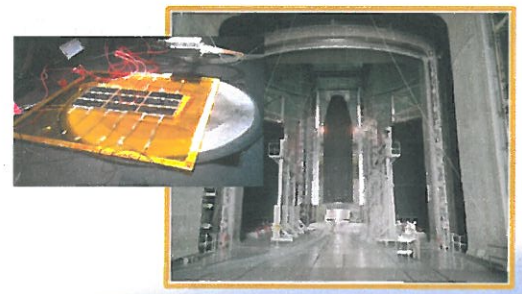
## Goals

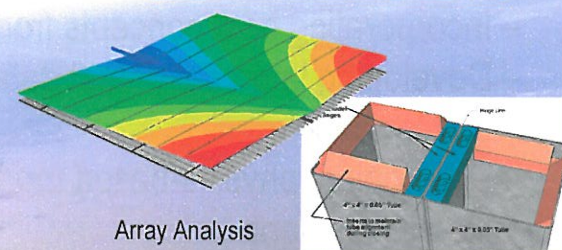
- Develop reliably deployable high power solar arrays (30kW-class)
  - Extensible to 300kW vehicles
  - Operable at high voltage (160-300V) with high strength/stiffness
  - Stowed volume commensurate with mission.
- Characterize electronic parts needed for high voltage (300V) PMAD and power processing in the deep space environment

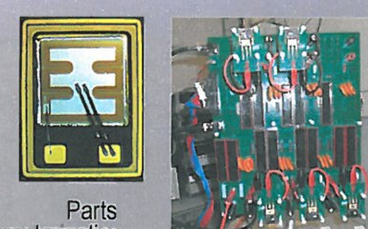
## FY13/FY14 Activities

- Designing and building 30kW-class Solar Array Engineering Demonstration Units
  - MegaFlex and Mega-ROSA designs
  - Coupon plasma testing for electric thruster environment
  - Thermal-Vacuum testing planned for Spring 2014
- Developing analysis models and tools to evaluate very large solar array designs
- Destructive single-event upset testing planned for June 2013 SiC transistors, diodes, bridge drivers, and gate drivers


Array Development


System Testing


Array Analysis


Parts Characterization

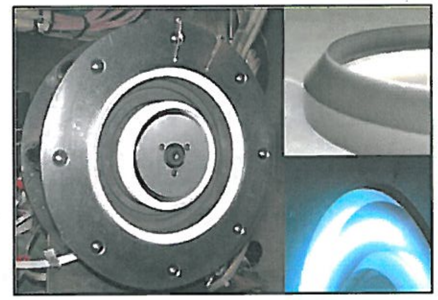
# Electric Propulsion Technology Development

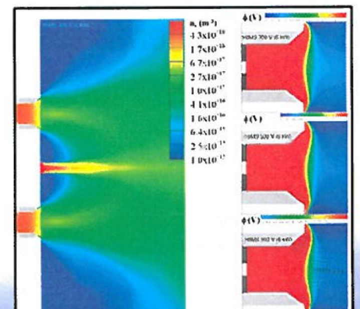
## Goals

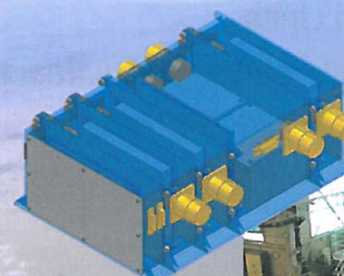
- Develop high power Hall thruster 15KW-class (~1 N Thrust) and system components for 30kW class vehicle
  - Life commensurate with mission
- Develop high voltage (i.e. 300V input) Power Processing Unit/Direct Drive Unit compatible with Hall Thruster and advanced solar arrays.

## FY13/FY14 Activities

- Designing and building 15kW Hall Thruster Engineering Design Unit
  - Incorporating best concepts from recent NASA thruster designs
  - Developing large set of test data related to high power thruster performance
  - Developing physics-based models of performance and life assessment
- Designing and building high voltage PPU (300V) EDU Designing and building high voltage Direct Drive (300V) EDU
- Integrating Thruster EDU and PPU and DDU for test by end of FY14


