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Gravity Tractoring with Local Mass Augmentation

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Gravity Tractoring Basics

- Gravity tractoring is the only deflection method that does not require any physical contact
  - Avoids any need to despin asteroid
- For gravity tractoring, the spacecraft weight equals the average thrust that can be applied to the system (asteroid + spacecraft)
  - Spacecraft SEP thrust levels of 1-2 N can be achieved for spacecraft dry masses in the ~2-4T range
  - Spacecraft weight at asteroids with radii less than 500m is <<1 N
  - *Traditional gravity tractoring is relatively propellant efficient, but takes a long time*
- When operating at an average altitude of one radius:
  - $W = G\ m\ \rho\ \pi\ r / 3$, where m is the spacecraft mass (assuming spherical asteroid)
  - *Mass increase is the only way to increase weight*
- Significant mass can only be added after arrival at the asteroid
  - Launch capability and transit time limit initial spacecraft mass
  - Adding mass requires physical contact, but only for a short period of time

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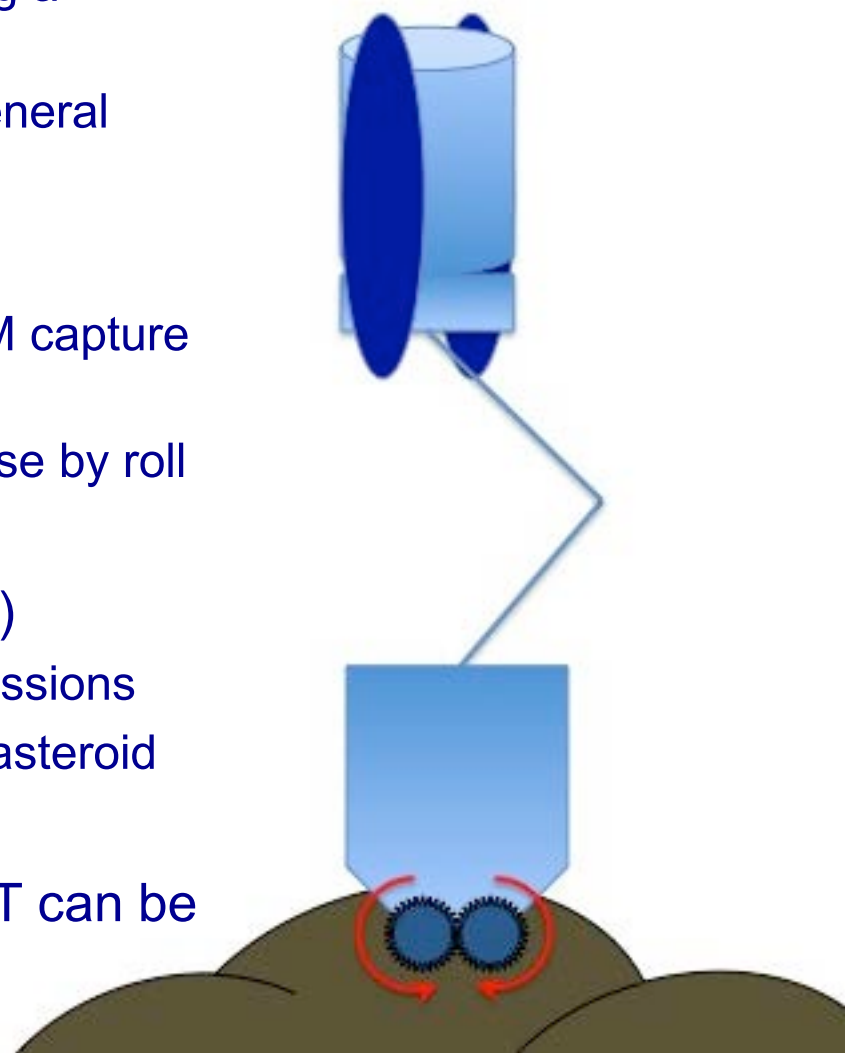
Mass Augmentation Methods

