

# DTM Summit

Eric E. Palmer  
Planetary Science Institute  
1 Feb 2016

# SPOC SPC Verification and DRM Validation

Phase 1 - No Error — 07/15

F1a/b

Gaskell Blind  
Palmer Not

Full Mission  
Shape Model Test

Verification - Global 75cm, 35cm,  
10cm TAG 5cm

F2

Calibration — “Best case”  
accuracy for all phases

Phase 2 - Effect of Error Injection, 12/15

F3

Sensitivity Analysis

Evaluate  
Requirements &  
DRM

Phase 3 - Error Injection — 05/16

F4

App/PreSurv  
Shape Model

Validation - 75cm

F5

FDS Shape Model  
Validation

F6

Detailed Survey  
Shape Model

Validation - 35cm

NFT A

Feature  
Development  
Thread Test

NFT B

Departure to  
TAG  
Flight Simulation

NFT C

TAG site at 5cm

Note: Dates are completion times

# Overview

- Requirements
- Goal for ORR/FRR
- Goal for Launch
- What We've Learned From Our Tests
- Possible Solutions

# Requirement Summary from MRD Rev J

	Ground Sample Distance	Accuracy	Relative Vertical Accuracy	Post-fit Residuals	Data	When
FDS Global 75cm	75cm	100cm		38cm	PreSurv	Orb A
FDS Global 35cm	35cm	75cm		18cm	Detailed Survey	Orb B
<del>NFT Global 10cm</del>	10cm	63cm	17cm	3.2cm	Detailed Survey	<del>Orb B</del>
<del>NFT TAG 5cm</del>	5cm	14cm	1.8cm	1.7cm	Orbit B	PreRecc

# Requirement Summary from MRD Rev K

	Ground Sample Distance	Accuracy	Correlation Score	1st Peak Distance	Data	
Global 35cm	35cm	75cm			Detailed Survey	Over 80%
TAG Site	5cm	14cm			Orbit B	
NFT Features	Various		0.6	2 pixels 1 sigma	Detailed Survey / Orbit B	300 Features



# Science Requirements

- Requirements remain unchanged since CSR
  - Defined by map resolution

	Ground Sample Distance	Accuracy	Vertical Precision	Horizontal Relative Accuracy		Product source and required timing
Sci 100cm	<100cm	<100cm			MRD 122	SPC – PreSurvey/Orb A OLA –Detailed survey
Sci 5 cm	<5cm	<100cm	<5cm		MRD 115	SPC-Detailed Survey OLA-Orb B/Recon
Sci tilt 32 cm for 12 tag	<32cm	<100cm	<4cm	<32cm	MRD 608	Detailed Survey OLA-Orb B

# Lesson's Learned

# Testing Accuracy

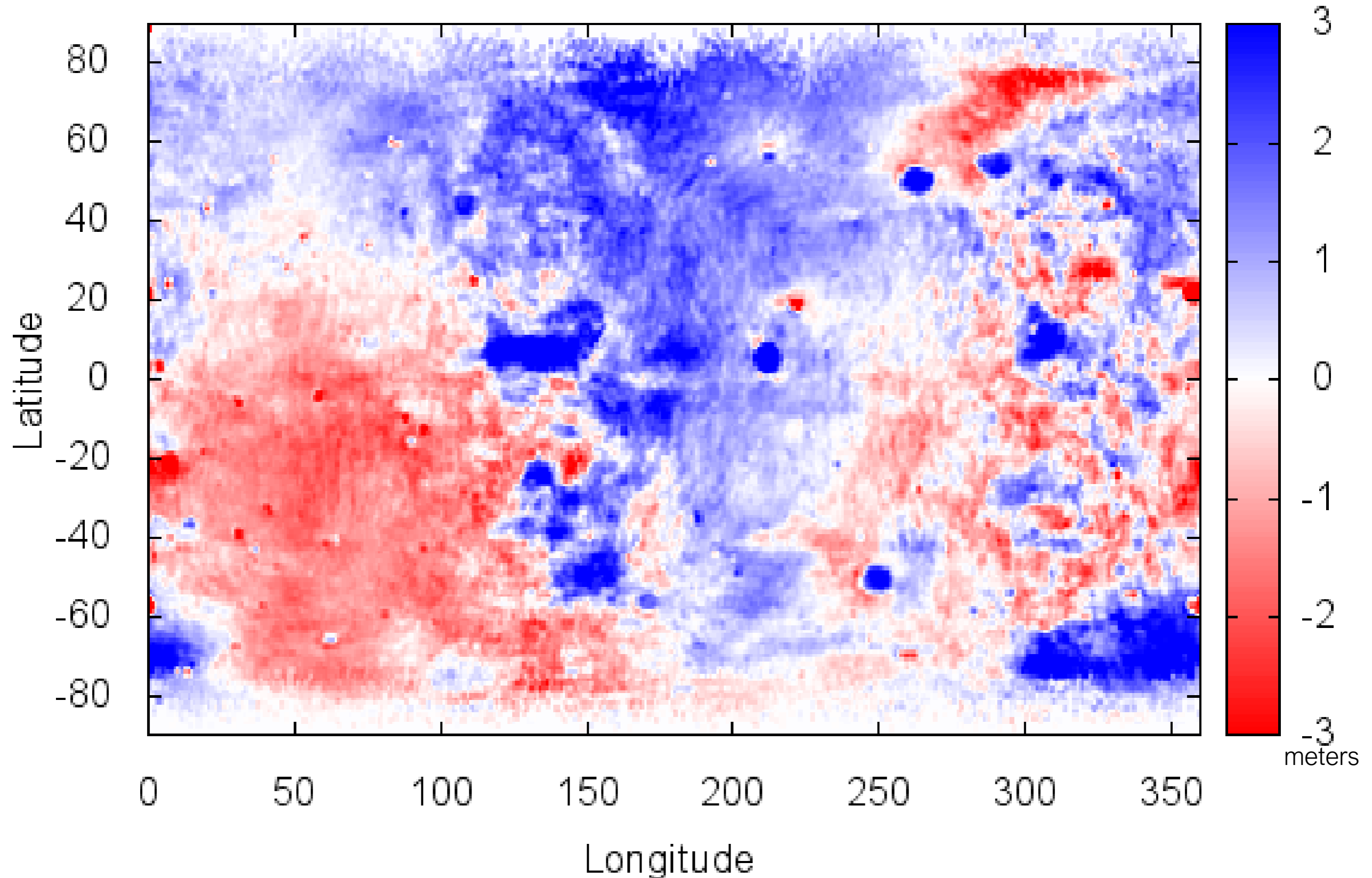
- No Nav Error DTM (F1A)

Product	Requirement	Gaskell (100%)	Palmer (100%)
FDS Global 75cm	100cm	56.5cm	92.0cm
FDS Global 35cm	75cm	49.2cm	42.0cm
Global 10cm	63cm	18.5cm	18.8cm
TAG 5cm	14cm	4.5cm	5.08cm

- 1 Sigma Nav Error (F3A)

Product	Requirement	Palmer (100%)	Palmer (80%)
FDS Global 75cm	100cm	106 cm	72 cm
FDS Global 35cm	75cm		
Global 10cm	63cm		
TAG 5cm	14cm		

# Deviation (Truth F3A-P13)



# Post Fit Residual Error

Each image contains

- Known position
- Known pointing
- Pixel/Line location

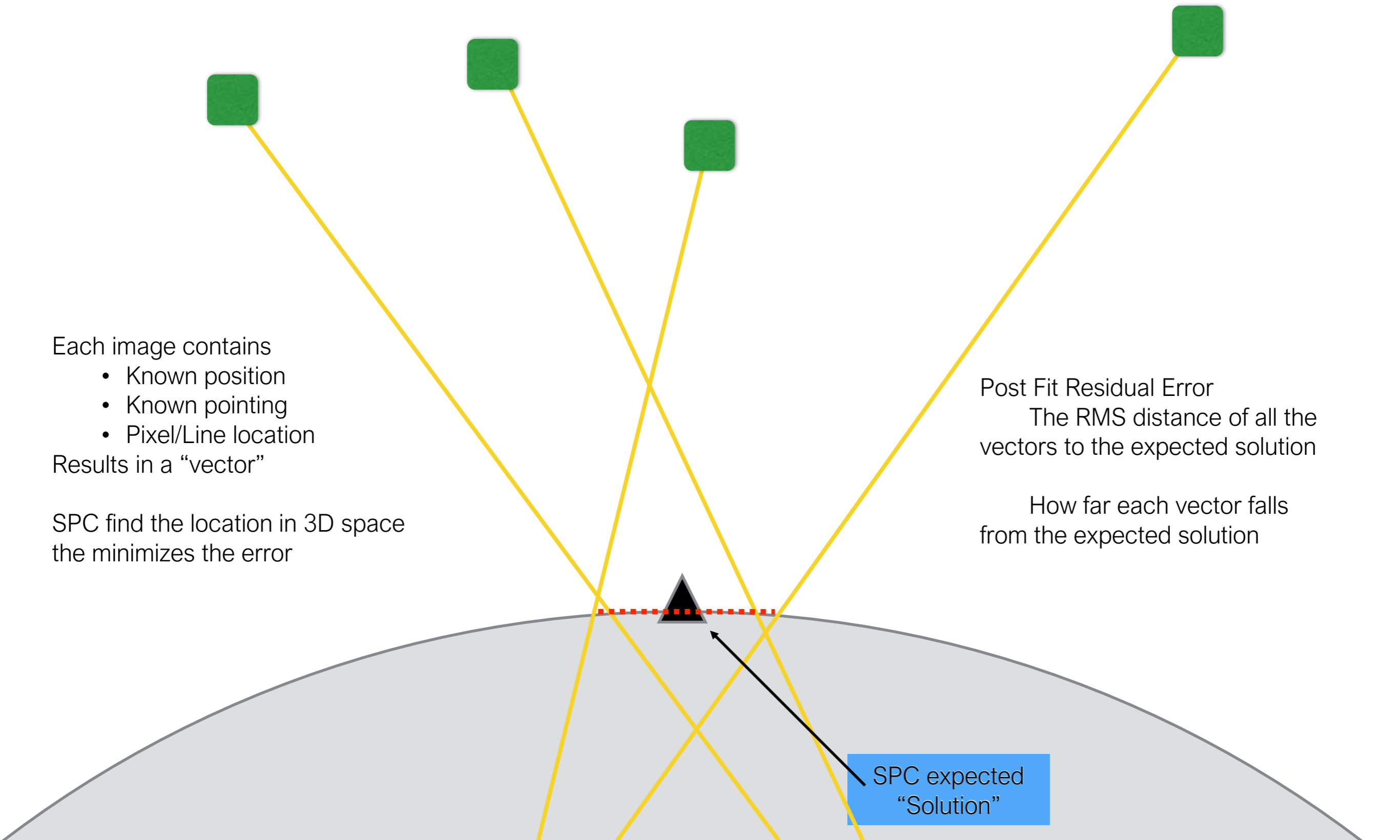
Results in a “vector”

