THE UNIVERSITY OF UTAH

Air Shower Detection By Bistatic Radar

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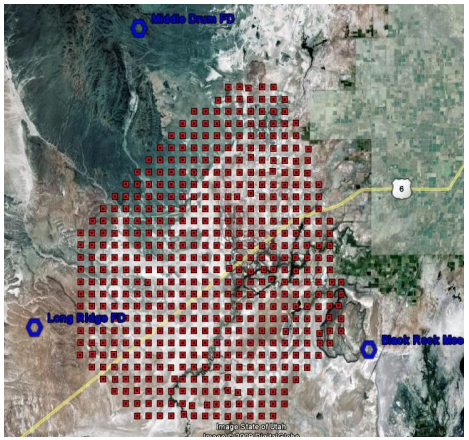
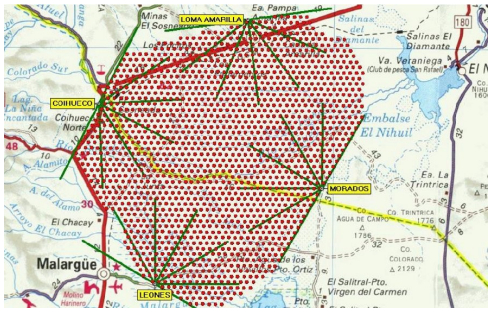
BROOKHAVEN NATIONAL LABORATORY

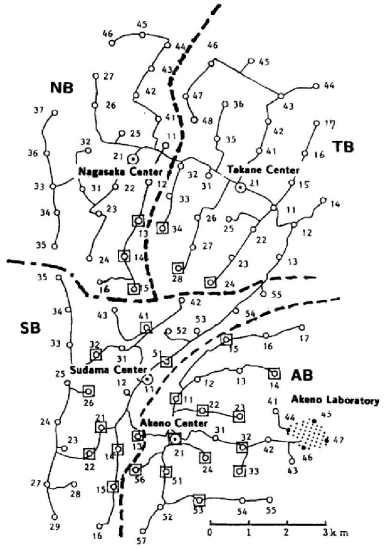
UNIVERSITY OF Nebraska

KU THE UNIVERSITY OF KANSAS

UHECR Techniques: Ground Arrays

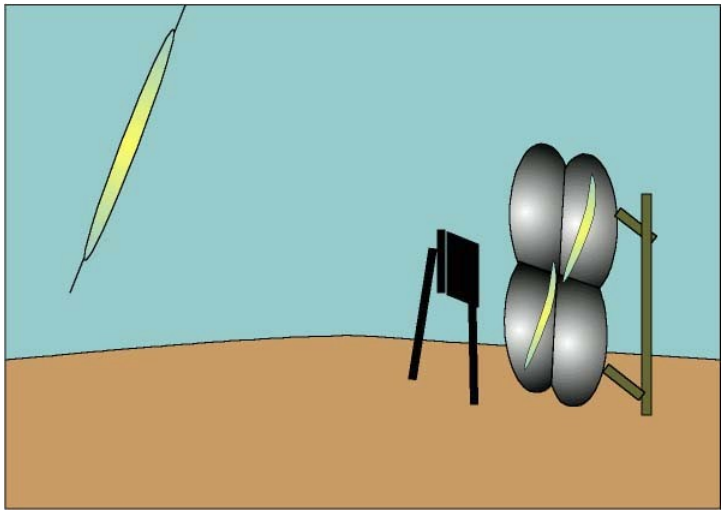






- Airshower particles may be observed directly with detectors on the ground.
- Typically ground array detectors cover areas comparable to a large city. (e.g. TA covers roughly the land area of New York City.)
- Costs of instrumentation and availability of land limit this method.

The Fluorescence Technique



- Uses the atmosphere as part of the detection system.
- Remote detection at distances up to 40 km.
- Limited to 10% duty cycle by sun, moon.

Other Techniques: Radio Emissions

- Geomagnetic synchrotron radiation (>250 MHz)
  - LOFAR
  - ARENA
- Askaryan Effect (in solids)
  - ANITA
- Molecular bremsstrahlung (microwaves)

Radar: The Basic Idea

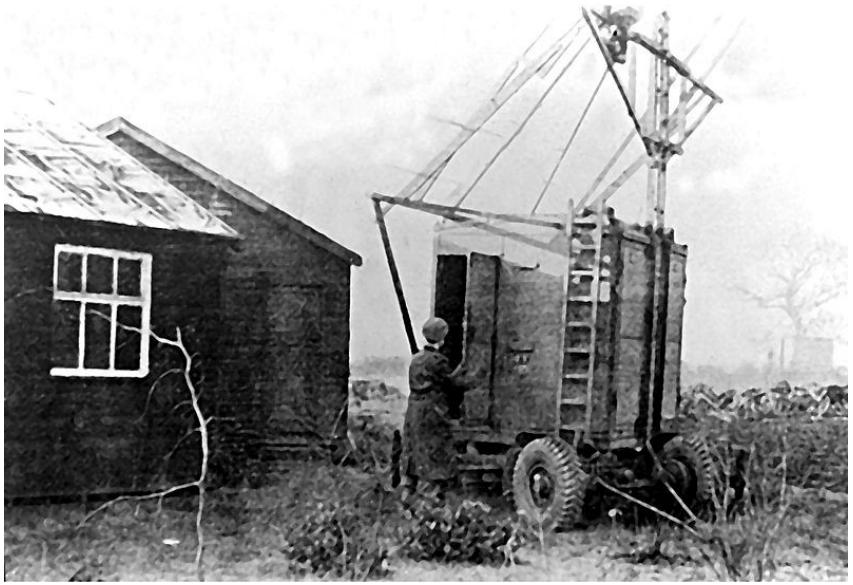
- Ionization densities > $10^{13}/m^3$ near the core of few EeV air shower.
- Corresponding plasma frequency ~50 MHz (low-VHF)
- Airshowers reflect TV transmissions!

