Orbital-R Science Phase Plan

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Purpose

The purpose of this document is to describe the nominal observation plan for the Orbital-R phase of the mission. It is intended to provide enough 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.

The first half of this document focuses on the observation plan and provides an overview of the requirements. The second half of this document focuses in more detail on the requirements, the constraints needed to meet those requirements, 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_CCv0068.xlsx

Mission Plan Workbook: Mission_Plan_Workbook_2019-08-14

SPK:

- orx_190805_200101_190730_od170-R-M1C-P-M13R_v1.bsp

Observation Envelope and Templates: OrbitR_Templates.r1_draft.xlsx

Kernel set for SPP development:

- naif0012.tls
- pck00010.tpc
- bennu_v14.tpc
- de424.bsp
- orx_190805_200101_190730_od170-R-M1C-P-M13R_v1.bsp
- orx_v14.tf
- orx_navcam_v02.ti
- orx_ocams_v07.ti
- orx_ola_v01.ti
- orx_otes_v00.ti
- orx_ovirs_v00.ti
- orx_struct_v00.ti
- g_12630mm_spo_obj_0000n00000_v034.bds
- ORX_SCLKSCET.00047.tsc
- orx_struct_polycam_v01.bc
- orx_struct_mapcam_v01.bc

FDS delivery of products for Orbital-R are described here:
OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\OrbitalR

- NAV DELIVERY of REFOD170 (RECON A BASELINE).pdf
- 190802_Recon1250m_DeliverySummary.pptx

MRD Overview

The observations taking place in Orbital-R are supplementary observations that contribute to the completion of MRDs but are not satisfying the MRDs outright.

The OCAMS calibrations support the following requirements:

1. Global Color Maps (MRD-141)
2. Bennu Light Curve (MRD-157)
3. Bennu Phase Function (MRD-158)

The driving requirements for the other Orbital R science activities are as follows:

1. Local Thermal Inertia Maps (MRD-540)
2. Active Asteroid Characterization (MRD-142 and MRD-144)

In addition to the MRDs, REXIS has three internal requirements these data will address:

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

Observation Strategy

The Orbital-R mission phase is scheduled for October 28, 2019 through Jan 5, 2020 (WOY 44-52, and WOY 1). Orbit insertion will take place in WOY 44 and the spacecraft will remain in orbit through the end of this phase. OpNavs and low cadence particle monitoring images will be collected throughout the Orbital R time period.

WOY 45

WOY 45 will be used to complete calibration requests from the OCAMS team and the OVIRS team. These calibrations will address the following SOCRs:

- SOCR-157 Opportunistic OCAMS Absolute Color Calibration Using Blurred Vega Observations
- SOCR-170 OCAMS Non-linearity Flight Calibration
- SOCR-176 OVIRS Solar Cal After Recon A

WOYs 46 & 47.

Science data will be collected with OTES, OVIRS, MapCam, REXIS, and NavCam1 during WOY 46 and 47. OTES drives the observations, with OVIRS, MapCam, and REXIS participating as

secondary instruments. NavCam1 will be used for OpNavs and particle monitoring images. The available downlink data volume is low in these weeks, so we cannot collect data continuously for all participating instruments over the entire 18-hour Science Observation Window (SOW). The downlink rate is 600 kbps, and the current science downlink plan allows an average of 1.75 hours/day in the first week and 2.5 hours/day in the second week. The science data collection plan is developed assuming the DSN coverage remains consistent with these preliminary numbers.

In order to simplify the operations yet still spread the data over different parts of the orbit, we are planning on having a single 6-hour science ATF, which will be run three times each day. We are collecting more science data than can be downlinked during these two weeks, but the observation plan will be set up so that the on-board storage is not exceeded with the planned available downlink times. We are directing the NavCam images for particle monitoring to the OCAMS partition (along with the MapCam images) because of the large partition size, however this means we cannot make use of the overflow partition. In the event there is a decrease to the planned downlink time, an OpNav-only ATF will be substituted at one or more of the standard science ATF execution times.

In Orbital-B, we were able to plan different data collections at different points in the orbit three weeks in advance. We will not be able to do that in Orbital-R due to the short duration of the 2-week science collection period and the placement of the start of the mapping period within two weeks of orbit insertion.

