Radio Detection of UHE Neutrinos and Cosmic Rays of Taiwan

ANITA, ARA, T-510, SFLASH & TAROGE

T.C. Liu

LeCosPA,
National Taiwan University

TKU Seminar, Spring 2018

Outline

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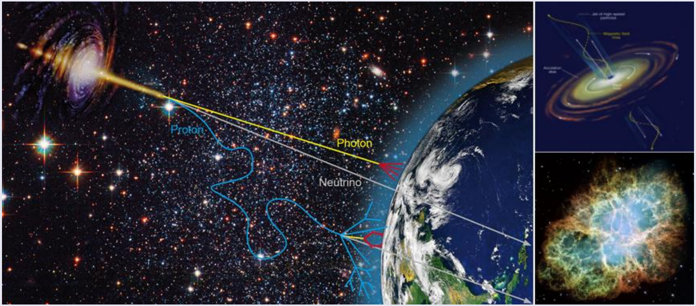
1. Introduction of Cosmic Rays and Neutrinos
   - What??
   - Why??
   - How???
2. Experiments
   - ANITA (The ANtarctic Impulsive Transient Antenna) at 32km
   - ARA at -200m
   - T-510 Radio Emission from Particle Cascades in the Presence of a Magnetic Field
   - Fluorescence in Air from Showers (sFLASH)
   - Taiwan Astroparticle Radio wave Observatory for Geo-synchrotron Emission(TAROGE)
3. Summary & Future Plans

Cosmic Rays

Definition Cosmic rays are high-energy radiation, mainly originating outside the Solar System.

Source Crab Nebula, supernovae, active galactic nuclei, quasars, gamma-ray bursts...



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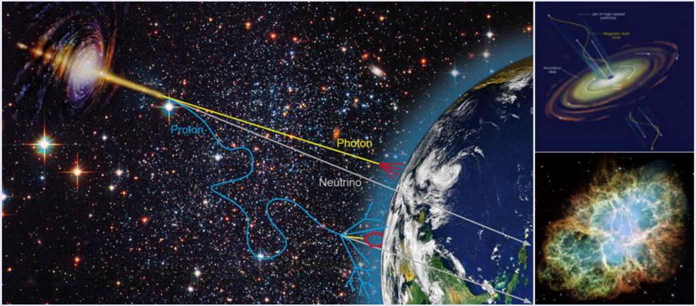

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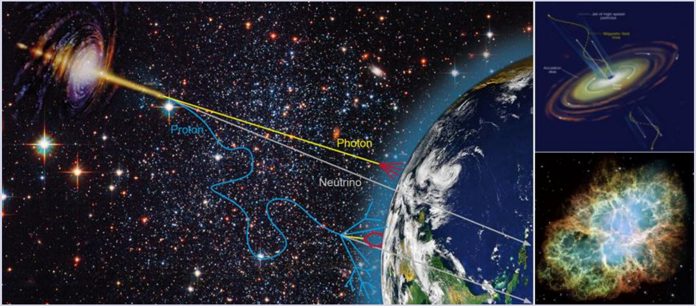

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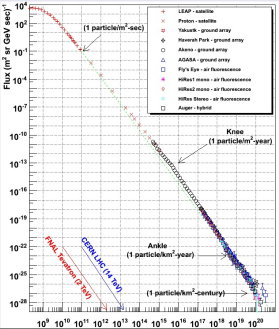

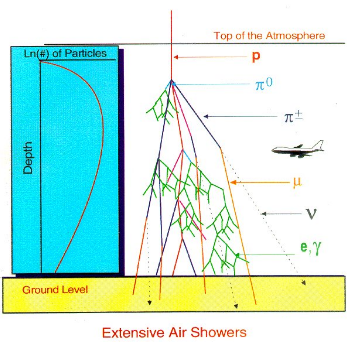

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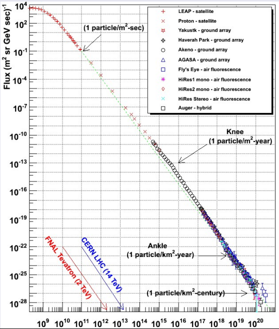

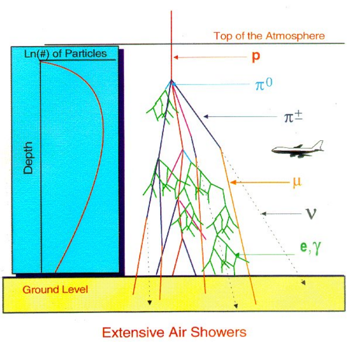

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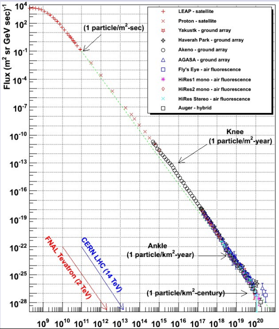

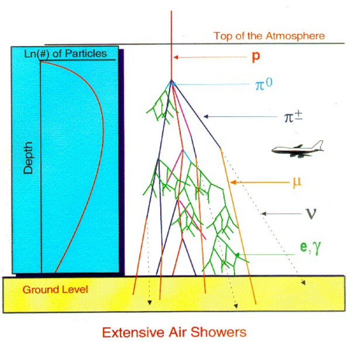

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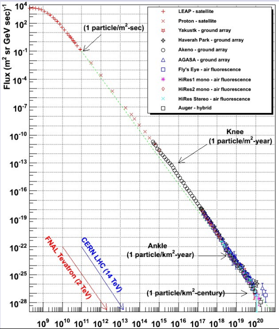

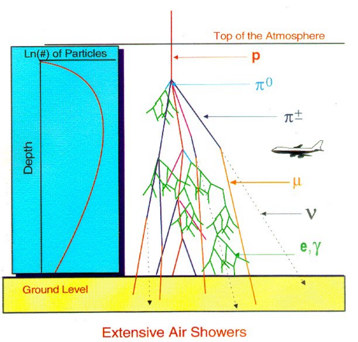

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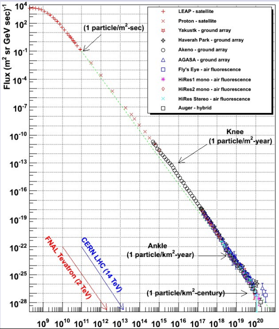

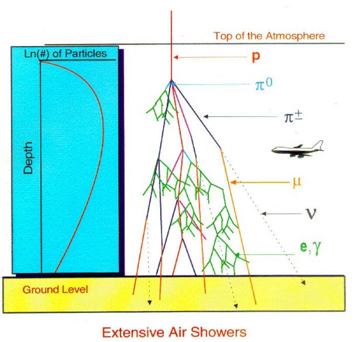

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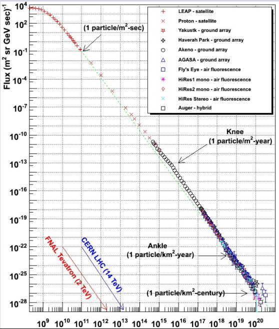

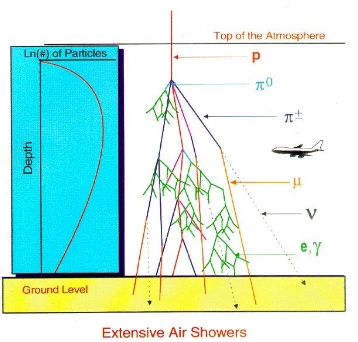

Discovery of Neutrino

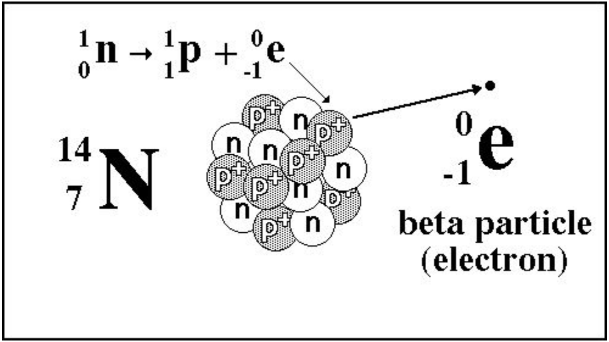

Figure: Pauli hypothesized an undetected particle that he called a "neutron" in keeping with convention.

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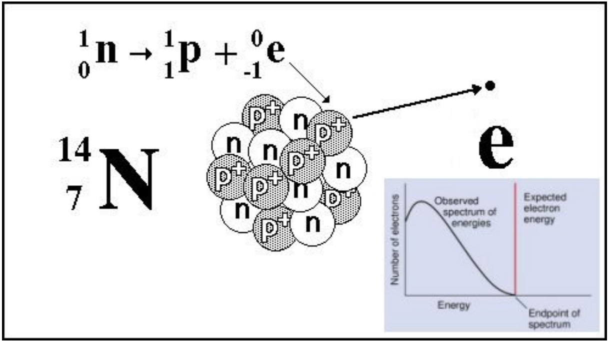

Figure: Pauli hypothesized an undetected particle that he called a "neutron" in keeping with convention.

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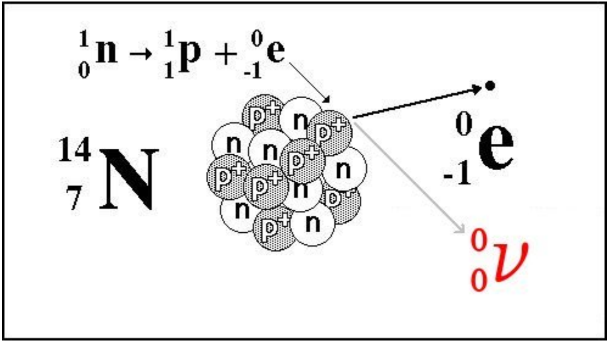

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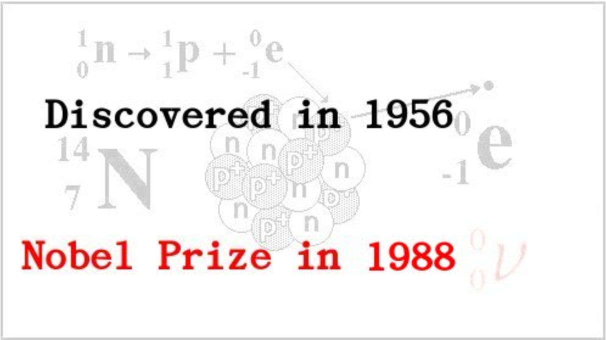

Figure: Pauli hypothesized an undetected particle that he called a "neutron" in keeping with convention.

