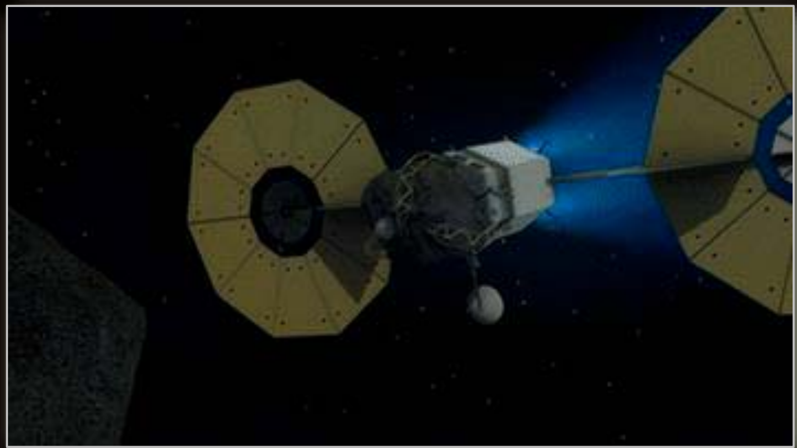
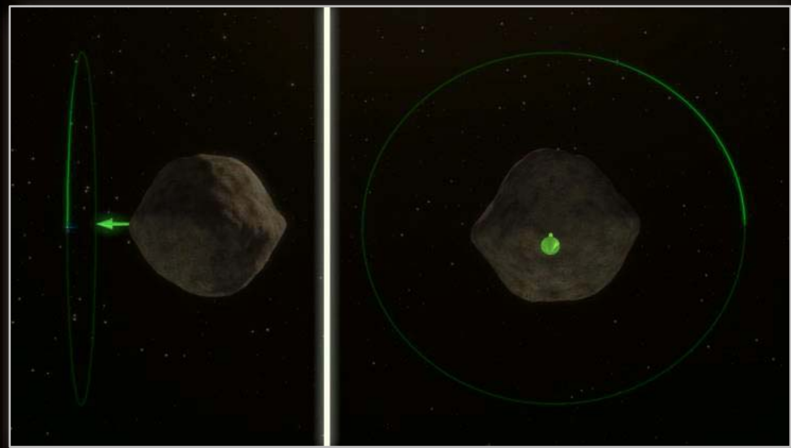
National Aeronautics and Space Administration

# Enhanced Gravity Tractor Technique for Planetary Defense






Presented by Dan Mazanek[1]

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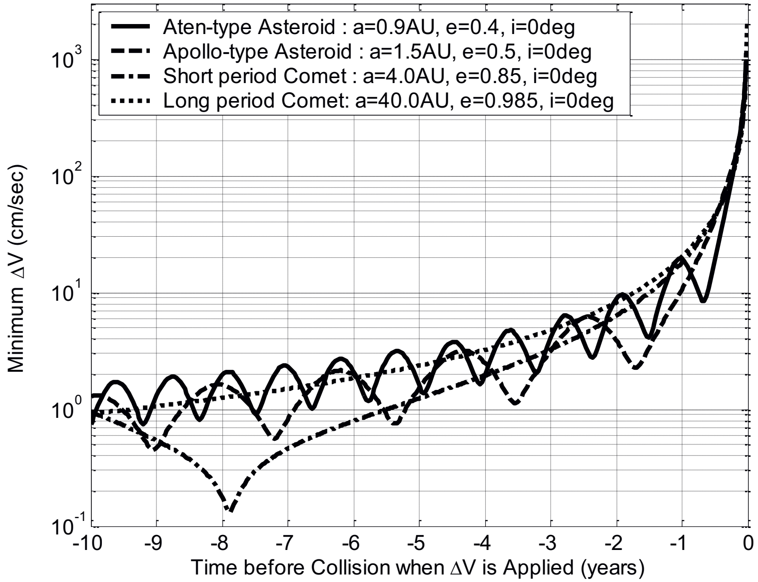
# Background

- Early response requires less ΔV to deflect an impactor
- Rapid impulse techniques (e.g., kinetic impactors and nuclear detonations)
  - Require the least amount of warning time
  - Effectiveness depends on the Near-Earth Object (NEO) properties, which are uncertain and vary substantially
  - Application of a large, concentrated force has the potential to fragment the NEO
- "Slow push/pull" techniques (e.g., gravity tractor, laser ablation, ion beam deflection, etc.)
  - Require significant warning time
  - Accelerate the impactor in a uniform manner with only small forces any internal structural stresses
  - Effective against binary or even ternary systems



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# Introduction

- Standard Gravity Tractor
  - Requires low-thrust, high-efficiency propulsion
  - Applied force is exceedingly small
    - Depends on the mass of the spacecraft
    - Many years or decades of operations

Image Credit: Dan Durda/FIAAA/B612 Foundation.

