University and Government Partnership in Morehead Ground System Development for Space Mission Operations

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Outline

- How partnership is formed
- Background information
- System architecture
- Operational concept
- System performance
- System validation incrementally
- What makes it works

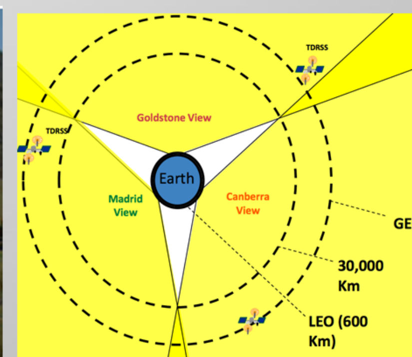
Partnership

- Connection between MSU and DSN
  - via Lunar IceCube/Exploration Mission 1

Lunar IceCube

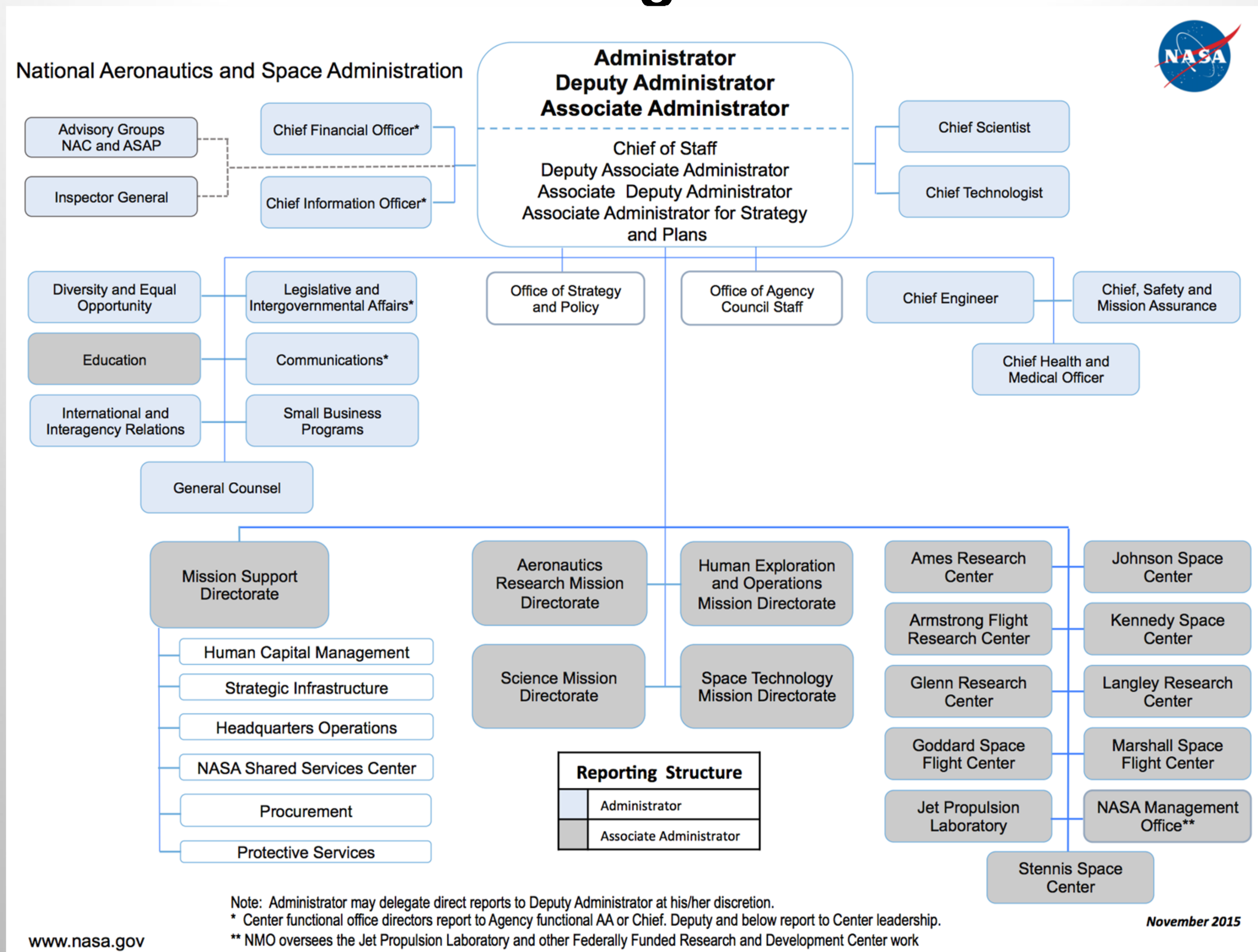
EM-1

21-m MSU antenna



DSN antennas (34-m/70-m)

