NASA'S ASTEROID REDIRECT MISSION (ARM) CONCEPT OVERVIEW

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Introduction

NASA's Asteroid Redirect Mission (ARM) is a capability demonstration mission that will develop, test, and demonstrate several capabilities required for enabling Human Exploration of the Solar System. These capabilities are focused on in-space power and propulsion, transportation and mission operations, and extravehicular activities (Fig. 1). Completion of the ARM human space flight demonstration objectives are an important early step for NASA to develop longer duration crew activities in deep space. Specifically these involve:

- Conducting advanced autonomous proximity operations and rendezvous in deep space
- Transporting multi-ton objects utilizing advanced solar electric propulsion
- Performing integrated crewed/robotic vehicle operations in deep space staging orbits
- Conducting astronaut EVAs for sample selection, collection, handling, and containment
- Developing Earth return trajectories and emergency return strategies

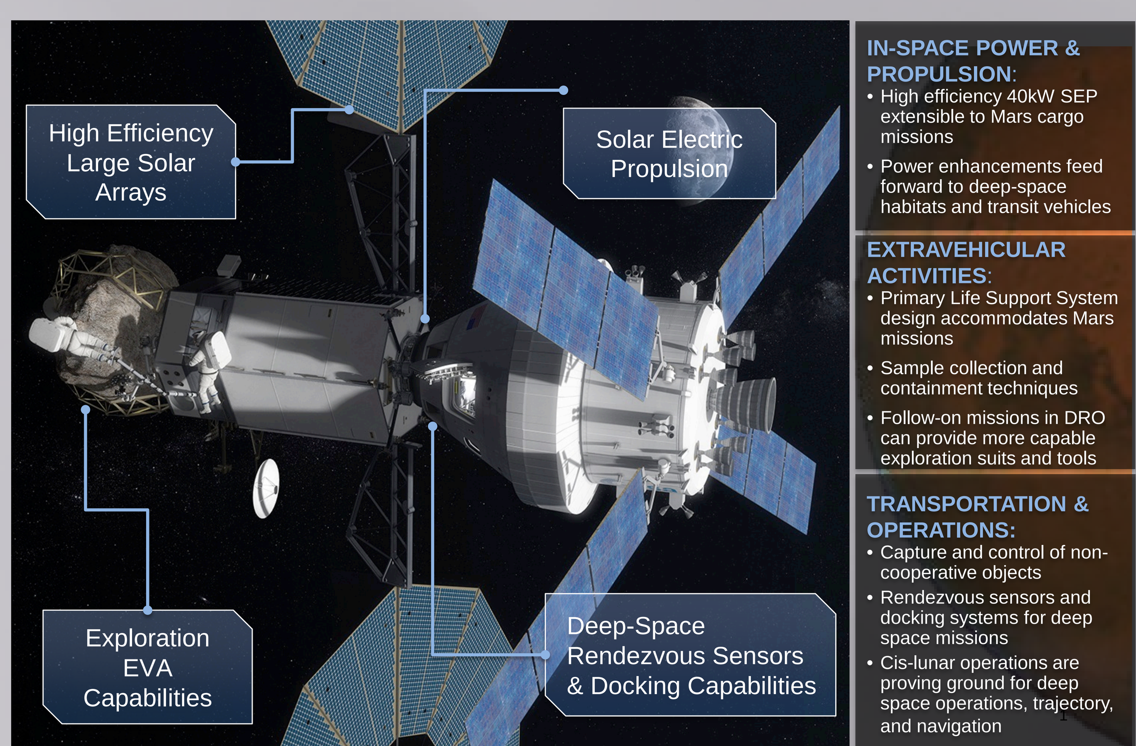


Figure 1: The prime capability demonstrations of the ARM

The ARM is divided into three segments (Fig. 2). The first segment is the identification and characterization of potential target asteroids, utilizing NASA's Near-Earth Object (NEO) observations program; the second segment embodies the Asteroid Redirect Robotic Mission (ARRM), which has the objective of deflecting an asteroid and returning a large boulder to cis-lunar space; the third segment is the Asteroid Redirect Crewed Mission (ARCM) in which astronauts explore the boulder and bring samples of it back to Earth.

