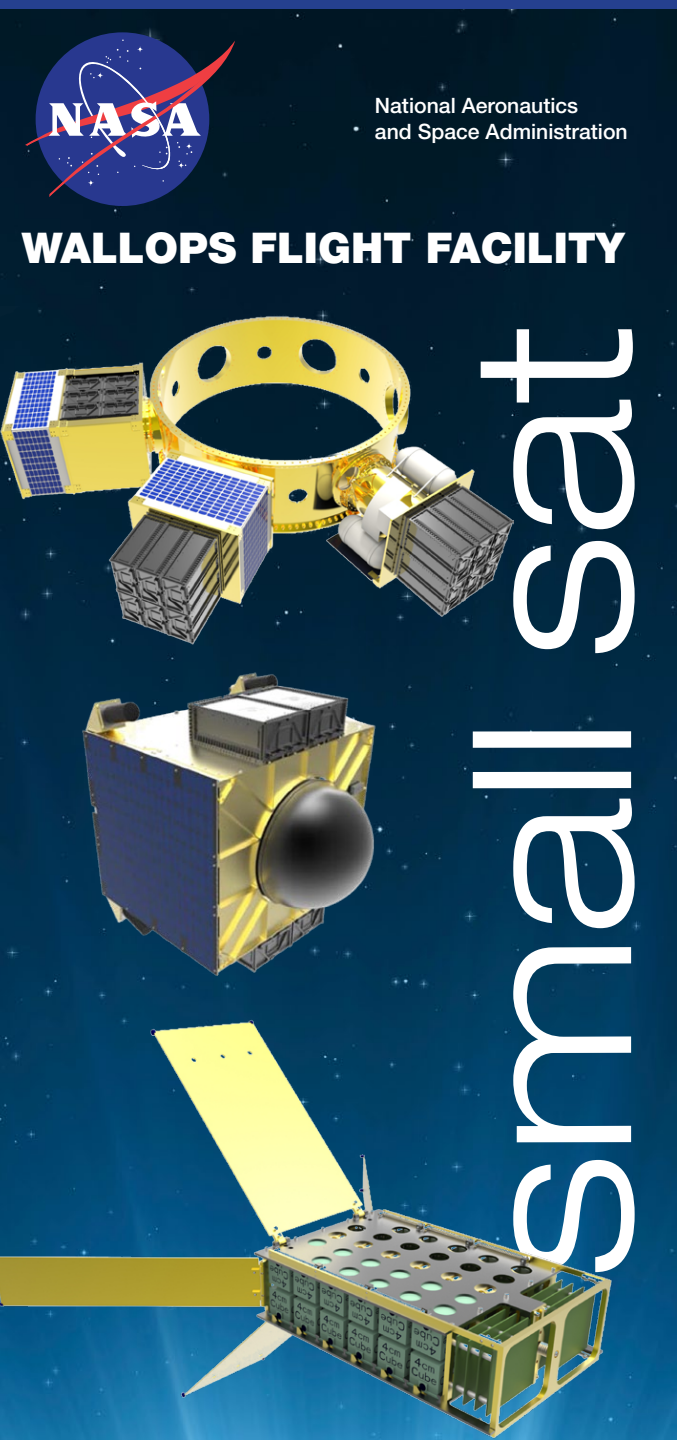


Creating Facilities, Tools and Services for Scientific Collaboration

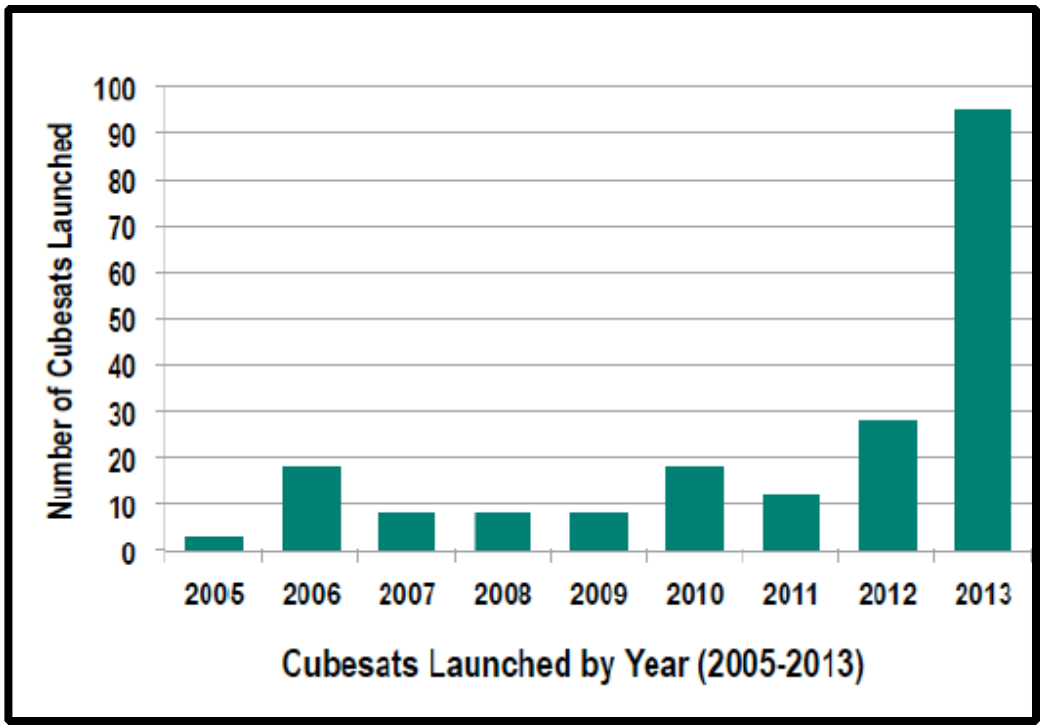
iCubeSat 2015

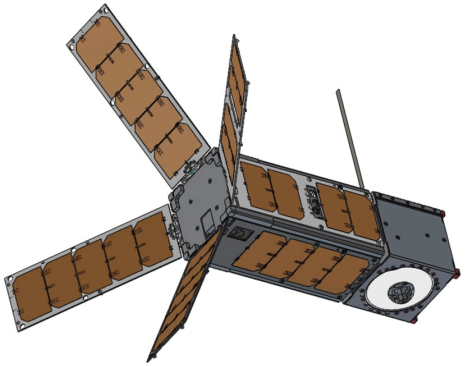
May 27-28, 2015

Brenda Dingwall
Technology Project Manager
NASA/GSFC/Wallops Flight Facility
brenda.j.dingwall@nasa.gov
757-824-2969

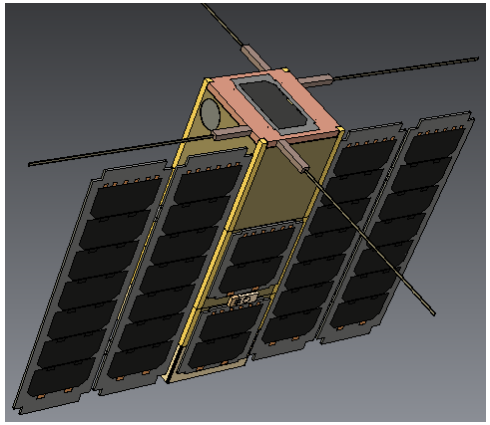
FLIGHT CENTER

The Age of Small Satellites is Here





MIT's Micro-sized Microwave Atmospheric Satellite (MicroMAS) demonstrates an increase in science sophistication of CubeSats



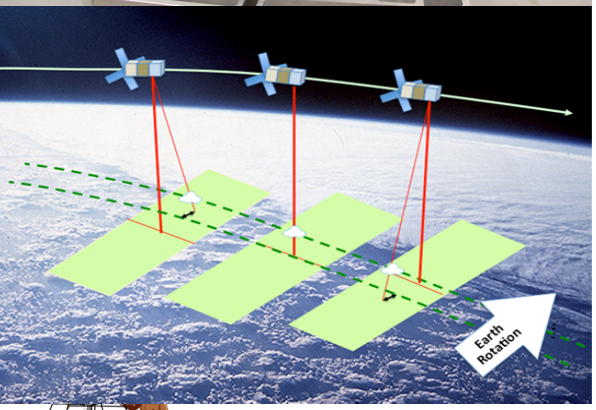
GSFC's IceCube 3U CubeSat team will develop and validate a commercially available flight-qualified 874-GHz receiver for future use in ice cloud radiometer missions

Opportunity….

- NASA GSFC/WFF has the largest collection of satellite scientists in the world.
  - *Heliophysics*
  - *Astrophysics*
  - *Planetary Science*
  - *Earth Science*
- NASA GSFC/WFF has decades of experiencing managing Low Cost Access to Space programs
- International cooperation has been part of national space policy since 1958

Reach New Heights *Reveal the Unknown* *Benefit all Humankind*

GSFC/WFF CubeSat Mission and Services



MISSION: *To enable new and exciting science, technology, and educational Small Satellite missions by providing low-cost, value-added services and technologies at the request of the Principal Investigator*

SERVICES

- Mission Planning
- Engineering
- Project Management
- Technology Development
- Fabrication
- Integration and test equipment
- Vehicle Integration support
- Range Services
- Ground Station Support

