Enabling University-Operated Ground Support Development with the Morehead State University 21 m Ground Station

Interplanetary SmallSat Workshop

May 1, 2017

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EARTH AND SPACE SCIENCES
MOREHEAD STATE UNIVERSITY

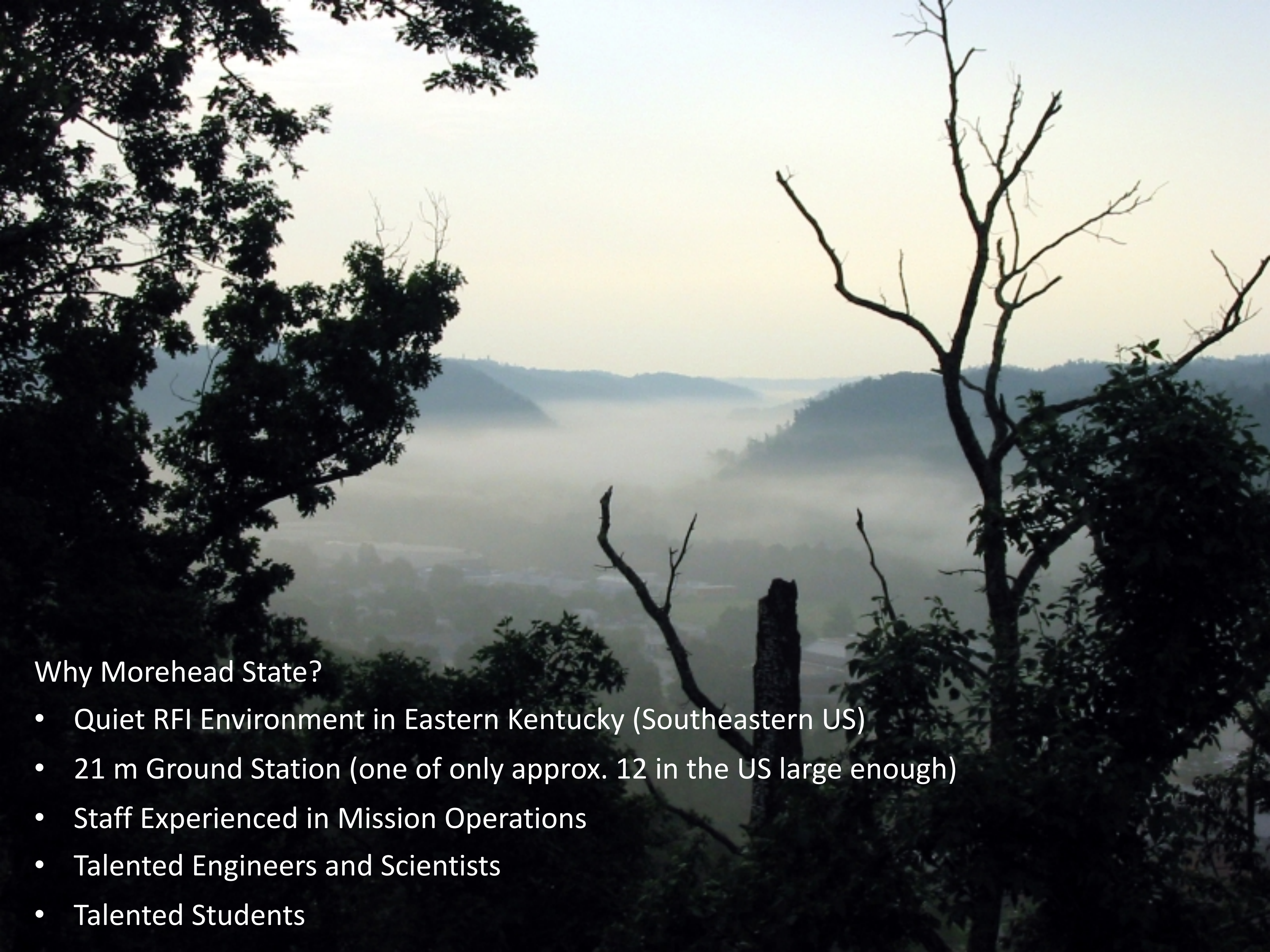
MOREHEAD STATE UNIVERSITY

In Partnership with

NASA

Jet Propulsion Laboratory

California Institute of Technology



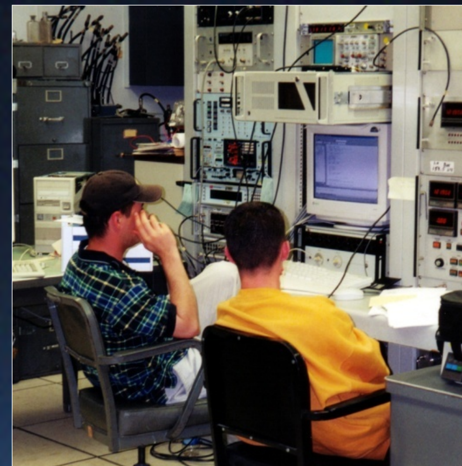
Why Morehead State?

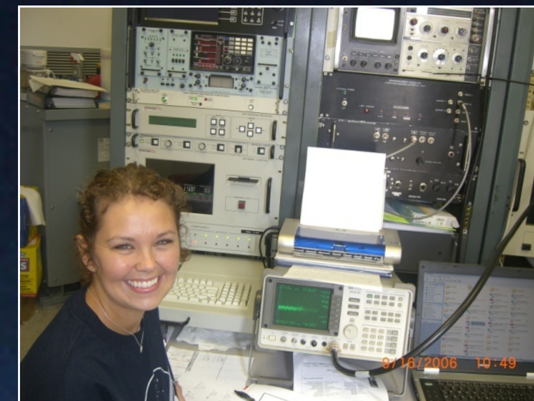
- Quiet RFI Environment in Eastern Kentucky (Southeastern US)
- 21 m Ground Station (one of only approx. 12 in the US large enough)
- Staff Experienced in Mission Operations
- Talented Engineers and Scientists
- Talented Students

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 $3.4 M -a variety of sources- Morehead State, Federal and State Funds, KSTC, NASA
- Built and Installed by VertexRSI (General Dynamics)
- Feeds Designed and built by VertexRSI, APL, and MSU
- Operational in 2006

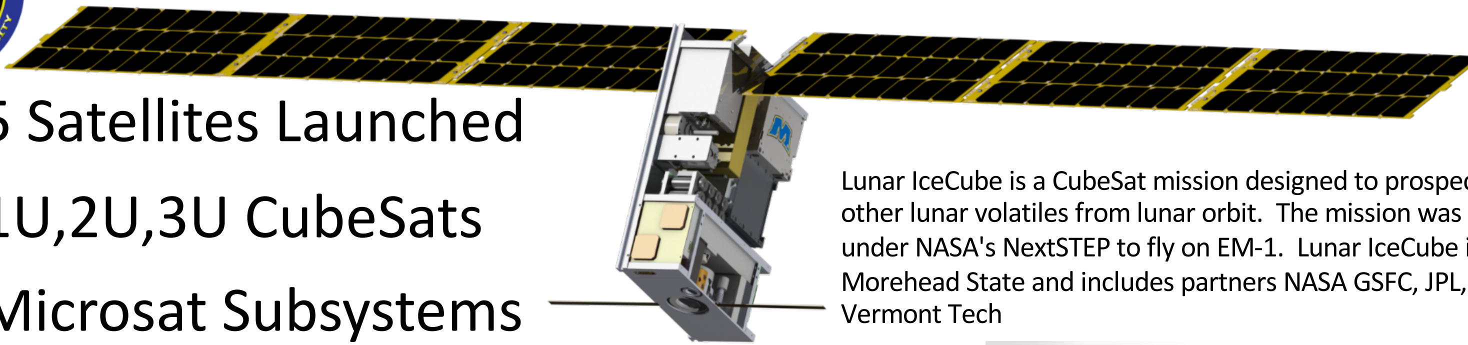
Space Projects Create Opportunities for Students



