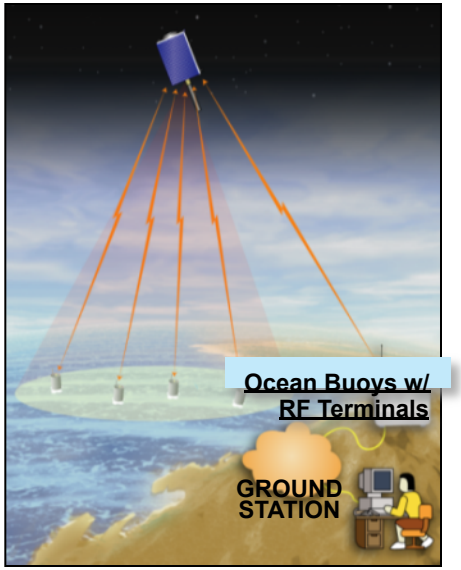
Cubesat Remote Data & Comms Transponders

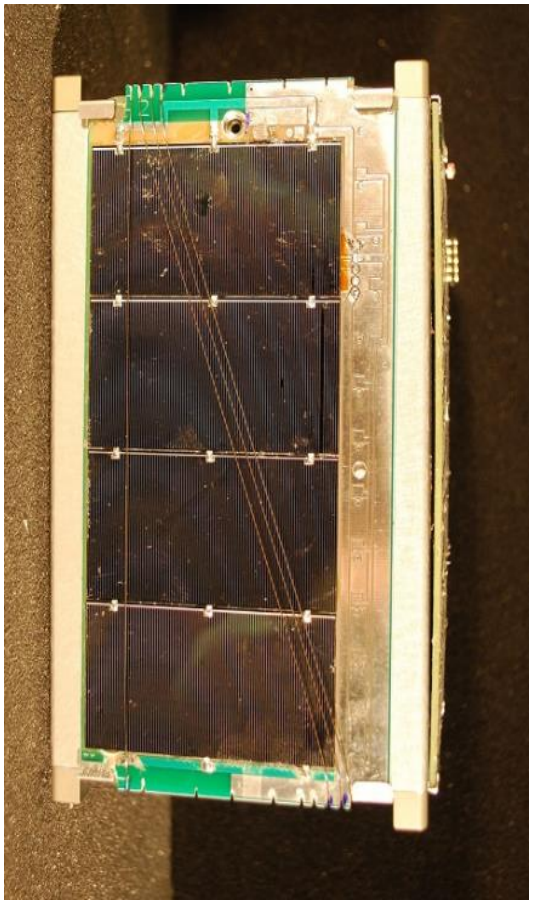
2015 Smallsat Cubesat Conference, Utah



Bob Bruninga WB4APR
US Naval Academy Satellite Lab
bruninga@usna.edu

Dr. Mirek Kasal OK2AQK
Tomas Urbanec, P. Vágner

Mike Ruprecht, DK3WN



A satellite relay channel for Amateur Satellite User data anywhere on earth.

PSAT

Cubesat Remote Data & Comms Transponders

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

The Earth

The Air

The Climate

The Water

The Wildlife

Humanity

Human-to-Human communications

Remote Robot communications

Cubesat Remote Data & Comms Transponders

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

Cubesat Remote Data & Comms Transponders

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

Problem with Spacecraft segment focus:

Multi-year, often delayed, expensive small cubesats do not well meet these particular undergraduate objectives.

Solution: Ground Terminal Applications Focus

Supports Student Experimenters world wide

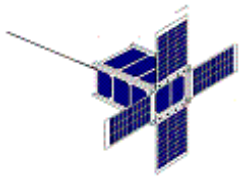
OR

OR

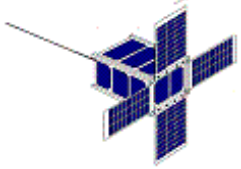
OR

Quicker Student involvement using a Ground Terminal Operational Concept

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

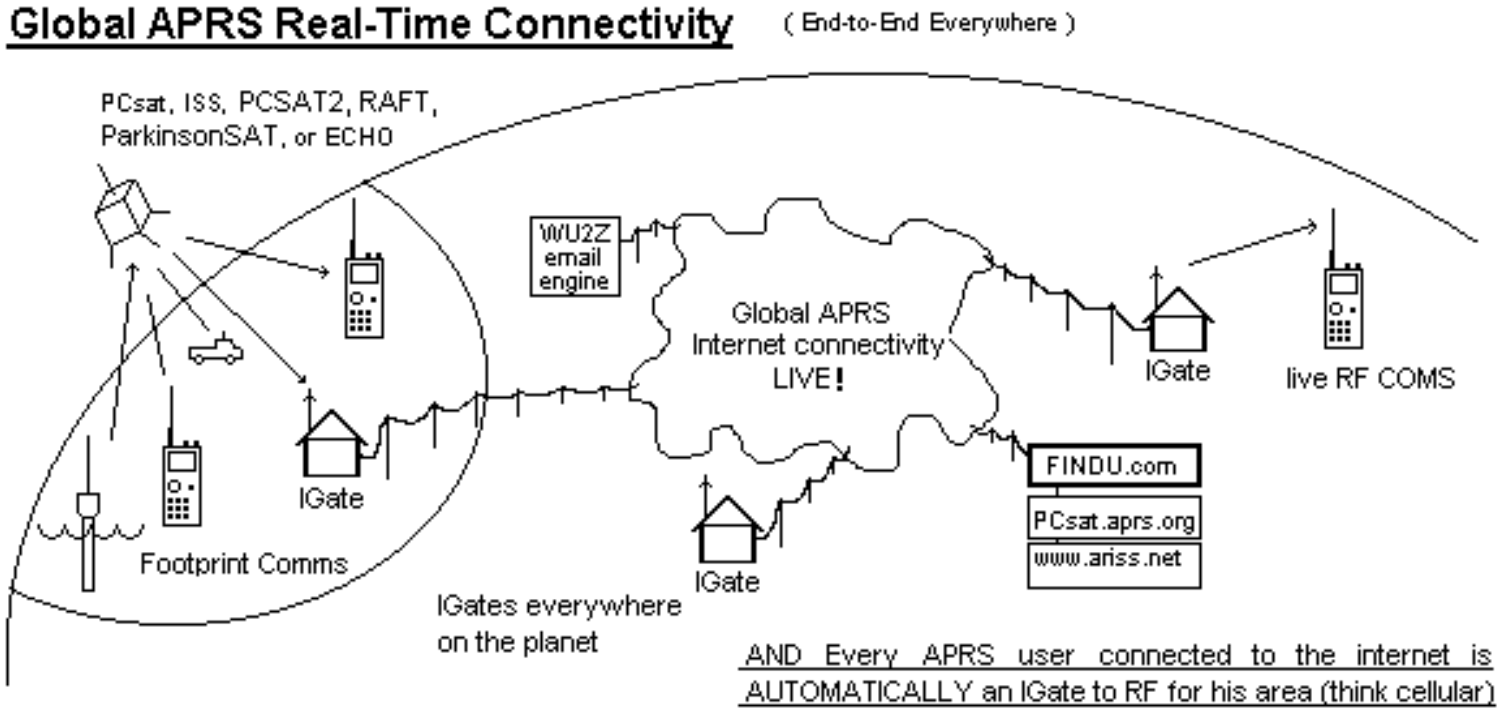
Education

Force

Multiplier!

APRS Global data network

APRS Local & Global Internet linked Data Network



APRS Global Packet Radio Network

Internet Linked for live Communications

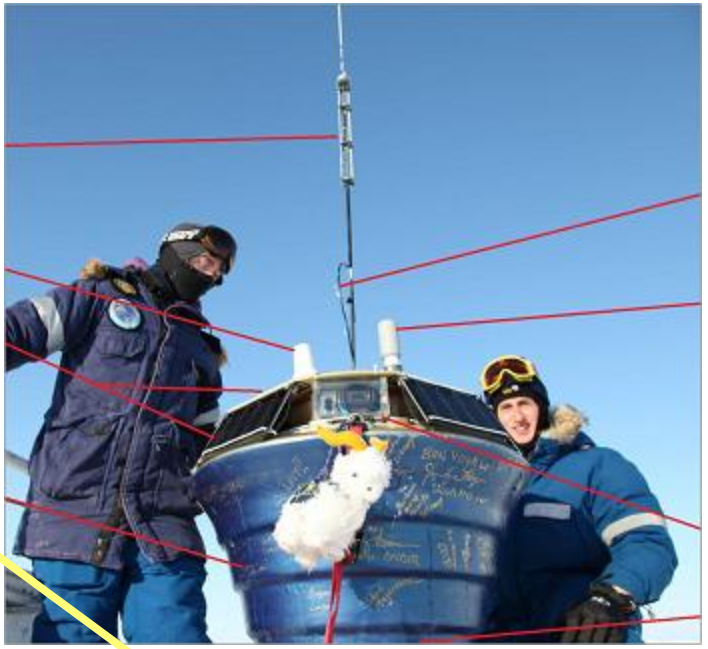
Automatic Packet Reporting System

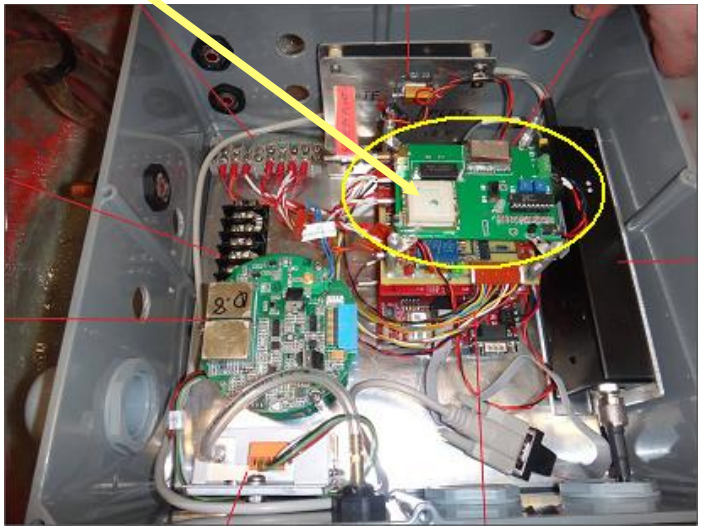
APRS Global data network

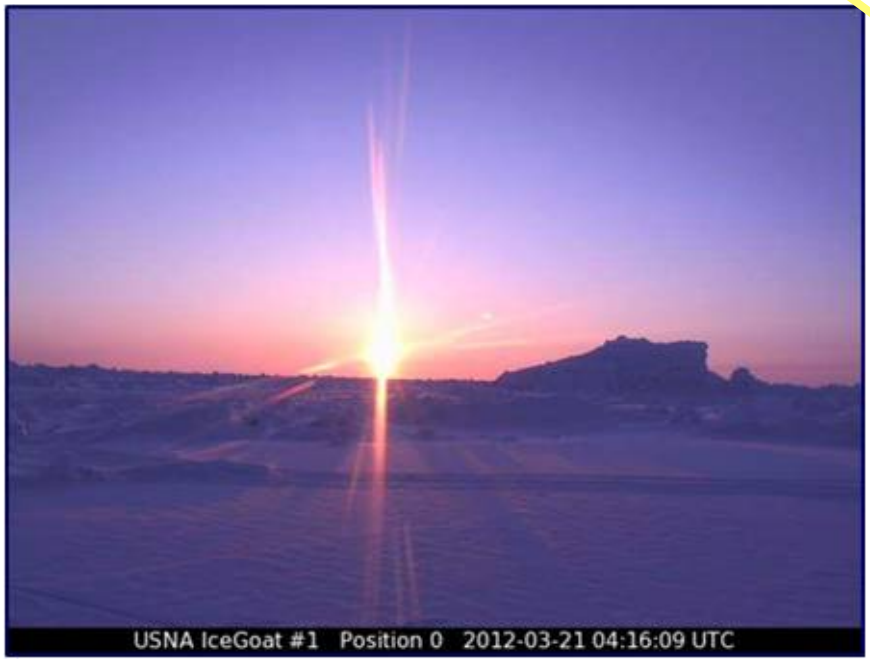
Arctic Buoy Student Experiment

- USNA Arctic Buoy deployed March 2012

The APRS piece

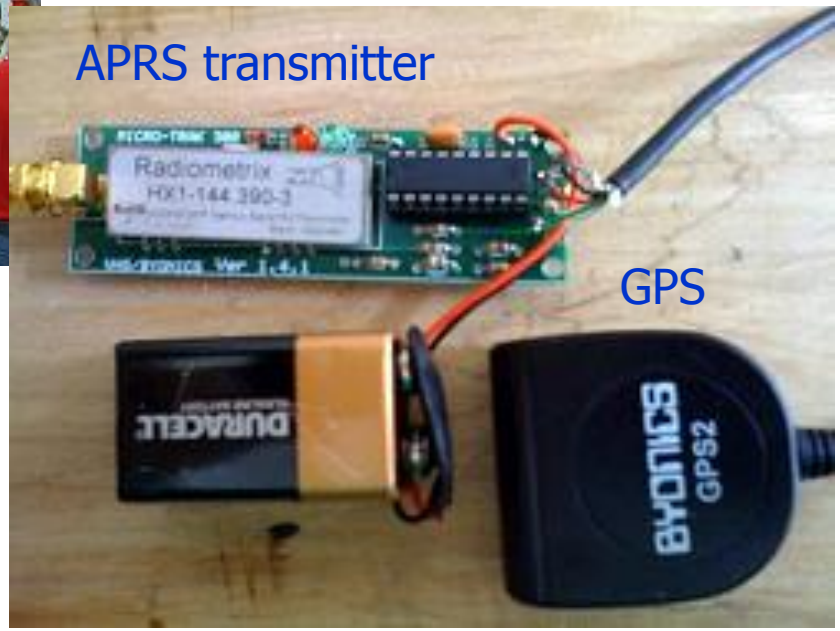






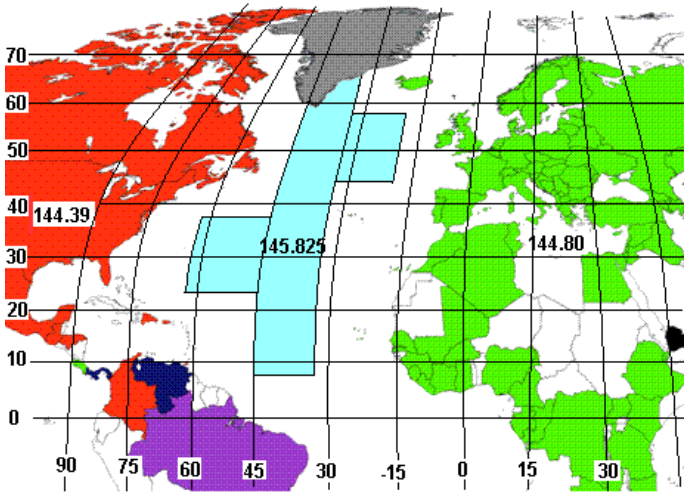
Example Remote Sensors using APRS Protocol

Very Simple



Why We Need Psat Satellite Transponders

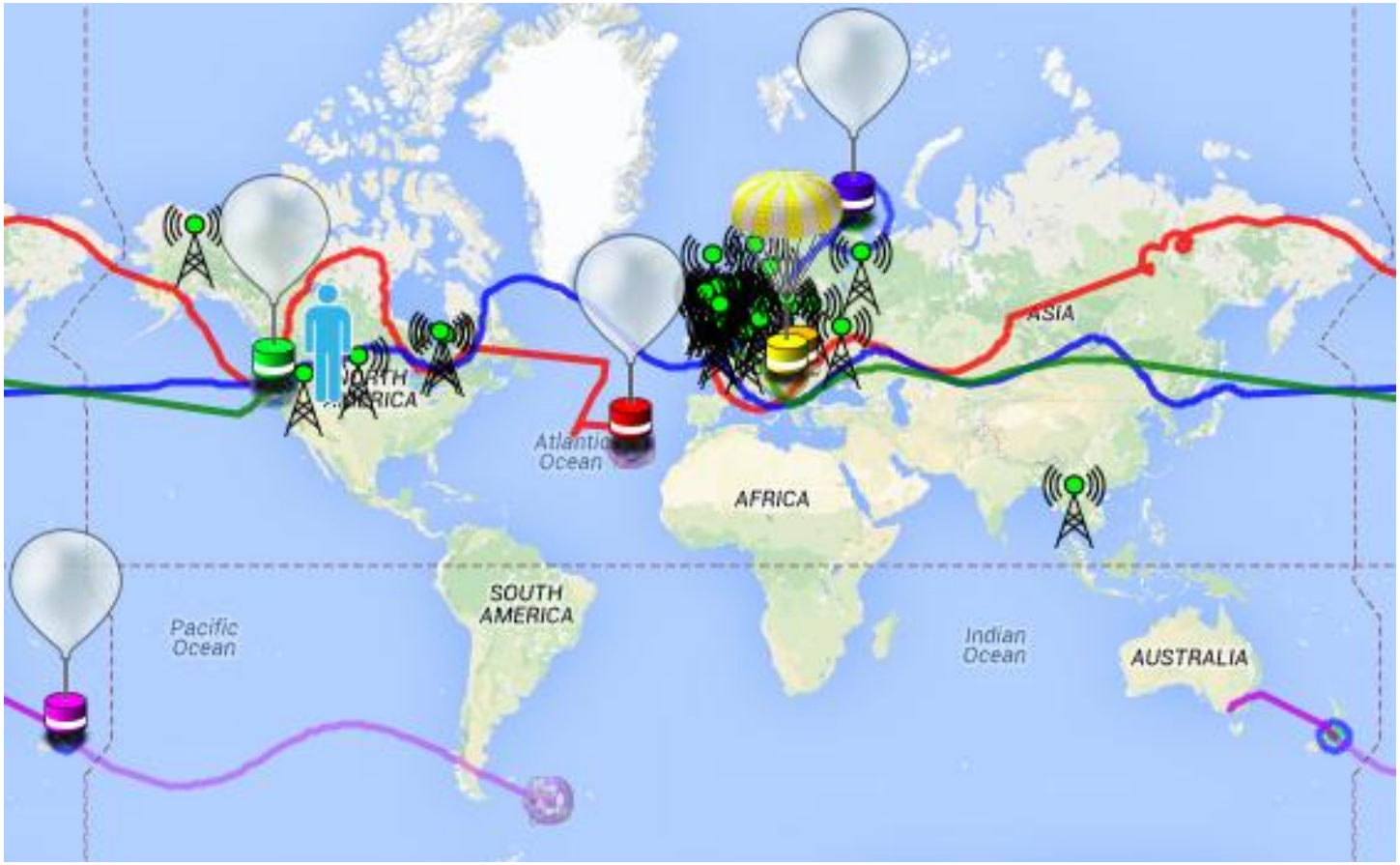
- Transatlantic APRS balloon launched and tracked through terrestrial network
- Lost comms over Atlantic Ocean
- It could have been picked up by our Psat/Pcsat transponder or the ISS



Possible APRS TransAtlantic Freq Plan

Global Wilderness Areas (90% of Earth)

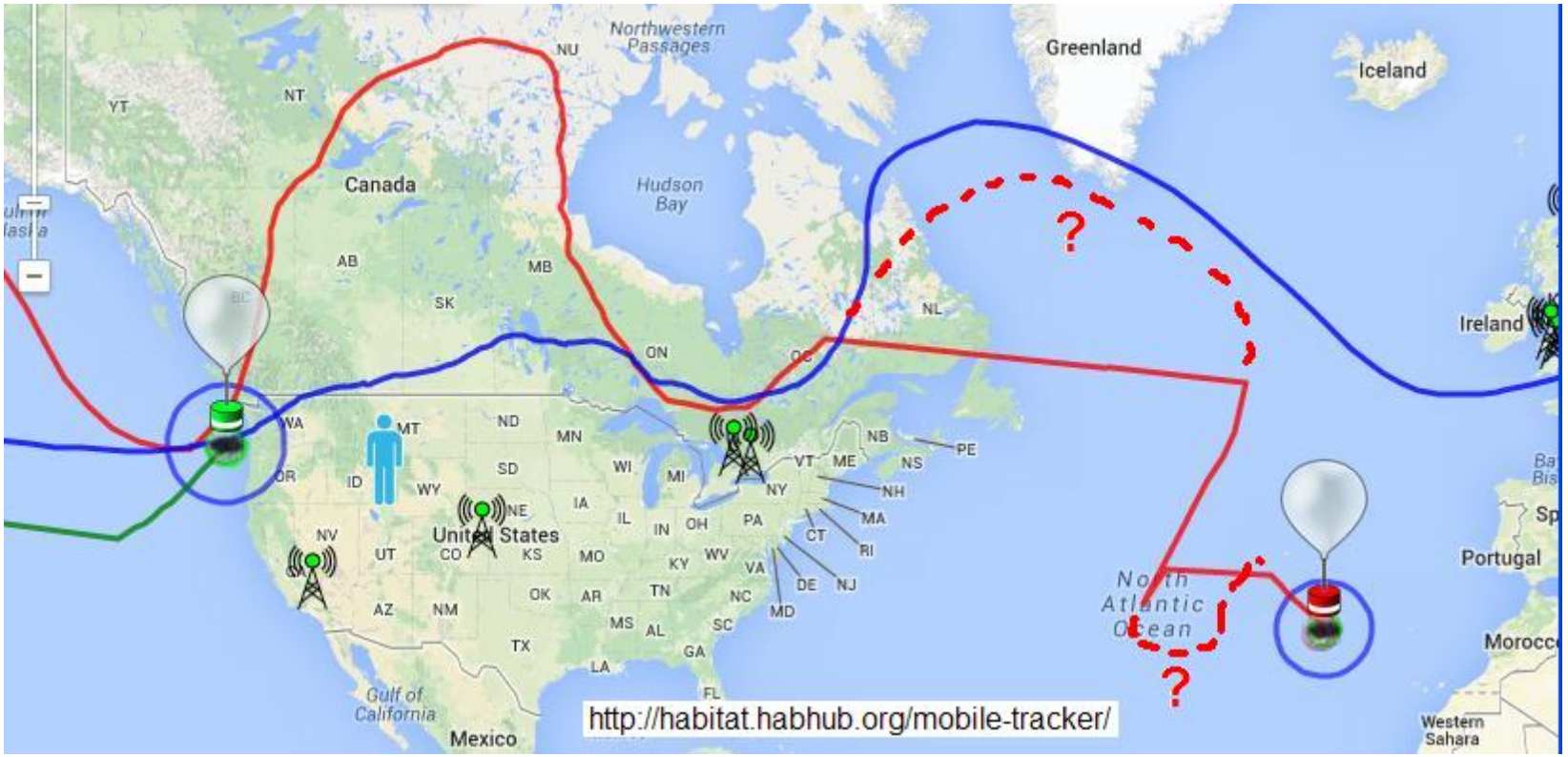
- Live Global APRS Balloon Tracking Web Page



