2010 ASTEROID RETURN MISSION FEASIBILITY STUDY

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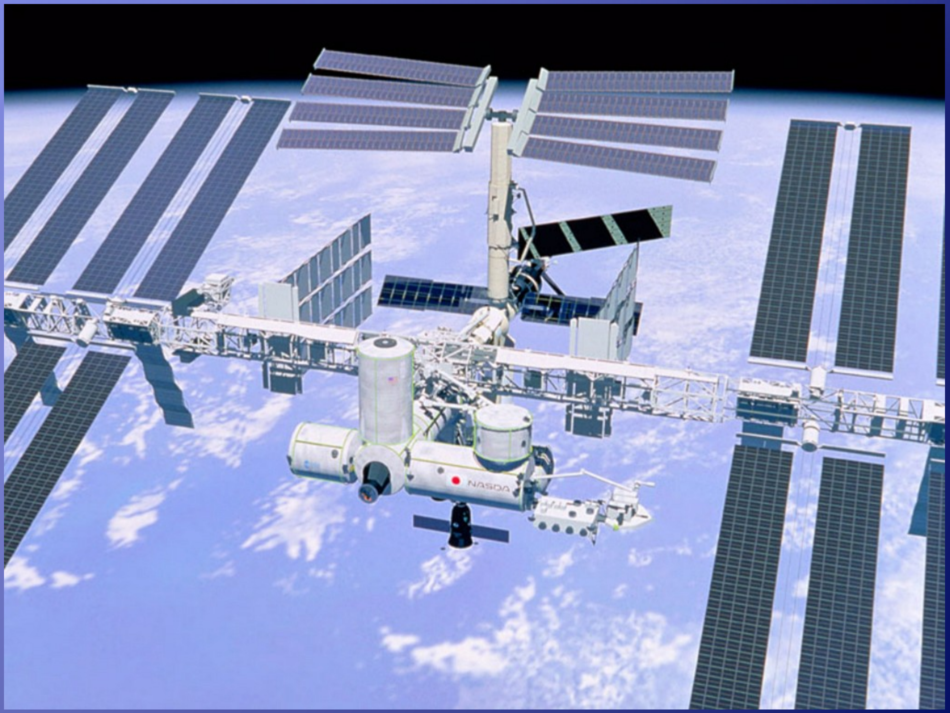
Feasibility Investigation

We conducted a study to investigate the technical feasibility of returning to the International Space Station (ISS) an entire near-Earth Asteroid (NEA)

- Supported by a NASA Innovation Fund in 2010



Why Return an Entire Asteroid?

- Scientific investigation.
- Evaluation of its resource potential for exploration and commercial use.
- Determination of its internal structure and other aspects important for planetary defense activities.
- To serve as a testbed for human operations in the vicinity of an asteroid.
- The ISS would serve as:
  - A geology lab in space
  - A test bed for learning how to handle and process asteroid material in space

Expanding on this will be one of the key objectives of the Kiss Study

Self-Imposed Ground Rules

1. Launch by the end of this decade
2. Require only a single Evolved Expendable Launch Vehicle (EELV)
3. Total round-trip flight time of ~5 years
4. Select an asteroid that has an unrestricted Earth return Planetary Protection categorization
5. Return asteroid to the ISS

The Workshop will need to determine a similar set of ground rules

What Size Asteroid?

- Even very small asteroids are quite massive
- A 2-m diameter asteroid may have a mass of ~10,000 kg
- ***Therefore, a key feasibility issue is how to find and characterize such a small object***

Asteroid Diameter (m)	Asteroid Mass (kg)		
	1.5 g/cm^3	2.5 g/cm^3	3.5 g/cm^3
1.0	790	1,310	1,830
1.5	2,650	4,420	6,190
2.0	6,280	10,500	14,700
2.5	12,300	20,500	28,600
3.0	21,200	35,300	49,500

Relative size of a ~10,000-kg NEA and an astronaut

Astronomers inspect a big stony-iron meteorite that was found in Altay prefecture, Xinjiang Uygur autonomous region, on **July 17, 2011**. The above-earth part of the rock is 2.2 meters long and 1.25 meters tall, with a width of 1.2 meters (average data). Its weight is estimated at 25 tons. [Photo/Xinhua]

Why Now?

This is the right time to investigate the feasibility of this mission.

- The capability for identifying sufficiently small NEOs is just becoming or is projected to become available in the next few years
- Sufficiently large solar electric propulsion systems can be developed that enable the return an entire small NEO to low Earth orbit with a reasonable flight-time.
- The ISS makes an ideal platform for experimenting on this object in micro-gravity and eliminates the need to return the entire object to the Earth's surface.
- Need ISS operations to continue beyond 2025.

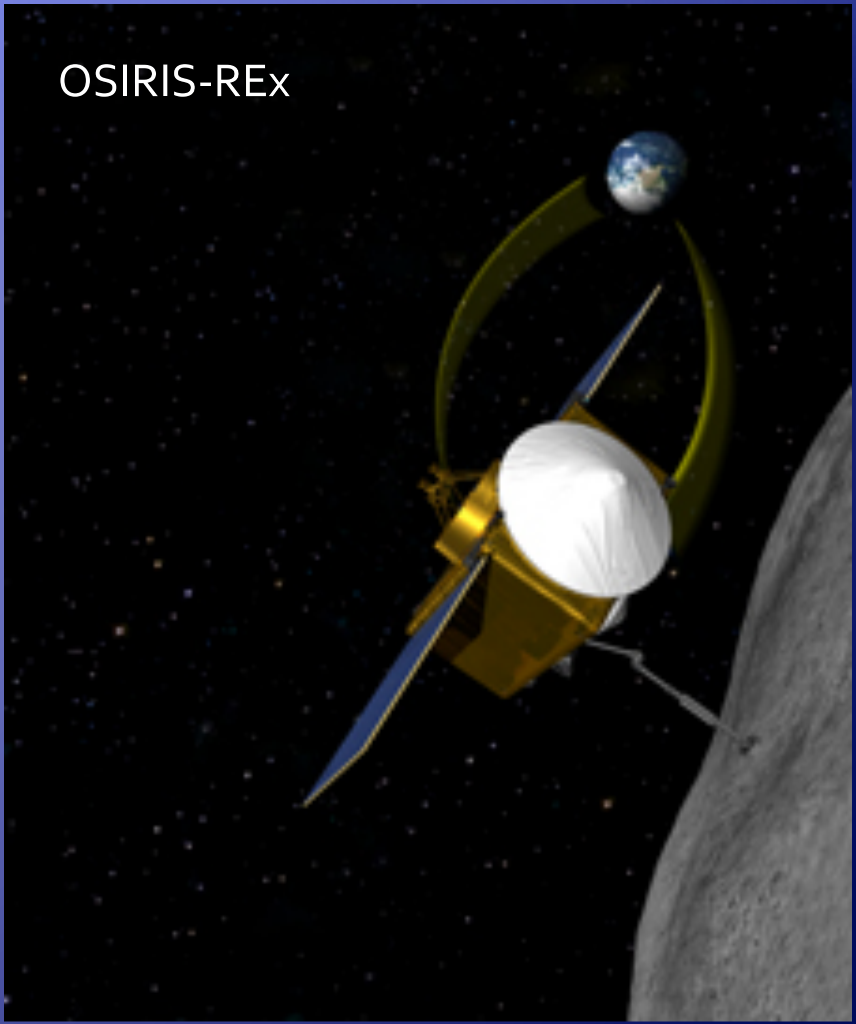
Perspective

The Apollo missions returned 382 kg of moon rocks in six missions.

