PRELIMINARY SURVEY

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Purpose

The purpose of this document is to describe the nominal observation plan for the Preliminary Survey Phase of the mission. It is intended to provide enough information for the science teams and instrument 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.

MRD Overview

The Mission Requirements Document (MRD) Rev K includes 9 requirements that drive science observations taken during the Preliminary Survey phase or that describe derived science data products. During Preliminary Survey, OSIRIS-Rex is intended to observe the sun-lit side of Bennu as well as both poles with the primary objectives of getting a preliminary mass estimation of Bennu, refining the Bennu shape and spin state models, and collecting sufficient data to generate a global 75cm shape model. MRD-427 describes obtaining a 2% mass estimation prior to completion of the Preliminary Survey phase as a requirement for insertion to Orbital A. This requirement will be satisfied with Doppler data accompanied by OpNav images and OLA data. As in the Approach Phase, MRD-678 describes the requirement for < 75-cm shape model of Bennu. OCAMS images acquired during Preliminary Survey will be used to build on this SPC-derived shape model and ultimately deliver a preliminary version of the 75-cm shape model to FDS by phase end. MRD-124, MRD-127, MRD-128, and MRD-129 describe the requirements for determining the Bennu spin state, which includes shape model center of figure, Bennu rotation pole, wobble of Bennu rotation pole, and Bennu rotation period. As these Spin State parameters are refined, the Bennu Coordinate system (MRD-125) will also be updated. Preliminary Survey will also be the first opportunity to measure Bennu's position with great enough detail to support understanding of the magnitude of the Yarkovsky Effect. The Yarkovsky measurement is described by MRD-150. In addition, Preliminary Survey is an opportunity to collect high-phase data that will help constrain the MapCam photometric models in the phase angle range of 50˚ to 75˚. MapCam Photometric models are captured by MRD-149a-c.

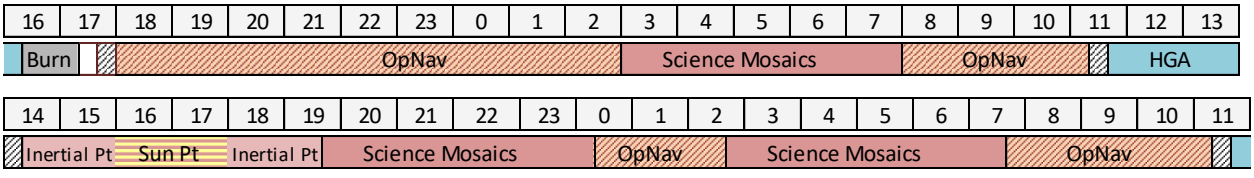

Figure 1. The observation template shows the time (UTC in top rows) for different operations on the third north polar flyover and the south polar flyover. OLA data are taken near closest approach in the time labeled inertial point. The distant mosaics (the first and last science mosaic windows above) are looking at lower latitudes, and the close mosaics (immediately after Inertial Pt) are looking at polar latitudes and the equatorial limb. The exact time of the

mosaics may move somewhat from here. The first north polar flyover is similar except the distant mosaics are about 2 hours nearer to closest approach. The equatorial flyby is similar except there are no close mosaics, and the distant mosaics are about 2 hours nearer to closest approach.

Inputs

Observation Constraints Spreadsheet:

UA-OPS-4.0-1001_Observation Constraints_DRAFT_4.n_CCv0057

This document can be found on ODOCS 4.0 in the Data Product Planning Documents folder.

The Mission Plan Workbook is on ODOCS in the following location. The version listed below is a draft version that reflects this observation plan, but there will be a later version of the Mission Plan Workbook after this plan is approved.

OSIRIS-REx 02.0 PSE\Mission Plan\Mission Plan Workbook\ Mission Plan Workbook 2017-10-23 (draft).xlsx

SPK:

orx_dev_fob/FDS/SPK/orx_170117_210312_refMPRevB_v1.bsp

The trajectory state error (TSE) files contain the expected navigation uncertainties and are listed below. The TSE files were used only for the nadir point observations made for the high phase angle photometric model observations. They will be available on SPOC flight and currently are in the following location on the FOB. ORX_FOB/FDS/TSE/Mission_Plan_RevB:

orx_tse_181202_190107_pre-M1P_v2.txt
orx_tse_181203_190107_pre-M1P_v2.txt
orx_tse_181204_190107_pre-M2P_v2.txt
orx_tse_181205_190107_pre-M2P_v2.txt
orx_tse_181206_190107_pre-M3P_v2.txt
orx_tse_181207_190107_pre-M3P_v2.txt
orx_tse_181208_190107_pre-M4P_v2.txt
orx_tse_181209_190107_pre-M4P_v2.txt
orx_tse_181210_190107_pre-M5P_v2.txt
orx_tse_181211_190107_pre-M5P_v2.txt
orx_tse_181212_190107_pre-M6P_v2.txt
orx_tse_181213_190107_pre-M6P_v2.txt
orx_tse_181214_190107_pre-M7P_v2.txt

orx_tse_181215_190107_post-M7P_v2.txt
orx_tse_181216_190107_post-M7P_v2.txt
orx_tse_181217_190107_post-M7P_v2.txt
orx_tse_181218_190107_post-M7P_v2.txt

