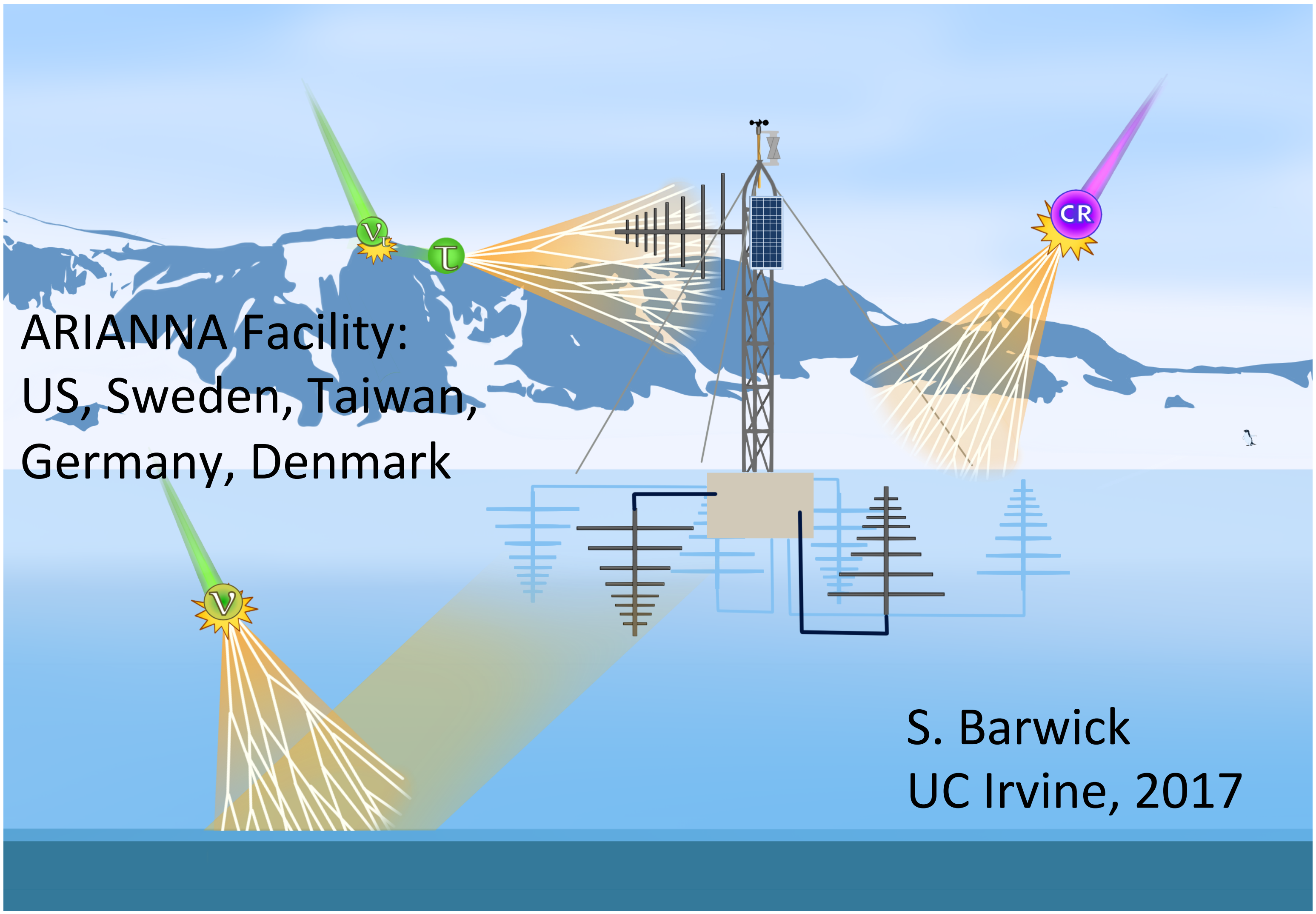
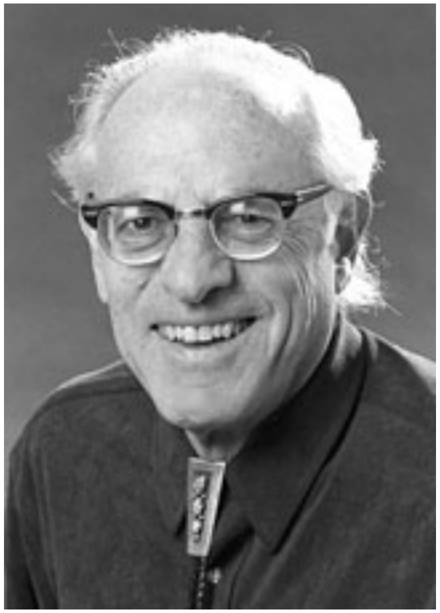
# High Energy Neutrino Telescopes



# Why Neutrinos?

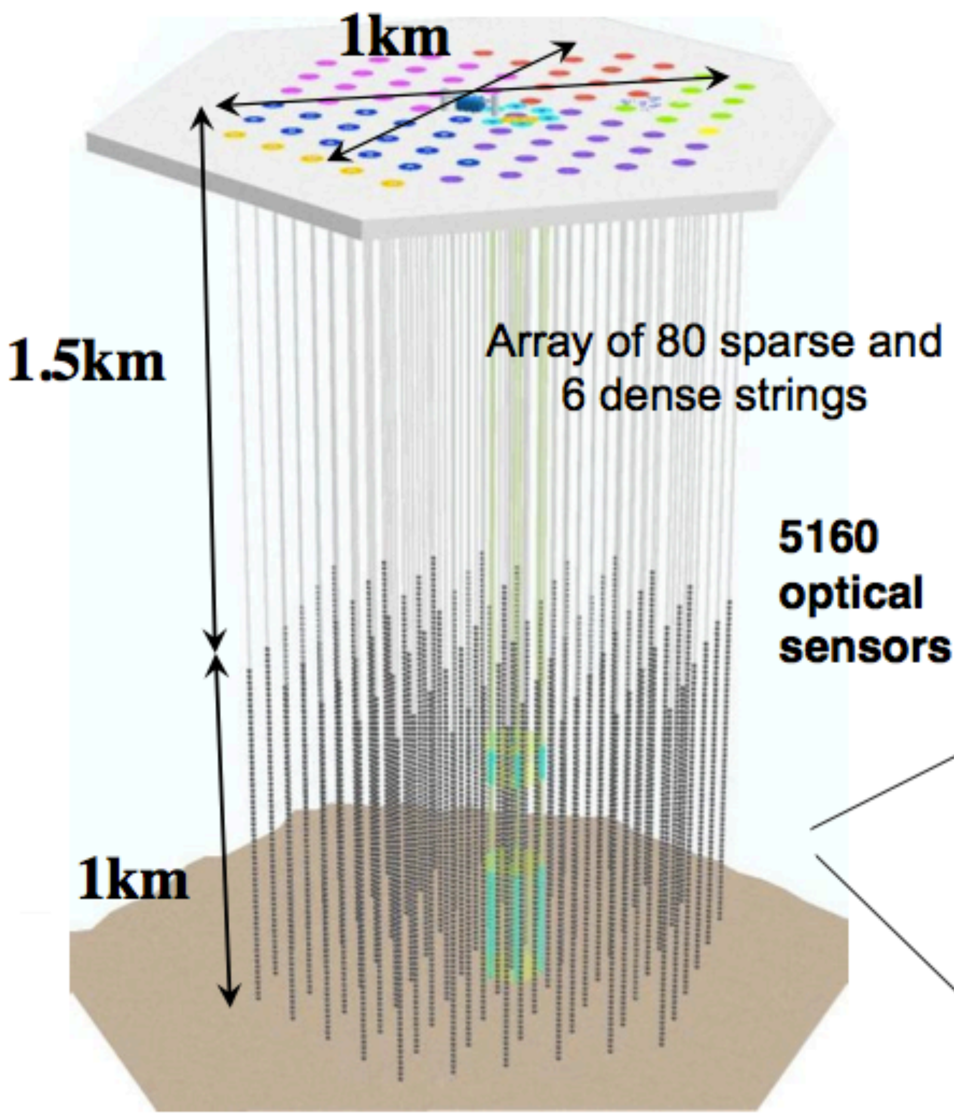


Fred Reines
Nobel Laureate
UCI founding father
Discovered neutrino

- Little mass, no electric charge, stable
- Unlike photons, neutrinos can escape from just about any environment
- Unlike photons, they penetrate through just about anything in the way
- Like photons, they travel in straight lines, so you can look back to see what made them

