National Aeronautics and Space Administration

Asteroid Redirect Mission Update

Briefing to Small Bodies Assessment Group

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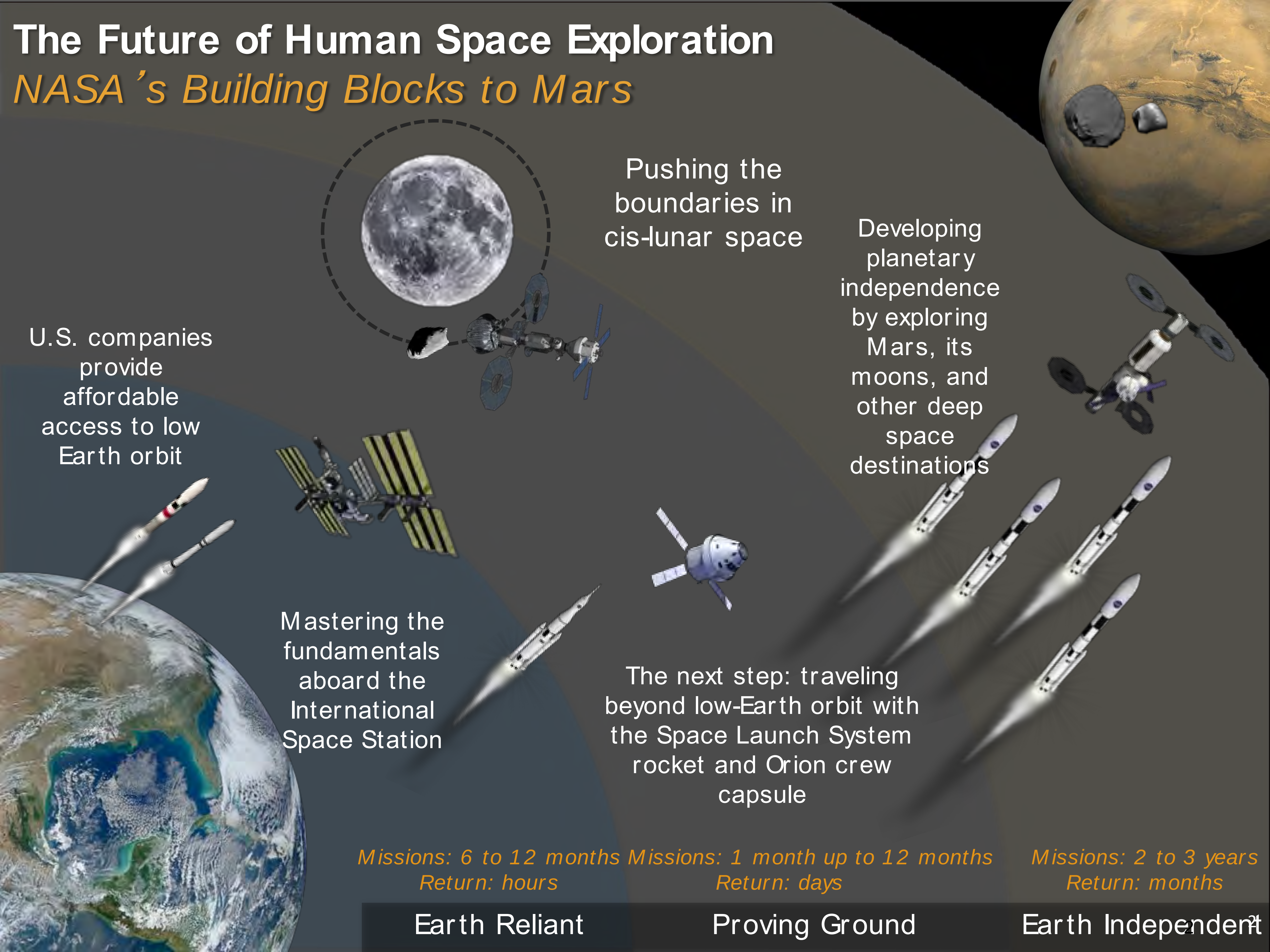
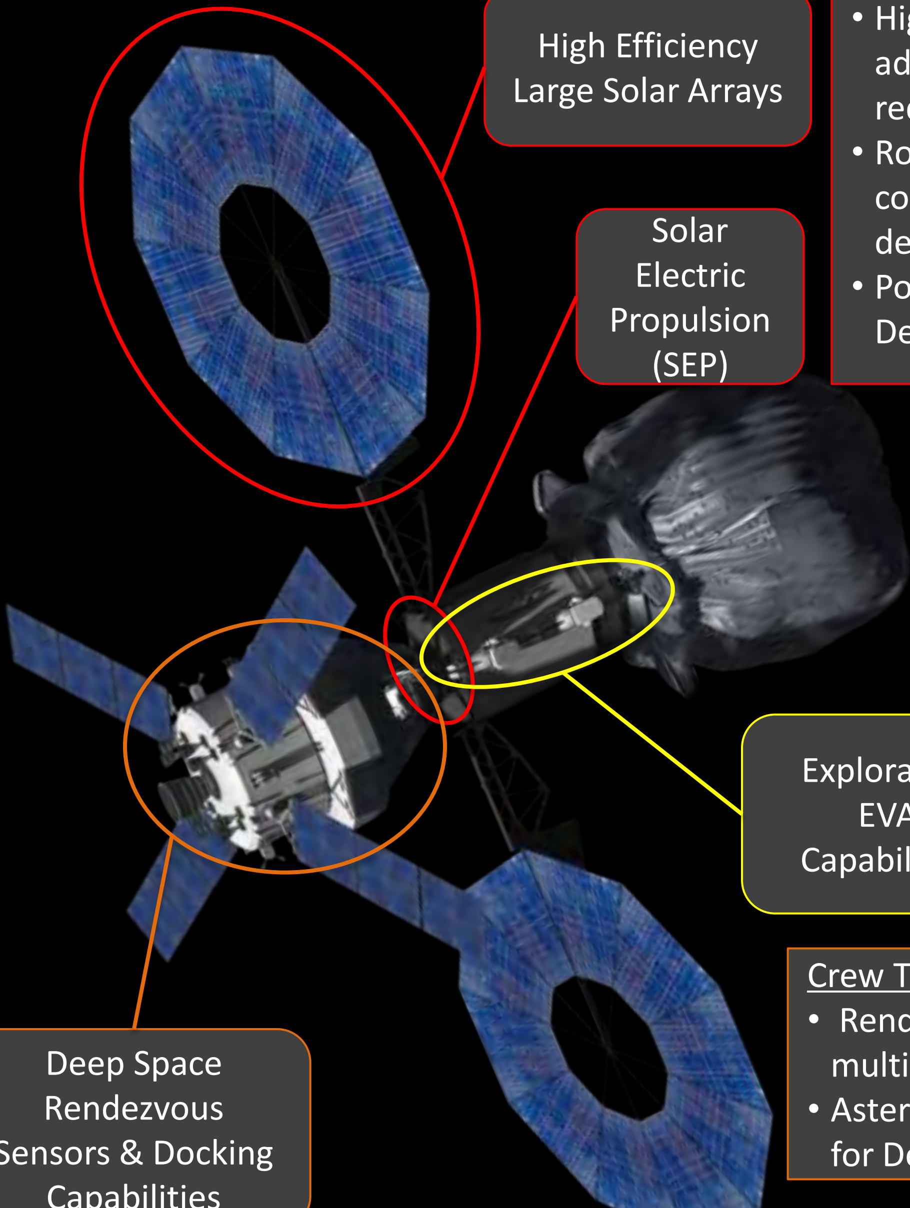
July 30, 2014

