Deep Space Station 17: A University-Operated Affiliated Node on the NASA Deep Space Network Providing Telemetry, Tracking and Command Services for Interplanetary SmallSat Missions

Interplanetary Small Satellite Conference

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MOREHEAD STATE UNIVERSITY

In Partnership with

Jet Propulsion Laboratory

California Institute of Technology

21 Meter Space Tracking Antenna at Morehead State University

- Conceived and 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- has supported LRO, ISEE-3, Planet Labs, KySpace
- Program Funded by AES in 2016 to Upgrade the 21 m Toward DSN Compatibility

Recently provided tracking support to JPL's Asteria Mission

MOREHEAD STATE UNIVERSITY

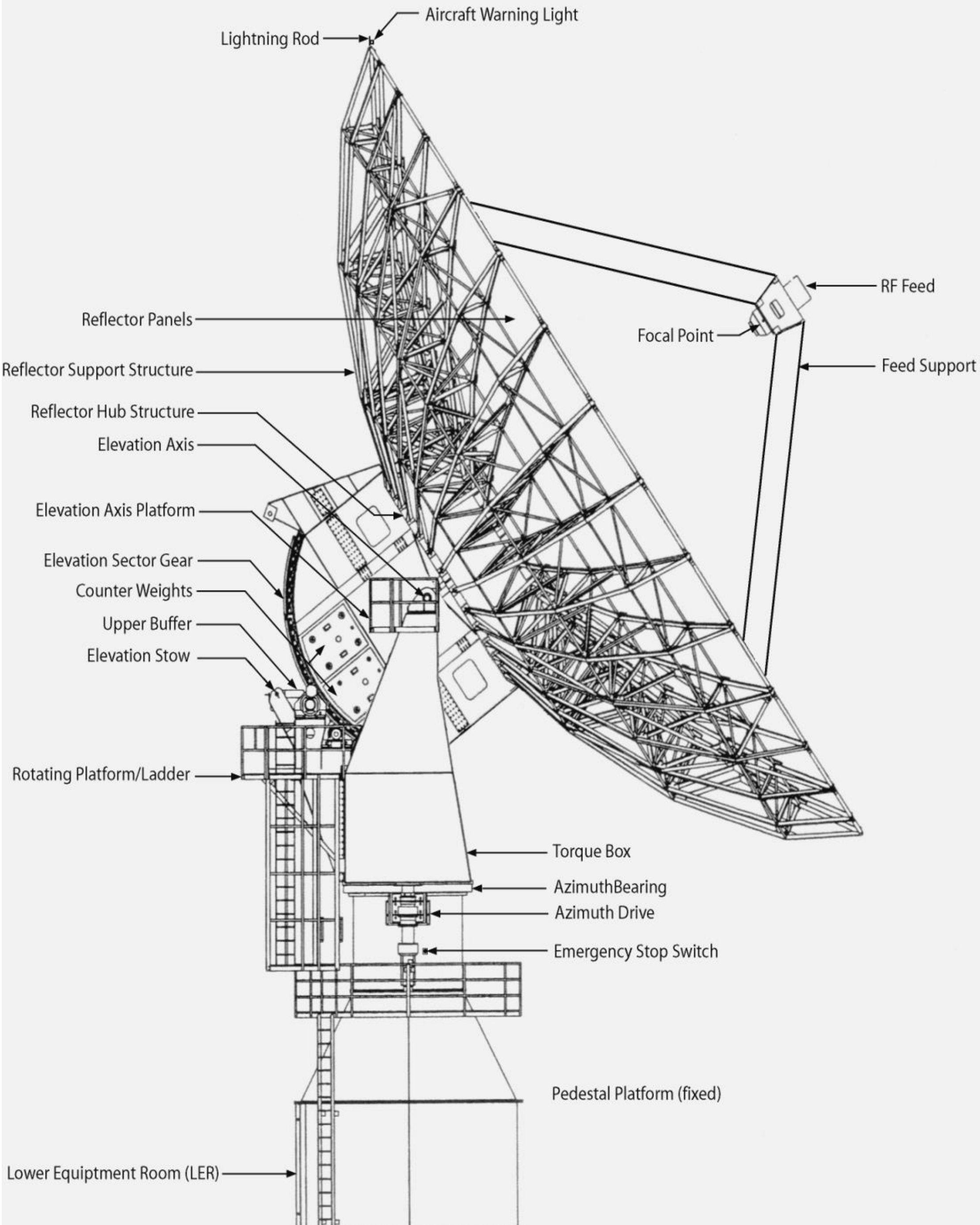
The Morehead State University Ground Station

