Asteroid Redirect Mission (ARM) Status

Briefing to Small Bodies Assessment Group

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NASA Headquarters

January 28, 2016
JOURNEY TO MARS

- HUBBLE
- INTERNATIONAL SPACE STATION
- SPACE LAUNCH SYSTEM (SLS)
- ORBITERS
- LANDERS
- PHOBOS DEIMOS
- ORION
- SOLAR ELECTRIC PROPULSION
- ASTEROID REDIRECT MISSION
- MARS TRANSFER SPACECRAFT
- IN-SPACE HABITAT

- TECHNOLOGY
- SCIENCE
- EXPLORATION
- COMMERCIAL CARGO AND CREW

- MISSIONS: 6-12 MONTHS RETURN: HOURS EARTH RELIANT
- MISSIONS: 1 TO 12 MONTHS RETURN: DAYS PROVING GROUND
- MISSIONS: 2 TO 3 YEARS RETURN: MONTHS EARTH INDEPENDENT
A Sustainable Exploration Approach
Mars Split Mission Concept

Getting to Mars

- DESTINATION SYSTEMS
  SEP pre-deploy to Mars orbit

- TRANSIT HAB TO MARS
  Aggregate in Cis-lunar space

- CREW
  Launch to Cis-lunar space

Transit: 2-3 Years

- CREW/TRANSIT HAB
  Aggregation in HEC/DRO

- HABITATS
  Return to staging point for refurbishment

- 6-9 Months
  CREW/TRANSIT HAB
  To Mars orbit via chemical propulsion

- 6-9 Months
  CREW/TRANSIT HAB
  Return to Earth & DRO

Surface Operations:
30-500 Days

Returning to Earth
ARM Objectives in Support of Human Exploration

- Transporting multi-ton objects with advanced solar electric propulsion
- Integrated crewed/robotic vehicle operations in deep space staging orbits
- Advanced autonomous proximity operations in deep space and with a natural body
- Astronaut EVA for sample selection, handling, and containment
Key Technology Highlights

- High Efficiency, High Power Solar Arrays
- Exploration EVA Capabilities
- Autonomous Deep-Space Proximity Operations
- High Power, High Throughput Electric Propulsion
- Deep-Space Rendezvous Sensors & Docking Capabilities
Asteroid Redirect Mission Progress

✓ Asteroid Redirect Robotic Mission Capture Mission downselection Dec 2014
  ✓ Capture “option B” to acquire a multi-ton boulder from a large asteroid
  ✓ Transport the multi-ton asteroidal mass to a lunar orbit for sampling by astronauts in the mid-2020’s
  ✓ Planetary defense demonstration

✓ Formulation Assessment and Support Team (FAST) Established Aug 2015
✓ Public comments due on FAST draft report Dec 2015
  • https://www.nasa.gov/feature/arm-fast

✓ Robotic mission requirements technical interchange meeting Dec 2015
✓ ARM leadership team strategy meeting on partnerships and Engagement (part 1) Dec 2015
✓ ARRM spacecraft industry early design study contracts selected Jan 2016
ARM Organization (as of 12/3/15) 
being updated

ARM HQ Leadership Team

STMD
Deputy AA for Programs STMD
SEP Program Executive

HEOMD
ARM Program Director
ARRM Program Executive*

SMD
NEO Program Executive/Planetary Defense Officer

HEOMD ISRS Program Executive*

ARRM Project Management (JPL)

Commercial Partnerships (ARC)

Investigation Team (LaRC)

Capture Module (GSFC)***

Capture Module Technology through EDU & qual (GSFC)***

Microspine (JPL)

Contact & Restraint System (LaRC)

SEP-related Systems (GRC)**

Electric Propulsion Strings (GRC)**

* Dual assignment
** Dual assignment/same GRC team
*** Dual assignment/same GSFC team

Direction/Reporting

Information/Coordination
Collaborative/Participatory Elements

- Center-to-Center Collaboration and Partnership
- Cross-Directorate Collaboration
- Evolution of SBAG Interaction
- Participatory Formulation through the Formulation Assessment and Support Team
- Leveraging Commercially Available Spacecraft Industry
- Potential for “Commercial” (Entrepreneurial) Collaboration
- Continued Discussions with International Potential Partners
FAST chartered by NASA in August 2015 to:

- Assist in developing an initial list of potential mission investigations and provide input on potential hosted payloads and partnerships.

