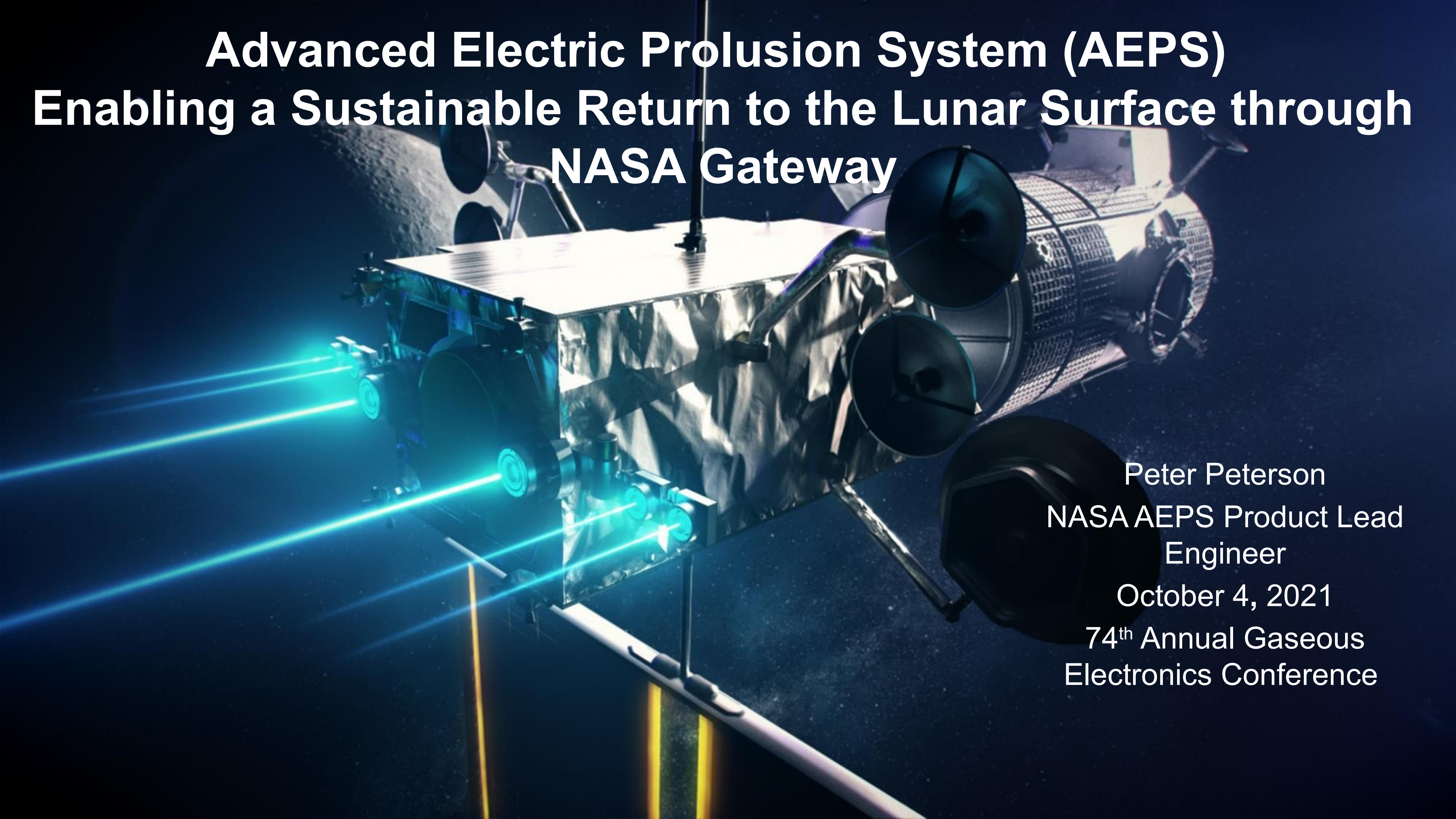
Advanced Electric Prolusion System (AEPS) Enabling a Sustainable Return to the Lunar Surface through NASA Gateway



Peter Peterson

NASA AEPS Product Lead Engineer

October 4, 2021

74th Annual Gaseous Electronics Conference

Space Policy Directive 1: To the Moon, then Mars

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations…"

The Artemis Program

Artemis is the twin sister of Apollo and goddess of the Moon in Greek mythology. Now, she personifies our path to the Moon as the name of NASA's program to return astronauts to the lunar surface by 2024.

