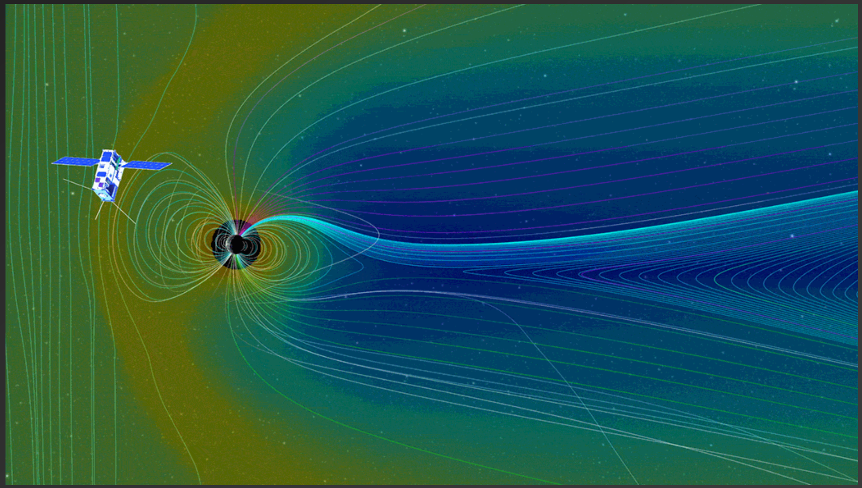
NASA Near Earth Network (NEN), and Space Network (SN) Support of CubeSat Communications

Scott Schaire
NASA Goddard Space Flight Center (GSFC)
Near Earth Network (NEN) Wallops Manager
Contributions from **Harry Shaw, Serhat Altunc, George Bussey, Peter Celeste, Obadiah Kegege, Yen Wong, Yuwen Zhang, Chitra Patel, David Raphael, Jacob Burke, La Vida Cooper, James Schier, William Horne, David Pierce**



The CubeSat to study Solar Particles, or CuSP, will launch from the inaugural flight of NASA's Space Launch System in late 2018. Here a (not-to-scale) CubeSat is shown within an artist's rendition of the constantly moving magnetic fields around Earth. Credits: NASA's Goddard Space Flight Center. CuSP is a 6U CubeSat ~10 cm by 20 cm by 30 cm, mass ~6 kg. For the purposes of this presentation a CubeSat is defined as up to 6U in volume and mass.

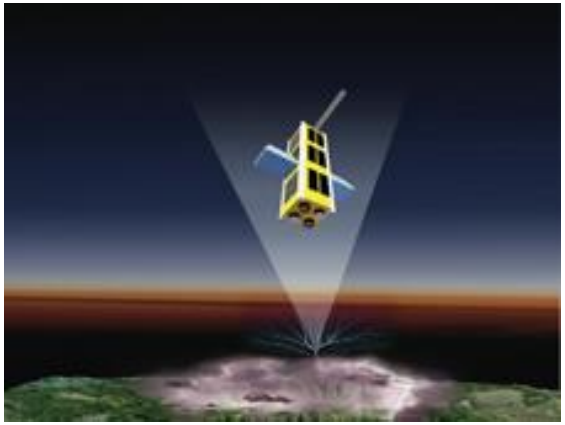
March 2016

Agenda

- Age of Small Satellites (Including CubeSats) Is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSats) Mission Characteristics
- NEN and SN Support for CubeSats
- Flight Radios
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

Age of Small Satellites (Including CubeSats) Is Here

- **Numerous organizations including NASA are developing concepts for small spacecraft**
- **Per the NASA Spectrum program's list of small satellites, more than 520 small satellites (spacecraft < 100 kg) have launched between 2002 and December 2015**
- **Many more have been identified but not yet launched (1000's including large commercial constellations)**
- **Applying small satellites to NASA's science and exploration missions is still emerging**

