

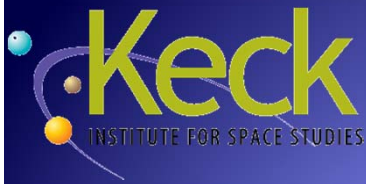
# ASTEROID RETRIEVAL MISSION FEASIBILITY STUDY

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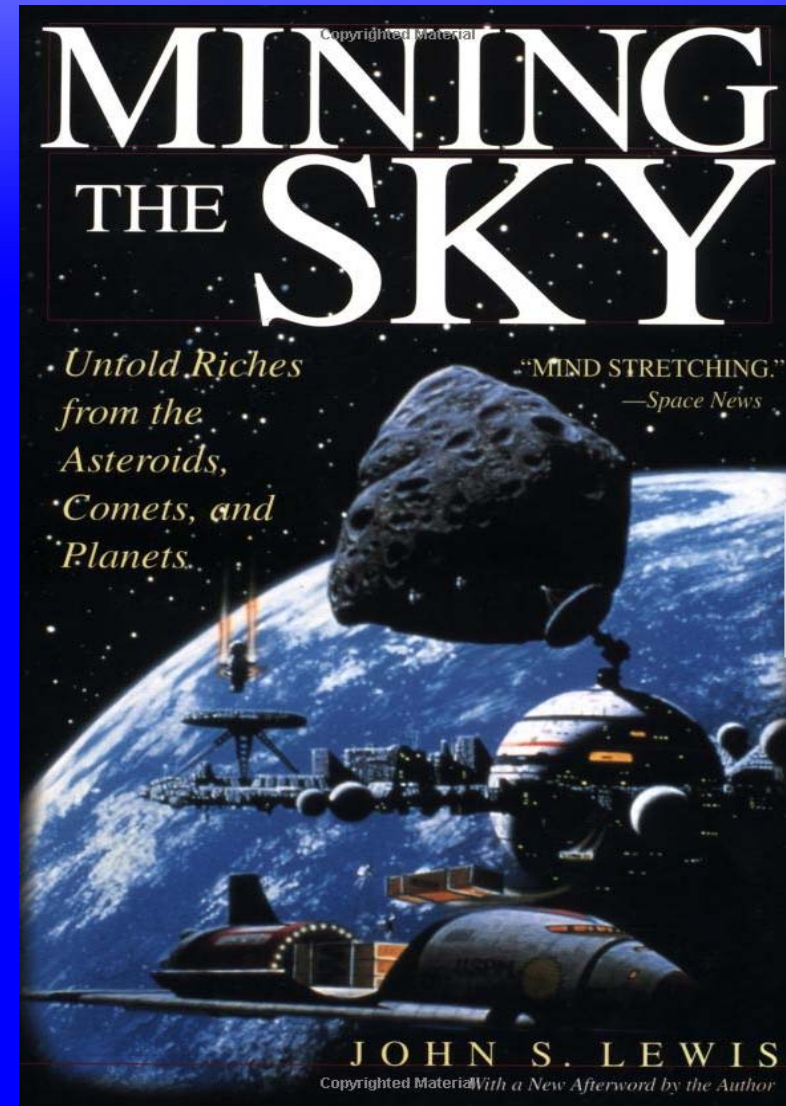
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**Two Workshops – Sep 2011, Feb 2012**