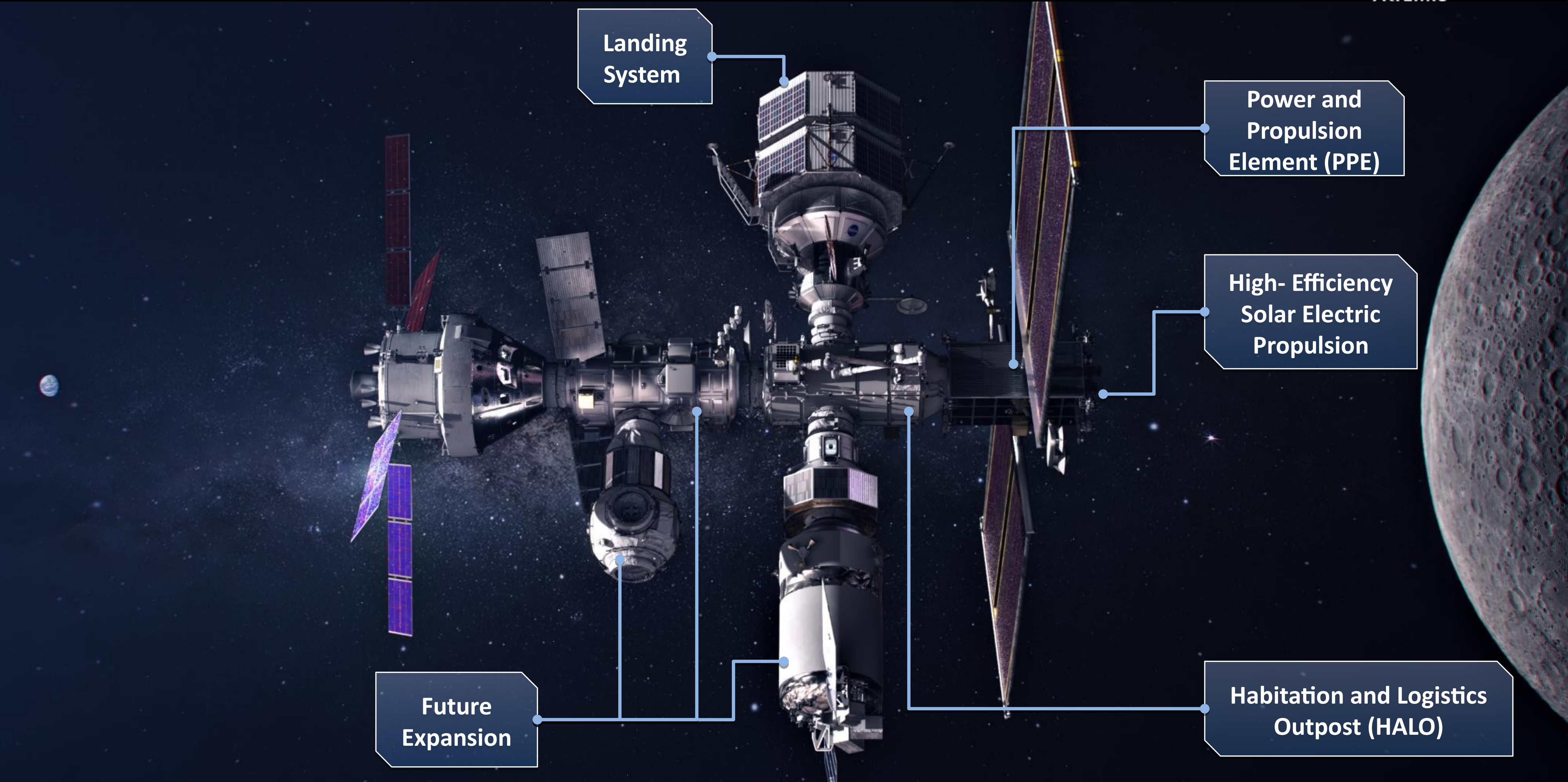
When they land, Artemis astronauts will step foot where no human has ever been before: the Moon's South Pole.

With the horizon goal of sending humans to Mars, Artemis begins the next era of exploration.

NASA Artemis Plan

Credit: NASA

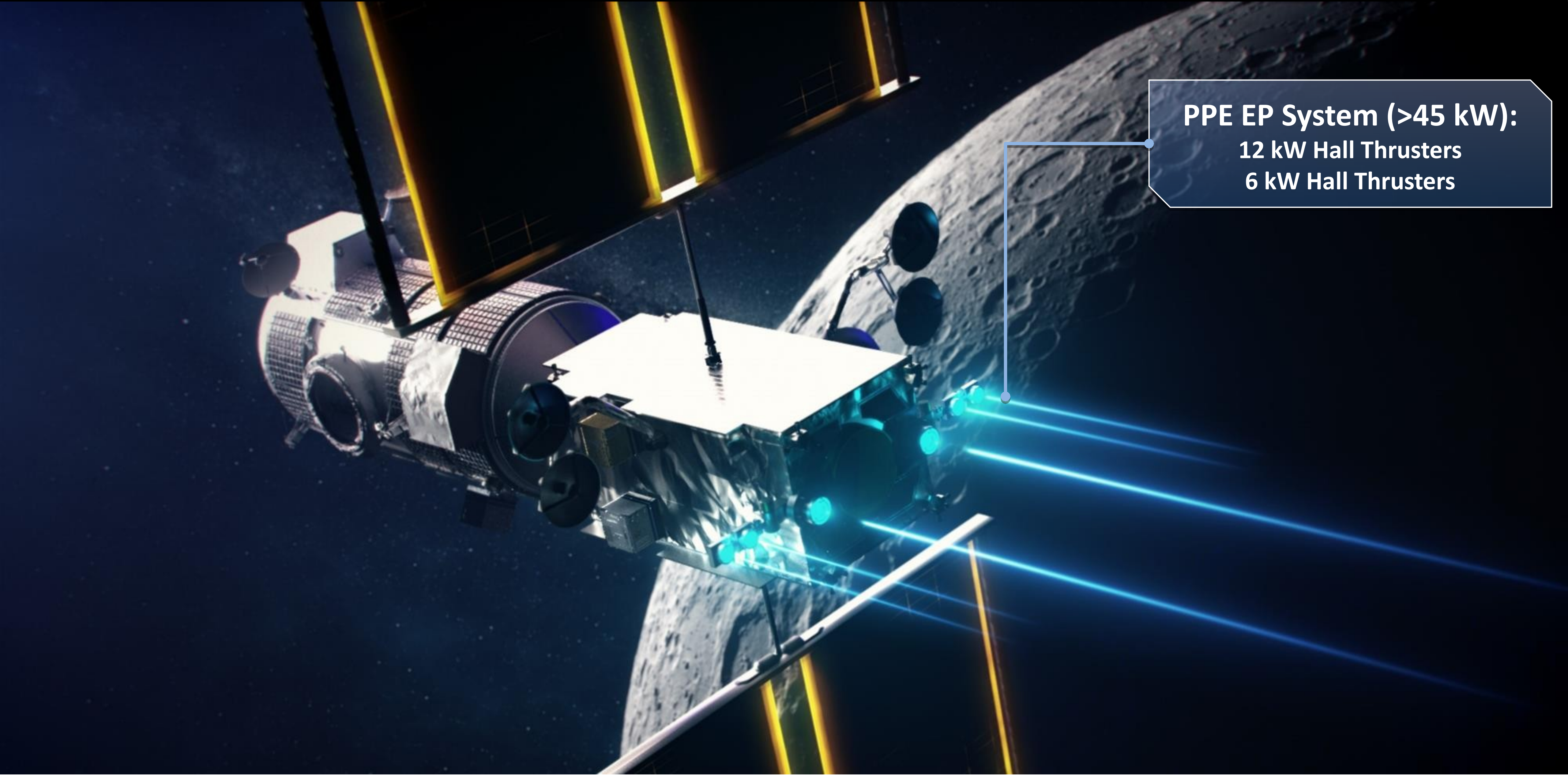
Gateway Configuration: PPE & HALO Co-Manifest Vehicle (CMV)



