ION BEAM DEFLECTION
(AKA PUSH-ME/PULL-YOU)

October 1, 2013

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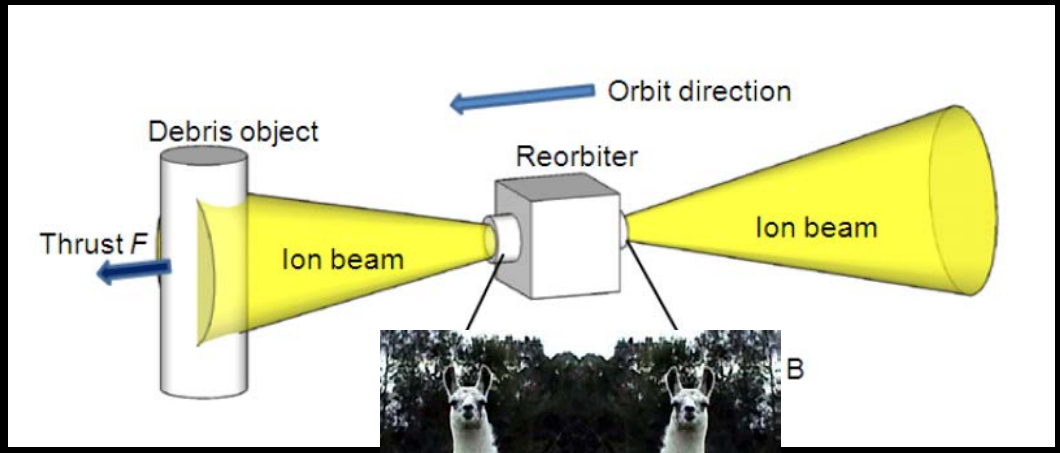
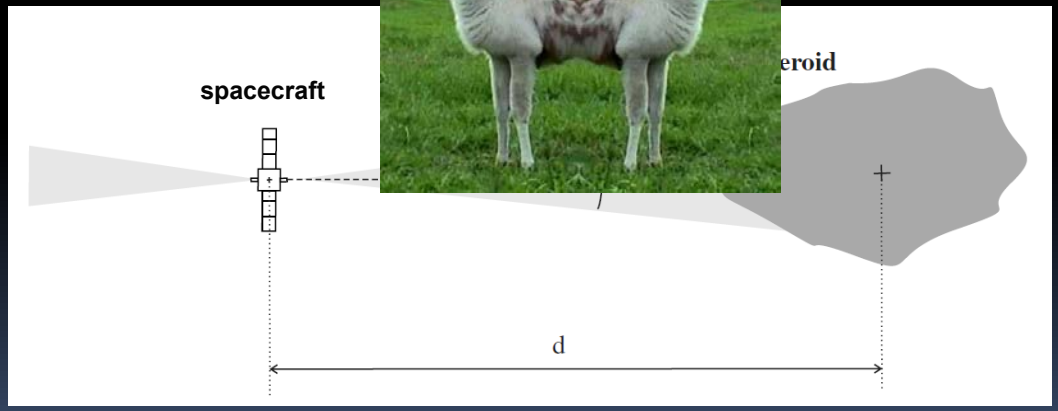
Concept Overview

- Kitamura, S., “Large Space Debris Reorbiter Using Ion Beam Irradiation,” IAC-10-A6.4.8, 61st International Astronautical Congress, September 2010.

- C. Bombardelli and J. Pelaez, J. of Guidance, Control, and Dynamics, Vol. 34, No.4, July-August 2011.

