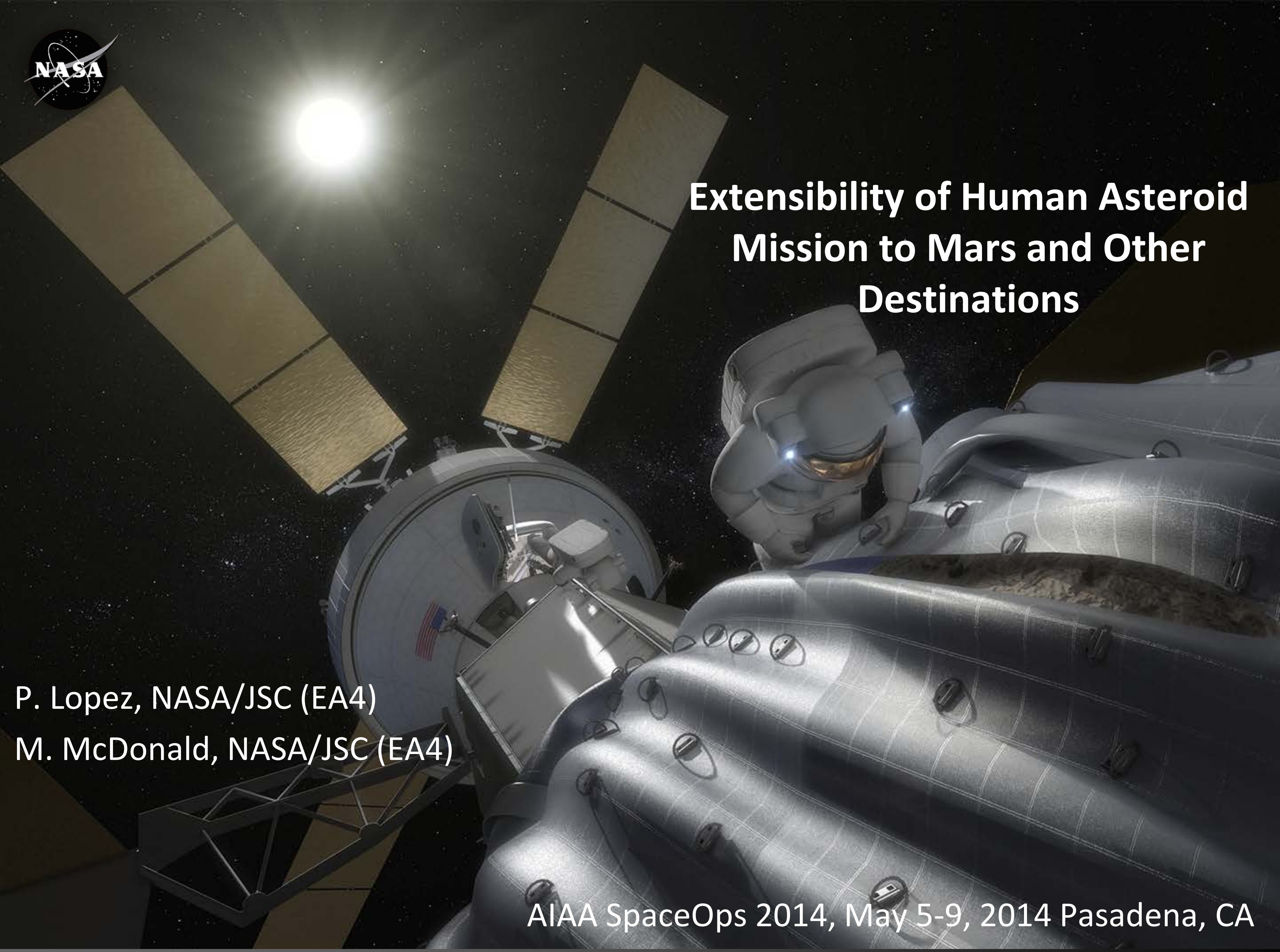

Extensibility of Human Asteroid Mission to Mars and Other Destinations

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Agenda

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- Observation Campaign Extensibility
- Asteroid Redirect Robotic Mission Extensibility
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Asteroid Redirect Mission Overview

Overall Mission Consists of Three Main Segments

Identify

Asteroid Identification Segment:

Ground and space based NEA target detection, characterization and selection

Redirect

Asteroid Redirection Segment:

