DETAILED SURVEY EQUATORIAL STATIONS

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Purpose

The purpose of this document is to describe the nominal observation plan for the Detailed Survey Equatorial Stations 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 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.

REXIS calibration and cover opening activities nominally scheduled for Detailed Survey are covered in SPP SOCR-41.

Inputs

The initial Science Phase Plan development was completed with a trajectory that represented the revised Equatorial Station order from Mission Plan Rev A but was based on the schedule for DRM Rev C. Those kernels and uncertainties are listed in the rev 4 inputs below. The updated rev 5 SPP was completed with the inputs as listed in the rev 5 section below. The major difference between these two sets of inputs are in the dates and times of the observations. A check of the observation design was completed with the updated inputs. No significant difference between the rev 4 and rev 5 J-Asteroid plans was found.

Observation Constraints Spreadsheet:

UA-OPS-4.0-1001_Observation Constraints_DRAFT_4.n_CCv0058

Mission Plan Workbook:

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 2018-04-20.xlsx

Inputs for rev 4 SPP

Kernels used in J-Asteroid planning and the productions of CKs:

LSK = naif0012.tls
PCK = pck00010.tpc
PCK = bennu_v10.tpc
SPK = de424.bsp
SPK = orx_190118_190317_DS_reordered.bsp

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.00016.tsc

The TSE files listed below are in the following location on the FOB

/orxfob/DocumentLibrary/FDS/TSE/ DRM_RevC/Detailed_Survey/:

orx_tse_190126_190201_obs-45_v1.txt
orx_tse_190202_190208_obs-230a_v1.txt
orx_tse_190209_190215_obs-0_v1.txt
orx_tse_190216_190222_obs-330_v1.txt
orx_tse_190223_190301_obs-270_v1.txt
orx_tse_190302_190308_obs-130a_v1.txt
orx_tse_190309_190315_obs-90_v1.txt

A memo describing the trajectory dispersions from Monte Carlo analysis is stored in the following location on ODOCS:

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

Inputs for rev 5 SPP

A memo describing the inputs is stored in the following location on ODOCS:
OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\Detailed Survey Equatorial Stations\DS_BBD_SOPG

The TSE files listed below are on the FOB and in the following location on SPOCFlight:
https://spocflight.lpl.arizona.edu/#/hilp
Choose Working Group: FOB
Choose Product: Trajectory State Errors (OIA-109) (FDS-TSE)

3 PM: orx_tse_190424_190610_DS-NOM_v1.txt
3:20 AM & Dust Search: orx_tse_190501_190610_DS-NOM_v1.txt
12:30 PM: orx_tse_190508_190610_DS-NOM_v1.txt
10:00 AM: orx_tse_190515_190610_DS-NOM_v1.txt
6:00 AM: orx_tse_190522_190610_DS-NOM_v1.txt
8:40 PM & Dust Search: orx_tse_190529_190610_DS-NOM_v1.txt
6:00 PM: orx_tse_190605_190610_DS-NOM_v1.txt

MRD Overview

The Mission Requirements Document (MRD) Rev K includes 4 requirements that drive science operations, 3 ride-along requirements and 11 requirements that fall out of the driving requirements. Equatorial Stations is intended to be the major science campaign that will ultimately yield global high-level products (HiLPs) and top maps that will inform down-select to a primary and back-up sample site which will be investigated at a finer scale during the Reconnaissance phase. The Top Maps refer to the Global Safety Map (MRD-183a1), the Global Deliverability Map (MRD-183b1), the Global Sampleability Map (MRD-183c1), and the Global Science Value Map (MRD-183d2). During Equatorial Stations, OSIRIS-REx will execute a series of periodic slews between Bennu's north and south poles and take observations from seven different stations with seven sun illumination conditions as well as conduct 2 dust and gas plume searches. These seven stations are listed below in Table 1.

Table 1 - The seven stations and instruments that will be operating for each station/activity. REXIS will be powered on but not collecting science data.

Station	PolyCam	MapCam	OVIRS	OTES	OLA	REXIS
3pm (45˚ lon.)	X	✓	✓	✓	✓	✓
3:20am (-130˚ lon.)	X	✓	✓	✓	X	✓
12:30pm (7.5˚ lon.)	X	✓	✓	✓	✓	✓
10am (-30˚ lon.)	X	✓	✓	✓	✓	✓
6am (-90˚ lon.)	X	✓	✓	✓	✓	✓
8:40pm (130˚ lon.)	X	✓	✓	✓	X	✓
6pm (90˚ lon.)	X	✓	✓	✓	✓	✓
Dust Plume Search (3:20am)	X	✓	✓	✓	X	✓
Dust Plume Search (8:40pm)	X	✓	✓	✓	X	✓
Off-Nadir (3:20am)	X	✓	✓	✓	X	✓
Off-Nadir (6am)	X	✓	✓	✓	X	✓

*With respect to the Sun North Coordinate Frame

The 4 driving requirements include:

1.) Global Spectral Mapping (MRD-140)
2.) Dust and Gas Plume (MRD-142b)
3.) OVIRS and MapCam Photometric Models (MRD-149)
4.) Global Temperature and Thermal Inertia Maps (MRD-155)

The 3 ride-along requirements include:

1.) Dust and Gas Plume Spectral Characterization (MRD-143)
2.) Global 75cm Shape Model from OLA (MRD-678b)
3.) Global 35cm Shape Model from SPC (MRD-687a)

The fall-out requirements can be seen in the Derived Data Products section at the end of this document.

The following table maps each requirement to the stations/activities listed above.

Table 2 - Mapping of requirements to stations. Blue indicates the requirement is a ride-along.

