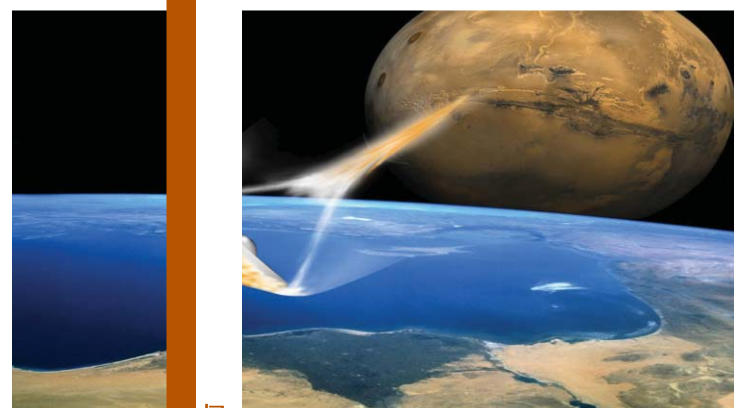
# Status of Propulsion Technology Development u er the NASA In-space Propulsion Technology Progr n



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Space Propulsion 2014, Cologne, Germany
May 21, 2014

# NASA's In-Space Propulsion Technology (ISPT) Program

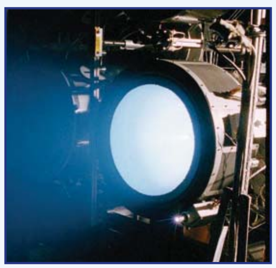
NASA's ISPT Program develops critical propulsion, entry vehicle, and other spacecraft and platform subsystem technologies to enable or significantly enhance future planetary science missions.

- *Enable access to more challenging and interesting science destinations or benefit future robotic science missions*
- *By significantly reducing travel times to distant bodies, increasing scientific payload capability, or reducing mission cost and risk.*
- *The current ISPT focus is TRL 3-6+ product development.*

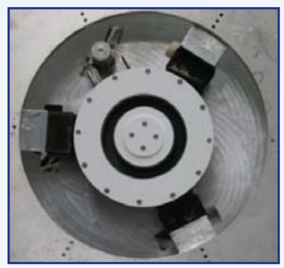
## Propulsion System Technologies

**AMBR High-Temp Rocket Engine**

**7 kW NEXT Ion Propulsion System**

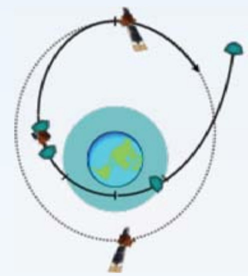


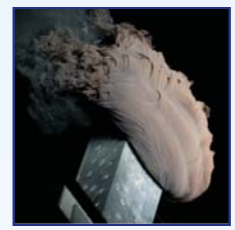
**4 kW HIVHAC Thruster & Hall Propulsion System**



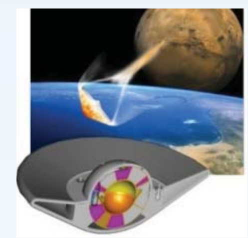
## Entry Vehicle Technologies

**Aerocapture**





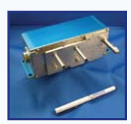
**Multi-Mission Earth Entry Vehicle**



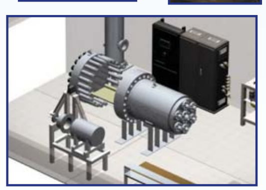
## Spacecraft Bus & Sample Return Technologies

