



Aerospace at Morehead State University: Small Satellite R&D, Space Mission Operations and Academic Programs

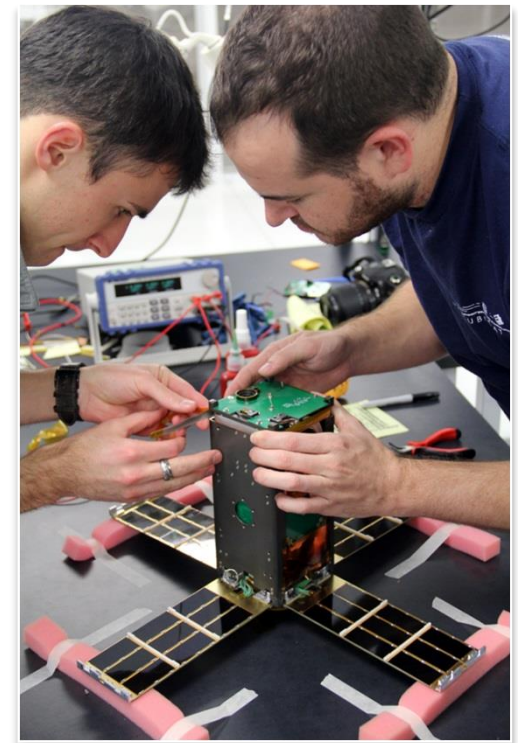


Dr. Ben Malphrus
Executive Director
Space Science Center



Briefing for the IJC on
Economic Development and
Workforce Investment

11/21/2019



Kentucky is an Aerospace State

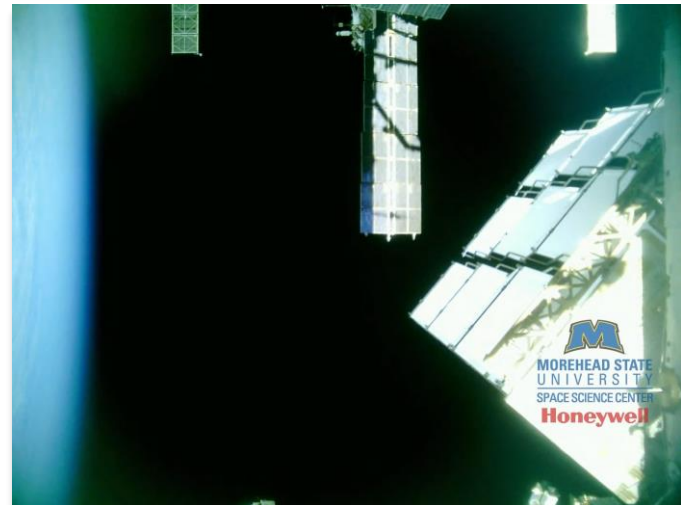
The aerospace/aviation footprint is expanding in Kentucky in almost every sector from parts manufacturing to supply, from air freight service to education and workforce development. Several factors contribute to the intense interest in Kentucky, chiefly a highly skilled and experienced workforce, excellent infrastructure and location.

AEROSPACE EXPORTS:

- KY's #1 Manufactured Export is Aerospace
- Aerospace exports have increased 183% in the past five years.

AEROSPACE EXPORTS:

- According to the U.S. Census Bureau, Kentucky ranked 2nd in the country in international exports of Aerospace Product and Parts in 2018, valued at \$12.56 billion,
- > \$14 billion in 2019



Aerospace in the Commonwealth

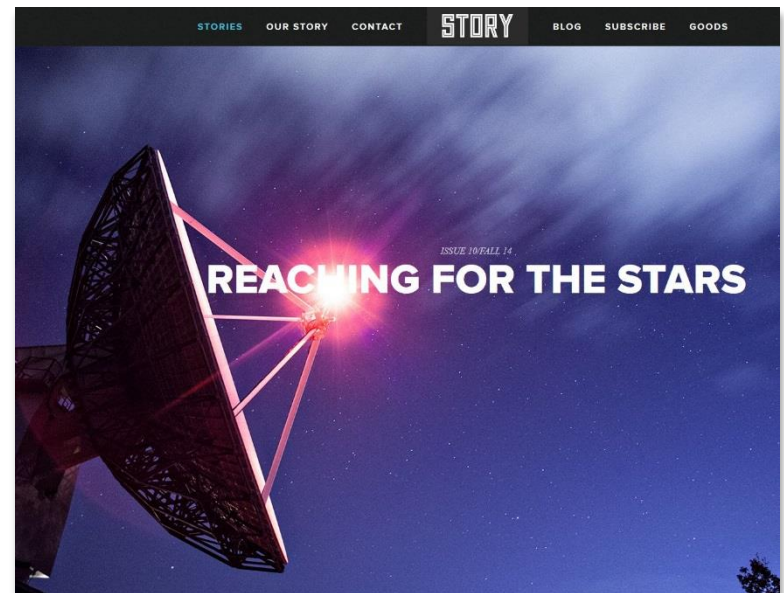


AEROSPACE EMPLOYMENT

In total, the cluster supports close to 21,000 jobs and \$1.46 billion in wages. There are approximately 9,300 people directly employed in the cluster, but the economic activity it generates supports additional jobs.

AEROSPACE EMPLOYEE INCREASE:

Kentucky has seen a 63 percent employee increase in the private aerospace products and parts manufacturing industry since 200



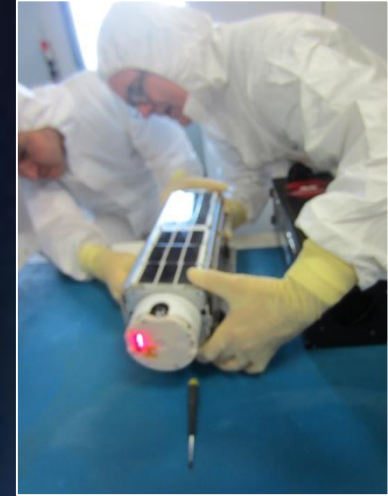
Morehead State and Aerospace- the Space Side of Aerospace



Bob Twiggs was one of the originators of the CubeSat concept while at the department of aeronautics and astronautics at Stanford University. Since 2009 he has been a professor at Morehead State University in Kentucky. Twiggs has a B.S. in electrical engineering from the University of Idaho and an M.S. in electrical engineering from Stanford.



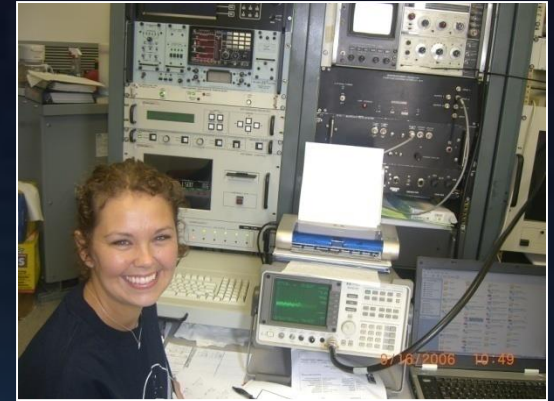
By 2005, Kris Kimel (KSTC) envisioned KY becoming a world leader in space technologies...



- Morehead State's Space Science Center has become Internationally Recognized as a Center for Excellence in Small Satellite Technologies and Space Mission Operations
- Morehead State has flown 6 small satellite missions with 4 in Development
- Morehead is the home of the inventor of the CubeSat satellite
- Morehead Currently has 7 NASA Contracts
- Aerospace Workforce Pipeline is in Place
 - Space-Related Degree Programs at Morehead State University
 - First Engineering Program in Eastern Kentucky
 - Only Aerospace Engineering CIP Code Degrees in Kentucky
 - Space-Trek, Space Prep, Go for Launch, Craft Academy



Creating the Next Generation Aerospace Workforce



Morehead State University Academic Programs Provide:

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



Kentucky's Best Assets for the Aerospace Industry
 Low operating costs
 Kentucky Aerospace Industry Consortium
 UPS Worldport
 Prime Air Hub
 Kentucky's Most Important Employers in the Aerospace Industry
 UPS
 GE Aviation
 Raytheon
 Lockheed Martin
 Safran Landing Systems
 Also receiving votes: BAE; Belcan; DHL; Prime Air; Meggitt; Phoenix Products; Space Tango.



The Best in Aerospace R&D in Kentucky

Morehead State University

University of Louisville
 Eastern Kentucky University
 Kentucky State University

Kentucky's Best Colleges for Aerospace Worker Training

Morehead State University

University of Louisville
 Eastern Kentucky University

Best Sites in Kentucky for Large Aerospace Assembly
 Glendale Megasite - Hardin County, Ky.
 West Kentucky Megasite - Graves County, Ky.

