Asteroid Redirect Mission Update

SBAG Meeting 1/8/14
Exploration Activities Related to Small Bodies

Michele Gates/NASA HEOMD

Leveraging Capabilities for an Asteroid Mission

- **NASA is leveraging key on-going activities in Science, Space Technology, and Human Exploration and Operations Mission Directorates**
  - Asteroid identification and characterization efforts
  - High power solar electric propulsion
  - Autonomous guidance and control
  - Orion and Space Launch System vehicles
  - Technologies for astronaut extra-vehicular activities

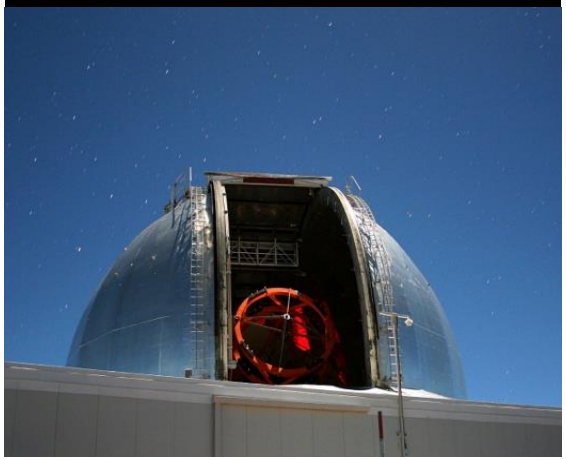
- **Each individual activity provides an important capability in its own right for human and robotic exploration**

- **We are working to utilize all of these activities to**
  - Identify and redirect a small asteroid to a stable orbit in the lunar vicinity; and
  - Investigate and return samples with our astronauts.

- **The FY14 budget supports continued advancement of the important individual elements and furthers the definition of the overall potential mission.**

Asteroid Redirect Mission

Identify



Asteroid Identification:

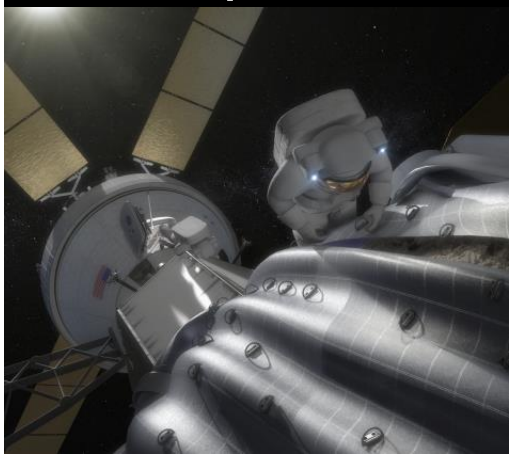
Ground and space based near Earth asteroid (NEA) target detection, characterization and selection

Redirect

Asteroid Redirect Robotic Mission:

High power solar electric propulsion (SEP) based robotic asteroid redirect to lunar distant retrograde orbit

Explore

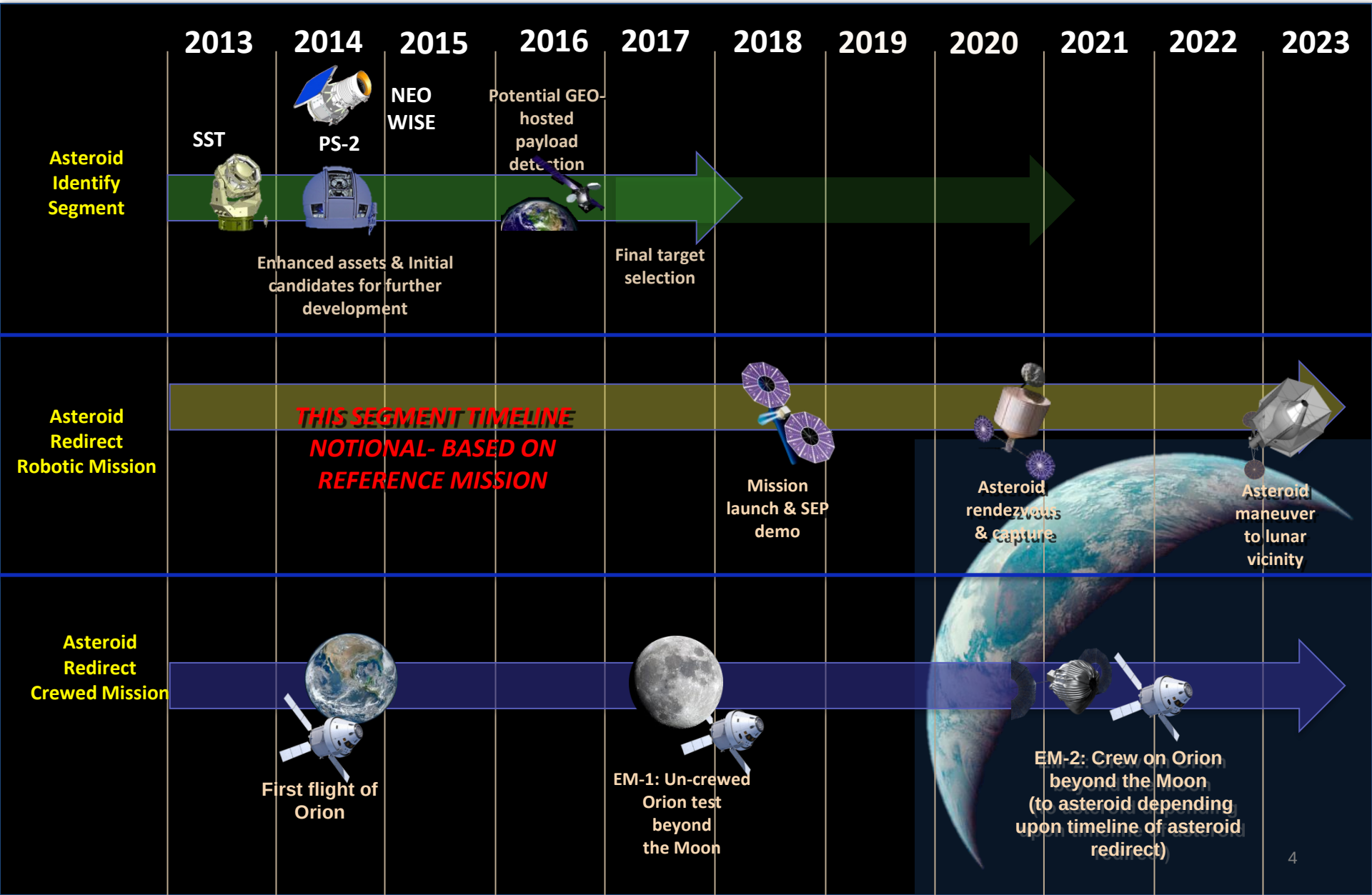


Asteroid Redirect Crewed Mission:

Orion and Space Launch System based crewed rendezvous and sampling mission to the relocated asteroid

Leveraging On-Going Activities
Each Provides Important Individual Capability

Alignment Strategy



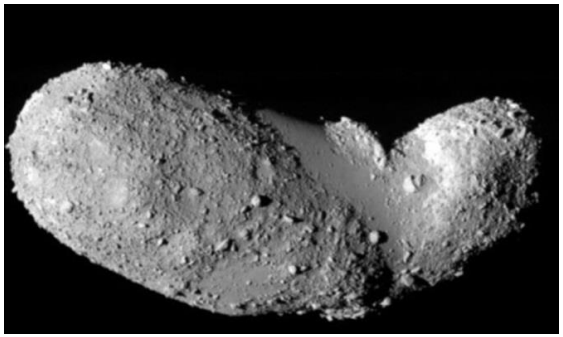
Preliminary Asteroid Redirect Mission Objectives for Option Integration

- **Primary Objectives**
  - **Human Exploration to an Asteroid in the mid-2020's that Prepares for Future Exploration**
    - Initial use of systems and components, operational experience beyond LEO, crew risk reduction
  - **Technology Demonstration: Advanced Solar Electric Propulsion**
    - High power, long lifetime
    - Enables future deep-space human exploration and enables multiple applications for Nation's aerospace community
  - **Enhanced Detection and Observation of Near Earth Asteroids for Planetary Defense**
- **Secondary Objectives**
  - **Asteroid Deflection Demonstration/Proof of Concept for Planetary Defense**
  - **Science**
  - **Future Commercial Use**
  - **Future Resource Use**
  - **Partnership Opportunities (International and Commercial)**
- **Ground Rules**
  - **Affordability**
  - **Manageable Technical Risk Tolerance**
  - **Programmatic Viability**

