In-ice radio arrays for the detection of ultra-high energy neutrinos

Prof. Amy Connolly

Oct. 12, 2018

Outline

- Science motivation for in-ice radio arrays
- Radio Cerenkov
- Other techniques
- Future

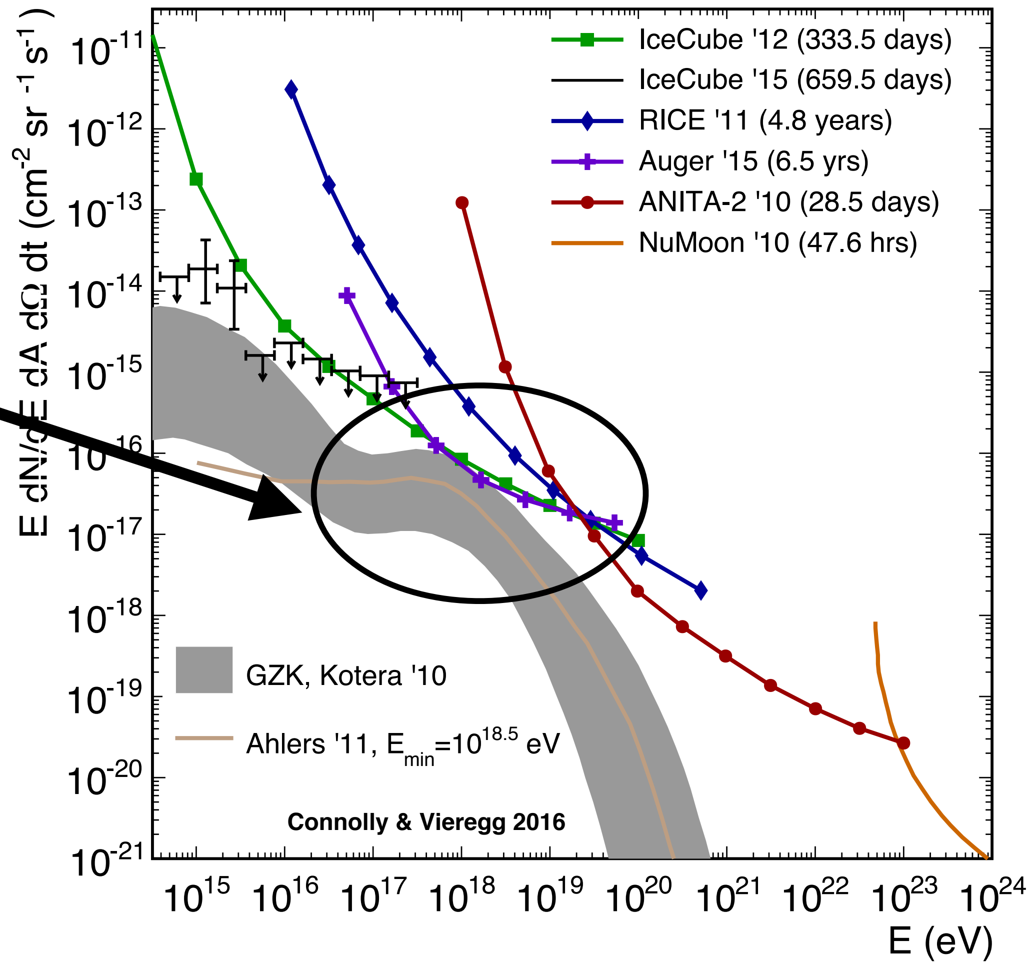
Science motivation

astronomy

High Energy Neutrino Astronomy

Want to dig deep into this region here

- Where does astrophysical flux measured by IceCube cutoff?
- Measure astrophysical flux at ultra-high energies, from sources or cosmogenic



