Dismantling Rubble Pile Asteroids with Area-of-Effect Softbots (AoES)

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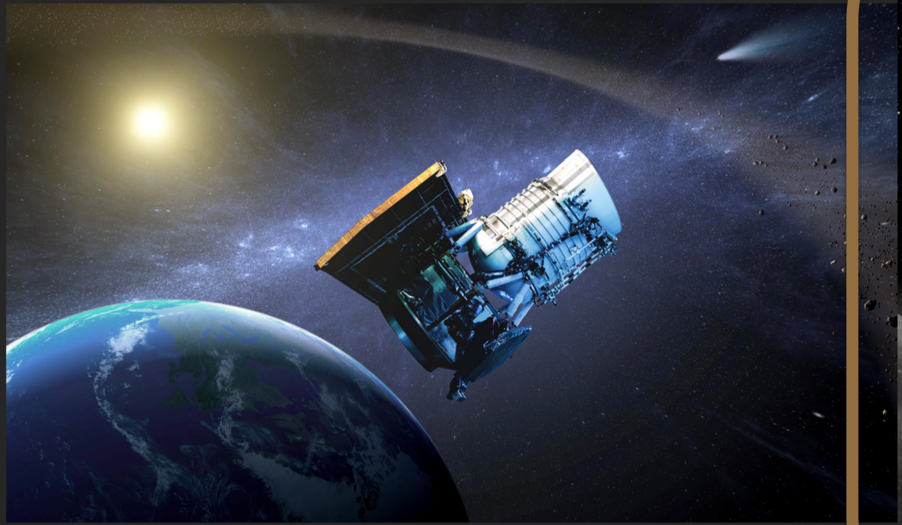
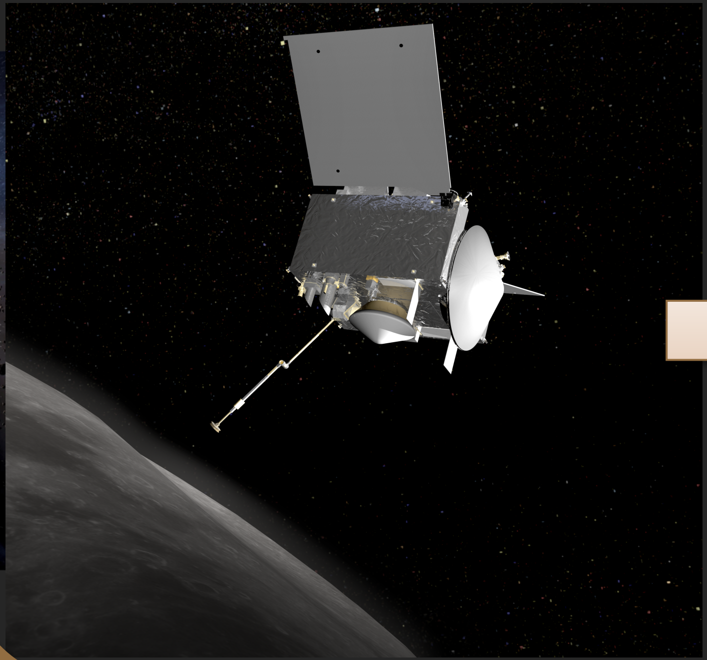
The Asteroid Mining Cycle

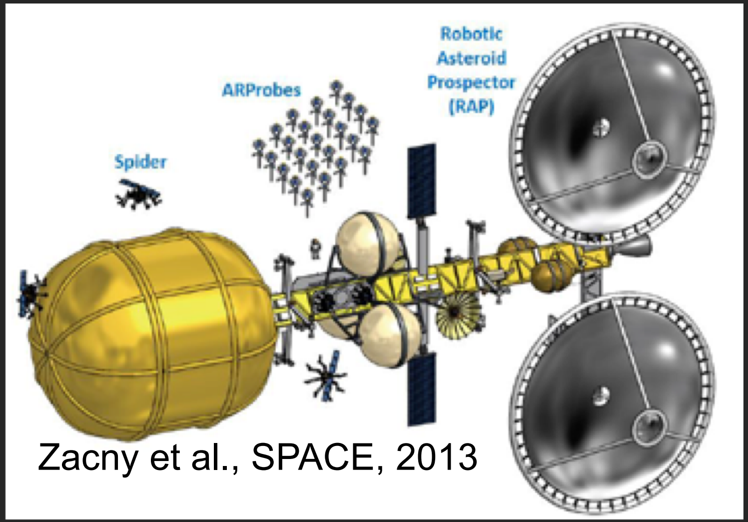
Prospect



Extract



Refine

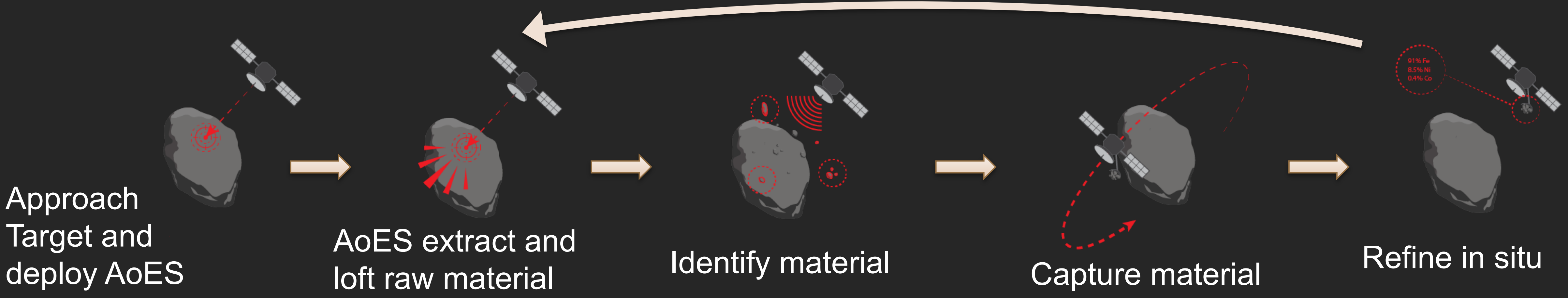


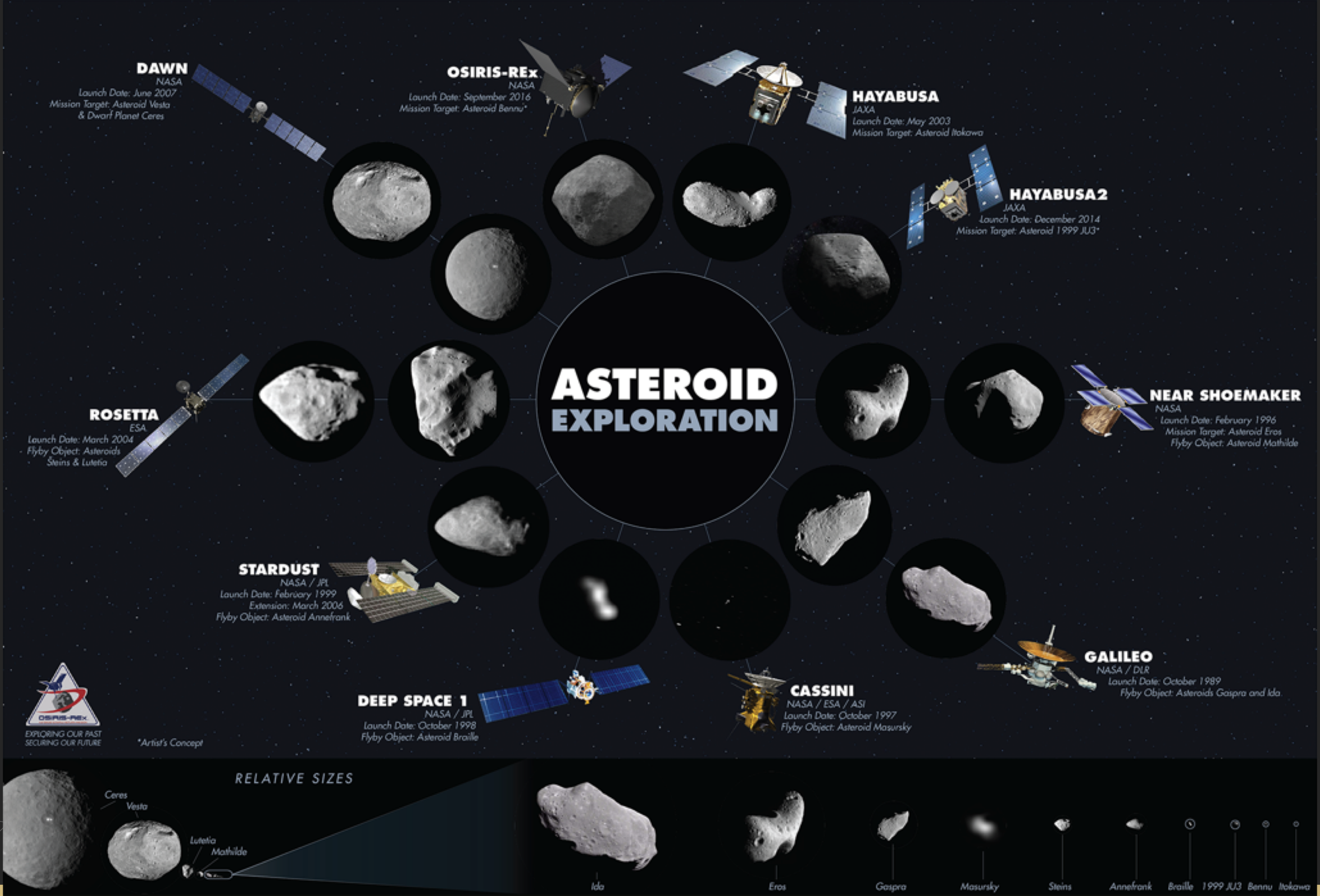
Zacny et al., SPACE, 2013

How do we get a lot of material from the surface to the refinery efficiently?