$$\omega_p = \left(\frac{n_e e^2}{m_e \varepsilon_0} \right)^{\frac{1}{2}}$$

$n_e = electron\ number\ density$

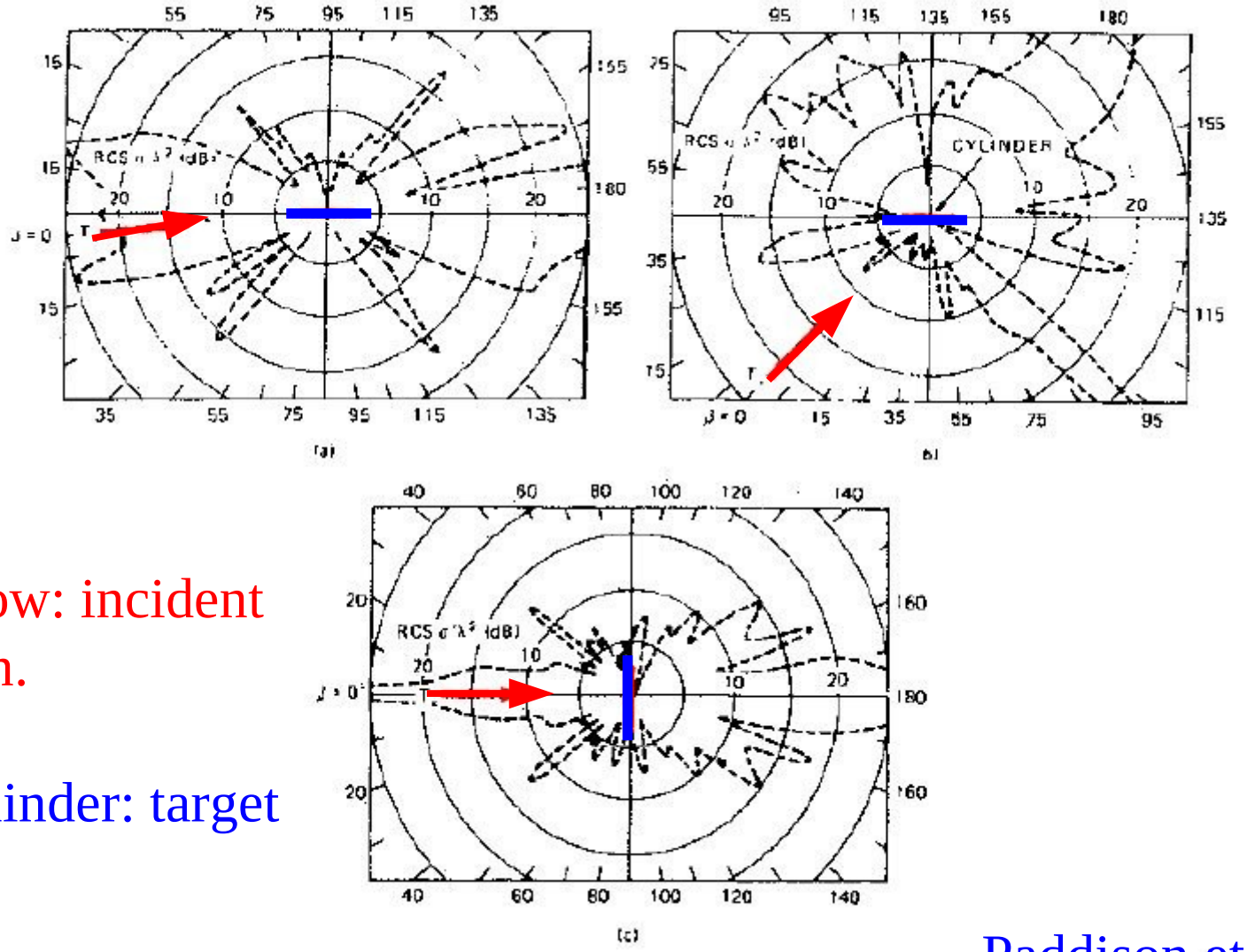
Radar and Cosmic Rays

- 1940 – Blackett and Lovell; Used to explain anomalies in atmospheric data. Built "facility", no results 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.
- 2009 – Takai → *Bistatic* radar



Jodrell Bank radar cosmic ray observatory, 1945

Forward Scattering: Where the Power is!



Red arrow: incident direction.

