Electric Propulsion Research and Development at NASA

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Outline

- **Current and Recent Missions**
- **Future Potential Missions**
- **Flight System Development Projects**
- **Research and Technology Activities**

Current and Recent Missions

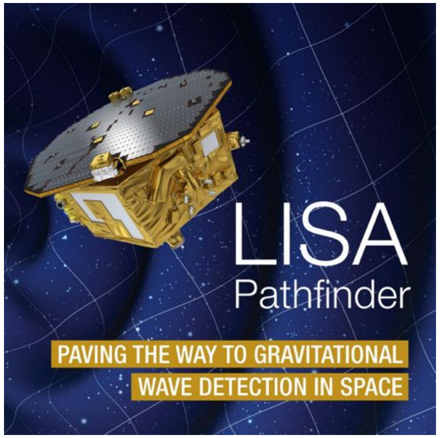
Dawn

- Orbital exploration of Vesta and Ceres.
- Launched in September 2007. Vesta orbit in July 2011 followed by Ceres orbit in March 2015.
- Three NSTAR gridded ion thruster strings.
- ΔV of 11 km/s and distance of 3.5×10^9 miles travelled.
- Planning ~3 months Extended Mission 2. Life ultimately limited by amount of remaining hydrazine propellant for RCS.

Dawn spacecraft

LISA Pathfinder

- ESA-led technology demonstrator for Laser Interferometer Space Antenna (LISA) planned for 2034.
- Launched in December 2015 and completed scientific phase by Summer of 2017.
- Colloid Micronewton Thrusters in Space Technology 7 (ST-7) Disturbance Reduction System (DRS).
- Based on work started by Busek in 1998 under Phase I SBIR with JPL.
- Challenge now is demonstrating sufficient lifetime. Focus of JPL, Busek and UCLA through 2022.



LISA Pathfinder ST-7 DRS CMNT cluster

Future Potential Missions

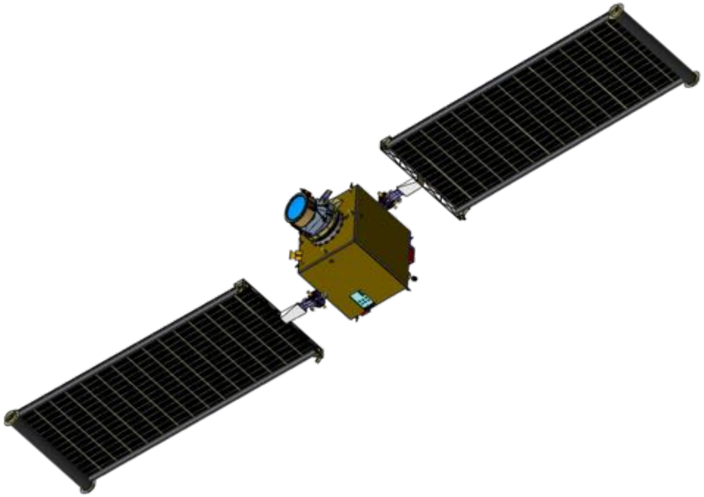
Psyche

- Exploration of largest metal asteroid, comprised almost entirely of Fe-Ni.
- NASA Discovery mission awarded to JPL in 2017, currently in Phase B (preliminary design).
- Planned for launch in 2022, arriving at Psyche in 2026 with Mars gravity assist in 2023.
- Utilizes SPT-140 Hall thruster system integrated into commercially available Space Systems Loral (SSL) bus.

Psyche spacecraft concept

Double Asteroid Redirection Test (DART)

- Demonstrate kinetic effects of crashing an impactor spacecraft into an asteroid to significantly deflect its trajectory for planetary defense.
- Direct-funded mission to Applied Physics Laboratory (APL) which will demonstrate a kinetic impact on the small binary asteroid/NEO Didymos.
- Primary propulsion provided by single NEXT-C gridded ion thruster string.
- PDR held in April 2018 with a planned launch readiness date in 2022.

