

ASTROPHYSICS IN ANTARCTICA

STEM LECTURE NIGHTS - Los NIETOS MIDDLE SCHOOL

Jordan C. Hanson (jhanson2@whittier.edu)

September 26, 2018

Whittier College

OUTLINE

- I. Cosmic Ray Origins ... *A 100 year journey*
- II. Antarctic Science ... *Beautiful and Dangerous*
- III. Detectors and Discoveries ... *Culmination*
- IV. Future Designs ... *Expanding the Horizon*

COSMIC RAY ORIGINS

COSMIC RAY ORIGINS ... DEFINITION OF A COSMIC RAY

Definition of a Cosmic Ray *A cosmic ray is a relativistic particle in deep space.* Often in science, decades of work can be encapsulated in a single statement. Cosmic rays, like all other particles, have the following properties:

Total Energy and Rest Mass

N/Z , the number of nucleons, the number of protons

Momentum, in a certain direction

Flux, in units of particles per area per solid angle per time

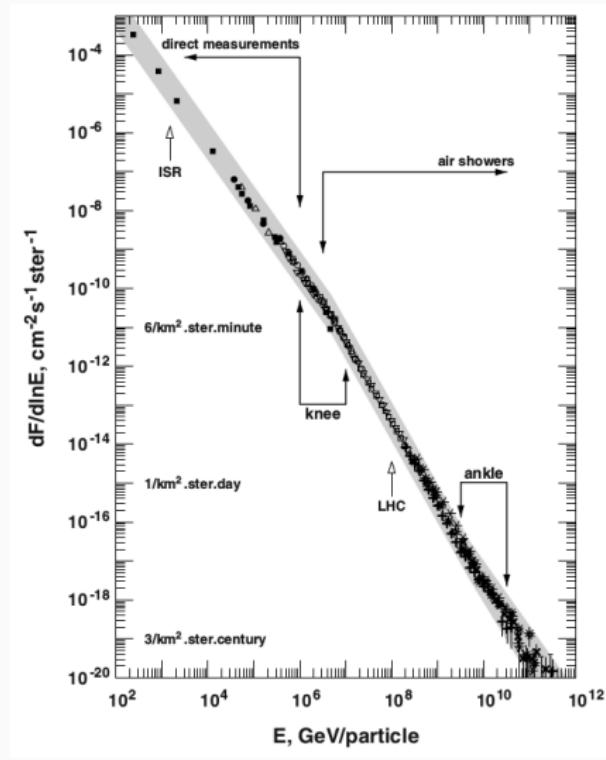
PARTICLES AND ASTRO-PHYSICS

LEPTONS

mass → $\approx 2.3 \text{ MeV}/c^2$ charge → 2/3 spin → 1/2	u up	≈ 1.275 GeV/c^2 2/3 1/2	c charm	≈ 173.07 GeV/c^2 2/3 1/2	t top	0 0 1	g gluon	≈ 126 GeV/c^2 0 0 0	H Higgs boson
≈ 4.8 MeV/c^2 -1/3 1/2	d down	≈ 95 MeV/c^2 -1/3 1/2	s strange	≈ 4.18 GeV/c^2 -1/3 1/2	b bottom	0 0 1	γ photon	0 0 1	
0.511 MeV/c^2 -1 1/2	e electron	105.7 MeV/c^2 -1 1/2	μ muon	1.777 GeV/c^2 -1 1/2	τ tau	0 0 1	Z Z boson	91.2 GeV/c^2 0 1	
<2.2 eV/c^2 0 1/2	ν_e electron neutrino	<0.17 MeV/c^2 0 1/2	ν_μ muon neutrino	<15.5 MeV/c^2 0 1/2	ν_τ tau neutrino	80.4 GeV/c^2 ±1 1	W W boson		

GAUGE BOSONS

COSMIC RAY ORIGINS ... THE ENERGY SPECTRA



Definitions

Flux in
 $\text{km}^{-2} \text{str}^{-1} \text{min}^{-1}$

Direct
Measurement

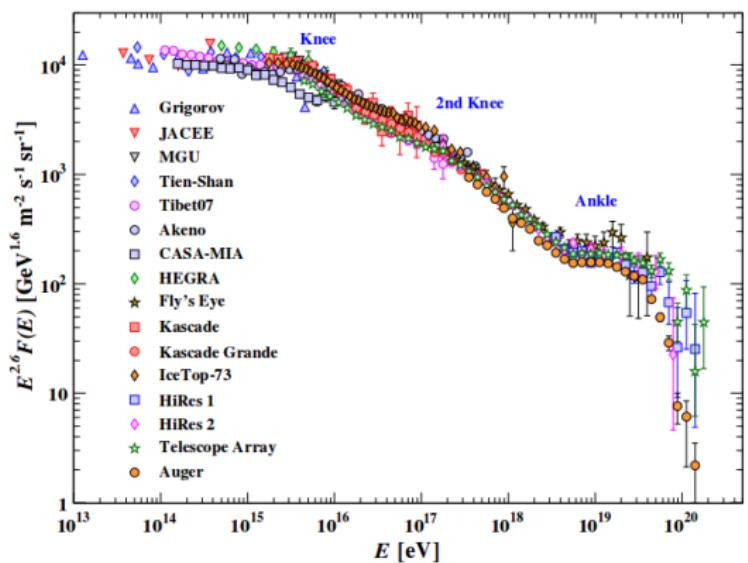
Air Shower

Energy in GeV

LHC

Knee, Ankle

COSMIC RAY ORIGINS ... THE ENERGY SPECTRA



Definitions

Flux in $\text{km}^{-2} \text{str}^{-1} \text{min}^{-1}$

Direct Measurement

Air Shower

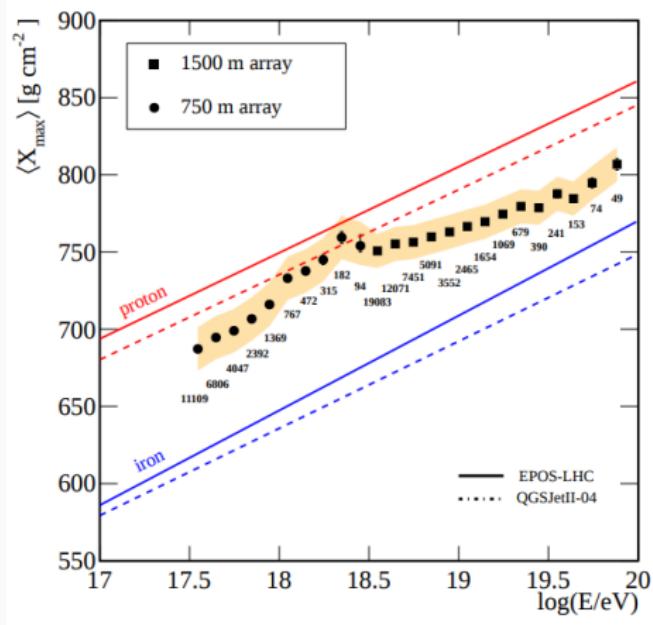
Energy in eV

Knee, Ankle

The GZK cutoff, at right

The GZK cutoff is a result of UHECRs and the CMB (more later)

COSMIC RAY ORIGINS ... CHEMICAL COMPOSITION



Definitions

X_{\max} - depth of shower maximum

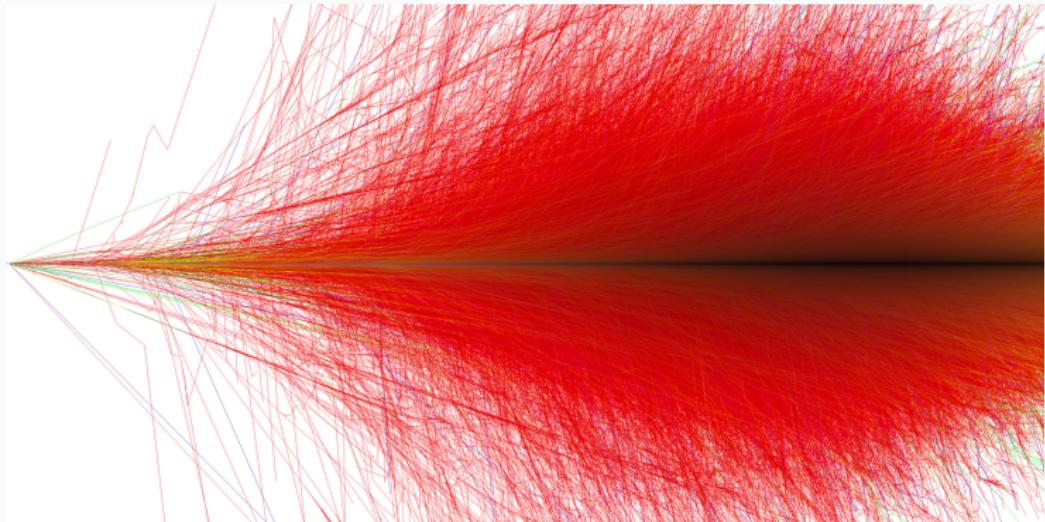
Direct Measurement

Air Shower

Energy in eV

Ankle

COSMIC RAY ORIGINS ... EXAMPLE OF AN AIR SHOWER



(Left side: one proton, big energy. Right side: many particles, small energy)

From Earth or from Space?