NASA Asteroid Redirect Mission Internal Studies

Reference robotic mission concept

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

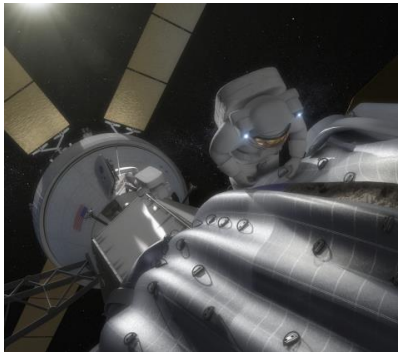


Alternate robotic mission concept

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

Crewed Mission

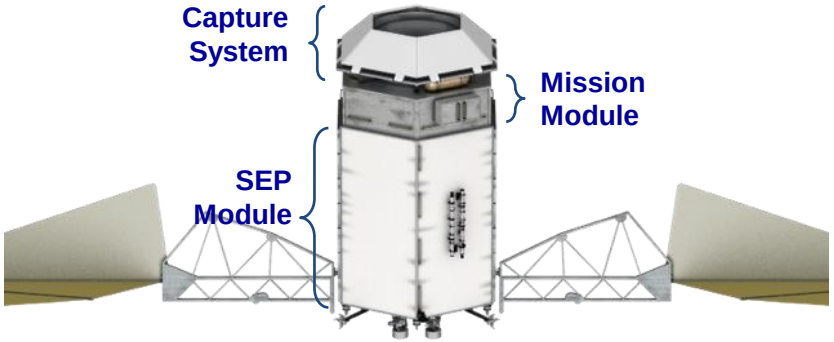
- Crew rendezvous and sampling for either concept
- Led by the Johnson Space Center



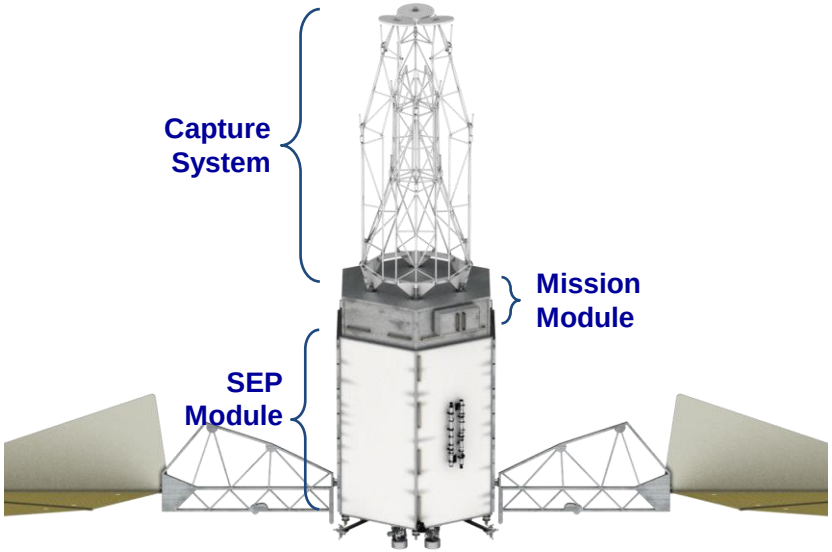
Robotic Concept Integration Team kicked off October 24

Reference and Alternate Robotic Mission Concepts Flight System Top Level Comparison

Reference



Alternate



- Identified Alternate Approach changes relative to the Reference Concept:
  - Current concept capture system differences.
  - Additions to the Mission Module:
    - Two high-speed computers (terrain relative navigation and robotics control)
    - Wide field of view and medium field of view cameras

Asteroid Initiative RFI & Ideas Synthesis Workshop

- **402 responses received for Asteroid Initiative RFI this summer**
  - Ideas Synthesis Workshop transparently explored the 96 highest rated responses

- **Workshop objectives:**
  - Further examine and foster a broad discussion on these newest ideas to help inform NASA's planning activities.
  - Specifically, to listen, discuss, debate, and synthesize 96 of the RFI responses.
  - Recommend further studies and next steps.

- **Workshop sessions covered six RFI areas + Grand Challenge (G/C):**
  - Asteroid Observation
  - Asteroid Redirection Systems
  - Asteroid Deflection Demonstrations
  - Asteroid Capture Systems
  - Crew Systems for Asteroid Exploration
  - Partnerships and Participatory Engagement
  - Crowdsourcing and Citizen Science (G/C)
  - Next Generation Engagement (G/C)

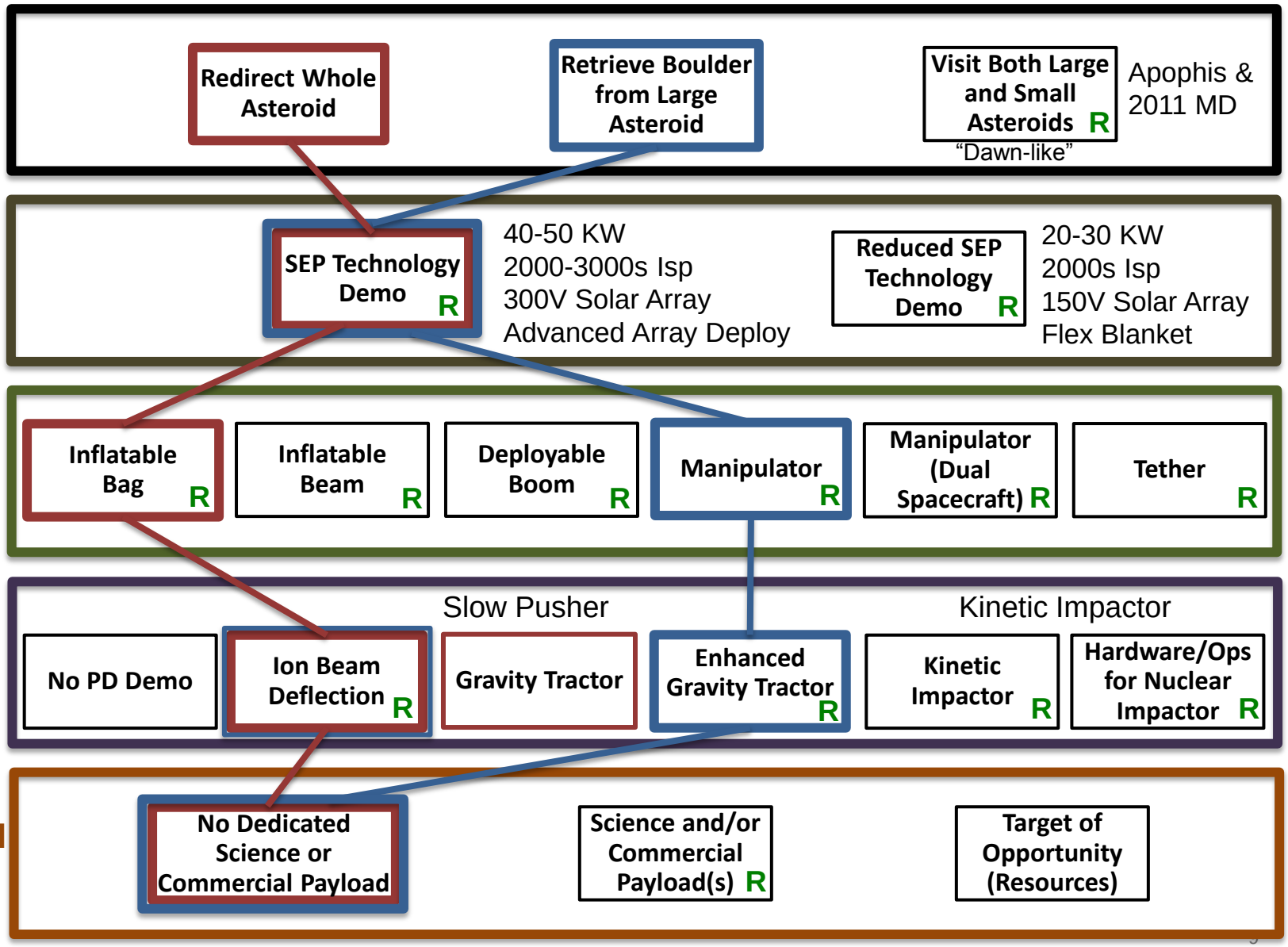
- **Workshop was held at Lunar and Planetary Institute in two parts:**
  - First part was completed September 30 before government shutdown. Approximately 150 people attended.
  - Second part was held on November 20-22. Approximately 119 people attended.
  - Over 2,000 virtual participants during both parts.

