



Deep Space Station 17: A University-Operated Affiliated Node on the NASA Deep Space Network for Interplanetary Small Satellite Missions

Briefing for the Interplanetary Smallsat Conference

May 2, 2022

Tim Pham, Jay Wyatt (JPL)

Ben Malphrus, Jeff Kruth (MSU)

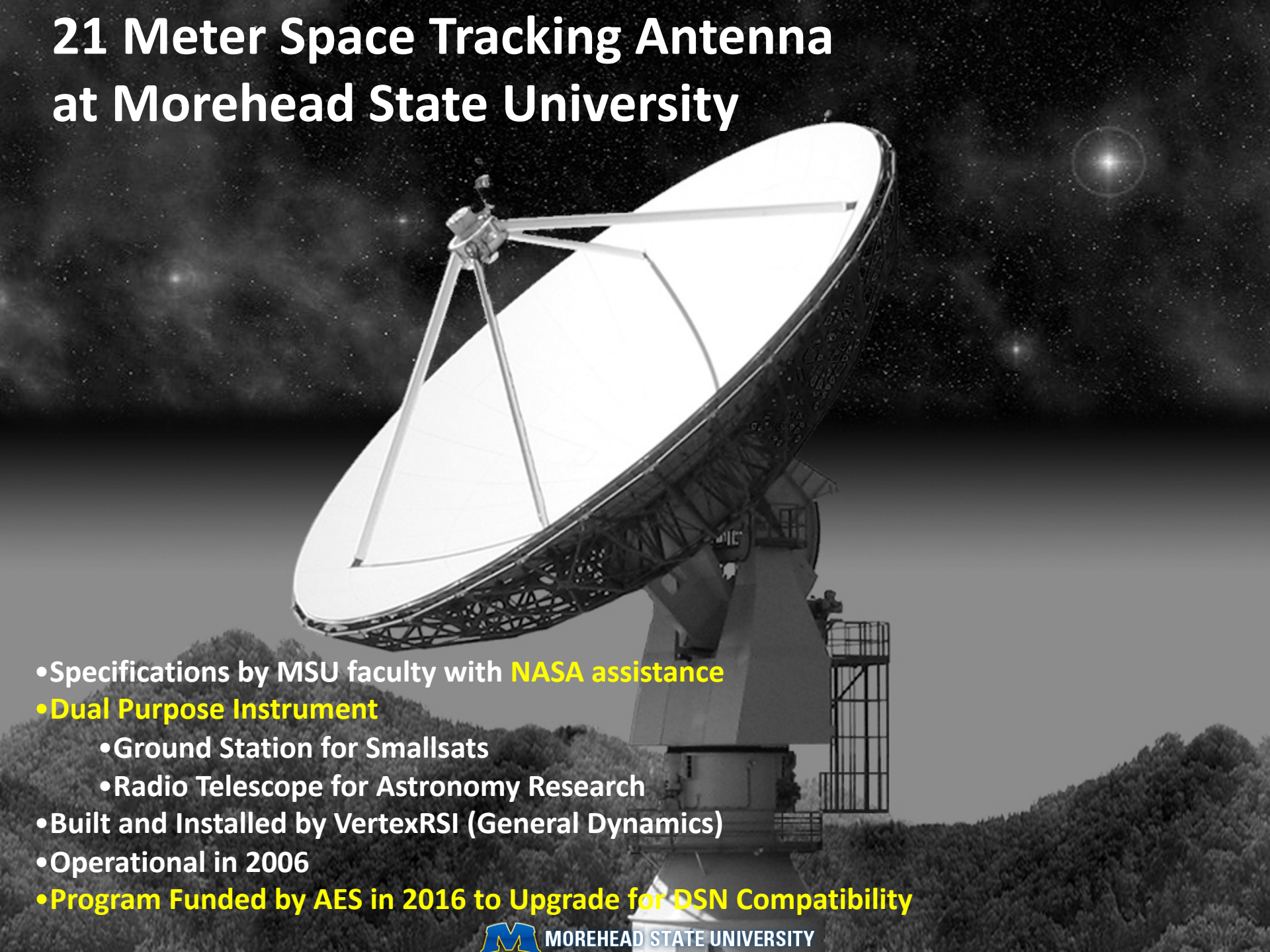
MOREHEAD STATE UNIVERSITY

In Partnership with

Jet Propulsion Laboratory

California Institute of Technology

21 Meter Space Tracking Antenna at Morehead State University



- Specifications by MSU faculty with NASA assistance
- Dual Purpose Instrument
  - Ground Station for Smallsats
  - Radio Telescope for Astronomy Research
- Built and Installed by VertexRSI (General Dynamics)
- Operational in 2006
- Program Funded by AES in 2016 to Upgrade for DSN Compatibility

MOREHEAD STATE UNIVERSITY

The Morehead State University Ground Station

- Relatively Quiet RFI Environment in Eastern Kentucky
- 21 m Ground Station (few in the US large enough for DSN Work)
- Staff Experienced in Mission Operations

Caveats:

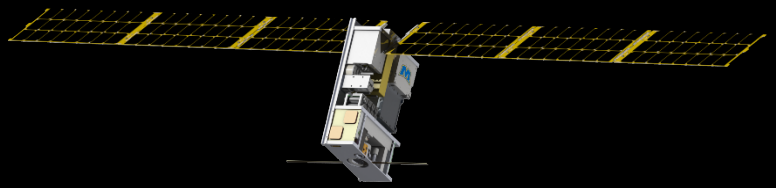
- There is weather in Kentucky!
- University-based Asset- with Single String Instrumentation

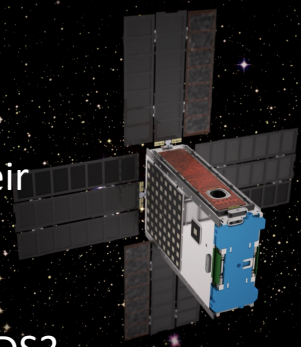
21 M Operations

Pre-DSN Compatibility Upgrade

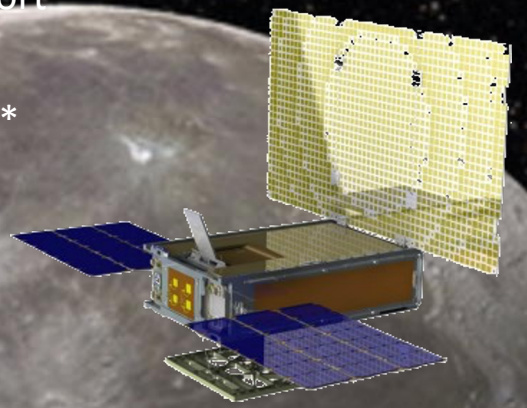
- Satellite Ground Station for Morehead State SmallSat Missions and Others
- JPL ASTERIA Ground Station
- Radio Telescope Mode for Research in Astrophysics
- Test-Bed for Experimental Communication Systems and Processes- DTN, Autonomous Ops, OMSPA

A New Era of Planetary Exploration with Small Satellite Platforms





- History was Made in 2018 with the Launch of MarCO A and their subsequent success
- Artemis 1 will Launch 13 Interplanetary CubeSats
- Numerous Interplanetary SmallSat Missions are in Planning (PSDS3 Studies, Others at NASA Centers and in the Private Sector)
- All Need Deep Space Communications and Ranging Support
- DSN is Heavily Subscribed
- Idea Emerged to Utilize Large Aperture non-NASA Assets*
- This Project Represents the Prototype Experiment



* Suggested by Rob Staehle JPL in 2014

DSS-17 Affiliated Station

Goldstone, California

Morehead State Univ.

