OSIRIS-REx
Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer
Asteroid Sample Return Mission

Presentation to the
Small Bodies Assessment Group

Science Overview

Dante S. Lauretta
Principal Investigator
With modifications by
Beth Ellen Clark
Mission Asteroid Scientist
OSIRIS-REx–
The Right Team For The Job

Principal Investigator: Dante Lauretta (UA)
Deputy PI: Robert Jenkens (GSFC)
Project Manager: Joe Vellinga (LM)

University of Arizona
Principal Investigator & Deputy PI
Project Planning and Control Officer
Mission Instrument Scientist
Science Team Management
OSIRIS-REx CAMera Suite (OCAMS)
Science Processing and Operations Center (SPOC)
Data Management and Archiving
Education & Public Outreach

Goddard Space Flight Center
Project Management
Project Scientist & Deputy Project Scientist
Mission Systems Engineering
Safety & Mission Assurance
OSIRIS-REx Visible and Near InfraRed Spectrometer (OVIRS)
Flight Dynamics Lead

Lockheed Martin
Flight System
Sampling System
Sample Return Capsule
Mission Operations

Canadian Space Agency – OSIRIS-REx Laser Altimeter (OLA)
Arizona State University – OSIRIS-REx Thermal Emission Spectrometer (OTES)
KinetX – Navigation/Flight Dynamics
Johnson Space Center – Sample Curation
Ithaca College – Asteroid Science
OSIRIS-REx Guiding Principles

- **OSIRIS-REx addresses deep questions** – Where did we come from, what is our destiny?
  - Sample return leverages the evolution of ground-based instrumentation
- **OSIRIS-REx uses a focused approach to technical implementation and cost control**
  - If it doesn’t support sample return, it’s not on the spacecraft
- **OSIRIS-REx has built an experienced multigenerational team**
  - We’re developing the next generations of science, engineering, and management leaders
- **OSIRIS-REx has built a badgeless, integrated team**
  - Science, engineering, and management all understand each other’s requirements
  - The “Buck Stops” with the P.I.
- **OSIRIS-REx provides near continuous public and scientific engagement for over a decade**
  - Near live coverage of RQ36 operations and return to Earth enthralls the general public
  - Asteroid encounter and sample return energizes the scientific community
Objective 1

Return and analyze a sample of pristine carbonaceous asteroid regolith in an amount sufficient to study the nature, history, and distribution of its constituent minerals and organic material.
Objective 2

Map the global properties, chemistry, and mineralogy of a primitive carbonaceous asteroid to characterize its geologic and dynamic history and provide context for the returned samples.
Objective 3

Document the texture, morphology, geochemistry, and spectral properties of the regolith at the sampling site in situ at scales down to the sub-millimeter.
Objective 4

Measure the Yarkovsky effect on a potentially hazardous asteroid and constrain the asteroid properties that contribute to this effect.
Objective 5

Characterize the integrated global properties of a primitive carbonaceous asteroid to allow for direct comparison with ground-based telescopic data of the entire asteroid population.
OSIRIS-REx Science Requirements Flow Down to All Levels of the Mission

NASA Solar System Exploration Roadmap  
NRC Opening New Frontiers in Space/NF3 AO

Mission Objectives

Level-1 Requirements

Science Requirements  
Mission System Requirements  
Design Reference Mission  
Mission Assurance & Environmental Requirements

