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Update and News on Cosmic Ray Radar Detection System

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Rehak's First Law of Presentation's Quality

The product between the quality of talk and fanciness of presentation is a constant!

Science Motivation

Cosmic rays with energy larger than 10^{20} eV have been detected.

These events happen at a rate of few per square kilometer per year!

They should not exist, or their flux greatly attenuated, if sources are outside our galaxy because they would interact with the microwave cosmic background (Greisen-Zatsepin-Kuzmin cutoff).

To study them we need very large detectors - in fact there are few under construction and few operating (~3,000 km^2)

Prospects of funding for something larger | /dev/null
Not realistic to wait 20 years, I'd rather go fishing - new ideas are needed.

Long relationship between radar and cosmic rays.

Blacket and Lovell - 1940's

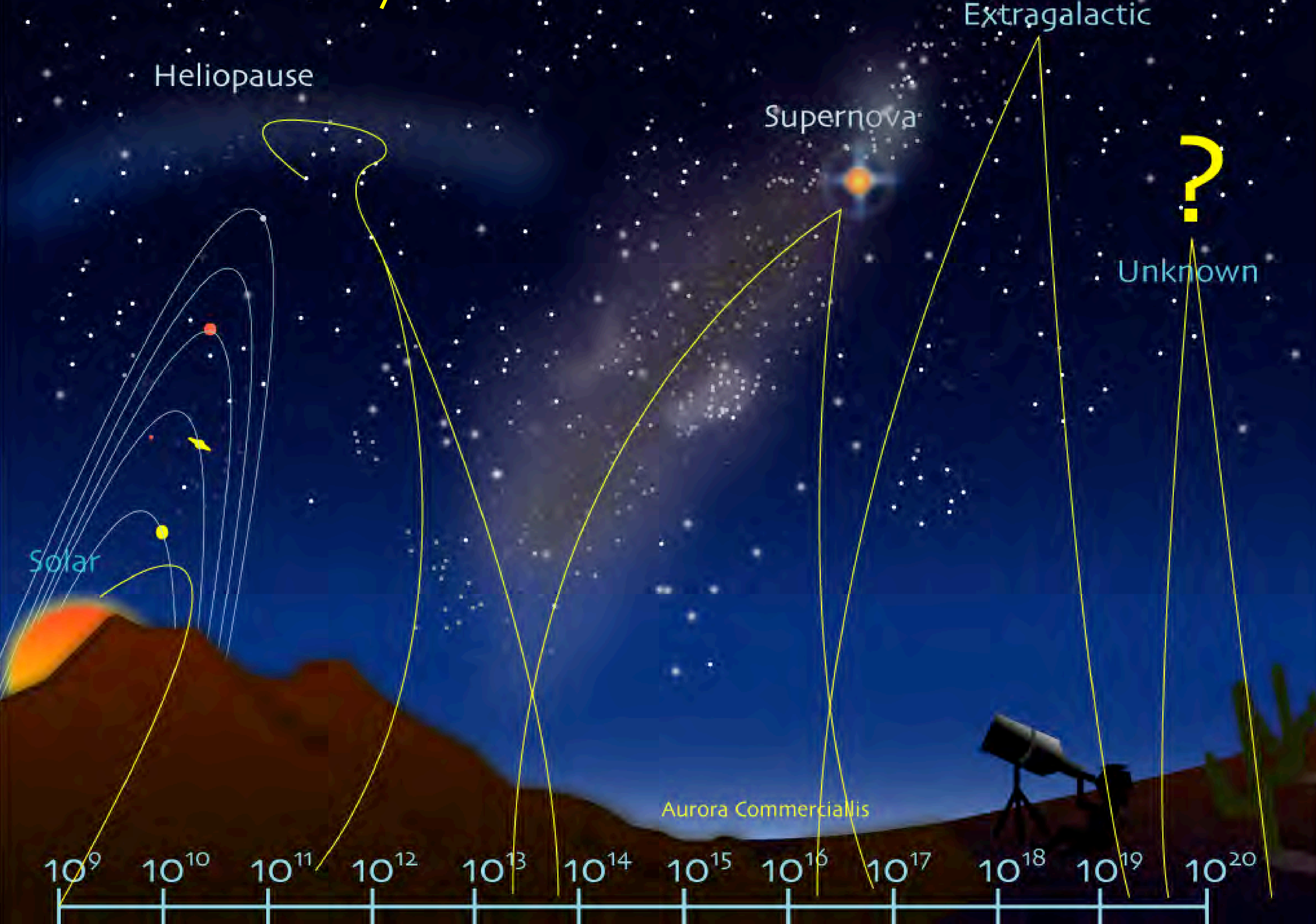
The Early Days at Jodrell Bank

In late 1945 Dr. Bernard Lovell (as he was then) returned to Manchester University after working on the development of radar during the war years. His aim was to continue his researches into cosmic rays - highly energetic particles that enter the Earth's atmosphere from outer space. He had the idea that sporadic echoes sometimes received by military radars might be the result of cosmic rays entering the atmosphere and thus radar observations might provide a new way to continue his researches. Radar observations were not practical in the centre of Manchester so he took his ex-army radar system out to the University's Botanical Grounds at Jodrell Bank, some twenty miles to the south. By the middle of December 1945, the system was operating and his team was soon able to prove that the echoes were coming not from cosmic rays but from ionized meteor trails left behind when small particles, mostly released from comets, burn up in the upper atmosphere of the Earth.

http://www.jb.man.ac.uk/booklet/History.html

Extreme Energy Cosmic Ray

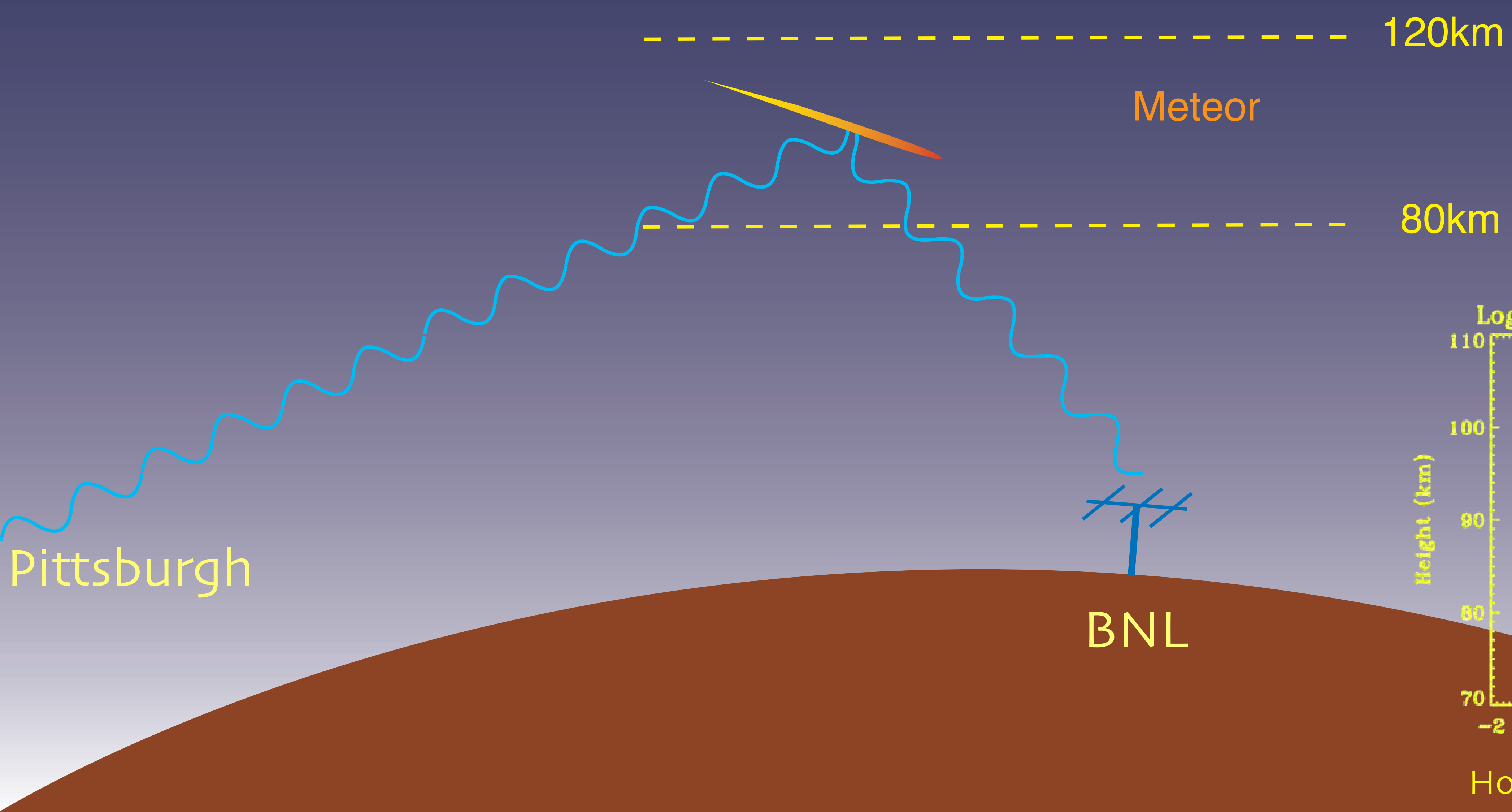
Where do they come from?

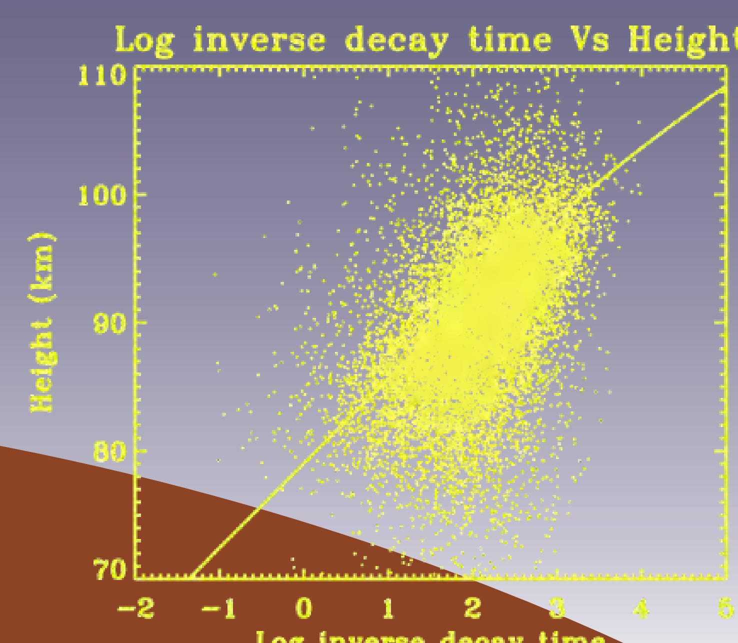


Radio Meteor Scatter

Meteors when entering earth's atmosphere vaporizes creating an ionized trail.

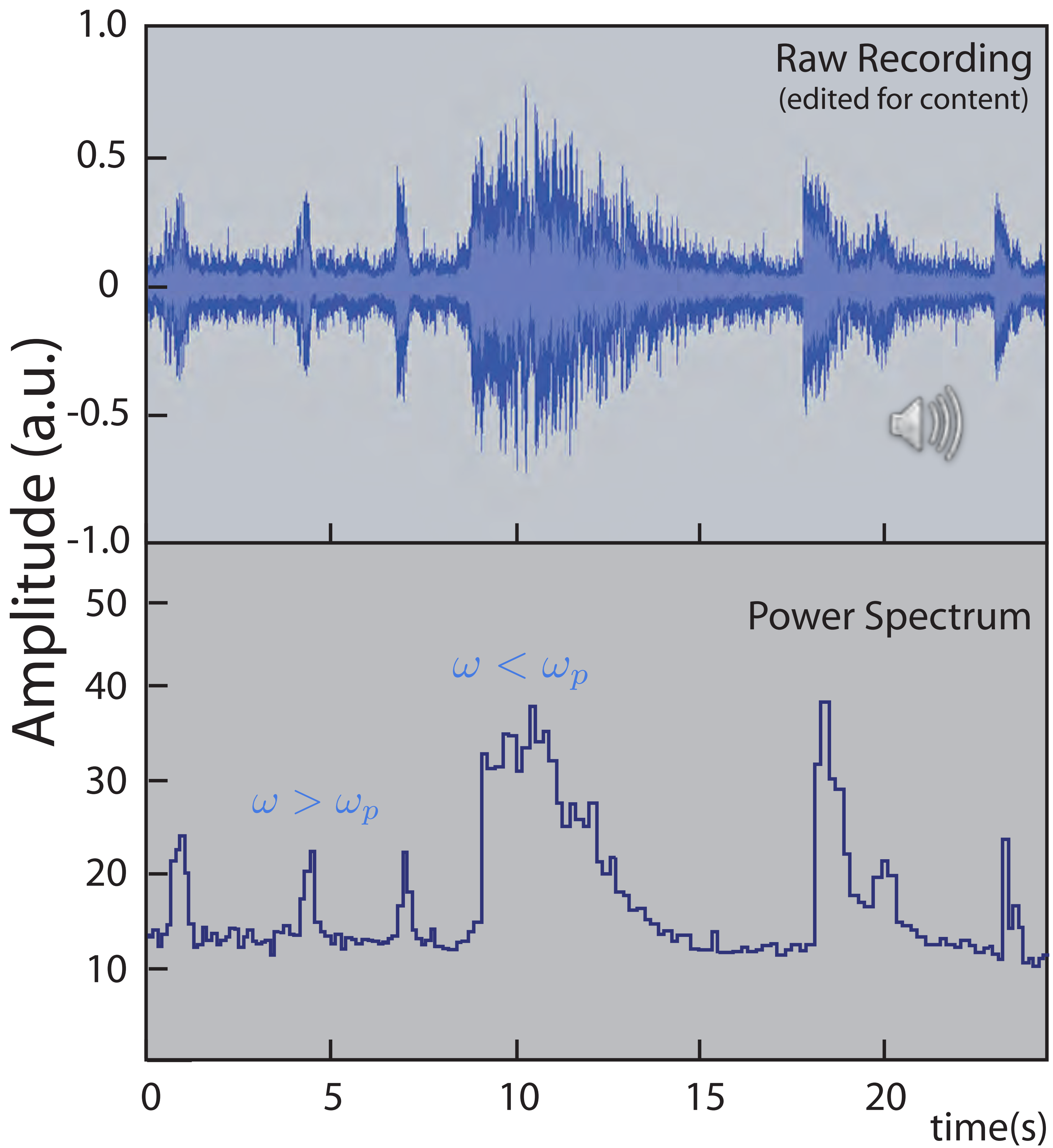
Radio waves from far (1000-2000 km typical) are reflected by the ionization created by them.





Holdsworth,Reid and Cervera

Recording of Meteor Signal



Recorded "sound" of meteors. PCR 1000 radio receiver and 8 bit digitizer.

After FFT and loose selection of frequencies around carrier frequency

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

for 50 MHz, $n_e \sim 10^{13}$ e/m^3

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Can we use radio to detect Cosmic Rays?

Radio is scattered by electrons and not by ions, hence the signal exists while electrons are free

Ionization in meteor trails can last for several sec.

How about cosmic ray showers?

Ionization process in showers is very different than meteors.

We resort to air shower simulations.

A more recent publication

The concept evolved over the years, and the most recent publication addresses the issue in detail.

P. Gorham - 2001 [Astroparticle Physics 15(2001)177]

ELSEVIER

Astroparticle Physics 15 (2001) 177–202

Astroparticle Physics

www.elsevier.nl/locate/astropart

On the possibility of radar echo detection of ultra-high energy cosmic ray- and neutrino-induced extensive air showers

Peter W. Gorham

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove, Drive, Pasadena, CA 91109, USA

Received 1 February 2000; received in revised form 30 May 2000; accepted 24 July 2000

Their main goal has been the use of active radar for cosmic ray detection. None on passive radar. However, we profit greatly from their theoretical studies.

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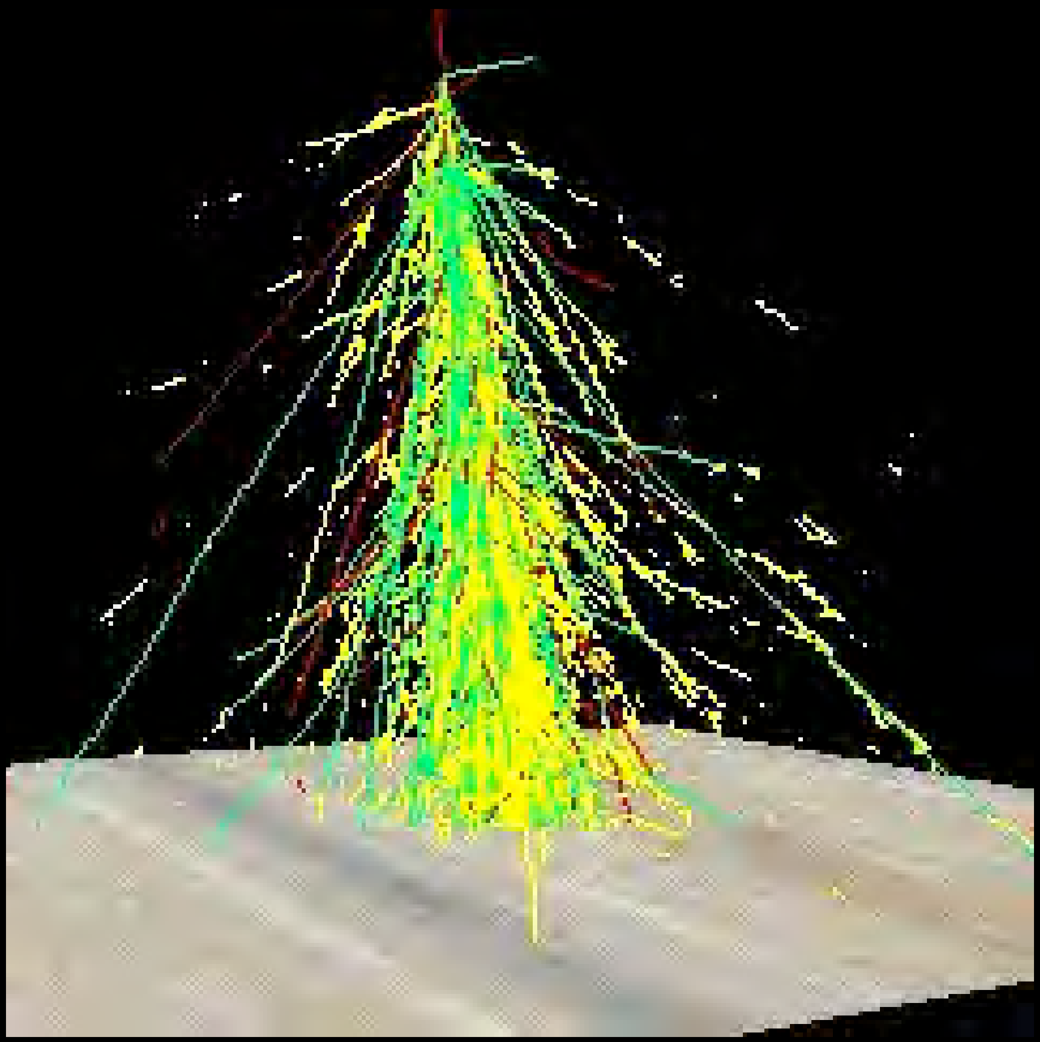
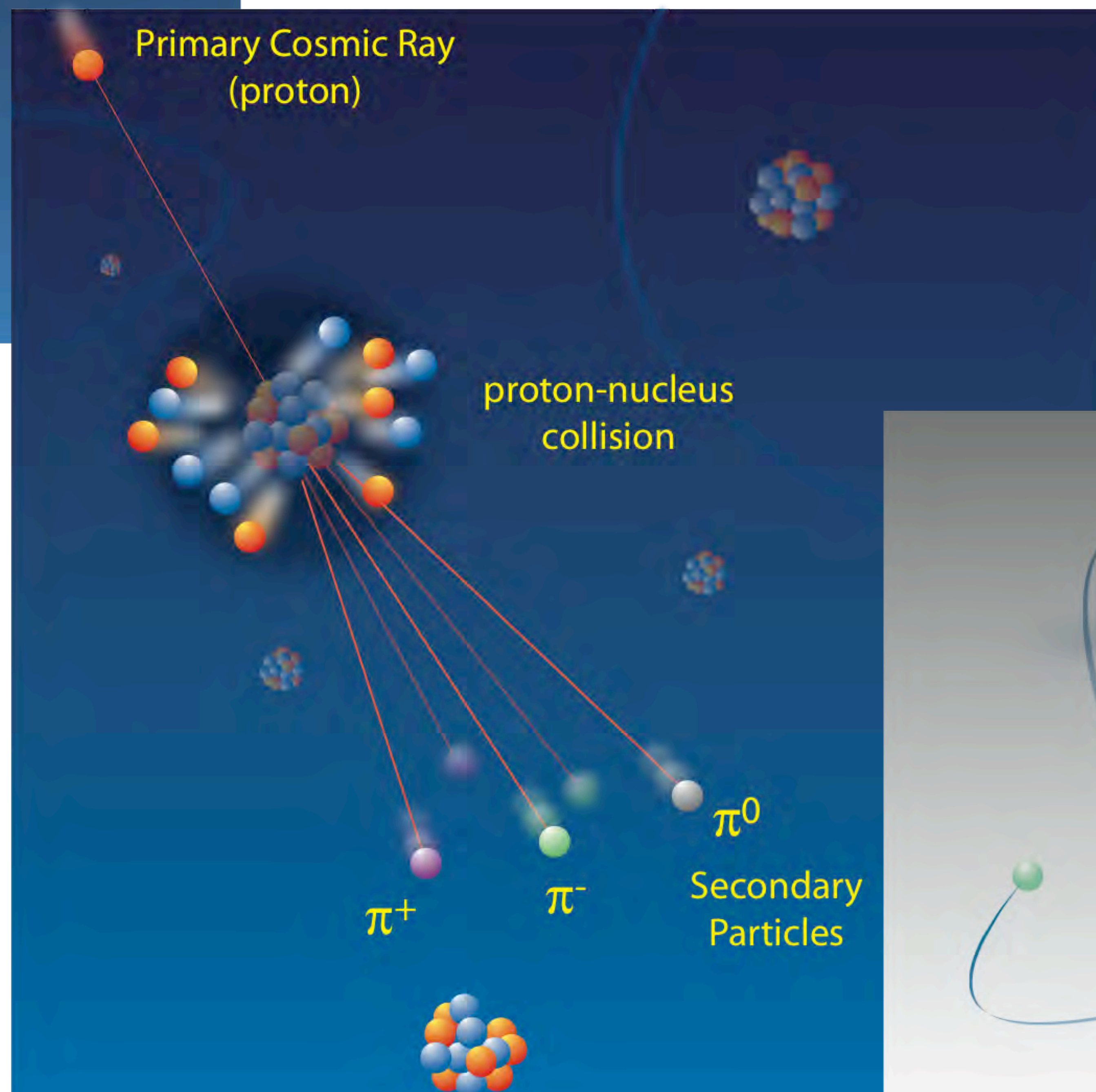
Simulated Cosmic Ray Shower

