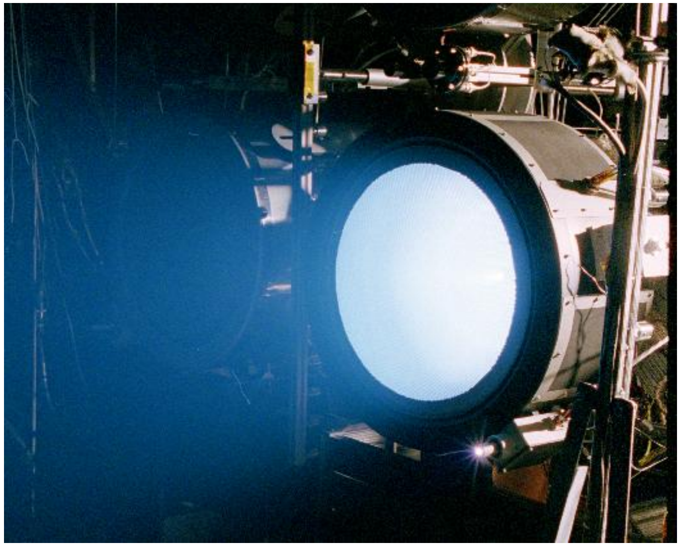
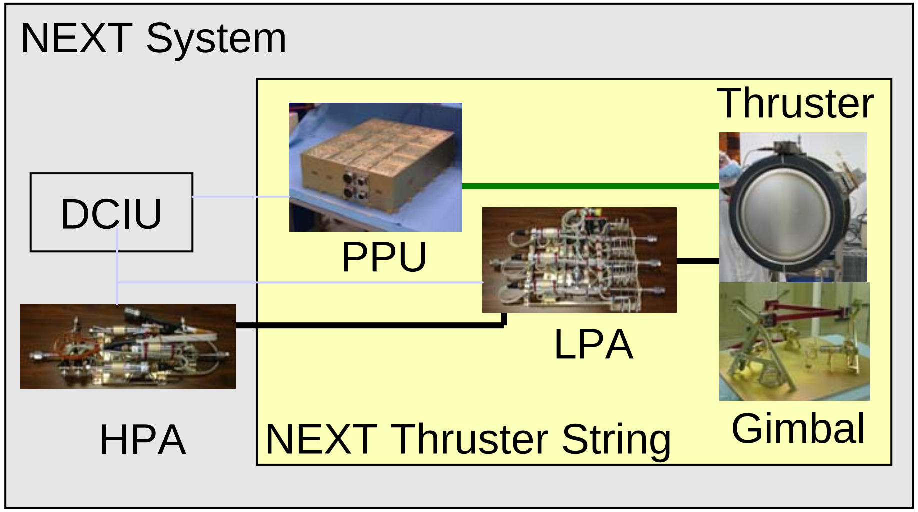
In-Space Propulsion Technology Current Products, Future Plans, and Relevance to Small Body Missions



John Dankanich
ISPT System Analysis

January 13, 2009

NASA's Evolutionary Xenon Thruster (NEXT)



Thruster Attribute	NSTAR	NEXT
Max. Input Power, kW	2.3	Up to 6.9
Throttle Range	4:1	>12:1
Max. Specific Impulse, s	3,170	4,190
Efficiency @ Full Power	62%	71%
Propellant Throughput, kg	157	>300 (design) 500 (projected)
Specific Mass, kg/kW	3.6	1.8

A GRC, Aerojet, JPL, and L-3 Comm. team are developing a high performance IPS to TRL 6.

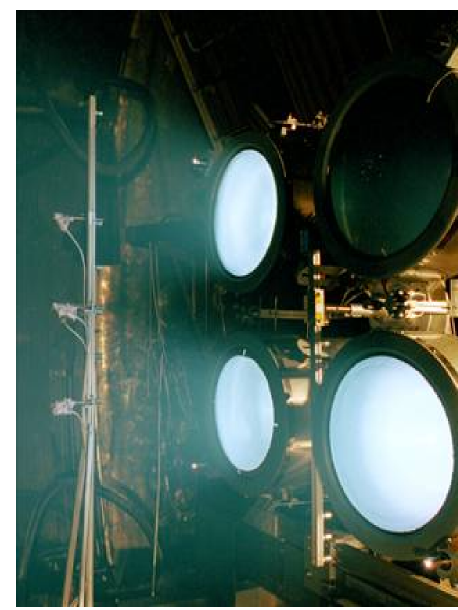
Twice the propellant capability, higher efficiency, and three times the power.