Remaining weeks. The remaining weeks will consist of taking images for OpNavs and low cadence particle monitoring. No other data collection will be planned except for the TAGCAMS Calibrations in WOY 50. See SOCR-166 for more information regarding the TAGCAMS calibration activities scheduled for WOY 50.

Orbit parameters

Orbit-R is a slightly elliptical orbit with a semi-major axis of about 1.2 km (fig. 1). Its orbital parameters are selected to put it in a stable orbit.

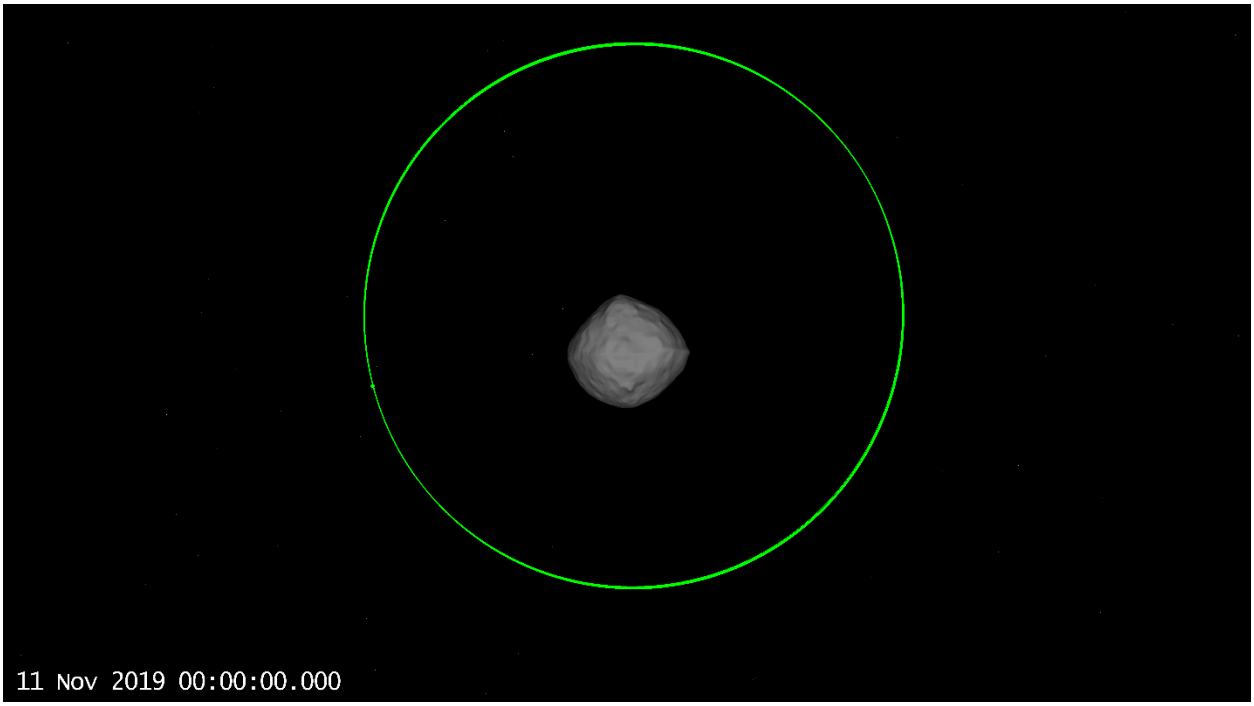

Figure 1. Two week duration of Orbital-R viewed from the sunward direction.