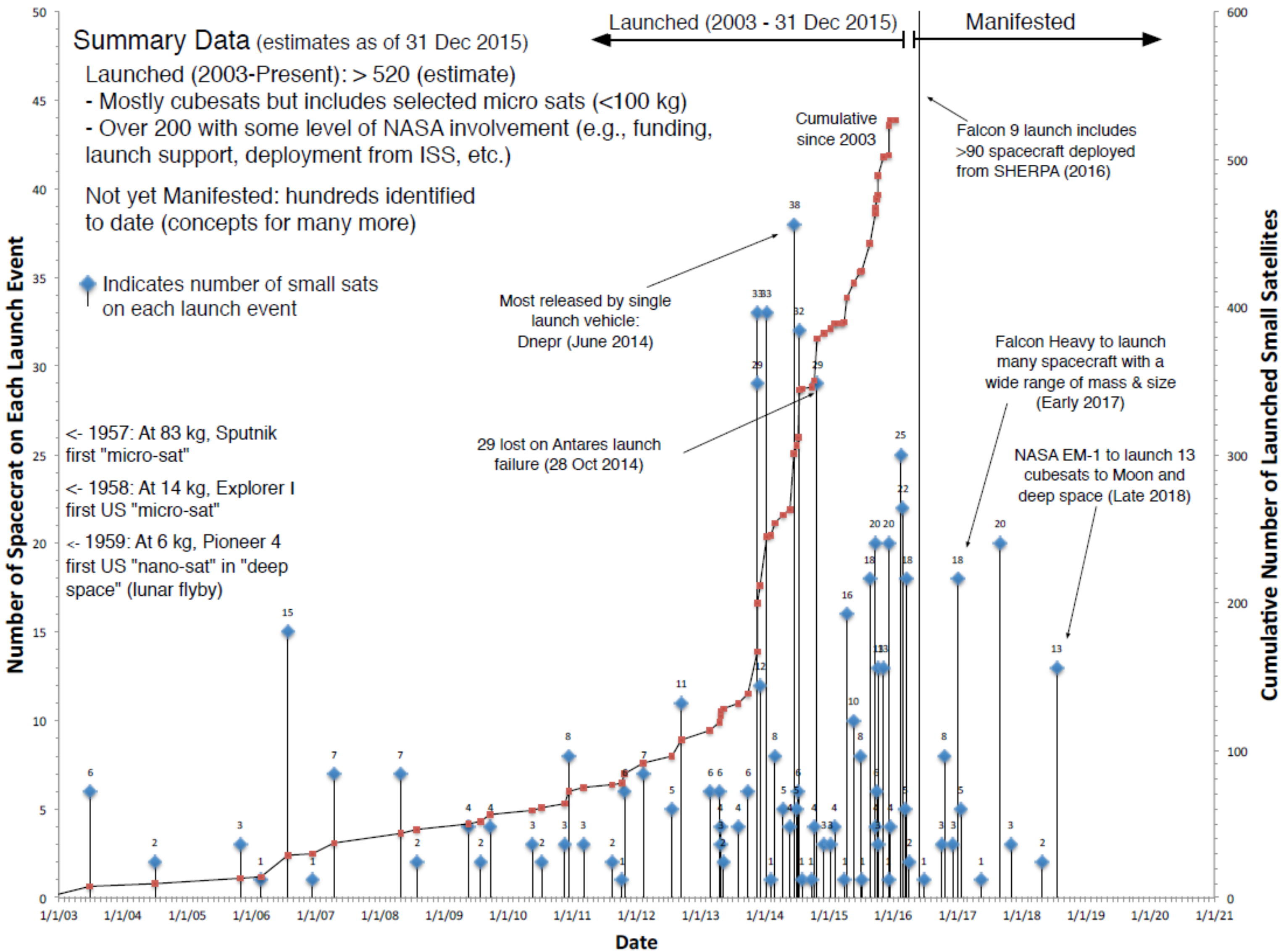


GSFC's Firefly CubeSat demonstrated an increase in science sophistication of CubeSats

CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT), a new CubeSat mission to test RFI-mitigation strategies

Smallsat/CubeSat Launches: Past & Future

(as captured in NASA/Spectrum data set - data does not include all Smallsats)

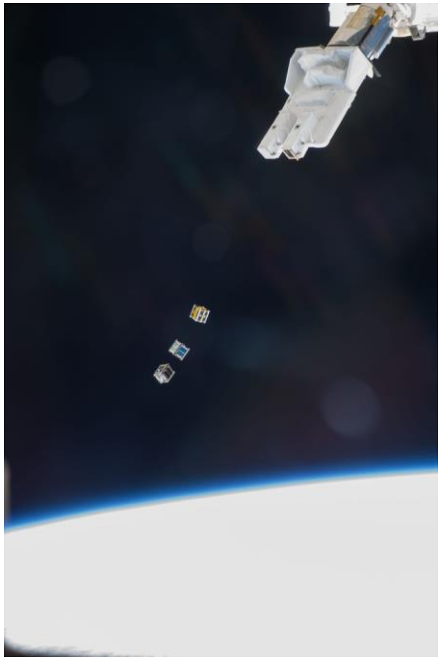


Agenda

- Age of Small Satellites (Including CubeSats) Is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSat) Mission Characteristics
- NASA Support for CubeSats
- Flight Radios and Antenna Development
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

NASA Small Satellite (Including CubeSat) Initiatives

- **NASA, across its mission directorates and Centers, is actively involved in all aspects of small satellite missions including launch support, science, and technology development**
  - Launch & deployment support: CubeSat Launch Initiative, deployment from ISS
  - SMD is sponsoring a variety of missions, often via grants, with some notable projects such as the Earth Science CYGNSS mission (Oct 2016 launch of eight (8) 18 kg spacecraft)
  - SMD is also sponsoring both an internal study and a National Academies study, co-sponsored by the National Science Foundation (NSF), to identify what science can be obtained using small satellites



Nano satellites released from the International Space Station (ISS)

Agenda

- Age of Small Satellites Is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSats) Mission Characteristics
- NEN and SN Support for CubeSats
- Flight Radios
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

Small Satellite (Including CubeSats) Mission Observations

- **To date, almost all small satellites have operated in low Earth orbit**
- **Small satellites have and will also operate in highly elliptical orbits, in the cis-lunar area, and in deep space**
- **Communications support will need to address all space locations**
- **A significant source of CubeSat deployments is via the ISS**
  - **A total of thirty-three CubeSats were deployed from the ISS in early 2014**
  - **Most common CubeSat proposal design is a 400 km, 52 degree inclination (ISS is at 51.6 degrees)**
- **The maximum data volume for any of these users is 10 GBytes (Gb)/day with the majority of users around 3Gb/day**
- **Typical X band design is with a two watt transmitter and a 0 dBi antenna gain**

Antares lifts off from Goddard/Wallops Flight Facility (WFF), with 3 CubeSats onboard in April 2013 deployed en route to the ISS

Agenda

- Age of Small Satellites (Including CubeSats) is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSat) Mission Characteristics
- NEN and SN Support for CubeSats
- Flight Radios
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

NASA Supports National Telecommunications and Information Administration (NTIA) Satellite Communication Bands

- **Bands with significant global network support and NTIA licenses for near-Earth and deep space Smallsats include, but are not limited to:**
  - 400 – 470 MHz - Selected bands within range
  - 2025-2120 MHz & 2200-2300 MHz
  - 7145-7235 MHz & 8025-8500 MHz
  - 22.55-23.55 GHz & 25.5-27.0 GHz
  - 31.8-32.3 GHz & 34.2-34.7 GHz
- **NASA Space Communication and Navigation (SCaN)**
  - NASA funded infrastructure for NASA missions
  - Near Earth Network: S, X, Ka
  - Space Network: S, Ku, Ka
  - Deep Space Network: S, X, Ka

