Reconnaissance B Science Phase Plan

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Purpose

The purpose of this document is to describe the nominal observation plan for part B of the Reconnaissance phase of the mission, which includes 2 medium (~700-625 m) sorties of a primary and back-up sample site. 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_CCv0069.xlsx

Mission Plan Workbook: Mission_Plan_Workbook_2019-10-28.xlsx

SPKs for SPP development:
orx_191101_200204_190916_od180-R-R1P1-P-R1R_CQ13_v1.bsp
orx_191101_200204_190916_od180-R-R1P1-P-R1R_DL06_v1.bsp
orx_191101_200204_190916_od180-R-R1P1-P-R1R_DL15_v1.bsp
orx_191101_200204_190916_od180-R-R1T1-P-R2T2_EX07_v1.bsp

TSE files on ODOCS: OSIRIS-REx Mission Operations System 7.0\Science Operations Planning Group (NON-US persons access)\Supporting Material\Recon\
orx_tse_200121_200122_od180_CQ13_Nominal_v1
orx_tse_200121_200122_od180_DL06_Nominal_v1
orx_tse_200121_200122_od180_DL15_Nominal_v1
orx_tse_200121_200122_od180_EX07_Nominal_v1

Observation Envelope and Templates: ReconB_Templates.r2

Kernel sets for SPP development utilize the SPKs above plus the following kernels:
- LS: naif0012.tls
- PCK: pck00010.tpc
- PCK: bennu_v15_DRAFT2.tpc
- SPK: de424.bsp
- FK: orx_v14.tf

IK: orx_navcam_v02.ti
IK: orx_ocams_v07.ti
IK: orx_ola_v01.ti
IK: orx_otes_v00.ti
IK: orx_ovirs_v00.ti
IK: orx_rexis_v01.ti
IK: orx_struct_v00.ti
SCLK: ORX_SCLKSCET.00048.tsc
CK: orx_struct_mapcam_v01.bc
CK: orx_struct_polycam_v01.bc
DSK: g_12620mm_spc_obj_0000n00000_v042.bds

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\191014_ReconB_DeliverySummary_CCv0001.pptx

Locations and vectors used for FDS trajectory design:

- EX07 Sandpiper
    - NFT footprint: -50.50, 322.00
    - Surface normal vector: 0.518253 -0.465636 -0.717354
- DL06 Osprey
    - NFT footprint: 13.41, 89.00
    - Surface normal vector: 0.038922 0.854951 0.517246
- CQ13 Kingfisher
    - NFT footprint: 13.50, 57.00
    - Surface normal vector: 0.416301 0.784574 0.459496
- DL15 Nightingale
    - NFT footprint: 57.28, 44.63
    - Surface normal vector: 0.394316 0.565411 0.724448

Locations for SPP development 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: 58.00, 44.63

MRD Overview

There are a total of 6 MRDs with defined science observation constraints for the Reconnaissance phase. During Recon B, data will be collected for 5 of the 6 MRDs with Natural Feature Tracking (NFT) as the primary driver. Color imagery and spectroscopy are best-effort.

Table 1 Full list of Recon MRDs.

MRD#	Description	Derived MRDs	Recon	Phase Driver?
115b	5cm DTMs from OLA	608b	B/C	NO/YES
116	Sampleability/Local PSFD, Local Particle Database/Particle Maps, & Local image Mosaics	NONE	A/C	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 Recons A and B is to collect PolyCam images of an area centered on the NFT footprint for the first image post Match Point for the primary and back-up sample sites with appropriate viewing geometry such that NFT features can be built using SPC 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

The albedo look and two of the topography looks were conducted in Recon A. Recon B serves to achieve the remaining two topography looks. In addition to the PolyCam imaging, the spectrometers will be secondary instruments throughout these observations, MapCam color data will be acquired as opportunity allows, and OLA data will be collected both to help focus PolyCam and to provide an independent determination of topography.

Below is a summary of the observation constraints as documented in the official Observation Constraints document and agreed upon during Recon meetings.

Table 2 Observation constraints for the Medium pass sorties

Activity	Projected Pixel Size (m/pix)	Range (m)	Coverage	Local Solar Hour	Emission Angle (deg.)	Phase Angle (deg.)	Incidence Angle (deg.)	Notes
PolyCam NFT Topo	0.01	≤740	25m-radius area centered on 3 sigma 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)
OLA			100% 3σ TAG ellipse		<45			These observations are NOT a trajectory driver
MapCam Color	≤0.04	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 B mission phase is scheduled for Jan 6 through Feb 16, 2020. The spacecraft will spend the majority of this phase in orbit, with Recon sorties for the prime and backup sites on Jan 21 and Feb 11, respectively. At the time of this writing, the sites have not been selected from the four candidate sample sites. We have therefore generated plans for all four sites and will adjust the plans for the final two sites during tactical planning for this phase.

Particle monitoring images will be conducted on a two-hour cadence (riding along with OpNavs) throughout this phase, except on the Recon sortie days. On the Recon sortie days, particle imaging will not be acquired during the sortie observation window, but particle images will be acquired at a 30 minute cadence during the Post-ORM OpNav ATL to coincide with the increased OpNav cadence (data volume permitting).

Observation Strategy

Collecting PolyCam data during Recon presents many challenges:

1. The trajectory is such that the altitude of the spacecraft changes with time.
2. There are 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 rough surface of Bennu and varying topography make it difficult to meet the observation constraints for emission and incidence angles for all images due to the tilts of the different facets in the shape model.

All data are collected via a sortie flyover of the area 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 area rotates through different lighting conditions.

The area to be scanned during the topo observations 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 footprints to identify and build features for NFT to use during the TAG approach. The MapCam color observations are centered on the TAG point coordinates and are planned to cover a 10-m radius circle.

Observation Plan

For each flyby there are ~60 minutes where the NFT topo constraints are met. Each topo look is achieved during approximately half of the allocated window. All the topo plans will be produced in J-Asteroid 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. To optimize viewing geometry, scanning is North-South and begins on the leading edge of the targeted ellipse, with the exception of DL06 topo 2. In this case it is necessary to scan along the major axis to conserve time and remain within the observation constraint window. All observations are planned to cover as close to 100% of the targeted ellipse area as possible without gores. DL15 topo 2 requires some additional manual target tweaking to eliminate across-slew gores. In this case adjacent targets are moved closer to each other by 5-10% of the distance originally between them.

Each elliptical raster scan has between 109 and 178 images and achieves coverage between 98-99.99%. Along-track overlap ranges between 18.5-47% and across-track overlap ranges between 10-50% with no gores between slews.

Color observations are planned as a best-effort using 2x2 point and stare mosaics boresighted to MapCam such that full color-sets utilizing two different exposure times for each filter (pan, v, b, w, x) can be acquired where all color frames overlap ~100%. For each site these observations are planned between the two topo looks, with the exception of DL15. There is not sufficient time between DL15 topo 1 and topo 2 to acquire MapCam color without sacrificing some aspect of the topo observations, therefore in this case color is acquired after topo 2 with degraded observation constraints.

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 ~33-39% and OTES coverage ranges from ~69-79%.

OLA will be collecting data via linear scans in the cross-slew direction using the LELT, which operates at 10 kHz. The scan width will be 50mrad, with 100μrad spot spacing.

Below is a table with achieved coverage for each observation as planned on the reference trajectory:

Table 3 Summary of topo elliptical raster scan coverage. The along-track and across-track metrics apply to the PolyCam images.

	EX07		DL06		CQ13		DL15	
	Topo 1	**Topo 2**	**Topo 1**	**Topo 2**	**Topo 1**	**Topo 2**	**Topo 1**	**Topo 2**
PolyCam Coverage	99.79%	99.99%	99.99%	99.99%	99.99%	99.99%	99.1%	98.2%
OTES Coverage	73.78%	72.20%	79.30%	76.43%	69.0%	72.8%	74.9%	74.8%
OVIRS Coverage	36.07%	35.11%	38.77%	37.80%	33.7%	35.4%	38.3%	38.1%
Along-track overlap	28.89-21.02%	28.55-44.72%	28.3-40.7%	29.15-42%	28.3-40.7%	28.5-42.1%	19.4-47.0%	18.4-55.9%
Across-track overlap	~10-30%	~20-30%	~20-50%	~20-30%	~16-30%	~20-35%	~14-50%	~12.5-45%
# of Images	125	158	141	132	109	131	111	178

In addition to the PolyCam images noted above, there will be 40 MapCam images for each site. For PolyCam there will be 2 darks before and after each topo for a total of 8, and for MapCam there will be 20 before and after each color set (2 each at 10 exposure times) for a total of 40.

Sensitivity Analysis

To mitigate against loss of coverage due to trajectory perturbations from burn dispersions, we expand the sizes of the scan areas for the NFT topo looks to account for as much uncertainty as possible. MapCam color observations are planned to cover a 10-m radius circle plus as much uncertainty as is feasible from a time perspective, which will vary for each site.

Sensitivity analysis results for EX07 Sandpiper using the full 3000 perturbed trajectories from the FDS Monte Carlo analysis have revealed that a 2-sigma confidence interval of the Monte Carlo uncertainties is robust against perturbations. For these observations we allow J-Asteroid to automatically calculate the uncertainties in the normal and transverse directions using a TSE file delivered by FDS. Sensitivity analysis for Osprey is still in progress, but results for Kingfisher using a set of 1000 perturbed trajectories similarly demonstrate that Kingfisher is robust against perturbations, as shown in Table 5. In the case of DL15 topo 2, sensitivity analysis indicated a slightly larger than 2-sigma confidence interval in the normal (across-track) direction was necessary to be robust. In this case the confidence interval in the normal direction was manually increased and the targeted center coordinates of the ellipse were also adjusted to be more favorable for coverage robustness. The sensitivity analysis results for this updated plan are shown in Table 6.

Figure 1 shows an example of the results generated for the sensitivity analysis, in this case for the nominal trajectory for topo 1 of EX07 Sandpiper.

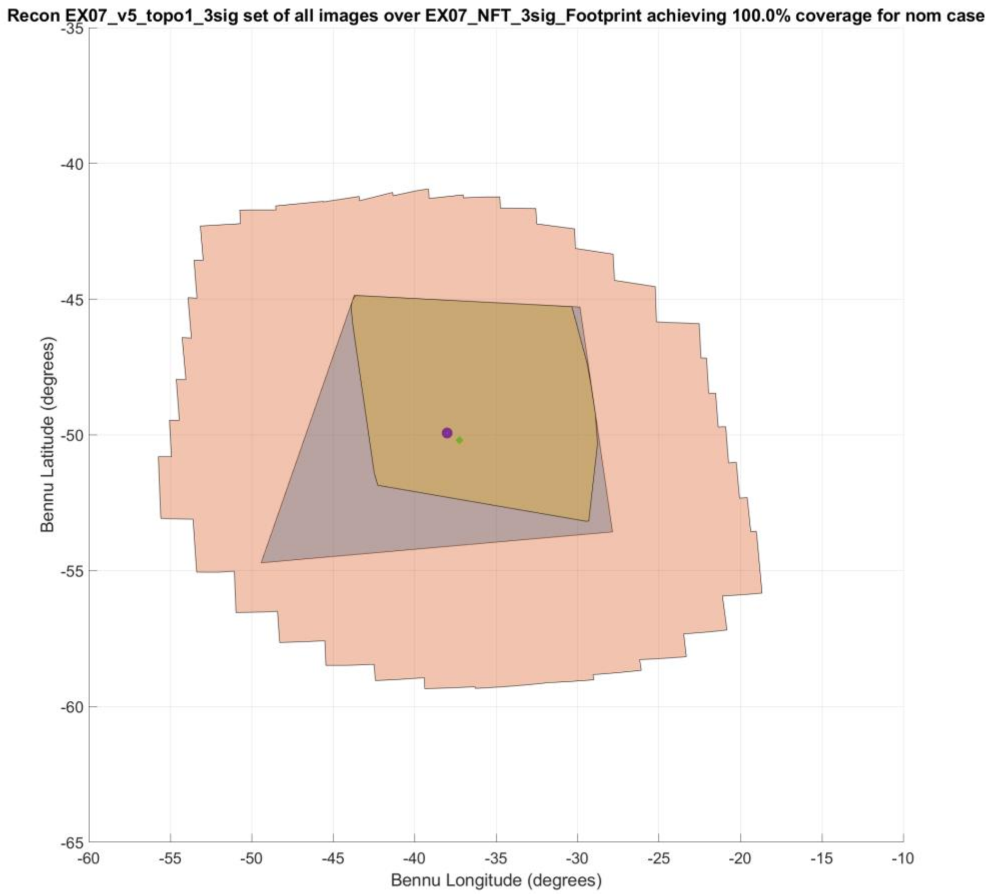


Figure 1 This figure shows a collection of all of the PolyCam image footprints associated with the Topo 1 portrayed as a single salmon-colored polygon. This polygon is shown on top of the NFT 3-sigma footprint (gray) in which landmarks will be identified to support TAG operations. For this nominal case, the PolyCam image set covers 100% of the NFT 3-sigma footprint region. The yellow polygon within the gray one provides visualization of the area which satisfies the image geometry constraints for PolyCam (Table 2).

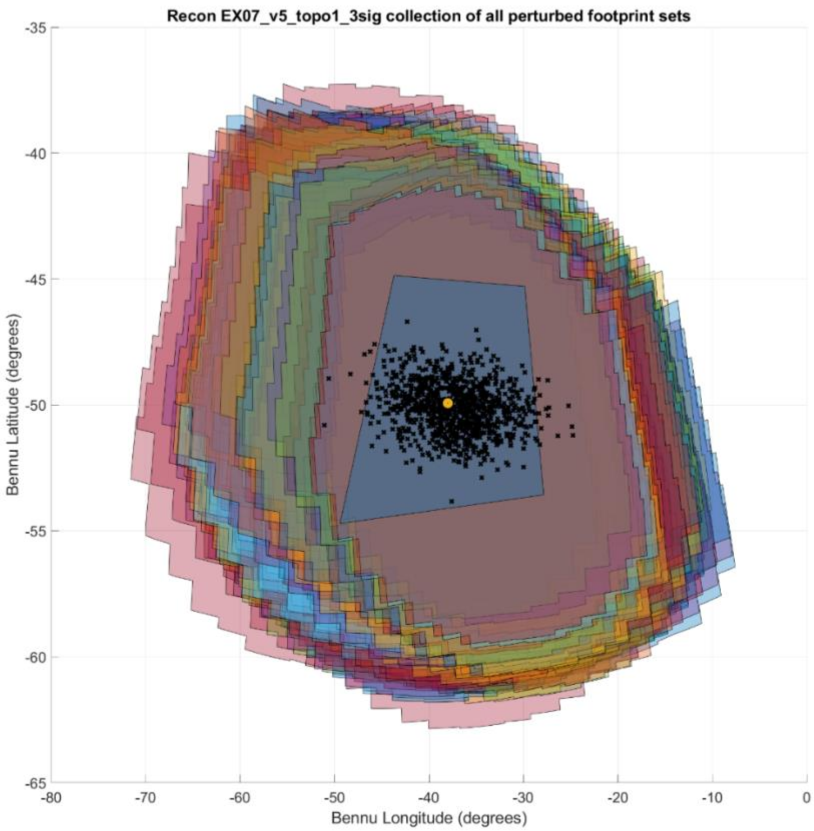


Figure 2 shows the combined result of all 1000 Monte Carlo perturbed trajectories and the nominal one. The yellow dot represents the center of the NFT 3-sigma target, and each black dot is an approximate center of a particular case's scan pattern. The collection of all of the scan centroids provides a sense of the variation in latitude and longitude.