The Approach Mission Plan Rev B trajectory dispersions from Monte Carlo analysis were provided by email on April 19, 2017 and are stored on ODOCS: OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\Preliminary Survey\

The draft observation template from MSA is on ODOCS in the following location:

OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\Preliminary Survey\

Other kernels used for J-Asteroid planning:

```
LSK = naif0012.tls
PCK = pck00010.tpc
PCK = bennu_v10.tpc
SPK = de424.bsp
SPK = bennu_refdrmc_v1.bsp
#FK = orx_v06.tf
FK = orx_v07.tf
IK = orx_navcam_v01.ti
IK = orx_ocams_v06.ti
IK = orx_ola_v00.ti
IK = orx_otes_v00.ti
IK = orx_ovirs_v00.ti
IK = orx_rexis_v00.ti
IK = orx_struct_v00.ti
DSK = RQ36mod.oct12.bds
SCLK = ORX_SCLKSCET.00015.tsc
```

Preliminary Survey Mass Estimation (2% mass estimation)

Requirement:

MRD-427: OSIRIS-REx shall estimate the mass of Bennu to within 2% (1-σ) prior to the end of the Preliminary Survey Phase.

NOTE: MRD-427 is an operational requirement, but it will also feed the science requirement MRD-133 during Preliminary Survey. MRD-133 will use Doppler observations during Orbital B to build on MRD-427 and ultimately determine the mass of Bennu to within 0.5%.

Observation Constraints:

- LGA and HGA Doppler tracking throughout North Pole, South Pole, and Equatorial flybys, particularly during closest approach.
- OpNav sampling with NavCam approximately every 3 hours (8 OpNav sets per 24 hours) throughout Preliminary Survey.

Observation Plan:

There are no specific observations needed for these requirements, but a two-hour window around the closest approach is left cleared of observations to permit communication with Earth via the LGA at this time. In addition, OpNav observations are planned at regular intervals.

Data Products:

N/A

NOTE: The science data product associated with MRD-133 is the Asteroid Mass Model (RS-005). RS-005 is an ASCII file produced by the Radio Science Working Group (RSWG) using Doppler data, OpNav images, the Altimetry Working Group (ALTWG) Global Parameters PCK (ALT-06), SPICE, and additional DSN data. RS-005 is delivered after Orbital B. It is a minimum sample return requirement that supports operations and TAG.

75-cm Shape Model from SPC

Requirement:

MRD-678a: The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.75 m in ground sample distance (sample resolution).

NOTE: SPC is driving MRD-678 during Preliminary Survey, not OLA.

Observation Constraints:

<u>OCAMS Imaging (Distant Mosaics)</u>

Inbound Topography Suite North and South Pole:

Imaging Coverage: 0˚ lat. to 90˚ lat. for the North, 0˚ lat. to -90˚ lat. for the South

For 0˚ lat. = 12:00 ± 0:30 local time <0.75-m pixel size

For ±30˚ lat. = 12:00 to 8:00/16:00 local time <0.75-m pixel size

For ±50˚ lat. = 12:00 to 7:00/17:00 local time<0.75-m pixel size

For anything above ±60˚ lat. 12:00 local time to terminator

Rotational sampling frequency: Image Bennu every ~10˚ of rotation

20% overlap between images and scan lines

Max emission angle of 50˚

Outbound Topography Suite North and South Pole:

Imaging Coverage: 0˚ lat. to 90˚ lat. for the North, 0˚ lat. to -90˚ lat. for the South

For 0˚ lat. = 12:00 ± 0:30 local time <0.75-m pixel size

For 30˚ lat. = 12:00 to 8:00/16:00 local time <0.75-m pixel size

For 50˚ lat. = 12:00 to 7:00/17:00 local time <0.75-m pixel size

For anything above ±60˚ lat. = 12:00 local time to terminator

Rotational sampling frequency: Image Bennu every ~10˚ of rotation

20% overlap between images and scan lines

Max emission angle of 50˚

Equatorial Topography Suite

Imaging Coverage: -50˚ lat. to +50˚ lat.