Solar electric propulsion (SEP) based robotic asteroid redirect to trans-lunar space

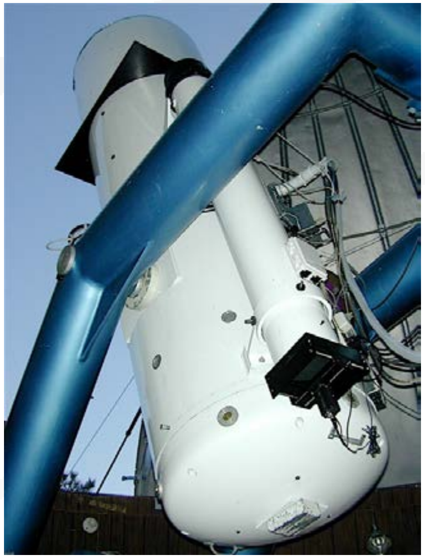
Explore

Asteroid Crewed Exploration Segment:

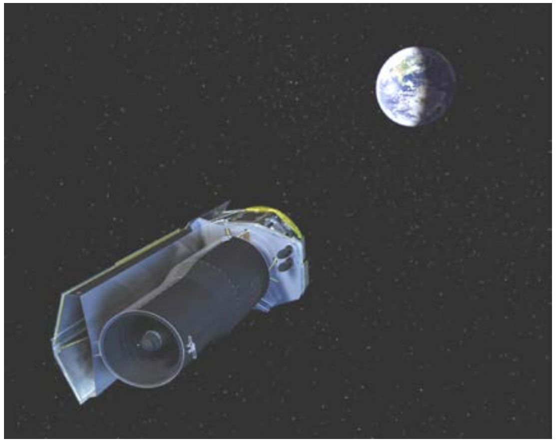
Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid

Observation Campaign Extensibility

- Leverages off of NASA’s Near-Earth Asteroid (NEA) discovery and characterization effort
- Utilizes existing ground and space-based observation assets
- New telescopes are coming online, and existing surveys are being upgraded with greater time allocations and improved cameras in support of ARM observation campaign
  - Will increase discovery rate of candidate asteroids for ARM
- These enhancements are also applicable to discovery of hazardous asteroids in general



