# Capturing Asteroidal Material

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# Spin Periods of Near-Earth Asteroids

- Many small NEAs are spinning too fast to be Rubble Piles; no regolith?
- For few-m radius, we need to plan for spin periods of as low as minutes.
- Expect tumbling.
- Figure from “The Rotation Rate Distribution of Small Near-Earth Asteroids” by Desireé Costo Figueroa, Master’s Thesis, Ohio University, Nov. 2008.

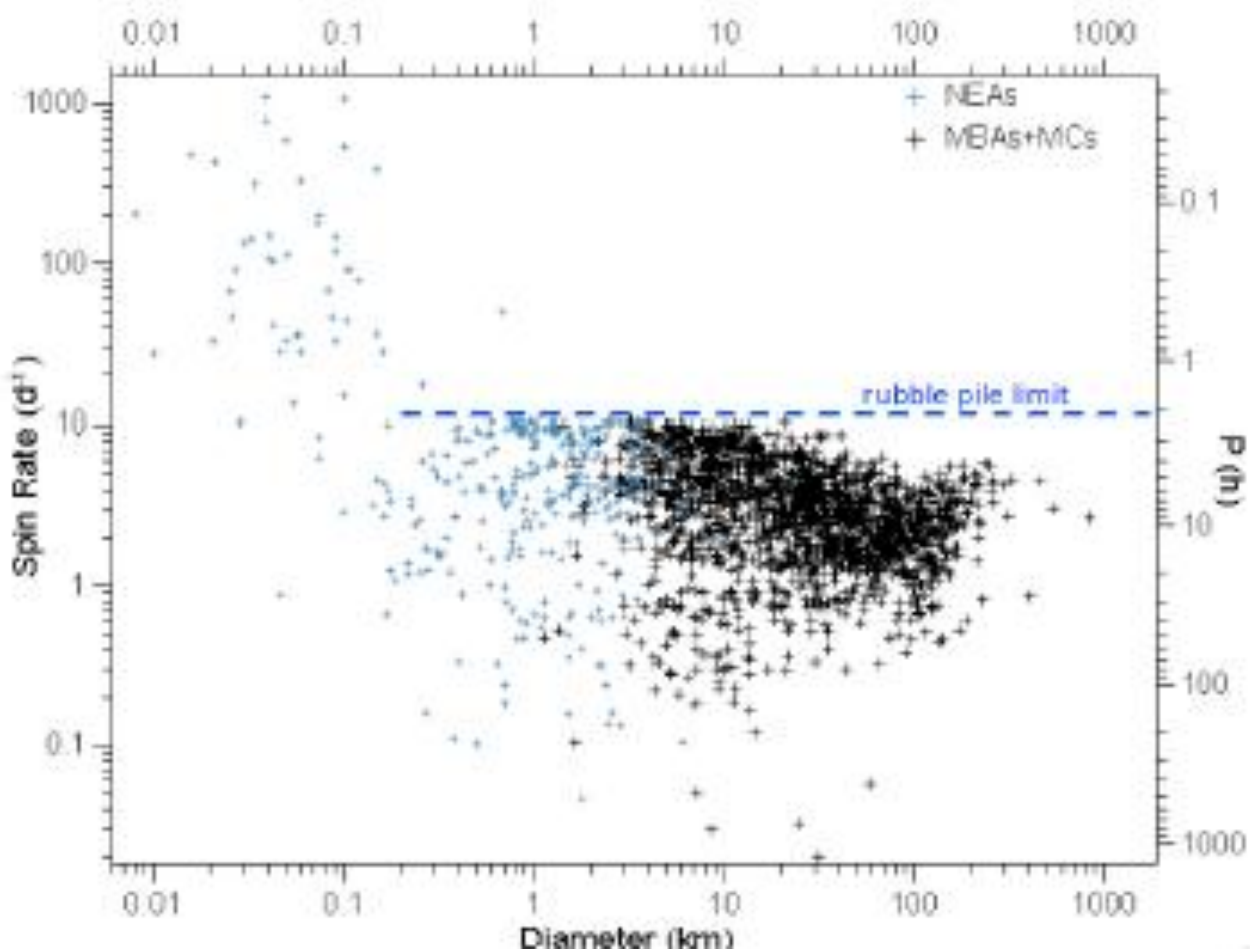



Figure 1.4: The Rotation Rate Distribution for Solar System Bodies. Upper and lower scale indicate approximate diameters. The vertical scale on the right indicates the period in hours. The blue crosses are data from NEAs and the dashed black crosses are data from main-belt asteroids and some main-belt comets. The blue dashed line indicates the rubble pile limit. Modified from Pravec and Harris (2007b).

