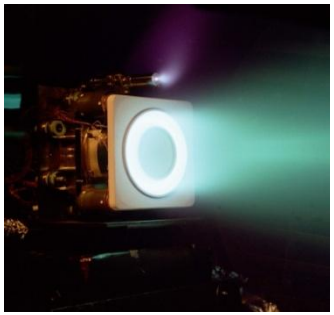
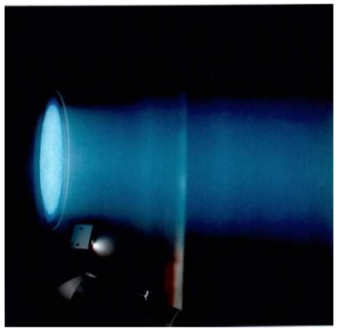
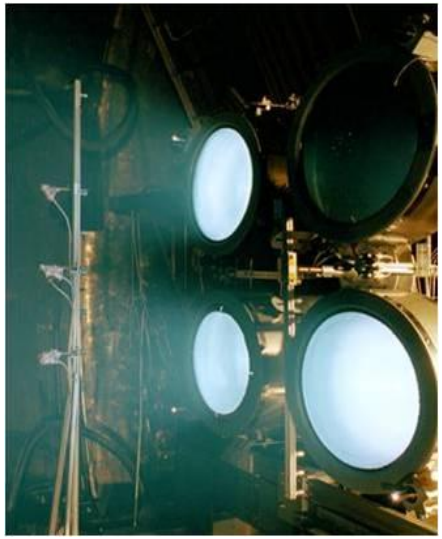
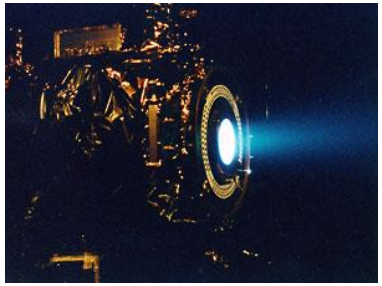
Electric Propulsion Options for Small Body Missions

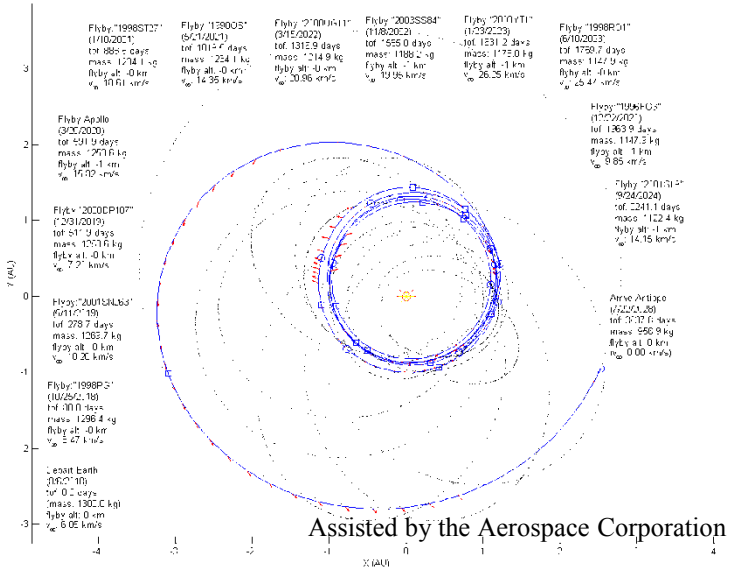






John Dankanich
NASA's In-Space Propulsion Technology Project

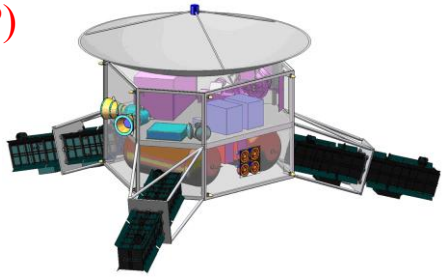
November 18, 2009

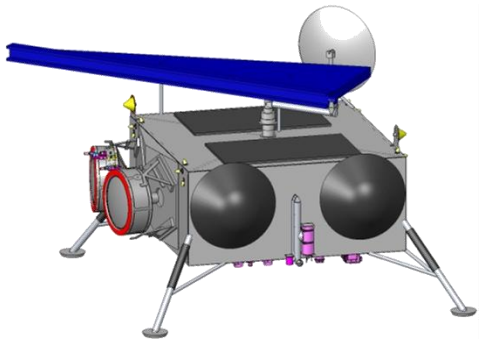
How is EP Relevant to Small Body Missions?

- **Nearly all small body missions are enhanced or enabled by electric propulsion:**
  - Mega-multi flyby missions
  - Multiple small body rendezvous missions
  - NEA Sample Return
  - Multi-body Sample Return
  - Phobos and Diemos Sample Return
  - Comet Surface Sample Return
  - Main belt Asteroid Sample Return
  - Trojan Rendezvous
  - Centaur Rendezvous (REP)
  - Comet Nucleus Sample Return
  - Kuiper Belt Rendezvous (Large REP)

