The MARIACHI Experiment

Radar detection of UHECR

Helio Takai

Physics Department, Brookhaven National Lab. &
Dept. of Physics and Astronomy, Stony Brook University

takai@bnl.gov

Motivation

Radar *can potentially* cover larger detection areas for the detection of ultra high energy cosmic rays.

Radar *can potentially* be used to detect horizontal showers produced, e.g. by high energy neutrinos.

Radio vs Radar

Radio - Detection of Radio Frequency from Cosmic Ray Shower, i.e. Geo-Synchrotron Radiation.

Radar - Detection of Radio Frequency scattered of the ionization created by a Cosmic Ray Shower.

However: They both share similar type of problems, namely, antenna design, receivers, data acquisition, and more importantly **noise**!

There are *(at least)* **two types of radar**: monostatic and bistatic.

Radio

- G.A. Askaryan Sov. Phys. JETP 14(1962) 441(and others).

- CASA/MIA and Radio - K. Green et al., NIM A498 (2003) 256.

- *Synchrotron Radiation at radio frequencies from Cosmic ray showers.* D. Suprun et al., Astroparticle Phys. 20(2003)157

- *Accelerator measurements of the Askaryan effect in rock salt: A roadmap toward teraton underground neutrino detectors*, P. Gorham et al., Phys. Rev. D 72, 023002 (2005)

- **CODALEMA** - *Radio detection of cosmic ray air showers by the CODALEMA experiment*, O. Ravel et al. NIM A 518(2004)213

- **LOPES** - Falcke et al. (LOPES collaboration) Nature(2005)435

Radar

- P.M.S. Blackett and A.C.B. Lovell, **Radio Echos and Cosmic Ray Showers**, Proc. Roy. Soc. A 177(1940)183.

- K. Suga, **Methods for Observing Extremely Large Extensive Air Showers**, Proceedings of the Fifth Interamerican Seminar on Cosmic Rays, La Paz, Bolivia (1962) XLIX-1.

- T. Matano, M. Nagano, K. Suga, and G. Tanahashi,**Tokyo large air shower project**, Canadian Journal of Physics, Vol. 46 (1968) S255.

- P. Gorham, **On the possibility of radar echo detection of ultra high energy cosmic ray and neutrino induced extensive air showers**, Astroparticle Physics 15(2001)177.

- A. Iyono, N. Ochi, Y. Fujiwara, T. Nakatsuka, S. Tsuji, T. Wada, I. Yamamoto, Y. Yamashita, **Radar Echo Detection System of EAS Ionization Columns as Part of a LAAS Detector Array**, Proc. of the 28th International Cosmic Ray Conference. July 31-August 7, (2003) 217

The Radar Technology Concept

Key Concept: Free electrons will reflect electromagnetic waves via Thomson Scattering.

When electron density is very high the reflection regime is specular: plasma scattering.

$$\nu_p = \sqrt{\frac{n_e e^2}{\pi m_e}}$$

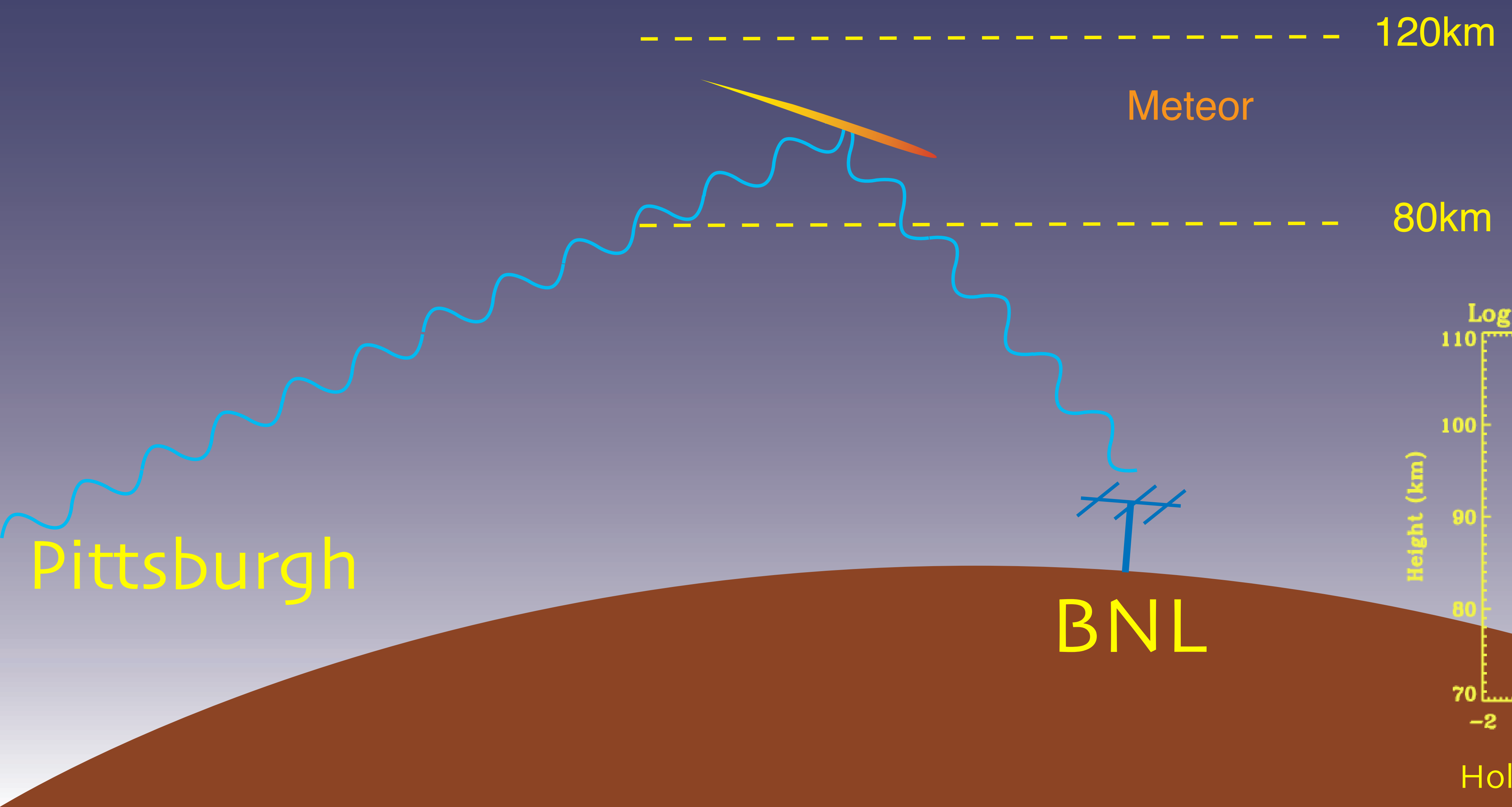
Forward Scattering has more scattered power, thus bistatic radar is the favored technique.

