



Asteroid and Comets – Future Possibilities and Impact Protection

Presentation and Q&A for the Rochester Speculative Literature Association

Dan Mazanek

Senior Space Systems Engineer
NASA Langley Research Center

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- **Asteroid Redirect Mission (defunded in 2017) - Overview and Benefits**
- **Summary of Planetary Defense Techniques**
- **Thoughts on Future Applications and Value of Asteroids and Comets**

Asteroid Redirect Mission: Three Main Segments



IDENTIFY

Ground- and space-based assets detect and characterize potential target asteroids



Pan-STARRS



NEOWISE

Goldstone



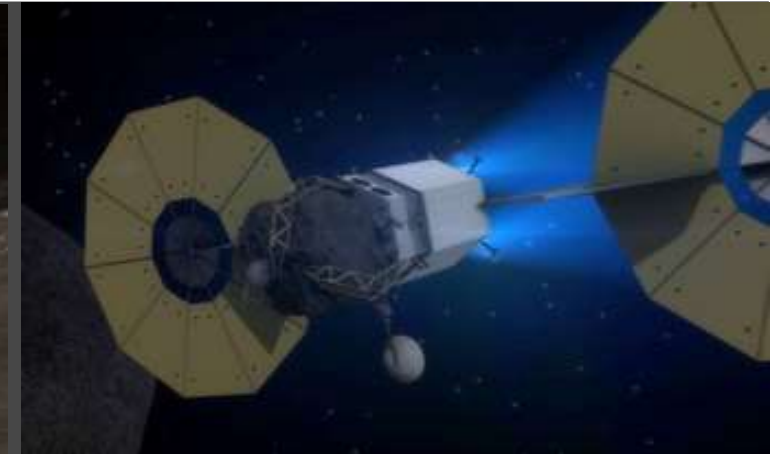
Arecibo



Infrared Telescope Facility

REDIRECT

Solar electric propulsion (SEP) based system redirects asteroid boulder to cis-lunar space.



EXPLORE

Crew launches aboard SLS rocket, travels to cis-lunar space in Orion spacecraft to rendezvous with returned boulder, studies and returns samples to Earth



Asteroid Redirect Mission Objectives

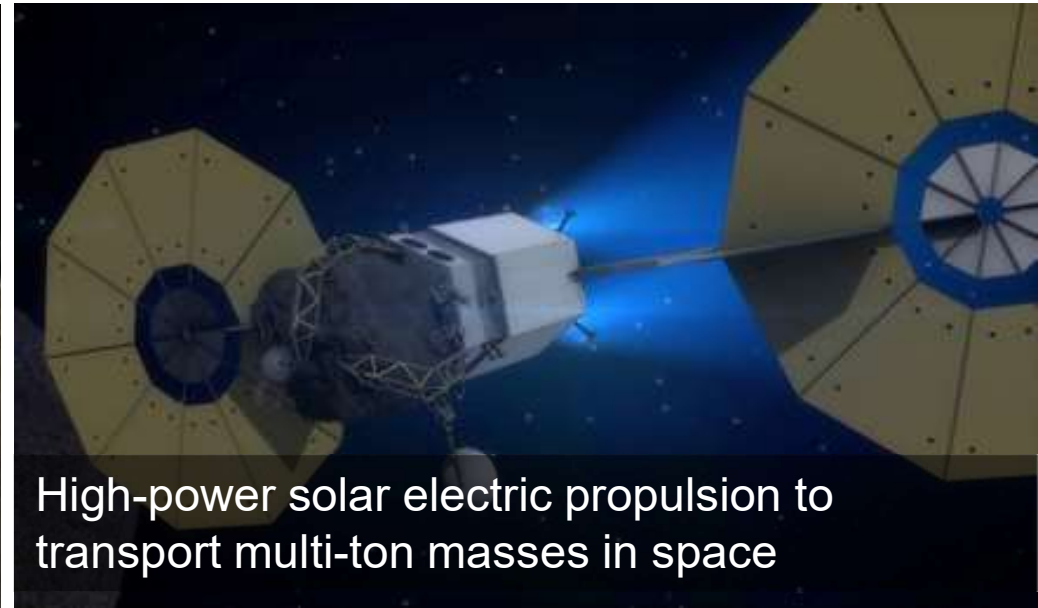


- 1. Conduct a human exploration mission involving in-space interaction with an asteroid boulder in the mid-2020's, providing systems and operational experience required for human exploration of Mars.**
- 2. Demonstrate an advanced solar electric propulsion (SEP) system, enabling future deep-space human 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.**