The Future of Human Space Exploration

NASA's Building Blocks to Mars



Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions



<u>In-space Power and Propulsion</u> :
- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 40kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

<u>EVA</u>:
- Build capability for future exploration through Primary Life Support System Design which accommodates Mars
- Test sample collection and containment techniques including planetary protection
- Follow-on missions in DRO can provide more capable exploration suit and tools

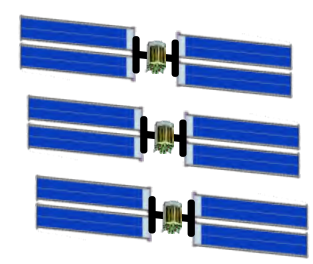
<u>Crew Transportation and Operations:</u>
- Rendezvous Sensors and Docking Systems provide a multi-mission capability needed for Deep Space and Mars
- Asteroid Initiative in cis-lunar space is a proving ground for Deep Space operations, trajectory, and navigation.

Use of ARM Solar Electric Propulsion (SEP)

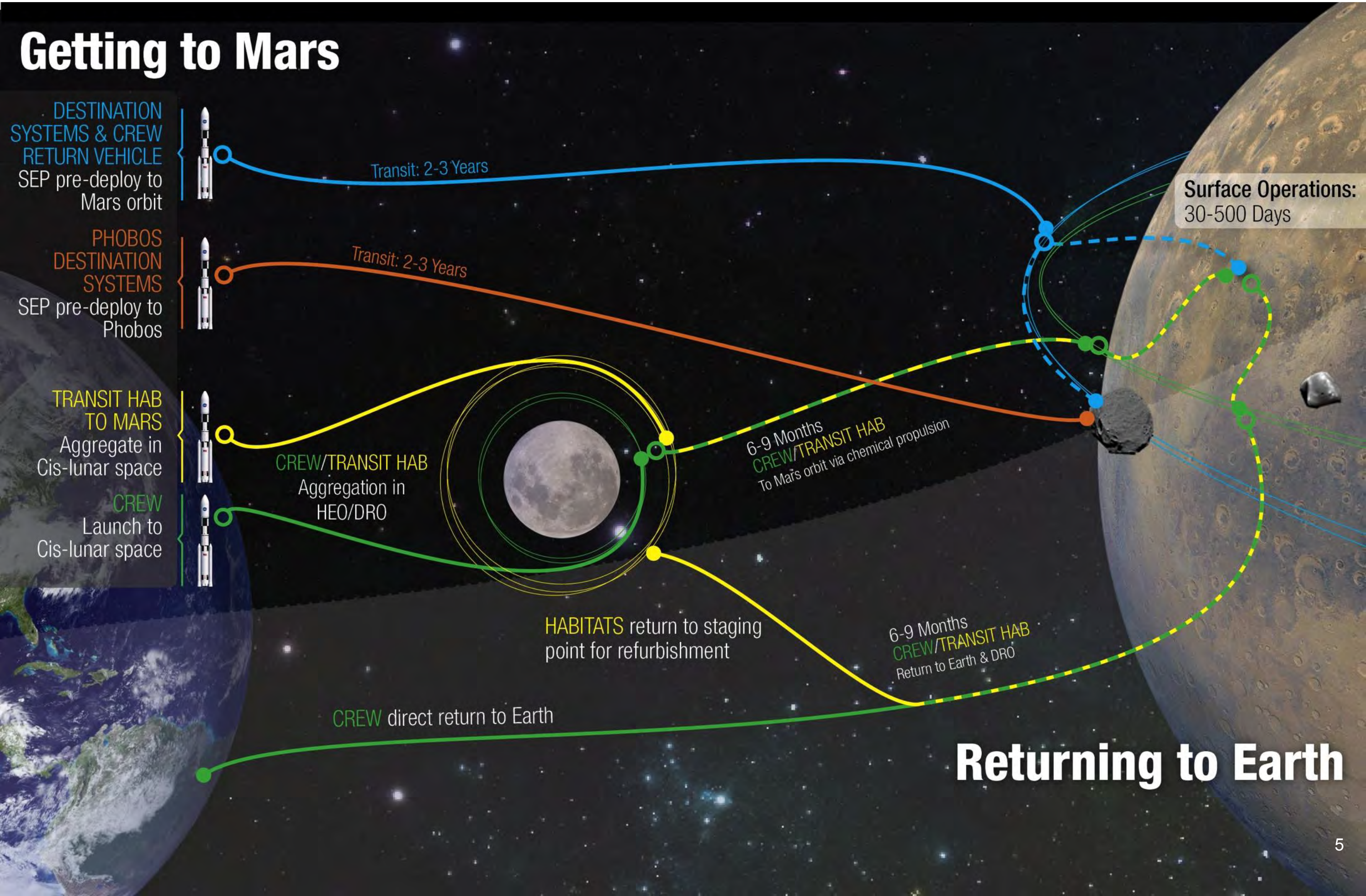
- Previous assessments have shown that human Mars missions utilizing a single round-trip monolithic vehicle architecture requires very high power SEP (up to 1 MW total power)
- Current architecture concepts utilize ARM derived SEP
  - Pre-deploy crew mission assets to Mars utilizing high efficient SEP, such as
    - Orbit habitats: Supports crew while at Mars
    - Return propulsion stages and/or return habitats
    - Exploration equipment: Unique systems required for exploration at Mars.
  - High thrust chemical propulsion for crew
    - Low-thrust SEP too slow for crew missions
    - Crew travels on faster-transit, minimum energy missions: 1000-day class round-trip (all zero-g)

