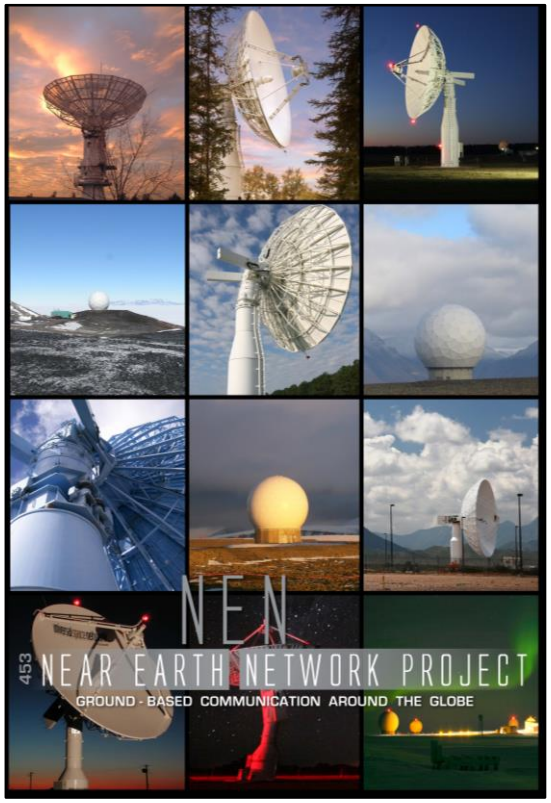
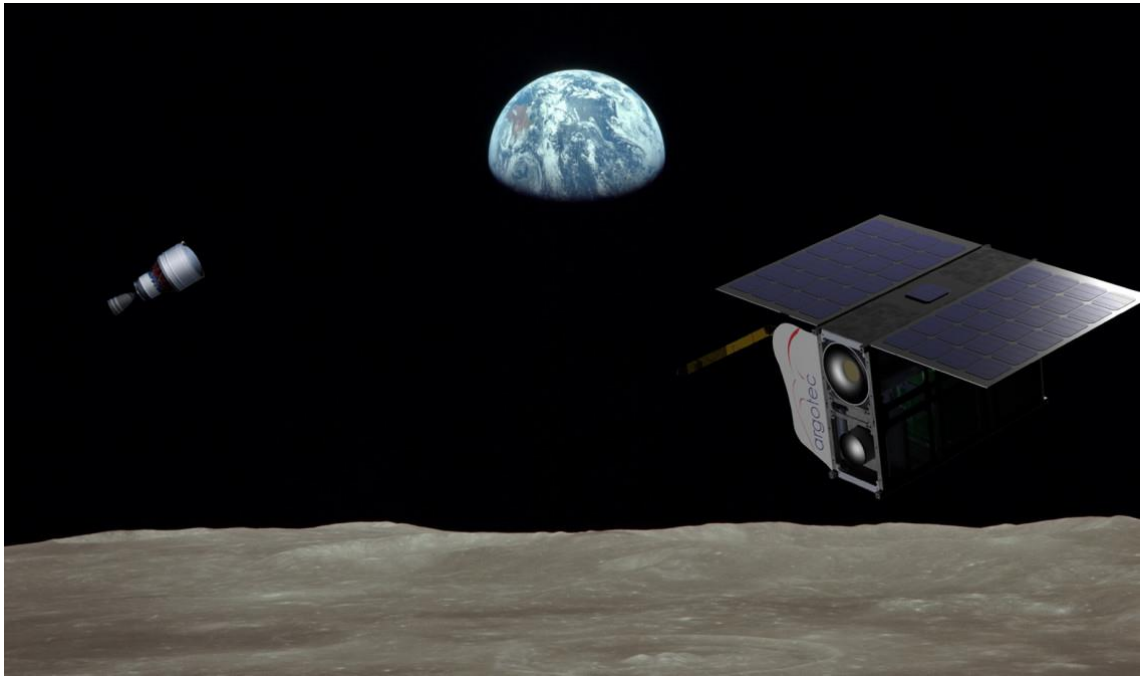
# NASA Near Earth Network (NEN) Support for Lunar and L1/L2 CubeSats

Scott Schaire

April 2017




EXPLORATION AND SPACE COMMUNICATIONS PROJECTS DIVISION
NASA GODDARD SPACE FLIGHT CENTER




**The European Space Agency (ESA) ArgoMoon, is one of 13 CubeSats to be launched with the Space Launch System (SLS) for the Exploration Mission 1 (EM-1) scheduled for February 2019.**

# Agenda

- Overview
- Upcoming CubeSat Support for NEN
- NEN Lunar/L1/L2 CubeSat Support
- NEN Evolution
- Conclusion

# Near Earth Network Overview

- **As shown on the following slide, the NASA Near Earth Network (NEN) is composed of stations distributed throughout the world**
- **NEN services**
  - NASA-owned and operated ground stations
  - Partner agencies (e.g., National Oceanic and Atmospheric Administration (NOAA) Command and Data Acquisition (CDA))
  - Commercial ground station providers (e.g., Kongsberg Satellite Services (KSAT), Swedish Space Corporation (SSC) and its subsidiaries, Deutsches Zentrum für Luft- und Raumfahrt (DLR))
- **The NEN supports orbits in the Near Earth region from Earth to 2 million kilometers**
  - Communication services are provided for various low-Earth orbits (LEO), geosynchronous orbits (GEO), highly elliptical orbits (HEO), LaGrange orbits, lunar and suborbital, and launch trajectories