Overview of NEA Mining Concept

- Go to ~Bennu sized NEA selected from previous prospecting
- Refinery "mother ship" deploys AoES to surface from safe orbit
- AoES land on surface, find, extract, and launch material
- Orbiting refinery identifies desirable raw material via remote sensing, captures, and refines in situ
  - Lofted Regolith Sampling (LoRS) concept with Advanced Space




ASTEROID EXPLORATION
DAWN
NASA
Launch Date: June 2007
Mission Target: Asteroid Vesta
& Dwarf Planet Ceres
OSIRIS-REx
NASA
Launch Date: September 2016
Mission Target: Asteroid Bennu*
HAYABUSA
JAXA
Launch Date: May 2003
Mission Target: Asteroid Itokawa
HAYABUSA2
JAXA
Launch Date: December 2014
Mission Target: Asteroid 1999 JU3*
ROSETTA
ESA
Launch Date: March 2004
Flyby Object: Asteroids
Šteins & Lutetia
NEAR SHOEMAKER
NASA
Launch Date: February 1996
Mission Target: Asteroid Eros
Flyby Object: Asteroid Mathilde
STARDUST
NASA / JPL
Launch Date: February 1999
Extension: March 2006
Flyby Object: Asteroid Annefrank
GALILEO
NASA / DLR
Launch Date: October 1989
Flyby Object: Asteroids Gaspra and Ida
DEEP SPACE 1
NASA / JPL
Launch Date: October 1998
Flyby Object: Asteroid Braille
CASSINI
NASA / ESA / ASI
Launch Date: October 1997
Flyby Object: Asteroid Masursky
OSIRIS-REx
EXPLORING OUR PAST
SECURING OUR FUTURE
*Artist's Concept
RELATIVE SIZES
Ceres
Vesta
Lutetia
Mathilde
Ida
Eros
Gaspra
Masursky
Steins
Annefrank
Braille
1999 JU3
Bennu
Itokawa

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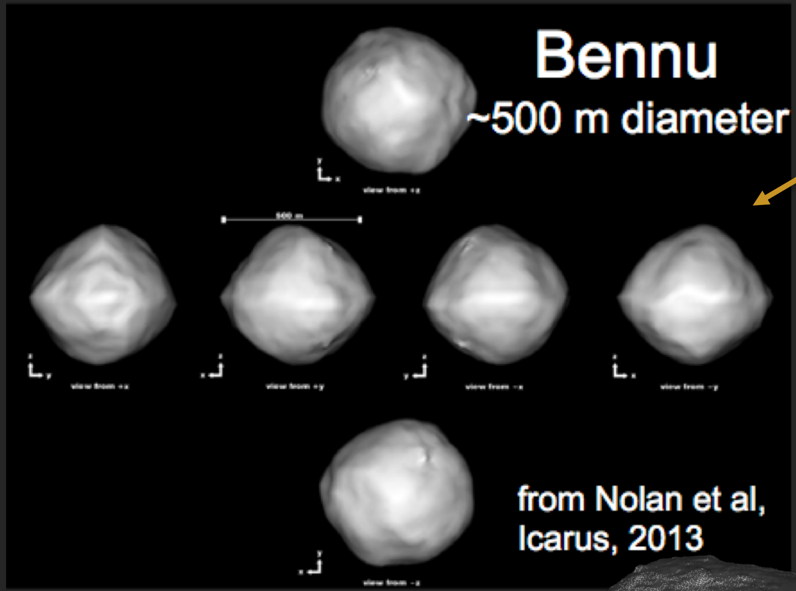
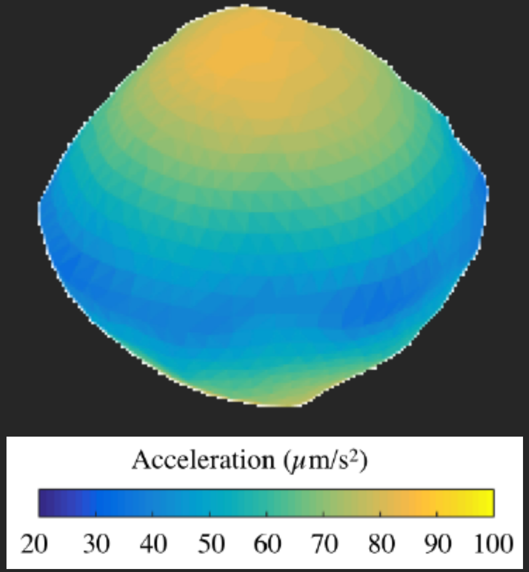
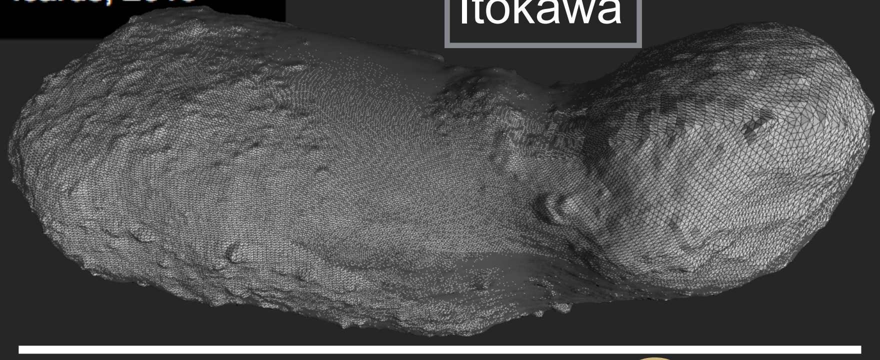
Small NEAs Have Unique Dynamical Environments



Surface gravity is
< 10 micro-g's!



Itokawa



~535 m

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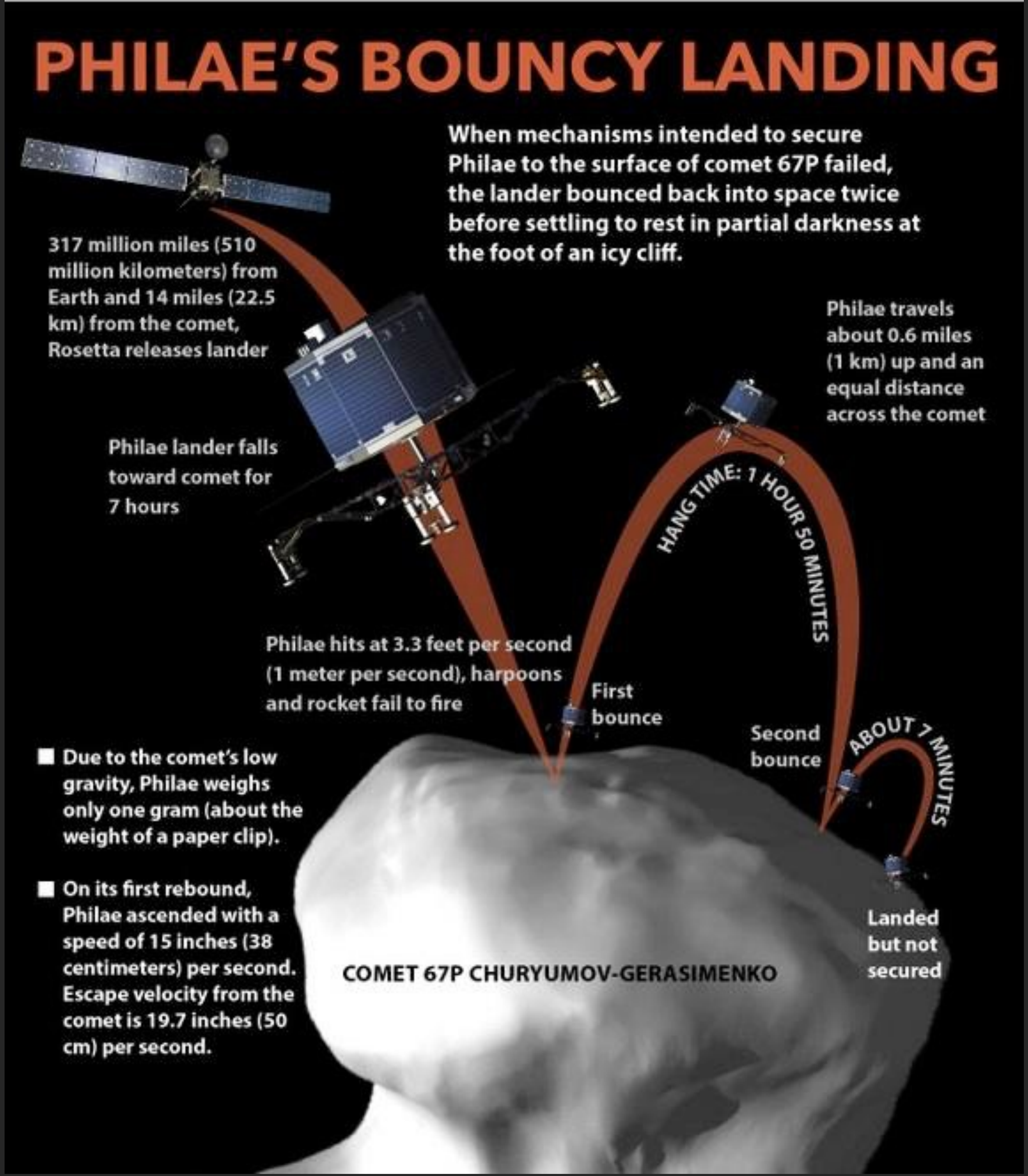
Landing in low Gs