Madrid, Spain

Canberra, Australia

JPL, Monrovia
Network Operations Control Center (NOCC), DTF-21

JPL, Pasadena
Deep Space Operations Center (DSOC)

AES Program: 21m DSN Station (DSS-17)

Project Description and Objectives

Demonstrate a cost-effective process for expanding DSN capabilities by utilizing non-NASA assets to provide communication and navigation services to CubeSat missions to the Moon and inner solar system, thereby enabling interplanetary research with small spacecraft platforms. DSS-17's Operational Philosophy is:
"A Class-D Ground Station Supporting Class D Interplanetary CubeSats"

Technical Approach

- Develop and implement a strategy to transfer Deep Space Network (DSN) equipment, processes and protocols to the MSU 21 m antenna system to enable integration into the DSN as an auxiliary station to support small spacecraft missions.
- Implement deep space communications, tracking and navigation techniques as well as adoption of CCSDS standards.
- Implement systems upgrades, conduct tests/demonstrations, and transition to an operational capability.

Benefits

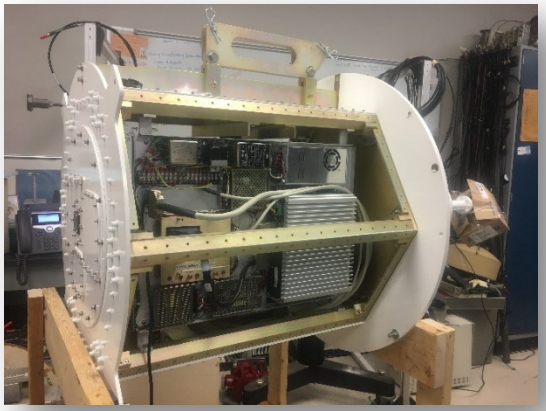
- Serves as a test-case for other non-NASA ground stations to provide auxiliary deep space navigation and tracking support for interplanetary small spacecraft missions.
- Serves as an Experimental Station for Advanced DSN Communications Experiments
- Transparent to Missions Being Supported

Targets

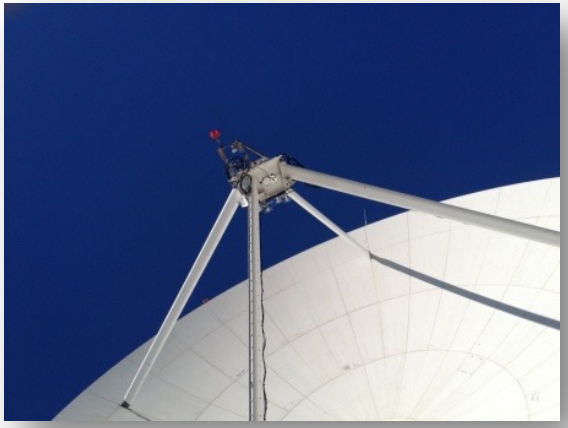
Full DSN Compatibility
Scheduled by DSN
Support CCSDS-SLE
DSN Tracking and Ranging
Support Lunar, NEA, Lagrange Point Missions

Morehead State University 21m Upgrade to DSN Compatibility Challenging Technical Implementation

Cryogenic X-band Feed

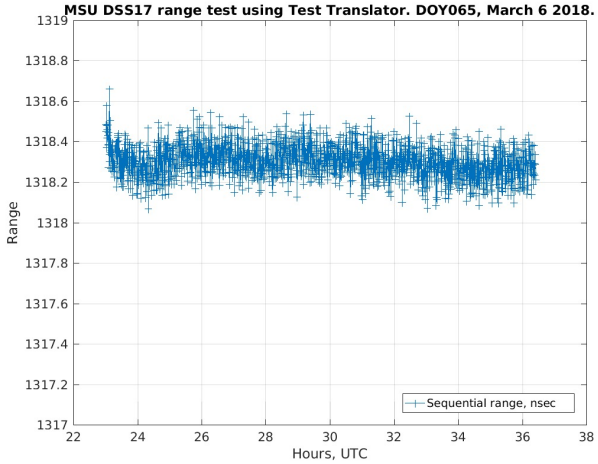


Custom X-band feed is based on a cryogenically cooled LNA that operates at <20K.



X-band Feed is located at the prime focus

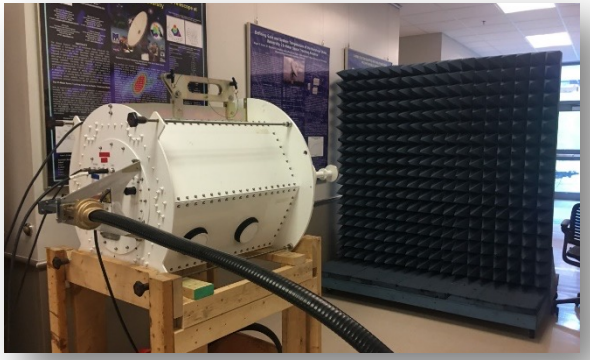
High Power Amplifier



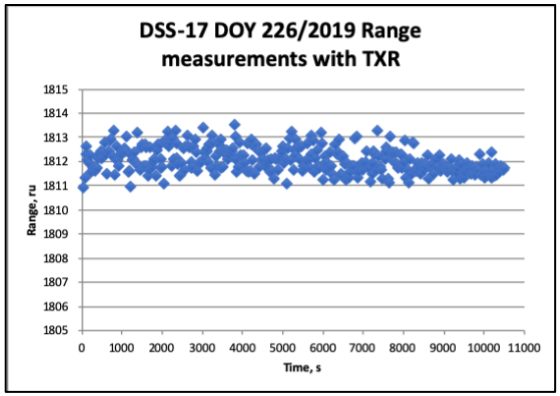
DSS-17 Ranging Stability Results- measurement stability over > 13 hours exceeds requirement