One Very Large SEP

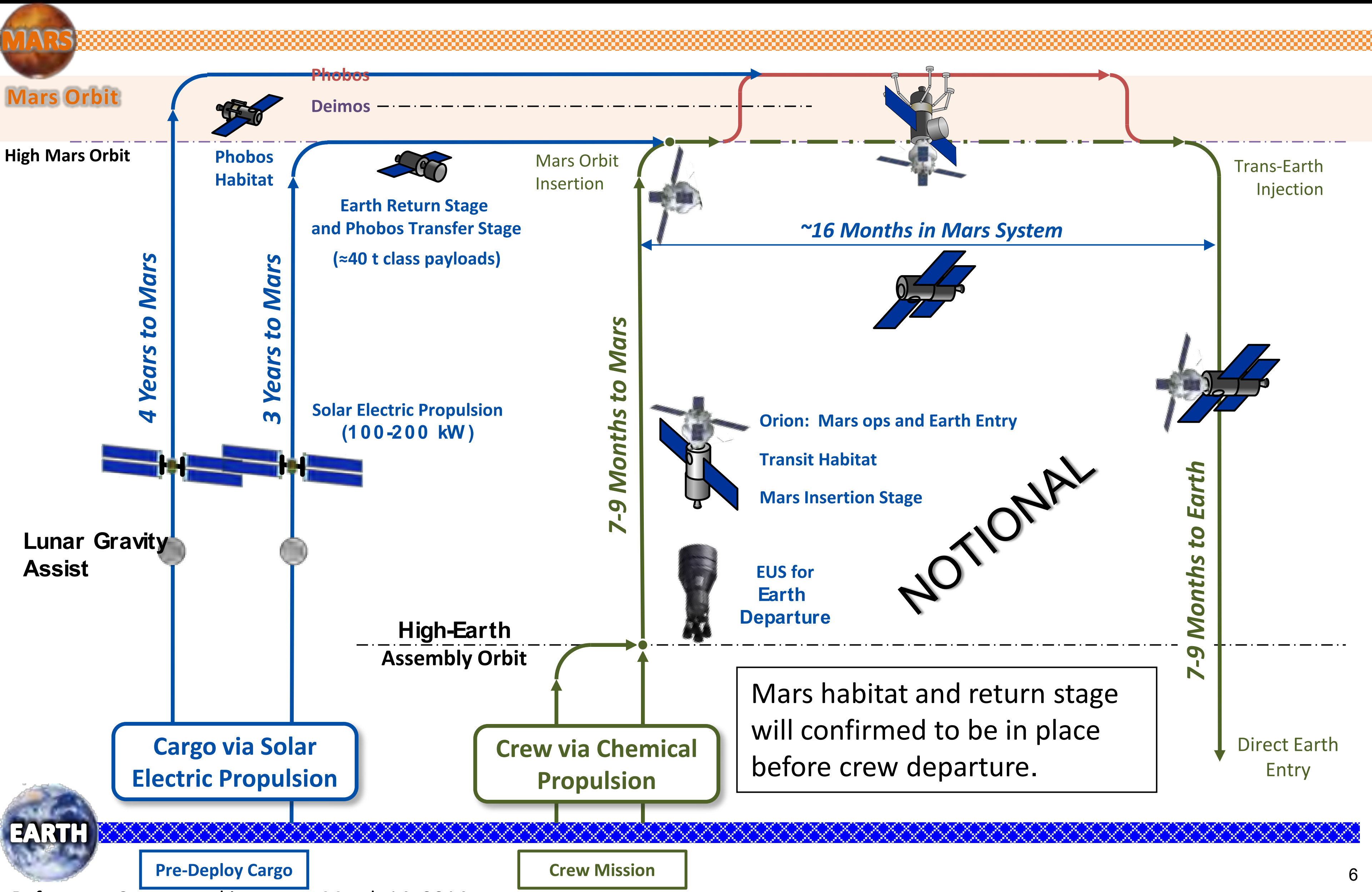
Multiple ARM derived SEPs (100-250 Kw Class)



Mars Split Mission Concept



Notional Phobos Mission



Reference: Center working group March 14, 2014

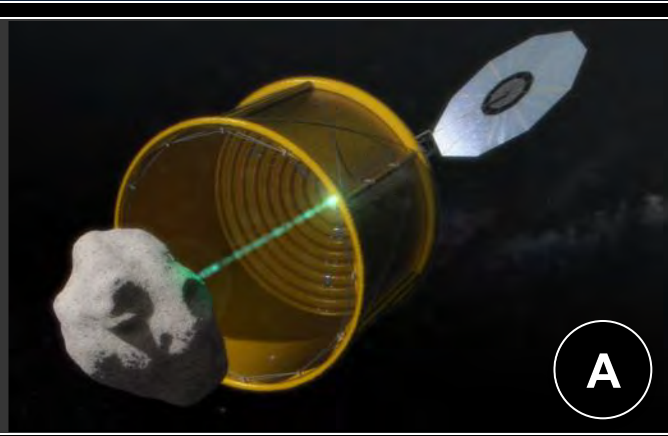
Asteroid Redirect Mission: Three Main Segments

IDENTIFY

Ground and space based assets detect and characterize potential target asteroids

REDIRECT

Solar electric propulsion (SEP) based system redirects asteroid to cis-lunar space (two capture options)