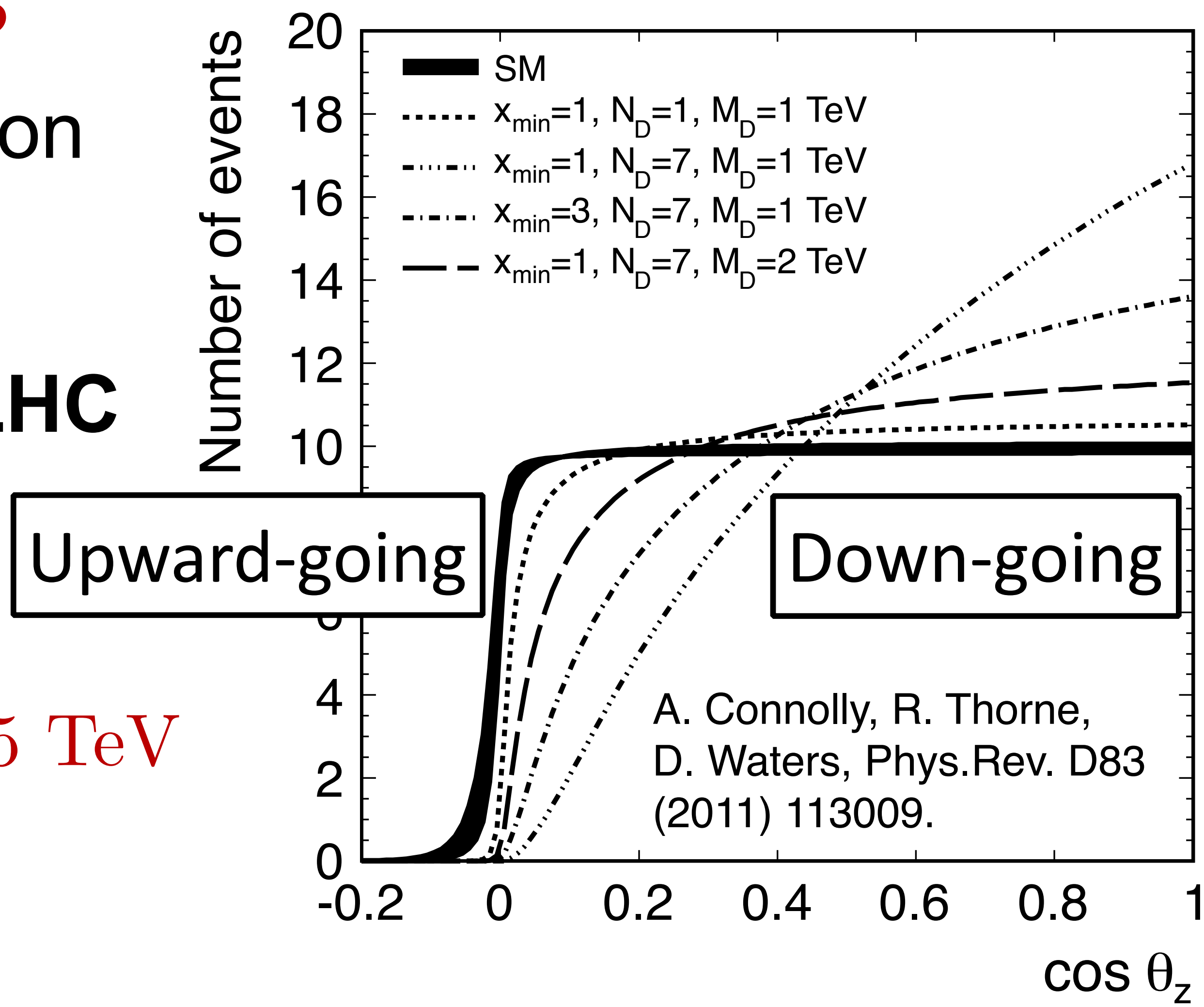
fundamental physics

Cross Sections

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

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

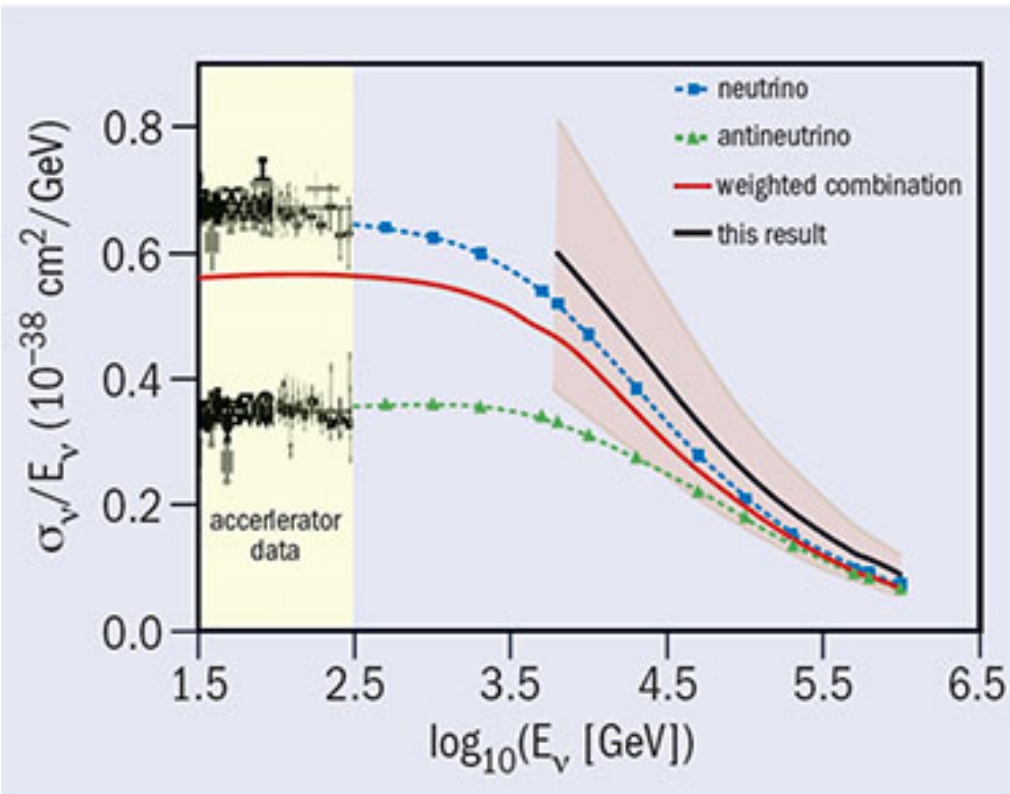
$$E_{\rm CM} = \sqrt{2 m_N E_\nu} = 45 \text{ TeV}$$



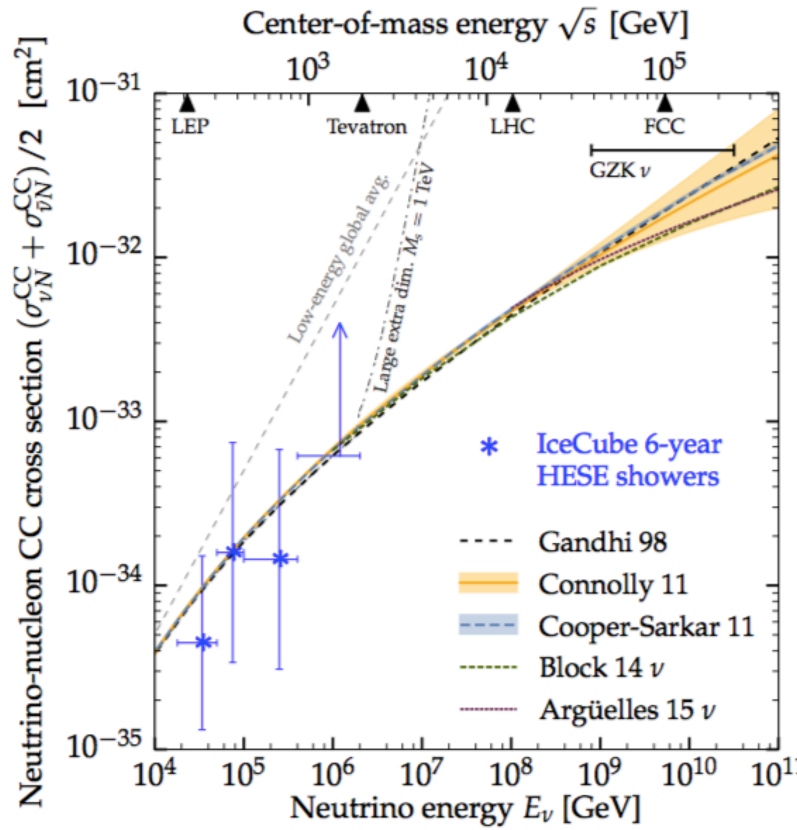
ED model predictions from J. Alvarez-Muniz and E. Zas, Phys. Lett. B411, 218 (1997).