9:00 local time < 0.75-m pixel size

15:00 local time < 0.75-m pixel size

Rotational sampling frequency: Image Bennu every ~10˚ of rotation

20% overlap between images and scan lines

Max emission angle of 50˚

<u>OCAMS Imaging (Close Mosaics)</u>

North and South Pole context and limb suite

Filter: Pan

Imaging Coverage: 40˚ lat. to 90˚ lat. for the North, -40˚ lat. to -90˚ lat. for the South

Local Time: All

Rotational sampling frequency: Image Bennu every ~10˚ of rotation

20% overlap between images and scan lines

Limb observations every 10˚ of rotation (must have center of asteroid in FOV; e = 0˚)

Pixel Size: < 0.75m

Max emission angle of 50˚

Observation Plan:

Summary:

75-cm Shape Model Observations (OCAMS Distant Mosaic):

- Instrument: MapCam
- Observation Type: Rectangular Raster Scan
- Observation Duration: 4.5 hours per activity
- Latitudes of Bennu to be observed: -35° to +90° (north polar); ±50° (equatorial); +35° to -90° (south polar)
- MapCam FOV across track overlap: 20%
- MapCam FOV along track overlap: 20%
- Navigation uncertainty: 2 sigma
- Filter: Panchromatic (filter index id 5)
- Calibration plan: 5 dark images taken prior to first raster scan slew with the same exposure time as the regular images, 5 dark images taken after the last raster scan slew with the same exposure time as the regular images, no darks during the scan activity
- Slew Rates:
    - Fast slew: 5.00 mrad/s slew rate limit and 0.0582 mrad/s^2 acceleration
    - Slow slew: 2.00 mrad/s slew rate limit and 0.0582 mrad/s^2 acceleration
- See Table 1 for the time of observations, range to Bennu, and rotational resolution

75-cm Shape Model MapCam Observations (OCAMS Close Mosaic):

- Instrument: MapCam
- Observation Type: Rectangular Raster Scan

- Observation Duration: 4.5 hours per activity
- Area of Bennu to be observed: Global
- MapCam FOV across track overlap: 20%
- MapCam FOV along track overlap: 20%
- Navigation uncertainty: 2.0-sigma
- Filter: Panchromatic (filter index id 5)
- Exposure time(s): TBD, single exposure time for all observations
- Calibration plan: 5 dark images taken prior to first raster scan with the same exposure time as the regular images, 5 dark images taken after the last raster scan with the same exposure time as the regular images, no darks during the scan activity
- Slew Rates:
    - Fast slew: 5.00 mrad/s slew rate limit and 0.0582 mrad/s^2 acceleration
    - Slow slew: 2.00 mrad/s slew rate limit and 0.0582 mrad/s^2 acceleration
- See Table 2 for the time of observations, range to Bennu, and rotational resolution

Overview:

The Preliminary Survey Phase consists of flybys over the North Pole, Equator, and South Pole. Initially the plan simply called for three flybys, but the initial flyby of the North Pole had large navigational uncertainties due to an uncertain location of the first maneuver following the Approach Phase. The current plan makes three flybys over the North Pole (figure 2) to reduce the uncertainties. This observation plan has MapCam and OLA observations on the first flyby and third flyby. There are no science observations planned on the second flyby.

The observation activities are planned around a slew rate of 2.00 mrad/s. At this slew rate, the maximum exposure time is 34 ms to maintain 1 pixel of blur or less. If a longer time is needed to improve SNR, there will need to be a trade between blur and SNR. The slew rate can be changed to a lower value to maintain the blur at a longer exposure time, but a slower slew rate will decrease coverage, either in uncertainty limits or in rotational resolution.

The activities are designed around the 2-σ Monte Carlo navigational uncertainties. During this mission phase, we will not have determined the mass of Bennu, so we have to account for the uncertainty in its mass as well. The Monte Carlo uncertainties used are sufficient to account for the mass uncertainties. It is worth noting, that at the tactical stage trades can be made between coverage and navigational uncertainty. For example, the distant MapCam activities currently provide 10° rotational resolution at the 2-σ level, but we could achieve 2.5-σ or 3-σ with 12° or 14° rotational resolution, respectively.

