Reconnaissance A Science Phase Plan

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Purpose

The purpose of this document is to describe the nominal observation plan for part A of the Reconnaissance phase of the mission, which includes 4 high (1000-1250m) Detailed Survey-like flybys of 4 candidate sample sites. 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 and constraints. The second half of this document focuses 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_2019-08-07

SPK for SPP development:

- Flyby 1: orx_190805_191010_190712_od165-R-M1C-P-M3R_v1.bsp

SPK for Recon A tactical planning:

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

TSE file on ODOCS: OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\Recon\orx_tse_190920_191001_High-Recon-TM11-Baseline_v1

Observation Envelope and Templates: ReconA_Templates.r7

Kernel set for SPP development:

- naif0012.tls
- pck00010.tpc
- bennu_v14.tpc
- de424.bsp
- orx_190805_191010_190712_od165-R-M1C-P-M3R_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_12580mm_spc_obj_0000n00000_v020.bds
- ORX_SCLKSCET.00045.tsc
- orx_struct_polycam_v01.bc
- orx_struct_mapcam_v01.bc

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

- NAV DELIVERY OF REFOD165 (EX07 HIGH RECON FLYBY AND DS BBD2 REFLY)_CCv0001.pdf
- 190717_EX07Recon1250m_DeliverySummary.pptx

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

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

Locations and vectors used for FDS trajectory design:

- EX07: -47.18, 321.33 [0.593, -0.401, -0.698]
- DL06: 13.41, 89.00 [0.0674, 0.8972, 0.4364]
- CQ13: 11.254, 55.775 [0.34802, 0.84379, 0.40853]
- DL15: 57.28, 44.63 [0.4483, 0.5337, 0.7171]

Site locations for planning:

- EX07 site: -47.18, 321.33
- EX07 NFT footprint: -50.50, 322.00
- DL06 site: 11.69, 87.93
- DL06 NFT footprint: 13.41, 89.00
- CQ13 site: 11.254, 55.775
- CQ13 NFT footprint: 13.50, 57.00
- DL15 site: 55.50, 40.72
- DL15 NFT footprint: 57.28, 44.63

MRD Overview

There are a total of 6 MRDs with defined science observation constraints for the Reconnaissance phase. Recon A is primarily driven by Natural Feature Tracking (NFT). In addition to NFT, Sampleability is a secondary priority. Color imagery and spectroscopy are best-effort.

Table 1 Full list of Recon MRDs. In addition to those listed here, MRD-141 will be satisfied by the DS BBD FB2 re-fly.

MRD#	Description	Derived MRDs	Recon	Phase Driver?
115b	5cm DTMs from OLA	608b	B	YES
116	Sampleability/Local PSFD, Local Particle Database/Particle Maps, & Local image Mosaics	NONE	A/B	YES/YES
118	Local Minerals and Organics Maps and Local Dust Cover Index Maps	NONE	A/B	NO/NO
119	Sample Site Color Maps	NONE	A/B	NO/NO
540	Local Thermal Inertia Maps	411	A/B	NO/NO
728	300 NFT Features	115a 730 732	A/B	YES/YES

The primary goal of Recon A is to observe an area centered on the NFT footprint for the first image post Match Point for 4 candidate sample sites with appropriate viewing geometry such that NFT features can be built to be used during TAG. The necessary viewing geometry includes 5 different “looks”:

1. Topography suite North look
2. Topography suite South look
3. Topography suite East look
4. Topography suite West look
5. Albedo look

It is the plan to achieve the albedo look and two of the topography looks during Recon A. The other two topography looks are being planned in Recon B. Imaging to assess Sampleability will be acquired during periods of time in between the NFT topography looks that provide the desired low emission and mid-phase angles. MapCam color will take advantage of the time surrounding the albedo looks.

An addional goal of Recon A is to re-fly the Detailed Survey Baseball Diamond (DS BBD) Flyby 2 to address lien 141-1. This lien resulted from degraded performance on this flyby as described in the section *Global Color Maps (MRD-141).*

Below is a summary of the observation constraints that were agreed upon during Recon meetings. The detailed observations constraints that were baselined in the Observation Constraints document can be found with the descriptions for each MRD. Some values in the summary table may vary from those in the Observation Constraint document due to compromises or analysis that were made post document approval. The constraints in the summary table are the constraints that were ultimately used for trajectory planning and J-Asteroid planning purposes.

Table 2 Observation constraints for the Recon high pass flybys

Activity	Projected Pixel Size (m/pix)	Range (m)	Coverage	Local Solar Hour	Emission Angle (deg.)	Phase Angle (deg.)	Incidence Angle (deg.)	Notes
PolyCam NFT Albedo	0.02	1000-1250	25m-radius area centered on 3s dispersed NavCam2 footprint for image 27	12pm ±30 min (prefer am side)	0-30	>10	±15˚ from site lat.	N/A
PolyCam NFT Topo	0.02	1000-1250	25m-radius area centered on 3s dispersed NavCam2 footprint for image 27	8am-4pm	20-45	>10	<60	1 set at 10 AM local time 1 set at 2 PM local time Delta Azimuth between these two sets > 45 deg (>80 desired)
PolyCam Sampleability	N/A	N/A	100% 2σ TAG ellipse	N/A	0-20	25-60	25-65	Ideally nadir pointed
MapCam Color	N/A	N/A	100% 2σ TAG ellipse	11am-1pm	0-30	5-15	0-30	For non-Equatorial sites, LSH and emission are the driving constraints. For higher latitude sites, desire is to be as close to noon as possible. **These observations are NOT a trajectory driver.**
OVIRS/OTES	5/8	1250/1000	≥40% of 2σ TAG ellipse/ ≥80% of 2σ TAG ellipse	10:30am-12pm	0-30	N/A	N/A	**These observations are NOT a trajectory driver.**

Observation Schedule

The Recon A mission phase is scheduled for September 9 through October 27, 2019 (WOY 37-43). The spacecraft will remain in the Orbital C frozen orbit for the first 12 days of Recon A. The maneuver to leave orbit is scheduled for September 21, with the following week (WOY 39) dedicated for the re-fly of Detailed Survey Baseball Diamond (DS BBD) Flyby 2 on September 26. After completing Flyby2, the Recon high pass flybys will be conducted on a weekly cadence with one flyby dedicated to each of the Final Four candidate sample sites.

WOY 37 (9/9-9/15) will be used for additional high cadence particle monitoring, with a pair of nadir long exposure NavCam images taken every 12.5 minutes. Particle monitoring imaging will be conducted on a two hour cadence (riding along with OpNavs) starting on September 16 at the beginning of WOY 38 and continuing through the end of Recon A, except during the Recon high pass flyby observation windows. No particle monitoring imaging will be conducted in the science observation windows for the high pass flybys.

For DS BBD Flyby 2, MapCam will be the primary instrument and OTES and OVIRS will ride-along. The observation will be done with the Point and Stare observation type, using all of the MapCam color filters. These data will fill in the missing northern hemisphere low-phase color imaging and will be used to resolve the current lien on MRD-141. See SOCR-168 for more information on the re-fly of DS BBD Flyby 2.

The following sections describe the Recon high pass flyby observations in detail.