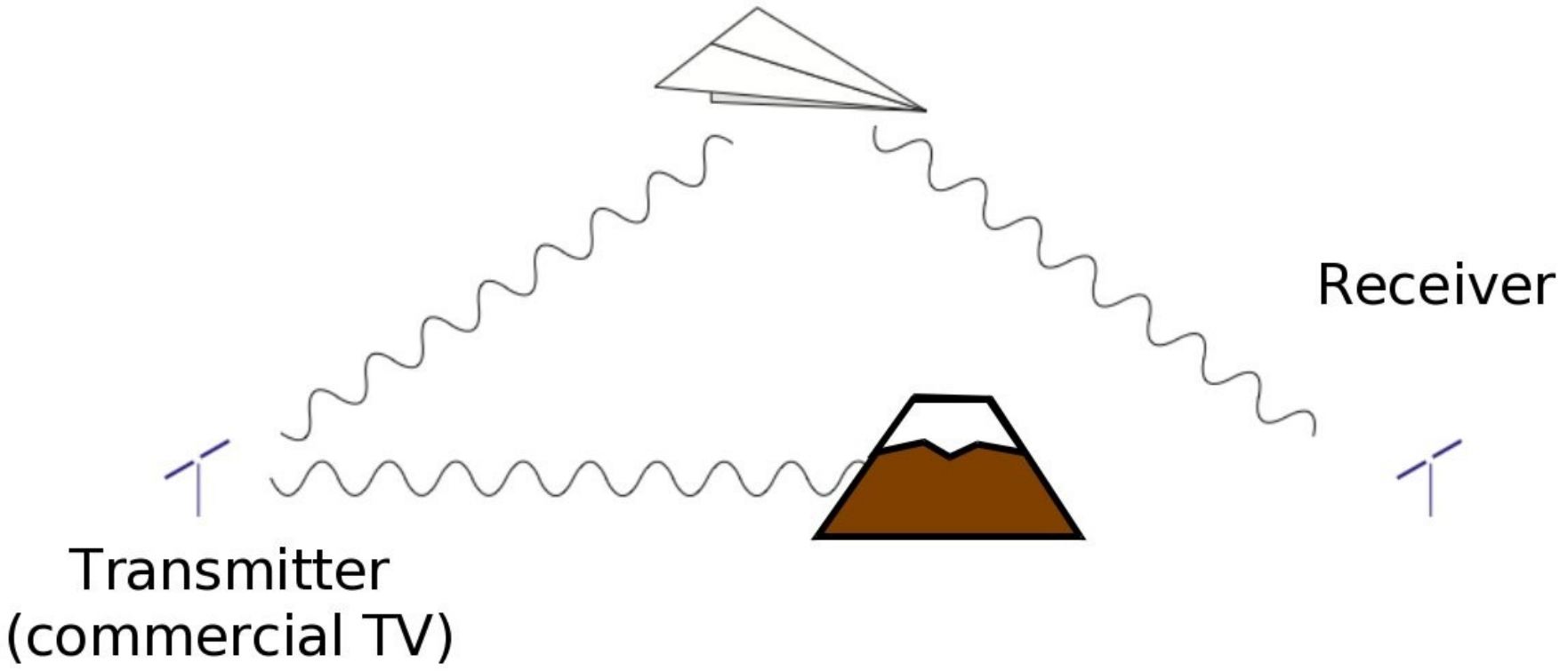
Blue cylinder: target

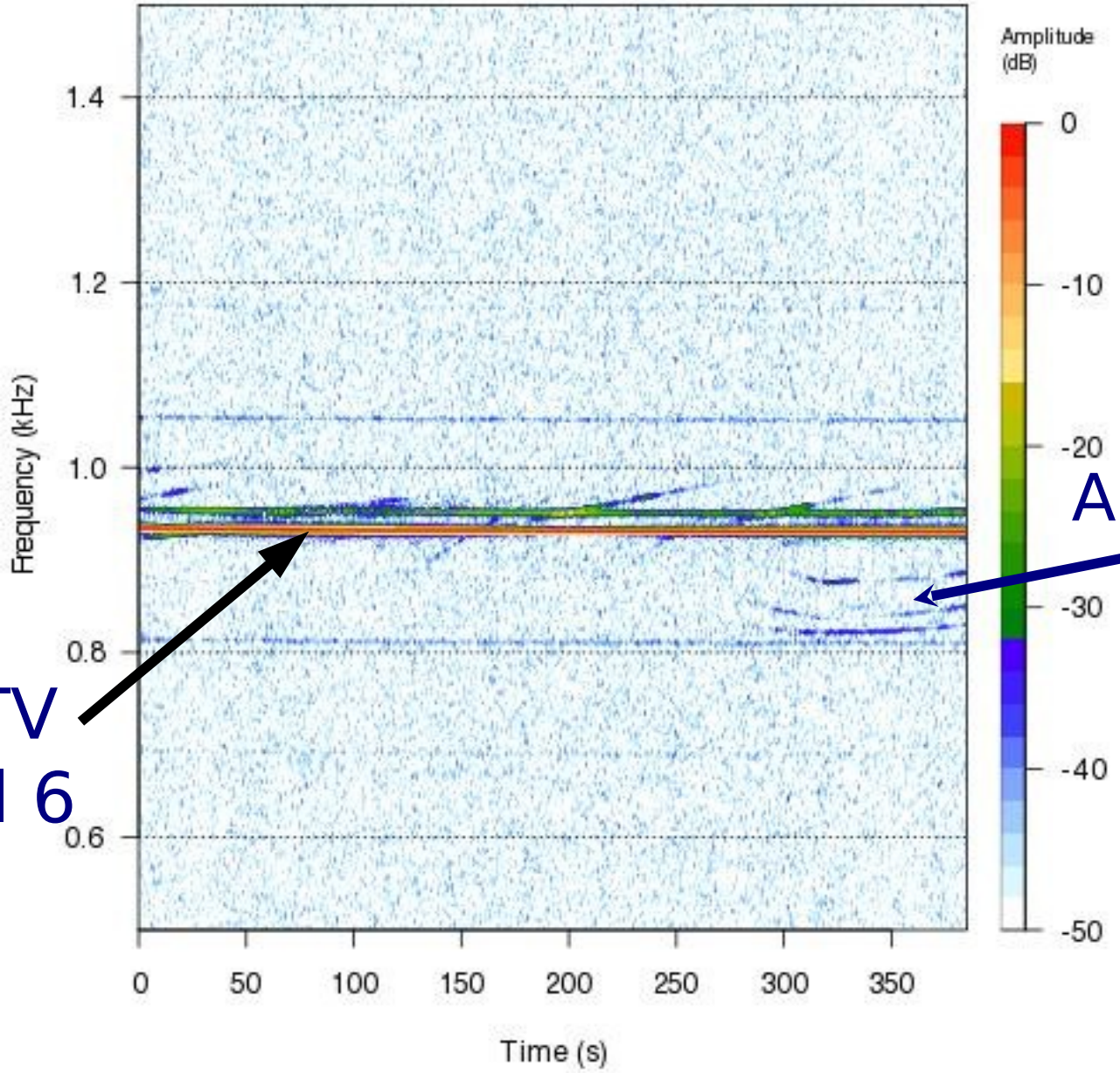
Paddison et al,
Electromagnetics **5** (1985)

Mixed Apparatus for Radar Investigation of Atmospheric Cosmic-rays of High Ionization

planned offline low rate active

“Parasitic” Bistatic Radar

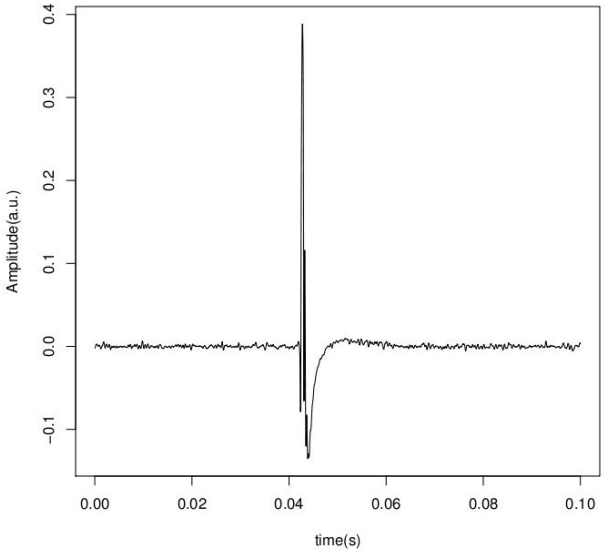


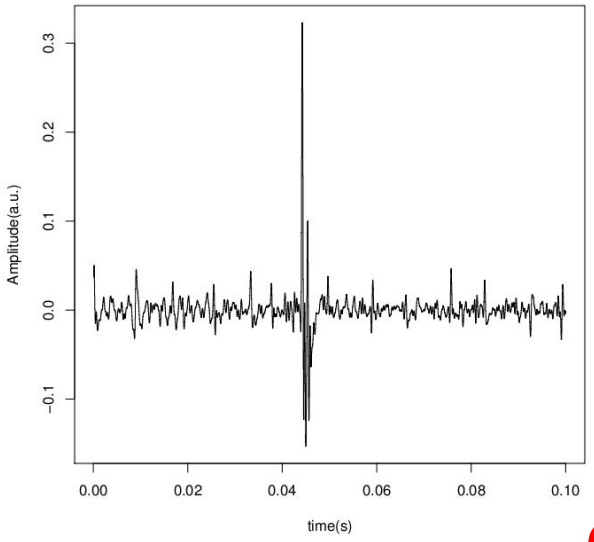


Digital TV
Channel 6

Airplanes

Power ~2 kW @ 260 km

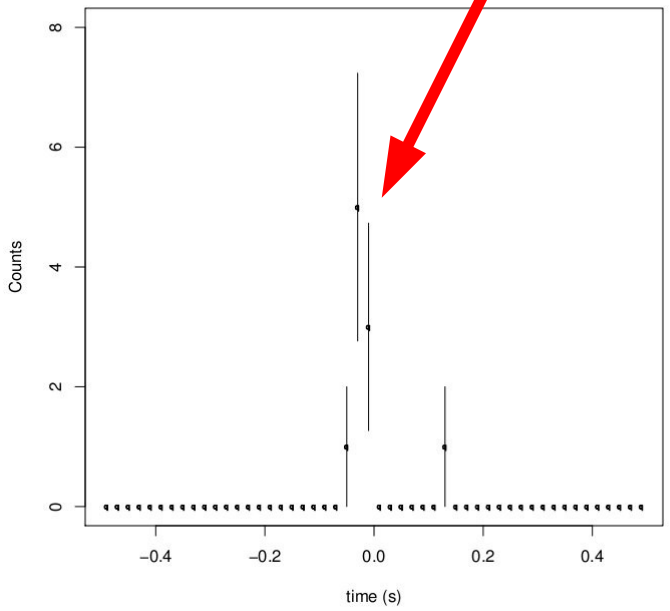




Simulated airshower response (left) and echo in coincidence with MARIACHI scintillators (right)

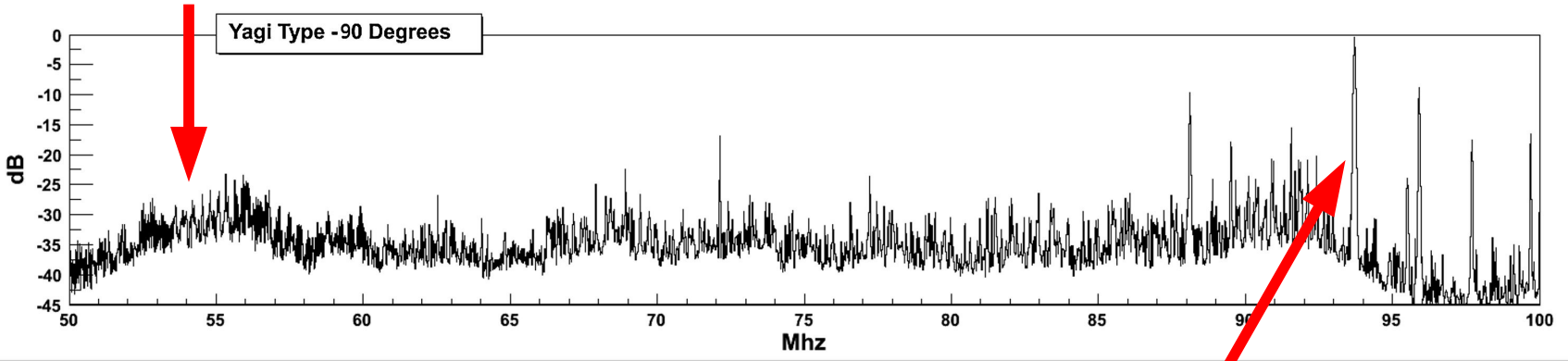
Cosmic Ray Signal!