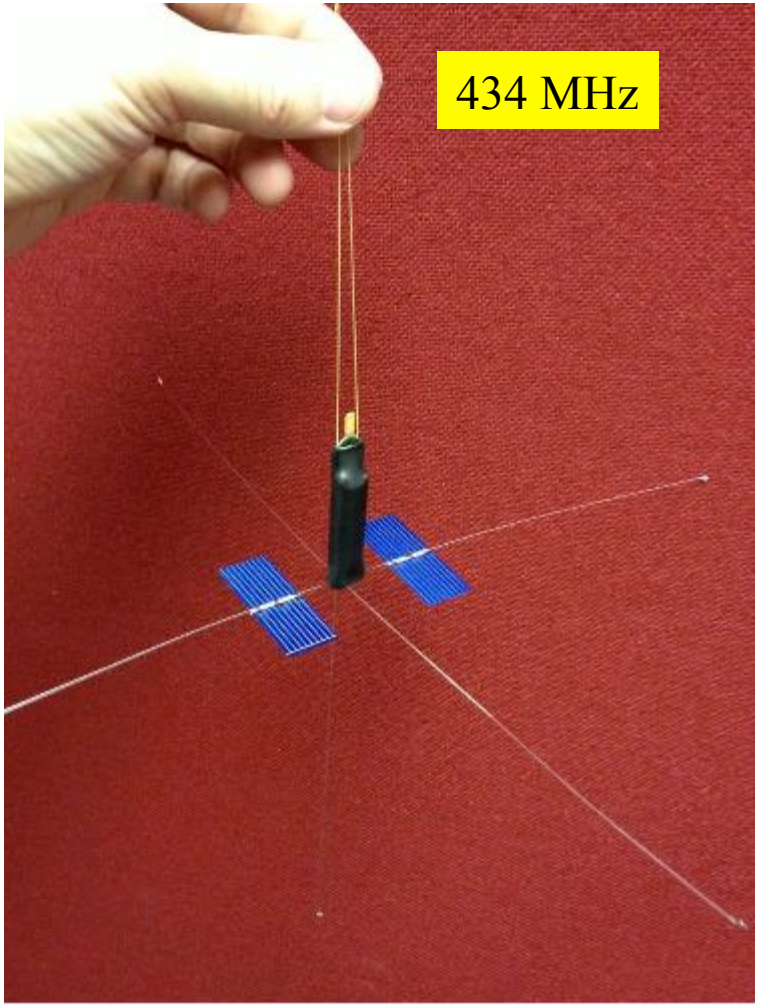
Global Wilderness Areas (90% of Earth)

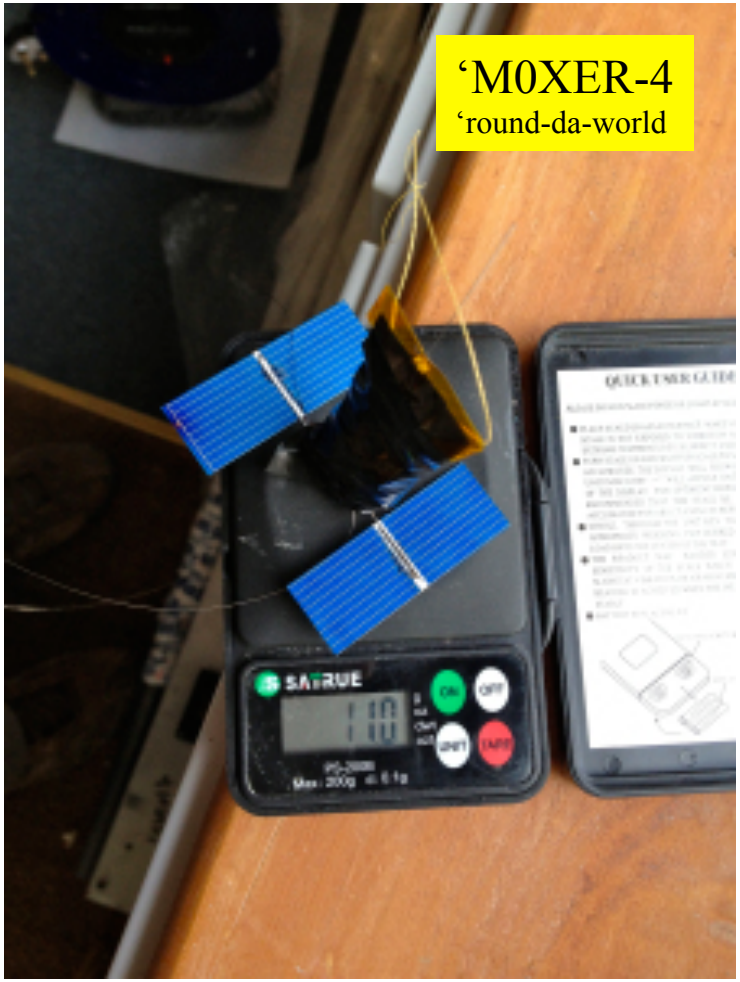
M0XER-3, 4 and 6

- Live Global APRS Balloon Tracking Web Page



Tiny M0XER APRS (balloon data) payloads

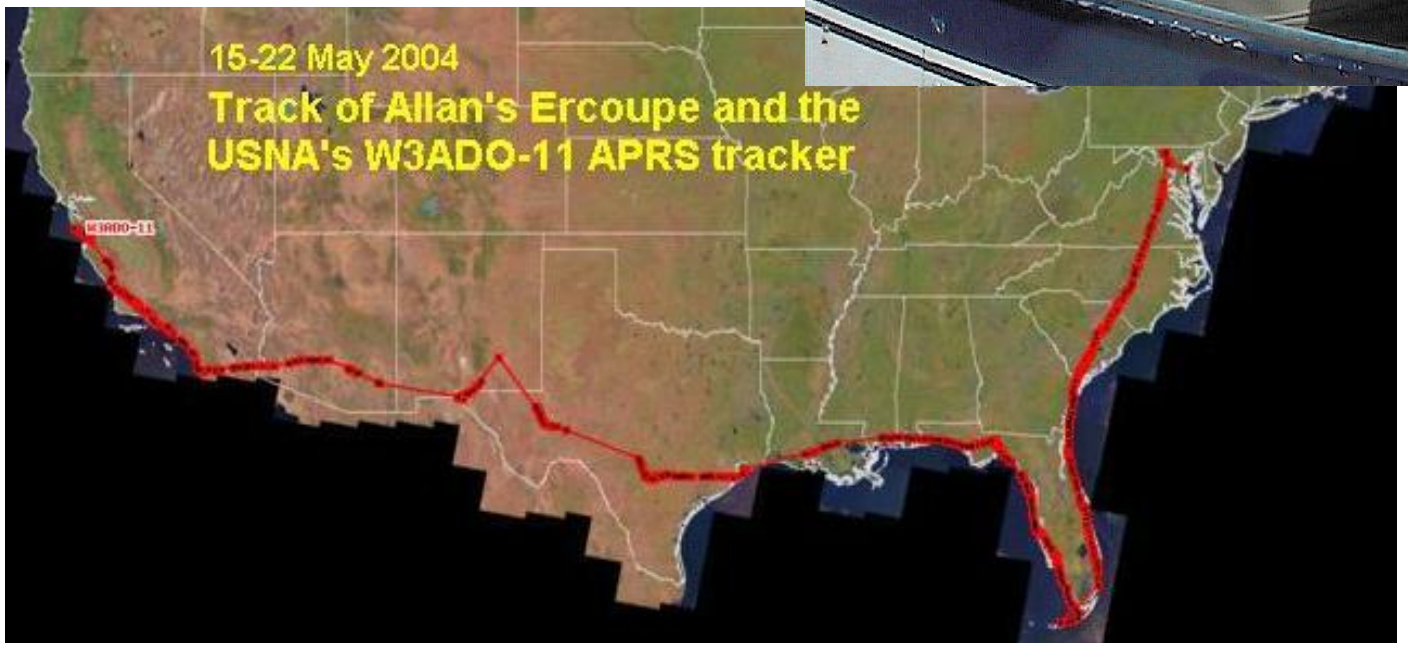




"APRS" Tracking

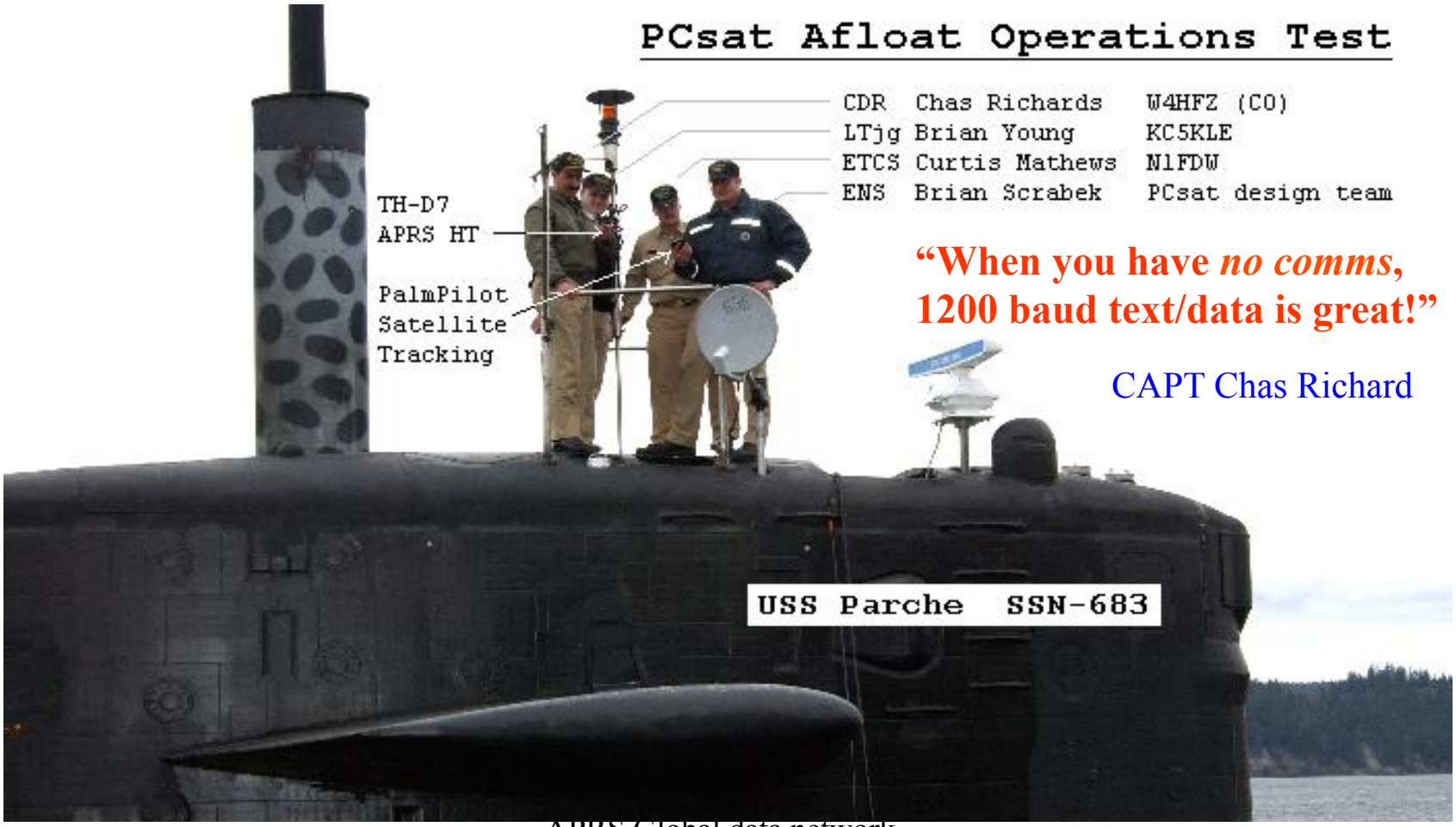
Track any experiment anywhere and collect data

Tactical situational awareness

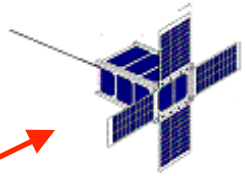


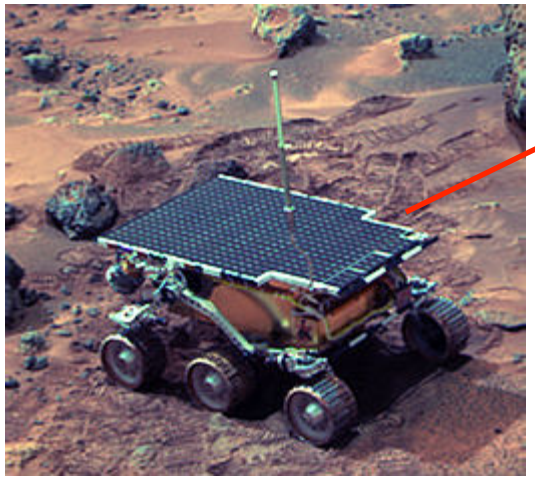
Hand-Held Satcom via APRS & Psat

Ground Terminal is Walkie-Talkie, and Palm Pilot

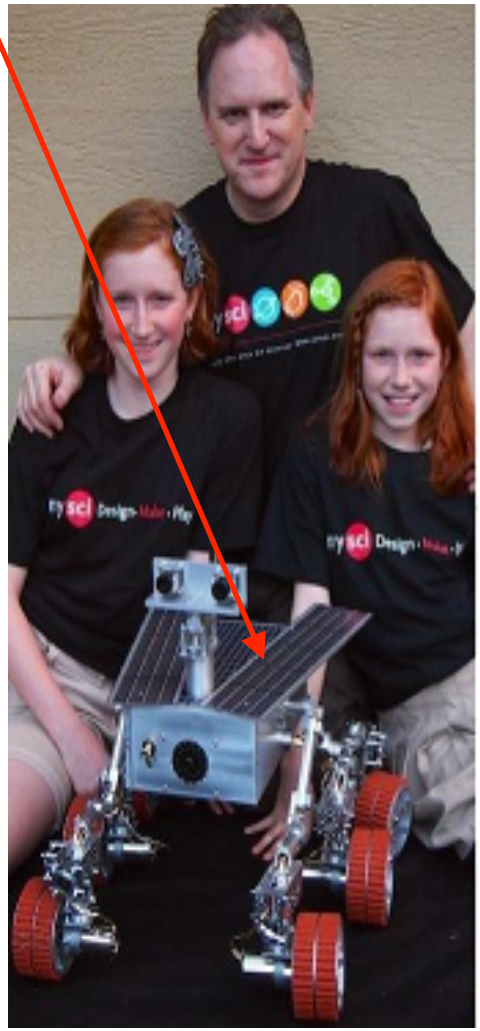


MAREA* Rover Projects (ARRL)





- STEM School projects
- Excite kids with Robotics
- Drive anywhere on Earth!
- Via APRS links

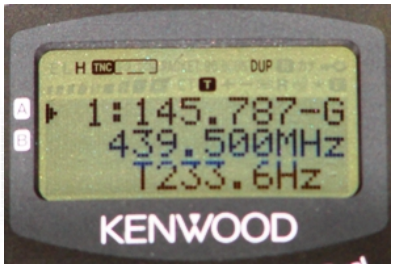


*http://www.arrl.org/marea-ham-radio-robotics

Ground Terminal Applications Focus

Tactical Situational Awareness and Text Messaging

Last 100 stations!

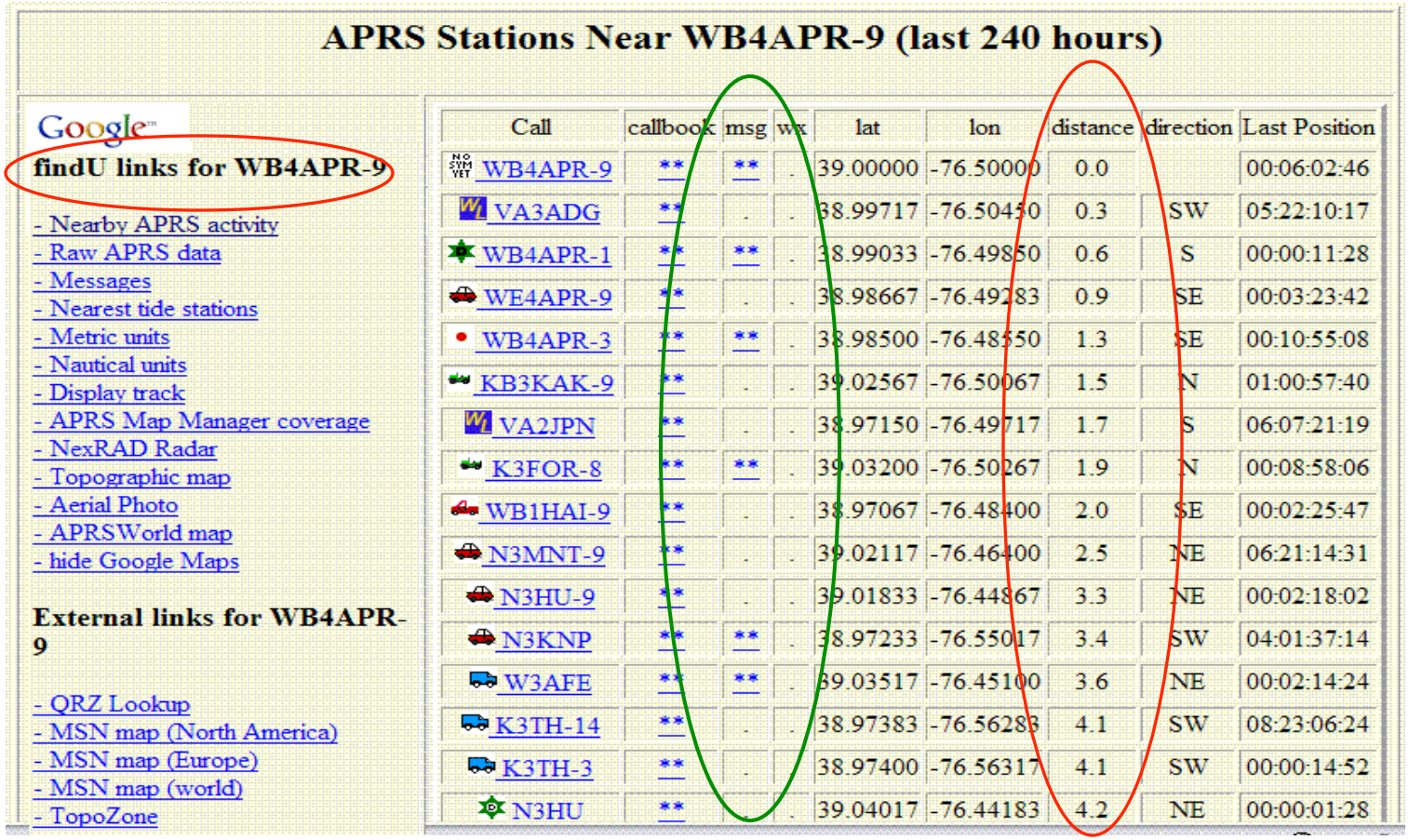


Direction & Distance

Frequency and Tone

APRS Experiment Data Access (via internet)

http://map.findu.com/wb4apr* to see data on ANY experiment in the world



APRS Stations Near WB4APR-9 (last 240 hours)

Google

findU links for WB4APR-9

- Nearby APRS activity
- Raw APRS data
- Messages
- Nearest tide stations
- Metric units
- Nautical units
- Display track
- APRS Map Manager coverage
- NexRAD Radar
- Topographic map
- Aerial Photo
- APRSWorld map
- hide Google Maps

External links for WB4APR-9

- QRZ Lookup
- MSN map (North America)
- MSN map (Europe)
- MSN map (world)
- TopoZone

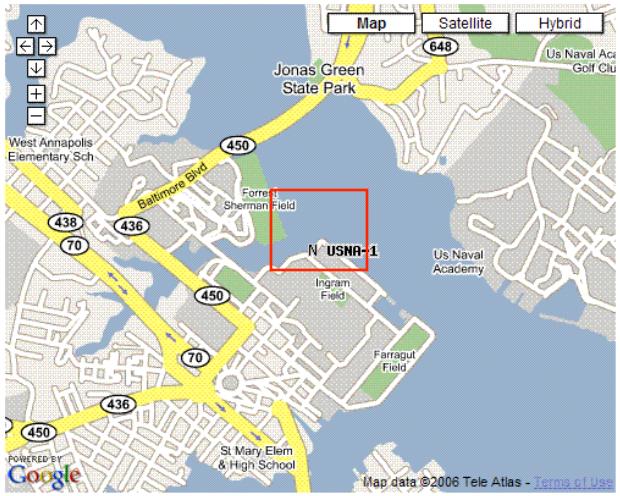
Call	callbook	msg	wx	lat	lon	distance	direction	Last Position
WB4APR-9	**	**	.	39.00000	-76.50000	0.0		00:06:02:46
VA3ADG	**	.	.	38.99717	-76.50450	0.3	SW	05:22:10:17
WB4APR-1	**	**	.	38.99033	-76.49850	0.6	S	00:00:11:28
WE4APR-9	**	.	.	38.98667	-76.49283	0.9	SE	00:03:23:42
WB4APR-3	**	**	.	38.98500	-76.48350	1.3	SE	00:10:55:08
KB3KAK-9	**	.	.	39.02567	-76.50067	1.5	N	01:00:57:40
VA2JPN	**	.	.	38.97150	-76.49717	1.7	S	06:07:21:19
K3FOR-8	**	**	.	39.03200	-76.50267	1.9	N	00:08:58:06
WB1HAI-9	**	.	.	38.97067	-76.48400	2.0	SE	00:02:25:47
N3MNT-9	**	.	.	39.02117	-76.46400	2.5	NE	06:21:14:31
N3HU-9	**	.	.	39.01833	-76.44867	3.3	NE	00:02:18:02
N3KNP	**	**	.	38.97233	-76.55017	3.4	SW	04:01:37:14
W3AFE	**	**	.	39.03517	-76.45100	3.6	NE	00:02:14:24
K3TH-14	**	.	.	38.97383	-76.56283	4.1	SW	08:23:06:24
K3TH-3	**	.	.	38.97400	-76.56317	4.1	SW	00:00:14:52
N3HU	**	.	.	39.04017	-76.44183	4.2	NE	00:00:01:28

