Overview of NASA's Solar Electric Propulsion Project

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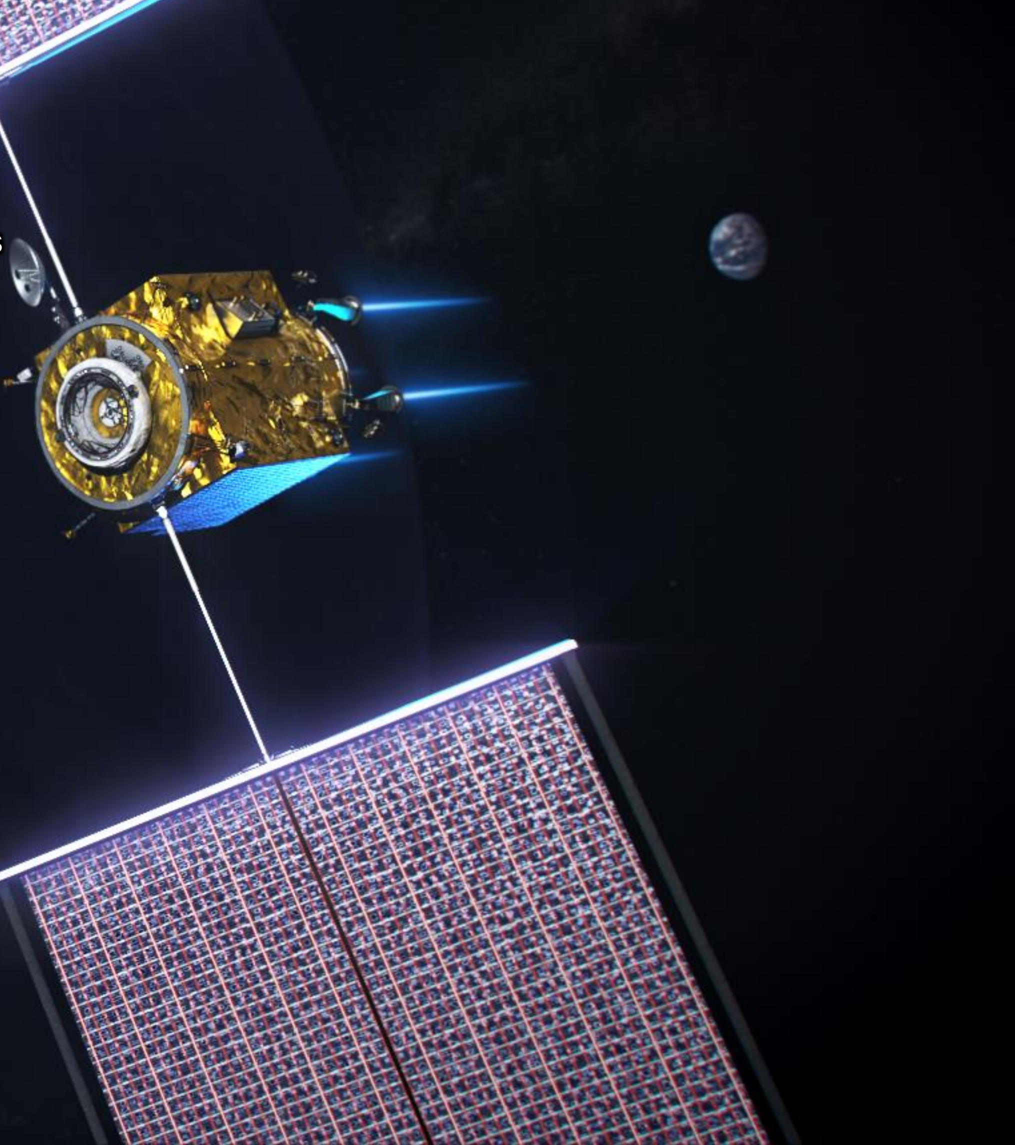

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NASA Solar Electric Propulsion Technology Demonstration Mission (SEP) Project

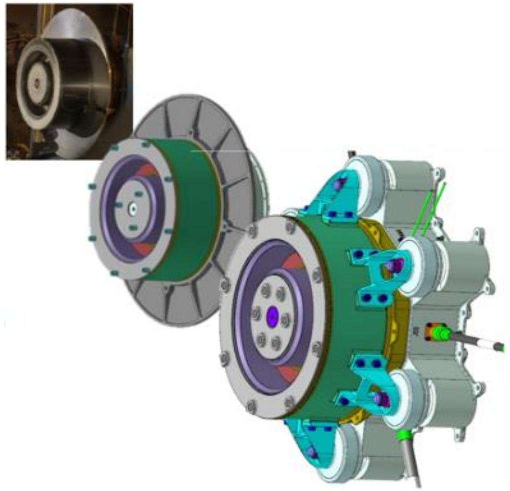
- **NASA SEP Project is under NASA Space Technology Mission Directorate**
  - SEP Project Objectives:
    - Develop and qualify high power electric propulsion technologies for NASA exploration that benefit US government and private-sector missions
    - Empower the US space industry to accelerate the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