**Mars Ascent Vehicle**

**Spacecraft Bus Components**

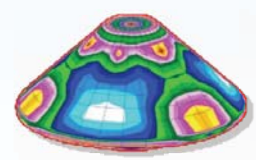


**Extreme Environments**

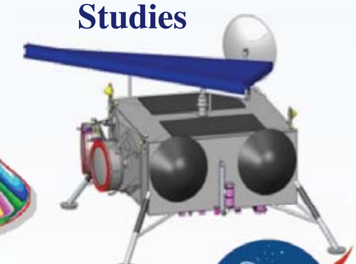


## Systems & Mission Studies

**Mission Analysis Tools**

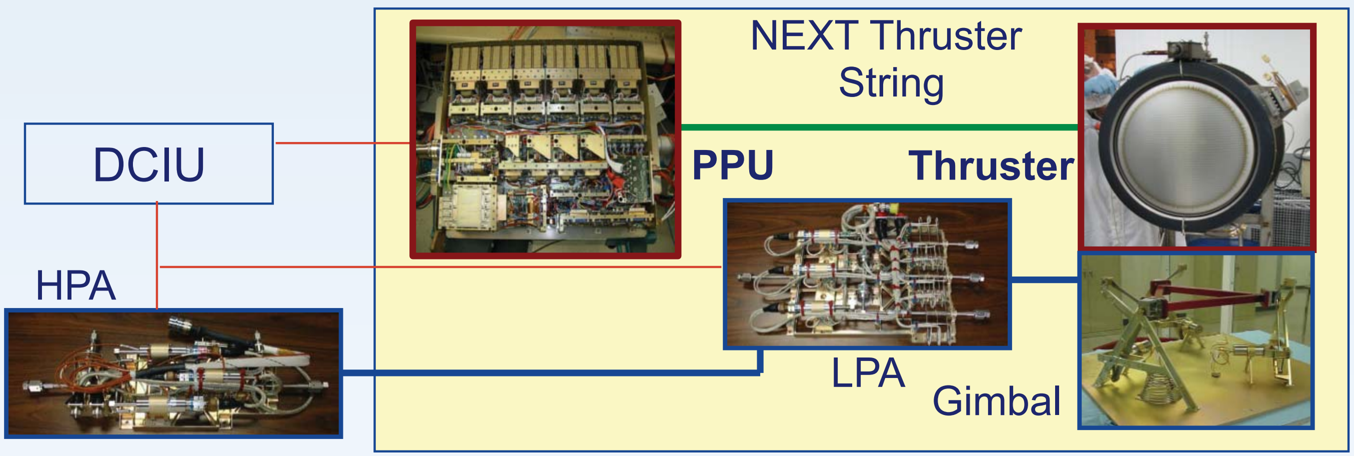


**Mission and System Studies**



# NASA's Evolutionary Xenon Thruster (NEXT)
## Expanding SEP Applications For Science Missions

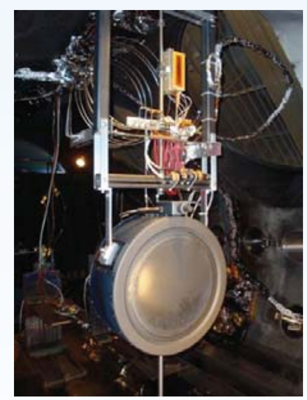
***Objective:*** ***Improve the performance and life of gridded ion engines to reduce user costs and enhance/enable a broad range of NASA SMD missions***




* Rated Capability Goal 300Kg → Design/Qualification Goal (1.5x Rated) 450Kg
Demonstrated Life Limit >900Kg → Potential Rated Capability >600Kg

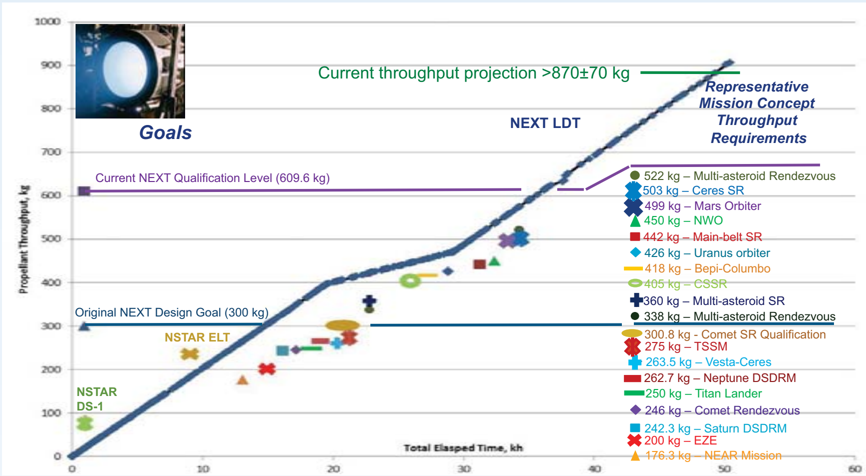
| Characteristic300 | NSTAR (SOA) | NEXT |
|---|---|---|
| Thruster Power Range (kW) | 0.5= 2.3 | 0.5-6.9 |
| Max. Thrust (mN) | 92 | 236 |
| Max. Specific Impulse (sec) | >3100 | >4100 |
| Max. Thruster Efficiency | >61% | >70% |
| Total Impulse ($x10^6$ N-sec) | >5 | 35.5 |
| Propellant Throughput (kg) | 135 | 918 |
| PPU Specific Mass (kg/kW) | 6.0 | 4.8 |
| PMS Single String Mass (kg) | 11.4 | 5.0 |
| PMS Unusable Propellant Residual | 2.40% | 1.00% |

- NEXT development included critical components for ion propulsion system
- Single-String & Multi-String System Integration Tests completed
- NEXT TRL assessments completed by multiple mission center customers
- Unprecedented diagnostics used for NEXT thruster performance characterization and spacecraft interaction effects testing ongoing
- Thruster and feed system are ready-to-go. 2nd design iteration of PPU being planned.



