# ASTEROID REDIRECT MISSION REFERENCE CONFIGURATION PLUS ALTERNATIVES FROM THE KISS STUDY

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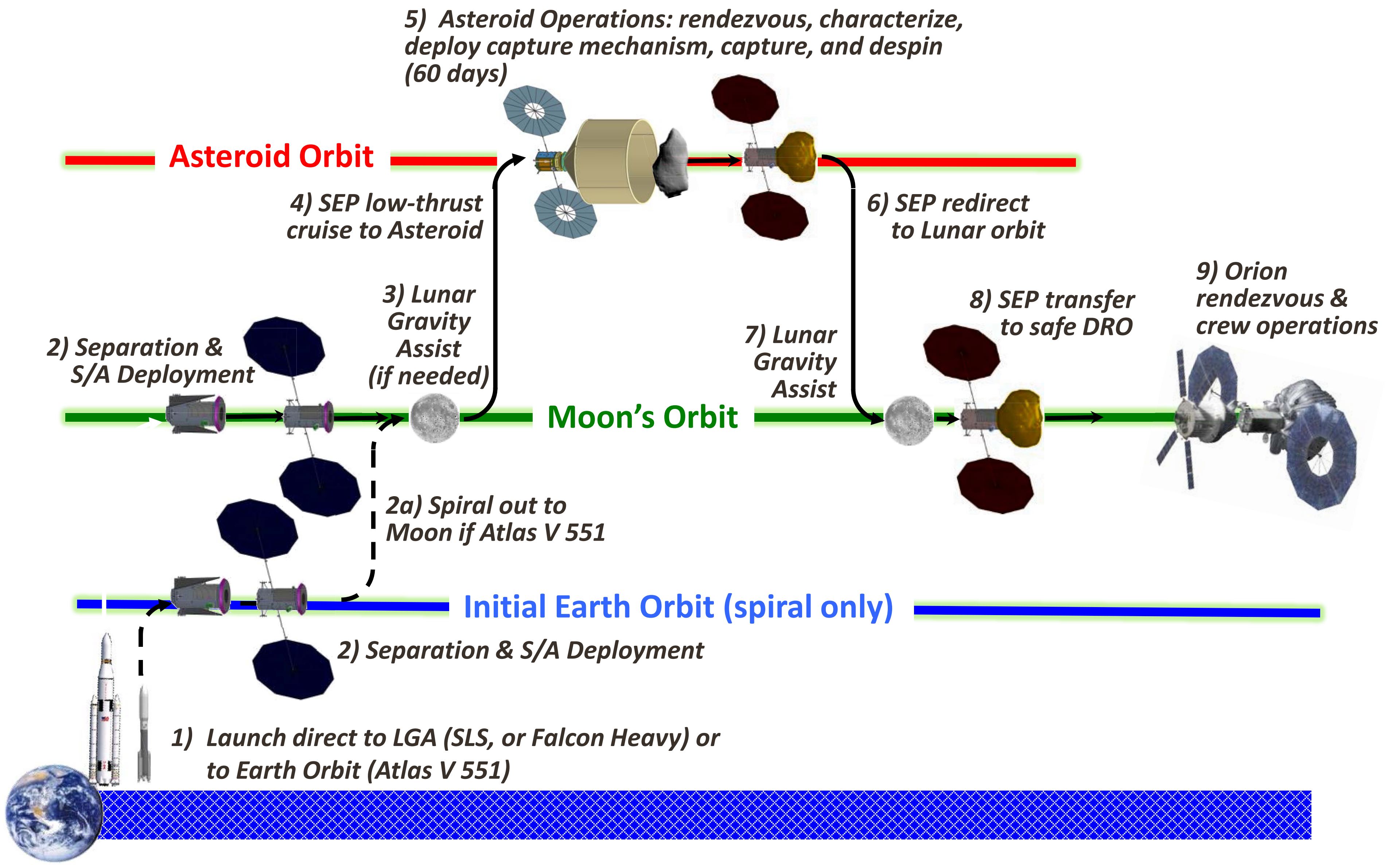
# Outline

- Status of the Asteroid Redirect Vehicle
- Alternatives Considered in the Study Sponsored by the Keck Institute for Space Studies (KISS)

# Reference Mission Overview

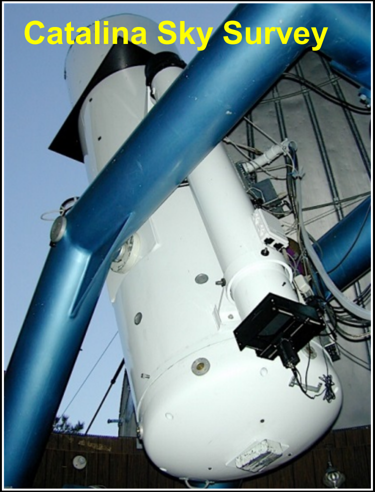


# Asteroid Redirect Mission (ARM) Status

- Launch Vehicle Options
  - EELV, Falcon Heavy, SLS
- Final Storage Orbit
  - Lunar Distant Retrograde Orbit (DRO)
- Flight Time (for 2009 BD)
  - 6.2 years (7.6 years if launched to an elliptical Earth orbit on an EELV
- Propellant Mass
  - Up to 10 t of xenon
  - Up to 400 kg of hydrazine
- Solar Array
  - ~50 kW BOL at 1 AU
- EP System Power
  - 40 kW