Catalina Sky Survey Telescope

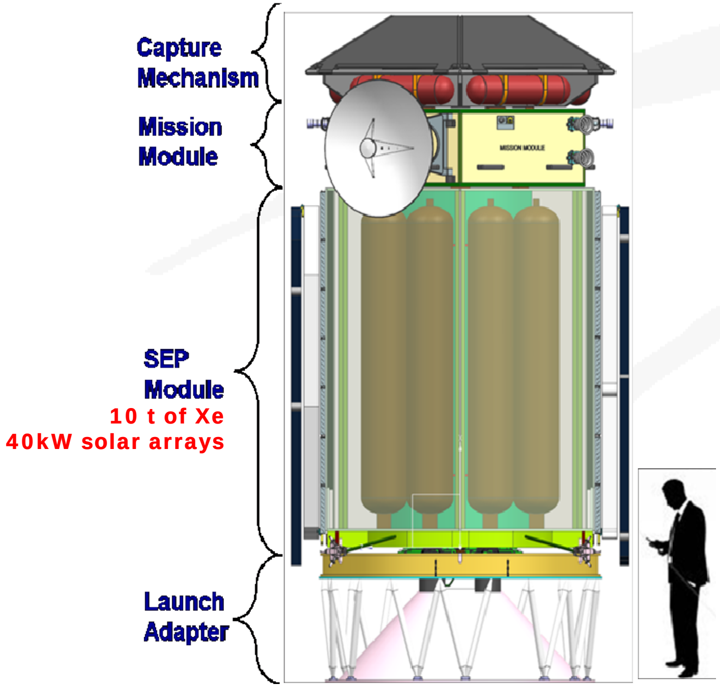


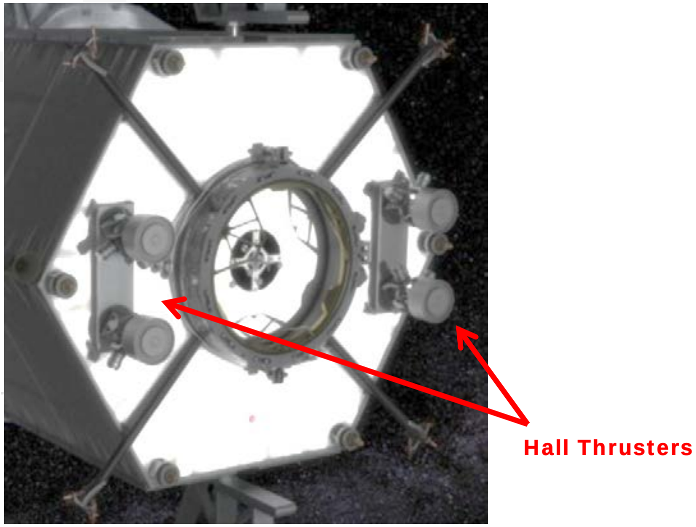
Spitzer Infrared Space Telescope

Asteroid Redirect Robotic Mission Extensibility

Solar Electric Propulsion (SEP)

- Capability of SEP system on ARRV could be used in other human exploration missions
  - Longer duration near-Earth missions in cislunar space
  - Cargo delivery for human Mars missions
    - Will require higher power for SEP systems; addressed via solar array systems being demonstrated under current STMD effort (extensible to 125 kW per wing via modularity and scalability)



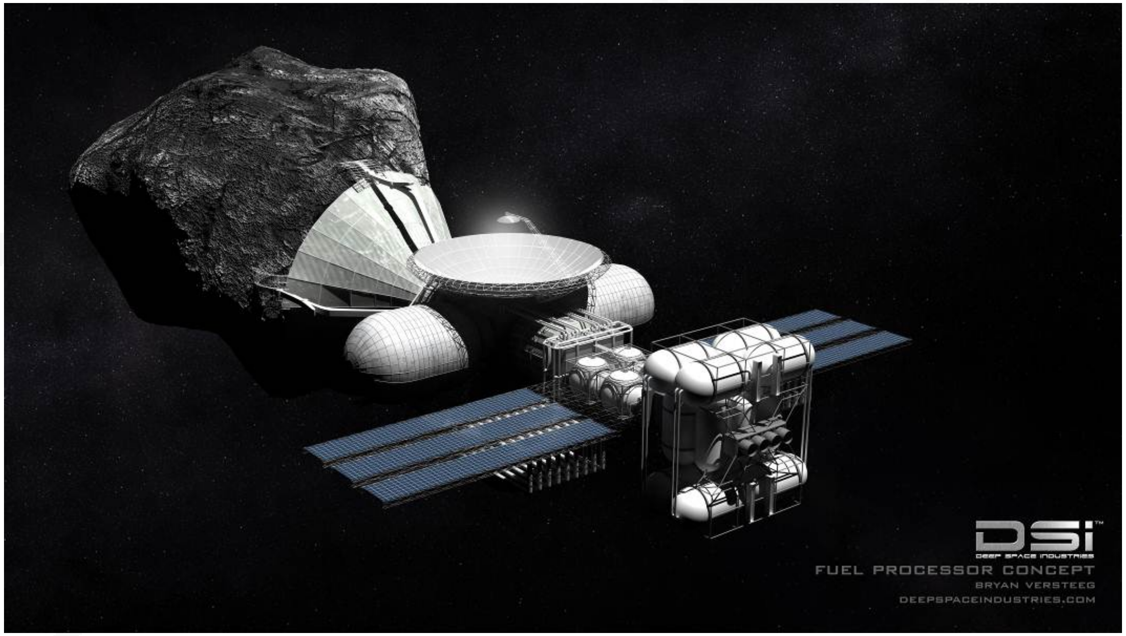


Aft View of ARRV

Asteroid Redirect Robotic Mission Extensibility (Cont.)

