ASTEROID RETRIEVAL MISSION FEASIBILITY STUDY

May 30, 2012

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Two Workshops – Sep 2011, Feb 2012

Study Objectives

- Determine the feasibility of robotically capturing and returning a small near-Earth asteroid to the vicinity of the Earth using technology available in this decade.

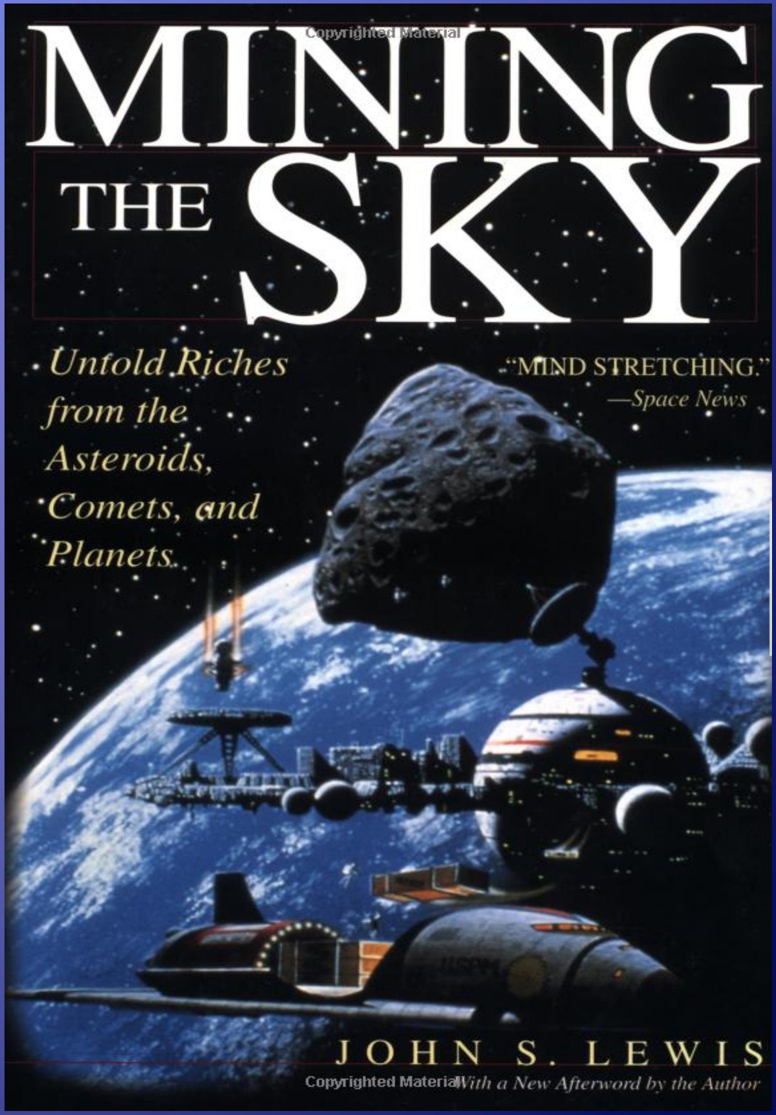
- Identify the benefits to NASA, the scientific community, the aerospace community, and the general public of such an endeavor.

- Identify how this endeavor could impact NASA's and the international space community's plans for human exploration beyond low-Earth orbit.

Introduction

The idea to exploit the natural resources of asteroids is older than the space program.

- In 1903 "exploitation of asteroids" was one of Tsiolkovskii's fourteen points for the conquest of space.
- In 1996, detailed in John Lewis' book *Mining the Sky*
- It has long been a major theme of science fiction stories.



Why Now?

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

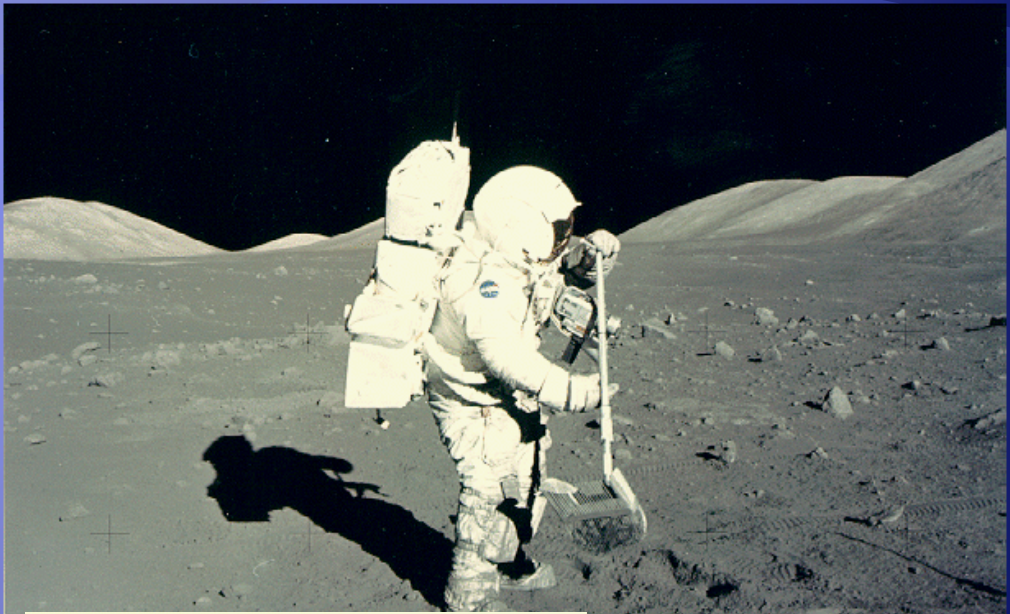
1. The capability for discovering and characterizing sufficiently small NEAs is just becoming available .
2. Sufficiently large solar electric propulsion systems required to transport the NEAs are just becoming available.
3. The human spaceflight activity is planning for a crewed exploration capability in cislunar space in the 2020's.

Perspective

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

The OSIRIS-REx mission will return at least 60 grams of surface material from a NEA by 2023.

We evaluated the feasibility returning an entire ~7-m dia. near-Earth asteroid, with a mass of order 500,000 kg, to a high lunar orbit, by 2026.



OSIRIS-REx

Why Return an Entire Asteroid?

- Placing a 500-t asteroid in high lunar orbit would provide a unique, meaningful, destination for astronaut crews in the next decade.
- It would provide a high-value target in cislunar space that would *require* a human presence to take full advantage of this new resource.
- It would offer an affordable path to providing operational experience with astronauts working around and with a NEA that could feed forward to much longer duration human missions to larger NEAs in deep space.
- Robotic spacecraft retrieval of significant quantities of valuable resources could be exploited by astronaut crews to enable human exploration farther out into the solar system.
- The capture, transportation, examination, and dissection of an entire NEA would provide valuable information for planetary defense activities.

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Asteroid Mass vs Diameter

Diameter (m)	Asteroid Mass (kg)		
	1.9 g/cm^3	2.8 g/cm^3	3.8 g/cm^3
2.0	7,959	11,729	15,917
2.5	15,544	22,907	31,089
3.0	26,861	39,584	53,721
3.5	42,654	62,858	85,307
4.0	63,670	93,829	127,339
4.5	90,655	133,596	181,309
5.0	124,355	183,260	248,709
5.5	165,516	243,918	331,032
6.0	214,885	316,673	429,770
6.5	273,207	402,621	546,415
7.0	341,229	502,864	682,459
7.5	419,697	618,501	839,394
8.0	509,357	750,631	1,018,714
8.5	610,955	900,354	1,221,909
9.0	725,237	1,068,770	1,450,473
9.5	852,949	1,256,977	1,705,898
10.0	994,838	1,466,077	1,989,675

