TARA: Radar Detection of UHECRs

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for the *T*elescope *A*rray *RA*dar Project
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The TARA Project

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and the Telescope Array Collaboration

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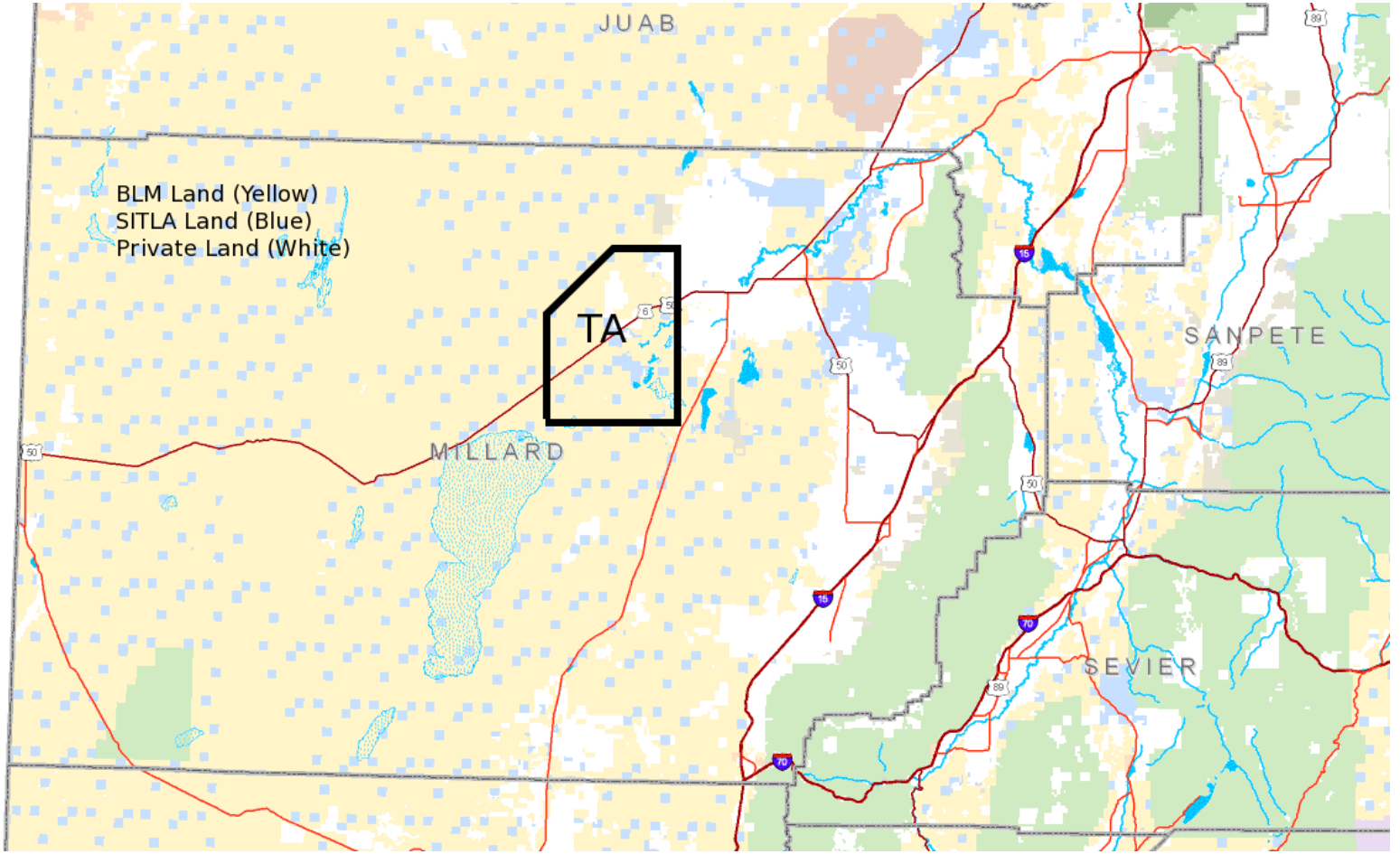
Salt Lake City TV stations KUTV, ABC4

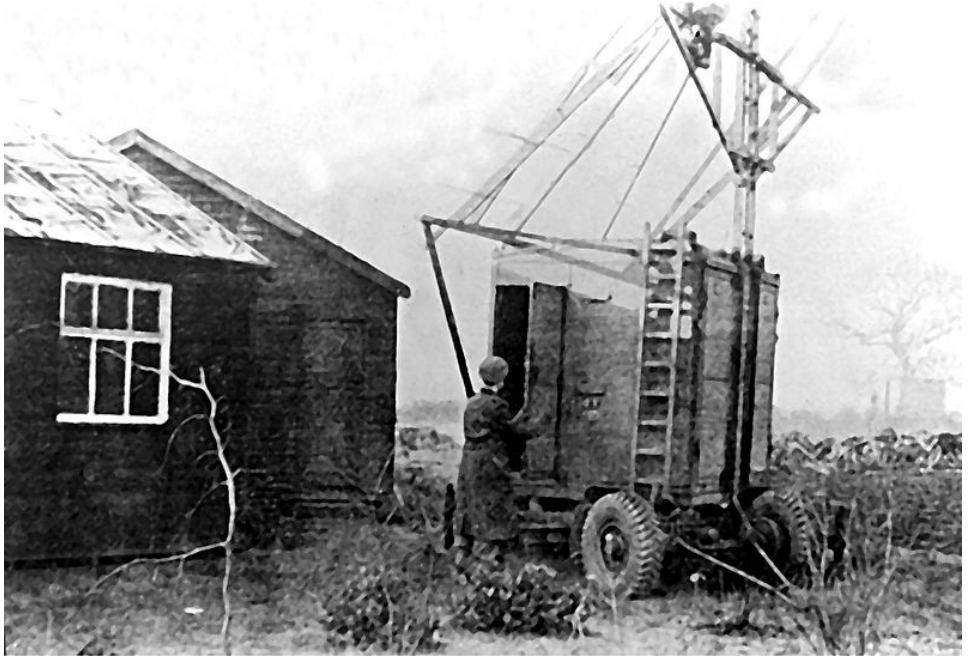


Telescope Array: Expandable?

- Next order of magnitude increase in aperture
  - Anisotropy
  - Neutrinos
- Need remote sensing!