Science Team  
Payload  
Spacecraft  
Ground System

Mission Cost Profile/Schedule/Risks/Mitigation

Flow-down to lower levels  
Traceability to higher levels

### Fifteen Level-1 Requirements Define our Science Implementation Strategy

<table>
<thead>
<tr>
<th>Requirement</th>
<th>TAGSAM</th>
<th>PolyCam</th>
<th>MapCam</th>
<th>SamCam</th>
<th>Radio Sci</th>
<th>OLA</th>
<th>OVIRS</th>
<th>OTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Return 60 g of bulk sample</td>
<td>X</td>
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<tr>
<td>1.2 Document sample contamination</td>
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<td>1.3 Contact 26 cm$^2$ of surface material</td>
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<td>1.4 Document the sampling site</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>1.5 Produce a sample catalog and analyze samples</td>
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<td>1.6 Produce a shape model</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>1.7 Determine slopes, accelerations, and geopotential</td>
<td>X</td>
<td>X</td>
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<td>1.8 Determine density, structure, and gravity field</td>
<td>X</td>
<td>X</td>
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<td>1.9 Map the surface geology</td>
<td>X</td>
<td>X</td>
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<tr>
<td>1.10 Map minerals &amp; organics</td>
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<td>1.11 Search for &amp; characterize volatile outgassing</td>
<td>X</td>
<td>X</td>
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<td>1.12 Search for &amp; characterize satellites</td>
<td>X</td>
<td>X</td>
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<td>1.13 Search for &amp; characterize space weathering</td>
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<td>1.14 Measure the Yarkovsky effect</td>
<td>X</td>
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<td>1.15 Measure point-source properties</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>L.1</td>
<td>Level 2 science requirement</td>
<td>T or B</td>
<td>Rationale</td>
<td>Mission Phase</td>
<td>Mission Element</td>
<td>Primary Co-I</td>
<td>Working Group</td>
<td>Notes</td>
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<tr>
<td>2.1.1</td>
<td>Return ≥15 g of bulk material for analysis in support of mission science objectives</td>
<td>T</td>
<td>Amount of returned sample required to achieve mission science objectives</td>
<td>8. Sample Collection</td>
<td>TAGSAM, SRC</td>
<td>Ben Clark</td>
<td>Regolith Development</td>
<td></td>
</tr>
<tr>
<td>2.1.2</td>
<td>Return and archive ≥45 g of bulk material in support of NASA objectives</td>
<td>T</td>
<td>NASA requirement not to consume more than 25% of returned sample</td>
<td>8. Sample Collection</td>
<td>TAGSAM, SRC</td>
<td>Righter</td>
<td>Regolith Development</td>
<td></td>
</tr>
<tr>
<td>2.1.3</td>
<td>Return and maintain the bulk sample exposed to total carbon contamination &lt;180 ng/cm² on the TAGSAM surface</td>
<td>B</td>
<td>Analysis of key prebiotic compounds is central to mission science objectives. Science rationale for contamination derives from NRC guidelines for &quot;Exploring Organic Environments in the Solar System&quot;</td>
<td>All</td>
<td>TAGSAM, SRC, Spacecraft</td>
<td>Dworkin</td>
<td>Contamination Control</td>
<td></td>
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<tr>
<td>2.1.4</td>
<td>Limit total hydrazine contamination on TAGSAM to &lt;180 ng/cm²</td>
<td>B</td>
<td>Total allowable hydrazine contamination equal to total organic carbon contamination allowed by mission guidelines</td>
<td>All</td>
<td>Spacecraft, Mission Design</td>
<td>Dworkin</td>
<td>Contamination Control</td>
<td></td>
</tr>
<tr>
<td>2.1.5</td>
<td>Return and maintain the bulk sample exposed to total amino acid contamination &lt;180 ng/cm² on the TAGSAM surface</td>
<td>B</td>
<td>Stardust contamination control successfully achieved mission science objectives. Stardust worst case is 180 ng/cm² amino acids</td>
<td>All</td>
<td>TAGSAM, SRC, Spacecraft</td>
<td>Glavin</td>
<td>Contamination Control</td>
<td></td>
</tr>
<tr>
<td>2.1.6</td>
<td>Return and maintain the bulk sample exposed to total inorganic contamination &lt;TBD ng/cm² on the TAGSAM surface</td>
<td>B</td>
<td>Trace element and isotopic analysis are critical to achieve sample-analysis objectives</td>
<td>All</td>
<td>TAGSAM, SRC, Spacecraft</td>
<td>Messenger</td>
<td>Contamination Control</td>
<td></td>
</tr>
<tr>
<td>2.2.1</td>
<td>Document the contamination acquired by the TAGSAM Head during flight</td>
<td>T</td>
<td>Ensure a chain of evidence linking the acquired sample with its contamination experience</td>
<td>All</td>
<td>TAGSAM, SRC</td>
<td>Dworkin</td>
<td>Contamination Control</td>
<td></td>
</tr>
<tr>
<td>2.2.2</td>
<td>Generate and follow the requirements in a project contamination control plan</td>
<td>T</td>
<td>Details of the project contamination control and documentation procedures are best described in a detailed plan (to be completed in Phase B)</td>
<td>All</td>
<td>All</td>
<td>Dworkin</td>
<td>Contamination Control</td>
<td></td>
</tr>
<tr>
<td>2.3.1</td>
<td>Return 6.5 cm² of the surface-contact pad capable of acquiring particles from 10 μm to 1 mm in size while the TAGSAM head is in contact with the asteroid surface</td>
<td>T</td>
<td>Backup sample collection technique in case primary bulk sample acquisition is unsuccessful. 10 μm is the average size of interplanetary dust particles. 1 mm is the average size of coarse-grained components in carbonaceous chondrites</td>
<td>8. Sample Collection</td>
<td>TAGSAM, SRC</td>
<td>Marshall</td>
<td>Regolith Development</td>
<td></td>
</tr>
<tr>
<td>2.3.2</td>
<td>Return and archive ≥ 19.5 cm² of the surface-contact pad capable of acquiring particles from 10 μm to 1 mm in size while the TAGSAM head is in contact with the asteroid surface</td>
<td>T</td>
<td>NASA requirement not to consume more than 25% of returned sample</td>
<td>8. Sample Collection</td>
<td>TAGSAM, SRC</td>
<td>Righter</td>
<td>Regolith Development</td>
<td></td>
</tr>
<tr>
<td>2.3.3</td>
<td>Image the TAGSAM Head contact surface with TBD resolution prior to stowing the Head in the SRC.</td>
<td>T</td>
<td>Image analysis provides estimate of amount surface sample collected. Shows if material on TAGSAM contact surface could prevent stowage of the Head</td>
<td>8. Sample Collection</td>
<td>TAGSAM, OCAMS</td>
<td>Smith</td>
<td>Regolith Development</td>
<td></td>
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</tbody>
</table>