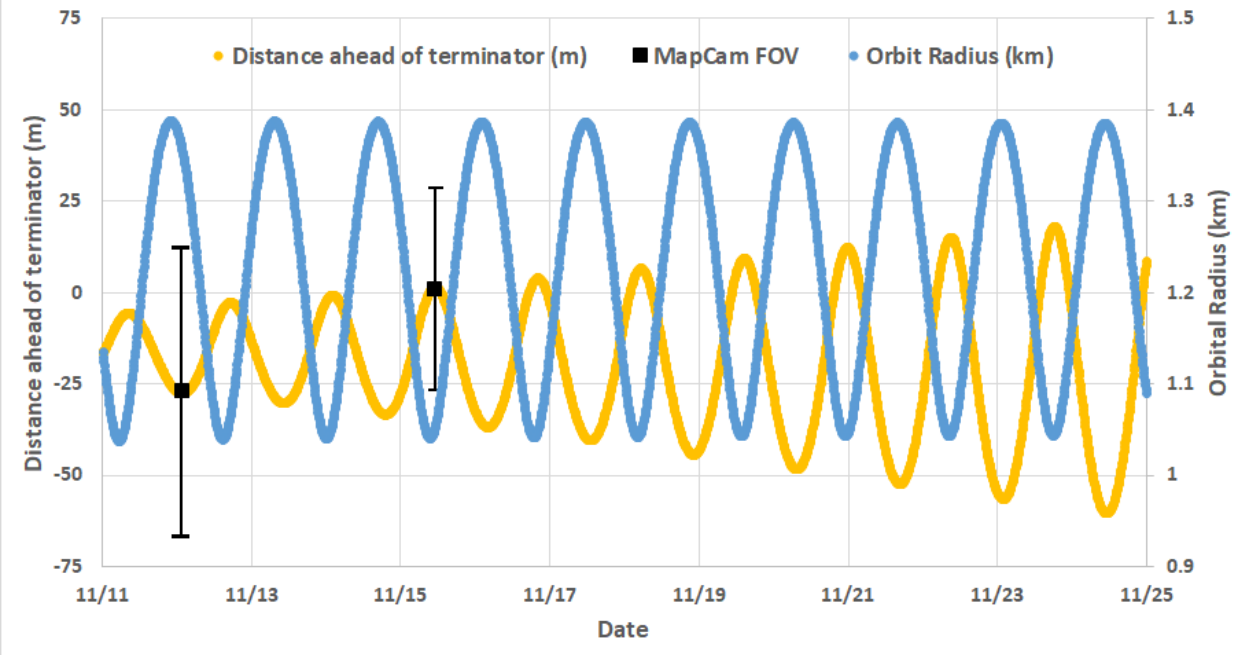

Figure 2. Orbital radius and distance ahead of terminator for Orbital-R.

It can be seen in fig 2 that most of the time the spacecraft is actually behind the terminator. The size of the MapCam FOV changes with orbital radius, and two examples show the limits of the FOV indicating that most of the time at least a portion of its FOV is in sunlight. For

spectroscopic observations aimed at understanding the thermal properties of the surface, the night-time observations are preferred.

WOY 45 Calibration activities

OCAMS Absolute Color Calibration (SOCR-157): This observation was originally requested to occur in the L+30 timeframe but was deferred to L+36. OCAMS will utilize MapCam to image a bright standard star for absolute radiometric calibration. The bright standard star that is visible during the Orbital R timeframe is Vega. PolyCam will also acquire Pan images of Vega to cross-calibrate with MapCam. The spacecraft will initially slew to point Vega just beyond the MapCam FOV. The spacecraft will then perform a linear scan, allowing Vega to move into the MapCam FOV with a direction of motion along a detector row. Images will be taken with a single color filter per scan. At the end of the scan, MapCam will move to the next color filter, and the spacecraft will then perform a slew in the opposite direction, imaging during the scan. This will be repeated for all color filters. Then a point and stare observation will be executed to acquire slightly defocused Pan PolyCam images. Each color band will be imaged 3 times, along with 3 PolyCam point and stare images. Darks will also be acquired. Since this activity will require off-pointing from the default attitude of NADIR, it will need to occur during a dedicated Science window. This activity will be ATF-driven.

Due to the location of Vega relative to Bennu, Bennu will likely come into view of the Instrument deck during the Absolute Color Calibration. This is undesired for the OCAMS calibration which requires observing a Bright Standard star in dark sky. The Absolute Color Calibration will occur ~1 week after the spacecraft transitions to the Orbital-R orbit, and therefore at the time the calibration is planned, we will not have knowledge to determine the best Vega viewing times to avoid Bennu in FOV. The proposal is therefore to execute the OCAMS Absolute Color Calibration twice, ~18-24 hours apart, during the L+36 calibrations, in order to ensure that one of the two observations occurs in the opposite quadrant from Bennu (similar to the concept of operations of the PolyCam Thru Focus in WOY 2019-31).

