National Aeronautics and Space Administration

Asteroid Redirect Mission Status

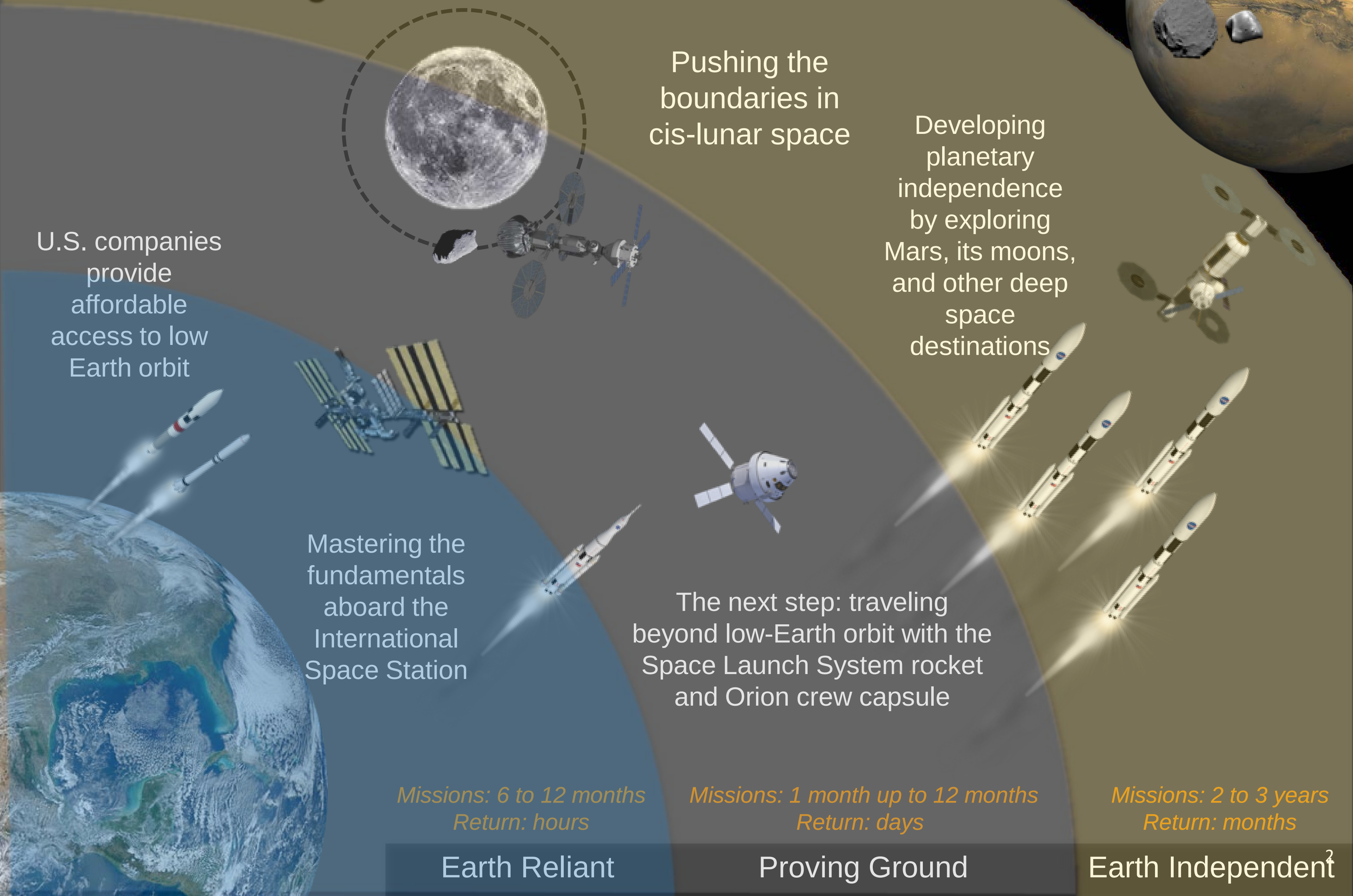
08 April 2015

Michele Gates

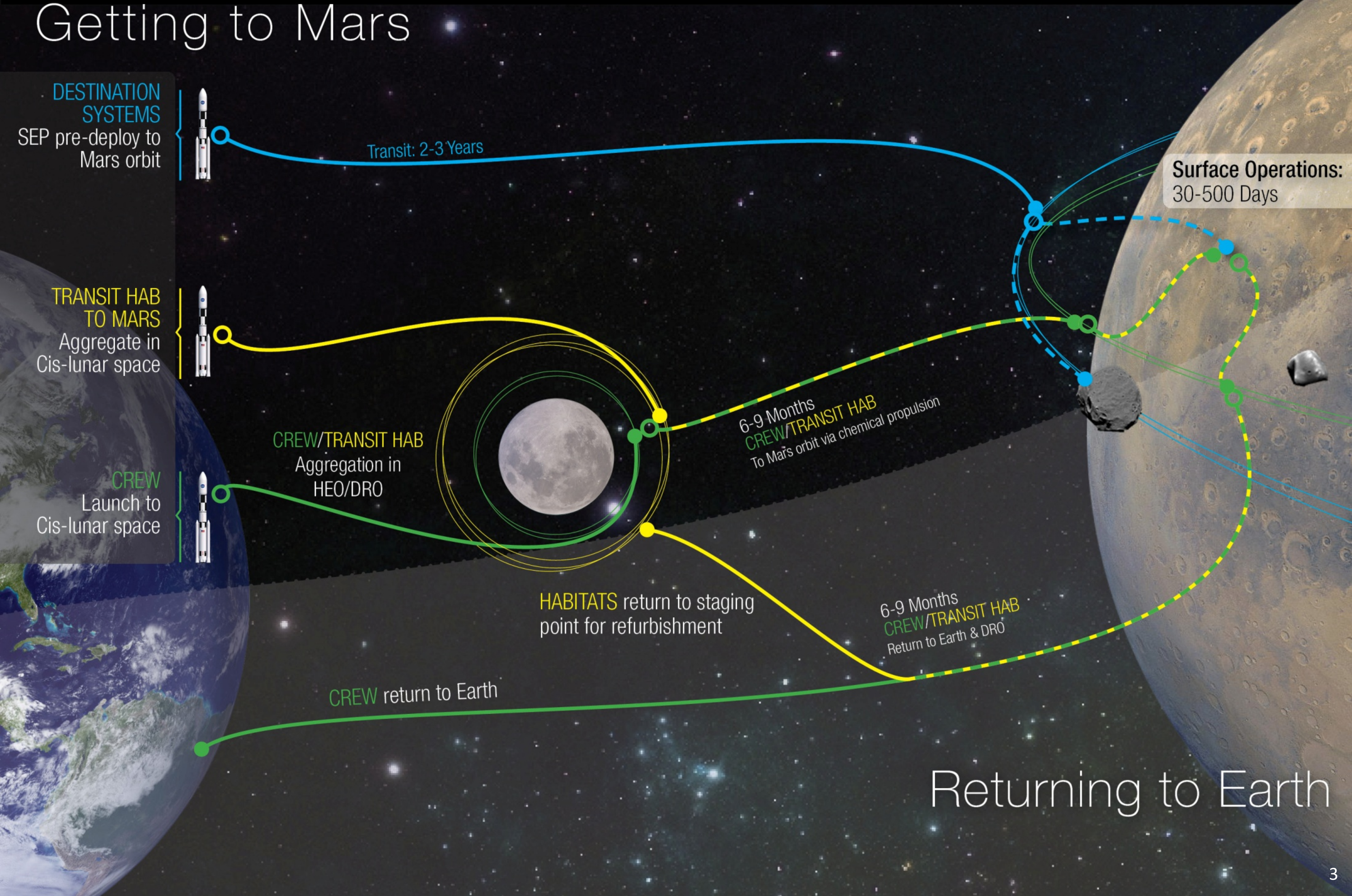
Asteroid Redirect Mission Program Director

Sustainable Human Space Exploration

NASA's Building Blocks to Mars

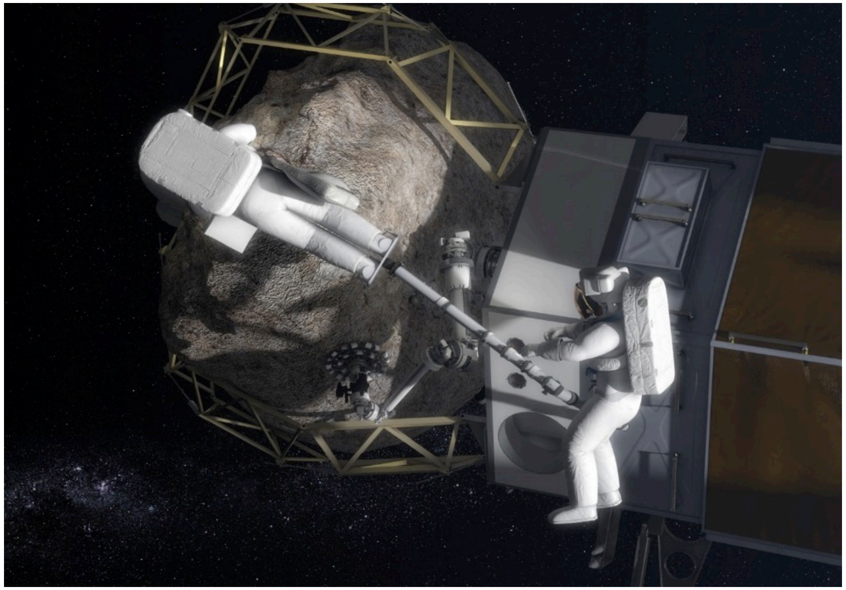


A Sustainable Exploration Approach
Mars Split Mission Concept



Key Aspects of ARM

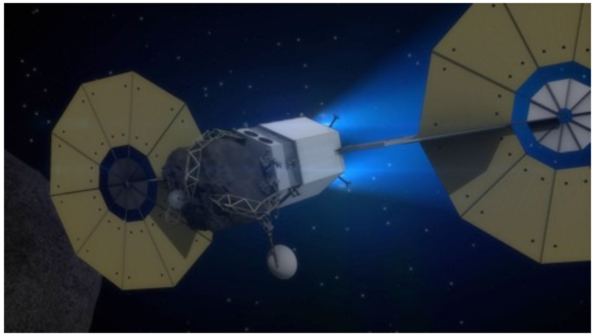
- **Moving large objects through interplanetary space using SEP**
- **Integrated crewed/robotic vehicle operations in lunar distant retrograde orbit (DRO)**
  - Integrated attitude control, e.g. solar alignment
  - Multi hour EVAs
- **Lean implementation**
  - Clean interfaces, streamlined processes
  - Common rendezvous sensor procurement for robotic vehicle and Orion
- **Integrates robotic mission and human space flight (HSF) capabilities**
  - HSF hardware deliveries to and integration and test with robotic spacecraft
  - Joint robotic spacecraft and HSF mission operations