# THE NEAR EARTH NETWORK PROJECT

**NOAA:** National Oceanic and Atmospheric Administration
**FCDAS:** Fairbanks Command & Data Acquisition Station
**KSAT:** Kongsberg Satellite Services
**DLR:** Deutschen Zentrums für Luft- und Raumfahrt (German Space Agency)
**SANSA:** South African National Space Agency
**SSC:** Swedish Space Corporation

### White Sands Complex
White Sands, New Mexico
WS1 (18m), WSC VHF 1 (Quad Helix), WSC VHF 2 (Quad Helix)

### Alaska Satellite Facility
Fairbanks, Alaska
AS1 (11m), AS3 (11m)

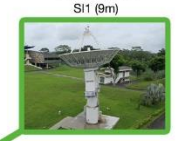
### NOAA: FCDAS/Gilmore
Gilmore Creek, Alaska
GLA (13m), GLB (13m), GLC (13m)

### SSC: North Pole Satellite Station
North Pole, Alaska
USAK01 (13m), USAK03 (5m), USAK04 (7m), USAK05 (11m)

### KSAT: Svalbard Satellite Station
Svalbard, Norway
SG1 (11m), SG2 (11m), SG3 (13m)

### SSC: Esrange Satellite Station
Kiruna, Sweden
KU1S (13m), KU2S (13m)

### KSAT: Seletar Earth Station
Singapore
SI1 (9m)



### South Point Hawaii Satellite Station
South Point, Hawaii
USHI01 (13m), USHI02 (13m)

### DLR: Weilheim Ground Station Complex
Weilheim, Germany
WU1S (15m), WU2S (15m)

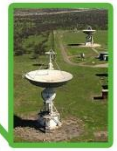
### Launch Communications Stations
Florida and Bermuda
Tel-4 (6m) (Air Force), JDMTA (15m) (Air Force), BDA (7m) (Research Range Services)

### SSC: Australia Satellite Station
Dongara, Australia
AUWA01 (13m), AUWA02 (7m)

### Wallops Ground Station
Wallops, Virginia
WG1 (11m), WG2 (5m), WGS VHF 1 (Quad Helix), WGS VHF 2 (Quad Helix)

### Launch Communications Stations
Florida
KUS (6m), PDL (6m)

### SSC: Santiago Satellite Station
Santiago, Chile
SA1 (9m), SA2 (13m)



### SANSA: Hartebeesthoek Station
Hartebeesthoek, Africa
HBK02 (12m), HBK05 (10m)

### KSAT: Troll Satellite Station
Troll, Antarctica
TR2 (7m), TR3 (7m)

### McMurdo Station
McMurdo, Antarctica
MG1 (10m)

**NASA**
**Commercial**
**Partner**

JUNE 2016

## ABOUT:

### Scheduling

The Near Earth Network (NEN) is comprised of tracking stations distributed throughout the world in locations as shown on this map.

The NEN provides Telemetry, Tracking, and Commanding (TT&C) and ranging services to an extensive and diverse customer base, which includes approximately 40 missions - from the high-rate Earth Observing System (EOS) missions such as Aqua, Aura, SMAP, AIM, EO-1, GPM, GRACE, DSCOVR, and OCO-2, to Small Explorer (SMEX) missions including IRIS and HESSI.

### Pre-Mission Testing

It also provides TT&C services for an average of about 150 passes per day. Commercial stations such as Kongsberg Satellite (KSAT) Svalbard Ground Station (SGS) in Norway and SSC/USN Alaska Ground Station in North Pole, Alaska provide almost half of the 150 passes per day collectively.

## QUICK FACTS:

### Pre-Mission Planning & Analysis

- Space communications at Goddard and Wallops goes back to the beginning days of NASA.
- GSFC software and hardware engineers in the 80's and 90's conceived and were responsible for what is today the NASA NEN 10 meter and 11 meter ground stations at Wallops, Alaska, and McMurdo.
- Today, GSFC is fortunate to continue its leadership role for the Near Earth Network.
- The Near Earth Network (NEN) supports about 40 NASA and other agency satellites.

### Global Network Monitoring, Control & Coordination

- The NEN collects about 1,500,000,000,000 science bytes/day, which is the equivalent of 100 two-hour DVD quality movies/day.
- Today the NEN average data rate is 100 million bits/sec and the highest satellite downlink rate is 300 million bits/sec from the Lunar Reconnaissance Orbiter.
- Future satellite data rates are expected to be an order of magnitude greater, four thousand million bits/sec.
- The NEN constantly strives to reduce costs, improve the reliability of data transmission, and meet new and evolving mission requirements.

# NEN Frequencies and Bandwidths for NTIA Licensing

| Band | Function | Frequency Band (MHz) | Bandwidth (MHz) | Maximum Bandwidth per Transmitter (MHz) |
|---|---|---|---|---|
| S Uplink | Earth to Space | 2025-2110 | 85 | Typically <5 |
| X Uplink | Earth to Space | 7190-7235 (Two NEN sites to 7200) | 10 | Typically <5 |
| S Downlink | Space to Earth | 2200-2290 | 90 | 5 |
| X Downlink | Space to Earth, Earth Exploration | 8025-8400 | 375 | 375 |
| X Downlink | Space to Earth, Space Research | 8450-8500 | 50 | 10 |
| Ka Downlink | Space to Earth | 25500 – 27000 | 1500 | 1500 |