Time distribution of radar echos relative to nearest MARIACHI scintillator firing

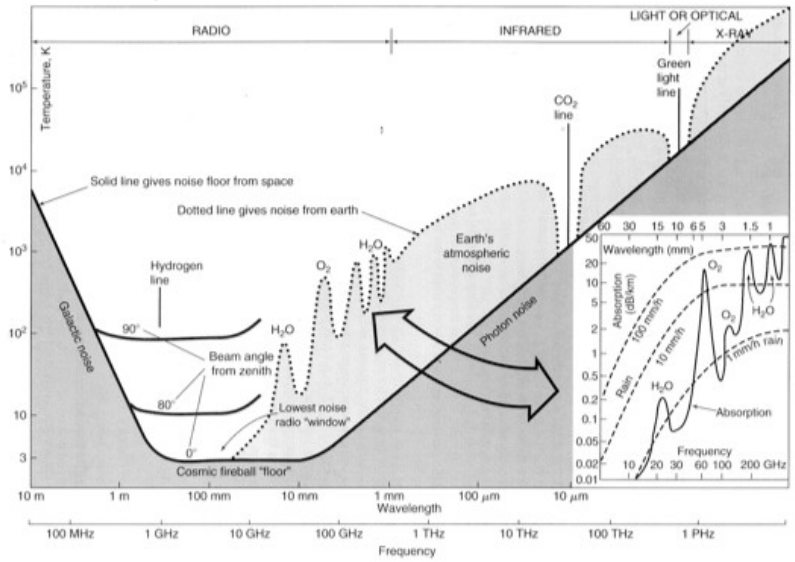


Radio Environment in Western Utah

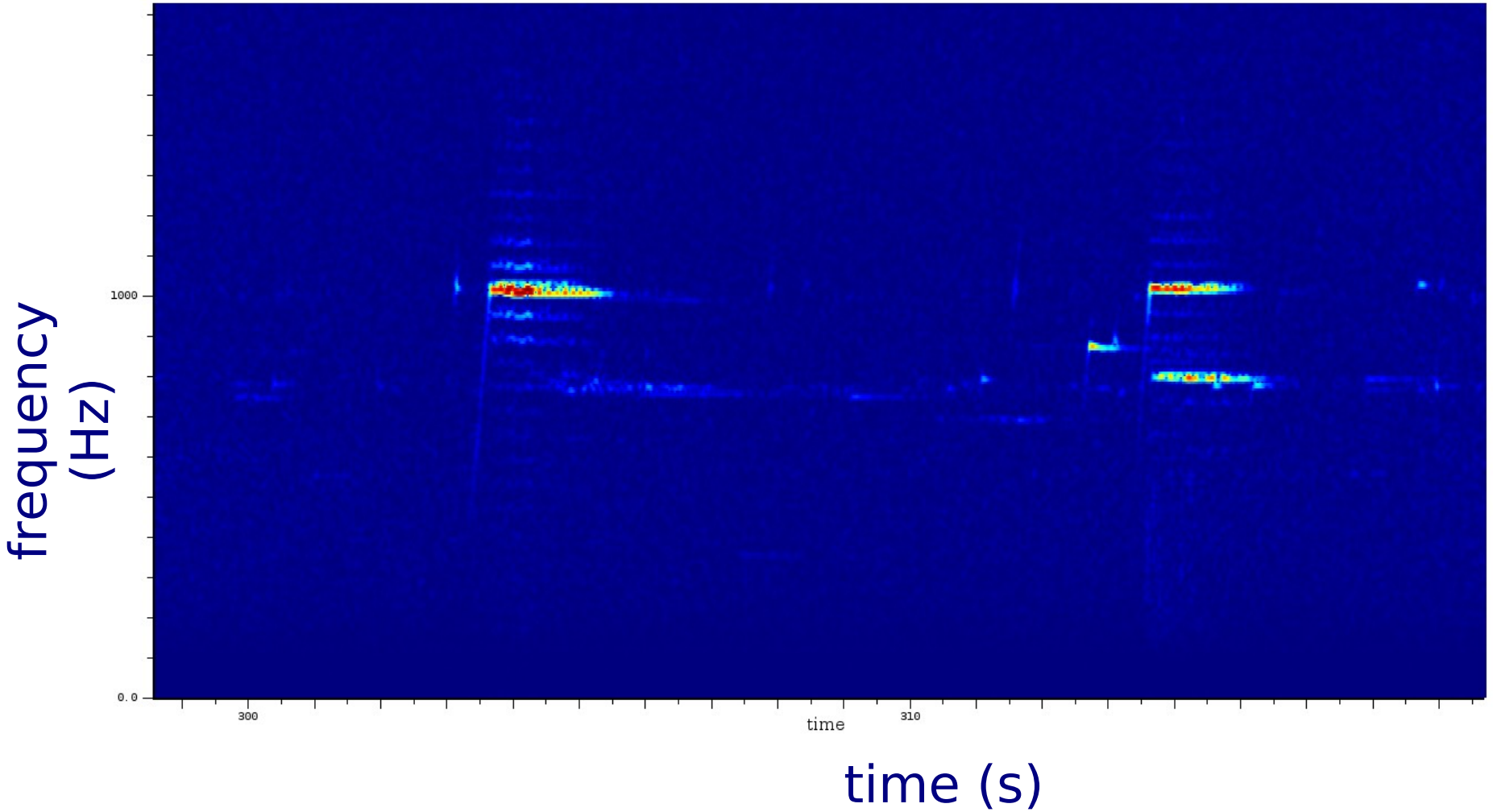
WF2XHR



500 W FM radio repeater@70km, behind a mountain

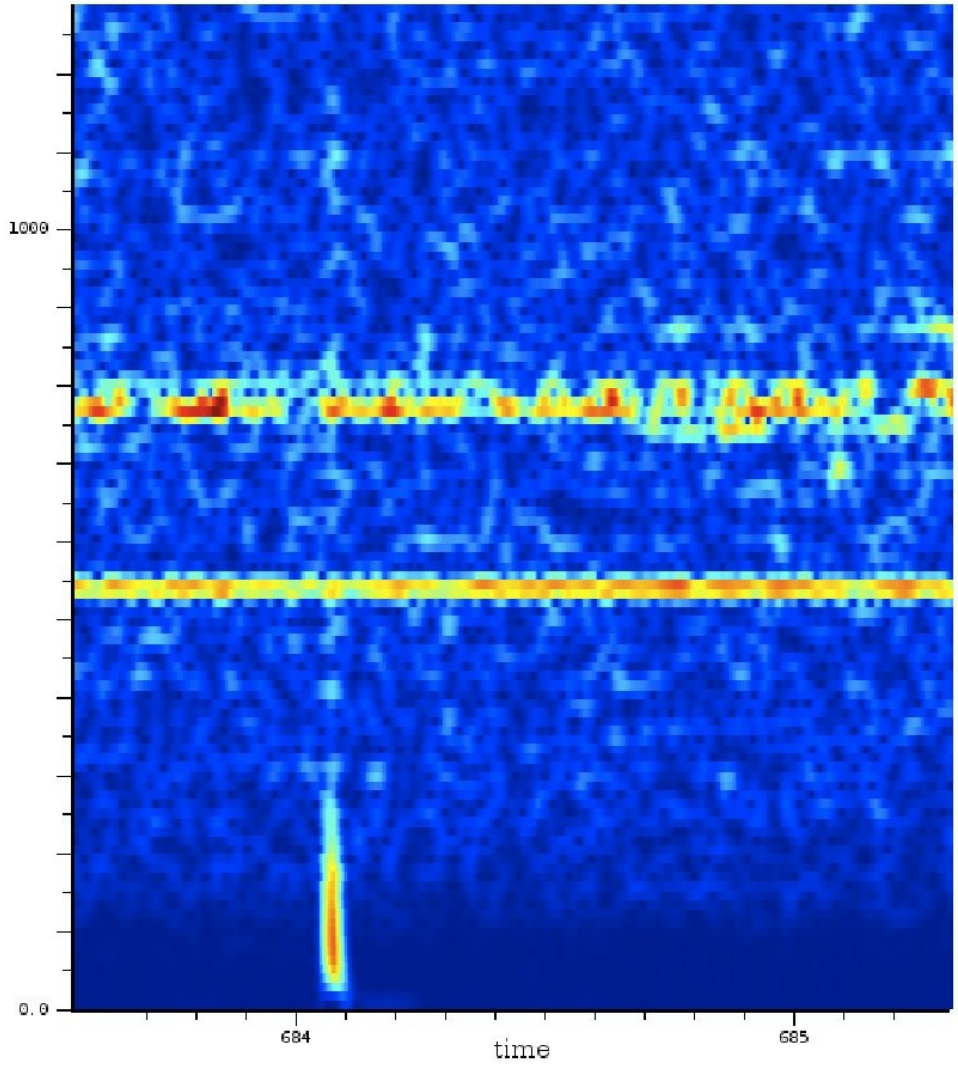


Sky noise (D. Krauss)

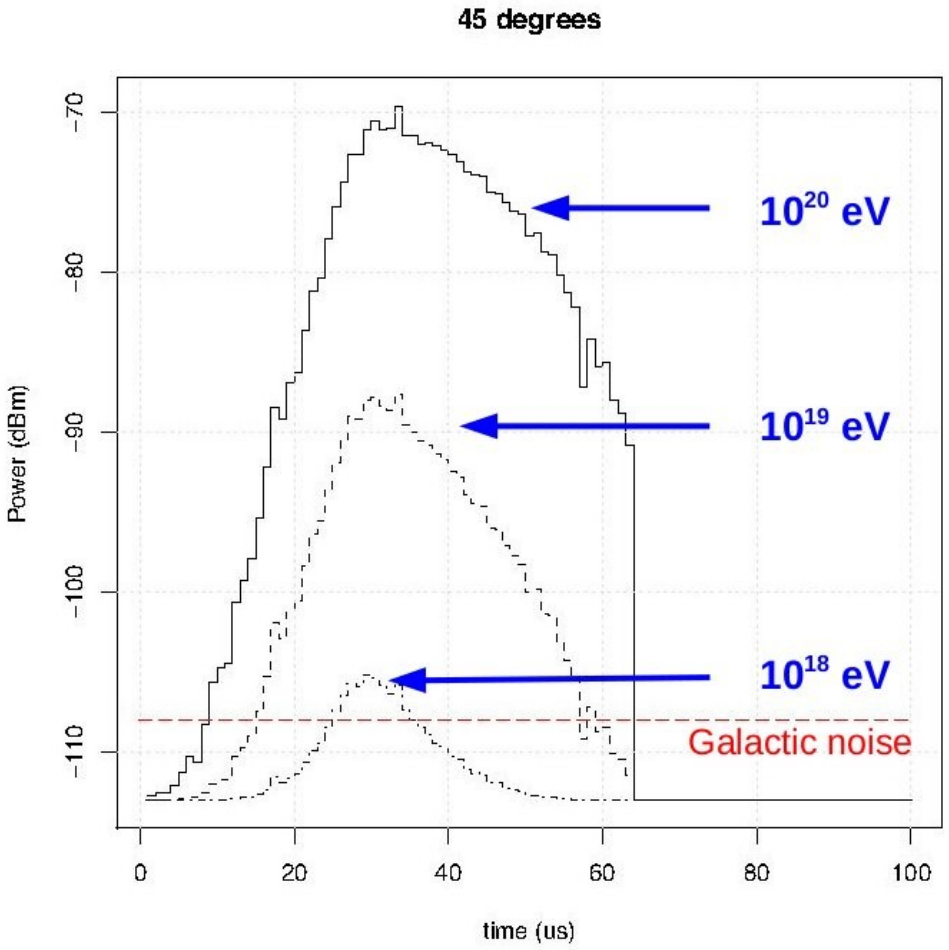


Micrometeor echoes,