How Many Generations?

Figure: When the third type of lepton, the tau, was discovered in 1975 at the SLAC, it was expected to have an associated neutrino (the tau neutrino).

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Neutrino Flux is not Conserved ?!

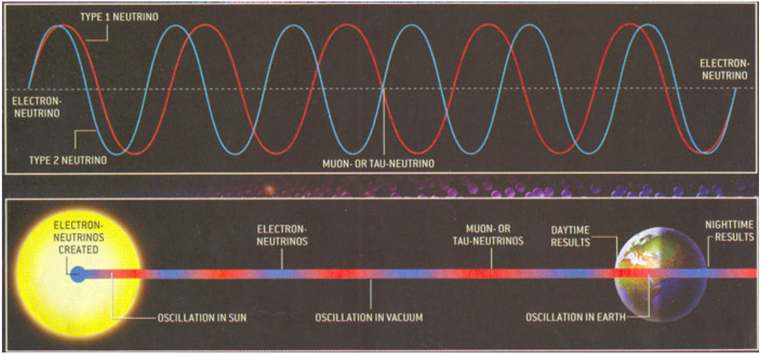


Figure: Measurements of solar neutrino types were not consistent with models of the Sun's interior

Super nova neutrino

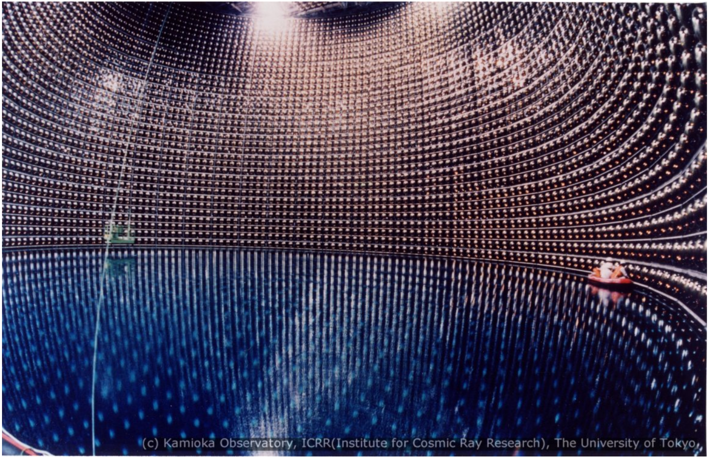


Figure: Super-Kamiokande observed super nova neutrino.

Super nova neutrino

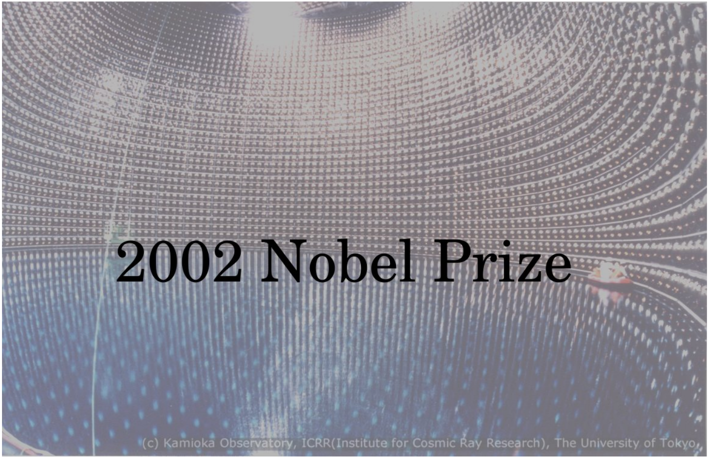


Figure: Super-Kamiokande observed super nova neutrino and confirm the

Fundamental Forces

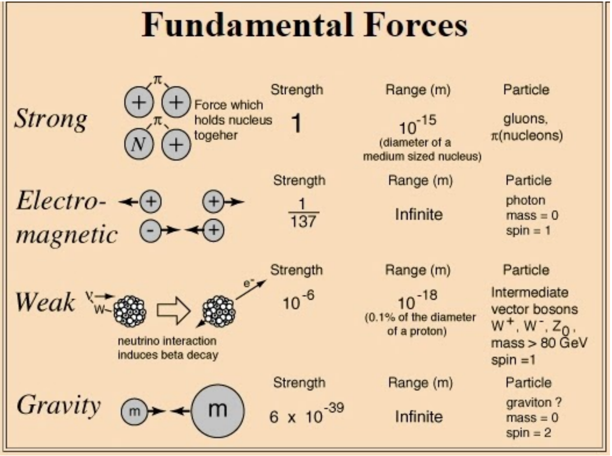
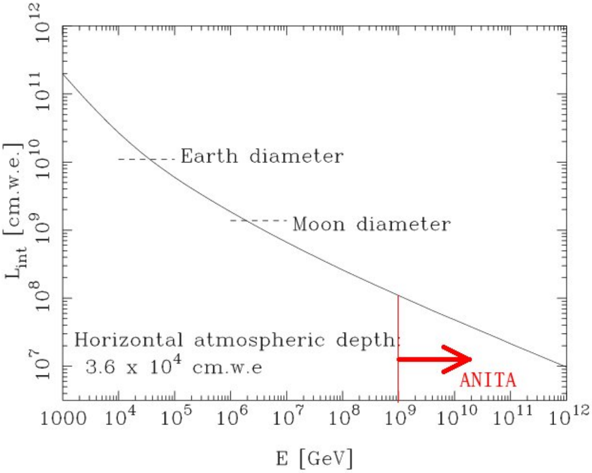


Figure: Fundamental Forces.

Interaction Length of Neutrinos



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Why? Cosmic rays

- **Acceleration** How to accelerate the particles?
- **Origin** where are the particles from?
- **Stellar Magnetic fields** By studying the path of cosmic rays.
- **Relation with dark matter** galactic nuclei are capable of converting dark matter into high energy protons.
- **Testing Hadronic Interactions** PAO has detected more muons from cosmic-ray showers than predicted by the most up-to-date particle-physics models.

Archaeology???

Figure: Cosmic rays ionize the nitrogen and oxygen molecules in the atmosphere, Ex: ^{14}C

Muon Tomography

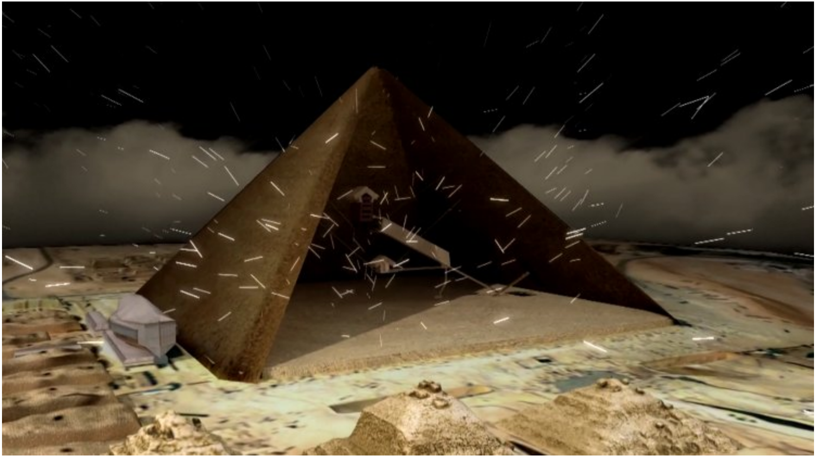


Figure: Cosmic ray muons have been used for decades to radiograph

Muon Tomography

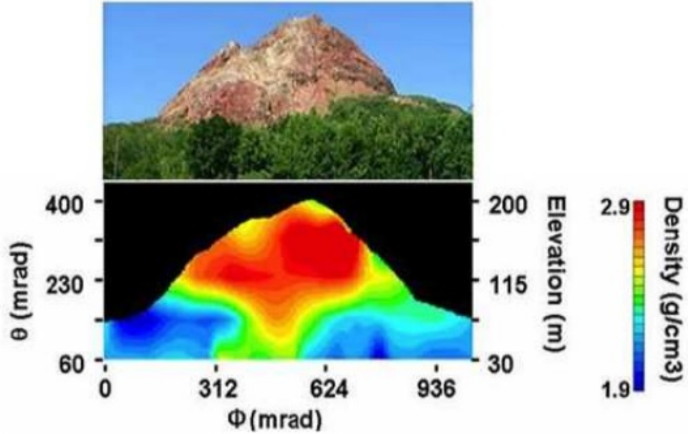


Figure: view of the Showa-Shinzan lava dome

Cosmic Rays & Climate

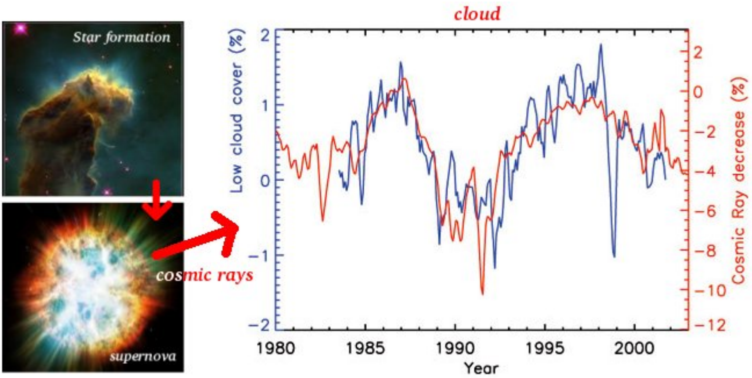


Figure: The correlation between cosmic ray flux and the low altitude cloud cover using ISCCP satellite data set.