Robotic Concept Trade Space

R = Received RFI Unique Inputs

Reference PoD

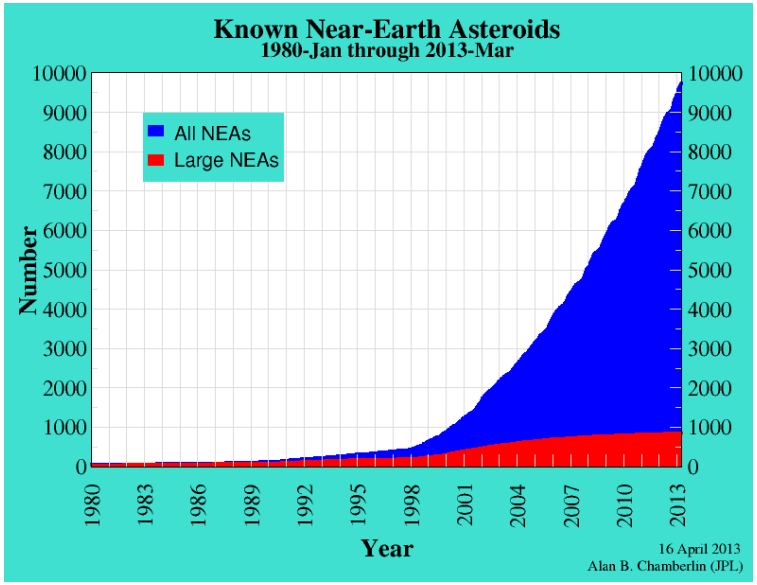
Alternate PoD

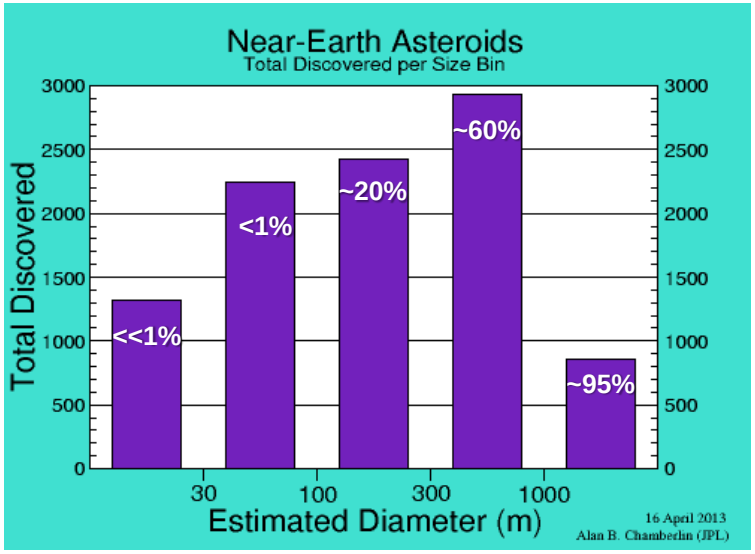


Note: Slow Pushers could work for either Reference or Alternate concepts

Near-Earth Asteroid (NEA) Population

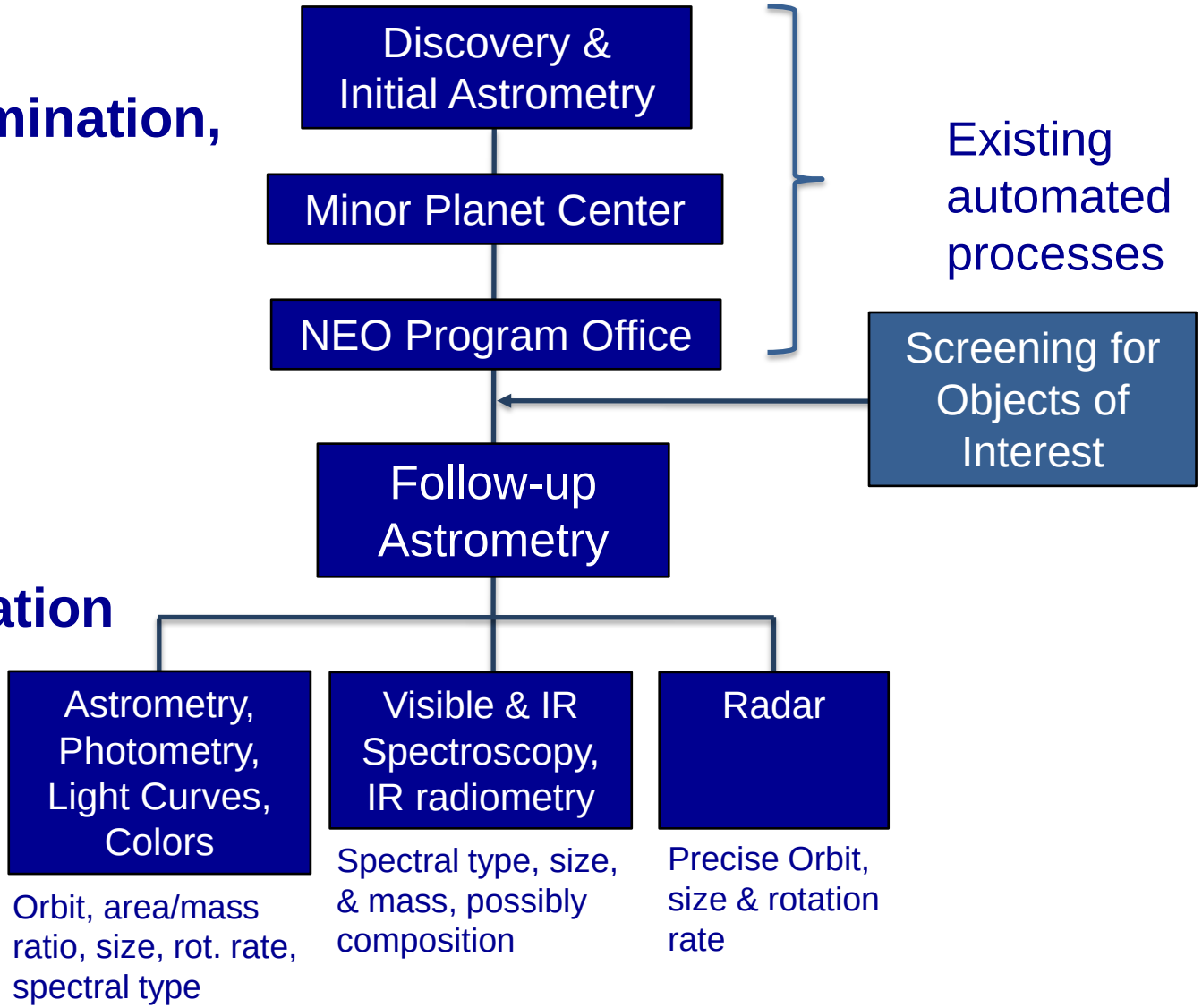
- 99% of Near-Earth Objects are asteroids (NEAs). Remaining 1% are comets.
- Current number of known NEAs: ~10,000, discovered at a rate of ~1000 per year.
- Since 1998, NASA's NEO Observation Program has led the international NEO discovery and characterization effort; this responsibility should continue in the search for smaller asteroids.
- 95% of 1-km and larger NEAs have been found; the completion percentage drops for smaller asteroids because the population increases exponentially as size decreases and they are harder to detect.