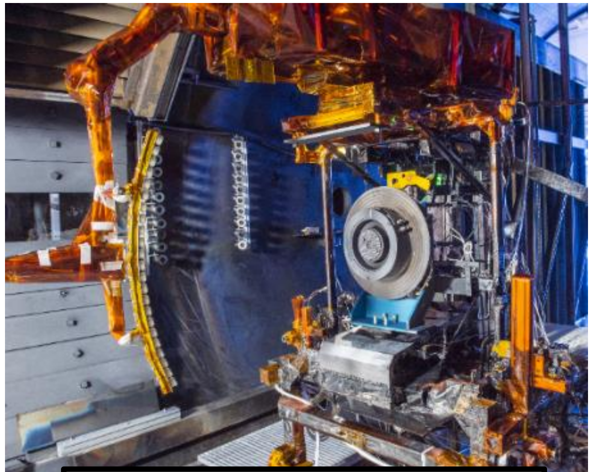
NASA Solar Electric Propulsion Technology Demonstration Mission (SEP) Project

- **The SEP Project consist of four elements**
  - AEPS
    - The AEPS is a next-generation electric propulsion capability that will enable human missions to the Moon and Mars. It consists of a power processing unit (PPU), 13 kW class magnetically-shielded Hall thruster, low-pressure xenon flow controller and electrical harness.
  - SEP
    - Conduct insight/oversight of the AEPS contract and provide NASA/JPL resources to conduct risk-reduction activities that can improve the success of the AEPS string development.
  - PDP
    - The PDP will enable collection of plasma plume data in orbit from the PPE ion propulsion system. The PDP consists of a Main Electronics Package (MEP), discharge current sensors and probes housed in a Thruster Probe Assembly (TPA).
  - Testbed
    - The Testbed is a modular and reconfigurable testbed designed to meet the needs of current and future SEP missions by providing an end-to-end evaluation and test capability for SEP systems. The testbed provides a platform to characterize the performance of integrated high-power SEP power systems up to 60kW

SEP HERMeS TDU Evolution to Advanced Electric Propulsion System (AEPS)

