Electric Propulsion Options for Small Body Missions

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NASA’s In-Space Propulsion Technology Project

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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)
What are the EP options?

- Qualified for GEO - Operates with Regulated Bus, Investments by JPL
- GEO Flight Heritage - Qualification investments by JPL
- TRL – 6, Incentive for NF AO Available to entire community
- DS1 and Dawn – cost / risk PPU
- Engineering Model – Earliest availability in ~2012, Thruster Only
- Qualified for GEO - Operates with Regulated Bus, Investments by JPL
Do we need more than one thruster?

Optimal Specific Impulse for Comet Rendezvous
Why isn’t the highest $\eta$ and $I_{sp}$ the best?

Higher thrust systems can reduce the total mission $\Delta V$ resulting in higher mission performance with a lower specific impulse thruster.
Then there is cost...

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 $\Delta V$, 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 $\Delta V$, 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
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

- **Arrive: Ceres (2/28/2015)**
  - tof: 2712.0 days
  - mass: 703.9 kg
  - flyby alt: 0 km
  - \(v_e = 0.00 \text{ km/s}\)

- **Flyby: Mars (2/18/2009)**
  - tof: 510.0 days
  - mass: 991.0 kg
  - flyby alt: 300 km
  - \(v_e = 4.18 \text{ km/s}\)

- **Depart: Earth (9/27/2007)**
  - tof: 0.0 days
  - mass: 1080.0 kg
  - flyby alt: 0 km
  - \(v_e = 2.95 \text{ km/s}\)

- **NSCP - Check-Out (11/11/2007)**
  - tof: 45.0 days
  - mass: 1060.0 kg
  - (impulsive \(\Delta v = 0.000 \text{ km/s}\))

- **Depart: Vesta - End Stay (4/27/2012)**
  - tof: 1674.0 days
  - mass: 624.6 kg
  - flyby alt: 0 km
  - \(v_e = 0.30 \text{ km/s}\)

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### Mass, kg

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<tr>
<th>Component</th>
<th>Mass, kg</th>
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<td><strong>Dry Mass Total</strong></td>
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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
Rendezvous Comet Kopff
- Launch July 2014
- Falcon 9 (Delta II Class)
  $a = 3.46$ AU
  $e = 0.54$
  $i = 4.7^\circ$

Mission required high AU rendezvous
Required mass derived from Dawn (same dry / reduced ACS)
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.
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
BPT-4000 cannot close the mission

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