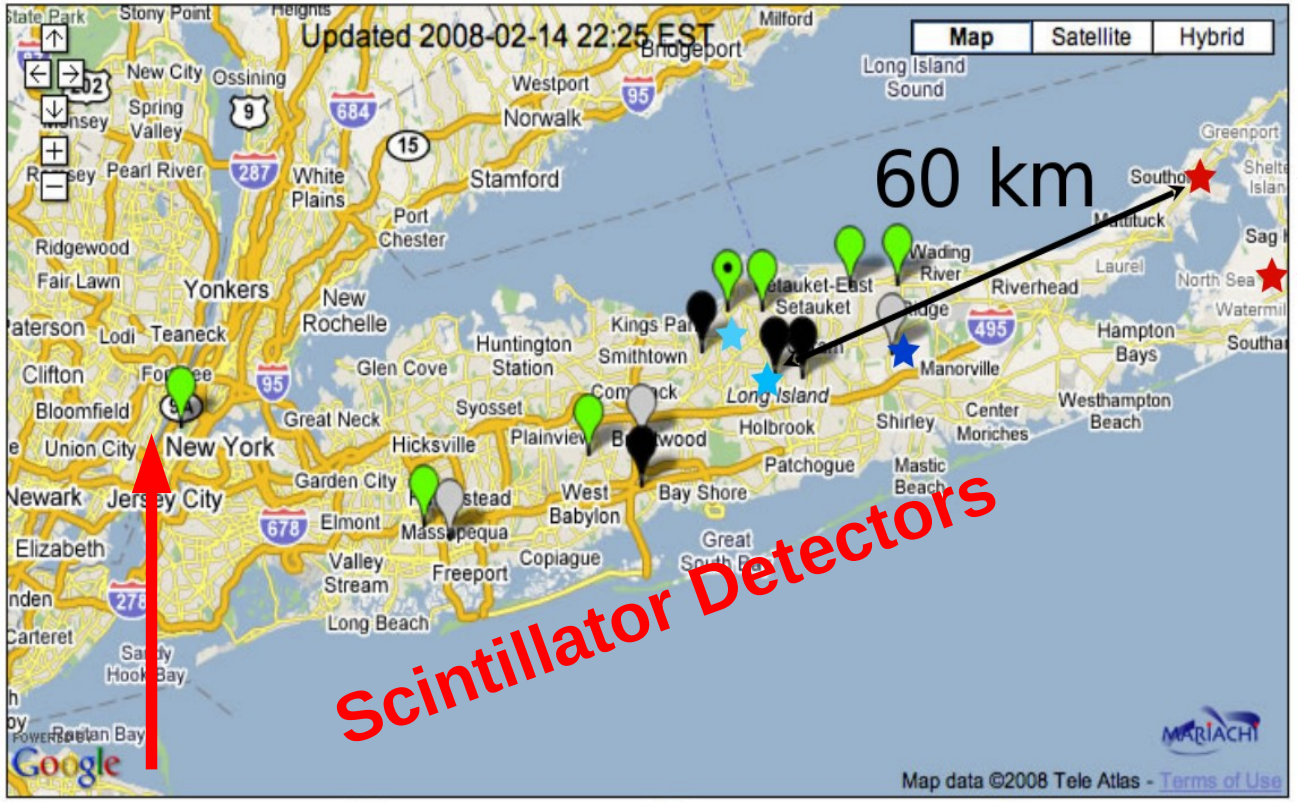
Cosmic Rays and Radar Detection

- 1940 – Blackett and Lovell; Used to explain anomalies in atmospheric radar data. Built “facility” (right), no signals reported.
- 1968 – Suga et al; Propose experiment, but no results.
- 2000 – Gorham; revisits, updates calculations
- 2003 – Iyono et al; propose measurements with LAAS array. No results reported.
- 2007 – Wahl et al (Jicamarca), anomalies seen; consistent with CR?
- 2009 – Terasawa et al (Shigaraki), anomalies seen; consistent with CR?
- 2009 – MARIACHI → Parasitic *Bistatic* radar

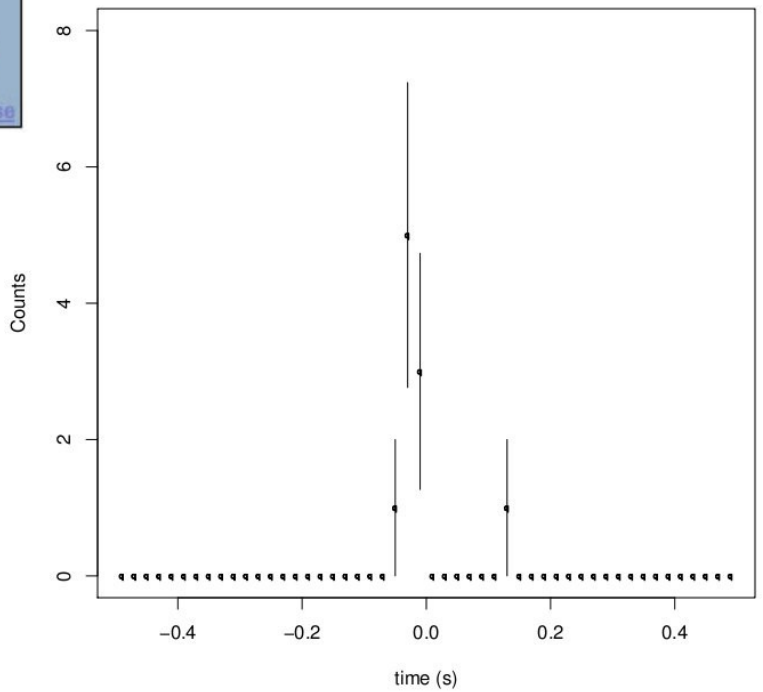


Jodrell Bank radar cosmic ray observatory, 1945

MARIACHI



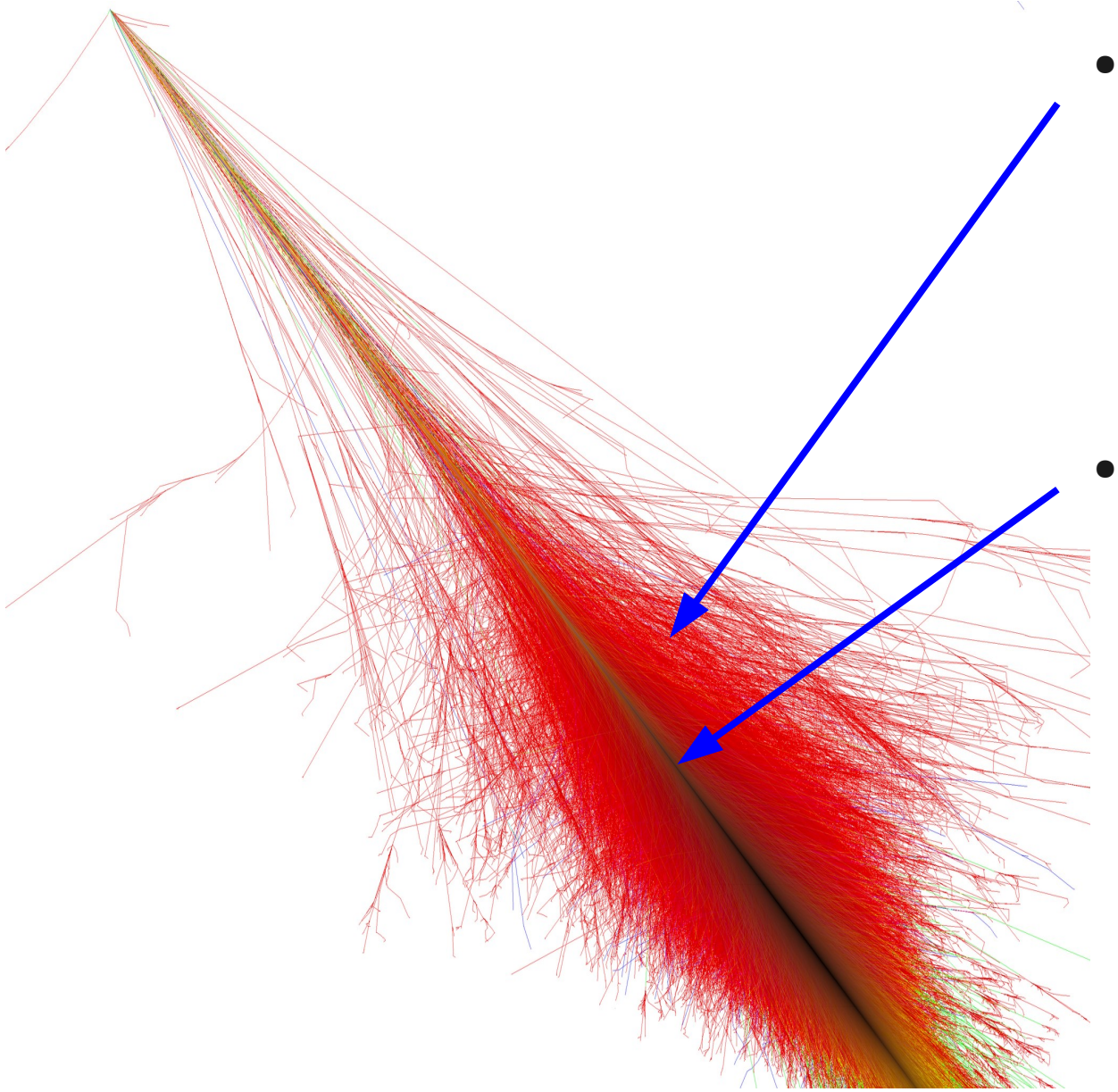
Time distribution of radar echos relative to nearest MARIACHI scintillator firing