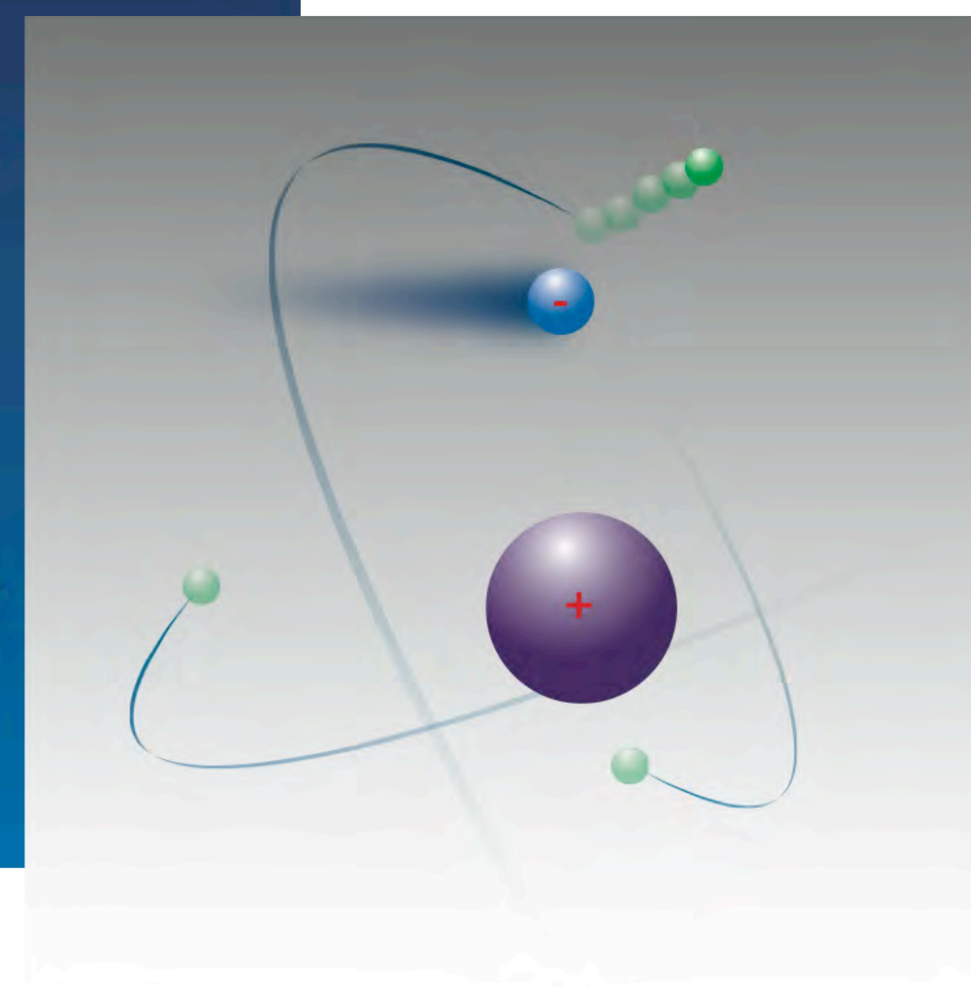


Shower production and ionization

Meteor

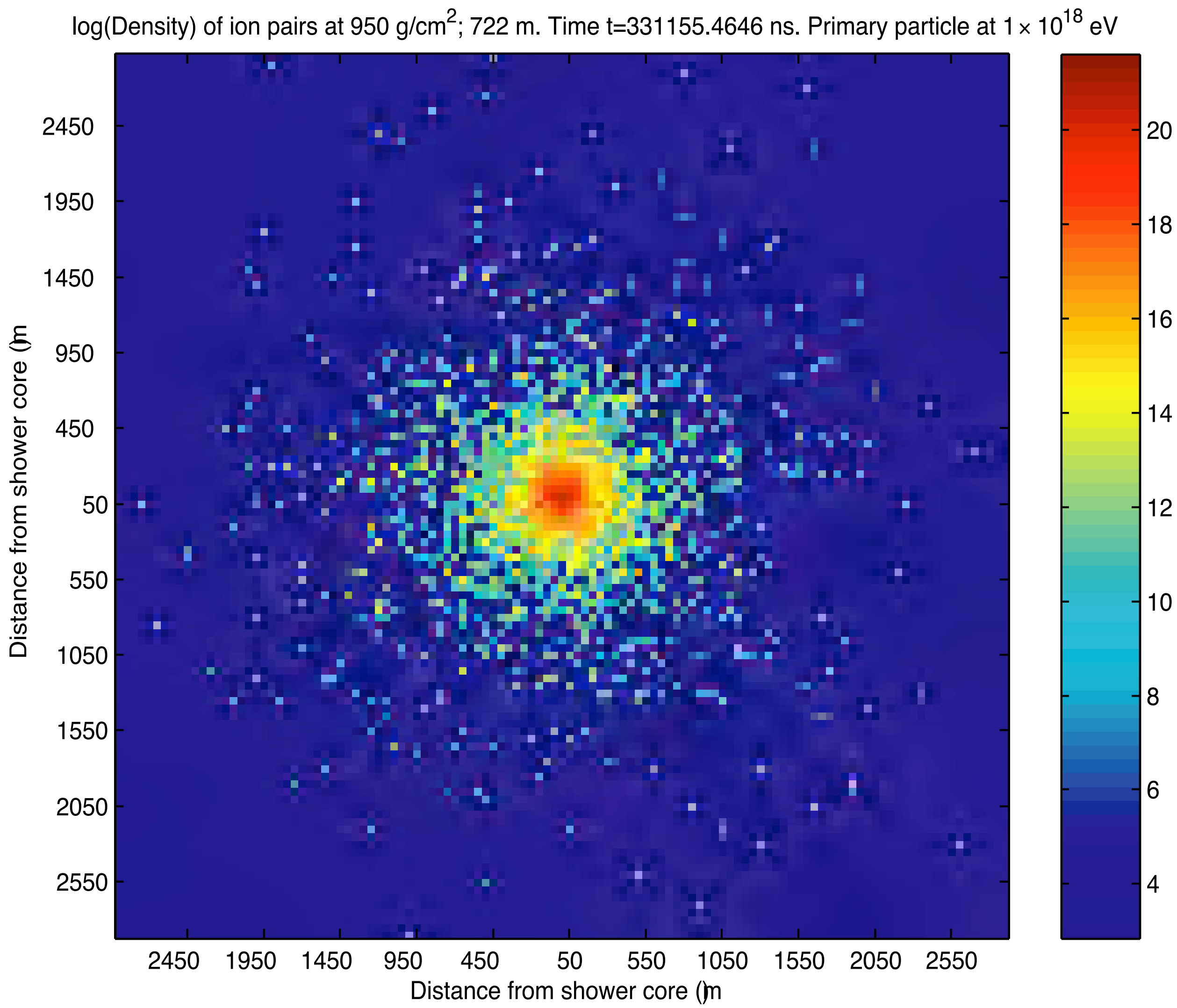
Particle Production

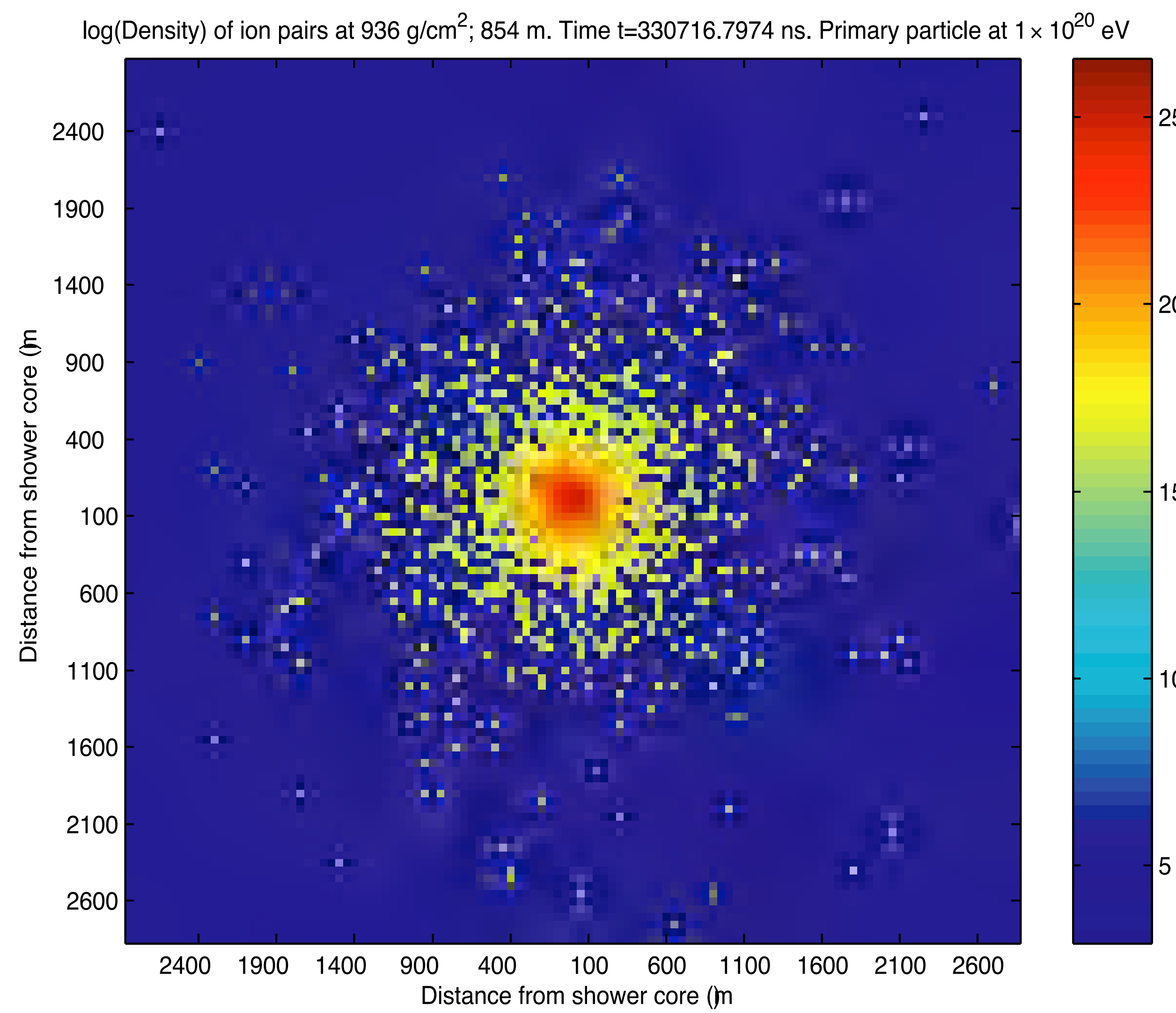




Cold Ionization

Electron Density





at 10^{18} eV, core ionization (r<2m) reaches 5×10^{13} e/m^3

at 10^{20} eV, this number grows to <u>2×10^{17} e/m^3</u>

<u>Caveat</u>: p+A physics is known only up to RHIC energies.

leap of faith - "QCD works at simulated energies"

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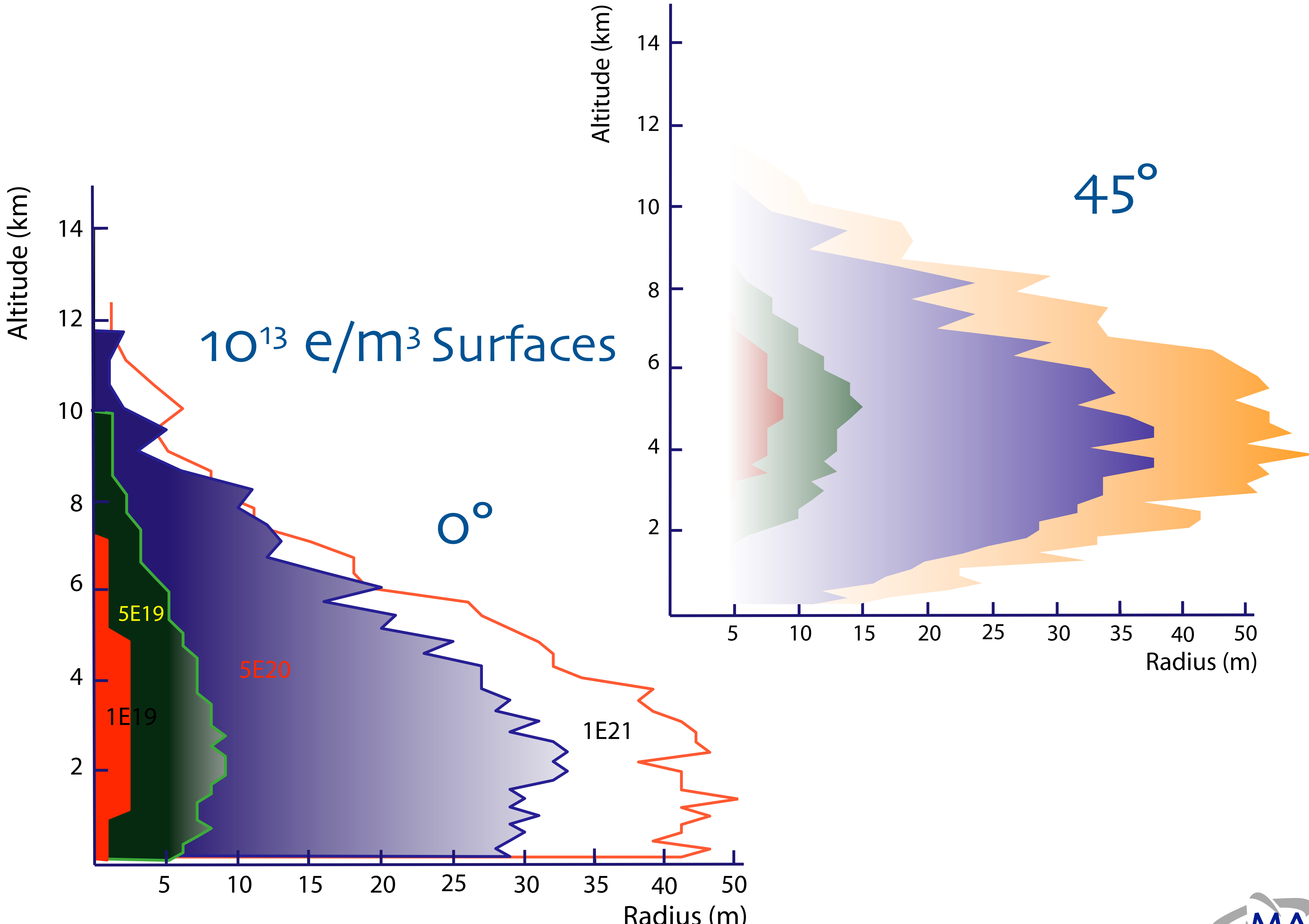
Electron Cloud Profiles



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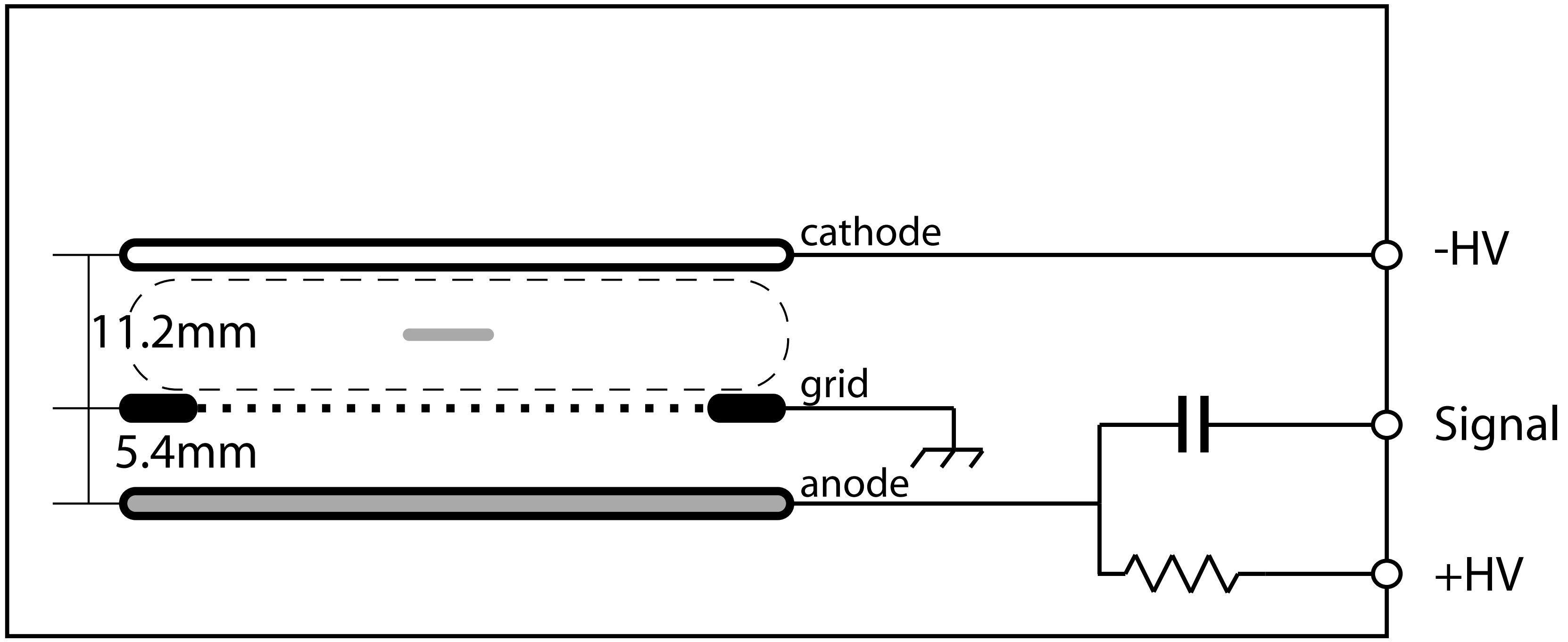
NSLS measurement

Create a lot of electrons, let them interact with air and collect what is left ... after a while.