recorded in Delta, Utah
(parasitic mode)

A Cosmic Ray Echo?

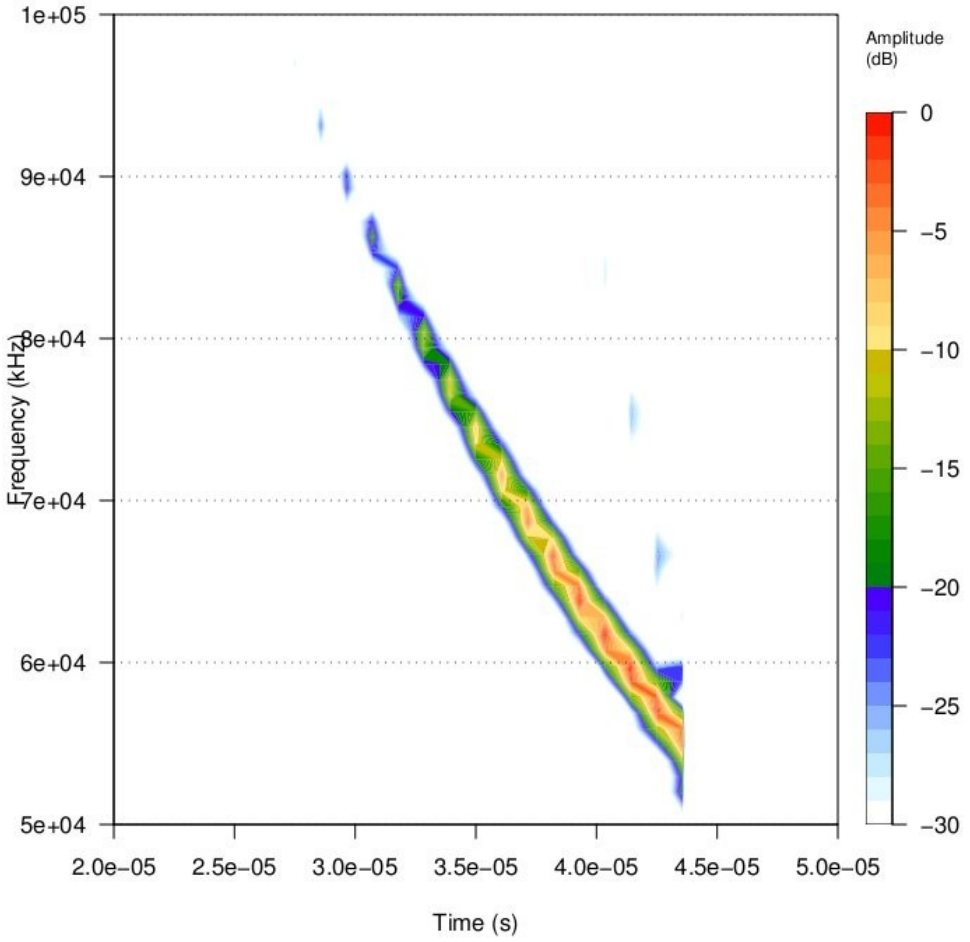


Challenges: Establishing a Threshold



- Above what energy can we (a) detect (b) reconstruct cosmic ray airshowers?
- Figure: simulation of reconstructed power versus time for a typical air shower geometry. (20 kW transmitter).
- Conservative reconstruction threshold 3×10^{18} eV.