# What the NEXT LDT Demonstrated in 9 yrs of Testing

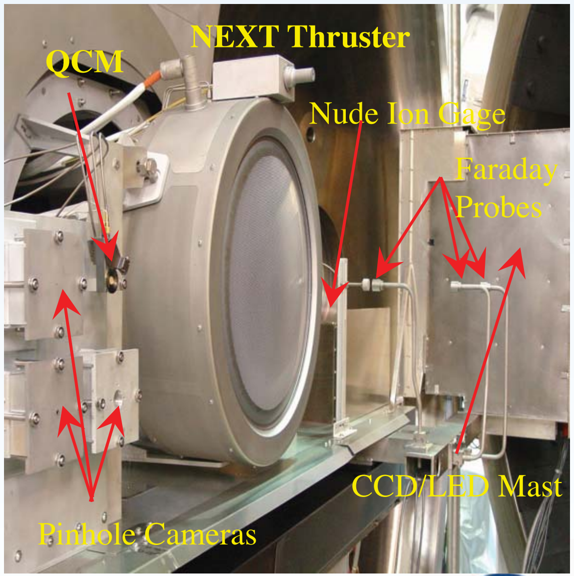
- NEXT Long Duration Test (LDT) was voluntarily concluded on 1 April 2014
  - Collected end-of-test data with repaired and fully functional diagnostic suite to compare with beginning-of-life data
  - Post-test inspection an analysis is underway




Equivalent Qualification Level: 609.6 kg
Projected Qualification Level: >580 kg
Original NEXT Design Goal : 300 kg

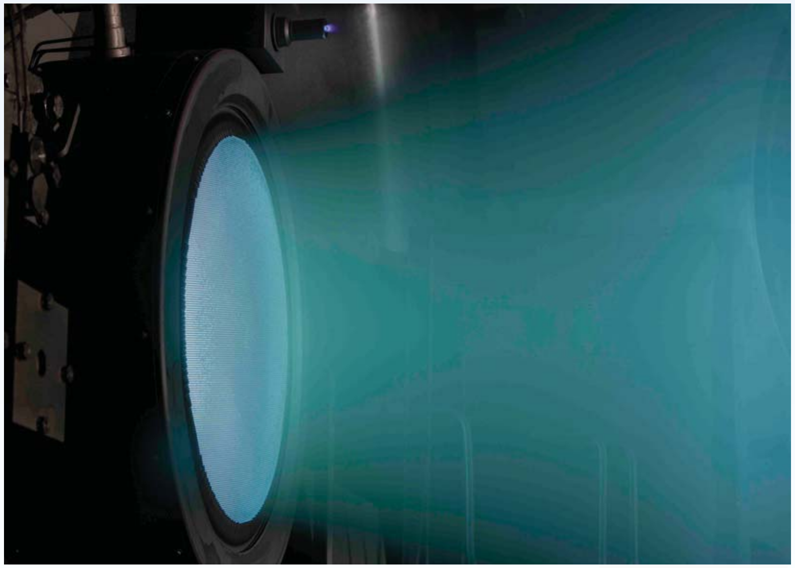
**NEXT LDT Demonstrated (as of 2/12/2014): 914.4 kg**
Projected Throughput: >870 kg
Original NEXT Qualification Requirement: 450 kg

- The NEXT thruster exceeded design requirements
  - Throttle thruster to a deep space mission profile
    - Goal ≥450Kg qualification level propellant throughput
  - Characterized thruster operation over a wide operating table
  - NEXT LDT sets Throughput and Duration World Records
    - **51,200 hours** of operation
    - **918.2 kg Xenon throughput**
    - **35.5 MN-s of total impulse** delivered



# What the NEXT LDT Demonstrated in 9 yrs of Testing

- Demonstrated that thruster life-limiting phenomena and wear mechanisms associated with ion thruster operations have been addressed in the NEXT design
  - NEXT LDT post-test inspections/analysis will help confirm
- Improved models for future mission planning and operation
  - Compared measured thruster wear rates with those predicted from life models
  - Carbon back-sputter and enhanced charge-exchange facility impact analysis completed
    - Engineering correction factor on wear-rate test results determined
      - <4% reduction for carbon back sputter
      - ~8-10% increase for charge-exchange
  - Current Life prediction is 870Kg $\pm$70Kg