Station	MRD-140	MRD-142b	MRD-149	MRD-155	MRD-143	MRD-678b	MRD-687a
3pm (45° lon.)	✓ OTES Prime	X	✓ MapCam/OVIRS	✓ OTES	X	✓ OLA	✓ MapCam
3:20am (-130° lon.)	X	X	✓ MapCam/OVIRS	✓ OTES	X	X	✓ MapCam
12:30pm (7.5° lon.)	✓ OVIRS/OTES	X	✓ MapCam/OVIRS	✓ OTES	X	✓ OLA	✓ MapCam
10am (-30° lon.)	✓ OVIRS Prime	X	✓ MapCam/OVIRS	✓ OTES	X	✓ OLA	✓ MapCam
6am (-90° lon.)	X	X	✓ MapCam/OVIRS	✓ OTES	X	✓ OLA	✓ MapCam
8:40pm (130° lon.)	X	X	✓ MapCam/OVIRS	✓ OTES	X	X	✓ MapCam
6pm (90° lon.)	X	X	✓ MapCam/OVIRS	✓ OTES	X	✓ OLA	✓ MapCam
Dust Plume Search (3:20am)	X	✓ MapCam Prime OVIRS/OTES Ride-Along	X	X	✓ OVIRS/OTES	X	X
Dust Plume Search (8:40pm)	X	✓ MapCam Prime OVIRS/OTES Ride-Along	X	X	✓ OVIRS/OTES	X	X
Off-Nadir (3:20am)	X	X	✓ OVIRS Prime MapCam Ride-Along	X	X	X	X
Off-Nadir (6am)	X	X	✓ OVIRS Prime MapCam Ride-Along	X	X	X	X

Observation Plan Summary

Table 3 - Observation plan summary for each station.[1]

Station	Observation Type	Clocking	# of Slews/Mosaics	Avg. Slew Duration (sec.)	Targets Per SOW	Targets Per Mosaic	Avg. Rotation Per Slew/Mosaic (deg.)	Avg. Rotational Resolution Between Filters (deg.)	Avg. MapCam Along-slew Overlap (%)	Total MapCam Images per Station	Gores	Time Outside OSZ (min.)	Star Tracker KOZ Violations (min.)	Navigational Uncertainties
3pm	Linear Scan	SUN	102	157.04	104	NA	3.65	18.23	80	933	YES, minor OVIRS	7.73 during initial slew	NA	2-sigma
3:20am	Linear Scan	SUN	108	147.91	140	NA	3.44	17.58	65	374	NO	NONE	NA	2-sigma
3:20am off-nadir	Linear Scan	SUN	26	150.79		NA	3.51			78	NO	NONE	NA	2-sigma
Dust Search (3:20am)	Annulus/point-and-stare hybrid	SUN w/ -55 deg offset	14	1000	145	9	26	NA	NA	645	NO	NONE	NA	2-sigma
12:30pm	Linear Scan	VELOCITY	144	110.02	147	NA	2.55	14.12	80	770	YES, minor OVIRS	55.77 total 45.56 not including initial slew	8.7 STU1	2-sigma
10am*	Linear Scan	SUN	77	208.06	79	NA	4.84	24.70	78	435	YES	NONE	NA	2-sigma
6am	Linear Scan	SUN	132	120.7	168	NA	2.81	14.30	80	710	NO	NONE	NA	2-sigma
6am off-nadir	Linear Scan	SUN	32	122.11		NA	2.84			160	NO	NONE	NA	2-sigma
8:40pm	Linear Scan	SUN	107	151.4	112	NA	3.52	17.81	47	371	NO	7.89 during initial slew	NA	2-sigma
Dust Search (8:40pm)	Annulus/point-and-stare hybrid	SUN w/ -55 deg offset	14	1000	145	9	26	NA	NA	645	NO	NONE	NA	2-sigma
6pm	Linear Scan	SUN	134	122.38	136	NA	2.84	14.42	80	1200	NO	NONE	NA	2-sigma

[1]Note that the number of images includes those needed for calibration activities. The 3 pm and 6 pm stations have an additional 3 hours of data collection to account for timing uncertainties, hence the number of images from these stations have been scaled up by a factor of 1.67 over the amount needed to account for the nominal 4.5 hours of data collection. See operational considerations section for more information

Equatorial Stations

The observations are made from seven south-to-north trajectories nominally over the equator crossing at a radius of ~5 km. As shown in Table 3, three of the stations (3:20 AM, 6 AM, and 8:40 PM) have additional science activities placed immediately after the end of the nominal equatorial science windows.

The observation stations are separated in time by one week and spread over different solar longitudes (different local times of day). OVIRS, OTES, and MapCam will be operating at all 7 stations. OLA will operate at all of the stations with the exception of the 3:20am and 8:40pm stations. REXIS will be powered on during part of this mission phase (at the discretion of the REXIS team) but will not be acquiring science data (except as described in SOCR-41) in order to maintain the detectors and electronics in a known state.

The initial SPP development was completed with a trajectory that represented the revised Equatorial Station order from Mission Plan Rev A but was based on the schedule for DRM Rev C. The updated trajectory and uncertainty products as described in the inputs section reflect updated Mission Plan dates as listed in the below table. Note that a check of the observation design was completed with the updated inputs and no significant differences were found. Therefore the products (i.e. CKs) used by the working groups to validate the rev 4 Equatorial Stations plans remain valid.

Table 4: Expected observation dates for Equatorial Stations

Observation Station	**Date**
3:00 PM	25 April, 2019
3:20 AM	02 May, 2019
12:30 PM	09 May, 2019
10:00 AM	16 May, 2019
6:00 AM	23 May, 2019
8:40 PM	30 May, 2019
6:00 PM	06 June, 2019

Continuous linear scans will be performed for 4.5 hours during each equatorial station, with accumulation times of 0.91 s and 2.0 s for OVIRS and OTES respectively, that overshoot the limb of Bennu by 24mrad (3 times the OTES FOV) with 2-sigma along-track navigational uncertainties. MapCam will also perform observations during these linear scans. MapCam is planned to only cover the Bennu polar radius (508m) and 2-sigma navigational uncertainties, nominally taking 5 images during each slew, with exceptions at the 3:20am and 8:40pm stations, where only 3 images will be taken during each slew due to OCAMS data volume constraints. The imaging is done through five different filters: pan, b, v, w, & x, with exposures listed in table 4. After every slew, MapCam will change filters, so that after five slews all of the MapCam filters have been used. OLA will operate in ride-along mode with the HELT laser conducting across-track linear scans with ~8mrad scan width (roughly equal to or slightly exceeding the OTES FOV) and ~0.37mrad angular spacing. In order to adequately contribute to the MRDs that OLA is tied to for this phase, a minimum of 3 Equatorial Stations are required in addition to one Northern and one Southern station during Baseball Diamond. Spacecraft clocking (planar alignment) for Equatorial Stations is nominally SUN.

Table 5: MapCam Equatorial Stations Exposure times.