Thruster Development


Thruster Analysis

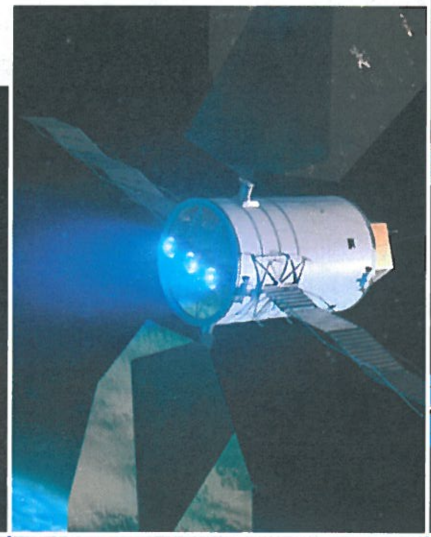
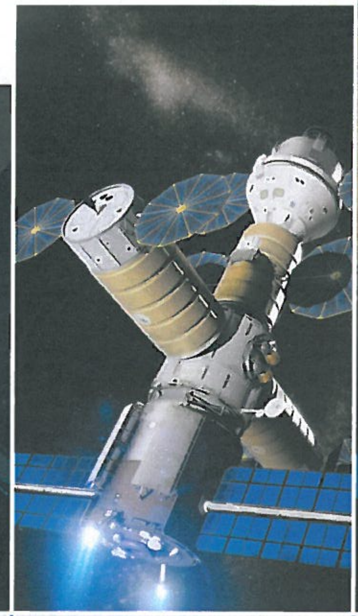
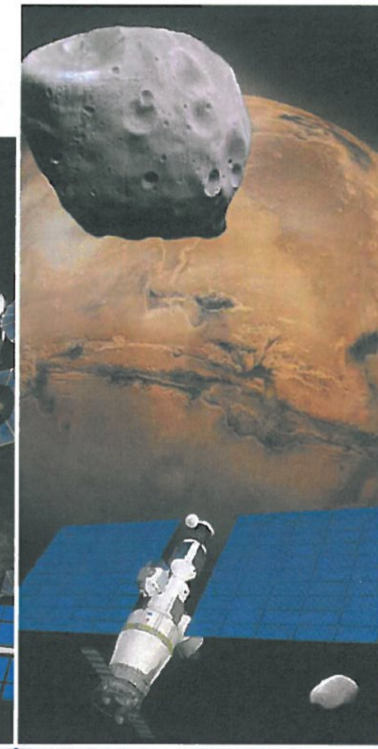

Power Processing


System Testing

# 30kW-Class Mission as a Stepping Stone to Future Exploration

## A natural progression that retires key risks and provides near-term capability



| Deep Space 1<br>1998 | Dawn<br>2007 | 30kw-class SEP<br>~ 2017 | Mid-term Exploration<br>Missions circa 2020's | Far-term Exploration<br>Missions circa 2030's |
|---|---|---|---|---|
| Technology Demonstrator | Deep-Space<br>Science Mission | Operational mission with advanced technology | Crewed mission to<br>cis-lunar space | Crewed mission beyond Earth space |
| 490kg | 1220kg | ~2000kg | 30,000 kg | 70,000 kg |
| 2.5 kW power system<br>2kW EP system | 10 kW power system<br>2.5kW EP system | 30kW-class power<br>20kW-class EP | 30kW-class power system<br>20kW-class EP | 350kW-class power system<br>300kW-class EP |
| DV = 2.7km/s | DV = 10km/s | DV > 10 km/s | DV ≈ 3 km/s | DV ≈ 8 km/s |

# SEP Demonstration Trades

## Technology

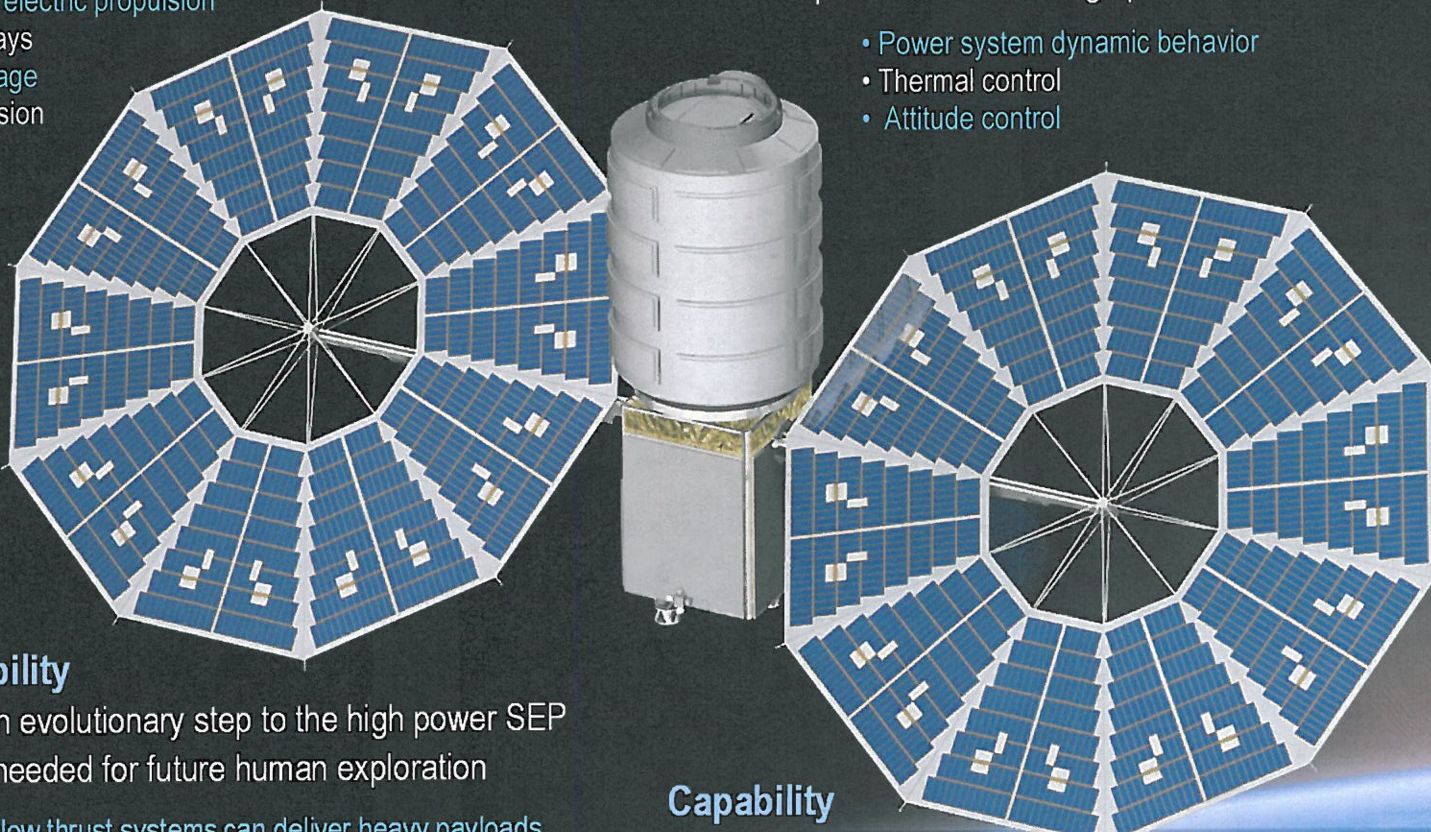
Demonstrate enabling SEP technologies in all relevant space environments (*from* LEO to beyond GEO)