* Click to see all stations on map

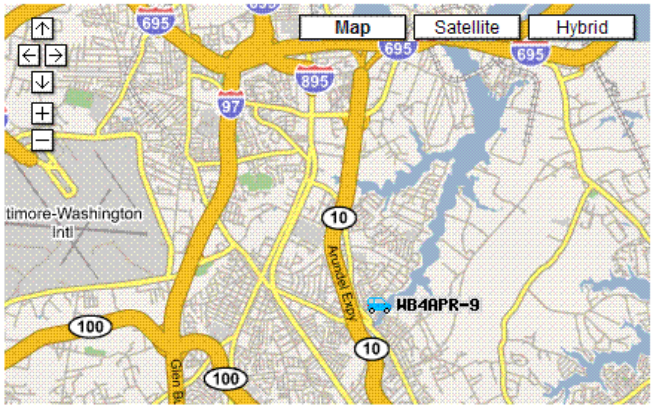
Based on the USNA Automatic Packet Reporting System

Tracking (on Google Earth)

http://aprs.fi

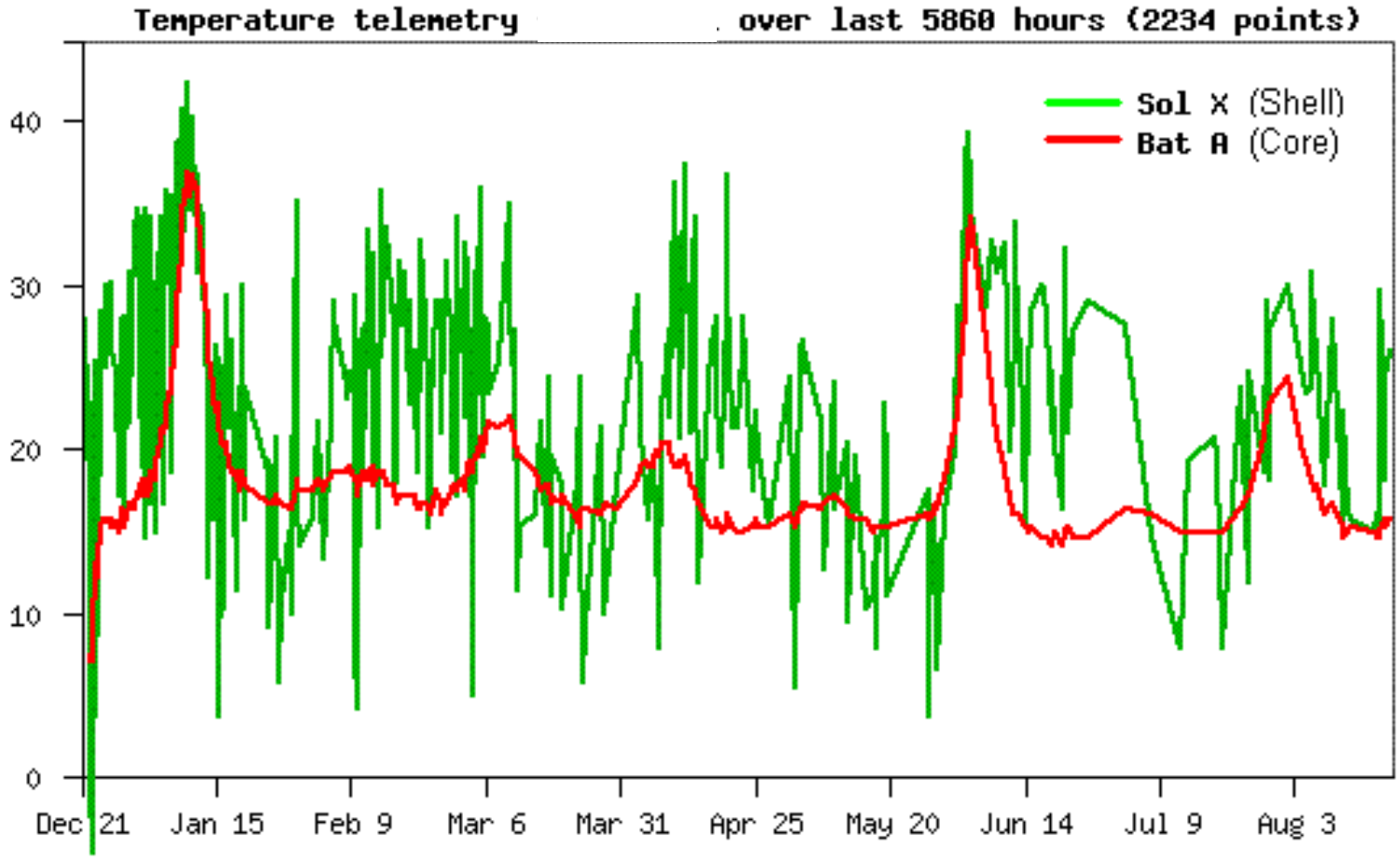


Tactical situational awareness



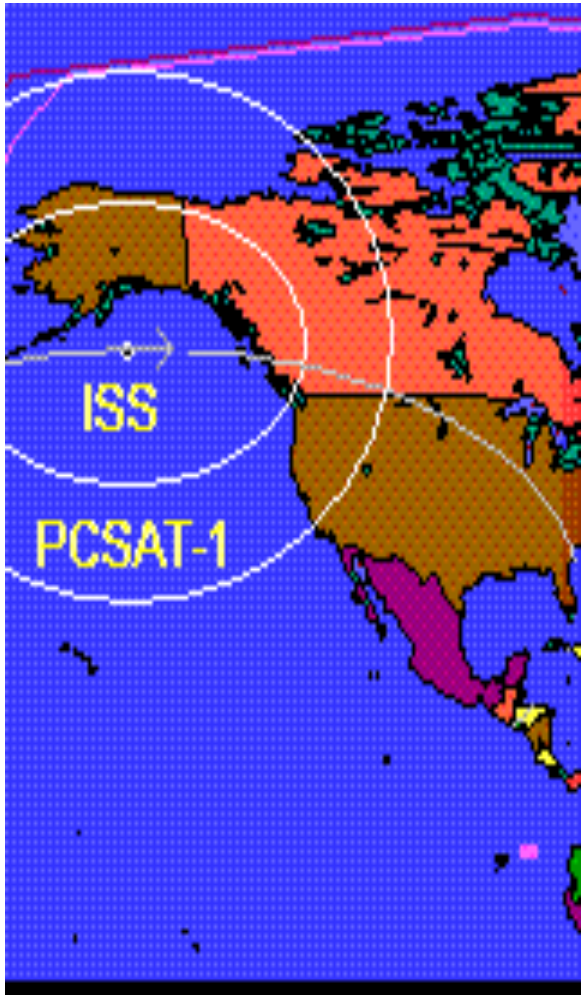
Findu.com Telemetry Plots

Live Example: www.aprs.org/wb4apr-15.html

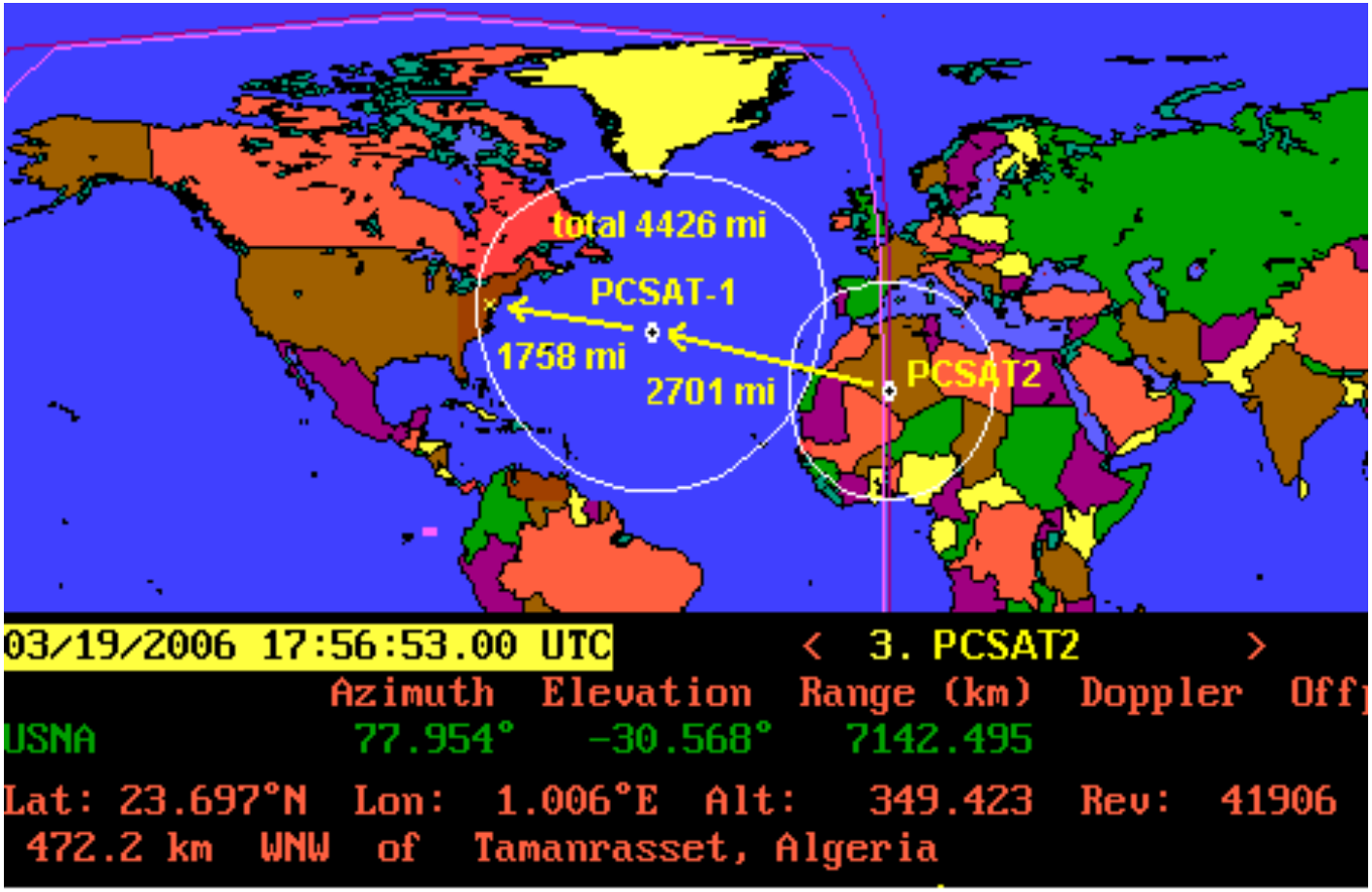


Our Amateur Satellite Data Relay Problem

- ISS – Always there, but
  does not cover the poles
- PCSAT-1 since 2001, but only
  works when it wants to…
- NEED a continuous presence
  in space for these relays!
- The more the better!

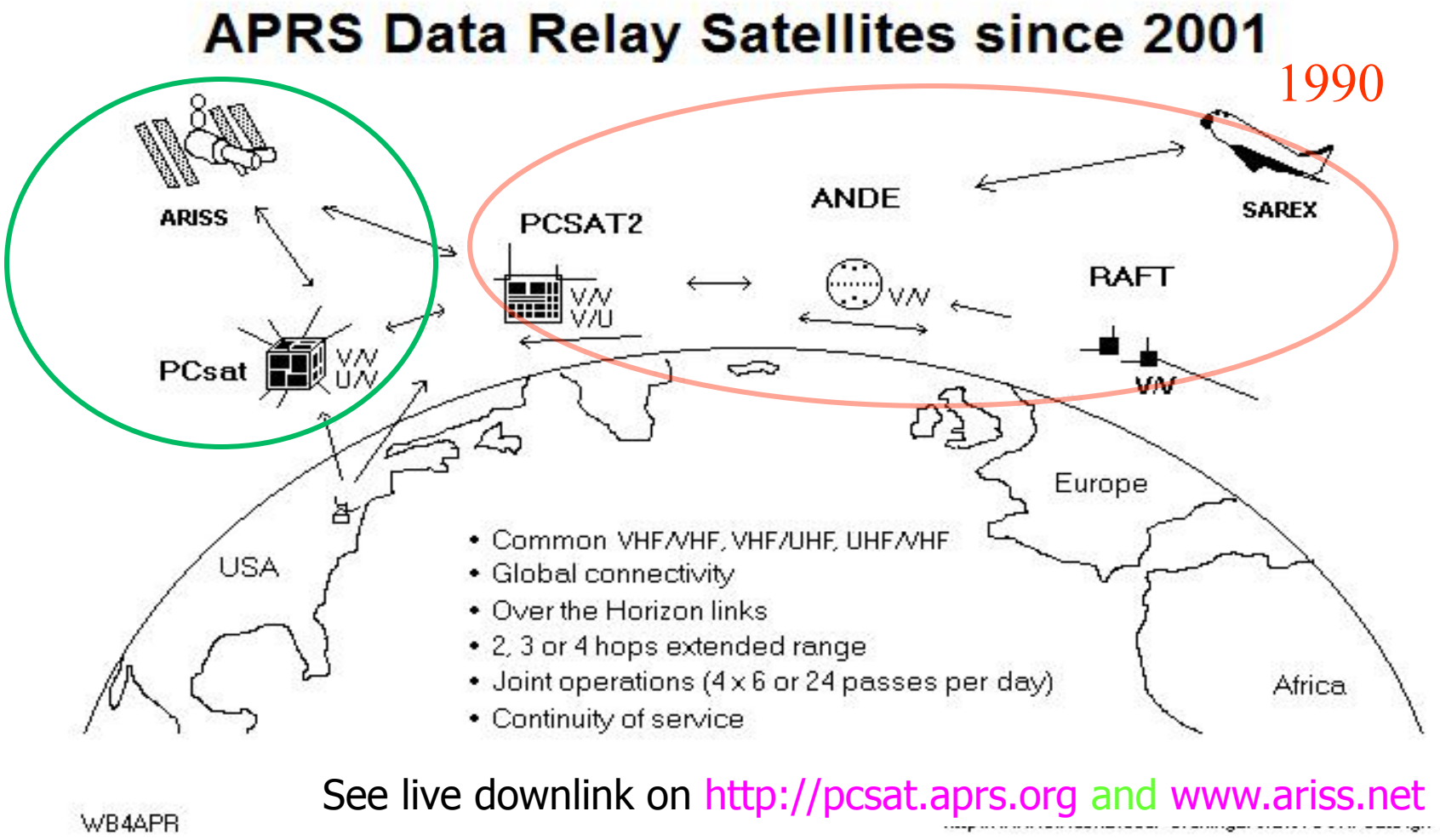


Dual Hop Operations with PCSAT-1 and PCSAT2:



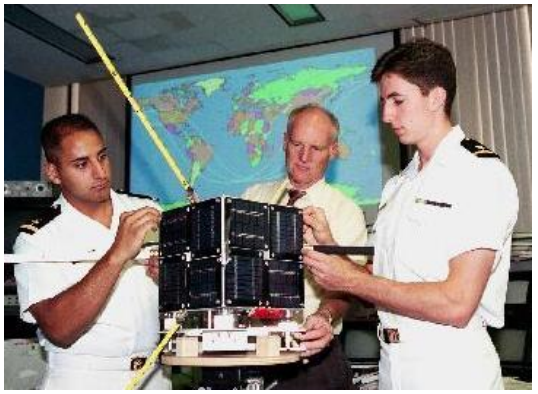
During the March 2006 joint PC1<=>PC2 operations period, numerous dual hop elemetry and user packets were observed. This telemetry packet from PCSAT2 is just about as far as we can get with satellite-to-satellite-to USNA. Notice how few European or USA users were in the footprint making it more probable that PCSAT-1 could hear PCSAT2's signal. WB4APR

All on 145.825 MHz

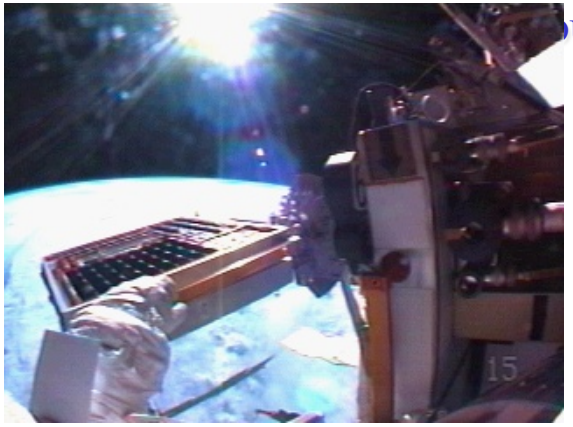


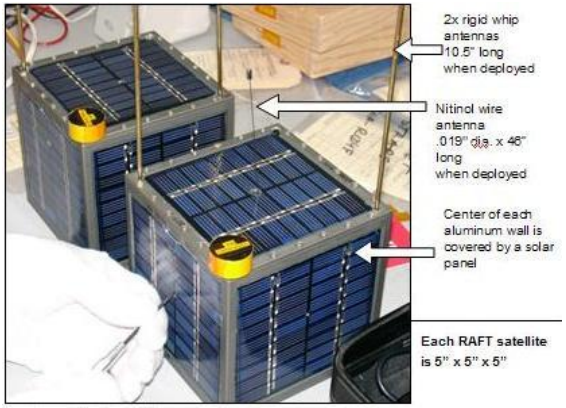
See live downlink on http://pcsat.aprs.org and www.ariss.net

APRS in Space
Automatic Packet Reporting System



- 2001 PCSAT-1 Prototype Comm (semi-operational)
- 2006 PCSAT2 on ISS (returned after 1 year)
- 2007 ANDE de-orbited in 1 year
- 2008 RAFT de-orbited in 5 months
- 2007 Present ISS semi-operational due crew settings
- 2014 CAPE II AX.25 U of Louisiana (Nick Pugh)
- 2015 PSAT APRS and PSK31

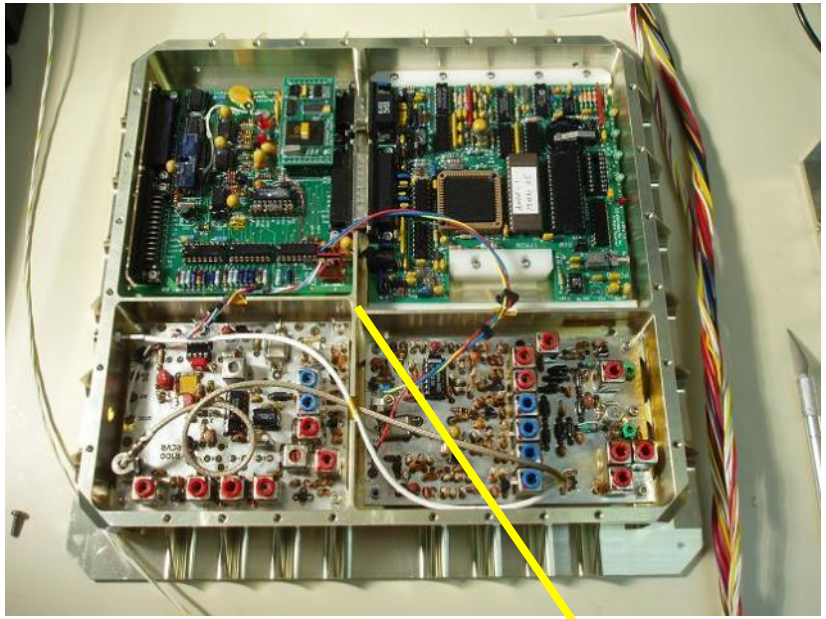




APRS space frequency is published as 145.825

See live downlink on http://pcsat.aprs.org and www.ariss.net

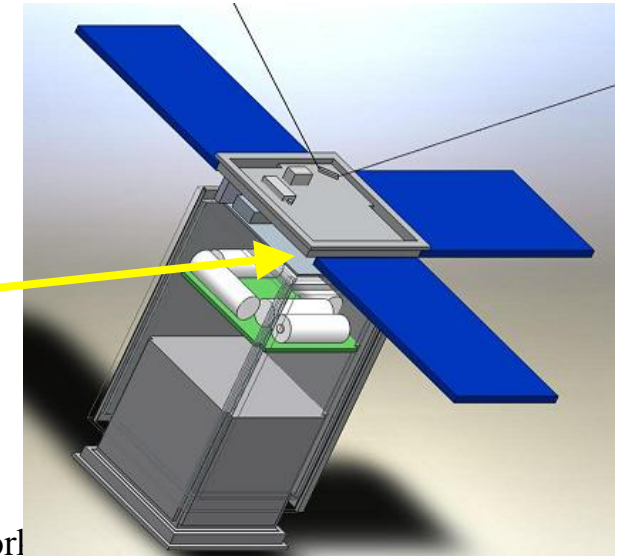
Huge reduction from transponders on PCSAT's 1,2, ANDE and RAFT missions



Earlier reductions to 5" cubesat on RAFT (2006)

4:1

Now reduced 18:1 in volume/mass for 4" cubesat 2009



APRS Global data networl

AX.25 A single 3” Square card 145.825 MHz

Mission: Remote Data Relay, Data Exfiltration, Remote Sensor Relay

Benefit: Support Space Education on the ground through space applications and student experimental access

Hardware: VHF simplex data Xsponder 145.825 MHz

Size/Mass: < 10 cu.in (1 PCB 3.4” square), <0.1kg

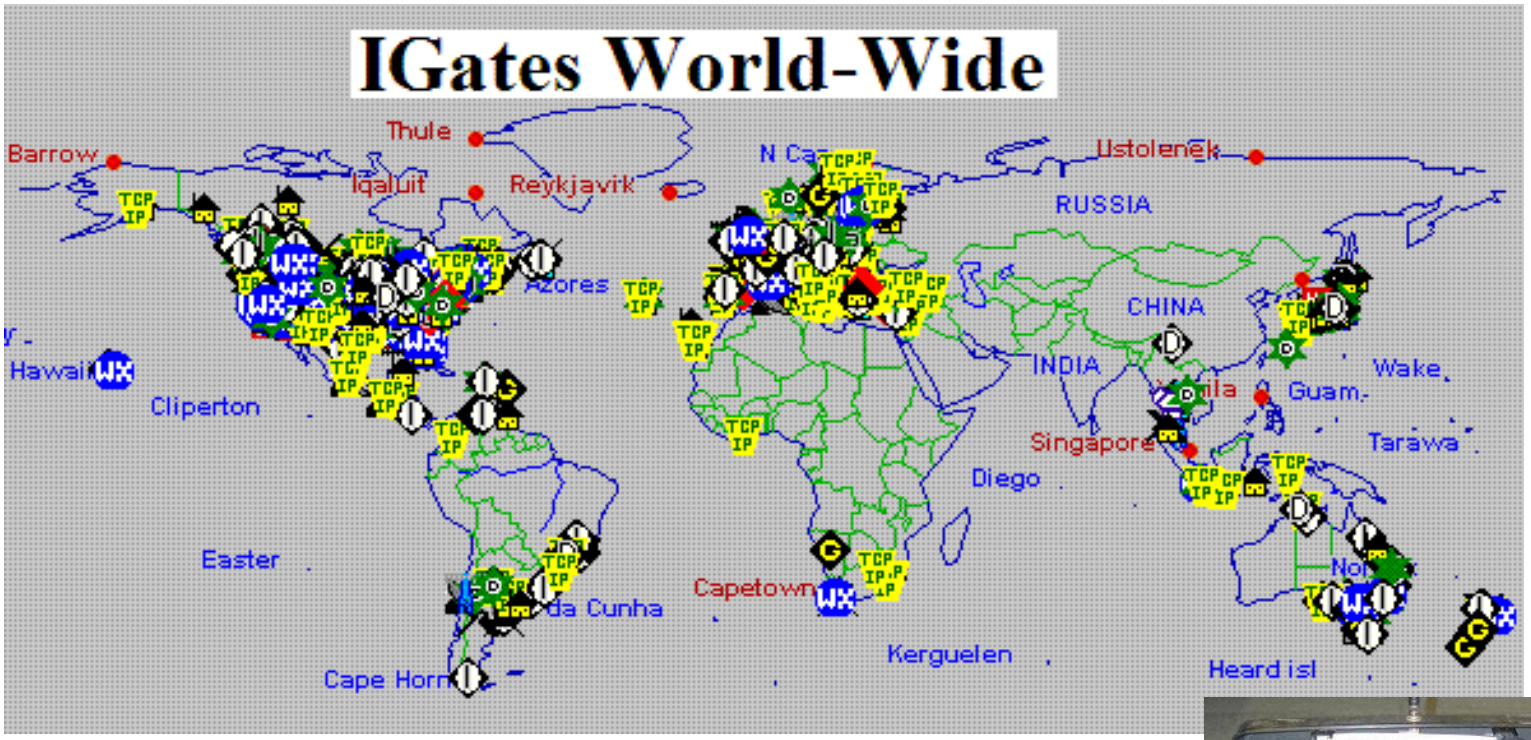
Power: < 1W orbit average, 5 volts.