Mission Planning

- Plan missions, write proposals, and perform visual analysis for launch support, small satellites, CubeSats, and suborbital missions
- Tools
  - Systems Tool Kit (STK) Professional
    - Communications, Coverage, Radar
    - Aircraft Mission Modeler (AMM)
    - Missile Modeling Tools (MDT, MFT)
    - Space Environment and Effects Tool (SEET)
  - Orbit Determination Toolkit (ODTK)
  - Spacecraft Design Tool (SDT) & Satellite Builder
    - Enables users to rapidly design a complete spacecraft, including sensors, actuators, and attitude determination and control systems
  - SAP Visual Enterprise Author
  - MATLAB, MS Visual Studio, Java
  - 3D EM Simulation Tools: HFSS, GNEC and GRASP
- Products
  - Proposal Compliance Matrix
  - Spacecraft bus system proposal write-ups
  - Master Equipment List (MEL)
  - Report out and analysis by discipline engineers (GN&C, Power, Thermal, etc)
  - Concept of Operations
  - Technical Budgets: Cost, Power Mass
  - Visualization or 3D printed model.

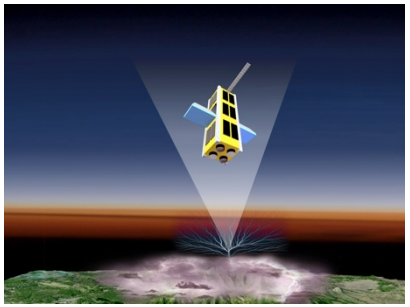
The CUPID CubeSat will image the solar wind plasma entering the terrestrial cusp to determine the spatial and temporal nature of magnetic reconnection and what factors control its properties.

Dr. Michael Collier's 3U Heliophysics CubeSat mission, CUsp Plasma Imaging Detector (CUPID) that is planning to be proposed to the next ROSES Heliophysics Technology and Instrument Development for Science (HTIDS) announcement

Spacecraft Design Tool (SDT) and Satellite Builder

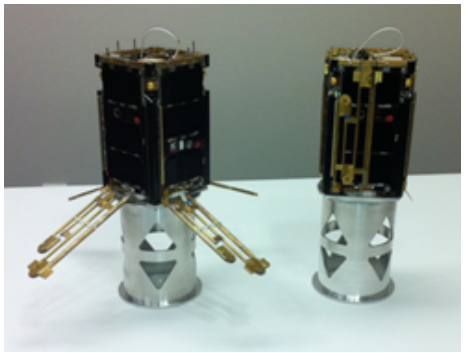
Engineering & Project Management

- Supporting the National Science Foundation CubeSat Program since 2008
- GSFC/WFF support role includes:
  - P-POD hardware and associated documentation & testing
  - Safety documentation with launch vehicle provider
  - Re-entry casualty analysis
  - Integration and test pico-satellite into P-POD and preparation for flight
  - Integration clean room space, thermal vacuum, GPS simulation, EMI/EMC antenna testing and vibration
  - Radio frequency allocation and licensing
  - Flight hardware technical expertise
  - Reviews
  - UHF Ground Station support
  - Project Management

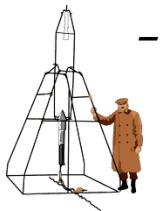


Firefly (Terrestrial Gamma-Ray Flashes) – GSFC, Siena College, USRA, Hawk, UMES

Radio Aurora Explorer (RAX-2) – U. of Michigan, SRI International



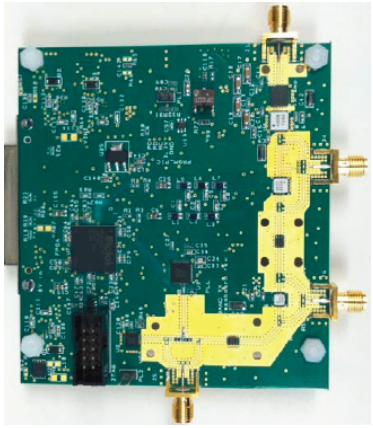
Dynamic Ionosphere CubeSat Experiment (DICE) –USU, Embry-Riddle, Clemson

