National Aeronautics and Space Administration

Asteroid Redirect Robotic Mission (ARRM) Concept Overview

Briefing to SBAG

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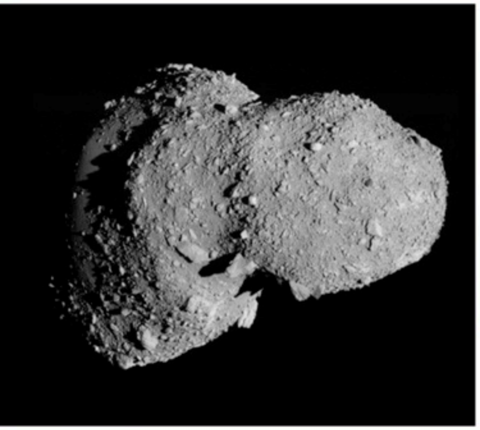
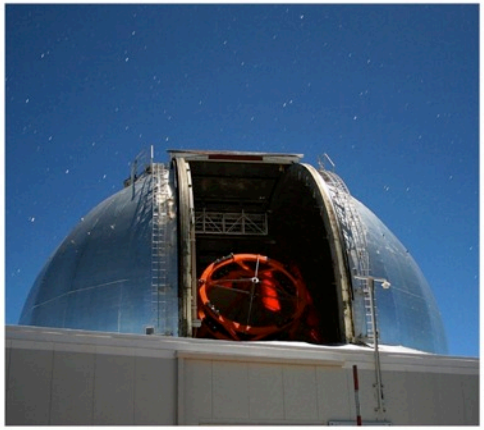
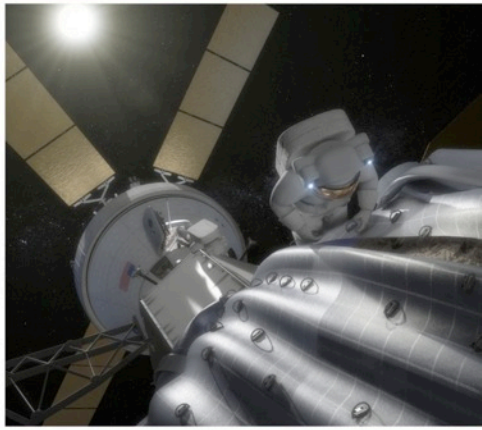
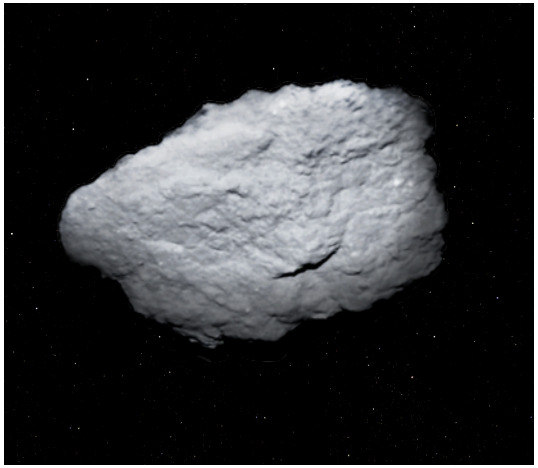
July 30, 2014

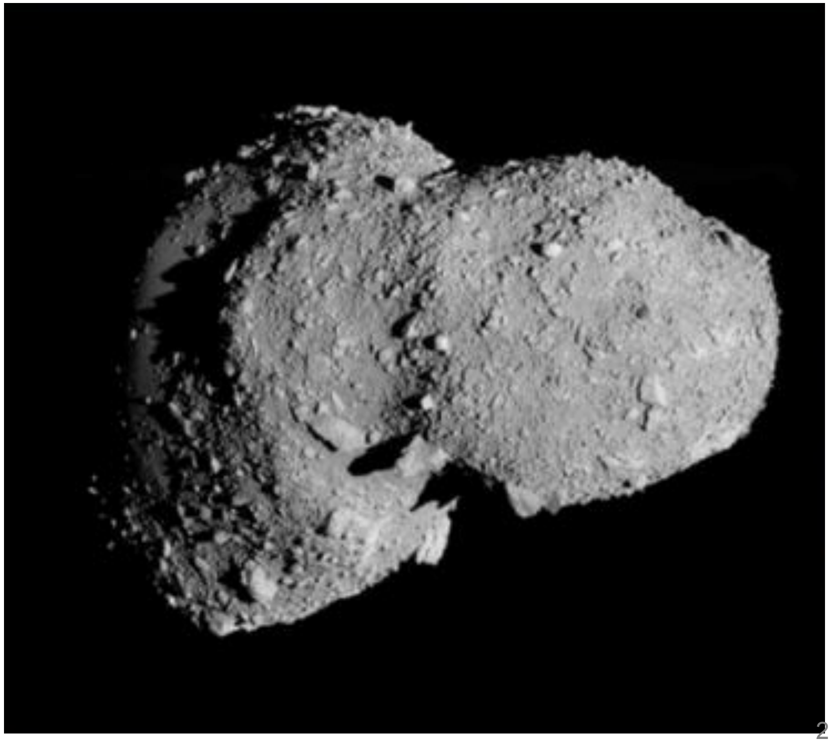





ARRM Mission Concept

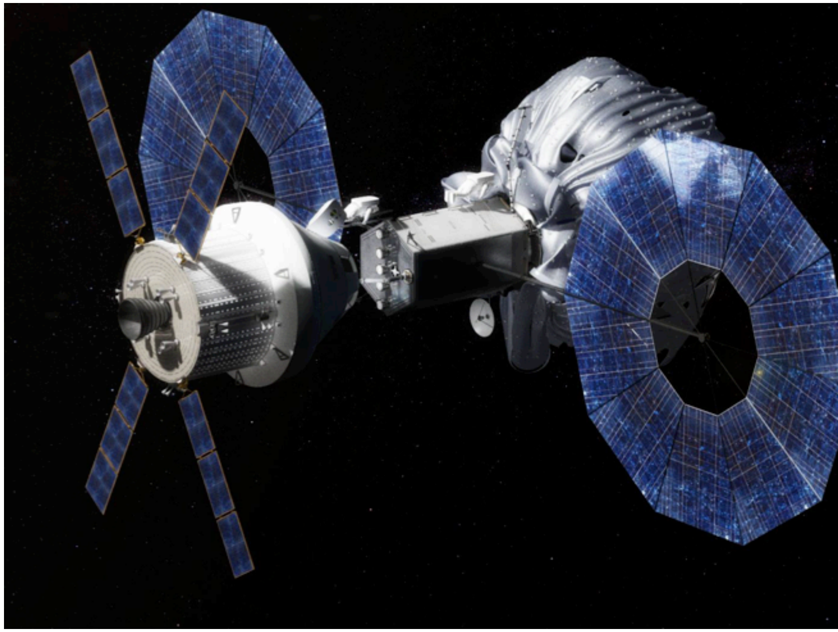
- Rendezvous with an asteroid and either redirect a whole small asteroid or, a boulder from a large asteroid to the moon's orbit where astronauts can visit it.
- Available for crewed exploration by mid-2020's





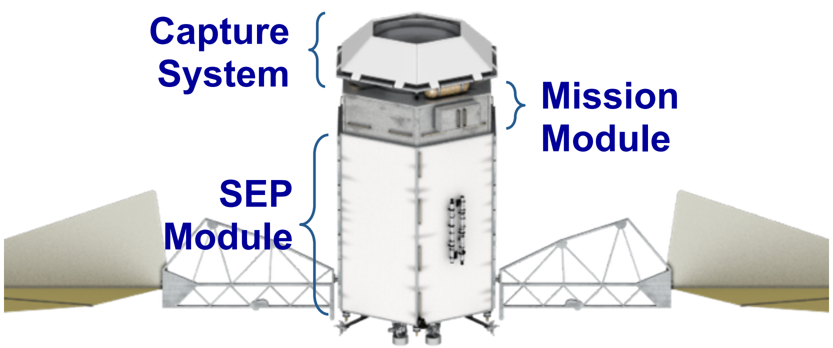
Why?

- Mission would bring together important NASA objectives:
  - High power SEP tech demo
  - Operate in close proximity to a near-earth asteroid and return material for exploration
  - Demonstrate planetary defense techniques
  - Prove out SLS/Orion capabilities beyond LEO
  - Extensible to proving ground and Mars mission objectives
  - Demonstrate lean implementation techniques to reduce cost and cost risk

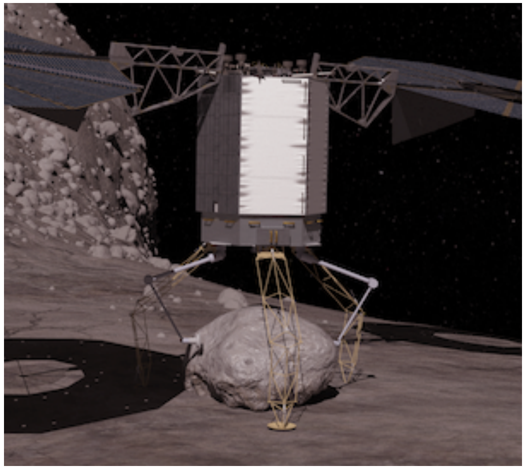


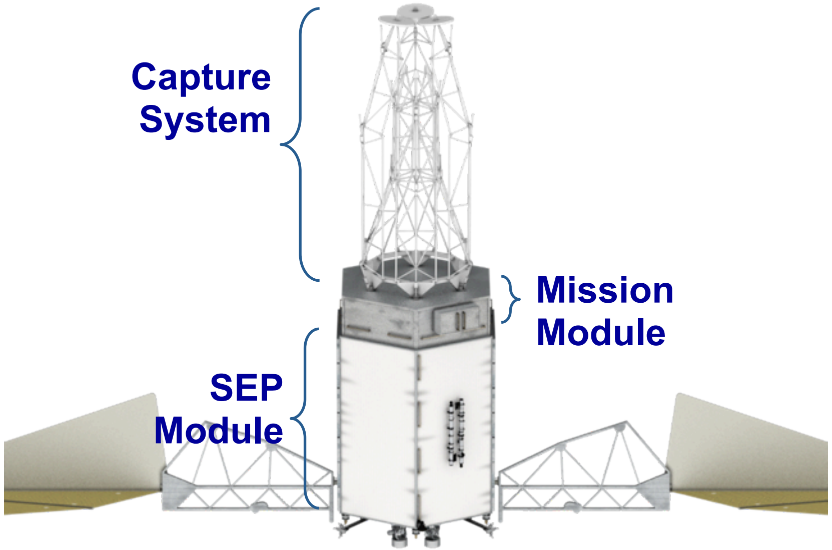
Asteroid Redirect Mission Robotic Concepts

Small Asteroid Capture, Option A



Robotic Boulder Capture, Option B

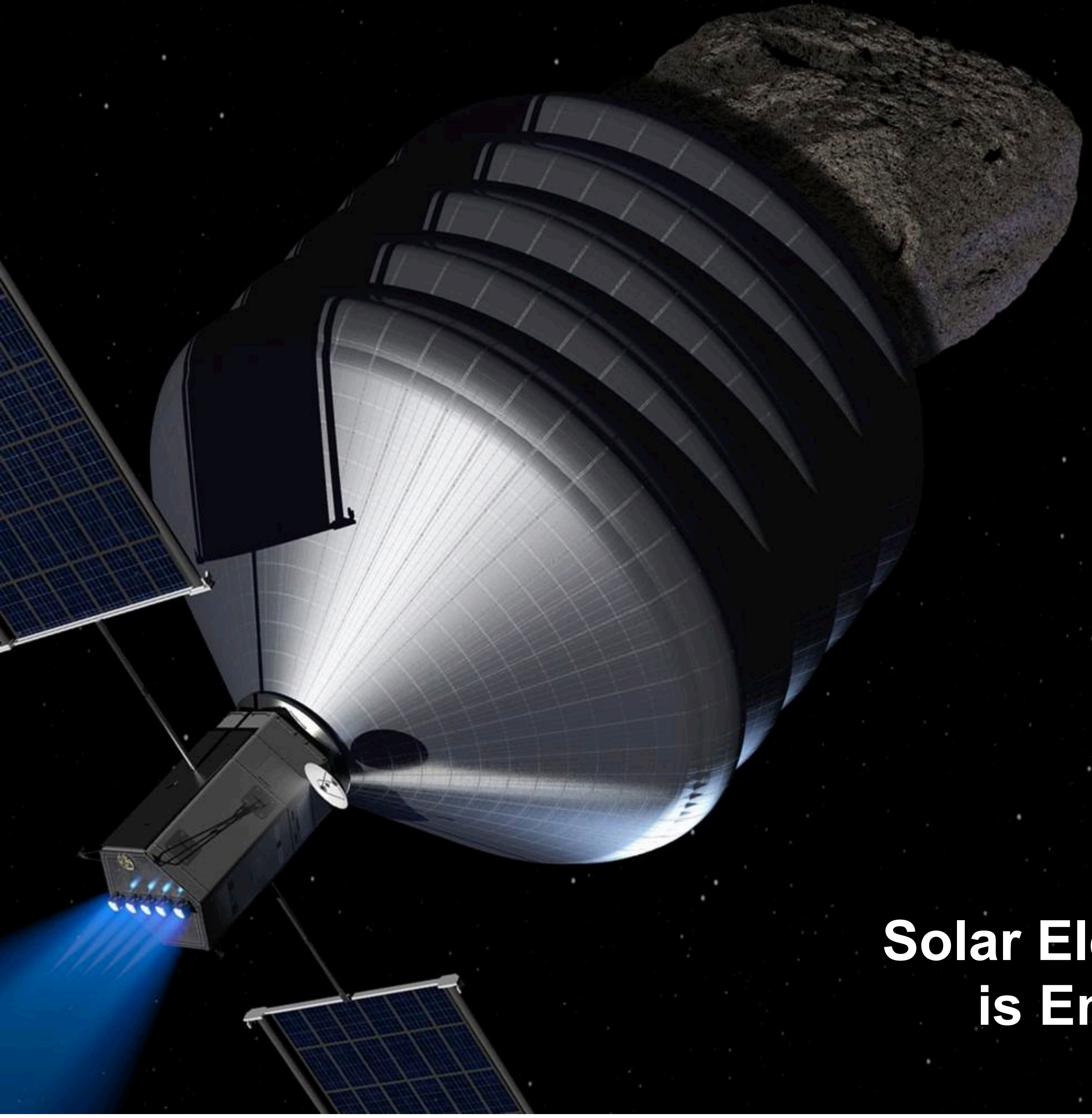


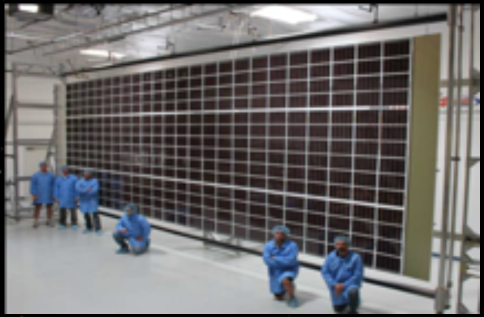


Current Valid Candidate Asteroids for Mission Design

- **June 2019 launches on Delta IV Heavy assumed**
- **Data still *preliminary*, will be finalized in August**