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

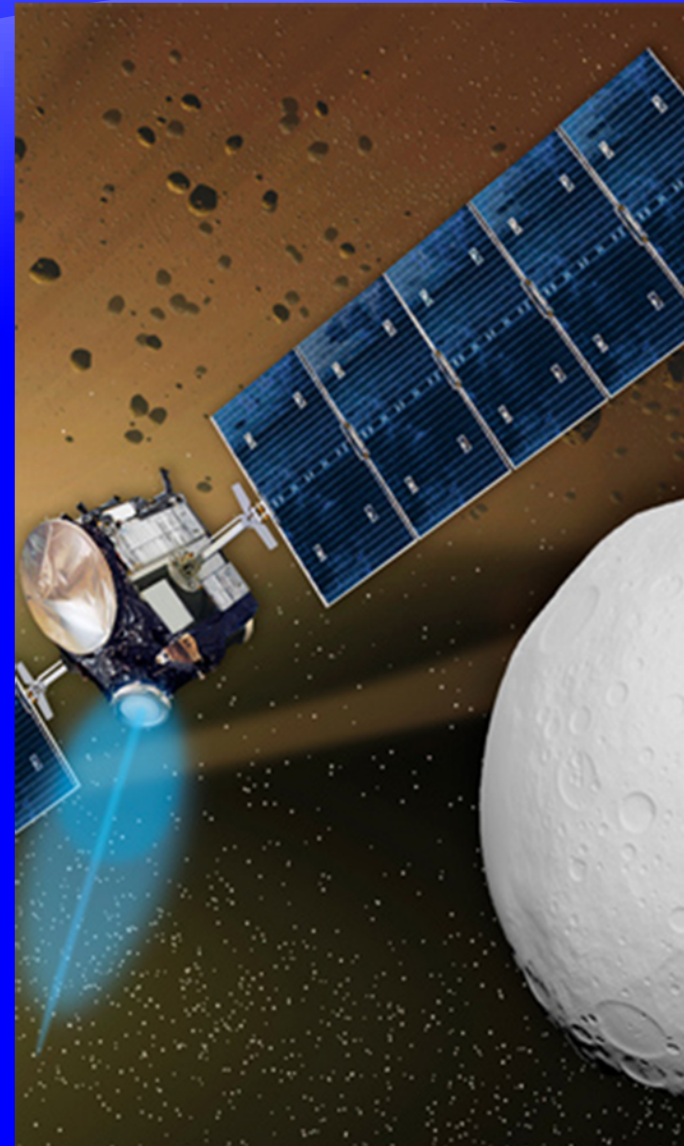
- ❑ In 1903 “exploitation of asteroids” was one of Tsiolkovskii’s fourteen points for the conquest of space.
- ❑ In 1996, detailed in John Lewis’ book *Mining the Sky*
- ❑ It has long been a major theme of science fiction stories.



# 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.





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



# 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)



# Why Return an Entire Asteroid?

- ❑ Create a near-term mission target in cislunar space that requires the presence of a human crew
  - First step on flexible path into the solar system
  - Test bed for human exploration operations
- ❑ Enable Asteroid Exploitation/Resource Utilization
  - Water
  - Propellants
  - Materials for radiation shielding
- ❑ Scientific investigation



# 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.



# Key Feasibility Issues

- ❑ Finding them
- ❑ Capturing it
- ❑ Moving it



- ❑ **Need to identify sufficient candidates around which a mission can be planned 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<sub>2</sub>, N<sub>2</sub>, NH<sub>3</sub>, etc.)