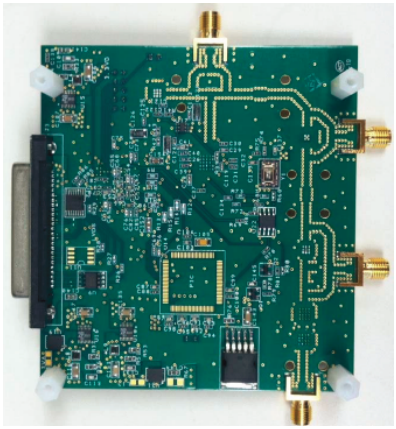


Technology Development
LASP/GSFC X-Band Radio Development Effort

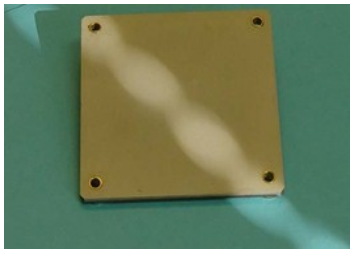
LASP and GSFC are currently undertaking a X-Band Cube Satellite Communication System development project with the following objectives:

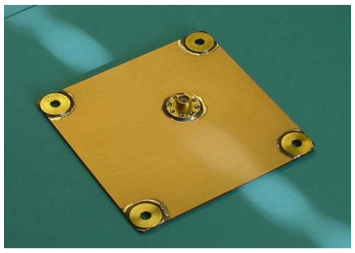
1. Investigate different X-band communication system architectures that can be used as a baseline
2. Design, simulate and test a NEN compatible CubeSat S- and X-band communication system
3. End-to-end demo of X-band CubeSat communication system with a Balloon to a NEN station
4. An end-to-end innovative, compact, efficient and low cost S-band uplink and X-band downlink CubeSat Communication System Demonstration between a balloon and a NEN ground



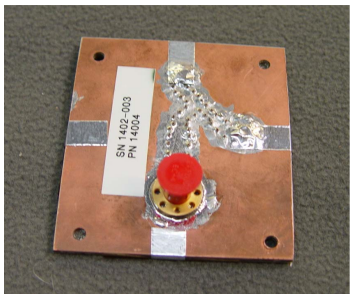


HRCCS X-Band transmitter prototype module top and bottom view





Ant Dev Corp Low Gain S-band Patch
- 4X4X0.25 inches



Ant Dev Corp Medium Gain X-band Patch Array Antennas
- 2.5X2.75X0.13 inches

Wallops In-House Fabrication & Testing Capabilities

Electro-Mechanical Fabrication Facility

Telemetry Ground Stations

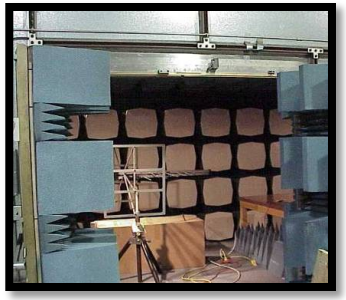
Integration Labs

Thermal Vac

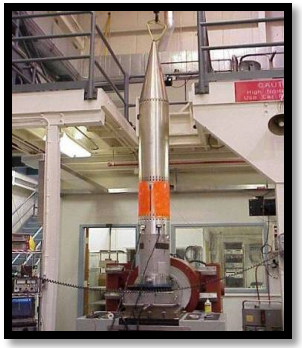
Bend Testing

Spin Deployment Facility

Magnetic Calibration Facility

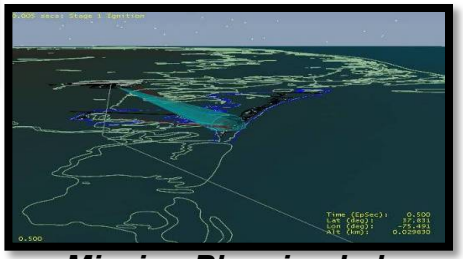


EMI/RFI Test Chamber

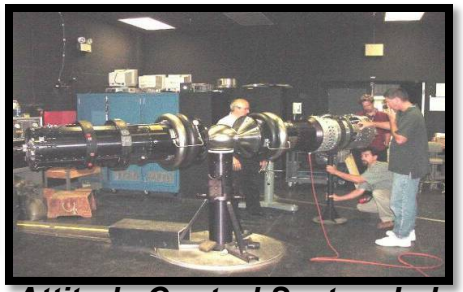


Vibration Test

Spin Balance



Mission Planning Lab



Attitude Control System Lab

Moment-Of-Inertia Testing

GPS Simulation & Test Lab

Antenna Patterning Chamber

Balloon Materials Lab

Clean Room/Tents

NASA Responded to Popularity of UHF for CubeSats
Wallops UHF CubeSat Ground Station (not SCaN)

