Enabling University-Operated Tracking and Communications for Deep Space Smallsat Missions

CubeSat Developers' Workshop

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EARTH AND SPACE SCIENCES · MOREHEAD STATE UNIVERSITY

MOREHEAD STATE UNIVERSITY

In Partnership with

Jet Propulsion Laboratory
California Institute of Technology

Morehead State University
21 Meter Space Tracking Antenna

- Specifications by MSU faculty with NASA assistance
- Dual Purpose Instrument
    - Ground Station for Smallsats
    - Radio Telescope for Astronomy Research
- Funded $6 M -a variety of sources- Morehead State, Federal and State Funds, KSTC, NASA
- Built and Installed by VertexRSI (General Dynamics)
- Operational in 2006

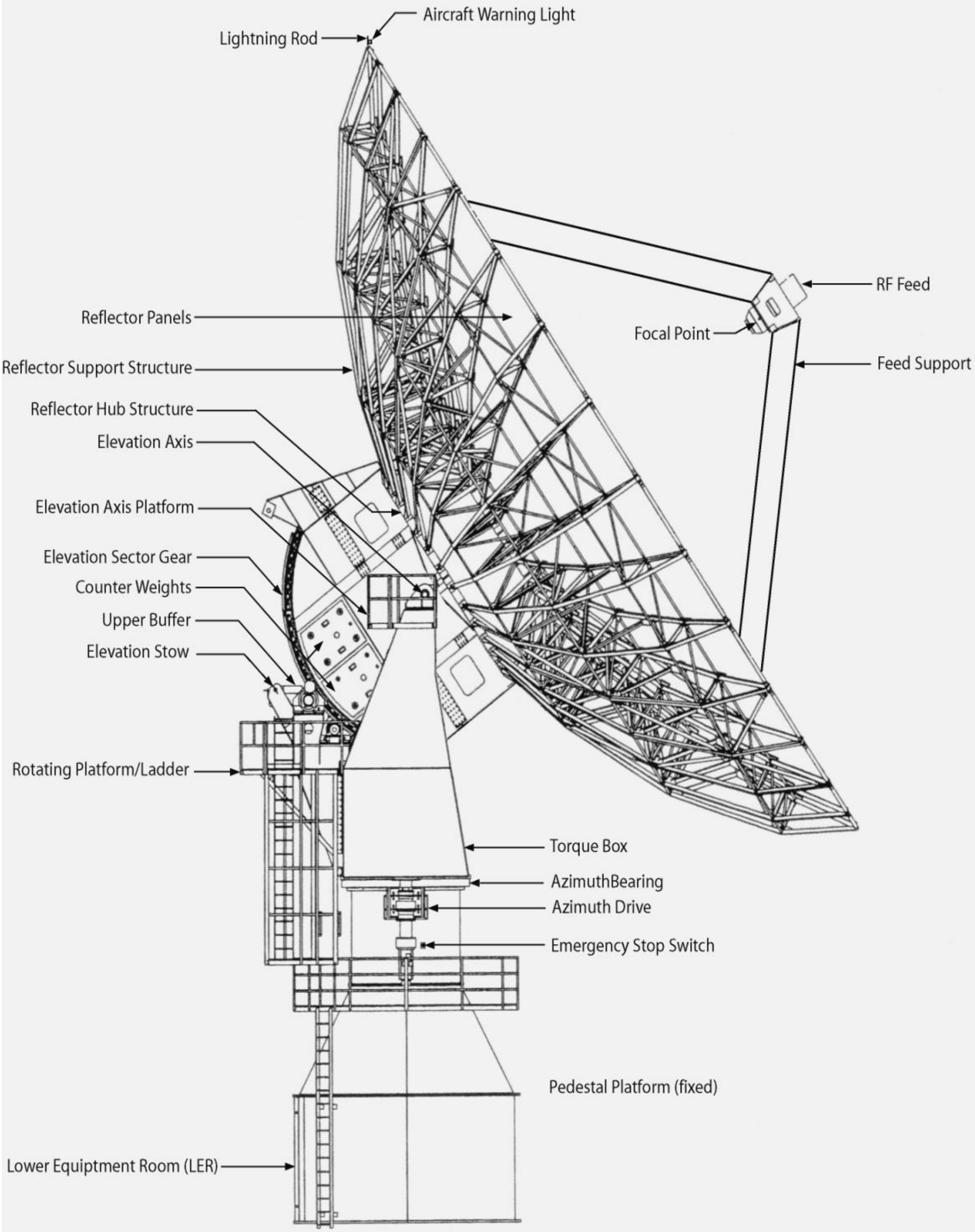
The Morehead State University Ground Station

- Quiet RFI Environment in Eastern Kentucky (Southeastern US)
- 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