EXPLORE

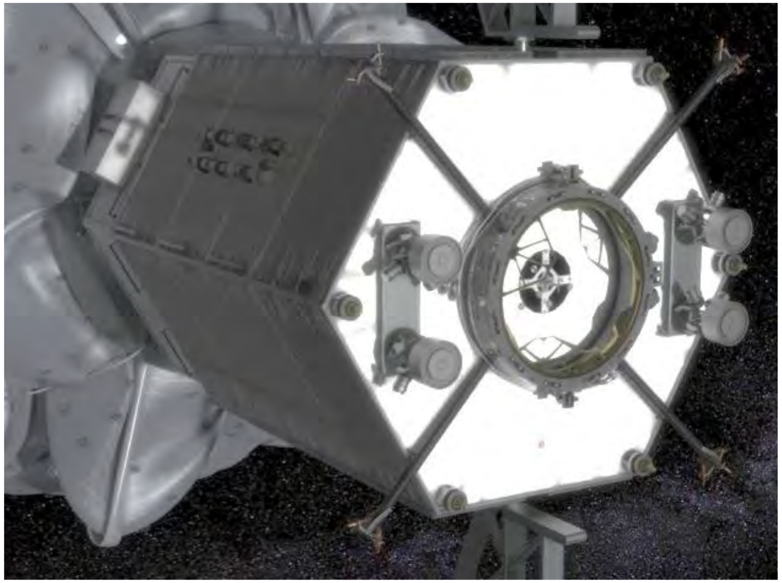
Crews launches aboard SLS rocket, travels to redirected asteroid in Orion spacecraft to rendezvous with redirected asteroid, studies and returns samples to Earth


ARM in NASA's Exploration Strategy

- ARM leverages **on-going activities** across the Agency to implement a **compelling** and **affordable** human exploration mission **in the proving ground**, providing systems and operational experience for human missions to **Mars**
- ARM technologies, systems, capabilities are part of a sustainable exploration strategy
  - High power SEP systems scalable to support human missions to Mars, e.g. pre-emplacement of cargo
  - Industry inputs on options for upgradable SEP spacecraft systems/bus options sought through recent Broad Agency Announcement (BAA)
  - Capture and control of non-cooperative objects
  - Common rendezvous sensors, international docking system, beyond LEO in-space EVA capabilities
  - Opportunities for science, in-space resource utilization demonstrations and strategic partnerships sought through recent BAA
- Our studies have determined that essentially the same flight system can support both robotic mission capture options A and B. Regardless of the capture option, the SEP spacecraft can make substantial asteroid mass available for crewed exploration and sampling in the mid 2020's.

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 science and human space flight (HSF) capabilities**
  - HSF hardware deliveries to and integration and test with robotic spacecraft
  - Joint robotic spacecraft and HSF mission operations

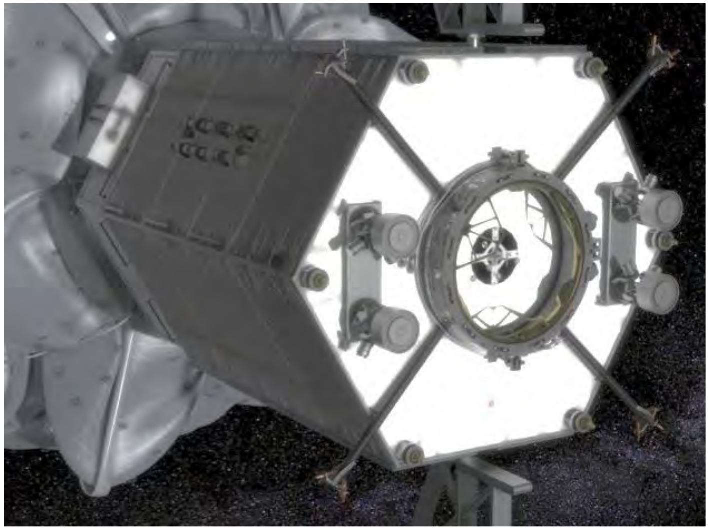


FY14 Accomplishments to Date

- Enhanced asteroid observations underway with new asteroids identified
- Solar electric propulsion technology development activities on-going
- Study and testing of ARM concept technologies and systems extensibility to crewed missions to Mars.
- NBL testing to gain confidence that there is a path to use a launch and entry suit derived from the modified advanced crew escape suit (MACES) for this mission.
- Public synthesis of the highest rated responses of a Request for Information though an Ideas Synthesis workshop
- Detailed study of a reference and alternate robotic mission concept (Options A and B)
- Stood up Robotic Concept Integration Team; completed assessment of options
- Community engagement through the Small Bodies Assessment Group (SBAG); Curation and Analysis Planning Team for Extra-terrestrial Materials; planetary defense experts; Opportunities Forum; and Broad Agency Announcement.
- Developed common Automated Rendezvous and Docking sensor approach for robotic spacecraft and crewed mission
- Issued Broad Agency Announcement and completed selections
- Remainder of FY14:
  - Internal risk reduction and BAA contracts; preparations for robotic mission concept downselect, mission concept baseline (MCR) and acquisition strategy

Current Objectives of Asteroid Redirect Mission

- Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.
- 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.
- Enhance detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.
- Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies to defend our home planet.
- 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.



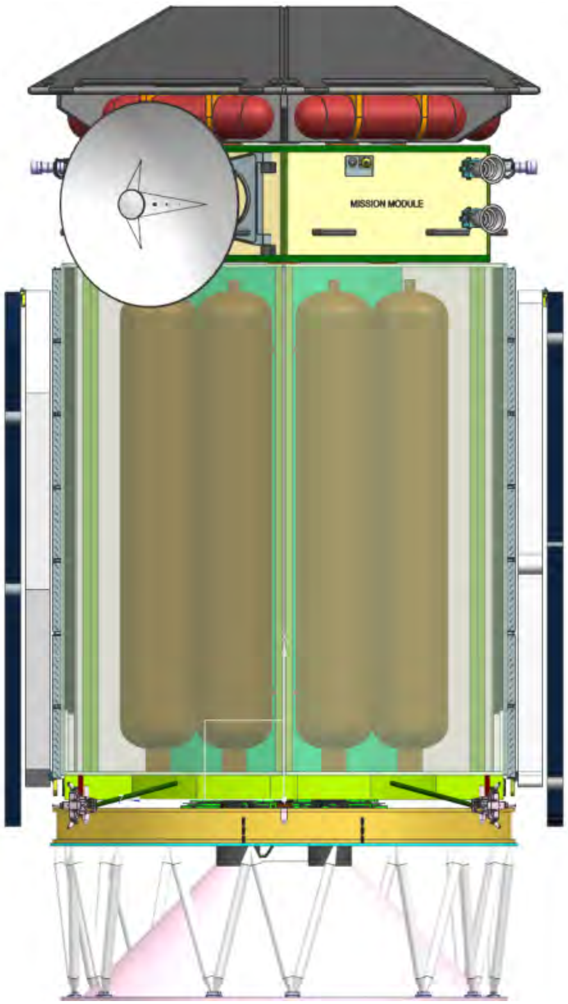
Robotic Mission Spacecraft Reference Configuration Key Features