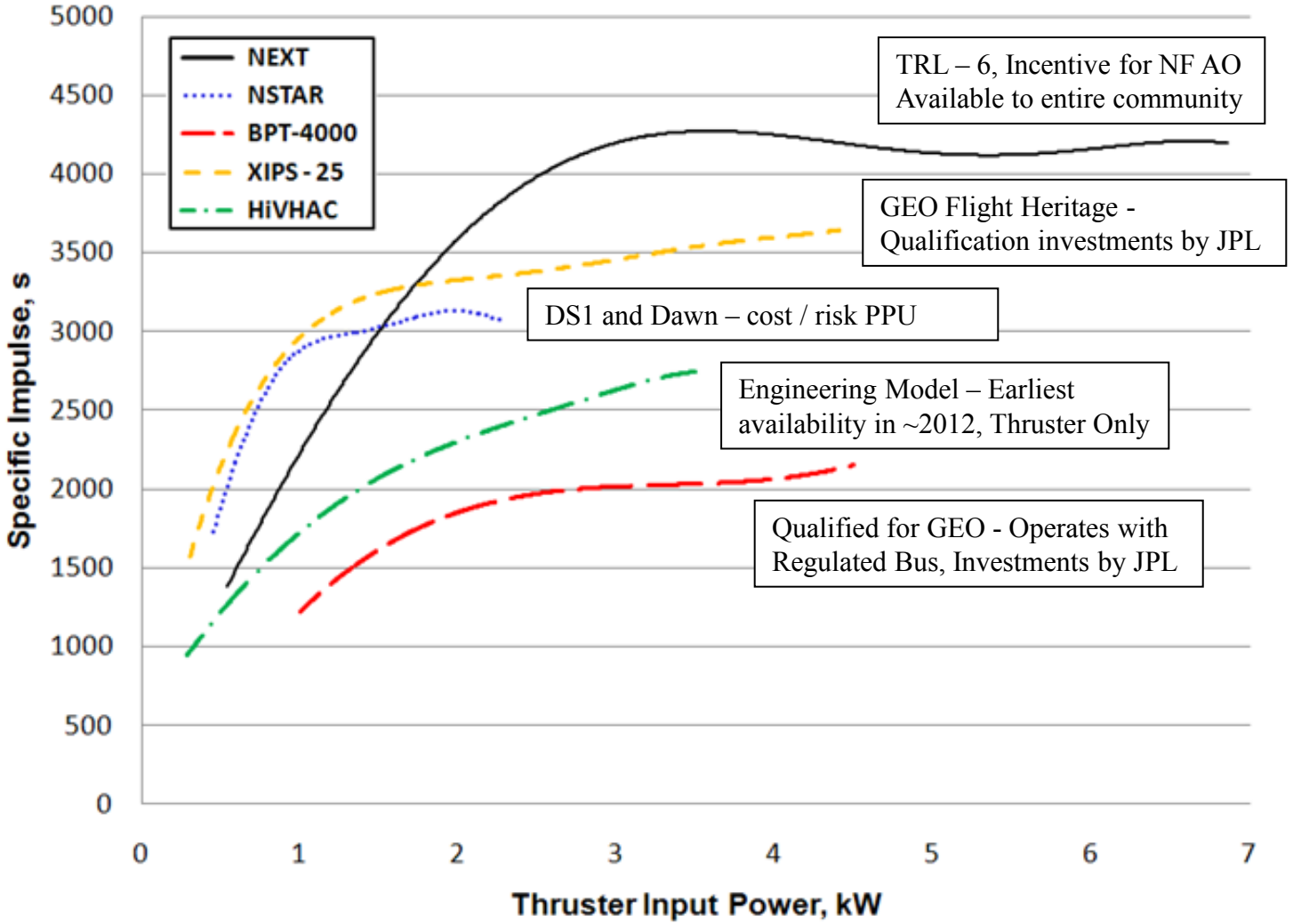


Assisted by the Aerospace Corporation

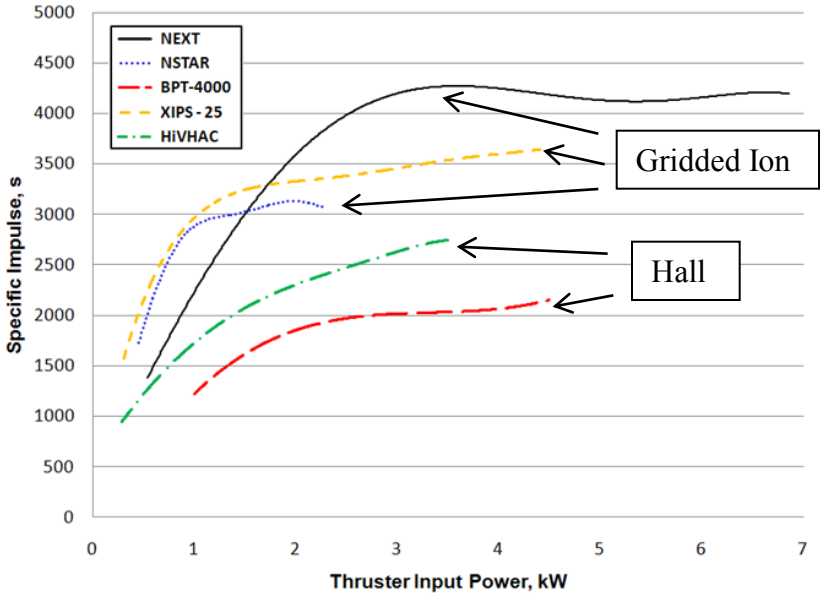


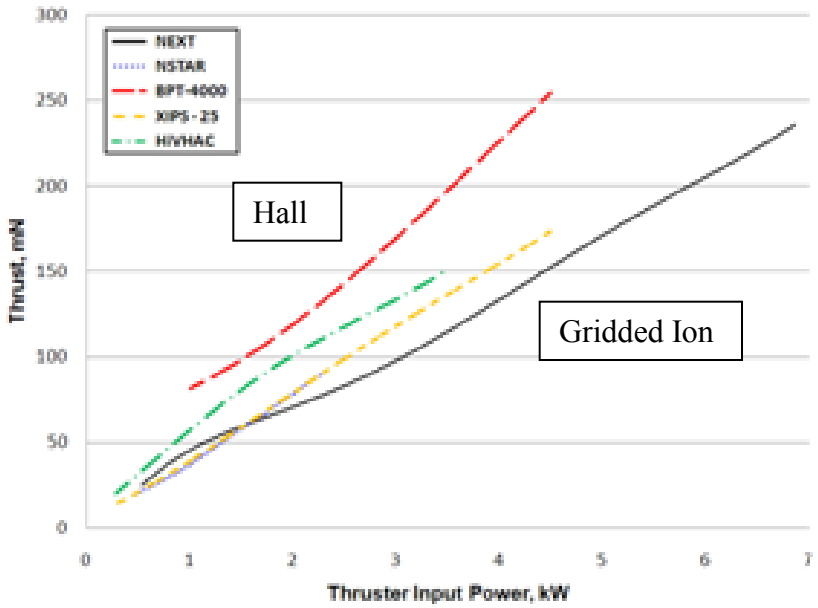


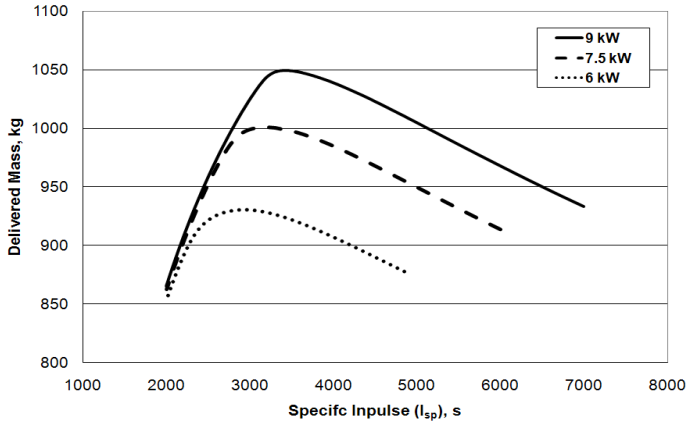
What are the EP options?



Do we need more than one thruster?