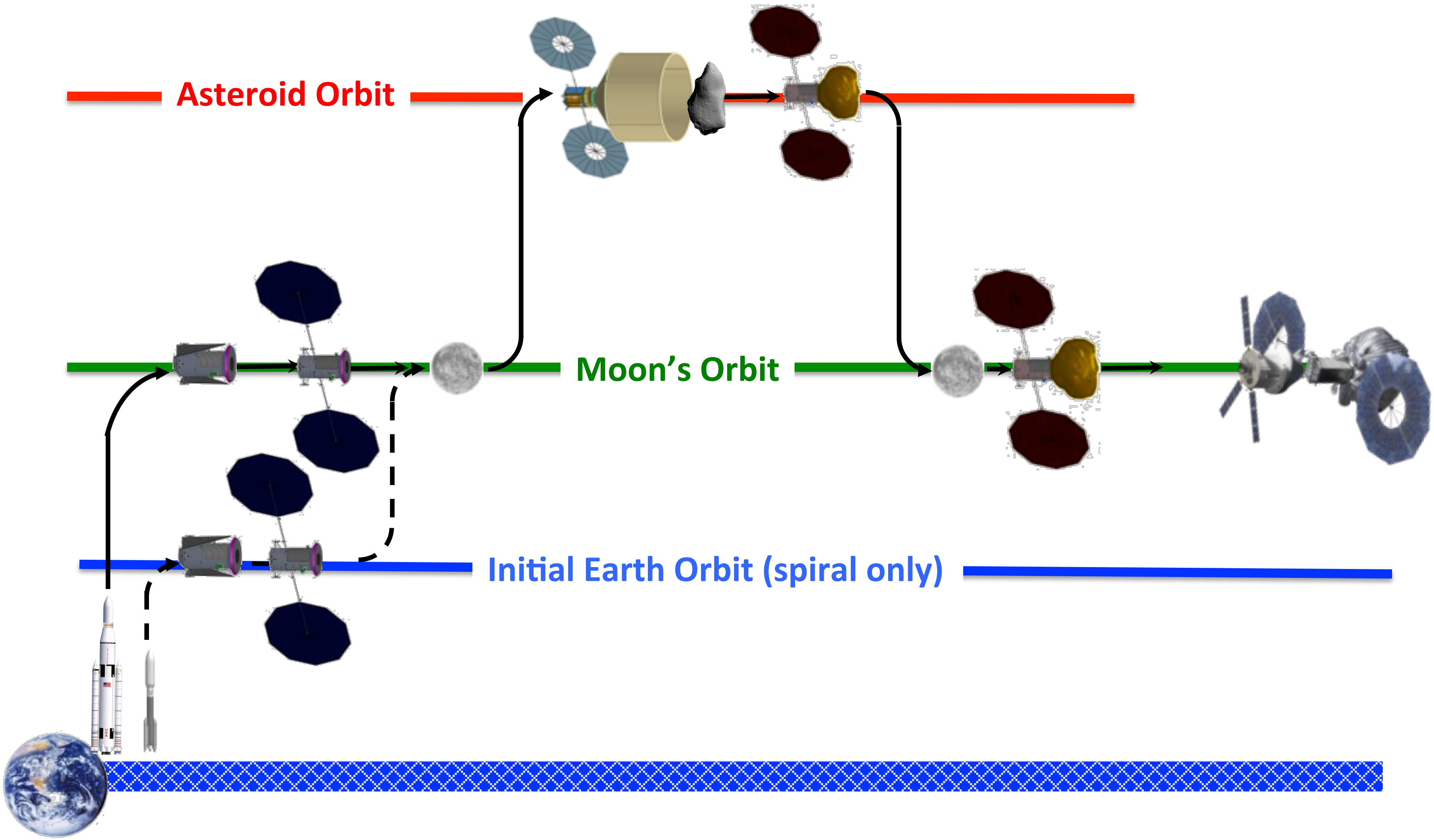
Asteroid	Entire Asteroid or Boulder	Return Mass (*max possible)	Asteroid or Boulder Size	Earth Return Date	Crew Accessible in DRO
2009 BD	entire	145 t	3-7 m	Jun 2023	Oct 2023
2011 MD	entire	600 t*	4-12 m	Jul 2024	Aug 2025
2013 EC20	entire	43 t	3-4 m	Sep 2024	Oct 2025
Itokawa	boulder	3.6 t*	1.3-1.6 m	Jun 2024	Jul 2025
Bennu	boulder	9.9 t*	2.2-2.7 m	Feb 2024	Mar 2025
2008 EV5	boulder	14.1 t*	2.5-3.0 m	Jun 2024	Jul 2025





Solar Electric Propulsion is Enabling for ARRM

Mission Design Overview



Mission Profile Comparison – Points of Departure

Phase/Activity	Small Asteroid (2009 BD)		Robotic Boulder (Itokawa)	
	Date/Duration	Xenon Use	Date/Duration	Xenon Use
Launch	**June 1, 2019**		**June 1, 2019**	
Outbound Leg	1.2 years	920 kg	1.8 years	2,742 kg
Asteroid Rendezvous & Proximity Ops				
Arrival	**Jul. 28, 2020**		**Jun. 22, 2021**	
Characterization & Capture	30 days		51 days	
Capture Phase Margin	30 days		18 days	
Planetary Defense Demo	1 hour		51 days	
Missed Thrust Margin	30 days		30 days	
Departure	**Oct. 26, 2020**		**Nov. 19, 2021**	
Inbound Leg	2.2 years	1,890 kg	2.6 years	2,160kg
Lunar DRO Insertion	Feb. 2024	130 kg	Aug. 2025	20 kg
ARCM Availability in DRO**	**Mar. 2024**		**Sept 2025**	

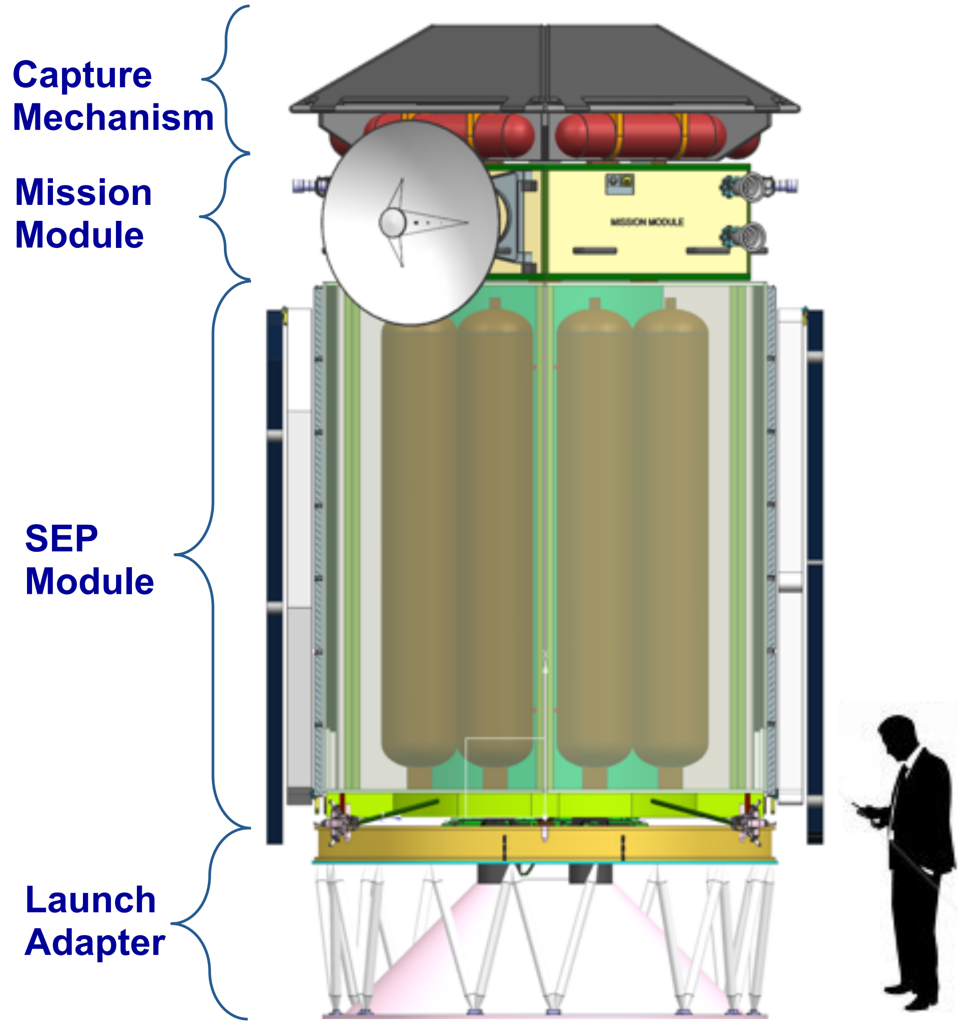
Assumes Delta IV Heavy for PoD. SLS could improve performance. *Can return greater mass with later return dates. ** Earlier dates are possible in different transient orbits.

Xe used: 2,940 kg
SEP Op Time: 1243 days
Asteroid Return Mass: 30-145t (2.6-7m mean diameter)

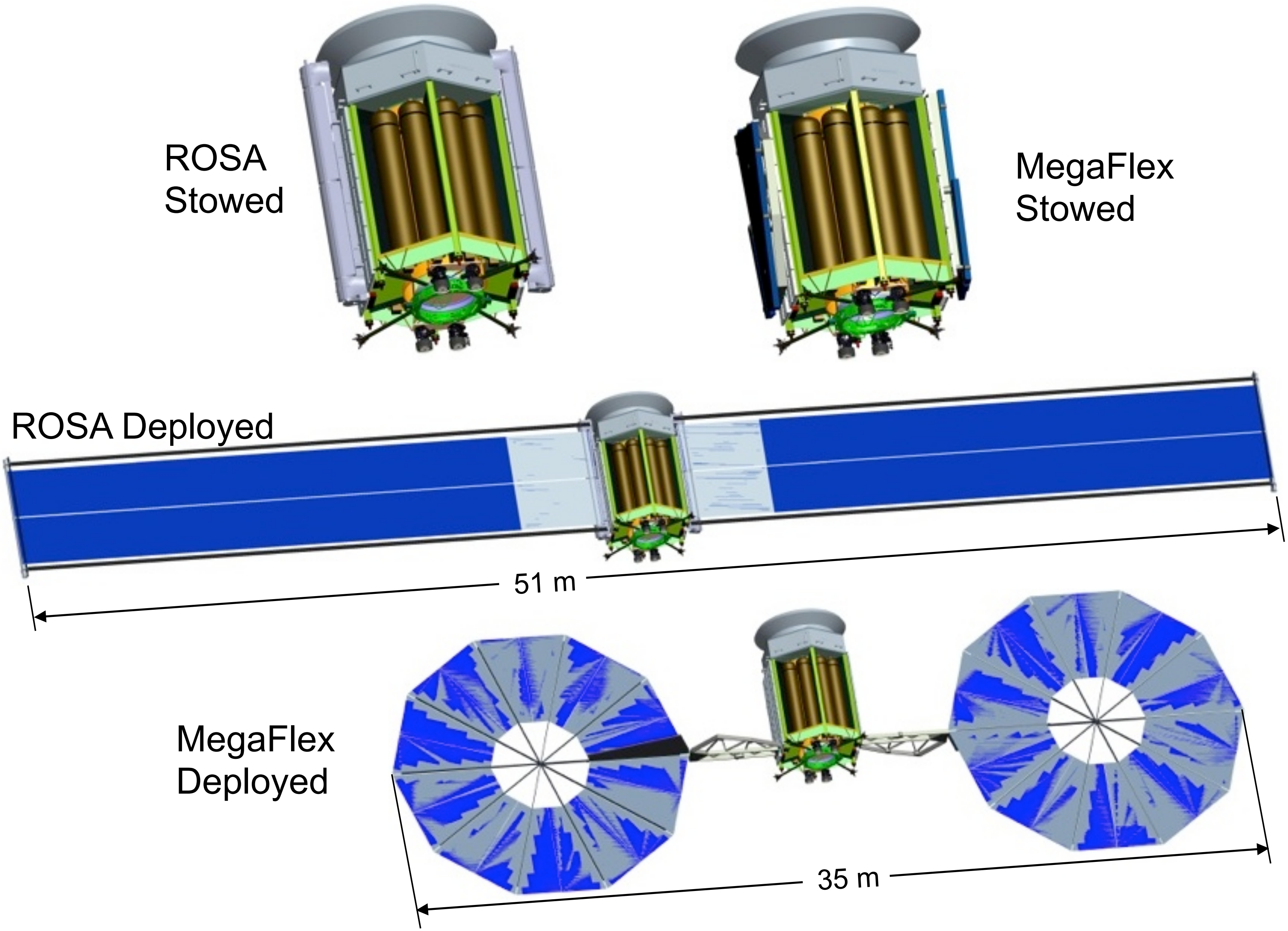
Xe used: 4,922 kg
SEP Op Time: 1334 days
Boulder Return Mass*: 3.6 t (1.3 m spherical, 1.6 m max extent)