Asteroid Resource Utilization

- Accessibility to asteroid material in cislunar space allows in-situ resource utilization (ISRU) demonstrations to determine if material can be converted into useful products
  - Benefits future human exploration of the solar system
  - May be critical in advancing commercial efforts to mine asteroids

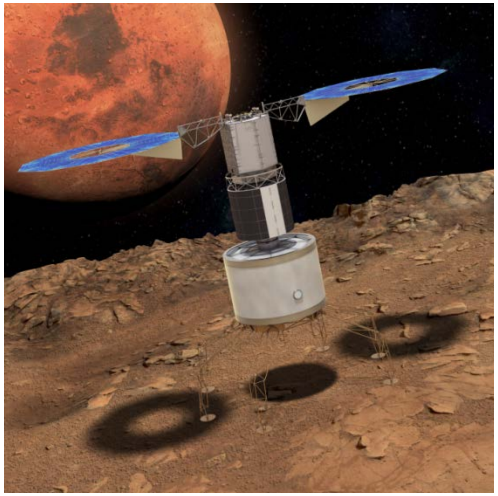


Asteroid Propellant Processing Concept

Robotic Boulder Capture (RBC)

- Use of robotic arms to interact with an asteroid is applicable to other NASA missions
  - Satellite servicing and refueling
  - Providing surface contact and manipulation for a future crewed mission to NEAs or Martian moons
- End-effector/grippers (i.e., microspine technology) can be used for:
  - Future robotic exploration (lunar, Mars, Mars moons)
  - Exploration of bodies like NEAs, Phobos, Deimos, and main belt asteroids like Ceres

Hybrid Capture System Concept for the ARRM RBC Option



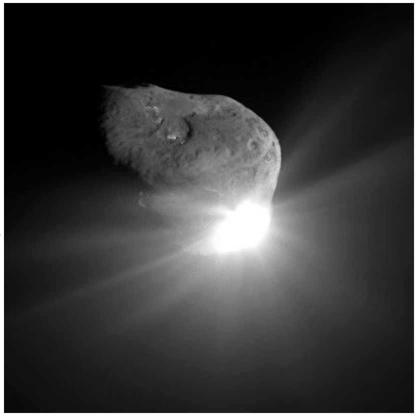
Spaceframe Capture Arms integrated with a Habitat on Phobos Surface

Asteroid Redirect Robotic Mission Extensibility (Cont.)

Planetary Defense

- Planetary Defense techniques and experience possible through the Robotic Boulder Capture (RBC) option are relevant and extensible to future missions
  - Demonstrations performed on large NEA
    - Potential demonstrations include Enhanced Gravity Tractor (EGT), Ion Beam Deflection (IBD) and kinetic impact approach
- Current RBC option mission timeline includes EGT technique demonstration
  - Applicable to diverting NEAs from Earth-impacting trajectories given sufficient warning time
- Kinetic impact demonstration could be conducted and effectiveness compared to EGT

Demonstration of Enhanced Gravity Tractor on a Large NEA

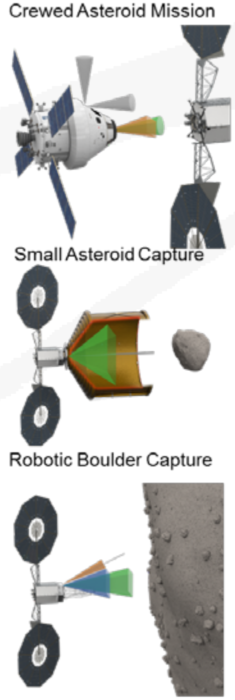


Kinetic Impact on Comet 9P/Tempel by the Deep Impact Mission

Asteroid Redirect Crewed Mission Extensibility

Common Automated Rendezvous and Docking/Capture Sensors

- NASA needs automated rendezvous and docking/capture (AR&D) sensors for multiple missions
- NASA is pursuing a common suite of AR&D sensors to apply across multiple AR&D missions starting with the asteroid missions
  - Visible cameras paired with selectable lenses per mission needs
    - Medium resolution (narrow angle)
    - High resolution (wide angle)
  - 3D LIDAR
  - Infrared camera
- NASA created a common specification addressing environment and performance for each sensor which will fulfill each mission's AR&D needs
- NASA released a BAA to pursue sensors meeting this spec



Long Range	Medium Range	Close Range	Application of Common Suite
S-Band Transponder for Range/Range Rate to reduce timeline; Star Tracker for bearing High Resolution Camera for bearing		3D LIDAR for precise alignment for docking High Resolution Camera for secondary pose	High Resolution Camera 3D LIDAR
Medium Resolution Camera for asteroid acquisition, spin rate and bearing to the asteroid		3D LIDAR for asteroid characterization and alignment for bag capture	Medium Resolution Camera 3D LIDAR
Medium Resolution Camera for bearing to the asteroid	Medium and High Resolution Cameras for spin rate, 3D map of the surface and boulder identification	3D LIDAR for 3D range images to the target boulder Medium and High Resolution Cameras for spacecraft pose and images of boulder collection areas	High Resolution Camera Medium Resolution Camera 3D LIDAR

