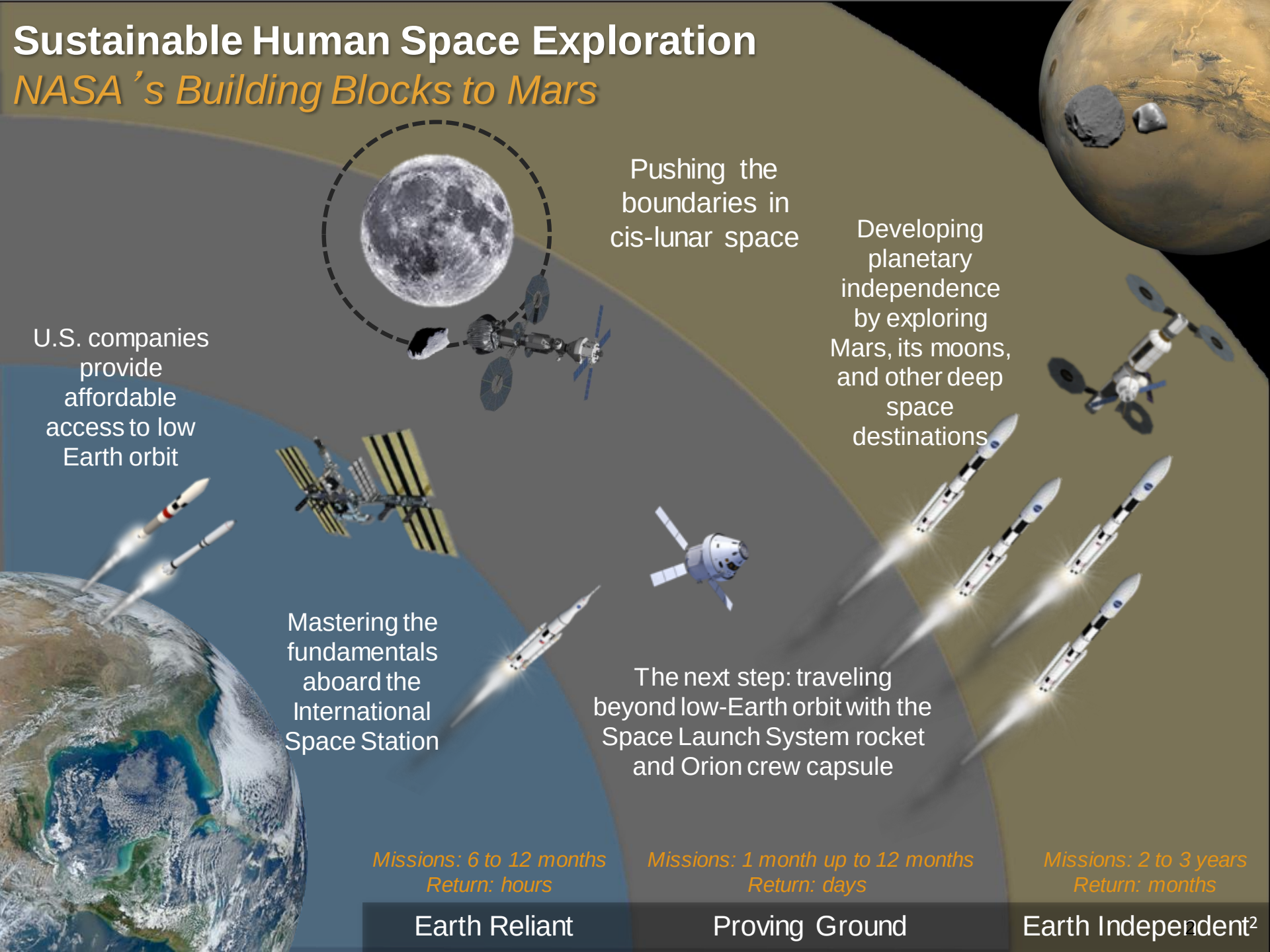
National Aeronautics and Space Administration

Asteroid Redirect Mission (ARM) Overview
NASA Advisory Council
Planetary Protection Committee
November 17, 2014

Dr. Michele Gates, ARM Program Director
Steve Stich, ARM Crewed Mission Lead
Bob Gershman, Planetary Protection Considerations

Sustainable Human Space Exploration

NASA's Building Blocks to Mars



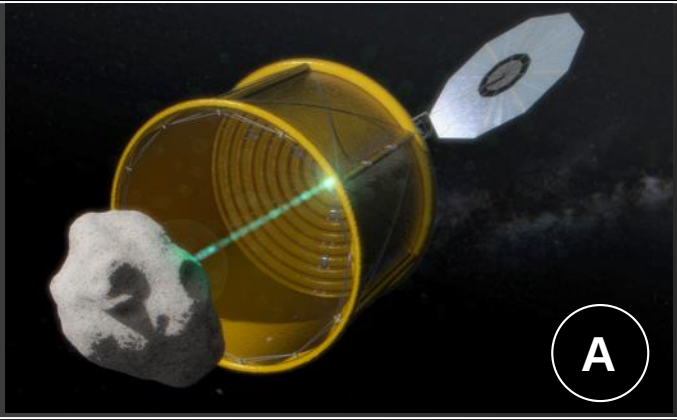
Asteroid Redirect Mission: Three Main Segments

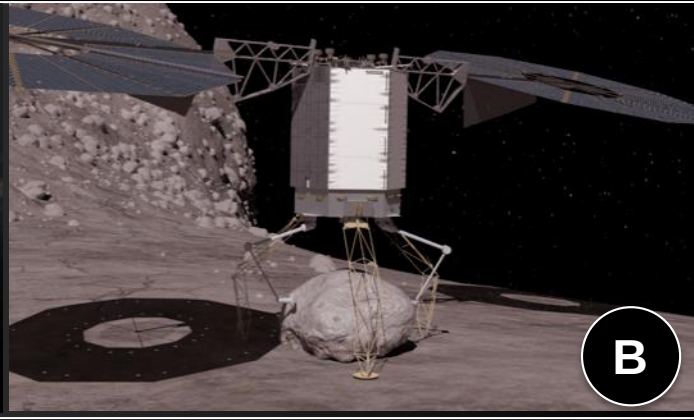
IDENTIFY

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

Asteroid Redirect Mission
Current Objectives

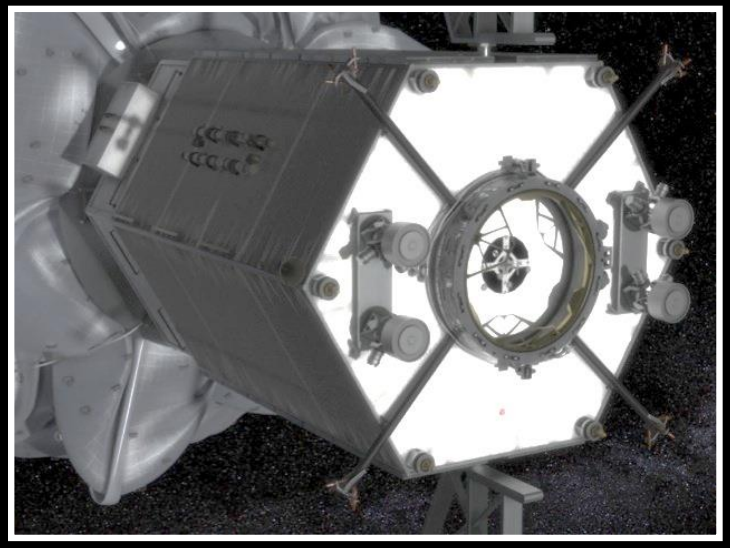
1. **Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.**

