

Asteroid Redirect Mission: Three Main Segments

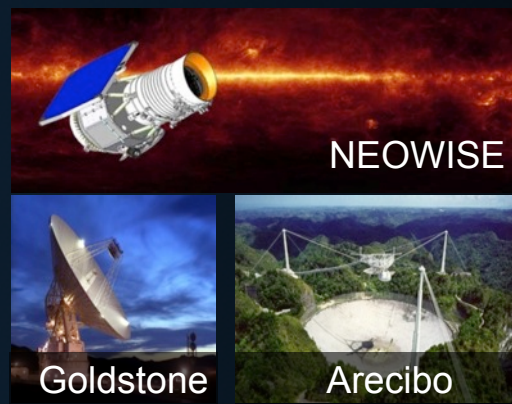


IDENTIFY

Ground and space based assets detect and characterize potential target asteroids



Pan-STARRS



NEOWISE



Goldstone



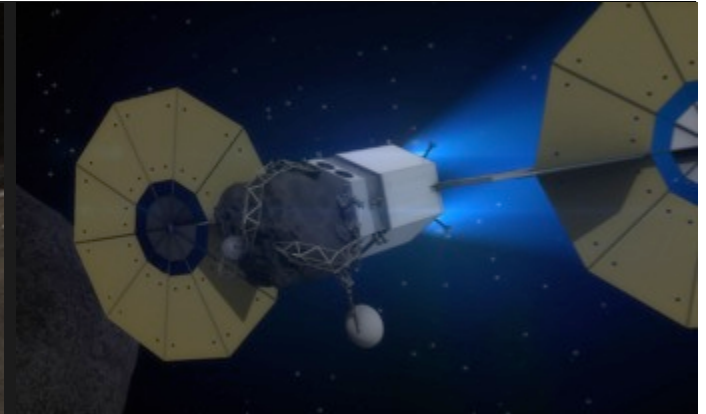
Arecibo



Infrared Telescope Facility

REDIRECT

Solar electric propulsion (SEP) based system redirects asteroid to cis-lunar space.



EXPLORE

Crew launches aboard SLS rocket, travels to redirected asteroid in Orion spacecraft to rendezvous with redirected asteroid, studies and returns samples to Earth