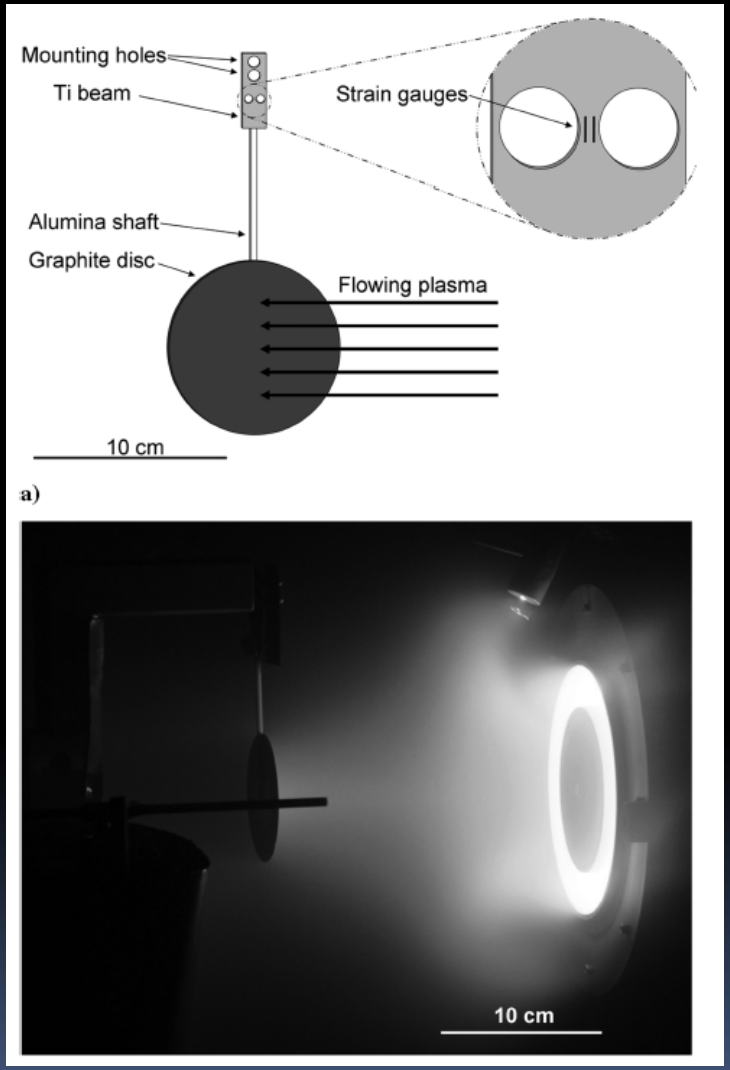




Ion Beam / Asteroid Interactions

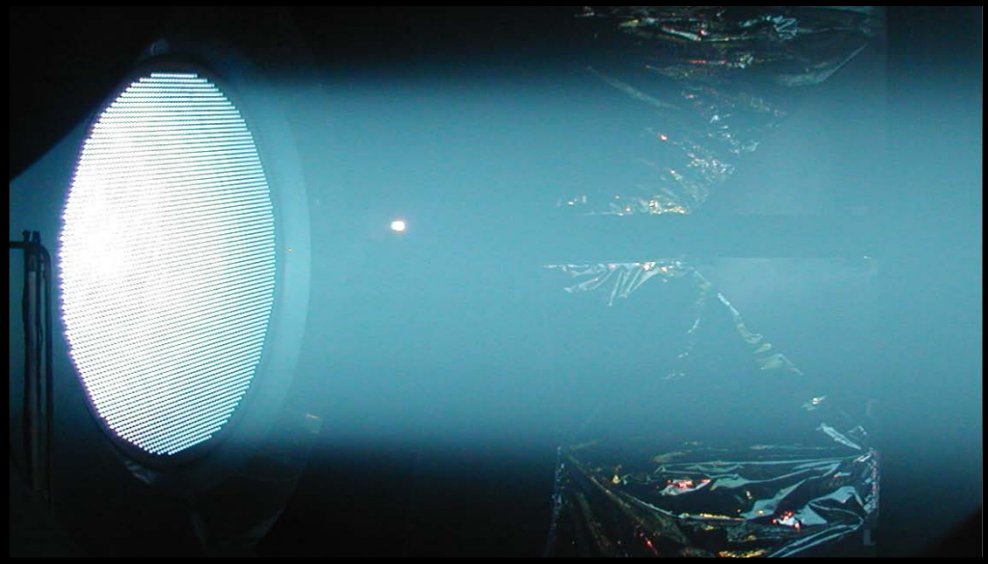
- The electric thruster exhaust impinging on the asteroid will impart a force approximately equal to the thrust (within a couple of percent).
  - This has been verified experimentally where a “plasma momentum flux sensor” that intercepts the entire exhaust plume of a Hall thruster feels a force equal to the measured thrust produced by the thruster*.

- Other Effects:
  - Some of the thruster exhaust may miss the asteroid
    - Minimized by selecting the right separation distance between the thruster and asteroid surface based on the size of the asteroid and the divergence angle of the thruster exhaust.
  - Sputtering of the asteroid surface
    - Sputtered products are known to leave the surface with low velocities relative to that of the incoming ions
  - Elastic collisions of the ions
    - Experiments indicate this to be a minor effect
  - Asteroid charging
    - Not expected to be a significant effect since the thruster exhaust is quasi-neutral



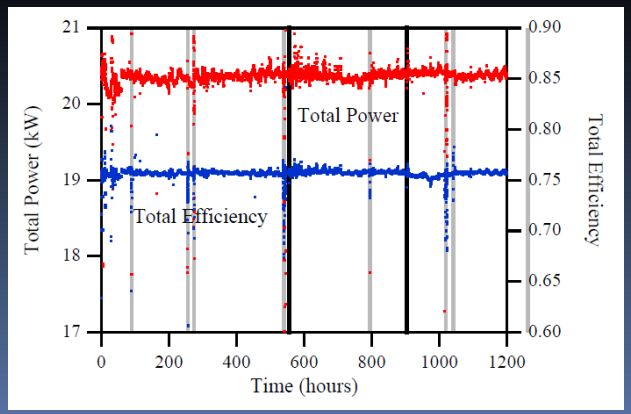
*Longmier, B.W., et al., “Validating a Plasma Momentum Flux Sensor to an Inverted Pendulum Thrust Stand,” *J. of Propulsion and Power*, Vol. 25, No. 3, May-June 2009