Dawn mission would only require one NEXT operating thruster.

SMD "encouraging" proposals using NEXT.

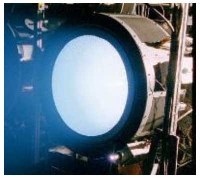
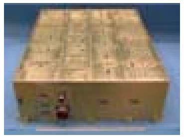
Shown enhancing and/or enabling for a large variety of small body missions

- High inclination rendezvous, Main belt tour, multi-NEO sample return, Phobos and Deimos SR, Comet Surface SR, etc.



NASA's Evolutionary Xenon Thruster (NEXT)

Critical tests have been completed, or are imminent, on high fidelity hardware

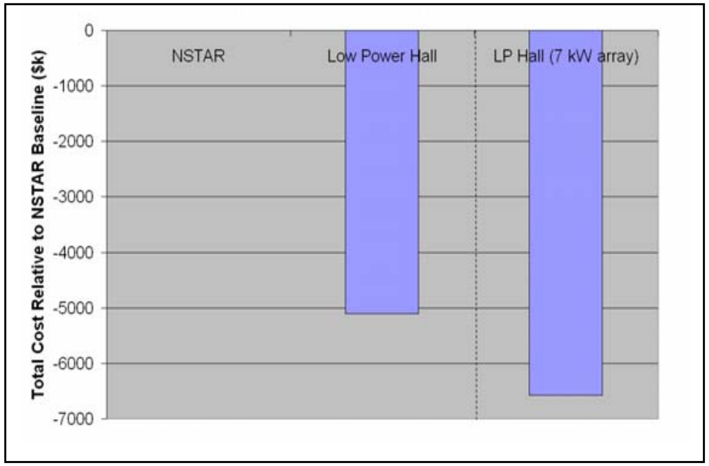
	PM1	PM1R	PPU	Feed System	Gimbal
					
Functional & Performance Testing	**Complete**	**Complete**	**Complete**	**Complete**	**Complete**
Qual-Level Vibration Test	**Complete**	**Complete**	**FY09**	**Complete**	**Complete**
Qual-Level Thermal/ Vacuum Test	**Complete**	**Complete**	**FY09**	**Complete**	**Not Planned**

NEXT life test has already demonstrated >400 kg of propellant throughput.

NEXT is available for all current and future mission opportunities.

High Voltage Hall Accelerator (HiVHAC)

Input Power	0.3 - 3.5 kW
Specific Impulse	1600 - 2700 s
Efficiency*	> 55% @ 3.5 kW
Thrust	20 – 150 mN
Propellant Throughput	> 300 kg
Specific Mass*	2.4 kg/kW
Operational Life	> 10,000 hrs



Reduced cost relative to NSTAR baseline

NASA-103 Thruster

- Demonstrated 0.54η and 2700 s at 3.5 kW
- Demonstrated in-situ discharge channel replacement
- Demonstrated ~100 kg of Xe throughput
- Provided critical thermal data for EM thruster

EM HIVHAC Thruster

- Completed a Preliminary Design Review
- Component fabrication initiated
- Delivery of 2 thrusters scheduled for May 2009

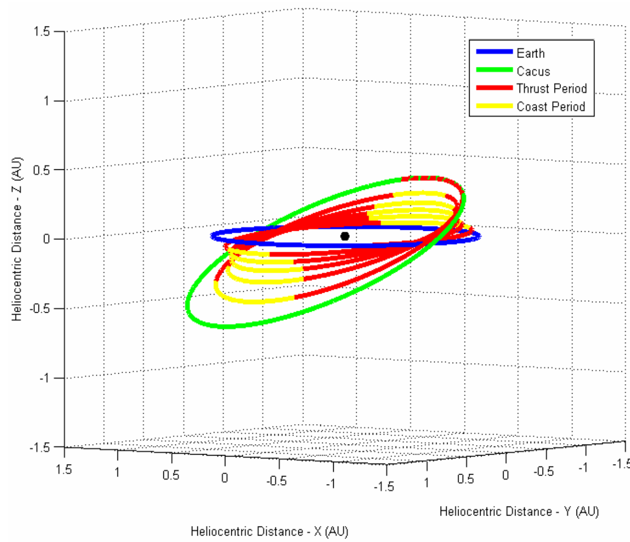
First thruster specifically focused on providing a low-cost electric propulsion option

