National Aeronautics and Space Administration

NASA's Asteroid Redirect Mission

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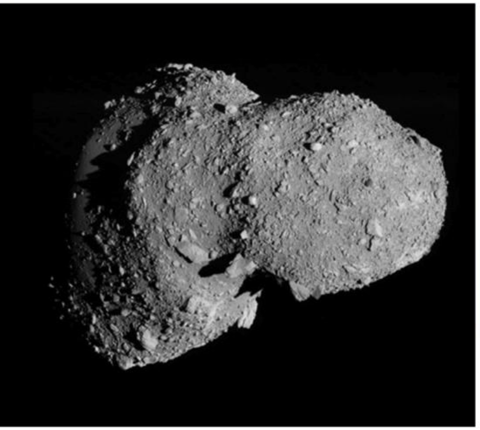
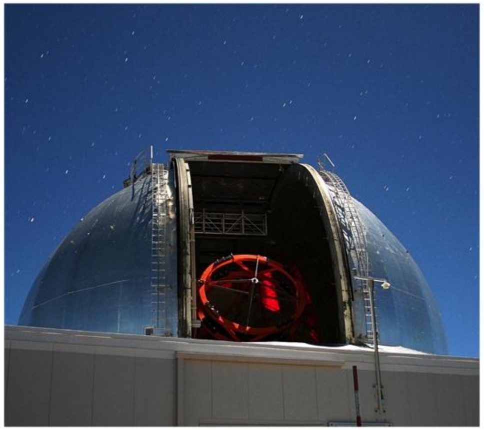
Human Exploration and Operations Mission Directorate

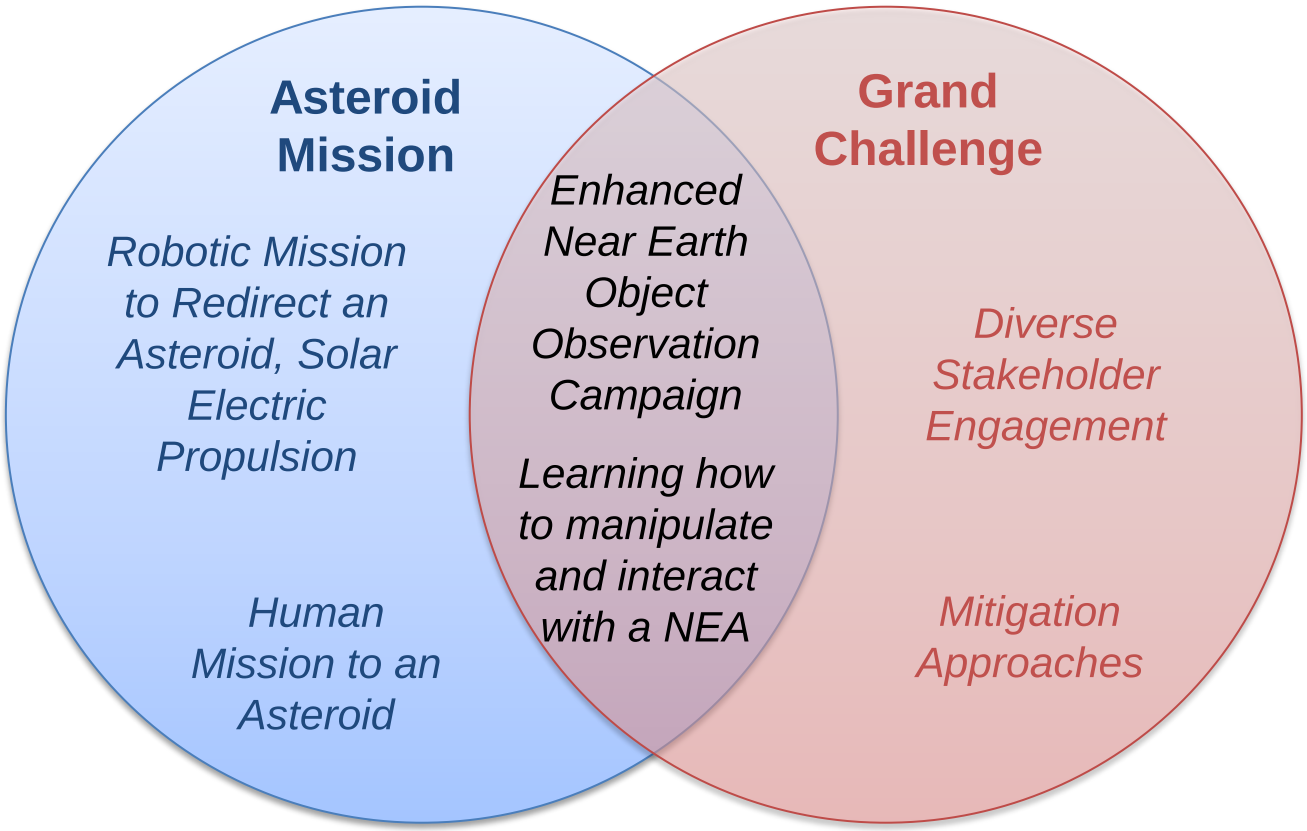



September 5, 2013

NASA's Asteroid Initiative

- NASA is leveraging relevant portions of science, space technology, and human exploration capabilities toward a first-ever mission to capture and redirect a near Earth asteroid to earth-moon space, followed by a human exploration and sampling mission.
- The mission will demonstrate technologies for deep space exploration, advance efforts in planetary defense, and engage new industrial capabilities and partnerships. There are other benefits.
- NASA will also lead a broad effort to find all asteroid threats to human populations and know what to do about them: a "Grand Challenge"
- These two activities are mutually supporting, and both leverage on-going activities.
- This initiative includes a parallel, forward-looking mission development approach, partnership opportunities (nationally and internationally), open innovation, and participatory engagement.

FY14 Asteroid Initiative: What and How



Both sets of activities leverage existing NASA work while amplifying participatory engagement to accomplish their individual objectives and synergize for a greater collective purpose.

Leveraging Capabilities for an Asteroid Mission

- **NASA is aligning key activities in Science, Space Technology, and Human Exploration and Operations Mission Directorates**
  - Asteroid identification and characterization efforts for target selection
  - Solar electric propulsion for transport to and return of the target asteroid
  - Autonomous guidance and control for proximity operations and capture
  - Orion and Space Launch System (SLS) missions for asteroid rendezvous
  - Technologies for astronaut extra-vehicular activities
- **Each individual activity provides an important capability in its own right for human and robotic exploration**
- **We are working to utilize all of these activities to**
  - Identify and redirect a small asteroid to a stable orbit in the lunar vicinity;
  - Test human spaceflight systems and operations beyond LEO; and
  - Investigate and return samples with our astronauts using the Orion and SLS assets.
- **The FY14 budget supports continued advancement of the important individual elements and furthers the definition of the overall potential mission.**

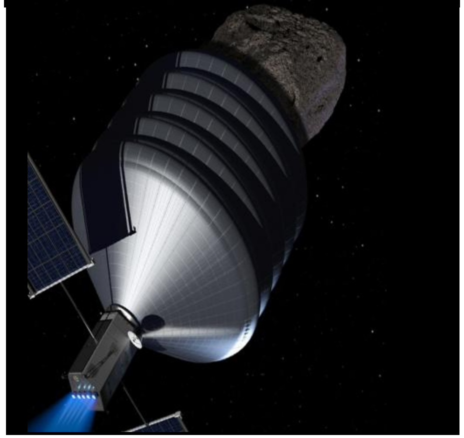
Overall Mission Consists of Three Main Segments

Identify

Asteroid Identification Segment:

Ground and space based NEA target detection, characterization and selection

Redirect



Asteroid Redirection Segment:

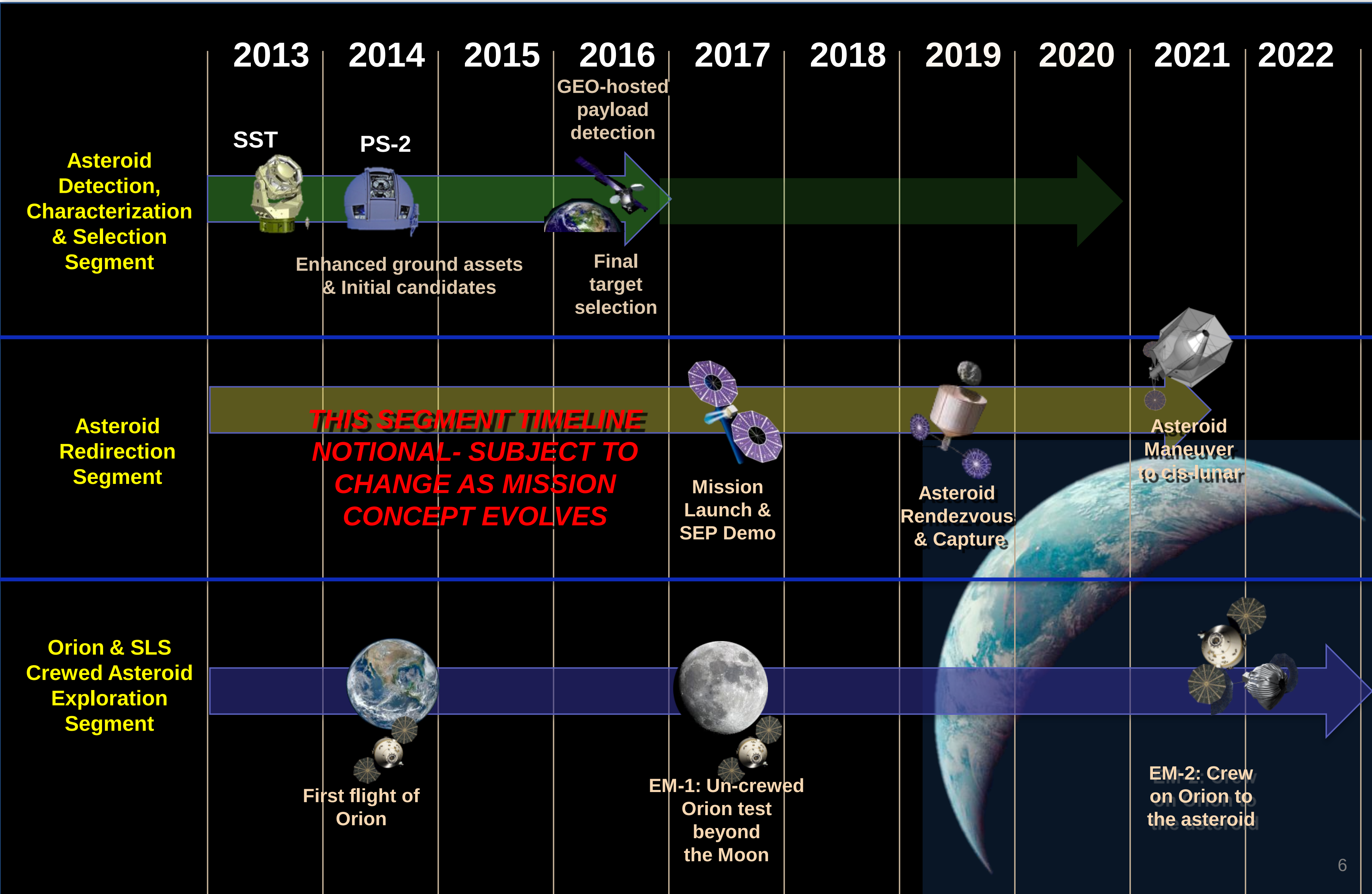
Solar electric propulsion (SEP) based robotic asteroid redirect to trans-lunar space