NASA Gateway:

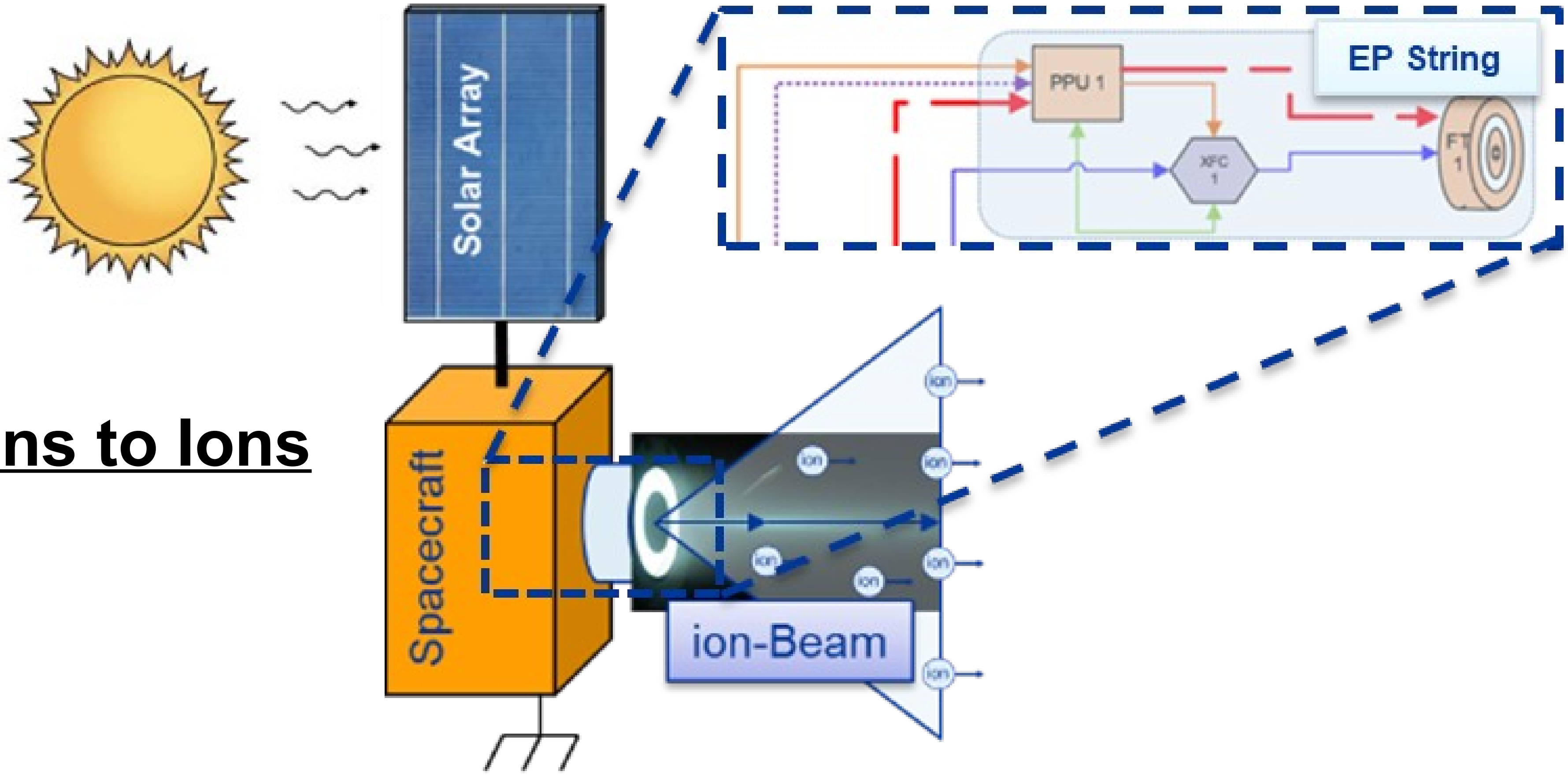
Credit: NASA

Propelling NASA Gateway: High-Power Electric Propulsion



Solar Electric Propulsion String

Photons to Ions



- **Spacecraft SEP System**
  - Solar Array
  - Power Distribution System
  - Propellant Management System
  - EP String

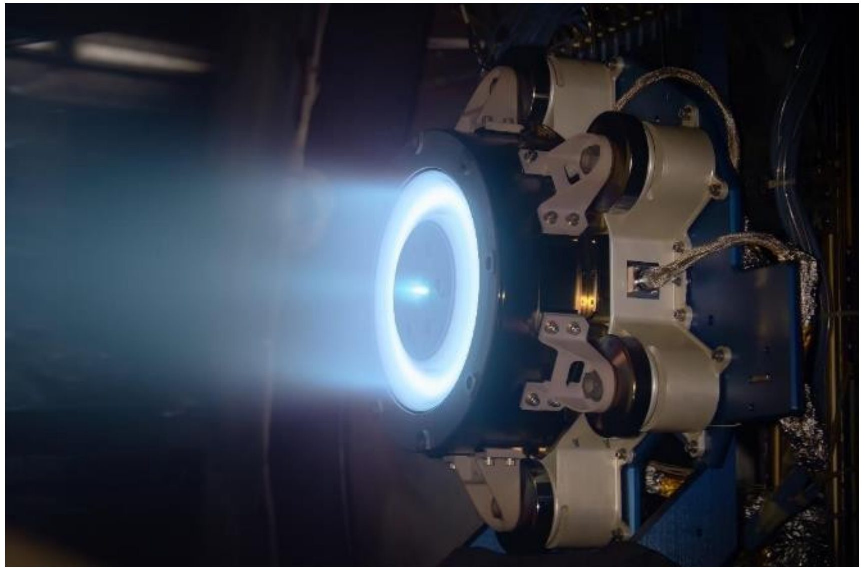
- **EP String**
  - Thruster
  - Power Processing Unit
  - Propellant Flow Controller