Fr. Theodor Wulf (Jesuit priest), electroscope discharge vs. height, Eiffel Tower, 1909

Domenico Pacini, Prof. Physics, Bari, Italy. Electroscope discharge vs. depth underwater, Livorno, Italy, 1911

Victor Hess, Prof. Physics, Vienna, Austria. Electroscope discharge vs. balloon height, Austria, 1911-12

Robert Millikan and Arthur Compton. Research confirmed that particles were from space, and charged. 1930s Chicago, California

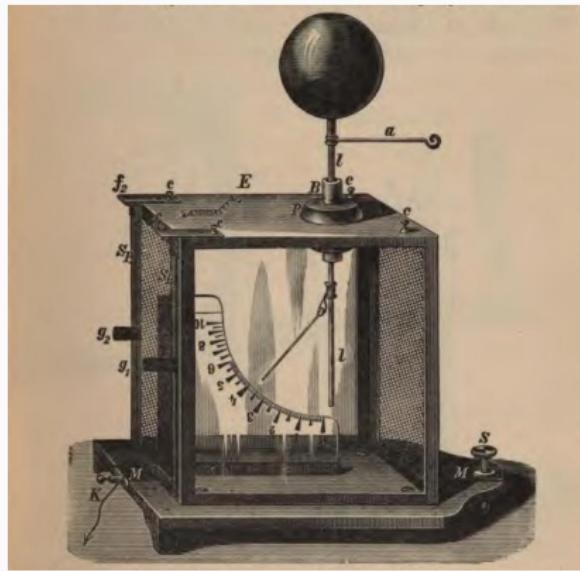
COSMIC RAY ORIGINS ... DISCOVERIES THAT LED TO THIS PICTURE

But what's in there?

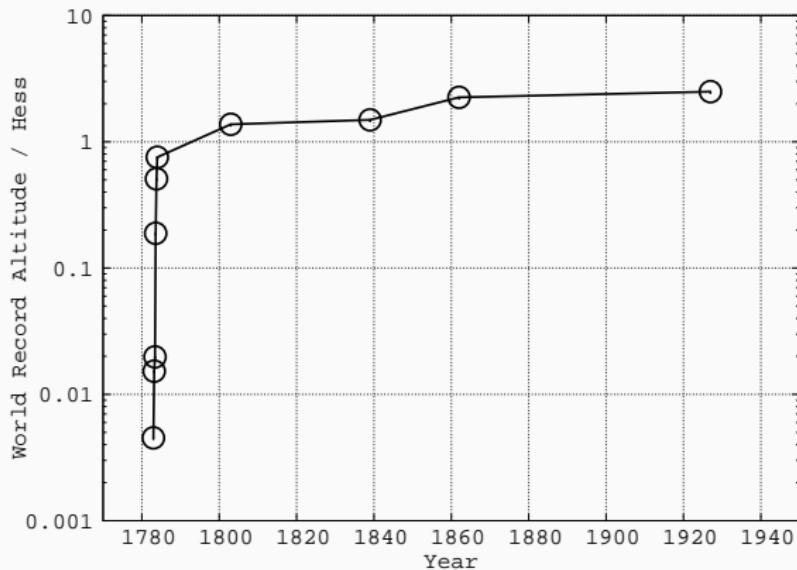
Charles Wilson wins Nobel Prize for invention of cloud chamber, 1927. Allows photography of sub-atomic tracks

Carl Anderson discovers muon and positron, shares 1936 Nobel Prize with Victor Hess. Anti-matter (positron) discovered in cosmic rays

COSMIC RAY ORIGINS ... 1936 NOBEL PRIZE, CULMINATION



COSMIC RAY ORIGINS ... 1936 NOBEL PRIZE, CULMINATION



COSMIC RAY ORIGINS ... 1936 NOBEL PRIZE, CULMINATION

Table 2.1 Summary of Hess' results

Mean height from ground (m)	Measured radiation (ions per cc per second)		
	Electrosc. 1	Electrosc. 2	Electrosc. 3
0	16.3	11.8	19.6
Up to 200	15.4	11.1	19.1
300–500	15.5	10.4	18.8
500–1,000	15.6	10.3	20.8
1,000–2,000	15.9	12.1	22.2
2,000–3,000	17.3	13.3	31.2
3,000–4,000	19.8	16.5	35.2
4,000–5,200	34.4	27.2	—

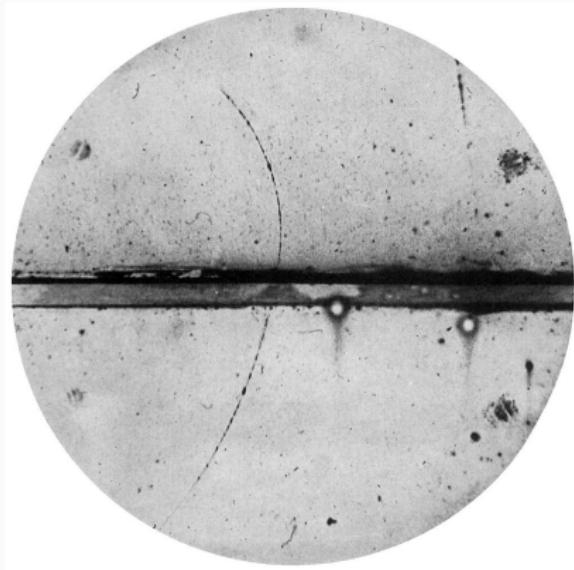
Table 2.2 Differences between altitude and ground measurements

Mean height from ground (m)	Variation between altitude and ground (ions per cc per second)			
	Electrosc. 1	Electrosc. 2	Electrosc. 3	Mean
300–500	−0.8	−1.4	−0.8	−1
500–1,000	−0.7	−1.5	1.2	−0.3
1,000–2,000	−0.4	0.3	2.6	0.8
2,000–3,000	1	1.5	11.6	4.7
3,000–4,000	3.5	4.7	15.6	7.9
4,000–5,200	18.1	15.4	—	11.2

COSMIC RAY ORIGINS ... 1936 NOBEL PRIZE, CULMINATION



COSMIC RAY ORIGINS ... 1936 NOBEL PRIZE, CULMINATION



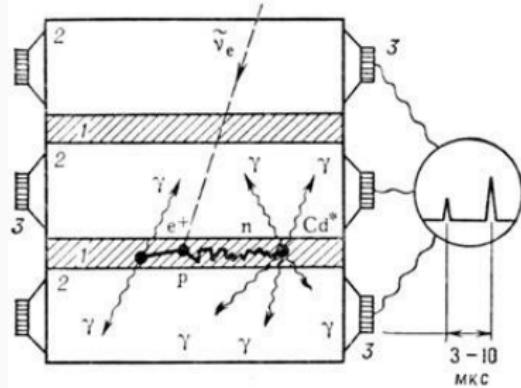
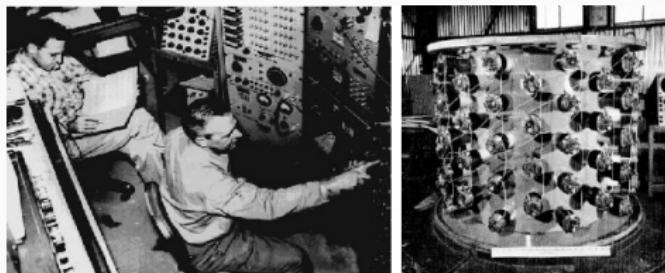
All the best discoveries are simple and clear. The lead plate decreases energy of the positron, increasing curvature. The magnetic field goes into the page.

COSMIC RAY ORIGINS ... 1950S, NUCLEAR REACTORS, AND THE NEUTRINO

Wolfgang Pauli
proposal in 1930s

Enrico Fermi
completed theory of
beta decay in 1934
(neutron discovered in
1932)

In 1956, Frederick
Reines (**UCI!**) and
Clyde Cowan recorded
neutrino hits coming
from a nuclear reactor



COSMIC RAY ORIGINS ... 1960S-1970S SOLAR NEUTRINOS, ATMOSPHERIC NEUTRINOS

The "solar neutrino problem" - the Sun should produce neutrinos, but not enough

John Bahcall, Ray Davis: neutrino deficit in the late 1960s at the Homestake Mine

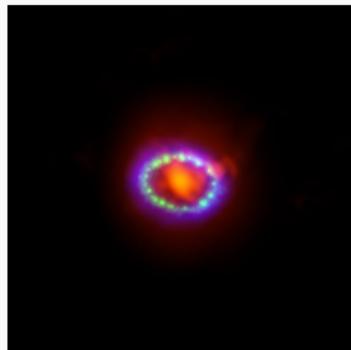
Bruno Pontecorvo in 1968: neutrinos *oscillate* (solves problem)

1988 Nobel Prize to Lederman, Swartz, and Steinberger for discovery of *muon neutrino*

1995 Nobel Prize to Frederick Reines for discovery of first neutrino (*electron neutrino*)

Nobel prize awarded in 2015, after a long history of atmospheric and solar neutrino detections - neutrinos have mass, and oscillate

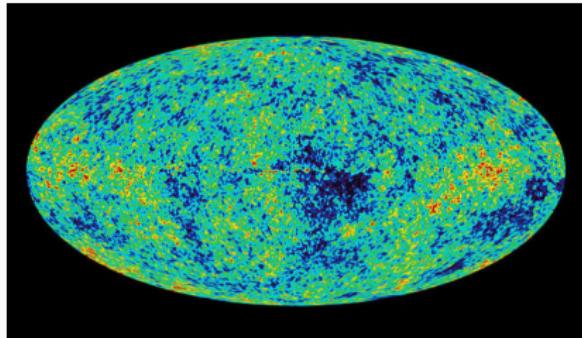
COSMIC RAY ORIGINS ... SN1987A



SN1987A occurred in the Large Magellanic Cloud. Ninety-nine percent of the energy of an exploding star is radiated in neutrinos. Three different detectors recorded hits on Earth (USA, Japan, Russia). Separate indications that neutrinos have mass.