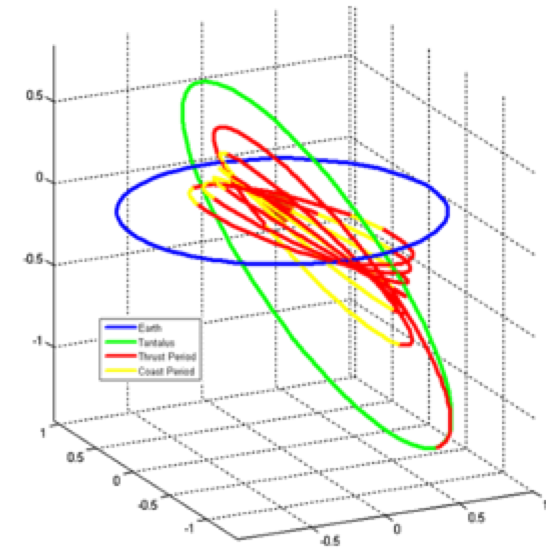
Potential to cost enable electric propulsion on a wide range of Discovery class missions

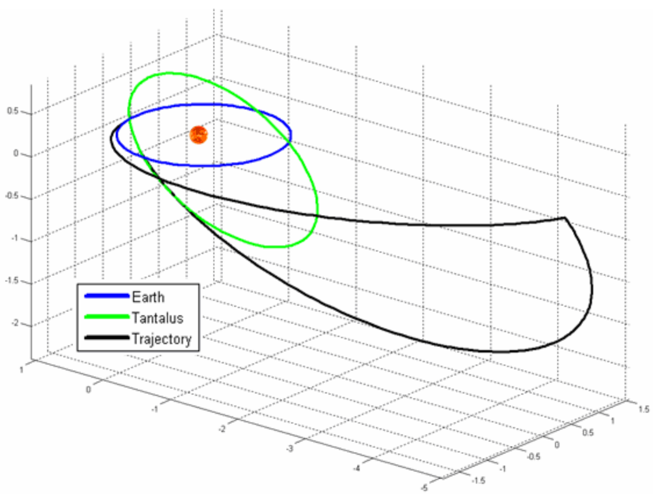
Past Small Body Studies
General Results

Electric propulsion is ideal for small body rendezvous and sample return missions

- High AU or eccentric targets
- Inclined targets
- Multiple targets
- Sample Return Missions