Best Places in North Kentucky for Aerospace Companies
 Jefferson County - Louisville, Ky.
 Boone County - Burlington, Ky.
 Kenton County - Covington, Ky.
 Campbell County - Newport, Ky.

Best Places in West Kentucky for Aerospace Companies
 Hopkins County - Madisonville, Ky.
 Daviess County - Owensboro, Ky.
 McCracken County - Paducah, Ky.
 Graves County - Mayfield, Ky.



MAJOR IN YOUR PASSION FOR THE STARS.

The Space Science Center at Morehead State University (Morehead, Kentucky) is a research and education center that focuses on the design, development and operation of small satellites and on providing hands-on training to the next generation of aerospace engineers through three degree programs.

SPACE SCIENCE PROGRAMS

- Master of Science in Space Systems Engineering
- Bachelor of Science in Astrophysics
- Bachelor of Science in Space Science

The Center provides satellite telemetry, tracking and control services with the 21 meter Space Tracking Antenna. The Center also provides spacecraft environmental testing services including vibration analysis, T-Vac testing, EM testing, and residual gas analysis.

The Center's staff and students have successfully flown several small satellite space missions with NASA and industry partners. Lunar IceCube, currently in development under a partnership with NASA's Goddard Spaceflight Center, JPL, and Boeing, has been selected to fly on NASA's Exploration Mission-1 in 2018: the maiden voyage of the Space Launch System—the most powerful rocket ever built.



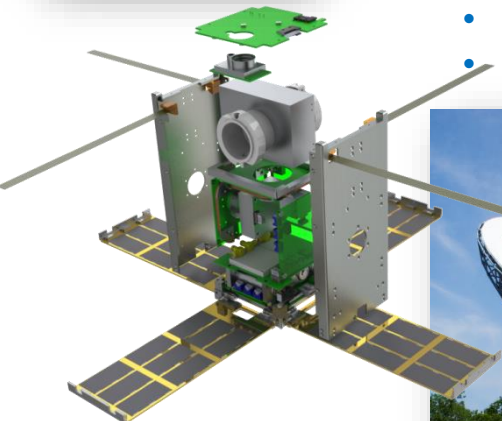
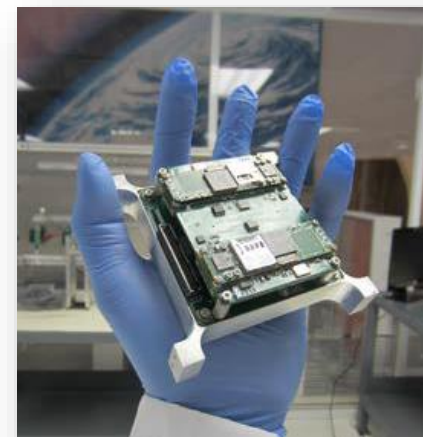


Aerospace Degree Programs:

- B.S. in Space Science
- B.S. in Physics Area Astrophysics
- M.S. in Space Systems Engineering

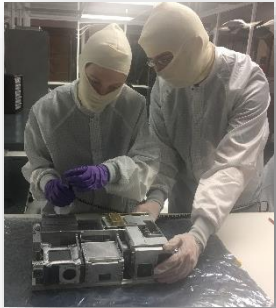
Program Highlights:

- B.S. in Space Science has ca. 100% Job Placement
- Extreme Hands-On Experiences
- Students Work on Actual Space Missions
- Students Develop Skillsets in:
 - Space Systems Development and Operation
 - Mechanical Systems Design and CAD
 - Electronics- Electrical Engineering
 - Microelectronics
 - Coding and Software Systems Development
 - Space Physics
 - Space Mission Architecture and Operations





B.S. in Space Science

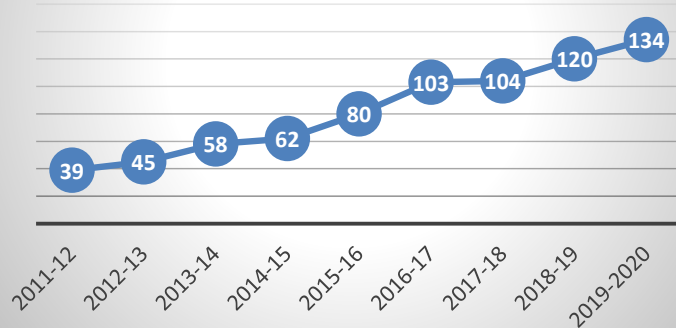


- Currently a Hybrid Science-Astronautical Engineering Program
- One of Only 5 Similar Undergraduate Programs in the U.S.
- **Transitioning into B.S. in Space Systems Engineering (Astronautical Engineering) Fall 2019**

Program Highlights:

- B.S. in Space Science has **Nearly 100%**
- **Job Placement**
- **40% of the Students are Female**
- Extreme Hands-On Experiences
- Students Work on Actual Space Missions
- Students Develop Skillsets in:
 - Space Systems Development and Operation
 - Mechanical Systems Design and CAD
 - Electronics- Electrical Engineering
 - Microelectronics
 - Coding and Software Systems Development
 - Space Physics
 - Space Mission Architecture and Operations
- Experience Significant Growth
- Poised for Expansion

Student Population in the
B.S. in Space Science
Program





M.S. in Space Systems Engineering



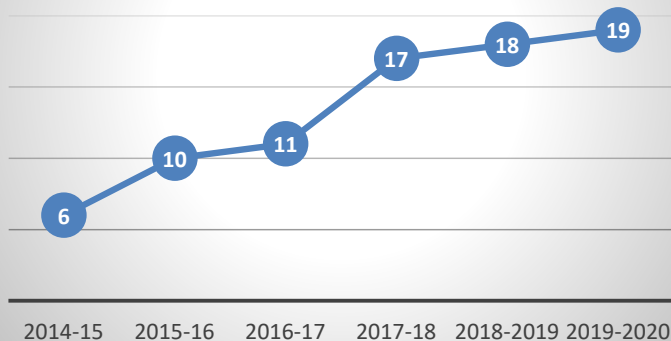
- Established in 2014
- First Engineering Program in Eastern Kentucky
- Produces Design-level Engineers
- Attracts Traditional and Non-Traditional Students

Program Highlights:

- M.S. in Space Systems Engineering has **Approximately 100% Job Placement**
- 80% of the Students are from U.S.*
- Extreme Hands-On Experiences
- Students Work on Actual Space Missions
- Students Develop Skillsets in:
 - Space Systems Development and Operation
 - Space Systems Design
 - Electronics- Electrical Engineering
 - Microelectronics
 - Software Systems Development
 - Program Management
 - Space Mission Architecture and Operations

* ITAR and EAR Considerations Restrict the number of International Students to NATO Countries

Student Population in the
M.S. in Space Systems
Engineering Program





B.S. and M.S. in Space Systems Engineering Where Students Originate and Where They Go

Origins- Morehead State Students Originate from:

Undergraduate:
80% from Kentucky
20% from Other States:
Ohio, WV, NY, CA



Graduate:
85% from U.S.
15% International:
Italy, England, Korea, Viet Nam,
Ukraine, Russia*

*Morehead State's ITAR Compliance Policy restricts the international students and the projects that they can be involved with/exposed to

Workforce Placement- Morehead State Graduates are Employed by:

- JPL
- NASA Johnson Space Center
- NASA Glenn Research Center
- Air Force Institute of Technology
- Rajant Corporation
- Space Micro, Inc
- Space Dynamics Laboratory
- Tyvak
- Lockheed Martin
- ViaSat
- Honeywell
- Aerotek
- Terran Orbital

Accepted into Ph.D. Programs at:

- MIT, Cornell, Purdue, GA Tech, University of Michigan



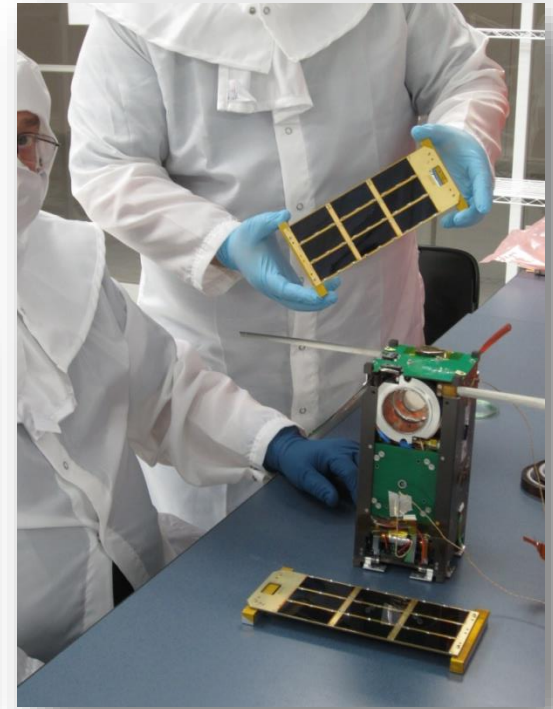
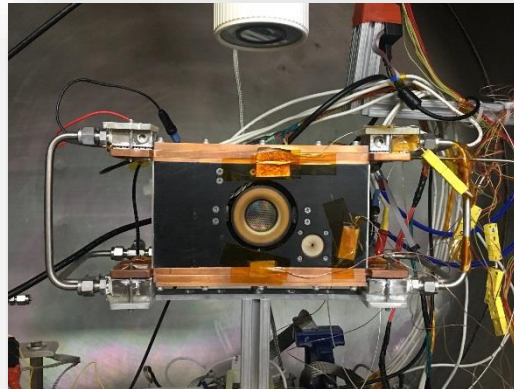
MOREHEAD STATE UNIVERSITY