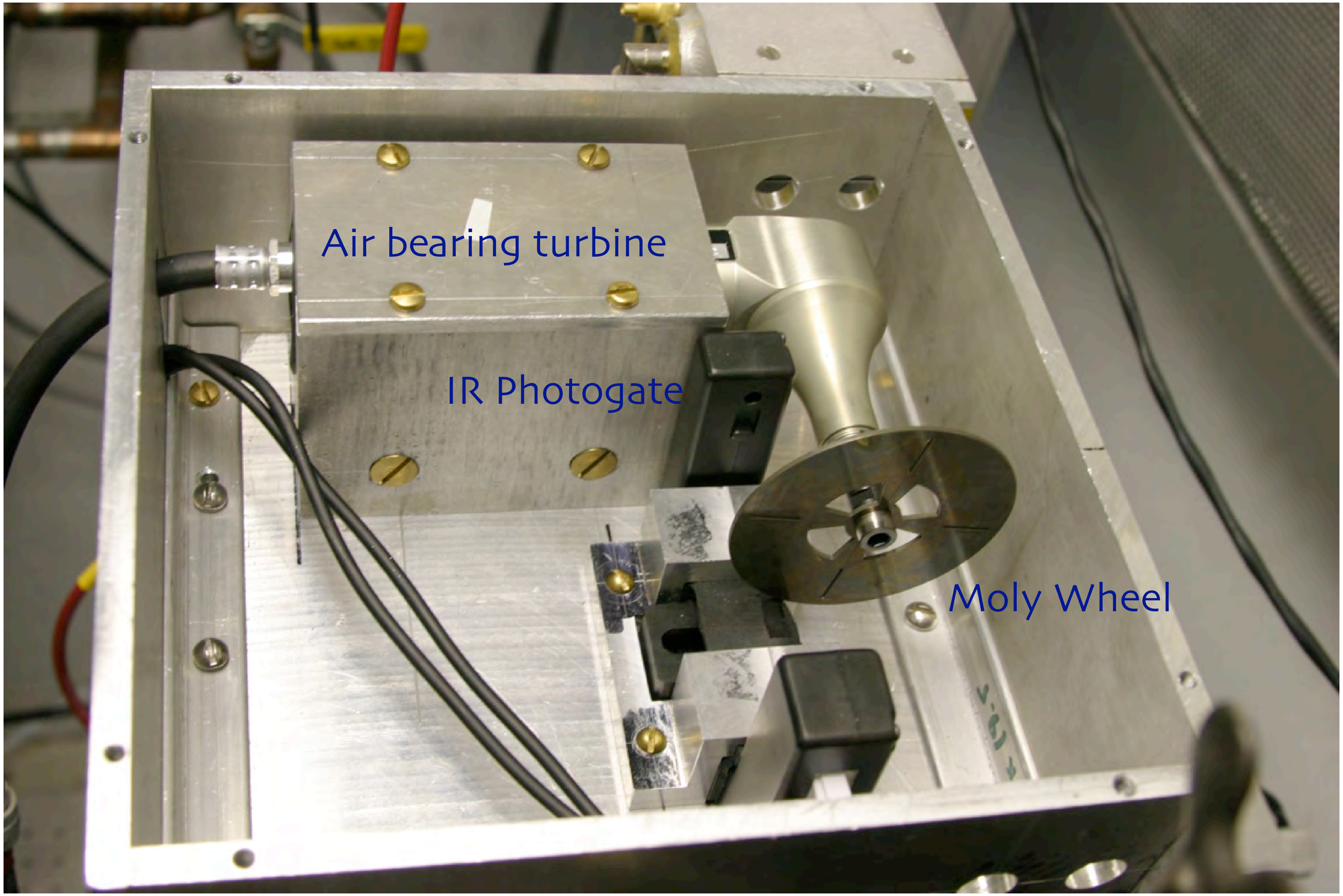


Recombination vs Attachment

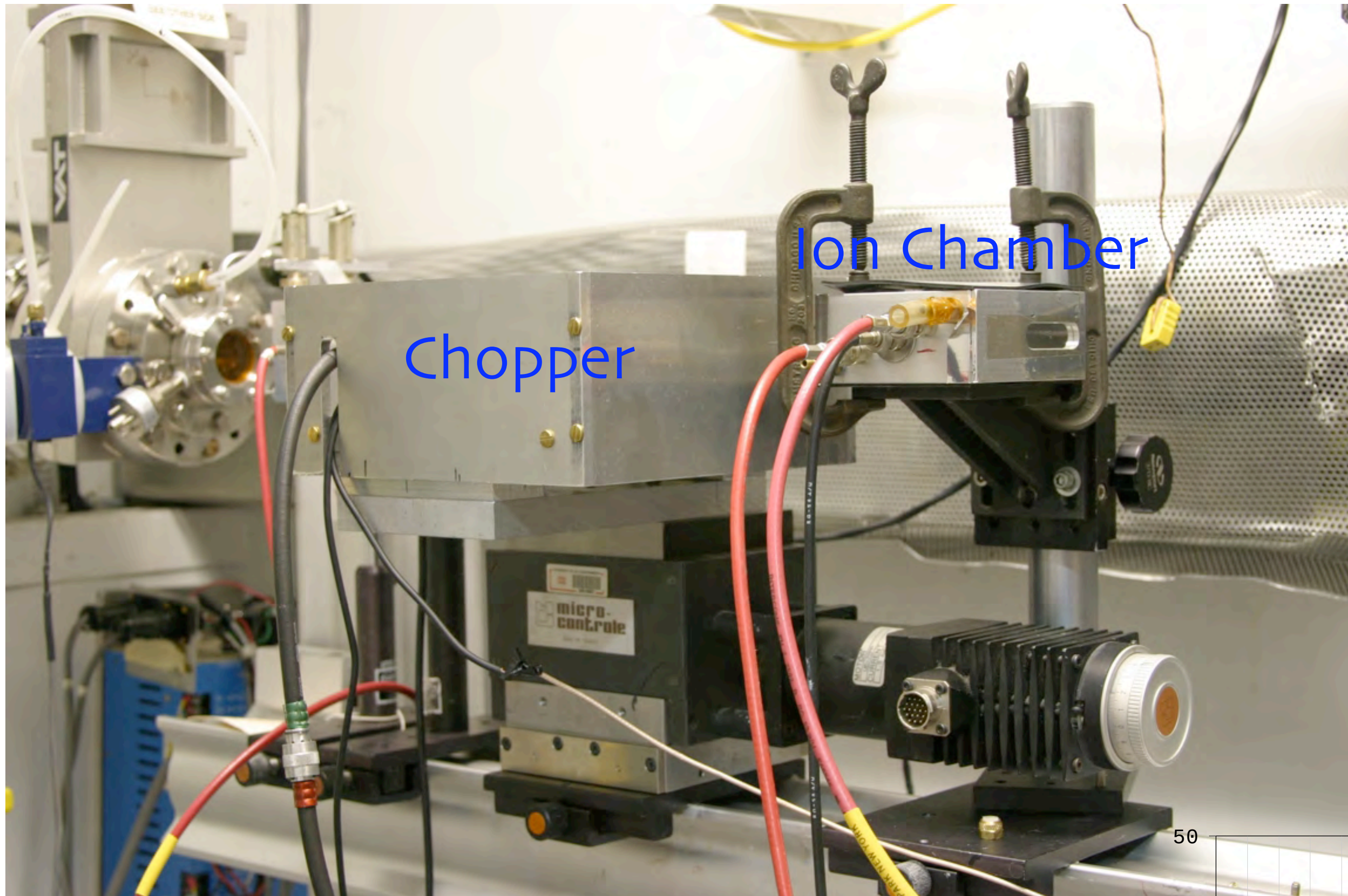
Use X-rays from the NSLS to produce ionization densities similar to what we expect.

X-Ray Beam Chopper

Can't use continuous beam - need to chop X-Rays

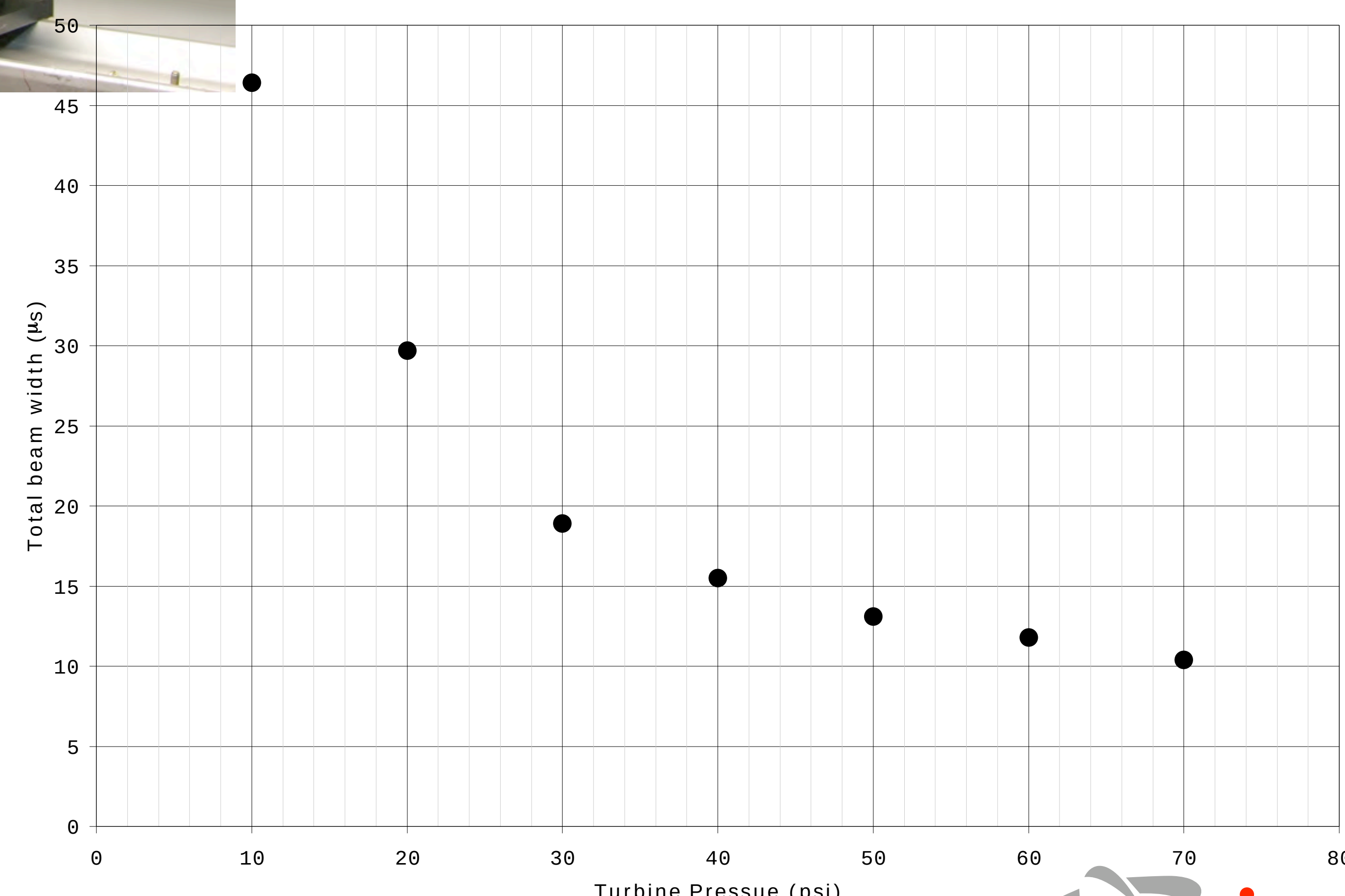


X16C beamline setup



Experimental setup at the BNL Synchrotron Light Source. A 10keV beam is chopped and ionizes air (or gas) inside the ion chamber. Electrons are collected after interacting with gas in the chamber.

Measured total x-ray beam width as function of air turbine pressure. Measurements done with a photodiode. Shorter beam times are possible with different "wheels".



Lifetime Measurement

Performed at the NSLS- BNL using chopped X-ray beam at atmospheric pressure (lower pressures under analysis).

Lifetime ~ 0.4 μs for ionization density given by simulations.

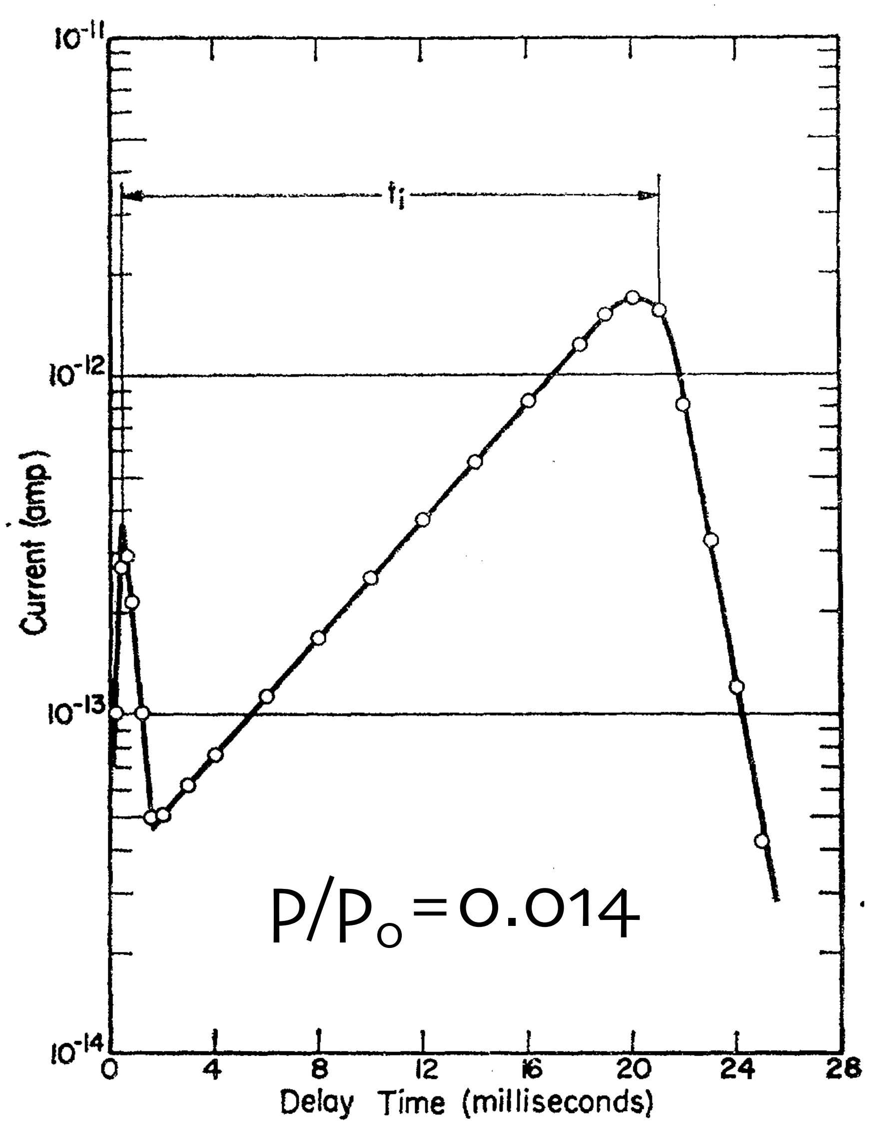
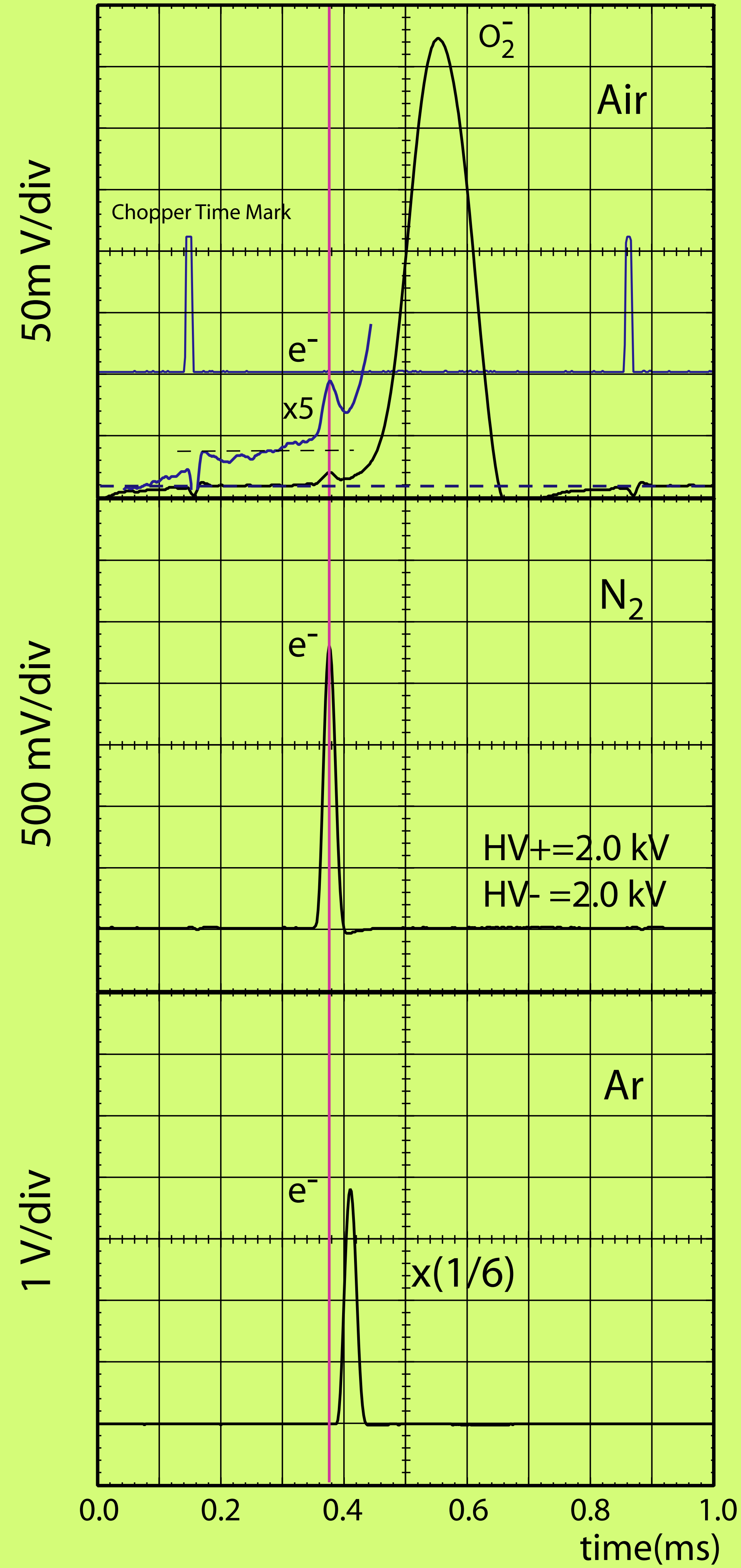


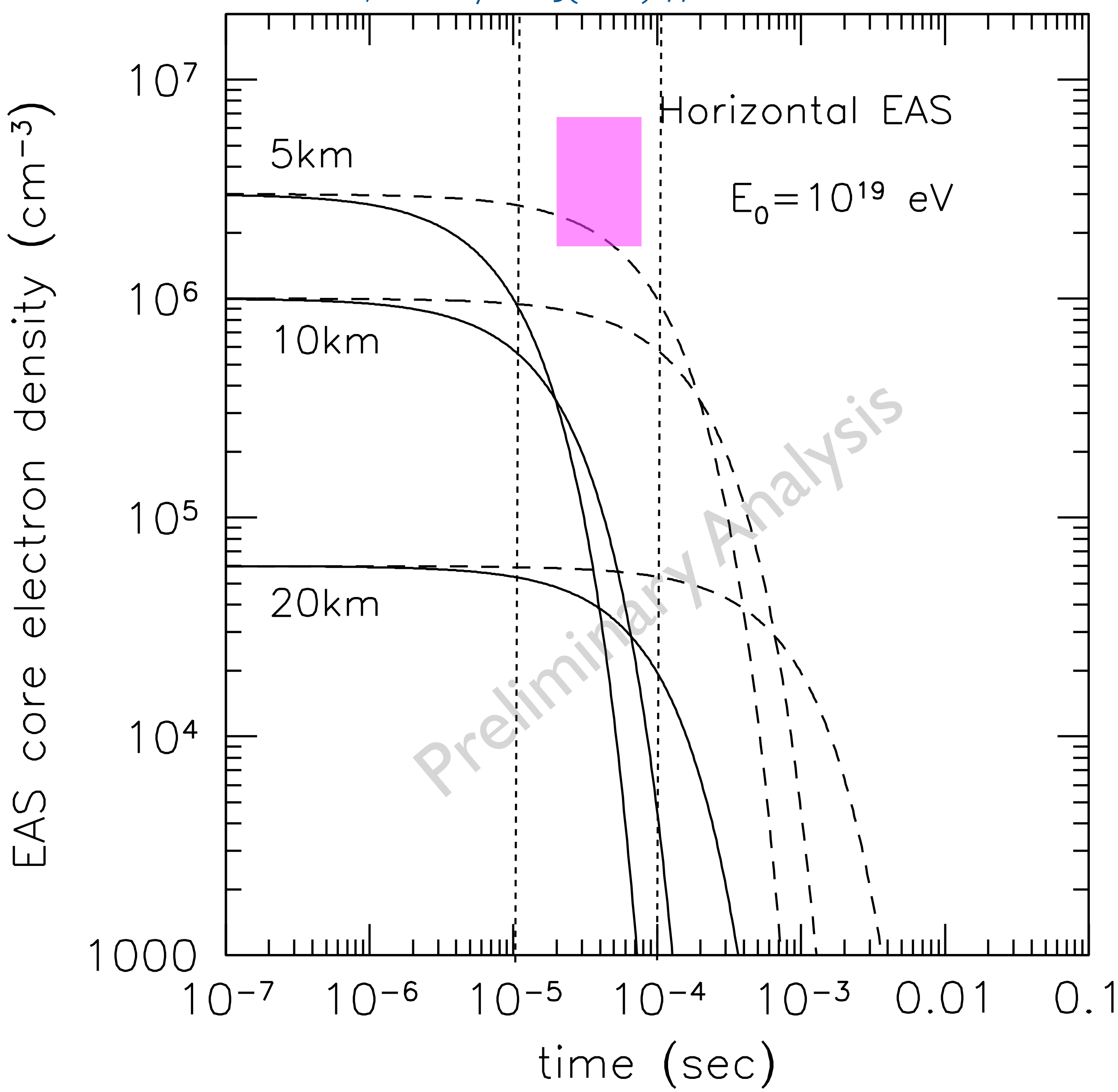
FIG. 3. Observed current waveform with pure O_2 for $E/p=0.25$ volt/cm-mm Hg and $p_{300}=10.5$ mm Hg. The first peak is due to electrons which cross the tube without attaching to the oxygen. The remainder of the waveform is due to the negative ions.

