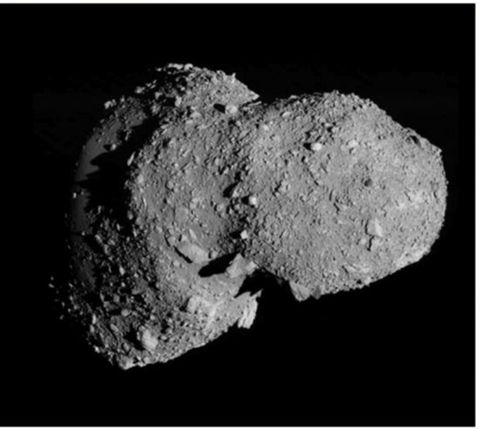
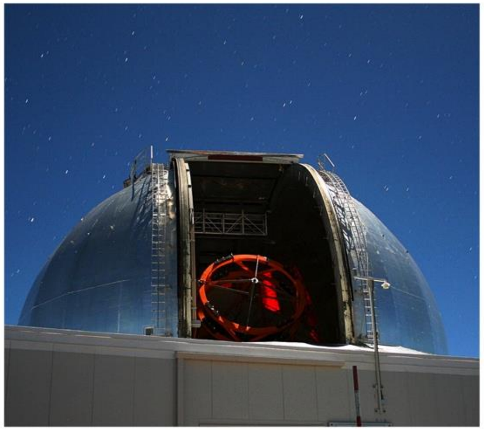
National Aeronautics and Space Administration