NANOSATELLITE TECHNOLOGIES

AT

MOREHEAD STATE UNIVERSITY

Leading the Space Segment of Aerospace
in Research and Development
And Workforce Training



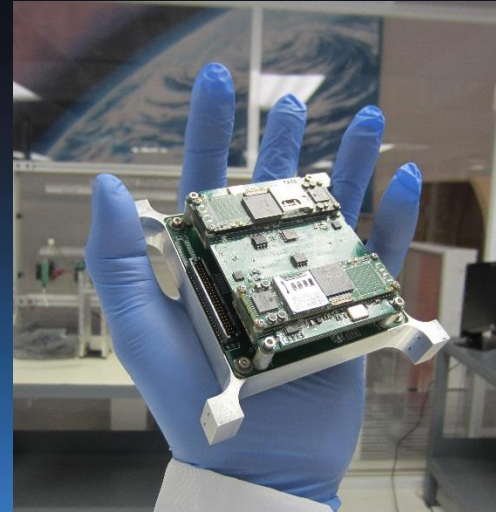
The Next Big Thing is Small

- Projections indicate substantial growth, with an estimated 500 nano/microsatellites launched globally by 2020
- Constellations of Small Sats Used for:
 - Data Transfer
 - Financial Transactions
 - Homeland Defense
 - Tactical Security
 - GPS
 - Navigation, AIS
 - Earth Remote Sensing (with un-precedented refresh rates)
 - Inventory from Space



Small Size, Big Capability

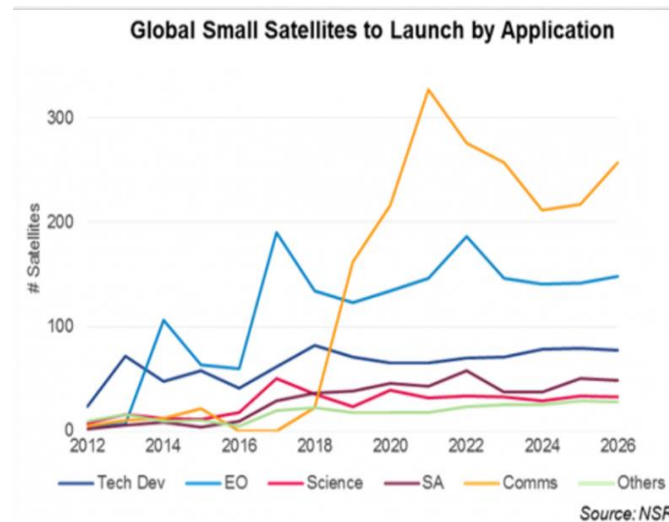
- Constellations of SmallSats Used for:
 - Data Transfer
 - Financial Transactions
 - Homeland Defense
 - Tactical Security
 - Asset Tracking
 - Internet Delivery
 - Earth Remote Sensing (with un-precedented refresh rates)
 - Data Exfiltration from Unattended Ground Sensors
 - Interplanetary Research



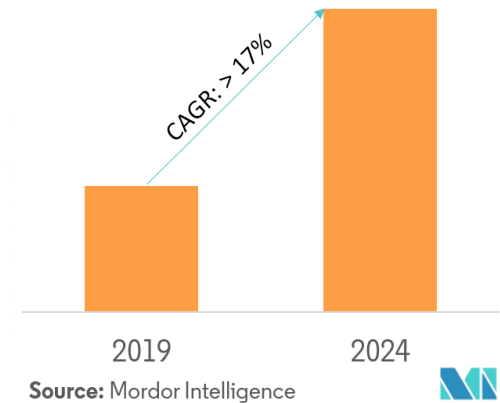
DM-7 Designed
and Built by
Morehead
State and
Honeywell
Space and
Defense
Technologies

SmallSat Market

- Smallsat market forecast to exceed \$30 billion in coming decade- *SpaceNews August 9, 2017*
- The small satellite market was valued at \$3,632.4 million in 2018, and is expected to reach \$15,686.3 million by 2026, *Allied Market Research 2019*
- SmallSat market requires a different operational model than large monolithic GEO constellations



Small Satellite Market - Summary



CST's alliance with strategic partners fills a significant market niche when mobilized in the window of opportunity



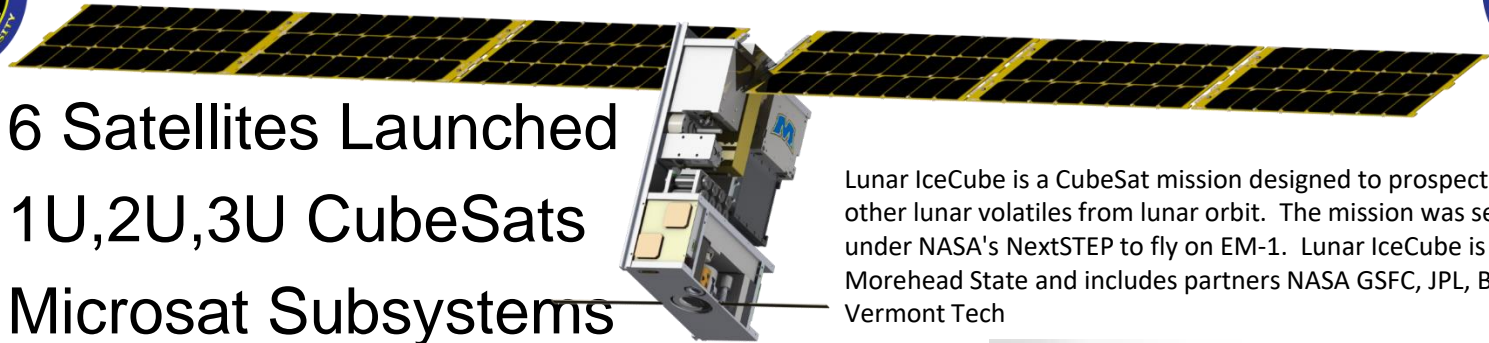
Morehead State SmallSat Missions



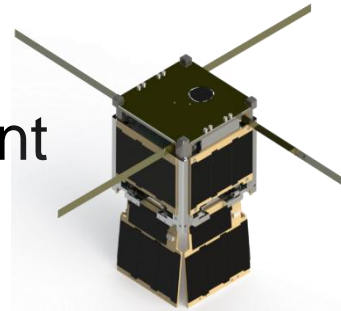
- 6 Satellites Launched
- 1U,2U,3U CubeSats
- Microsat Subsystems
- PocketQubs
- 6U Bus in Development
- Interplanetary Mission
- Variety of Customers



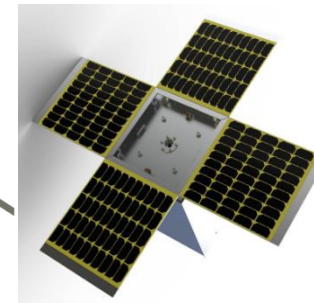
KySat-1
Secondary
on NASA's
Glory
Mission



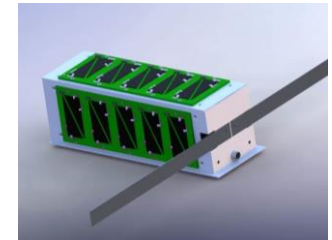
Lunar IceCube is a CubeSat mission designed to prospect for water ice other lunar volatiles from lunar orbit. The mission was selected under NASA's NextSTEP to fly on EM-1. Lunar IceCube is led by Morehead State and includes partners NASA GSFC, JPL, Busek, and Vermont Tech