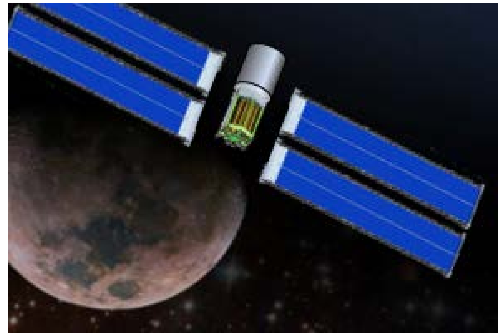


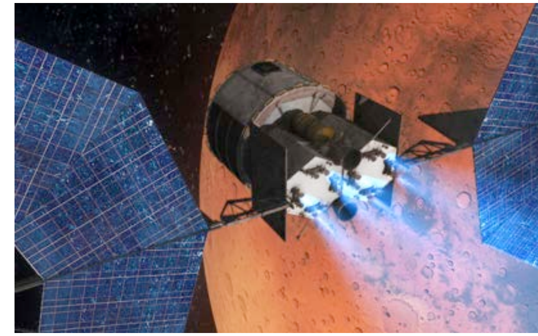
ARM Contributions to Future Deep Space Missions

- **Through ARM, NASA will utilize a number of key capabilities that will be needed for future exploration purposes, as well as providing other broader benefits**
  - Advanced high-power, long-life, high through-put solar electric propulsion
  - Autonomous rendezvous and proximity operations
  - Capture and control of non-cooperative objects
  - Rendezvous and docking systems
  - Deep space trajectory and navigation methods
  - Advanced crew extra-vehicular activity (EVA) technologies and techniques
  - Crewed sample collection and containment
- **Demonstration of basic asteroid deflection techniques that will inform future planetary defense approaches**
- **Opportunities for science and partnership interests, such as for in-situ resource utilization and follow-on use of the SEP based spacecraft**

SEP Module Extensibility for Mars







Block 1

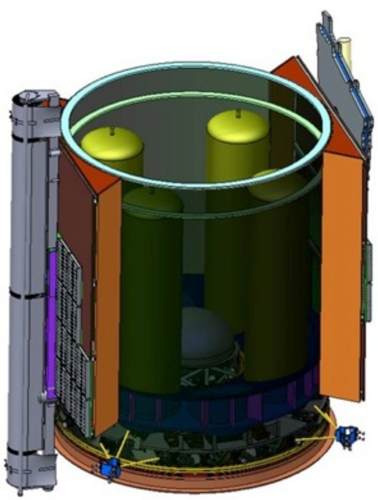
- 50-kW Solar Array
- 40-kW EP System
- 10-t Xenon Capacity

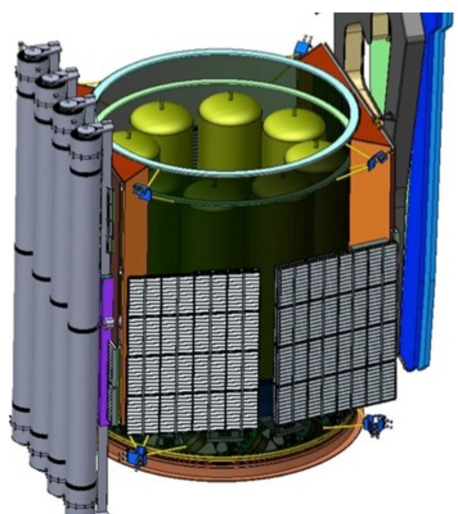
Block 1a (SEP/Chem)

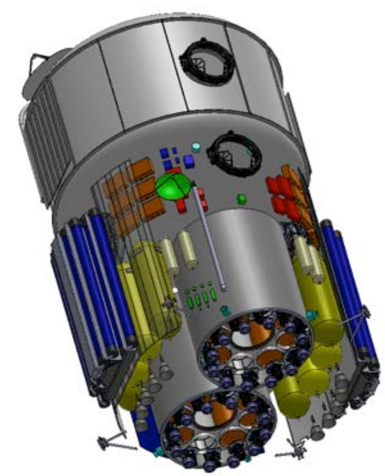
- 190-kW Solar Array
- 150-kW EP System
- 16-t Xenon Capacity

Hybrid

- 250 to 400-kW Solar Array
- 150 to 200-kW EP System
- 16-t Xenon Capacity With Xe Refueling Capability