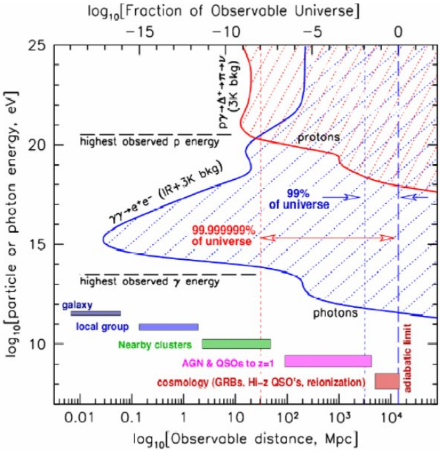
Cosmic Rays & Lightning?

Figure: Cosmic rays have been implicated in the triggering of electrical

Why?? Neutrinos

- GZK cut-off & Missing Spectrum
- Neutrino Mass
- Neutrino Hierarchy
- Mixing Angles
- Neutrino Decay
- Neutrino Oscillation
- Neutrino Interaction Model

What I want? The Ideal UHE Messenger



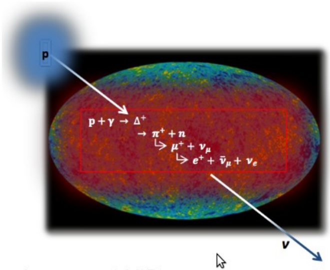
- Photons lost above 100 TeV (pair production on CMB & IR)
- Protons and Nuclei suffer curvature induced by B fields
- But: we know there are sources up to 10^{20} eV!!

UHE Neutrino Detectors Study:

- Highest energy observation of extragalactic sources
- Very distant sources
- Deep into opaque sources

from A. G. Vieregg

UHE Neutrino & GZK Effect



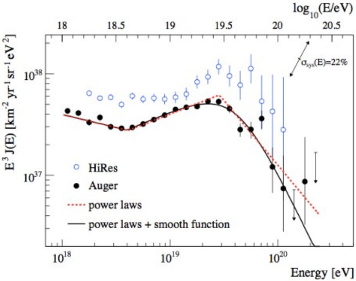
Auger and HiRes measurements of UHE cosmic rays consistent with GZK cut-off

Guaranteed GZK neutrino flux, but how large?

copy from Jonathan's slides

At energies above ~$10^{19.5}$eV cosmic rays will interact with CMB photons producing neutrinos

Process is known as the GZK effect



The Pierre Auger Collaboration (2010): Phys. Lett. B 685 (4–5): 239–246. HiRes Collaboration, Astropart. Phys. 32 (2009) 53.

GZK Radius

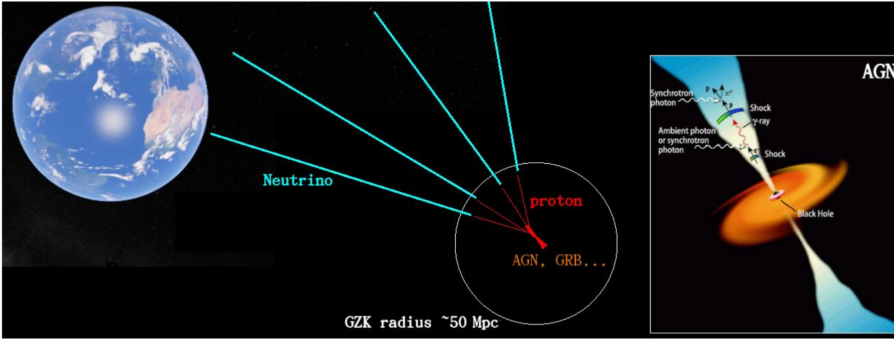


Figure: The UHE neutrinos can point back to the original UHE source without bending of B field.

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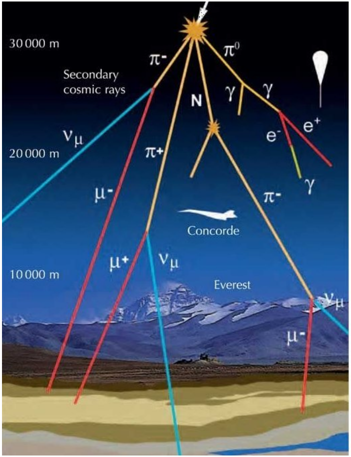
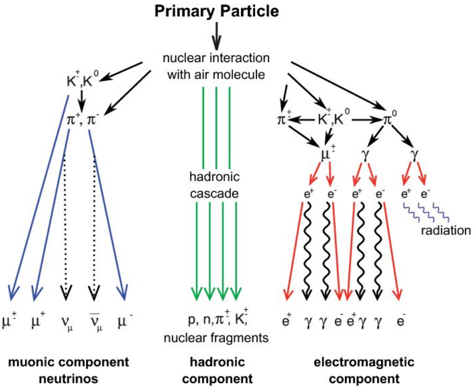
Shower Components





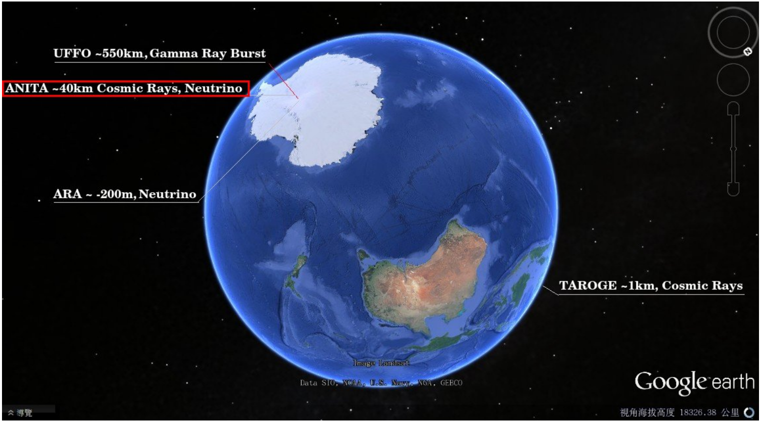
Shower Simulation

Take a short break, Let's us watch a video of shower develop.

- 400 GeV shower (Υ, p, and C_{13})
- 400 GeV Υ shower

Outline

The ANtarctic Impulsive Transient Antenna (ANITA)



UHE Neutrino Interact with Earth

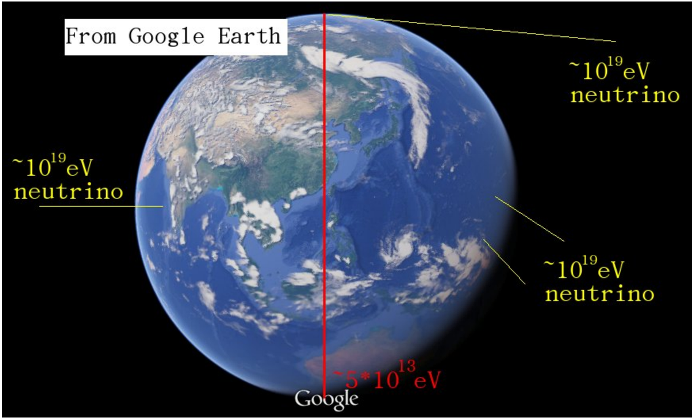


Figure: The interaction length of neutrino with $5 * 10^{13}$ eV is close to diameter of Earth. The interaction length for 10^{19} eV neutrino is $6 * 10^{7}$

ANITA Collaborations

Figure: University of Hawaii at Manoa, University of California, Los Angeles, The Ohio State University, The University of Delaware, The University of Kansas, Washington University, the NASA Jet Propulsion Laboratory, University College London, University of Chicago, National Taiwan University and the California Polytechnic State University.

Base

The ANtarctic Impulsive Transient Antenna

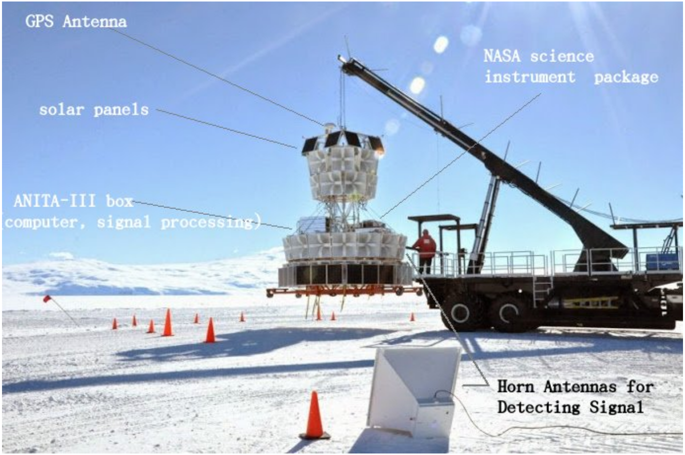


Figure: ANITA instrument

The ANITA's Concept

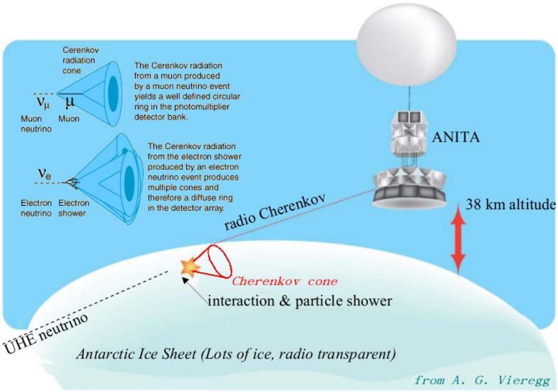


Figure: Cherenkov radiation is electromagnetic radiation emitted when a charged particle passes through a dielectric medium at a speed greater than the velocity of light in that medium.