Table 4 Coverage results of all 1000 Monte Carlo perturbed trajectories for Sandpiper, which shows that >95% of Topo cases have >95% coverage of the 3 sigma NFT footprint. The constrained coverage for MapCam color observations was not analyzed.

Coverage Threshold	Medium Recon - EX07 Sandpiper					
	v5 - nominal departure					
	Topo 1		Color (MapCam)		Topo 2	
	Simple Coverage	Constrained Coverage	Simple Coverage	Constrained Coverage	Simple Coverage	Constrained Coverage
== 100	71.33	0	98.1	---	79.4	0
>= 98.5	89.71	0	98.4	---	90.8	0
>= 95	96.6	0	98.6	---	95.7	0
>= 90	98.6	0	98.9	---	98	0
>= 80	99.6	0	99.3	---	99	0
>= 70	99.7	0.2	99.4	---	99.5	0.8
>= 60	100	99.3	99.4	---	99.7	92.2
>= 50	100	99.9	99.6	---	100	99.8
< 80	0.4	100	0.7	---	1	100

Table 5 Coverage results of 1000 Monte Carlo perturbed trajectories for Kingfisher, which shows that >95% of Topo cases have >95% coverage of the 3 sigma NFT footprint. The constrained coverage for MapCam color observations was not analyzed.

Coverage Threshold	Medium Recon - CQ13 - Sandbox Full Distrubtion					
	v5					
	Topo 1		Color		Topo 2	
	Simple Coverage	Constrained Coverage	Simple Coverage	Constrained Coverage	Simple Coverage	Constrained Coverage
== 100	90.01	0.00	91.21	---	89.81	0.00
>= 98.5	96.5	96.30	93.11	---	95.60	92.91
>= 95	98	98.00	94.81	---	97.10	96.60
>= 90	98.7	98.70	96.30	---	98.20	98.10
>= 80	99.4	99.40	97.90	---	99.50	99.50
>= 70	99.8	99.80	98.20	---	99.80	99.80
>= 60	99.9	99.90	98.80	---	99.90	99.90
>= 50	100	100.00	99.20	---	99.90	99.90
< 80	0.60	0.60	2.10	---	0.50	0.50
< 50	0.00	0.00	0.80	---	0.10	0.10

Table 6 Coverage results of 1000 Monte Carlo perturbed trajectories for Nightingale, which shows that >93% of Topo cases have >95% coverage of the 3 sigma NFT footprint. The constrained coverage for MapCam color observations was not analyzed.

Coverage Threshold	Medium Recon - DL 15 - Sandbox Full Distrubtion					
	v24c					
	Topo 1		Color		Topo 2	
	Simple Coverage	Constrained Coverage	Simple Coverage	Constrained Coverage	Simple Coverage	Constrained Coverage
== 100	29.87	0.00	98.6	---	80.42	0.00
>= 98.5	83.22	0.00	98.90	---	93.21	0.00
>= 95	93.81	0.00	99.40	---	96.90	0.00
>= 90	97.5	95.40	99.50	---	98.00	93.71
>= 80	99.4	99.30	99.60	---	99.40	99.40
>= 70	99.7	99.70	99.70	---	99.70	99.70
>= 60	99.9	99.90	99.70	---	99.90	99.90
>= 50	99.9	99.90	99.70	---	99.90	99.90
< 80	0.60	0.70	0.40	---	0.60	0.60
< 50	0.10	0.10	0.30	---	0.10	0.10

Sandpiper (EX07) Results

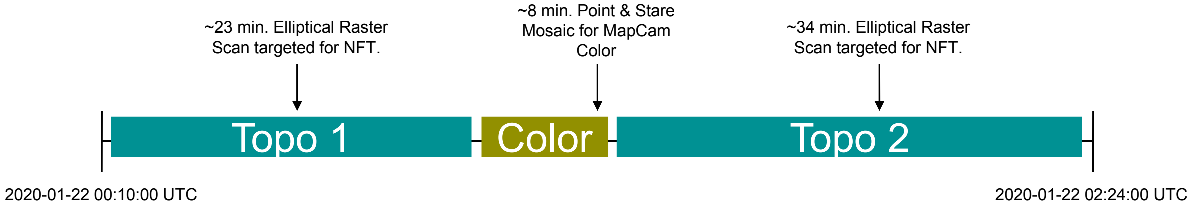


Figure 3 EX07 Sandpiper achieved observation timeline.

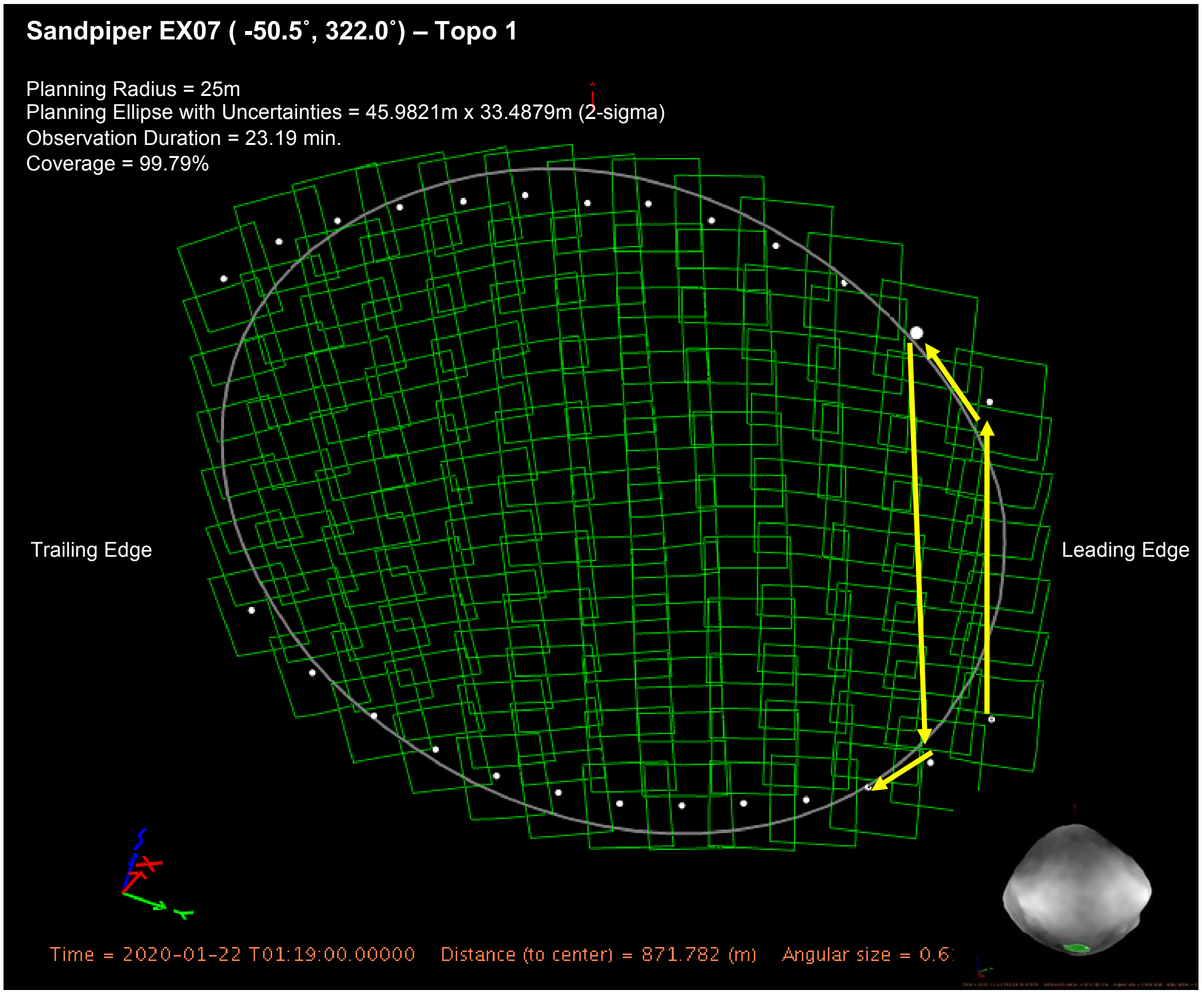


Figure 4 Elliptical Raster Scan observation for NFT Topo 1 at EX07 Sandpiper. The ellipse shown is the 45.98-m x 33.49-m radius ellipse planned to allow for navigational uncertainties.

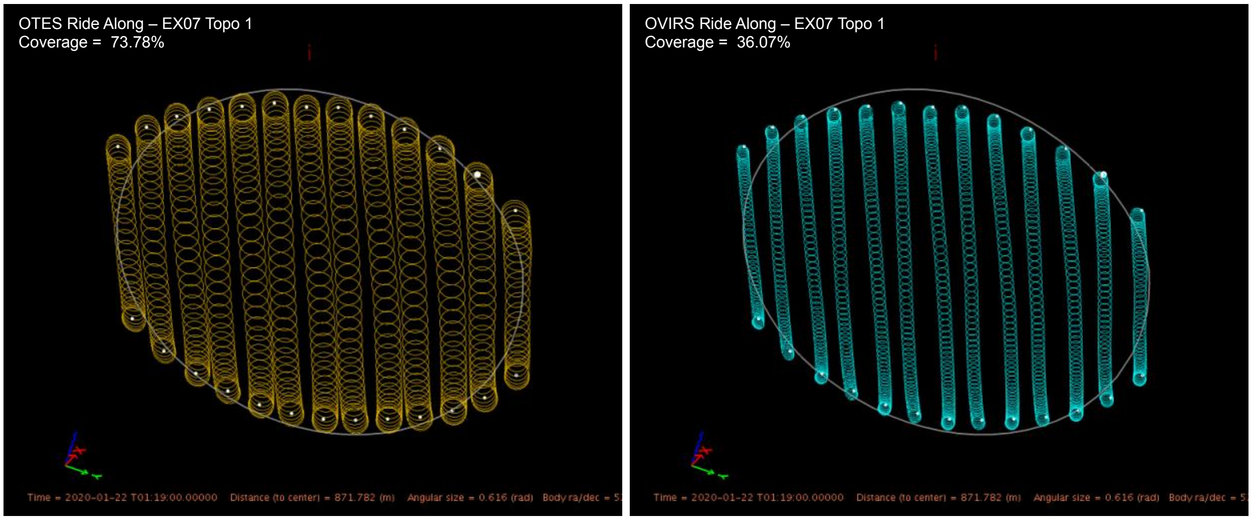


Figure 5 Spectrometer coverage for NFT Topo 1 observations at EX07 Sandpiper.

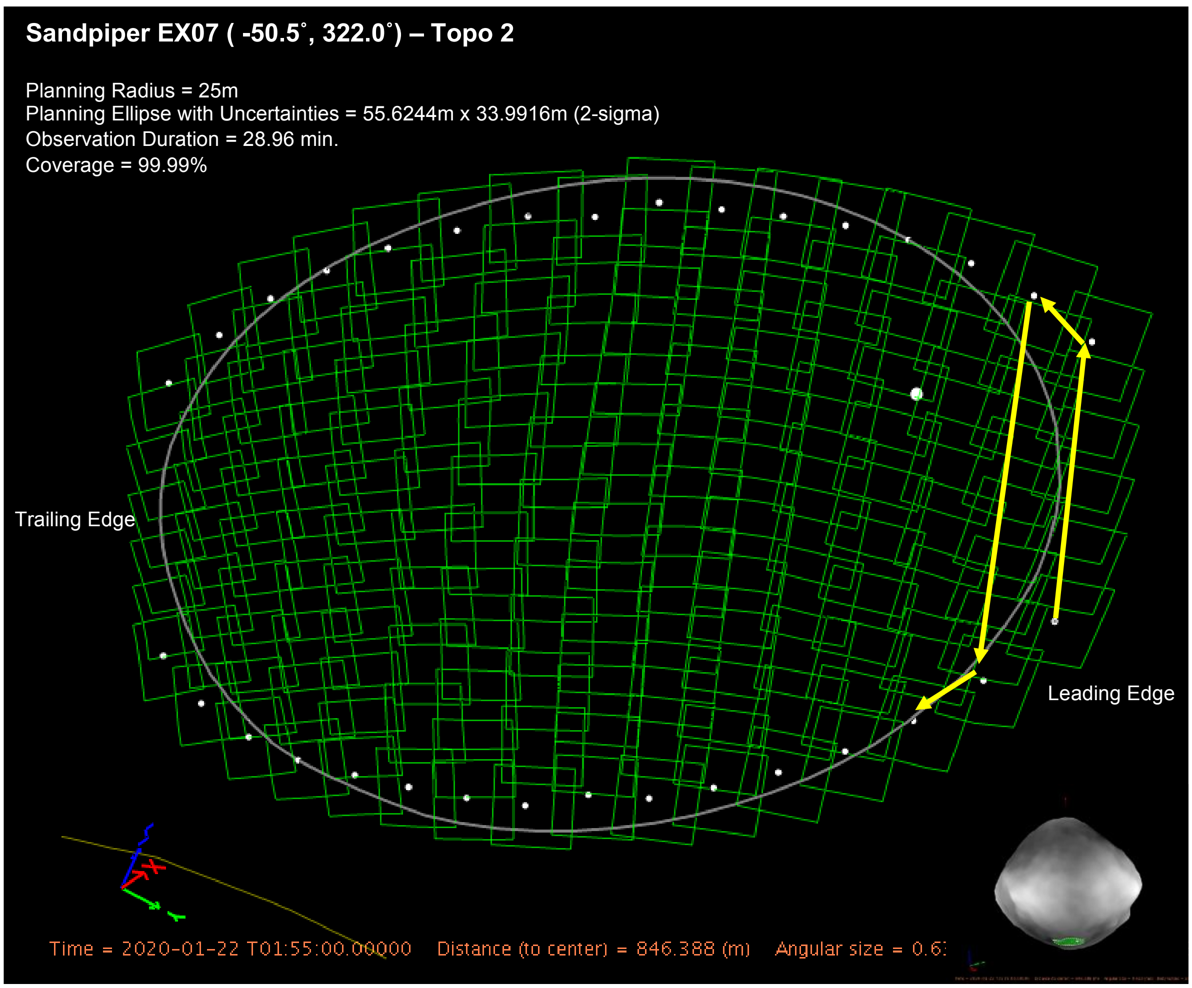


Figure 6 Elliptical Raster Scan observation for NFT Topo 2 at EX07 Sandpiper. The ellipse shown is the 55.62-m x 33.99-m radius ellipse planned to allow for navigational uncertainties.