Flight System Summary

- **Key Driving Objective:**
  - Minimize the cost and technology development risk with extensibility to future missions within constraints
- **Architected to provide balanced risk to:**
  - Uncertainties in asteroid characteristics
  - Proximity operations complexity and duration
  - Safe crew operations
- **Flight system features:**
  - Clean interfaces between SEP, Mission and Capture System modules
  - High heritage Mission Module, avionics, sensors and core SW
  - Conops validated by model-based systems engineering analysis
  - JPL Design Principles technical margins

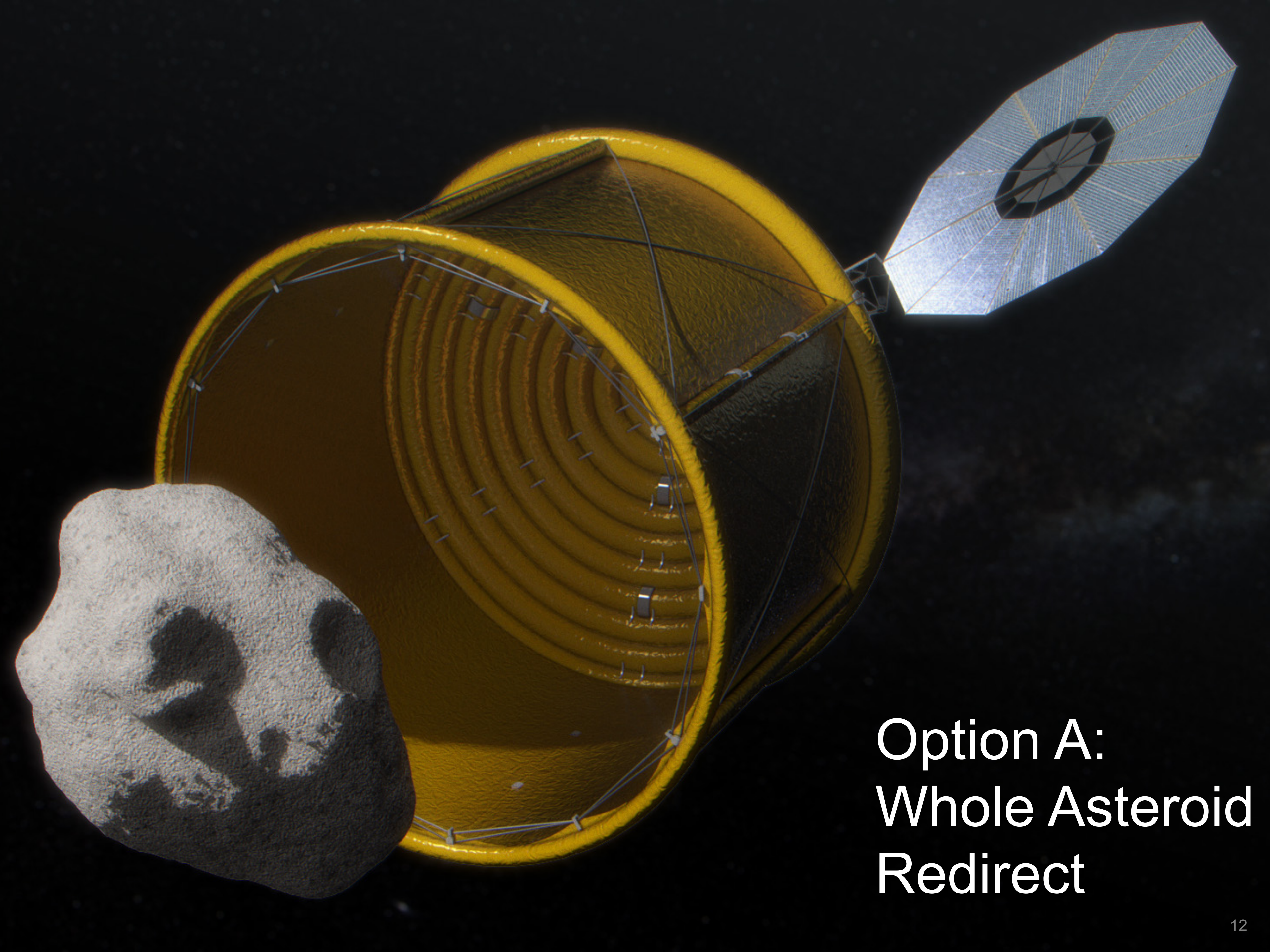


Flight System Deployed Configurations



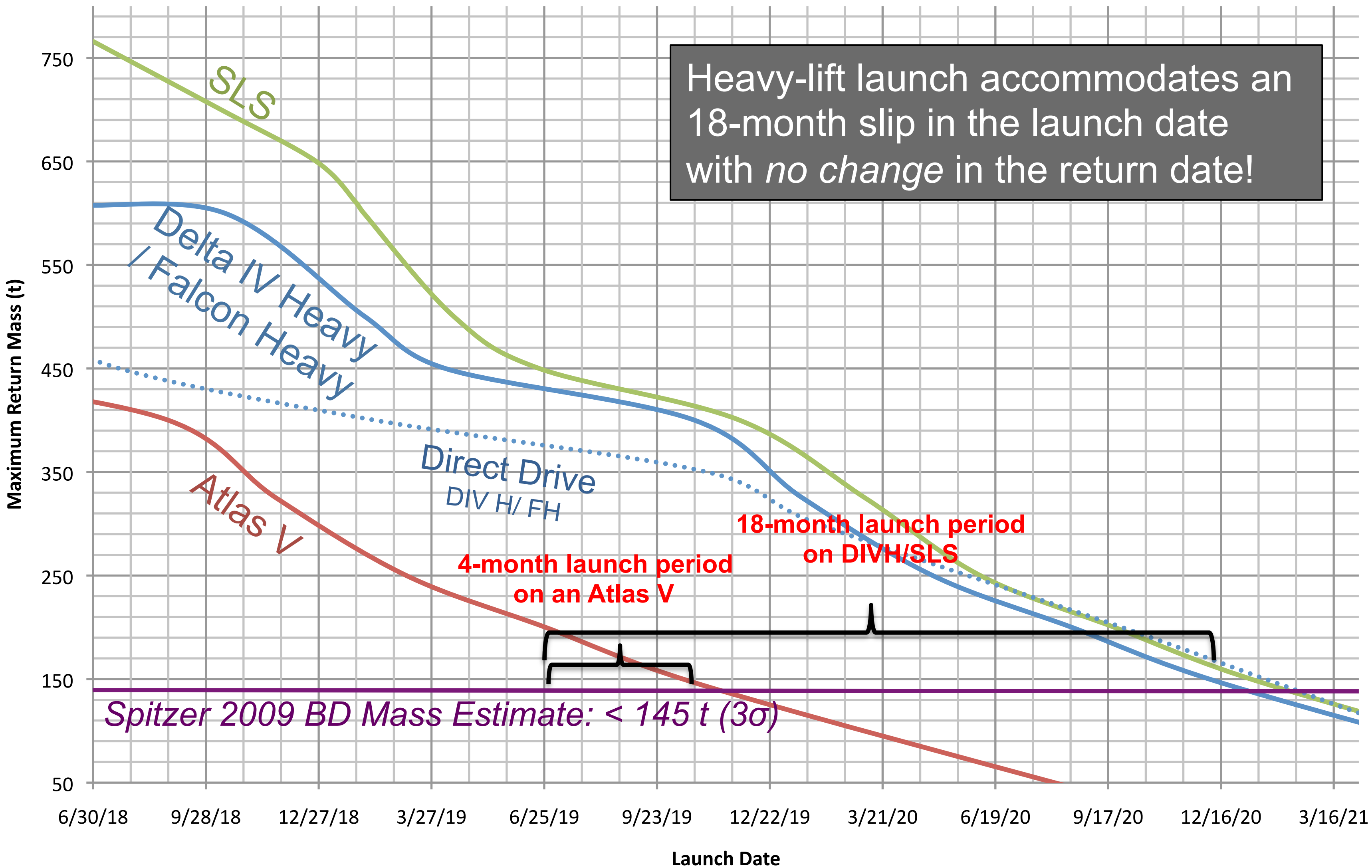
Architecture-Level Trade Areas

- **Reference targets:**
  - Option A: S-type (2013 EC20, 2009 BD, 2011 MD), TBD (including possible C-type)
  - Option B: S-type (Itokawa), C-type (Bennu, 2008 EV5), TBD
  - Option C: Phobos/Deimos
- **Launch vehicles: Atlas V, Delta IVH, Falcon Heavy, SLS**
- **Launch: June 2019 or June, 2020**
- **Inform Planetary Defense**
  - Demo: IBD, GT or EGT operations capability and/or demo measureable deflection
- **Capture system design options**
  - Option A: bag, inflatable, mechanical
  - Option B: hybrid, hover (contingency option for later evaluation), bag
  - Common design for both
- **Arrival for crew accessibility: 2023 through 2025, possible extension to 2026**
- **BAA inputs for capture systems, sensors, commercial S/C capabilities and add'l payloads**
- **Implementation/Acquisition: range from in-house to system contract**
- **Metrics: Cost, cost risk, technical risk, cost phasing**
- **FOMs:**
  - Extensibility to Mars and the Proving Ground
  - Potential science return
  - Planetary defense demo value
  - Technology infusion to commercial users
  - Commercial/International participation

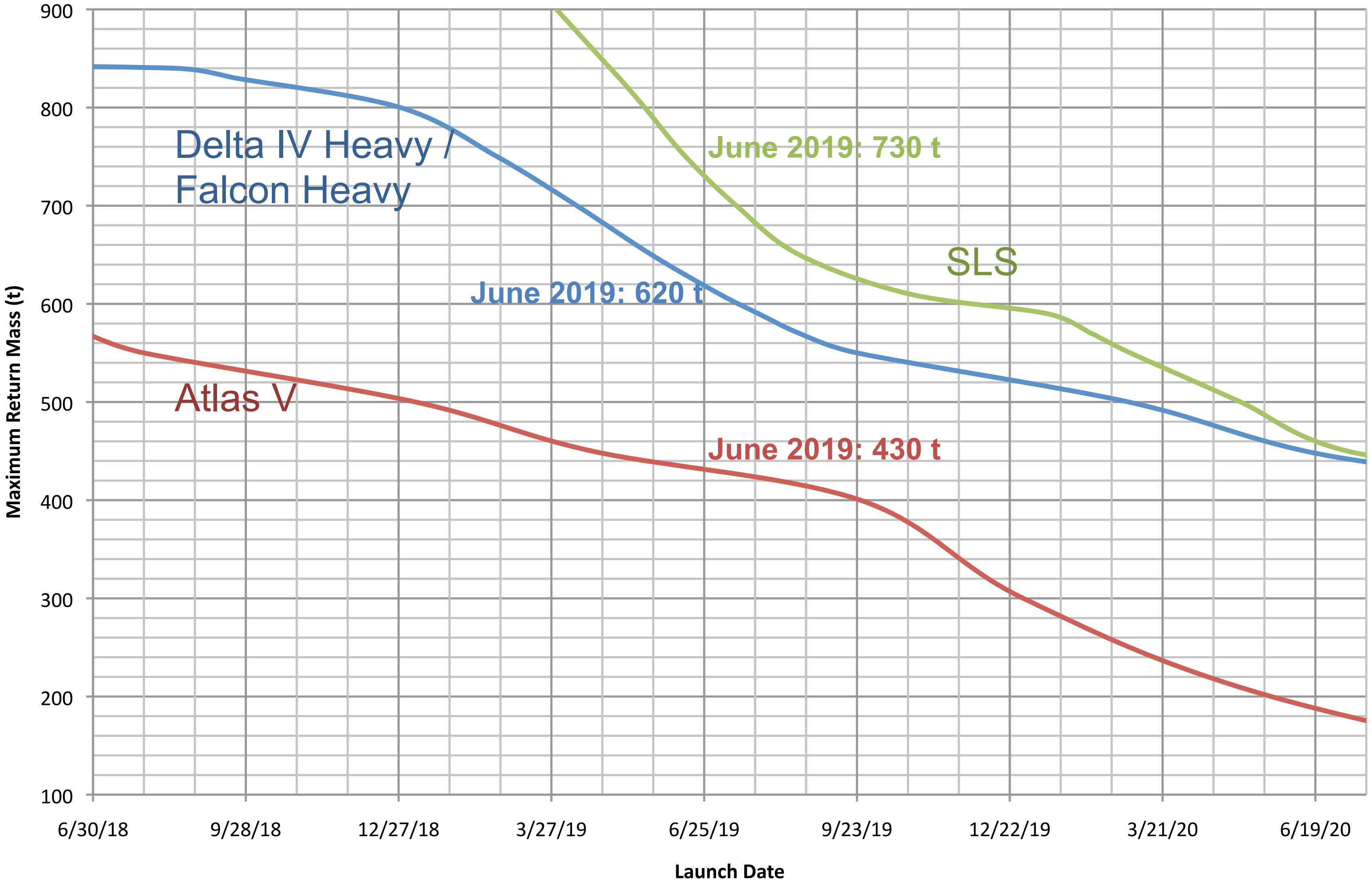


Option A: Whole Asteroid Redirect

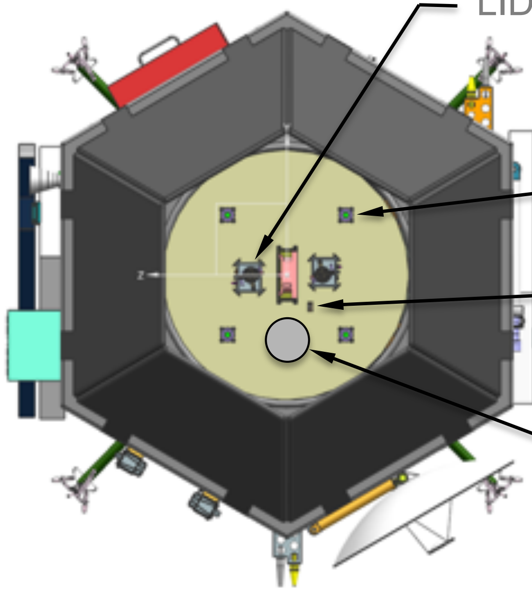
2009 BD: Max Return Mass vs. Launch Date