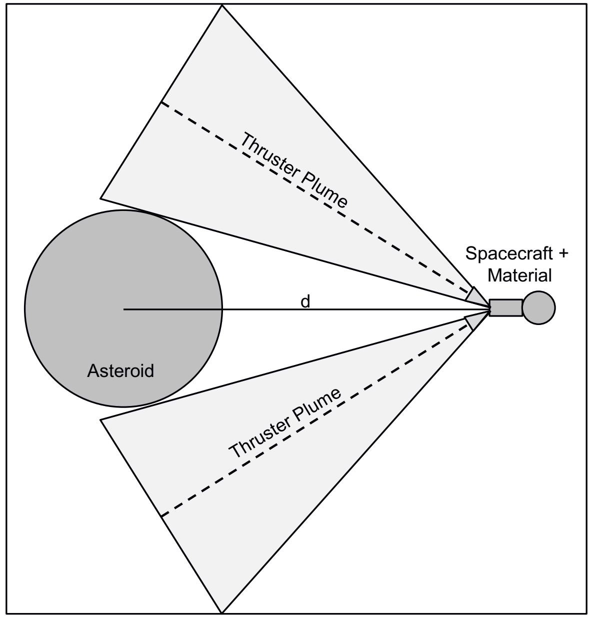
- On March 25, 2015, NASA announced that the Asteroid Redirect Mission (ARM) robotic segment would visit a large near-Earth asteroid (NEA) to capture a multi-ton boulder and return it to the Earth-Moon system
  - Advanced 50 kW-class Solar Electric Propulsion (SEP) Asteroid Redirect Vehicle (ARV)
  - First demonstration of Enhanced Gravity Tractor (EGT) – technique conceived during mission concept development

Image Credit: NASA/AMA, Inc.