- Specifications
  - Beamwidth: 2.9 degrees
  - Frequency Range: 380 to 480 MHz
  - Secondary Frequency Band: X-Band available for future high data rate CubeSat communication
  - Antenna Main Beam Gain: 35 dBi
  - Diameter: 18.3 meters (60')
- UHF Radar as a CubeSat Ground station
  - 1st used with Utah State University Dynamic Ionosphere CubeSat Experiment (DICE)
    - Interference
    - Morehead added as a back-up
  - Cutting-Edge CubeSat communication over a government-licensed UHF frequency allocation that enables high data rates (3.0 Mbit/Sec)
  - Currently communicating with the Firefly spacecraft
  - Slated for use for MiRaTA, Delingr, CeREs, HARP, IceCube, and many proposed CubeSats

Wallops UHF on left, S-Band on right

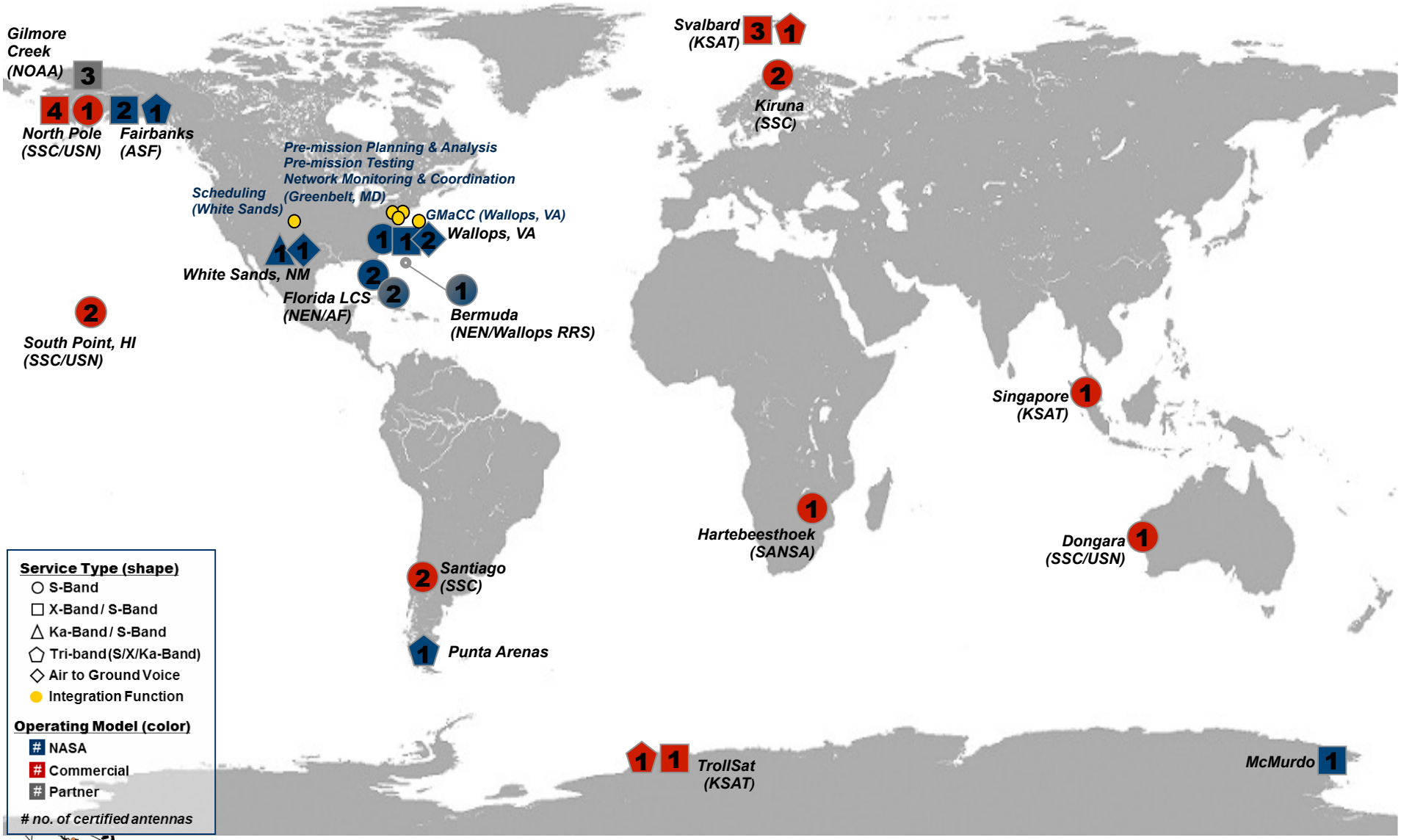
Morehead State University 21 Meter antenna

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 to maximizes reuse of ground station configurations

