The Ion Propulsion System for the Solar Electric Propulsion Technology Demonstration Mission

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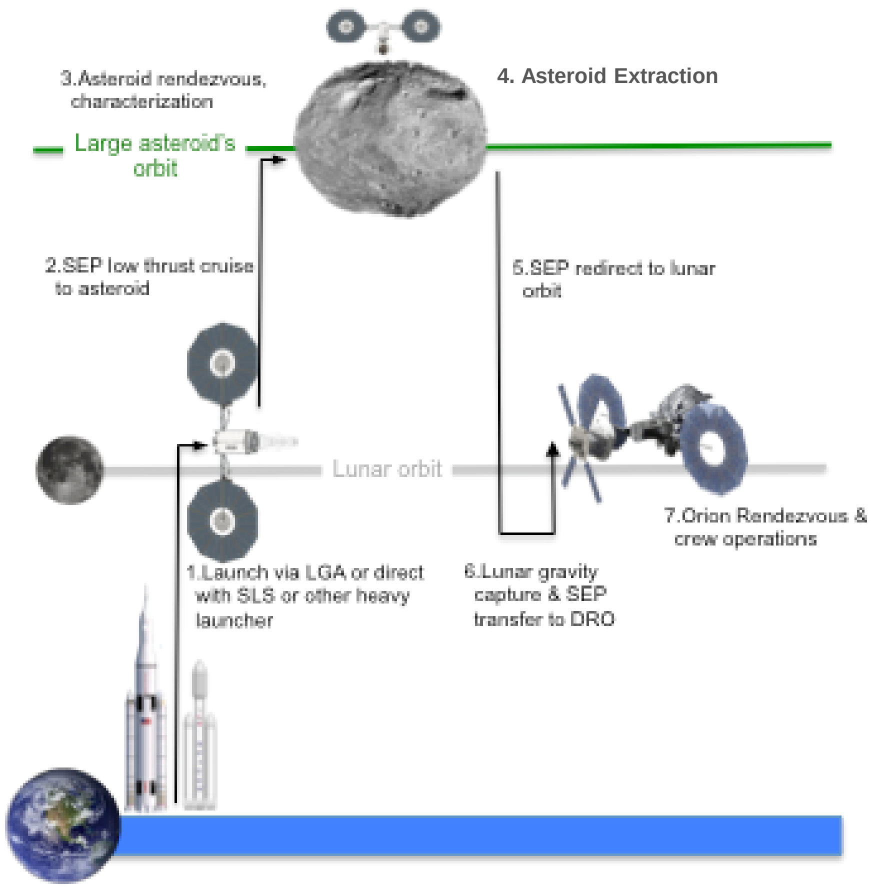
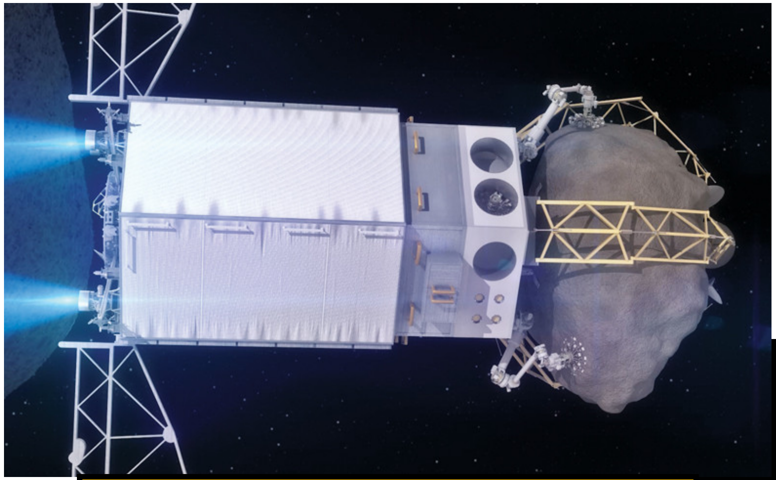
Outline

- SEP TDM, ARRM, and EMC Overview
- Ion Propulsion System Overview
- NASA In-House Technology Development Status
  - 12.5 kW HERMeS Thruster
  - 13.3 kW HP-120V PPU
- Engineering Development and Flight Hardware Plan
- Conclusions

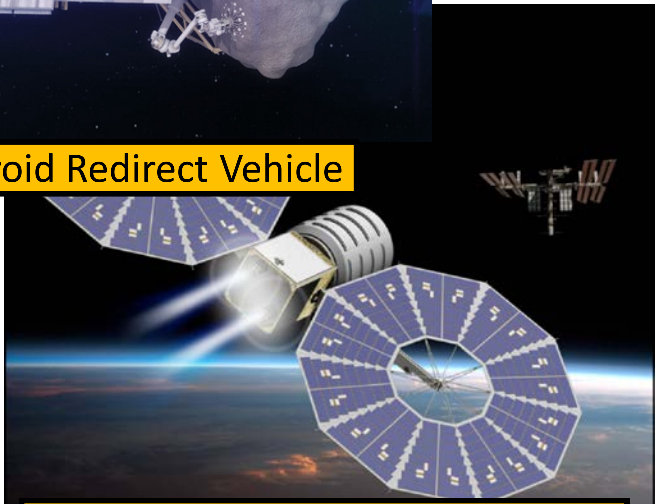
Solar Electric Propulsion Technology Demonstration Mission

- High-power SEP can be enabling for both near-term and future exploration architectures and science missions
- NASA is maturing mission design for a 50kW-Class SEP Demonstration
  - Most mature concept is the Asteroid Redirect Robotic Mission