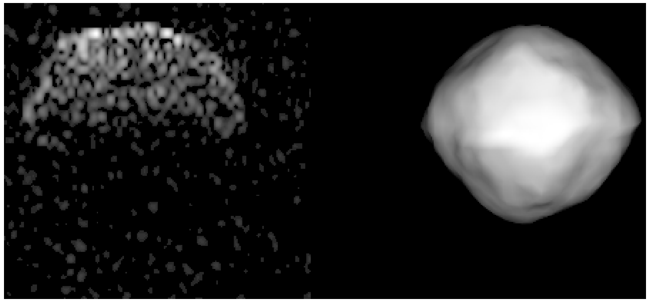


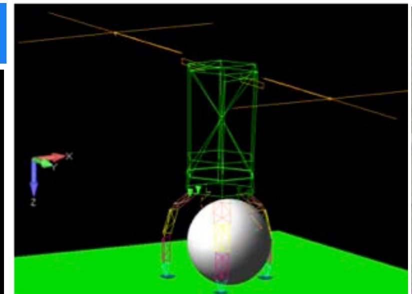


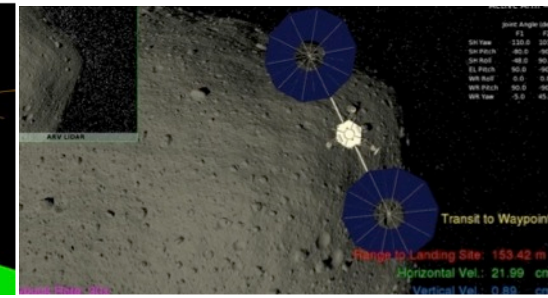


Asteroid Redirect Mission: 2014 Advancements

IDENTIFYING CANDIDATE ASTEROIDS

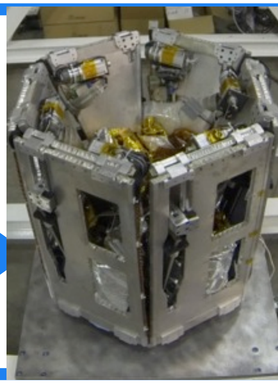


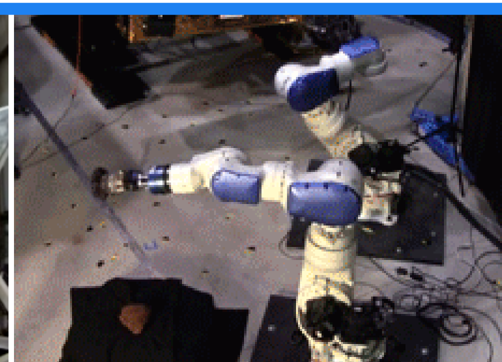




MISSION DESIGN AND SIMULATION OF CRITICAL MISSION OPERATIONS

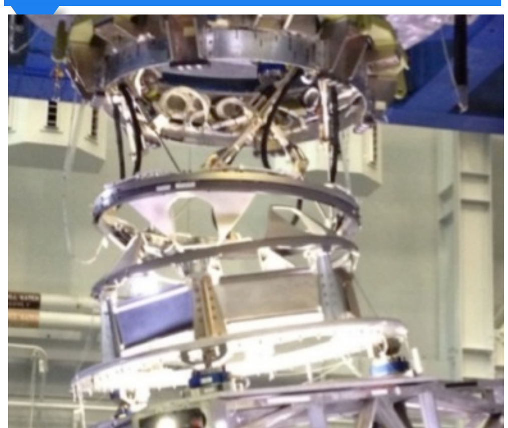
PROTOTYPING AND TESTING CAPTURE OPTIONS

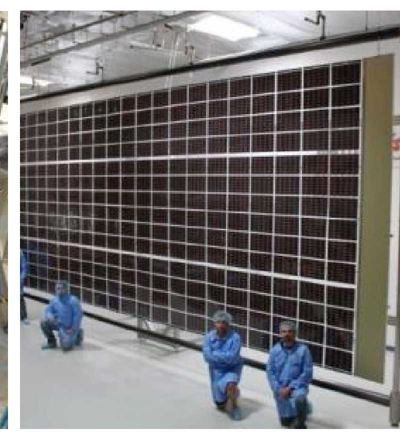




PROTOTYPING AND TESTING MODIFIED LAUNCH AND ENTRY SUIT

INTERNATIONAL DOCKING SYSTEM

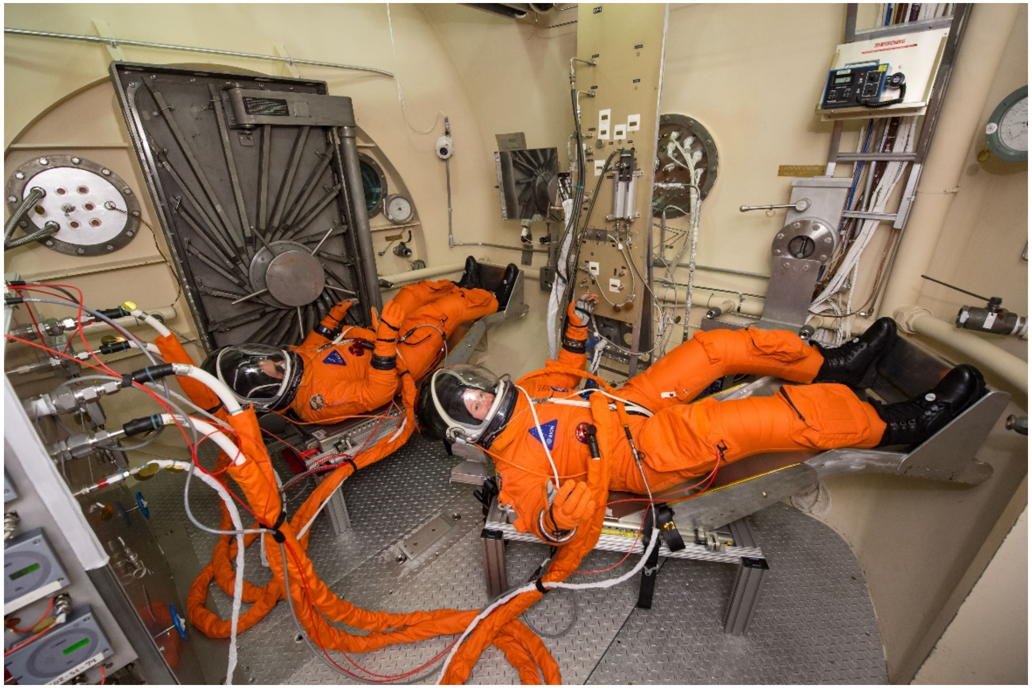




SOLAR ELECTRIC PROPULSION

Orion MACES Testing

- Orion completed four MACES suited evaluation in the March Vacuum Pressure Integrated Suit Test (VPIST).
- Modified ACES is an evolutionary step from shuttle crew survival suit for closed-loop crew protection for launch, entry, aborts.
- Testing evaluated integrated performance of Orion’s vehicle ECLSS hardware in a vacuum chamber.
    - 100% oxygen
    - MACES
    - Orion Suit Loop with Amine Swingbed CO2 Scrubbing
- Testing verified ability of MACES and Orion ECLSS systems to operate as designed.



VPIST Testing is first time since Apollo that developmental pressure suits have been combined with a vehicle-level closed loop ECLSS system to provide life support while test subjects are at full vacuum.

Robotic Mission Concepts and Trades
Summary of Study Contract Results (1)

- **Asteroid Capture Systems (Option A related):**
  - Contractors: Airborne, Jacobs
  - Developed alternate design concepts to capture a small asteroid including all-inflatable and all-mechanical architectures
  - Fabricated and performed demonstrations of approaches
- **Asteroid Capture Systems (Option B related):**
  - Contractors: Altius, SSL MDA
  - Developed alternate robotic system architectures to extract a boulder of the surface of an asteroid
  - Examined augmentation techniques to aid in boulder extraction involving anchoring, excavating, extracting, and dust collection
  - Conducted testing of various design concepts and prototypes
- **Rendezvous and Proximity Operations Sensors**
  - Contractors: Ball Aerospace, Boeing
  - Significant design progress and risk reduction work performed, demonstrating compliance to the common specification supporting Orion, ARM, and satellite servicing
  - Addressed modularity in designs, providing alternate design implementation approaches

Robotic Mission Concepts and Trades
Summary of Study Contract Results (2)

- **Adapting Commercial Spacecraft for the Asteroid Redirect Vehicle**
  - Contractors: Boeing, Exoterra, Lockheed Martin, SSL
  - Provided design concepts, cost and schedule data, and procurement approaches to adapt existing commercial spacecraft to support ARM
  - Demonstrated extensibility options for Mars cargo application
- **Future Partnership Opportunities for Secondary Payloads**
  - Contractors: Planetary Resources, Deep Space Industries, Honeybee Robotics, Applied Physics Lab, Planetary Society
  - Provided concepts for secondary spacecraft support to enhance asteroid missions in a public-private partnership approach
  - Provided concepts for secondary payloads which could be manifested on the ARM robotic mission to enhance the missions
- **Future Partnership Opportunities for the Asteroid Redirect Crewed Mission:**
  - Contractors: Planetary Resources, Deep Space Industries, Honeybee Robotics
  - Provided commercial perspectives and addressed economic fundamentals of partnership potential for asteroid resource utilization
  - Developed concepts for drilling tools and sample caching systems that could be used by astronauts during a spacewalk on the asteroid.

Asteroid Redirect Robotic Mission (ARRM)
Mission Concept Review (MCR)

- **Objective: Review and Decisions**
  - **MCR**: Evaluate the feasibility of the proposed mission concept(s) and its fulfillment of the program's needs and objectives. Determine whether the maturity of the concept and associated planning are sufficient to begin Phase A.
  - **For approval to enter Phase A/KDP-A**: Project addresses critical NASA need; Proposed mission concept(s) is feasible; and associated planning is sufficiently mature to begin Phase A, and the mission can likely be achieved as conceived.
- **Meeting product:** Decision memo including high level formulation authorization
- **Meeting forum:** March 24, 2014 via VITS
- **MCR Board:**
  - Chair: NASA Associate Administrator Robert Lightfoot
  - Members: Mission Directorate Associate Administrators
  - Office of the Chief Engineer
  - Office of Safety & Mission Assurance

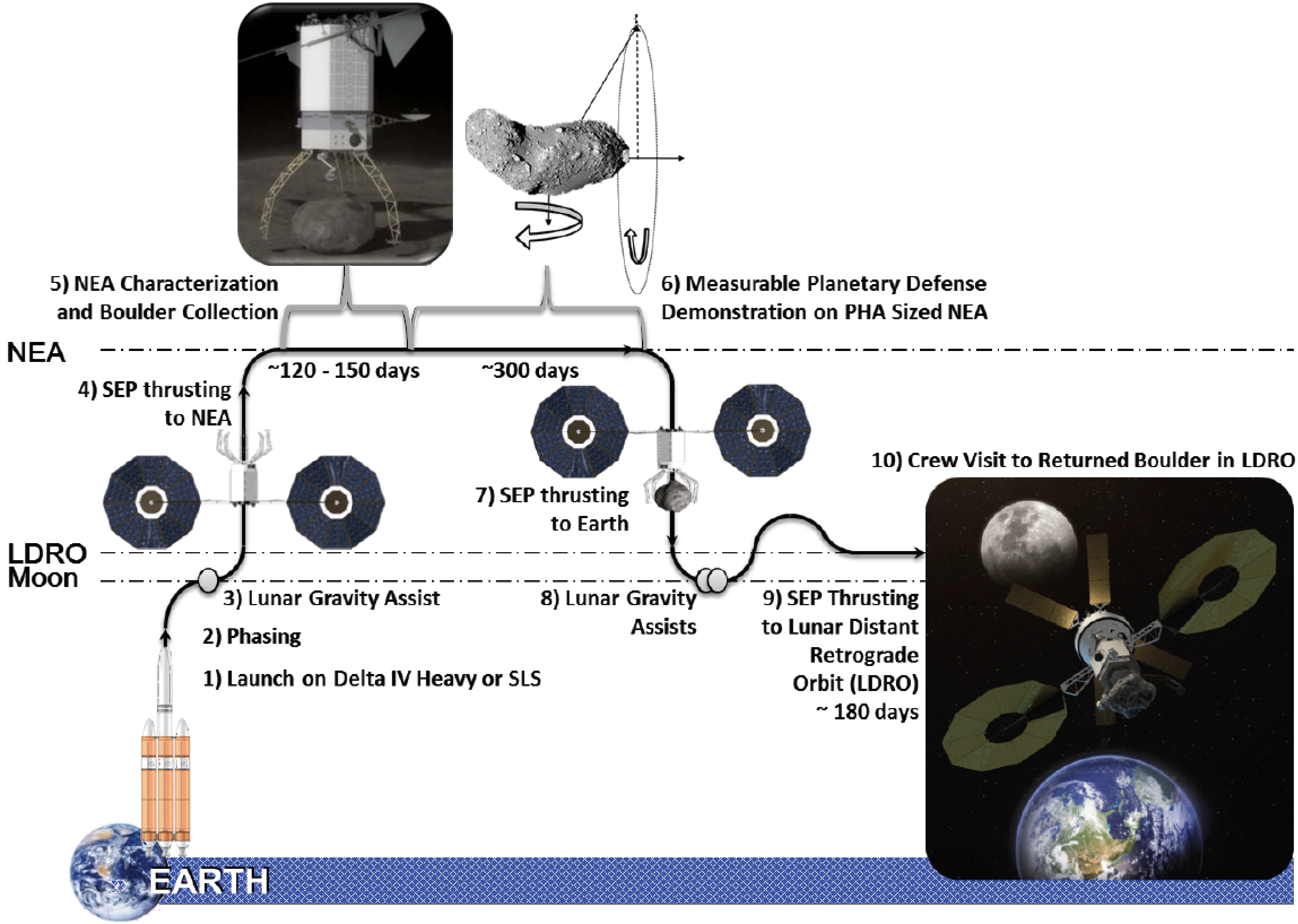
MCR Success Criteria

1. Mission objectives and draft level 1 requirements are clearly defined and stated.
2. The mission has evaluated alternative concepts and is shown to be able to meet the draft level 1 requirements and currently defined programmatic constraints.
3. The justification for the mission has been clearly identified including extensibility path to NASA's exploration plans.
4. The cost and schedule estimates are credible and sufficient resources are available for project formulation.
5. Technical and programmatic planning is sufficient to proceed to a project start including an approach for lean implementation
6. Risk and risk mitigation strategies have been identified and are reasonable based on technical risk assessments.
7. System design and functional requirements are sufficiently mature to initiate early procurements (e.g., solar, thrusters, PPU, tanks).