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.**

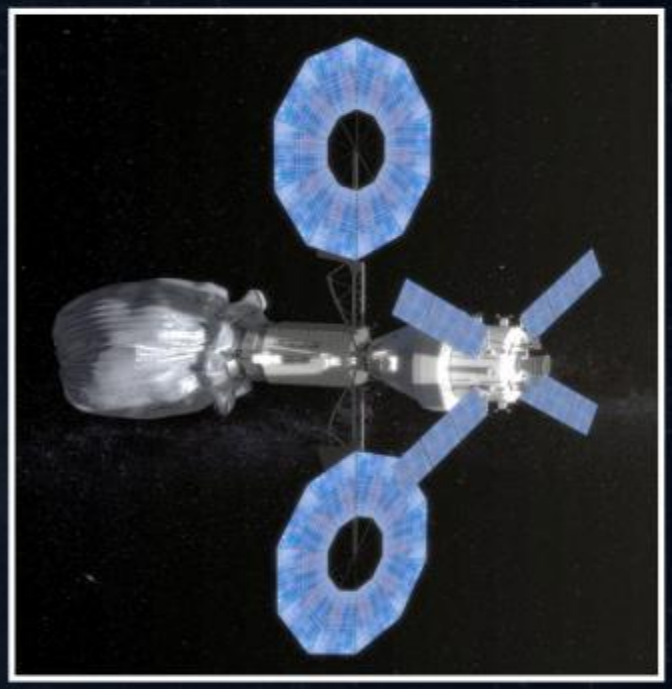
5. **Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroid resources for commercial and exploration needs.**



Asteroid Redirect Crewed Mission Overview

Deliver Crew on SLS and Orion

Orion Travels To and Docks with Robotic Spacecraft



Perform extra-vehicular activity to retrieve asteroid samples

Return crew safely to Earth with asteroid samples in Orion

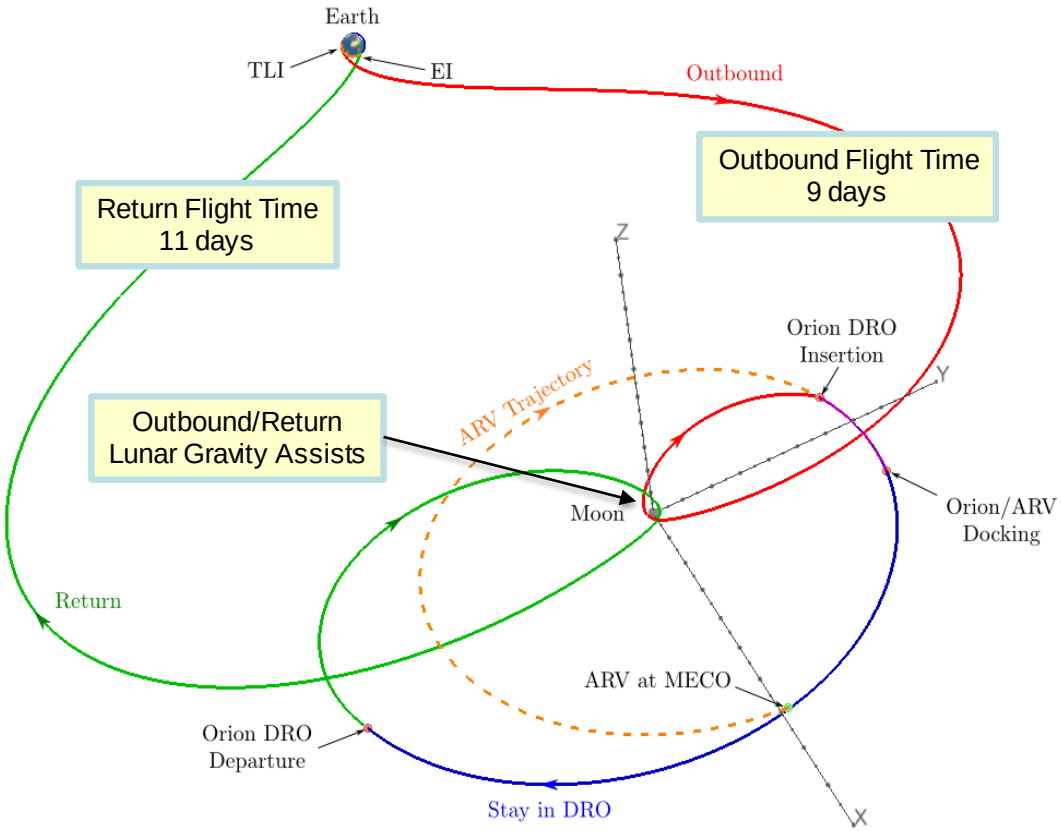
Crewed Mission Sample Trajectory: Earliest Mission for 2009BD

- MECO Epoch: 2024-May-16 14:36:08 TDB
- Entry velocity: 10.99 km/s

- Total iCPS Δv: 2820 m/s (All iCPS capacity)
- Total Orion Δv: 1010 m/s
- Total Mission Duration: 25.65 days

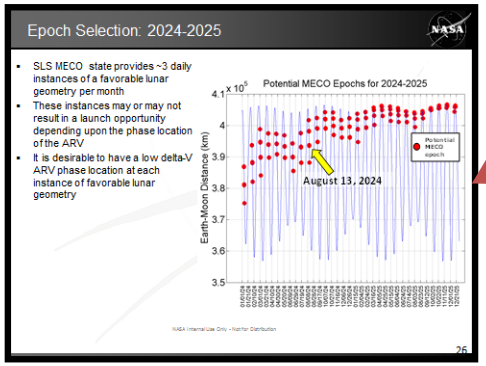
- Outbound
  - Flight Day 1 – Launch/TLI
  - Flight Day 1-7 – Outbound Trans-Lunar Cruise
  - Flight Day 7 – Lunar Gravity Assist
  - Flight Day 7-9 – Lunar to DRO Cruise
- Joint Operations
  - Flight Day 9-10 – Rendezvous
  - Flight Day 11 – EVA #1
  - Flight Day 12 – Suit Refurbishment, EVA #2 Prep
  - Flight Day 13 – EVA #2
  - Flight Day 14 – Contingency/Departure Prep
  - Flight Day 15 – Departure
- Inbound
  - Flight Day 15 – 20 – DRO to Lunar Cruise
  - Flight Day 20 – Lunar Gravity Assist
  - Flight Day 20-26 – Inbound Trans-Lunar Cruise
  - Flight Day 26 – Earth Entry and Recovery