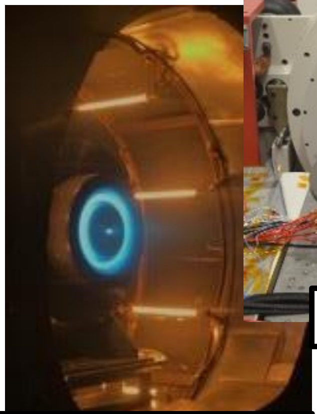
HERMeS TDU



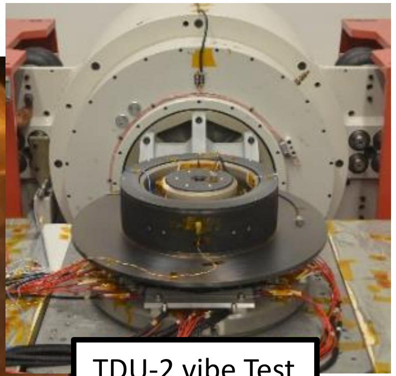


Thrust Vector Probe & TDU-3 HCT

AEPS



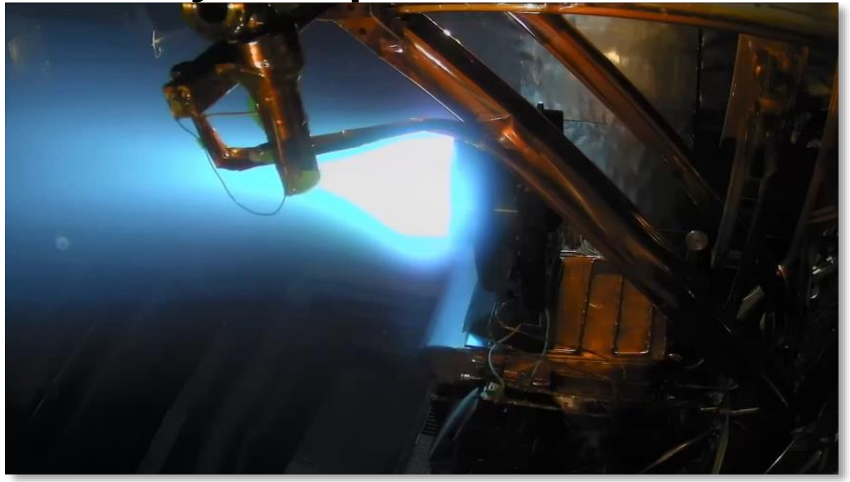
TDU-2 during initial TVAC operation



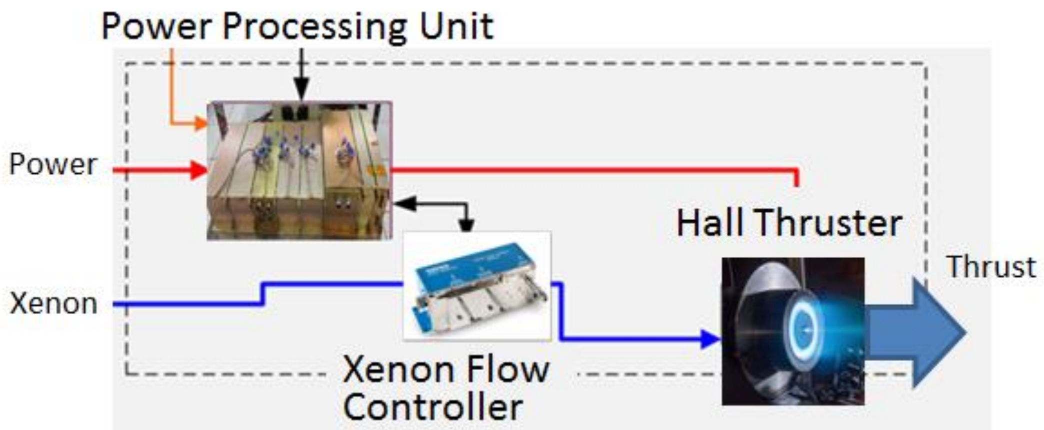
TDU-2 vibe Test

SEP TDU HCT and PPU Integration Test

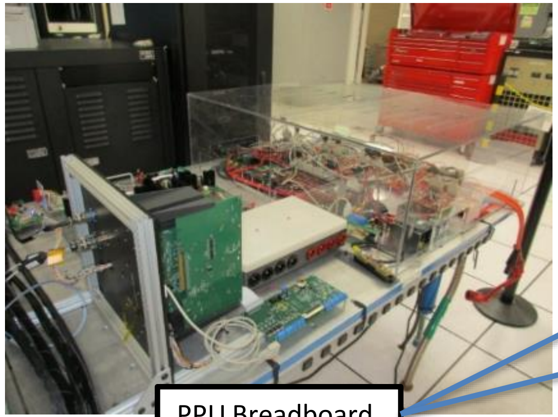
- **13-kW class Hall thruster ion propulsion string developed for 50-kW SEP vehicles.**
  - **Power: 12.5 kW**
    - *3X SOTA discharge power*
  - **Propellant Throughput: 1,700 kg**
    - *7X SOTA propellant throughput*
  - **Maximum Isp: 2,600 s**
    - *1.5X SOTA discharge voltage*
- **Utilizes magnetic-shielding previously demonstrated by NASA to achieve the required thruster lifetime.**
- **Aerojet Rocketdyne is prime contractor on the AEPS**

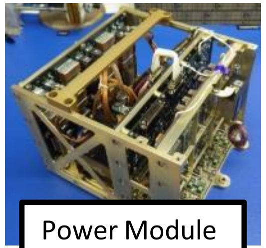


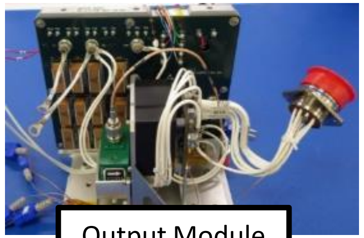
Advanced Electric Propulsion System (AEPS)

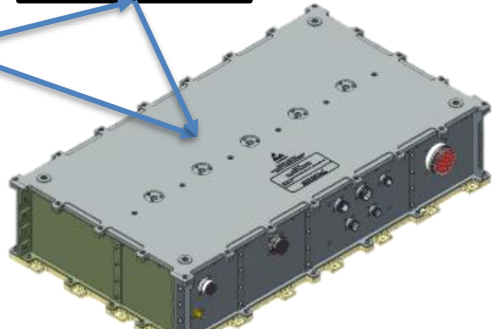


Electric Propulsion (EP) String

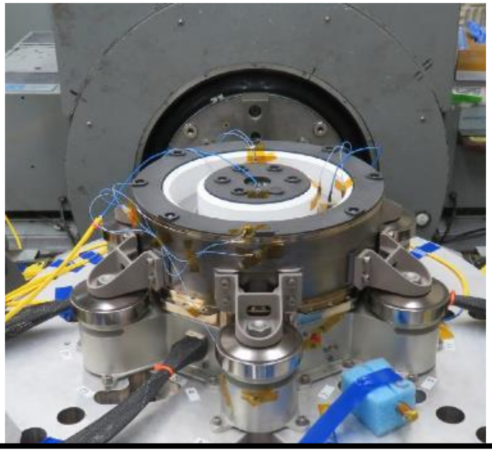

PPU Breadboard


Power Module

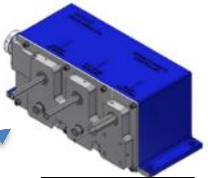

Output Module


AEPS PPU


Special Test Equipment


AEPS ETU-1 thruster on AR vide test stand


EDU#2 and EDU#1 XFC


AEPS XFC

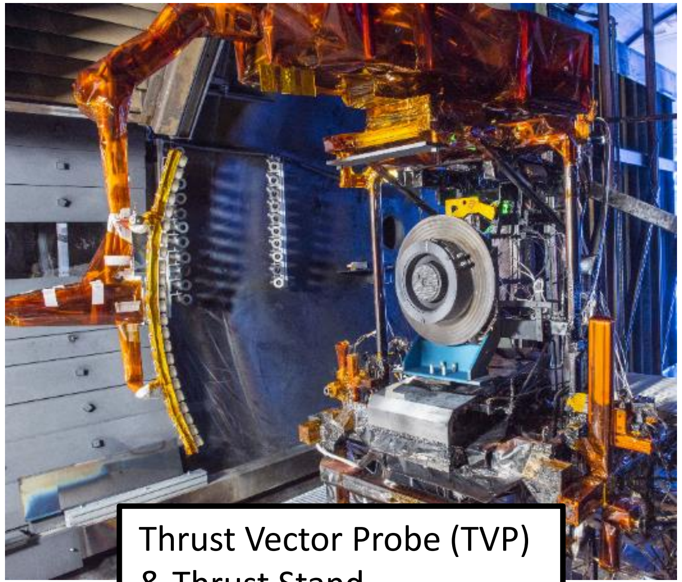
Aerojet Rocketdyne is on the path to complete the AEPS contract with qualification of a 13 kW EP String