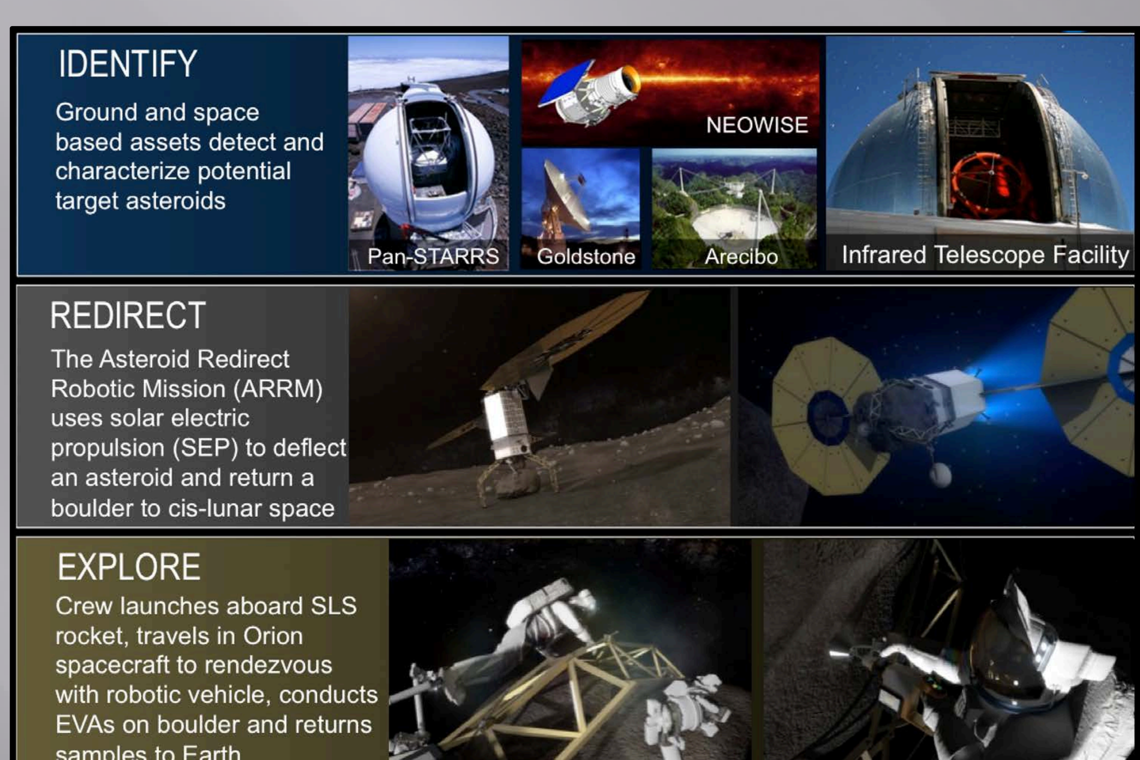


Figure 2: The three phases of the ARM

There are five main objectives for the ARM as a whole. These are listed below and have relevance to the Space Technology Mission Directorate (STMD), the Human Exploration and Operations Mission Directorate, and the Science Mission Directorate (SMD).

1) Conduct a human exploration mission to an asteroid in the mid-2020's, 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.

The Asteroid Redirect Robotic Mission (ARRM)

The Asteroid Redirect Robotic Mission (ARRM) passed its mission concept review in February of 2015. The option to retrieve a 1 – 6 meter multi-ton boulder from the surface of a potentially hazardous sized near-Earth asteroid has been approved to proceed to Phase A. There is a strong desire to select an organic- and volatile-rich asteroid target, which has benefits from both a science and *in situ* resource utilization perspective. The main objective for this portion of the ARM is to place the boulder in cis-lunar space where it will be available for the crewed mission in the 2025 timeframe. There is a secondary objective of collecting regolith samples from the vicinity of the boulder using the geological context sample pads of the robotic vehicle, which will also be available for retrieval during the crew EVAs. The currently proposed launch date for the ARRM is no later than December 2021.

The ARRM has four mission phases at the asteroid (Fig. 3). There is an approach phase for general characterization and identification of potential hazards (e.g., satellites, plumes, etc.); a detailed characterization phase for asteroid shape modelling, target identification, and sample site selection; a boulder collection phase for the actual retrieval of the boulder; and a planetary defense demonstration using the extra mass of the boulder with the robotic spacecraft to conduct an enhanced gravity tractor deflection of the near-Earth asteroid.

