QuakeSat:

Low Cost University/Commercial Nanosatellite Collaboration

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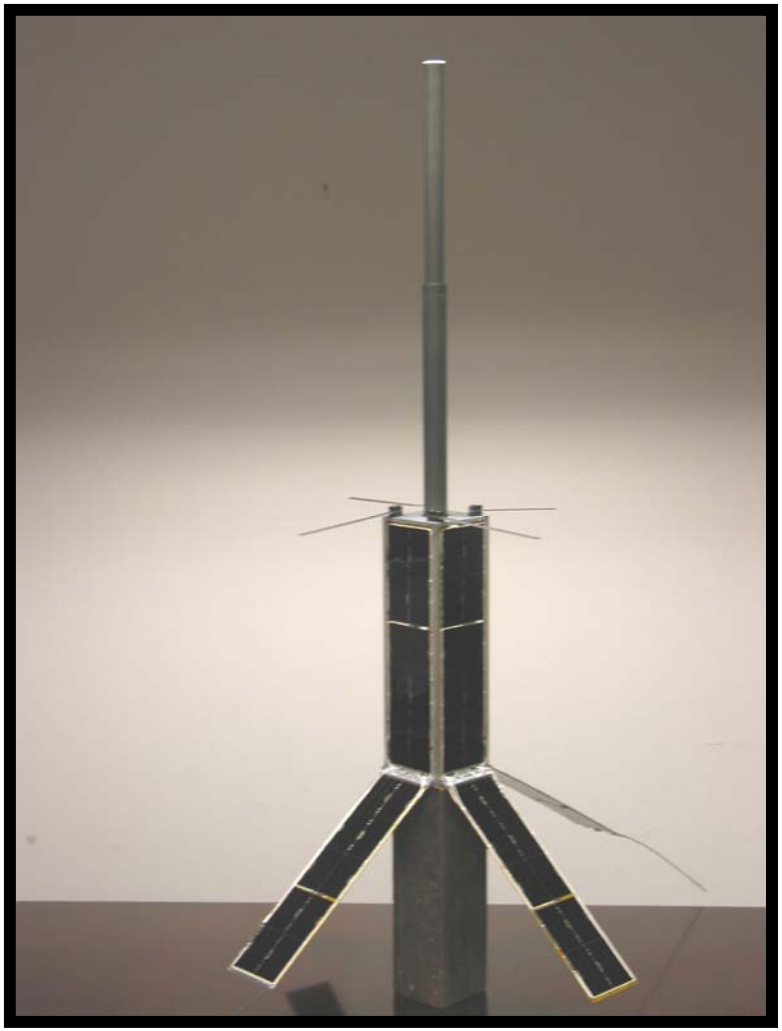
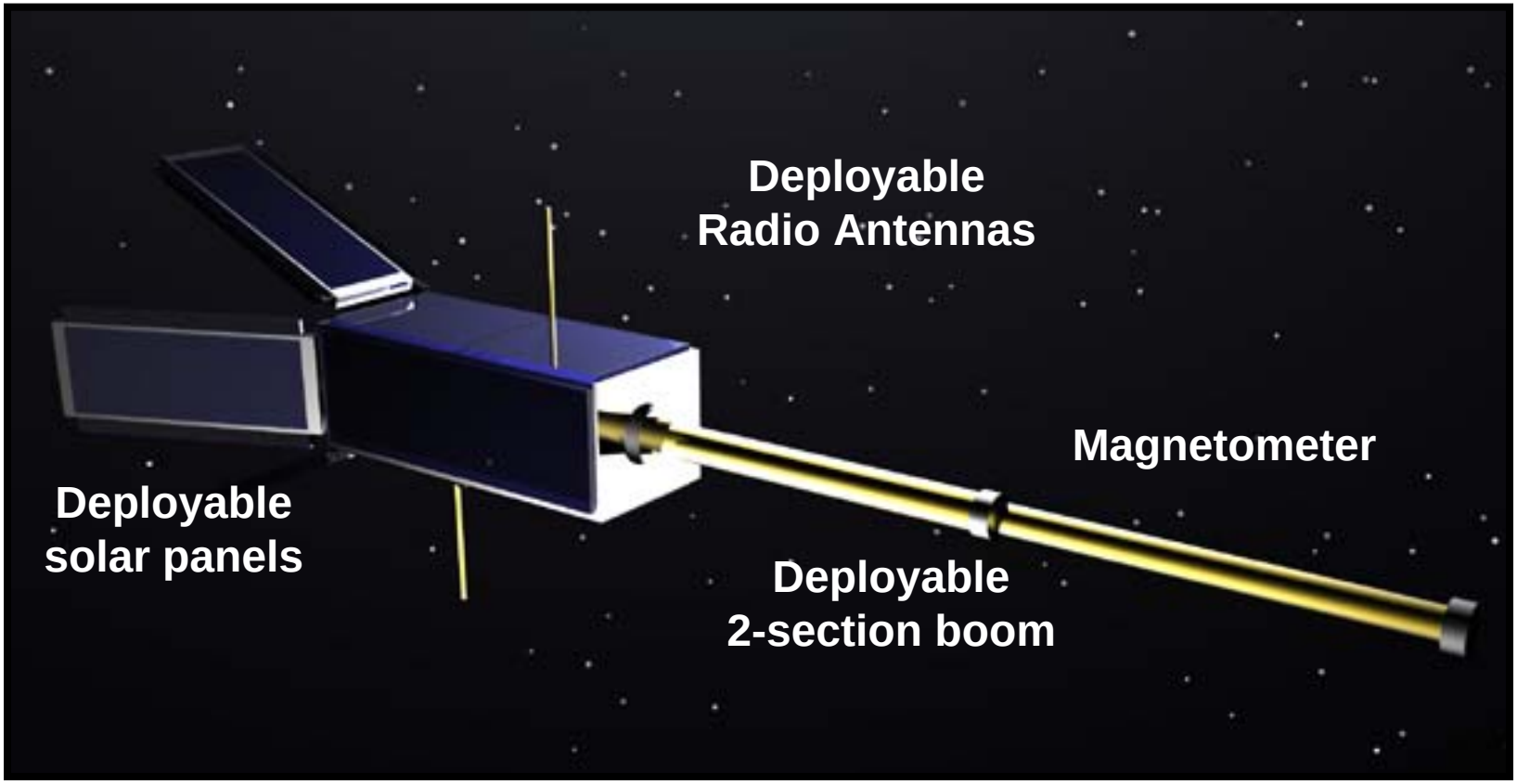
QuakeSat and Team



Nanosat (QuakeSat) Size

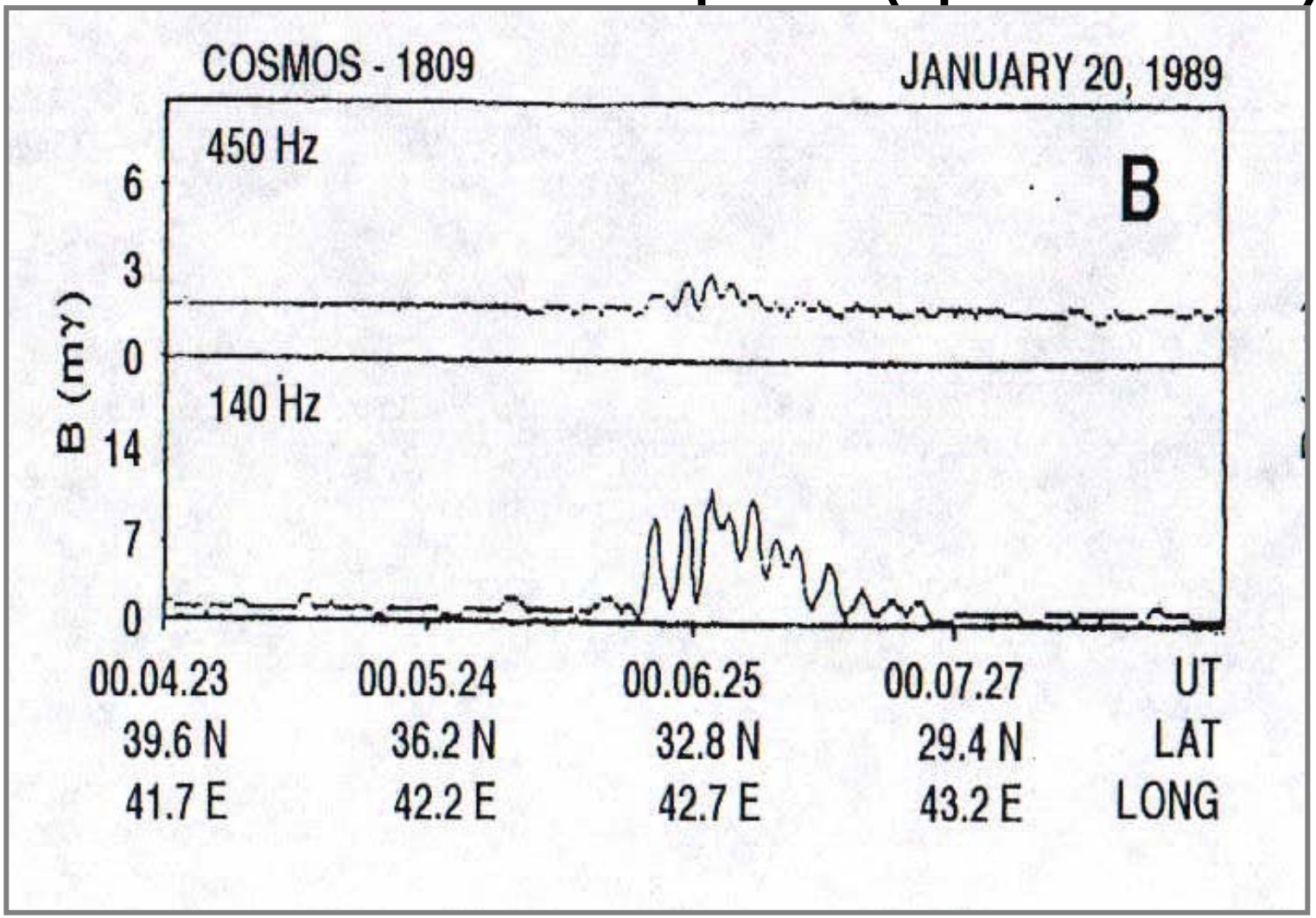


Total weight = 9.9 lbs (4.5 kg)