Explore

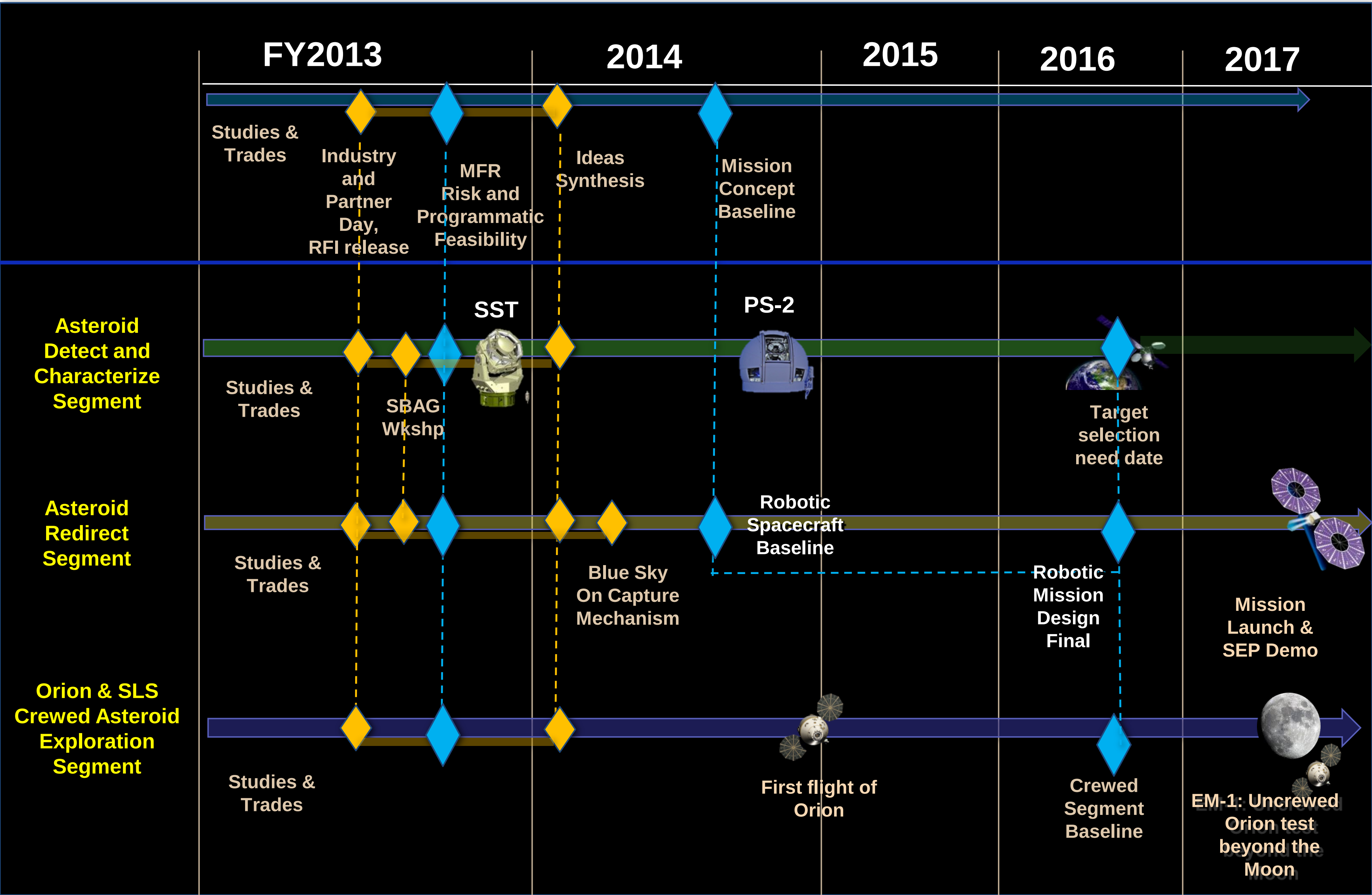
Asteroid Crewed Exploration Segment:

Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid

Alignment Strategy



Decision and Engagement Strategy

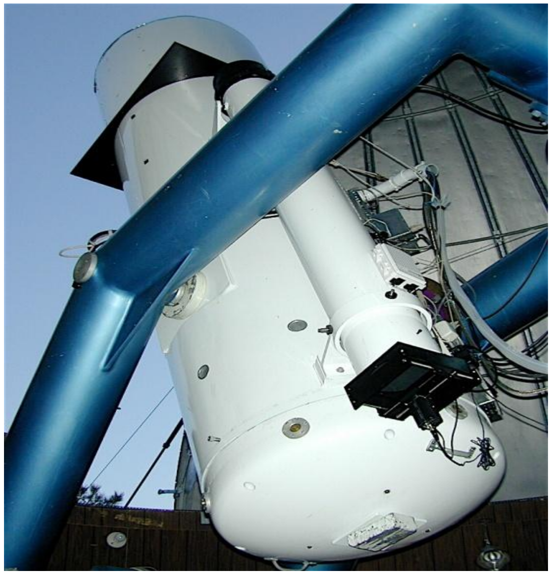


Asteroid Initiative Request for Information

- **RFI released June 18; responses due July 18**
- **Areas of request:**
  - Asteroid Observation
  - Asteroid Redirection Systems
  - Asteroid Deflection Demonstrations
  - Asteroid Capture Systems
  - Crew Systems for Asteroid Exploration
  - Partnerships & Participatory Engagement
- **402 responses received**
- **Ideas Synthesis Meeting Sept 30 - Oct 2**
  - Transparently explore the 96 highest rated responses
  - International, industry, science will be specifically invited
  - Meeting structured to provide input to planning

NASA's NEO Search Program: Current System

Catalina Sky Survey



U of AZ – Tucson, Arizona

Pan-STARRS

U of HI - Haleakala, Maui

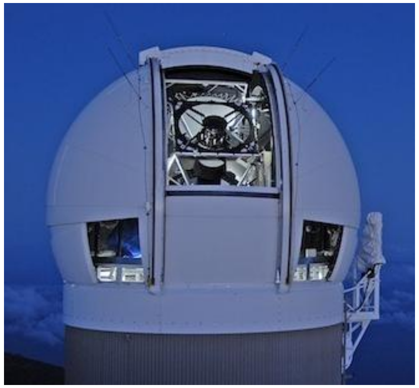
LINEAR

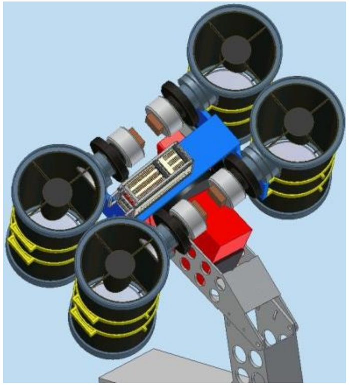
MIT/LL - Soccoro, NM

- Currently, most Near-Earth Asteroid discoveries are made by:
  Catalina Sky Survey (60%), Pan-STARRS-1 (30%), and LINEAR (3%)
- Data correlation and orbit determination is done by the IAU Minor Planet Center. Precision orbital analysis is performed by the NEO Program Office at JPL.
- Enhancements and new surveys can come online in the next 2 years.
- These improvements will increase capabilities to find hazardous asteroids as well as ARRM candidate targets

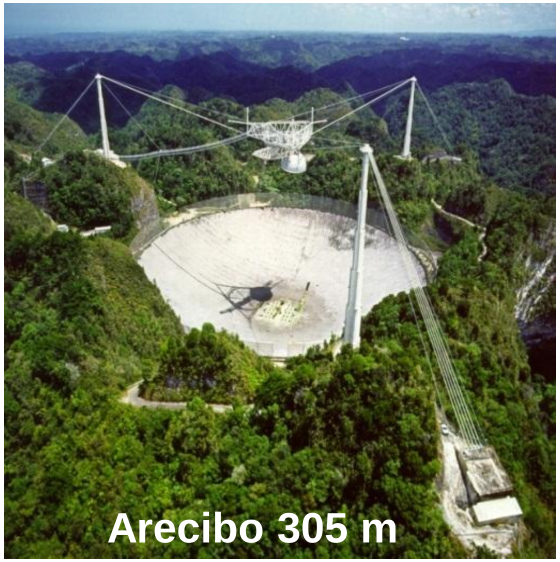
Primary Enhancements for ARRM Candidate Discovery