3 kW High Power Amplifier under test

Ranging



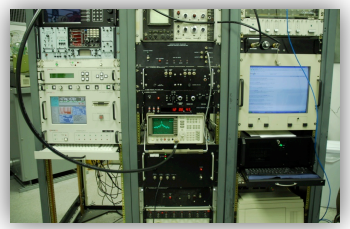
Initial Transmit and Ranging laboratory tests proved successful



DSS-17 Ranging Results- precision within +/-1 range unit (0.94 ns). Implies 1 meter accuracy ranging at the Moon

DSS-17 System Architecture

Morehead State 21 m Antenna System



21 m Antenna Control System

"Lite" Version of DSN Block 6 Exciter System Developed for Morehead State

Deep Space Operation Center- JPL Mission Control

Updated Cryogenic X-Band Feed

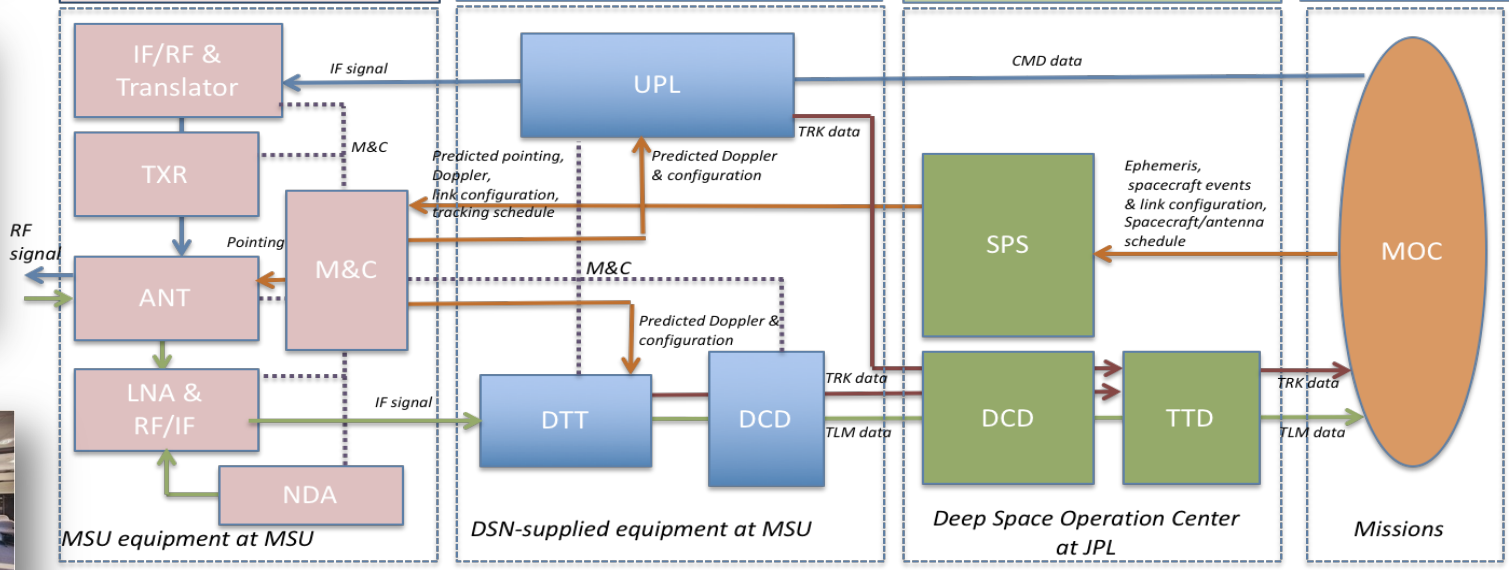
- IF/RF – Intermediate Frequency/Radio Frequency Upconverter
- TXR – Transmitter
- ANT – Antenna
- LNA – Low Noise Amplifier
- RF/IF DC – Radio Frequency/Intermediate Frequency Downconverter
- NDA – Noise Diode Assembly
- M&C – Monitor & Control

H- MASER

- UPL – Uplink
- DTT – Downlink Tracking & Telemetry
- DCD – Data Capture & Delivery

- SPS – Service Preparation Subsystem
- DCD – Data Capture & Delivery
- TTD – Tracking & Telemetry Delivery

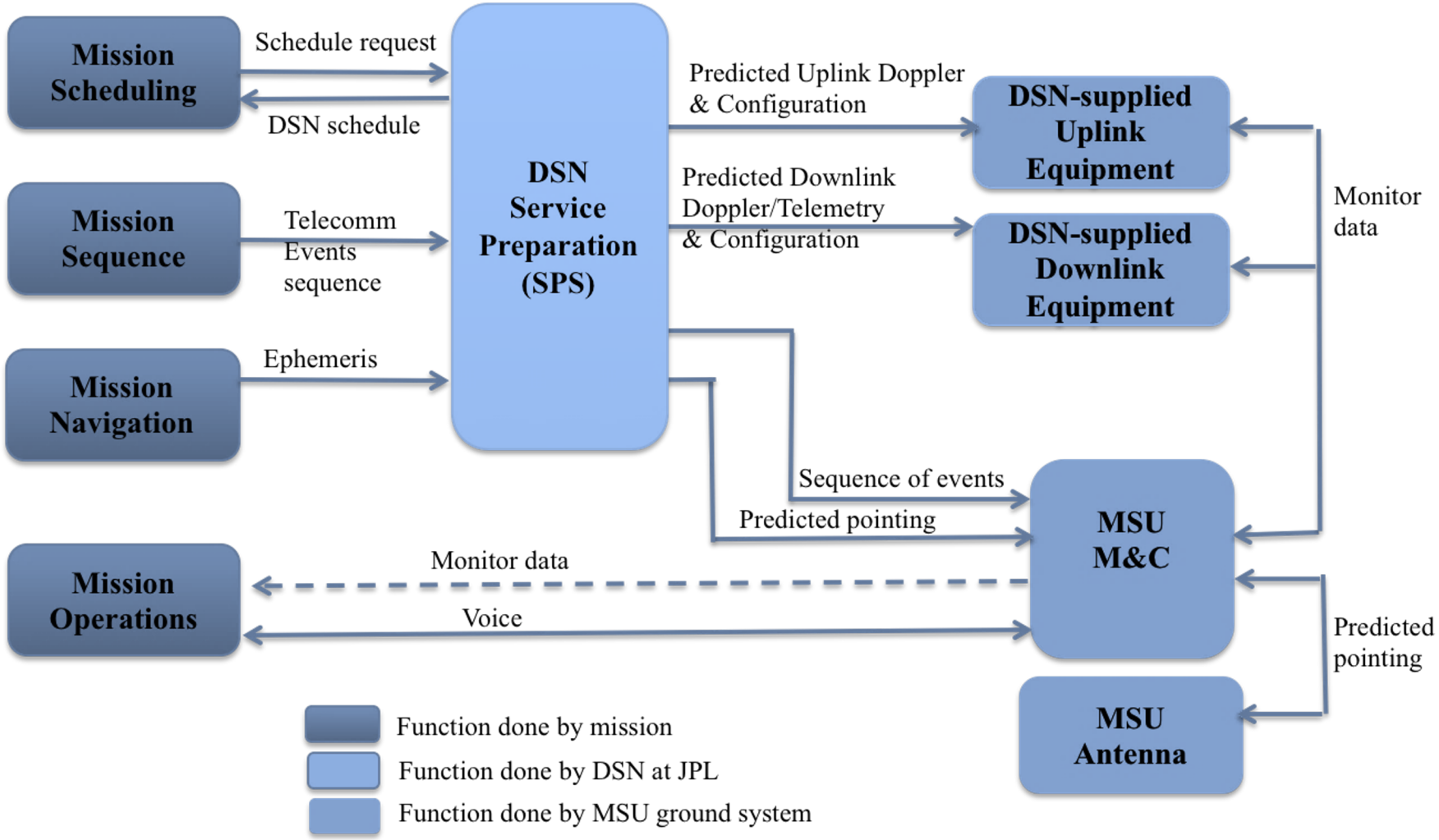
- MOC – Mission Operation Center
- CMD – Command
- TRK – Tracking
- TLM - Telemetry