The International Space Station has a mass of about 450,000 kg

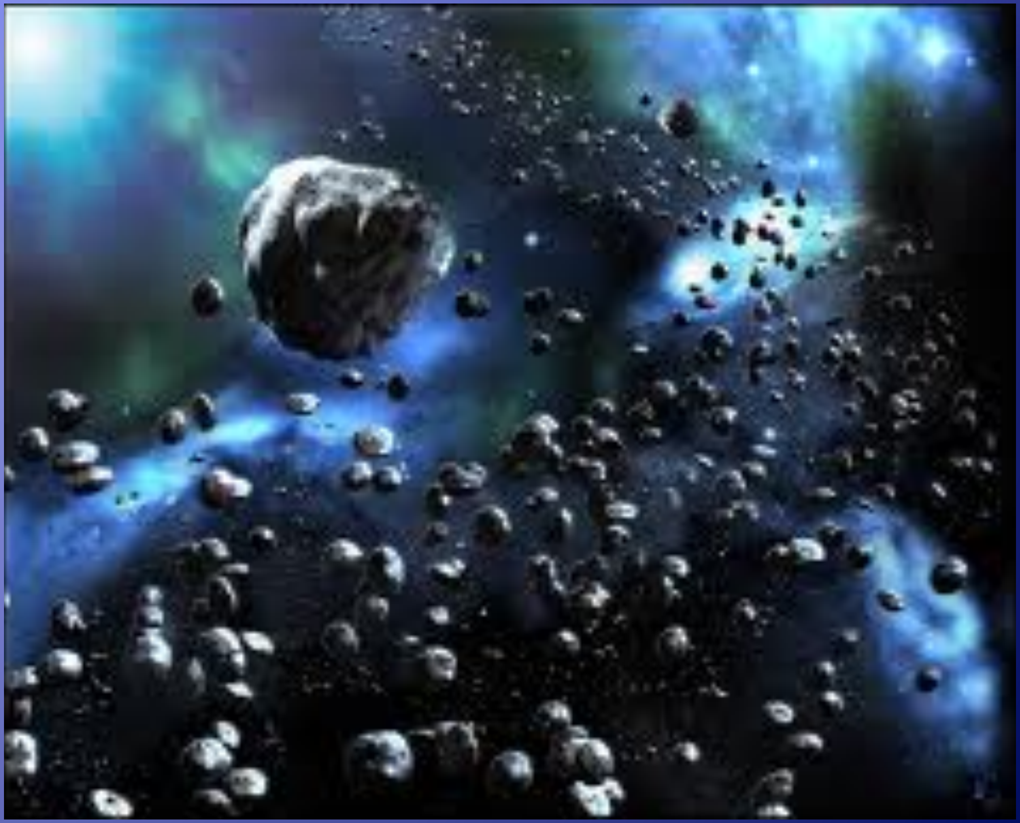
Most NEAs have densities between 1.9 and 3.8 g/cm^3

6.5-m, 340-ton Boulder

21 ½ foot, 340-ton boulder selected by artist Michael Heizer as the centerpiece of his latest creation 'Levitated Mass.' (AP Photo/The Press-Enterprise, Mark Zaleski, File)

Key Feasibility Issues

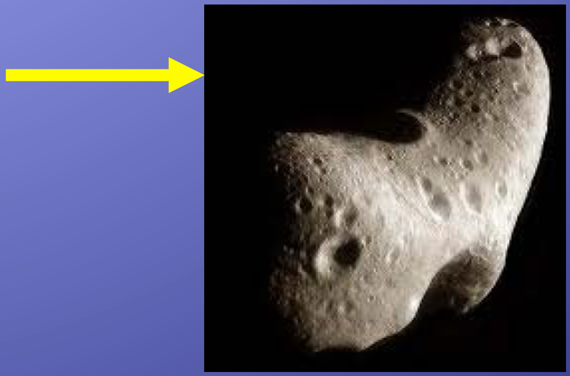
- ☐ Discovery & Characterization
- ☐ Capture
- ☐ Transportation



Finding Them

- **Need to identify sufficient candidates around which a mission can be planed for a launch around 2020.**
  - Larger asteroids easier to discover and characterize but much harder to move.
  - Volume and mass scale as the cube of the diameter, projected area (and brightness) scales as the square of the diameter

- **Determine the overlap between NEAs large enough to be discovered and characterized and those small enough to be moved.** For each candidate target asteroid need to know:
  - **orbit**
  - **spectral type**
  - **size**
  - **shape**
  - **spin state**
  - **mass**
  - **synodic period**

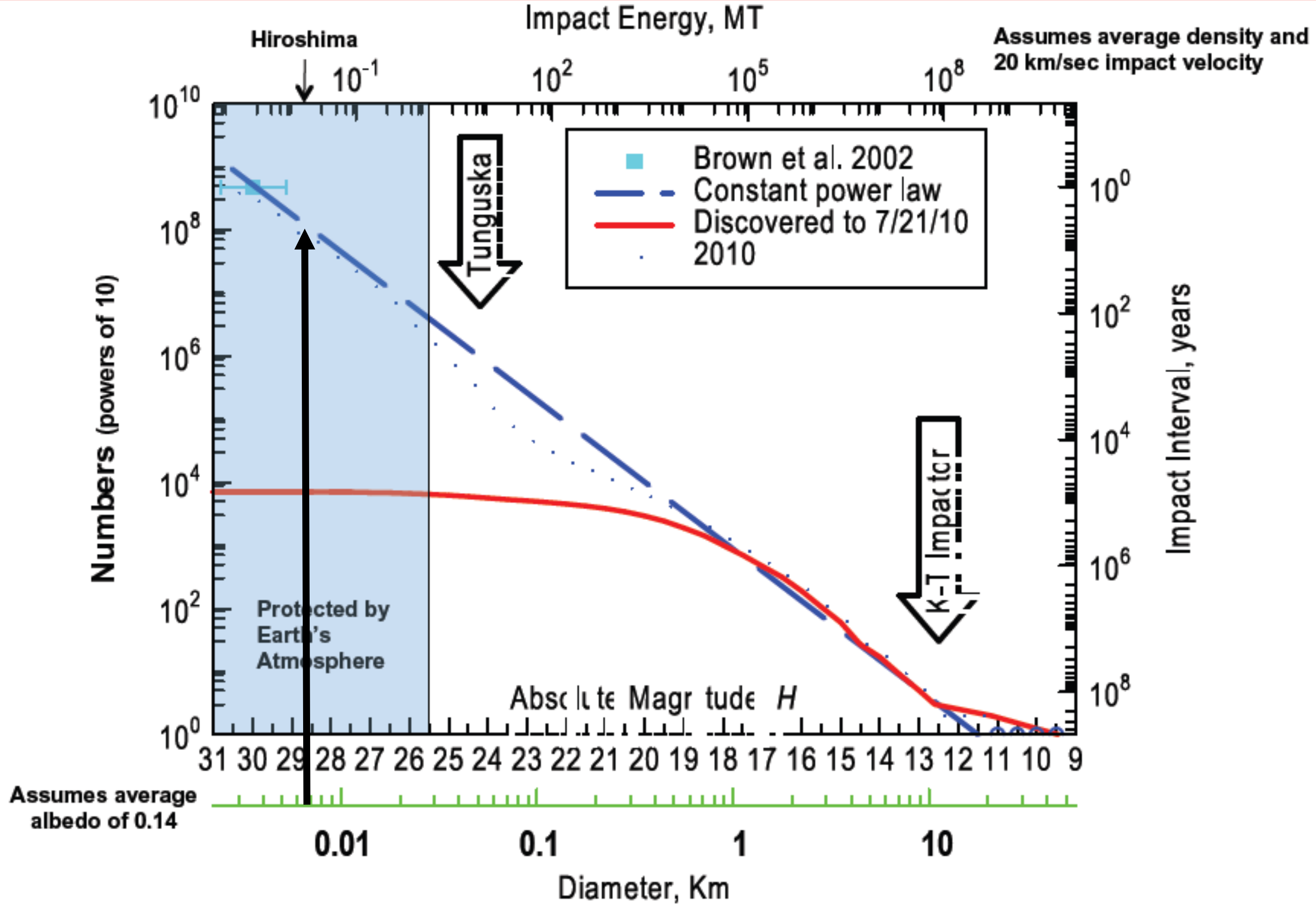


Want a C-Type Carbonaceous Chondrite Asteroid:

- Up to 40% volatiles (water, CO_2, N_2, NH_3, etc.)