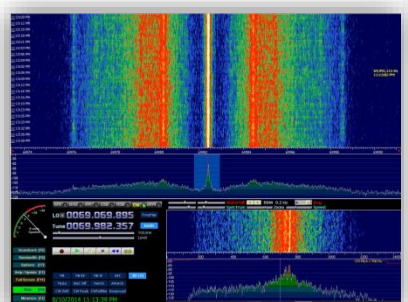
Parameter	Measured Values
Axis Slew Velocity	
Azimuth	> 3.0 °/sec minimum
Elevation	> 1.6 °/sec minimum
Polarization	> 0.7 °/sec minimum
Axis Acceleration	
Azimuth	1.0 °/sec^2
Elevation	0.6 °/sec^2
Travel Range	
Azimuth	± 269.8°
Elevation	1.0° to 90.3°
Polarization Range	± 90°
Pointing Accuracy	0.005°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

Interplanetary SmallSat Ground Ops: Morehead State 21 M Ground Station- Current Operational State

Morehead State University
21 M Ground Station

- Fully Operational, Full-Motion, 21 M Antenna
- Operational Experience: LRO, ISEE-3, Planet Labs, KySpace, JPL ASTERIA
- High Gain, Pointing and Tracking Accuracy
- Station is ideal for Inner Solar System Experiments
- Full Remote Control of All Systems
- UHF and S-Band Uplink and Downlink
- NASA NEN Compatible
- Software-Defined TT&C Processor (SoftFEP) and High Data Rate Digitizer for Experimental Missions
- Extensive use of Student Operators (STEM Engagement)

Student Operators in the MSU 21 M LER



ISEE-3 Carrier During Lunar Fly-by Sept 2014

Student Operators in the MSU Mission Ops Center

MSU 21 Meter Current RF Capabilities

Radio Band	Frequency Range	Gain	Uses of Band
UHF	400-480 MHz	30 dBi	Satellite Telecom
S-Band	2.2-2.5 GHz	52.8 dBi	Both Satellite Telecom and Radio Astronomy
X-Band	7.0-7.8 GHz	62.0 dBi	Primarily Satellite Telecom
Ku-Band	11.2-12.7 GHz	65.50 dBi	Primarily Satellite Telecom

AES Program: Upgrade the 21 m for Interplanetary Smallsat Support to Reduce DSN Loading

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 operational capability to support EM-1 CubeSat missions in the 2018- 2019 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 128-256 kbps

Enabling Interplanetary Smallsat Ground Support- Toward DSN Compatibility

Primary Tasks

- Design, Develop and Implement Single-channel, Customized "Lite" Versions of DSN Equipment:
  - DTT- Downlink, Tracking and Telemetry
  - DCD- Data Capture and Delivery
  - UPL (USG- Uplink Signal Generator and UPA-Uplink Processing Assembly)
- Develop a 21 m version of NMC
- Implement 5 KW Power Amplifier
- Implement Hydrogen MASER
- Design and Fabricate Cryogenic X-Band Feed
- Modify IF Stages
- IT and Physical Security Upgraded
- Implement DSN Ranging Techniques
- Calibrate, Test and Validate System and all Subsystems
- Perform a Series of Downlink, Uplink and Ranging Demonstrations
- Commission as an Affiliated DSN station
- Add DSS-17 to DSN Scheduling
- Support Operational Readiness Review in Advance of EM-1

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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

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New System Architecture Required

