ORBITAL B PARTICLE MONITORING AND GLOBAL MAPPING

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Purpose

The purpose of this document is to describe the observation plan for the Orbital B phase of the mission. It is intended to provide information for the science teams and instruments teams to ensure that the plan is consistent with the instrument capabilities and that it meets the observation constraints, or where it does not, the plan is nevertheless acceptable. Engineering details sufficient to determine if the plan fits within the spacecraft capabilities and available mission resources are provided here and in the Mission Plan Workbook.

Since Orbital_B_Global_Mapping_Phase_Plan_Narrative_Rev-7b was published, we found that Bennu was releasing a large number of particles into space. The trajectories of some of these particles have been mapped to show that some re-accrete onto the surface and some have sufficient velocity to escape. This document has been updated to describe the new subphase for Particle Monitoring and revisions to the Global Mapping subphase, which now includes MapCam imaging over the polar regions to look for changes in the surface over time.

The first half of this document focuses on the description of the observation plan. The second half of this document describes requirements, the constraints needed to meet those requirements and whether the constraints are met in the plan, and the resulting data products.

Inputs

Observation Constraints Spreadsheet:
OSIRIS-REx Bennu Proximity Operations\Science Planning (All Access)\UA-OPS-4.0-1001_Observation Constraints_CCv0066_v6.xlsx
Mission Plan Workbook: OSIRIS-REx 02.0 PSE\Mission Plan\Mission Plan Workbook\ Mission_Plan_Workbook_2019-03-20 working

Observation Envelope and Templates: Orbit-B -- Observation Envelope & Templates.r3
Kernel Set:

- naif0012.tls
- pck00010.tpc
- bennu_v14.tpc
- de424.bsp
- orx_190302_200101_190207_od097-R-M1D-P-M15B_v1.bsp
- orx_v14.tf
- orx_struct_polycam_v01.bc
- orx_struct_mapcam_v01.bc
- orx_navcam_v01.ti
- orx_ocams_v06.ti
- orx_ola_v01.ti
- orx_otes_v00.ti
- orx_ovirs_v00.ti
- orx_rexis_v01.ti

orx_struct_v00.ti
g_12580mm_spc_obj_0000n00000_v020.bds
ORX_SCLKSCET.00040.tsc

FDS delivery of products used for science planning are described here:
OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\Orbital B\OB_SOPG_v2.docx

Notes on reference trajectory assumptions:
The current baseline reference trajectory for Orbital B is orx_190302_200101_190207_od097-R-M1D-P-M15B_v1.bsp. Ref OD097 targets a nominal 930-meter radius orbit and uses the latest knowledge on Bennu's ephemeris, gravity model, and GM.

The trajectory orx_190605_190826_OrbitalB_MPRevB_v1.bsp used as the basis for the SOCR-54 version of the SPP targets a nominal 950-meter radius circular orbit in June 2019 and includes only a single trim burn during the first week of July.

The trajectory orx_170117_210312_refMPRevB_v1.bsp used for the OTES analysis is an older reference dating to January 2017. This reference has the orbit insertion sequence beginning in early May 2019; it includes the DRM Rev C baseline five-maneuver-orbit-insertion sequence; it updates the spacecraft mass from 1200 kg to 1392 kg; it targets a nominal circular orbit with a 1000-meter orbit radius. Due to the natural evolution of the circular orbit over time, this trajectory includes orbit trim burns approximately every four weeks that target back towards a circular condition.

MRD Overview

The Mission Requirements Document (MRD) Rev K includes 6 requirements that drive science operations during Orbital B and 12 requirements that fall out of the 6 drivers. In addition to what is in MRD Rev K, there are also 3 REXIS requirements and new particle imaging requirements to support particle monitoring. Orbital B is comprised of several subphases. This SPP covers the Particle Monitoring and the Global Mapping subphases. Post global mapping particle monitoring and/or the Radio Science Campaign (if applicable) will be covered in another Science Phase Plan.

The Particle Monitoring subphase will be used to determine if major/minor ejection events are still ongoing. The primary goals of the Global Mapping subphase include global PolyCam imaging that provide intermediate resolution images for Sampleability and OLA observations that contribute to producing local 5-cm DTMs, global shape and topography products at <32cm spatial resolution and NFT products in support of hybrid TAG. OTES and REXIS will also be on to collect data for local thermal inertia and global X-ray spectral surface mapping, respectively. Particle monitoring will continue during the Global Mapping Phase, but will not drive operations.

Ultimately data collected during Orbital B will contribute to site selection products, TAG, and long-term science products. Below is a list of the driving science requirements. The "fall-out" requirements can be found in the Derived Data Products section at the end of this document.

The 6 driving requirements include:

1. 5cm DTMs from OLA (MRD-115b)
    - Feeds the Safety, Deliverability, Sampleability, Science Value, and hybrid TAG.
2. Intermediate Sampleabilty Map Imaging (MRD-183c2)
    - Feeds Sampleability
3. Bennu Mass (MRD-133)
    - Supports operations and long-term science.
4. Local Thermal Inertia Maps (MRD-540)
    - Feeds Safety, Sampleabilty and Science Value
5. Measurements of Earth to Bennu Range (MRD-602)
    - Feeds long-term science
6. Active Asteroid Characterization (MRD-142 and MRD-144)

The 3 REXIS requirements include:

1. Global Element Abundance Ratios (REX-1a)
2. Collimator Mode Elemental Abundance Map (REX-2a)
3. Imaging Mode Elemental Abundance Map (REX-3a)

Orbital B Overview

The Particle Monitoring subphase is scheduled to take place over 14 days from June 17 through June 30, 2019. The Global Mapping subphase will take place over the following 5 weeks from July 1 through August 4, 2019. The Particle Monitoring subphase will utilize 2x1 mosaics of NavCam-1, while all of the data collection in the Global Mapping subphase will be from a nadir-pointing attitude. Four days of trim burns or contingency burns are scheduled during which only reduced data collection is permitted. Additionally five days of engineering activities are scheduled during the Global Mapping subphase. REXIS and OTES will observe for three of those days and OLA will participate in two of those days, but otherwise these engineering activities will not include science observations.