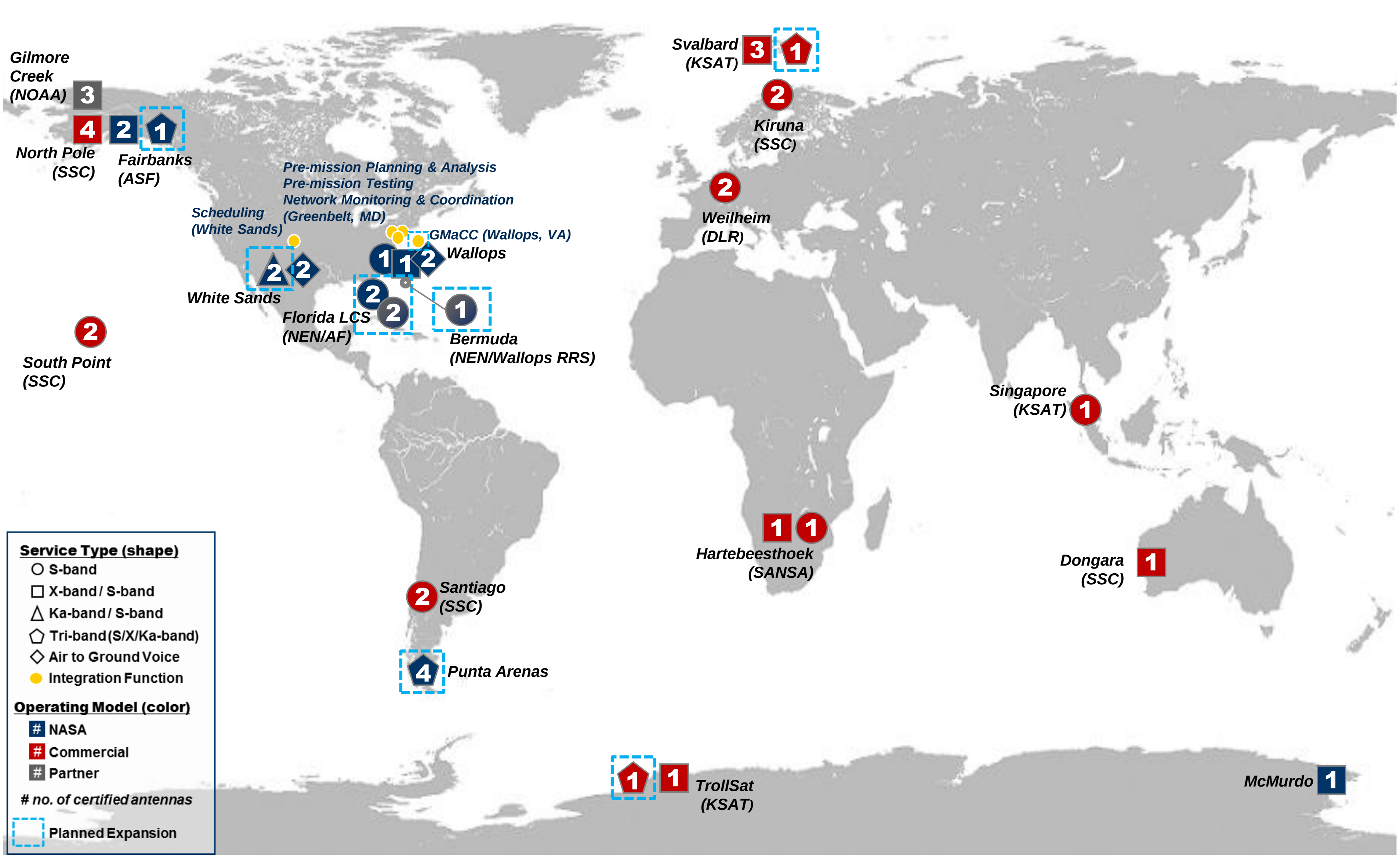
NEN McMurdo Ground Station

Near Earth Network (NEN) Description

- Best value communications & tracking services
- Missions in near-earth region
- Supports multiple robotic missions in low Earth, geosynchronous, highly elliptical, and lunar orbits using a mix of NASA-owned stations and cooperative agreements with commercial and international space communications providers
- Lights out automation on each ground station
- Small staff at Wallops Global Monitor and Control Center (GMaCC) for 24*7 365 day monitoring of passes
- Streamlined planning process maximizes reuse of ground station configurations

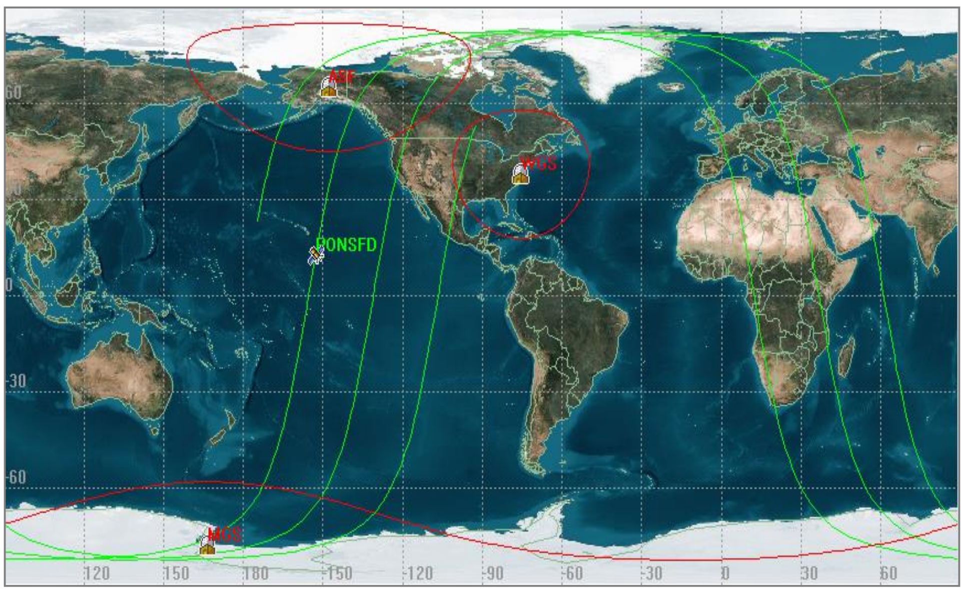
NEN Alaska Satellite Facility 11 Meter class antennas

NEN Baseline after Projected Expansions (FY20)



NEN Upcoming CubeSat Support

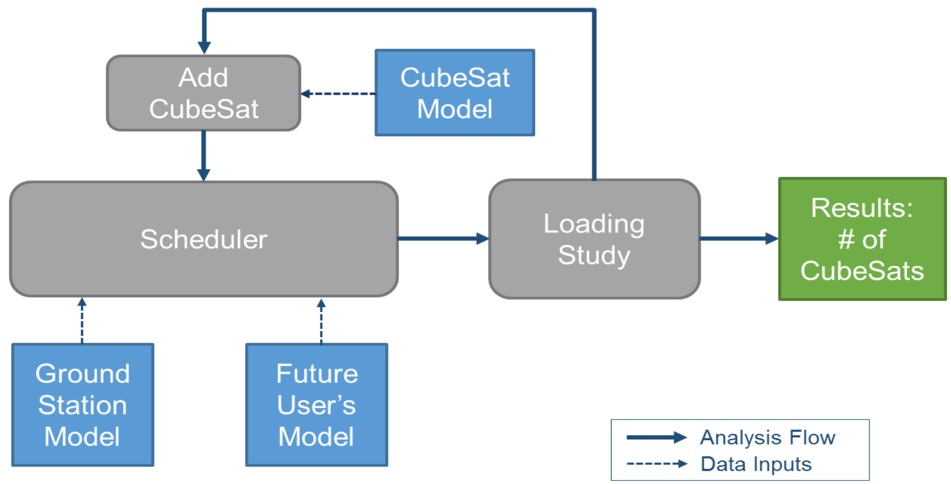
- **NEN will provide first time support to a CubeSat mission, CubeSat Proximity Operations Demonstration (CPOD), when it launches in 2016**
  - Supporting Station: WGS 11m, ASF 11m, MGS 10m
  - Level of Support: 2 contacts per day with a minimum duration of 5 minutes
  - Service Provided: S-Band Telemetry
  - Data Rates: 1 Mbps or 500 kbps
  - Service Duration: L+30 days to L+6 months (possible extension of up to L+12 months)