Chanin, Phelps and Biondi, P.Review 128(1962)219

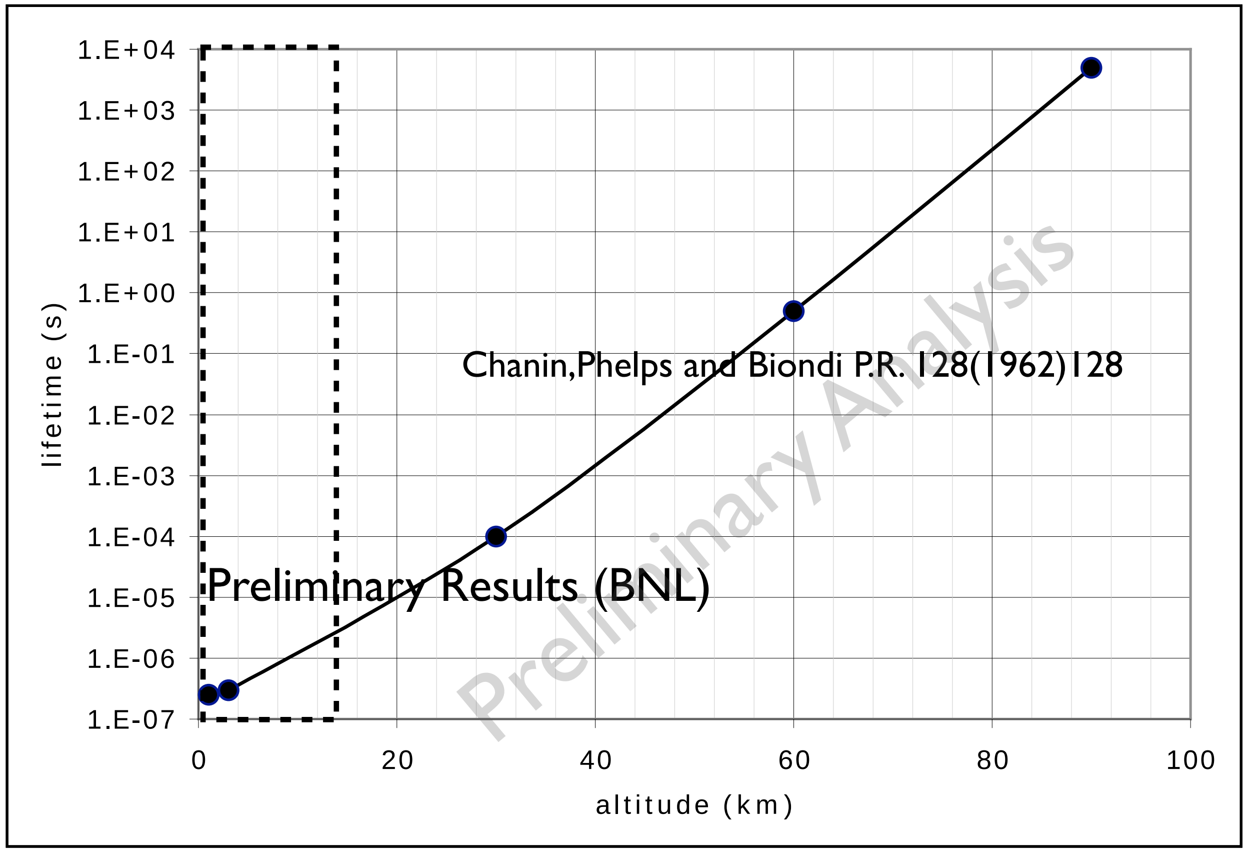


Lifetime Considerations

P. Gorham, Ast. Physics 15(2001)177

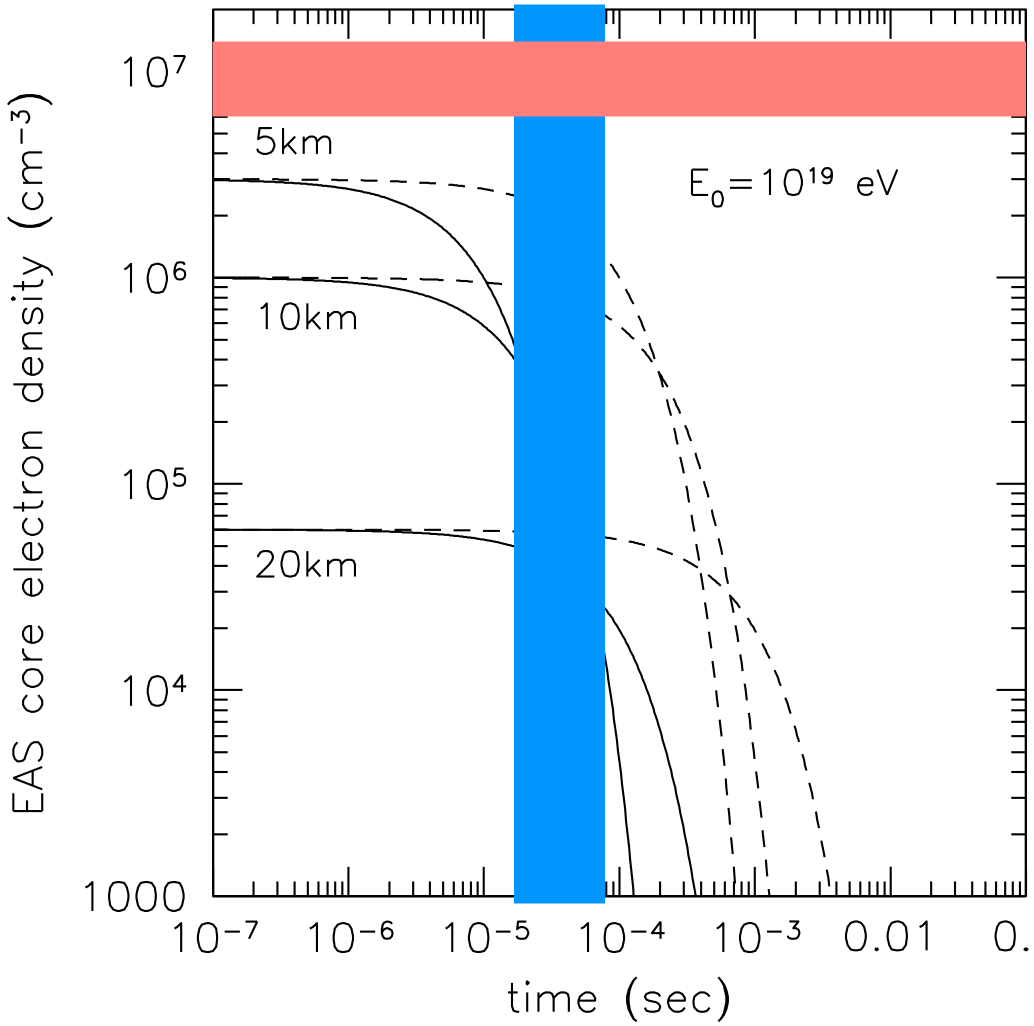


Present measurements indicate signal duration of about 30-50 μs for a 10^{19} eV cosmic ray.



Possible or not Possible?

P. Gorham, Ast. Physics 15(2001)177



Analysis of data taken at atmospheric pressure and at very low drift field show that the attachment lifetime is ~0.5 μs. For 10^{19} eV, it takes ~30 μs for the shower to develop. Therefore the signal should last ~40 μs.

Measurements simulating higher altitudes are needed. However data from higher altitudes can be used and information interpolated. This could give us a good estimate of signal duration and other quantities.

If these numbers hold, the experiment can be realized. To prove its feasibility a coincidence experiment should be built and it will look like this:

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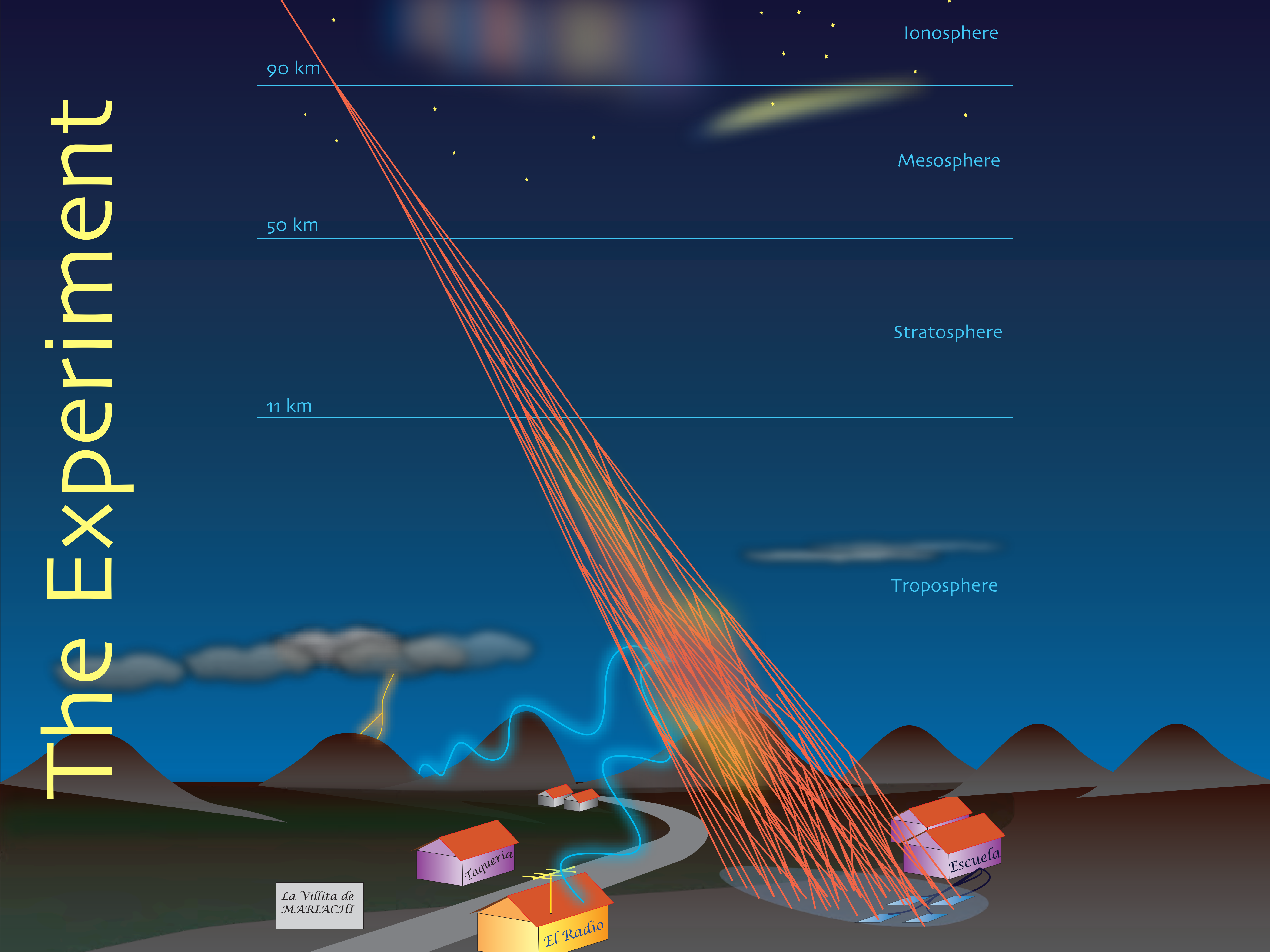
The Experiment
Ionosphere
90 km
Mesosphere
50 km
Stratosphere
11 km
Troposphere
Taqueria
La Villita de
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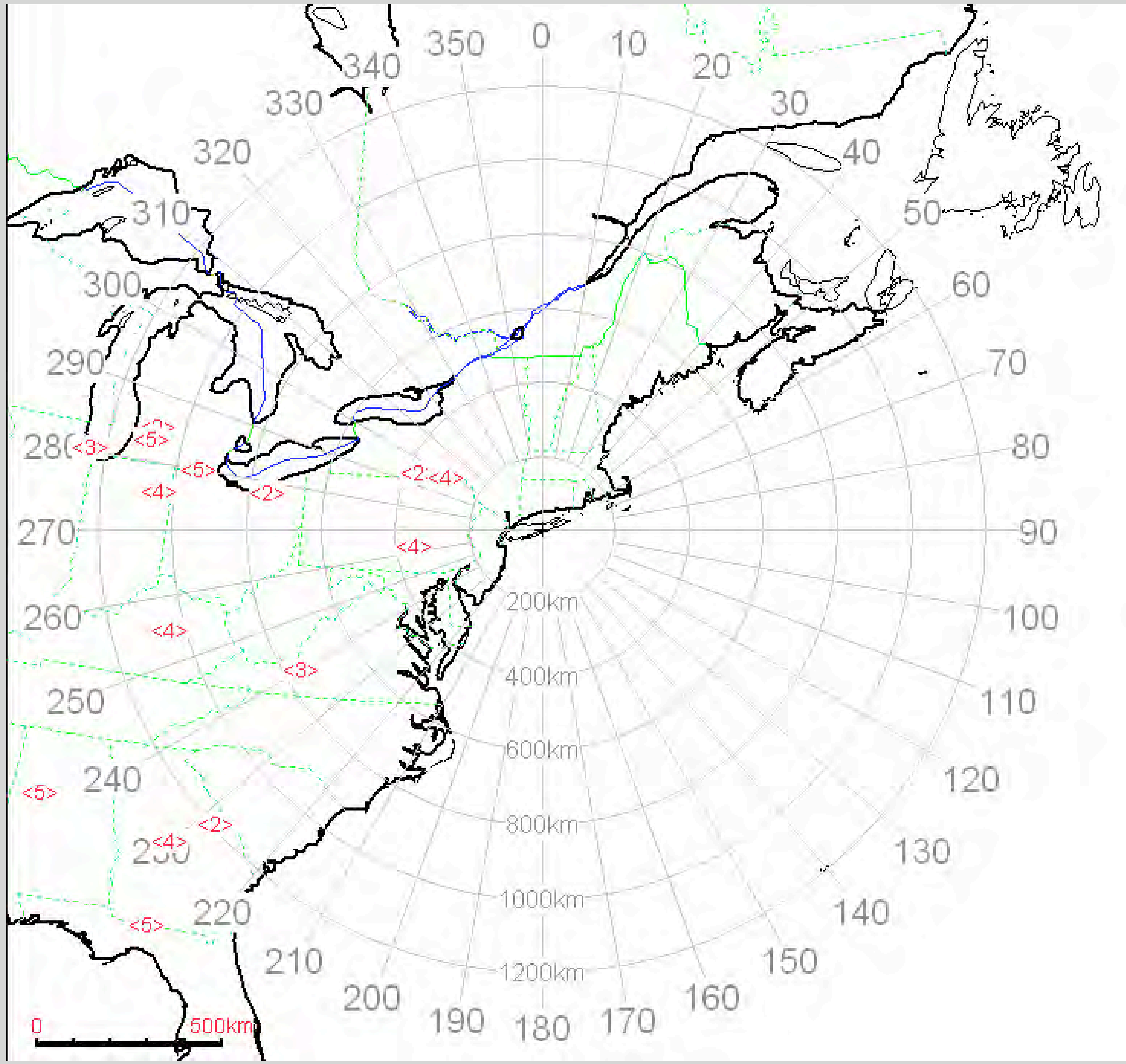
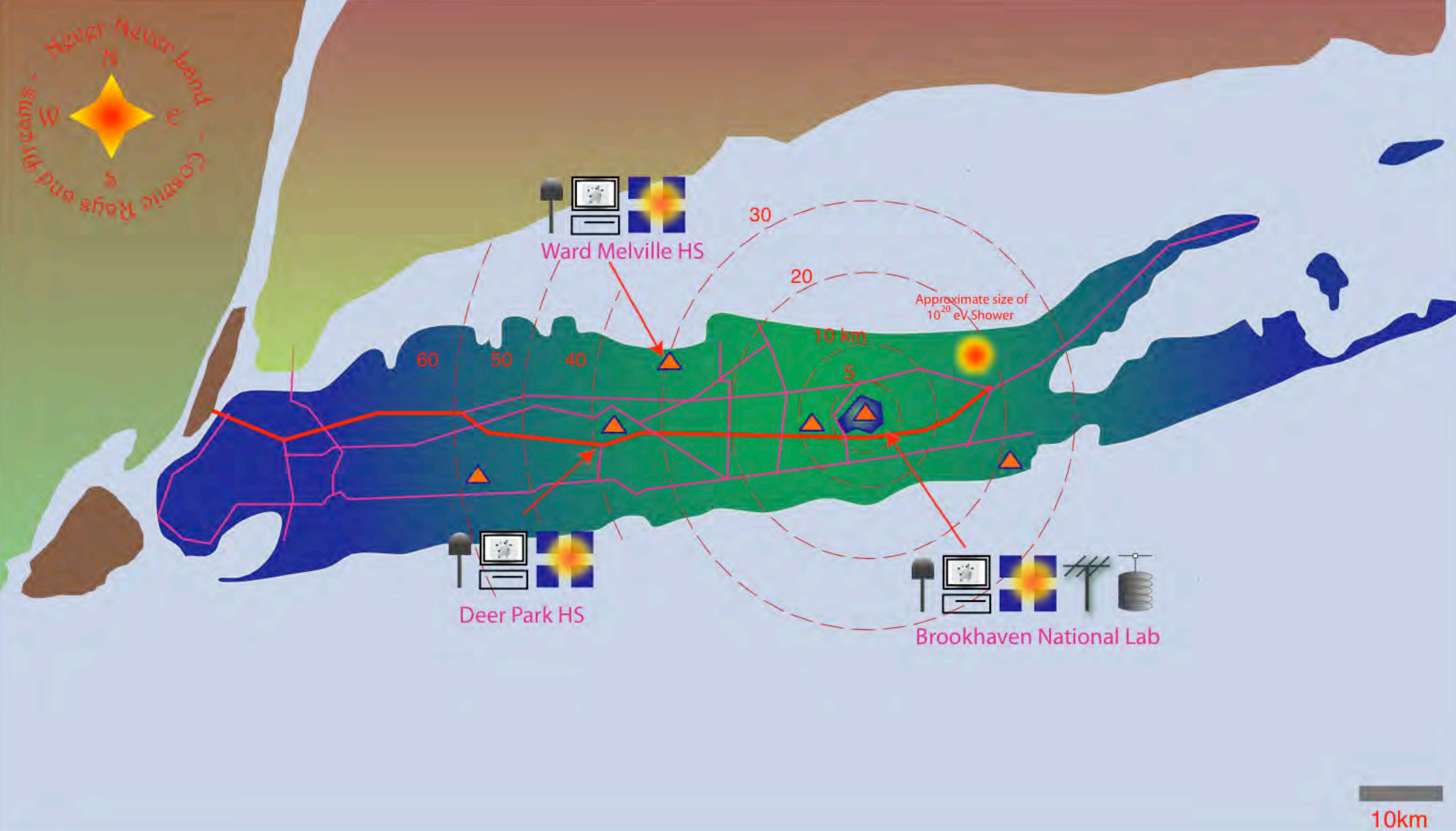
El Radio
Escuela

Digital TV Stations (our favorites)





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

Two pilot radio stations in operation, 7 high schools involved (2 in Md), 2 colleges, SB and BNL

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Radio Stations

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Radio detection system

At the moment we have two pilot stations with PCR 1000 receivers and we record continuously for periods of 1 week.