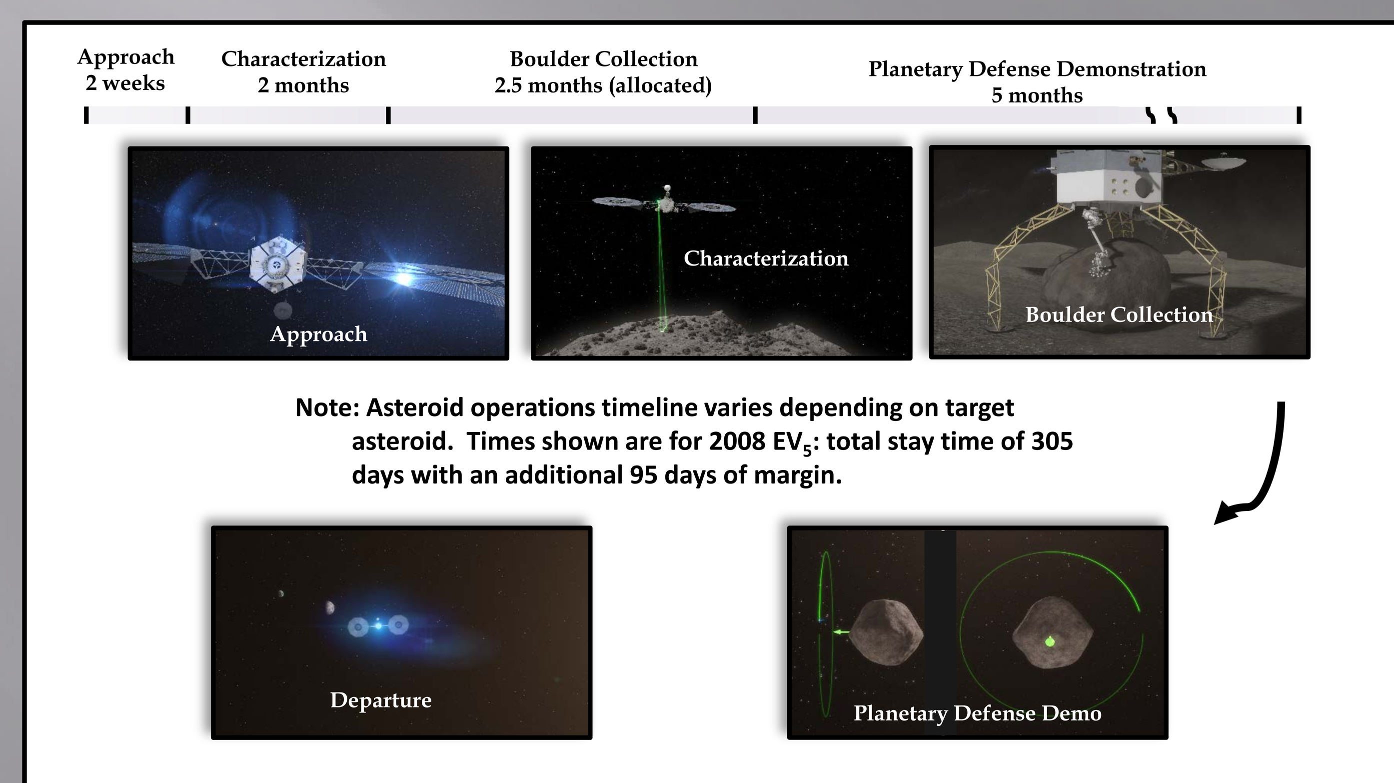
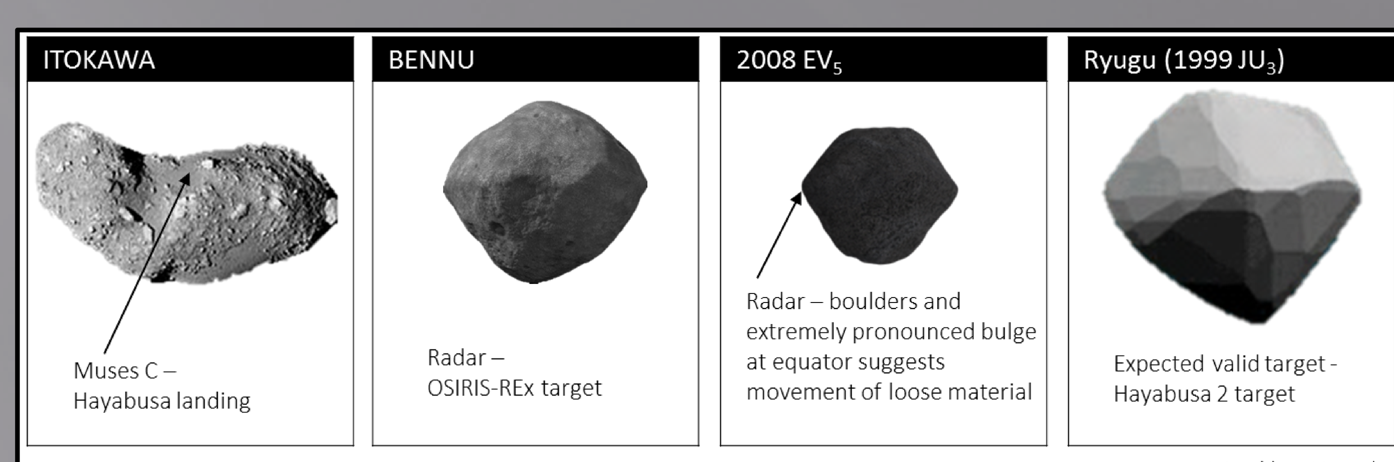