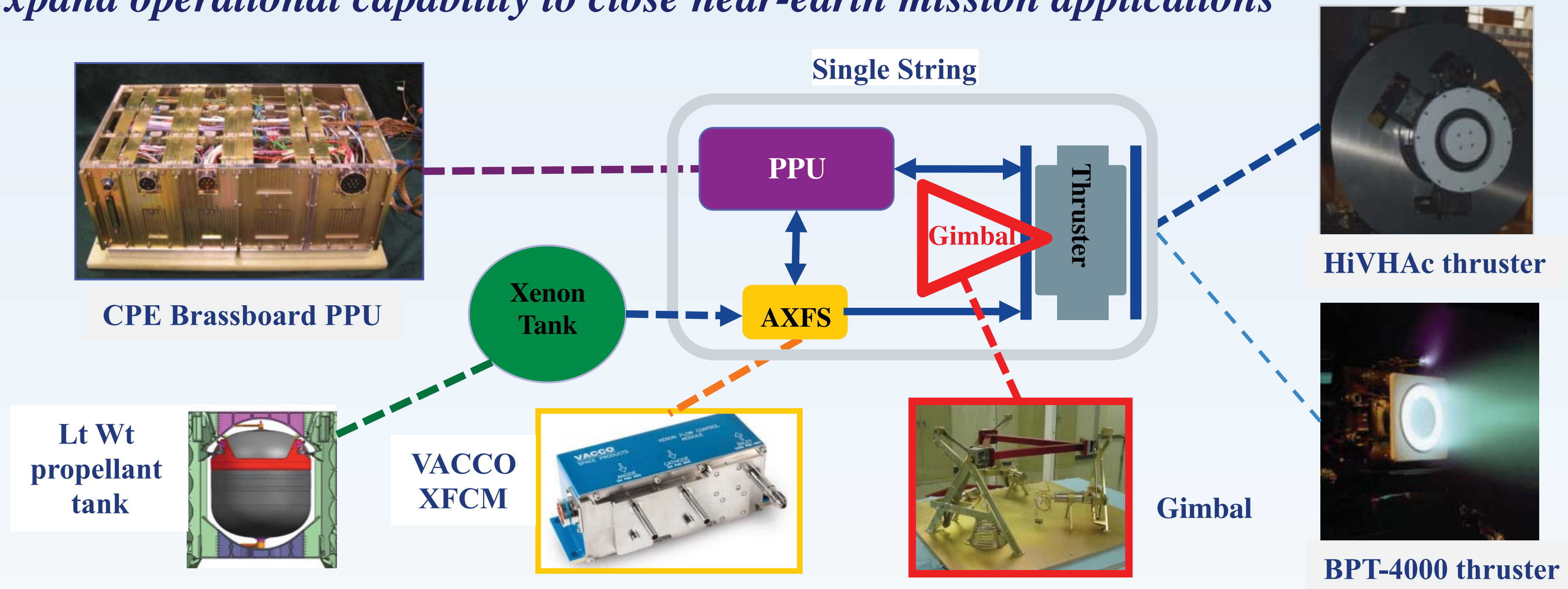


**NEXT thruster has exceeded expectations!**

# High Voltage Hall Accelerator (HIVHAC)

## Electric Propulsion for low cost Discovery-class Missions

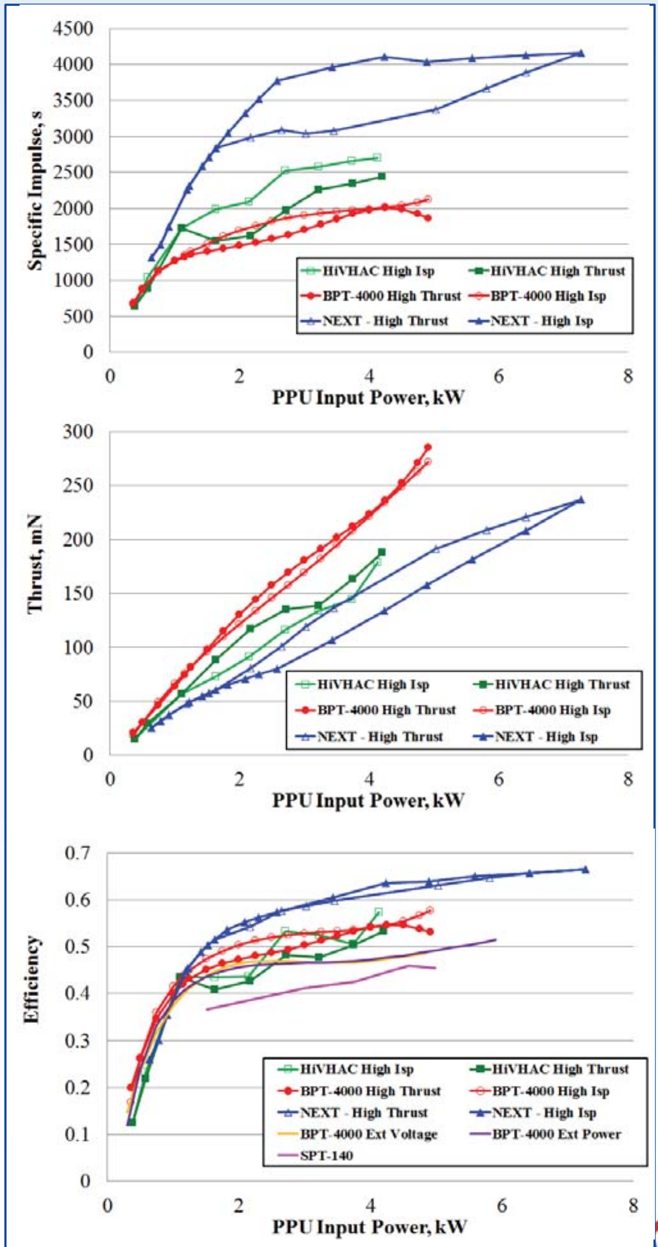
***Objective:*** *Develop key components of a HiVHAc Hall propulsion system (thruster, PPU/DCIU, feed system) to TRL 6 to enable/enhance new SMD Discovery missions; expand operational capability to close near-earth mission applications*