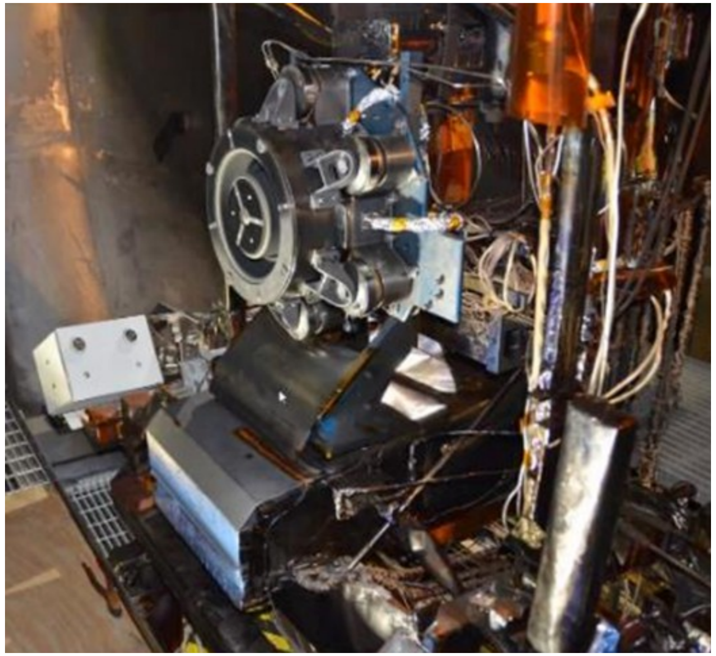
NASA Solar Electric Propulsion Technology Demonstration Mission (SEP) Project under NASA STMD

- **NASA SEP Project is under NASA Space Technology Mission Directorate**
  - SEP Project Objectives:
    - Develop and qualify high power electric propulsion technologies for NASA exploration that benefit US government and private-sector missions
    - Empower the US space industry to accelerate the adoption of high-power electric propulsion technologies by reducing the risk and uncertainty of integrating SEP technologies into space flight systems
    - Develop and qualify an advanced 12 kW EP thruster applicable to human/robotic exploration and commercial spaceflight missions including the Power and Propulsion Element (PPE)
  - Access to Space/Demo Details:
    - Provide Advanced Electric Propulsion System (AEPS) string qualification data and information to Power and Propulsion Element (PPE)
    - Deliver Plasma Diagnostic Package (PDP) to PPE prime contractor for flight integration to enable characterization of EP technology

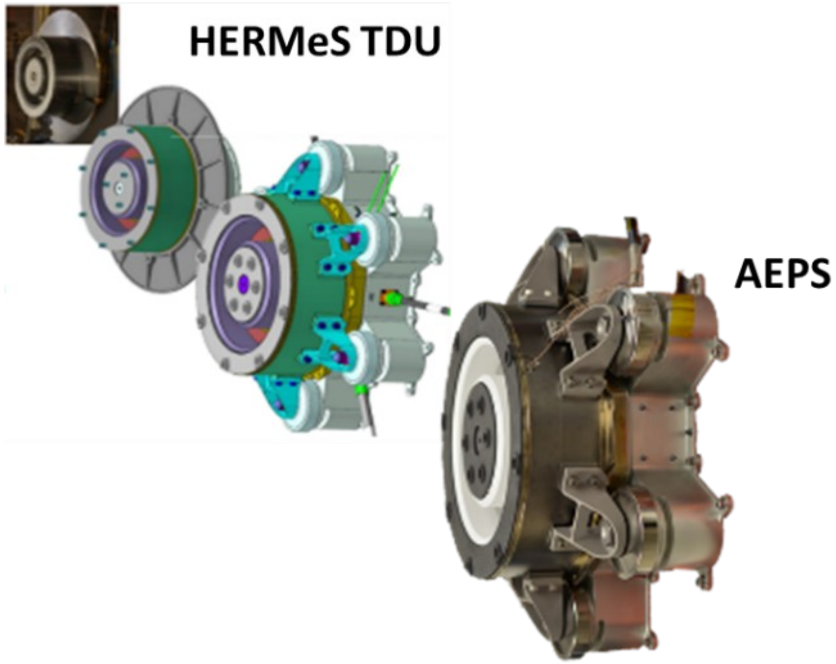
NASA Solar Electric Propulsion Technology Demonstration Mission (SEP) Project

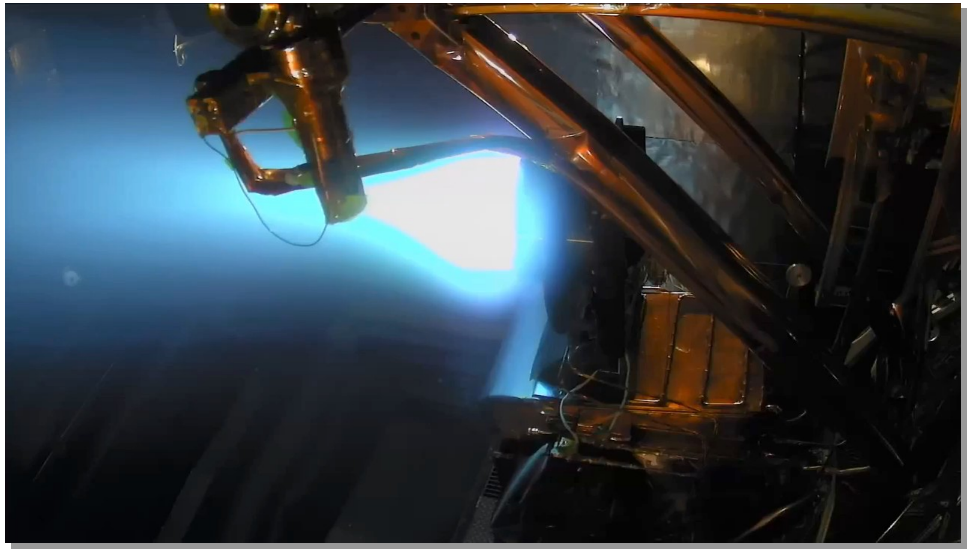
- **The SEP Project consist of two elements**
  - Advanced Electric Prolusion System (AEPS)
    - The AEPS is a next-generation electric propulsion capability that will enable human missions to the Moon and Mars.
    - 12-kW class Hall thruster developed for 50-kW class ion propulsion system (IPS)
      - ***Power: 12 kW (3X SOTA)***
      - ***Propellant Throughput: >1,700 kg (7X SOTA)***
      - ***Maximum Isp: >2,600 s (1.5X SOTA)***
  - Plasma Diagnostic Package (PDP)
    - The PDP will enable collection of plasma plume data in orbit from the AEPS propulsion system
    - The PDP consists of a Main Electronics Package (MEP), discharge current sensors and probes housed in a Thruster Probe Assembly (TPA)