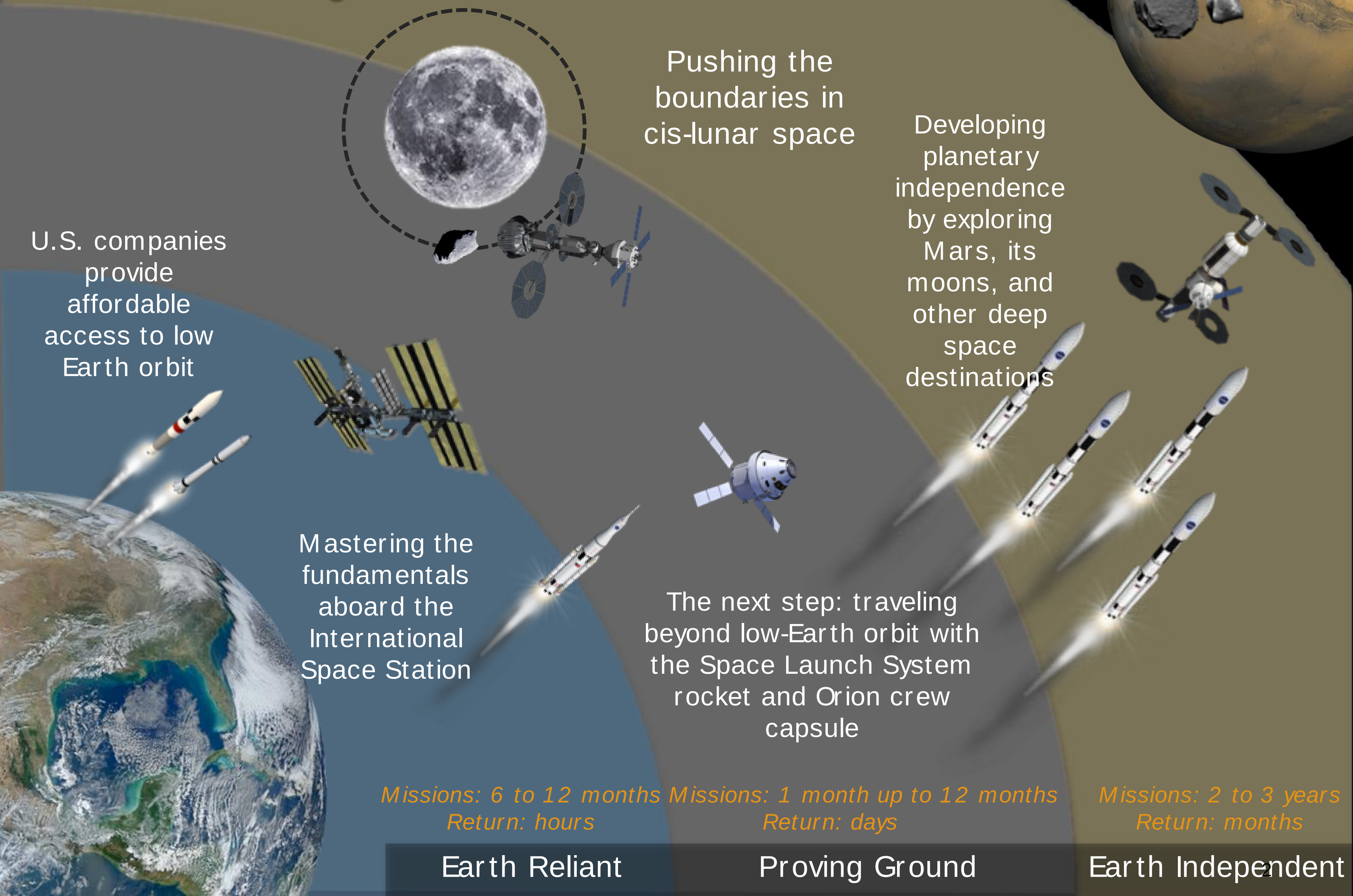
NASA's Asteroid Redirect Mission

SSERVI Exploration Science Forum
July 23, 2014

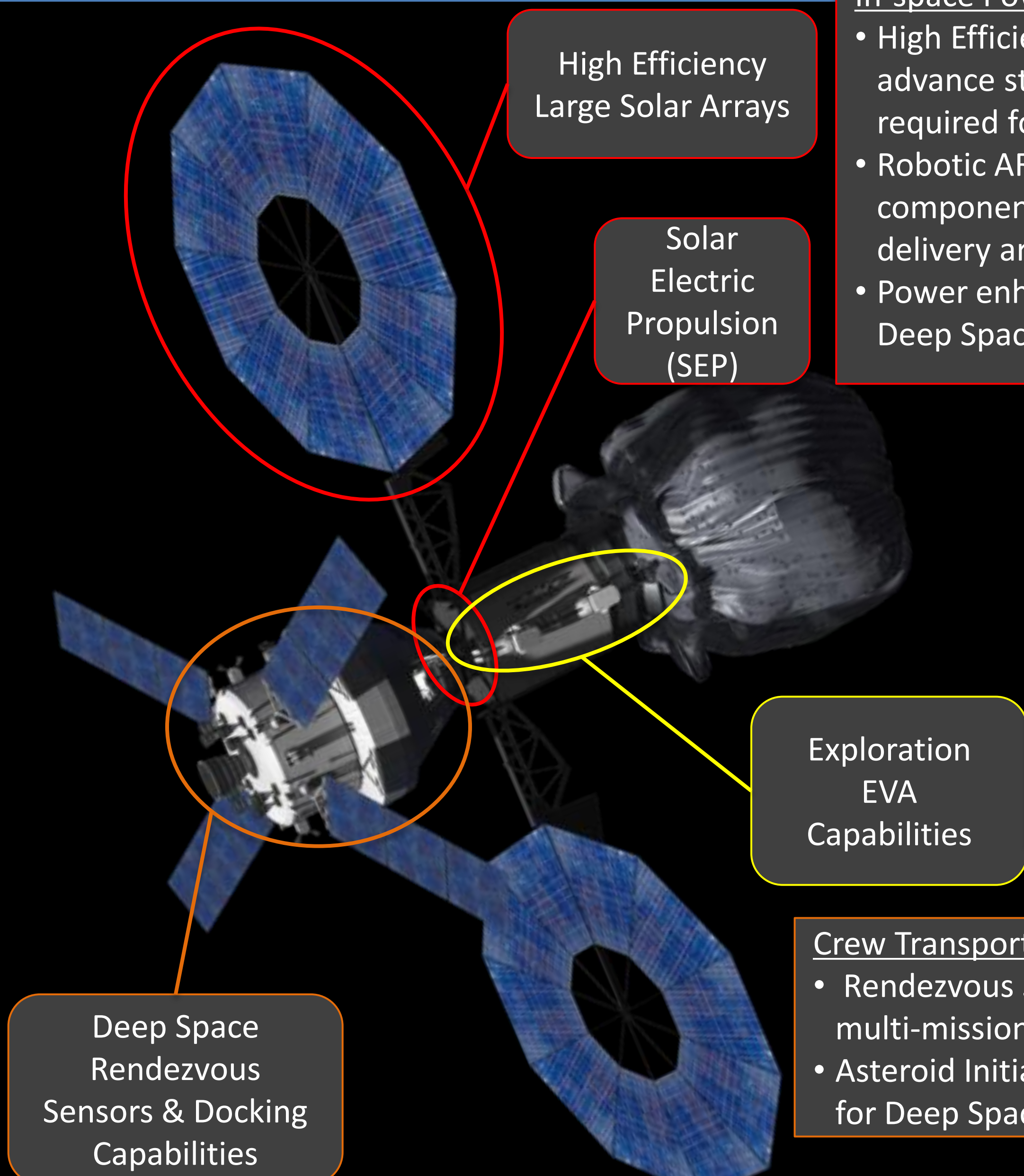



The Future of Human Space Exploration

NASA's Building Blocks to Mars



Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions



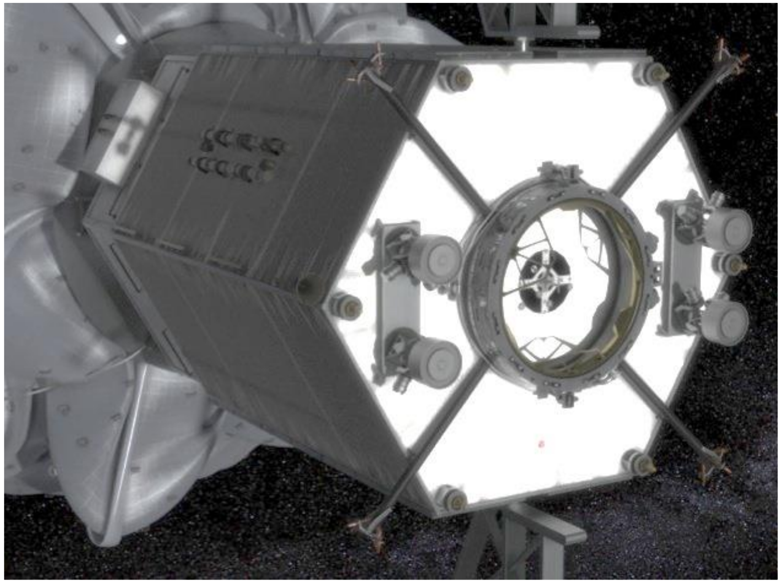
<u>In-space Power and Propulsion</u>:
- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 40kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

<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.

Key Aspects of ARM

- **Moving large objects through interplanetary space using solar electric propulsion**
- **Integrated crewed/robotic vehicle stack operations in interplanetary space-like trajectory**
  - Integrated attitude and control, e.g. solar alignment
  - Multi hour EVAs
- **Lean implementation**
  - Clean interfaces, streamlined processes
  - Common AR&D procurement for ARRM and Orion
- **Opportunity for workforce to share experience and learn together**
  - HSF hardware deliveries to and integration and test with robotic spacecraft
  - Joint robotic spacecraft and HSF mission operations



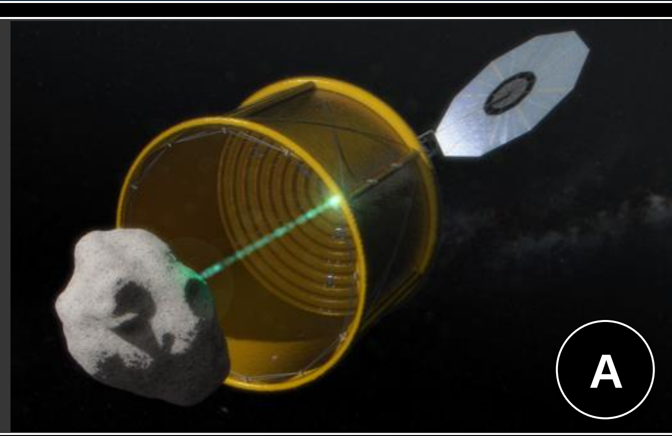
Asteroid Redirect Mission: Three Main Segments

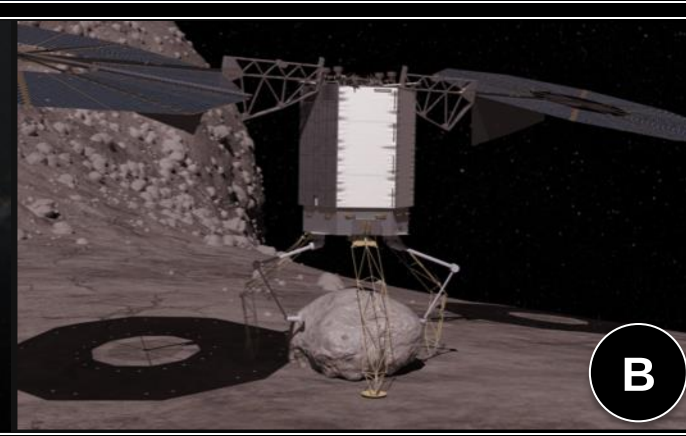
IDENTIFY

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

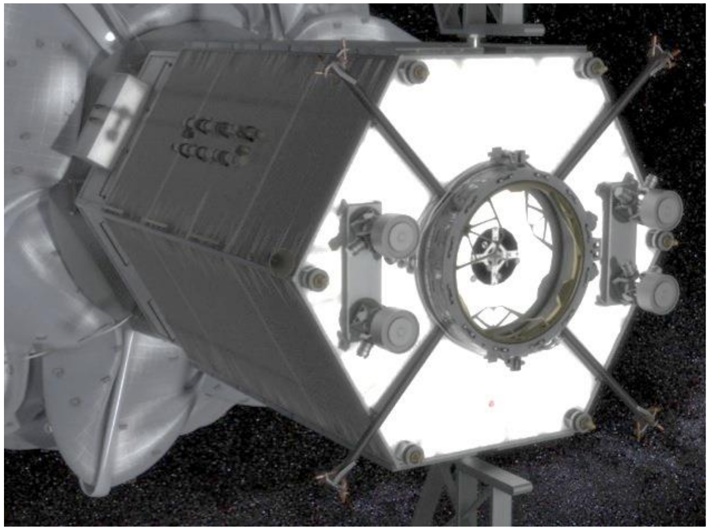
- ARM leverages **on-going activities** across the Agency to implement a **compelling** and **affordable** human exploration mission **in the proving ground**, providing systems and operational experience for human missions to **Mars**