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

Radio

The case for going beyond optical

~ 10 cosmogenic neutrinos / km^2 / year

10^{18} eV: νN 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 Cerenkov Technique

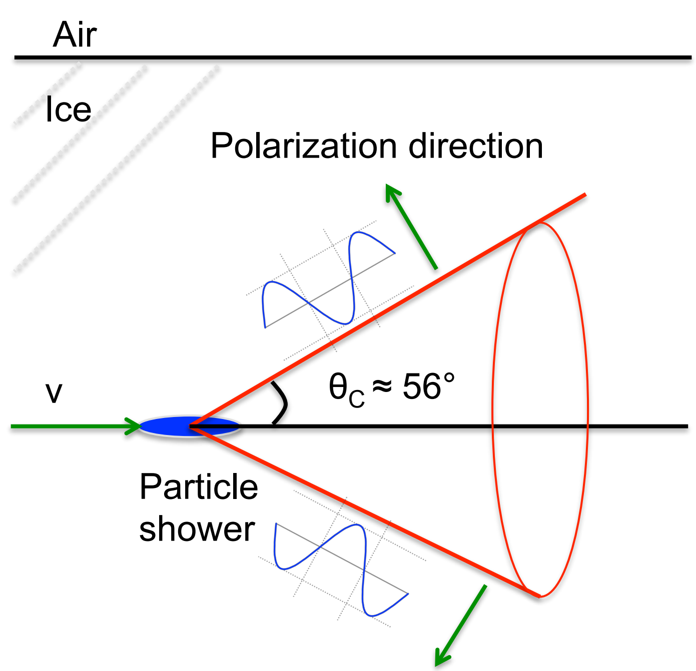
- Shower - 20% charge asymmetry
- Cerenkov radiation
- *Coherent* for λ ≫ 10 cm

→ RADIO

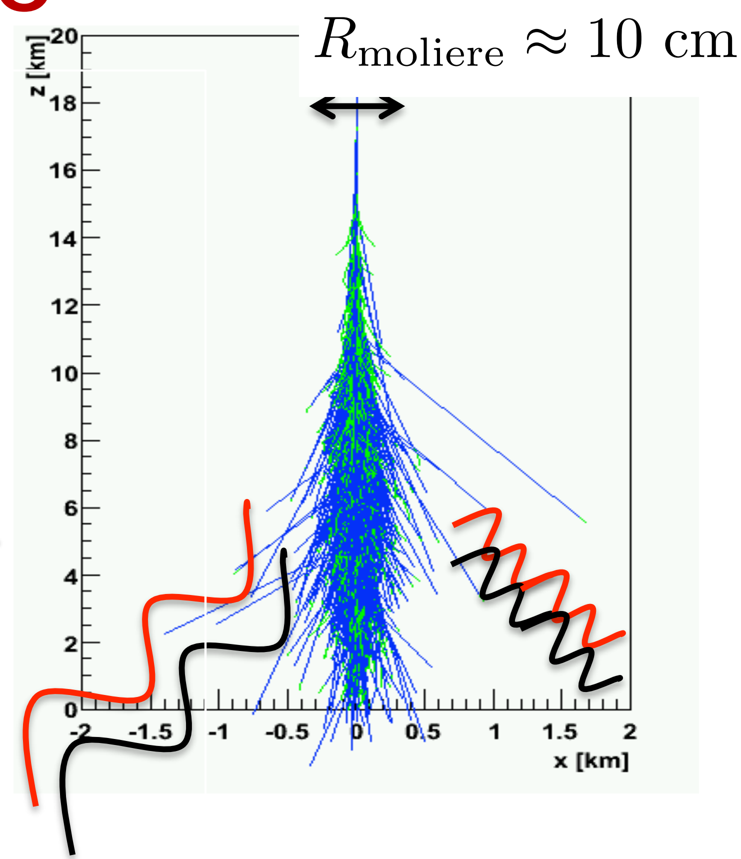
$\text{Power} \propto E_{shower}^2$

Confirmed experimentally in sand, salt, ice:

PRL 86, 2802 (2002);
PRD 72, 023002 (2005);
PRD 74, 043002 (2006);
PRL 99, 171101 (2007)