Coherent Radio Emission (Askaryan Radiation)

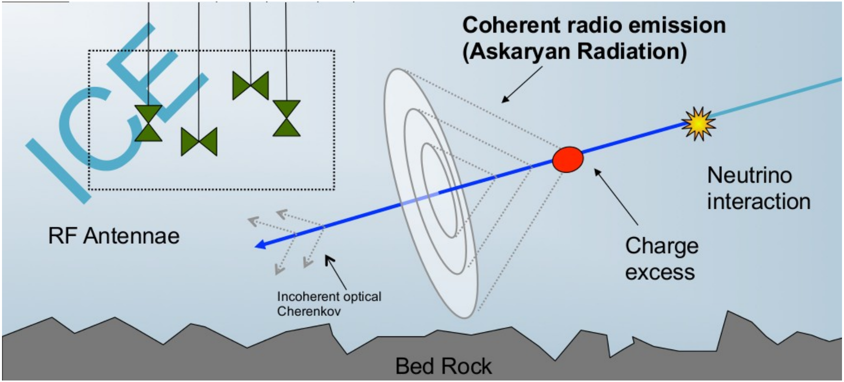
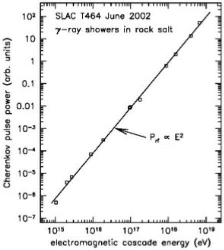
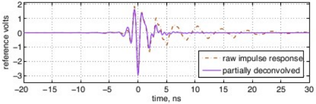


Figure: Detect radio emission from neutrino induced particle cascades in ice

Askaryan Radiation Experiment in SLAC

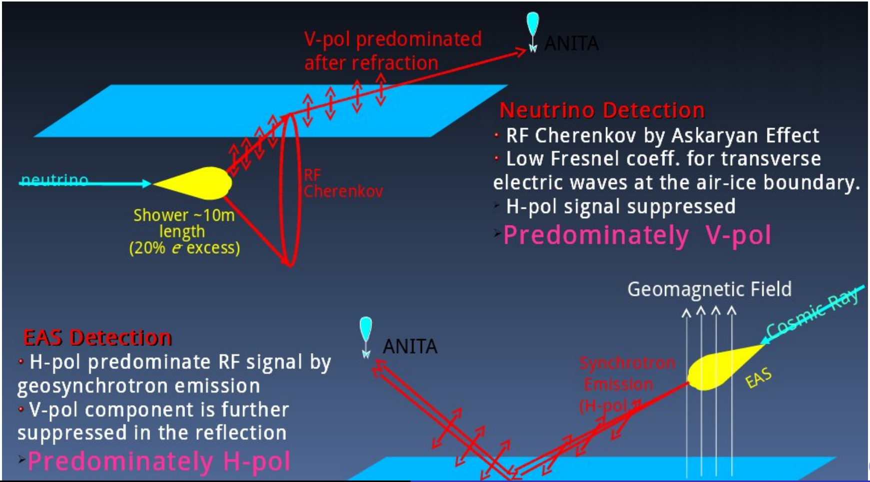




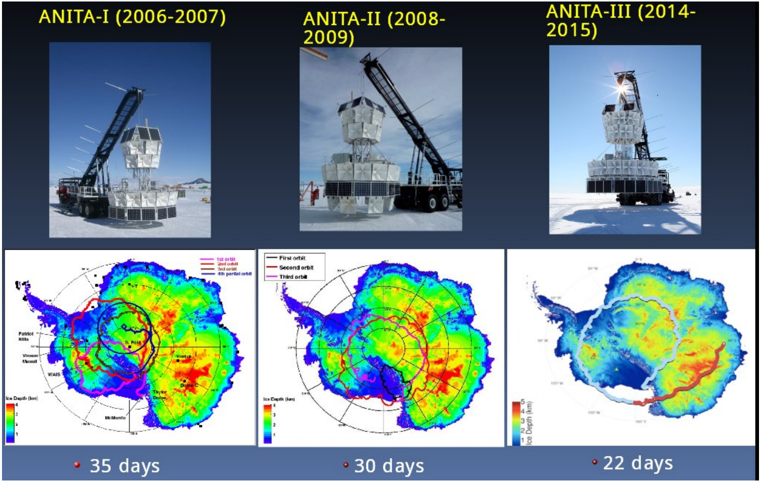
PRL 99, 171101 (2007)
see also:
PRE 62, 8590 (2000),
PRL 86, 2802 (2001),
PRD 72, 023002 (2005)
PRD 74, 043002 (2006)

copy from Ryan's slides

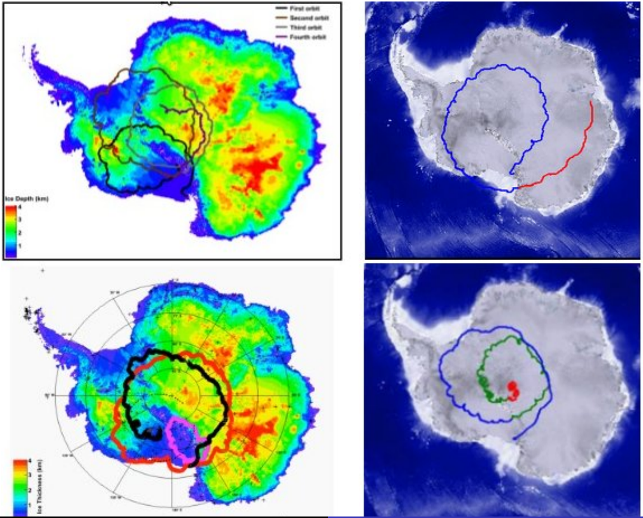
Signal Type (Neutrino VS. EAS)



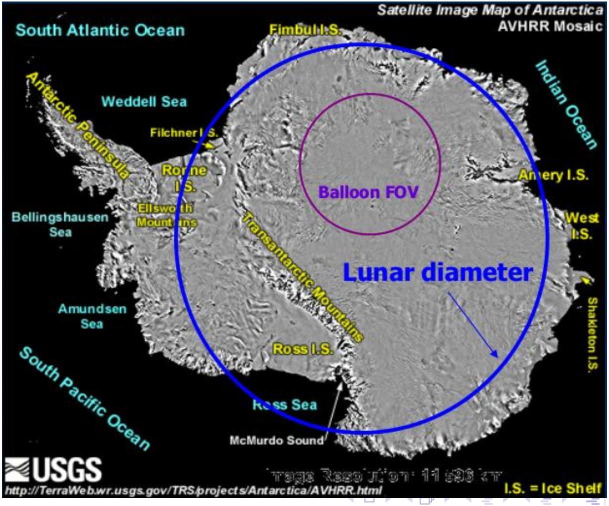
The ANITAs


ANITA-I (2006-2007)
ANITA-II (2008-2009)
ANITA-III (2014-2015)
1st orbit
2nd orbit
3rd orbit
4th partial orbit
First orbit
Second orbit
Third orbit
Ice Depth (km)
35 days
30 days
22 days

Trajectory of ANITAs

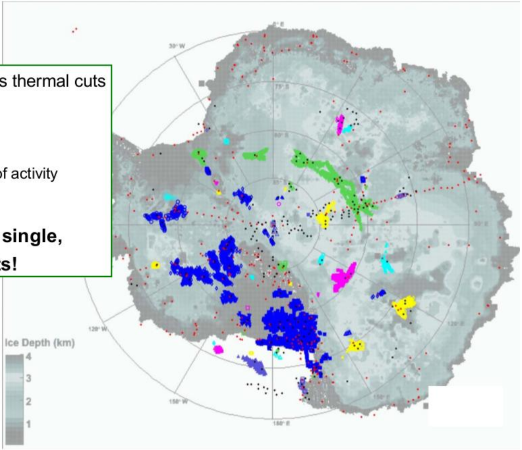


FoV of ANITA


Satellite Image Map of Antarctica
AVHRR Mosaic
South Atlantic Ocean
Fimbul I.S.
Indian Ocean
Antarctic Peninsula
Weddell Sea
Filchner I.S.
Ronne I.S.
Amery I.S.
Balloon FOV
Ellsworth Mountains
Bellingshausen Sea
West I.S.
Transantarctic Mountains
Lunar diameter
Shakleton I.S.
Amundsen Sea
Ross I.S.
South Pacific Ocean
Ross Sea
McMurdo Sound
USGS
http://TerraWeb.wr.usgs.gov/TRS/projects/Antarctica/AVHRR.html
I.S. = Ice Shelf

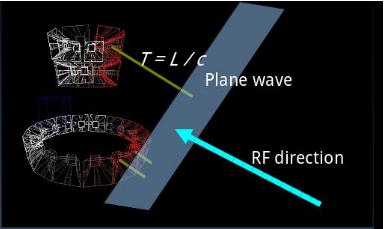
Man-Made EVENTs of ANITA

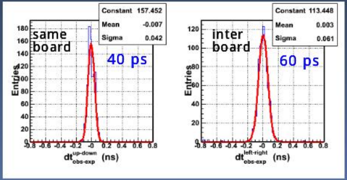
- 300k events pass thermal cuts
- Cluster with:
  - Other events
  - Known bases of activity
  - "Hot-Spots"
- **Neutrinos are single, isolated events!**



Event Reconstruction

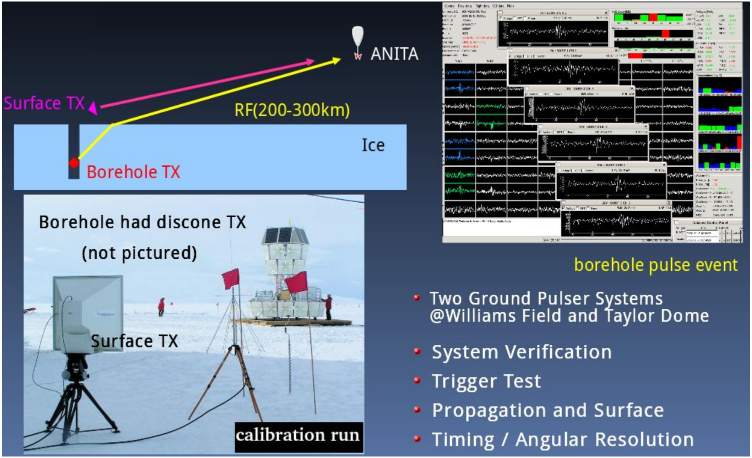
- Angular reconstruction is a crucial part in the ANITA data analysis.
- Powerful background rejection
  - incoherent thermal events (99% of data set)
  - anthropogenic RF events from existing bases
  - air shower RF events.
- Neutrino reconstruction
  - neutrino direction information
  - provides R and refraction angle for energy measurement.
- Angular reconstruction using timing.
- time resolution; 40-60 ps
  - (time difference between channels)
- Achieved angular resolution;
  - 0.2° (zenith) and 0.8° (azimuth.)