# Near Earth Network (NEN) Upcoming CubeSat Support

| Mission | Launch Date (No Earlier Than) |
|---|---|
| CPOD/PONSFD (A and B) | TBD |
| SOCON 1 | 2017 |
| MicroMAS (A and B) | 2017 |
| Jefferson High | 2017 |
| CryoCube | 2018 |
| iSAT | 2018 |
| SOCON 2 | 2018 |
| Lunar IceCube | 2019 |
| ArgoMoon | 2019 |
| BioSentinel | 2019 |
| CuPiD | 2019 |
| Burst Cube | 2019 |
| RadSat | 2019 |
| TROPICS (9 CubeSats) | 2020 |
| CUTIE | 2021 |
| CSIM | TBD |
| Propulsion Pathfinder (RASCAL) | TBD |
| Kit Cube | TBD |
| PIC/USIP | TBD |

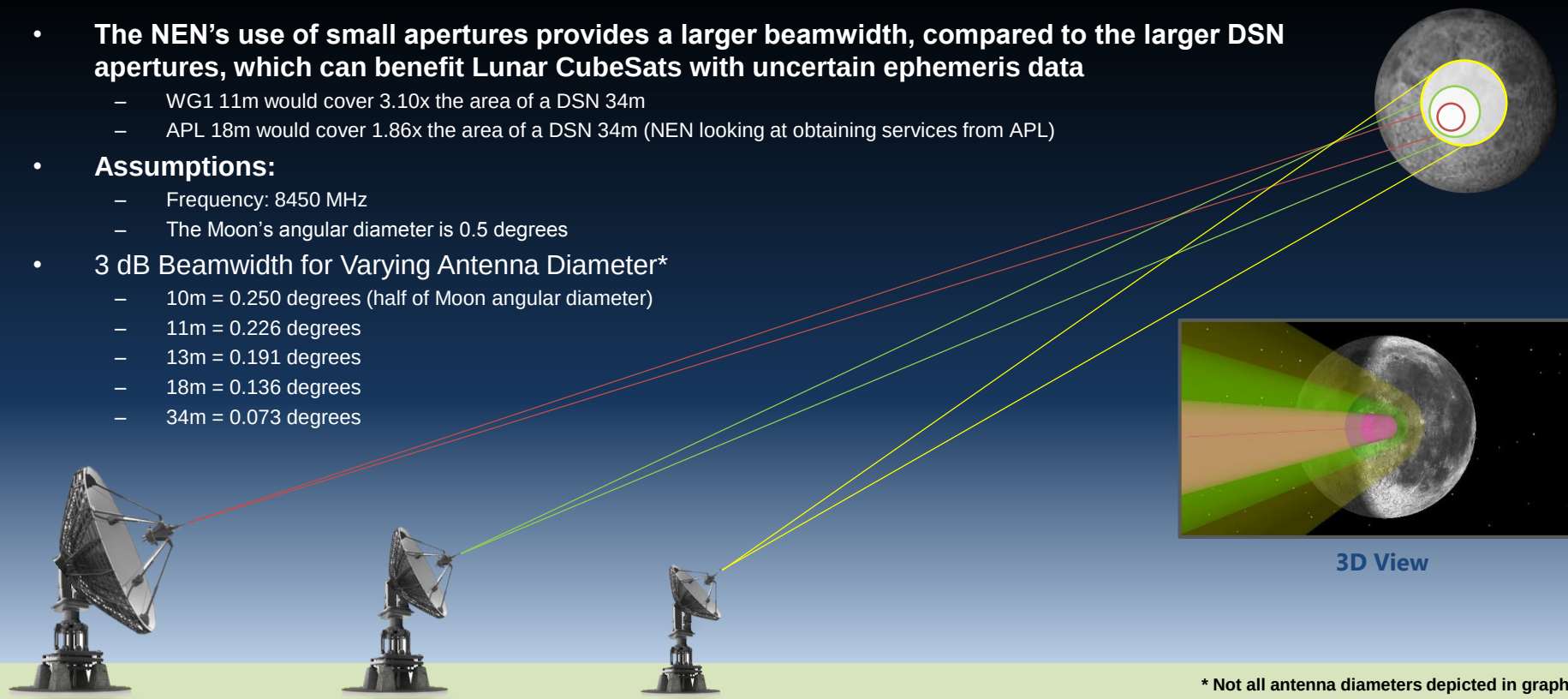
# NEN Potential Benefits for EM CubeSats

**NEN offers "as-is" and upgradable ground system solutions for lunar, L1/L2, and future exploration CubeSat missions that could benefit the EM-1 CubeSat missions**

- **The NEN may benefit EM-1 CubeSat missions utilizing the IRIS radio in the form of coverage and larger beamwidth**
  - NEN ground systems are positioned around the globe and are able to provide significant to full coverage, depending on sites utilized, for CubeSats in Lunar orbit or beyond (e.g., L1/L2 missions)
  - NEN coverage could be utilized to provide higher data rate support to EM-1 CubeSat missions immediately following dispersal from Orion (~35,000 km through 100,000km)
  - Smaller NEN apertures (e.g., 11m), compared to other apertures, provide a larger beamwidth, which can benefit CubeSat missions in the event of navigation/ephemeris uncertainty
  - DSN, can provide complete coverage to lunar CubeSats; however, the NEN, if upgraded, could provide supplemental support to close gaps and provide backup coverage during single DSN coverage times
  - NEN could also be utilized during periods of time when DSN has coverage, but are unable to support any one particular CubeSat due to other commitments (e.g., to another of the nine EM-1 CubeSats being supported by DSN)