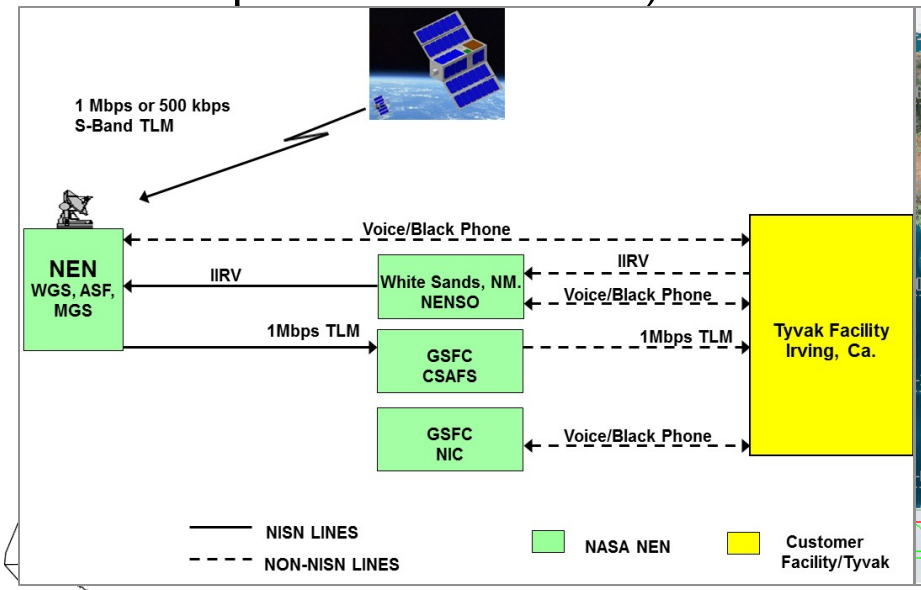
Near Earth Network Alaska Satellite Facility 11 Meter class antennas

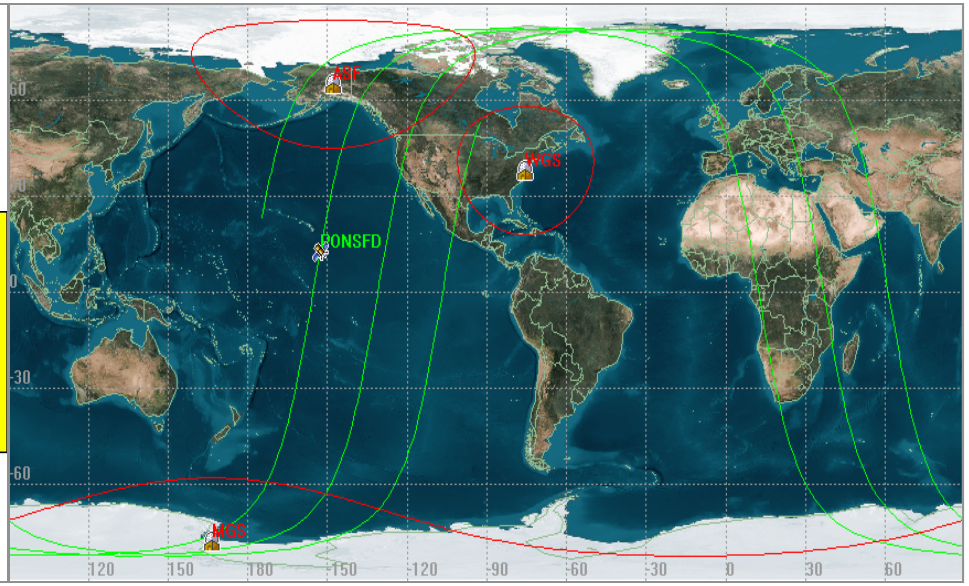
NEN Baseline after Projected Expansions (FY20)