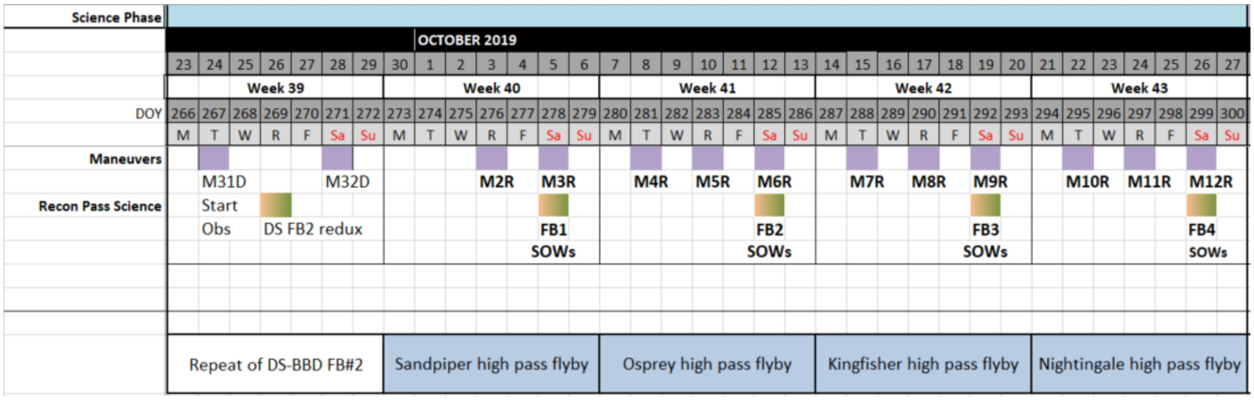

Figure 1 This Recon A flyby timeline shows the schedule for the re-fly of DS BBD Flyby 2 and the schedule for conducting the Recon high pass flybys over each of the Final Four candidate sample sites.

Observation Strategy

Collecting data during Recon presents many challenges:

1. The trajectory is such that the altitude of the spacecraft changes with time.
2. There are five different sets of observations to collect, each of which has different illumination and observation constraints
3. The areas to scan receive proper illumination for only a short period of time.
4. Higher altitudes provide a larger FOV, which makes coverage quicker, but too high an altitude degrades the spatial resolution.
5. The site specific observations are targeted to two different areas and the rough surface of Bennu and varying topography make it difficult to meet all of the observation constraints.

The data are collected via a flyover of the areas to be observed with the time of the observation sets coordinated to meet the constraints, as well as possible, to different illumination and viewing conditions as the areas rotate through different lighting conditions.

There are two different areas to be scanned: one is the size of the TAG region of interest, preliminarily chosen as a 10-m radius circle; the other is a 25-m radius circle large enough to encompass most of the area of the first NFT image expected to be taken following Match Point on the TAG trajectory. This radius was chosen in consultation with the NFT team to ensure we are covering a large enough area of the nominal and 3-sigma NFT footprint to identify and build features for NFT use during the TAG approach.

Observations of the TAG region of interest are intended to better understand the characteristics of the site in terms of its compositional differences (MapCam color and spectrometers) and its sampleability (PolyCam images to determine the proportion of larger and smaller rocks). This region is much smaller than the NFT region, but the constraints on the imaging are more stringent than for NFT.

As noted above, five different observations are needed for stereophotoclinometry (SPC) of the NFT region: four are looking at the site from four different (nearly orthogonal) directions to get topography, and the fifth is looking at high sun to get albedo information. Only two of the topography observation sets are made in Recon A.

Figure 2 shows the different areas that need to be observed for the EX07 Sandpiper candidate sample site. The results discussed in the next section are optimized as much as possible to satisfy all of the observational constraints, but compromises were necessarily made since not all of the constraints could be satisfied in the time available. In addition, since these are site specific observations of different regions on a rough surface with varying local topography, it is difficult to perfectly meet the observation constraints.

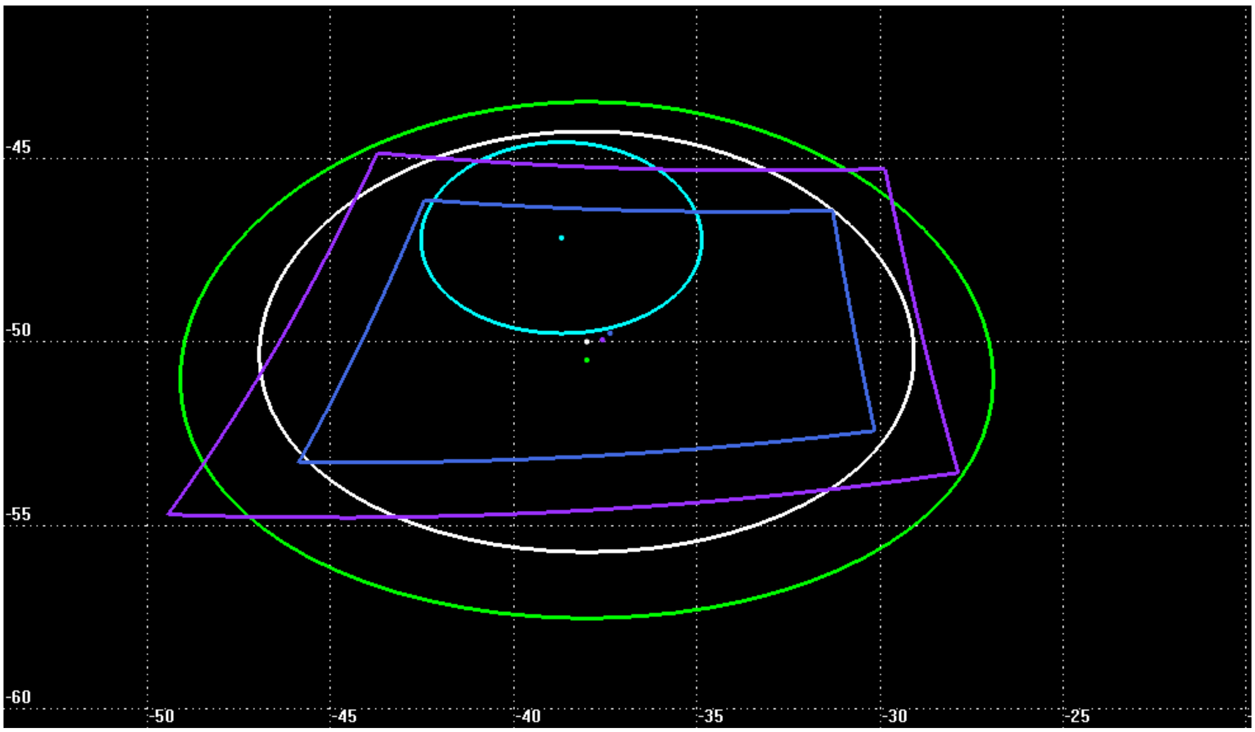

Figure 2 shows the areas to be observed during Recon A for site EX07 Sandpiper. The blue and magenta polygons show the limits of the nominal and 3-sigma footprints, respectively, of the first NFT image following Match Point. The white and green circles (22 and 27 meter radii) are example scan areas to sample these footprints. The blue circle (10 meter radius) defines the TAG region of interest. The circles show as ellipses due to the cylindrical projection. The actual size of the scan areas will be larger than the circles shown here to account for uncertainties in the location of the spacecraft during the Recon pass.