# Finding Valid Candidates: Small Asteroids

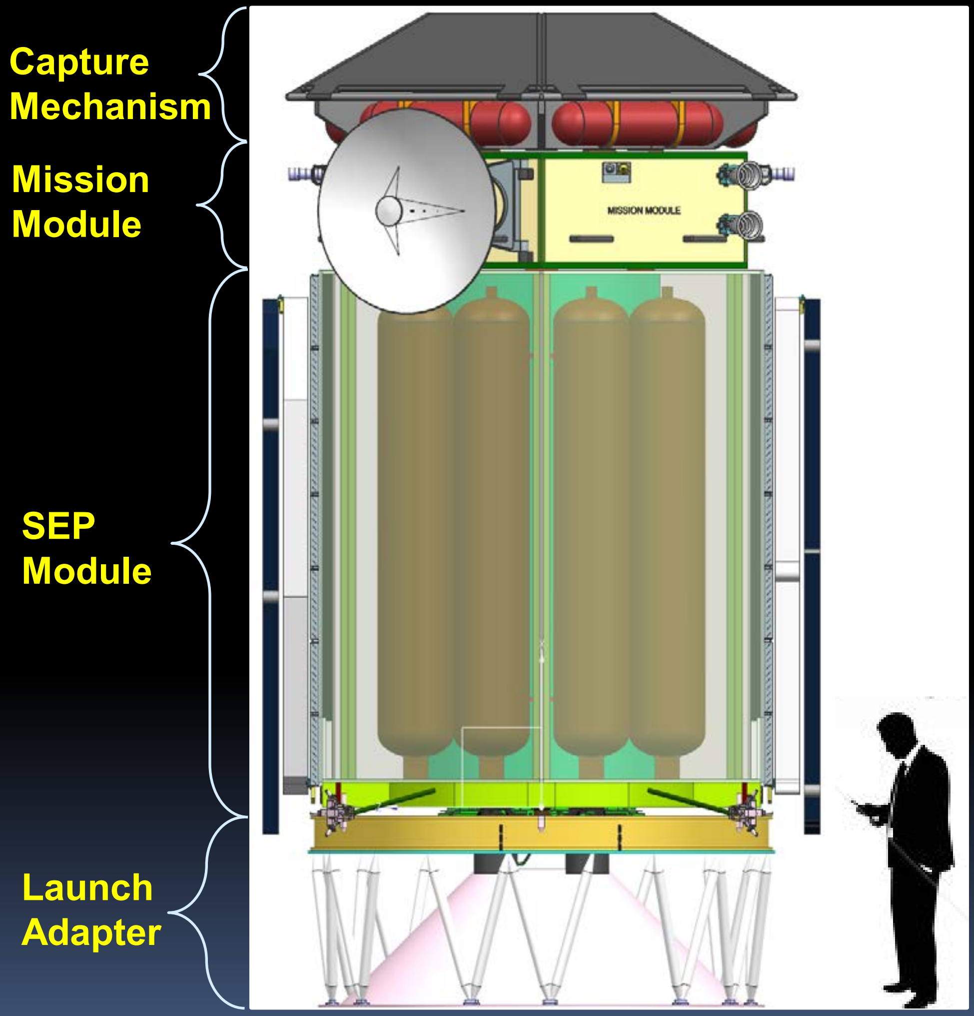
- Small candidates must lie in a narrow range of Earthlike orbits so that they are within the capability of ARM to successfully redirect them into lunar DRO.
- Two good small asteroid candidates are already known: 2009 BD and 2011 MD.
- Discovery rate for new small candidates will increase due to enhancements to existing surveys and new surveys coming online; a conservative projection is that the rate will increase to **at least 5 per year**.
- With at least another 3-4 years to accumulate discoveries, at least **15 more small candidates are expected**.
- With rapid-response characterization capabilities in place, there will be good opportunities to physically characterize these new candidates.
- ***The expected discovery rate of new small candidate targets and the use of rapid-response characterization assets will provide a more-than-adequate number of valid candidate targets for a small-asteroid redirect mission***