AEPS ETU-1 Thruster Shipped to JPL

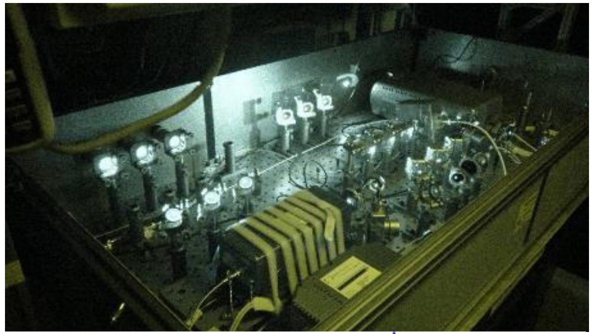
- The first AEPS thruster (ETU-1) was shipped to JPL
- AR AEPS testing team and JPL are working to install ETU-1 for first hot-fire acceptance testing August 2019

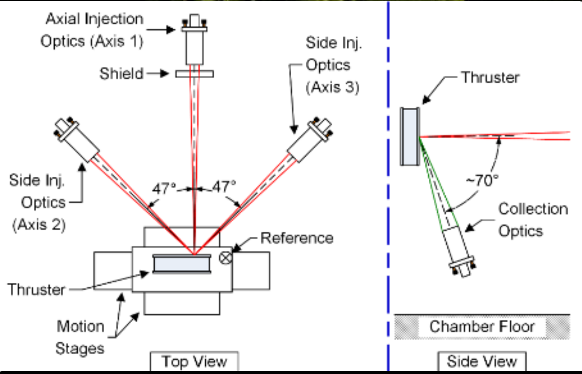
NASA SEP Status: Key Instrumentation for AEPS

- **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 Table Top Erosion Diagnostics**
  - The erosion diagnostic measures and monitors thruste 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

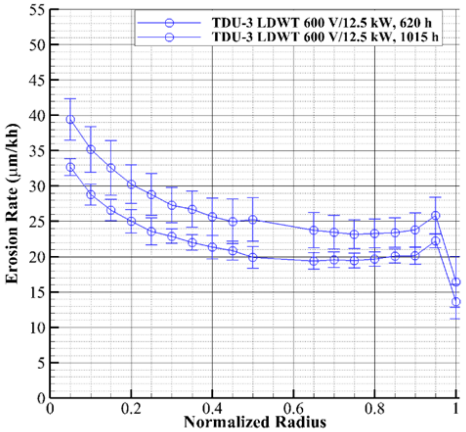


Thrust Vector Probe (TVP) & Thrust Stand

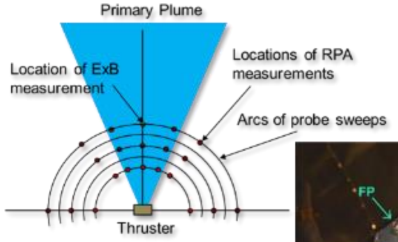




Laser Induced Fluorescence (LIF)



