U.S. Naval Academy Small Satellite Program's Story:

Lessons Learned and Un/common Practices

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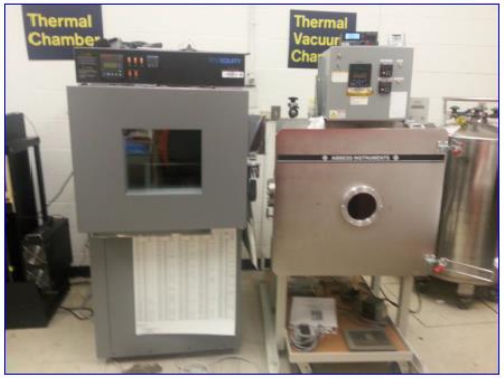
Naval Academy Small Satellite Program (NASSP)

The foundation of our space systems curriculum for the Astro Track students

- Provides midshipmen full-range of hands-on space system development experiences
  - Satellite design
  - Bus and payload development, integration, and testing
  - Mission operation
- Guides students through regulatory and validation procedures
- Educates future naval officers
- Research for future space technologies

Shaker



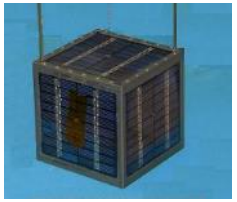
Thermal and Thermal Vacuum Chambers

Solar Simulator

Missions:

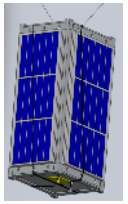
- Sapphire
- PCSat
- PCSat-2 (ISS)
- ANDE
- MidSTAR
- RAFT/MARScom
- PSAT
- DRAGONsat
- USS Langley
- BRICSat
- QIKCOM-1 (hosted)
- QIKCOM-2 (hosted)
- BRICSat-2
- PSAT-2
- RSat

PCSAT (2001)

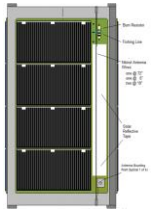


RAFT(2006)

ARISS on ISS

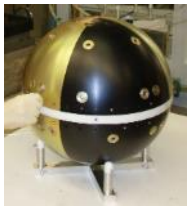


PSAT(2015)

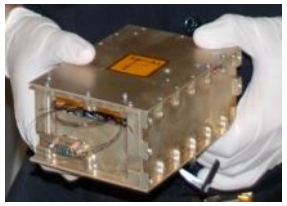


PSAT-2(2017)

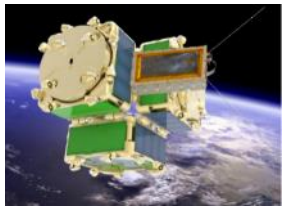
PCSAT2(2006)



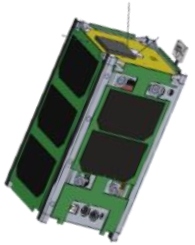
ANDE(2006)



QIKCOM-1 on ISS



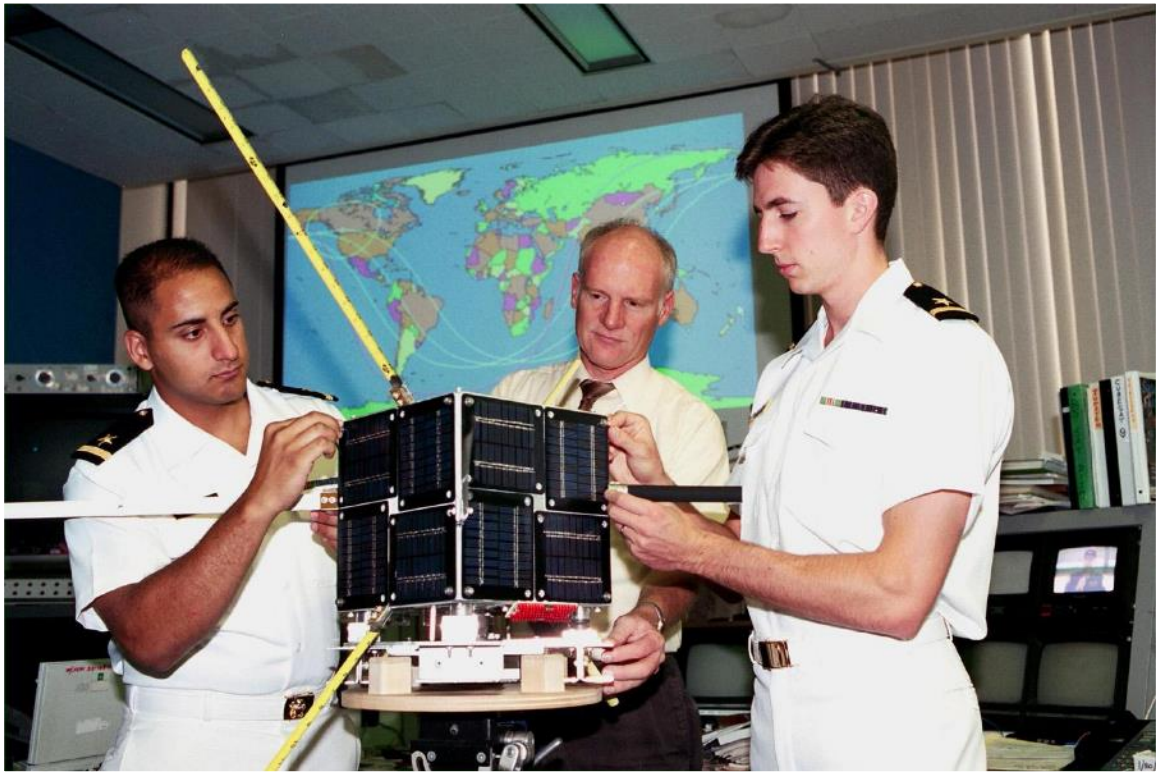
QIKCOM-2 (Aug 2016)



- Education and training, not product
- Did we deliver and launch? → success

Past Projects

USNA-1: PCSat



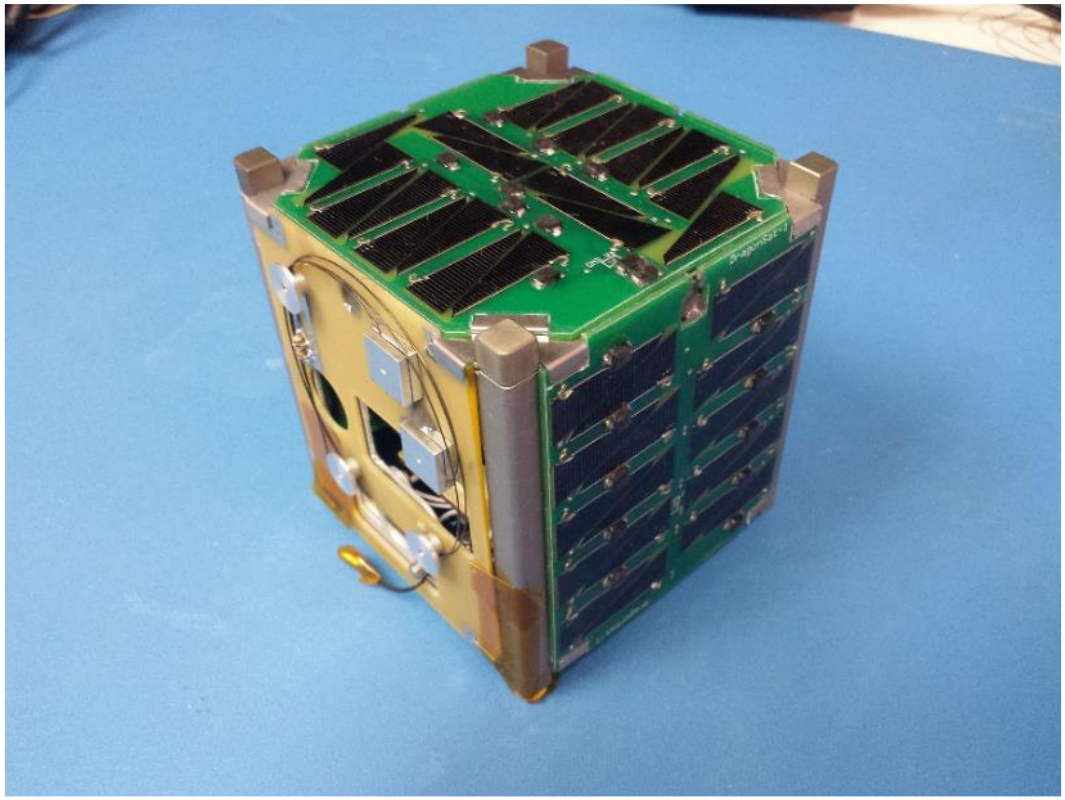
PCSat, active

- First USNA space launch
- Two-way hand-held APRS communications
- Oldest surviving student-built satellite in space
- Launched in Sept. 2001

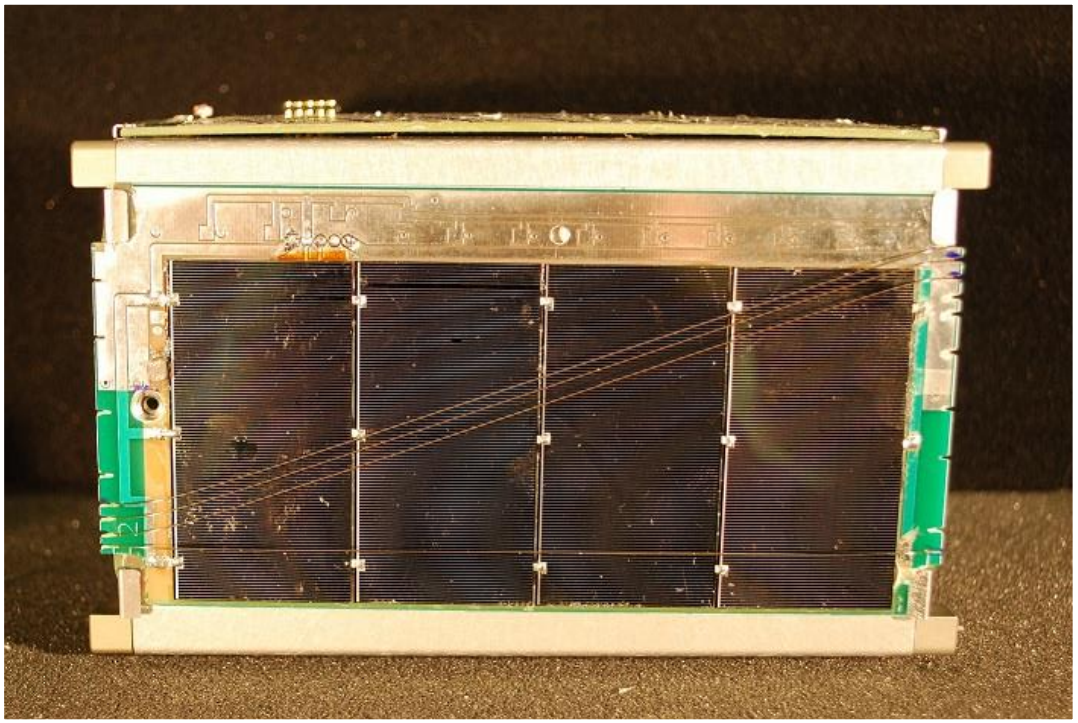
USNA-8: DragonSat-1

DRAGONSat-1

- First USNA CubeSat
- 1U satellite with a 1.5 m long gravity gradient boom
  - 60 g tip mass for passive stabilization
- Launched on NASA ELaNa IV mission in Nov. 2013