MARIACHI → TARA

- **MARIACHI** coincidences intriguing but inconclusive
  - Low sampling rate receivers, crude surface detectors
  - Order-of-magnitude uncertainties on sounding radiation
- **TARA** is the ideal laboratory for testing radar technique
  - Single transmitter in radio quiet environment
  - Access to world class cosmic ray detector facility
  - High sampling rate receivers, smart triggering
- *TARA is the most ambitious effort to date to test the 70+ year-old idea that extensive air showers should reflect RF.*

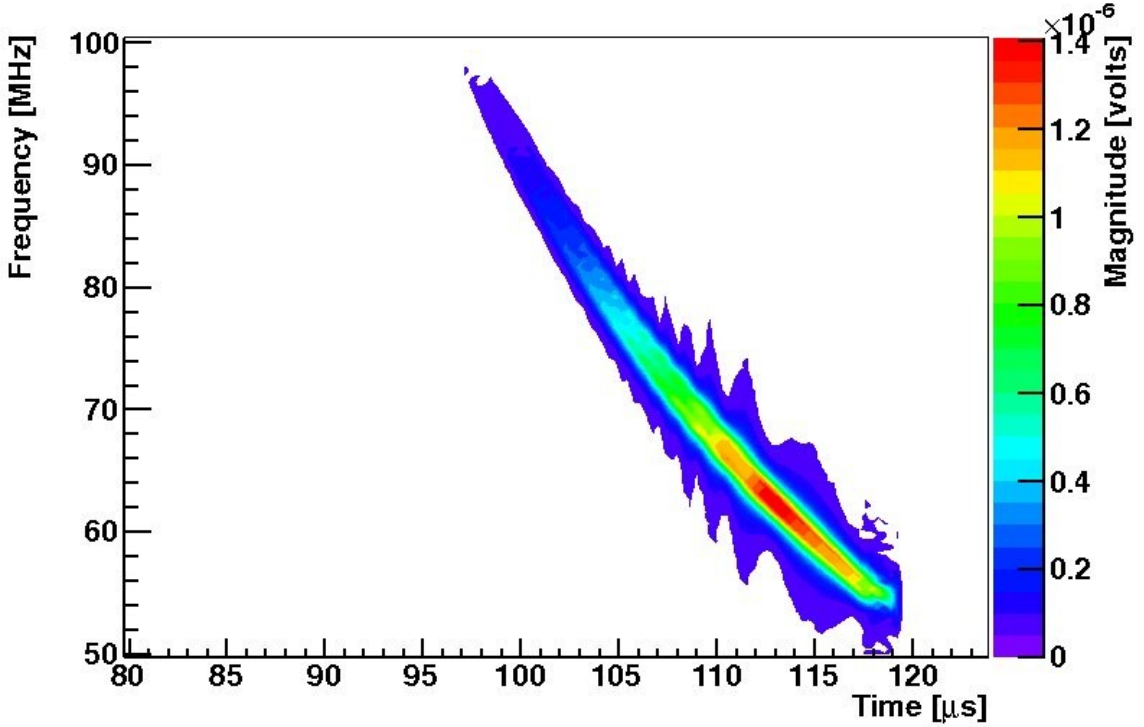
What is the Radar Cross Section?



- Underdense Region
  - Most of the particles
  - σ = (Thomson x N_e)
  - "Collisional Damping"
- Overdense Region
  - Macroscopic target
  - How big? Skin depth?

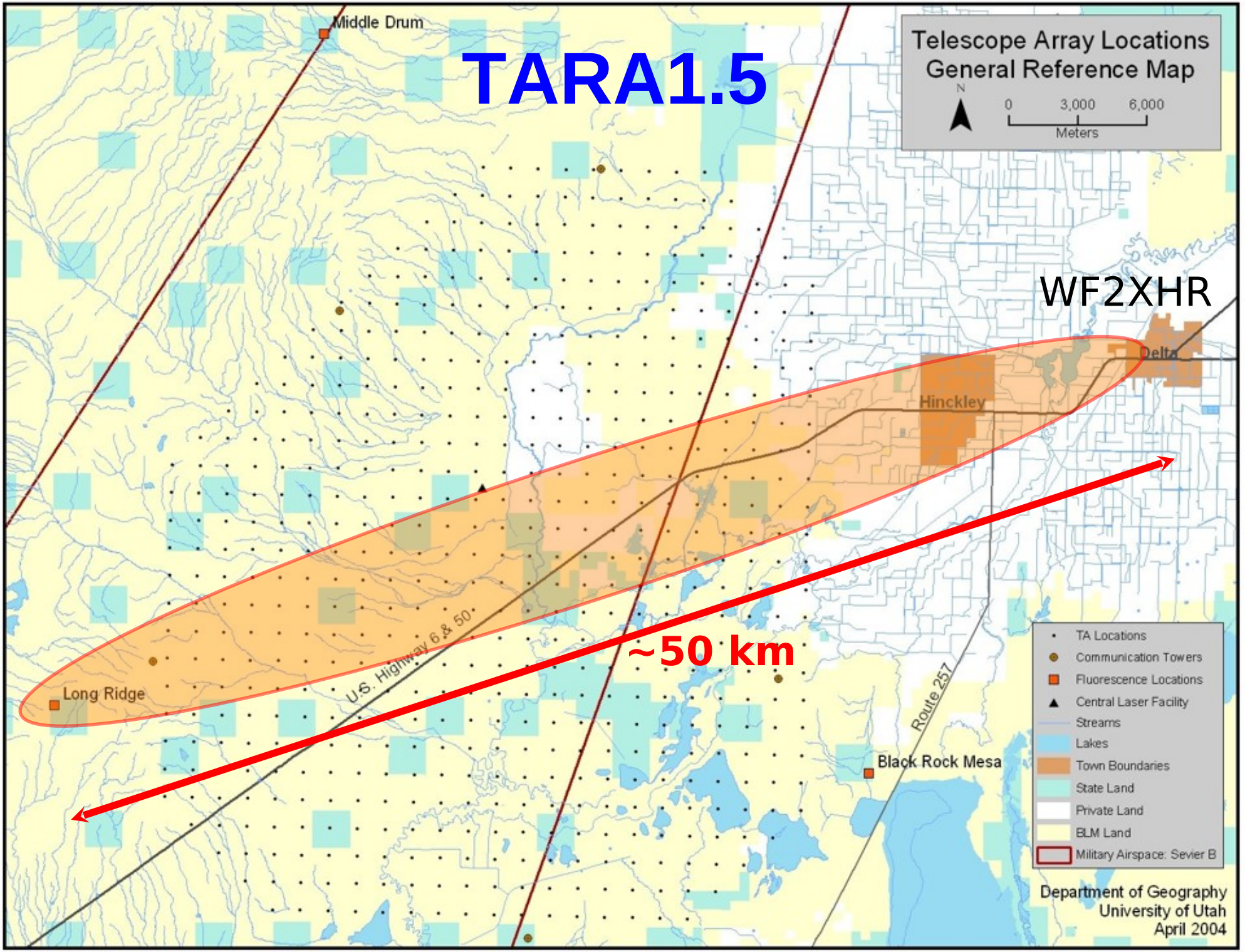
$$\nu_e = \sqrt{\frac{n_e e^2}{m\epsilon_0}\frac{1}{2\pi}}$$