ASTEROID REDIRECT MISSION HIGHLIGHTS

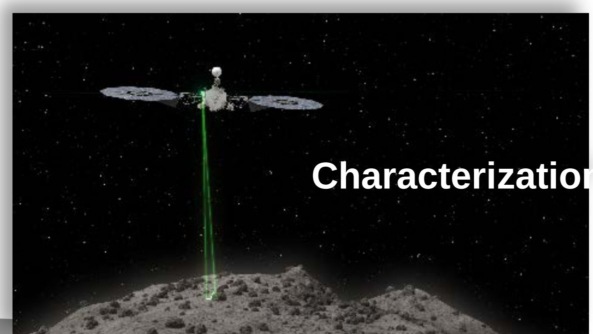
(1) The Asteroid Redirect Vehicle (ARV), powered by advanced Solar Electric Propulsion, is deployed to rendevous with a large asteroid. (2) The ARV prepares to descend to the asteroid surface. (3) The ARV captures a boulder from the asteroid's surface. (4) The ARV demonstrates planetary defense on a hazardous-size asteroid before it (5) begins its transit toward a stable orbit around the moon. (6) The powerful Space Launch System rocket leaves Earth (7) with two crew members (8) aboard the Orion spacecraft. (9) The astronauts conduct spacewalks to investigate the asteroid boulder before returning to Earth with samples.

ARRM Mission Overview



ARRM Capture Phase Overview

Approach	Characterization	Boulder Collection	Planetary Defense Demo
14 days	72 days	69 days	150 days (30 deflection + 120 hold & verify)



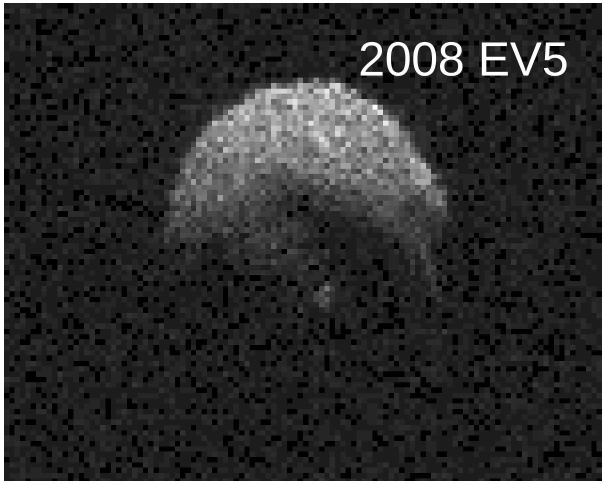
Note: Asteroid operations timeline varies depending on target asteroid. Times shown are for 2008 EV_5: total stay time of 305 days with 95 days of margin.

Valid ARRM Candidate Asteroid Targets

Candidate Targets	Type	Mass, Diameter	Spin Period	V_∞ (km/s)	*Perihelion (AU)*	Absolute Magnitude *H*
2008 EV5	C	$7.0x10^7$t, 400m	3.73 hrs	4.41	1.04	20.0
Bennu	C	$7.8x10^7$t, 490m	4.30 hrs	6.36	1.36	20.8
1999 JU3	C	$6.9x10^8$t, 870m	7.63 hrs	5.08	1.42	19.2
Itokawa	S	$3.5x10^7$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



Reference ARRM Target

Objectives of Asteroid Redirect Mission

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.

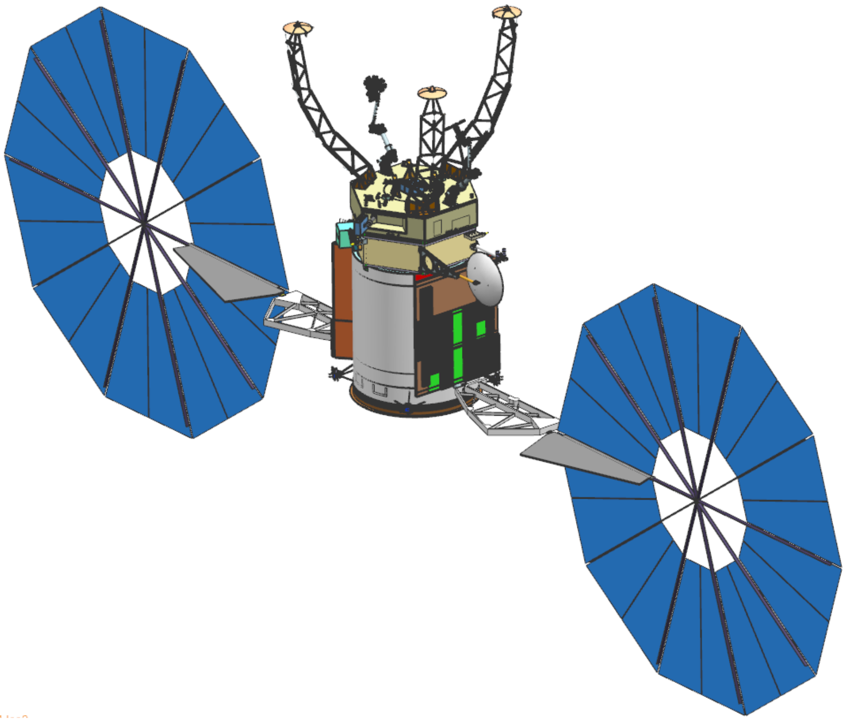
ARRM Formulation Guidance

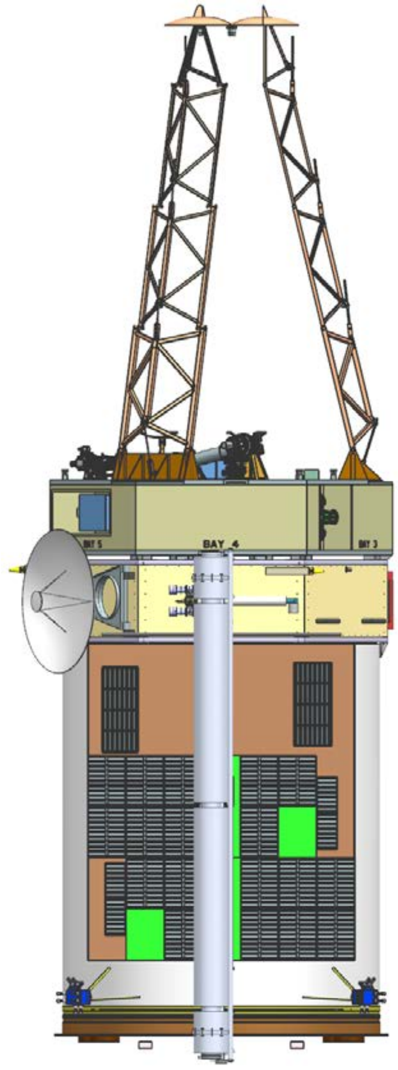
- **Capture option B**
- **Launch date Dec 2020**
- **Cost cap $1.25B not including launch vehicle and mission operations**
- **Internal and external dependencies**
- **Defining implementation approach**

ARRM DRAFT Level 1 Requirements

	Draft Level 1 Requirement	ARM Objective
1	ARRM shall develop and demonstrate a high-power, high-total impulse SEP system with input power level of at least 40kW and propellant load capability up to 10 t that is directly extensible to future human and robotic missions to Mars at a power level of at least 150 kW and 16 t of xenon.	2
2	The ARRM mission shall pick up a boulder (2-4m mean diameter, TBR) from a large asteroid, and redirect it to a stable, orbit in cis-lunar space, dependent on target, launch vehicle and return date	1,3,5
3	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
4	ARRM shall perform a demonstration of a “slow push” planetary defense asteroid deflection technique.	4
5	ARRM shall provide volume, mass, power, data for contributed hardware (TBR).	5
6	ARRM shall be interface compatible with EELV-class launch vehicles and SLS until launch vehicle selection, expected by Project System Design Review.	---
7	ARRM shall implement the project as a capability demonstration mission including defining and applying lean implementation techniques to achieve an launch readiness by the end of 2020 with a cost capped budget of <$1.25B (TBR) (not including LV or Operations).	---
8	ARRM shall provide resources including power and communications for future potential visiting vehicles, release of the asteroid and provide the provisions for future refueling (Xe and N_2H_4).	---