And many others…

# ARV Flight System

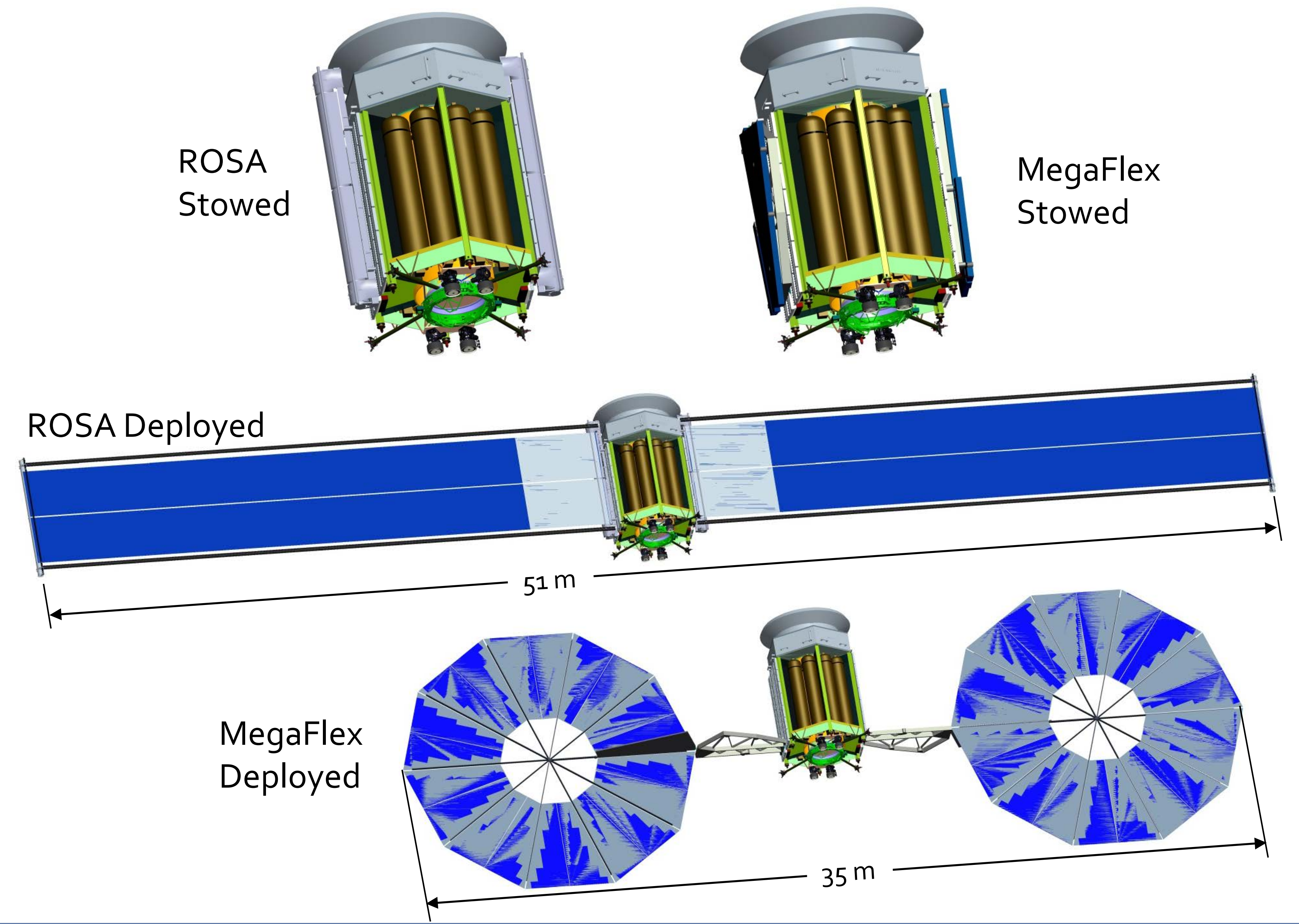
- Key Driving Objective:
  - Minimize the cost and technology development risk for an asteroid redirect mission with extensibility to future missions
- Balanced risk across major elements
  - Asteroid discovery and characterization
  - Transportation technology development
  - Proximity operations time
  - Accessibility of storage orbits
- Developed a baseline flight system and conops approach
  - Modular Flight System: SEP Module, Mission Module, Capture System
  - Conops validated by model-based systems engineering analysis
- Flight system development for a 2018 launch is feasible and includes appropriate technical margins



# Key Requirements

| Key and Driving Requirements | Derived Key Design Drivers for Costing Baseline |
|---|---|
| Launch Date: mid 2018 | Drives flight system implementation schedule<br>• Drives technology choices (e.g. limit maximum solar array power ~50 kW) |
| Return Date: 2021 to 2025 | EP system power: 40 kW; 50-kW BOL solar array<br>EP specific impulse: ~3000 s<br>Accommodate up to 10,000 kg of xenon<br>Proximity operations schedule<br>Capture Mechanism sizing |
| Enable capture of asteroids in the 5 to 10-m size with maximum dimension of ≤ 14 m and a mass up to 1,000 metric tons | |
| Launch on an SLS, EELV, or Falcon Heavy | Launch direct to lunar gravity assist or provide the capability for spiral out from low-Earth orbit for EELV launch |
| Accommodate asteroid structural integrities ranging from a ruble pile to a single solid rock | Capture the asteroid in a bag as opposed to a net, harpoon, mechanical arms, etc. |
| Include at least 90% of otherwise acceptable target asteroids based on spin rate | Asteroid spin rates up to 2 RPM<br>Accommodate up to 400 kg of hydrazine |
| Provide the capability for autonomous capture and despin control | Sensor suite includes cameras and LIDAR<br>Flight software for controls and fault protection |
| Minimize flight time to the asteroid to maximize return leg thrusting time | Be compatible with operation over solar ranges from 0.8 to 1.3 AU |
| Asteroid Redirect Crewed Mission and Extensibility | Docking ring, S-Band transponder, EVA tools, Human safe, power interface |