During this observation, the Spacecraft heaters should be transitioned back to the thermal set points to keep PolyCam at the cruise setting (~ -24C). This will be done at least 24 hours prior to the first Absolute Color Calibration activity. The thermal set points will remain at this setting through the OCAMS Non-Linearity cal.

The proposed dates for executing the OCAMS Absolute Color Calibration are 2019-Nov-04 (DOY 308, after the Background Sequence transition) and 2019-Nov-05 (DOY 309).

OCAMS Non-Linearity (SOCR-170): OCAMS will perform a non-linearity calibration in order to characterize the non-linearity limits, which were originally defined via ground testing. This observation involves all three cameras. For each camera, the shutter will be left in the blocking position, and the cal lamp will be turned on. A series of images at varying exposure will be taken for each camera to fully explore the dynamic range of the detector. The estimated number of images is ~30 per camera plus darks. No specific pointing is required for this

observation. Nominally it will occur during an available OpNav or Science window while the spacecraft is at its default attitude of NADIR. This activity will be non-ATF-driven.

PolyCam thermal set points will be set to the cruise setting (~ -24C) prior to the Absolute Color Calibration and remain at these set points thru the OCAMS Non-Linearity activity. The set points will be returned to the Orbital setting (~ +10C) immediately following the OCAMS Non-Linearity Calibration.

The proposed date for executing the OCAMS Non-Linearity Calibration is 2019-Nov-08 (DOY 312).

OVIRS Solar Calibration (SOCR-176): OVIRS will perform their standard solar calibration during the Orbital R timeframe. This will be a repeat of a calibration completed previously in 2019 and 2018, and uses previously exercised sequences to slew the spacecraft and acquire OVIRS data. This activity is non-ATF-driven.

The OVIRS Solar Cal runs ~65 minutes, and therefore will be scheduled either during a dedicated Science window or during an OpNav window in between 2-hr OpNav imaging.
The proposed date for executing the OVIRS Solar Calibration is 2019-Nov-9 (DOY 313).

WOYs 46 & 47 Observation Plan

MapCam: We cannot afford the data volume of taking a continuous series of non-compressed MapCam images with overlap between all adjacent images. Consequently we are planning on taking MapCam images compressed via a lookup table (LUT). The cadence of the MapCam images was set so that the images would be contiguous even over the equator where the surface moves the most rapidly.

OVIRS: Because of its high data volume per hour, we are planning on collecting OVIRS data for 4 hours in the three ATFs that will be executed per day for a total of about 12 hours per day. Running three short ATFs, rather than one with 12 hours of continuous OVIRS data collection, allows the OVIRS data to be distributed over three different latitude regions on each orbit. An integration time of 6.3 seconds will be used instead of the standard 1 second integration. The surface motion at the equator is 0.10 m/s and the OVIRS FOV is 3.8 meters, so a 6.3-sec integration time would increase footprint size to only 4.4 meters. At higher latitudes, where the surface motion is less, the increase in the footprint size is driven by the spacecraft motion. At periapsis, the footprint size is 3.2 m, and the spacecraft motion is only 0.016 m/s on the surface, which is obviously trivial.

OTES: The OTES data volume is low enough that we can collect data continuously using its normal 2-sec integration time.

REXIS: REXIS will be power cycled daily during the two weeks of Orbital R mapping. The first time REXIS is powered on prior to the two weeks of mapping, the 1 hour preheat will be

included, however the daily power cycling will not include the 1 hour preheat time since REXIS will already be warmed up. REXIS will not begin data collection until 30 minutes after the start of the ATF to accommodate the power cycle at the beginning of the science window and will run until the end of the ATF. REXIS image processing parameters will be updated at the start of REXIS observations when no other commands are being sent to REXIS. Since the ATF will be reused three times per day, the total daily REXIS observation time will be 16.5 hours.