~100 Million 7-m NEAs

Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2006)



Required Observation Campaign

- Generally people haven't been interested in very small asteroids
  - 280 NEAs ~10-m diameter discovered to date
  - Few have secure orbits, none have known spectral types

New Telescopes

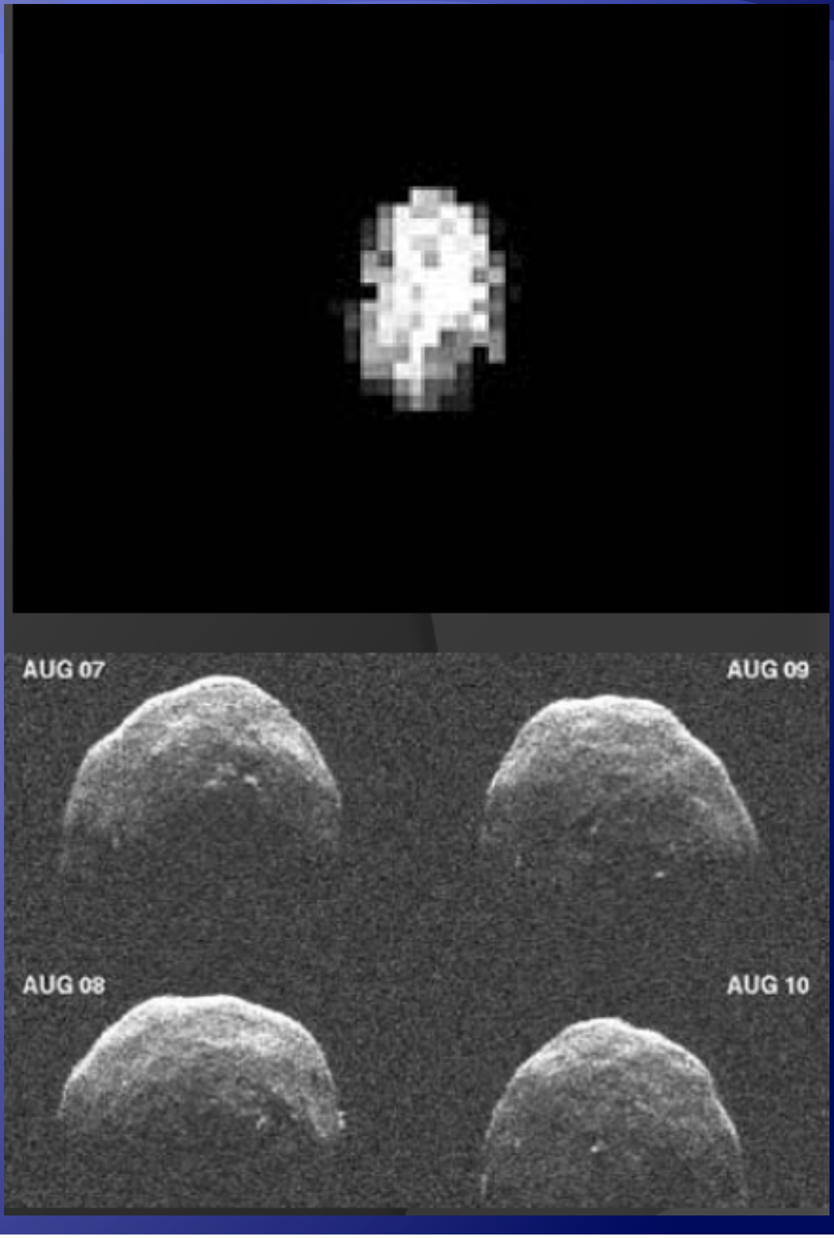
- PanSTARRS 1 on Haleakala in Maui will be about 6.5 time better than the current SOA.
- PanSTARRS 4 will be about 26 times better.
- The Large Synoptic Survey Telescope (LSST), which will be a 8.4 meter aperture wide field telescope in Chile that hopes for first light in 2018. The LSST will be ~150 times more efficient at finding NEOs.

- Observation Campaign
  - Both Pan-STARRS and Palomar Transient Factory (PTF) automatically reject fast-moving objects
  - Step 1: modify pipelines to report such detections
  - Step 2: Screen for follow-up observations which must be made in a matter of hours or days
  - Step 3: Follow-up observations
    - Optical lightcurve
    - Spectroscopy (optical and near-IR)
    - Radar imaging

The Panoramic Survey Telescope & Rapid Response System

Follow-up Measurements

- Thermal infrared flux measurements for object's albedo
  - For small objects dimensions are only accurate to ~30-40%
- Radar ranging measurements to determine orbit and dimensions
  - Goldstone Radar can image asteroids with 3.75-m resolution (expected to improve to 2-m resolution)
- Radar and composition information can reduce asteroid mass uncertainty to a factor of 4 for most objects



Finding Them – Bottom Line

Time Since Discovery	Rate (#/day)	Follow-Up Observation
< 12 hrs	10	Astrometry
< 24 hrs	0.5	Additional astrometry, colors
< 48 hrs	0.2	Lightcurves (spin rate)
< 48 hrs	0.1	Spectroscopy (type)
< 72 hrs	0.06	Radar (orbit, size, spin)

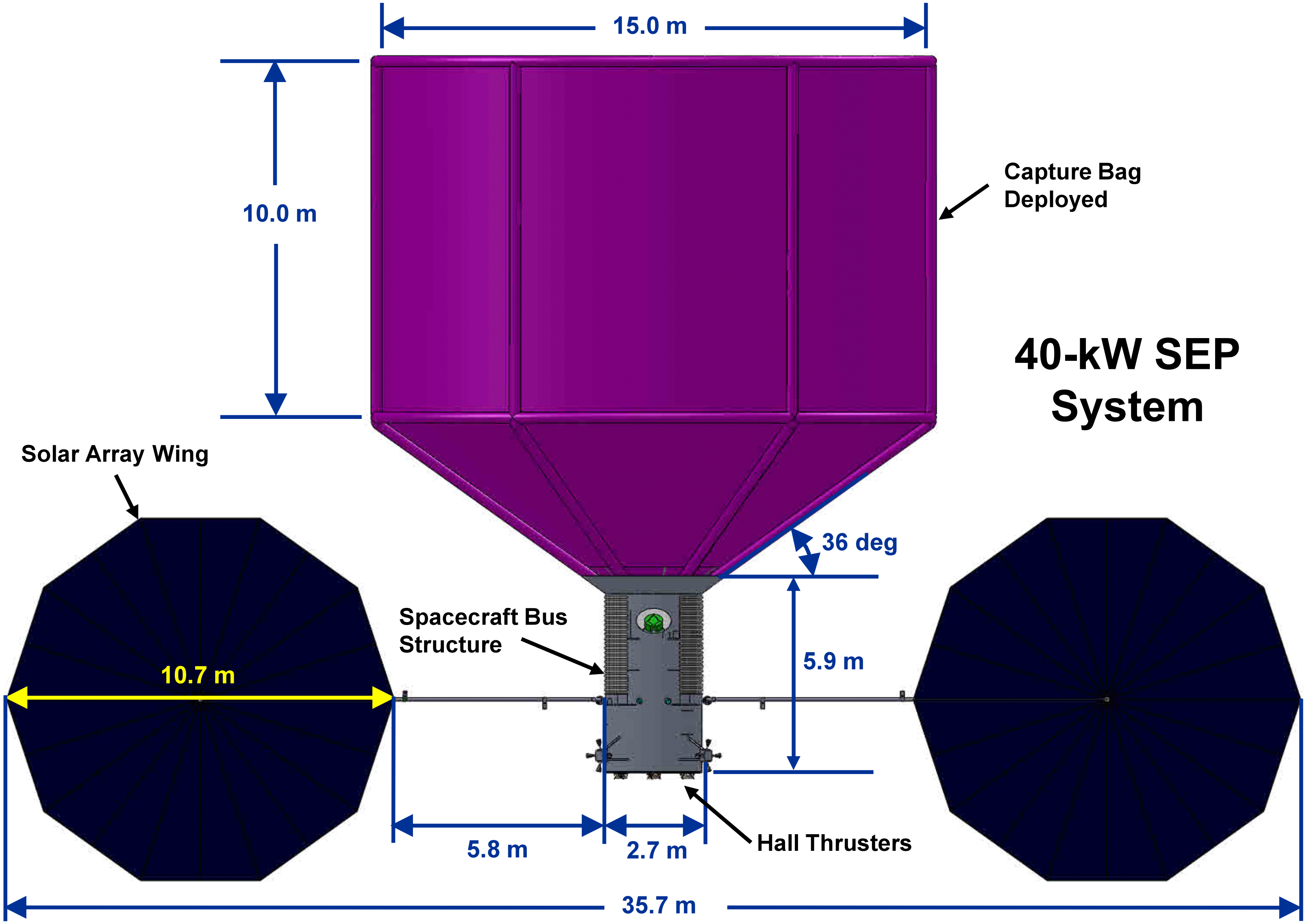
- >3,500 new discoveries per year
- Yield: ~5 good targets per year (right size, type, spin state, and orbital characteristics)