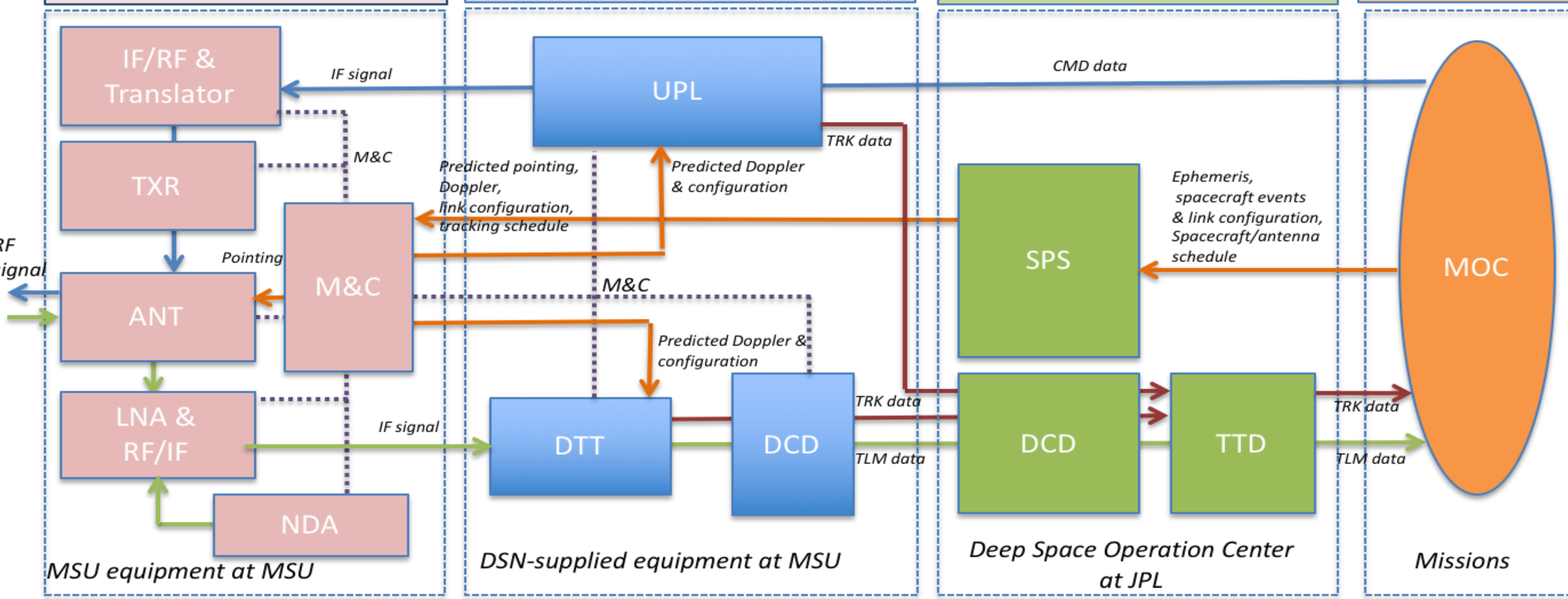
DSS-17 System Architecture

- 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

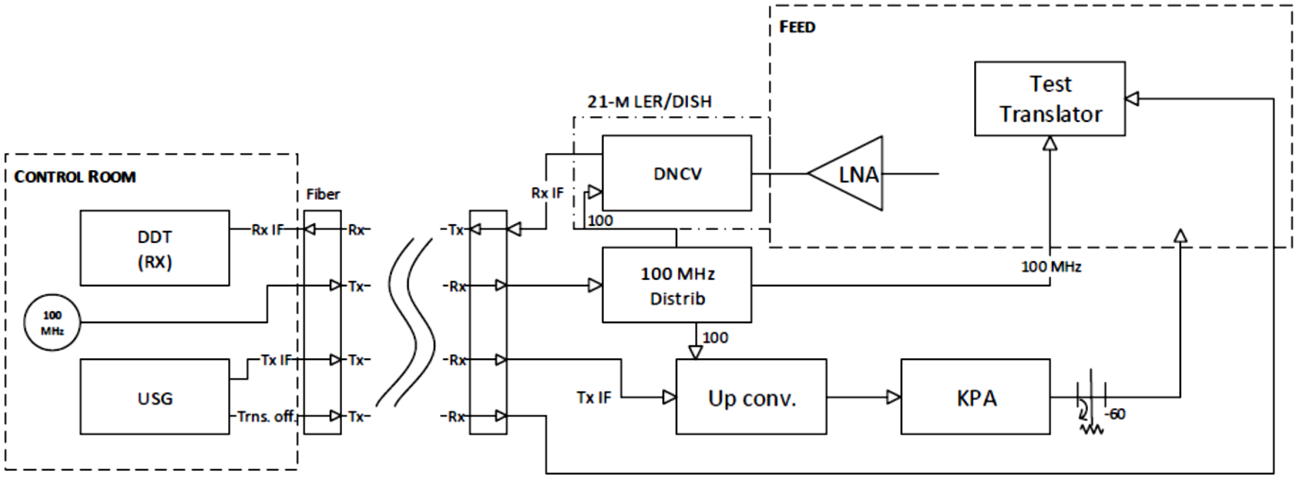
- SPS – Service Preparation Subsystem
- DCD – Data Capture & Delivery
- TTD – Tracking & Telemetry Delivery