USNA-7: PSAT-1



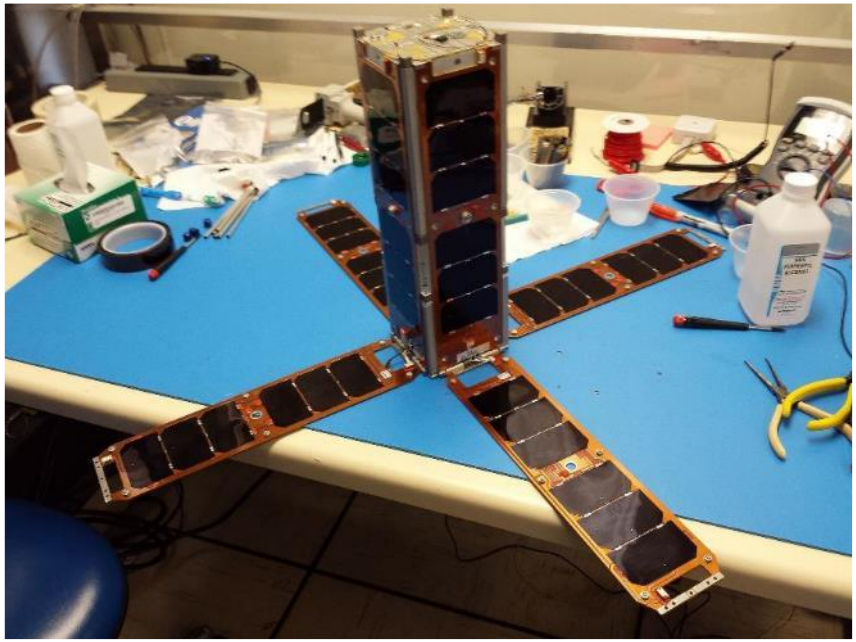
PSAT-1, active

- 1.5U CubeSat supporting follow-on mission of PCSat
- Supports Amateur Radio PSK31 multi-user text messaging
- Launched on ULTRA mission in May 2015

USNA-10: USS Langley

USS Langley

- 3U Colony-1 CubeSat
- Linux-based file server operating on S-band
  - Demonstrate on-orbit internet server capability
- Launched on ULTRA mission in May 2015



USNA-11: BRICSat-1

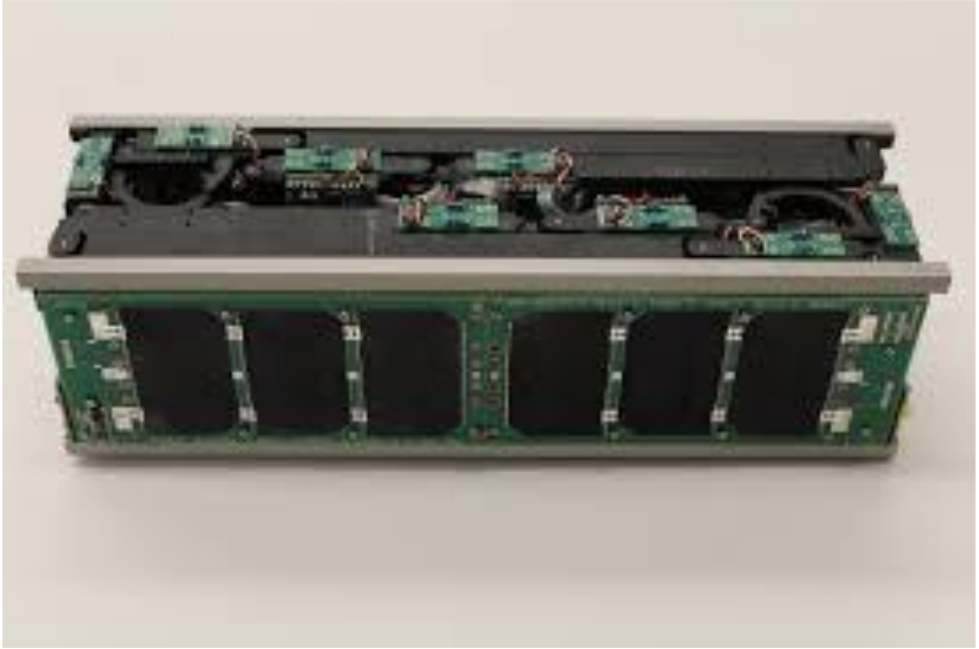
BRICSat-1

- 1.5U CubeSat testing attitude control
  - Four micro-cathode electrical thrusters from George Washington University
- Supports Amateur Radio PSK31 multi-user text messaging
- Launched on ULTRA mission in May 2015

USNA-19: RSat

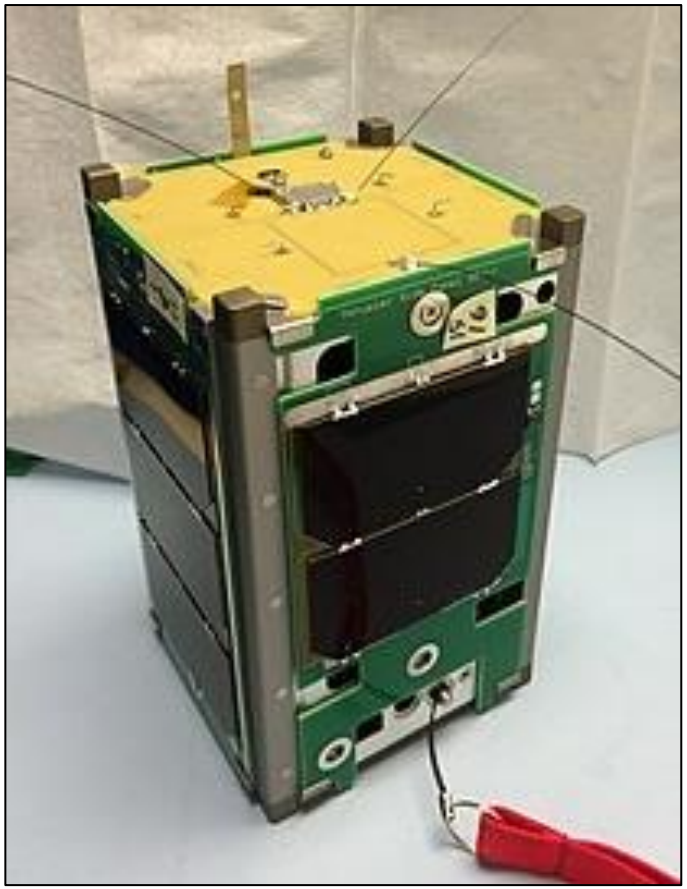
RSAT

- 3U CubeSat for robotic investigations and manipulation in space
  - 3D-printed robotic arms with seven degrees of freedom include cameras on each end
- Launched on NASA ELaNa XIX mission in Dec. 2018



Recent Projects

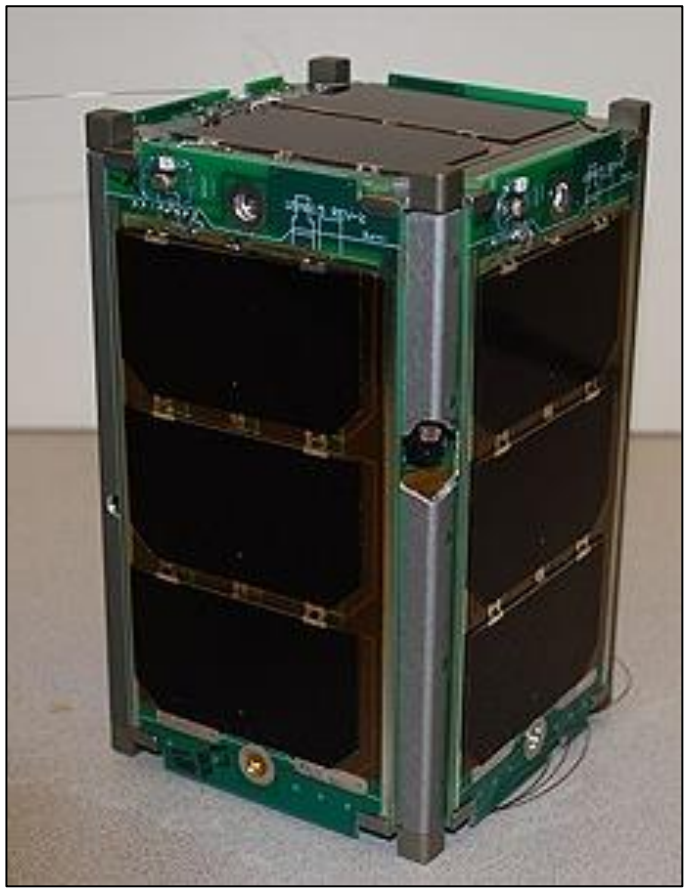
USNA-14: BRICSat-2



BRICSAT-2, active

- 1.5U CubeSat continuing to test attitude control
- Micro-cathode electrical thrusters from George Washington University
- Supported AX.25 Packet Radio Digipeater

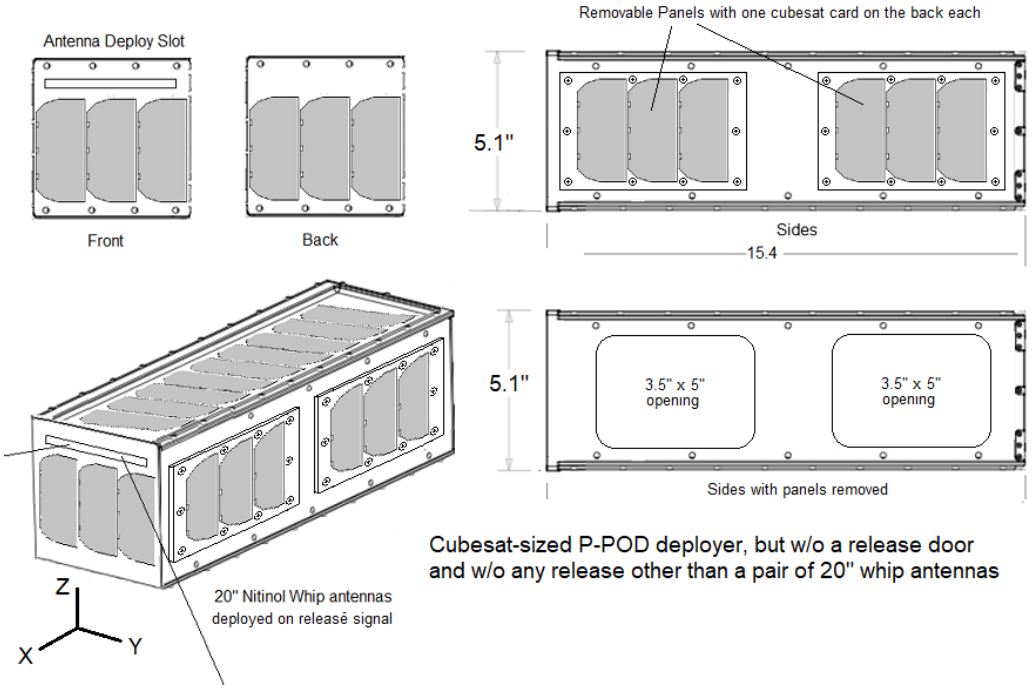
USNA-15: PSAT2



PSAT2, active

- Follow on to PSAT-1
- Integrated APRS command and control and transponder on a single circuit
- Includes the PSK-31 HF/UHF xponder
- Touchtone Texting
- Texting-to-voice synth
- SSTV camera

USNA-16: PSAT3



Cubesat-sized P-POD deployer, but w/o a release door and w/o any release other than a pair of 20" whip antennas

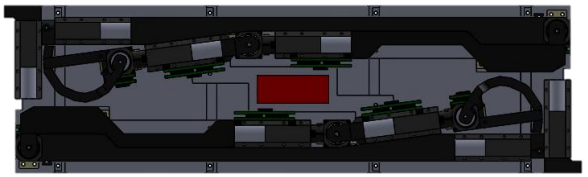
Included in PSAT3:

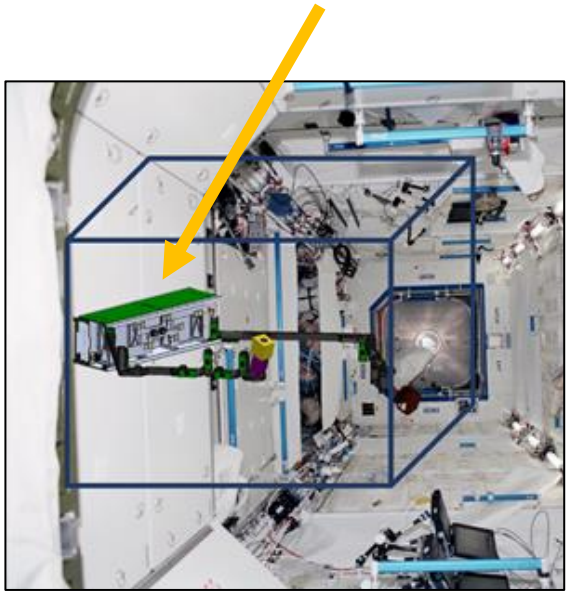
- Amateur radio transponder
- SATT4 comms board
- Touchtone-Texting
- Text-to-voice synthesizer
- Nitinol whip antenna
- Burn-release mechanism
- Brno University SSTV camera

USNA-17: NSTAR

NSTAR

- 3U Robotic testing platform
- Internal ISS experiment
- Demonstrate on orbit robotic assembly of spacecraft and satellites





Lessons Learned: Education and Training

Some Unique Aspects of NASSP

- All undergraduate students
- Great for students – they get to manage full project and equipment
- Not so great for long duration project – continuity of project lies ONLY with professors

→ Requires much shorter development cycle

CDIO Model

- Conceiving – Designing – Implementing – Operating (CDIO) is great
  - CDIO is an innovative educational framework for producing the next generation engineers
  - Fits very well with NASSP's Vision
  - Great model for Capstone Design curriculum

- But added challenges for CubeSat community due to difficulties associated with:
  - Finding and coordinating for launch
  - Launch slips
  - Licensing timeline
  - Other regulatory restrictions

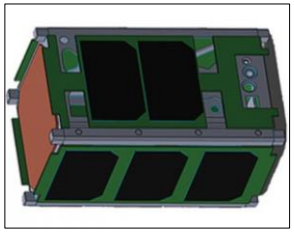
NASSP's O-CDI model

Start here!

USNA Satellite Dish

USNA Ground Station

Concept



PSAT-2 Concept

- Provides midshipmen full-range of hands-on space system development experiences
  - Satellite design
  - Bus and payload development, integration, and testing
  - Mission Operation
- Guides students through regulatory and validation procedures
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Operation

Research and Design

RSAT Solar Panel Construction

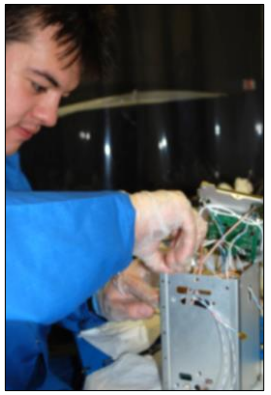
Thermal and Thermal Vacuum Chambers

Test

Fabrication

Solar Simulator

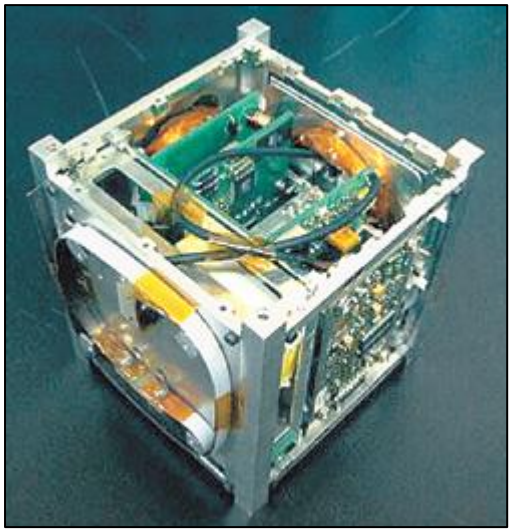
Shaker



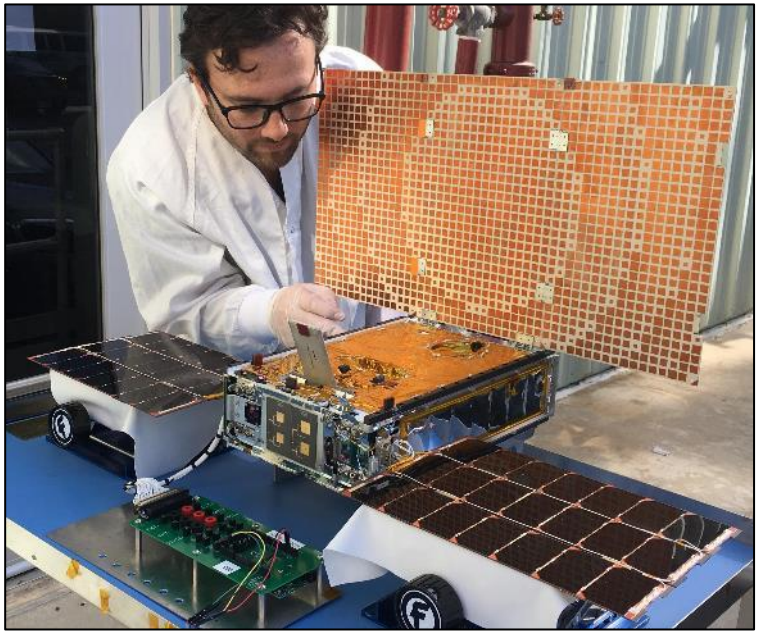
BRICSAT-1 Construction

My Take on Current Landscape

- CubeSat-class satellites missions becoming more and more important
  - From school projects to key mission enablers for government
  - Simple experiments to key capability augmentation tool



HAUSAT-1
[news.donga.com]



MARCO
[https://solarsystem.nasa.gov/resources/2281/marco-cubesat-test/]

Industry Engaged and Moving Fast

- Many small satellite or CubeSat specific companies providing high-tech solutions

SmallSat Conference
[https://alen.space/smallsat-2018-utah/]

- Dedicated launch vehicles are now available

Electron Launch Vehicle
[nasaspaceflight.com]

All Well and Good… But Poses Challenges

- Vendor specifications change too often
- Price and capability continue to increase, beyond what is needed at student-project level
- More attention from the government, resulting in an increase in regulatory requirements

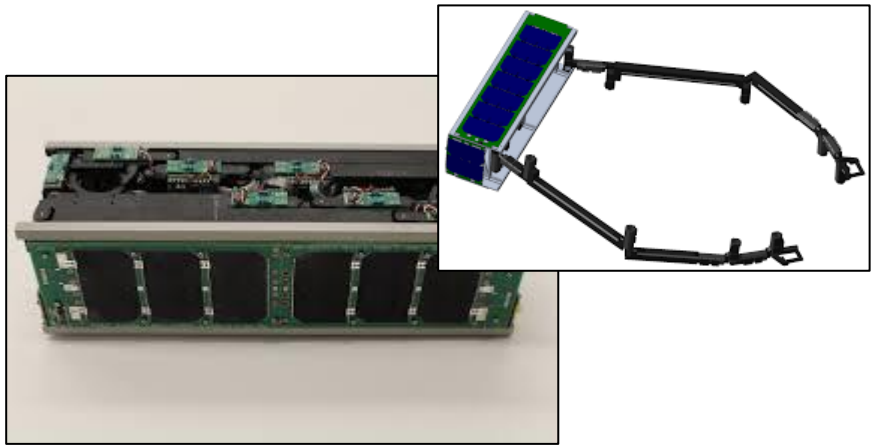
- Makes it hard to fit student schedule and curriculum
  - Need a “standard bus” that can shorten the development cycle
  - (Almost) impossible to nail down a standard bus due to frequent changes

NASSP Solution: two flavors of student satellite projects

Dual-track CubeSat Projects

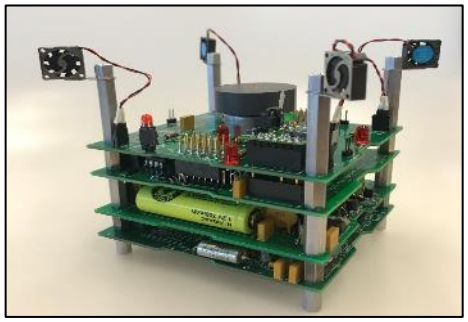
Multi-year, higher capability CubeSat project

- Consists of COTS components
- Often mission oriented
- Higher capability using higher performance parts
- Multi-disciplinary
- Students of all class years



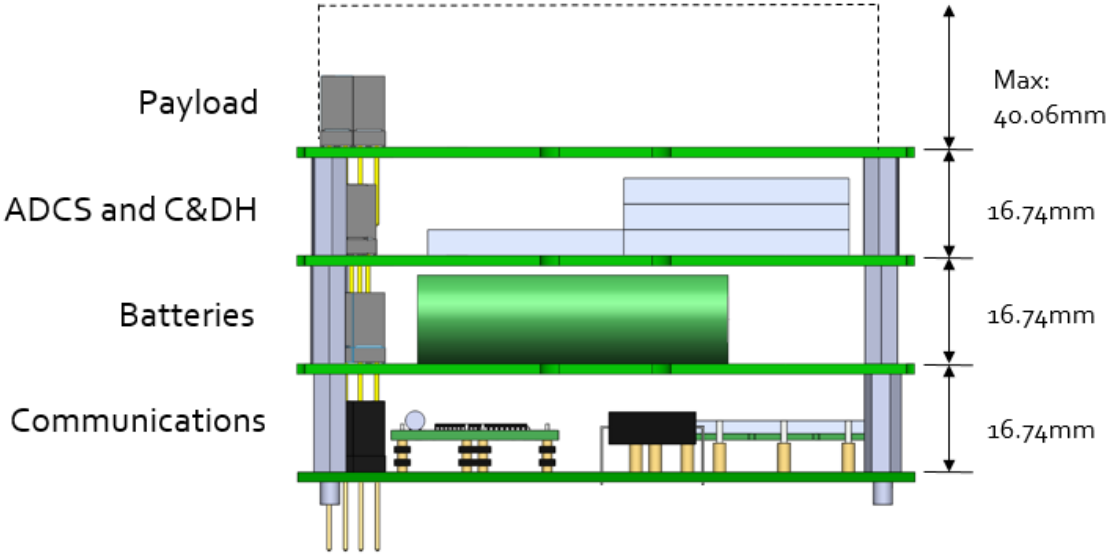
CubeSat projects leveraging in-house standard bus

- Electronics developed and built in-house by NASSP Senior Engineer, Bob Bruninga
- Put together by student teams in 2 months
- Education/training/tech-demo oriented missions
- Lower-performance
- **Independent of vendor changes**