Safety

Belt and Suspenders approach to safety

- A 7-m diameter asteroid is too small to be considered a potentially hazardous object (PHO)
- Carbonaceous asteroids are expected to have the strength of "dried mud" and will breakup harmlessly in the Earth's atmosphere
- The spacecraft will keep the asteroid on a non-collision course with Earth at all times
- The final destination is a high lunar orbit

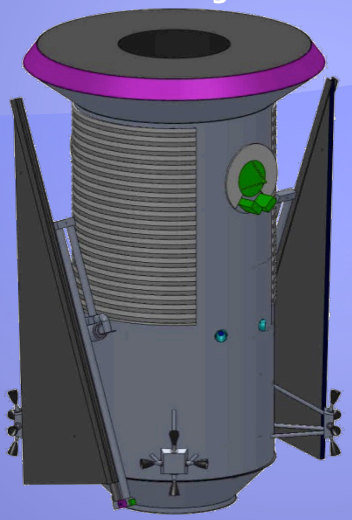
Flight System



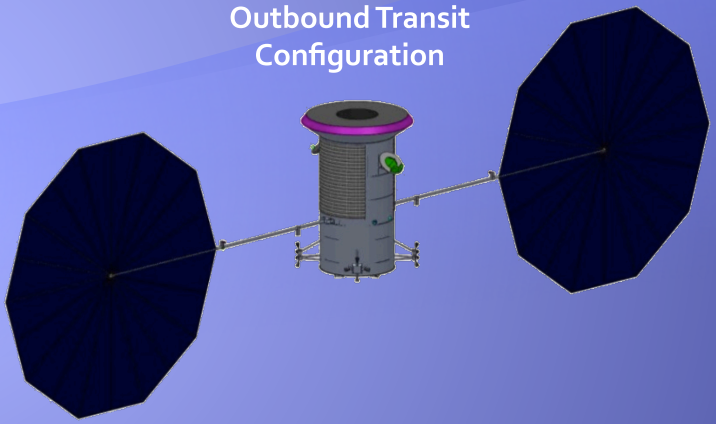
40-kW SEP System