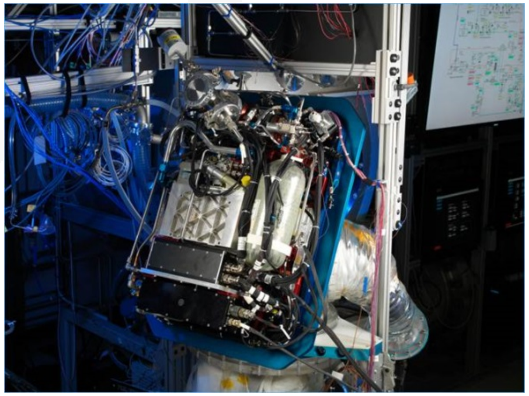
* Addition of infrared camera on asteroid missions for robustness is being assessed

Asteroid Redirect Crewed Mission Extensibility (Cont.)

Extravehicular Activity (EVA)

- Aspects of the EVA segment within ARCM that are extensible to other missions include:
  - Providing contingency EVA capability to all manned Orion missions
    - Use of MACES (Orion LEA suit) with mobility enhancements
  - Exploration Portable Life Support System (PLSS) technologies applicable to exploration missions
    - Rapid Cycle Amine (RCA) swing bed for carbon dioxide removal
      - Vacuum missions only; addition of sweep gas required for use on Mars surface
    - Suit Water Membrane Evaporator (SWME) for thermal conditioning
  - Exploration PLSS combined with Z suit will be the EVA suit for all future human exploration missions
  - EVA tools and worksite stability techniques are extensible to any microgravity EVA including moons of Mars


Mobility Enhancements Testing of MACES in the NBL


PLSS 2.0 Test Unit on the Space Suit Assembly Simulator


Z2 Suit with PLSS

Asteroid Redirect Crewed Mission Extensibility (Cont.)

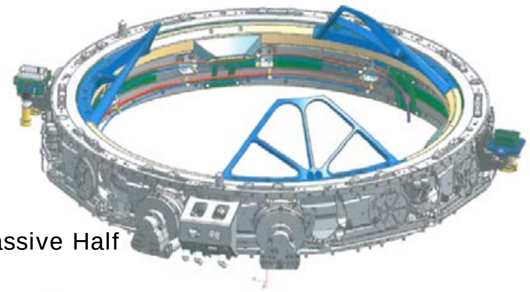
Sample Collection

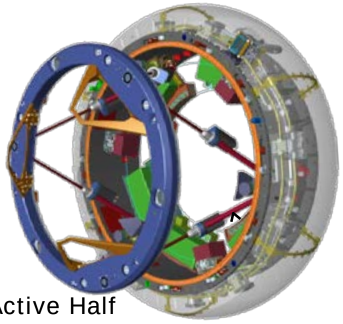
- Sample collection tools/techniques developed for ARCM that are extensible to future NASA missions include:
  - Collection of macroscopic samples from various locations on surface and/or interior
  - Sampling operations on small, airless body under low-gravity conditions
  - Methods to store and maintain samples during return journey for subsequent laboratory analyses on Earth
- Lessons learned from ARM can be applied to EVA planning for sample site assessment, documentation, sampling operations, and storage/containment activities on Phobos/Deimos

Asteroid Redirect Crewed Mission Extensibility (Cont.)

Automated Docking

- Use of International Docking System Standard (IDSS)-compliant NASA Docking System (NDS) as standard docking system for all spacecraft allows delivery of different assets in separate flights that can be integrated later during the mission
  - Enables missions to Mars vicinity (Phobos and/or Deimos)
- Power and data transfer capabilities supports integrated stack control and power sharing