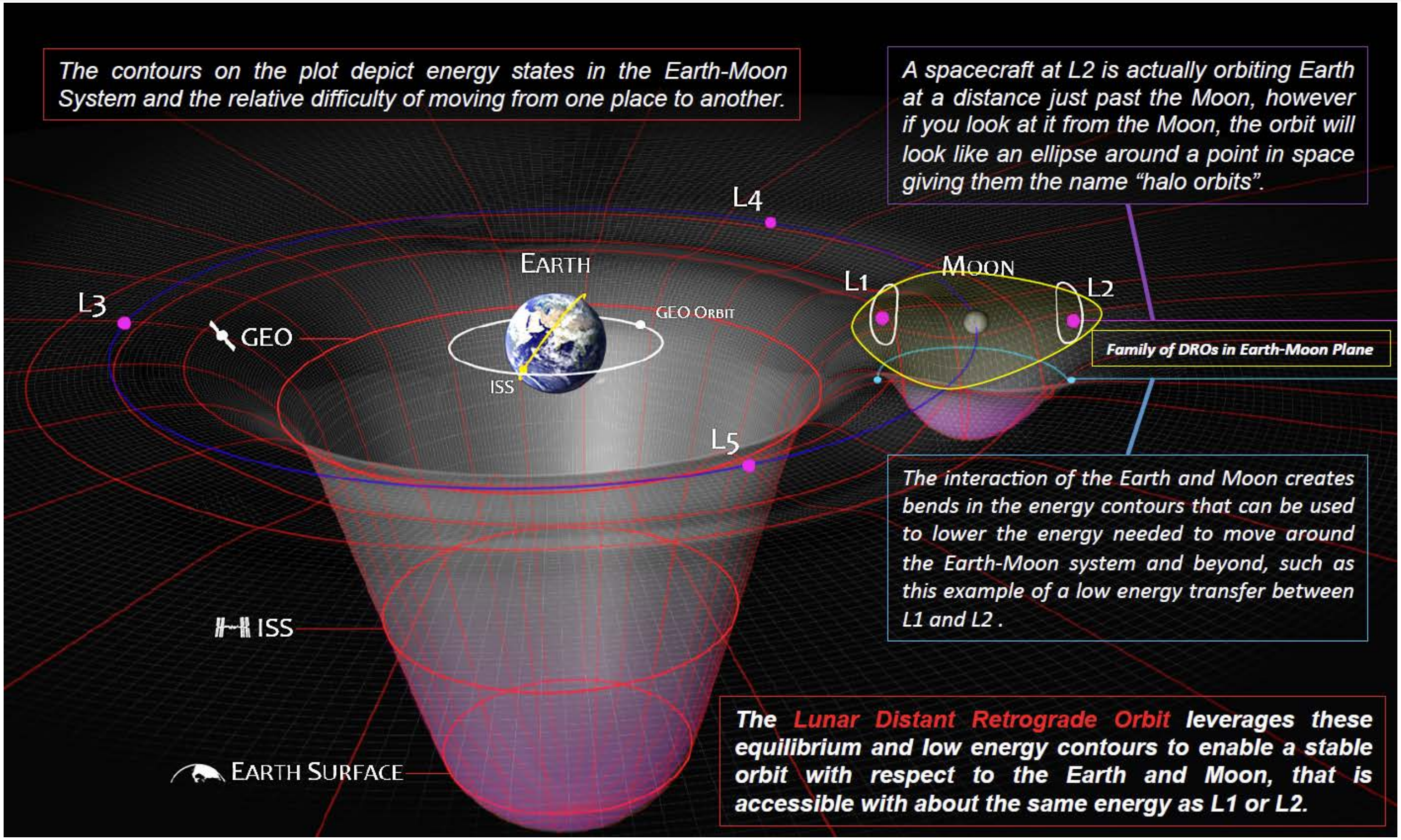


Notional Asteroid Redirect Vehicle



30kW-Class SEP TDM: L2 Logistics

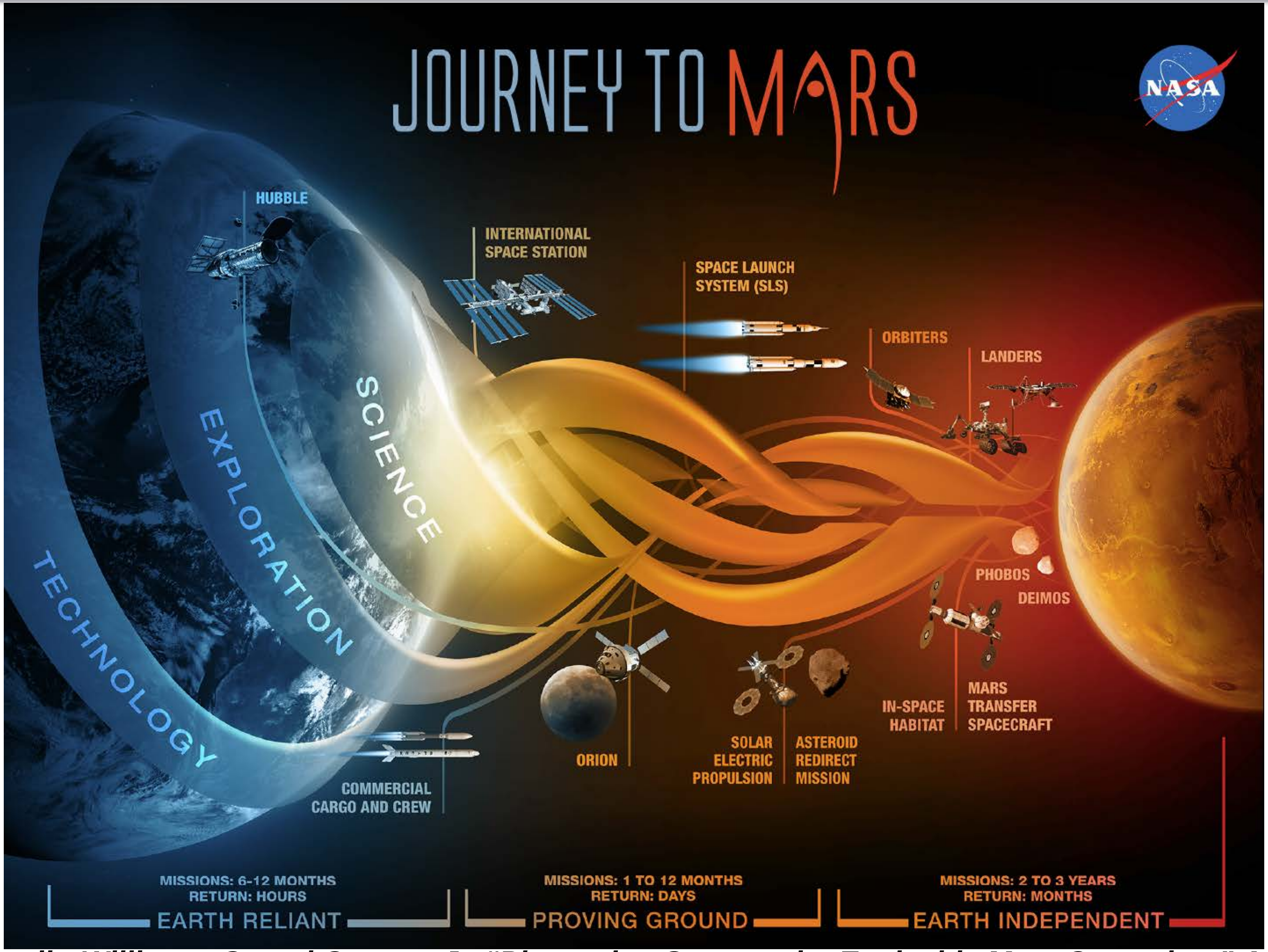
Long-Term, Stable Asteroid Storage for Crew Access