The BNL setup has two types of antennas, one Yagi and one Log Periodic Dipole Array. A radio 'hut' in BNL was built with 'generous' contributions from many experiments...

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Station at SCCC

A station with two receivers and a GPS clock was installed at SCCC to prove that the same event can be observed at two distant locations.

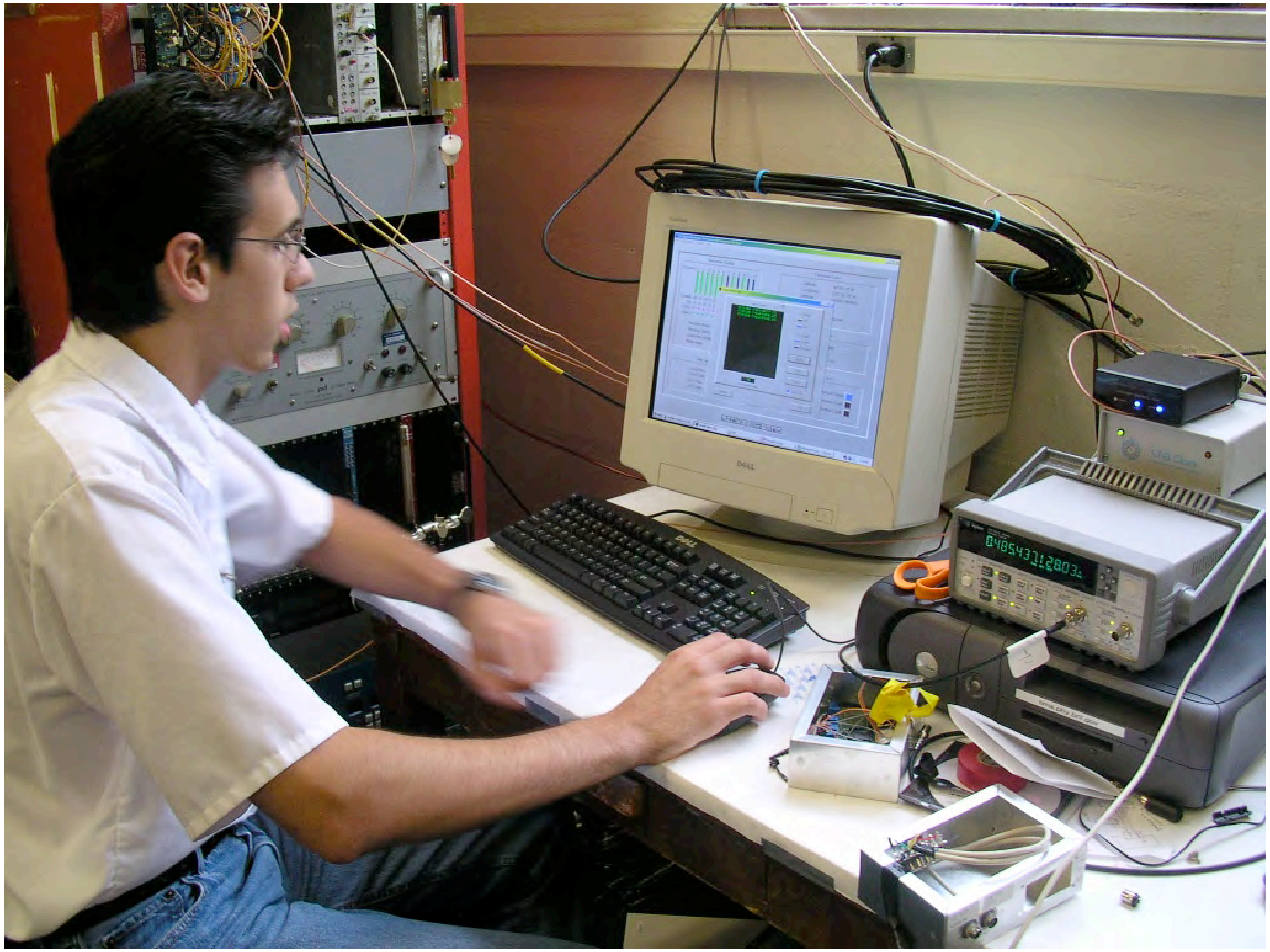
One run that lasted 7 days was taken with data transfered to BNL using removable disks.

Analysis is showing us a lot about how to deal with radio.

With 4 stations one should be able to pin-point the source of signal, and more.

Bob Warasila, Tom Breeden and Mike Inglis, SCCC

GPS clocks



It is relatively easy to setup GPS clocks with ~1-10 μs precision.

It is not so difficult to install clocks with inherent 100 ns precision.

It is difficult to setup clocks with 5-10 ns precision.

For better precision, only atomic clocks!

We have evaluated 4 different GPS clocks - all COTS.

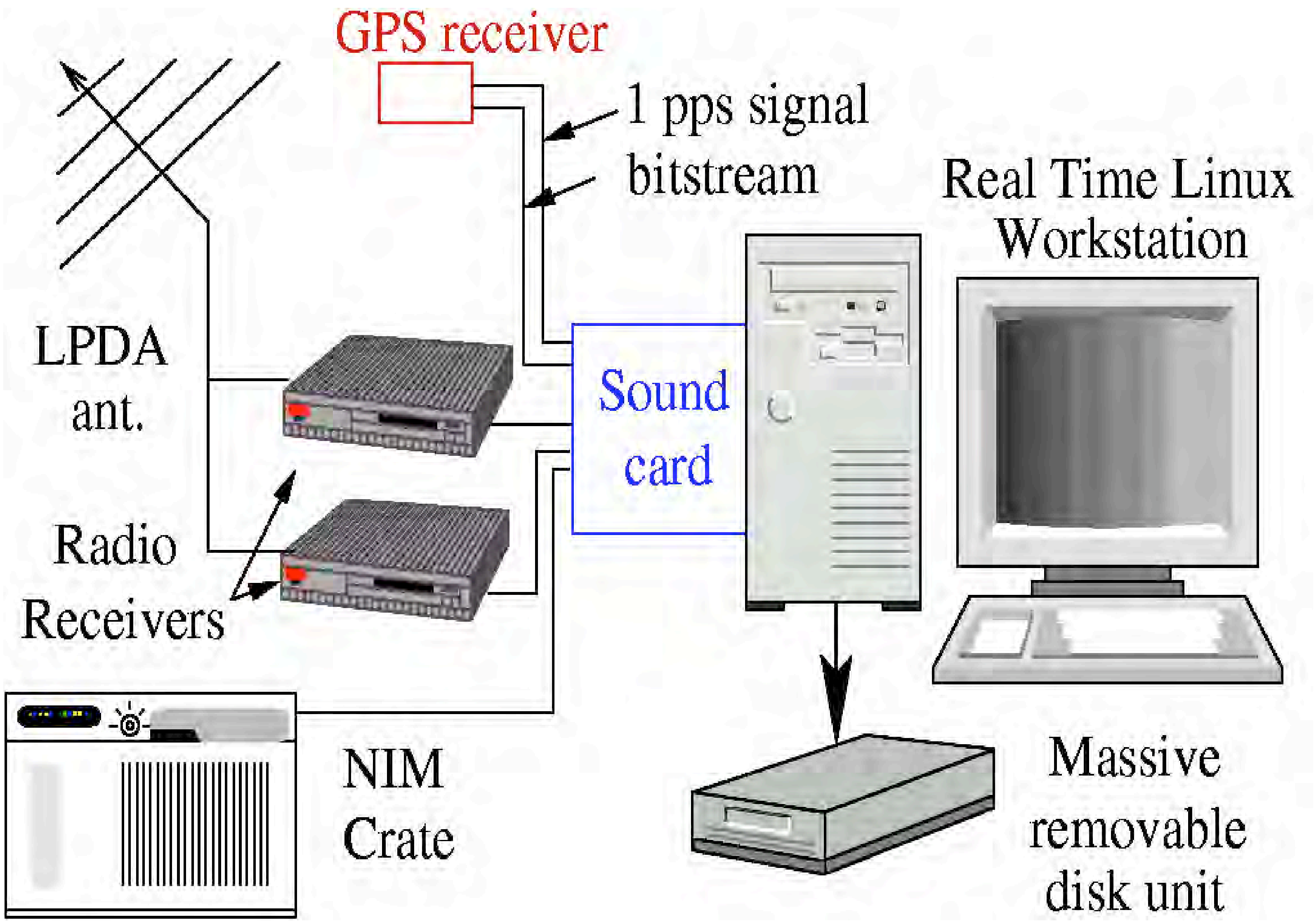
Not all GPS clocks are born the same!
Spectrum Instruments GPS clock is our baseline.

DATA Acquisition System

DAQ is based on radio receivers and real time linux workstations.

The GPS data stream is directly recorded with the data for better timing accuracy. (De Luo GPS)

Data is stored in large disks and transported to BNL for analysis.

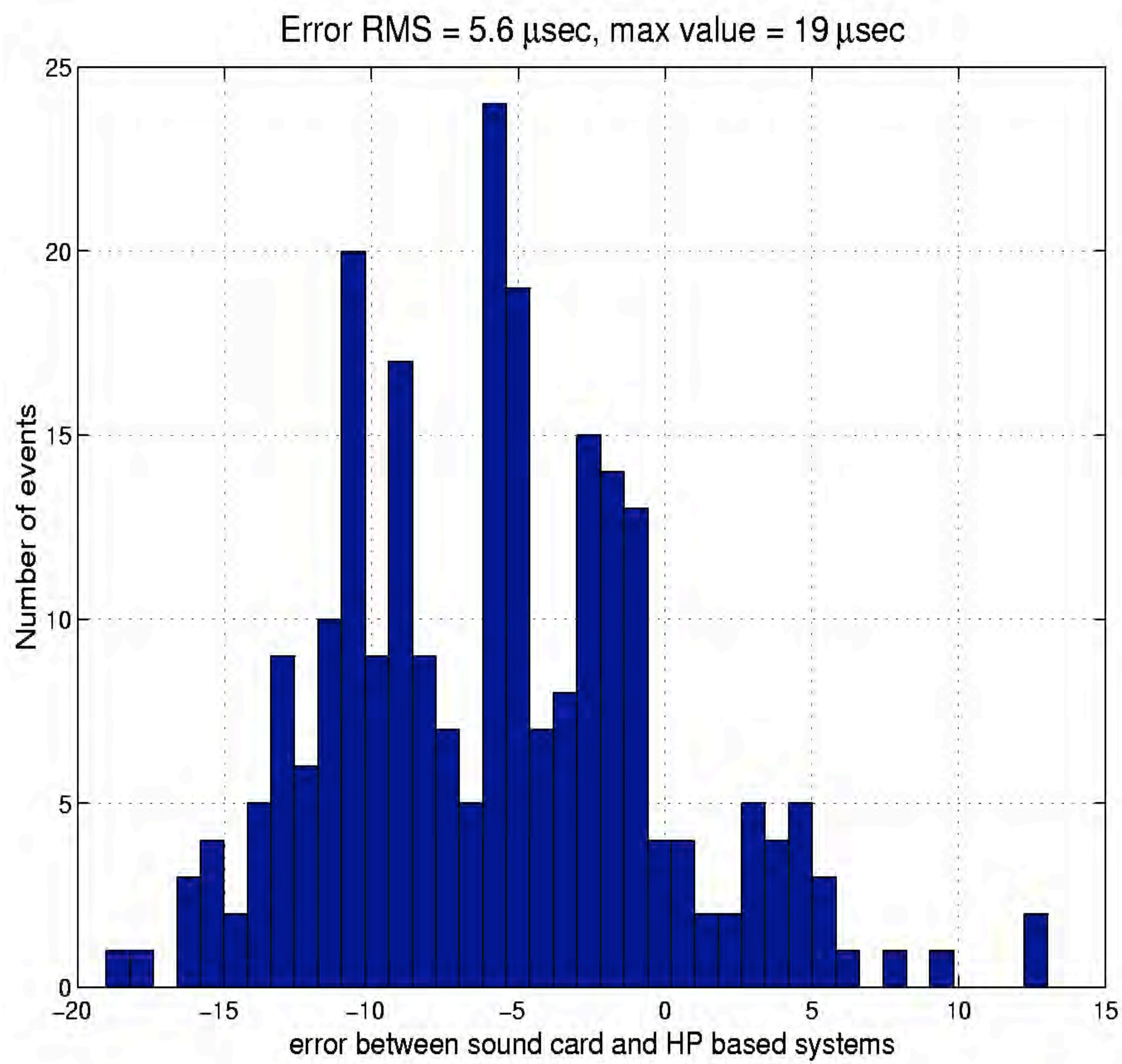


DATA Acquisition System

The NMEA millisecond mark is updated of 1 msec at around 150/180 seconds.

Using this one can interpolate and get a higher precision.

A comparison with a HP+expensive GPS (ns precision) was performed.



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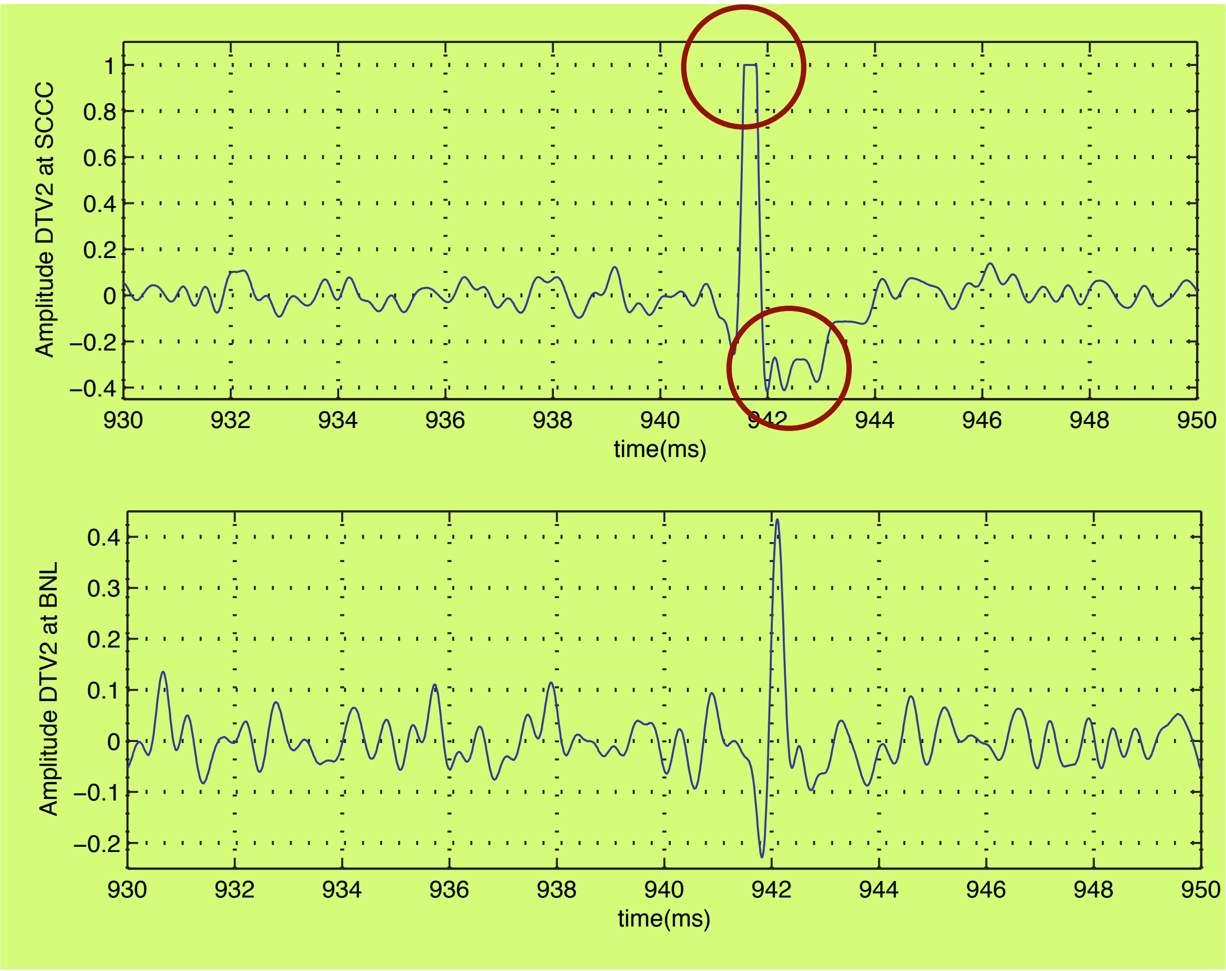
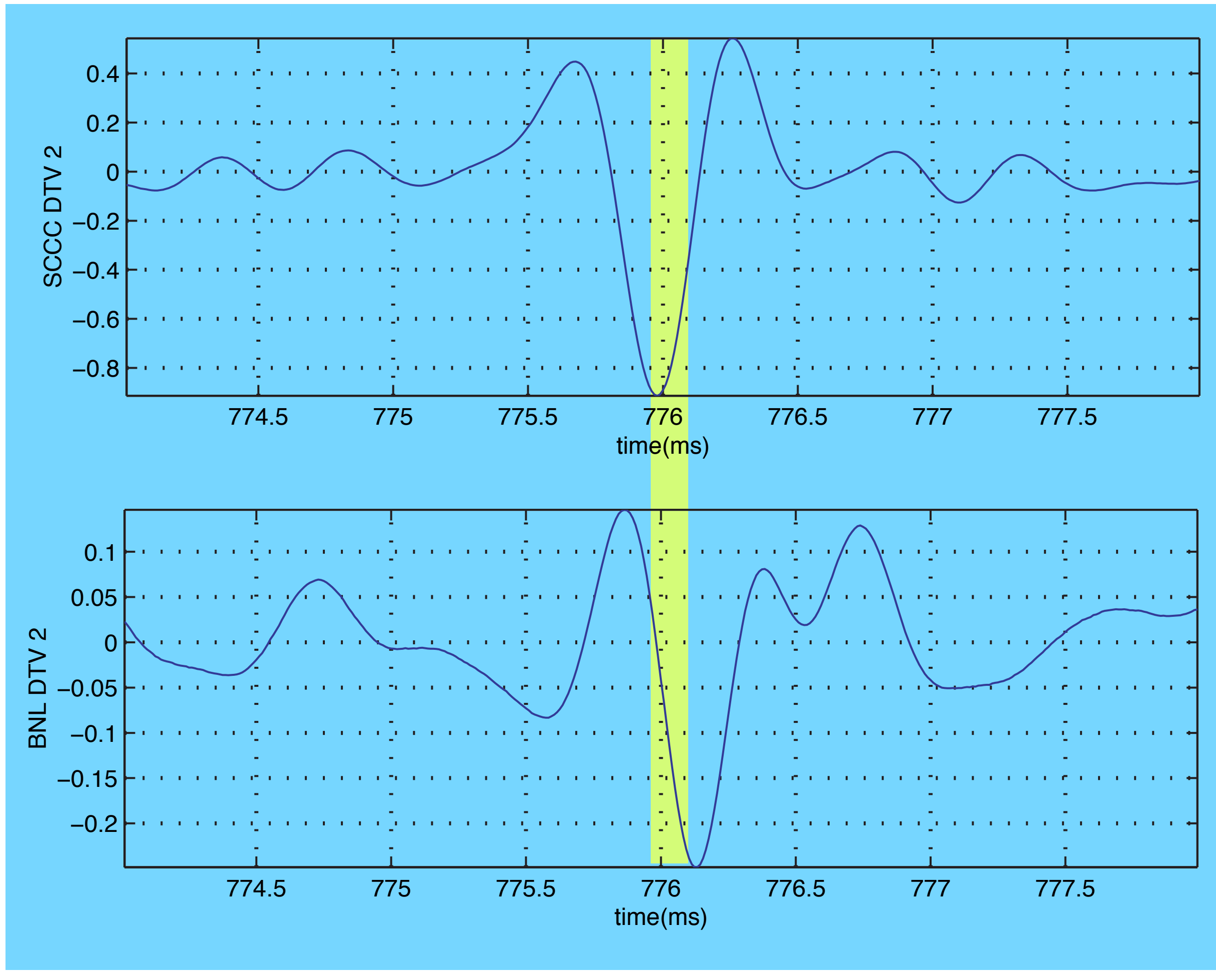
Lessons

We are starting to correlate information from the 2 pilot stations - SCCC and BNL, and one compact shower detector in BNL.