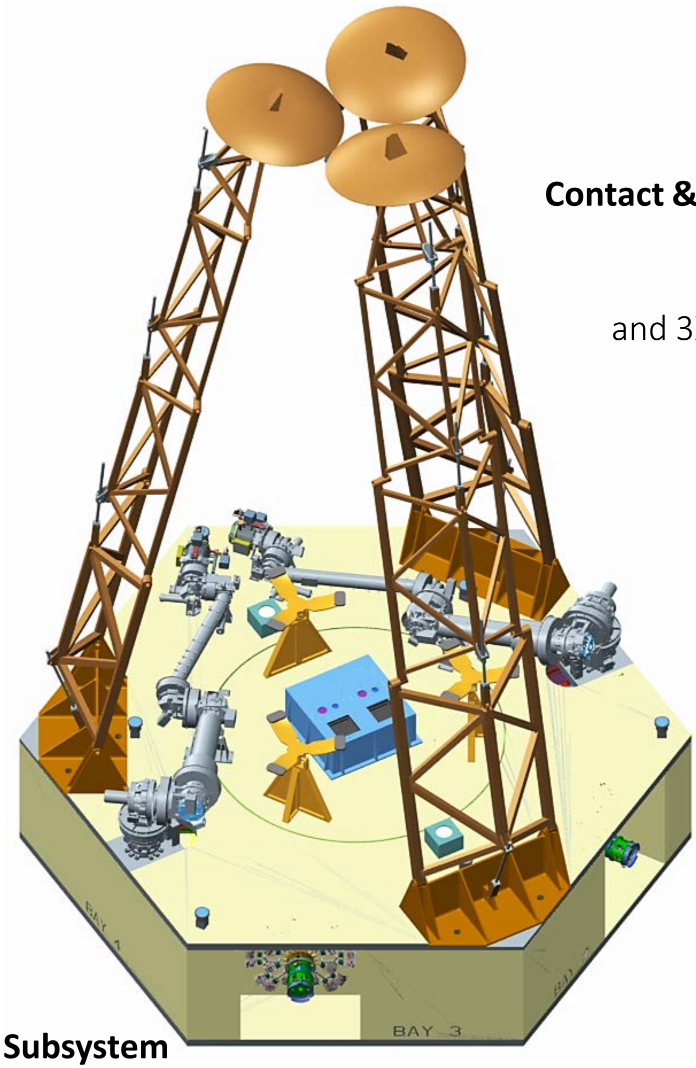
ARRM Baseline Concept Flight System Overview

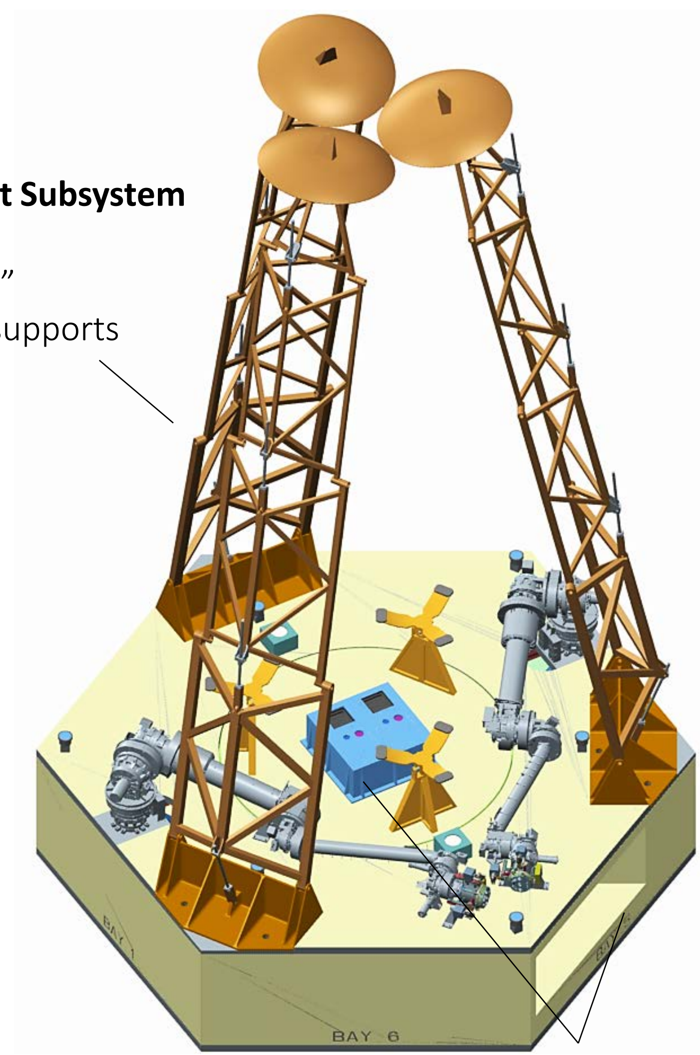




ARRM launch configuration

ARRM Baseline Concept Capture Module





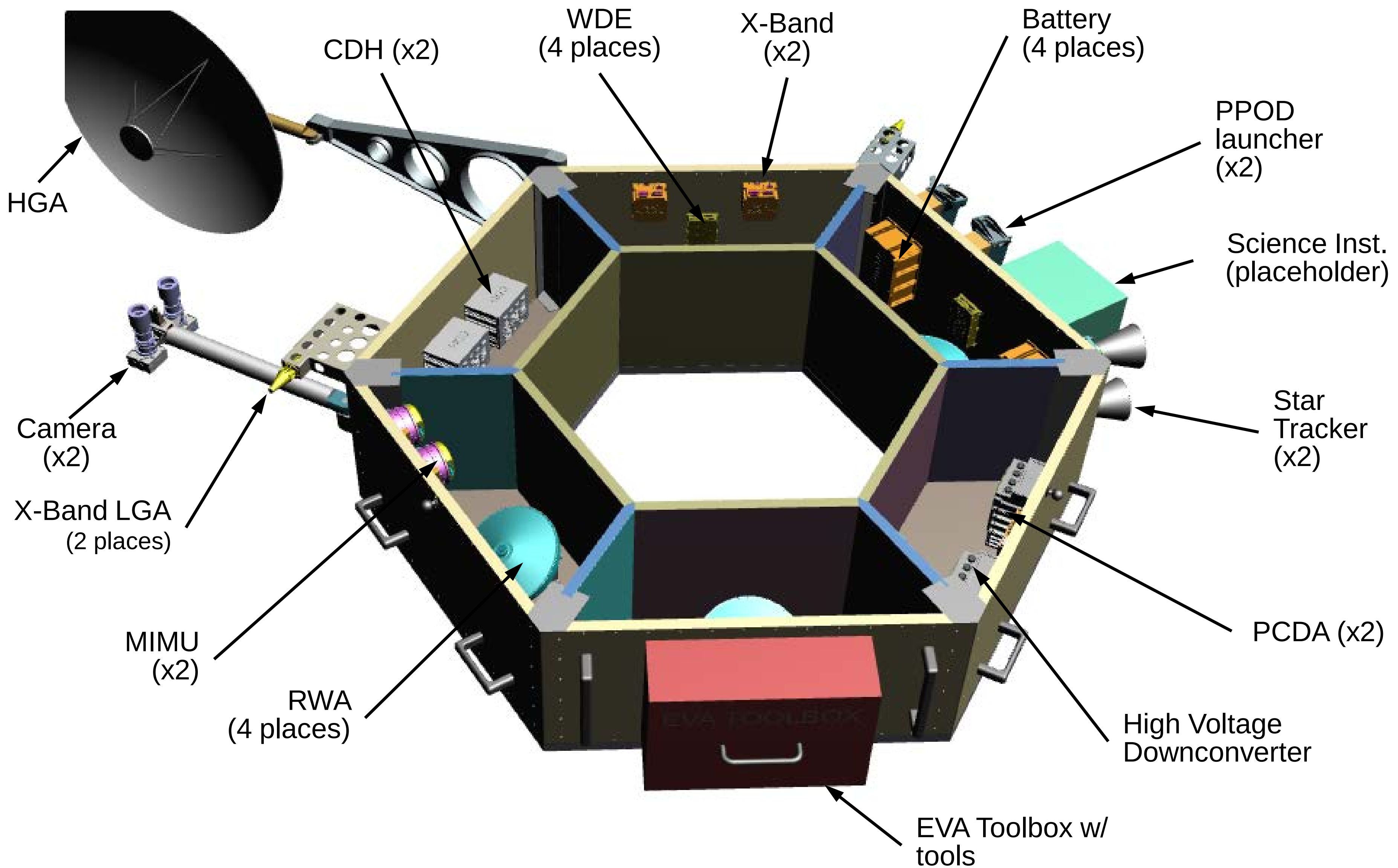
Contact & Restraint Subsystem (CRS)
3X "legs"
and 3X cradle supports

Robot Subsystem
Capture arms (2X)
and tool stowage (2X)

- 3 SpaceCube computers, VDSU w/ 128 Gigabytes storage

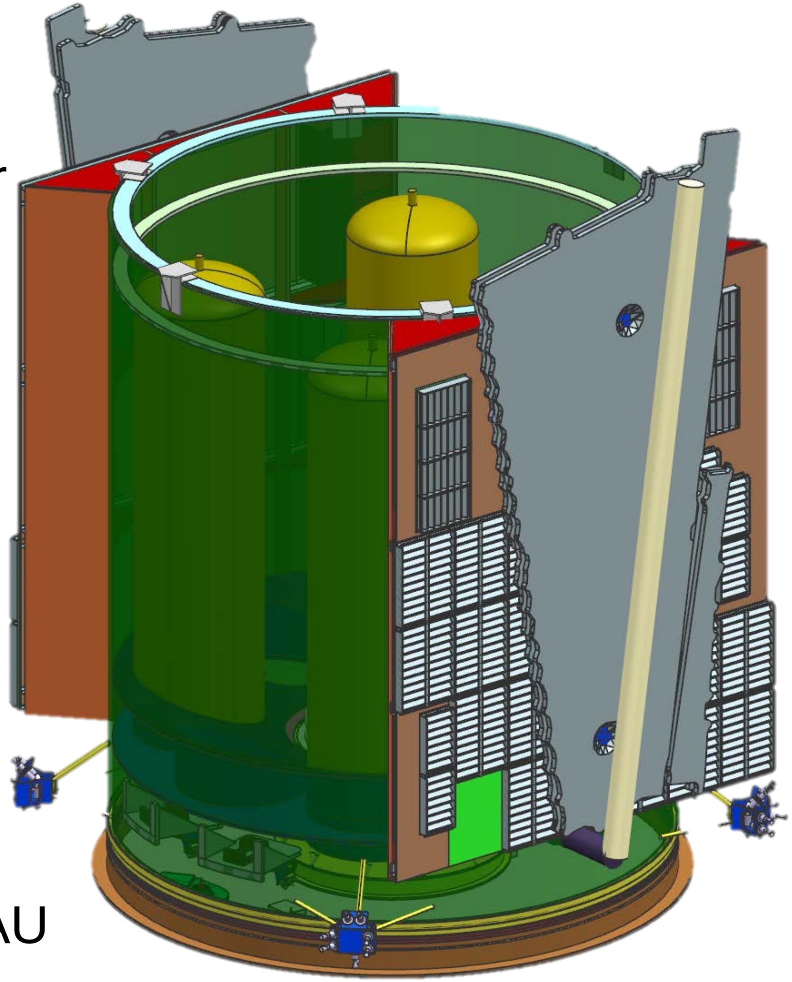
Relative Navigation Subsystem (RNS)
Deck sensor assembly and
gimbal sensor suite (shown stowed)