Discovery & Characterization Processes

Discovery, Orbit Determination, Rough Size Estimation



Physical Characterization

Target Nomenclature Guide

- **“Potential Candidate”:**
  - Orbit parameters satisfy rough constraints on launch date, return date and total mission delta-v.
  - Absolute magnitude indicates size lies roughly in the right range.
- **“Characterizable”:**
  - Approaches the Earth (or Spitzer) close enough, and with suitable enough observing geometry, that its physical properties can be adequately characterized.
- **“Valid Candidate”:**
  - Physical properties have been adequately characterized and lie within acceptable ranges to achieve mission goals.
  - Detailed mission design has been performed using feasible launch and return dates, and the upper bound on the mass is less than the maximum return mass from the mission design.
- **“Selectable Target”:**
  - Meets programmatic constraints (eg. on achievable schedule and minimum return size), and has identified but manageable risks.

Current Potential Candidates for Reference Mission

- Selected list of Potential Candidates for the Reference Mission:

	Name	Estimated Size (m)	V_∞ (km/s)	Earth Approach Date	Maximum Returnable Mass (t)†
	2008 EA9	5 - 22	1.9	5/6/2021	45
	2007 UN12	3 - 14	1.2	12/7/2021	90
	2010 UE51	4 - 17	1.2	12/12/2022	90
	2013 LE7	7 - 30	2.5	5/21/2023	100
Current baseline	2009 BD	2.6 - 7	1.2	6/26/2023	430
	2013 PZ6	5 - 20	n/a	8/11/2023	100
	2011 MD	4 - 20	1.0	8/10/2024	620
	2013 EC20	2 - 3	2.6	9/20/2024	45
	2013 GH66	5-18	2.0	4/18/2025	100
	2013 EC20	2 - 3	2.6	4/24/2025	90
	2013 XY20	11 - 55	1.8	12/15/2025	310
KISS baseline	2008 HU4	4 - 18	0.5	4/26/2026	800

†Assumes Falcon Heavy and launch dates no earlier than June 2019.

- Two (2009 BD and 2013 EC20) have been accurately characterized; two others (2011 MD and 2008 HU4) are characterizable.
- **Currently, there is one Valid Candidate: 2009 BD**
- Potential candidates are discovered at a rate of **2-3 per year**.
- Enhancements to discovery assets, when they come online, will likely lead to a doubling in the discovery rate.

Current Candidates for Alternate Mission:
Mid-2019 Launch & 2023-24 Return

- There are ~200 potential candidates for the Alternate Mission with return mass >~10 t and return date before the end of 2024; there are ~700 Potential Candidates with return mass >1 t.
- The current list of valid or characterizable candidates for the Alternate Mission is:

Target	Type	Asteroid V_∞ (km/s)	Earth Escape	Earth return	Max Return mass (t)	Boulder max diam (m)[c]	Characterization
Itokawa[a]	S	5.7	3/22/2019	10/7/2023	7	1.6 - 1.9	Visited by Hayabusa in 2005
Bennu[b]	C	6.4	5/13/2019	11/8/2023	10	1.9 - 2.1	OSIRIS-REx, mid-2018
1999 JU3	C	5.1	6/19/2019	7/2/2023	14	2.1 - 2.4	Hayabusa 2, mid-2018
2008 EV5[a]	C	4.4	1/10/2020	1/10/2024[d]	24	2.5 - 2.8	Radar in Dec. 2008, SNR= 240,000
2011 UW158	?	5.3	7/19/2018	7/11/2024[d]	10	1.8 - 2.1	Radar in Jul. 2015, SNR = 280,000
2009 DL46[a]	?	5.7	11/6/2019	8/12/2024[d]	11	1.9 - 2.2	Radar in May 2016, SNR= 48,000

[a]Earth gravity assist ~1yr prior to capture
[b]Falcon Heavy with 13.2 t to C_3 = -2 km^2/s^2
[c]Assuming densities in the range 2.0 to 3.0 g/cm^3
[d]2024 return

- This table assumes a Falcon Heavy L/V, Earth departure in mid-2019, 100-day stay, and return in mid-2023, unless otherwise noted.
- Green rows indicate characterization by imaging from a prior mission.
- Grey rows indicate characterization by radar and inference of appropriate-sized boulders.
- Candidates are being characterized by radar at an average rate of ~1 per year.

Current and Possible Future Valid Currently Known Candidates

- **Reference Mission:**
  - Currently, 1 valid candidate: **2009 BD**.
  - Possibly another valid candidate in 2 months: **2011 MD**.
  - Possibly another valid candidate in 2016: **2008 HU4**.
  - Potentially future valid candidates, at a rate of a few per year.

- **Alternate Mission:**
  - Currently, 1 valid candidate: **Itokawa**.
  - 2 more valid candidates expected in 2018 (after characterization by other missions): **Bennu** and **1999 JU3**.
  - 1 possibly valid candidate with inferred boulders: **2008 EV5**.
  - Potentially future valid candidates with inferred boulders, at a rate of ~1 per year.

Solar Power Technology Development for SEP

Both solar array developments on target

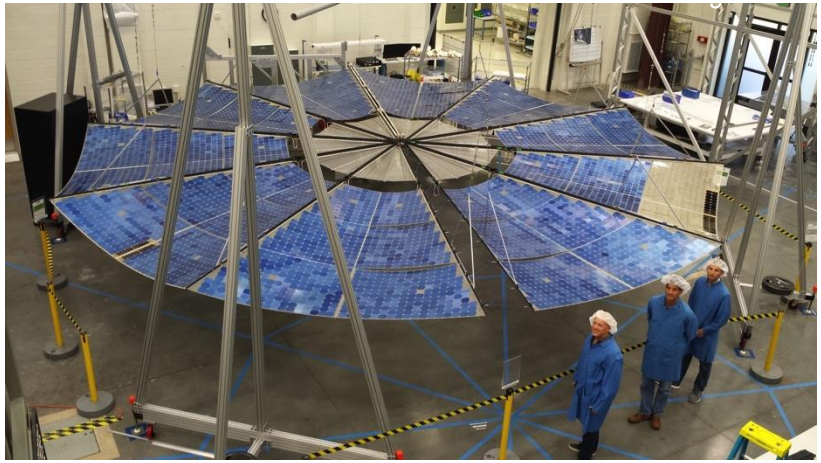
- MegaFlex “fold-out” solar array (TRL 5 Apr 2014)
- Mega-ROSA “roll-out” solar array (ROSA TRL 5 Jun 2014)

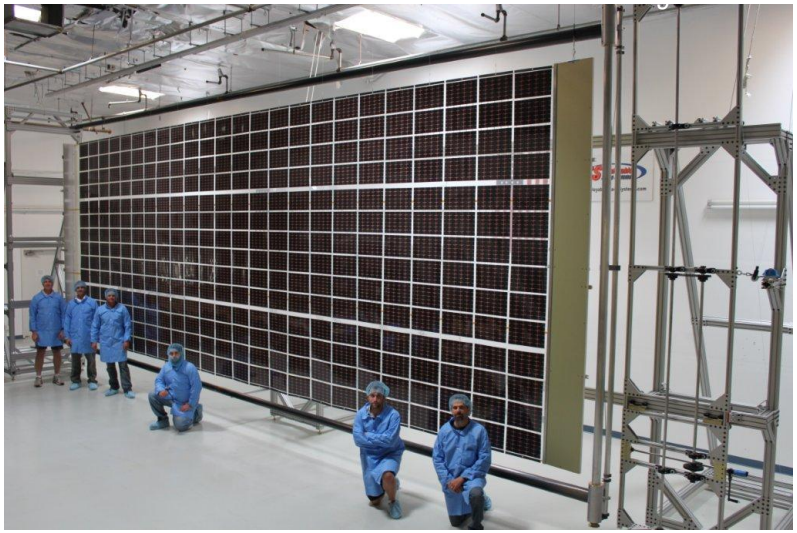
Testing to include

- Thermal vacuum deployment
- Stowed wing vibro-acoustic exposure

Recent/Near-term activity

- ATK MegaFlex solar array successfully completed TRR on 21 Nov 2013
- ATK MegaFlex Deployment & Open House 09 Dec 2013
- ATK MegaFlex delivery to GRC/PBS mid-Jan; testing Jan/Feb 2014
- DSS MegaROSA TRR scheduled 21 Jan 2014