Asteroid	Escape Speed [cm/s]
Itokawa	13.0
Bennu	20.3



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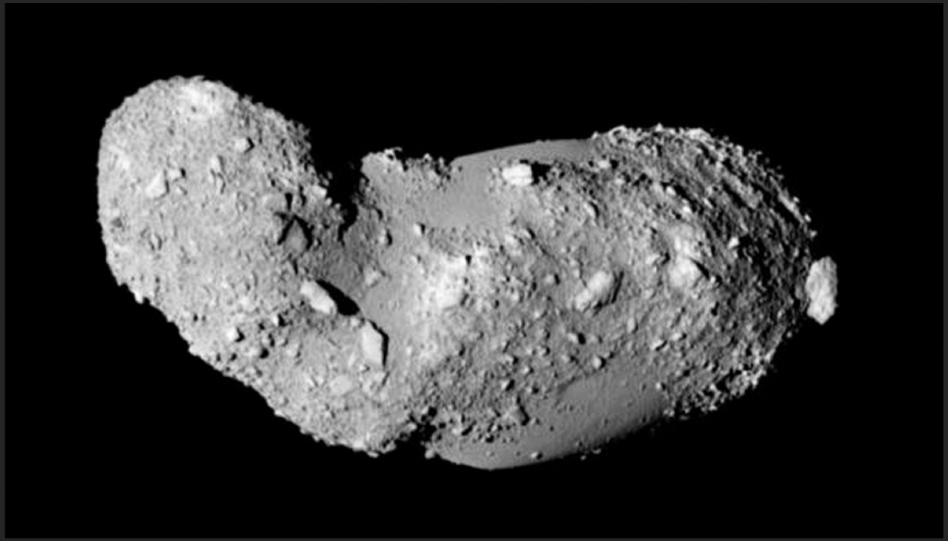
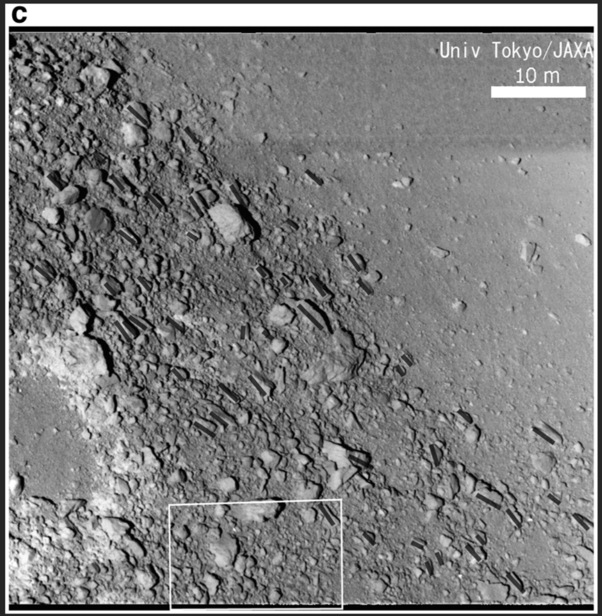
What are rubble piles?

- Asteroid interior structures are unknown
- Surfaces could be boulders, rocks, pebbles… or dust
- How do we operate on these types of surfaces?





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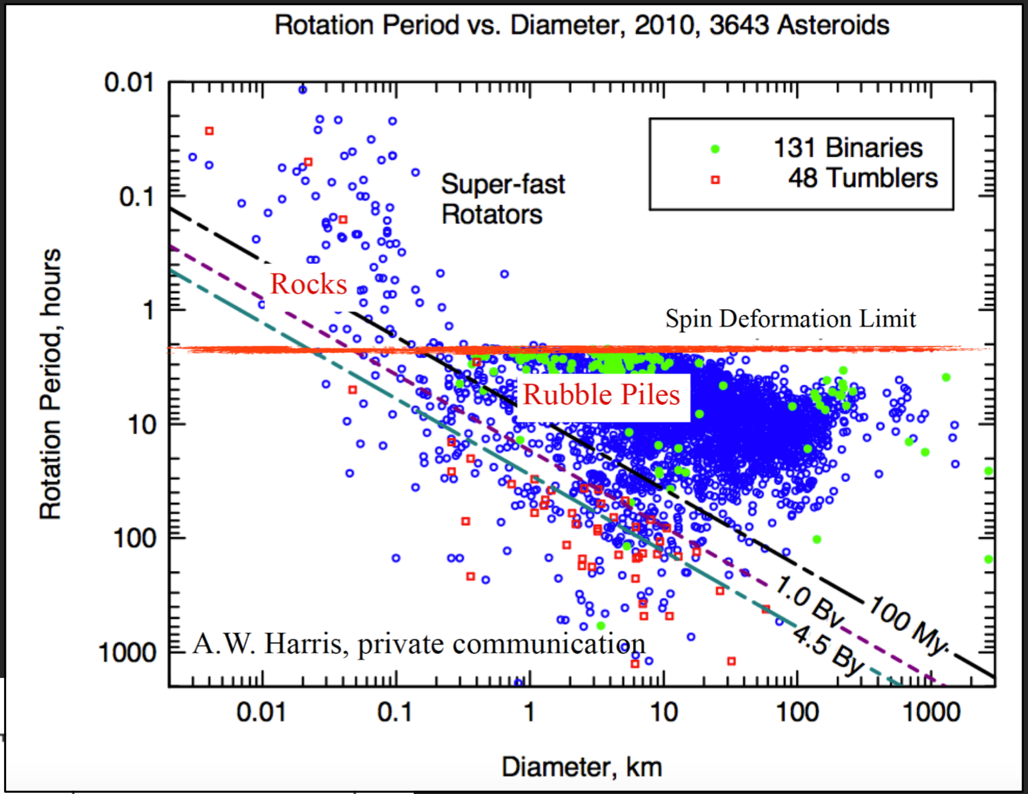
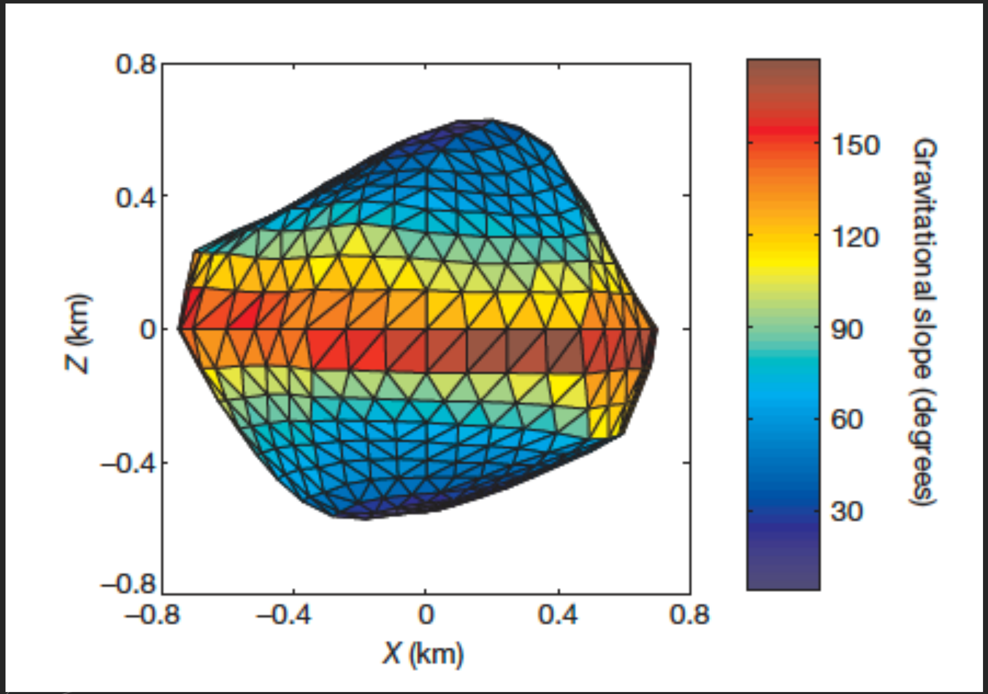
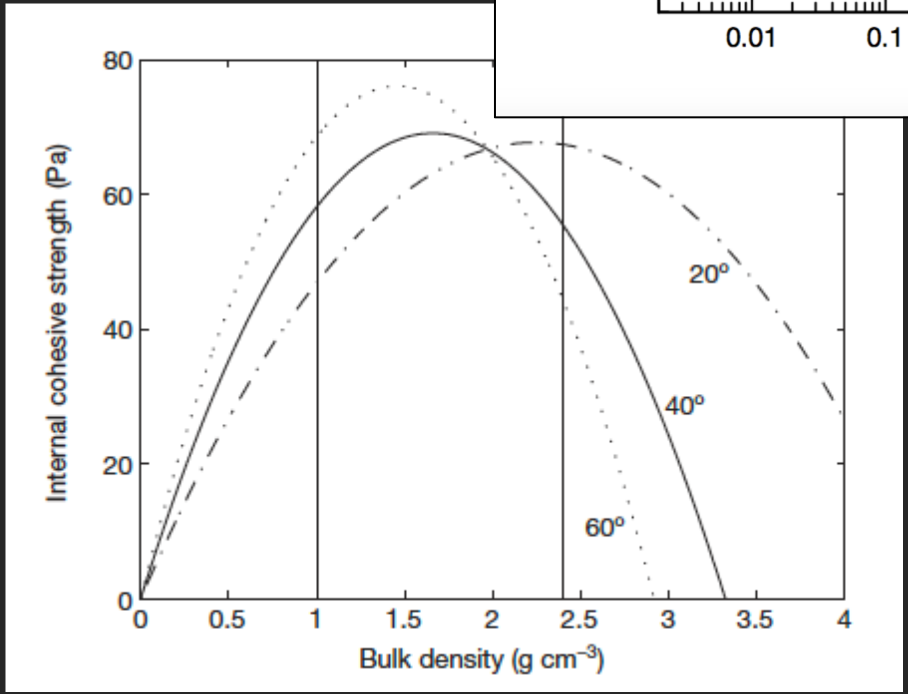
Asteroid Cohesion (observed)