Key Benefits for Solar System Exploration



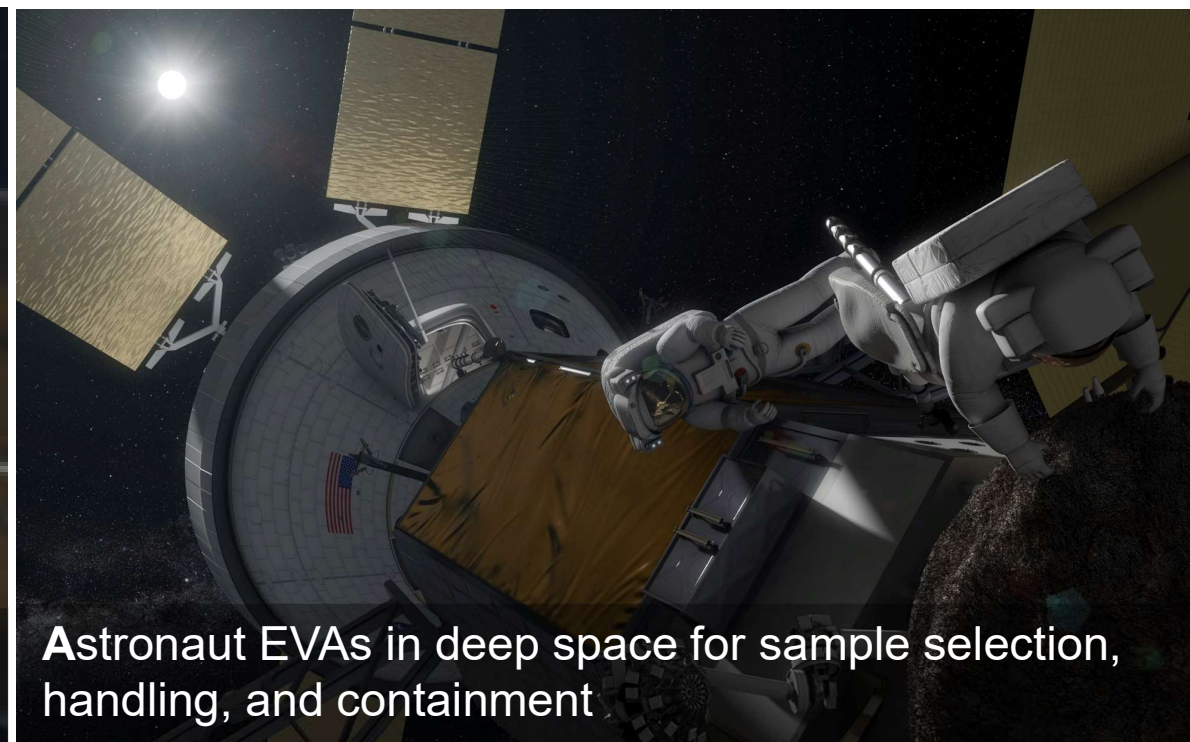
Advanced autonomous proximity operations in deep space with a natural body