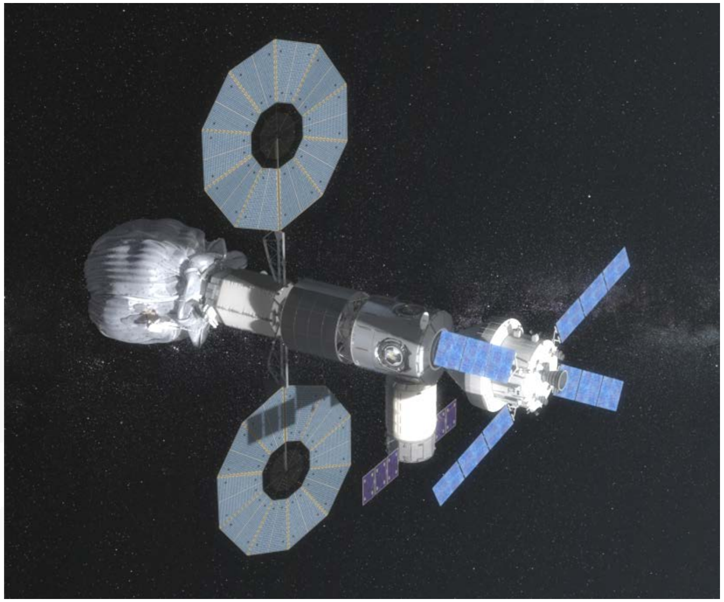


IDSS-Compliant NASA Docking System; passive half on ARRV, and active half on Orion

Extensibility to Missions Post-ARCM

Extended Crewed Missions to Asteroid in DRO

- Many possible opportunities for further utilization of the Asteroid
  - Testing of anchoring techniques
  - In-situ Resource Utilization (ISRU) Demonstration
  - Additional Asteroid Sample Collection
  - Lunar and Mars sample return
  - Scientific Experiments
  - Many other possibilities
- Addition of utilization elements provide:
  - Extended crewed mission duration and additional EVA capability
  - Enhance crew safety with more robust systems and infrastructure
  - Testbed for crew operations and systems required to sustain life for longer deep-space missions