# Tumbling, or just Spinning?

- "Tumbling Asteroids" by Alan W. Harris (JPL, at the time), Icarus, 1993 (http://trs-new.jpl.nasa.gov/dspace/ bitstream/2014/32558/1/94-0304.pdf) says time constant of damping of rotation to align with principal axis is inverse with angular velocity cubed and radius squared. NEA Toutatis (r~2km), a slow-rotator (~7.5 day) is estimated to have damping time constant ~$1.5 \times 10^{12}$ years.
- Under these assumptions, a ~1 m asteroid could have a spin period as slow as 10 minutes and still have a damping time constant as long as the age of the solar system. Small objects have collisional lifetimes much less than the age of the solar system.

# Physics of Stopping a Spinning NEA

- Using SEP to stop a spinning NEA is simple if it can be grappled effectively.
- A 30 kW SEP system can stop a NEA w/ 2-m radius & 10-minute spin period in 1 revolution.

| | | |
|---|---|---|
| Earth's gravity | 9.81 | m/s2 |
| Gravitational contant | 6.67E-11 | MKS units |
| Solar flux at 1 AU | 1350 | W/m2 |
| density of asteroid | 2500 | kg/m3 |
| spin period | 0.16666667 | hours |
| radius | 2 | m |
| mass | 8.38E+04 | kg |
| moment of inertia | 134041.287 | MKS units |
| angular velocity | 0.01047198 | radians/s |
| angular momentum | 1403.67707 | kg*m/s |
| | | |
| SEP propulsion | | |
| Power | 16,500 | W |
| Isp | 3000 | seconds |
| mass flow rate | 3.8101E-05 | kg/s |
| thrust | 1.12130479 | N |
| torque | 2.24260958 | Nm |
| time to thrust | 625.912366 | seconds |
| total propellant mass | 0.02384772 | kg |