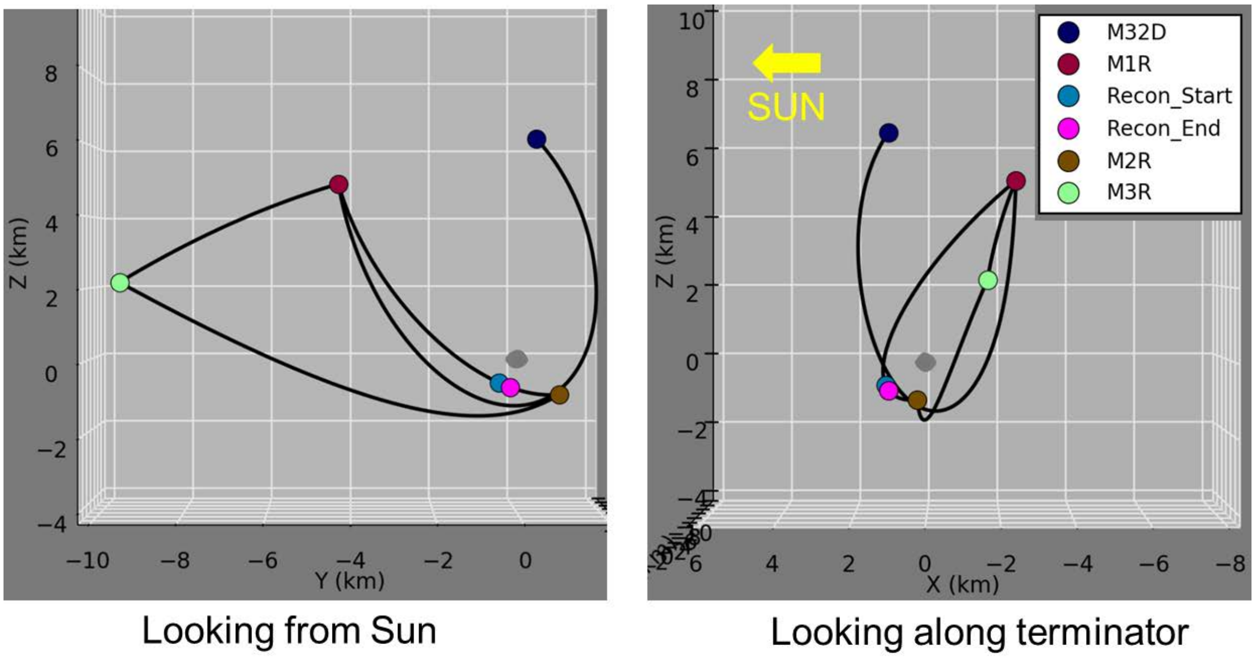

Figure 3 Illustration from FDS of trajectory design for EX07 Sandpiper. The observations take place between the blue and magenta circles.

Observation Plan

The ideal Recon A high pass flyby timeline is laid out below:

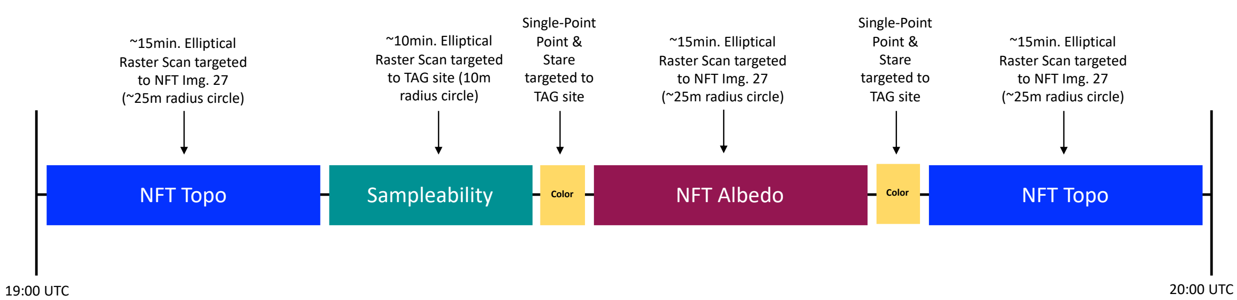

Figure 4 This shows the Recon high pass flyby timeline. Note that this timeline and observation durations are variable depending on the site. The Sampleability window may fall before or after the NFT Albedo window depending on how the observation constraint windows are achieved on the trajectory. In addition, it may only be possible to achieve one color observation.

All Recon A plans will be produced in J-Asteroid. NFT and Sampleability observations will be achieved using the Elliptical Raster Scan observation type boresighted to PolyCam. This observation type allows the planner to specify a local Bennu latitude/longitude and the X and Y radii for an ellipse (or circle) that is to be the targeted area to cover. The Elliptical Raster Scan attempts to minimize observation durations as much as possible by only covering the user-defined ellipse area and not producing a full rectangular scan pattern. Minimizing the observation duration is particularly important for Recon because we want 100% coverage of as large of an area as possible during the time period when specific viewing geometry observation constraints are met.

For each flyby there is ~60-75 minutes where the various observation constraints are met. Within that 60-75 minutes, a specific constraint (e.g., topo east) may only be met for 10-30 minutes and may overlap in part with another requirement's window. Given these limitations and the fact that there are 5 sets of observations for each flyover, observations are limited to have maximum durations of ~15-18 minutes. To further optimize for meeting observation constraints and to mitigate against relative asteroid surface motion, scans are set to slew North-South with respect to Bennu and begin on the leading edge of the ellipse. To help ensure the most robust image overlap and total ellipse coverage, FOVs are also specifically oriented such that each image lines up "square-to-square" as opposed to "diamond-to-diamond."

Color observations are planned as a best-effort and are single-target point and stare observations boresighted to MapCam so that a full color-set utilizing two different exposure times for each filter (pan, v, b, w, x) can be acquired where all color frames overlap ~100%. The spectrometers will be collecting data for the duration of the science observations on each flyby, but due to time constraints, pointing will not be optimized for spectrometer coverage. OVIRS coverage on a given Elliptical Raster Scan ranges from ~30-40% and OTES coverage ranges from ~65-75%.

The figures below show example scan patterns for the EX07 Sandpiper Recon high pass flyby.

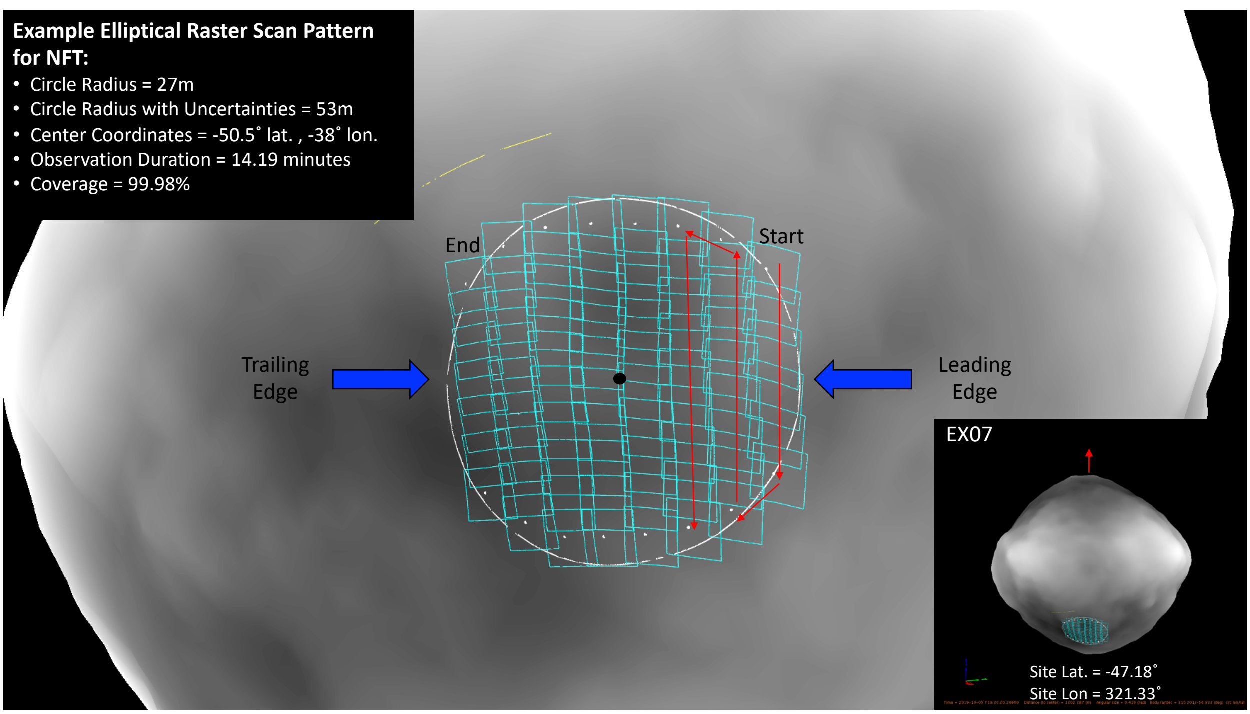

Figure 5 Elliptical Raster Scan observation for NFT at EX07 Sandpiper. The circle shown is the 53-m radius circle planned to allow for navigational uncertainties.