Only known particle messenger that can travel from distant extragalactic sources if $E > 10^{11}$ GeV; not protons, not photons

# The IceCube Detector

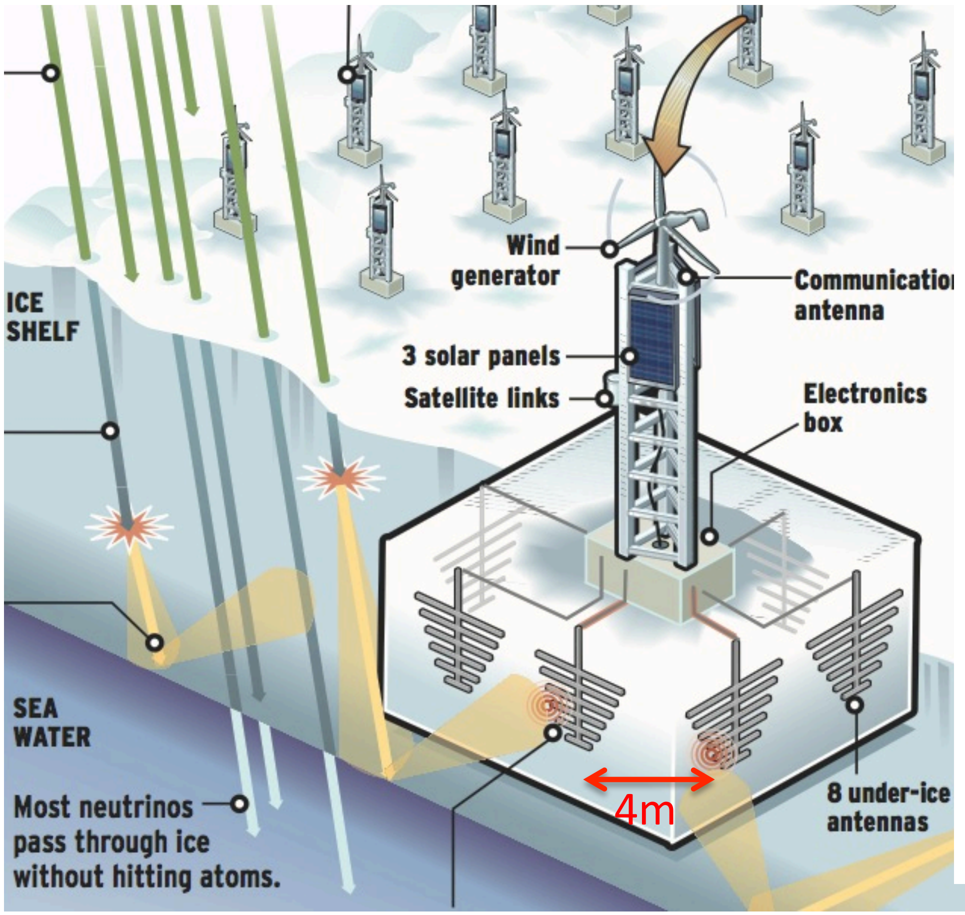



Completed in 2010


"Optical"

# “Radio” Neutrino Telescopes

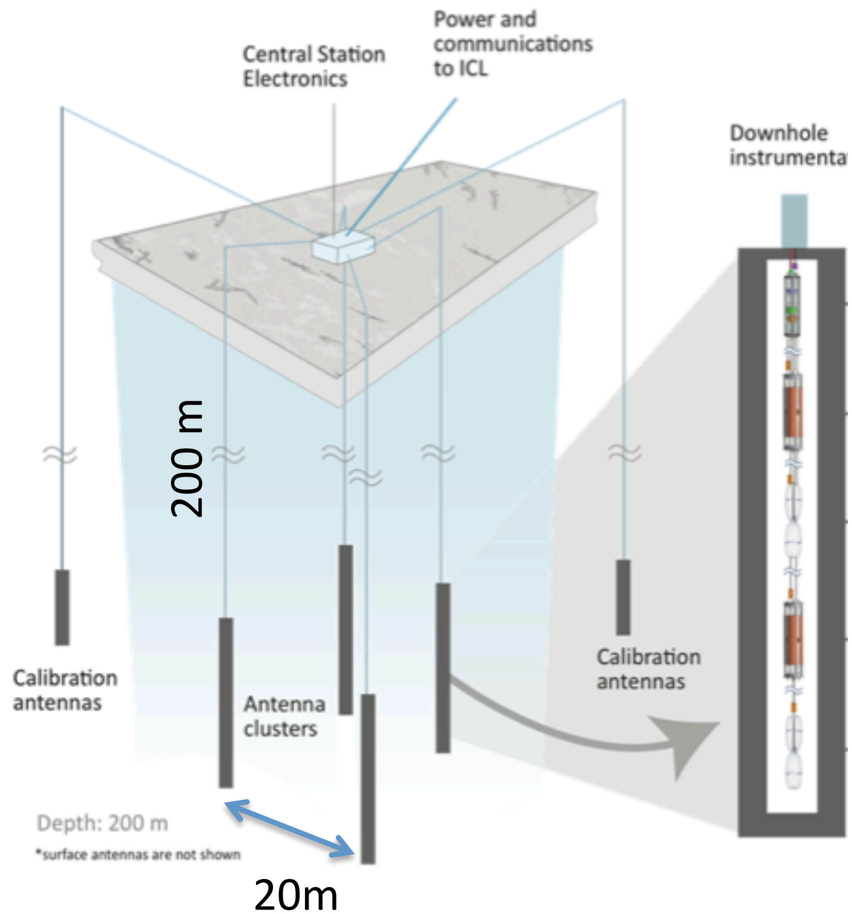
1 station in array of 36 x36, 1km spacing