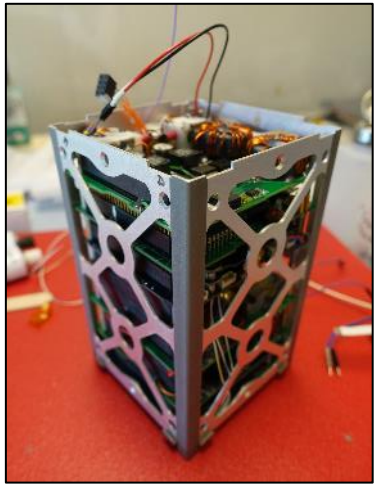
PSAT Standard Bus

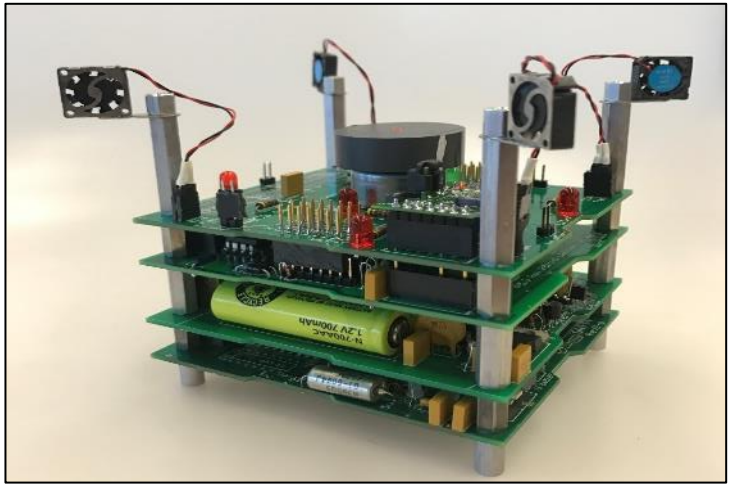
- Based on PSAT-1, 2 currently on orbit
- Enables development cycle to be reduced to one year
  - Perfect fit for year-long Capstone Design curriculum for seniors
  - Students can concentrate on payload and mission development
  - Provides hands-on education of building satellites



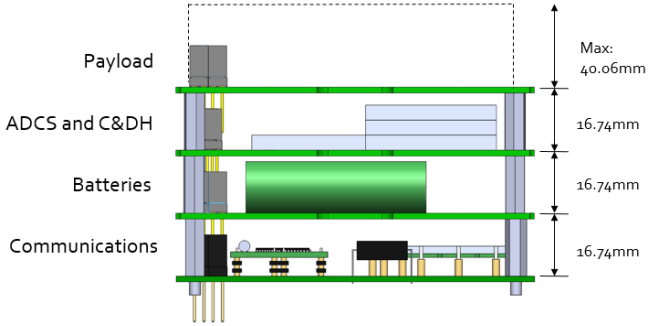
Current Capstone Design Model

- Applying the Conceive Design Implement Operate (CDIO) initiative, students will develop multiple satellites every year as a part of the project curriculum
  - Approximately 4 teams each year
  - Completely student-built using in-house manuals
  - Exceptional components will be assembled into flight satellites
    - One or two complete satellites every year
    - Stored on the shelf and flown on available launch opportunities
  - Other components will be assembled into LabSats to be used as an in-class education tool

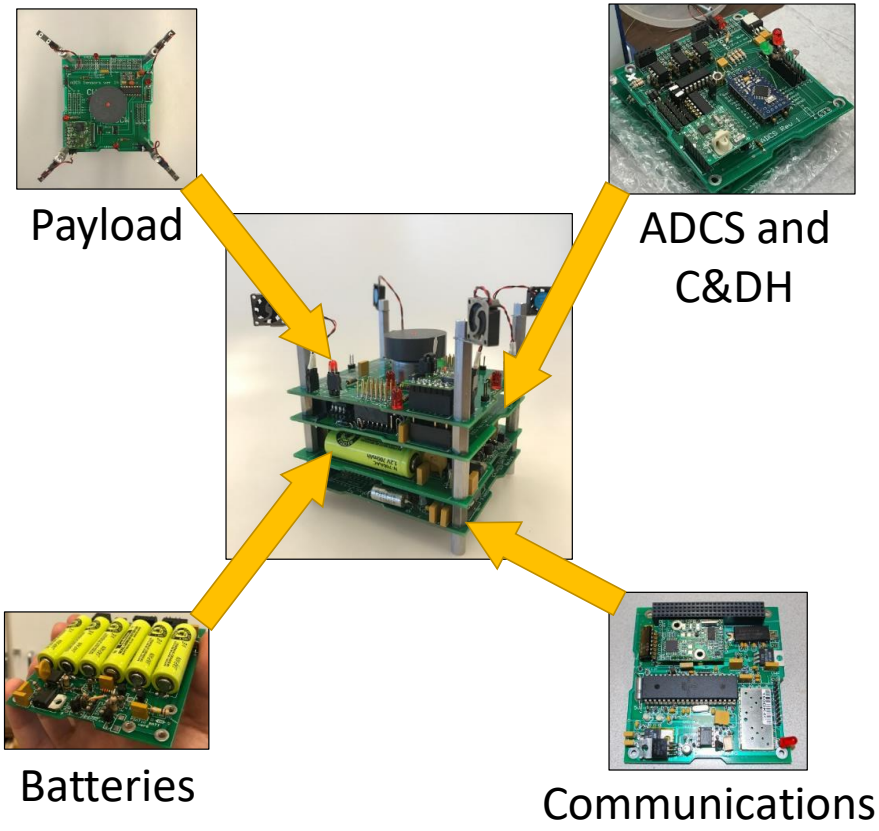




PSAT Specs and Subsystems



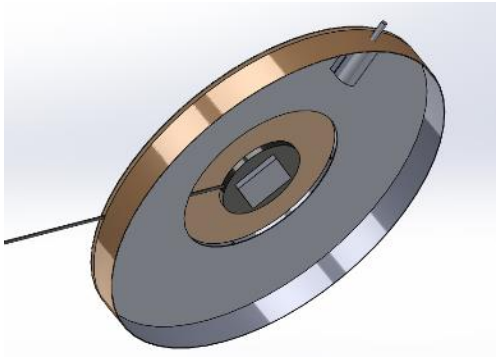
Satellite Specifications	
Mass	Max: 1500 g
Size	1U
Power Generation	2.85 W in sunlight
ADCS	Magnetorquers
Communications **VHF** (data)	145.825 MHz (uplink and downlink)

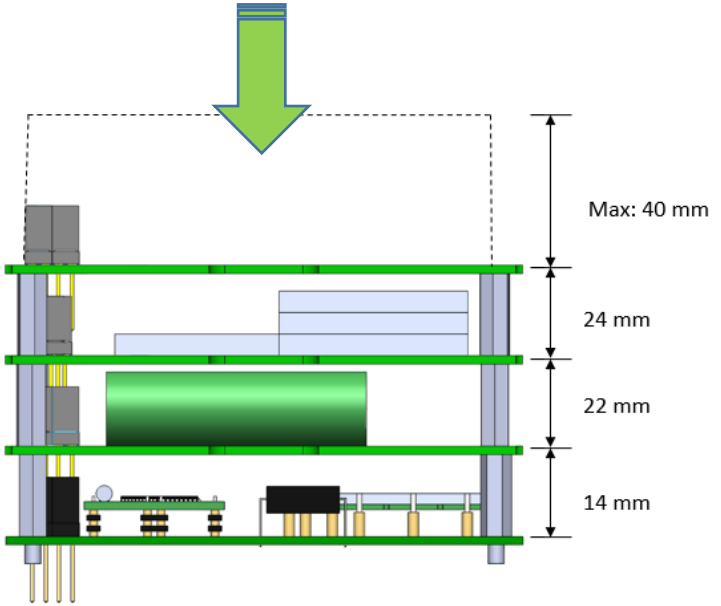


Concentrating on Payload Development

Payload Development

- Each student team will develop their own payload
  - Partnerships with other organizations
- Payload requirements:
  - Volume: 247.1 cm^3
    - Max height: 4.0 cm
    - Max width: 8.0 cm
    - Max depth: 7.7 cm
  - Power: 1.92 @
    - Daylight at 3.3 V
  - Mass: 566 g





Amateur Radio is an Important Part of Education and Training

Amateur Radio is Great

145.825 MHz - A satellite relay channel for Amateur Satelilte User data anywhere on earth.

Engineering Educational Objective:

One or two semester student engineering projects

Individual engineering responsibility

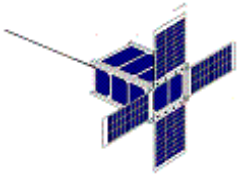
Low cost

Driven to completion

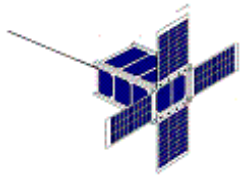
Where Failure (learning) is an option

Quicker Student involvement using a Ground Terminal Operational Missions

Ground Terminal Applications Focus (force tracking and text-messaging)



Supports Student Experimenters
School missions/movements
Theater area communications
and Emergency Response Comms



The Yard Patrol Craft

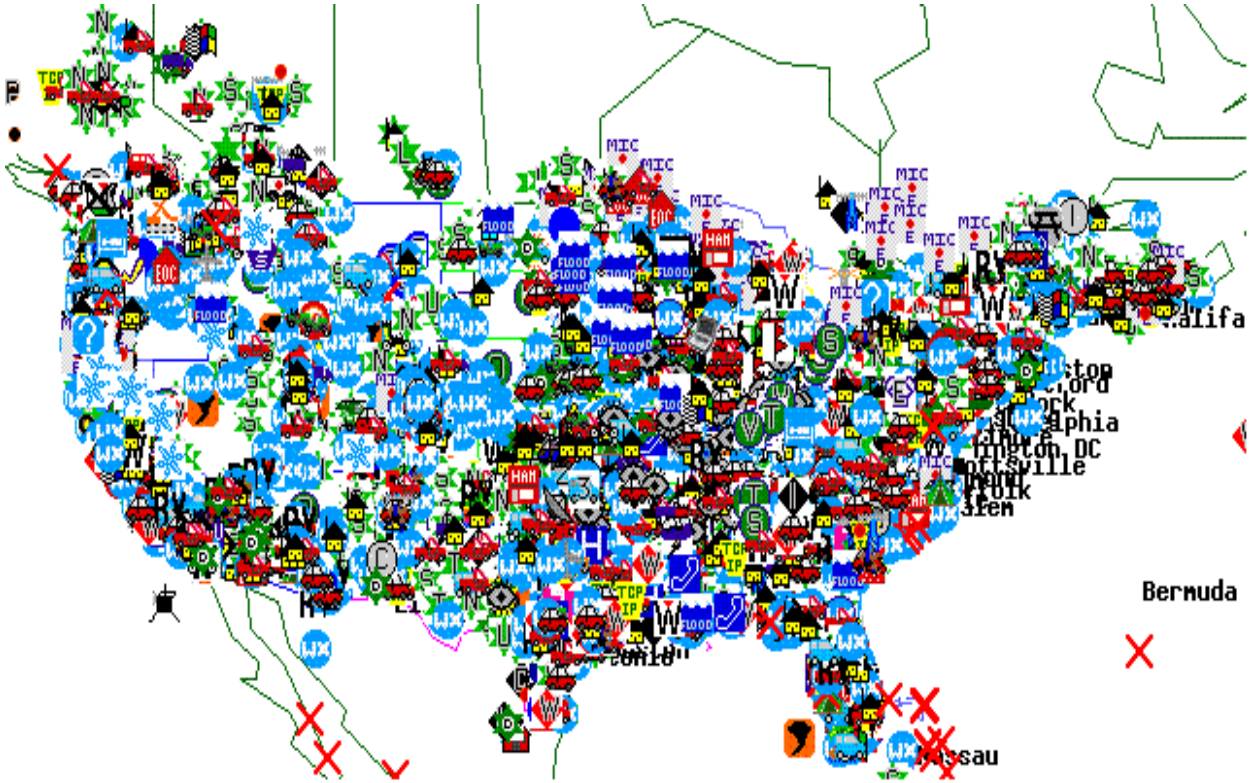
Education

Force

Multiplier!