Hayabusa-2 seeks to return 1 gram of near-Earth asteroid material by 2020.

The newly-selected New Frontiers mission OSIRIS-REx seeks to return 60 grams of surface material from a NEA by 2023.

The Asteroid Return Mission would return ~10,000 kg by 2025.



Key Feasibility Issues

1. Is it possible to identify and characterize sufficiently small and scientifically interesting NEAs?
2. How would you capture, secured to the spacecraft, and de-tumble the NEA while in deep-space?
3. Are there low-thrust trajectories that would be consistent with returning a 10,000-kg asteroid in a total flight time of ~5 years?
4. Are there solar electric propulsion system technologies projected to be available this decade that would be consistent with the low-thrust trajectory analysis?
5. Would the overall flight system mass be consistent with a single EELV launch?
6. It is feasible to approach and dock a spacecraft containing a 10,000-kg asteroid with this ISS?
7. Could a 10,000-kg asteroid be safely handled at the ISS?
8. How would you curate an entire Asteroid at the ISS? What scientific investigations could/should be performed onboard the ISS, and what investigation should be performed on the ground?

Identification and Characterization of ~2-m NEAs

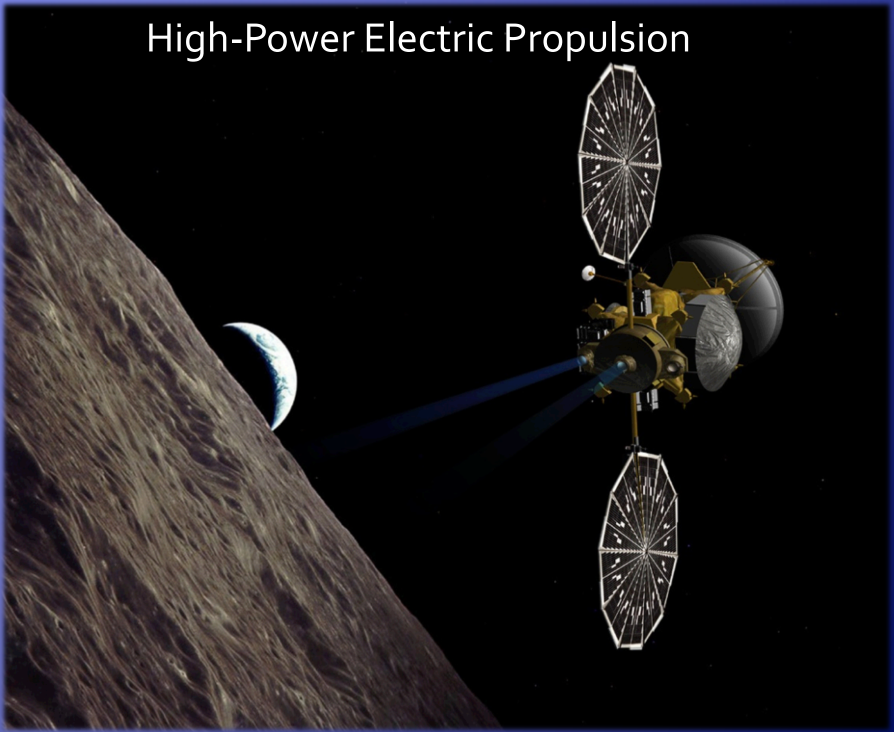
See Don Yeomans' talk following this one.

Transportation

"Like all other endeavors so far attempted in space, the limiting factor on profitability of space resource use is transportation cost."