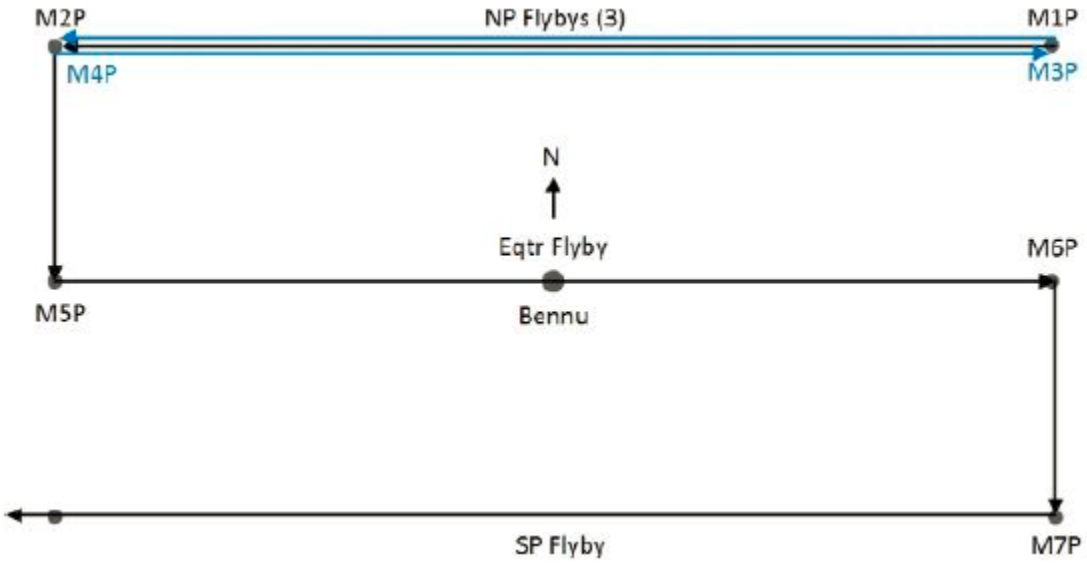

Figure 2. Schematic of Preliminary Survey showing three passes over the North Pole. Each trajectory leg lasts two days. The observations consist of MapCam mosaics made far from Bennu, both on the inbound and outbound legs from closest approach, OLA observations made near closest approach, both inbound and outbound, and additional MapCam mosaics made soon after the OLA observations but on the outbound legs of the polar flybys only. The times of closest approach to the pole is set at a nominal 17:00 UTC for all flybys.

OCAMS Distant Mosaics: The distant MapCam Observations from Bennu are taken with a scan area sized to accommodate 2-σ navigational uncertainties. To meet the pixel size constraint, the range to the surface was reduced relative to that planned for PolyCam. To satisfy the constraint of 10° of rotational resolution, we increased the slew rate to 2.0 mrad/s from the 1.35 mrad/s value used for Approach. This higher slew rate limits the exposure time to 34 ms to avoid image blur greater than 1 pixel.

The results for all six MapCam data collection activities from the distant locations are presented in Table 1. In addition to the size of the scans, which increase with decreasing range to the surface, the coordinates of nadir, expressed here in the sun anti-momentum frame, also change from the beginning to the end of the activities.

Table 1. Observation parameters for distant MapCam activities.

	North Pole-1				North Pole-3				Equator				South Pole			
	Inbound (12/4)		Outbound (12/5)		Inbound (12/8)		Outbound (12/9)		Inbound (12/12)		Outbound (12/13)		Inbound (12/16)		Outbound (12/17)	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
Observation Time (UTC)	4:45	9:15	0:45	5:15	2:52	7:22	2:45	7:15	4:45	9:15	0:45	5:15	2:52	7:22	2:45	7:15
Distance to center of Bennu (km)	11.4	9.1	9.1	11.4	12.4	10.0	10.0	12.5	11.1	8.8	8.8	11.1	12.5	10.0	10.1	12.6
Latitude of nadir (deg-SAM)	39.2	52.3	52.4	39.3	35.2	46.1	45.9	35.1	0.0	0.0	0.0	0.0	-35.1	-46.0	-46.0	-35.1
Longitude of nadir (deg-SAM)	89.8	89.9	-89.9	-89.8	94.4	94.5	-85.2	-85.1	-51.6	-38.2	37.9	51.4	89.7	89.8	-89.8	-89.7
Radial 1-σ uncertainty (m)	299	300	210	290	238	244	280	285	139	138	136	135	165	169	182	182
Transverse 1-σ uncertainty (m)	231	244	495	528	307	263	237	280	143	127	146	170	171	163	178	194
Normal 1-σ uncertainty (m)	369	332	241	235	253	235	239	257	187	174	159	165	230	230	238	241
Phase Angle to nadir (deg)	89.8	89.9	89.9	89.8	94.4	94.5	85.2	85.1	51.6	38.2	37.9	51.4	89.7	89.8	89.8	89.7
MapCam FOV (m)	766	612	612	766	841	673	675	842	746	590	589	746	842	675	681	849
MapCam pixel size (cm)	74.8	59.8	59.7	74.8	82.1	65.7	65.9	82.2	72.9	57.6	57.5	72.8	82.2	65.9	66.5	82.9
Mosic Size	2x3	3x3	5x3	5x2	3x2	3x2	3x3	3x2	2x2	2x2	2x2	2x2	2x2	2x2	2x2	2x2
Rotational resolution (deg)	12		15		10		10		10		10		10		10	
Number of images per activity	267		270		216		219		144		144		144		144	