QuakeSat Status

- Successful launch on June 30, 2003
  - One of eight satellites
  - Eurockot booster (Plesetsk)
  - Breeze upper stage (restartable, multiple launcher)
- Orbit Parameters
  - 820 km, circular orbit
  - 98.8 degree Inclination
- 6 month expected life (actual 7+ mos)
- 1 GB data (1700 files)

Satellite Example of ELF Magnetic Field Signals Associated with Earthquakes (Spitak Armenia)

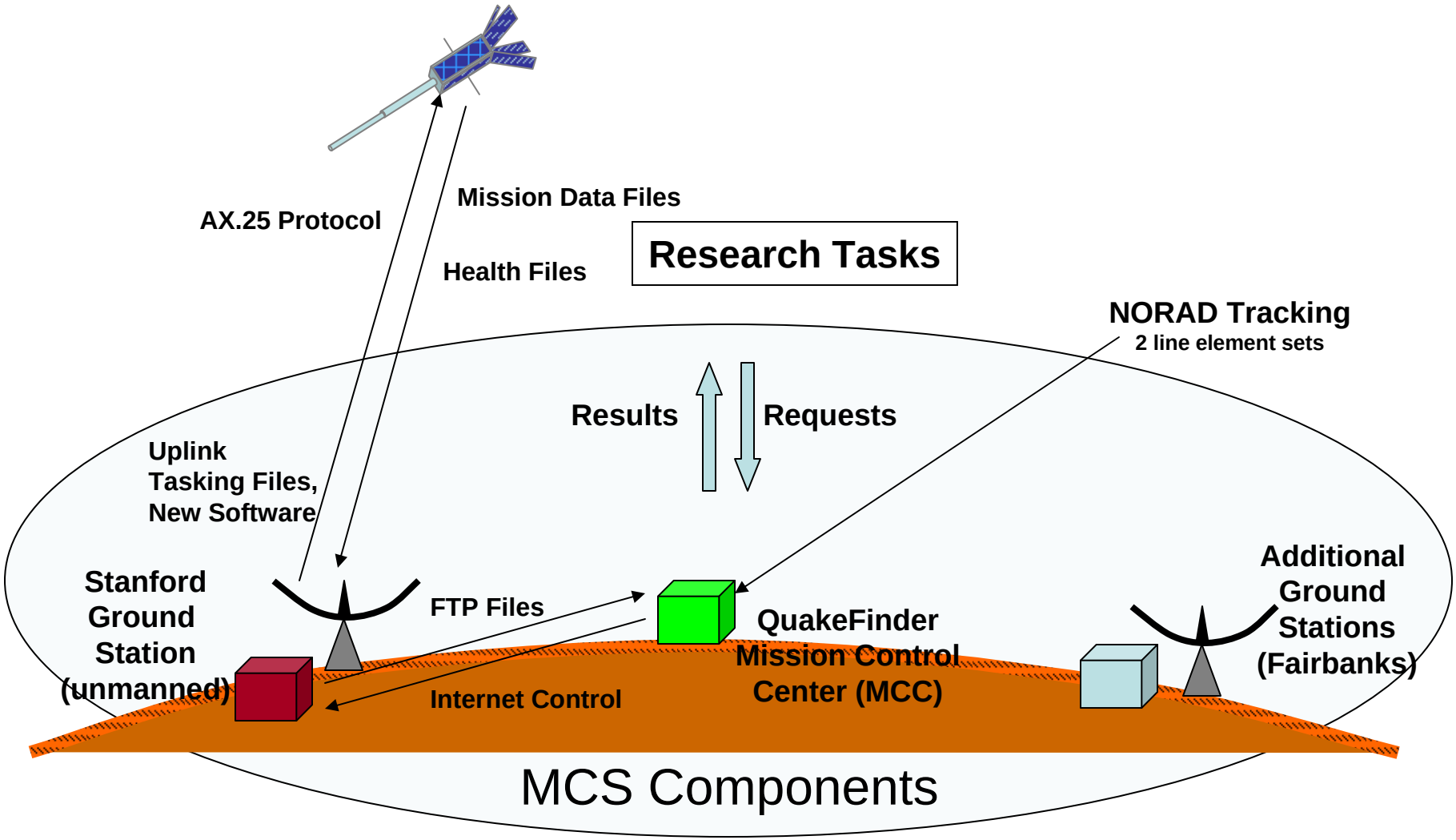


QuakeSat and P-POD

Linux and Prometheus

- Pros Linux
  - Drivers (baypac & ax25) built-in
  - <10k loc+linux = flight software
    - 3k loc for low level A/D timers
  - Utilities already written
    - Md5sums (errror checking)
    - Bzip2 (file compression)
    - Shell utilities
- Pros Prometheus
  - 16 channel/16bit A/D built-in
  - Hardware timers/interrupts
  - Multitasking 66 MHz
  - 32 Meg RAM/128 Meg Flash
- Cons
  - Power hog 2.5 W
  - Flexibility require more testing!!