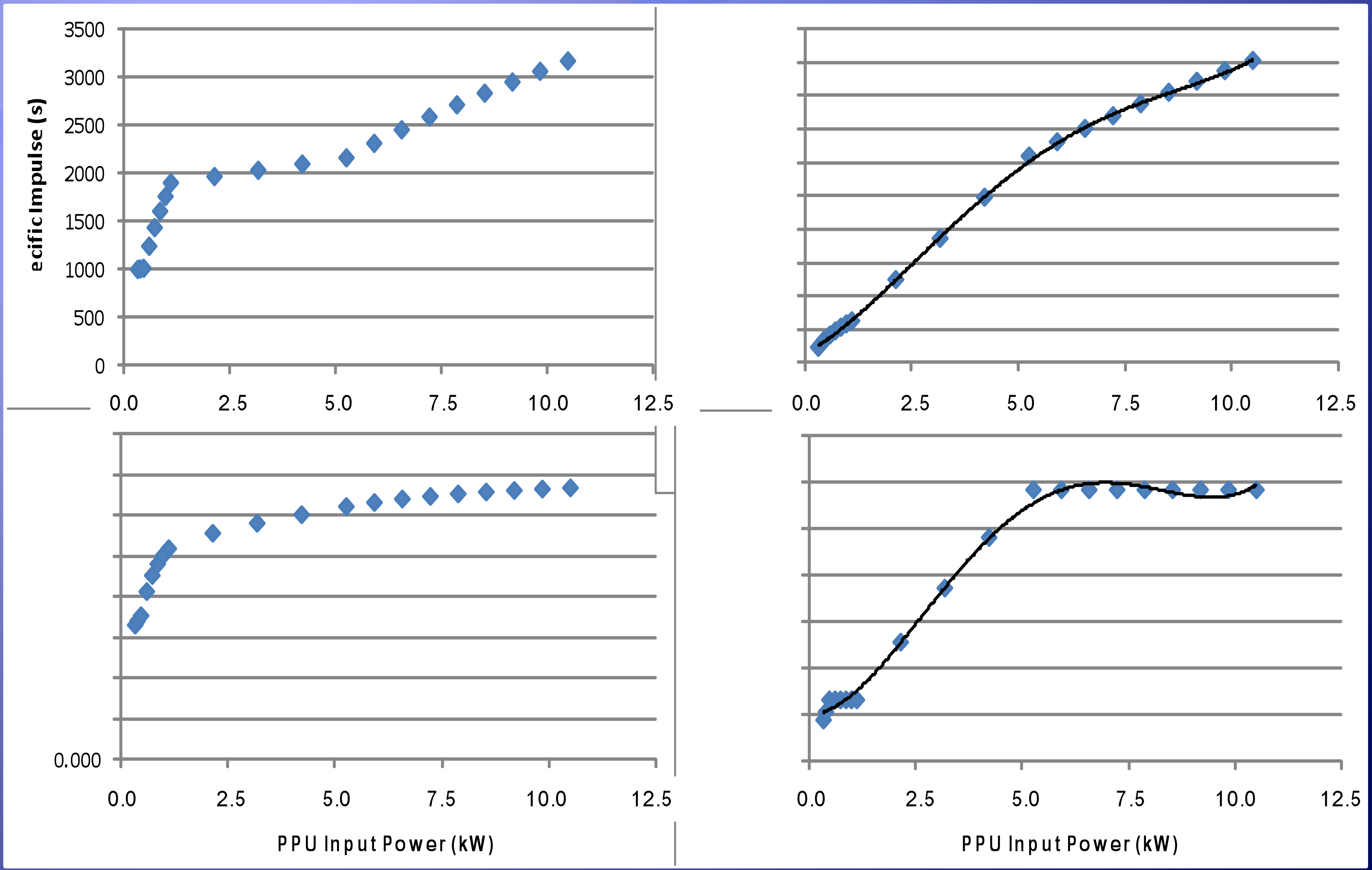
-- John Lewis

We assumed the use of solar electric propulsion (SEP) for all of the post-launch ΔV with the expectation that this would provide the lowest transportation cost

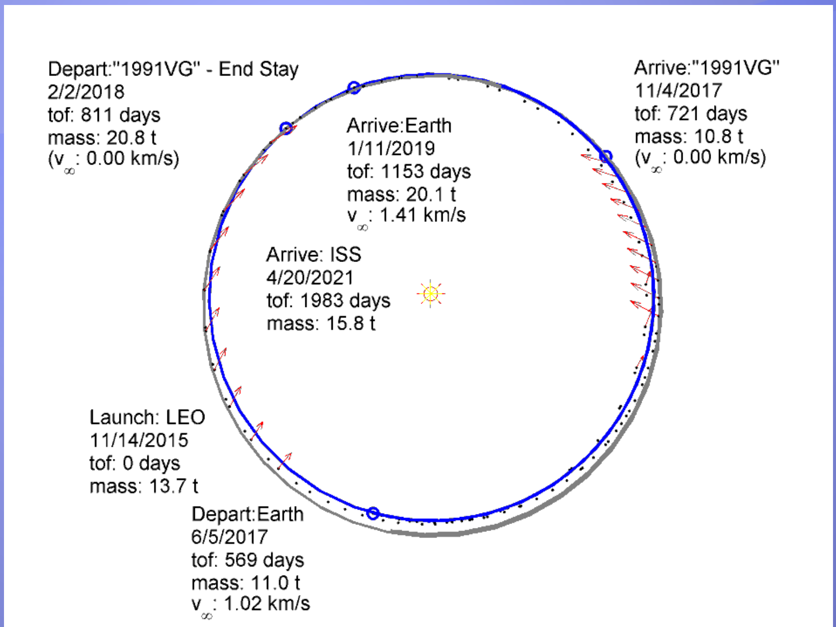


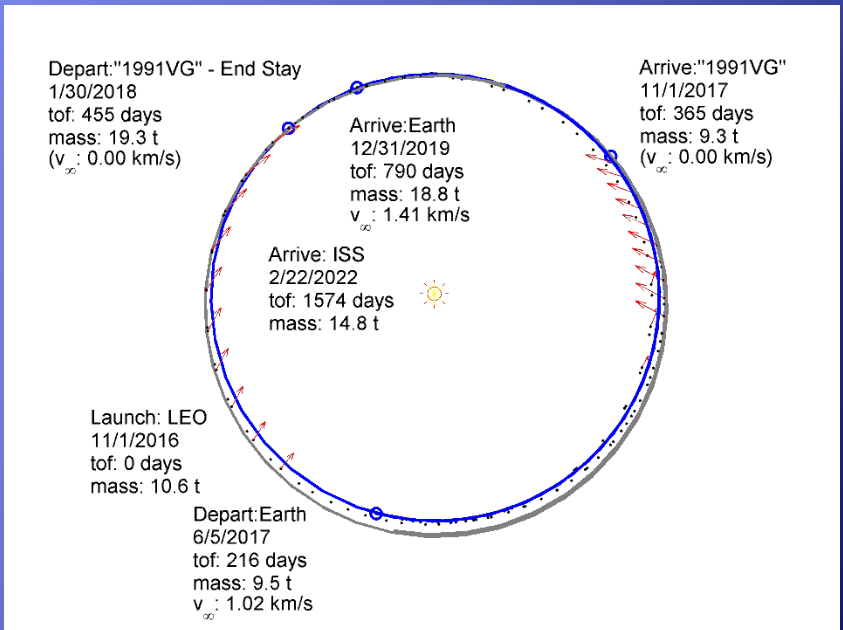
A 40-kW electric propulsion system is required to meet our self-imposed ground rules