# Modeling

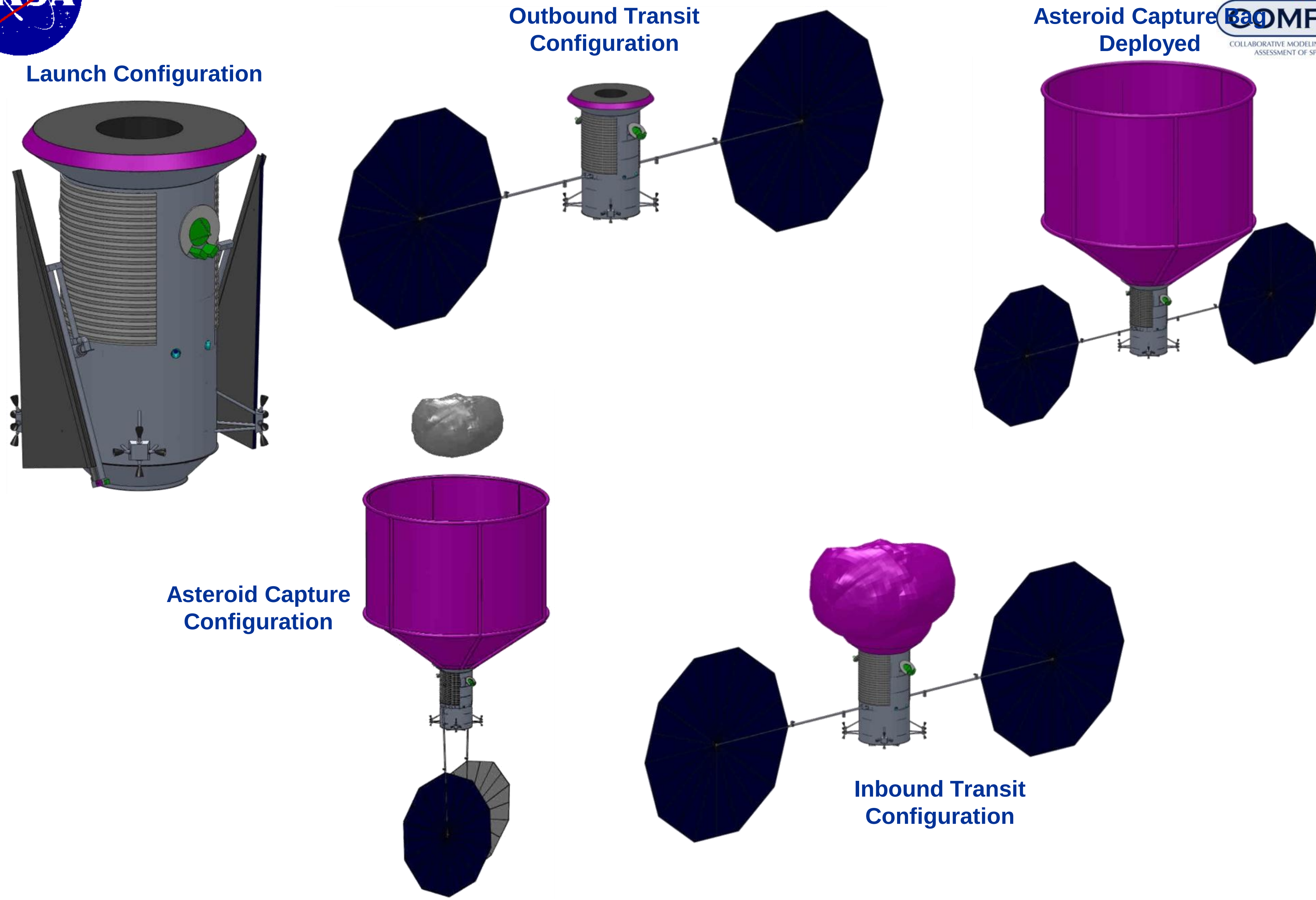
- Custom or commercial stereo vision or laser scanning systems can create precise 3-D model of complex objects:
  - Custom stereo (e.g. MER stereo vision system)
  - Commercial “cloud” multi-image processors (e.g. Microsoft, CAD vendors)
  - LIDAR processing algorithms (custom or commercial)
- Illumination and albedo modeling to compare observed image with prediction at given illumination and viewing angles.