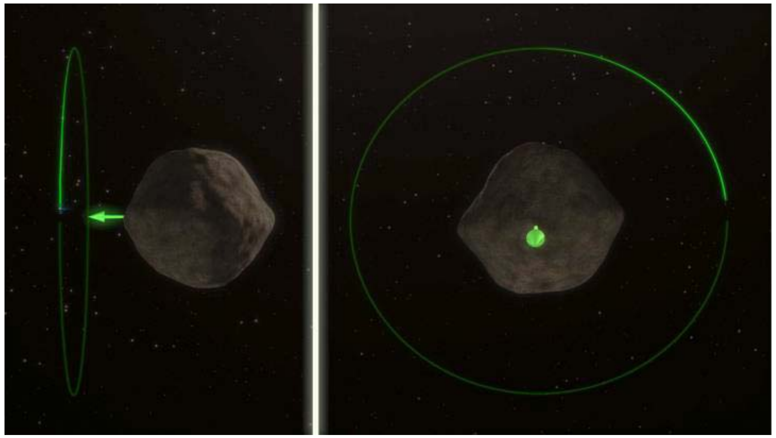
ARM Animation

# Concept of Operations

- Once in the proximity of a hazardous NEO, the EGT operations consist of five phases:
  - Initial orbit determination
  - Characterization
  - Material collection
  - Tractoring
  - Final orbit determination




**In-line Tractoring Method**



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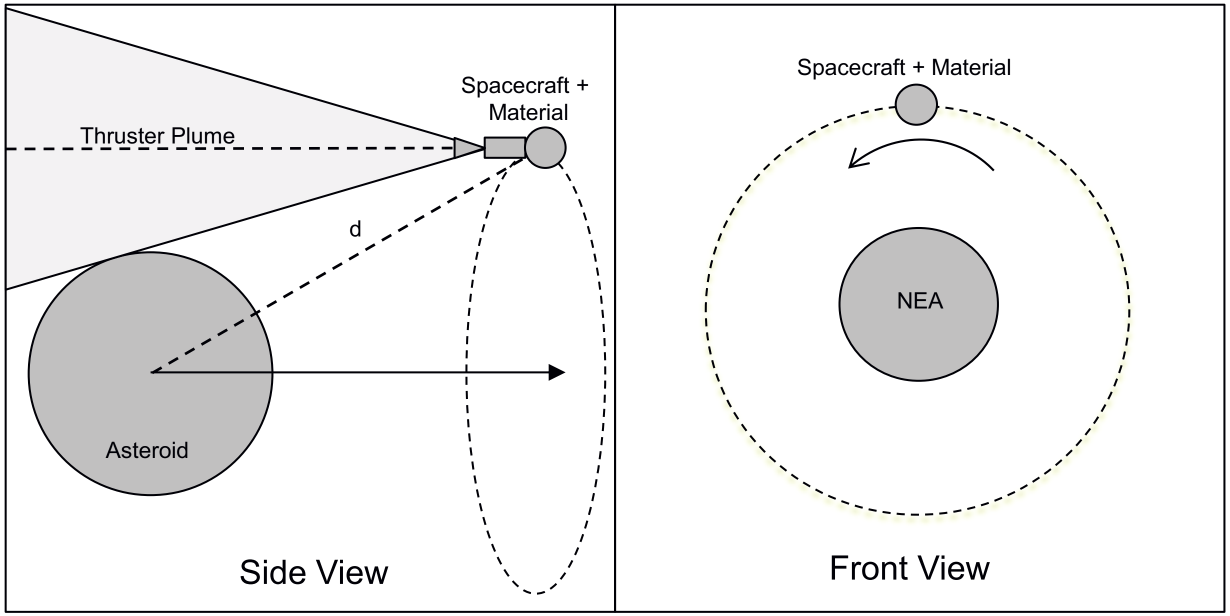
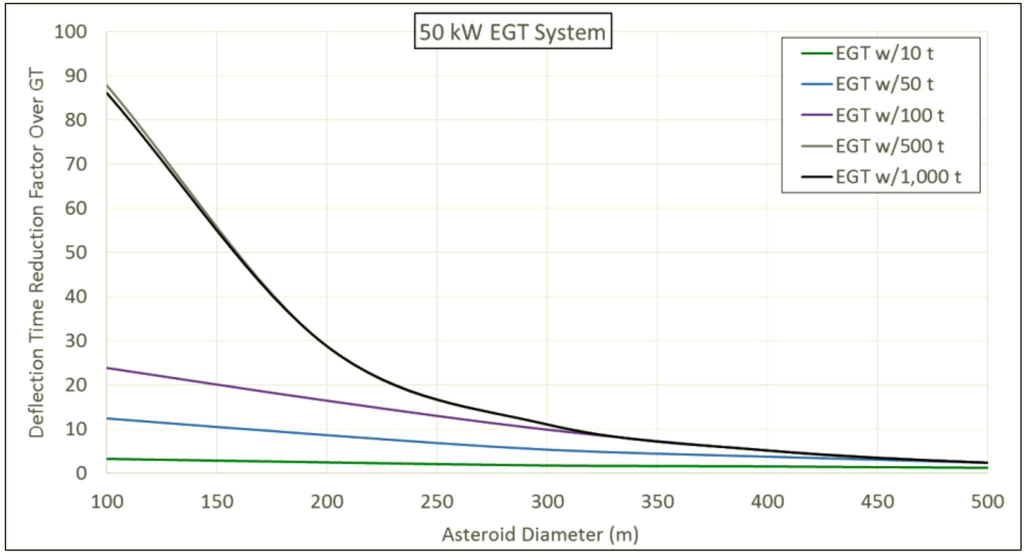
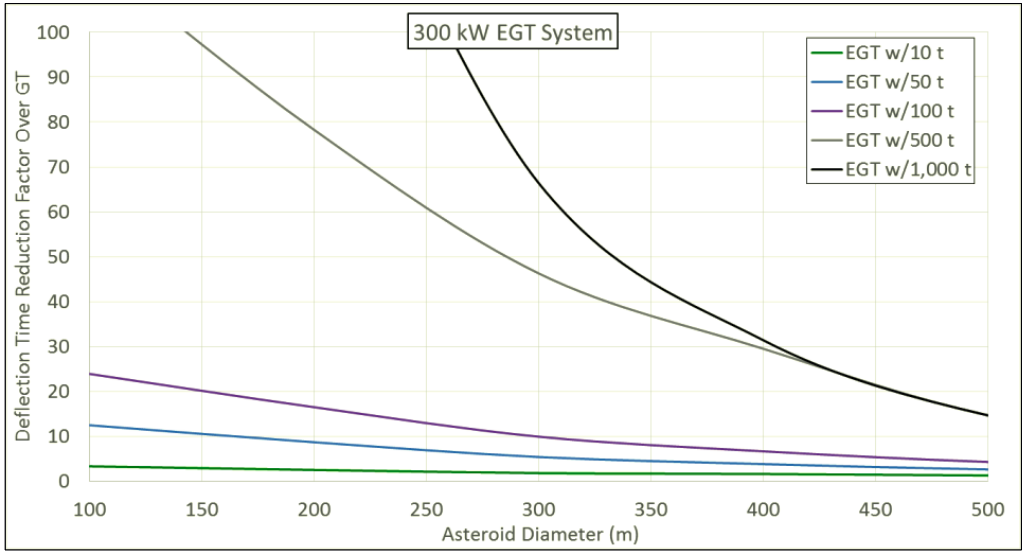