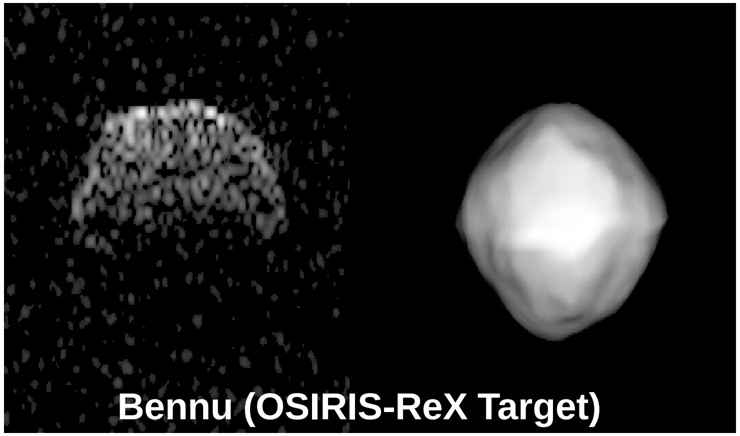
- **NEO Time on DARPA Space Surveillance Telescope**
  - Large 3.6m telescope, first light: Feb 2011, now in testing.
  - Eventual operations by AFSPC for DoD Space Situational Awareness.
  - Testing of NEO detection capability: Sep 2013.
- **Enhancing Pan-STARRS 1, Completing Pan-STARRS 2**
  - Increase NEO search time to 100% on PS1: Early 2014.
  - Complete PS2 (improved copy of PS1): Late 2014.
  - Simulations suggest the ARRM candidate discovery rate for PS2 alone at 100% will be ~5 per year.
- **Accelerated Completion of ATLAS**
  - Set of small telescopes with extremely wide fields of view covering the entire night sky every night, but not as deeply.
  - Final design selection soon. Completion: Early 2015.
  - Simulations suggest the ARRM candidate discovery rate for ATLAS will be ~10 per year.

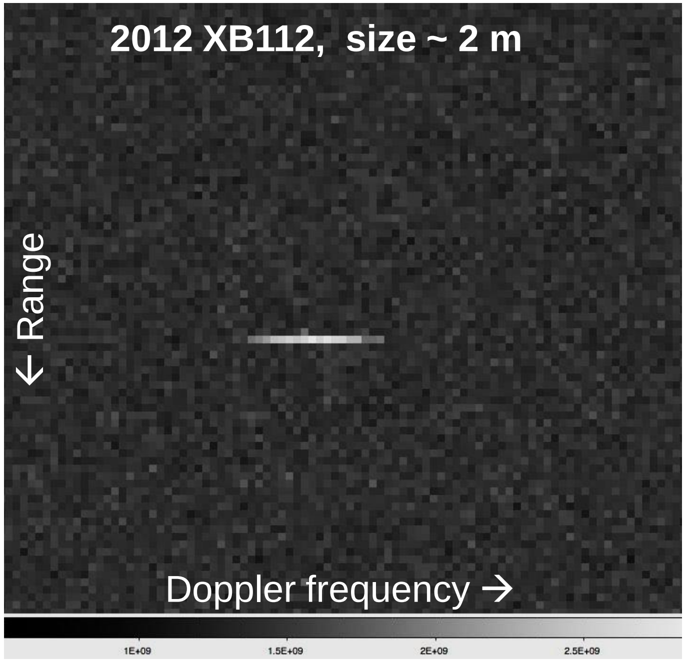




Radar Observations of NEOs



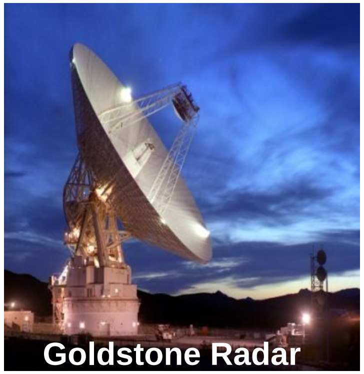




- These are complementary capabilities.
- Currently, 70-80 NEOs are observed every year.
- A 10-m-class ARRM candidate must pass within ~5 lunar distances to be detected; ~80% of the 14 known candidates could have been detected.
- Radar observations can provide:
  - Size and shape to within ~2 meters.
  - High precision range/Doppler orbit data.
  - Spin rate, surface density and roughness.

NEO Characterization Enhancements

Radar (Goldstone and Arecibo)
- Increase time for NEO observations.
- Streamline Rapid Response capabilities.



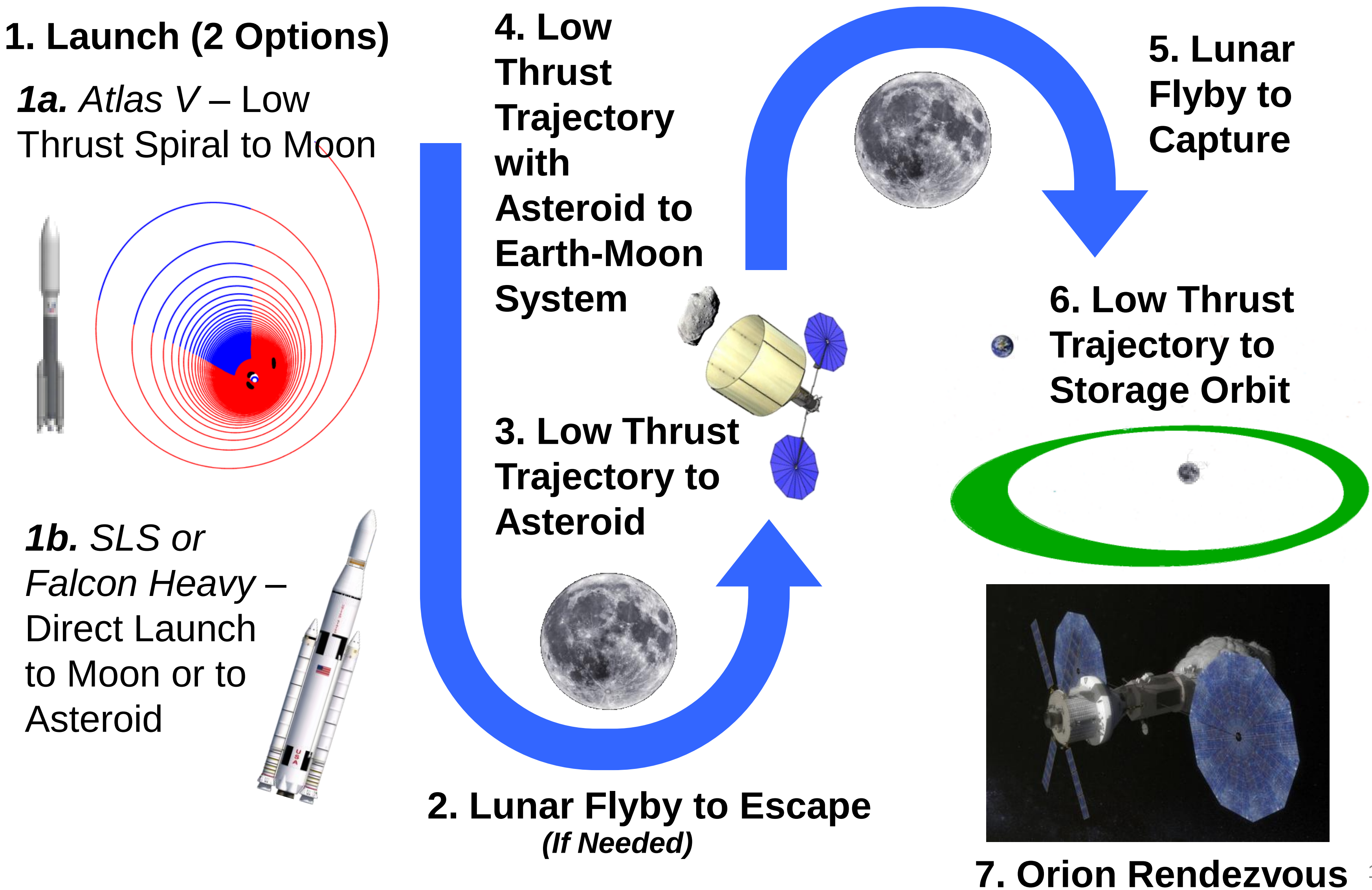
NASA InfraRed Telescope Facility (IRTF)
- Increase On-call for Rapid Response.
- Improve Instrumentation for Spectroscopy and Thermal Signatures.

Reactivate NEOWISE
- ~3 year warm phase dedicated to NEO Search/Characterization data collection.

Space Technology and the Asteroid Initiative

- **Early Stage programs will foster innovation in**
  - Asteroid detection, characterization and mitigation for planetary defense and asteroid retrieval mission target selection
  - Asteroid proximity operations and resource utilization techniques
- **The redirect mission leverages high powered SEP demonstration capability**
  - SEP is the primary propulsion for the robotic asteroid rendezvous and redirection
  - The redirect mission is not possible without SEP
  - SEP component technologies serve commercial needs
  - SEP is also enabling for deep space human exploration
- **Asteroid Robotic Redirect Mission will serve as a critical technology demonstration of a high-power SEP system**
- **Key high-power SEP system components include**
  - 30kW – 50kW advanced solar arrays
  - 10kW to 15kW magnetically shielded Hall thrusters
  - Power Processing Units (PPUs)
  - Xenon propellant tanks

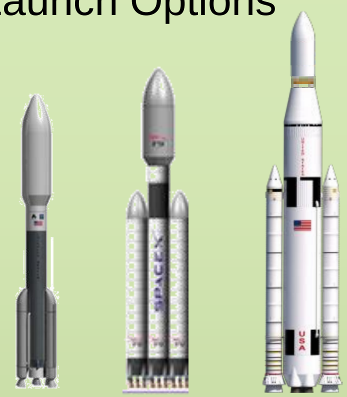
Reference Robotic Mission Design Executive Summary