High-power solar electric propulsion to transport multi-ton masses in space

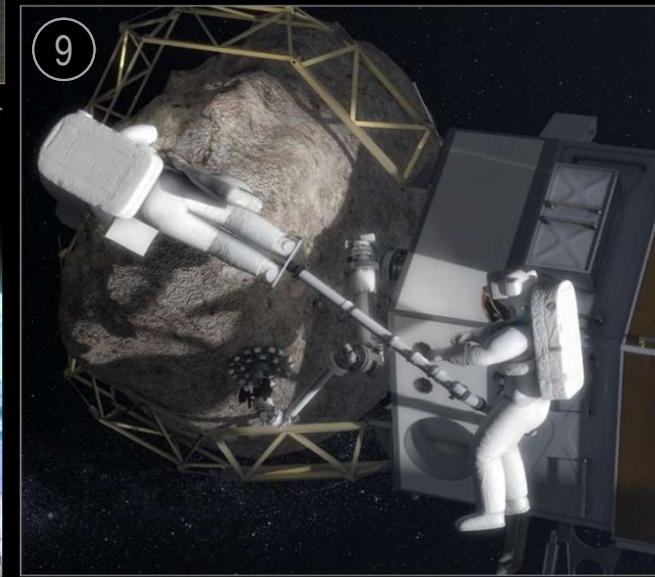
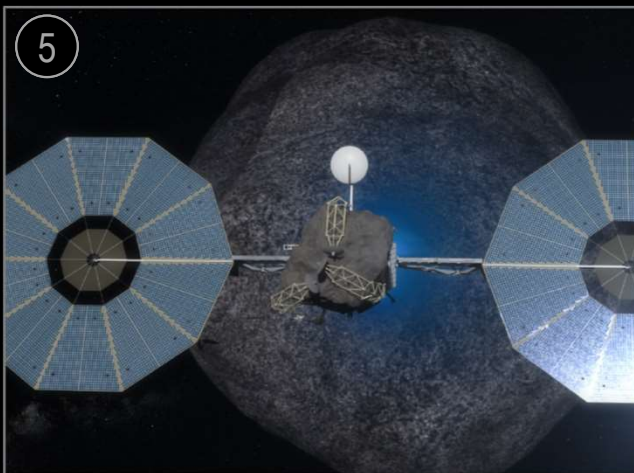
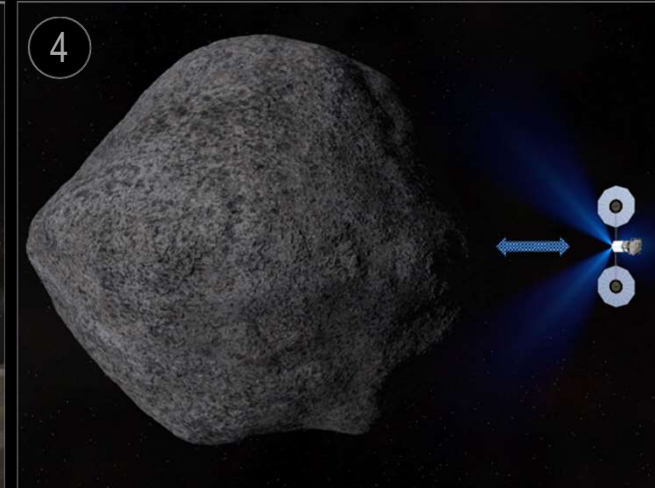
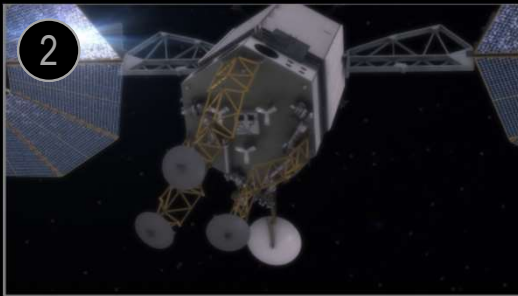
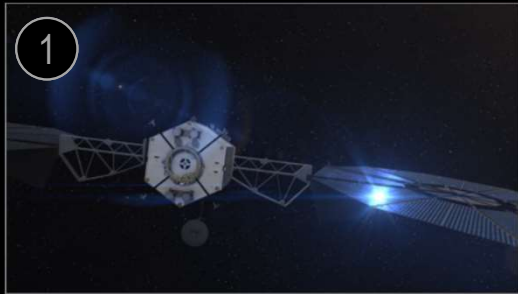