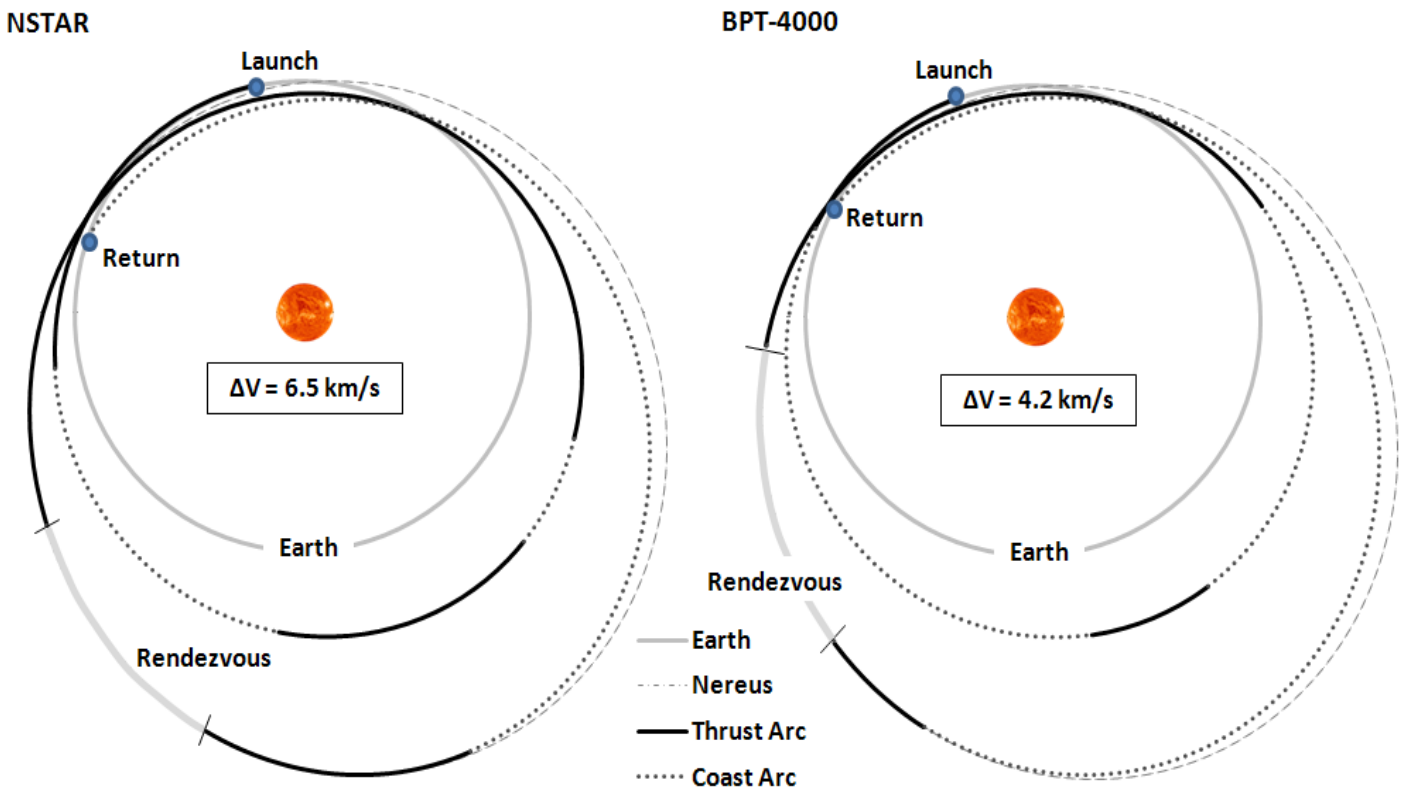






Optimal Specific Impulse for Comet Rendezvous

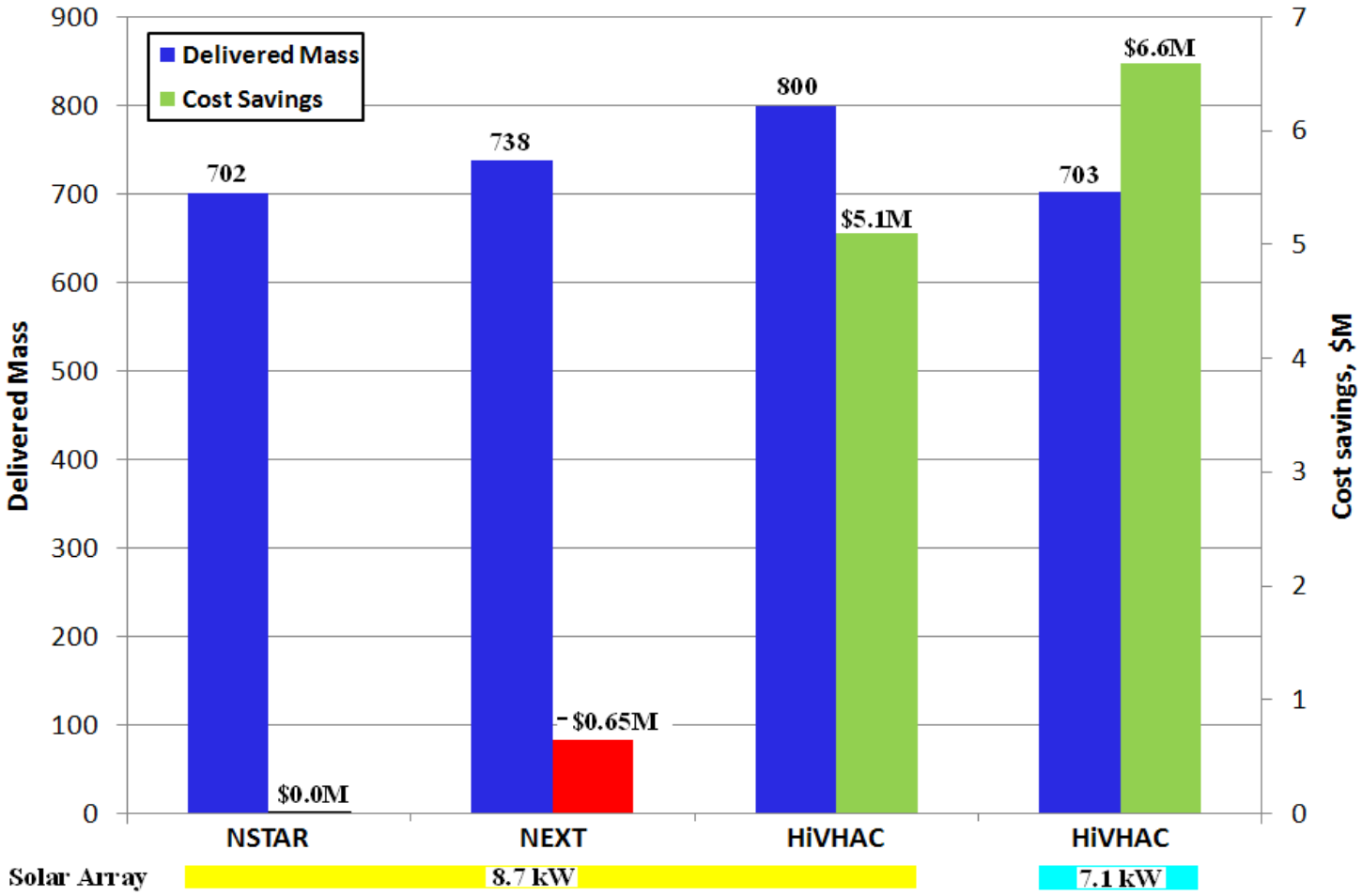
Why isn't the highest η and I_{sp} the best?



$$\frac{m_{final}}{m_{initial}} = e^{\frac{-\Delta V}{g I_{sp}}}$$

Higher thrust systems can reduce the total mission ΔV resulting in higher mission performance with a lower specific impulse thruster.