- 1950 DA
  - Rozitis, *Nature*, 2014
- Some minimum cohesive strength necessary to keep asteroid together







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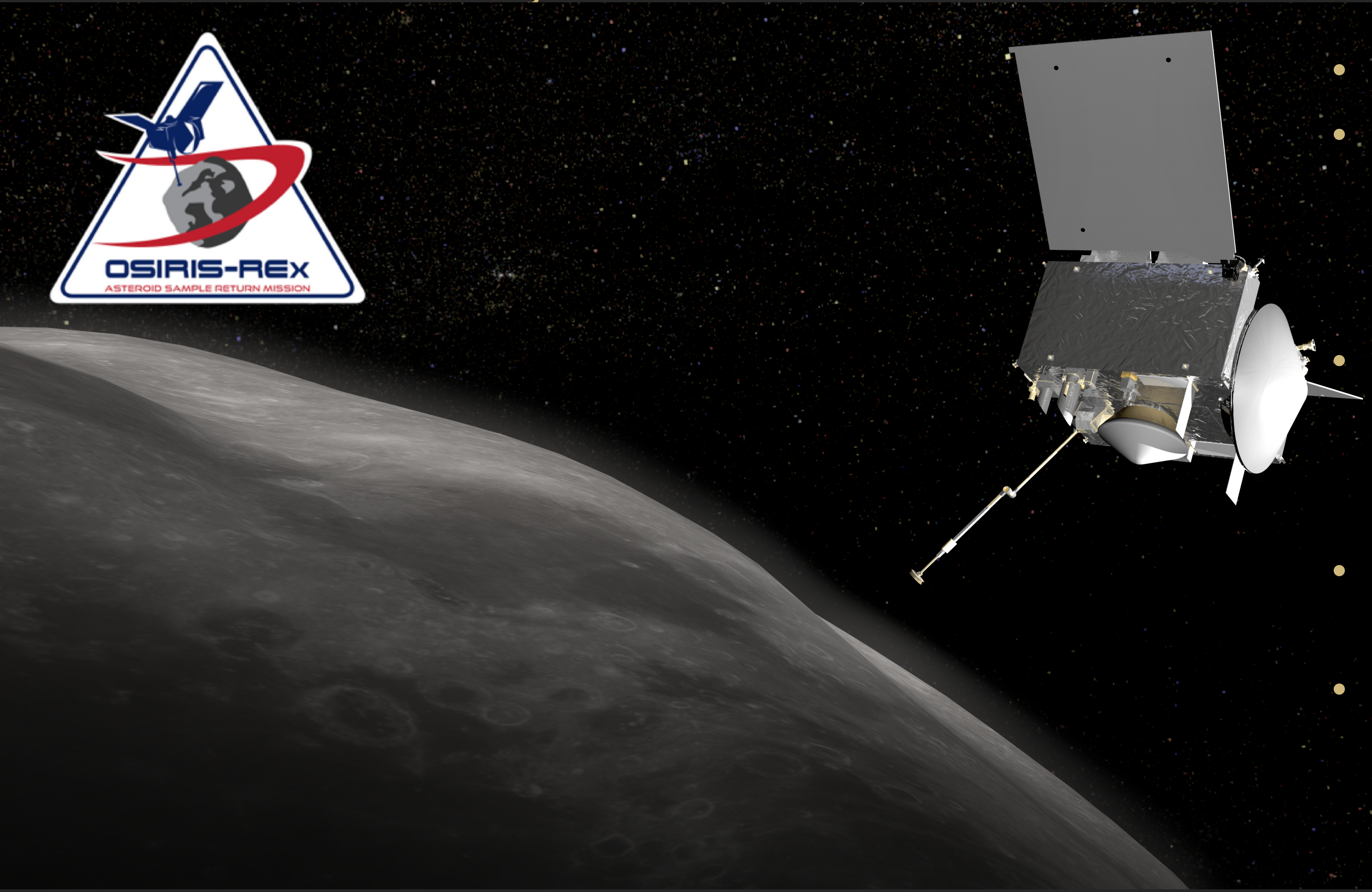
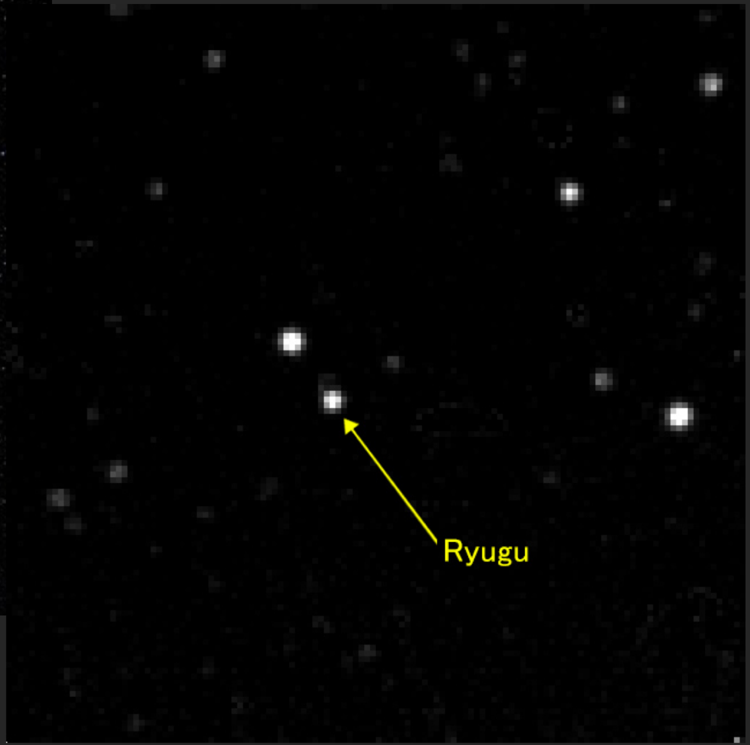
Extraction today: OSIRIS-REx Touch-and-Go Sampling



