

# Touchstone: The OSIRIS-REx Design Reference Mission

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# Outline

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- OSIRIS-REx Mission Overview
- Phase-by-Phase Description
- The Role of the DRM in the Selection of OSIRIS-REx
- Critical Design Review and Beyond

# OSIRIS-REx Mission Overview





# History

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- **OSIRIS = Origins, Spectral Interpretation, Resource Identification, and Security**
  - Proposed to NASA’s Discovery Program in 2004
    - University of Arizona and Lockheed-Martin (no NASA partner)
  - Re-proposed to Discovery in 2006
    - Added GSFC as partner
    - Selected for Phase A Concept Study, but GRAIL selected
- **OSIRIS-REx = OSIRIS Regolith Explorer**
  - Proposed to the New Frontiers Program in 2009 and selected as the 3<sup>rd</sup> New Frontiers mission in May 2011
  - Same principal partners



# Science Objectives

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- **Return and Analyze a Sample**

- 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

- **Provide Sample Context**

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

- **Understand Asteroid Geology, Dynamics, and Spectroscopy**

- 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

- **Understand the Interaction Between Asteroid Thermal Properties and Dynamics**

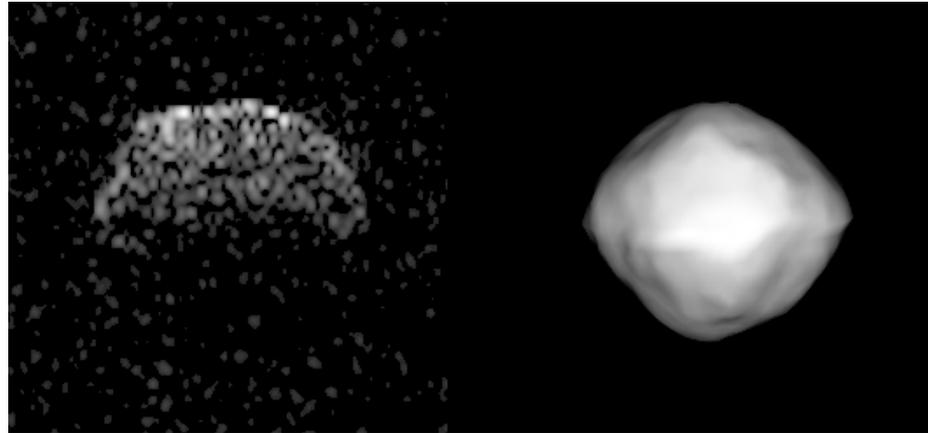
- Measure the Yarkovsky effect on a potentially hazardous asteroid and constrain the asteroid properties that contribute to this effect

- **Improve Asteroid Astronomy**

- 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



# Target: Near-Earth Asteroid (101955) Bennu



- It is primitive B-class carbonaceous asteroid, with a spectral signature suggesting a carbon- and volatile-rich surface
- Its size (500-m), shape (spheroidal “spinning top”), and rotation state (4.3hr period, 180° obliquity) are known from extensive astronomical characterization
- All available data suggest abundant regolith on the surface available for sampling
- Study of this Potentially Hazardous Asteroid is strategically important to NASA and Congress



# Mission Engineering Drivers

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- **Accurately navigating to the asteroid surface**
  - Early determination of Bennu mass, shape, and spin state
  - Surface approach initiated from well-characterized, stable orbit
  - Maneuver parameters updated < 24 hours after tracking data cut-off
  - Step-by-step Touch-and-Go (TAG) maneuver sequence simulated and rehearsed
- **Producing remote sensing data products for site selection**
  - Early, intensive, global mapping of Bennu
  - Science data processing centralized to provide timely turnaround of integrated surface information for sample site selection
- **Acquiring abundant regolith**
  - Simulated and tested TAG Sample Acquisition Mechanism (TAGSAM) and Bennu surface contact parameters optimized for low-gravity environment
  - Spacecraft design optimized for precise maneuvering and low dynamic disturbance (solar radiation pressure, surface contact dynamics)
- **Safely returning the sample to Earth**
  - Stardust mission heritage Sample Return Capsule, personnel, and entry, descent, landing, and recovery procedures utilized



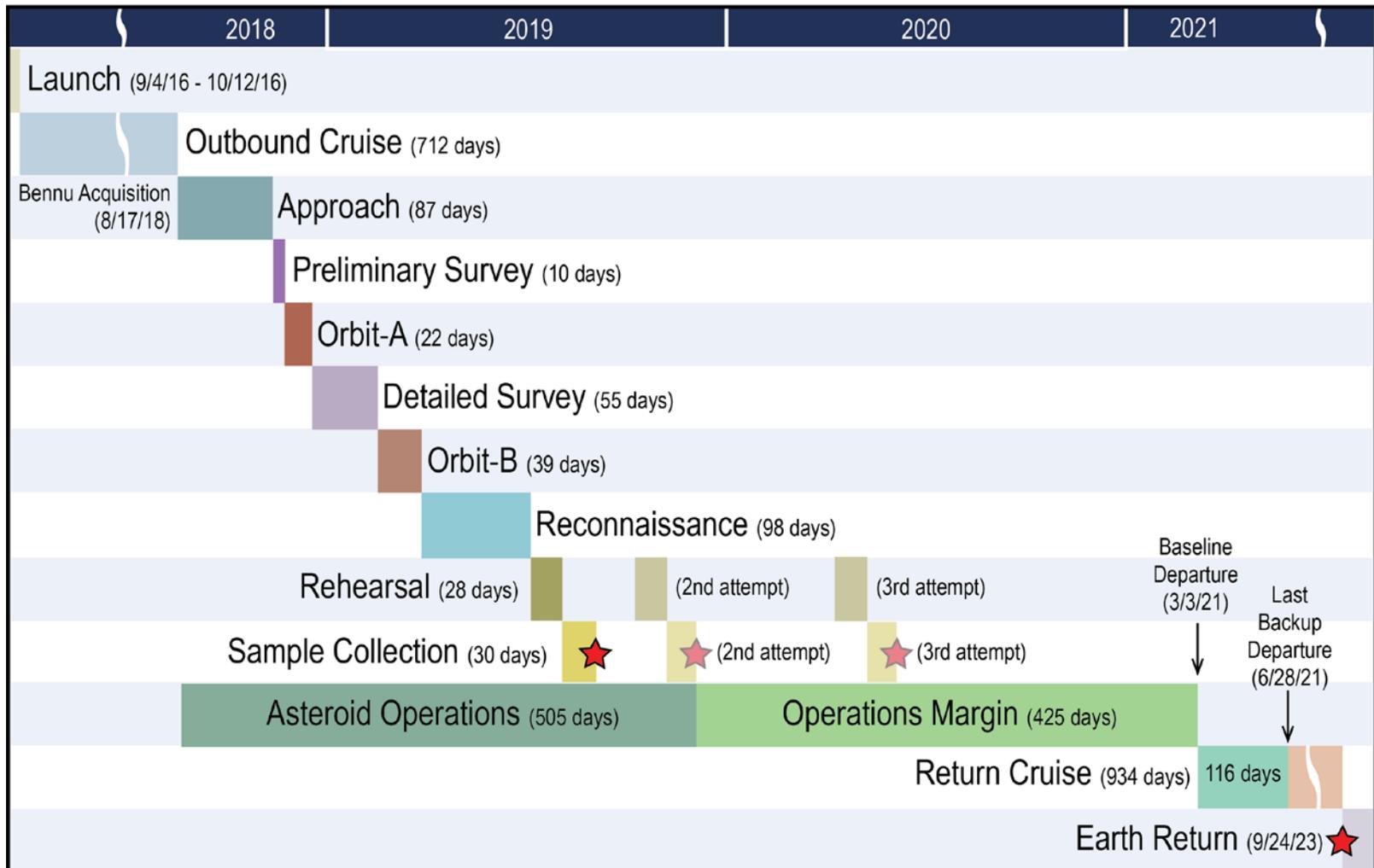
# What is the Design Reference Mission?