Credit: Williams, G. and Crusan, J., "Pioneering Space – the Evolvable Mars Campaign," April 2015.

- Earth-Moon Lagrange points provide stable, crew-accessible destination while expanding exploration capability toward long-term deep-space operations
  - Serve as a staging point for large cargo masses en route to Mars

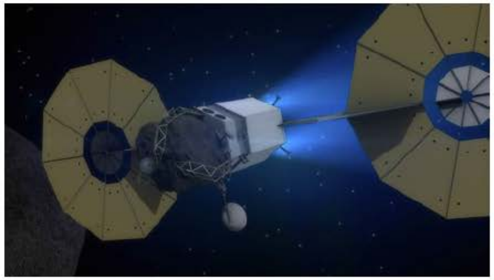
High-Power SEP Critical to NASA Exploration Vision

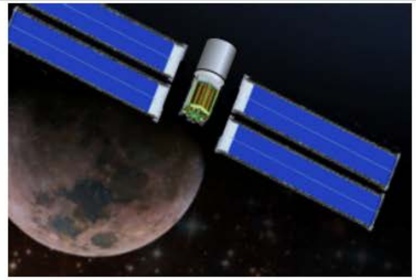


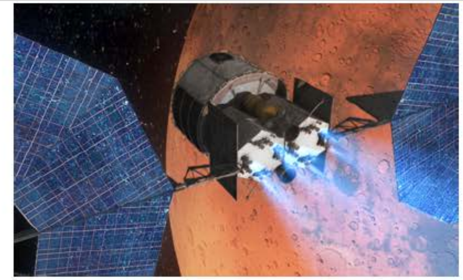
Credit: Williams, G. and Crusan, J., "Pioneering Space – the Evolvable Mars Campaign," April 2015.

- High-Power SEP systems required to move large masses in interplanetary space
  - Leveraged in a multi-use, evolvable space infrastructure

High-Power SEP Module Extensibility for Mars







Block 1

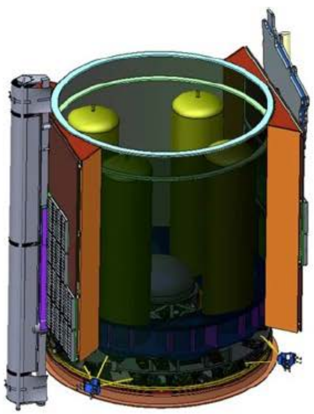
- 50-kW Solar Array
- 40-kW EP System
- 10-t Xenon Capacity

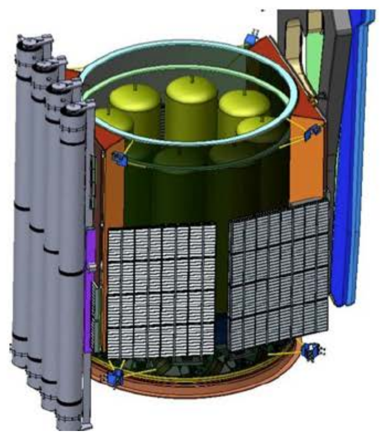
Block 1a (SEP/Chem)

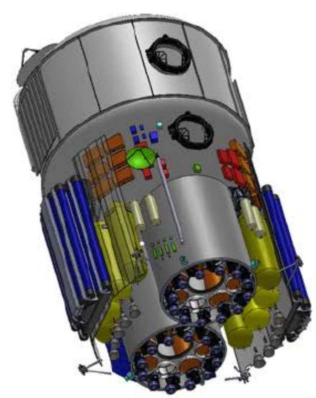
- 190-kW Solar Array
- 150-kW EP System
- 16-t Xenon Capacity

Hybrid

- 250 to 400-kW Solar Array
- 150 to 200-kW EP System
- 16-t Xenon Capacity With Xe Refueling Capability