Filter	Exposure Time (ms)
pan	2
b	19
v	15
w	11
x	16

The 3pm, 12:30pm, and 10am station plans produce OVIRS gores. 10am, having the worst gores, is a special case described below. The 3pm station produced very minor equatorial gores across-slew for between 6 to 10 slews. The worst gore spanned approximately 0.4° (1.77m). The 12:30pm station gores were even more minor, being isolated between only two slews, with the worst gore area only spanning approximately .36° (1.60m).

For MRD-140 it is desirable that OVIRS data is obtained at one station with less onboard averaging in order to improve the signal-to-noise ratio (SNR) and decrease the chance of data corruption. The 10am station is the ideal station to collect these data to meet science requirements including mapping organics. Normal operation sums 8 pixels (SP=8), which could produce a decreased SNR that could inhibit organics mapping. For the 10am station, SP=2 will be implemented. This plan should increase SNR in the data, and the bad pixel map will not include good pixels if OVIRS is operating colder than assumed. This approach results in 4 times the normal data volume and requires the overflow partition, however OCAMS and OLA do not expect to be using that partition during the 10am station. After receipt on the ground, the data will go through normal ingest at the SPOC to produce Level 0 data. A new routine will be needed to produce ground summed data that can be run through the L0-L2 pipeline. This process will be validated prior to detailed survey.

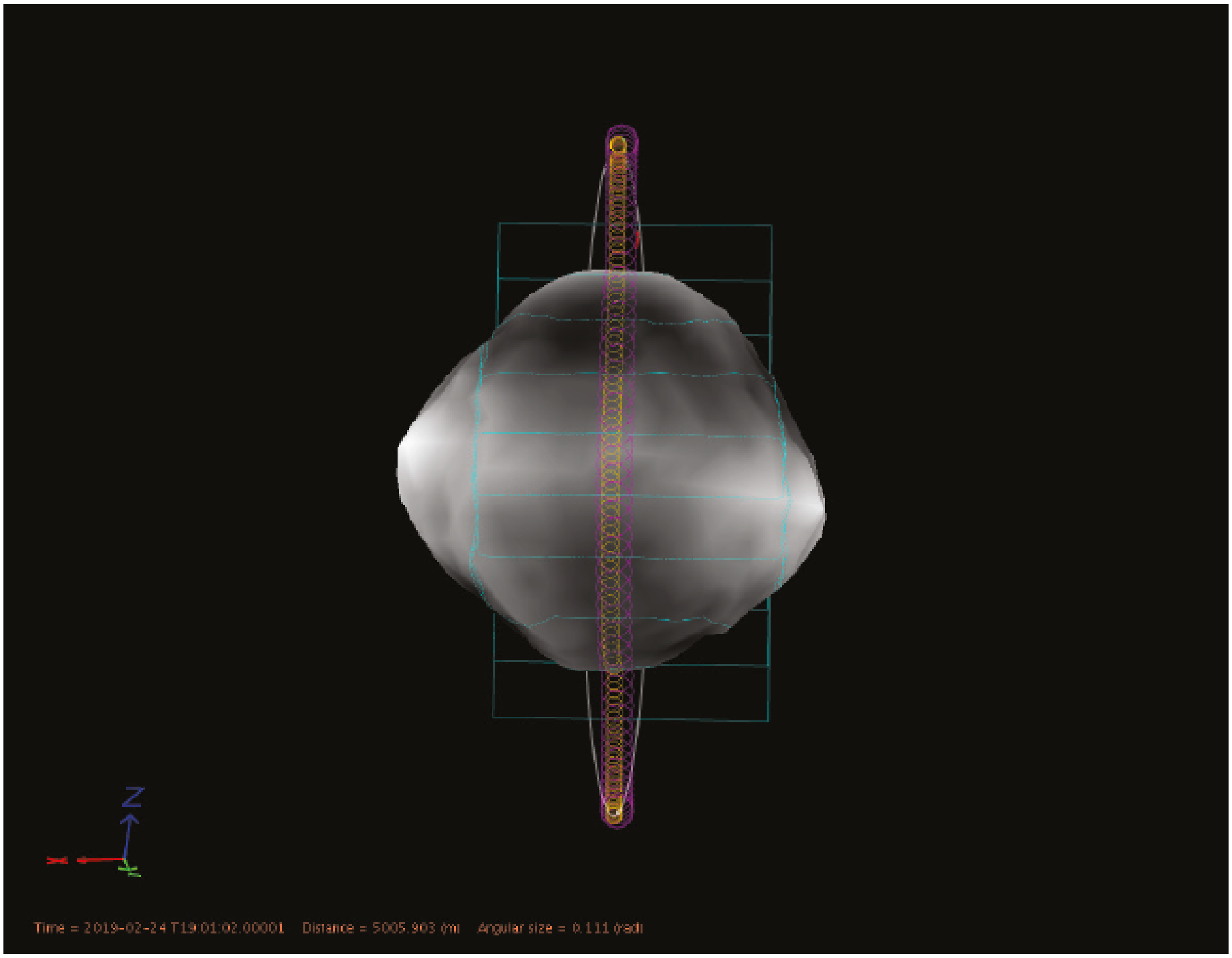

Figure 1: Nominal Equatorial stations plan. MapCam in blue, OTES in pink, OVIRS in yellow. OLA is not pictured.

There are a few exceptions to the nominal plan described above. The 12:30 station is the only station that will use velocity clocking and is planned to only overshoot one pole at a time in order to minimize excursions outside the Operational Safe Sone (OSZ). Note that the OSZ is pending updates and thus the OSZ numbers listed below and in Table 3 are expected to change. Without utilizing this strategy of overshooting one pole at a time, we excurse the OSZ for 85.36 minutes. Utilizing this strategy brings us down to 55.77 minutes. For the first 2.25 hours, the OVIRS and OTES slews will overshoot the south pole by 24mrad and for the last 2.25 hours the OVIRS and OTES slews will overshoot the north pole by 24mrad. The OVIRS gores described above are partially a result of the transition from the south overshoot to the north overshoot. MapCam will still be planned as described above, to only cover the Bennu disk. OLA will also continue to operate in ride-along mode. In addition, during the last ~45 minutes of the 12:30-station observations, the Keep Out Zone (KOZ) for Star Tracker 1 is violated by the sun for 8.7 minutes. The rev 5 trajectory and updated version of J-Asteroid no longer show this violation, however there may still be a possibility of Bennu-based Star Tracker violations during the 12:30

station. This is not a safety issue but could result in pointing degradation if the violation continues for a long time. This will continue to be investigated.