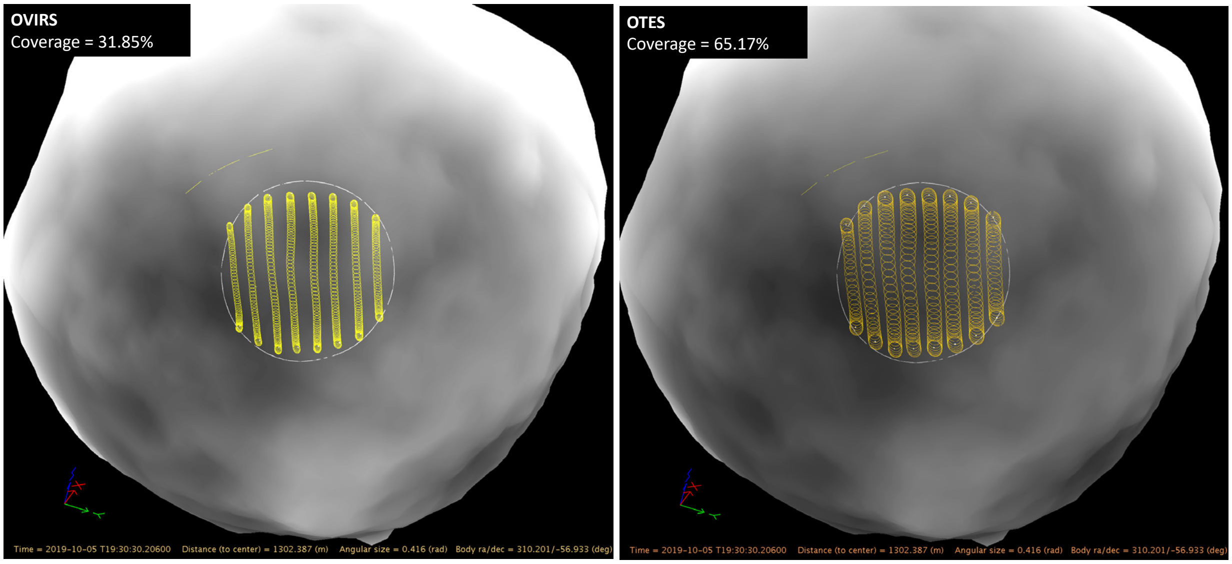

Figure 6 Spectrometer coverage for NFT observations at EX07 Sandpiper.

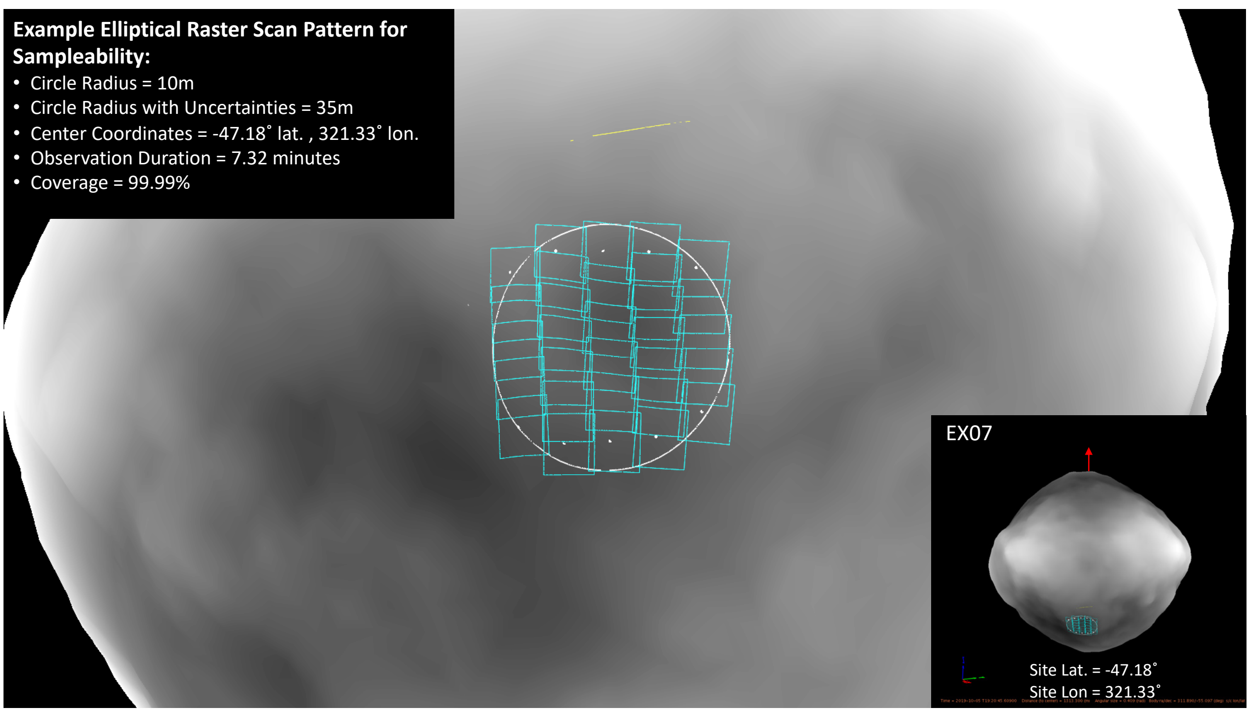

Figure 7 Elliptical Raster Scan with Polycam for Sampleability at EX07 Sandpiper. Here the circle is the 35-m radius circle actually scanned.

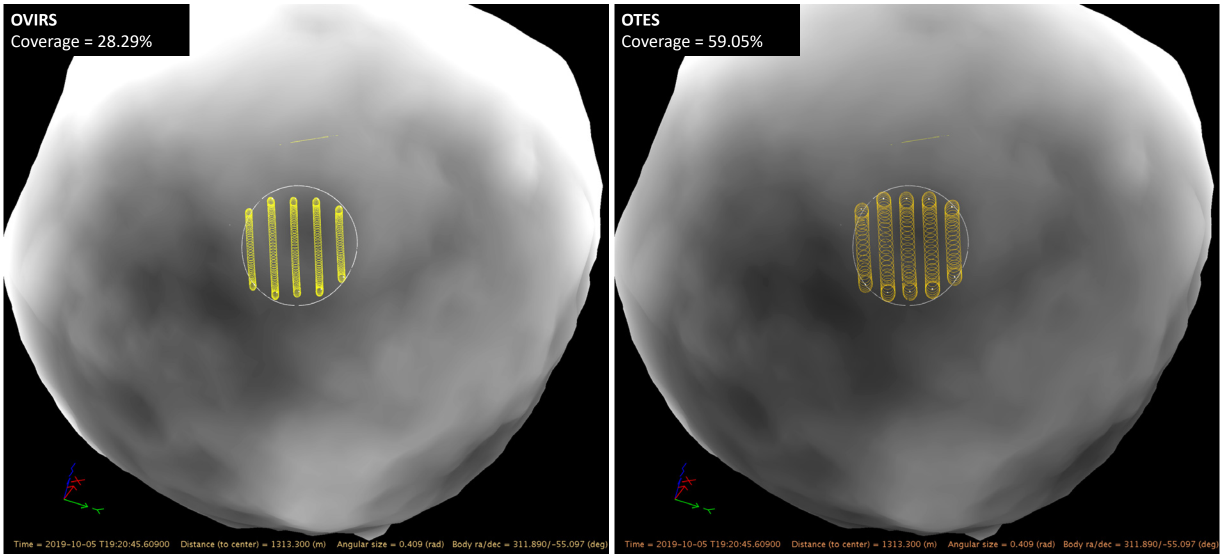

Figure 8 Spectrometer coverage for the Sampleability observation at EX07 Sandpiper.