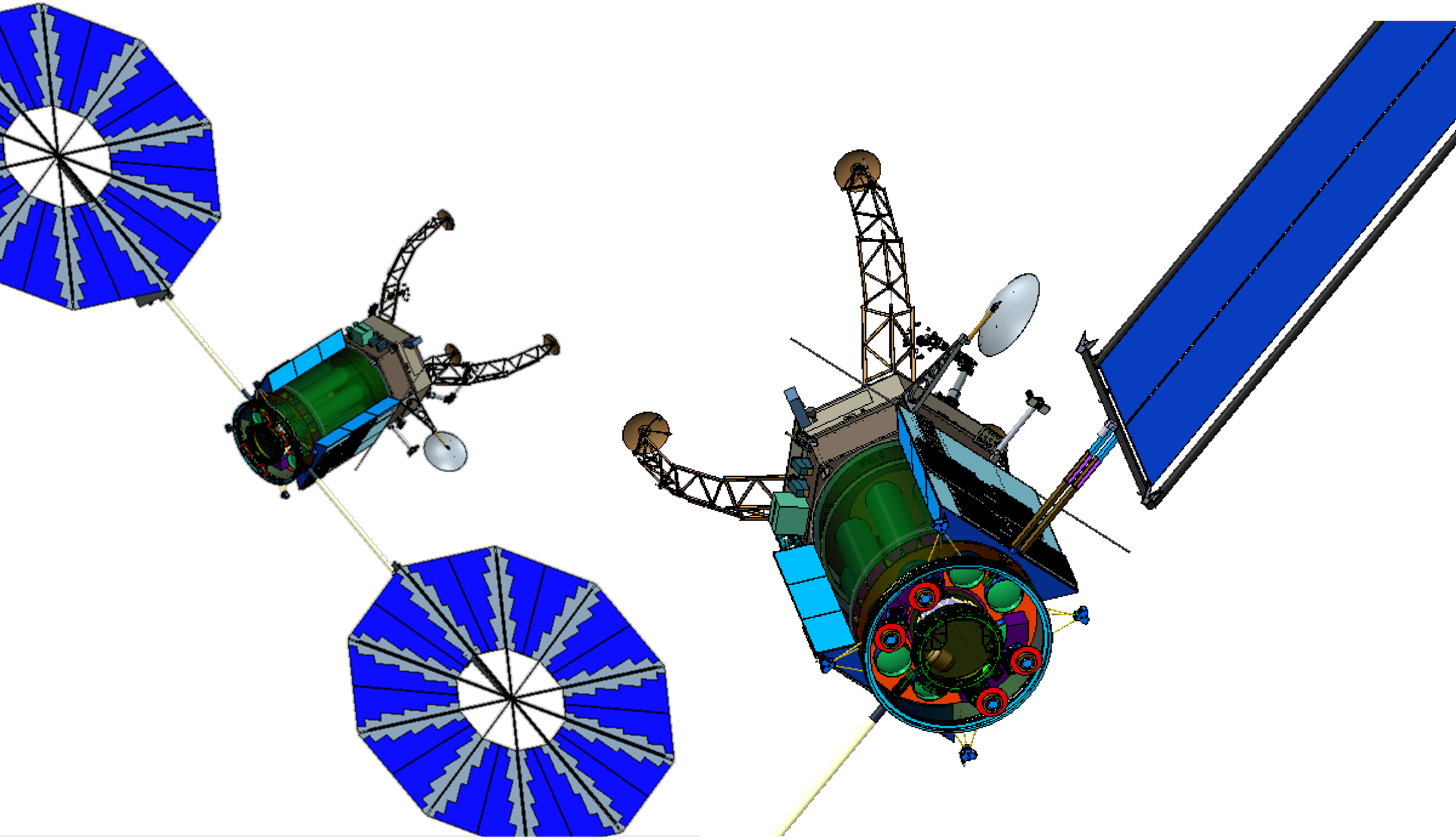




Credit: Williams, G. and Crusan, J., "Pioneering Space – the Evolvable Mars Campaign," April 2015.

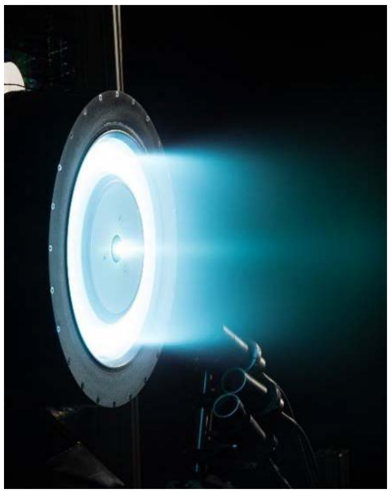
- High-Power SEP systems required to move large masses in interplanetary space
  - Leveraged in a multi-use, evolvable space infrastructure

Asteroid Redirect Robotic Vehicle Conceptual Design

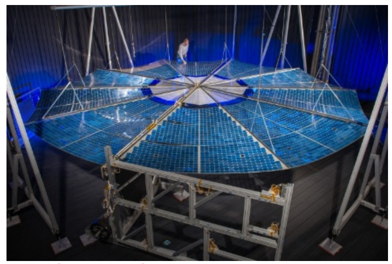


High-Power SEP Technology Investments

- NASA is developing the requisite technologies for a 50kW-Class Solar Electric Propulsion Demonstration to enable SEP missions and applications at higher power levels

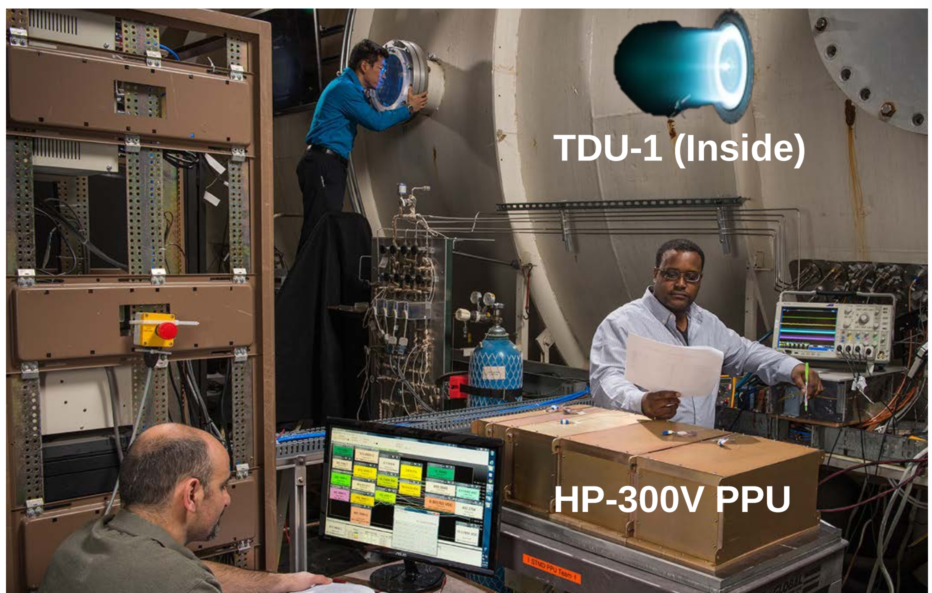


12.5kW HERMES TDU-1



25-kW Solar Array Structures: MegaFlex (left) and ROSA (right).