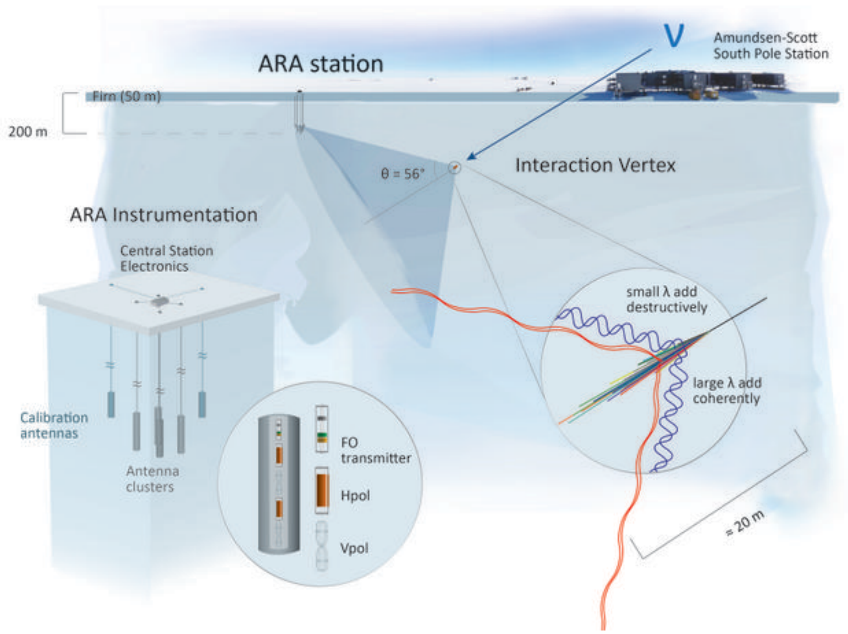
Graphics: Carl Pfendner



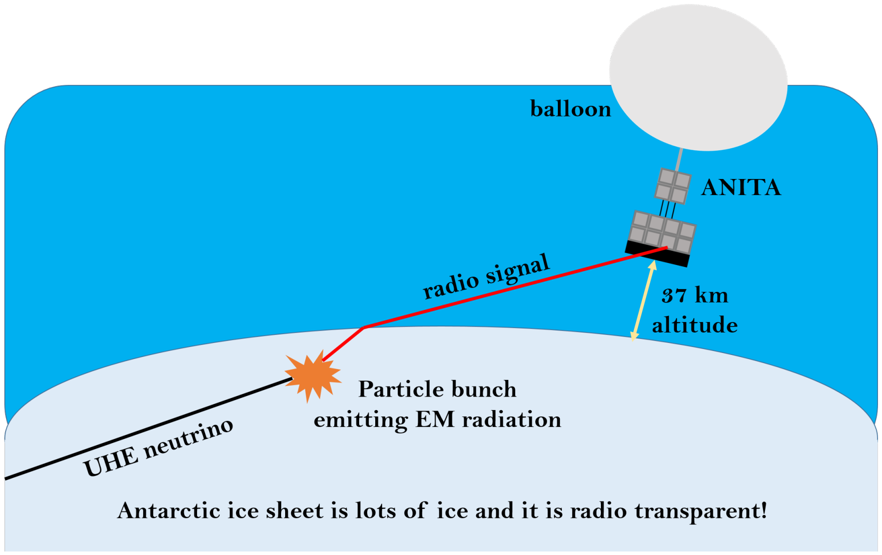
Gurgen Askaryan, 1962

Two classic approaches

Instrument the ice



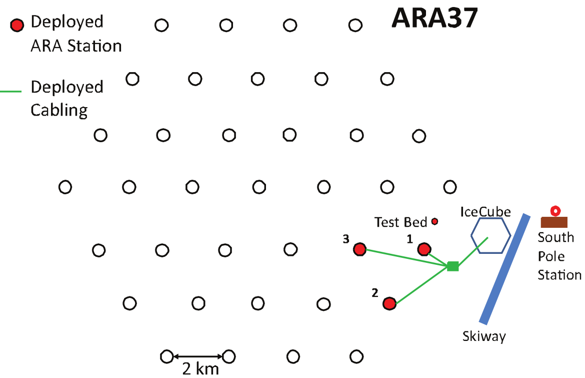
View from a distance

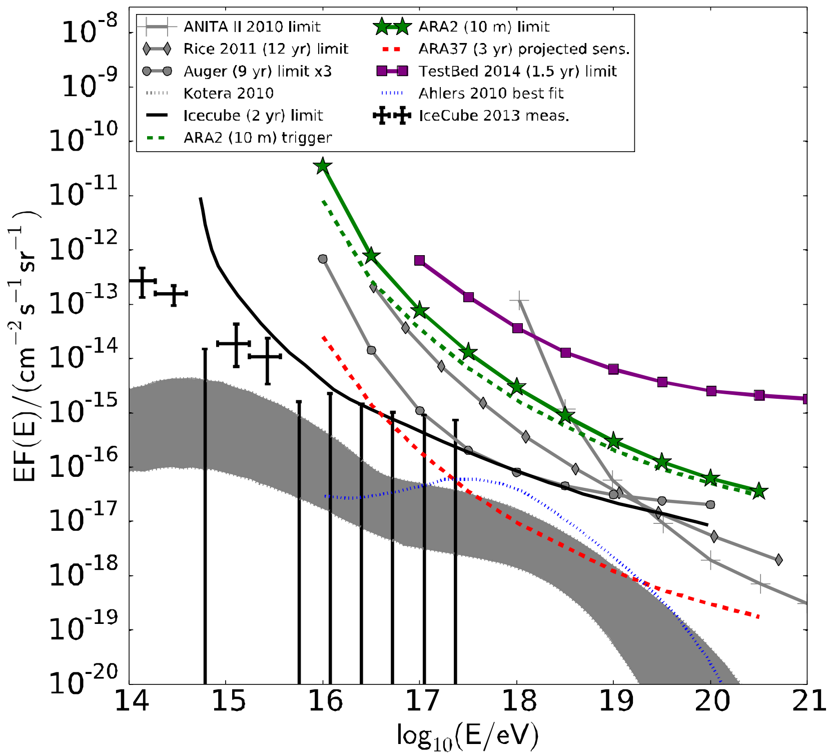


Graphic: Oindree Banerjee

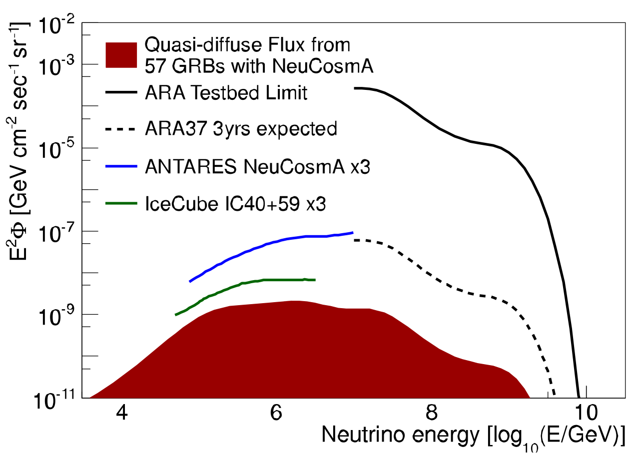
- Pure ice is low-loss for radio: field attenuation lengths ~1 km

Askaryan Radio Array (ARA)