Design Resilience to Launch Date for 2009 BD

2009 BD Mission Options (assuming 325 t asteroid)

Launch Options



A5 FH SLS

Atlas V Xe Prop

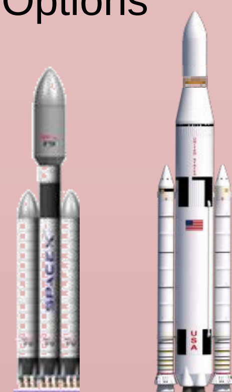
7.5 t

Heavy LV Xe Prop

4 t

Mid 2018 Launch

Launch Options



FH SLS

Heavy LV Xe Prop

6 t

Early 2019 Launch

Launch Options

SLS

SLS Xe Prop

10 t (tanks full)

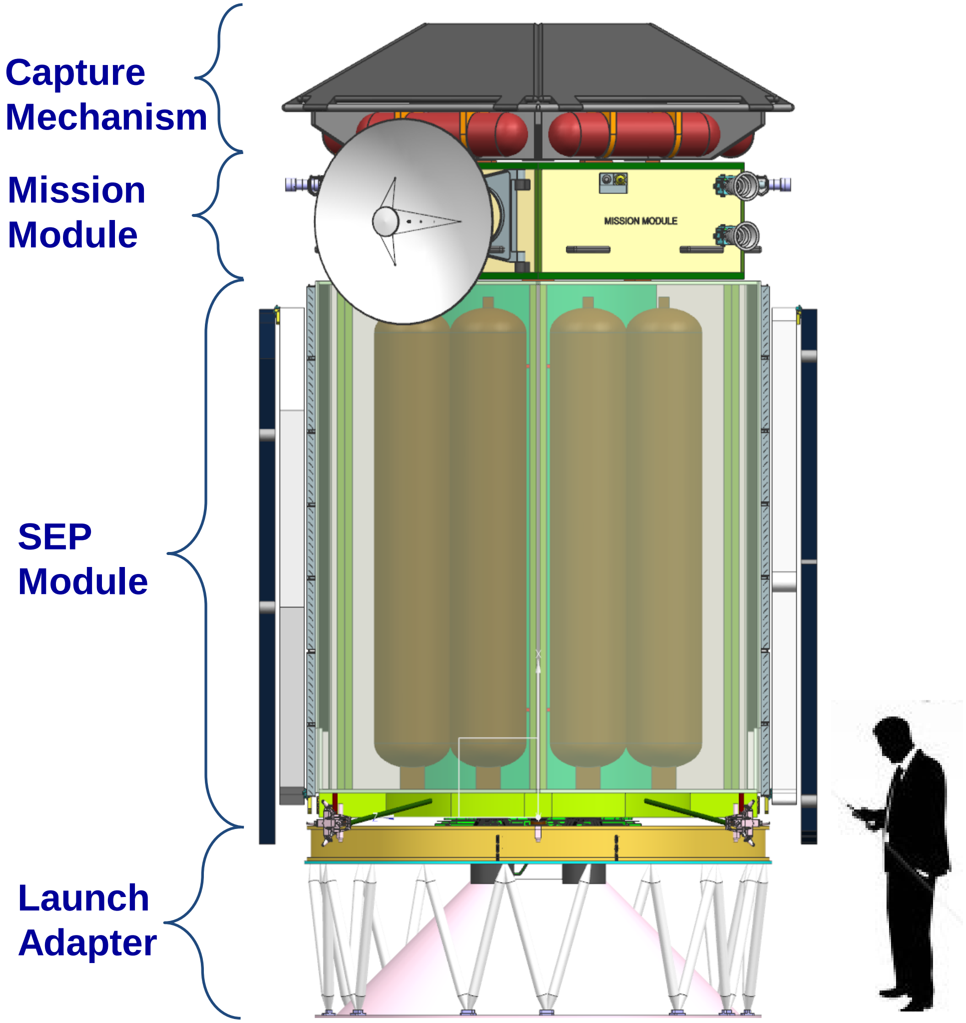
Mid 2019 Launch

ARRM architecture is resilient to changes in launch date. Alternate targets also provide resilience

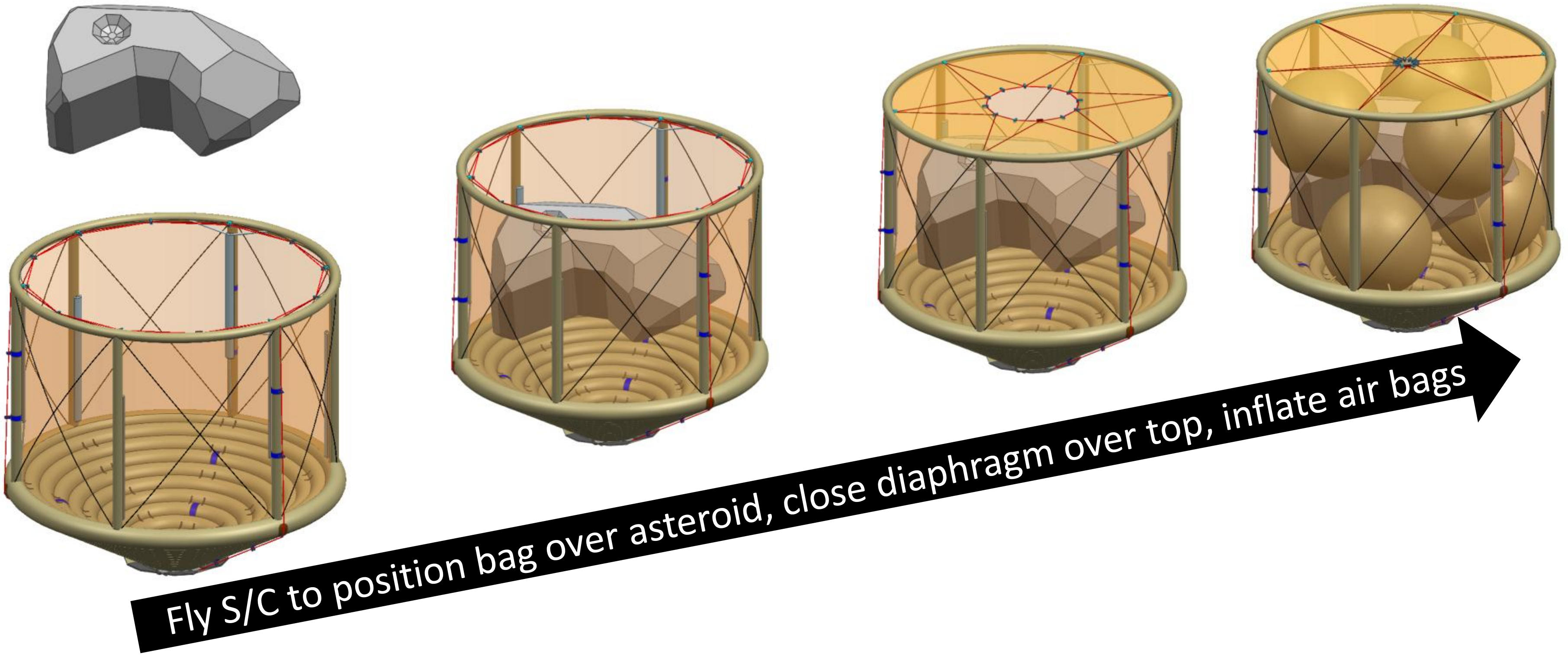
Mission and Flight System Executive Summary

- Key Driving Objective:
  - Minimize the cost and technology development risk with extensibility to future missions
- Balanced risk across major elements
  - Asteroid discovery and characterization
  - SEP technology development
  - Proximity operations and capture approach
- Developed a baseline flight system and conops approach
  - Modular Flight System: SEP Module, Mission Module, Capture System

Flight system concept is feasible and includes appropriate margins



Capture Sequence



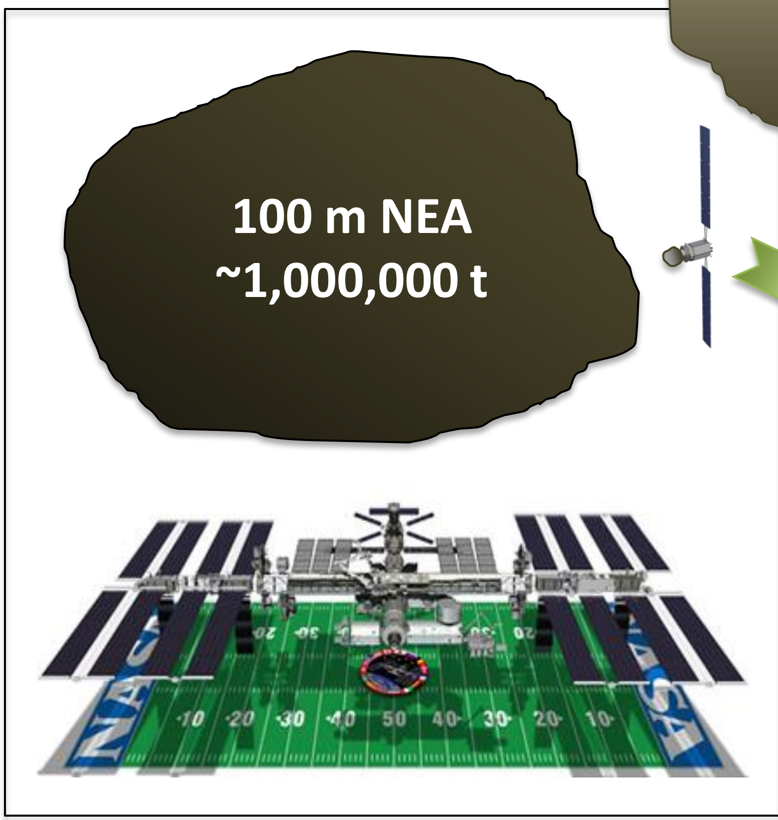
- S/C approaches and matches spin along projected asteroid spin vector
- When asteroid is centered in the bag, close top diaphragm, and at the moment spin is matched, inflate air bags w/pressure <<1 PSI to limit loads on surface of asteroid, achieving controlled capture quickly
- Mechanism provides elasticity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