KySat-2 Launched in
October 2013



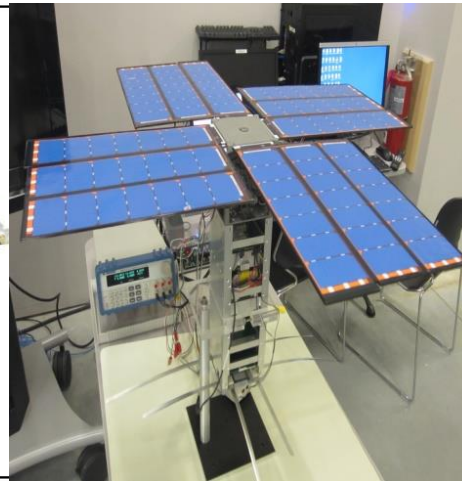
UniSat-5 w/ Univ. of
Roma-GAUSS launched
2014



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



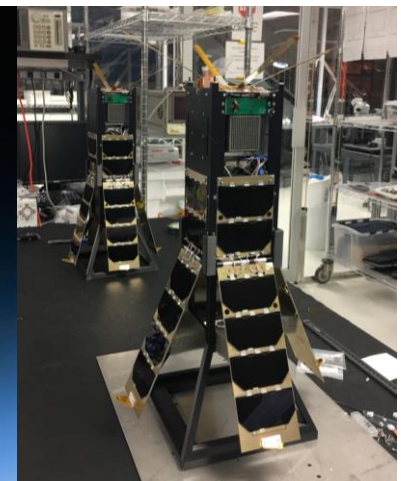
CXBN Launched in 2012



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



Standard MSU 3-U Bus



CXBN-2 Launched in 2016

Partnerships: Government, Universities and the Private Sector

– Government

- NASA- JPL, GSFC
- Department of Defense
 - DARPA, Space and Missile Defense Command



– Universities & Consortia

- University of Rome
- Stanford and Calpoly
- Johns Hopkins APL
- Craft Academy
- MIT

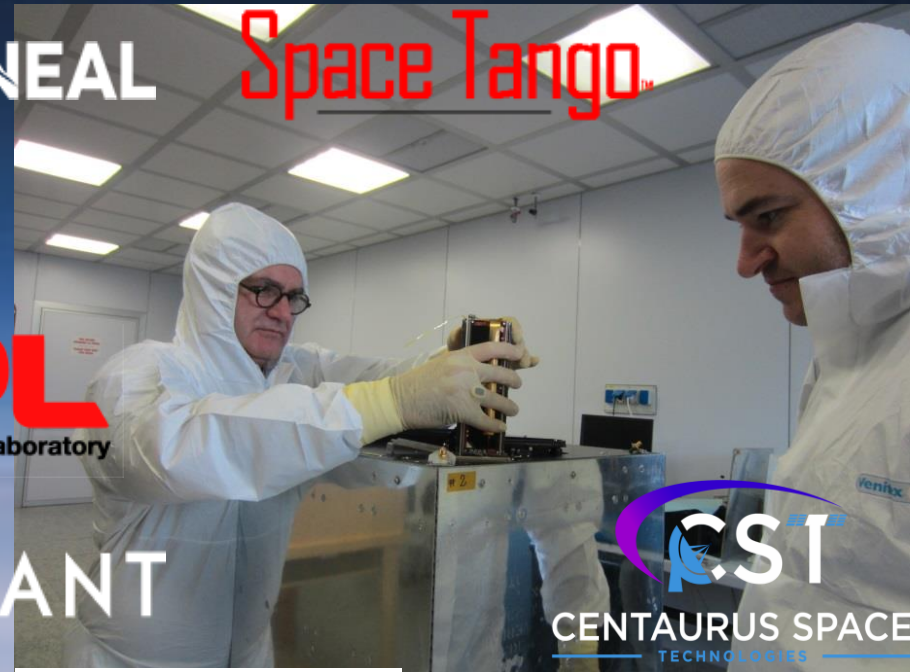


BONEAL

Space Tango

– Aerospace and Related Companies

- Honeywell Space and Defense
- Radiance
- Busek
- GAUSS
- Kosmotras
- Space Tango
- Rajant
- MEDO



Morehead State University Space Science Center Partnerships



Massachusetts
Institute of
Technology



Partnerships with
Government,
Universities, and the
Private Sector



PUCP



Space Science Infrastructure at Morehead State

- \$15.4 M Facility Devoted to Space Research and Development
- Small Spacecraft Designed, Built, Tested Entirely in House
- On-Orbit Operations with 21 M Space Tracking Antenna
- Infrastructure Development Supported by:
 - State of Kentucky
 - Federal Appropriations
 - Morehead State
 - NASA
 - KSTC
 - US DoD
 - MSU Foundation
 - Alumni/ Donors
 - Faculty-Staff
 - Grants
 - Service Contracts



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Mars Curiosity

With Mars Methane Mystery Unsolved, Curiosity Serves Scientists a New One: Oxygen

New Horizons

New Horizons Kuiper Belt Flyby Object Officially Named 'Arrokoth'

NASA Events

Thu., Nov. 14, 11:45 a.m.: Vice President Pence Visits the Ames Research Center

Fri., Nov. 15, 6:30 a.m. EST: NASA TV Coverage of AMS Repair Spacewalk

Sun., Dec. 1, 6:30 a.m. EST: Russian Progress Cargo Spacecraft Launch to Space Station (NASA TV Begins 6 a.m.)

Tues., Dec. 3, 8 a.m. EST: Russian Progress Docking to Space Station

REGISTRATION OPEN: NASA Social - Boeing Starliner Uncrewed Flight Test, Kennedy Space Center

REGISTRATION OPEN: NASA Social - Artemis Day at Michoud Assembly Facility, New Orleans

[NASA TV Schedule](#) [Launches and Landings](#)

Mercury Transits the Sun

On Mon., Nov. 11, Mercury passed between the Earth and the Sun, silhouetting it against our home star. The passage, which astronomers call a transit, won't be visible again from Earth until 2032. NASA's Solar Dynamics Observatory sent back images of the transit. The NASA HQ photo team also captured images.

Moon to Mars

NASA Opens Previously Unopened Apollo Sample Ahead of Artemis Missions

Moon to Mars

All Four Engines Are Attached to the SLS Core Stage for Artemis I Mission

TESS

NASA's TESS Presents Panorama of Southern Sky

Solar System and Beyond

NASA's Mars 2020 Will Hunt for Microscopic Fossils

Exoplanets

NASA Instrument to Probe Planet Clouds on European Mission

CubeSats

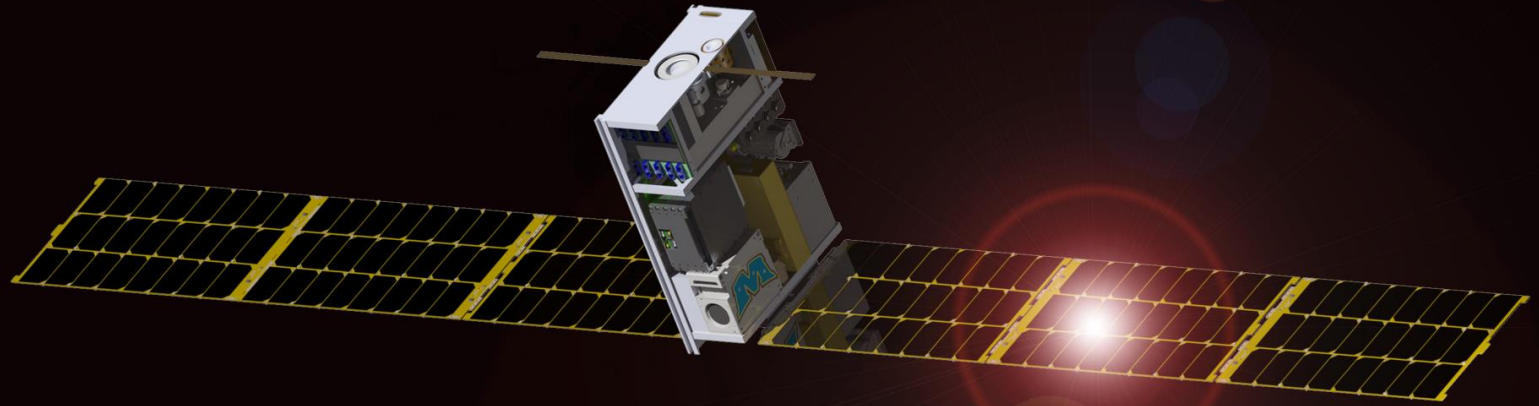
Small Satellite to Study Resources Needed for Sustained Lunar Presence

MORE STORIES



Lunar IceCube

- Winner of NASA's NEXTStep Contract
- NASA Lunar Mission Led by Morehead State
- \$24M Mission
- Launches on the Maiden Voyage of SLS in 2020- the most powerful rocket ever built
- Front Page News- NASA Website on 11/14/2019



Lunar IceCube Selected for Launch on Artemis 1 in 2020
Currently Under Development at