Ten dark images are planned for each MapCam activity (5 dark images with the same exposure duration as the regular images will be taken prior to the first raster scan slew and an additional 5 dark images will be taken following the completion of the last raster scan slew).

Performance relative to constraints:

In general the emission angles will span very large ranges depending on how far off nadir one is looking. On the equatorial flyby, we will image the equator at local noon. Except for the first north polar pass, we achieve the 10° rotational resolution constraint.

OCAMS Close Mosaic:

The Close MapCam observations are taken immediately following OLA on the outbound legs of the first and third North-Pole flybys and on the South-Pole flyby. The MapCam mosaics are planned around 2-σ uncertainties and 20% image overlap. Ten dark images are also included in the plan (5 dark images with the same exposure duration as the regular images will be taken prior to the first raster scan slew and an additional 5 dark images with the same exposure duration as the regular images will be taken following the completion of the last raster scan slew). The observation parameters are given in Table 2.

Table 2. Observation parameters for close MapCam activities.

	North Pole-1		North Pole-3		South Pole	
Date	12/4/2018		12/8/2018		12/16/2018	
	Start	End	Start	End	Start	End
Observation Time (UTC)	19:30	24:00	19:30	24:00	19:30	24:00
Distance to center of Bennu (km)	7.48	8.81	7.47	8.80	7.54	8.88
Latitude of nadir (deg-SAM)	76.1	55.2	76.3	55.3	-76.4	-55.4
Radial 1-σ uncertainty (m)	201	200	284	281	186	184
Transverse 1-σ uncertainty (m)	425	488	179	211	153	167
Normal 1-σ uncertainty (m)	262	243	222	230	234	236
Phase Angle to nadir (deg)	90.0	89.9	85.3	85.2	90.0	89.9
MapCam FOV (m)	516	608	516	607	521	613
MapCam pixel size (cm)	50	59	50	59	51	60
Mosaic size	5x3	6x3	3x3	3x3	3x3	3x3
Rotational resolution (deg)	18		12		12	
Number of images per activity	327		270		270	

Performance relative to constraints:

We cover the required latitude range with emission angles < 50°. We achieve 12° rotational resolution (vs. the constraint of 10°) on both poles, but we achieve only 18° rotational resolution on the first pass over the North Pole.

Operational Considerations:

The MapCam shape model observations use the slow slew with 2.00 mrad/s slew rate limit and 0.0582 mrad/s^2 acceleration. The slew configuration will need to be changed between Approach and Preliminary Survey. These activities are planned with respect to the nominal trajectory (no science late updates will be used). In DRM rev-C, no slewing was planned for the Close MapCam activities. Here slewing is needed due to the larger uncertainties.

Note that the observation times listed in this document may need to shift by a few minutes in either direction in order to accommodate the placement of OpNav observations. In particular, the Close Mosaics will likely need to shift a few minutes later in order to take an OpNav observation before the mosaics.

The observation times listed in this document are the times when the science observations actually begin. In most cases, the Science Observation Windows will open at least 12 minutes prior to the start of the science observations.

We have added spectroscopy observations to this plan, and OVIRS has a significant impact on data volumes. Nevertheless, with the greatly reduced data volumes relative to the PolyCam imaging, we are still not taxing the downlink. The plan is robust even against missing two consecutive downlink windows.

Data Products:

There is a suite of products generated by the Altimetry Working Group (ALTWG) after the 75-cm shape model from SPC is defined. This suite of products will be used as an input for virtually

all global-map science data products. The 75-cm shape model is derived from OCAMS data. After OCAMS data acquisition in Preliminary Survey, a preliminary version of the 75-cm shape model from SPC will be delivered to FDS. The final version of the 75-cm shape model from SPC for global mapping is released in Orbital A.