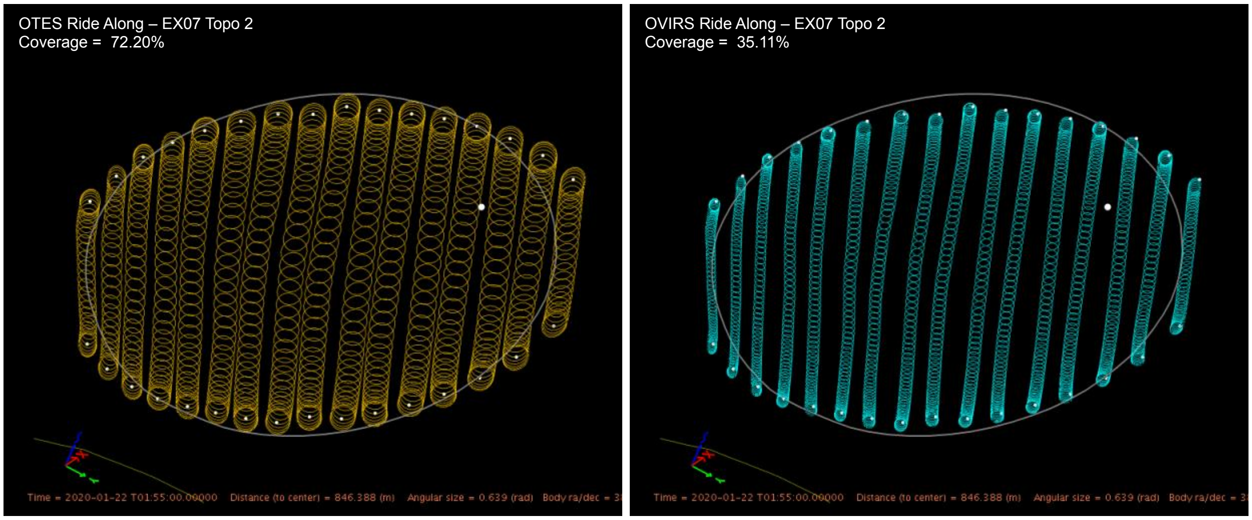


Figure 7 Spectrometer coverage for NFT Topo 2 observations at EX07 Sandpiper.

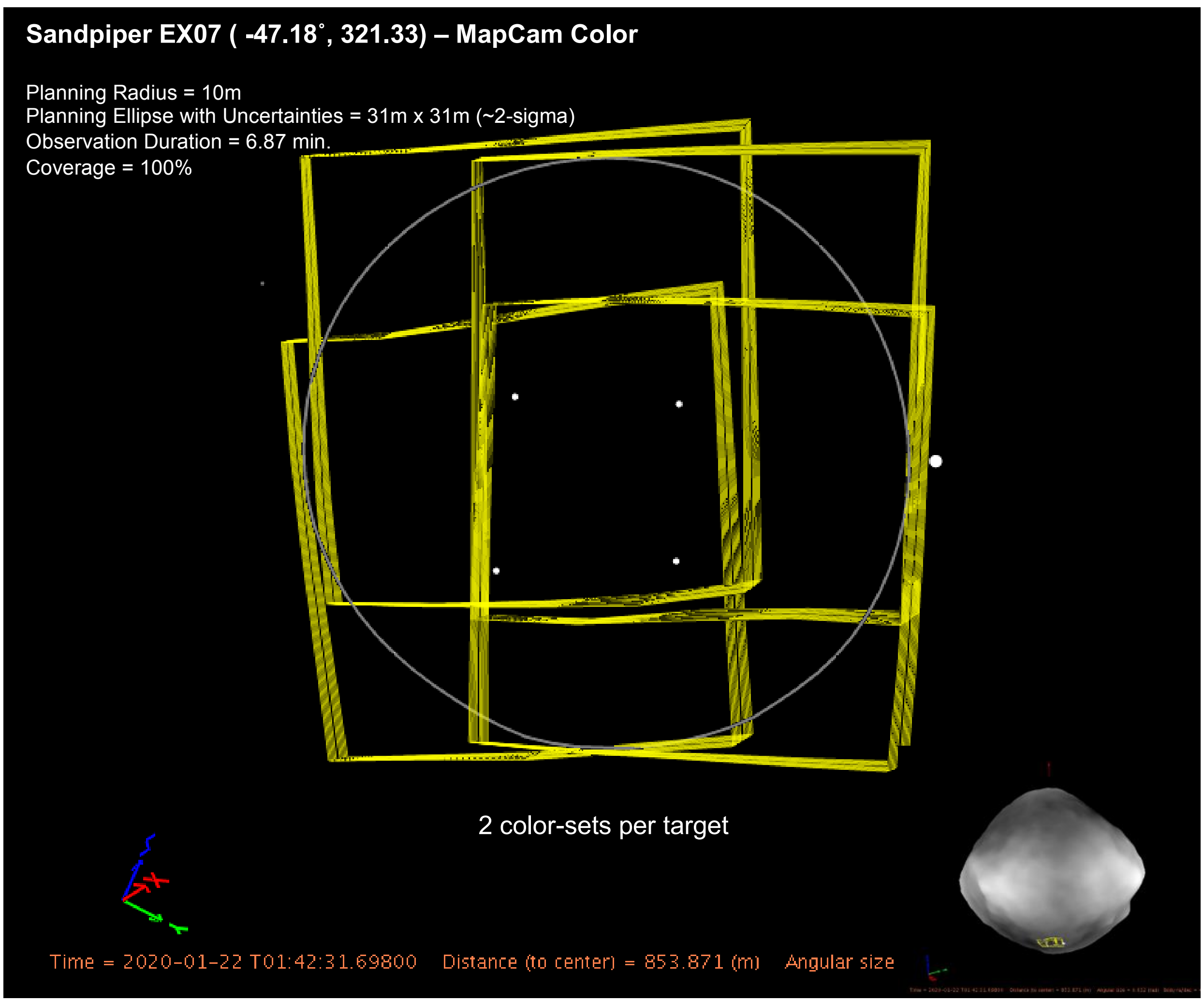
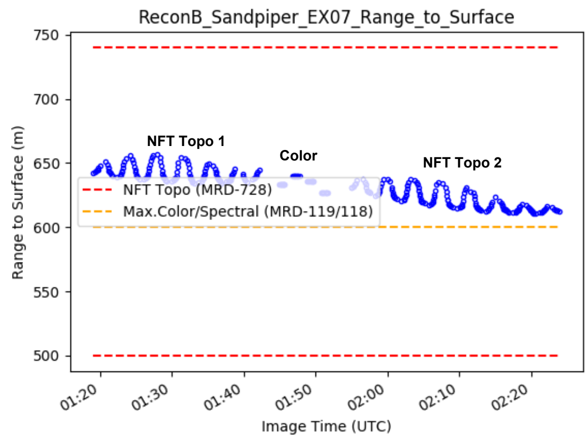
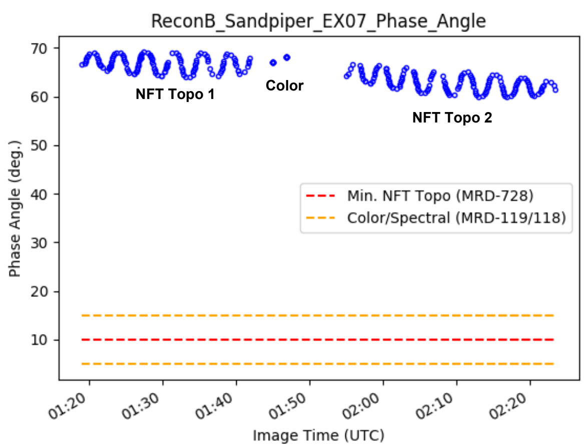
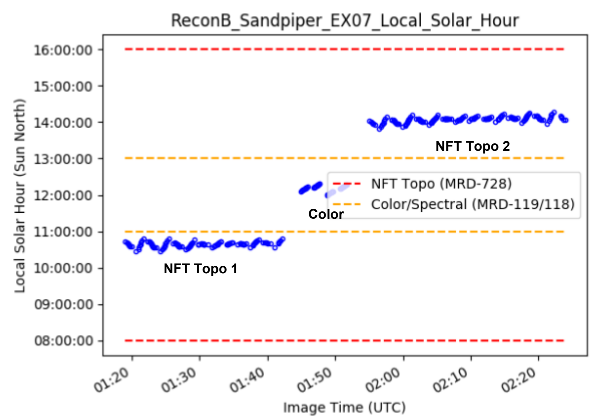


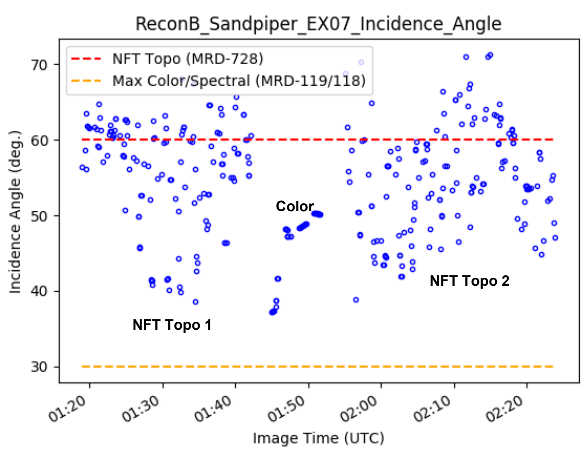
Figure 8 MapCam color observation for EX07 Sandpiper.

The graphs below show how we are meeting EX07 NFT and color observation constraints. Note some graphs show sinusoidal-like variations with time due to the scanning, but emission and illumination angles show scatter due to the tilt of whichever facet is being imaged at that time.









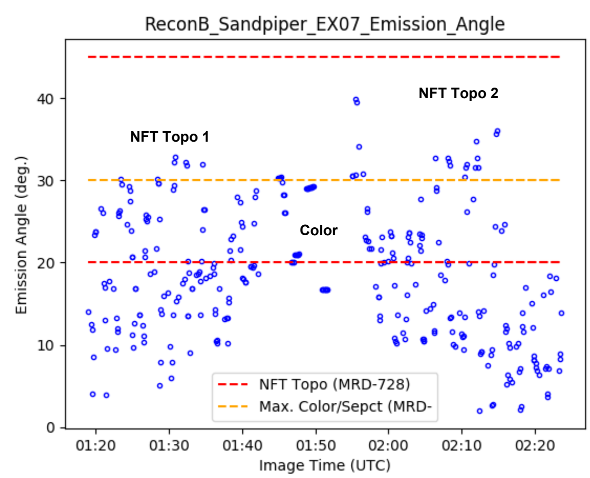


Table 7 Summary of the achieved viewing geometry for EX07 Sandpiper

		Topo 1	Topo 2	Color
Range to Surface (m)	Min.	634.32	610.63	626.79
	Max.	656.90	638.84	639.84
Phase Angle (deg.)	Min.	64.00	59.83	66.18
	Max.	69.16	66.89	68.05
Local Solar Hour	Min.	10:26:54	13:49:53	11:59:47
	Max.	10:48:50	14:16:21	12:18:48
Incidence Angle (deg.)	Min.	38.67	38.91	37.27
	Max.	68.1	71.25	50.30
Emission Angle (deg.)	Min.	3.87	2.02	16.67
	Max.	32.88	39.81	30.35

Osprey (DL06) Results

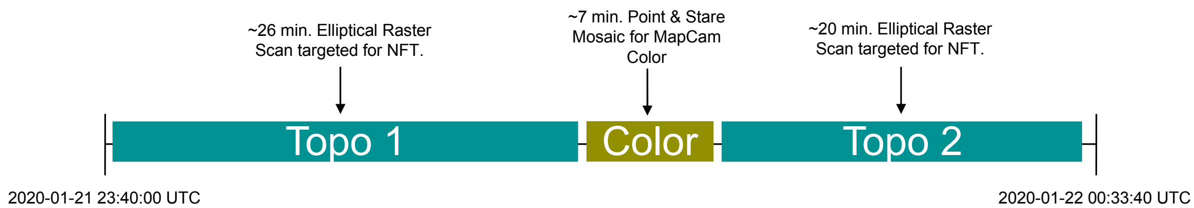


Figure 9 DL06 achieved observation timeline.