SPC find the location in 3D space  
the minimizes the error

Post Fit Residual Error  
The RMS distance of all the  
vectors to the expected solution

How far each vector falls  
from the expected solution

SPC expected  
“Solution”



# Post Fit Residual Error

- No Nav Error DTM (F1A)

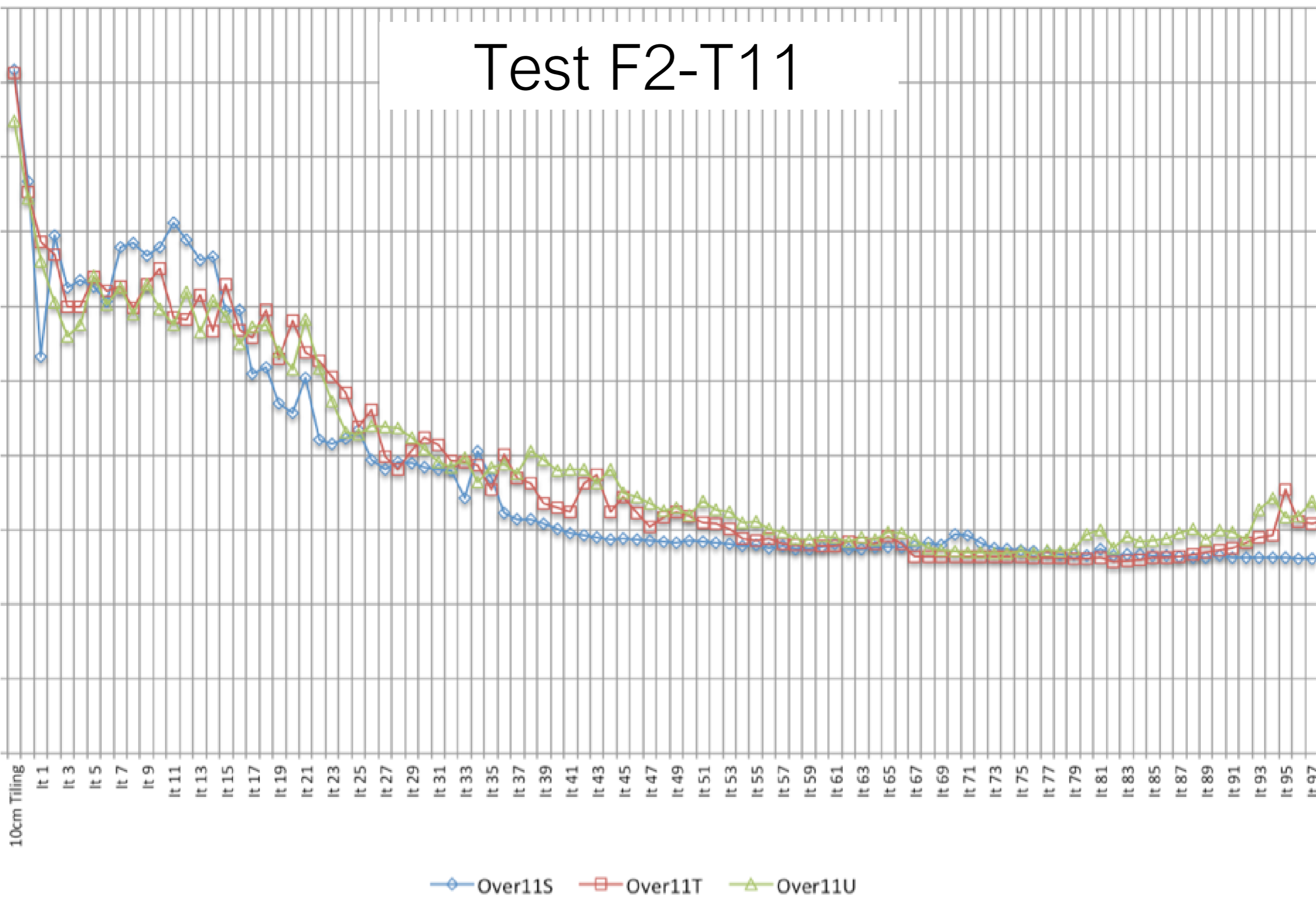
Product	Requirement	Gaskell (100%)	Palmer (100%)
FDS Global 75cm	38cm	49cm	109.0cm
FDS Global 35cm	18cm	45cm	134.0cm
NFT Global 10cm		27cm *	13.4cm +
NFT TAG 5cm		4.5cm+	5.17cm +

- 1 Sigma Nav Error (F3A)

Product	Requirement	Palmer (100%)	Palmer (80%)
FDS Global 75cm	38cm	44cm	? 33cm
FDS Global 35cm	18cm		
NFT Global 10cm			
NFT TAG 5cm			

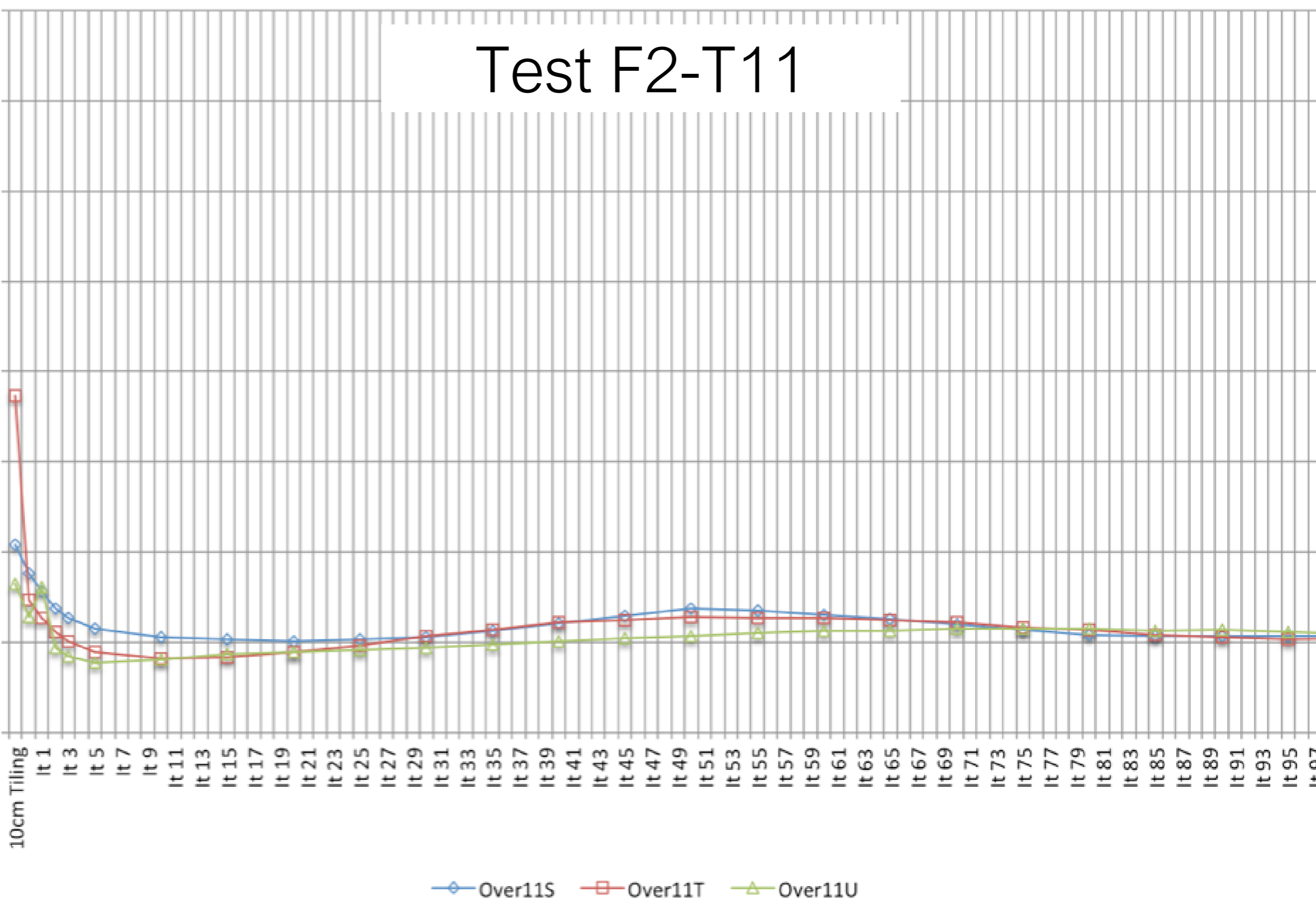
# SC Zenith Variations: Formal Uncertainty

