THE OHIO STATE UNIVERSITY

The Future of Radio Neutrino Detection

Prof. Amy Connolly

June 12, 2018

The plan for this talk

- Historical perspective
- Science motivation for continuing to pursue UHE neutrinos
- In the ice
- From a distance
- From altitude
- Thoughts as we plan for the future

Historical perspective

The beginning

- First radio neutrino meeting RADHEP-2000

First International Workshop on
Radio Detection of High-Energy Particles

** Trasnsparencies **

** Write-ups **

** Worshop Photos **

** List of Participants**

UCLA Faculty Center
University of California, Los Angeles
November 16-18, 2000

Major Topics

- Latest progress in UHE cosmic-ray models and observations
- Historical Review of Radio Detection
- Status of radio cosmic-ray detection experiments
- Status of simulations
- "Active sensing" (eg, radar) experiments and ideas
- Other radio detection experiments (axions, etc.)
- Topics in antenna and EM theory
- Accelerator tests: past & future
- Acoustic experiments
- Discussion of open questions
- Future Experiments

The beginning

- Beam tests had only just confirmed Askaryan emission
- Anita-lite launched 2003
- AMANDA (1996-2005)
- RICE (from 1995)

Peter Gorham, David Saltzberg

Phys.Rev. E62 (2000) 8590-8605.
Phys.Rev.Lett. 86 (2001) 2802-2805.

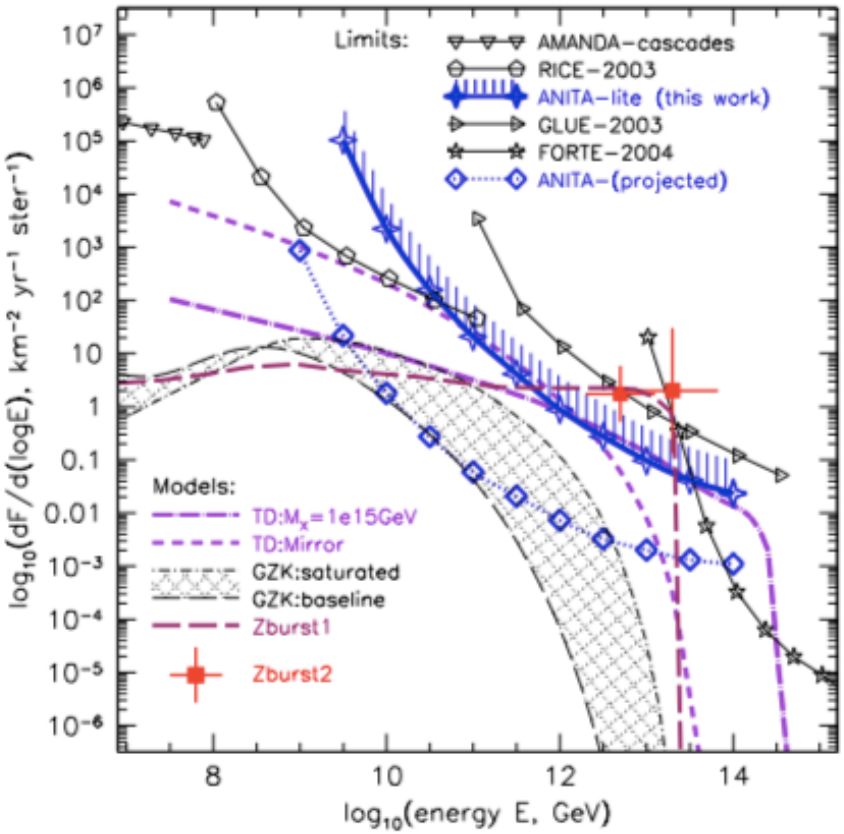
Dave Besson

Astropart.Phys. 19 (2003) 15-36

GLUE Phys.Rev.Lett. 93 (2004)041101
FORTE Phys.Rev. D69 (2004) 013008

The beginning

- Z burst models were a thing
- T. Weiler, Phys. Rev. Lett. 49 (1982) 234.
- Topological defects
- S. Yoshida et al., Ap. J. 479 (1997) 547
- 2001 Engel Seckel Stanev
- Phys.Rev. D64 (2001) 093010



Phys.Rev.Lett. 96 (2006) 171101

Now

- ANITA four successful flights
- Radio geosynchotron at high and ultra-high energies
- ARA and ARIANNA have had successful detectors operational for years
- IceCube measured astrophysical neutrino flux - gives us definite target
- Radio has provided fantastic career opportunities for young people!

  - Large number of faculty positions for our size
  - 3 NSF CAREER awards

Science motivation

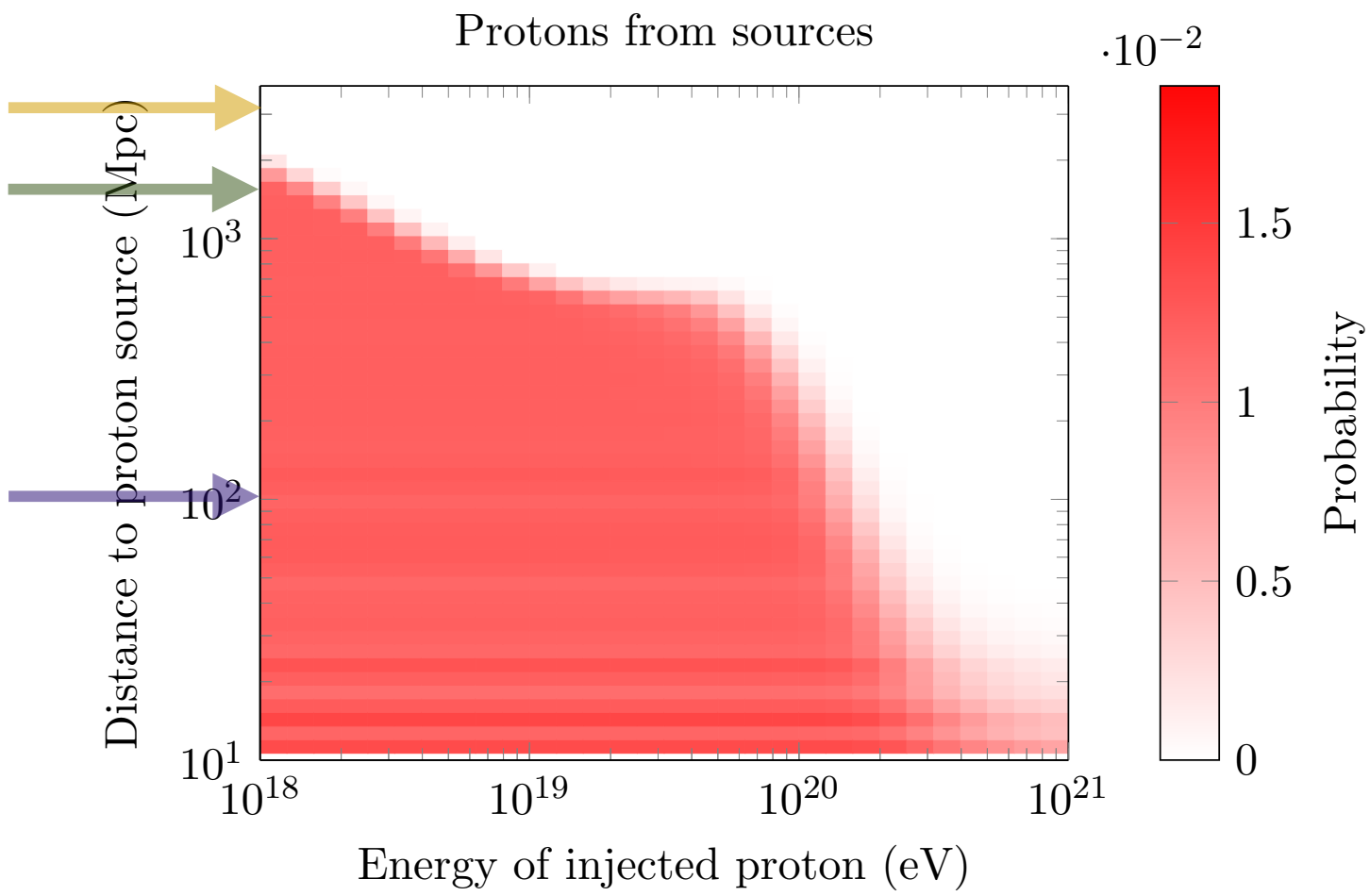
Astronomy

Which sources can cosmic rays see?

AGN densities peak

Star formation rate peaks

Size of our galactic supercluster



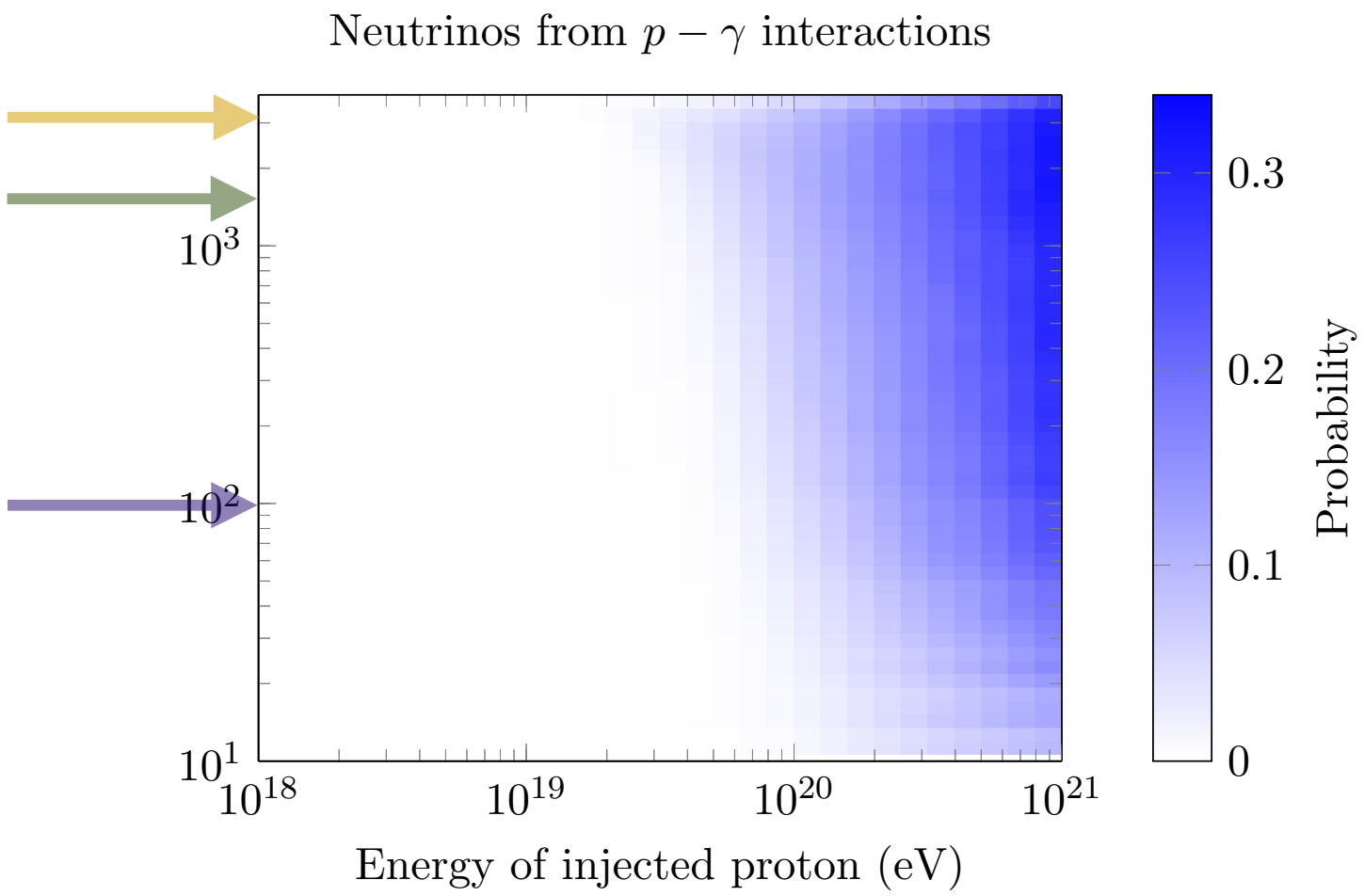
Which sources can neutrinos see?

UHECRs produce *neutrinos* when they interact with cosmic microwave background light

AGN densities peak

Star formation rate peaks

Size of our galactic supercluster



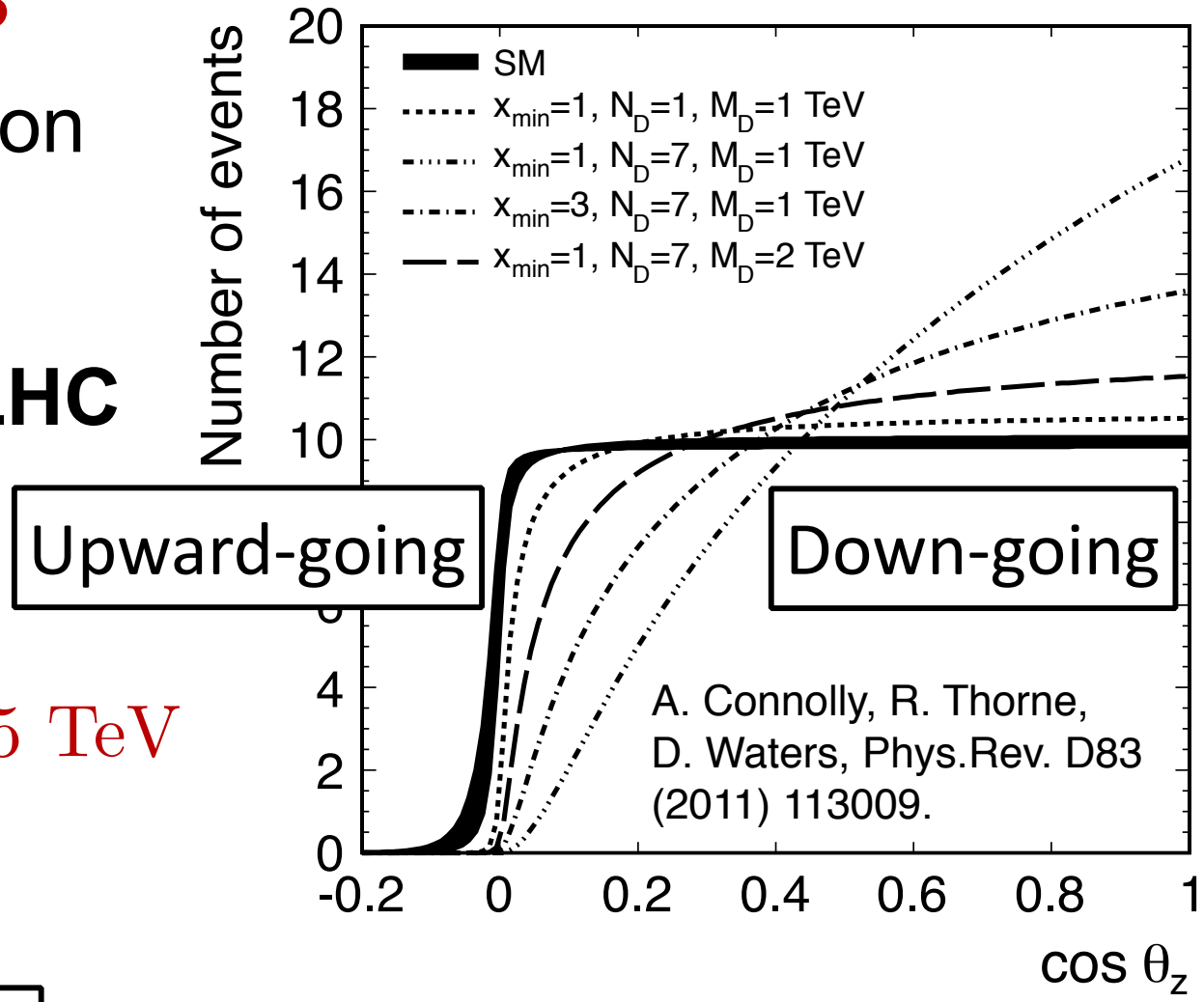
Fundamental physics

Cross Sections

- UHE neutrino-nucleon interactions probe **center-of-mass energies beyond LHC**

$E_\nu = 10^{18}$ eV:

$$E_{\rm CM} = \sqrt{2 m_N E_\nu} = 45 \text{ TeV}$$

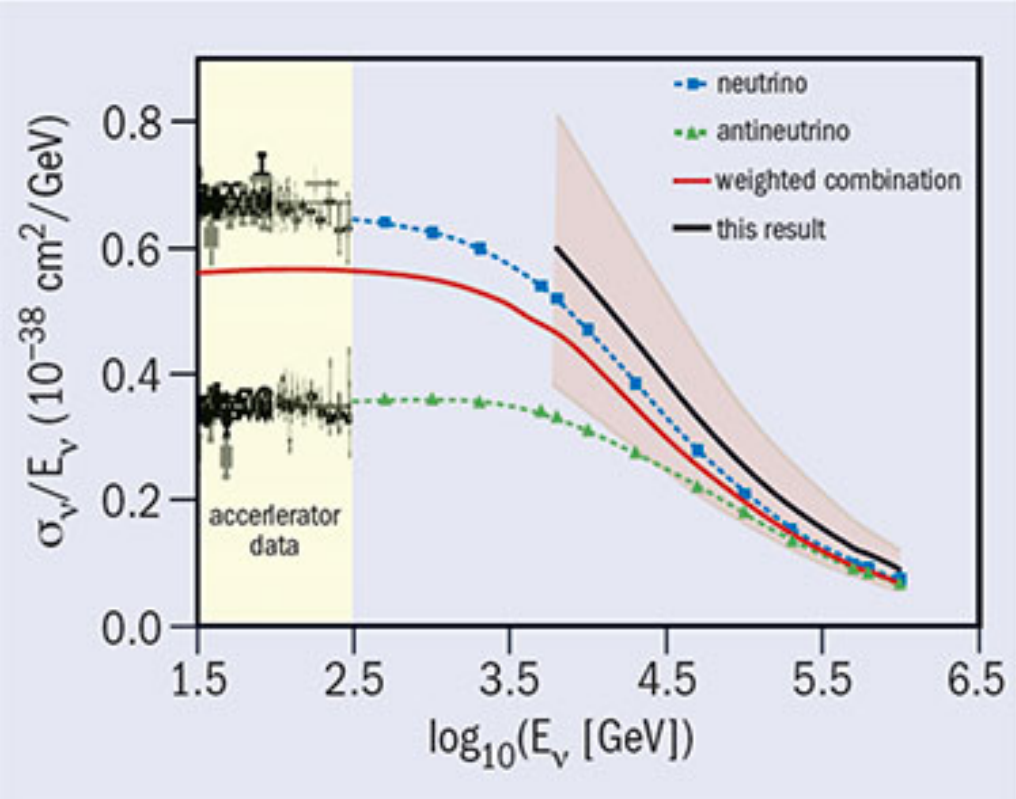


ED model predictions from J. Alvarez-Muniz and E. Zas, Phys. Lett. B411, 218 (1997).

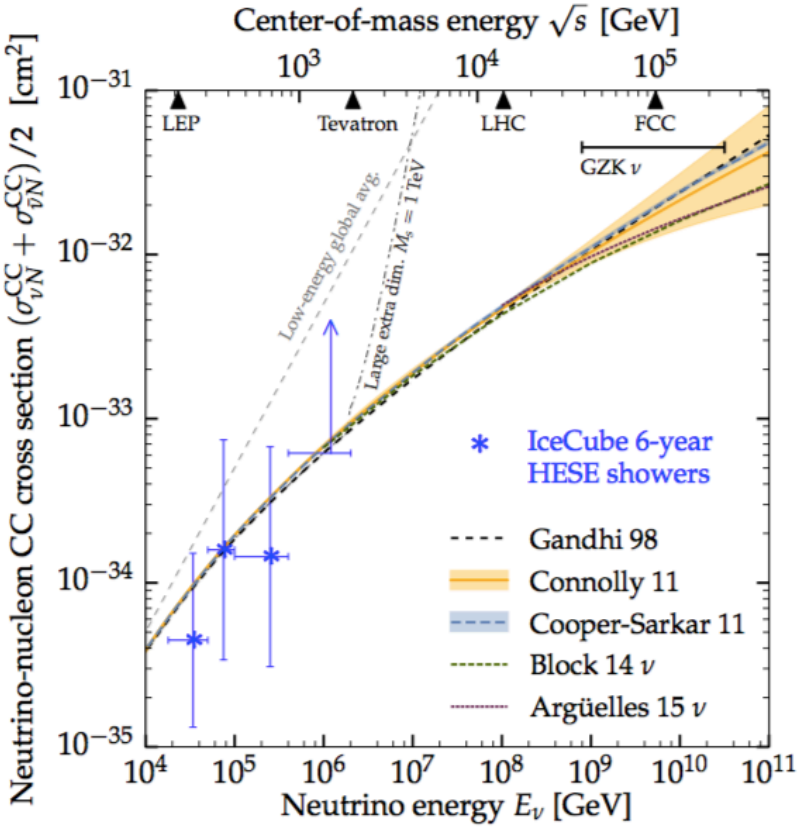
Assumes isotropic neutrino flux !

Real measurements now!

IceCube Collaboration



IceCube Collaboration 2017 *Nature* **551** 596.



M Bustamante and A Connolly 2017 arXiv:1711.11043

CERN COURIER

Jan 15, 2018

The case of the disappearing neutrinos

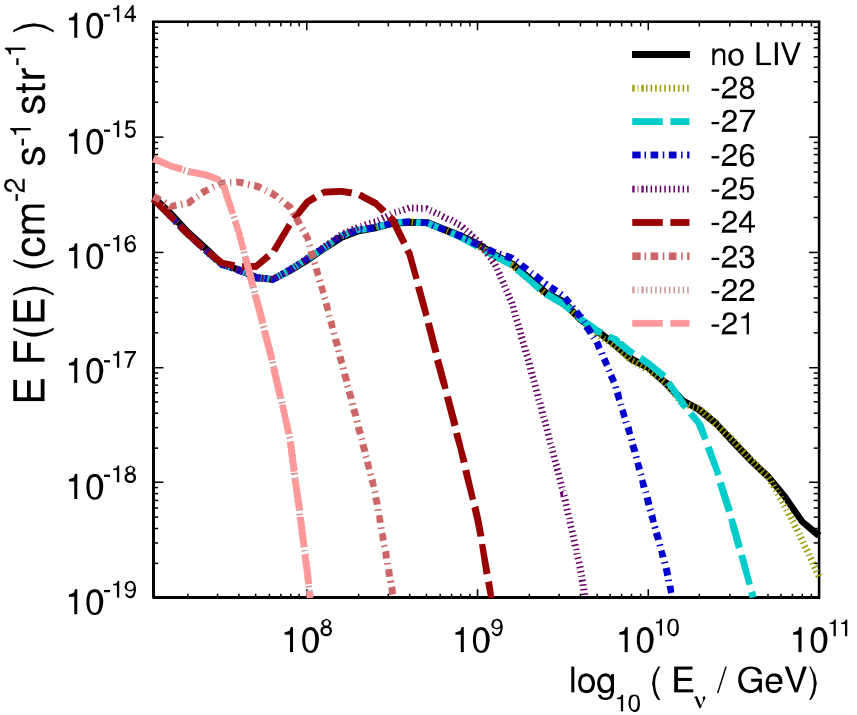
Lorentz Invariance Violation (LIV)

- Only particles we will be able to see at
  1 Joule after traveling
  1 billion light years

$$E_\nu = p_\nu c(1 + \alpha_\nu)$$

$$\nu_i = \nu_i' + e^- + e^+$$

$$\tau_\nu \propto E_\nu^{-5} \alpha_\nu^{-3}$$



P.W. Gorham, A. Connolly *et al.*, Phys.Rev. D86 (2012) 103006.

→Sensitive test of LIV

Danny Marfatia
NEUTRINO 2018

- Modified dispersion relation

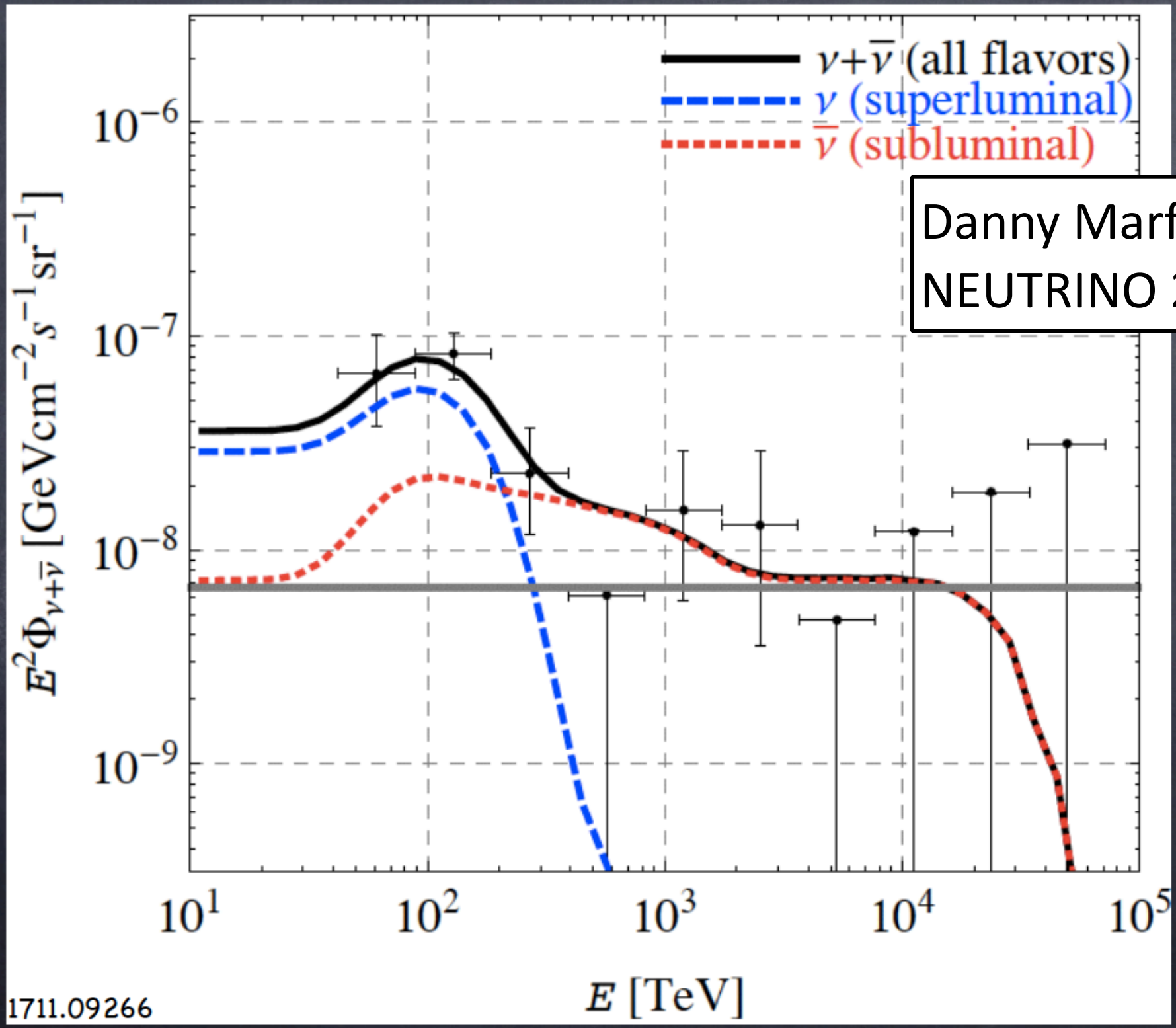
$$E^2 - p^2 = m^2 + 2\delta E^2$$

$$\delta = \kappa \frac{E}{M_{Pl}}$$

- Assume all neutrino flavors have same LIV parameter to be consistent with neutrino oscillation data

- Dispersion relation for antineutrinos: $\delta \to -\delta$

- Our choice $\delta > 0 \implies$ neutrinos are superluminal and antineutrinos are subluminal


$\nu+\bar{\nu}$ (all flavors)
ν (superluminal)
$\bar{\nu}$ (subluminal)
Danny Marfatia
NEUTRINO 2018
$E^2\Phi_{\nu+\bar{\nu}}$ [GeVcm$^{-2}s^{-1}$sr^{-1}]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^1
10^2
10^3
10^4
10^5
E [TeV]
1711.09266

What other new physics can we search for?