- 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
- Experienced RF and Telecom Engineers and Scientists
- Talented, Intrepid Students

21 M Operations

- 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

21 M Overview



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 °/sec²**
Elevation	**0.6 °/sec²**
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**

AES Program: 21 m 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 small spacecraft missions to the Moon and inner solar system, thereby enabling interplanetary research with small spacecraft platforms.

Technical Approach

- Develop and implement a strategy to transfer Deep Space Network (DSN) 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 small spacecraft missions.
- Develops an 2020 timeframe
- 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 at 64-256 kbps

Morehead State University 21m Upgrade to DSN Compatibility
MSU 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

H- MASER

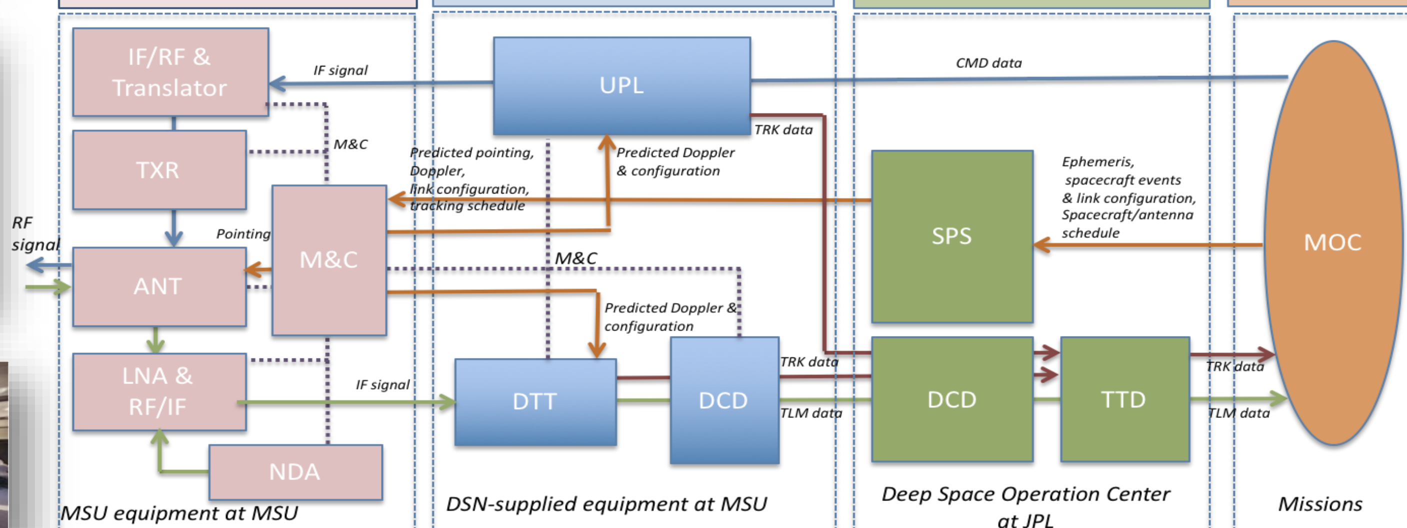
Morehead State University Mission Operations Center

- 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

- 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



Enabling Interplanetary Smallsat Ground Support- Toward DSN Compatibility

Incremental Delivery and Testing

Delivery Increment	Test Focus
DSN-provided Uplink, Downlink and Data capture & delivery	a. Generation of command data b. Generation and correlation of ranging signal, for both sequential and pseudo-noise ranging c. Extraction of telemetry data d. Data transfer between the uplink and downlink equipment and the Data Capture & Delivery
Connection to NASA Mission Backbone Network	a. IP connection (after IT Security scan) b. Data delivery between the MSU DCD and JPL DCD (verifying all routing permissions in the firewall setting, both for MSU & JPL) c. Simulated data flow from DTT (at MSU) to TTD (at JPL)
Installation of downlink RF equipment at the antenna	a. Extraction of telemetry and delivery to JPL
Installation of uplink RF equipment and Transmitter at the antenna	a. Generation of command data with Transmitter in the loop, with connection from SLE user to MSU Uplink equipment b. Correlation of ranging signal, including the Transmitter and LNA components c. Radiometric (Doppler/Ranging) data delivery to JPL