- Several methods may be possible
  - Focus of presentation is not on selecting a particular method
  - Two methods are discussed to show general feasibility
- Grab a boulder:
  - Uses something like the baseline ARRM capture system
  - May be able to verify that boulder is loose by roll tracks on surface
- Brush-wheel sampler (“BWS”, pictured)
  - Proposed for previous sample return missions
  - Collects loose regolith from surface as asteroid rotates under collector
- For either method, assume up to 1000T can be obtained



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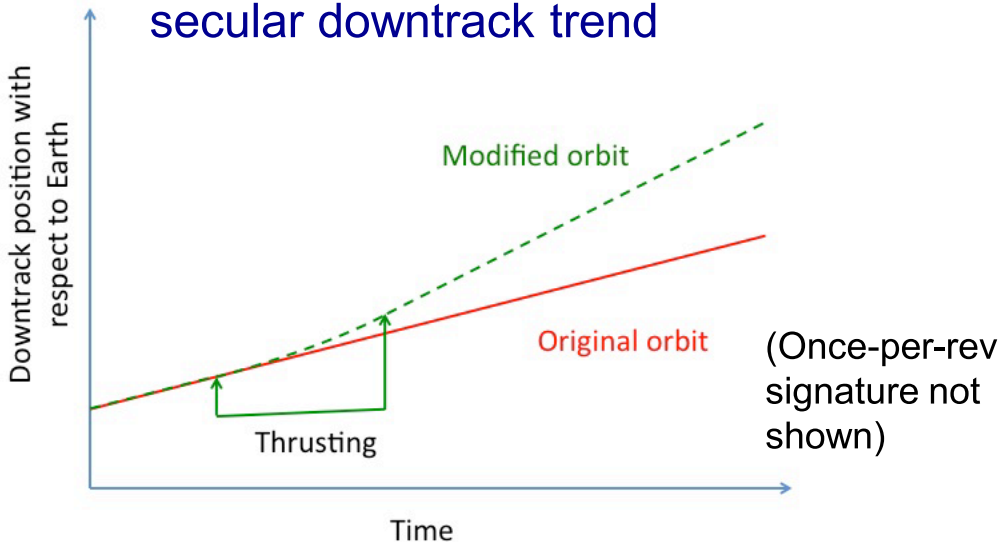
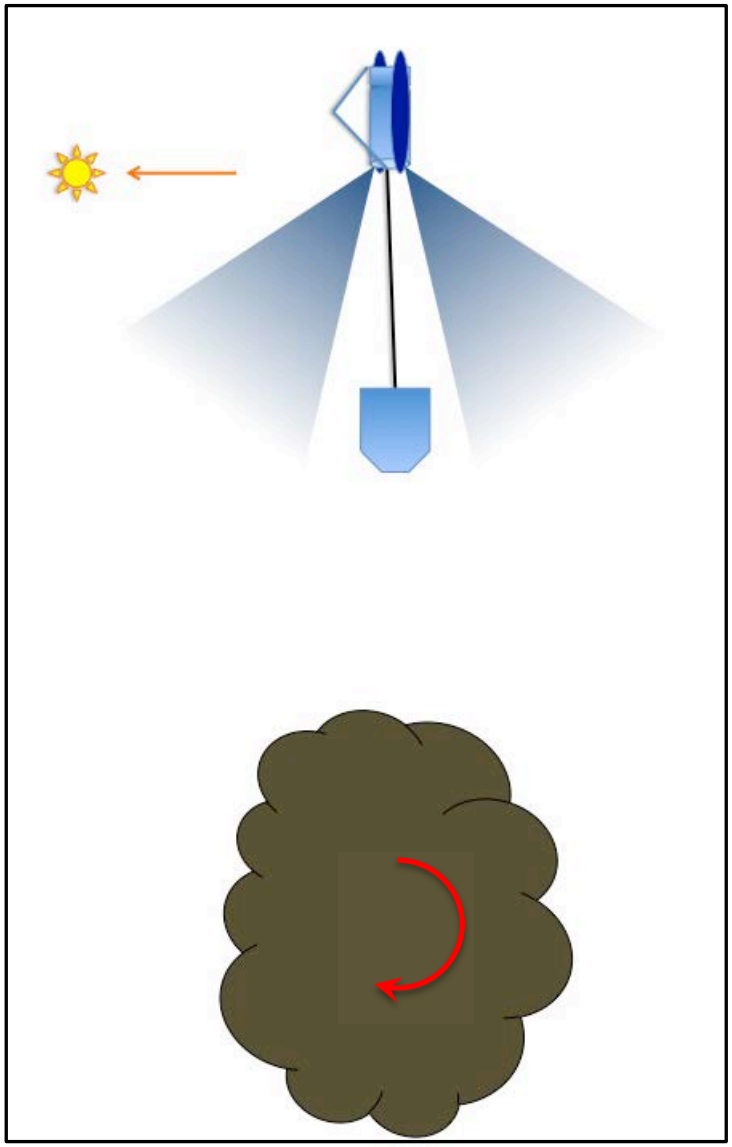
Gravity Tractoring Ops