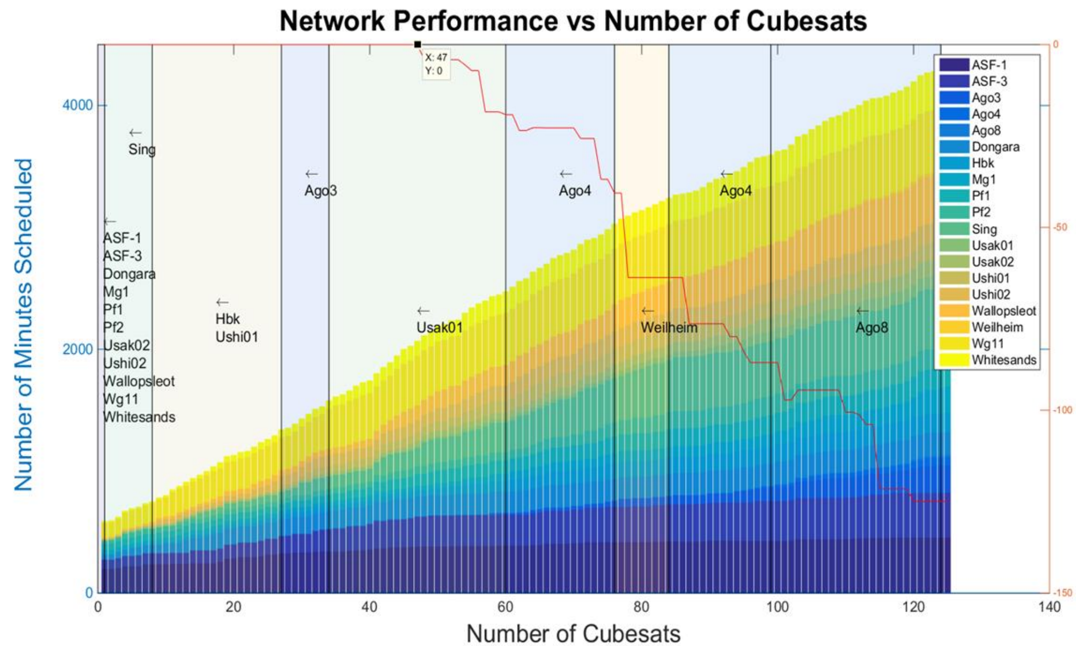


Mission	Launch Date (No Earlier Than)
CPOD/PONSFD (A and B)	10/1/2016
SOCON	Mid 2017
iSAT	11/1/2017
CryoCube	3/1/2018
Lunar Ice Cube	7/1/2018 (EM-1)
BioSentinel	7/1/2018 (EM-1)
Burst Cube	2019
Propulsion Pathfinder (RASCAL)	TBD

Near Earth Network (NEN) Low Earth Orbit Small Satellite (Including CubeSats) Communication Support

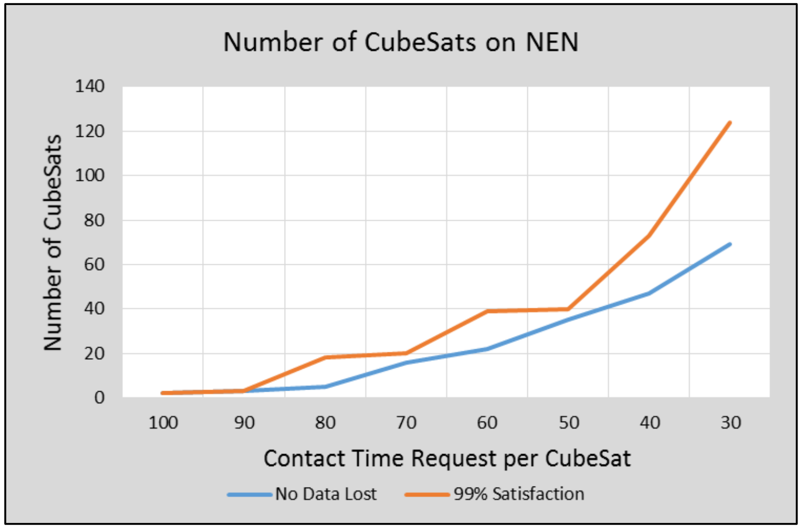
- NEN performed a trade study to answer the question of how many CubeSats the network could support
- Study showed significant capacity if mission communication designs are coordinated with NEN
- Majority of NEN assets support polar orbiting missions
- Probable that interference between satellites will be the most limiting factor in the polar regions
- Growth and distribution in mid and lower latitude sites might be more effective at adding capacity and reducing latency
- Equatorial capacity could be improved with the addition of lower latitude stations to the NEN





NEN Network Requested Time vs Number of Supportable CubeSats

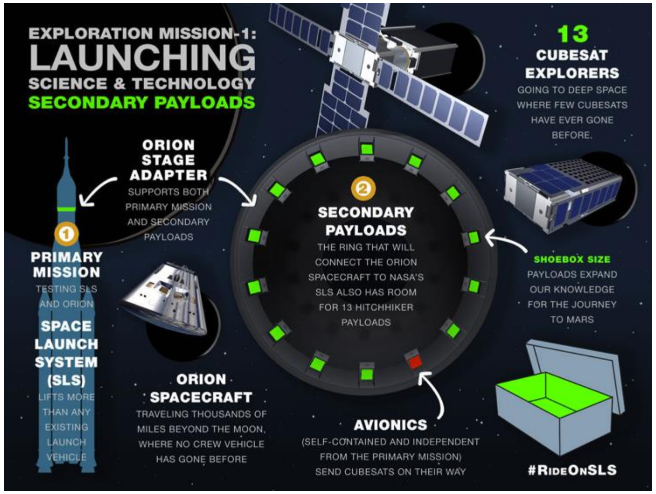
- The total number of CubeSats is **non-linearly** related to the request of the individual CubeSat
- Network **Scheduling Efficiency** is highest when request for passes/day is lowest
- The NEN is exceptional at supporting large numbers of user's that request few passes/day