## Test F2-T11



# SC Zenith Variations: CompareOBJ With Opt Trans & Rot RMS

Test F2-T11



# Imaging

# TAG Site: Suggested 1cm Imaging Requirements

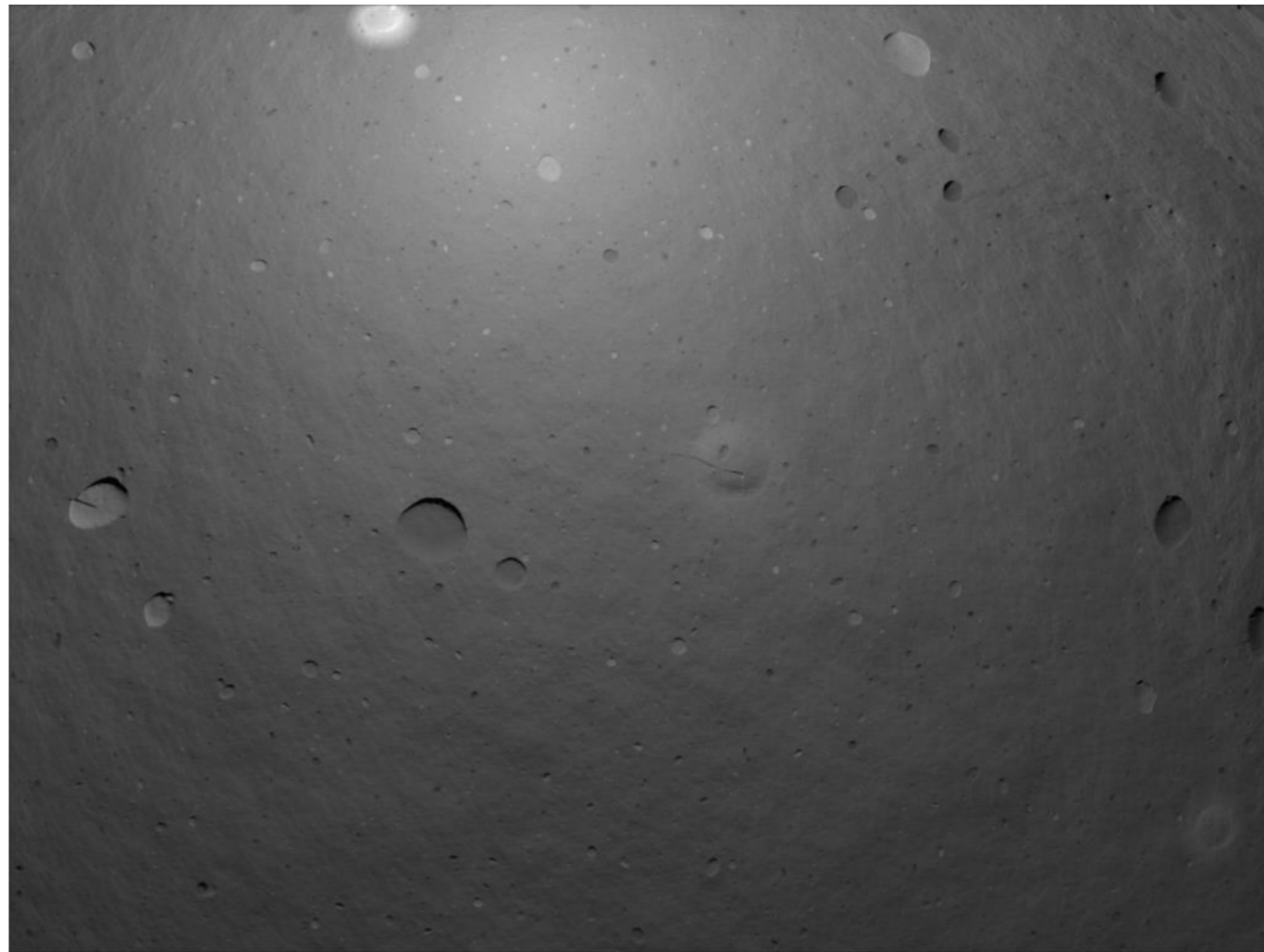
- 4 image sets, PolyCam - 1cm pixel size
- Illumination Conditions (Two different positions, could be as many as four)
  - Sun Azimuth: Generally east and west
  - Sun Zenith: 30-45°. Min 15°, Max 60°. Two sets within 30-45°.
- Viewing Geometry: (Four unique sets)
  - Spacecraft Azimuth: Four angles  $\sim 90^\circ$  between them (i.e. 90, 180, 270, 360)
  - Elevation: 45°
    - Desired: 45°. Max is 55°. Minimum of 0°.
  - Two datasets must have a stereo angle  $> 60^\circ$
- TAG site further from the equator may not allow some of these constraints. We would be wanting imaging from Orbit A or Orbit B to provide additional angles