NASA AEPS Development





- **NASA began the development of the higher power Hall thruster EP system in 2011**
  - First 12 kW-class Hall-Effect Rocket with Magnetic Shielding (HERMeS) Technology Development Unit (TDU) in 2014
- **Flight hardware devolvement was transitioned to Aerojet Rocketdyne (AR) via a competitive procurement selection for the AEPS contract in May 2016**
  - AR and NASA completed all engineering qualification level development testing of the AEPS thruster
  - CDR is schedule for Feb 2022
  - Flight hardware delivery in 2023

AEPS Engineer Thruster Shipped to NASA

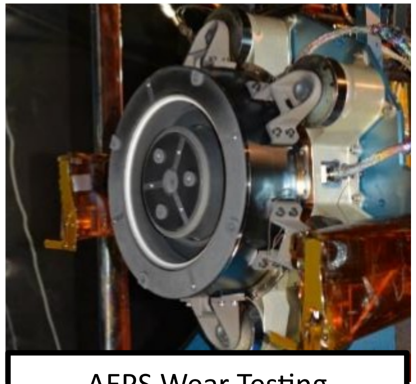
AEPS Engineer Thruster Flight Development Testing

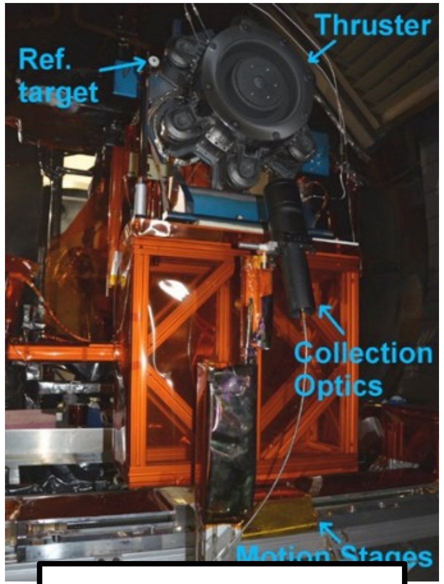

AEPS Performance Testing

Vibration Testing

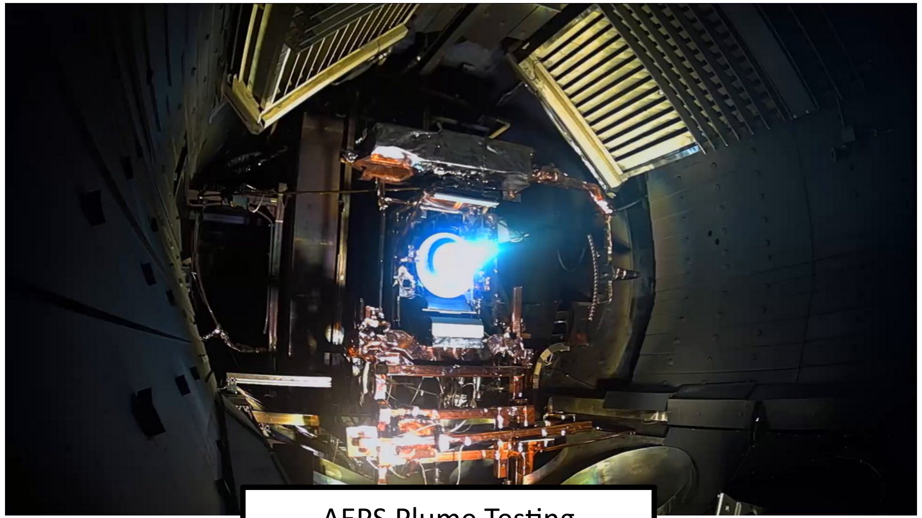

Shock Testing


AEPS TVAC


AEPS Wear Testing

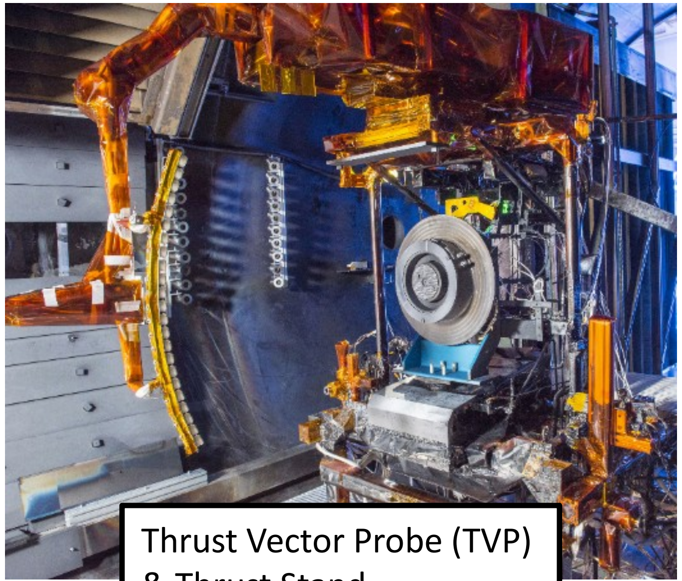


AEPS LIF Testing

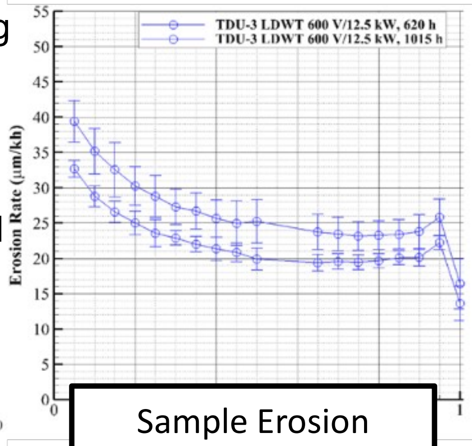

AEPS Plume Testing

NASA SEP Status: Key Instrumentation for AEPS

- **Thrust Stand**
  - Based on decades of successful performance measurements of various EP systems
  - Accurately measures the performance of an EP thruster
  - Demonstrated thrust stand uncertainty of 0.8% (±5.0 mN)
- **Thrust Vector Probe (TVP) and Plasma Diagnostics**
  - Measure the plasma plume properties of the EP thruster
  - Beam current centroid measurement to approximate direction of thrust vector
- **In-Situ and Tabletop Erosion Diagnostics**
  - The erosion diagnostic measures and monitors thruster surface erosion and deposition periodically during testing
  - In-Situ probe allows for measurements during long-duration testing without venting between test segments
- **Laser Induced Fluorescence (LIF)**
  - LIF diagnostic is used to measure ion velocity inside and near the thruster
  - The data is used to refine thruster plasma model for life assessment of the thruster