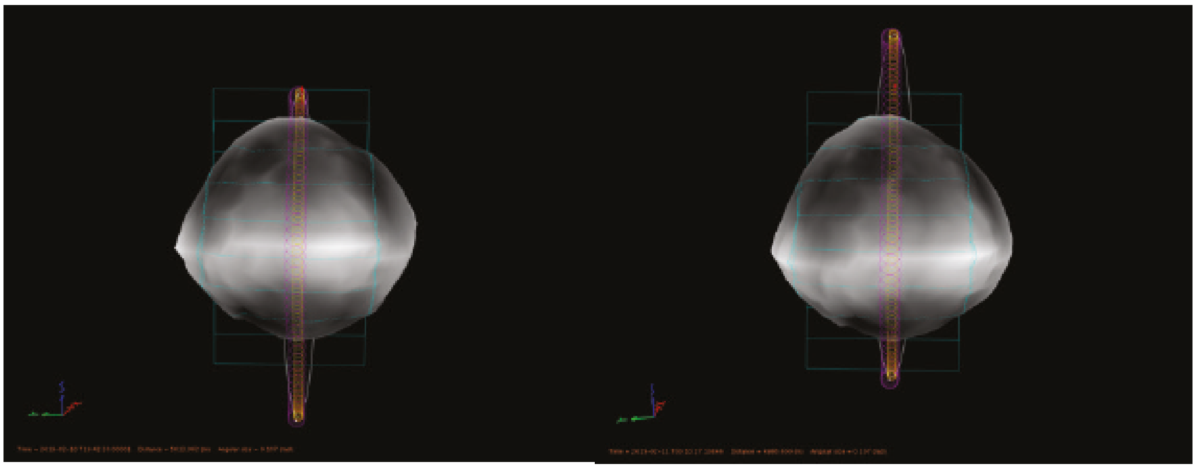

Figure 2: 12:30pm station with 24mrad overshoot on the south pole only (left) and 24mrad overshoot on the north pole only (right).

The 3:20am and 6am stations are also exceptions to the rule. At the end of the nominal 4.5-hour window, additional off-nadir observations will be taken for a quarter rotation of Bennu (~1.1hours). During the 3:20am station, the spacecraft will look at 8am and during the 6am station the spacecraft will look at 7am. The linear scans will still be planned to overshoot both poles by 24mrad. OVIRS is the primary instrument for these observations but OTES and MapCam will also be operating. MapCam will change filters every slew as nominally planned.

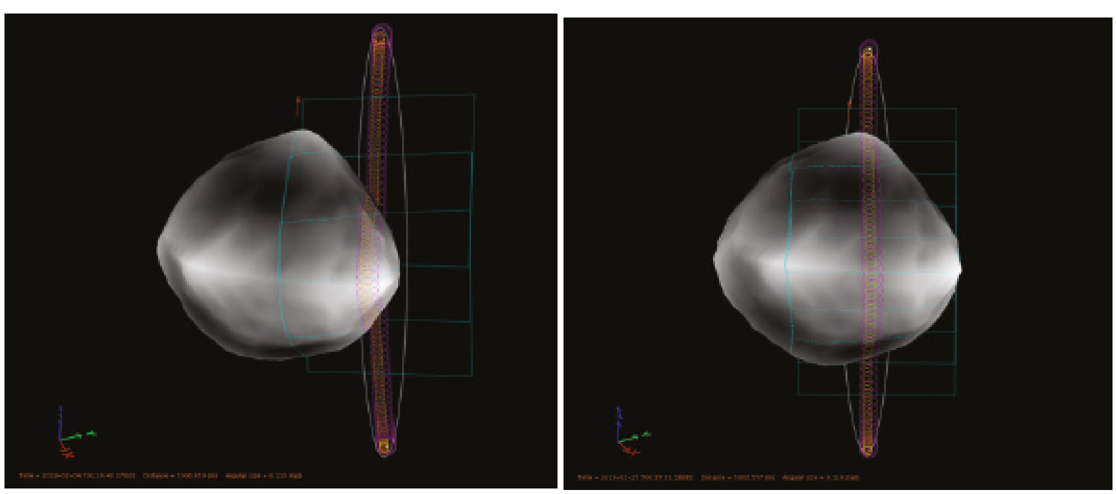

Figure 3: 3:20am off-nadir station looking to 8am (left) and 6am station looking off-nadir to 7am (right). Note that the 3:20am off-nadir observations only have 3 MapCam images per slew whereas the 6am off-nadir observation include 5 MapCam images per slew.

As a final note, due to limitations in the current version of J-Asteroid, the 10am station produced abnormal results that include much longer slew durations and significant OVIRS gores. As of now J-Asteroid can only plan slews in the direction of the trajectory. In the case of 10am, the trajectory does not exactly follow the Bennu north-south pole lines and therefore the slews also do not. A new J-Asteroid capability will be implemented that should enable slews to be pivoted to better align with the desired direction. It is expected that with this capability, the 10am station will produce results very similar to the 3pm station.