The orbit during these subphases will be sized to a 930-m radius to avoid resonances with Bennu's rotation, avoid an orbit period of exactly 24 hours, and to stay within OLA's ranging constraints. FDS used the following constraints in scheduling trim maneuvers in this reference trajectory:

- Apoapse radius < 1.1 km (OLA)
- Orbit plane <15 deg from terminator (phase angle at 90 +/- 15 deg)

The first trim burn will occur during the Particle Monitoring subphase while the second trim burn will nominally occur the week after Global Mapping is complete. The placeholders for trim burn contingencies are scheduled in the first, third, and fifth weeks of Global Mapping.

Table 1. Orbit parameters

Semi-major axis (m)	Orbit Period (hrs)	# Bennu Rotations
930	**22.38**	**5.20**

The Science Observation Window (SOW) for all nominal science days will be 16 hours and 20 minutes. The SOW on Thursdays of the trim burn and contingency trim burn weeks will be reduced to 7 hours and 40 minutes but to simplify operations planning, we will use only 5.44 hours of that window by using just one of our ATFs.

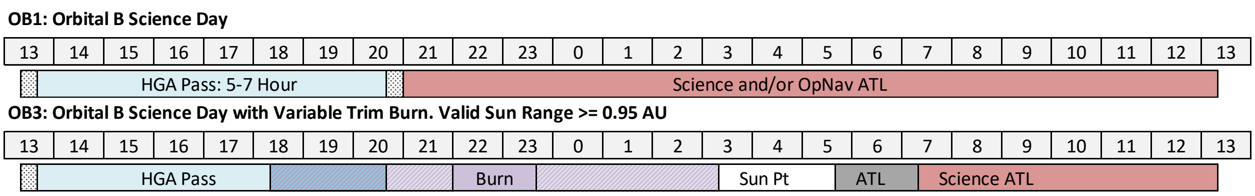

Figure 1 Orbital B templates displaying the nominal 16 hours and 20 minutes Science Observations Windows and the shortened windows during trim burn days.

Particle Monitoring Observation Plan Summary

All of the particle monitoring will be done with NavCam-1 using a 2x1 mosaic of pointing targets. Two images with 5-second exposures will be taken at each target, spaced by 138 seconds, to determine which points are true particles vs. points generated by cosmic rays or other artifacts. The slews will be ~200 mrad in either direction from nadir along the spacecraft velocity vector.

The nominal plan will be to take 38 mosaics per Science Observation Window, with a 25.6-min period. This plan results in 152 particle monitoring images per day, which fills the amount of downlink capacity we have in 5 hours of downlink. On the Thursday with the trim burn, only 18 mosaics will be taken due to the shortened SOW.

Eight OpNav Images per day will be taken in nadir point during this subphase and will be interspersed with the particle monitoring images.

Global Mapping Observation Plan Summary

This new plan collects data that are largely similar to those collected in the former plan with a few important differences. In the former plan the spacecraft was making 2x1 mosaics for OpNav imaging, but in this plan the spacecraft will be continuously pointed at nadir. Science collection is permitted over the 16.33-hour Science Observation Window (SOW) except for the days noted above. We divide the data collection into three Absolute Target Files (ATFs) of equal duration (5.44 hours), and during the last two weeks, we change which data are collected over the polar regions based on predictions of where we expect the spacecraft to be. See *Operational Considerations* for details.

We will build five different ATFs to collect different data at different locations. All of the ATFs will collect three NavCam image sets on a 108.9-minute cadence. Each NavCam set will include a short exposure for OpNav and two long exposures, separated by 138 seconds, for particle monitoring. In addition, all of the ATFs will collect OTES and REXIS data.

The differences in the ATFs are based on the nature of the data collected with OLA or OCAMS. The differences in the ATFs and their anticipated use are given below.

1. OLA only (used over the mid-latitudes when the spacecraft is significantly behind the terminator).
2. MapCam only (used over the polar regions during the last two weeks).
3. PolyCam only (used when data bandwidth does not permit collecting OLA data).
4. OLA and PolyCam (used extensively in the first three weeks and over mid-latitudes in the last two weeks).
5. None (used at times when we need to reduce the amount of data stored on-board to fit within downlink capacity).

In the ATFs in which OLA rasters are collected, 19 rasters are collected with a 17.56-minute period; for ATFs with PolyCam, 46 images are collected with a 7.10-minute period, and for ATFs with MapCam, 24 images are collected with a 13.6-minute period.

OLA

Observation Plan:
OLA will be collecting data using the Low-Energy Laser Transmitter (LELT) at 10 kHz in the form of an X-Y raster scan. The scan is nominally ±5° in both directions (174.5 mrad full range) relative to nadir. The scan moves rapidly in the cross-track direction and slowly along track moving in the direction of spacecraft travel. The time for the scan is 5.4 minutes, which provides a spot spacing of 0.097 mrad.

The nominal planned orbit is over the terminator, has a 930-m semi-major axis, and a period of about 22.38 hours. It evolves between elliptical and circular between planned orbit-trim maneuvers. Even in the most elliptical orbit, the nominal orbital radius (~1050-m in the north polar region) will still meet the 800-m range to the surface constraint of OLA. The analysis to determine the 3-sigma maximum radius has not been completed yet, but because we only need to collect OLA data infrequently over the poles, the OLA data collected over the north pole can be ignored if the range to the surface exceeds the 800-m constraint.