Signal Characteristics: The “Chirp”



Calculation: Isaac Myers

- Predicted signal for 10^{19} eV shower, 30º from zenith; frequency vs time.
- Rapid movement of “target” produces Doppler-like frequency shift.
- Shape from **geometry**, not electron lifetime.
- Requires very high bandwidth/sampling rate receiver.
- Unique signature for air shower echoes.


TARA1.5
Telescope Array Locations
General Reference Map
N
0
3,000
6,000
Meters
WF2XHR
Middle Drum
Delta
Hinckley
Long Ridge
U.S. Highway 6 & 50
~50 km
Route 257
Black Rock Mesa
TA Locations
Communication Towers
Fluorescence Locations
Central Laser Facility
Streams
Lakes
Town Boundaries
State Land
Private Land
BLM Land
Military Airspace: Sevier B
Department of Geography
University of Utah
April 2004

TARA1.5: Low-Power Transmitter

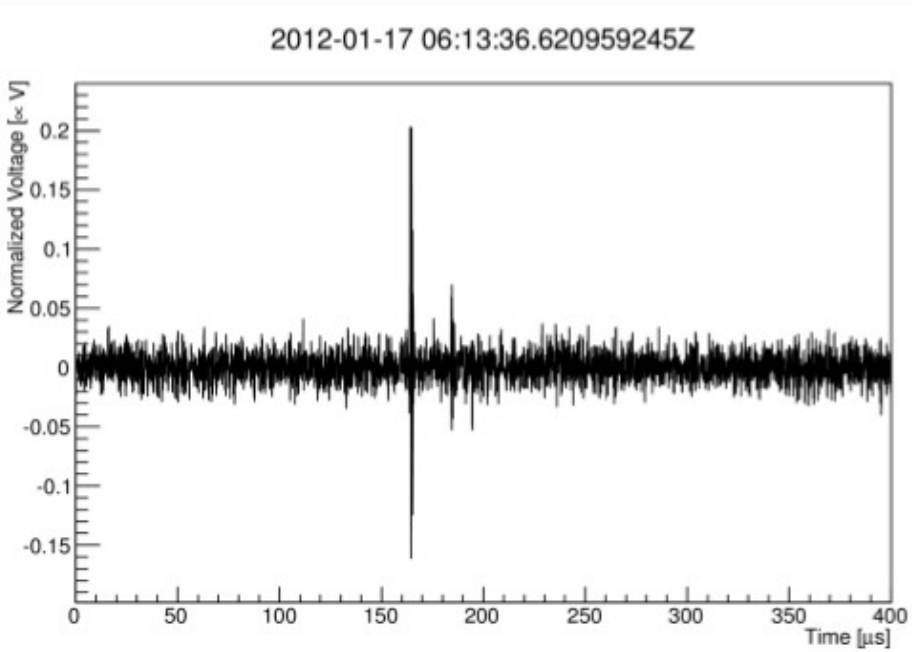
* April 2011 to July 2012,
  54.1 MHz sine wave at 1.5 kW