Spacecraft Configurations

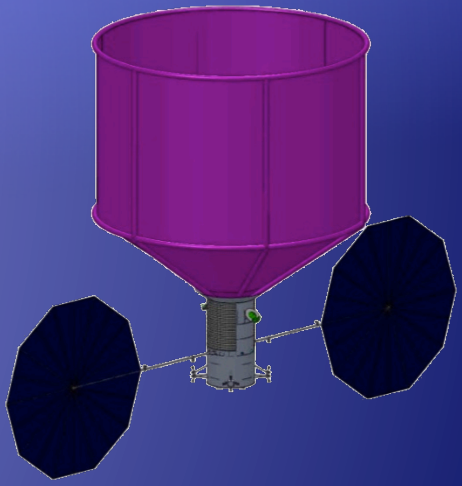
Launch Configuration



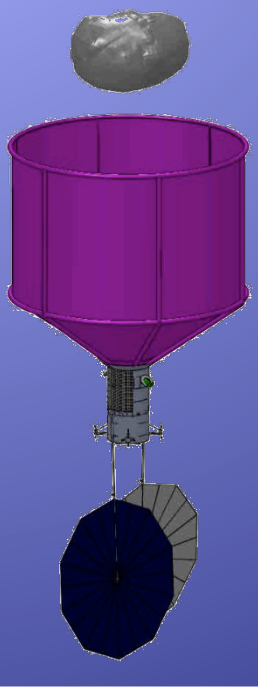
Outbound Transit Configuration



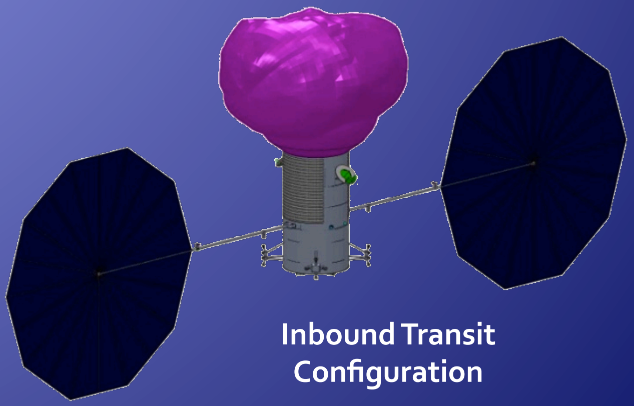
Asteroid Capture Bag Deployed



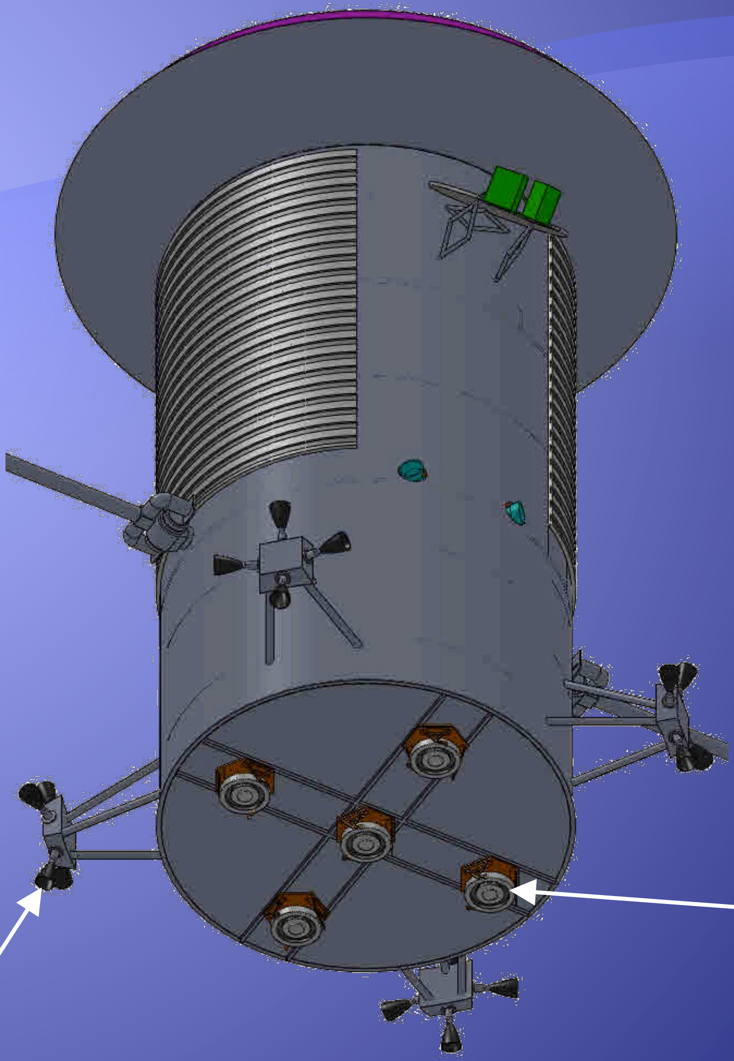
Asteroid Capture Configuration



Inbound Transit Configuration



Spacecraft Thruster Locations



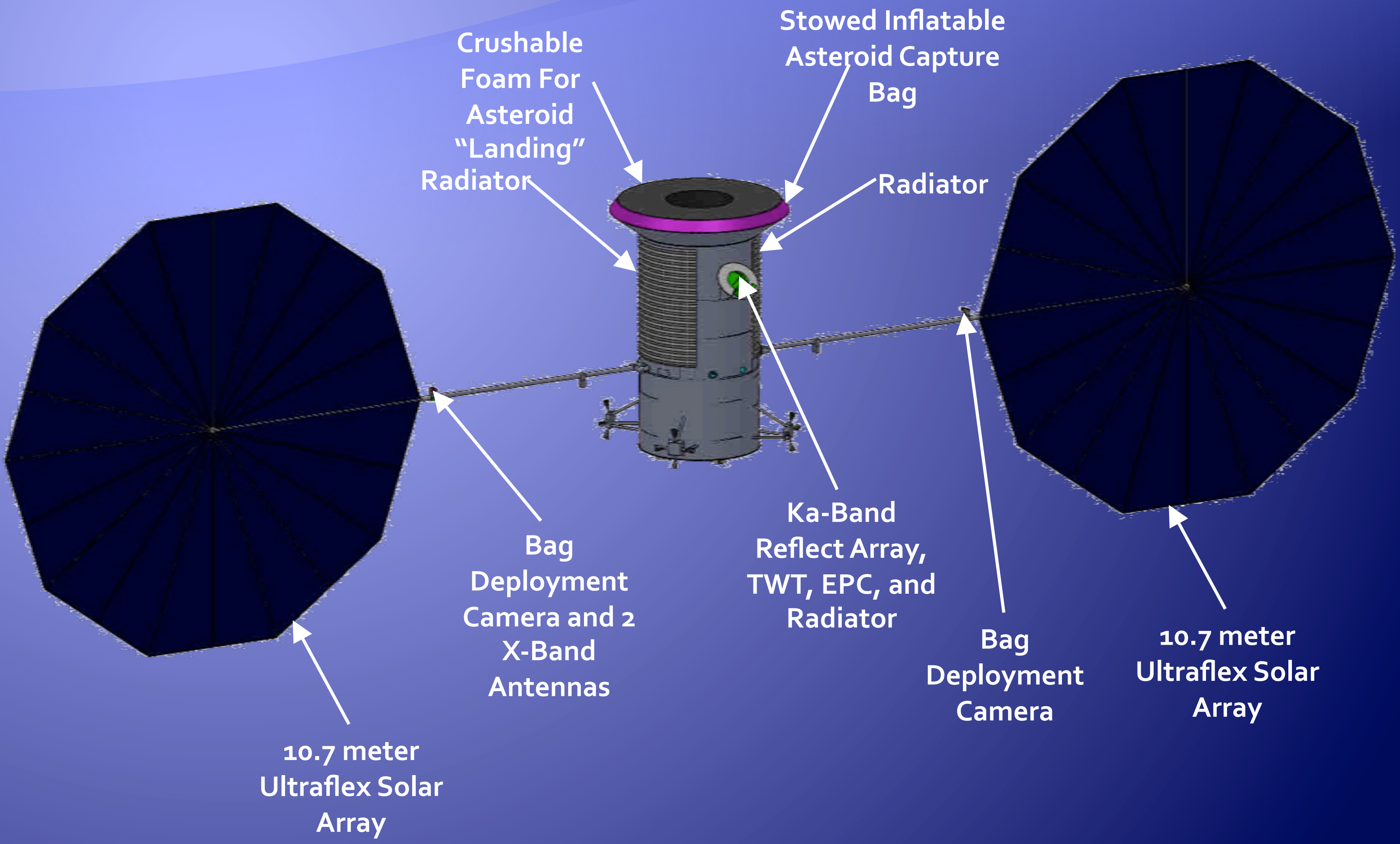
4 Pods of 4 Roll Control Thrusters

5 Total Hall Thrusters and Gimbals