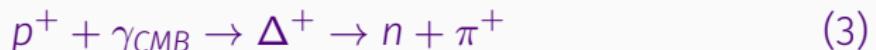
COSMIC RAY ORIGINS ... A FINAL IDEA FROM THE 1960S AND 1970S

Cosmogenic neutrinos and astrophysical neutrinos. 1968:
Kenneth Greisen, Vadim Kuzmin, and Georgiy Zatsepin
independently concluded that UHECRs **cannot exist** with
 $E > 10^{19.5}$ eV (≈ 8 Joules)



WHAT IS THE GZK EFFECT?

One version:



The initial cosmic ray (the proton) cannot propagate across the universe forever. It interacts with ambient photons and decays into electrons, positrons, neutrinos, and *lower energy cosmic rays*.

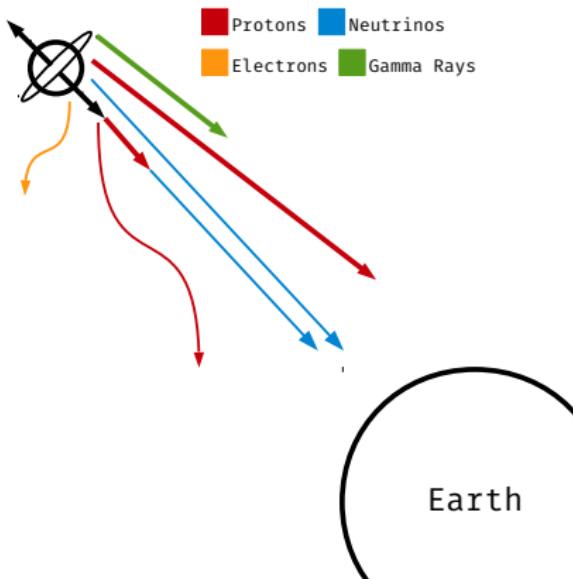
COSMIC RAY ORIGINS ... FROM THE 1960S TO TODAY

Multi-messenger astrophysics and particle physics =
astro-particle physics

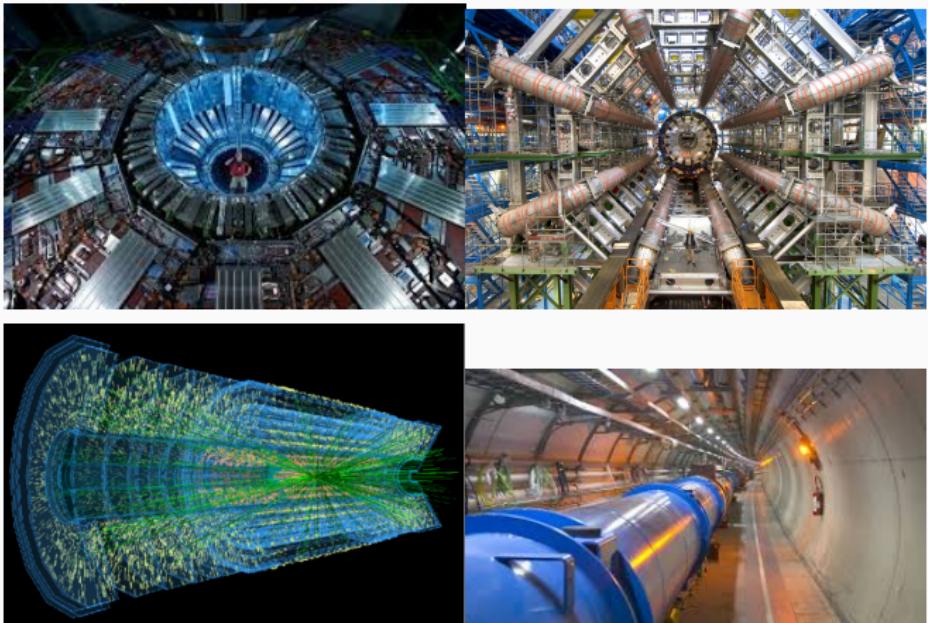
The GZK-cutoff

Double-edged
sword

Unimaginable
distances



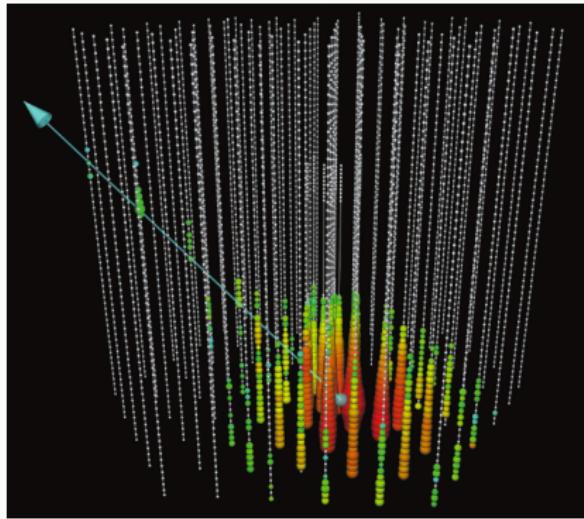
AND THEN CAME THE MACHINES ... (10 TeV)



ANTARCTIC SCIENCE

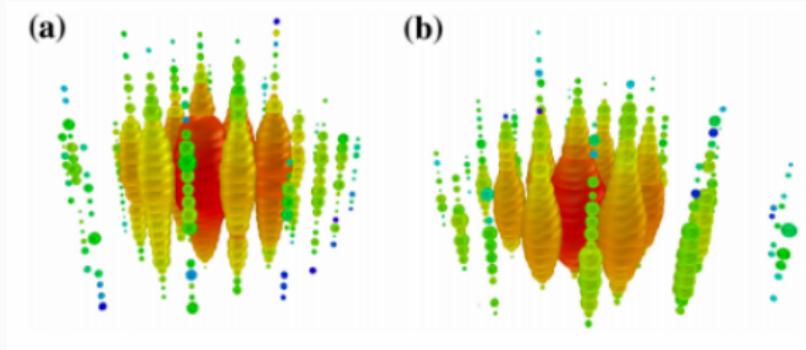
ANTARCTIC SCIENCE ... A BEAUTIFUL, SCIENTIFIC WONDERLAND



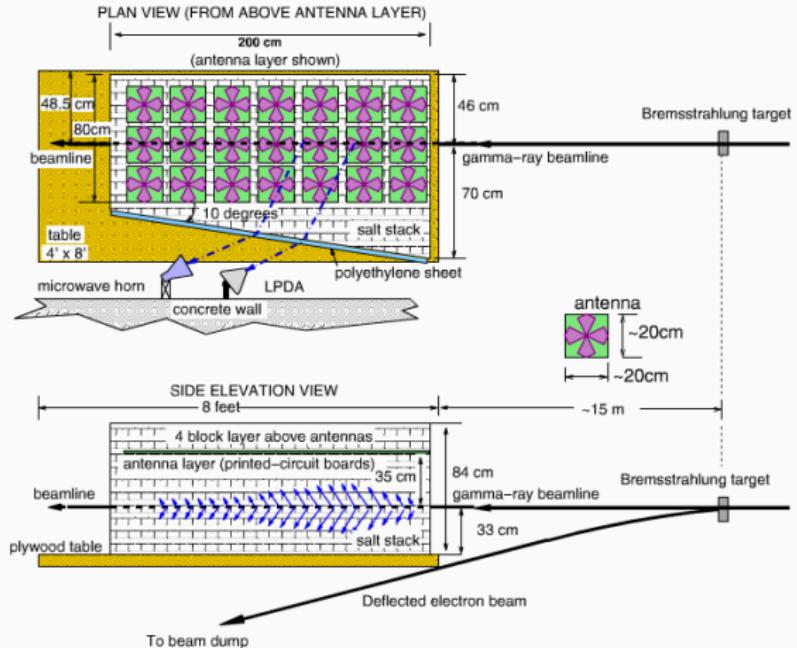


Charged particles depositing energy in ice, leads to moving charges that radiate optical photons.