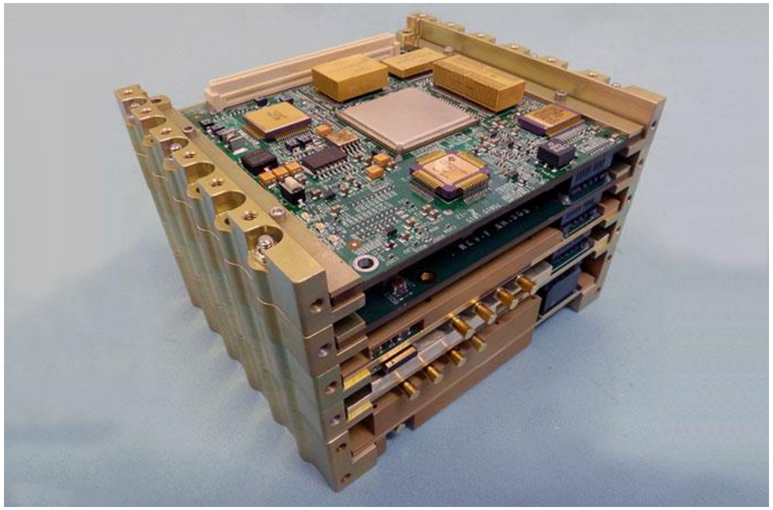
CubeSat Request (minutes)	Num CubeSats Allowable (w/o losing data)	Num CubeSats to 99% Network Satisfaction
100	2	2
90	3	3
80	5	18
70	16	20
60	22	39
50	35	40
40	47	73
30	69	124

Exploration Mission (EM-1) and Future Exploration CubeSats

- NEN offers high gain large ground systems that are separated around the earth for full coverage of L1/L2 and Lunar missions
- Several of the EM-1 CubeSat missions propose to use the IRIS X-band radio with four X-band patch antennas, two for receive and two for transmit
- NEN Commercial Service Providers (CSP) have X-band uplink
- NASA NEN is considering increasing X-band uplink capability and with this upgrade EM1, EM2 and future CubeSat missions using X-band uplink radios (e.g. IRIS) can be supported beyond early orbit trajectory phase
- Adding X-band uplink to these ground systems would allow for CubeSats to also use the IRIS radio in near earth orbits also



EM-1 Secondary Payloads



IRIS X-band Radio

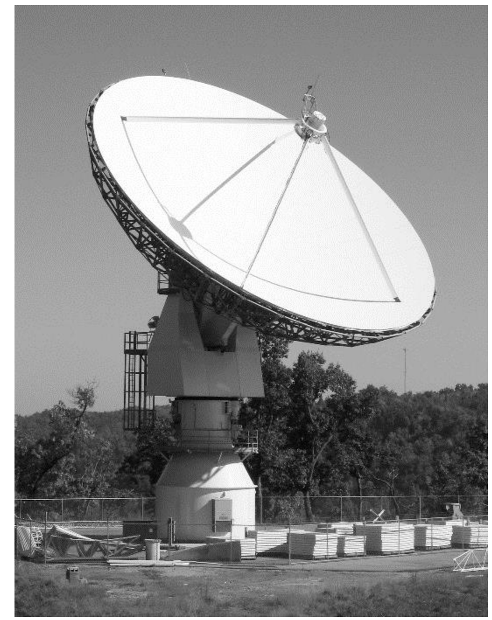
NEN Ground System Performance Enhancements Required for Lunar/L1/L2

- The gain of the earth station to the total system noise temperature, Gain/Temperature (G/T), is a crucial performance characteristic of the ground station antenna systems
- G/T measurements are basically the ratio of the antenna gain to the system noise temperature
- The most effective way of decreasing the system temperature is utilizing a low noise amplifier (LNA) to diminish the system temperature right after the antenna
- Currently NEN uses LNAs which have ~150 degrees Kelvin noise temperature
- However NEN can potentially consider upgrading the LNAs with less than 50 degrees Kelvin and ground systems can gain ~3-6+ dB in the ground system performance (i.e. that of ~18m)

Example Cryogenic Low Noise Amplifier

Capitalizing on Commercial Service Providers (CSP)/Academic Partnerships

- **NEN today successfully manages commercial services**
- **CubeSats, because of their limited size and power, may require large ground stations (>11m) to support their data rate in Lunar, L1/L2 and LEO**
- **Potential commercial service and Academic Partnership large apertures may complement the existing worldwide fleet of 11m class X/S-band antennas and the 18m Ka/S-band antenna in White Sands**
- **Pass rate costs, required upgrades, existing capability and availability will be traded against potential benefits**
- **Morehead State University Space Science Center operates a 21-Meter Space Tracking Antenna that is capable of providing telemetry, tracking, and command (TT&C) services for a wide variety of space missions**