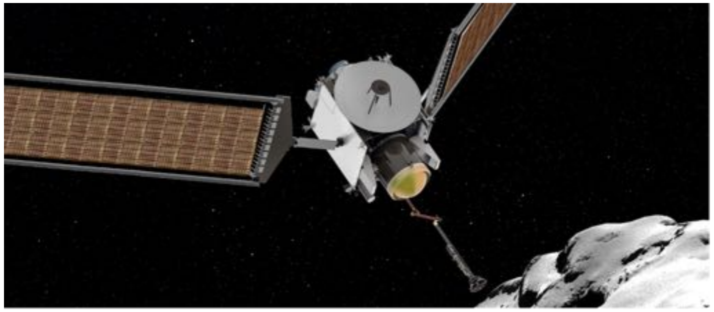


DART spacecraft concept

Future Potential Missions

Comet Astrobiology Exploration Sample Return (CAESAR)

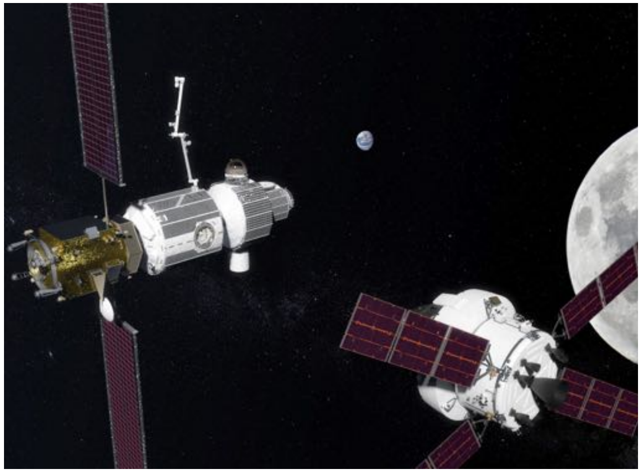
- One of two New Frontiers mission finalists selected in December 2017. Both currently undergoing Phase A studies with downselect to one mission in July 2019.
- Launch in 2024-2025 to comet 67P/Churyumov-Gerasimenko with return of capsule to Earth in 2038.
- Managed by NASA Goddard Space Flight Center.
- Employs three (2 + 1) NEXT-C thruster strings.



CAESAR spacecraft concept

Lunar Orbital Platform - Gateway (LOP-G)

- International partnership to develop crew-tended cis-lunar space station. Used in conjunction with Orion spacecraft to support exploration activities on the Moon and eventually deep space.
- Modular design features a Power and Propulsion Element (PPE) which would be launched and deployed first into lunar orbit in 2022.
- PPE under development by NASA GRC.
- Employs four Advanced Electric Propulsion System (AEPS) Hall thruster strings under development by NASA GRC and JPL.

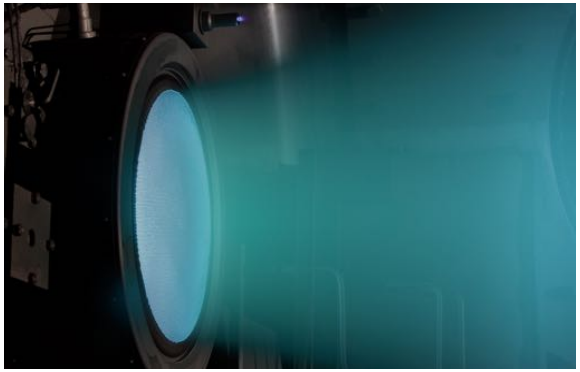


LOP-G with rendezvousing Orion spacecraft

Flight System Development
NEXT-Commercial (NEXT-C)