HP-300V Brassboard PPU



HP-300V PPU and HERMeS TDU-1 Integration Test

HP-120/800V Brassboard PPU

Ion Propulsion System and Thruster Requirements

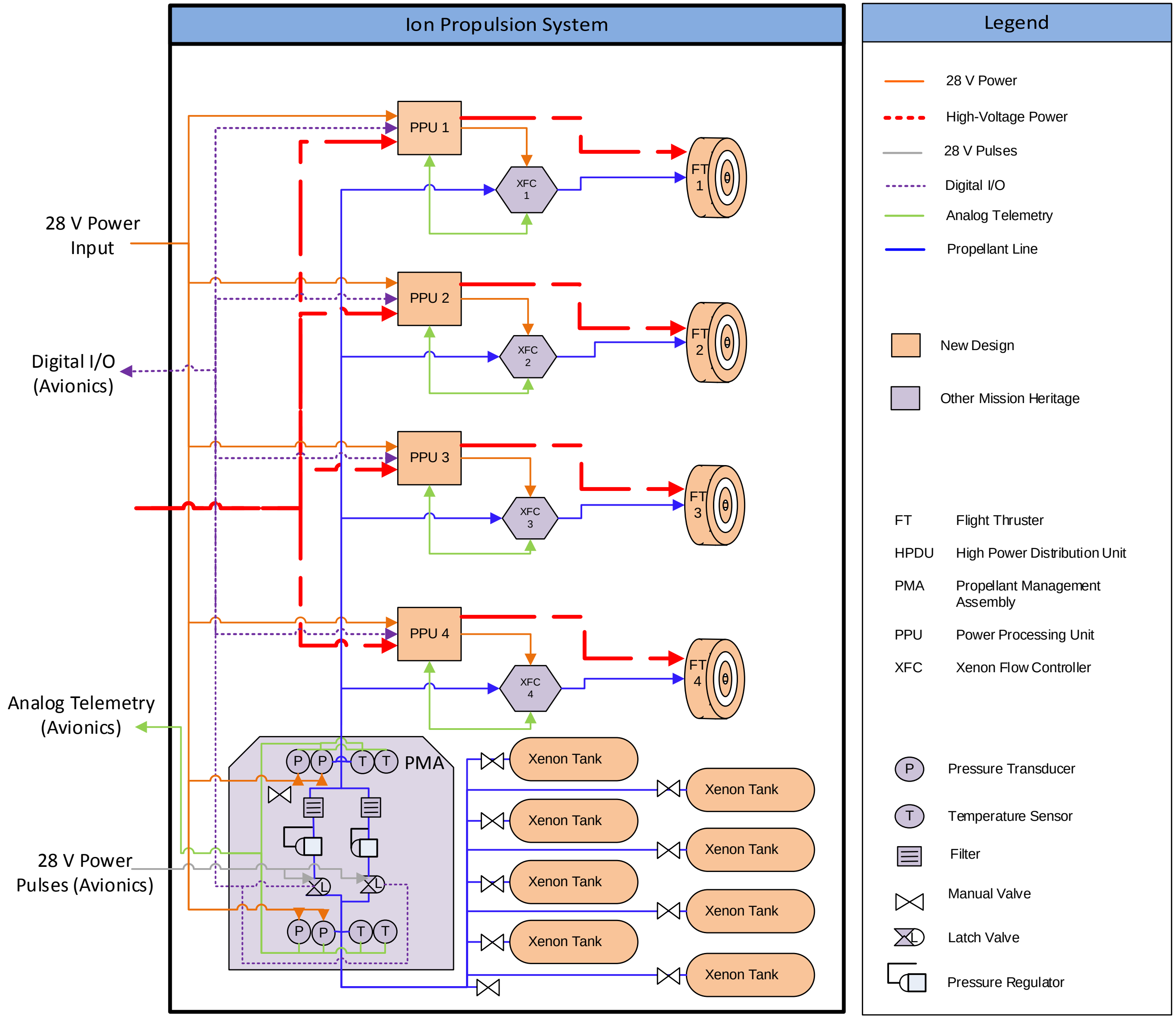
- Reference Ion Propulsion System (IPS) capability

Capability	Value
Total system power	40 kW
Maximum specific impulse	3000 s
Xenon throughput	10,000 kg
String fault tolerance	Single
Solar range	0.8 – 1.9 AU
Input voltage range	95 – 140 V

- Attributes of a single HERMeS thruster assuming 40 kW EP Power divided by 3 active EP strings and one non-operating spare (assumes PPU efficiency is 94%)

Attribute	Value
Maximum input power to PPU	13.3 kW
Maximum discharge power	12.5 kW
Discharge voltage at 3000s I_{sp}	800 V
Discharge current at 3000s I_{sp}	15.6 A
Service life (unmargined)	50,000 h
Minimum discharge power	6.25 kW (50% maximum power)

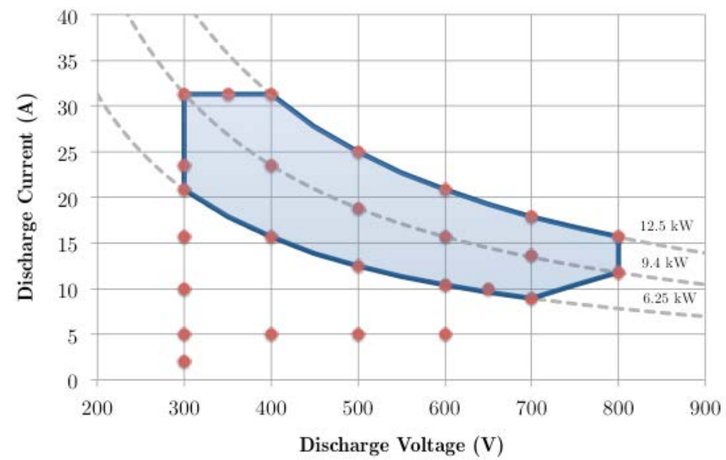
IPS Functional Block Diagram



- 3+1 EP Strings consisting of four elements
  - Flight Thrusters (FT)
  - Power Processing Unit (PPU)
  - Xenon Feed System (XFS)
  - Mechanical Integration Hardware (MIH)
- Thruster gimbal is part of spacecraft structures and mechanisms