NASA Programs



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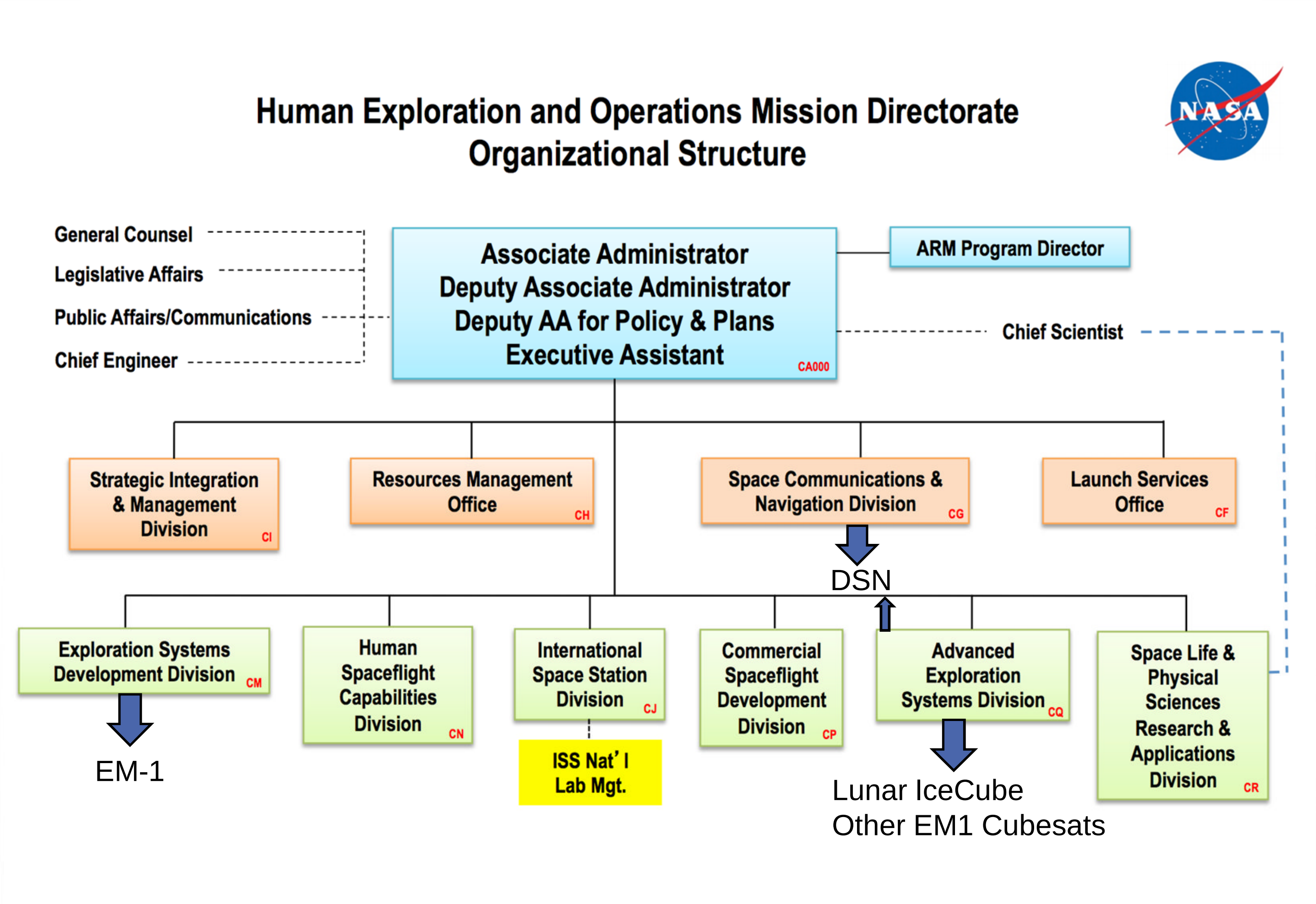
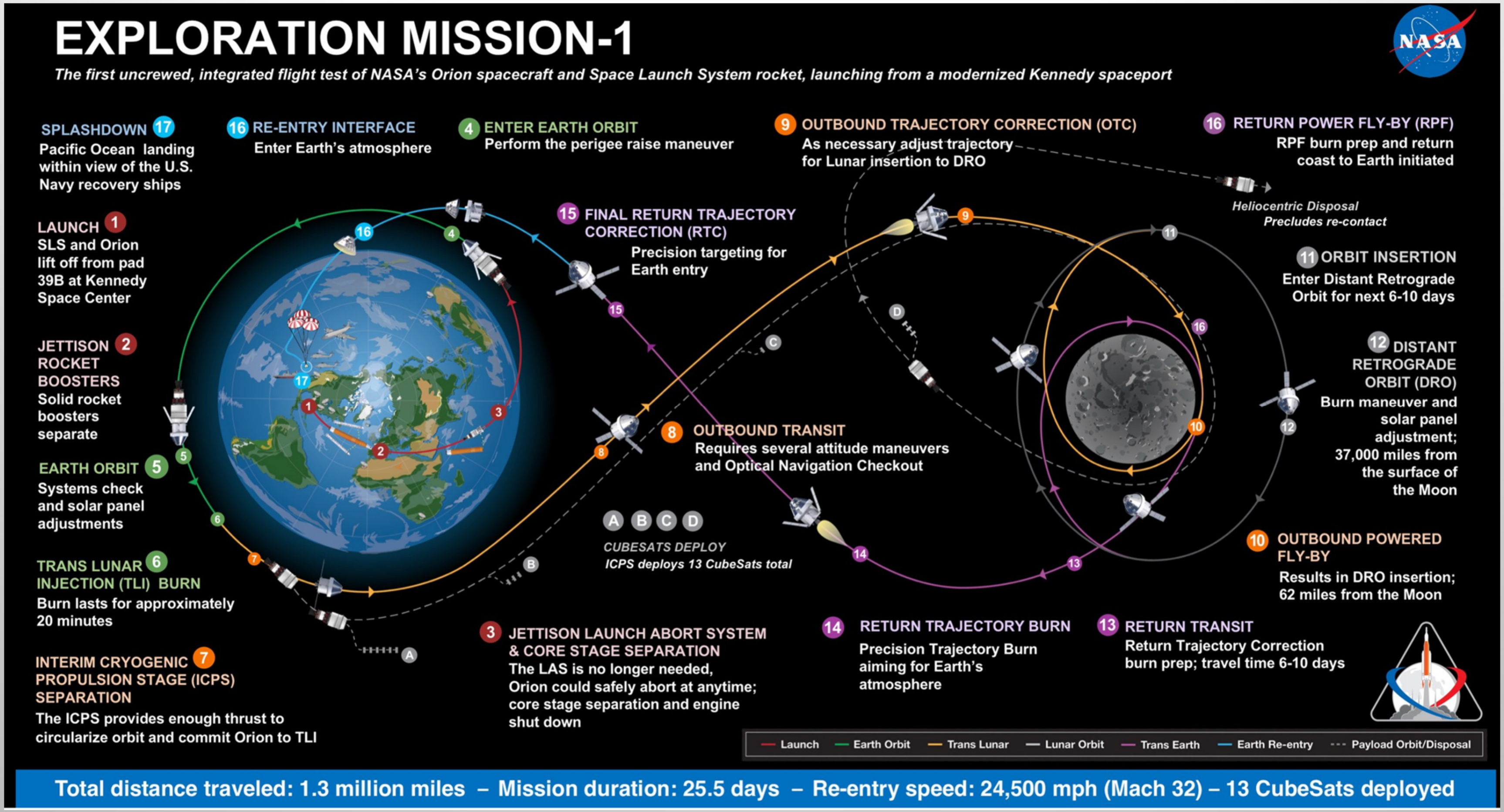
Human Exploration & Operations Mission Directorate

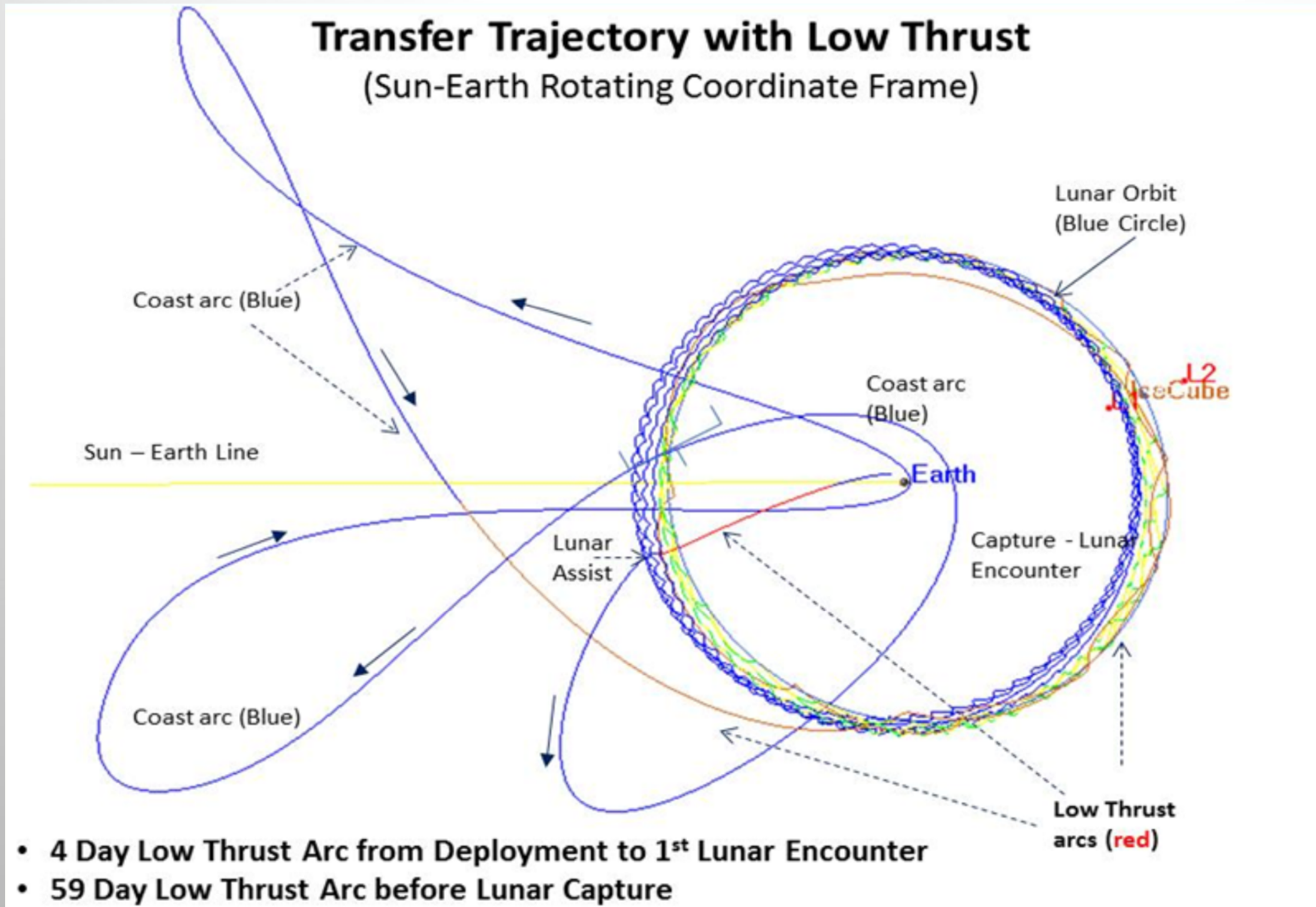


EM-1



https://en.wikipedia.org/wiki/Exploration_Mission-1#/media/File:EM1-Mission-Map_Update.jpg

Lunar IceCube



Morehead State University and Goddard are partnering to create the Lunar IceCube mission shown in this artist's rendition.
Credits: Morehead State University

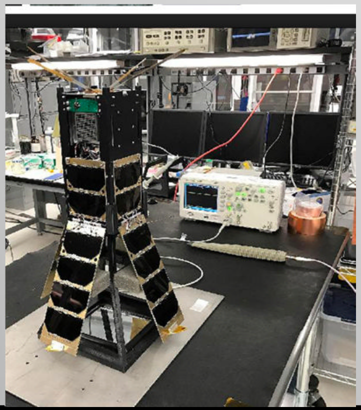
The Busek Company is developing Lunar IceCube's low-thrust electric propulsion system, the RF Ion BIT-3 thruster.
Credits: Busek Company

https://www.nasa.gov/feature/goddard/lunar-icecube-to-take-on-big-mission-from-small-package