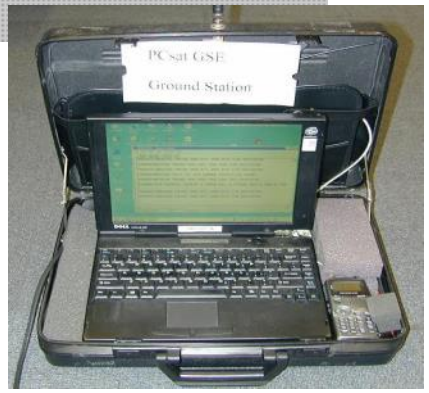
Integration Requirement: Simply, on/off (or *)

Structure Impact: Needs 19” thin wire whip antenna (1 cu.in)

Benefit to Spacecraft: High visibilty to worldwide educational institutions, fosters collaboration, orders of magnitude greater student experimental access to space systems (ground segment). * Independent back-up telemetry command/ control channel, RS232 serial data, 16 on/off discretes, backdoor reset capability. Worldwide Telemetry Beacon access via global station network.

Psat APRS Network Architecture





Global Volunteer Ground Station Network

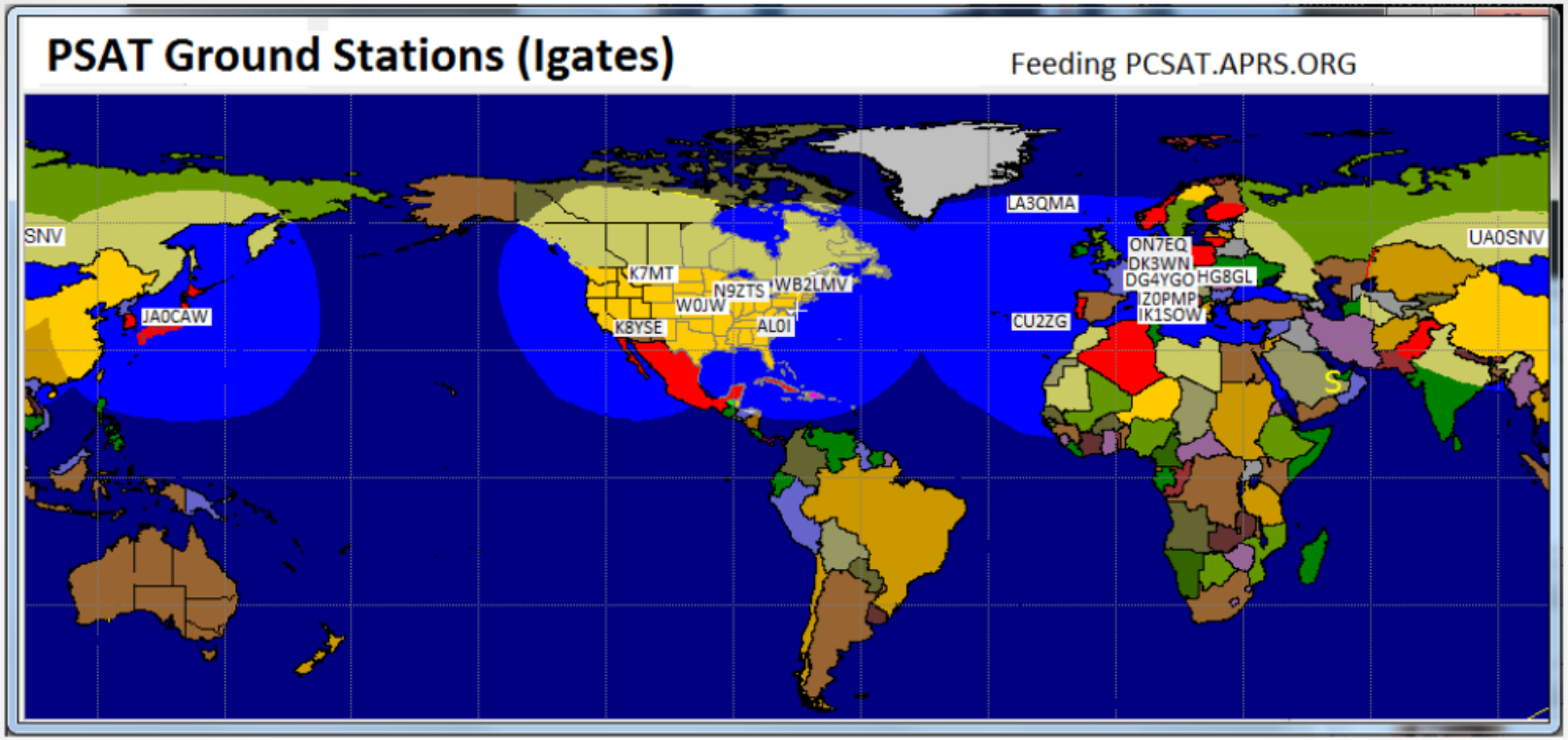
Internet Linked for live Telemetry

APRS Global data network

Global Volunteer Groundstations

feed live downlink into Internet

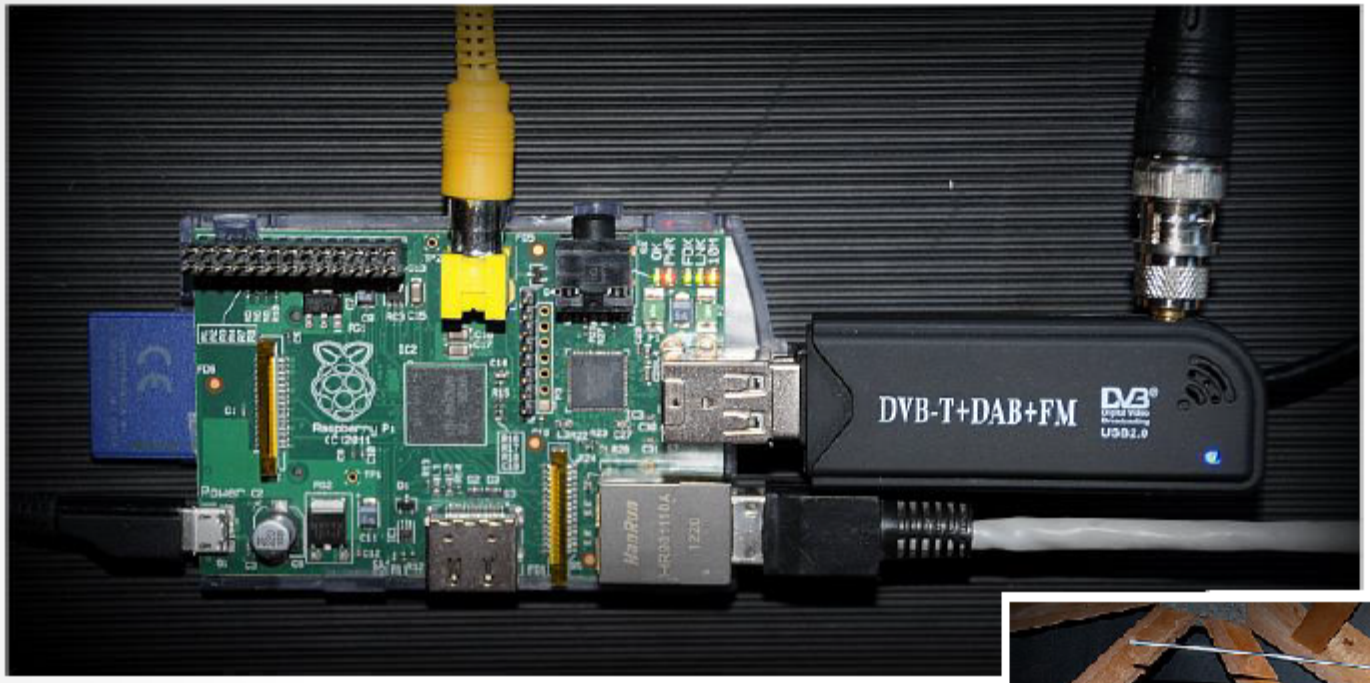
70 APRS Satgates hear ISS, but only 10 hear PSAT (- 17 dB)



9W2CEH, 9W2DIE, 9W2JDY, AI9IN, AL0I, BD8TE, CU2ZG, DG4YGO, DH7JC, DK3WN, DL5MAM, EA1JM, EA6XQ, F4GUK, F8COD, FR1GZ, HG8GL, HR1PAQ, HS0BBD, IK1SOW, IS0AML, IZ0PMP, JA0CAW, JA2PIT, JA5BLZ, JE9PEL, JH1LWU, JH4XSY, JJ1WTK, K0KOC, K4AG, K7GPS, K7MT, K8YSE, KB1CHU, KB1PVH, KB3KBR, KB9ZWL, KC2WBX, KC4AAC, KC9DOA, KD0KZE, KD0PGM, KD8TH, KG6HSQ, LA3QMA, LU1DZL, LU1WFU, LU2HAM, LW2DTZ, M0NRT, N0AGI, N5DUX, N5KAR, N9ZTS, NK7N, ON7EQ, PA3EKM, PA3GUO, PA6HAP, PP5CAM, PT2AP, R4UAB, RA2FG, SM5RVH, SQ5RTW, SV3RNJ, UA0SNV, UW7HR, VK2JNG, VK4CBW, VK8MA, VO1BIL, W0JW, W7HR, W7KKE, WA8LMF, WB2LMV, YD0NXX, ZL1KM, ZL2CIA, ZS5YE, ZS6AAG

APRS Global data network

APRS iGate



APRS IGate
with Raspberry Pi
and DVB-T stick

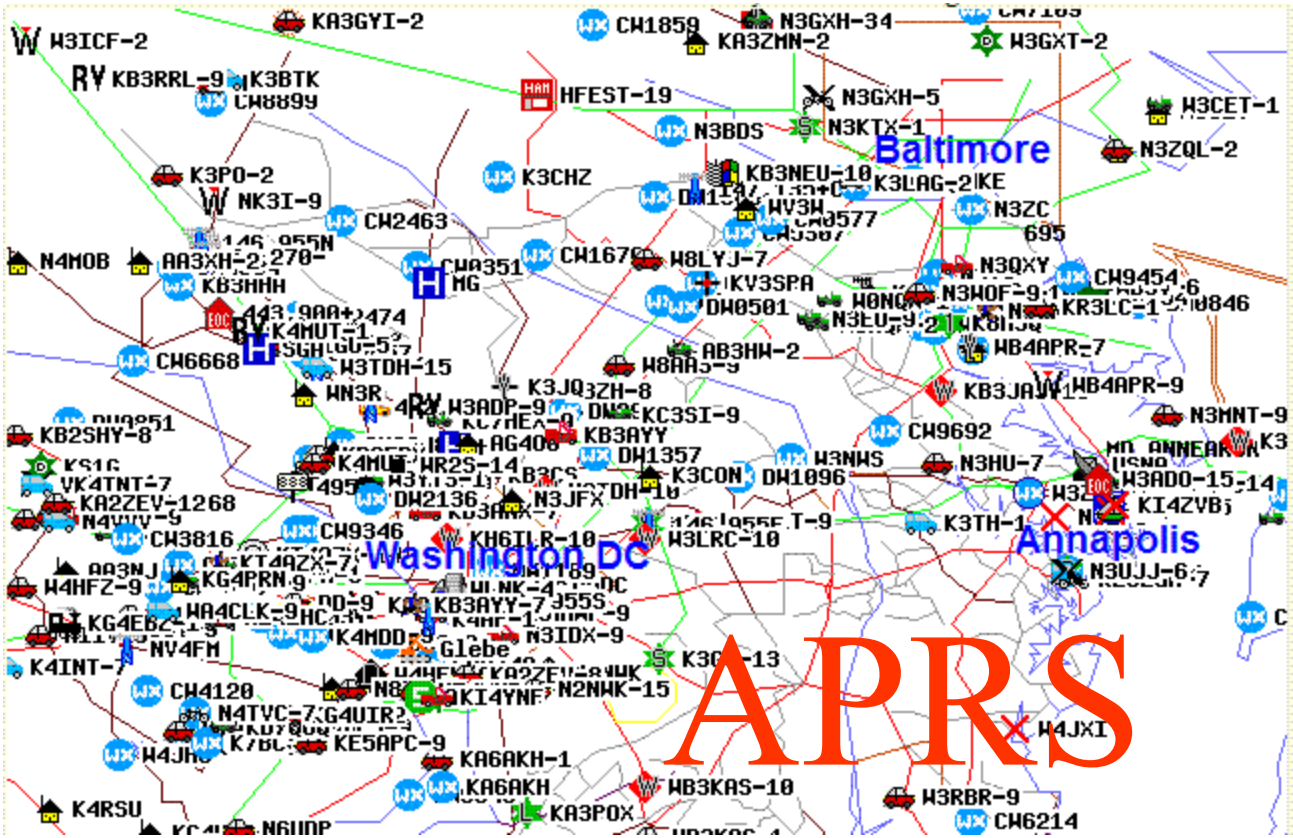
DK3WN

http://www.kubonweb.de/?p=130
http://www.mstewart.net/super8/aprs/RASP/index.htm
http://n5dux.com/ham/raspberrypi/igate.php
http://www.radio.cc/post/aprs-igate-with-raspberr-pi-setup

Raspberry PI iGate APRX with soundmodem
https://www.youtube.com/watch?v=MtUnuJn_70o

Communications Mission Background

APRS is everywhere * (Remote Data Relay)



FOCUS:

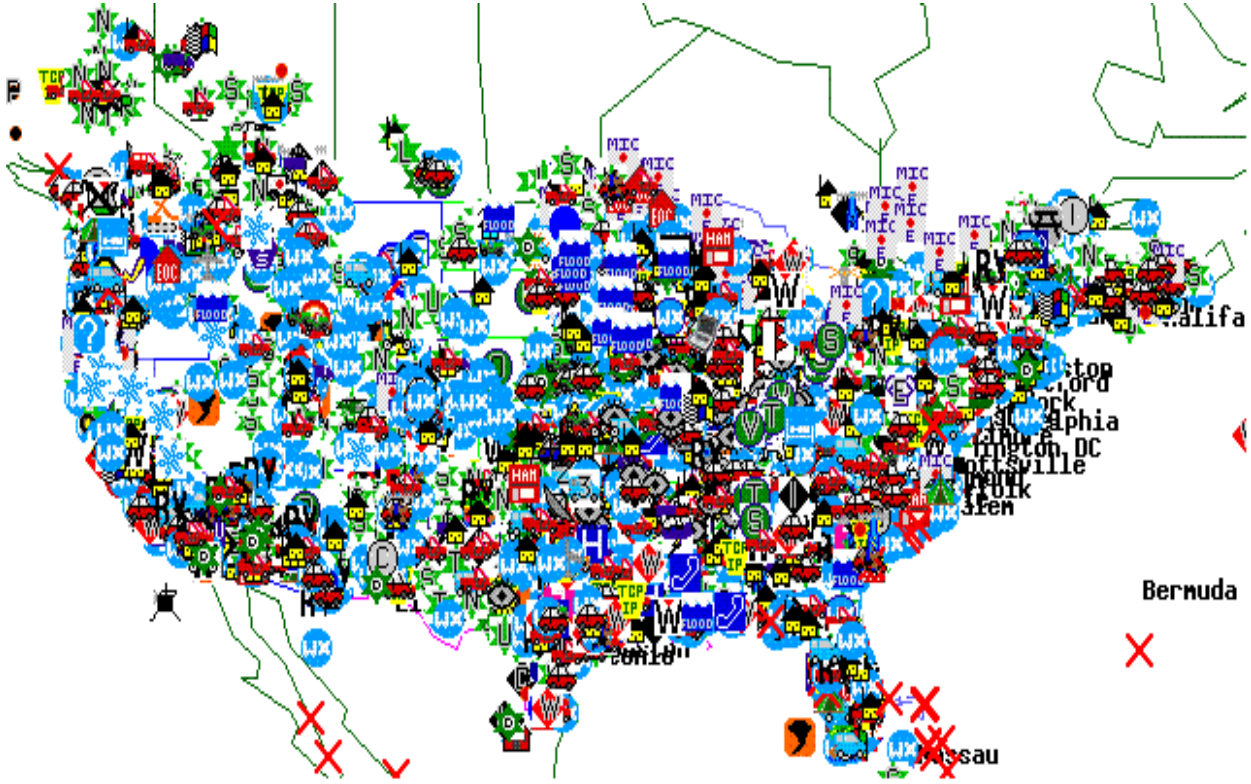
"Network Centric" & Remote Sensor Experiments

300 stations
In 35 miles

Find any station, Any map, Anywhere- http://aprs.fi

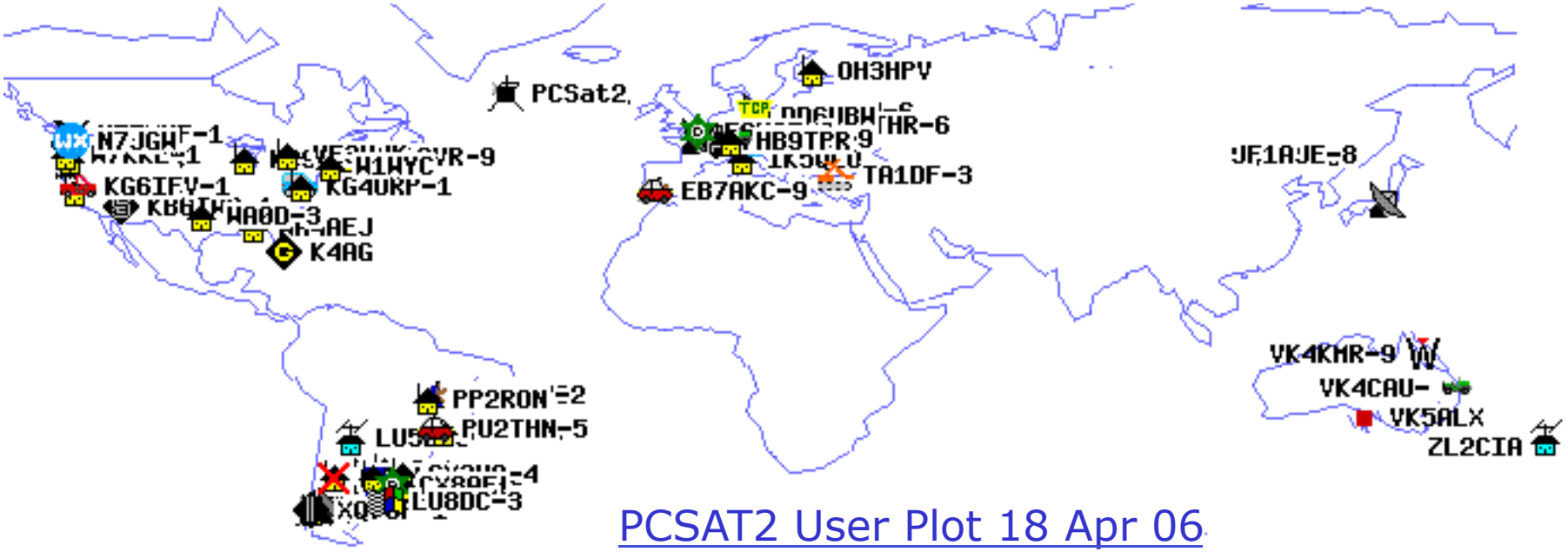
APRS Terrestrial Data Relay Network

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

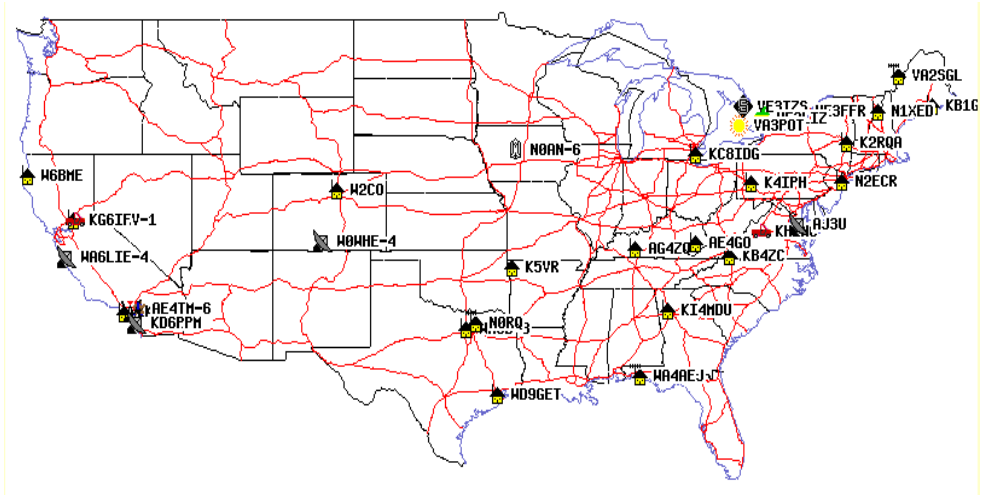


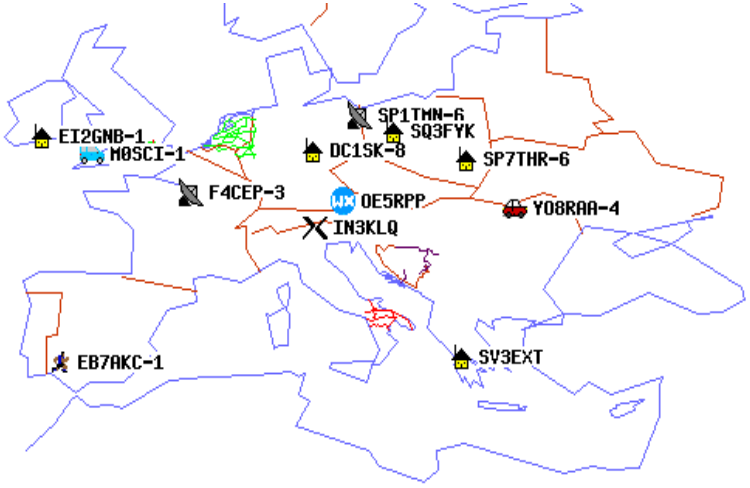
- But stops at the shoreline and has huge holes in the wilderness