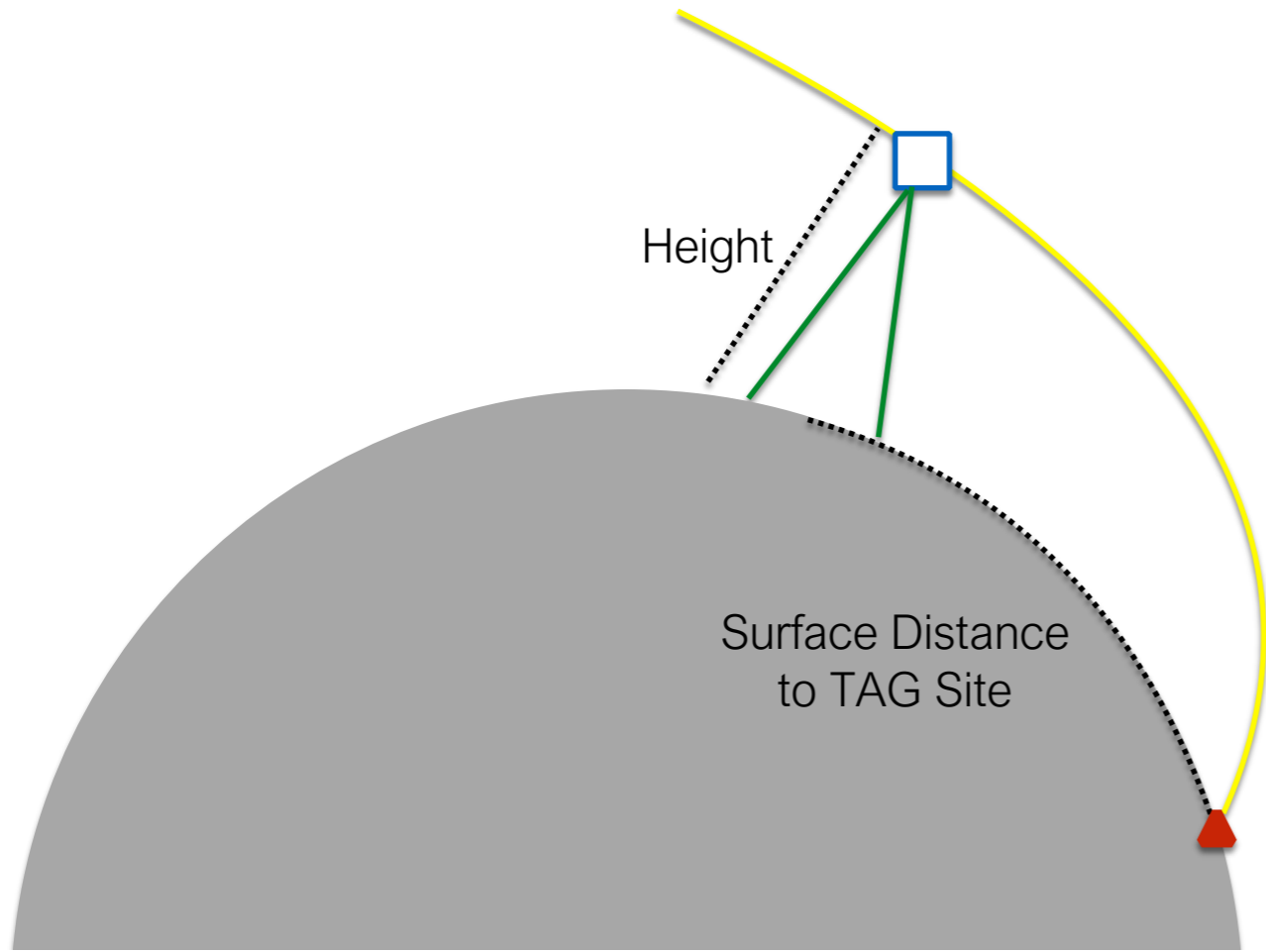
# Example NFTCam Descent Images

Image #3

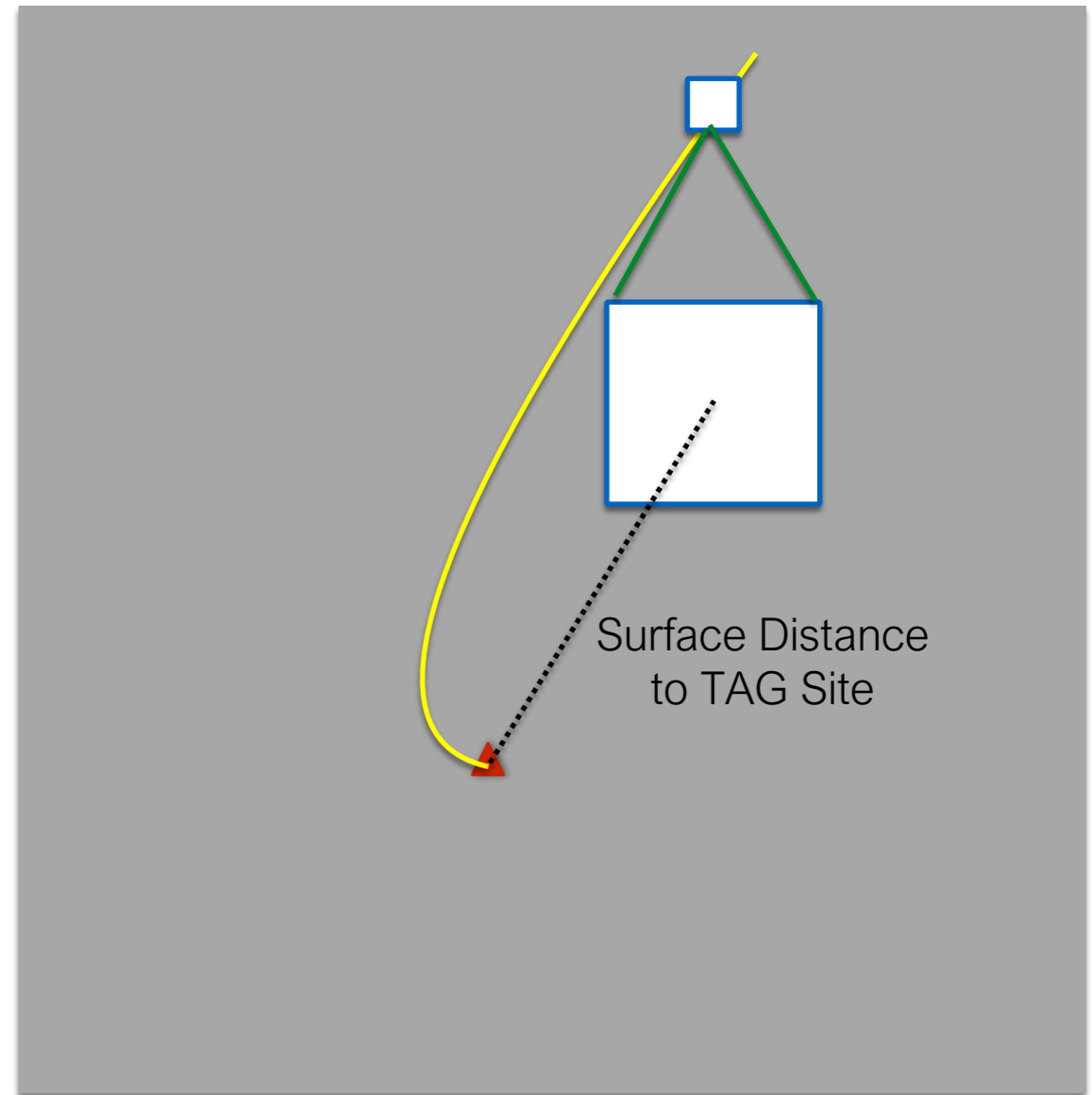


Image #20





Profile View



Overhead View

# NFT Feature Resolutions

I updated the table to include height

Image #	Minimum Range to Asteroid (m)	Minimum Resolution (m/pix)	Distance to center of TAG Site Surface distance (m)
1	589.6	0.163	724.3346
2	558.4	0.155	688.1979
3	534.1	0.148	651.0606
4	511.2	0.142	613.3283
5	480.4	0.137	575.1239
6	449.8	0.128	536.4864
7	418.1	0.120	497.4177
8	387.3	0.109	457.8897
9	355.5	0.098	417.8507
10	325.6	0.090	377.2264
11	301.6	0.083	339.1732
12	271.1	0.071	275.8536
13	245.2	0.065	254.3385
14	225.8	0.059	232.6328
15	209.4	0.056	210.7733
16	196.0	0.052	188.8249
17	183.9	0.050	166.9035
18	171.7	0.048	145.1992
19	160.1	0.045	124.0149
20	149.4	0.042	103.8419
21	130.4	0.036	70.2078
22	128.6	0.035	63.2937
23	125.2	0.034	58.6074
Checkpoint Maneuver			
24	106.7	0.028	56.5029
25	93.3	0.025	48.3636
26	79.2	0.021	35.8719
Matchpoint Maneuver			
27	44.9	0.012	23.8494
28	36.3	0.010	15.6925
29	26.8	0.007	11.6902
30	16.6	0.004	8.02
31	13.1	0.004	4.7405
32			1.9179
33			1.5433

Early Features

Descent Features (DS)

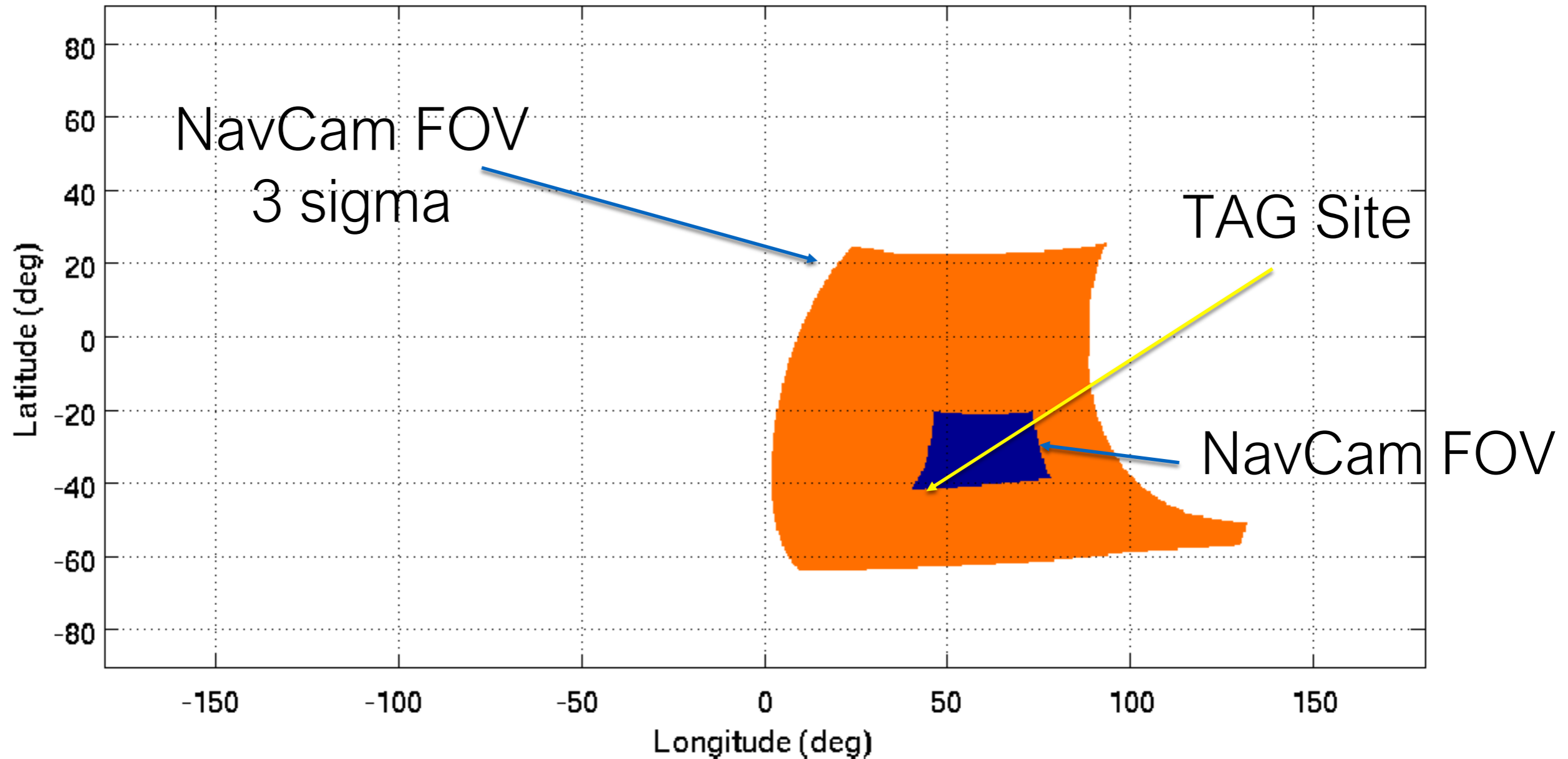
Descent Features (Extra)

TAG Site Features

How far Sub/Space point is from the TAG Site

# Descent Imagery Footprint

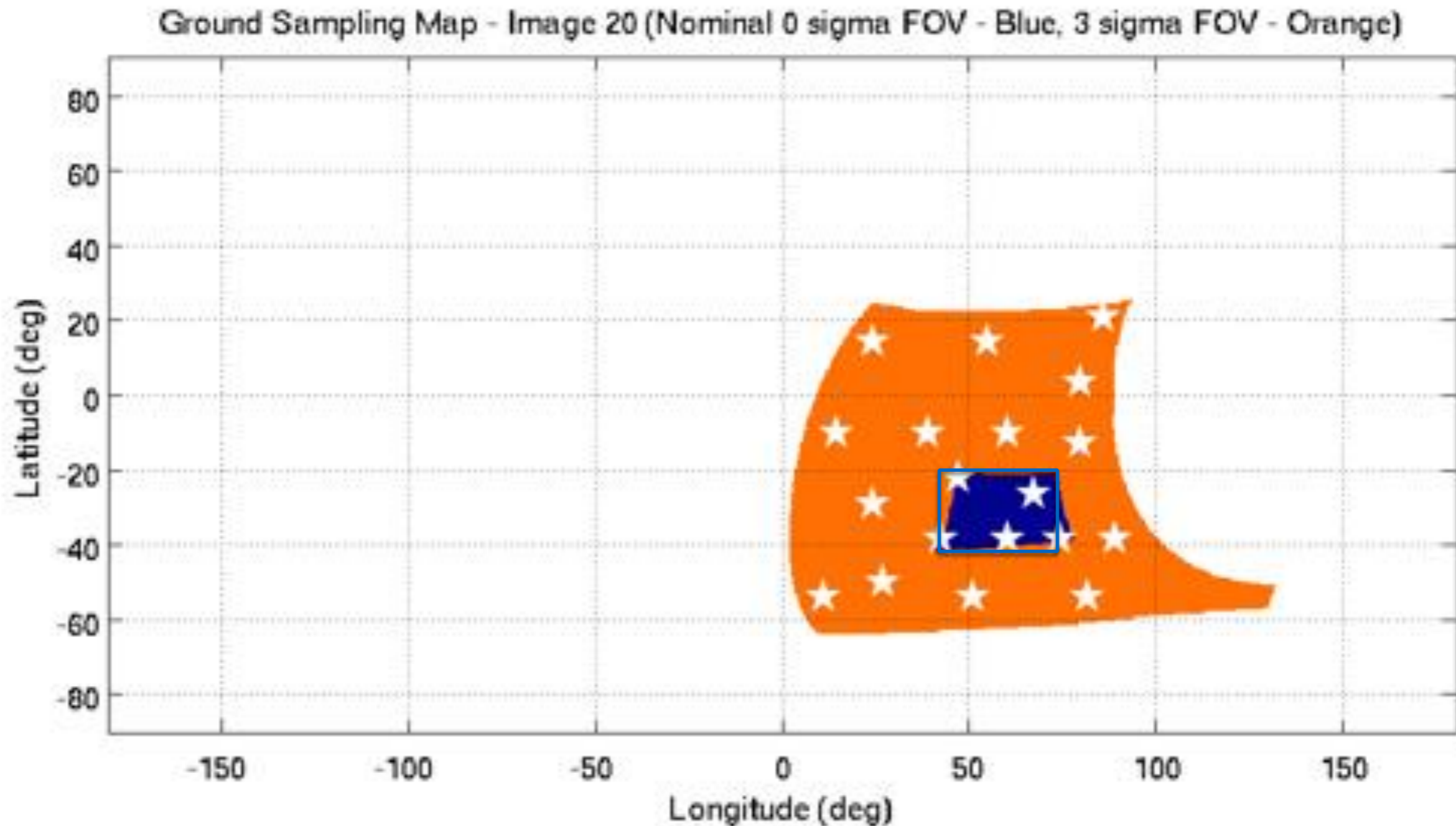
Ground Sampling Map - Image 20 (Nominal 0 sigma FOV - Blue, 3 sigma FOV - Orange)



# Descent Image #20

Last image used to calculate the final burn.