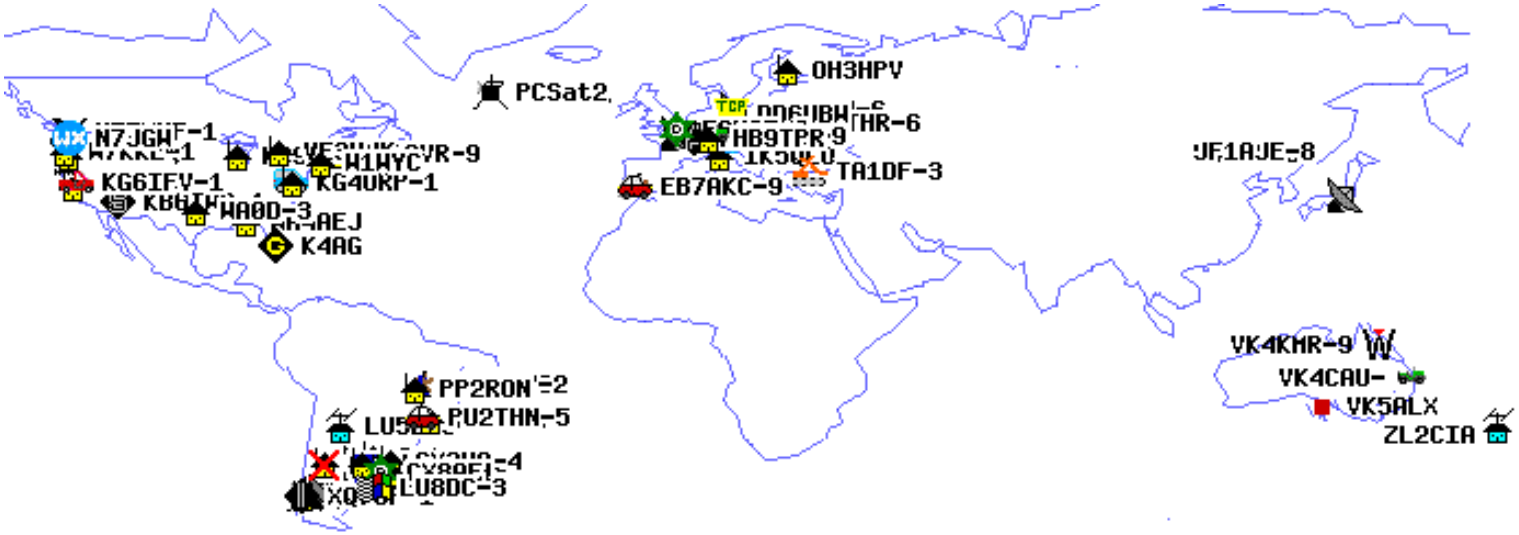
APRS Terrestrial Network is Great

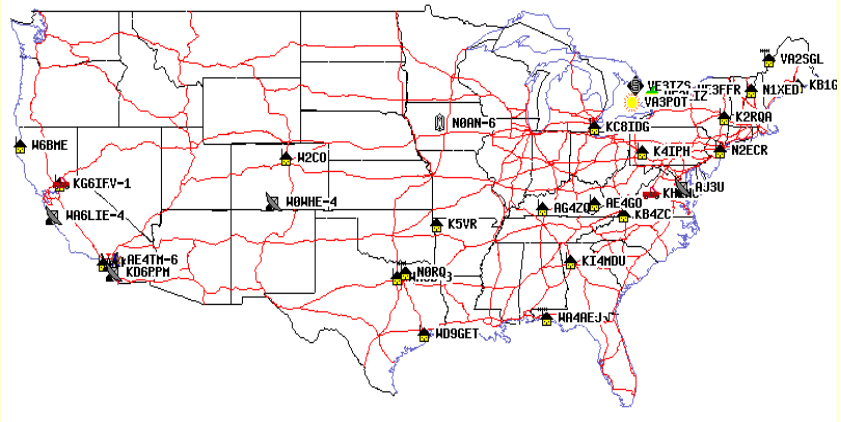
- Supports over 20,000+ terrestrial users and experimenters.

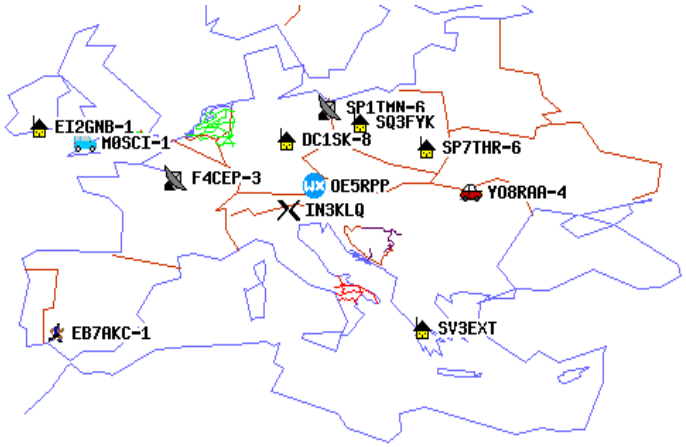


- But stops at the shoreline and has huge holes in the wilderness

APRS Satellite Network Users







All Volunteer World-wide Coverage

- PSAT-1 launched in May 2018
- Data from the first 18 months of operation (still going strong):

Telemetry Packets Collected

- 335 users captured data packets and logged them online
- 57,972 unique telemetry packets were collected

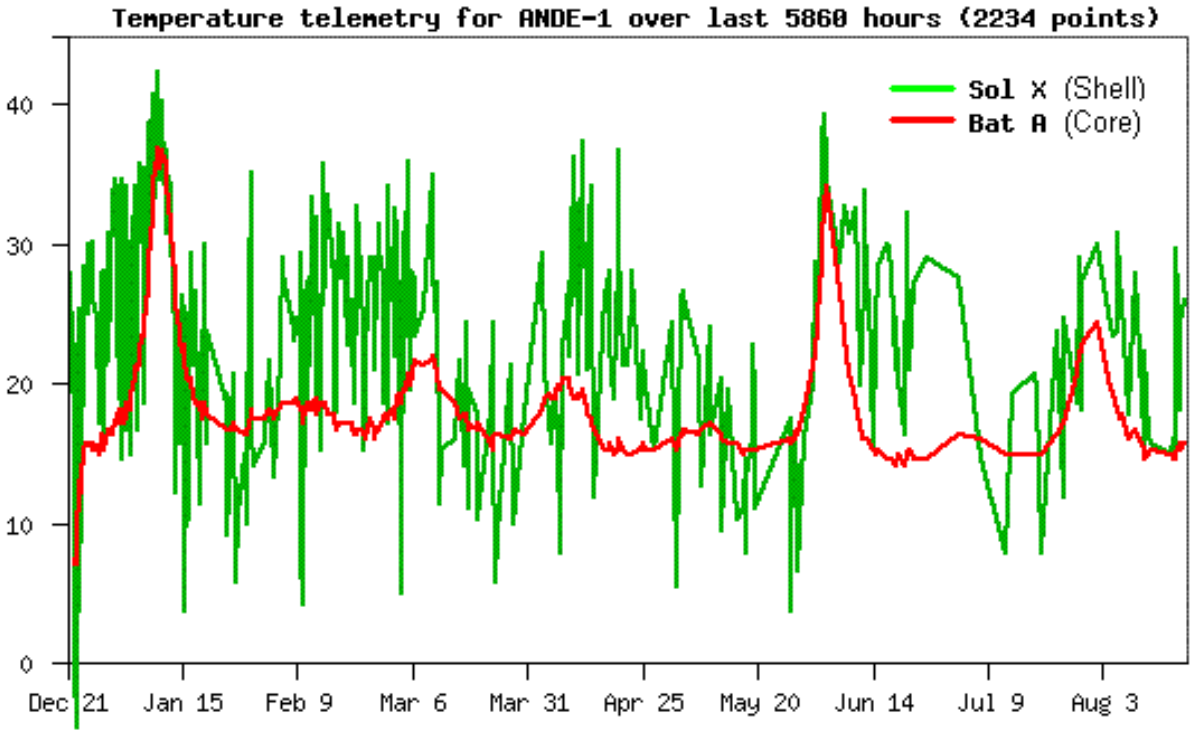
Digipeat Service Users

- 550 users from 44 different countries
- More than 22,121 user messages

COUNTRY	NUMBER OF USERS
USA	227
UNITED KINGDOM	36
GERMANY	30
ITALY	24
SPAIN	23
CANADA	19
ARGENTINA	18
ROMANIA	15
NETHERLANDS	14
AUSTRALIA	11
AUSTRIA	10
INDONESIA	10
POLAND	10
FRANCE	9
JAPAN	9
BELGIUM	8
RUSSIA	8
GREECE	6
TRINIDAD & TOBAGO	6
CROATIA	5
MEXICO	5
PORTUGAL	5
SWEDEN	5
BRAZIL	4
SWITZERLAND	4
IRELAND	3
NEW ZEALAND	3
THAILAND	3
CHILE	2
NORWAY	2
SERBIA	2
TURKEY	2
CHINA	1
CUBA	1
CZECH REPUBLIC	1
DENMARK	1
ERITREA	1
FINLAND	1
HUNGARY	1
INDIA	1
ISRAEL	1
MALAYSIA	1
MOLDOVA	1
UKRAINE	1

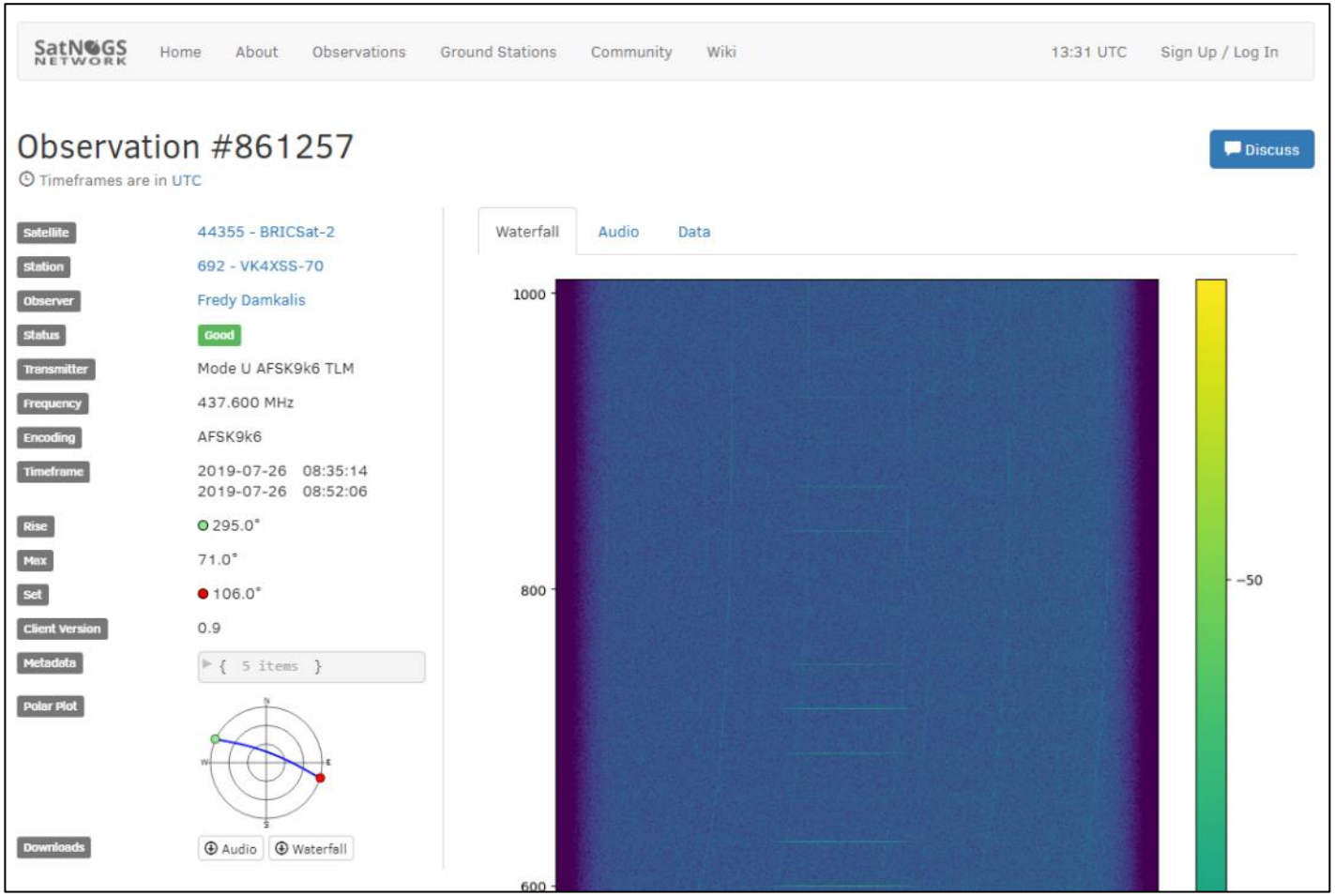
Like Having Multiple Ground Stations

- Very little telemetry data gaps
- You can almost fly these satellites without a dedicated command and control ground station
  - Would require asking the community to send up your command, etc.