High-power, Low-beam-divergence Ion Thruster (NEXIS)



J. Polk, et al., "Performance and Wear Test Results for a 20 kW-Class Ion Engine with Carbon-Carbon Grids," AIAA 2005-4393, 10 - 13 July 2005, Tucson, Arizona

- Thruster Input Power: 20 kW
- Ion Velocity: ~70 km/s
- Thrust: 0.45 N
- Flat Carbon-carbon Grids
- Ion Beam Divergence Half-angle: < 5°
- Wear Tested for 1,200 hours

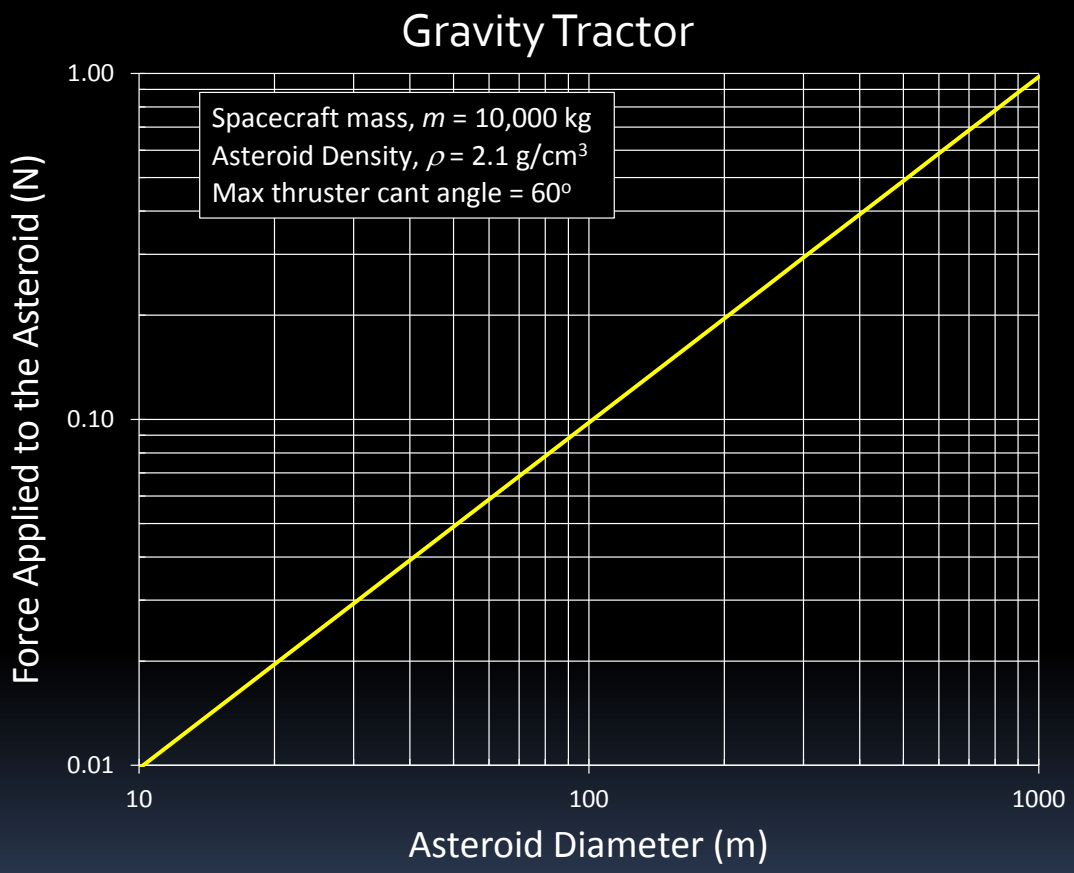


Other Asteroid Deflection Concepts

- Gravity Tractor

$$F = \frac{GMm}{r^2}$$

  - F = 0.10 N for a 100-m asteroid



- Kinetic Impactor

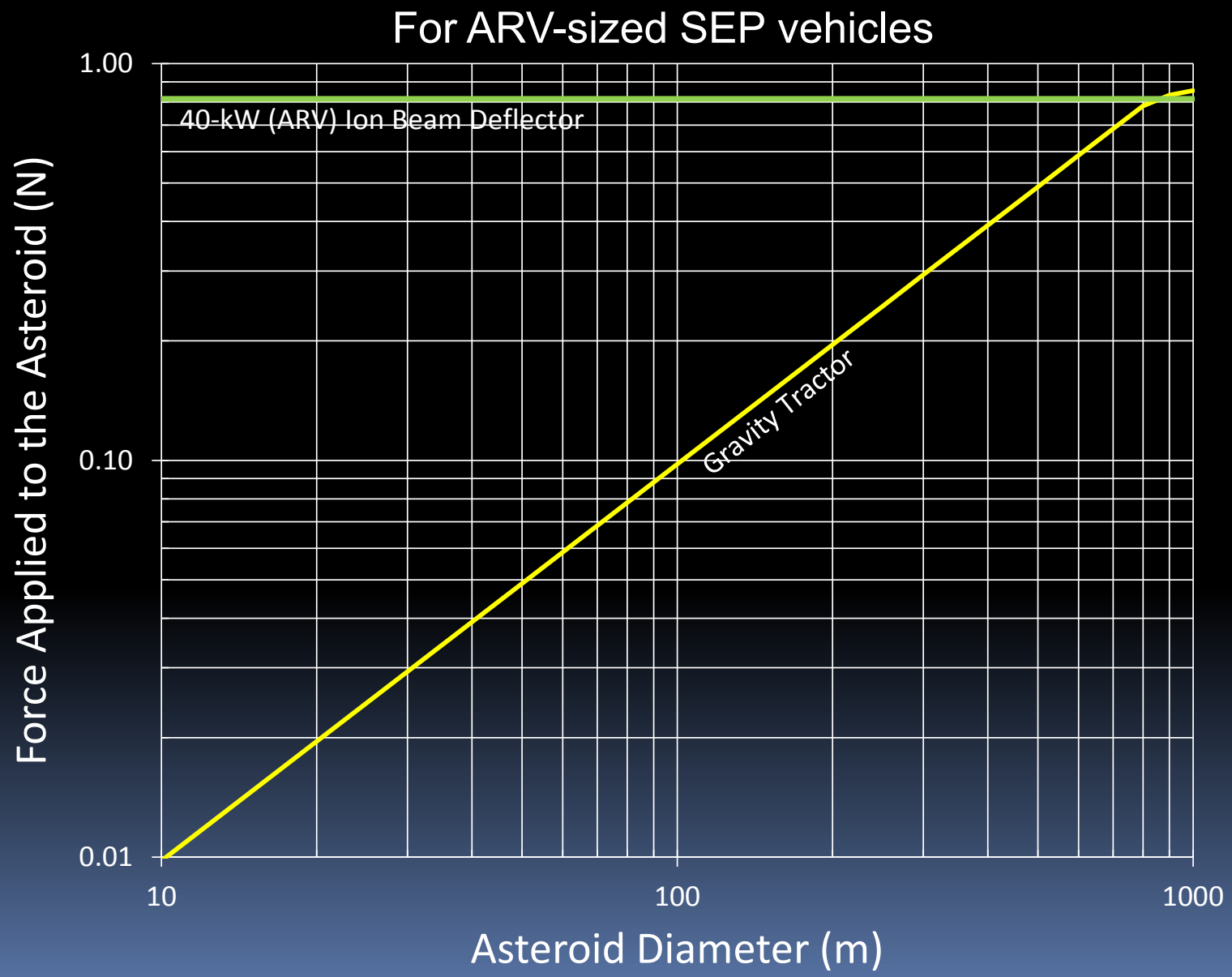
$$\Delta V = \beta \left(\frac{m}{M}\right) V_\infty$$

  - Representative Values
    - V_∞ between 5 km/s and 25 km/s
    - $m \leq$ 10,000 kg