QuakeSat Tasking & Data Flow Concept



UHF Ground Stations – Stanford, Fairbanks

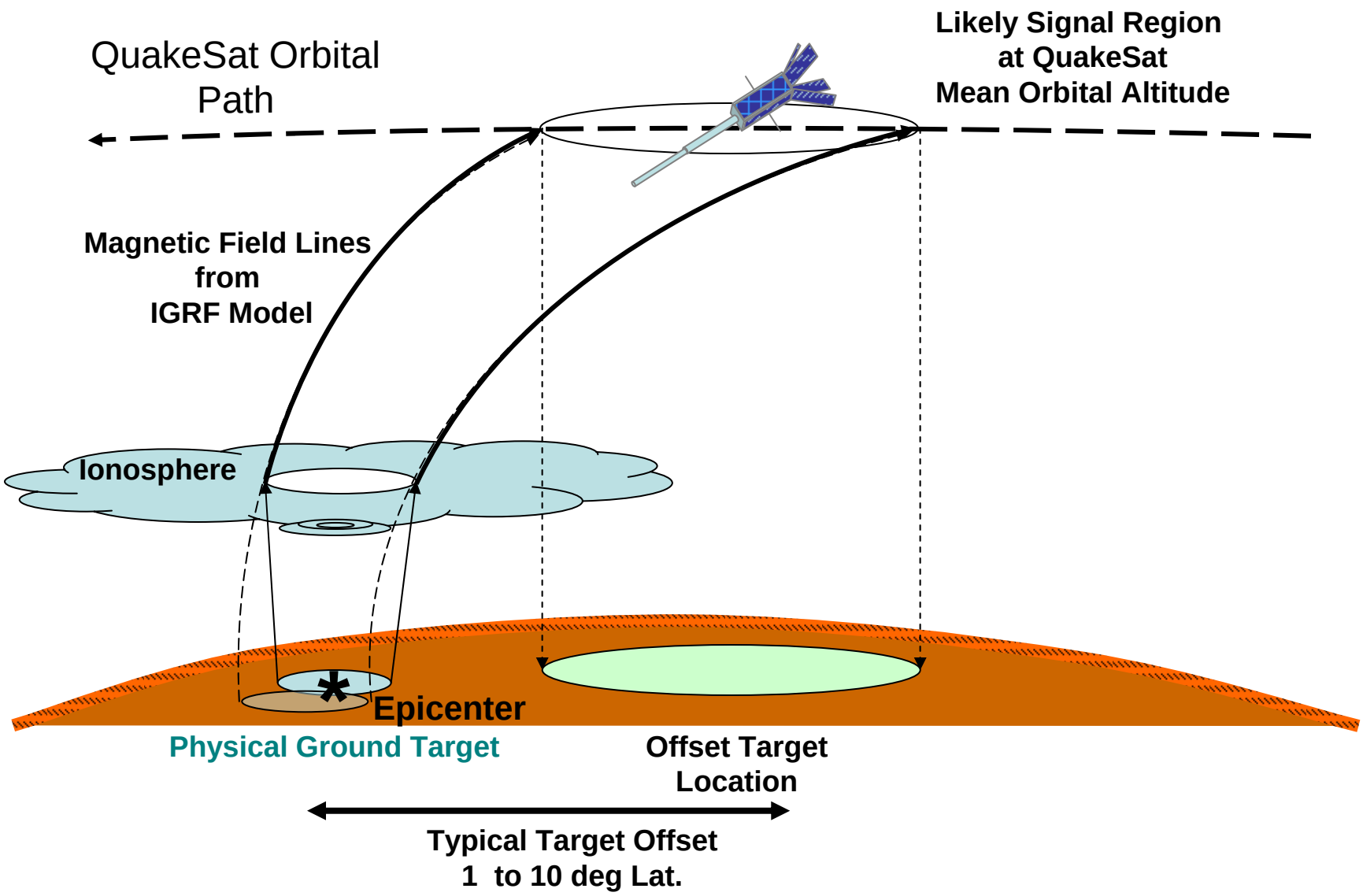
Mission: Earthquake Detection

ELF Signals Detected

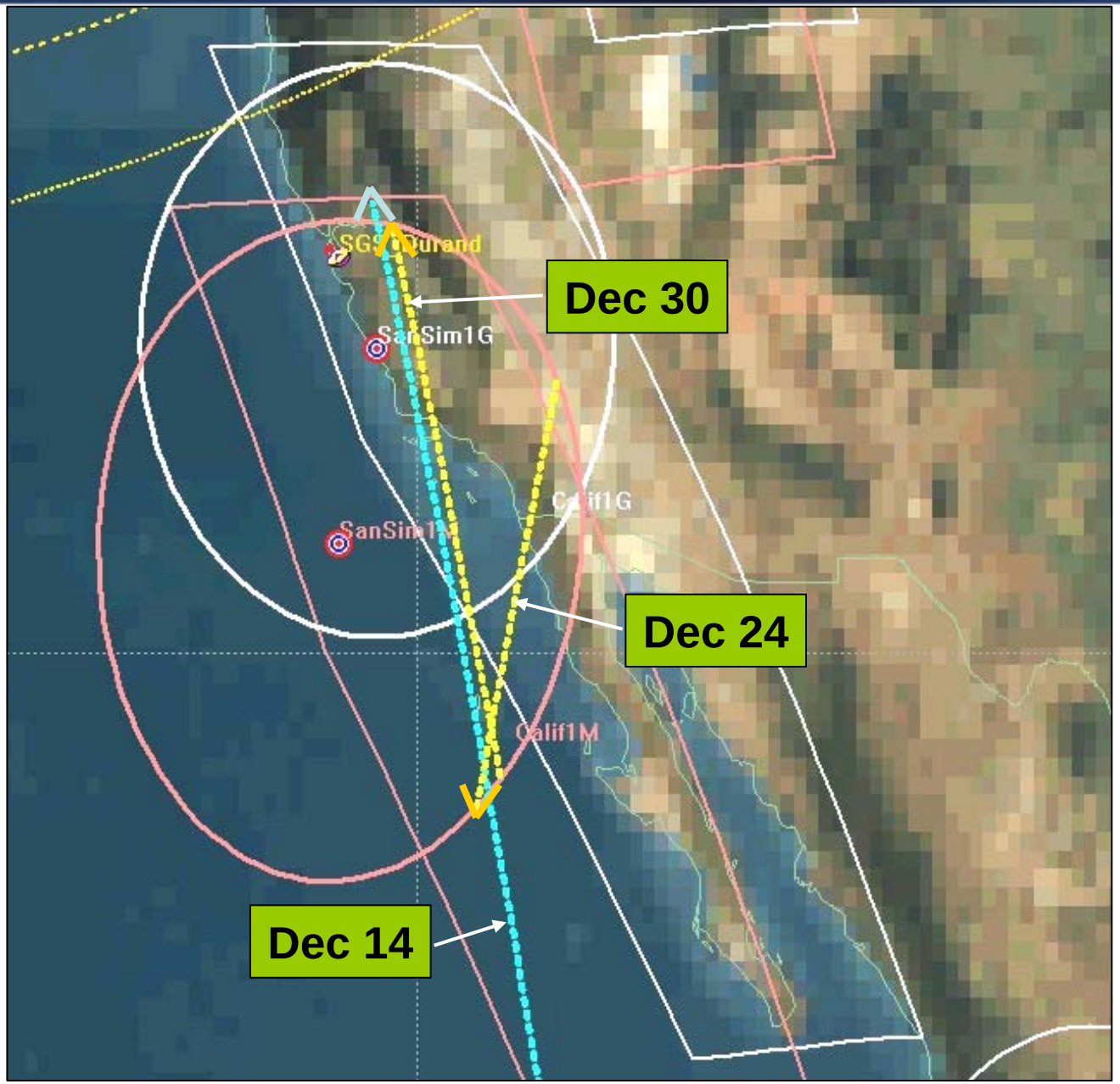
near San Simeon

Dec. 22, 2004 M6.5 Quake

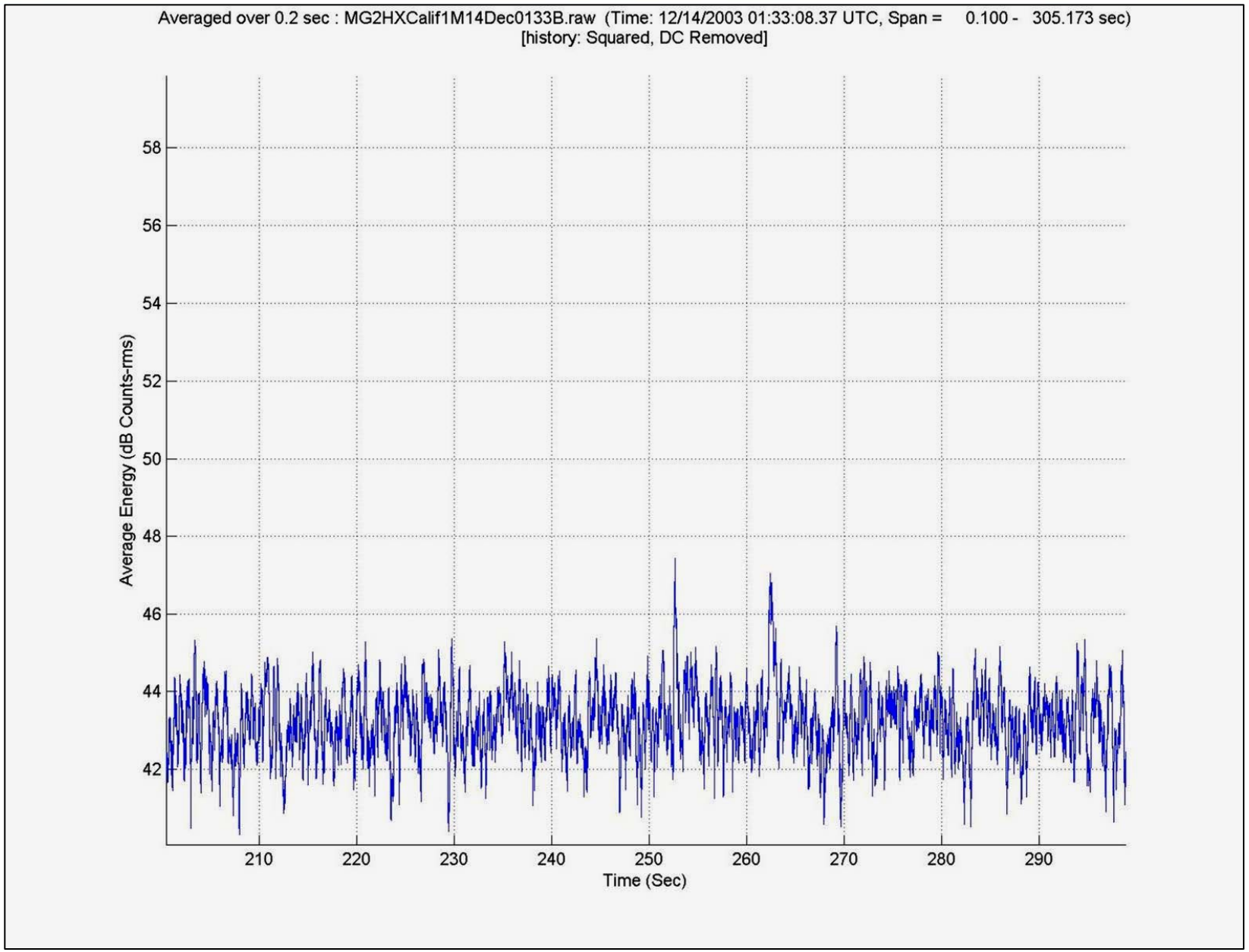
QuakeSat Offset Targeting



QuakeSat Collection Geometry



Dec 14, 2003 10-150 Hz



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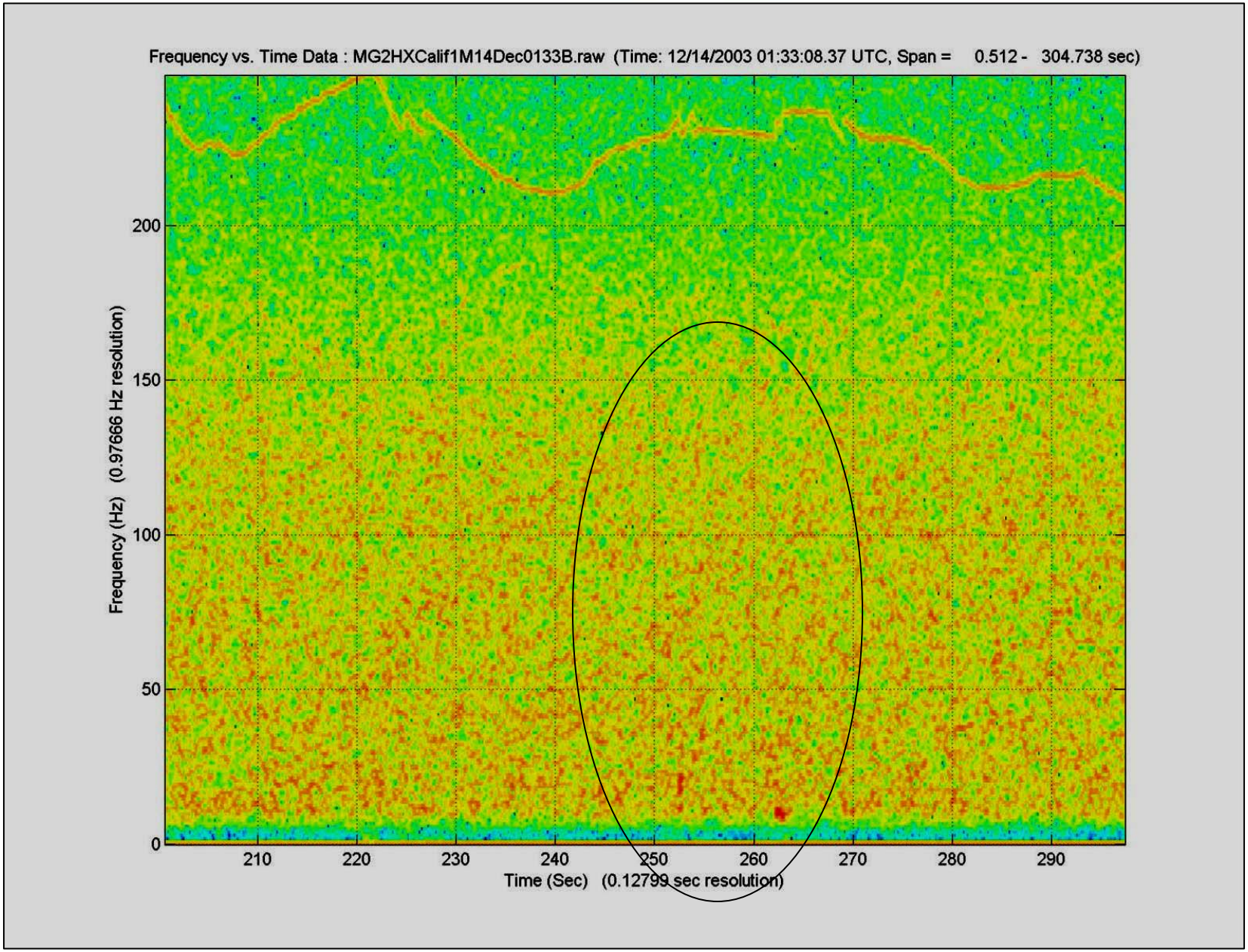
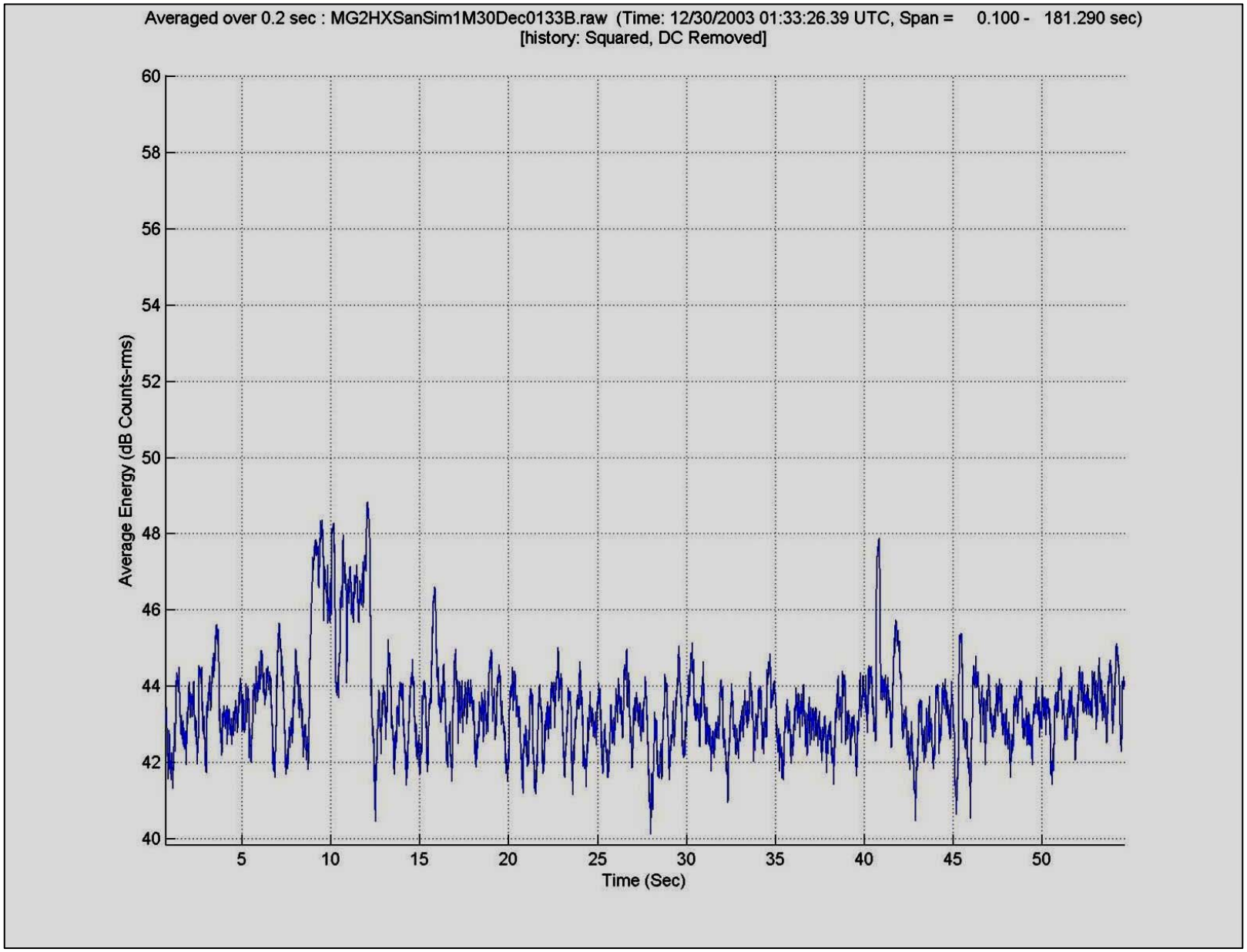