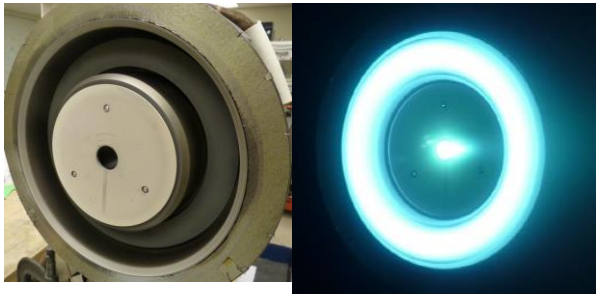
Electric Propulsion Technology Development for SEP

Thruster and PPU developments on target

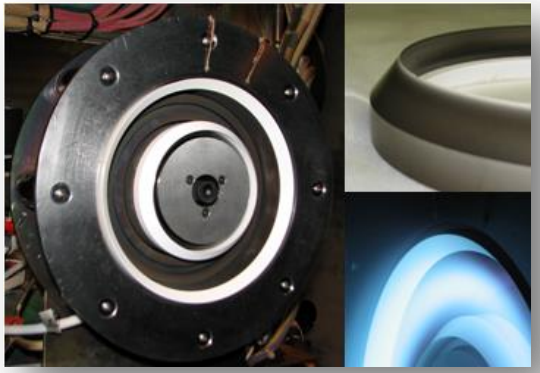
- Design, build and test 12.5 kW Hall thruster
- Design, build and test PPU/DDU systems compatible with Hall Thruster implementations

Recent/Near-term activity

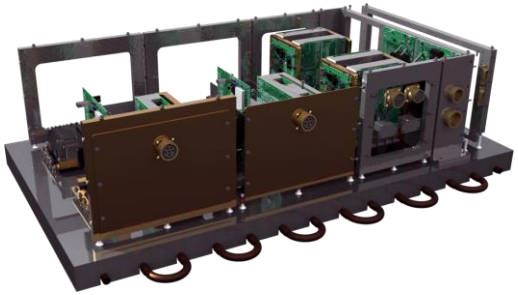
- Design progressing on 12.5 kW Hall thruster EDU
- Viability of using magnetic shielding to mitigate channel erosion demonstrated at up to 3000-sec specific impulse and 20 kW power with NASA 300M and JPL H6 thrusters
- High-voltage (300V) PPU EDU design complete. Fabrication in progress.
- Design progressing on moderate-voltage (120V) PPU EDU
- Design progressing (fabrication on hold) for high-voltage direct drive (300V) EDU
- Integrated thruster performance and wear test with 120V PPU by end of FY14



GRC 300M with magnetic shielding



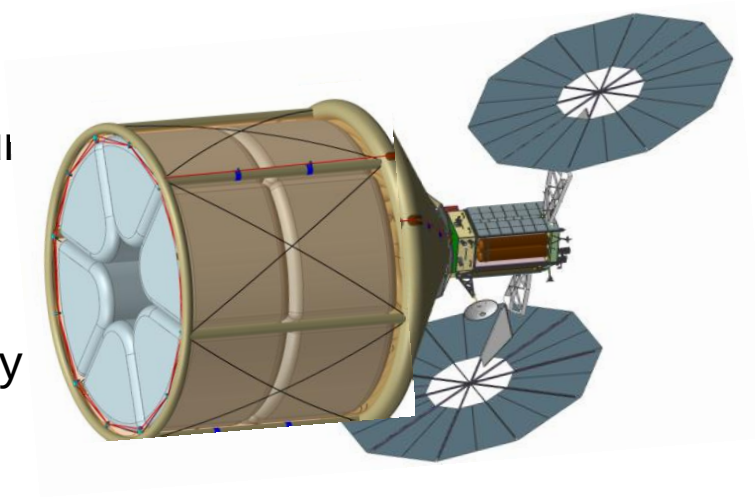
JPL H6 with magnetic shielding

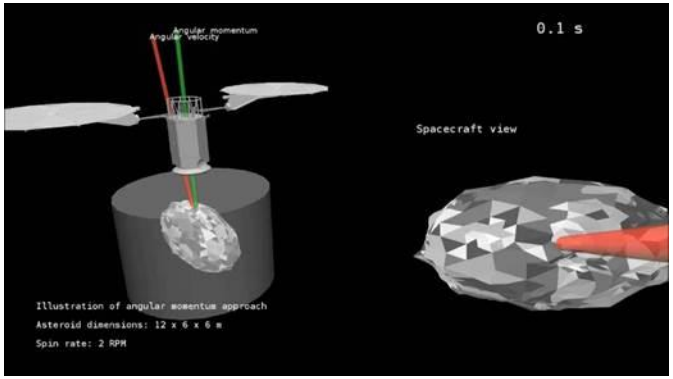


Cut away of NASA 300V PPU

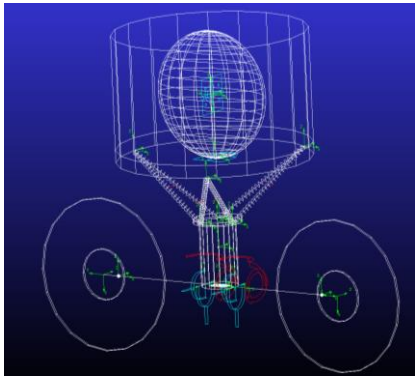
Inflatable Capture Mechanism Concept Status

- Capture bag designed to capture/control a worst case irregular shaped “rubble pile” asteroid with maximum dimension of up to ~13 meters. Maximum target size also dependent on maximum mass that can be returned from target’s orbit.
- Design is evolving based on discussions with potential vendors about materials, manufacturability and costs.
- RFI inputs provide other options for capturing slow rotators that will be studied more in coming months





- Performed two independent dynamics analyses to assure robust system for capture at slow and fast rotation states while limiting forces on S/C.
- Monte Carlo analyses show good performance over wide range of asteroid size and mass properties



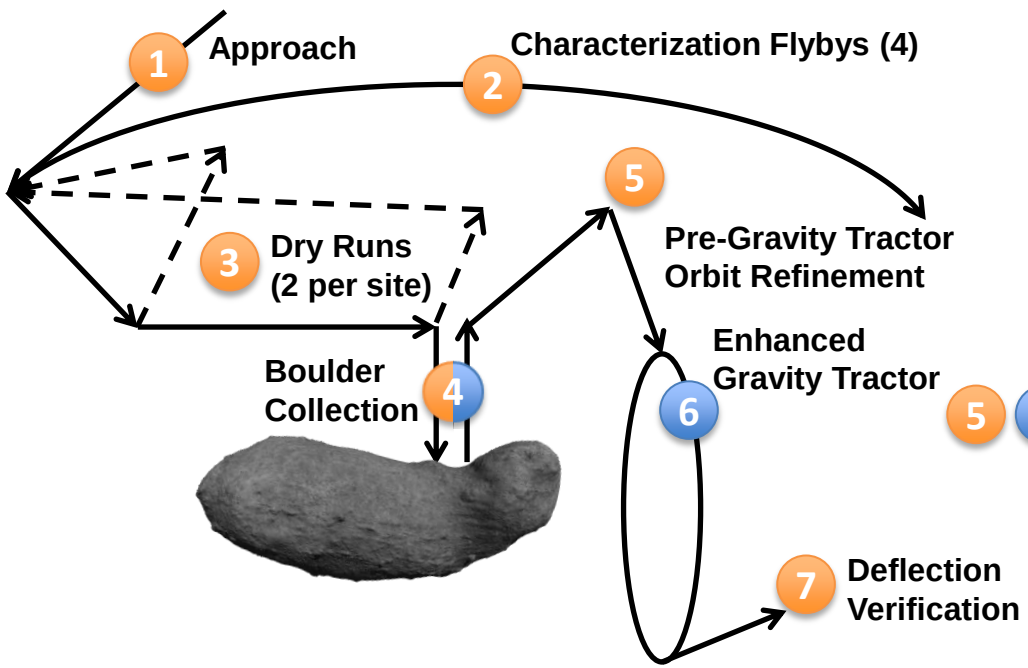
Alternate Robotic Mission Concept Proximity Operations Overview

Proximity Operations Timeline (400 days)

1	2	3	4	Reserve (3 & 4)	5	6	Reserve (6) & Wait	7	Margin

Operations heritage to prior robotic missions

Mission unique operations



1 2 **Approach, Flybys, & Characterization:** 37 days to verify and refine shape, spin, and gravity models, and obtain ~cm imagery for majority of the surface.