# NEN Beamwidth Advantage for Lunar EM-1 CubeSats

- **The NEN's use of small apertures provides a larger beamwidth, compared to the larger DSN apertures, which can benefit Lunar CubeSats with uncertain ephemeris data**
  - WG1 11m would cover 3.10x the area of a DSN 34m
  - APL 18m would cover 1.86x the area of a DSN 34m (NEN looking at obtaining services from APL)
- **Assumptions:**
  - Frequency: 8450 MHz
  - The Moon's angular diameter is 0.5 degrees
- 3 dB Beamwidth for Varying Antenna Diameter*
  - 10m = 0.250 degrees (half of Moon angular diameter)
  - 11m = 0.226 degrees
  - 13m = 0.191 degrees
  - 18m = 0.136 degrees
  - 34m = 0.073 degrees




* Not all antenna diameters depicted in graphic

# NEN Achievable Data Rates with Representative EM CubeSat Missions (Based on Analysis)

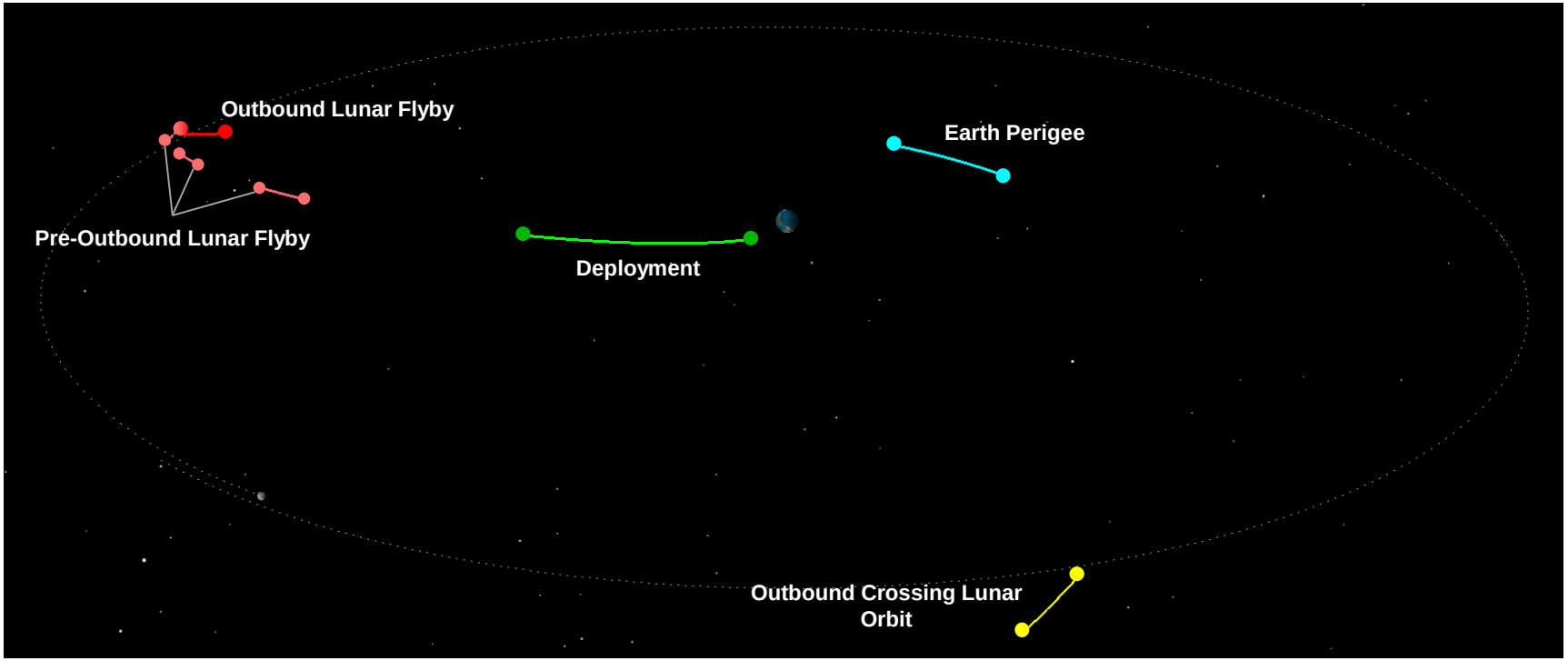
- **NEN would be in a position to support a majority of the discrete IRIS radio downlink rates assuming the NEN implements the upgrade to ensure IRIS downlink compatibility**
  - The IRIS radio does not support a continuous range of data rates, but rather discrete rates (not all possible rates have been tested/verified)
- **Notes/Considerations:**
  - Morehead without cryogenic LNAs was not shown since Morehead is planning to upgrade the asset

- **CubeSat Radio/Antenna Assumptions:**
  - Frequency: 8.45 GHz
  - Modulation = BPSK
  - COTS CubeSat radio: PA output power of 4W
  - COTS antenna with 11 dBi gain @X-band
  - Passive loss of 1 dB
- **General Assumptions:**
  - Acheivable rates assume a 1.3 dB margin
  - Slant range of 405,221 km (Max Lunar Distance)
  - 10 degrees elevation
  - Link availability for propagation effects : 99%

| Asset Size | Reference Antenna | Cryogenic LNAs | G/T [1] (dB/K) | Conv. ½ [2] Rates kbps | Turbo 1/6 Rates kbps | NEN Asset Capable of Supporting IRIS Discrete Data Rates (kbps) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 4 | 8 | 16 | 32 | 64 | 128 | 256 |
| 11m | WG1 | No | 30.74 | 18.7 | 50.8 | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| | | Yes | 31.64 | 23.0 | 62.5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| 13m | SSC Hawaii/ Australia | No | 33.32 | 37.0 | 100.5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| | | Yes | 34.22 | 45.5 | 123.6 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | x | ✗ |
| 18m | APL | No | 34.15 | 41.0 | 111.4 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | x | ✗ |
| | | Yes | 35.05 | 50.4 | 137.1 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| 21m | Morehead | *No* | *NA* | - | - | - | - | - | - | - | - | | - |
| | | Yes | 38.15 | 105.4 | 237.5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | x |