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

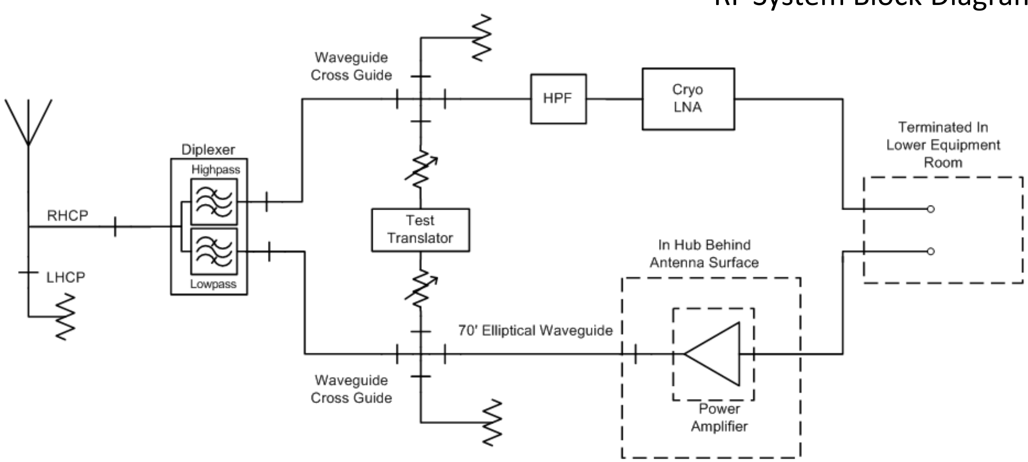


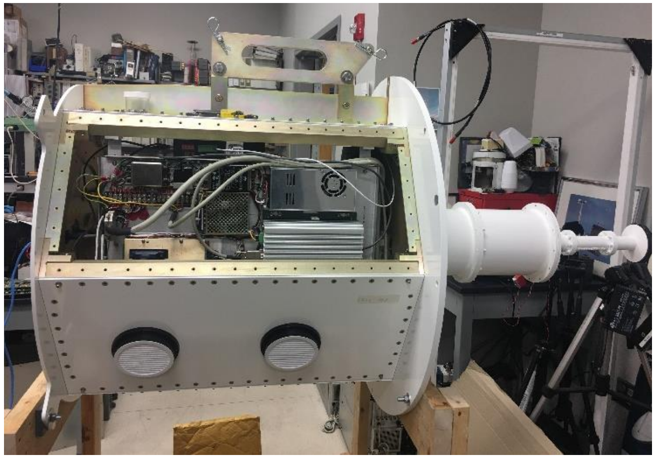
DSS-17 RF System and X-Band Feed

New X-Band Feed Required with Cryogenic LNA and High Power TX Capability



RF System Block Diagram





X-Band Feed Diagram

X-Band Feed

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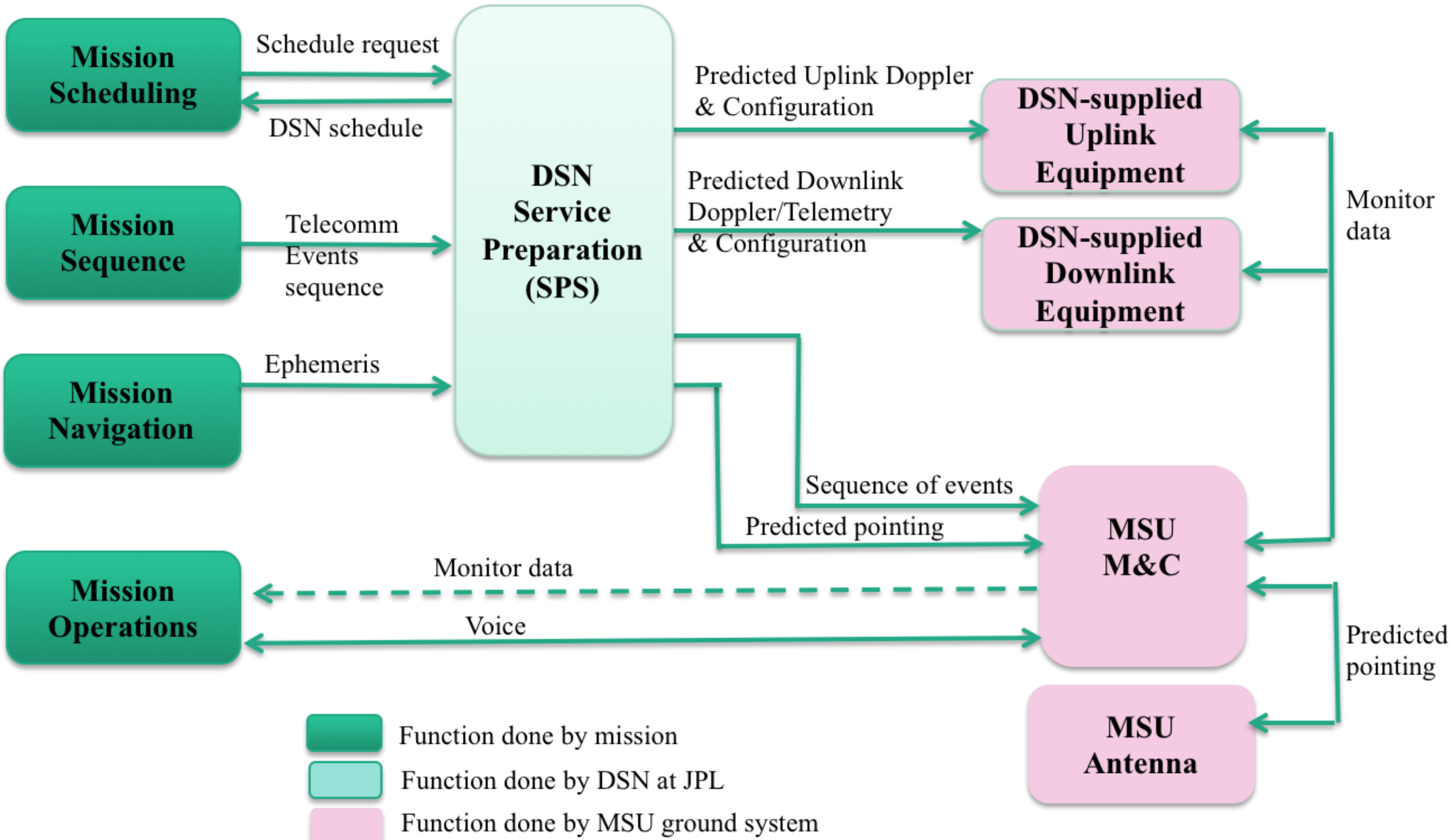
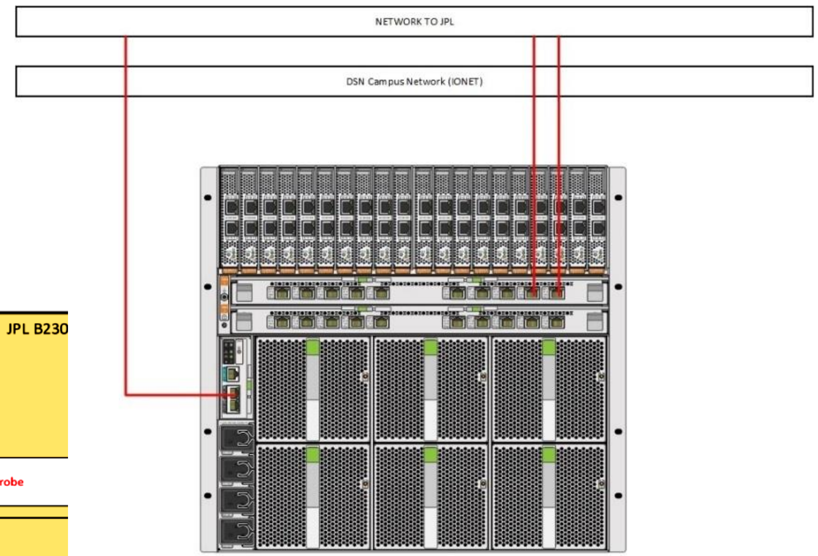
Service Management Data Flow