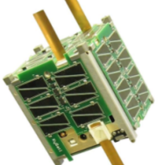


- **Undergraduate Research Experiences**
- **Instrumentation Experience**
- **Engineering Design**
- **Observational Astrophysics Research**
- **Ground Ops (TT&C)**
- **Project Management Experience**
- **Systems-level Engineering Experience**

Morehead State SmallSat Missions

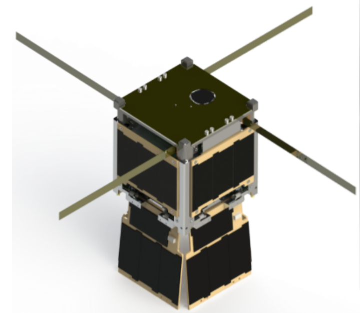


- 5 Satellites Launched
- 1U,2U,3U CubeSats
- Microsat Subsystems
- PocketQubs
- 6U Bus in Development
- Interplanetary Mission
- Variety of Customers

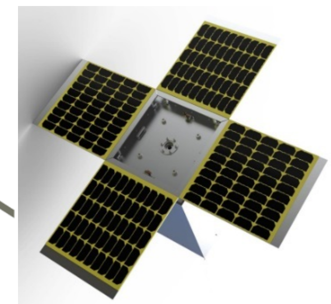


KySat-1 Secondary on NASA's Glory Mission

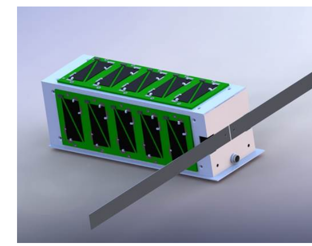
Lunar IceCube is a CubeSat mission designed to prospect for water ice other lunar volatiles from lunar orbit. The mission was selected under NASA's NextSTEP to fly on EM-1. Lunar IceCube is led by Morehead State and includes partners NASA GSFC, JPL, Busek, and Vermont Tech



KySat-2 Launched in October 2013

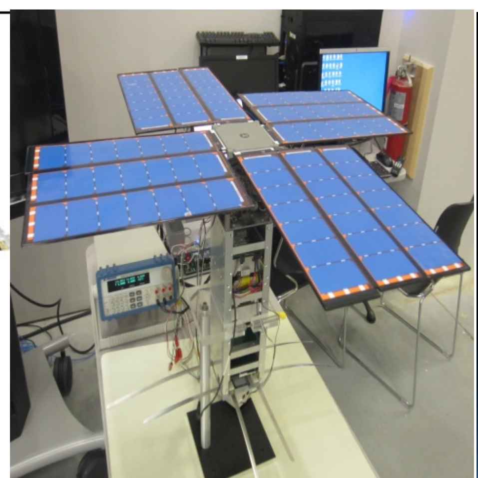


UniSat-5 w/ Univ. of Roma-GAUSS launched 2014



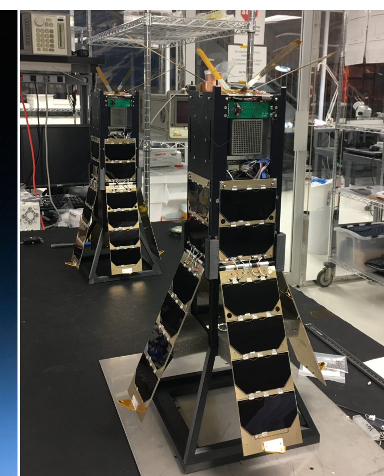
T-LogoQube (Eagle-1) Launched in October 2013

CXBN Launched in 2012



TechSat-1 In Developed for SMDC (w/ Radiance and Honeywell)

Standard MSU 3-U Bus



CXBN-2 Launched April 2017

21 M Operations

- Satellite Ground Station for Ground Ops/Mission Support- for our SmallSat Missions and Others
- Radio Telescope Mode for Research in Astrophysics
- Test-Bed for Experimental Communication Systems for Small Satellite Systems

21 M Ground Station Mission Support

Support SmallSats Missions in:

- LEO
- MEO
- GEO
- Lunar
- Near-by Asteroids
- Approaching Comets

Missions Operations For:

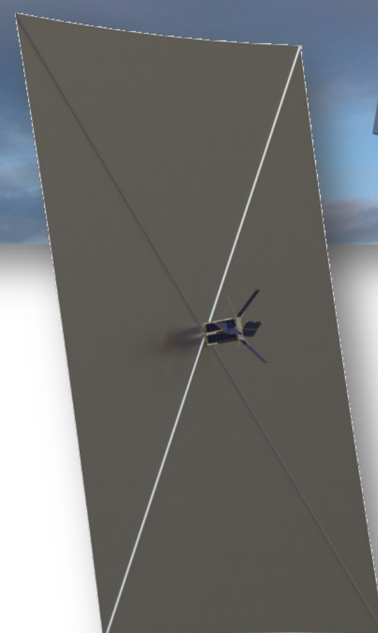
•Planet Labs Dove Constellation

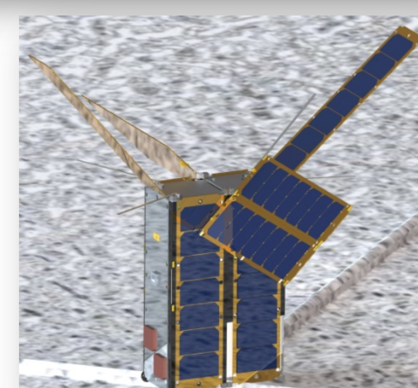
•LRO (Mini-RF Comms)