To minimize gaps in coverage, the time between rasters is set to have overlap between their footprints on the surface. This time is determined by the rotation rate of Bennu and the size of the raster on the surface. The raster period was originally set to 17.9 minutes, but to fit within the 5.44-hour duration of the ATF, it was changed to provide 19 rasters at a 17.56-minute period.

Figure 2 shows the coverage we get over the north pole in just three days of 19 rasters per day. It can be seen that we get full coverage down to past 60° latitude. Unless more accuracy is needed, we would never need to collect more OLA data over this pole. We get similar results over the south pole as well. This figure illustrates the greatly improved efficiency we get by not collecting OLA data every time we fly over the poles as we did in the previous plan.

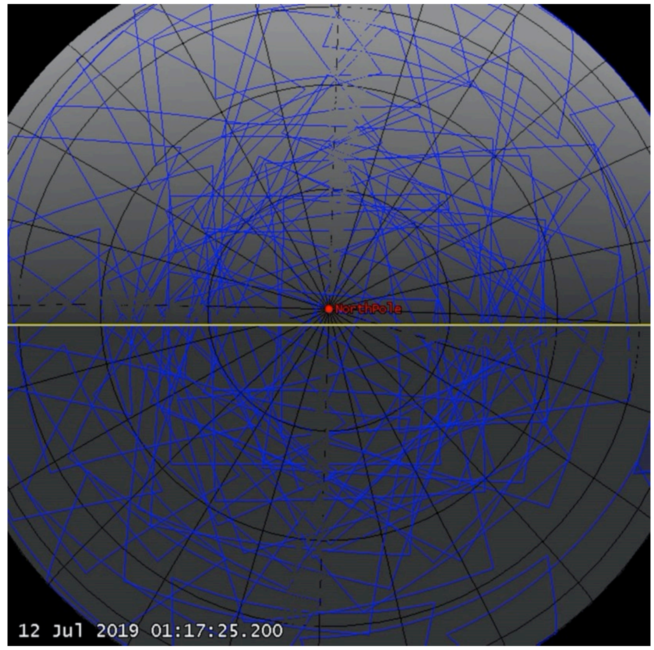

Figure 2: OLA raster footprints over the north pole on three consecutive days of 5.44 hours each day. (Grid spacing is 15°.)

Figure 3 shows the distribution of rasters on the surface for a one-day and a two-day simulation of data collection over the mid-latitudes. The scan activity generates a candy-cane-like stripe over the surface due to the rotation of Bennu and the motion of the spacecraft in its orbit. It can be seen that the second day is nearly able to fill in the gap between the stripes on the first day, but the size of the rasters is not large enough to completely fill the gap. One additional day is sufficient to fill in all of the mid-latitude region if the observations are well placed in latitude.

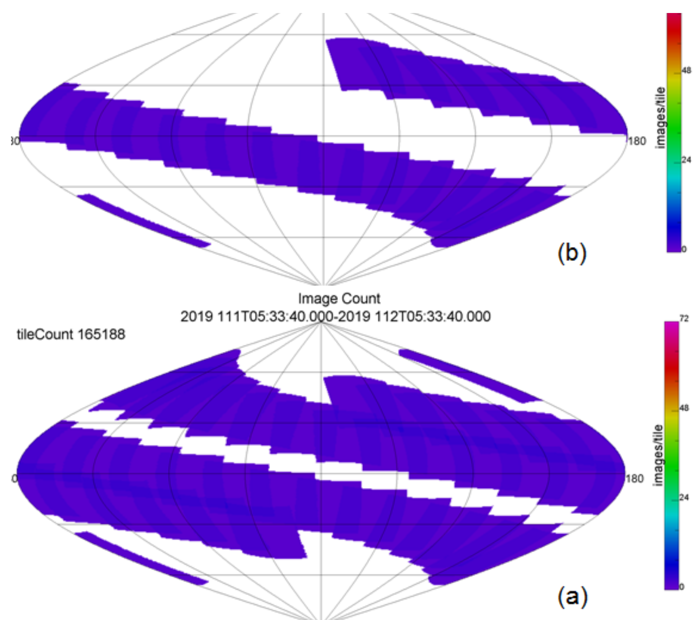

Figure 3: Maps of OLA rasters over the surface based on a one-day (a) and a two-day (b) simulation of 19 raster scans per day.

Allowing for navigational uncertainties:
For OLA, the navigational uncertainties are only significant in the along-track direction. Because the spacecraft points OLA toward where it believes nadir to be located, an along-track error has the effect of pointing OLA ahead or behind nadir. The OLA data have an observational constraint of a 45° limit on emission angle. Assuming a spherical Bennu of 250-m radius and a nominal circular orbit of 930-meter

radius, the 5° limit of the scan mirror yields an emission angle of 21° at the edge of its FOV and 29° at its corners. With 1-sigma uncertainties, two days after ephemeris updates, the edge and corner emission angles increase to 45° and 52°, respectively.

PolyCam Imaging

The constraints noted below in the Requirements section, require at least one PolyCam image in every 10° x 10° bin on the surface between ±60° latitude, and these images must meet certain viewing constraints partitioned into three buckets (noted below under *Intermediate Resolution Sampleability Imagery*). To fill the spatial bins, we are planning on taking a PolyCam image slightly more often than before, which was 10° of Bennu rotation (7.17 minutes). To be consistent with the 5.44-hour duration of the ATFs, we will collect 46 images with a 7.10-minute period. During the first three weeks on days where our data collection is not limited by engineering constraints, we will collect PolyCam data with all three ATFs yielding 138 images per day.

We previously modelled the ability of the PolyCam images to meet the observational constraints in 30-days of Orbital-B. Although there was some uncertainty in the expected coverage with the model, it appeared the 30 days modeled was adequate, though with little margin, to meet the constraints. Here we have 35 days with 5 days of no data collection, so we expect the results to be similar.