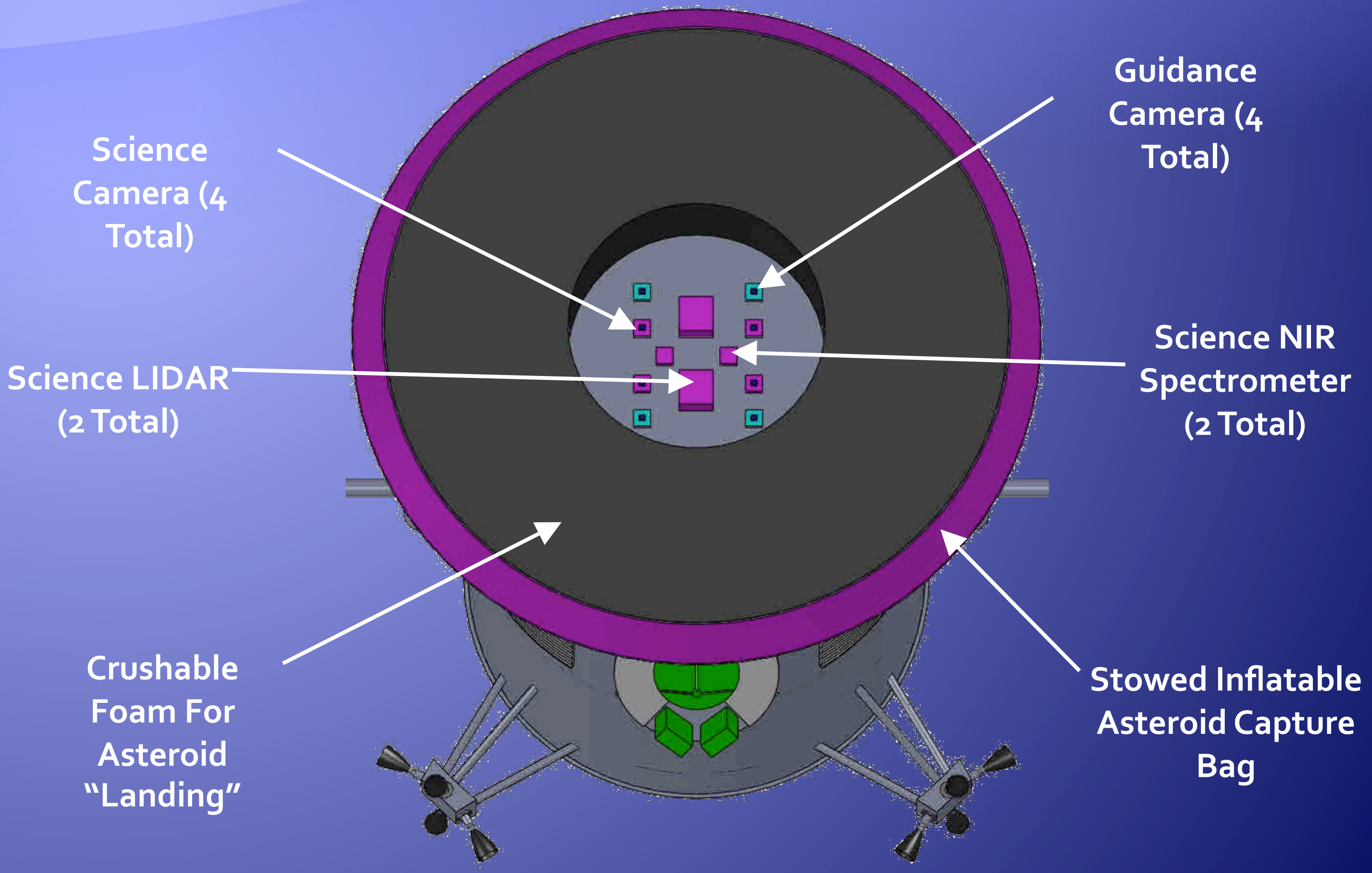
Hall Thruster and Gimbal

Roll Control Thruster

Spacecraft External Components

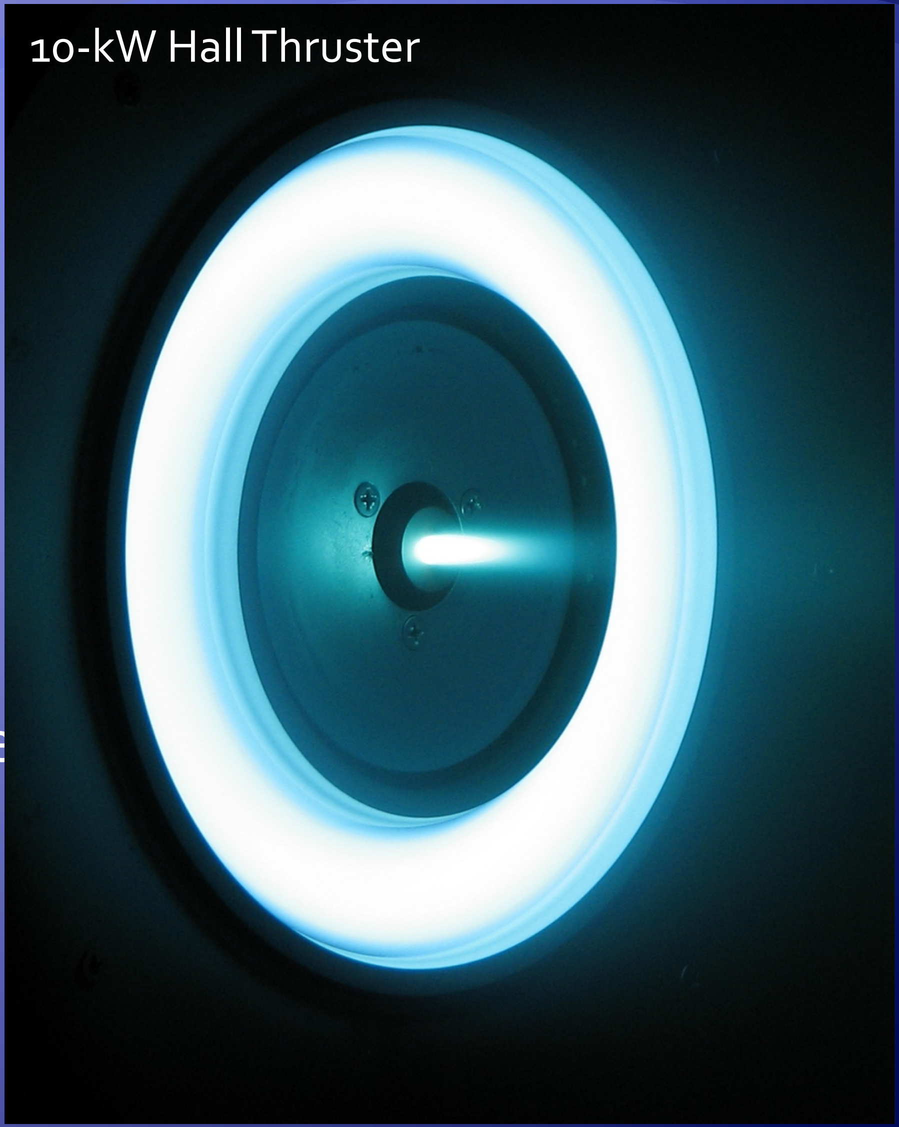


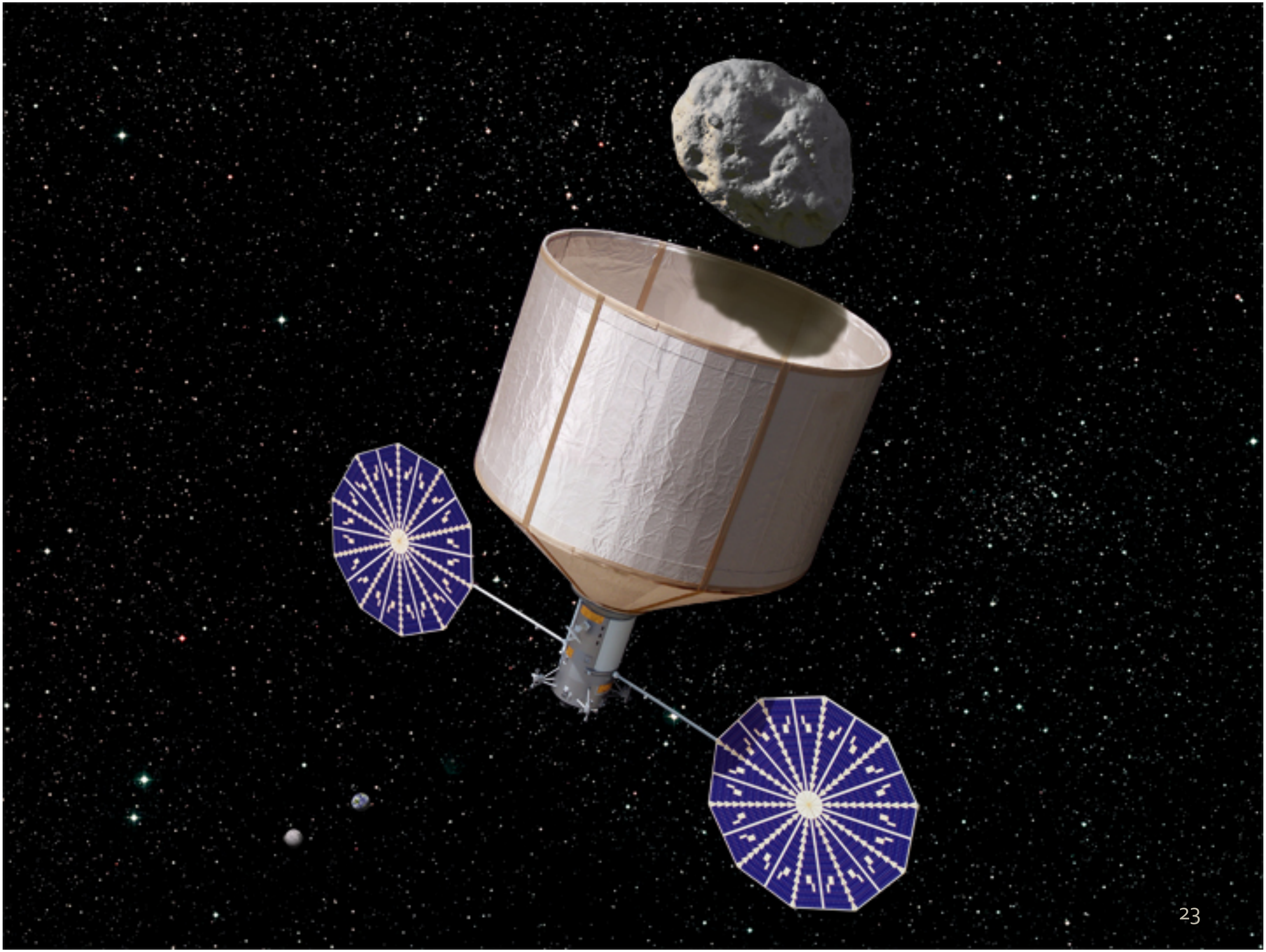
Instrumentation



Solar Electric Spacecraft

- 40-kW EOL solar array
- Two wings of 71 m^2 each
- Five 10-kW Hall thrusters
  - Isp = 3,000 s
- Multiple cylindrical COPV xenon tanks to store 12,000 kg of xenon
  - 650 mm dia. x 3,500 mm long
- Inflatable, rigidizable capture mechanism with high-strength bag and cinching capbles