Morehead State University 21m Upgrade to DSN Compatibility
Detailed Project Status and Remaining Tasks

Major Tasks Completed

- System Architecture Design Complete
- DSN Designation Assigned: DSS-17
- Connection to NASA Backbone Network Complete
- DSN Equipment Installed and Tested
- Hydrogen MASER in Operation (on semi-permanent loan from MIT)
- Antenna Control Systems Tested
- All Hardware Complete and Installed: X-Band Feed, kPA, DSN Equipment
- Station Monitor System Designed and Hardware Installed

Major Tasks Remaining

- Install/Test new gearbox (maintenance activity)
- Complete Characterization of System Performance
    - Characterize Doppler and ranging performance
    - Test command performance over space link
- Complete Staff and Student Training
- Implement Monitor Control System Updates
- Conduct Series of Validation Demonstrations
- Conduct Operational Readiness Review
- Complete Preparations for Artemis-1 CubeSat Support

Antenna Feed Swap

Hydrogen MASER

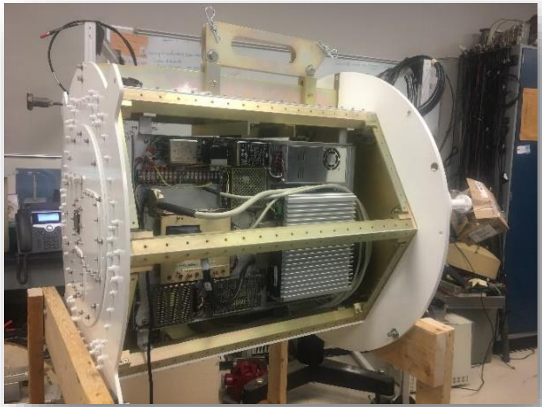
DSN Equipment

Purple Glow from the Hyperfine Transition of Atomic Hydrogen

Antenna Operations Center

Morehead State University 21m Upgrade to DSN Compatibility
Recent Technical Accomplishments