# Asteroid Mass vs Diameter

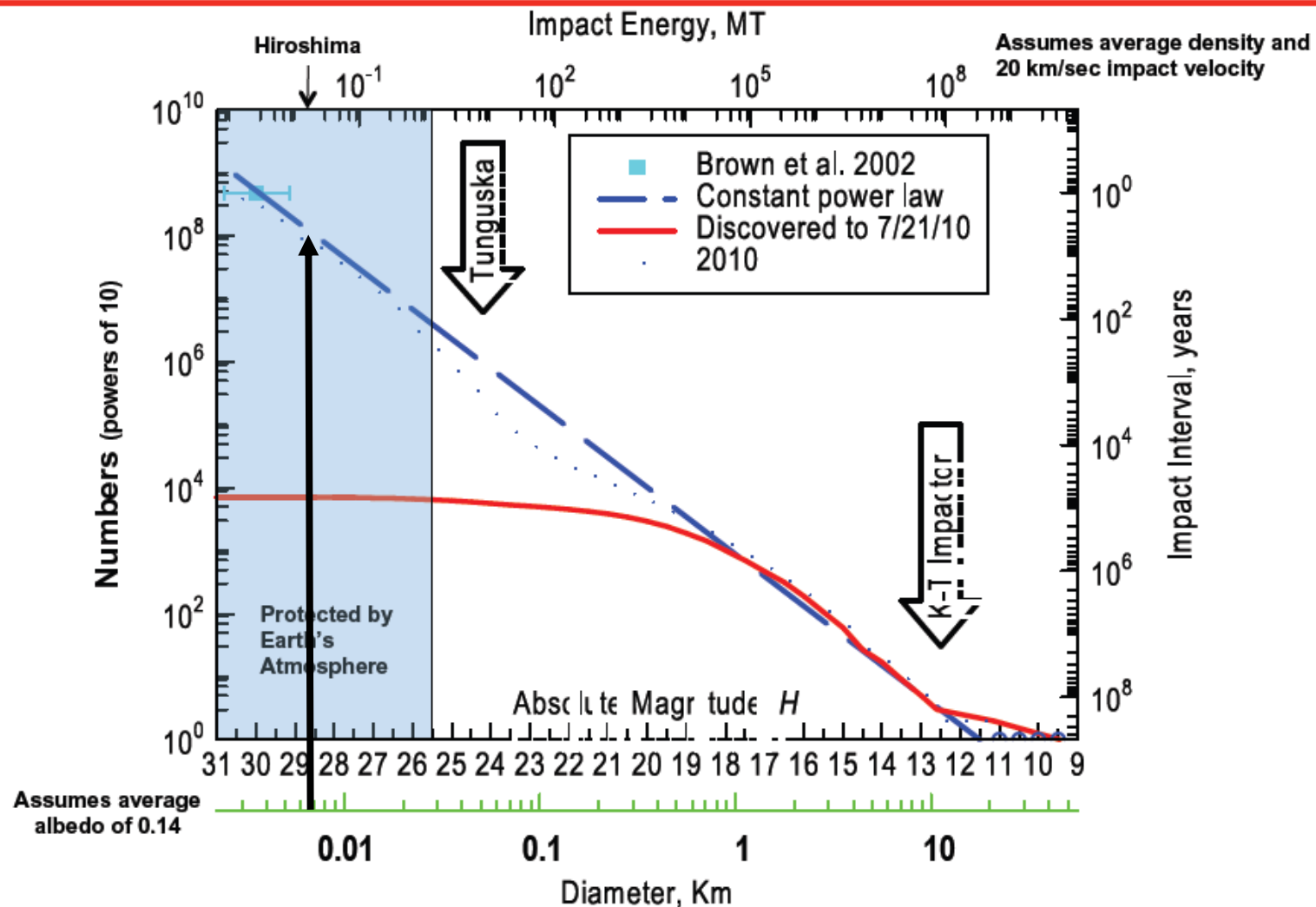
Diameter (m)	Asteroid Mass (kg)		
	1.9 g/cm <sup>3</sup>	2.8 g/cm <sup>3</sup>	3.8 g/cm <sup>3</sup>
2.0	7,959	11,729	15,917
2.5	15,544	22,907	31,089
3.0	26,861	39,584	53,721
3.5	42,654	62,858	85,307
4.0	63,670	93,829	127,339
4.5	90,655	133,596	181,309
5.0	124,355	183,260	248,709
5.5	165,516	243,918	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<sup>3</sup>



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



- ❑ 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 times 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

