Synergies of Robotic Asteroid Redirection Technologies and Human Space Exploration

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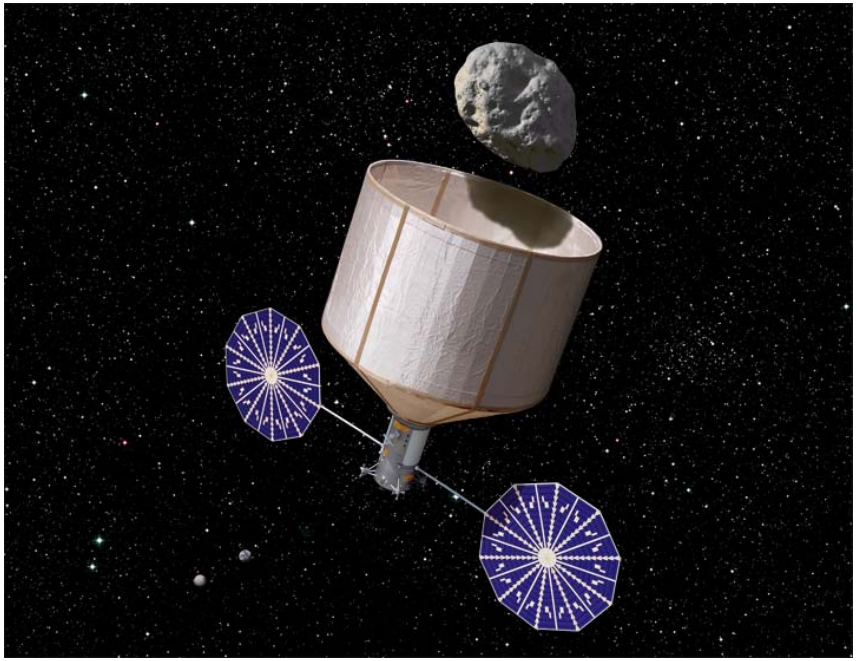
3 Year Study (2011-2014)

- **Initial Study Results**
  - **ARM uniquely enables human exploration of a celestial body beyond the Moon by 2025**
  - **Spacecraft and Mission are feasible within current program**
  - **Requires and develops Solar Electric Propulsion**
- **Follow-on Study Results**
  - **SEP provides significant advantages for humans to Mars**
  - **A series of increasingly deep-space missions is enabled with asteroid redirection technology**
  - **Asteroid resources can be exploited for human space flight**
  - **Strong synergy exists with commercial and planetary defense objectives**