- 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)
  - 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 Broad Agency Announcement

- 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.

Current Objectives of Asteroid Redirect Mission

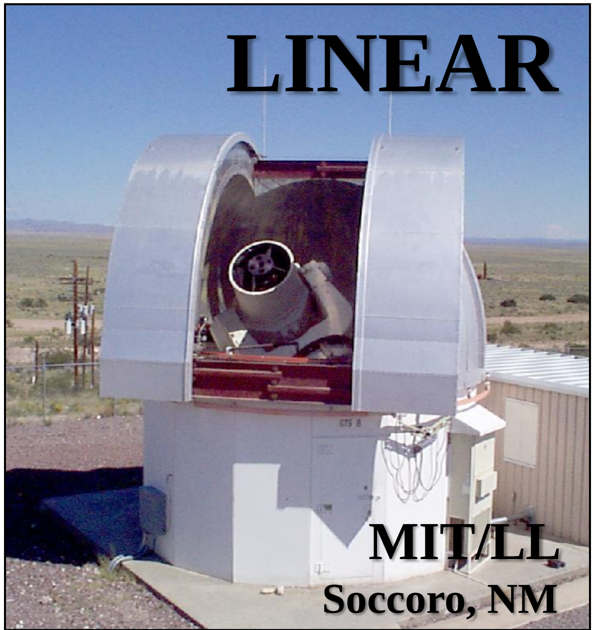
- Conduct a human exploration mission to an asteroid in the mid-2020’s, providing systems and operational experience required for human exploration of Mars.
- Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation’s 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.

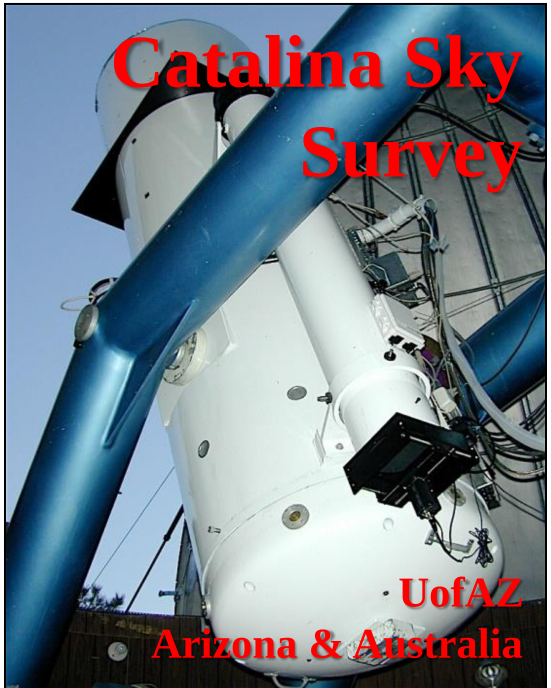


NASA's NEO Observations Program
(Current Systems)

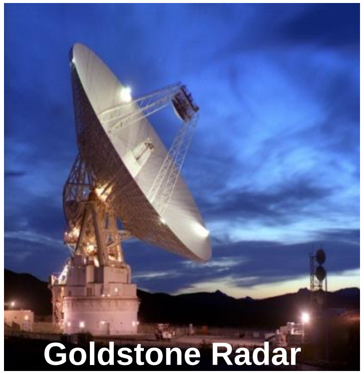
Minor Planet Center (MPC)
- IAU sanctioned
- Int'l observation database
- Initial orbit determination:
  www.cfa.harvard.edu/iau/mpc.html

NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY: http://neo.jpl.nasa.gov/



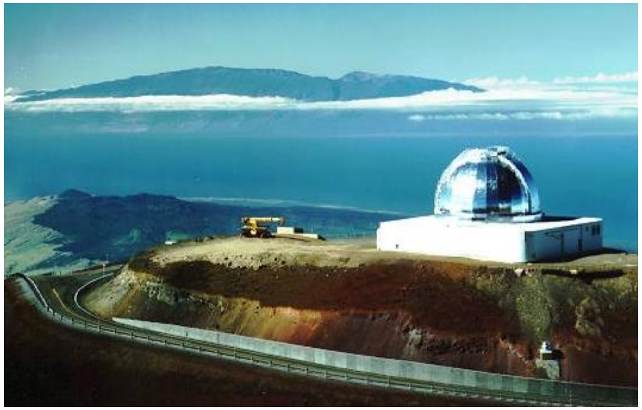


Primary NEO Characterization Assets and Enhancements



Radar (Goldstone and Arecibo)

- Increased time for NEO observations
- Streamlining Rapid Response capabilities
- Improve maintainability



NASA InfraRed Telescope Facility (IRTF)

- Increased call-up for Rapid Response
- Improving operability/maintainability
- Improve Instrumentation for Spectroscopy and Thermal Signatures

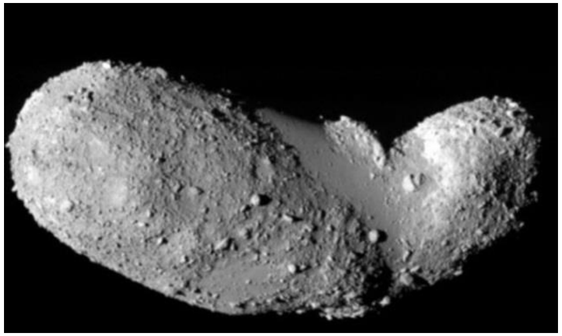
Spitzer Infrared Space Telescope

- Orbit about Sun, ~176 million km trailing Earth
- In extended Warm-phase mission
- Characterization of Comets and Asteroids
- Thermal Signatures, Albedo/Sizes of NEOs
- Longer time needed for scheduling

NASA Asteroid Redirect Mission Internal Studies Completed

Robotic mission concept option A

- To redirect a small near Earth asteroid and potentially demonstrate asteroid deflection
- Study led by the Jet Propulsion Laboratory