Morehead State



NASA GSFC



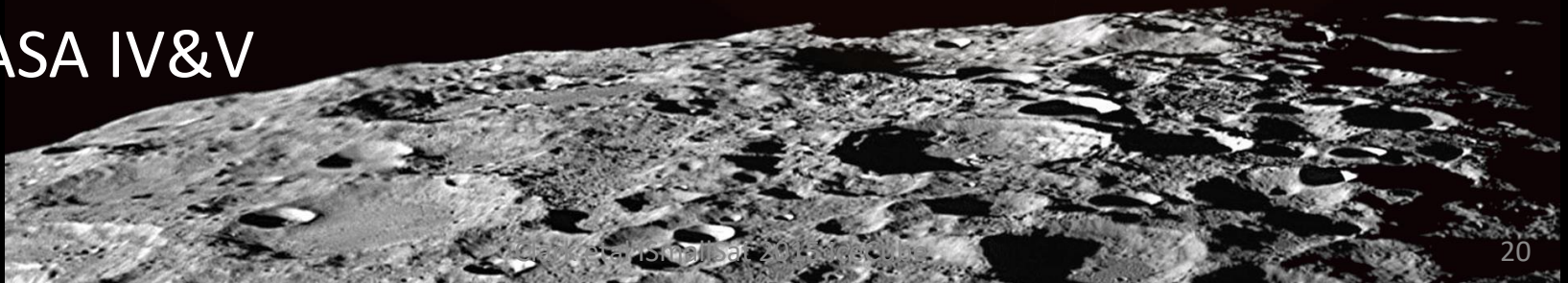
JPL



Busek



NASA IV&V



Lunar IceCube Project Team



A small scale (\$24M USD) interplanetary mission undertaken by a small team

The Team consists of university, NASA, and private sector partners:

- **Morehead State University Space Science Center**
 - Ben Malphrus (PI), Jeff Kruth, Kevin Brown, Michael Combs, Jose Garcia,
 - **48 Students (24 Graduate Students and 24 Undergraduate Students)**
 - **40% of Student Team is Female**
- **The Busek Company**
 - Mike Tsay, John Frongillo, Josh Model
- **NASA Goddard Spaceflight Center**
 - **BIRCHES Team:** Clifford Brambora, Terry Hurford, Robert MacDowall
 - **Navigation and Tracking:** David Folta, Sun Huir-Diaz
 - **Attitude Control:** Paul Mason, Robert Nakamura, Joseph Breeden
 - **FSW:** Justin Morris, Matt Grubb, Scott Zemerick, Cody Cutright
- **NASA JPL**
 - Pamela Clark (Science PI), Kris Angkasa, Vaughn Cable, Alessandra Babuscia



Lunar IceCube Project Overview



Mission Description and Objectives

Lunar IceCube is a 6U small satellite whose mission is to prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, inclined lunar orbit using NASA GSFC's BIRCHES - IR spectrometer. **1.)** Lunar IceCube will be deployed by the SLS on EM-1 and **2.)** use an innovative RF Ion engine combined with a low energy trajectory to achieve lunar capture and a science orbit of 100 km perilune.

Strategic Knowledge Gaps

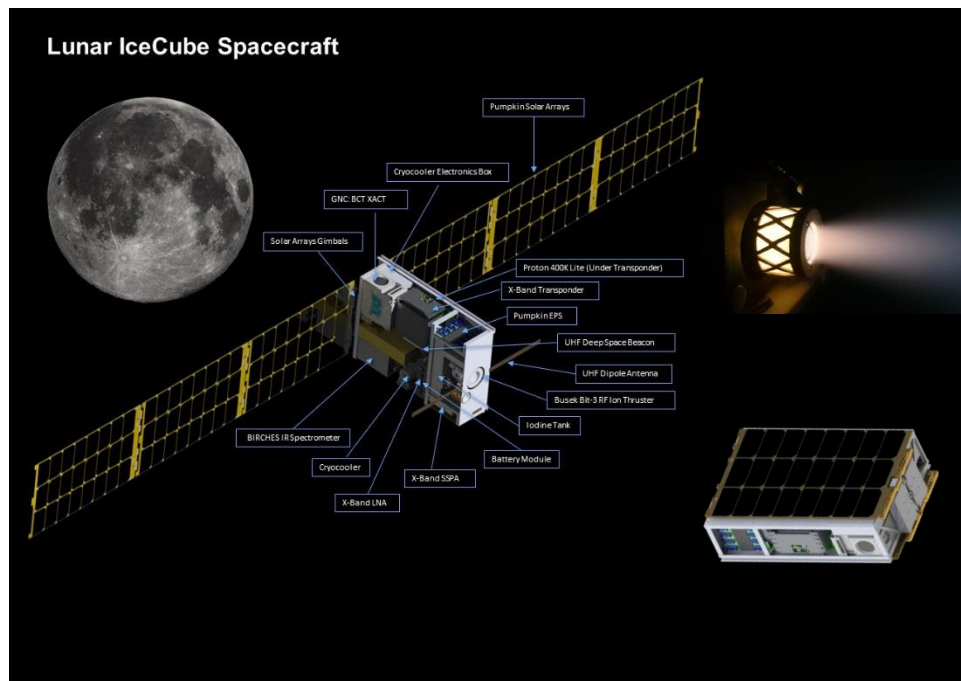
1-D Polar Resources 7: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H₂O deposits toward PSR retention

1-D Polar Resources 6: Composition, Form and Distribution of Polar Volatiles

1-C Regolith 2: Quality/quantity/distribution/form of H species and other volatiles in mare and highlands regolith (on the final inclination of the Lunar IceCube orbit)

Technology Demonstrations

- **Busek BIT 3** - High isp RF Ion Engine –
- **NASA GSFC - BIRCHES** Miniaturized IR Spectrometer - characterize water and other volatiles with high spectral resolution (5 nm) and wavelength range (1 to 4 μ m)
- **Space Micro C&DH-** Inexpensive Radiation-tolerant Subsystem
- **JPL Iris v. 2.1** Ranging Transceiver
- **BCT- XACT** ADCS w/ Star Tracker and Reaction Wheels
- **Custom Pumpkin-** High Power (120W) CubeSat Solar Array

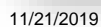
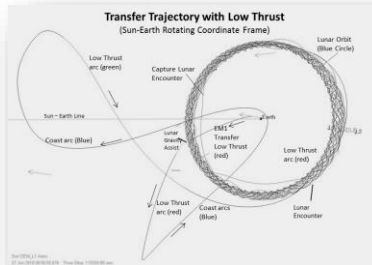


Current Status

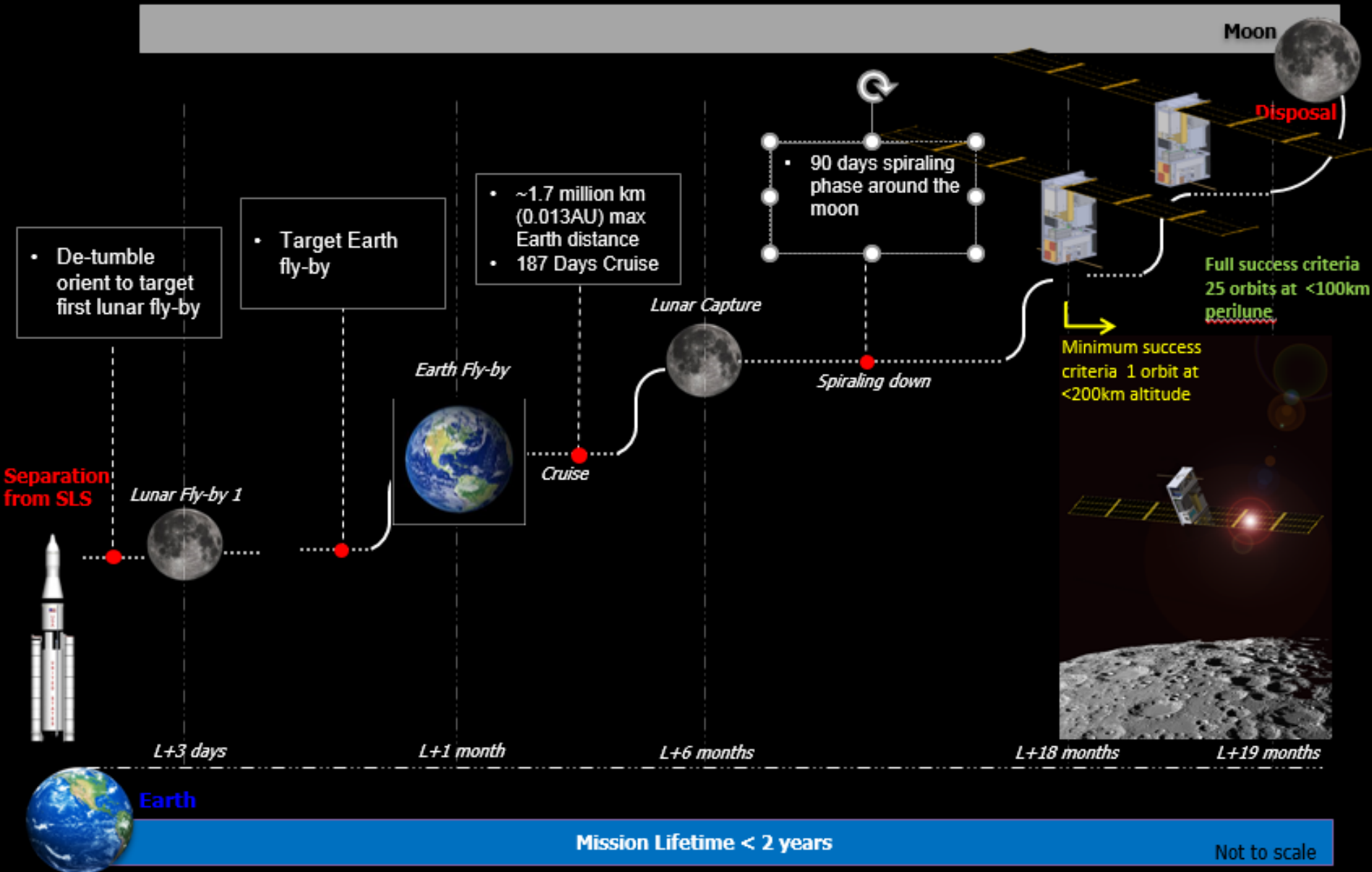
- Team is in **AI&T**, Delivery of final Flight Hardware anticipated in November
- Dry Build Underway
- Preparing for Flight Build and Comprehensive Performance Testing
- FSW in testing
- ACS Model Refined, Closed-Loop Control in Development
- Working Toward Closing Phase III Safety SVTLs (5/6 are Closed)
- FRR Scheduled for 03/21/2020