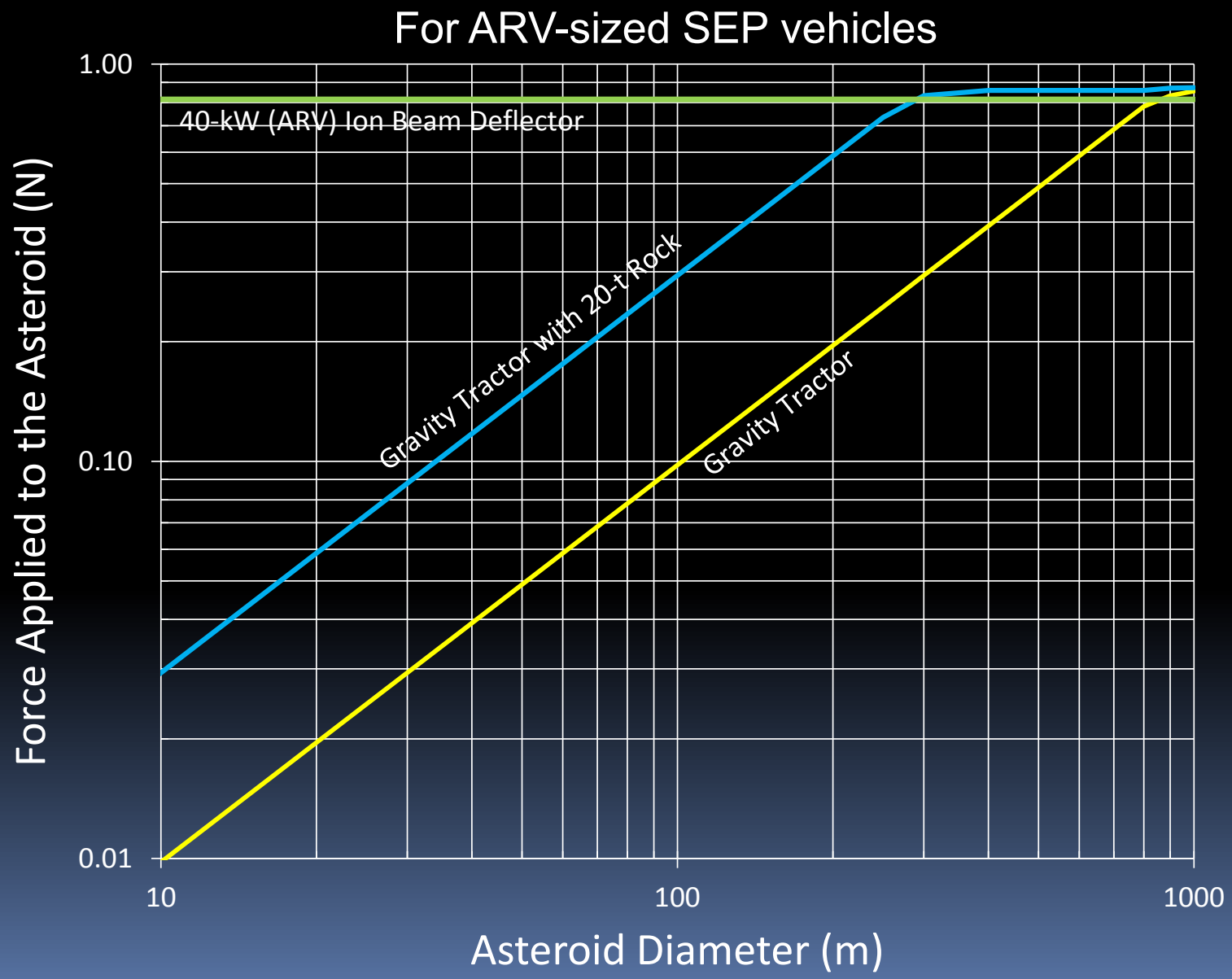
Ion Beam Deflection (IBD)

- Assume the approximate capabilities of the Asteroid Redirect Vehicle (ARV)
  - 10,000 kg delivered to the asteroid
  - 6,000 kg of propellant
  - Ion Exhaust Velocity 30 km/s
- Since the IBD must thrust in both directions, only approximately half the propellant is available to impact the asteroid
  - 3,000 kg at 30 km/s
  - This is comparable to the momentum in a kinetic impactor, and can be directed along the velocity vector

