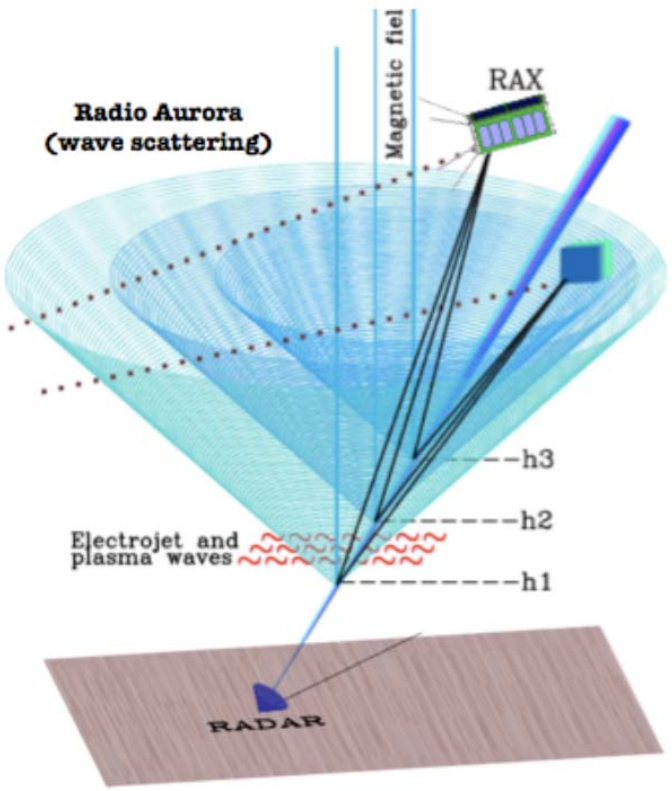
On-Orbit Performance of the RAX-2 CubeSat

John Springmann, James Cutler, Hasan Bahcivan

CubeSat Developers' Workshop
April 18, 2012

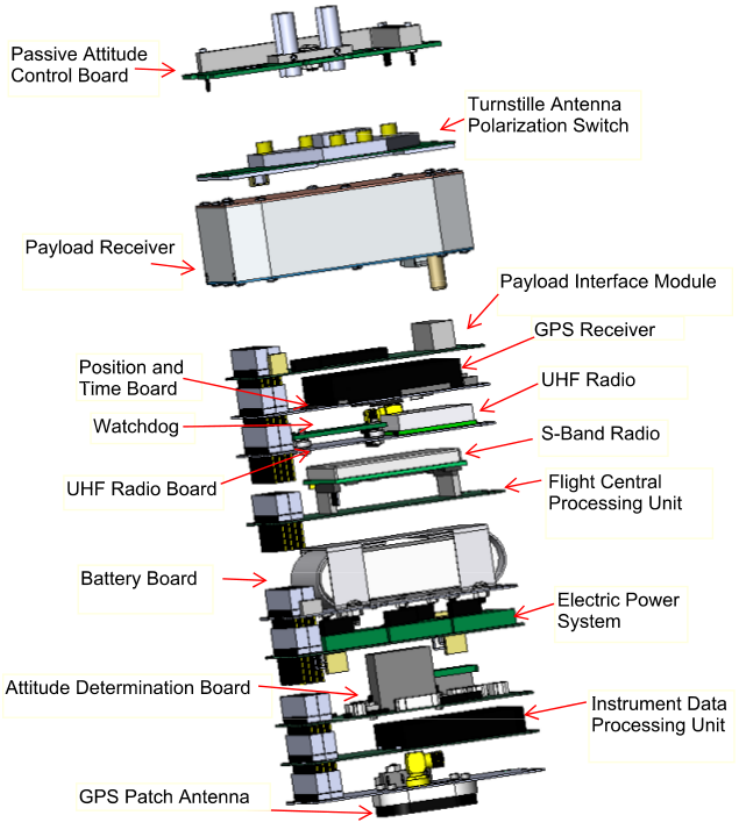
RAX Mission: High-resolution mapping of ionospheric irregularities

Team:	SRI International University of Michigan
Payload:	UHF Radar receiver (426-510 MHz)
Transmitter:	Megawatt-class Incoherent Scatter Radars
Funding:	NSF Small Satellite Program for Space Weather Research. Launch provided by NASA ELaNa
Launch/Orbit:	Delta II with NPP, 102° inclination, 400 x 820 km elliptical
Mission Duration:	1 year expected



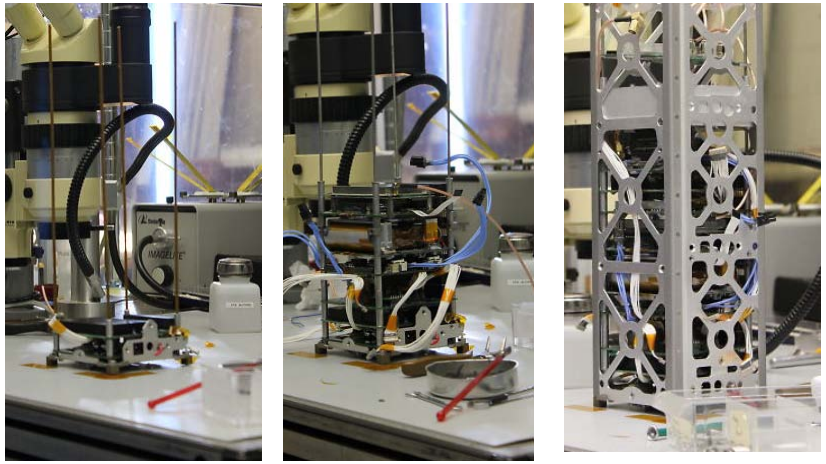
Measurements made with novel bistatic radar configuration