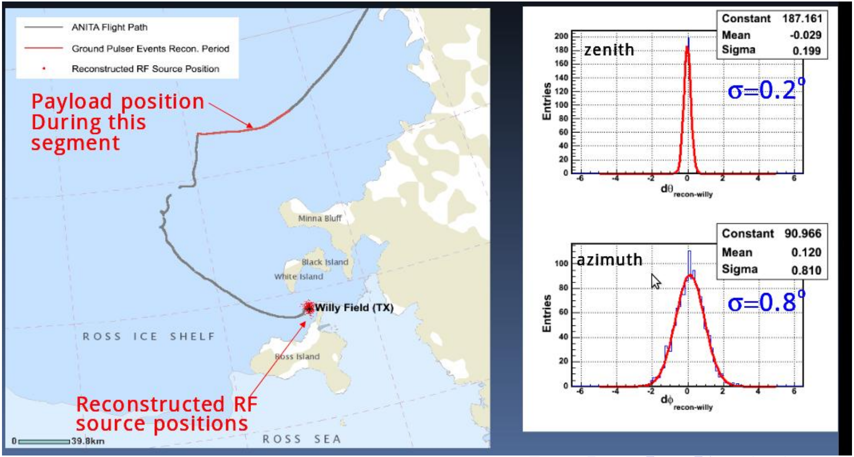


from jiwoo Nam

Ground Pluser System

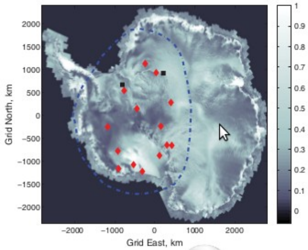


Angular Resolution



Results of ANITA I & II (cosmic rays)

PRL **105**, 151101 (2010)



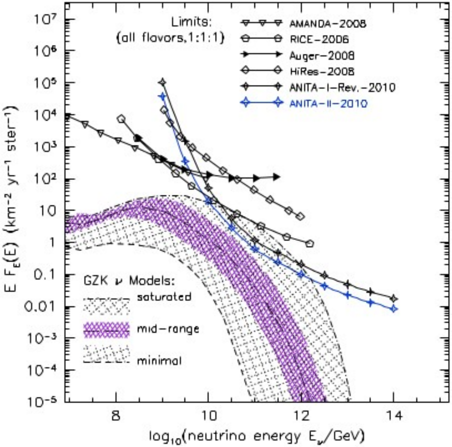
- A combination of **vxB** and Fresnel coefficients result in air shower emission being horizontally polarised at the payload
- ANITA-I detected 16 isolated H-pol candidate UHECR events
- ANITA-II did not trigger on the H-pol channels
  - –Doh!!
- Still detected 5 UHECR candidate events

Results of ANITA I & II (Neutrino)

- ANITA-II Results

Isolated v-pol events	1
Expected background events	0.97 ± 0.42

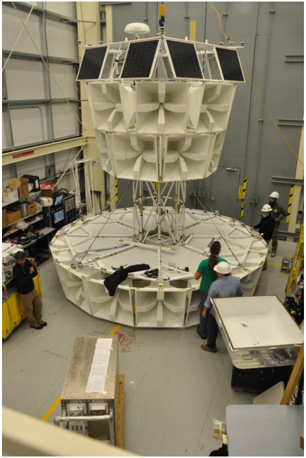
- Combine with efficiency to extract world's best limit on UHE neutrino flux above 10^{19}eV



Some Photos of ANITA Project

Some Photos of ANITA: Starting Point

Some Photos of ANITA: Payload House



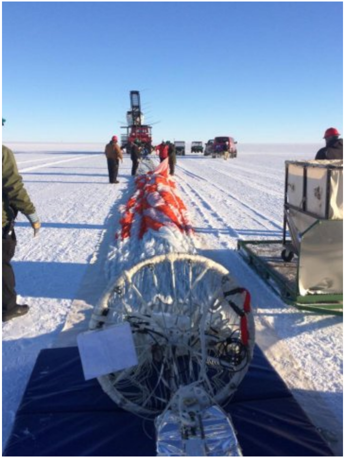
Some Photos of ANITA: Payload House

Some Photos of ANITA-IV

Some Photos of ANITA

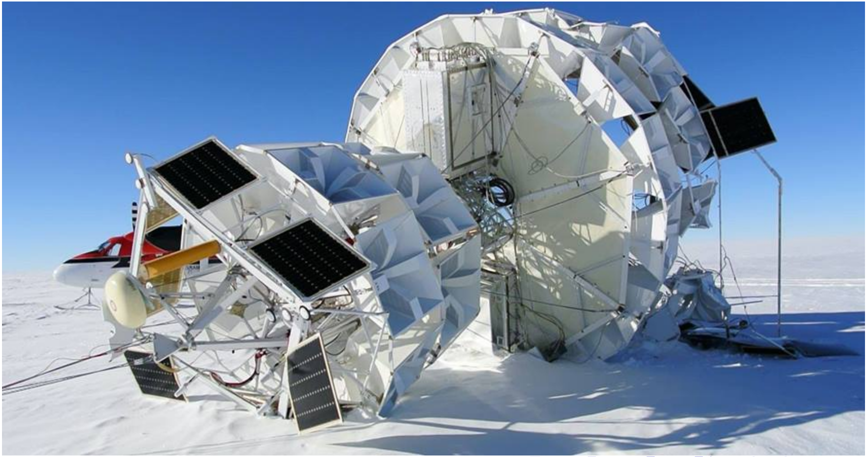
Some Photos of ANITA-IV

Some Photos of ANITA-IV

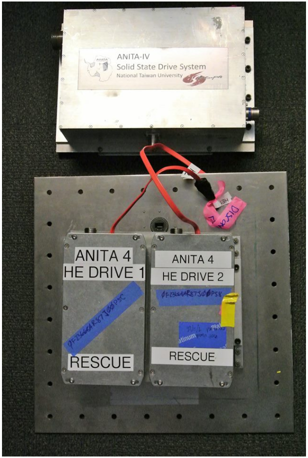


Some Photos of ANITA-IV

Some Photos of ANITA-IV

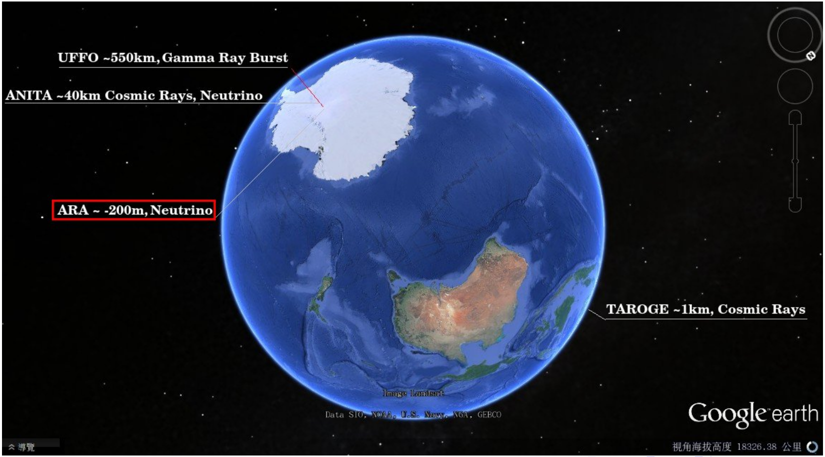


Some Photos of ANITA-IV

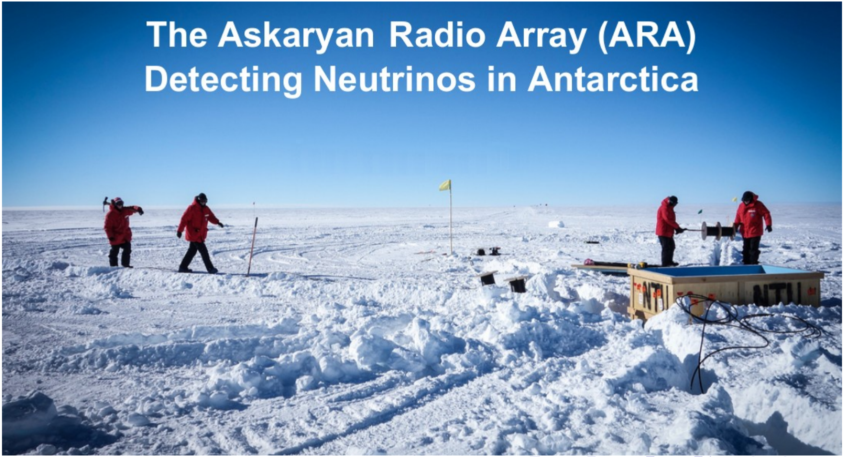


Outline

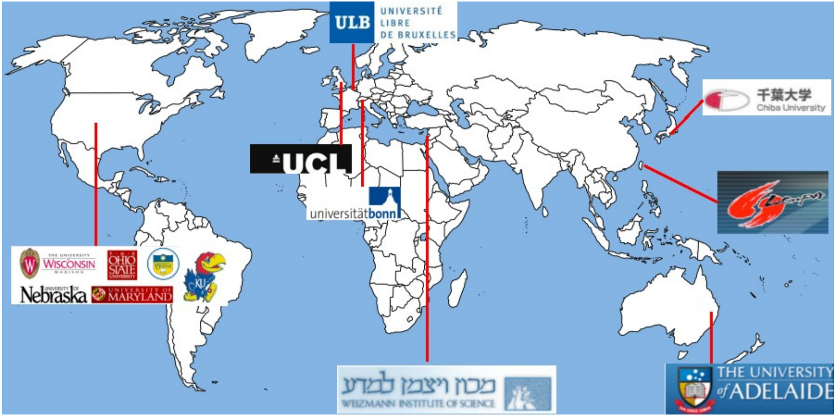
ARA at -200m


UFFO ~550km, Gamma Ray Burst
ANITA ~40km Cosmic Rays, Neutrino
ARA ~ -200m, Neutrino
TAROGE ~1km, Cosmic Rays
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
視角海拔高度 18326.38 公里
導覽