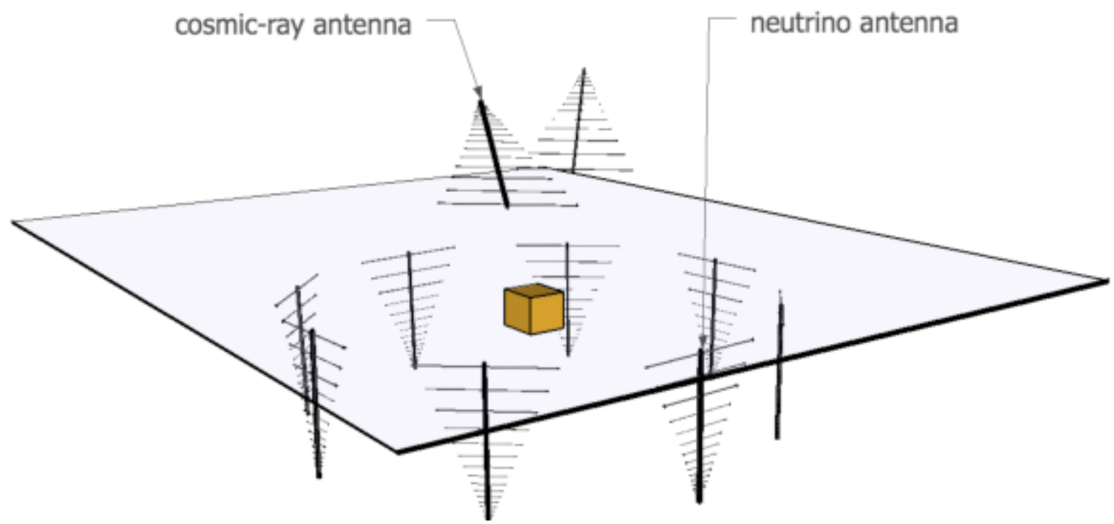





Credit: Mike Duvernois, ARA/NSF



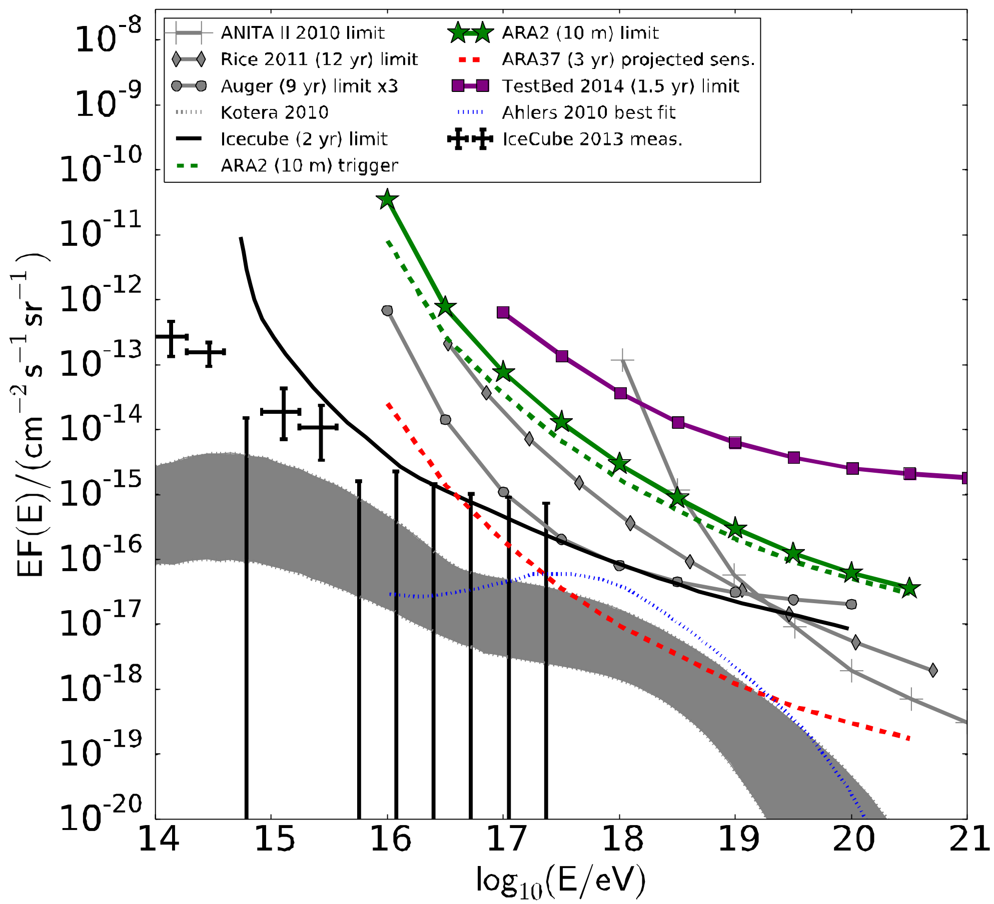
ARIANNA - Moore's Bay



- ARIANNA designed for minimum power and remotely powered operation, surface design allows for access
- Observes cosmic rays

In-ice expansion - *move down and left*

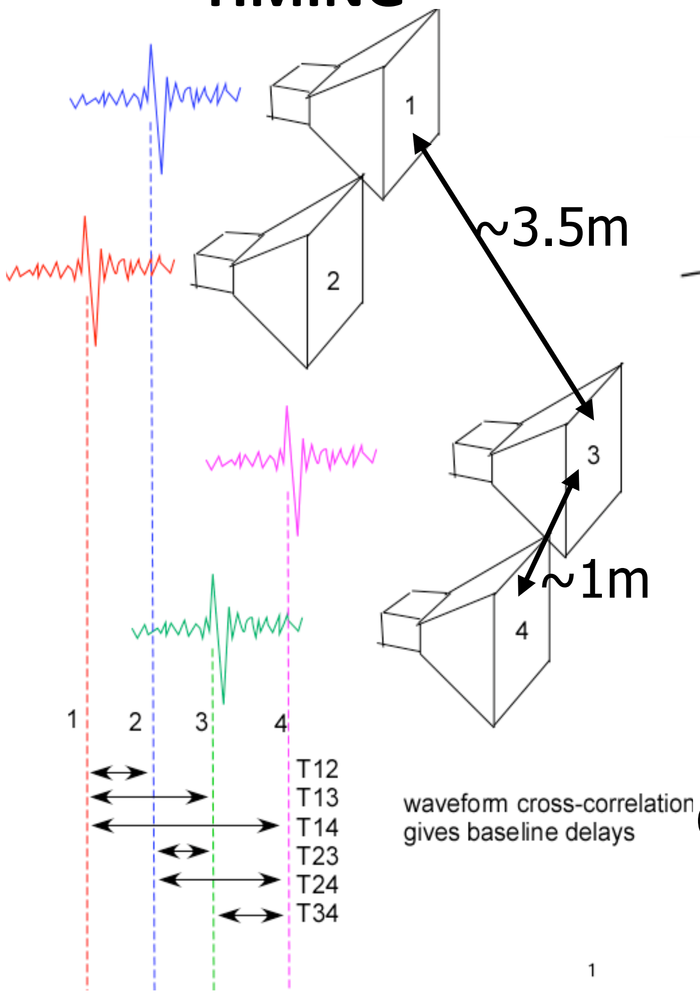
- On EdN/dE plot
  - By expanding you move down
  - By reducing thresholds you move left