•ISEE-3 Reboot

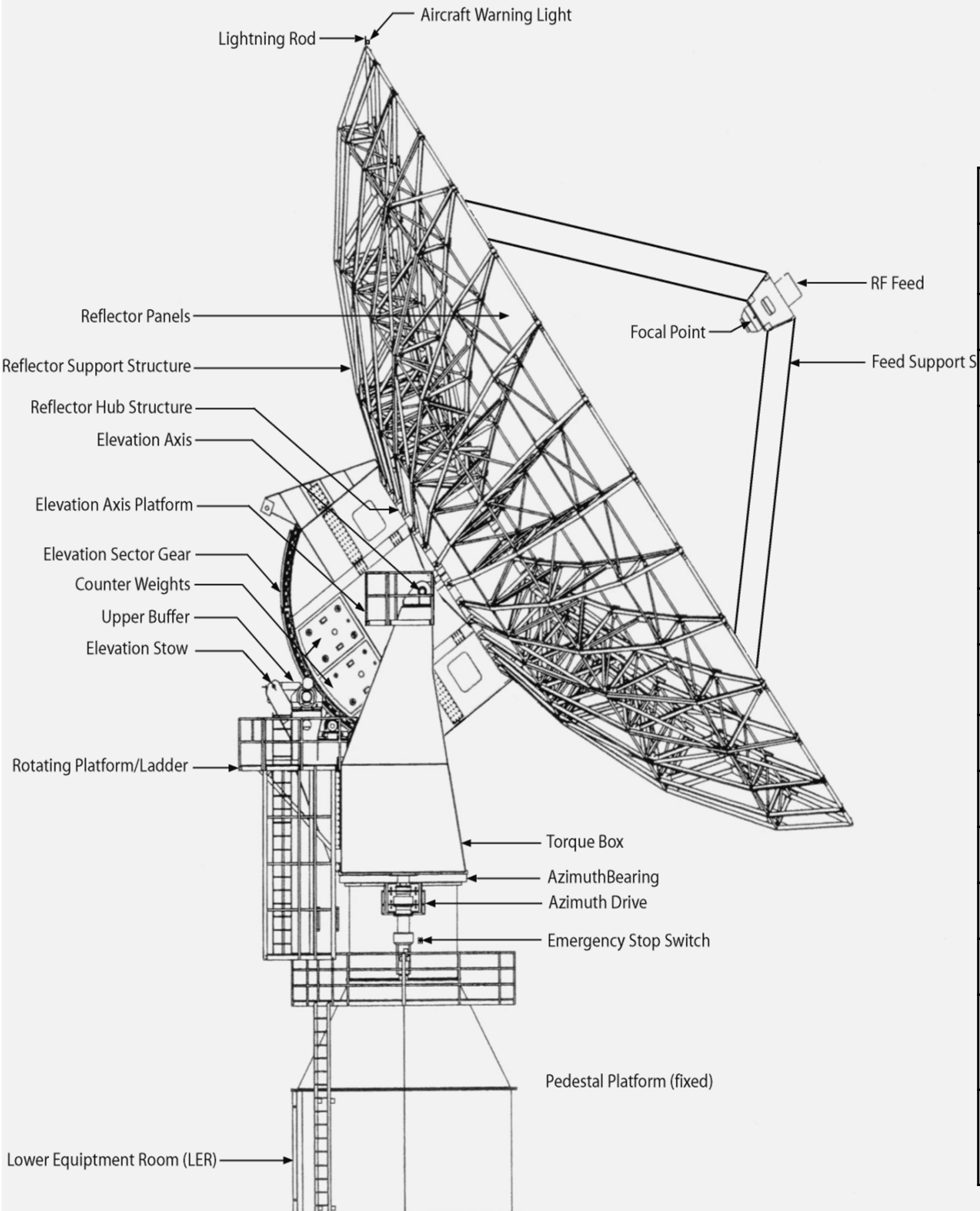
•CubeSats and MicroSats:

- CXBN, KySat-2, Firefly, T-LogoQube, Eagle-2, UniSat-5, EduSat, UniSat-6, SERPENS





21 M Overview

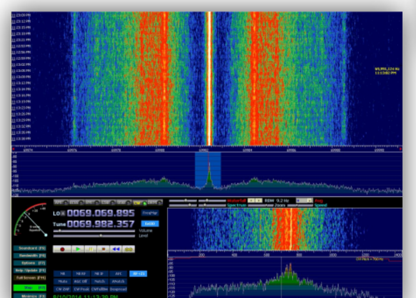


Parameter	Measured Values
Axis Slew Velocity	
Azimuth	**> 3.0 °/sec minimum**
Elevation	**> 1.6 °/sec minimum**
Polarization	**> 0.7 °/sec minimum**
Axis Acceleration	
Azimuth	**1.0 °/sec^2**
Elevation	**0.6 °/sec^2**
Travel Range	
Azimuth	**± 269.8°**
Elevation	**1.0° to 90.3°**
Polarization Range	**± 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 State

Morehead State University
21 M Ground Station

Student Operators in the MSU 21 M LER



ISEE-3 Carrier During Lunar Fly-by Sept 2014

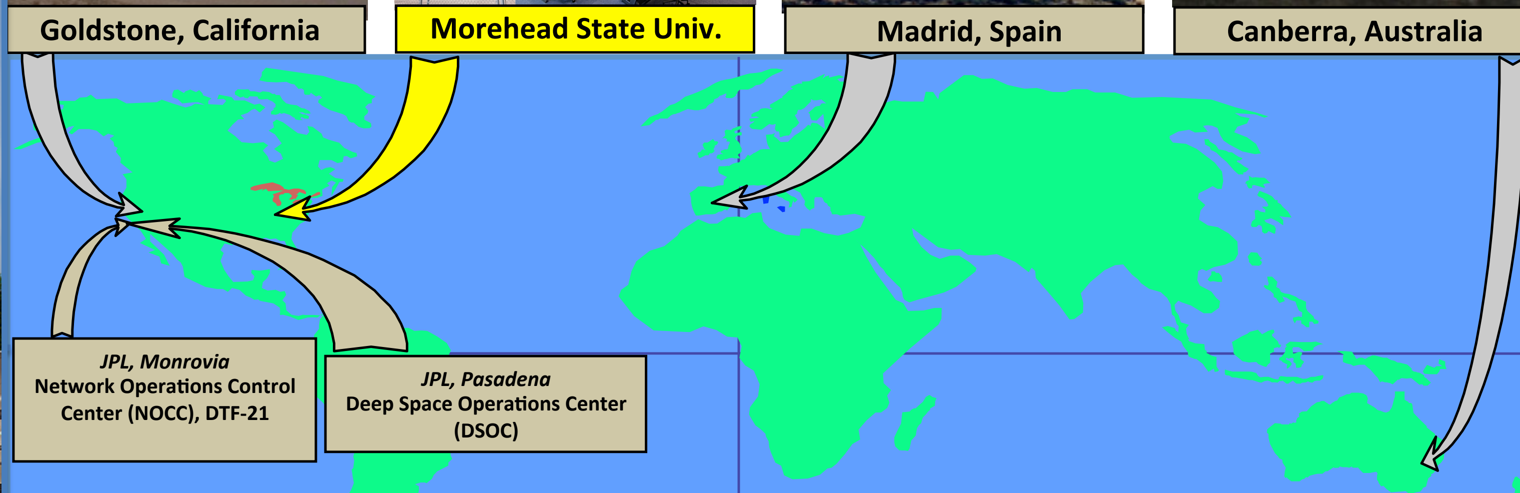
Student Operators in the MSU Mission Ops Center

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

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

Morehead State University 21m Upgrade to DSN Compatibility



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Objective:

- 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.

Benefits:

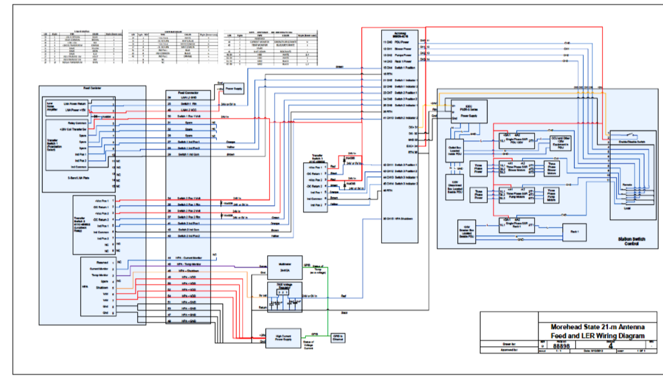
- Serves as a test-case to define a path for other non-NASA ground stations to provide auxiliary deep space navigation and tracking support for small spacecraft missions.
- Develops an operational capability to support EM-1 Cubesat missions in the 2018 timeframe

Technical Approach:

- Develop and implement a strategy to transfer Deep Space Network (DSN) processes and protocols to the MSU 21 m antenna system and to upgrade the antenna hardware and software systems to enable integration into the DSN as an auxiliary station to support small spacecraft missions.
- The project is focused on the implementation of deep space communications, tracking and navigation techniques as well as adoption of CCSDS data interface standards such as the Space-link Extension service.
- Implement systems upgrades, conduct tests/demonstrations, and transition to an operational capability.