Background on MSU Capabilities

The Morehead State University Ground Station

- Relatively quiet RFI environment in eastern Kentucky
- 21-m ground station operational since 2006
  - Few in the US large enough for deep space tracking
  - Built under university funding
- Experienced RF and telecom engineers and scientists
- Experienced staff/students in mission operations
  - LRO, ISEE-3, Planet Lab, KySpace, ASTERIA



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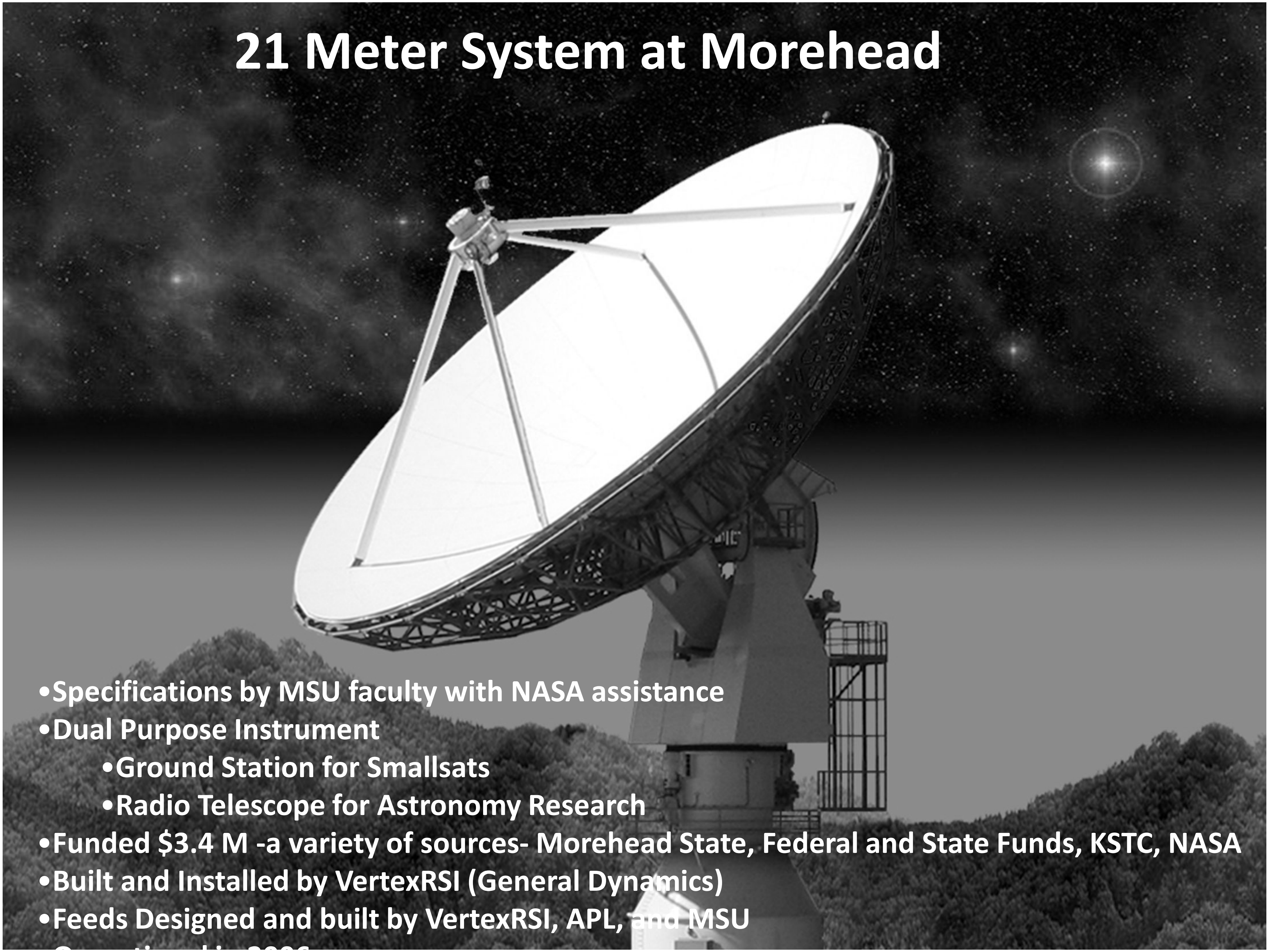
21 Meter System at Morehead

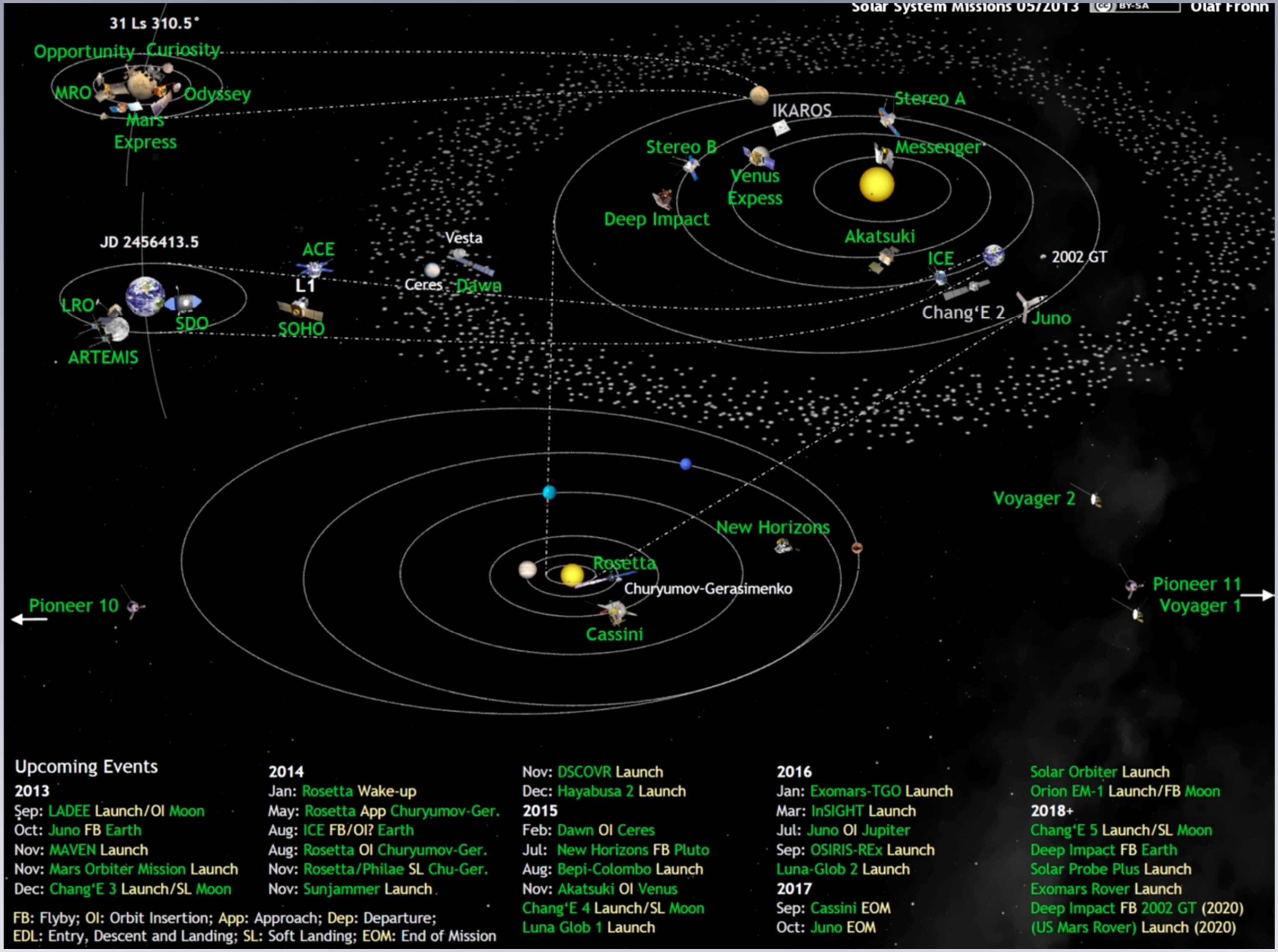


- Specifications by MSU faculty with NASA assistance
- Dual Purpose Instrument
  - Ground Station for Smallsats
  - Radio Telescope for Astronomy Research
- Funded $3.4 M -a variety of sources- Morehead State, Federal and State Funds, KSTC, NASA
- Built and Installed by VertexRSI (General Dynamics)
- Feeds Designed and built by VertexRSI, APL, and MSU