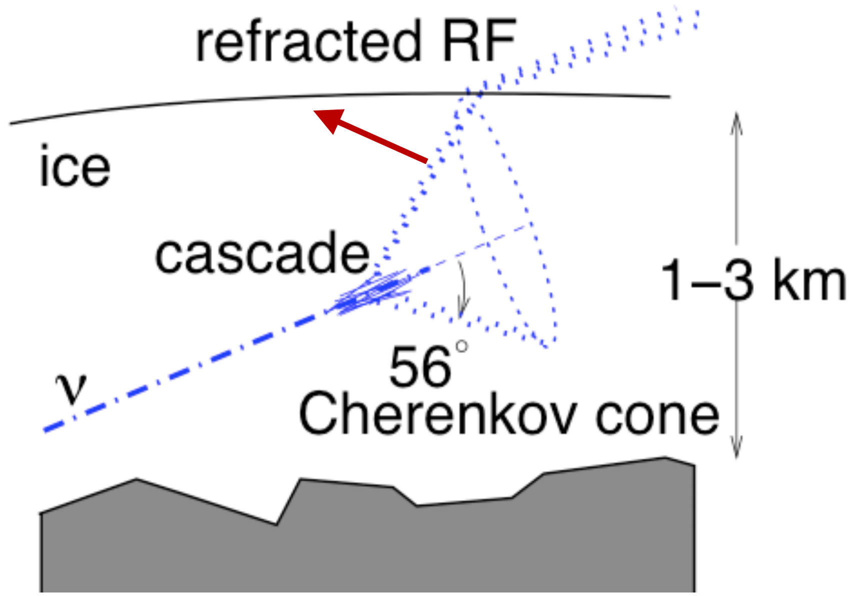
Reducing thresholds - *move left*

- Using complementary features to lower thresholds

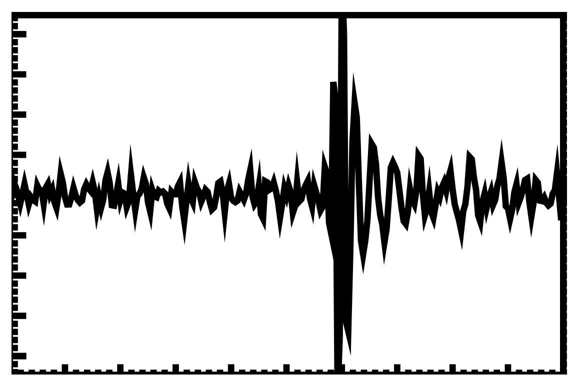
TIMING



POLARIZATION



PULSE SHAPE



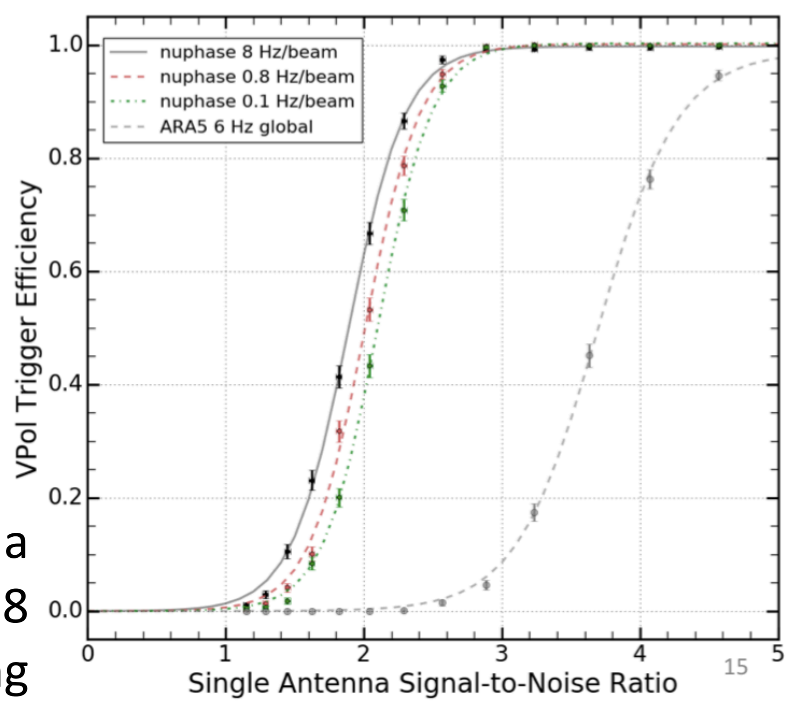
OTHER IDENTIFYING CHARACTERISTICS OF BACKGROUNDS

Phased array

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

- Calculate *summed correlation* in electronics before trigger decision
- Newly deployed in ARA station 5 last season
  - SNR reduction as expected!

Shown by Eric Oberla
ARENA 2018
Paper draft circulating



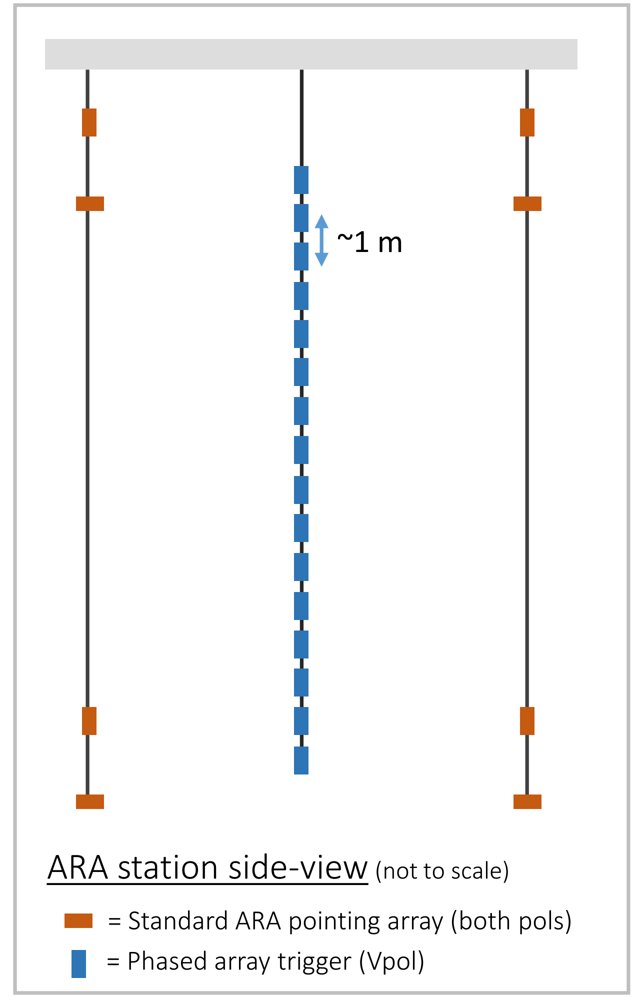


Figure credit: Eric Oberla
Univ. of Chicago

In-ice expansion Next-Generation Radio Array (NGRA)