Dec 30, 2003 10-150 Hz



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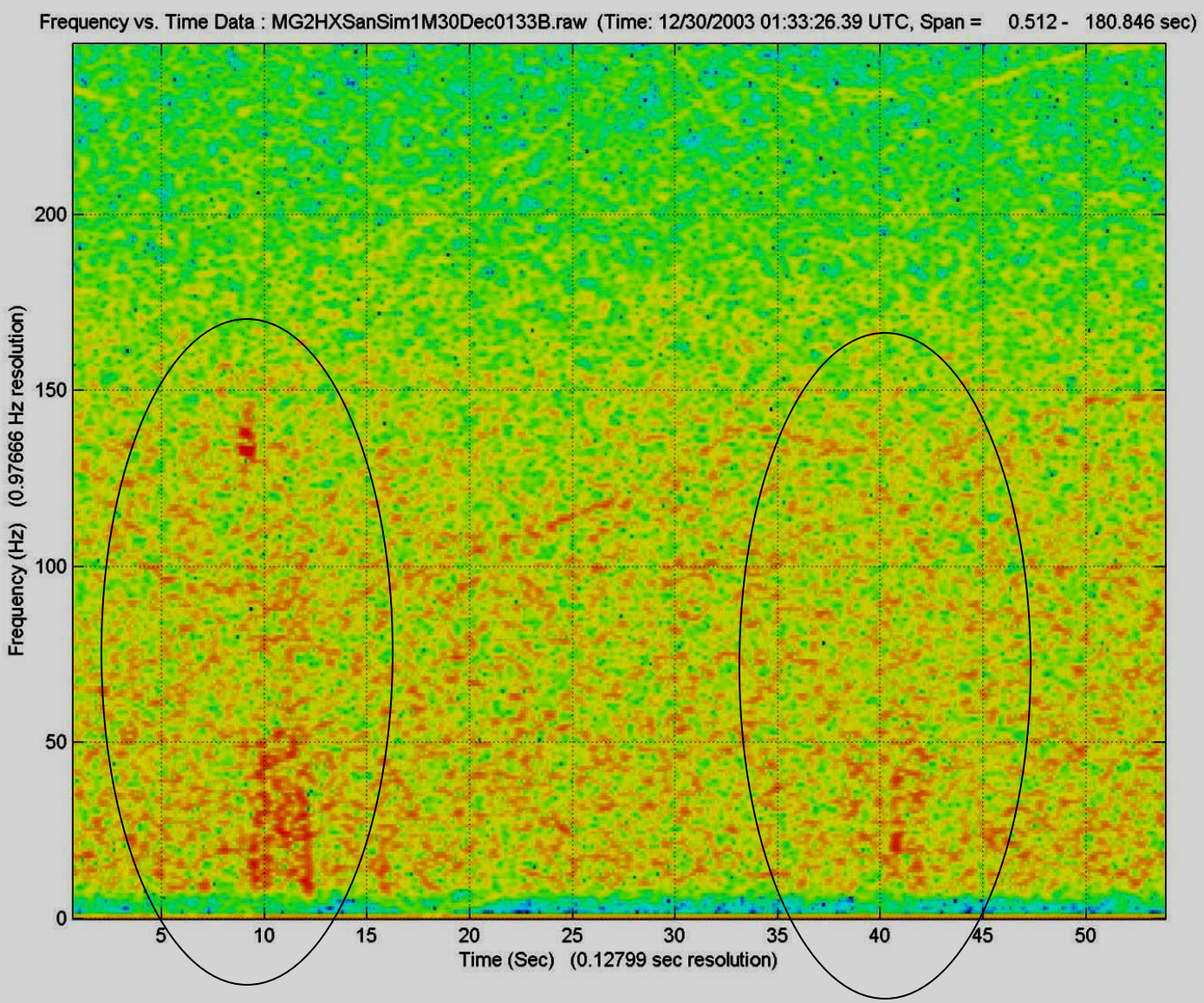


Lessons Learned for Students

- Define clearly what you want to accomplish
  - Short term mission (days-weeks) or long term (months+)
  - Construction and operations costs
- Have enough help (students, engineers, mentors)
- Have enough time
  - 12 mos for single, simple, satellite
  - 18-24 mos for larger more complex satellite
  - Include time for ITAR process and grd systems (station, Mission Control)
- Have enough funds
  - $10-50K for satellite parts (assumes “free” access to testing facilities)
  - $30-50K per kg for launch (assumes Russian launch)
  - Have 50% funding reserves (paying “customer” is preferred)
- Build a full prototype including the flight computer
  - Test it thoroughly, including end-to-end, with ground station
- Use good designs for grounding, and RF control
  - Unipoint ground, 3 layer boards with grd plane, EMI filters on power lines
  - Strongly consider using Stanford Ground Station (network)

Low Cost Science-Breaking Barriers

- “You can’t build and launch a satellite for under $10M”
- “You can’t do space science for under $10M”
- University/industry collaboration is good
- Ideas & tech development from Universities
- Construction, integration, test, operations, facilities, support staff from Industry
  - Execution to a tight schedule
- Every barrier must be overcome
  - Borrowing facilities, using mentors, COTS parts
  - Finding multiple funding sources
- Positive attitude goes a long way

Back Up

QuakeSat Costs

- $ 50K for satellite parts
  - Triple CubeSat (2 engr.models + flt model + sim)
  - Assumes “free” access to testing facilities
- $120K for Integration and Launch
  - $30-50K per kg for launch (assumes Russian launch)
- $ 0K for 5 students (Stanford/LM) for 14 mos. part time
  - Mission design, S/W development, power, attitude,RF, testing
- $850 K QuakeFinder Costs
  - Design, build, test, integrate Magnetometer
  - Design, build, test, power/tlm and watchdog boards
  - Build mechanical structures (outsourced), Integrate, test
- $ 0K Stanford Ground Station (part of Phd. Project)

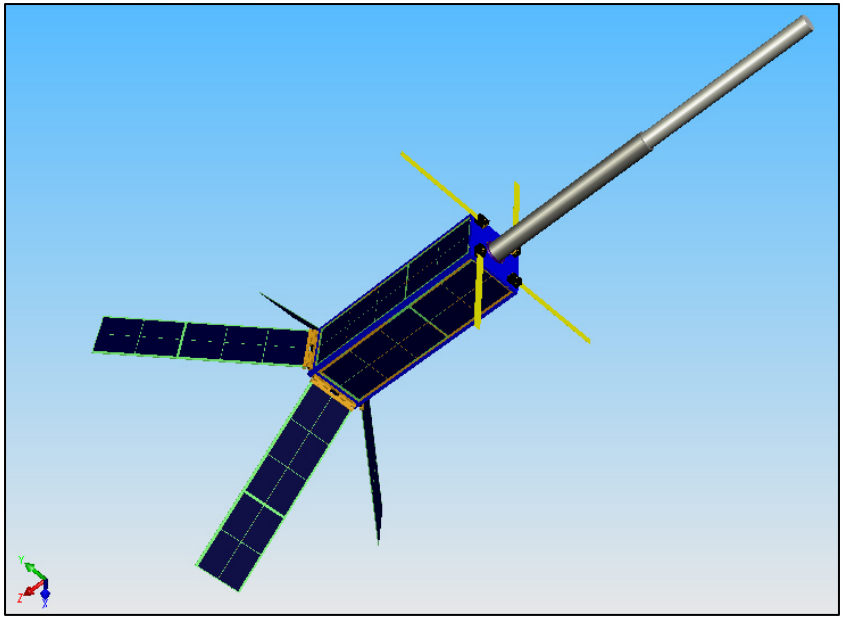
- Total cost to build and launch; $1M
- Operation cost: $170K per mo.
  - Run operations: 2 shift per day, 5 days/wk (4)
  - Science Mission: Develop ops and signal analysis processes (3)