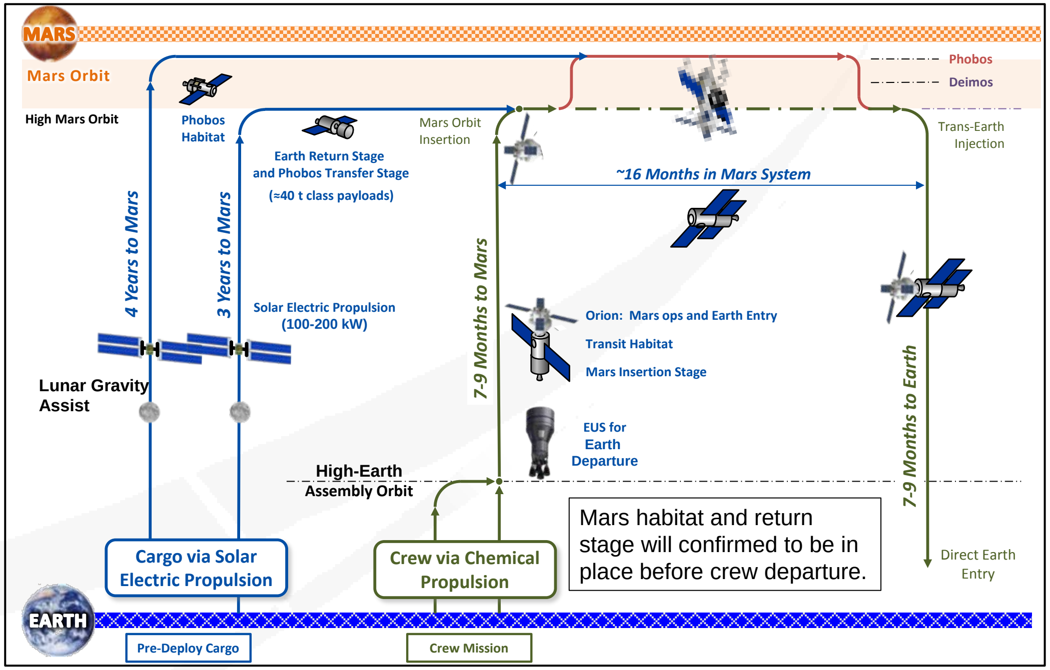


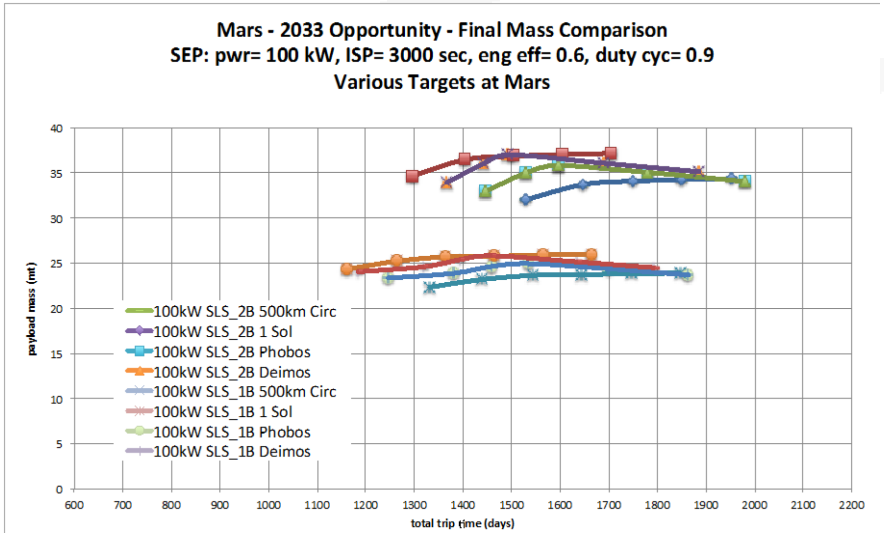
Notional Example of Extensibility of Asteroid Mission

Extensibility to Missions Post-ARCM (Cont.)

Mars Phobos Mission

- ARV-derived SEP requires “Split-Sprint” mission approach
- SEP used to pre-deploy crew habitat, Phobos systems, and return propulsion stage to Mars orbit
- Crew sent on “one-way” mission to Mars orbit via high-thrust chemical propulsion (critical rendezvous at Mars)
- Crew utilizes pre-deployed assets for Phobos exploration and eventual return to Earth