3 **Dry Runs:** 2 dry runs at up to 3 sites refine local gravity, provide sub-cm imagery, and verify navigation performance.

4 **Boulder Collection:** Reserving for up to 5 boulder collection attempts provides contingency against surface and boulder anomalies.

5 6 7 **Enhanced GT Demonstration:** 260 days allows for operations and proper Earth-Itokawa alignment to verify deflection.

6 **Enhanced Gravity Tractor (EGT):** 180 days reserved for EGT operations, 60 days required for measurable deflection.

Operations Margin: In addition to conservative operations profile, 19 days of unencumbered operations schedule reserve is provided in mission plan.

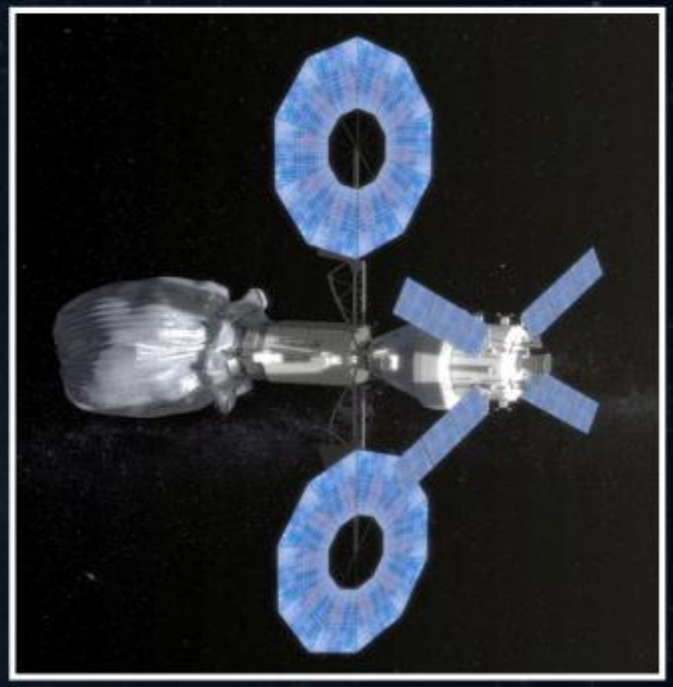
Why ARM for HSF?

- Early crewed beyond LEO missions should do four things:
  - Be consistent with the Administration's Space Policy involving an Asteroid in mid 2020s and Mars in 2030s
  - Support and be aligned with the Global Exploration Roadmap and interests of our International Partners which includes missions in the lunar vicinity
  - Take advantage of existing capabilities being developed within HEOMD and other parts of the Agency
  - Be affordable and sustainable with our Congressional stakeholders with only very modest budget increases
- We looked at numerous mission possibilities with the early SLS and Orion and concluded that bringing an asteroid to cis-lunar space so that it could be sampled by astronauts in Orion was the best use of all the capabilities being developed and provided the most compelling early mission that advanced exploration as fast as possible given the four objectives above.
- This mission also leverages the STMD Solar Electric Propulsion technology, including the advanced solar arrays and magnetically shielded hall thrusters, that feed forward to delivering cargo to Mars and the lunar vicinity.
- This mission also advances EVA, the International Docking System Block II, Automated Rendezvous & Docking, and complex operations which all feed forward to future deep space and Mars exploration.
- We essentially move forward as fast as possible given all the constraints and in the process move a heavenly body from one place in the solar system to another with only a small increase in budget.

Asteroid Redirect Crewed Mission Overview

Deliver crew
on SLS/Orion

Attached Orion to robotic spacecraft



Perform extra-vehicular activity (EVA) to retrieve asteroid samples

Return crew safely to Earth with
asteroid samples in Orion

Principles for Incrementally Building Capabilities

Six key strategic principles to provide a sustainable program:

1. Executable with current *budget with modest increases*
2. Application of *high Technology Readiness Level* (TRL) technologies for near term, while focusing research on technologies to address challenges of future missions
3. *Near-term mission* opportunities with a defined cadence of compelling missions providing for an incremental buildup of capabilities for more complex missions over time
4. Opportunities for *US commercial business* to further enhance the experience and business base learned from the ISS logistics and crew market
5. *Multi-use* space infrastructure
6. Significant *international and commercial participation*, leveraging current International Space Station partnerships and commercial companies

Asteroid Redirect Crewed Mission Leverages On-Going Work

- STORRM (Sensor Test for Orion RelNav Risk Mitigation) recent tests in Space Operations Simulation Center
  - Rendezvous sensor leveraged from shuttle & demonstration test on ISS
  - Vision Navigation Sensor & high def docking camera
- NASA Docking System Block 1 making progress and completed PDR
- Modified Aces Testing in Neutral Bouyancy Testing with two four hour duration EVAs and plan for 2014
- Progress on Exploration Portable Life Support System and Variable Oxygen Regulator Testing at White Sands
- Completed contingency abort analysis for the mission and initial stack attitude control analysis

FY13 Modified ACES Testing Progress

Winter 2012

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

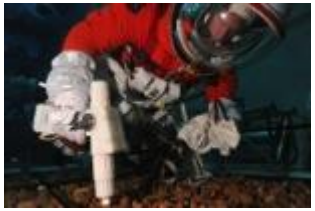
June 28th – Test #3 (2hr)

Improvements in suit fit procedures needed

July 22nd – Test #5 (2hr)

Great capability improvements observed in subsequent runs indicating that training on the suit is vital.

Sept. 25th – Test #8 (4hr)



Best demonstration of suit capability, attributed to good suit fit that allowed the subject easier access to standard work envelope.

May | June | July | August | September

May 5th – Test #1 (2hr)

Established baseline weigh out and ECS interface (both to be improved)

June 7th – Test #2 (2hr)

Established need for robust EVA gloves (EMU PhaseVI)

July 12th – Test #4 (2hr)

Two-handed task difficulties established need for suit shoulder biasing and better worksite stabilization

Sept. 6th – Test #6 (3hr)

Suit fit specific to EVA operations continues to be a significant performance factor

Sept. 16th – Test #7 (4hr)

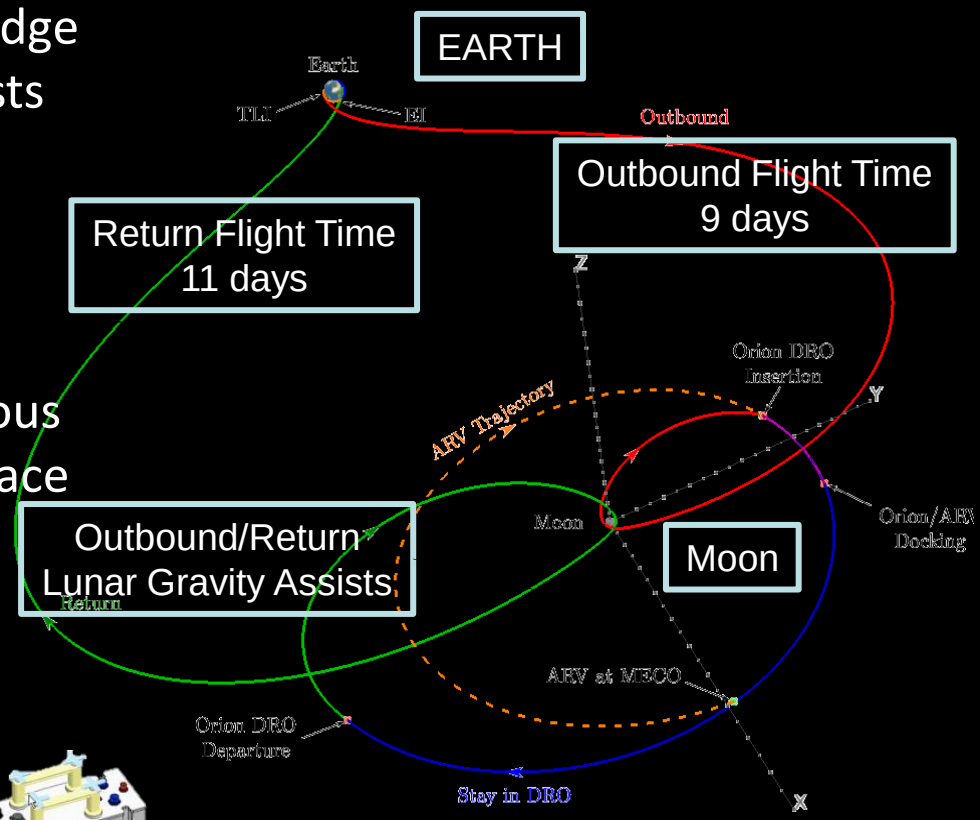
Suit system demonstrated feasibility of 4 hour EVAs.