# Capture Mechanism: Baseline

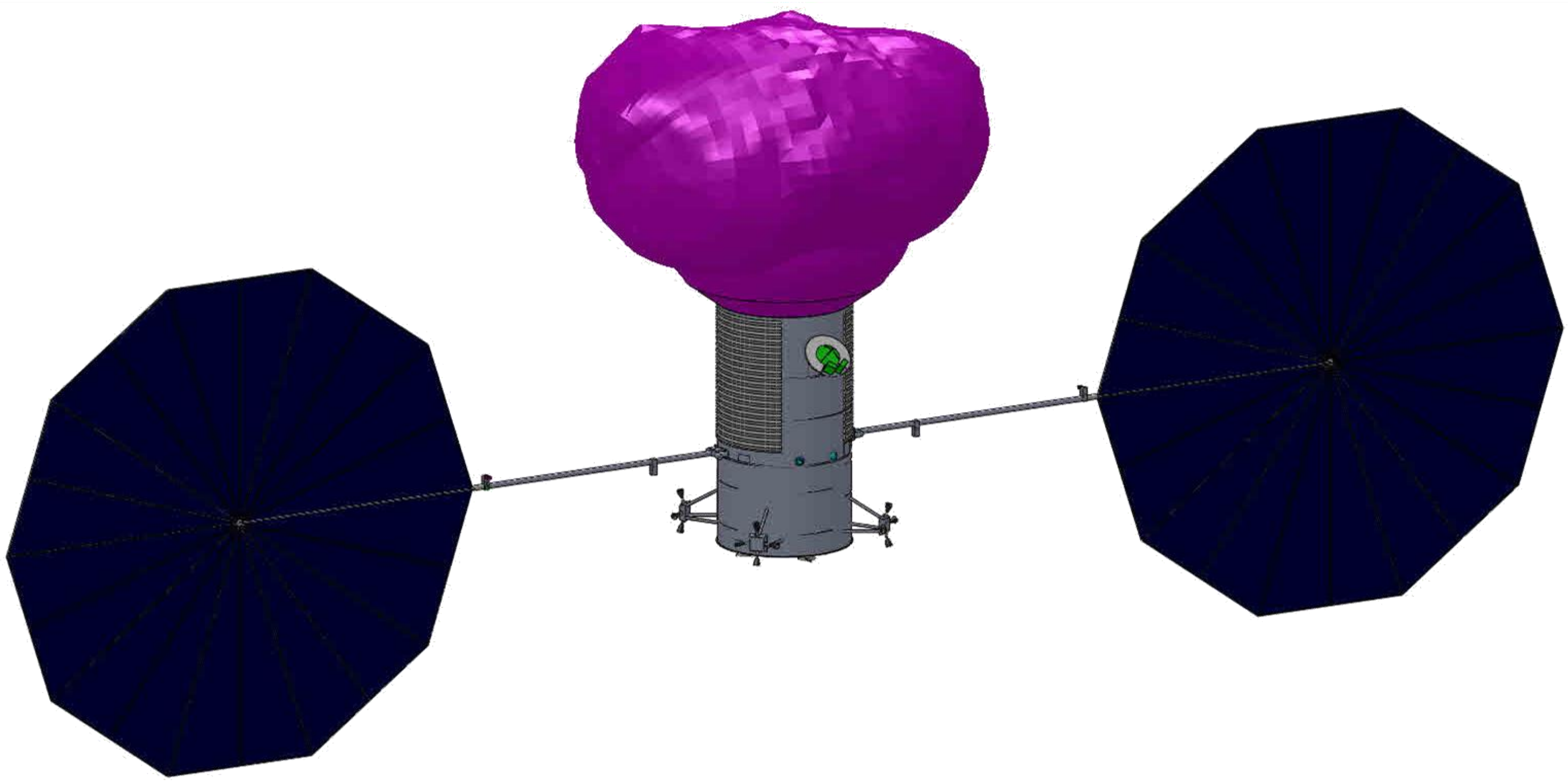
- Asteroid
  - Diameter
    - 6m x 12m  Max
    - 3m x 6m Minimum
  - Mass: 100 to 1300 metric tons (solid or particulate-if asteroid is a pile of rubble)
- Bag
  - Options
    - A: Inflatable (kiddie pool) rings, cinch top with motor, cinch sides with motor as you deflate appropriate rings (depending on size/shape)
    - B: Inflatable arms with single ring (like legard inflatable antenna experiment
    - C: Deployable frame and baggie
- Conops :
  - Unfurl Bag
  - Unfurl or store solar arrays (optional)
  - Match spin and nutation rate using chemical propulsion
  - Encapsulate asteroid
  - Cinch up the bag to a load carrying plate on S/C
  - De-tumble asteroid/spacecraft using chemical propulsion
  - Redeploy solar arrays (if needed)
- Nominal Operating Power: ?W (motors, valves)
- Material – MER airbag