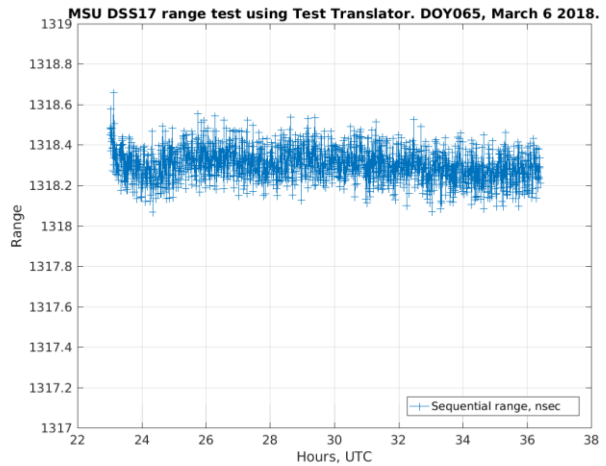
X-band Feed



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

X-band Feed is located at the prime focus

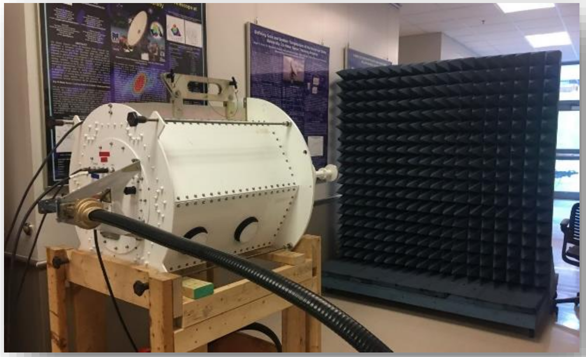
High Power Amplifier



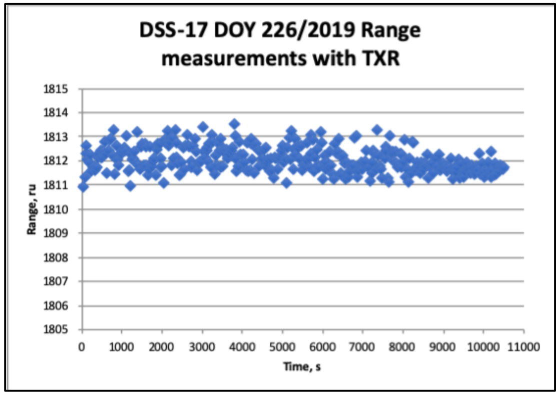
DSS-17 Ranging Stability Results- measurement stability over > 13 hours exceeds requirement