Integrated crewed/robotic vehicle operations in deep space



Astronaut EVAs in deep space for sample selection, handling, and containment

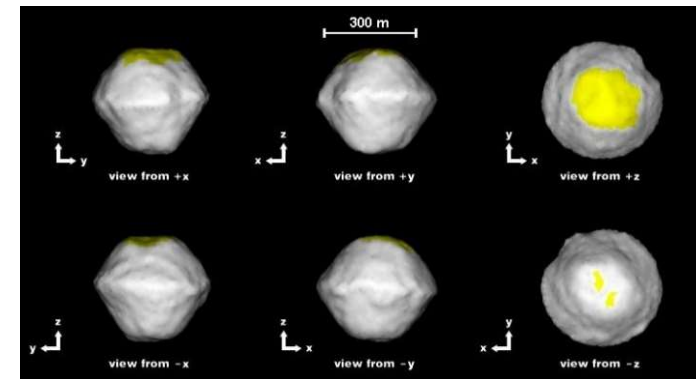
Asteroid Redirect Mission Highlights



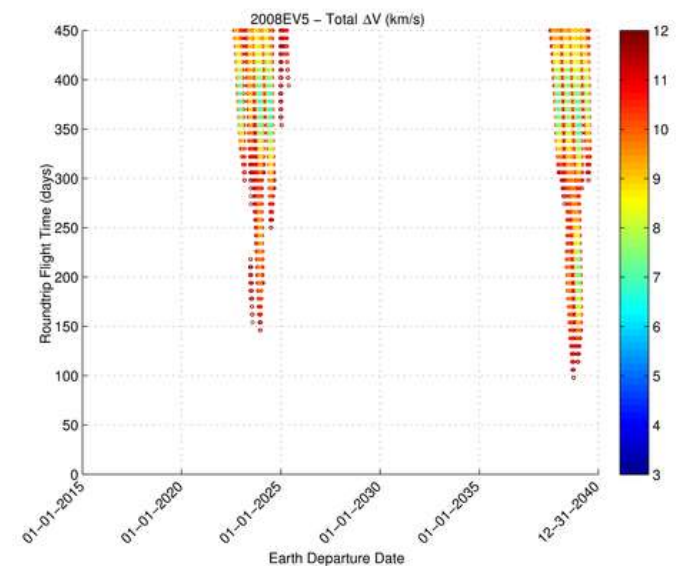
Reference Target 2008 EV₅



- **Significant interest from the science and small bodies communities with well-documented investigation opportunities.**
 - Primitive, C-type (carbonaceous) believed to be rich in volatiles.
 - Target of ESA's Marco Polo-R candidate sample return mission (not selected).
- **Largest asteroid with lowest mission ΔV (6.3 km/s) of the 1988 objects (as of 3/17/17) in the Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) list.**
 - Potential human mission target in late 2030s.
 - Possible target for resource collection.
- **Large, hazardous-size asteroid provides representative target for planetary defense demonstration.**