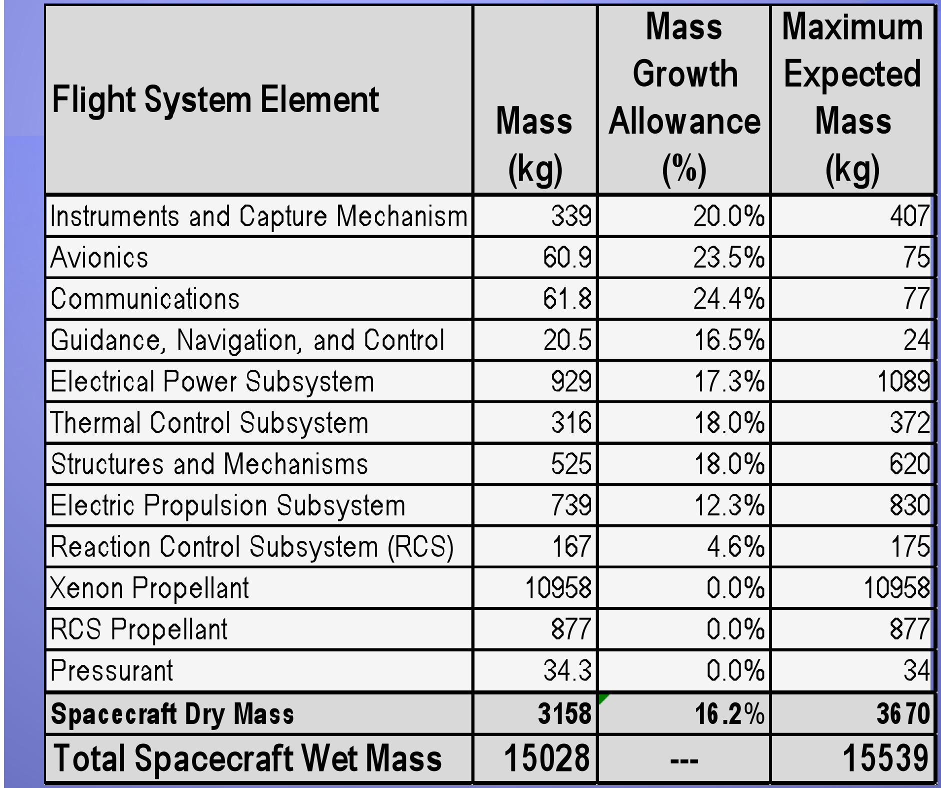

10-kW Hall Thruster



Mass & Cost Estimates

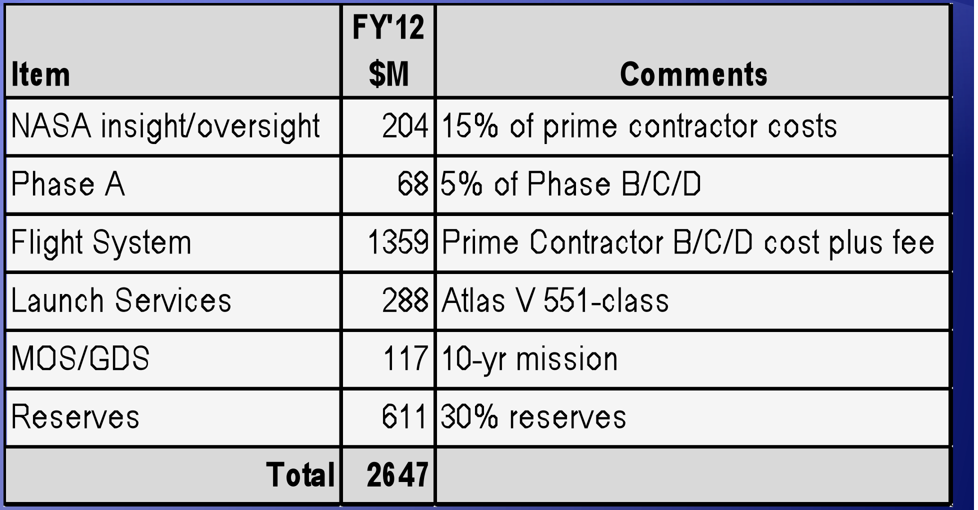
from GRC COMPASS Team

Mass Estimate



Flight System Element	Mass (kg)	Mass Growth Allowance (%)	Maximum Expected Mass (kg)
Instruments and Capture Mechanism	339	20.0%	407
Avionics	60.9	23.5%	75
Communications	61.8	24.4%	77
Guidance, Navigation, and Control	20.5	16.5%	24
Electrical Power Subsystem	929	17.3%	1089
Thermal Control Subsystem	316	18.0%	372
Structures and Mechanisms	525	18.0%	620
Electric Propulsion Subsystem	739	12.3%	830
Reaction Control Subsystem (RCS)	167	4.6%	175
Xenon Propellant	10958	0.0%	10958
RCS Propellant	877	0.0%	877
Pressurant	34.3	0.0%	34
Spacecraft Dry Mass	**3158**	**16.2%**	**3670**
Total Spacecraft Wet Mass	**15028**	**---**	**15539**

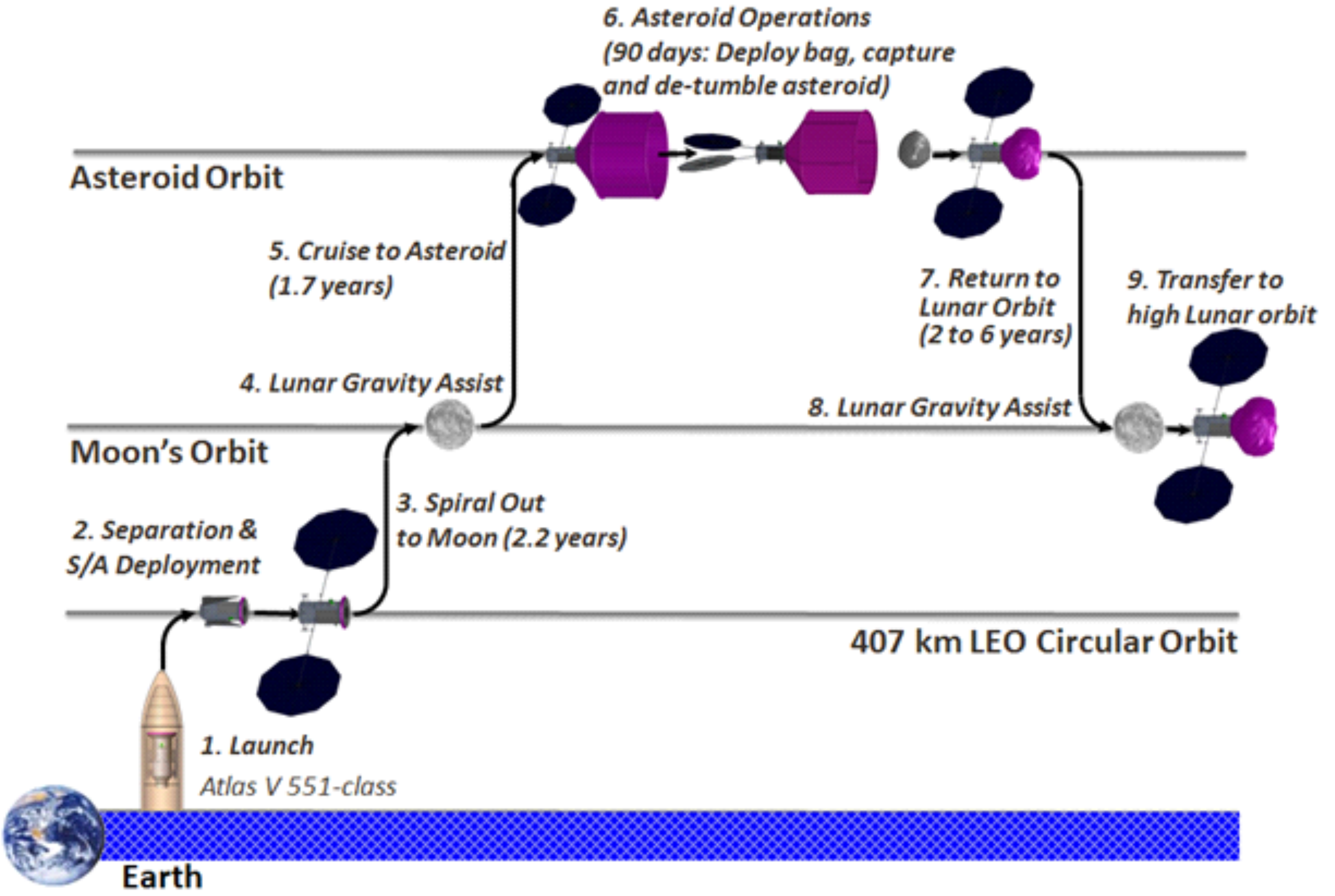
Cost Estimate



Item	FY'12 $M	Comments
NASA insight/oversight	204	15% of prime contractor costs
Phase A	68	5% of Phase B/C/D
Flight System	1359	Prime Contractor B/C/D cost plus fee
Launch Services	288	Atlas V 551-class
MOS/GDS	117	10-yr mission
Reserves	611	30% reserves
Total	**2647**	