# Flight System Configurations



# Flight System Key Features

Instrumentation with flight heritage

Capture bag with force-limiting mechanism

Deep Space spacecraft avionics with flight heritage

Simple interface between modules

Conventional thermal control

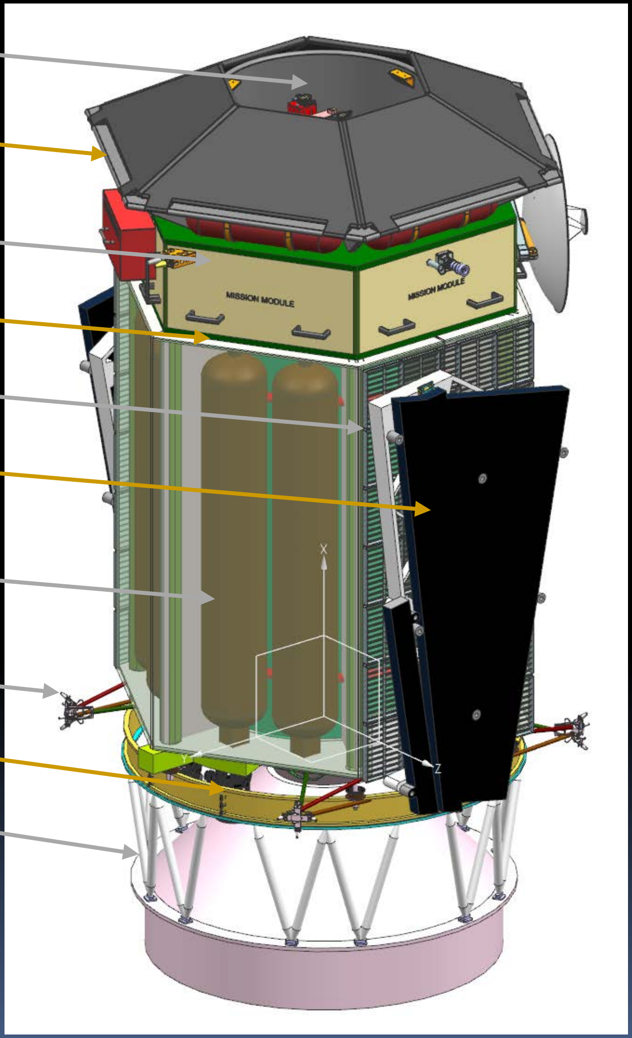
Compatible with either STMD solar array at 50 kW BOL

Conventional low-cost, light-weight xenon tanks

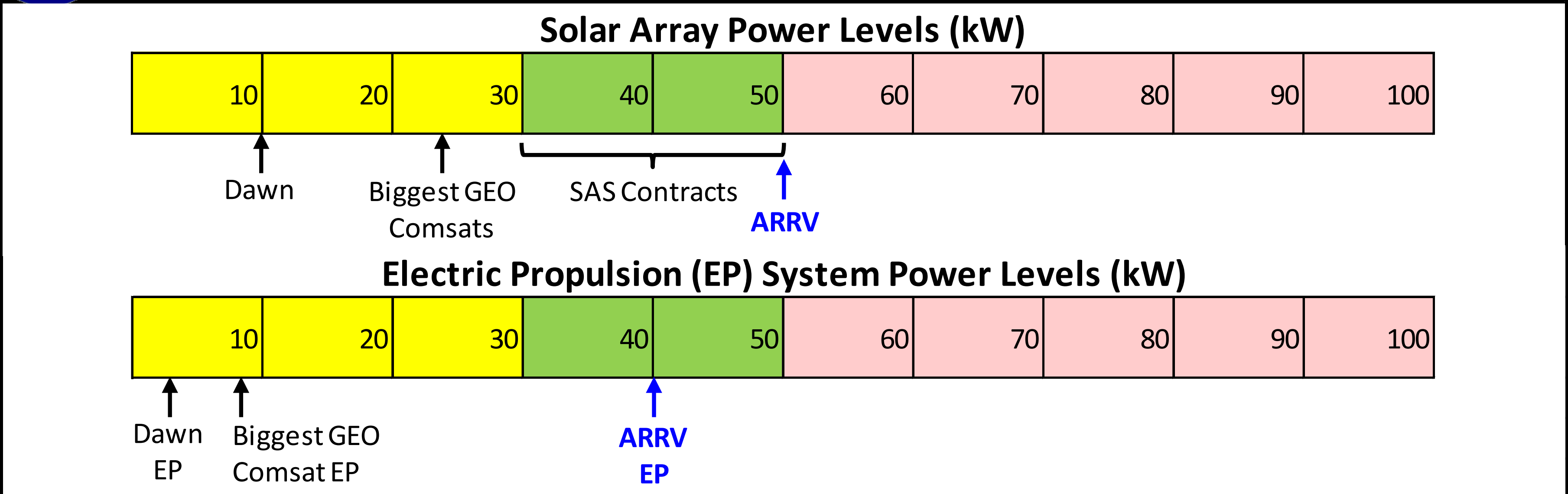
Conventional Reaction Control Subsystem

STMD Hall thruster/PPU technology

Compatible with Atlas V, SLS, or Falcon H launch vehicles



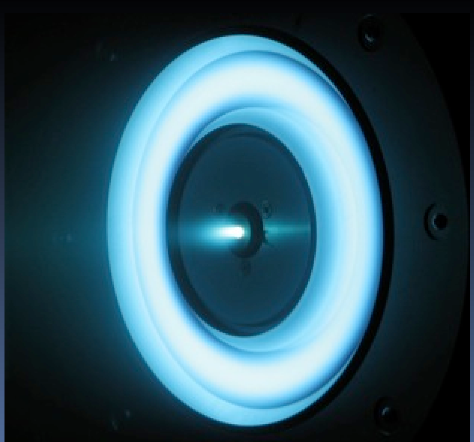
# Power and Propulsion Subsystems




- Solar Array
  - Solar Array System (SAS) contracts underway
  - 300 Vdc main bus voltage
  - Extensibility to ≥ 250 kW required in SAS contracts


- Electric Propulsion
  - 13.3-kW Hall Thruster/PPUs with Isp = 3,000 s
  - Three thruster/PPU strings and one cold spare
  - 8 seamless Al-lined COPVs for Xe storage with 5% tankage fraction

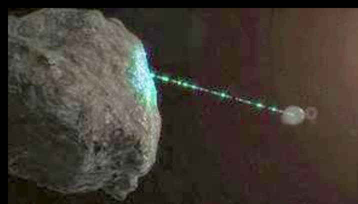
9-kW, 3000-s Hall Thruster in 100-hr Test at JPL