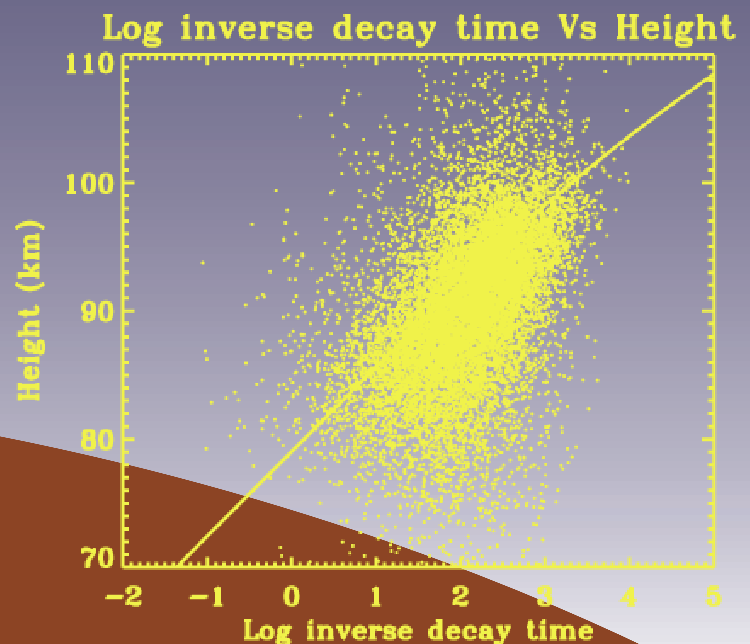
Locate Transmitter far from Receiver.

Radio Meteor Scatter

Meteors when entering earth's atmosphere vaporizes, and creates an ionized trail.

Radio waves from far (600-2000 km typical) are reflected by the ionization created by them.



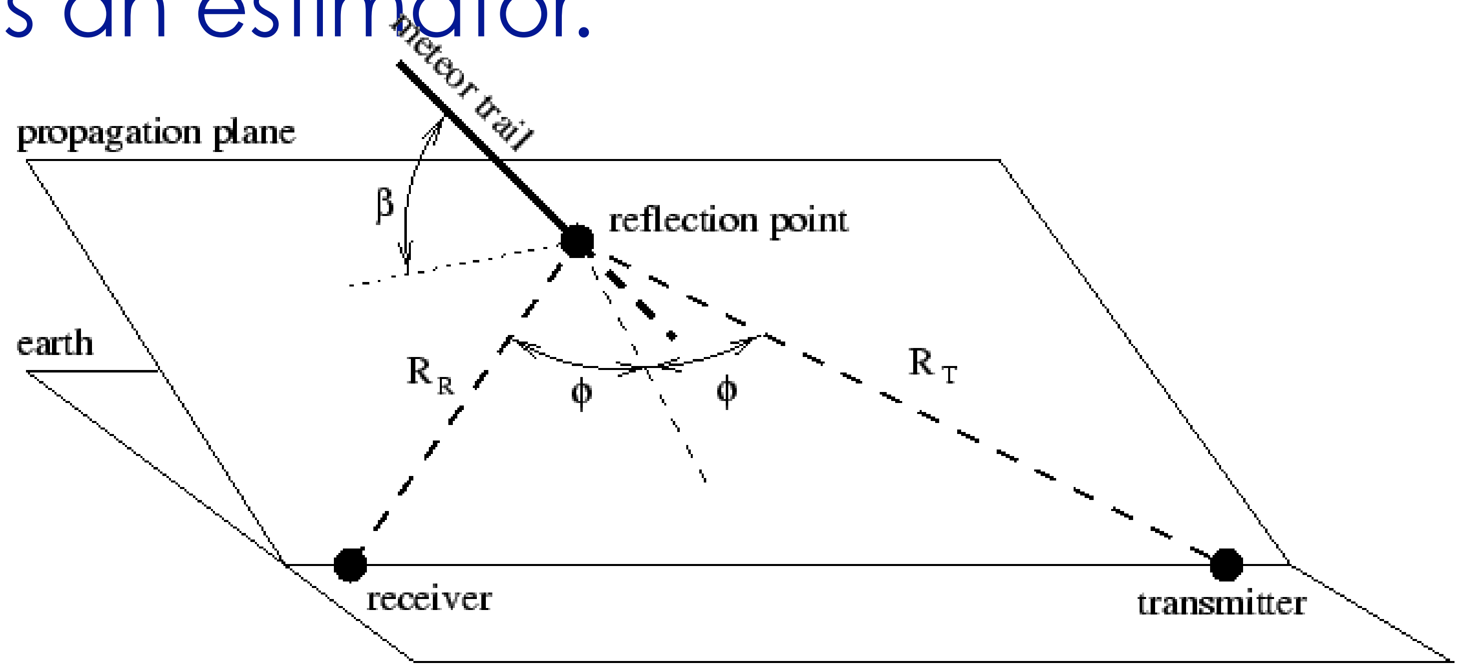


Holdsworth,Reid and Cervera

Estimating Scattered Power

Cosmic Rays with E > 10^{18} eV will produce a *cylindrical* ionization of few meters in diameter with densities larger than the plasma frequencies for frequencies between 50-100MHz.

The same formalism used for meteors forward radio scattering can be used as an estimator.



$$P_R(t) = \frac{P_T G_T G_R \lambda^3 q^2 r_e^2 \sin^2 \alpha}{16\pi^2 R_T R_R (R_T + R_R)(1 - \cos^2 \beta \sin^2 \phi)} \cdot \exp(-\frac{8\pi^2 r_0^2}{\lambda^2 sec^2 \phi}) \cdot \exp(-\frac{32\pi^2 Dt}{\lambda^2 sec^2 \phi})$$

Selected list of Problems

Lifetime - The ionization happens at low altitudes (<20km). This means short "free electron" lifetime.