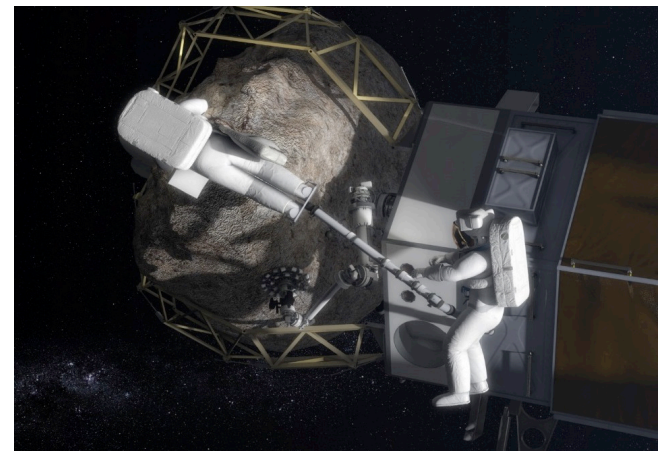


Journey to Mars Objective

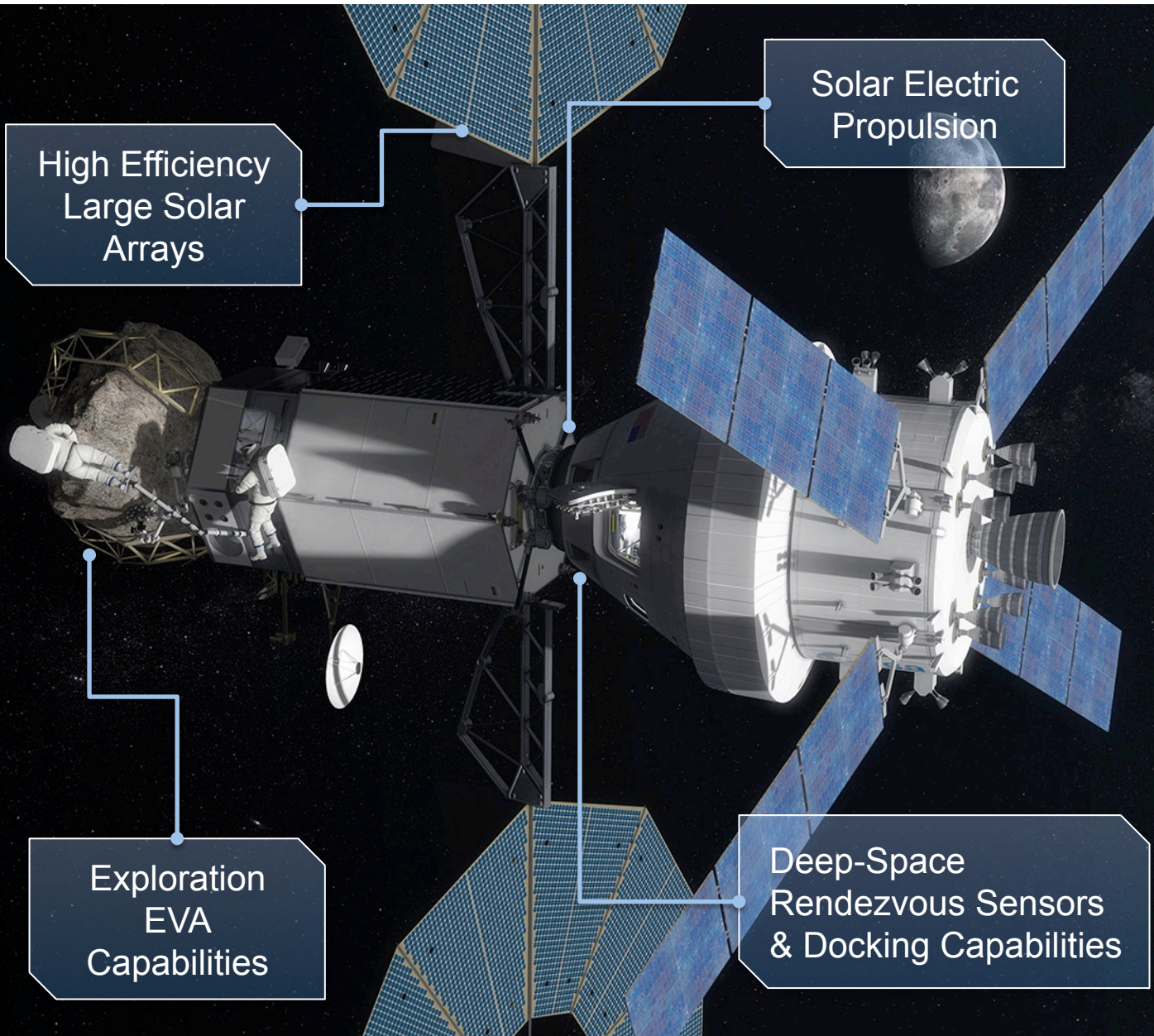


ARM human space flight demonstration objectives in the Proving Ground are an important early step to longer term crew activities in deep space

- **Transporting multi-ton objects with advanced solar electric propulsion**
- **Integrated crewed/robotic vehicle operations in deep space staging orbits**
- **Advanced autonomous proximity operations and rendezvous in deep space and with non-cooperative objects**
- **Astronaut EVA for sample selection, handling, and containment**
- **Maintaining Earth return trajectories and emergency return strategies**



ARM: A Capability Demonstration Mission



IN-SPACE POWER & PROPULSION:

- High efficiency 40kW SEP extensible to Mars cargo missions
- Power enhancements feed forward to deep-space habitats and transit vehicles

EXTRAVEHICULAR ACTIVITIES:

- Primary Life Support System design accommodates Mars
- Sample collection and containment techniques
- Follow-on missions in DRO can provide more capable exploration suit and tools

TRANSPORTATION & OPERATIONS:

- Capture and control of non-cooperative objects
- Rendezvous sensors and docking systems for deep space
- Cis-lunar operations are proving ground for deep space operations, trajectory, and navigation