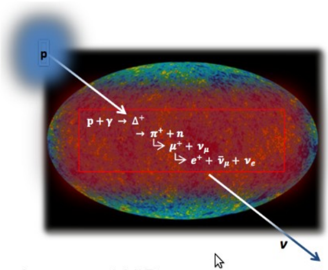
ARA at -200m


The Askaryan Radio Array (ARA)
Detecting Neutrinos in Antarctica
NTU
NTU

The ARA Collaboration



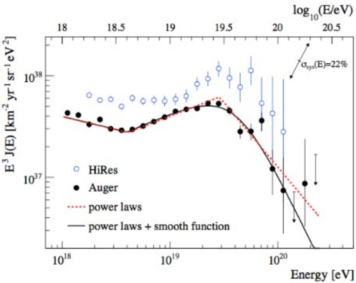
The Askaryan Radio Array (ARA) is an Ultra High Energy (UHE) Neutrino Detector at the South Pole



At energies above ~$10^{19.5}$eV cosmic rays will interact with CMB photons producing neutrinos

Process is known as the GZK effect

Auger and HiRes measurements of UHE cosmic rays consistent with GZK cut-off



Guaranteed GZK neutrino flux, but how large?

copy from Jonathan's slides

The Pierre Auger Collaboration (2010): Phys. Lett. B 685 (4–5): 239–246. HiRes Collaboration, Astropart. Phys. 32 (2009) 53.

ARA-37

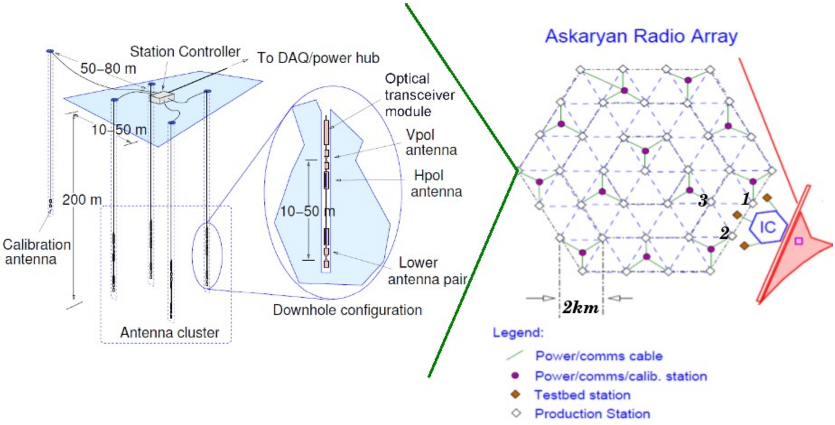
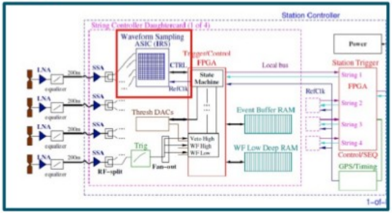


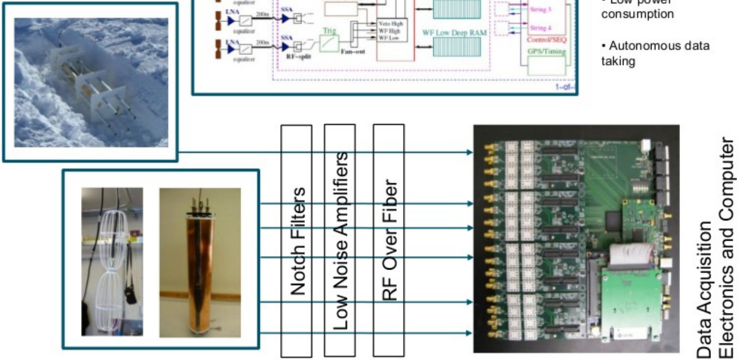
Figure: ARA 37 Layout, 37 Stations 200m below the surface∼200km^2

DAQ System and Antenna Cluster

ARA Sub-Station – DAQ



- 150-850 MHz bandwidth
- 3.2 GSa/s sampling (4x Nyquist)
- Low power consumption
- Autonomous data taking



DAQ System and Antenna Cluster

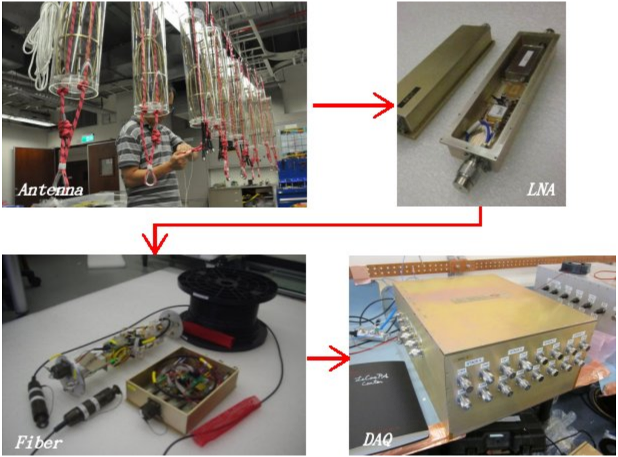


Figure: Each station has 4 string with 16 channels

Build & Test in Taiwan

Figure: Building ARA2 & ARA3 last year

Delivery

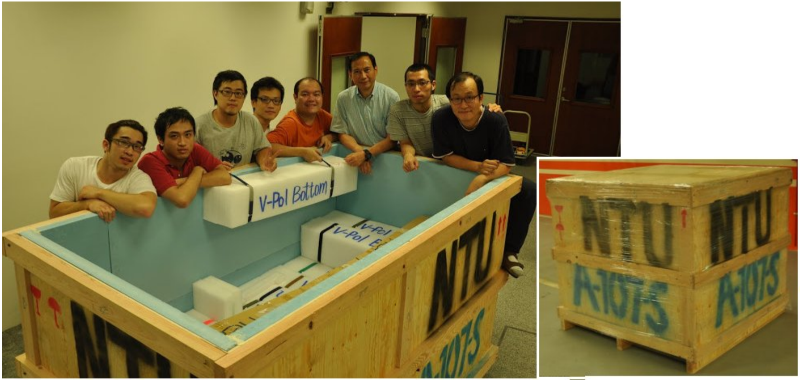
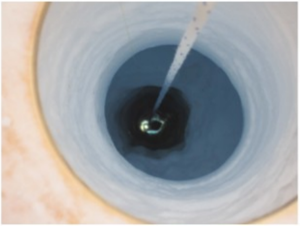


Figure: delivery for 2 stations

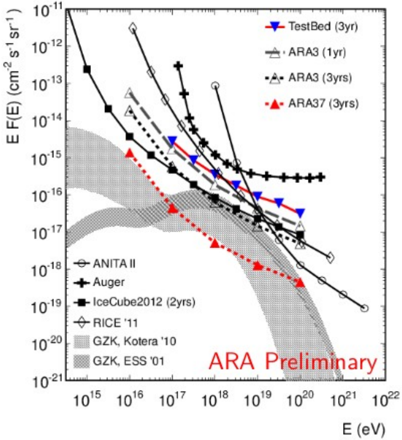
Drilling and Deployment

- Hot water drill creates 6" wide holes
- Holes are pumped dry
- Approaching $\sim 8\,\mathrm{hr} \times \sim 1$ drill crew per 200 m hole
- Instrumentation deployed from greenhouse sled



Simulation & Expected Sensitivity

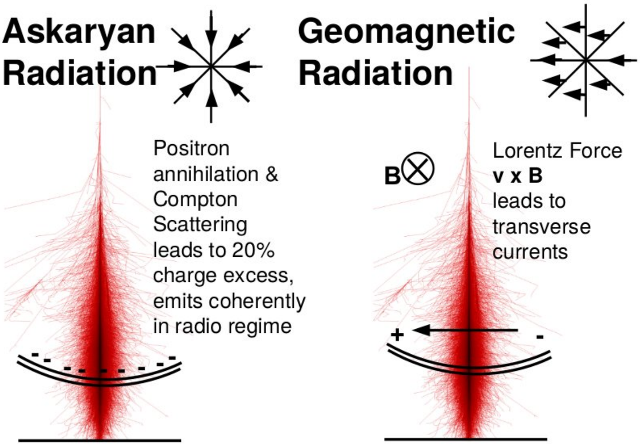
- In-house tool called AraSim
- Simulates
  - → neutrino interaction
  - → radio emission
  - → radio propagation
  - → instrument response
  - → thermal, instrument noise
  - → hardware trigger
  - → digitized waveforms
- Has been used to calculate trigger-level neutrino sensitivity



Outline

T-510

Radio Detection of T-510 (Geo-Synchrotron Radiation)



T-510 Collaborations

JPL Jet Propulsion Laboratory, California Institute of Technology — NASA

Andrew Romero-Wolf
Charles Naudet

KIT Karlsruhe Institute of Technology

Tim Huege
Anne Zilles

UCL

Ben Strutt
Ryan Nichol

Stefan Funk
Christopher Williams

UCLA

Konstantin Belov (PI)
David Saltzberg
Stephanie Wissel
Joe Lam
Kyle Borch
Kyle Kuwatani
David Urdaneta