**Spiral Tractoring Method**

# Comparison of Traditional and Enhanced Gravity Tractor



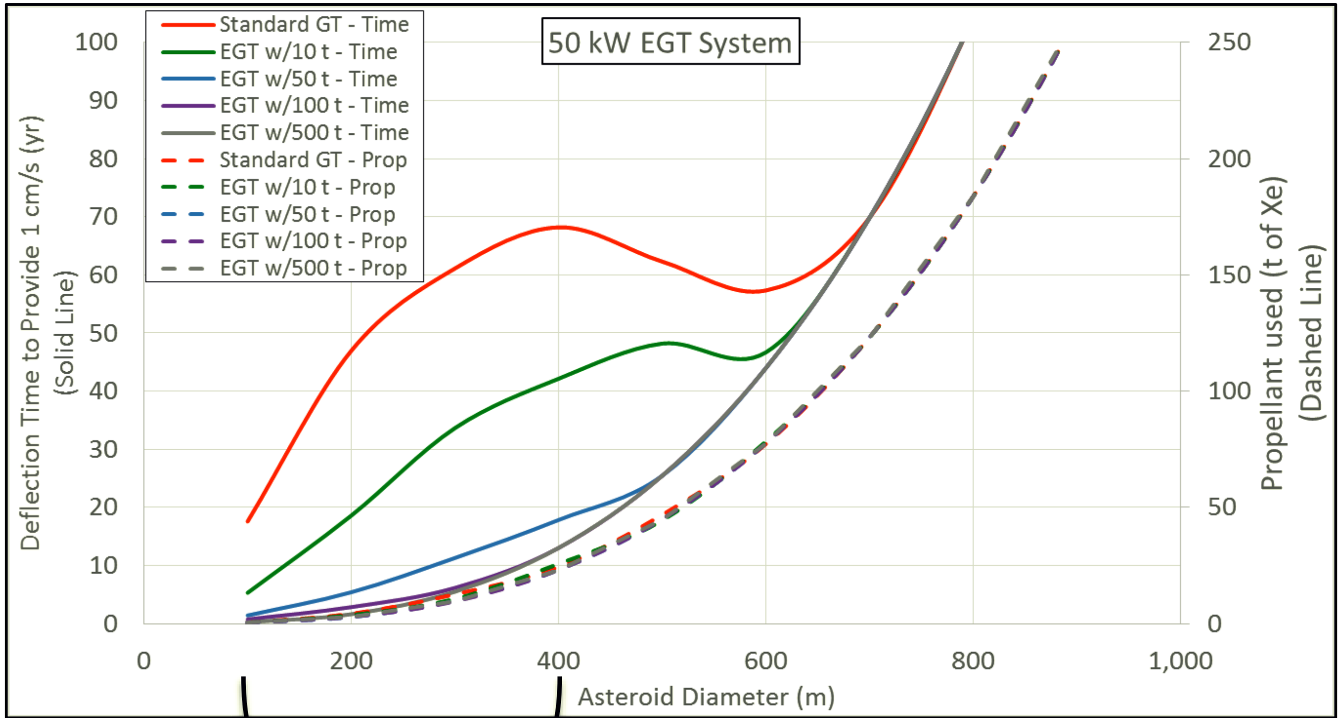

- 50 kW ARV-class SEP vehicle
- 1.63 N maximum thrust

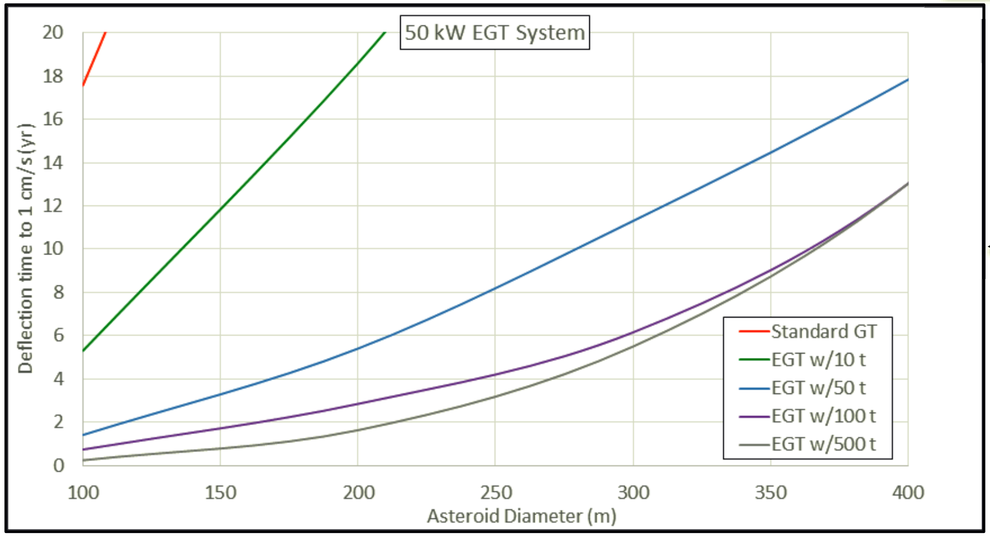
- 300 kW human-mission-class SEP vehicle
- 9.78 N maximum thrust

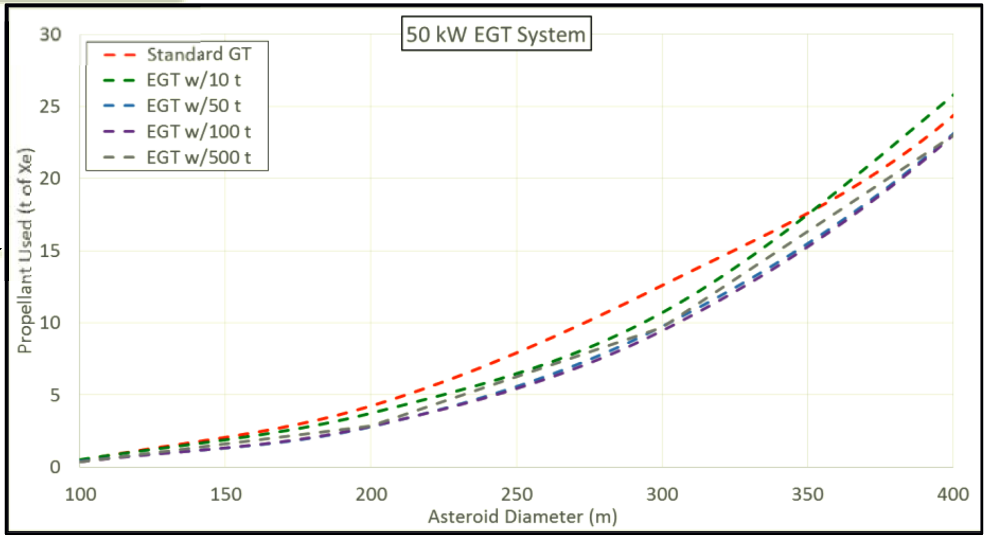
- Common Assumptions:
  - Spherical asteroid with a constant density of 2 $g/cm^3$
  - Minimum range of one asteroid radius above the assumed spherical asteroid's surface
  - Assumed maximum thrust available independent of solar range and no specific asteroid orbit