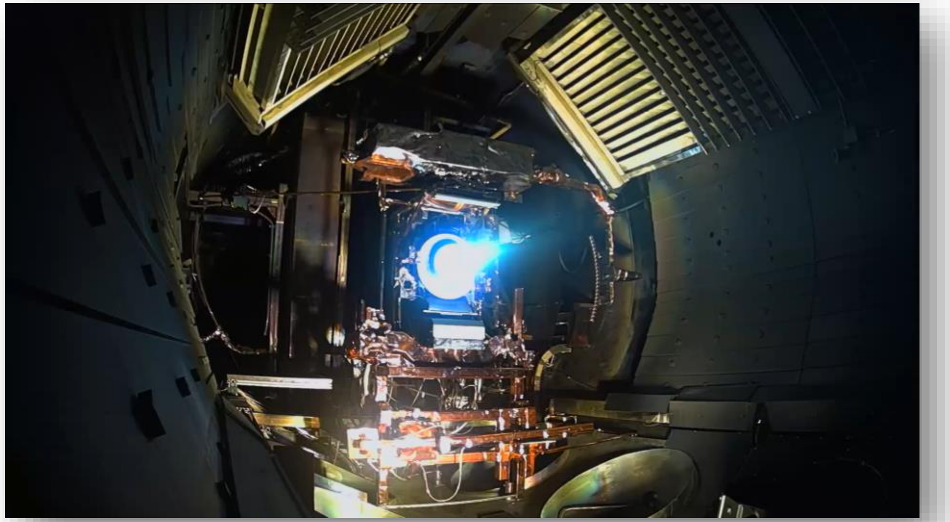
In-Situ Erosion Diagnostic



Plasma Probe

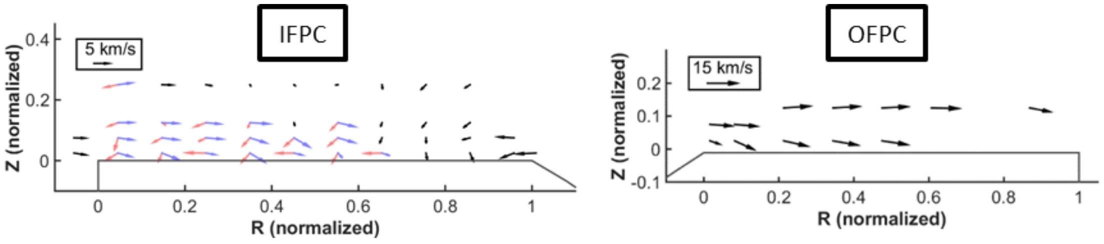
NASA SEP Risk Reduction

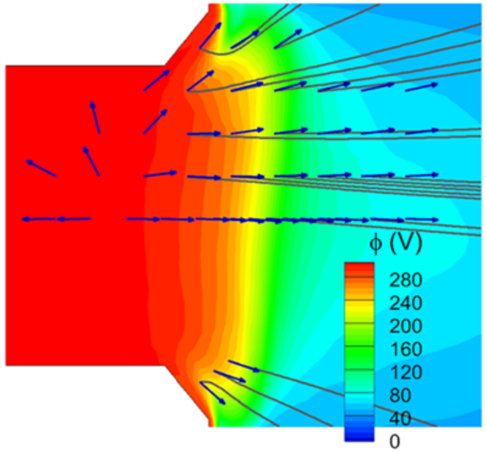
- **NASA in-house risk reduction to support the AEPS string development and mission application**
  - PPU
    - The overall goal of the SEP PPU risk reduction activities is to inform the NASA and AEPS team of various options to improve the PPU design robustness and to reduce risk on a development breadboard hardware.
    - The NASA PPU team has assembled a breadboard DSU and auxiliary power supplies (keeper, heater, and inner/outer magnet).
  - HCT
    - NASA has conducted a series of wear tests to identify erosion phenomena and the accompanying failure modes, as well as to validate life models for magnetically shielded thrusters.
    - Performance, stability, and plasma plume data was gathered over 3 khr wear test
    - Magnetic Field Optimization
      - The objectives of the magnetic field optimization tests was to evaluate magnetic field topologies to find a balance between discharge channel erosion and front pole erosion while maintain the performance and stability of the HERMeS thruster

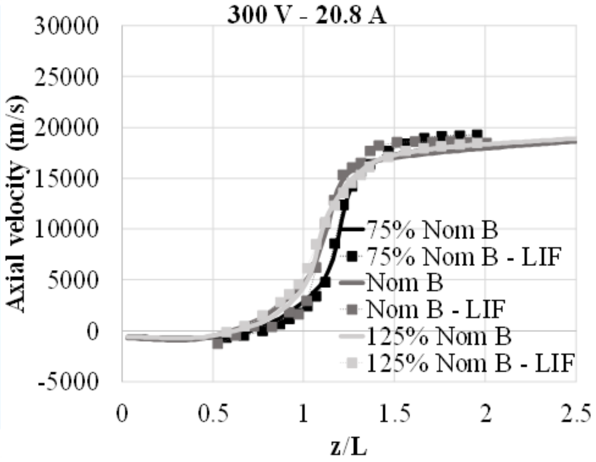


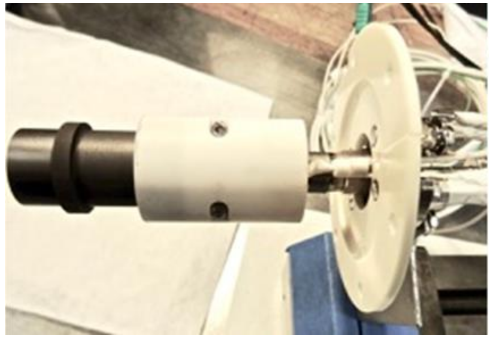
NASA SEP Risk Reduction

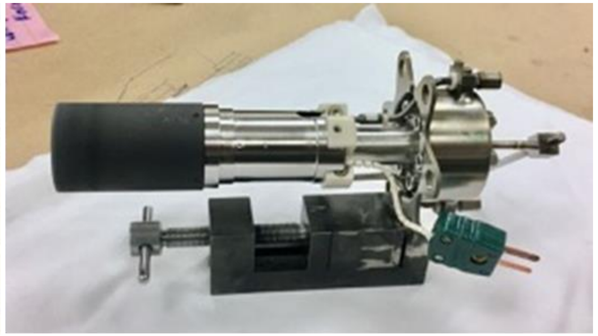
- **NASA in-house risk reduction to support the AEPS string development and mission application**
  - LIF
    - The goal of the LIF diagnostic is to map, near the exit channel, ion velocity distribution and directions, and to be used for thruster plasma model validation that would benefit the qualification process of the AEPS thruster
  - Cathode
    - The SEP team at NASA and JPL is supporting risk reduction testing of the AEPS hollow cathodes through a series of component tests.
      - Cathode heaters fabricated will be tested verify life capability through cyclic testing over an equivalent thermal range
      - EDU cathode will be cyclically tested to three times the cycle life requirement of the cathode and cathode heater.
      - EDU cathode will be operated test facility for the full duration of the mission requirement to verify cathode capability through end of life.
      - All AEPS cathodes will be tested in magnetic field simulators to ensure the hollow cathode will experience a thruster-like environment