It should be recognized that the terminator orbit is not generally really over the terminator. The orbit is oriented such that normally half of the orbit is ahead of the terminator and the other half is behind the terminator (see Figure 3). Obviously imaging when the spacecraft is ahead of the terminator provides much better viewing geometry. During the first three weeks when the navigational uncertainties are large, we will collect data throughout the science window, so some of the images will be in darkness.

MapCam Imaging

The discovery of particle ejection from the surface of Bennu has led to a requirement to image the surface at different times in the mission to look for changes in the surface due to particle ejection or return. In Global Mapping, our MapCam imaging is concentrated on the polar regions, where the Baseball Diamond imaging did not do so well. We will only have navigation data of sufficient accuracy to target the timing of the polar-region overflights during the last two weeks of Global Mapping.

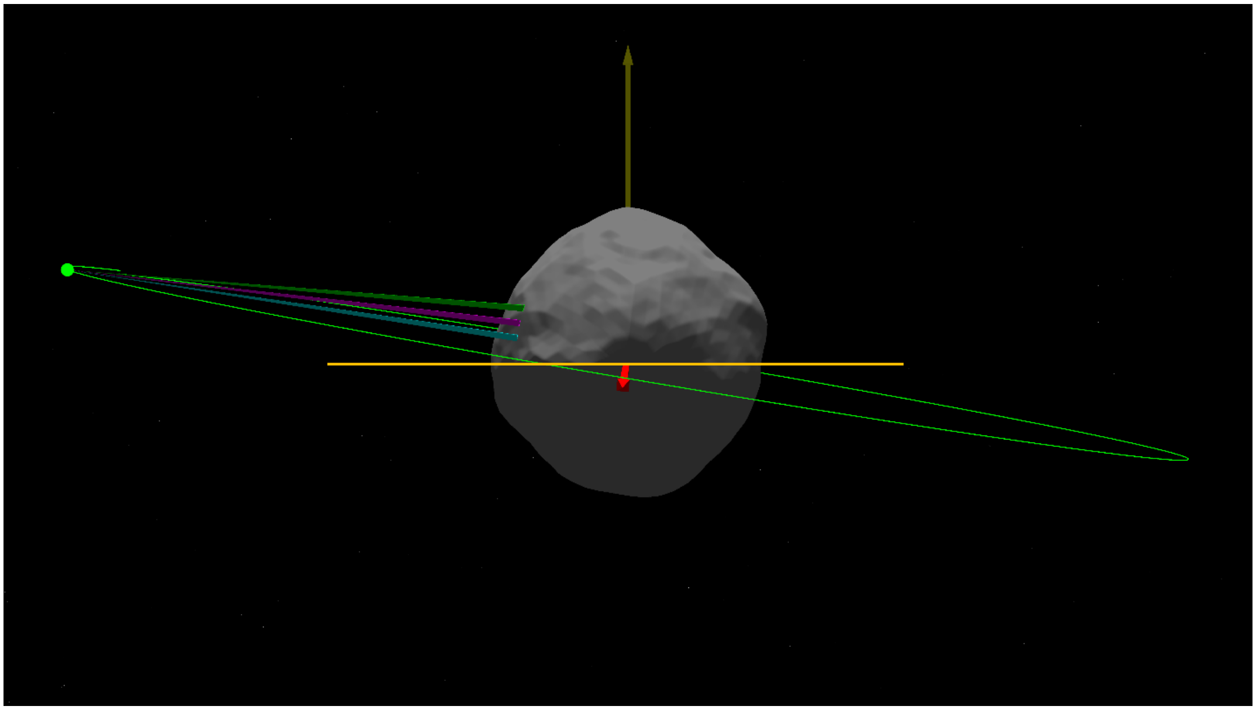

Figure 4: View from the north showing the relationship of the orbit plane to the terminator. Here the spacecraft is over the afternoon surface with three possible viewing offsets of 0°, 2°, and 4°. As shown, the orbit is inclined 10° relative to the terminator.

REXIS

REXIS will be collecting data continuously during the Science Observation Windows and will remain powered on during the spacecraft downlink windows. The data volume considerations are generated assuming quiet-sun conditions, but even under active sun, the data volume is still only a small fraction of the total daily data volume. Bias maps and raw frames will need to be downlinked occasionally (daily to weekly) throughout Orbital B. REXIS loses its ability to detect Sulfur above a 5 deg. along-track pointing angle with increasingly severe losses in sensitivity to the other elements as the off-point angle increases. This along-track offpoint constraint is the current best estimate calculated assuming 1) a spherical asteroid model with a radius of 250m, 2) exposure to a solar spectrum defined by a 4MK single temperature Chianti model with an A1.0 equivalent flux at Bennu's aphelion, 3) an orbital radius of 1000m, and 4) worst-case illumination fraction from a 10 deg off-terminator observation point. Because of navigational uncertainty, the nominal observation time allocated to REXIS (33days * 16hrs/day) may not meet the REXIS observation constraints. Additional observing time in the Orbital B geometry, perhaps during the safe-home orbit of the Reconnaissance Phase, may be needed to enable REXIS to meet its requirements.

OTES Coverage during Orbital B

Coverage analysis of the OTES instrument was conducted over a 28 day period of Orbital B using orx_170117_210312_refMPRevB_v1.bsp. This analysis period started at 2019/09/03 00:00 UTCG and ended at 2019/10/01 00:00 UTCG. During this analysis, it was assumed that OTES collected data for 16 hours every day and that the trajectory is known perfectly. These assumptions serve to allow an estimate of how much total integration time is required, however that integration time may be divided up amongst the time spent in the Safe Home Orbit. Additionally, this coverage analysis is conducted against a spheroid representation of Bennu.