ARRM Baseline Concept Mission Module

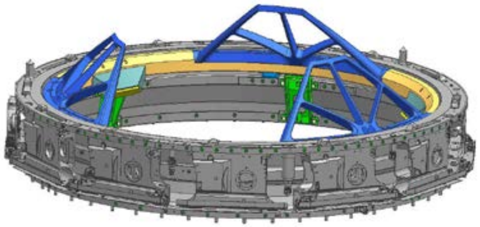


ARRM Baseline Concept Solar Electric Propulsion Module

- 50kW of SA power BOL
- 40kW of EP power at 1 AU EOL
- EP with Isp of at least 3000 s and 6 year life
- Up to 24kW power transfer capability
- Operates from 0.8 to 1.9 AU
- Fits within 5 meter fairing
- Accommodates docking interface
- Compatible with crewed operations
- Extensible to 16 Mt of xenon
- Extensible to 190 kW of SA power
- Extensible to 150 kW of EP power at 1 AU



ARRM Crewed Mission Accommodations (Docking)

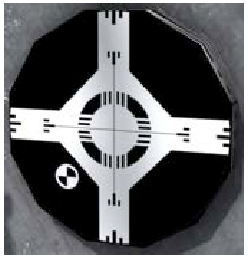


IDSS IDD-Compliant Docking Mechanism

Passive docking mechanism on ARRM
(active mechanism on crewed vehicle)

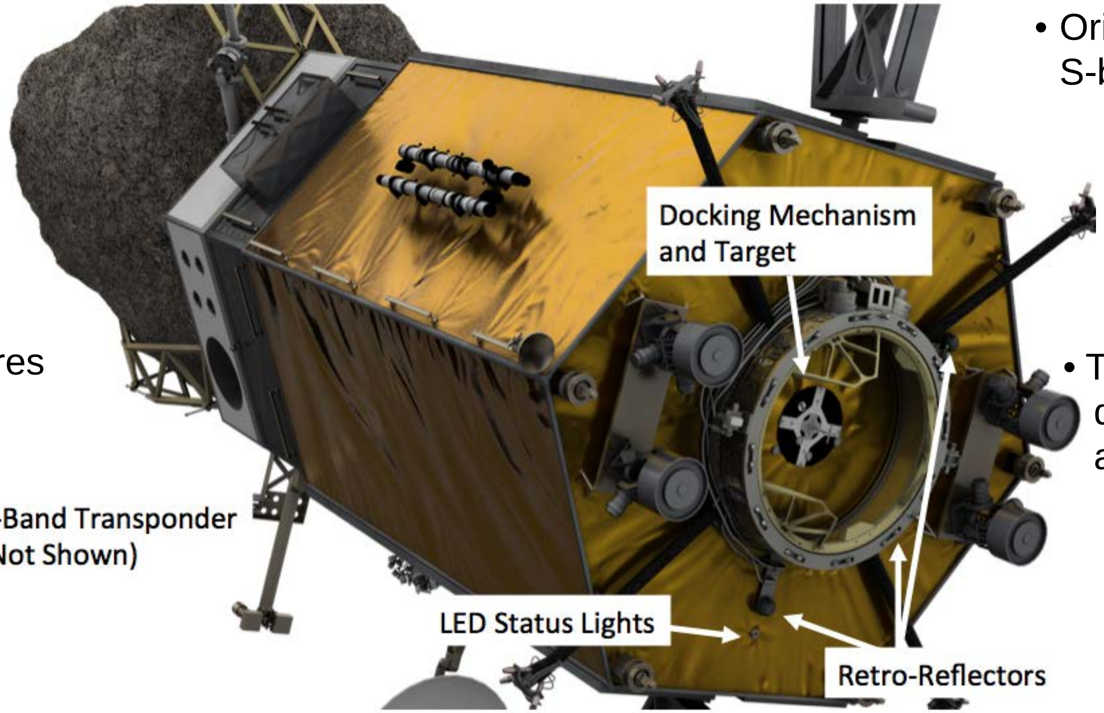
Rendezvous Aid

- Orion-compatible low-rate S-band transponder



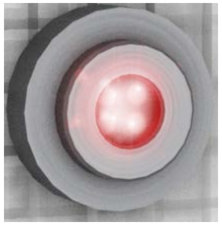
Docking Target

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



Retro-Reflectors

- Tracked by the LIDAR during rendezvous and docking



LED Status Lights

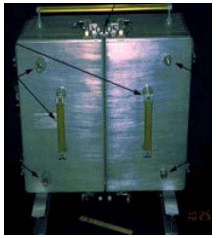
- Indicate the state of the ARRM systems, inhibits and control mode

Power and Data Transfer

- Power and data connectors integrated into the docking mechanism.
- Data transfer used during ARCM
- ARRM power transfer is available for future missions.

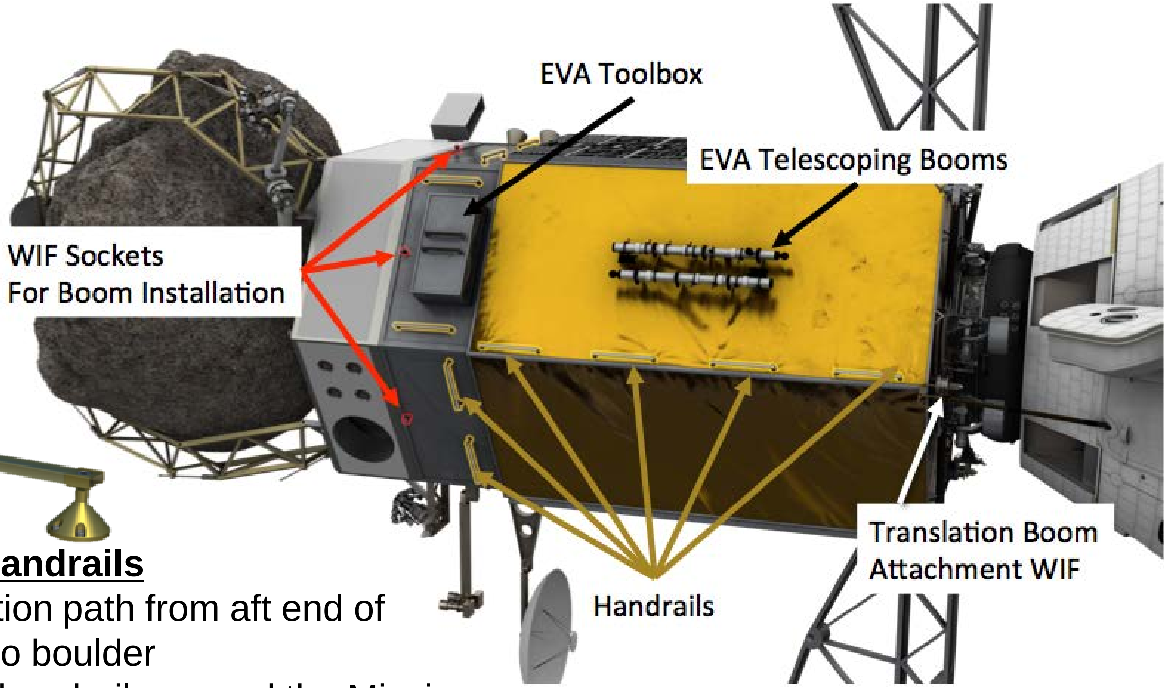
ARRM Crewed Mission Accommodations (EVA)

EVA Telescoping Booms
- Telescoping Booms for positioning the EVA astronaut on the boulder

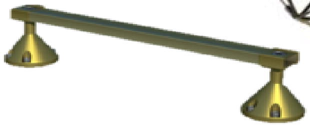


EVA Tool Box with tools
- Tool box to offset Orion mass (85kg tools)

WIF Sockets
- Provide boom attach points to ARRM.