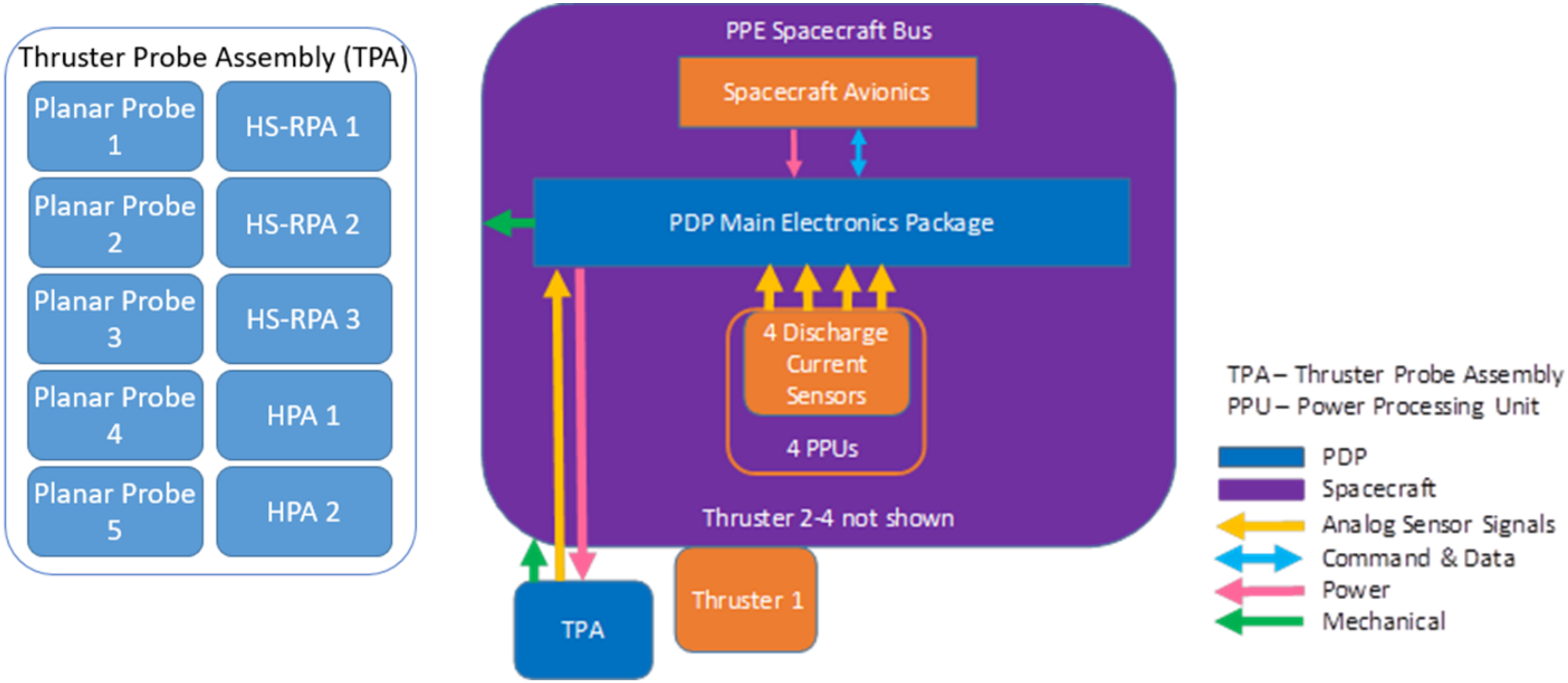




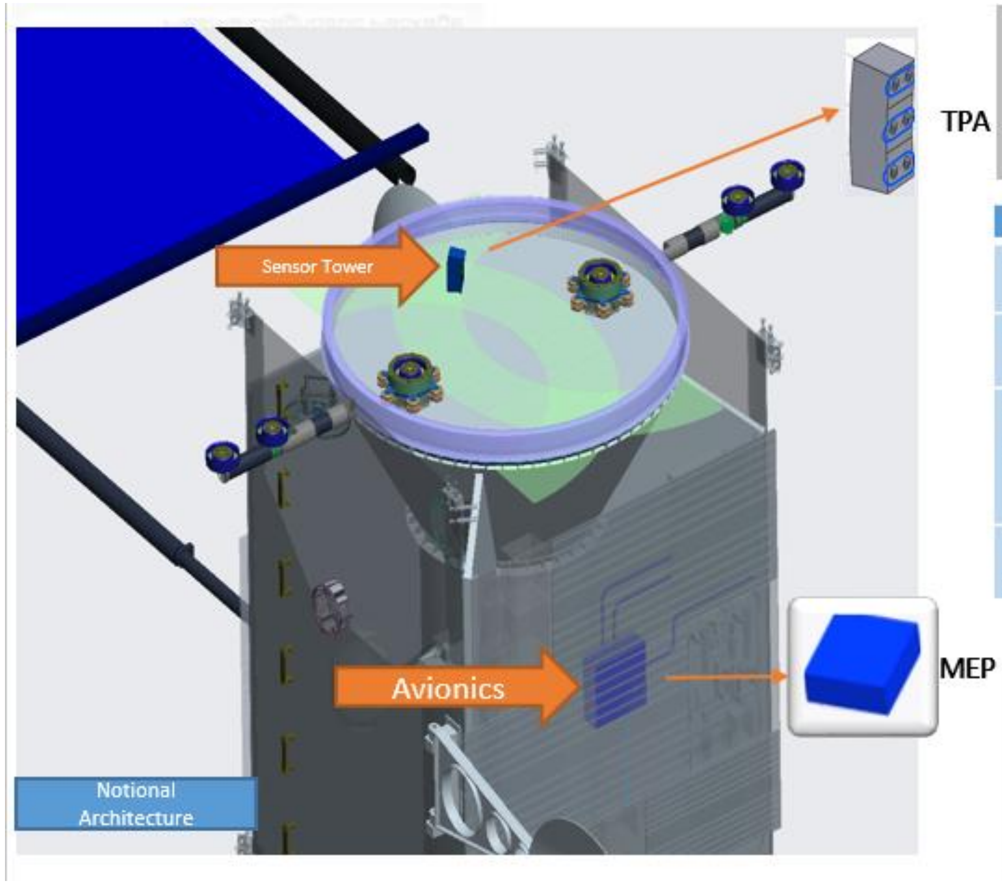


NASA SEP Plasma Diagnostics Package (PDP)

- SEP will provide PDP to characterize high-power solar electric propulsion on-orbit operating characteristics and assess plasma interactions on US space flight missions including the Power and Propulsion Element (PPE)
- The PDP will provide the data needed to validate models of high-power SEP operation