Space Projects Create Opportunities for Students

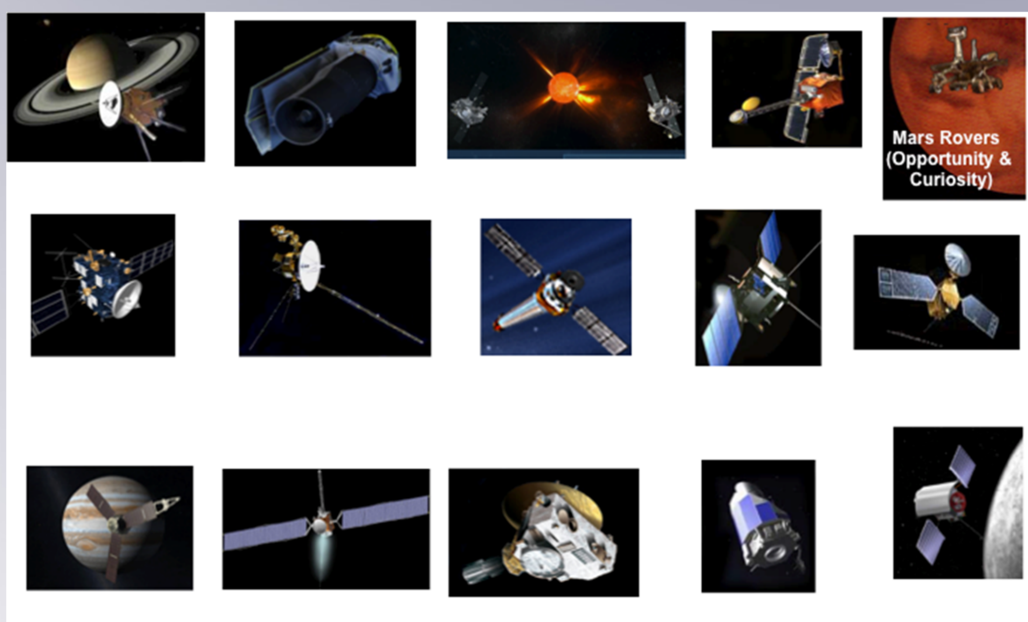
- **Undergraduate Research Experiences**
- **Instrumentation Experience**
- **Engineering Design**
- **Observational Astrophysics Research**
- **Ground Ops (TT&C)**
- **Project Management Experience**
- **Systems-level Engineering Experience**

Exploring spacecraft throughout Solar System



Deep Space Communications Challenges

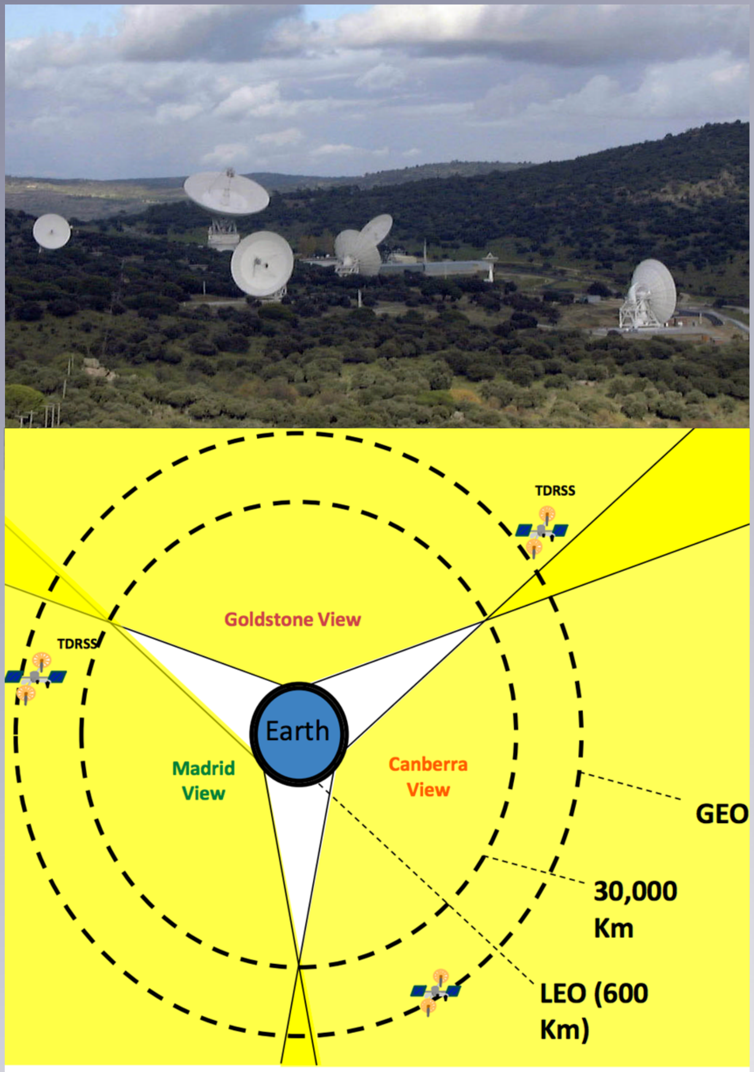
- Deep space - Interplanetary communications
  - Extended to the edge of Solar System
    - Voyager spacecraft ~130 AU
- Difference between deep space and LEO communications
  - LEO: ~1000 km
  - Deep space: ~400,000 km (0.003 AU) – 130 AU



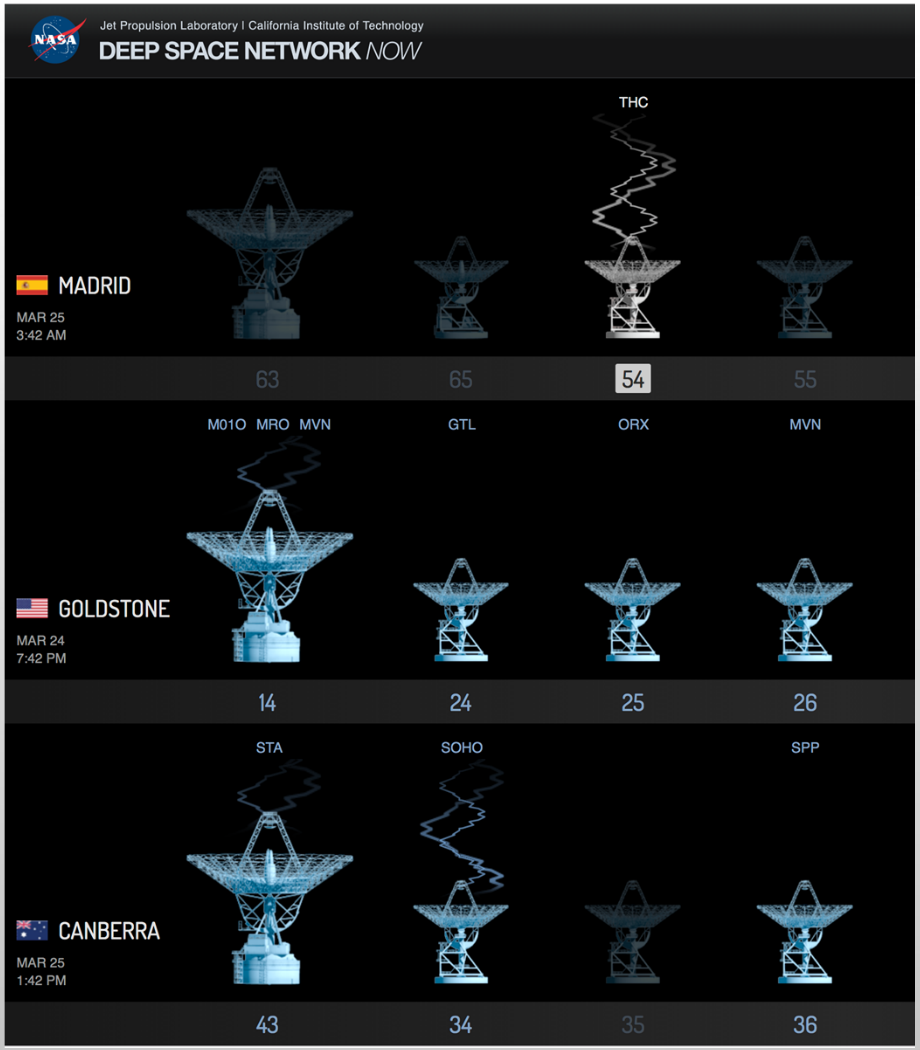
Distance	Power reduction
Moon	1.5E+05
Larange points	2.3E+06
Mars	2.3E+10
Jupiter	6.1E+11
Saturn	2.0E+12
Pluto	2.0E+13
Heliosphere	3.3E+14