First PeV neutrinos ever observed, courtesy of IceCube collaboration (more later).



ANTARCTIC SCIENCE ... CERENKOV RADIATION (OPTICAL/ASKARYAN RF)



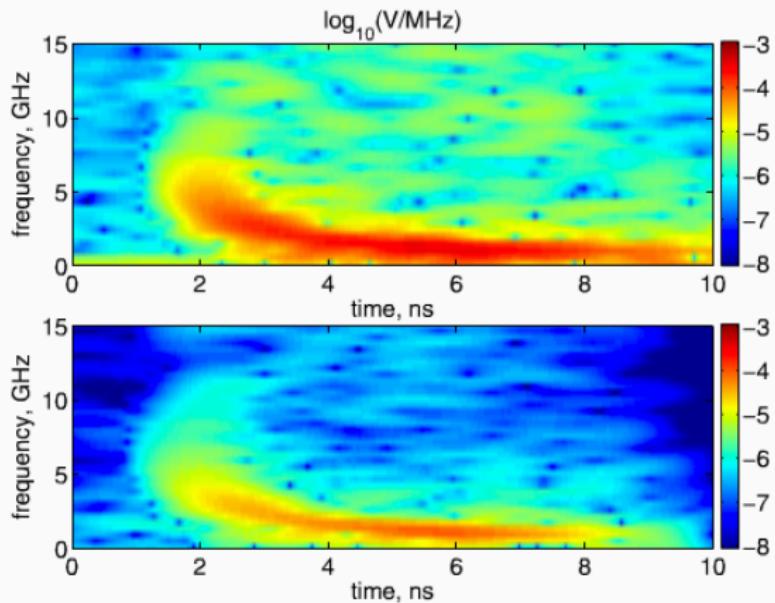
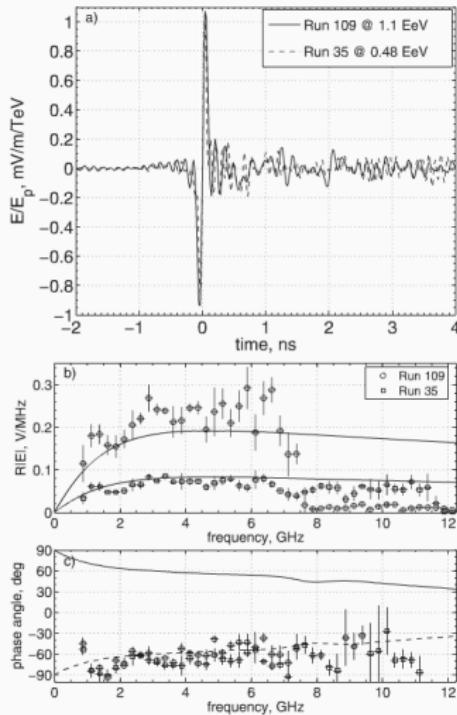


FIG. 3 (color online). Spectrograms of signals recorded in runs 109 and 35 (top and bottom). The color indicates the logarithm of the square root of the signal power per unit frequency.

ANTARCTIC SCIENCE ... CERENKOV RADIATION (OPTICAL/ASKARYAN RF)

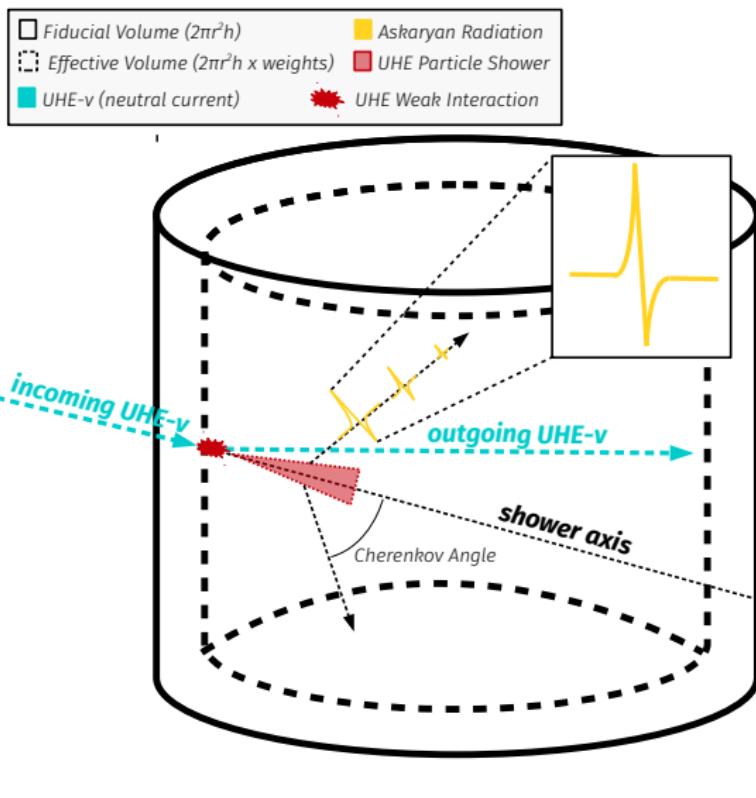


Askaryan theory and simulation match data

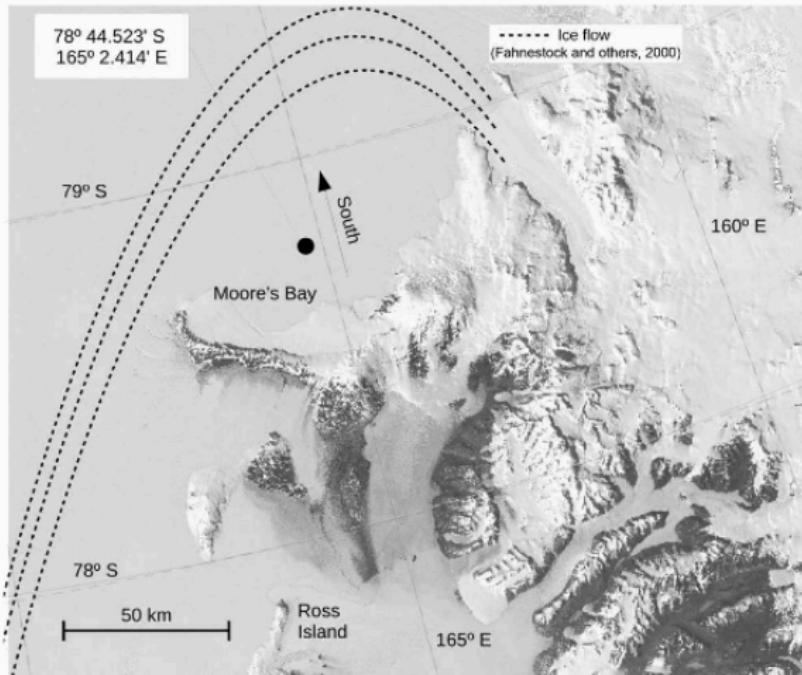
If it's a field, must match *amplitude* and *phase*

So if **optical** and **radio** radiation may be produced by cascades, the next question is how far does it go in ice?

ANTARCTIC SCIENCE ... ANTARCTIC ICE IS RADIO CLEAR



ANTARCTIC SCIENCE ... IN THE NAME OF SCIENCE: MCMURDO BASE



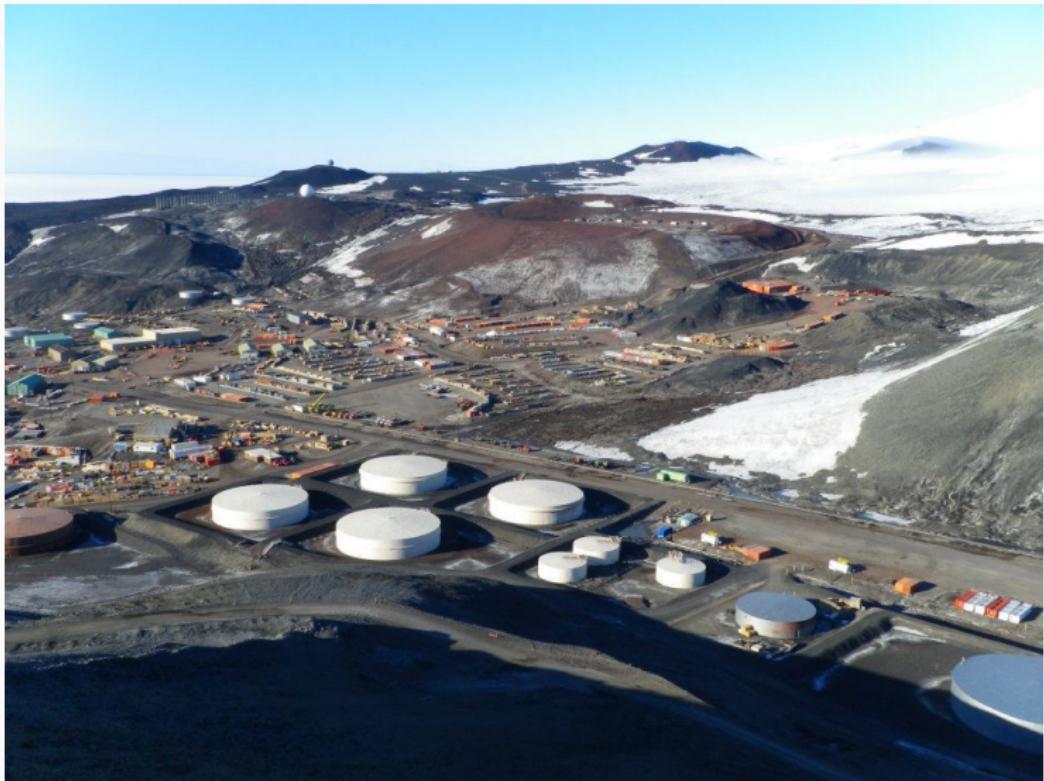
ANTARCTIC SCIENCE ... MCMURDO BASE. NICE VACATION SPOT.



