Origins Spectral Interpretation Resource Identification Security-Regolith Explorer (OSIRIS-REx) Project

DETECTION OF A DUST PLUME CONTINGENCY PLAN

Associated with the Design Reference Mission (DRM)

OSIRIS-REx-PLAN-0057

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1.0 Introduction

1.1 Overview

A dust and gas plume indicates active volatile out-gassing from the interior and/or surface of Bennu or other processes that liberate dust from Bennu. Dust in the operational region around Bennu – the region in which the spacecraft operates from Preliminary Survey through Sample Collection – that persists for days to weeks due to replenishment from an active region of the surface presents a contamination hazard to the spacecraft, potentially coating optical and thermal control surfaces. The plume itself, depending on the energy and quantity of the regolith particles ejected, is also considered an impact hazard to the spacecraft (although the spacecraft must survive the gas and dust plume it generates during TAG to fluidize and collect regolith sample). In addition, OSIRIS-REx has a Level 1 requirement to characterize the source regions of detected gas and dust plumes.

The existence of dust and gas being released from Bennu is highly unlikely though physically plausible. Asteroids with a similar carbonaceous B-type taxonomy to Bennu have been observed to experience cometary outgassing resulting in the formation of cometary comae and tails. Other asteroids have been observed to possess long-lived tails due to impacts by smaller bodies and mass shedding due to rapid rotation. This document will present the plan for searching for dust, present possible scenarios, and describe plans for mitigating operational hazards and scientifically characterizing any detected plumes and their source regions.

1.2 Relevant Requirements

This document satisfies the requirement for a dust and gas plume contingency plan:

MRD-598	The Ground System shall develop a contingency plan to characterize and operate in the presence of detected dust and gas plumes.

The following requirements drive the dust and gas plume search and characterization:

MRD-142	OSIRIS-REx shall search for dust and gas plumes originating from the asteroid surface, and characterize their source regions and column densities.
MRD-143	OSIRIS-REx shall characterize the spectral properties of any detected dust and gas plumes.
MRD-561	OSIRIS-REx shall collect OCAMS panchromatic data with < 2m spatial resolution and > 13.0 magnitude/arcsec2 sensitivity off the limb of Bennu in < 15° (goal of 10°) increments over two rotation periods.

1.3 Scenario Description

Searches for dust and gas plumes will be conducted during two phases, a long-distance search during Approach and a search at large phase angles during Detailed Survey. The Approach survey will be able to detect material located at distances out to 35,000km from Bennu as well as the presence of unresolved material in the vicinity of Bennu. This search may not be able to place adequate constraints on the location of the active regions. The Detailed Survey search will be able to resolve the plumes as they rise from the surface of Bennu and will be able to determine the location of the active source regions on the surface. The detection of active or recent dust and gas release from Bennu will trigger a period of mapping and characterization to identify the source of the activity, spatial distribution, temporal variations in activity levels, velocity of material, and size distribution of dust.

1.4 Scope

This plan describes the activities that will allow the Flight and Science Teams to characterize the spatial, temporal and physical characteristics of any dust and gas plumes and re-plan the mission as necessary to safely continue in the presence of known hazards. This is not a comprehensive step-by-step plan since the applicability of the actions/activities can vary widely depending on the nature and variability of the detected plume.

1.5 Applicable Documents

Document Number	Title
PLA-OSIRIS-REx-RQMT-0001	OSIRIS-REx Mission Requirements Document
PLA-OSIRIS-REx-OPS-0001	Design Reference Mission
OSIRIS-REx-PLAN -0079	Mission Plan
PLA-OSIRIS-REx-PLAN-0066	Navigation Plan
OSIRIS-REx-SOPS-PLAN-0131	Science Operation Plan
OSIRIS-REx-PLAN-0056	Detection of a Natural Satellite Contingency Plan

2.0 Actions

2.1 Overview of Approach Search

The first search for dust and gas plumes will take place during the Approach phase at a distance from Bennu of about 1,000,000km. Navigation, Bennu Lightcurve, Bennu Phase Function and Natural Satellite Search observations will also be used to search for evidence of dust and gas plumes. Three different techniques will be utilized on the observations.

1. *Direct detection of gas and dust in the vicinity of Bennu*. This involves the detection of features separated from Bennu that are indicative of gas and dust release. Direct searches of accompanying gas and dust can be conducted on any images taken of Bennu during the Approach phase. A deep search will be conducted where 100-200 images of Bennu and the

surrounding region will be co-added to search for a faint signature of past and present activity.