Your idea here

The case for going beyond optical

~ 10 cosmogenic neutrinos / km^2 / year

10^{18} eV: vN interaction length O(1000) km

→ 0.01 neutrinos / km^3 / year

At most, we see 1/2 the sky

→ 0.005 neutrinos / km^3 / year

Neutrinos from sources at a similar level

We need >100's of km^3 detection volumes

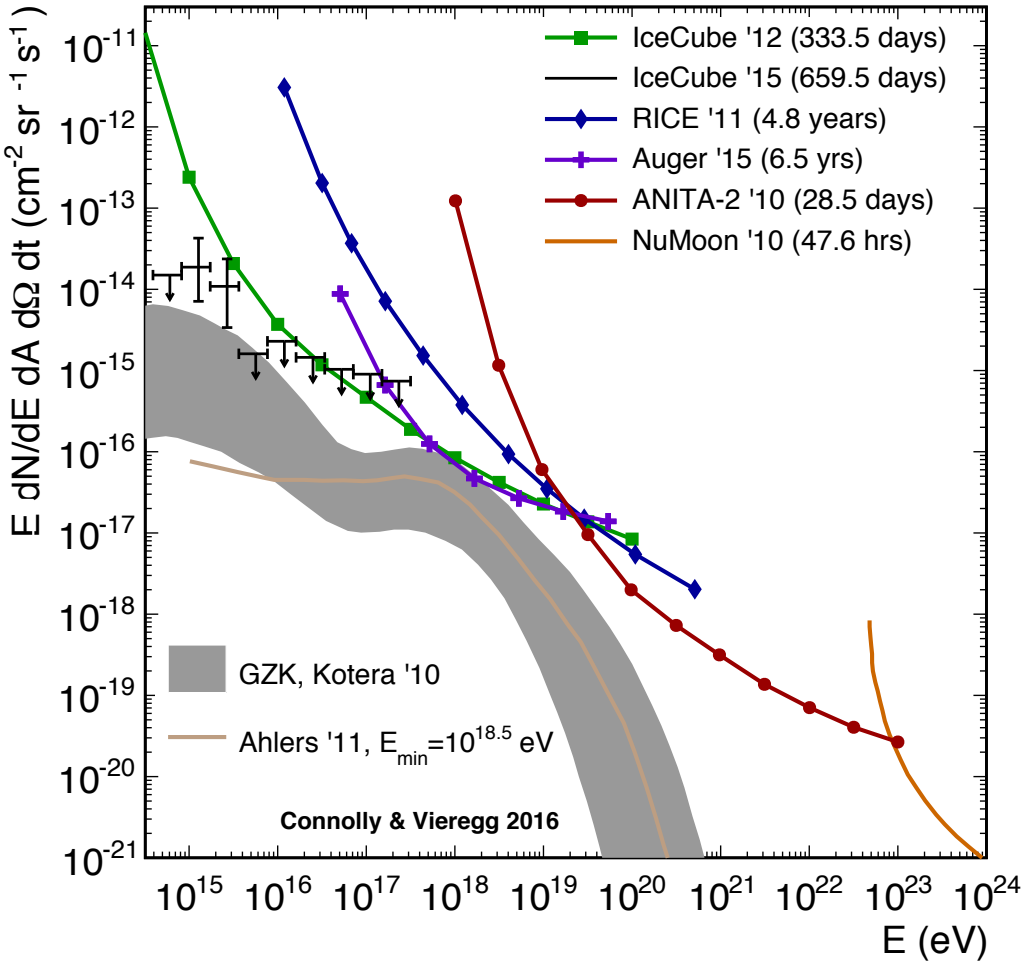
Radio

High Energy Neutrino Astronomy

$<10^{19}$ eV: IceCube and Auger most competitive

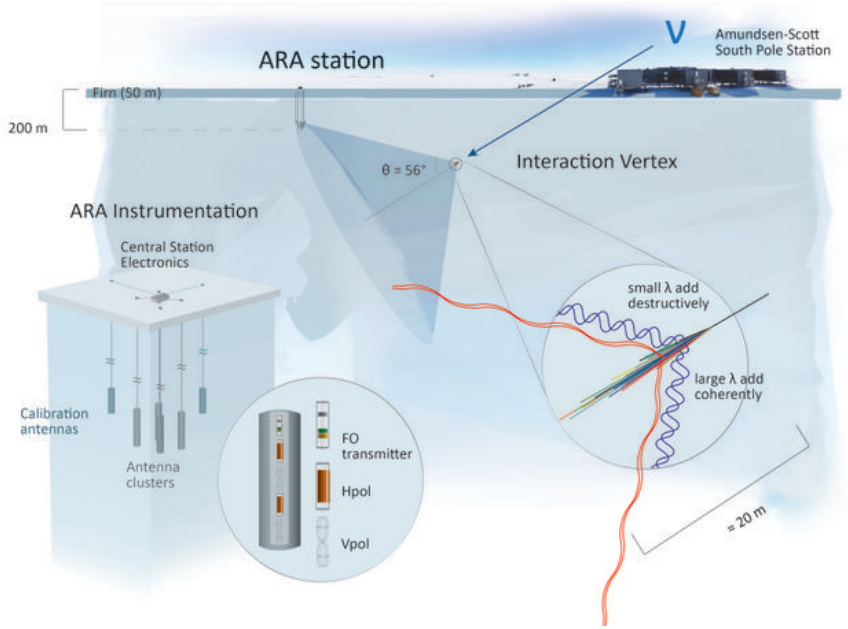
$>10^{19}$ eV: radio dominates (ANITA)

- To improve sensitivity:
  - Move left (lower threshold)
  - Move down (increase area, livetime)

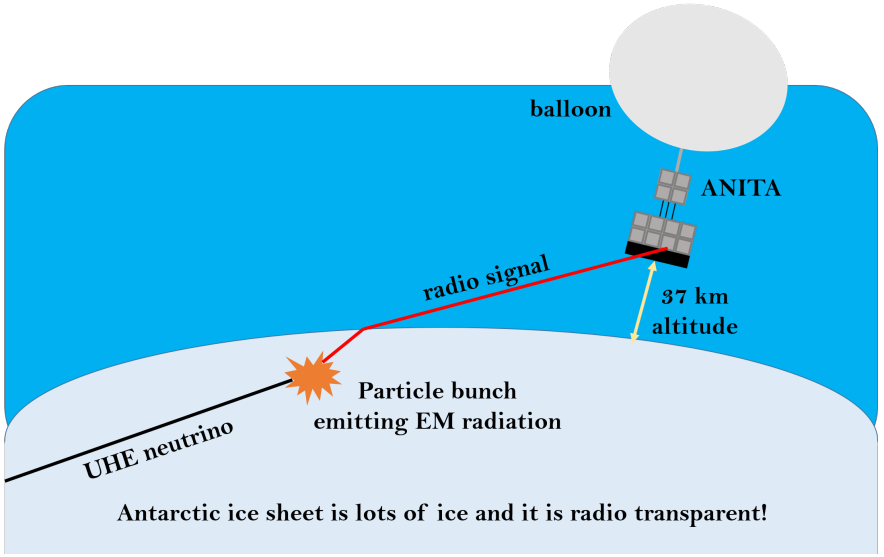


Two classic approaches

Instrument the ice



View from a distance



Graphic: Oindree Banerjee

- Pure ice is low-loss for radio: field attenuation lengths ~1 km

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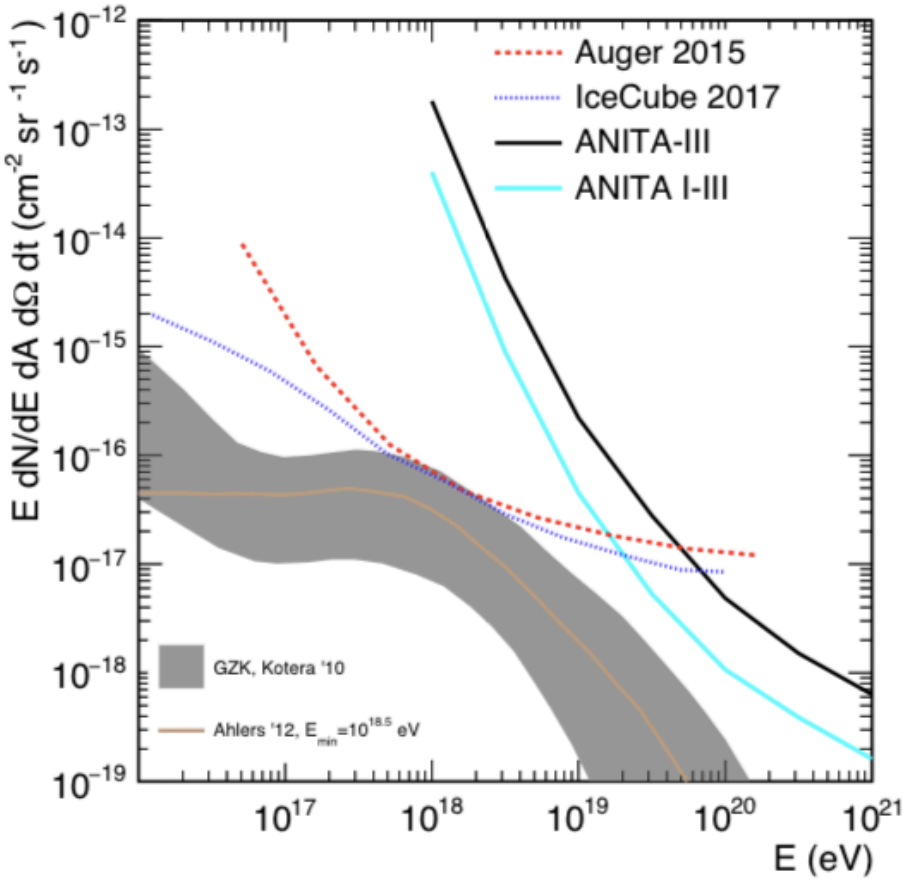
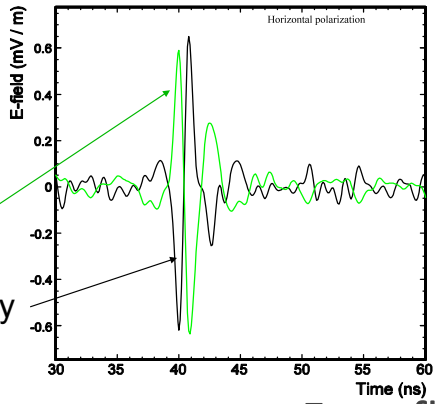
CCAPP

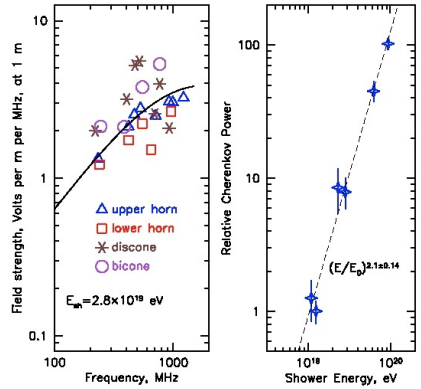
University of Hawaii, University of California, Los Angeles, University of Delaware, Jet Propulsion Laboratory, University of Kansas, National Taiwan University, The Ohio State University, Washington University in St. Louis, University College London

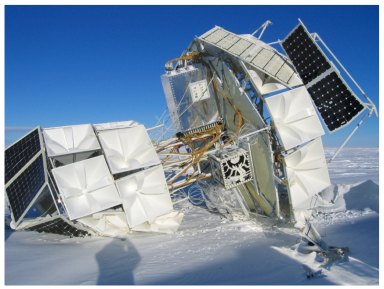




from ice

from sky





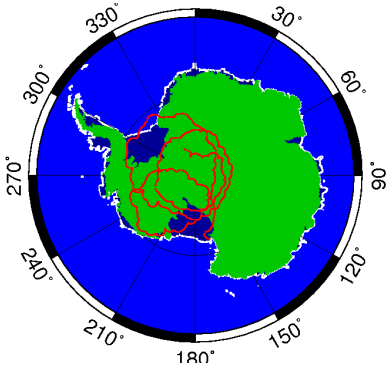
Four flights

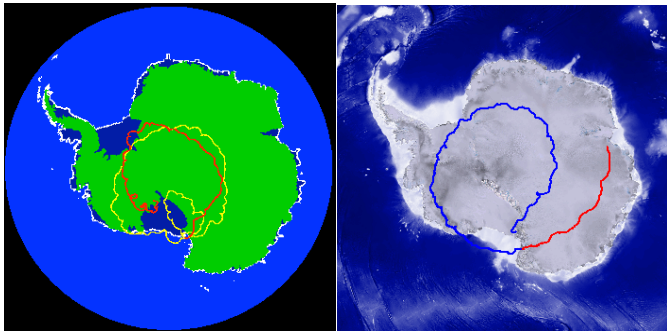
ANITA-1 2006

ANITA-2 2009

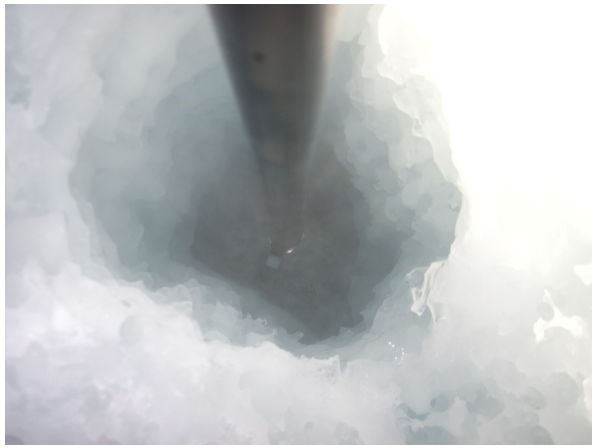
ANITA-3 2014

ANITA-4 2016





ARA
South Pole

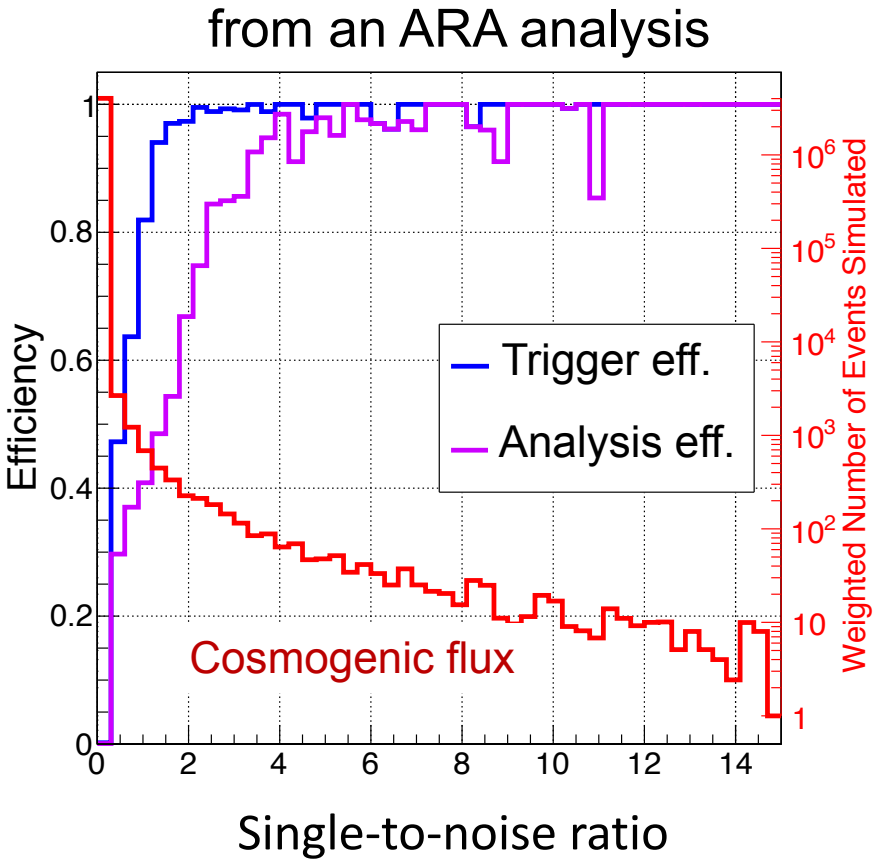


Credit: Mike Duvernois, ARA/NSF

ARIANNA
Minna Bluff

Future

Importance of Thresholds



- There are events to be gained by reducing thresholds
- Lowering *trigger* thresholds brings the exciting challenge of extracting physics from weaker events in *analysis*