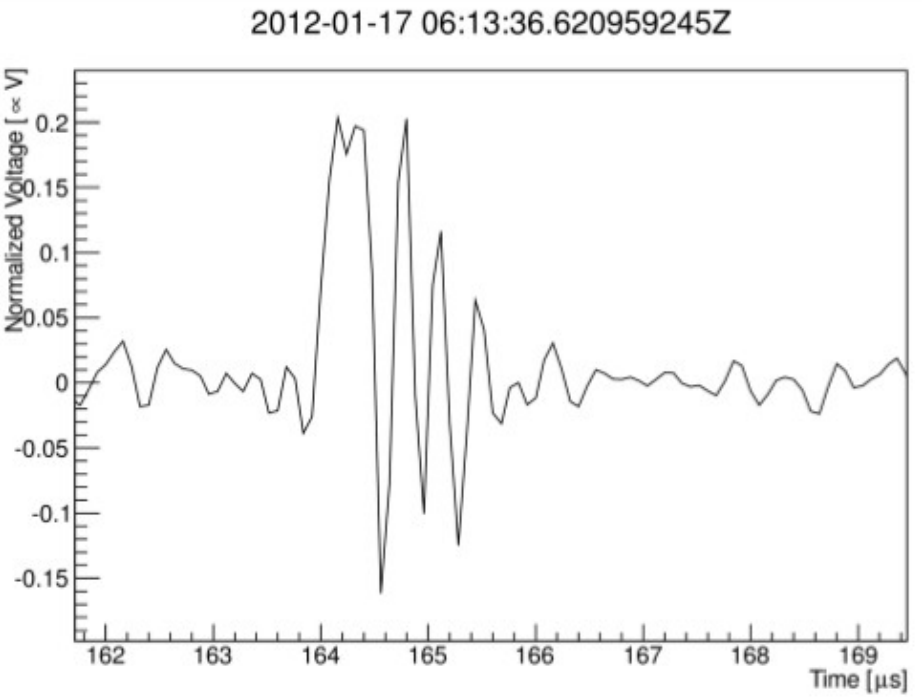
* Low-gain (8.5 dBi) antenna

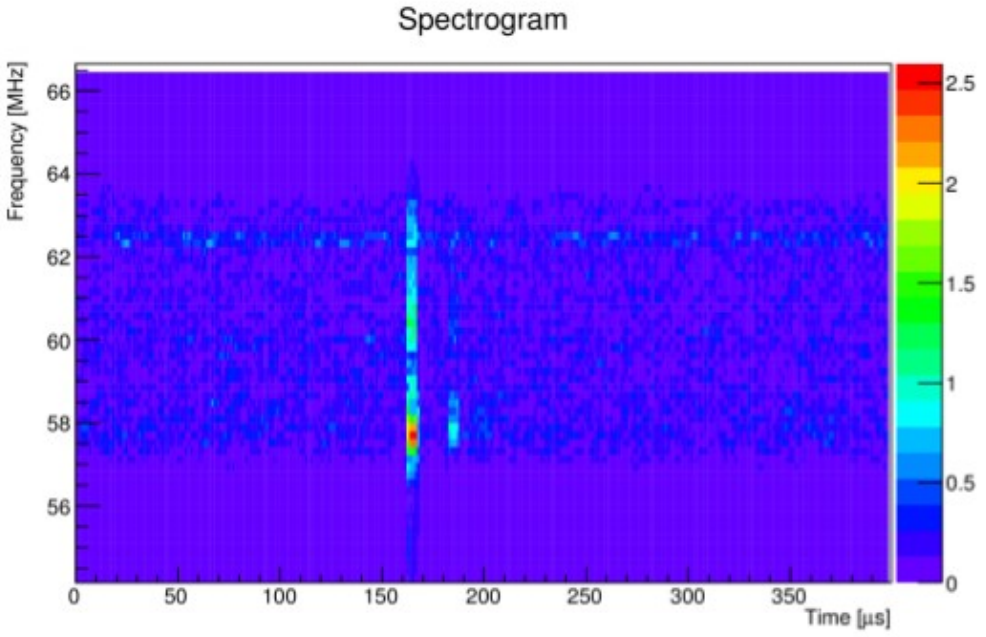
TARA1.5 Receiver Station at Long Ridge

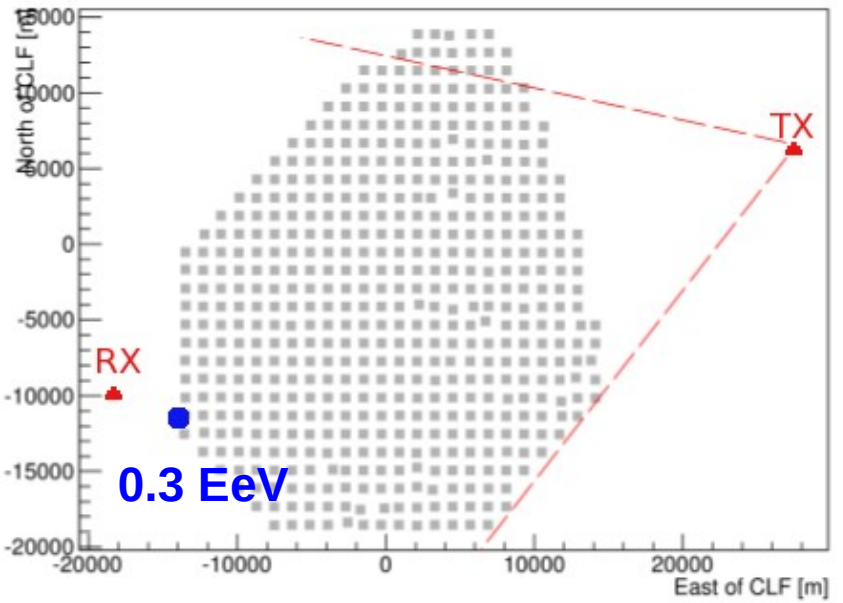
- Array of low-VHF log-periodic antennas (KU)
- USRP2 Software-defined radio RX
- FD Trigger, read at 12.5 Ms/s.
- 5σ threshold trigger, read at 6.25 Ms/s.

Interesting Event, TARA1.5 FD-Trigger Stream







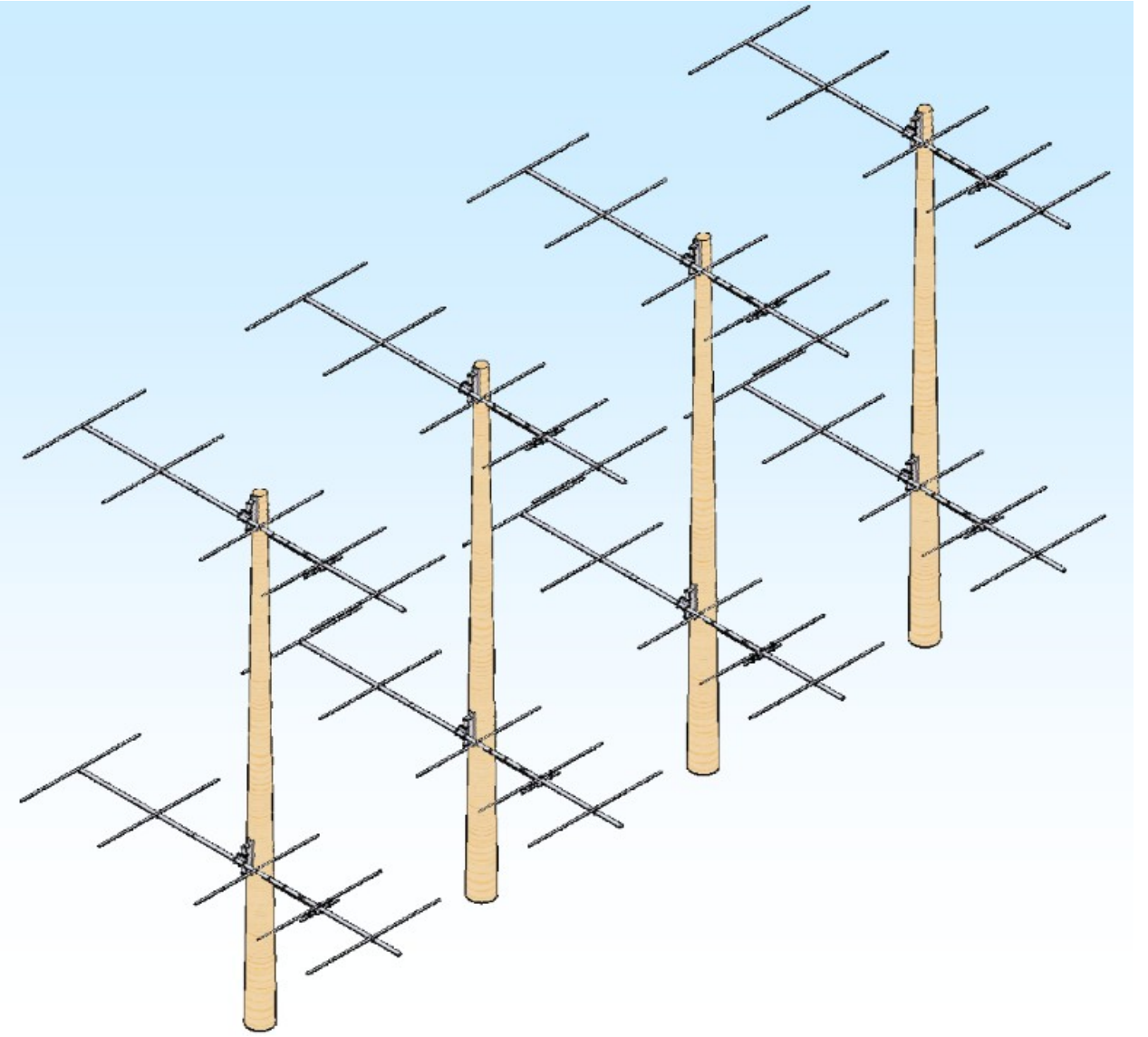


Spring 2013: TARA40

- 40 kW transmitter (x27)
- High-gain antenna (x5)
- Closer to ground array (x2.5)
- Improve RX DAQ

TARA40: 8-Yagi Array

- Replace single 3-element Yagi with eight 5-element Yagis in phased array.
- Gain of ~21 dB above isotropic.
- 8 MW ERP, continuous!