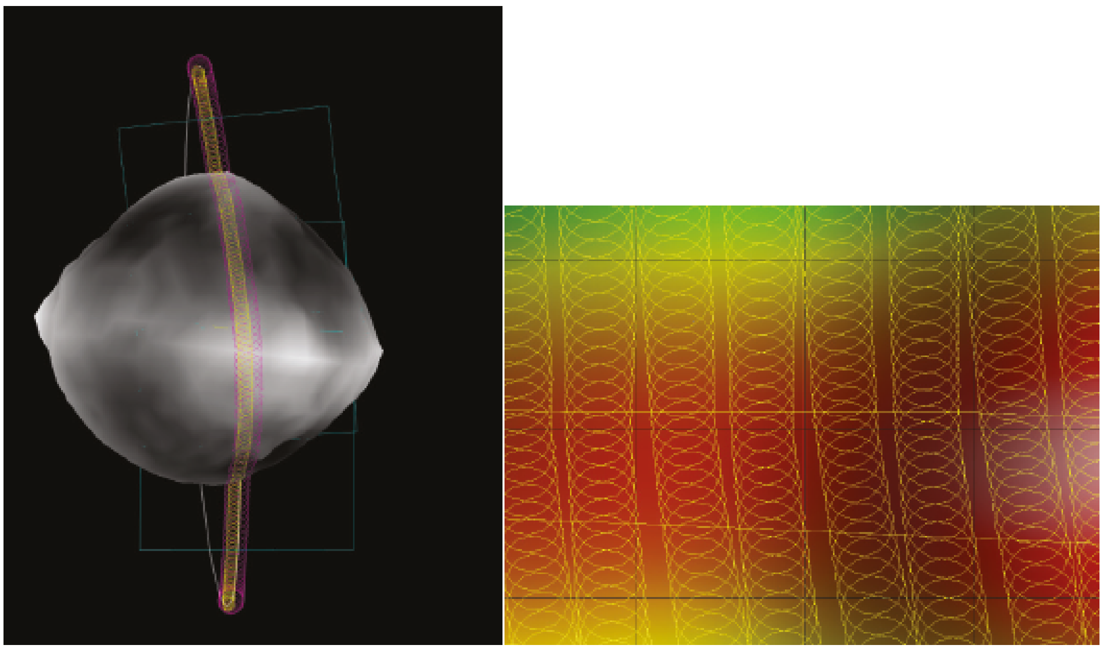

Figure 4: 10am station where slew does not follow Bennu north-south poles producing longer slews and significant OVIRS gores.

Nominal Equatorial Station plans were produced in J-Asteroid assuming a Bennu polar dimension of 508m. In order to overshoot the poles by 24mrad for the purpose of spectrometer calibrations, 121m was added to the end of each pole making the total dimension of 750m. MapCam observations were always planned to 508m and 2-sigma along-track navigational uncertainties and the spectrometers were planned to 750m and 2-sigma along-track navigational uncertainties. In addition to the nominal planning, an analysis was conducted to determine whether the plan would break if planned with the maximum Bennu polar dimension for Bennu of 550m. This analysis was conducted on the 3pm and 6am stations with MapCam planned to 550m and 2-sigma navigational uncertainties and the spectrometers planned to 792m to account for the 24mrad overshoot of the poles. This plan resulted on average in a ~2 sec. slew duration increase. Though this slight slew duration increase did produces more gores between slews in the 3pm station, the gores did not increase in size and can likely be mitigated when new J-Asteroid slew pivot capabilities are implemented. The 6am station continued to not produce any gores. Ultimately, this analysis showed that the Equatorial Stations plans do not break if indeed Bennu has the maximum possible polar radius.

Calibration Plan:
OCAMS – Before the first science slew of each station, 5 MapCam dark images are taken for each exposure time used for the science observations. After the last science slew of each station, 5 additional MapCam dark images are taken for each exposure time used for the science observations.

OTES – Deep Space calibrations conducted before and after each station. Internal calibration observations are to be conducted once every ~20 minutes for the duration of a single slew. Depending on the station and length of the slews, this works out to an OTES internal calibration every 7th to 11th slew.

OVIRS – Two Solar calibrations will be planned in support of OVIRS Equatorial Stations observations. The first will occur three days prior to the first equatorial station conducted. The second will occur three days after the last equatorial station conducted. The Solar calibrations will produce a baseline with the Deep Space and internal calibrations that accompany each station (described in the next paragraph) providing trending data between the Solar calibrations.

Stand-alone Deep Space calibrations (including blackbody and filament internal cals) conducted before and after each station. Blackbody calibrations are conducted at one end of each slew. Filament calibrations are conducted at the other end of each slew. During the 12:30 am station where only one end of a slew is off-body, filament and blackbody calibrations are acquired on alternating slews. If this cannot be accomplished for any reason, filament calibrations can be done on every scan instead.

Dust Plume Search

After the 3:20 am and 8:40 pm stations, a search for dust in the vicinity of Bennu will be conducted with MapCam. OVIRS and OTES will be active as ride-along instruments. The observing geometries of the searches will leverage the light scattering properties of dust particles due to forward scattering at high phase angles.

The dust searches will begin 9 hours after equator crossing for both 3:20 am and 8:40 pm stations. This start time ensures that no KOZ violations occur for 3-sigma trajectory dispersions.

The dust search mosaics consist of 8 targets imaged in an annulus (ring) around Bennu and a single target centered on the sunlit portion of Bennu. The cadence of observations is as follows:

1. instrument calibrations (described below)

2. single target centered on the sunlit portion of the Bennu
3. eight (8) targets imaged in an annulus (ring) around Bennu
    steps 2 and 3 are conducted 15 times
4. single target centered on the sunlit portion of the Bennu
5. instrument calibrations (described below)

The single target biased towards the sunlit portion of Bennu is offset from the Bennu nadir point by +100 mrad in the X (sunward) direction. The radius of the annulus along which the center of each MapCam FOV is placed is 450 m and offset from the Bennu nadir point by +30 mrad in the X (sunward) direction. Over 4.3 hours, 14 annulus mosaics can be conducted resulting in a rotational resolution of 26°.

OVIRS and OTES will ride-along during the Dust Search and collect data for the entire 4.3 hours.

- Instrument: OCAMS – MapCam, OTES, OVIRS
- MapCam Filter(s): Panchromatic
- Observations Type(s): Point and Stare, Annulus Mosaic
- Spacecraft clocking: Sun clocking with -0.96 rad (-55 deg) angular offset to minimize scattered light onto the MapCam detector
    - Additional analysis is required by the SPT and MSA to determine if there are any thermal or power limitations due to this sun clocking angular offset
- Settle Time: 30 seconds
- Number of mosaics: 14
- Number of targets per mosaic: 9
- Number of images per target:
    - Off-limb target: 5 long images
    - On-limb target: 1 short and 2 long exposures
- Total number of images: 605 science images + 20 sky flat images + 20 dark images = 645 total images per station
- Rotational Resolution: ~26 degrees
- Exposure Times (subject to change):
    - Short: 20 msec
    - Long: 5000 msec

Calibration Plan:
OCAMS

Before the start of dust search science observations

1. Five darks are acquired at the short exposure duration and five darks are acquired at the long exposure duration.

2. Five regular (light) observations are obtained at the long exposure duration. The images will be used to produce a 'Flat field' to correct for any scattered light from the spacecraft onto the MapCam detector. These observations are taken of a region of deep

space with an X-offset of +120 mrad from the center of Bennu placing the image >1 MapCam FOV from the limb of Bennu. The images will have the same Sun clocking angle as the Dust Survey images (-0.96 rad [-55 deg] angular offset).