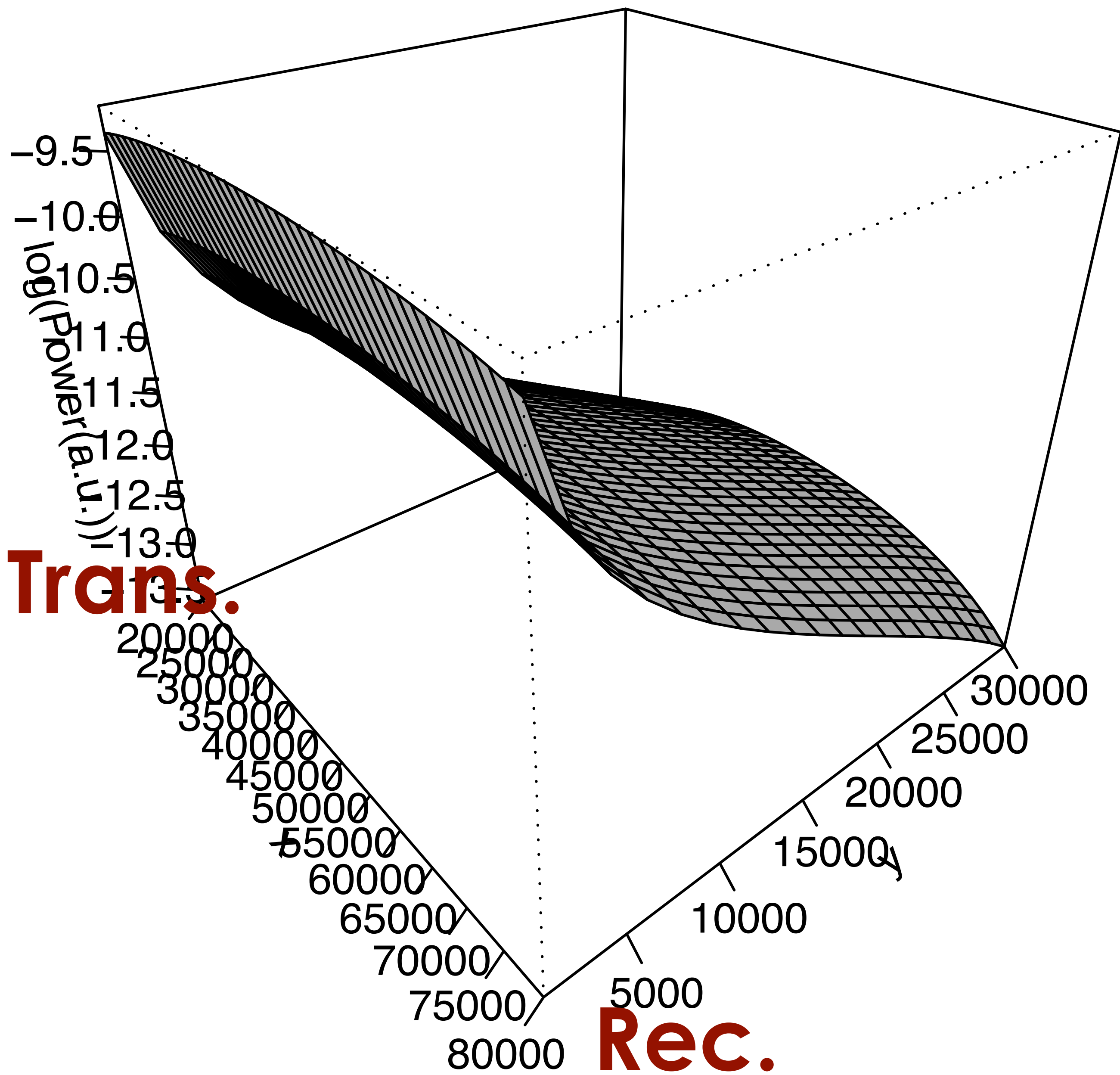
Dampening - While electrons are oscillating they will scatter from neutral molecules and others causing dampening.

Refractive media - Surrounding the dense ionization core there is a "haze" of electrons. This media is refractive and needs to be considered. (not covered today)

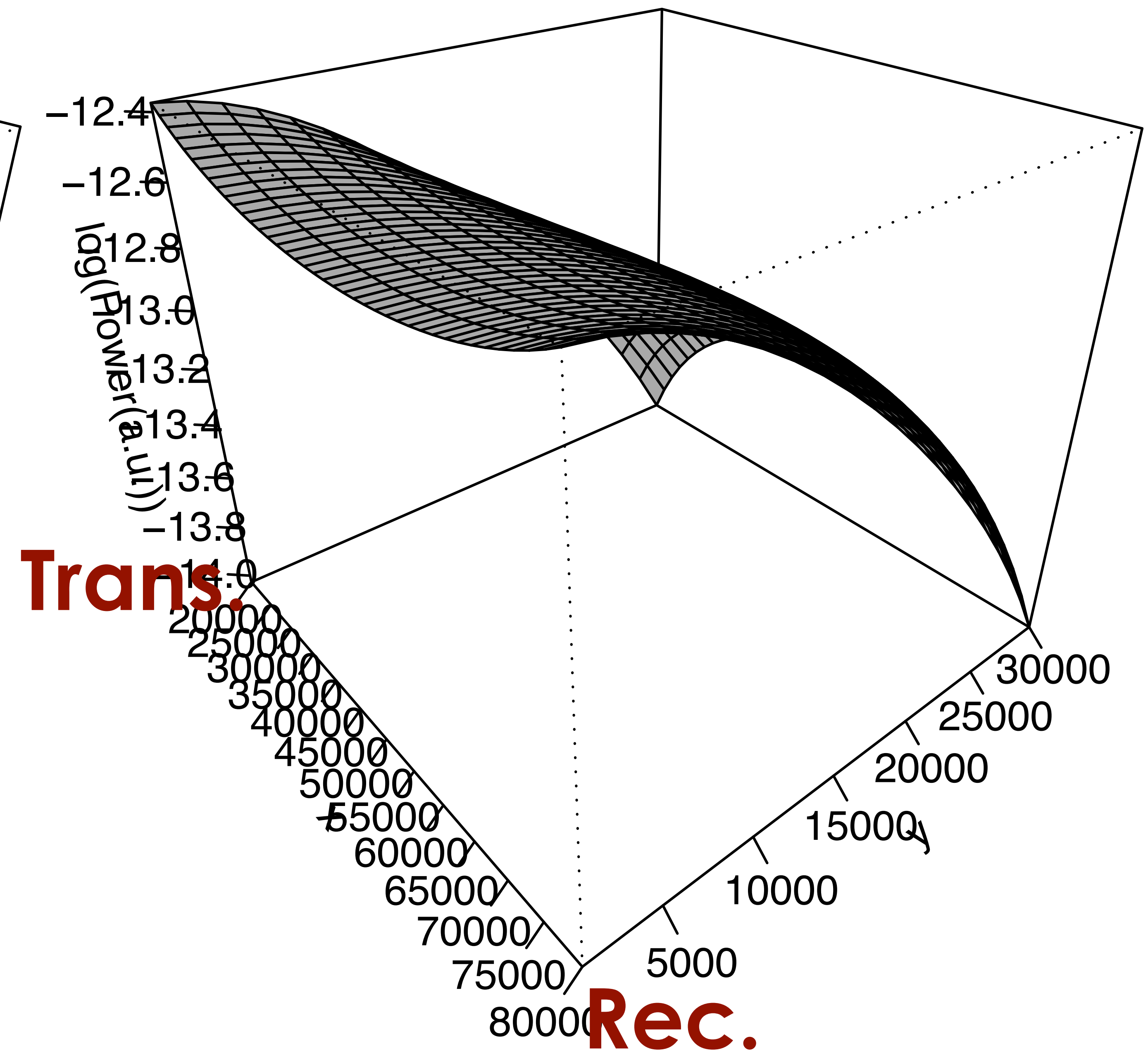
Polarization - Loss of polarization is possible as it is observed in meteor scattering.

Received Power

(For long lifetime)