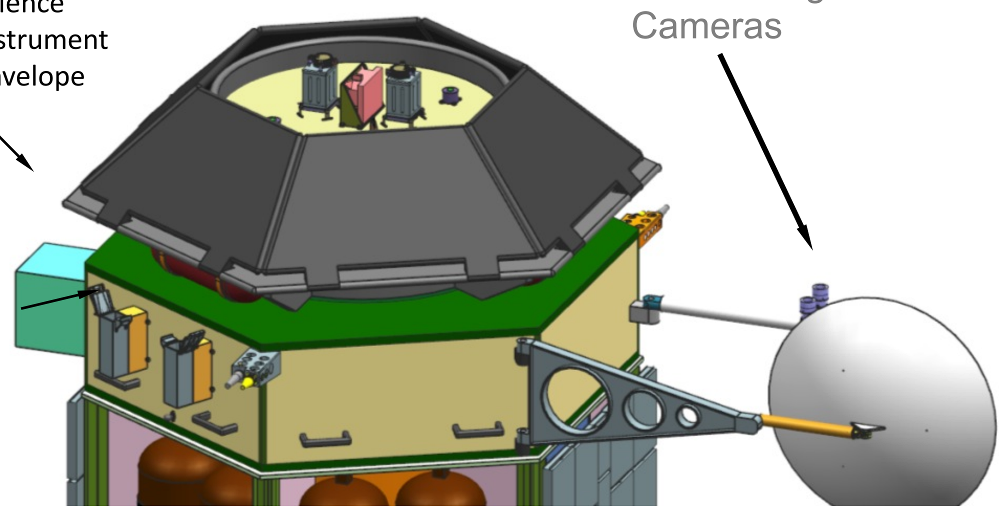


2011 MD: Max Return Mass vs. Launch Date



Rendezvous & Prox-Ops Sensors and Other Payloads

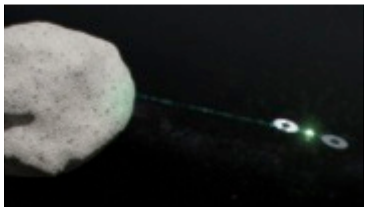




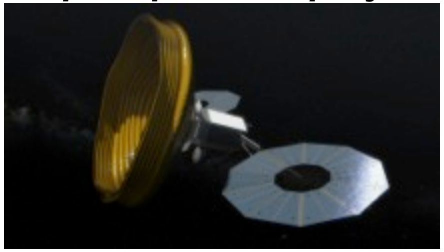
Rendezvous and Proximity Operations Phases

Orbit Refinement and Rendezvous
(Radio and Optical)

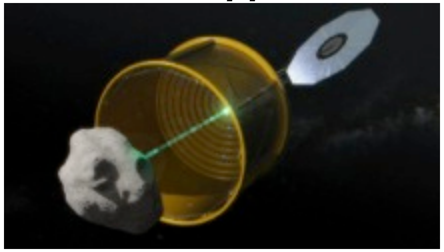
Characterization



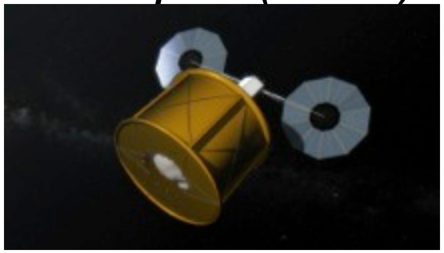
Pre-Capture
Spin up and Deploy



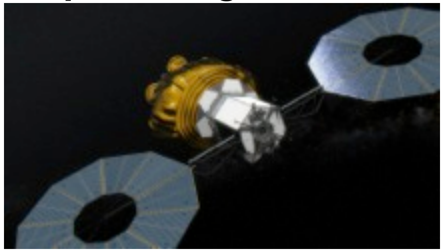
Final Approach



Capture
Mechanical Contact and Capture ("Dock")