National Aeronautics and Space Administration

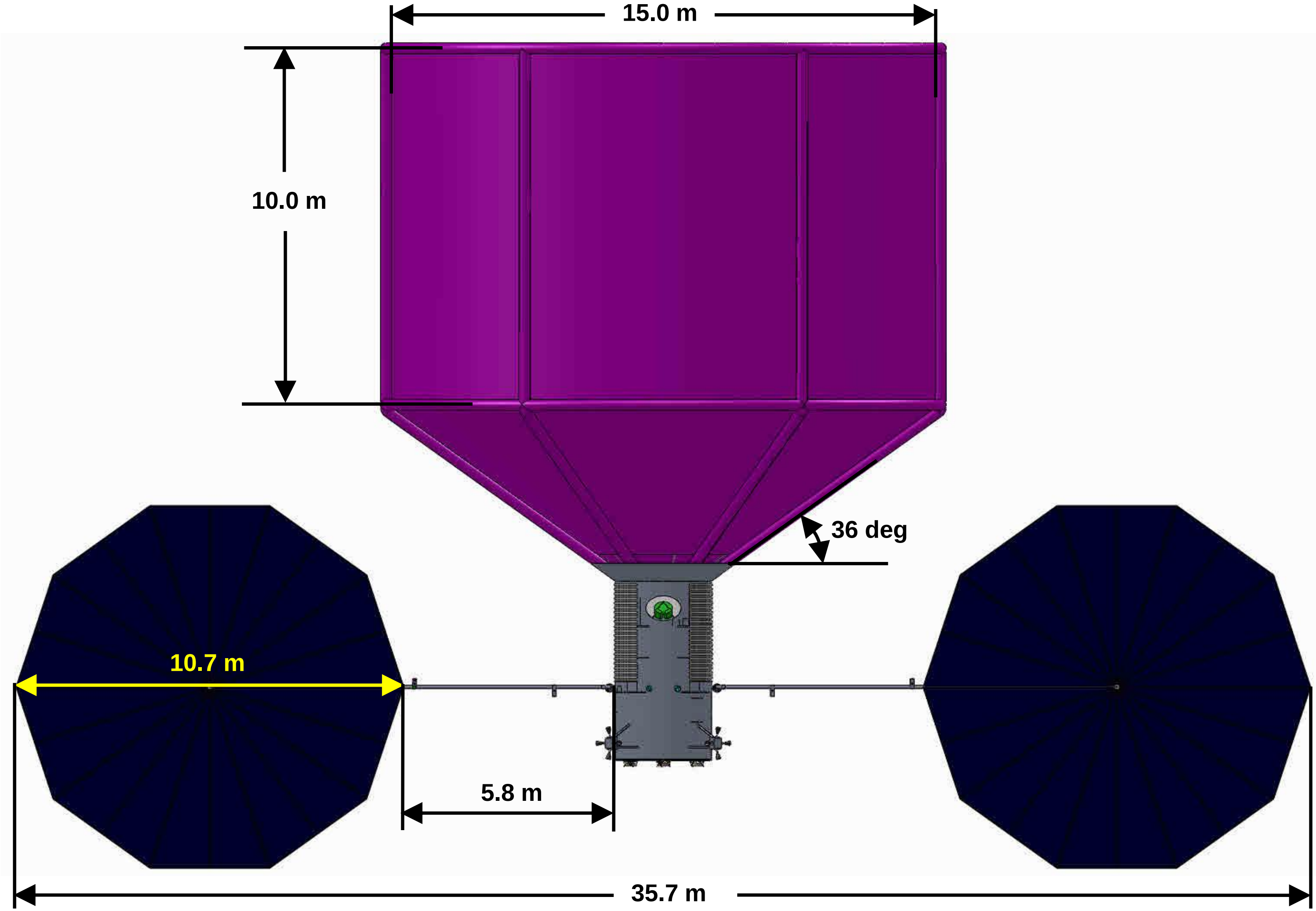
## FETCH Spacecraft Various Configurations



# FETCH Spacecraft Inbound Configuration



# FETCH Spacecraft Deployed Dimensions



# The Bag

- The bag needs to comfortably accommodate 1000 cubic meters of sample, which means that it is more than 10 meters in diameter and 10 meters long.
- This is too large to fit in present-day launch shrouds, so it must be deployed.
- Having the "arms" that open the bag be inflated tubes so that the whole assembly is made of fabric and deploys out of a compact package seems attractive.

# Alternate Logic Tree – Ground Rules

1. The sample return mission must launch within 10 years from now,
2. The target must have extremely similar orbital parameters to Earth so the required delta-V is low, and
3. The target must be classified as a water-rich carbonaceous chondrite,

Then we conclude that the target body must already be known and spectrally classified and therefore large (>100 m). So we need to consider how to pluck a ~10m rock off the surface of a >~100 m asteroid or, failing in that, collect a similar mass of regolith or smaller rocks.

# A Separable S/C?

- A premise of this effort is that the spacecraft (S/C) uses Solar Electric Propulsion (SEP). It will have very large deployed solar arrays, extending tens of meters or more from the main S/C body. These solar arrays are very light and delicate, so they cannot be allowed to make contact with the asteroid surface nor to be blasted by particles lofted from the asteroid surface from plumes of Reaction Control System (RCS) firings that are used for attitude control.
- So we might assume that the flight system can separate into two parts:

1. A SEP stage that has the electric propulsion engines, propellant tank, solar arrays, power electronics, and also the high-gain communications antenna and transceiver for long-range communications with Earth as well as short-range (omnidirectional) communications with the other part of the flight system, and
2. A separable S/C with all other functions, including RCS, Guidance Navigation & Control (GN&C), Command and Data Handling (C&DH), short-range communications with the SEP stage, and asteroid bulk material acquisition and handling. In the following we will refer to this as "the separable S/C" (or just the S/C), with the other part referred to as the "SEP stage".