- The HiVHAc thruster offers improved performance and mission benefits over SOA
- Developing a Power Processing Unit (PPU) with a Digital Control Interface Unit (DCIU) to advance the HiVHAc propulsion system readiness
- A flight-qualified Xenon Flow Control Module (XFCM) was delivered to NASA GRC in March 2012 and has been integrated with the HiVHAc thruster. Designed to work with the above PPU.

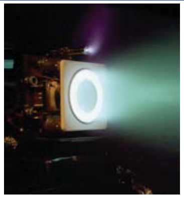
# HiVHAc Development Status

- Testing of the thruster was performed in NASA GRC's Vacuum Facility 5 (VF5) during the Fall of 2013
  - Testing of the thruster was performed at various background pressure conditions
  - Measurements included: performance mapping, plasma mapping, and thermal characterization
- Testing of the EDU2 HiVHAc thruster with a brassboard PPU and the VACCO Xenon Feed System was completed in GRC's VF12 during March of 2014
- A HiVHAc thruster with a modified magnetic circuit was recently tested
  - The discharge erosion starts downstream of the magnetic poles, which protects the poles for a 2 times increase to the projected throughput



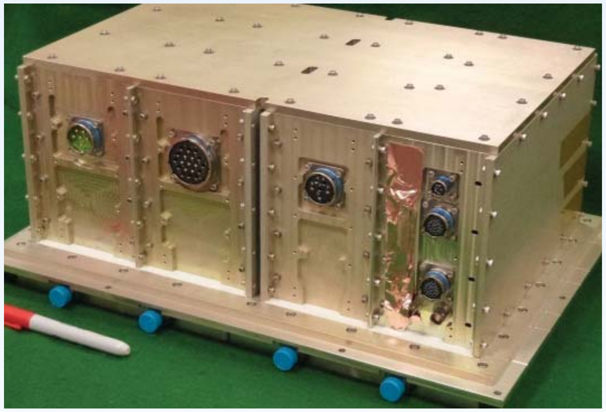

**Performance Characteristics of HIVHAC vs. SOA Hall (BPT-4000).**

| Characteristic | BPT-4000 | HIVHAC |
|---|---|---|
| Thruster Power Range, kW | 0.3-4.5 | 0.3-3.9 |
| Throttle Ratio | 15:1 | 12:1 |
| Operating Voltage, V | 150-400 | 200-700 |
| Specific Impulse, sec | 710-2100 | 860-2700 |
| Thrust, mN | 22-260 | 20-207 |
| Efficiency | 0.25-0.58 | 0.32-0.62 |
| Propellant Throughput, kg | 450 | >300 |



# Hall Propulsion Power Processing Unit

- PSD's In-Space Propulsion Technology (ISPT) Program has been working with a promising Small Business Innovative Research (SBIR) project to develop a low-cost 4.5-kW class wide output range Hall Power Processing Unit (PPU) for Discovery-class planetary missions.
  - Colorado Power Electronics (CPE) has successfully developed a PPU and is poised to take the design to flight certification (TRL 6) by September 2016
  - Qualification Model (QM) PPU will incorporate control electronics for the PPU power modules, VACCO TRL 7 xenon feed system, and thruster/PPU telemetry
  - CPE has submitted a cost proposal and NASA programs have committed funding to start the effort



- The PPU is being designed to operate several Hall thrusters:
  - NASA's High Voltage Hall Accelerator (HiVHAc), Aerojet-Rocketdyne XR-5 (BPT-4000), Space Systems Loral SPT-140.
  - Thruster acquisition and Hall propulsion system development to be addressed by mission proposal teams.

# Ultra Lightweight Tank Technology (ULTT) for future planetary missions

## Objective:

- Develop a Composite Overwrapped Pressure Vessel (COPV) tanks for propellants and pressurants for Mars Sample Return (MSR) mission
- To design ultra-lightweight propellant and pressurant tanks sized for Mars Skycrane with an option to manufacture and qualify.