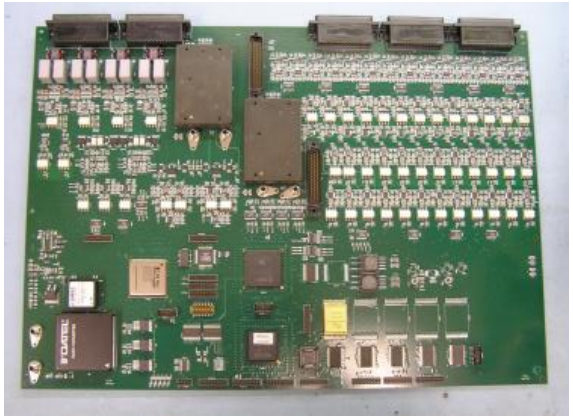
Then there is cost…



Oh, D., "Evaluation of Solar Electric Propulsion Technologies for Discovery-Class Missions," *Journal of Spacecraft and Rockets*, Vol. 44, No. 2., March-April 2007, pp 399-411.

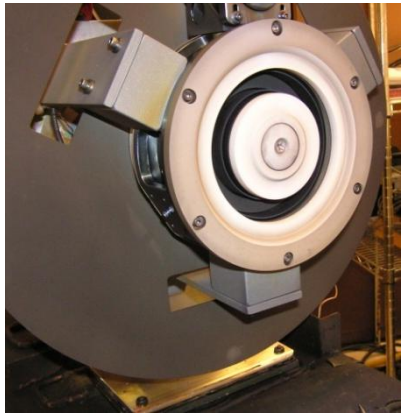
Current ISPT Project Investments

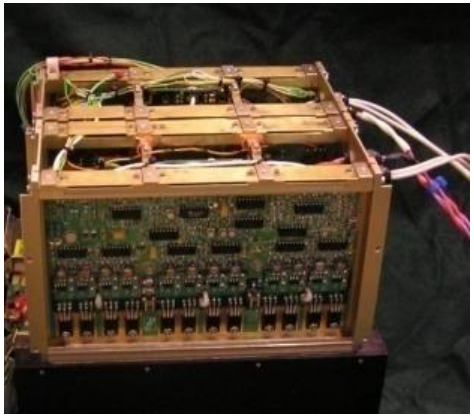
- NEXT Risk Reduction
  - Continuing Thruster Life Test
  - Continuing PPU Testing
  - Continuing DCIU Investments
  - Working with SMD / SS Office to benefit all potential users

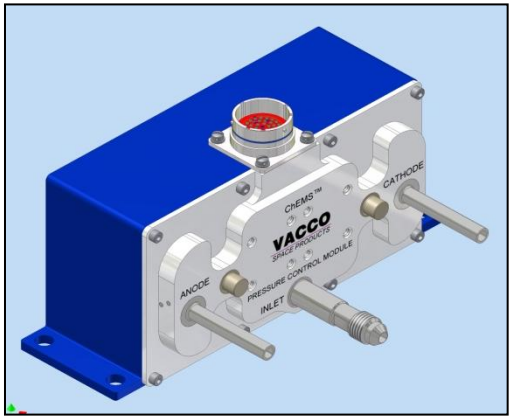


- HiVHAC Development
  - Contracted with Aerojet to build two Engineering Model thrusters
  - Low-cost manufacturing and integration
  - Performance testing
  - Long duration testing in FY10
  - Leveraging non-SMD funds

Together NEXT and HiVHAC offer significant mission capture for a wide range of missions.







Which thruster is right for you?

Every mission is unique and the highest performance thruster is mission specific

- NEXT
  - **Available to the entire science community**
  - Large throttle range
  - High Isp
  - High throughput capability

  Ideal for missions with abundant power, very high ΔV, long duration, and/or very large payloads. (Flagship through Discovery)
  - Multi-NEA flyby
  - Multi-body rendezvous
  - Inner Solar System
  - CSSR / CNSR
  - Multi-sample return
  - Main belt sample return*
  - Flagship missions

- BPT-4000
  - Qualified for GEO Operation, Regulated Bus, Additional Investments by JPL
  - High Thrust
  - High throughput capability
  - Expected Lower Cost
  - Limited throttling

  Ideal for missions with moderate ΔV, small/medium payloads, constrained missions, and/or in a gravity well.
  - NEA Rendezvous
  - NEA Sample Return
  - Mars Sample Return

Which thruster is right for you?

Every mission is unique and the highest performance thruster is mission specific

- XIPS
  - Qualified for GEO Operation, additional investments by JPL
  - Moderate Isp
  - Limited throughput capability

  Ideal for missions with moderate ΔV, and/or moderate payloads. (Discovery Class Missions)
  - Multi-NEA flyby
  - Multi-body rendezvous
  - Main belt sample return*

- HiVHAC
  - **Available to the entire community**
  - Moderate thrust / specific impulse
  - High throughput capability
  - Very large throttle range
  - Designed specifically for low cost
  - **Low maturity, thruster only**

  Ideal for missions with low power, moderate ΔV, small/medium payloads, high AU missions, and/or constrained missions. (Discovery Class Missions)
  - Multi-NEA flyby
  - Multi-sample return
  - High AU rendezvous
  - CSSR
  - NEA sample return

Summary

- Electric propulsion is critical to future small body missions
- One thruster is not suitable for all missions
  - NEXT is currently available for current and future AOs
  - Commercial BPT-4000 and XIPS are receiving independent IR&D investments
  - HiVHAC has potential for a future lower cost EP option