ANTARCTIC SCIENCE ... IN THE NAME OF SCIENCE: MCMURDO BASE



ANTARCTIC SCIENCE ... IN THE NAME OF SCIENCE: MCMURDO BASE



ANTARCTIC SCIENCE ... IN THE NAME OF SCIENCE: MCMURDO BASE



ANTARCTIC SCIENCE ... IN THE NAME OF SCIENCE: MCMURDO BASE



ANTARCTIC SCIENCE ... IN THE NAME OF SCIENCE: ALL NATIONALITIES WELCOME

Antarctica is governed by the Antarctic Treaty, which safeguards the environment, mandates sharing of land and resources, and promotes international cooperation. *People don't say no, they say yes.*



ANTARCTIC SCIENCE ... MCMURDO BASE: TRAINING



Formal name: Snow School 1. Actual name: **Happy Camp**.
Menu: Beef noodles, tears (before they freeze).

ANTARCTIC SCIENCE ... AMUNDSEN-SCOTT BASE, SOUTH POLE



ANTARCTIC SCIENCE ... AMUNDSEN-SCOTT BASE, SOUTH POLE



ANTARCTIC SCIENCE ... AMUNDSEN-SCOTT BASE, SOUTH POLE



ANTARCTIC SCIENCE ... AMUNDSEN-SCOTT BASE, SOUTH POLE



ANTARCTIC SCIENCE ... LIVE WEBCAMS

For more information, go to

<http://usap.gov> - United States Antarctic Program

<https://arianna.ps.uci.edu>

<http://ara.wipac.wisc.edu/home>

<http://icecube.wisc.edu>

<http://www.phys.hawaii.edu> (ANITA)

DETECTORS AND DISCOVERIES

DETECTORS AND DISCOVERIES

List of Neutrino Detectors in Antarctica with Active Campaigns

IceCube - km³ volume, optical photon detector at the South Pole.

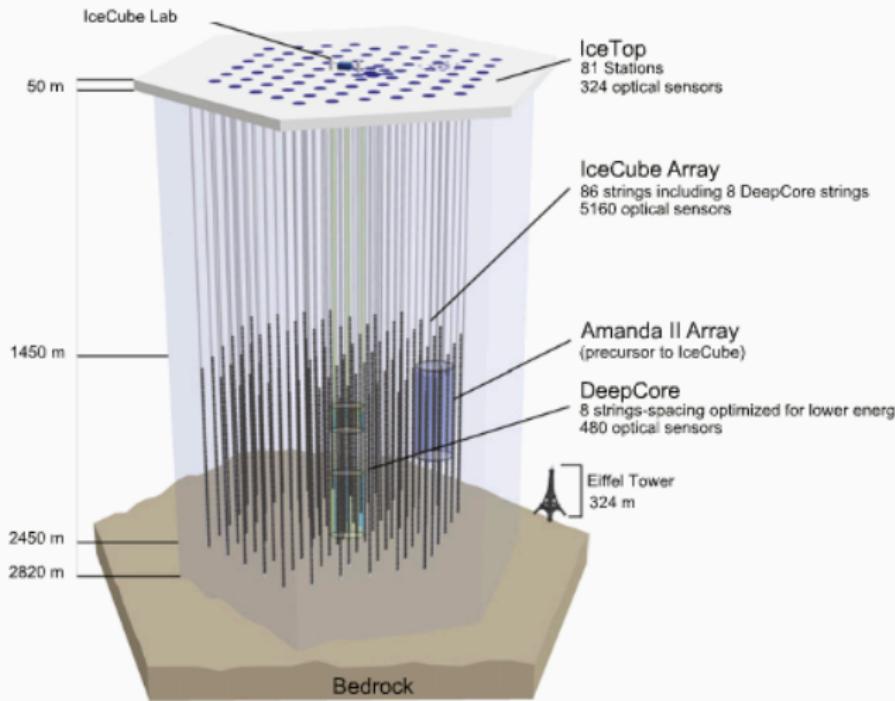
HRA (ARIANNA) - Askaryan-based cosmogenic neutrino detector in Moore's Bay.

ARA6 - Askaryan-based *in-situ* cosmogenic neutrino detector at the South Pole.

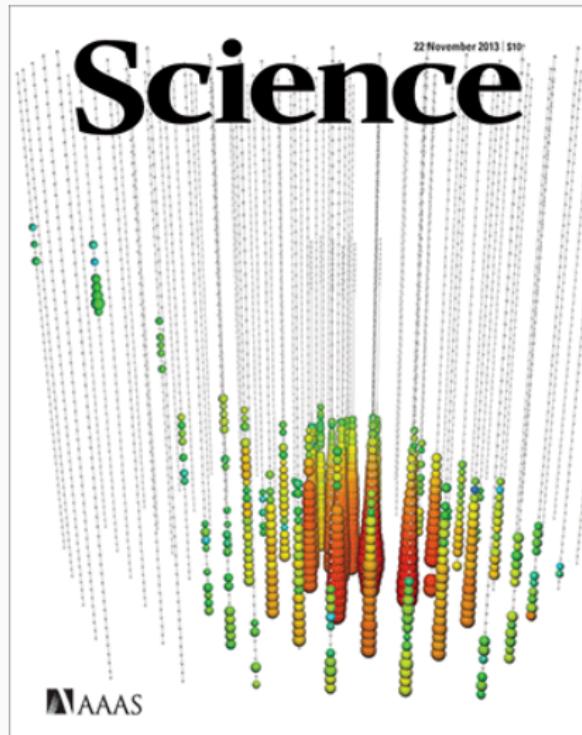
Potential merge between ARA and ARIANNA...*fingers crossed!*

ANITA-1, ANITA-2, ANITA-3 - Balloon-borne cosmogenic neutrino and cosmic ray detector launched from McMurdo

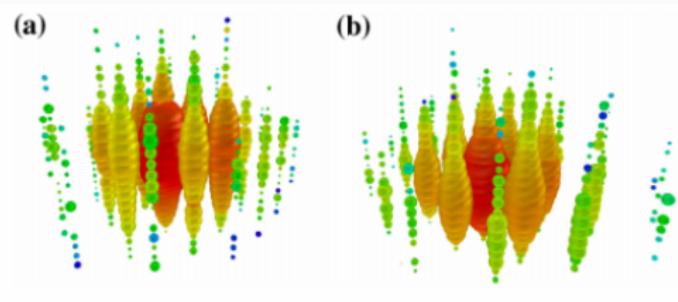
DETECTORS AND DISCOVERIES ... ICECUBE (AMANDA, DEEPCORE, DMICE, ICETOP, RICE)



DETECTORS AND DISCOVERIES ... ICECUBE (AMANDA, DEEPCORE, DMICE, ICETOP, RICE)



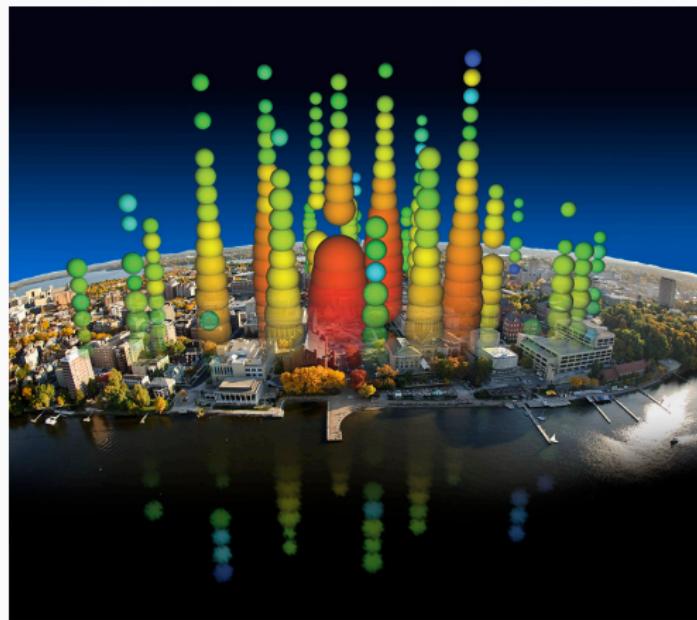
DETECTORS AND DISCOVERIES ... ICECUBE (AMANDA, DEEPCORE, DMICE, ICETOP, RICE)



First observation, 2013. Reconstructed energies of 1.04 ± 0.16 and 1.14 ± 0.17 PeV, from the number of photo-electrons that hit DOMs. These are two "cascade" type events.