High Phase Angle MapCam Data for Photometric Models

Requirements:

OSIRIS-REx shall, for > 80% of the asteroid surface, map the variation in spectral properties in regions where the albedo is > 1% using photometrically corrected (to 30˚ phase angle) and normalized (at 1.3 microns) reflectance spectra over a wavelength span of at least 0.3 microns within the region 0.4-1.5 microns with <5% accuracy and <2% precision.

Observation Constraints:

MapCam Imaging

Filters: Pan, b,v,w,x

Coverage: Need substantial coverage, but does not have to be ≥80%

Phase angle range: 55˚ to 75˚ (60˚ is ideal)

Ground Sample Distance: <0.50 m

Signal to Noise: ≥100

Observation Plan:

Summary:

High Phase MapCam Observations:

- Instrument: MapCam
- Time of Observations: See Table 3.
- Observation Type: Nadir
- TSEs used: orx_tse_181210_190107_pre-M5P_v2.txt, orx_tse_181212_190107_pre-M5P_v2.txt
- Observation Duration: ~0.2 hours per set (5 regular images in total, pan and 1 in each color filter)
- Area of Bennu to be observed: One hemisphere at time of observation
- MapCam FOV across track overlap: N/A

- MapCam FOV along track overlap: N/A
- Rotational resolution: N/A
- Filter: pan (id 5), b (id 4), v (id 3), w (id 2), x (id 1)
- Exposure time(s): TBD, each filter may have unique exposure times
- Calibration plan: 2 dark images taken prior for each exposure time used for the regular images, and 2 dark images taken after for each exposure time used.

Sets of five MapCam images, one with pan and one with each color filter, will be taken at different times during Preliminary Survey as specified in Table 3. These observations span a range of phase angles from ~50° to 84°. Previously it was assumed imaging in Orbital-A would provide the phase angles on the order of 80° to 90°, but currently no images are planned for Orbital-A so the range here was extended out to 84°.

Table 3. Summary of MapCam observations for photometric models.

Date	Time	Longitude (deg-SAM)	Latitude (deg-SAM)	Range (km)	FOV (m)	Larger of Nav Errors (m)	Size Margin (m)	Number of Sigma
12/13/2018	5:15	51.4	0.0	11.3	780	171	132	0.78
12/13/2018	10:00	60.8	0.0	14.0	969	200	227	1.14
12/13/2018	19:00	70.1	-0.9	18.4	1272	59	378	6.45
12/14/2018	17:00	78.4	-11.3	18.1	1247	133	366	2.74
12/15/2018	5:00	83.7	-16.9	18.2	1256	182	370	2.04

The seventh column gives the larger of the two orthogonal 1-σ navigational uncertainties, but they are usually comparable. The “Size Margin” is half the difference between the FOV and the diameter of Bennu, so it specifies how much margin we have on Bennu being entirely within the MapCam FOV. The “Number of Sigma” is the “Size Margin” divided by the “Larger of Nav Errors.” The probability of Bennu being entirely in the FOV in the first entry in the table is 56%; the probability of at least half of Bennu being in the FOV for this entry is 88%.

Operational Considerations:

The observations will be made in nadir-point mode and will take less than 2 minutes. All of the observations are taken at a time when the spacecraft is nadir pointed for OpNav images, so we are riding along without requiring any additional spacecraft pointing beyond that already planned. Settling time is not an issue since the exposure times are small, hence the placement can be determined by whatever is operationally most simple. Since these are ride-along observations with OpNav, the exact time of these observations may change.

Data Products:

These data will contribute to achieving the accuracy and precision goals for the Global MapCam Photometric Model data products (IP-13) that are necessary to close out MRD-149a-c and build the global imaging mosaics. IP-13 includes 6 photometric models: one for each MapCam filter (panchromatic, b, v, w, & x) and a PolyCam photometric model. The MapCam panchromatic photometric model is planned to be used in lieu of the PolyCam photometric model, as currently planned there is not enough phase angle coverage to provide a high-fidelity PolyCam photometric model. The PolyCam photometric model is therefore "best effort" and not required. The MapCam panchromatic photometric model is required and is planned to be used to photometrically correct global and local PolyCam image mosaics (IP-4 & IP-9). These photometrically corrected image mosaics will be used as the base maps for viewing virtually all other acquired data. The MapCam color photometric models will be used to photometrically correct the global and local MapCam color-ratio and true-color maps (IP-20 & IP-21), which feed into the Science Value Maps. In addition, the MapCam x-band photometric model is of particular importance as it will be used to photometrically correct MapCam x-band image mosaics (IP-7 & IP-8) which in combination with the OVIRS Color Ratio Map (SA-43) will inform the Safety Map and ensure that the surface that will be observed with LIDAR to determine range to surface is within the range of reflectance values in which LIDAR is designed to operate. All IP-13 products are FITS files and will not be delivered until after Equatorial Stations as Equatorial stations data is required to further constrain the disk function.