People often comment that EP is too expensive…

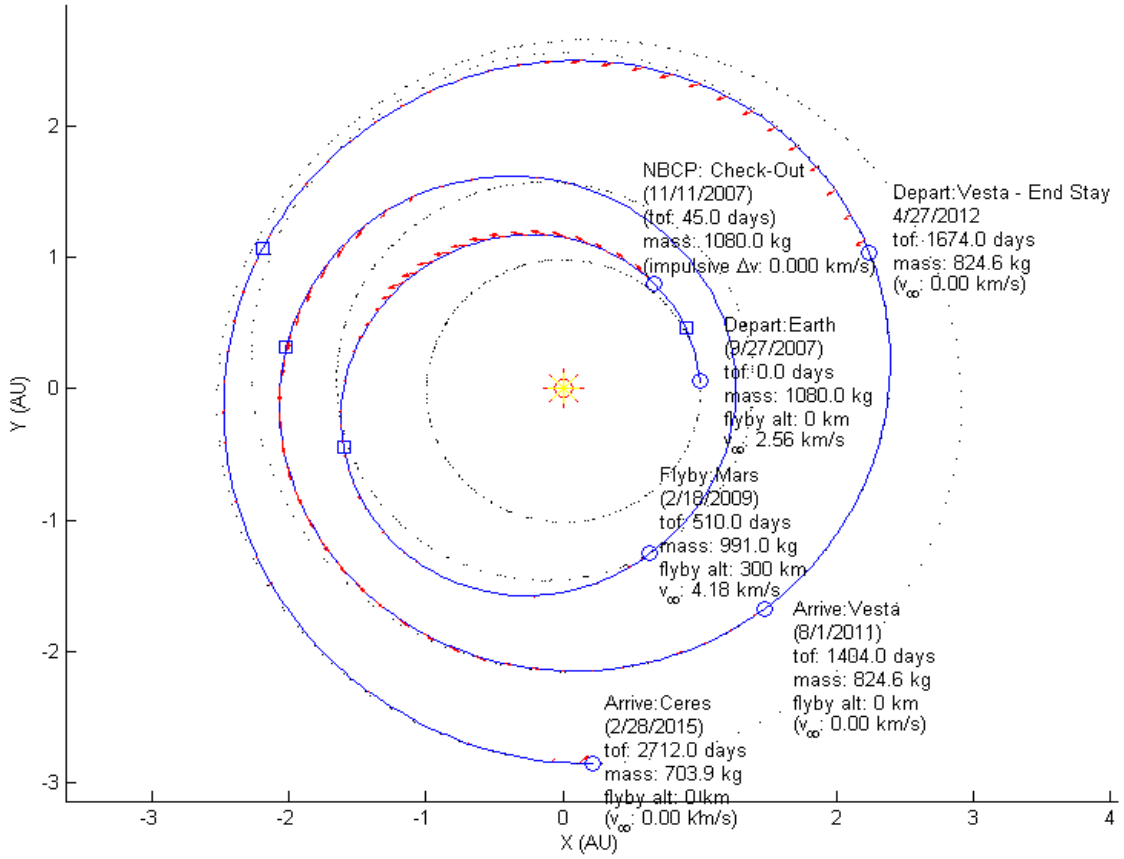
While it is true that EP is currently difficult in the Discovery cost cap, Dawn, Cacus Rendezvous, Multi-body Sample Return, etc. are Discovery class EP missions and flagship chemical missions.

EP also enables a large number of missions that cannot be performed chemically.

We currently have a highly capable system and are working towards a low cost alternative.

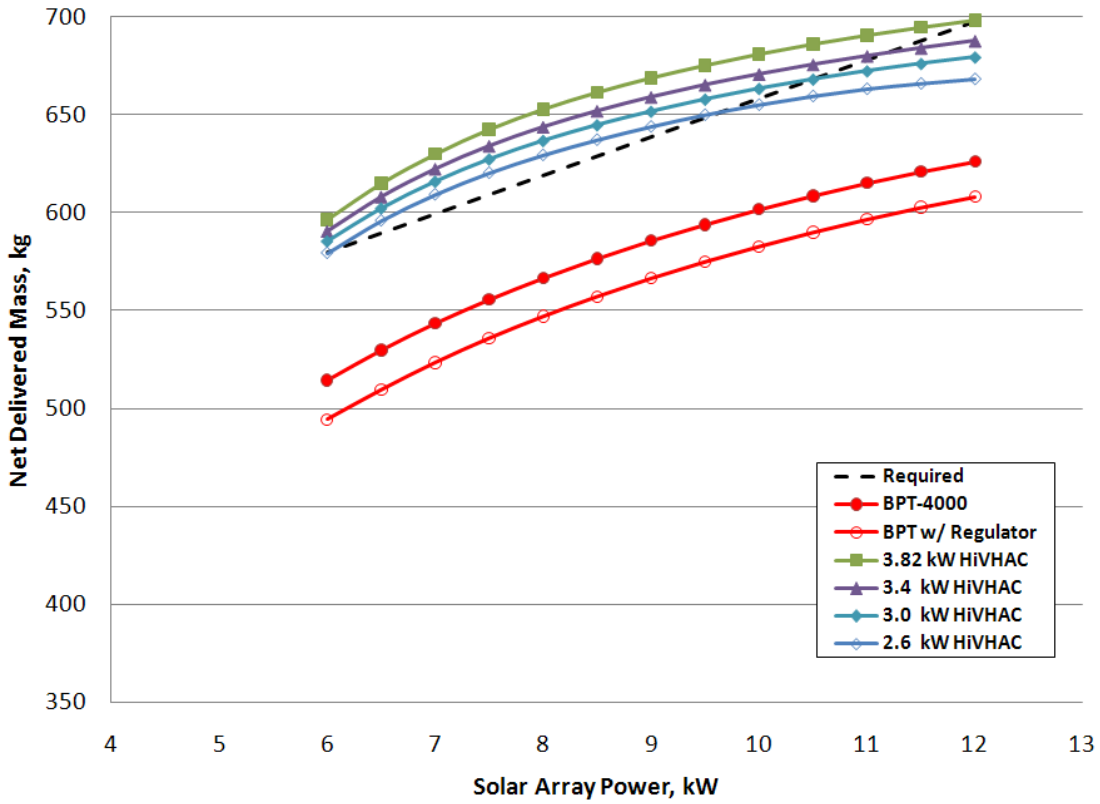
Backup

Dawn Mission



	Mass, kg
IPS	123
EPS	202
Harness & Cabling	55
Mechanisms and Structure	97
Telecom	30
Balance	15
ACS	37
RCS Hardware	13
Thermal	40
C&DH	24
Uncertainty	79
Payload	27
Dry Mass Total	**742**