# Alternate Mission Profile

- The mission profile calls for the S/C to rendezvous with the target asteroid and to separate, with the SEP stage "parked" a safe distance away - perhaps spin-stabilized with the high-gain communications antenna pointed at Earth and the solar arrays pointed approximately at the sun (the asteroid, the Earth and Sun are likely to nearly aligned in the sky if the rendezvous occurs as the asteroid "passes" the Earth in its orbit).
- The separable S/C then proceeds to approach the asteroid, and to match its spin (and tumbling, if necessary) so that one patch of its surface is presented almost stationary to the bulk material acquisition and handling system.

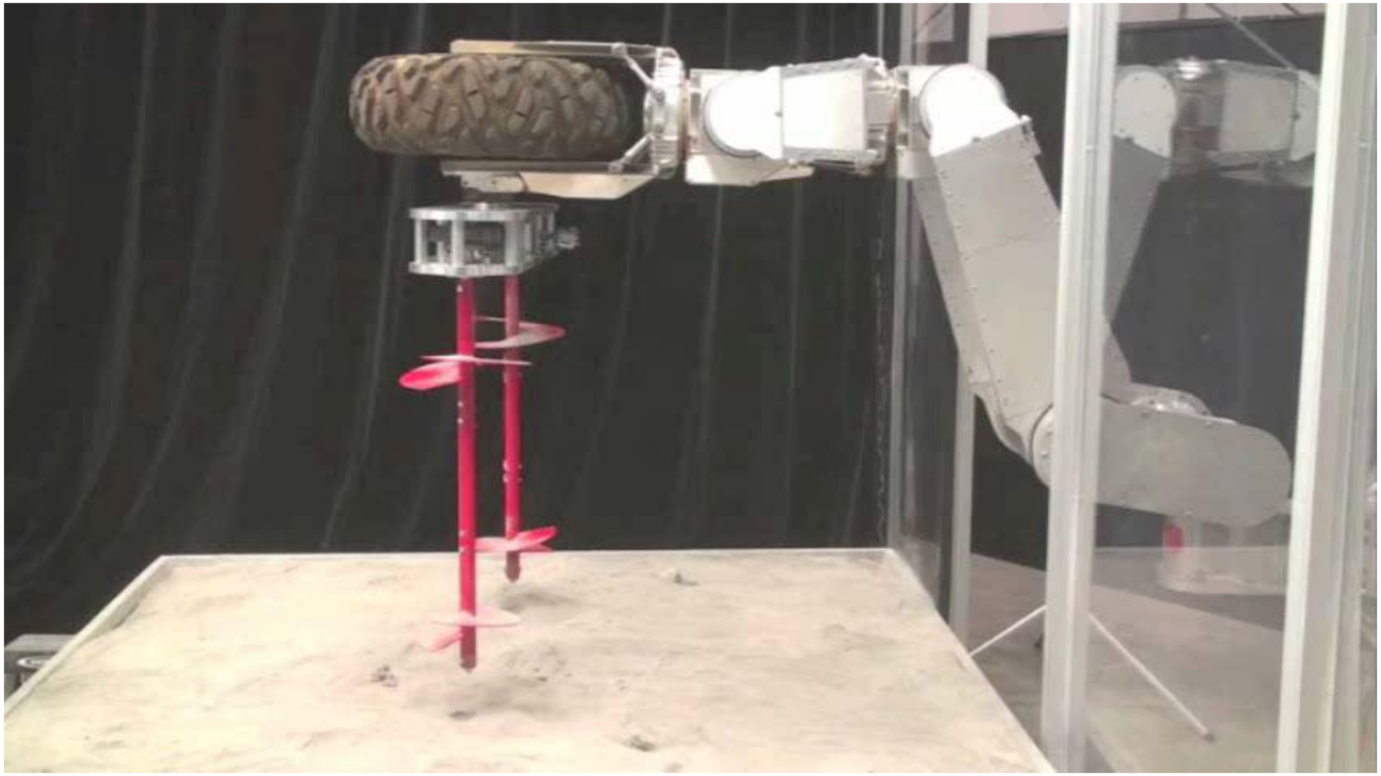
# A Loose Rock

- The bag will have multiple "draw strings" that can cinch-close the opening of the bag and can also be cinched-tight against the bulk material.
- Ultimately, the tightly-cinched bag of bulk material will be drawn up against a ring (perhaps a Stewart Platform) that constrains its position and attitude so that its center-of-mass is controlled and forces and torques can be applied by the S/C and ultimately the attached SEP stage.
- If the S/C attempts to bag a large rock that appears loose on the surface of the asteroid, but finds that this rock is actually not loose, it is possible that multiple concentric bags are held by the arms, so that the cinched bag around the stuck rock can be released, exposing a fresh bag for another attempt on a different rock.
- Note that this same bulk material acquisition and handling system could engage a small satellite of the asteroid if that were the right size, or an entire small asteroid if that were the target. So this approach is not unique to the subsampling of a large asteroid.