ARIANNA

S. Barwick, et al., IEEE Trans. Nucl Sci. (2015)

1 station of 37, 2km spacing



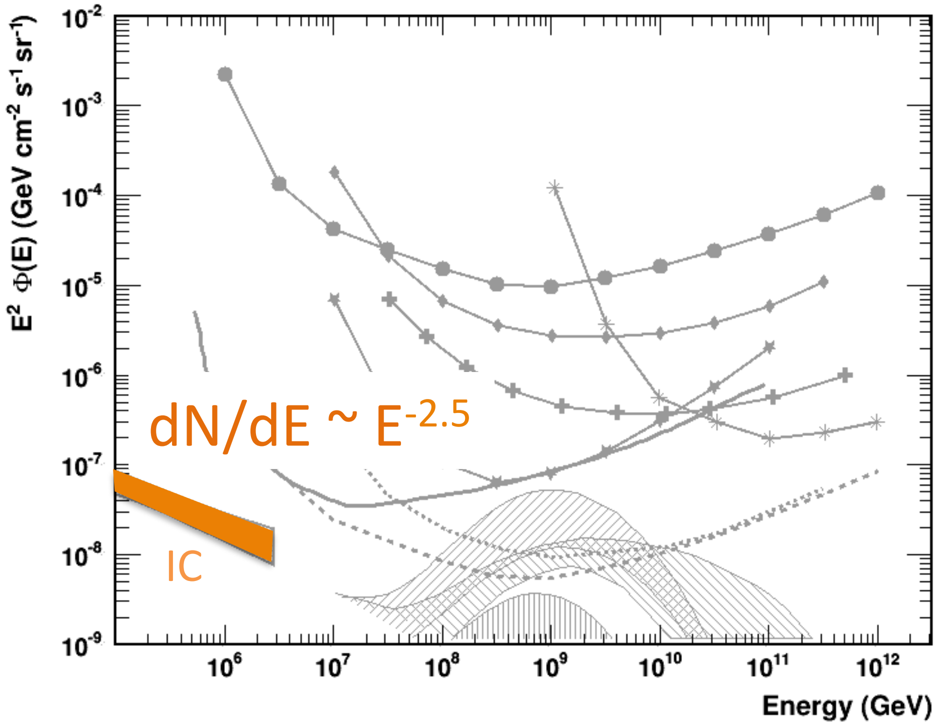

ARA

P. Allison, et al, Astropart. Phys. 35 (2012)

# HE Neutrino landscape 2017

- Energy Spectrum is either ~ $E^{-2.5}$

Modified from K-H Kampert and M.Unger, 2012



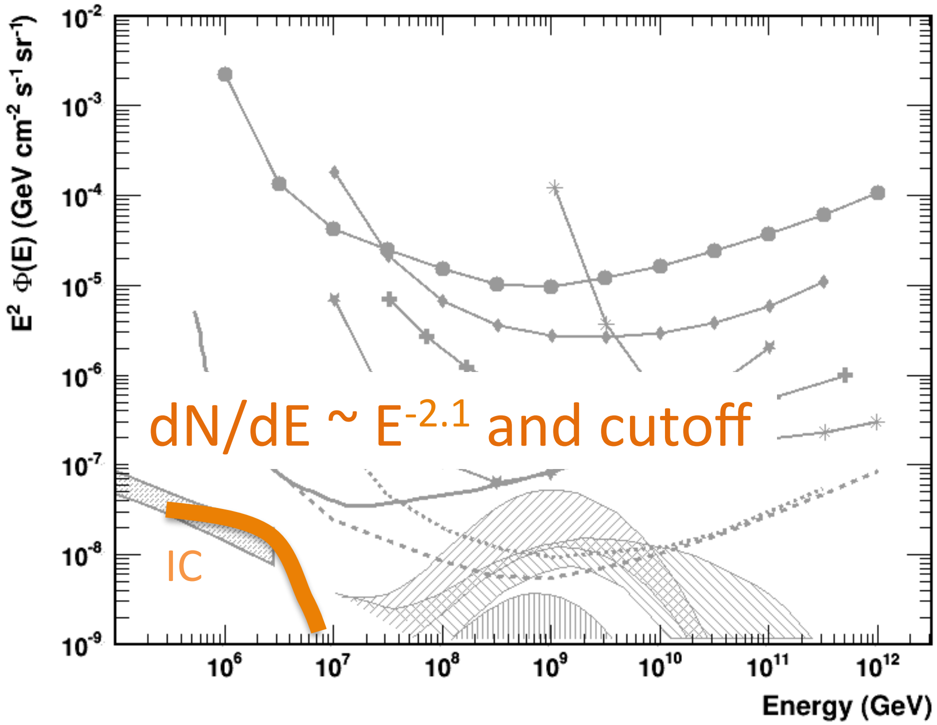

Icecube has detected astrophysical with energies up to a few x $10^6$ GeV.

The energy spectrum is uncertain

# HE Neutrino landscape 2017

- Energy Spectrum may be ~ $E^{-2.1}$ and cutoff

Modified from K-H Kampert and M.Unger, 2012



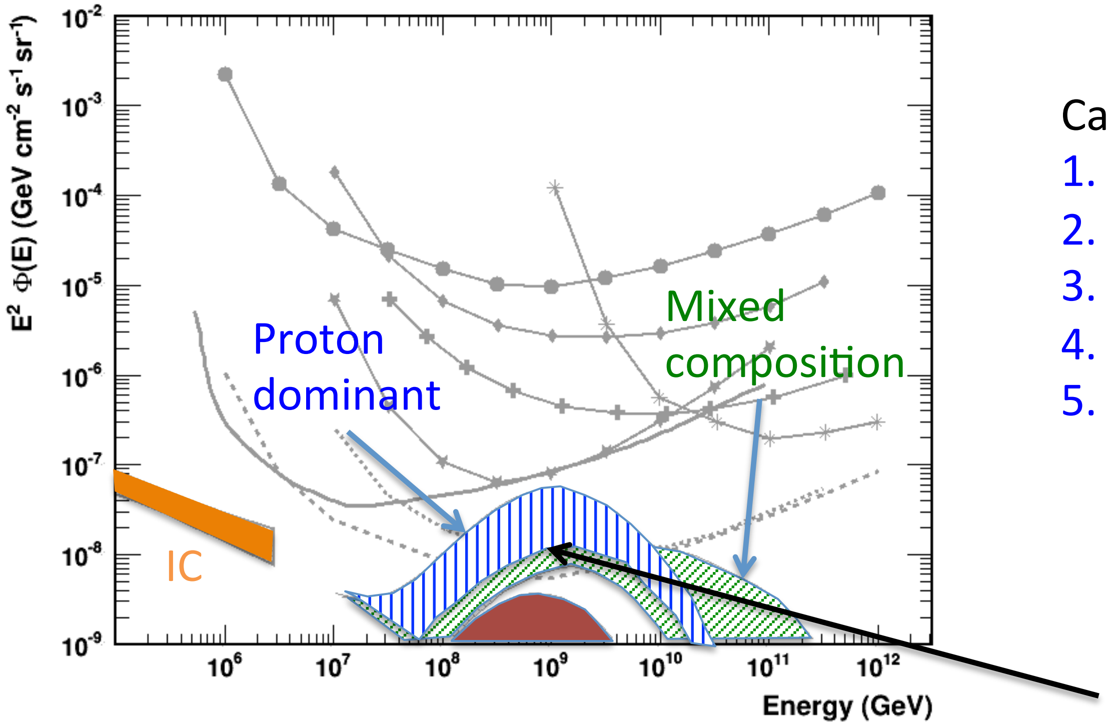

Icecube has detected astrophysical with energies up to a few x $10^6$ GeV.