Figure 3: The operational timeline of the ARRM

Selectable asteroid targets for the ARRM must be located in fairly accessible orbits and be several hundred meters in size, they must also have their surfaces characterized well enough that scientists can be confident that sufficient numbers of boulders are available. Four NEAs are currently considered selectable: 2008 EV_5, Bennu, Ryugu (1999 JU_3), and Itokawa. The latter was already well characterized by JAXA's *Hayabusa* spacecraft in 2005, while the middle two will be visited by NASA's *OSIRIS-REx* and JAXA's *Hayabusa2*, respectively. The current baseline target is 2008 EV_5, which will not have been previously visited by a spacecraft before ARRM arrives; its surface, however, has been well characterized by ground-based radar. All of the selectable target asteroids except for Itokawa are C-type, which makes them of great interest both scientifically and for *in situ* resource utilization purposes. Figure 4 summarizes the physical and orbital properties of the selectable targets for ARM.



Comparison of current selectable target asteroids

	Itokawa	Bennu	2008 EV_5	Ryugu (1999 JU_3)
Size	535 x 294 x 209 m	492 x 508 x 546 m	420 x 410 x 390 m	870 m diameter
V_∞	5.68 km/s	6.36 km/s	4.41 km/s	5.08 km/s
Aphelion	1.70 AU	1.36 AU	1.04 AU	1.42 AU
Spin Period	12.13 hr	4.297 hr	3.725 hr	7.627 hr
Type	S	B (C-grp volatile rich)	C (volatile rich)	C (volatile rich)
Precursor	Hayabusa (2005)	OSIRIS-REx (9/2016 launch, 8/2018 arrival)	None currently planned (boulders implied from 2008 radar imaging)	Hayabusa 2 (launched 12/4/2014, 7/2018 arrival)

NASA continues to look for additional targets in accessible orbits. Reference ARRM Target

Figure 4: The four selectable target near-Earth asteroids for the ARRM

The Asteroid Redirect Crewed Mission (ARCM)

Two astronauts will launch aboard the Orion capsule via the Space Launch System to begin the Asteroid Redirect Crewed Mission (ARCM) once the retrieved boulder is located in cis-Lunar space. The crew will utilize a Lunar gravity assist trajectory during their outbound flight and rendezvous with the robotic vehicle and boulder (Figs. 5 & 6). Once the Orion and robotic vehicle are securely docked, the crew will conduct 2 four-hour extra-vehicular activities (EVAs) to investigate the boulder, collect samples, and deploy instruments (Figs. 5 & 7). Current plans for the length of ARCM operations are to last approximately 5 days with one a day for rendezvous, one day each for the 2 EVAs, one day between EVAs, and one day for contingency operations. After the samples are securely stowed the crew will return to Earth using another Lunar gravity assist and splash down off the cost of San Diego, CA (Figs. 5 & 6). Total mission duration for the ARCM is roughly 26 days including the 5 days docked to the robotic vehicle. The Orion has a mass return capability of 100 kg, which includes samples, packaging, and containment.