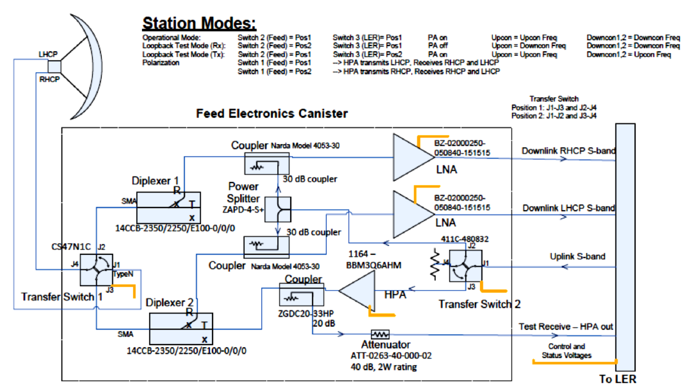
Enabling Interplanetary Smallsat Ground Support- Toward DSN Compatibility

- Is Extremely Challenging:
- Only Three Stations in the World and Some (ESA and JAXA providing Cross Support)



- No Commercial Off-the-Shelf Equipment Exists
  - No Tracking Receivers
  - No Telemetry Receivers
  - No Uplink Transmitters
  - No Data Collection Systems
  - GPS Not Good Enough for a Time Standard
  - Atomic Clocks Not Good Enough for a Time Standard

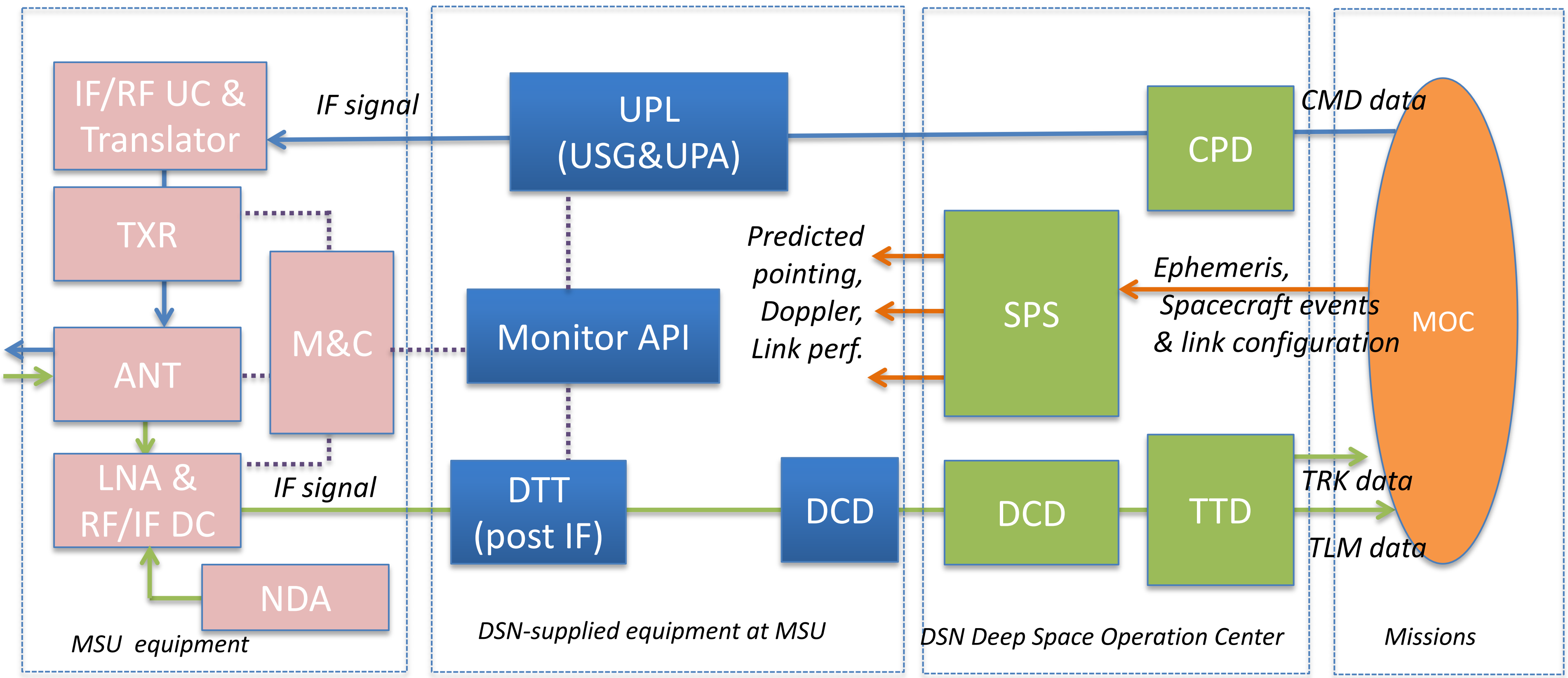
- Existing X-Band Feed Not Adequate
- IF Processors Not Adequate
- All Equipment Must Be Custom Built
- IT and Physical Security Must Be Upgraded