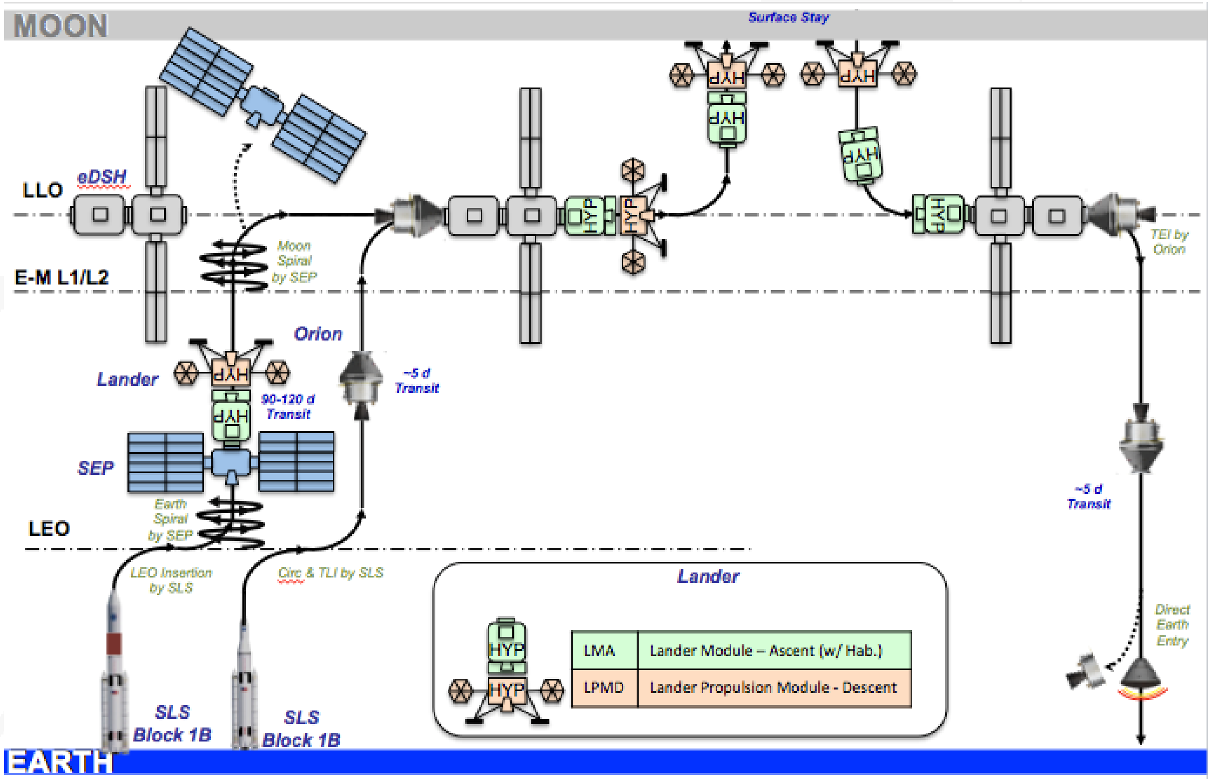
ARRV-Derived SEP Cargo Tug

- Performance estimates indicate that ARRV-derived SEP may be sufficient for Phobos exploration
- Further assessments required to confirm performance including determining how this type of strategy can feed forward to future landed missions (heavier cargo elements such as Mars landers)

Extensibility to Missions Post-ARCM (Cont.)

Lunar Mission

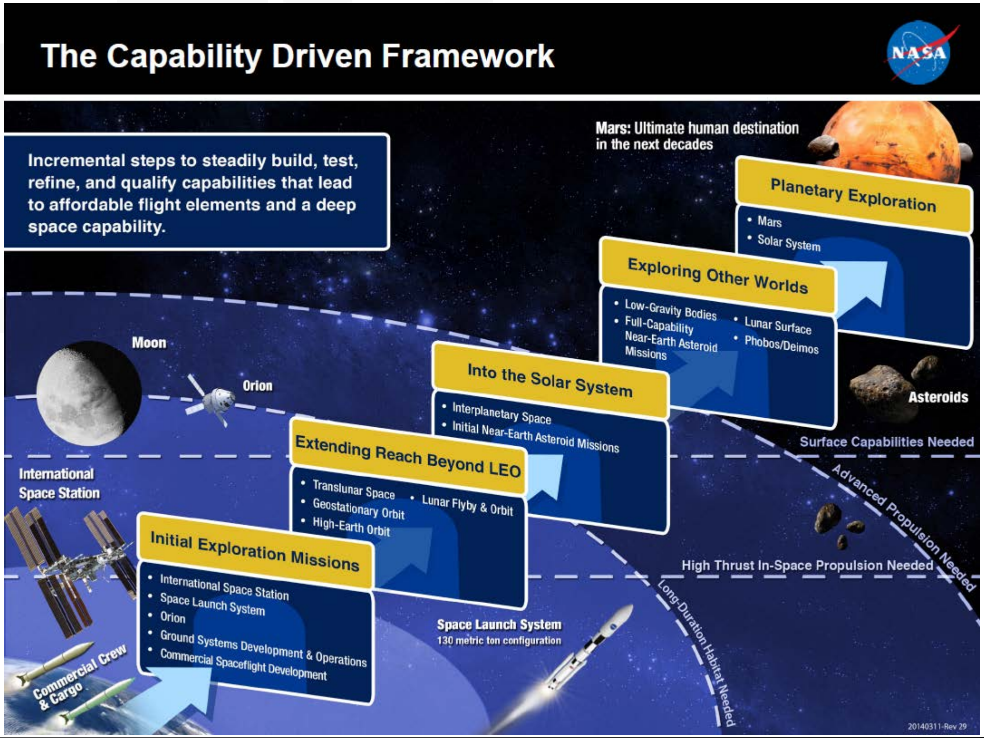
- ARM operational experience and systems could be leveraged to support exploration of the lunar surface
  - Delivery of uncrewed assets to lunar vicinity using SEP system, allowing for additional payload/mission capabilities
  - SEP bus could be derived from ARRV



Extensibility to Missions Post-ARCM (Cont.)

Capability Driven Framework (CDF)

- ARM technologies support the CDF as they enable implementation of many possible missions
  - ARM SEP system could be used to support lunar missions
    - Power level could be evolved to preposition assets for Mars missions
  - AR&D sensor suite directly support lunar, Mars, and other possible missions
  - Orion and SLS systems enable "extending reach beyond LEO"
  - Provides operational experience working on low gravity bodies ("exploring other worlds")



Conclusion

- The Asteroid Redirect Mission has great promise for extensibility
  - SEP, AR&D sensors, and RBC Capture mission are all extensible to possible lunar or Mars moon missions
  - Docking and EVA systems generically support all human exploration missions
- Investment in ARM concept provides logical stepping stones to future exploration goals

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