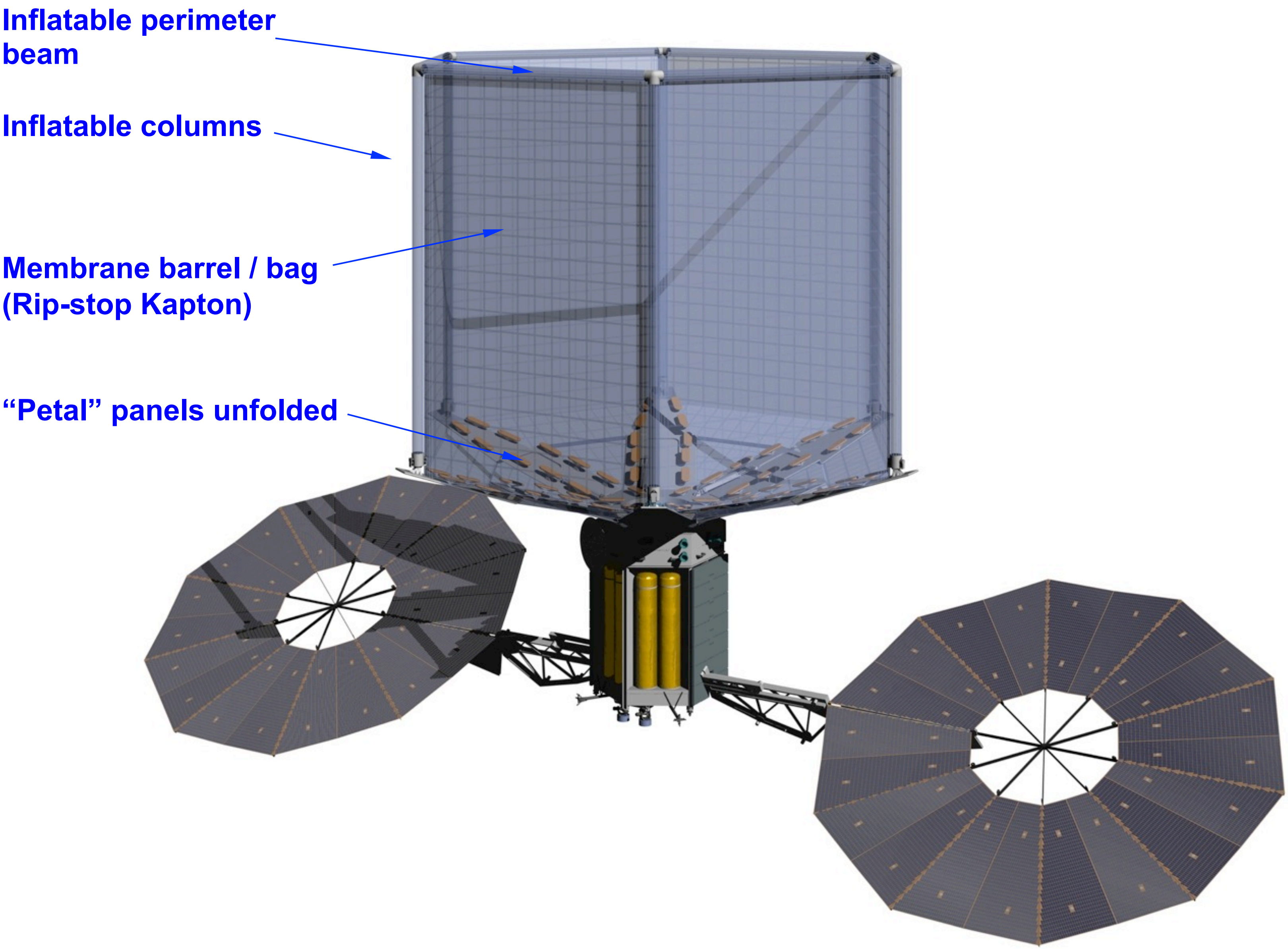


Capture Bag Retraction

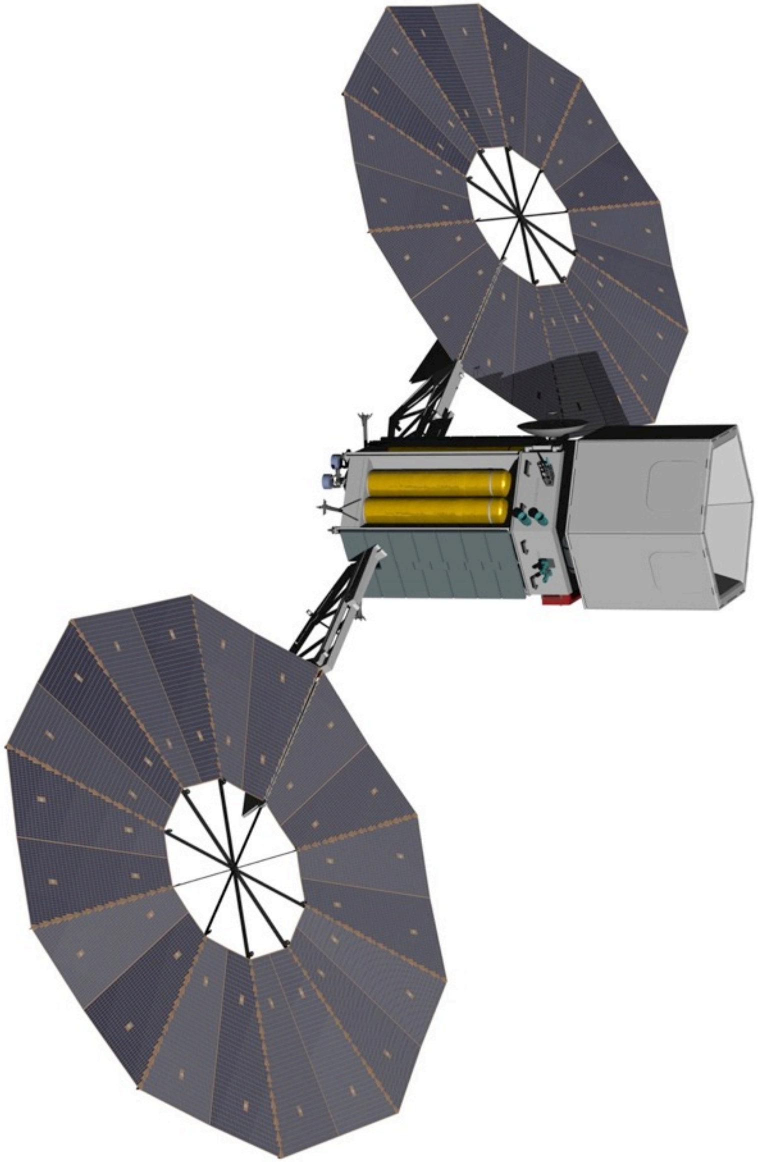


Spin down

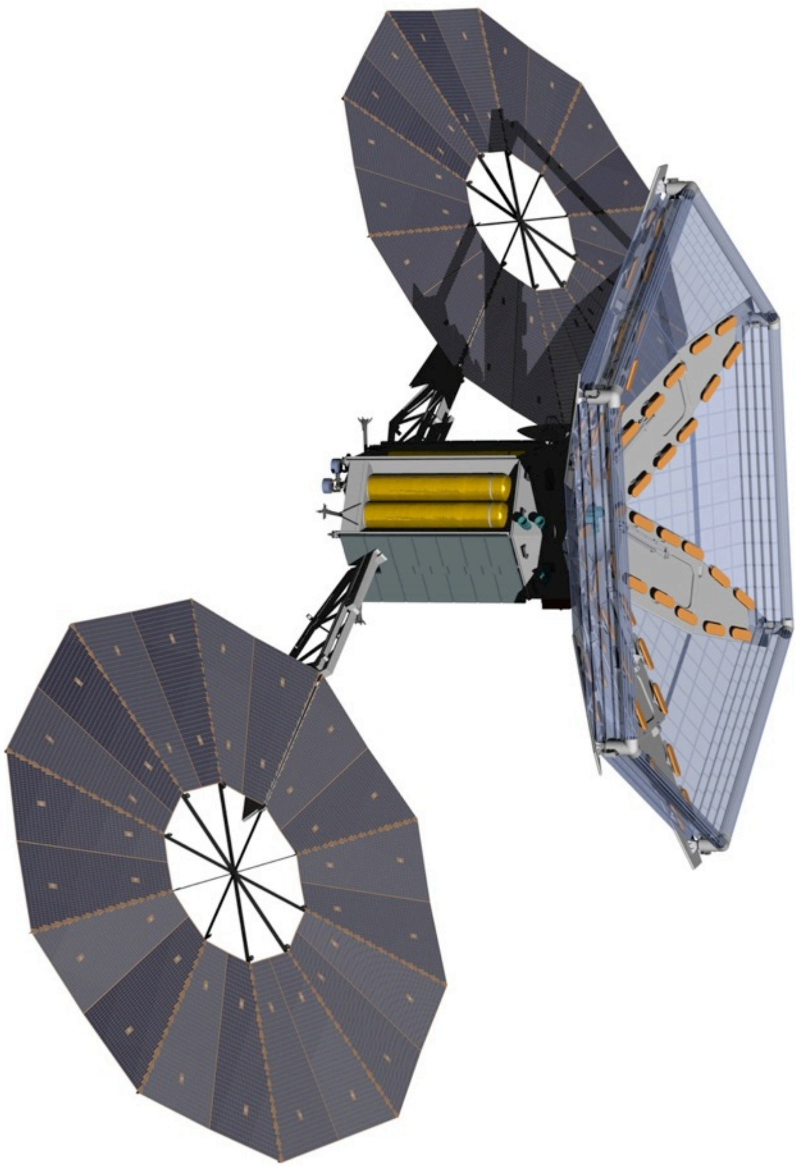
ARM Capture Device Deployed



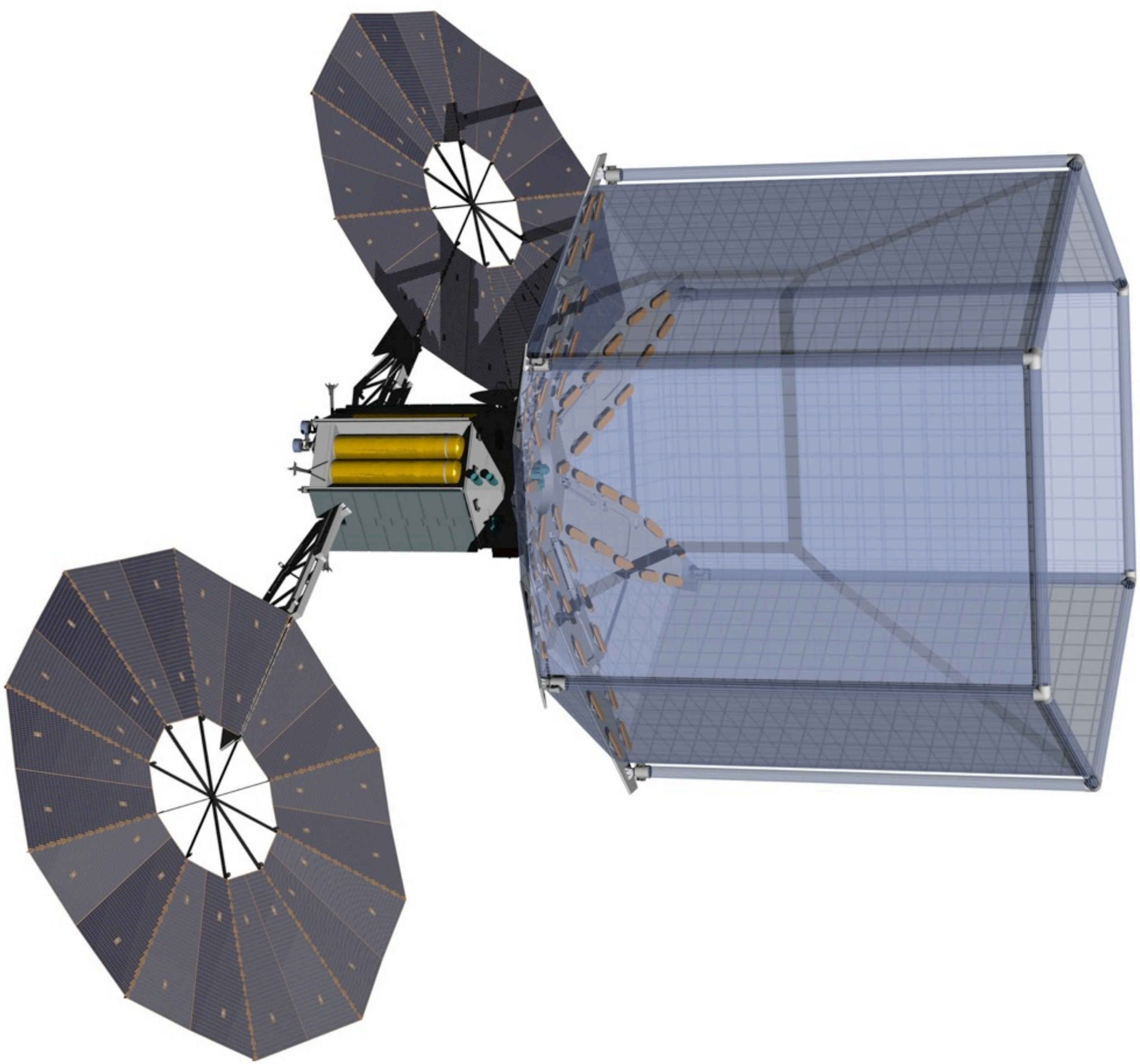
ARM Capture Device Sequence: Stowed



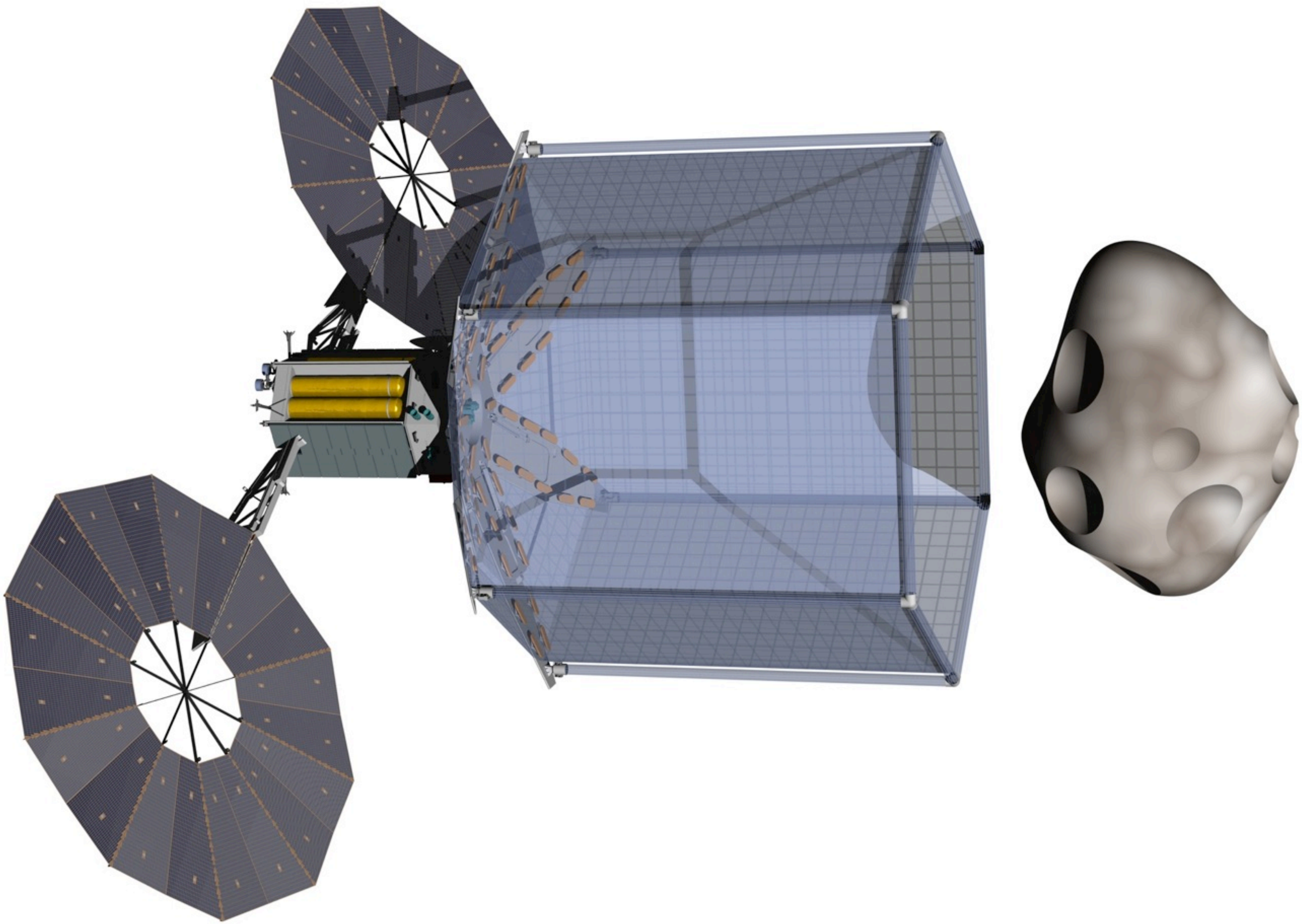
ARM Capture Device Sequence: Petal Deployment



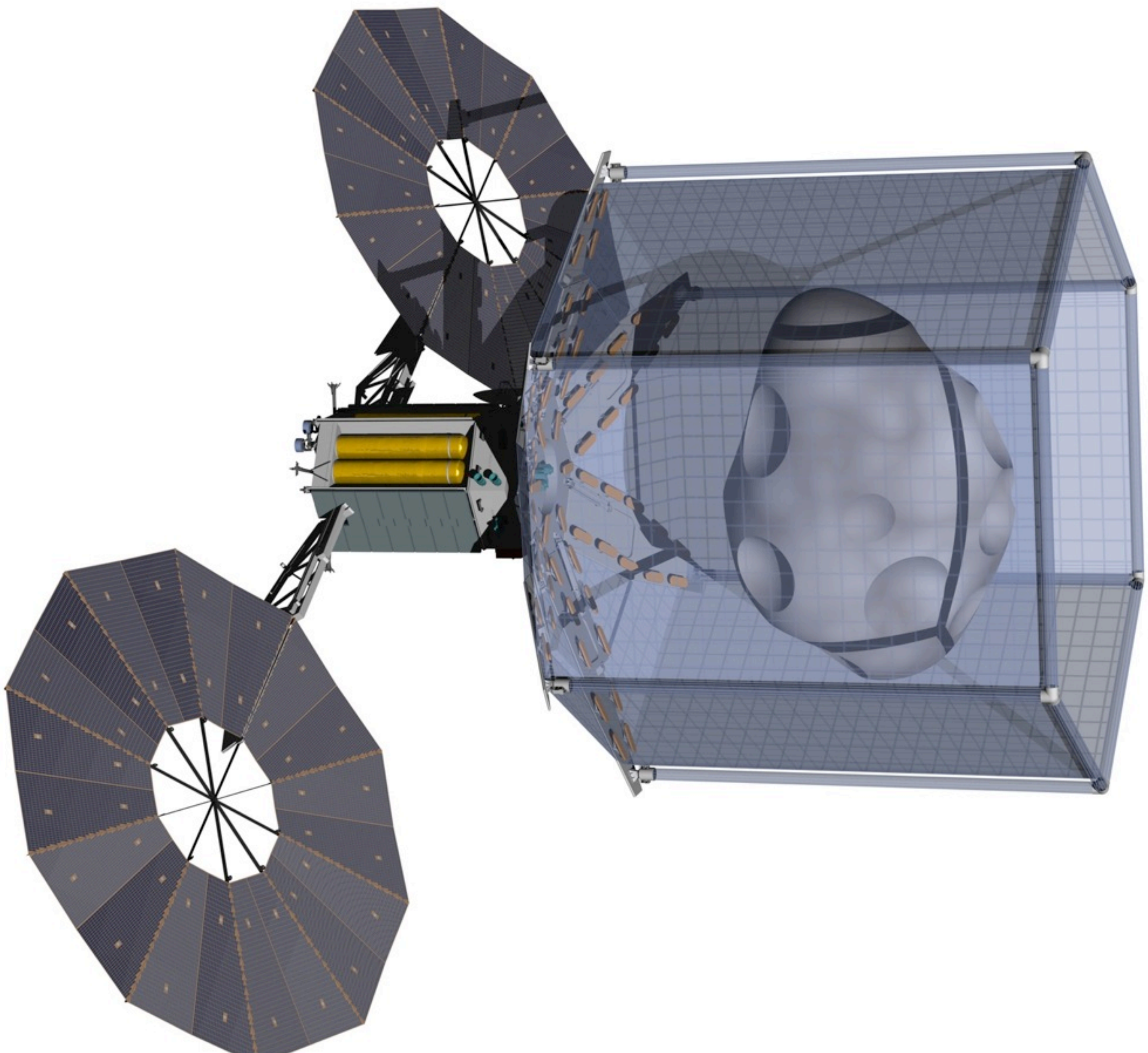
ARM Capture Device Sequence: Bag Fully Deployed