Mission Duration and timing of specific events will vary slightly based on launch date and trajectory strategy



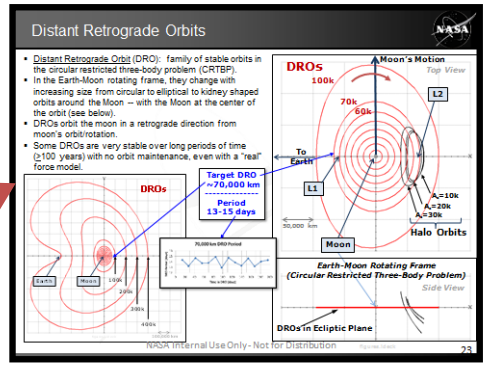
Outbound Flight Time: 8 days, 9 hrs
Return Flight Time: 11 days, 6 hrs
Rendezvous Time: 1 day
DRO Stay Time: 5 days

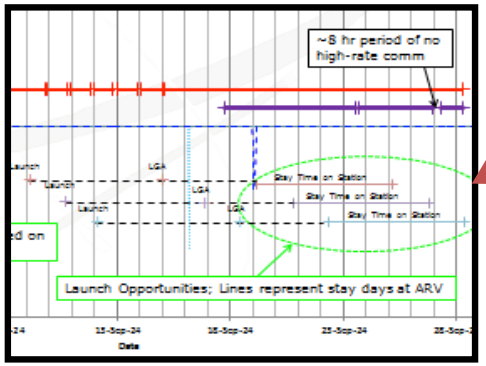
Crewed Mission Design Considerations



Launch Availability ~2-3 opportunities per month

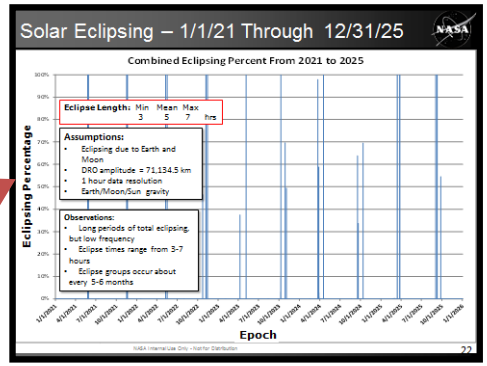
71433km DRO improves launch availability by syncing with Lunar period

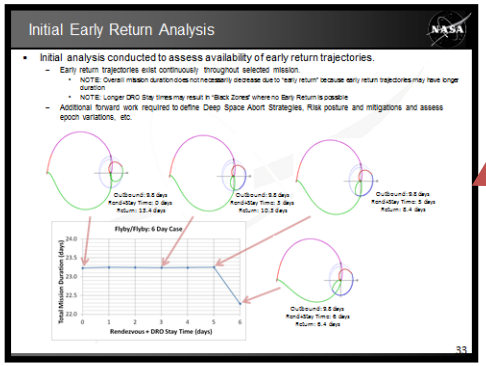




Acceptable Communications Coverage for Orion/ARRV

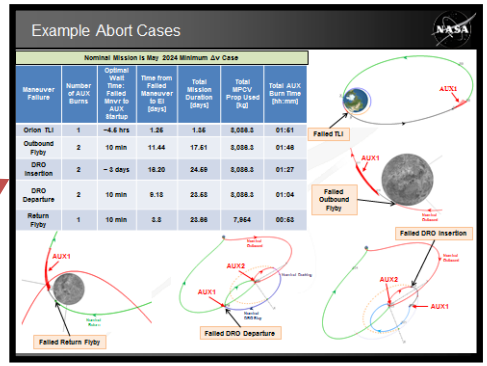
Long Solar Eclipse Periods Manageable for launch availability





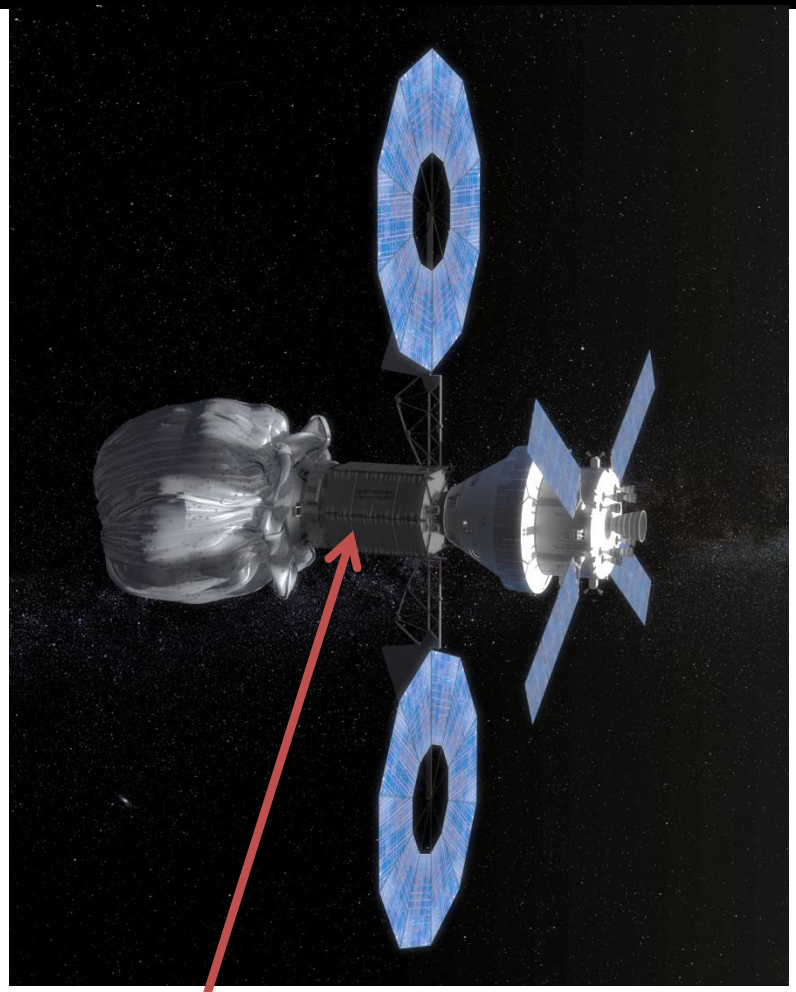
Orion Propellant Available for Early Return Throughout Mission