# Comparison of Traditional and Enhanced Gravity Tractor

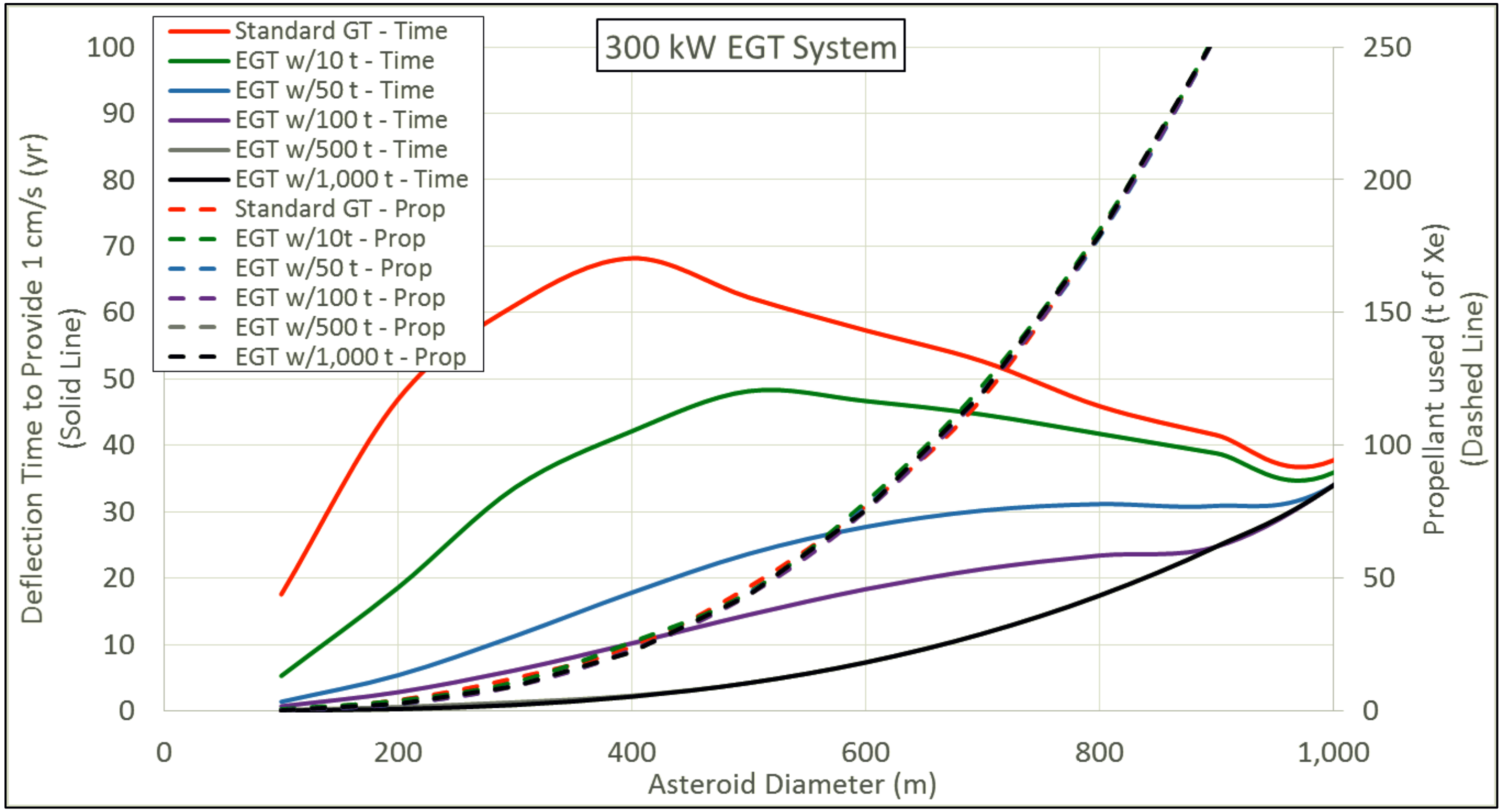
- 50 kW ARV-class SEP
- 1.63 N maximum thrust



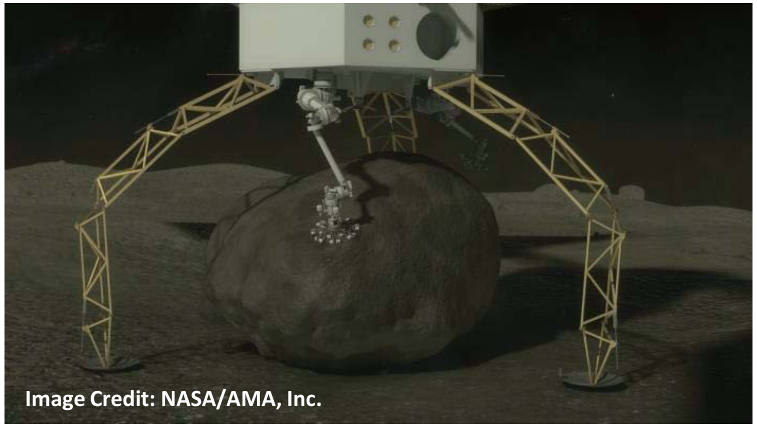
# Comparison of Traditional and Enhanced Gravity Tractor