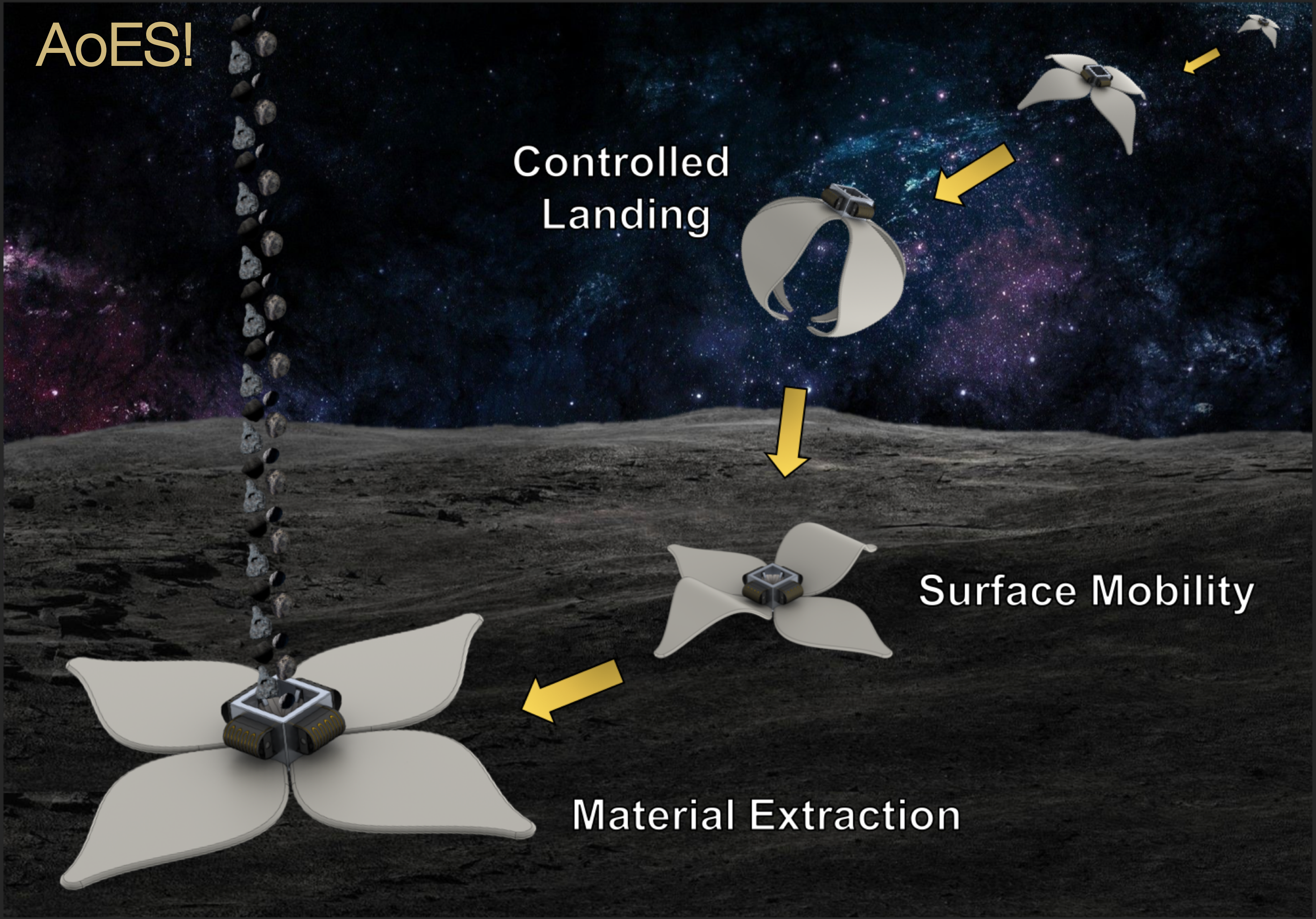
- Launched September 2016
- The EGA closest approach was on 9/22/17 with closest approach distance of 17,237 km
- Arrival & approach in Fall 2018
  - Start seeing Bennu from 2 million km
- Sampling targeted for July 4, 2020!
- Return sample to Earth on September 24, 2023

Extraction today: Hayabusa 2

- Launched December 2014
- Arrival in Summer 2018
- Target asteroid Ryugu

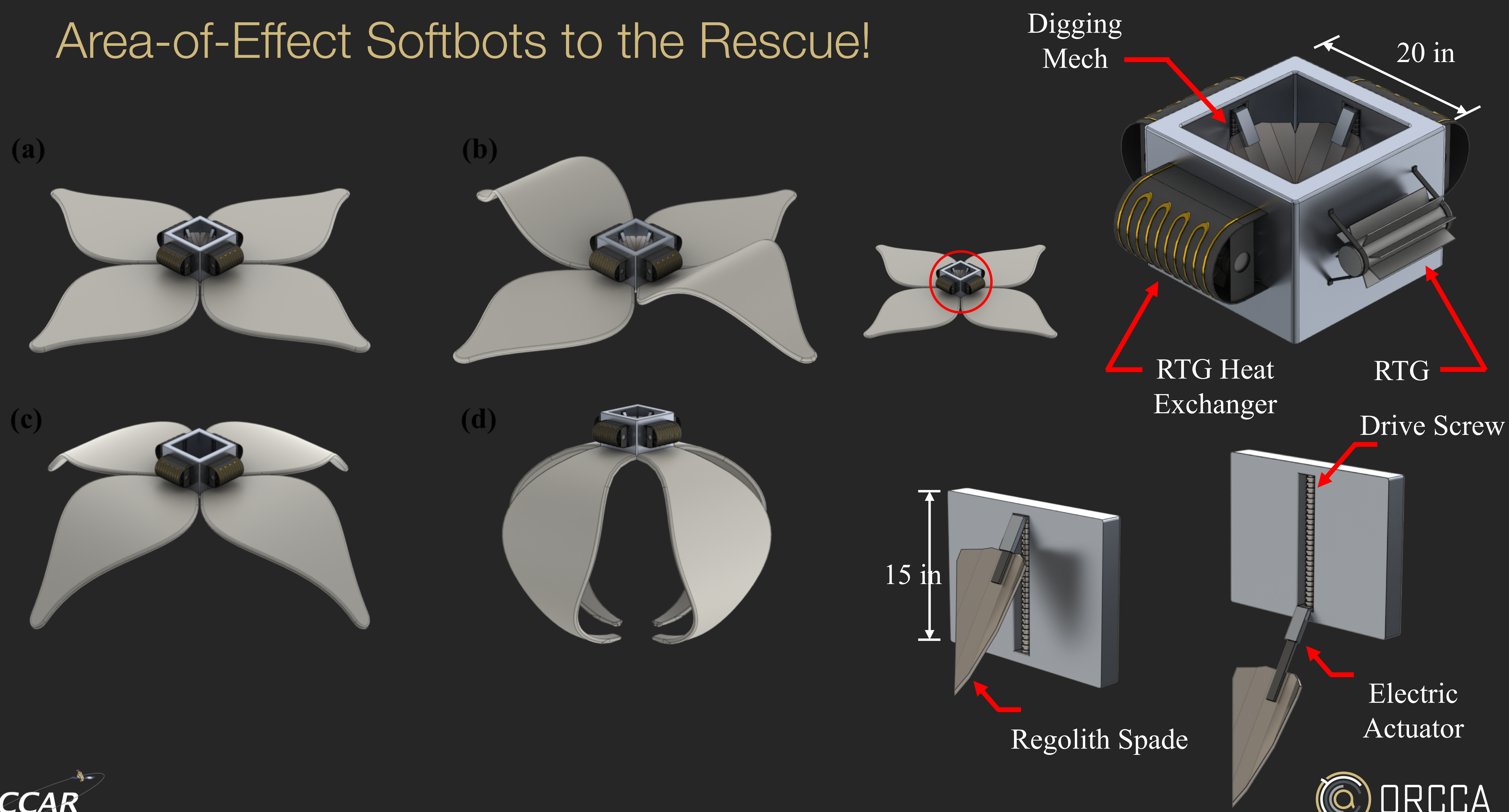


http://astro.oamaru.net.nz/2015/12/japanese-hayabusa-2-asteroid-spacecraft.html



- What are Area-of-Effect Softbots?
- Soft robotic spacecraft (AoES) with a large, flexible, actuated surface area uses adhesion to anchor to asteroid surfaces
- Large surface area also allows for solar sailing orbit control and hopping across the asteroid surface
- AoES support an ISRU mission by dismantling rubble pile asteroids by lofting material from the surface to be collected by an orbiting processing vehicle for resource extraction

Area-of-Effect Softbots to the Rescue!