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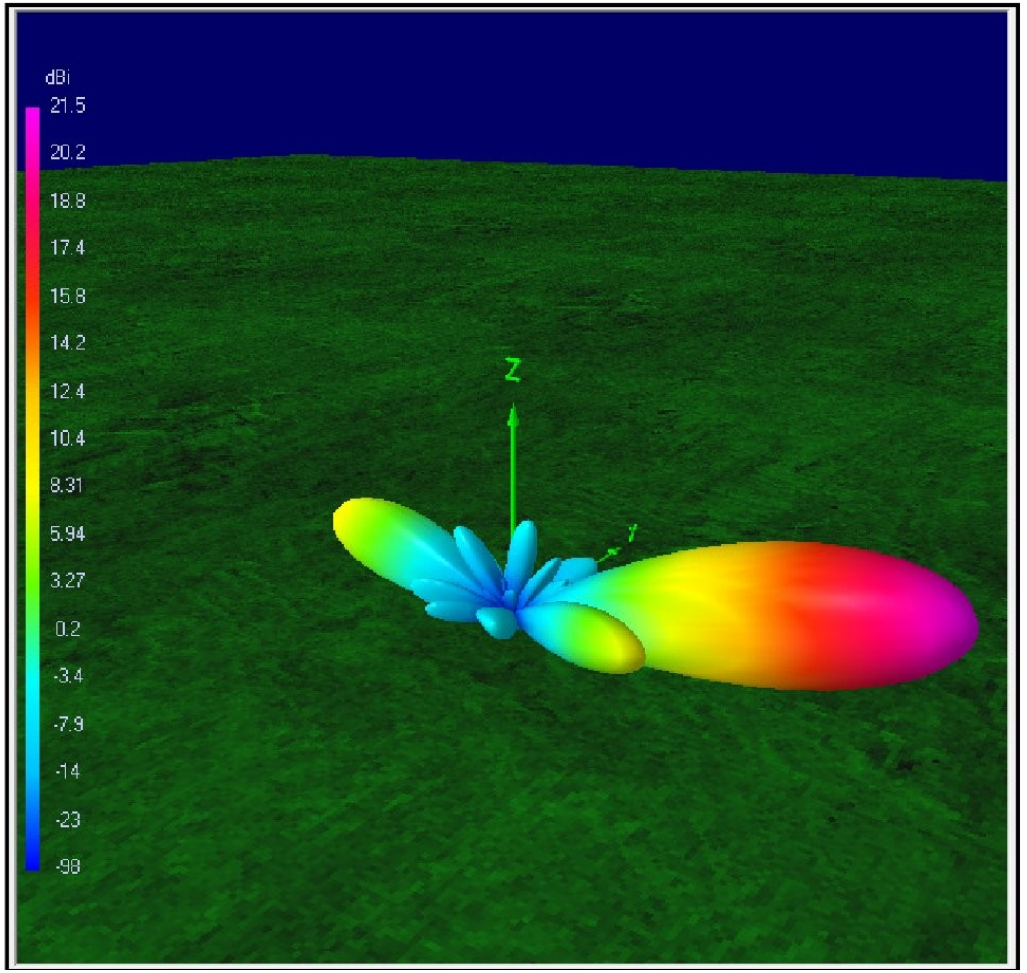

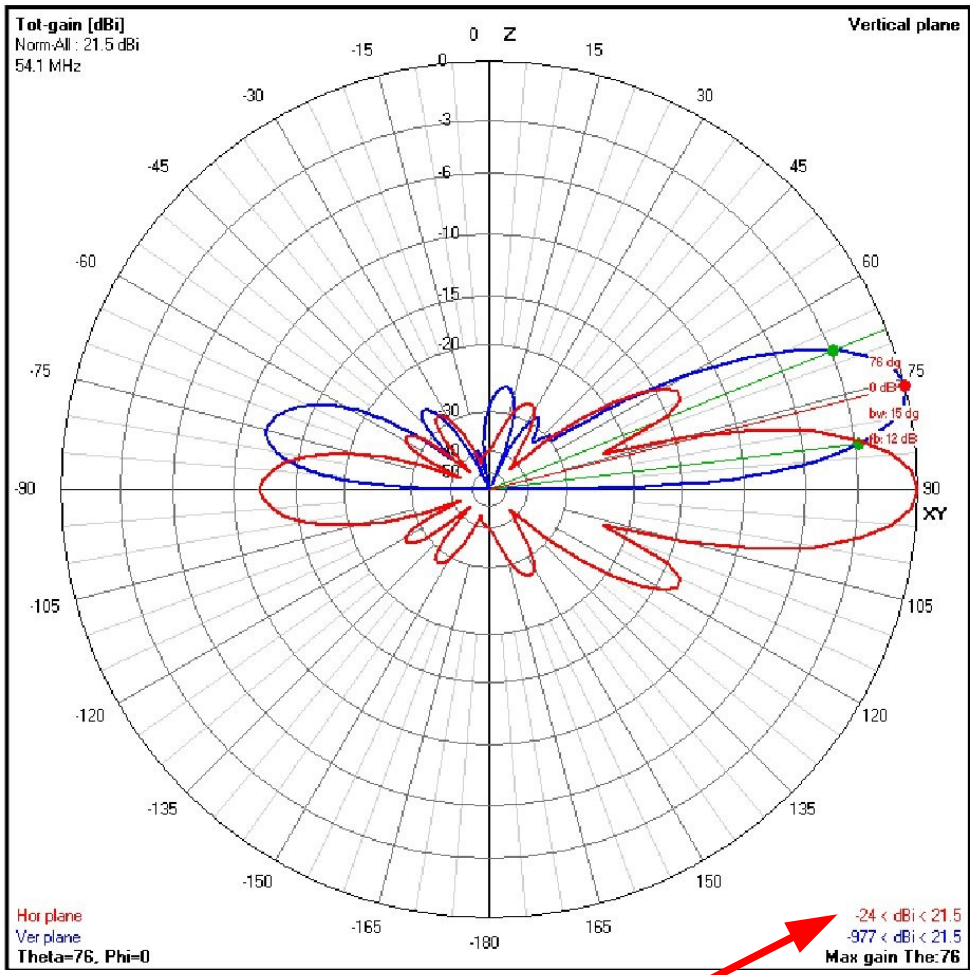

21.5 dBi = Gain of 140!