Transfer Switch
Position 1: J1-J3 and J2-J4
Position 2: J1-J2 and J3-J4

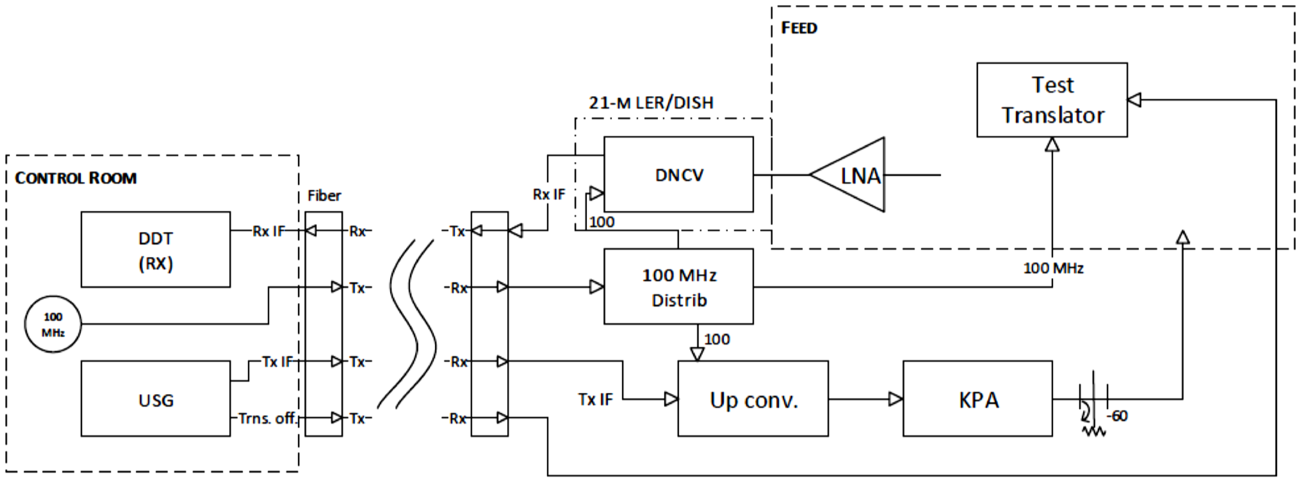
New System Architecture Required

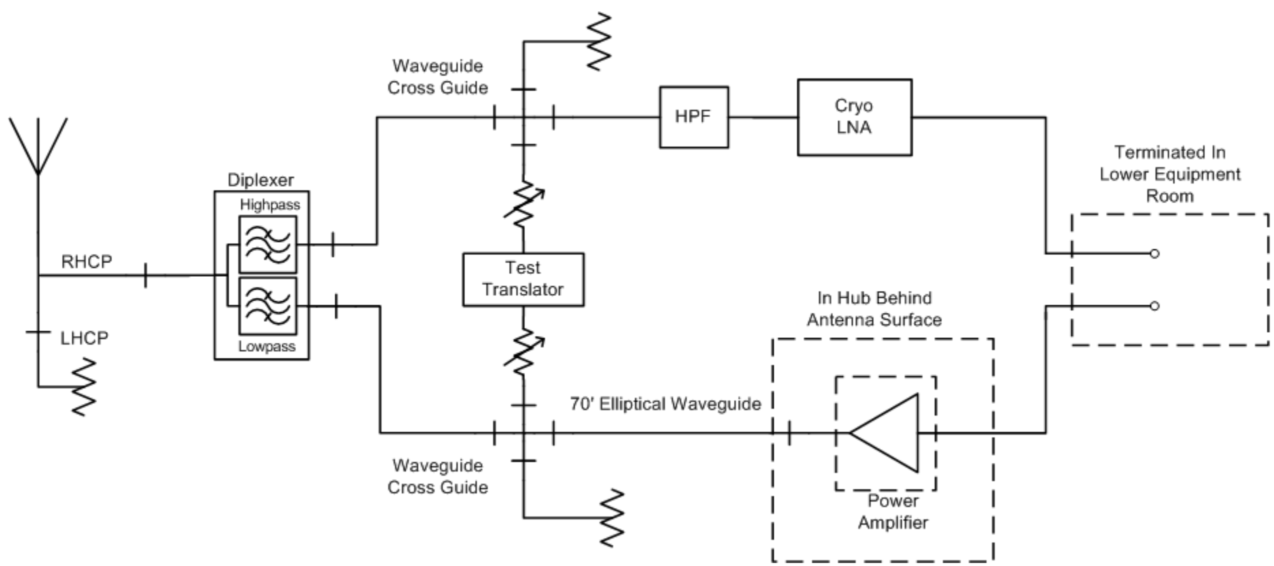
System block diagram



Becoming a DSN-Compatible Station

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

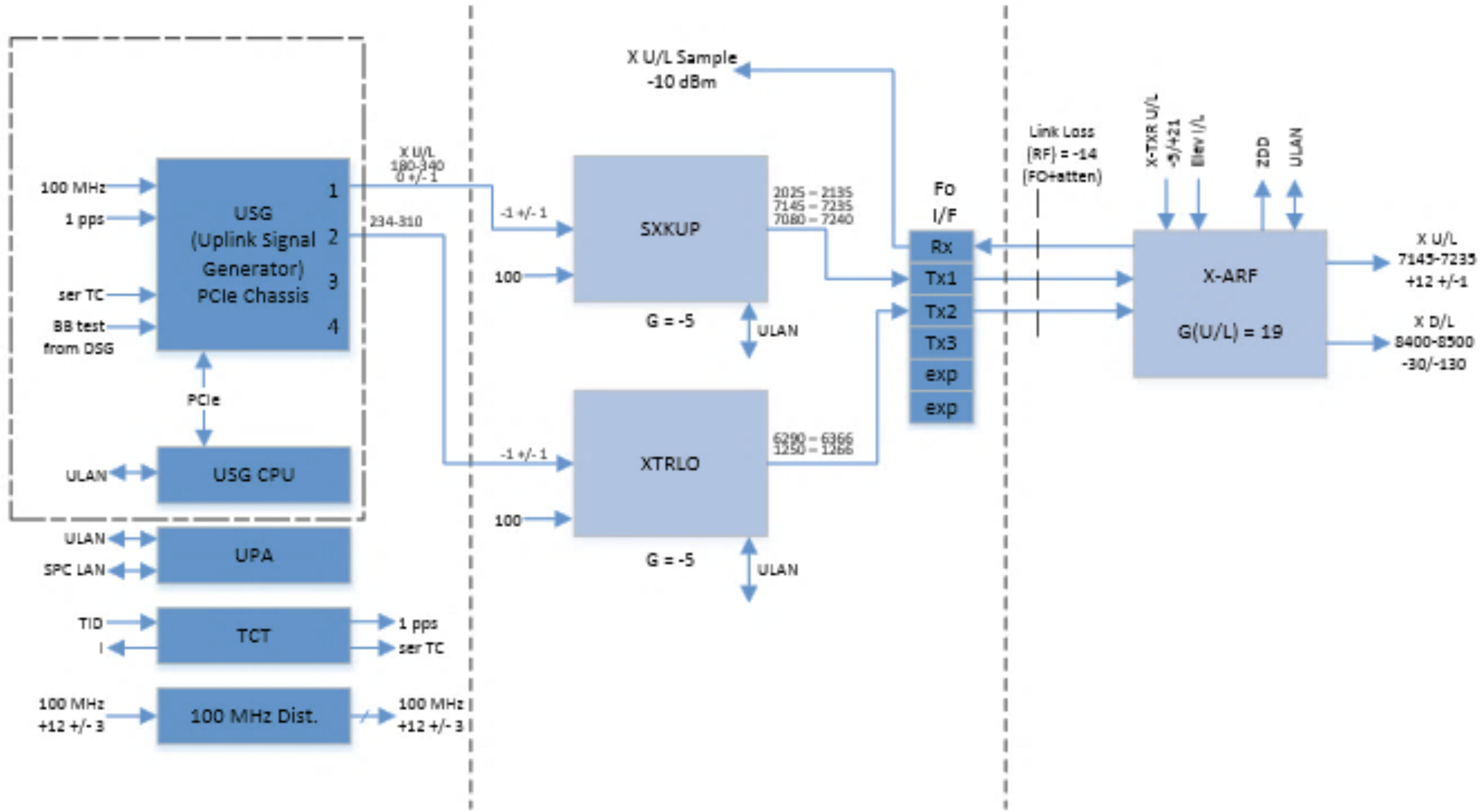




Becoming a DSN-Compatible Station

Command Capabilities Required

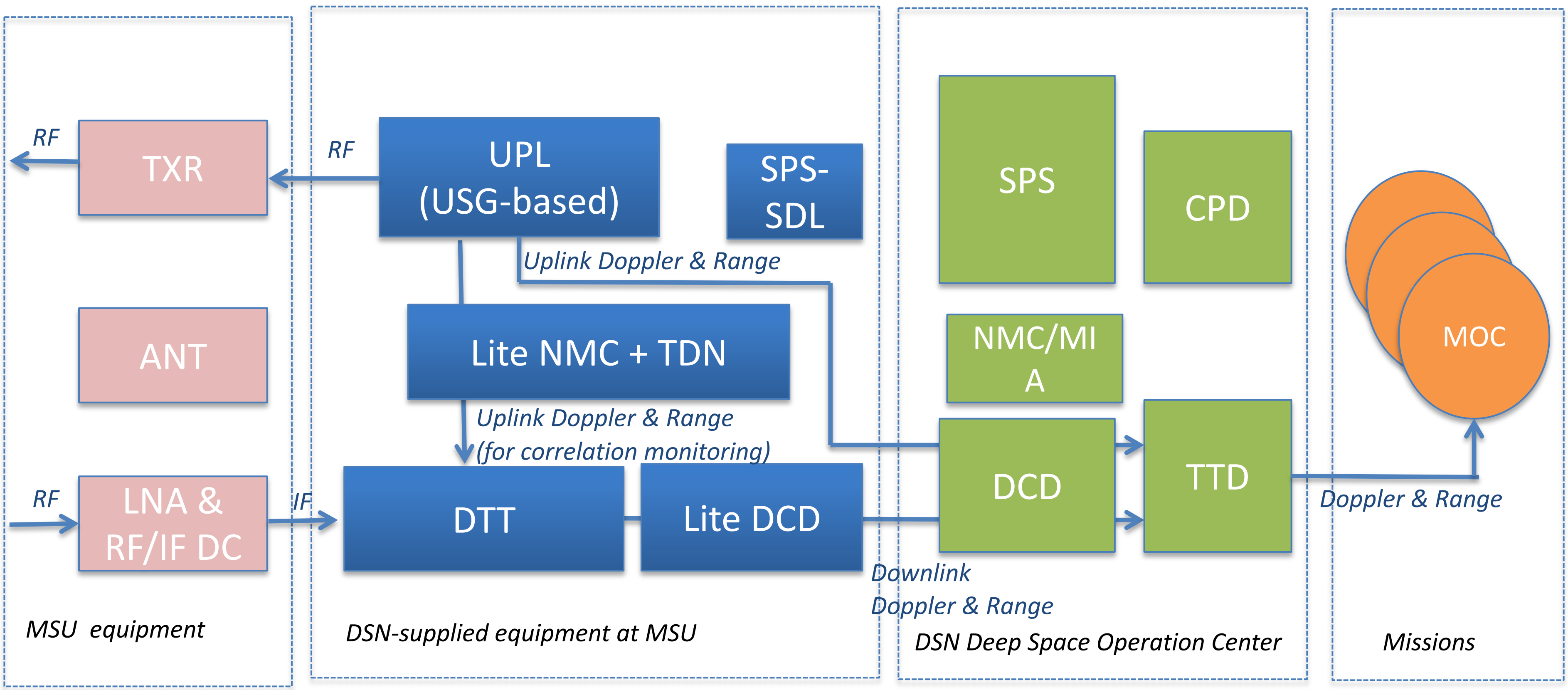
- USG-Based B6E/UPL
- 1 KW Power Amplifier