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

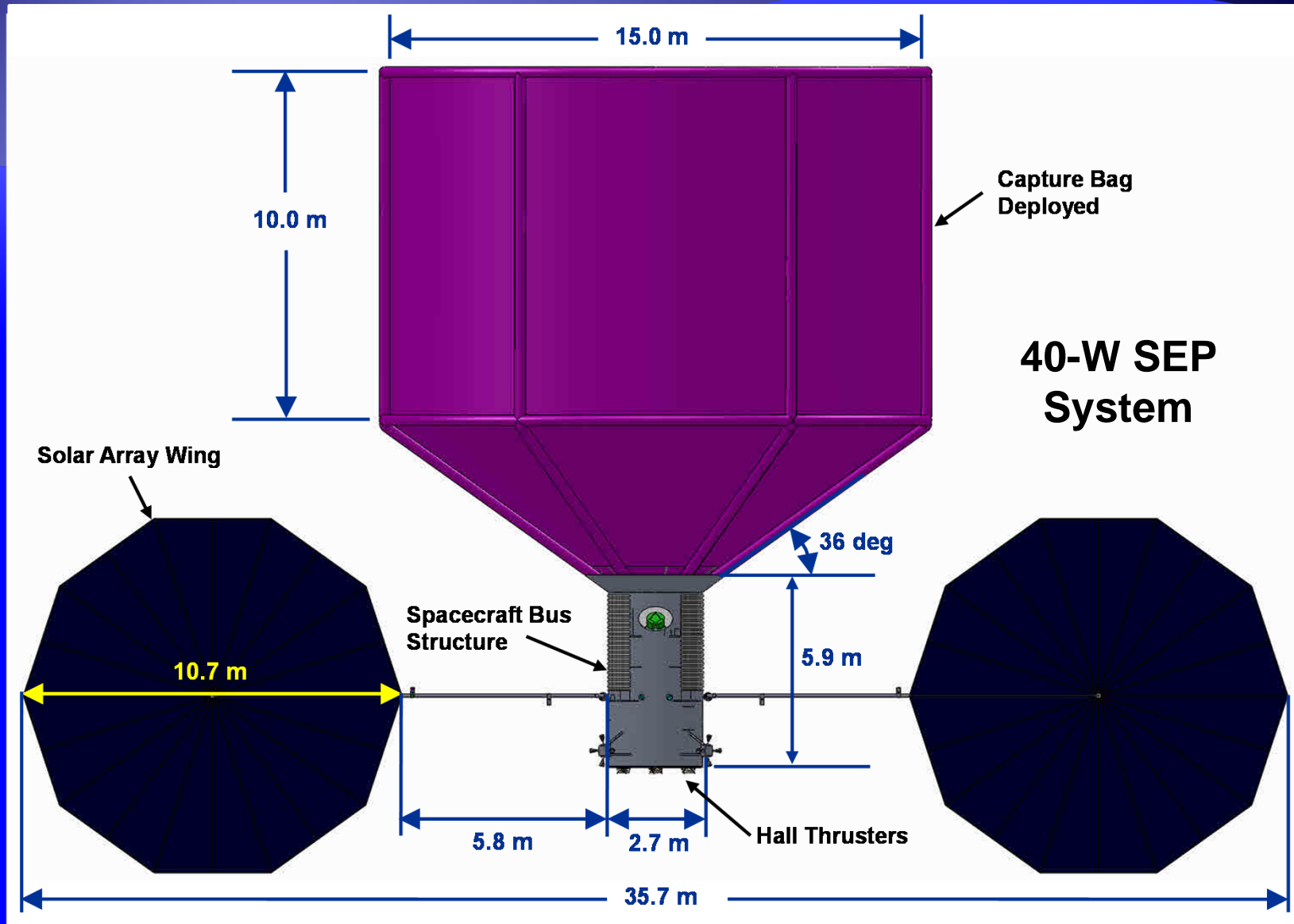
- >3,500 new discoveries per year
- Yield: ~5 good targets per year (right size, type, spin state, and orbital characteristics)