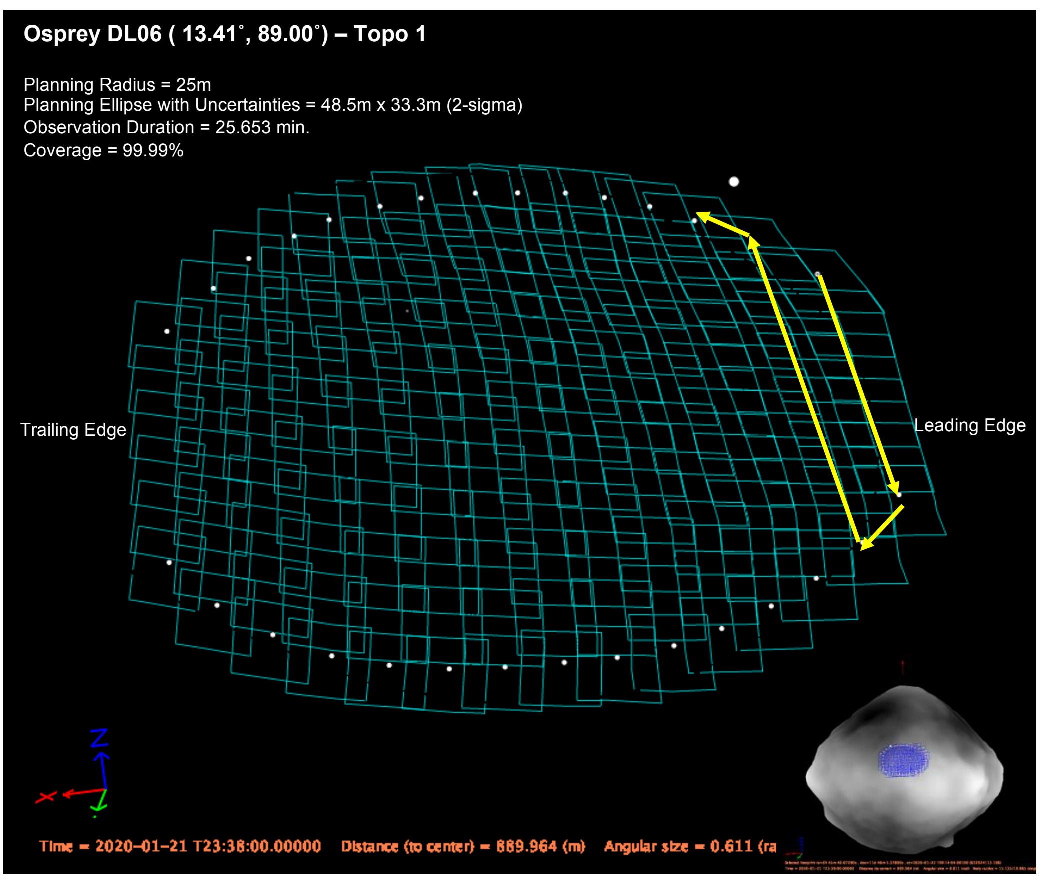


Figure 10 Elliptical Raster Scan observation for NFT Topo 1 at DL06 Osprey. The ellipse shown is the 48.5-m x 33.3-m radius ellipse planned to allow for navigational uncertainties.

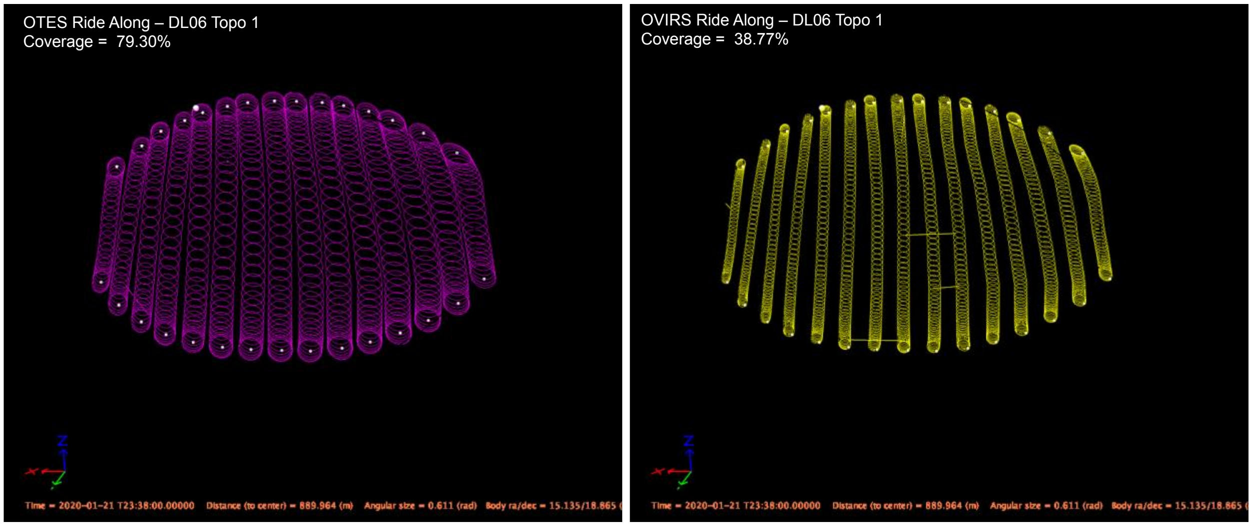


Figure 11 Spectrometer coverage for NFT Topo 1 observations at DL06 Osprey.

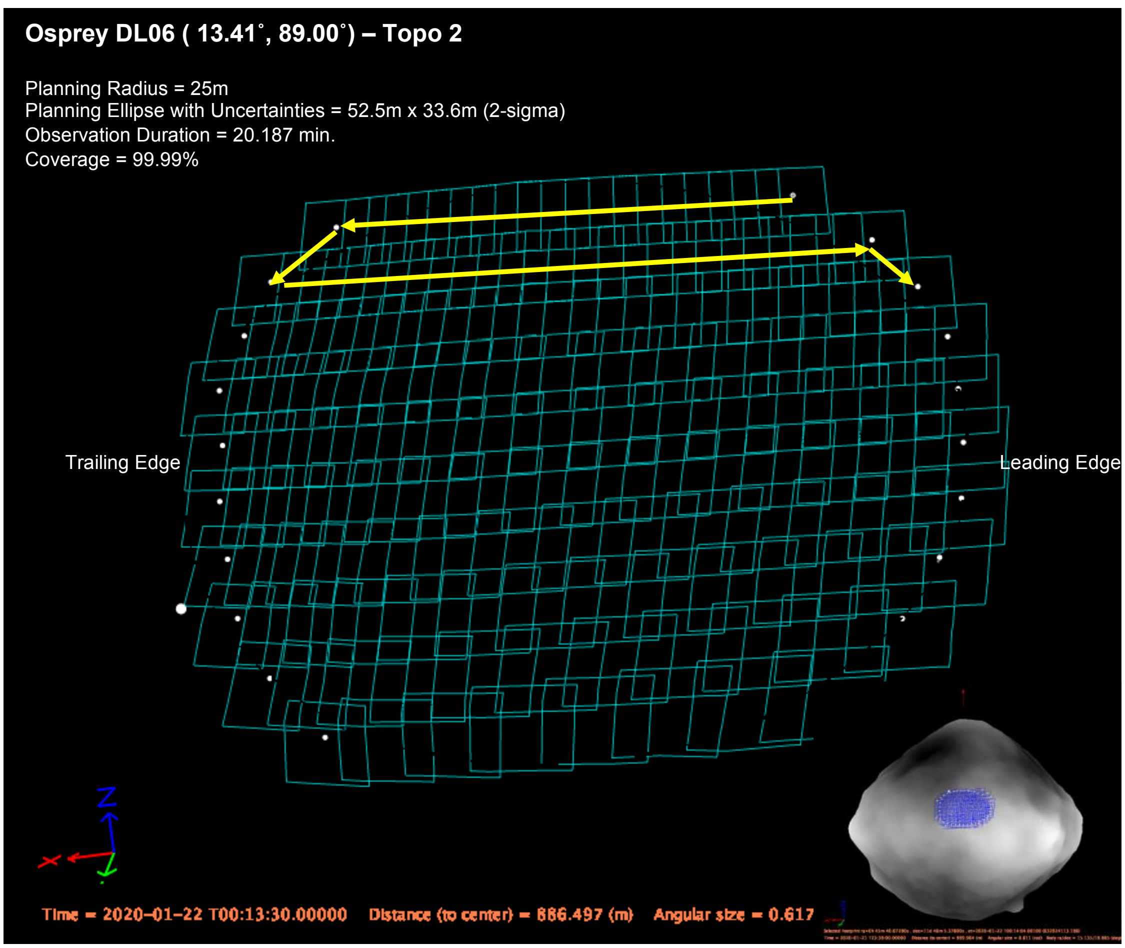
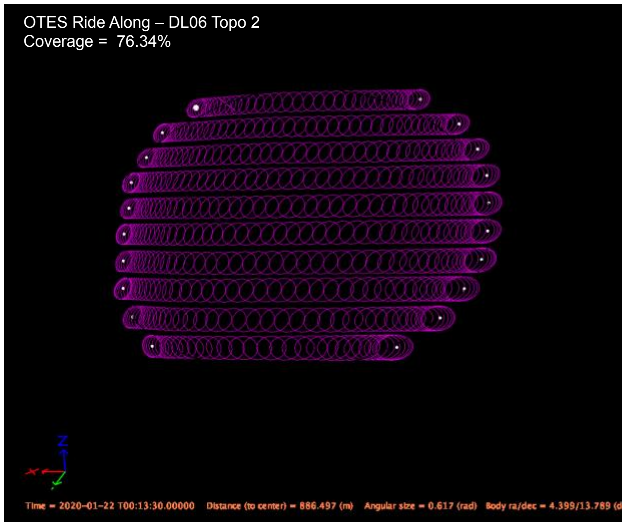


Figure 12 Elliptical Raster Scan observation for NFT Topo 2 at DL06 Osprey. The ellipse shown is the 52.5-m x 33.6-m radius ellipse planned to allow for navigational uncertainties. Different from DL06 Topo 1 and the other sites, scanning is along the major-axis (East-West) of the planning ellipse as opposed to North-South. Scanning along the major-axis reduces the number of slews ultimately saving time and allowing the observation to remain within the desired observation constraint window.



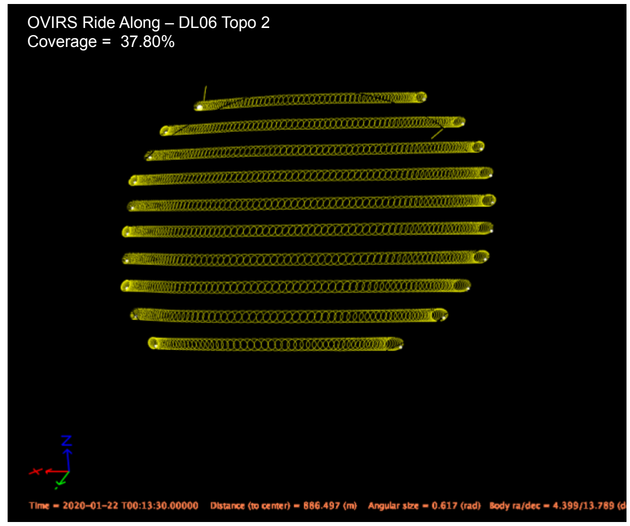


Figure 13 Spectrometer coverage for NFT Topo 2 observations at DL06 Osprey.

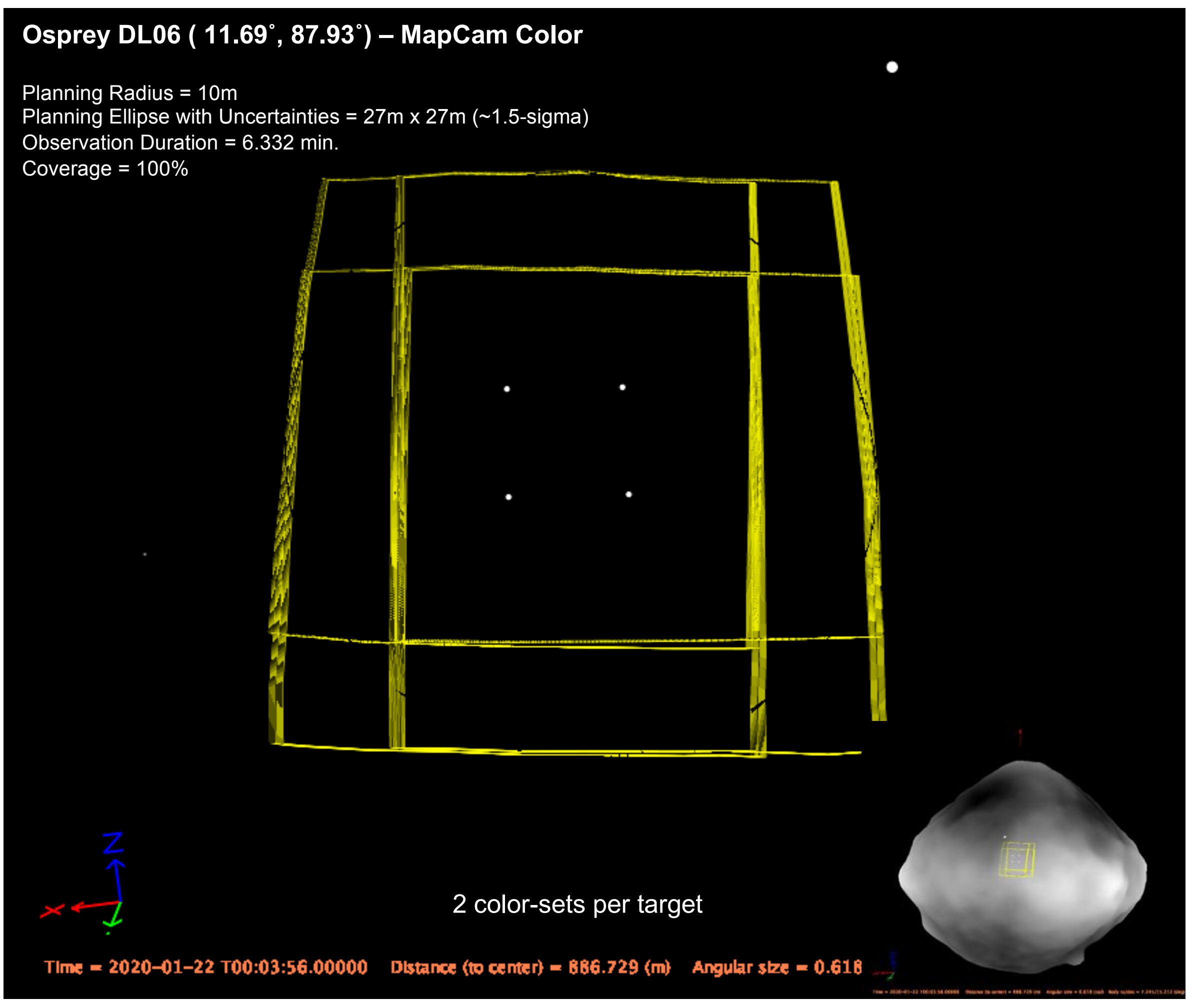
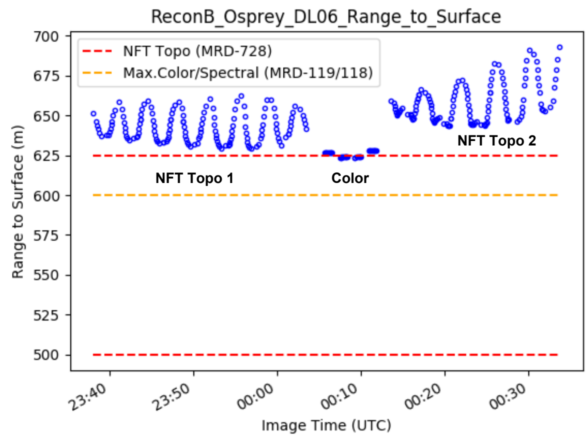
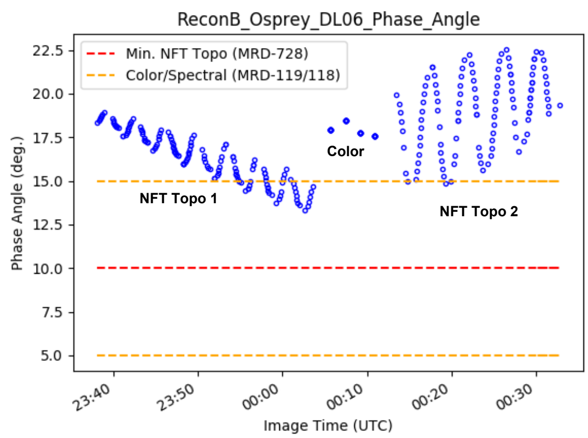
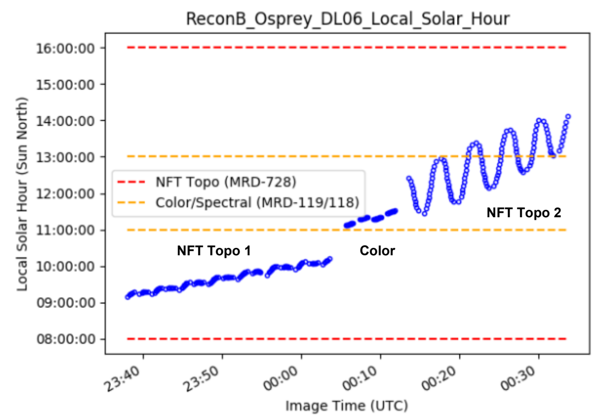