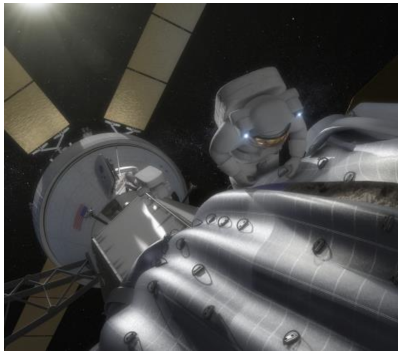


Robotic mission concept option B

- To redirect a boulder from a larger asteroid and potentially demonstrate asteroid deflection
- Study led by the Langley Research Center

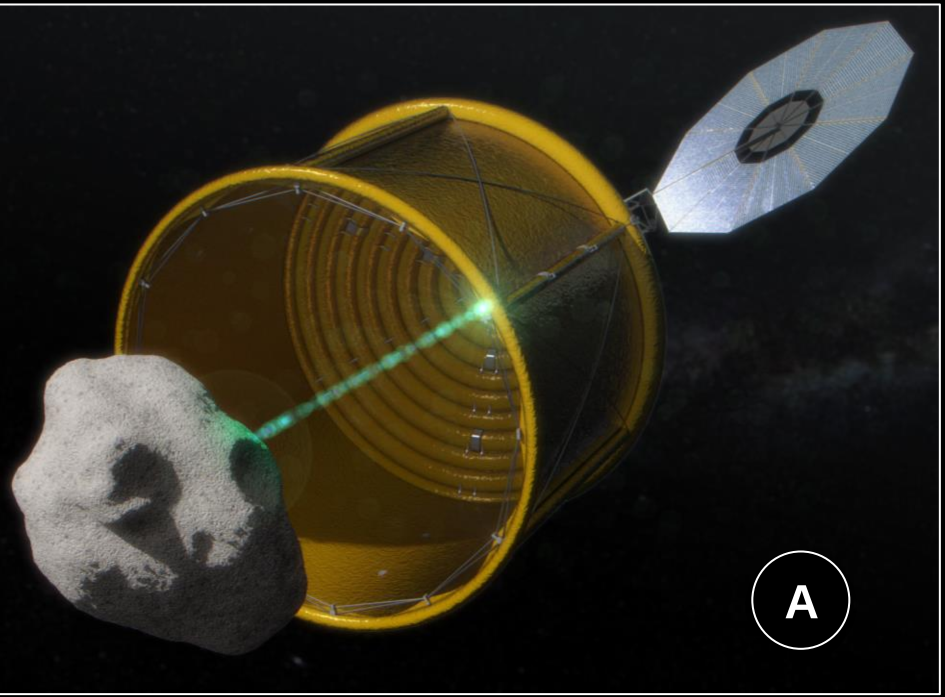
Crewed mission concept

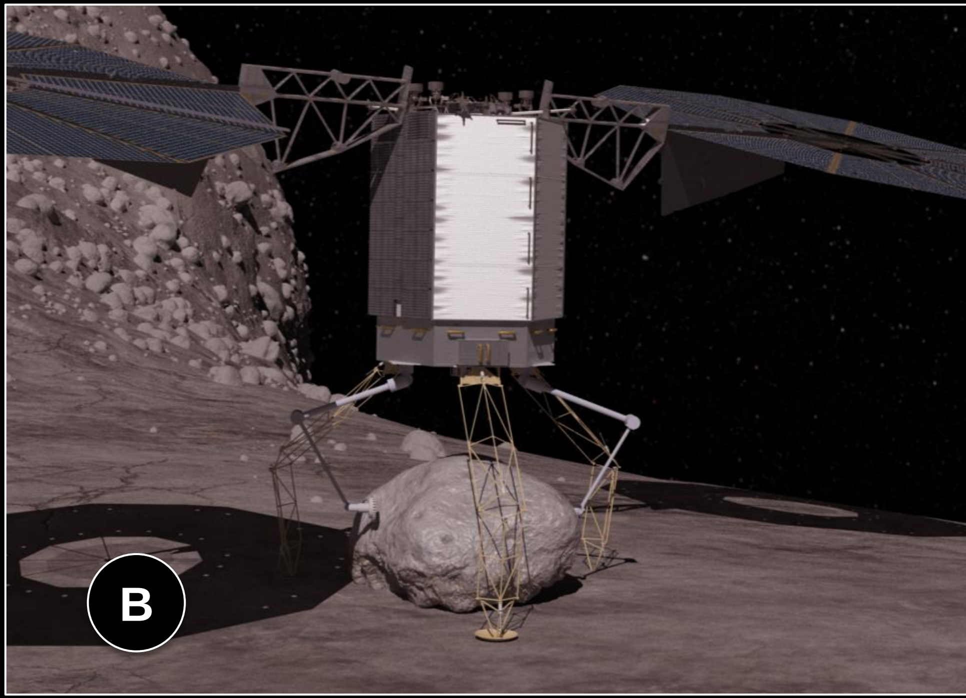
- Crew rendezvous and sampling for either concept
- Led by the Johnson Space Center



Robotic Concept Integration Team comparative assessment

Asteroid Redirect Mission: Two Robotic Capture Options





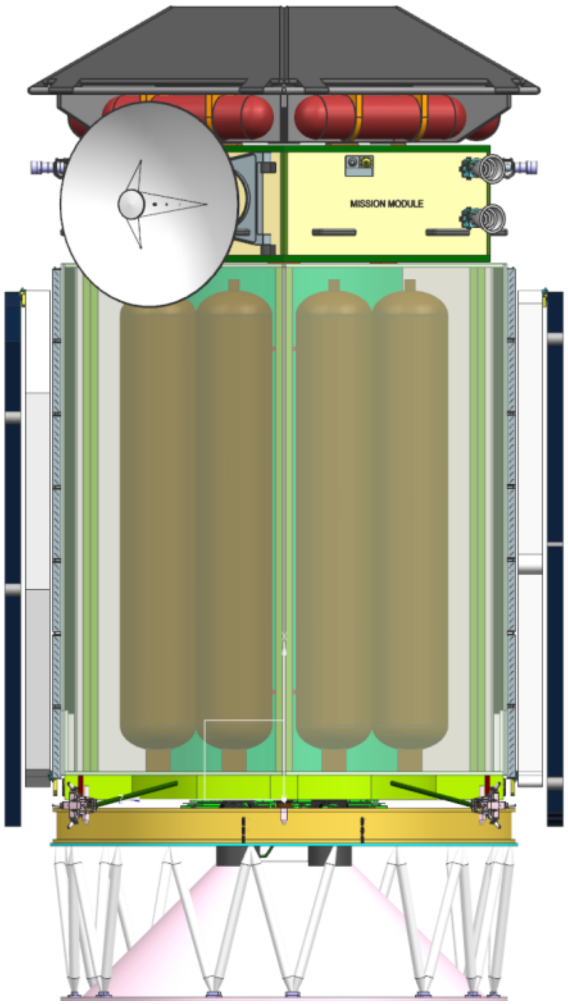
Robotic Mission Spacecraft Reference Configuration Key Features