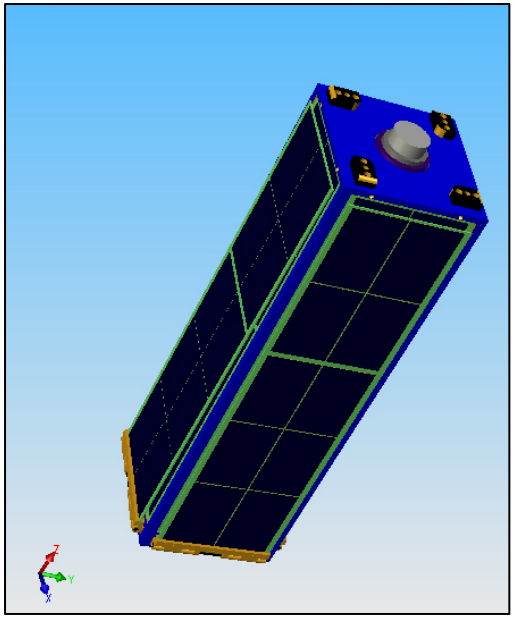
Cost of Satellite

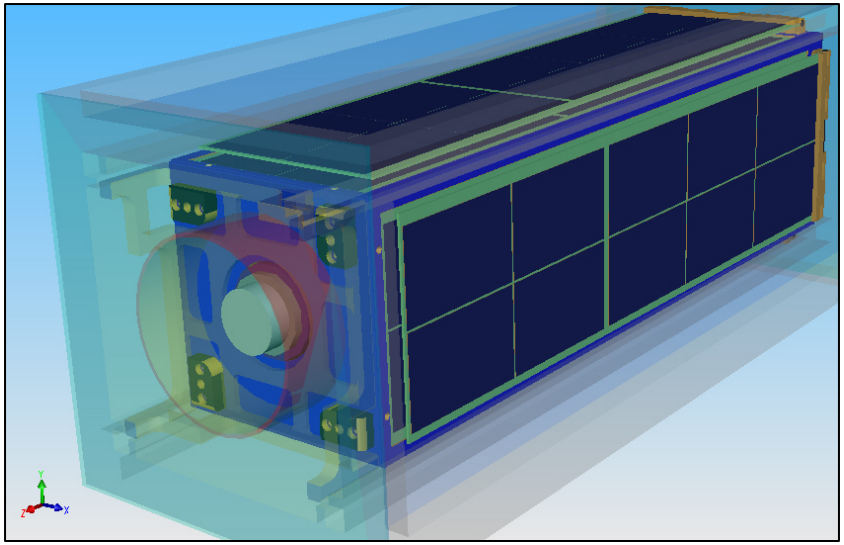
- Losing all your weekends 1.5 years.
- Feeling guilty if you knocked-off before 10pm
- Cold pizza becoming a breakfast stable
- Count coffee drank by pots not cups
- Put on 20 lbs…
- Having to do more presentation/briefings than your day job

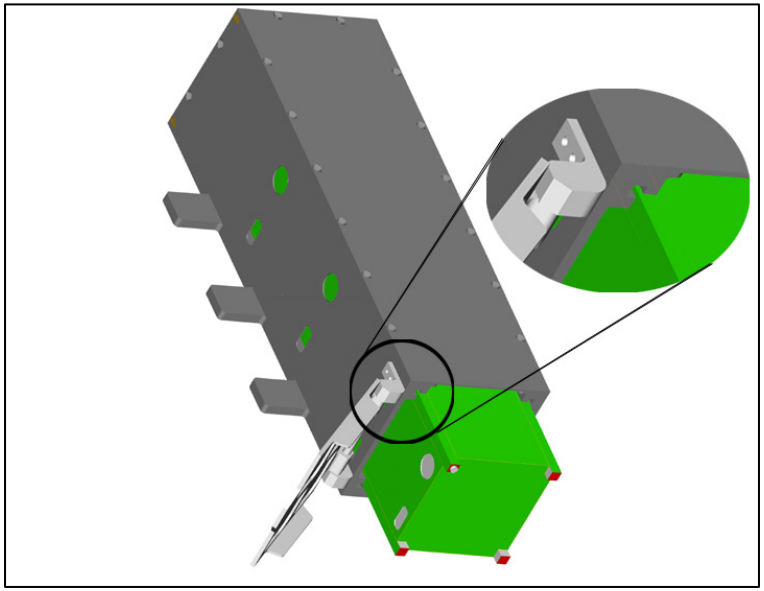
- YOU and your Nephew's thumbprint in space…. PRICELESS