The ARM Spacecraft

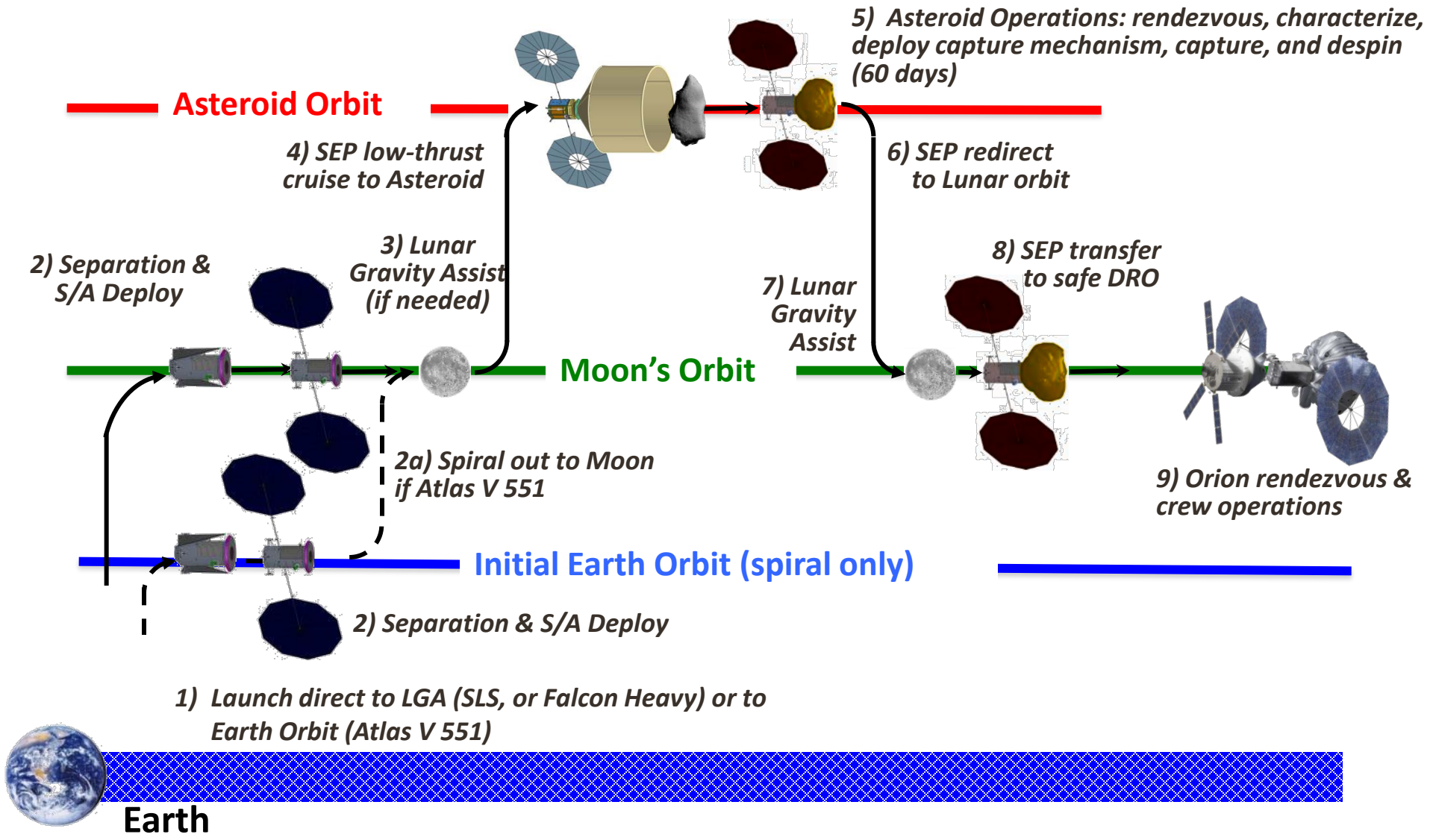
Capture a Small Asteroid



Pick up a Boulder

Asteroid Redirect Mission Design

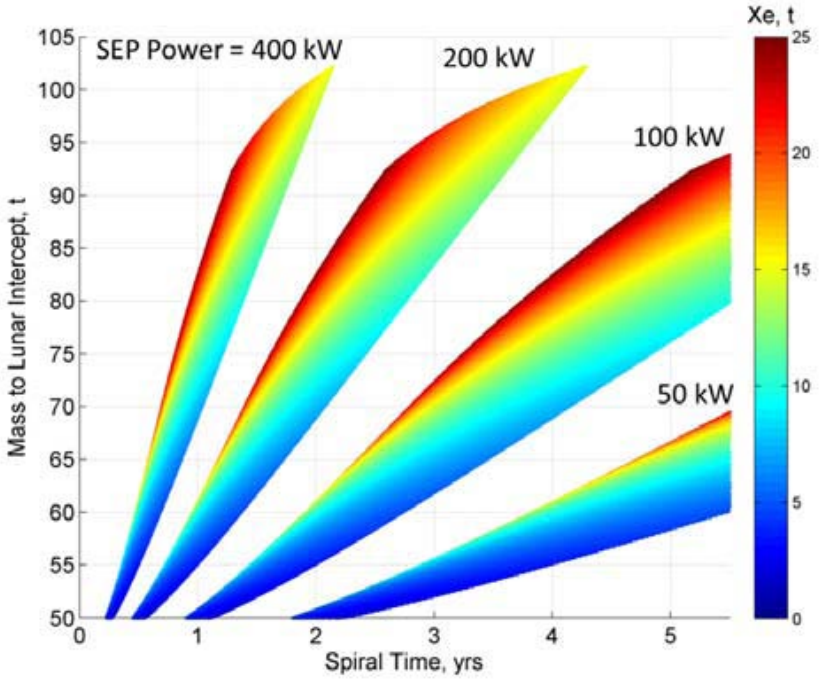
(NOTIONAL)