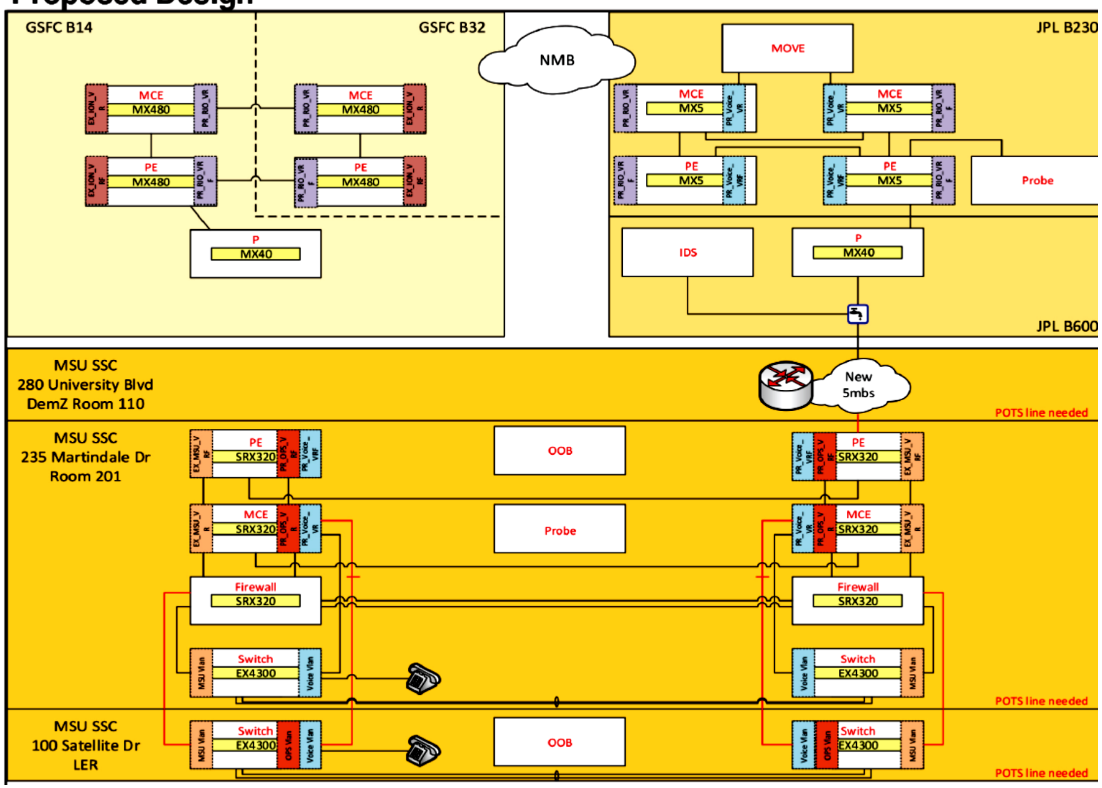
IT Security and NMB Connection

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



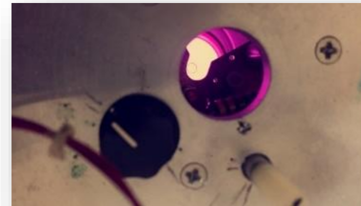
Project Status and Remaining Tasks

Primary Tasks Complete/In Process

- DSN Designation Assigned- DSS-17
- System Architecture Design Complete
- DSN Equipment Installed and In Testing
- Hydrogen MASER in Operation (on semi-permanent Loan from MIT)
- X-Band Feed Designed and Fabricated
- IF Systems Complete
- Antenna Control Systems Tested
- IT Security Scans Being Conducted
- Initial Staff and Student Training Conducted