RAX-2 Subsystems and Integration



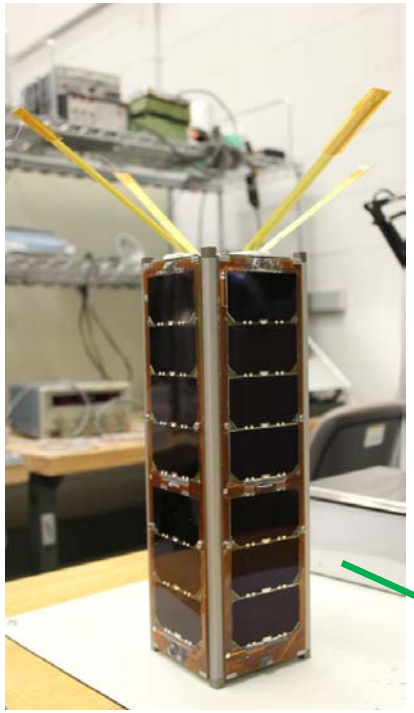
CAD model showing subsystems

SRI-developed radar receiver



Flight unit integration, July-August 2011

Launch Oct 28, 2011, NASA ELaNa, Delta II with NPP

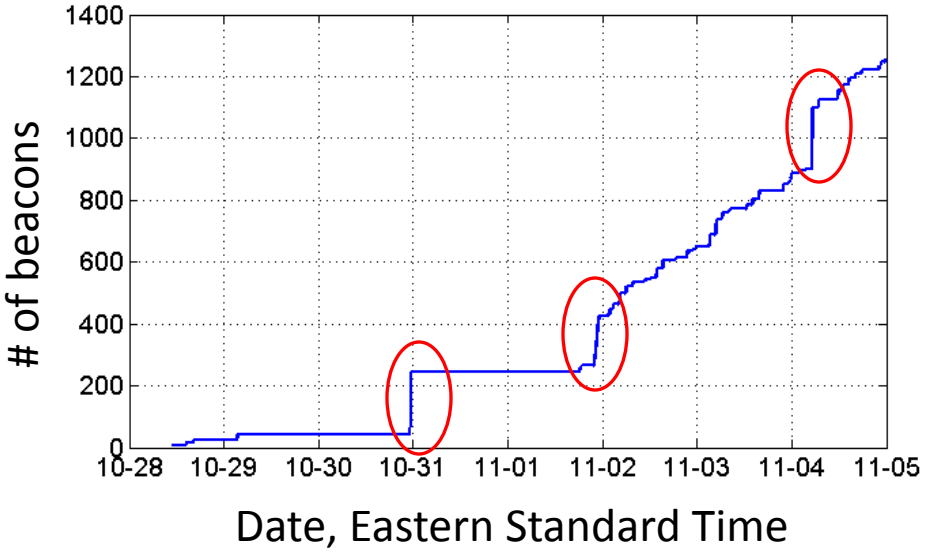


DICE, E1P, MCubed, AubieSat-1

Rocket photos courtesy spaceflightnow.com

Successful launch, initial beacons heard hours after launch

The cumulative number of ***beacons*** heard over the ***first week***:



Circles show batch uploads to the database, which are common early in the mission as HAMs begin using the RAX-2 client. Nominally, beacons are uploaded immediately after decoding.

Successful launch, initial beacons heard hours after launch

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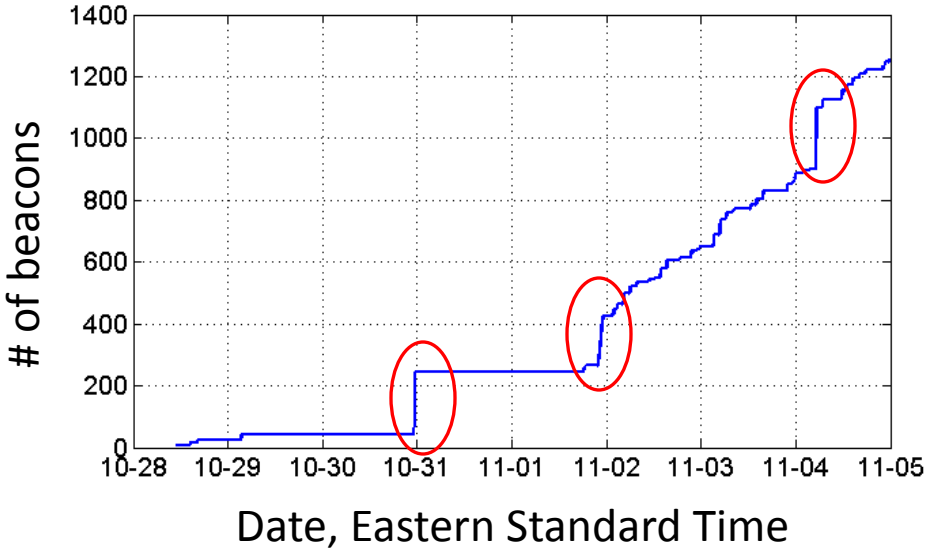
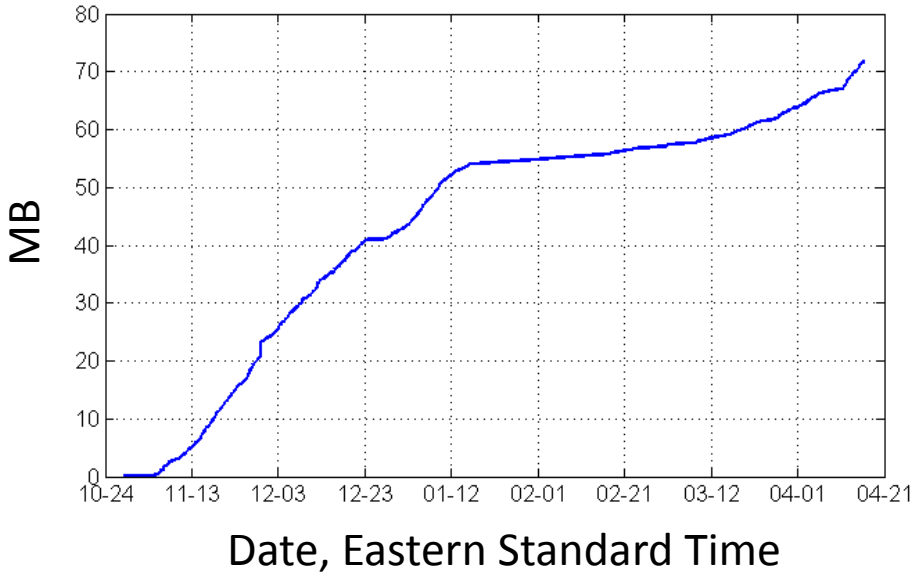