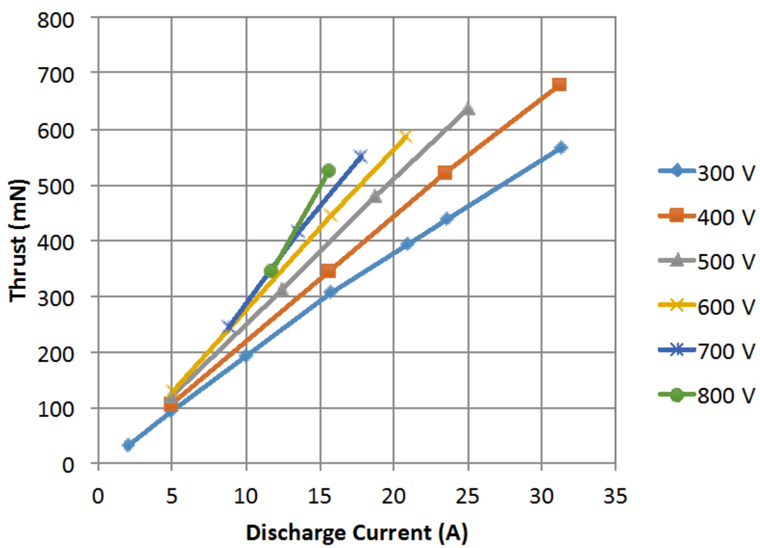
HERMeS Thruster Development Status

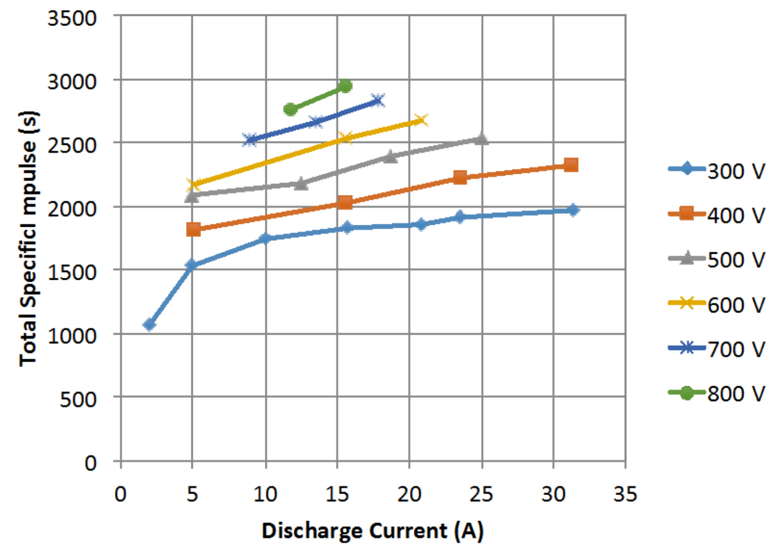
- NASA GRC and JPL developed 12.5 kW Hall Effect Rocket with Magnetic Shielding (HERMeS) to demonstrate viability and address mission risks
  - Hall Thruster Lifetime Qualification
  - Ground Test Facility Effects
  - Spacecraft Accommodation
- First Technology Demonstration Unit (TDU-1) fabricated and extensively tested
  - Operating envelope (blue) spans 300-800 V, 8.9-31.3 A (3.5:1), & 6.25-12.5 kW
  - TDU-1 testing has demonstrated operating points (red) as low as 300 V, 2 A

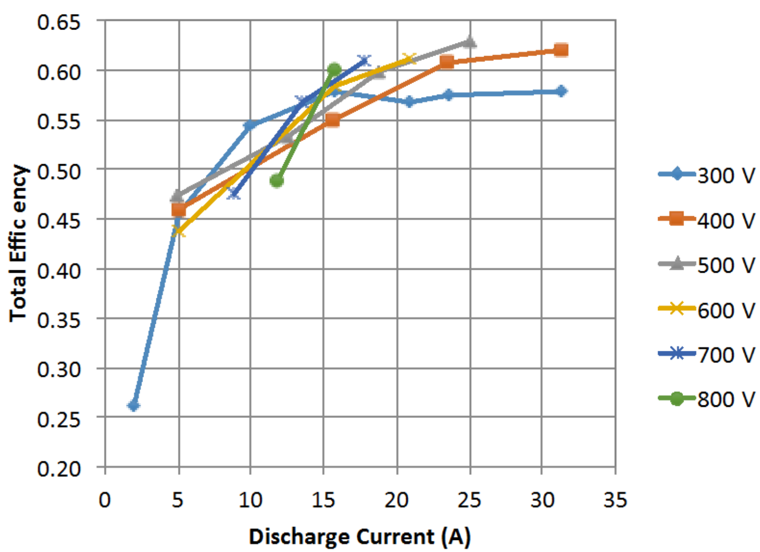


    - Performance and plume mapping: including facility effects characterizations, magnetic field strength optimization, magnetic field symmetry assessment, cathode flow fraction characterization, and plume flux, energy, and charge state
    - Multiple thermal characterizations to quantify thermal margin
    - Wall probe measurements to verify magnetic shielding require for long-life
- Second thruster (TDU-2) being fabricated for environmental testing