NASA Deep Space Network

- Provide global coverage at 3 sites around the globe
    - One 70m and three-four 34m antennas at each site
- Support missions from HEO to edge of solar system
- Optimize high performance for deep space communications
    - Compared to typical 10m commercial tracking station
        - Lower noise (3x-6x)
        - Higher gain (10x – 50x)

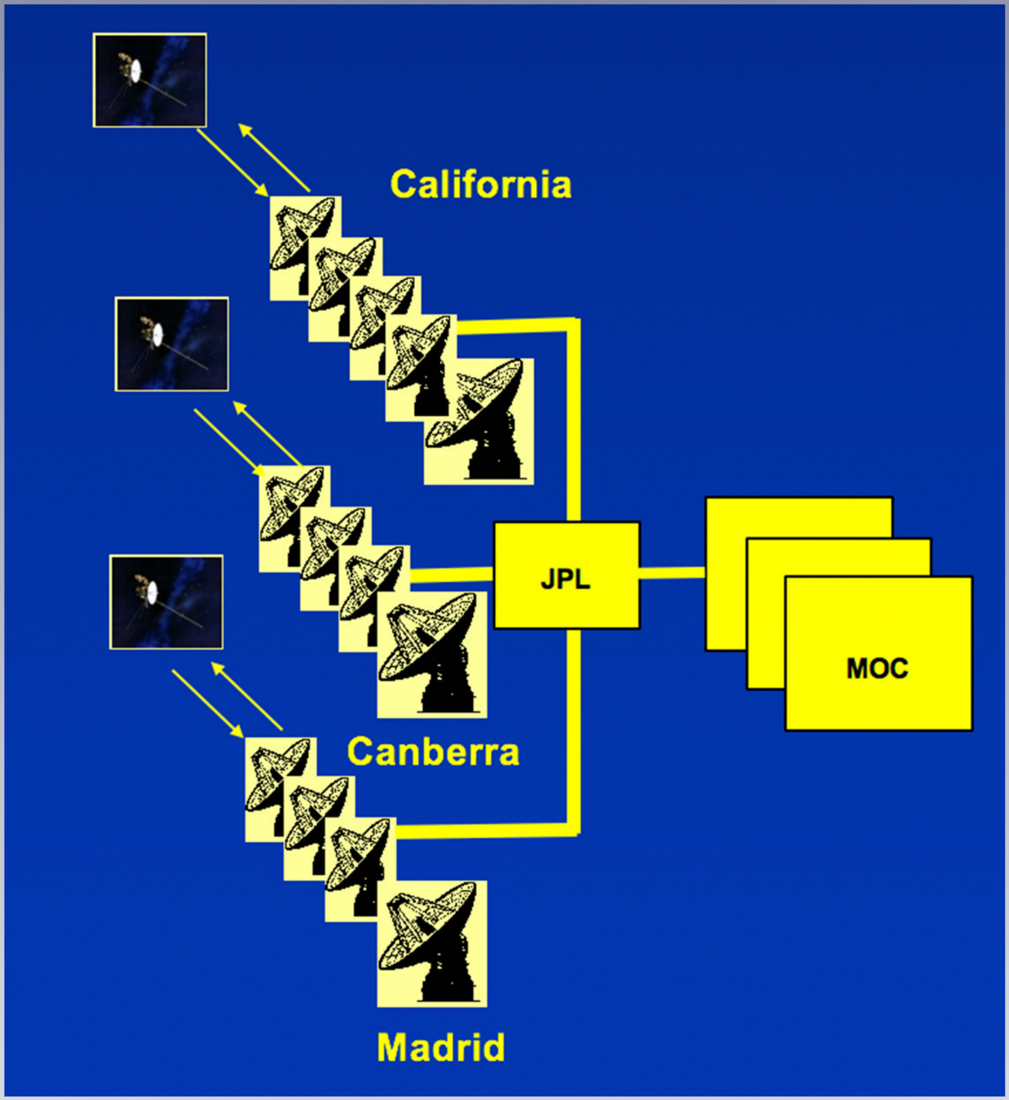


NASA Deep Space Network



https://eyes.nasa.gov/dsn/dsn.html

NASA Deep Space Network Architecture



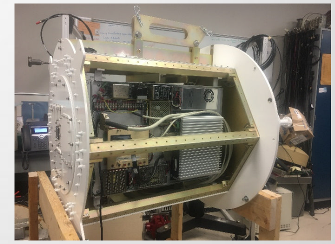
Transition from LEO to Lunar Orbit

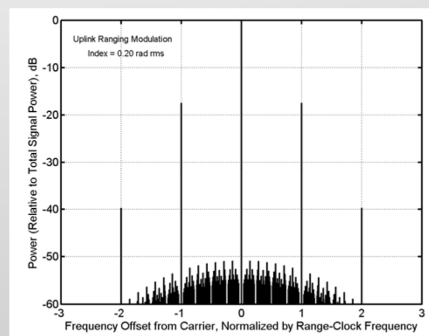
- Distance: 1000km >> 400,000 km
  - Signal power reduction proportional to distance squared

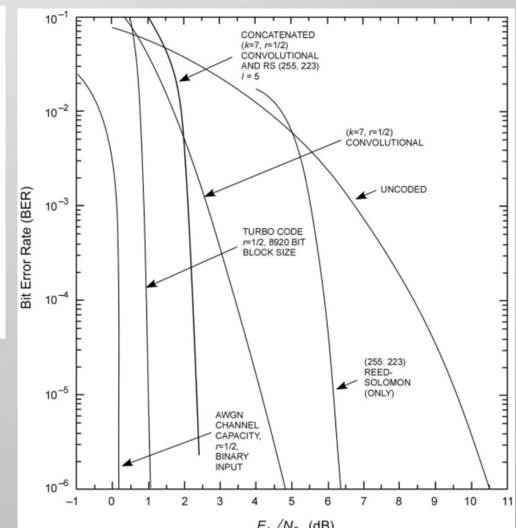
- Require better link performance
  - Higher frequency: UHF (400 MHz) >> X-band (8 GHz)
  - Lower system noise temperature: 300K >> 100K
  - Higher perform FEC: RS >> Turbo

Implementation Objectives

- Upgrade MSU 21-m antenna to support Lunar IceCube and other EM-1 Cubesats
  - X-band operations
    - Deep space and near Earth
  - Full TTC functions
    - 3 kW power amplifier
  - Deep space specialization
    - Highly efficient FEC (e.g., turbo code, LDPC)
    - Pseudo-noise/sequential ranging
  - Interoperability with DSN and CCSDS compliant

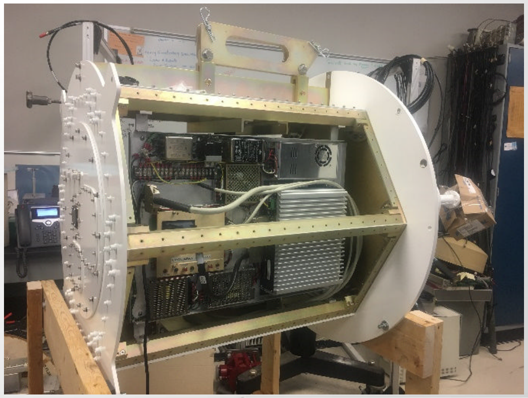






System Attributes

- Minimize implementation cost
  - Leverage on DSN-developed equipment
    - Specialized deep space signal processing for telemetry decoding and ranging
    - Adapt the already-built equipment to only necessary functions
  - Implement the rest with COTS equipment
    - New and surplus components
- Adopt common user interfaces
  - Data delivery at JPL, as with other DSN antennas
- Create opportunity for student-developed projects
  - Station monitor & control
  - System Integration and testing
  - Equipment operations