Cumulative sum of total data received, as of ***4/16/12***:

137,668 beacons and counting

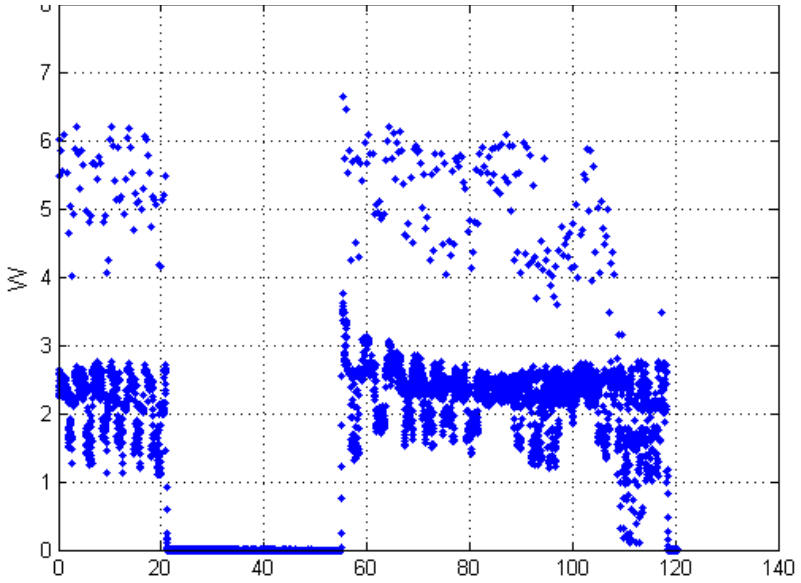
70MB of data



Reliable commanding by early November, checkout begins

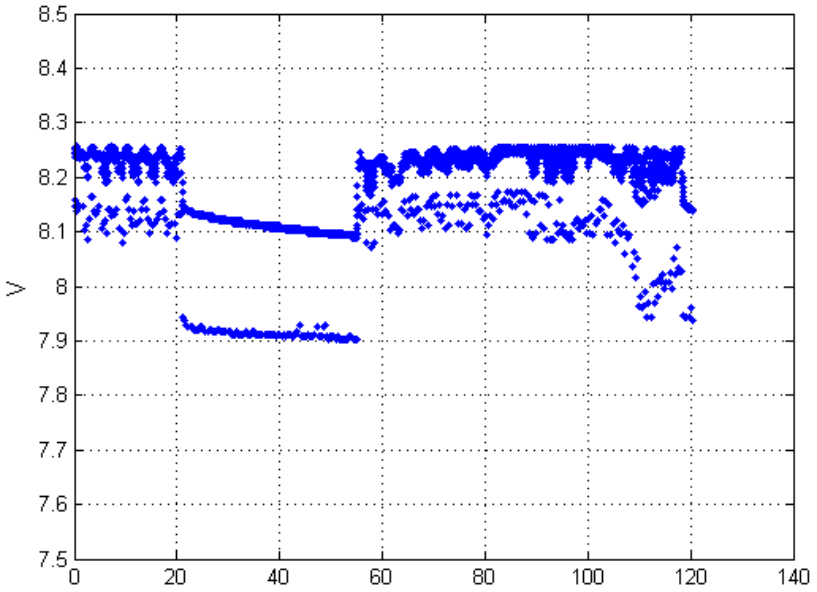
120 minutes of 1 Hz telemetry collected November 4 demonstrated **expected subsystem performance**. 1 Hz telemetry continued to be collected weekly for detailed analysis.