TDU-1 Performance, VF5 at NASA GRC, May 2015







- TDU-1 testing to date has spanned 300-800 V, 0.6-12.5 kW

- References
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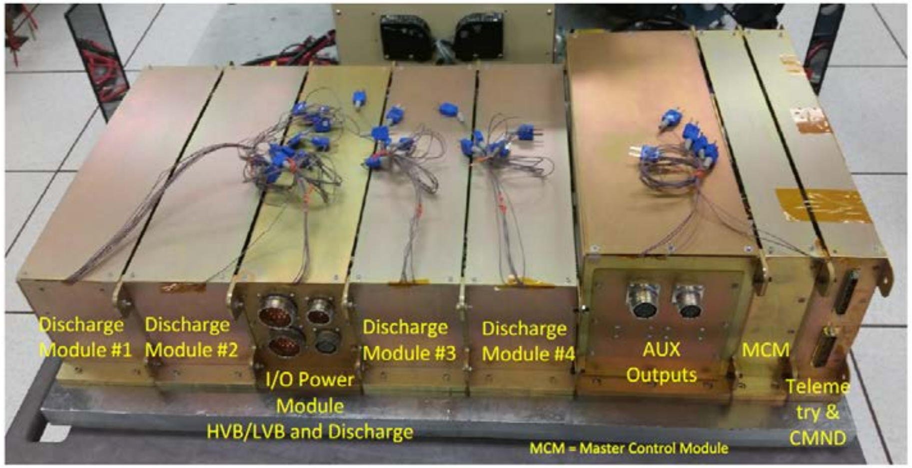
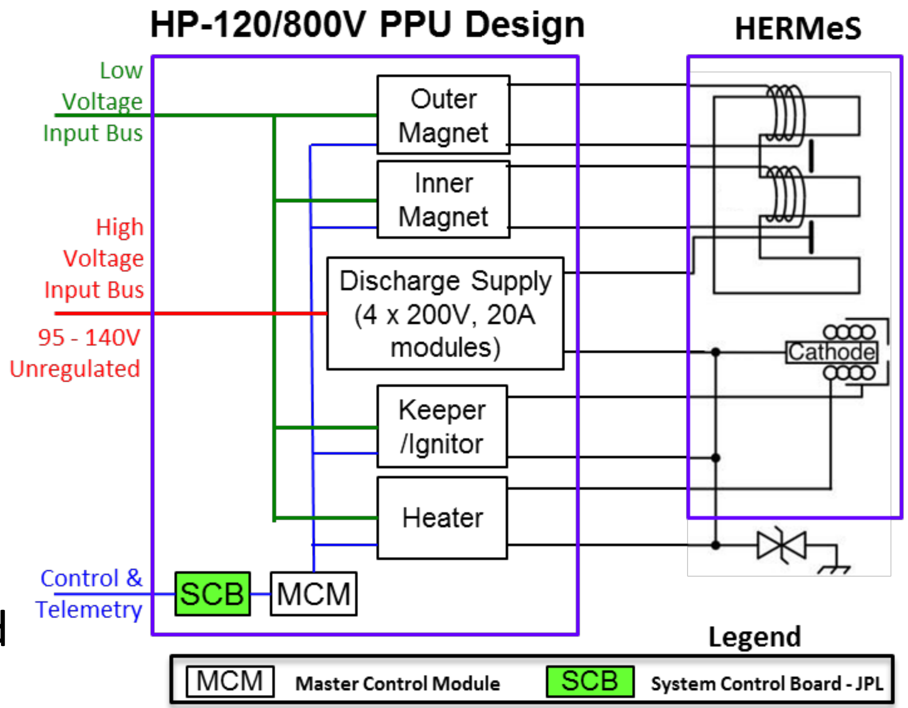
  - Hofer, et al, IEPC 2015

HP-120V PPU Development Status

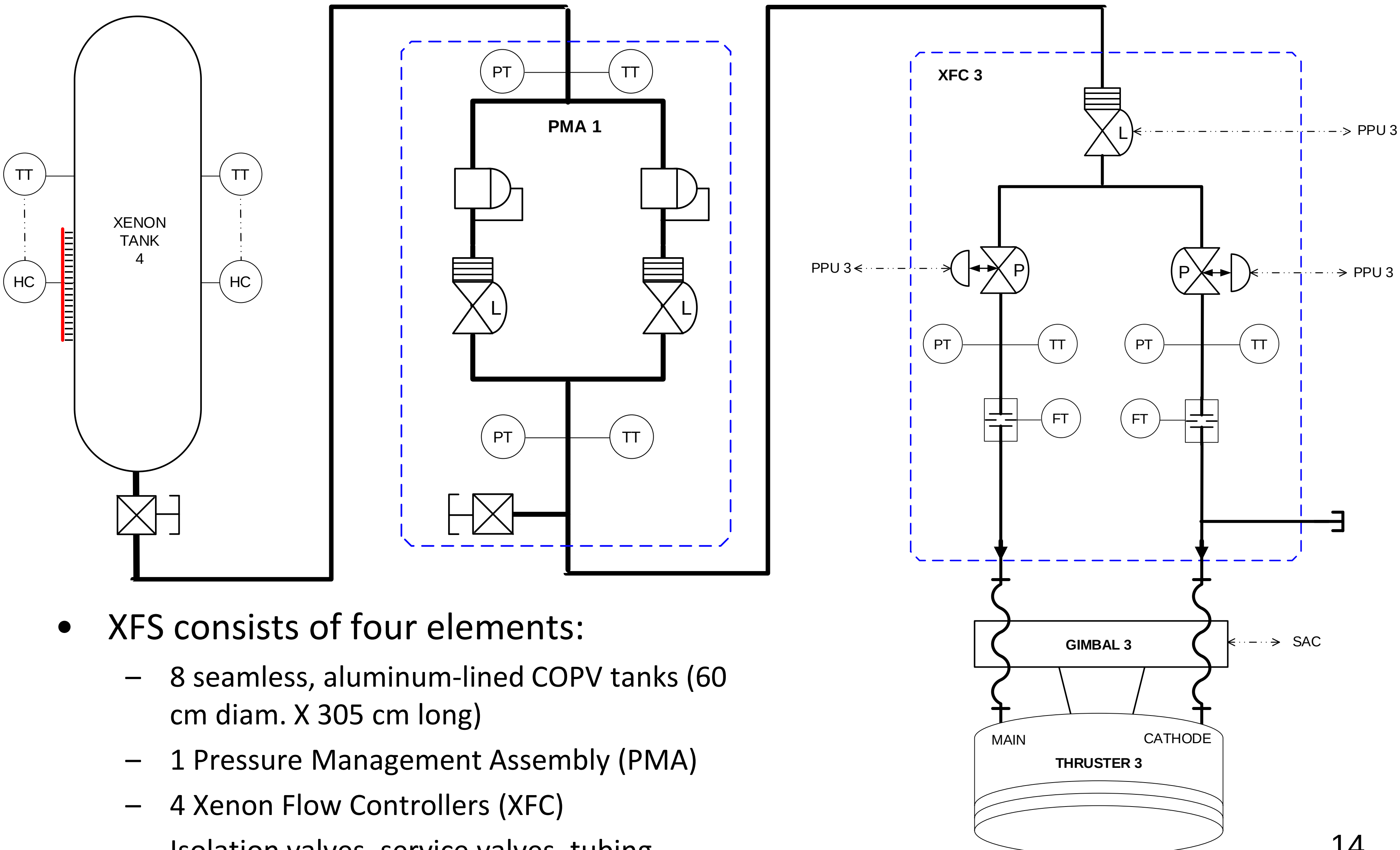




– Pinero, et al, JPC 2015

- 13.3 kW HP-120V Full-Bridge Topology Power Processing Unit (PPU) developed to demonstrate viability and address mission risks
  - PPU development schedule
- Brassboard unit developed and tested over operating range 2 – 14 kW, 95 – 140 V input, and 200 – 800 V output demonstrating 94.0 – 95.5% efficiency
  - Ambient functional testing
  - Vacuum performance characterization
  - HERMeS thruster compatibility testing including 12.5 kW, 3000 s thruster design point

