CubeSat Identification Tag (CUBIT): Architecture and Test Results from an On-Orbit Demonstration

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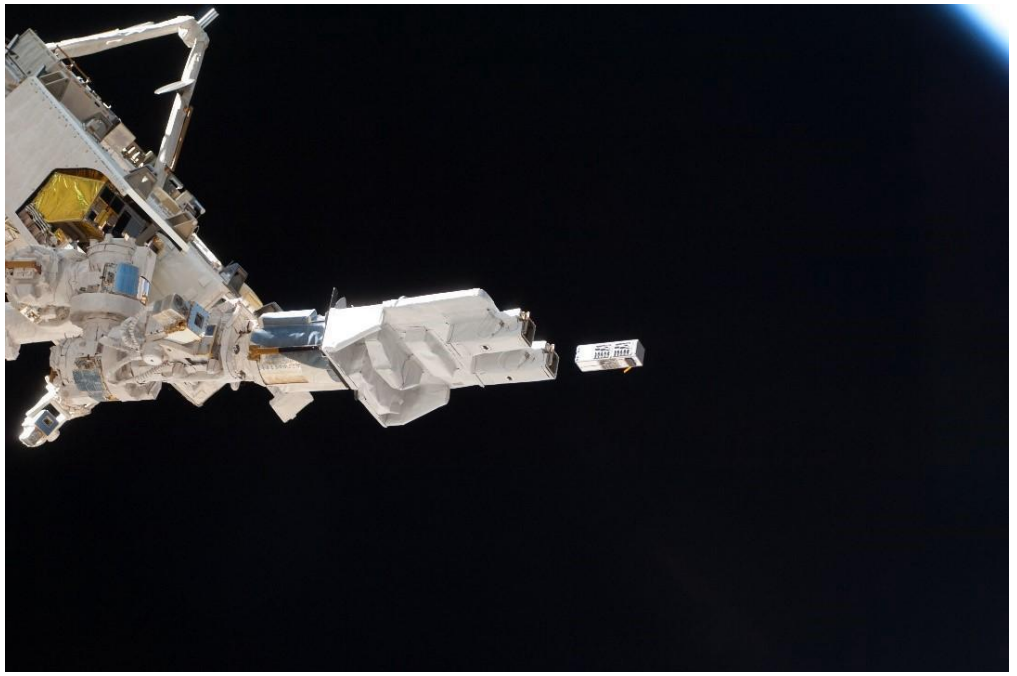

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SRI International®

Who We Are

SRI International

A world-leading independent R&D organization

- SRI is an independent, nonprofit R&D corporation
  - Founded by Stanford University in 1946 ("Stanford Research Institute")
  - More than 1900 employees, 20 locations worldwide
- SRI's Signals and Space Technology Laboratory specializes in developing sensing technology for extreme environments and novel applications
  - Create *new paradigms for innovation* in signals and space technology
  - Enable rapid and low-cost technology-driven demonstrations and missions
  - Invest in new architectures and capabilities
  - Move technology across "valley of death"
    - Transition concept to mission operations
  - Increase space access
- SRI owns and/or operates a number of radar and RF facilities for R&D

SRI/Washington – Rosslyn, VA / Washington, D.C.

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SRI Ground Systems

Supporting On-Orbit ConOps development and demonstration

150ft Dish (the "Big Dish")

Located: Foothills of Stanford University
Operated by SRI International
Current Uses: Satellite performance verification, spacecraft command and telemetry, radio astronomy and weak signal detection.

Typical Gain, Efficiency and Beamwidth			
150 MHz	35 dB	55%	3.0°
400 MHz	43 dB	55%	1.0°
1420 MHz	52 dB	35%	0.25°

60ft Dish

Located: Foothills of Stanford University
Operated by SRI International
Current Uses: Spacecraft command and telemetry, and weak signal detection.
Supported CubeSats for on-orbit communication issues.

Typical Gain and Beamwidth		
430 MHz	35 dB	3°
915 MHz	42 dB	1.2°
1400 MHz	44 dB	0.9°
2400 MHz	46 dB	0.8°

Jamesburg Earth Station

Location: Carmel Valley, CA
Operated by SRI International
98ft solid surface dish with C-band feed

Typical Gain, Field of View and Resolution			
1.5 GHz	53 dB	2.3°	170"
3 GHz	59 dB	1.2°	
6 GHz	65 dB		

Allen Telescope Array (ATA)

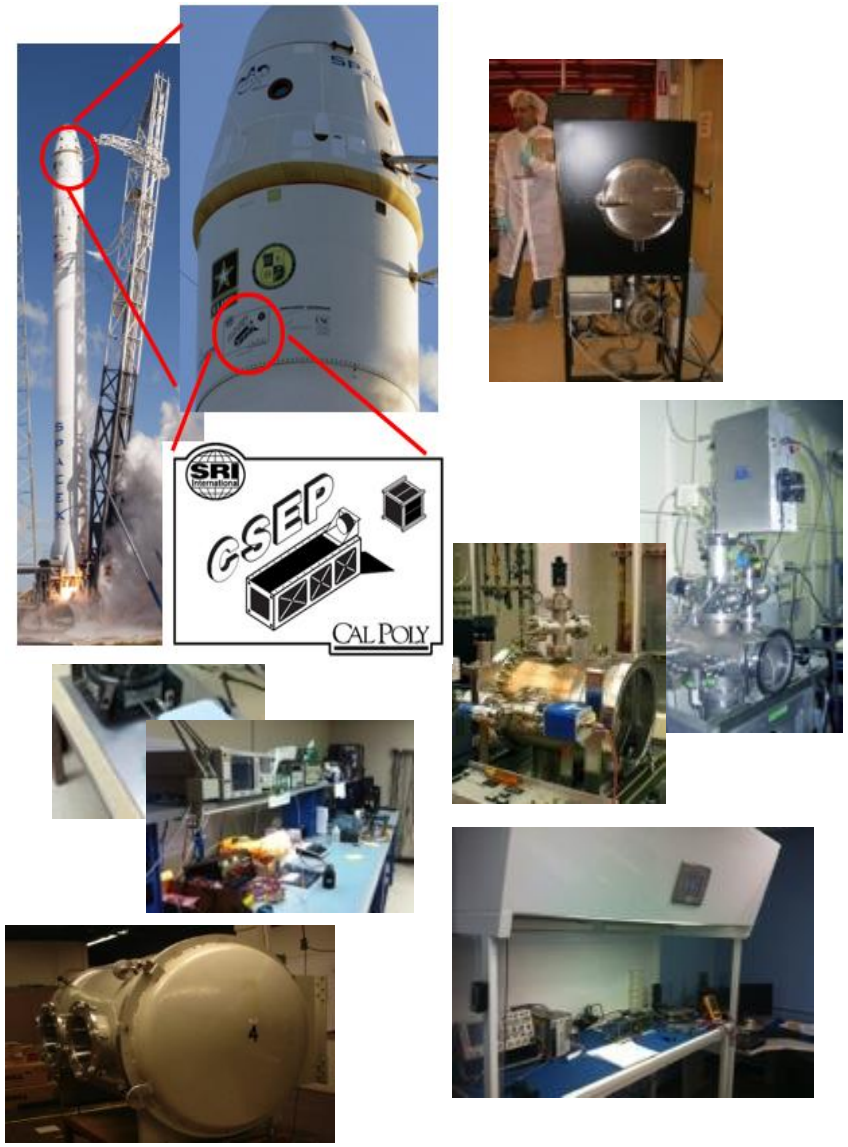
Location: Hatcreek Radio Observatory
Operated by SRI International
Array of 42 small 20ft dishes with frequency range 0.43 GHz to 11.2 GHz is capable of creating images and spectra.
Current Uses: SETI, communication and tracking, ConOps studies