Tracking Capabilities

Tracking and Ranging Capabilities Required Additional Equipment and Processes

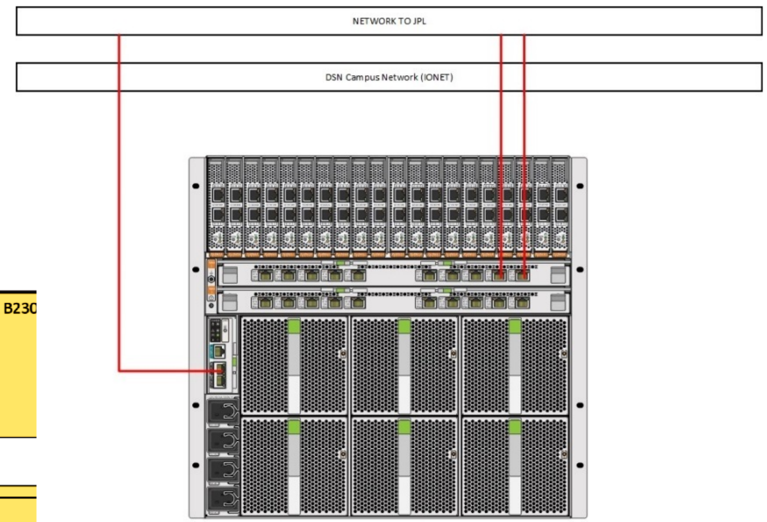
- UPL (Also for Commanding)
- NMC (Very Lite Version)
- DTT (Also for Telemetry Down)



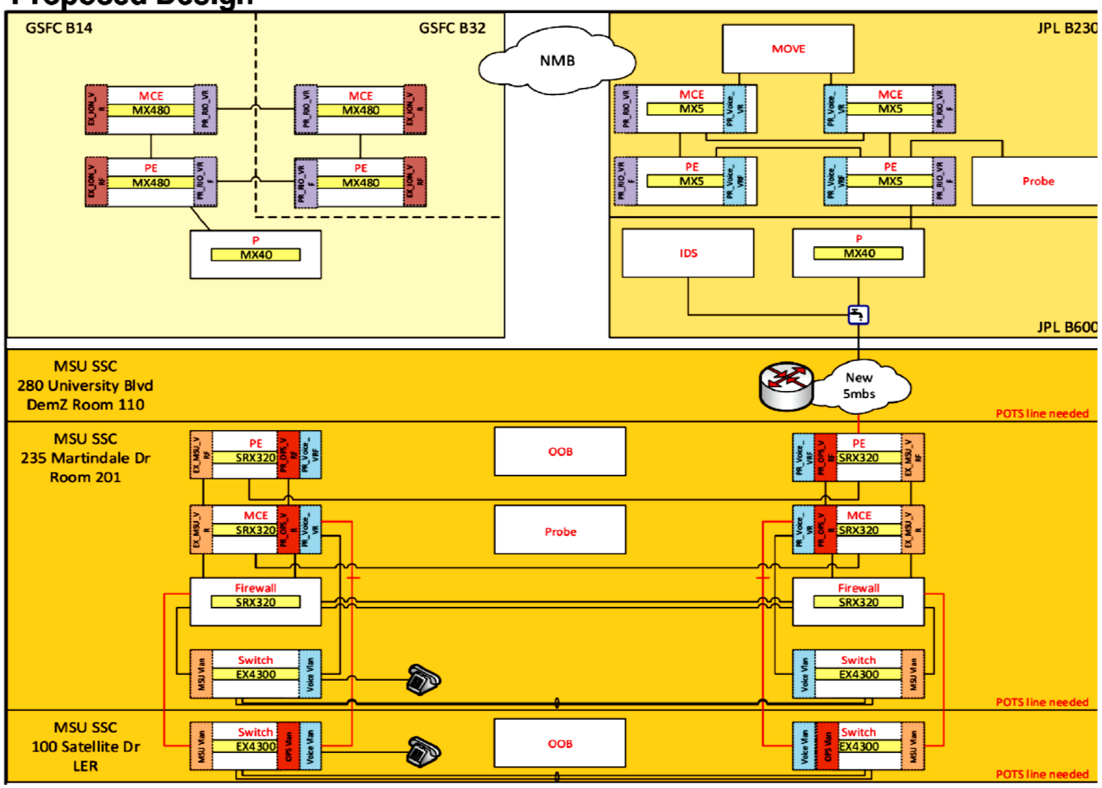
Becoming a DSN Station

High Security IT and Network Connection Required

- Independent Network
- Architecture Designed with JPL and CSO
- Behind NASA Firewall
- Designed by NASA CSO
- Direct Connection to the NASA IoNet