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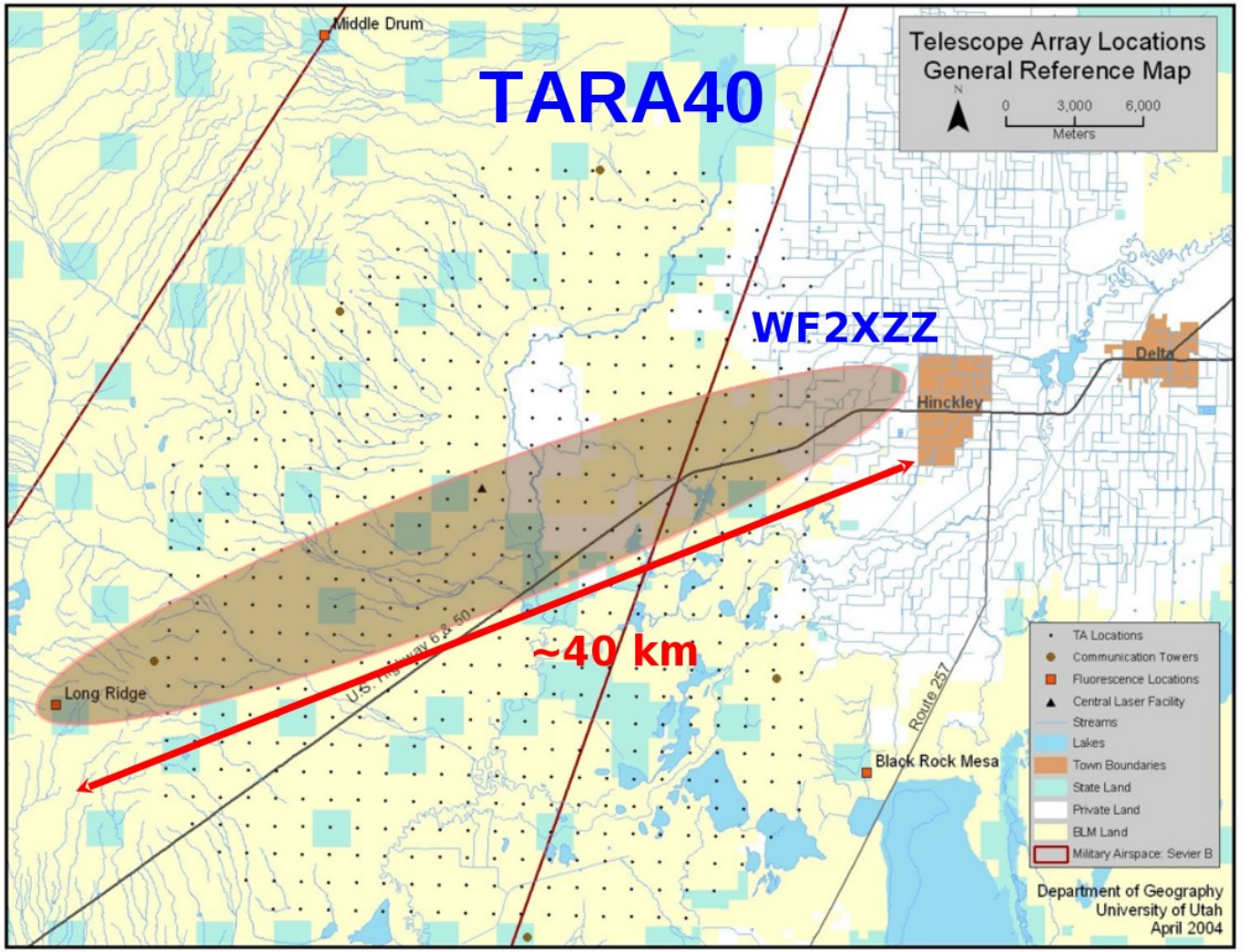

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- Real-time “Matched Filter” trigger algorithm, search for ~1 MHz/µsec “chirps”
- Analysis (for now) focused on
  - Verifying trigger
  - Understanding noise triggers
- Future: Hough transforms...

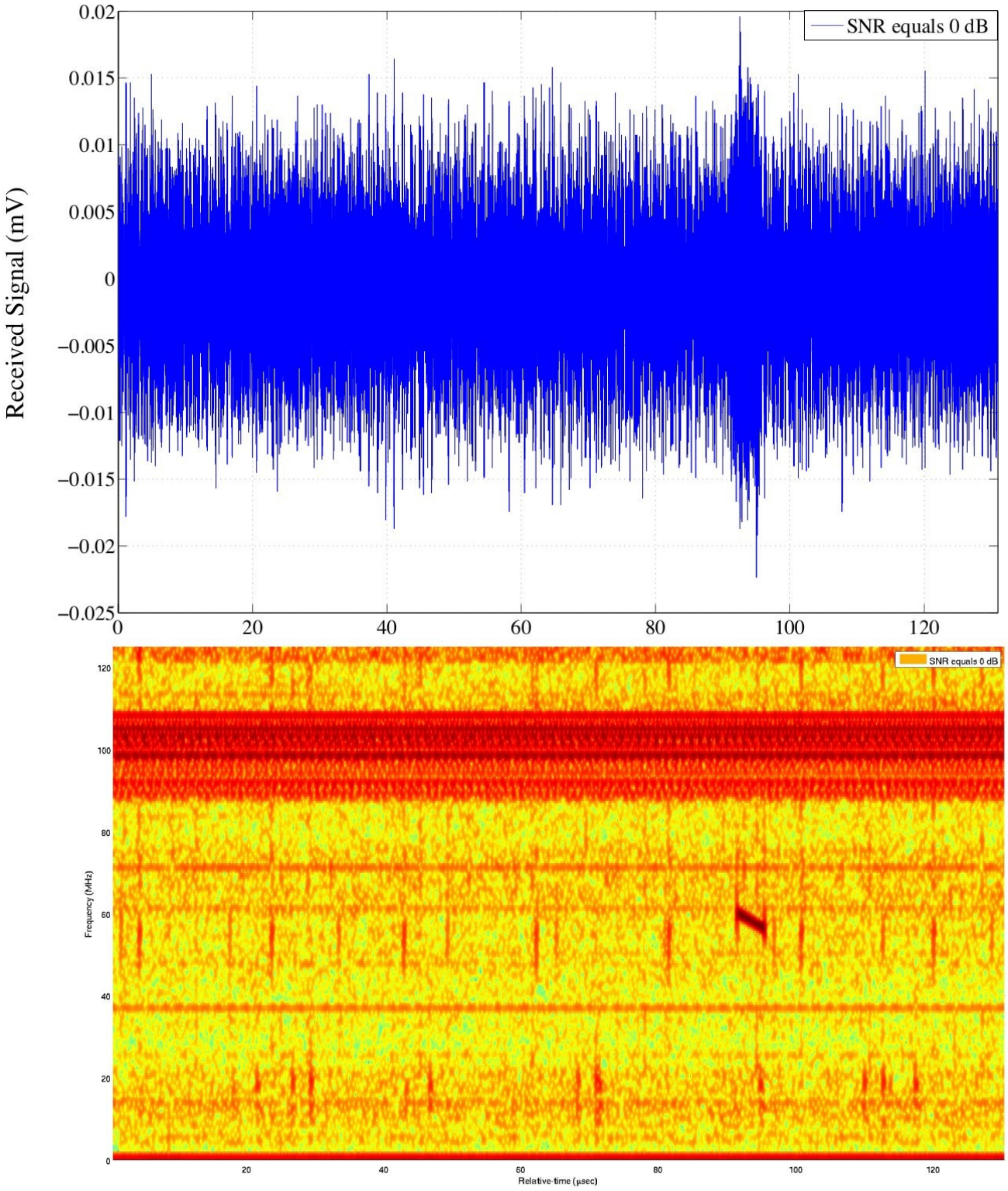
NI PXIe / FlexRIO

- **250 MHz ADC**
- complete control of FPGA
- **large FPGA**
- **256 MB DRAM (data buffering)**
- computer and FPGA in same chassis
- 400 MHz clock