Typical Gain, Field of View and Resolution			
1.5 GHz	53 dB	2.3°	170"
3 GHz	59 dB	1.2°	83"
6 GHz	65 dB	0.58°	42"

SRI Space-related Facilities

Space Technology Integration

- **Small Satellite Technology Evaluation Lab (SSTEL)**
  Mission planning and analysis, ground operations, electronics development and technology assessment
- **CubeSat Integration Lab (CIL)**
  Facilities approved for fabrication, assembly, integration and vacuum bakeout of Cal Poly P-PODs
- **Spacecraft Materials Characterization Lab (SMCL)**
  Electrostatic discharge characterization, electron bombardment, and UV illumination of materials to simulate space environment interactions
- **Space Particle Source Test Lab (SPSTL)**
  Vacuum systems including ion and electron sources, life test, oxygen plasma, and scanning Langmuir probe
- **Sensor Payload Development Lab (SPDL)**
  Facilities for instrument development, thermal vacuum testing, UV testing, and clean assembly
- **Tank Lab**
  Two clean benches and bonded stores for flight h/w.
- **Vacuum Test Chamber**
  Existing SRI thermal vacuum chamber being reconditioned for larger CubeSats

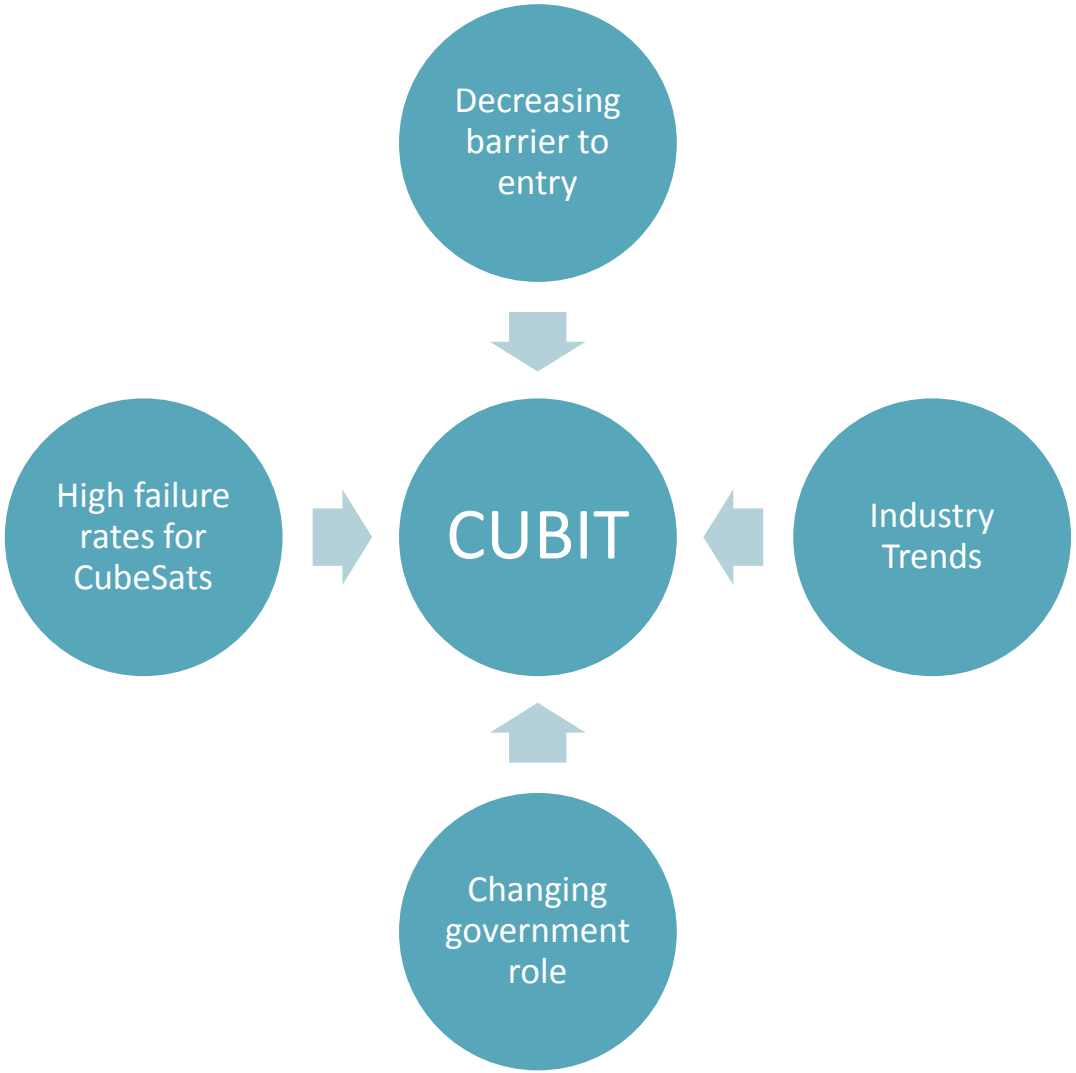


SRI CubeSat Flights and Prototyping Programs

1. **RAX 1** – NSF w/Univ. Michigan Bus - P-band bistatic radar receiver (1 launched. 2010)
2. **RAX 2** – NSF w/Univ. Michigan Bus - P-band bistatic radar receiver (1 launched, 2011)
3. **SENSE** – SMC w/Boeing 3U-Bus - CTIP UV photometer instrument (1 launched)
4. **MIST** – AFRL ionospheric beacon experiment payload for MicroSat, not CubeSat (integrated, waiting for launch)
5. **Cricket** – Client Private FemtoSat (<100gm satellite) design and prototyping (many prototyped and tested; never flown)
6. **Messenger** – Client Private (w/Tyvak Bus) SDR-based communications and signals experiment (2 launched, 2015)