Satellite Users more sparse – Need to Track to Use



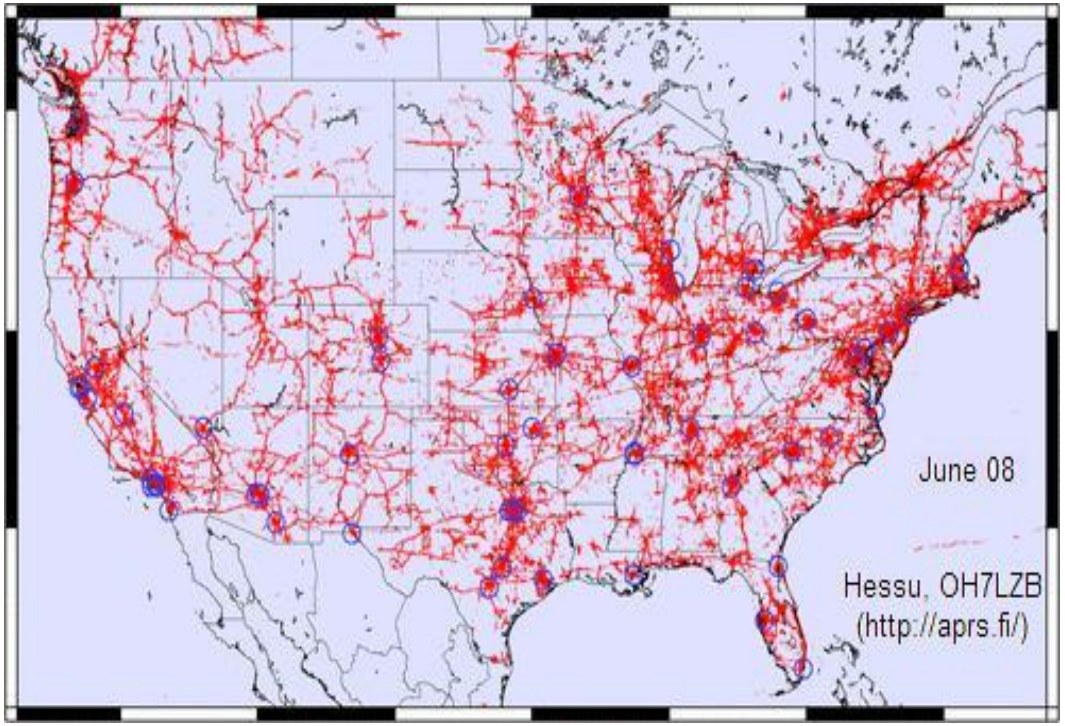
PCSAT2 User Plot 18 Apr 06





APRS Global data network

There are terrestrial network holes everywhere

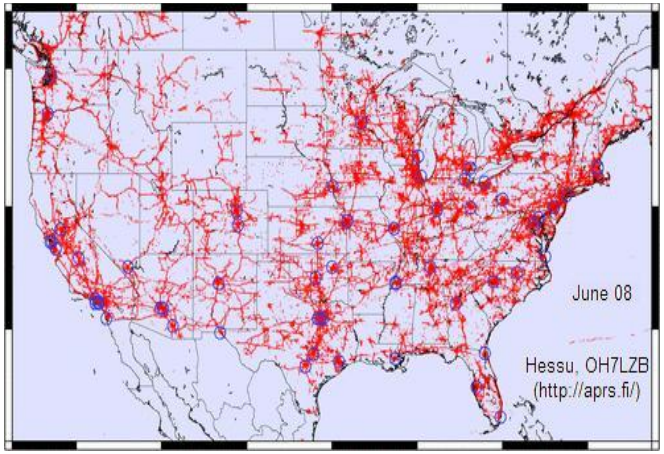


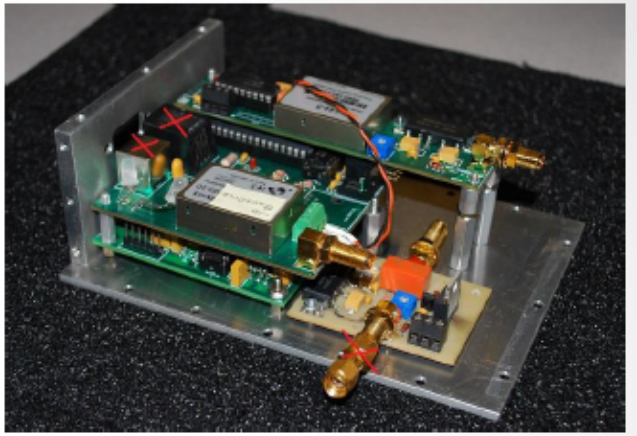
Just like cell coverage,

Maybe 70% of USA users are actually out of range of the terrestrial network in rural areas

And the terrestrial user does not know when the next APRS satellite is in view…

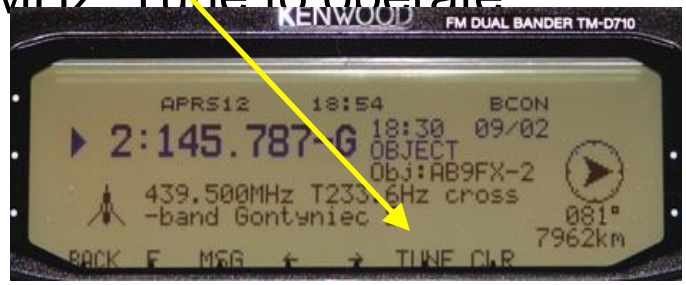
Our next QIKCOM-1 has an alert Beacon





When over USA, a 1 minute beacon on terrestrial frequency:

- **Won't** be heard amongst the din on the terrestrial freq in coverage areas
- **Will** be heard by mobile out of range of terrestrial connectivity
- Format is QIKCOM-1: 145.825MHz. Tune to operate
- One-button satellite access!
- On the front panel of the radio!

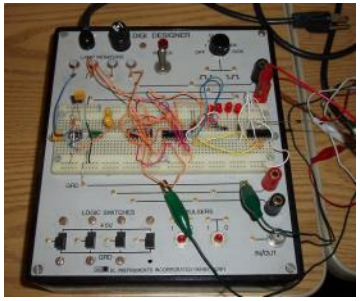


Remote Sensor Baseline

Naval Academy Student Project

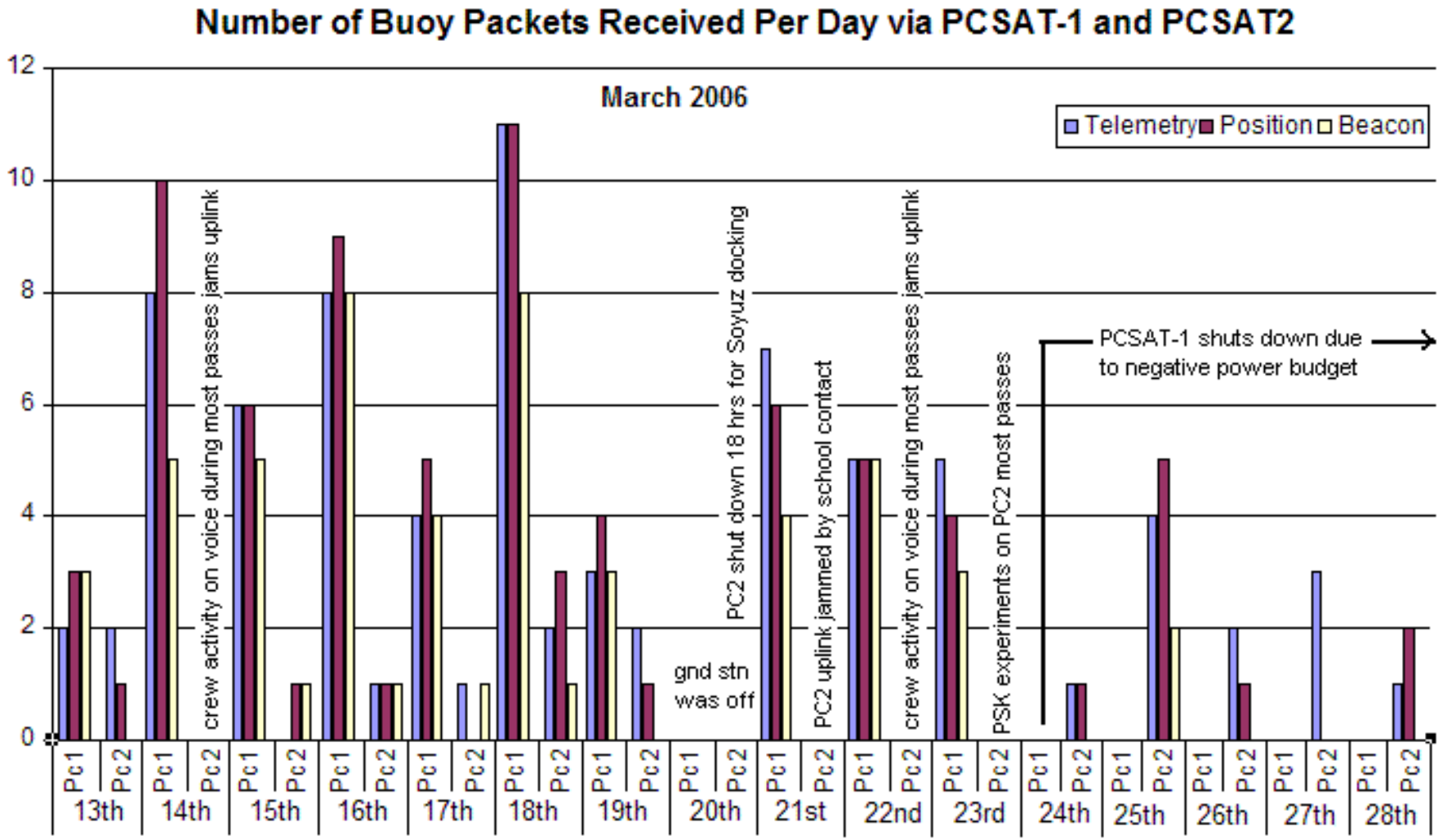
* If free-floating, do not disturb.
* If aground, move to deep water and advise bruninga@usna.edu
* If later than 30 Nov 2006, recover and advise above.

2006 15:1 reduction 2008



See Buoy Location and Telemetry at
http://www.ew.unsa.edu/~bruninga/buoy4.html

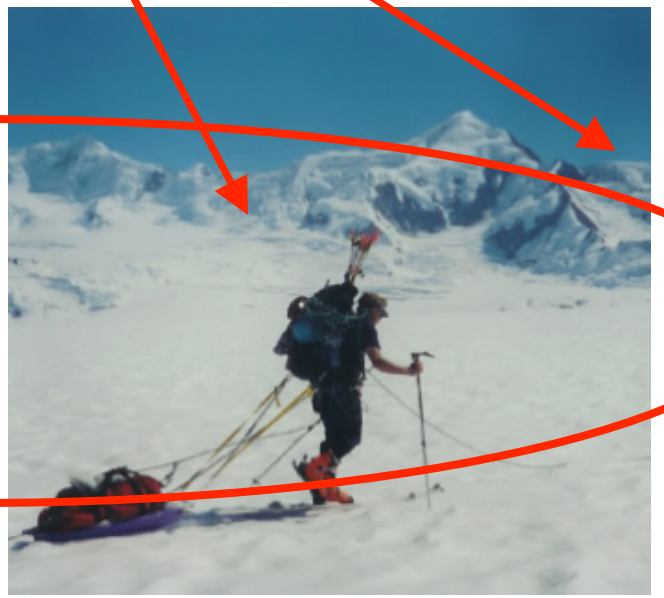
Remote Buoy Baseline Test – Success of 1 min Xmit rate



APRS Global data network

If it flies, it could have an APRS transponder on it

- If it is off the ground we want a TRANSPONDER on it!
- Range at 5000’ = 100 miles

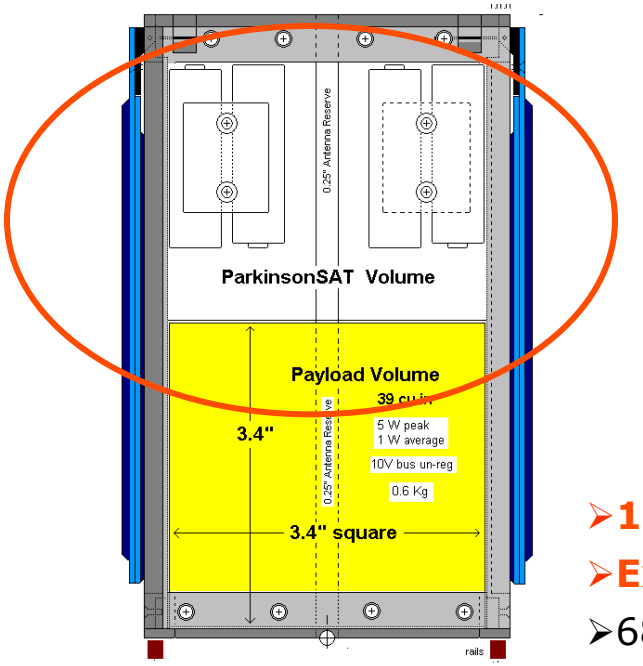


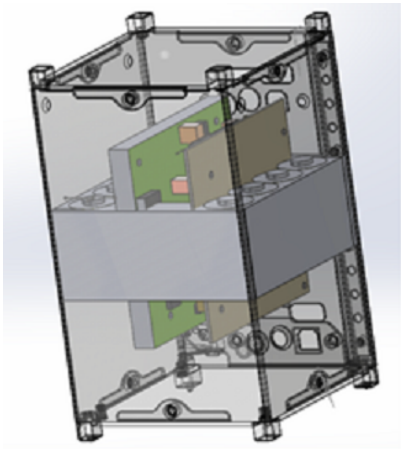
QuickLook: Global APRS Data Network

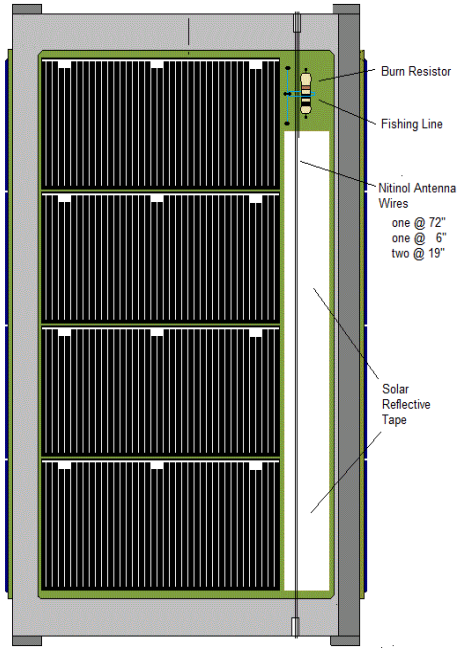
- aprs.fi - Every Packet on Earth
- ariss.net - Every packet via ISS
- pcsat.aprs.org – Every packet via PCSAT

Psat Transponder & Aux Payload

75% Payload Space Available! (only 50% shown here)



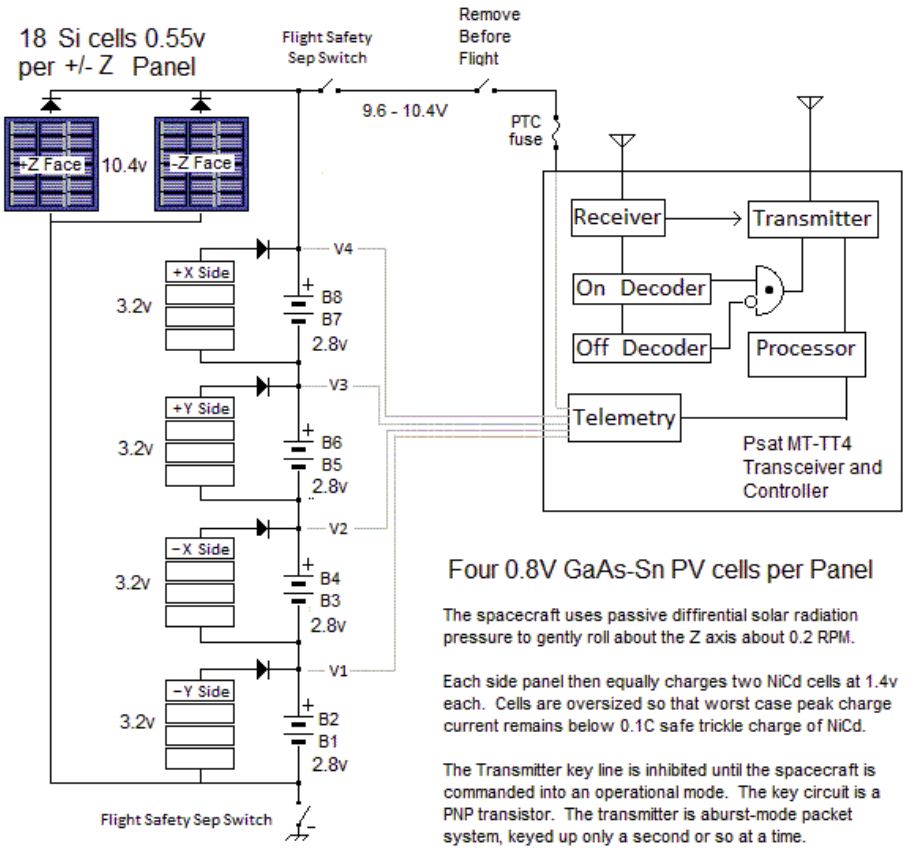




- **18 cu.in for Transponder**
- **External 19” whip antenna**
- 68 cu.in for Aux Payload (SPMS?)
- Aux payload gets 4” external panel
- Aug payload gets .5 kg – self contained
- 1 to 3W average power for aux payload

PSAT Unique parallel-charge EPS Design

- Uses 2 NiCd cells per solar panel

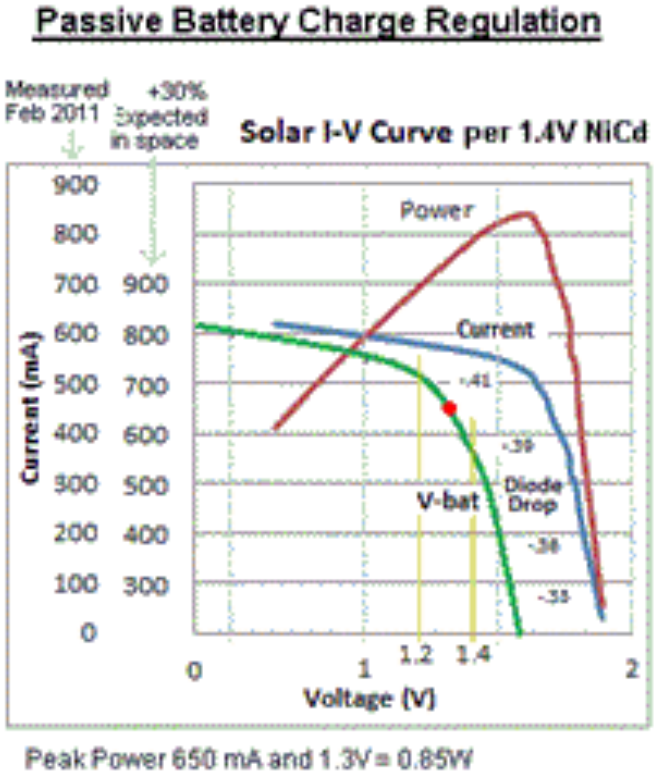


Four 0.8V GaAs-Sn PV cells per Panel

The spacecraft uses passive diffrential solar radiation pressure to gently roll about the Z axis about 0.2 RPM.

Each side panel then equally charges two NiCd cells at 1.4v each. Cells are oversized so that worst case peak charge current remains below 0.1C safe trickle charge of NiCd.

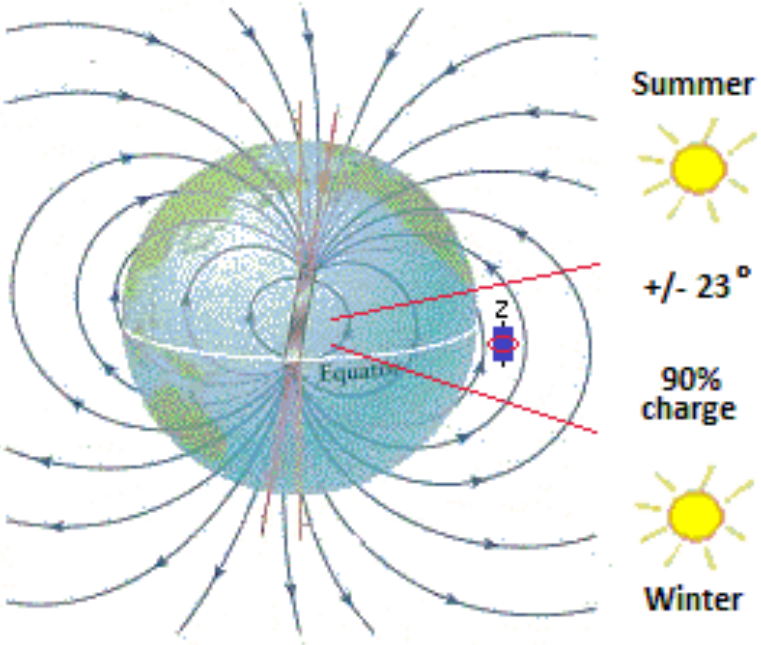
The Transmitter key line is inhibited until the spacecraft is commanded into an operational mode. The key circuit is a PNP transistor. The transmitter is aburst-mode packet system, keyed up only a second or so at a time.