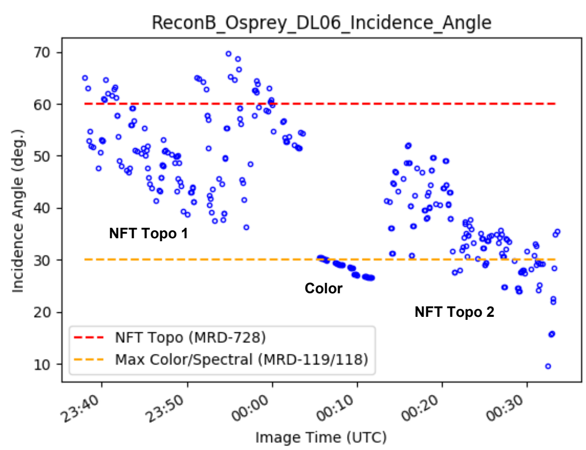
Figure 14 MapCam color observation for DL06 Osprey. Different from the other sites which were planned with a ~2-sigma confidence interval, due to time constraints DL06 color was planned to ~1.5-sigma.

The graphs below show how we are meeting DL06 NFT and color observation constraints. Note some graphs show sinusoidal-like variations with time due to the scanning, but emission and illumination angles show scatter due to the tilt of whichever facet is being imaged at that time.









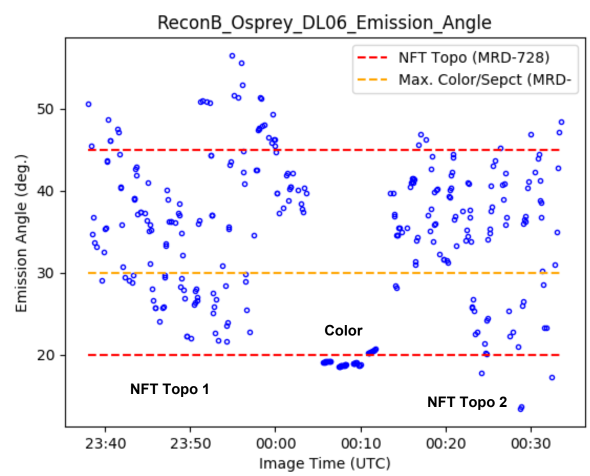


Table 8 Summary of the achieved viewing geometry for DL06 Osprey.

		Topo 1	Topo 2	Color
Range to Surface (m)	Min.	629.06	643.46	623.7
	Max.	662.73	692.86	628.12
Phase Angle (deg.)	Min.	13.3	14.59	17.57
	Max.	18.96	22.53	18.49
Local Solar Hour	Min.	09:09:33	11:27:04	11:06:55
	Max.	10:12:05	14:06:35	11:31:06
Incidence Angle (deg.)	Min.	34.9	9.63	26.54
	Max.	63.9	52.15	30.51
Emission Angle (deg.)	Min.	20.8	13.43	18.55
	Max.	50.7	48.38	20.71

Kingfisher (CQ13) Results

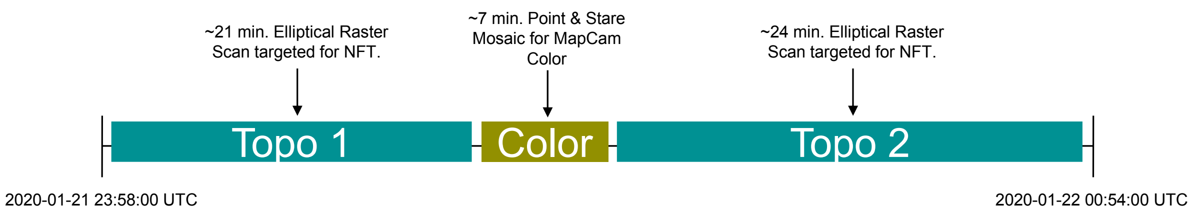


Figure 15 CQ13 achieved observation timeline.

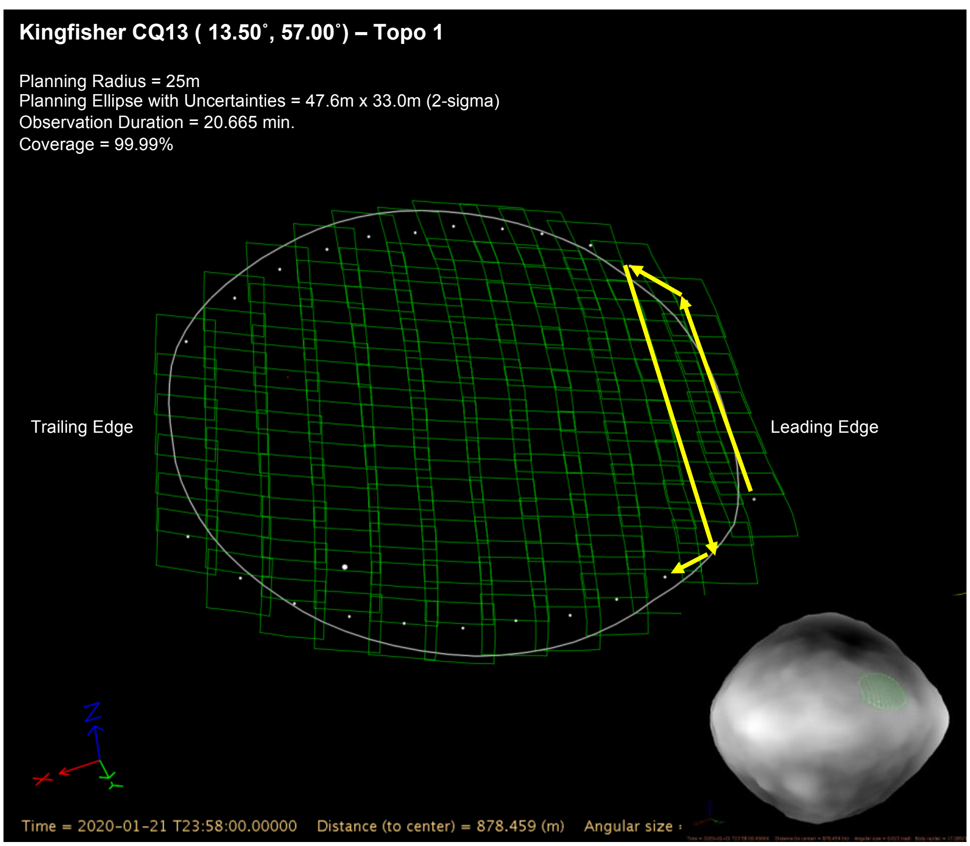


Figure 16 Elliptical Raster Scan observation for NFT Topo 1 at CQ13 Kingfisher. The ellipse shown is the 47.6-m x 33.0-m radius ellipse planned to allow for navigational uncertainties.

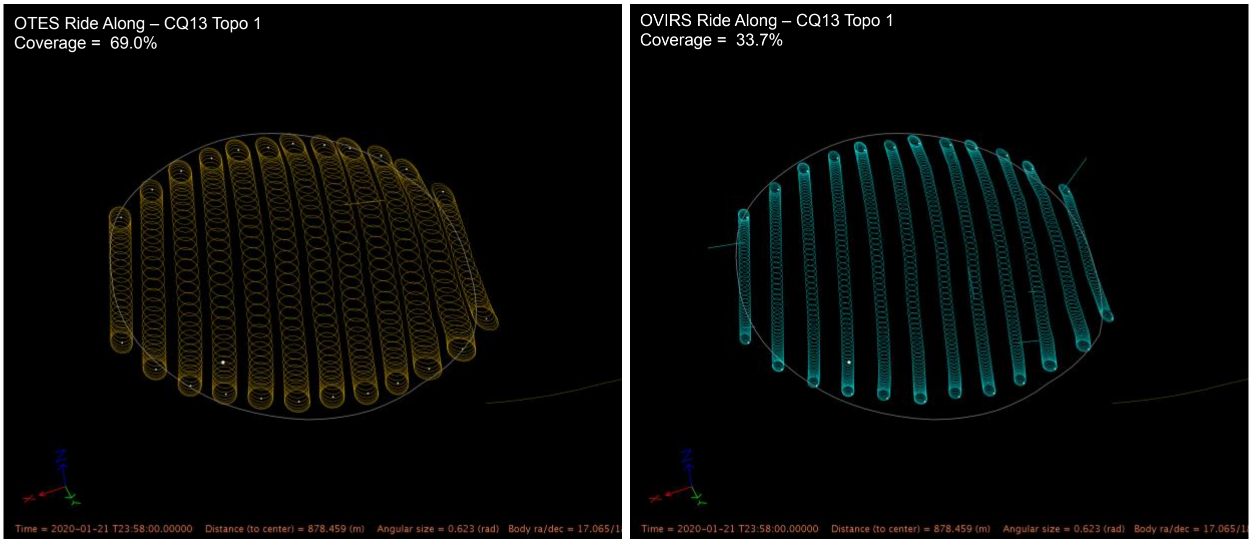


Figure 17 Spectrometer coverage for NFT Topo 1 observations at CQ13 Kingfisher.

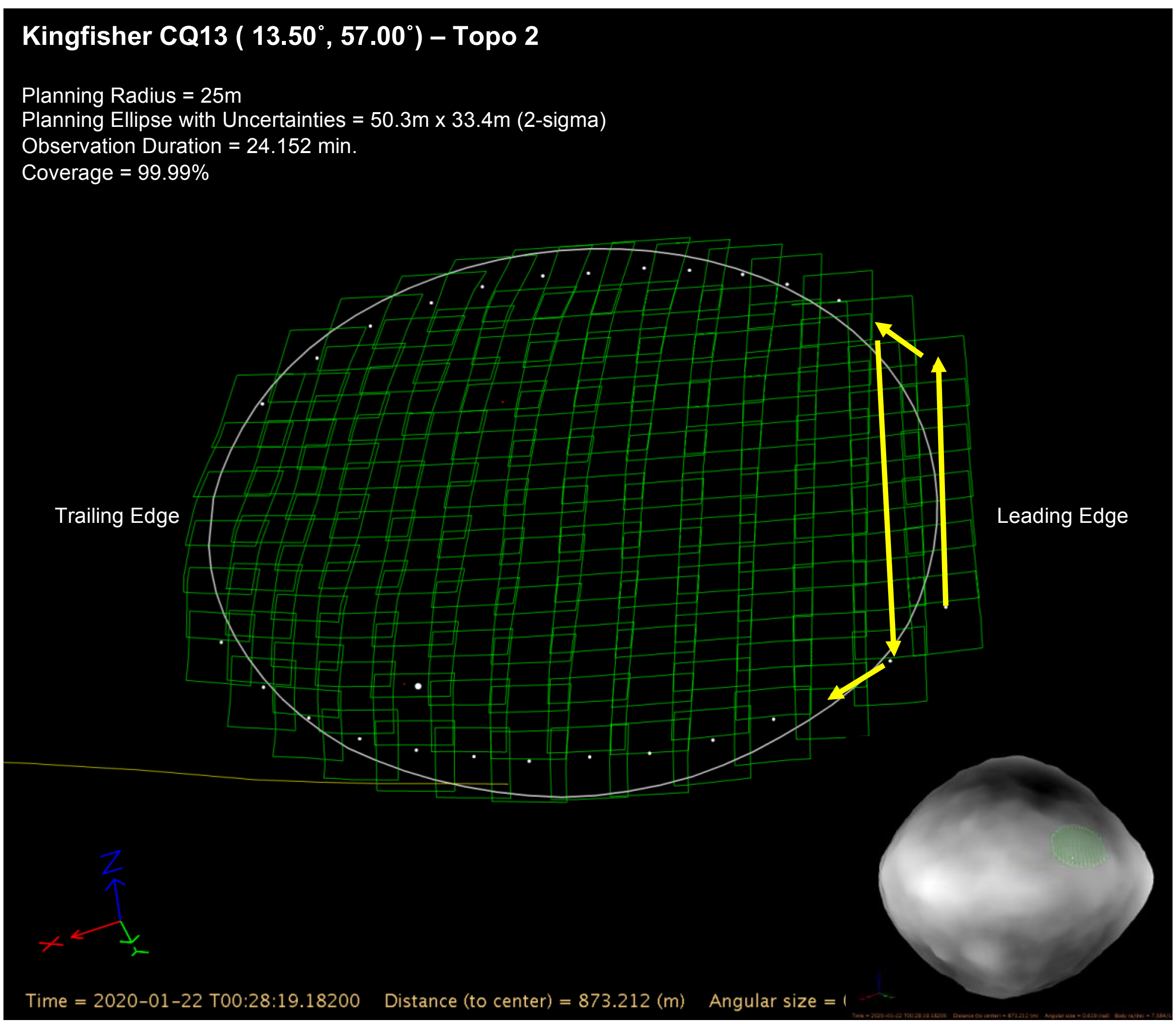


Figure 18 Elliptical Raster Scan observation for NFT Topo 2 at CQ13 Kingfisher. The ellipse shown is the 50.3-m x 33.4-m radius ellipse planned to allow for navigational uncertainties.