Morehead State University Mission Operations Center

Jet Propulsion Laboratory
California Institute of Technology

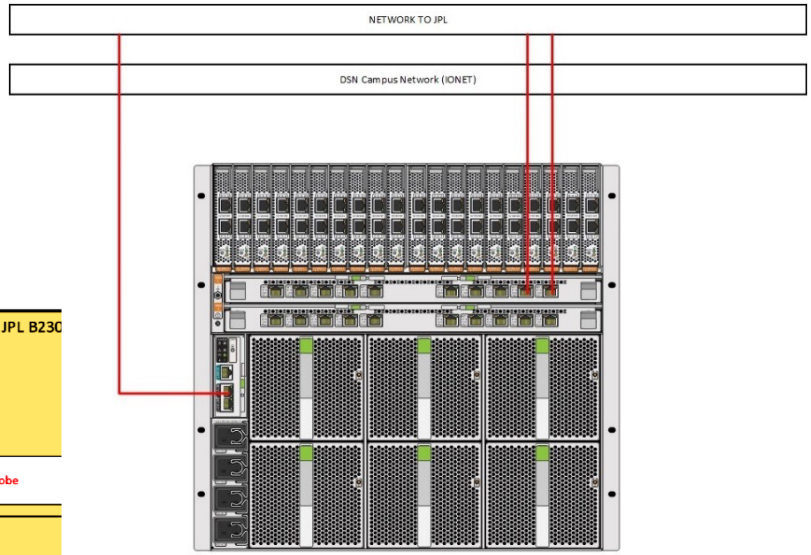
Service Management Data Flow For NASA Missions



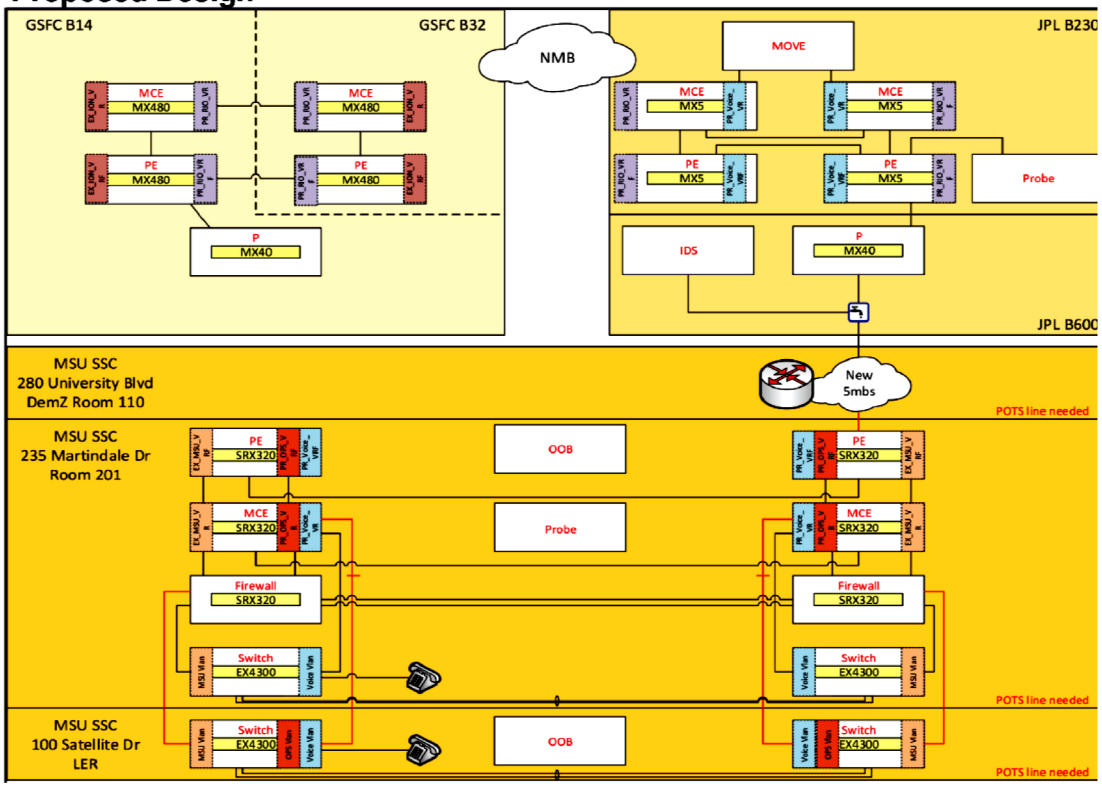
IT Security and NMB Connection

IT Security and Network Connection Required

- LAN Independent of University Network
- Architecture Designed with JPL and CSO
- Behind NASA Firewall
- Designed by NASA JPL and CSO
- Direct Connection to the NASA NMB