Mechanical Layout

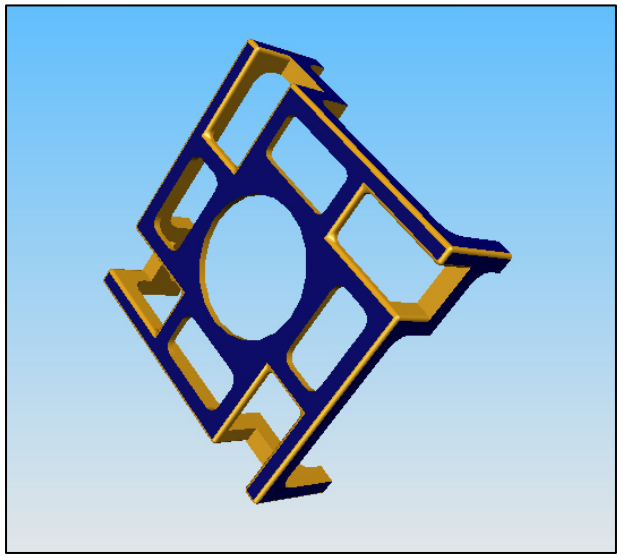


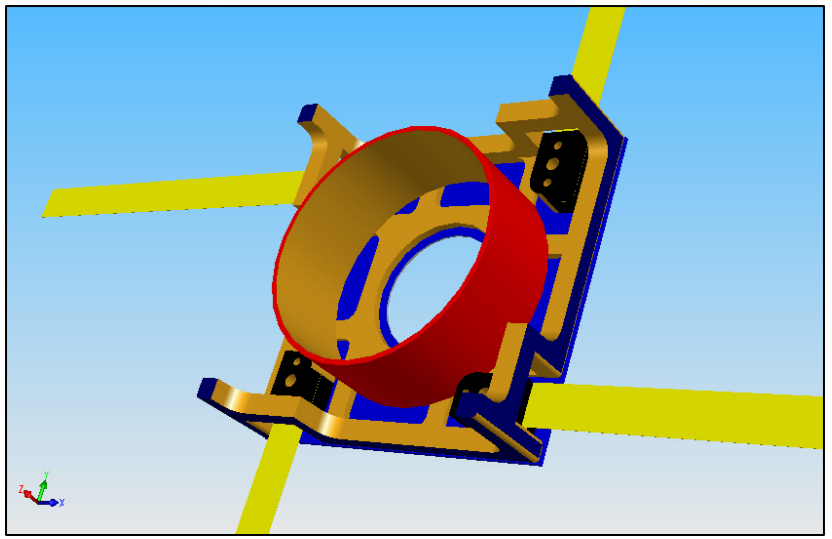


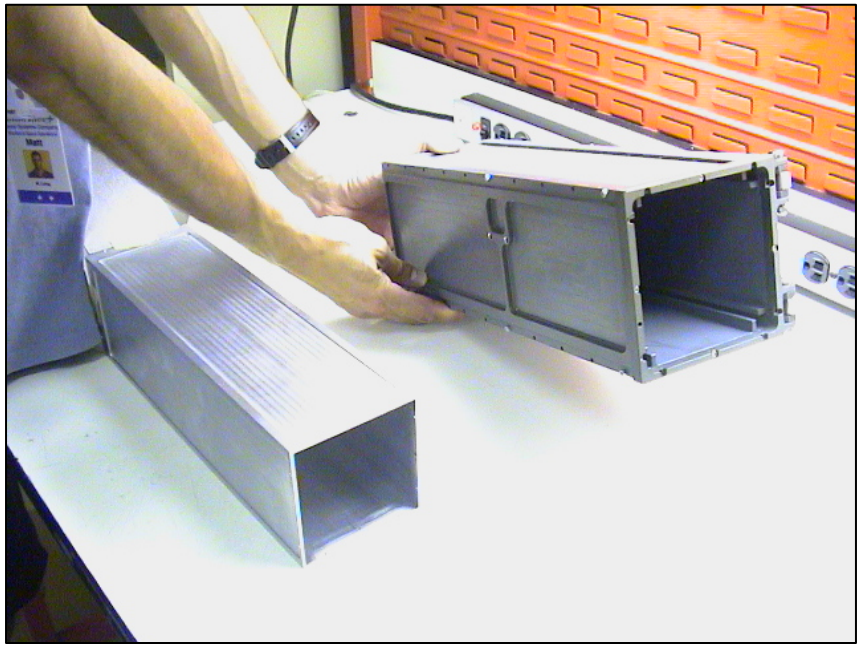


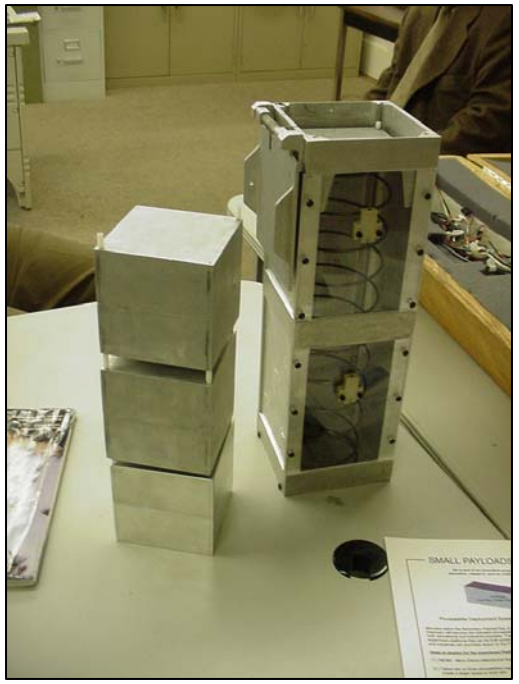


Mechanical Layout



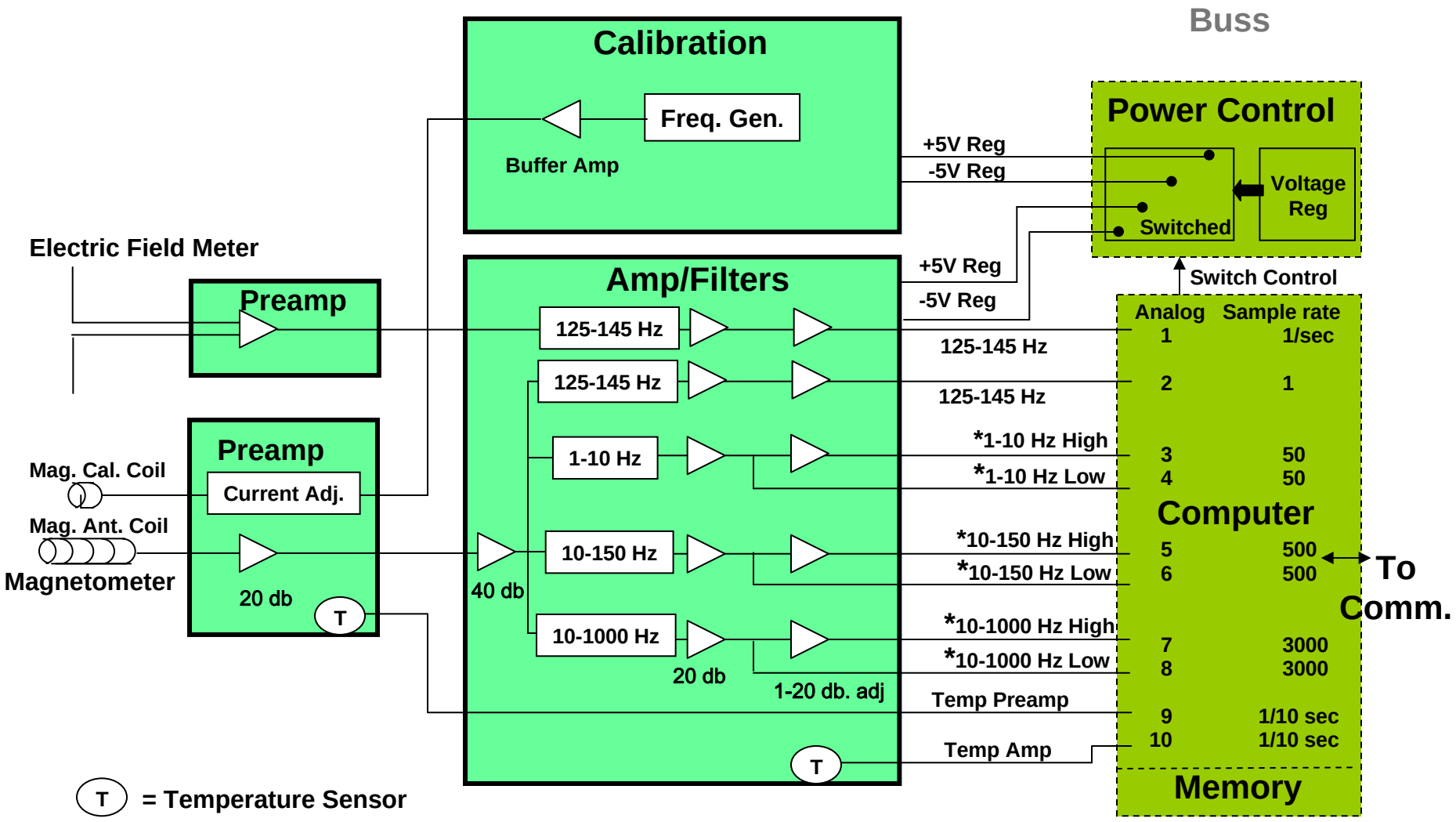






Payload Block Diagram

Rev.2



* These channels recorded only over predetermined areas of the earth

Communication

- 9600 baud, AX.25 packet system
- Stanford developed a customized version with PFR/PFS to handle packet control of long files (fill holes)
- Typical magnetometer and housekeeping file length is 100-300kB
  - Longest file in one pass: 700kB
  - Avg. 8 magnetometer collects per day (1 MB)
- Beacon every 10 sec. (disabled w/ mag. collects)
  - 33 data points plus time and date
- Stanford Ground Station (SGS)
  - Access via Internet, remote controlled, standardized I/F
  - 15 db Yagi, auto antenna control using El Sets
  - New features being added, (polarity control, signal strength)

Government Approval Process

- Technical Assistance Agreements (ITAR) State Dept Requirement
  - Approval to discuss sensitive technology
  - For P-POD and QuakeSat
- DSP-5 (ITAR) -for permanent export of unclassified tech items and data
- DSP-73 (ITAR) -for temporary export (GSE) and items that go into orbit
- TTCP Technology Transfer Control Plan-new process (“self monitoring”)
  - DoD requirement
- AMSAT Frequency Coordination Request
- FCC Frequency request
  - Experimental Satellite
- NAFTA (Required for ITAR items)
- Commercial Invoices, Shippers Letters of Instructions
- Russian Satellite Value Declarations and Duties

- ½ time for 6 mo. (internal staff, then consultant)

QuakeSat History

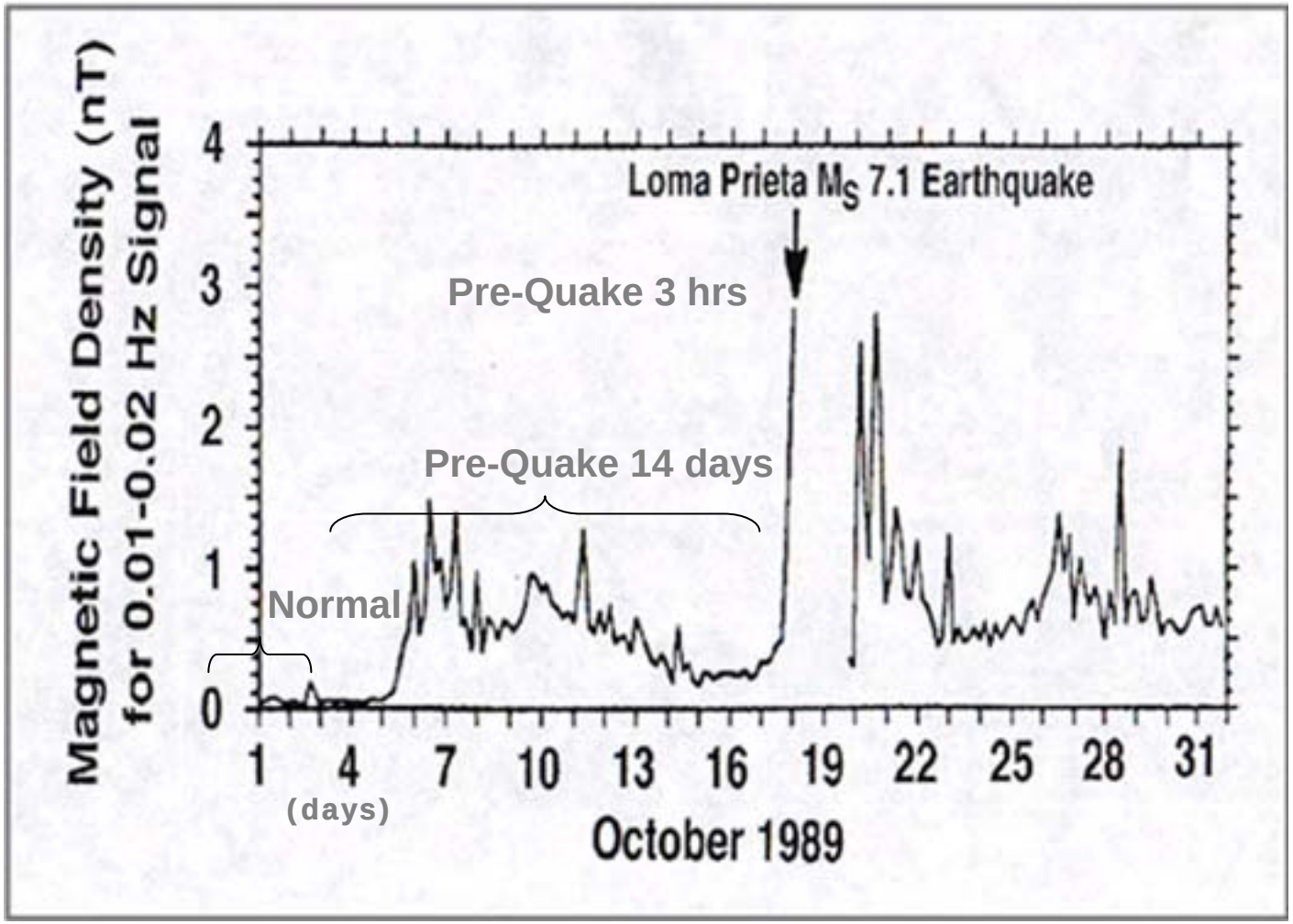
- Stanford (Prof. Bob Twiggs) started class 2001
  - Students to build “CubeSats” (4” x 4” x 4”)
  - launched 3 at a time in a P-POD (Cal Poly)
- 2001/2002 class building 4 CubeSats, and needed payloads
- QuakeFinder built and donated ELF payload and provided technical assistance

Hypotheses for Origin of ELF/ULF Earthquake Signals

- Cracking crystalline rock (resulting electron release and plasma currents) Nitsan, ’77 GRL
- Semiconductor nature of rock under stress (charge carriers, resulting currents and high fields) Freund, ‘02 AGU
- Electrokinetic (dilatency, streaming ionic water, resulting currents/fields)
- Piezeomagnetic effects (rock stress and resulting weak magnetic fields)