- 7-kW class gridded ion thruster and PPU suitable for broad range of NASA science missions and commercial applications.
- Development of two flight qualified thruster/PPU strings utilizing knowledge gained from NEXT technology project held from 2002 to 2012.
- Aerojet Rocketdyne (AR) is prime contractor with ZIN technologies as subcontractor for PPU development.
- Thruster/PPU strings have been offered as Government Furnished Equipment (GFE) for recent Discovery program solicitation. Now one string being utilized for DART mission.
- NEXT-C designed for Solar Electric Propulsion (SEP) applications that must accommodate variable input power from changes in solar range over the mission:
  - Power: 0.5 to 6.9 kW
  - Thrust: 25 to 235 mN
  - Isp: 1,400 to 4,220 s
- Preliminary Design Review (PDR) held in February 2016.
- Critical Design Review (CDR) completed in March 2018.
- Delivery date to NASA in May 2019 for DART mission.

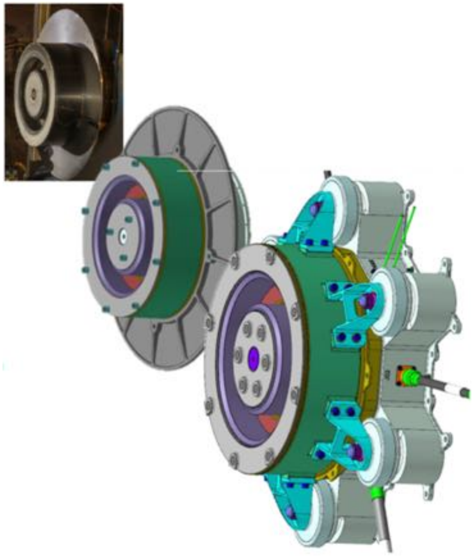

NEXT-C thruster development prototype


NEXT thruster Long Duration Test (LDT) at NASA GRC

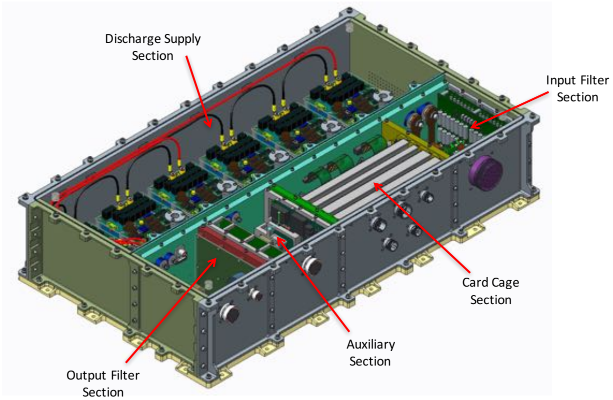
Flight System Development

Advanced Electric Propulsion System (AEPS)

- 13.3-kW class Hall thruster/PPU string developed for PPE, 40-kW SEP vehicles and eventually interplanetary cargo missions. Formerly baselined for use on ARRM.
- Based on technology development at JPL and GRC on magnetically-shielded Hall thrusters.
- Aerojet Rocketdyne is prime contractor with ZIN technologies as subcontractor for PPU development.
    - Base period up to February 2019: Develop, test and deliver one Engineering Development Unit (EDU) string.
    - Option period up to December 2019: Deliver five flight strings.
- AEPS designed for SEP applications requiring higher thrust orbital and interplanetary transfer.
    - Power: 12.5 kW
    - Propellant Throughput: 1,700 kg
    - Maximum Isp: 2,600 s
- Preliminary Design Review (PDR) held in August 2017.
- Engineering Development Units (EDU) being fabricated for test campaign at GRC in late 2018.