2. *Point Spread Function (PSF) modeling*. The PSF of the Bennu will be compared to those of field stars in the same image frames. A broadening of the PSF is indicative of unresolved material close to Bennu. This technique can be used on all Bennu images taken during the Approach phase.

3. *Phase function analysis*. The brightness of Bennu will be compared to the ground-based derived phase function. Any brightening of Bennu is indicative of unresolved material near Bennu. This technique can be used on all Bennu images taken during the Approach phase.

The search for dust and gas during the Approach phase will be conducted about 5 weeks prior to AAM2. The criteria for a positive detection of dust in the environment include any of the following: 1) the detection of dust/gas moving with the motion of Bennu, 2) a Full Width Half Maximum (FWHM) profile for Bennu that is 1.25 times that of the average of the FWHM of background stars, and 3) an increase in the expected nominal brightness of Bennu (after correction for the Sun-Bennu distance, OSIRIS-REx-Bennu range, and phase angle) of 0.5 magnitudes to account for rotational lightcurve variations (in practice, this is -0.5 magnitudes since an increase in brightness corresponds to a decrease in magnitude).

Additional observations will be planned for the duration of the Approach phase if dust in the operational environment is detected. These observations will allow temporal and spatial changes to be determined. Observations taken at different epochs are necessary to fully constrain the temporal and spatial history of dust/gas activity. These observations will indicate if the dust is the result of recent activity that has since ceased, or if the dust is being replenished by some "steady state" source. Contingency follow-up dust plume characterization observations will consist of the following observations with MapCam and/or PolyCam depending on the extent of the dust plumes.

1) 4.5 hours of OCAMS/MapCam and/or PolyCam images taken at +3, +4, +5 days and then at weekly intervals at +8, +15 and +22 days after the time of the initial dust plume search. These observations will focus photometry and PSF modeling of the environment near Bennu to constrain the longitude of source locations and their diurnal variation in dust production.
2) 64 1-s co-added OCAMS/MapCam and/or PolyCam images taken at +7 days, +14 days and +21 days from the time of the initial dust plume search (2018-Sep-12). These dates (for +7, +14 and +21 days) correspond to 2018-Sep-19 (range 711,000 km), 2018-Sep-26 (range 402,000 km) and 2018-Oct-03 (143,000 km). The ranges above assume no change in the Approach trajectory after plume detection. These observations will focus on changes in the morphology of dust at large distances from Bennu. Such changes constrain the activity levels in the recent past.
3) Bennu Integrated Lightcurve Photometry and Phase Function Photometry will be obtained with MapCam at +28, +29 and +31 days from the initial plume search (2018-Oct-10/11/13). This data will also be used to characterize any detected dust plume.
4) Observations at high phase angles from the "braking" maneuver position at a range of 40-

50 km from Bennu. OCAMS/MapCam and/or PolyCam observations at phase angles of 0°, 30°, 60°, 90°, 120° and 135° constrain particle size distribution and mass of the plumes.

2.2 Overview of the Detailed Survey Search

Dust plume observations during the Detailed Survey Search will consist of using the OCAMS/MapCam for imaging and OTES and OVIRS for spectral measurements. The plume survey is described in PLA-OSIRIS-REx-OPS-0001, “Design Reference Mission”.

2.2.1 Determine Plume Characteristics

During the Approach phase search, only the existence of dust in the environment and/or a large plume will be determined. Due to the low-resolution nature of these early observations, the location of plume source regions on the surface will be difficult to determine.

The plume search during the Detailed Survey will measure the size and location of a plume from OCAMS measurements. Plume location will be determined relative to the limb or the center of the asteroid. Plume size will be retrieved from knowledge of the pixel size of OCAMS. Note that plume location and size can be temporally variable on short timescales (seconds to minutes). It is highly likely based on our knowledge of cometary plumes that any plume on Bennu will be diurnally variable (i.e. active during the day and inactive at night with the highest level of activity being at the time of greatest solar heating).

The Science Team’s Regolith Development Working Group has developed a plume model that will be correlated with the plume imagery to determine the location, density, and composition of any observed plumes. The imagery and output of this model, along with any observed periodicity associated with the plume activity, will be used to define the keep-out zones for TAG operations.

2.2.2 Plume Spectral Characterization

OTES and OVIRS spectra from Detailed Survey Phase observations will be processed to derive mineral and chemical abundances (OTES) and spectral parameter strengths (OVIRS). These data will be used to help constrain the size-frequency distribution and composition of any observed plume(s). Producing this list will require that OTES and OVIRS calibrated spectral data are available (along with reconstructed geometry) and have been processed to retrieve mineral and chemical abundances.