7. **ISX** – NASA w/CalPoly Bus – 4-channel radar receiver (ready for integration into bus; launched 2018)
8. **TBEx** – NASA w/Univ. Michigan Bus - Tri-band RF ionospheric beacon experiment (Launch NET 9/2018)
9. **IT-SPINS** – NASA w/ APL + MSU/SSEL Bus - CTIP UV photometer-enabled ionospheric tomographic mission (Launch NET 10/2018)
10. **CHSI** – CubeSat Hyperfine Spectral-line Imaging instrument development (NRO IEI program, 2008)
11. **SINOD** – Client Private deployable antenna, SDR-based, and crosslink technology maturation (prototypes, 2010-2014)
12. **Manta** – DARPA radar and communications characterization satellite (detailed design project; not funded for flight)
13. **Lemur** – Client Private communications network constellations (design and prototyping project)
14. **CIRES** – NASA Earth observation CubeSat SAR Payload and system design (prototype built, tested, ready for airborne test)
15. **C-SAR** – Commercial CubeSat-scale SAR system designs (2 design projects)
16. **EA FemtoSat** – DARPA CubeSat tech demo of electroadhesion and FemtoSat platform
17. **AERIE** – NASA Univ. Michigan and SwRI, 6 microsatellites each with 4 SRI photometers, not CubeSat (Under Review)
18. **CamdenYards** – DARPA HF ionospheric receiver (detailed design and prototyping (Phase 1 completed)

CubeSat Identification Tag (CUBIT) Architecture

CUBIT Fulfills a Growing Need

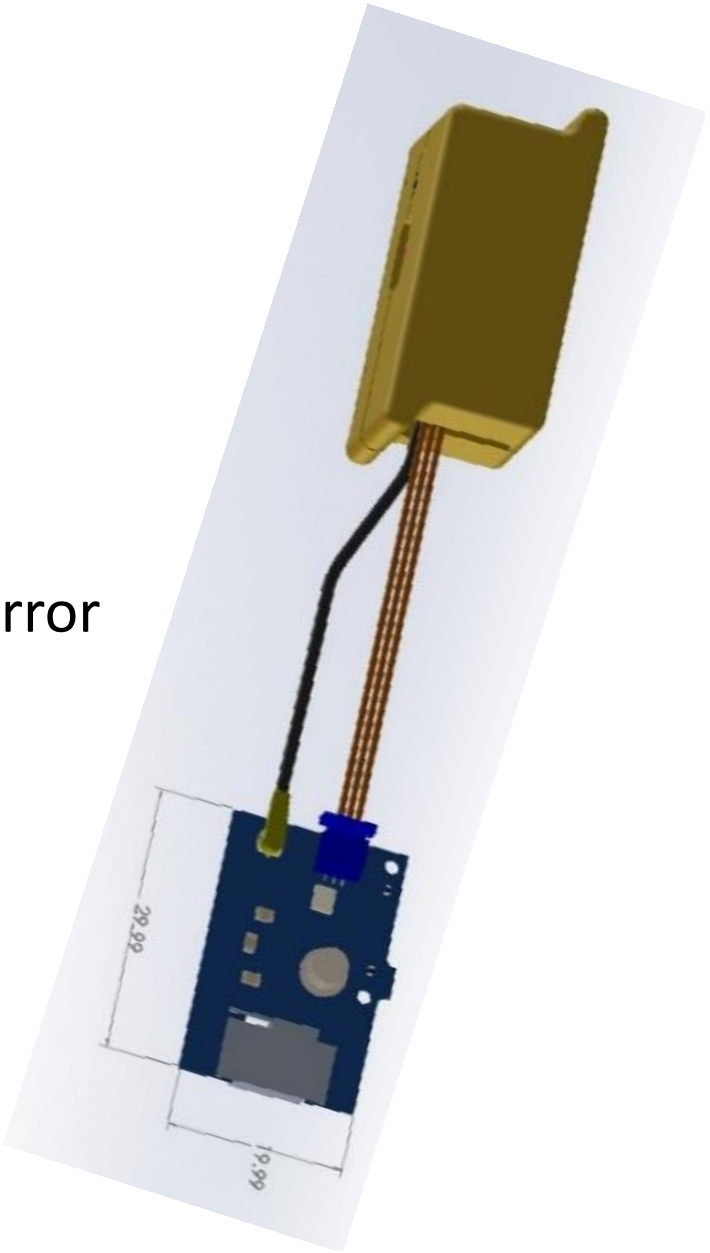


- Decreasing barrier to orbit
  - Reduced launch costs
  - Increasing launch availability
- Industry trends:
  - CubeSat constellations to replace larger satellites
  - Clustered launches
- CubeSat reliability
  - DOA exceeds 18%^
  - 60% operation after 2 years
- Changing Government role
  - CSpOC seeking to reduce role in CubeSat tracking