NEN Upcoming CubeSat Support

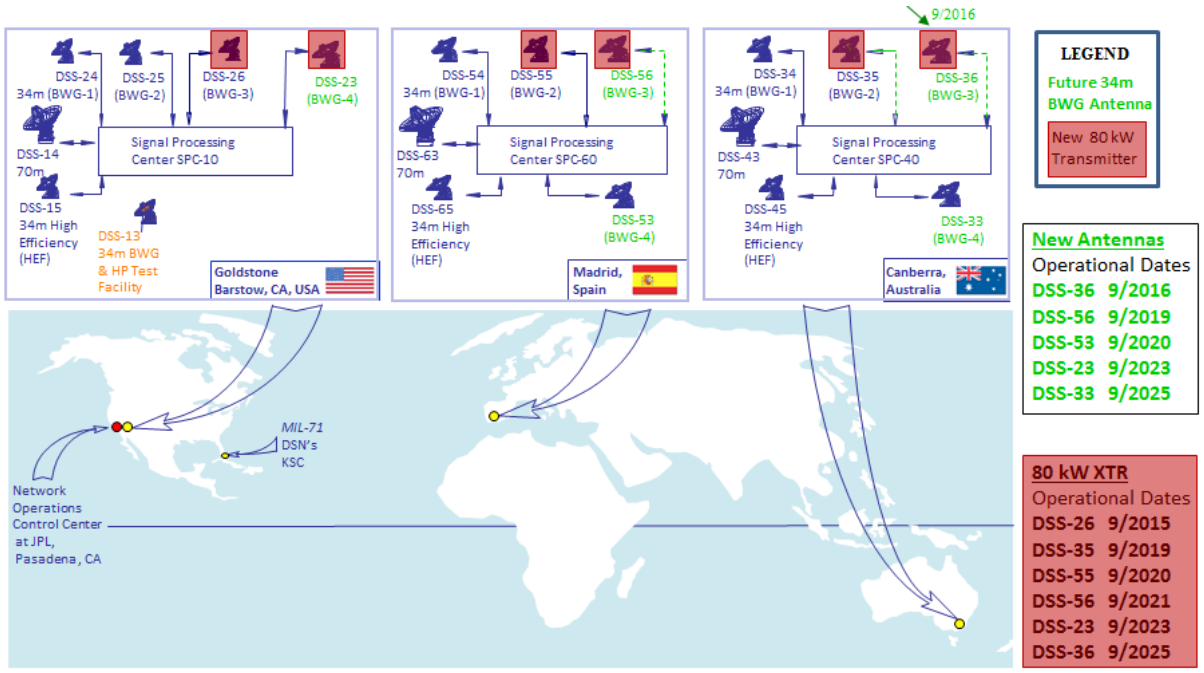
- The NEN will provide first time support to a CubeSat mission, CubeSat Proximity Operations Demonstration (CPOD), when it launches in 2015
  - Supporting Station: WGS 11m, ASF 11m, MGS 10m
  - Level of Support: 2 contacts per day with a minimum duration of 5 minutes
  - Service Provided: S-Band Telemetry
  - Data Rates: 1 Mbps or 500 kbps
  - Service Duration: L+30 days to L+6 months (possible extension of up to L+12 months)





Deep Space Network (DSN) Description

- NASA's international array of giant radio antennas that supports interplanetary spacecraft missions
- Operated by NASA's Jet Propulsion Laboratory (JPL), which also operates many of the agency's interplanetary robotic space missions
- Consists of three facilities spaced equidistant from each other – approximately 120 degrees apart in longitude – around the world, Goldstone, near Barstow, California; near Madrid, Spain; and near Canberra, Australia

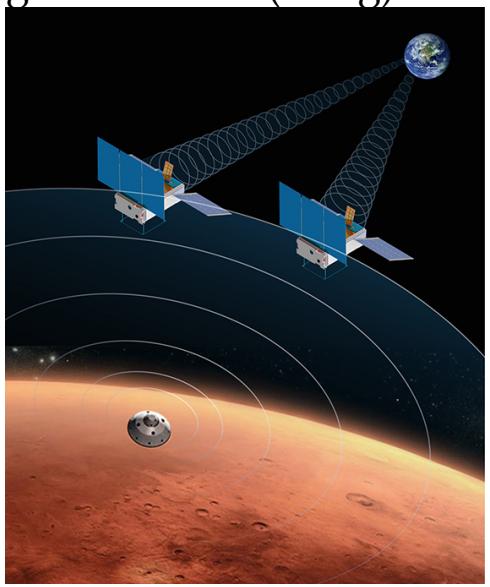


DSN Deep Space Station (DSS) Resources as of December 11, 2014

DSN: Beyond Earth Orbit SmallSat & CubeSat Support

- To date, no identified CubeSat has operated in cis-Lunar space or in deep space (> 2M km); however, small sats (e.g. micro-sats < 100 kg) have . . .
  - Lunar fly-by: Pioneer 4 (1959, 6 kg) first U.S. probe to escape from the Earth's gravity
  - Lunar orbit-first micro-sat?: Apollo 15 subsatellite (PFS-1) (36 kg) (1971)
  - Current Operational Example: ARTEMIS P1 & P2 (THEMIS B & C) (77 kg + 49 kg fuel at launch) currently operating in cis-Lunar and supported by DSN and NEN
  - Deep Space Example: Three (3) microsatellites were released with Hayabusa 2 (launch Dec 2014) in trajectories toward deep space including PROCYON (65 kg) which plans an asteroid flyby in 2016