Horizontal Showers

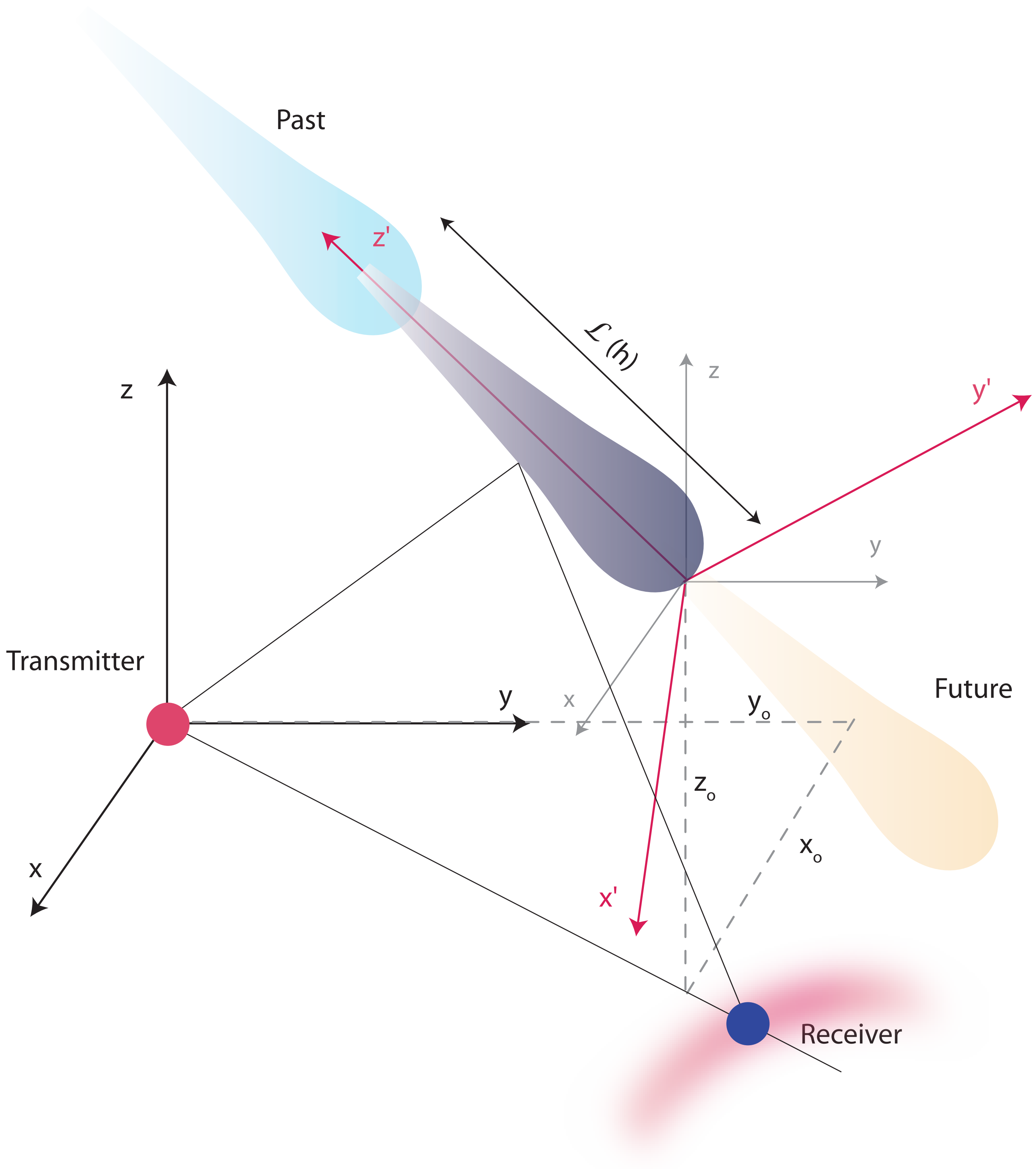


Vertical Showers

100W transmitter located at 100 km from receiver.

Note: 80km is about the limit for flat earth approximation.

Received Power and Signal Duration



τ~250 ns (depends on ionization mechanism)

$$t \sim 50\ \mu s$$

Received power τ→∞

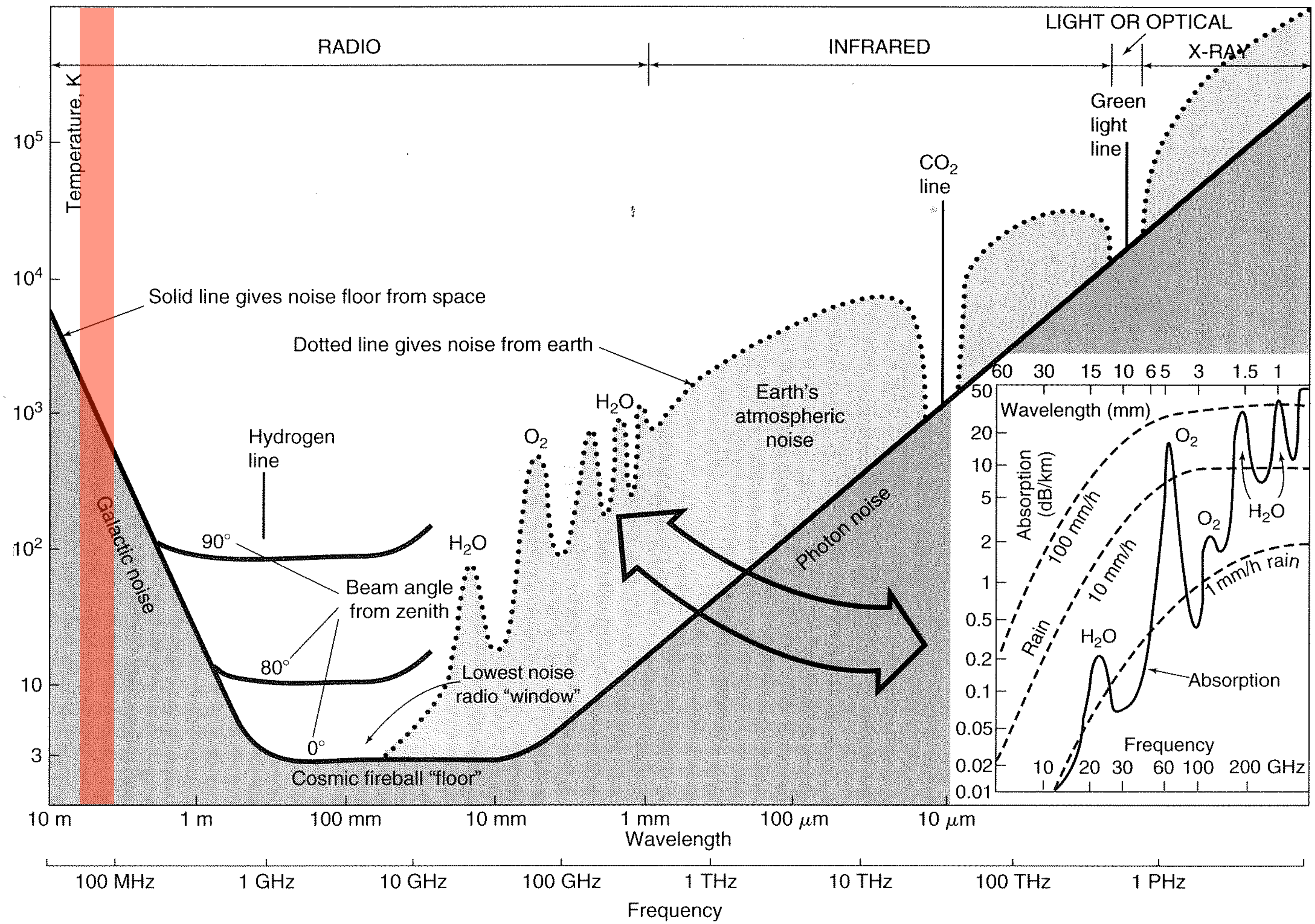
$$P_R \sim 10^{-12}\ Watts$$

Dampening adds an attenuation of 10^{-4}, with $\nu_e \sim 10^9$,

$$f_{scat} = \frac{m_e^2}{M^2}\left(\frac{1}{(\nu_e/\pi\nu)^2 + 1}\right)$$

$$P_R \sim 10^{-16}\ Watts$$

Sky Noise



$$P_N = k \cdot T_{eq} \cdot B \sim 10^{-18}\ W$$

D. Krauss

Noise

Your noise is somebody else's signal!