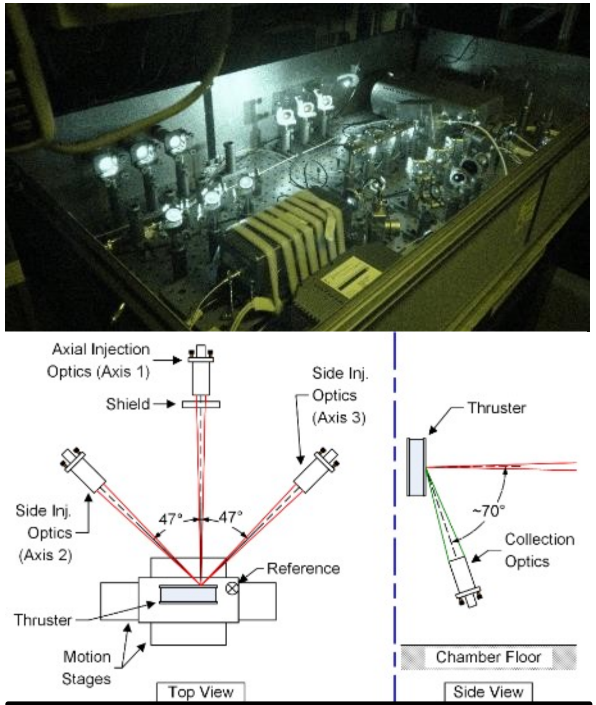


Thrust Vector Probe (TVP) & Thrust Stand

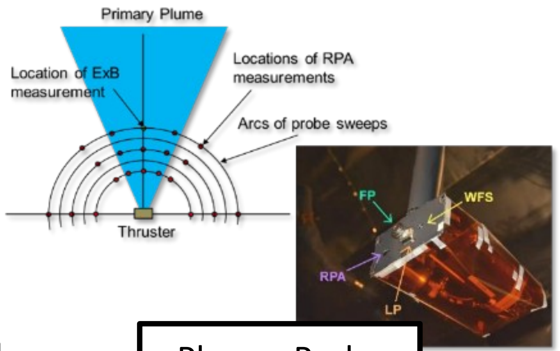


Sample Erosion Measurements

In-Situ Erosion Diagnostic

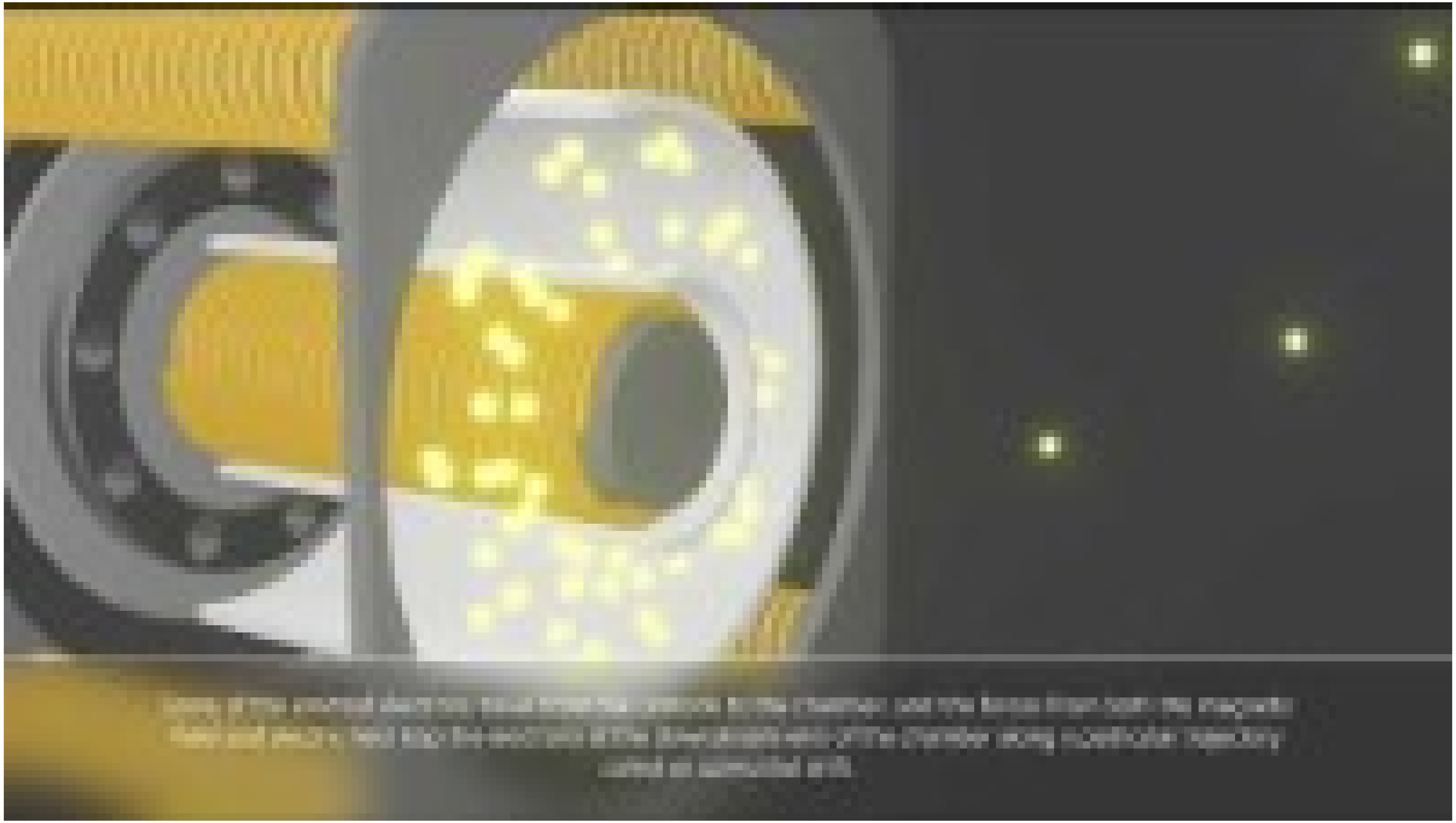


Laser Induced Fluorescence (LIF)



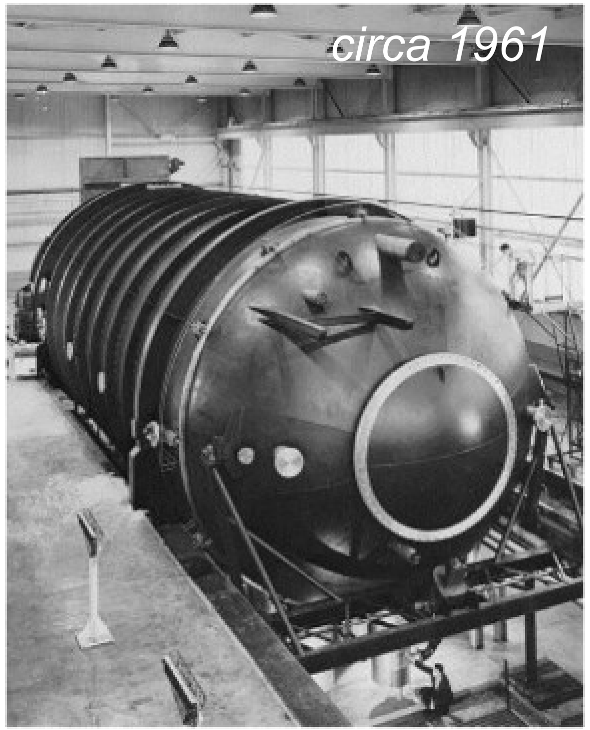
Plasma Probe

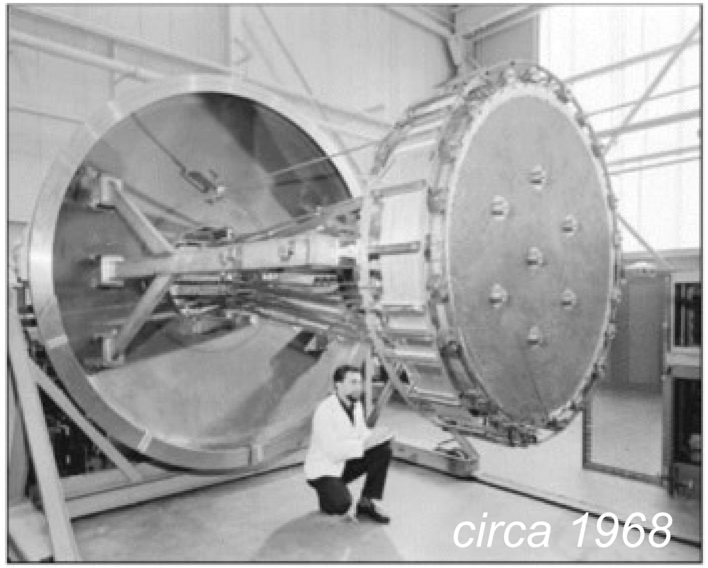
How Does a Hall Thruster Work



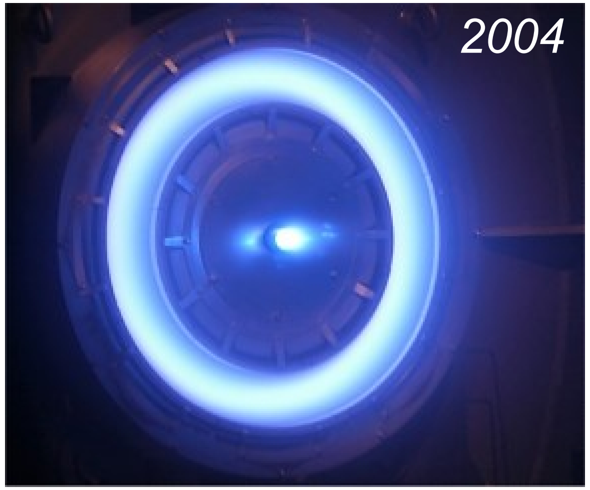
Credit: NASA Psyche Mission Capstone Project

GRC Electric Propulsion History





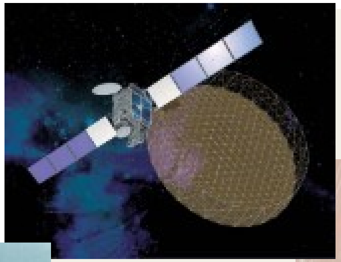
- NASA GRC (formally LeRC) performing low-thrust trajectory analysis as early as 1956
- These analysis resulted in the initiation of EP facility studies in 1957
- First EP facilities operational in Electric Propulsion Research Building in 1959 and large chambers in the Electric Propulsion Laboratory in late 1961.
- First flight of an ion thruster on SERT-1 in 1964
- Active area of R&D, space flight h/w development, facility maintenance and upgrade at GRC.