Evolution from Technology Demonstration Unit (TDU) to Engineering Development Unit (EDU) thruster design (left to right)

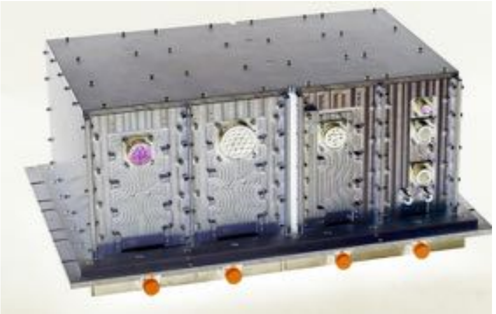


EDU PPU design

Flight System Development

Multipurpose Hall 4.5 kW PPU

- GRC, in partnership with JPL, managing Phase III SBIR contract with Colorado Power Engineering (CPE) to develop and test TRL 6 prototype Hall 4.5-kW PPU capable of operating with:
  - NASA-developed HiVHAc Hall thruster
  - SPT-140 thruster
  - Aerojet XR-5 thruster
- GRC will conduct integrated system testing with HiVHAc thruster after delivery of prototype.
- PPU CDR completed in September 2017 with authority to proceed with fabrication given in January 2018.
- Testing of prototype PPU will take place in late 2018 with plan to enable development of flight hardware in separate follow-on contract.



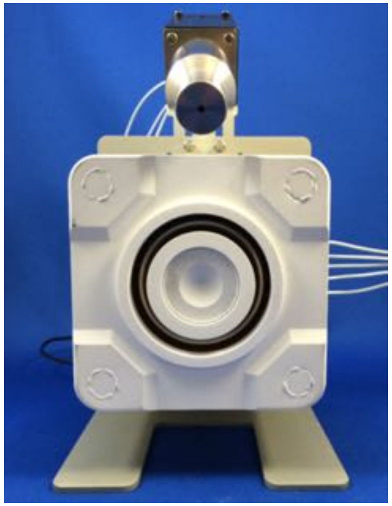
Engineering Model (EM) PPU

EM PPU in GRC VF-70 undergoing functional/performance testing

Flight System Development

Other Flight Development Activities

- NASA is working with Busek under a Space Technology Announcement of Collaborative Opportunity (ACO) to perform life testing of Busek 600 W Hall system.
  - BHT-600 thruster
  - BHC-2500 cathode
  - PPU
- GRC is providing test facilities and test support for 5,000-hour qualification life test between June 2018 and June 2019.
- Testing will reduce cost for future customers.



Busek's BHT-600 Hall thruster

- For Lunar IceCube and LunaH-Map missions, NASA supporting Busek to qualify its BIT-3 RF ion thruster for use with iodine propellant.
- Currently designed to operate at 60 W, and to produce thrust of 1.4 mN and Isp of 3,500 with xenon propellant.
- Under Phase II SBIR extension, Busek will conduct up to 4,000 hours of wear and integration testing starting in May 2018.
- Iodine-compatible BIT-3 hardware is scheduled for delivery in summer of 2018.

Busek's Iodine BIT-3 RF ion thruster

Research and Technology

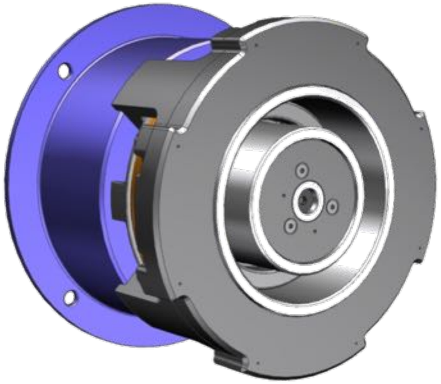
500-W Hall Thruster Technology

- Sub-kilowatt EP for small spacecraft (wet mass 100-500 kg). Two parallel technology activities at JPL and GRC:
  - Magnetically Shielded Miniature (MaSMI) Hall thruster (JPL internal funding)
  - Sub-Kilowatt Electric Propulsion (SKEP) technology (NASA STMD funding)
- Both activities seek to develop long-life, high-performance thruster/PPU strings with power levels from 200 to 800 W.