IBD Compared to Gravity Tractor

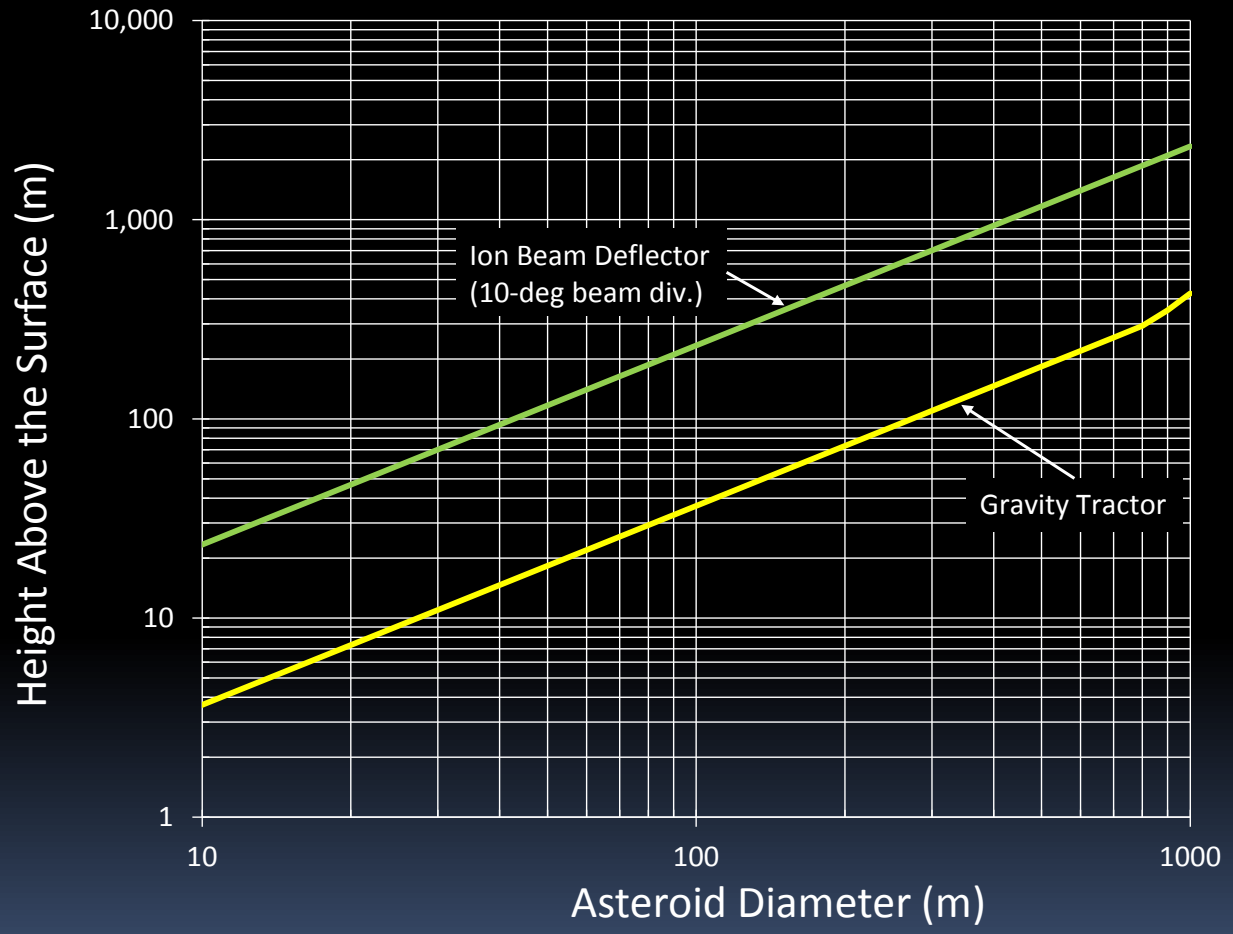


IBD Compared to Gravity Tractor (cont.)