Capture Mechanism
- Flight heritage instrumentation
- Inflatable capture bag

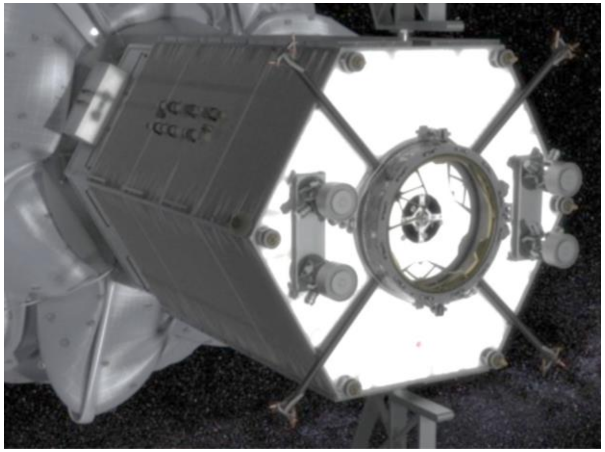
Mission Module
- Flight heritage avionics
- Simple Interface with SEPM

SEP Module
- Compatible with STMD solar array technology at 50 kW
- EP derived from STMD Hall thruster/PPU technology
- Xe tanks seamless COPV with at least 10 t capacity
- Unique structure design
- Conventional thermal control
- Conventional reaction control subsystem

Launch Vehicle I/F
- Compatible with 5m fairings
- Unique adapter depending on LV selected



Orion docking I/F



Crew access path

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.

Candidate Target Boulder Return Sizes

Launch no earlier than June 2019

Crew Availability in stable LDRO in February - May of:

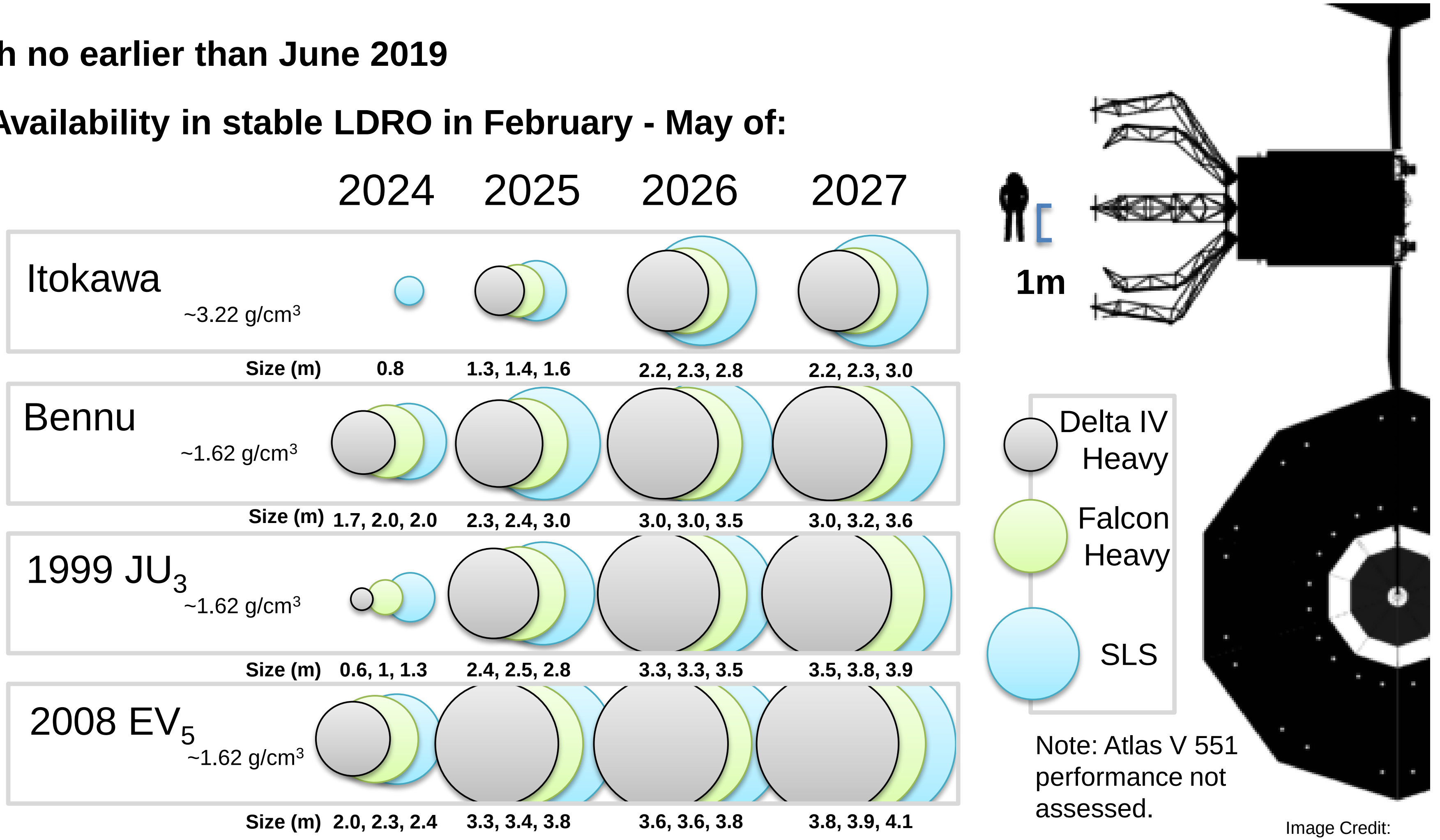


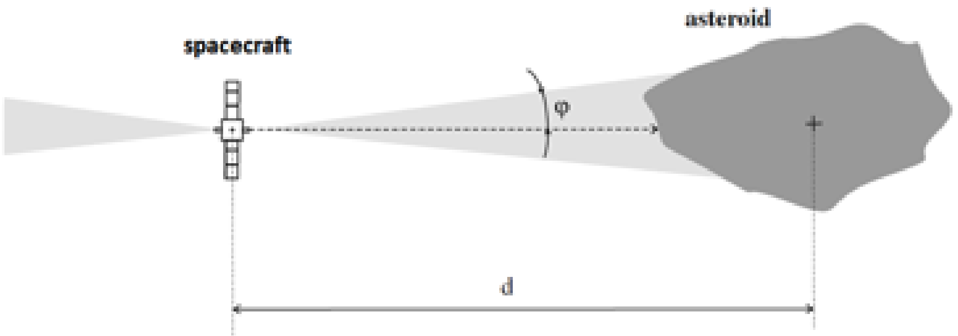
Image Credit: NASA/AMA, Inc.

Robotic Boulder Capture Option has a set of candidates that are robust to changes in return dates.