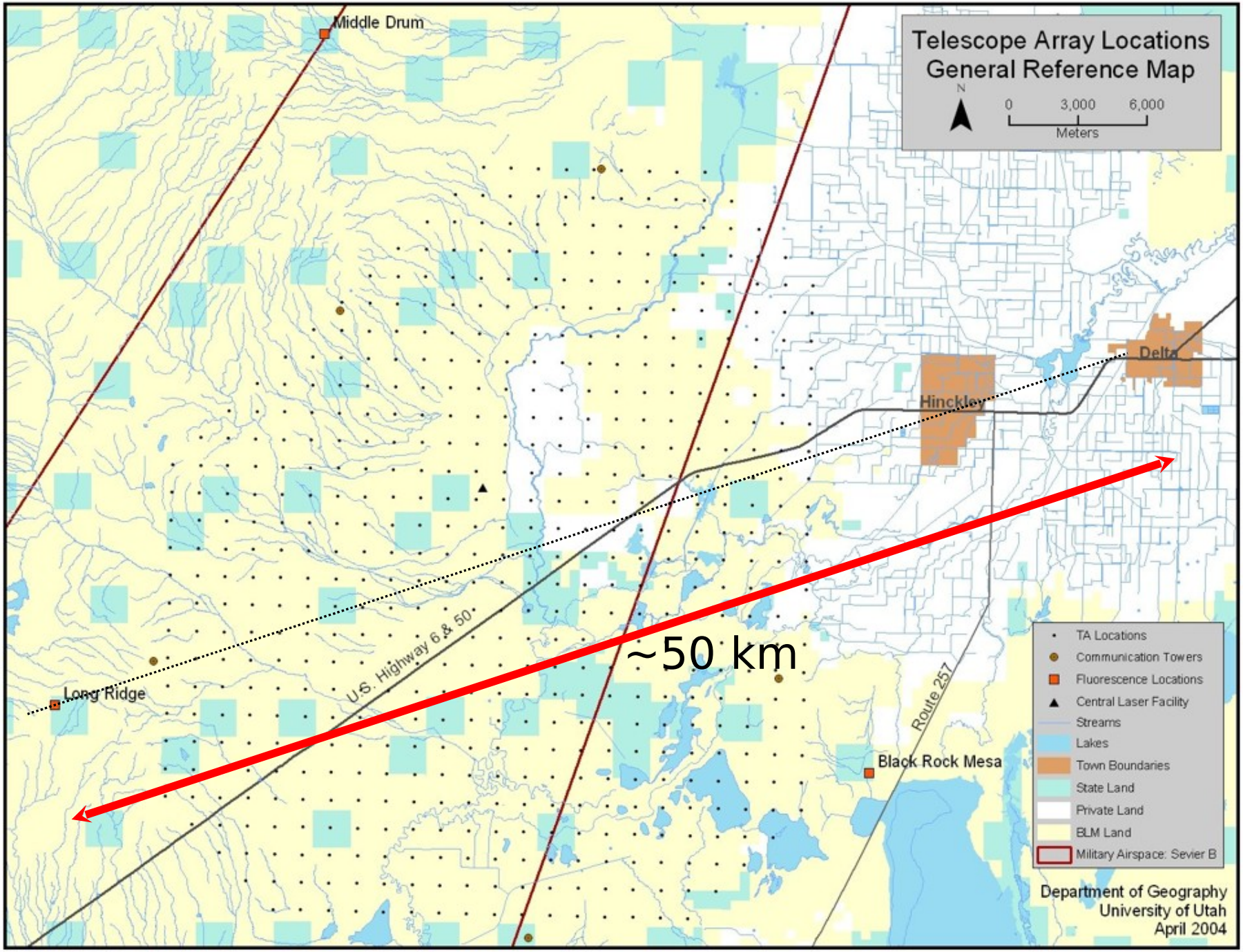
Challenges: Wide-Bandwidth Signals



- Primary frequency of received signal experiences significant “Doppler” shift.
- Typical “chirp” shown at left, in frequency vs time.
- 40 MHz bandwidth requires ≥ 80 MHz sampling!

Bistatic Radar: Plan

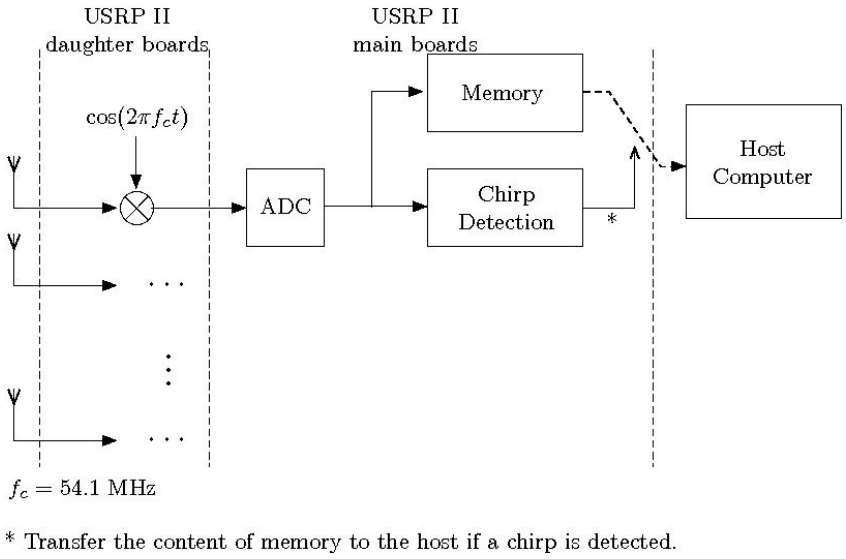
- This group received donation of 2 kW, 20 kW analog transmitters from Salt Lake KUTV-2. (54-60 MHz).
- We have obtained FCC station license WF2XHR to broadcast at 54.1 MHz.
- Have obtained NSF support for operation of 2 kW transmitter
- Seeking support for operating 20 kW transmitters and development of suitable receiver stations.