Example SatNOGS Pass

- BRICSat-2 and PSAT-2 are at low inclination, making contact from USNA difficult → distributed ground station networks are a huge help



Another Great Source, findu.com

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20191106133447,USNAP1-1>APOFF,ARISS,qAR,VK6HAM-2:>Bank0-SAFE
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20191106160004,USNAP1-1>APOFF,TCPIP*,qAR,KE4AZZ-4:T#017,746,000,000,000,670,01000100
```

Captures every Telemetry or data packet heard anywhere

Enabler for Other Student Projects

- Having data relay transponders in space enables other remote-sensing student projects
- Ex) Ocean and Arctic Buoy

Challenges of Working with Students

- Operational vs. educational
  - Naval Academy Small Satellite Program does not develop operational satellite
  - Only and main goal is student education and training – may result in some undesirable programmatic consequences
    - Working to launch deadline may not be the best model
    - Scope of mission can often change
    - Reliability not necessarily main concern
- Grades/incentive can only go so far
  - Building something that will fly in space is very cool
  - … but students have priorities and obligations
  - Conferences and external sponsors serve as great motivator
  - … but if students decide to “give up”, not much can be done

Lessons Learned: Satellite System and Low Tech Solutions

Documentation

- Documentation is very important
  - Everyone knows this, but students don't "feel it" until it is too late
  - Difficult to encourage students to follow good documentation practices

- My solution: force them to do it anyway with good templates
  - Providing templates, list of docs I want, and details help them produce decent documentation
  - Still don't know why they are dong it... BUT they DO appreciate it later

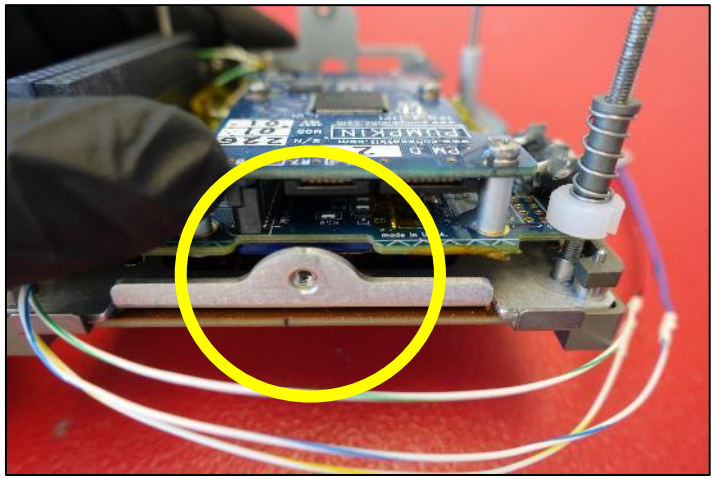
Students:
"What is this materials list thing. Seems like a lot of unnecessary busy work. I want to start building…"

First telecon with NASA Launch Coordinators:
"Can you send us your materials list so we can prevent any potential issues right away?"

Students:
!!!

Pictures of Everything

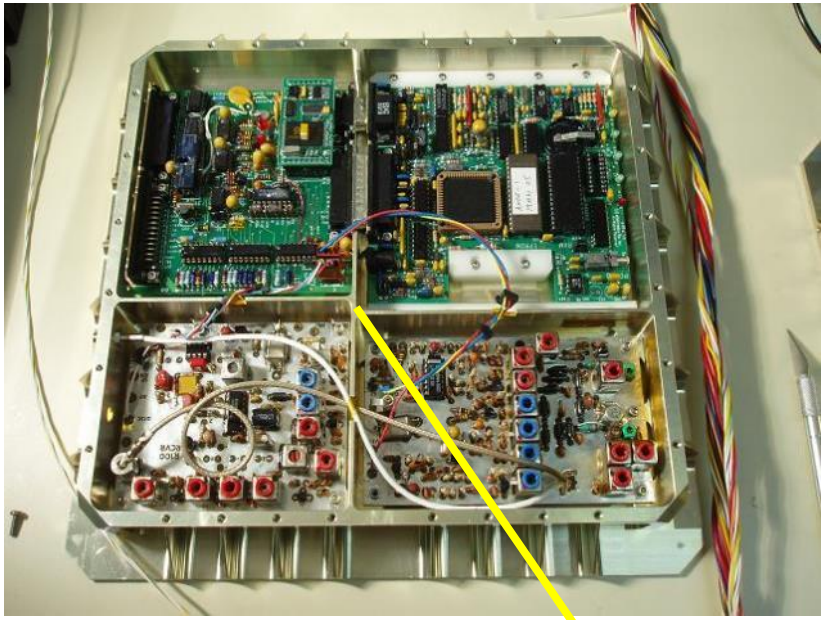
- Take pictures of everything!
- Take pictures of everything!
- More importantly, upload them immediately with proper labels so they can be found/traced later
- It may save you a lot of time and effort later on
  - When critical information has not been documented, pictures can be very useful in proving positive/negative
  - Very helpful in generating documents



Distributed C&DH