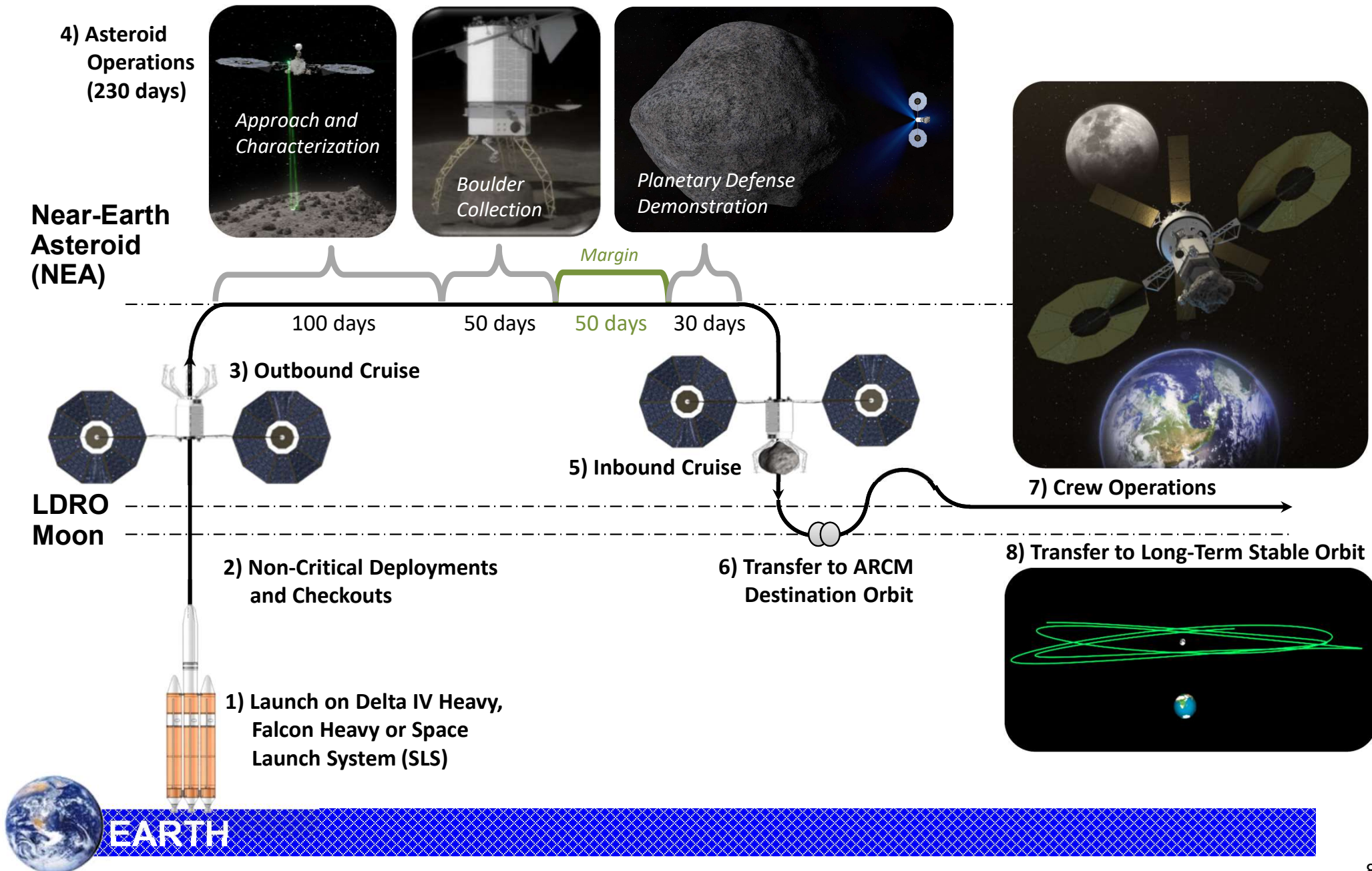


2008 EV₅ shape model from radar observations.



2008 EV₅ Minimum Mission ΔV for 2015-2040.

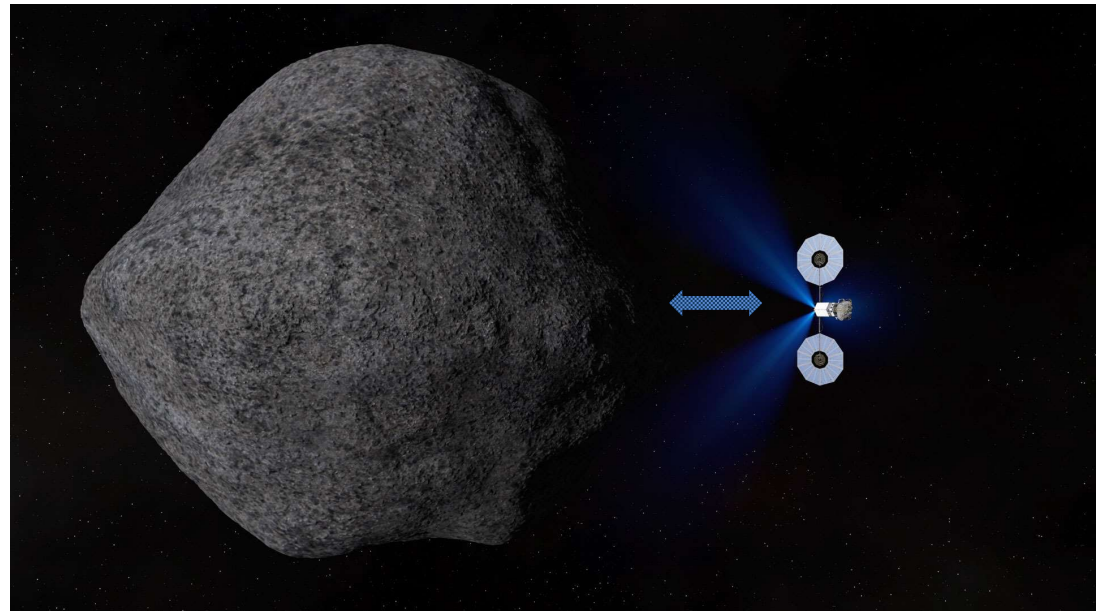
ARM Robotic Segment Overview



Planetary Defense Demonstration



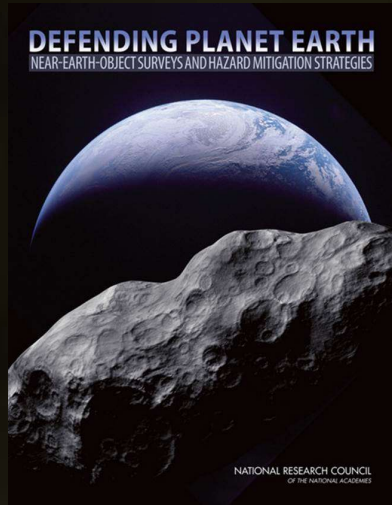
- **Enhanced Gravity Tractor (EGT)**
 - Uses the mass of the collected boulder to augment the mass of the spacecraft and increase the gravitational attraction
- **Small, but measurable deflection will be imparted on hazardous size asteroid**
 - 2008 EV₅ deflection can be verified using ground-based radar (opportunities available in 2023, 2024, and 2025)
 - Other targets may require the Asteroid Redirect Vehicle (ARV) to loiter near the asteroid for deflection verification via differential ranging to the ARV
- **Actual EGT planetary defense mission could collect much more mass, increasing the effectiveness of this technique**



ARM Animation



Planetary Defense Strategies



2010 National Research Council Committee

“Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies”

- Finding: **No single approach to mitigation is appropriate and adequate** for completely preventing the effects of the full range of potential impactors, although civil defense is an appropriate component of mitigation in all cases. **With adequate warning, a suite of four types of mitigation is adequate to mitigate the threat from nearly all NEOs except the most energetic ones.**

TABLE 5.1 Summary of Primary Strategies for Mitigating the Effects of Potential Impacting Near-Earth Objects

Strategy	Range of Primary Applicability
Civil defense (e.g., warning, shelter, and evacuation)	Smallest and largest threats. Threat of any size with very short warning time.