JPL MaSMI thruster

Electrospray Thruster Technology

- Several activities over last few years focused on Microfluidic Electrospray Propulsion (MEP)
- JPL-developed MEP thruster demonstrated excellent stability and controllability with a thrust of 100 μN and Isp > 3,200 s.

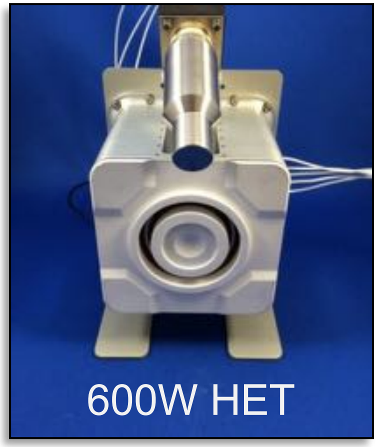


GRC SKEP thruster design

Iodine EP System Technology

- NASA STMD's Advanced In-Space Propulsion (AISP) project is supporting technology development of 600-W iodine compatible thruster, cathode, PPU, and propellant storage and feed system.
- Efforts so far have resulted in successful 1,174-hour durability test (limited by depletion of iodine propellant load).

AISP Iodine Investment Areas



Test Procedures

Propulsion CONOPs

AISP Iodine

Thrusters

Facilities

Power Processing

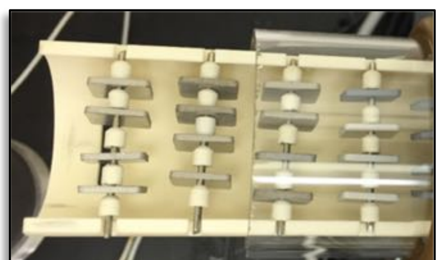
Materials / Coatings

Cathodes

Feed Systems

I_2 Storage

Final 600W-IHT PPU configuration

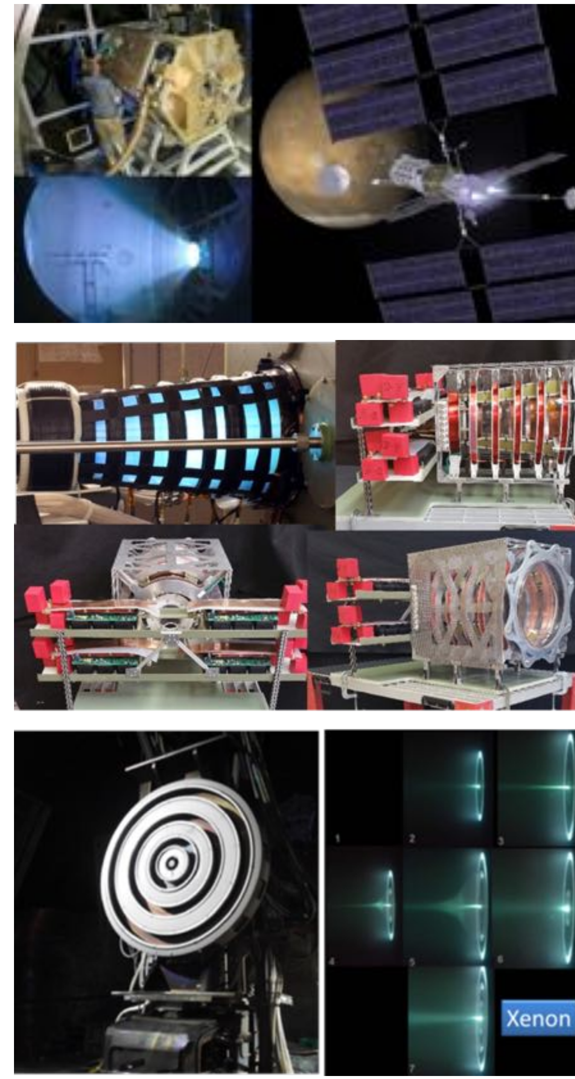


AISP seeks to advance iodine electric-propulsion technology across a wide range of component and system level topics toward risk reduction for future iodine missions.