Man Made

Computer, Spark Plug, Airplane, Transformer, Fluorescent Lamp, Radar, TV, Radio, Walkie-Talkie, Cell Phone, Photo tubes, Electronics, etc....

Natural

Aurora, Sporadic-E, Meteor, Lightning, Clouds, Sun, Galaxies, etc....

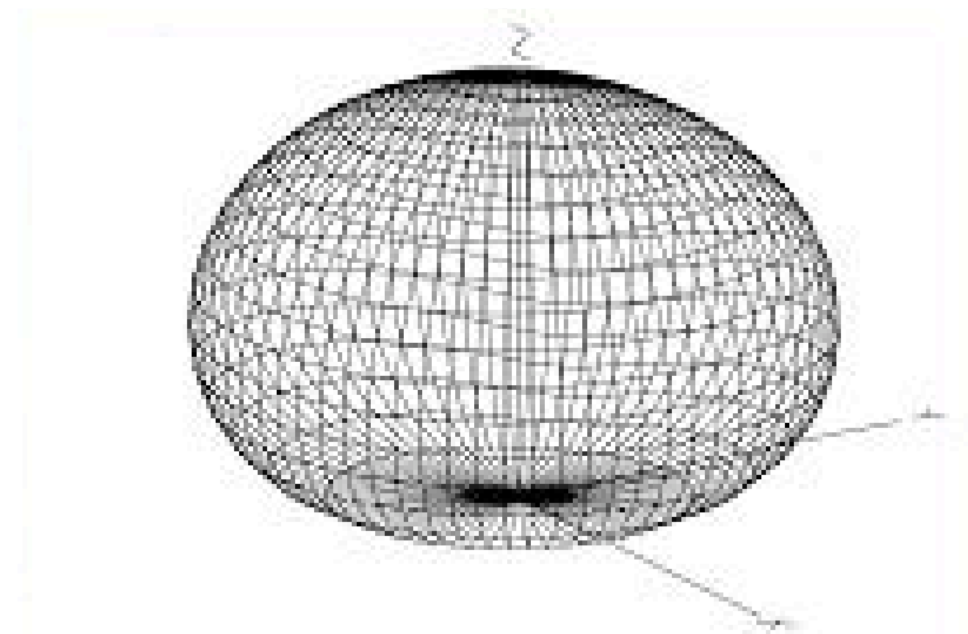
We need to understand it!

Antennas

Our Antenna

Double Inverted V Dipole.

When phased properly it has the following radiation pattern:



An amplifier will be installed in the "can" for long cable runs.

The problem with antennas: **GROUND**

Receivers, Transmitters and GPS.

Fast developing new technologies. Computer controlled radio available for systematic scans.

Radio Astronomy in the 10-200MHz range (decametric) has developed radio receivers for phased arrays.

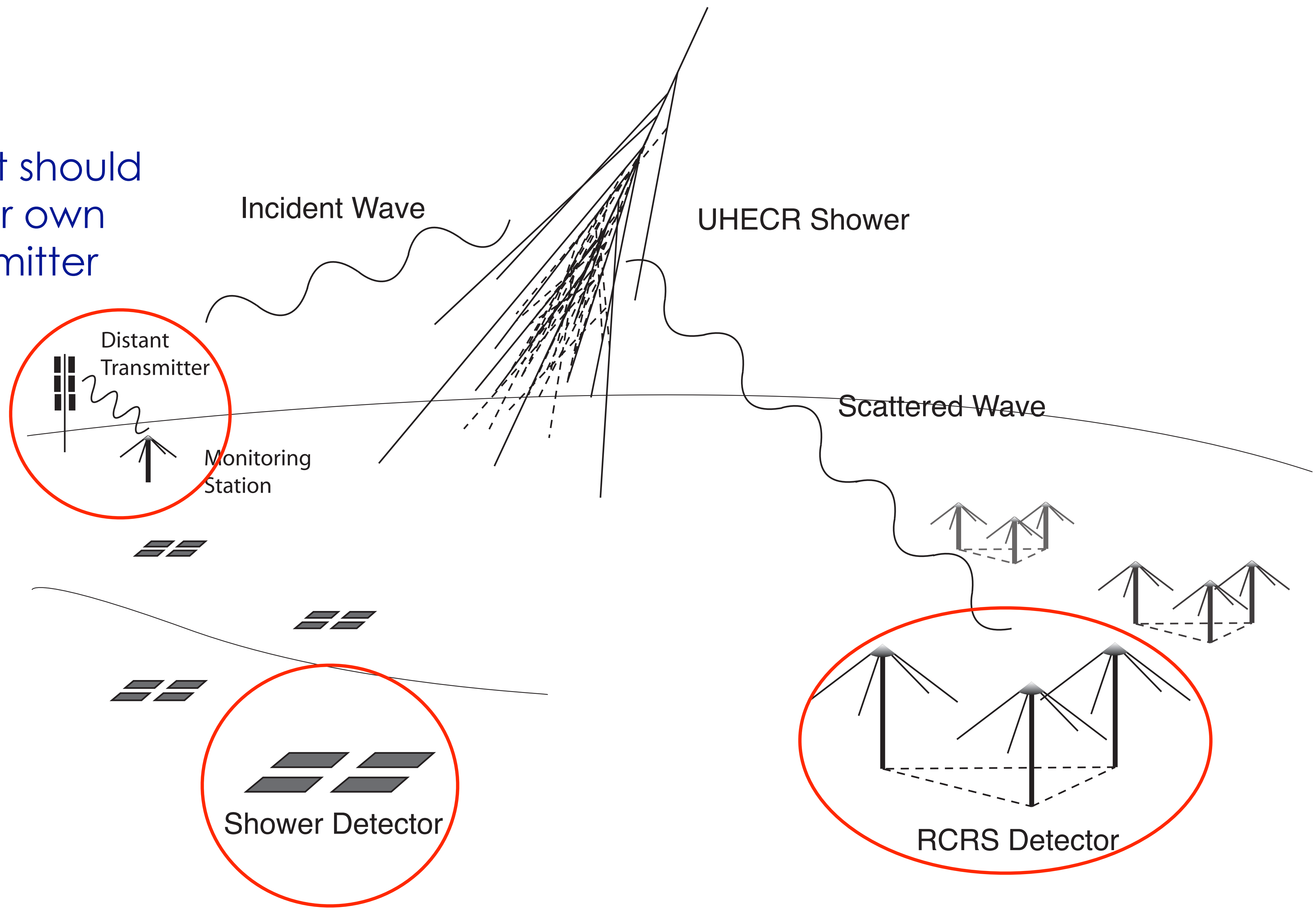
GPS conditioned frequency generators is a reality.

Software Defined Radio for example **GNU Radio**.

Good timing with GPS.