Has the highest need for accuracy



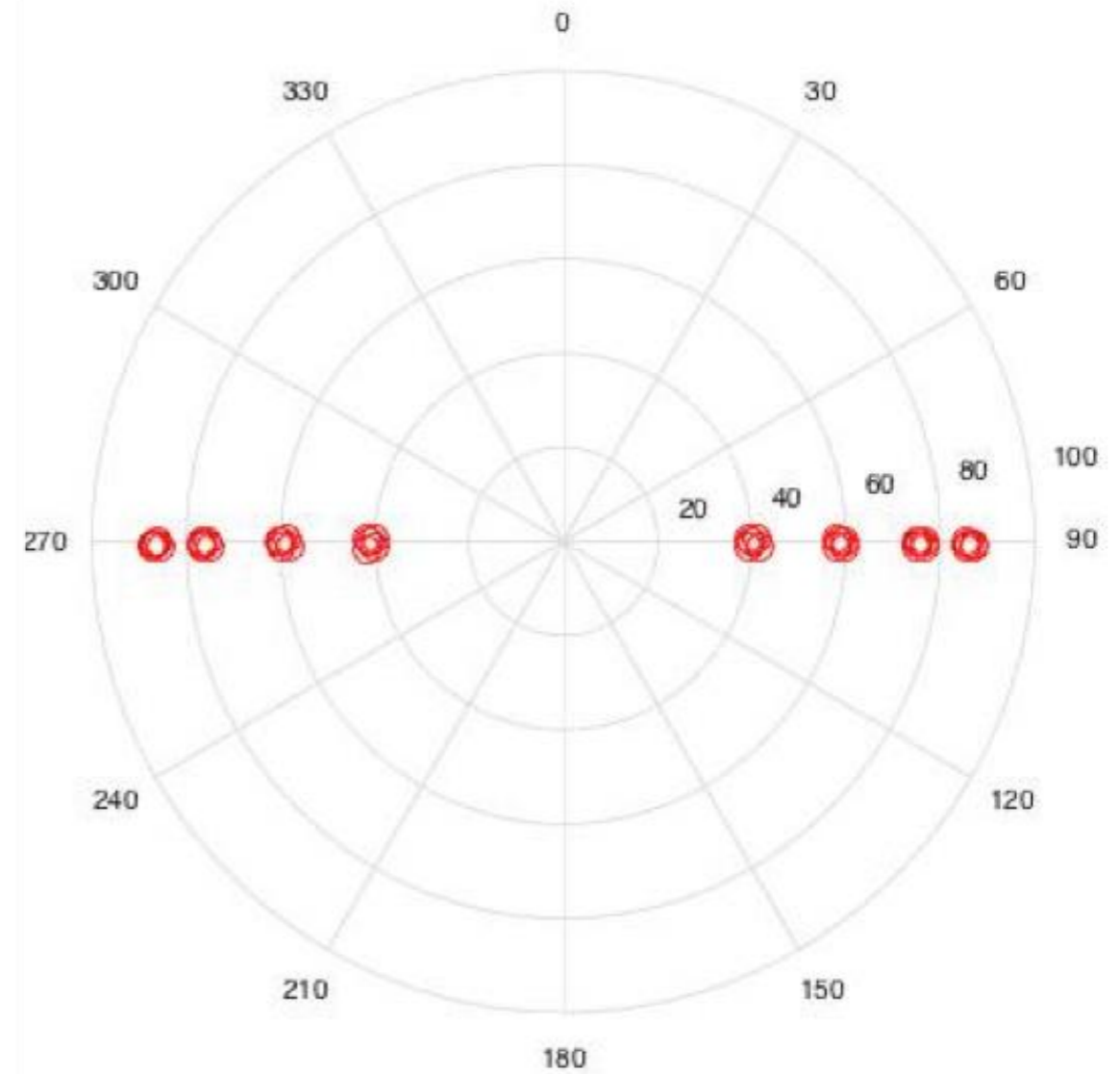
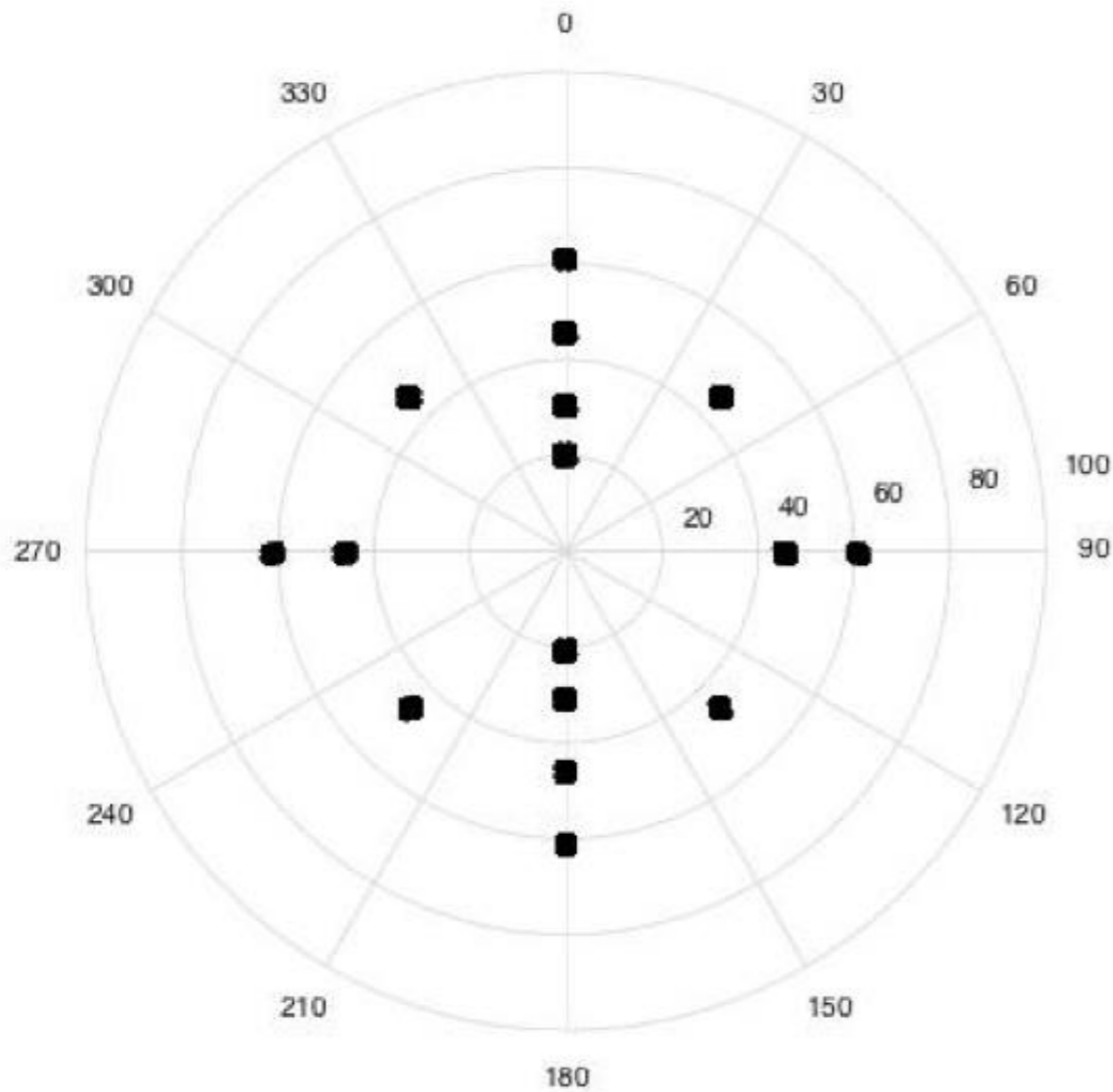
# Performance

	DetSurv DRM Rev C [cm]	OB DRM Rev C [cm]	(Non-baseline) Optimum OB [cm]
Center 5m	6.96	5.08	2.98
Center 10m	9.30	6.29	3.04
MMAPL1 2.5m	14.62	5.25	1.34
MMAPL2 2.5m	10.68	8.04	No Data
MMAPL3 2.5m	9.25	4.03	2.83
MMAPL4 2.5m	4.46	3.72	1.72
MMAPL5 2.5m	8.29	4.08	2.20
Average	9.21	5.40	2.35

- DRM Rev C - The baseline as currently implemented by the SPOC
  - There is room for significant improvement (in progress)
- Optimal — The best images possible, 5cm pixel size
- Optimum OB - Theoretically best image collection during Orbit B

# Orbit B Optimal

- Assumes only a  $90^\circ$  phase limitation





# FEATURES

(renderings shown for 55-deg sun angle)

## Feature 1

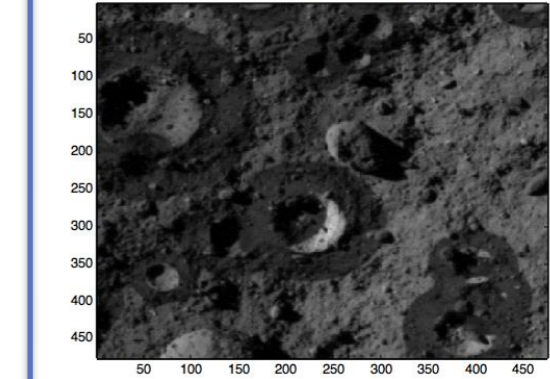
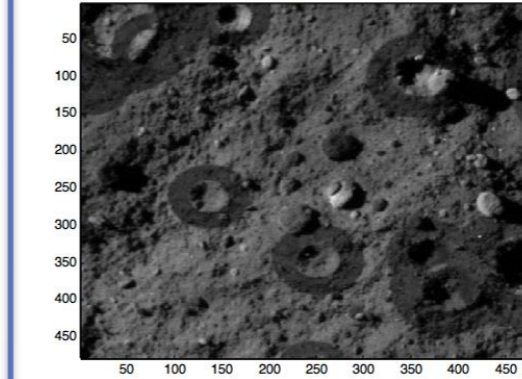
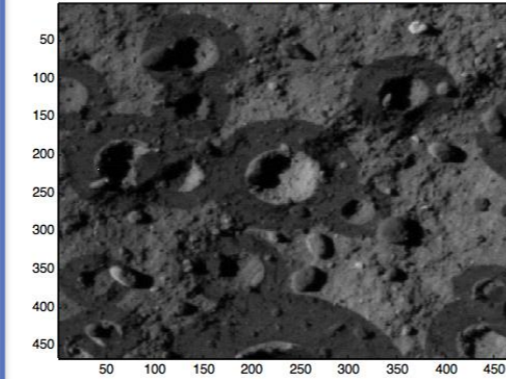
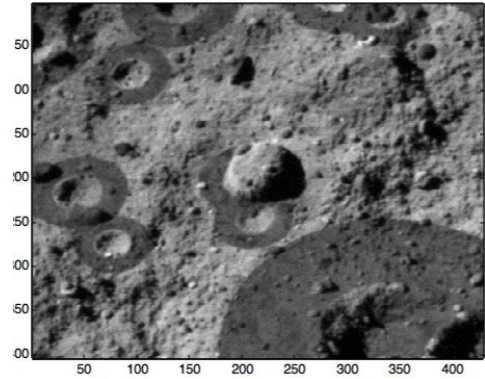
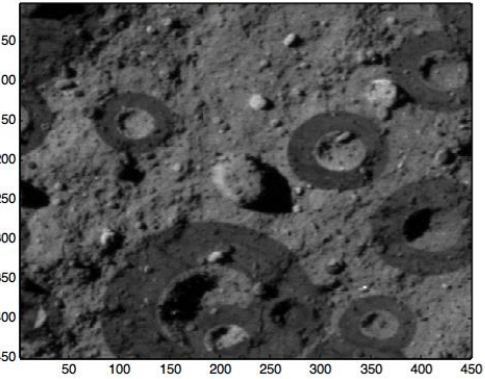
## Feature 2