Examining the results of that coverage analysis, ~60% coverage was achieved with OTES over the 28-day analysis period, as shown in Figure 5. Figure 6 shows the level of coverage (number of accesses) of OTES with Bennu's surface in a sinusoidal projection. In this map, red represents no coverage, yellow represents only 1 pass of coverage, green represents 2 – 4 passes, cyan represents 5 – 9 passes, and blue represents >= 10 passes. Figure 6 shows that the coverage is distributed evenly in Bennu body fixed latitude and longitude. Because the Orbit B trajectory is a nominal terminator orbit, all of this coverage is acquired at either local sunrise or local sunset. Deviations of as much as ± 15° from true sunrise or sunset can occur due to orbital evolution during this time period.

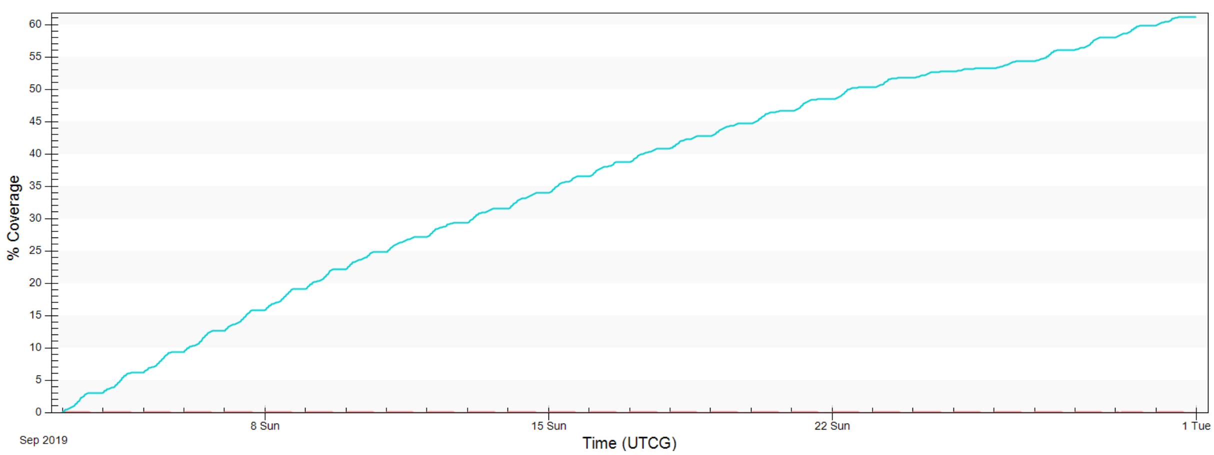

Figure 5: Accumulated percent coverage of Bennu's surface with OTES during the analysis period

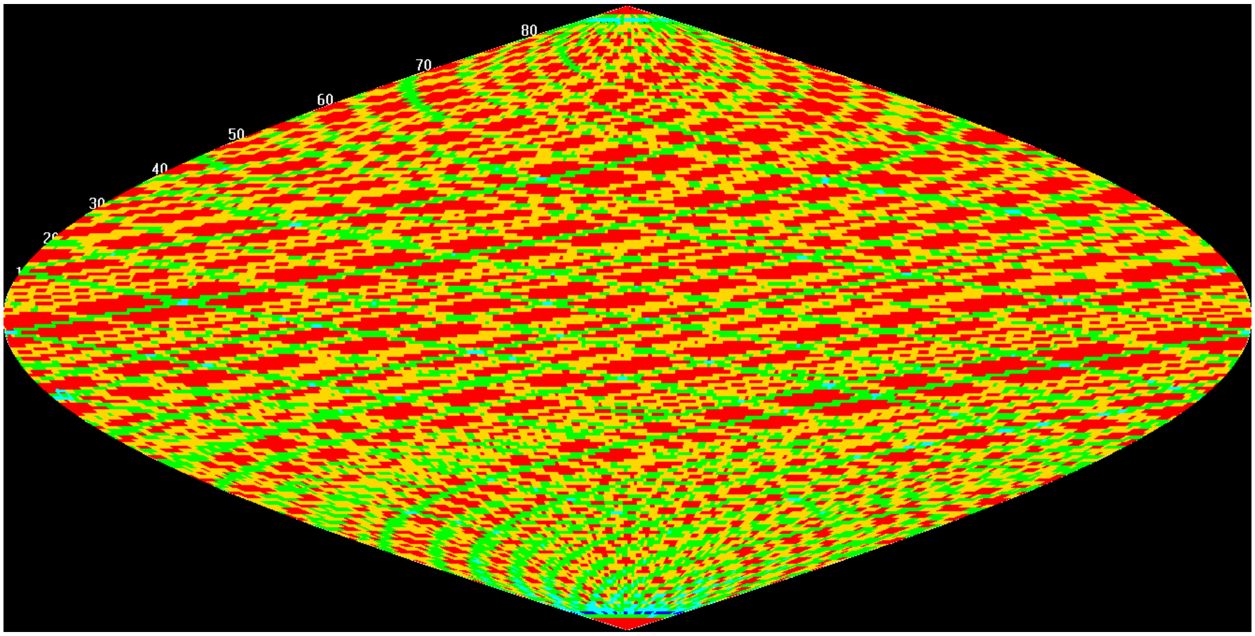

Figure 6: Sinusoidal projection map of coverage of OTES during the analysis period

Table 2: Coverage map legend

Color	Number of Accesses
Red	= 0
Yellow	= 1
Green	>= 2
Cyan	>= 5
Blue	>= 10

Operational Considerations for Orbital B

The default slew config file will be used during Orbital B. The entire Global Mapping phase is done with nadir pointing so no slewing is required other than each ATF begins with a 12-minute nadir slew. These slews are required by J-Asteroid planning, but they are not required to be completed before data collection is initiated because we are expecting to be in nadir point at the beginning of each ATF.