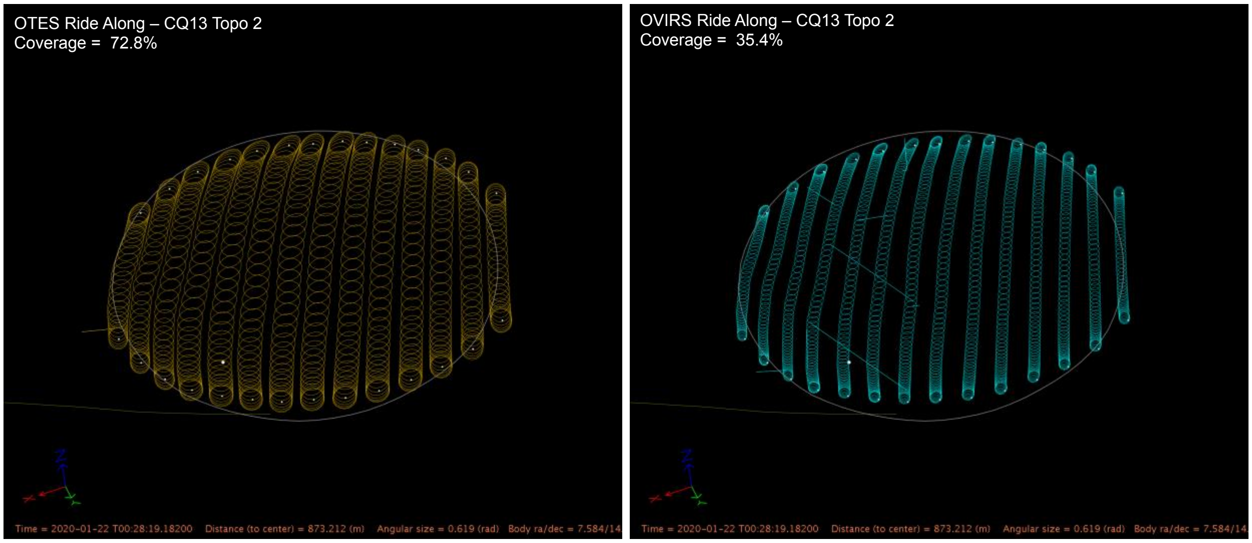


Figure 19 Spectrometer coverage for NFT Topo 2 observations at CQ13 Kingfisher.

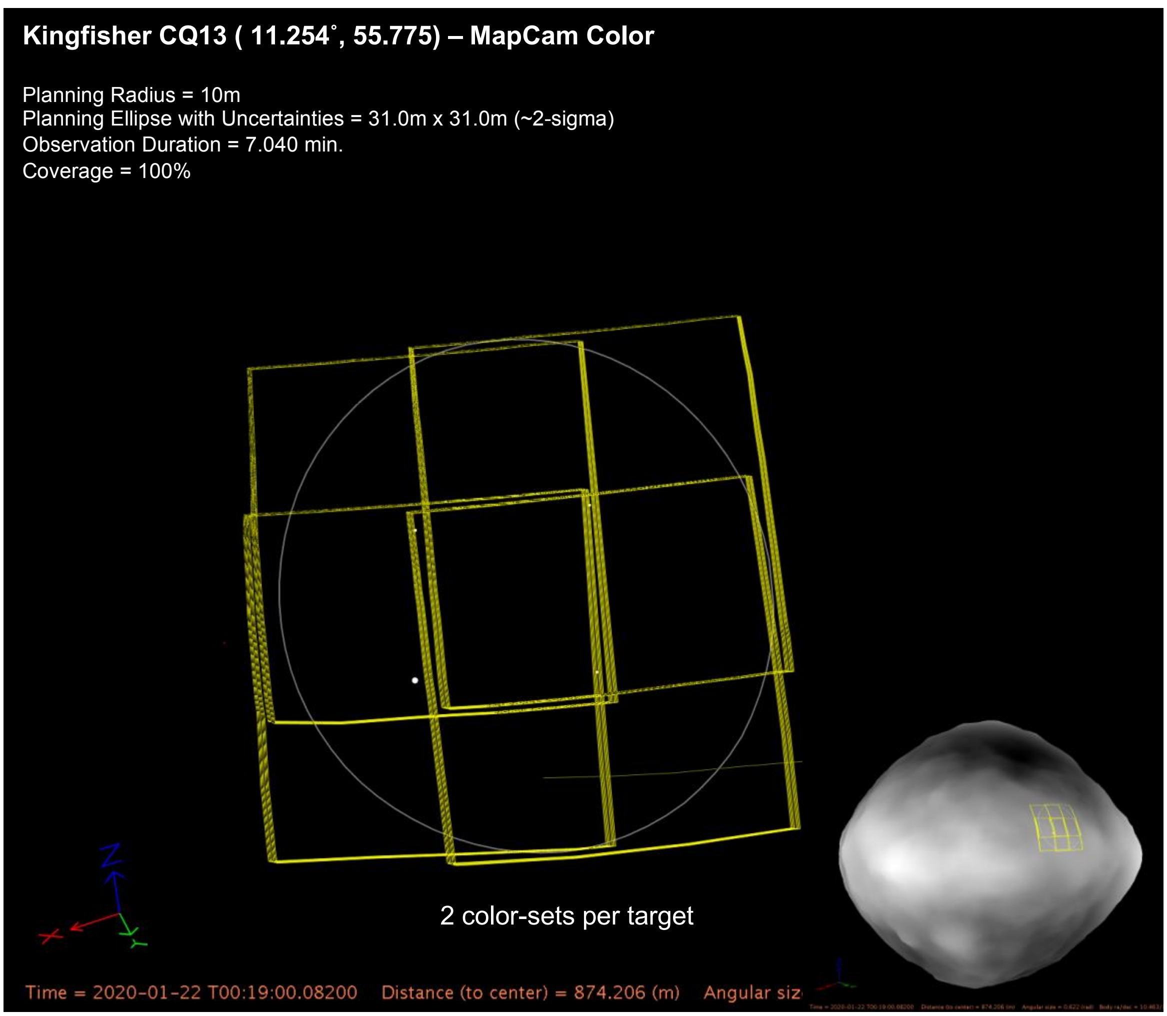
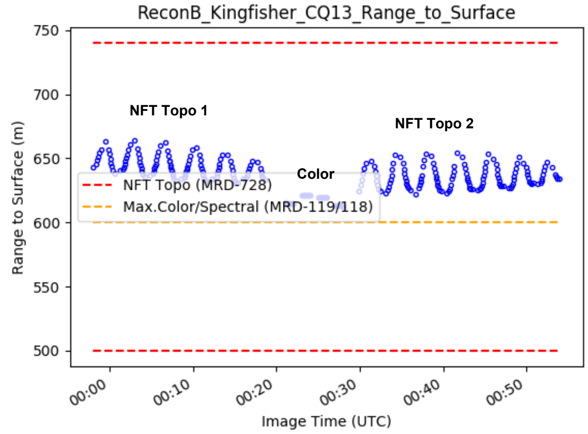
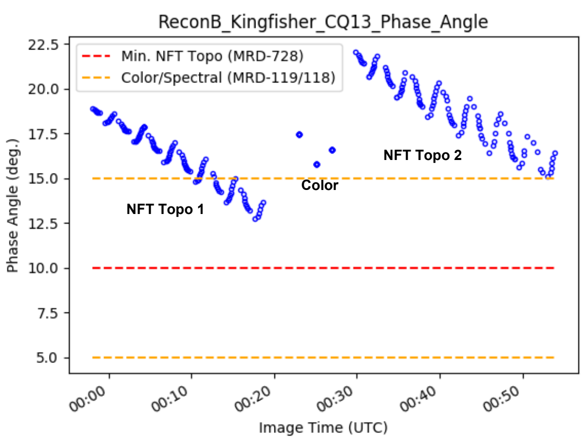
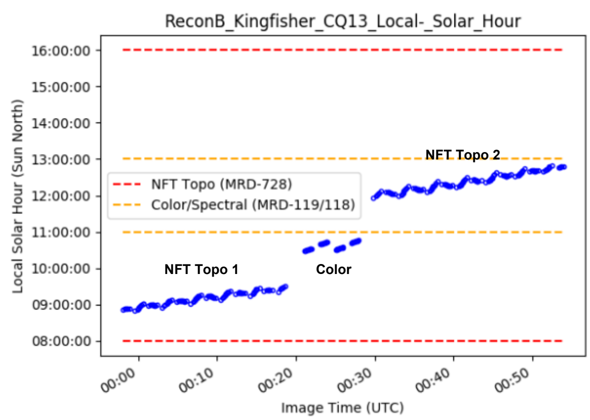


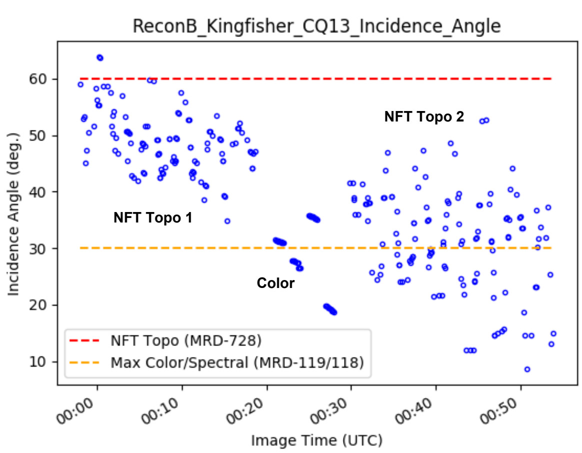
Figure 20 MapCam color observation for CQ13 Kingfisher.

The graphs below show how we are meeting CQ13 NFT and color observation constraints. Note some graphs show sinusoidal-like variations with time due to the scanning, but emission and illumination angles show scatter due to the tilt of whichever facet is being imaged at that time.









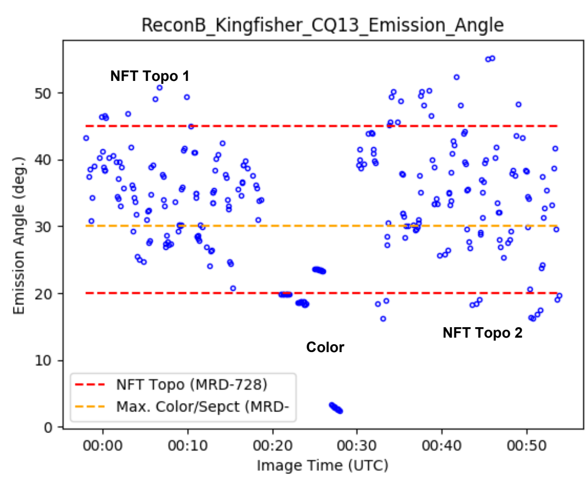


Table 9 Summary of the achieved viewing geometry for CQ13 Kingfisher.

		Topo 1	Topo 2	Color
Range to Surface (m)	Min.	630.6	622.4	612.7
	Max.	663.8	654.4	621.4
Phase Angle (deg.)	Min.	12.7	15.1	15.8
	Max.	18.9	22.0	17.9
Local Solar Hour	Min.	8:48:28	11:55:14	10:28:54
	Max.	9:30:22	12:49:27	10:45:59
Incidence Angle (deg.)	Min.	34.9	8.7	18.7
	Max.	63.9	52.8	35.8
Emission Angle (deg.)	Min.	20.8	16.3	2.4
	Max.	50.7	55.2	23.7

Nightingale (DL15) Results

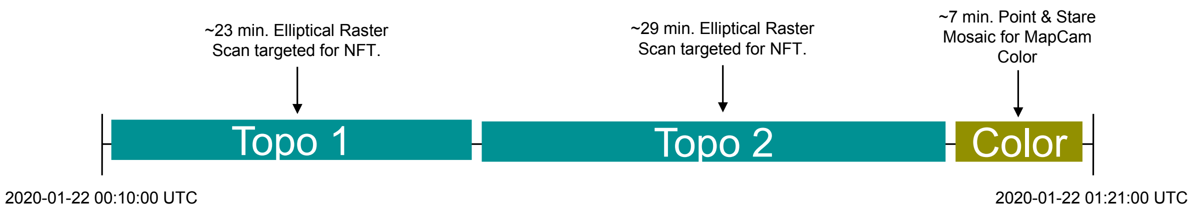


Figure 21 DL15 achieved observation timeline. Color is planned after topo 2 as there is no time between topo 1 and topo 2.