PDR	Phase 1	CDR/	Δ CDR	Phase 2	Phase 3	FRR	Launch	Mission Ops	Mission Duration	Project Closure
05/19/2016	06/20/2016	05/16/17	03/14/18	04/26/2018	05/23/2019	03/21/2020	NOV 2020	2020-2022	2 years incl. ext.	2022-23

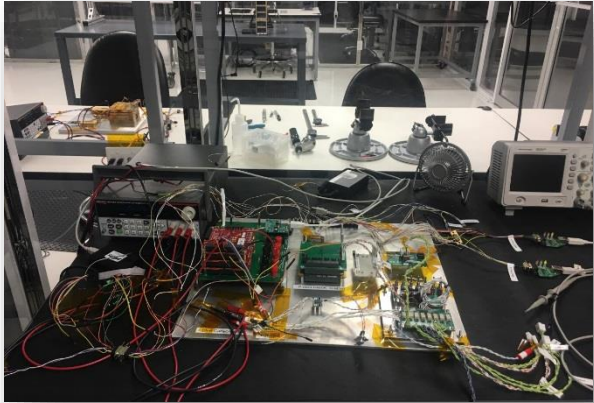
- Busek BIT 3 - High isp RF Ion Engine –
- NASA GSFC - BIRCHES Miniaturized IR Spectrometer - characterize water and other volatiles with high spectral resolution (5 nm) and wavelength range (1 to 4 μm)
- Use of Analytic tools to Define Low Energy Manifold Trajectory for Lunar Trajectory and Capture
- Space Micro C&DH- Inexpensive Radiation-tolerant Subsystem
- JPL Iris v. 2.1 Ranging Transceiver
- BCT- XACT ADCS w/ Star Tracker and Reaction Wheels
- Custom Pumpkin- High Power (120W) CubeSat Solar Array



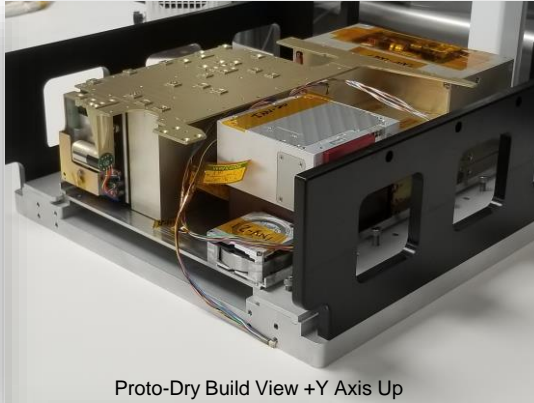
Lunar IceCube ConOps



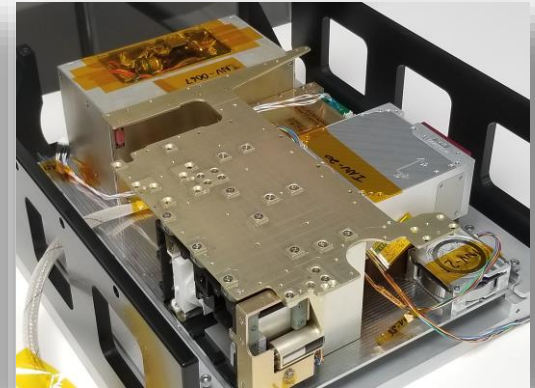
Lunar IceCube Hardware Developments to Date



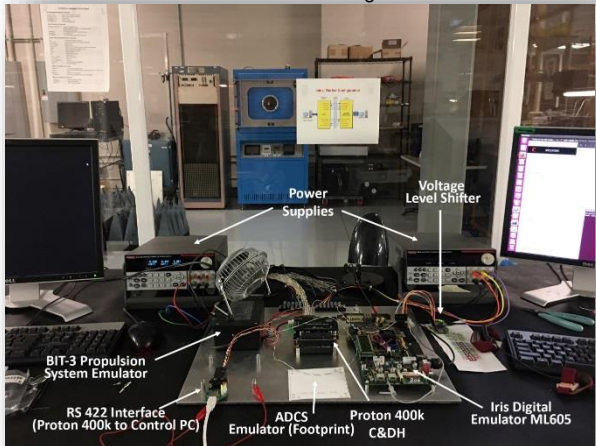
FlatSat- Current Configuration



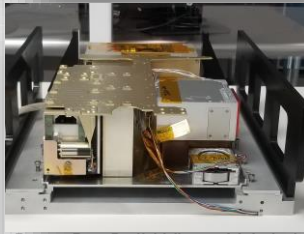
Proto-Dry Build View +Y Axis Up



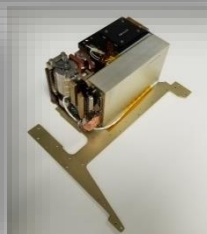
Proto-Dry Build View +Y Axis Up



FlatSat- Configuration 1.0 with Labels



Proto-Dry Build View +Y Axis Up



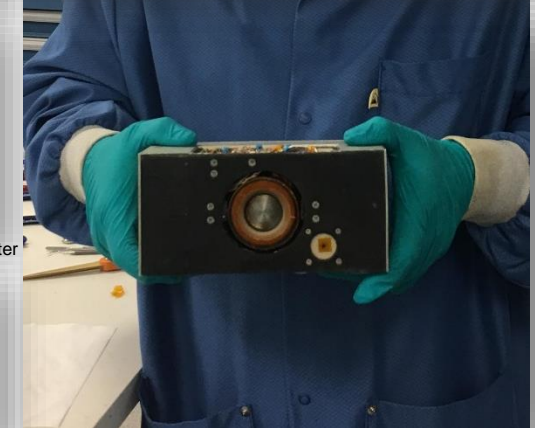
BIRCHES IR Spectrometer



BIT-3 Propulsion System QM



BIRCHES IR Spectrometer



BIT-3 Propulsion System FM



Enabling University-Operated Tracking and Communications for Deep Space Smallsat Missions

Funded by NASA's Advanced Exploration Systems (AES)

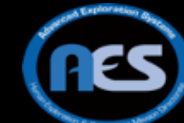
Ben Malphrus, Jeff Kruth (MSU)
Tim Pham, Jay Wyatt, (JPL)



MOREHEAD STATE UNIVERSITY



In Partnership with
Jet Propulsion Laboratory
California Institute of Technology



DSN Affiliated Ground Station (DSS-17) for Interplanetary SmallSats- Morehead State 21 m

Project Description and Objectives

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.

Technical Approach

- Develop and implement a strategy to transfer Deep Space Network (DSN) processes and protocols to the MSU 21 m antenna system to enable integration into the DSN as an auxiliary station to support small spacecraft missions.
- Implement deep space communications, tracking and navigation techniques as well as adoption of CCSDS standards.
- Implement systems upgrades, conduct tests/demonstrations, and transition to an operational capability.