^Swartwout , 2016; Langer, 2016

CUBIT Design Drivers

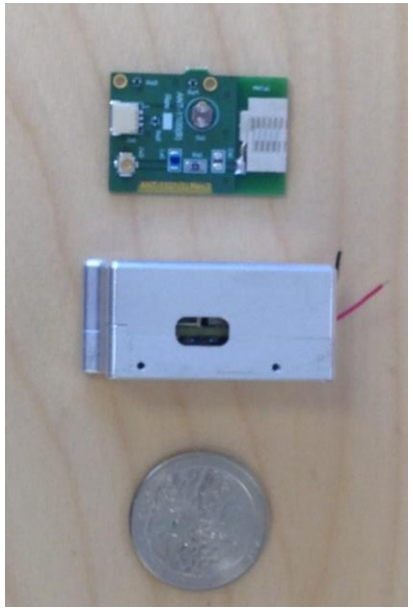
- Low On-Orbit SWAP
  - Minimize impact on CubeSat developers
  - Impact on ground station
- Minimal integration with host
  - Physical-only interface reduces effect on CUBIT if host has error
  - Repeatability increases robustness
- Low Cost
  - Promote wide-scale adoption
  - COTS



CUBIT Tag Data Sheet

- CUBIT enables unique, aircraft transponder-like identification for CubeSats
- Identification independent of satellite operational status
- Self-contained system requires no interface with CubeSat for operation
- Vetted and proven design reduces risk to identification

Feature	Value
Electronics Unit (EU) Size *Mounted internally	~41 mm x 20 mm x 18 mm
Antenna Unit (AU) Size *Mounted externally	~ 20 mm x 30 mm
Mass	21 g
Mounting	two #0-80 screws, EU orientation unrestricted
Operational Frequency	915 MHz
Transmit Power	~0.01 W, for 20ms per each interrogation received
Transmissions per orbit	25/orbit. Tag will only transmit when interrogated by ground station, for total of 500ms.
Battery characteristics	110 mAh - 3.7V
RF inhibits	Timer: 45 min delay of tag function after launch Command inhibit: Will only transmit when interrogated by SRI ground station (coded command).
Deployment Power Inhibits	Photocell inhibits between Power Supply and EU



(Above) CUBIT tag with quarter as size comparison.

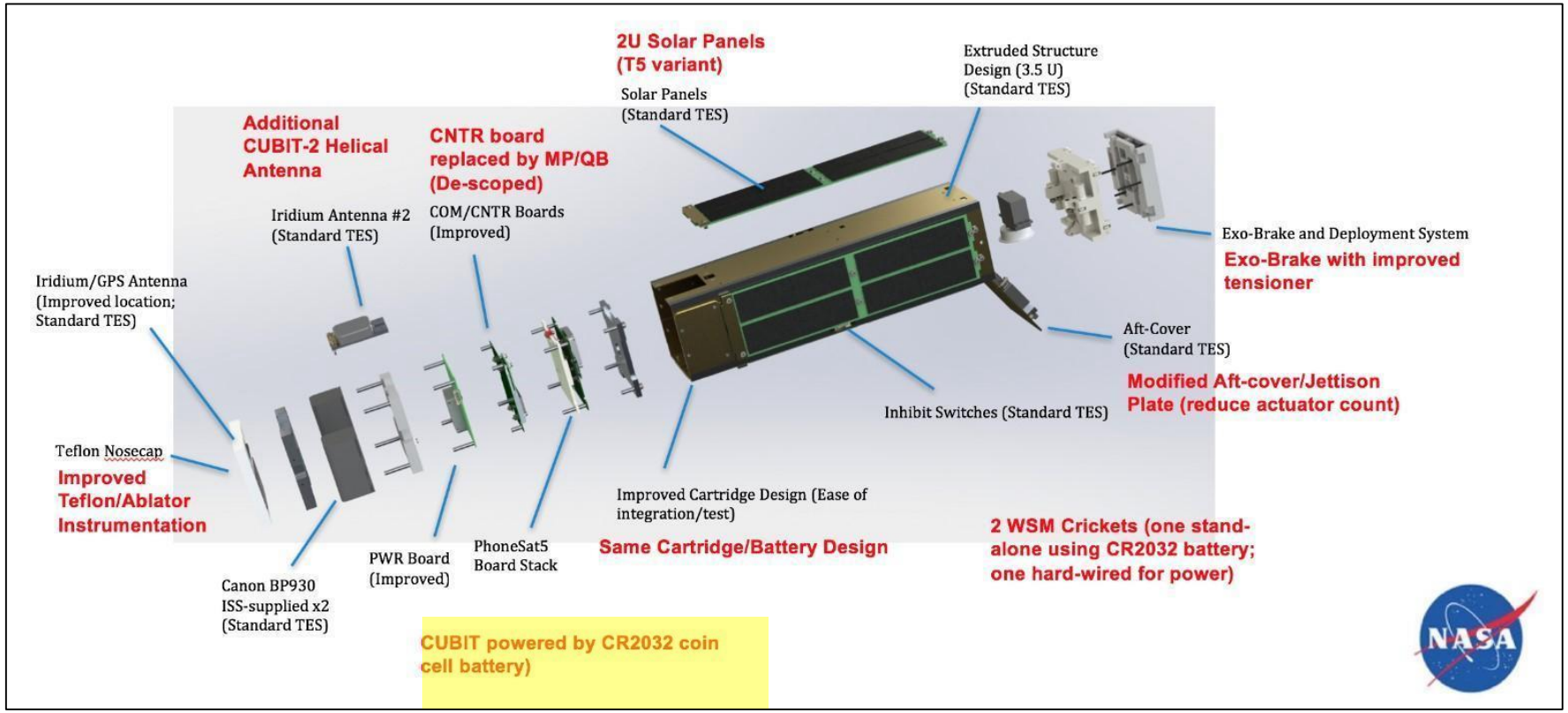
(Right) CUBIT components assembled for operation.