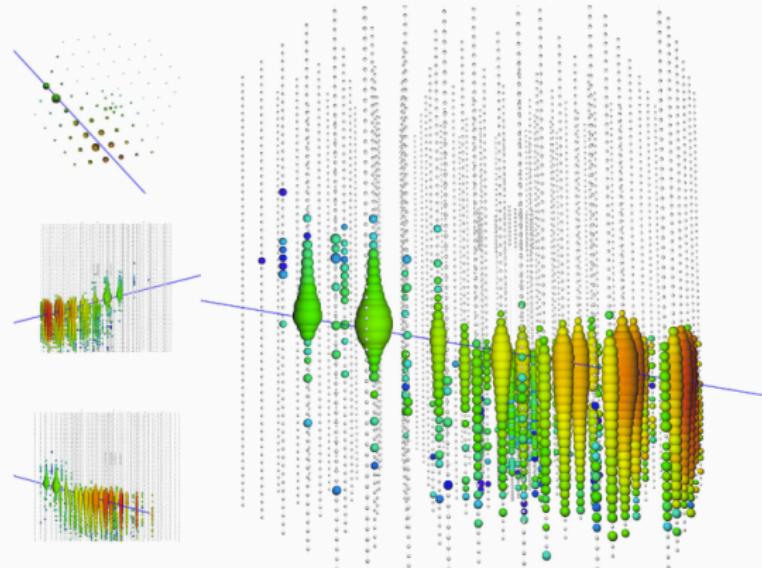
DETECTORS AND DISCOVERIES ... ICECUBE (AMANDA, DEEPCORE, DMICE, ICETOP, RICE)

To scale, at higher energies. That's the University of Wisconsin.

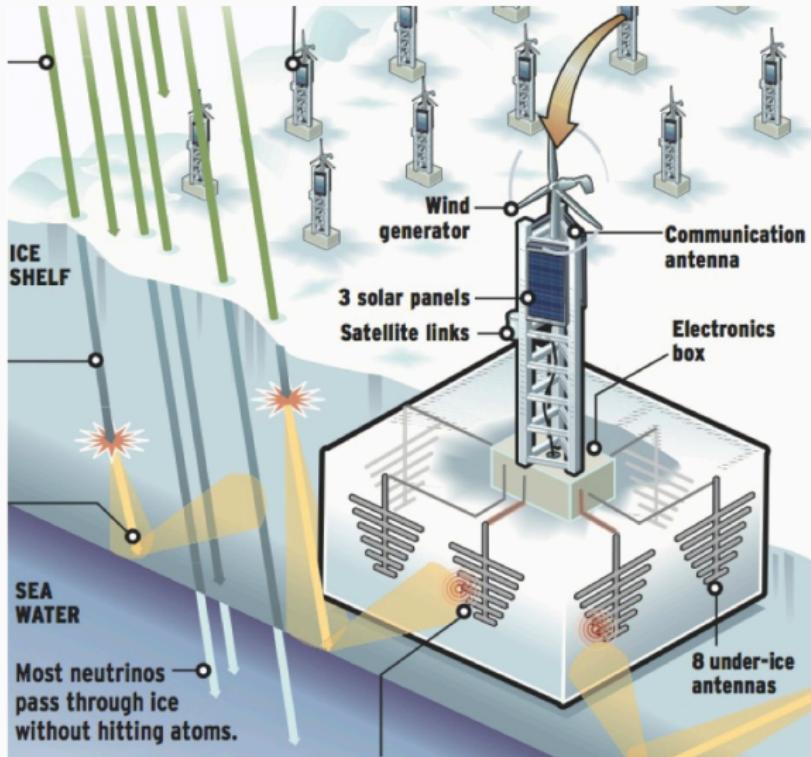


DETECTORS AND DISCOVERIES ... ICECUBE (AMANDA, DEEPCORE, DMICE, ICETOP, RICE)

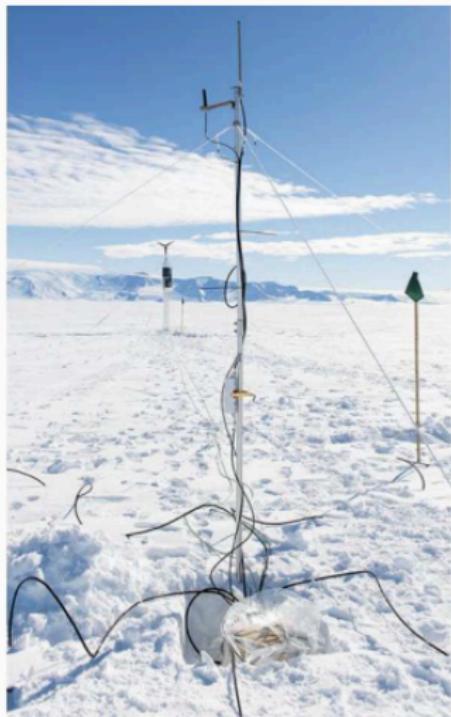
Deposited energy: (2.6 ± 0.3) PeV. Muon energy: (4.5 ± 1.2) PeV.
Neutrino energy: 8.7 PeV