OLA will be powered off at the end of the science window. OLA will be in armed mode between rasters. OCAMS, OTES, and REXIS will be powered on continuously, and OVIRS is off for all of Orbital B.

As discussed in the Orbital B overview, five days of engineering activities are scheduled during the 35 days of Global Mapping. REXIS and OTES will observe for the full 16.33 hour SOW on the three scheduled NFT Nav Checkout (NavCam1) days, but no other science observations will be included. The two days set aside for the LIDAR-OLA Cross Calibration will include 10 OLA scans, but will otherwise not include any science observations.

Data Management: As currently planned, both subphases take place with a downlink rate of 917 kbps. The data collection is planned assuming a full 5 hours of downlink available for science each day. Data volume will be managed as needed by selecting some times with no PolyCam or OLA data collection (REXIS and OTES will still collect data).

OLA overflow will be routed to the OVIRS partition since OVIRS will not be observing during this phase. NavCam images for particle monitoring will be routed to the OCAMS partition during Orbital B. During the Particle Monitoring subphase, OCAMS will not be observing, and the OCAMs partition is therefore fully available for these observations. During Global Mapping, these particle monitoring images will share the OCAMS partition with the PolyCam and MapCam images, but there is plenty of margin on the storage availability.

CONOPS: During the first three weeks of Global Mapping, we will collect data similar to the former plan for Global Mapping by collecting OTES and REXIS data continuously, PolyCam images on a 7.10-minute cadence, and OLA data on a 17.56-minute cadence. PolyCam data will be collected in all three ATFs for 138 images, but OLA data collection is limited to two ATFs providing 38 rasters; the data are limited by downlink and on-board storage. Because of uncertainties of the orbit's semi-major axis and the spacecraft location in its orbit, we will use the OLA data to focus the PolyCam. Though we don't need to focus so often, for operational simplicity we will refocus every PolyCam image based on the range to the surface from the most recent OLA raster.

During the last two weeks, we will collect MapCam data over the poles by selecting the appropriate ATF when the spacecraft is expected to be over the polar regions. Recognizing we will have a large amount of PolyCam and OLA data taken over the poles in the first three weeks, we will collect only MapCam images over the polar regions during the last two weeks. During this time we will alternate the MapCam-only ATF (#2) with the OLA-PolyCam ATF (#4). On some days we fly over both poles during the SOW, in which case the ATFs are run in the order 2-4-2. On other days we fly over only one pole, in which case the ATFs are run in the order 4-2-4.

Requirements

5cm DTMs from OLA (MRD-115b)

Requirement:
MRD-115b: OSIRIS-REx shall, for 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a topographic map at <5cm spatial resolution and <5cm (1-sigma) vertical precision.

Note that OLA 8-cm products will be produced from Orbital B data, while the 5-cm products will be produced from Recon data.

Observation Constraints:

Observation constraints are with respect to the Sun North Coordinate Frame.

Instrument	Constraint	Fulfilled in SPP	Notes
OLA	LELT	✓	
	>95% coverage to ensure accuracy of <14cm	✓	Because we are not pointing the spacecraft, the location of the rasters on the surface depend on the location of the spacecraft in its orbit relative to the rotation of Bennu. To ensure that all locations on the surface are accessible to an OLA scan, we need to avoid some orbital periods. If the orbit period were exactly N Bennu rotations, the rasters would always fall in the same place; at N+½ Bennu rotations, the rasters would fall into one of two locations, but it takes three different raster scans to cover the mid-latitudes. Thus the orbit period cannot be N, or N+½ rotations of Bennu. Because it takes three rasters scan activities to fill in the mid-latitude region, the idea orbit period is N+1/3 or N+2/3 Bennu rotations.
	Emission angle ≤45˚	▼	Depending on when the observations occur relative to the DCO, the entire OLA raster is not filled at the 45° emission angle constraint at the 1-sigma limit.
	Up to 10˚ by 10˚ scans, constant spot spacing at <0.1mrad between spots, scan timing such that they will overlap by >10%	✓	Scan limit is not symmetrical about the s/c/ z-axis. In the s/c +Y axis, the limit is 0.083rad (~4.75˚) Scan limits are as follows: • viewField-minAzimuth -0.129 rad (S/C -X) • viewField-maxAzimuth +0.105 rad (S/C +X) • viewField-minElevation -0.123 rad (S/C -Y) • viewField-maxElevation +0.083 rad (S/C +Y)
	Minimum of 500 sec. between scans	✓	
	Nadir pointing	✓	
	<800m altitude	▼	OLA would like to ensure entire orbit is below 800m from the surface. A circular orbit significantly simplifies observations. The nominal semi-major axis of 930 m will satisfy this constraint, however the orbit does have some eccentricity. If the trim burn scheduled prior to the start of Global Mapping results in 2-3 sigma performance and provides us with an orbit that has a semi-major axis 1050 m or larger,

			we will likely need to do another trim in order to shrink it back down.
	90˚ orbital inclination	✓	

Liens:
One DRM lien was associated with MRD-608 (derived from the same observations as MRD-115b). Lien-ALT-10 was closed with the SOCR-54 approved SPP and Orbital B trajectory (nominal 950 m circular orbit).

Lien-ALT-10: lien on Orbit-B altitude. To acquire adequate data during Orbit-B, the spacecraft must maintain an altitude of less than 800 m. This constraint must be added into the DRM.