CUBIT On Orbit Experiment & Results

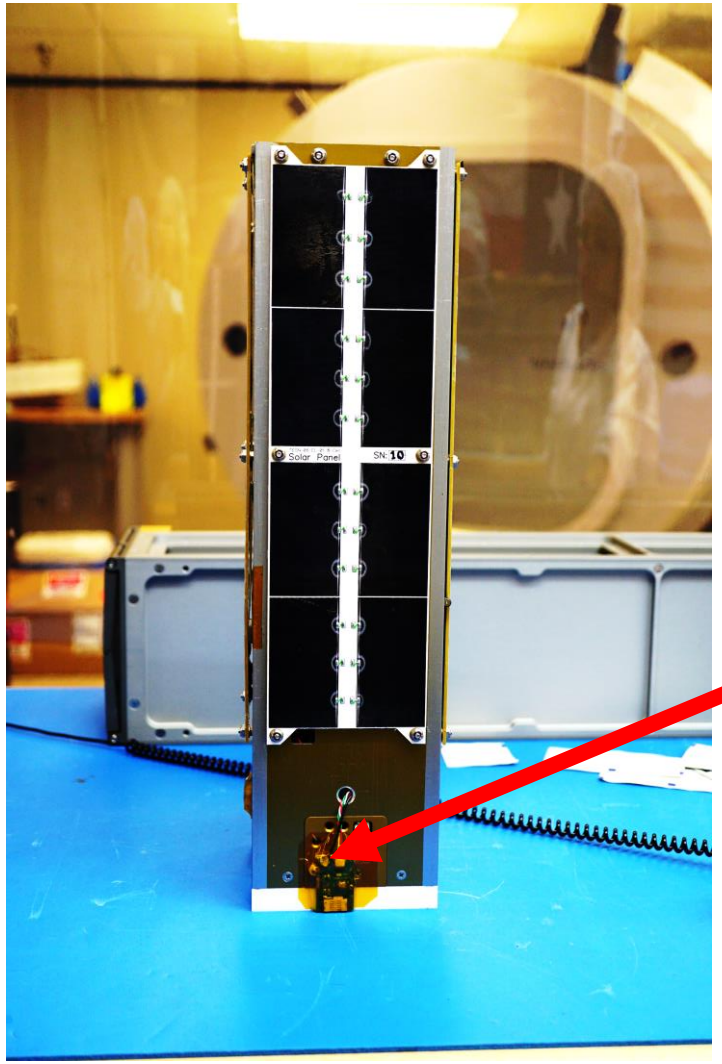
CUBIT First Flight OnBoard TechEdSat 6

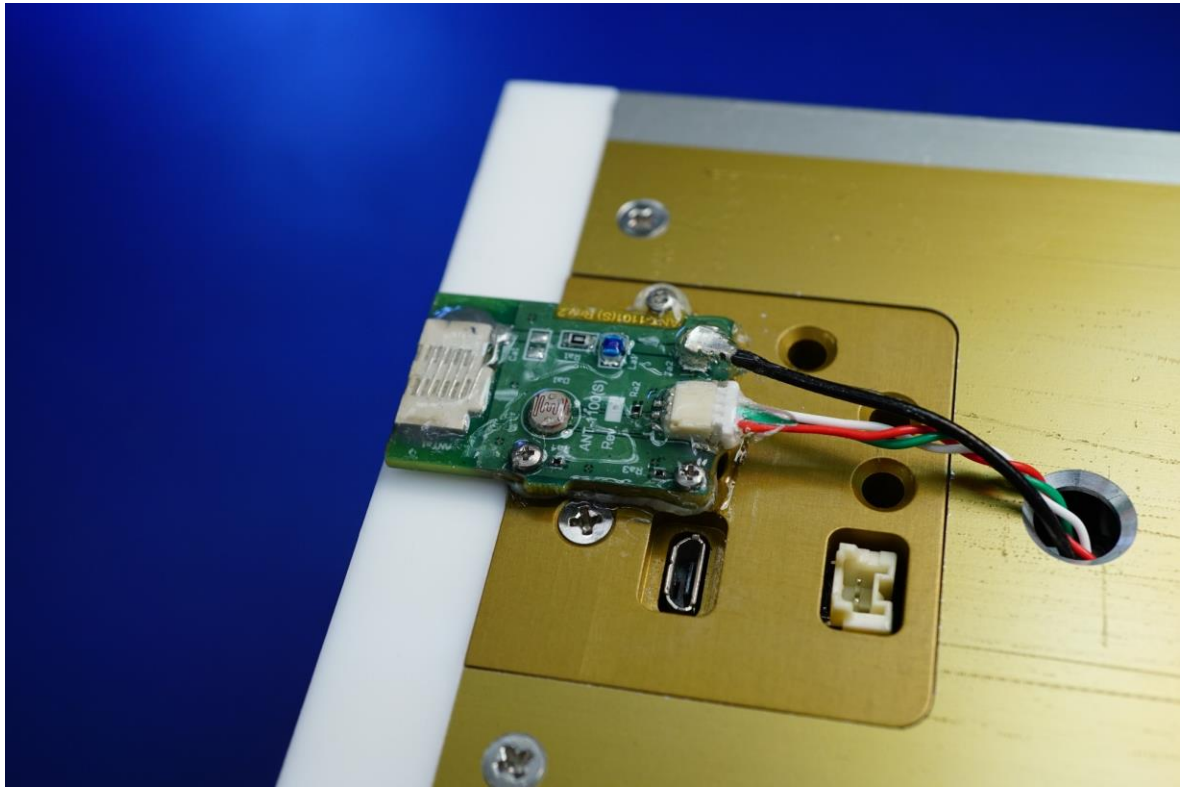
- Partnership with NASA-Ames for CUBIT technology demonstration
- Launched aboard Cygnus CRS-8 Nov 12, 2017
- Deployed from ISS Nov 20, 2017