## Feature 3

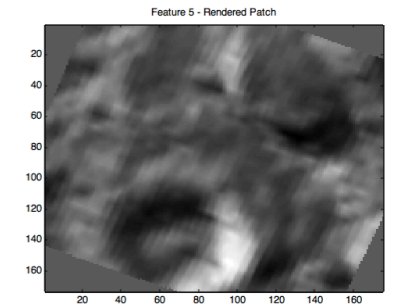
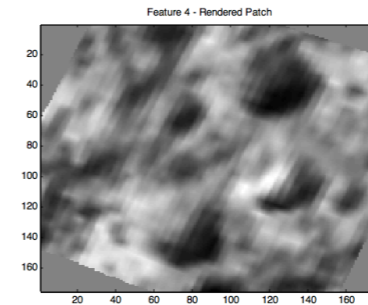
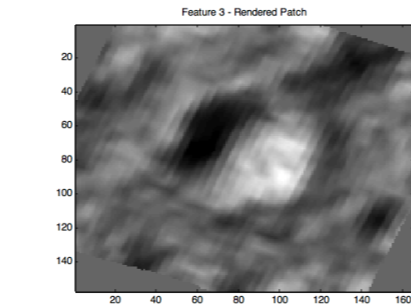
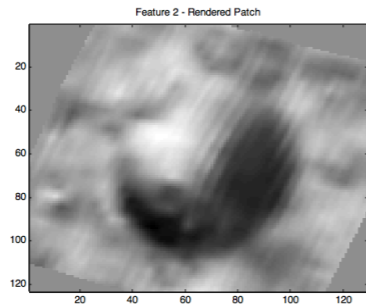
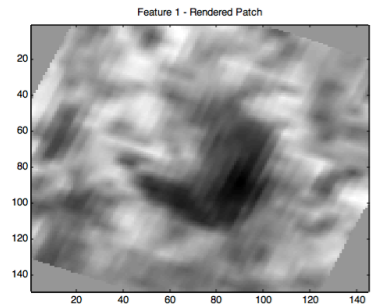
## Feature 4

## Feature 5

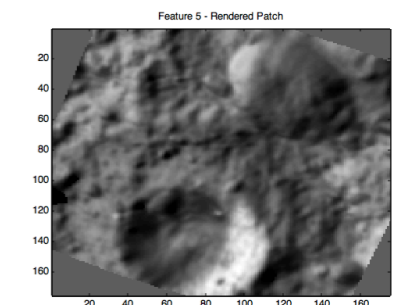
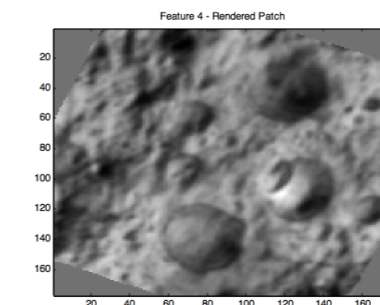
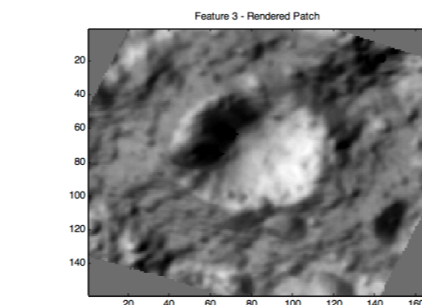
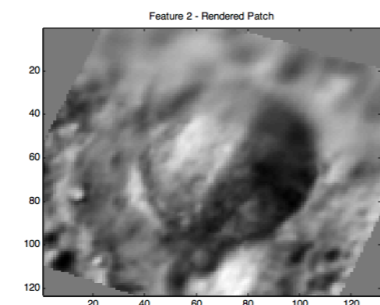
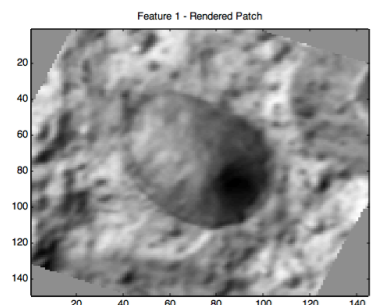
### Renderings from 5mm Truth Model (with Relative Albedos)