The SEP System Assumed the Following Hall Thruster Performance



Trajectory Analysis



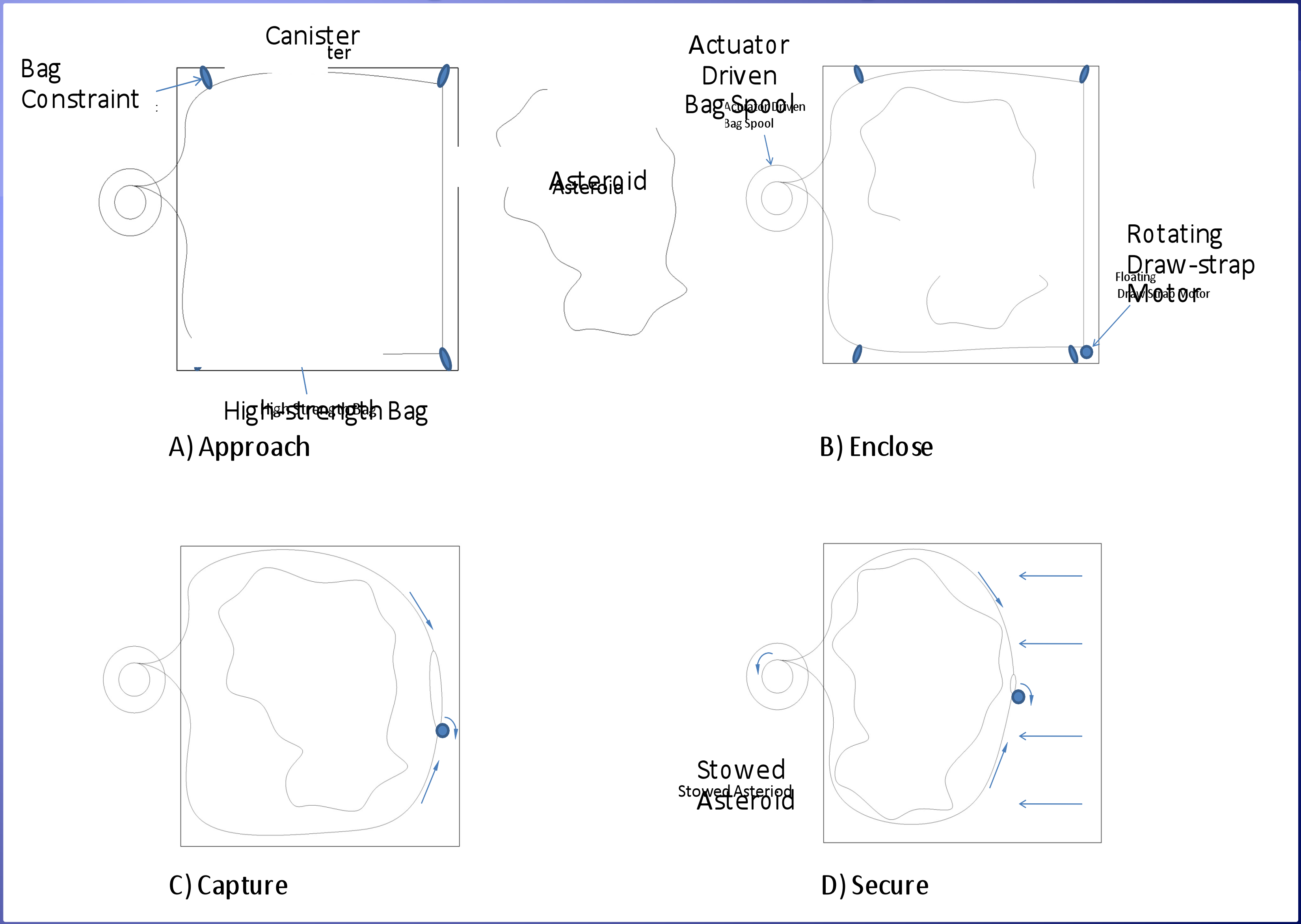


- Launch to LEO
- 5.4-year flight time

- Launch to GTO
- 4.3-yr flight time

See Damon Landau's talk on Low-Thrust SEP Trajectories

Asteroid Capture Concept



See Brian Wilcox talk on Capturing Non-Cooperative Objects

Mass Estimate for a 40-kW SEP Vehicle

- Launch mass of 13,700 kg
- Return ~10,000 kg Asteroid
- Ratio of 73%

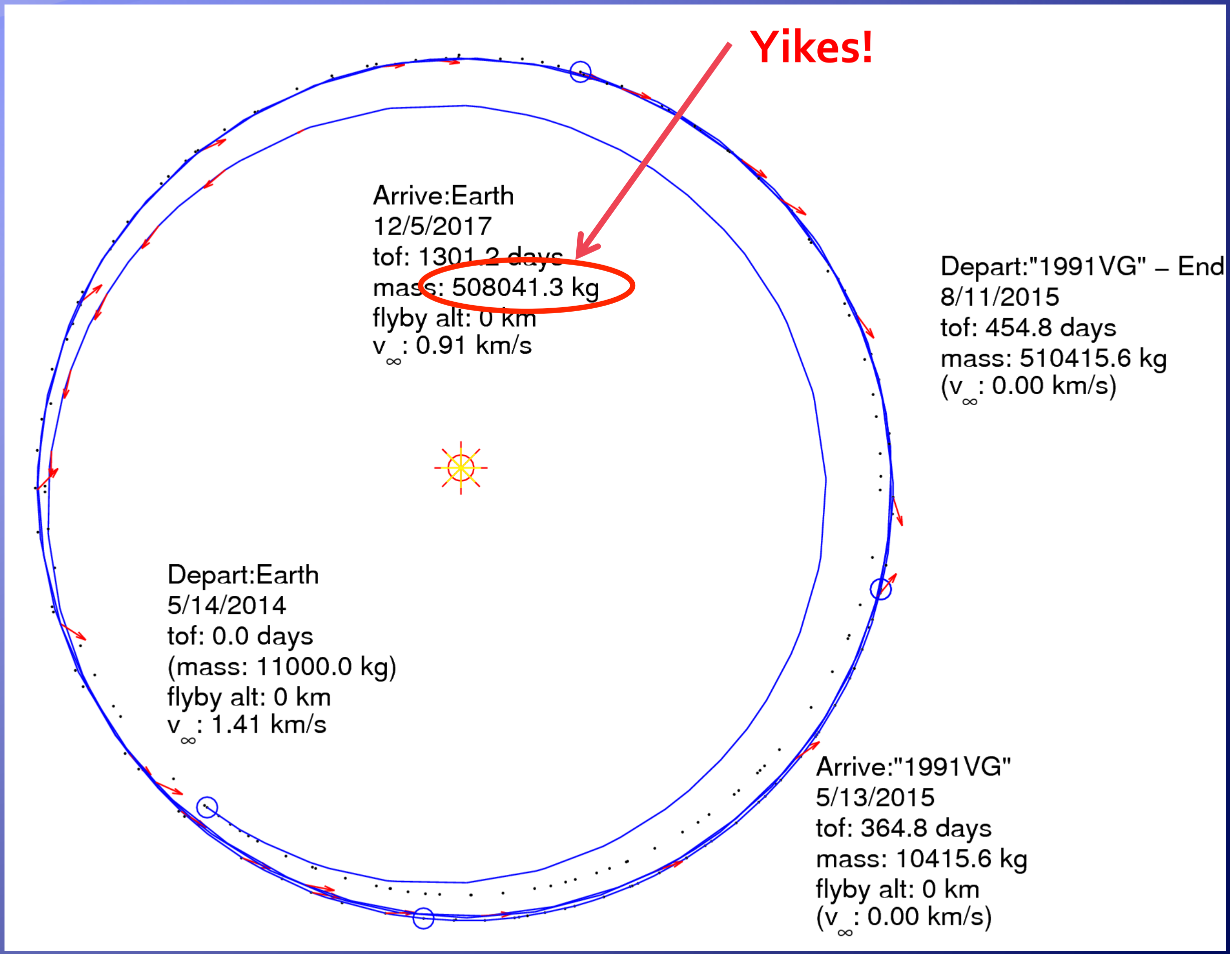
Subsystem/Component	Unit Mass CBE	# of Flight Units	Total Mass CBE
Structures & Mechanism Subsystem			**375**
Ion Propulsion Subsystem (IPS)			**694**
Hall Thruster	19	5	97
Hall Thruster Gimbal	8	5	39
Xenon Pressure Management Assy	9	1	9
Xenon Flow Controller	6	5	32
Xenon Tanks	46	8	369
Latch Valves	0.1	5	1
Service Valves	0.1	5	1
Lines, Bkts, Harness, Misc	14	1	14
Power Processing Unit (PPU)	19	5	97
PPU / Thruster Harness	7	5	35
Electrical Power Subsystem (EPS)			**633**
Solar Array Wings	114	2	227
Solar Array Hold/Release Mechanism (HDRM)	10	2	20
Solar Array Drive Assembly (SADA), 1 Axis	25	2	50
Solar Array Drive Electronics (SADE)	10	2	20
Fuse Assy	10	1	10
Li-Ion Battery	68	2	136
Low Voltage Power Distribution Electronics (LVPDU)	30	1	30
High Voltage Power Distribution Unit (HVPDU)	140	1	140
Reaction Control Subsystem (RCS)			**101**
Command & Data Handling (C&DH)			**24**
Attitude Control Subsystem (ACS)			**14**
Thermal Control Subsystem (TCS)			**244**
RF Communications (Telecom)			**32**
Spacecraft Harness			**100**
Total Bus Dry Mass (CBE)			**2218**
Payload			**250**
Capture Subsystem	200	1	200
Instruments	50	1	50
Flight System Dry Mass CBE			**2468**
Xenon Mass (includes 10% contingency)			**9236**
Hydrazine Mass			**775**
Total Flight System Wet Mass			**12479**
Launch Vehicle Capability (Atlas V 521)			**13700**
Flight System Dry Mass Allocation			**3689**
Flight System Dry Mass Margin (Alloc. - CBE) / Alloc.			**33.1%**