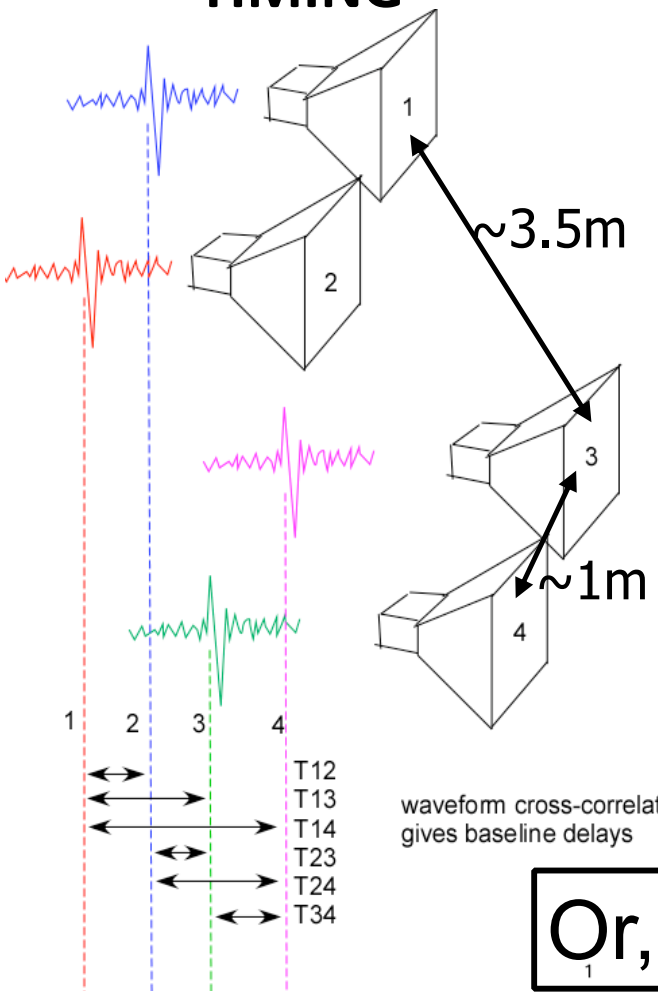
- For an E^{-3} flux:

$$N_{\rm det} = \int_{\rm th}^{\infty} \frac{1}{E^3}\, dE \sim \frac{1}{E_{\rm th}^2}$$

Reducing thresholds - *move left*

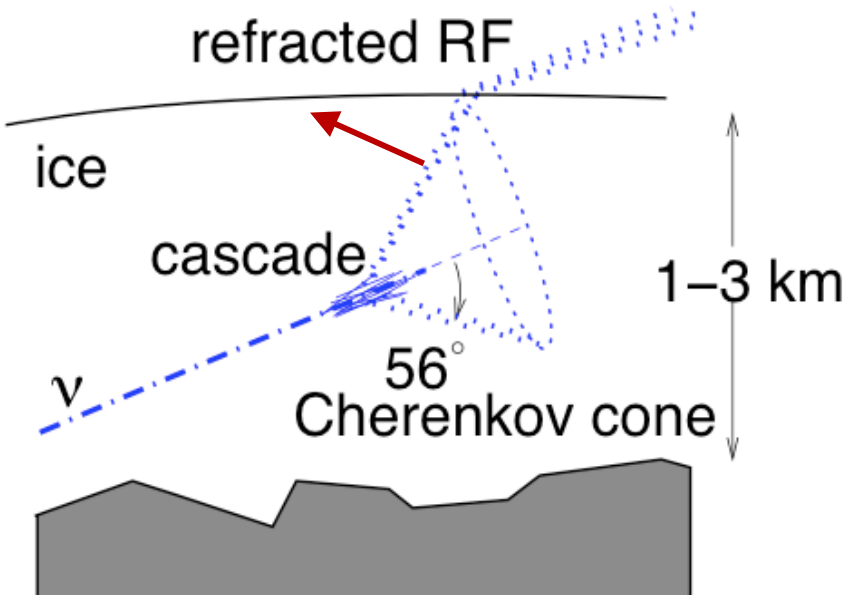
- Using complementary features to lower thresholds

TIMING

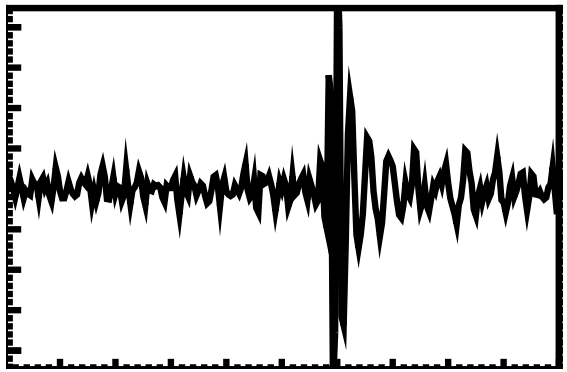


waveform cross-correlation gives baseline delays

POLARIZATION



PULSE SHAPE



OTHER IDENTIFYING CHARACTERISTICS OF BACKGROUNDS

Or, find another creative technique!

Phased array

A. G. Vieregg, et al., JCAP 1602 (2016) no.02, 005.

- Calculate *summed correlation* in electronics before trigger decision

- Newly deployed in 2017-2018 in ARA station #5
  - signal-to-noise reduction as expected!

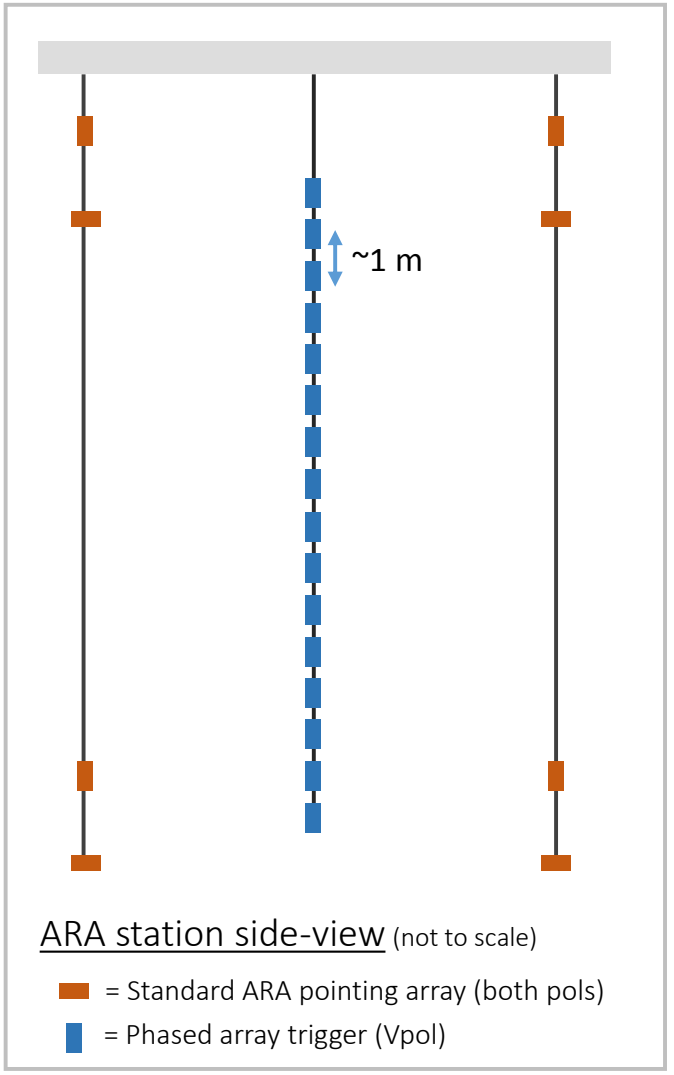


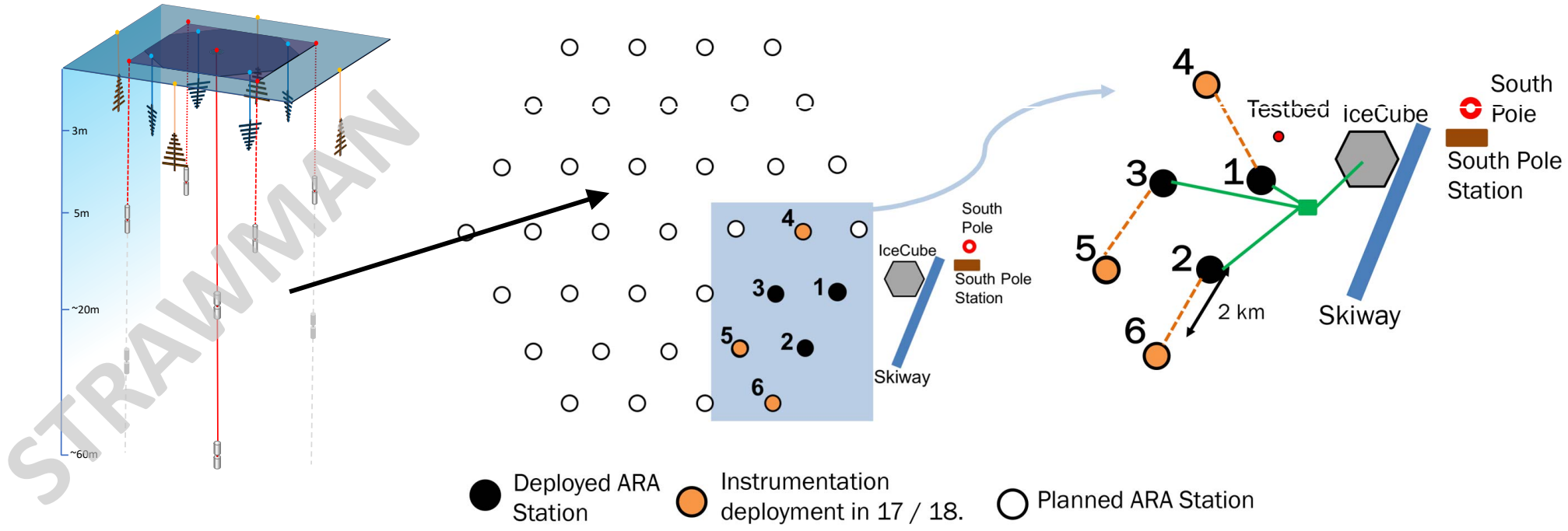
Figure credit: Eric Oberla Univ. of Chicago

In-ice expansion - *move down and left*
Antarctic Radio In-Ice Array

- Folks from existing in-ice arrays have been working together to design the next-generation array in the ice
- Discussions and optimizations ongoing
- Aiming for a proposal to NSF end of 2018

In-ice expansion - *some recent thoughts*

- Make existing cabled region a *low-threshold zone*
  - phased array triggers, reduce analysis thresholds
- Further out deploy mostly *autonomous stations*, at first



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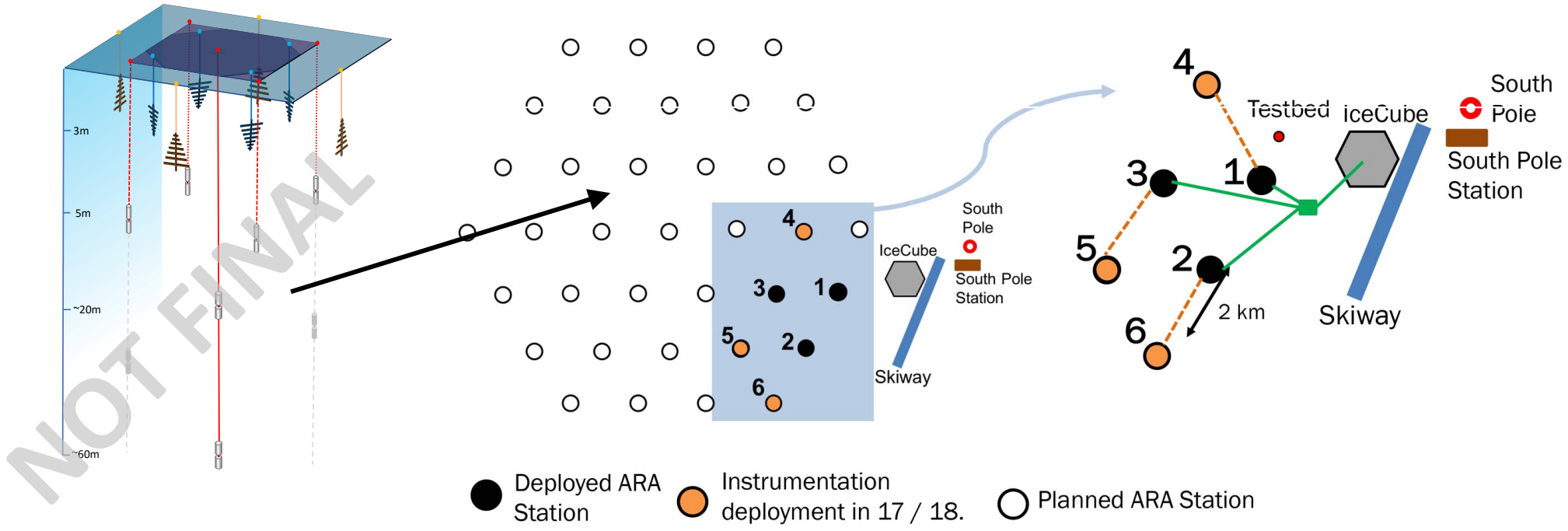