Capture Mechanism
- Flight heritage instrumentation
- Two mass capture options

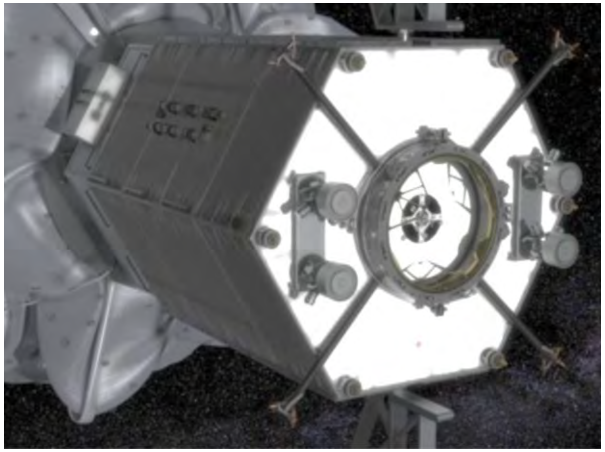
Mission Module
- Flight heritage avionics
- Simple Interface with SEPM

Solar Electric Propulsion Module (SEPM)
- Compatible with Space Technology Mission Directorate (STMD) solar array technology at 50 kW
- Electric propulsion derived from STMD thruster/power processing technology
- Xenon tanks seamless composite overwrapped pressure vessel with at least 10 t capacity

Launch Vehicle Interface
- Compatible with 5m fairings
- Unique adapter depending on launch vehicle selected



Orion docking I/F



Crew access path

STMD Solar Array Technology Work in FY 2014

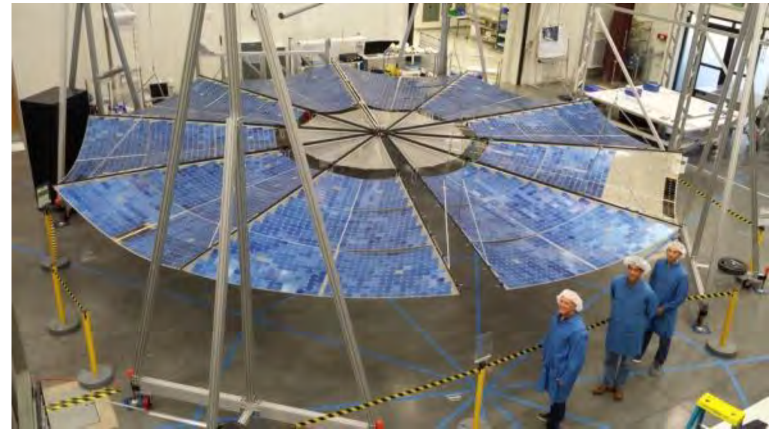
Design, Build and Test of Solar Arrays
- MegaFlex "fold out" solar array
- Mega-ROSA "roll out" solar array

Environmental Testing Completed
- Thermal vacuum full scale deployment
- Stowed wing vibration or acoustic exposure

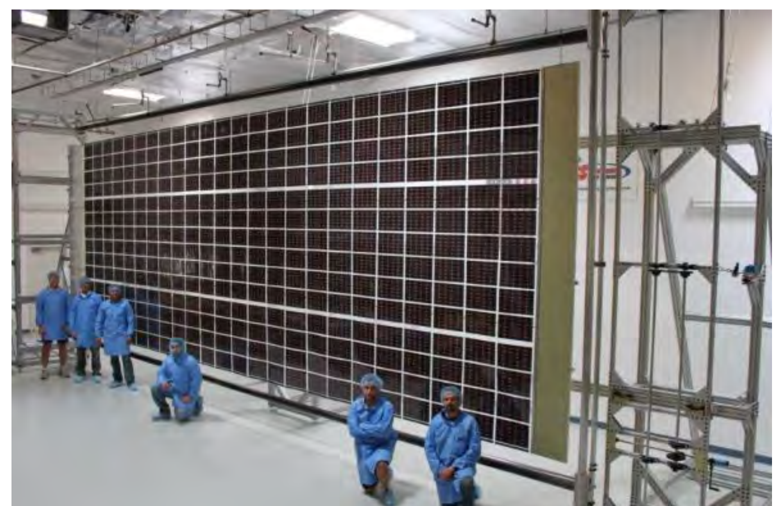
Analyses and Models include:
- Design extensibility to 250kW system
- Finite element (stowed and deployed)
- CAD models (stowed and deployed)
- Structural Dynamics (stowed and deployed)
- Thermal

Design, Build and Test Solar Cell Coupons for 300V operation

Test Power Electronics for 800V operation
- Transistors, diodes, drivers
- Destructive single event radiation testing



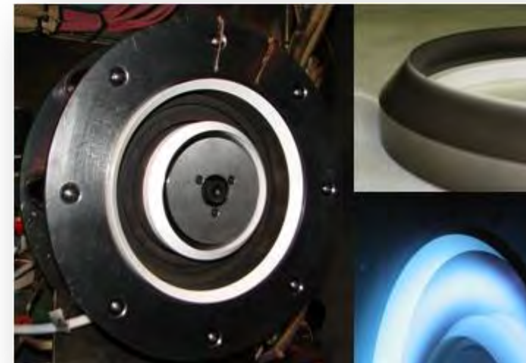
Each wing sized for nominally 20kW BOL



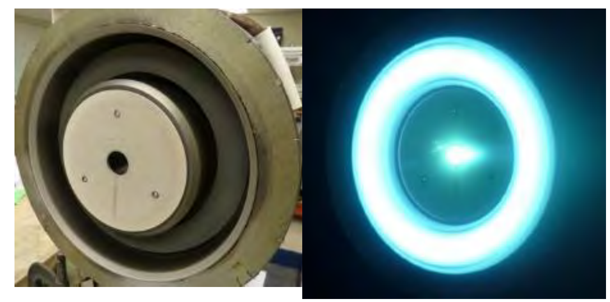
STMD Electric Propulsion Work in FY14

NASA's Goal
- Develop high power Hall thruster 12.5 kW-class (2X current SOA)
- Developed magnetically shielded design to provide long life commensurate with ARM and future missions
- Pursued high voltage (i.e. 300V input) PPU system compatible with high power thrusters