What if we bring the Asteroid to a high-Earth orbit instead?

What size asteroid could we return?

Asteroid Return to High-Earth Orbit

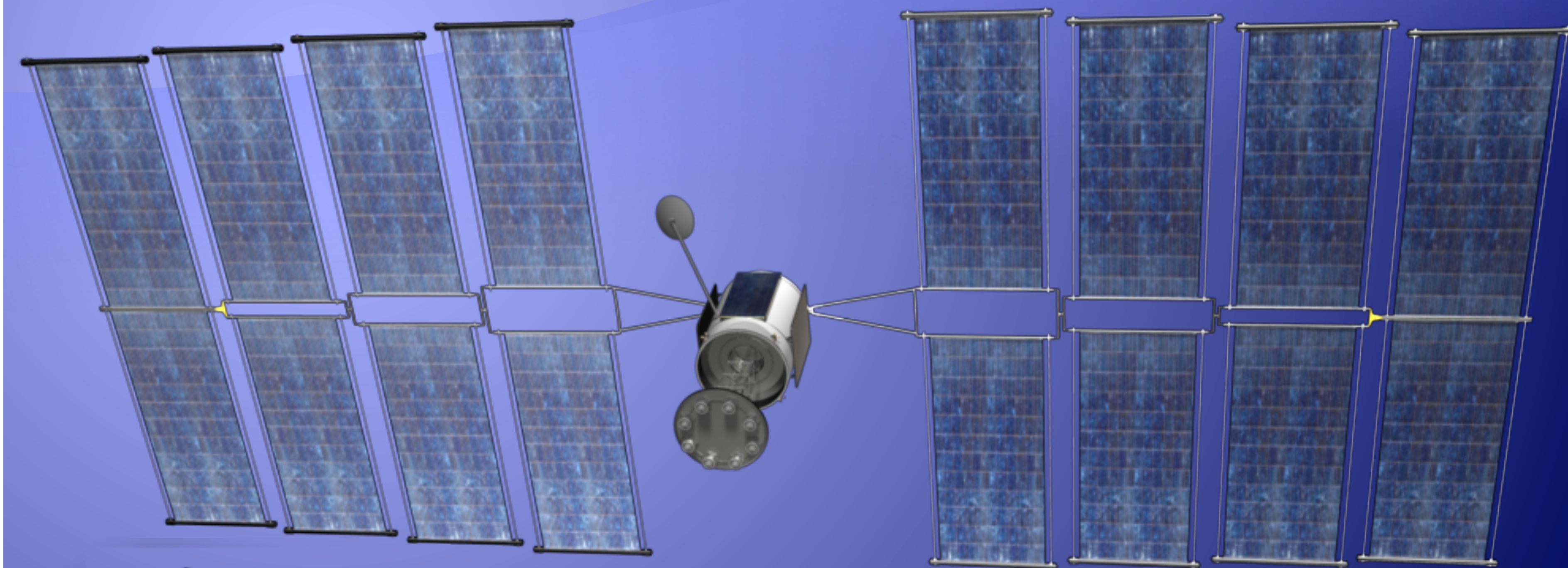
- Initial Launch Mass: 13,700 kg
- Total Flight Time 5 years
- Return Mass 500,000 kg
- **Mass Amplification 35-to-1**

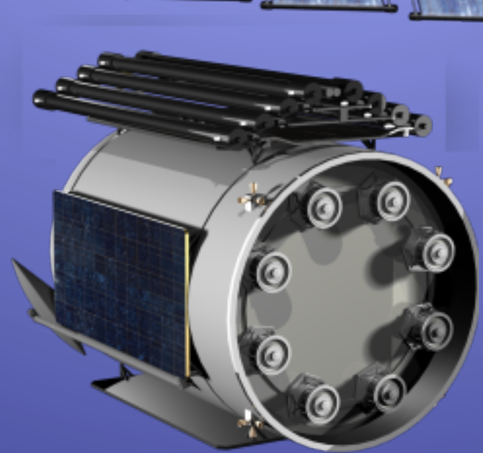


Asteroid Sizes Revisited

Asteroid Diameter	Asteroid Mass (kg)		
	1.5 g/cc	2.5 g/cc	3.5 g/cc
1.0	785	1,309	1,833
2.0	6,283	10,472	14,661
3.0	21,206	35,343	49,480
4.0	50,265	83,776	117,286
5.0	98,175	163,625	229,074
6.0	169,646	282,743	395,841
7.0	269,392	448,986	628,580
8.0	402,124	670,206	938,289
9.0	572,555	954,259	1,335,962
10.0	785,398	1,308,997	1,832,596
11.0	1,045,365	1,742,275	2,439,185
12.0	1,357,168	2,261,947	3,166,725
13.0	1,725,520	2,875,866	4,026,213
14.0	2,155,133	3,591,888	5,028,643
15.0	2,650,719	4,417,865	6,185,011

400-kW SEP Vehicle for Human Missions to a Near-Earth Object





- 400-kW input to the electric propulsion subsystem
- Includes 8 each 57-kW Hall Thrusters and PPUs
- Operates 7 thrusters simultaneously with one cold spare
- Produces a thrust of 24 N at an Isp of 2,000 s