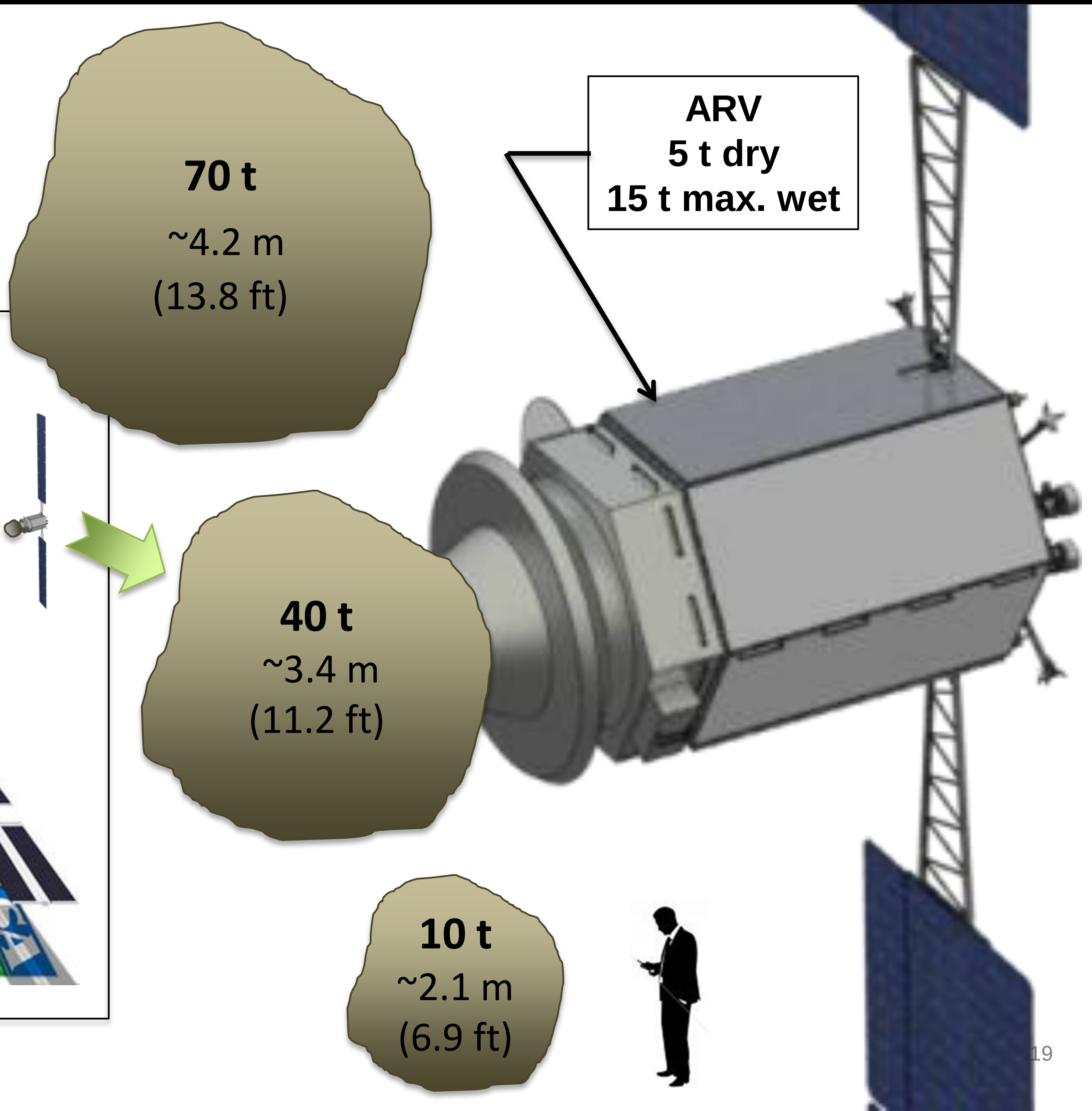
Alternate Approach: Robotic Concept

- **Concept: Demonstrate planetary defense (PD) and retrieve coherent/monolithic boulder(s) from a larger NEA**
  - Target a ~100+ m size NEA (hazardous size, but not necessarily a PHA)
  - Demonstrate PD techniques and measurably alter the trajectory of the NEA Capture a 1-10 m boulder (coherent rock) and return it in the 2020-2025 timeframe
  - Assess options for planetary defense demonstrations and delivery of other payloads
    - Take advantage of solar electric propulsion spacecraft capabilities and/or captured mass, as well mission capability for kinetic impact demonstration at the end of mission
    - Payload(s) emplaced prior to capture operations in case of failure and/or left behind before spacecraft departure
  - Identify required NEA stay time to perform proximity and surface operations

Target NEA & Boulder Size/Mass Comparison

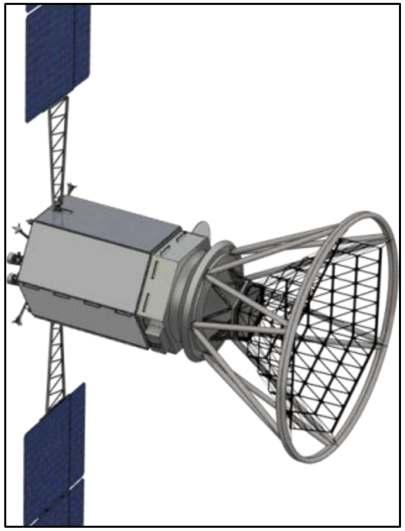
NEA & boulder mass estimates assume density of 2 g/cm^3



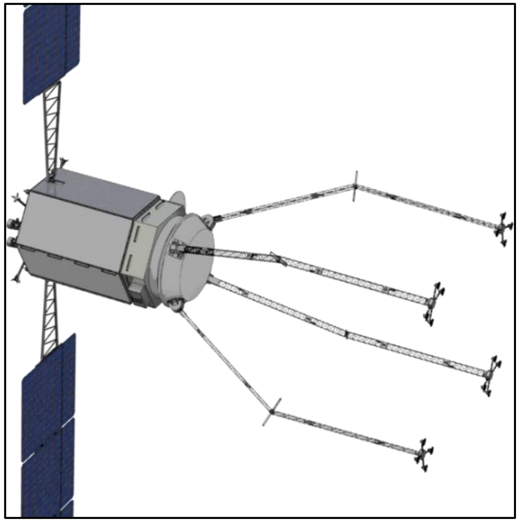


Multiple Options for Boulder Retrieval

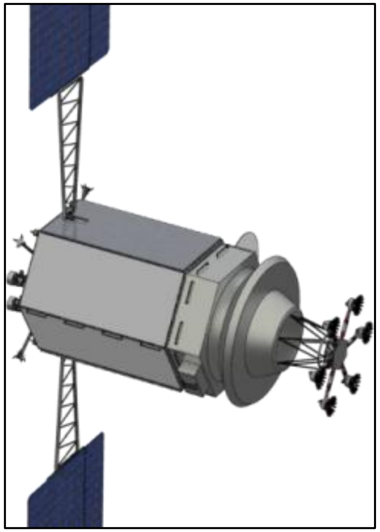
Capture System Option Examples



Net with inflatable/deployable mechanism



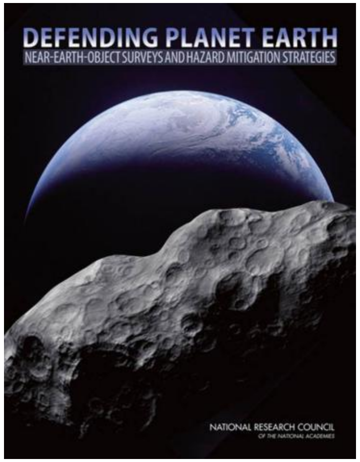
Manipulators with end effectors/grippers



Grippers only

- A variety of capture system options and technologies are applicable for retrieving a coherent/monolithic boulder – optional bag for containment
- Specialized robotic tools and end effectors can be utilized
  - Manipulator or spacecraft mounted
  - Grapple, anchor, push/pull, sample, position, cut, drill, etc.
- In the unlikely event that a suitable boulder or boulders could not be retrieved, a contingency capability to collect regolith can be included (surface contact pads, OSIRIS-REx sample collector, etc.)

Planetary Defense Approach



2010 National Research Council Committee

"Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies"

- **Finding: <u>No single approach to mitigation is appropriate and adequate</u>** for completely preventing the effects of the full range of potential impactors, although civil defense is an appropriate component of mitigation in all cases. **<u>With adequate warning, a suite of four types of mitigation is adequate to mitigate the threat from nearly all NEOs except the most energetic ones.</u>**

TABLE 5.1 Summary of Primary Strategies for Mitigating the Effects of Potential Impacting Near-Earth Objects

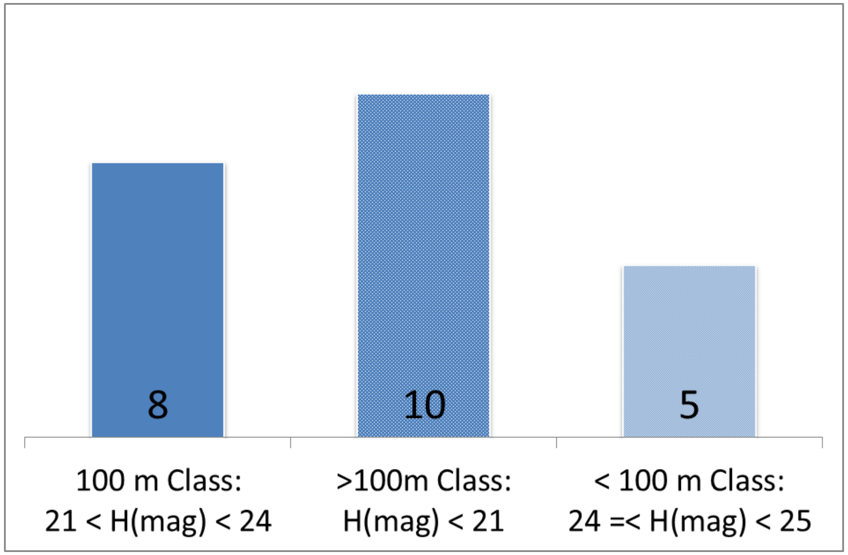
Strategy	Range of Primary Applicability
Civil defense (e.g., warning, shelter, and evacuation)	Smallest and largest threats. Threat of any size with very short warning time.
Slow push (e.g., "gravity tractor" with a rendezvous spacecraft)	A fraction (<10%) of medium-size threats. Usually requires decades of warning time.
Kinetic impact (e.g., interception by a massive spacecraft)	Most medium-size threats. Requires years to decades of warning time.
Nuclear detonation (e.g., close-proximity nuclear explosion)	Large threats and short-warning medium-size threats. Requires years to decades of warning time.