Power collected by all 4 solar panels



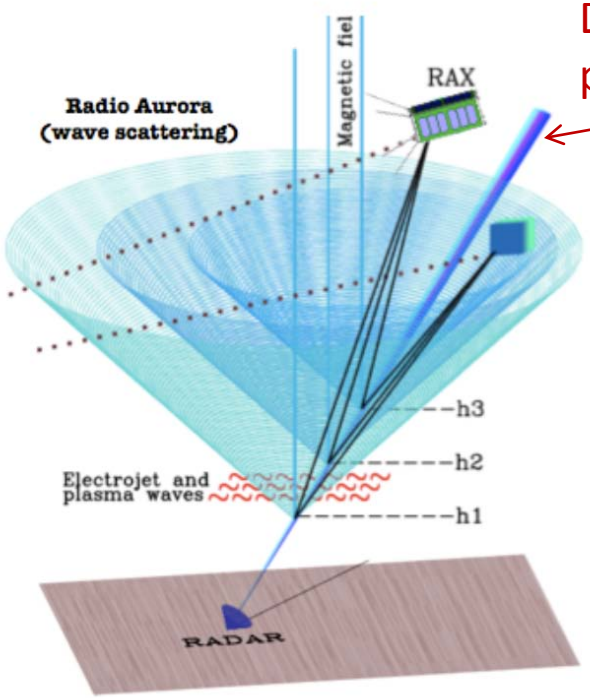
Minutes since 11/4/11 18:29:45 UTC

Battery voltage



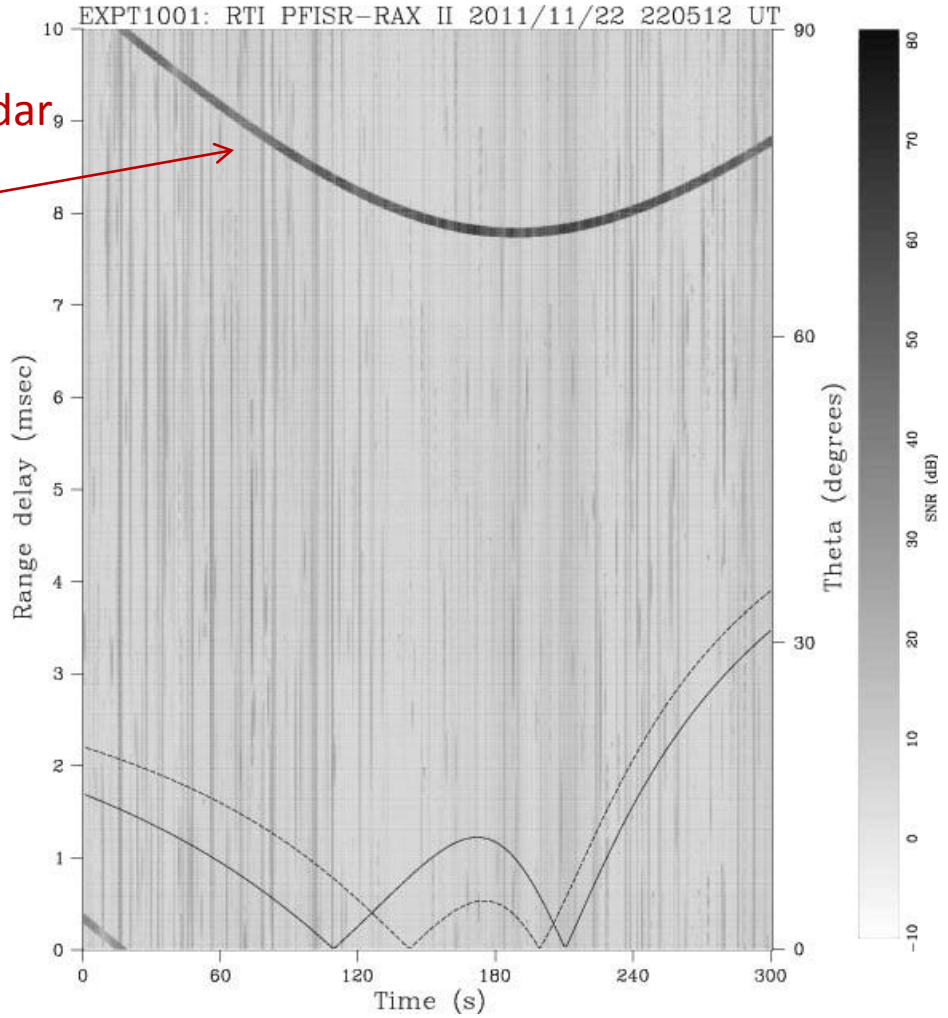
Minutes since 11/4/11 18:29:45 UTC

First radar experiment on Nov. 22



Poker Flat Incoherent Scatter Radar station (PFISR) was used.

Direct radar pulses



Resulting range-time-intensity plot. No radar echoes detected.

The frequency of radar experiments gradually increased to the planned one per day

Experiment dates:

November: 22

December: 1,18,29

January: 6,7,8,10,11,12,13,15,16

Pause for SD card recovery

February: 20

March: 6,7,8

+ 3 experiments not processed due to quiet geomagnetic conditions

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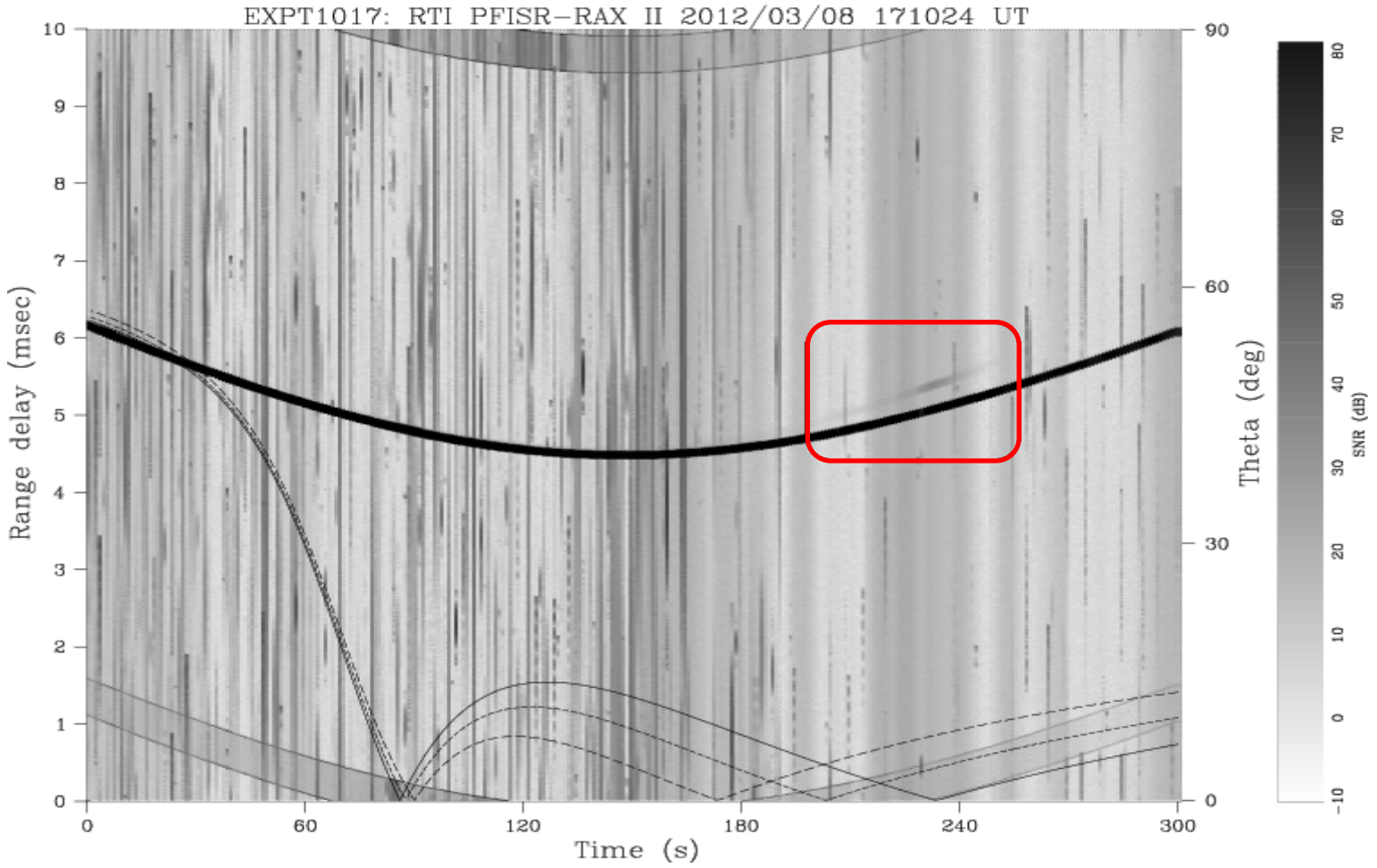
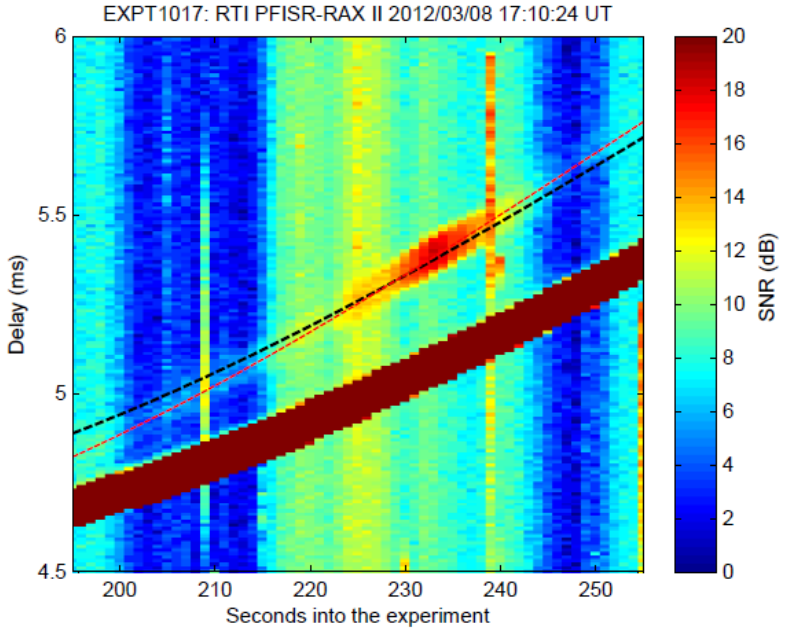
Total of 17 processed experiments from RAX-2, so far.

RAX-2 detects radar echoes on March 8!

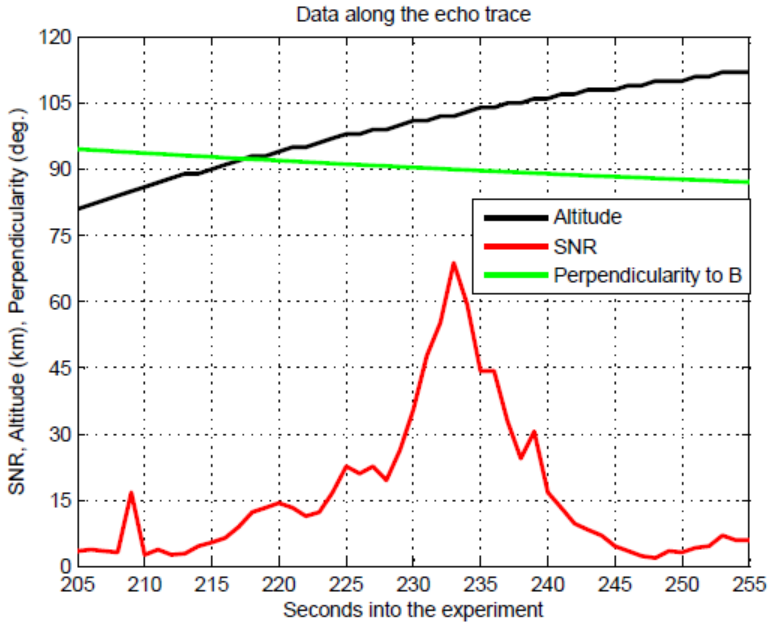


Range-time-intensity plot for the experiment

RAX-2 detects radar echoes on March 8!