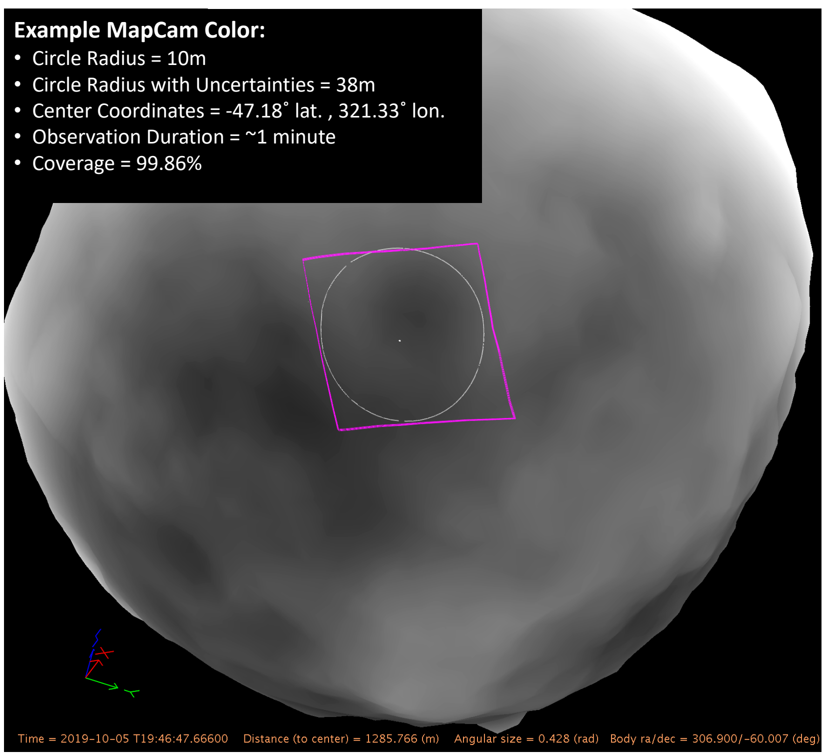

Figure 9 MapCam color observation for EX07 Sandpiper.

The trajectory design allows an ephemeris update to occur after the burn that initiates the observation leg and immediately before the observations execute on the spacecraft. This allows planning to the covariance uncertainties as opposed to the burn dispersion (Monte Carlo) uncertainties. However, since the nadir-relative frame is not a surface-relative targeting system, the observations need to be planned to cover more than the nominal covariance uncertainties to remain robust to the possible burn dispersions.

For all observations, to mitigate against loss of coverage due to trajectory perturbations from burn dispersions, we expand the sizes of the scan area to account for as much uncertainty as possible. Sensitivity analysis results using the full 1000 perturbed trajectories from the FDS Monte Carlo analysis have revealed that a ~3-4-sigma confidence interval of the covariance uncertainties is robust against perturbations. There is, however, some nuance to the accounting of these uncertainties. Rather than accounting for the transverse (along-track) and normal (across-track) errors in their respective directions, the larger of the two uncertainties, which are the transverse, are applied in both directions creating a circle that accounts for a ~3-4-sigma confidence interval in the transverse direction but much larger (nearly double) errors in the normal direction. MapCam color observations are not explicitly designed with a confidence interval for coverage robustness with perturbed trajectories. We are not mosaicking, so we are as robust as a single MapCam FOV can be.

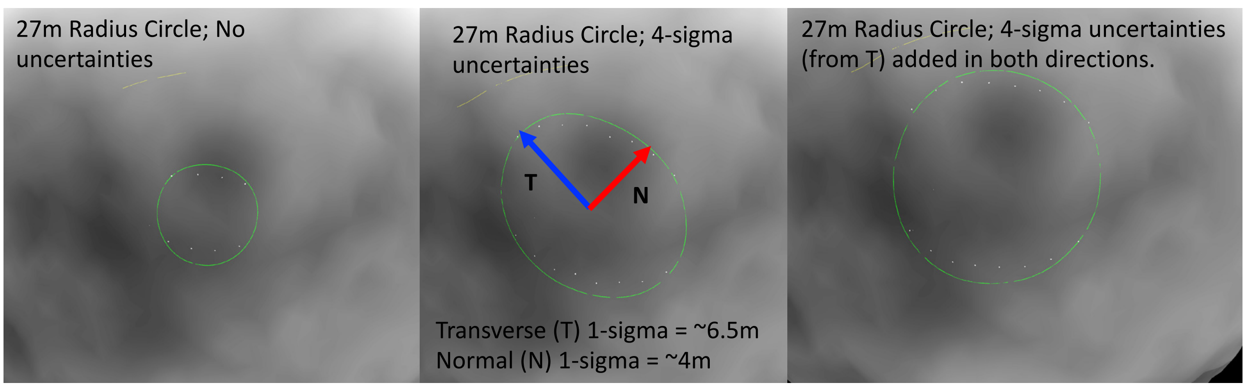

Figure 10 Example of how uncertainties are factored in to planning the scans.

Table 3 Sensitivity analysis results for EX07 Sandpiper using all 1000 perturbed trajectories delivered from FDS, showing the percentage of perturbed trajectories that result in a specific coverage achieved for the area of interest.

Objective	**Topo 1**	**Sampleability**	**Albedo**	**Topo 2**
Target	**EX07 NFT Image**	**EX07**	**EX07 NFT Image**	**EX07 NFT Image**
== 100%	96.70	63.26	98.00	99.00
>= 98.5%	98.00	70.67	98.40	99.50
>= 95%	98.40	78.38	98.80	99.50
>= 90%	98.70	84.68	99.20	99.80
>= 80%	99.00	91.29	99.70	99.90
< 80%	1.00	8.71	0.30	0.10

The graphs below show how we are meeting observation constraints during this timeline:

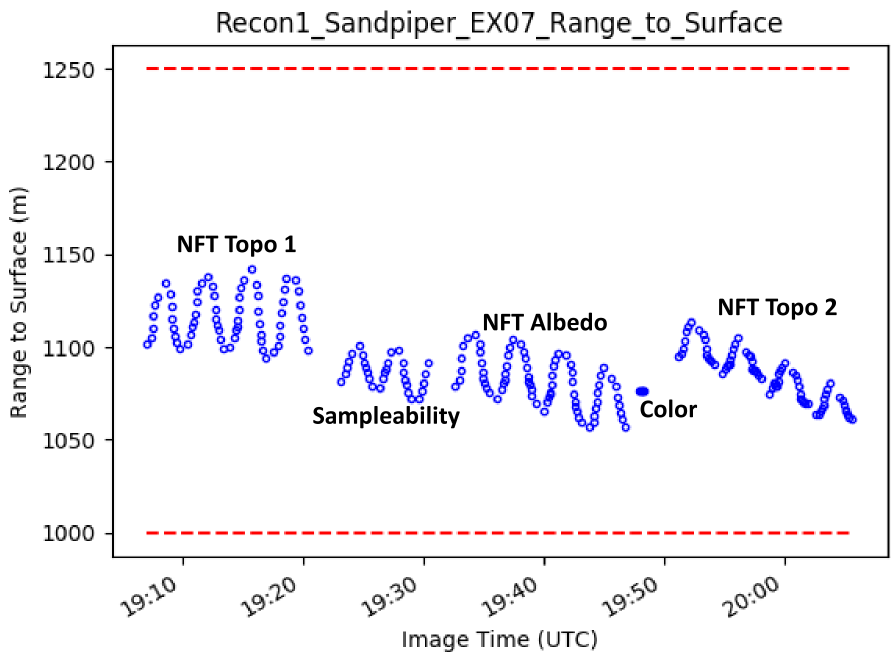

Figure 11 Range for the EX07 Sandpiper nominal trajectory shows that we are meeting the identified constraints.