# Rendezvous and Proximity Operations Phases

**Orbit Refinement and Rendezvous**
***(Radio and Optical)***

**Characterization**



**Pre-Capture**
***Capture System Deploy***

***Final Approach***

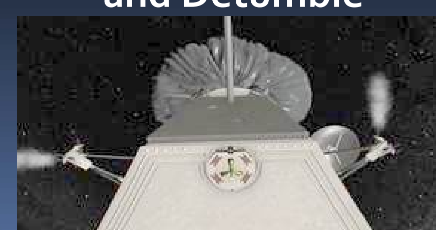
**Attitude Control Disabled**

**Capture**
***Mechanical Capture***

***Capture Bag Retraction***

**Attitude Control Enabled**

**Characterize, Spin down, and Detumble**



# Key Characteristics of Asteroid for Capture

## Composition/Strength

- Rock (>>1PSI)
- Dirt Clod (~1PSI)
- Rubble Pile(<<1PSI)

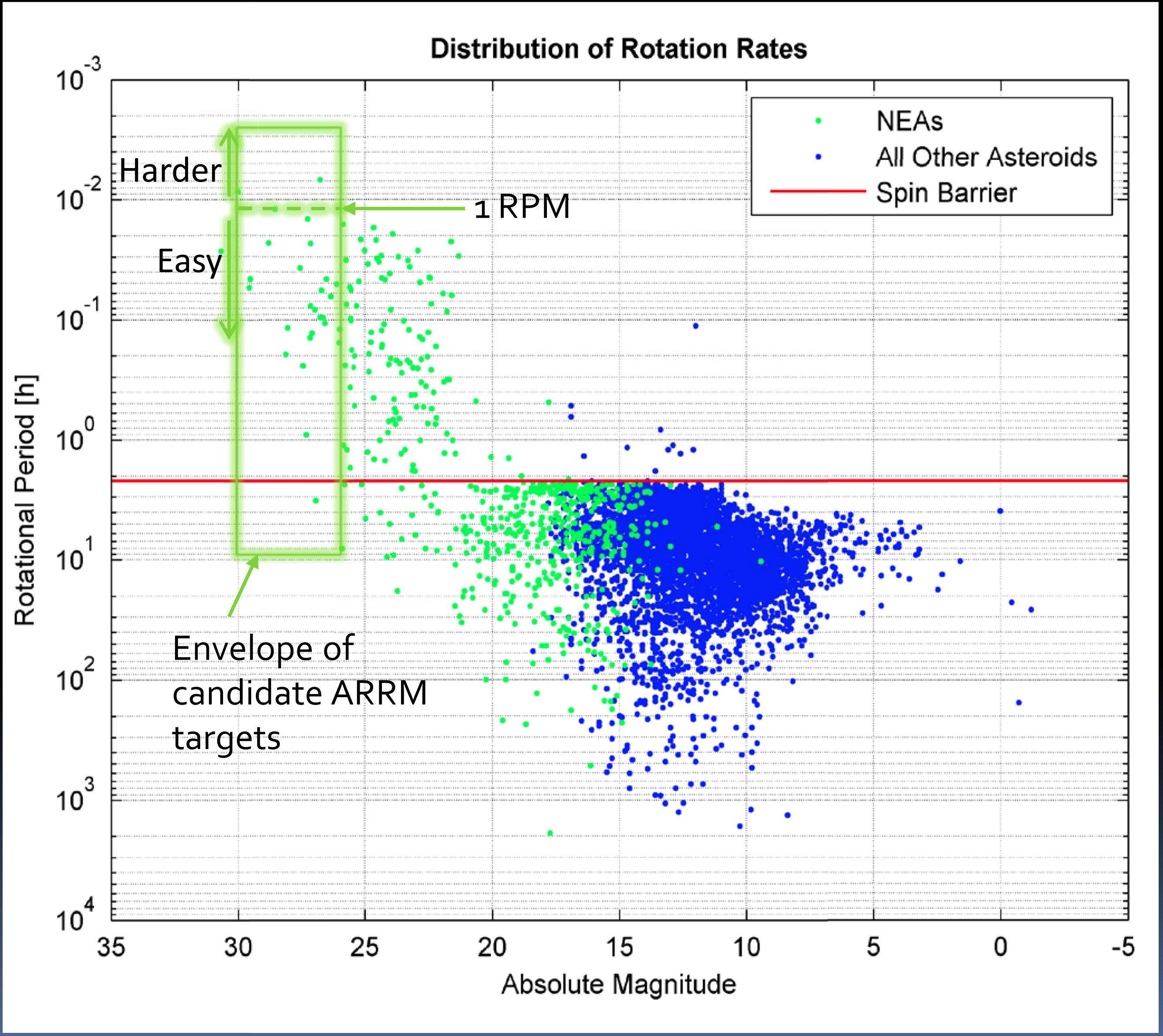
## Spin State

- Slow (<<1RPM), Simple Spin
- Slow (<<1RPM), Tumbling
- Fast (~>1RPM), Simple Spin
- Fast (~>1RPM), Tumbling

