Air Shower Detection
By Bistatic Radar

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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 $\sim 50$ MHz (low-VHF)
- Airshowers reflect TV transmissions!

$$\omega_p = \left( \frac{n_e e^2}{m_e \epsilon_0} \right)^{1/2}$$

$n_e = \text{electron number density}$
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*
Forward Scattering: Where the Power is!

Red arrow: incident direction.

Blue cylinder: target

Mixed Apparatus for Radar Investigation of Atmospheric Cosmic-rays of High Ionization
“Parasitic” Bistatic Radar

Transmitter (commercial TV)

Receiver
Power ~2 kW @ 260 km

Digital TV Channel 6

Airplanes
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

Yagi Type -90 Degrees

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 $3 \times 10^{18} \text{ eV}$. 
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.
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

- 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

* Transfer the content of memory to the host if a chirp is detected.
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
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.
WF2XHR ~50 km
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.