The energy spectrum is uncertain

# Cosmogenic (GZK) Neutrinos

- Created from collision of CR and CMB photons if $E_{CR}/A > \sim 5 \times 10^{10}$ GeV

Modified from K-H Kampert and M.Unger, 2012




Calculations depend on:

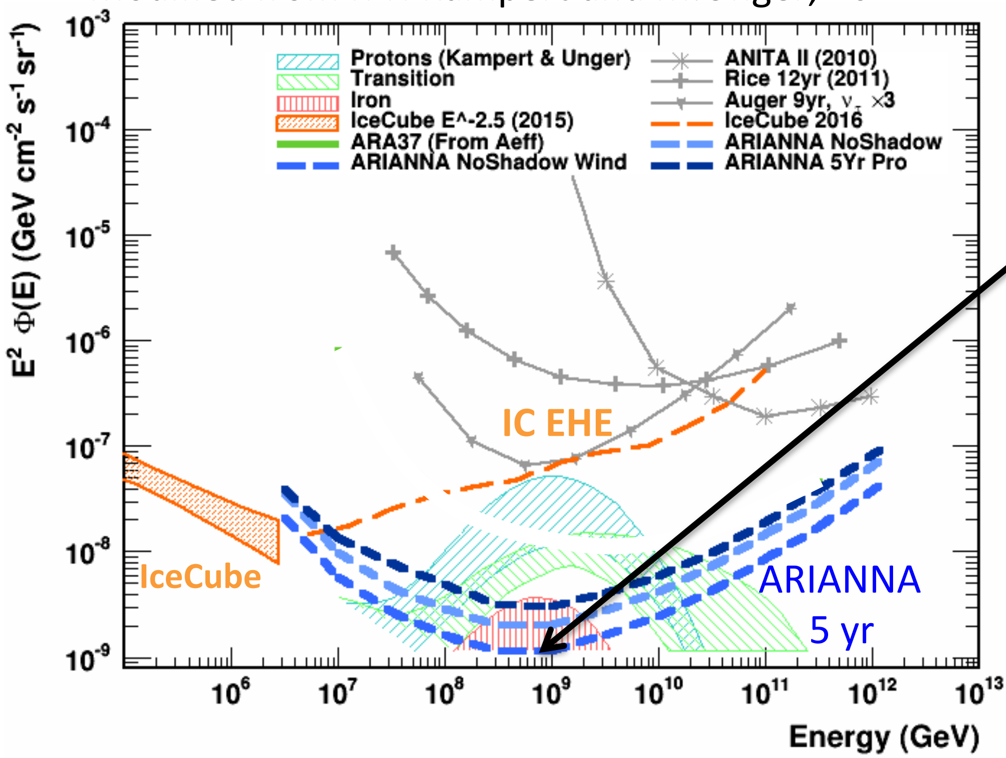
1. Composition [p, mix, Fe]
2. Evolution of sources
3. Highest energy, $E_{max}$
4. Injection Spectrum
5. End of Gal. CR

Smallest $\nu$ flux from all proton CR is $10^{-8}$

# 1st Gen Radio Neutrino Detectors

- Optimized ARIANNA 5 year sensitivities (including published livetimes and analysis efficiency)

Modified from K-H Kampert and M.Unger, 2012




Year round operation
By Wind Gen power

Prototype began
operating in 2016

Non-observation at $10^{-9}$ implies p < 10% of CR.

# 1st Gen Radio Neutrino Detectors

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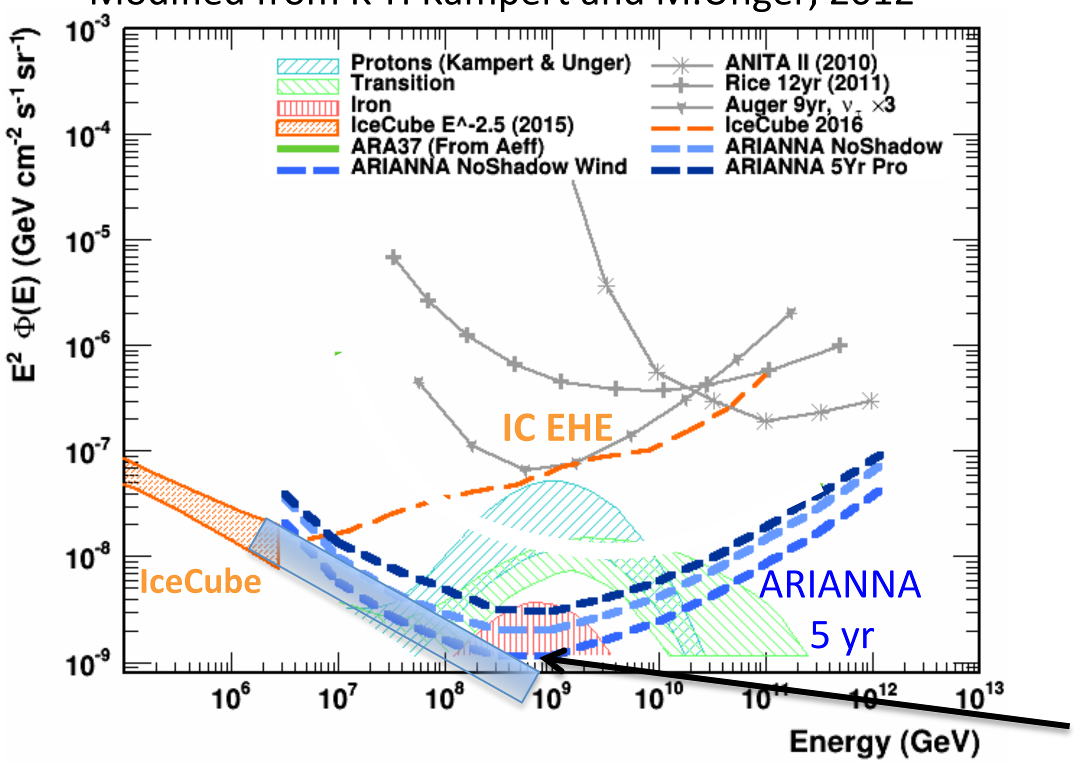
Modified from K-H Kampert and M.Unger, 2012




Continue IceCube flux to $10^9$ GeV if $dN/dE \sim E^{-2.5}$

# 1st Gen Radio Neutrino Detectors

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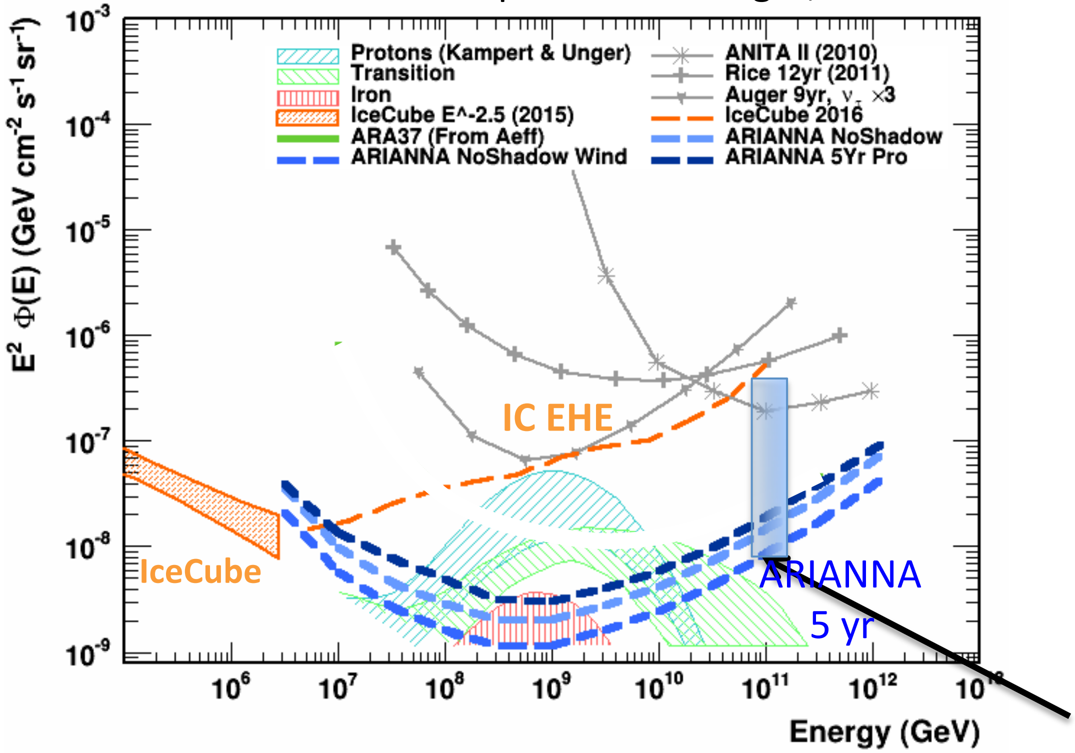