The contingency plan for plume spectral characterization is based on plume detection by MapCam with a minimum signal-to-noise of 11 per pixel. This will result in an estimated signal-to-noise of 3 per spectral resolution element in OVIRS and OTES. We assume that a plume is the same size or smaller than the MapCam field of view, variable on a relatively short timescale, and without detectable gaseous species. Thus we anticipate that the best strategy for characterizing faint plumes is to "point and stare"; i.e., collect OVIRS and OTES spectra simultaneously with the MapCam plume search.

It is not clear if spectral maps will be warranted; if a plume is sufficiently bright to allow spatially resolved observations, the mapping pattern would have to use a point on the limb of the asteroid or the center of the asteroid as a reference point. At this time we are assuming that there will be

no maps, just "spot" values. If we decide to map any plume bright enough we will use the experience of plume detection maps from OCAMS. Creation of the plume detection maps with OCAMS should require approximately 2 days creating the Level-2 images and around 5 days to create the image mosaics. The plume detection maps should be available after another week's worth of processing. During the period when the plume model was being developed it took approximately 2 weeks to reproduce the EPOXI Hartley-2 plume morphologies. Processing any Bennu plumes will be informed by that experience.

2.3 Spacecraft in Danger

Given the following:

- Only ~0.01% of observed asteroids show cometary activity,
- Bennu has spent ~7Myear within 1AU of the Sun, and
- Earth-based observations have not detected dust around Bennu,

The OSIRIS-REx Science Team believes the likelihood that any volatiles remain near the surface is extremely low, much less the likelihood of encountering an active plume during proximity operations. However, OSIRIS-REx has a Level 1 requirement to search for and characterize such plumes. In the unlikely event one is found, the project intends to avoid it to the extent practicable during TAG operations, from the orbit departure maneuver through the back-away maneuver after surface contact, due to the potential – particularly on approach to the surface – for the plume to interfere with navigation (GN&C LIDAR, NFTCam) and attitude determination (star tracker) sensors.

The "red limits" – or more appropriately "keep-out zone" – in time and space for TAG will be determined based on the characterized properties of the observed plume, including its location, dimensions and density as functions of time, and periodicity.

2.3.1 Perform Maneuver

A pre-planned satellite contingency "braking" maneuver to abort the approach will be ready for uplink and execution by early November 2018. If a dust plume hazard is detected then the spacecraft will execute the braking maneuver. The current DRM calls for the braking maneuver to be executed on November 16, 2018 at ~44 km range. The station-keeping trajectory maintenance relies on maneuvers every 14 days, which allows for a reduced navigation level of effort while FDS is heavily engaged with re-planning the DRM (**Error! Reference source not found.**). To maintain spacecraft safety and facilitate additional dust environment/plume characterization, the selected station-keeping trajectory maintains the spacecraft's range to Bennu between roughly 42-56 km. Plume observations at phase angles of 0°, 30°, 60°, 90°, 120° and 135° are required to constrain the particle size distribution and mass of the plumes.

Recent dust-generating activity prior to Bennu departure may require a re-plan of the departure trajectory to avoid the trailing orbit plane of Bennu.