Path Forward for Advancement
- Designing and building 12.5 kW EDU at GRC
- Testing the magnetic shielding design now demonstrated up to 3000-sec specific impulse and 20 kW power with JPL H6 and NASA 300M thrusters.
- Designing and building moderate- and high-voltage PPU TDUs (120 V input with 800 V output to thruster, 300 V input with 400 V output to thruster; both are throttleable)
- Designing and building high-voltage Direct Drive Unit TDU
- Integrating Thruster EDU and PPU for test by end of FY14



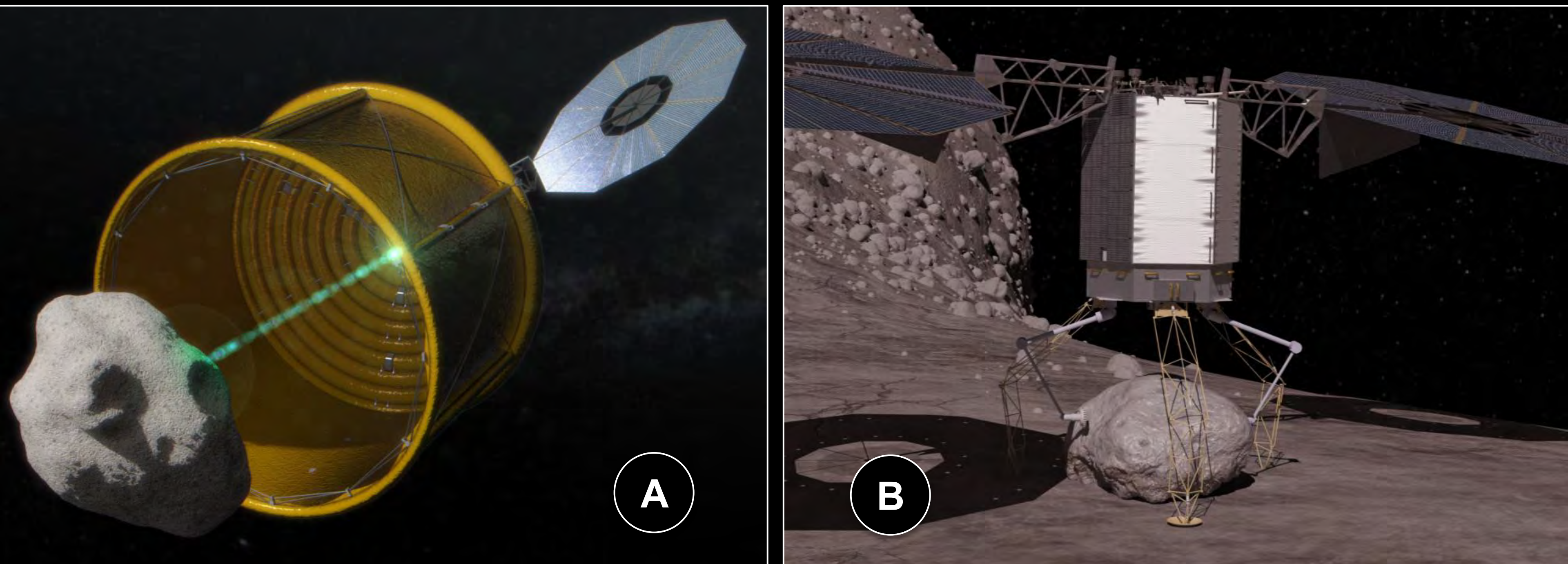
JPL H6 with magnetic shielding



GRC 300M with magnetic shielding

Cut away of NASA 300V PPU

Asteroid Redirect Robotic Mission: Two Capture Options



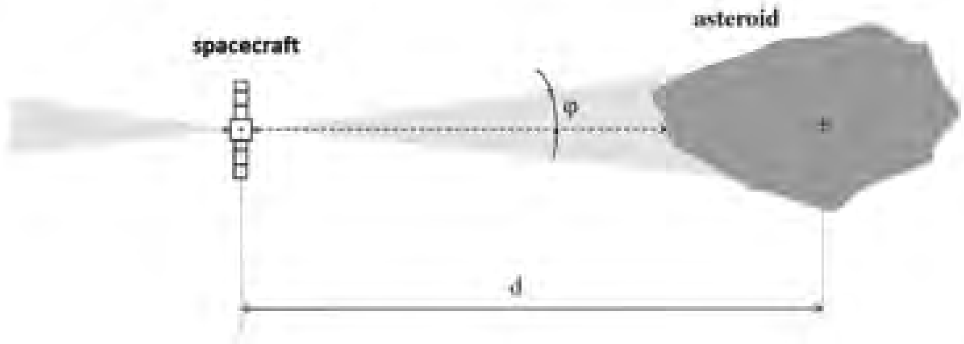
Currently Known Candidate Asteroids for ARM

- **For Option A:**
  - Currently, 9 potential candidates; 3 found last year
  - 3 validated candidates:
    - **2009 BD** – ~ 4 meter size inferred by Spitzer data
    - **2013 EC20** – ~ 2 meter size determined by radar imaging
    - **2011 MD** – ~ 6 meter size determined by Spitzer data
  - Possibly another candidate validated in 2016: **2008 HU4** – radar opportunity
  - Additional valid candidates expected at a rate of 1-2 per year
- **For Option B:**
  - Lots of potential candidates
  - Currently, 3 validated candidates:
    - **Itokawa** - imaged by Hayabusa
    - **Bennu** and **2008 EV5** – imaged by radar
  - 1 possible valid candidate in 2018: **1999 JU3** - Hayabusa 2 target
  - Potentially future valid candidates with inferred boulders, rate of ~1 per year