Courtesy NASA



Tech Ed Sat 6 With CUBIT

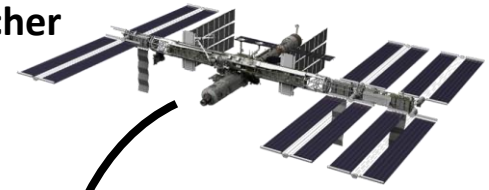




CUBIT TechEdSat 6 Experimental Setup

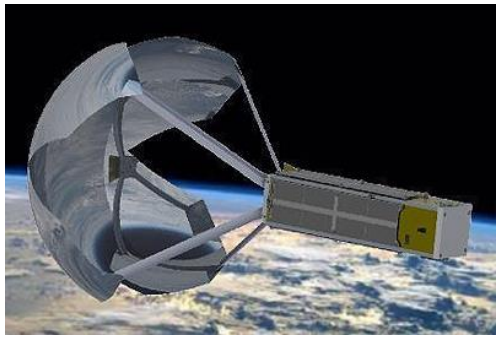
1. TES 6 manifested on Cygnus CRS-8 launch

2. TES 6 arrives at ISS and transferred to launcher



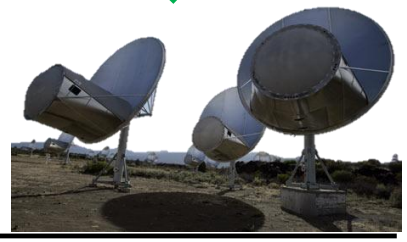
3. TES 6 deployed from Nanoracks Nanolauncher

4. Main TES 6 experiment executed while CUBIT tag is powered on



5. SRI's Stanford Dish interrogates CUBIT, using TES 6 TLE

6. Allen Telescope Array (ATA) receives CUBIT response & TES 6 signals



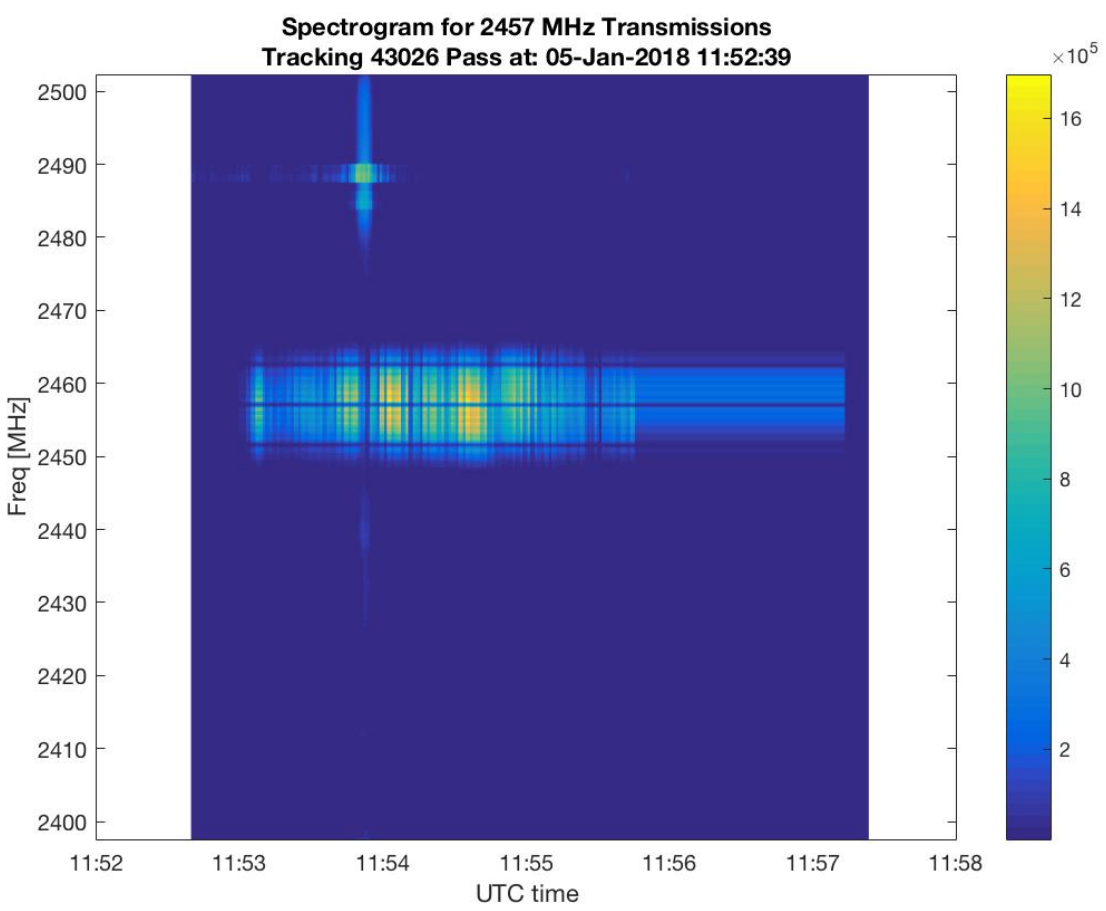
7. Collocated TES 6 2.4 GHz beacon provides additional verification

ATA Setup

- Correlator mode (Interferometry imaging, no I/Q time domain data)
- Integration dump size is 1 second
- Collected with 10 antennas (reduced size to allow faster dump size)
- Fxa collected at fc = 915 MHz, bw = 3 MHz, 1024 frequency bins
- Fxc collected at fc = 2450 MHz, bw = 100 MHz, 1024 frequency bins
- TLE uploaded from space-track at 1:30 PST
  - 1 43026U 98067NK 18005.16510731 .00047214 00000-0 57536-3 0 9990
  - 2 43026 51.6386 110.2996 0003020 318.6602 41.4163 15.60011722 6993
- Pass #1:
  - Rises > 16.5 deg: Fri Jan 05 02:18:10 PST 2018
  - Sets < 16.5 deg: Fri Jan 05 02:21:21 PST 2018
- Pass #2:
  - Rises > 16.5 deg: Fri Jan 05 03:53:41 PST 2018
  - Sets < 16.5 deg: Fri Jan 05 03:57:50 PST 2018