Objectives of Asteroid Redirect Mission

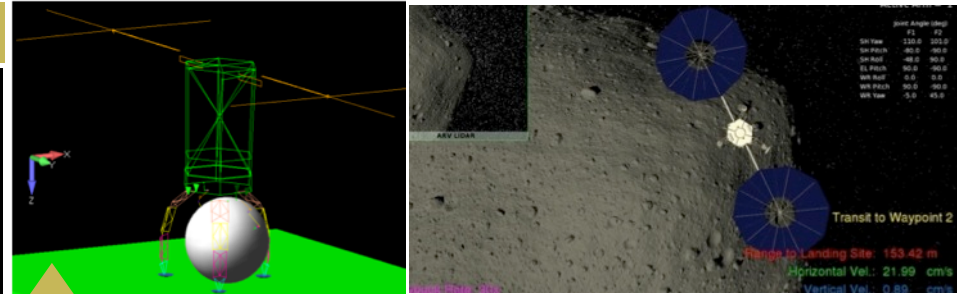
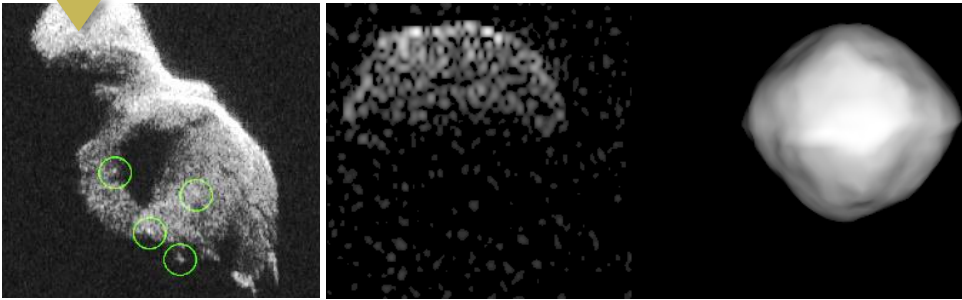


- 1. Conduct a human spaceflight mission involving in-space interaction with an asteroid boulder, providing systems and operational experience required for human exploration of Mars.**
- 2. Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.**
- 3. Enhance detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.**
- 4. Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies to defend our home planet.**
- 5. Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroid resources for commercial and exploration needs.**

Asteroid Redirect Mission: 2015 Advancements



IDENTIFYING CANDIDATE ASTEROIDS



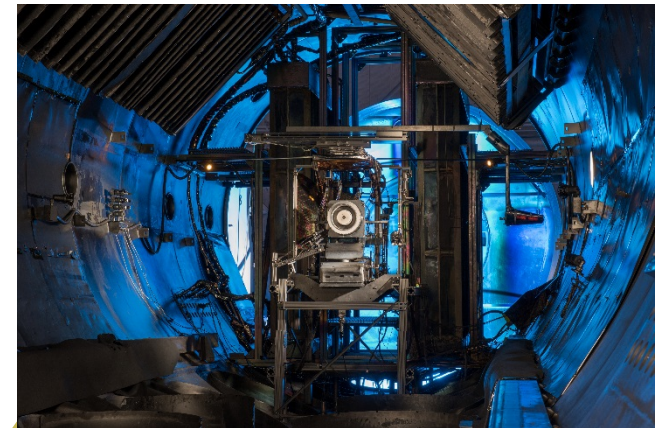
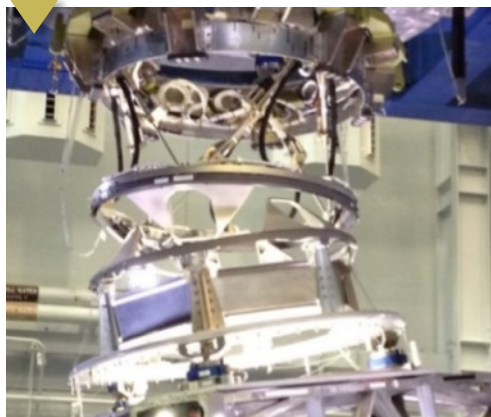
MISSION DESIGN AND SIMULATION OF CRITICAL MISSION OPERATIONS

PROTOTYPING AND TESTING CAPTURE OPTIONS



VACUUM PRESSURE INTEGRATED SUIT TESTING

INTERNATIONAL DOCKING SYSTEM



SOLAR ELECTRIC PROPULSION

Formulation Assessment and Support Team (FAST)



- Formulation Assessment and Support Team (FAST) consists of NASA and non-NASA participants who will:
 - participates in requirement formulation efforts during the initial development phase of the Asteroid Redirect Robotic Mission (ARRM) in support of the ARRM Requirements Closure Technical Interchange Meeting (TIM) currently planned for mid-December of 2015
 - provides initial inputs for potential investigations and payloads related to the following four main areas:
 - **Science**
 - **Planetary Defense**
 - **Asteroidal Resources and In-Situ Resource Utilization (ISRU)**
 - **Capability/Technology Demonstration**
 - works in collaboration with ARM management and technical personnel at the participating field centers to provide input during the requirements definition phase of the ARRM, which includes spacecraft interfaces, requirements, and design considerations as they relate to the Asteroid Redirect Crewed Mission (ARCM).
 - provides input to NASA on potential secondary payloads and partnerships.