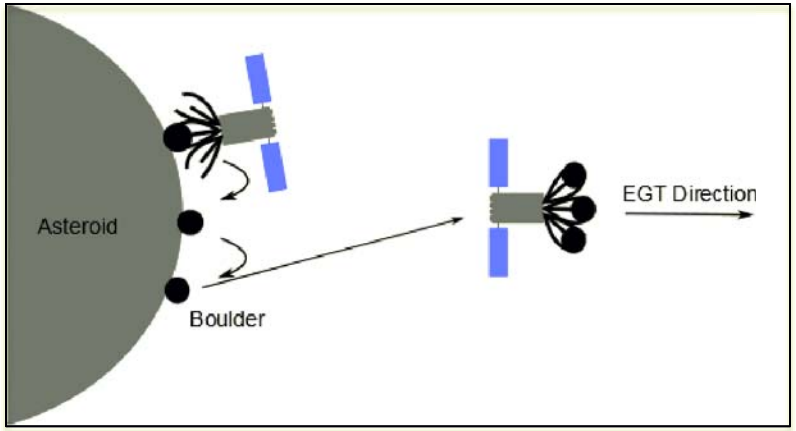

- 300 kW human-mission-class SEP vehicle
- 9.78 N maximum thrust

# Mass Collection Option Examples

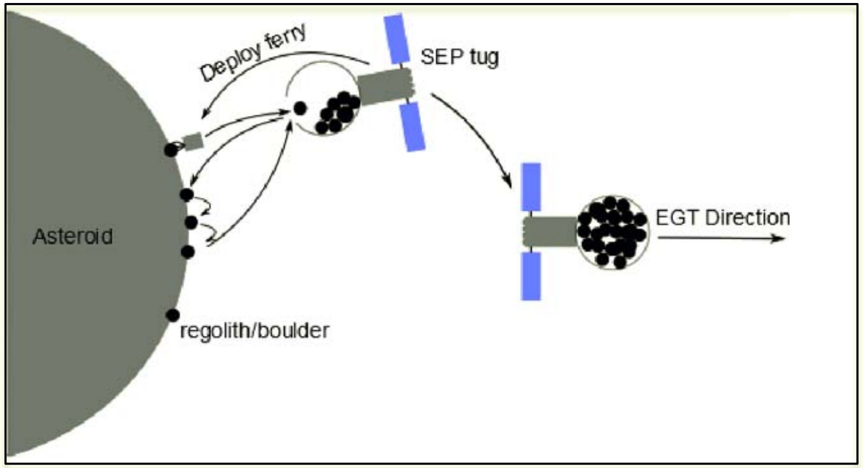
Concept 1 – Collecting a Single Boulder



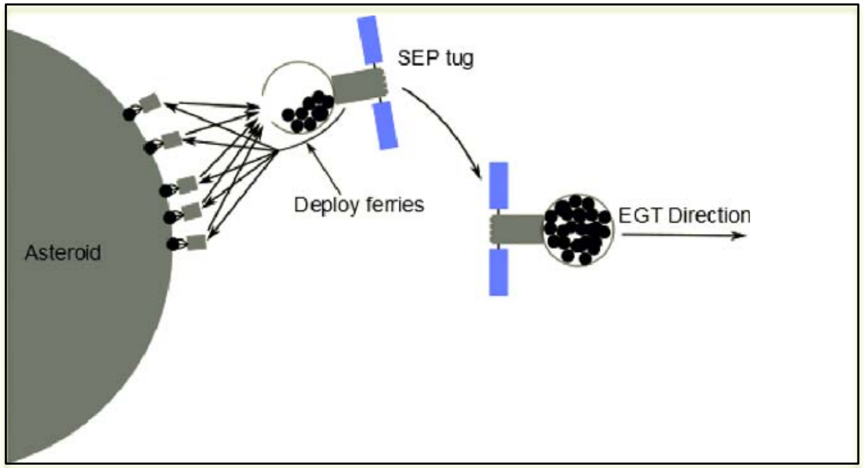

Concept 2 – Collecting Multiple Boulders




Concept 3 – Separable Collection Spacecraft and SEP Tug



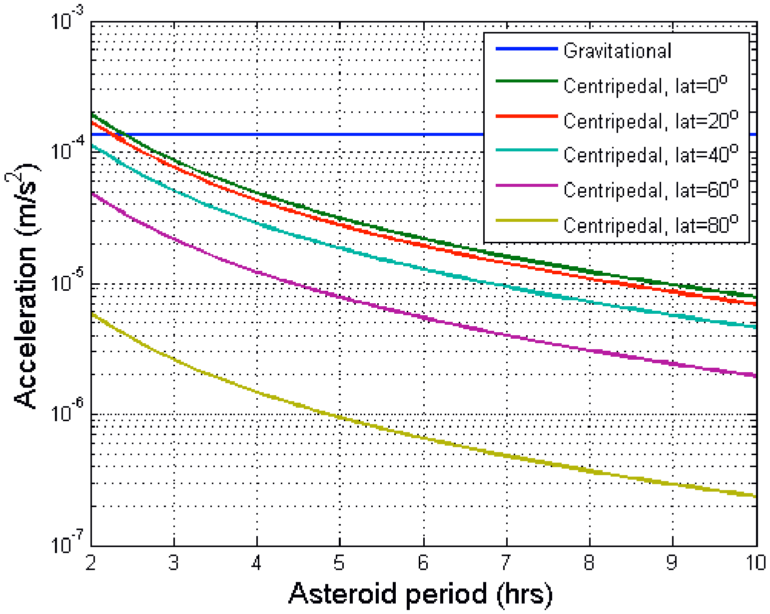

Concept 4 – Multiple Collection Spacecraft and SEP Tug




- Many other collection techniques (electromagnets, large quantity regolith collection, etc.) and operational concepts (tethers, solar sails, etc.) are possible
- Synergy with the extraction and processing of asteroidal resources

# Operational Challenges of Mass Augmentation

- Collection Site Selection
  - Depends on many factors (lighting, communications, thermal, etc.)
  - Equatorial regions are likely rich in material and may facilitate collection due to maximum centripetal acceleration levels
  - Commercial interest in asteroid mining indicates that collecting many tons of mass from the surface is feasible




- Existence of Collectable Material
  - Centripetal acceleration for small, fast rotators can exceed the gravitational forces leading to a monolithic body without collectable material
  - Very few large asteroids have been observed to rotate above the ~2.3 hour rubble pile "speed limit"
  - Observations indicate that the vast majority of large asteroids have surface material that is loosely bound and readily collectable, thus making EGT a credible deflection technique for hazardous-sized impactors