Major Tasks Remaining

- Implement and Test HPA
- Transfer Tracking and Ranging Processes
- Complete Staff and Student Training
- Implement Monitor Control
- Conduct Series of Validation Demonstrations
- Commissioning
- EM-1 ORR



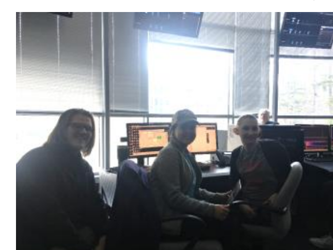
Purple Glow from the Hyperfine Transition of Atomic Hydrogen

Hydrogen MASER

Duration (s)	Detector reading	Measured Allan Deviation	Required
1	4.50E-013	3.18198E-13	3.30E-13
10	6.00E-014	4.24264E-14	1.00E-13
100	2.00E-014	1.41421E-14	3.30E-14

21 m Station Control System

DSN Equipment at DSS-17



Morehead State Student Operators Gaining Invaluable Experience during JPL ASTERIA mission

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Expected 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

Planned Testing and Validation Demonstrations

MarCO

- Downlink Using X-Band Feed and DSN Equipment
- Downlink Using X-Band Feed and MarCO Receiver System
- OMSPA Using X-Band Feed and Custom SDR-based Multiple Receiver System
- UHF Uplink Simulating Insight for MarCO Testing