SLAC NATIONAL ACCELERATOR LABORATORY

Carsten Hast
Keith Jobe

Pisin Chen
Jiwoo Nam
TsungChe Liu

Katharine Mulrey
John Clem
David Seckel

W&M

Rachel Hyneman

CAL POLY

Stephanie Wissel

Washington University in St.Louis

Brian Rauch
Bob Binns
Martin Israel
Viatcheslav Bugaev

KU THE UNIVERSITY OF KANSAS

Dave Besson
Mark Stockham
Jessica Stockham

Peter Gorham
Harm Schoorlemmer
Ben Rotter

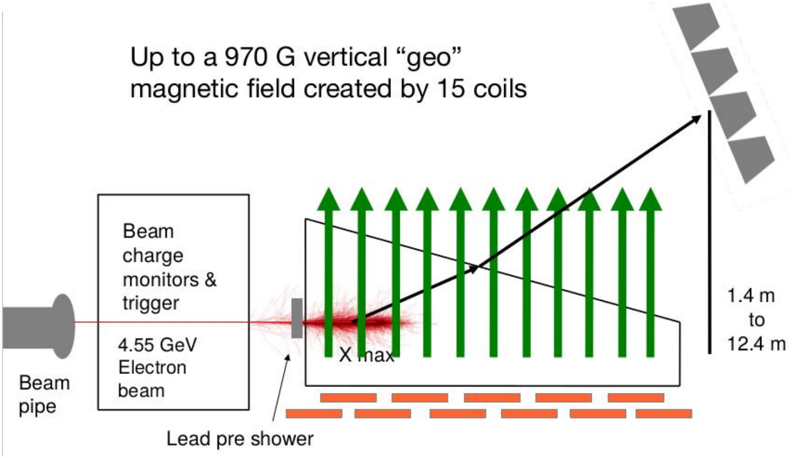
Keith Bechtol
Abigail Vieregg

End Station A (4.55 GeV)

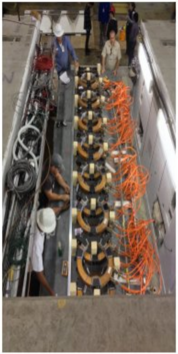
3 km linear accelerator

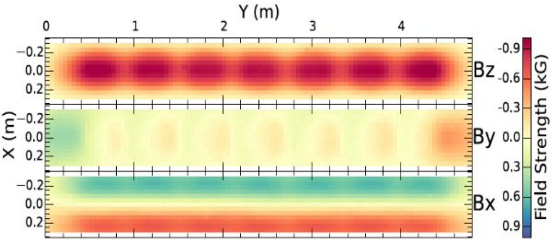
End Station A

Setup of T-510



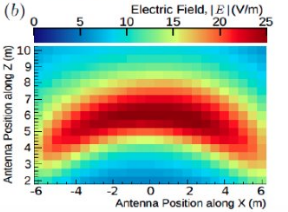
Magnet of T-510

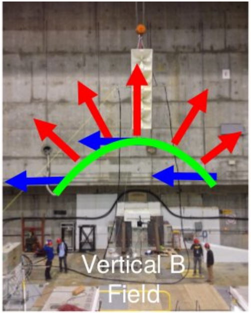




- Two layers of staggered solenoids to produce uniform magnetic field
- Measured in a 5cm x 5cm grid at beam height
- Primarily vertical to induce radiation in the horizontal direction

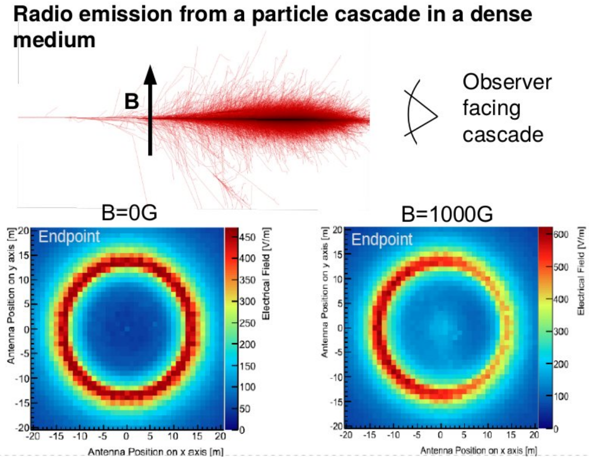
Radio Signal of T-510



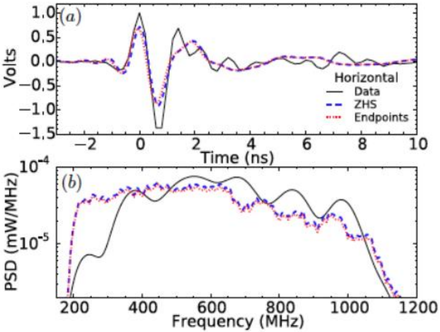


Cherenkov Cone
Askaryan
Magnetic Induced

Radio Signal of T-510



Comparing Data & Simulation



Vertically polarized signal on the Cherenkov cone

- ZHS and Endpoint formalisms agree to within 3%
- Data peak amplitude exceeds simulation by 35% (commensurate with systematic uncertainty)