- Spacecraft center-of-mass should be as close to asteroid as possible
  - Thrusters want to be far away due to cant angle losses
- Using collected mass makes this easier
- Thrusting typically performed in downtrack direction
  - Produces period change that generates secular downtrack trend



(Once-per-rev signature not shown)



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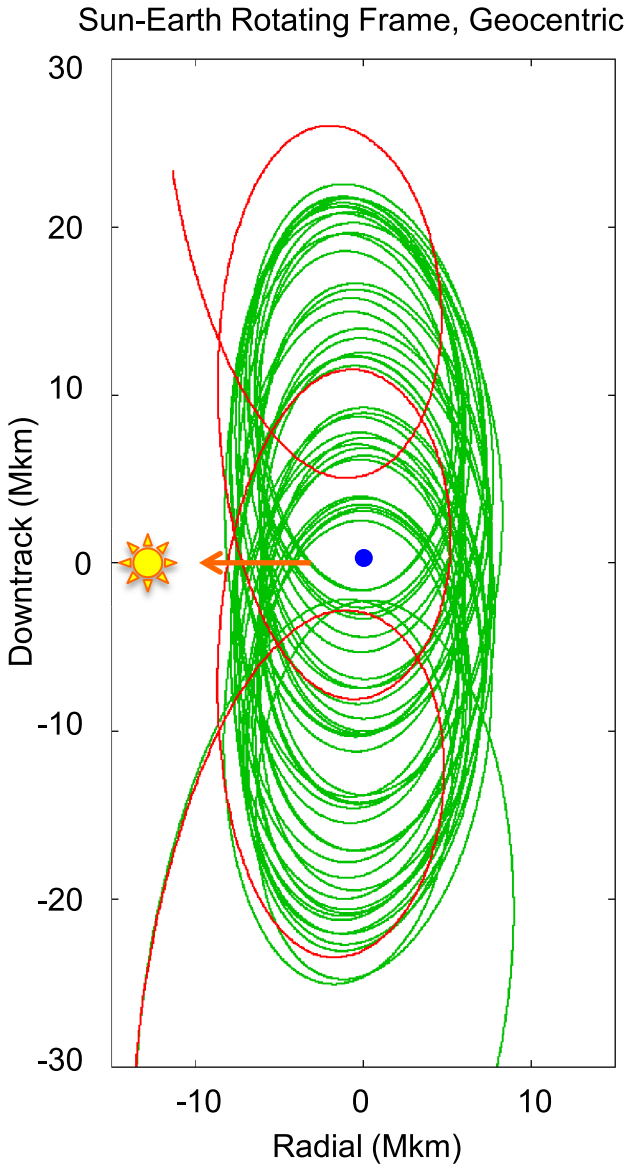
2000 SG344 Example