GRC Hall Propulsion Accomplishments

Russian-developed Hall Effect Thruster technology evaluated at GRC (1991)

GRC serves as DoD agent for development of Hall propulsion systems for use by BMDO



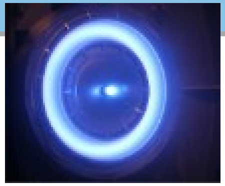
Quantified S/C integration impacts of 1.5kW prop systems onboard Loral geo-comsats

1,000 hour feasibility demonstration of 10kW class Hall thruster

600 W Hall prop system developed and flown on NRL spacecraft (1998)

Flight Experiment to evaluate plume interactions onboard Russia Spacecraft (2001)

Demonstration test of a 100 kW Hall Effect Thruster (2003)

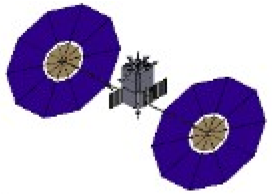


First demonstration of a efficient krypton Hall thruster operation at 5000 seconds (2004)

Invention of 2500 second Hall thruster technology for deep space missions awarded multiple patents

DSS and ATK awarded solar array contracts for 30-50 kW systems with extensibility to 250 kW (2012)

GRC performs in-house and contracted studies of SEP TDM mission concepts (2012)



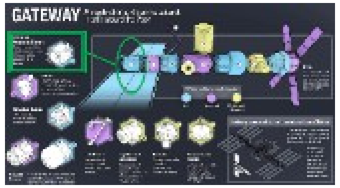
GRC/JPL develop and demonstrate 12.5 kW Hall technology for SEP TDM/ARRM (2013-Present)

GRC/JPL/Univ. of Michigan/Aerojet Rocketdyne NASA NEXTStep demonstration of a 100 kW EP system with the X3 Nested Hall Thruster (2015-Present)

SSL/JPL/GRC Demonstration test of SPT-140 Hall thruster for NASA Discovery mission Psyche (2016-Present)

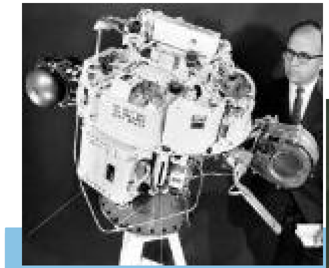
GRC Sub-kW Hall thruster ion propulsion system (2017-Present)

GRC Lead of the Power & Propulsion Element of NASA Gateway

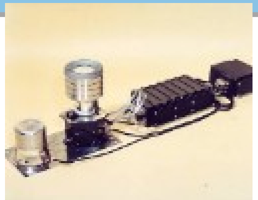


GRC Ion Propulsion Accomplishments

SERT I & II Flight Experiments

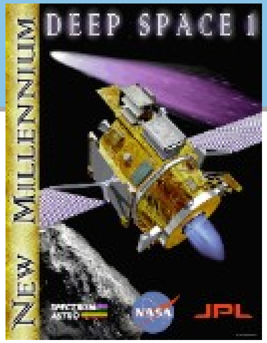


Electron Bombardment Ion Engine Invented (1958)



IAPS developed to flight status (1980)

GRC supplied hollow cathodes used for ISS charge control



GRC responsible for development of DS1 ion engines and power processors (1997)

Boeing XIPS-13 and XIPS-25 use GRC developed technology (1997)

R&D 100 Award for the Ring Cusp Ion Thruster (2001)

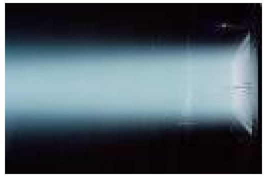
NASA Invention of the Year for ISS hollow cathode (2002)

16,265 hours of in-space operation of the DS1 ion engine (2002)

GRC chosen by SMD to lead development of 7 kW class next generation ion propulsion system (2001)

GRC makes critical contributions to the development of the DAWN IPS (2007)

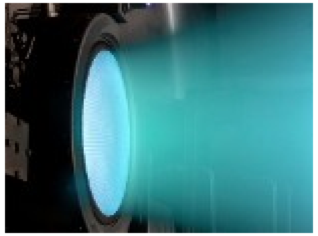
GRC Lead for the JIMO electric propulsion element; develops 25 kW class HiPEP ion engine, completed breadboard testing (2003)



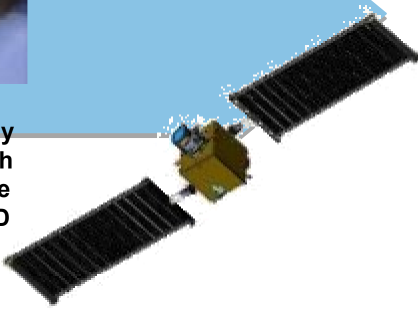
NEXT ion thruster demonstrates >51,000 hours of operation

Maturity of NEXT ion propulsion system allows for inclusion in ‘09 & ’10 SMD New Frontiers & Discovery Mission solicitation

Contract award for NEXT-C flight hardware fabrication (2015)



NEXT collaboratively evaluated with the AF for use on future DoD assets



Double Asteroid Redirection Test (DART) Mission with GRC/Aerojet Rocketdyne NEXT-C ion propulsion system

GRC Electric Propulsion Facilities

- 19 active EP test facilities at NASA GRC that roughly fall into 4 categories
- Numerous standalone belljars for EP component level testing
- Supporting infrastructure including dedicated buildup areas, class 1000 and 10K clean rooms, bonded storage.

Small	Medium	Large	Belljars
VF-1, 2, 3, 8, 14, 17, 18, 67	VF-7, 11, 12, 16	VF-5, 6	VF-55, 56, 61, 62, 65
Typical Dimensions • 1.5m ⌀ x 4.5m long • Diffusion pump (3) • Turbo pump (2, 14, 18) • Cryogenic (1, 8, 17, 67)	Typical Dimensions • 3.0m ⌀ x 9m long • Cryogenic (11,12,16) • Diffusion pump (7) Xenon pumping speed • 100-200 kL/s	VF-5: 4.6m ⌀ x 18m long VF-6: 7.6m ⌀ x 21m long Cryogenic pumping Xenon pumping speed • 700 kL/s (VF-5) • 300 kL/s (VF-6)	
			

GRC Electric Propulsion Facilities

Credit: NASA GRC

Acknowledgements

The authors would like to thank the Space Technology Mission Directorate through the Solar Electric Propulsion Technology Demonstration Mission Project for funding the joint NASA GRC and JPL development the HERMeS and PPU TDUs and contracting Aerojet Rocketdyne flight development of Advanced Electric Propulsion System. The authors would also like to thank the many NASA/JPL team members and subject matter experts for providing their expertise and technical guidance in the development of AEPS.

NASA