3. Five additional regular (light) observations are obtained at the long exposure duration in order to produce a 'Flat field'. These observations are taken of a region of deep space offset with an X-offset of -120 mrad from the center of Bennu placing the image >1 MapCam FOV from the limb of Bennu. The images will have the same Sun clocking angle as the Dust Survey images (-0.96 rad [-55 deg] angular offset).

After the end of dust search science observations:
1. Five regular (light) observations are obtained at the long exposure duration. The images will be used to produce a 'Flat field' to correct for any scattered light from the spacecraft onto the MapCam detector. These observations are taken of a region of deep space with an X-offset of +120 mrad from the center of Bennu placing the image >1 MapCam FOV from the limb of Bennu. The images will have the same Sun clocking angle as the Dust Survey images (-0.96 rad [-55 deg] angular offset).

2. Five additional regular (light) observations are obtained at the long exposure duration in order to produce a 'Flat field'. These observations are taken of a region of deep space offset with an X-offset of -120 mrad from the center of Bennu placing the image >1 MapCam FOV from the limb of Bennu. The images will have the same Sun clocking angle as the Dust Survey images (-0.96 rad [-55 deg] angular offset).

3. Five darks are acquired at the short exposure duration and five darks are acquired at the long exposure duration after all other dust survey observations.

OTES – Deep Space calibrations conducted before and after each dust search. Internal calibration observations are not conducted during the dust search.

OVIRS – Stand-alone Deep Space calibrations (including blackbody and filament internal cals) conducted before and after each dust search. Internal calibration observations are not conducted during the dust search.

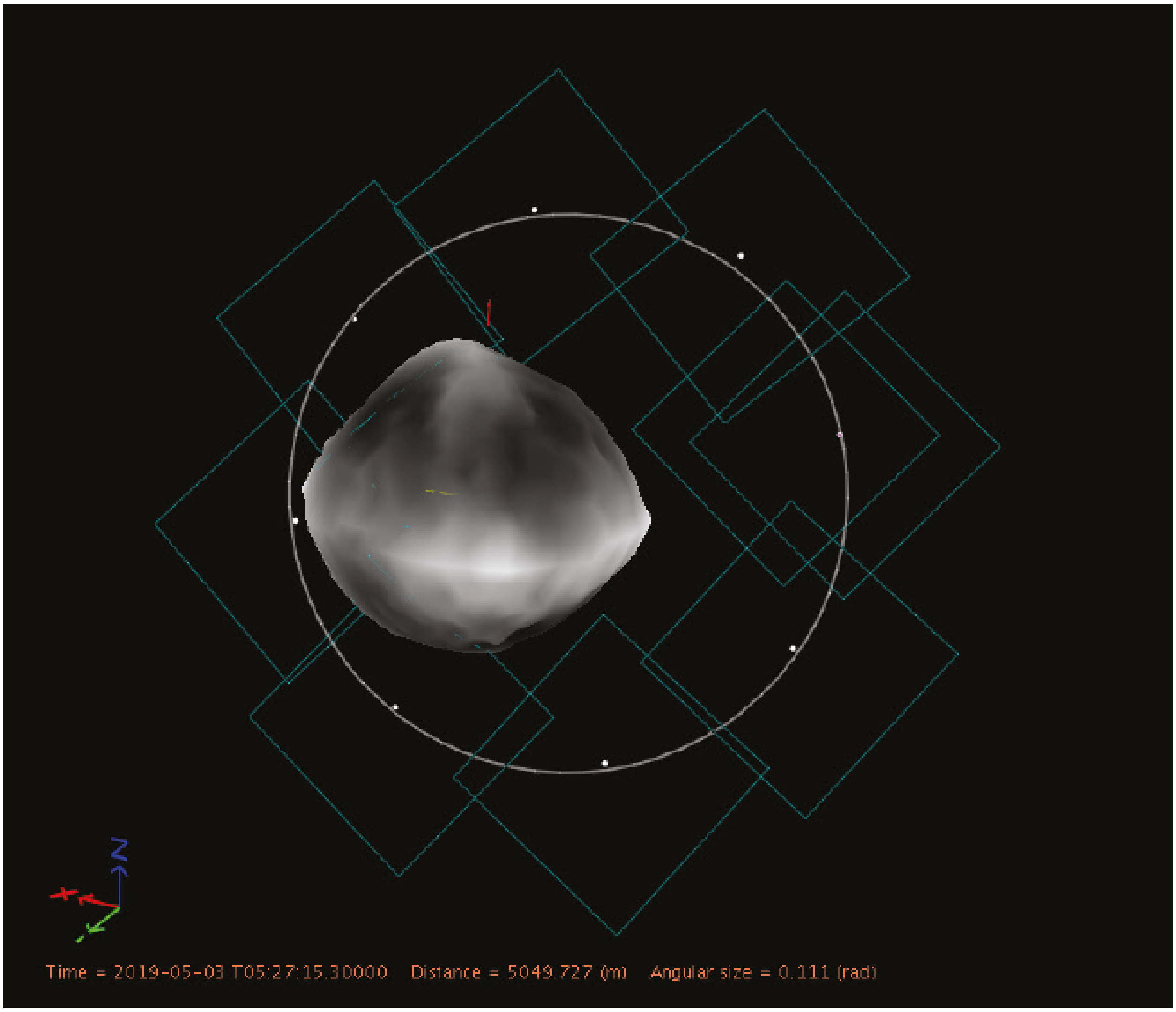

Figure 5 - Placement and orientation of 3:20 am dust plume search MapCam fields on 2018-May-03. The image shows the eight images along the annulus (ring) and the single image biased towards the sunlit part of Bennu. The Sun is located off the right of the figure. Image produced in J-Asteroid.

Operational considerations:

The slow slew rate is 2.0 mrad/s, and the fast rate is 5.0 mrad/s. Both slews use the slew acceleration rate of 0.0582 mrad/s^2. The linear scan observations use the 2 mrad/sec slew rate.

The 12:30 PM station will use velocity clocking and will experience excursions outside the operational safe zone.

Because the activities are scheduled 7 days apart, we have planned data volumes based on the instruments being off between the stations with the exception of REXIS, which is on continuously but not collecting science data.

The maneuver dispersion uncertainties (represented in a Monte Carlo analysis by FDS) are too large to allow the execution of the specified observations without using the late update capability. The observations described in this document use the TSE assigned to that particular station, which means that a 24 hr late update is assumed. The activities scheduled to occur immediately after the equatorial station window will use the same TSE as the equatorial station.