Small Bodies Assessment Group (SBAG) Semi-Annual Meeting June 2015



“SBAG appreciates NASA’s efforts to engage and communicate with the planetary defense and small bodies science communities about the Asteroid Redirect Mission (ARM) and the extent to which modifications in mission design have been responsive to concerns from those groups.

In particular, the reference target asteroid 2008 EV5 offers well-documented opportunities and has been extensively studied as the sample return target for ESA’s MacroPolo-R [*sic*] candidate mission. SBAG encourages continued engagement between mission planners and the small bodies community as the mission moves forward and supports the plans for the competed Formulation Assessment and Support Team (FAST) and the succeeding Investigation Team (IT). However, it is important to note that for science-driven missions, SBAG continues to support the priorities identified in the Decadal Survey to guide use of Planetary Science Division (PSD) resources and funds.”

<http://www.lpi.usra.edu/sbag/findings/index.shtml#jul2015>

2015 IAA Planetary Defense Conference



Regarding planetary defense deflection demonstrations such as ARM and AIDA:

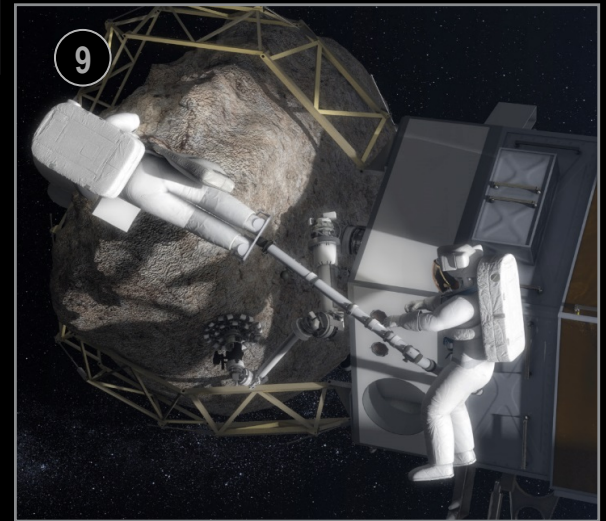
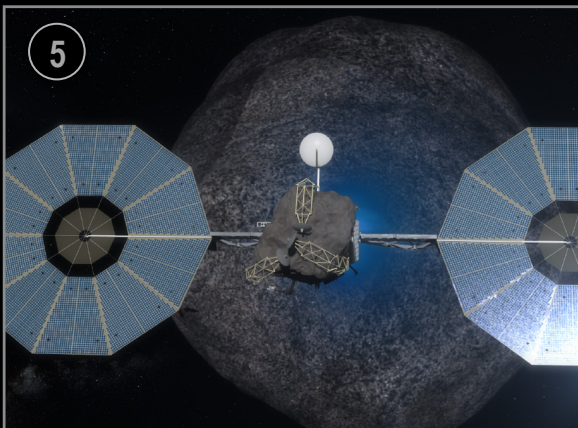
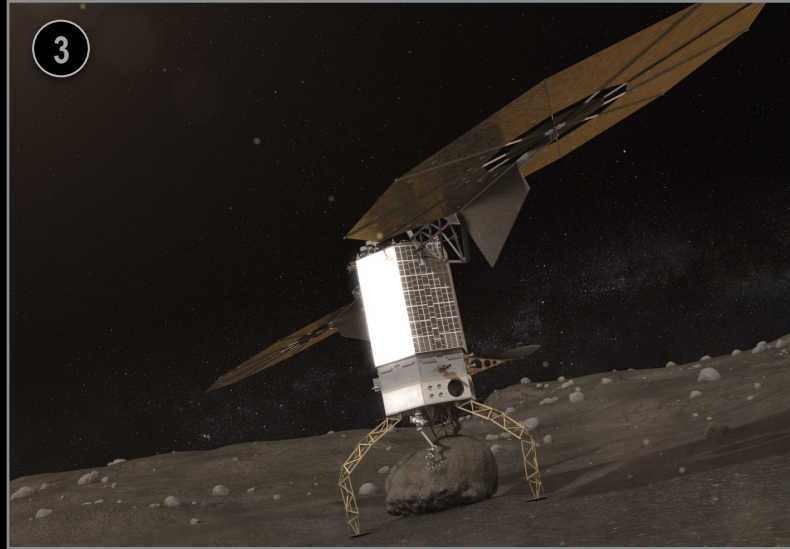
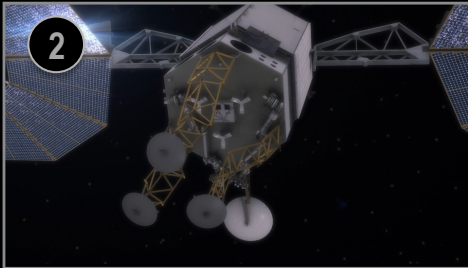
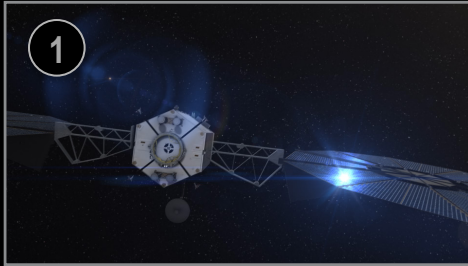
The joint NASA-ESA Asteroid Impact and Deflection Assessment (AIDA) mission, which will measure the effect of a kinetic impactor on a moon of a binary asteroid, and NASA's test of the enhanced gravity tractor concept as part of its **proposed Asteroid Redirect Mission (ARM)**, which would utilize a boulder from the target asteroid to increase the mass of the gravity tractor, **would both help lower uncertainties of these two deflection techniques and give confidence about capabilities to move an asteroid in a controlled way.**