Enhanced gravity tractor approach using mass of retrieved boulder increases applicability

Expanded Target Set

- **117** targets with return mass > 10 t
- **4** targets with past or future robotic mission with > 9 t return mass
  - Itokawa (1998 SF_{36}) (PHA)
  - Bennu (1999 RQ_{36}) (PHA)
  - 1999 JU_3 (PHA)
  - 2008 EV_5 (PHA) – mission still in selection process
- **8** targets in the 100 m class with radar observation opportunities before 2018 and with > 10 t return mass
  - 2002 NV_{16} (PHA)
  - 2006 CT
  - 2011 BT_{15} (PHA)
  - 1996 XB_{27}
  - 2007 EC
  - 2000 AC_6 (PHA)
  - 2010 VB_1
  - 2000 SJ_{344}

Targets with Radar Observation Opportunities and Return Mass > 10 t by Dec 2024



Falcon Heavy to TLI, ≥ 200 day stay

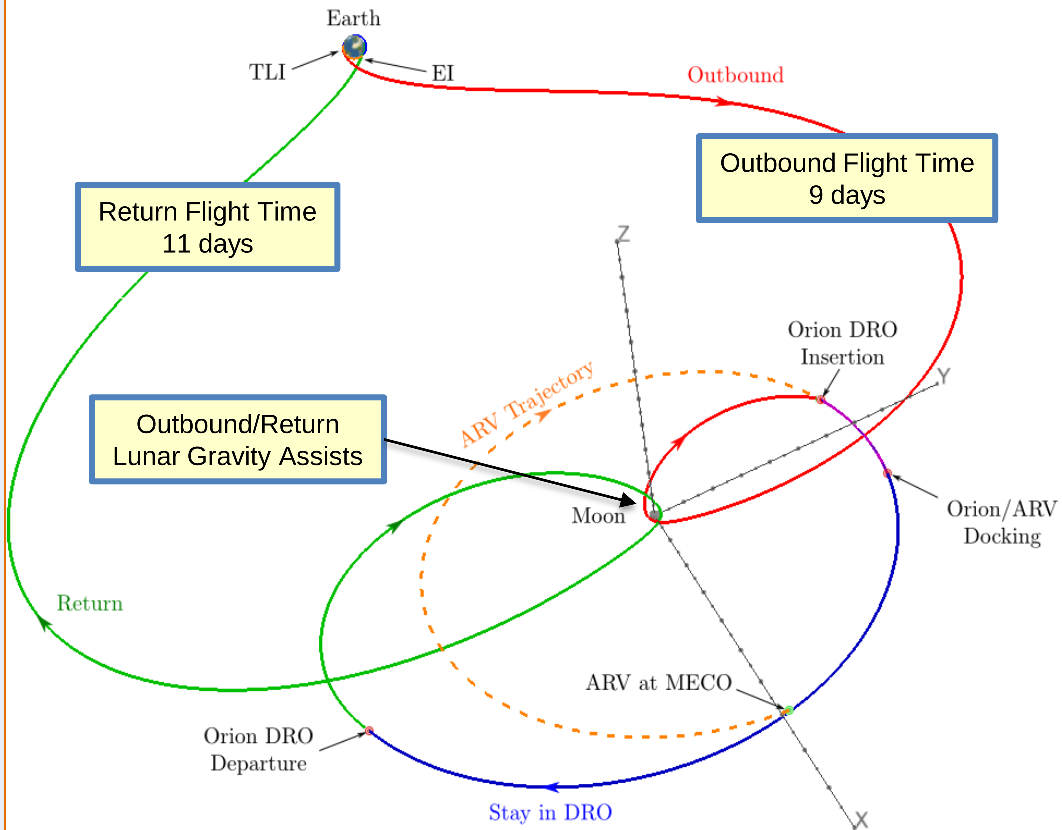
- **15** additional targets with radar observation before 2018 exist
- **12** additional targets with radar observation if return date is extended by one year to 2025 (100 m & > 100 m class)
- Return mass increases with later arrival date for many targets and new targets become available
- Observation of targets by space-based assets not yet studied (Spitzer or NEOWISE restart or archived data)

Crewed Asteroid Mission

Reference Trajectory Update: Earliest Mission for 2009BD

- Outbound
  - Flight Day 1 – Launch/TLI
  - Flight Day 1-7 – Outbound Trans-Lunar Cruise
  - Flight Day 7 – Lunar Gravity Assist
  - Flight Day 7-9 – Lunar to DRO Cruise
- Joint Operations
  - Flight Day 9-10 – Rendezvous
  - Flight Day 11 – EVA #1
  - Flight Day 12 – Suit Refurbishment, EVA #2 Prep
  - Flight Day 13 – EVA #2
  - Flight Day 14 – Departure Prep
  - Flight Day 15 – Departure
- Inbound
  - Flight Day 15 – 20 – DRO to Lunar Cruise
  - Flight Day 20 – Lunar Gravity Assist
  - Flight Day 20-26 – Inbound Trans-Lunar Cruise
  - Flight Day 26 – Earth Entry and Recovery

Mission Duration and timing of specific events will vary slightly based on launch date and trajectory strategy



Outbound Flight Time: 8 days, 9 hrs
Return Flight Time: 11 days, 6 hrs
Rendezvous Time: 1 day
DRO Stay Time: 5 days

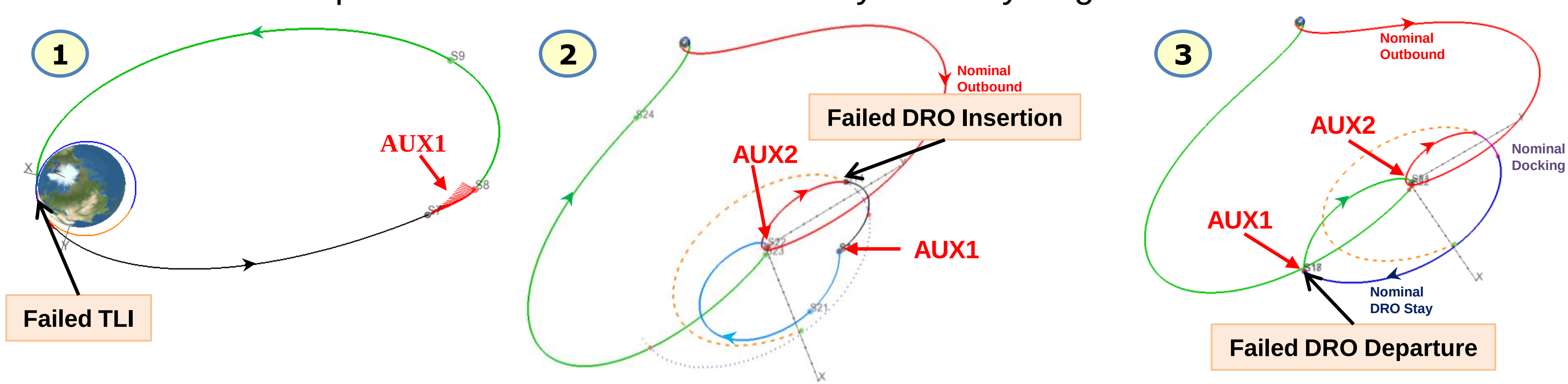
Contingency Trajectory Planning

MFR Reference Mission: May 2024, Min-ΔV			
Maneuver Failure	Number of Aux Burns		Total Mission Duration [days]
Orion TLI	1	1	1.36
Outbound Flyby	2		17.57
DRO Insertion	2	2	26.69
DRO Departure	2	3	23.61
Return Flyby	1		23.66

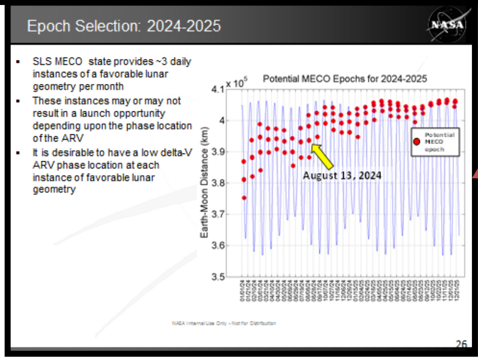
All usable Orion Propellant Utilized in Abort Cases to minimize return duration

- Examined failure of Service Module (SM) Main Engine throughout mission as part of trajectory planning
- Orion SM contains substantial additional propellant above the nominal mission requirement and 30 days of crew consumables (O2, N2, food, etc.)
- Assessment concluded that Auxiliary Thrusters could complete the mission should SM Main engine fail although mission duration may be longer than nominal mission