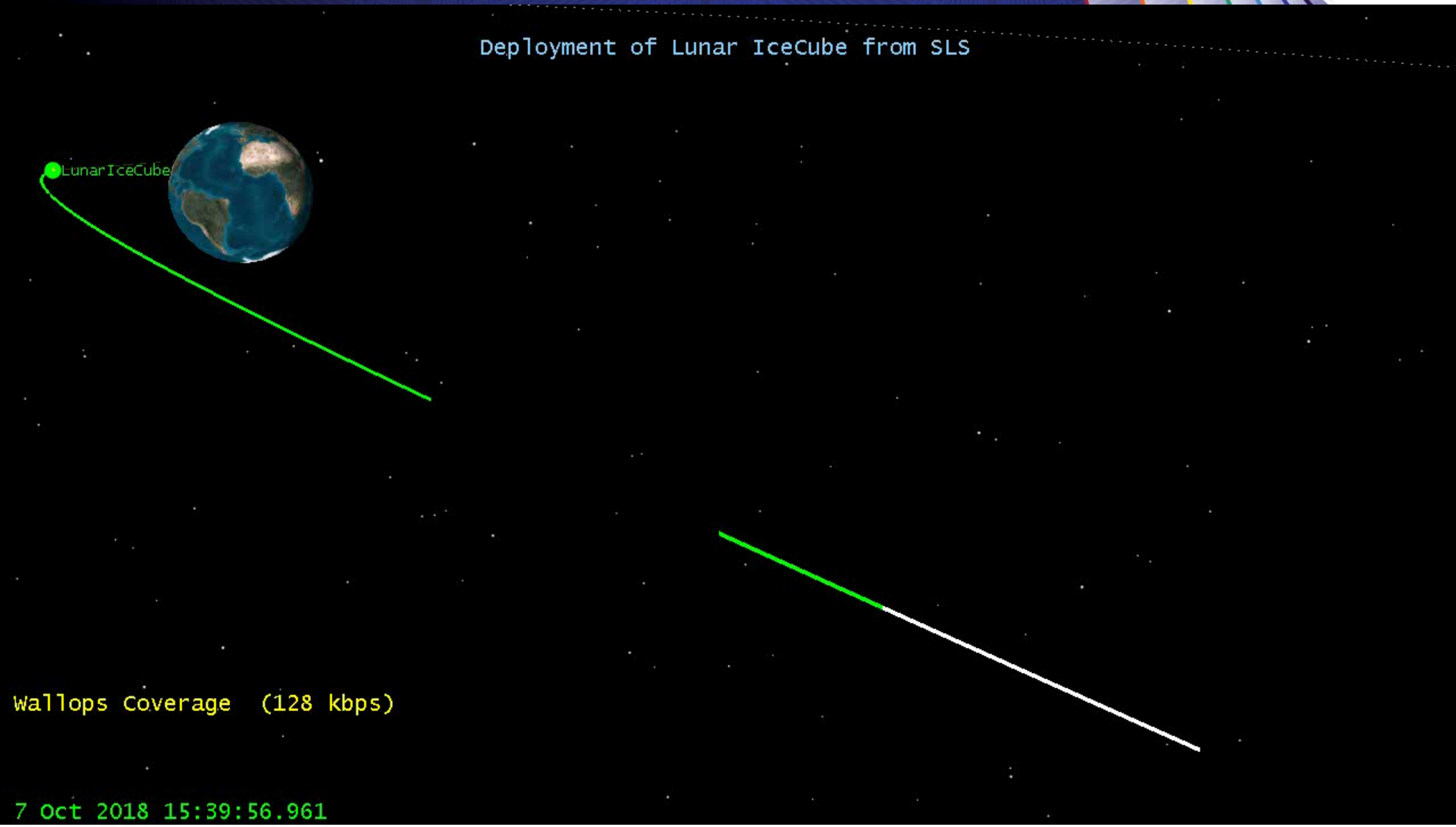
**[1] Includes a Lunar noise effect of 2.9 dB (WG1) and 3.767 dB (SSC). Morehead and APL Lunar Noise effects are approximate.**
**[2] Capabilities are currently untested with the IRIS radio.**