3 kW High Power Amplifier under test

Ranging



Initial Transmit and Ranging laboratory tests proved successful

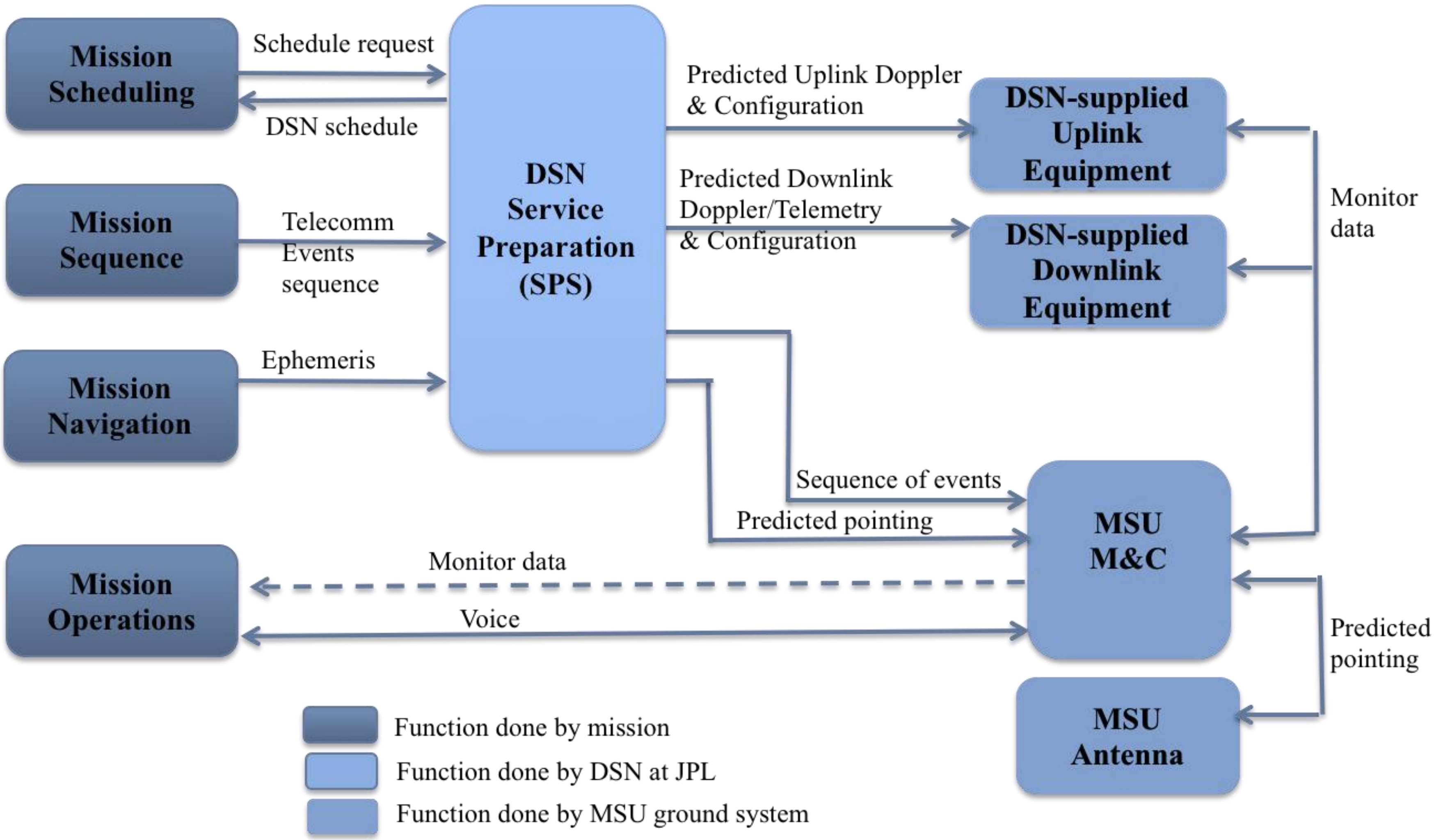


DSS-17 Ranging Results- precision within +/-1 range unit (0.94 ns). Implies 1 meter accuracy ranging at the Moon

21m Performance

Performance Measure	Pre-Upgrade	Post-Upgrade
X-Band Frequency Range	7.0 – 7.8 GHz	7.0 – 8.5 GHz
LNA Temperature	70 K	< 20 K
System Noise Temperature	215 K	<100 K
Antenna Gain	62 dBi (@7.7 GHz)	62.7 dBi (@8.4 GHz)
System Noise Spectral Density	-175 dBm/Hz	<-178 dBm/Hz
G/T at 5° Elevation	37.5 dB/K	40.4 dB/K
Time Standard	GPS (40 ns)	Hydrogen maser (1 ns/day)
EIRP	N/A	93.7 dBW
HPBW	0.124 deg	0.115 deg
SLE Compliance	N/A	Yes
CCSDS Compliance	N/A	Yes
Forward Error Coding	Reed Solomon/Convolutional	Reed Solomon/Convolutional, Turbo, Low Density Parity Check
Radiometric	Angle, Doppler	Angle, Doppler, Ranging

Service Management Data Flow For NASA Missions



Jet Propulsion Laboratory
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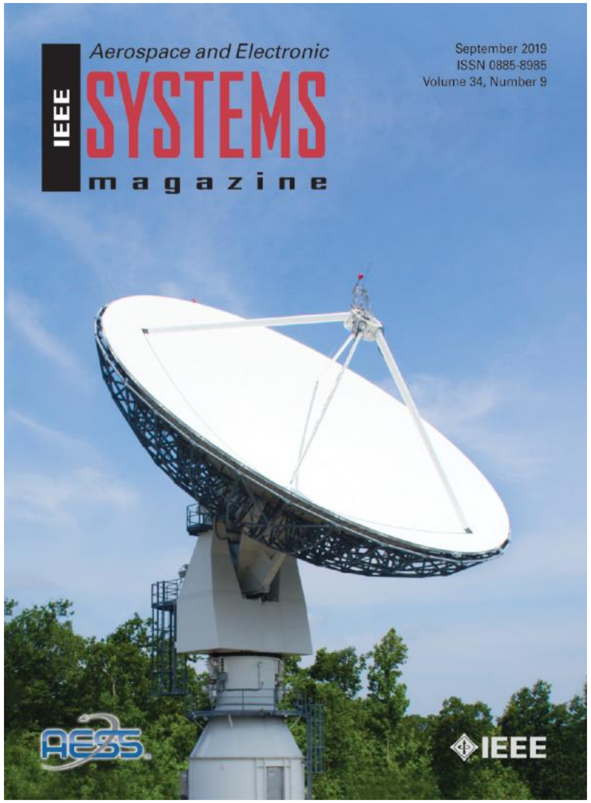
Morehead State University 21m Upgrade to DSN Compatibility



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**
  - Initial Ranging Measurements Successful
    - Results imply 1m ranging accuracy at the Moon
- **Conducted MarCO Downlink Demonstration** Using Software Defined Radio (SDR) based receiver 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