SCCC

BNL





Signal from a small meteor.

A short signal located at t=776 ms, triggered by a shower signal at t=500ms.

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

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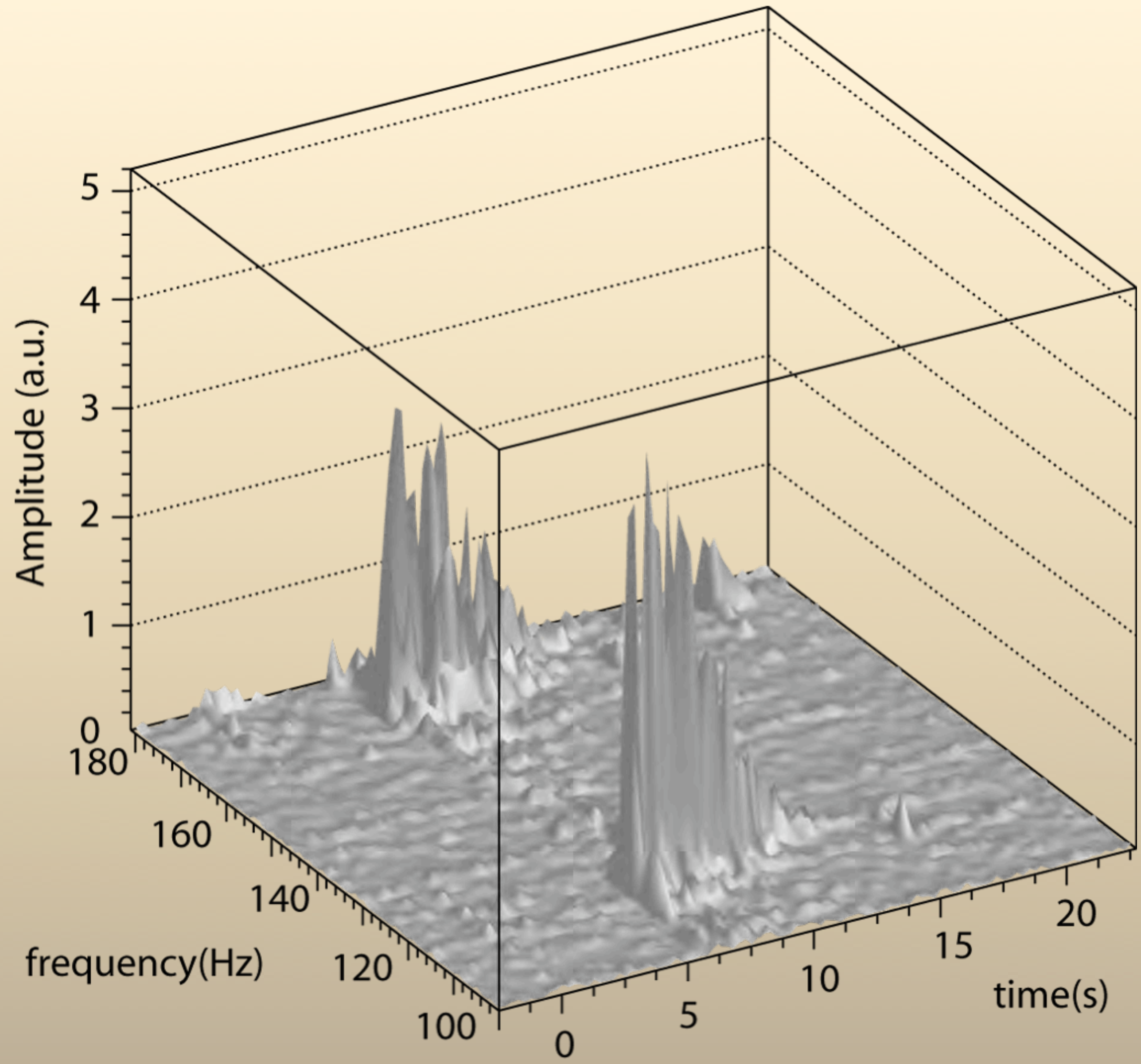
Lessons



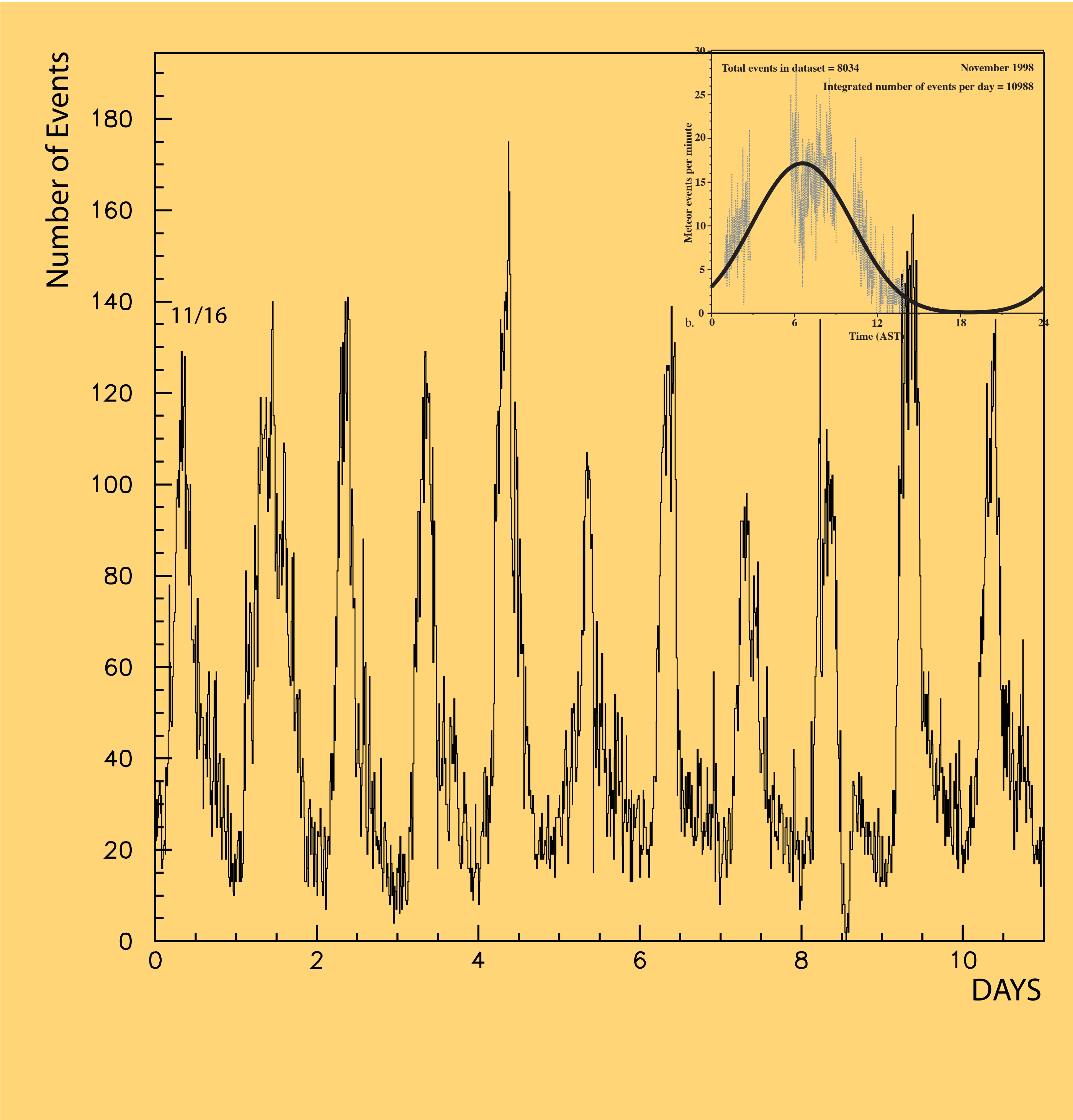
FFT analysis

Signals of two CH4 stations reflected of the same meteor trail after detailed FFT analysis.

Correlation studies

Two power spectra are combined to enhance signal to noise. Currently the same analysis is being done for two distant stations.

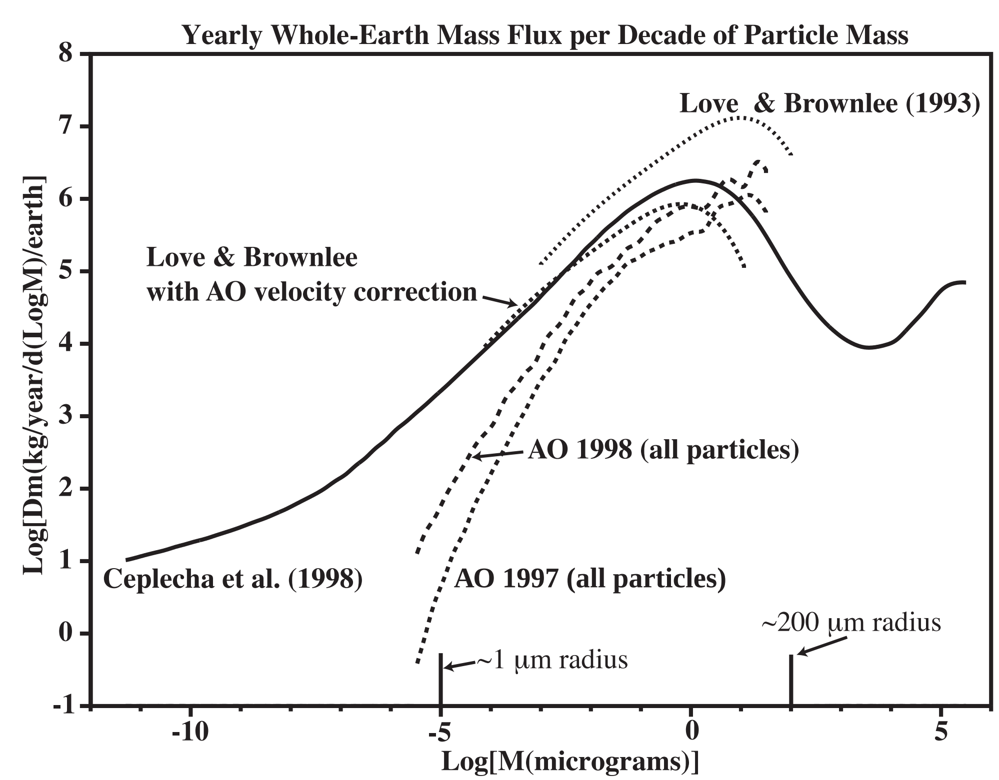
Meteors



A 24h period is observed. Meteors detected, about 5000/day, should have masses between 1-10 µg.

Daily fluctuations are expected.

Data taken during the August Perseids shower is now being analyzed.



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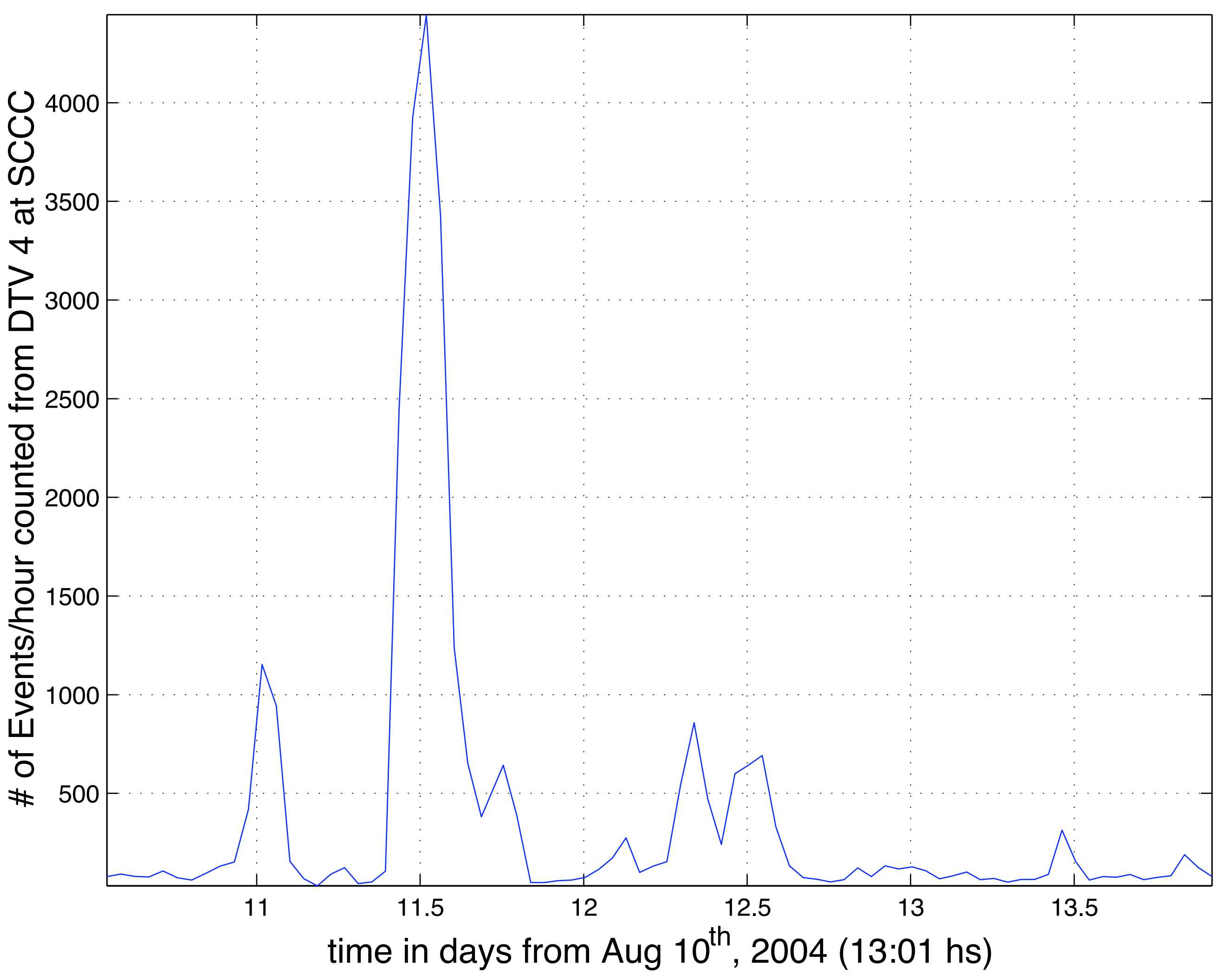
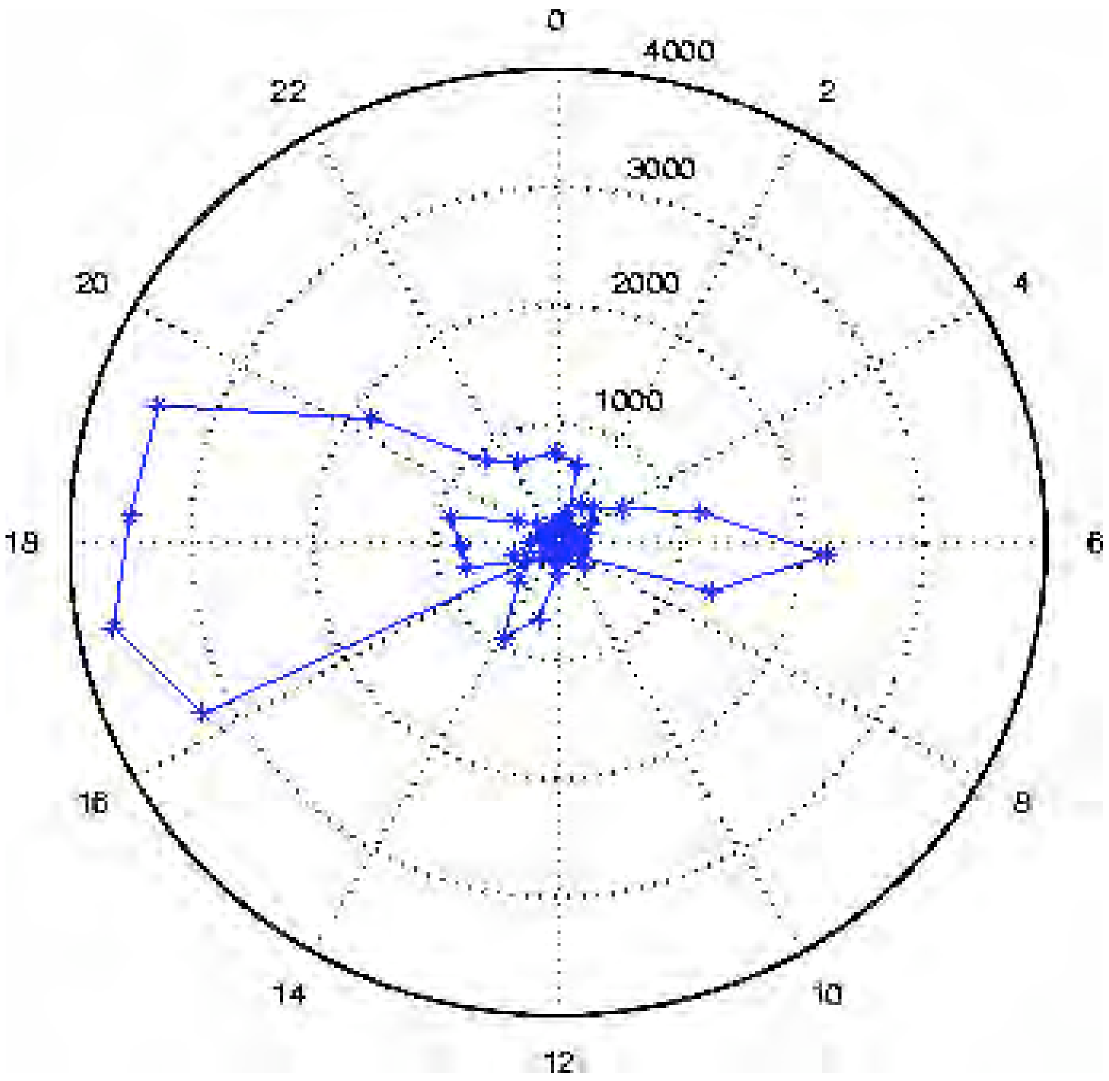
Perseids Meteor Shower