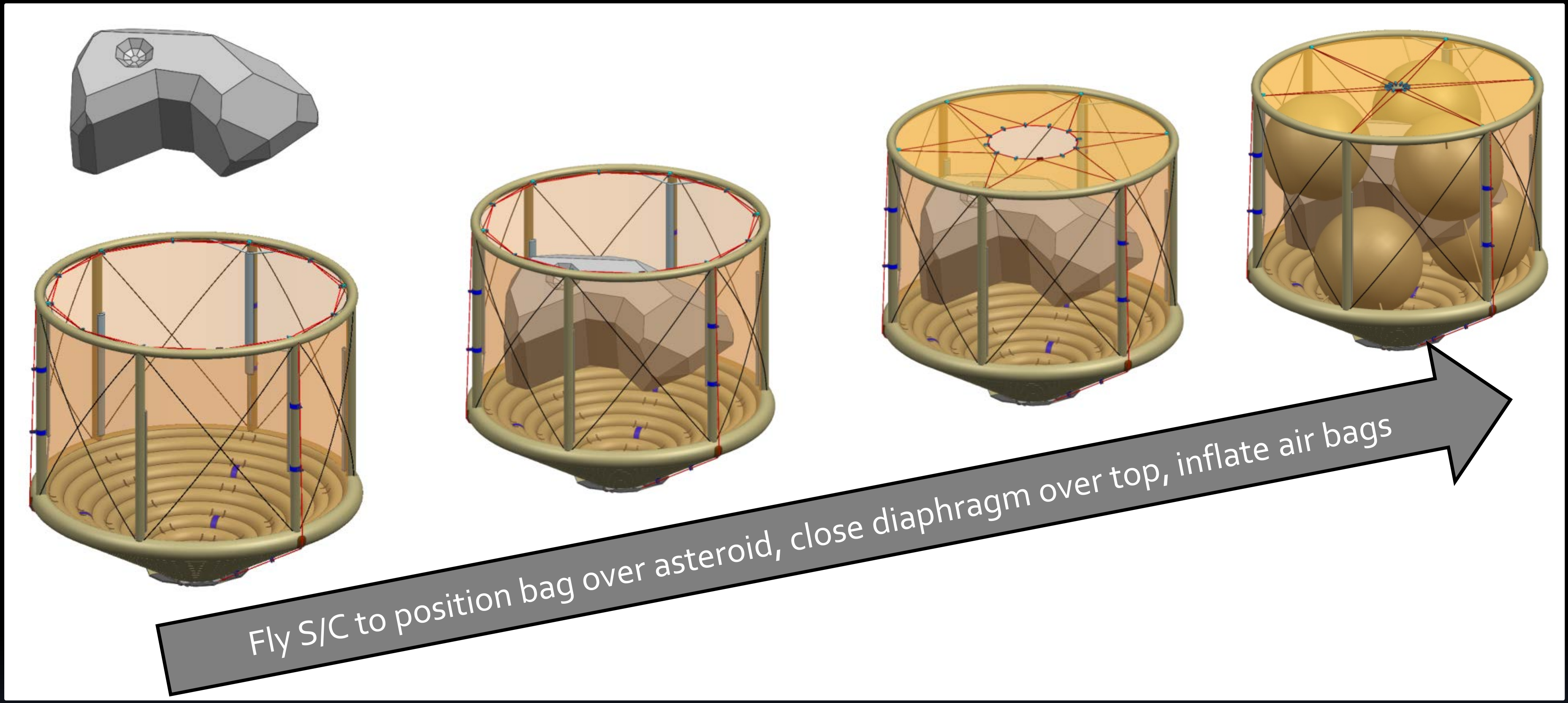
- For capture, the primary concerns are composition/strength and spin state
- Evaluated passive and active control options that limit forces on the spacecraft/solar arrays to < 0.1 g peak for the fast/tumbling state

# Spin Periods of Near-Earth Asteroids

- Many small NEAs spin faster than the rubble pile spin barrier, but may be "dirt clods“
- Worst case assumed to be 5-13 m diameter NEA with a spin rate of 2 RPM and tumbling



# Capture Sequence




- Spacecraft approaches and matches spin along projected asteroid spin vector a short time in the future.
- When asteroid is centered in the bag, close top diaphragm, and at the moment spin is matched, inflate air bags w/pressure <<1 PSI to limit loads on surface of asteroid, achieving controlled capture quickly; cinch asteroid tight to S/C while venting.
- Mechanism provides elasticity to control loads to solar arrays.

# Major Technical Risks

| Top Three Technical Development Risks | | | |
|---|---|---|---|
| # | L×C Before | Risk | Mitigation Strategy |
| 1 | 3×3 | Capture mechanism design and V&V is more complicated than expected | Conduct workshop to solicit concepts from industry and other NASA centers. Update design as needed and validate through early analysis and prototype testing. |
| 2 | 3×3 | The approach for the life qualification of the electric thruster is considered inadequate | Select and implement a thruster technology that has such large margins against wear-out failure that can be qualified by reasonable testing and analysis |
| 3 | 2×4 | The xenon feed system fails point-of-use-purity test after loading. Could require replacement of the entire xenon load. | Flight qualify the LaB6 cathode technology. This cathode technology is robust against xenon impurities. |

# KISS Alternatives

- Instrument Suite
- Pick-up-a-rock
- Scoop-up-regolith
- Separable Spacecraft Architecture
- Pre-deployment of equipment at a NEA to support subsequent human exploration