Benefits

- Serves as a test-case 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 2019 timeframe



Current Status

- DSN “Lite” System Defined and in Development/Procurement
- H-MASER Procured
- Cryogenic X-Band LNA Procured
- X-Band Feed in Development

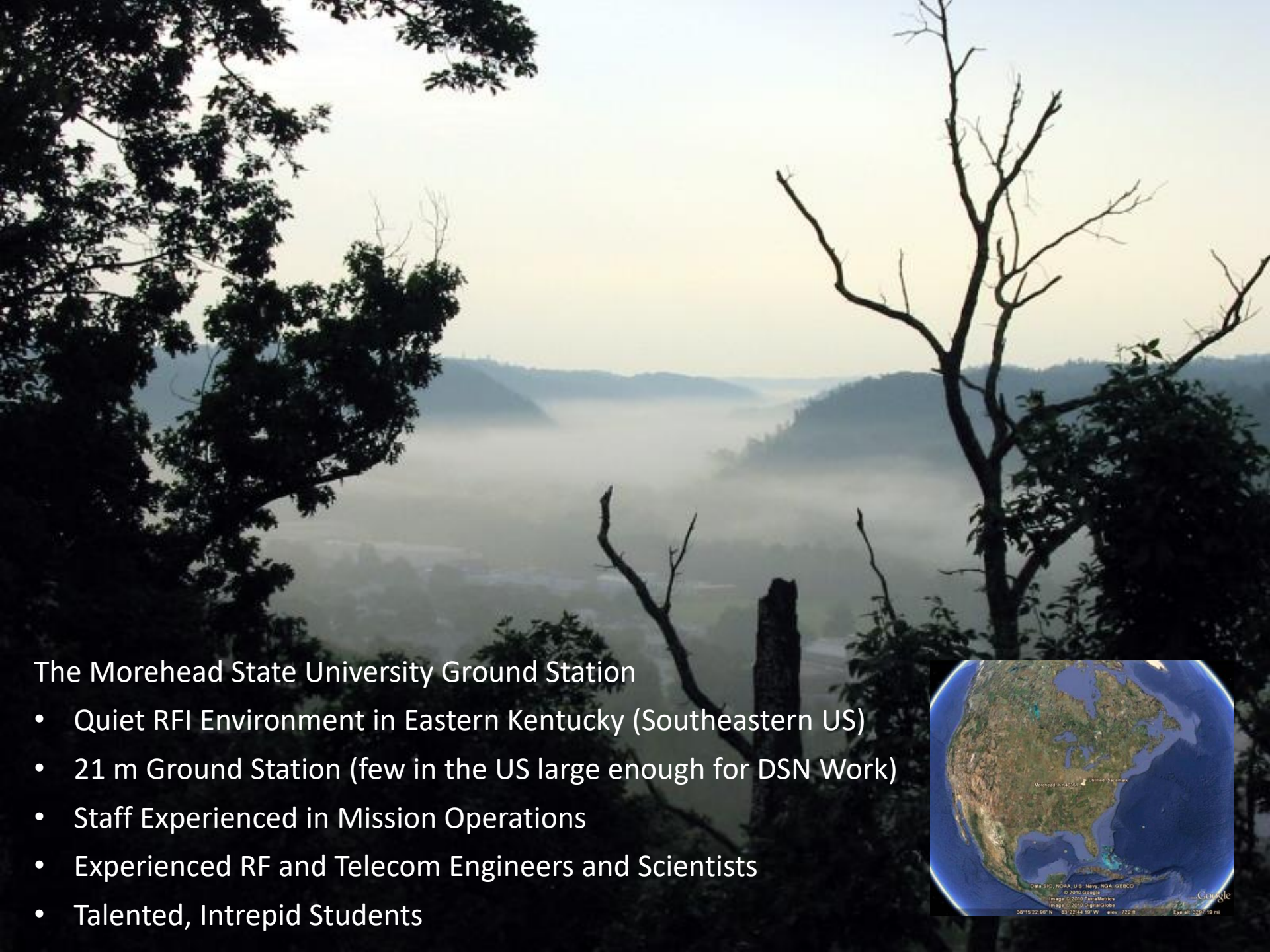
Critical Milestones

ΔSRR	IoNet Connection	Downlink Demo-MarCO	Uplink Demo	Ranging Demo	ORR	Operational	Mission Ops	Mission Duration	Project Closure
01/15/2016	05/30/2018	5/15/2017	02/15/2019	5/15/2018	10/30/2019	10/15/2019	1/1/2020	EM-1 CubeSats Duration	EM-1 CubeSats Closure

Morehead State University

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 \$6 M -a variety of sources- Morehead State, Federal and State Funds, KSTC, NASA
 - Built and Installed by VertexRSI (General Dynamics)
 - Operational in 2006

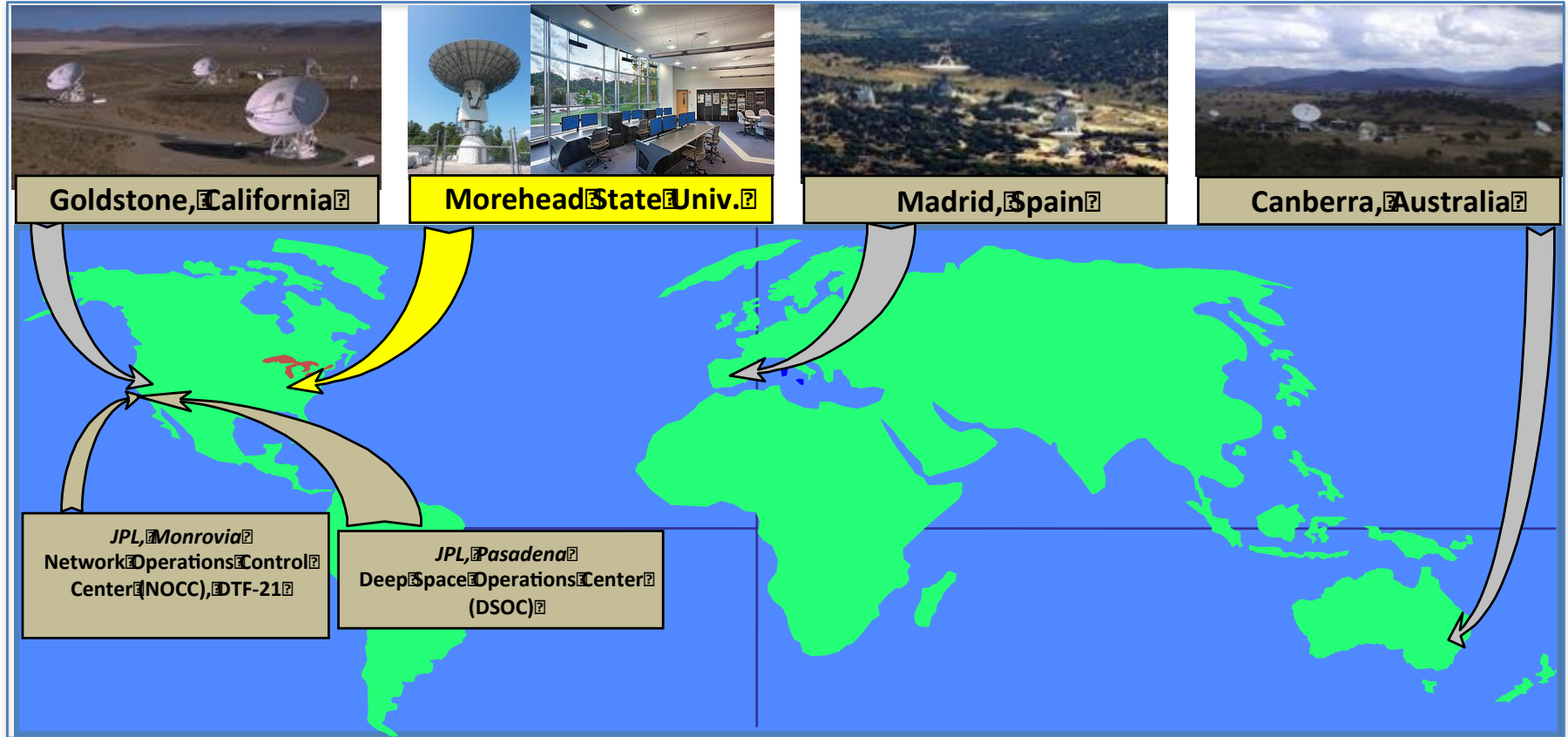


The Morehead State University Ground Station

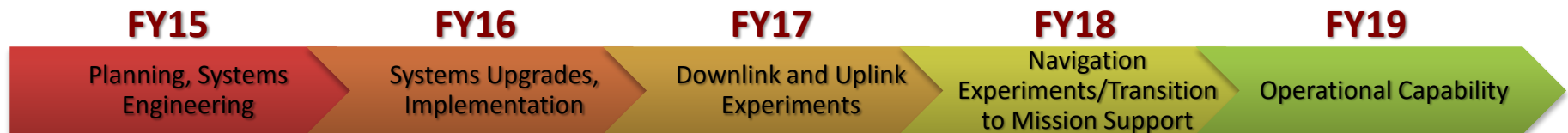
- Quiet RFI Environment in Eastern Kentucky (Southeastern US)
- 21 m Ground Station (few in the US large enough for DSN Work)
- Staff Experienced in Mission Operations
- Experienced RF and Telecom Engineers and Scientists
- Talented, Intrepid Students