Orion Propellant Allows Auxiliary Thruster Contingency Return

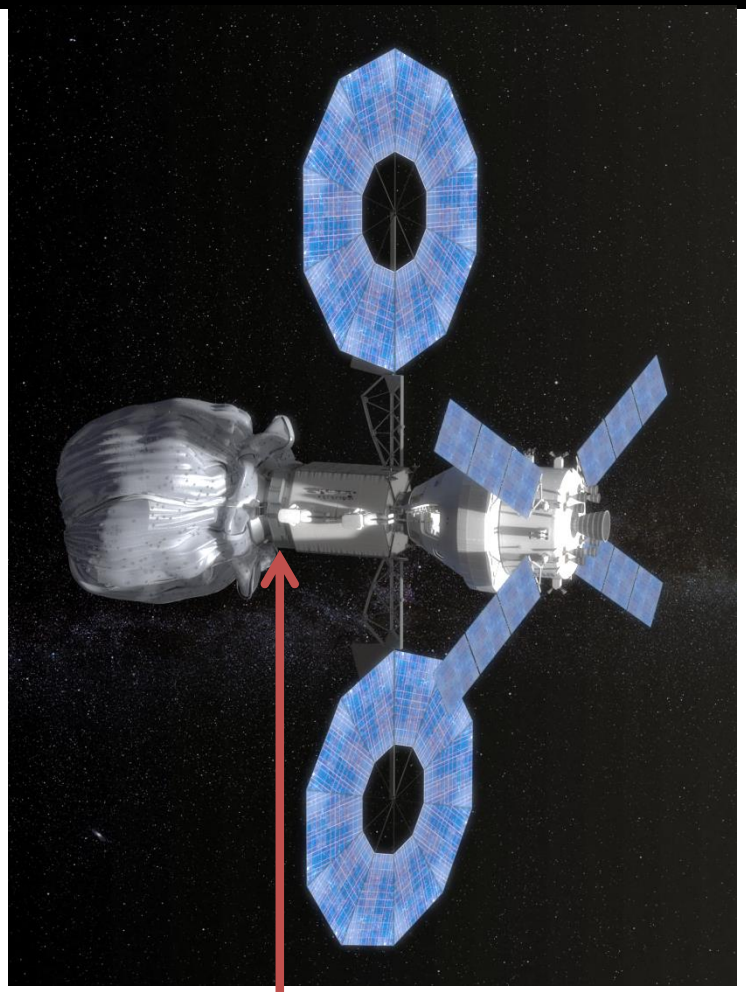


Maneuver Failure	Number of AUX Burns	Optimal Wait Time: Failed Mnvr to AUX Startup	Time from Failed Maneuver to ID (days)	Total Mission Duration (days)	Total MPCV Prop Used (kg)	Total AUX Burn Time (hh:mm)
Orion TLI	1	~4.6 hrs	1.26	1.56	8,088.3	01:61
Outbound Flyby	2	10 min	11.44	17.61	8,088.3	01:48
DRO Insertion	2	~ 3 days	18.20	24.69	8,088.3	01:27
DRO Departure	2	10 min	9.13	23.63	8,088.3	01:04
Return Flyby	1	10 min	3.3	23.88	7,964	00:63

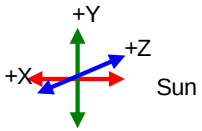
Assessment of Integrated Flight Attitude



Solar Inertial Attitude



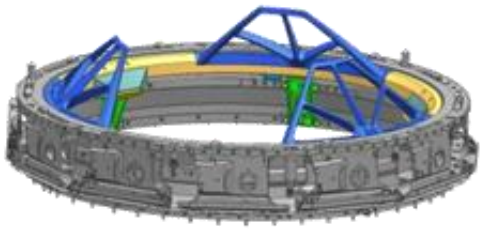
EVA Biased Attitude



NOTE : Established joint ARRV/Orion/Integrated Stack Coordinate Reference Frame

- Extensive shading in unbiased solar inertial attitude
- Biasing attitude allows for adequate EVA lighting and thermal conditions

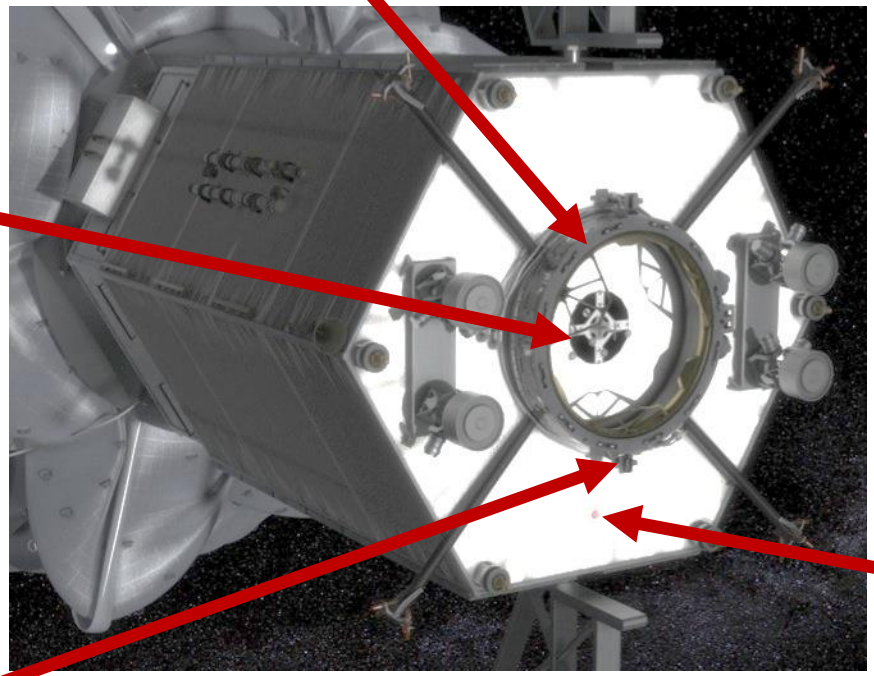
Accommodations for Crewed Mission (Docking)



Docking Mechanism
- IDSS-compatible, passive side

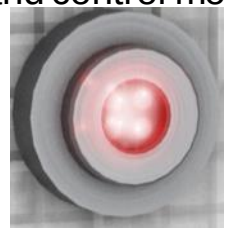
Vehicle-to-Vehicle Comm
- Orion compatible low-rate S-band with transponder

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



Reflectors
- Tracked by the LIDAR during rendezvous and docking

LED Status Lights
- Indicate the state of the ARRV systems, inhibits and control mode



Power and Data Transfer
- Transfer through connectors already part of the docking mechanism design; Supports extensibility

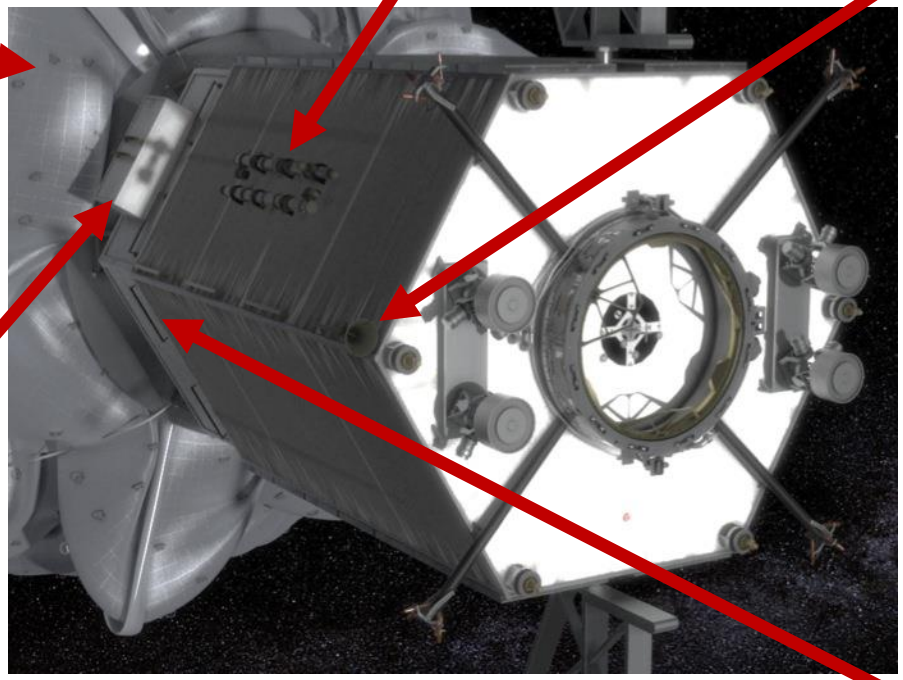
Accommodations for Crewed Mission (EVA)