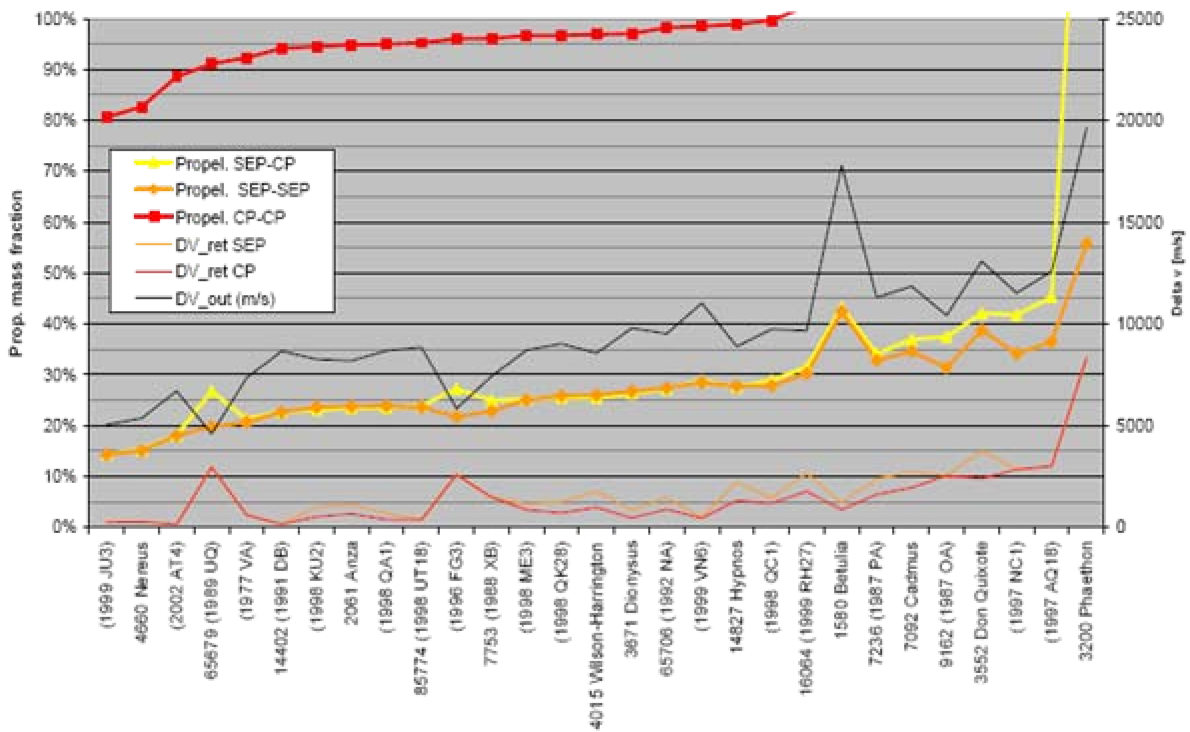


	Launch Vehicle	Depart	Arrive	Transfer Time (Years)	ΔV (km/s)	Departure Mass (kg)	Propellant Mass (kg)	Arrival Mass (kg)
NEXT	Delta IIH	Earth	Cacus	4.65	17.57	1478.2	511.88	966.32
	Atlas 551	Earth	Tantalus	4.45	31.55	1879.0	1046.00	833.00
Bi-prop	Delta IIH	Earth	Cacus	NA	>10.52	NA	NA	NA
	Atlas 551	Earth	Cacus	6.31	10.52	850.0	815.39	34.61
	Atlas 551	Earth	Tantalus	5.38	14.01	1175.0	1158.46	16.54

Past Small Body Studies (ESA – NEA)

ESA concluded a technology reference study in 2007 with an objective to "establish a cost-efficient, scientifically meaningful and technologically feasible mission architecture for a NEA space-based mission concept."

The findings shows that low-cost chemical options exist for a limited number of targets. After evaluating over 4000 NEAs, the report states "a limited number of targets (a few dozens) are within reach of a chemically propelled spacecraft while solar electric propulsion opens up many more opportunities."



Agnolon, D., et al., "Study Overview of the Near Earth Asteroid Sample Return," SCI-PA/2007/004/DA, ESA Technology Reference Study, May 30, 2007.

Past Small Body Studies (CSSR – APL)

NASA recently directed a study with APL to evaluate the Comet Surface Sample Return (CSSR) mission and stated that "The low-thrust mission is much more forgiving and provides access to many more targets and regular launch opportunities."