Experimental Setup

Ideally it should be our own Transmitter

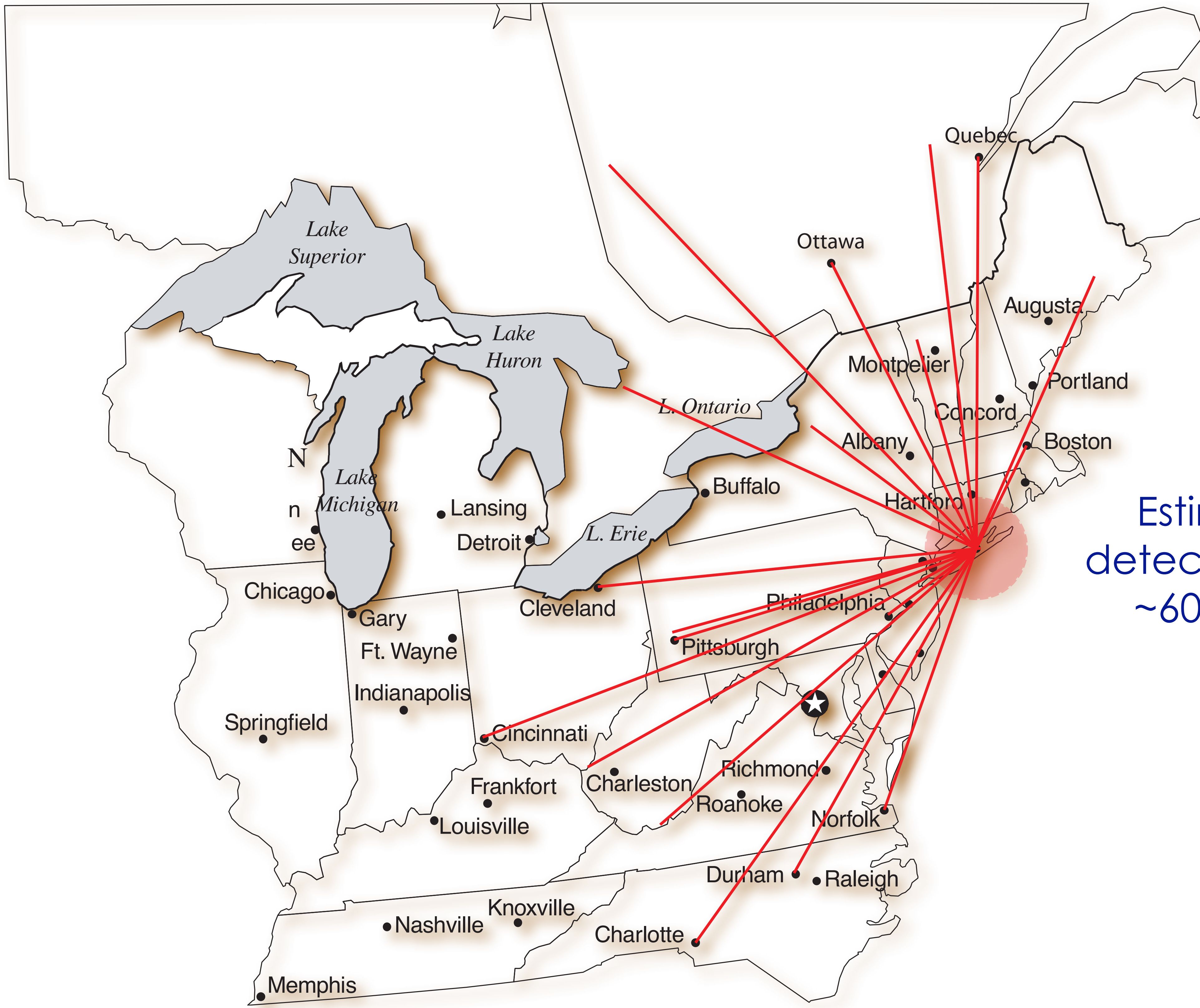


5 scintillation counters installed in High Schools

Phased array?

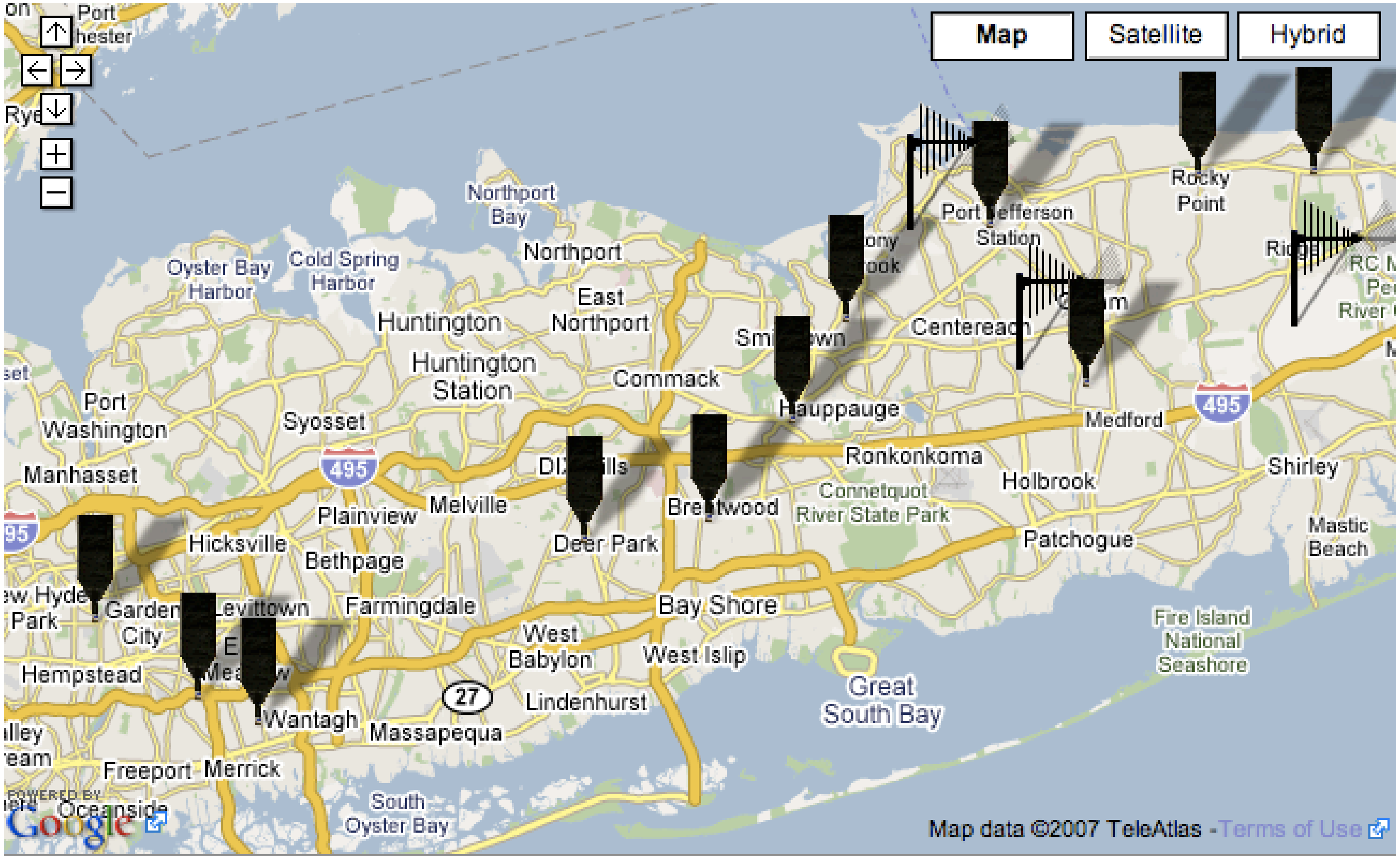
Stations are distant and **independently** operated.