Outline

sFLASH Collaborations

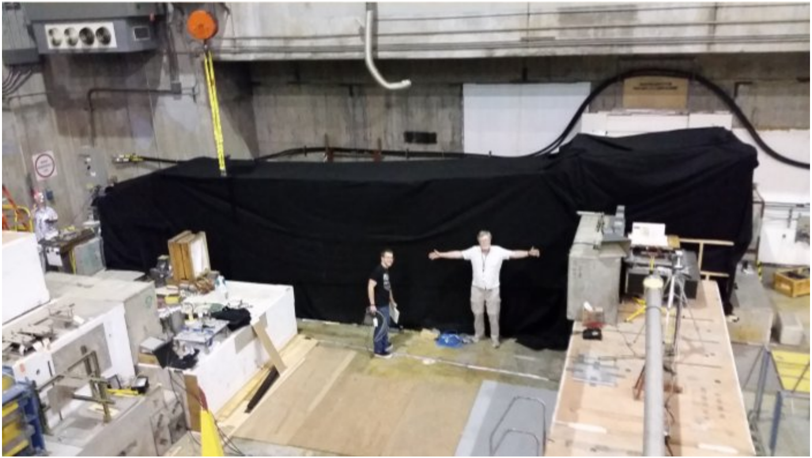
THE UNIVERSITY OF UTAH 1850

NASA JPL
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

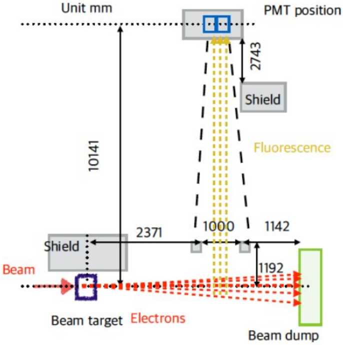
大阪市立大学
OSAKA CITY UNIVERSITY

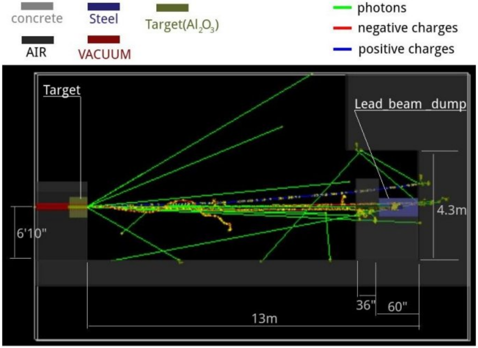
SLAC NATIONAL ACCELERATOR LABORATORY

sFLASH in SLAC

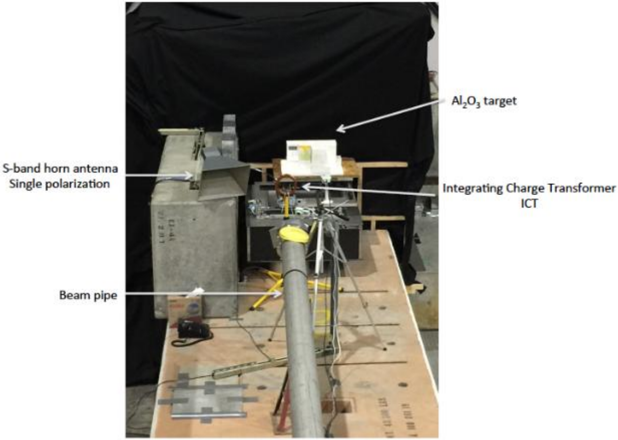


sFLASH setup

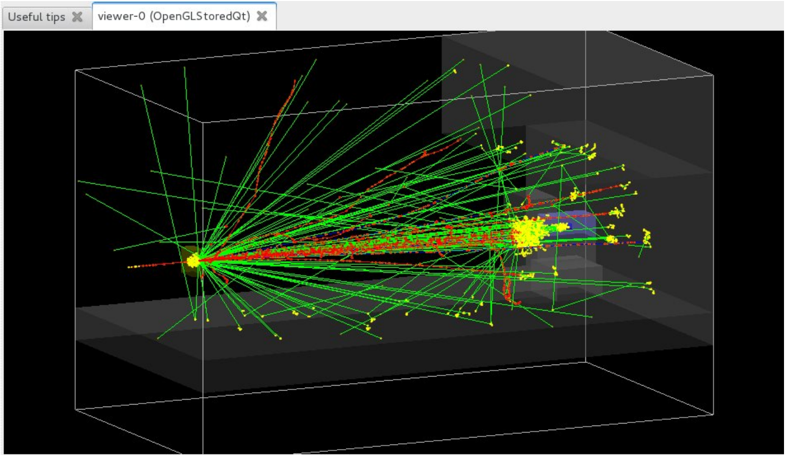




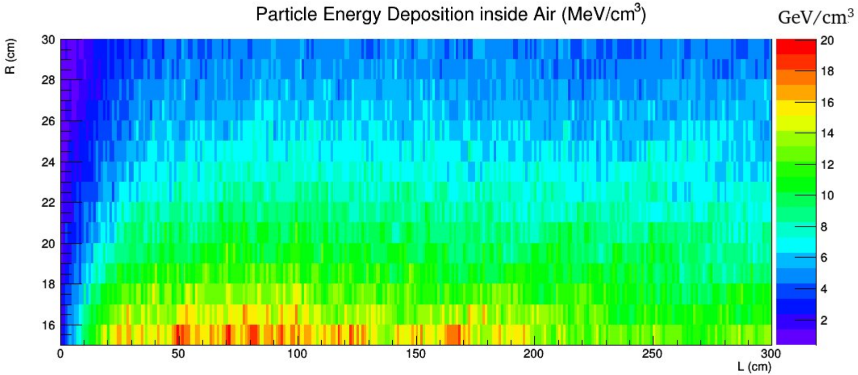
sFLASH Target setup



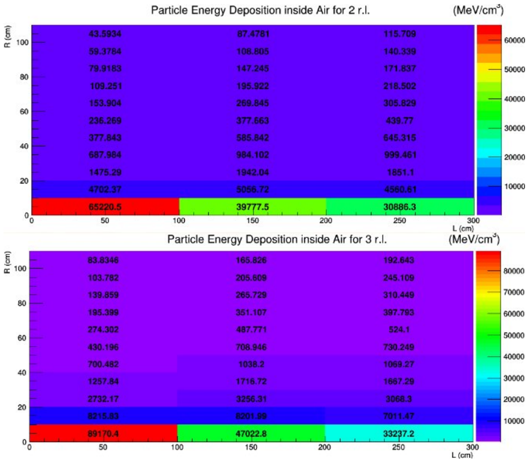
sFLASH Simulation



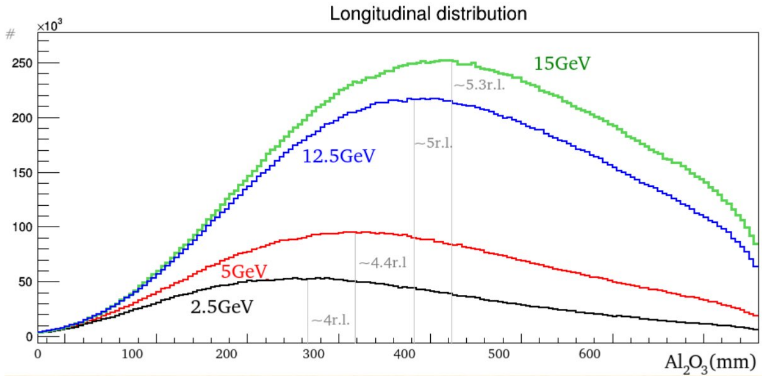
sFLASH Simulation



sFLASH Simulation

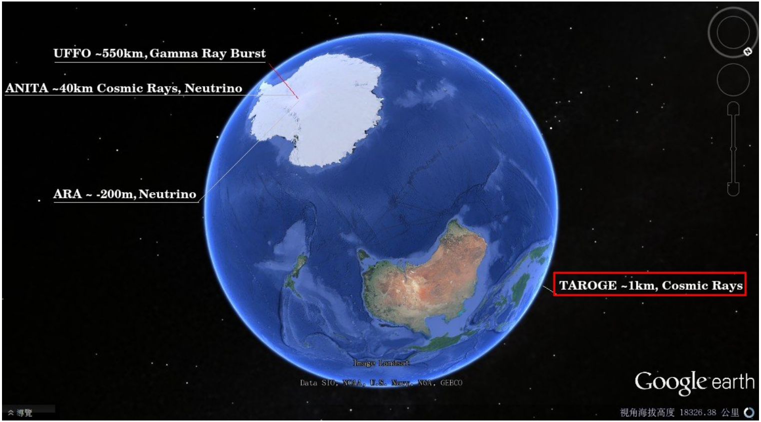


sFLASH Simulation

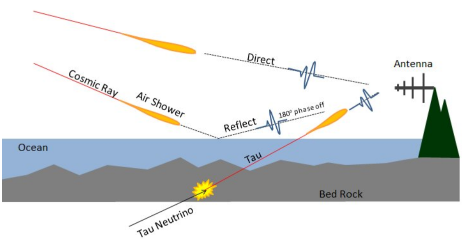


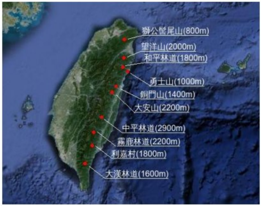
Outline

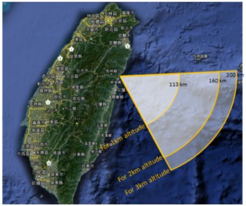
Outline: The Distribution of Experiments



Taiwan Astroparticle Radiowave Observatory for Geo-synchrotron Emission(TAROGE)

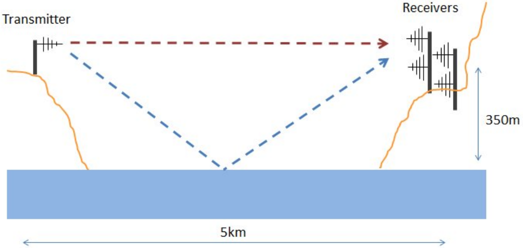


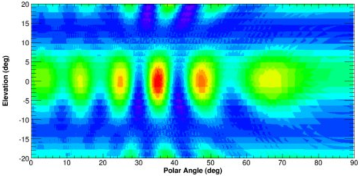


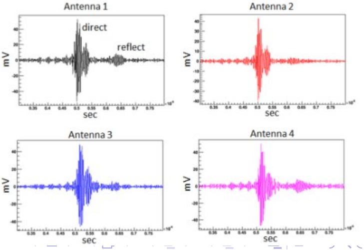


TAROGE at 1200~2000m

Reflection Test of TAROGE

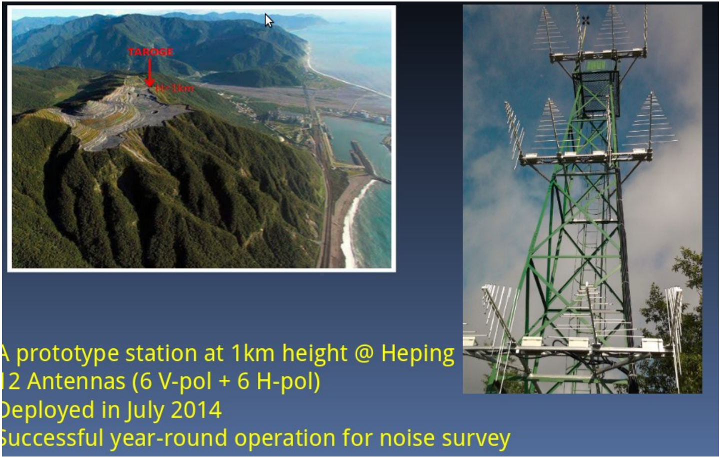




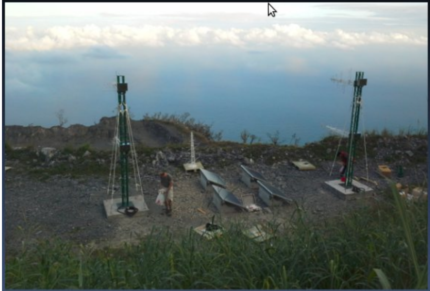


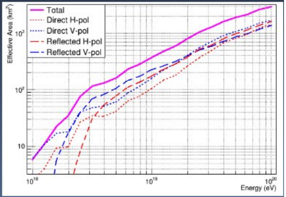
TAROGE I at He-Ping

TAROGE I


TAROGE
A prototype station at 1km height @ Heping
12 Antennas (6 V-pol + 6 H-pol)
Deployed in July 2014
Successful year-round operation for noise survey

TAROGE-II





6 dual pol. LPDA antennas on 3 towers
No town in FOV / CW insensitive trigger
Longer baseline, time resolution improved
→ Better pointing resolution
Off-grid power

TAROGE 2 and Future

Future Plans

- ANITA-5 (2020): Neutrino & cosmic rays
- SWORD(TBD): Neutrino & cosmic rays
- ARA37 (within 6 years): Neutrino
- TAROGE-10 (within 4 years): Neutrino & cosmic rays
- HCR (>4 years): Neutrino & cosmic rays

Thank you!

The Synoptic Wideband Orbiting Radio Detector (SWORD)

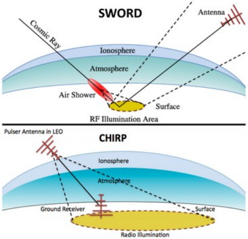


Figure 1: The top figure outlines the SWORD mission concept. The UHECR interacts in the atmosphere to produce an extended air shower. The geo-magnetic field separates the positrons and electrons in the shower to produce a geo-

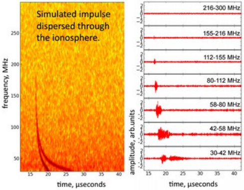


Figure 2: An example of a simulated 2×10^{20} eV cosmic ray induced geo-synchrotron radio impulse after propagation through an ionospheric profile with 14 TECU. The spectrogram of the signal (left) shows the effect of dispersion and birefringence (Equation 1) for a signal detected by a linearly polarized antenna. Waveforms (right) for the bands used in SWORD show the progressively larger amount of

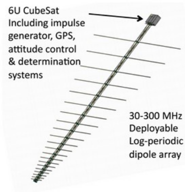


Figure 4: The CHIRP satellite consists of a deployable log-periodic dipole antenna that is 4.7 meters in length with 3.7 meter longest dipole element. The antenna is stowed in a 1.5U volume of the 6U CubeSat bus, which contains all the major subsystems needed for the mission.

Potential and Issues

- ANITA-5 (2020): Neutrino & cosmic rays
- SWORD(TBD) :cosmic rays
- ARA37 (within 10 years): Neutrino
- TAROGE-10 (within 4 years): Neutrino & cosmic rays

For Further Reading I

A. Author.
Handbook of Everything.
Some Press, 1990.

S. Someone.
On this and that.
Journal on This and That. 2(1):50–100, 2000.