Both of these missions have significant science benefits and are representative of how we can build confidence in deflection technologies by merging the two interests.

Final Report Posted July 22, 2015

<http://iaaweb.org/iaa/Scientific%20Activity/pdcreportfinal.pdf>

Asteroid Redirect Mission Highlights



ARRM Draft Level 1 Requirements (Update 6/30/15)



Level 1 Requirements		ARM Objective
1	ARRM shall develop and demonstrate a high-power, high-total impulse solar electric propulsion (SEP) system with input power level of at least 40kW and propellant load capability up to 10 t that is extensible to future human and robotic missions to Mars at a power level of at least 150 kW and 16 t of xenon (Xe) .	2
2	The ARRM spacecraft shall be capable of acquiring a boulder that has a 6m maximum extent, from a near-Earth asteroid.	1,3,5
3	ARRM shall acquire and redirect a mass of at least 20 t from a near-Earth asteroid to a stable, crew accessible orbit in cis-lunar space.	1, 5
4	ARRM shall enable crew-safe joint mission operations with Orion and provide access to the ARRM Flight System and asteroid material in a crew-accessible orbit by no later than 2025 (TBR).	1
5	ARRM shall perform a demonstration of a “slow push” planetary defense asteroid deflection technique.	4
6	ARRM shall provide volume, mass, power, data for contributed hardware.	5
7	ARRM shall be interface and performance compatible with Delta IV Heavy, Falcon Heavy and Space Launch System (SLS) until launch vehicle (L/V) selection, expected by Project System Design Review.	---
8	ARRM shall implement the project as a capability demonstration mission including defining and applying unique implementation techniques to achieve launch readiness by the end of 2020 with a cost capped budget of <\$1.25B (TBR) (not including L/V or Operations).	---
9	ARRM shall be capable of providing: power and communications resources for future potential visiting vehicles, release of the boulder and provisions for future refueling (Xe and hydrazine).	---

ARRM Capture Phase Overview

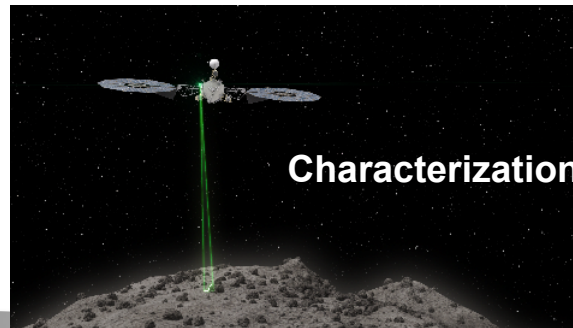
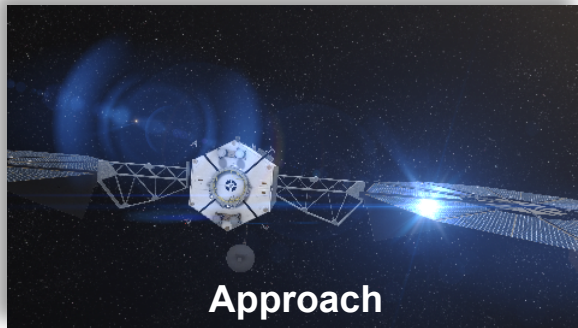