### Rendered DRM Features

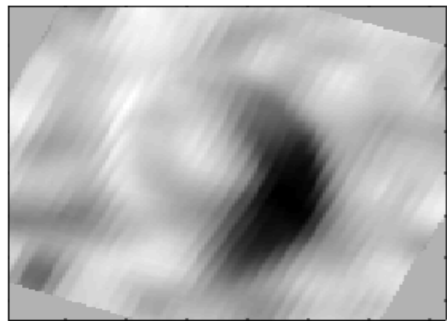


### Rendered OrbitB Optimal Features

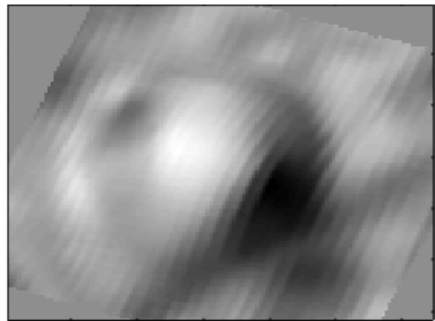


# Testing Features

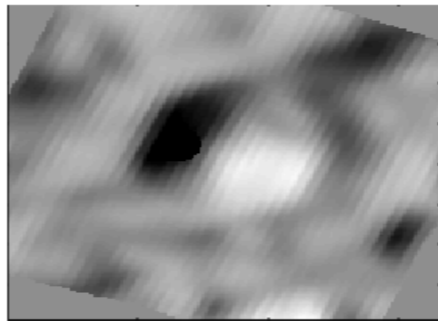
Feature 1



Feature 2



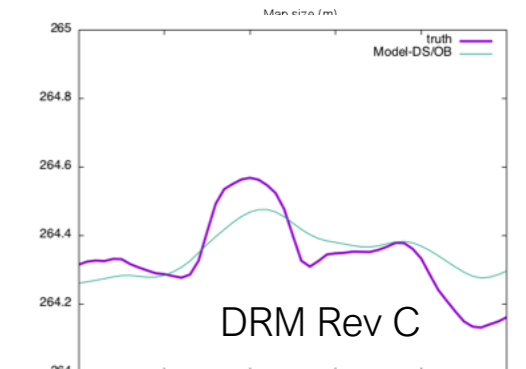
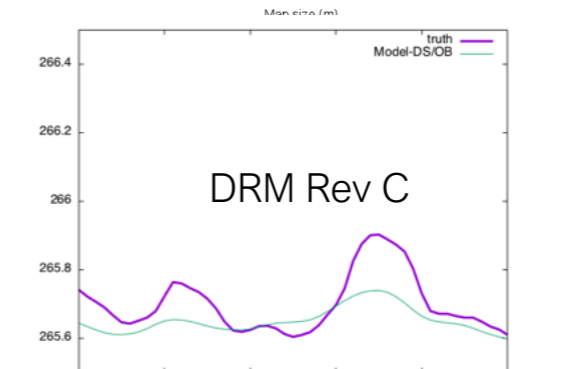
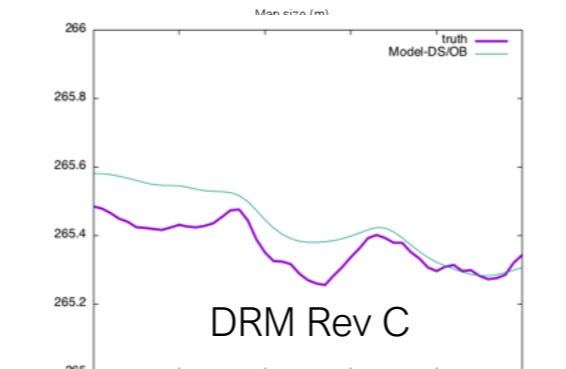
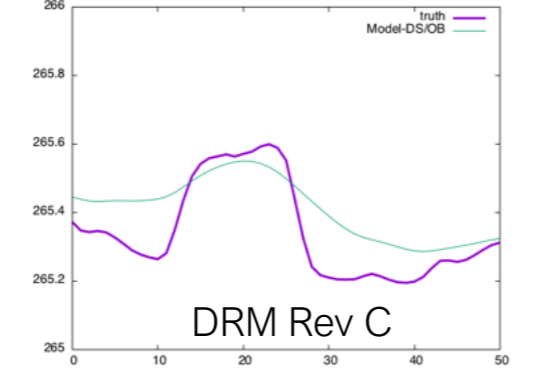
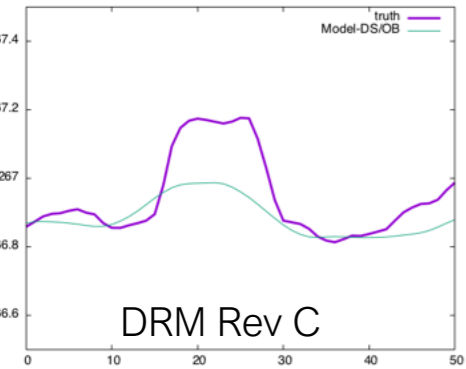
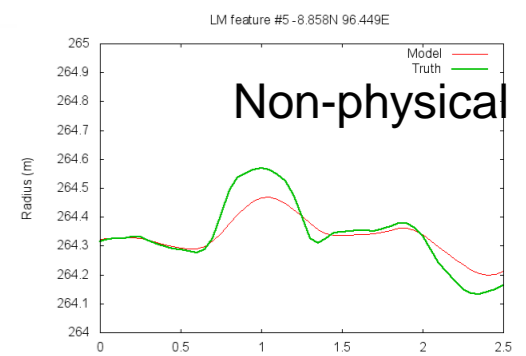
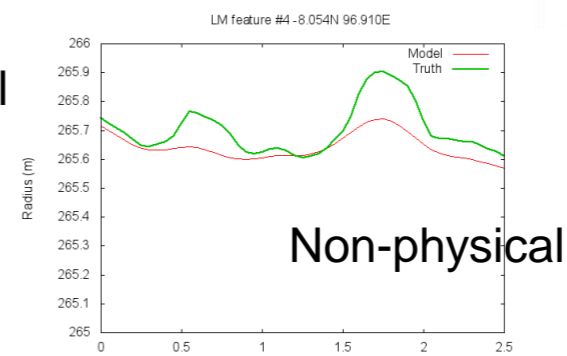
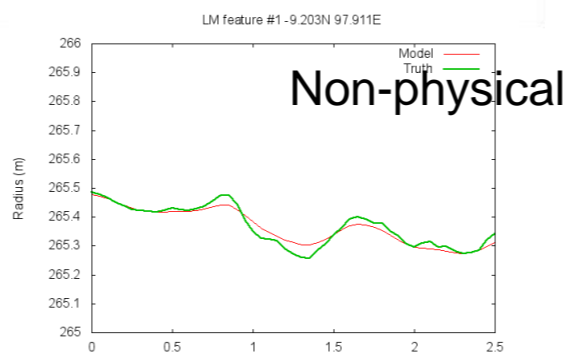
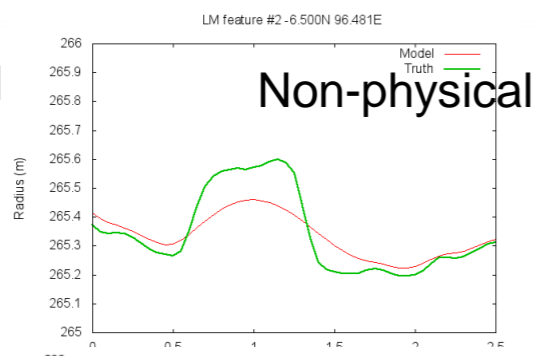
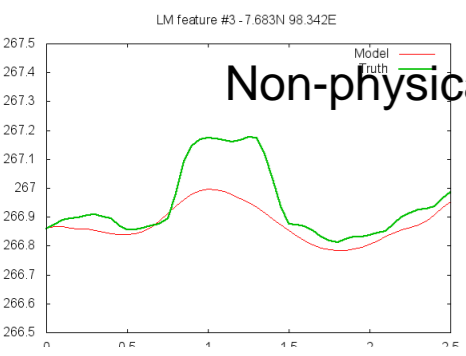
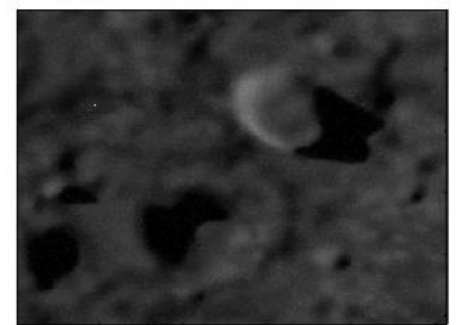
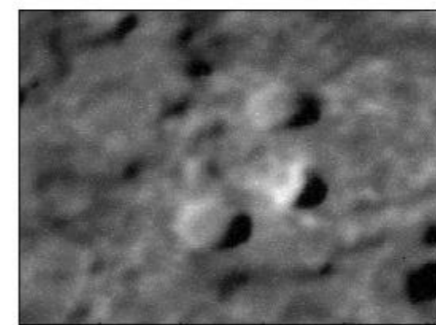
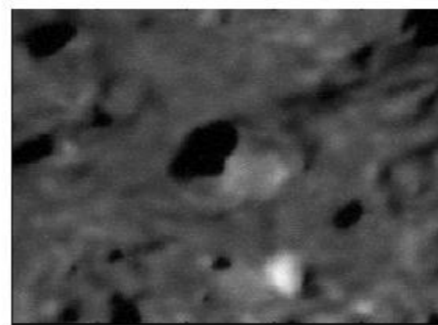
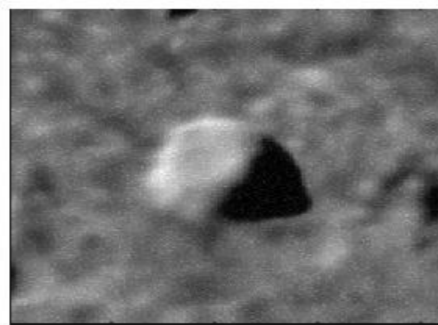
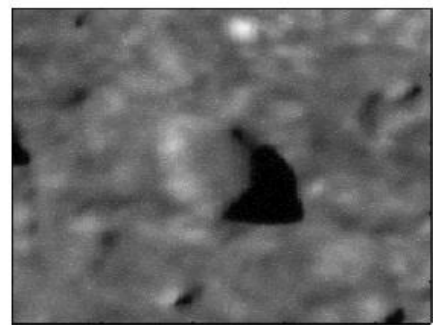
Feature 3



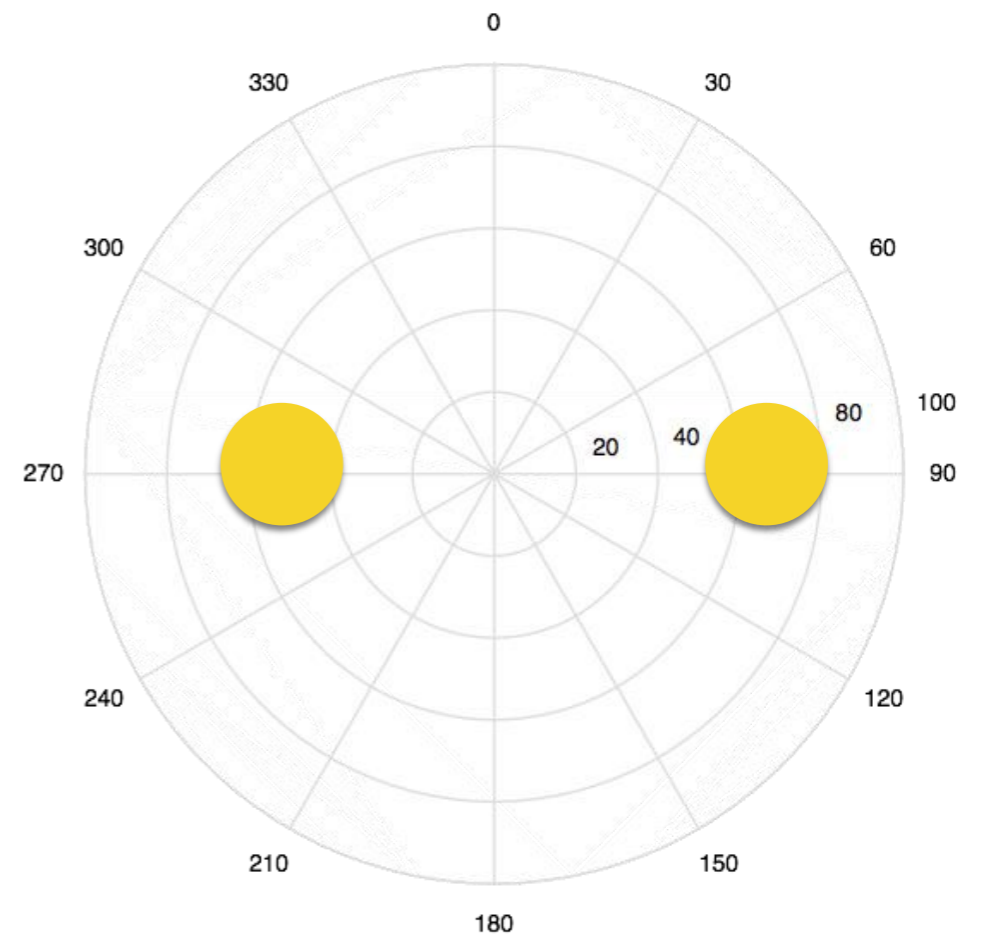
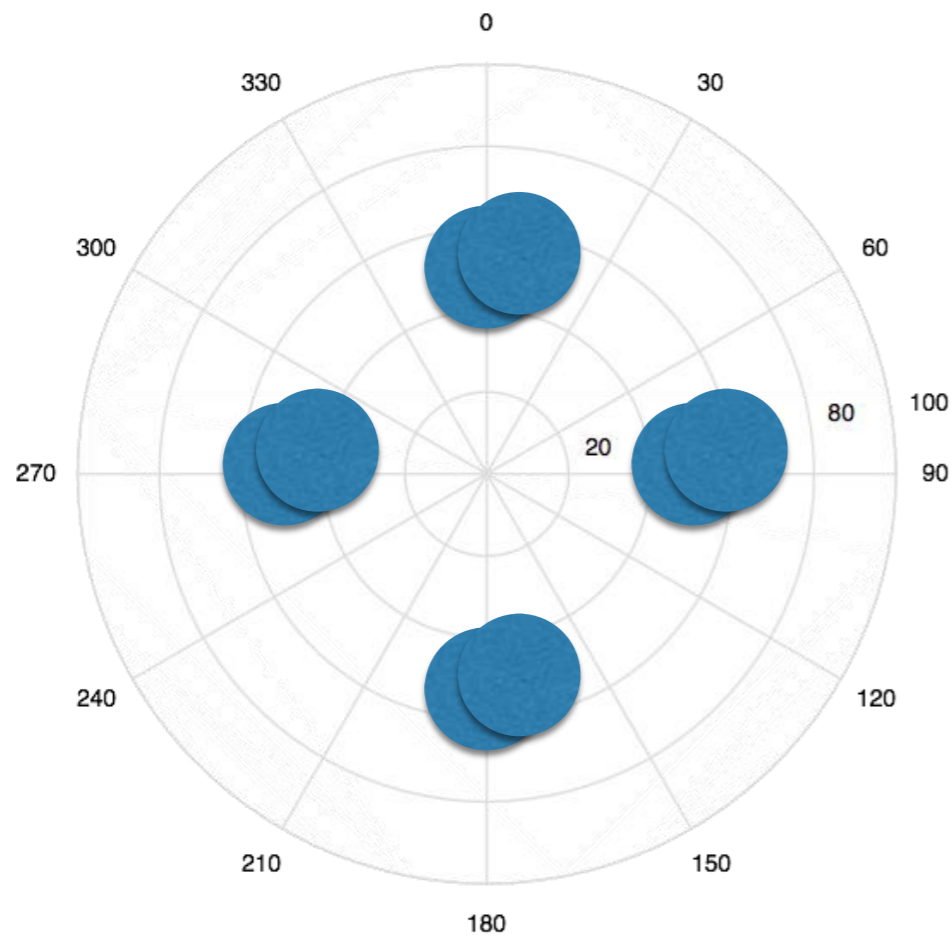
Feature 4