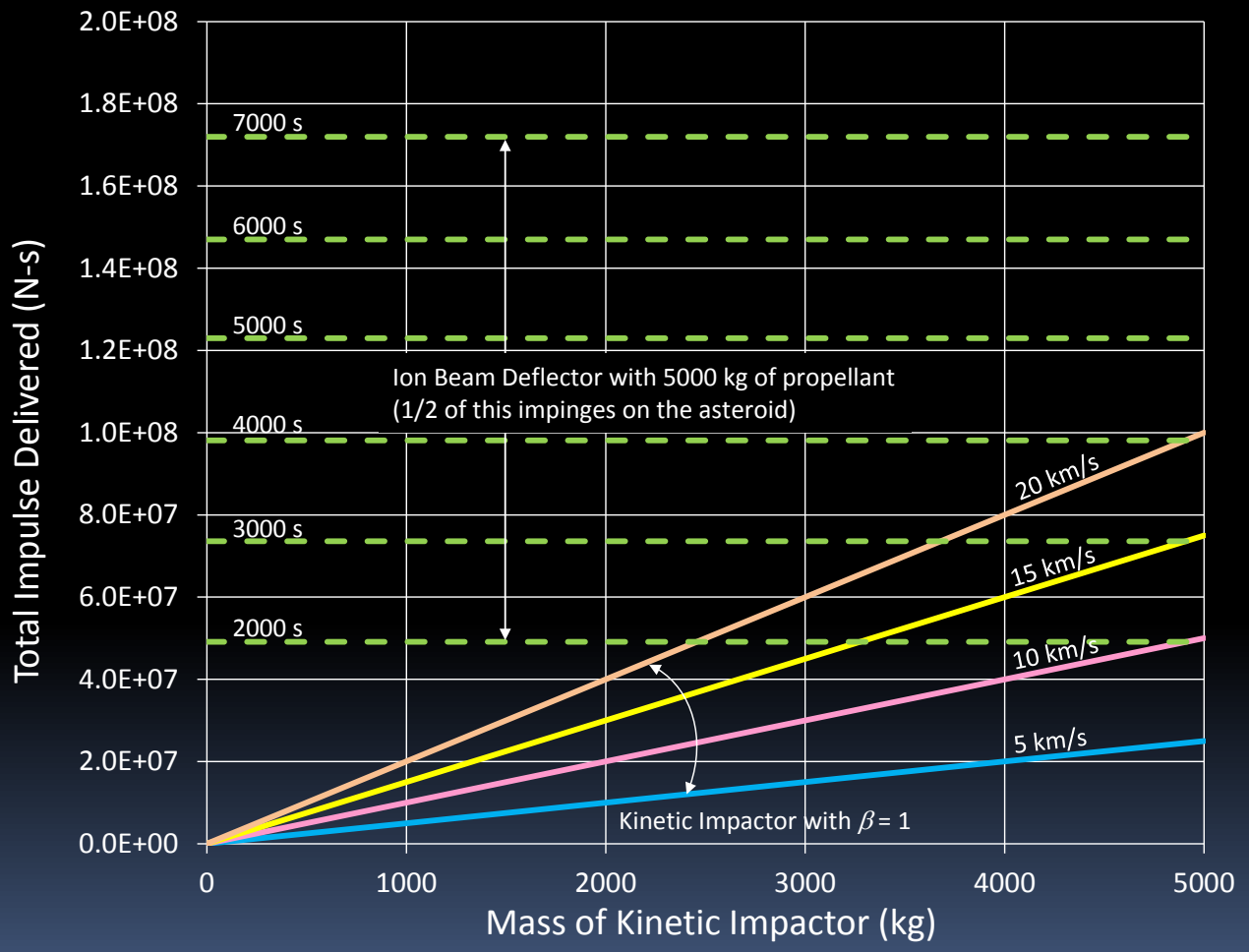
Height Above the Asteroid Surface

- IBD enables greater separation distances from the asteroid surface
- These distances minimize back-sputter contamination of the spacecraft
- NEXIS ion thruster has an ion beam divergence < 5°



IBD Potential Capability