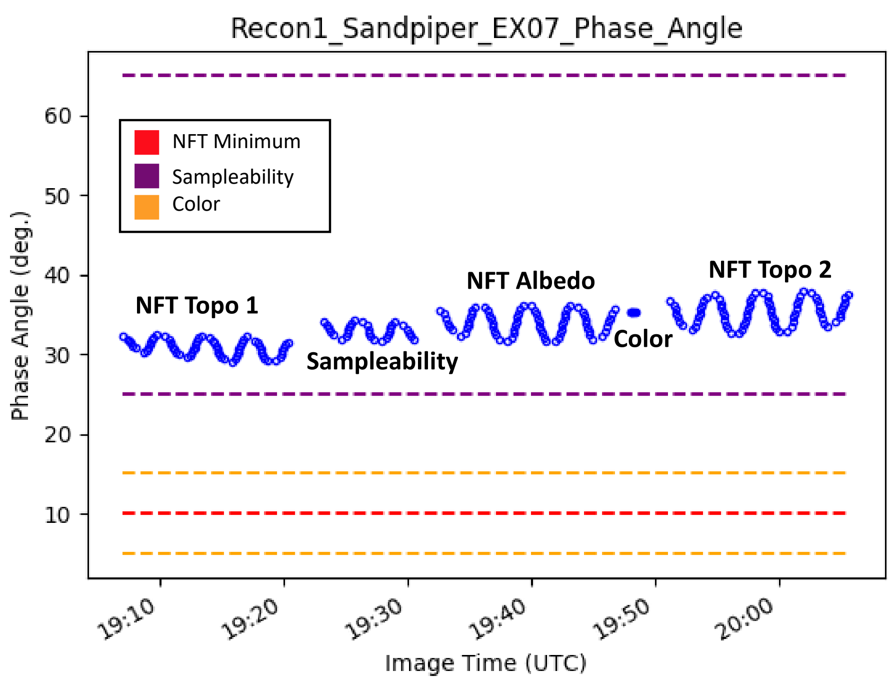

Figure 12 Phase angle for EX07 Sandpiper falls within the identified constraints for NFT and Sampleability. Note that we are not meeting phase angle observation constraints for color observations.

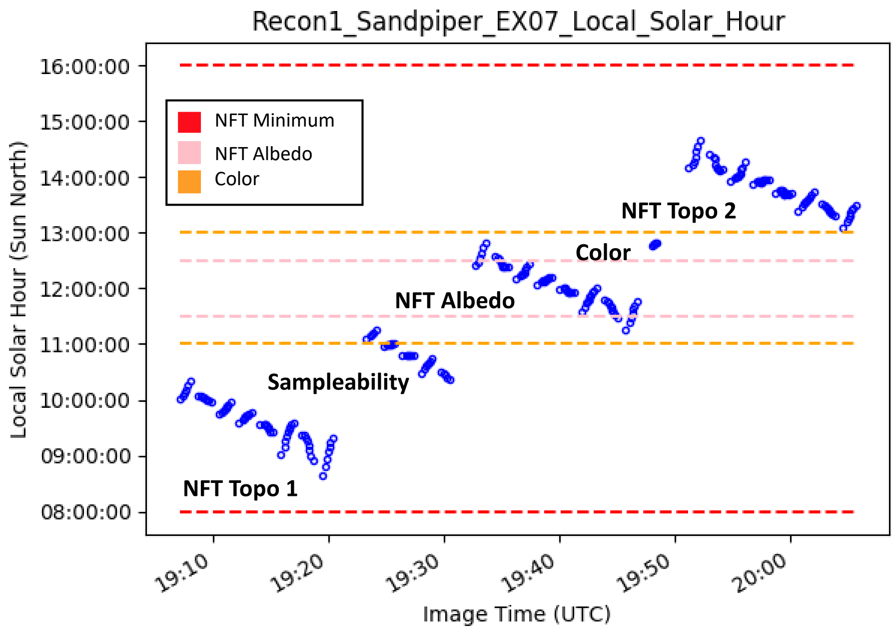

Figure 13 Local solar hour for the EX07 Sandpiper nominal trajectory shows we are compliant with the NFT Topo and color constraints. The NFT Albedo constraints are met for the majority of the observation.

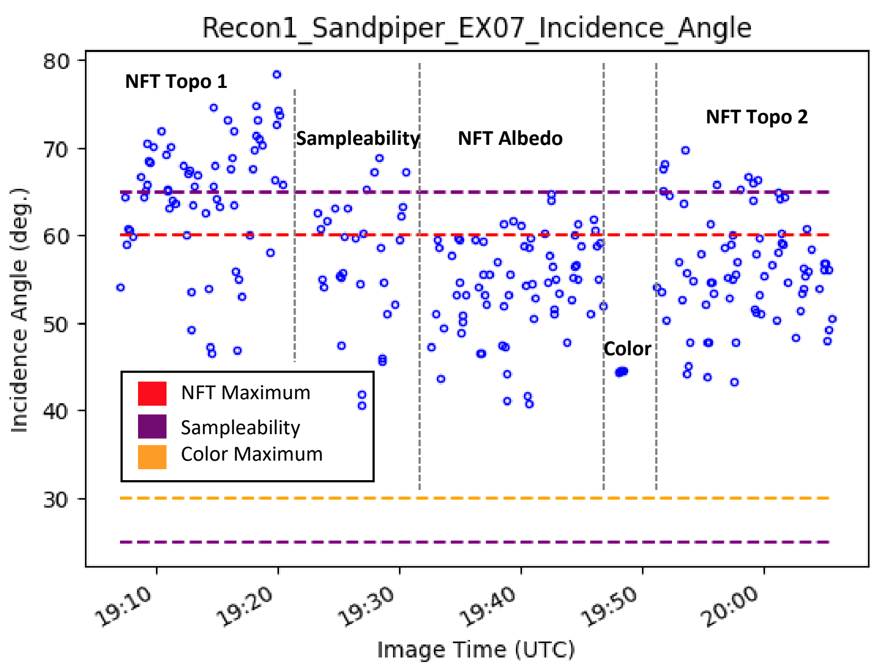

Figure 14 Incidence angle for the EX07 Sandpiper nominal trajectory.

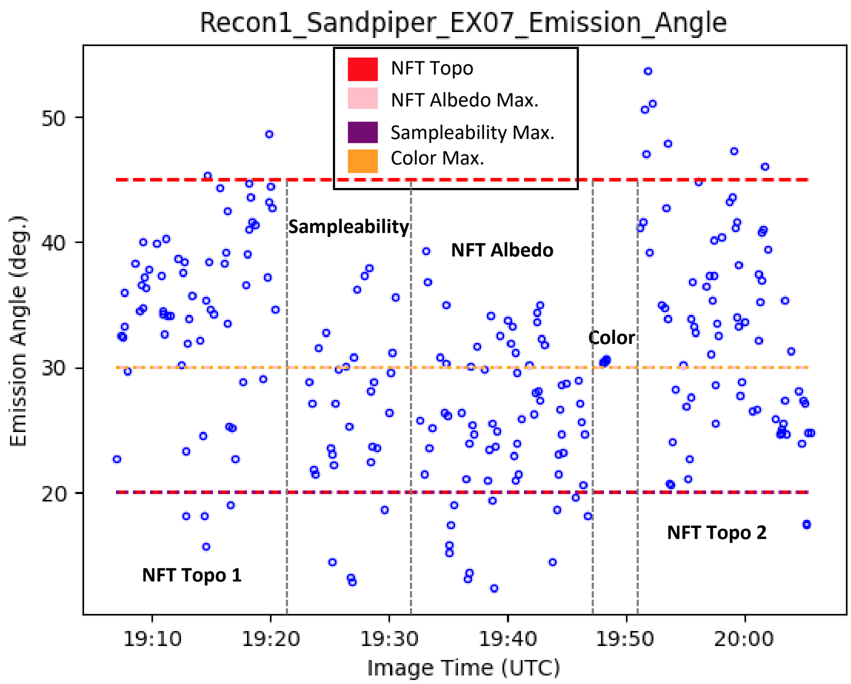

Figure 15 Emission angle for the EX07 Sandpiper nominal trajectory.

Table 4 Summary of the achieved viewing geometry for EX07 Sandpiper.