Inputs focus on scientific return and knowledge gain from ARM in the areas of:

- Science
- Planetary defense
- Asteroidal resources and in-situ resource utilization (ISRU)
- Capability and technology demonstrations

U.S. membership composed of 18 NASA and non-NASA participants, plus Mission Investigator, Deputy Investigator, and Analysis and Integration Lead. Participants selected from exactly 100 applicants.

Final report release last week of January: [http://www.nasa.gov/feature/arm-fast](http://www.nasa.gov/feature/arm-fast)
- Provided information on the nature of the asteroid target and boulders
- Provided ideas and recommendations to enhance the scientific return including a wide range of observations and instruments

### Organization

| NASA Langley Research Center (Mission Investigator) |
| NASA Johnson Space Center (Deputy Investigator) |
| NASA Langley Research Center (IT Analysis and Integration Lead) |
| Arizona State University |
| Penn State University |
| Arizona State University |
| Southwest Research Institute |
| University of Central Florida |
| University of Central Florida |
| Jet Propulsion Laboratory |
| John Hopkins University-Applied Physics Laboratory |
| NASA Johnson Space Center |
| Missouri University of Science and Technology |
| NASA Goddard Space Flight Center |
| University of Maryland |
| Planetary Science Institute |
| NASA Goddard Space Flight Center |
| University of Colorado |
| TransAstra |
| United States Geological Survey |
| Honeybee Robotics |

**FAST Leadership**

**FAST Participants**
An ARM Investigation Team (IT) is planned to be formed in the summer of 2016 with a call for membership expected in April of 2016 (following KDP-B).

The multidisciplinary IT will support ARM through mission formulation, mission design and vehicle development, and mission implementation.

- Assist with the definition and support of mission investigations.
- Support ARM program-level and project-level functions.
- Provide technical expertise.
- Support NASA Headquarters interactions with the technical communities

Support for post-docs, research, travel planned.

Formulation of how the IT will be structured is currently in process.

The entire ARM team looks forward to continued engagement with the small bodies community and others with potential interest in the mission!
Current Candidate Parent Asteroids

<table>
<thead>
<tr>
<th>ITOKAWA</th>
<th>BENNU</th>
<th>2008 EV5</th>
<th>1999 JU3</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="ITOKAWA.png" alt="Image" /></td>
<td><img src="BENNU.png" alt="Image" /></td>
<td>![Image](2008 EV5.png)</td>
<td>![Image](1999 JU3.png)</td>
</tr>
<tr>
<td>Muses C – Hayabusa landing</td>
<td>Radar – OSIRIS-REx target</td>
<td>Radar – boulders and extremely pronounced bulge at equator suggests movement of loose material</td>
<td>Expected valid target - Hayabusa 2 target</td>
</tr>
</tbody>
</table>

Comparison of current candidate parent asteroids

<table>
<thead>
<tr>
<th></th>
<th>Itokawa</th>
<th>Bennu</th>
<th>2008 EV₅</th>
<th>1999 JU₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>535 x 294 x 209 m</td>
<td>492 x 508 x 546 m</td>
<td>420 x 410 x 390 m</td>
<td>870 m diameter</td>
</tr>
<tr>
<td>$V_\infty$</td>
<td>5.68 km/s</td>
<td>6.36 km/s</td>
<td>4.41 km/s</td>
<td>5.08 km/s</td>
</tr>
<tr>
<td>Aphelion</td>
<td>1.70 AU</td>
<td>1.36 AU</td>
<td>1.04 AU</td>
<td>1.42 AU</td>
</tr>
<tr>
<td>Spin Period</td>
<td>12.13 hr</td>
<td>4.297 hr</td>
<td>3.725 hr</td>
<td>7.627 hr</td>
</tr>
<tr>
<td>Type</td>
<td>S</td>
<td>B (C-grp volatile rich)</td>
<td>C (volatile rich)</td>
<td>C (volatile rich)</td>
</tr>
</tbody>
</table>

NASA continues to look for additional targets in accessible orbits.
### Capture Phase Overview

**Asteroid Redirect Robotic Mission**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>14 days</td>
</tr>
<tr>
<td>Characterization</td>
<td>85 days</td>
</tr>
<tr>
<td>Boulder Collection</td>
<td>60 days + 30 day margin</td>
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</table>