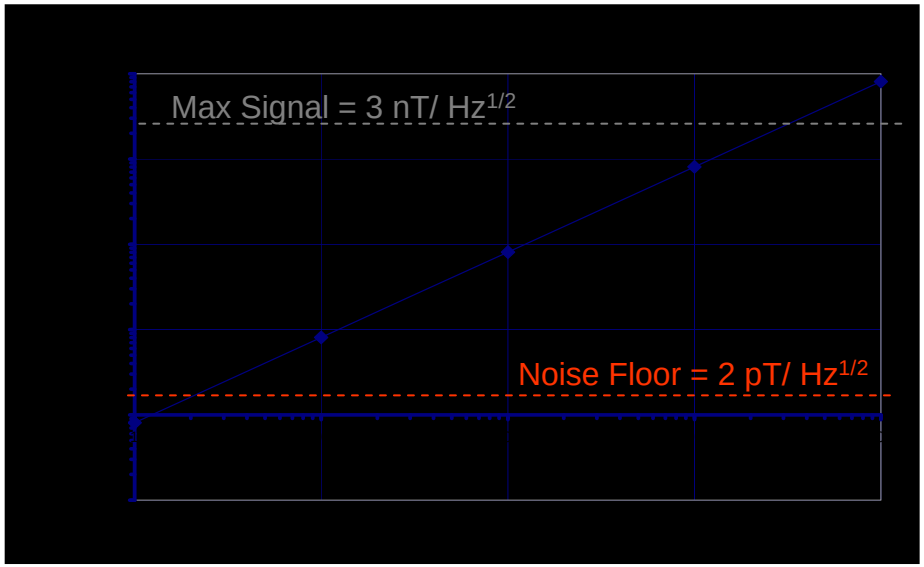
Loma Prieta Earthquake San Francisco Oct 18, 1989

Extremely Low Frequency (ELF) Magnetic Field Fluctuations



Stanford Data: Dr. Tony Fraser-Smith, et al

QuakeFinder Approach - Ground

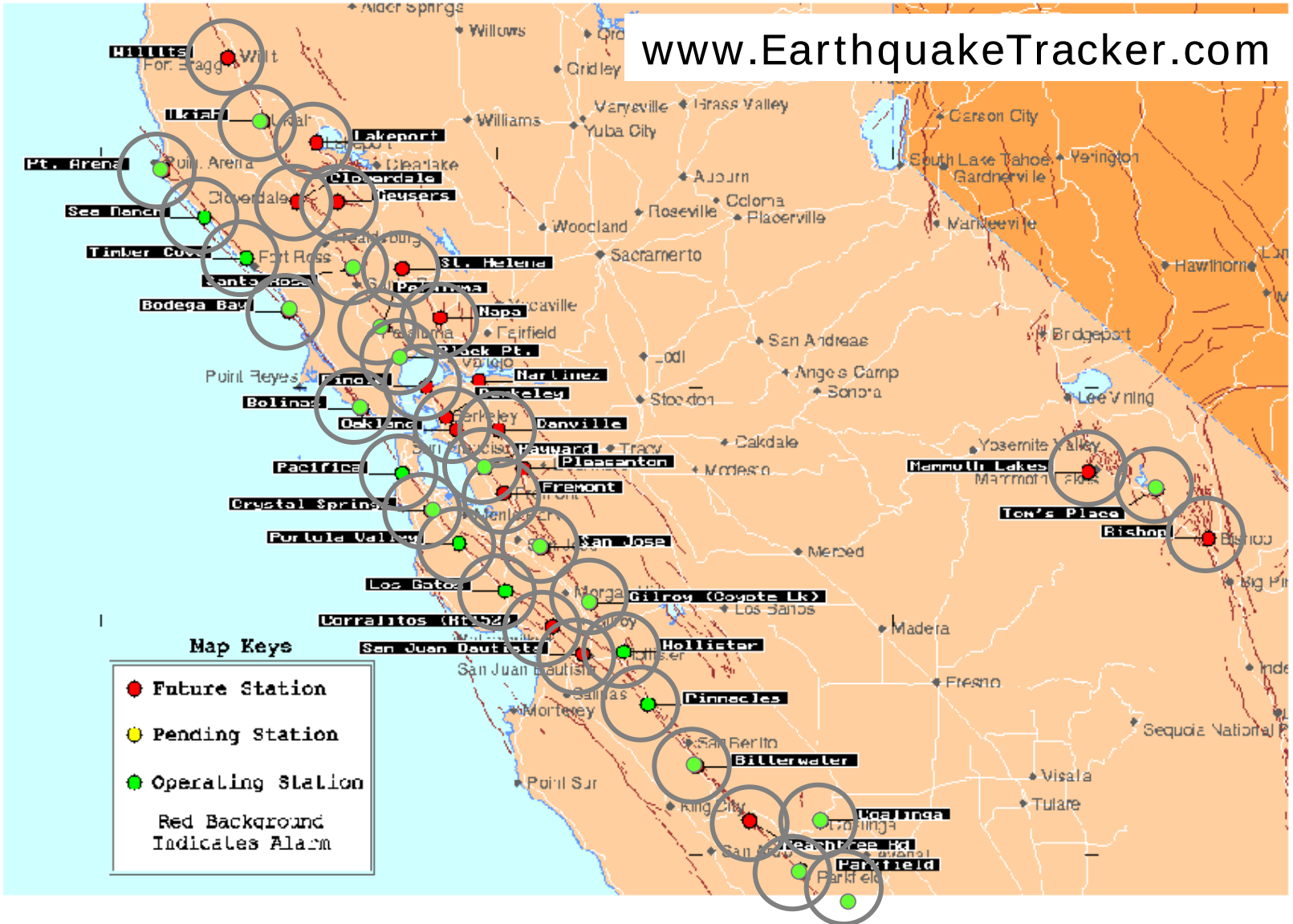


Frequency = 0.05 to 4 Hz

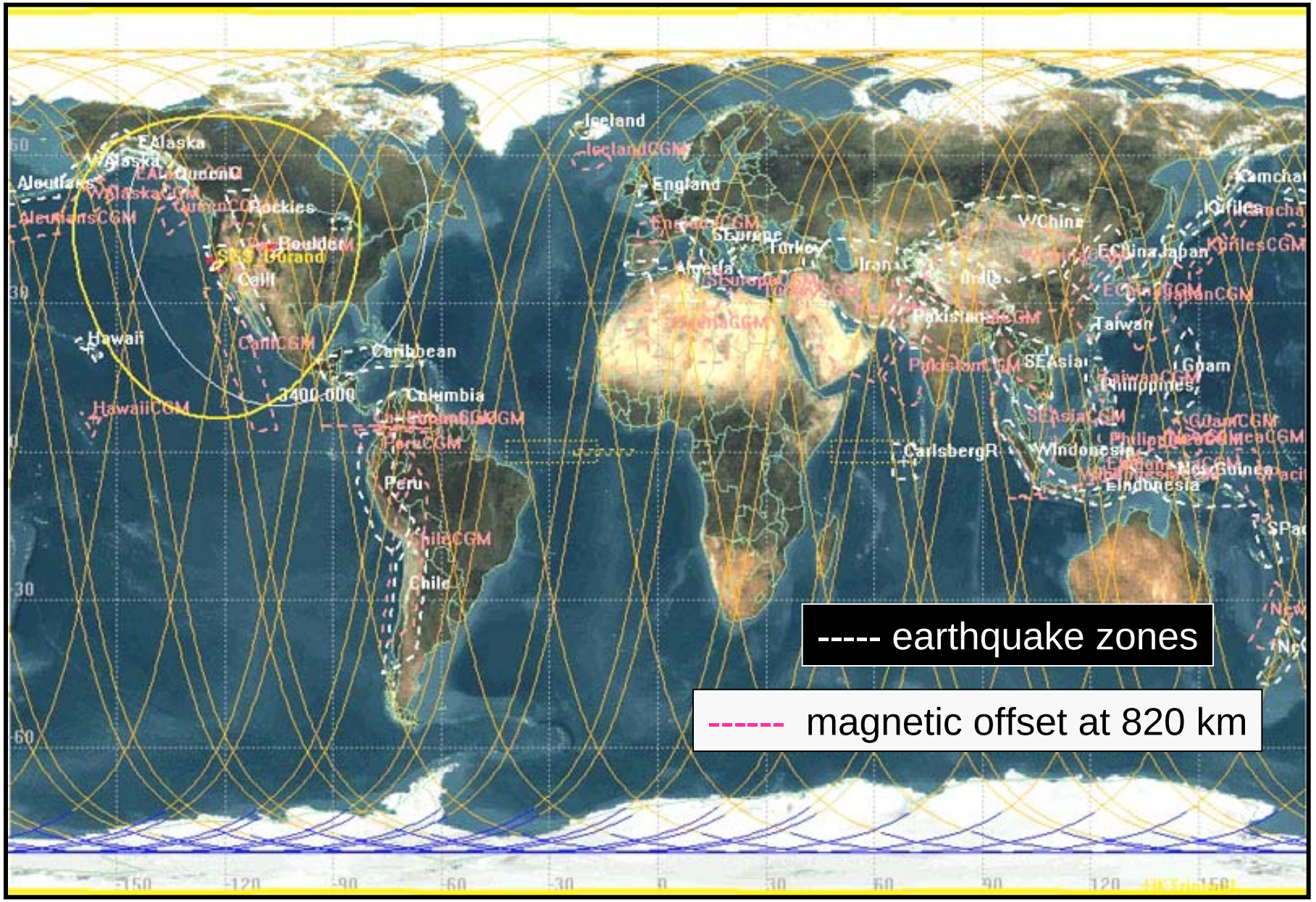
QF1000
Ground Instrument

High School Instrument (25/50)