Proposed Design



DSS-17 Performance

Parameter	Measured Values
Axis Slew Velocity	
Azimuth	> 3.0 °/sec minimum
Elevation	> 1.6 °/sec minimum
Polarization	> 0.7 °/sec minimum
Axis Acceleration	
Azimuth	1.0 °/sec^2
Elevation	0.6 °/sec^2
Travel Range	
Azimuth	± 269.8°
Elevation	1.0° to 90.3°
Polarization Range	± 90°
Pointing Accuracy	0.005° RMS
Tracking Accuracy	0.0004° RMS
Aperture Efficiency, η (L/Ku)	0.653/0.563
Surface Tolerance @ 35 mph wind	< 0.020" RMS

Performance Measure	DSS-17 Performance Metric
X-Band Frequency Range	7.0 – 8.5 GHz
LNA Temperature	< 20 K
System Noise Temperature	90 K
Antenna Gain	62.7 dBi (@8.4 GHz)
System Noise Spectral Density	<-178 dBm/Hz
G/T at 5° Elevation	41.25 dB/K
Time Standard	Hydrogen maser (1 ns/day)
EIRP	93.7 dBW
HPBW	0.115 deg
SLE Compliance	Yes
CCSDS Compliance	Yes
Forward Error Coding	Reed Solomon/Convolutional, Turbo, Low Density Parity Check
Radiometric	Angle, Doppler, Ranging

COMPARISON to 34m BWG

- G/T: 10 dB less (~ 5 dB less Gain, 5 dB higher noise temperature)
- EIRP: 92.7 dBW vs. 110 dBW (1 kW PA vs 20 kW PA)
- Ranging Accuracy: 1 m (1 sigma accuracy) vs 1 m (1 sigma accuracy)

Performance Metrics

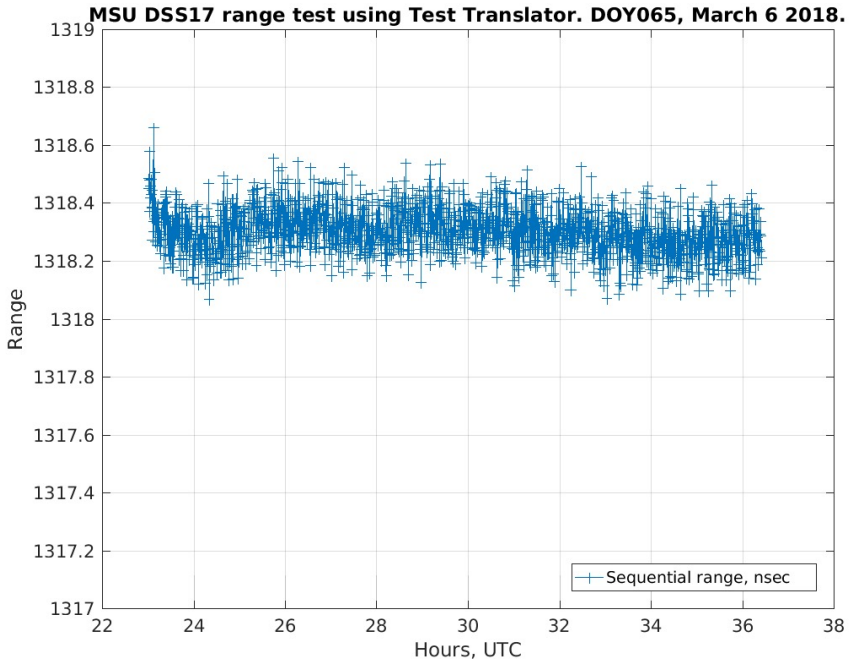
The Morehead State University and DSN/JPL teams performed the following set of tests to empirically determine the performance of DSS-17:

1) G/T as a function of elevation (from 0° to 90° in 5° intervals)
2) SNT as a function of elevation (from 0° to 90° in 5° intervals)
3) EIRP
4) Pointing and Tracking Error Measurements
5) Telemetry Tracking of S/C: Chart that includes Coding and Modulation Tests- examples from Missions; Telemetry Data Capability (Capture Rates and grades)
6) Commanding (DTT locks to carrier and sub-carrier, measure variations, command verification. Confirm that USG generates signals of X, at a bit rate of Y)
7) Radiometric Measurements- Ranging Data- loop back test with command
   Stability of Ranging Measurements - STEREO A 3-Way
   Doppler Noise
8) Horizon Mask
9) Operational Tests (retrieval of predicts, achieving carrier and symbol lock, etc.)

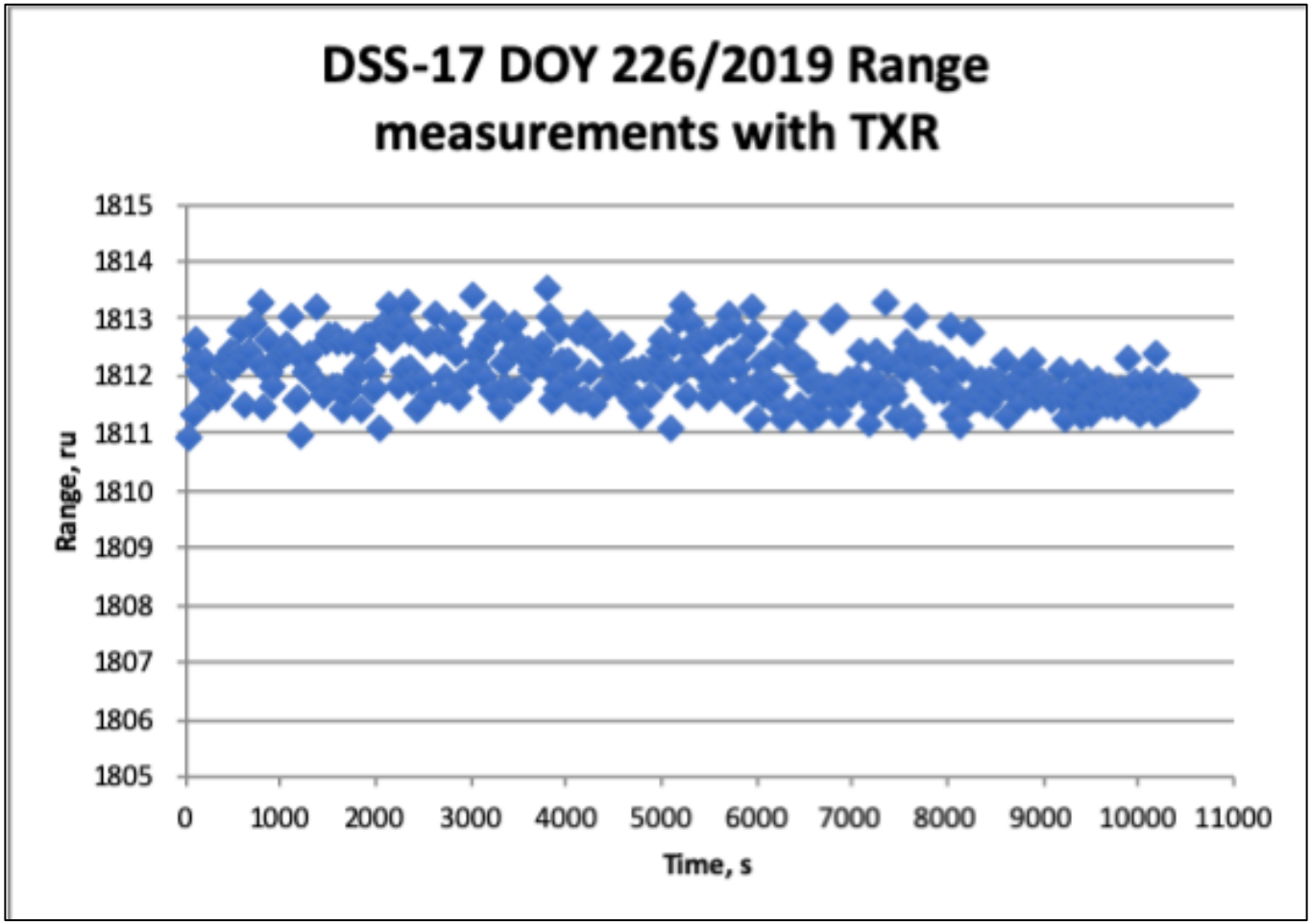
Reference 4 and 6, Spacecraft Tracks (SNR, data rates, modulation schemes, etc.)