#### Phases:
- **Approach**: 14 days
- **Characterization**: 85 days
- **Boulder Collection**: 60 days + 30 day margin
- **Departure**:
  - **Planetary Defense Demo**: 30 days (deflection + verify if needed)
The acquisition strategy for the ARRM spacecraft leverages existing commercially available U.S. industry capabilities for a solar-electric-propulsion (SEP) based spacecraft for the agency's Asteroid Redirect Robotic Mission

- Align with U.S. commercial spacecraft industry plans for future use of SEP
- Reduce costs and cost risk to ARRM

Strategy includes procurement of the ARRM spacecraft bus through a two-phase competitive process

- Phase 1 through design studies
- Phase 2 competition for development and implementation of the flight spacecraft bus by one of the study participants

JPL selected four companies to conduct Phase 1: Lockheed Martin Space Systems, Littleton, Colorado; Boeing Phantom Works, Huntington Beach, California; Orbital ATK, Dulles, Virginia; and Space Systems/Loral, Palo Alto, California.
Electric Propulsion String
Electric Thruster & Power Processing Unit (PPU)

Demonstrated full performance compatibility between thruster and PPUs

Hall Effect Rocket with Magnetic Shielding Technology Development
thruster with radiator

12.5 kW, 3,000 s hot-fire thruster test in GRC Vacuum Facility-5

Electric Propulsion System Procurement

Thruster & Power Processing Unit Development for an Advanced EP System

- RFP released in July 2015, final proposals received and under evaluation
- Anticipated award in late Spring 2016
Capture System Prototyping/Testing
Asteroid Redirect Robotic Mission

Prototype contact and restraint system development at LaRC
- Full scale welded metal prototype delivered
- Flat-floor testing of landing, extraction, and ascent completed

Microspine gripper development at JPL
- Updated design of gripper, drill, drivetrain, and anchor
- Prototypes completed and tested with surrogate asteroid material

7-DOF Robot “Capture” Arm at GSFC
Leveraging satellite servicing technology common development robot arm and controller
Modified ACES Suit Feasibility Testing
Asteroid Redirect Crewed Mission

Adjustable portable foot restraint operations tested

Two handed tasks demonstrated with body restraint tether

Crew performed sampling tasks including worksite imaging, float sample collection, hammer chiseling and pneumatic chiseling.

Orion program completed four MACES suited evaluations in the Vacuum Pressure Integrated Suit Test applicable to ARM
ARM Upcoming Events

• Update with Small Bodies Assessment Group  Jan 2016
• Complete 6th of 6 total Peer Reviews for Restore-ARRM  Jan 2016

Synergy Subsystems
• Crewed segment operational requirements meetings at JSC  Feb 2016
• ARM leadership team strategy meeting on partnerships and engagement (part 2)  Feb 2016

• ARRM Key Decision Point – B  Apr 2016 (TBR)
• Investigation Team Call Release  Apr 2016 (TBR)
• Electric Propulsion Thruster and PPU contract award  May 2016
• Actuated prototype of contact and restraint system complete Sep 2016
Back Up
• June 2013: NASA issued a Request for Information (RFI) to seek new ideas on how to implement the ARM and Agency Grand Challenge, alternative ARM concepts, and innovative approaches to broaden participation from partners and the public.
  – Received 402 responses, invited 96 response ideas for further exploration, acted on many of them

• Ideas Synthesis

• March 2014: NASA issued the Asteroid Redirect Mission Broad Agency Announcement (BAA), soliciting proposals for concept studies in areas including asteroid capture systems, rendezvous sensors, adapting commercial spacecraft for the Asteroid Redirect Mission and feasibility studies of potential future partnership opportunities for secondary payloads and the crewed mission.
  – In June 2014, NASA announced it selected 18 of the 108 BAA proposals for six-month studies, totaling $4.9 million in awards.
External Engagement (2)

• Interactions and assessments, information during pre-formulation
  – Briefings and interactions with feedback
  – SBAG Special Action Team – August 2014
  – Curation and Planning Team for Extra-Terrestrial Materials input – December 2014

• Expert and Citizen Assessment of Science and Technology
  – Phoenix, AZ and Boston, MA: fall and winter 2014

• May 2015: NASA issued another RFI for Spacecraft Bus Concepts to Support the Asteroid Redirect Robotic Mission and In-Space Robotic Servicing
  – Additional information for acquisition strategy

• June 2015 Notice of formation of FAST
  – Toward Investigation Team for mission
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 EV$_5$ offers well-documented opportunities, having been previously the sample return target for ESA’s MacroPolo-R 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.