Approach
14 days

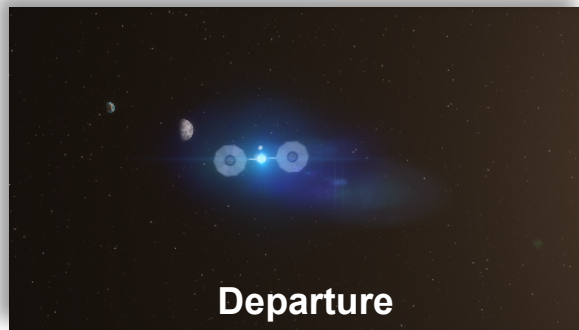
Characterization
72 days

Boulder Collection
69 days

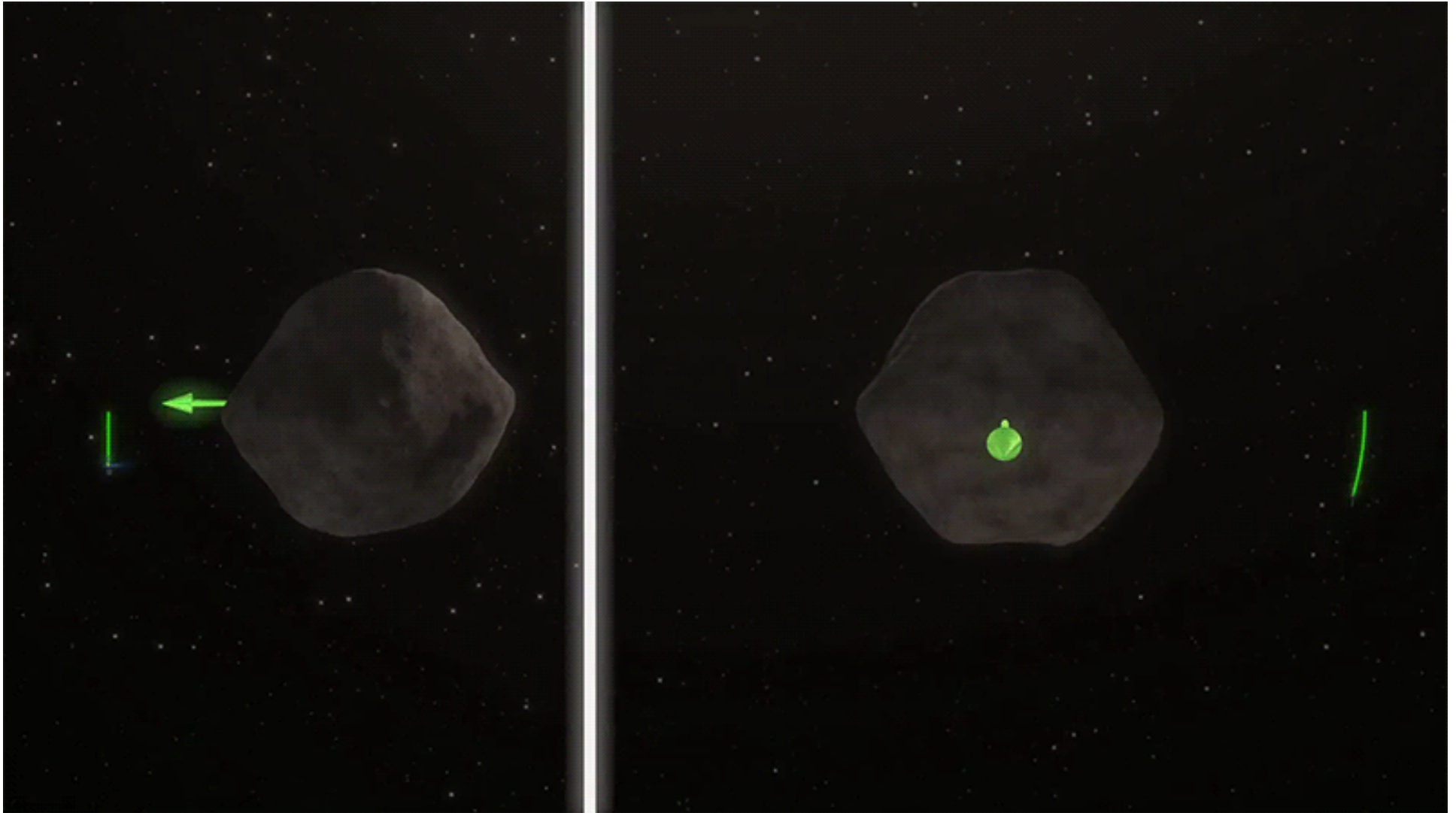
Planetary Defense Demo
150 days (30 deflection + 120 hold & verify)



Note: Asteroid operations timeline varies depending on target asteroid. Times shown are for 2008 EV₅: total stay time of 305 days with 95 days of margin.