Comet	Apparitions	Perihel., AU	Aphel., AU	Incl., deg.
9P/Tempel 1 [1]	2016 Aug. 2, 2022 Mar. 4	**1.54**	4.75	10.5
19P/Borrelly [2]	2015 May 29, 2022 Feb. 2	**1.31**	**5.90**	**29.3**
81P/ Wild 2 [3]	2016 July 20, 2022 Dec. 15	**1.59**	5.31	3.2
67P/Churyumov-Gerasimenko [4]	2015 Aug. 13, 2021 Nov. 2, 2028 Apr. 9	1.21	5.70	3.9
21P/Giacobini-Zinner [5]	2018 Sep. 10, 2025 Mar. 25	1.01	**5.98**	**32.0**
22P/Kopff [6]	2015 Oct. 25, 2022 Mar. 17	**1.56**	5.33	4.7
6P/d'Arrest [7]	2015 Mar. 2, 2021 Sep. 17	**1.35**	5.64	**19.5**
43P/Wolf-Harrington [8a]	2016 Aug. 19 (before 2019 Mar.)	**1.36**	5.34	**16.0**
43P/Wolf-Harrington [8b]	2025 Aug. 5 (after 2019 Mar.)	**2.44**	**6.22**	9.3
46P/Wirtanen [9]	2018 Dec. 12, 2024 May 19	1.05	5.13	11.8
73P/Schwassmann-Wachmann 3-C	2017 Mar. 17	0.97	5.21	11.2
41P/Tuttle-Giacobini-Kresak	2017 Apr. 11	1.05	5.12	9.2
103P/Hartley 2	2017 Apr. 20	1.07	5.89	13.6
P/2001 Q2 Petriew	2018 Jan. 27	0.93	5.27	14.0
79P/du Toit-Hartley	2018 Sep. 13	1.12	4.77	3.1
P/1999 RO28 LONEOS	2019 July 1	1.12	5.73	7.5
P/2003 H4 LINEAR	2015 Apr. 24, 2020 Oct. 5	1.17	5.02	2.6
P/2004 R1 McNaught	2015 Aug. 14, 2021 Jan. 26	0.97	5.22	4.9
P/2000 G1 LINEAR	2016 Mar. 15, 2021 July 11	1.00	5.10	10.4
15P/Finlay	2014 Dec 27, 2021 July 13	0.99	**6.02**	6.8

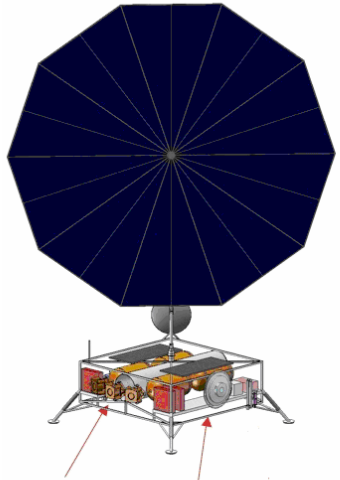
Electric propulsion required for the majority of targets.

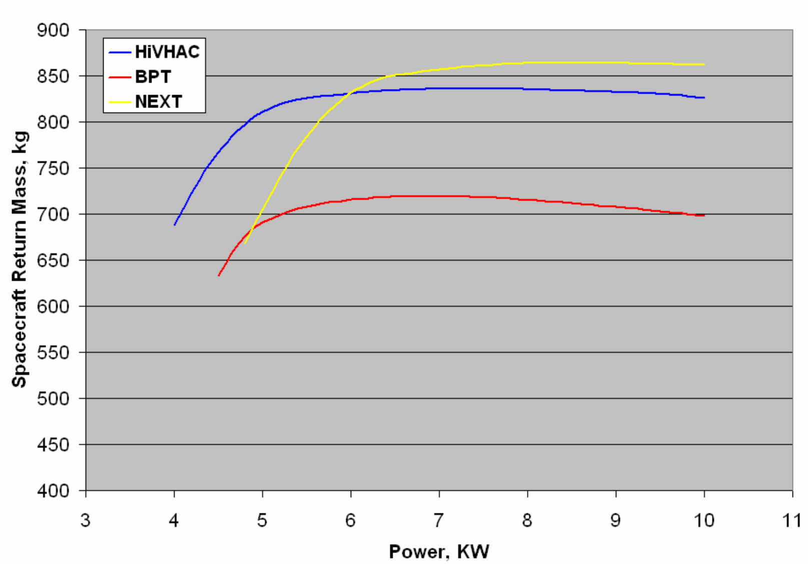
Fountain, G. H., et al., "Comet Surface Sample Mission Study," SDO-11998, Prepared for NASA's Planetary Science Division, April 30, 2008.