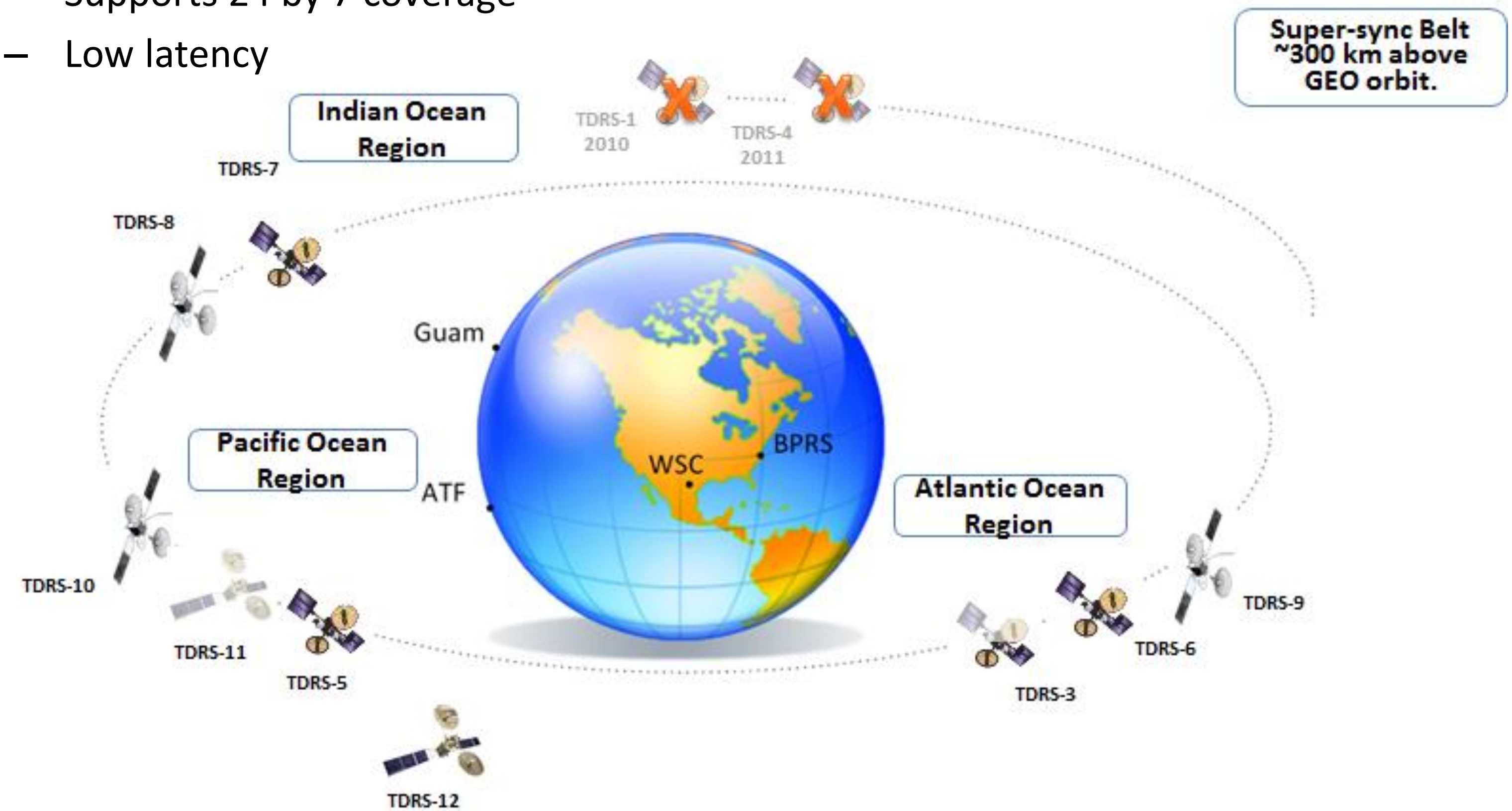
Morehead State University Space Science Center 21-M Ground Station, Morehead, KY

Achieving High Data Rates for CubeSats with Bandwidth Efficient Signal Techniques (e.g. Space Science X-band 10MHz Allocation)

Modulation	Coding	Max Data Rate	Implementation loss at 10-5 BER	Comment
OQPSK	7/8 LDPC	16 Mbps	3.6 dB	There is significant positive link margin assuming a CubeSat equivalent isotropically radiated power (EIRP) with 8.0 dBW (2 Watt TX Power).
8PSK	7/8 LDPC	23.6 Mbps	4.1 dB	For the 6 dB implementation loss case, it was assumed that the CubeSat transmitter distortions are the same as defined in the Space Network Users Guide (SNUG). S-band Single Access Return (SSAR) user distortions were used except with a lower Power Amplifier (PA) nonlinearity. For the 5 dB case, it was assumed the CubeSat transmitter had less distortions than the SNUG defined SSAR user distortions amount and lower PA nonlinearity.
16 APSK	7/8 LDPC	28 Mbps	> 6 dB	For the 6 dB case, same as in 8 PSK. For the 5 dB case, it was assumed the CubeSat transmitter had much less distortions than the SNUG defined SSAR user distortions amount and lower PA nonlinearity.
			~ 5 dB	
32 APSK	7/8 LDPC	30 Mbps	>> 6dB	32 APSK should not be considered because it has minimum benefits on data rate.
			~ 5 dB	
16 QAM	7/8 LDPC	28 Mbps	> 6 dB	Considering 16 APSK can achieve the same data rate with less stringent constraints, 16 QAM should not be considered.
			~ 5 dB	

Space Network (SN) Description

- **A constellation of geosynchronous (Earth orbiting) satellites named the Tracking Data Relay Satellite (TDRS)**
  - Ground systems that operate as a relay system between satellites
  - Satellites in low Earth orbit (LEO) above 73 km
  - Supports 24 by 7 coverage
  - Low latency