RX DAQ Upgrades

- Top: FADC trace of artificially generated chirp, which triggered FlexRIO
- Bottom: Spectrogram

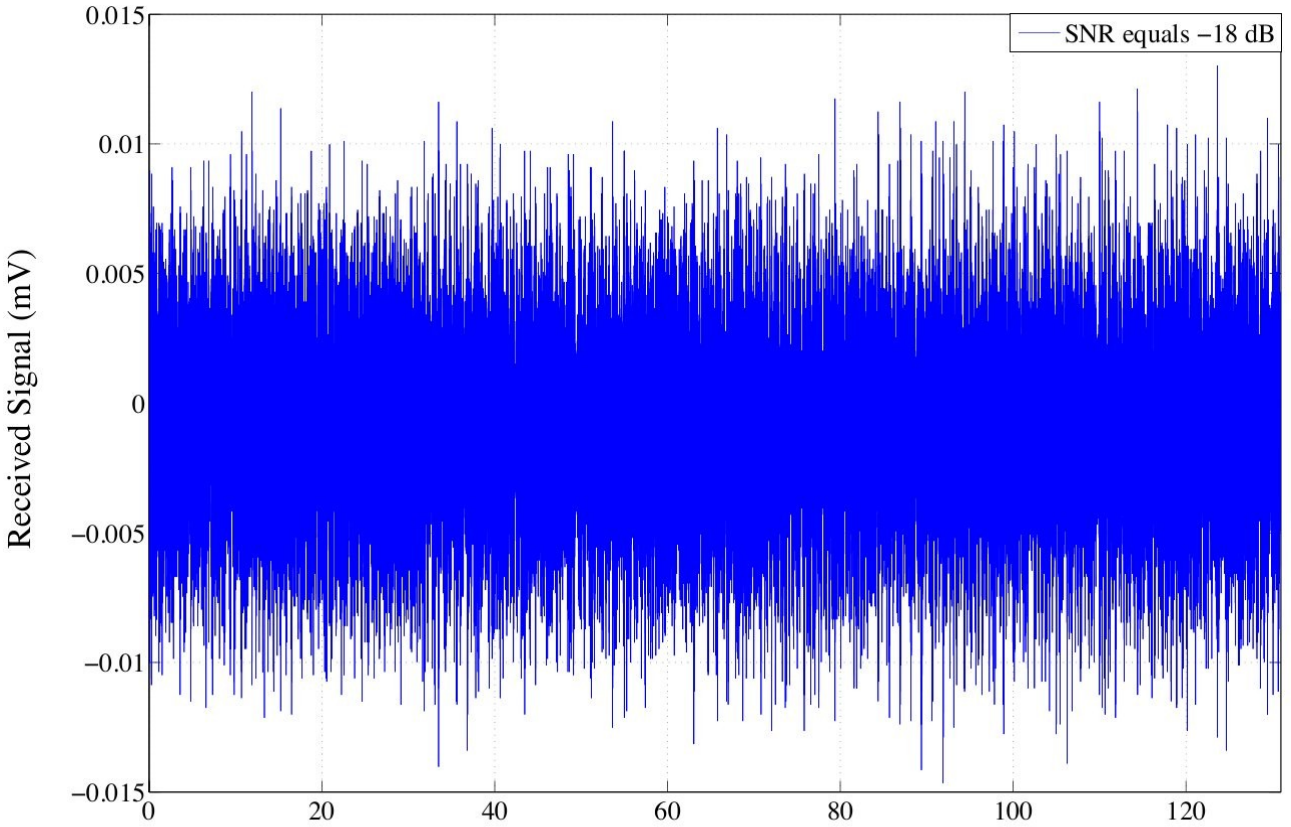
0 dB SNR

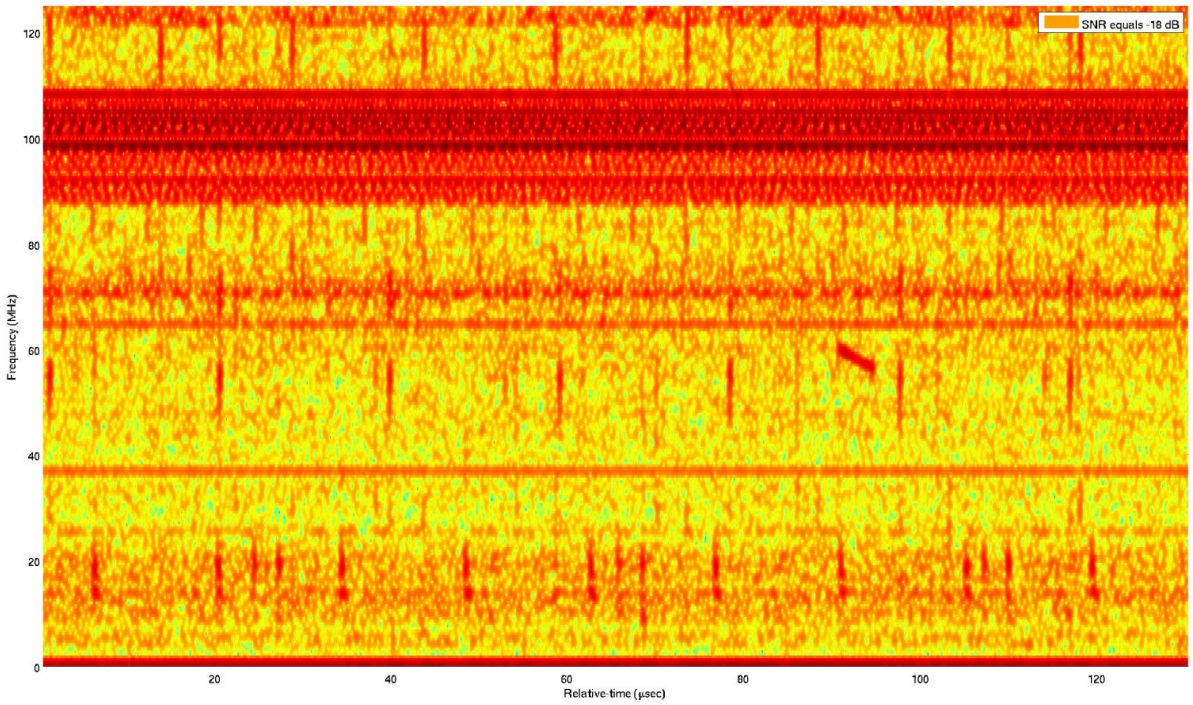


RX DAQ Upgrades

- Top: FADC trace of artificially generated chirp, which triggered FlexRIO
- Bottom: Spectrogram

-18 dB SNR





TARA1.5 → TARA40 Enhancements

TX Power	**27**
TX Antenna Gain	**5**
TX Location	**2.5**
TX Total	**337**
RX Trigger SNR	**~100**

Summary

- TARA is the ideal testbed for the bistatic radar idea:
  - Single transmitter under our control
  - Radio-quiet environment
  - Co-located with state-of-the-art “conventional” cosmic ray observatory
- TARA1.5 has been operating for ~1 year.
- TARA40 upgrades underway spring 2013 will *substantially* increase sensitivity.