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- **The DRM is the mission-level (L2) operations concept for OSIRIS-REx.**
  - Provides an end-to-end, detailed description for how the mission addresses the OSIRIS-REx science objectives and engineering drivers
  - Includes 13 mission phases, from launch through Bennu proximity operations, to delivery of the sample to the curation facility following Earth return
  - Defines technical criteria for transitioning from one mission phase to the next, including both science and navigation criteria
- **OSIRIS-REx DRM themes**
  - Focus on *the sample*: context, collection, & safe return
  - Exercise a slow, methodical, deliberate approach
  - Apply lessons learned
  - Reduce operations risk and increase sample context knowledge with each step



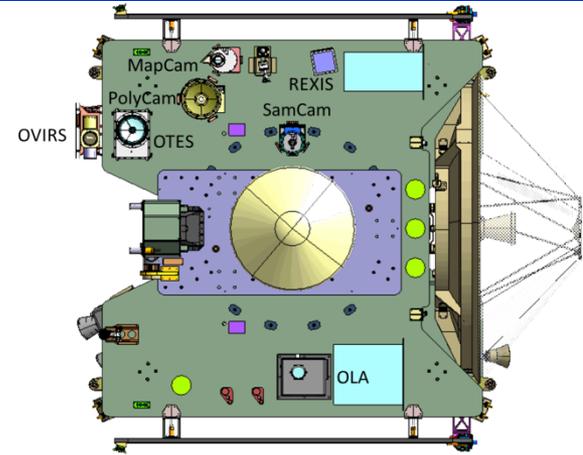
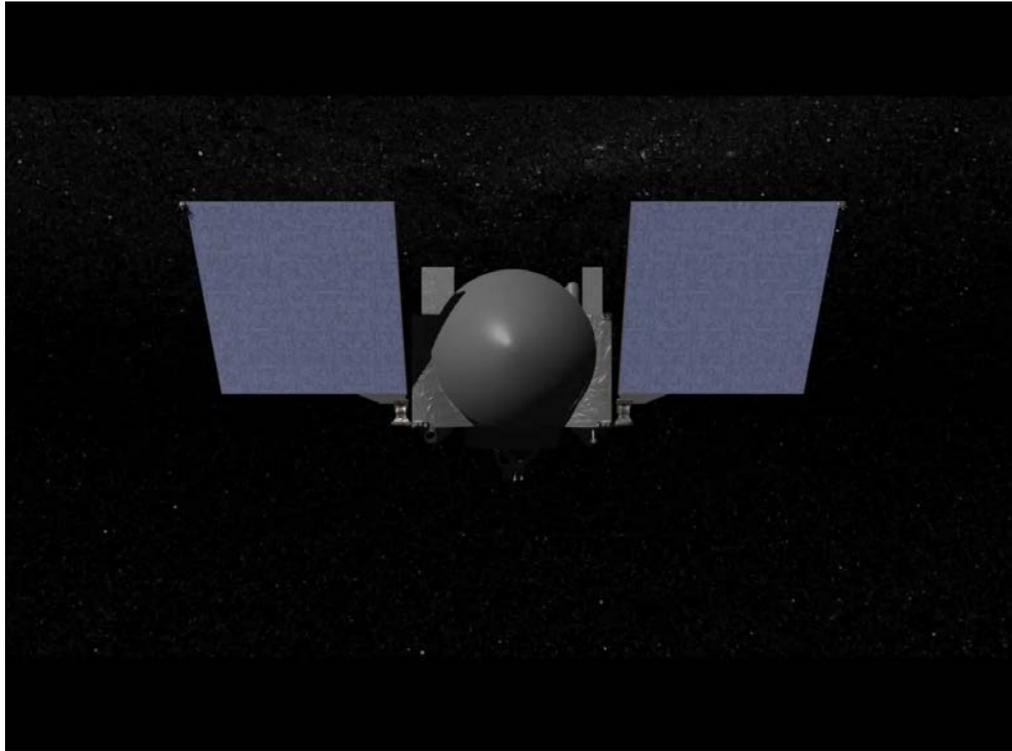
# Mission Timeline



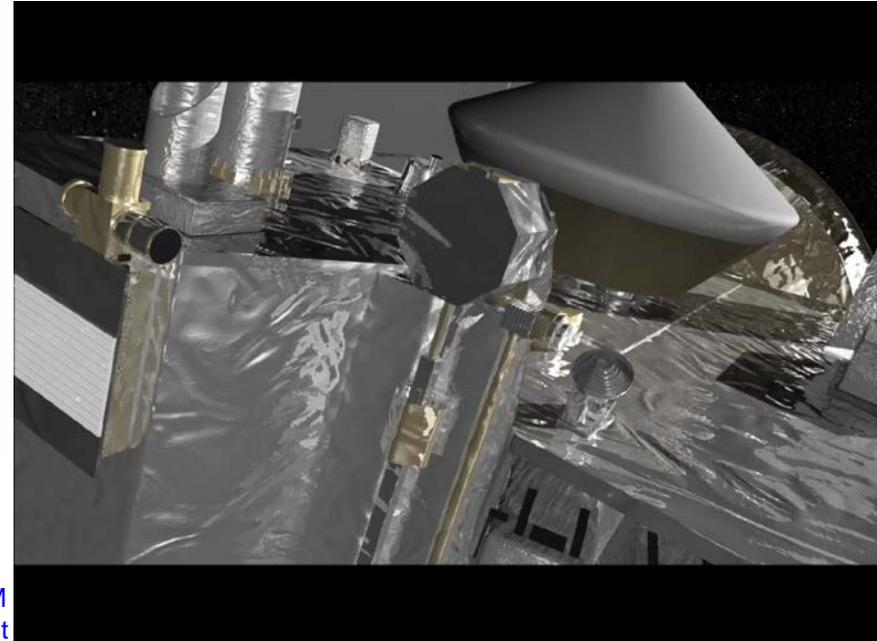


# OSIRIS-REx Flight System

Video: Spacecraft views



Video: TAGSAM deployment



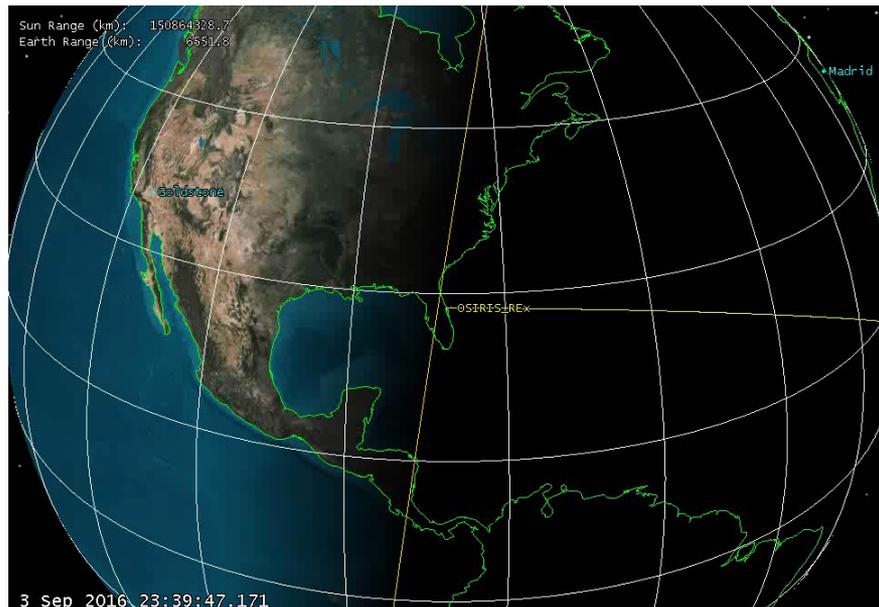
# Phase-by-Phase Description





# Launch

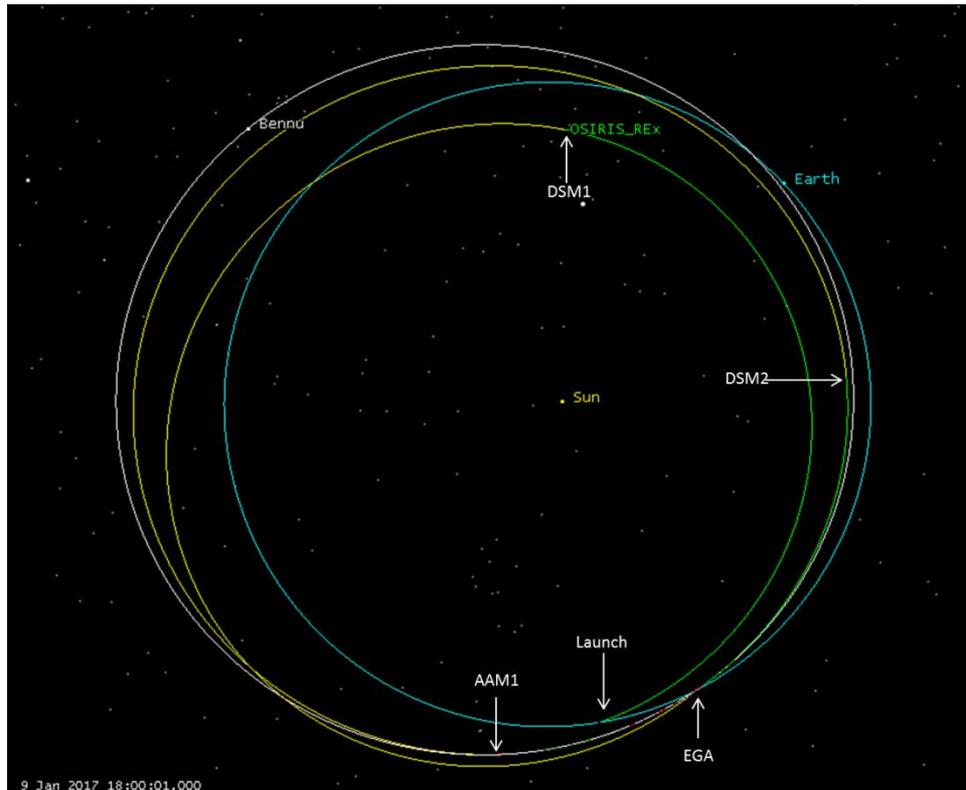
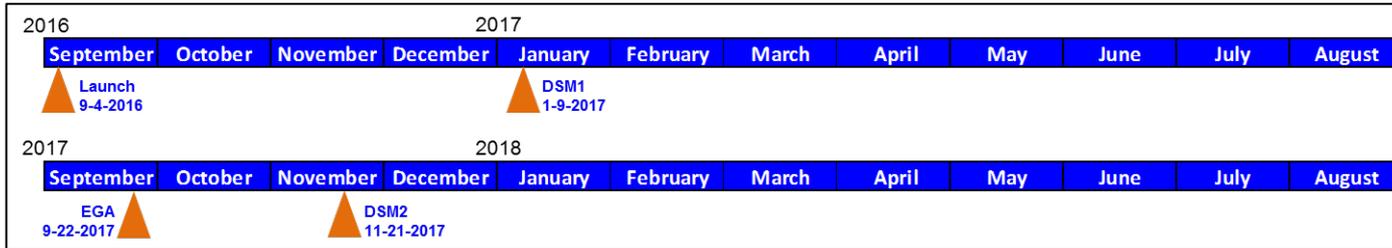
- 39-day launch period, opening September 4, 2016
- Atlas V 411 launch vehicle (1955kg to C3 =  $29.9\text{km}^2/\text{s}^2$ )
- Back up launch opportunity in September 2017