# Lunar IceCube Pre-Lunar Capture/Orbit Events



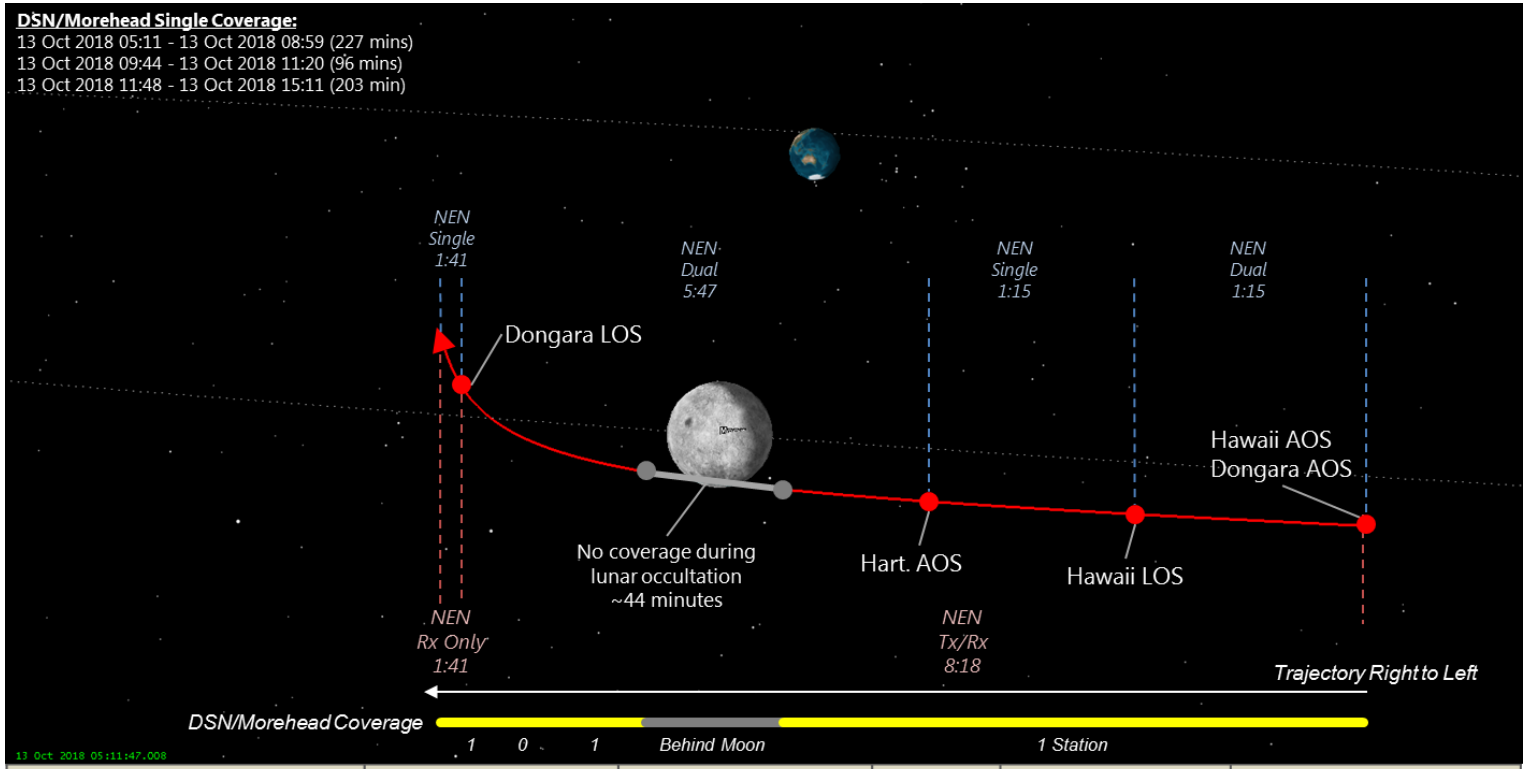

| Color | Event | Start Time | Stop Time | Dur. (min) | Distance (km) | Data Rate | NEN Stations with Coverage of Event |
|---|---|---|---|---|---|---|---|
| | Deployment | 7 Oct 2018 15:39 | 8 Oct 2018 03:52 | 733 | 20,773 - 137,319 | 128 - 256 kbps | Wallops, Hawaii, Dongara |
| | Pre Outbound Lunar Flyby | 9 Oct 2018 11:56 | 13 Oct 2018 05:11 | 5,355 | 280,942 - 385,862 | 4 - 32 kbps | Hawaii, Wallops, Dongara, Hart. |
| | Outbound Lunar Flyby | 13 Oct 2018 05:11 | 13 Oct 2018 15:11 | 600 | 370,207 - 401,505 | 4 - 32 kbps | Dongara, Hawaii, Hart. |
| | Earth Perigee | 16 Oct 2018 17:11 | 17 Oct 2018 03:11 | 600 | 145,025 - 150,762 | 32 - 128kbps | Dongara, Hart., Wallops |
| | Outbound Crossing of Lunar Orbit | 20 Oct 2018 17:11 | 21 Oct 2018 03:11 | 600 | 383,923 - 416,856 | 4 - 32 kbps | Hawaii, Wallops, Dongara, Hart. |

# Lunar IceCube Deployment Event from SLS



# Outbound Lunar Flyby (10 hour event)

**Summary: This complete event has single DSN station coverage. Dongara and Hartebeesthoek could be used to provide support during the entire event, except during lunar occultation when Lunar IceCube will be out of contact.**



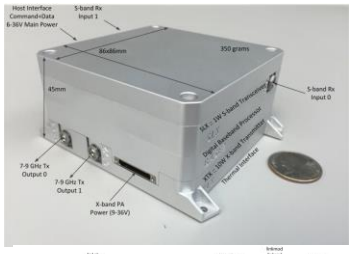

| Station | AOS | LOS | Dur. (min) | Distance (km) | Achievable Data Rate |
|---|---|---|---|---|---|
| Hawaii | 13 Oct 2018 05:11 | 13 Oct 2018 06:26 | 75 | 400,580 - 401,505 | 32 kbps |
| Dongara Pre Lunar Occultation | 13 Oct 2018 05:11 | 13 Oct 2018 08:58 | 227 | 381,307 - 398,211 | 32 kbps |
| Dongara Post Lunar Occultation | 13 Oct 2018 09:43 | 13 Oct 2018 13:29 | 225 | | |
| Hartebeesthoek Pre Lunar Occ. | 13 Oct 2018 07:42 | 13 Oct 2018 08:57 | 74 | 370,207 - 400,463 | 4 kbps (6.95 kbps) |
| Hartebeesthoek Post Lunar Occ. | 13 Oct 2018 09:42 | 13 Oct 2018 15:11 | 329 | | |