OSIRIS Rex and MAVEN

- Uplink Testing
- Downlink Testing
- Ranging Tests

Mission	Uplink Margin, dB	Downlink Margin, dB
Osiris Rex	20.9	5.8
Maven	17.3	5.5

LRO

- Tracking Precision Testing
- SNR and CNR Measurements

Lunar IceCube

- DTN Demonstration

DSS-17 Next Steps

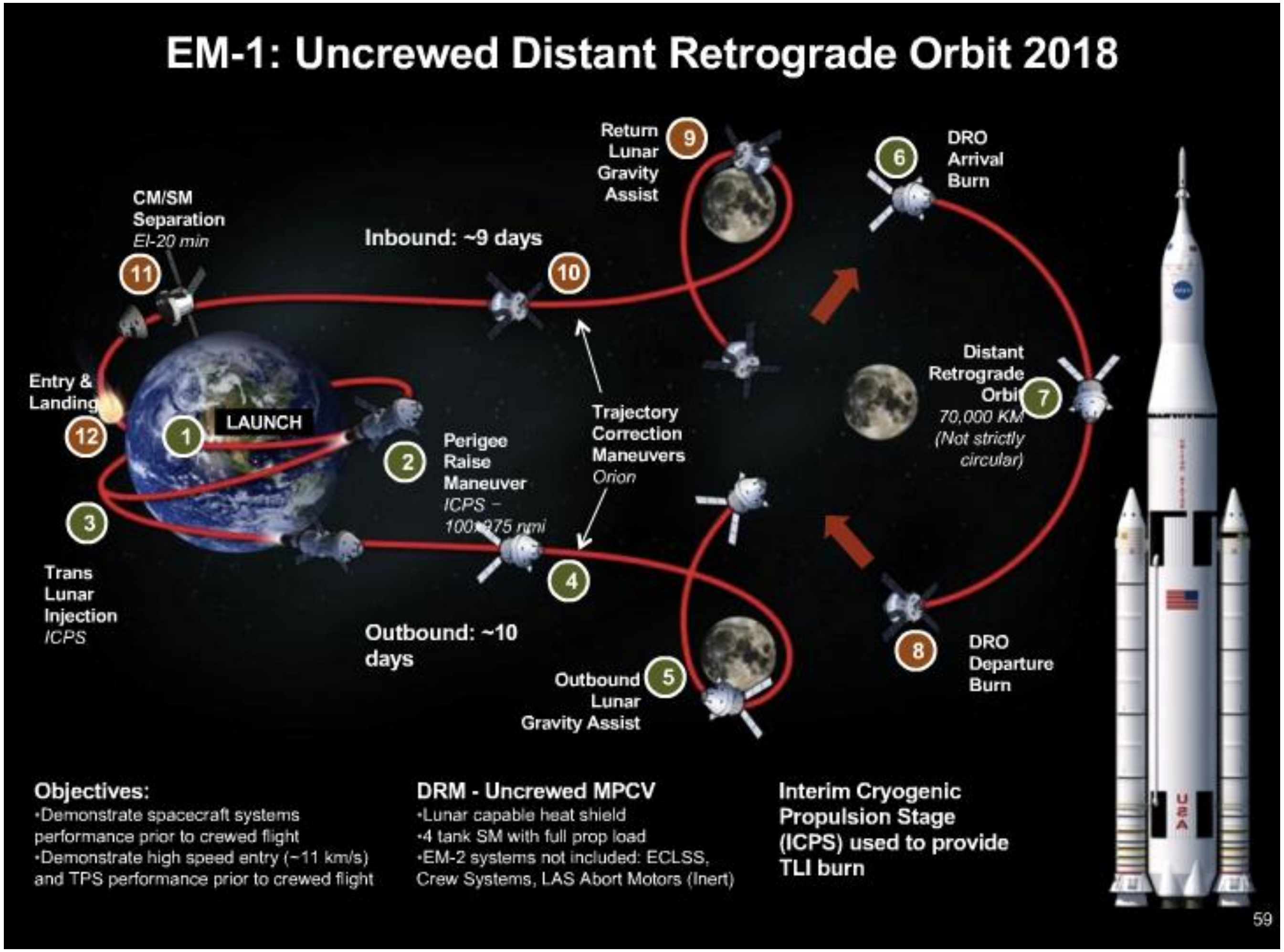
Remaining Critical Milestones

Downlink Demo	NASA NMB Connection	Downlink Demo	Uplink Demo	Ranging Demo	ORR	Operational	EM-1 Mission Ops	Mission Duration	Future Interplanetary Smallsats
5/5/2018	06/30/2018	5/5/2018	3Q 2018	4Q 2018	Q3 2019	Q4 2019	Q4 2019	EM-1 CubeSats Duration	Beyond EM-1

On Target for Operational Readiness for EM-1

Prepared to Provide Support for NASA EM-1 CubeSats

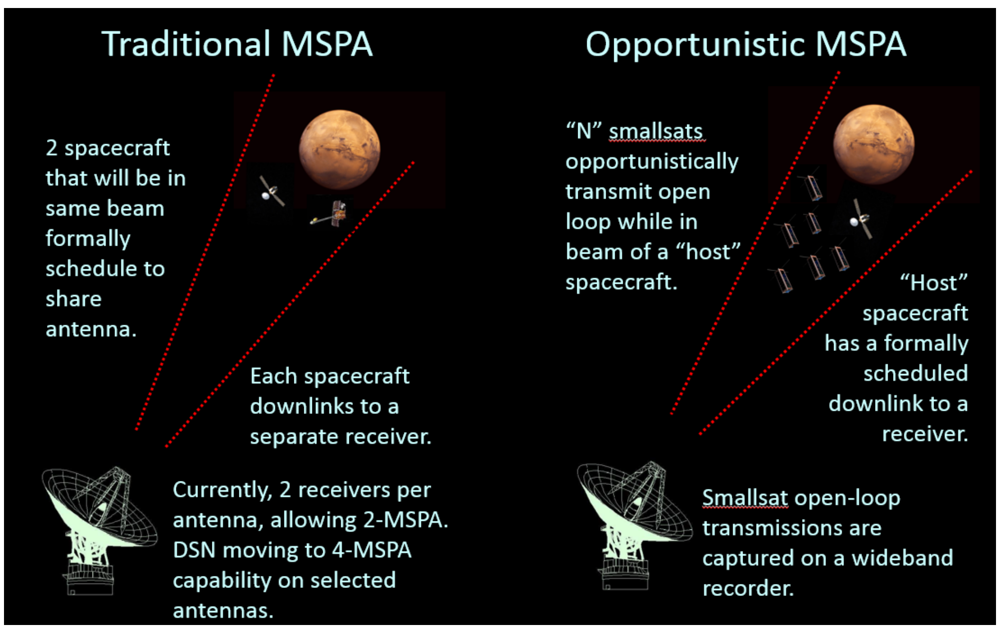
Lunar IceCube
NEA Scout
LunaH- Map
Lunar Flashlight
Biosentinel