Planetary Defense Demonstration Options

Ion Beam Deflector – Options A & B

- **Size of asteroid irrelevant**
- **Performance:** For <500 t target, could impart 1 mm/s in < 1 hour

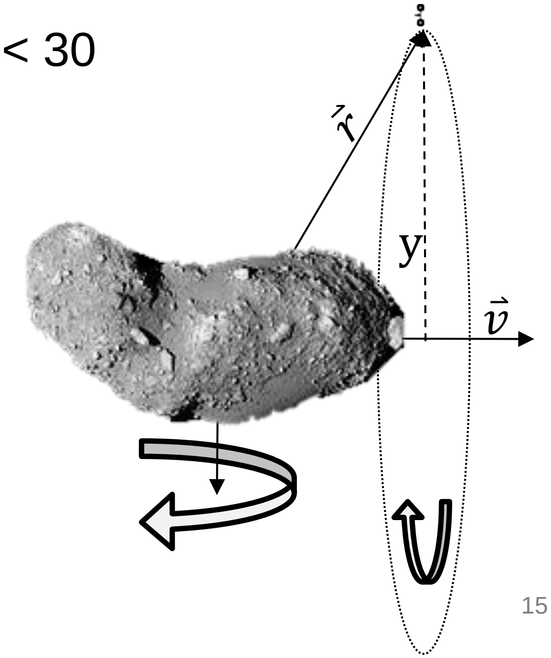


Gravity Tractor – Options A & B

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

Enhanced Gravity Tractor – Option B

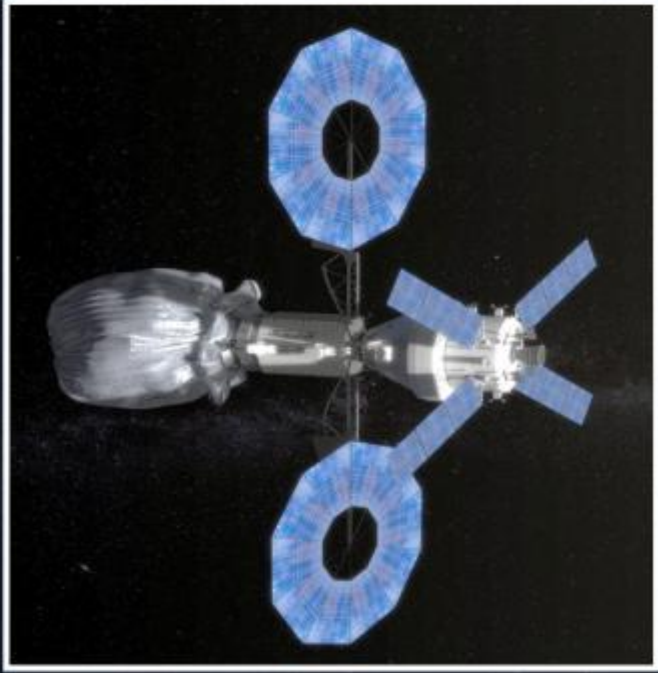
- **Leverages collected boulder mass.**
- **Relevant to potentially-hazardous-size NEAs**: efficiency increases as boulder and NEA masses increase.



Asteroid Redirect Crewed Mission Overview

Deliver crew on SLS/Orion

Orion Docks to Robotic Spacecraft

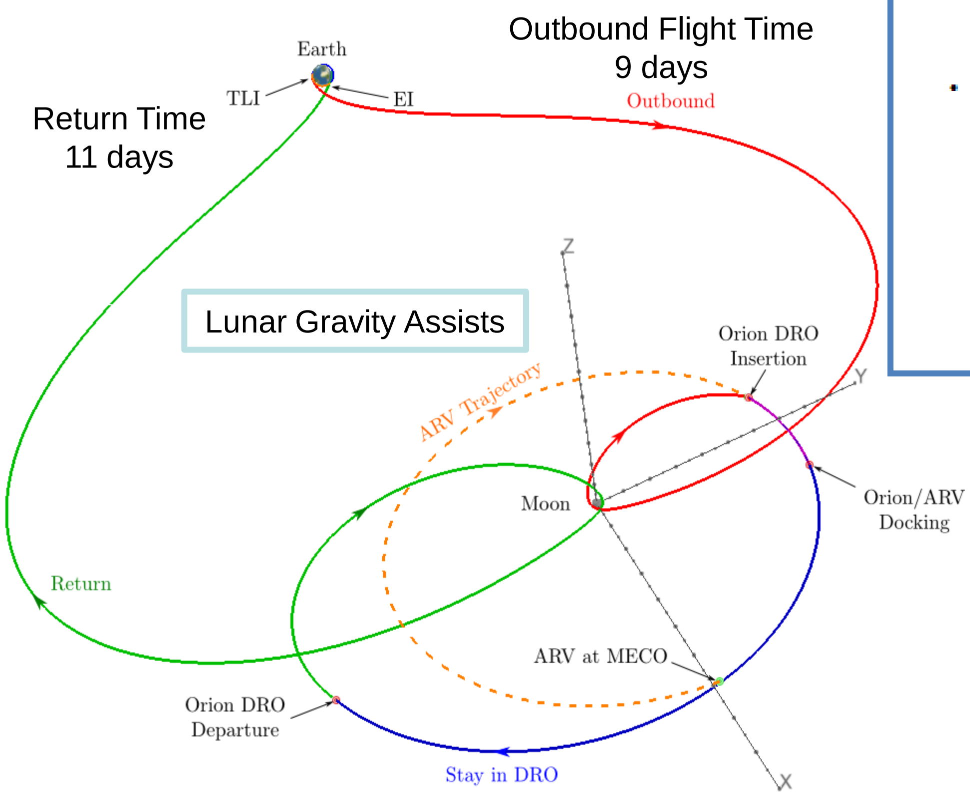


EVA from Orion to retrieve asteroid samples

Return crew safely to Earth with asteroid samples in Orion

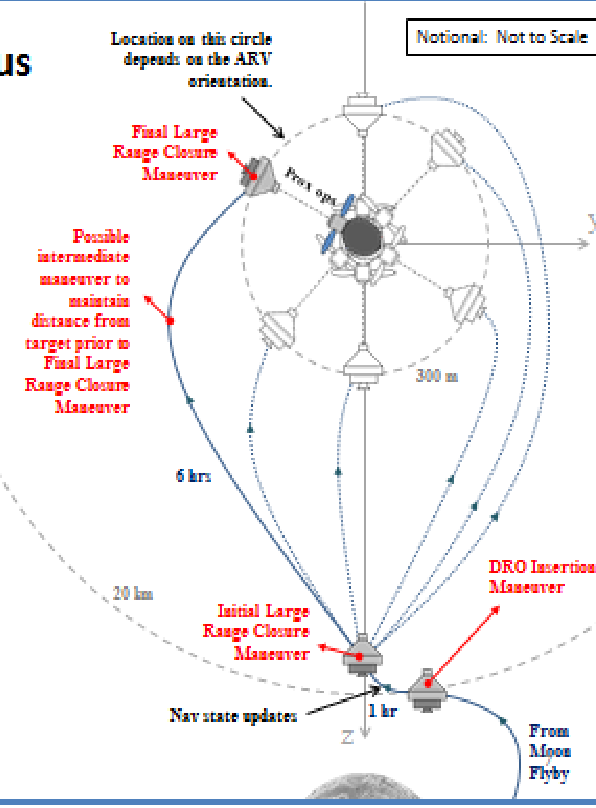
Trajectory, Rendezvous, and Proximity Operations