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SEP Technology

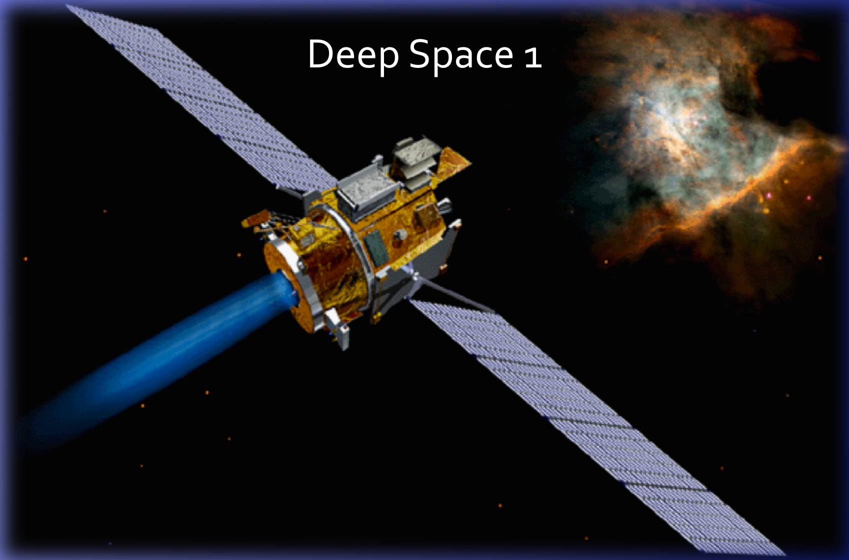
SEP Has Been Used on Two NASA Deep Space Missions – So Far

Deep Space 1:

- Technology Demonstration Mission
- Retired the following risks:
  - Thruster life
  - Guidance, navigation and control of an SEP spacecraft
  - Mission operations Costs
  - Spacecraft contamination
  - Communications impact
  - Electromagnetic compatibility

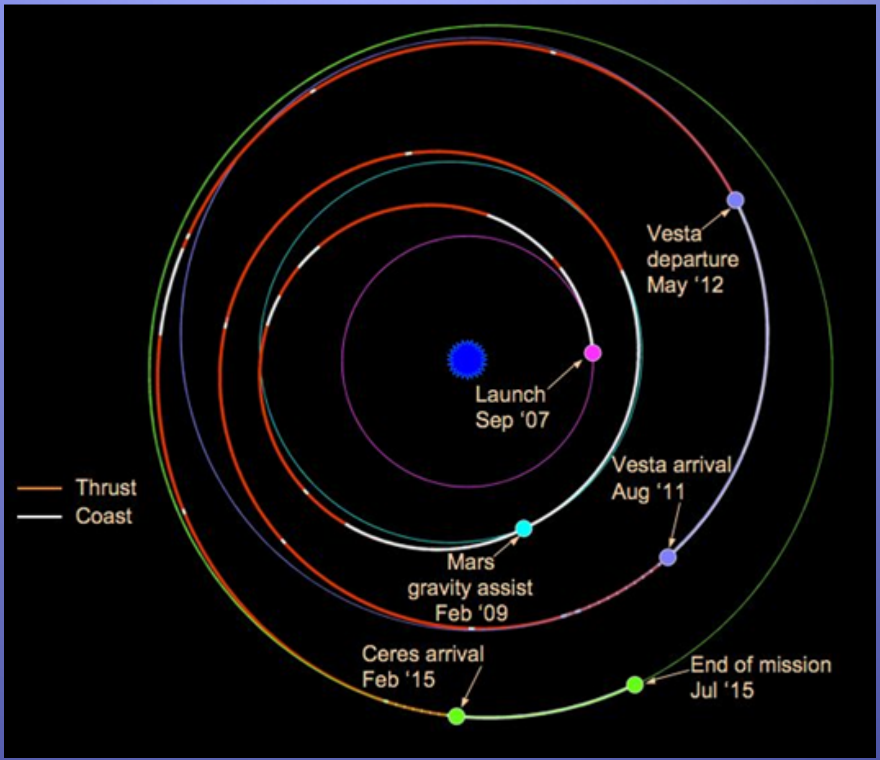
Dawn:

➢ **The use of SEP on Dawn reduced the cost of a multiple main belt asteroid rendezvous mission from New Frontier-class to Discovery-class – a difference of over $200M**



Current Status: Dawn

- Will orbit both the main-belt asteroid Vesta and the dwarf planet Ceres
- 1218 kg launch mass (dry mass of 750 kg)
- 10-kW Solar Array (at 1 AU)
- Has provided a ΔV of 6.8 km/s so far, this will be ~**11 km/s** at the end of the mission