Proposed Design



Becoming a DSN-Compatible Station

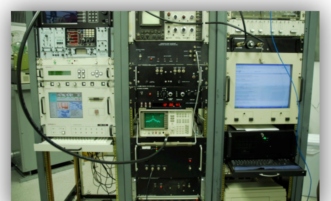
Status of Project

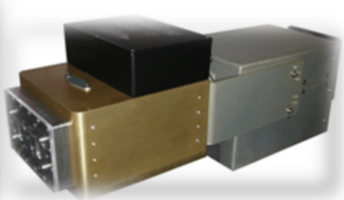
- System Architecture Design Complete
- DSN “Lite” Equipment in Fabrication at MSU and JPL
- Hydrogen MASER in Operation (on semi-permanent Loan from MIT)
- X-Band Feed Designed and in Fabrication
- Cryogenic LNA Under Test
- Antenna Control Systems Tested

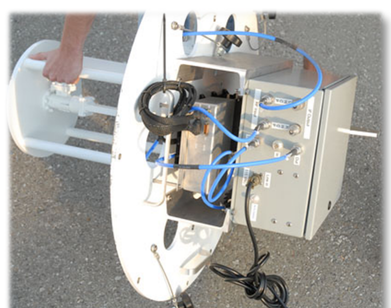
Duration (s)	Detector reading	Measured Allan Deviation	REquired
1	4.50E-013	3.18198E-13	3.30E-13
10	6.00E-014	4.24264E-14	1.00E-13
100	2.00E-014	1.41421E-14	3.30E-14

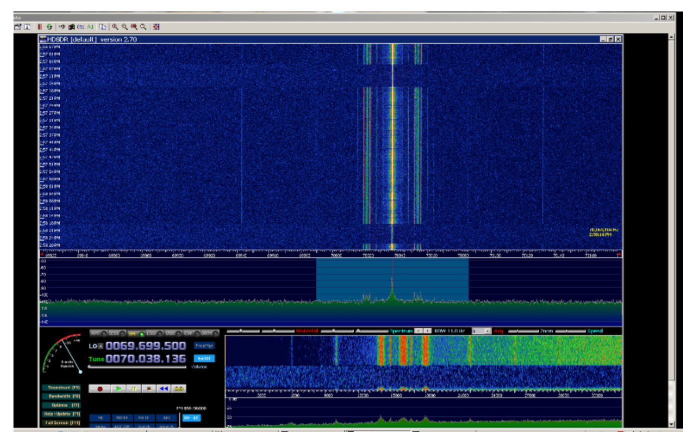
Expected 21m Performance

Performance Measure	Current Values	Post-Upgraded Targets
X-Band Frequency Range	7.0 – 7.8 GHz	7.0 – 8.5 GHz
LNA Temperature	70 K	< 20 K
System Temperature T_{sys}	215 K	<100 K
Antenna Gain	62.0 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 dBi/K	40.4 dBi/K
Time Standard	GPS (40-ns)	Cesium (2ns/day)
SLE Compliant	No	Yes
CCSDS Capable	No	Yes

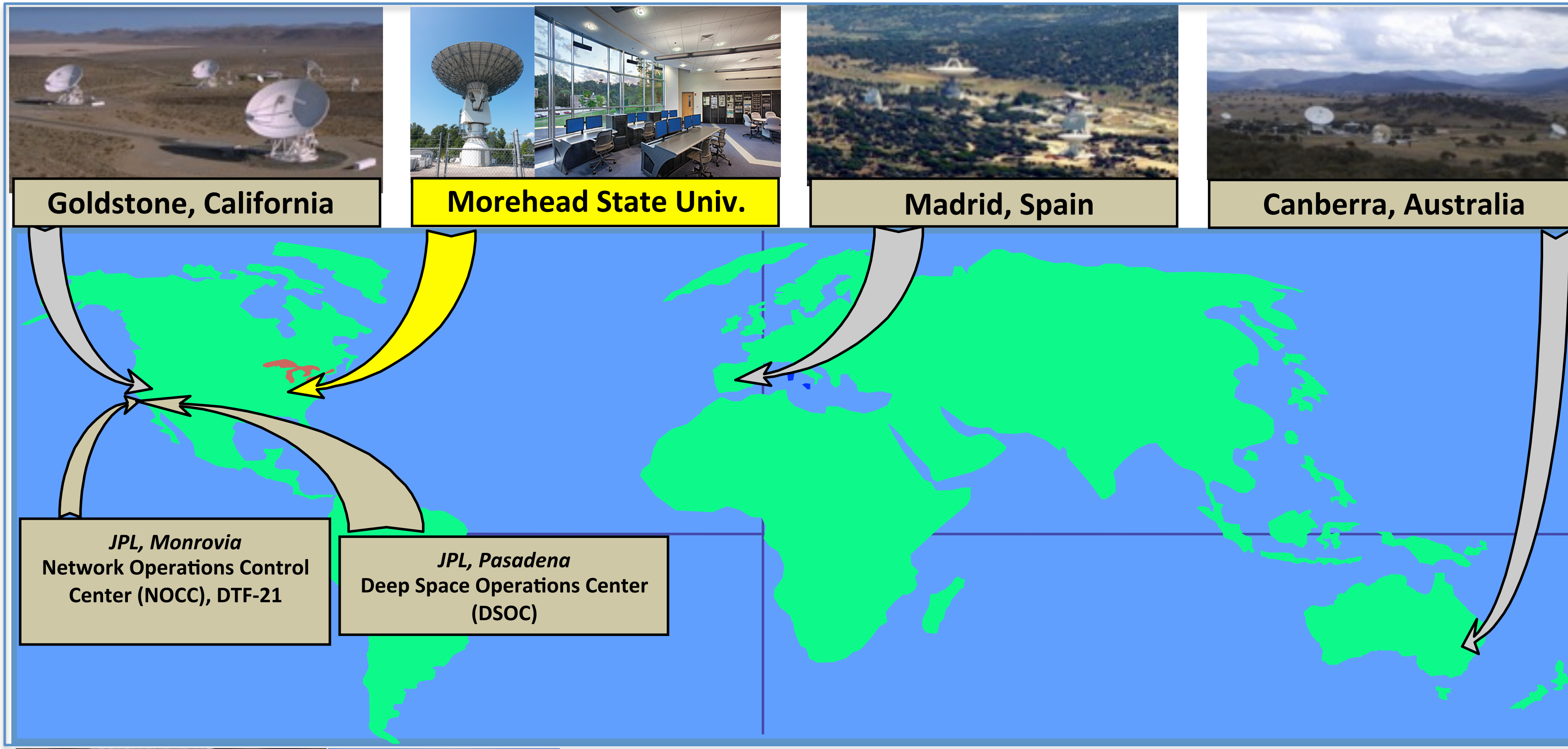








DSS-17


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)