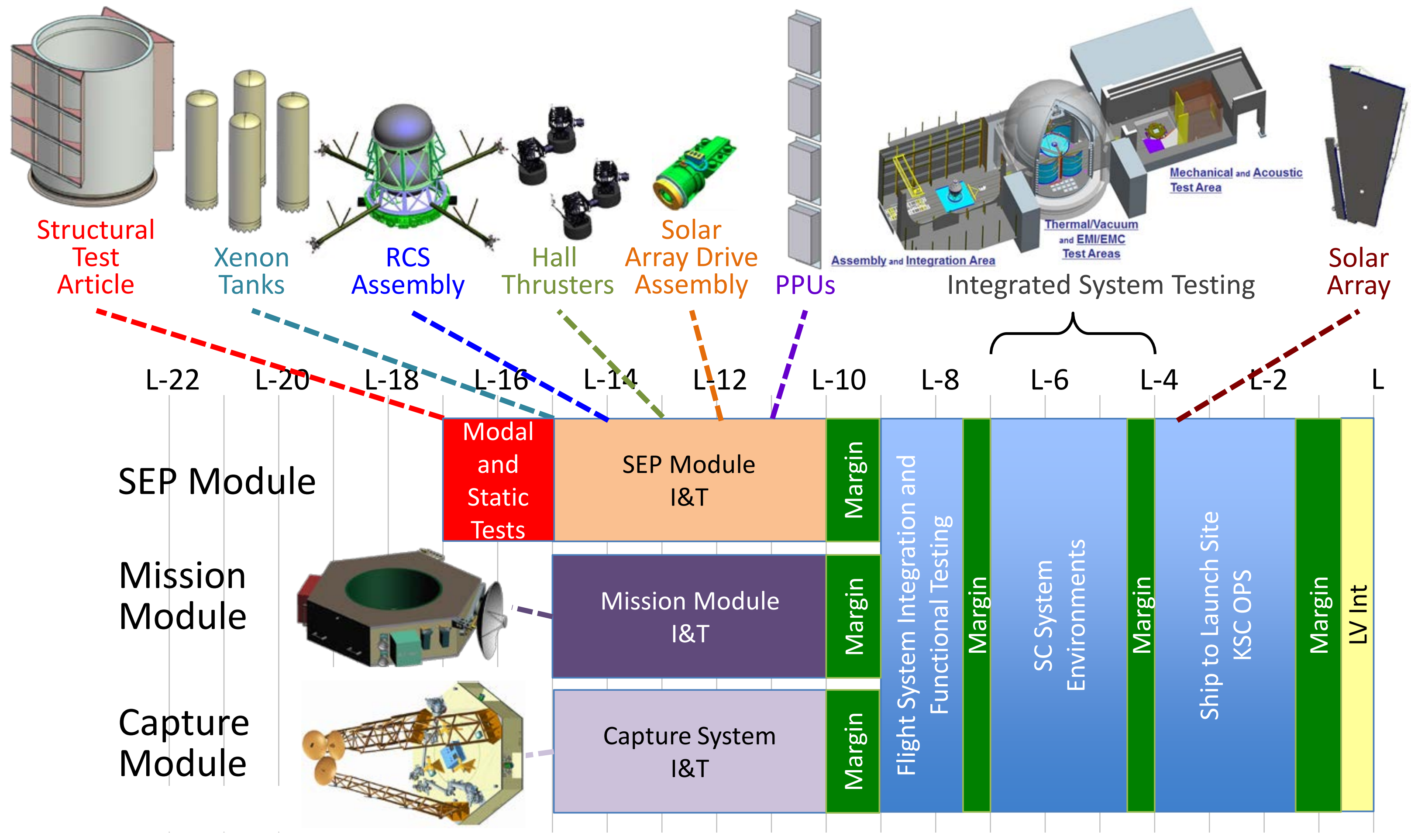


Crew Safe Certification
- Spacecraft designed for Crew Safety including EVA kick loads, sharp edge, safety inhibits and Caution and Warning annunciation.
- ARRM Flight System is NOT Man Rated



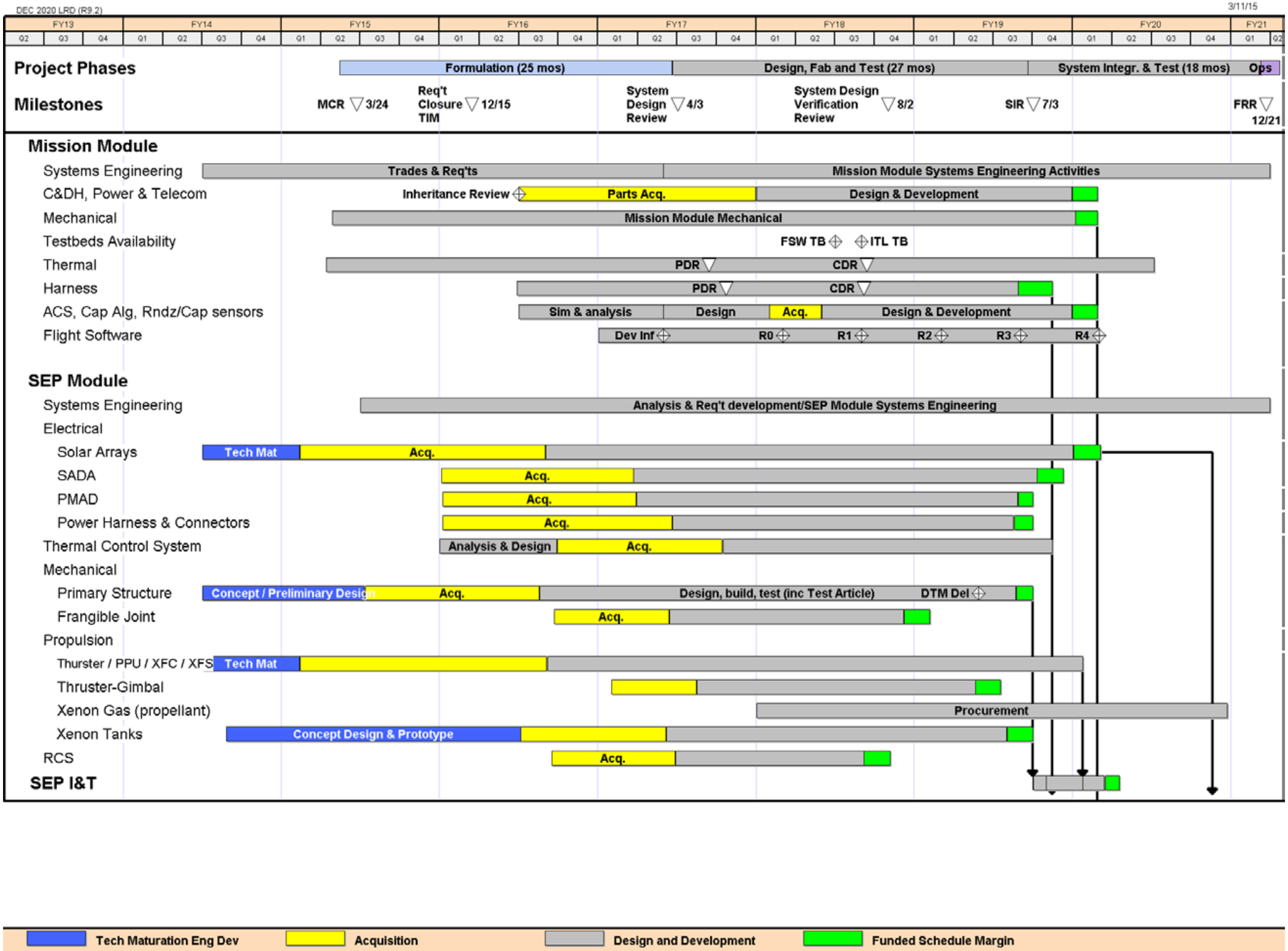
24” EVA Handrails
- Translation path from aft end of ARRM to boulder
- Ring of handrails around the Mission Module near the boulder

ARRM Integrated Test Flow

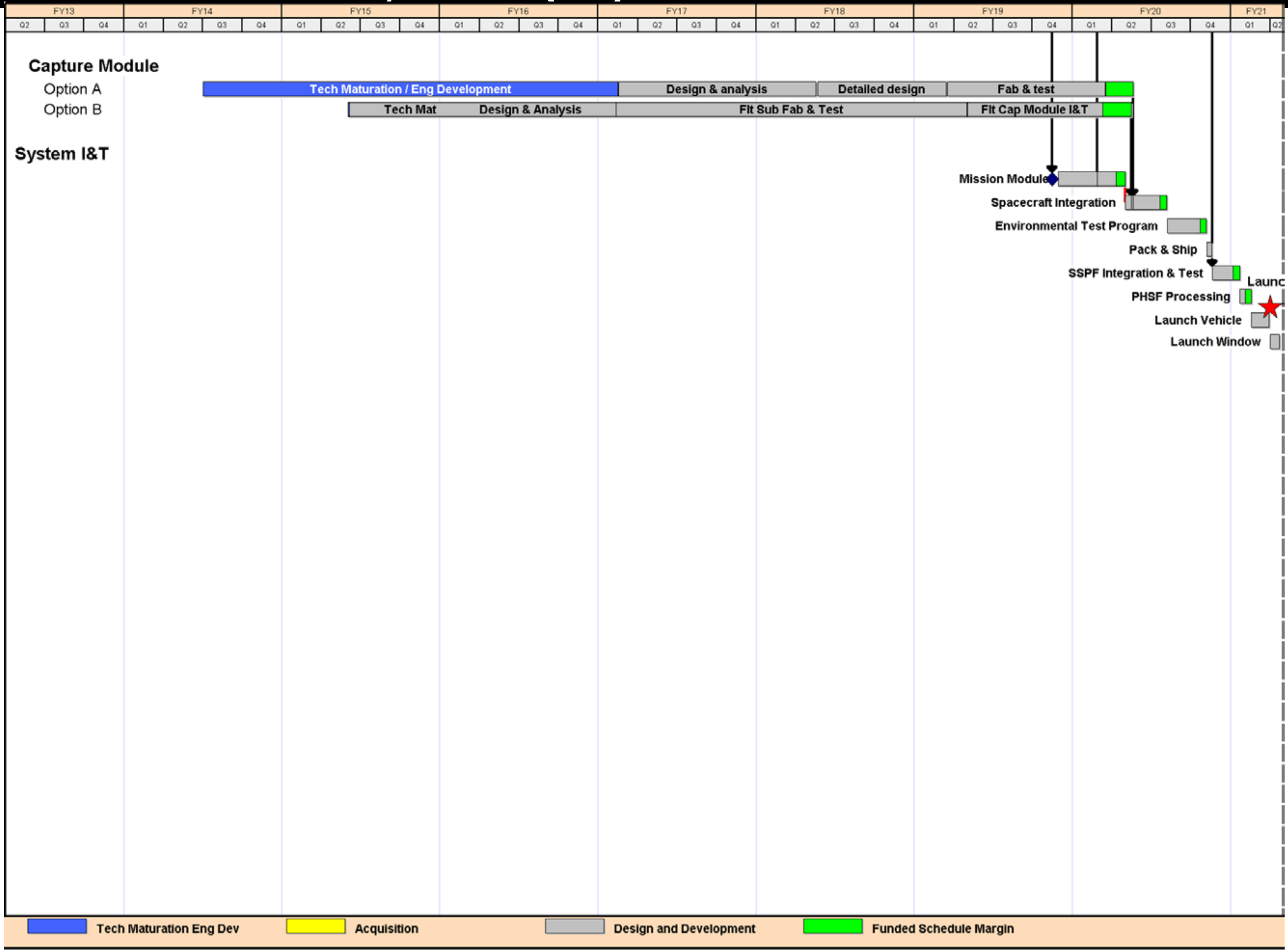


- **Qualification testing at the component level**
- **Functional testing at the module level**
- **Functional and workmanship testing at system level**