Data Products:
MRD-115b includes a suite of Altimetry Working Group products, which includes local DTMs, OBJs, tilt, and slope maps as well as DTMs in a specific format for NFT. These products are needed to produce local Safety, Deliverability, Sampleability, and Science Value Maps of the primary and backup candidate sample site. In addition, the NFT DTMs are required for hybrid TAG and NFT to the surface. Though the final versions of these products will not be delivered until Recon, the data collected in Orbital B is critical for registering Recon OLA data, obtaining <14cm accuracy for the NFT DTMs as per MRD-732, and obtaining a better solution for wobble of Bennu's rotation pole as per MRD-128.

Intermediate Resolution Sampleability Imagery (MRD-183c2)

Requirement:
OSIRIS-REx shall select a sample site that satisfies the following criteria: c. ≥80% probability of acquiring ≥60g of bulk sample per sampling attempt

Observation Constraints:
Observation constraints are with respect to the Sun North Coordinate Frame.

Instrument	Constraint	Fulfilled in SPP	Notes
PolyCam	≥5% of Bennu surface, in-between ±60˚ lat.	✓	Want to get context imagery covering a wide range of latitude and longitudes to ensure wide sampling of different surface geologies. Need this imagery to bridge the gap between 5cm data acquired in Detailed Survey and the 0.5cm data collected in Recon.

	One image every 10˚ of rotation for every 10˚ of longitude.	✓	
	0.025 m pixel size	✓	
	A given image must fall into one of 3 defined buckets: • Bucket 1: If phase id 95˚ – 105˚, emission must be 30˚ – 60˚ • Bucket 2: If phase is 90˚ – 95˚, emission must be 10˚ – 30˚ • Bucket 3: If phase is <90˚, emission must be 0˚ – 30˚	▼	Concerns regarding losing opportunities to collect data that fall within the defined buckets when the orbit period was closer to ~24.35 hours are somewhat decreased with the new orbit period which is closer to ~22hours. The total coverage that will be achieved however is still unknown.
	Any off-nadir pointing should be towards the sunlit side of the terminator.	✓	

Liens:
There is one DRM lien on MRD 183c. While it was originally written against MRD 576 (as described below), it has now been transferred to MRD 183c. The plan described in this SPP facilitated closure of Lien-IP-10

Lien-IP-10-Lien on DRM: MRD 576 was a requirement written to acquire images that satisfy the needs of products generated from stereophotoclinometry. MRD 576, however, is the only requirement that describes imaging during the Orbital B phase and has therefore been applied to image processing products despite the distinctly different observational needs of these products (emission, incidence, and phase angles are exceed required thresholds for mosaicking, depending on the observation). Resolving this lien involves designing an observation that is adequate (for) mosaic products.

Data Products:
These observations support sample site down-select prior to Recon. They primarily feed Sampleability and resolving features down to 5cm.

Local Thermal Inertia Maps (MRD-540)

Requirement:
MRD-540: OSIRIS-Rex shall, for >80% of a 2-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, measure the absolute flux of thermally emitted radiation with 3% accuracy and use it to derive and map thermal inertia at a spatial resolution <8m.

Observation Constraints:
Observation constraints are with respect to the Sun North Coordinate Frame.

Instrument	Constraint	Fulfilled in SPP	Notes
OTES	≥80% of Bennu surface	▼	Allowing 16 hours of science observations per day, only 60% coverage will be achieved during the 30 day period currently assigned to global mapping. It is hoped that we will be able to continue observing while in orbit beyond Orbital B, to gradually build up the desired amount of global coverage. In addition, there is the caveat that OTES does not necessarily even need ≥80% coverage as this was originally a local observation requirement.
	Ideally would like observation between 1am and 5am, however the only unacceptable time of day is the same time of day as the Recon passes.	✓	OTES measurements at more than one time of day would significantly improve thermal inertia retrieval. Two times of day do not need to be achieved in Orb B alone, but should be achieved between Orb B and Recon.
	<8m footprint	✓	
	0˚ to 60˚ emission angle (<30 is preferred)	✓	Larger than 60˚ emission angles are strongly affected by unknown emission phase function.
	If possible, would like to ride-along during PolyCam imaging in the hopes of getting off-nadir observations.	✓	Off-nadir observations would be extremely beneficial. Several orbits looking off-nadir (by e.g. 30 deg) would be satisfactory. These can be tied to off-nadir imaging observations - just turn OTES on during those observations. In that case, it would also be beneficial to turn OVIRS on for those orbits. Capturing the thermal tail (i.e., short wavelength thermal emission) will provide a more complete measurement of off-nadir thermal radiance for Yarkovsky and YORP science.

Data Products:
MRD-540 is a TAWG requirement. These data will feed into the Local Temperature Maps (TA-004), Local Thermal Inertia Maps (TA-005), and Local Predicted Temperature Maps (TA-006) which will feed the Local Safety Map, Local Sampleability Map, and Local Science Value Maps for the primary and back-up sample sites.

Active Asteroid Characterization

Requirement:
MRD-142: Search for dust and gas plumes originating from the asteroid surface and characterize their source regions, particle re-impact sites, and column densities
MRD-144: Detect with 95% confidence natural satellites >10-cm diameter with albedo ≥0.03 within 35 km of Bennu

Observation Constraints:

Instrument	Constraint	Fulfilled in SPP	Notes
NavCam1	**Dedicated Particle Imaging:**		
	2x1 NavCam1 mosaics every 25.6 or 31.6 minutes	✓	Cadence is driven by dat volume constraints.
	Each mosaic target consists of two 5-sec. exposures that are between 2 and 5 minutes apart.	✓	
	Particle Imaging During Global Mapping:		
	Two 5 sec. exposures added to regularly scheduled OpNav imaging. The nominal conops for OpNav is NADIR NavCam every 2 hours	✓	
	The 5-sec. image pair should be spaced out by 2-5 minutes.	✓	

Ideal Observation Constraints:

Type of particle events (events type #)	Instrument	Pairs	Pair Spacing	Exposure Time	Mosaic Size	Cadence (between pairs)	Frequency
Large Ejection Events (1) >20 particles per event	NavCam1 (and/or 2)	Yes	~2-5 min	~5 sec	2x2	~10 min	Every 60 degrees of Bennu orbit, ~2.4 months for 2 weeks
Small Ejection Events (2)* <20 particles per event	NavCam1 (and/or 2)	Yes	~2-5 min	~5 sec	2x2	~20 min	Every 60 degrees of Bennu orbit, ~2.4 months for 2 weeks
Individual Satellites: Orbit Determination (3)*	NavCam1 (and/or 2)	Yes	~2-5 min	~5 sec	2x1	~20 min	Every 60 degrees of Bennu orbit, ~2.4 months for 2 weeks; or before we move to a lower altitude
Individual Satellites: Number Density (4)	NavCam1 (and/or 2)	Yes	~2-5 min	~5 sec	Single nadir pointed image	~2 hours	Continuous (rest of encounter)

*Individual ejection events can also lead to short-lived ballistic and hyperbolic trajectories

*These objects are considered part of events 2 and 3

REXIS

Requirements:

REX-1a: REXIS shall measure the elemental weight ratios of [Mg/Si] within 30%, [Fe/Si] within 45% and [S/Si] within 40% with a minimum 480 hour integration (2σ).

REX-2a: REXIS shall measure the elemental weight ratios of [Mg/Si] within 30%, [Fe/Si] within 45% with a minimum 90 h integration for spatially resolved measurements of elemental abundances within 100 m regions on Bennu's surface (2σ).

REX-3a: For elevated solar states the REXIS instrument shall be capable of imaging significant enhancements of elemental abundance with scale sizes of 50 m.

Observation Constraints:

Observation constraints are with respect to the Sun North Coordinate Frame.

Instrument	Constraint	SPP Status	Notes
REXIS	Sun must stay within ±7˚ in Y-axis of SXM boresight. Sun must stay within ±20˚ in Z axis SXM boresight.	✓	On average need 47% of asteroid within FOV illuminated over total REXIS integration time For FOV, refer to REXIS file with coded aperture function, to be provided by REXIS team. Aphelion Worst Case Scenario Nadir Pointed Observations with orbital radius <= 1 km 480 hour integration time minimum required (480 hours is the minimum of useful scientific integrations, pointed on target) Solar Constraint: A1.8 4.0 MK single temperature plasma model minimum required for collimator and spectral mode performance Solar Constraint: B1.8 5MK threshold required for Imaging Mode (minimum required) SXM Pointing Constraint: Sun must stay within +/- 7 deg in Y axis of SXM boresight. SXM Pointing Constraint: Sun must stay within +/- 20 deg in Z axis of SXM boresight. SPOC Soft Constraint: Sun must be in the SXM field of view while REXIS is observing Bennu. The Soft Constraint does not specify specific bounds on the allowed range of angles but those bounds are listed in the SXM pointing column (AM). The Soft Constraint will be updated to incorporate those angles. The minimum coverage specified here is intended to enable the spectral characterization of a minimum of 2 independent patches near the asteroid equator and 2 independent patches away from the asteroid equator to characterize potential regolith migration from the poles toward the equator and probe asymmetries within those sub-regions. The Sun must stay within +11/-90deg relative to the XY plane and within +0/-4deg relative to the XZ plane so that it does not shine on REXIS and heat up the detectors If the REXIS detectors heat up as a result of offpointing activities, then the Sun must be in the zone described above for at least 3 hrs to allow the detectors to cool down before REXIS will meet performance requirements ▼ Because of navigational uncertainty, the nominal observation time allocated to REXIS (30days * 16hrs/day) may not meet the REXIS observation constraints. Additional observing time in the Orbital B geometry may be needed to enable REXIS to meet its requirements. -REX-1a (global ratios) is achievable within the nominal 30-day period of the Orbital B SPP for Mg/Si and Fe/Si, but not for S/Si unless the pointing errors turn out to be smaller than the 1-sigma level described in the current TSE document; -REX-2a (collimator-mode mapping) is achievable within the 30 days for Mg/Si, but Fe/Si mapping at 100-m scales may not be achievable. Fe/Si can be determined for at least 2 spectral regions (e.g. hemispheres) with the current estimate of pointing drift, which is a coarser resolution than the 100-meter spots in the requirement. -O/Si is not part of the requirements but is not limited by exposure time; the SPP is compatible with the O/Si measurement. -The main issue with meeting the S/Si and Fe/Si mapping requirements is that useful data can be acquired when pointing is within 5 degrees of nadir, but the time within 5 degrees of nadir is very limited with the current TSEs. -Either additional REXIS integration time in an Orbital-B-like geometry or improved TSEs would improve the S/Si results and Fe/Si mapping. Both of those things would give REXIS more observation time in which the boresight is within 5 degrees of nadir.
	≥75% coverage of Bennu	✓	
	Sample every 4 seconds for a minimum of 480 hours integration time with constraints met. 480 hours does not have to be contiguous.	▼	
	Nadir Pointing 2:1 Ratio of fraction of FOV (weighted by the coding fraction) with illuminated asteroid to fraction of FOV looking off of asteroid (weighted by the coding fraction).	▼	
	Incidence and Emission 0˚ to 90˚	✓	

Derived Products Summary

	MRD-115b	MRD-133	MRD-142	MRD-183c2	MRD-540
MRD-128	✓				
MRD-126		✓			
MRD-130		✓			
MRD-131		✓			
MRD-193		✓			
MRD-194		✓			
MRD-411					✓
MRD-608b	✓				
MRD-687b	✓				
MRD-732	✓				

Driving Requirement
Ride-Along Requirement
Derived Product