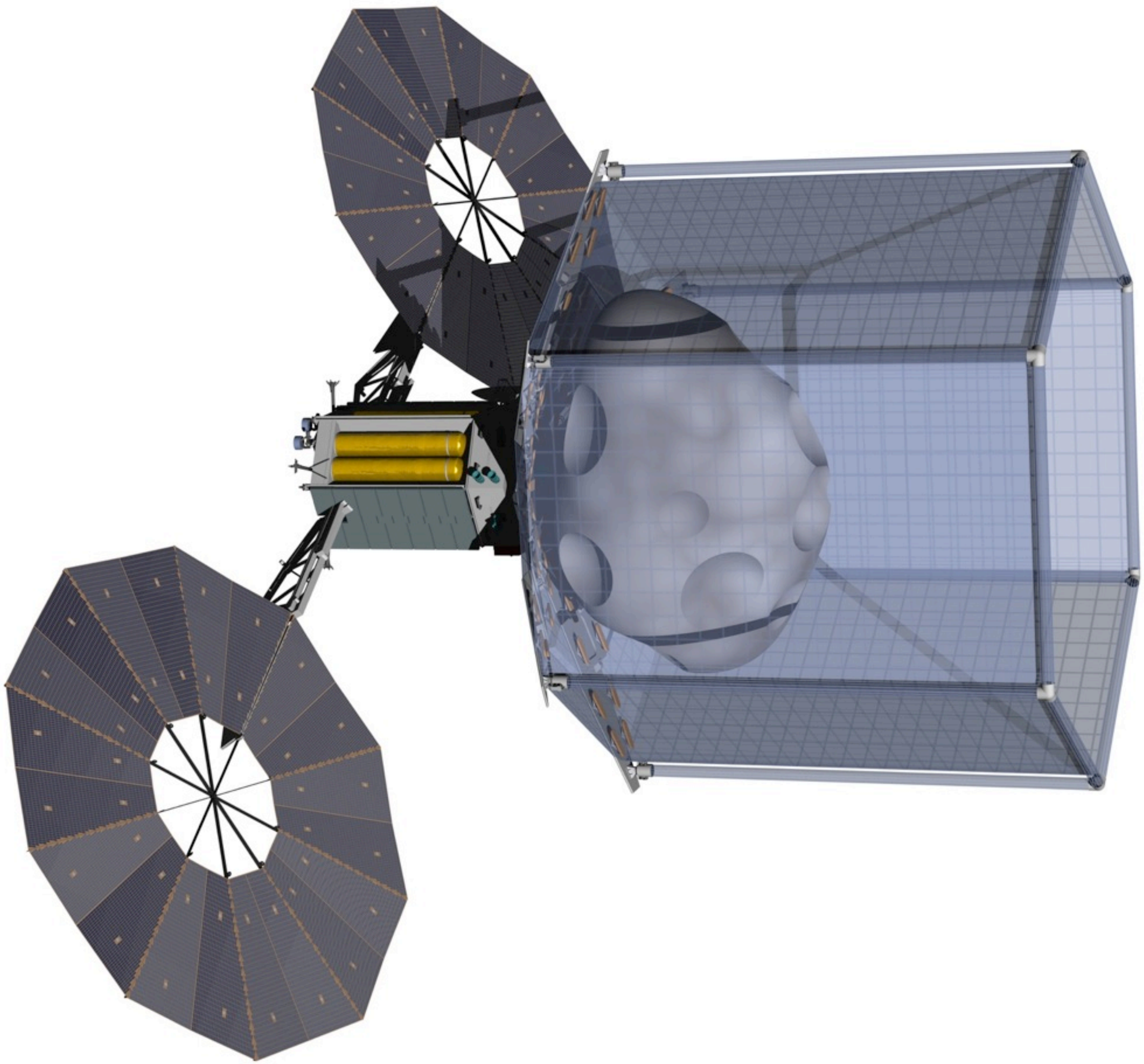
ARM Capture Device Sequence: Approach



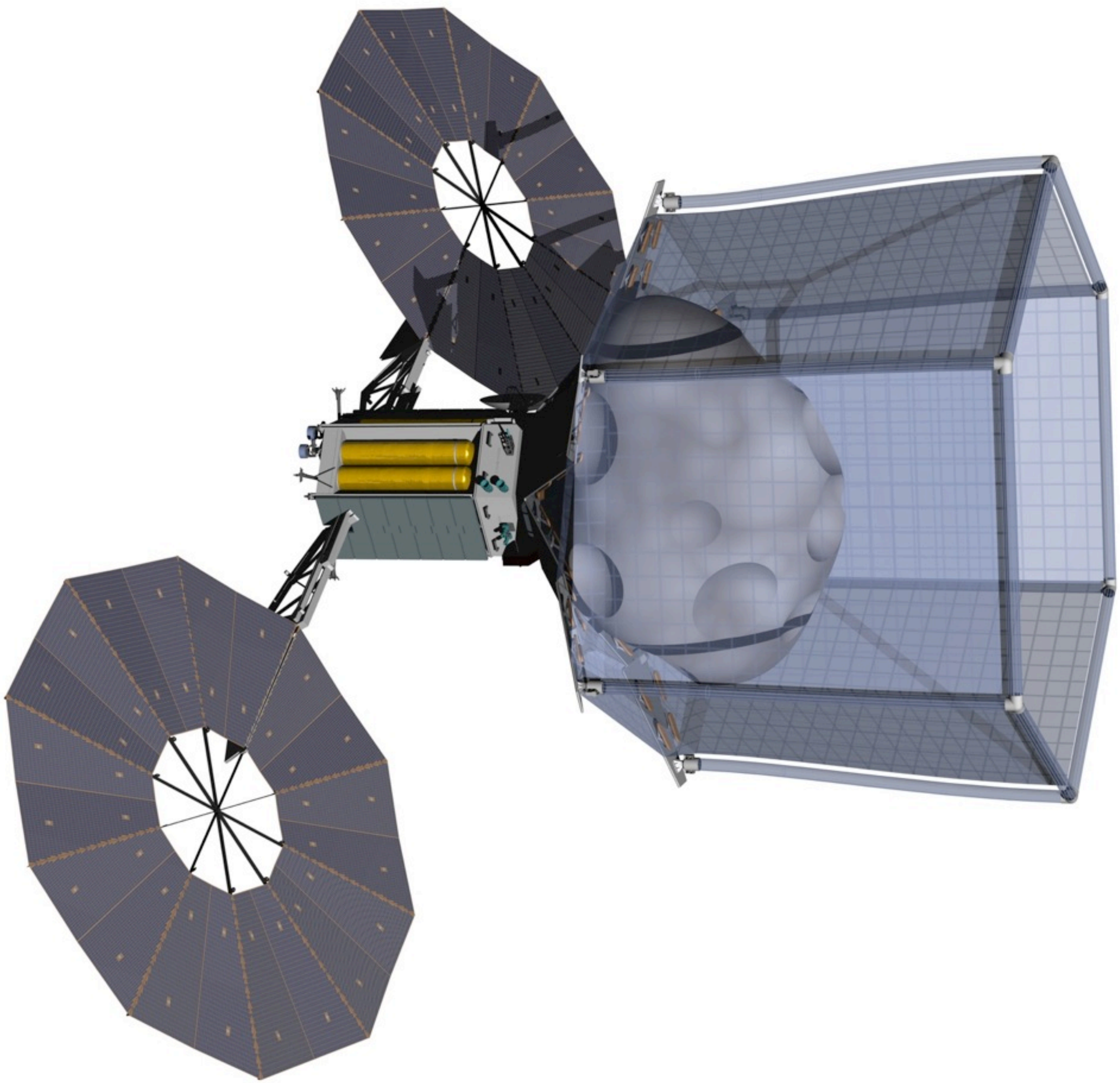
ARM Capture Device Sequence: Approaching Contact



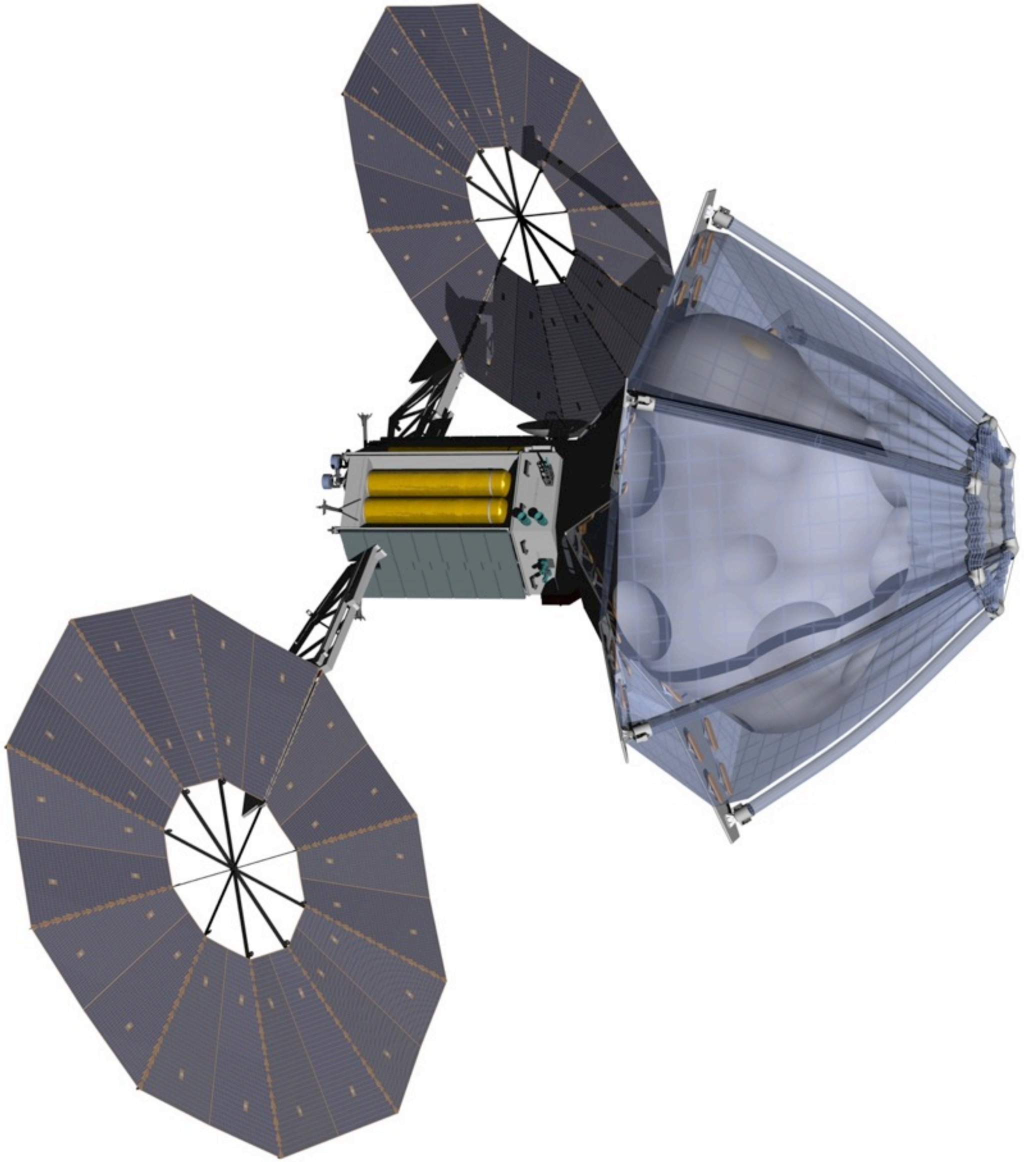
ARM Capture Device Sequence: Contact ("Docked")



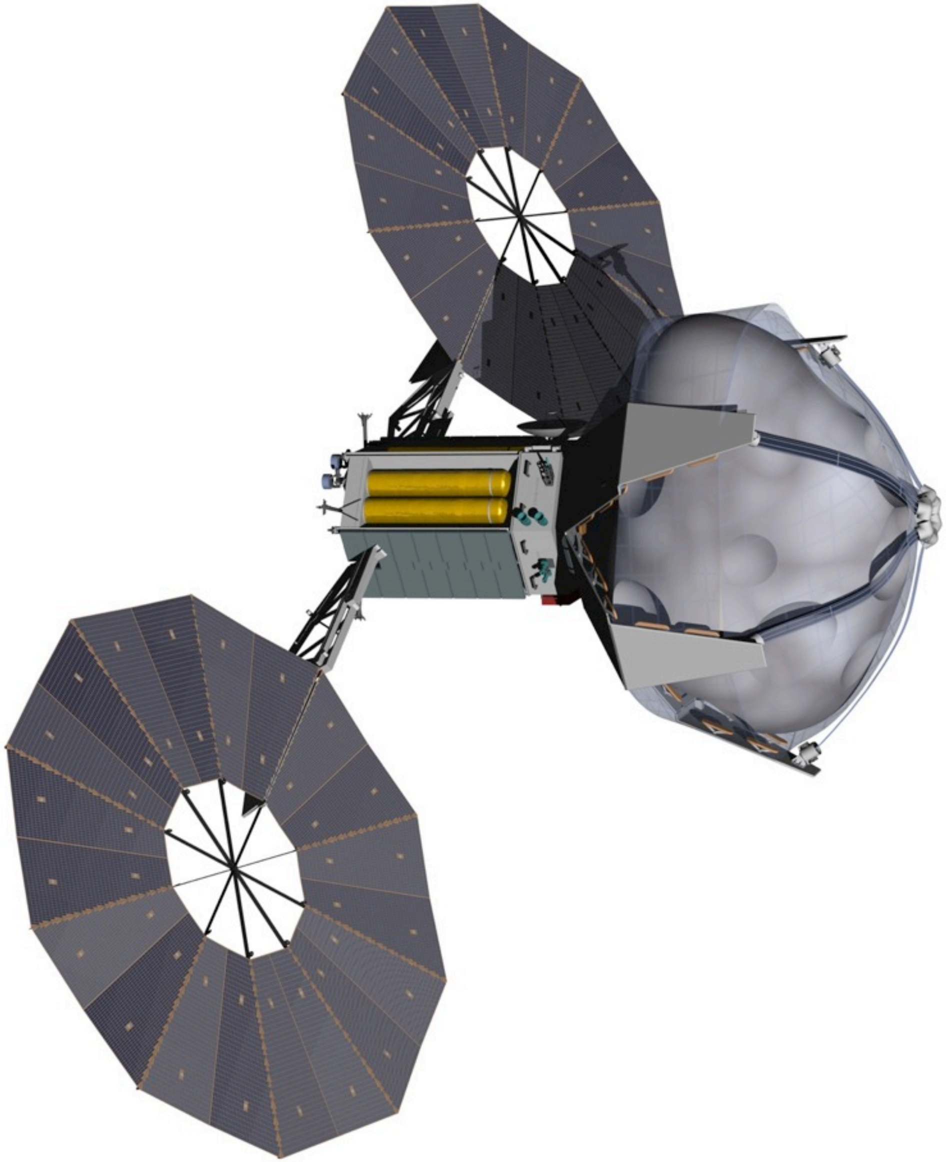
ARM Capture Device Sequence: Initiate Closure