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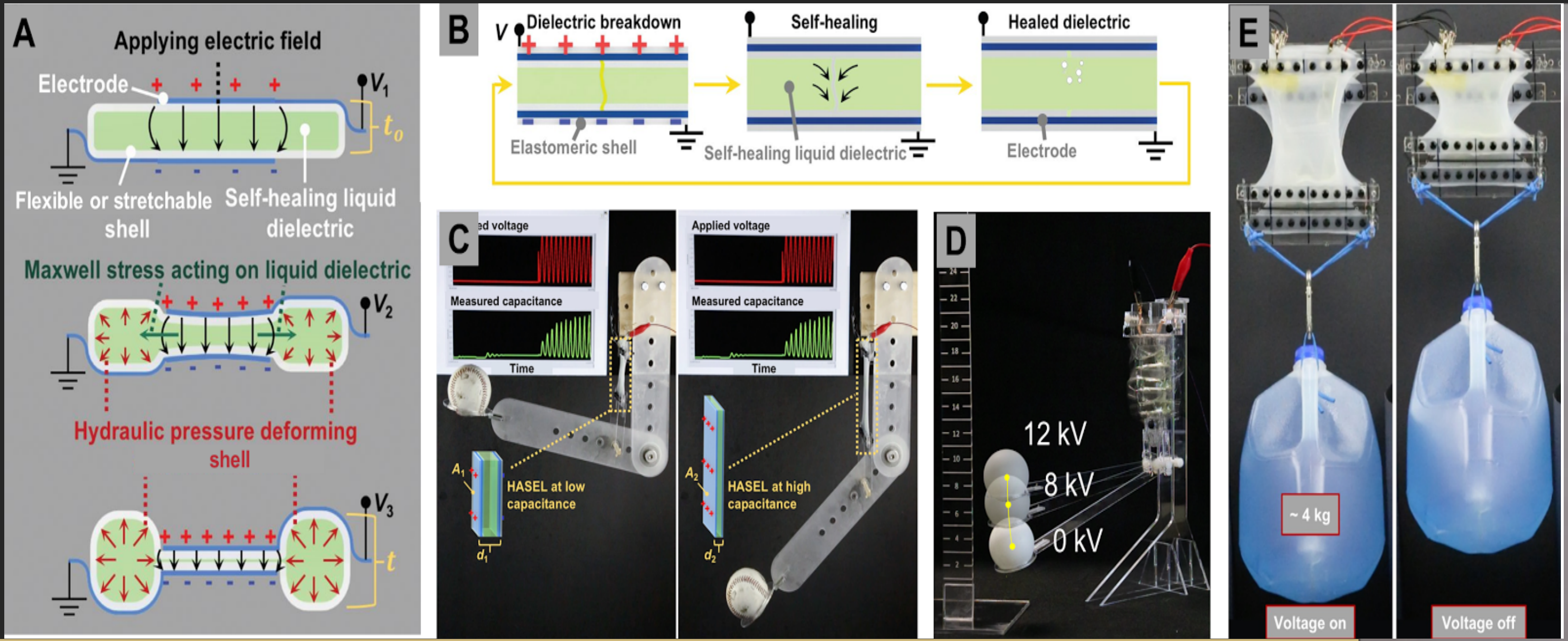
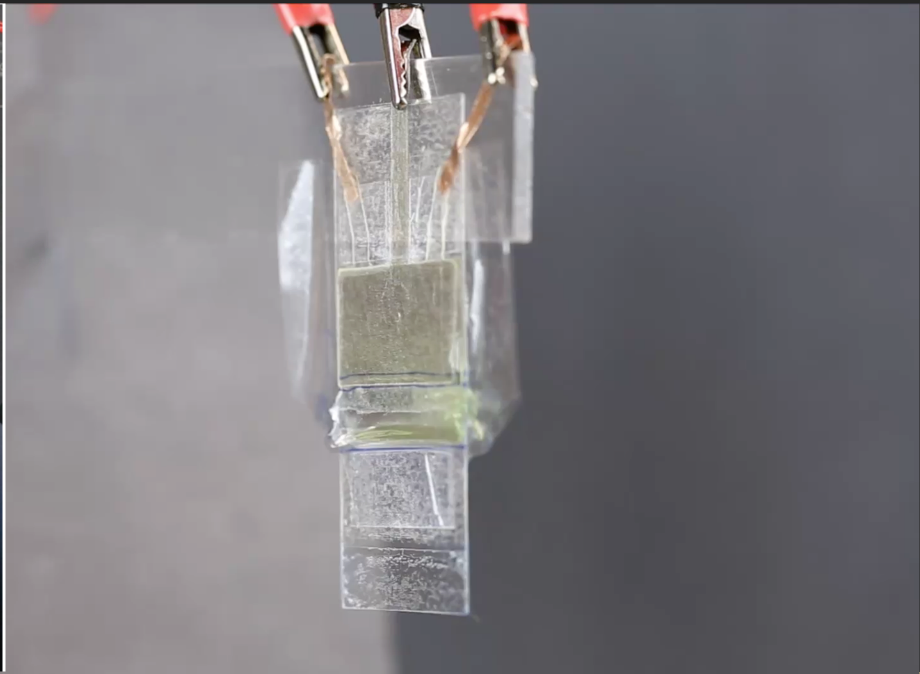
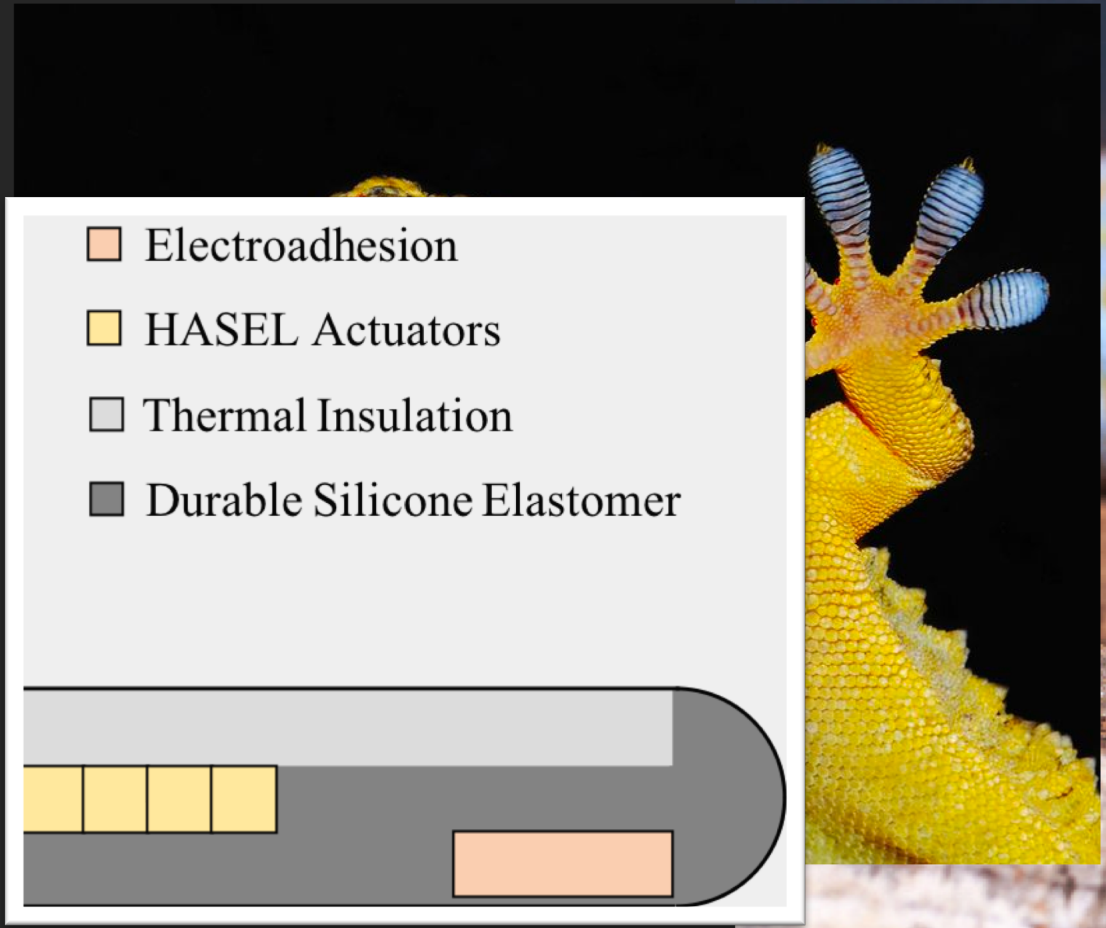
Soft Robotics

- Robots build from actuated, flexible material
  - Often take inspiration from biological sources
- Use HASEL actuators, developed by Christoph Keplinger at CU