Research and Technology

100-kW Thruster Technology

- Advanced propulsion subsystems being developed under HEOMD's Advanced Exploration Systems (AES) program:
  - Ad Astra: VASIMR (Variable Specific Impulse Magnetoplasma Rocket)
  - MSNW: ELF-250 (Electrodeless Lorentz Force)
  - Aerojet-Rocketdyne (AR): AR-100 Nested Hall Thruster
- Primary goal of each 3-year effort is to demonstrate 100-hour of continuous, steady-state operation at 100-kW. Subsystem includes thruster, PPU and feed system.
- Key performance goals include Isp range of 2,000 to 5,000 s, total subsystem efficiency > 60%, operational life > 10,000 hrs, total subsystem specific mass < 5kg/kw, and scalability to MW levels
- All three efforts have accomplished significant testing. AR completed thruster/facility risk reduction test at GRC and 10-kW thruster/PPU/feed system test at Univ of Michigan
- Schedule for completion of final 100-hour, 100-kW steady state tests:
  - VASIMR: November 2018 at Ad Astra facility
  - ELF-250: November 2018 at MSNW facility
  - Aerojet Rocketdyne: August 2018 at GRC

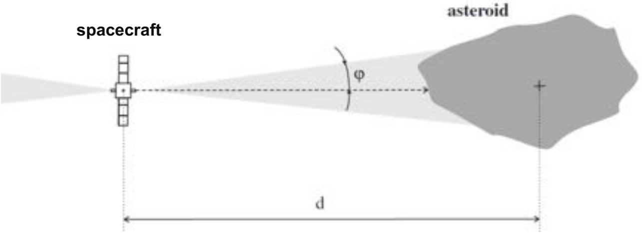


VASIMR Tests (top), ELF-250 thruster (middle), and Nested Hall thruster tests (bottom)

Research and Technology

EP for Planetary Defense

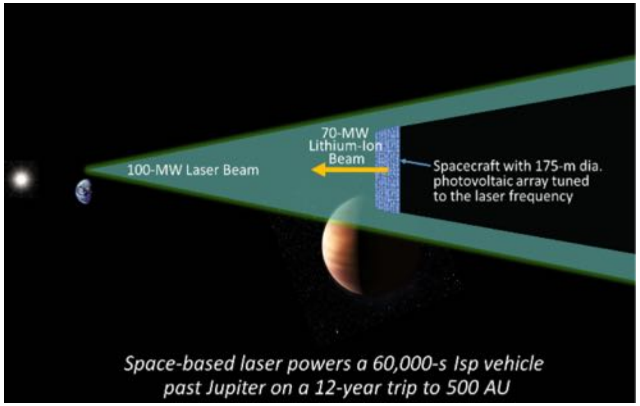
- JPL evaluating use of EP ion beam to impart a velocity/ trajectory change to threatening planetary objects
- Beam that imparts momentum balanced by an equivalent opposing ion thruster
- Approach has several potential advantages compared to other proposed deflection techniques for asteroids in the size range of 10 to 150 km
- Key technology challenge is development of ion optics that produce beams with divergence angles less than 4 degrees



EP provided ion beam deflection for planetary defense

Ultra-High Specific Impulse Technology

- JPL continuing technology work on lithium-based gridded ion thruster technology with goal of Isp ~ 50,000 s
- Technology applicable to missions requiring ΔV of 100 to 200 km/s, such as an interstellar precursor mission
- Potential candidate is a mission to 550 Astronomical Units (AU) in less than 15 yrs. Allows utilization of gravity lens effect around Sun to enable viewing of exoplanets.
- High velocities possible with concurrent reduction in onboard power system mass by using Earth orbital-based laser and onboard tuned photovoltaics – current NIAC study



Interstellar precursor mission enabled by high-Isp EP and high-power laser source

NASA