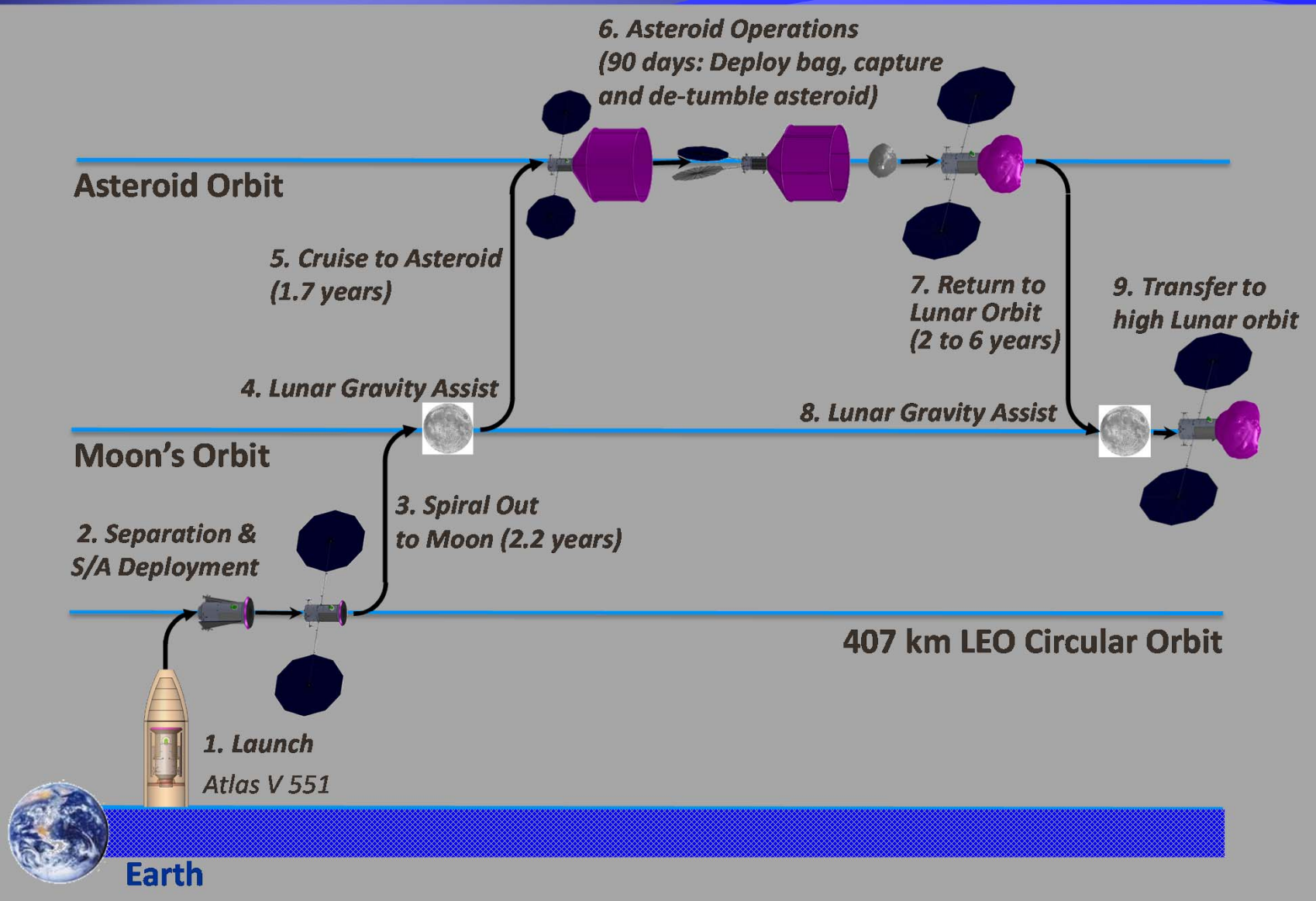
## Belt and Suspenders approach to safety