NASA's DEEP SPACE NETWORK (DSN)



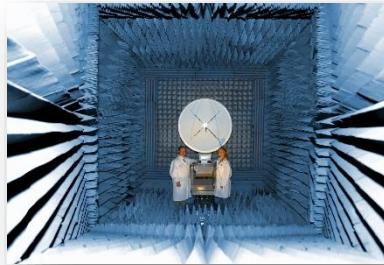
- MSU 21 M will become the first non-NASA asset on the DSN
- NASA investing \$650K in 21 M Upgrades





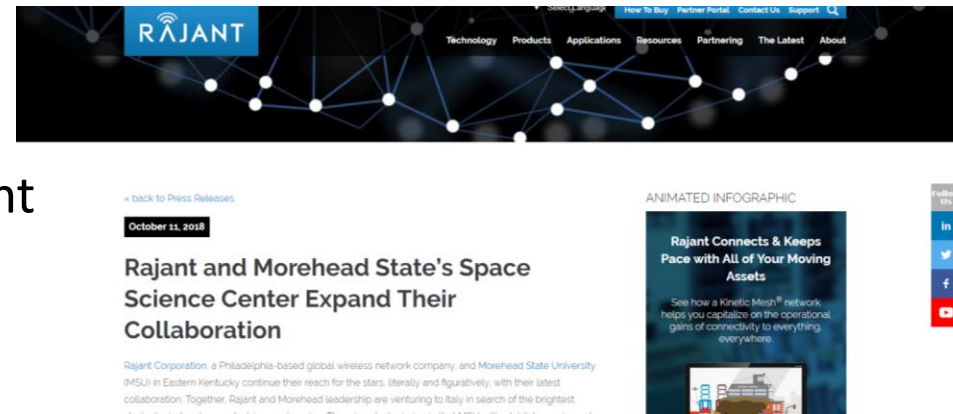
Private Sector Partnership- Regional Economic Development Initiatives

- Business Incubator Partnership- Innovation Launch Pad
- Spin-Offs
 - Morehead Electronics and Space Technologies
 - Centaurus Space Systems
 - K-MEC
 - AstroDev
- Graduate's Companies
 - Labyrinth Inc.
 - Bamboo RF
- Affiliated Companies/Partnerships
 - Rajant Technologies
 - Honeywell Space and Defense
 - GAUSS
 - Busek Inc.
 - Roccoor



Private Sector Partnership- A Case Study Rajant Technologies

- Rajant- Pioneer of Kinetic Wireless Mesh Technologies
- HQ in Philadelphia, U.S.
- Partner on Tech Development, Contracts, Grants
- Located R&D Subsidiary in Morehead, KY
- Hired Nearly 30 Graduates to Date
- 23 Work at Morehead Location
- Utilize Space Science Center Staff Talent Facilities
- Undertake Joint Talent Recruitment Efforts
- Effective Symbiotic Relationship



SmallSat Constellations for Defense Applications- Utilizing DTN, High-level Encryption and SpaceMesh

RAJANT



An Overview Briefing v.11.10.2019

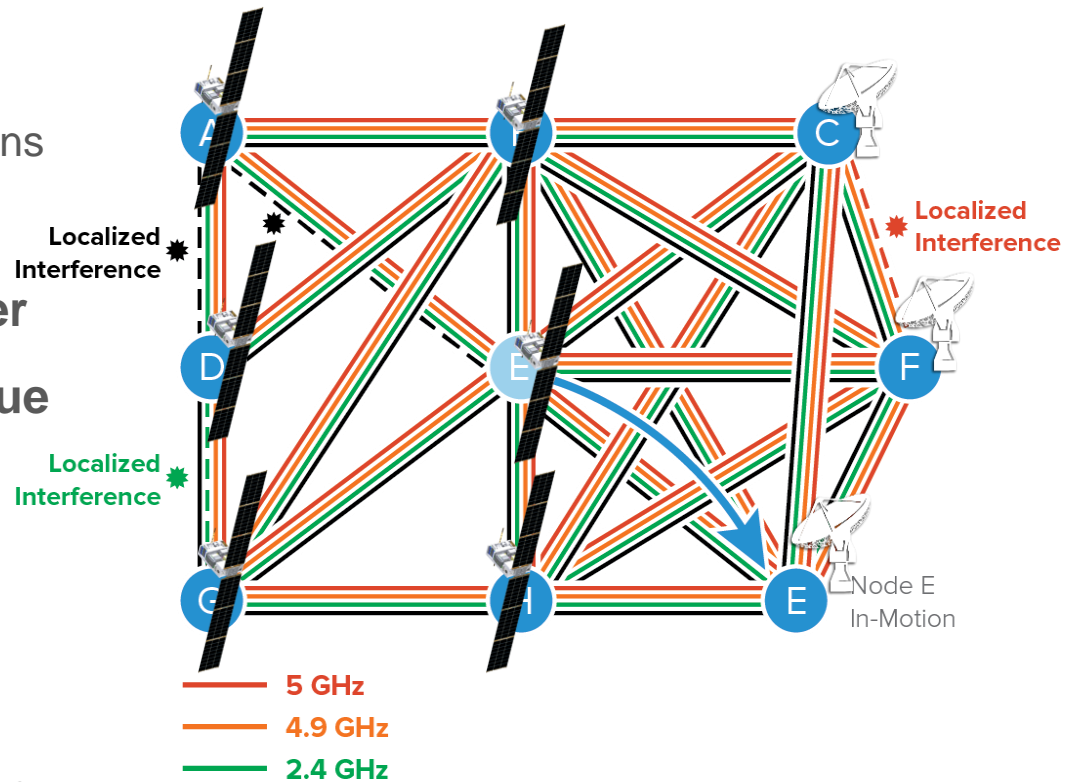


CENTAURUS SPACE TECHNOLOGIES

InstaMesh® to be Expanded to Constellations- SpaceMesh

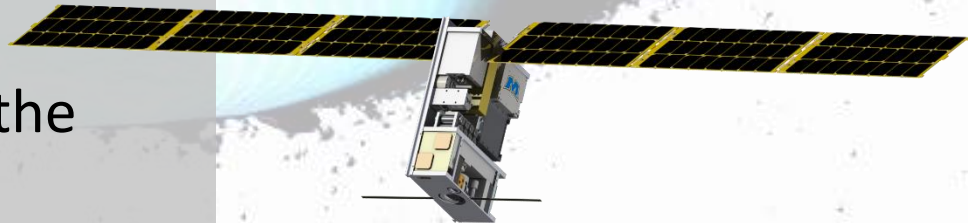
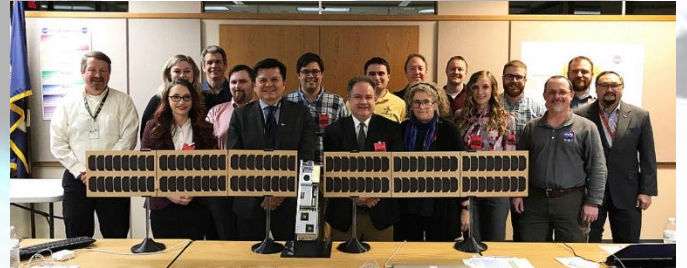
Rajant, CST and Morehead State are working toward adapting the InstaMesh technology for inter-satellite constellations

- **Inter-satellite comms, *when accomplished*, is a game-changer**
- **Turns groups of satellites into true constellations**
- **Tremendously improves:**
 - Data throughput
 - Latency
 - Ground network optimization
- **Allows the use of DTN- disruption tolerant networking**



In Conclusion

- Kentucky has (quietly) become an Aerospace-based Economy
- Many opportunities for Young Kentuckians to join the aerospace industry, related R&D and related technology innovation
- Morehead State's Lunar IceCube will be on the Maiden Voyage to the Moon of the Most Powerful Rocket Ever Built
- We are entering a new era of Space Exploration with Small Satellite Platforms- Artemis 1 and Constellations: Morehead is at the Forefront



Questions?



Me transmittite sursum, Caledoni

Back-Up

NASA Video

https://www.youtube.com/watch?v=OZvDAAl_JM0&feature=youtu.be