TDRS Spacecraft Constellation – The Space Segment

Space Network White Sands Complex – The Ground Segment

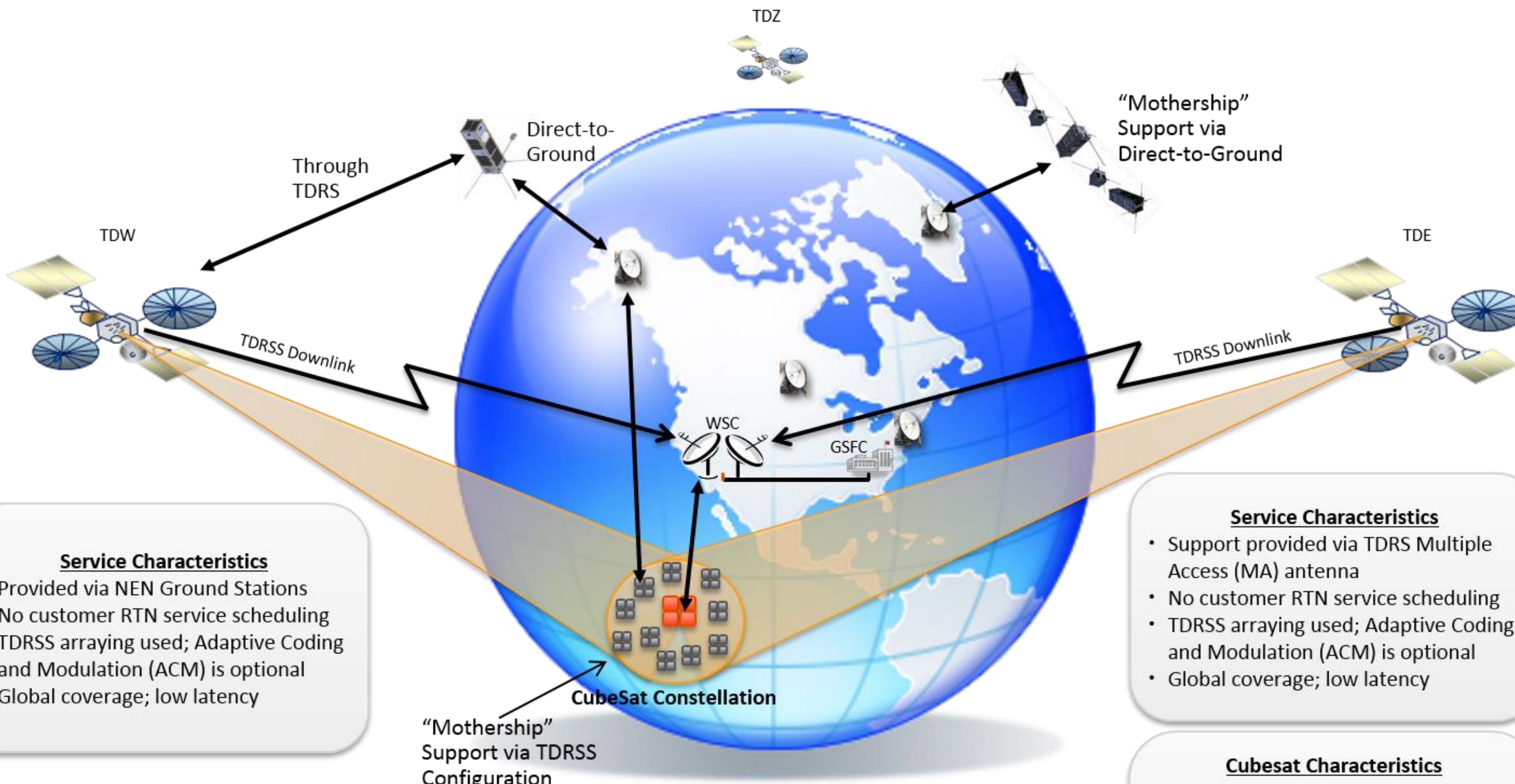
- **The WSGT is composed of the following subsystems:**
  - Two Space-Ground Link Terminals
  - Three 18.3-meter Ku-Band antennas
  - One 10-meter S-Band Telemetry, Tracking and Command (STTC)
  - Two dual S/Ku-Band 4.5-meter antennas for end-to-end tests
  - Data Interface System
  - One TDRS Operations Control Center (TOCC)

- **The STGT includes the following subsystems:**
  - Three Space-Ground Link Terminals (SGLTs)
  - Three 19-meter Ku-band antennas
  - One 10-meter S-Band (STTC)
  - Two dual S/Ku-band 4.5-meter antennas for end-to-end tests
  - Data Interface System
  - One TDRS Operations Control Center (TOCC)

White Sands Ground Terminal (WSGT)

Second TDRSS Ground Terminal (STGT)

SN and NEN Support both Single CubeSats and CubeSat Constellations



Service Characteristics
- Provided via NEN Ground Stations
- No customer RTN service scheduling
- TDRSS arraying used; Adaptive Coding and Modulation (ACM) is optional
- Global coverage; low latency

Service Characteristics
- Support provided via TDRS Multiple Access (MA) antenna
- No customer RTN service scheduling
- TDRSS arraying used; Adaptive Coding and Modulation (ACM) is optional
- Global coverage; low latency

Cubesat Characteristics
- Mothership: S-band transmit and receive; directional antenna (i.e., attitude / antenna pointing requirements); high rate burst transmissions; transponder required if TDRSS tracking services required
- Subordinates: Proximity link comm only; GPS position determination

Constellation Characteristics
- One Mothership, however, multiple CubeSats have the ability to fulfill the role of Mothership
- Two or more Cubesat architectures (Mothership-capable CubeSats, subordinate Cubesats)

SN CubeSat Services

- **LEO CubeSats typically have low RF power output, low EIRP, and long slant ranges to TDRS**
- **Typical concepts of operations**
  - CubeSat location finding and emergency recovery
  - High percentage global coverage with low latency (up to 24 x 7)
- **Low data rate users (e.g., CubeSat constellations) may utilize the Multiple Access Service, which will require spread spectrum communications systems onboard the user CubeSat**
  - Non-spread spectrum systems may cause spectrum management and interference issues
  - SN is working on identifying spread spectrum radio options for CubeSat users

Agenda

- Age of Small Satellites (Including CubeSats) is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSat) Mission Characteristics
- NEN and SN Support for CubeSats
- Flight Radios
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

Selected Common CubeSat Radios

Freq.	Transceiver Name/Vendor	Size (cm)	Mass (g)	Flight Heritage	Max. Data Rate	Modulation/FEC	NASA Network Compatibility
UHF-band	L3 Cadet UHF Tx	6.9 x 6.9 x 1.3	215	DICE, MicroMAS, CeREs	2.6 Mbps	BPSK	None
	ISIS Transceiver (ITRX)	9.6 x 9.0 x 1.5	85	Delfi-n3Xt	1.2 Kbps Downlink/9.6 Kbps Uplink	Rx AFSK/Tx BPSK	None
S-band	Innoflight SCR-100	8.2 x 8.2 x 3.2	300	Sense NanoSat	4.5 Mbps	BPSK,QPSK,OQPSK GMSK,FM/PCM FEC: Conv. and R/S	NEN, SN, DSN
	Tethers Unlimited SWIFT-SLX	10 x10 x 3.5	380	None	15 Mbps	BPSK	NEN,SN,DSN
	L3 Cadet S-Band Tx (CXS-1000)	6.9 x 6.9 x 1.3	215	None	6 Mbps	BPSK, QPSK, SOQPSK, SGLS M/FSK	None
	Clyde Space S-Band TX (STX)	9.6 x 9.0 x 1.6	< 80	UKube-1			
	Nimitz Radio S-band Tx/UHF Rx	9 x 9.6 x 1.4	500	None	50 Kbps Downlink/1 Mbps Uplink	Uplink FSK, GFSK Downlink BPSK	None
	MHX-2420	8.9X5.3X1.8	75	RAX	230 Kbps Downlink/115 Kbps Uplink	FSK	Partially NEN
X-band	LASP/GSFC X-band Radio	9.8 x 9 x 2	500	None	12.5 Mbps Downlink/50 Kbps Uplink	BPSK/OQPSK R/S and Conv.	NEN
	Syrlinks/X-band Transmitter	9 x 9.6 x 2.4	225	None	5 Mbps	BPSK/OQPSK R/S and Conv.	NEN
	Marshall X-band Tx	10.8 X 10.8 X 7.6	<1000	FASTSat2	150 Mbps Downlink/50 Kbps Uplink	BPSK/OQPSK LDPC 7/8	NEN
	Tethers Unlimited SWIFT-XTS	8.6 x 4.5 (0.375U)	500	None	100 Mbps	{8,16A,32A}PSK	NEN,SN,DSN
	JPL /Iris Transponder	0.4U	400	INSPIRE	62.5 Kbps Donwlink/1 Kbps Uplink	BPSK bit sync, CCSDS frame size	DSN
Ka-band	Canopus Systems/ Ames Ka-band Tx	18 x 10 x 8.5	820	None	125 Mbps	{Q,8,16A,32A}PSK, DVB-S2, CSSDS, LDPC Concatenated with BCH	NEN,SN,DSN
	Tethers Unlimited SWIFT-KTX	8.6 x 4.5 (0.375U)	500	None	100 Mbps	{Q,8,16A,32A}PSK, DVB-S2, CSSDS	NEN,SN,DSN