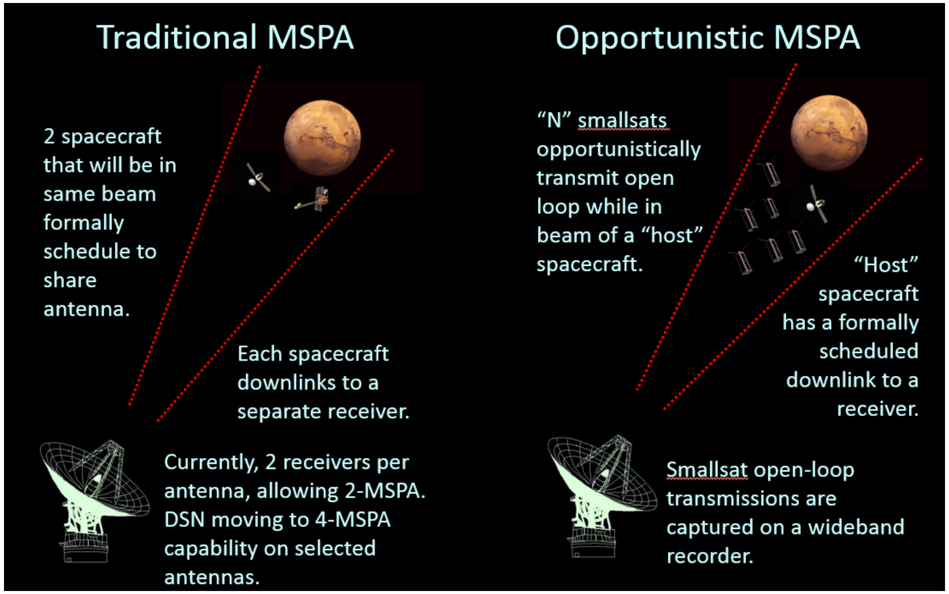
Critical Milestones

ΔSRR	NMB Connection	Downlink Demo	Uplink Demo	Ranging Demo	ORR	Operational	Mission Ops	Mission Duration	Project Complete for Artemis 1
01/15/2016	6/15/2018	5/5/2018	9/1/2020	9/15/2020	10/15/2020	11/30/2020	Artemis-1	Artemis 1 CubeSat Mission Duration	Artemis 1 CubeSats Closure

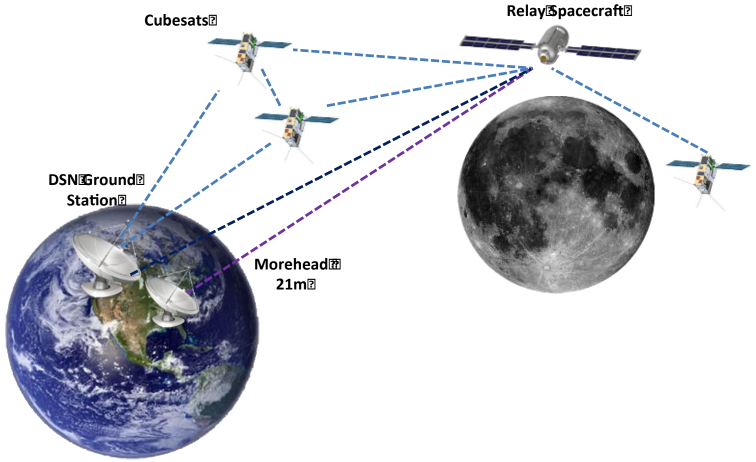
Future of DSS-17

Possible Extensions and Adaptations

- Multiple Spacecraft per Aperture (MSPA) and Opportunistic MSPA (OMSPA)-
    - Past and Future Experiments
- Delay/Disruption Tolerant Networking (DTN
    - Ground Demos in 2018 and 2019, 2020
    - Lunar IceCube Demonstration in 2021
- Beacon Tone Service for CubeSats, Fleets, Constellations, and Autonomous Spacecraft that can extend the reach of DSS-17 to Mars and Beyond.