Demonstration of Basic Asteroid Deflection Techniques



Animated version also available here: <http://www.nasa.gov/content/asteroid-redirect-mission-images?id=350296>

Current Valid ARRM Candidate Asteroid Targets



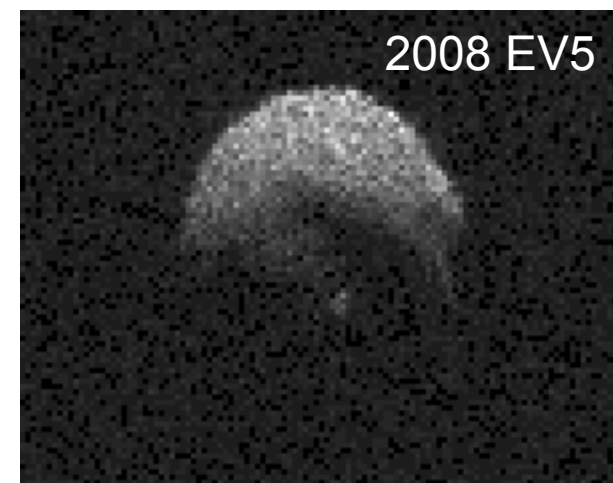
Candidate Option B Targets	Type	Mass, Diameter	Spin Period	V_{∞} (km/s)	Perihelion (AU)	Absolute Magnitude H
2008 EV5	C	7.0×10^7 t, 400m	3.73 hrs	4.41	1.04	20.0
Bennu	C	7.8×10^7 t, 490m	4.30 hrs	6.36	1.36	20.8
1999 JU3	C	6.9×10^8 t, 870m	7.63 hrs	5.08	1.42	19.2
Itokawa	S	3.5×10^7 t, 320m	12.1 hrs	5.68	1.70	19.2

Precursors:

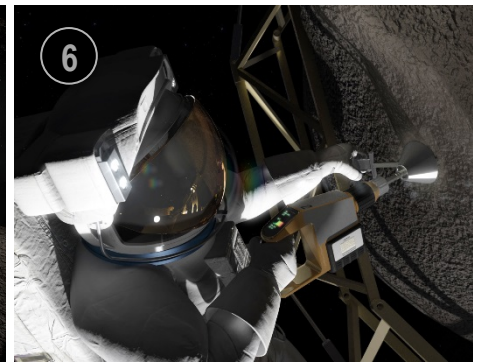
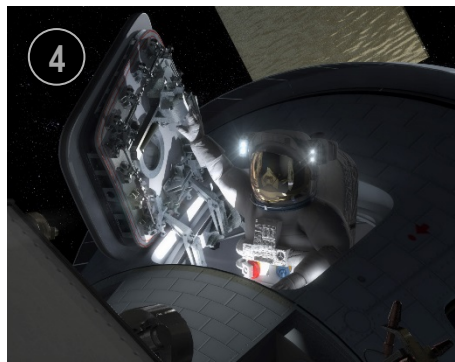
- Itokawa: Hayabusa (visited 2005)
- 1999 JU3: Hayabusa 2 (scheduled 2018)
- Bennu: OSIRIS-REx (scheduled 2018)
- 2008 EV5: No precursor, but radar detected boulders in 2008

NASA continues to look for additional targets in accessible orbits.