X-band Feed and LNA

DSN Equipment

Hydrogen MASER

System Architecture

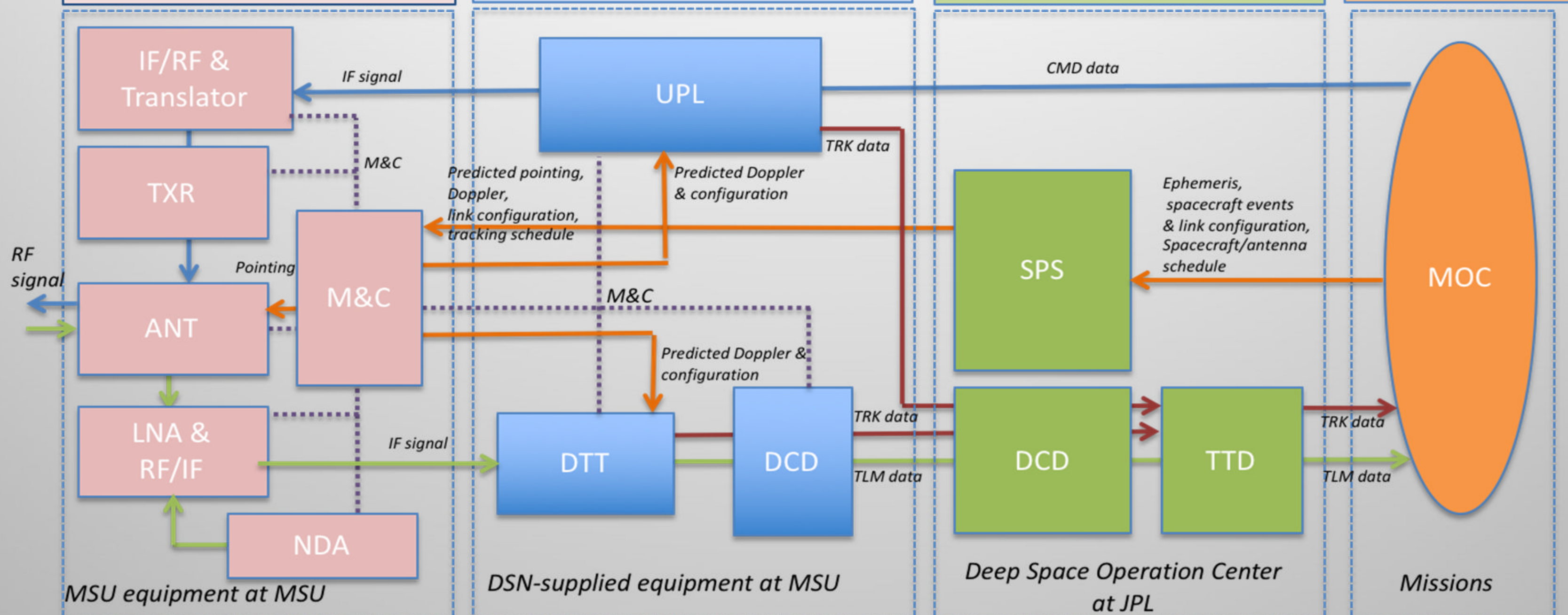
- Geographically distributed
- Common interface to missions that use DSN & MSU

- 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



Operation Concept

Few weeks before track

- Antenna scheduling via DSN
  - Transition to operational multi-mission support
    - Schedule conflict resolution

Few days before track

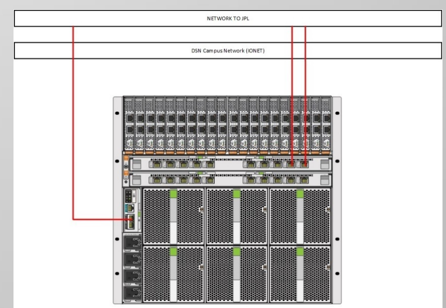
- Prediction data generation by DSN
  - Data retrieved by MSU

Real-time during track

- Data delivery via DSN interface points
  - Command, telemetry, radiometric data
  - WAN Connection to JPL via NASA mission backbone
    - IT security clearance by NASA

Real-time & Post track

- System monitor control and diagnostics
  - Locally controlled and archived
  - Voice network communications with MOS team



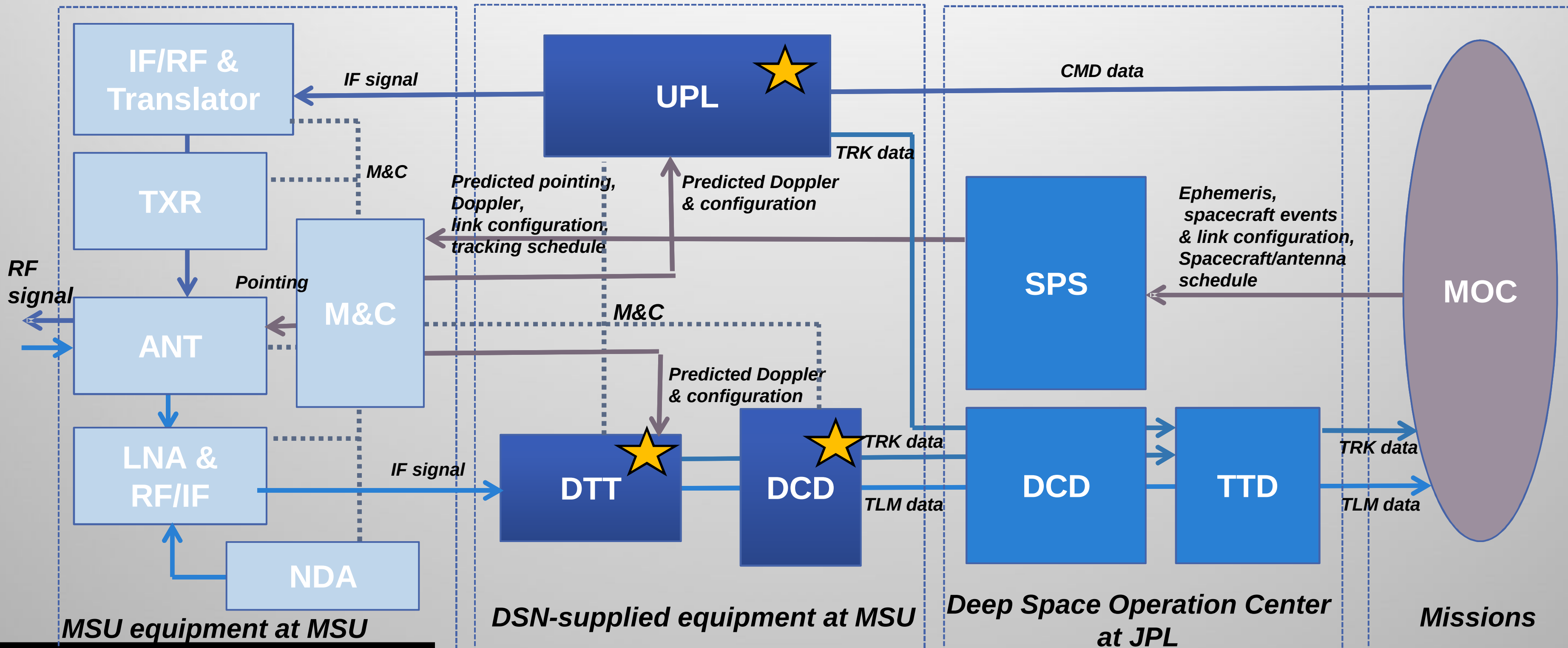
System Performance

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
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