Dawn Results



HiVHAC Thruster at all Pmax levels can complete the mission

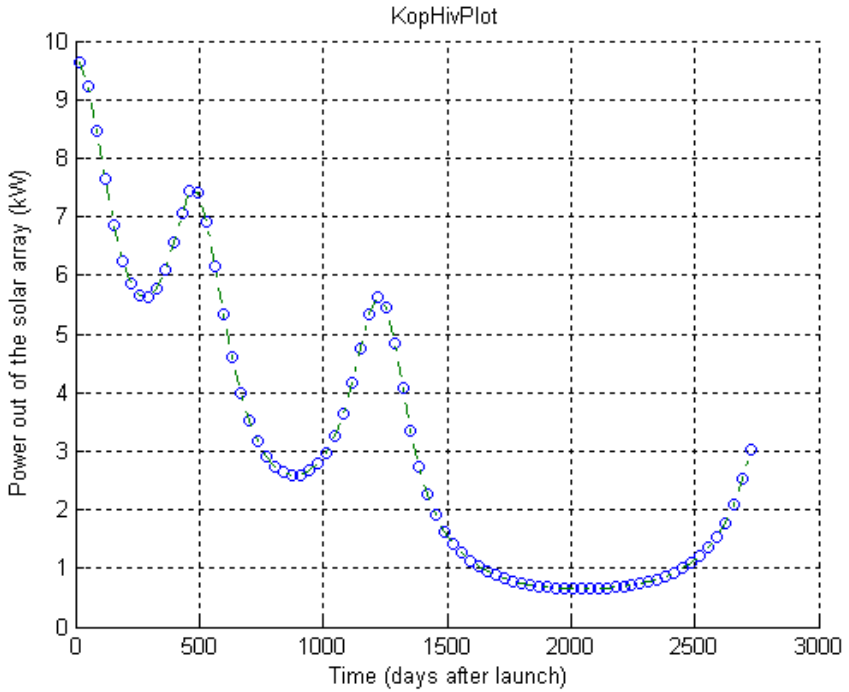
Performance degrades by 2kg per 100W Pmax reduction

BPT-4000 cannot close the mission

Consistent with previous JPL results: 2.8kW thruster with 7.1kW array

Kopff Mission

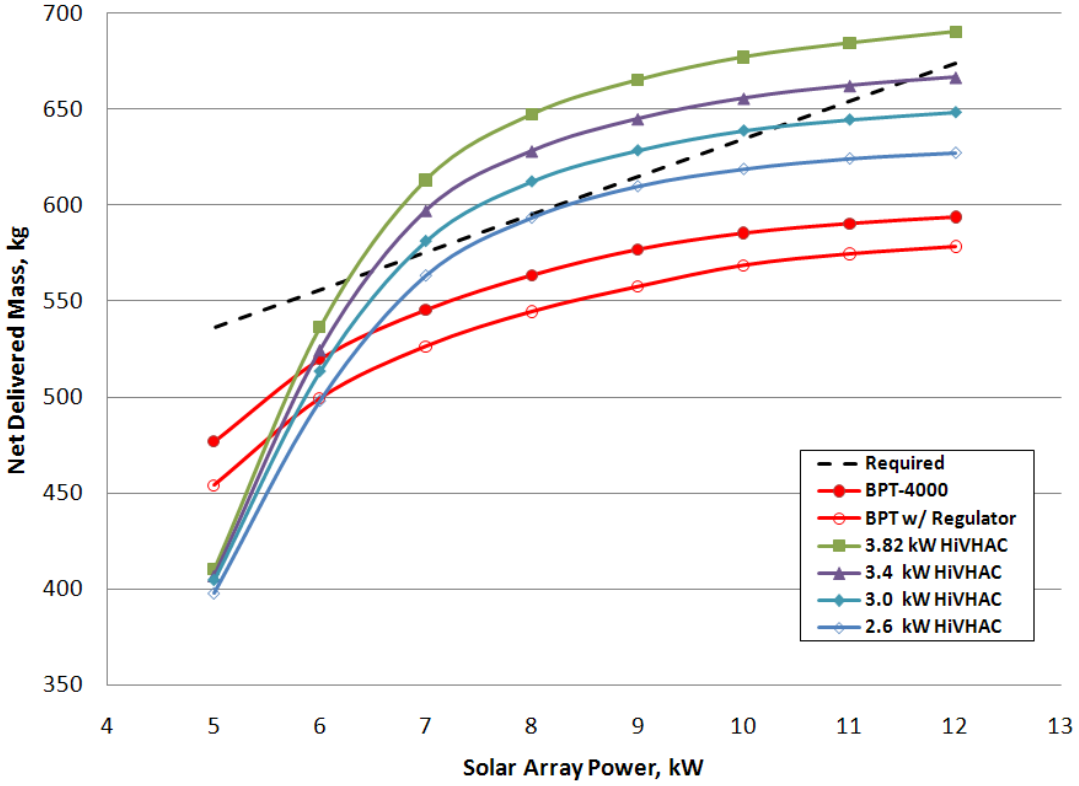
- Rendezvous Comet Kopff
  - Launch July 2014
  - Falcon 9 (Delta II Class)
    - a = 3.46 AU
    - e = 0.54
    - i = 4.7°



Mission required high AU rendezvous

Required mass derived from Dawn (same dry / reduced ACS)