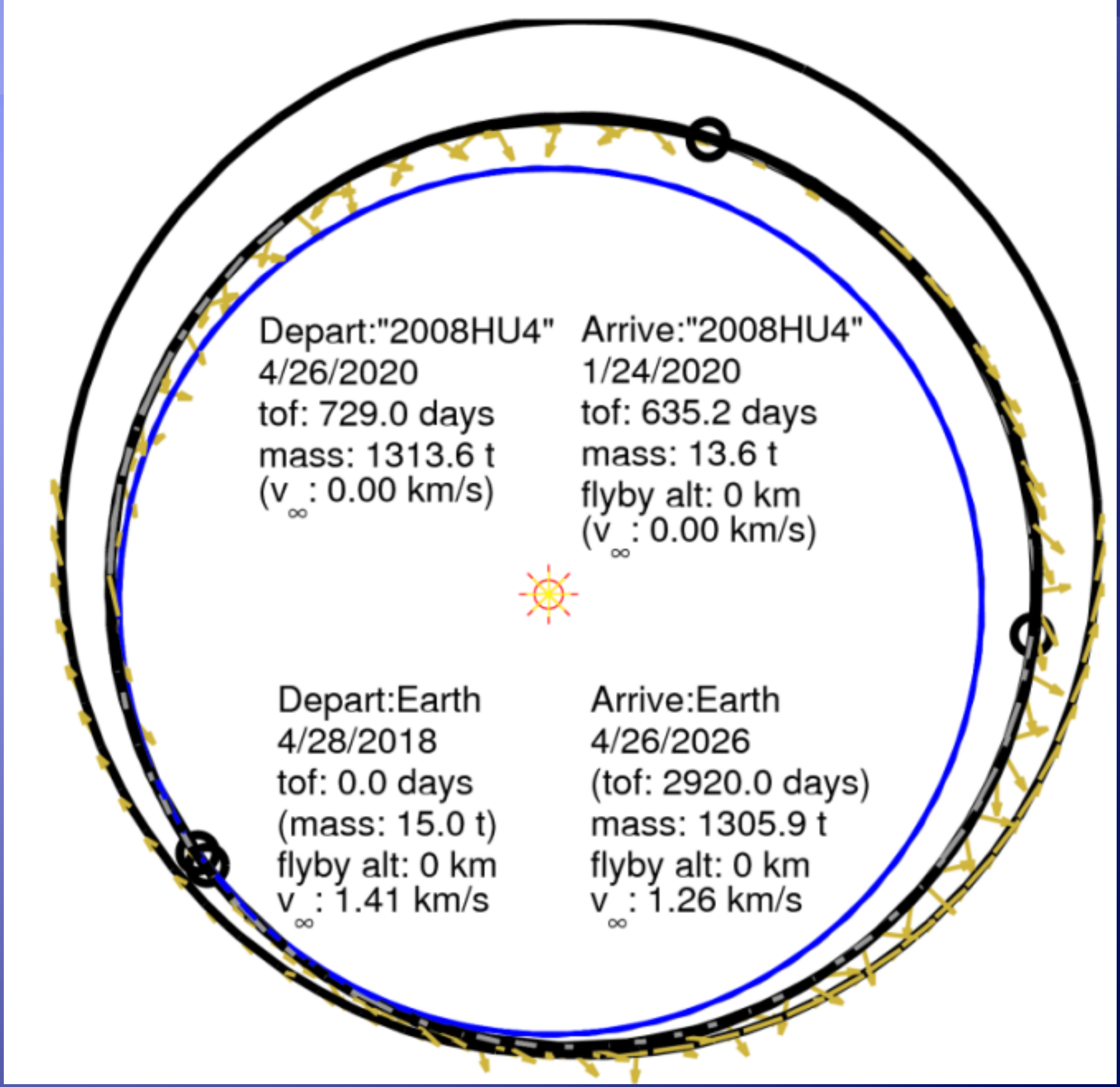
Launch vehicle capability to LEO: 18,800 kg

Asteroid Retrieval Bat Chart



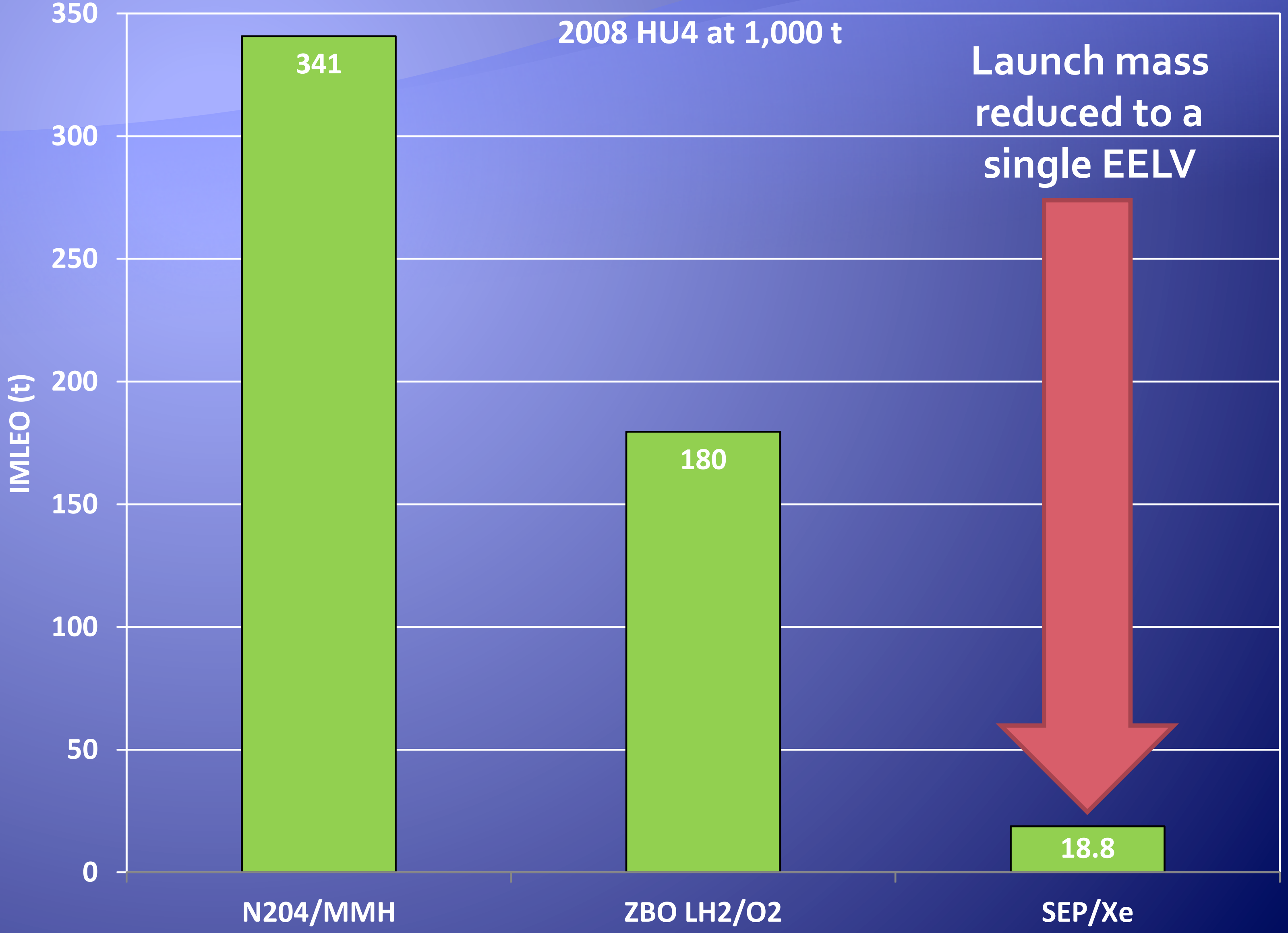
Proof-of-Concept Trajectory 2008 HU4

- Initial Launch Mass: 18,000 kg
- Return Mass 1,300,000 kg
- Total Flight Time 10 years
- Mass Amplification 70-to-1



High-Power SEP is Enabling

Mass launched to Low-Earth Orbit



Launch mass reduced to a single EELV

Asteroid Resources

A C-type asteroid is may have up to 40% of extractable volatile material and about 18% metals

A 1000 metric ton C-type asteroid may contain

- 400 t of volatiles (water, carbon dioxide, nitrogen, ammonia, etc.)
- 180 t of metals (roughly 170 t of iron, 13 t of nickel, 2 t of cobalt)
- 400 t of other stuff.

Summary

- Robotic SEP is ***enabling*** for this mission concept
- This mission concept ***requires*** a human crew in cislunar space to "process" the 500,000 kg asteroid
- This represents a new ***synergy*** between robotic and human missions