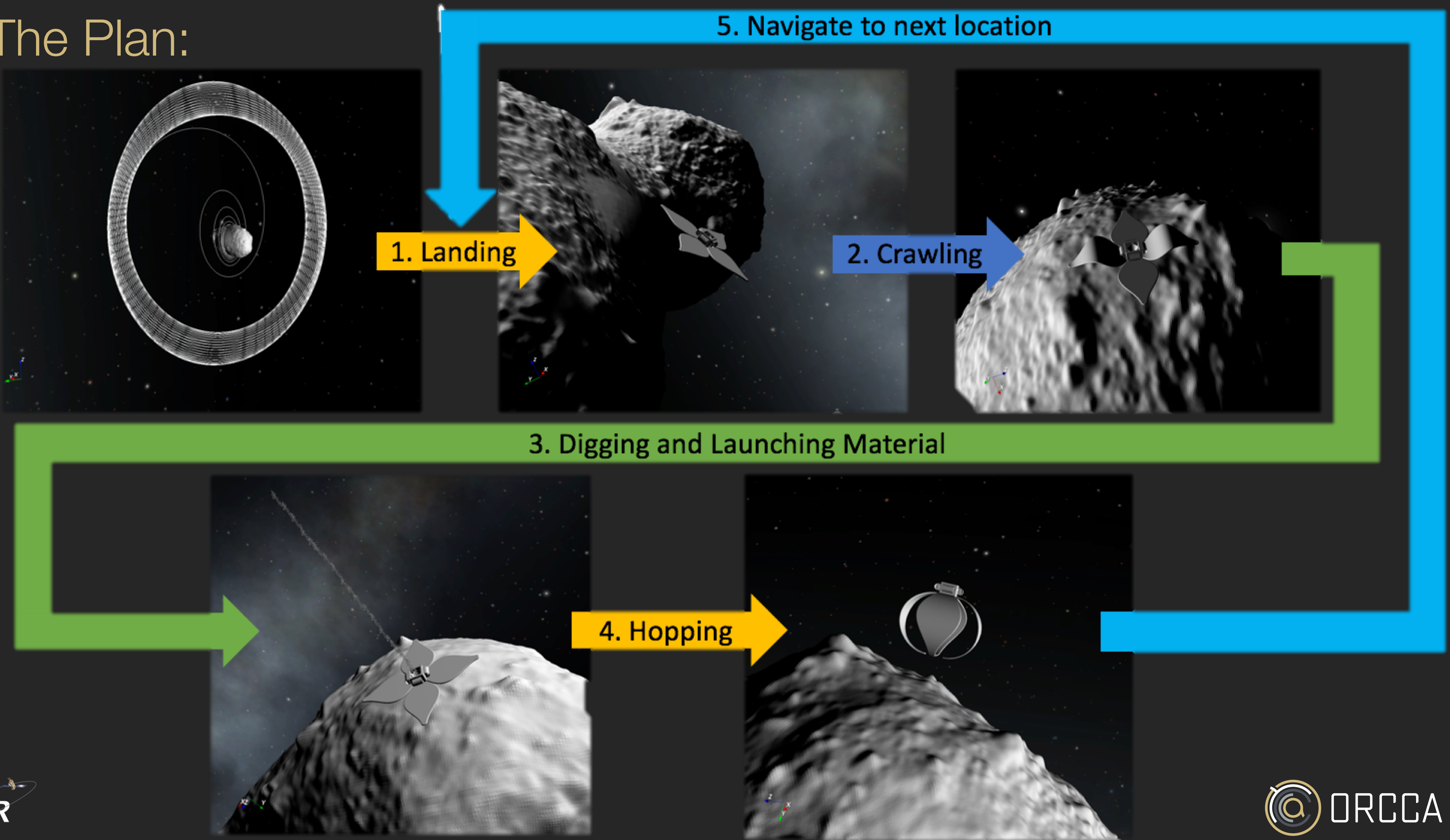




Using Adhesion for Anchoring



The Plan:



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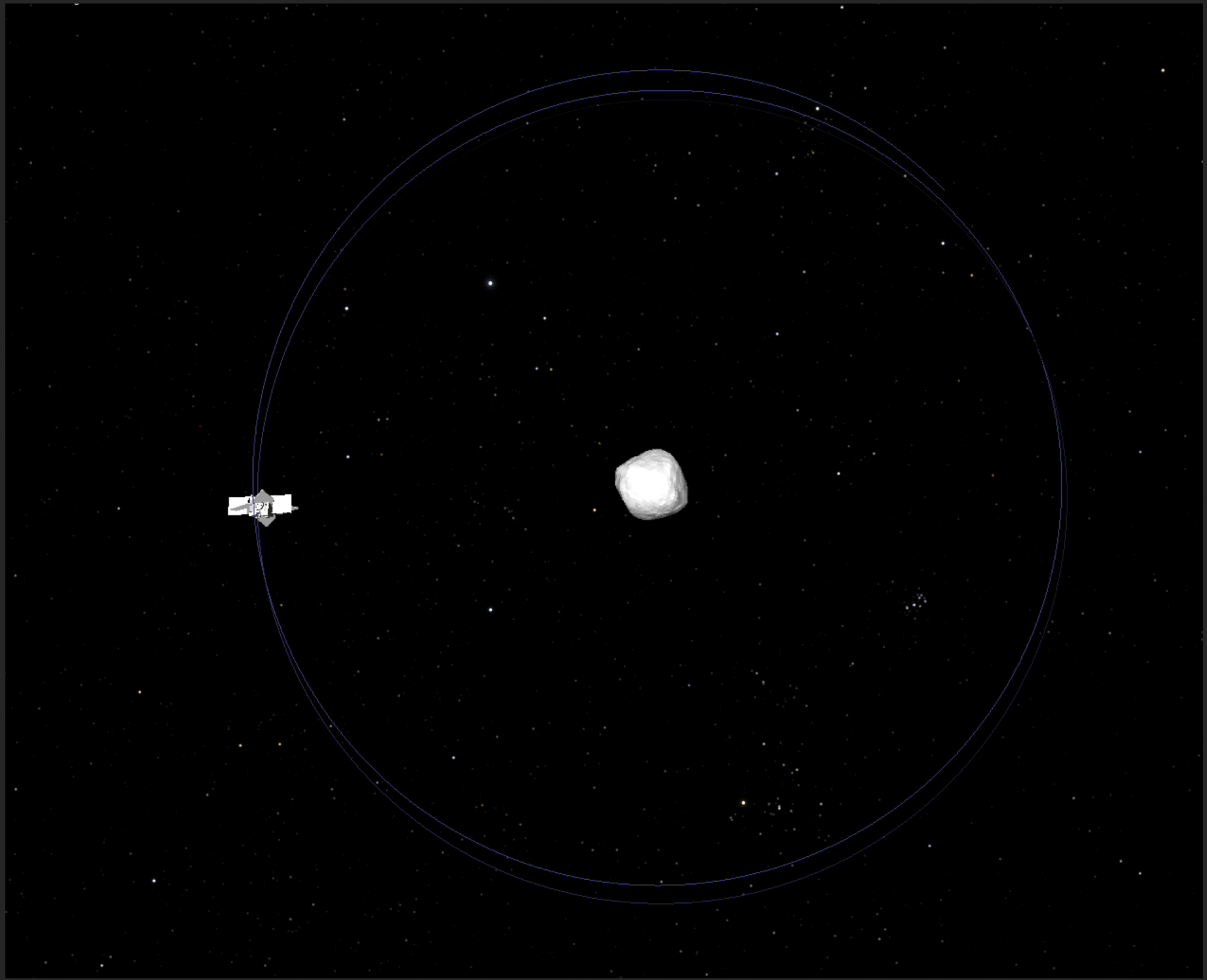
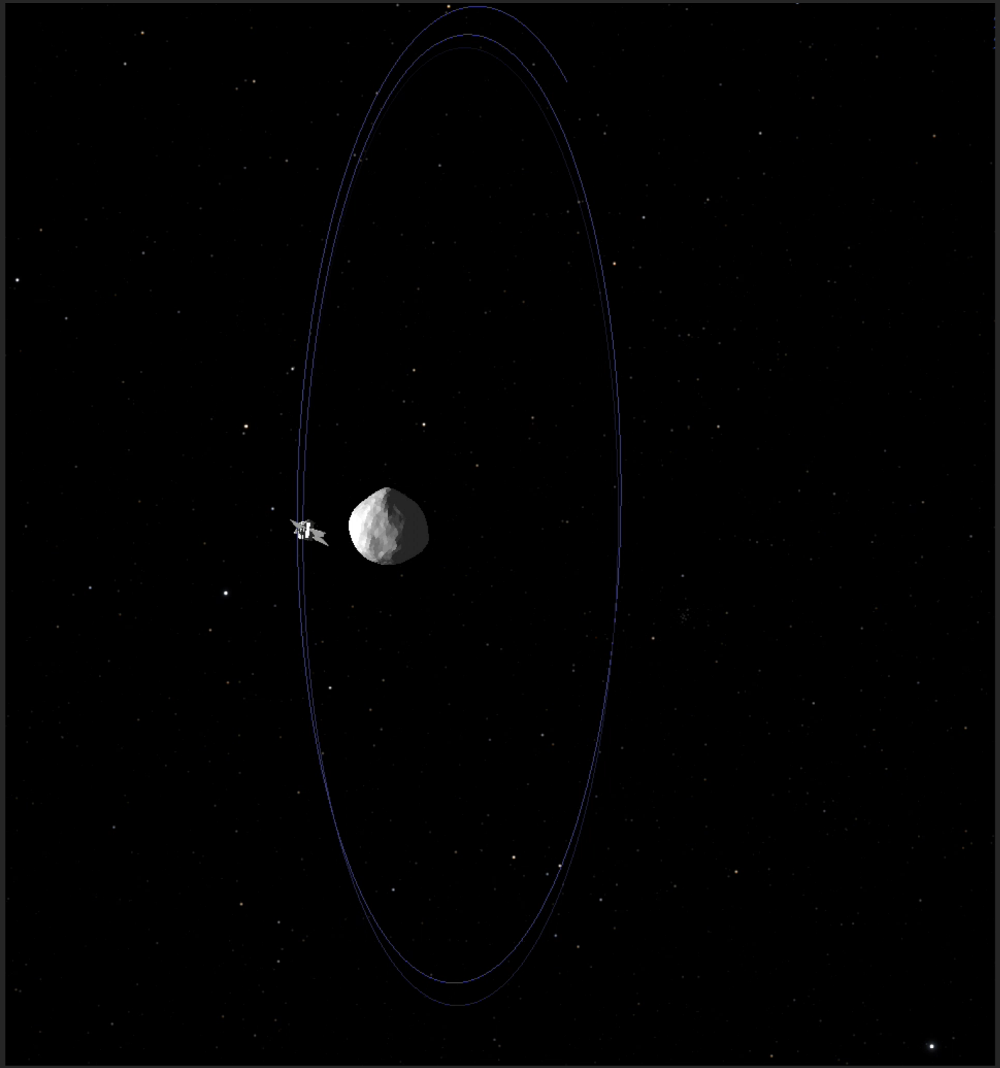
Landing on an Asteroid using Sunlight