and spacecraft plasma interactions, design tools that are critical for enabling high-power SEP spacecraft to support future human and robotic missions to Mars



NASA SEP Plasma Diagnostics Package (PDP)

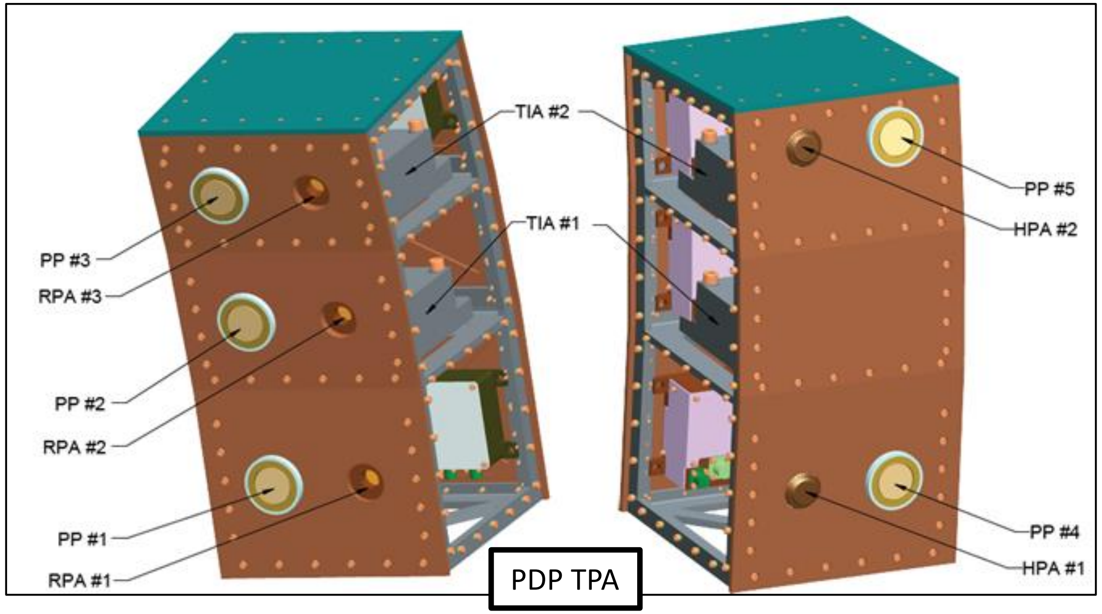


10 Plasma Sensors Located Near the High-power Ion Propulsion System (~1 meter away)

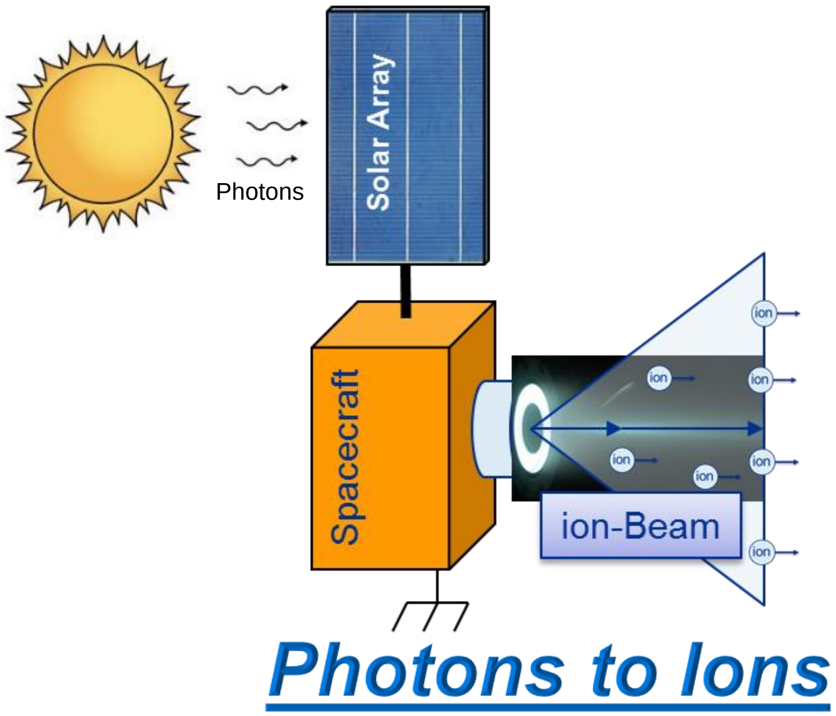
Green arcs around AEPS thrusters are preferred locations of TPA