In-ice expansion - *some recent thoughts*

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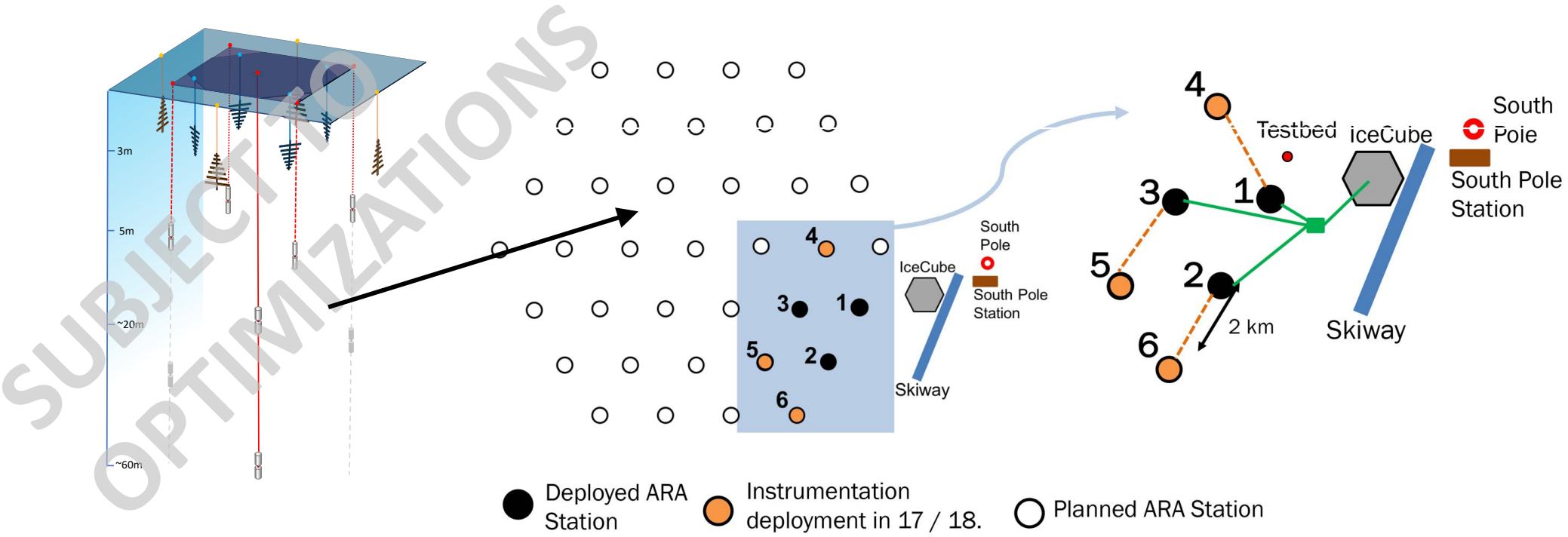
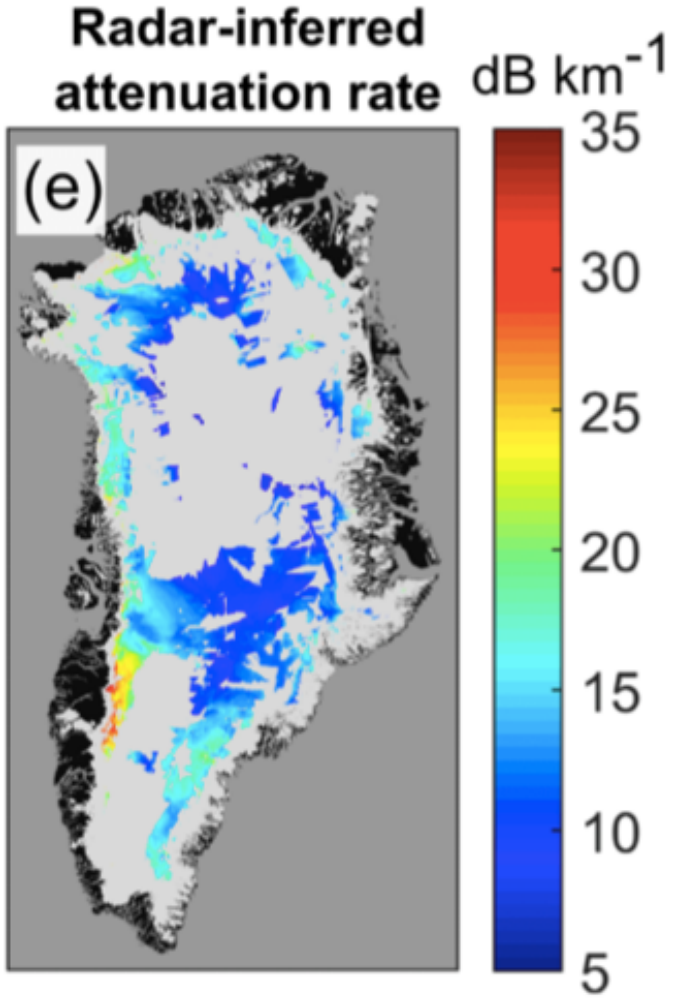


ARENA pre-meeting on Greenland



The Cryosphere, 10, 1547–1570, 2016

- Monday pre-ARENA meeting on Greenland as possible site for radio activities
- Main conclusions:
  - Greenland is an appealing site for rapid R&D
  - In the future we can imagine the same experiment in N&S

Americans and Europeans are united in seeing expansion of array at South Pole the way forward now

Allan Hallgren
shown yesterday

Region covered from SP, ‘deep’
+
Region covered from SP, ‘shallow’

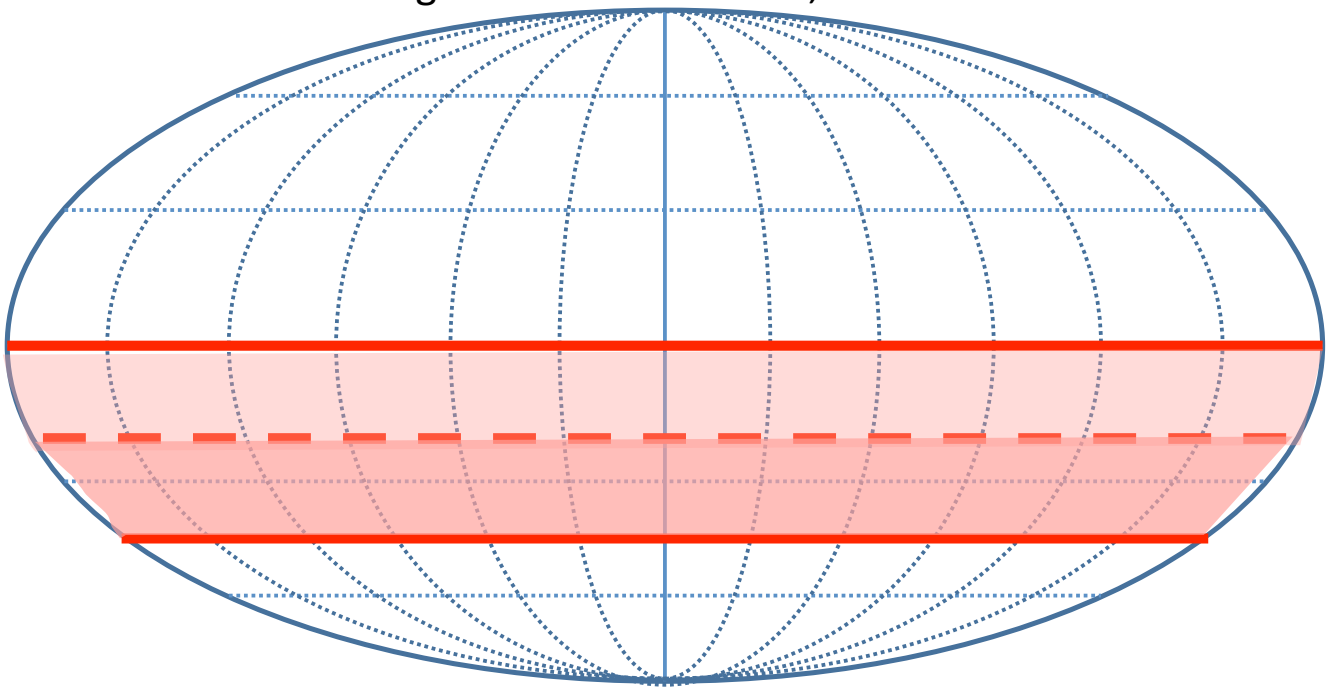


Figure is indicative, hand-drawn.
Different regions will be covered varying time-fraction
More careful calculation needed.

Allan Hallgren
shown yesterday

Region covered Greenland, ‘deep’ +

Region covered Greenland, ‘shallow’

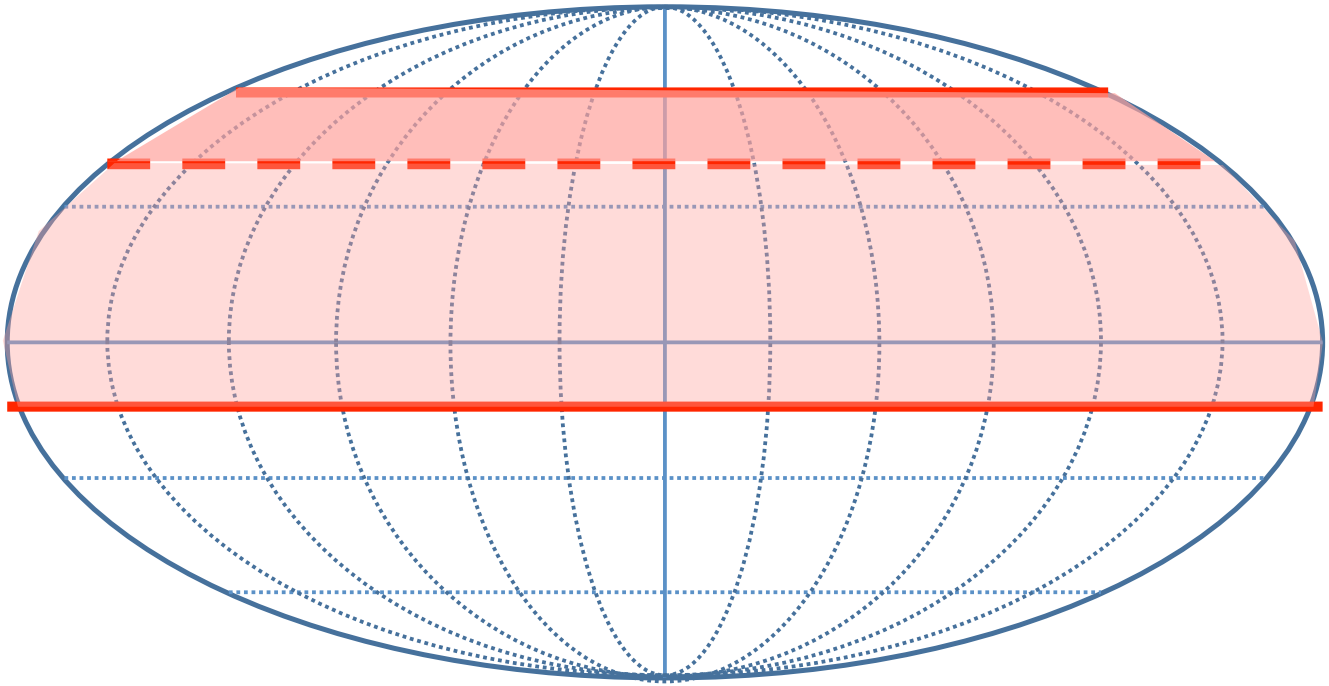


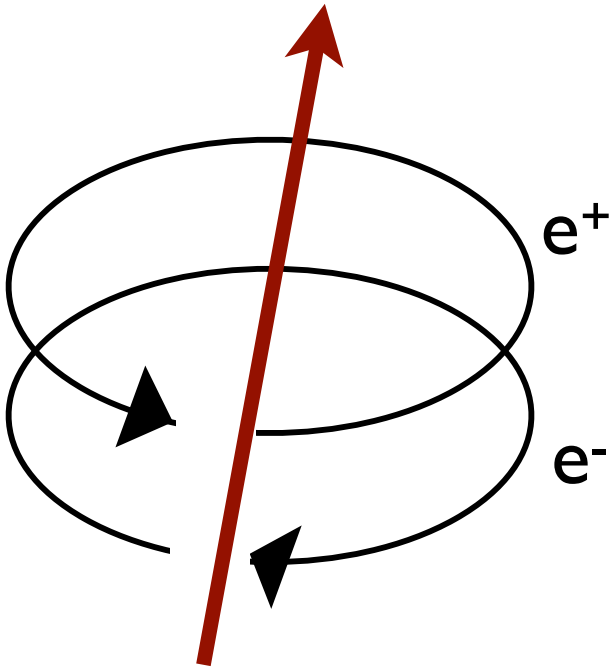
Figure is indicative, hand-drawn.
Different regions will be covered varying time-fraction
More careful calculation needed.