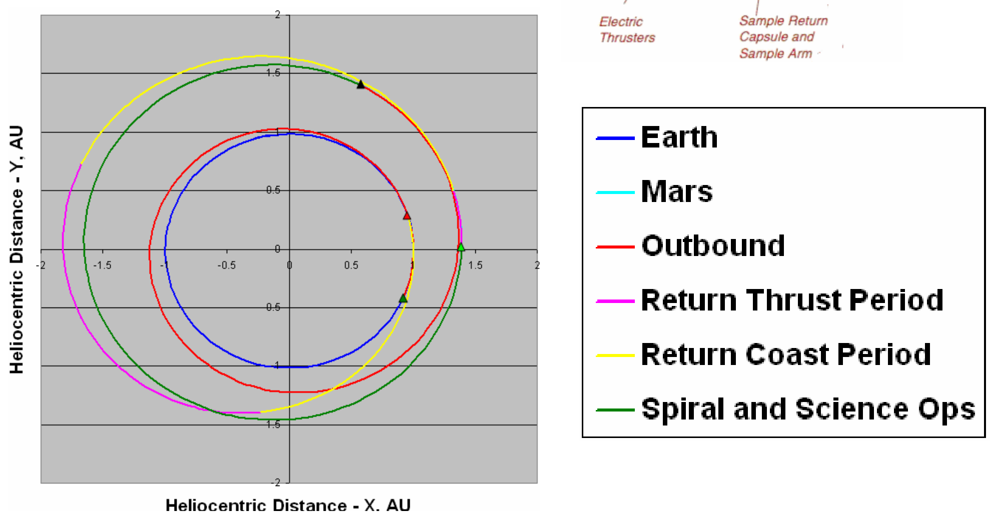
Past Small Body Studies (GRC / Ames– Deimos and Phobos SR)

Evaluated potential of Discovery/Scout Deimos and Phobos SR mission using electric propulsion

- Low-thrust to Mars, spiral to Phobos, three samples, spiral to Deimos, three samples, escape to Earth
- Only one target possible with chemical propulsion system
- Did not meet Discovery cost cap. New Frontiers cost feasible, but not a high priority NF target.







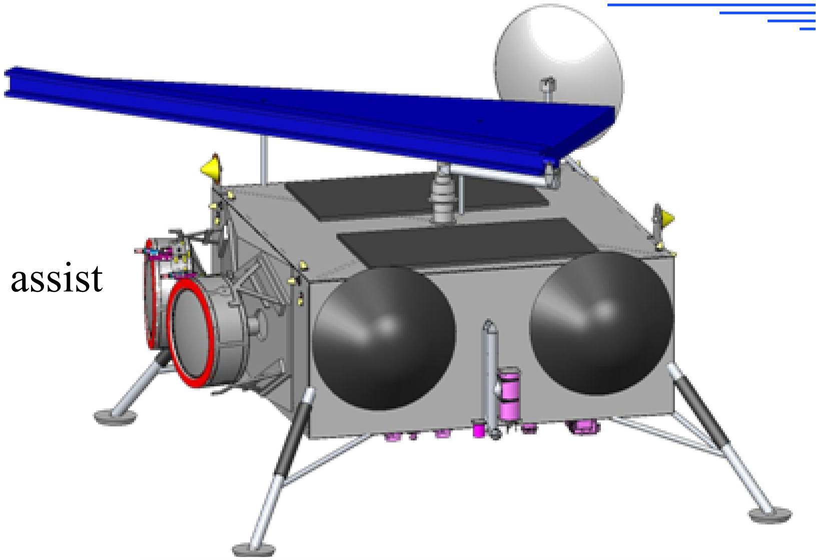
Electric propulsion enables a single SR mission from both Deimos and Phobos

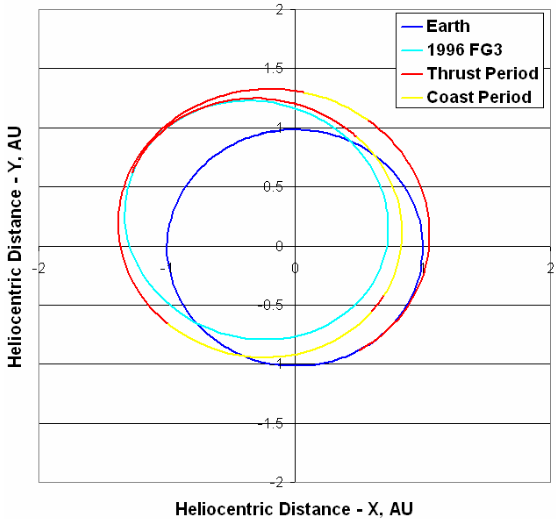
Recent Study
NEXT and HiVHAC Applicability to NEA SR