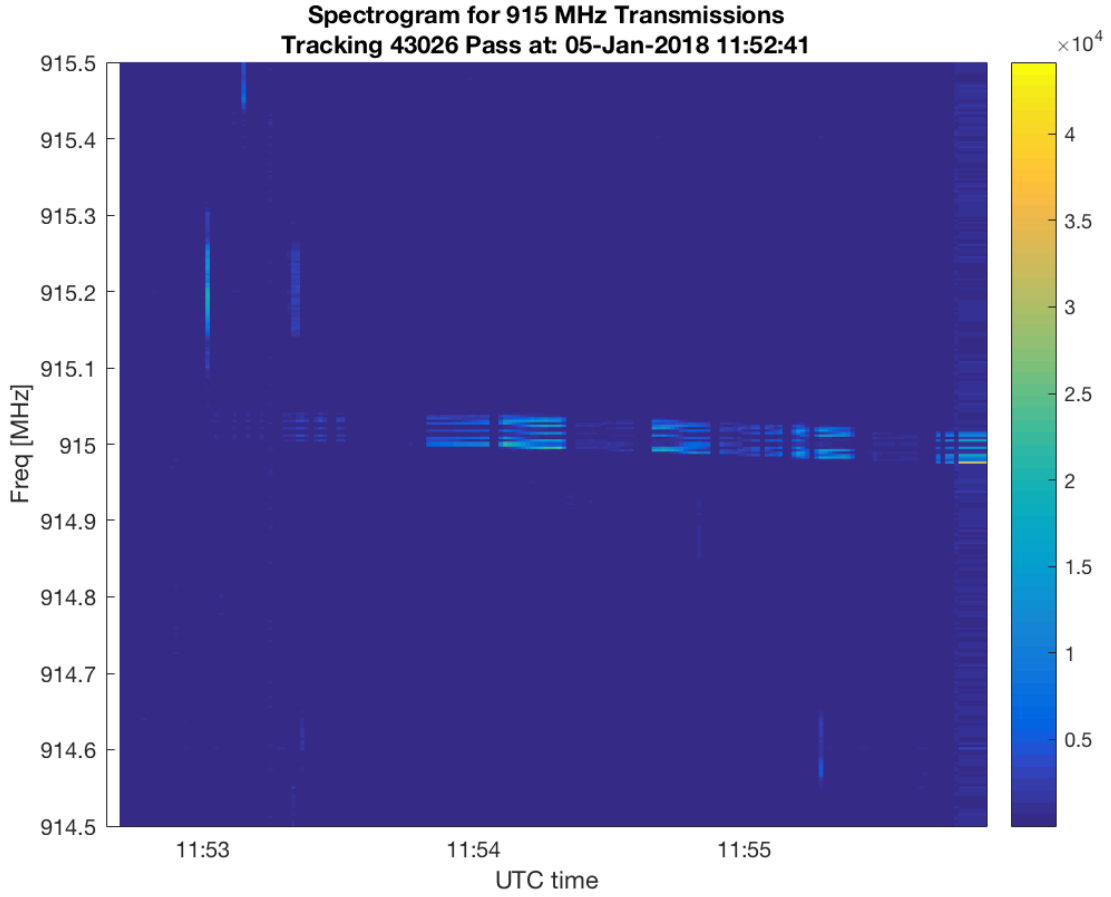
Pass #2: 2457 MHz

Full Spectrum: Successful acquisition of TES 6 Beacon

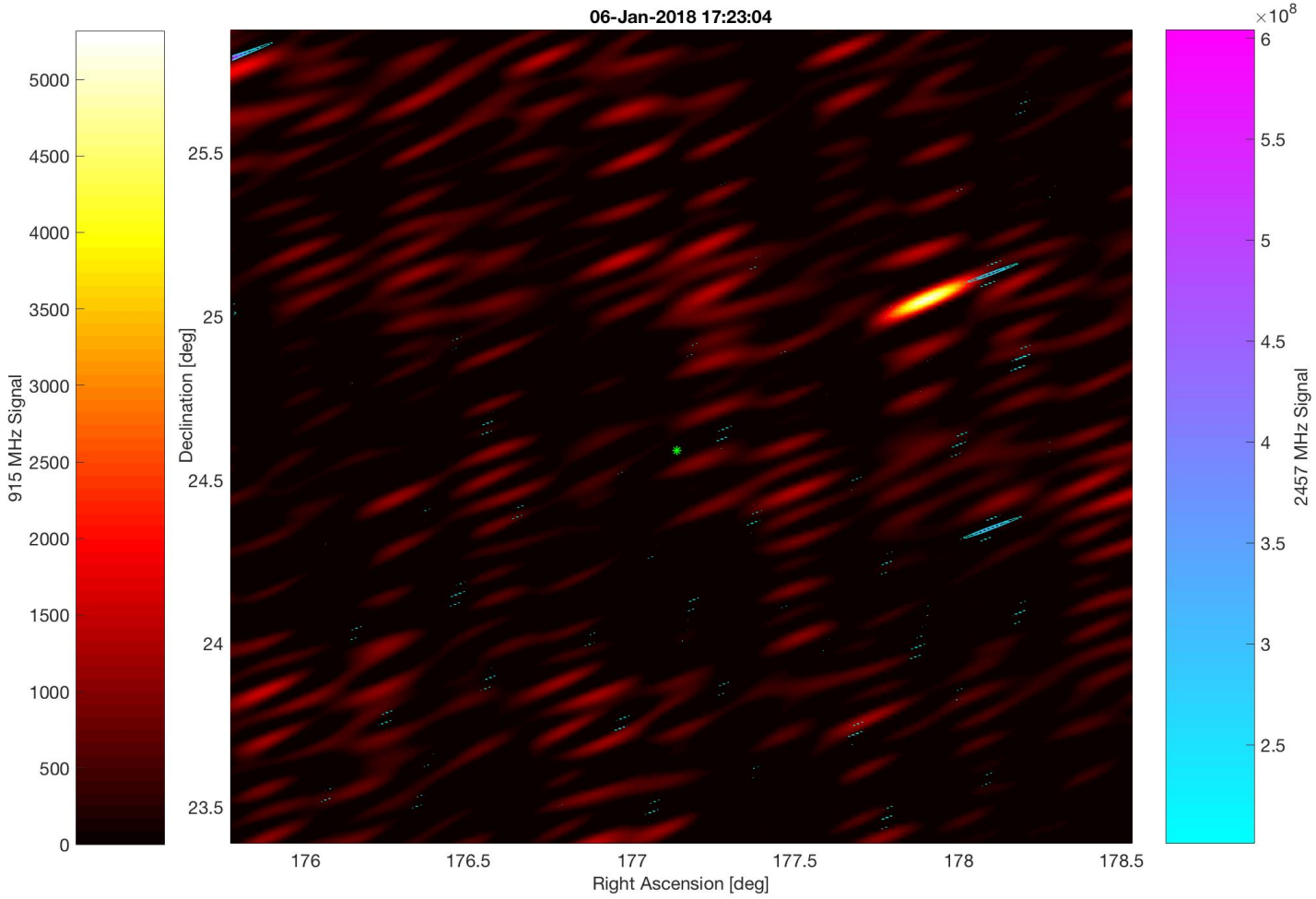


Pass #2: 915 MHz

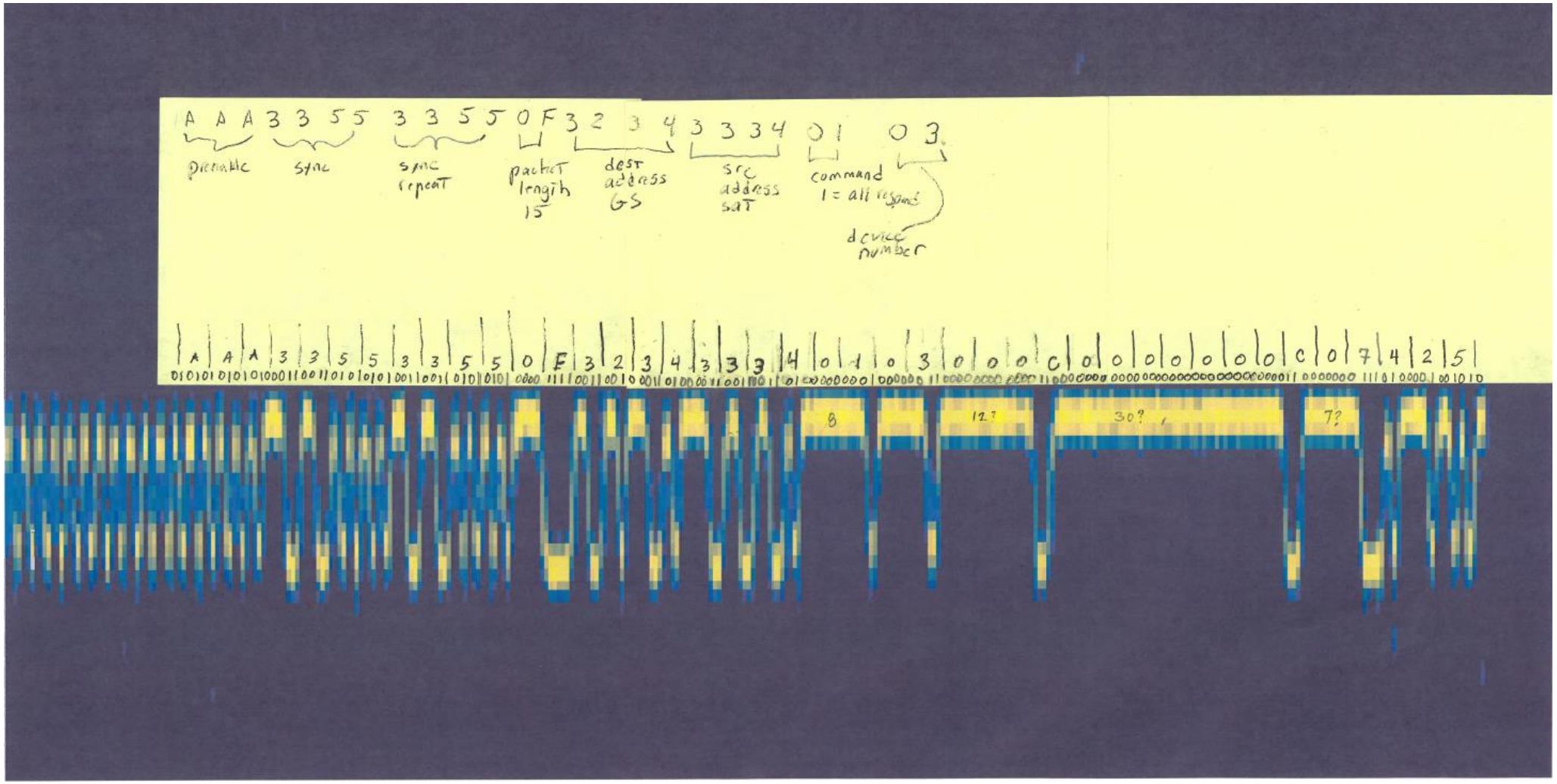
Zoomed Spectrum: Successful acquisition of ISM signal



Collocation of Beacon and CUBIT Signal Demonstrates On-Orbit Operation



ATA “Direct to Disk” Mode Provides Time Domain Signal Confirmation



Lessons Learned

- Paperwork, paperwork, paperwork
- Poor TLEs and tight Tx beam = no return signal
  - ATA & Stanford Dish not necessary for link
  - Ground station design is important
- Split design increases flexibility and makes CUBIT more acceptable to developers
- Onboard power was useful, but not necessary

Future CUBIT Developments

Future Tag Efforts: Advanced CUBIT Technology & Concepts

- Simultaneous deployment of multiple Tags

- Future advanced tags: toward operational, wide-scale deployment
  - Higher fidelity positioning using both onboard and ground-based tracking systems
  - Alternative methods of tracking and providing unique ID
  - “Blackbox” capability for improved CubeSat troubleshooting
  - Improved Ground Station “kit” for widespread use

Goal: a CUBIT “License Plate” for every CubeSat

Thank you!

- DARPA
- Tech Ed Sat 6 Team of NASA Ames
- Robert Avery and Shaobei Xu (AFSPC AFSMO/AFSMO/SMI)
- Cynthia Wilson (18 SPCS/MAO)