Current Status: International

SMART-1: Small Mission for Advanced Research in Technology

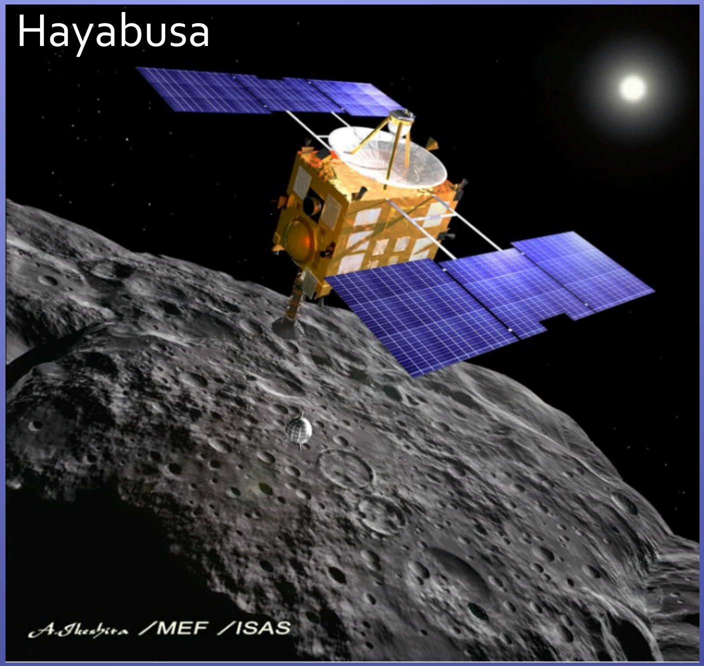
- Launched: September 2003

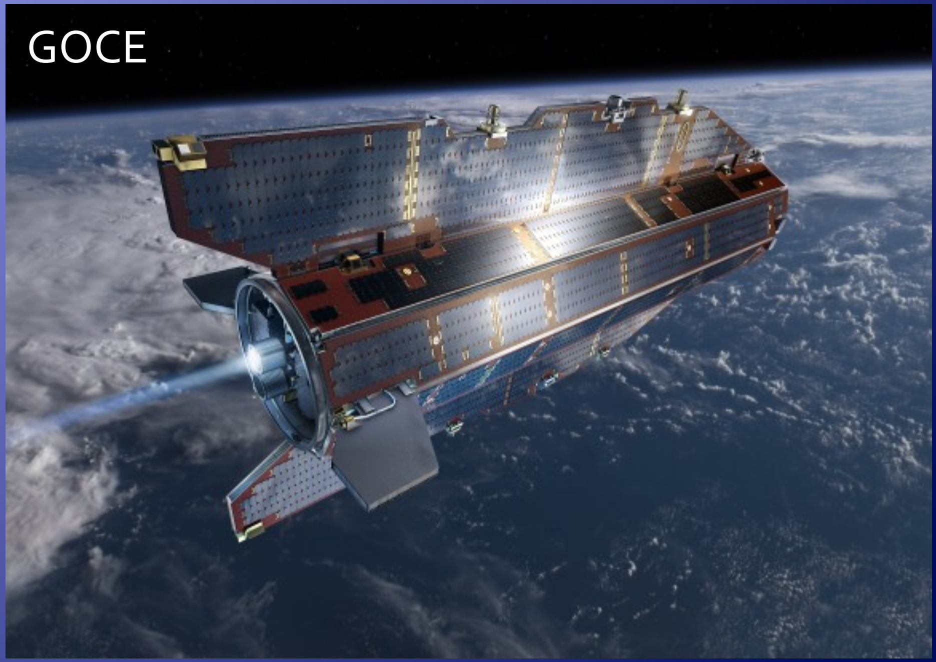
Hayabusa: Near-earth asteroid sample return

- Launched: May 2003
- Returned: June 2010

GOCE: Gravity field and steady-state Ocean Circulation Explorer

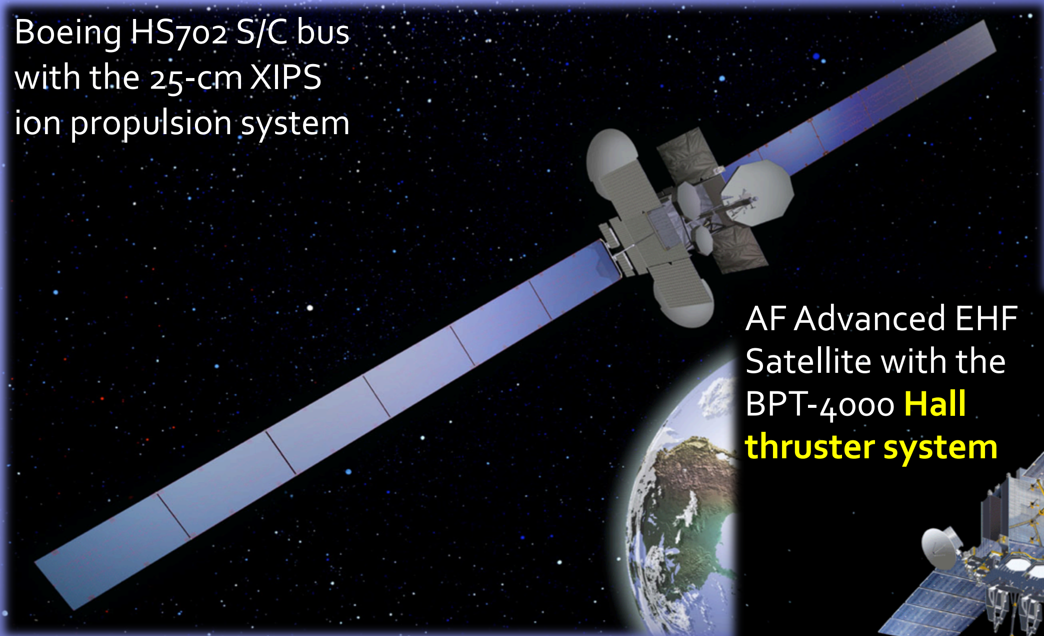
- Launched: March 2009



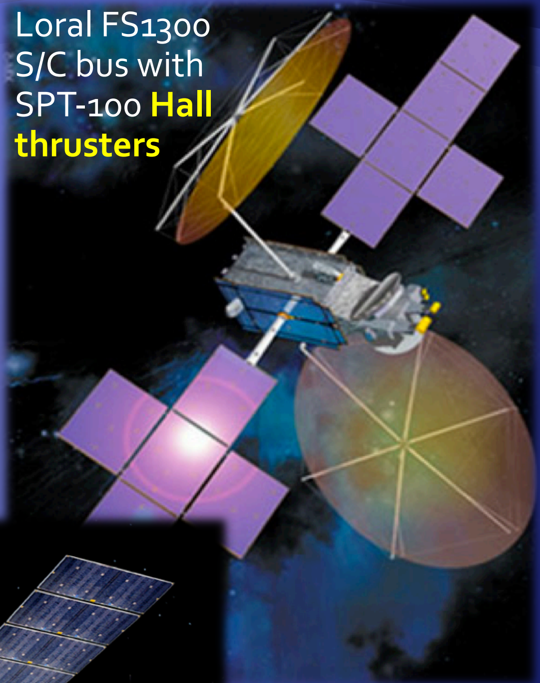


Current Status: Commercial

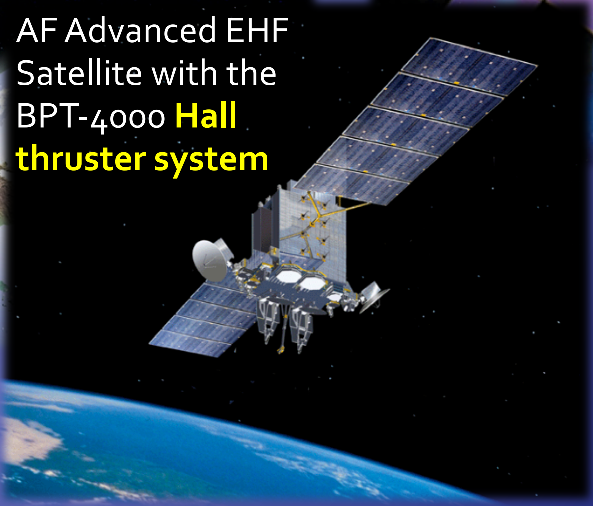
- **> 53 commercial satellites** now flying with xenon ion propulsion
- Commercial satellites now flying with up to **24 kW** of solar power at beginning of life