# The “Snow-Blower”

- If no rock on the surface of the asteroid seems suitable, then it is desired to collect bulk regolith instead.  This would be accomplished by
- anchoring the S/C onto the surface,
- having a "snow blower" that can pivot around the anchor point so as to fill the sample bag with collected material entering via a chute from the snow-blower.
- The snow-blower, just like its name-sake on Earth, would use forces imparted by a spinning blade to fling the regolith into the chute, where it would propagate by its own inertia along the chute into the bag.
- If it is desired to collect up to 1000 cubic meters of loose regolith, and it is assumed that the snow-blower can (on successive passes) dig up to 1 meter deep, and is able to process an annulus ranging from 10 to 20 meters away from the anchor pivot, then each anchor point could provide all the needed material.  It may be prudent to plan for multiple anchoring attempts, however.

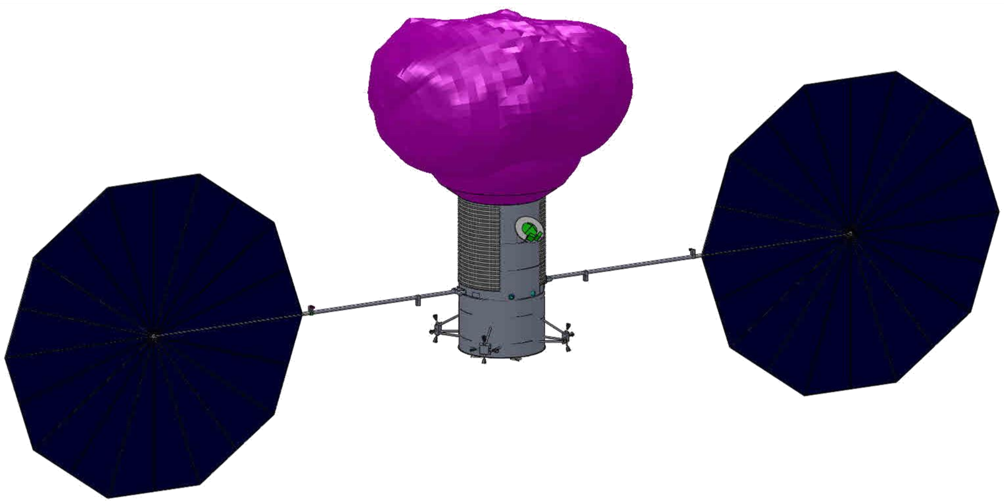
# Augering into Regolith

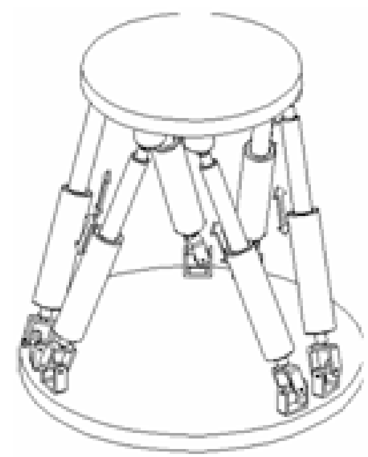


- Counter-rotating helical augers have no net torque reaction.  Separation between flutes reduces friction without reducing pull-out force compared to continuous flute.

# Conclusions

- Smallest NEAs may be fast-spinners of solid rock (no regolith) or larger, slower-spinning with regolith,
- Spectrally-characterized NEAs are larger.
- Bag can grab entire small NEA, or rock or loose regolith off larger NEA,
- May need “Stewart Platform” at base of cinch bag for CG management.





Stewart Platform for coarse CG management