Portion of the range-time-intensity plot corresponding showing echoes. The black line marks the arrival time of echoes from an altitude of 100 km. The red line is a visual fit of the echo peak.



Altitude, SNR, and perpendicularity data along the red trace shown on the left plot. The peak SNR corresponds remarkably well to the exact perpendicularity of the Bragg wave vector with the geomagnetic field.

More science details available on the poster

A first for CubeSats (and science in general)

Irregularities located with an altitude resolution of 3 km and sub-degree resolution in aspect angle, is unprecedented for aural region measurements.

The measurements enable improved characterization of meter-scale irregularities.

FCPU SD Card Failure and Recovery

On Jan. 16, the SD card used by the flight computer failed.

Symptoms

- Unexpected execution of commands stored on card
- Approx 7 mA increase in current draw
- Nonsensible error status from the card
- Can’t read or write to the card
- Spacecraft reboots and power cycles do not help

Debugging attempts

- Uplinked custom code to try to diagnose the failure. No conclusions on the cause or exact failure.
- We can communicate with the card, but cannot initialize it, read, or write data.

FCPU SD Card Failure and Recovery

Implications: cannot execute stored commands, record data to the card, or download data from the card

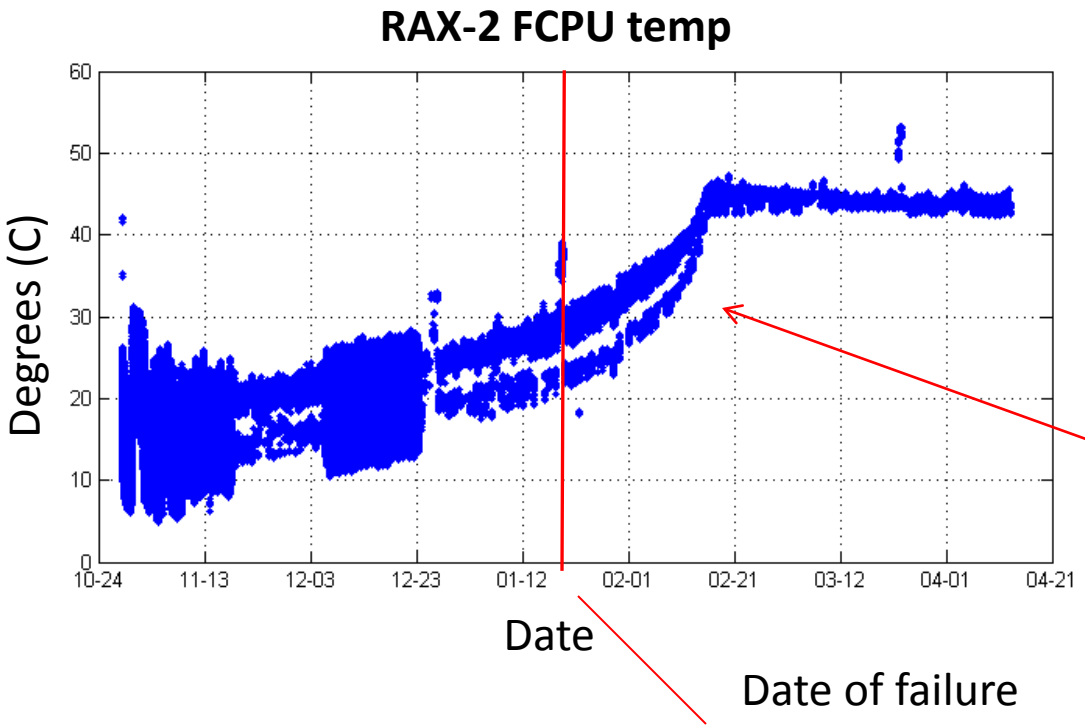
Recovery:

- There is 2 kB of available codespace on the FCPU RAM. We upload code to the spacecraft and execute the code. This includes the ability to schedule commands.
- Science data downloads resume Feb 17.
- Experiments resume Feb 20.
- Still in development: the ability to store telemetry on-board as well as log GPS data.