Slow push (e.g., “gravity tractor” with a rendezvous spacecraft)	A fraction (<10%) of medium-size threats. Usually requires decades of warning time.
Kinetic impact (e.g., interception by a massive spacecraft)	Most medium-size threats. Requires years to decades of warning time.
Nuclear detonation (e.g., close-proximity nuclear explosion)	Large threats and short-warning medium-size threats. Requires years to decades of warning time.

Rapid “Impulsive” Techniques for NEA Deflection



- **Application produces immediate result**
- **Effectiveness is dependent on the NEA properties (highly uncertain and variable)**
- **Large, concentrated forces have the potential for NEA fragmentation/disruption**
- **Examples:**
 - Kinetic Impactor
 - Conventional Explosives (surface or sub-surface)
 - Nuclear Detonation (stand-off, surface, sub-surface) with potential delivery system using a very-high-velocity impactor

Slow “Push/Pull” Techniques for NEA Deflection



- **Long duration (months to many years depending on NEA size) and small forces applied**
- **Efficient use of resources (propellant, power, in situ materials)**
- **Four basic categories:**
 - Enhance natural effects
 - Apply contact force
 - Apply gravitational force
 - Ablation/expulsion of surface material
- **Examples:**
 - Albedo/Thermal Response Modification (Yarkovsky effect) - likely centuries required for a 200 m NEA
 - Direct Push (“Space Tug”)
 - Mass Driver
 - Gravity Tractor (GT) and Enhanced Gravity Tractor (EGT)
 - Ion Beam Deflection (IBD)
 - Surface Ablation (laser and solar)

“The Earth is the cradle of humanity, but mankind cannot stay in the cradle forever.”