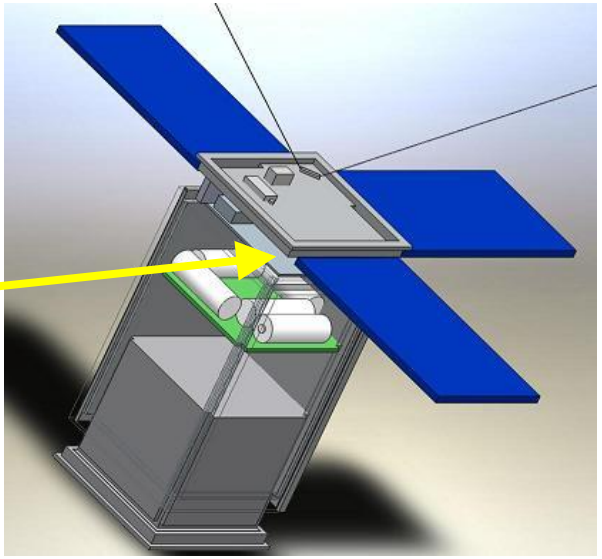
- Main computing based on microcontroller
  - Low power
  - All we need
  - Great for satellite command managing and house keeping
- But has drawbacks
  - Technology moves ahead at a fast pace
  - C language microcontroller programming too much for non-software engineers
- USNA's solution: Arduino minis
  - Very easy for students to learn on
  - Each subsystem that requires any kind of processing uses an Arduino mini
  - Then each subsystem communicates with the main processor (microcontroller) at very high level
  - Plenty of libraries for peripherals

Electronics Shrink, But Benefit to Big Parts



Earlier reductions to 5” cubesat on RAFT (2006)

4:1



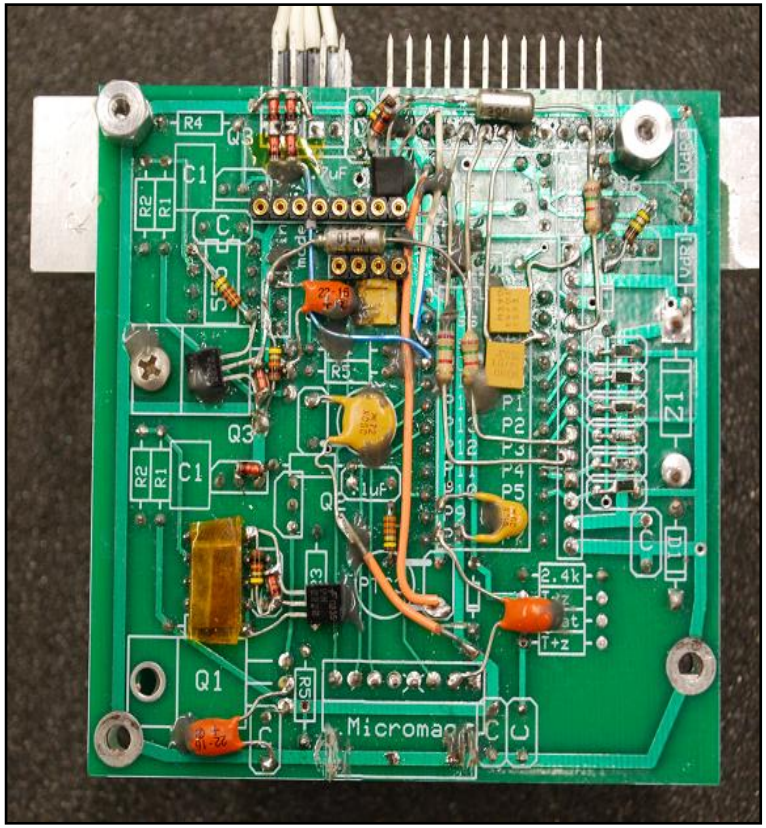
Now reduced 18:1 in volume/mass for 4” cubesat

For Student Built Satellites, Big is Good

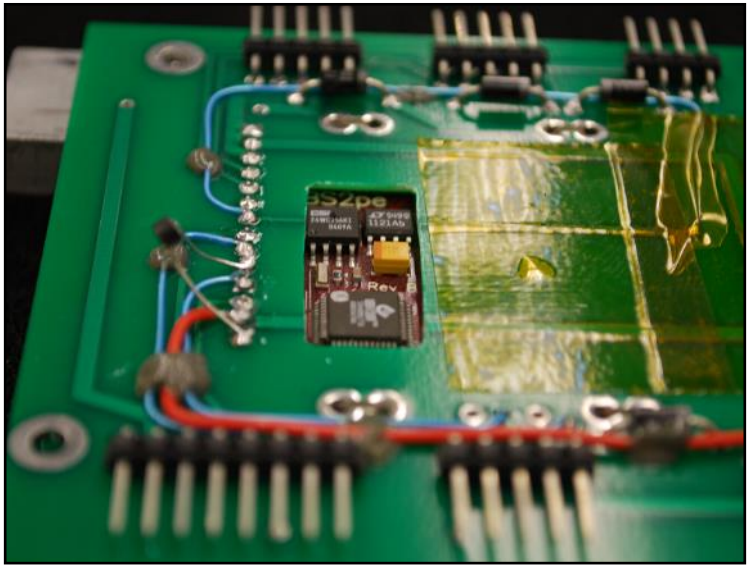
- Easy Through-hole parts for components to be soldered
- Easy to troubleshoot/repair

Knowing When It Is “Good Enough”

- Remember, components are larger!
- Having large components leads to temptation for endless modification

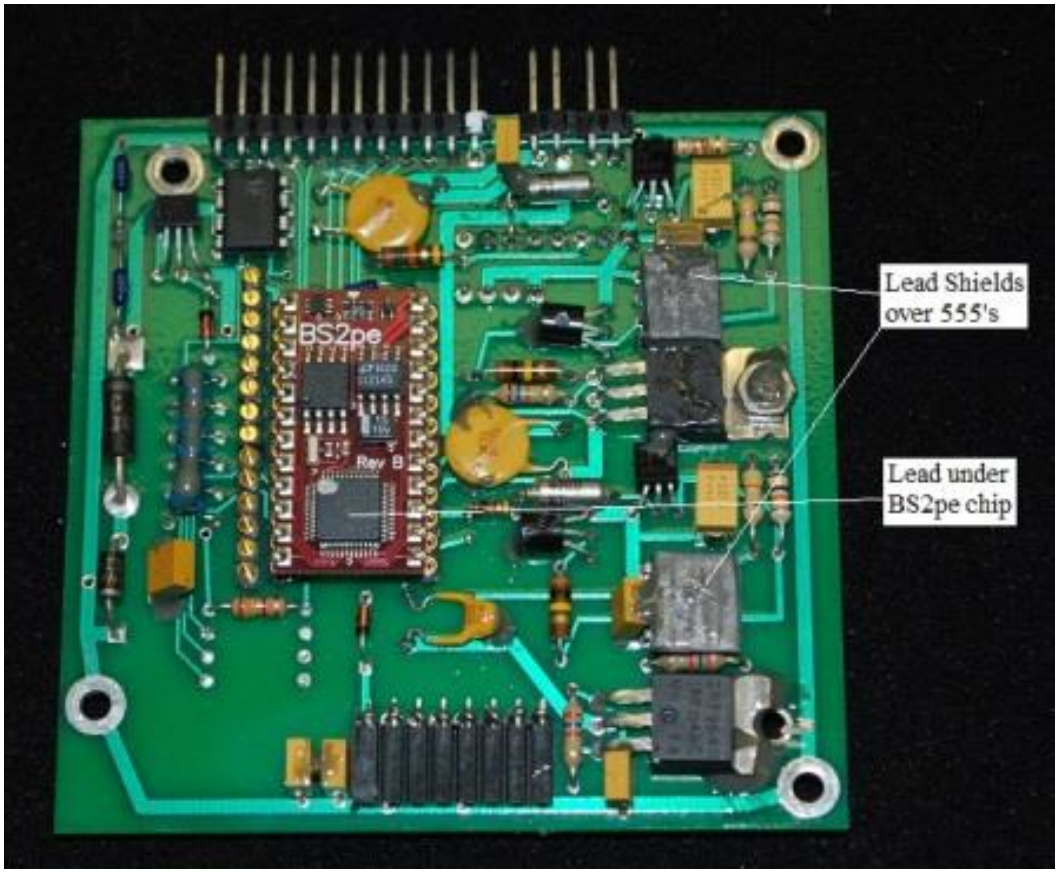


Stop adding neat features…



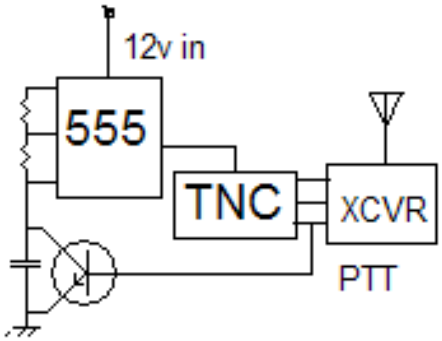
Make sure it fits

Multiple Reset Schemes



Multiple Resets:

- 555 Watchdog

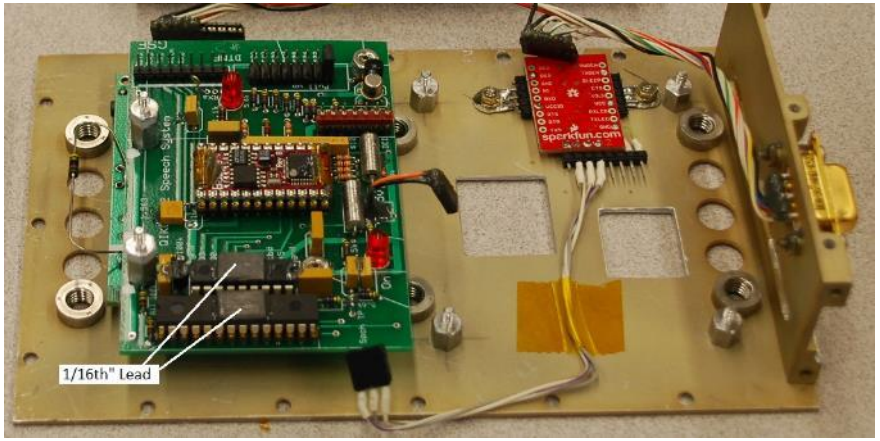


- Command bit
- 5 day timeout
- Second RX
- Touchtone

Lead shields over CPU, RAM and other critical dies

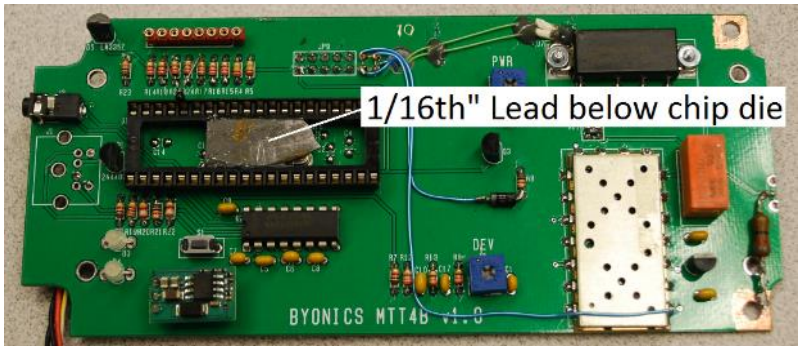
Radiation Shielding Also Considered

- CubeSats do not have the luxury to put ¼” AL casing around the components
- … pieces of lead only on critical chips?



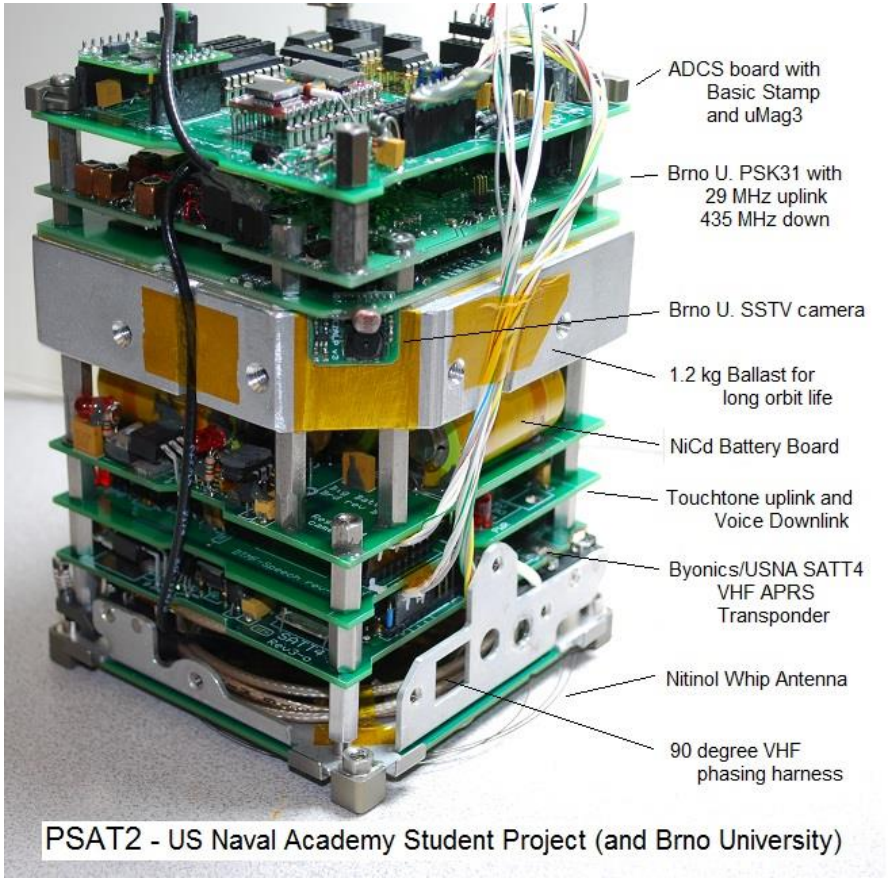
Radiation Shielding
(Lead vs Tantalum)

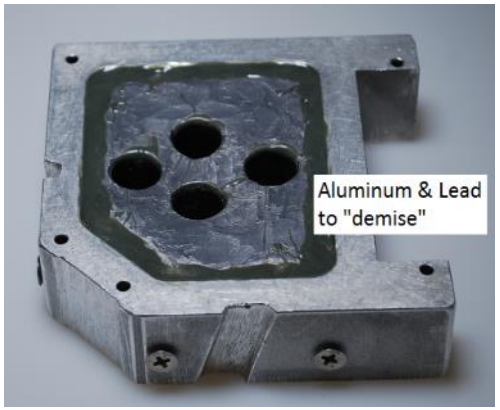
Top and bottom of CPUs, RAMS
And EEPROMS



Now Too Light…

- Most of our new satellites are below mass limits
- Ballast is good to keep satellite longer in orbit





1.2 kg Ballast for long life

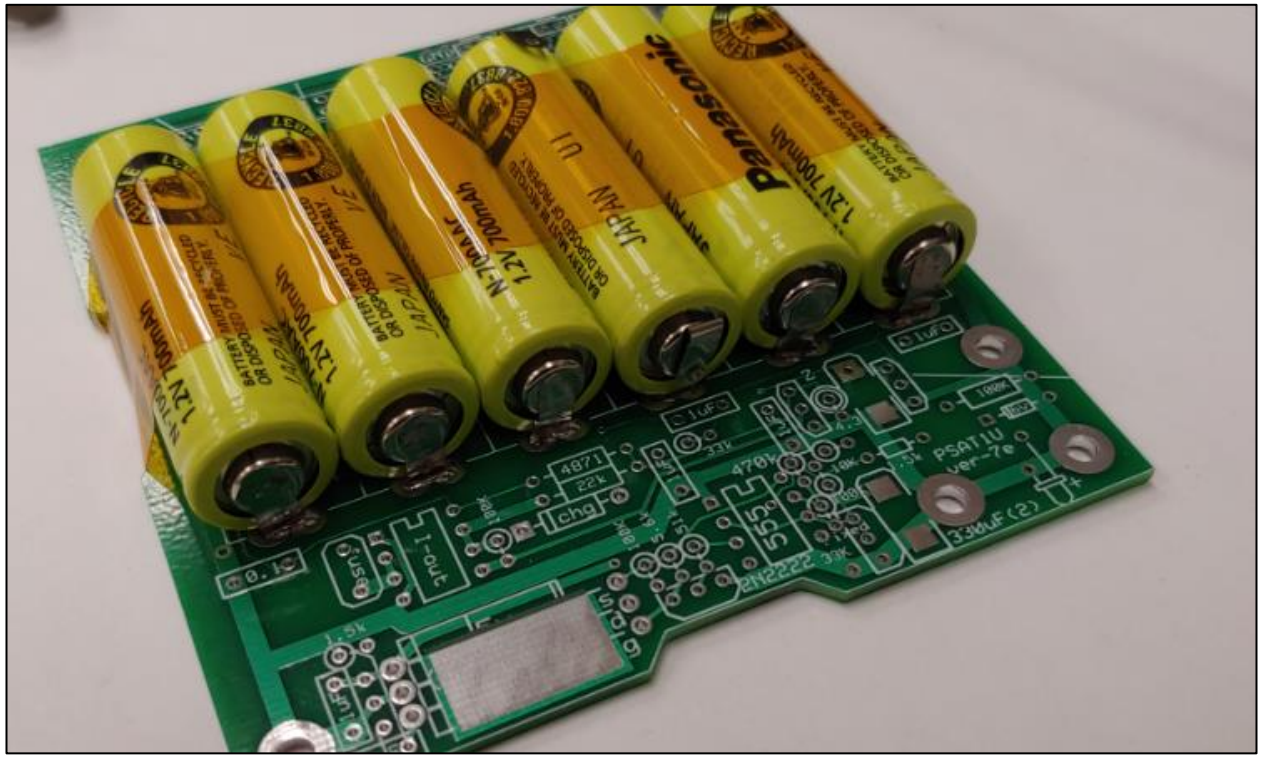
Never Leave Bakeout Unattended

Never leave flight hardware unattended….

Especially in a “found” thermal chamber with cord cut off…

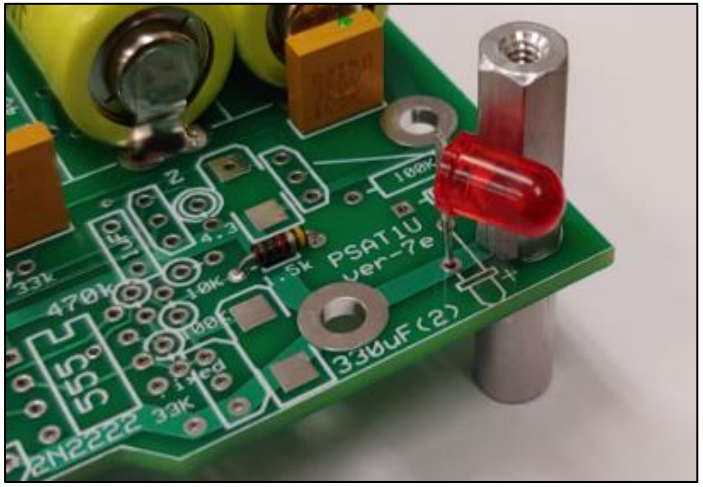
Don’t Be Afraid of NiCd Batteries

- Literally, don’t have to be afraid of them blowing up
- Students can handle them more easily
- Works great in space



Value of LEDs – (and use of corners)

- Why do you need LEDs in space?
  - You don't, but they are hugely helpful on ground
- May result in huge resource saving

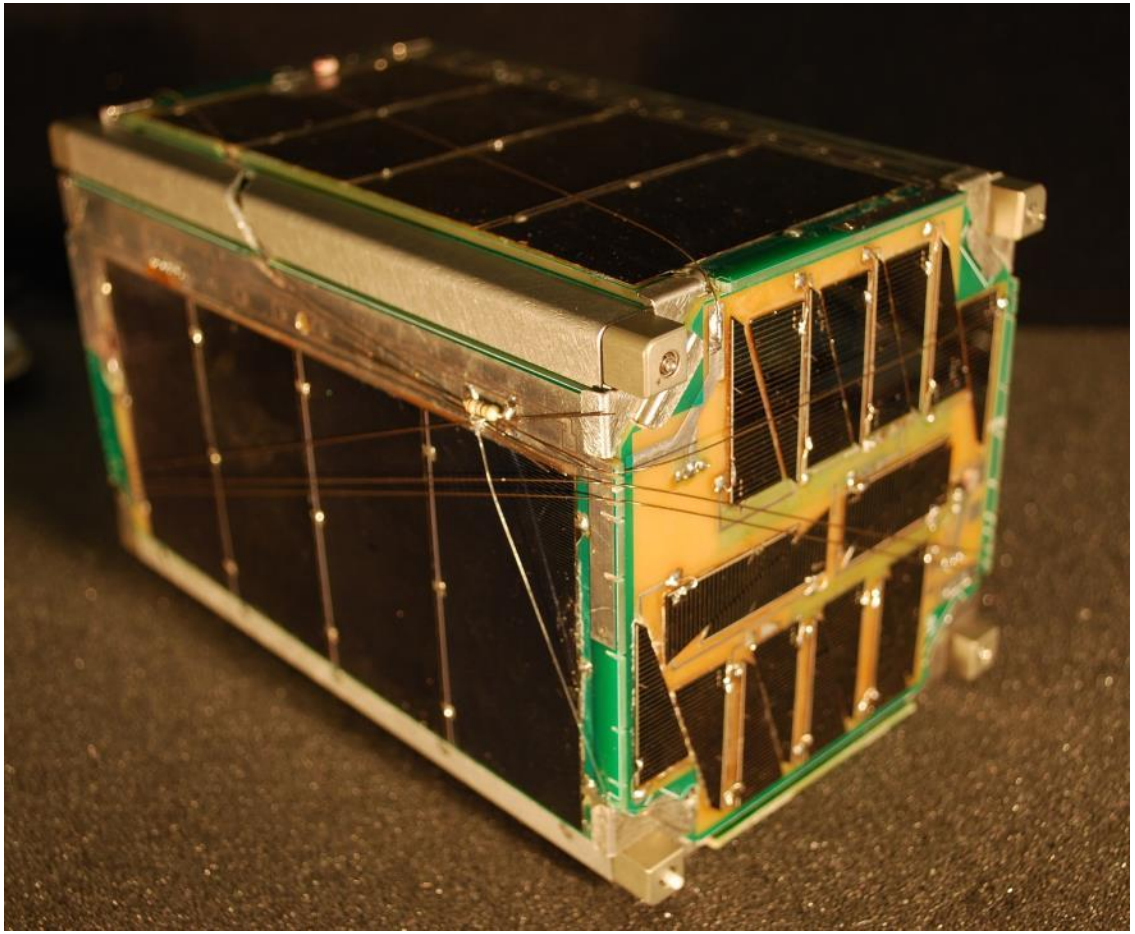


Camera Port

Troubleshooting LED view ports

