Gathering asteroid dust guided by OSIRIS-REx images

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Gathering asteroid dust with OSIRIS-REx

01 One

The significance of planetary sample return and the OSIRIS-REx mission

02 Two

Overcoming challenges to gather dust from the early solar system

03 Three

The future of OSIRIS-REx
Gathering asteroid dust with OSIRIS-REx

# One
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# Two
Overcoming challenges to gather dust from the early solar system

# Three
The future of OSIRIS-REx
Of the >200 planetary exploration spacecraft launched by humankind, 9 have been sample return missions. Samples have been successfully retrieved from the Moon, solar wind, comet Wild 2, and asteroids Itokawa, Ryugu, and Bennu.
Asteroids hold clues to our past and future

- Asteroids are remnants of the formation of the solar system and bare the fingerprints of ancient processes
- Carbon-rich asteroids contain materials thought to be precursors to life, including water and organic molecules
- Metal, stony, and carbon-rich asteroids hold incredible potential for resource utilization
- Asteroids have been responsible for major extinction events in Earth’s history (e.g., Chicxulub impactor) and many potential hazardous asteroids have been detected
- Some asteroids types have been delivered to Earth as meteorites, but our atmosphere acts as a powerful mechanical filter and has created a bias in the types of materials found in our meteorite collection
Sample return from asteroid Bennu

Launched in 2016, OSIRIS-REx arrived at asteroid Bennu in December 2018.
Before the OSIRIS-REx spacecraft’s arrival at its target, the team developed a detailed assumptions about Bennu that were used to inform the OSIRIS-REx mission design (Lauretta et al., 2015, 2017).

- Telescopic data implied centimeter-scale particles were widespread on Bennu’s surface as loose material in the geopotential low at the equator:
  - Mid-infrared thermal inertia (Emery et al., 2014),
  - Near-infrared spectra (Binzel et al., 2015)
  - Radar polarization ratio measurements (Nolan et al., 2013)
- The original sampling strategy was designed to target patches of loose regolith 50 m in diameter with particles smaller than 2 cm (Lauretta et al., 2017; Bierhaus et al., 2018).
Meeting Bennu

PolyCam Image Mosaics
December 2, 2018
~33 centimeters/pixel

~500 m in diameter
4.3 hr rotation period

Phase angle ~48°
Emphasizes rubble-pile nature of Bennu’s surface
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**OSIRIS-REx design principles that led to mission success**

1. **Clear traceability** to Mission Level (L1) requirements
2. A well defined but **flexible** implementation plan and tools
3. Addressing and minimizing single-point failures by having independent but **redundant** systems
4. Strong and transparent **team culture**

![Mission Timeline](image-url)

<table>
<thead>
<tr>
<th>Event</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>Baseline Departure</th>
<th>Last Backup Departure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>9/8/16</td>
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<td></td>
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<tr>
<td>Outbound Cruise</td>
<td></td>
<td></td>
<td></td>
<td>3/2/21</td>
<td>4/10/22</td>
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<tr>
<td>Hazard Survey, Ephemeris Updates</td>
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<td></td>
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<tr>
<td>Initial Shape and Gravity Models</td>
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<tr>
<td>Transition to Landmark Tracking</td>
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<tr>
<td>Global Mapping, Initial 12 Site Selection</td>
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<td></td>
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<tr>
<td>Topographic and Spectral Mapping, Refined Gravity, Down Select to 4 Sites</td>
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<tr>
<td>High Resolution Observations, Final Site Selection</td>
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<tr>
<td>TAG Operational Refinement</td>
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<tr>
<td>Sample Retrieval</td>
<td></td>
<td></td>
<td></td>
<td>403 days</td>
<td></td>
</tr>
<tr>
<td>Baseline Asteroid Operations</td>
<td></td>
<td></td>
<td></td>
<td>431 days + 308 days</td>
<td></td>
</tr>
<tr>
<td>Rehearsal</td>
<td></td>
<td></td>
<td></td>
<td>42 days + 185 days</td>
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<tr>
<td>Sample Collection</td>
<td></td>
<td></td>
<td></td>
<td>23 days + 47</td>
<td></td>
</tr>
<tr>
<td>Return Cruise</td>
<td></td>
<td></td>
<td></td>
<td>634 days</td>
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</tr>
</tbody>
</table>
Major mission adaptations

1. Sample-site selection decision process
   - How do we evaluate and choose the best place on the asteroid for sampling and spacecraft safety?