- 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



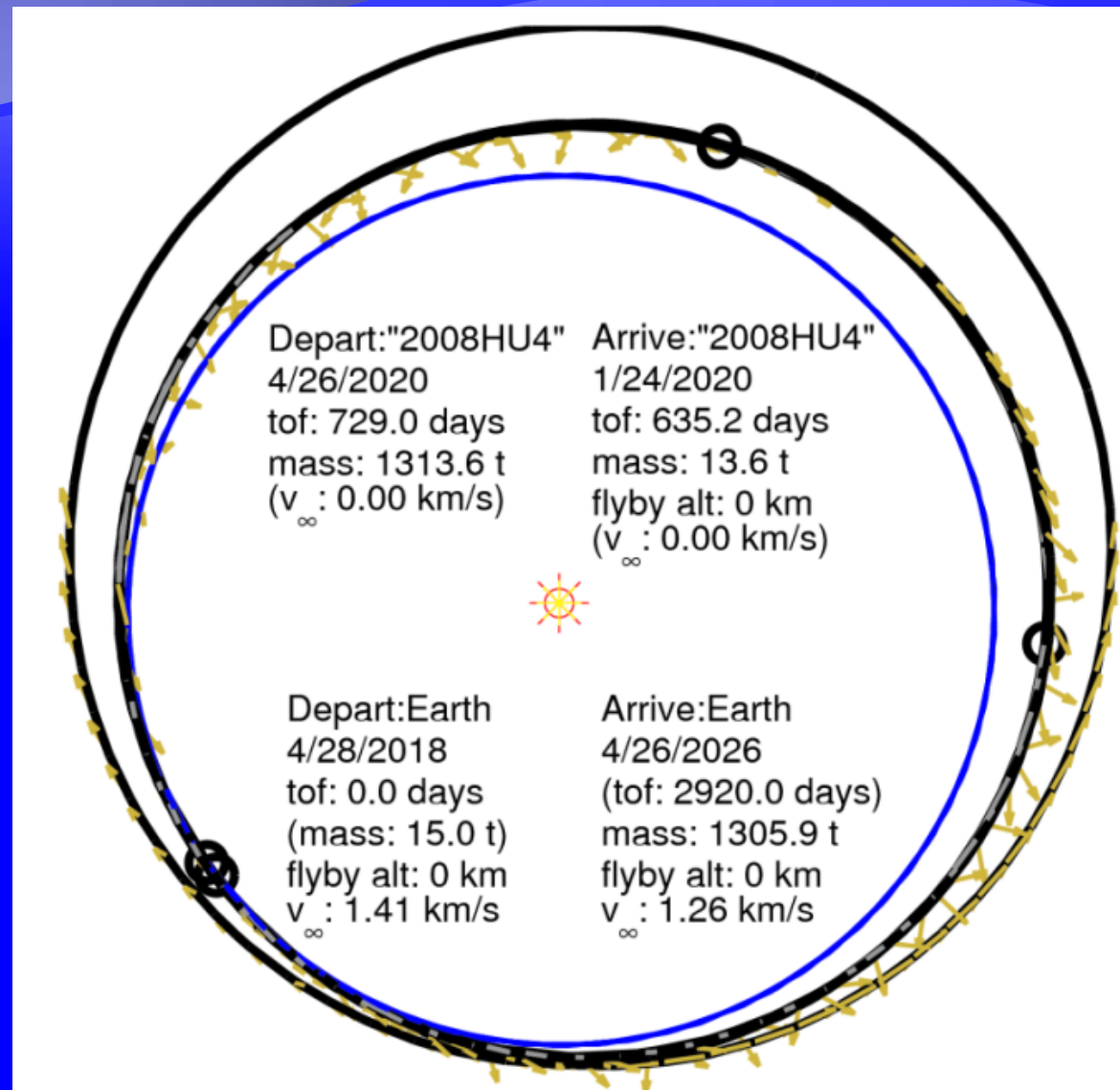
# Asteroid Retrieval Bat Chart





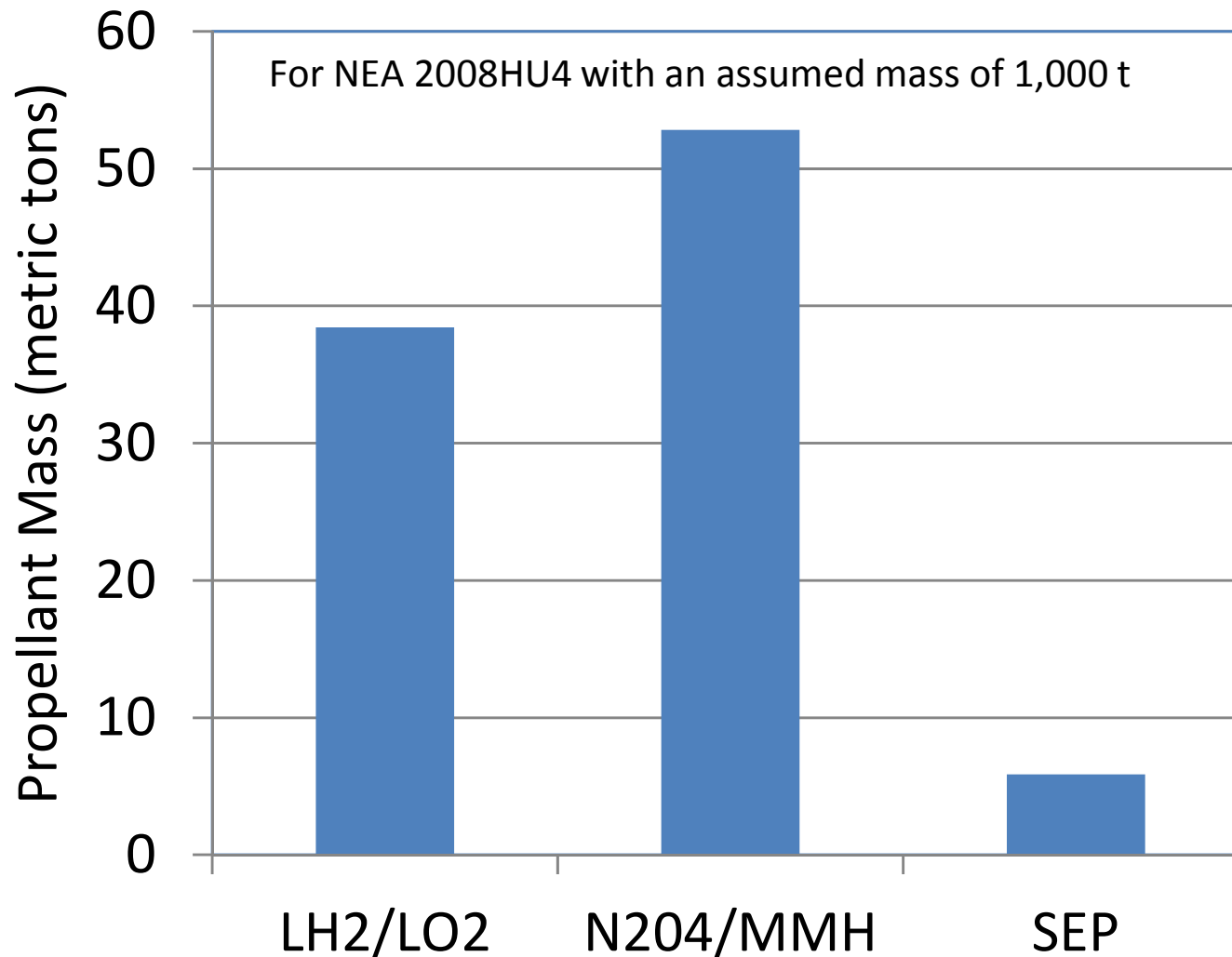
# Proof-of-Concept Trajectory 2008 HU<sub>4</sub>

- 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

## Required Propellant Mass at the NEA



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.

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