The 3:20 am and 8:40 pm stations both include a dust plume search scheduled to start 9 hours after equator crossing. The observation templates that apply to these 3:20 AM and 8:40 PM stations are only valid if the sun range is greater than 1.0 AU.

With the relative-ATL capability in place, the late update is expected to be limited to a time shift accompanied by an update to the onboard ephemeris which updates the nadir reference. At the 2 sigma level, a shift of +/- 1.5 hours around the nominal observation window is expected (see table below). The observation template should be constructed to allow for such a shift in the science window during the late update time period.

Table 6 - This table looks at what the delta time (in minutes) is for a latitude crossing for the nominal case and a transverse perturbation, based upon the rev5 SPP input reference trajectory and the maneuver burn dispersion data referenced in the input products section.

Case	Nominal Equator Crossing (UTC)	1-sigma Correction (sec)	2-sigma Time Correction Needed (minutes)
Station 1 - 3 PM	2019/04/25 20:00:00	2291.536	76
Station 2 – 3:20 AM	2019/05/02 20:00:00	2034.619	68
Station 3 - 12:30 PM	2019/05/09 20:00:00	2193.14	73
Station 4 - 10 AM	2019/05/16 20:00:00	2371.637	79
Station 5 - 6 AM	2019/05/23 20:00:00	2199.212	73
Station 6 – 8:40 PM	2019/05/30 20:00:00	2322.617	77
Station 7 - 6 PM	2019/06/06 20:00:00	1774.398	59

Requirements

Global Spectral Mapping (MRD-140)

Requirement:

MRD-140: OSIRIS-REx shall, for >80% of the asteroid surface, map those spectral features listed in MRD-140 Table (Absorption Features of Key Mineralogical & Organic Molecules) with > 5% absorption depth and <50m spatial resolution.

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

Instrument/s	OTES		OVIRS	
Station/s	ALL, 3pm Prime	✓	ALL, 10am Prime	✓
Coverage	≥80%	✓	≥80%	✓
Sub S/C lon. Uncertainty	±6°	✓	±6°	✓
Sub S/C lat. Uncertainty	±5°	✓	±5°	✓
Pointing	Nadir-relative scanning ±7.5°	✓	Nadir-relative scanning ±7.5°	✓
Footprint	<50m	✓	<50m	✓
SNR	>320	✓	>50	✓

Data Products:
Global Spectral Mapping (MRD-140) includes the Global Mineral and Chemical Maps (SA-40) and the Global Dust Cover Index Map (SA-35) HiLPs. These products are generated with OVIRS data (primarily acquired at the 10am station) and OTES data (primarily acquired at the 3pm station) using the SPOC programs Get_Spots and Makes_Maps. These maps feed the Global Safety Map and Global Science Value Map. All of the products associated with MRD-140 are produced by SAWG.

Global Temperature and Thermal Inertia Maps (MRD-155)

Requirement:
MRD-155: OSIRIS-REx shall, for > 80% of the asteroid surface, measure the absolute flux of thermally emitted radiation with < 3% accuracy and produce maps of the temperature at seven different solar times plus the derived thermal inertia at spatial resolution < 50m.

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

Instrument/s	OTES	
Station/s	ALL	✓
Coverage	≥80%	✓
Sub S/C lon. Uncertainty	±6°	✓
Sub S/C lat. Uncertainty	±5°	✓
Pointing	Nadir-relative scanning ±7.5°	✓
Footprint	<50m	✓

Data Products:

The Global Temperature Maps (TA-007) and Global Thermal Inertia Maps (TA-002) are the HiLPs that satisfy MRD-155. TA-007 is generated using OTES data form all 7 stations and then TA-002 is generated using TA-007 in combination with Global Bolo Bond Albedo (SA-37). TA-002 is also used as input to a Global Predicted Temperature Map (TA-009), which contributes to satisfying the Thermal Model for Operations Support requirement (MRD-411). TA-009 ultimately feeds the Global Safety Map. Data collected for MRD-155 also feeds MRD-156 which describes the Comprehensive Thermal Model requirement and contributes to MRD-140. These MRDs feed the Global Safety Map, the Global Sampleability Map, and the Global Science Value Map. TAWG is responsible for producing the products associated with MRD-155.

MapCam and OVIRS Photometric Models (MRD-149)

Requirement:
MRD-149: 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:
Observation constraints are with respect to the Sun North Coordinate Frame.

Instrument/s	MapCam	
Station/s	ALL	✓
Coverage	≥80%	✓
Sub S/C lon. Uncertainty	±6˚	✓
Sub S/C lat. Uncertainty	±5˚	✓
Pointing	Nadir-relative scanning ±7.5˚	✓
Filters	pan, b, v, w, x	✓
SNR	≥100	✓

Instrument/s	OVIRS	
Station/s	3pm, 12:30, 10am	✓
Coverage	≥80%	✓
Sub S/C lon. Uncertainty	±6˚	✓
Sub S/C lat. Uncertainty	±5˚	✓
Pointing	Nadir-relative scanning ±7.5˚	✓
Footprint	19.1m	✓
Along-Slew Overlap	~50% (central 75% revieves 90% signal	✓
Across-Slew Overlap	~50% (central 75% revieves 90% signal	✓
Incidence Angle	0˚ to 90˚	✓
Emission Angle	0˚ to 90˚	✓
Phase Angle	0˚ to 37.5˚	✓

Instrument/s	OVIRS		OVIRS	
Station/s	3:20am, 8:40pm	✓	6am, 6pm	✓
Coverage	≥80%	✓	≥80%	✓
Sub S/C lon. Uncertainty	±6˚	✓	±6˚	✓
Sub S/C lat. Uncertainty	±5˚	✓	±5˚	✓
Pointing	Nadir-relative scanning ±7.5˚	✓	Nadir-relative scanning ±7.5˚	✓
Footprint	19.1m	✓	19.1m	✓
Along-Slew Overlap	~50% (central 75% revieves 90% signal	✓	~50% (central 75% revieves 90% signal	✓
Across-Slew Overlap	~50% (central 75% revieves 90% signal	✓	~50% (central 75% revieves 90% signal	✓
Incidence Angle	0˚ to 80˚	✓	0˚ to 75˚	✓
Emission Angle	0˚ to 80˚	✓	0˚ to 75˚	✓
Phase Angle	100˚ to 135˚	✓	45˚ to 90˚	✓

Instrument/s	OVIRS		OVIRS
Station/s	6am off-nadir	✓	3:20am off-nadir
Pointing	off-nadir, looking to ~7am	✓	off-nadir, looking to ~7am

Liens

One DRM lien was associated with MRD 149. The observation plan as described in this SPP was sufficient to close the lien.