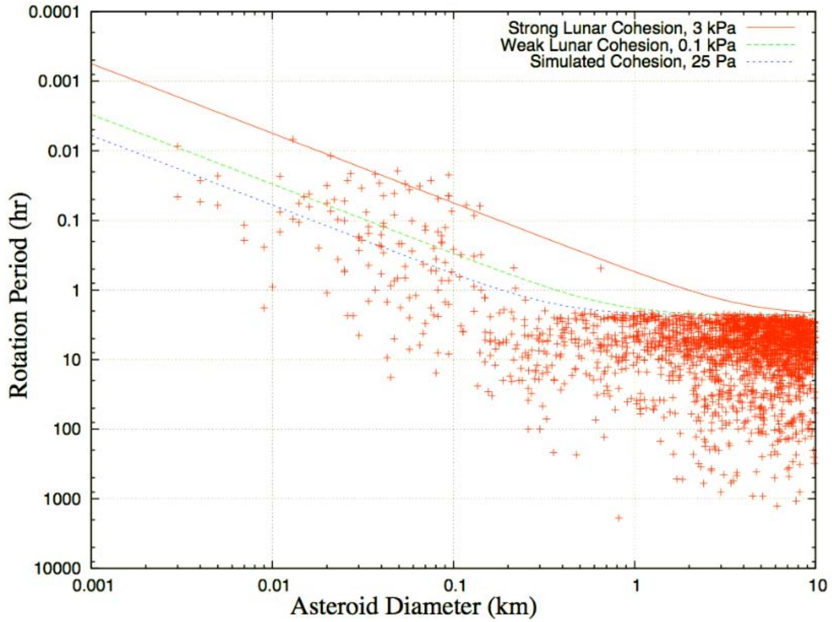
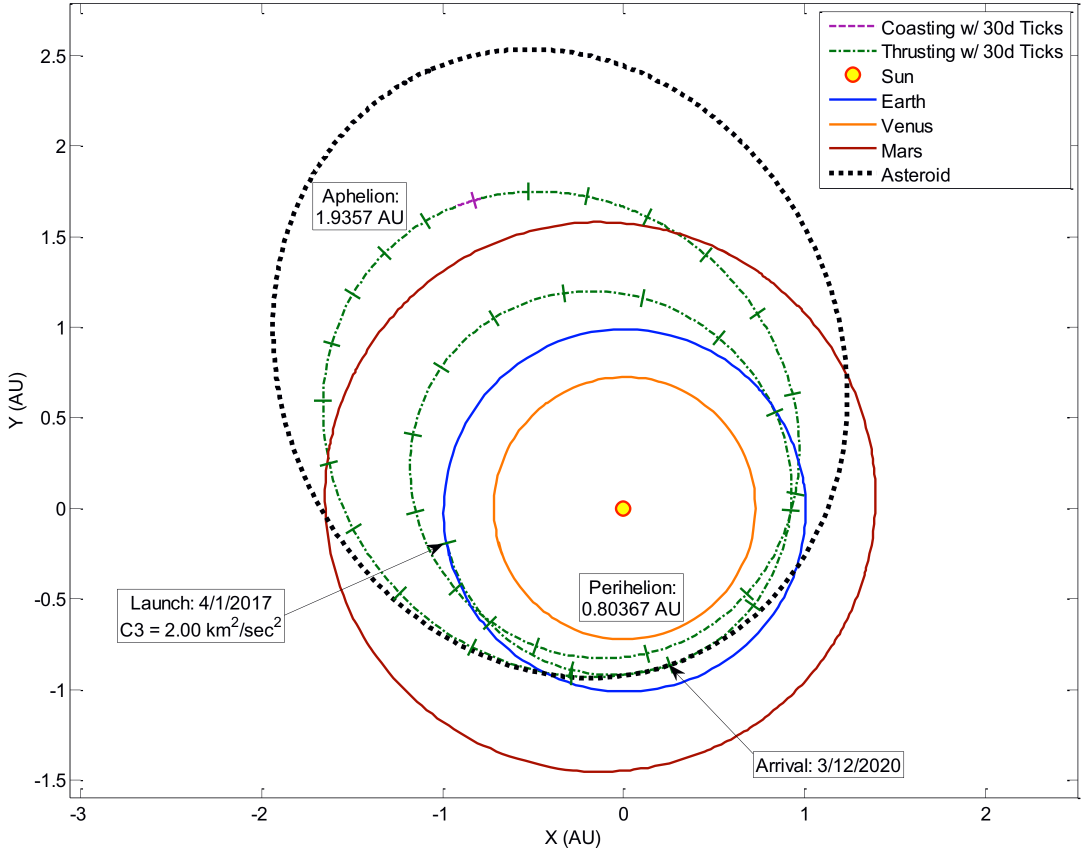



**Image Credit: Paul Sánchez and Dan Scheeres**

# Applicability to Hypothetical Threat "2015 PDC"

- Analyzed the ability of a 50-kW EGT spacecraft like the ARV to deflect hypothetical asteroid "2015 PDC"
- Two major challenges in this scenario:
  - Only 5.5 years total duration assuming launch or departure in spring 2017 and impact in September 2022
  - Aphelion of 2.65 AU limits the power during parts of the diversion to only about 15% of the 1 AU insolation
- Found some solutions where deflection is possible
  - Stony asteroid with a mass of 1.7 million tons (H = 21.7, albedo = 0.3, and density of 2.5 g/cm$^3$) – smaller and less massive than the most likely values, but reasonable
  - Assumed 2:1:1 ellipsoid with dimensions of ~87 x 87 x 175 m (spherical equivalent diameter of 110 m)
- Arrival at 2015 PDC on March 12, 2020
  - 3 month reconnaissance and mass collection
  - EGT performed for next 824 days
- Deflection from subterranean 2,790 km Earth periapsis radius (i.e., an impact) to 6,930 km allowing for a miss of 560 km altitude from the surface



# Warning Time and EGT Compatibility with other Options

- EGT can significantly overlap the kinetic impactor regime, especially if a SEP spacecraft like the ARV has been developed and operated or can be expediently refueled in space
  - ARVs ready to launch and/or already operational in space (e.g., cislunar logistics deliveries, Mars missions, etc.)
  - Repurposed for its critical new mission of planetary defense