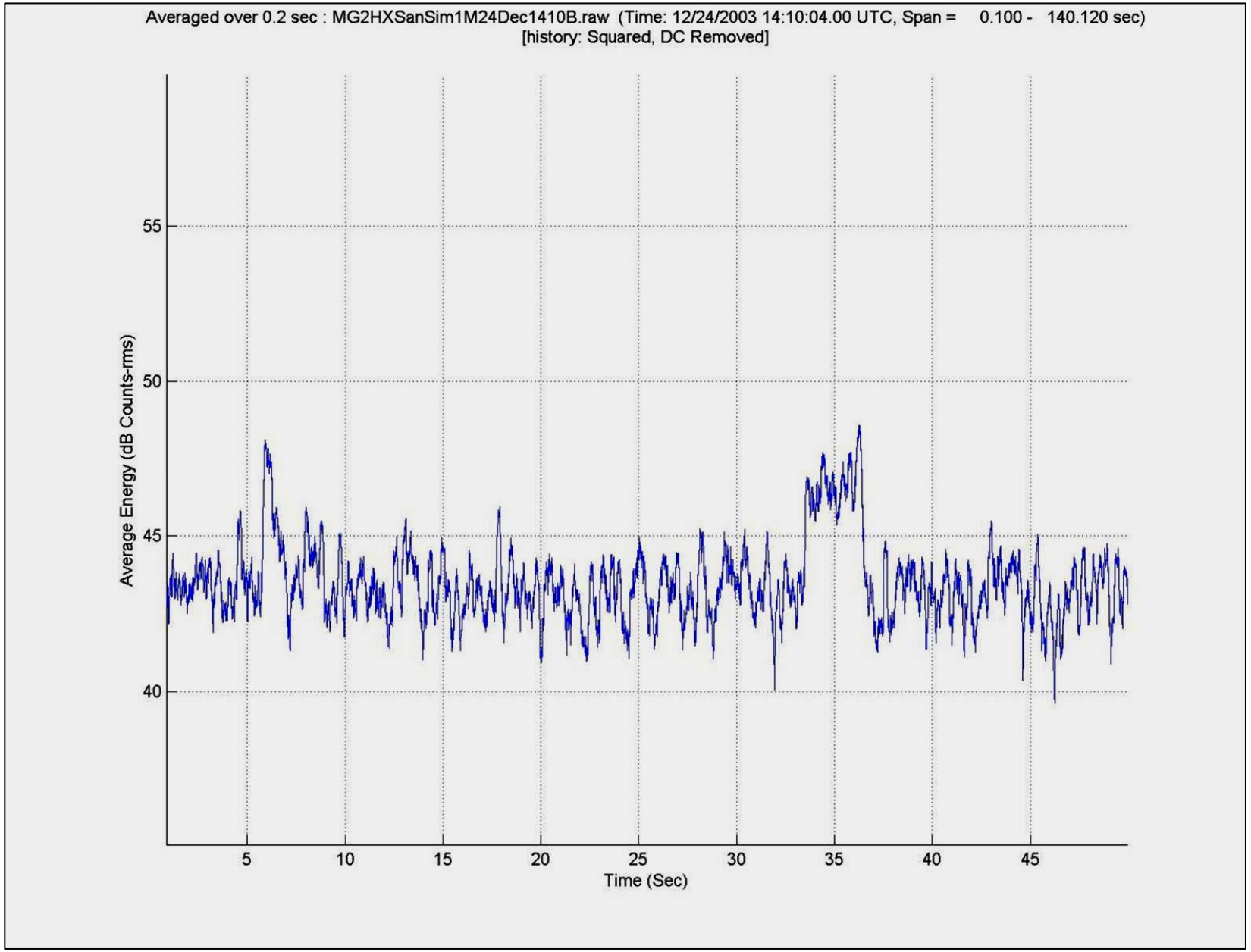
QuakeFinder Network of Ground Sensors (Schools)



QuakeSat Operations



Dec 24, 2003 10-150 Hz



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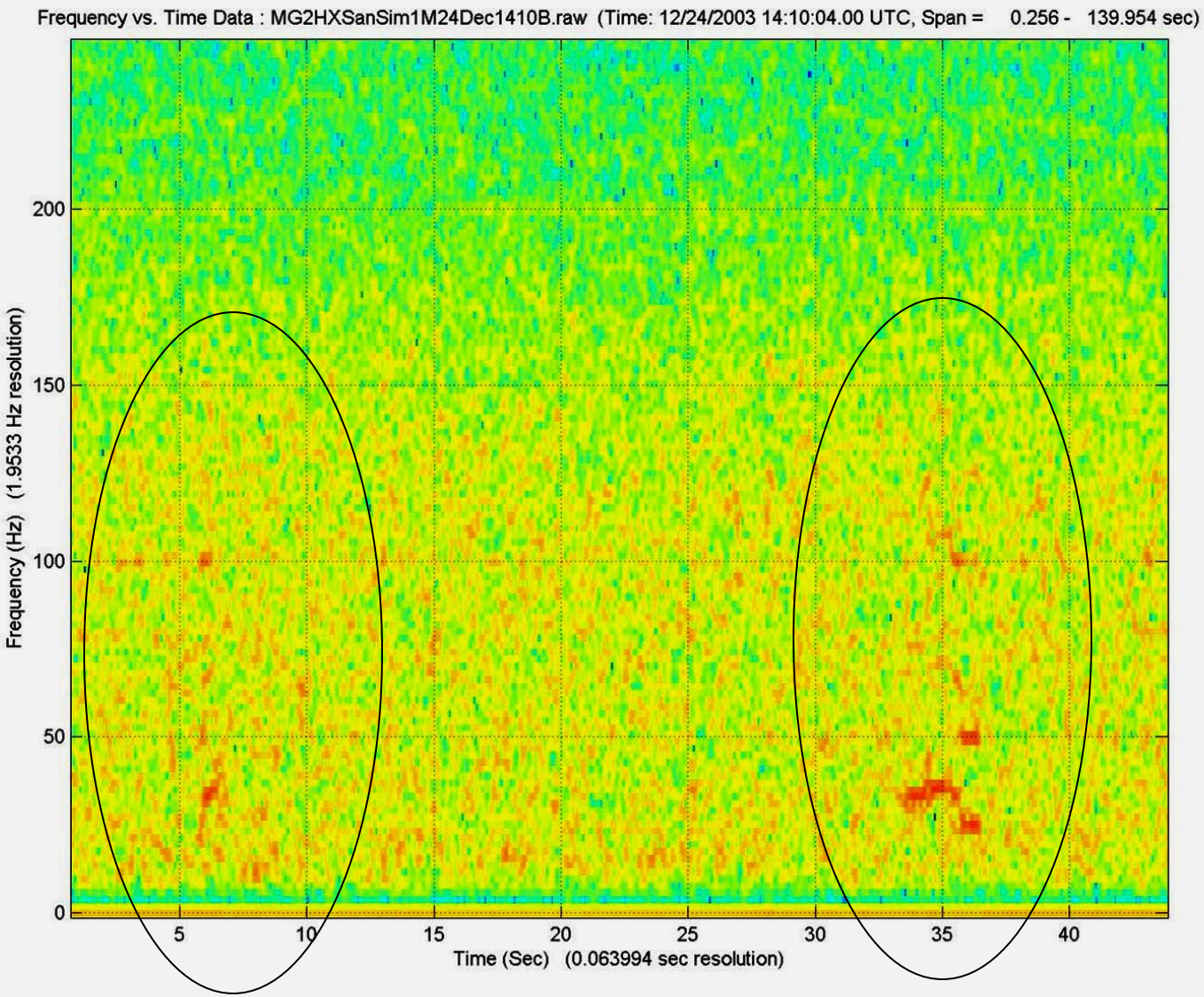
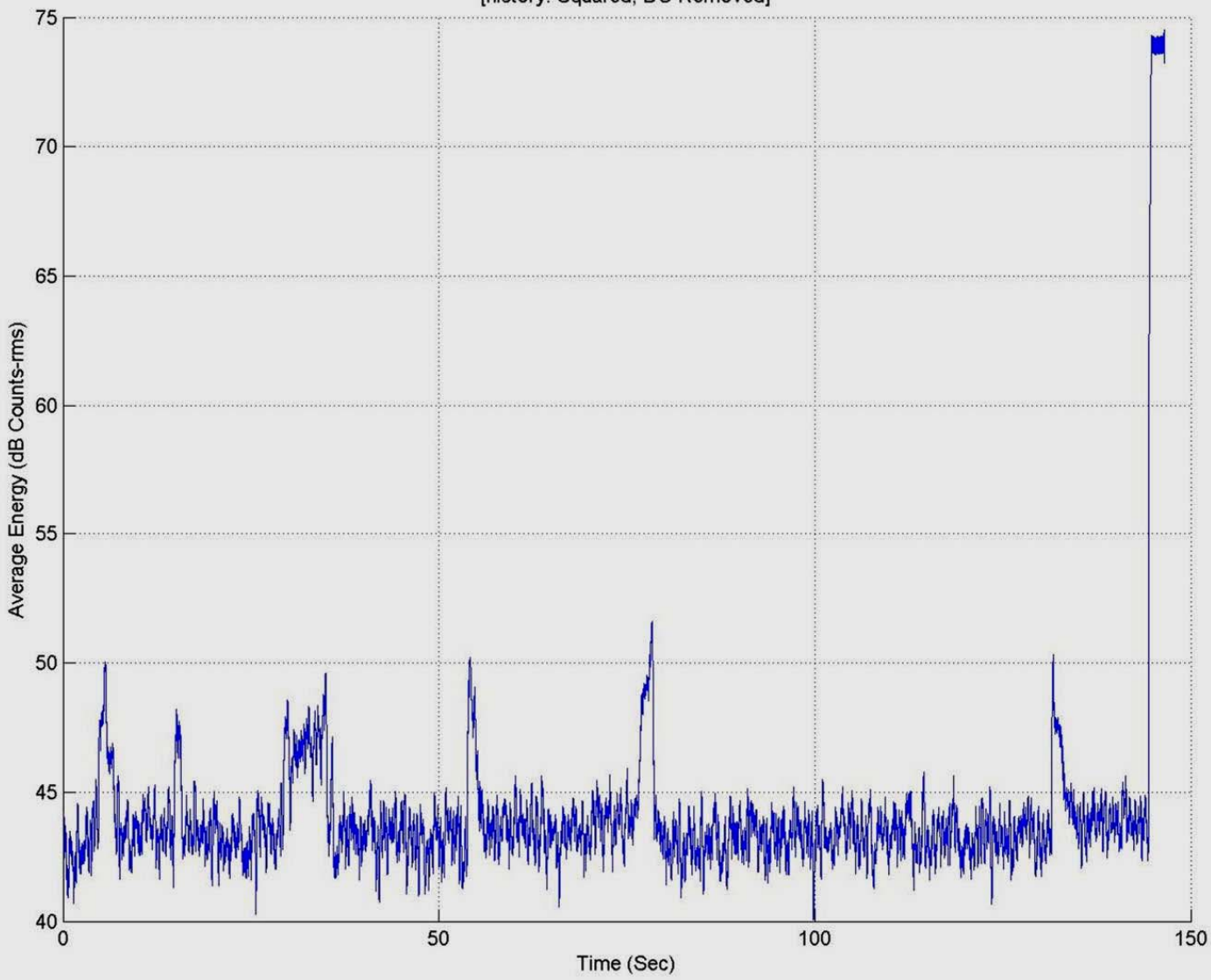


Xin China 11 Dec 2003



Xin China 11 Dec 2003