		Topo 1	Sampleability	Albedo	Topo2
Range (m)	Min.	1094.39	1072.23	1057.27	1061.56
	Max.	1141.78	1100.71	1106.79	1113.51
	Avg.	1116.29953	1086.36	1081.20	1085.02
Phase (deg.)	Min.	29.07	31.55˚	31.55˚	32.62˚
	Max.	32.42˚	34.32˚	36.16˚	37.84˚
	Avg.	30.83˚	32.98˚	33.95˚	35.30˚
Local Solar Hour	Min.	08:38:53	10:22:06	11:15:09	13:05:49
	Max.	10:20:08	11:15:20	12:49:44	14:39:27
	Avg.	09:34:20	10:48:17	12:02:40	13:49:01
Incidence (deg.)	Min.	46.62˚	40.59˚	40.80˚	43.38˚
	Max.	78.45˚	68.92˚	64.85˚	69.78˚
	Avg.	64.75˚	57.12˚	54.38˚	56.28˚
Emission (deg.)	Min.	15.66˚	12.81˚	12.37˚	17.35˚
	Max.	48.66˚	37.93˚	39.3˚	53.68˚
	Avg.	34.71˚	26.50˚	25.71˚	33.47˚

For EX07 Sandpiper it is expected we will take ~80 PolyCam images for each NFT observation, ~30 PolyCam images for Sampleability, and up to 20 MapCam images (depending on how many color observations we can achieve). Without factoring in darks, this is a total of 270 PolyCam images and 10 MapCam images. We are planning on 20 darks for PolyCam and 24 for MapCam. The observations for the other sites are expected to produce a similar numberof images.

Operational Considerations

The default slew config file, with a slow (science) slew rate of 2 mrad/seconds, will be used for these observations. The Elliptical Raster Scan is constructed to use the slow (science) slew during imaging and the fast slew of 5 mrad/s on the short slews used to transition between the science slews. Fast slews are also used for targeting Point and Stare MapCam color observations.

Sun Point will be the default attitude. All plans will be built nadir-relative with an initial attitude of Sun Point and will include a slew at the end of science that returns the spacecraft back to Sun Point.

The spacecraft is VELOCITY clocked for all observations, meaning the spacecraft ±X or +Y axis is planar aligned with the spacecraft velocity vector. The spacecraft axis that is aligned is specifically chosen to comply with OSZ scores and solar array configuration and to optimize for slew durations.

OCAMS, OTES, OVIRS, and TAGCAMS will be used during the Recon high pass flybys. OLA and REXIS will be off for all of Recon A. OTES and OVIRS will be powered on in WOY 39 and will remain powered on for the rest of Recon A. Deep space cals will take place on the initial slew to nadir point and during the final slew back to Sun point. OVIRS will be switched to SP=2 mode prior to each of the Recon high pass flybys and will be switched back to SP=8 immediately following each flyby. OCAMS will be reset weekly on Tuesdays. NavCam1 will be used for OpNavs bracketing the science observations and will ride-along with the Recon high pass flyby MapCam color observations.

PolyCam Refocusing during Recon A

PolyCam will acquire images during the NFT Topo, Sampleability and NFT Albedo segments of the Recon pass high flybys. As discussed below, the depth of field of PolyCam is such that active focusing via OLA will not be required, thus OLA will not be lasing during Recon A.

Assuming a nominal range to surface of 1.25 to 1.1 kilometers, PolyCam has a depth of field around 450 meters, which gives us a real allowable range variation of 225 meters. Based on OD-165, we expect that PolyCam may move thru the following focus positions during Recon High Flybys: 3C1E, 3B6A, 3AB5 and 3A01 or 28B, 28A, 27C and 27B. With this large allowable range variation and a small 2-sigma uncertainty in range to surface (~80 meters), we do not need active refocusing of PolyCam. Instead, PolyCam will be manually refocused prior to the start of each PolyCam imaging objective (each objective is ~10-12 minutes in duration) and then moved back to the shutter position after the last objective. This will be handled using the ocm_poly_focus_change block (for focus adjustments) and the ocm_poly_nss_shutdown (to move back to a shutter position and take darks). The ocm_poly_focus_change block should be called during the FAST_NADIR_REL slew back to the start of the observation ellipse, and will take ~15-30 seconds maximum to complete execution. In cases where the range has not exceeded the real allowable range variation, ocm_poly_focus_change block will be commanded to the current focus position and no focus movement adjustments will occur. The focus position parameter can be adjusted within the OCAMS sequences until the flight product Final Build start (Friday of Execution-3 weeks).

Initially, when OCAMS is powered ON ahead of the DS BBD Flyby 2 Refly, we will run the Recon Weekly Reset sequence, which will select PolyCam and home it. This can be done either before or after the Detailed Survey BBD Flyby 2 Refly. PolyCam will continue to be heated by spacecraft heaters (similar to Orbital B) during Recon A.

Requirements and Data Products

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.

One lien is associated with MRD-141. The re-fly of DS BBD FB2 is expected to satisfy this lien. Lien-141-1: The requirement to calculate the desired color indices at a spatial resolution < 2 m, and at the desired spectrophotometric accuracy, over 80% of the asteroid was not met with the data from the combined Flybys 2 and 7 due to the Flyby 2 degradation. An ephemeris and time-shift late update did not occur due to a blizzard in Denver that prevented MSA personnel from working. The resulting FB2 observations were therefore biased toward the southern hemisphere instead of pointing at the equator.

Data product: IP-20 Global Color Ratio and True Color Maps

300 NFT Features:

MRD Description:

MRD-728: This requirement ensures the production of a catalog with an adequate number of sufficiently defined features for NFT to perform its functions of Checkpoint navigation state estimate, the TAG navigation state estimate and the time of touch estimate.

Observation Constraints:

Constraint	Value	Satisfied During Recon A?	Notes
Instrument:	PolyCam	✓	
Local Solar Hour:	***Applicable to looks 1, 2, 3, & 4*** Between 8am & 4pm – 1 set at 10am and one set at 2pm. Three sets must have a local time different by 1 full hour.	✓	
Azimuth:	**Look 1:** 0˚ ± 30˚ (North)	!	Planned for Recon B
	Look 2: 180˚ ±30˚ (South)	!	Planned for Recon B
	Look 3: 90˚ ±30˚ (East)	✓	
	Look 4: 270˚ ±30˚ (West)	✓	
	Look 5: 0˚ or 180˚ (North or South for albedo)	✓	

Δ in Azimuth between observation set:	***Applicable to looks 1, 2, 3, & 4*** >45˚ required, >80˚ desired	✓	
Pointing:	***Applicable to looks 1, 2, 3, & 4*** At least 3 looks must be off-nadir (20˚ to 45˚ zenith). 4 looks meeting this criterion is ideal.	✓	
Range to Surface:	**1000m – 1250m**	✓	EX07 Reference Plan: 1057.27m – 1141.78m
Pixel Size:	Between all 5 looks, two sets must achieve a 1cm pixel size and 3 sets must achieve a 2cm pixel size.	✓	
Phase Angle:	>10˚	✓	
Incidence Angle:	**<60˚ (topo)** **±15˚ from site lat. (albedo)**	!	EX07 Reference Plan: Constraints are met the majority of the time. Local topography has large affect on results. Topo 1 = 46.62˚ – 78.45˚ Albedo = 40.8˚ – 64.85˚ Topo 2 = 43.38˚ – 69.78˚
Emission Angle:	**20˚ – 45˚ (topo)** **0˚ – 30˚ (albedo)**	!	EX07 Reference Plan: Constraints are met the majority of the time. Local topography has large affect on results. Topo 1 = 15.66˚ – 48.66˚ Albedo = 12.37˚ – 39.30˚ Topo 2 = 17.35˚ – 53.68˚

Sampleability/Local PSFD, Local Particle Database/Particle Maps, & Local Image Mosaics:

MRD Description:

MRD-116: OSIRIS-REx shall, for >80% of a 2-sigma TAG delivery error ellipse around at least 2 candidate sampling sites map the areal distribution and determine the particle size-frequency distribution of regolith grains <2cm in longest dimension.
Intermediate products: IP-1, IP-5 but only at a ~10cm scale.