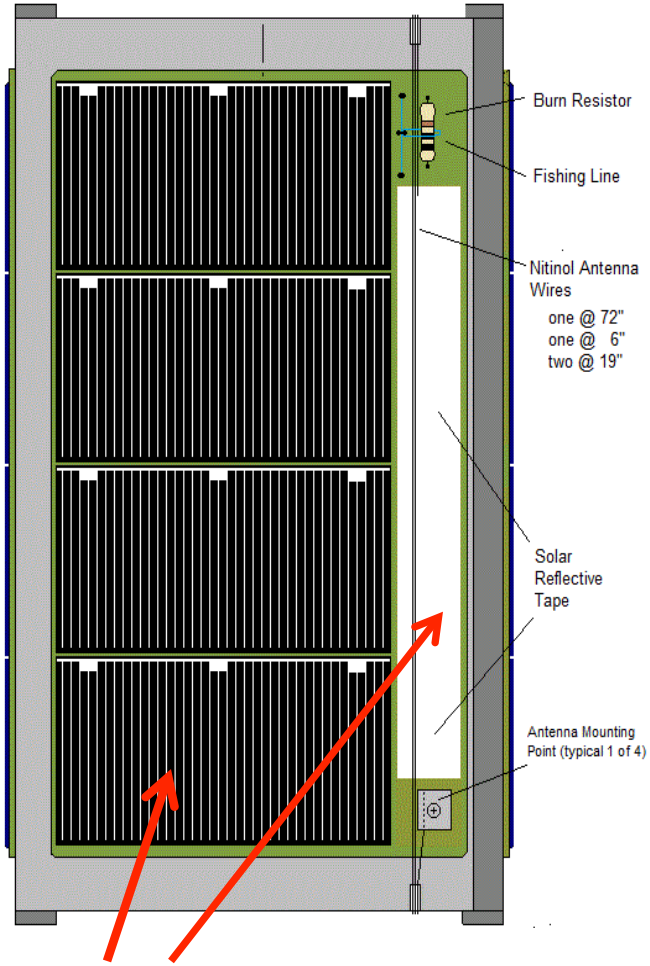


Peak Power 650 mA and 1.3V = 0.85W

Unique Power Attitude – Z coil ADCS

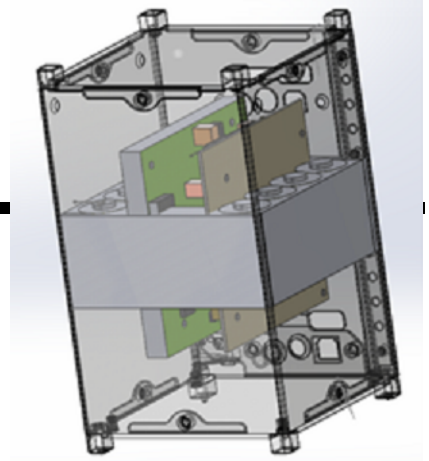
- Uses only one Z coil for attitude Control
  - Fires only within +/- 20 deg of Equator
  - Solar Panel angle better than 95% power
  - Higher reliability
  - Passive Spin maintenance

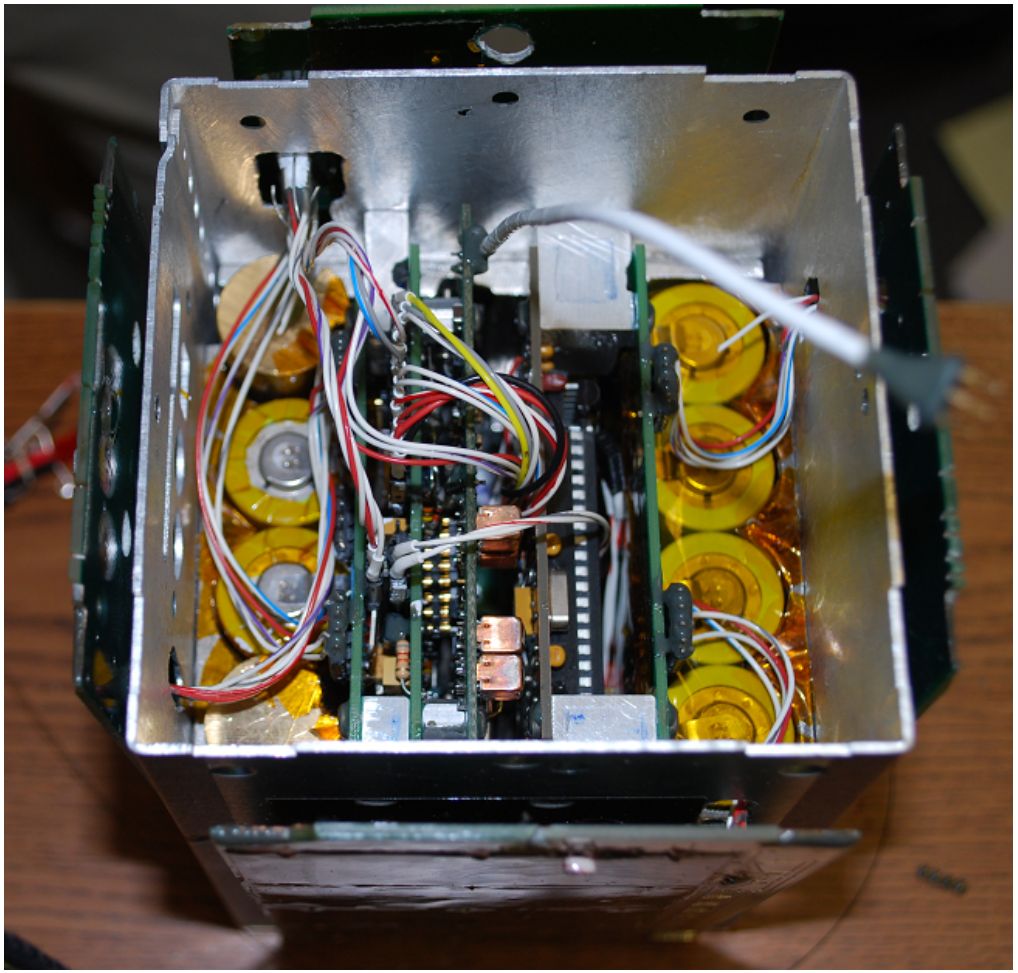




Differential Radiation Spin

PSAT's mass is centered in Z



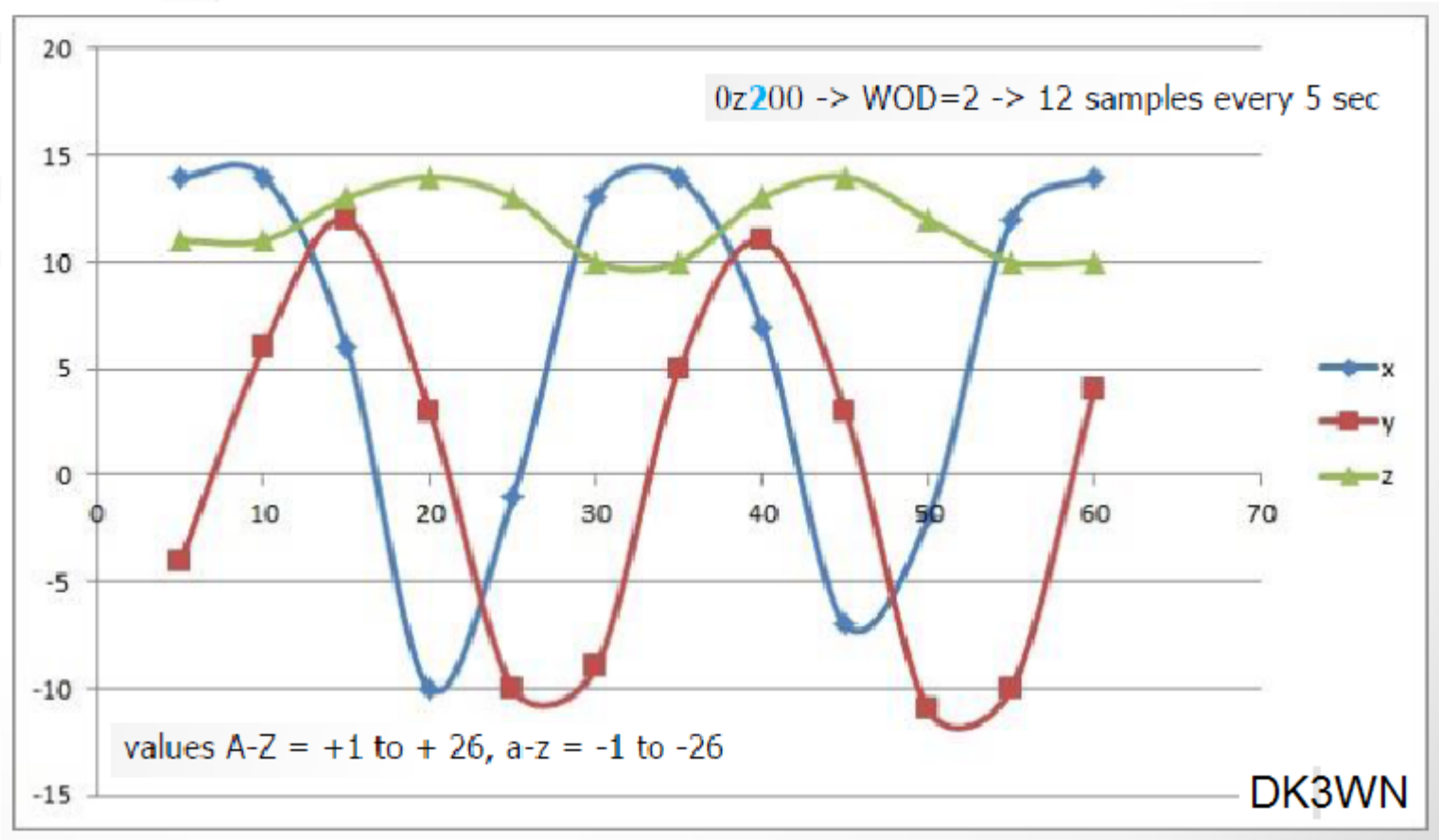


- For Maximum MOI about Z
- Batteries to outside for MOI & Shielding
- Stainless steel belt around everything

PSAT BS2 CPU telemetry – spin analysis

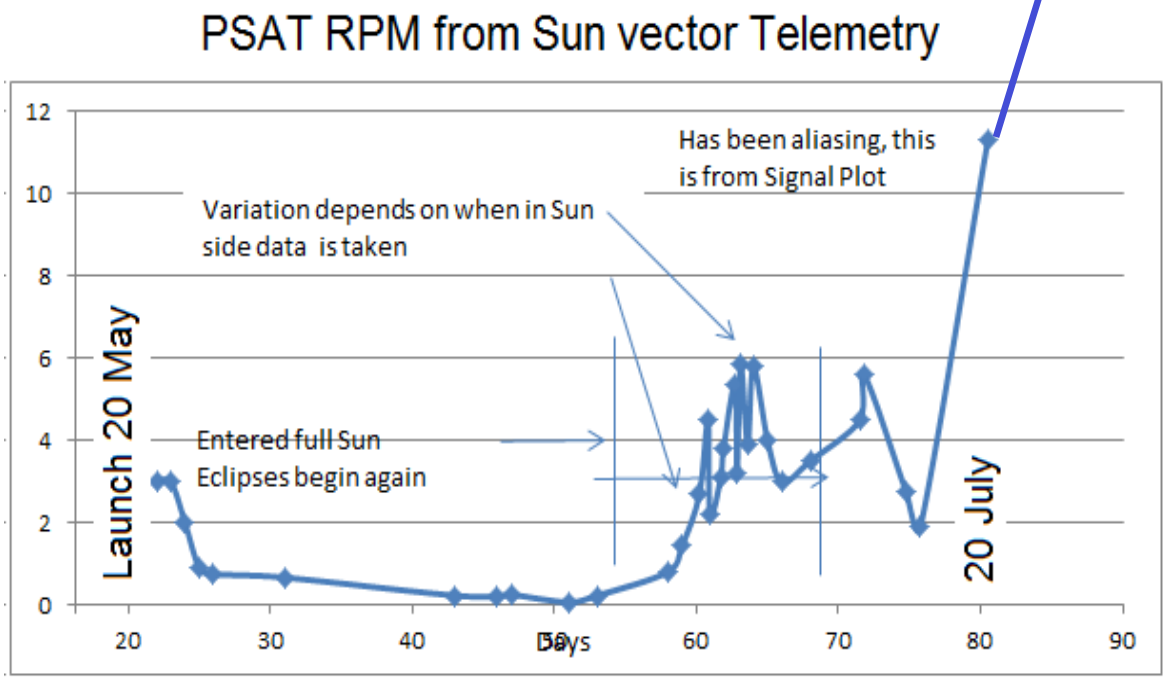
S#033814,0z290,qhDqhEqhFqhHqhIqhIpiJpiKpiLphLphMphM

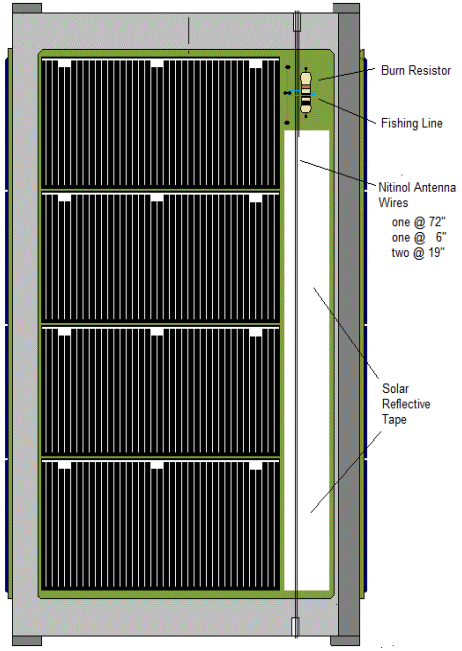
sun vector triplets xyz xyz xyz xyz xyz xyz xyz xyz xyz xyz xyz xyz



1 Aug is 27 RPM!

- When we find the time we are really looking forward to understanding our Solar Radiative Spin system.

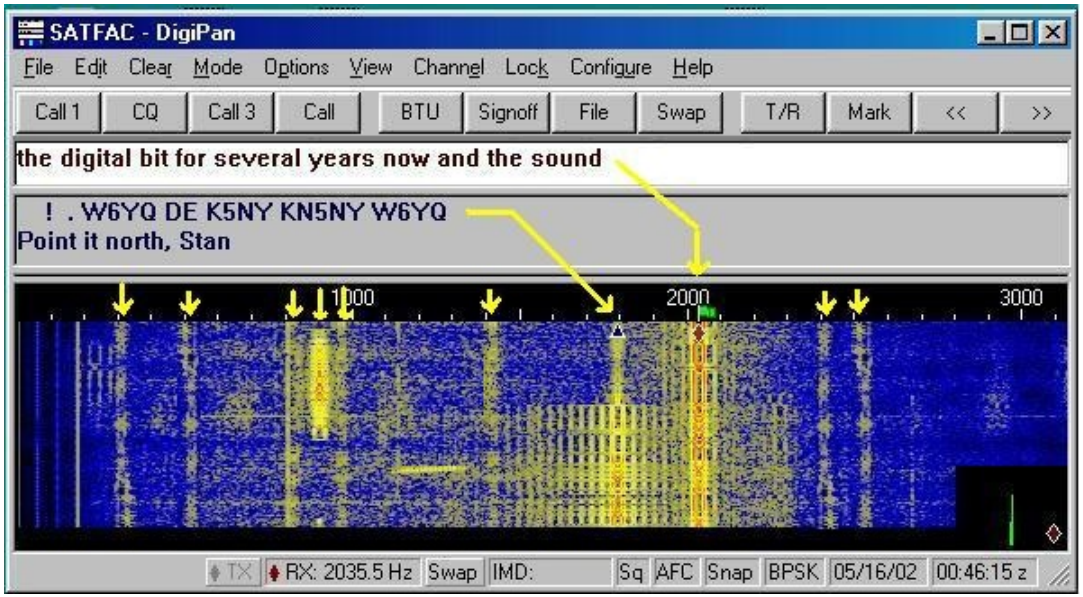




PSAT: Aux PSK31 Transponder Payload

- Flew on PCSAT2 on ISS but astronaut broke off HF antenna
- Flew on RAFT but took 1 kW uplink and negative power budget
- Now Operational since May 2015 launch of PSAT and BRICsat
- Both transponders built at Brno Univ, Czech Republic.

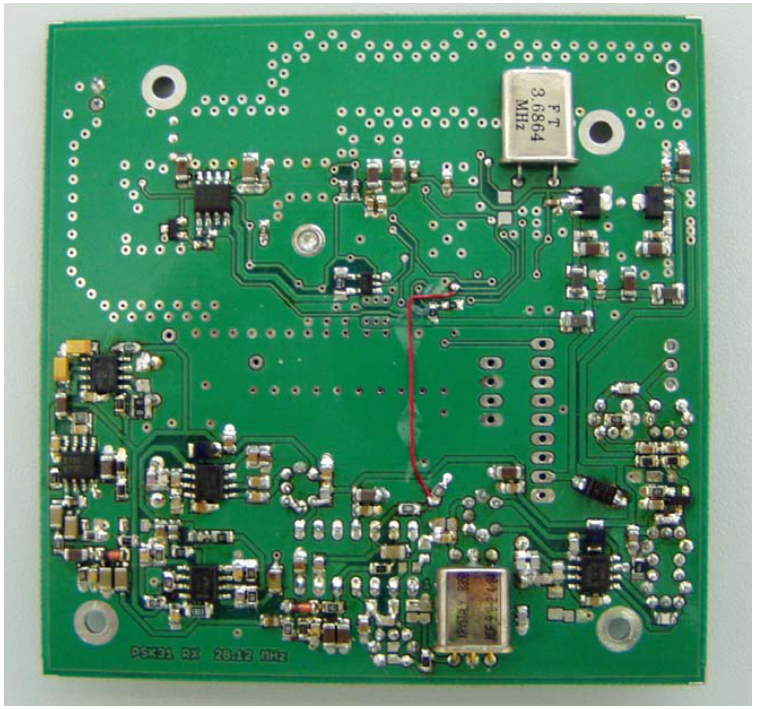
28 MHz
SSB uplinks



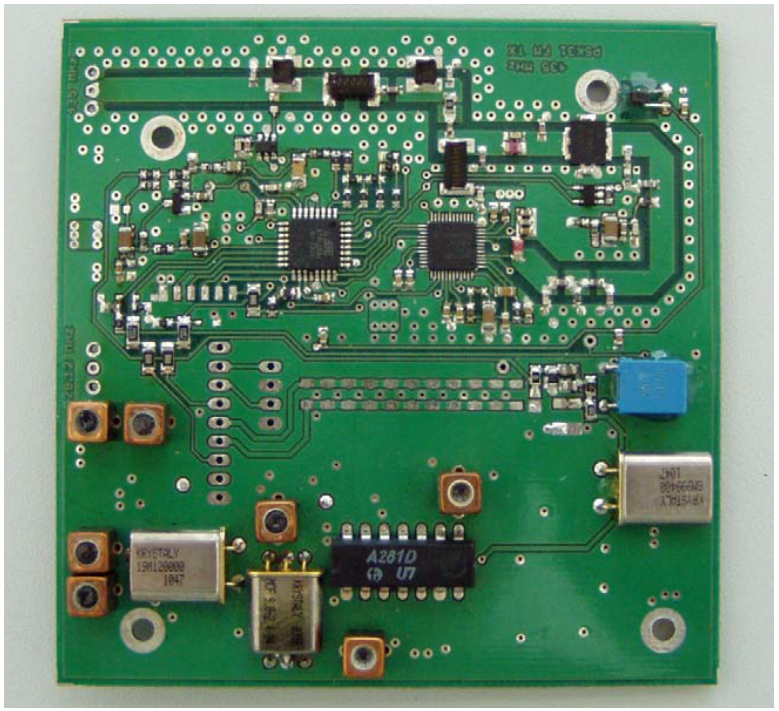
435.350
FM downlink

PSAT: PSK31 Transponder Payload !!!