GRC COMPASS evaluation of NEARER, multi-body SR

- Minimize risk by returning sample before 2nd target
- Maximize gravity assist for 2nd more challenging target
- EP is very forgiving, must target Earth not optimal gravity assist

Launch	December 2014
Arrive at Nereus	June 2016
Return to Earth	January 2018
Arrival at 1996 FG3	May 2020
Return to Earth	November 2021



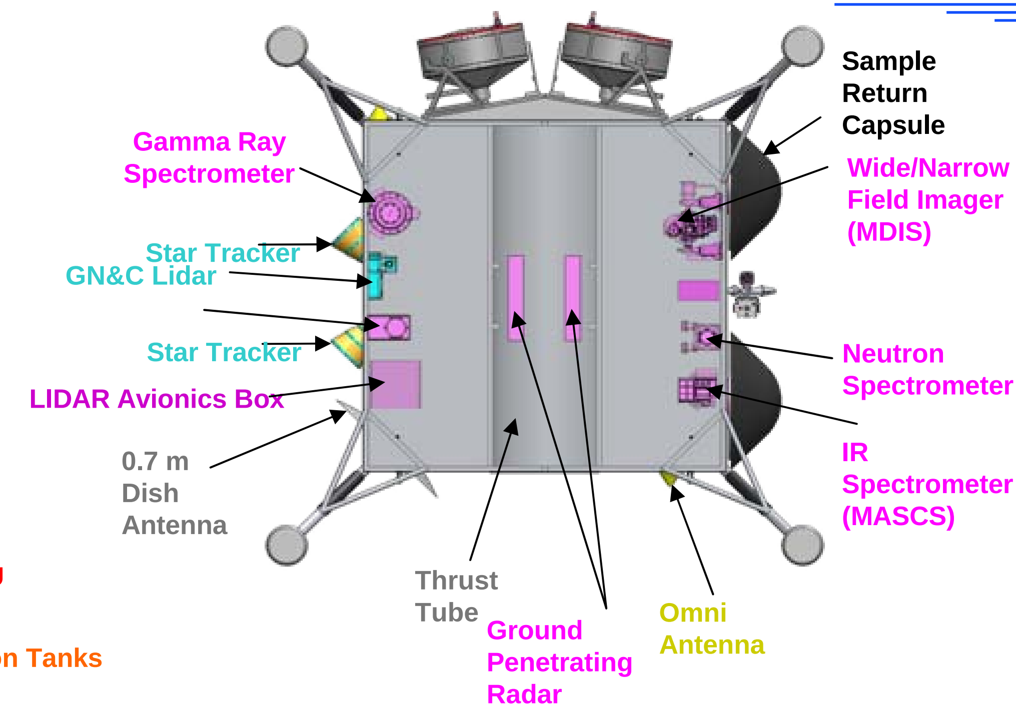


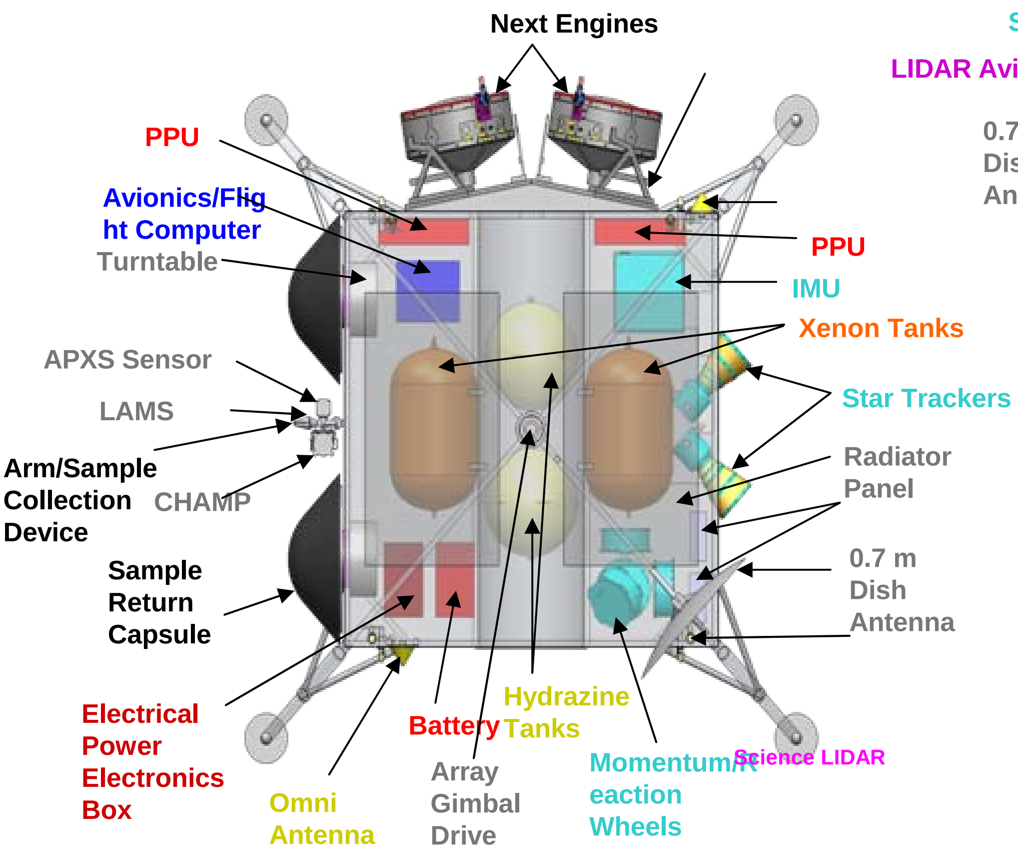
Multi-body sample return is enabled using electric propulsion

SR and Lander Science (Top View)

Science package and mission operations based on input from APL science team

Science instruments identified for in-situ analyses and for sample characterization





NEXT 1+1 ion propulsion system

Single ultra flex Orion based solar array

Enough xenon and hydrazine for three landings, two departures, and required transfers

Findings and Comparison to Dawn

	NEARER	Dawn
Solar Array Po	6.5 kW	10.3 kW
Mission Duration	6.9 years	7.8 years
Spacecraft Dry Mass	680 kg	715 kg
Required Propellant	380 kg	450 kg*
Number of Thrusters	1+1 NEXT	2+1 NSTAR

Mission was not viable within the Discovery cost cap.

NEXT, BPT-4000, and HiVHAC can all deliver basic sample return package

NEXT can deliver substantial mass for additional science package and propellant for 3rd target

Mission costs:	NEXT	$568M
	HiVHAC	$539M
	NEXT w/ Full Science +	$641M ($81M for science)

Multi-body sample return mission appears cost feasible within NF cost cap

ISPT EP products offer significant small body mission benefits with increased science over chemical alternatives.

ISPT's New Focus

The focus of ISPT will be on **"Sample Return Propulsion Technologies"** and one of its areas of interest is for **"Small Body Missions"**

Completing analyses, but near-term primary propulsion solutions currently exist

- Chemical, NEXT, BPT-4000, and HiVHAC

One area identified has been near-body and surface operations

Landing without contaminating samples

- propellants
- operations

Surface mobility and collection stability

- unknown surface properties
- weak gravity field

Looking for options that will benefit a wide range of future competed missions

ISPT will be working closely with science community and implementers before proceeding with technology investments

Summary

- Electric propulsion offers significant advantages for small body missions
  - NEXT is available for current and future AOs
  - HiVHAC has potential for a future lower cost EP option
- Technology challenges may still exist for small body missions
  - The ISPT project is planning to investigate propulsion needs for near-body operations and surface mobility

    - Feedback from the science community (SBAG)

    - Site visits with mission implementers (APL, GSFC, JPL, etc.)

    - Community workshop
- Prioritization of bodies would be very beneficial
  - Cacus rendezvous is a Discovery class EP mission, flagship chemical mission
  - Is Cacus a high valued science target? Tantalus?