Improve sensitivity at $10^{11}$ GeV by 10

# Plans

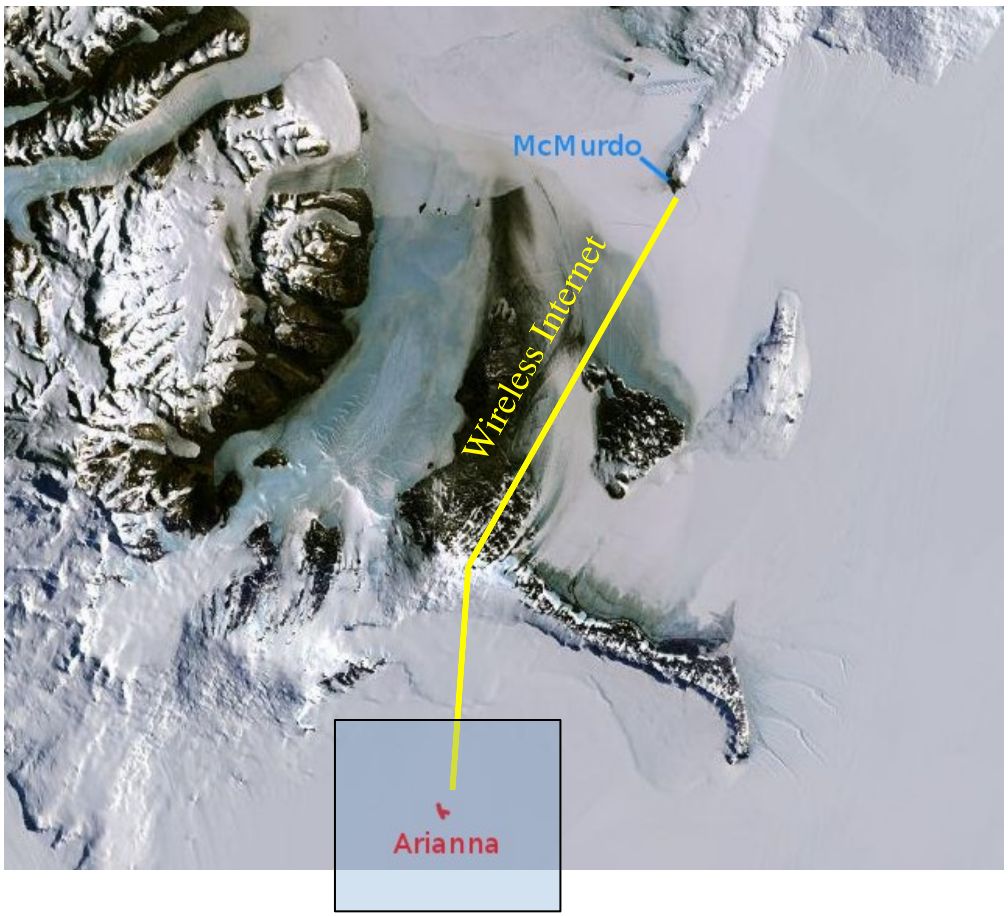
- Submit proposal for Gen 1 radio neutrino telescope to NSF in 2018
  - $10M in hardware, ~$25M total cost
  - 4 year construction
  - Data taking begins with installation of 1st station

- Gen 2 will reach $E^2 dN/dE \sim 10^{-10}$ $GeV cm^{-2} s^{-1} sr^{-1}$
  - Radio Component of IceCube Gen2
  - Construction begins no earlier than 2025

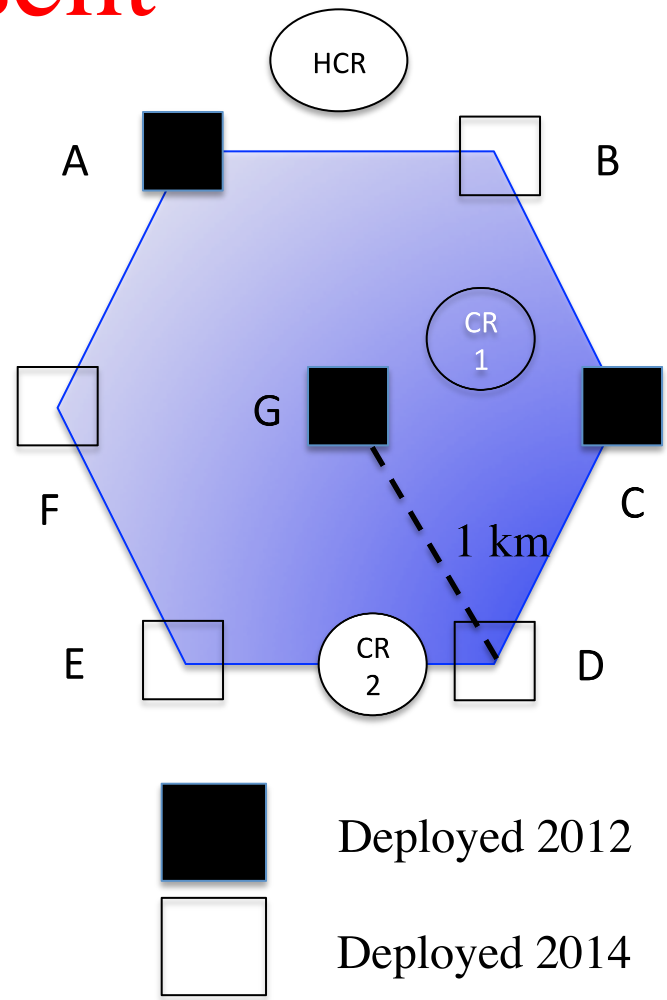

Shown: (Left to right) Joulien Tatar, Chris Persichilli, James Walker, Corey Reed