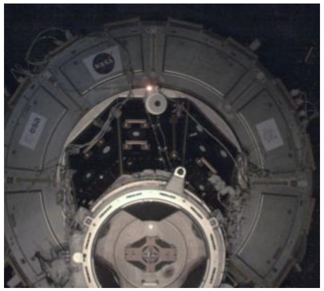
- Common Rendezvous/prox-ops sensors leveraging Space Shuttle Detailed Tests
- Rendezvous /proximity operations maneuvers result largely in rectilinear motion
- Trajectory, launch window, rendezvous, and navigation techniques enable Mars

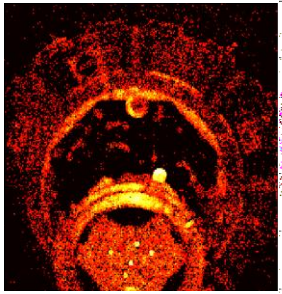


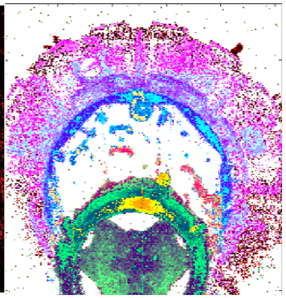
Far-Field Rendezvous Strategy

- A large (~20 km) range closure (2-burn) maneuver sequence places the Orion 300 m range from ARV/Asteroid
- The near rectilinear motion in the DRO allows for many possible transfer approaches to the 300 m ARV/Asteroid offset
- The path can be selected to provide desirable collision avoidance and final prox-ops approach geometry (e.g., Sun behind Orion on approach)

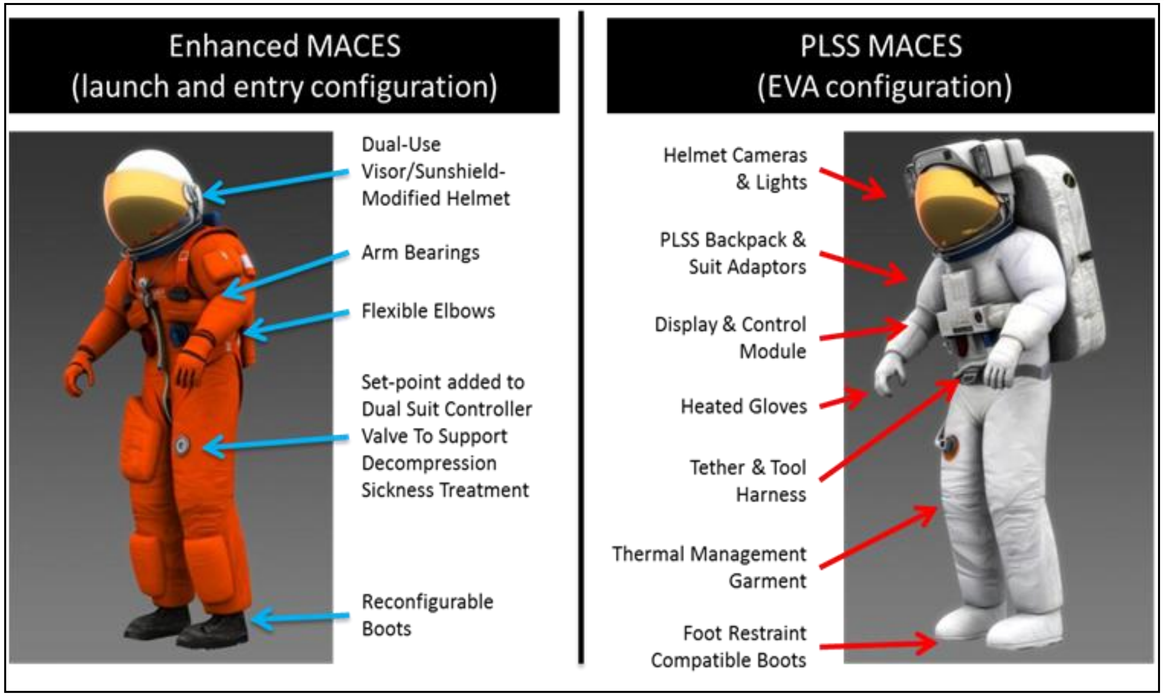






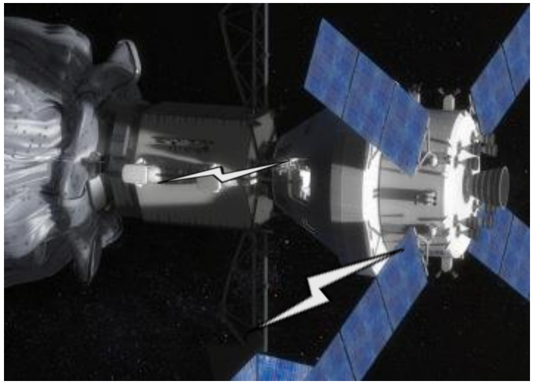


Mission Kit Concept Enables Affordable Crewed Mission

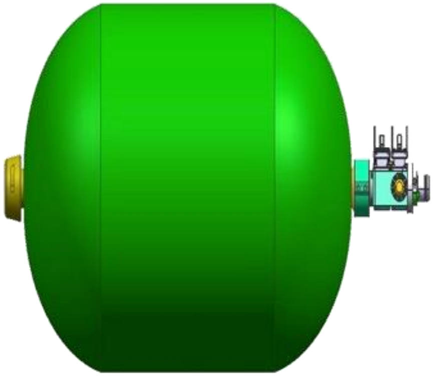


Tools & Translation Aids

Sample Container Kit



EVA Communications Kit



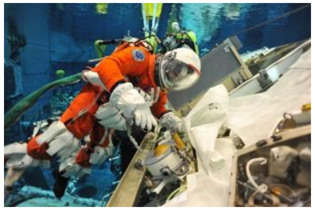
Repress Kit

Modified ACES Feasibility Testing Summary

Lab, Zero G, ARGOS tests

MACES EVAs are demonstrated as feasible and neutrally buoyant testing is warranted

NBL Series #2 – 5 tests (2, 3 and 4 hours long)



Task complexity increases while improvements are made to the suit including EMU gloves, drink bag, etc.

Need for improved stability and work envelope

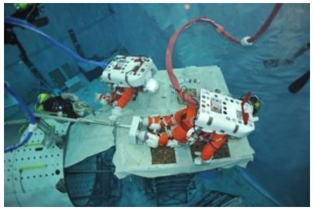
Initial NBL testing has shown feasibility of doing many asteroid retrieval sampling tasks using a MACES. Continued testing with a variety of crew member sizes, along with incremental suit and tool enhancements is critical in order to validate the concept.

May | June | July | August | Sept | Oct – Jan | February | March | April | May

NBL Series #1 – 3 tests (2 hours long)

Established NBL Interface, ability to weigh-out the suit, and the subject's ability to use the suit underwater.