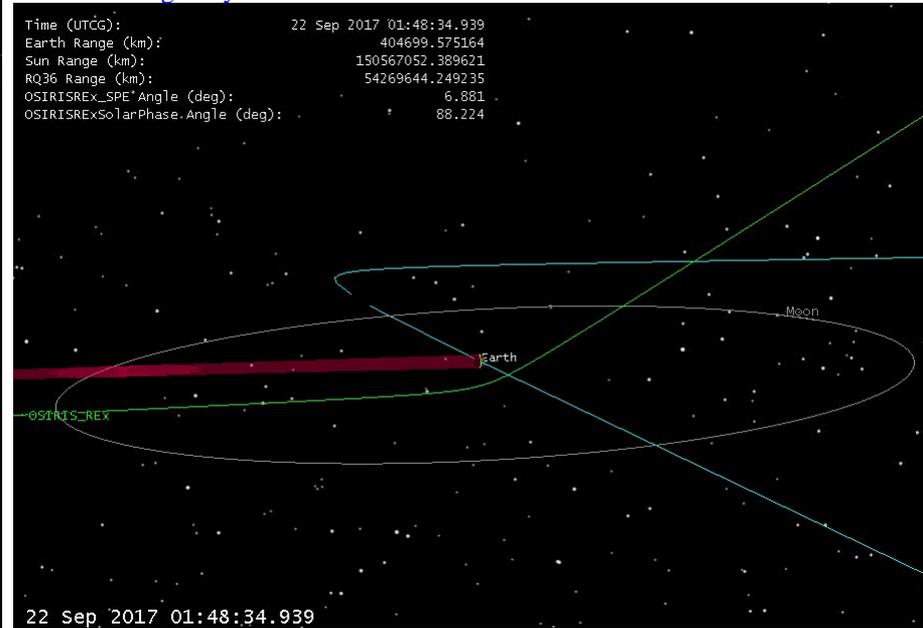
Video: Launch ground track



# Outbound Cruise

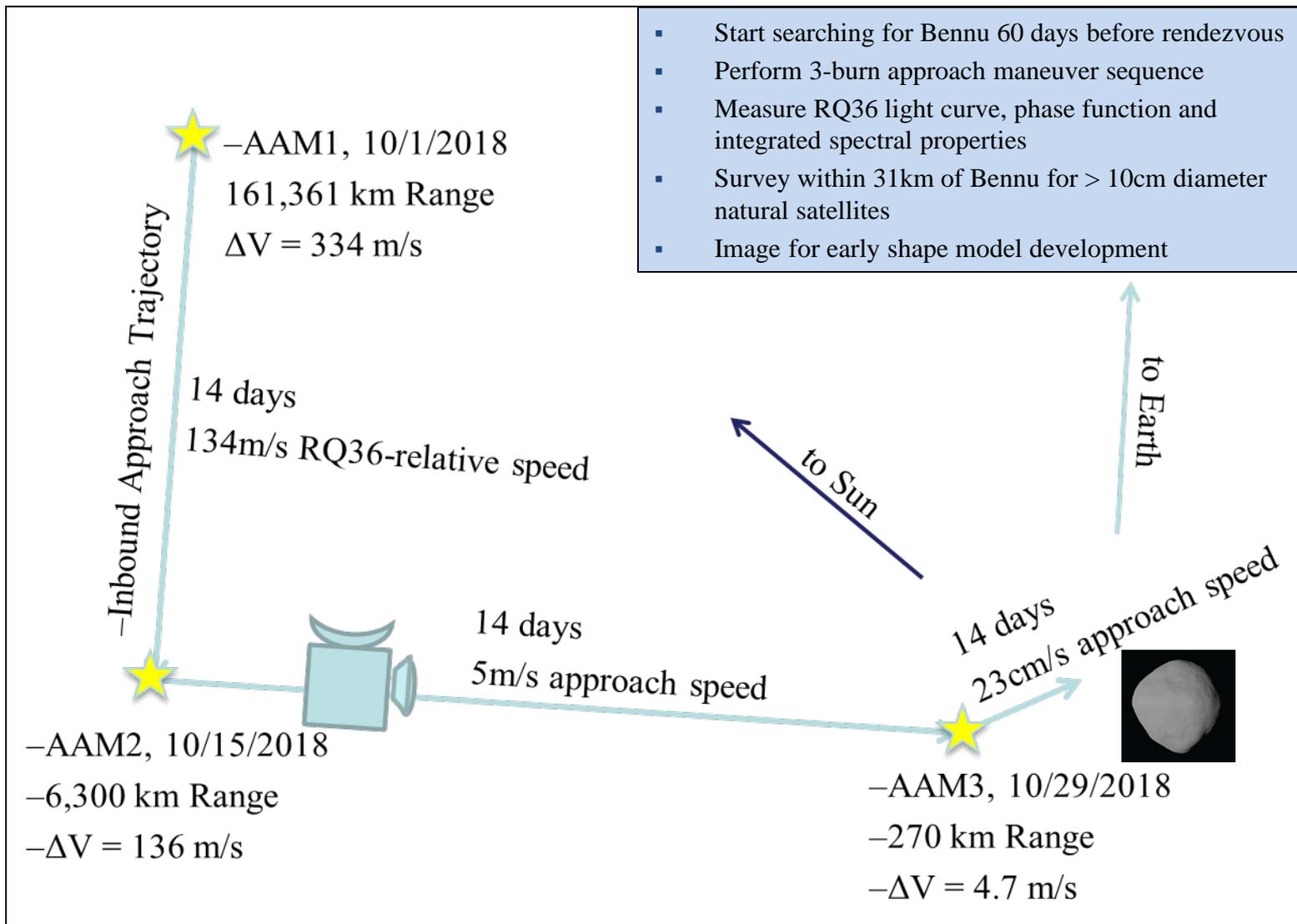


Video: Earth gravity assist





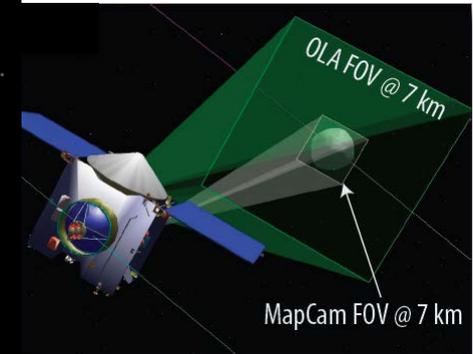
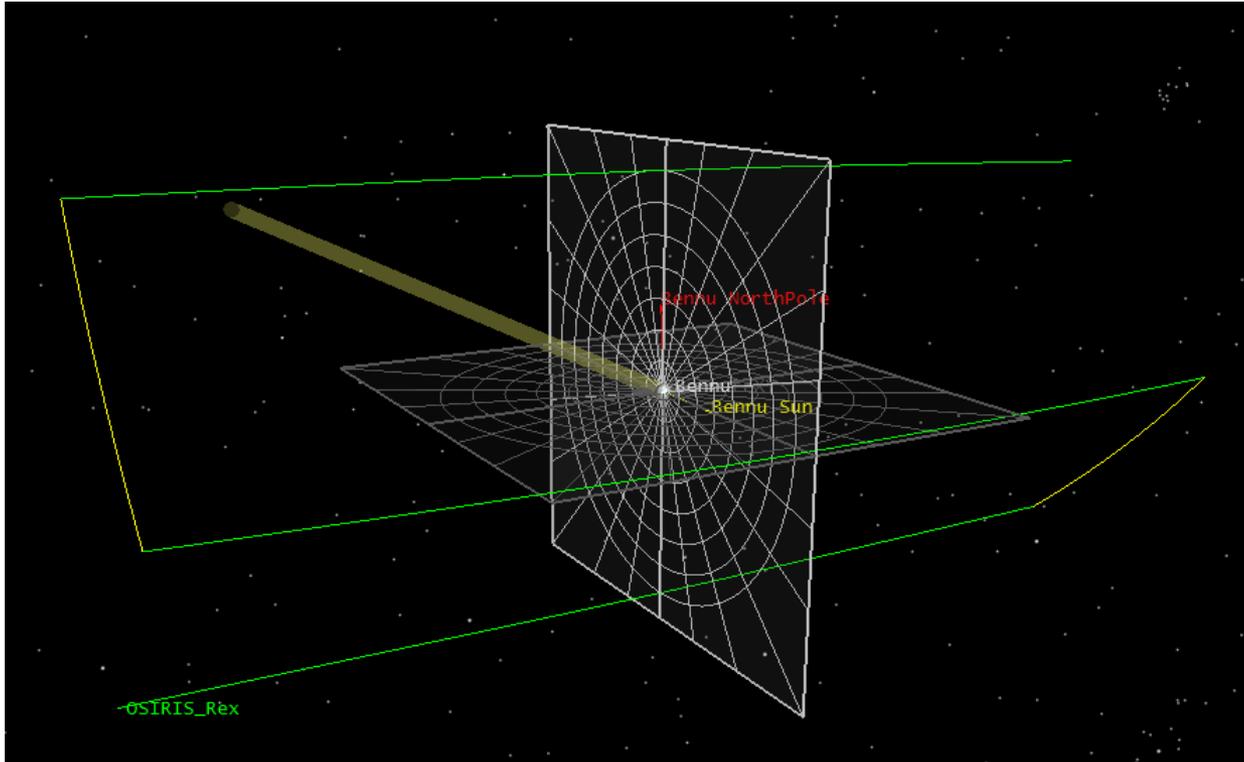
# Approach