Telescope Array Locations
General Reference Map
N
0
3,000
6,000
Meters
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

Transmitter Facility

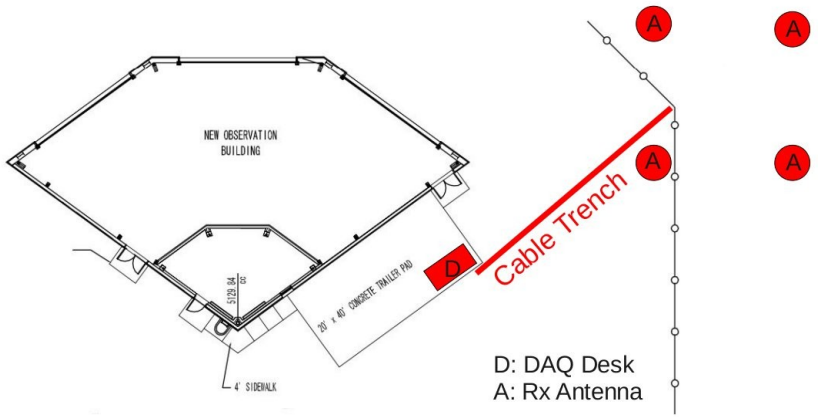
- Millard County Cosmic Ray Center
- Former 4,000 sq. ft. commercial building, now owned by U. of Utah
- Locus of Telescope Array scientific and outreach activities in Delta
- Future site of transmission facility

Receiver Stations



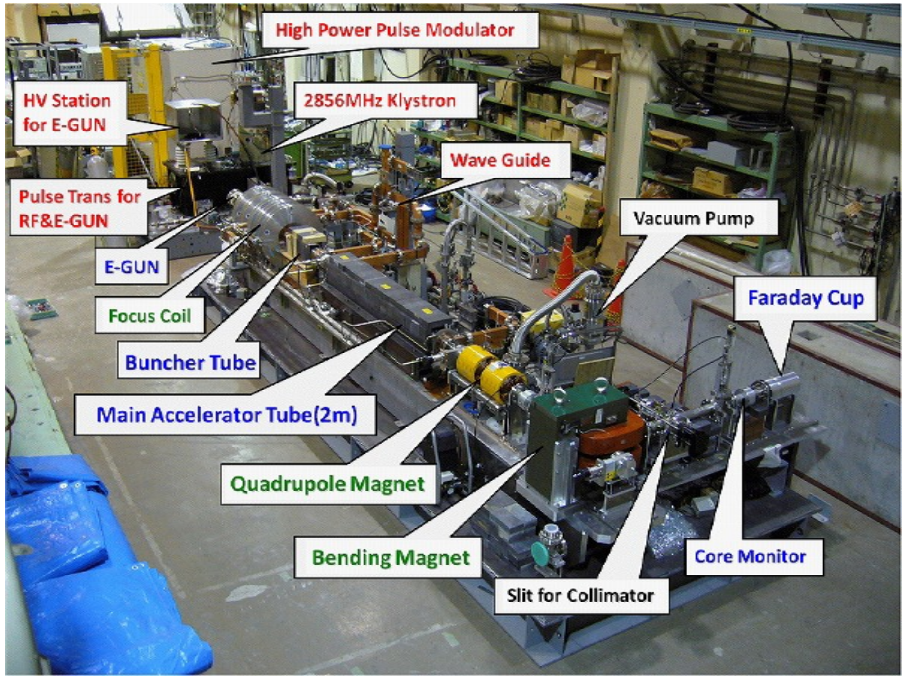
* Transfer the content of memory to the host if a chirp is detected.

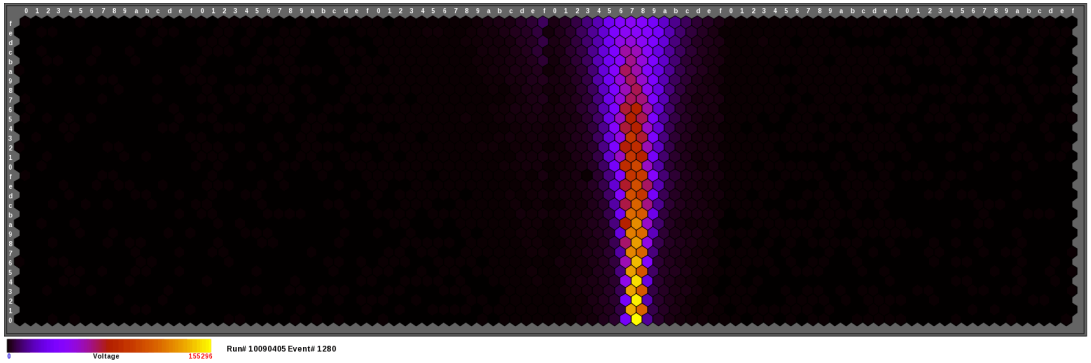
- First site “tethered” to Long Ridge fluorescence detector.
- Four log-periodic antennas, read out by software defined GNU-radio receivers.
- Signal candidates or “chirps” identified in real time.
- Reasonable data volume



Other Resources: Electron Light Source

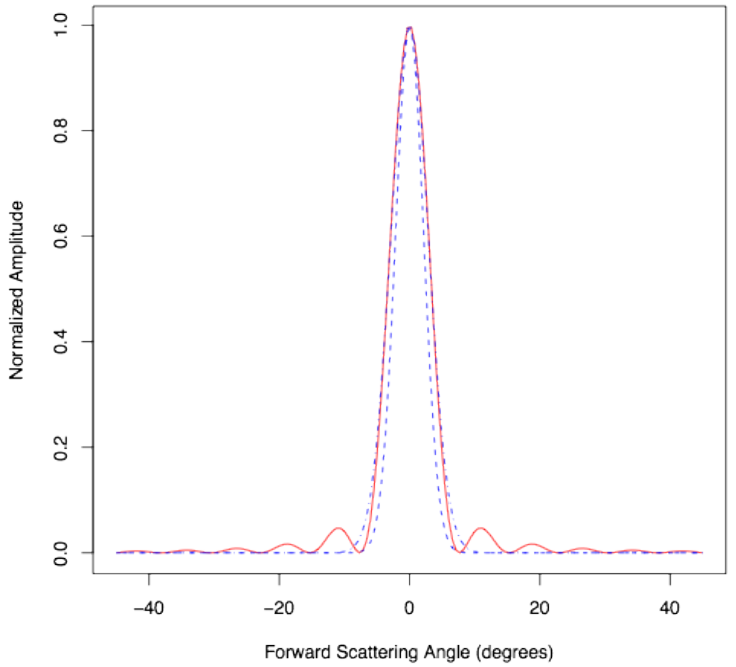
- A man-made “air shower” for calibrating Telescope Array fluorescence detectors.
- 40 MeV LINAC configured to fire electrons into the Millard County air.
- Saw first light September 2010!
- Enable direct measurement of free-electron lifetime in air.