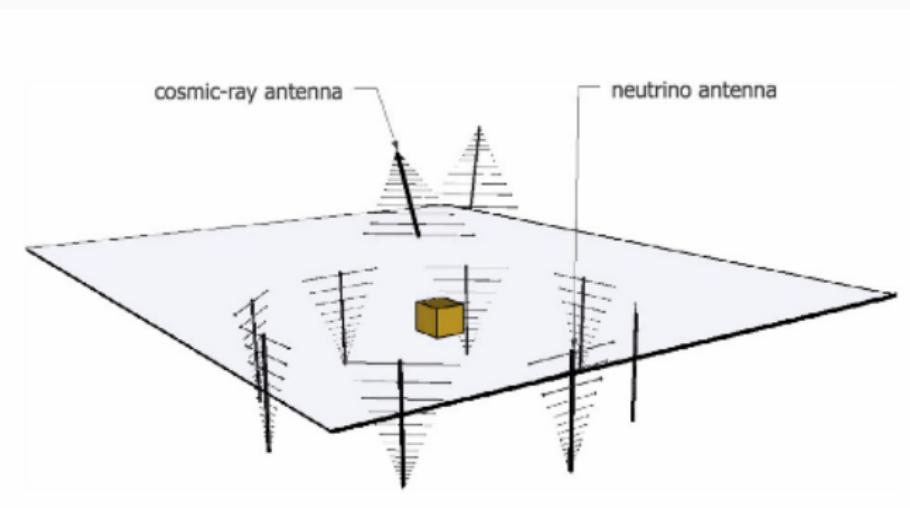
DETECTORS AND DISCOVERIES ... ARIANNA



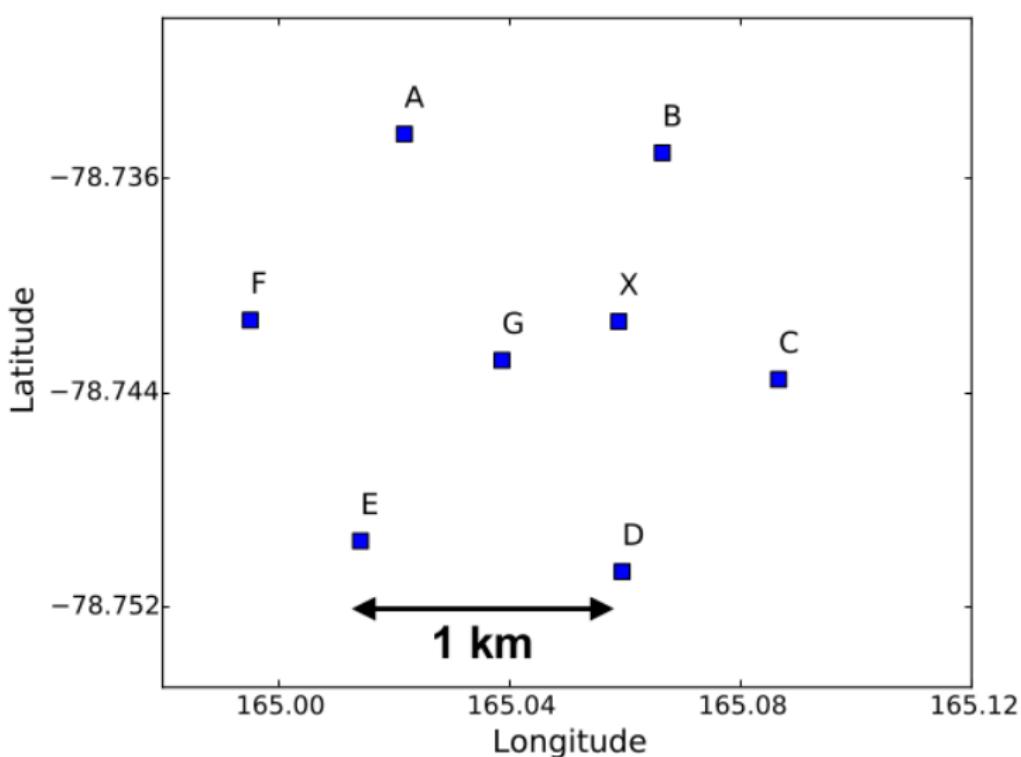
DETECTORS AND DISCOVERIES ... ARIANNA



DETECTORS AND DISCOVERIES ... ARIANNA

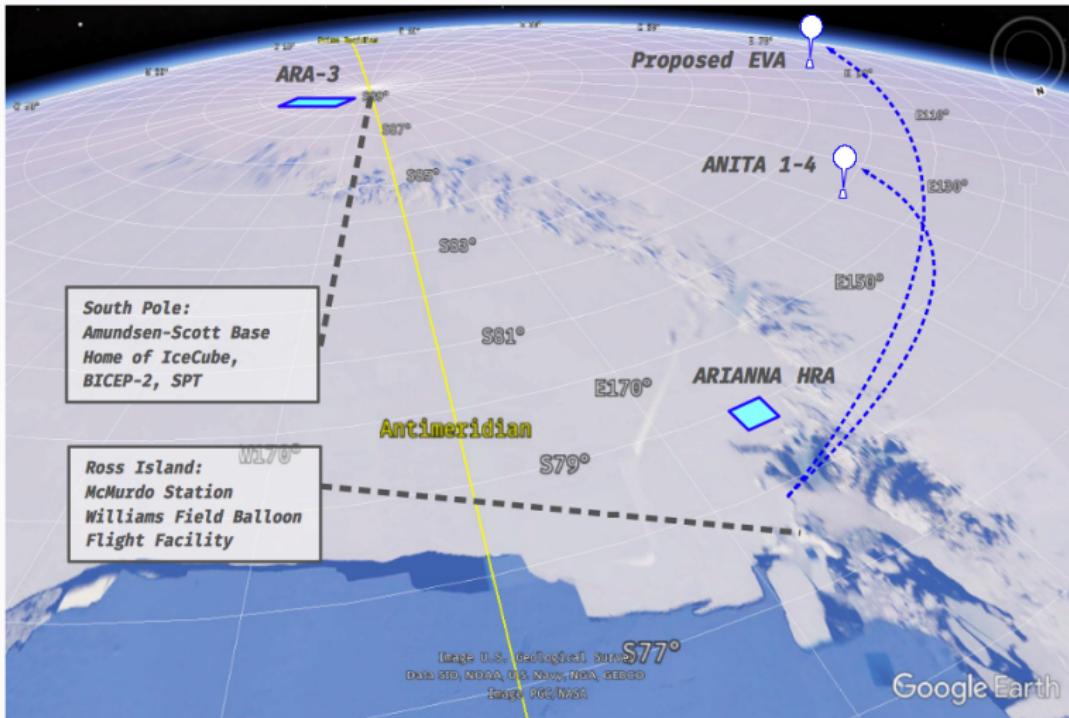


DETECTORS AND DISCOVERIES ... ARIANNA



INTERLUDE: ARIANNA DEPLOYMENT

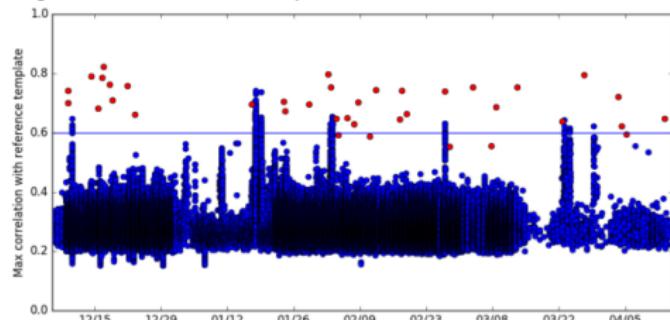
DETECTORS AND DISCOVERIES



Cosmic Rays in upward antenna

Site X

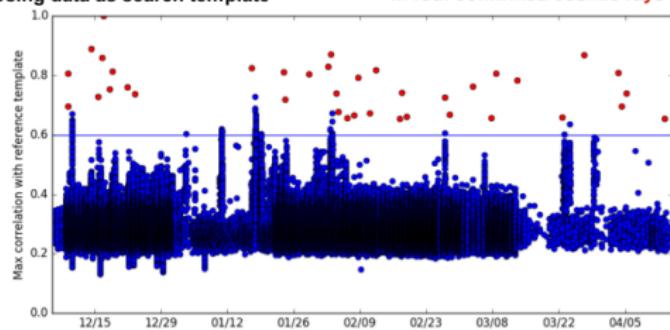
Using simulations as search template



- Cosmic rays in through front-lobe of LPDA have predicted **unique characteristic**

Using data as search template

in red: confirmed cosmic rays

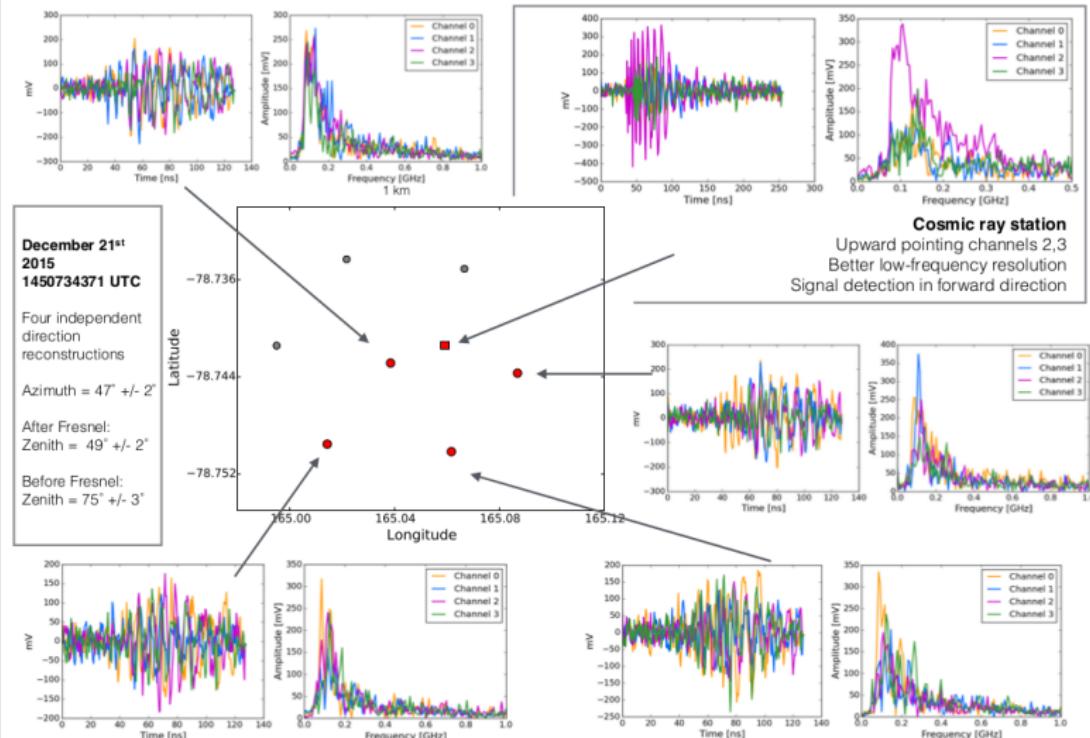


- Correlation with simulations show separate population of individual events, in RFI free periods

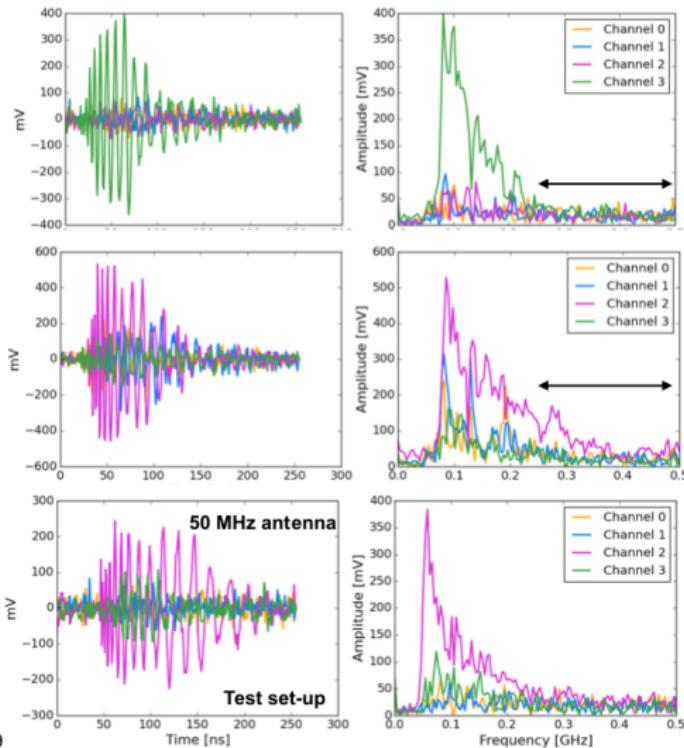
- Signals are strongly polarized and in qualitative agreement with expectations