# KISS Candidate Instrument Suite

| | | | | | |
|---|---|---|---|---|---|
| |  |  |  | N/A |  |
| Parameters | Vis Cam (OpNav) | Vis Cam (ProxOps) | NIR Spec | LIDAR | CubeSat probes; pod |
| Format/ Heritage | High resolution | Ecliptic | Pushbom M3 | 3D flash STORRM | 3-4 x 1 U; 1-2 x 2 U? 3-axis accels; comm; explosive pod? (BATC) |
| FOV (deg) | 2 x 2 | 10 x 10 | 25 x 1 | < 200 mrad | ~5 x 5 |
| IFOV | 30 $\mu$rad | 200 $\mu$rad | 1 mrad | 0.2 mrad | 100 $\mu$rad |
| Range | 0.4-0.9 $\mu$m | 0.45-0.9 $\mu$m | 0.4-3 $\mu$m | 1$\mu$m < 30 km | RGB |
| Resolution | <0.1 m @ 1 km | ~ 0.2 m @ 1 km | 2 m @ 1 km | < 200m @ 1 km | ~1 cm @ 50 cm |
| Mass (kg) | 5 | 2 | 8 | 20 | 1 kg/cubesat; 5kg/pod |
| Power (W) | 15 | 5 | 10 | 50 | N/A |
| Telemetry rate | 12 Mbits/image | 12 Mbits/image | 2 Mbits/sample | 0.1 Mbits/sample | 5 Mbps |

# Pick-up-a-Rock

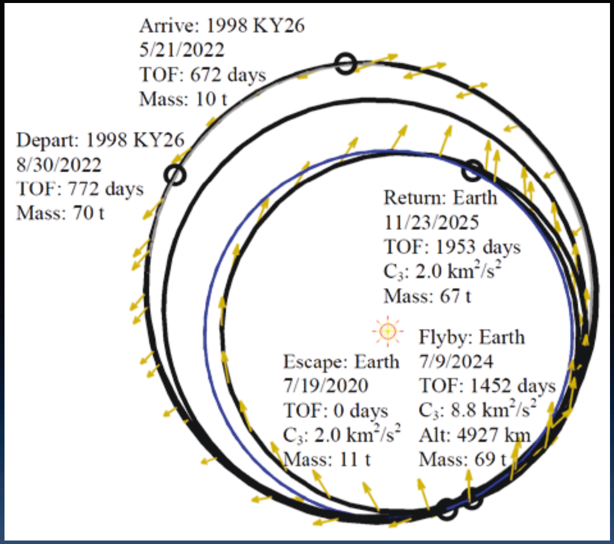
- Concept: Pick up a ~7-m "rock" off the surface of a larger asteroid that is known to be a carbonaceous type
- There are no large NEAs, with known spectral types, that have low C3's relative to Earth
  - Severely limits that amount of mass that can be brought back relative to the launch mass
  - 1998 KY26 is a known C-type NEA
  - 2000 SG344 is of an unknown type

For an Atlas V Launch to LEO

| Target Asteroid Designation | Mass of Returned Material (t) | "Rock" Dia (m)[a] | Xe[b] (t) | Earth Escape Date | Flight Time[b] (yrs) | Arrival C3, ($km^2/s^2$) |
|---|---|---|---|---|---|---|
| 1998 KY26 | 30 | 2.7 | 4.9 | 11/11/2019 | 4.7 | 2.0 |
| 1998 KY26 | 60 | 3.4 | 4.2 | 7/19/2020 | 5.3 | 2.0 |
| 2000 SG344 | 1800 | 10.5 | 1.8 | 3/8/2027 | 2.6 | 2.0 |
| 2000 SG344 | 3600 | 13.2 | 1.5 | 2/14/2027 | 2.6 | 2.1 |

[a]Assuming a density of 3 $g/cm^3$
[b]not including the Earth spiral

1998 KY26




~30-m dia. Carbonaceous NEA

# Scoop Up Regolith

- Anchor the S/C onto the surface and have a "snow blower" that could pivot around an anchor point to fill the sample bag via a chute from the snow-blower.
- The snow-blower would use forces imparted by a spinning blade to fling the regolith into the chute, where it would propagate by its own inertia along the chute into the bag.
- Assumptions:
  - It is desired to collect up to 1000 cubic meters of loose regolith
  - It is assumed that the snow-blower could (on each pass) dig up to 1 meter deep
  - Each pass would process an annulus ranging from 3 to 10 meters away from the anchor pivot
  - Each anchor point could provide up to about 250 cubic meters of material
  - 4 different anchor points would be needed for 1000 $m^3$ of material
- The bag would have inflatable "arms" that open the bag so that the whole assembly would be made of fabric and deploy out of a compact package.
- Similarly, the chute and support for the snow-blower could also be inflated. Computer-controlled winch cables would cinch the drawstrings of the bag(s), modulate the radius of operation of the snow-blower, etc.
- Anchoring of the S/C would be necessary:
  - Currently this is envisioned as one or more auger-type anchors that can be "screwed" into the terrain.
  - Two counter-rotating augers (one right-hand and one left-hand) can provide anchoring with no net torque reaction. These anchors could be released so that multiple anchor points can be provided as needed to acquire 1000 cubic meters of regolith.