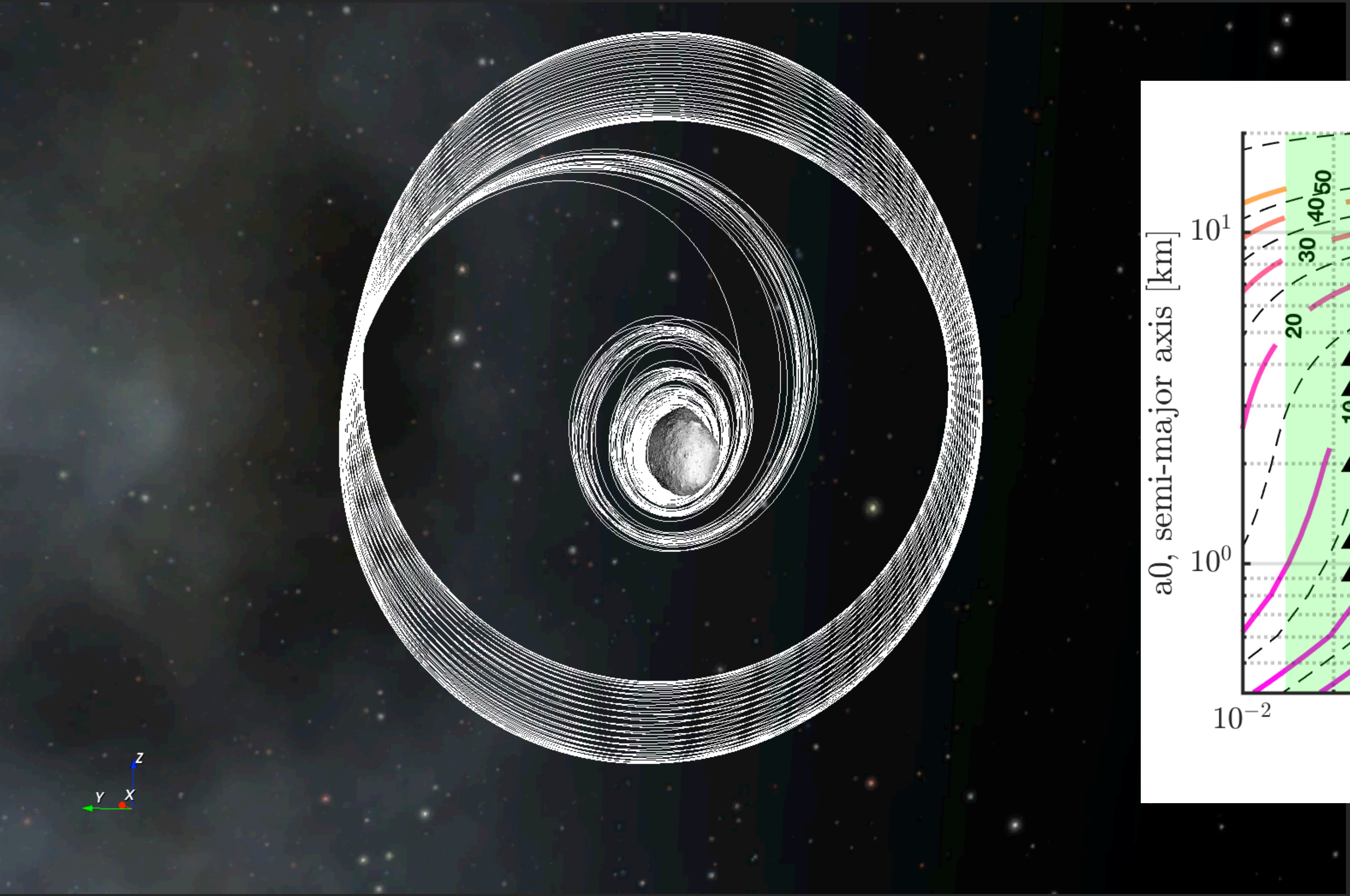


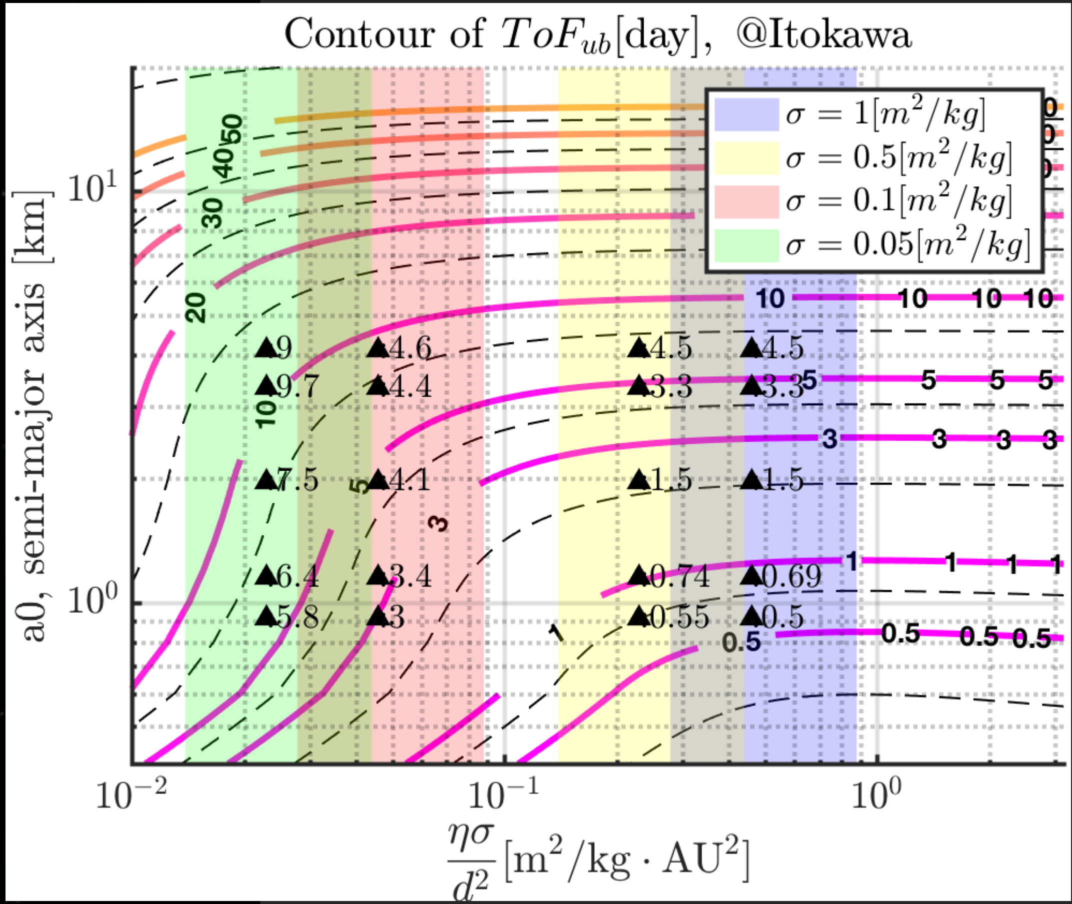
View from Sun



View from terminator

Preliminary Landing Results





Summary of Approach and Benefits

- **Technical Approach**
- Key technical challenges addressed:
  - Adhesive Anchoring testing
  - Detailed actuation kinematics and control with full leg design
  - Regolith digging/launching system design and mechanics
  - HASEL actuator refinement (miniaturization, space materials)
  - Heating system to ensure operational material temperatures
  - Robust navigation and control for landing (deformable shape solar sailing, navigation information and sensors)
- Phase II testing and demonstration of leg motion, digging, adhesion with reduced gravity and asteroid regolith simulants

- **Potential & Benefits**
- Material retrieval is a key unsolved component of enabling ISRU at asteroids
- AoES based architecture provides many advantages over state of the art concepts for gathering material from rubble pile surfaces
  - Robust to uncertainties on surface structure; large area won't sink, and soft structure can adapt to roughness
  - Reduces system risk by leaving the majority of spacecraft infrastructure in orbit away from the surface
  - Surface mobility reduces landing accuracy requirements
  - Soft structure can absorb energy to reduce bouncing

Enable robust mining of Near-Earth Asteroids!

Area-of-Effect Softbots to the Rescue!

Thank you for your attention!

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