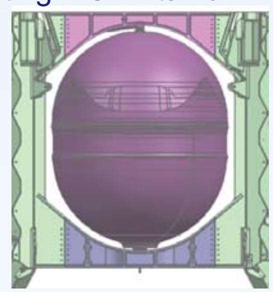
## Benefits

- **19.5** kg mass savings are achievable for 3 tanks sized for the Skycrane **(40% mass reduction)**
  - Mass savings can be passed on to the scientific payload or increase mass margin
- Broad impact to virtually ALL space missions as most use liquid propellants or pressurant
  - Europa Explorer tank mass can be reduced by 60 kg

## Accomplishment Status

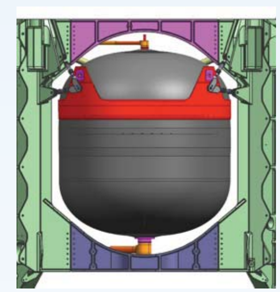
- Critical Design Review CDR) held Feb 2014
- Mars 2020 mission will use build-to-print Skycrane tanks
- Conclude NDI techniques, and no further design or fabrication due to funding limitations and no Mars 2020 adoption

Existing MSL Titanium Tank

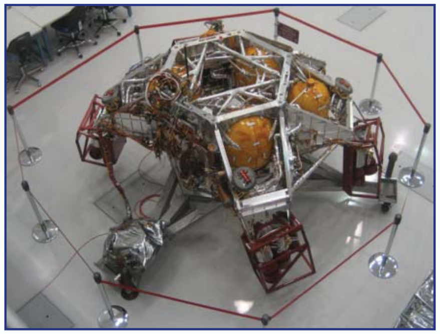


594mm Diameter, ~720mm Tall

Drop in replacement ultralight tank



594mm Diameter, 684mm Tall



**Skycrane Descent Stage Propellant Tanks**

# Summary

- Concluded NEXT and Ultra-lightweight Tank development
- Concluded NEXT TRL Assessments and Tech Infusion Study, and identified gaps for customer adoption and improve future technology development
- 2014 concludes all ISPT activities. Wrapping up and documenting remaining ISPT work.
    - HIVHAC Thruster development
    - NEXT LDT post-test characterization, inspection, documenting
  - Will continue to support flight infusion
    - NEXT Thruster and PPU may be offered as Government Furnished Equipment (GFE) on upcoming Discovery Announcement of Opportunity
    - 4.5kW Hall PPU development will continue through other funding
- ISPT investments have expanded Planetary Science mission capabilities

## Questions?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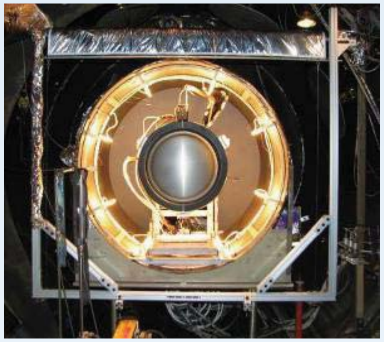
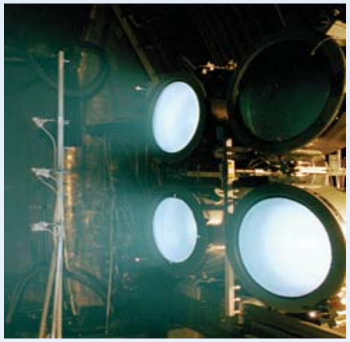
# NEXT Mission Benefits & Applicability