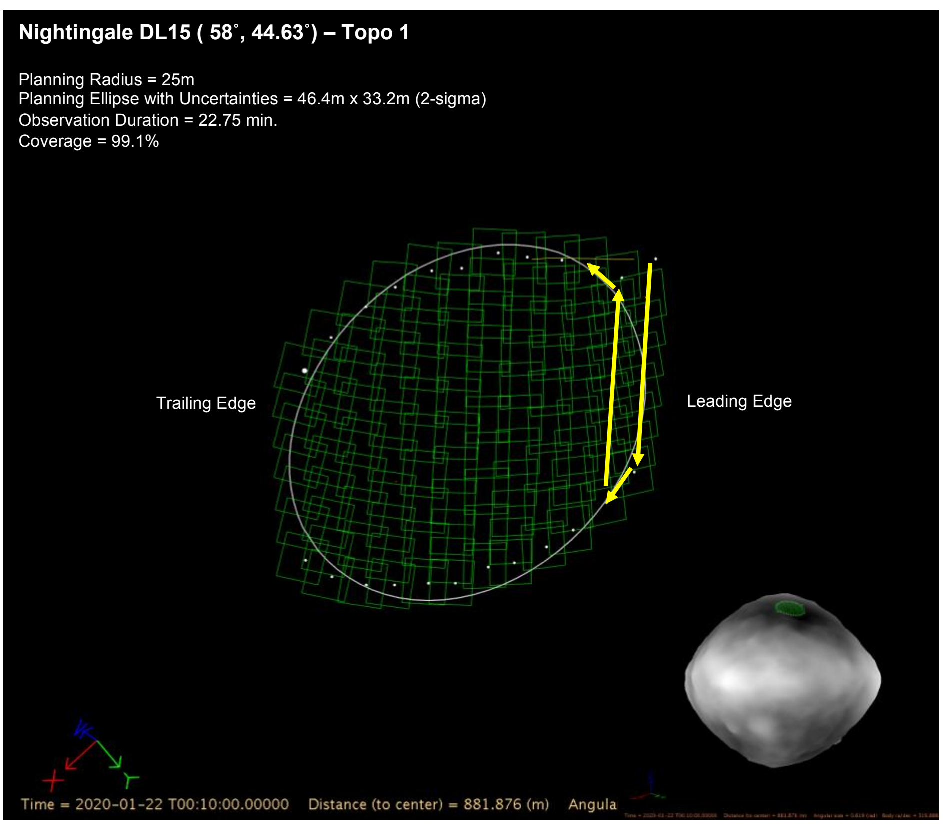
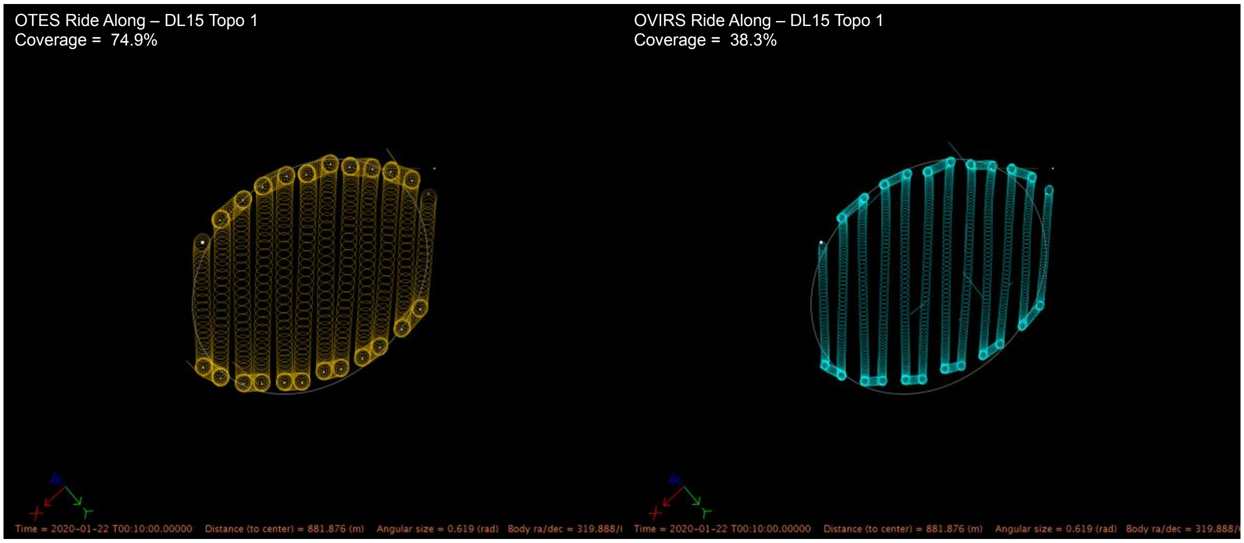


Figure 22 Elliptical Raster Scan observation for NFT Topo 1 at DL15 Nightingale. The ellipse shown is the 46.4-m x 33.2-m radius ellipse planned to allow for navigational uncertainties.



Time = 2020-01-22 T00:10:00.00000 Distance (to center) = 881.876 (m) Angular size = 0.619 (rad) Body ra/dec = 319.888/

Figure 23 Spectrometer coverage for NFT Topo 1 observations at DL15 Nightingale.

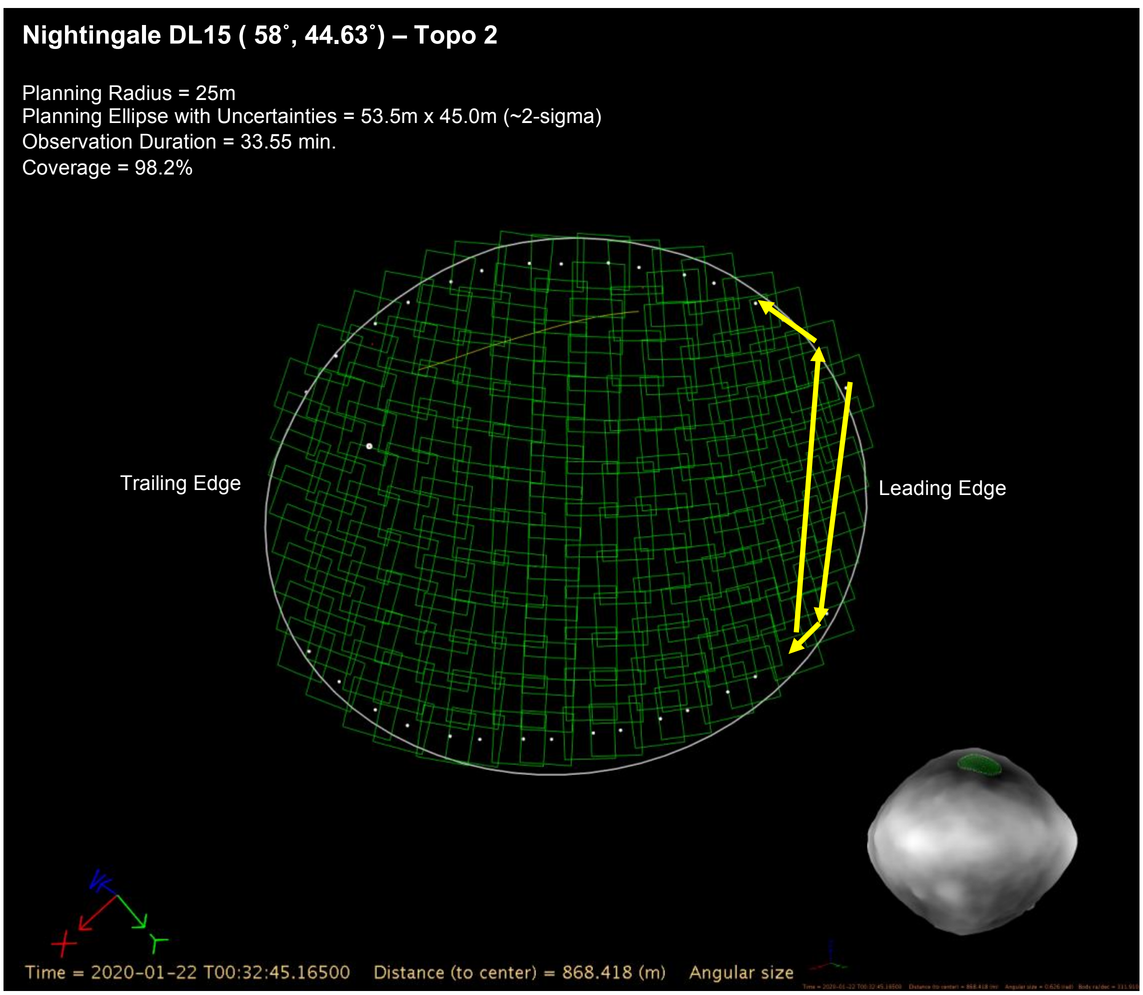


Figure 24 Elliptical Raster Scan observation for NFT Topo 2 at DL15 Nightingale. The ellipse shown is the 53.5-m x 45.0-m radius ellipse planned to allow for navigational uncertainties. Note for DL15 Topo2 observations were planned to 2-sigma in the

transverse direction and >2-sigma in the normal direction. The decision to do this was driven by sensitivity analysis results to mitigate against coverage loss. In addition to eliminate across-slew gores, targets pairs were manually adjusted to be closer to each other by 5-10% of the original distance between them.

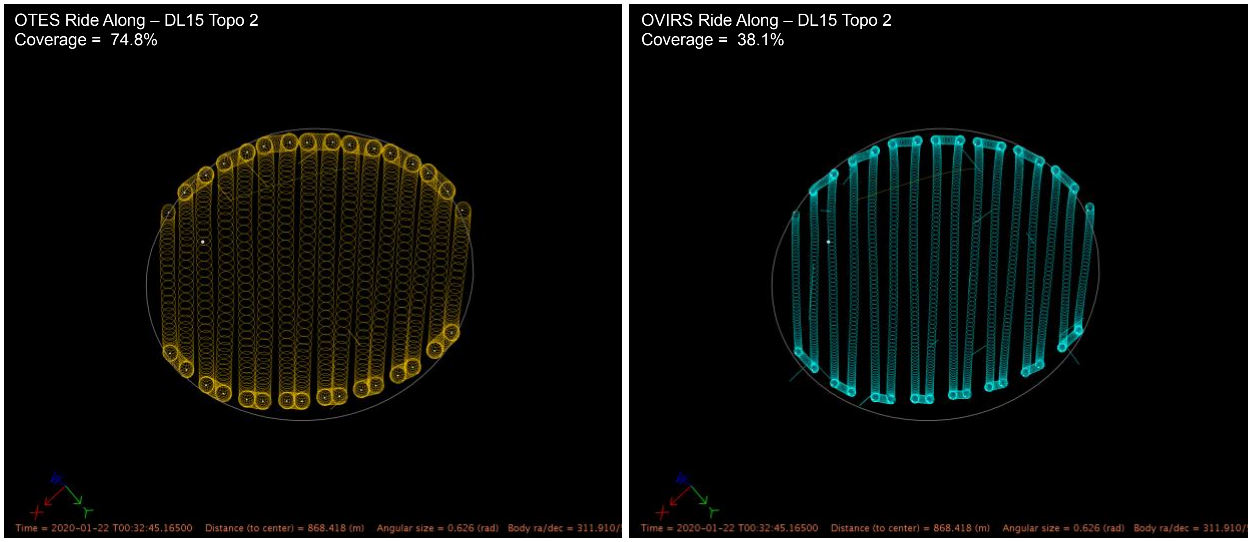


Figure 25 Spectrometer coverage for NFT Topo 2 observations at DL15 Nightingale.

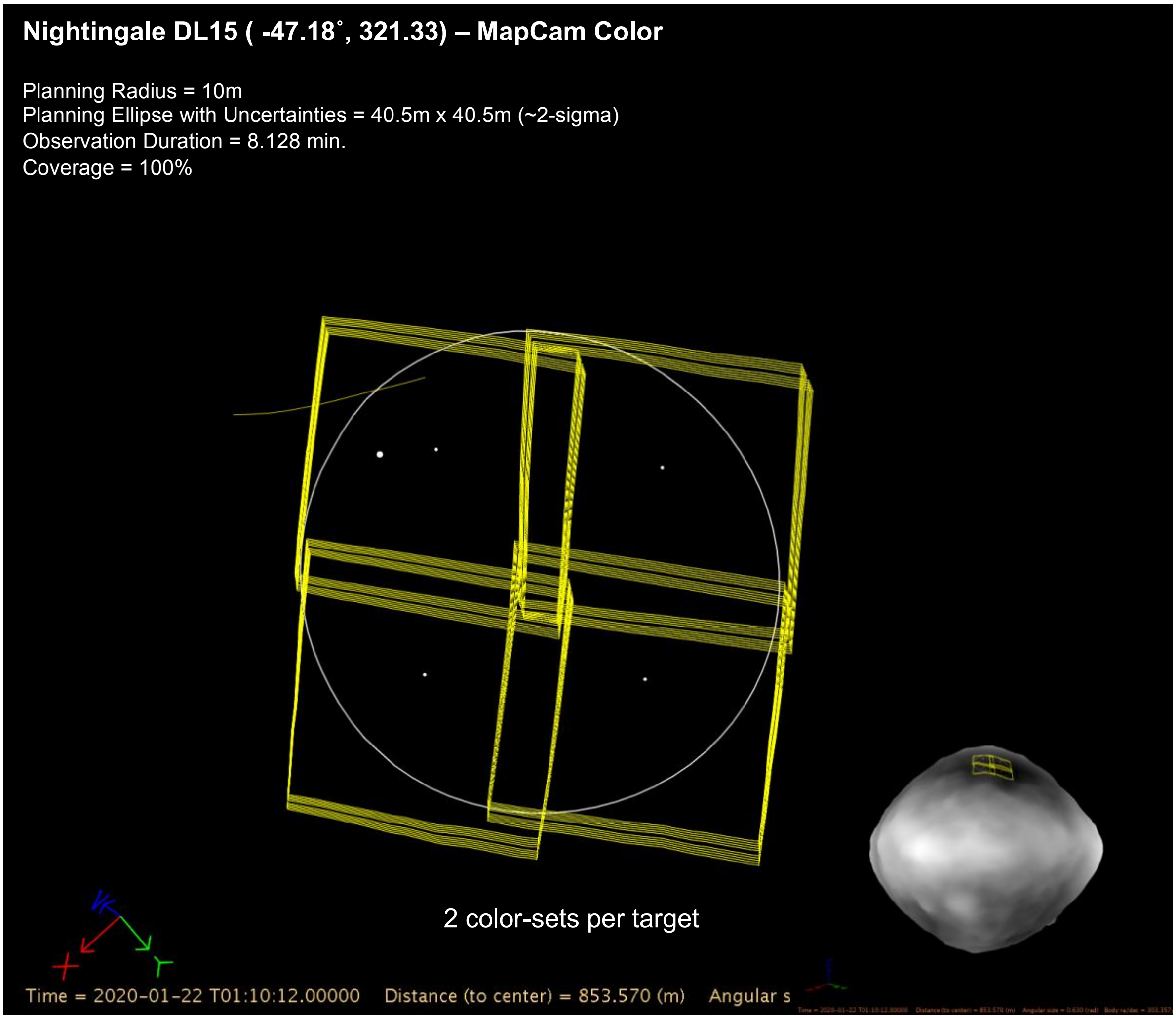
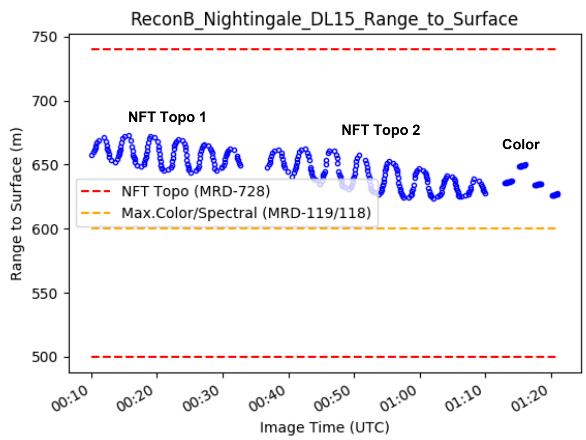
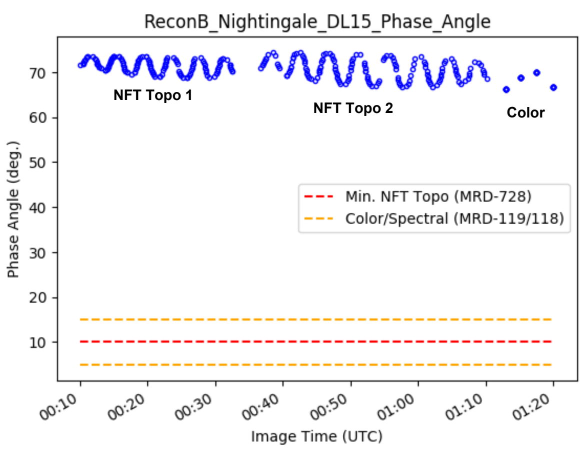
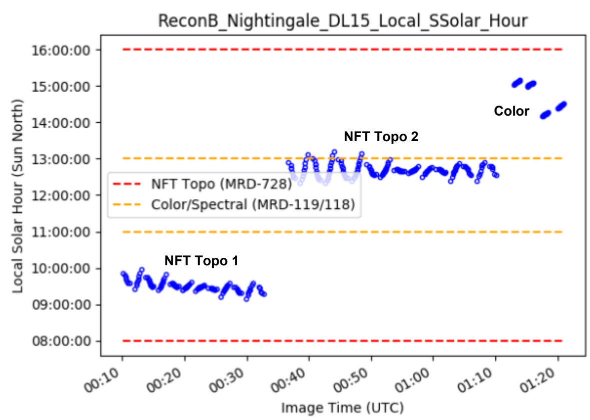