# CubeSat Flight Hardware Options for Lunar and L1/L2 missions

- **In addition to evaluating the NEN's ability to support EM-1 CubeSats that will utilize the IRIS Radio, the NEN performed a number of evaluations that may benefit future CubeSats:**
  - Developed CubeSat radio support requirements to achieve NEN compatibility to be provided to radio vendors
  - Identified alternative radios that may offer benefits
  - Identified a number of potential antennas for CubeSats to consider

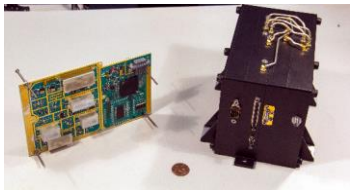
# Potential Radios for Lunar and L1/L2 CubeSats

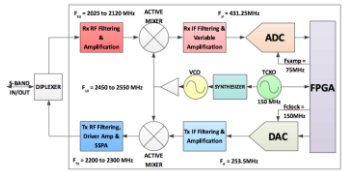
**Innoflight® CubeSat S-Band Transceiver (SCR-100)**



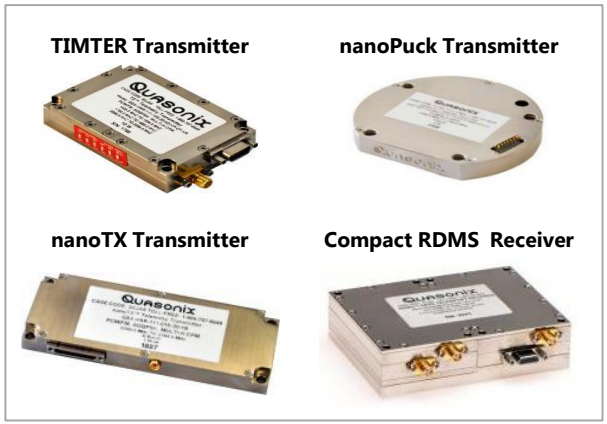
**Tethers SWIFT® Software Defined Radios**