# Backup Slides

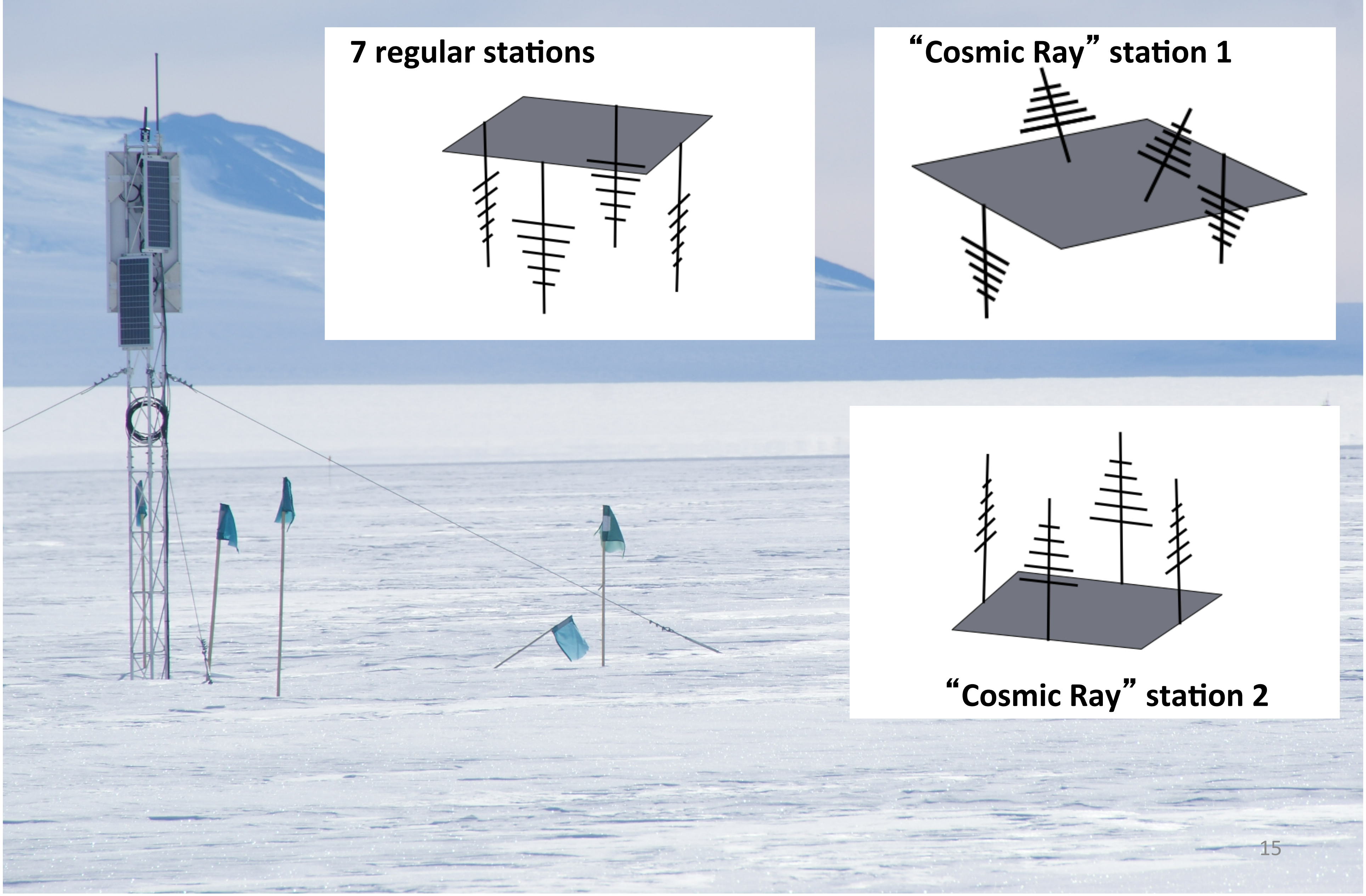
# Hexagonal Radio Array (HRA): 2012-present




Moore's Bay, 110 km from McMurdo Station



# Current status of ARIANNA - HRA



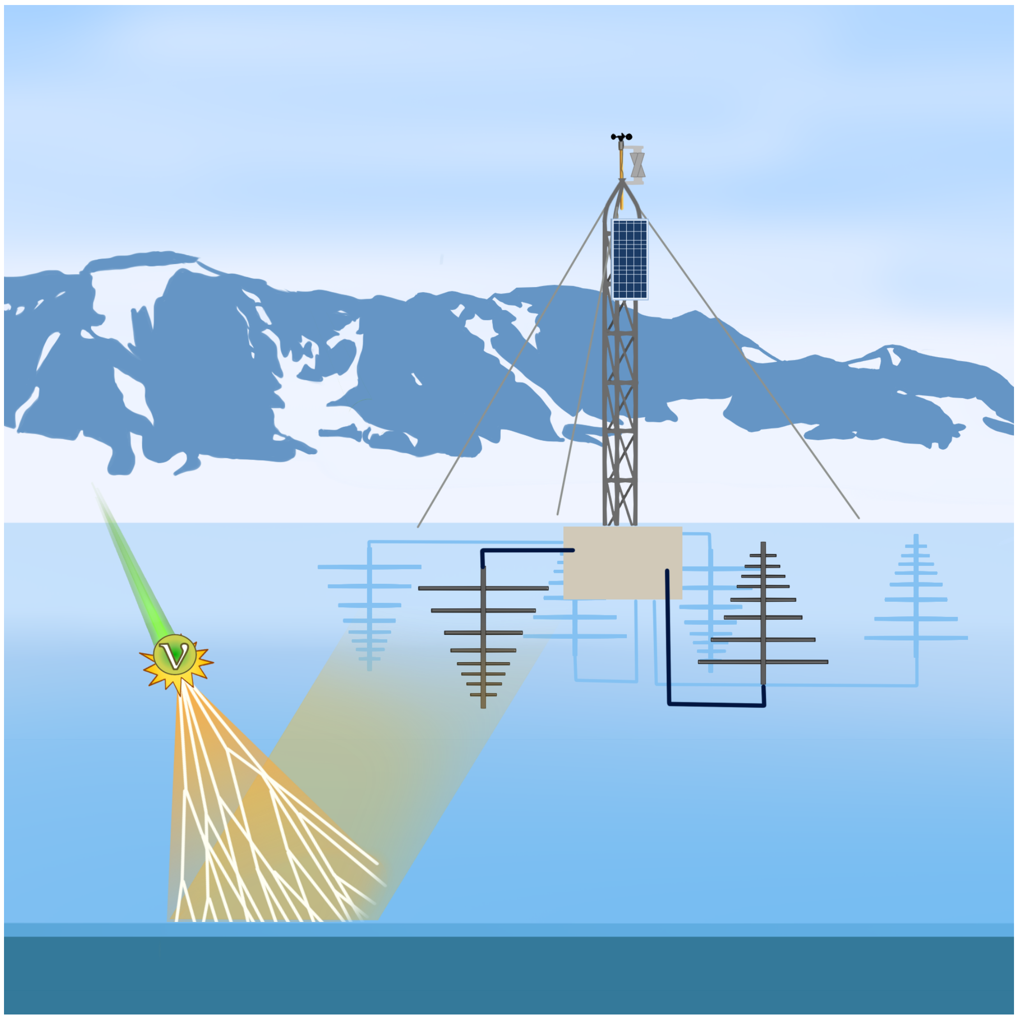
# Commentary

- IceCube neutrinos, especially those above $10^{15}$ eV provide strong incentive to probe to higher energies with larger detectors.
- Pilot programs of next generation of EHE neutrino radio-based detectors are completed (e.g., ARIANNA-HRA), and projects are gaining experience with sustained operation.
- Radio-based HE neutrino detectors optimized for EeV (though with capability to $10^{16}$ eV).

I believe the Antarctic neutrino projects will coalesce around common technique within the next year to produce a "mature" proposal supported by the community.