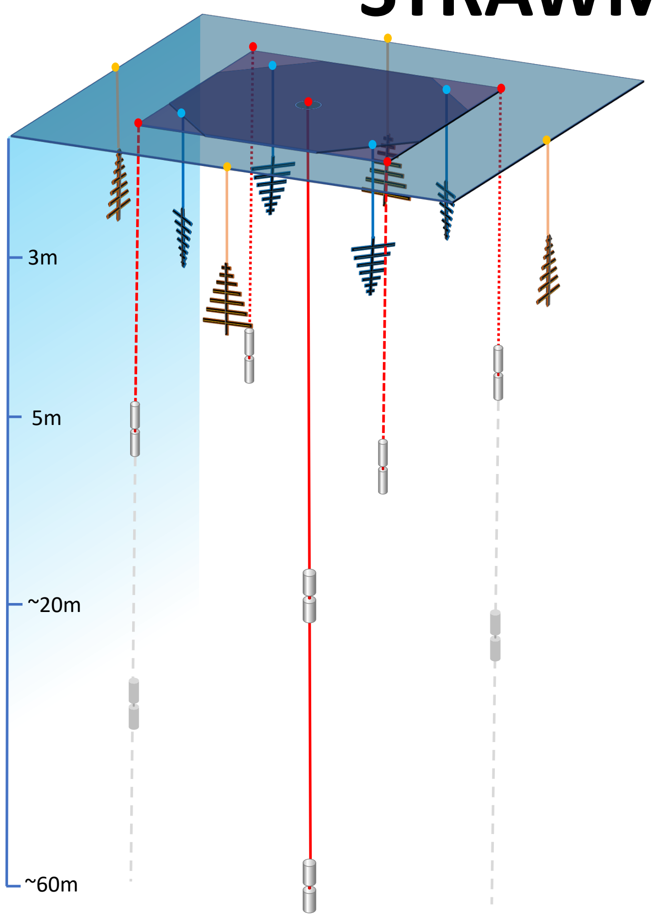
- Folks from existing in-ice arrays have been working together on combined proposed effort
- Intense discussions and optimizations ongoing
- Aiming for fast-approaching Dec 2018 deadline

Science goals for Antarctic Radio In-Ice Array

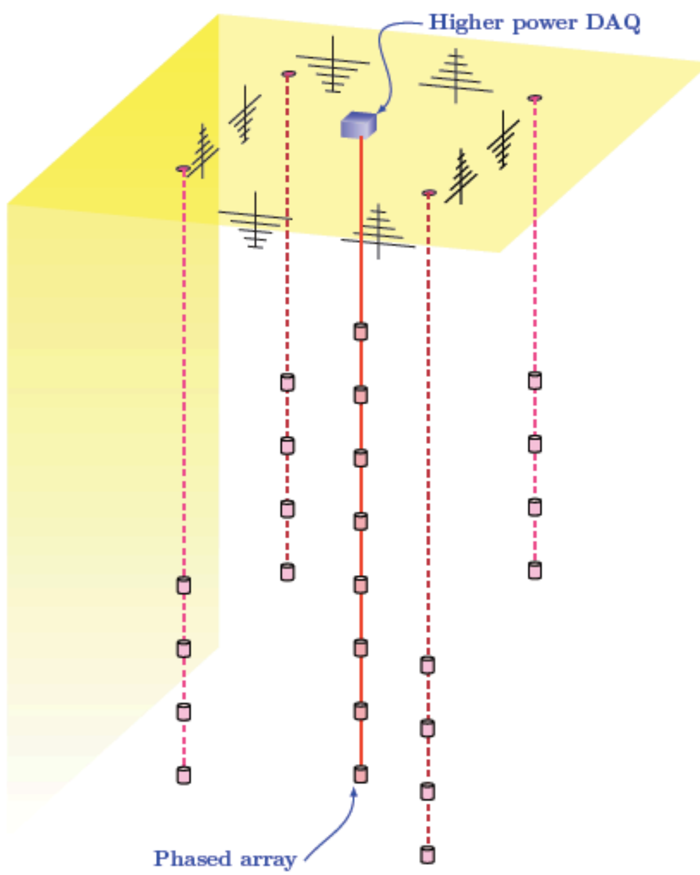
- Science goals two-fold
  - Aim to overlap with IceCube's sensitivity near 10^{16} eV
  - Explore new parameter space across broad energy range up to 10^{20} eV
- CRs:
  - Don't aim for CR physics itself
  - measure CRs as background to neutrino searches
  - validation - observe natural, radio impulses

Next-Generation Radio Array (NGRA) Designs being considered

STRAWMAN



PUNCH

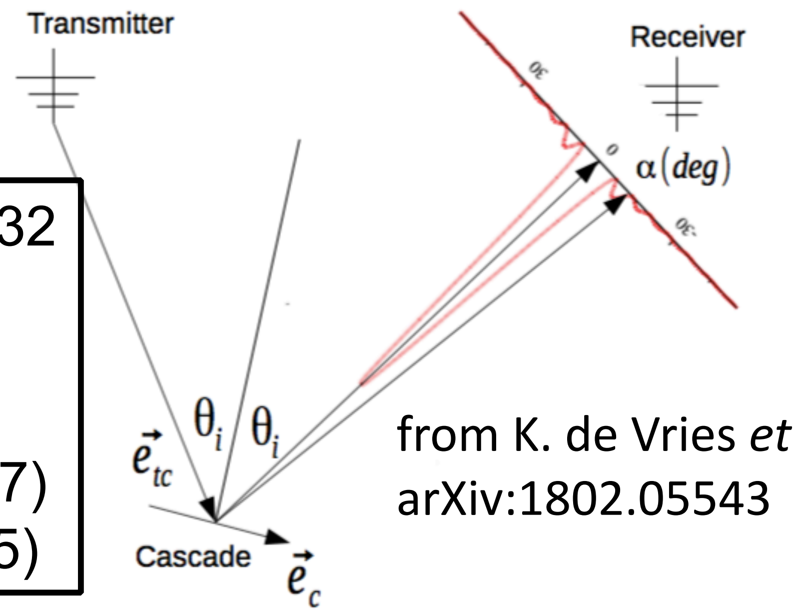


- Prefer to choose one station for uniformity
- Depth up to 100 m
- Simulators working round the clock!