Built *Dr. Mirek Kasal OK2AQK and students* Tomas Urbanec, P. Vágner



HF Linear RX



FM XMTR

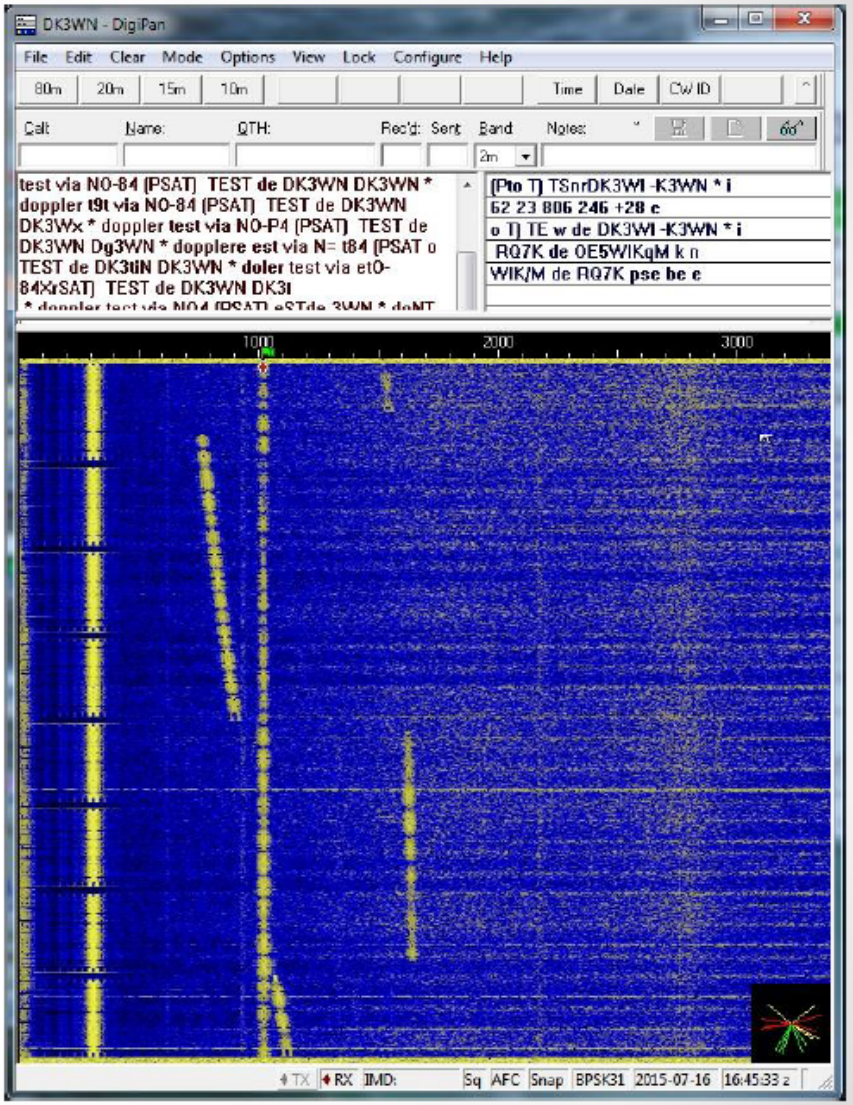
PSK DopplerPSK

by Andrew Flowers K0SM

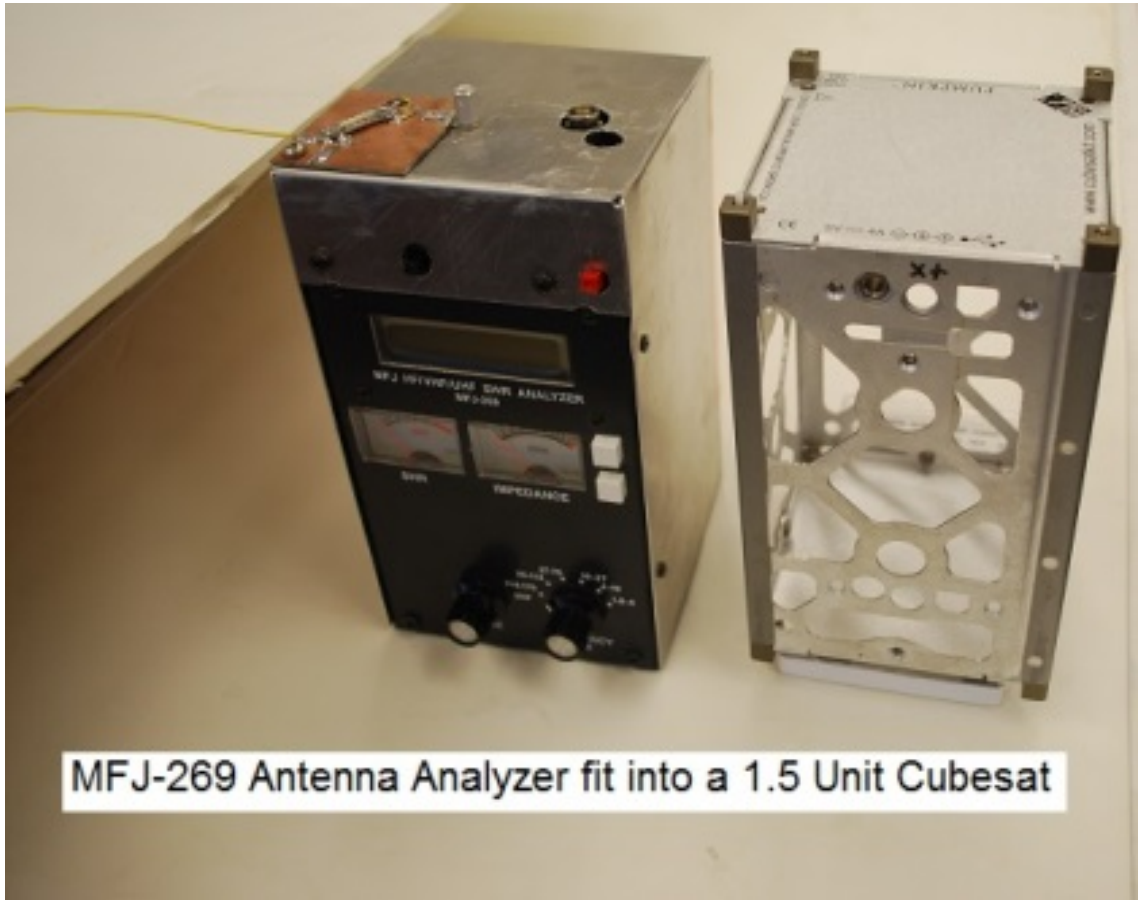
- experimental program to compensate the doppler shift on PSK31 uplinks

- its a PSK31 transmitter that is merged with an orbital propagator to cause your the transmitted signal to drift exactly opposite to uplink doppler effect

http://www.frontiernet.net/~aflowers/dopplerpsk/dopplerpsk.html



Tuning Antennas on a 7” Spacecraft

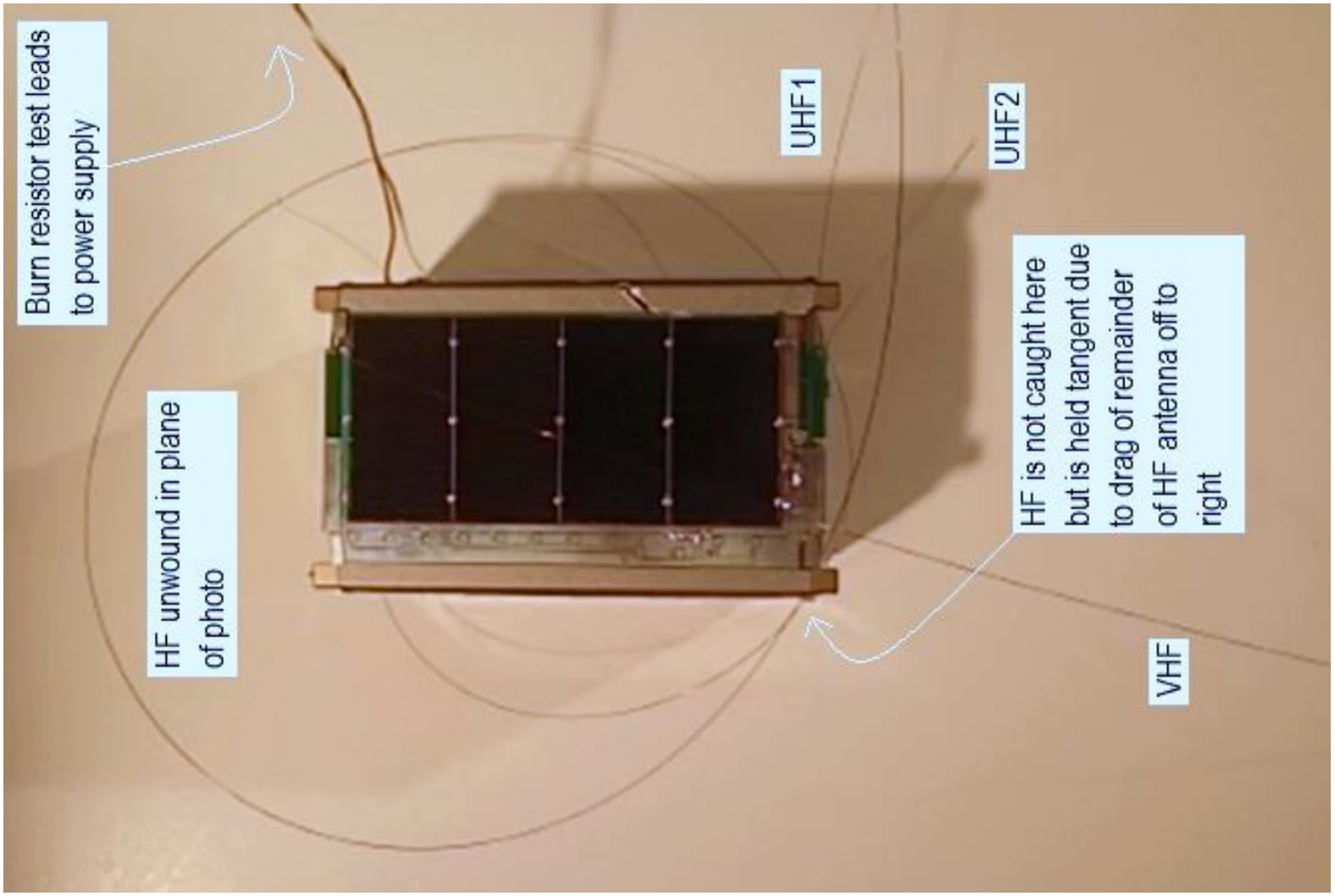


Imagine turning a 6’ HF whip on a 7” spacecraft Ground plane!

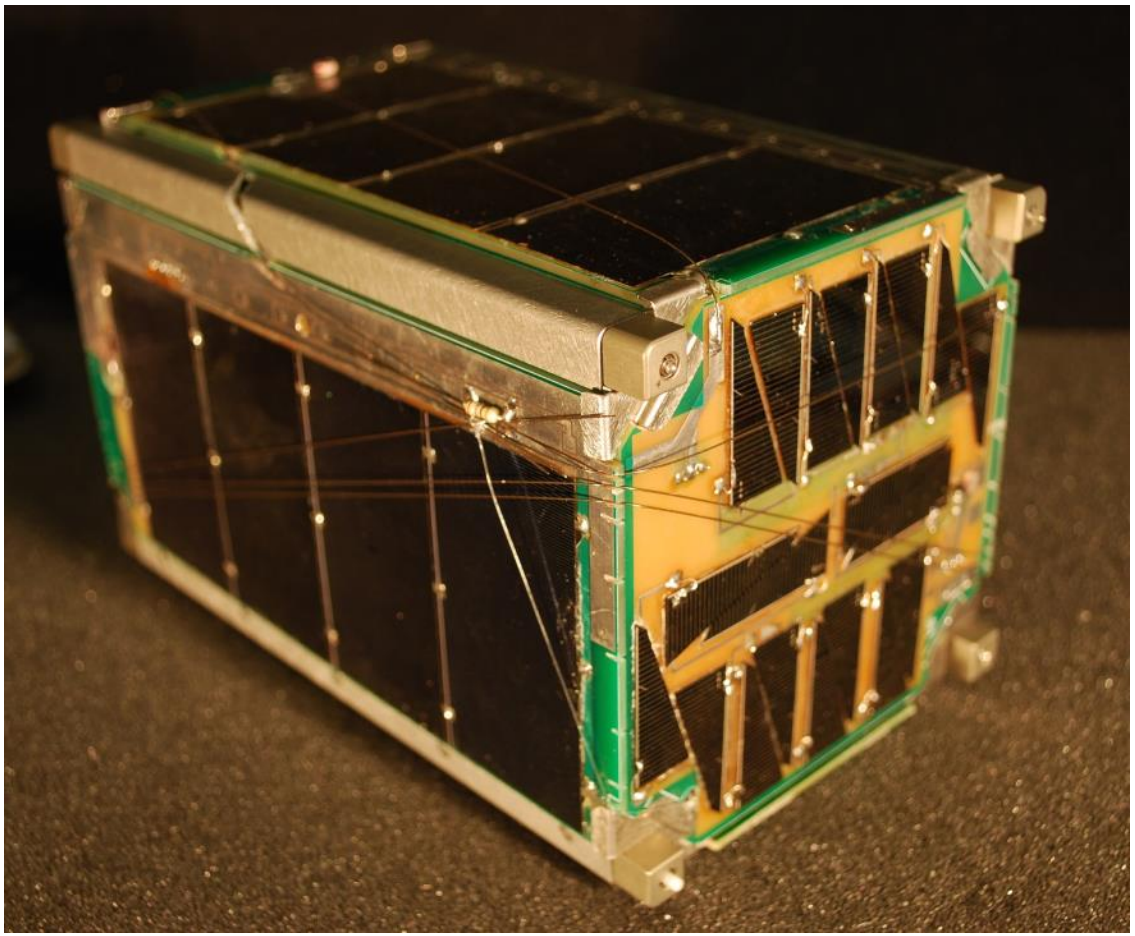
Any instrument connection detunes SWR to infinity

So, Put Analyzer inside!

PSAT Nitinol Wire Whip Antennas



Wrapping Antennas to one Burn Resistor



2 Orthogonal UHF whips

One VHF whip

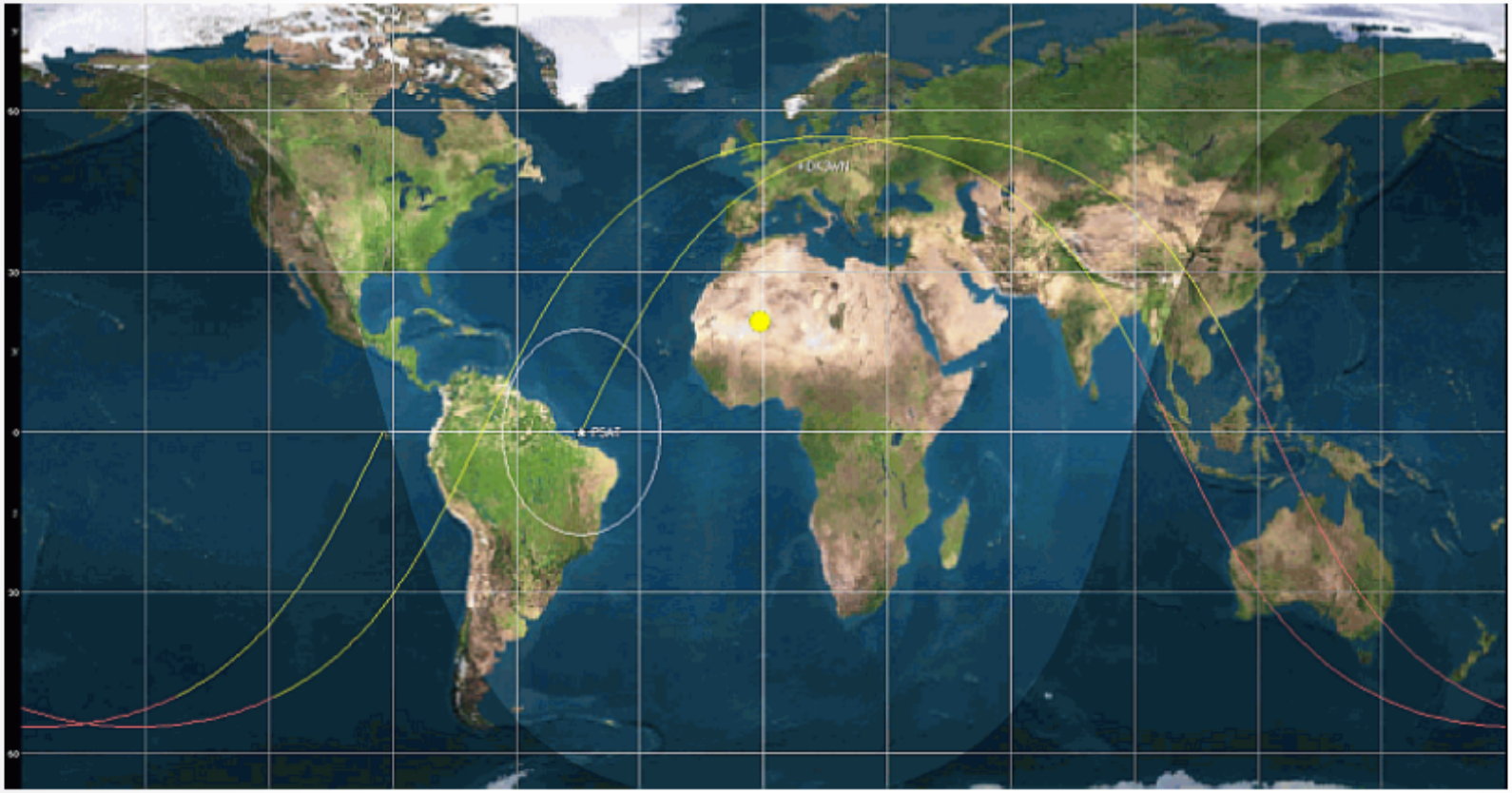
One 6’ HF whip

3rd Enable Switch

PSAT position packets

!48 . N\027 . ES120/999/W3ADO s#000133,0z090

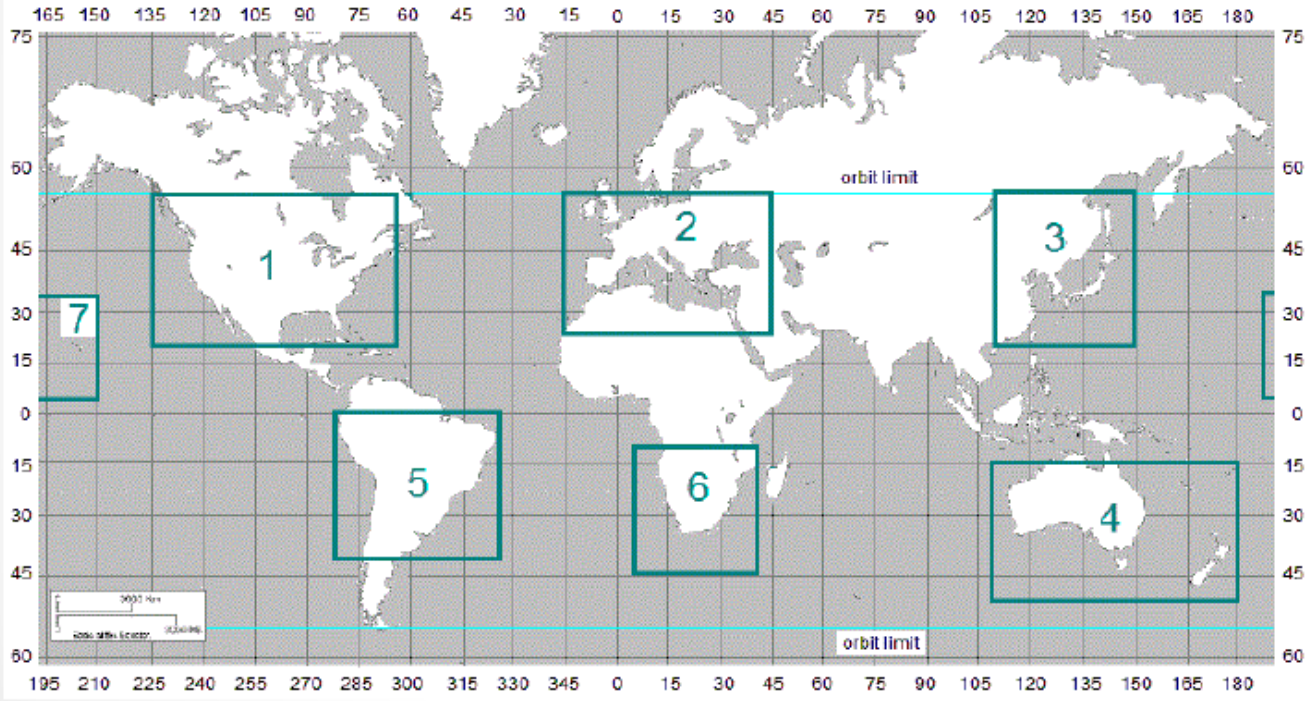
PSAT can generate its own APRS position report from a simple Lat/Long orbit table




```
20150629001541,PSAT>APRSON,ARISS,qAR,DK3WN-8: !48 . N\027 . ES120/999/W3ADO s#000133,0z090
20150629001641,PSAT>APRSON,ARISS,qAR,DK3WN-8: !41 . N\023 . ES120/999/W3ADO s#000134,0z090
20150629012351,PSAT>APRSON,ARISS,qAS,K8YSE-4: !15 . N\118 . WS040/999/W3ADO s#000206,0z090
20150629012551,PSAT>APRSON,ARISS,qAS,K8YSE-4: !21 . N\114 . WS040/999/W3ADO s#000208,0z090
```

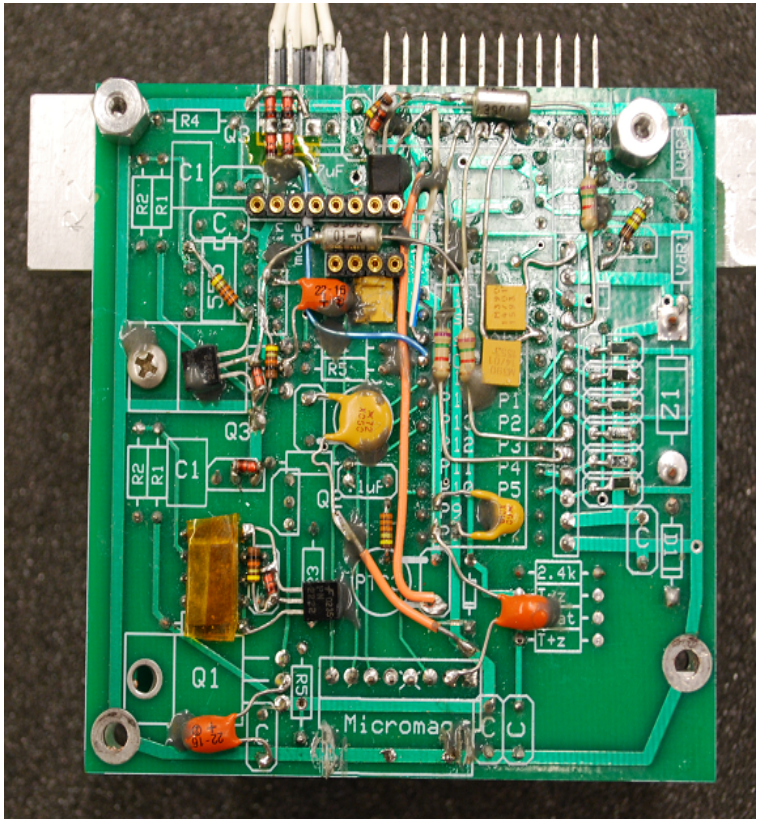
PSAT bulletin packets

PSAT contains 3 bulletins for every country area, BLN0USA, BLN1USA,BLN2USA for example over the USA. The same geographical areas are used for sending Bulletins.