- Start searching for Bennu 60 days before rendezvous
- Perform 3-burn approach maneuver sequence
- Measure RQ36 light curve, phase function and integrated spectral properties
- Survey within 31km of Bennu for > 10cm diameter natural satellites
- Image for early shape model development



# Preliminary Survey

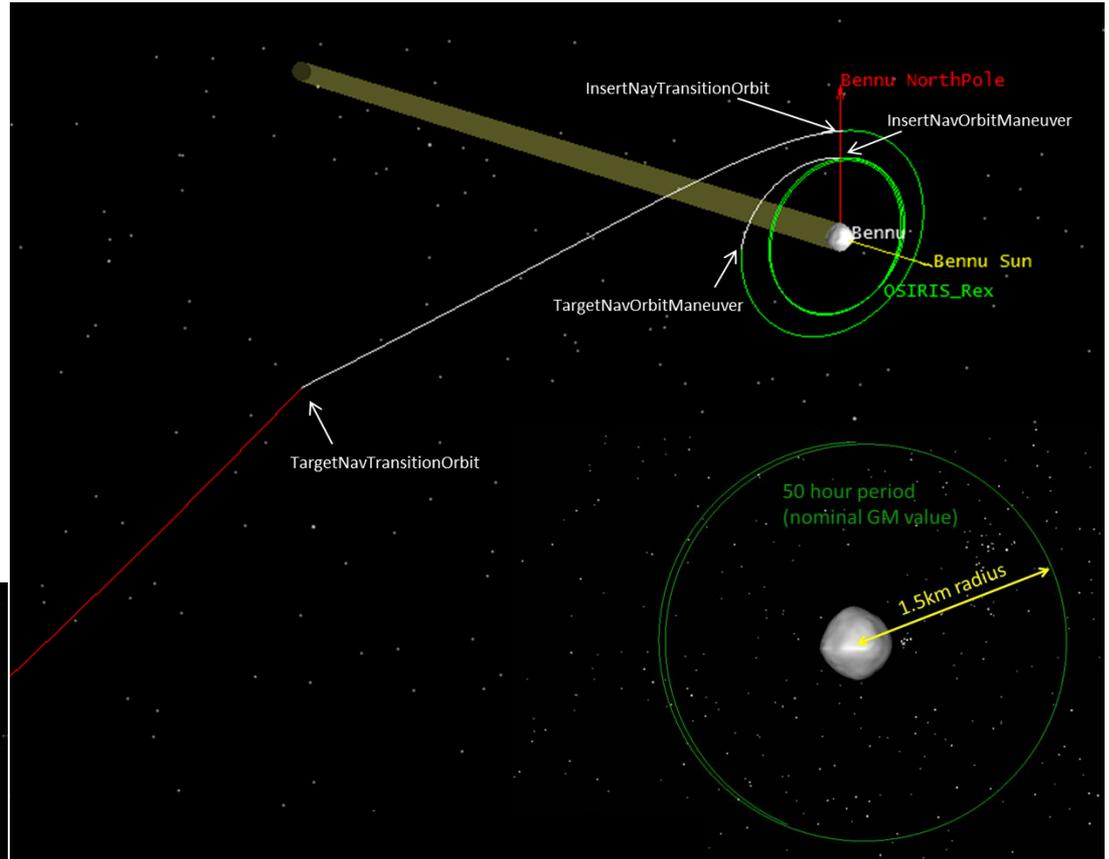
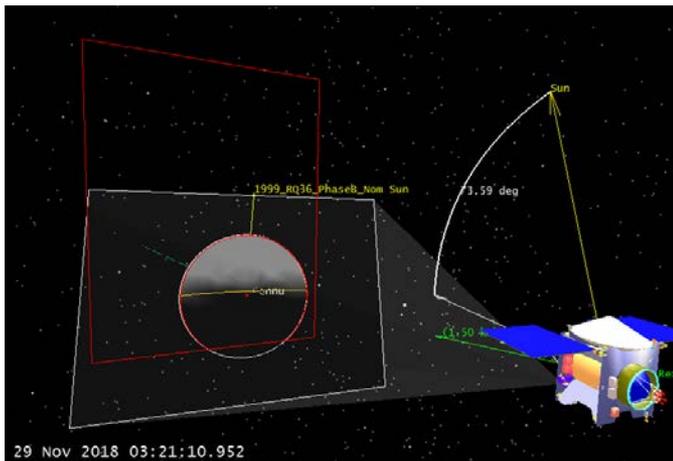


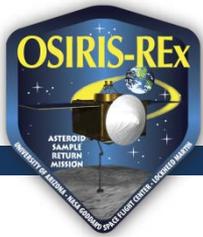
- Bennu mass estimated to 1% accuracy
  - DSN provides range & Doppler tracking during 3 hyperbolic survey passes
  - NavCam collects images at 4-hour intervals for optical navigation
  - PolyCam, MapCam, and OLA collect additional data to refine the shape model



# Orbital A

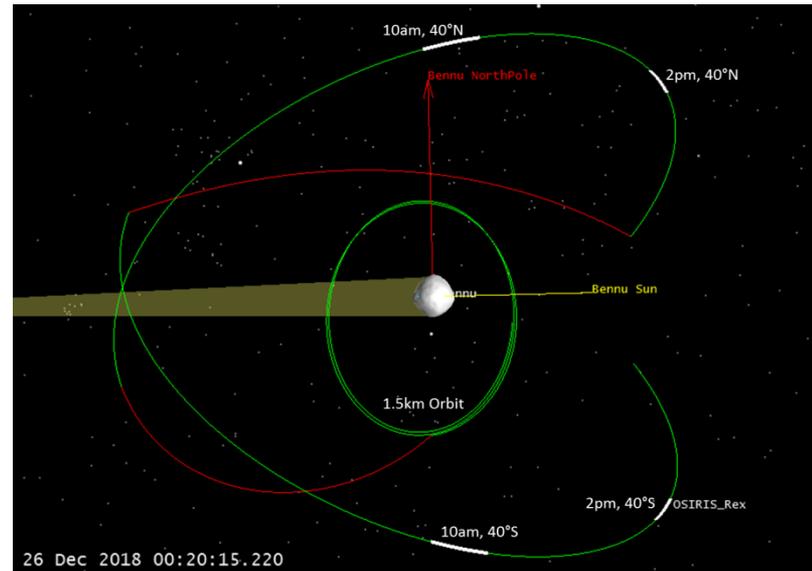
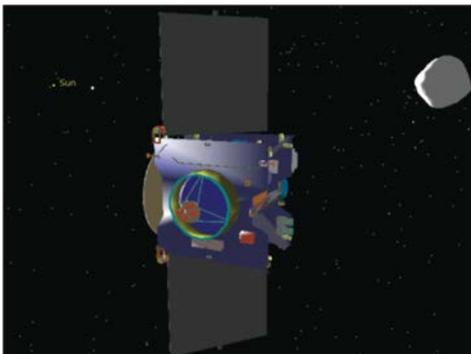
- Establish 1.5 km-radius circular terminator orbit
- Transition from stellar navigation to surface landmark optical navigation for asteroid-relative state
- Collect imagery for global high-resolution shape model