Planetary Defense Demonstration Options

Ion Beam Deflector – Options A & B

Performance: For <500 t target, could impart 1 mm/s in < 1 hour

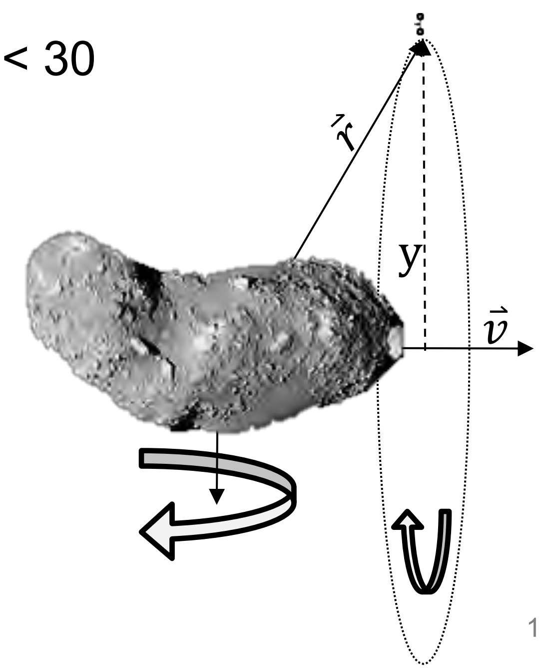


Gravity Tractor – Options A & B

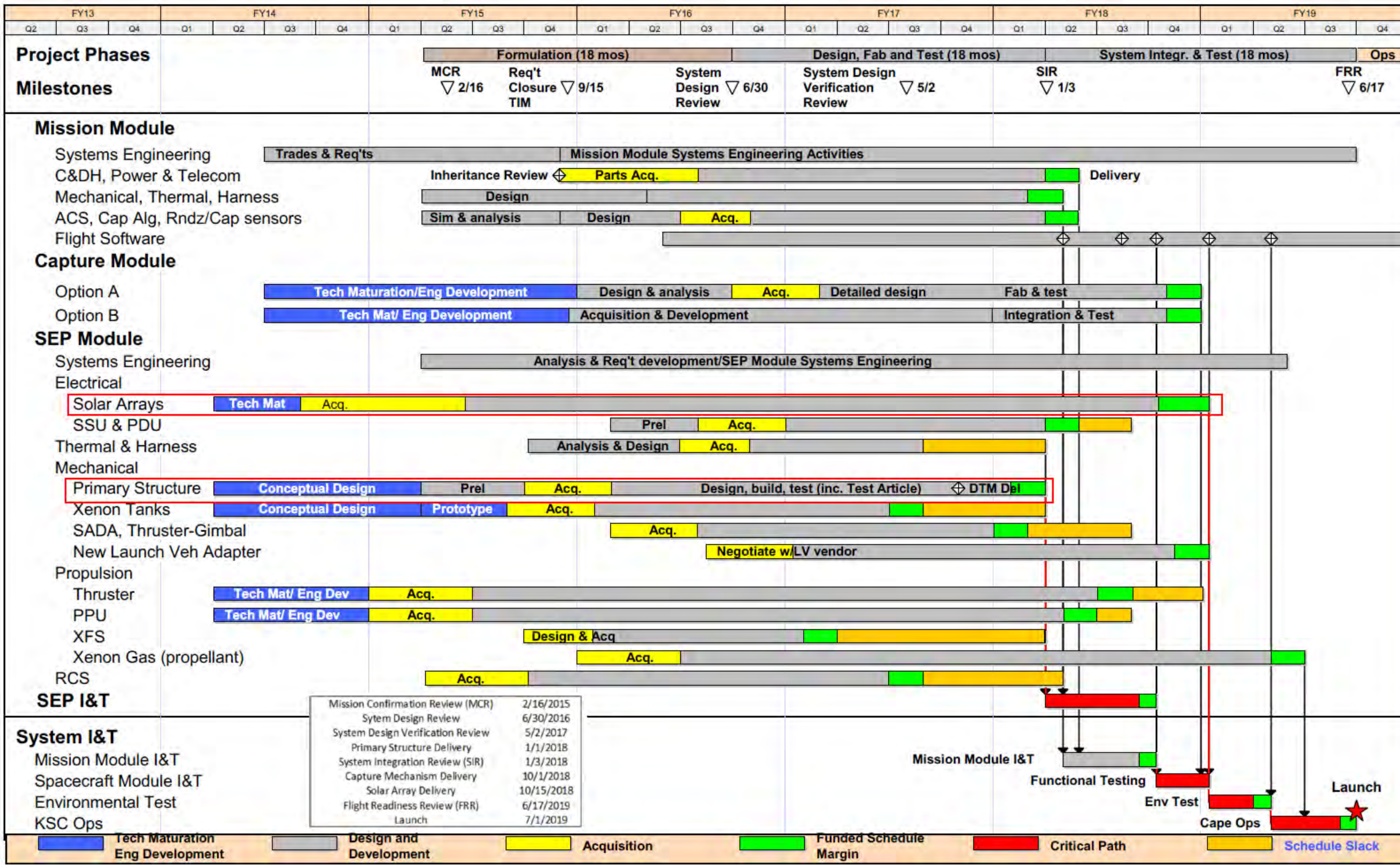
Performance: For <500 t target, could impart: 1 mm/s in < 30 hours

Enhanced Gravity Tractor – Option B

- **Leverages collected boulder mass.**
- **Relevant to potentially-hazardous-size NEAs**: efficiency increases as boulder and NEA masses increase.



Asteroid Robotic Redirect Mission Concept Schedule
LRD Option June 2019

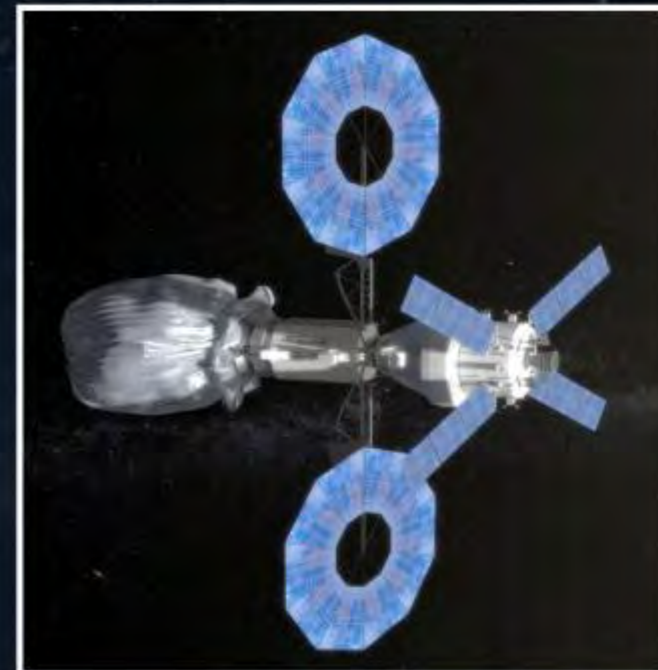


Mission Confirmation Review (MCR)	2/16/2015
Sytem Design Review	6/30/2016
System Design Verification Review	5/2/2017
Primary Structure Delivery	1/1/2018
System Integration Review (SIR)	1/3/2018
Capture Mechanism Delivery	10/1/2018
Solar Array Delivery	10/15/2018
Flight Readiness Review (FRR)	6/17/2019
Launch	7/1/2019