Example Failed Maneuvers followed by Auxiliary Engine Maneuvers

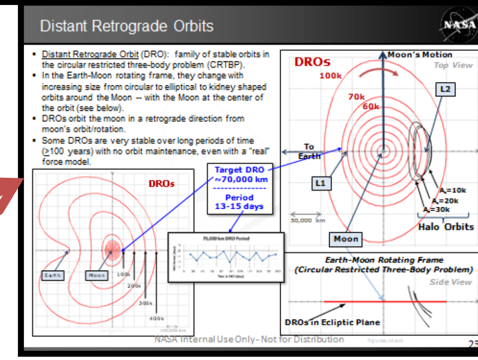


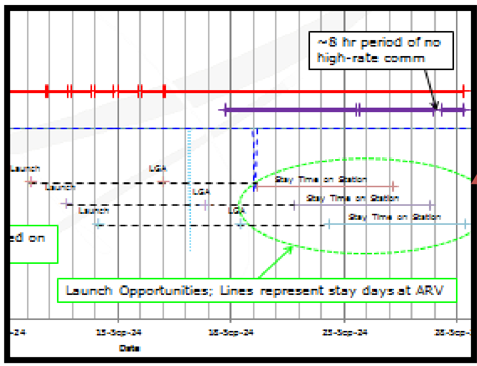
Mission Design Considerations



Launch Availability ~2-3 opportunities per month

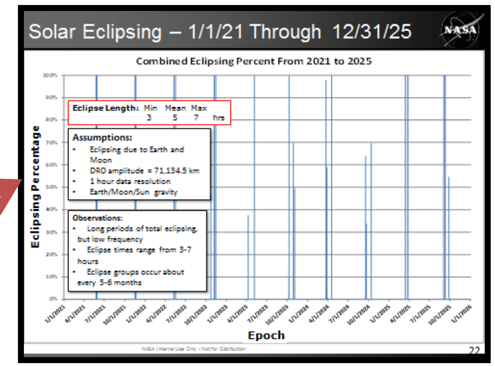
71433km DRO improves launch availability by syncing with Lunar period

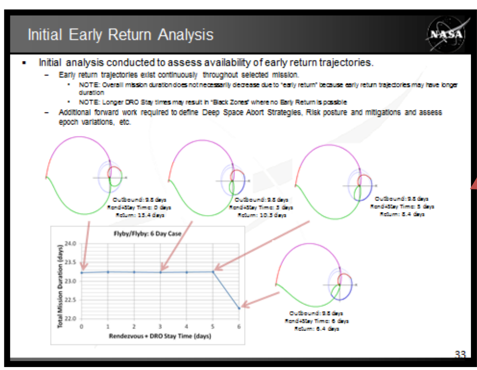




Acceptable Communications Coverage for Orion/ARRV

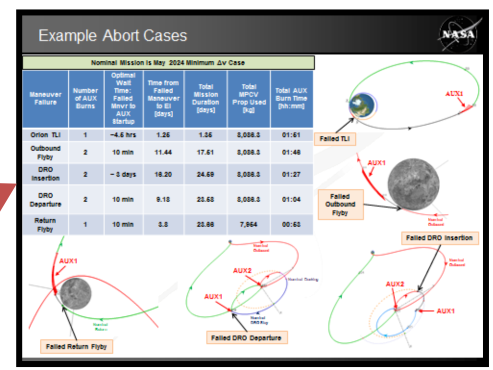
Long Solar Eclipse Periods Manageable for launch availability





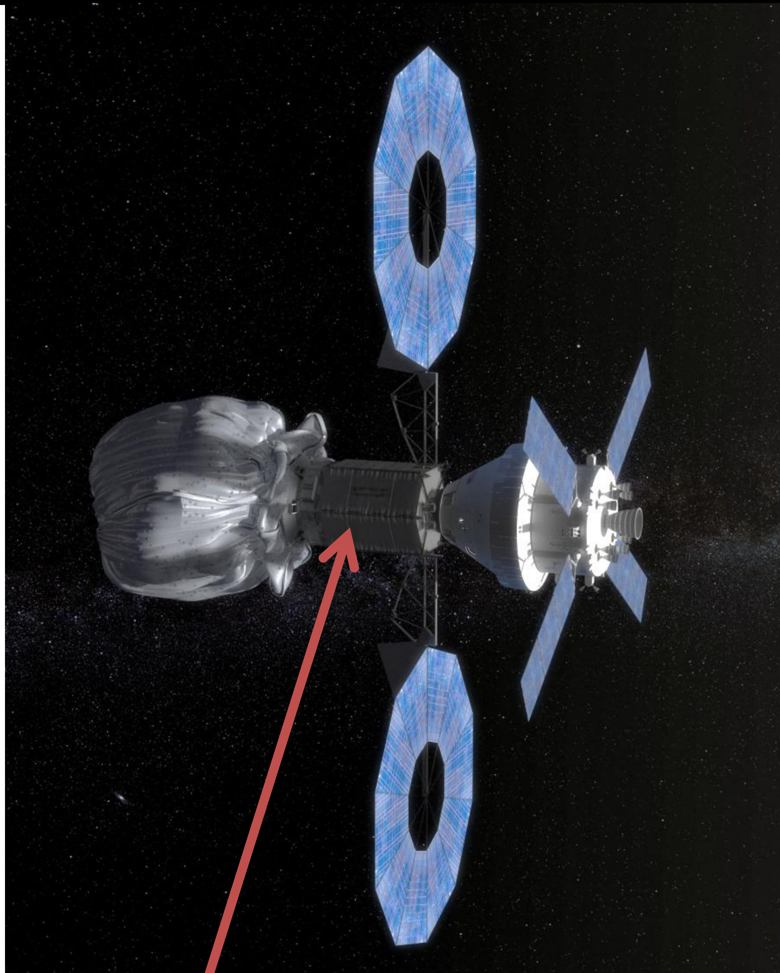
Orion Propellant Available for Early Return Throughout Mission

Orion Propellant Allows Auxiliary Thruster Contingency Return

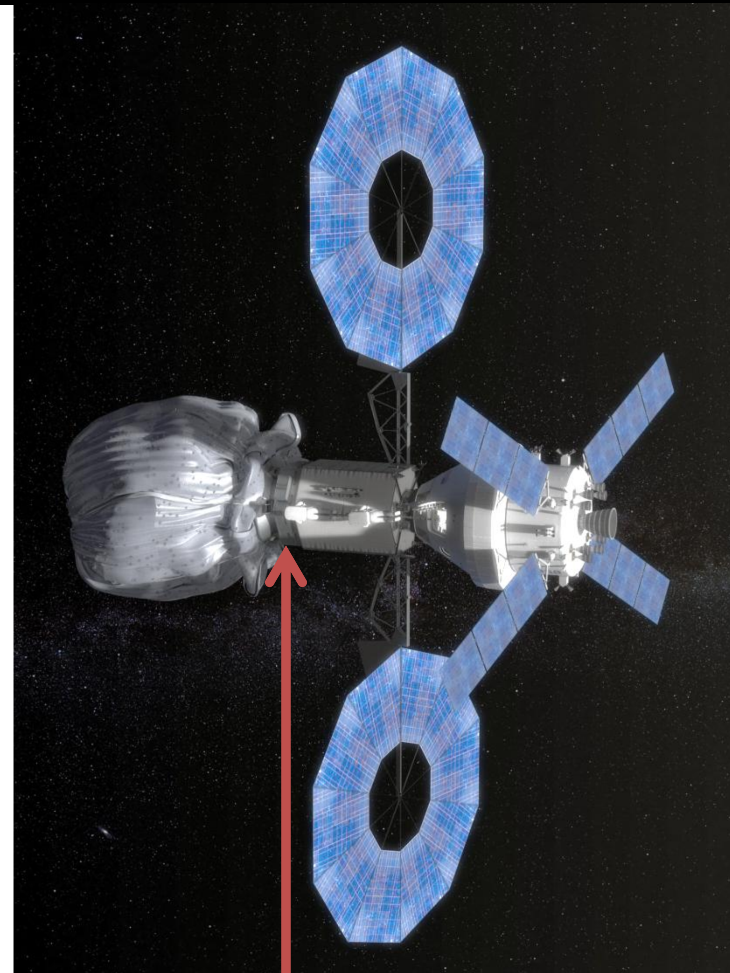


- All constraints currently satisfied for new MFR Reference Mission

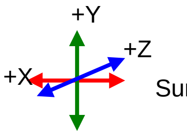
Assessment of Integrated Flight Attitude



Solar Inertial Attitude



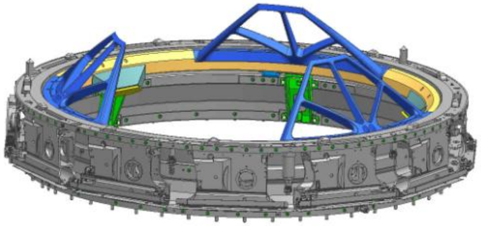
EVA Biased Attitude



- Extensive shading in unbiased solar inertial attitude
- Biasing attitude allows for adequate EVA lighting and thermal conditions
- Orion required to maneuver integrated vehicle to EVA attitude

ARRV Accommodations for Crewed Mission (Docking)

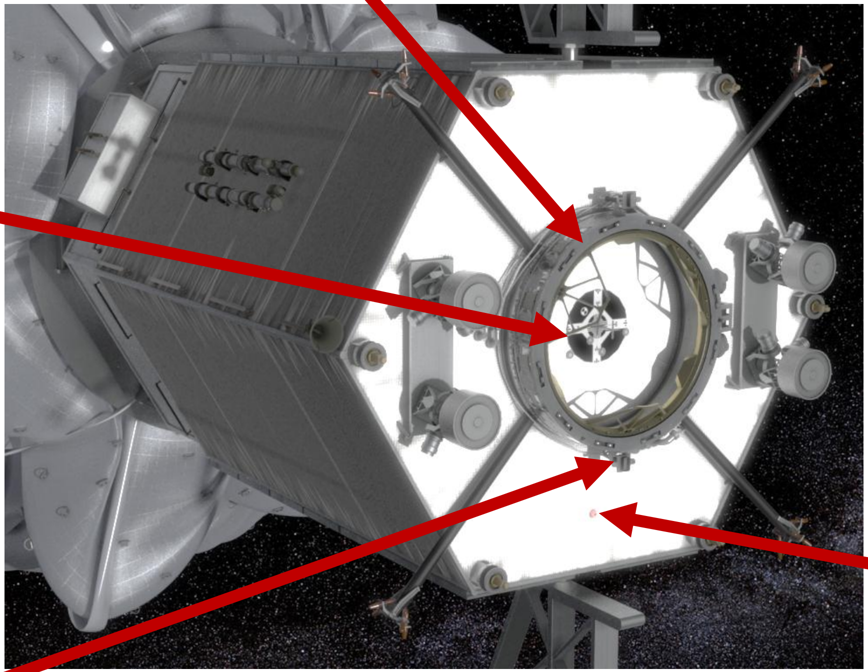
- Identified minimum ARRV hardware to accommodate Orion communication, docking using International Docking System Standard (IDSS) and extensibility