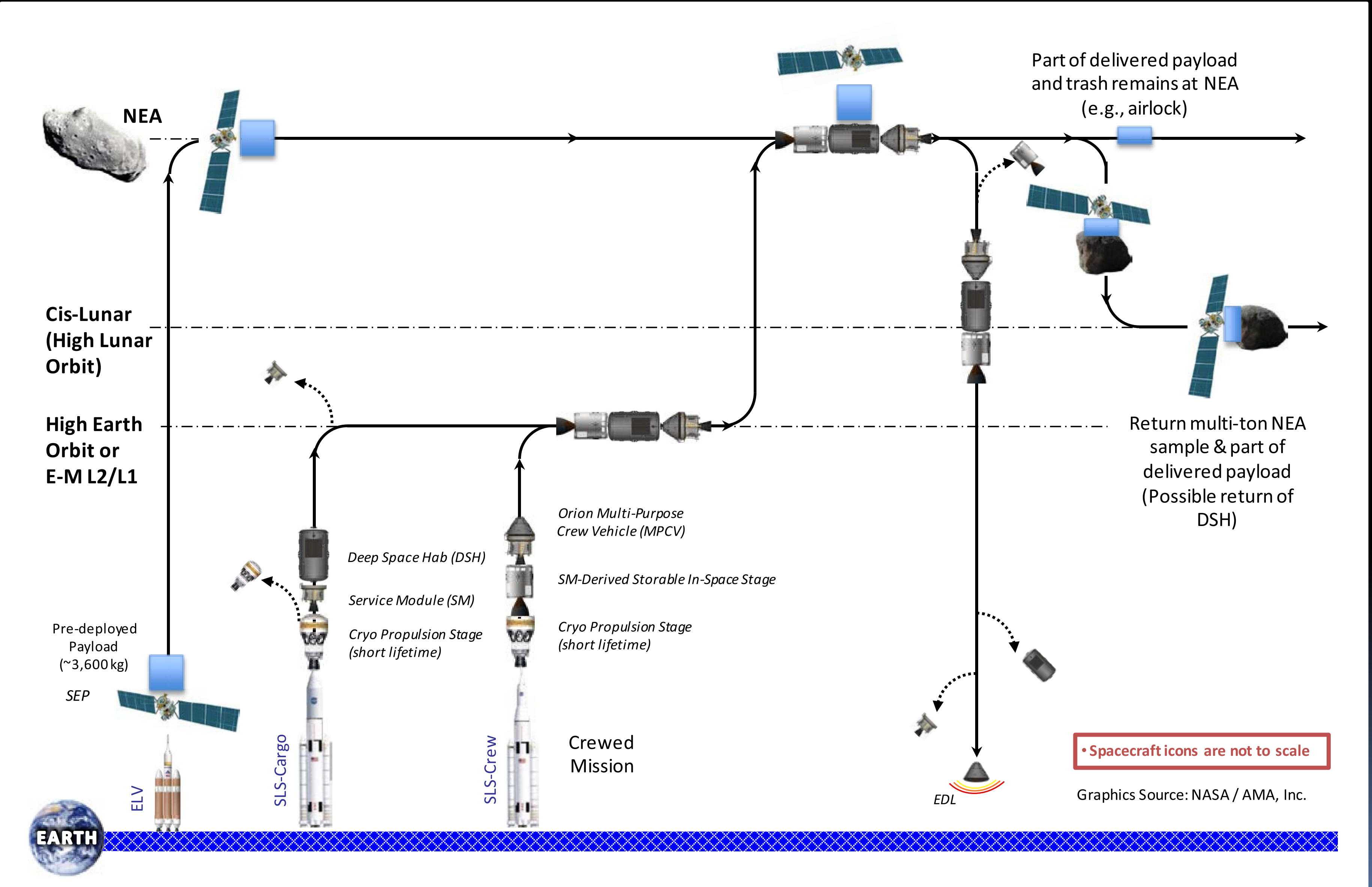
# Separable Spacecraft Architecture

- The spacecraft can separate into two parts, a SEP stage (SS) and a host spacecraft (S/C)
- The SEP stage would include:
  - the electric propulsion subsystem, the solar arrays, and the power management and distribution subsystem
  - An articulated high-gain antenna for long-range communications with Earth, short-range (omnidirectional) communications with the host S/C, Attitude Control Subsystem (ACS), Reaction Control Subsystem (RCS), and Command and Data Handling (C&DH).
- The host S/C would have the following functions:
  - ACS, RCS, C&DH, short-range communications with the SEP stage,
  - The instrument package for in situ characterization of the asteroid and cameras to assist in the asteroid capture.
  - An RCS system for agile maneuvering in the proximity of the target body and to de-tumble the asteroid.
  - An asteroid capture mechanism
- The SS would be responsible for transporting the host S/C + SS to the vicinity of the target, post-capture rendezvous with the S/C, and transporting the system back to the final destination. Articulation of the high-gain antenna would be essential to minimize the number of spacecraft rotations with the captured NEA just to point the antenna at Earth.
- The host spacecraft would separate from the SEP stage to capture and de-tumble the asteroid.

**Spacecraft Architecture Pros and Cons** –

- PROS:
  - The separable spacecraft architecture would provide the advantage that the S/C used to capture the asteroid would be smaller and more nimble than the single spacecraft with its large solar arrays and electric propulsion subsystem.
  - It could also use the SEP stage as a communications relay station to provide high-data rate communications with Earth during the asteroid capture and de-tumble activities.
- CONS:
  - Likely significantly higher cost (because essentially two complete spacecraft must be developed),
  - Requires autonomous rendezvous and docking with the SEP stage in deep space while “carrying” the captured asteroid
  - It would have limited energy capability once it separated from the SEP stage

# Pre-positioning of Equipment



# Summary

- The reference Asteroid Redirect Mission would:
  - Demonstrate high-power solar electric propulsion that would support near-term human exploration missions beyond low-Earth orbit, enable new robotic planetary science missions, and would be extensible to the systems required to improve the affordability of human exploration missions to Mars.
  - Provide a unique target destination for SLS/Orion in translunar space that would result in astronauts traveling farther from Earth than ever before, leaving low-Earth orbit for the first time in 50 years, and coming in contact with only the second celestial object in human history.
  - Significantly enhance our knowledge of the near-Earth object population and its potential threats to Earth.

- Three alternatives considered in the KISS study
  - Pick-up-a-rock
  - Scoop-up-regolith
  - Separable Spacecraft Architecture

  Are believed to be higher risk and more expensive than the reference concept