ARM Capture Device Sequence: Closing

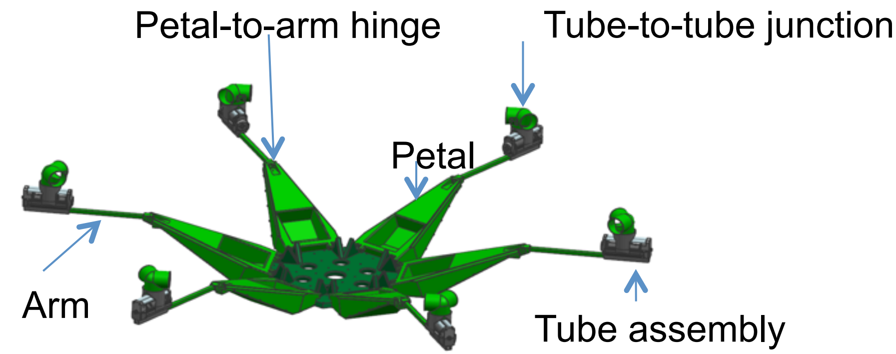


ARM Capture Device Sequence: Fully Captured



Option A: Development and Risk Reduction Status

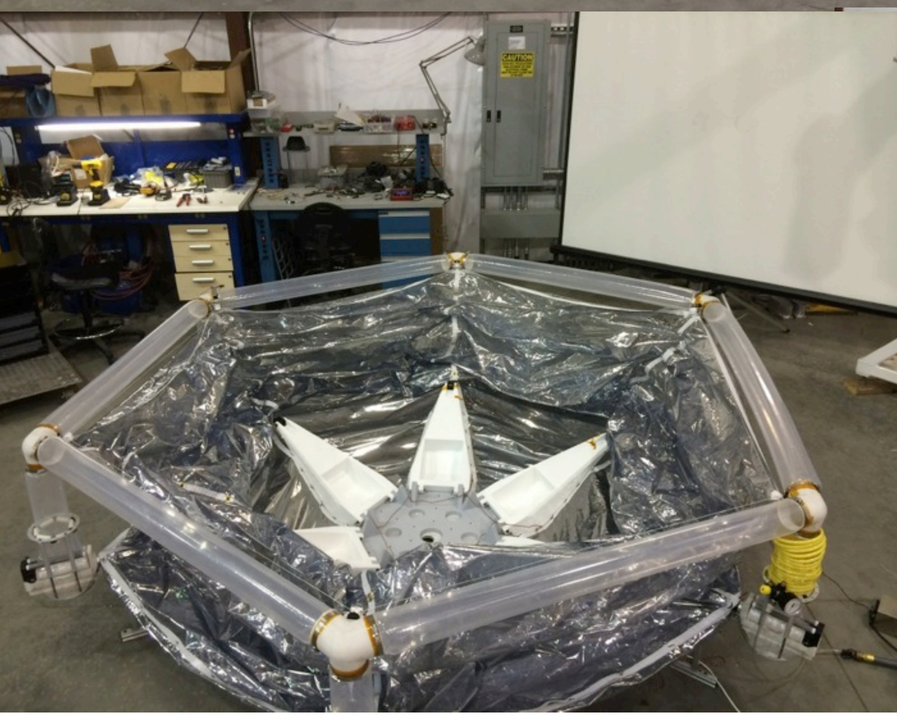
- Building new, high fidelity 1/5 scale testbed, 3 m dia x 2 m long, inflatable structure supported capture bag
- Design features mechanical initial deployment of 6 arms with inflatable booms at the end of the arms that deploy and control the bag material
- System is designed to be fully operational in 1 g including deployment and capture
- Initial testing of deployment/ inflation, "docking" to the asteroid, and bag closure, with force measurements, to be completed by end of FY'14



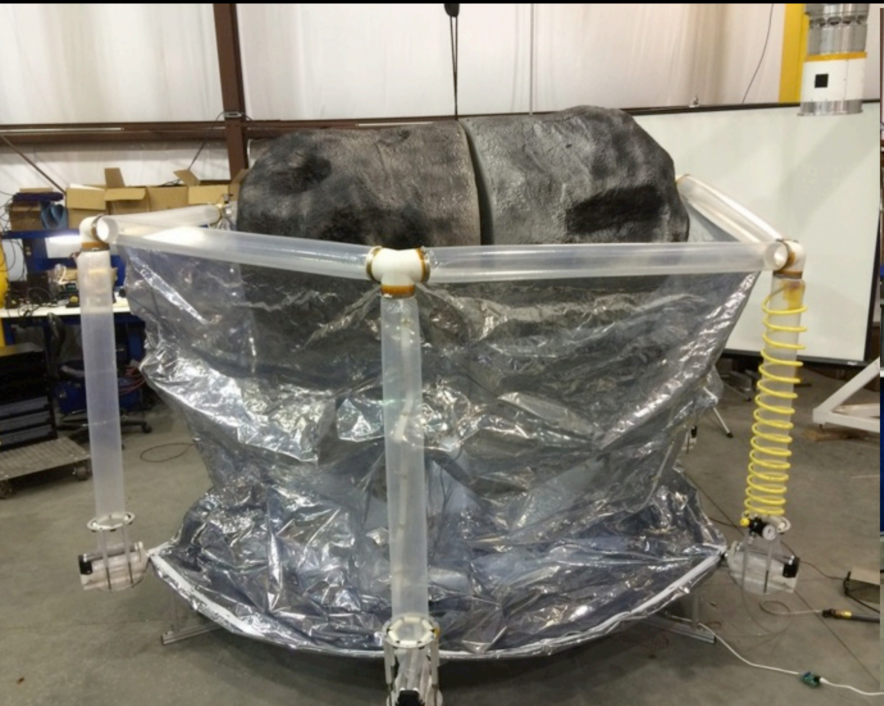
Initial Deploy

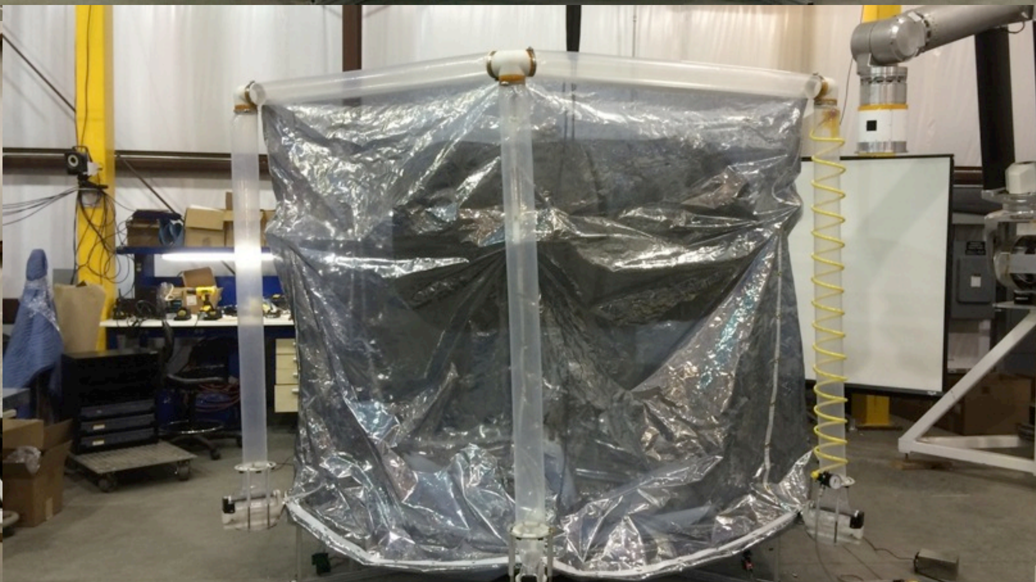
Full Deploy

Mechanical Deploy to Start of Inflation



Completing Inflation and Initiating Capture

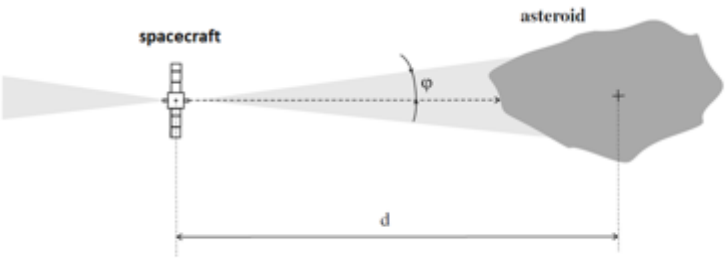




Planetary Defense (PD) Demonstration

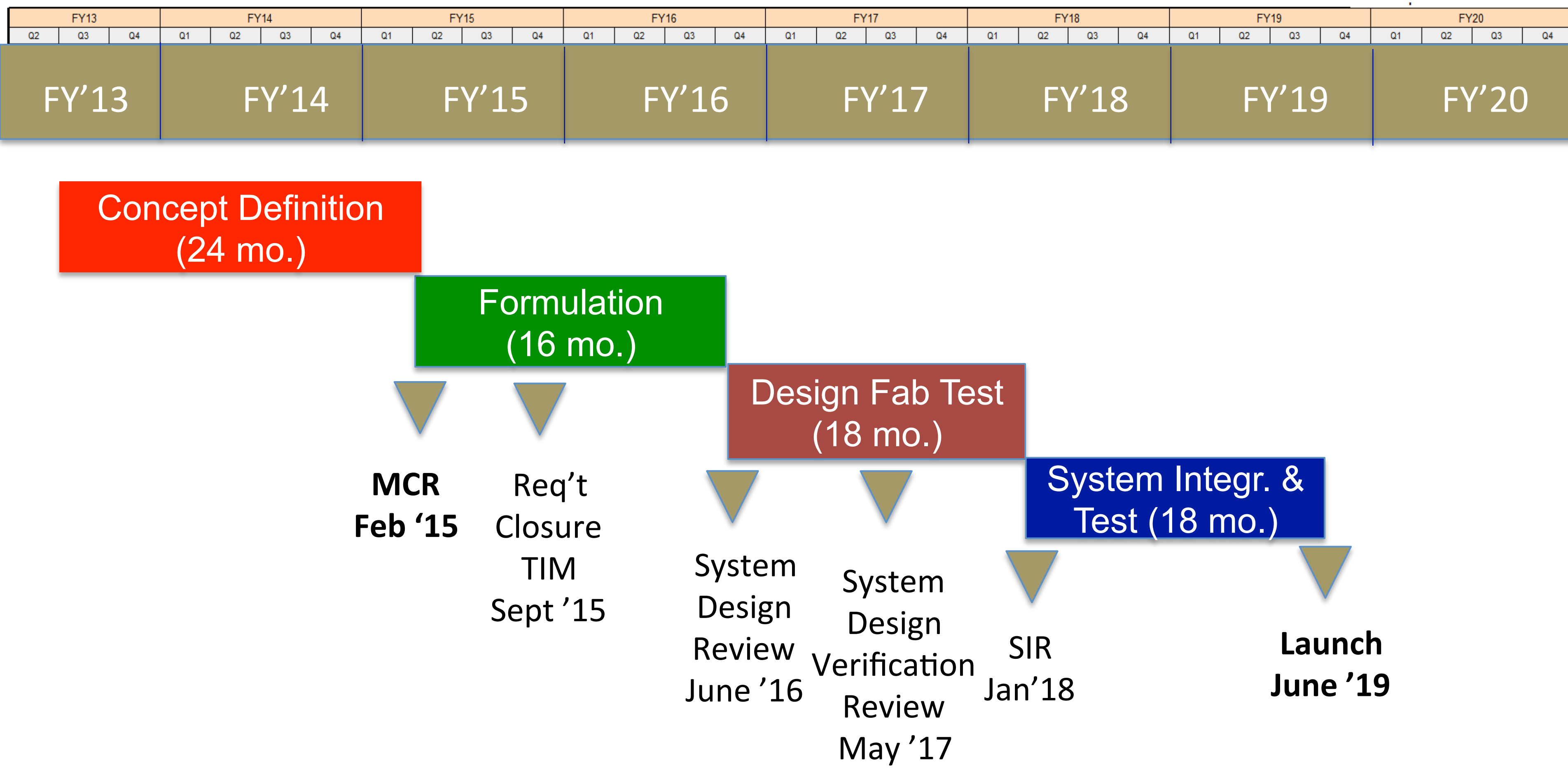
- **Mission could demonstrate the gradual, precise PD approaches of Ion Beam Deflection (IBD), Gravity Tractor (GT) or Enhanced Gravity Tractor (EGT) on a small or large asteroid, relevant to some classes of potential hazardous asteroids**
- **For Option A, a PD demo of either IBD or GT could be done on a small asteroid**
  - No known design changes, fits in existing timeline
  - IBD operations approach is likely independent of the size of the asteroid
  - IBD, <500 t target, could impart: 1 mm/s in < 1 hour
  - GT, <500 t target, could impart: 1 mm/s in < 30 hours