Extra Vehicular Activity (EVA) Translation Booms

- Translation Booms for Asteroid EVA

EVA Tether Points

- Hand-over-hand translation
- Temporary tool restraint
- Management of loose fabric folds



EVA Translation Attach Hardware

- Circumference of Mission Module at base of Capture System and ARV-Orion Interface

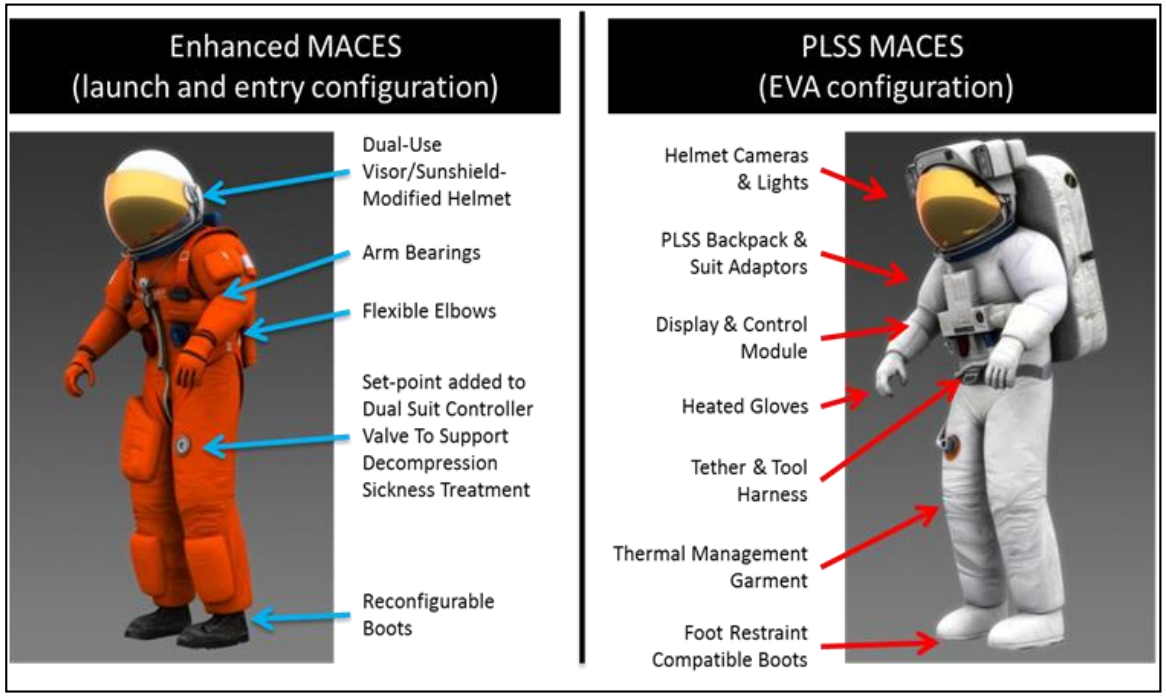
Hand Rails

- Translation path to capture bag
- Ring of hand rails near capture bag

Pre-positioned EVA Tool Box

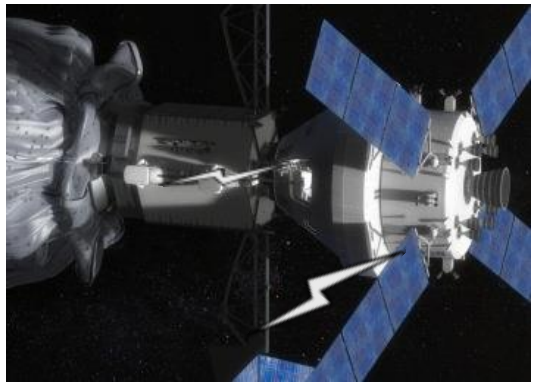
- Tool box stores 85 kg tools

Mission Kit Concept Enables Affordable Crewed Mission

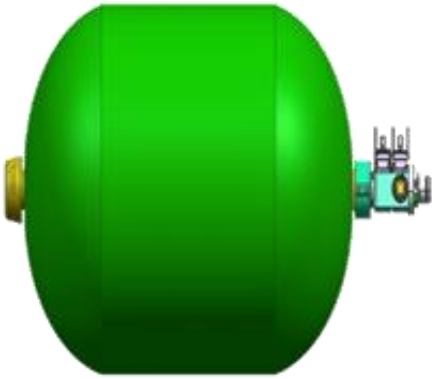


Tools & Translation Aids

Sample Container Kit



EVA Communications Kit



Repress Kit

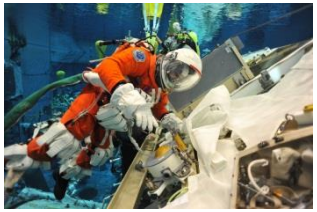
Most hardware needed for other exploration missions

Modified ACES Suit 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

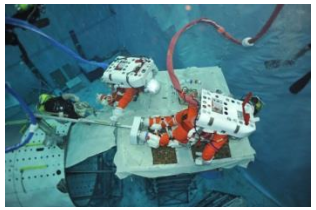
Initial NBL testing has shown feasibility of doing many asteroid retrieval sampling tasks using a MACES. Continued testing with a variety of crew member sizes, along with incremental suit and tool enhancements is critical in order to validate the concept.