Kopff Results

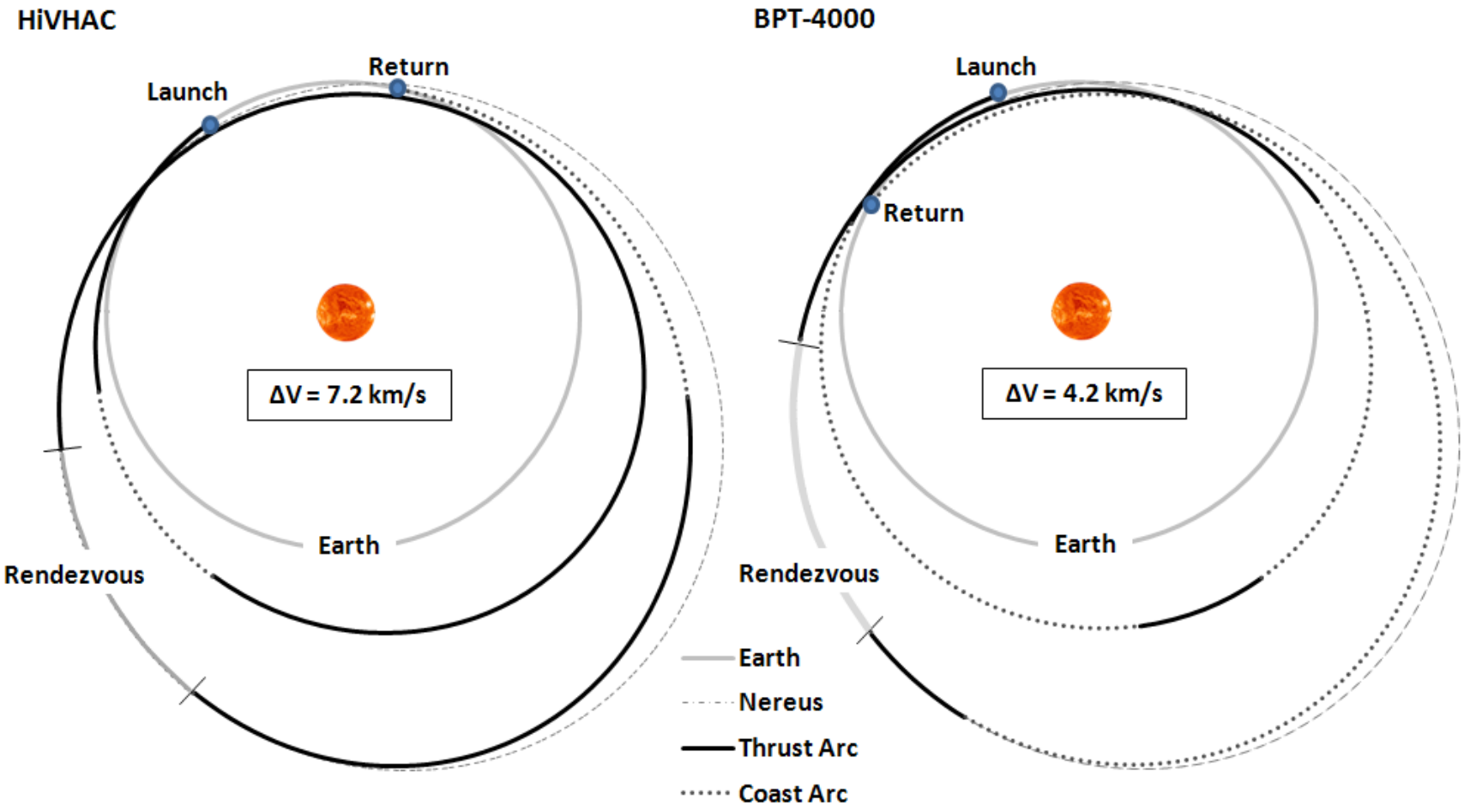


HiVHAC Thruster can complete the mission above 2.6kW Pmax

Performance degrades by 4.5kg per 100W Pmax reduction

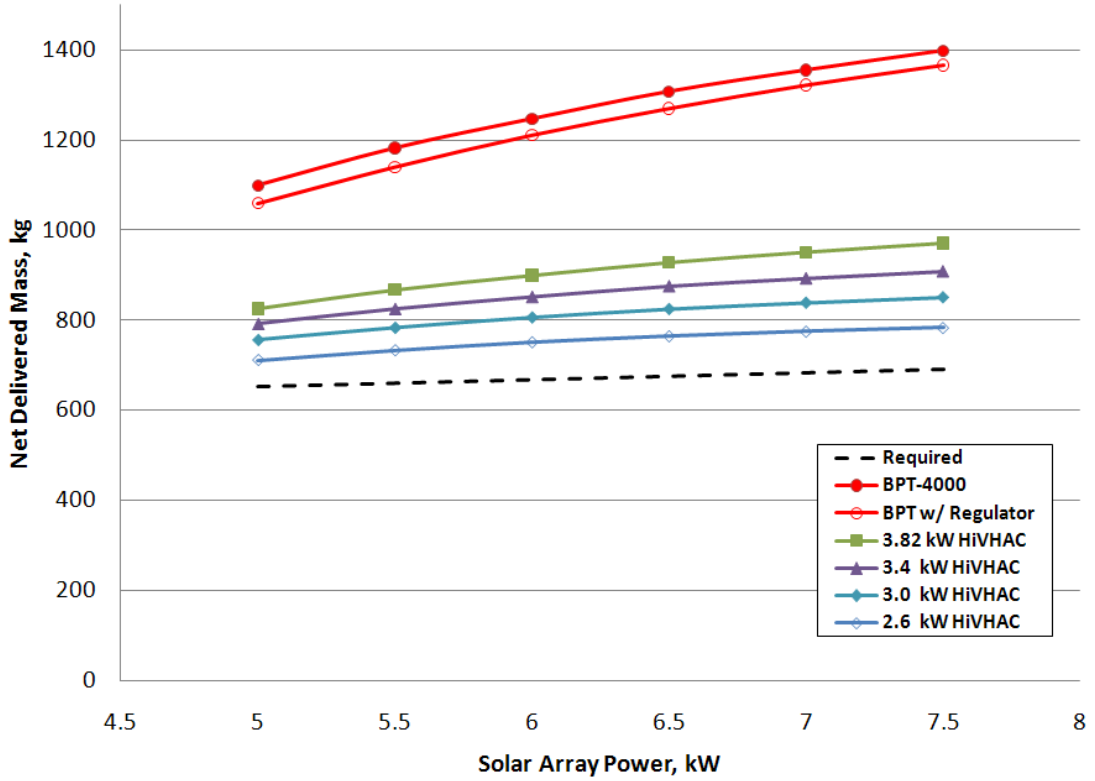
BPT-4000 cannot close the mission

NSR Mission



BPT-4000 has reduced thrust period, higher efficient maneuver, more robust.

NSR Results



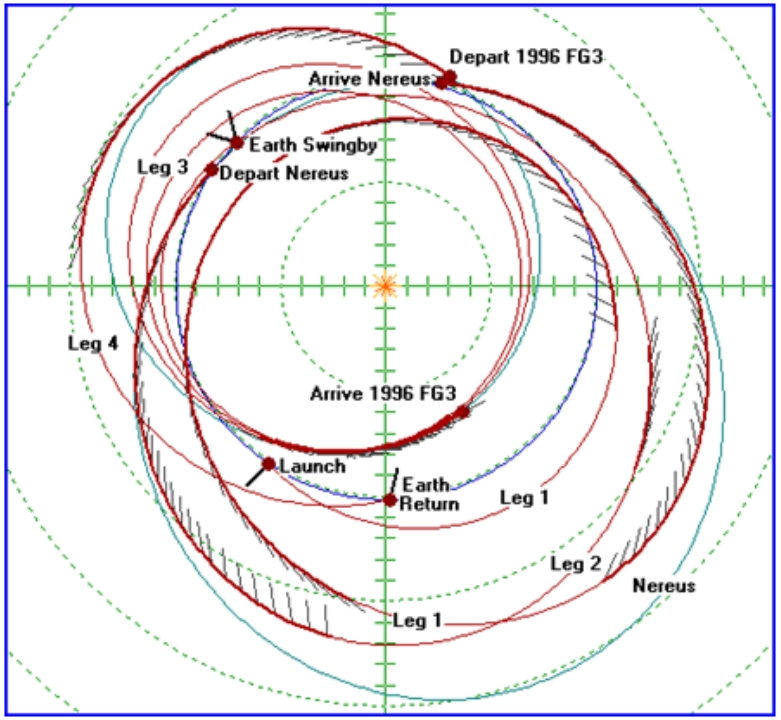
Higher thrust BPT-4000 significantly outperforms the HiVHAC