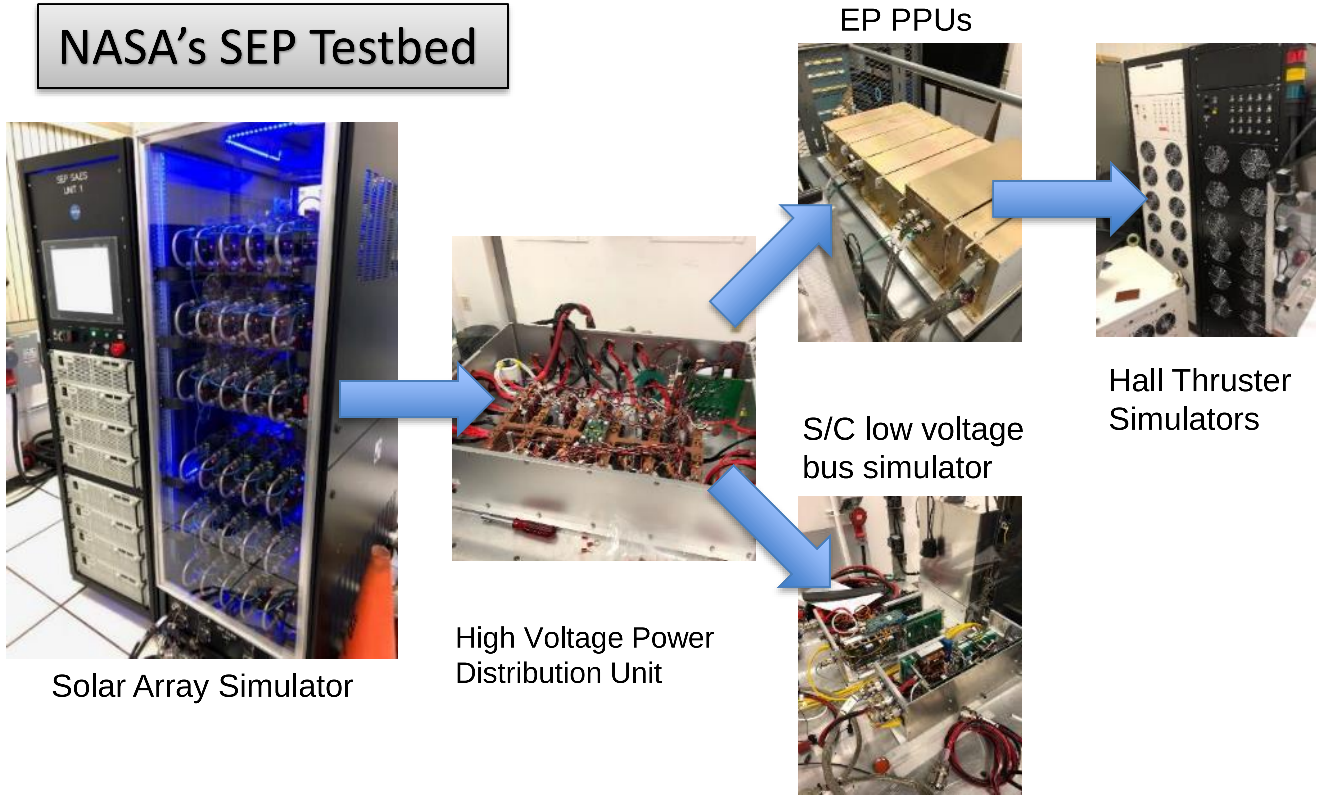
Probe types	Measured Plume Characteristic
Discharge Current Sensor (from PPE)	Discharge current waveforms (oscillations)
PP (Planar Probe – total 5 in TPA)	Time-resolved ion flux, electron temperature, plasma potential
HS – RPA (High-Speed Retarding Potential analyzer – total 3 in TPA)	Ion energy distribution, Time-resolved/energy-filtered ion characteristics
HPA (Hemispherical Potential Analyzer - total 2 in TPA)	Ion energy distribution

Sensor Biasing, Data Collection, & Spacecraft Communication. Located on the Radiator.



NASA SEP Testbed





- **SEP Testbed system development is aimed at demonstration of an integrated SEP end-to-end system performance**
  - Characterize the performance of integrated high-power SEP power systems
- **Full power capability of SEP Testbed is 60kW**
  - Currently performing integration testing and power quality testing with two EP string loads
  - Modular and reconfigurable to support a variety of SEP mission needs and requirements

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, PDP, and Testbed.

NASA