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)

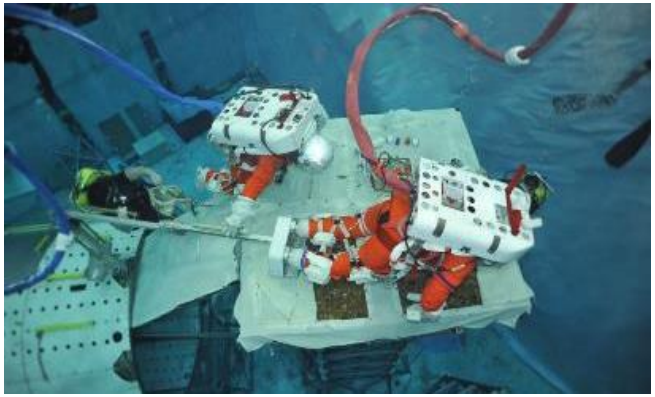
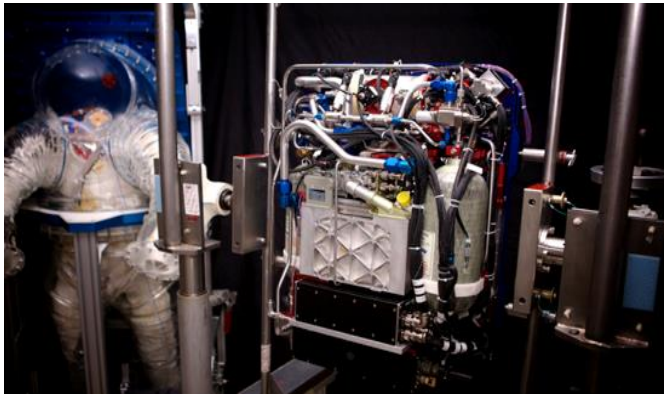


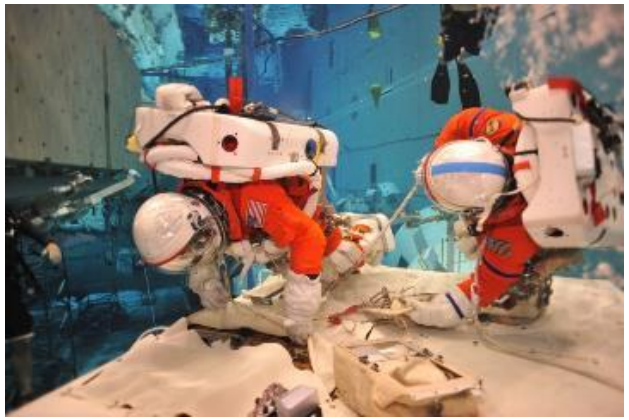
Evaluation of mobility enhancements, improved worksite stability, and testing on higher fidelity capsule mockups with tools culminating in a full ARCM EVA timeline.

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

EVA Suit and Primary Life Support System Testing



Curation and Planning Team for Extraterrestrial Materials

- Curation and Planning Team for Extraterrestrial Materials (CAPTEM) recommendations provided for :
  - Activities conducted during EVAs that are relevant for characterization, selection, collection, stowage, and transport of multiple samples to Earth.
  - Tool/instrument protocols relevant for sample collection and characterization.
  - High level objectives required to maximize the scientific usefulness of the EVAs and ensure the scientific integrity of the returned samples.

1. Asteroid needs to be multi-spectrally imaged prior to crew flight for site selection.
2. Communication with ground-based Science Team is critically important.
3. Photo-documentation of the samples before and after collection is vital
4. Contamination Control of both the samples and the crew areas is vitally important.
5. At least two diverse sites with 1000 g of material from each.
6. At least one 5-cm diameter, 4 cm deep (100 cm depth desirable) core sample of regolith from each of the two sites.

7. Preservation of volatiles is desirable, particularly if sampled asteroid is of type C, P, or D.
8. Measurement of porosity and internal structure of body using an acoustic survey is desirable.
9. Placement of instruments (e.g., retroreflectors) to measure deformation of the body during the mission is desirable.
10. Optical albedo measurements and measurements of Yarkovsky effect are not of high priority.

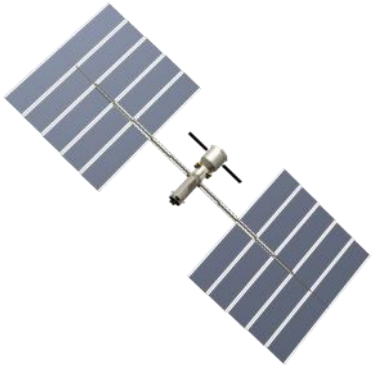
Use of ARM Solar Electric Propulsion

- **Current architecture concepts utilize ARM derived SEP**

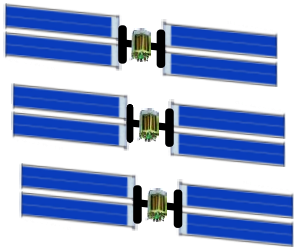
- **Pre-deploy crew mission assets to Mars utilizing high efficient SEP, such as**
  - Orbit habitats: Supports crew while at Mars
  - Return propulsion stages and/or return habitats
  - Exploration equipment: Unique systems required for exploration at Mars.

- **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)