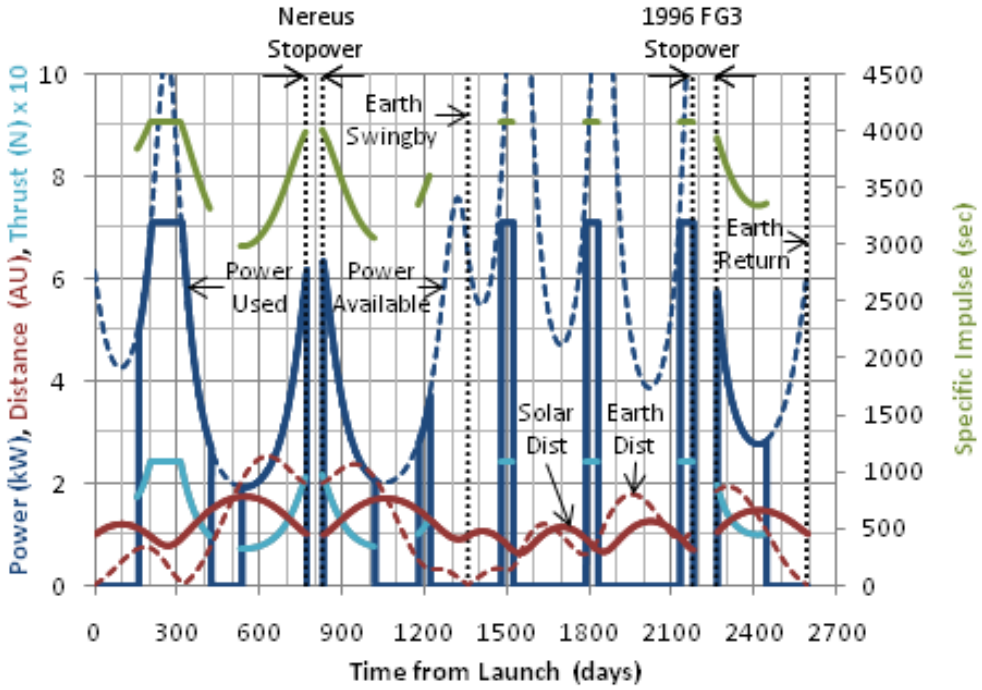
HiVHAC Thruster at all Pmax levels can complete the mission

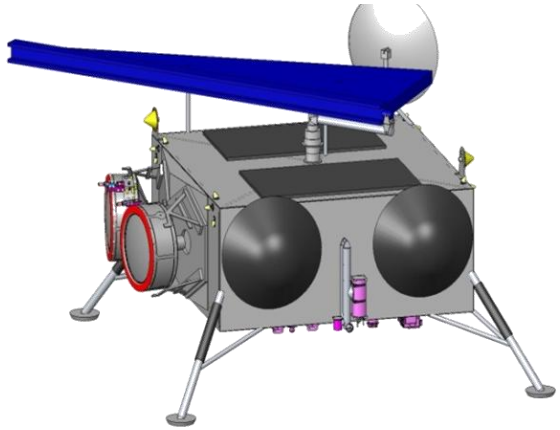
Performance degrades by 11-12kg per 100W Pmax reduction

Required mass from GRC COMPASS Concept Design

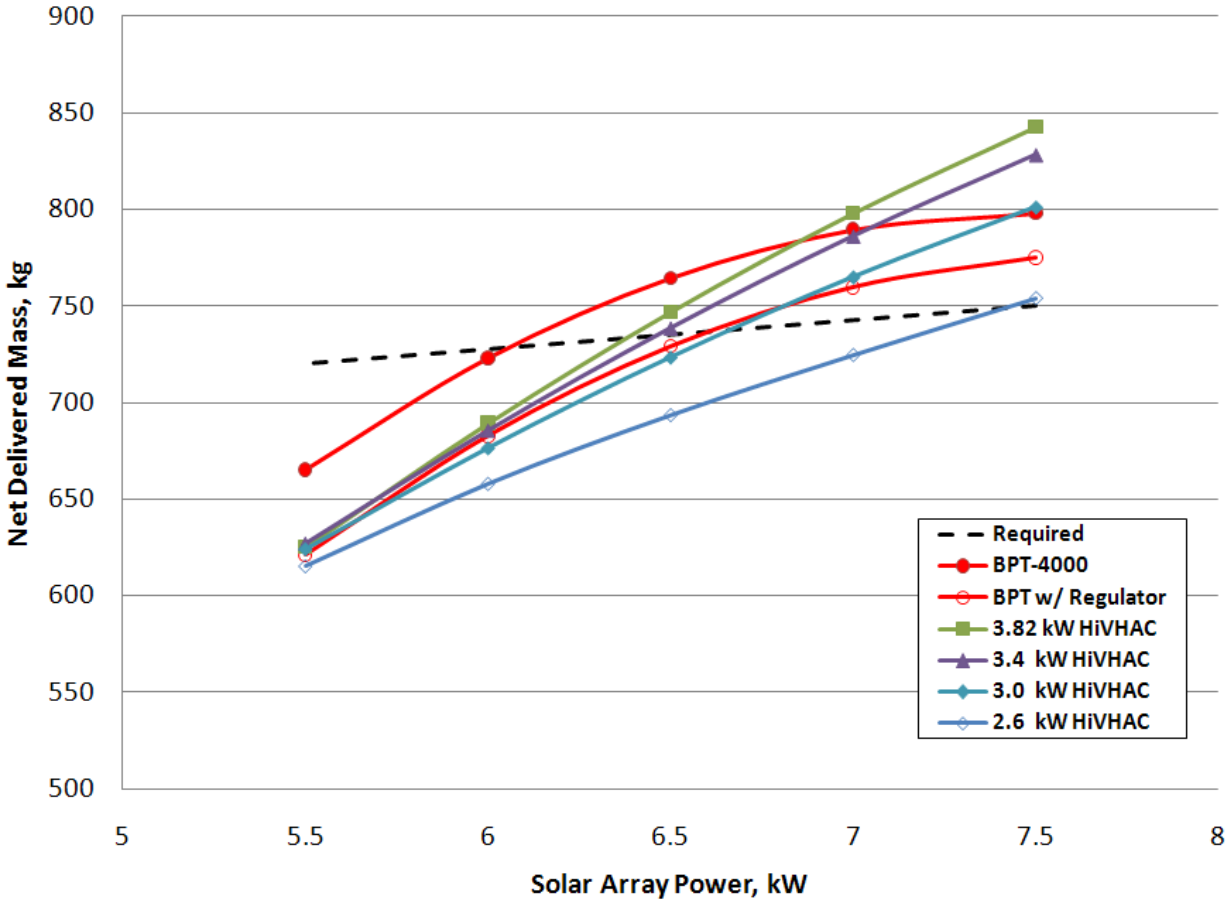
NEARER Mission







NEARER Results



BPT-4000 cannot close the mission

Consistent with previous JPL results: 2.8kW thruster with 7.1kW array