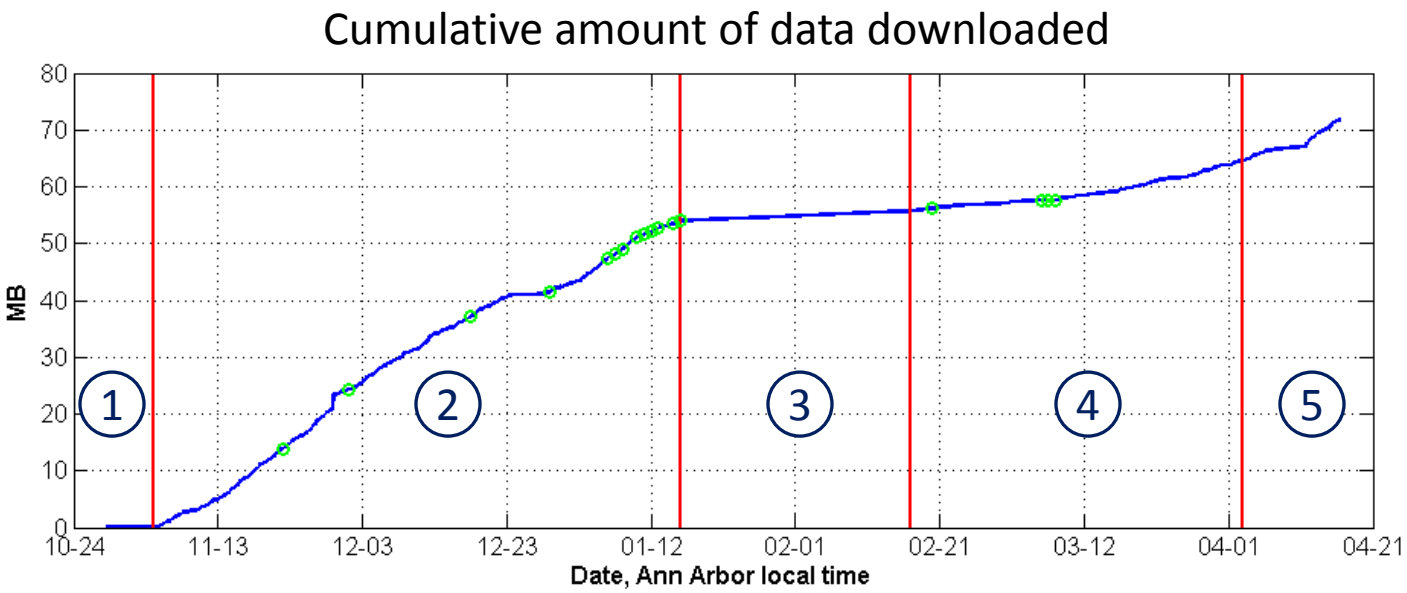
SD failure cause is unknown

– Thermal expansion resulting in partial connectivity?

– Radiation – Single event effect?



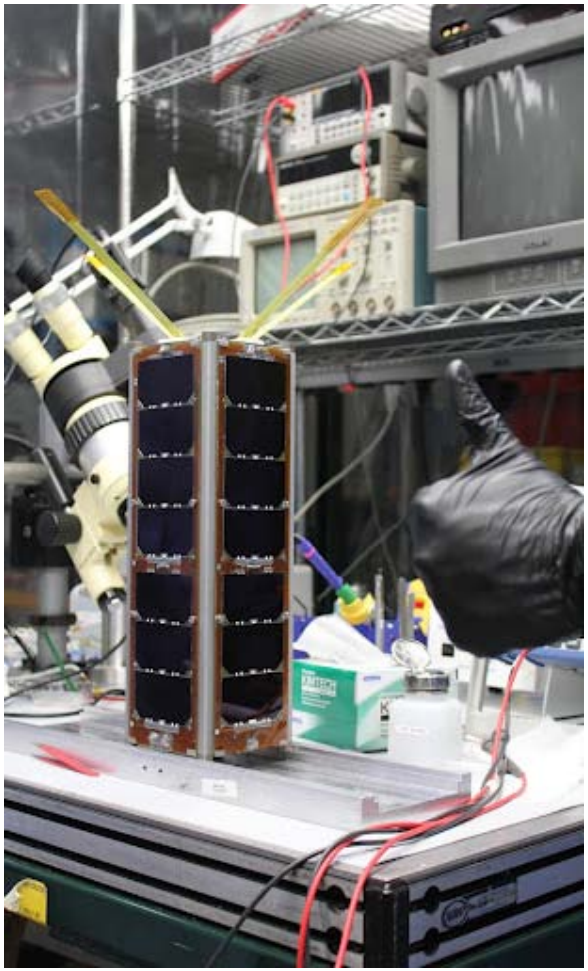
Operations Summary



1. Initial acquisition, beacon collection , basic commands
2. Full checkout moving to nominal operations. Data downloads scheduled over global HAMs
3. SD card debugging
4. Science capabilities restored. Experiments and downloads resume
5. Full command scheduler implemented without SD card. Aggressive download of Expt1017 raw data begins

RAX-2 Summary

- Demonstrated new and unique science capabilities
- Power system in good health; solar panel failure of RAX-1 corrected. Other bus subsystems performing as expected.
- Lessons learned with SD card – consider redundancies in hardware and software
- Analysis of 150,000+ telemetry points will feed into the design of future satellites with increased capabilities, improved modeling, etc.



Acknowledgements

National Science Foundation
WHERE DISCOVERIES BEGIN

NASA ELaNa

Ben Kempke, Alex Sloboda, and the rest of RAX-1 and RAX-2 teams

Global HAM community

Questions?