DSS-17 X-Band KPA

- New X-Band Feed High Power TX Capability
- CPI GEN IV Klystron PA
- Frequency Range 7.9 - 8.4 GHz
- Klystron Power Output 3.0 kW min. (64.77 dBm)
- Gain at 3 KW = 77 dB, min.
- Gain Stability vs. Time ±0.25 dB/24 hr. max. at constant drive and temperature
- Noise and Spurious = -65 dBW/4 kHz, 4.2 - 12.0 GHz

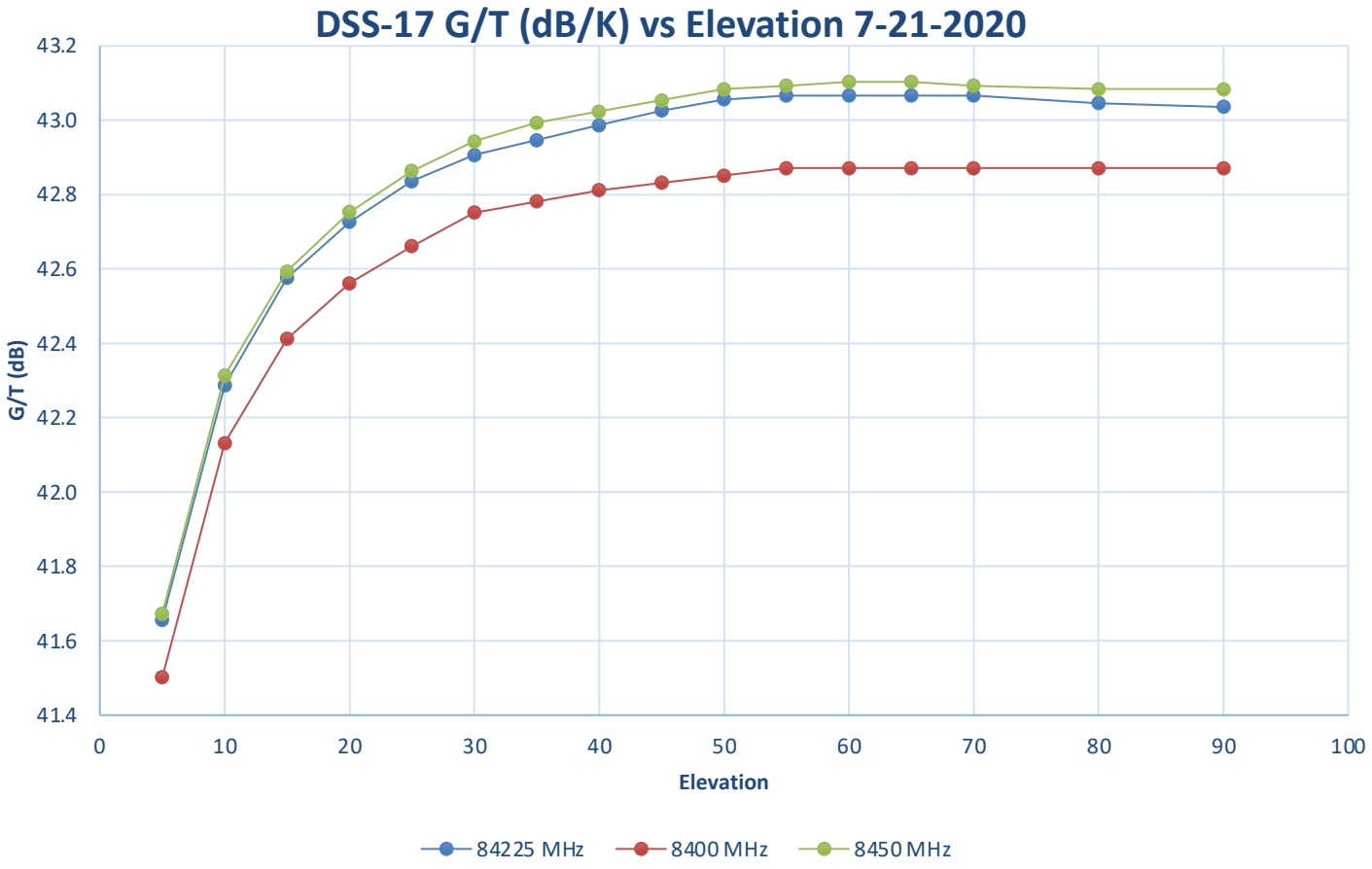


Ranging Accuracy Measurements



DSS-17 Ranging Results (Tx Stability)- precision within +/-1 range unit (0.94 ns). Implies 1 meter accuracy ranging at the Moon Lab Test

G/T Empirical Measurements



Pre-Operational Tests

Pre-Operational Tests involved testing all aspects of an operational track:

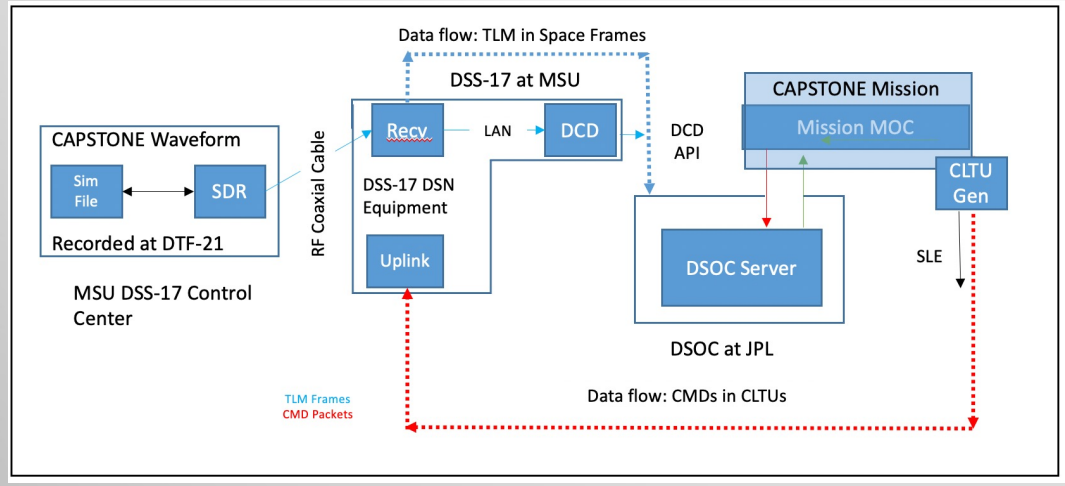
- Retrieval of Predicts and Configuration Files from the SPS Server
- Achieving carrier lock, Frame lock and Symbol lock
- Reference Telemetry Tracking
- Radiometric Measurements
- Flowing Data and Telemetry to DSOC
- Flowing Radiometric Data to FDF
- Testing Uplink (Unable to Complete- did not receive Mission Permission)

Additional Tests involved Shadow DSN tracking of missions with sufficient SNR (>10 dB link margin)

- Hayabusa2
- Osiris-Rex
- Maven
- STEREOA

Results with CAPSTONE GDS Test

- Successful command and telemetry data flows between DSS-17 and CAPSTONE MOC established on Mar. 24, 2021



Mission Services Activity Report

Name of Activity: CAPS Level 4 GDS Test on DOY 083 with DSS-17

Date: DOY 083/1430 UTC (03/24/2021)

Activity Level: 4

Activity Period:

DOY	BOA	BOT	EOT	EOA	DSS	USER	ACTIVITY	PASS	CFG	SOE	WKCF
083	1430	1500	1830	1845	DSS-17	CAPS	MSTA/GDS TEST	0083	T025	P	1A2
		CCP,NMC,RNG,RRPA,TLPA,TSA,UPL,XHMT,XTXL									

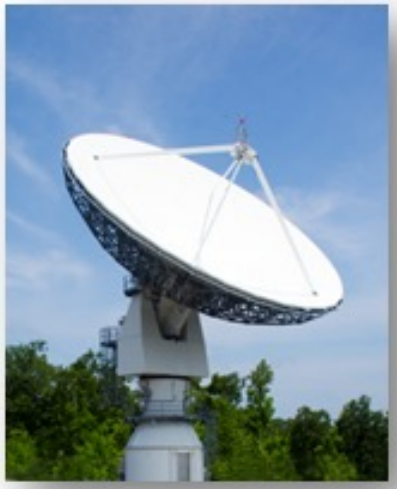
Supporting Facilities: DSS-17 / DSOC / MOC

1) Overview/Objective:
The purpose of this Ground Data System (GDS) test is to verify the end-to-end command and telemetry connectivity between DSS-17, located at Morehead State University (MSU), and CAPSTONE Mission Operation Center (MOC) located in Irvine Ca. CAPSTONE MOC will bind to the DSOC SLE Gateway Portal 2 (SLEGP2) for RAF services and conduct command bind operations with DSS-17 Uplink Processor Assembly (UPA) for FCLTU services. DSS-17 operations will configure per Table 7.1.

2) Activity Summary:
The CAPS GDS test with DSS-17 was supported and executed as planned. MOC was able to exercise telemetry and command bind. A total of 10 CLTUs were sent by MOC and received by DSS-17. Per JPL network engineering, the connectivity issues from the primary test on DOY 082 might be an IPSec tunnel issue that could resurface. Network engineering from both Tyvak and JPL both have access to reset the IPSec tunnel which should resolve the issue.

NOTE: DSS-17 is Prepared to Support GDS Testing with All Artemis 1 Missions for which Tracking Services are being Provided

E2E testing Capability – Overall Elements



Space Science Center

Clean Room

IRIS LNA

Coupler

Received Signal:
-115dBm

Attenuator

L=20dB

L=20dB

Cable Loss

L=50dB

DSS-17 Control Room

LNA

Horn Antenna Gain

G=50dB

G=20dB

Free Space Loss

L=179dB

DSS-17 Station

21m Antenna Gain

KPA Power: 250 W
Power (dB): 54dBm

G=30dB

USG

LIC MOC

AIT- Server

DSS-17 Milestones and Timeline

DSS-17 on the Cover of the IEEE Aerospace and Electronic Systems Magazine Special Issue on Artemis 1 (September 2019)

- **X-Band Downlink Capability Developed and Tested with Real Spacecraft, including Stereo, Osiris Rex, and MAVEN**
- **Telemetry connection to JPL over NASA Mission Backbone Network Operational**
  - Enables telemetry and commanding in the same manner as other DSN antennas
- **X-band Transmit and Ranging**
  - Ranging Measurements Successful
    - Results imply 1m ranging accuracy at the Moon
- **Conducted Series of DTN Demonstrations** Using Lunar IceCube (LIC), DSS-17 and LIC Ground Data System
- **Conducted first OMSPA Demonstration with a CubeSat** using the X-band Feed and custom SDR-based Multiple Receiver System
- **Successfully conducted approximately 1,000 S-band ASTERIA Mission passes**
  - Enabled staff and students to obtain significant operational experience

Critical Milestones

ΔSRR	NMB Connection	Downlink Demo	Uplink Demo	Ranging Demo	ORR	Artemis 1 Support	Artemis 1 Ops	Mission Duration	Future
01/15/2016	6/15/2018	5/5/2019	8/15/2019	9/15/2020	8/12/2021	Aug 2022	2022-2024	Artemis 1 Duration	CLIPS, Artemis

Deltas Between DSS-17 and DSN Stations

Jet Propulsion Laboratory
California Institute of Technology

DSS-17 is a Class D Station Supporting Class D Interplanetary Missions

- DSS-17 has operational differences including:
  - Simplified Monitor and Control System with MC Data stored locally
  - DSN discrepancy reporting has heritage
    - Interaction between DSN DR and DSS-17 ARs needs to be defined
  - Several single point of failures (SPFs)