Outline

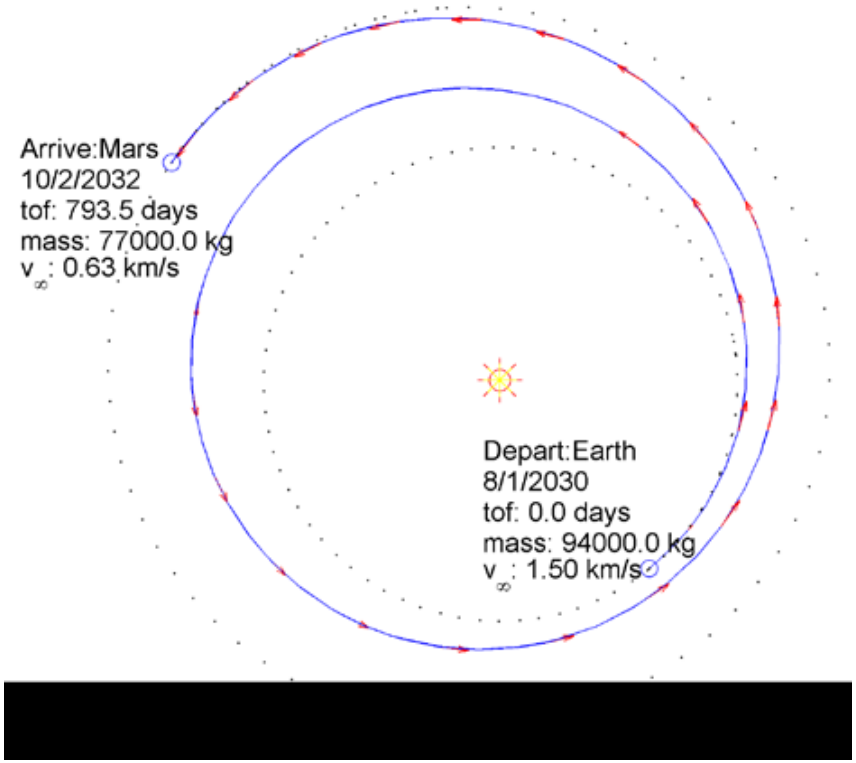
- **ARM Derivatives for Mars Missions**
  - **High Powered SEP Tugs**
  - **SEP Cargo Delivery**
  - **Intermediate Heliocentric Orbits for Stepping Stones**
    - **Earth Resonant Orbits**
    - **Earth-Mars Cyclers**
- **ARM and Planetary Defense**
  - **Early Warning**
  - **Deflection**
- **ARM and Resource Utilization**
  - **Radiation Shielding**
  - **Water**
  - **Building Materials**
- **Other**
  - **Communication Satellites**
  - **Deep Space Science Missions**
  - **Orbital Debris Removal**
- **New Research Areas in Physics and Materials**

High Power SEP Tugs



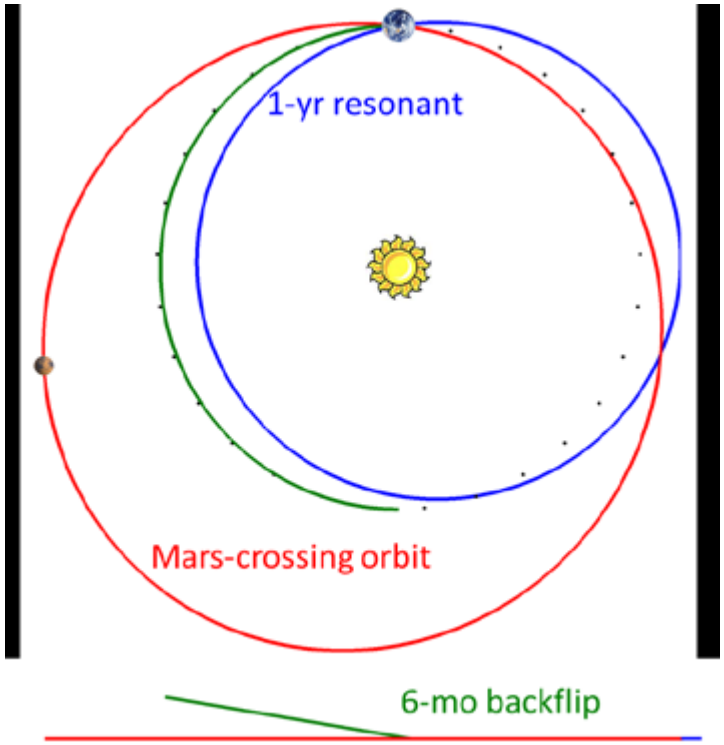
- SEP can roughly double the mass delivered to lunar-crossing HEO from a single SLS launch. The specific SLS assumptions to recreate this figure are 241 km LEO, 140.8 t in LEO with 23.6 t inert upper stage, 462 s *Isp.*
- *SEP spiral to 384000 km circular orbit for Lunar intercept, 44% efficiency at 1500 s, 67% efficiency at 5000 s.*

SEP Cargo Delivery for Mars Missions



A 270-kW SEP vehicle can perform a 1.5-revolution transfer to Mars (preceded by a geocentric spiral and lunar-assisted escape) and combined with a high-thrust capture maneuver at Mars would deliver a 70 t of payload to a 1-sol orbit from a single SLS Block 2 launch.