TV Broadcast Stations



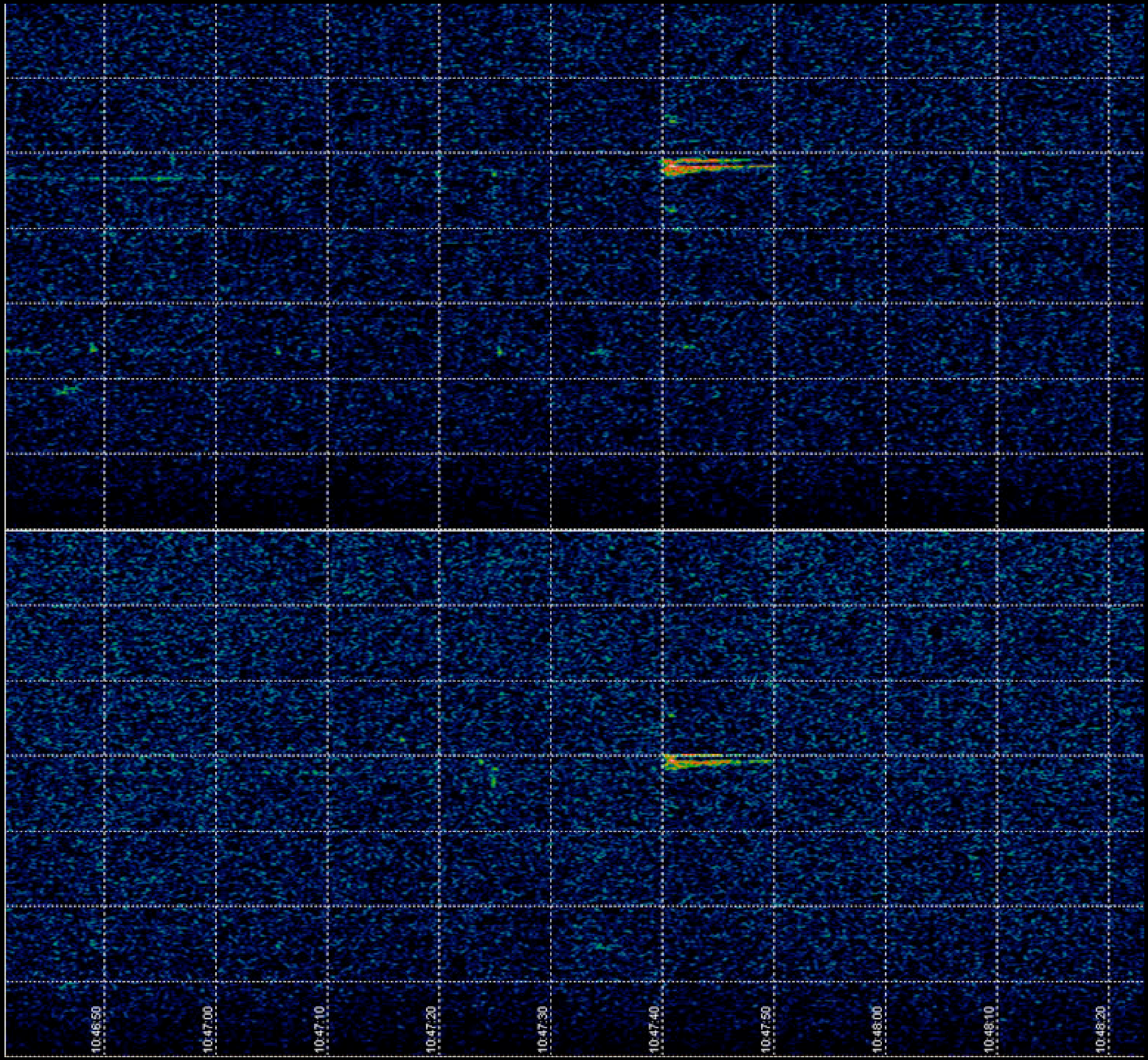
Estimated detection area ~6000 km^2

Mixed Apparatus for Radar Investigation of Atmospheric Cosmic-ray of Heavy Ionization