Xenon Feed System (XFS) Single String and Single High Pressure Components



- XFS consists of four elements:
  - 8 seamless, aluminum-lined COPV tanks (60 cm diam. X 305 cm long)
  - 1 Pressure Management Assembly (PMA)
  - 4 Xenon Flow Controllers (XFC)
  - Isolation valves, service valves, tubing

IPS Transition for Flight

- Acquisition for most major IPS components has been initiated to meet the Dec. 2020 ARRM launch date
  - Draft Request for Proposals (RFP) issued for Engineering Development Unit (EDU) EP String
    - Option for Qualification Model (QM) and Flight Model (FM) Hardware
    - Includes thruster, PPU, and XFC
      - With some additional development, the NASA in-house HERMeS thruster and HP-120V PPU designs could become the basis for future flight NASA missions

EP String Procurement Event	Date (Subject to Change)
Draft RFP Release	May 21, 2015
Industry Conference	June 10, 2015
Comments on Draft Due	June 22, 2015
Final RFP Release	July 14, 2015
Proposal Due Date	August 28, 2015
Contract Award	March 29, 2016

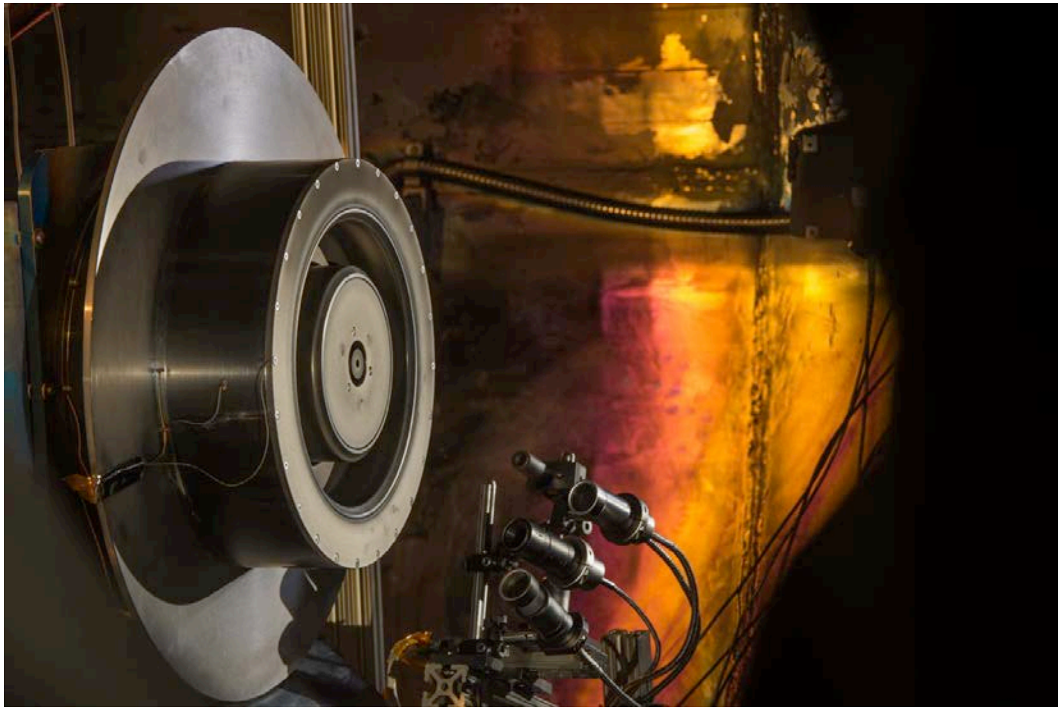
  - Draft Request for Proposals (RFP) for pathfinder, prototype xenon tank pending
- Acquisition of up to 10 metric tons of xenon being carefully planned to avoid market price run-off or disruption of availability

Conclusions

- NASA is developing a high-power SEP systems required to move large masses in interplanetary space as part of a multi-use, evolvable space infrastructure
- NASA is maturing mission design for a 50kW-Class SEP Demonstration
  - Most mature concept is the Asteroid Redirect Robotic Mission
- NASA is developing the requisite technologies for the SEP TDM, including ARRM, to enable these SEP missions and applications at higher power levels
  - HERMeS is a 12.5 kW Hall thruster co-developed by GRC and JPL for operation up to 3000 s specific impulse and a 50 kh lifetime that is enabled through the use of magnetic shielding
  - HP-120V PPU is a 13.3 kW full-bridge topology PPU capable of operating the HERMeS thruster at the 12.5 kW, 3000 s operating point and demonstrated efficiencies up to 95.5%
- An Ion Propulsion System design has been developed for the Asteroid Redirect Vehicle utilizing a 3 + 1 EP string architecture based on the NASA in-house developed technologies and their demonstrated performance
- Acquisition for most major IPS components has been initiated to meet the Dec. 2020 ARRM launch date (EP strings, xenon tank, xenon propellant in planning)

Acknowledgements

The support of the joint NASA GRC and JPL development of HERMeS by NASA's Space Technology Mission Directorate through the Solar Electric Propulsion Technology Demonstration Mission (SEP TDM) project is gratefully acknowledged.



12.5kW HERMES TDU-1 inside VF5 at NASA Glenn Research Center (May 2015)

SEP TDM supported papers at 2015 JANNAF, IEPC, & JPC

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