Draft Finding Released July 22, 2015

http://www.lpi.usra.edu/sbag/findings/SBAG13_07102015.pdf
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

### ARRM Alternate Target List

<table>
<thead>
<tr>
<th>Asteroid</th>
<th>H (mag)</th>
<th>Estimated Diameter (m)</th>
<th>Semi-Major Axis (au)</th>
<th>Orbit Period (yr)</th>
<th>Eccentricity (°)</th>
<th>Next Optical Opportunity</th>
<th>Next Arecibo Radar Opportunity</th>
<th>Next Goldstone Radar Opportunity</th>
<th>Asteroid returned mass (t)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008 EV5 (reference)</td>
<td>20</td>
<td>~ 400m</td>
<td>0.958</td>
<td>0.94</td>
<td>0.084</td>
<td>2021-12 [21.8]</td>
<td>2023-12 [9600]</td>
<td>2023-12 [320]</td>
<td>20</td>
</tr>
<tr>
<td>Bennu</td>
<td>20.9</td>
<td>~ 500m</td>
<td>1.126</td>
<td>1.2</td>
<td>0.203</td>
<td>2017-02 [20.1]</td>
<td>2037-01 [34]</td>
<td>none</td>
<td>1.2</td>
</tr>
<tr>
<td>2014 YD</td>
<td>24.3</td>
<td>24-107</td>
<td>1.07</td>
<td>1.11</td>
<td>0.087</td>
<td>2024-10 [22.0]</td>
<td>none</td>
<td>none</td>
<td>83.4</td>
</tr>
<tr>
<td>2000 SG344</td>
<td>24.7</td>
<td>20-89</td>
<td>0.978</td>
<td>0.97</td>
<td>0.067</td>
<td>2028-04 [19.1]</td>
<td>2028-05 [3.e3]</td>
<td>2028-05 [59]</td>
<td>34.7</td>
</tr>
<tr>
<td>2013 BS45</td>
<td>25.9</td>
<td>11-51</td>
<td>0.993</td>
<td>0.99</td>
<td>0.084</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>35.8</td>
</tr>
<tr>
<td>2001 QJ142</td>
<td>23.7</td>
<td>33-142</td>
<td>1.06</td>
<td>1.09</td>
<td>0.086</td>
<td>2023-11 [19.6]</td>
<td>2024-04 [74]</td>
<td>none</td>
<td>35.7</td>
</tr>
<tr>
<td>2012 UV136</td>
<td>25.5</td>
<td>14-62</td>
<td>1.01</td>
<td>1.01</td>
<td>0.138</td>
<td>2016-07 [22.3]</td>
<td>2020-05 [570]</td>
<td>2020-05 [22]</td>
<td>34.6</td>
</tr>
<tr>
<td>2001 CQ36</td>
<td>22.5</td>
<td>55-246</td>
<td>0.938</td>
<td>0.91</td>
<td>0.178</td>
<td>2021-01 [20.5]</td>
<td>2021-02 [18]</td>
<td>2031-02 [150]</td>
<td>9.5</td>
</tr>
<tr>
<td>2006 FH36</td>
<td>22.9</td>
<td>46-205</td>
<td>0.955</td>
<td>0.93</td>
<td>0.198</td>
<td>2019-03 [23.7]</td>
<td>2021-08 [17]</td>
<td>none</td>
<td>11.3</td>
</tr>
<tr>
<td>2007 UY1</td>
<td>22.9</td>
<td>46-205</td>
<td>0.951</td>
<td>0.93</td>
<td>0.175</td>
<td>2019-09 [23.4]</td>
<td>2020-10 [32]</td>
<td>2022-02 [18]</td>
<td>6.8</td>
</tr>
</tbody>
</table>

* Trajectory assumes Dec 2020 launch, 2025 return, medium thrust curve, 4820 kg SEP dry mass, 50% duty cycle on asteroid approach

Pre-decisional, for planning and discussion purposes only