– Konstantin Tsiolkovsky
“Father” of the Rocket Equation and Astronautics

Exploration



Pioneering



Settlement



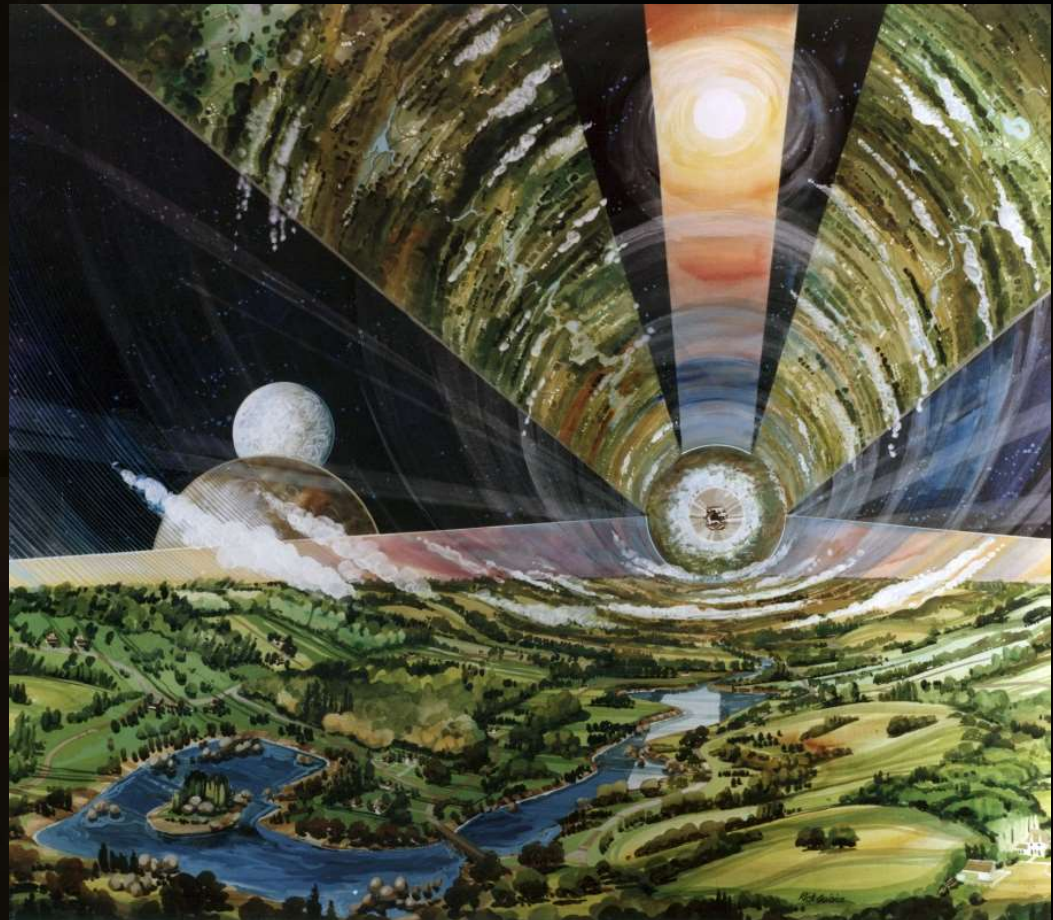
Permanent settlement – enabled
by the use of in-situ resources



Multi-planet species



Multi-star system species





The Economy!

- Survival of our species (as well as other lifeforms on Earth) is likely a long-term need, but economic return and growth drive decision making in the near term.
- The payback from space-based resources could be tremendous, but the start-up costs are high.
- As launch costs fall, the cost to extract and process space-based resources will also fall.
- NASA is already working on 3-D manufacturing in space, automated robotic construction using regolith, and self-replicating large structures.
- Possible platform/counter-weight for a lunar space-elevator and transfer depot, which could allow electromagnetic launch of asteroidal and lunar resources from the lunar surface in support of other deep-space missions. Could ultimately permit the cost-effective return of materials to markets on Earth.
- If costs can be lowered sufficiently, high-value commodities could even be returned to Earth.

Towards a Space-based Economy



- Future exploration and the permanent settlement of space will need resources from multiple locations (out of gravity wells and at the bottom of them) just as we get our resources from many locations on Earth.
- A vibrant space-based economy will require advanced technologies/capabilities along with lower launch costs to reduce the cost of doing business in space.
 - Reusability, automation, intelligence systems, 3-D manufacturing, self-replication & repair, etc.
 - Government funding of infrastructure that is beyond the means of commercial companies and consortiums is enabling (analogy of U.S. interstate highway system).
 - Economic “backfill” is needed to enable permanent settlement of space with eventually high-value products being returned to terrestrial markets (by-products of ISRU along with delivery systems).



Image Credits: Deep Space Industries



**Thank you for your time and attention.
Questions?**