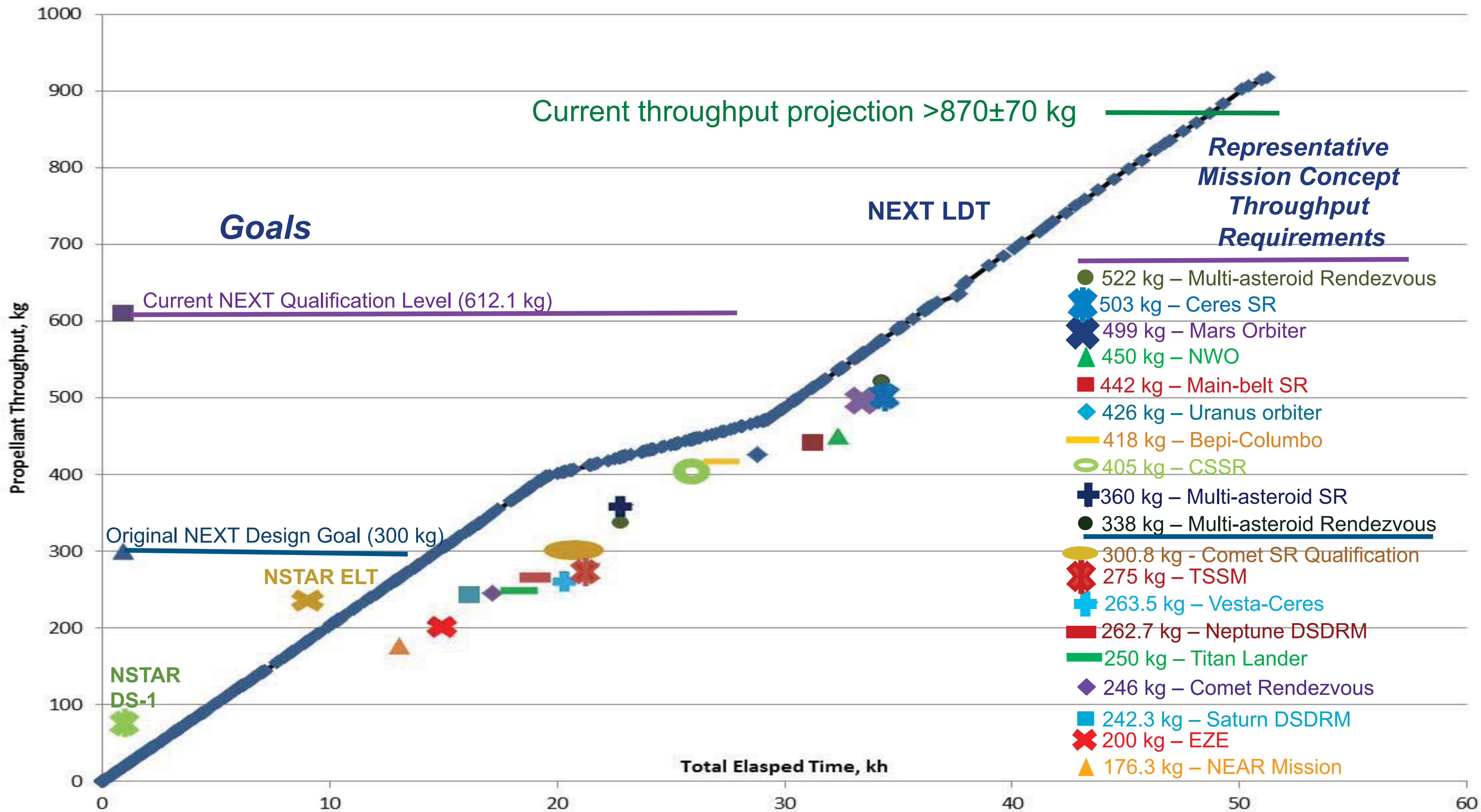




| CHARACTERISTIC | NSTAR (SOA) | NEXT | Improve-ment | NEXT BENEFIT |
|---|---|---|---|---|
| Max. Thruster Power (kW) | 2.3 | 6.9 | 3x | Enables high power missions with fewer thruster strings |
| Max. Thrust (mN) | 91 | 236 | 2.6x | |
| Throttling Range (Max. / Min. Thrust) | 4.9 | 13.8 | 3x | Allows use over broader range of distances from Sun |
| Max. Specific Impulse (sec) | 3120 | 4190 | 32% | Reduces propellant mass, enabling more payload and/or lighter spacecraft |
| Total Impulse ($10^6$ N-sec) | 4.6 | >35.5 | >7x | Enables low power, high $\Delta V$ Discovery-class missions with a single thruster |
| Propellant Throughput (kg) | 150 | 918 | >4x | |

* NOTE: NSTAR used on DS-1 and Dawn missions

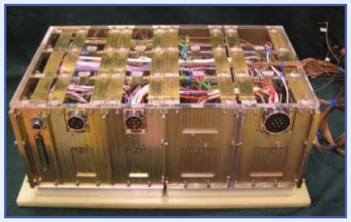
# NEXT Mission Benefits & Applicability




| | | | |
|---|---|---|---|
| Equivalent Qualification Level: | 612.1 kg | **NEXT LDT Demonstrated (as of 3/28/2014):** | **918.2 kg** |
| Projected Qualification Level: | >580 kg | Projected Throughput: | >870 kg |
| Original NEXT Design Goal : | 300 kg | Original NEXT Qualification Requirement: | 450 kg |

# Hall Propulsion Priorities for Planetary Science Missions

- Develop common flight Hall Power Processing Unit (PPU) with capabilities for PSD mission needs for any Hall thruster
  - 5 kW class, modular design
  - Qualify unit and procure 3 flight PPUs as GFE
- Evaluate commercial Hall thrusters (i.e. BPT-4000, SPT-140,…)
  - Delta-qual (as necessary) for PSD environments/life
  - Facility effects assessment and develop ground-test-to-flight-modeling protocols
- Complete the <u>High</u> <u>V</u>oltage <u>H</u>all <u>Ac</u>celerator (HiVHAc) system
  - Assess/incorporate Magnetic Shielding (MS), and qualify thruster
- Leverage STMD's 12-kW Hall system development to address planetary science mission needs
- Maintain Mission analysis capabilities and tool development
  - Community engagement with mission capabilities