Services to be Provided to Artemis-1 Interplanetary CubeSat Missions

Jet Propulsion Laboratory
California Institute of Technology

DSS-17 will Provide Support for NASA Artemis 1 CubeSats

Lunar IceCube
NEA Scout
LunaH-Map
Lunar Flashlight
CuSP
Plus CAPSTONE

Spacecraft		Downlink Band	Uplink Band	Bus Stop	DSS-17? Y/N	Near-Earth* or Deep-Space U/L
HMAP		X	X	2 -30mins	Y	Near-Earth
LFL		X	X	1	Y	Near-Earth
MLIC		X	X	1	Y	Near-Earth
NEAS		X	X	1 +90mins	D/L only	Deep-Space
CuSP		X	X	2 +120mins	Y (D/L only)	Deep-Space
	*Near-Earth X-Band Uplink: 7.145 GHz – 7.190 GHz Color Code: Uplink/Downlink/Ranging ■ Downlink Only ■					

DSS-17 Anticipated Upcoming Missions

Jet Propulsion Laboratory
California Institute of Technology

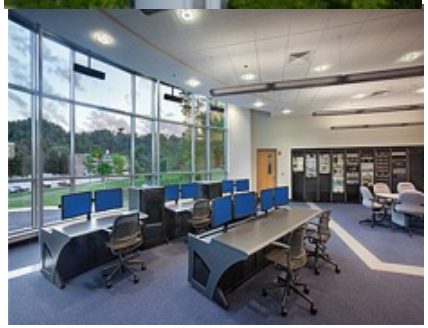
Mission	Services	Uplink	Downlink	Modulation	Regulatory	Duration	Launch
Lunar IceCube	Uplink, Downlink, Doppler, Ranging	7233.765	8498.95	PCM/PSK/PM 16kHz Sine	Included on NTIA Stage 4	24 months	SLS Launch- 11/2021
LunaH-Map	Uplink, Downlink, Doppler, Ranging	7193.6	8496.93	BPSK	Included on NTIA Stage 4	24 months	SLS Launch- 11/2021
NEAScout	Downlink Only	N/A	8402.78	PCM/PSK/PM	Included on NTIA Stage 4	24 months	SLS Launch- 11/2021
CuSP	Downlink Only	N/A	8416.36	BPSK, Manchester	Included on NTIA Stage 4	24 months	SLS Launch- 11/2021
CAPSTONE X-Band							
CAPSTONE	Uplink, Downlink, Doppler and Ranging	7235	8500	BPSK	Info for NTIA Stage 4 provided	9 months	November 2021
ISRO Cross Support X-Band							
Aditya-L-1	Uplink, Downlink, Doppler, Ranging	7219.611 & 7232.531	8482.32 & 8497.50	PM/PSK/PCM	Apply for Experimental?	TBD	TBD
CLPS S-Band							
NOVA-1 IM – Intuitive Machines	Uplink, Downlink, Doppler, Ranging	2035.594	2200-2290 (requested 2250)	PM/BPSK, for high data rate: OQPSK	FCC S-band Experimental? 21 m included on ITU Filing	4 weeks	January 28, 29, 30
LN-1 NASA – MSFC	Downlink Only – Navigation Beacon	N/A	2272.5	BPSK, NRZL, Bi-phase	Included on NTIA Stage 4	4 weeks	January 28, 29, 30

NOTE: Artemis 1 and CAPSTONE are the Primary Missions to be serviced by DSS-17. Others, including Aditya-L-1, NOVA-C, and LN-1 will be serviced on a non-interventional basis, that is when time is not scheduled on DSS-17 for Artemis 1 and CAPSTONE

Overview – New Technologies in the 21m Upgrade Project

MSU 21m Antenna Upgrade to DSN Compatibility

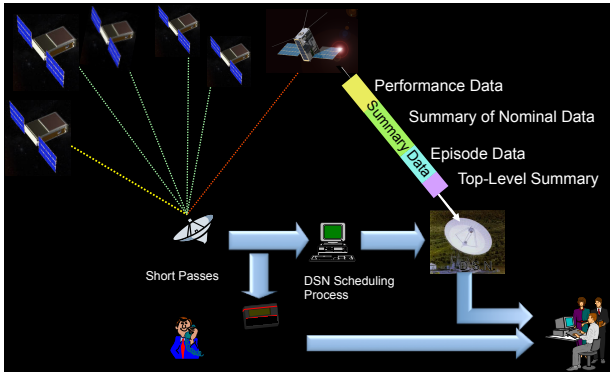
University Partnerships



Technology Enhancements

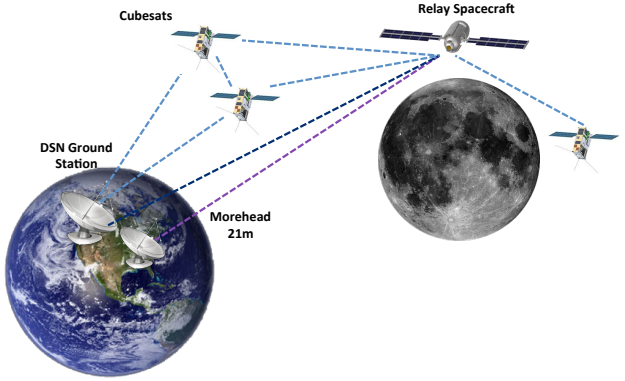
Spacecraft-Initiated Operations

Tracking On Demand



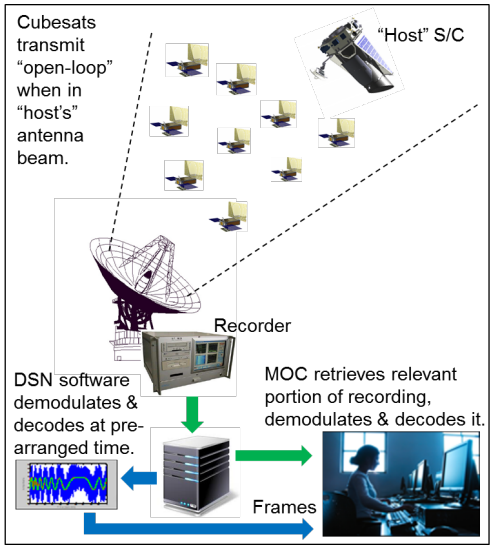
Disruption Tolerant Networking

More efficient communications



Opportunistic Multiple Spacecraft per Antenna

Inexpensive downlink



Future of DSS-17

DSS-17 Supports Interplanetary Class D Missions while MSU 12m (Gifted by JPL) Supports LEO SmallSat Missions and University student training

Q&A
“We’ve reached the end of the beginning”