Rails are great places for space ports
Without disturbing solar panels

Very simple Antenna Release



(Offset Solar panels provide 6 to 10 RPM spin)

One burn resistor releases 5 Antennas:

-2 Orthogonal UHF whips

-2 orthogonal VHF whips

-One 6’ HF whip

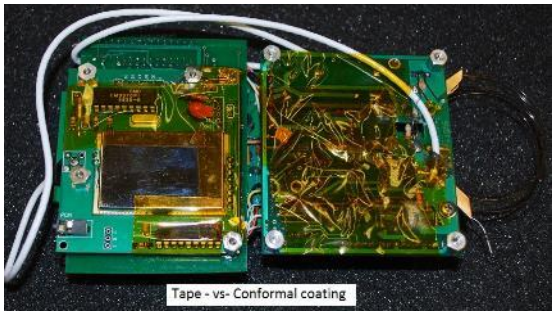
Solder pads provided on all solar panels for final location determination after all antennas tuned.

Debris-catching

- Conformal coating is great
- All big components staked with epoxy
- Helps to have debris catching tape

Conformal Coating

(just cover with tape)

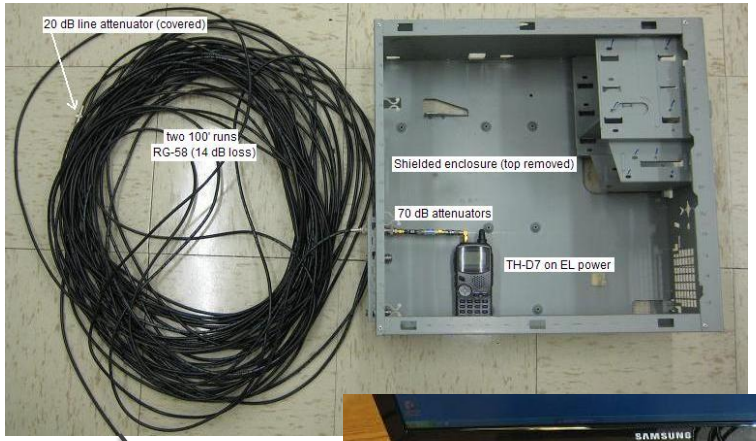


Debris catching

(Double sided tape)

RF Testing in the Lab

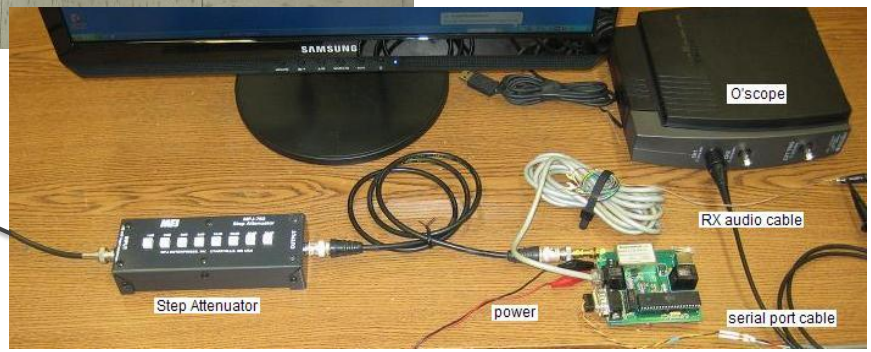
- Signals can “jump over” attenuators plugged back-to-back



“Bench top Testing”

=

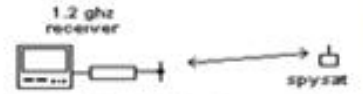
200’ Room-to-Room
And around corner



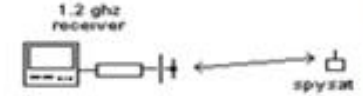
Distributed
100 dB
Attenuation

Even with Dummy Load on TX, still 5 mW is still radiated from radio!
Only 35 dB attn…

Final RF test includes Antennas



Basic link with fundamental dipole antenna but very susceptible to multipath fades and cancellations.



Adding a reflector off the back of the dipole gives 3 dB gain and possibly better viewing by eliminating half of the multi-path reflections.

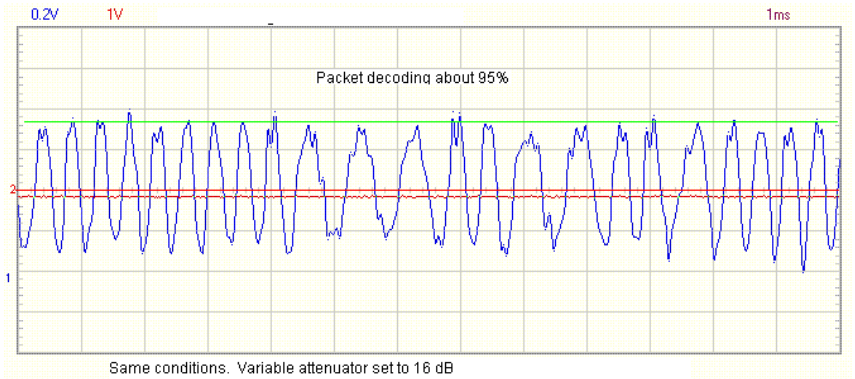
RF path of 1 mile test and 60 dB attn.

Same as 1000 mile LEO path

Give Students Early Experience

- Underclass students make satellite contact the “old fashion way”
  - Tuning manually with dial – following Doppler
  - Aiming manually with AZ-EL controls
- Helps them develop a sense for what a good signal feels like

16 dB S/N
95% decode



Does it look right?

Does it sound right?

Closing Remarks

- Even for CubeSat-class satellites, standardization is hard
  - Hard to lock down design with landscape changing too fast
- Naval Academy Small Satellite Program developed a USNA standard bus geared towards student education
  - Quick development cycle
  - Unique approach, different from higher-capability, more compact design
- Students are still students: challenges are there, but we have some good practices
  - Operate – then – Conceive, Design, Implement
- Amateur radio a critical component to student projects
  - Easier access to hands-on experience
  - Teach them to be practical engineers
- Certain lower-tech, but more-robust design features can greatly benefit student satellite development experiences
  - You can truly let students break flight hardware – more learning opportunities

Thank you.
Questions?