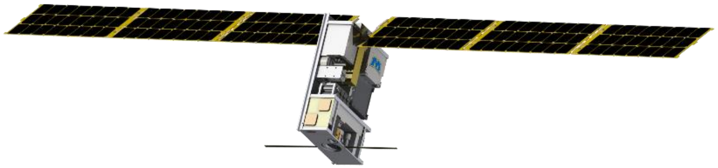
Support for Space Networking



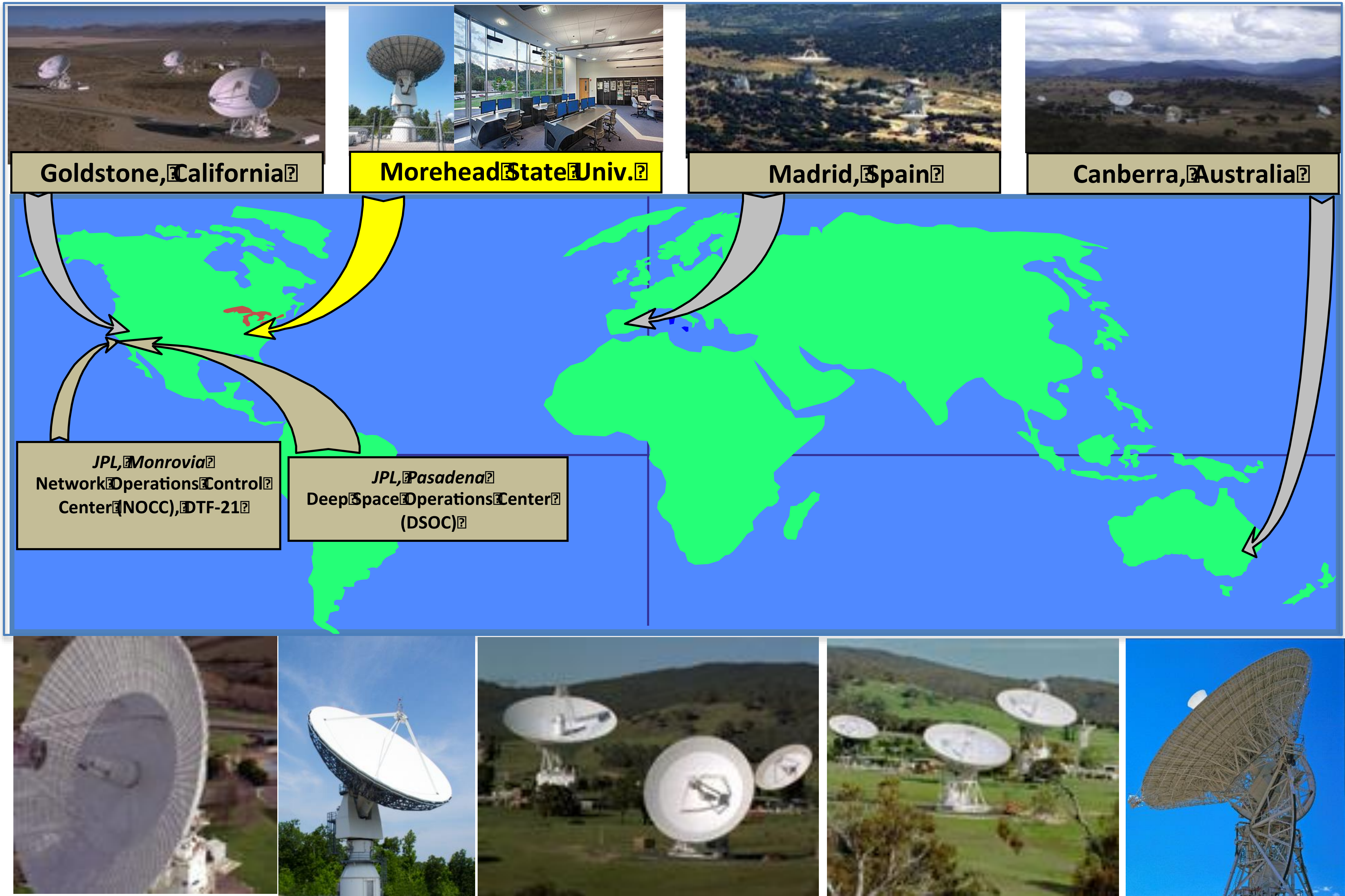
OMSPA was demonstrated at MSU on the MarCO spacecraft. For more information, see "InSight/MarCO Opportunistic Multiple Spacecraft Per Antenna (OMSPA) Demonstration"

(https://ieeexplore.ieee.org/document/8741775)

Lunar IceCube, managed by MSU, will demonstrate the DTN Bundle Protocol (BP) using NASA"s Core Flight Software (cFS) implementation onboard and NASA's ION DTN implementation on the ground during its 180 day cruise phase. ISSC paper by Nat Richard et al. 5/11/2020.



DSS-17 Affiliated Station



Questions?