2. How do we navigate to the surface for such a small sample site for the touch-and-go (TAG) maneuver?
1. Sample-site selection decision process

Challenge
• Loss knowledge for how best to interpret the thermal inertia as an indicator of grain size

Mission system design principal
• Traceability – We must reprioritize the acquisition of data that will allow us to observe 2 cm particles
• Redundancy – Images can provide indirect and direct evidence of 2 cm particles
• Flexibility – We can allocate schedule margin to obtain additional imaging data
• Strong culture – The team is up for the challenge of changing the sample-site selection process
**Outcomes: Sample-site selection**

### Sample-site Selection Process

<table>
<thead>
<tr>
<th>Phase</th>
<th>Key Data Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary Survey</td>
<td>- Global boulder mapping (&gt;8 m) - Global shape model</td>
</tr>
<tr>
<td>Detailed Survey</td>
<td>- Global imaging (&lt;5 cm/pixel)</td>
</tr>
<tr>
<td>Orbital B</td>
<td>- OLA shape model for 5 cm DTM</td>
</tr>
<tr>
<td>RECON A</td>
<td>- 1 cm/pixel imaging of Final Four candidate sample sites</td>
</tr>
<tr>
<td>RECON C Nightingale</td>
<td>- &lt;0.4 cm/pixel imaging of prime and backup sample sites</td>
</tr>
<tr>
<td>RECON C Osprey</td>
<td>- Successful sampling - 1 mm/pixel imaging</td>
</tr>
<tr>
<td>Sample Collection</td>
<td>- Predicted collection amount for primary and backup sample sites</td>
</tr>
<tr>
<td></td>
<td>- Sampleability predicts 256 – 575 g collection</td>
</tr>
</tbody>
</table>

**Sampleability Assessments**

- Selecting ROIs
- Assessing top 16 candidate sites
- ROIs via ArcMap unresolved material and tilt
- Assessing final four candidate sites via unresolved material and tilt
- Selecting Nightingale as prime and Osprey as backup

**Facet Material Coverage**

- Unresolved Material
- Resolved Particle < 2 cm
- Resolved Particle > 2 cm

**Dimensions**

- **A**: 10 m
- **B**: 5 m

**Key Points**

- 2019
  - Key Data Products
  - Global boulder mapping (>8 m)
  - Global shape model
- 2020
  - Global imaging (<5 cm/pixel)
  - OLA shape model for 5 cm DTM
  - 1 cm/pixel imaging of Final Four candidate sample sites
  - <0.4 cm/pixel imaging of prime and backup sample sites
  - Successful sampling - 1 mm/pixel imaging
  - Predicted collection amount for primary and backup sample sites
  - Sampleability predicts 256 – 575 g collection
2. How do we navigate to the surface?

Challenge

• The guidance navigation and control (GNC) system was designed to TAG sites > 50 m in shortest dimension and did not anticipate large vertical hazards

Mission system design principal

• **Traceability** – It is only possible for us achieve mission success (L1 requirements) if we sample at a smaller site

• **Redundancy** – Our backup natural feature tracking (NFT) technique will allow us to navigate to the surface more precisely that our GNC Lidar

• **Flexibility** – We can allocate schedule margin to obtain additional imaging data to build our NFT feature catalog and upgrading our onboard software

• **Strong culture** – The team is willing to work across elements to gather the inputs to successfully execute NFT
Outcome: Navigating to the surface

Nightingale image from Matchpoint during TAG
The OSIRIS-REx Touch-and-Go sampling event
The OSIRIS-REx Touch-and-Go sampling event
The OSIRIS-REx sample acquisition verification and stow
Summary and take-aways

• Bennu presented many challenges for the OSIRIS-REx mission, and several ‘unknown unknowns’ were encountered

• The mission adopted many good design principals during development, but the following four were vital to our success:
  1. Clear **traceability** to Mission Level (L1) requirements
  2. A well defined but **flexible** implementation plan and tools
  3. Addressing and minimizing single-point failures by having independent but **redundant** systems
  4. Strong and transparent **team culture**
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Sample analysis of Bennu material

• Samples of Bennu will be returned to Earth in September 2023
• Post-sample return a 2-year period of sample analysis will commence
• We predict ~100 grams of material which is will be the largest sample return since Apollo

OSIRIS-REx at Apophis

• After Earth return the spacecraft could go into an extended cruise period in the inner solar system
• In 2029 the OSIRIS-REx spacecraft can rendezvous with asteroid 99942 Apophis shortly after it’s close approach to Earth
• OSIRIS-REx is proposing a 2-year rendezvous around Apophis like what was conducted at Bennu
Thank you