Figure 5: ARCM operation and sequence of events

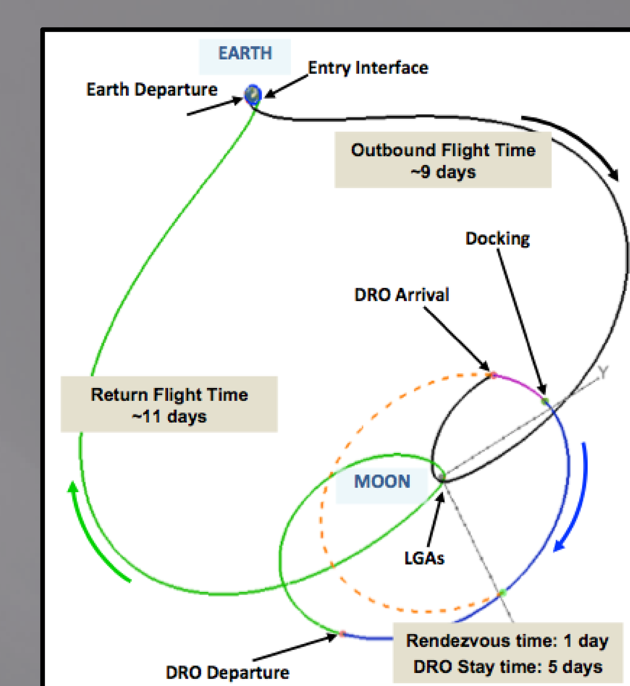


Figure 6: ARCM trajectory and timeline

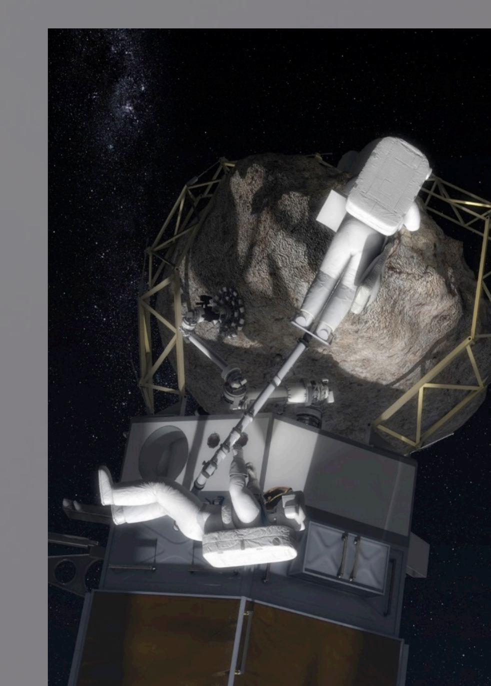


Figure 7: Crew conducting EVA

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The Ten Second Review

- The Asteroid Redirect Mission (ARM) is a major NASA initiative that will develop, test, and demonstrate several key capabilities needed for future human exploration of the Solar System.
- The ARM is comprised of the Asteroid Redirect Robotic Mission (ARRM) scheduled for launch late 2021 and the Asteroid Redirect Crewed Mission (ARCM) which is planned for late 2026.
- The ARRM will use a multi-purpose high-power Solar Electric Propulsion (SEP) vehicle and demonstrate its capabilities by visiting a large (100 m -1 km) Near-Earth Asteroid (NEA), touching down on its surface, capturing a multi-ton boulder, and bringing it back into a stable Lunar orbit.
- The crew of the ARCM will rendezvous with the robotic vehicle in Lunar orbit via Orion, conduct extra-vehicular activities (EVAs), investigate and sample the bolder, and then return to Earth.
- ARM offers: 1) an opportunity to study a NEA *in situ* and to perform a planetary defense demonstration on an asteroid of a hazardous size; 2) the ability to select a type of object to be brought back and sampled that is of interest for science and resource utilization; and 3) potential extensibility to a similar mission for exploring and bringing back samples from the moons of Mars.

http://www.nasa.gov/asteroidinitiative