Docking Mechanism
- IDSS-compatible, passive side

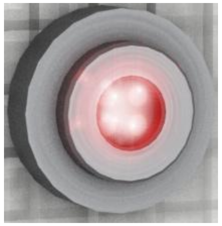
Vehicle-to-Vehicle Comm
- Orion compatible low-rate S-band with transponder

Docking Target
- Augmented with features for relative navigation sensors
- Visual cues for crew monitoring



Reflectors
- Tracked by the LIDAR during rendezvous and docking

LED Status Lights
- Indicate the state of the ARRV systems, inhibits and control mode



Power and Data Transfer
- Transfer through connectors already part of the docking mechanism design; Supports extensibility

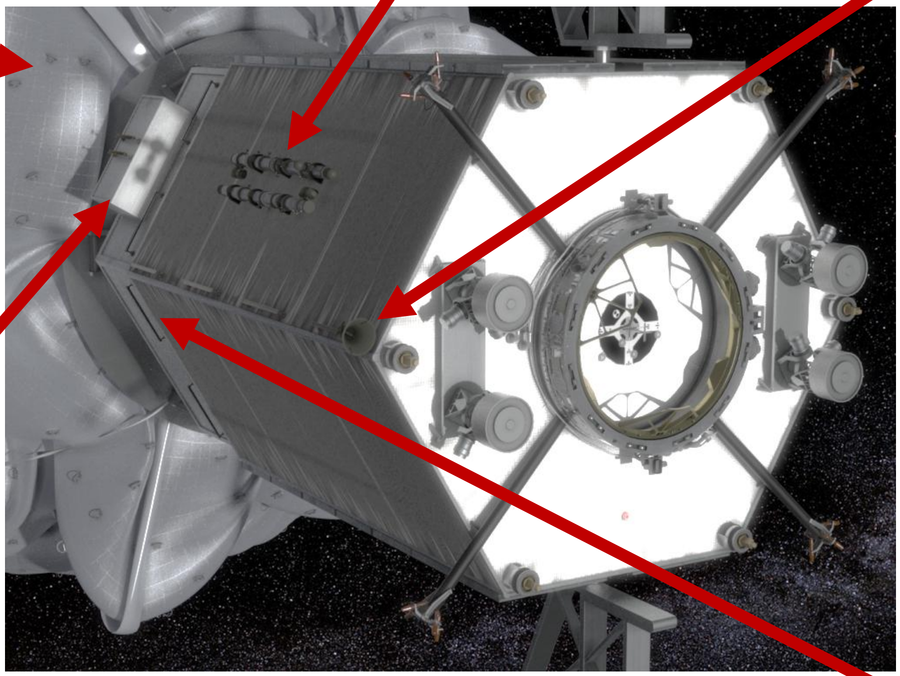
ARRV Accommodations for Crewed Mission (EVA)

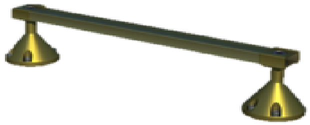
- Identified minimum set of hardware on ARRV to accommodate Orion EVA

EVA Tether Points
- Hand-over-hand translation
- Temporary restraint of tools
- Management of loose fabric folds

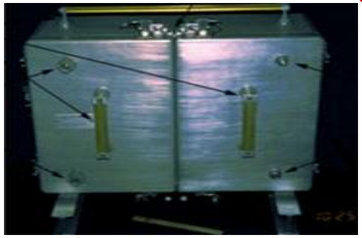
EVA Translation Booms
- Translation Booms for Asteroid EVA

EVA Translation Attach Hardware
- Circumference of Mission Module at base of Capture System and ARRV-Orion Interface





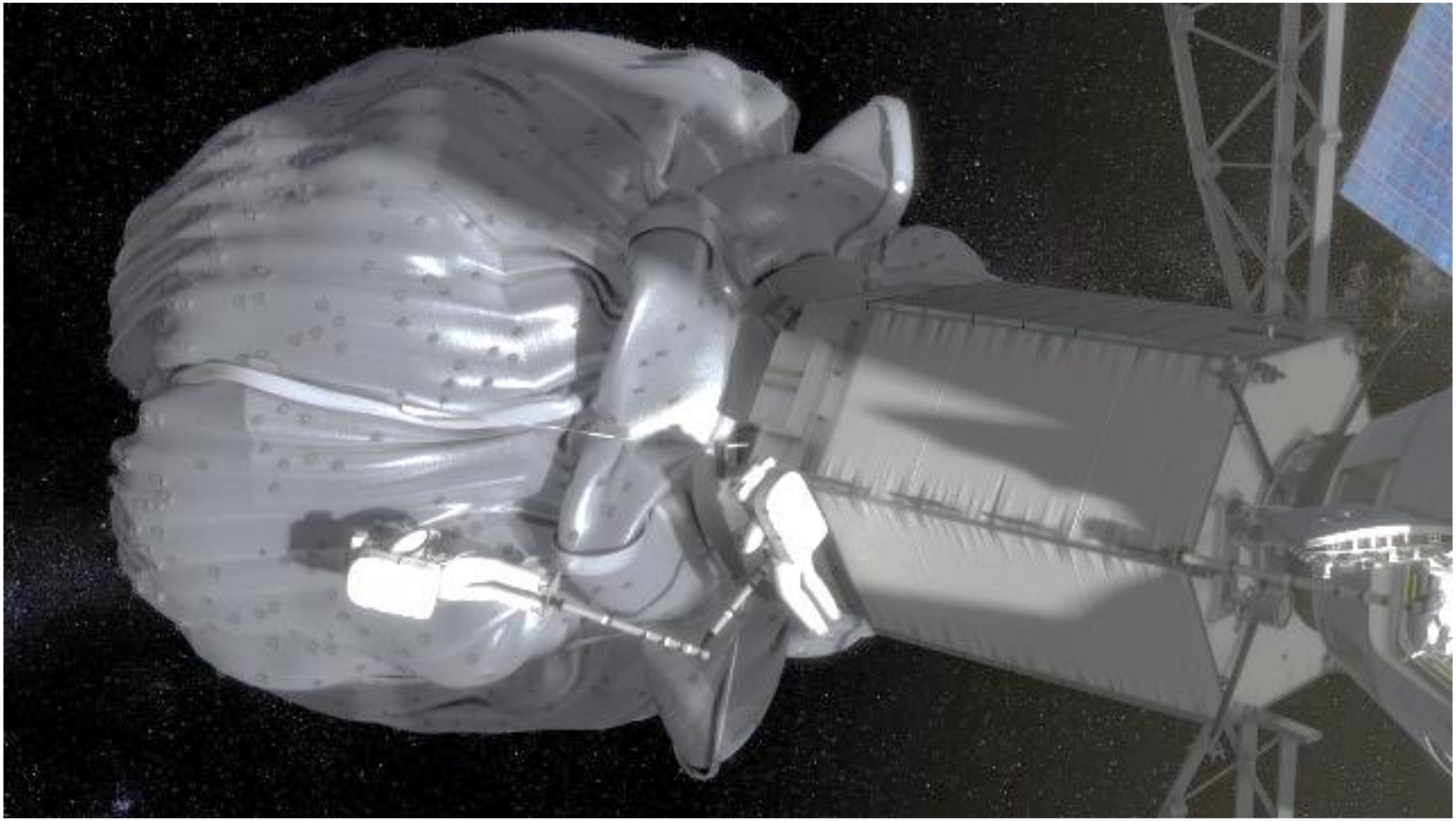
Hand Rails
- Translation path from aft end of ARRV to capture bag
- Ring of hand rails around ARRV near capture bag



Pre-positioned EVA Tool Box
- Tool box to offset Orion mass (85kg tools)

EVA Details

- Orion-Based EVA
- Two Crew per EVA
- Two EVAs + One Contingency
- Short Duration (~4 hr)



The First Steps Upwards to Mars……

Mission / Sequence	Current ISS Mission	Asteroid Redirect Mission	Long Stay In Deep Space	Humans to Mars Orbit	Humans to Surface, Short Stay	Humans to Surface, Long Stay
In Situ Resource Utilization & Surface Power						X
Surface Habitat						X
Entry Descent Landing, Human Lander					X	X
Aero-capture				X	X	X
Advanced Cryogenic Upper Stage				X	X	X
Deep Space Habitat	*		X	X	X	X
High Reliability Life Support	*		X	X	X	X
Autonomous Assembly	*		X	X	X	X
Solar Electric Propulsion for Cargo		X	X	X	X	X
Deep Space Guidance Navigation and Control		X	X	X	X	X
Crew Operations beyond LEO (Orion)		X	X	X	X	X
Crew Return from Beyond LEO – High Speed Entry (Orion)		X	X	X	X	X
Heavy Lift Beyond LEO (SLS)		X	X	X	X	X

Benefits of Asteroid Initiative

- **Makes progress toward NASA goals in human space exploration**
  - Challenging near term mission operations for human exploration beyond LEO & Early integration of foundational capabilities for deep space exploration
    - SLS and Orion initial capabilities for deep space
    - Navigation and piloting operations of deep space vehicles for human missions
    - Mission Kits for in-space assembly (EVA, Docking and Rendezvous)
    - Life support and deep space habitability
    - Complex ground and space operations, and sampling of small objects
- **Exercises collaboration between human and robotic missions of exploration**
- **Furthers science and technology**
  - Enhanced small bodies observation and characterization
  - Advanced solar electric propulsion
  - Asteroid sample return - but this is not a science mission
- **Strong commercial application**
  - Advanced solar electric propulsion
- **Planetary defense interests (testing of deflection techniques)**
- **Future utilization of in space resources**