Asteroid Redirect Crewed Mission Overview

Deliver crew on SLS/Orion

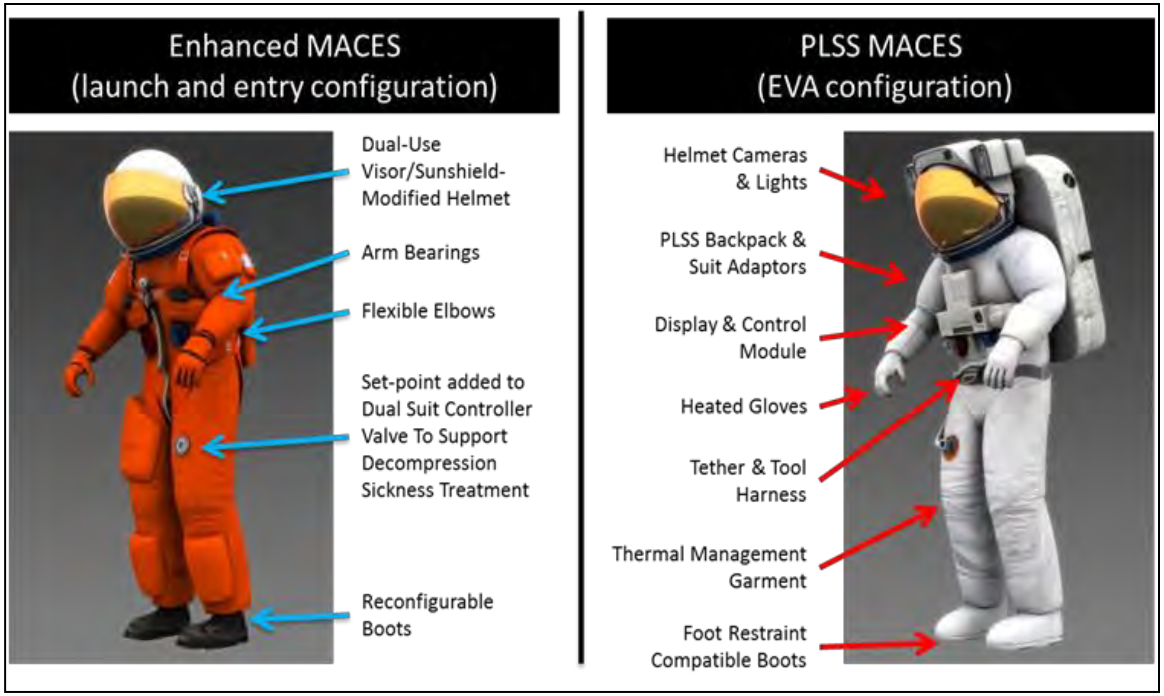
Orion Docks to Robotic Spacecraft



EVA from Orion to retrieve asteroid samples

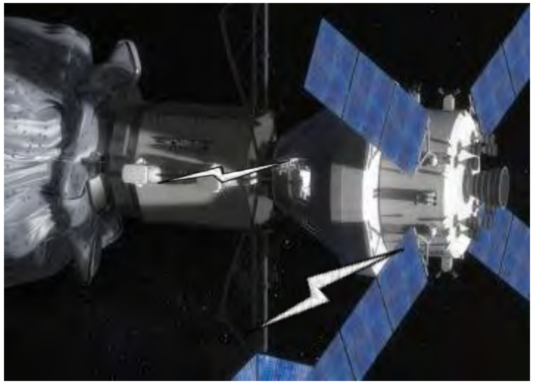
Return crew safely to Earth with asteroid samples in Orion

Mission Kit Concept Enables Affordable Crewed Mission

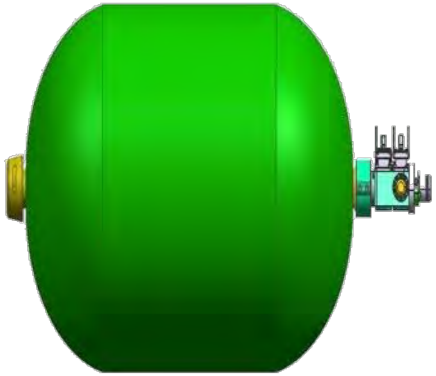


Tools & Translation Aids

Sample Container Kit



EVA Communications Kit



Repress Kit

Most capabilities needed for other exploration missions

Asteroid Redirect Mission
Broad Agency Announcement

Selected 18 (of 108) proposals totaling $4.9M for six-month studies to define and mature system concepts and to assess the feasibility of potential commercial partnerships. Study results will inform the Mission Concept Review.

Asteroid Capture Systems: *Inflatable and deployable capture systems, robotic arms, pneumatic jacks, and grippers.*

- **4 selections**

Rendezvous Sensors: *Sensor suite for AR&D commonality across multiple mission applications*

- **2 selections**

Adapting Commercial Spacecraft for ARM: *SEP modules based on existing buses to reduce development cost*

- **2 selections**

Partnerships for Secondary Payloads: *Leveraging external development of small spacecraft, hoppers, and kinetic impactors*.

- **5 selections**

Partnerships for Enhancing the Crewed Mission: *Including commercial objectives in ARM and developing EVA tools.*

- **3 selections**

ARM Milestones to Mission Concept Review, February 2015

➢ FY14 Risk Reduction Plan for Boulder Capture Concept Option	Apr 3, 2014
➢ BAA Notice of Intent Due	Apr 4, 2014
➢ PPBE16 program submits due	Apr 28, 2014
➢ BAA Proposal Due Date	May 5, 2014
➢ STMD Solar Array Systems development Phase 1 complete	Jun 2014
➢ BAA Awards	NET Jul 14, 2014
➢ **Option A Testbed Operational**	**End of Jul 2014**
➢ **STMD Integrated Thruster performance Test with 120V PPU**	**Sep 2014**
➢ **HEOMD MACES EVA end-to-end mission sim complete**	**Sep 2014**
➢ **Option B full scale 2D flat floor testing**	**Oct 2014**
➢ **BAA Interim Reports**	**Oct 31, 2014**
➢ **Robotic mission concept Option A/B downselect**	**Mid Dec 2014**
➢ **BAA Period of Performance Ends**	**Jan 15, 2014**
➢ **Mission Concept Review**	**Feb 2015**