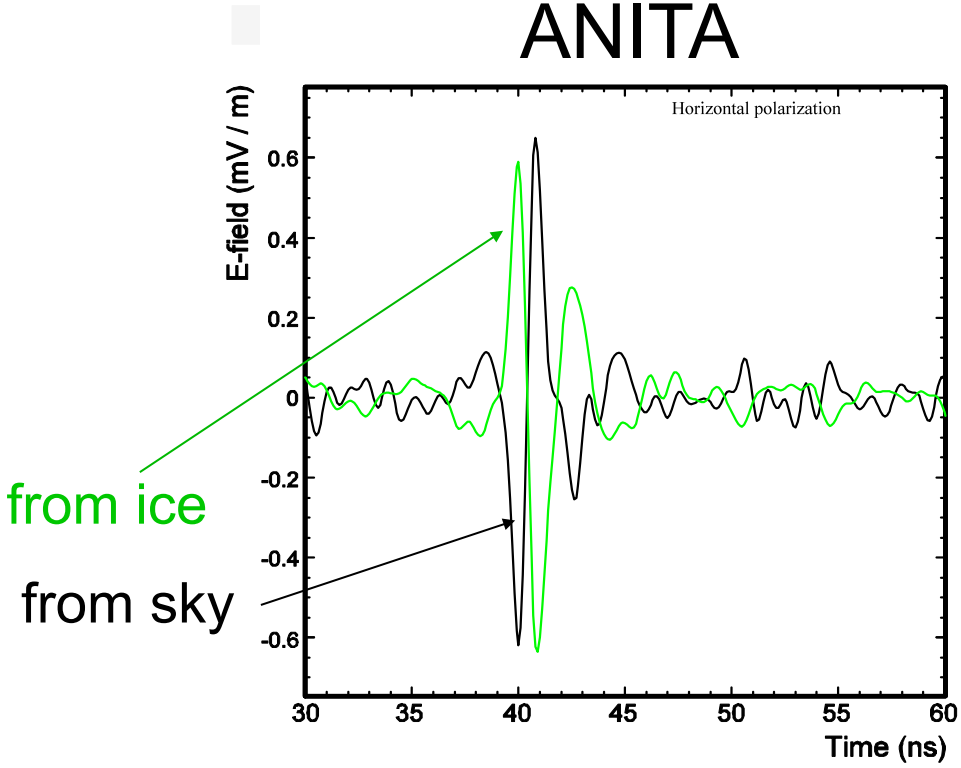
Other techniques…

…Tau-induced showers

Radio geosynchotron

- Air showers produce radio synchrotron emission due to earth's magnetic field (some Askaryan)
- Near South magnetic pole → field points "up"

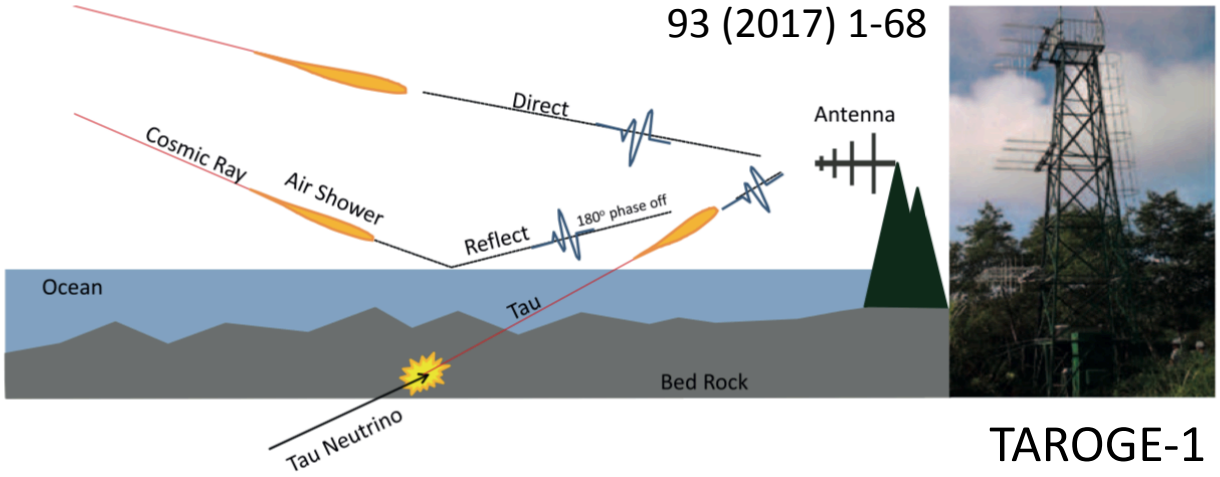




Air showers induced by tau neutrinos

- Experiments being planned to exploit this technique

Particle and Nuclear Physics
93 (2017) 1-68

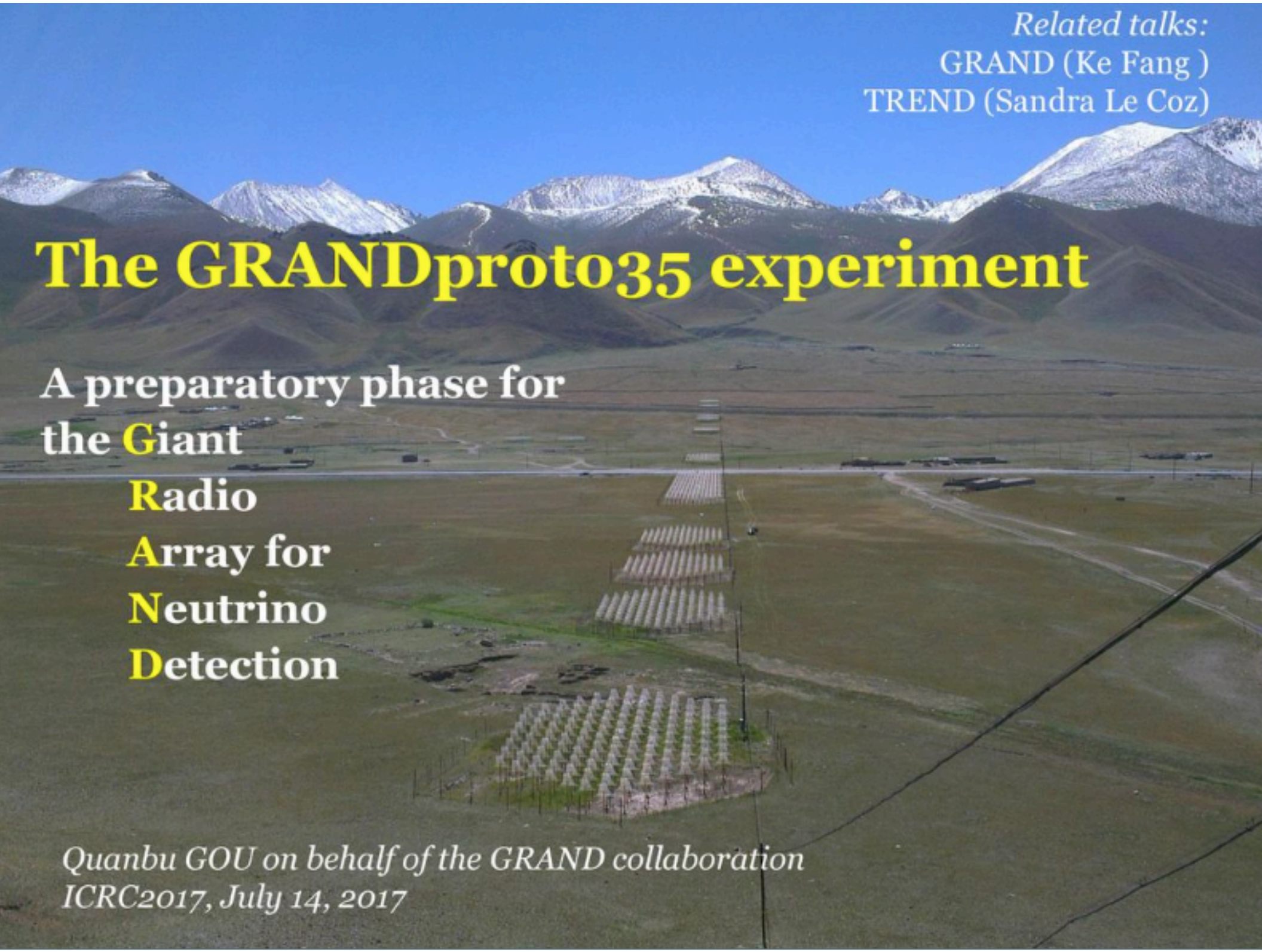


TAROGE-1

Other experiments -
POEMMA
arXiv:1708.07599
Trinity
See N. Otte, Apr. APS `18
TAROGE
ARIANNA
GRAND
arXiv:1508.01919
BEACON: Phased array atop a mountain - S. Wissel

- Auger uses similar mechanism to set strong limits
- ANITA has reported two events that would fit this signature but their steep angle would require a lower cross section than SM expectations predict

arXiv:1803.05088



Related talks:
GRAND (Ke Fang)
TREND (Sandra Le Coz)

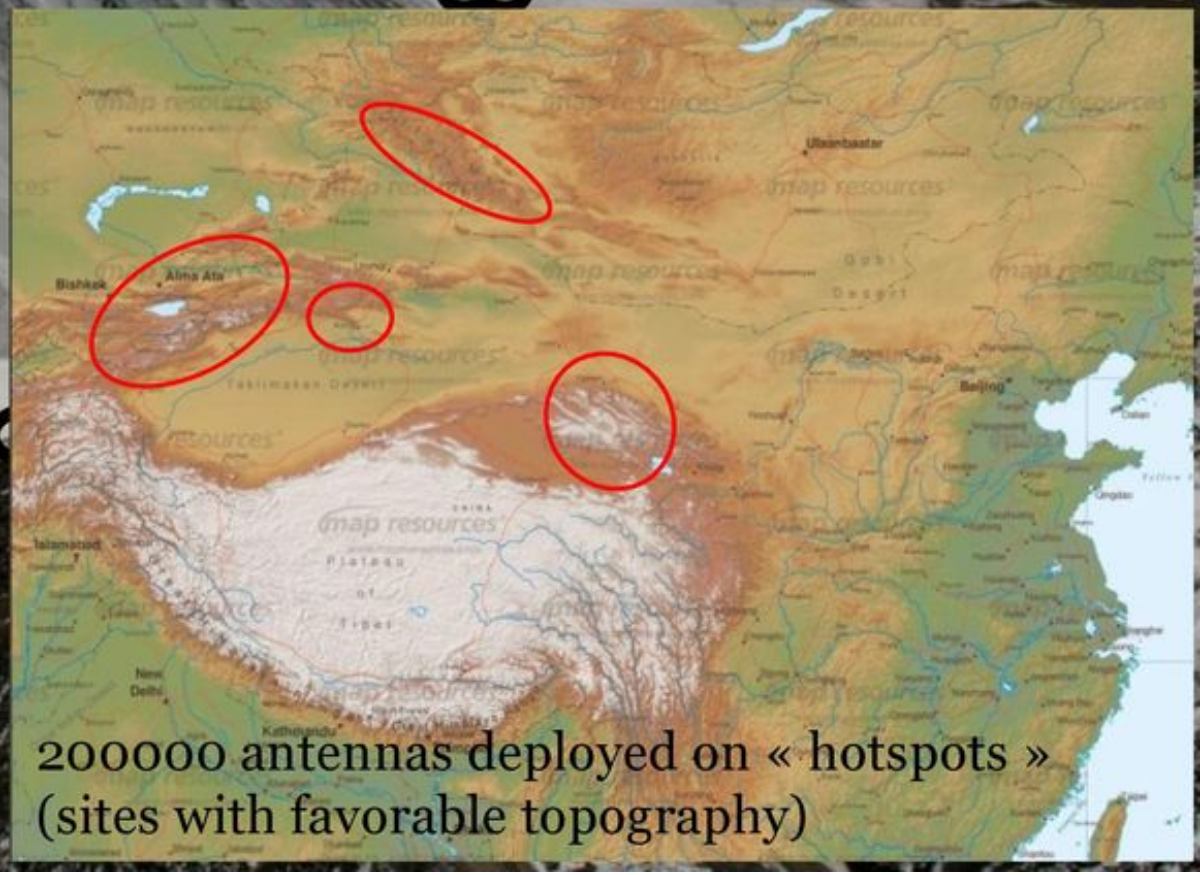
The GRANDproto35 experiment

A preparatory phase for the Giant Radio Array for Neutrino Detection

Quanbu GOU on behalf of the GRAND collaboration
ICRC2017, July 14, 2017

The GRAND project

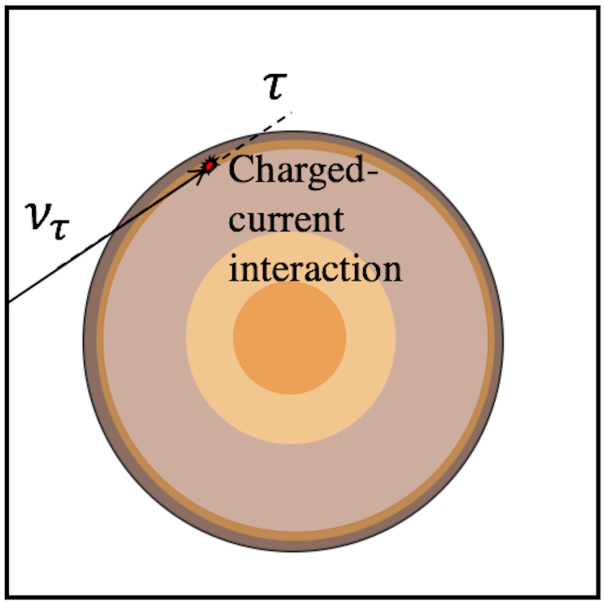
Quanbu Gou on behalf of
GRAND collaboration
ICRC2017

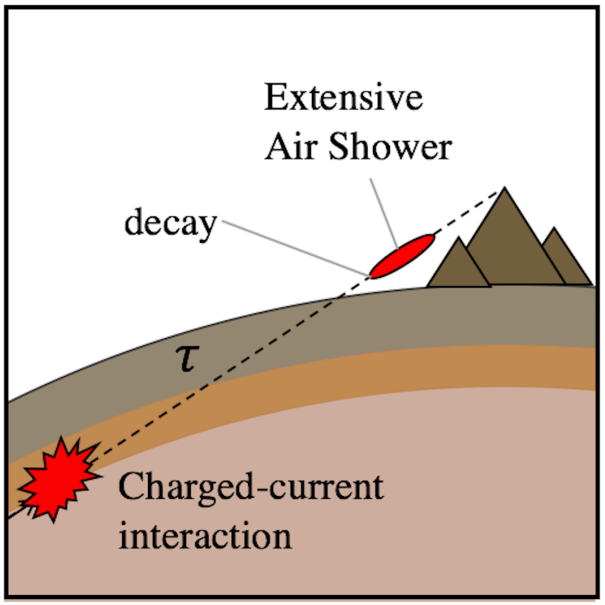


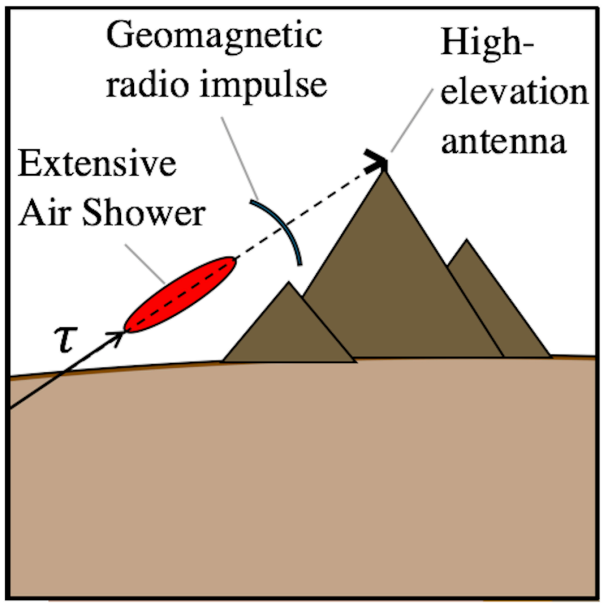
200000 antennas deployed on « hotspots »
(sites with favorable topography)

See Ke Fang's
GRAND talk

BEACON: Beamforming Elevated Array for COsmic Neutrinos







- **High Exposure :** High Elevation Mountain (>2 km) + Year-Round Duty Cycle
- **Scalable :** Inexpensive, low number of stations (~10) required for Kotera mix. models,
- Similar approach as TAROGE, ARIANNA, and GRAND, but optimizing for small-number of stations, high-elevation, & multiple sites

Challenges:

- Are the radio backgrounds manageable at high-elevation sites?
- Radio self-trigger on impulsive air showers?