NavCam: We are taking short exposure images for OpNav at a 2-hour cadence; three in each ATF. Along with the OpNav images, we are taking a doublet of long-exposure images for particle monitoring. The second image is delayed 138 sec from the first to allow confirmation of a real particle detection.

OLA: OLA will not be collecting data in Orbital-R.

The details of the science ATF is given below in Table 1. With this plan none of the on-board storage partitions overflow. The OCAMS partition fills to 88% capacity on the last day. At a downlink rate of 600kbps and 2.5 hr/day in WOY 48, it takes about 6 days for the partition to be emptied.

Table 1. Data Collection Summary for WOYs 46 & 47

Instrument	Data	Cadence	Duration	Data Volume (Mbits)
MapCam	108 LUT images	10 min.	18 hr.	977
OVIRS	6857 spectra	6.3 sec.	12 hr.	1241
OTES	32,400 spectra	2 sec.	18 hr.	741
REXIS	Continous	--	16.5 hr.	113
Particles	9 doublets	2 hr.	18 hr.	1590

Operational Considerations

The default slew config file will be used for Orbital R. For the science mapping, other than the initial slew to get to nadir tracking, no slewing will be used. The calibrations will include some unique pointings that require slewing.

Nadir point will be the default attitude after orbit insertion in WOY 44.

OCAMS will remain powered on with cameras off after the last Recon High Pass Flyby and will be reset weekly during Orbital R. OVIRS and OTES will be powered off after the last Recon High Pass Flyby. OVIRS will be powered on 4 or more hours prior to the OVIRS Solar Cal and will remain powered on through the Orbital R mapping. OTES will be powered on 4 or more hours prior to the first Orbital R mapping observation. As described in the observation plan, REXIS will

be power cycled daily in WOYs 46 & 47. A waiver will be required to forgo the hour preheat time for the daily power cycles.

WOY 46 will be planned with the 8 week tactical and implementation timeline. All other weeks of Orbital R will follow the shortened 5 week tactical and implementation cycle. The WOY 50 TAGCAMS calibrations will be planned by the MSA.

Requirements and Data Products

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:

Instrument	Constraint	Fulfilled in SPP	Notes
OTES	≥80% of Bennu surface	▼	A significant portion of this was fulfilled in Orbital B, but 80% was not achieved. These data will increase the total amount of coverage.
	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 the Recon time of day would significantly improve thermal inertia retrieval.
	<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 MapCam context images and OVIRS observations.	✓	

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.

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:**		
	Pairs of long exposure NavCam1 images every 12.5 minutes to every 2 hours, as supported by data volume constraints	▼	Cadence is driven by data volume constraints which in Orbital R only allow pairs of NavCam1 images every 2 hours.

Global Color Maps (MRD-141)

Requirement:

MRD-141: OSIRIS-REx shall, for >80% of the asteroid surface, map the surface in a panchromatic filter at < 1m resolution ad map the ECAS b-v color index, v-x color index, and the depth of the 0.7-microns absorption feature, relative to one or more recognized ECAS standard stars, with an accuracy of < 2% in regions where the signal-to-noise ratio is >100 at a spatial resolution of < 2m.

Data Products:

IP-20 Global Color Ratio and True Color Maps

Bennu Light Curve (MRD-157)

Requirement:

MRD-157: Produce four light curves of Bennu by measuring the variation in its irradiance over two rotation periods to within ≤ 3% relative brightness in four distinct wavelength regions that can be compared with observations of one or more recognized ECAS standard stars in the b, v, w, and x ECAS filters

Data Products:

There are three science data products associated with MRD-157: Bennu Photometry (AP-4), Temporal and Phased Light Curve Parameters (AP-12), and Light Curve Parameters (AP-13).

Bennu Phase Function (MRD-158)

Requirement:

MRD-158: Produce four phase functions of Bennu by measuring the variation in its irradiance over a minimum of ten degrees change in phase angle, to within ≤ 3% relative brightness in four distinct wavelength regions that can be compared with observations of one or more recognized ECAS standard stars in the b, v, w, and x ECAS filters.

Data Products:

There are three science data products associated with MRD-158: Phase Function Photometry and Models (AP-14), Phase Function Model Parameters (AP-15) and Bennu Point Spread Function (AP-19).