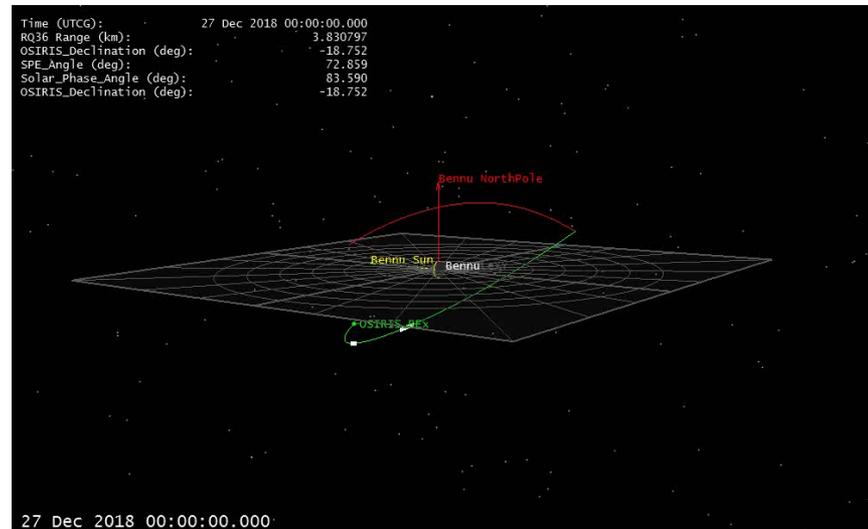


# Detailed Survey

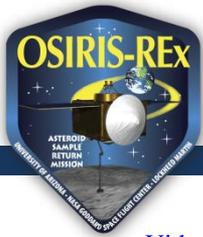
- Collect imagery for identification of safety hazards (rocks, craters)
- Gather global spectral data to determine composition
- Measure temperatures across the surface
- Search for dust & gas plumes



"Baseball Diamond" trajectory

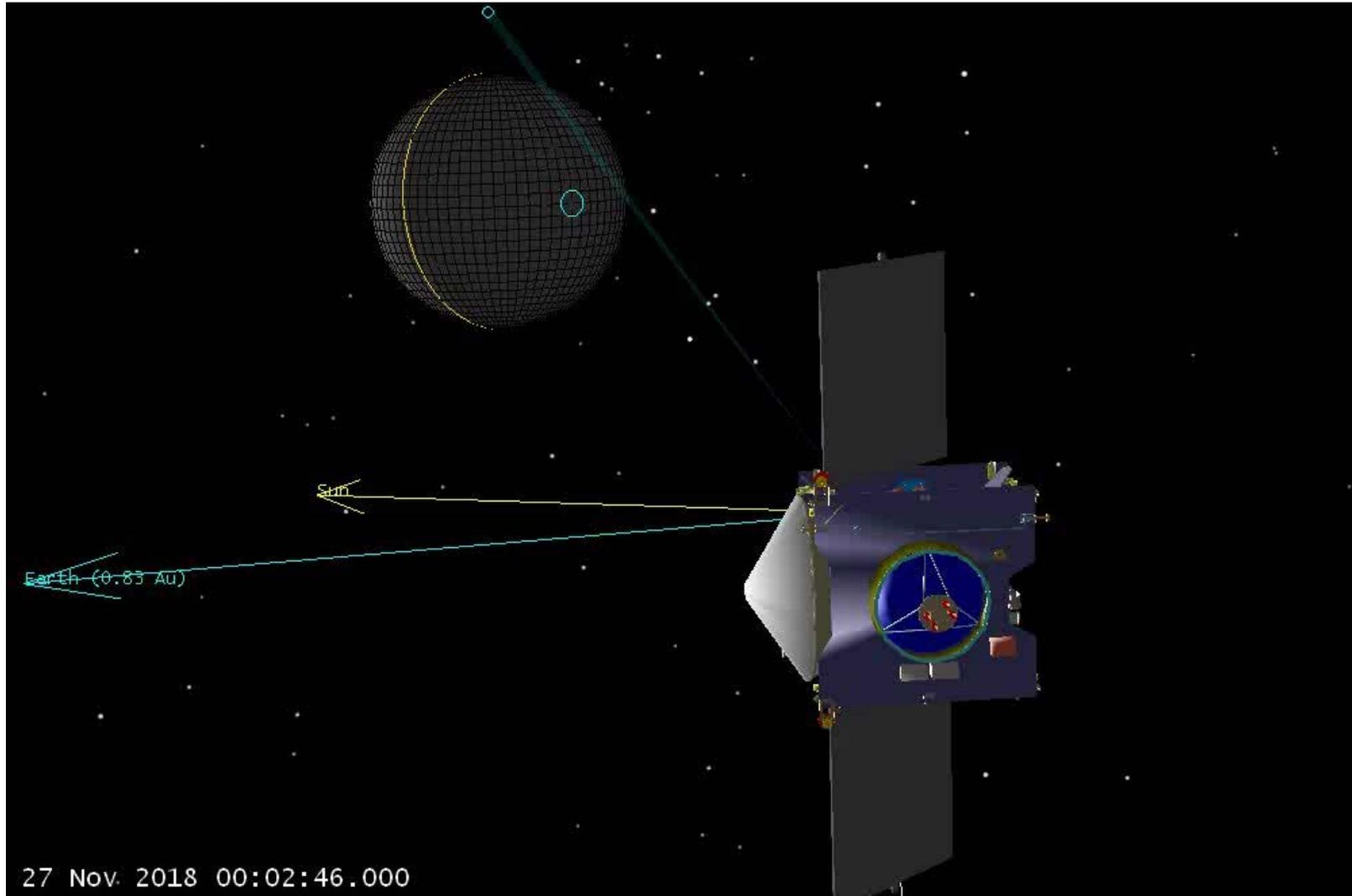


Video: Equatorial Survey trajectory



# Detailed Survey: Spectral Survey Scan

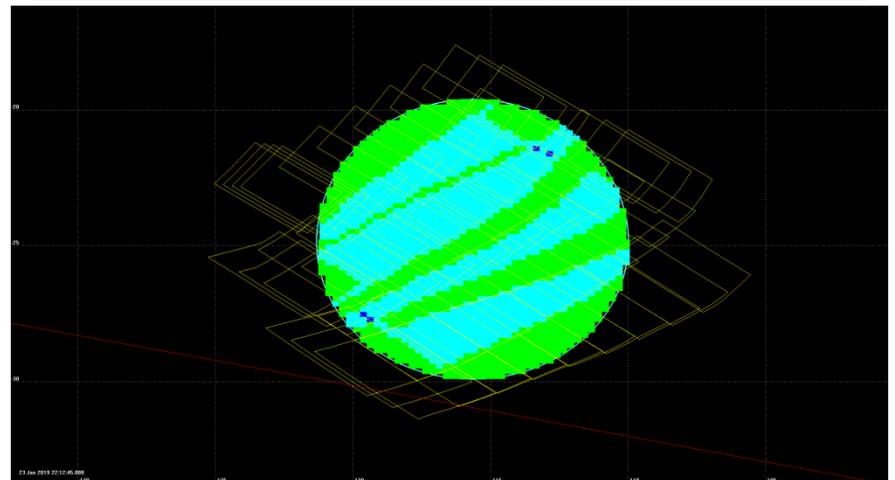
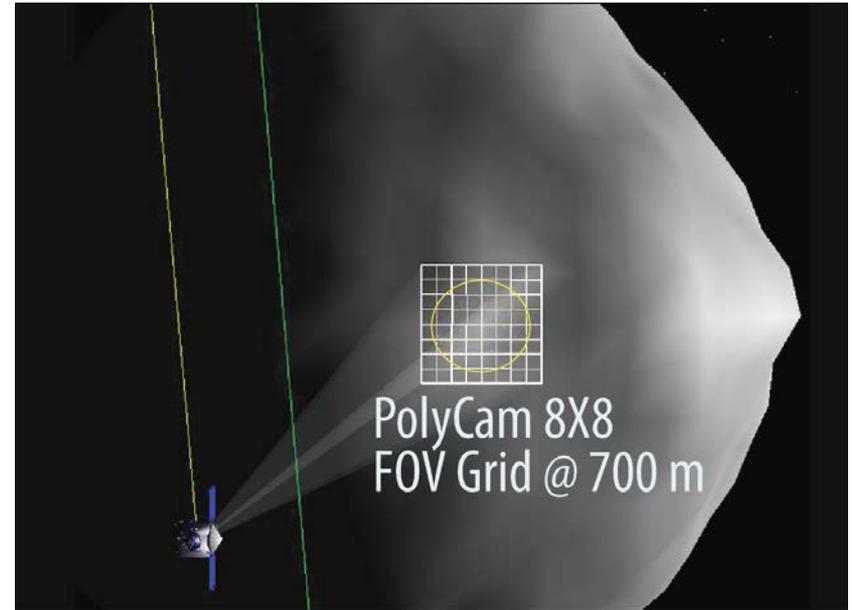
Video: Detailed Survey scan