- Next gen electric propulsion
- Solar arrays
- High voltage
- Tech infusion

## Integrated System

Solve the system technology and operational issues related to implementation of a high performance SEP vehicle

- Power system dynamic behavior
- Thermal control
- Attitude control



## Extensibility

Provide an evolutionary step to the high power SEP Systems needed for future human exploration

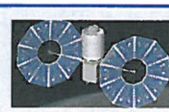
- Prove low thrust systems can deliver heavy payloads
- Build upon the recent success of AEHF
- Inform future exploration architecture studies
- Retire risks associated with Van Allen radiation belts

## Capability

Provide a valuable new beyond-LEO payload delivery capability

- Wide range of potential missions (HEOMD, SMD, comm)
- Enables cost savings via launch vehicle step down
- Operational capability enables partnership opportunities

# SEP Demo Mission Concepts

| Mission | Power | |
|---|---|---|
| LEO to E-M L2 payload delivery | 40kW |  |
| LEO to heliocentric space (asteroid rendezvous) | 38kW |  |
| LEO to GEO to LEO | 22kW |  |
| GTO to LEO | 30kW |  |
| LEO to low lunar orbit (LLO) | 25kW |  |
| LEO to GEO | 40kW |  |
| LEO to GEO | 12kW |  |
| Asteroid Retrieval Mission | 50kW |  |
| E-M L2 Maintenance | 40kW |  |
| GTO to MEO | 30kW |  |

Stand-alone missions designed to address all four demonstration objectives are being used for planning purposes

Partner-based or secondary payload-based mission concepts that de-scope some of the technical content may offer better value

| Partner | Mission Concept |
|---|---|
| NASA | Asteroid precursor mission |
| NASA | Cargo delivery for deep space hab |
| NASA | Various science missions |
| Commercial | Satellite servicing |
| Commercial | High-power commercial GEO comsat |
| Commercial | Large hosted payload system demo |
| DoD | Technology demonstrator |
| International | Contributed LV and/or subsystems |

# Solar Electric Propulsion Technology Development Summary

- Solar electric vehicles have been identified by NASA as critically important to reduce the cost of future human exploration missions. Electric propulsion has been classified as a "core" technology for the agency, and solar power has been classified as an "adjacent" technology that supports SEP.
- Representative vehicle concepts were developed for NEA and Mars missions and used to parametrically assess key power and propulsion technologies
- Reliably deployable, compactly stowable solar arrays and high voltage electronics are the key power technologies needed to enable very high power solar electric propulsion
- Propulsion and power technology development is focused on enabling high power solar electric propulsion
- 30kW-class solar electric vehicles will serve as a stepping-stone to the high power systems needed for beyond-LEO human crewed exploration missions and provide valuable commercial, and exploration, and science capability
- Development of a range of mission concepts is anticipated to continue through 2015 unless a high-value, cost-effective approach permitting an earlier start is identified

# Acknowledgements

- Glenn Research Center COMPASS Team
- Game Changing Technology Development Program Office
- Solar Electric Propulsion Project
  - Mission Formulation
    - GRC
  - Propulsion
    - GRC, JPL
  - Power
    - GRC, LaRC, GSFC, ATK, DSS