DSS-17 Next Steps

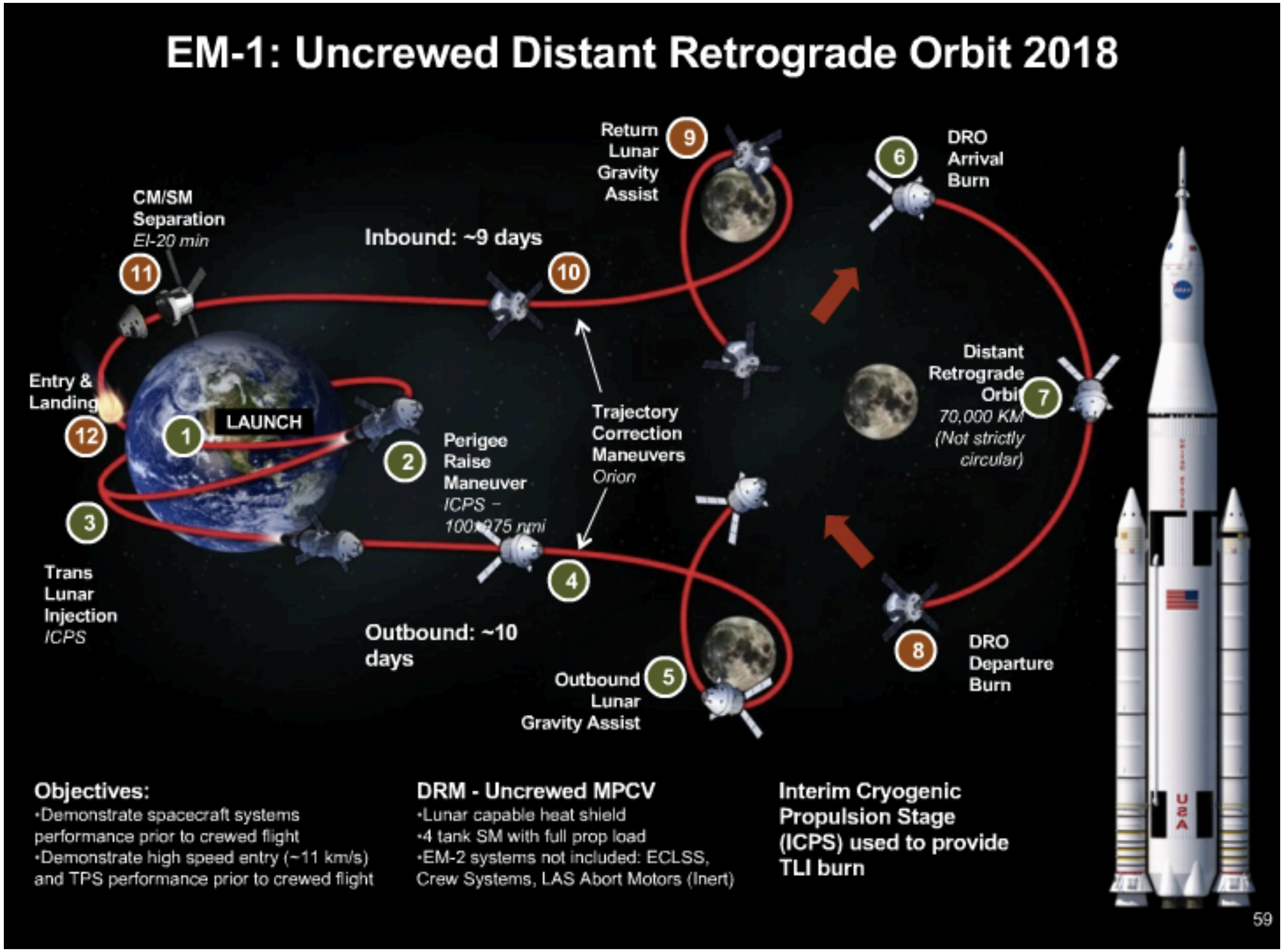
Critical Milestones

ΔSRR	IoNet Connection	Downlink Demo	Uplink Demo	Ranging Demo	ORR	Operational	Mission Ops	Mission Duration	Project Closure
01/15/2016	06/30/2017	12/15/2017	01/15/2018	03/15/2018	06/30/2018	10/15/2018	10/15/2018	EM-1 CubeSats Duration	EM-1 CubeSats Closure

Becoming a DSN Compatible Station

Provide Support for NASA EM-1 CubeSats

Lunar IceCube
Lunar Flashlight
LunaH Map
NEA Scout
Biosentinel

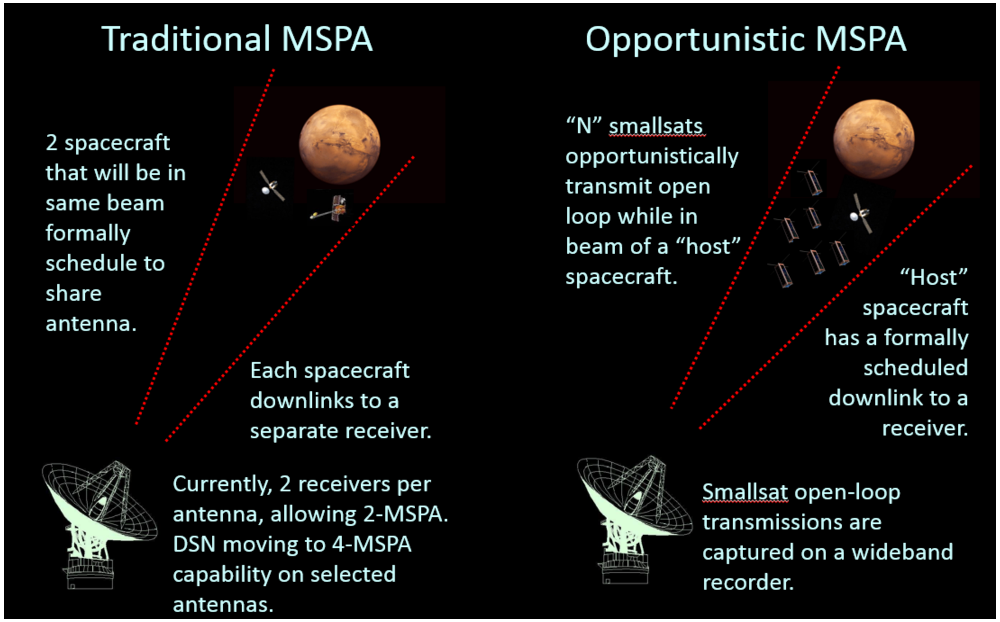


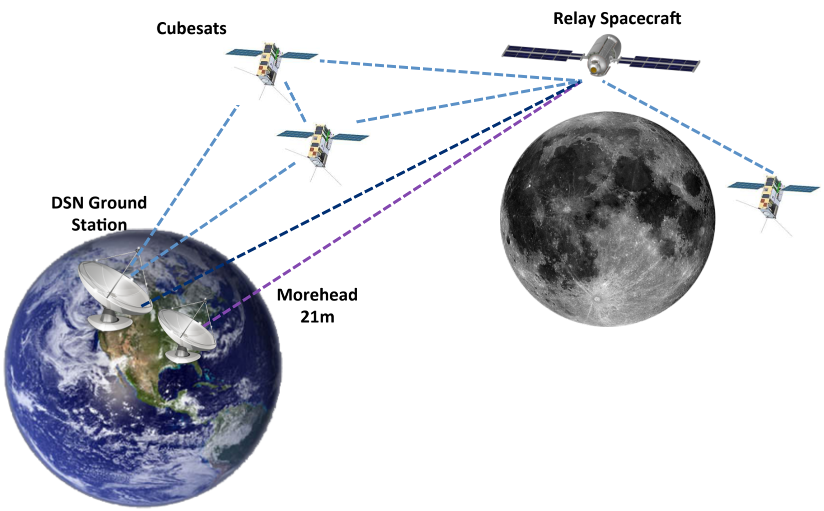
Future of DSS-17

Possible Extensions and Adaptations

- Multiple Spacecraft per Aperture (MSPA) and Opportunistic MSPA
- Delay/Disruption Tolerant Networking

Support for Space Networking





Questions?