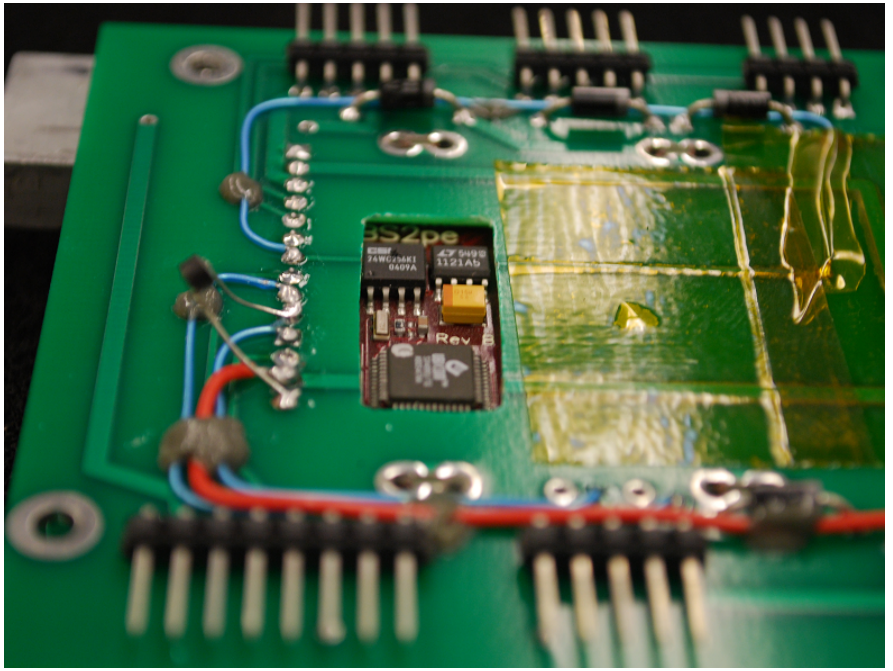



```
PSAT-1>APOFF,ARISS,qAR,ON7EQ-10::BLN0USA :PSK31 435.35 Up on 28.12
PSAT-1>APOFF,ARISS,qAR,HG8GL-5::BLN1USA :ARISS.NET & PCSAT.APRS.ORG
PSAT-1>APOFF,ARISS,qAR,ON7EQ-10::BLN2USA :See APRS.FI & 144.39 users
PSAT>APRSON,ARISS,qAR,DK3WN-8::BLN0EUR :PSK31 435.35 Up on 28.12
PSAT>APRSON,ARISS,qAR,DK3WN-8::BLN1EUR :Coming soon -> AMSAT-UK Colloquium July 24-26th at Guildford
PSAT>APRSON,ARISS,qAR,DK3WN-8::BLN2EUR :See APRS.FI & 144.80 users
```

How not to Make a Satellite

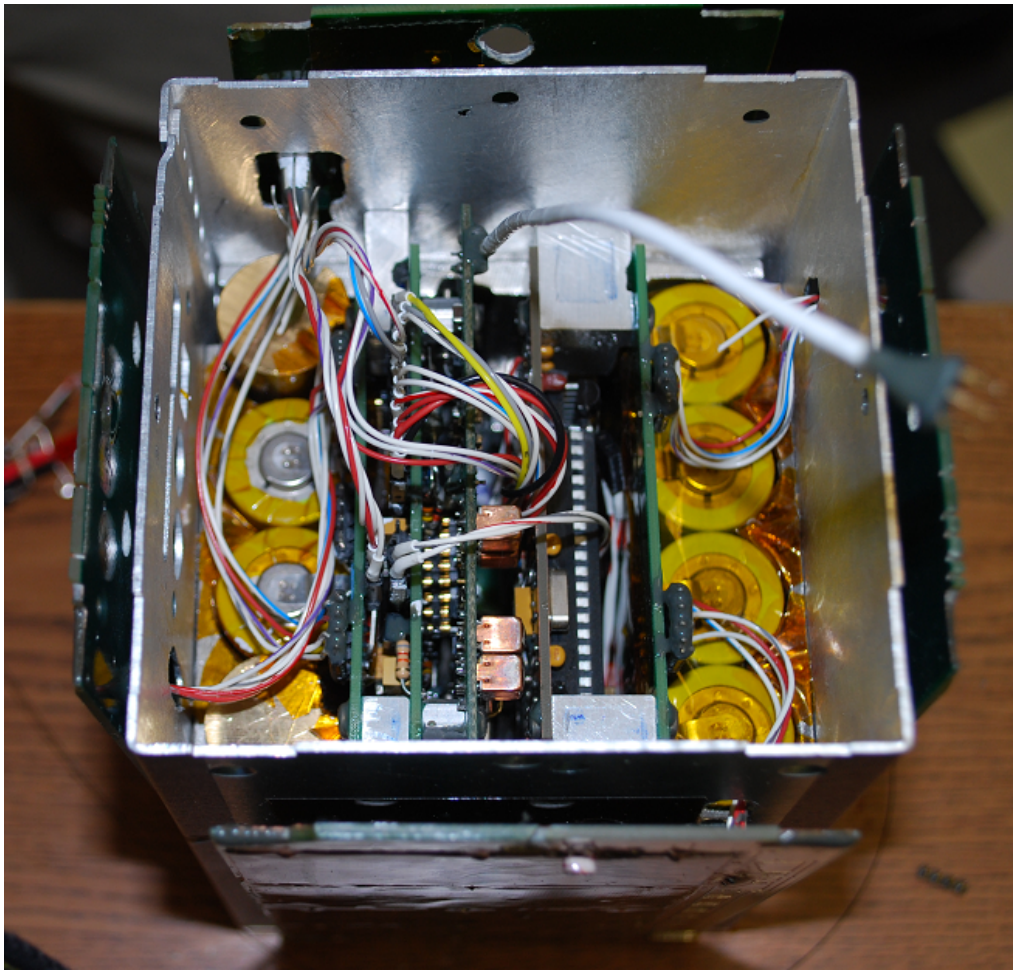


Stop adding neat features…



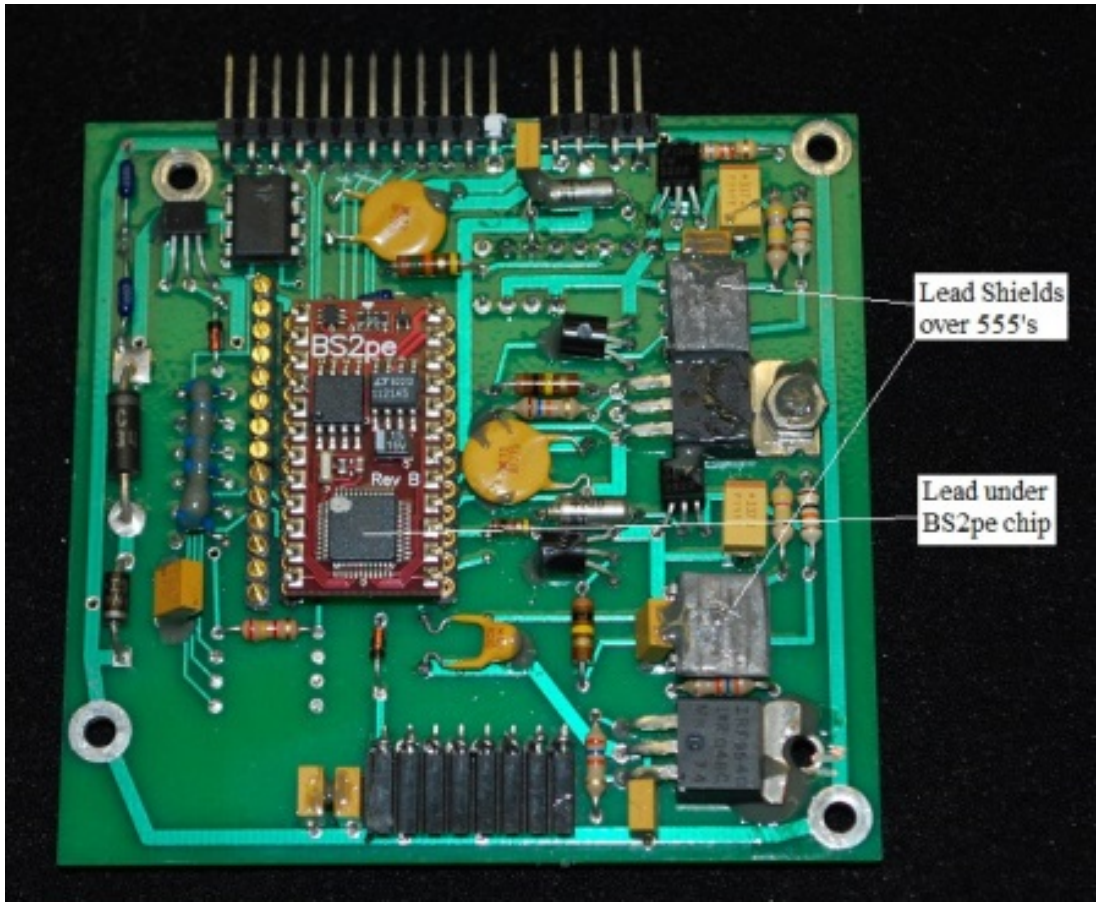
Make sure it fits

The boards stack across and zero clearance



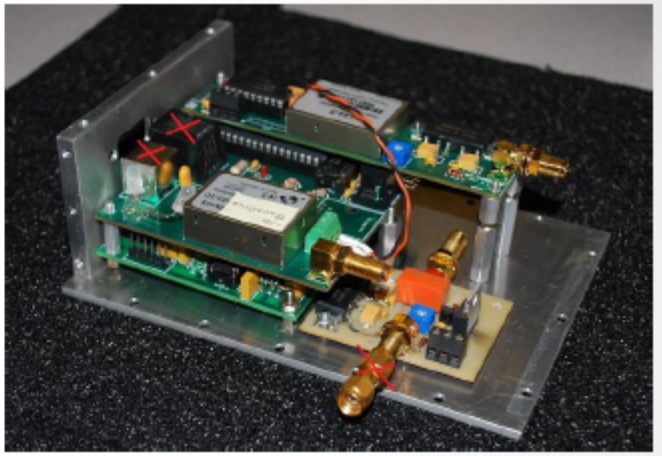
- For Maximum MOI about Z
- Batteries to outside for Shielding

Chip Radiation Shielding?



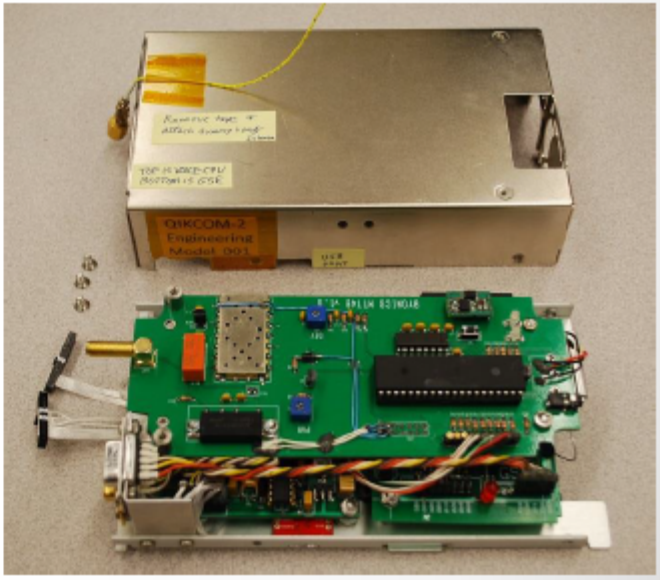
Epoxy Lead squares over critical chip dies

Our Next APRS Satellites



QIKcom-1

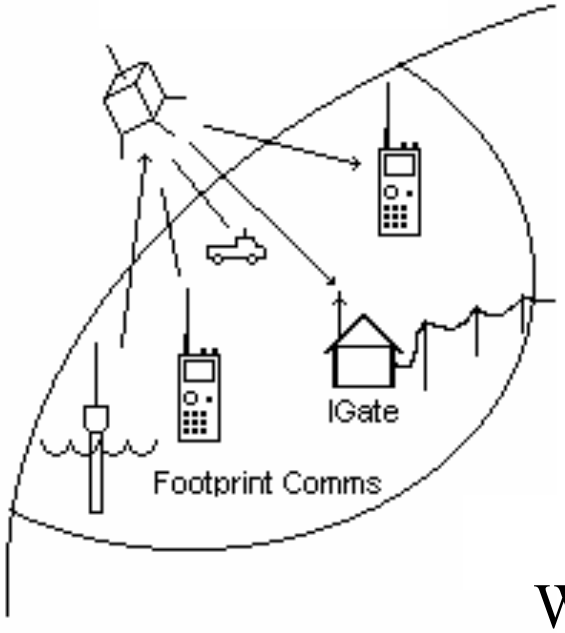
- APRS system (PSAT)
- Release from ISS in October 2015
- flies on host spacecraft (28V, no solar panels **or** ADCS)

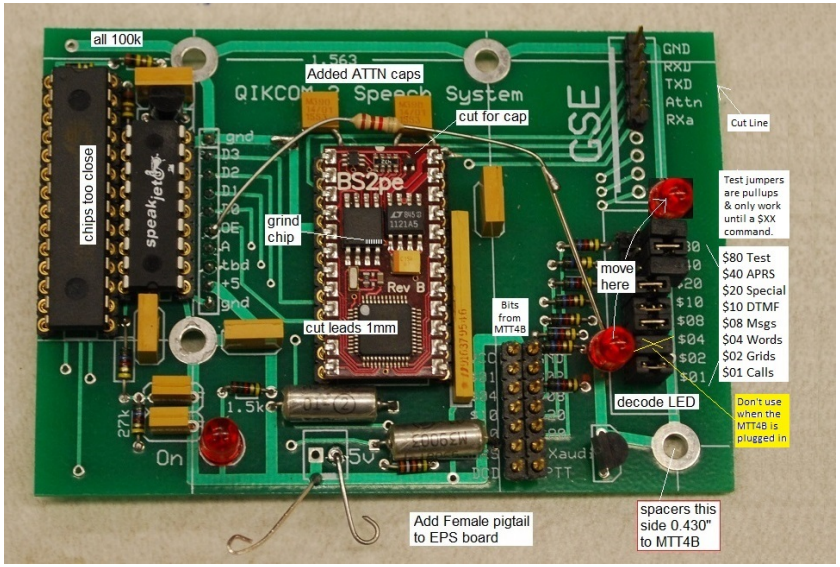


QIKcom-2

- launch December 2015
- 1st APRS TouchTone Satellite
- APRStt is a complete two way system that enters data using DTMF and receives APRS information by synthesized voice response.

QIKCOM-2 converts DTMF to both Voice and APRS and APRS data to voice!





With QIKCOM-2, not just APRS but DTMF data sources can be relayed among all users.

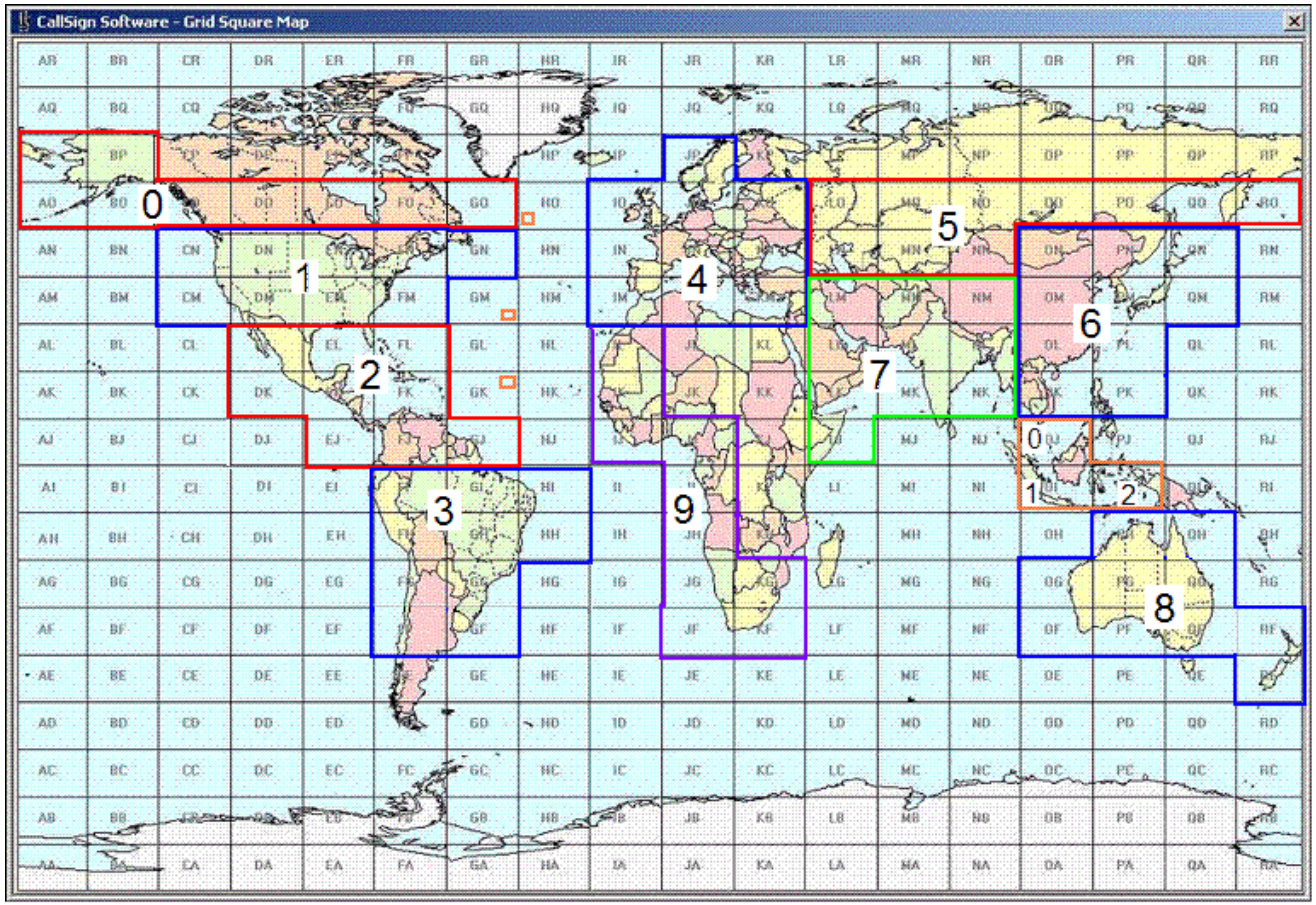
The 324 Grid system has 99 grids…
Position to 60 miles in 4 digits

	FM19	WB4APR		
*	18 19	9 24 27 7	15 58	#

1 2 0 1 1 2

six 2 bit nos showing locations of 6 letters on keys then converted to 4 digit decimal

wb4apr



0 - Canada
AP, BP, AO, BO, CO
DO, EO, FO, GO, OJ

1 - USA
CN, DN, EN, FN, GN
CM, DM, EM, FM, OI

2 - C America
DL, EL, FL, DK, EK
FK, EJ, FJ, GJ, PI

3 - S. America
FI, GI, HI, FH, GH
HH, FG, GG, FF, GF

4 - Europe
JP, IO, JO, KO, IN
JN, KN, IM, JM, KM

5 - Russia
LO, MO, NO, OO, PO
QO, RO, LN, MN, NN

6 - Japan, China
ON, PN, QN, OM, PM
QM, OL, PL, OK, PK

7 - India
LM, MM, NM, LL, ML
NL, LK, MK, NK, LJ

8 - Aus/NZ
PH, QH, OG, PG, QG
OF, PF, QF, RF, RE

9 - Africa
IL, IK, IJ, JJ, JI,
JH, JG, KG, JF, KF

The table at right begins at 00 thru 99 to give worldwide 4 digit Grids for the next APRStt DTMF satellite using DTMF only.

Standard Message communications (4 bytes)

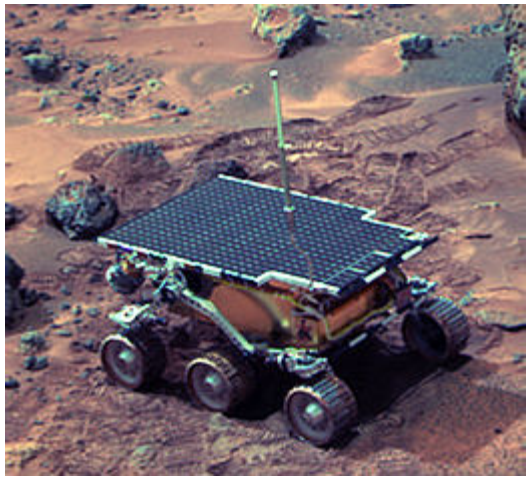
- Since 1800's for telegraph
- since1927 or so for radio
- Most of the time, most of what is said, has been said before
- Q2 has 99 messages and 99 modifiers

One Group -- For Possible RELIEF EMERGENCY Use

ONE Everyone safe here. Please don't worry.
TWO Coming home as soon as possible.
THREE Am in _____ hospital. Receiving excellent care and recovering fine.
FOUR Only slight property damage here. Do not be concerned about disaster reports.
FIVE Am moving to new location. Send no further mail or communication.
SIX Will contact you as soon as possible.
SEVEN Please reply by Amateur Radio through the amateur delivering this message.
EIGHT Need additional _____ mobile or portable equipment for immediate emergency use.
NINE Additional _____ radio operators needed to assist with emergency at this location.
TEN Please contact _____. Advise to standby and provide further emergency information,
ELEVEN Establish Amateur Radio emergency communications with _____ on _____ MHz.

TWELVE Anxious to hear from you. No word in some time. Please contact me as soon as possible.
THIRTEEN Medical emergency situation exits here.
FOURTEEN Situation here becoming critical. Losses and damage from _____ increasing.
FIFTEEN Please advise your condition and what help is needed.
SIXTEEN Property damage very severe in this area.
SEVENTEEN RLAC1 communications services also available. Establish RLAC1 communication with on channel .
EIGHTEEN Please contact me as soon as possible at _____.
NINETEEN Request health and welfare report on _____. (State name, address and telephone number.)
TWENTY Temporarily stranded. Will need some assistance. Please contact me at .
TWENTY ONE Search and Rescue assistance is needed by local authorities here. Advise availability.
TWENTY TWO Need accurate information on the extent and type of conditions now existing at your location. Please furnish this information and reply without delay.
TWENTY THREE Report at once the accessibility and best way to reach your location.
TWENTY FOUR Evacuation of residents from this area urgently needed. Advise plans for help.
TWENTY FIVE Furnish as soon as possible the weather conditions at your location.
TWENTY SIX Help and care for evacuation of sick and injured from this location needed at once.

Remember, lots of Space APS here on Earth



- STEM School projects
- Excite kids with Robotics
- Drive anywhere on Earth!
- Via APRS links

*http://www.arrl.org/marea-ham-radio-robotics