Hardware and Procedure Improvements

- Improved weights
- Phase IV Gloves
- Added tool harness
- Cooling System modifications
- Drink bag included
- Improved Poolside Procedure
- New liquid cooling garment

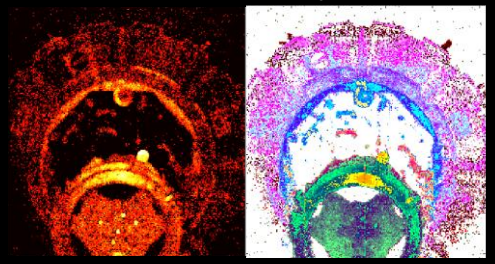
ARM Trajectory and Rendezvous

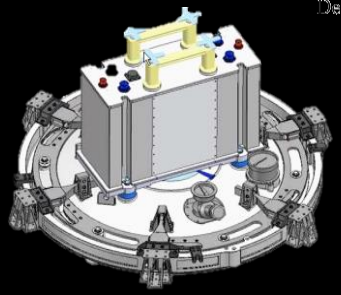
- Common sensors derived from knowledge gained from Space Shuttle Detailed Tests
- Synergy between crewed and robotic mission sensors
- Trajectory launch constraints, rendezvous techniques, navigation enable deep space



STORRM Camera Image

STORRM LIDAR Images

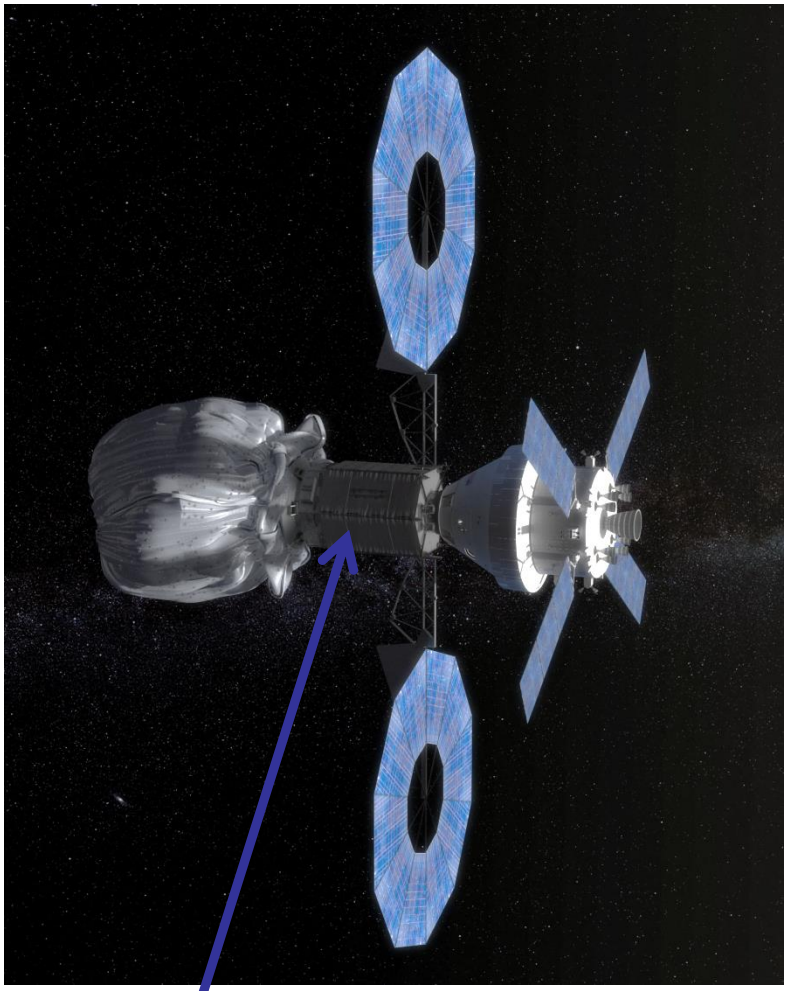




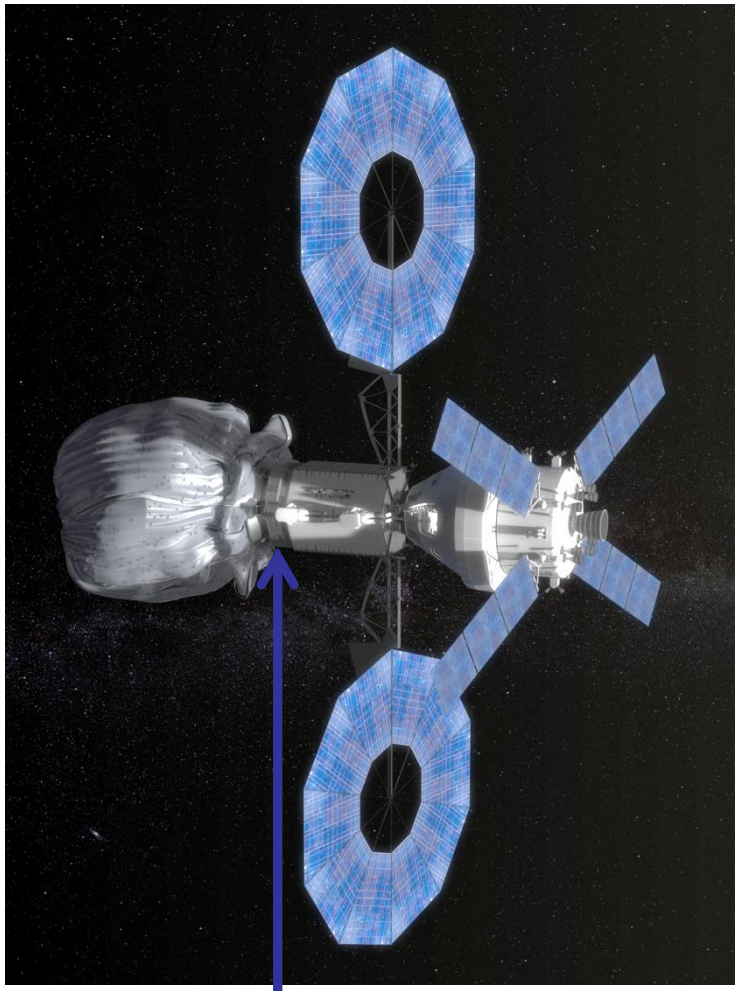
Notional Relative Navigation Sensor Kit

Outbound Flight Time: 8 days, 9 hrs
Return Flight Time: 11 days, 6 hrs
Rendezvous Time: 1 day
DRO Stay Time: 5 days

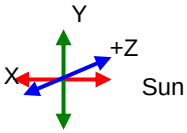
Integrated Stack Flight Attitude Analysis



Solar Inertial Attitude



EVA Biased Attitude



- Extensive shading in unbiased solar inertial attitude
- Biasing attitude allows for adequate EVA lighting and thermal conditions
- Orion required to maneuver integrated vehicle to EVA attitude