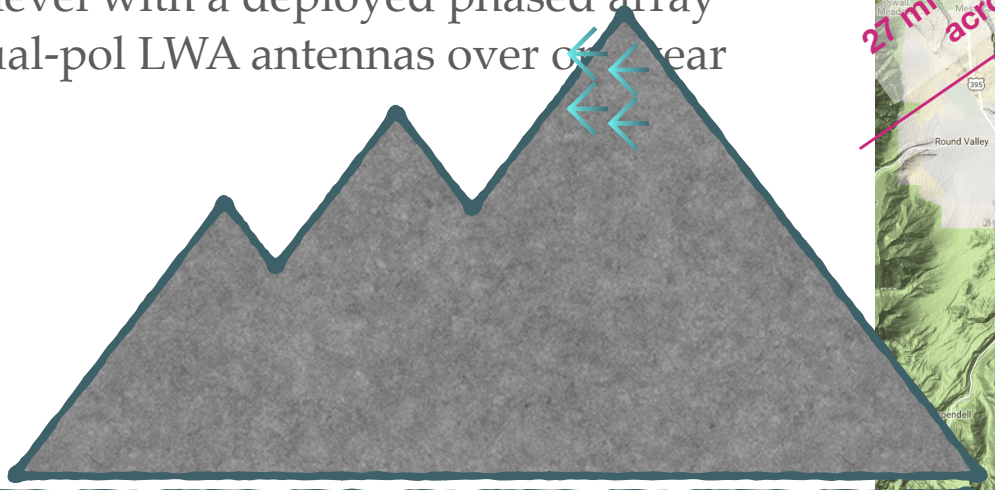
SAW NSF CAREER #1752922
#1752922

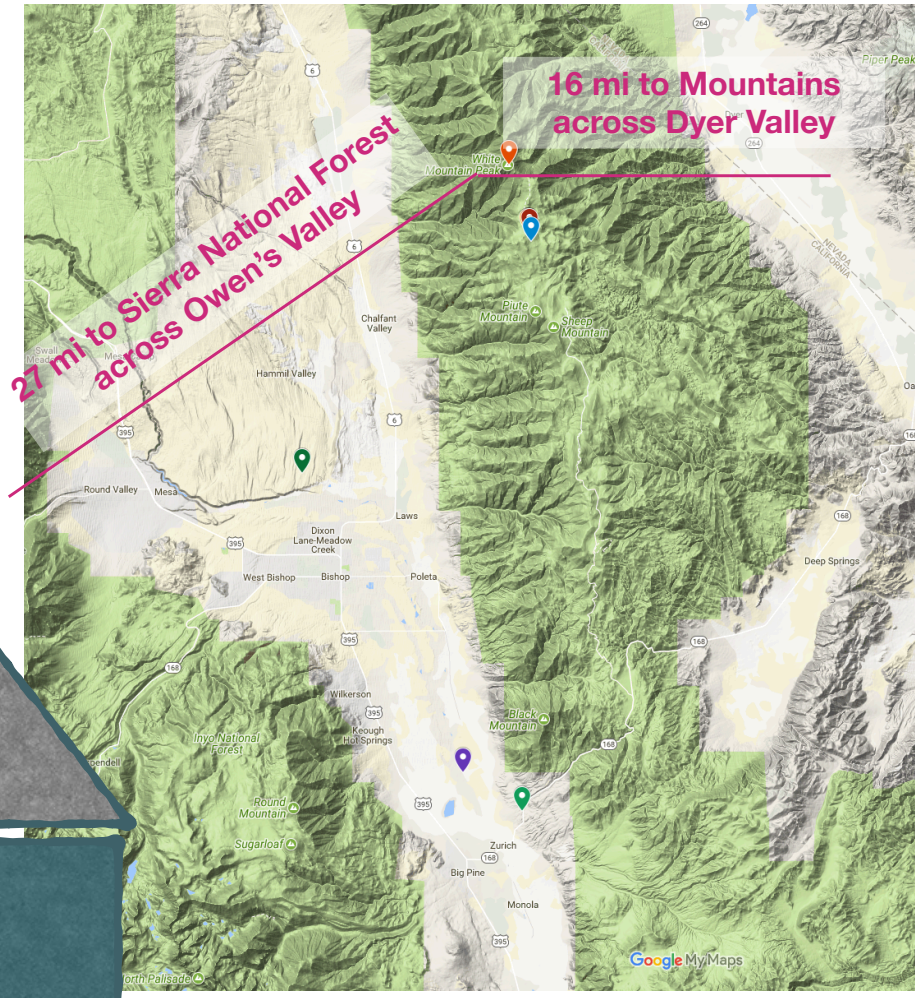
Challenge of RFI

- Site study this summer at White Mountain Research Station near Bishop, CA at ≥ 3.8 km, valley ~1.2 km

Site Study

1. Measure trigger rates, spectra, time-domain noise traces over week long period at several sites
2. Test out various RFI-rejection schemes at the firmware level with a deployed phased array using 4 dual-pol LWA antennas over c[illegible]ear





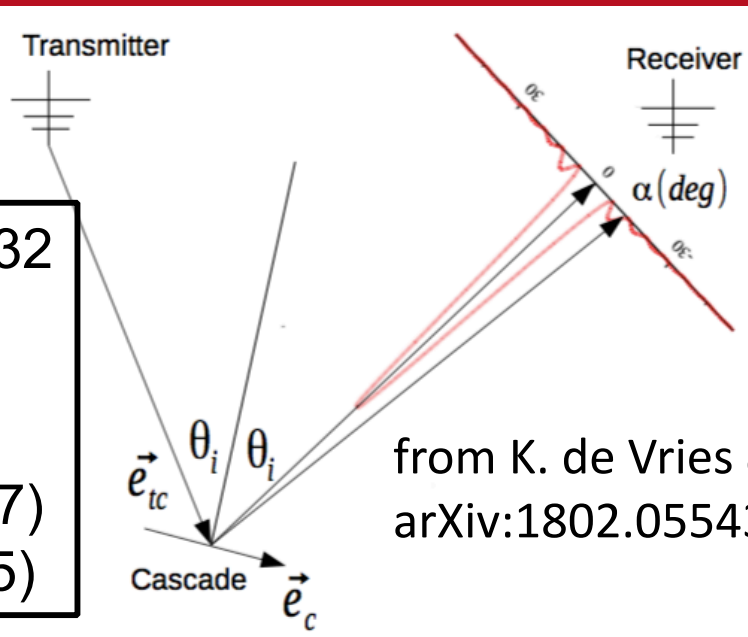
Collaborating with:

- Vieregg group (Chicago) on phased array deployment in strong RFI environment
- Hallinan group (Cal Tech) at OVRO-LWA on RFI-rejection strategies & RF-only air shower detection

…Radar?

RADAR

S. Prohira *et al.*, Nucl.Instrum.Meth. A890 126-132 (2018)
K. de Vries et al., arXiv:1802.05543
S. Prohira arXiv:1710.02883
R.U. Abbasi *et al.*, Astropart. Phys. **87** 1-17 (2017)
K. de Vries *et al.*, Astropart. Phys.60:25-31 (2015)



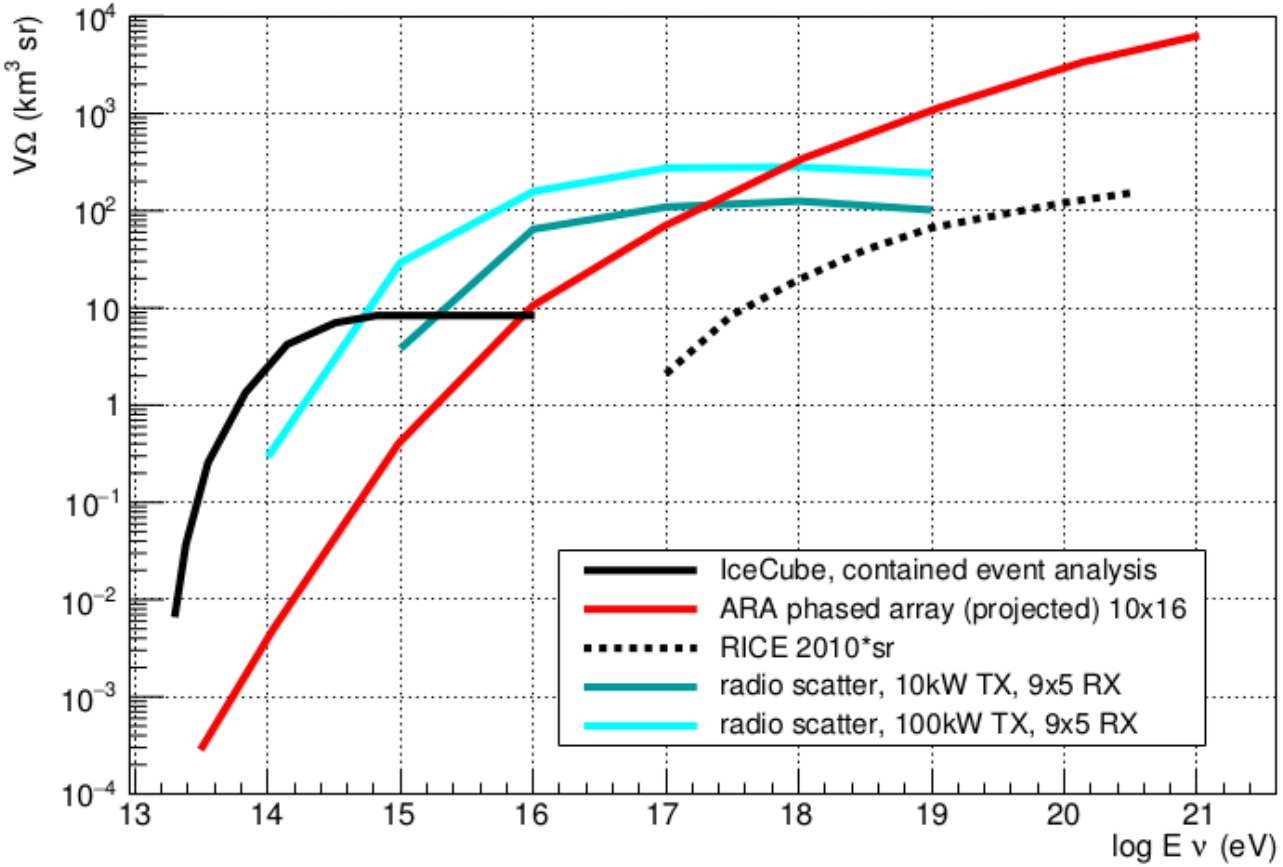
from K. de Vries *et al.*, arXiv:1802.05543

- K. de Vries *et al.* - low energy (40 MeV) beam test
- TARA experiment in Utah (PI's D. Besson & J. Belz) attempted with air showers
- Looks like dense media needed
- Steven Prohira (KU)-Starting CCAPP Fellow Fall 2018. Led SLAC beam test under DOE Office of Science Grad Fellowship - **Data analysis underway, results soon!**

RADAR

(left to right) Steven Prohira, Krijn de Vries, Jorge Torres Espinosa, Uzair Latif

RADAR



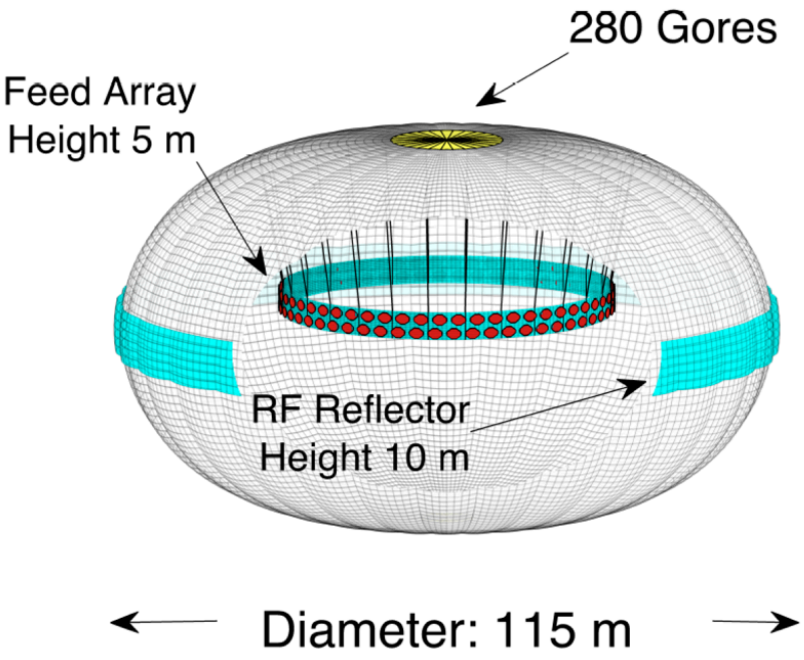
S. Prohira, arXiv:1710.02883

- Radar could fill in the energy gap between IceCube and in-ice Radio Cerenkov

Future of Ballooning

- ANITA-5 proposed with reduced threshold using phased trigger
  move left
- Super pressure balloons may offer more livetime -
  move down
- Next generation balloons
  - EVA idea - higher gain
    move left
  - feed array inside balloon