System Validation, using Internal Test Signal

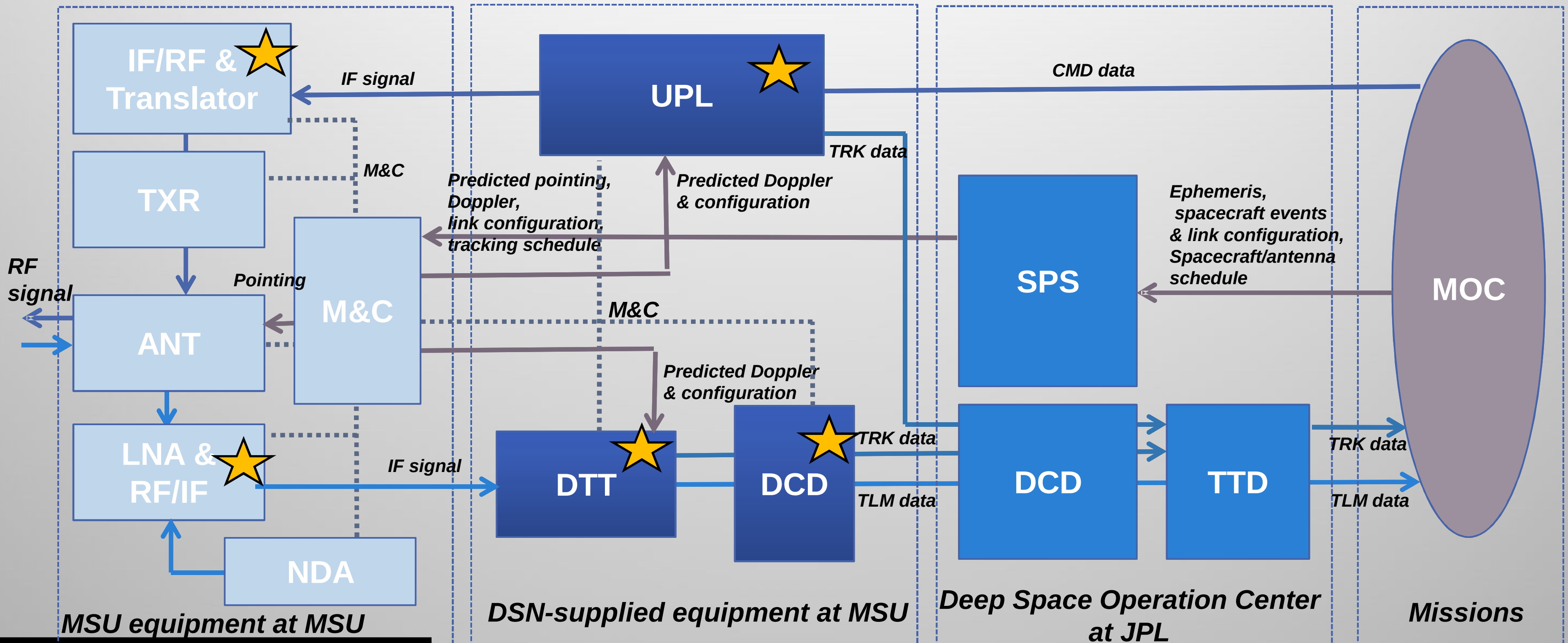
First Deployment (9/2017)

- Installed DSN equipment
- Conducted loopback tests between uplink and downlink equipment
    - Validated key TTC processing



System Validation, using Internal Test Signal with E2E flow

First Deployment (9/2017)
- Installed DSN equipment
- Conducted loopback tests between uplink and downlink equipment
  - Validated key TTC processing



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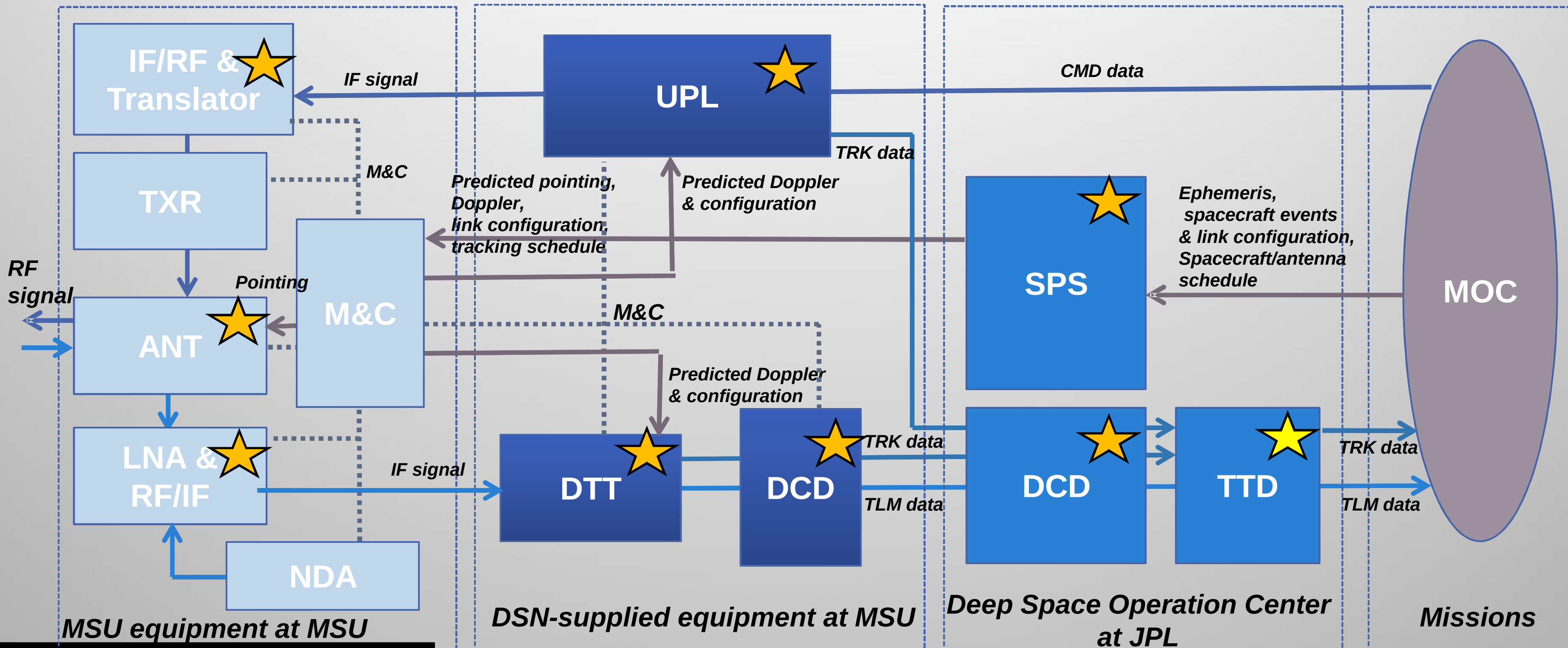
System Validation, with spacecraft

Second Deployment (5/2018)

- Additionally installed antenna feed, LNA, RF/IF downconversion
- Conducted testing with spacecraft downlink
    - MarCO, Osiris Rex, Maven, Hayabusa2



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Shadow Tracking Spacecraft

Currently in progress

- Expected 10-dB G/T difference between DSN and MSU antennas
  - Antenna Gain: MSU (21m)= 0.4* DSN (34m)
  - System Noise Temperature: MSU(100K) = 4*DSN(25K)

- Shadow DSN tracking of missions with sufficient SNR (>10 dB link margin)
  - Hayabusa2, Osiris and Maven

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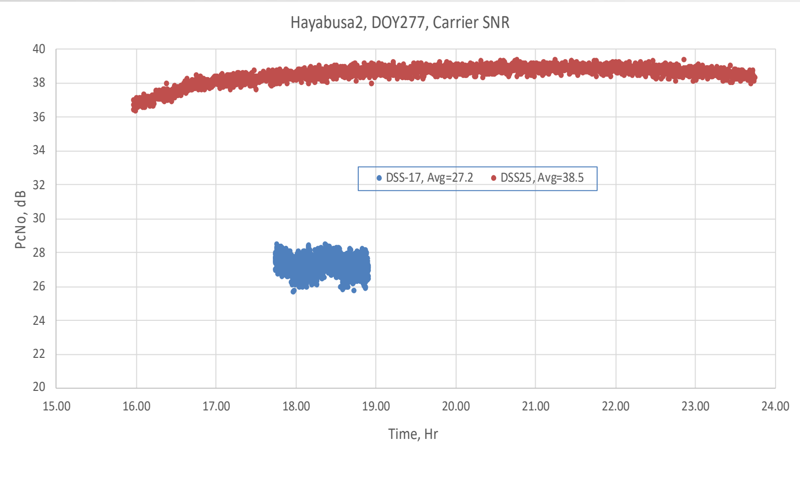
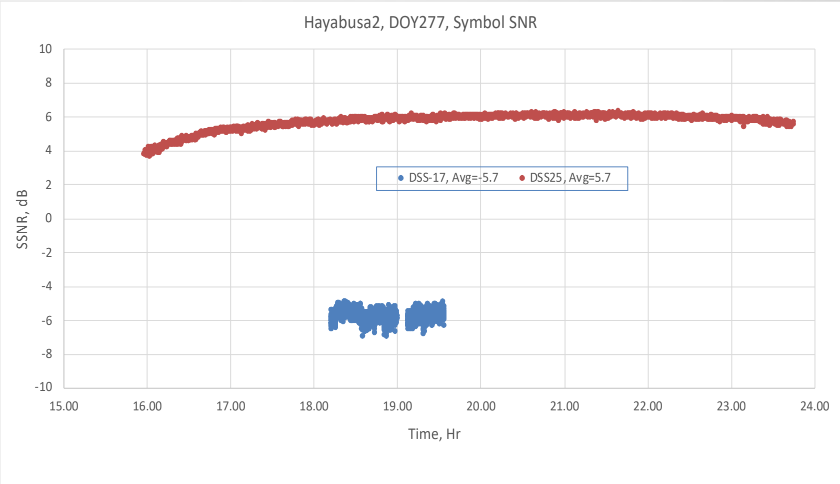
Results with Hayabusa2