# Multi-messenger Observatory

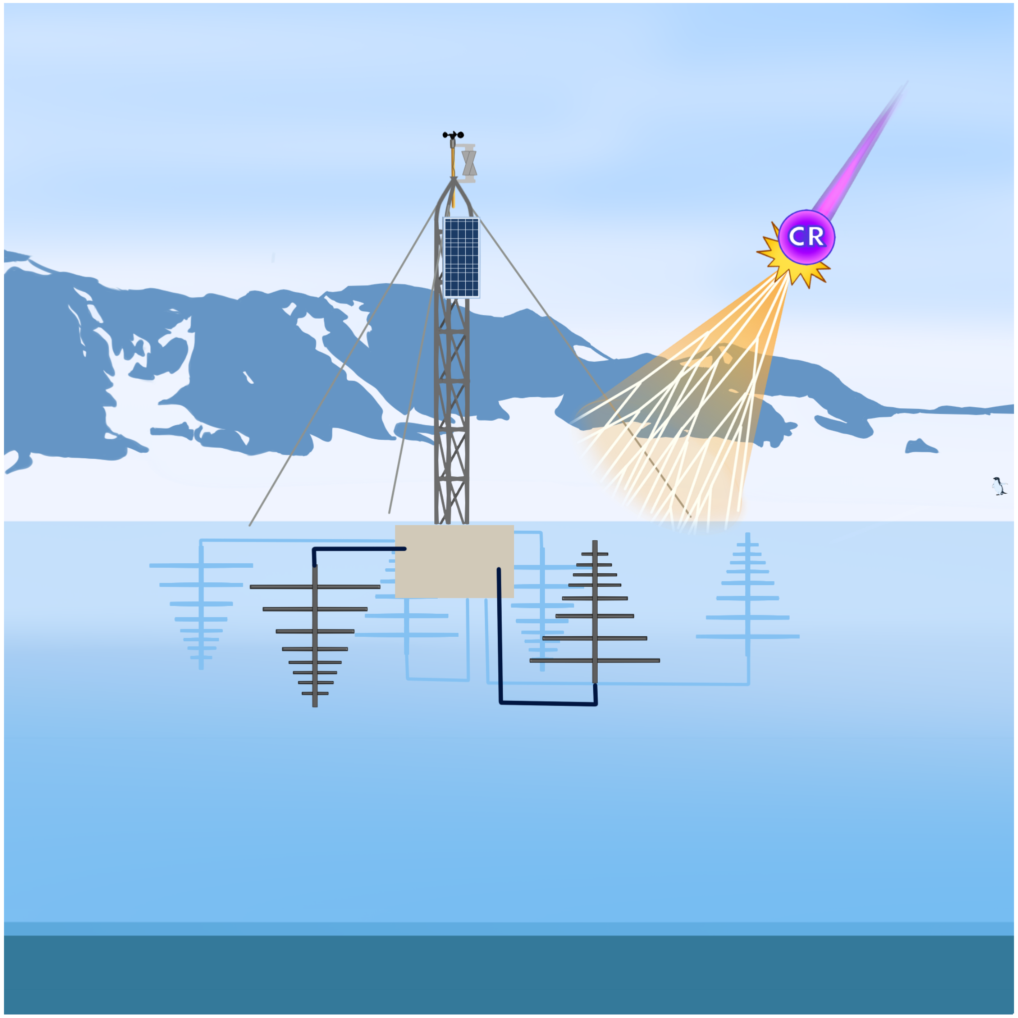
## ( ARIANNA all flavor-ν)



While some flavor identification may be possible,  it will be very difficult in my opinion