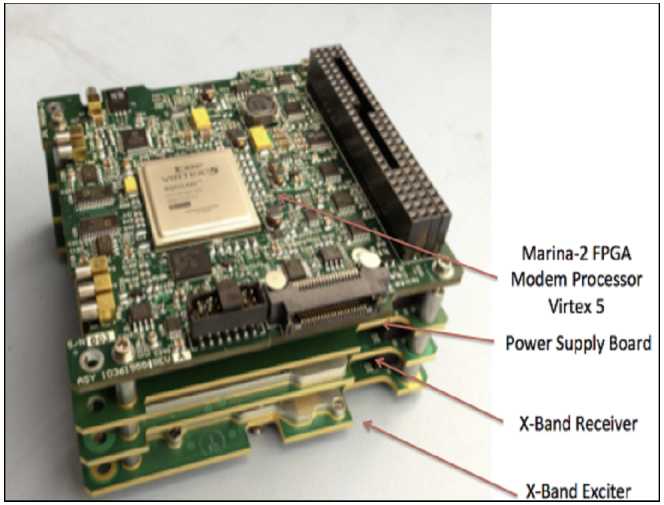
- **Deep Space (> 2M km) Planned Missions**
  - Mars Cube One (MarCO): Two (2) 6U CubeSats launching with Insight mission to Mars (March 2016)
    - Relay from InSight to MarCO at 401 MHz (8 kbps, Proximity 1 protocol standard)
    - Space-Earth support from DSN in 7/8 GHz deep space bands (8 kbps)
  - Other systems have been proposed and are even in development, but no deep space CubeSats are known to be manifested (except on EM-1 mission, next chart)



Concept Art of MarCO

DSN Evolution Toward CubeSat Compatibility (1)

- The DSN is pursing multiple efforts in response to the challenges associated with communication and navigation of SmallSats outside LEO, in lunar and deep space[1]
  - I. Developing a CubeSat compatible, DSN-compatible transponder: Iris
  - II. Developing CubeSat compatible high-gain antennas
  - III. Streamlining access and utilization processes for DSN and related services
  - IV. Developing methodologies for tracking & operating multiple spacecraft simultaneously
  - V. Coordination and collaboration with non-DSN facilities
- I. Iris Radio Development
  - Development began in 2013
  - DSN-compatible X-band transponder
  - Volume of 0.4 U and mass of 0.4 kg
  - CCSDS standards (e.g., AOS, Turbo, Conv., BPSK)
  - Return rates from 62.5 to 256,000 bps
  - Forward rates from 62.5 to 8000 bps
  - 32 Mbits of storage
  - Doppler, ranging, and delta-DOR tones supported



Iris Version 1 Prototype Stack

[1] *See the "Next-Generation Ground Network Architecture for Communications and Tracking of Interplanetary Smallsats" paper from corresponding author Kar-Ming Cheung for in depth details for each topic discussed regarding DSN Evolution*

Wallops Research Range

- The Research Range is a NASA-wide (& national) resource for providing safe, efficient, highly-capable services for flight research
  - >16,000 rocket launches since 1945
- Research Range Elements
  - Launch Range
  - Mobile Range
  - Research Airport
- End-to-end mission capabilities
  - Launchers & runways
  - Integration facilities
  - Tracking & data systems
  - Control centers
  - Range safety
  - Logistical services

Diverse Launch Capabilities

MARS Pad 0B

Runway-Based Launches

Pad 1 50K Launcher

20K ARC Rail Launcher

MARS Pad 0A

7.5 MRL Launcher

Navy Target Launchers

Overview of NASA International Cooperation

International cooperation at NASA

- Directed by the National Aeronautics and Space Act of 1958 and continues to be part of national space policy
- A cornerstone of NASA's activities throughout its history
- Includes over 3,000 agreements with over 100 nations
- Brings multiple benefits to NASA and its partners
- Pursued for a variety of reasons, through a combination of choice and necessity

Current international cooperation

- Nearly 500 active international agreements
- 8 partners account for 50% of agreements (France, Germany,ESA, Japan, UK, Italy, Canada, Russia)
- By mission area: 2/3 are in science missions
- By region: 1/2 are with partners in Europe

NASA International Cooperation Policy

- NASA international partners are generally government agencies due to the significant level of investment and legal requirements
- Cooperation must be consistent with U.S. foreign policy objectives
- **Projects/Partnerships:**
  - Must have scientific and technical merit
  - Must demonstrate a specific benefit to NASA, support Mission Directorate objectives
  - Are structured to protect against unwarranted technology transfer
  - Are structured to establish clearly defined managerial and technical interfaces to minimize complexity
  - Are documented in a formal agreement coordinated with the Department of State and other U.S. government agencies
- **Each Partner funds its respective contributions**
  - but contributions need not be equivalent
- **How Long Does it Take?**
  - On average, it takes 312 days to get an international agreement