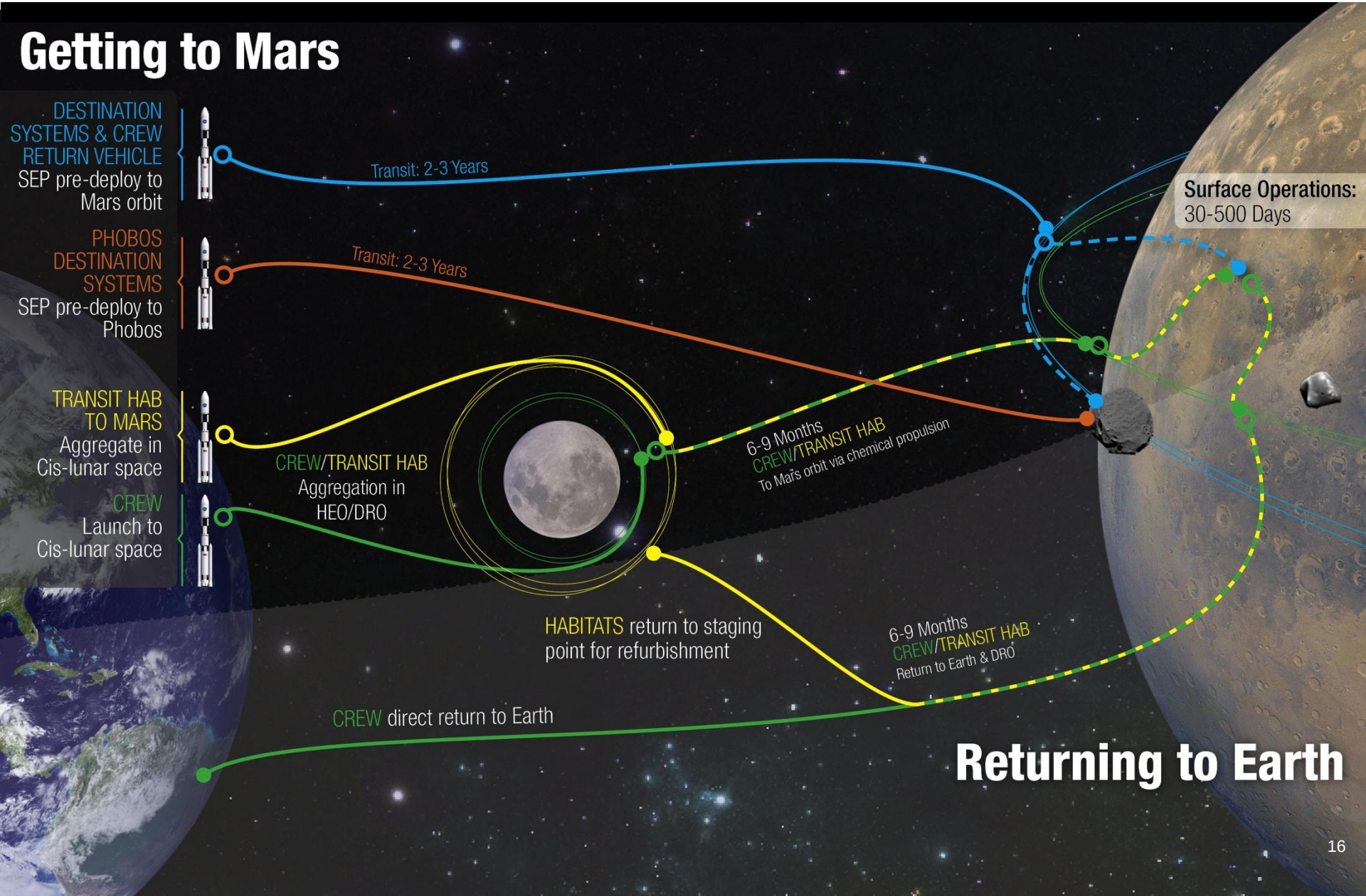
One Very Large SEP



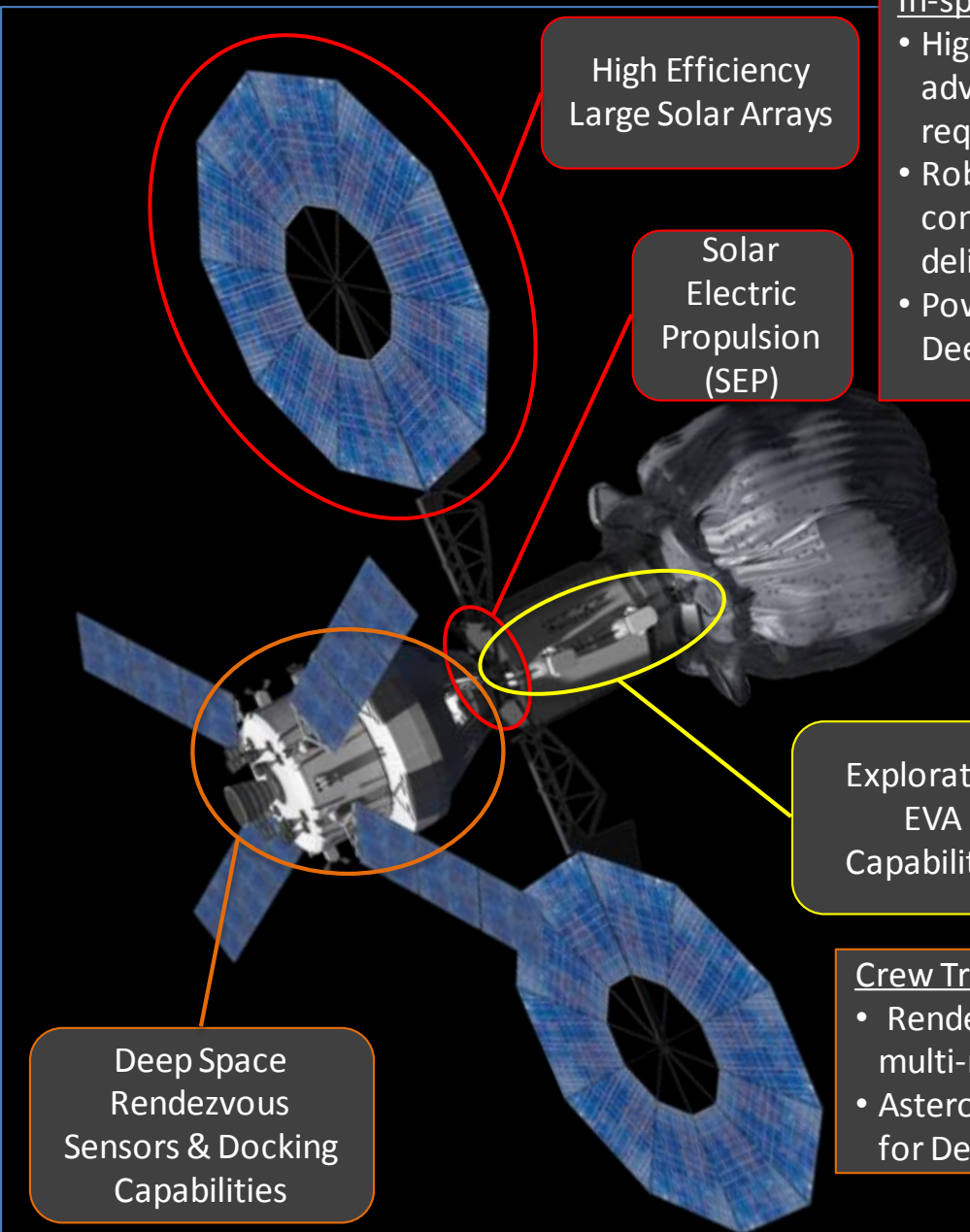
Multiple ARM derived SEPs (100-250 Kw Class)



A Sustainable Exploration Approach
Mars Split Mission Concept



Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions



In-space Power and Propulsion :

- 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

EVA:

- 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

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.

ISS and ARM Provides First Steps to Mars

	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	Deep Space Habitat			X	X	X	X
	Exploration EVA		X	X	X	X	X
	Solar Electric Propulsion for Cargo		X	X	X	X	X
	Deep Space Guidance Navigation and Control/Automated Rendezvous		X	X	X	X	X
	Crew Operations 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 Systems	*		X	X	X	X
	High Reliability Life Support	*		X	X	X	X
	Autonomous Assembly	*		X	X	X	X

Discussion on Earth Return Categorization

- NRC Space Studies Board (1998) addressed containment requirements for samples returned from asteroids
  - Conclusion: special containment provisions not warranted for most asteroid types, but reexamine on case-by-case basis
  - Posed six questions, any one sufficient to confirm special containment provisions not warranted
  - Promulgated in 8020.12D
- The Asteroid Redirect Robotic Mission presents a unique situation re planetary protection categorization
  - Final target selection shortly before launch, but
  - Cannot wait for final target selection to design for planetary protection
  - Mission capture option selection next month – defining differences between options (if any) re Earth return
- Today's presentation outlines the basis for our thinking regarding planetary protection

ARRM Options and NEAs of Interest

- Option A – Return entire small NEA
  - Can handle up to 10 m mean diameter
    - Many small NEAs have irregular shapes
  - Prefer C-group, but hard to find
  - Currently have 3 valid candidates
    - Two S-group
    - One L- or Xe-type
    - Mean diameters 3-6 m
- Option B – Return a boulder from a larger NEA
  - 2-3 m object likely, prefer C-group
  - Currently have 4 valid candidates:
    - Itokawa (S-type, samples returned by Hayabusa)
    - Bennu (B-type, OSIRIS-REx target)
    - 1999 JU3 (C-type, Hayabusa-2 target)
    - 2008 EV5 (C-type)

Planning Schedule for Categorization

Identify categorization issues affecting option selection	Nov. 2014
Mission option selection	Dec. 2014
Provisional categorization request	Sept. 2015
Provisional categorization	Dec. 2015
SDR, PP Plan	June 2016
Categorization request for candidate targets	mid 2018
Latest target selection	late 2018
Earliest launch	June 2019

8020.12D Question 5

Question: "Does scientific evidence indicate that … the target body has not been exposed to sufficient radiation for presumptive biological sterilization (e.g., by analogy to the tolerances of terrestrial organisms)?"