# Orbital B

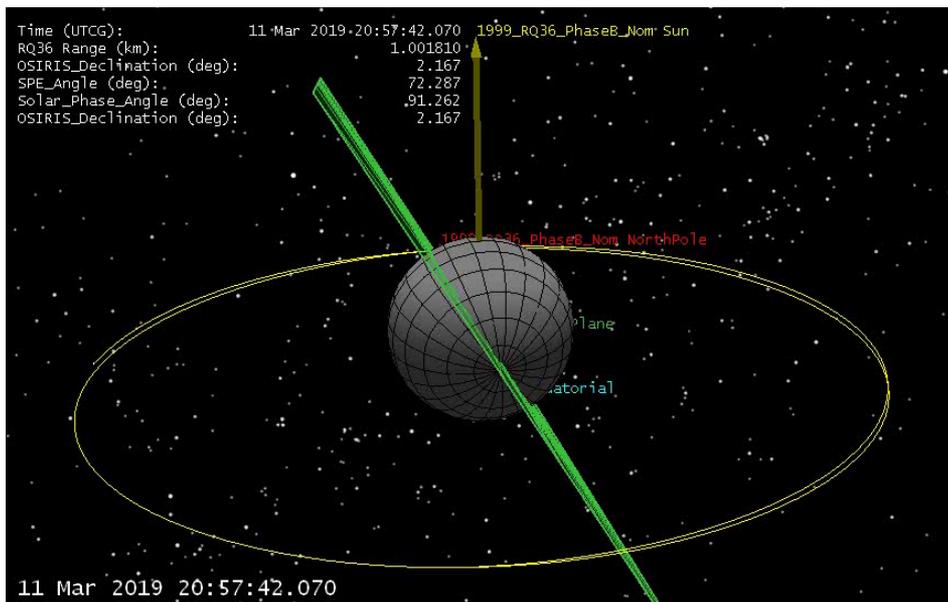
- Establish 1.0 km-radius terminator orbit, the staging point for recon & sampling
- Map gravity field via two 3-day periods of continuous DSN tracking
- Map topography with OLA
- Map elemental abundances with REXIS
- Characterize up to 12 candidate sample sites to 5 cm resolution with PolyCam
- Select 4 sites for detailed reconnaissance





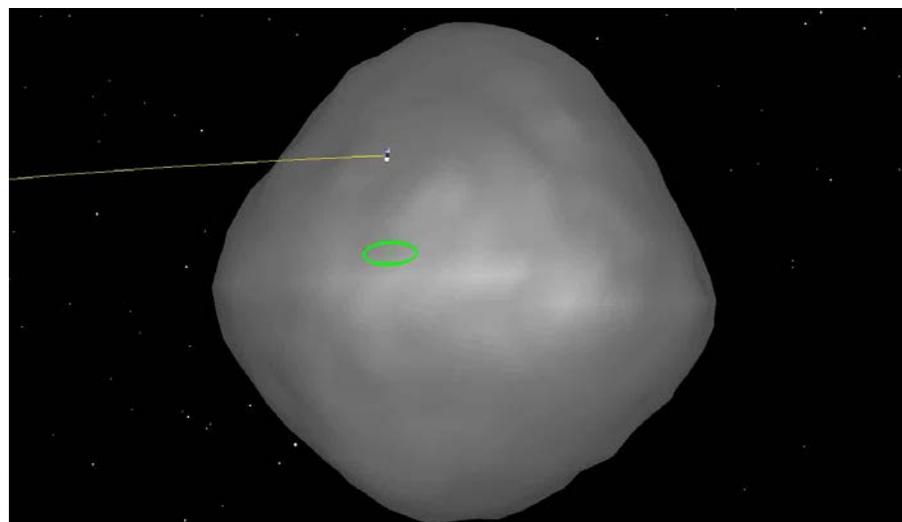
# Reconnaissance

Video: Flyover trajectory



- Fly over 4 sites at 225m range
- Acquire PolyCam images with sub-cm resolution
- Acquire MapCam images with 5cm resolution
- Fly over 2 best sites at 525m range
- Acquire MapCam color images
- Acquire OVIRS & OTES spectra
- Acquire OLA topographic data
- Select primary sample site

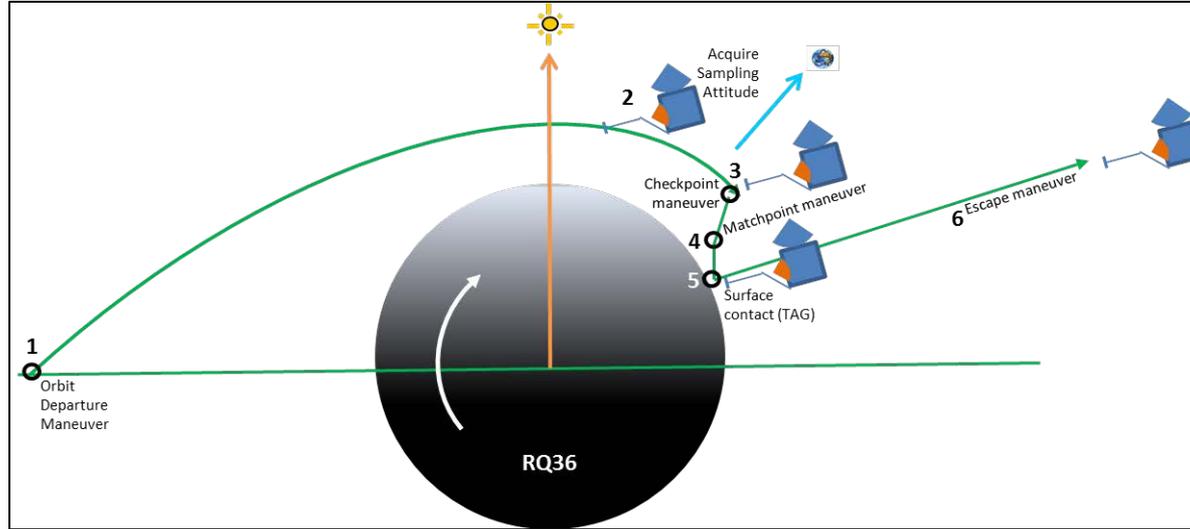
Video: Recon scan



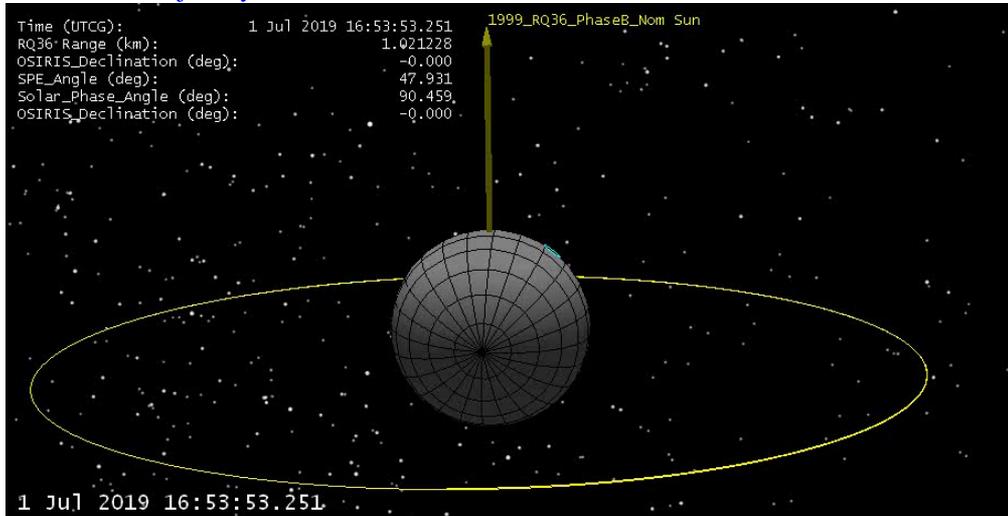


# TAG (1 of 2)

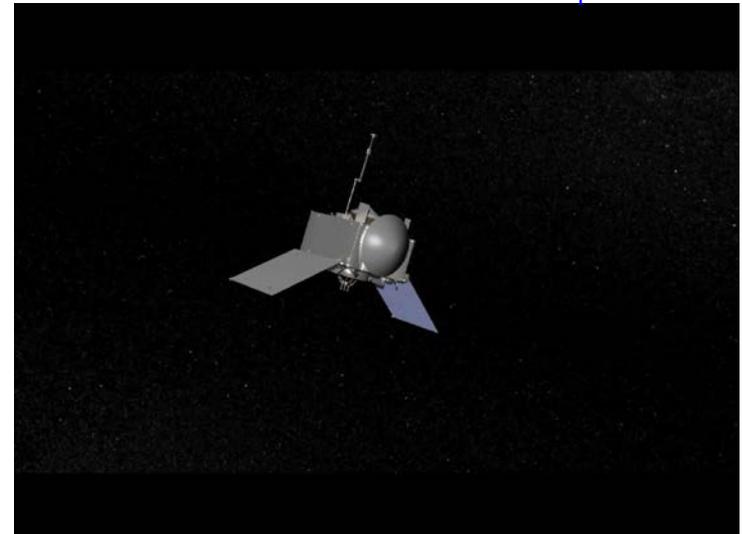
## (TAG Rehearsal & Sample Collection Phases)