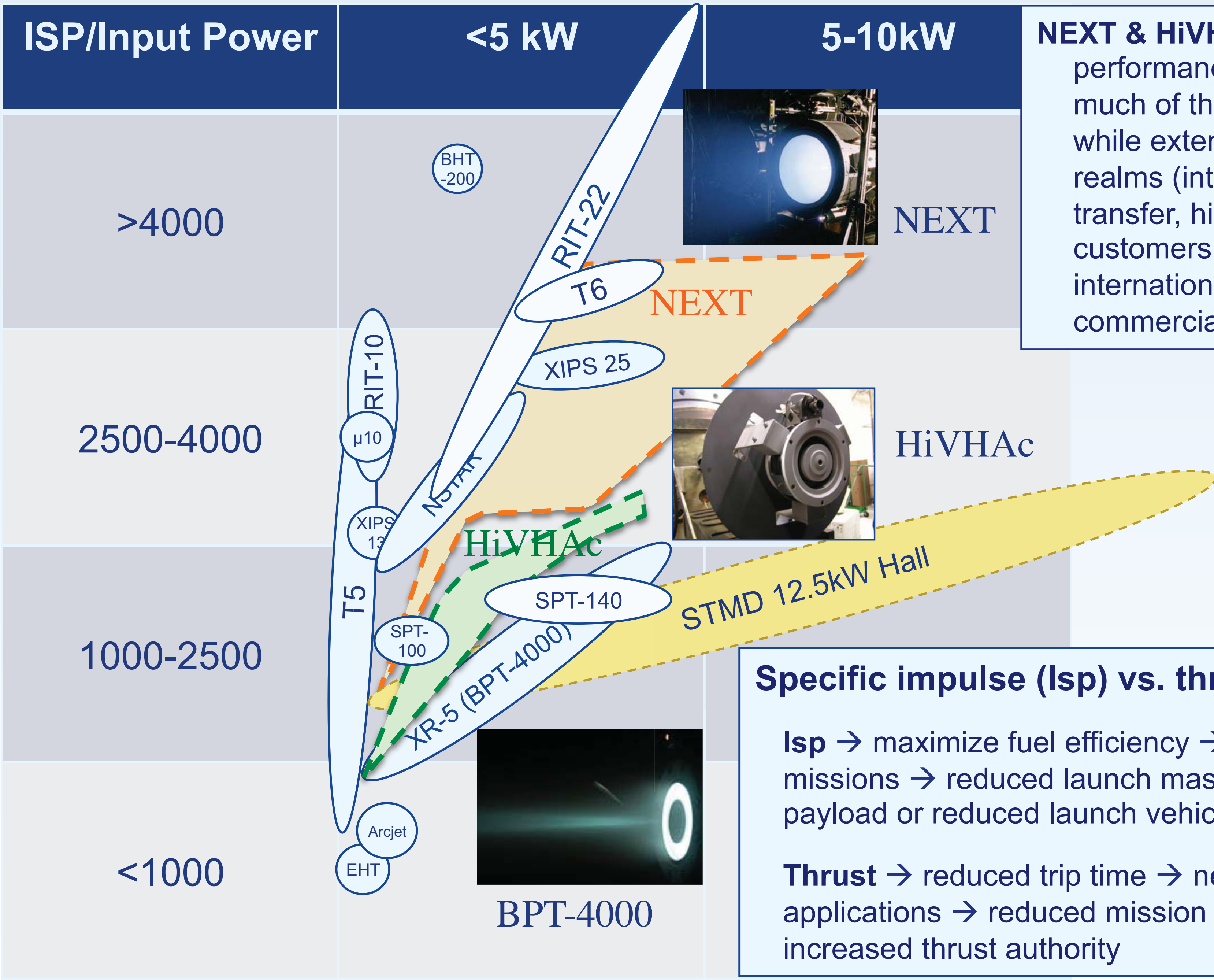


PPU

BPT-4000 thruster

HiVHAc thruster

# Solar Electric Propulsion Market Options




**NEXT & HiVHAc** flexibility & performance envelopes much of the existing market while extending new mission realms (interplanetary, orbit transfer, high mass) for new customers (e.g., international, government & commercial)

**Specific impulse (Isp) vs. thrust**

**Isp** → maximize fuel efficiency → interplanetary missions → reduced launch mass → more science payload or reduced launch vehicle size/cost

**Thrust** → reduced trip time → near-Earth applications → reduced mission ops costs → increased thrust authority