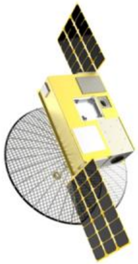
Agenda

- Age of Small Satellites (Including CubeSats) is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSat) Mission Characteristics
- NEN and SN Support for CubeSats
- Flight Radios
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

NEN Evolution

- Enhance CubeSat radios and NEN receivers to achieve high data rates for CubeSat missions
- Maximize ground performance through cryogenic LNAs
- Assist missions moving to X, S and Ka-band
- Add/modify small apertures
- Add X-Band Uplink
- Capitalize on Commercial Service Providers (CSP)/Academic Partnerships including small apertures, large apertures and X-Band uplink
- Streamline mission planning and integration and test and scheduling activities
- Continue to engage with the CubeSat community

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

SN Evolution for CubeSats

- **TDRSS can provide continual coverage of CubeSats compared to very limited contact time with just ground stations**
  - Continual coverage can be used by CubeSats to send status alerts instantly without waiting until a ground station is in view
  - Supports continual, real-time data flows without interruption
  - More coverage time allows using lower data rates (i.e. less power) to deliver more data than brief, intermittent ground station contacts
- **TDRSS can provide emergency support for CubeSats**
  - TDRSS 360° coverage can constantly listen for signals from CubeSats around the world and locate them when they are not visible to ground stations
  - TDRSS may be able to provide CubeSat location information by processing signal information from multiple TDRS's viewing a CubeSat
- **The use of Single Access (SA) mode for S, Ka-Band for TDRSS depends on the evolution of higher gain antennas for CubeSats for high data rates (>100 kbps)**

Agenda

- Age of Small Satellites (Including CubeSats) is Here
- NASA is Developing Exciting CubeSat Concepts
- Small Satellite (Including CubeSat) Mission Characteristics
- NEN and SN Support for CubeSats
- Flight Radios
- NEN and SN Evolution for Small Satellites (Including CubeSats)
- Summary

Summary

- Lack of publicly available S-band (1 Mbps) until recently, and X-band (10's of Mbps) CubeSat radios have prevented the widespread use of NEN and SN
- Improvements in flight hardware as well as ground systems could support very high rate (10's of Mbps) CubeSat missions in LEO orbits
- NEN and the SN are anticipating the needs of the CubeSat community with planned network enhancements and assistance to the CubeSat community of transitioning to flight hardware which best capitalizes on existing assets
- NEN and SN are investigating streamlining mission planning, integration, and test, to save costs and reduce the lead time, for all missions, whether CubeSat or not
- Some CubeSats, particularly of high science return and sophistication, may desire the high data rates of traditional non-CubeSat satellites, but are more constrained in flight power and volume for antennas than traditional non-CubeSat satellites
- Smaller apertures for traditional (non-CubeSat) NEN missions and low data rate CubeSat missions could free up larger apertures for those missions that need them
- Lunar, L1/L2, and even LEO CubeSat missions may require larger than 11-meter class apertures for NEN

Backup

Acronyms

AF	Air Force
AGO	Santiago Ground Station
AGS	Alaska Ground Station
ARC	Ames Research Center
ASF	Alaska Satellite Facility
BPSK	Binary Phase Shift Keying
CeREs	Compact Radiation belt Explorer
CPOD	CubeSat Proximity Operations Demonstration
CSLI	CubeSat Launch Initiative
CYGNSS	Cyclone Global Navigation Satellite System
DICE	Dynamic Ionosphere CubeSat Experiment
DSN	Deep Space Network
DSS	Deep Space Station
FEC	Forward Error Correction
FSK	Frequency Shift Keying
G	Grams
GHz	Gigahertz
GMaCC	Global Monitor and Control Center
GN	Ground Network
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HARP	Hyper Angular Rainbow Polarimeter
ISS	International Space Station
ITU	International Telecommunication Union
JPL	Jet Propulsion Laboratory
Kbps	Kilobits per second
Kg	Kilogram
Km	Kilometer
KSAT	Kongsberg Satellite Services AS
LASP	Laboratory for Atmospheric and Space Physics
LEO	Low Earth Orbit
M	Meter
Mbps	Megabits per second
MGS	McMurdo Ground Station
MHz	Megahertz
MicroMAS	Micro-sized Microwave Atmospheric Satellite
MinXSS	Miniature X-ray Solar Spectrometer (MinXSS)
MiRaTA	Microwave Radiometer Technology Acceleration
NASA	National Aeronautics and Space Administration.
NEN	Near Earth Network
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
RRS	Research Range Services
SANSA	South African National Space Agency
SCaN	Space Communications and Navigation
SMD	Science Mission Directorate
SNIP	SCaN Network Integration Project
SIA	Satellite Industry Association
SN	Space Network
SSC	Swedish Space Corporation
STGT	Second TDRS Ground Terminal
TDRS	Tracking and Data Relay Satellite
USN	Universal Space Network
W	Watt
WFF	Wallops Flight Facility
WGS	Wallops Ground Station
WSC	White Sands Complex
WS1	White Sands NEN 18m Antenna #1