Video: TAG trajectory



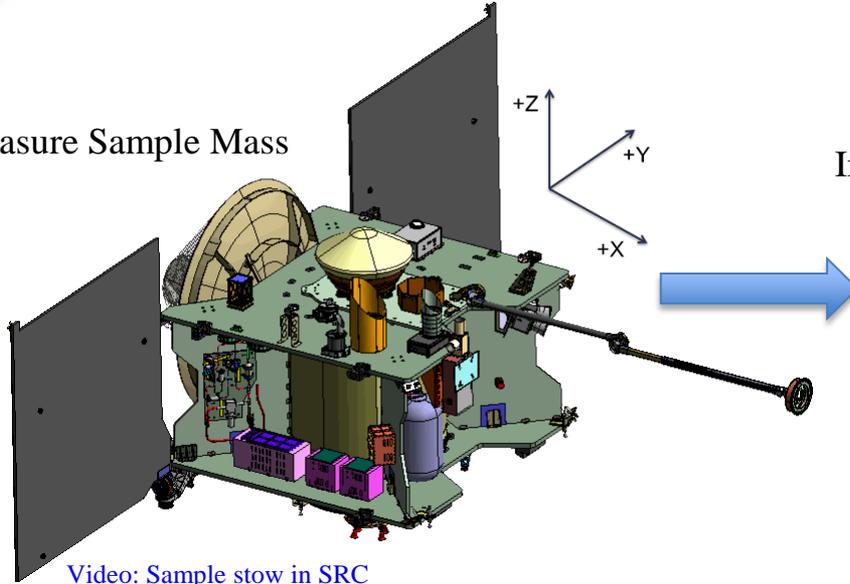
Video: Sample collection





# TAG (2 OF 2)

Measure Sample Mass



Video: [Sample stow in SRC](#)

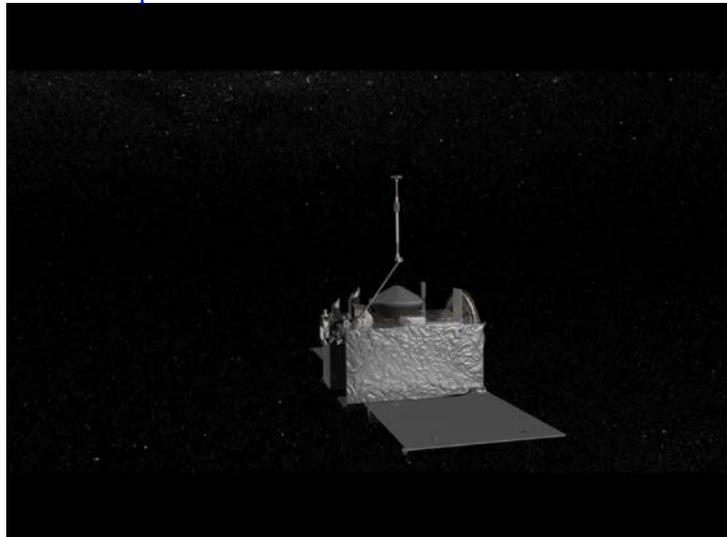
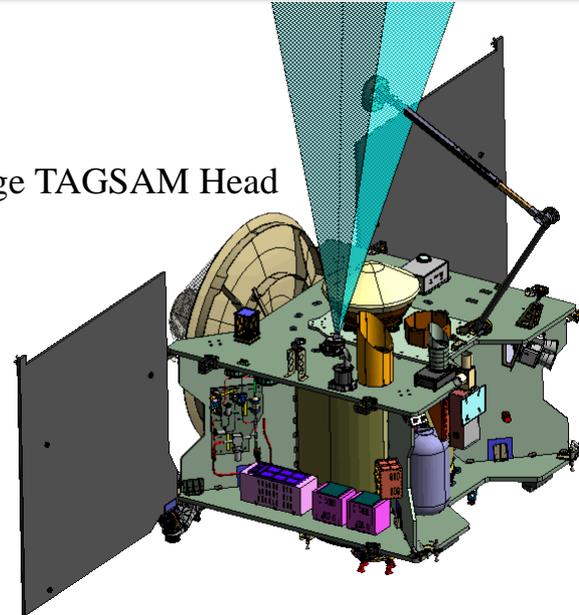
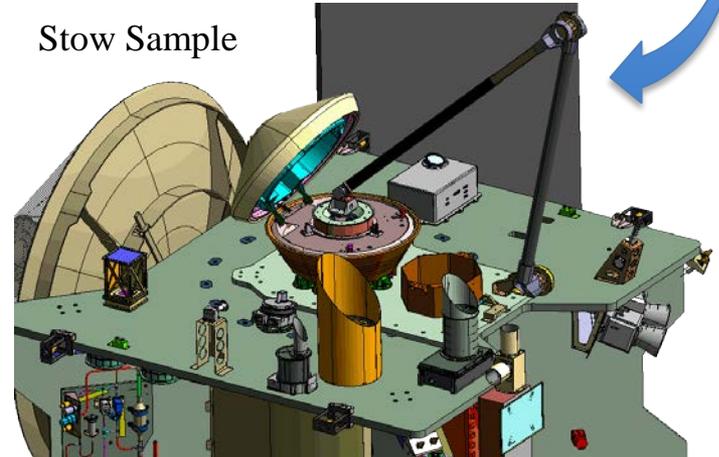