# Multi-messenger Observatory

## ( ARIANNA Cosmic Ray)

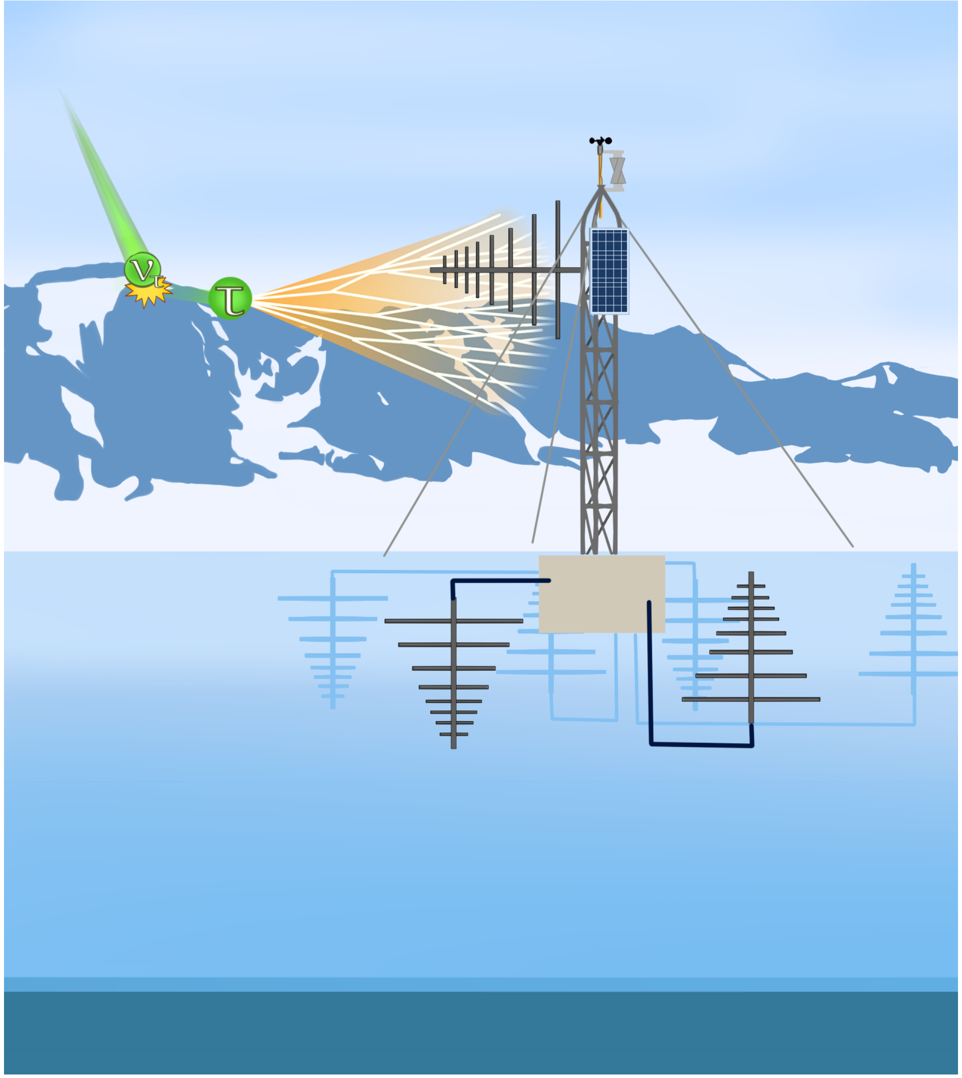



Energy spectrum between $3x10^{17}$ eV and $10^{20}$ eV

Anisotropies in southern sky

# Multi-messenger Observatory

## (ARIANNA nu-tau)



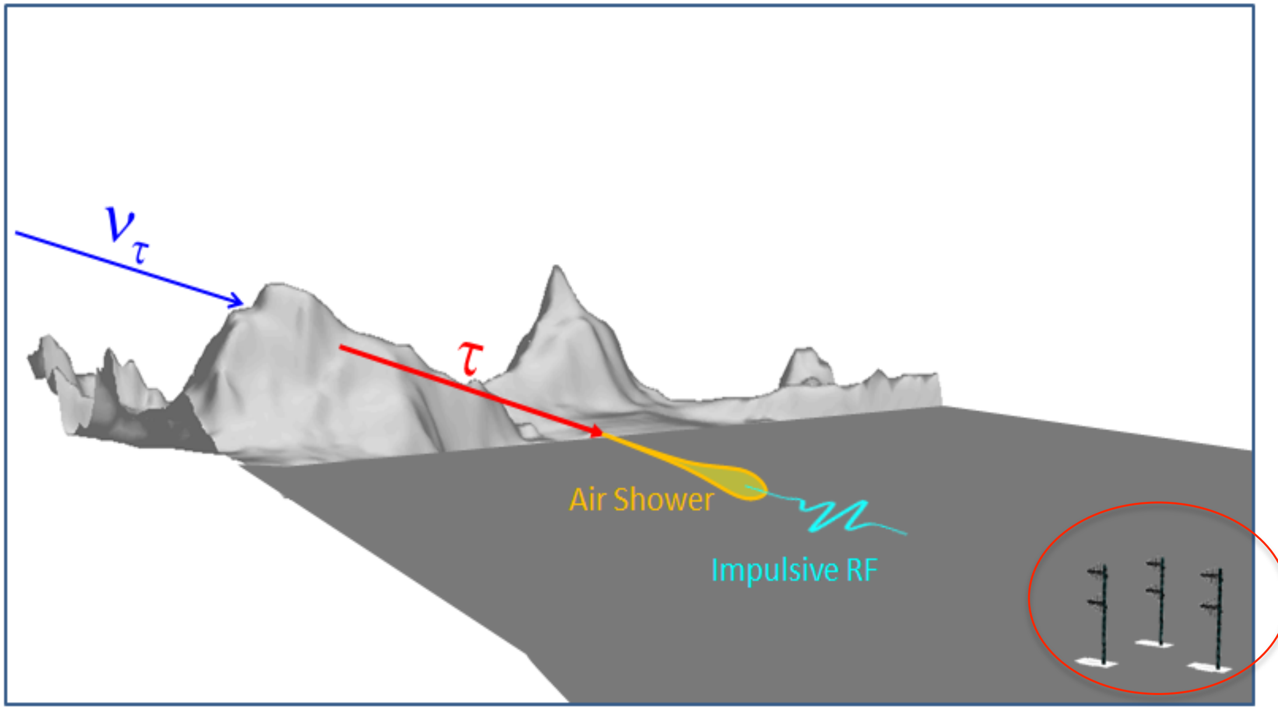
Prototype tower deployed in 2016

Measure RF noise

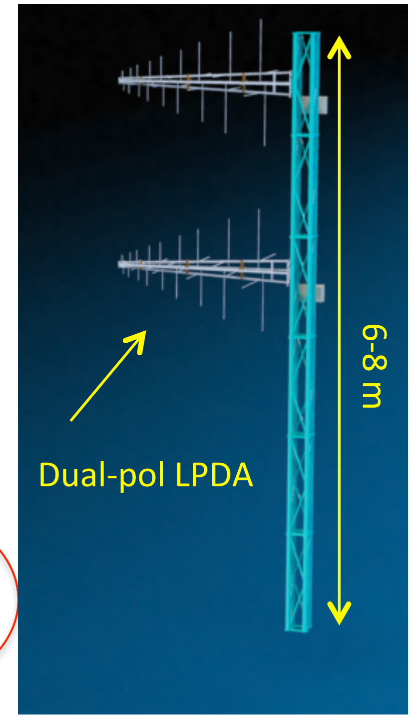
Evaluate Angular resolution

Interference from scattering?

# Nu-tau Detection with Radio




J. Nam, NTU, 2017




Concept:
$\nu_\tau$ station consist of 3 towers with 2 dual pol LPDA

**Flavor ratio is intriguing probe for ν**

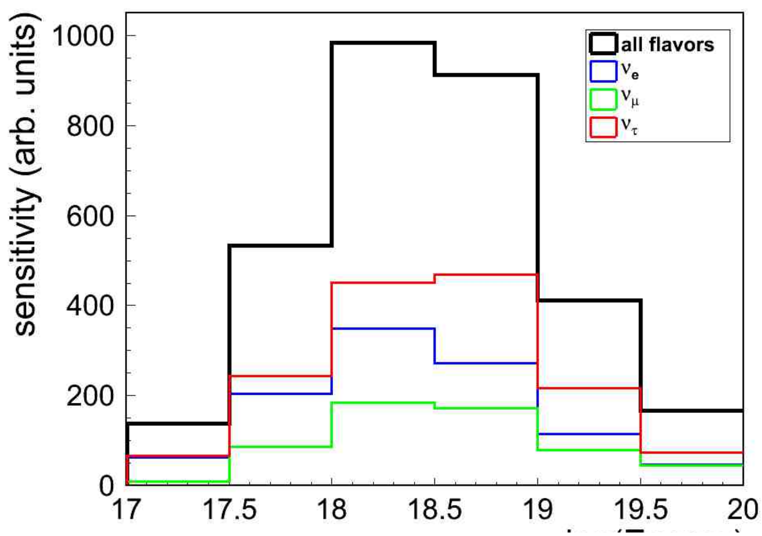
1) source physics 2) oscillation
3) decay 4)mass hierarchy

# EHE $\nu$ detectors: Comments

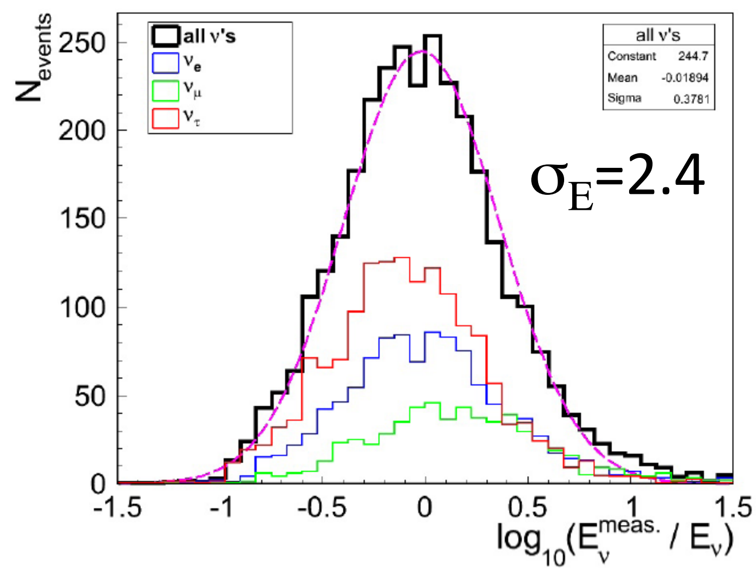
EHE neutrino detectors:

- Contribute to ongoing quest to understand EHE CRs
  - Neutrino measurements provide independent confirmation of GZK mechanism
  - Combined with CR and photon measurements, can help to constrain source class, evolution, $E_{max}$, and composition of CR
  - Direct measurements of CR
- Search for new physics
  - Beam of EeV neutrinos can uncover new physics at ~5-10 x $E_{cm}$ of LHC through cross-section and spectral modifications
- Search for new sources:
  - EeV neutrinos must point back to sources and direction can be measured with good precision ( and current procedures can be improved).

# ARIANNA Characteristics




log($E_\nu$) eV




Prelim. , refl., ESS spectrum

Energy Resolution

*Peak response at "sweet spot" of GZK spectrum*

*Details of waveform give energy info*

K. Dookayka, UCI PhD dissertation, 2011