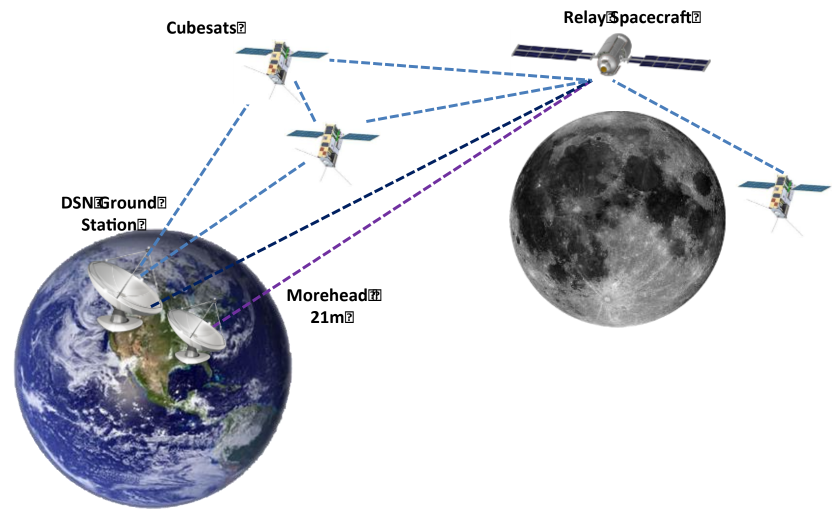
Future of DSS-17

Possible Extensions and Adaptations

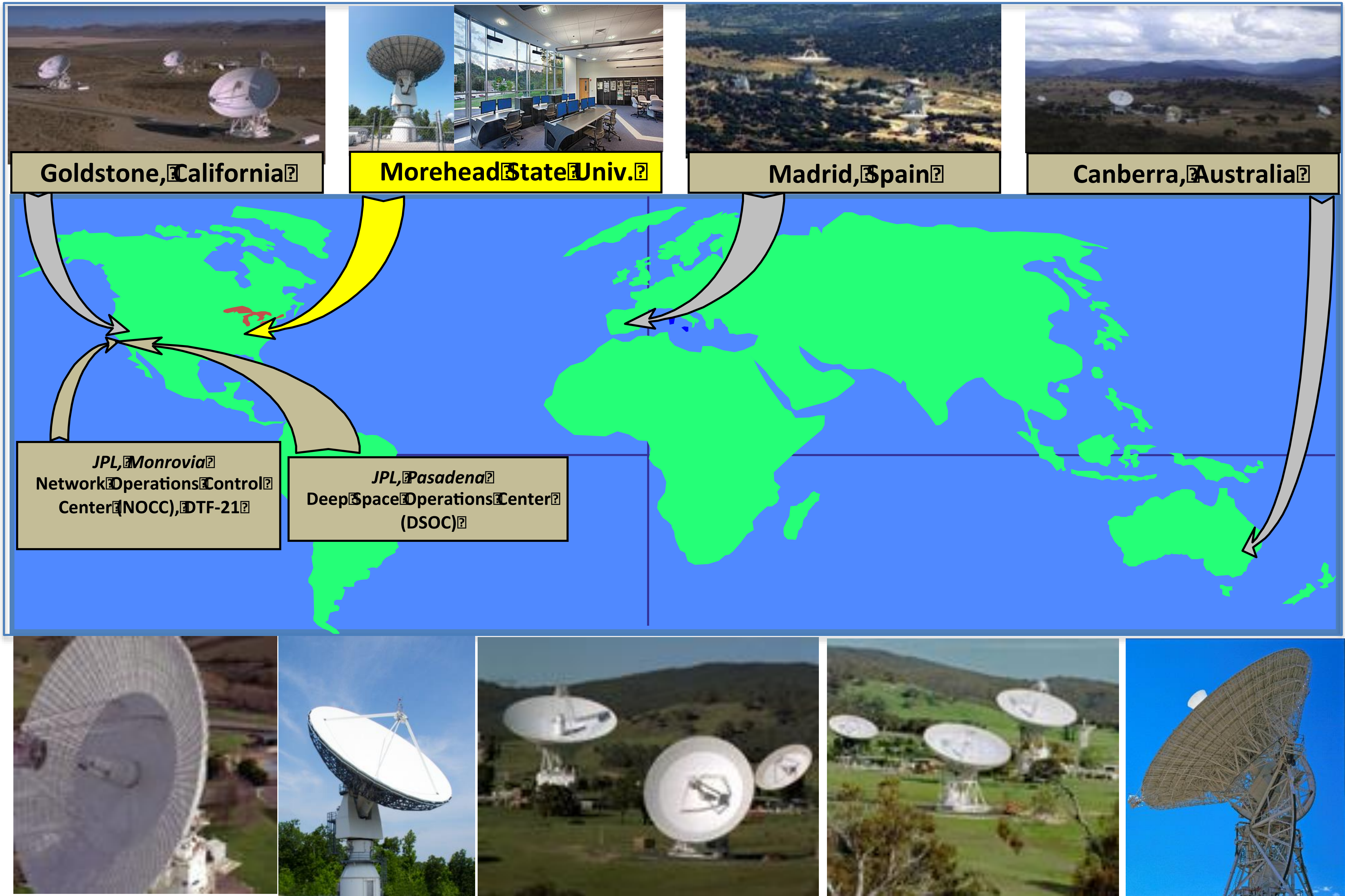
- Multiple Spacecraft per Aperture (MSPA) and Opportunistic MSPA (OMSPA)
- Delay/Disruption Tolerant Networking (DTN)
- UHF Uplink/X-band Downlink for MarCO Experiment



Support for Space Networking



DSS-17 Affiliated Station



Questions?