Earth Shadow Effect

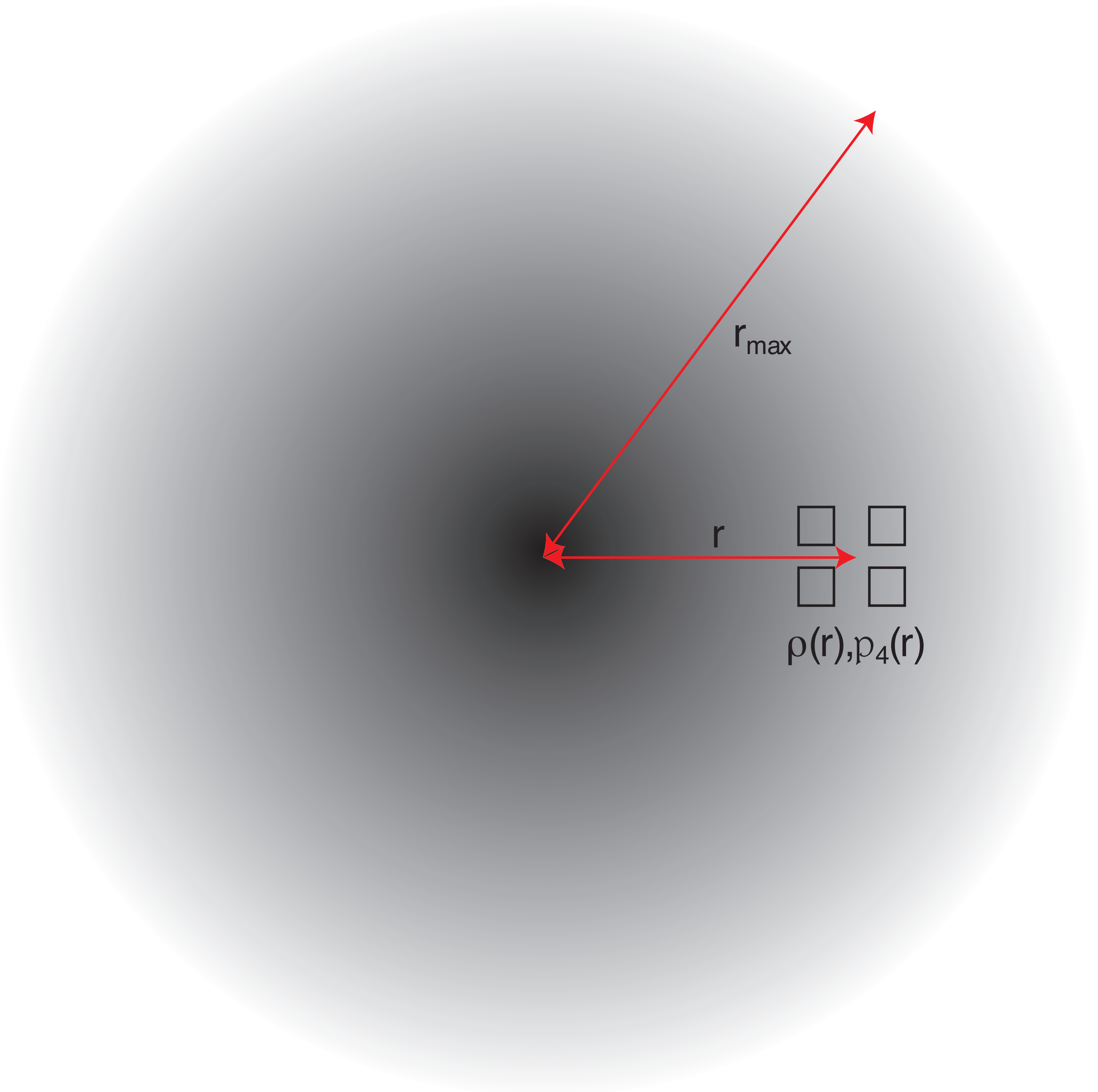
Compact Shower Detectors

It will be used to tag and select those events that are from EECR cosmic rays.

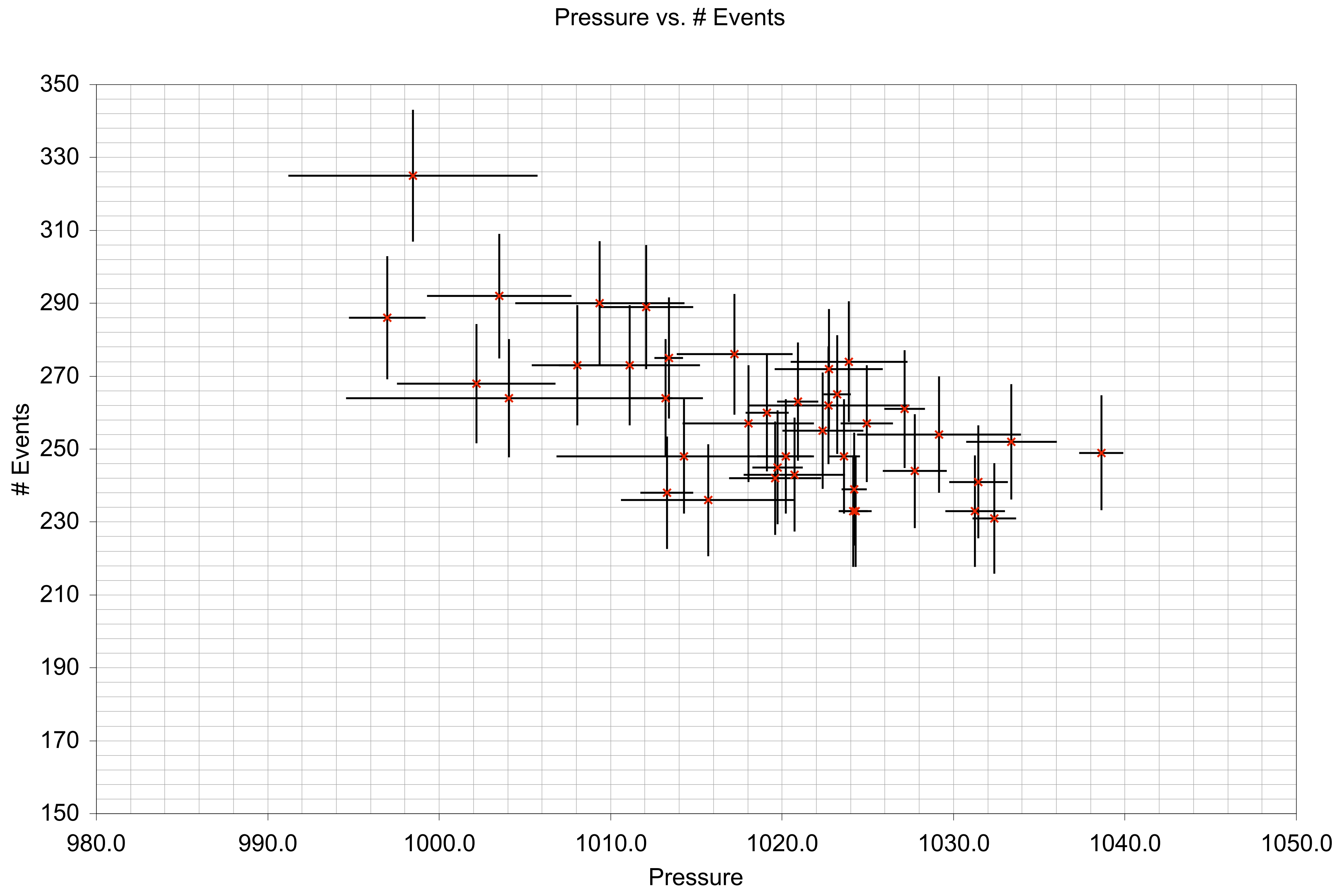
Use 4 scintillators in coincidence. The idea is to locate them in such a way to be sensitive to energetic primary cosmic rays.

When the event occurs we record the event time!

Detectors were developed together with Physics Teachers that are in QuarkNet.



Compact Shower Detectors



Event rate is ~10 events/hour, for 4-fold coincidence, and puts the threshold at around10^{17} eV. Number of events per day anti correlates with average barometric pressure.

Physics Teachers and Students

Last june, we organized a workshop where student teacher teams built 24 scintillation detectors. One result from the workshop is that we have now a good detector design.

We had the participation of 7 teachers (2 from Maryland), 23 HS students, 2 undergraduate students, 3 physicists, and 1 astronomer.

The final design

Intermission

After ~1.5 years we now know how to setup a radio station and have a good design for the compact shower detector.

The next big step is to install detectors in schools - a pilot is in progress (address problems such as unions, firewall, etc...). A detector system is operational at Deer Park HS and others will follow.

Data flow to a central computer is a big challenge. We are exploring the use of GRID computing technology for the experiment, and will profit from the US-ATLAS GRID development.

Science that can be done with MARIACHI, besides cosmic rays, is also becoming clearer.

Science, Education and Outreach of MARIACHI

(after discussions with NSF)

Four main Science topics are of interest:

- Cosmic Rays - coincidence measurement
- Meteors - nearly continuous monitoring
- Lightning - can cosmic rays induce lightning?
- Other exotic ionization clouds - Sporadic-E

Workshops will continue and more sites will hopefully join.

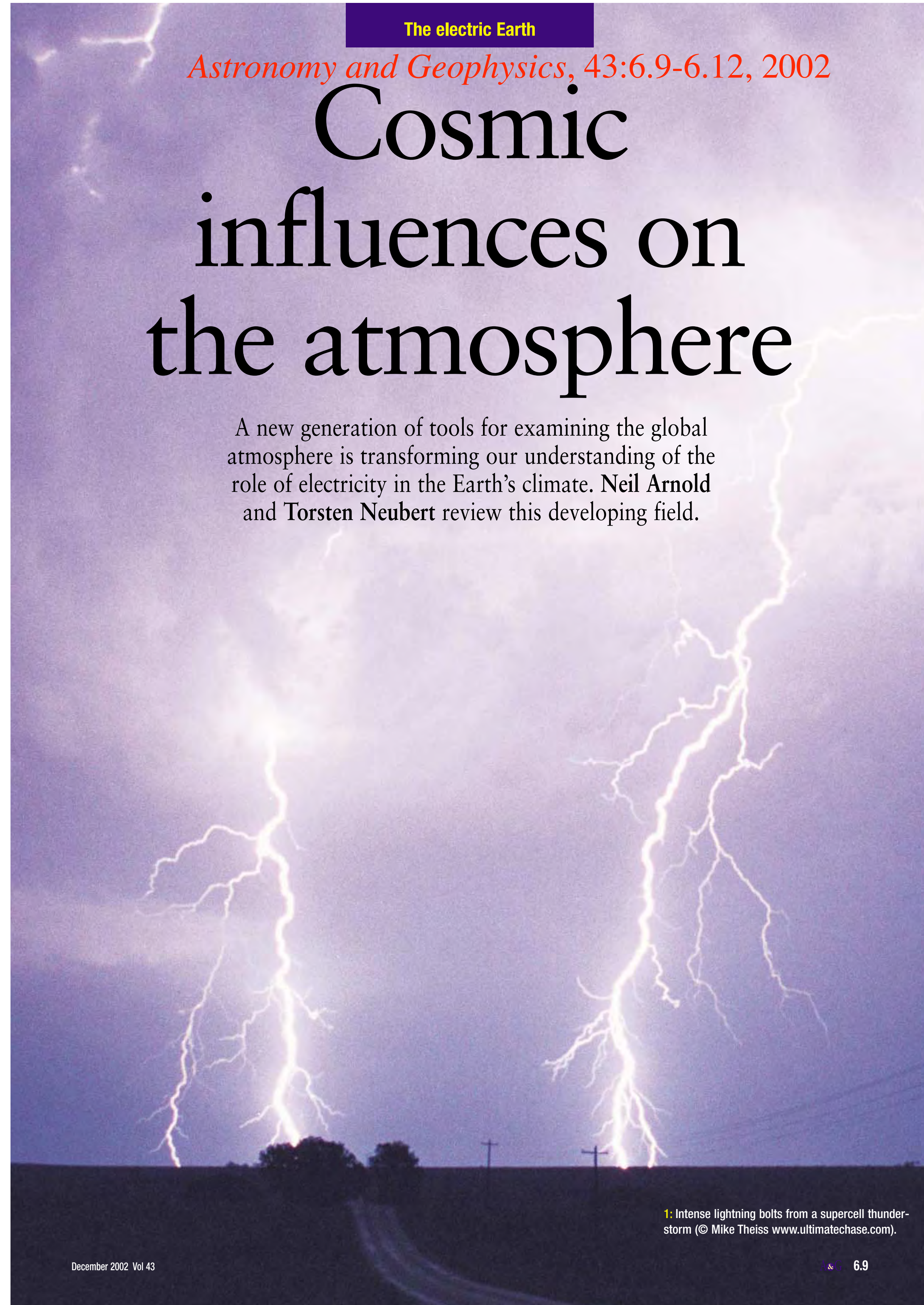
We have developed and will continue to develop educational projects with teachers and students.

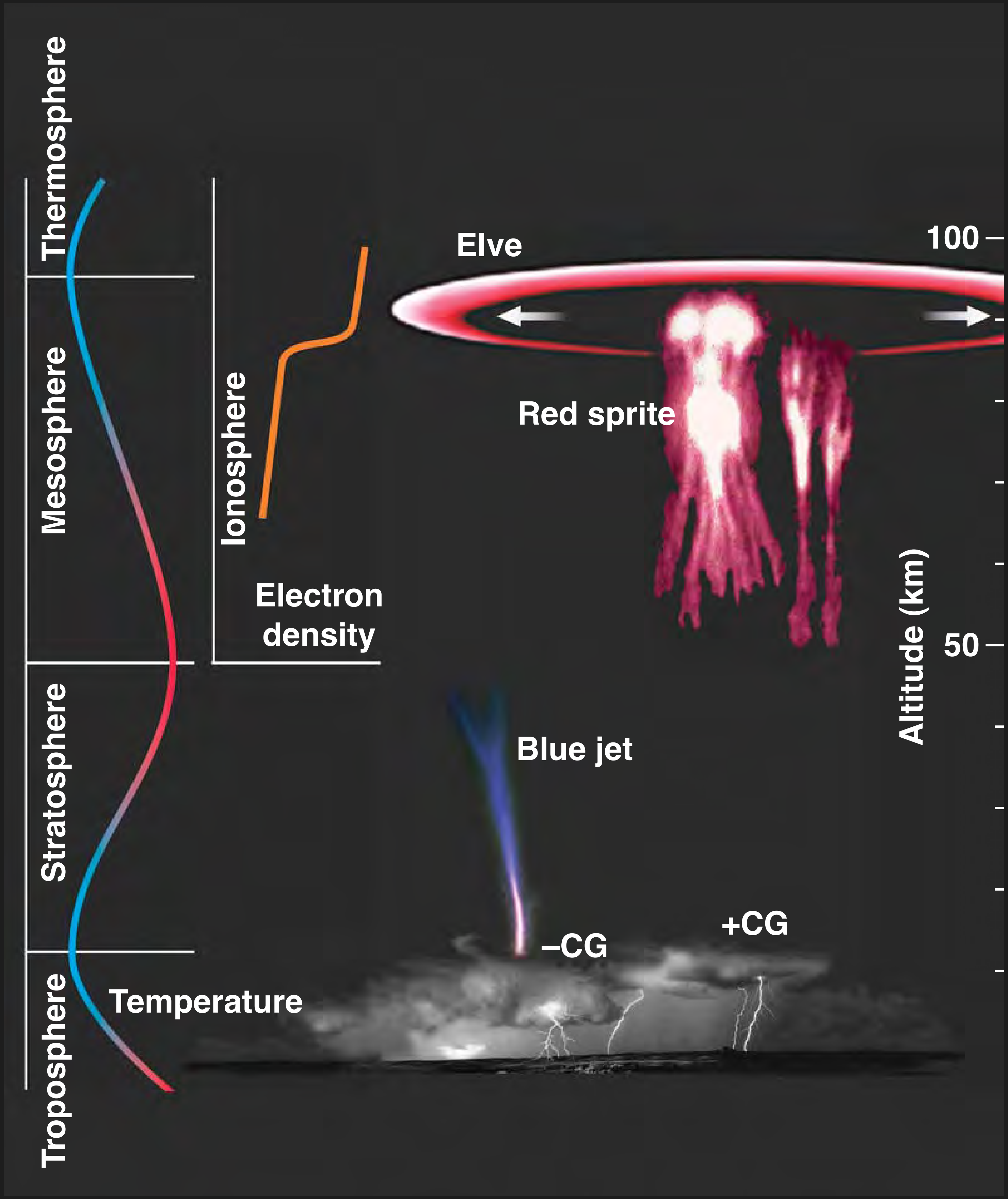
Together with LIGASE we are planning a museum display to explain particle physics and the science of MARIACHI.

Lightning

Science, Vol 300, Issue 5620, 747-749, 2 May 2003

It has been suggested that an electrical breakdown mechanism carried by relativistic electrons also operates in sprites (9). The idea is that free relativistic seed electrons generated by cosmic rays start an upward ionization avalanche, creating additional high-energy electrons. The existence of this process is supported by observations of x- and γ-radiation from the atmosphere above thunderstorms (observed by the Compton Gamma Ray Observatory), which suggest emission of bremsstrahlung by MeV-energy electron beams in the upper atmosphere (10). The role of relativistic breakdown in sprites remains a topic of intense research.




Thermosphere
Mesosphere
Stratosphere
Troposphere
Ionosphere
Electron density
Temperature
Elve
Red sprite
Blue jet
–CG
+CG
100
50
Altitude (km)