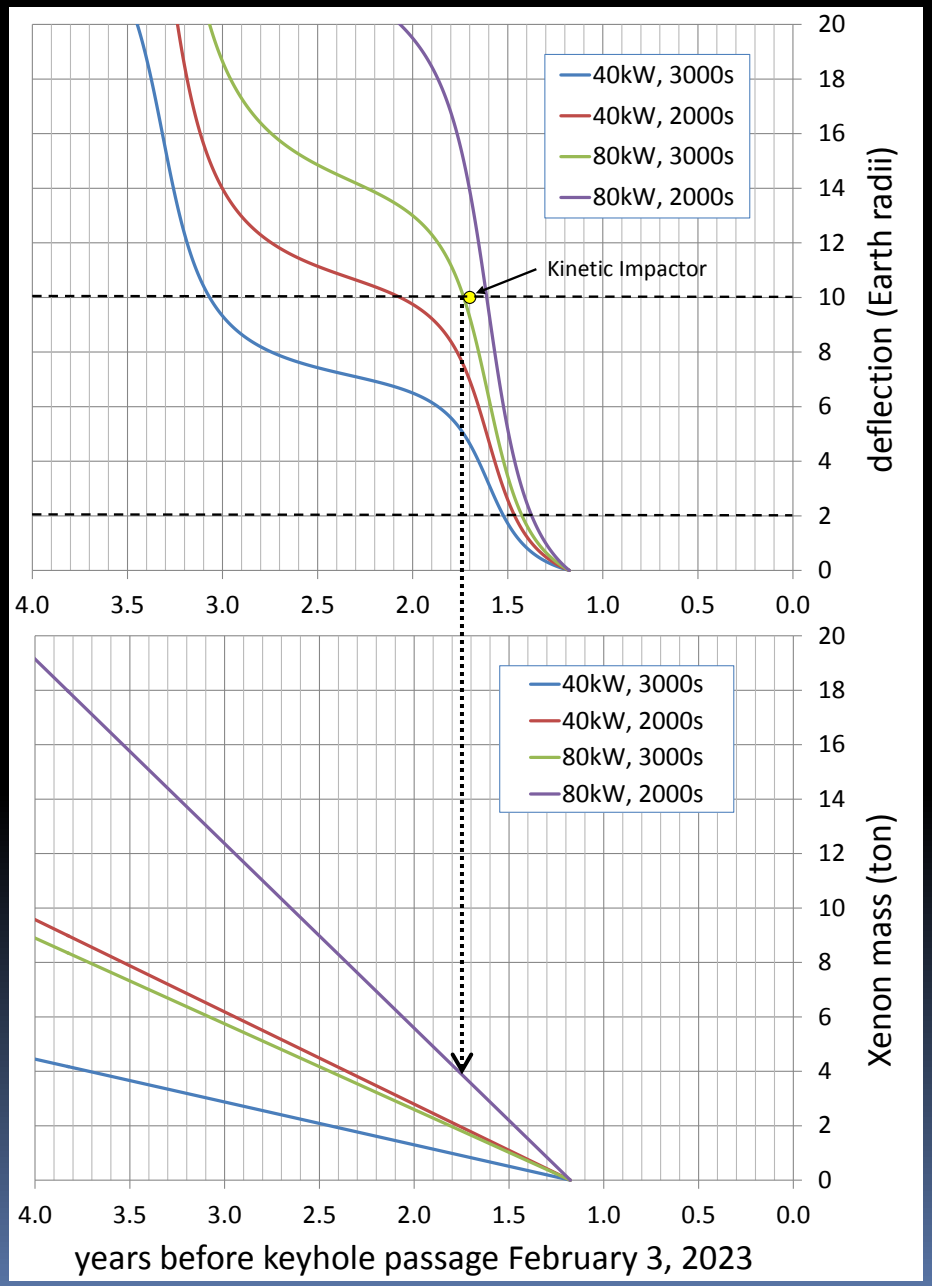
- Assume 5,000 kg of propellant delivered to the asteroid
- Assume half of this impinges on the asteroid
- Total impulse delivered is independent of:
  - The power level of the electric propulsion system
  - The asteroid size and spin state