Lien-PhoMod-1 is a lien on the DRM to provide the phase angle coverage of Bennu that is sufficient to predict the phase-angle dependency on surface brightness during a moderate phase-angle (30 to 70 degrees) TAG timeline. Currently, modeling simulations of the DRM Rev-C show that insufficient data are obtained between 55 and 75 degrees phase angle, making predictions of surface brightness in this phase angle range uncertain. Hence, the plans described in this Preliminary Survey Phase Plan address that concern and contribute to closing Lien-PhoMod-1.

75-cm Shape Model from OLA

Requirement:

MRD-678b: The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at <0.75 m in ground sample distance (sample resolution).

NOTE: SPC is driving MRD-678 during Preliminary Survey, not OLA.

Observation Constraints:

OLA observations during Preliminary Survey are for validation of the SPC shape model, meaning they do not drive the design of Preliminary Survey, with the exception that spacecraft pointing for the OLA observation periods is required to be as per the observation plan below. These OLA observations are key for testing the accuracy of image-derived shape models and verifying the navigation solutions.

OLA scans require the size of the Bennu disk (512m) and spacecraft position uncertainty (across-track) to be < ±5˚, inertial pointing, across-track linear scan, 2m spot spacing. Several NavCam1 images are taken over the duration of the OLA scan to be used to register OLA data.

Observation Plan:

The spacecraft will be in a fixed inertial point at the nominal location of nadir at the center of times for each collection activity (Table 4). OLA will be operated in a line-scan mode with the length of the lines being set to accommodate the 2-σ cross-track uncertainties. The motion of the spacecraft will sweep across Bennu allowing confidence that at least some of the line scans will collect returns from Bennu. To confirm the pointing of the spacecraft during these activities, NavCam1, images are requested during each OLA activity. As noted above, the navigational uncertainties are large enough that MapCam imaging needs slewing in order to compensate. To avoid the slewing, we will take advantage of the larger FOV of NavCam1. The plan calls for six equally spaced NavCam1 images to be taken during each OLA activity. With a total observation duration of 78 minutes, the NavCam1 observations will be taken every 15 minutes 36 seconds.

It should be noted that the transverse uncertainties translate to a time uncertainty on when Bennu will move through the OLA inertial point attitude. The uncertainties have been calculated for the nominal mass of Bennu and the needed time for the OLA observations will change with the mass of Bennu. It is expected that the mass of Bennu will be determined on the first two north-polar flybys, and the trajectory maneuvers on subsequent flybys can be adjusted to provide the planned time of observation.

Table 4. Observation parameters for OLA activities.

	North Pole-1				North Pole-3				Equator				South Pole			
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
	12/4/2018				12/8/2018				12/12/2018				12/16/2018			
Observation Time (UTC)	14:42	16:00	18:12	19:30	14:42	16:00	18:12	19:30	14:42	16:00	18:12	19:30	14:42	16:00	18:12	19:30
Radius of orbit	7.51	7.34	7.34	7.53	7.50	6.92	6.92	7.10	7.11	6.92	6.92	7.10	7.53	7.36	7.36	7.54
Latitude of nadir (deg-SAM)	76.0	84.3	84.4	76.1	75.9	84.1	84.5	76.3	0.0	0.0	0.0	0.0	-75.7	-84.0	-84.7	-76.4
longitude of nadir (deg-SAM)	90.0	90.0	-90.0	-90.0	94.6	94.6	-85.3	-85.3	-14.3	-6.0	5.4	13.8	90.0	90.0	-90.0	-90.0
Radial 1-σ uncertainty (m)	272	252	221	201	273	278	283	284	144	145	144	143	182	185	186	186
Transverse 1-σ uncertainty (m)	320	352	396	425	192	182	176	179	113	112	114	119	149	148	150	153
Normal 1-σ uncertainty (m)	293	283	270	262	221	220	221	222	163	161	159	158	232	232	233	234

Operational Considerations:

The spacecraft velocity vector is aligned with the spacecraft body Y axis during the north and south passes, and with the X axis during the equatorial pass. This means the OLA scan orientation should be azimuth during the North and South passes and elevation during the equatorial passes. The Monte Carlo uncertainties are sufficient that OLA can compensate for 2-σ navigational uncertainties with the ±5° range of their scan mirror. The time allocated for the OLA observations is 90 minutes for each of the two activities, however only 78 minutes are available for the altimetry data due to the 12 minutes required to achieve the inertial pointing attitude. A total of 6 NavCam images are needed for each activity for a total of 12 per flyby. It is expected that two of the twelve would be already planned for navigation, so an additional ten are included in the data volume allocation for each flyby. It is expected that the last NavCam observation on each inbound leg and the first NavCam observation on each outbound leg will be standard stellar OpNavs, during which star tracker updates to the attitude reference calculation are disabled for a few minutes.