Lien-PHOMOD-1: Lien on the Planning Group at the SPOC: If the spacecraft is always pointed nadir from a stationary position at the equator, then we may not obtain sufficient emission angle coverage - it is important to work with the Photometric Modeling team to ensure that observations are planned with sufficient phase and emission angle sampling for both Imaging and Spectroscopy.

Data Products:

MapCam and OVIRS Photometric Models (MRD-149) include a panchromatic photometric model using MapCam panchromatic images, a color photometric model using MapCam b,v, & w-filter images, an x-band photometric model using MapCam x-band images, and OVIRS photometric models using OVIRS data. The primary data for the MapCam photometric models will be acquired from all 7 stations. The primary data for the OVIRS photometric models will be acquired at all 7 stations with the addition of off-nadir data collected at the 3:20am station and 6am station. In addition, to fully satisfy MRD-149, some data is planned to be collected during Approach and Preliminary Survey. The OVIRS data collected for MRD-149 will also contribute to the Global Bolo Bond Albedo Map (MRD-154) and the Comprehensive Thermal Model (MRD-156). The photometric models ultimately feed the Global Safety Map, the Global Sampleability Map, and the Global Science Value Map. Furthermore, the MapCam photometric model is critical for photometrically correcting the PolyCam images mosaics which will be used as a base maps on the shape model to view virtually all other data on top of.

Dust and Gas Plume Search and Characterization (MRD-142b and MRD-143)

Requirement:
MRD-142: OSIRIS-REx shall search for dust and gas plumes originating from the asteroid surface, and characterize their source regions and column densities.
MRD-143: OSIRIS-REx shall characterize the spectral properties of any detected dust and gas plumes.

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

Instrument/s	MapCam	
Station/s	3:20am, 8:40pm	✓
Coverage	100%	✓
Sub S/C lon. Uncertainty	±6°	✓
Sub S/C lat. Uncertainty	±5°	✓
Pointing	On and off limb on both dark and light limbs Look at 9:20am and 9:20pm for the 3:20am station and look at 2:40am and 2:40pm for the 8:40pm station	✓
Filters	pan	✓
SNR	10	✓
Pixel Size	0.5m	✓
Incidence Angle	130° to 135°	✓
Emission Angle	90°	✓
Phase Angle	130° to 135°	✓

Data Products:
The Dust and Gas Plume Search (MRD-142b) requires MapCam images at the 3:20am and 8:40pm stations in order to get good on- and off-limb data. Though characterized as a contingency MRD, Dust and Gas Plume Spectral Characterization (MRD-143) will also be satisfied during this time with OVIRS and OTES data from the 3:20am and 8:40pm stations. The OVIRS and OTES data collected here is secondary and does not drive operations. Ultimately from these observations, a Global Plume Density Distribution (RD-8) product will be produced and will contribute to the Global Safety Map and Global Science Value Map.

Global 75cm Shape Model from OLA (MRD-678b)

Requirement:
MRD-678b:

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

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

Instrument/s	OLA	
Station/s	3pm, 12:30pm, 10am, 6am, 6pm	✓
Spot Spacing	1m	✓
Footprint	<1m	✓

Proper fulfillment of MRDs can be achieved with 200 µrad spot spacing across and along the slews. With the 100 Hz repetition rate of OLA, we achieve an average spot spacing of about 300 µrad, so we don't satisfy this constraint with a single station. Since we are collecting data from three different stations, however, we will ultimately get a point spacing that exceeds the 200-µrad constraint.

Data Products:
The 75cm shape model from OLA (MRD-678b requires we get OLA data from all stations except from the 3:20am and 8:40pm. These observations are categorized as ride-along and therefore do not drive operations. There is currently no plan to officially deliver a 75cm shape model from OLA, rather this data will be used to contribute to the 5cm Local DTMS from OLA (MRD-115b), Shapemodel Center of Figure (MRD-124), Rotation Pole (MRD-127), Wobble of Rotation (MRD-128), Rotation Period (MRD-129), and Bennu Volume (MRD-132), and NFT TAG Site DEMs (MRD-732 & MRD-734).

Global 35cm Shape Model from SPC (MRD-687a)

Requirement:
MRD-687a: The Ground System shall, for >80% of the asteroid surface, produce a set of DTMs at <0.35m in ground sample distance (sample resolution).

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

Instrument/s	MapCam	
Station/s	ALL	✓
Coverage	≥80%	✓
Sub S/C lon. Uncertainty	±6˚	✓
Sub S/C lat. Uncertainty	±5˚	✓
Across Slew Overlap	20%	✓
Along Slew Overlap	20%	✓
Pixel Size	≤.32m	✓
SNR	>2-0	✓
Emission Angle	Want limb images at <50˚, otherwise no maximum	✓

Data Products:
The 35cm shape model from SPC (MRD-687a) is also characterized as "ride-along. The MapCam observations required for MRD-149 and MRD-141 will drive the observations for MRD-687a. This data will contribute to Sample-site Tilt Maps from SPC (MRD-608a), 300 NFT features (MRD-728), and NFT TAG Site DEMs (MRD-732 and MRD-734). Nominally, the 75cm shape model from SPC (MRD-678a) will be used for all global mapping so the 35cm shape model from SPC (MRD-687a), depending on delivery schedule, may or may not feed into other HiLPs and global top maps. However, the 35cm shape model from SPC is required to transition from Orbital B to Recon.

Derived Products Summary:

	MRD-140	MRD-142b	MRD-149	MRD-155	MRD-143	MRD-678b	MRD-687a
MRD-115a							✓
MRD-115b						✓	
MRD-124						✓	
MRD-127						✓	
MRD-128						✓	
MRD-129						✓	
MRD-132						✓	
MRD-154			✓				
MRD-156			✓	✓			
MRD-411				✓			
MRD-608a							✓
MRD-728							✓
MRD-732						✓	✓

Driving Requirement
Ride-Along Requirement
Derived Product