More Detailed Comparison to Kinetic Impactor

Compare using asteroid 2011 AG5:*

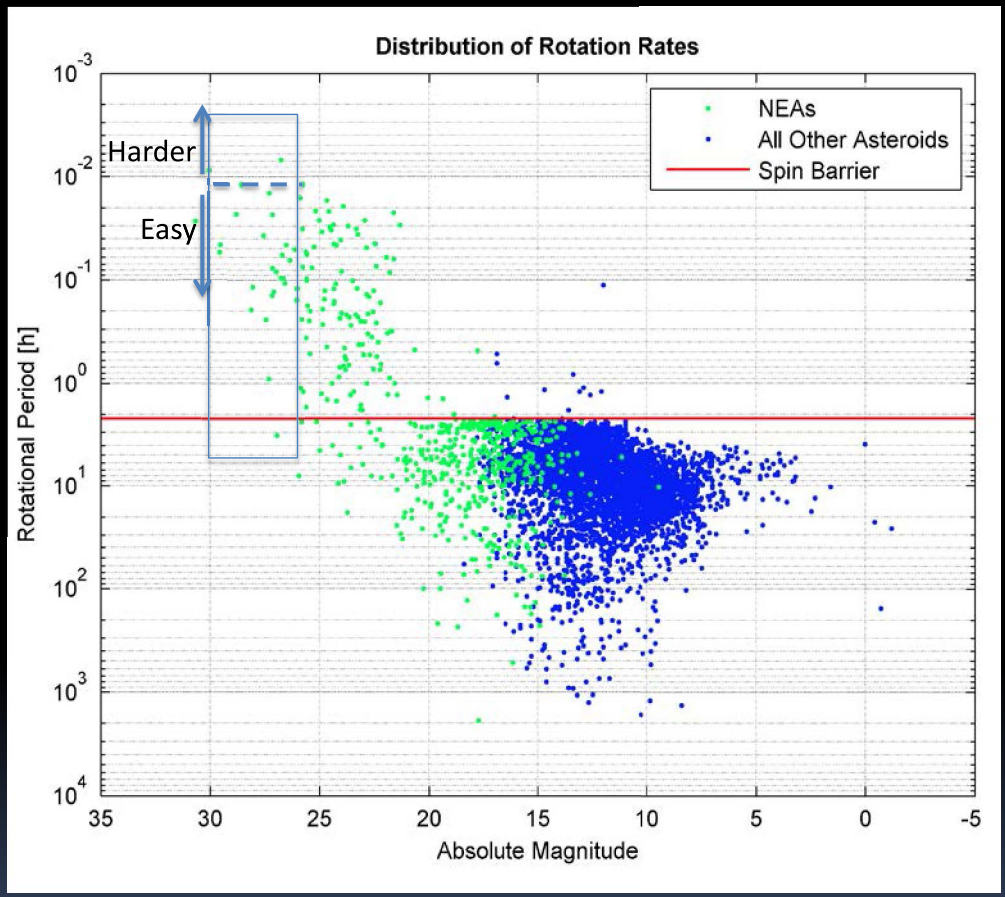
- Determine latest arrival time for a required deflection
- For a 10-Re deflection, an 80-kW IBD provides comparable performance to a 3000-kg, 12.5 km/s impactor
  - Would use about 4,000 kg of xenon
- But 10-Re may not be necessary for IBD
- For a 2-Re deflection, a 40-kW IBD can arrive at the asteroid just 1.5 years before the keyhole and use about than 1,300 kg of xenon



*Grebow, D., et al., "Deflection Missions for Asteroid 2011 AG5," 23rd International Symposium on Space Flight Dynamics, Pasadena, California, October 29 – November 2, 2012.

De-spinning with IBD

- An offset between the center-of-pressure of the ion beam and the center-of-mass of the asteroid will result in a torque on the asteroid changing its rotation state
- Andy Thomas (JSC) suggested that IBD could be used to slow down the rotation rate of a target asteroid for the Asteroid Redirect Mission, simplifying the capture process
- Propellant required would be manageable (~100 kg of xenon) due to the high Isp of the electric propulsion system



Conclusions

The Ion Beam Deflection provides the following potential advantages over other asteroid deflection systems

- Like the gravity tractor, it doesn't require despinning of the asteroid.
- Unlike the gravity tractor, it provides a significantly higher coupling force that is independent of the asteroid size
- The concept could be tested as part of the baseline Asteroid Redirect Robotic Mission.
- The thrust and total impulse are entirely within the design of the SEP vehicle.
- The total impulse is potentially competitive with kinetic impactors and eliminates the need for a second rendezvous spacecraft
- Gridded ion thrusters provide beam divergence angles of a few degrees enabling long stand-off distances from the asteroid.
  - Mitigating control issues
  - Minimizing back-sputter contamination risks