Feature 5



# Requested Imagery

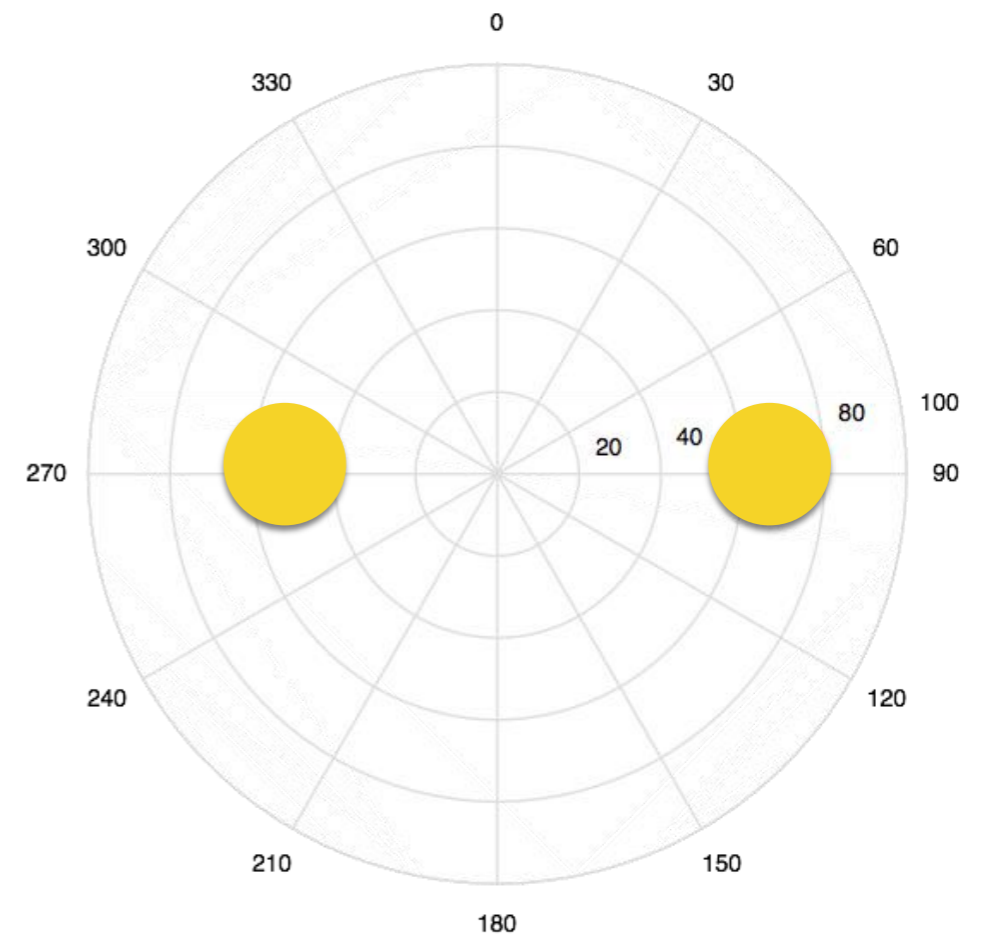
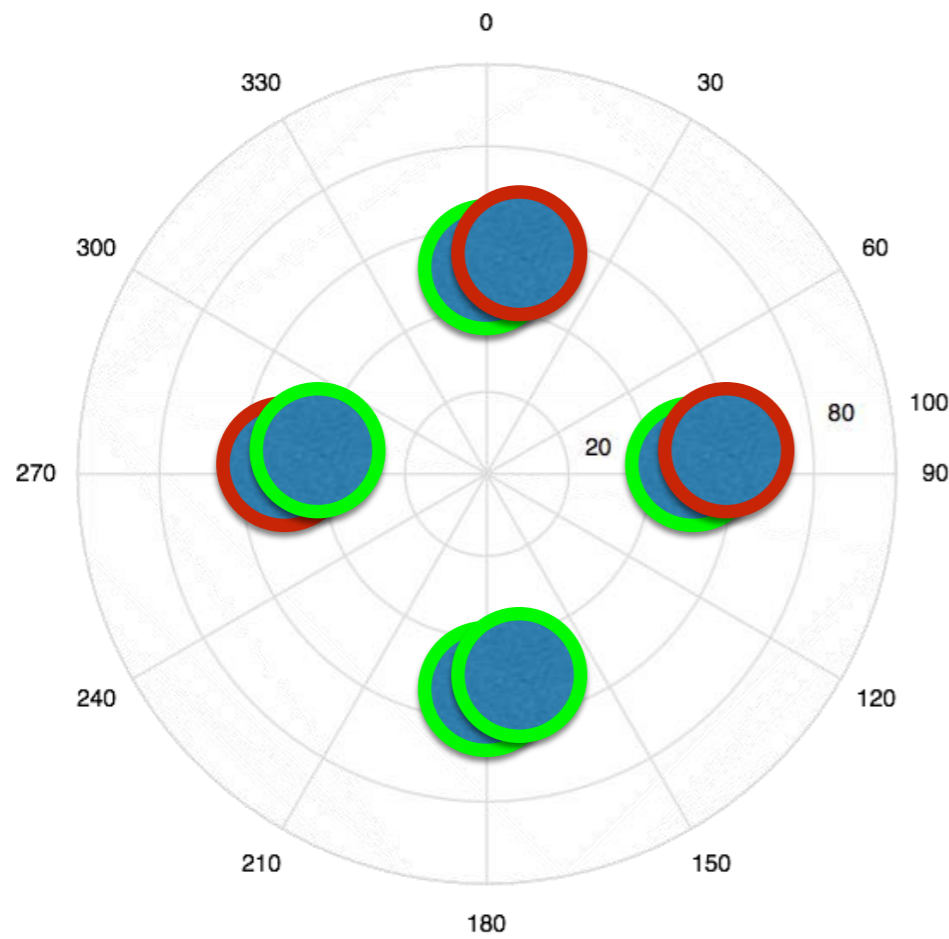


1cm data

# What can we get from Orbit B

Sun	East	East	East	East	West	West	West	West
S/C	East	South	West	North	East	South	West	North
Latitude								
-60	0	1	1	0	1	1	0	0
-40	0	1	1	0	1	1	0	1
-20	0	1	1	0	1	1	0	1
0	0	1	1	0	1	1	0	1
+20	0	1	1	0	1	1	0	1
+40	0	1	1	0	1	1	0	1
+60	0	0	1	1	1	0	0	1

# What can we get from Orbit B



1cm data

# How to build/evaluate NFT

- L2 (Suggested)
  - The Ground System shall generate a DTM of sufficient quality that allows onboard ephemeris to perform check-point and land within a 25 meter radius of the center of the TAG site.
  - The mission shall collect sufficient data for the generation of DTM to support NFT

# Suggested L3/L4 to Support NFT

- 3 - The mission shall generate 300 NFT Features useful for NFT navigation
- 3 - The mission shall generate NFT Features so that each decent image from de-orbit until Check Point will contain at least 3 when evaluated for the 3-sigma position/pointing error.
  - 4 - Lockheed, via the MSA (?FOB), will provide the definition of each NFT Feature by using a reference image, an x/y pixel on that image, its ground sample distance and its number of pixels in width.
  - Note: NFT features are defined by an x/y position on a specific image. This x/y corresponds to a lat/lon (but the frame can change, so we go back to the image for updates).

# Building the NFT Features

- 3 - The AltWG will generate an NFT Plane-Relative format DTM for each NFT feature at the requested GSD.
  - 4 - AltWG will generate a DTM for each feature using the "Standard Effort" method.
  - 4 - AltWG will provide the "Standard Effort" derived NFT Features 14 days after the end of Orbit B.
    - **Standard Effort** - Continue processing until delta residuals less than 1% (TBD) of previous iteration's value
  - 4 - NFT Features that do not meet the initial evaluation will be reprocessed by SPC using the "Maximum Effort" procedure.
    - **Maximum Effort** - Continue processing until the Delta residuals less than 0.25% (TBD) of previous iteration's value
  - 4 - NFT Features that fail after being processed with the "Maximum Effort" procedure will either be rejected or will require additional imaging.
  - 4 - The AltWG will provide Lockheed, via the MSA (?FOB) all error analysis, residuals, list of images used with deviation.
  - 4 - The AltWG will provide the updated NFT feature DTM 28 days after the end of Orbit B for features that underwent the "Maximum Effort" procedures.

# Testing the Features

- 3 - The mission shall perform evaluation of the NFT features using OCAMS images that approximate the descent profile.
  - 4 - Lockheed will evaluate the NFT Feature DTMs and verify that they are acceptable for navigation over a three-sigma range of errors in spacecraft position and pose.
  - 4 - Each NFT Feature shall have a normalized cross-correlation score of 0.6 for 95% probability of the evaluation cases.
  - 4 - Each NFT Feature shall have its best match within two pixels for 95% probability of the evaluation cases.
- 3 - The mission shall collect additional OCAMS images if none are available that match the observation/illumination geometries within 50% pixel size of what will be used during the decent profile.