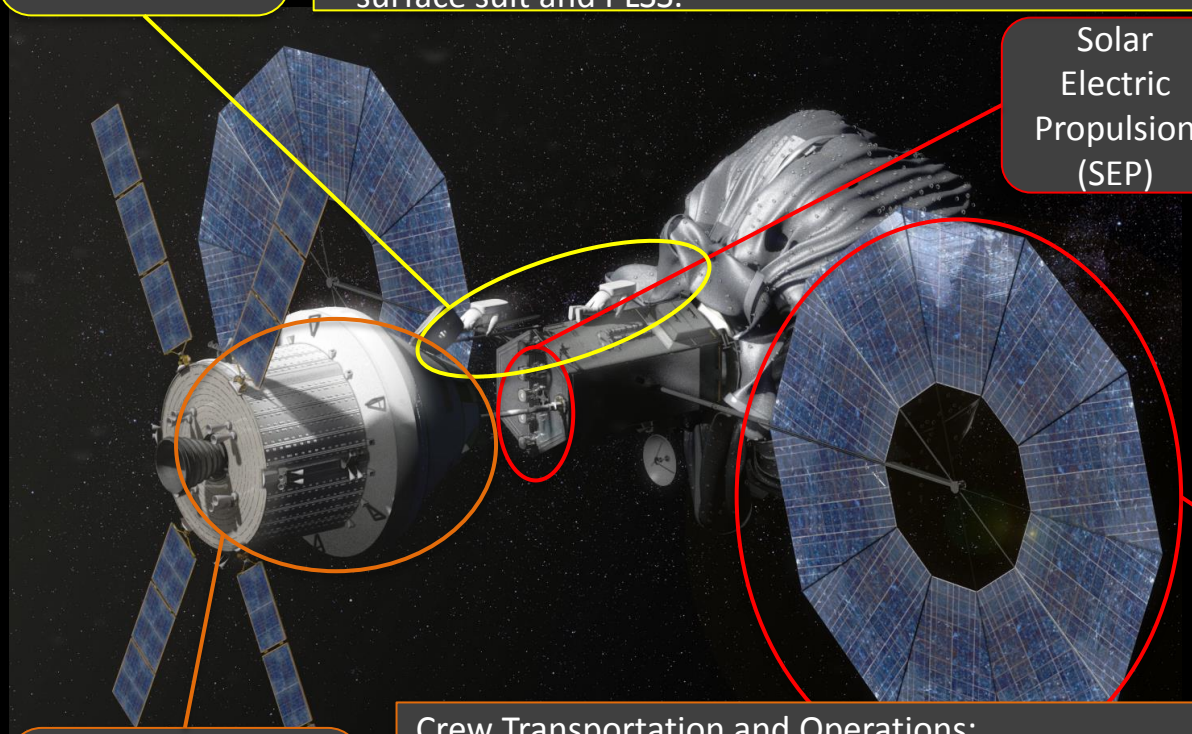
ARM Provides First Steps to Mars/Other Destinations

	Sequence \ Mission	Current ISS Mission	Asteroid Redirect Mission	Long Stay In Deep Space	Mars Orbit	Mars Surface, Short Stay	Mars Surface, Long Stay
Mars Destination Capabilities	In Situ Resource Utilization & Surface Power						X
	Surface Habitat						X
	Entry Descent Landing, Human Lander					X	X
	Advanced Cryogenic Upper Stage				X	X	X
Initial Exploration Capabilities	Solar Electric Propulsion for Cargo		X	X	X	X	X
	Exploration EVA		X	X	X	X	X
	Crew Operations beyond LEO (Orion)		X	X	X	X	X
	Deep Space Guidance Navigation and Control/Automated Rendezvous		X	X	X	X	X
	Crew Return from Beyond LEO – High Speed Entry (Orion)		X	X	X	X	X
	Heavy Lift Beyond LEO (SLS)		X	X	X	X	X
ISS Derived Capabilities	Deep Space Habitat	*		X	X	X	X
	High Reliability Life Support	*		X	X	X	X
	Autonomous Assembly	*		X	X	X	X

Asteroid Initiative Extensibility for future Deep Space/Mars Missions

Exploration EVA Capabilities

EVA:
- EVA kits build capability for future exploration:
  - MACES
  - PLSS (Design accommodates Mars)
- Follow-on Asteroid Utilization mission can provide more capable micro-g exploration suit
- Technologies allow NASA to develop the next generation surface suit and PLSS.



Solar Electric Propulsion (SEP)

In-space Power and Propulsion :
- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 50kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

High Efficiency Large Solar Arrays

Deep Space Rendezvous Sensors & Docking Capabilities

Crew Transportation and Operations:
- 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.

Target NEO2 Workshop July 9, 2013 Findings Compared to Planning Status

Target NEO2 Finding	Current ARM Planning Status
Establish clear [robotic mission] requirements and success criteria that demonstrate how the mission contributes to future human space exploration	Mission objectives have evolved during this period of pre-formulation. Current objectives were presented at the Asteroid Initiative Ideas Synthesis workshop Nov. 20. Mission requirements and success criteria will be established in formulation.
Establish a realistic and achievable schedule based on assessment of technical and programmatic requirements	Concept studies are examining aspects of technical options and programmatic feasibility. Mission cost and schedule will be established in formulation.
Provide a realistic, independently assessed cost cap that fully accounts for all mission-related costs	Cost and schedule options of concept studies are undergoing independent cost assessment sanity checks. Mission cost and schedule will be established in formulation.
Utilize the established processes of competition and peer review to define and assess the ARRM, to verify its feasibility within the established cost cap, and to determine and maximize the probability of mission success	The acquisition strategy for this activity is to leverage on-going activities . Pre-formulation includes two concept studies which are assessed by a robotic concept integration team, leading to selection of an independently assessed, viable concept for formulation.
Determine resources needed to provide upgrades to key ground-based observatories to improve detection rate and follow-up characterization capabilities	Initial upgrades to ground-based observatories for detection and follow-up characterization have been defined by the NEO Program. Improvements will continue to be identified.
Improve remote characterization follow-up procedures with identified assets	Improvements to follow-up procedures have been defined and are being implemented within the NEO Program. Improvements will continue to be identified.
Consider small robotic precursor missions to close characterization risks	Suggested robotic precursor missions are part of the Asteroid Initiative Request for Information released in June, open synthesis workshops, and robotic concept integration team assessments.
Fly a space-based NEO survey telescope	NASA's FY14 budget request includes doubling of resources for the NEO Program. NASA has also engaged in partnerships to increase the NEO detection rate. Concepts for hosted survey instruments are being assessed.

Near Term Schedule

• Request for Information Release	Jun 18, 2013 ✓
• Internal Concepts Review	Jul 30, 2013 ✓
• Ideas Synthesis Part 1 (RFI responses)	Sep 30, 2013 ✓
• Robotic Concept Integration Team Kicked Off	Oct 25, 2013 ✓
• Ideas Synthesis Resumed (RFI responses)	Nov 20-22, 2013 ✓
• Integrated Status	Dec 17, 2013 ✓
– Crewed Mission Concept Updates	
– Asteroid Observation Status	
– Reference Robotic Mission Concept Updates	
– Alternate Robotic Mission Concept Updates	
– Robotic Concept Integration	
• FY15 Budget Request Release	Feb 3, 2014
• Spitzer Observation of 2011MD	Feb 15, 2014
• Open Engagement Day (previously known as Industry Day)	Mid Mar 2014
• HEOMD MACES EVA end-to-end mission sim complete	Apr 2014
• STMD Solar Array Systems development Phase1 complete	Apr 2014
• STMC integrated thruster performance and wear test with 120V PPU	End of FY14
• MCR/ASM	End of FY14 (TBR)

Request to SBAG

- To inform mission pre-formulation, we request your scientific assessment in these areas:
  - Assessment of likely physical composition of near-Earth asteroids < 10m mean diameter
  - Assessment of likelihood and diversity of boulders on larger (>50 meter) near-Earth asteroids
    - Presence of “free-standing” boulders
    - Friability of boulders for various asteroid types
    - Also, assessment of <10m boulders on Itokawa
  - Current relevant findings based on meteorites collected on Earth
  - Sample selection, e.g. identification of objects/areas on a specific asteroid that would be of most interest from a science perspective
  - Science considerations for sample collection, e.g. important aspects and techniques
- *In addition,* a few SBAG members to represent the above to the RCIT and for science and planetary defense FOM assessment of the robotic mission


A DEEPER VISION, A BOLDER MISSION, ONE STEP AT A TIME
Step One:
2014