Considerations:

- All asteroid material has been subject to billions of years of radiation from decay of U^{238}, U^{235}, Th^{232}, K^{40}, and other active radionuclides.
  - Very low probability exception: shielding by ice pockets
  - New data exists as well
- After fragmentation most ARM targets have been exposed to GCR dosage far exceeding the gamma ray dosage used for the most extreme sterilization operations on Earth.
  - Limited investigation of meteorite exposure (several hundred samples) shows 4-pi exposure for tens of Myr in most cases
  - Possible exceptions: CM and CI meteorites (~2 dozen samples)
    - shorter exposures (hundreds of kyr)
    - Bennu and 1999 JU3 shows similarity to CM and CI meteorites

Radiation Dose (Mrad) at Center of Geological Object*

Object Size	Radius	Time in Space 10,000 yr	100,000 yr	1 Myr	10 Myr	100 Myr
	10 um	660	6,603	66,033	660,327	6,603,272
	30 um	280	2,797	27,967	279,673	2,796,729
Silt	0.1 mm	109	1,091	10,908	109,084	1,090,844
	0.3 mm	35	355	3,550	35,500	354,999
Sand	1 mm	10	96	961	9,614	96,141
	3 mm	3	29	292	2,919	29,190
Pebbles	1 cm	0.79	8	79	791	7,905
	3 cm	0.24	2	24	240	2,400
Cobbles	10 cm	0.065	0.65	6.5	65	650
	30 cm	0.035	0.35	3.5	35	350
Boulders	1 m	0.015	0.15	1.5	15	150
	3 m	0.01	0.1	1	10	100
Blocks	10 m	0.005	0.05	0.5	5	50
	30 m	0.003	0.03	0.3	3	30
	100 m	0.002	0.02	0.2	2	20

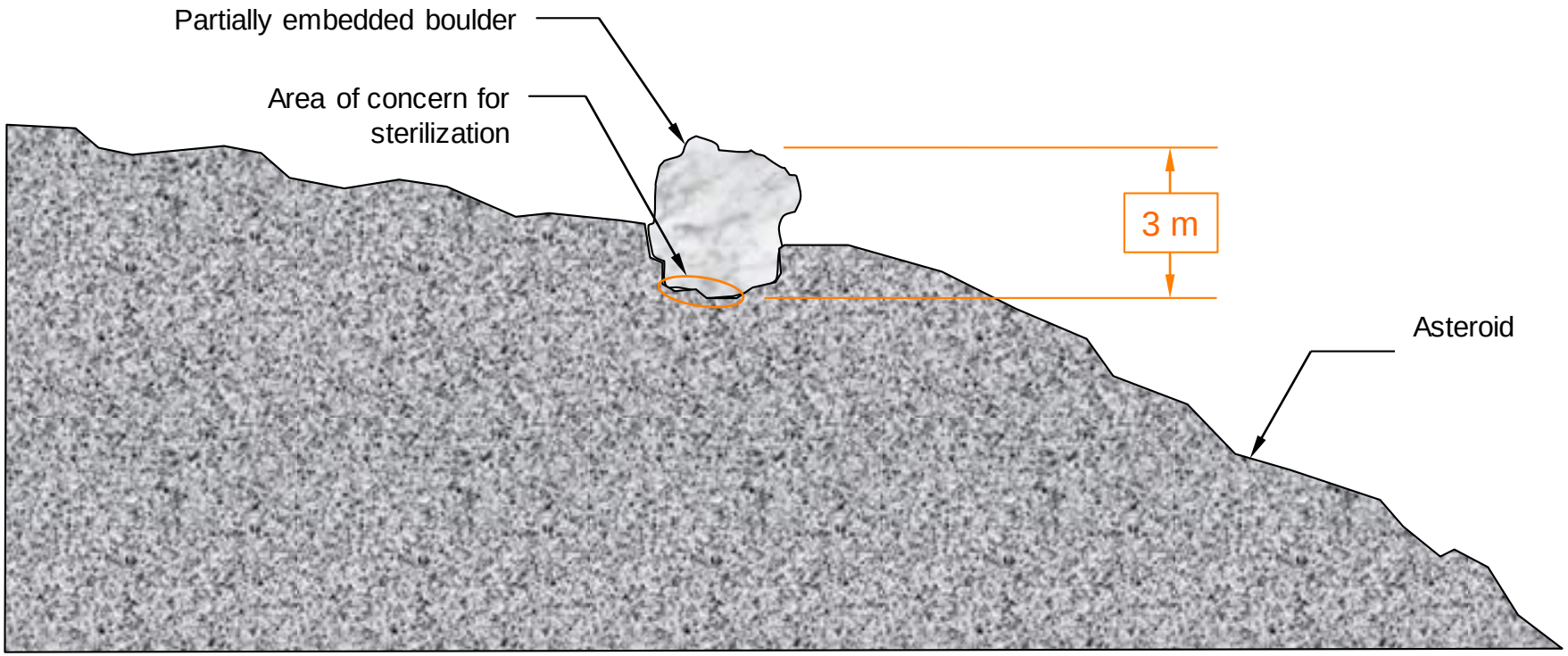
* (1 Mrad = 10 kSv)

Doses > 100 krad | Doses 1-18 Mrad | Doses >18 Mrad

* B. Clark, "Planetary Interchange of Bioactive Material: Probability Factors and Implications", 2001.

Geometric effects associated with shielding of underside of boulder

- Clark table assumes spherical object
- Rough approximation for flat surface: dosage at depth reduced by factor of 6
- Interpolating the table and dividing by 6 => bottom of 3m boulder sees 20 Mrad in 100 Myr



8020.12D Question 6

Question: "Does scientific evidence indicate that … there is no natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body?"

Considerations:

- Recent dynamics research indicates that practically all NEAs (ARM targets in particular) and meteorites are derived from the same limited number of dominant sources (~30).
- Material from these sources has been striking the Earth for from tens of millions of years to as long as billions of years.
- For most of these cases, the impacts would have been over a wide range of sizes, with some delivering material from asteroid interiors that could have been protected from external radiation damage.
- This implies that anything dangerous on these bodies already reached and contaminated Earth long ago.

Summary

- The material comprising our targets has been irradiated by decaying radionuclides for the life of the solar system.
- Most have also been bombarded with GCRs since the fragmentation events that created them millions of years ago.
- It is extremely unlikely that any target we would want to select would contain material not already received on Earth in large quantities.

- We expect to propose provisional Unrestricted Earth Return categorization to NASA HQ in 2015.
- Final categorization will be requested when a final target is selected.
  - Data will be available to preclude questionable objects.