John Springmann: jspringm@umich.edu

James Cutler: jwcutler@umich.edu

Hasan Bahcivan: hasan.bahcivan@sri.com

http://rax.engin.umich.edu

http://rax.sri.com

http://exploration.engin.umich.edu

Extra slides

Bus performance

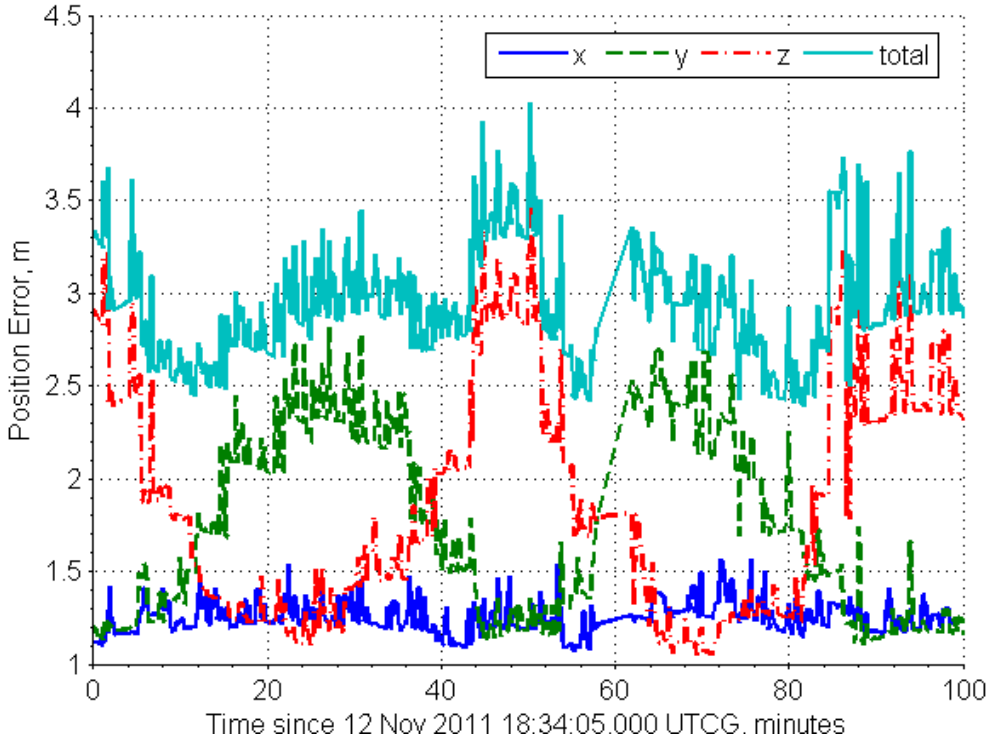
- Electrical power system
  - Full recovery from RAX-1 power failure.
- Attitude determination and control
  - Passive magnetic system aligned RAX with magnetic field in approx 20 days, angular rate reduced to approx 1 °/s from initial deployment of approx 16 °/s
  - Development and implementation of on-orbit sensor calibration techniques yield attitude uncertainty of < 5°
- GPS
  - Achieved lock with the GPS constellation
  - Demonstrated 3 m position accuracy on-orbit

Bus performance

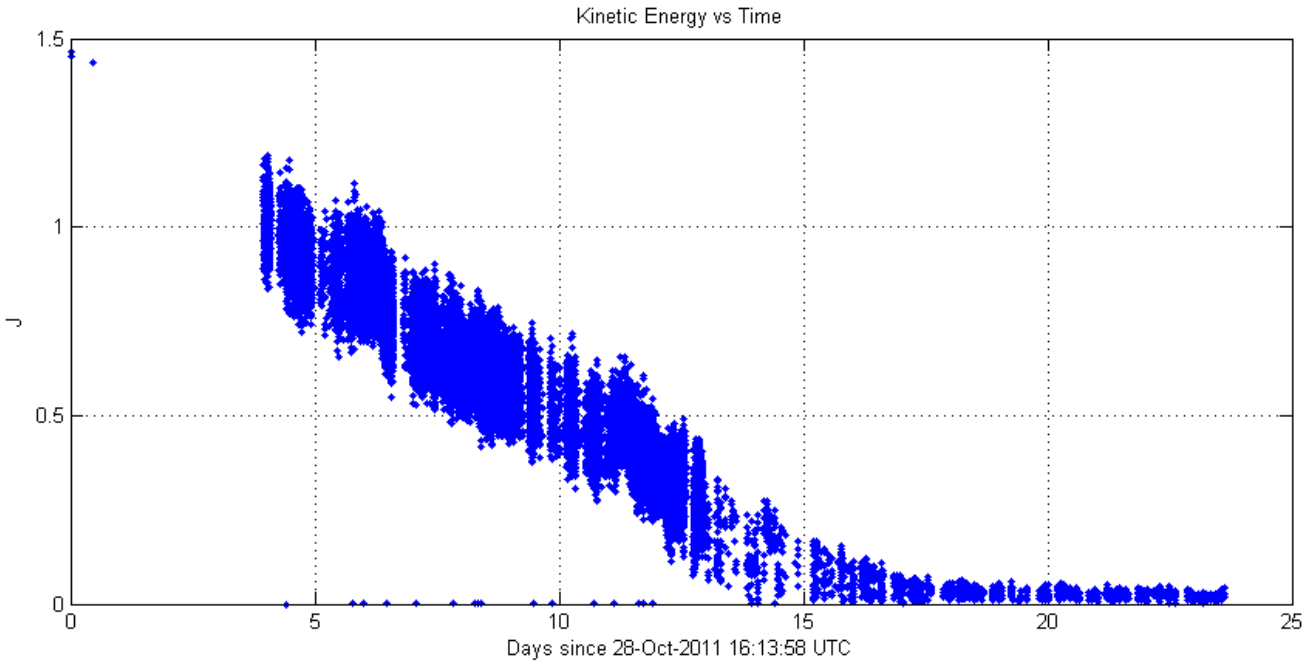
- Communication
  - AstroDev Lithium-1 UHF radio performing as expected. RAX-2 is utilizing the global HAM community for data downloads in addition to beacons.
  - MHX2400 S-band has not yet been tested
- Payload, Instrument data processing unit (IDPU), Payload interface module (PIM)
  - Subsystems performing nominally, multiple noise floor tests on-orbit as well as experiments with PFISR and RISR confirm expected performance of the radar receiver.

GPS results

RAX-2 achieved lock with the GPS constellation. Position error in ECEF coordinates over a sample orbit is shown below.



Attitude control 1



Attitude control 2