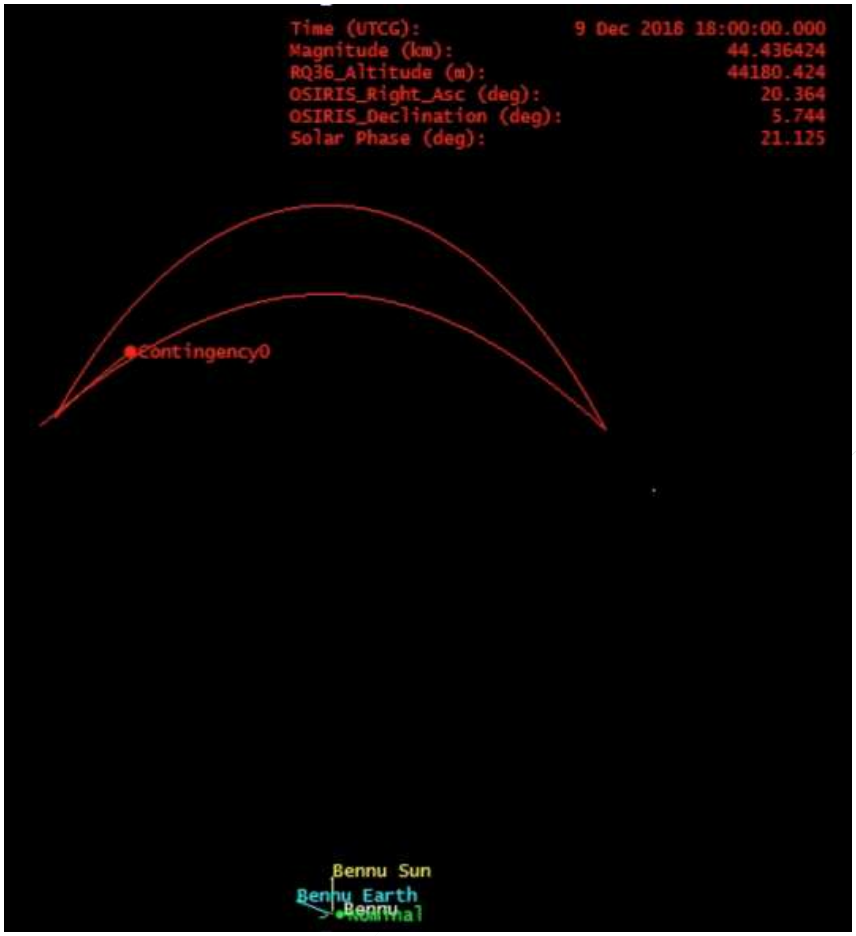

Figure 1.Station-keeping trajectory example.

2.3.2 Re-Plan Science Operations

The re-planning effort will commence as soon as the hazardous nature of the plume is confirmed. It is impractical to describe the re-planning process for this contingency, but the key objective is to develop a safe strategy for achieving the mission objectives, with special attention to the threshold objective of returning a sample to Earth. The re-planning exercise workshop described in “Detection of a Natural Satellite Contingency Plan”, OSIRIS-REx-PLAN-0056, is the forum wherein the issues and approaches will be understood.

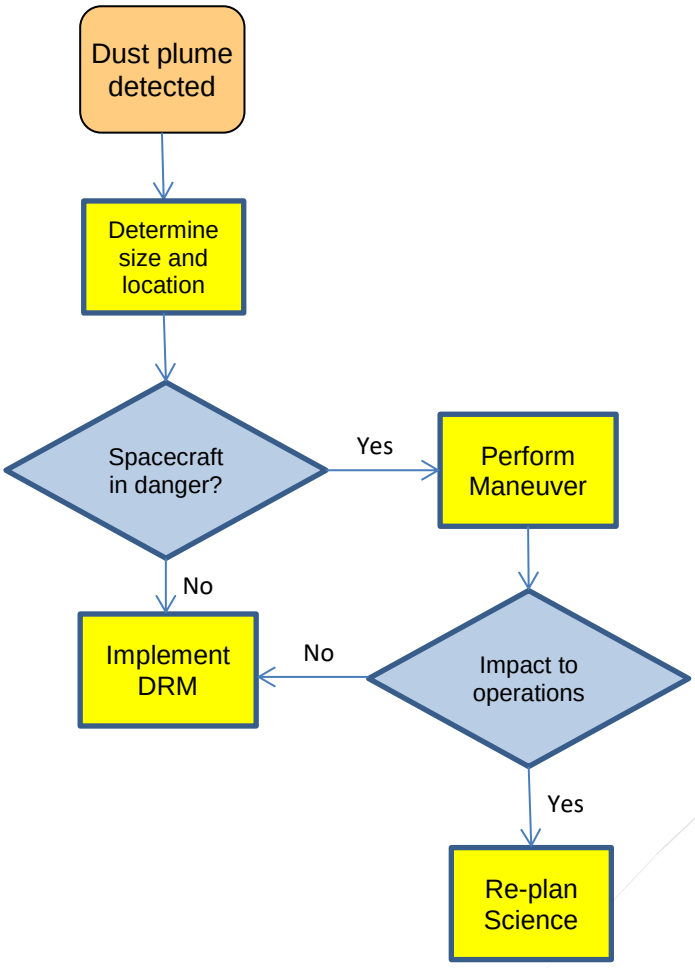

Figure 2: Decision Flow Diagram

APPENDIX A: ACRONYMS

AAM – Asteroid Approach Maneuver

DRM - Design Reference Mission

FDS – Flight Dynamics

FWHM – Full Width Half Maximum

GN&C – Guidance, Navigation, and Control

NFT – Natural Feature Tracking

OCAMS – OSIRIS-REx Camera Suite

OSIRIS-REx – Origins, Spectral Interpretation, Resource Identification, Security Regolith Explorer

OTES – OSIRIS REx Thermal Emission Spectrometer

OVIRS – OSIRIS REx Visible and Infrared Spectrometer

PSF – Point Spread Function

TAG – Touch-and-Go