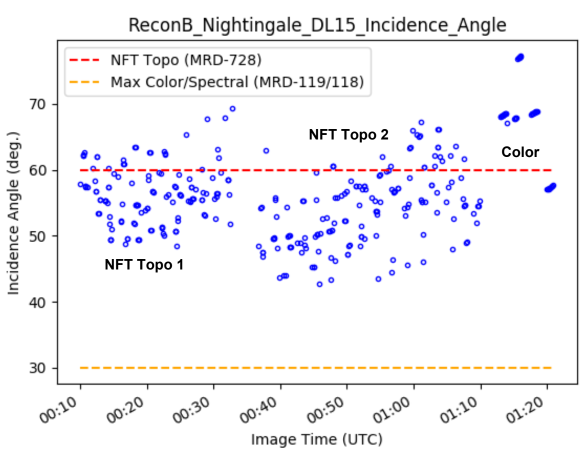
Figure 26 MapCam color observation for DL15 Nightingale.

The graphs below show how we are meeting DL15 NFT and color observation constraints. Note some graphs show sinusoidal-like variations with time due to the scanning, but emission and illumination angles show scatter due to the tilt of whichever facet is being imaged at that time.









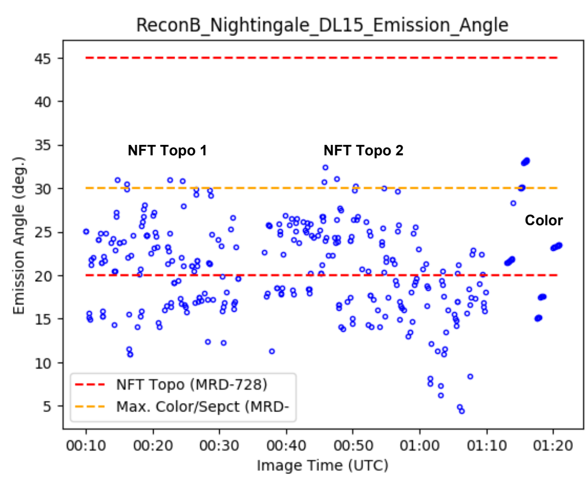


Table 10 Summary of the achieved viewing geometry for DL15 Nightingale.

		Topo 1	Topo 2	Color
Range to Surface (m)	Min.	644.2	623.8	625.9
	Max.	673.2	662.3	650.0

Phase Angle (deg.)	Min.	68.7	66.6	66.4
	Max.	73.6	74.4	70.1
Local Solar Hour	Min.	9:09:5	12:19:53	14:10:06
	Max.	10:07:45	13:11:33	15:09:19
Incidence Angle (deg.)	Min.	48.5	42.8	57.0
	Max.	69.3	67.3	77.3
Emission Angle (deg.)	Min.	10.9	4.4	15.0
	Max.	31.0	32.4	33.2

Operational Considerations

The default slew config file, with a slow (science) slew rate of 2 mrad/s, 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.

All plans will be built nadir-relative with an initial attitude of Sun Point and will include a slew at the end of science observations that returns the spacecraft back to Sun Point. Attitude information will be collected from the spacecraft at a rate of 10 Hz during the Recon B sorties.

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, OLA, OTES, OVIRS, and TAGCAMS will be used during the Recon B sorties. REXIS will be off for all of Recon B, and OLA, OTES, and OVIRS will be off other than the two days of the sorties. OCAMS will remain powered on through Recon B and will be reset weekly on Sundays prior to the HGA pass. The +10°C PolyCam thermal set point will be used for the sorties, with the switch occurring ~2 days prior to science and staying in place through the Low sorties. Deep space cals for OTES and OVIRS will take place during off-body pointing before and after the nominal science observations. OVIRS will be switched to SP=2 mode ~8 hours prior to each of the medium Recon sorties and will be switched back to SP=8 immediately following each sortie. NavCam1 and MapCam will be used for OpNavs bracketing the science observations and NavCam1 will ride-along with the Recon sortie elliptical raster scans and MapCam color observations.

All of the other days of this phase will consist of taking NavCam1 and MapCam images for OpNavs and NavCam1 images for low cadence particle monitoring. In addition, two sets of NavCam2 trending observations, planned by the MSA, will be acquired during Recon B separated in time by approximately three weeks. Each observation set will consist of ten images for a total of 20 NavCam2 images. No other data collection will be planned.

PolyCam Refocusing during Recon B

The depth of field of PolyCam is such that active focusing via OLA will be required. Assuming a nominal range to surface of around 630 meters during Recon B, PolyCam will have an allowable depth of field of around ±35 m. We expect that it will move through the following focus positions during Recon Medium Flybys: 33AE, 3462, 3516 and 35CA or 24B, 24C, 25A & 25B. This range variation with a 2-sigma uncertainty in range of ±40 meters is what requires the active focus. We expect to call the autofocus (ocm_poly_autofocus) command in between calls to calc_slew_image, the block that controls the spacing and timing of the images in a single slew across the target area. (There is not sufficient time between images to perform active refocusing in the middle of a slew). The range-informed refocus in between slews will occur on the edges of the region being targeted, but a preliminary examination of the predicted range to surface throughout this target region reveals that the error incurred will be of order 20-30 m at most and therefore acceptable when compared to the allowable depth of field.

Calls to ocm_poly_autofocus will take ~15-30 seconds maximum to complete execution. In cases where the range has not exceeded the real allowable range variation, ocm_poly_autofocus block will be commanded to the current focus position and no focus movement adjustments will occur. The block also accepts an offset, which could be used to adjust the range information collected at the edge of the target range to a value closer to the range to the central portion of the target region.

Requirements and Data Products

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 B?	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)	✓	
	Look 2: 180˚ ±30˚ (South)	✓	
	Look 3: 90˚ ±30˚ (East)	!	Planned in Recon A
	Look 4: 270˚ ±30˚ (West)	!	Planned in Recon A
	Look 5: 0˚ or 180˚ (North or South for albedo)	!	Planned in Recon A
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:	~742	✓	Baseline: ~610-692m (center of PolyCam FOV)

Pixel Size:	Between all 5 looks, two sets must achieve a 1cm pixel size and 3 sets must achieve a 2cm pixel size.	✓	Achieving 1cm during Recon B 2cm is achieved during Recon A Baseline: 0.823-0.934 (center of PolyCam FOV)
Phase Angle:	>10˚	✓	Baseline: ~12˚-75˚ (center of PolyCam FOV) EX07 = ~64˚-70˚ DL06 = ~13˚-23˚ CQ13 = ~12˚-22˚ DL15 = ~66˚-75˚
Incidence Angle:	<60˚ (topo) ±15˚ from site lat. (albedo)	✓	Not doing albedo during Recon B Baseline: ~8˚-71˚ (center of PolyCam FOV) EX07 = ~38˚-71˚ DL06 = ~9˚-64˚ CQ13 = ~8˚-64˚ DL15 = ~42˚-70˚
Emission Angle:	20˚ – 45˚ (topo) 0˚ – 30˚ (albedo)	✓	Not doing albedo during Recon B Baseline: ~2˚-55˚ (center of PolyCam FOV) EX07 = ~2˚-40˚ DL06 = ~13˚-51˚ CQ13 = ~16˚-55˚ DL15 = ~4˚-32˚

5cm DTMs from OLA:

MRD Description:

MRD-115b: 5-cm resolution over a 3-sigma TAG error ellipse is needed to assess safety and Sampleability of candidate sites. It is expected that maps produced from OCAMS data collected during Orbital B and OLA data collected during Recon will provide this resolution.

Observation Constraints:

Constraint	Value	Satisfied During Recon B?	Notes
Instrument:	OLA	✓	
Instrument Settings:	Linear scan opposite direction to S/C slew	✓	
Range to Surface:	<300m	!	Baseline: ~610-692m Planned to be satisfied during Recon C
Footprint:	<3 cm	!	Planned to be satisfied during Recon C
Along-Slew Overlap:	20% (30%-40% is ideal) Would like to achieve ≥4 returns per 5cm bin.	✓	
Across-Slew Overlap:	20% (30%-40% is ideal) Would like to achieve ≥4 returns per 5cm bin.	✓	
Emission Angle:	0˚ to 45˚ (<30˚ is preferred)	!	Would like 0˚ emission at NADIR Minimize emission angles across Recon site. Baseline: ~2˚-55˚

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 B?	Notes
Instrument 1:	**OVIRS**	✓	
Instrument Settings:	72hr cool-down period	✓	
Coverage:	>40% of 2-sigma TAG delivery error ellipse.	!	Not boresighting to OVIRS Baseline: ~33-39%
Pointing:	NADIR relative scanning	✓	Currently MRD-118 is not driving the pointing in either Recon A or B.
Footprint:	<5m	✓	Baseline: ~2.44-2.78m
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. Baseline: ~8:50am to 3:10pm Constraint being met during: EX07 Topo 1, DL06 Topo 2, CQ13 Topo 2, EX07 Color, DL06 Color, & CQ13 Color
Phase Angle:	0˚ to 15˚	!	Baseline: ~12˚-75˚ Constraint is being partially met during DL06 and CQ13, but is still a little high at times.
SNR:	>50	TBD	Not validated by SPT.
Instrument 2:	**OTES**	✓	
Coverage:	>40% of 2-sigma TAG delivery error ellipse.	✓	Not boresighting to OTES Baseline: ~69-79%
Pointing:	NADIR relative scanning	✓	Currently MRD-118 is not driving the pointing in either Recon A or B.
Footprint:	<8m	✓	Baseline: ~4.88-5.54m
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 Baseline: ~8:50am to 3:10pm Constraint being met during: EX07 Topo 1, DL06 Topo 2, CQ13 Topo 2, EX07 Color, DDL06 Color, & CQ13 Color
Phase Angle:	0˚ to 15˚	!	Baseline: ~12˚-75˚ Constraint is being partially met during DL06 and CQ13, but is still a little high at times.
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 B?	Notes
Instrument:	OTES	✓	
Coverage:	≥80% of candidate sample ellipse	!	Not boresighting to OTES Baseline: ~69-79%
Footprint:	<8m	✓	Baseline: ~4.88-5.54m
Local Solar Hour:	8pm to 5am (nighttime) or 10am to 12:30pm	✓	Baseline: ~8:50am to 3:10pm
Emission Angle:	0˚ to 60˚ (<30˚ is preferred)	✓	Baseline: ~2˚-55˚

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 B.

Observation Constraints:

Constraint	Value	Satisfied During Recon B?	Notes
Instrument:	MapCam	✓	
Coverage:	100% of a 2-sigma TAG delivery error ellipse.	✓	Baseline: 2x2 Point&Stare mosaics DL06 Color is planned to ~1.5-sigma
Pointing:	Nadir relative scanning	✓	
Along Slew Overlap:	>30%	!	Baseline: Not met during DL15 (~20%)
Across Slew Overlap:	>40%	!	Baseline: Not met during DL15 (~20%)
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	✓	Baseline: 0.0416-0.0442m (center of MapCam FOV)
Incidence Angle:	0˚ to 30˚	!	Baseline = ~18.7˚-77.3˚ Constraint met during DL06 and CQ13
Emission Angle:	0˚ to 30˚	!	Low emission angle required to minimize distortion, foreshortening, and other projection effects for 80% coverage. Baseline: ~2.4˚-33˚
Phase Angle:	5˚ – 15˚	!	Low phase angle but NOT 0˚. Ensures best possible SNR at shortest possible exposure time Baseline: ~16˚-70˚ Constraint is nearly met during DL06 and CQ13
Local Solar Hour:	11am–1pm	!	Baseline: ~10:30am to 3:10pm Constraint met for all sites except DL15.

SNR:	≥100	**TBD**	Not validated by SPT.

Summary of Data Products:

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