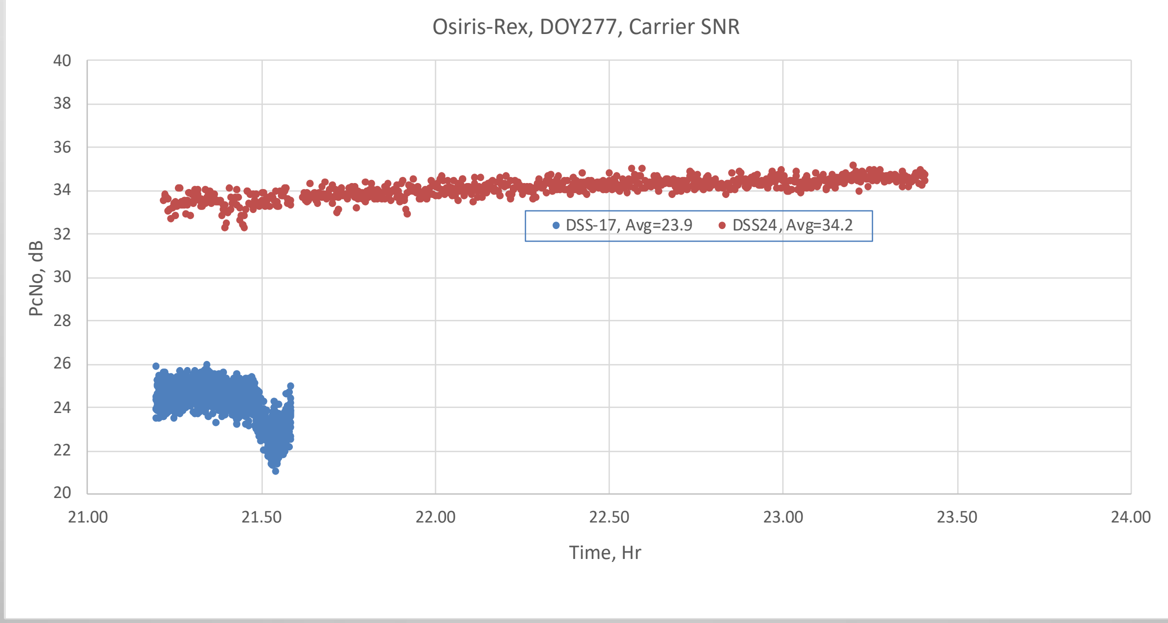
- Expected signal strong enough for carrier, subcarrier and symbol locks
  - Not strong enough for telemetry decoded
- Observed 11.3 dB difference between MSU and DSN antennas, based on carrier SNR and symbol SNR
  - Within bounds of 10 dB expectation





Results with Osiris

- Expected signal strong enough for carrier, subcarrier and symbol locks
  - Insufficient bit SNR (Eb/No) for telemetry frame decoding
- Observed
  - Achieved carrier lock, but not subcarrier nor symbol locks
    - 10.3 dB difference between MSU and DSN antennas
    - Consistent with expectation



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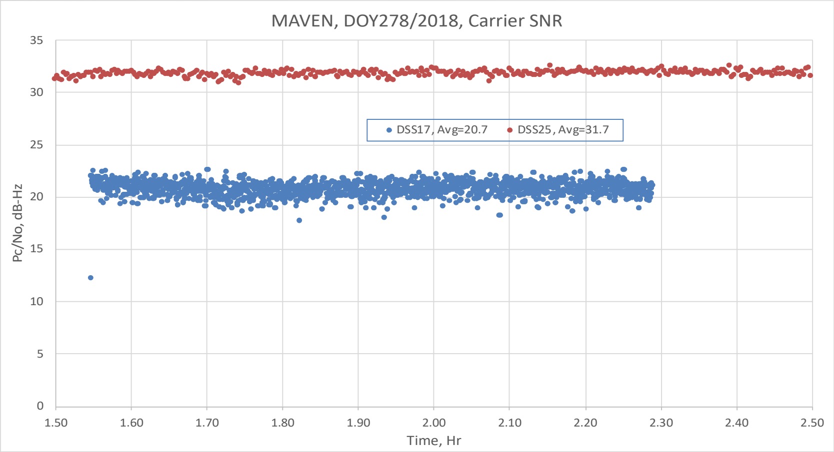
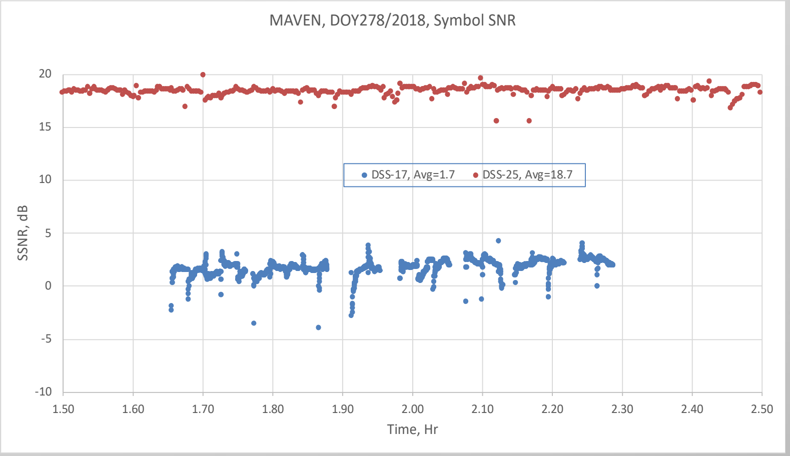
Results with MAVEN

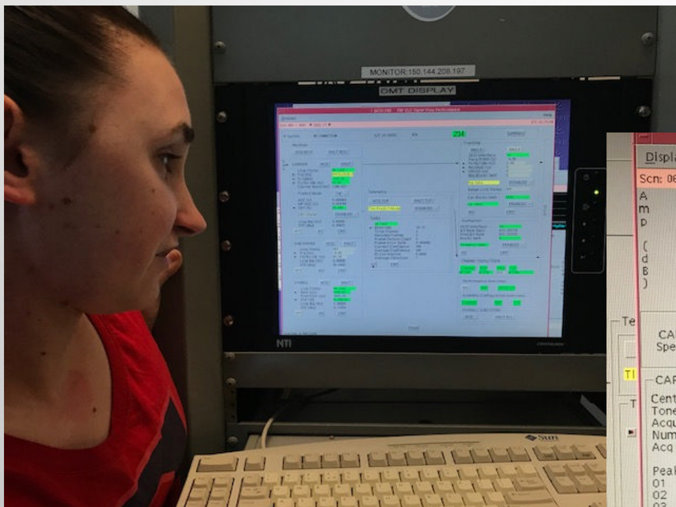
- Expected signal strong enough for carrier, subcarrier and symbol locks and telemetry decoded
- Observed
  - Carrier lock - 11.0 dB difference between MSU and DSN antennas
  - Subcarrier lock – Not achieved
  - Symbol lock – 17 dB difference, due to lack of subcarrier lock
  - Telemetry decode – Not achieved, due to lack of subcarrier lock

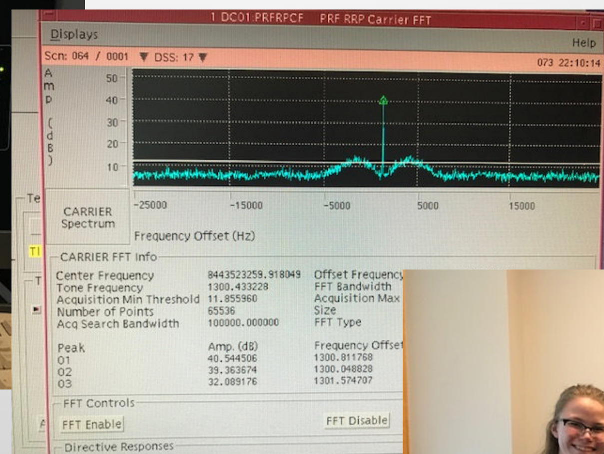




Recent results with Osiris & Stereo

- Success!!!
  - Fully decoded telemetry data





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What makes it works

- AES programmatic support
- Staff & students expertise
  - Previous Cubesat operations
  - Core engineering staff with RF experiences
  - Small focused team
- Ownership of system
  - Shared responsibilities
- Available funding support