NBL Series #3 – 5 tests (4 hours long)



Evaluation of mobility enhancements, improved worksite stability, and testing on higher fidelity capsule mockups with tools culminating in a full ARCM EVA timeline.

Hardware and Procedure Improvements

Improved weights
EMU Gloves
Added tool harness
Drink bag included
New liquid cooling garment
Mobility Enhancements
Dual Suit Ops
EMU Boots
PLSS Mockup
Body Restraint Tether

Asteroid Redirect Mission
Broad Agency Announcement Selections

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 ARM Mission Concept Review.

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

- **Airborne Systems**
- **Space Systems/Loral**
- **Jacobs**
- **Altius Space Machines**

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

- **Ball Aerospace**
- **Boeing**

Adapting Commercial Spacecraft for ARM:

SEP modules based on existing buses to reduce development cost

- **Boeing**
- **ExoTerra Resource**
- **Lockheed Martin**
- **Space Systems/Loral**

Partnerships for Secondary Payloads:

Leveraging external development of small spacecraft, hoppers, and kinetic impactors.

- **The Planetary Society**
- **Planetary Resources**
- **Honeybee Robotics**
- **Applied Physics Laboratory**
- **Deep Space Industries**

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

- **Deep Space Industries**
- **Planetary Resources**
- **Honeybee Robotics**

ARM Engagements with the Scientific Community

- **Internal to NASA**
  - Science Mission Directorate

- **Open Calls for Innovation:**
  - June 2013: Asteroid Initiative RFI
  - Nov 2013: RFI Synthesis Workshop, Houston
  - March 2014: BAA, public opportunities forum

- **External**
  - Small Bodies Assessment Group (SBAG)
  - Keck Institute
  - Lunar and Planetary Institute
  - SSERVI
  - COSPAR

- **Current and future opportunities:**
  - Small Bodies Advisory Group assessments and actions
  - External and international partners
    - Current study contracts
    - Partnerships on robotic mission
    - Partnerships on crewed mission

CAPTEM Assessment
based on lessons learned from prior sample return missions

Curation and Analysis Planning Team for Extraterrestrial Materials

1. **Textural and mineralogical heterogeneity** of the sampled body will be critically important for site and sample selection.
2. Active participation of a **ground-based Science Team** is critically important.
3. **Hand-held high-resolution cameras** and supporting analytical instruments will be valuable for sample selection.
4. **Contamination Control** is vitally important.
5. Collection of at least **1000g of material from two sites** that sample the apparent diversity of the body.
6. Collection of at least one **5-cm diameter core sample** of regolith from each of the two sites.
7. ***Preservation of volatiles*** is desirable, particularly if the sampled asteroid is of type C, P, or D.
8. ***Measurement of the porosity and internal structure of the body***, while not of highest priority, is desirable.
9. ***Placement of appropriate surveying tools*** on the surface could enable accurate assessment of any deformation of the body.

NEO Observations Annual Solicitation

- **Contained in annual omnibus Research Opportunities in Space and Earth Sciences (ROSES)**
  - Released February 18 this year (2014)
  - A component of Solar System Observations - Appendix C.6
  - See NSPIRES site:

    http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={3EFFB689-0398-0F85-601A-65877CBCE61C}&path=open

- **NEO Observations – Important dates**
  - Step 1 Notices of Intent due April 7th
  - Proposals due June 6th
  - Peer Reviewed in August
  - Awards announced when FY2015 budget available to fund

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
➢ Initial 6-DOF Closed-loop Prox Ops Sim	June 03, 2014
➢ STMD Solar Array Systems development Phase 1 complete	Jun 2014
➢ **BAA Awards**	**NET Jul 25, 2014**
➢ **Option A Test Bed Operational**	**end of July, 2014**
➢ **BAA Kickoff Meetings**	**Week of Jul 21**
➢ **STMD SEP Solar Array RFP release**	**Sep 1, 2014**
➢ **STMD Integrated Thruster performance Test with 120V PPU**	**Sep 2014**
➢ **HEOMD MACES EVA end-to-end mission sim complete**	**Sep 2014**
➢ **Full scale 2-D flat-floor landing testing**	**October**
➢ **BAA Interim Reports**	**Oct 31, 2014**
➢ **Robotic mission concept Option A/B downselect**	**mid Dec 2014**
➢ **BAA Period of Performance Ends**	**mid Jan, 2015**
➢ **Mission Concept Review**	**Feb 2015**

Conclusion

- **ARM is an important step in the proving ground of cis-lunar space to advance capabilities and techniques needed for space exploration**
- **Continued engagement with industry and international partners**
  - Current study contracts
  - International partnerships on robotic mission
  - International partnerships on crewed mission
- **Ongoing consultation with Small Bodies Advisory Group**
  - Assessments and actions
- **Mission Concept Review in February 15 is key next milestone**

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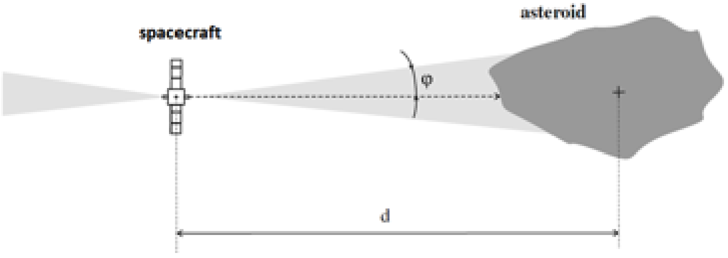
Planetary Defense (PD) Demonstration

- **Mission could demonstrate the gradual, precise PD approaches of Ion Beam Deflection (IBD), Gravity Tractor (GT) or Enhanced Gravity Tractor (EGT) on a small or large asteroid relevant to some classes of potential hazardous asteroids**
- **For Option A, a PD demo of either IBD or GT could be done on a small asteroid**
  - No known design changes, fits in existing timeline
  - IBD operations approach may be independent of the size of the asteroid
  - IBD, <500 t target, could impart: 1 mm/s in < 1 hour
  - GT, <500 t target, could impart: 1 mm/s in < 30 hours

Ion Beam Deflector



Asteroid size-independent planetary defense demo

Planetary Defense Demonstration at a Larger NEA

- **Demonstrating the applicability of Enhanced Gravity Tractor on potentially-hazardous-size NEA.**
- **Selected Enhanced Gravity Tractor for Itokawa Case Study**
  - Leverages collected boulder mass.
  - Efficiency increases as boulder mass increases.
  - Allows spacecraft to maintain safe, constant distance from NEA.
  - Demonstrates sustained operations in asteroid proximity.

Enhanced Gravity Tractor Concept of Operations for Itokawa

- Phase 1: Fly in close formation with the asteroid with collected boulder (60 days required for measurable deflection with 120 days of reserve performance).
- Phase 2: Wait for orbital alignment to become favorable to allow measurement of deflection beyond 3-σ uncertainty (~8 months from start of Phase 1).