**Vulcan®**



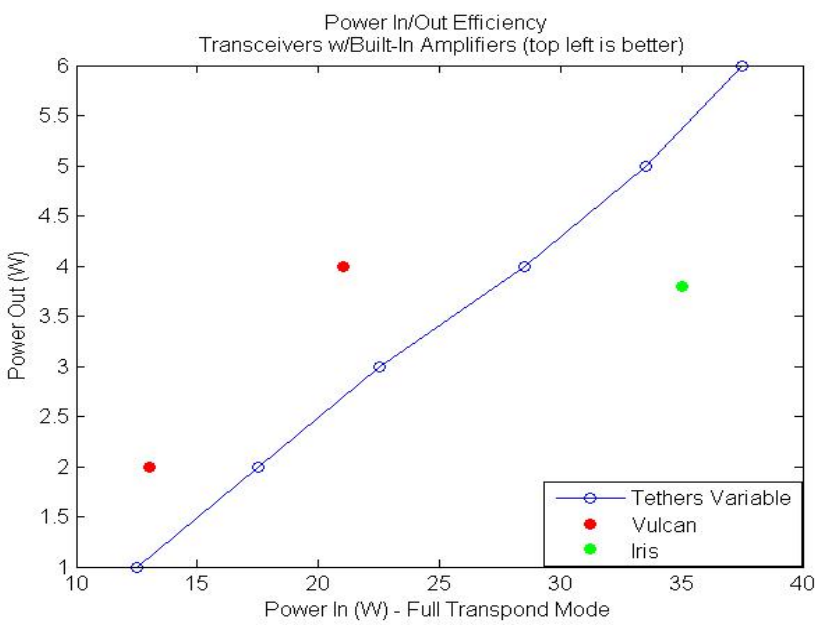


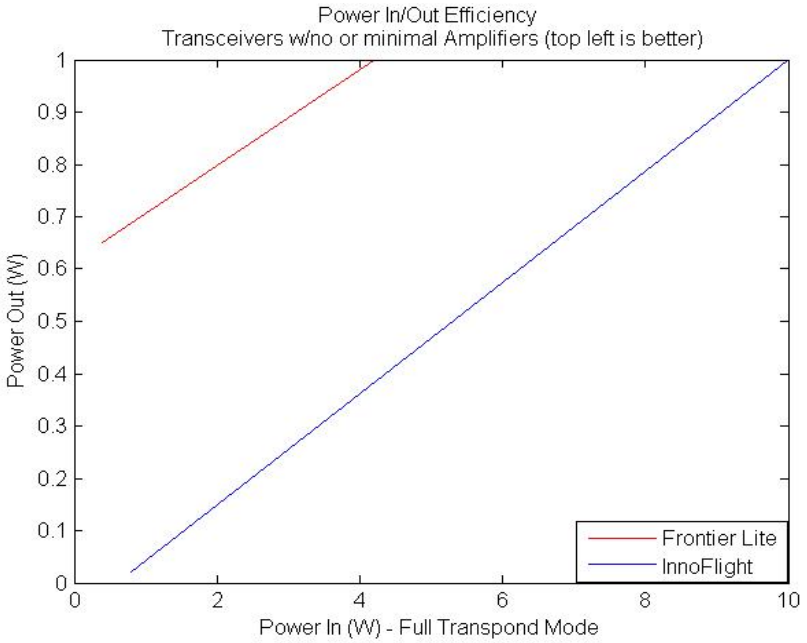

**APL CORESAT® Frontier Radio Lite**



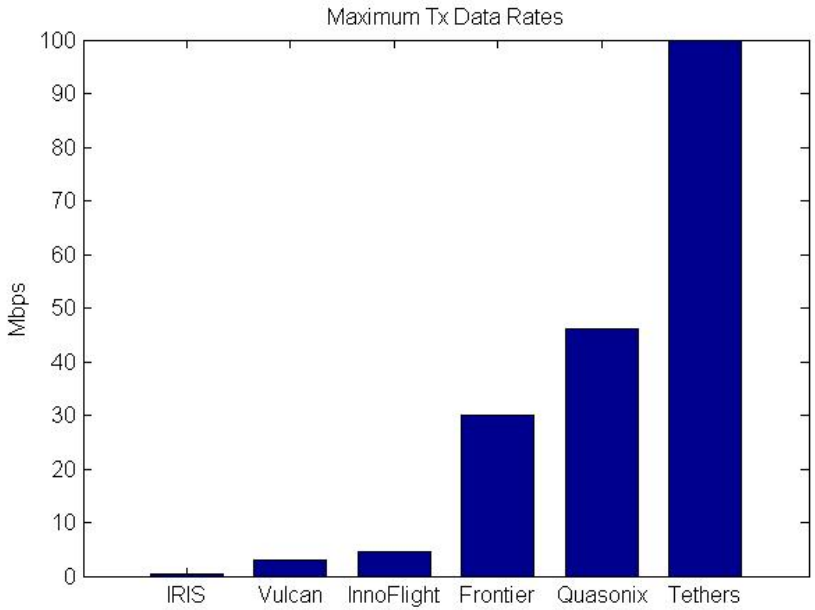

**Quasonix®**

# Comparison of Key Differentiating Features – Power Efficiency

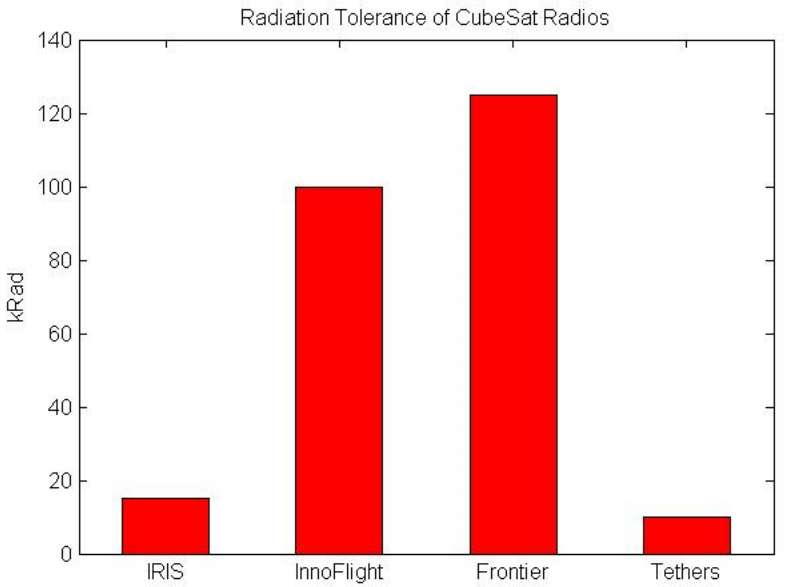


# Comparison of Key Differentiating Features – Data Rate, Radiation Tolerance




Note: Iris 256kbps tested; 8Mbps planned
Tethers w/QPSK=100Mbps; w/32APSK=300Mbps possible

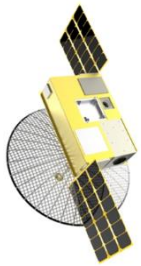



Note: Tethers 100kRad planned;
Vulcan not tested; Quasonix tested for LEO

# NEN Evolution

- **NEN is ready today to support CubeSats**
- **Planned NEN expansions provide increased CubeSat support**
- **CubeSat radios and NEN receivers achieve high data rates for CubeSat missions over X, S and Ka-band**
- **NEN is capitalizing on Commercial Service Providers (CSP)/Academic Partnerships including small apertures, large apertures and X-Band uplink**
- **NEN is investigating streamlining mission planning and integration and test and scheduling activities**

**NEN Wallops 11 Meter class antenna**



**NASA GSFC/Wallops LunarCube with deployable X-band antenna based on University of Colorado/Goddard X/S band CubeSat Radio and NEN**

# Conclusion

- After selection, no charge for pass supports for NASA missions using NASA-owned stations
- Mission Planning (e.g. RFICD, Coverage, Link Analysis, Loading Analysis), no charge prior to mission commitment
  - Mission Planning, Integration and Test (MPI&T) services after mission commitment are negotiable, function of risk versus cost
- Questions – contact Scott Schaire, scott.h.schaire@nasa.gov, 757-824-1120, NASA Goddard Space Flight Center, Near Earth Network Wallops Manager