Observation Constraints:

Constraint	Value	Satisfied During Recon A?	Notes
Instrument:	PolyCam	✓	
Coverage:	100% of 2-sigma TAG delivery error ellipse on Bennu Surface	✓	
Range to Bennu Surface:	225m – Driven by ground sample distance	!	This constraint was originally based on a having a Low recon pass. Could potentially achieve in Recon B.
Local Solar Hour:	Mid-to-late afternoon or early-to-mid morning	✓	EX07 Reference Plan: 10:22am – 11:16am
Pointing:	Nadir (0˚ emission at Nadir)	✓	
Along Slew Overlap:	20% required, 30-40% desired	✓	EX07 Reference Plan Achieving: ~30%
Across Slew Overlap:	20% required, 30-40% desired	!	May not have sufficient time. EX07 Reference Plan Achieving: ~5% overlap.
Pixel Size:	≤0.005m – 4 pixels required to resolve a feature	!	Will not be close enough to the surface to achieve in Recon A. Could be achieved in Recon B. EX07 Reference Plan Range to Surface: 1057.27m to 1141.78m
Incidence Angle:	25˚ to 65˚	!	EX07 Reference Plan: 40.59˚ – 68.92˚ Constraints are met the majority of the time. Local topography has large affect on results.
Emission Angle:	0˚ to 20˚	!	EX07 Reference Plan: 12.81˚ – 37.93˚ Constraints are met the majority of the time. Local topography has large affect on results.
Phase Angle:	25˚ to 60˚	✓	EX07 Reference Plan Achieving: 31˚ to 35˚

Local Minerals and Organics Maps and Local Dust Cover Index Maps:

MRD Description:

MRD-118: OSIRIS-REx shall, for >40% of a 2-sigma TAG delivery error ellipse around at least the prime sampling site, map the distribution of key species listed in the MRD-118 Table (Absorption Features of Key Mineralogical & Organic Molecules) that have spectral features with >5% absorption depth at a spatial resolution <5m.

Observation Constraints:

Constraint	Value	Satisfied During Recon A?	Notes
Instrument 1:	**OVIRS**	✓	
Instrument Settings:	72hr cool-down period	✓	
Coverage:	>40% of 2-sigma TAG delivery error ellipse.	!	EX07 Reference Plan: 25% to 35% coverage
Pointing:	NADIR relative scanning	!	Currently MRD-118 is not driving the pointing in either Recon A or B.
Footprint:	<5m	✓	EX07 Reference Plan Range to Surface: 1057.27m to 1141.78m
Local Solar Hour:	Between 10:30am and 12:00pm	✓	This constraint is a compromise between OTES and OVIRS. OVIRS prefers the morning for organics. OVIRS would still be able to meet SNR in the afternoon, but organics features may fill in from thermal emission if the surface is hot, in which case organics won't be detected. EX07 Reference Plan: 08:38:57 to 14:40:11 (constraint is met during NFT albedo observations and sampleability observations)
Phase Angle:	0˚ to 15˚	!	EX07 Reference Plan: 29.07˚ to 37.84
SNR:	>50	TBD	Not validated by SPT.
Instrument 2:	**OTES**	✓	
Coverage:	>40% of 2-sigma TAG delivery error ellipse.	✓	EX07 Reference Plan: 65% to 75% coverage
Pointing:	NADIR relative scanning	!	Currently MRD-118 is not driving the pointing in either Recon A or B.
Footprint:	<8m	!	EX07 Reference Plan Range to Surface: 1057.27m to 1141.78m
Local Solar Hour:	Between 10:30am and 12:00pm	✓	This constraint is a compromise between OTES and OVIRS. OTES prefers afternoon solar local time unless morning surface temperature is >320 K
Phase Angle:	0˚ to 15˚	!	EX07 Reference Plan: 29.07˚ to 37.84
SNR:	>320	TBD	Not validated by SPT.

Local Thermal Inertia Maps:

MRD Description:

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:

Constraint	Value	Satisfied During Recon A?	Notes
Instrument:	OTES	✓	
Coverage:	≥80% of candidate sample ellipse	!	EX07 Reference Plan: 65% to 75% coverage
Footprint:	<8m	!	EX07 Reference Plan Range to Surface: 1057.27m to 1141.78m
Local Solar Hour:	8pm to 5am (nighttime) or 10am to 12:30pm	✓	EX07 Reference Plan: 08:38:57 to 14:40:11 (constraint is met during NFT albedo observations and sampleability observations)
Emission Angle:	0˚ to 60˚ (<30˚ is preferred)	✓	Larger emission angles are strongly affected by unknown emission phase function. EX07 Reference Plan: 12.37˚ – 53.68˚

Sample Site Color Maps:

MRD Description:

MRD-119: OSIRIS-REx shall, for >80% of a 2-sigma TAG delivery error ellipse around the prime sampling site, map the surface in a panchromatic filter at <25cm resolution and map the ECAS b-v color index, v-x color index, and the relative depth of the 0.7-micron 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 <50cm.
Data Product: IP-21. This product is best effort for Recon A and will be at 35 cm resolution instead of 25 cm. Mid-Recon will achieve 25 cm resolution.

Observation Constraints:

Constraint	Value	Satisfied During Recon A?	Notes
Instrument:	MapCam	✓	
Coverage:	100% of a 2-sigma TAG delivery error ellipse.	✓	
Pointing:	Nadir relative scanning	✓	
Along Slew Overlap:	>30%	✓	Not mosaicking; single color set point & stare.
Across Slew Overlap:	>40%	✓	Not mosaicking; single color set point & stare.
Color Frame Overlap end-to-end:	90%	✓	As close to 100% as possible is ideal to minimize seams in the mosaic and minimize phase angle differences between frames in a color-set to avoid phase reddening.
Pixel Size:	≤0.05m	✓	
Incidence Angle:	0˚ to 30˚	!	High latitude of EX07 precludes meeting this constraint. EX07 Refernence Plan: ~44.5˚
Emission Angle:	0˚ to 30˚	✓	Low emission angle required to minimize distortion, foreshortening, and other projection effects for 80% coverage. EX07 Reference Plan: ~30.5˚
Phase Angle:	5˚ – 15˚	!	Low phase angle but NOT 0˚. Ensures best possible SNR at shortest possible exposure time EX07 Reference Plan: ~35˚
Local Solar Hour:	11am–1pm		EX07 Reference Plan: ~12:47pm
SNR:	≥100	TBD	Not validated by SPT.

Summary of Data Products:

MRD	Governing Working Group	Data Product Number	Data Product	Top Map					In Critical Path?	Notes
				D	SF	SM	SV	O		
115b/608b	ALTWG	ALT-23	Local OBJ and ancillary template	X	X	X	X			
	ALTWG	ALT-34	Local DTMs, DSK format	X	X	X	X			
	ALTWG	ALT-04	OLA Local DTM	X	X	X	X			
	ALTWG	N/A	See ALTWG Data Product section of table E-8 for complete product list	X	X	X	X			
115a	ALTWG	ALT-03	2 cm SPC Local DTM	X	X				YES	
	ALTWG	ALT-23	2 cm Local OBJ and ancillary template	X	X				YES	
	ALTWG	ALT-34	2 cm Local DTMs, DSK format	X	X				YES	
728/730/732	ALTWG	ALT-18	NFT Feature DTMs		X			X	YES	
116	RDWG	RD-4	Local Particle Size Frequency Distribution (PSFD) Map			X	X		YES	
	IPWG	IP-9	Local Image Mosaics			X	X		YES	
	IPWG	IP-1	Particle Geodatabase			X	X		YES	
	IPWG	IP-5	Particle Maps			X	X			
	IPWG	IP-28	Local Photometrically Corrected Image Mosaics			X	X			Not produced from Recon A
118	SAWG	SA-36	Local OTES Mineral and Chemical Abundance Maps		X		X			
	SAWG	SA-41	Local OVIRS Mineral and Chemical Maps		X		X			
	SAWG	SA-39	Local Dust Cover Index Map		X		X			
119	IPWG	IP-21	Local Color-Ratio and True-Color Maps				X			
540	TAWG	TA-004	Local Temperature Maps			X	X			
	TAWG	TA-005	Local Thermal Inertia Map			X	X			
	TAWG	TA-011	Local Thermal Inertia Maps 3-sigma				X			
411	TAWG	TA-006	Predicted Local Temperature Maps		X		X			
	TAWG	TA-012	Predicted Local Temperature Maps 3-sigma		X		X			