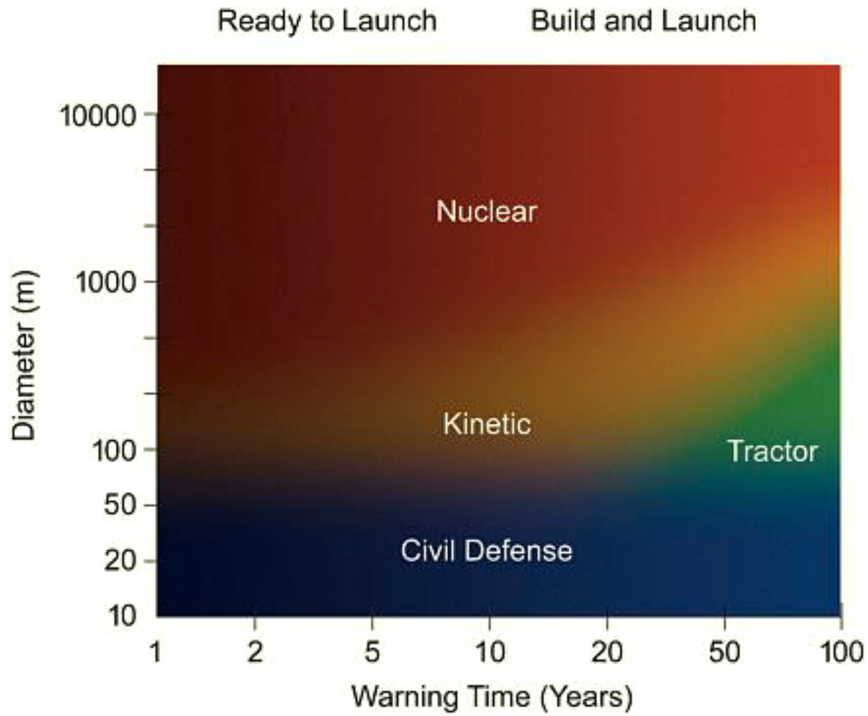
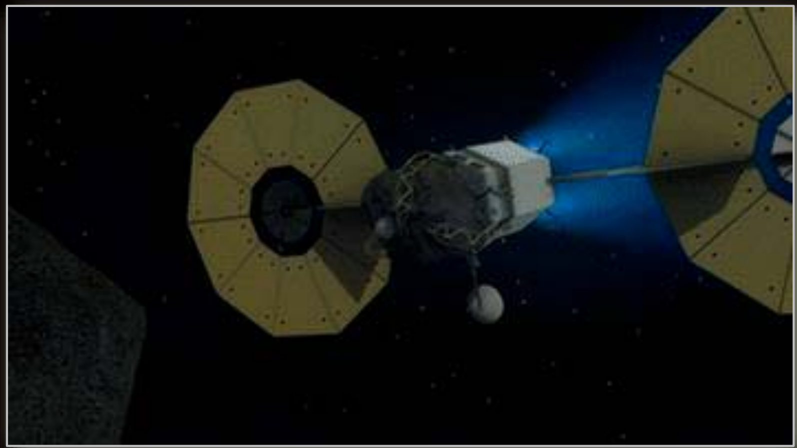


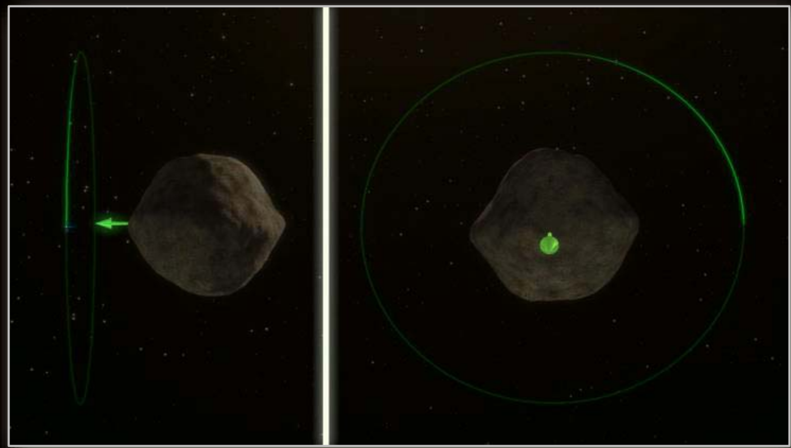
Image Credit: Tim Warchocki

- EGT spacecraft can also support other planetary defense techniques in a coordinated manner to maximize the successful deflection effort
  - Provide impact confirmation during rendezvous
  - Deliver payloads to the target asteroid's surface or vicinity
  - Provide targeting support for a kinetic impactor – spotter spacecraft capable of follow-up deflection operations
  - With refueling, could be used as a kinetic impactor augmented by mass collected during normal operations

# Closing Remarks

- The Enhanced Gravity Tractor technique is a novel, innovative variant of the traditional gravity tractor that can significantly reduce deflection time
- Augmentation with in-situ mass allows for significant increases in tractoring mass which greatly increases the gravitational force available
- NASA's Asteroid Redirect Mission (ARM) robotic concept to collect a boulder from the surface of a hazardous-sized near-Earth asteroid would provide the first ever demonstration of the EGT technique and validate one method of collecting in-situ mass
- Advancements in SEP propulsion, autonomous vehicles, and robotic systems applicable to human and robotic exploration, commercial asteroid mining, and the used of space-based resources can synergistically help provide a robust defense against future Earth impacts





Thank you for your time and attention.

Questions?