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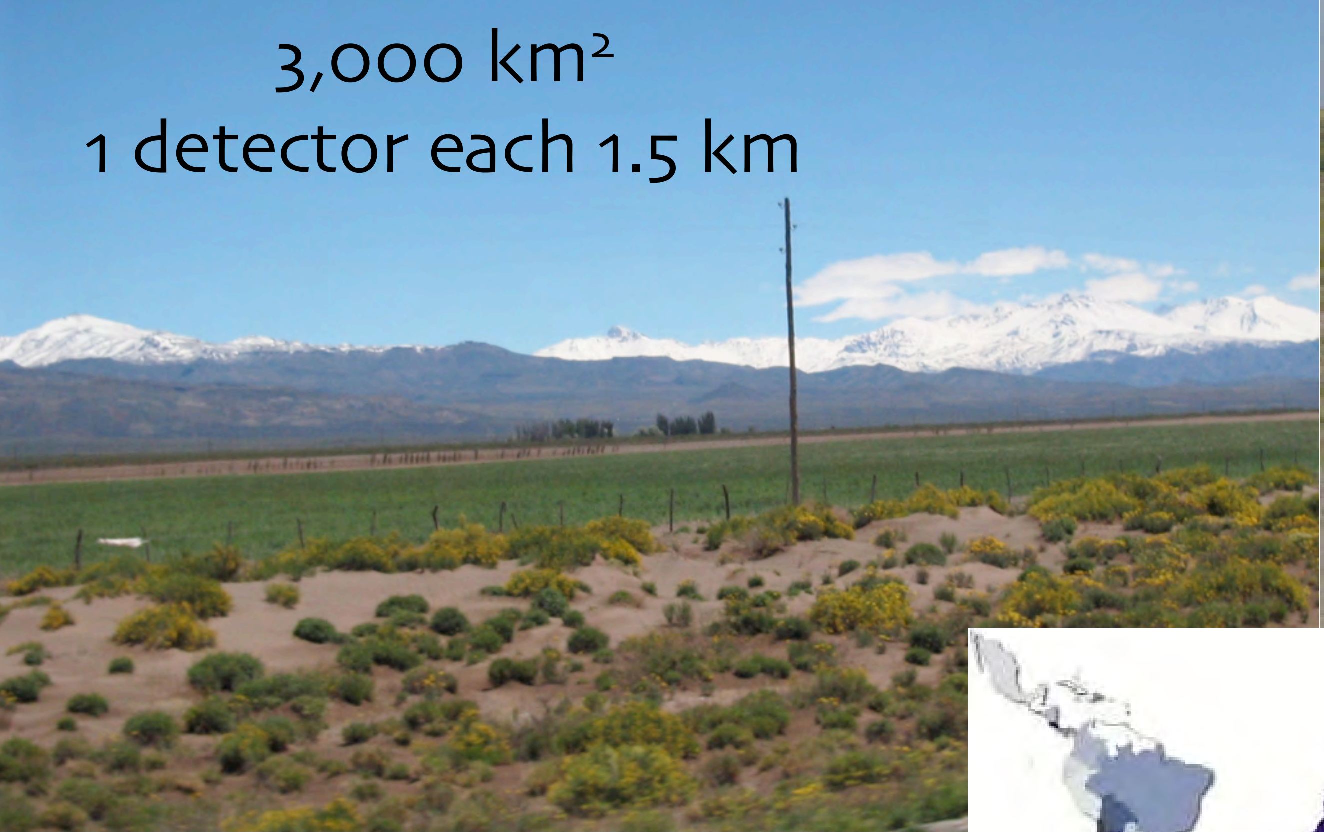
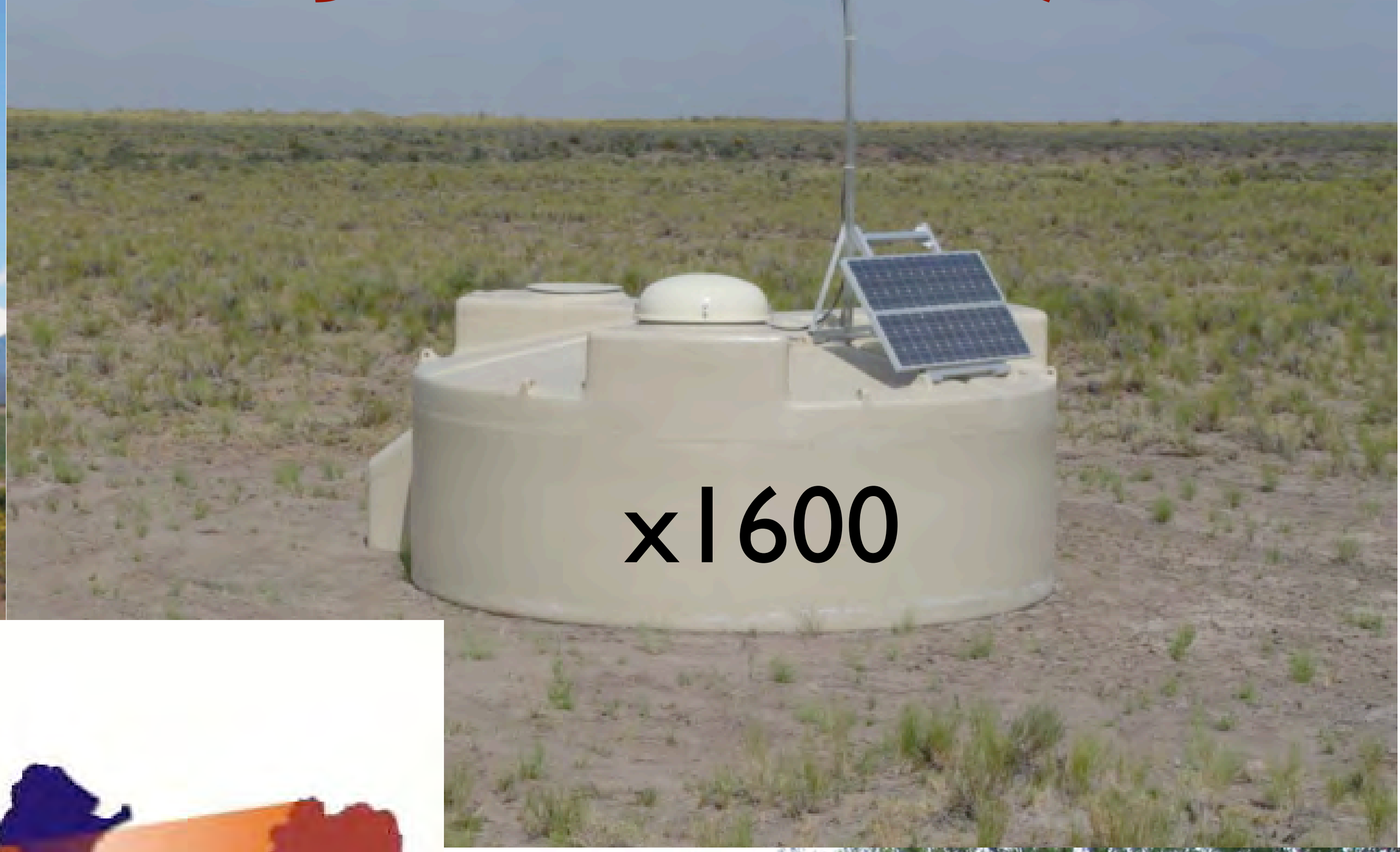
Discussions with Pierre Auger Observatory





Where we are heading (conclusions)

MARIACHI, is an unique experiment that involves physics teachers and students and the success of the experiment depends on them.

MARIACHI is unique also in the sense that uses conventional detection techniques to do unconventional physics.

We are now in the position that we can start the experiment. Radio and Compact Shower Detectors are well understood. Data transfer is still a challenge.

The educational aspect of the experiment is very important and science diverse. Working with teachers is a two way street - they contribute and we develop educational projects.

We have been discussing with NSF a possible funding for the continuation of this project.

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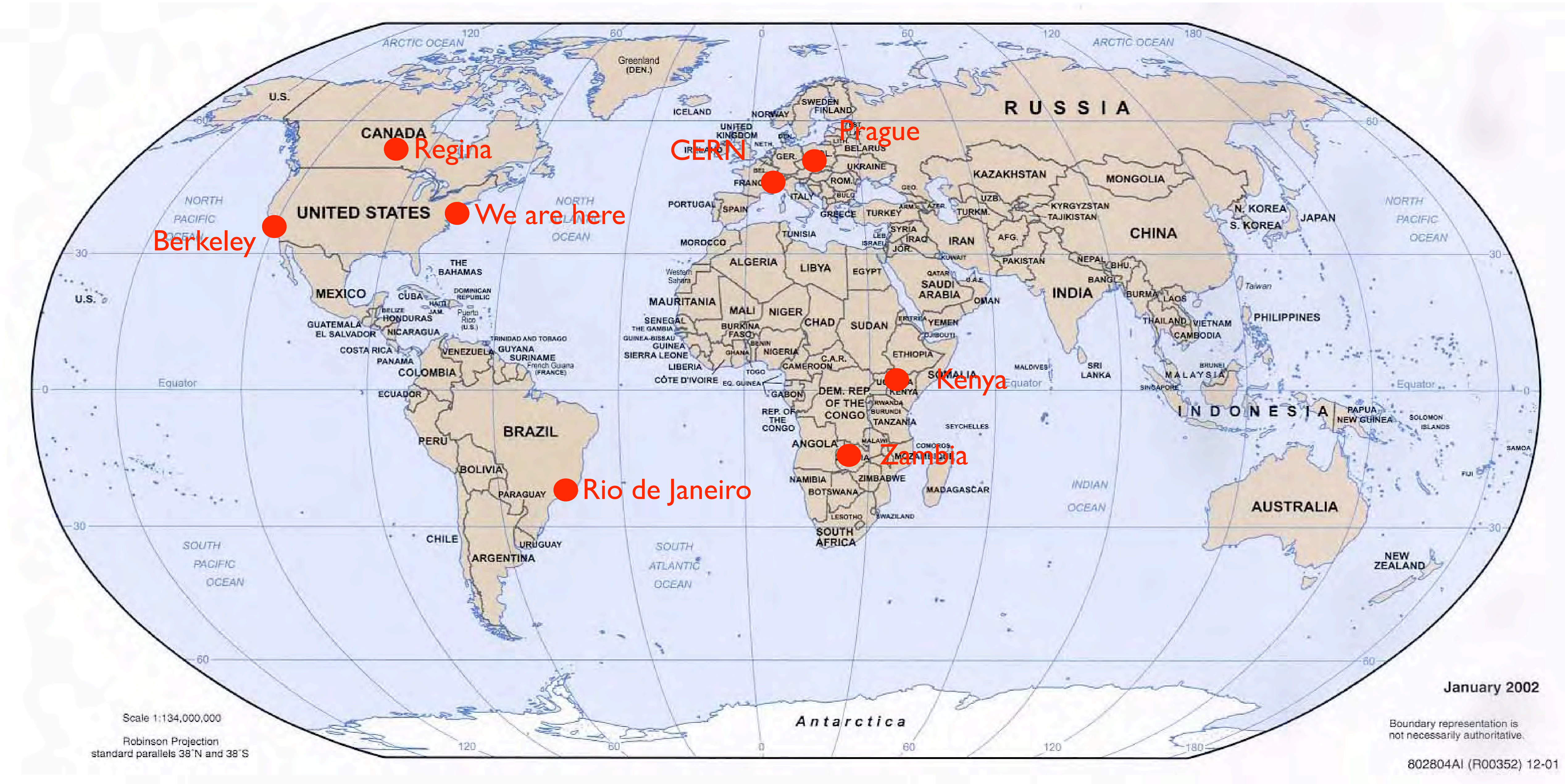
el MARIACHI

(Extremely Large MARIACHI)



We could franchise the experiment!

More than 9 billion showers detected!

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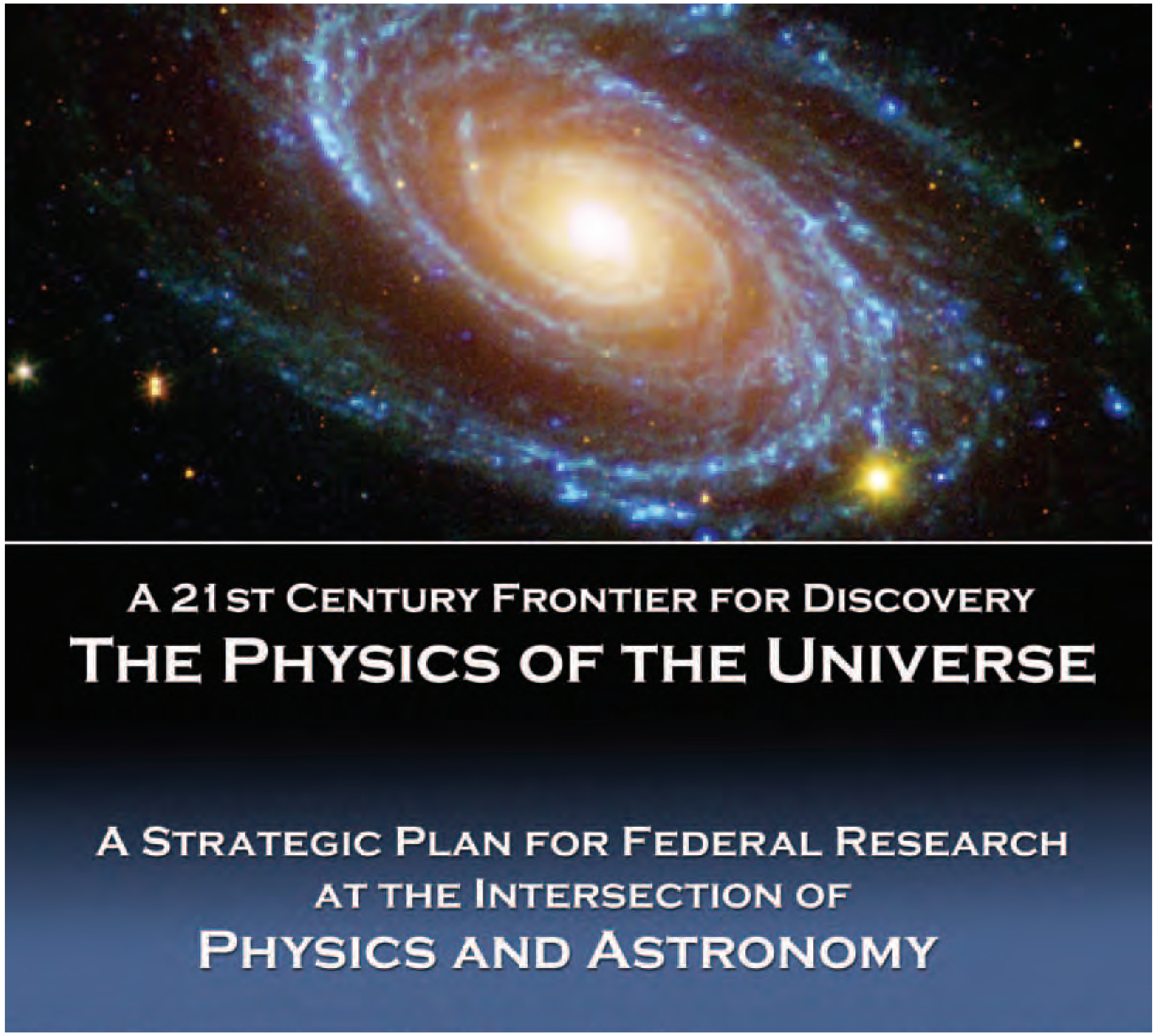
Relevance of this Project

Question 6. How Do Cosmic Accelerators Work and What Are They Accelerating?

"Physicists have detected an amazing variety of energetic phenomena in the universe, including beams of particles of unexpectedly high energy but of unknown origin. In laboratory accelerators, we can produce beams of energetic particles, but the energy of these cosmic beams far exceeds any energies produced on Earth."

Scientific Significance: The observation of particles in the universe with unexpectedly high energy raises several basic questions. What are the particles? Where are their sources? How did they achieve such high energies—up to billions of times more energetic than those generated in the most powerful laboratory accelerators? These are likely atomic and subatomic particles moving essentially at light speed, each carrying the kinetic energy of a major league baseball pitch. Their existence might point to new physics.



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MARIACHI-LIGASE-KOPIO

MARIACHI is integral part of a collaboration between MARIACHI, LIGASE and KOPIO as part of the RSVP Education and Outreach program.

MARIACHI, is an experiment that includes scientists, teachers and students from day one. It will continue its role of involving them in research and development of experiments in particle physics.

LIGASE, which is led by David Bynum, will take on establishing a state of art Physics Teaching Laboratory. The PTL will be in the Physics building and it will be a place to hold workshops for physics teachers (K-12)

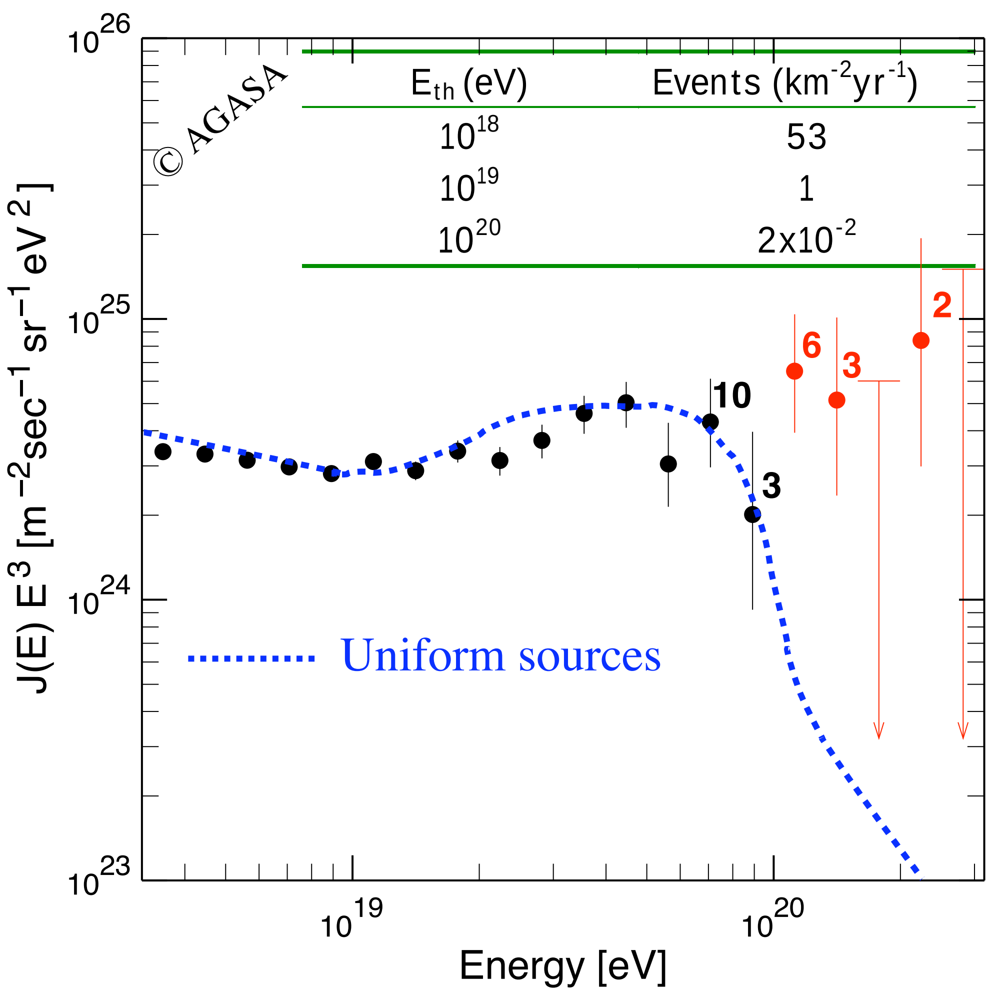
KOPIO, will have an educational program to involve students and teachers in the experiment.

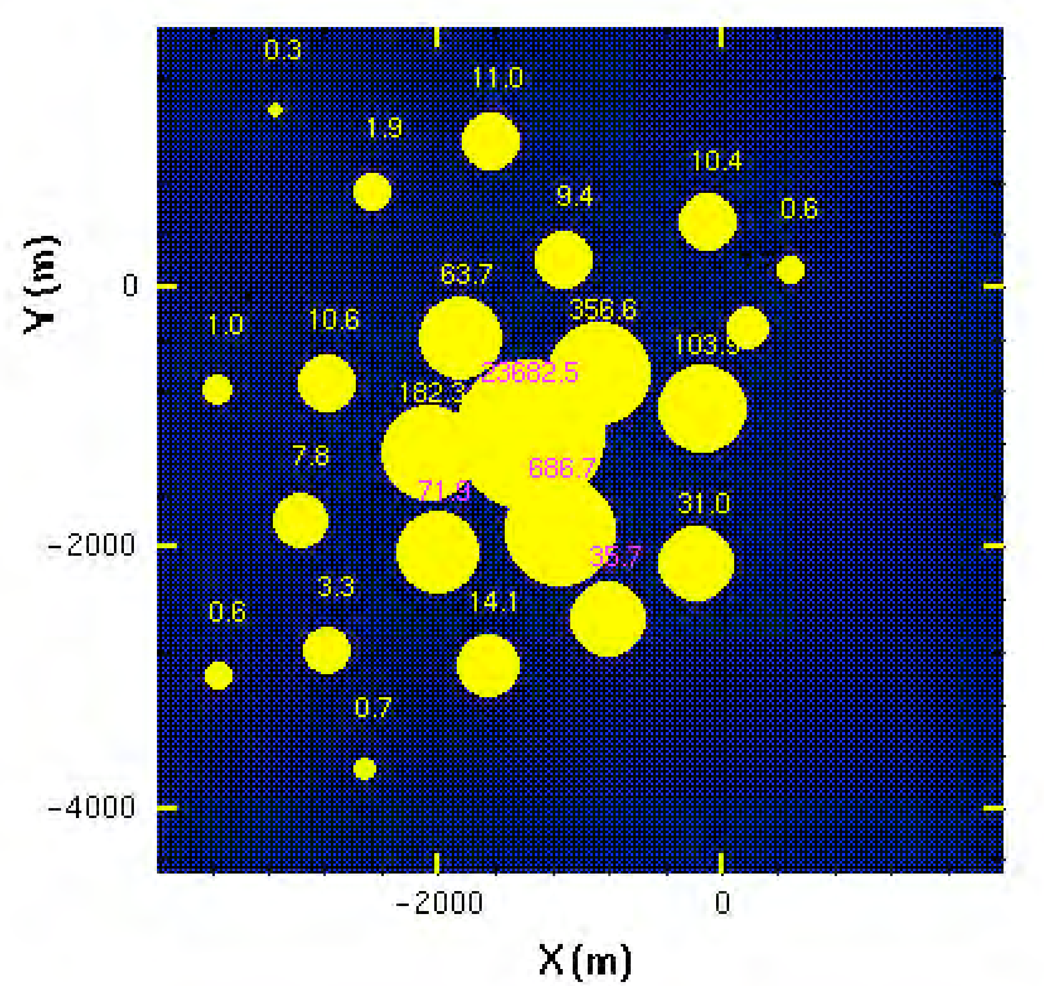
This program will initiate on Long Island and will expand.

... The only thing missing is a cool name!

Rate Estimate

For a rate estimate, we assume that with three radio stations and DTV stations we cover an area with R=500km.





The present CSD detector configuration will detect the presence of ~30 cosmic rays of 10^{19} eV per year.

With ~10 sites, 300 events will be detected.With a 50% duty cycle, we would detect ~150 events. Geometrical factors are not considered.

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Museum display concept


NE JAMAIS
ABANDONNER !
www.odyssee.net/mcordeau/