Boeing HS702 S/C bus with the 25-cm XIPS ion propulsion system



Loral FS1300 S/C bus with SPT-100 **Hall thrusters**



AF Advanced EHF Satellite with the BPT-4000 **Hall thruster system**

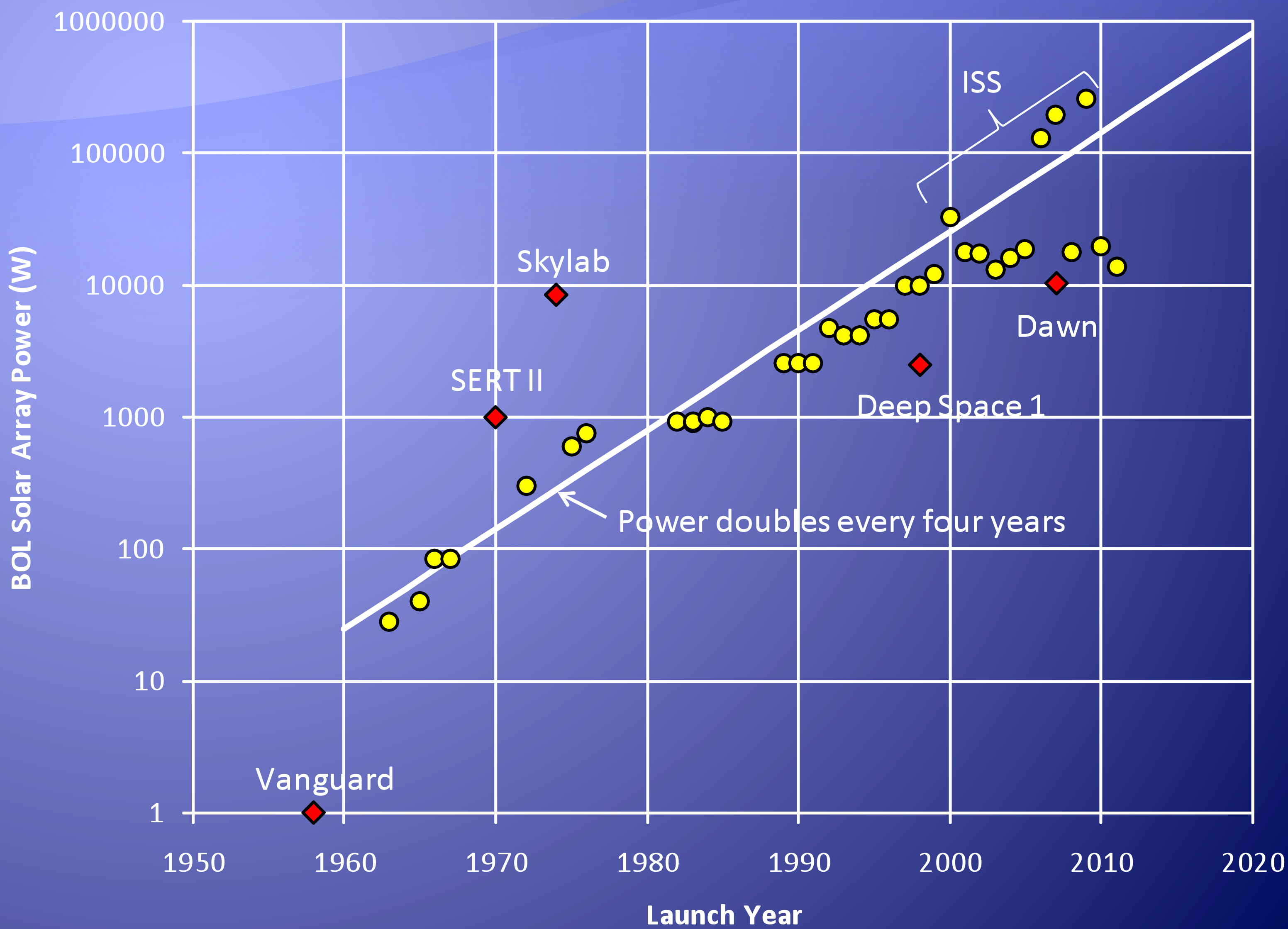
- **High power (> 20 kW) is now routine on commercial satellites**
- **Electric propulsion now used by almost all major satellite providers because it provides a significant economic benefit to the end user**

Operational Satellites with Electric Propulsion

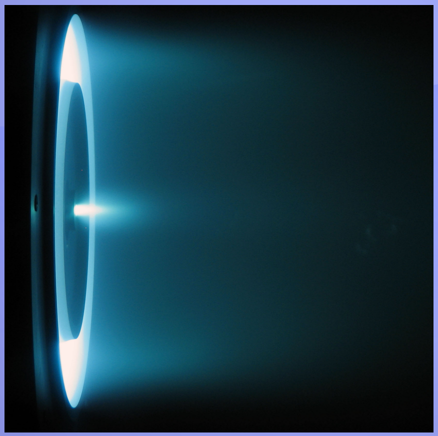
Cumulative Number of Satellites Employing EP = 226
Number of Satellites Employing Aerojet EP = 156

AEROJET

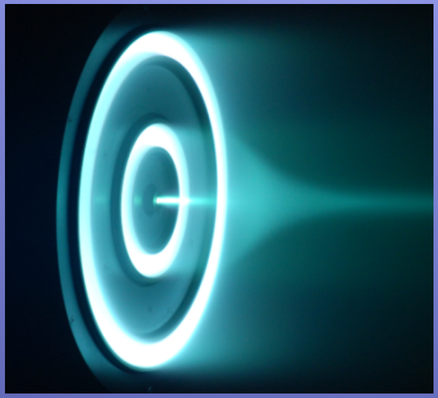
Space Solar Power is the Key



High-Power Hall Thrusters



Hall Thruster



Nested Hall Thruster

- Hall thrusters have extraordinary performance and are extremely scalable
  - Isp's from 1000 to 8000 s
  - Power levels from 200 W to 140 kW
- Magnetic shielding can enable huge advances in the technology
- Nested Hall Thrusters may facilitate high-power operation

Energy Comparison with SSME

SSME

$$P = \frac{1}{2}\dot{m}v^2$$

$$T = \dot{m}v \Rightarrow \dot{m} = \frac{T}{v}$$

$$P = \frac{1}{2}Tv$$

x 3

Vacuum Isp = 453 s → v = 4440 m/s

100% thrust at vacuum: T = 2090 kN

P = 0.5 (2.09 x 10^6 N) (4440 m/s) (3)

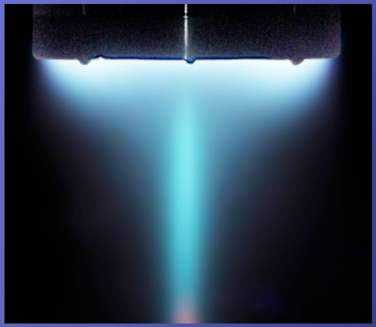
P = 13,900,000 kW (all three engines)

Energy: 8-minute burn

***E* = 1,860,000 kW-hrs (all three engines together)**

Propellant Mass: 835,000 kg

300-kW SEP



x 7

Isp = 2000 s → 21,700 m/s

Thrust : *T* = 18 N (all 7 engines)

Power: *P* = 0.5 (18) (21,700 m/s)

P = 195.3 kW (all 7 engines)

Energy: 10,000-hour burn

***E* = 1,950,000 kW-hrs (all 7 engines together)**

Propellant Mass: 32,500 kg