www-mariachi.physics.sunysb.edu

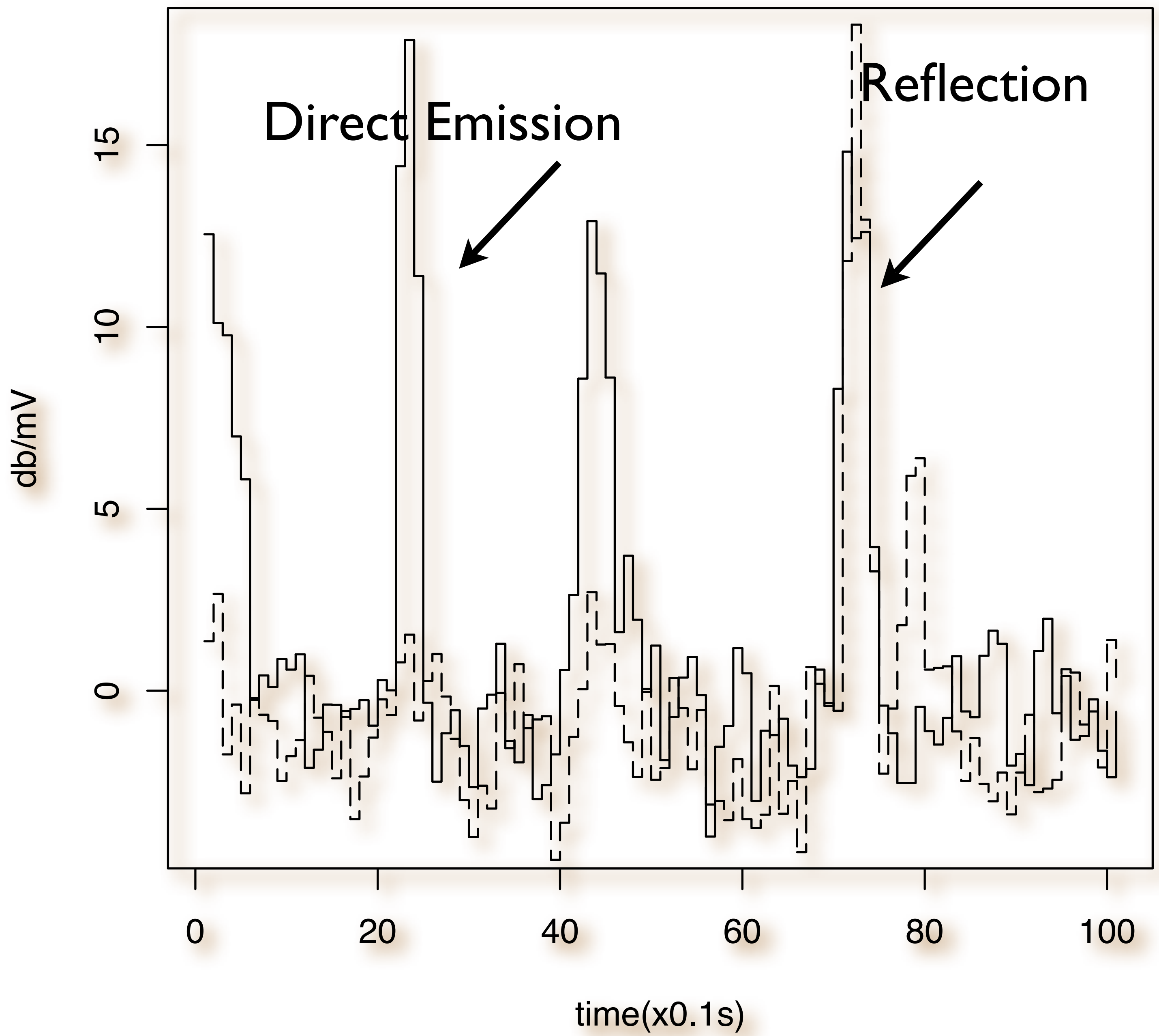
Sample Meteor Signal



E-W

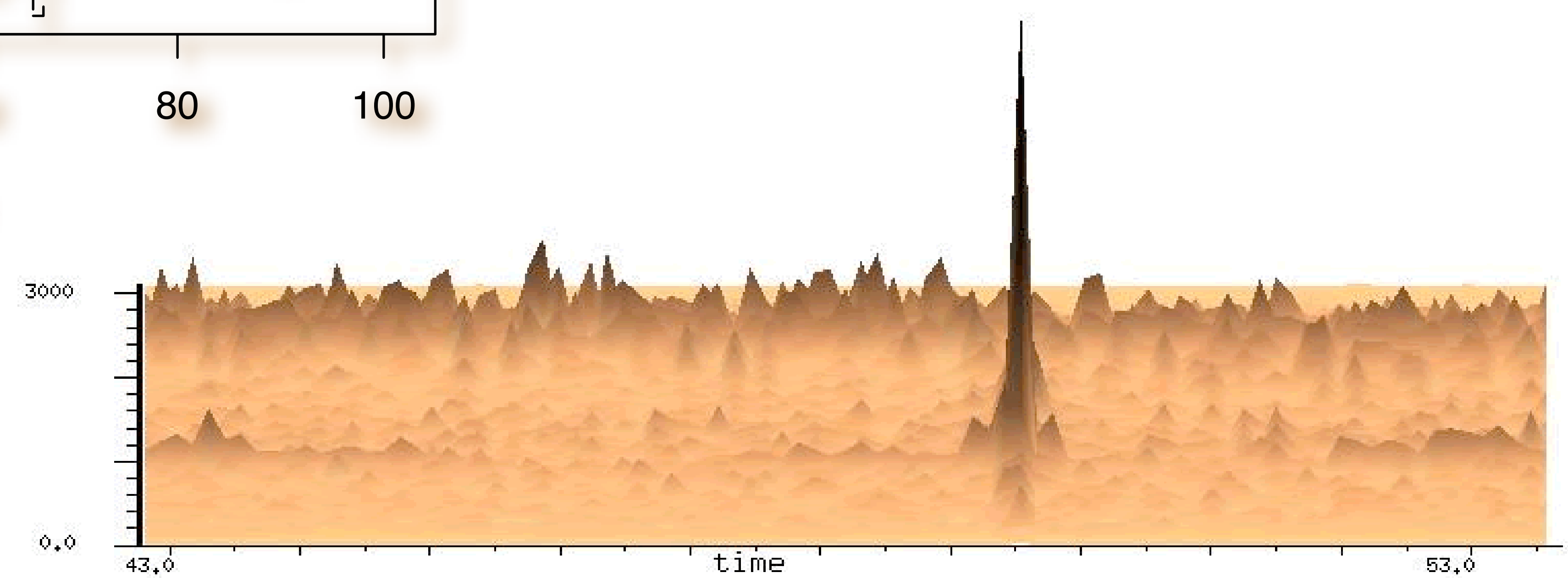
N-S

Lightning



Lightning produces a lot of ionization!

We receive direct emission and reflection. Perhaps from exotic forms?

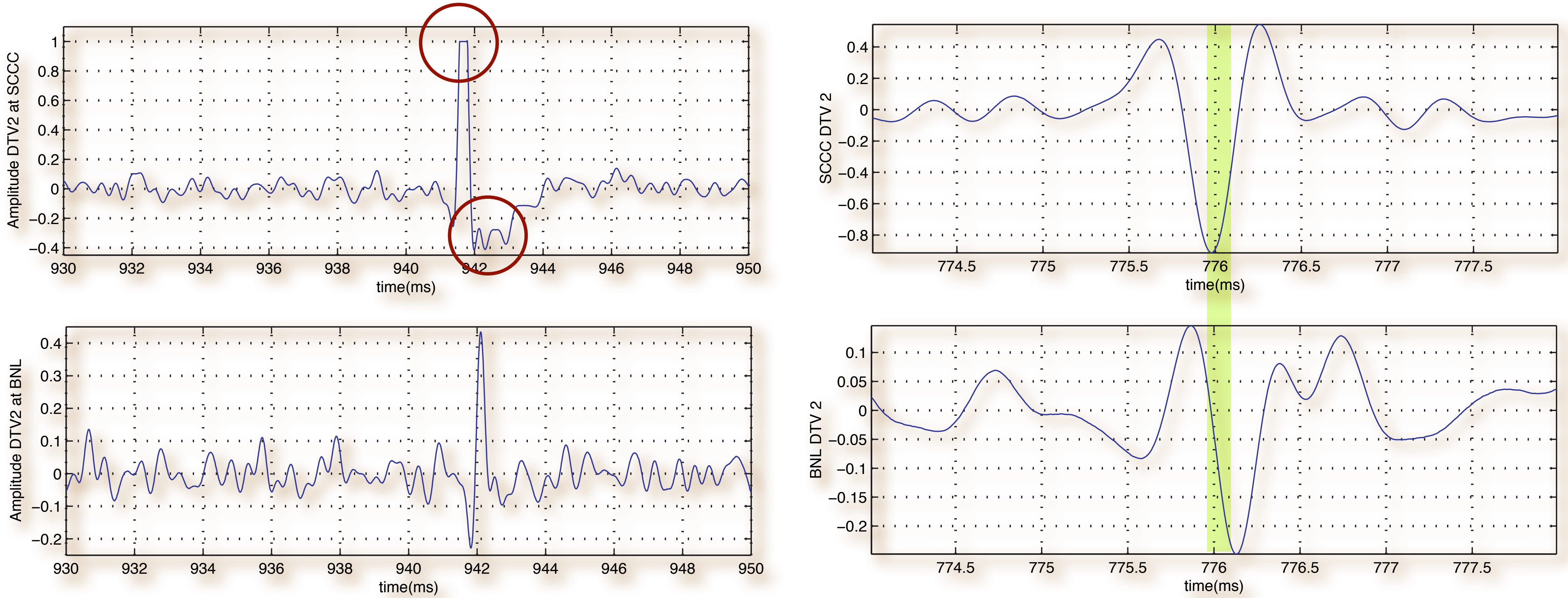


Coincidences

We are starting to correlate information from the 2 stations - SCCC and BNL

SCCC

BNL



Distance between SCCC and BNL is ~20km, or 67 μs.

Summary

Bistatic (Multistatic) Radar seems to be a feasible technology for the detection of UHECR.

Current estimates using modest transmission power yields received power levels that are above noise and detectable by current existing technology.

Software defined radio is an evolving technology (open source software and hardware) that could be used for a phased array detection system.

Noise is one of the most important issues in this business since radio is everywhere.

Simultaneous runs with established cosmic ray experiments is a must.