ARRM Concept Development Summary Schedule LRD December 31, 2020 (1/2)



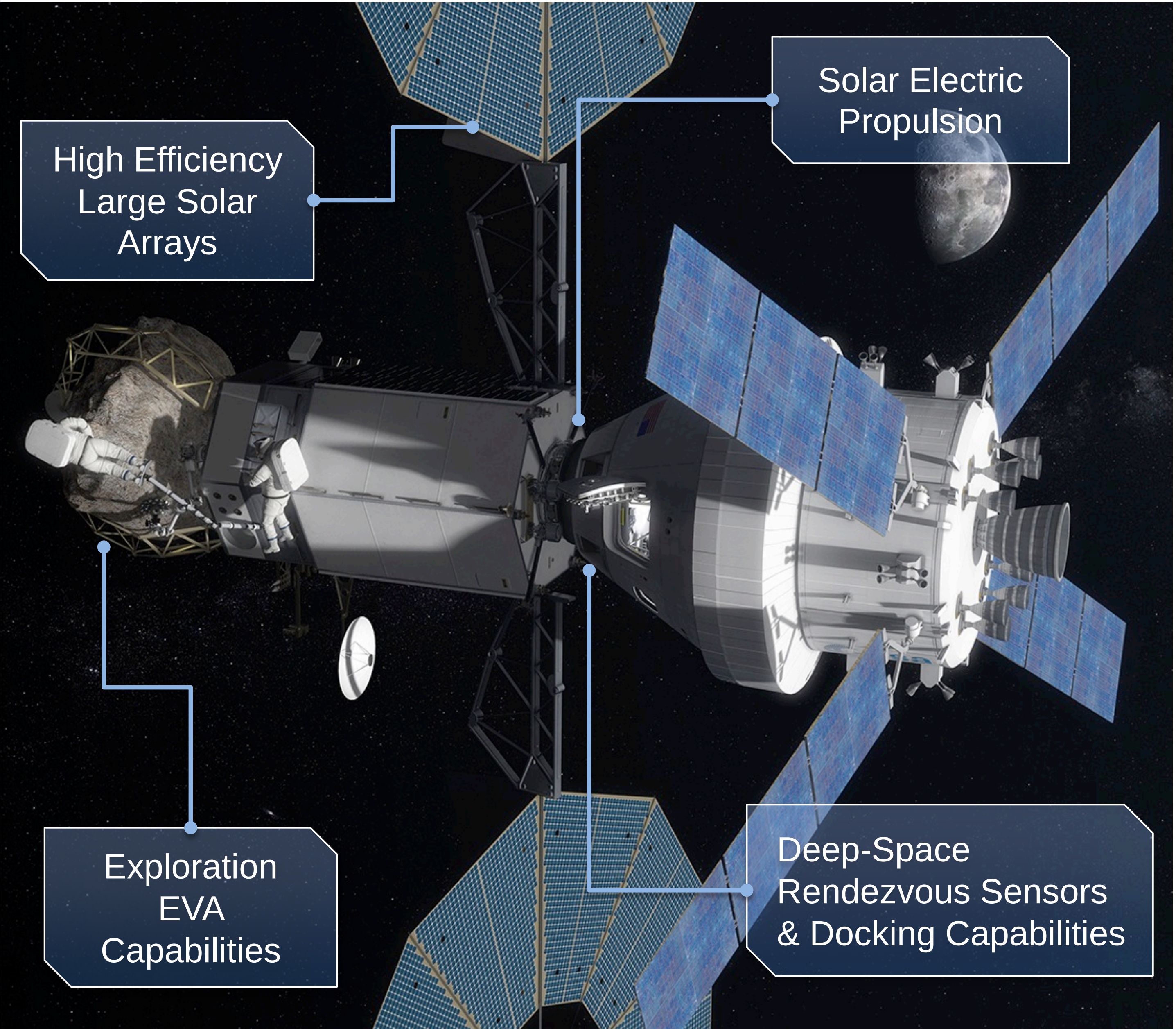
ARRM Concept Development Summary Schedule LRD December 31, 2020 (2/2)



Next Steps

- Continue asteroid observations and enhancements.
- Continue high power, long life solar electric propulsion system technology development toward demonstration.
- Entering Phase A to design integrated technology demonstration through ARRM.
- Continue toward industry and international partnerships
- ARRM Acquisition Strategy Meeting July 2015
- ARRM Integrated Requirements review December 2015
- ARRM KDP-B January 2016
- Continue human spaceflight system development and technology maturation as part of a sustainable exploration strategy.
- Continue concept development toward Asteroid Redirect Crewed Mission. Prepare for hardware deliveries to ARRM.

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

NASA

Back Up

APMC Asteroid Redirect Robotic Mission (ARRM) MCR Agenda

8:30	Roll Call and Building Safety Information	PMC Exec/L. Rochester
8:35	Opening Remarks	NASA AA/R. Lightfoot
	ARRM MCR/Formulation Authorization – *Decisional*	
8:40	Introduction, Objectives, Formulation Agreement	Michele Gates (AA)
8:55	Target Identification Status	Lindley Johnson (SMD)
9:00	ARRM Overview and Options Assessment	Brian Muirhead/John Brophy (JPL)
10:00	Flight System	Hoppy Price (JPL)
10:45	Solar Electric Propulsion Module	Mike Barrett (GRC)
11:15	Option A Capture Module	Brian Wilcox (JPL)
11:45	Option B Capture Module	Bo Naasz (GSFC)
12:15	Lunch	
12:30	Development and Mission Risk Assessment	John Brophy (JPL)
1:00	Investigation Team	Dan Mazanek (LaRC)
1:15	Management Approach, Schedule and Cost	Brian Muirhead (JPL)
2:15	ARM Crewed Mission Feasibility and Robotic Mission Interfaces	Mark McDonald (JSC)
3:15	Independent NASA Review Team Assessment	Jim Reuter (MSFC)
4:15	Discussions	
4:50	Action Item Review	PMC Exec
4:55	Closing Remarks	NASA AA
5:00	Adjourn	

PROVING GROUND OBJECTIVES

Enabling Human Missions to Mars

VALIDATE through analysis and flights

✓Advanced Solar Electric Propulsion (SEP) systems to move large masses in interplanetary space

✓Lunar Distant Retrograde Orbit as a staging point for large cargo masses en route to Mars

✓SLS and Orion operations in deep space

• Long duration, deep space habitation systems

✓Crew health and performance in a deep space environment

• In-Situ Resource Utilization in micro-g

• Operations with reduced logistics capability

• Structures and mechanisms

CONDUCT

✓EVAs in deep space with sample handling in micro-g

✓Integrated human and robotic mission operations

Asteroid Redirect Mission

✓ SEP system moves up to 80 mt asteroid material to stable LDRO

✓ Astronauts visit asteroid aboard SLS/Orion, monitor crew health, conduct EVAs and other integrated human-robotic operations

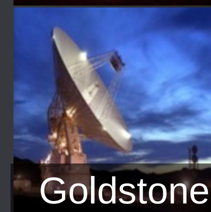
Asteroid Redirect Mission: Three Main Segments

IDENTIFY

Ground and space based assets detect and characterize potential target asteroids


Pan-STARRS


NEOWISE

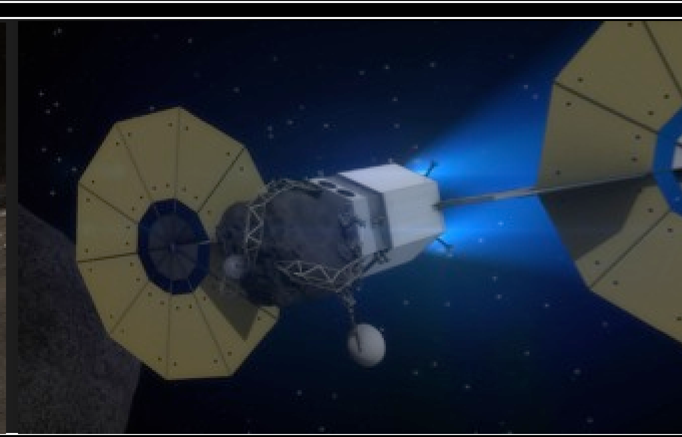

Goldstone


Arecibo


Infrared Telescope Facility

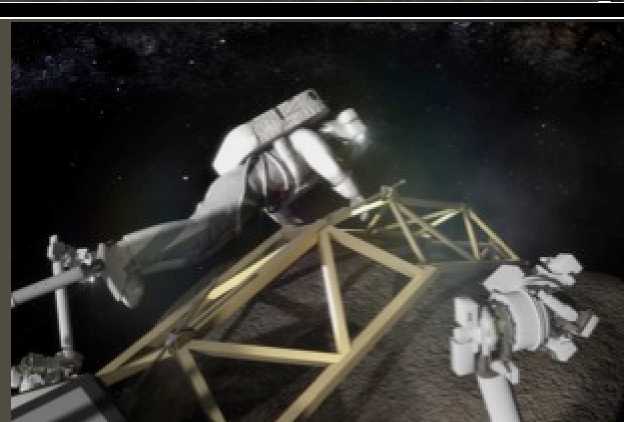
REDIRECT

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



ARM Alignment Strategy