Ion Beam Deflector



Asteroid size-independent planetary defense demo

Schedule for Launch in 2019



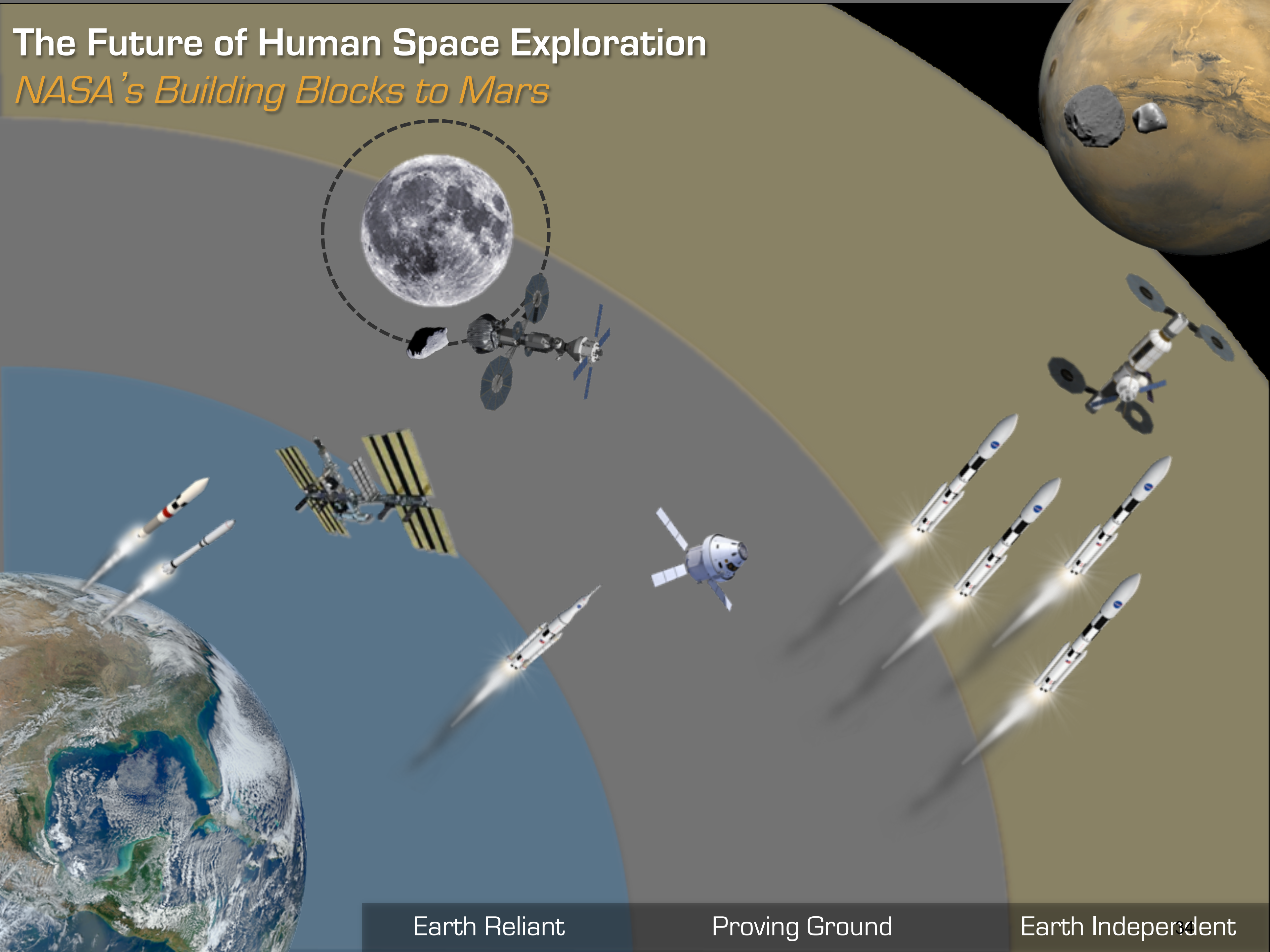
Next Steps

- Complete architecture trades studies and prepare for mission option decision meeting in Dec. 2014
  - Figures of merit analysis
  - Cost basis-of-estimate validation and cost update
  - Design refinement and risk reduction analysis and testing of capture system designs
  - Mission and capture systems risk analysis (development and mission)
  - Assessment of “selectability” of current valid candidate targets
- Continue preparation for MCR in Feb. 2015
  - Update design products based on mission decision
  - Establish success criteria and delivery products
  - Project implementation plan review and draft sign-off
  - Procurement strategy options and assessment

Backup and Reference Material

The Future of Human Space Exploration

NASA's Building Blocks to Mars



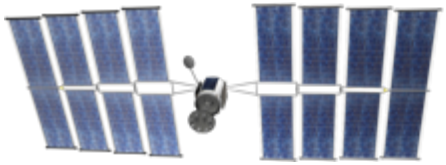
Architecture Mission Options

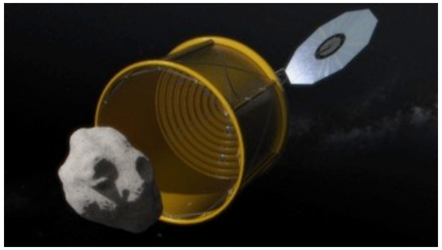
Option	Rationale
Option A	
2009 BD	Valid Retrievable Asteroid
2011 MD	Valid Retrievable Asteroid with Spitzer observation
2013 EC20	Valid Retrievable Asteroid with radar observation
To be discovered C-type, 10-m, 1000-t	Potential C-type asteroid
Option B	
Itokawa	Valid Host Asteroid; Valid Retrievable Boulders; Hayabusa precursor mission
Bennu	Valid Host Asteroid; B-type asteroid; OSIRIS-REx target
1999 JU3	Valid Host Asteroid (?); C-type asteroid; Hayabusa 2 target
2008 EV5	Valid Host Asteroid; C-type asteroid
To be discovered C-type	Potential for increased returned mass or improved characterization
Option C	
Phobos	Extensibility to Mars
Diemos	Extensibility to Mars
Core Capability	
SEP and Mission Module only	Original SEP TDM concept (for reference only)

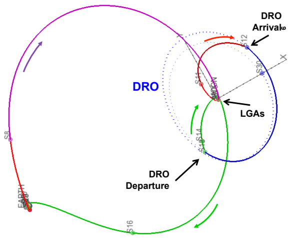
Option A Mission Primary Objectives

Architecture, mission design and flight system deliver the following primary mission functionality:

- **High performance, high throughput, solar electric propulsion system with power up to 40 kW operating beyond Earth orbit. Applicable/extensible to expanding human exploration beyond LEO:**
  - Higher power levels (e.g. 100-250kW) including direct drive
  - Spiral out of LEO (space tug)
- **Capability to rendezvous, characterize and operate in close proximity to a Near Earth Asteroid (NEA)**
- **Planetary Defense (PD):**
  - Capability for Ion Beam Deflection or Gravity Tractor prox-ops and deflection within mission cost and timeline
- **Capability of capturing and controlling an asteroid up to the 10m mean diameter with a mass of up to 1000t**
- **Capable of accommodating a wide range of alternate capture and mission concepts (e.g. Phobos)**
- **Capability of maneuvering/control and returning a NEA, into a stable, crew accessible lunar orbit by the early-mid 2020's, and provide accommodations for crew to explore the NEA**





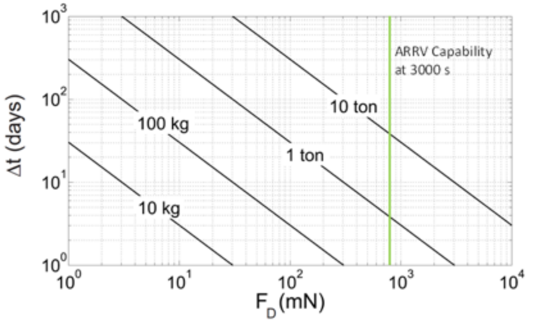


Option A Mission Secondary Objectives

Architecture, mission design and flight system can deliver the following additional secondary objective functionality:

- **Science: Provides a unique opportunity to understand the bulk composition and structure of a whole small NEA—a class of NEAs about which very little is known. The NEA could be any one of a wide range of asteroid types.**
- **Future Commercial Use:**
  - Demonstrates high-specific-power solar arrays and high-power SEP technology.
  - Demonstrates potential orbital debris removal technique via IBD on a *much larger mass*.
- **Future Resource Use: Demonstrates the ability to retrieve asteroid material mass >10x the mass launched to Earth orbit**
- **Partnership Opportunities (International and Commercial): Providing resources for contributed payloads or complementary missions**

IBD for Orbital Debris Removal



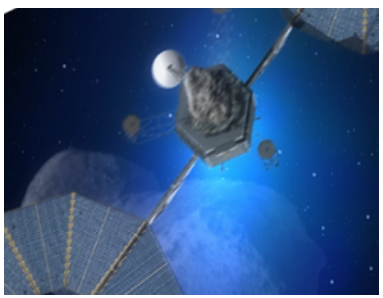
Mario Merino, Eduardo Ahedo, Claudio Bombardelli, Hodei Urrutxua, and Jesus Peláez, "Ion Beam Shepherd Satellite for Space Debris Removal," 4th European Conference for Aerospace Sciences, July 2011

Secondary Objectives and Extensibility

Planetary Defense

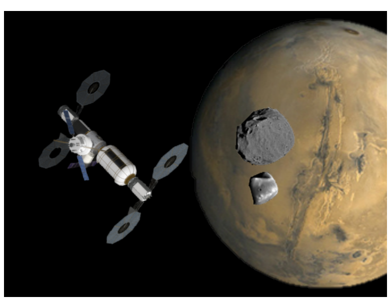
Small Asteroid Capture	Robotic Boulder Capture
• ARM prox ops, autonomous ops, characterization & algorithms applicable • Slow Push techniques implemented with small development costs	
• Slow Push techniques (IBD, GT) demonstrated much more quickly	• More relevant on a PHA • Opportunity for kinetic impactor

Science, Commercial and Resource Use



Small Asteroid Capture	Robotic Boulder Capture
• Applicability of high power SEP, ARM engineering instruments • Potential to host "target of opportunity" payloads	
• Opportunity to learn about <10m asteroids; ~1:10 are C-type	• Better opportunity to return desired material (if C-type) w/geologic context

Extensibility



Small Asteroid Capture	Robotic Boulder Capture
• In-space SEP and prox ops w/uncooperative target provides broad opportunities (human exploration, science, commercial) • Supports Exploration Roadmap with partnership opportunities – **Mars Forward**	
• Inflatable technology uses • Ion Beam Deflection for orbital debris	• Near surface ops; remote manipulator and gripper concepts applicability

Option A: The Asteroid Target and the Inflatable

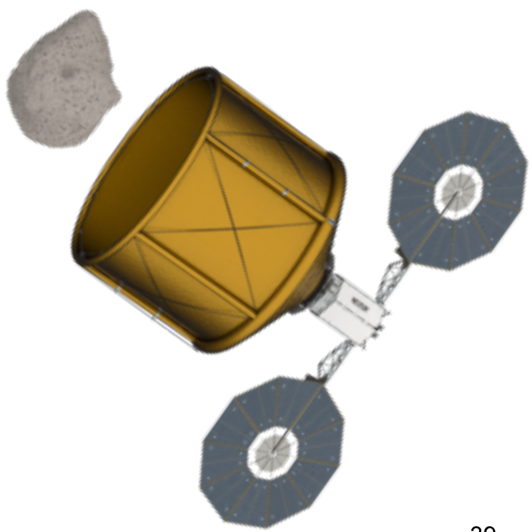
- ***Most large asteroids are believed to be loosely held together bodies, i.e. rubble piles.*** **The likelihood that small bodies are fragments of large bodies implies the need for containment in a bag.**
  - Tolerant of a wide range of asteroid shapes and mechanical properties
  - Assures containment and eliminates dust as hazard for S/C
  - Local forces on asteroid due to capturing, cinching, berthing and maneuvering are estimated to be small compared to the strength of the body
- **Based on inputs from the EVA office and the strong desire to minimize complexity and risk we have limited the design space to simple spinners or slow, <0.5 rpm, tumblers, estimated to include 75% of the small asteroid population**

Rubble Pile Compressive Strength

- Bolide Record: 0.1- 1.0 MPa (15-150 psi)
- "Dirt" Clod: .2-.4 MPa (30-60 psi)
- Possible lower strength <0.1MPa

Possible Spin States

- Slow (<0.5 RPM), Simple Spin
- Slow (<0.5 RPM), Tumbling
- Fast (~<2 RPM), Simple Spin
- Fast (~<2 RPM), Tumbling



Size Comparisons

Note: Sphere is representative only. Retrieved asteroid/boulder will not be spherical in shape