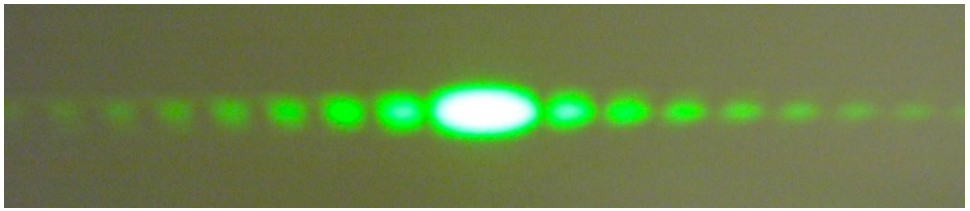


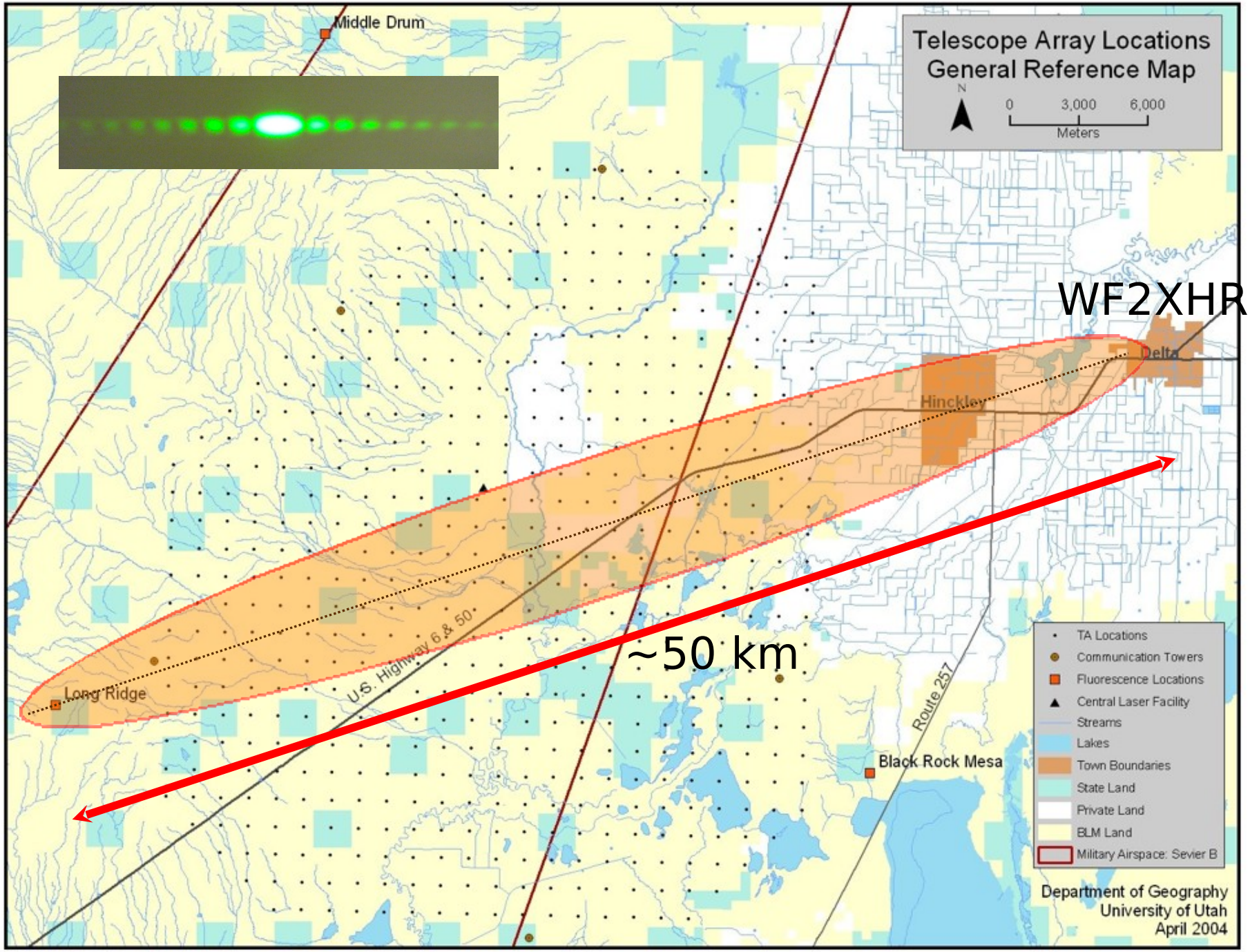


Guide to Signal Strength: Diffraction

- Scattering from thin rod similar to single slit diffraction (Babinet's Principle)
- Most output power will be in 15-degree wide central peak



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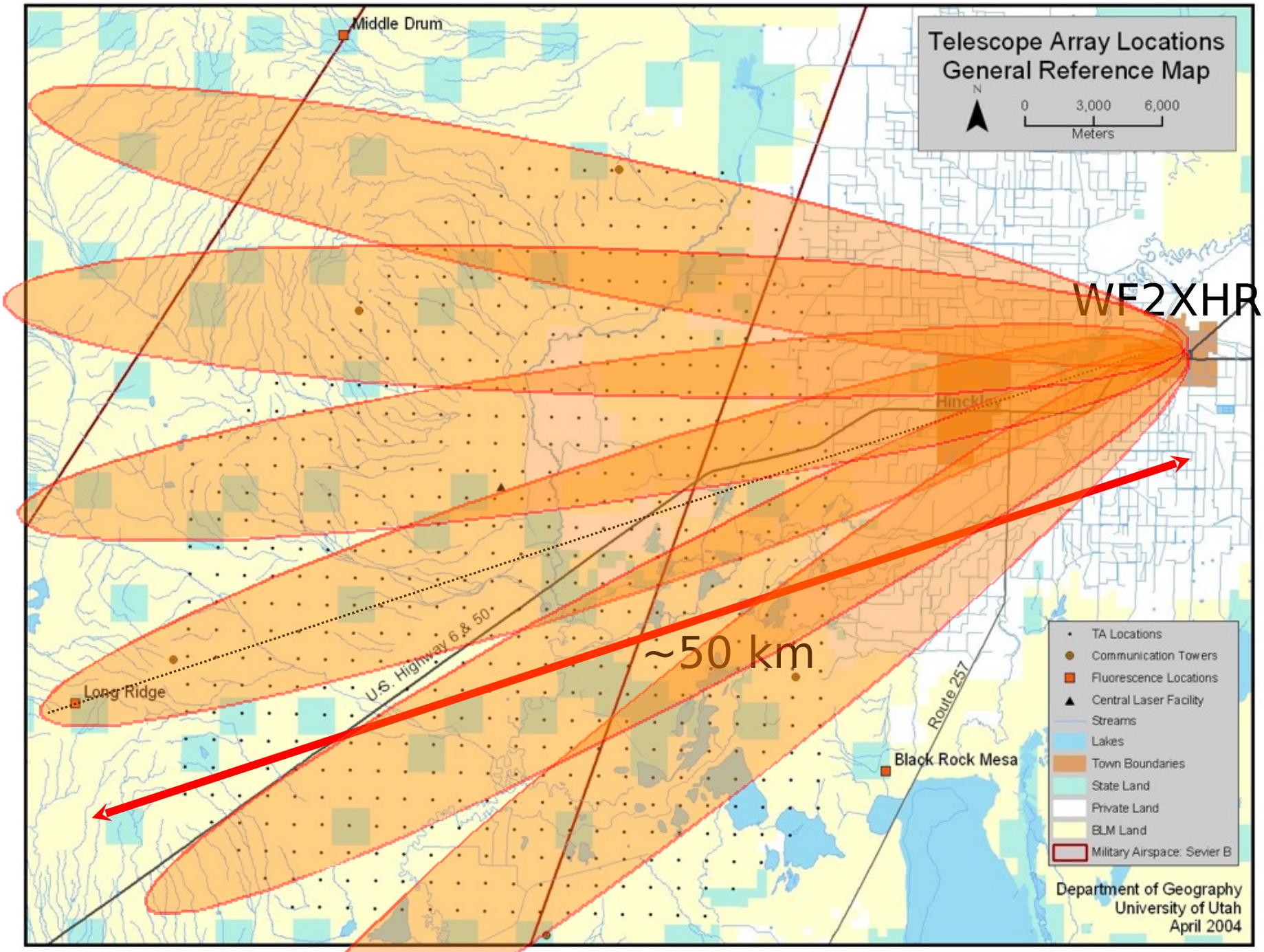
Central Laser Facility
Streams
Lakes
Town Boundaries
State Land
Private Land
BLM Land
Military Airspace: Sevier B
Department of Geography
University of Utah
April 2004

Ultimately...

- Cover entire Telescope Array active area
  - 20 kilowatt transmitter
  - 12 receiver stations
- Reconstruct air shower parameters
  - In parallel with “conventional” detector
  - Test models for scattering of air showers by radar.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Military Airspace: Sevier B
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Summary

- Bistatic radar is a candidate UHECR detection technique.
- We are deploying low-VHF TV transmitters and receiver stations at the Telescope Array site in Western Utah.
- The aim is to demonstrate the feasibility of this low-cost, 24-hour, remote sensing tool.