- Simulations are not as good as data (yet)

Measured air shower

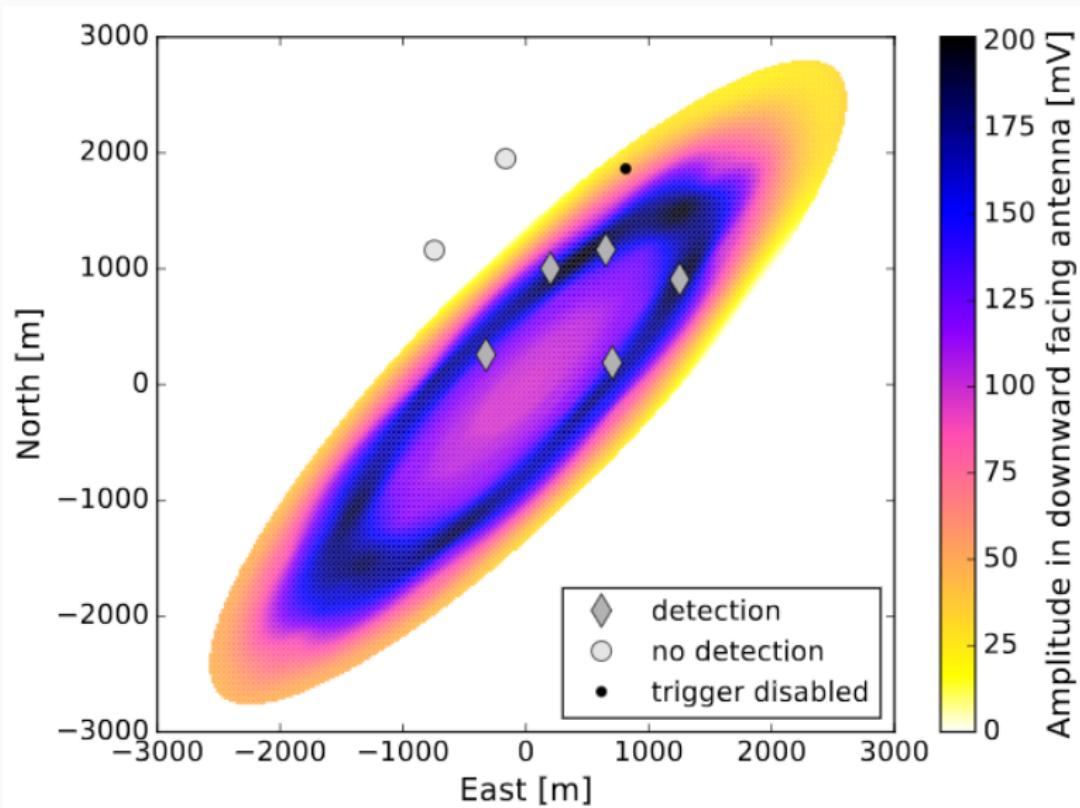


Measured air showers



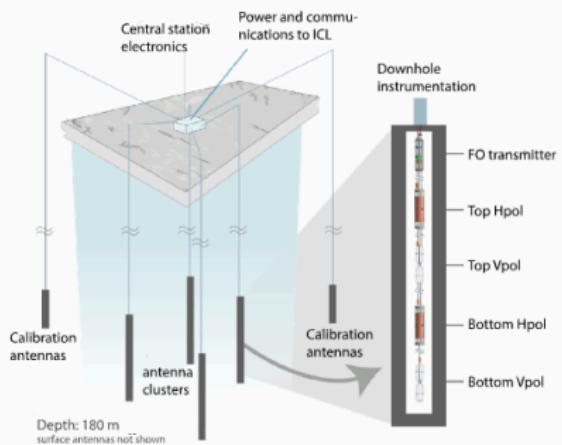
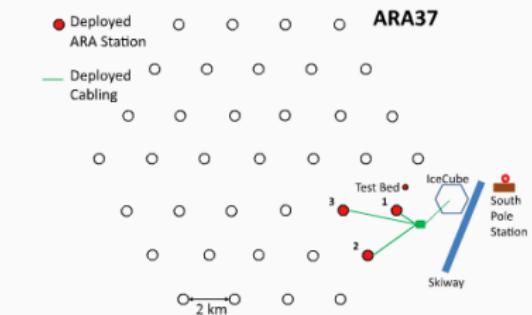
- ARIANNA directly measures air showers from 50 - 500 MHz with no filtering against RFI
- Signals will be interesting to study **spectral behaviour** of air shower signals
- Antenna and amp response still to unfold

DETECTORS AND DISCOVERIES ... ARIANNA: DETECTION OF UHECRS

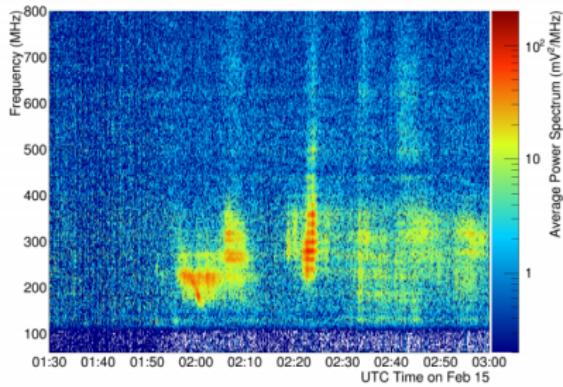
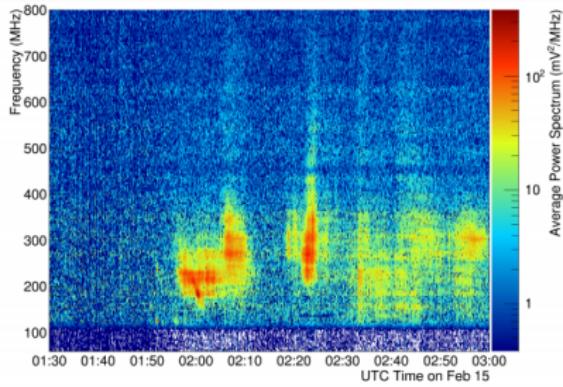


DETECTORS AND DISCOVERIES ... ARA

ARA is currently the most competitive of the *in situ* detectors.



DETECTORS AND DISCOVERIES ... ARA



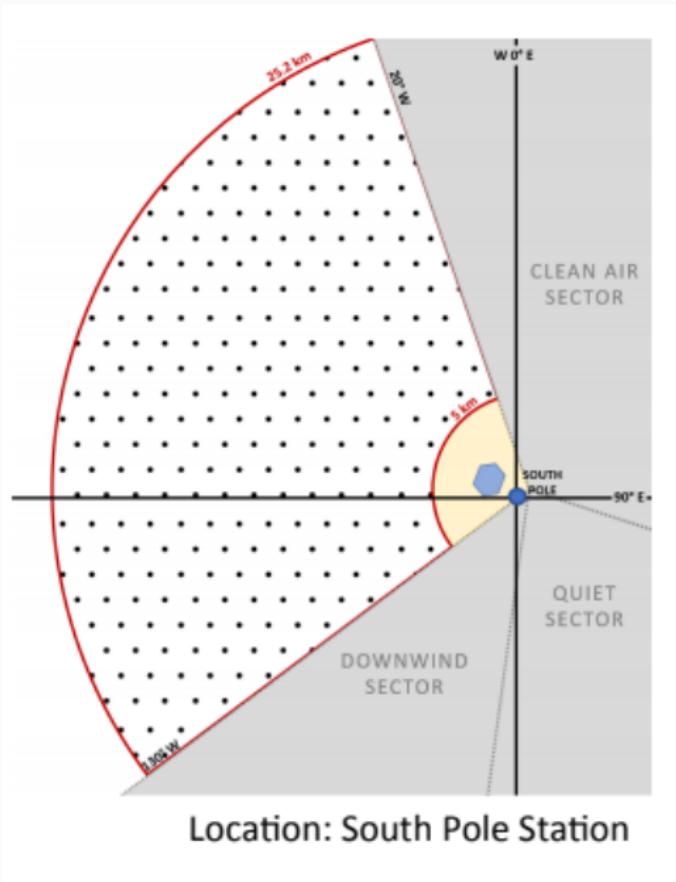
FUTURE DESIGNS

FUTURE DESIGNS



ARIANNA-SP DAQ Box

FUTURE DESIGNS



CONCLUSION

- I. **Cosmic Ray Origins** ... *A 100 year journey, about to be solved*
- II. **Antarctic Science** ... *Useful for science and worthy of continued preservation*
- III. **Detectors and Discoveries** ... *Major breakthroughs have taken place in recent years*
- IV. **Future Designs** ... *Soon, there will be a new form of astro-particle physics*