Heliocentric Stepping Stones



Redirecting small asteroids to Earth flybys could enable a wide variety of orbits where the asteroid could be "stored" including Earth-resonant orbits and Mars-crossing orbits.

Radiation-Shielded Mars Cyclers in Three Easy Steps

STEP 1: In Lunar DRO

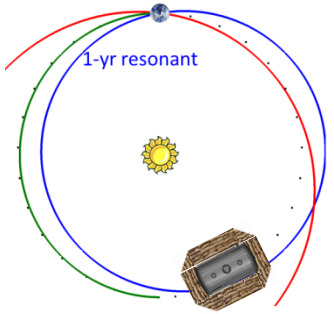
- Redirect an asteroid to lunar DRO (ARRM)
- Astronauts obtain samples and learn to how deal with the asteroid material (ARCM)
- Subsequent missions deliver a deep-space habitat to the lunar DRO where astronauts dismantle the asteroid and use it to radiation-shield their habitat

1st Radiation-shielded deep-space habitat created in lunar DRO from "sand-bagged" asteroid material

STEP 2: In Earth-Resonant Orbit

- Redirect a new asteroid to an Earth-resonant orbit
- Deliver a deep-space habitat with astronauts where they spend 6-months dismantling the asteroid to create a radiation-shielded habitat using the techniques learned in lunar DRO

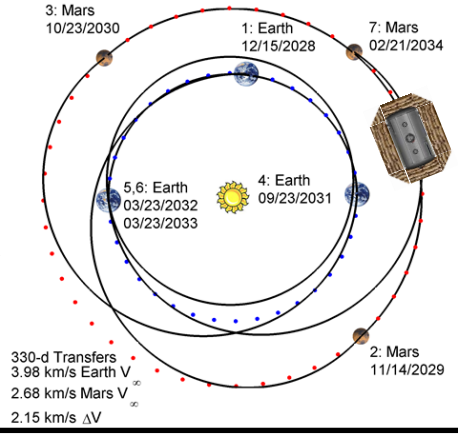
2nd Radiation-shielded deep-space habitat created in an Earth-resonant orbit from "sand-bagged" material from an new asteroid



STEP 3: Transfer to a Cycler Orbit

- Transfer the radiation-shielded habitat to a Mars cycler orbit using Earth gravity assists
- Astronauts travel to/from Mars in a deep-space habitat shielded against galactic cosmic rays

2nd Radiation-shielded, deep-space transferred to a Mars cycle orbit with very little ΔV



ARM and Planetary Defense

- Early Warnings, Observations
  - Discovery->Tracking->Orbit Determination->Prediction
  - Characterization: Mass, Size, Composition, Sturcutre
  - Observation campaigns have been enhanced
- Deflection
  - Enhanced near-asteroid operations experience
  - Ion beam deflection may be considered
  - Possible demonstration of deflection technologies
- Planetary Defense now recognized in government program
- ARM Mission secondary payload options
  - Observer spacecraft
  - Ion Beam Deflection Experiment

ARM and Resource Utilization

- Science experiments for composition and structure determination, drilling
- Mass for radiation shielding, >100 tons
- Water for propellant, oxygen, water
  - Asteroid may be 20% water (100-200 tons)
- Building materials: iron, nickel, cobalt, platinum-group

Other Applications

- Solar Array Technology Development
- Magnetically shielded Hall thruster systems
- Commercial geostationary satellite industry
  - Other GTO applications
- Deep space science missions
  - Small body rendezvous
  - Jupiter missions and beyond
- Orbital debris removal
- New areas of physics and materials research under study

Summary

Potential Post-ARM Applications

Planetary Defense

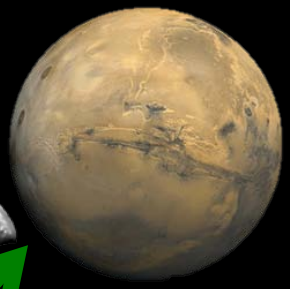
SEP vehicles for precise orbit determination of potentially hazardous asteroids or their deflection

Robotic Science Missions

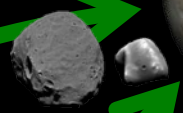
High performance SEP-based science missions

Flexible Path to Mars

Mars



Phobos, Deimos

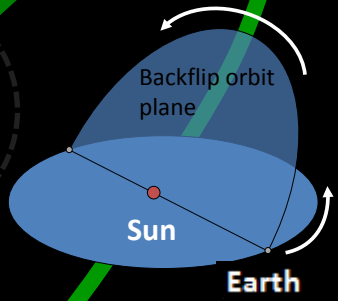


Lunar Support

- **Private**
- **International**

Cargo delivery to support human missions to the Moon or Mars

Earth Resonant Orbit



Habitat development, e.g.:

- 6-month Earth-resonant (depicted)
- Sun-Earth Lagrange Points
- Mars cycler orbits

Commercial Satellites

Improved competitiveness for U.S. comsats

Cargo Delivery

ISRU

Commercial Asteroid Mining

Extract Materials for:

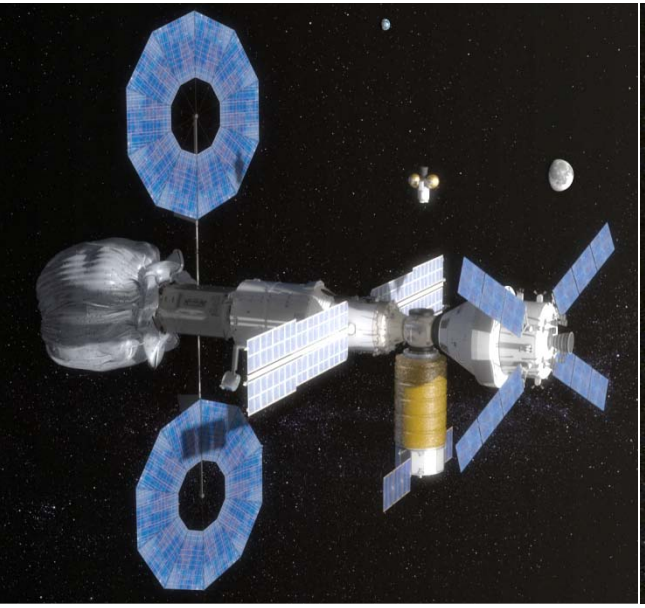
- Radiation Shielding
- Water
- Fuel
- Metals

Orbital Debris Removal

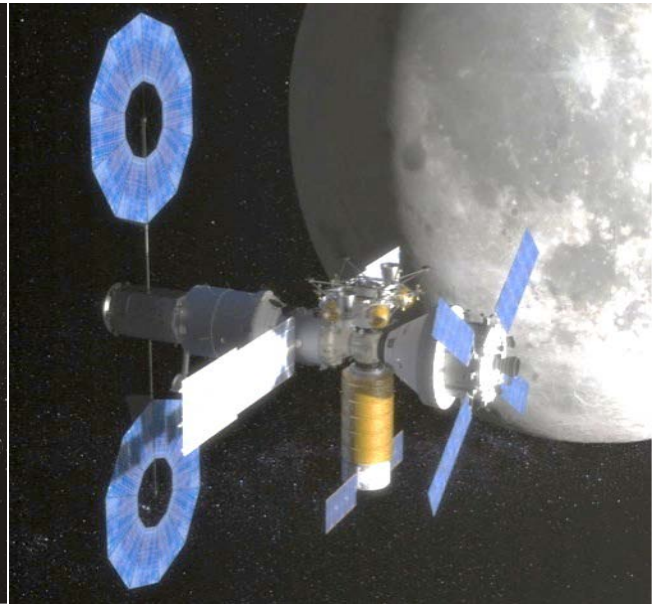
Removal of large pieces of orbital debris

Asteroid Redirect Mission

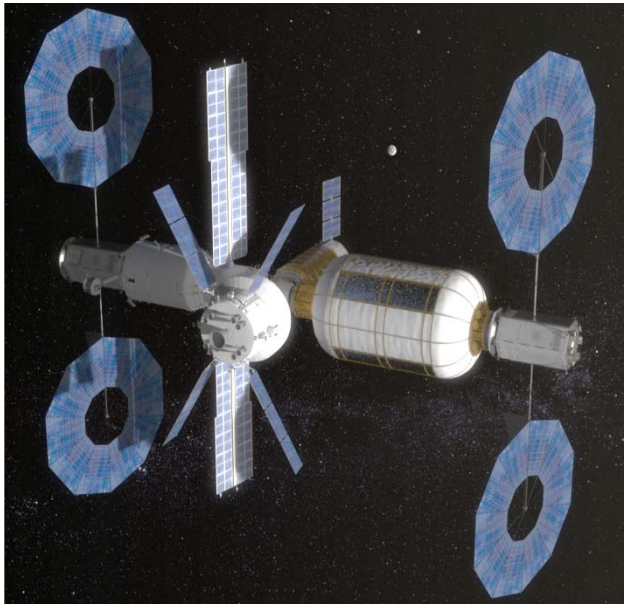
NASA Vision for Future Human Exploration Enabled by Asteroid Redirect Technology



Asteroid Exploitation Missions



Lunar Surface Missions



Deep Space Missions