EVA concept



Novel approaches should continue to be explored

THE OHIO STATE UNIVERSITY

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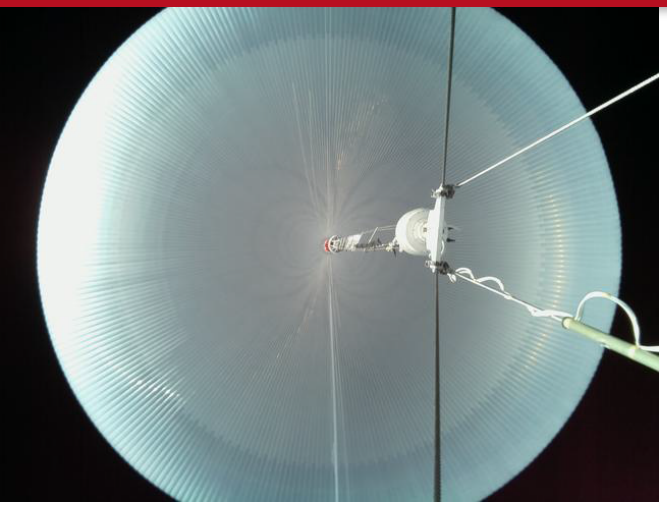
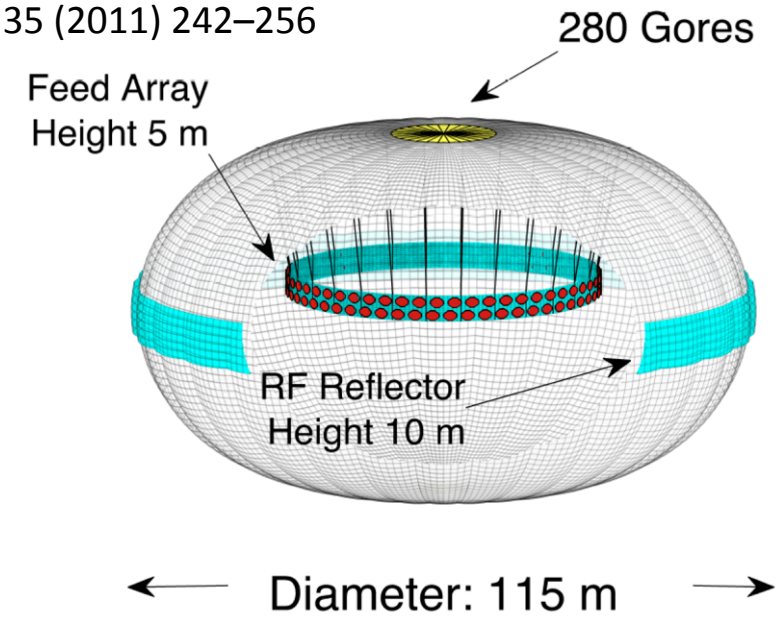
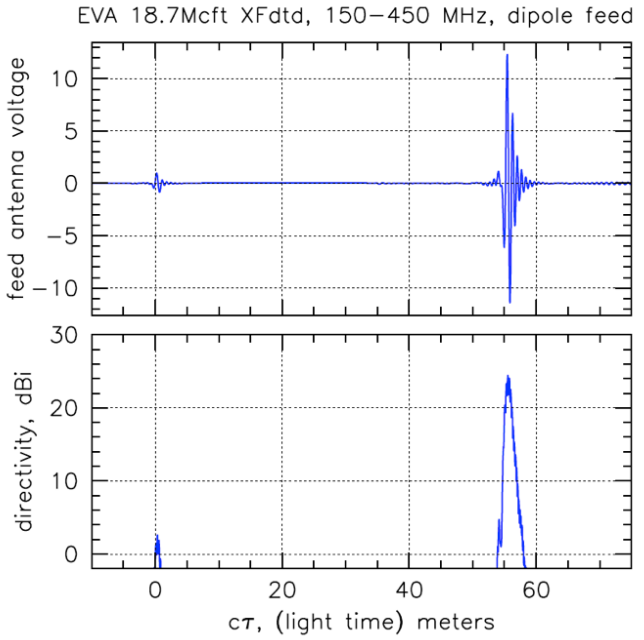


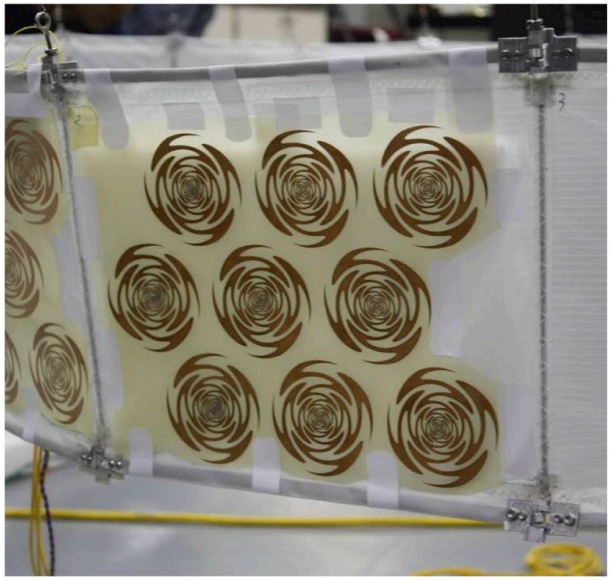
NASA 18.7 Mcft
super-pressure balloon.

Gorham *et al.*, Astroparticle Physics 35 (2011) 242–256



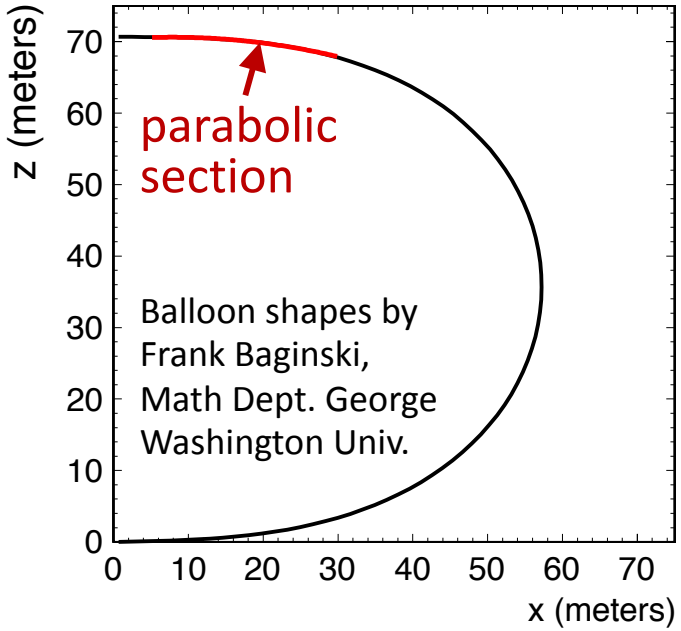


EVA 1:20 Prototype Test at Wallops Test Facility, September 2014



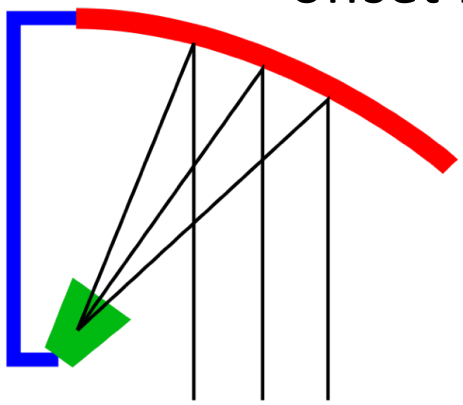
Measured 11.4 dBi gain consistent with detailed simulations

My thoughts



- Can we reflect off the top and receive with a phased feed

Dish antenna with offset feed



From wikipedia, Offset dish antenna

Focal point or "ring"

- Upward-going events reported by ANITA heightened interest in looking down?

Square Kilometer Array (SKA) telescope with phased array feed

Moving forward - plan for flexibility

- Power, communications
  - Be sure that an expansion does not preclude new ideas that may require more power, good comms
- Trigger electronics
  - Becoming clear that more flexible trigger electronics with longer readouts that can be swapped between experiments would facilitate a more nimble field

Moving forward - plan for flexibility

- Let's continue to be open to new ideas!
  - It is a great strength and has been a defining characteristic of this field from the beginning

GENETIS (Genetically Evolving NEutrIno TeleScopes

- With Prof. Stephanie Wissel (Cal Poly), Research Scientist Kai Staats
- Using genetic algorithms (type of ML) to evolve detector designs for neutrino telescopes
- Starting with antenna designs

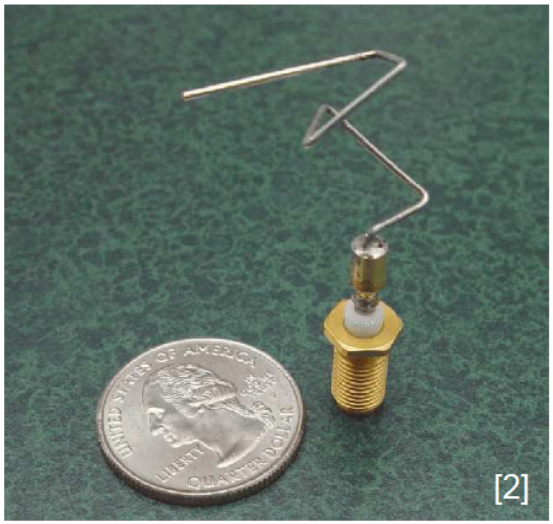
GENETIS Mini-Collaboration Meeting April APS 2018

Heavy involvement from undergraduates

u.osu.edu/connolly/genetis

GENETIS

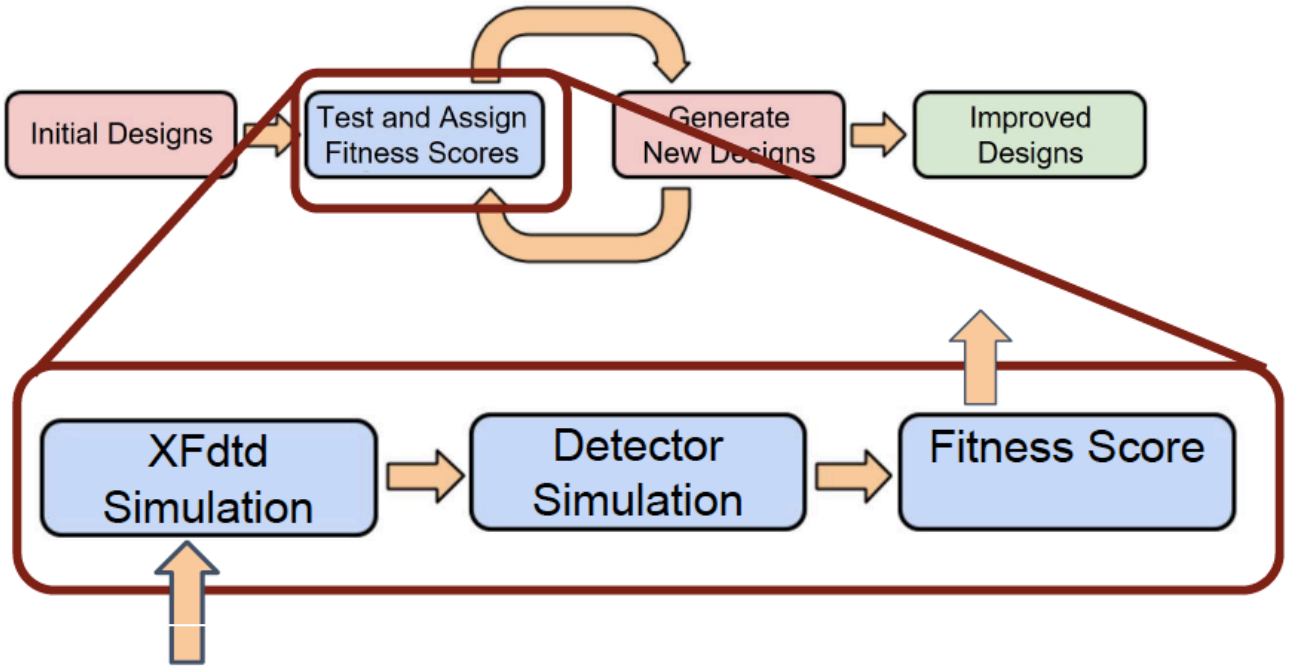
- Lately a growth in genetically evolved antennas (mostly narrow band)



ST5: A narrow-band antenna designed using genetic algorithms by NASA for satellite communications

[2] https://ti.arc.nasa.gov/m/pub-archive/1244h/1244%20(Hornby).pdf

GENETIS loop (now in action):



- May be well suited to design antennas under tight constraints

u.osu.edu/connolly/genetis

Antarctic canyons?

from Dave Seckel…?

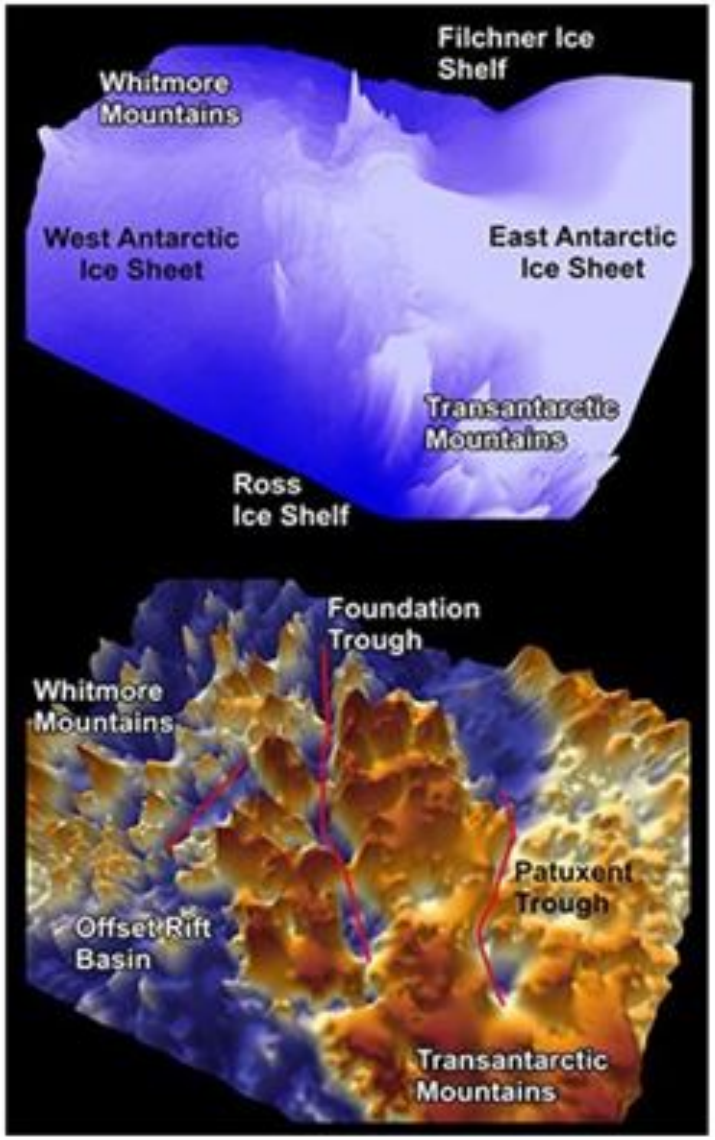
Vast hidden canyons and mountain ranges discovered in Antarctica

The enormous size of the troughs took scientists by surprise.

l 350 km
w 50
h 3 ?

$V =$ 50000 km

+ $\frac{1}{2}$-channel



Summary

- Let's see what nature has in store above 10 PeV!
  - UHE astronomy at cosmic distances
  - Tests of fundamental physics
- Current experiments are expanding and reducing thresholds
- Watch for the development of many novel approaches

Thank you!