Reference ARRM Target



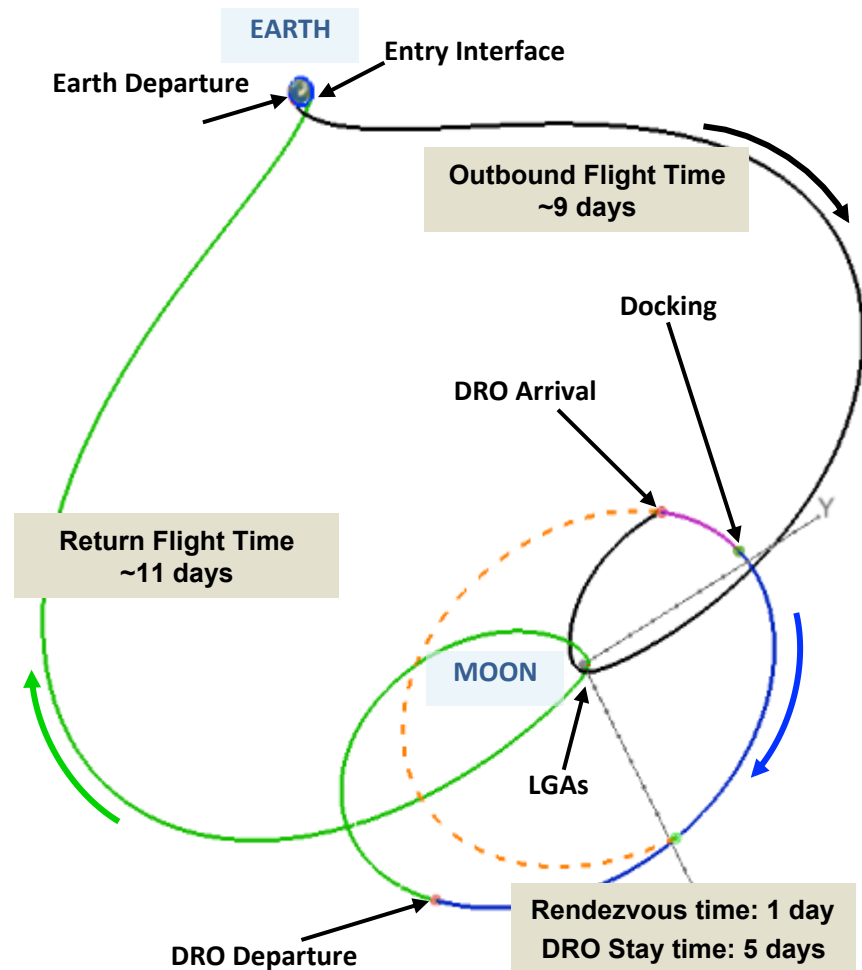
Asteroid Redirect Crewed Mission Overview



December 2025 Reference Crewed Mission Overview



- Orion launch via Block 1 SLS/ICPS
- Use Lunar Gravity Assist (LGA) trajectories for outbound and Earth return.*
- Total mission duration 26 Days with 5 days docked with Asteroid Return Vehicle (ARV).[†]
- Two person crew launched aboard Orion.
- Rendezvous/dock with ARV in ~71,000 km DRO above lunar surface.
- Conduct 2 four-hour EVAs using adapted Modified Advanced Crew Escape Suits (MACES) to observe, document and collect asteroid samples.
- DRO ops for 5 days: one day for rendezvous, one day for each EVA, one day in between EVAs and one day for undock/contingency
- Orion returns to Earth on an LGA trajectory, with a skip targeted return near San Diego, CA



***LGA Flight days shown represent one possible trajectory.**

Other trajectories may require additional flight days.

[†]Orion Consumables allow for a 30 day total mission duration.

ARRM Formulation Guidance



- **Capture option B**
- **Draft Level 1 requirements**
- **Target robotic mission launch date Dec 2020**
- **Robotic mission cost cap \$1.25B not including launch vehicle and mission operations (Phase E)**
- **Target crewed mission launch date Dec 2025**
- **Internal and external dependencies**
- **Define capability demonstration implementation approach**

NASA Approval to Proceed to begin Phase A Formulation for Robotic Mission

ARRM Progress since Mission Concept Review (MCR) and Milestone Plan



- Formulation investigation team* courtesy letter released Jun 24
- Spacecraft bus Request for Information responses due Jun 29
- Small Bodies Assessment Group Jun 29
- NewSpace Conference Jul 16-17
- STMD Electric Propulsion Request for Proposal Release Jul 24
- ARM update to NASA Advisory Committee HEO Committee Jul 27-30
- ARRM Acquisition Strategy Meeting Aug 4
- **Common visible/infra-red camera RFP release Oct 1**
- **STMD SEP 2nd thruster fab and assembly complete Oct 30**
- **Formulation investigation team draft report release to the public Nov 14**
- **Requirements Closure Technical Interchange Meeting Dec 15**
- **NASA Key Decision Point - B Feb 2016**
- **Mission Preliminary Design Review Apr 2016**
- **Spacecraft Integration and Test Start Jul 2019**
- **Launch Readiness Date Dec 2020**

* Formulation Assessment and Support Team (Sept - Dec 2015)