- 2000 SG344 is in a very Earth-like orbit
  - Could return 3000 to 7000 T in ~2028
  - Estimated asteroid mass range is 10,000 to 300,000 T
- Make some mid-range assumptions to see what might be possible
  - 50,000 T asteroid mass, 15m radius, ρ = 2.5
  - 1000 T s/c mass, at 55m radius, W = 1.1N
  - 1.9 mm/sec/day of acceleration
  - For Isp = 3000s, 1 m/s costs 2.4 T of Xe (with worst-case 45 deg cant angle)
- *Starting in 2021, 1.25 m/s produces a quasi-stable near-Earth orbit for 35 years*
  - Original orbit in red, modified orbit in green
  - Position at initial Earth encounter in 2028 changed by ~650,000 km



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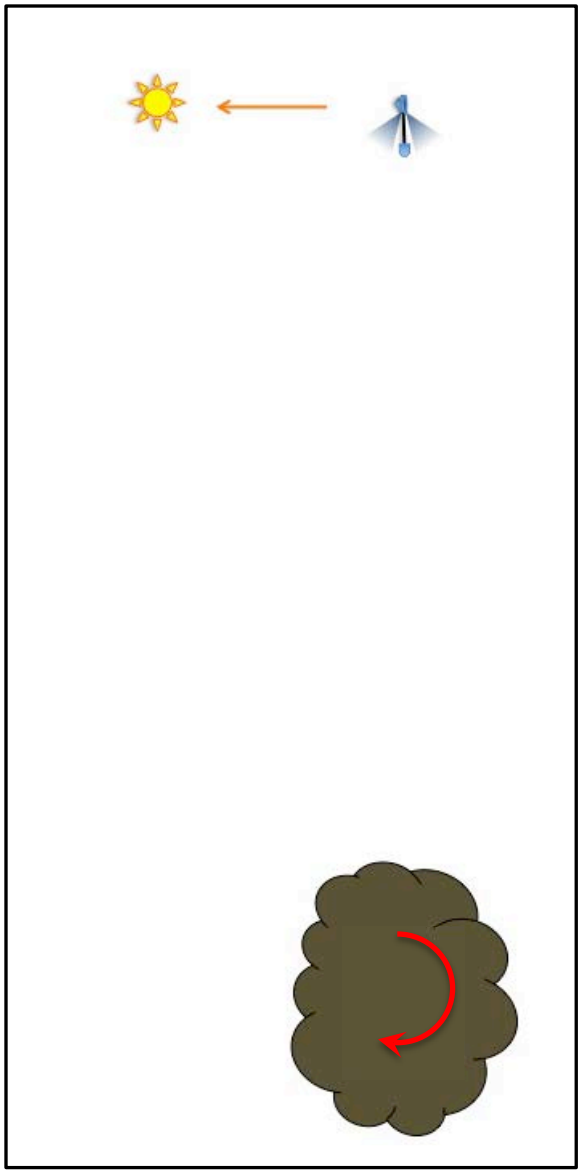
Apophis Example

- Apophis has Earth flyby “keyholes” in 2029 and 2061 that would lead to impacts in 2036 and 2068
  - First impact opportunity does not appear to be very likely
- Apophis mean diameter is 325m (~10X SG344 example)
- Gravity tractoring with only 350T at full thrust can be done at ~900m
  - Acceleration for 1.5N is ~3 μm/s/day
  - Downtrack displacement rate after 1 rev of thrusting is ~90 km/rev
  - 3 years of thrusting (5T of Xe) followed by 10 years of coasting produces ~2700 km of displacement
    - Thousands of km of displacement starts to be enough to prevent a direct impact (ie, not impact via a keyhole)
- *Mass augmented gravity tractoring can make a difference even for something as big as Apophis*



Conclusion

- *Mass augmentation makes gravity tractoring an attractive method for moving asteroids*
  - Uses all of the spacecraft thrust capacity (limited only by cant angle)
  - Works on asteroids as large as Apophis
  - Avoids any need to despin asteroid
- Methods of obtaining mass at the asteroid require more study
  - Feasible methods appear to exist
  - BWS may work at a variety of asteroid types
- 2000 SG344 can be kept near the Earth for a long time
  - Would be a possible target for future missions
    - Human missions
    - ISRU missions