Image TAGSAM Head



Stow Sample





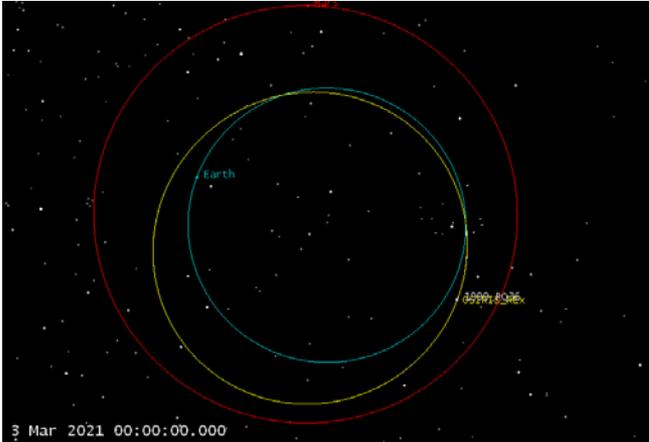
# Return Cruise

2021

2022



▲ Depart RQ36  
3-4-2021



2022

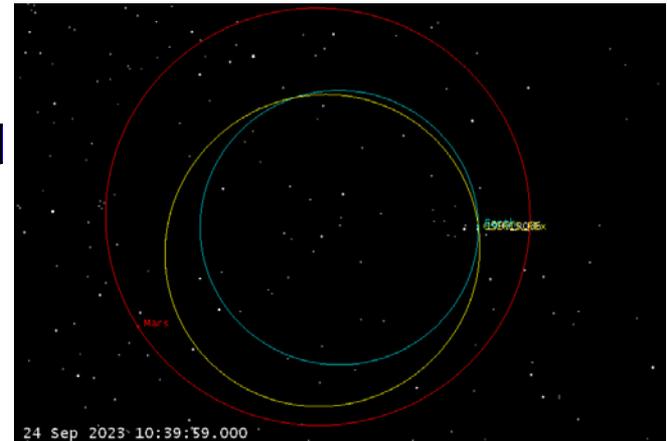
2023



2023

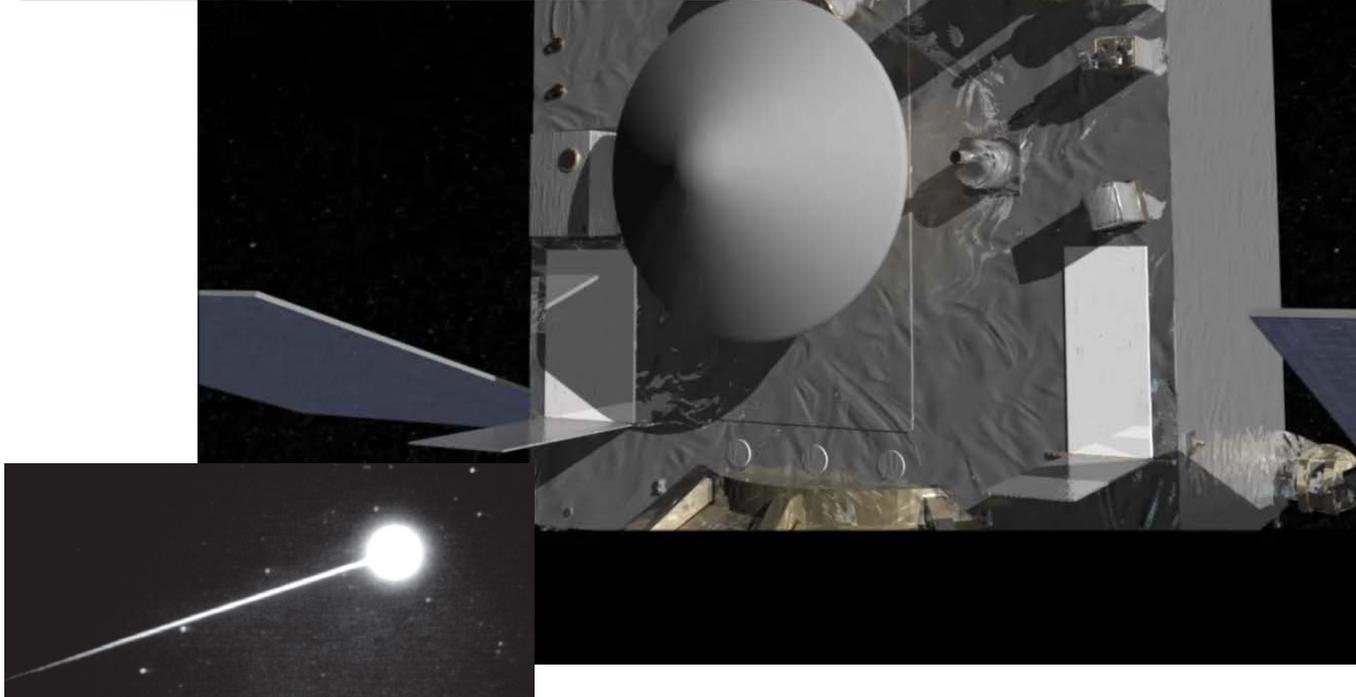


▲ Earth Return  
9-24-2023





# Earth Return & Recovery



Video: SRC release



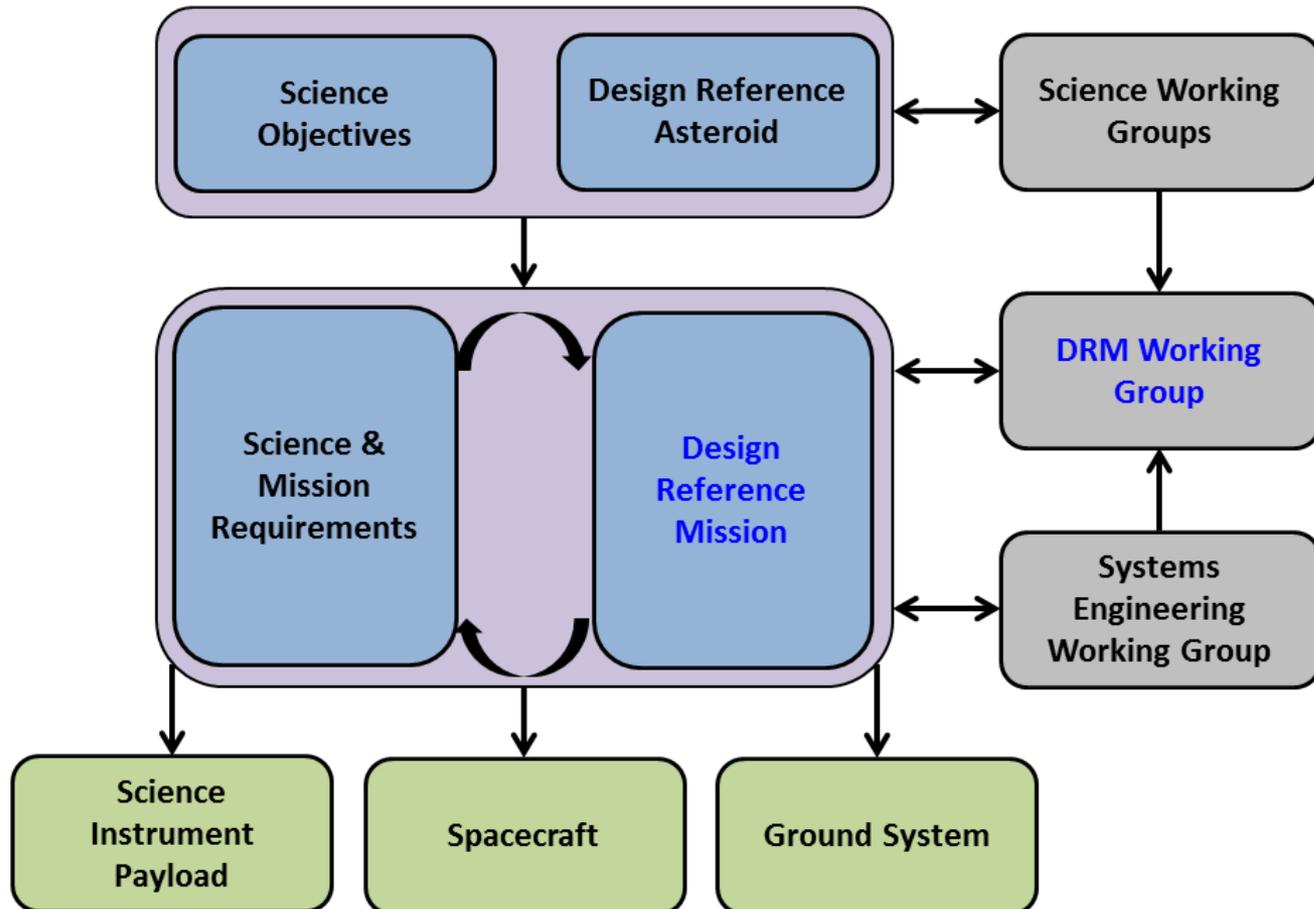
# The Role of the DRM in the Selection of OSIRIS-REx





# Mission Formulation Process

- Mission Product
- Mission Elements
- Working Groups





# “Low Risk” Ranking

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## Step 1 Proposal

“The OSIRIS-Rex mission has been rated LOW Risk. . . The combination of a credible Design Reference Mission, strong basis of estimate, and substantial cost saving opportunities gives the project an excellent pre-Phase A cost risk posture and demonstrates the feasibility of the proposed cost.

## Phase A Concept Study Report

“OSIRIS-Rex is rated LOW Risk . . . A detailed Design Reference Mission was developed that combined with the analysis performed verified the mission concept; provided a solid basis for the mission design and was an essential tool in the design process.”



# “Major Strength”

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## Step 1 Proposal

**“The OSIRIS-REx mission design approach, particularly the proposed proximity operations strategy, is mature, focused, appropriately cautious, and has significant margin.** The project has established a configuration controlled, sharply defined Design Reference Mission (DRM) baseline which serves as the backbone for focusing the design effort, both at the mission level and at the spacecraft level. The DRM design is described in extensive detail, indicating an extremely good understanding of the risks associated with an asteroid sampling mission and the approaches best suited to mitigate them.”

## Phase A Concept Study Report

**“The detail of the Design Reference Mission (DRM) combined with the analysis performed to verify the mission concept provides a solid basis for the mission design.** The project has established a well-defined DRM, which is a very effective tool for understanding the mission. The DRM focuses the design effort, both at the mission level and at the spacecraft level. The DRM design is described in extensive detail, indicating an extremely good understanding of the risks associated with an asteroid sampling mission and the approaches best suited to mitigate them.”



# Notable Quotes about the DRM

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## Step 1 Proposal

- “The learn-as-you-go approach to proximity operations and the detailed, cautious approach to the Touch-and-Go (TAG) event represent a very conservative approach to retrieving a sample from a small body.”
- “OSIRIS-REx does a thorough job of remotely characterizing the surface . . . “
- “The team’s operational experience is evident in the proposed approach, and the approach incorporates lessons learned from NEAR, Hayabusa, Phoenix, and Stardust.”

## Phase A Concept Study Report

- “The plan for asteroid reconnaissance and sample collection is thorough and well conceived.”
- “The Touch and Go (TAG) rehearsals of the spacecraft and sampler head approach to the surface are very well designed to assure that the sample is obtained with reliability within the surface velocity constraints of the Sampler Head.”
- “Margins are substantial (171 days) to incorporate lessons learned at the asteroid, and provision for three sampling operations is included when only one should be needed.”

# Critical Design Review and Beyond





# Verification, Validation, and Operations Planning

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- Serves as the starting point for developing contingency plans
  - Second sampling operation
  - Detection of a natural satellite around Bennu
  - Loss of a science instrument
- Serves as the starting point for science and mission operations planning, including development of command blocks
- Provides the scenarios for system-level verification and validation testing
  - System performance
  - Environmental
- Provides the scenarios for post-launch Operational Readiness Tests



# Summary

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- The OSIRIS-REx DRM was matured over multiple proposal cycles
- The DRM helps maintain the team's focus on OSIRIS-REx's primary objective: collect and return an asteroid regolith sample to Earth
- The DRM was a key contributor to OSIRIS-REx's selection as NASA's 3<sup>rd</sup> New Frontiers mission
- The DRM continues to guide system verification and validation testing and operations planning



# Acknowledgements

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- The late Dr. Michael Drake, first OSIRIS-REx PI, University of Arizona
- Dr. Dante Lauretta, current OSIRIS-REx PI, University of Arizona
- John Oberright, first OSIRIS-REx MSE, GSFC retired
- Dave Everett, current OSIRIS-REx MSE, GSFC
- Brian Sutter, first and current Mission Designer, Lockheed Martin