**Notes**

- Requirement clarified, particle size specified 11/30/2011
1999 RQ36 Rises to the Top of the Asteroid Charts
Asteroid 1999 RQ36 is an Excellent Sample Return Target

- It provides for the **most exciting science**, with a spectral signature suggesting a carbon- and volatile-rich surface
- It is a primitive B-class carbonaceous asteroid, a class of object **never before visited** by a spacecraft
- Its **size, shape, and rotation state are known** from extensive characterization by the Arecibo Planetary Radar System
- There is strong evidence for **abundant regolith** on the surface available for sampling
- Study of this Potentially Hazardous Asteroid is **strategically important** to NASA and Congress

--Arecibo Radar Data
• 1999 RQ36 is a B-class asteroid characterized by a linear, featureless spectrum with a bluish slope in the visible.
• The thermal tail longward of 2 microns suggests a very low albedo
• The CI/CM chondrites are the most likely meteorite analogs.
• RQ36 is spectrally similar to Themis and Pallas – other B-type asteroids.
  – Asteroid 24 Themis was recently discovered to have $\text{H}_2\text{O}$ ice and organics on its surface (Rivkin and Emery 2010; Campins et al. 2010).

–B. E. Clark et al. 2011
Radar Observations Provide Unparalleled Knowledge of 1999 RQ36

- Ephemeris position known to within 10 km
  - Enables navigation to the target
- Nearly spherical object—575 m diameter
  - Simplifies orbital and sampling operations
- Smooth surface—one discernable feature >7.5-m
  - Provides confidence in the presence of regolith
- 0° obliquity, retrograde rotation
  - Ensures illumination and Earth communication during sampling
• By Ross Dubois, UA
The Science Team is organized for flight and ground system development, data processing, and analysis.
OSIRIS-REx Bulk Sample Contains the History of 1999 RQ36

- 11.5 g of bulk sample for immediate analysis after Earth return
  - Measure the bulk abundances and isotopic compositions of the asteroid
  - Constrain the presolar, nebular, and parent-body history of 1999 RQ36
  - Test hypotheses based on dynamical and chemical evolution models of the Solar System
  - Perform first analysis of space-weathered carbonaceous material
  - Measure thermal properties important for the Yarkovsky Effect
  - Provide ground truth for remote-sensing data
- 3.5 g for margin
- 45 g archived for future generations
OSIRIS-REx Surface Samples Provide Critical Data for the Spectral Interpretation of Carbonaceous Bodies

• 5 cm² of surface sample for immediate analysis after Earth return
  – Provide a backup sample to the bulk collection
  – Characterize the optical properties of the upper surface layer
  – Constrain the mineralogy of the space-exposed surface
  – Perform first analysis of space-weathering on carbonaceous material

• 1.5 cm² for margin

• 73.5 cm² archived for future generations
Science requirements are fulfilled by our instrument capabilities

– **PolyCam** acquires 1999 RQ36 from 2M km range and refines its ephemeris

– **OLA** maps the shape and topography

– **MapCam** performs filter photometry and maps the surface

– **OVIRS** maps the spectral properties from 0.4 – 4.3 μm

– **OTES** maps the spectral properties from 5 – 50 μm
Observations performed at RQ36 achieve science beyond anything obtainable from Earth

- **Radio Science** reveals the mass, gravity field, internal structure, and surface acceleration distribution

- **SamCam** and **PolyCam** study the regolith at high-resolution and SamCam documents sample acquisition at 1 Hz
Requirements are fulfilled by our mission design...

The Design Reference Mission (DRM) . . . “serves as the backbone for focusing the design effort” -- from NF-3 Step 1 evaluation
...and our data analysis

- Sample Analysis

-2023 and beyond

All samples are archived in the Astromaterials Curatorial Facility at Johnson Space Center (JSC)

- Within six months of sample return, the OSIRIS-REx science team produces a catalog containing sufficient information to allow the community at large to propose research with the samples.
- During the subsequent six-month period, the Science Team is allocated samples to conduct the measurements required to address the mission science objectives.
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