NavCam images are only processed to Level-0 within SPOC Processing. Working groups will be able to access these Level-0 images in SPOCFlight.

Data Products:

There are no standalone data products required for the 75cm shape model from OLA. These observations are in support of navigation and SPC. OLA will make its first shape model delivery during Orbital B. This delivery entails a 35cm shape model associated with MRD-687b. There is no scheduled delivery for a 75cm shape model from OLA. As the Observation Constraint section specifies, these OLA observations are for validation and do not drive observations/science during Preliminary Survey.

Spectroscopic Observations

Requirement:

There are no specific spectroscopic requirements being addressed in Preliminary Survey. The spectrometers are being operated in a “ride-along” fashion.

Observation Plan:

OTES will be on during both the distant and close MapCam imaging activities but not during the OLA activities. OVIRS will be on during the distant MapCam imaging activities on the NP3, Equator, and South Pole flyovers. OTES will be collecting data at their nominal 2-s integration time; OVIRS will be collecting data at 0.91-s integration time. Since these are secondary instruments, they do not drive the design of the observations.

Derived Data Products

The following sections describe data products that are derived from Preliminary Survey observations but do not have any observation constraints.

Bennu Spin State (global parameters PCK)

Requirements:

MRD-124: Shape model Center of Figure

OSIRIS-REx shall produce a > 1 million vector shape model.

MRD-127: Rotation Pole

OSIRIS-REx shall determine the rotation pole (right ascension, declination, and obliquity) of Bennu relative to J2000 to within 1 deg. in each parameter.

MRD-128: Wobble of Rotation Pole

OSIRIS-REx shall determine the amount of wobble in the rotation pole of Bennu.

MRD-129: Rotation Period

OSIRIS-REx shall determine the amount of wobble in the rotation pole of Bennu.

Observation Constraints:

There are no observation constraints associated with MRD-124, MRD-127, MRD-128, or MRD-129. These requirements will be satisfied as shape model requirements are satisfied.

Data Products:

MRD-124, MRD-127, MRD-128, and MRD-129 make up the Bennu Global Parameters PCK (ALT-06). This product is produced by the ALTWG using OCAMS and OLA data acquired for shape modeling. Each time a global shape model is produced, these parameters are generated with the exception of MRD-124 (Center of Figure) which is generated by a separate SPC model and is relative to the center of mass of Bennu.

Bennu Coordinate System

Requirements:

MRD-125: OSIRIS-REx shall designate a prime meridian using a distinctive surface feature and define the coordinate system of Bennu.

Observation Constraints:

There are no observation constraints associated with MRD-125. These requirements will be satisfied as shape model requirements are satisfied.

Data Products:

From MRD-125 the Prime Meridian and Coordinate Definition (ALT-07) is generated. ALT-07 is generated by ALTWG. Upon encountering Bennu, a geologic feature will be identified and hence fourth will be the location of Bennu's prime meridian. As higher resolution imagery is obtained and the selected geologic feature location becomes clearer, the precise location of the prime meridian will be updated. Preliminary Survey will be one of these opportunities for update. The ALT-07 data product is an ASCII file containing the rotation angel needed to go from the coordinate system +X axis defined by Bennu's moment of inertia. The Global Parameters PCK (ALT-06) will also contain the prime meridian and coordinate system definition information.

Measurement of Yarkovsky Acceleration

Requirements:

MRD-150: OSIRIS-REx shall measure the Yarkovsky acceleration of Bennu with a Signal-to-Noise >400.

Observation Constraints:

There are no observation constraints for MRD-150 during Preliminary Survey. Any ranging measurements taken with OLA and/or by Radio Science will be used to measure Bennu's position and determine the magnitude of the Yarkovsky Effect.

Data Products:

The Bennu Ephemeris (RS-011) is the data product associated with MRD-150. RS-001 is produced by the Radio Science Working Group (RSWG) and will ultimately be delivered as a NAIF SPK. Data for RS-001 can be collected during Preliminary Survey, Orbital A, and Orbital B. RS-001 is planned to be delivered at the end of Orbital B and will support operations.