Looking ahead

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

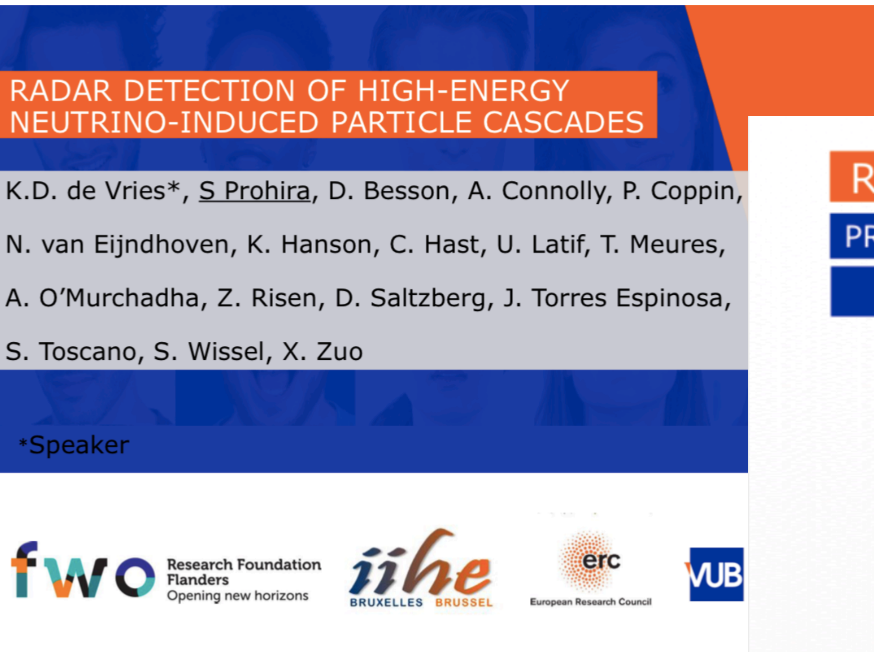
THE OHIO STATE UNIVERSITY

CCAPP

RADAR

- Preliminary results shown at TeVPA

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


RADAR DETECTION OF HIGH-ENERGY NEUTRINO-INDUCED PARTICLE CASCADES

K.D. de Vries*, S Prohira, D. Besson, A. Connolly, P. Coppin, N. van Eijndhoven, K. Hanson, C. Hast, U. Latif, T. Meures, A. O'Murchadha, Z. Risen, D. Saltzberg, J. Torres Espinosa, S. Toscano, S. Wissel, X. Zuo

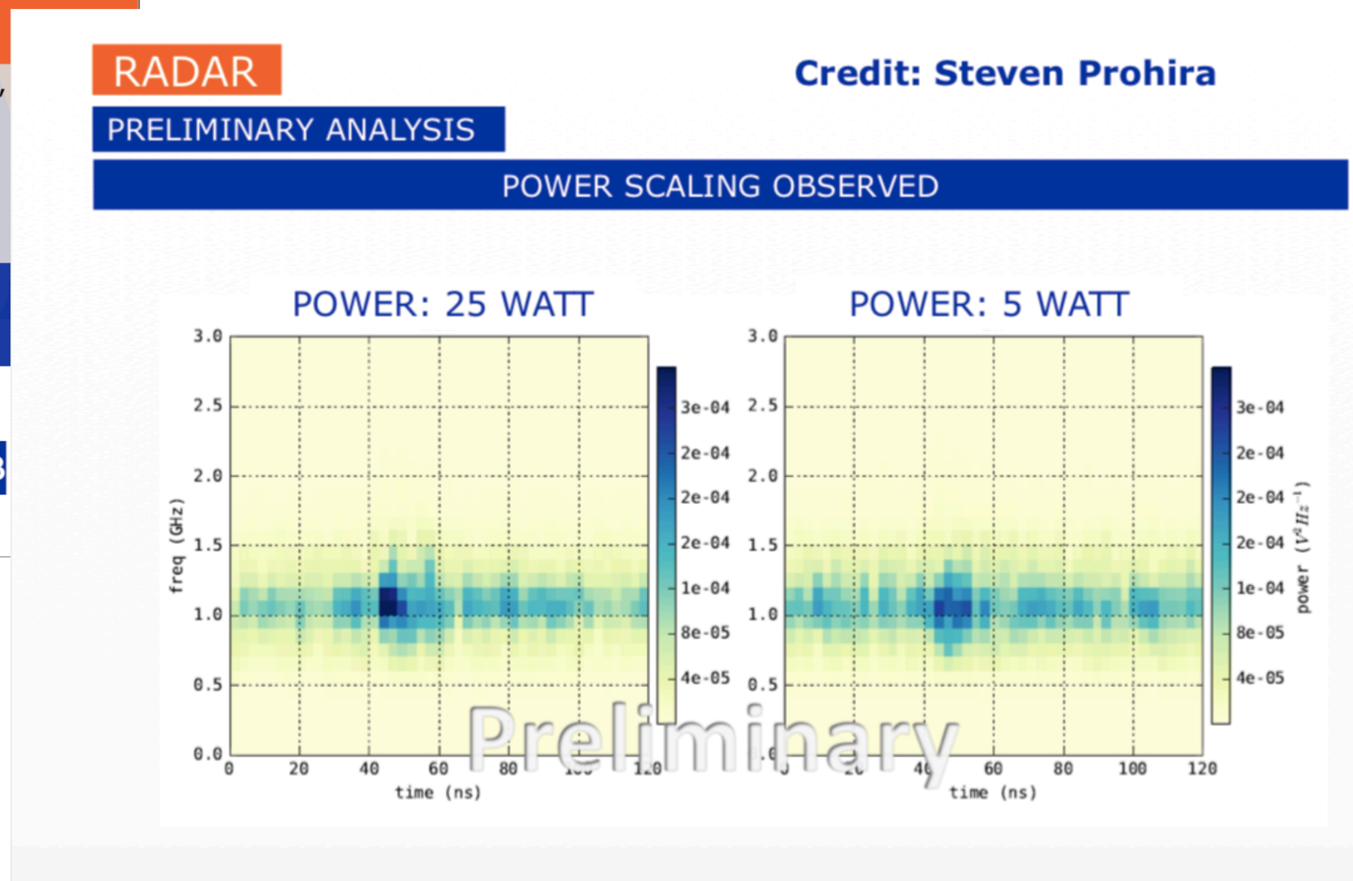
*Speaker

fwo Research Foundation Flanders Opening new horizons

iihe BRUXELLES BRUSSEL

erc European Research Council

VUB



Follow-up test scheduled for Oct. 2018

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

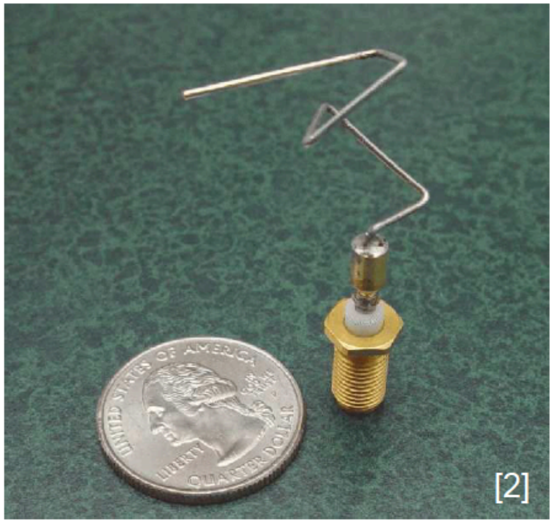
GENETIS Mini-Collaboration Meeting April APS 2018

Heavy involvement from undergraduates

u.osu.edu/connolly/genetis

GENETIS

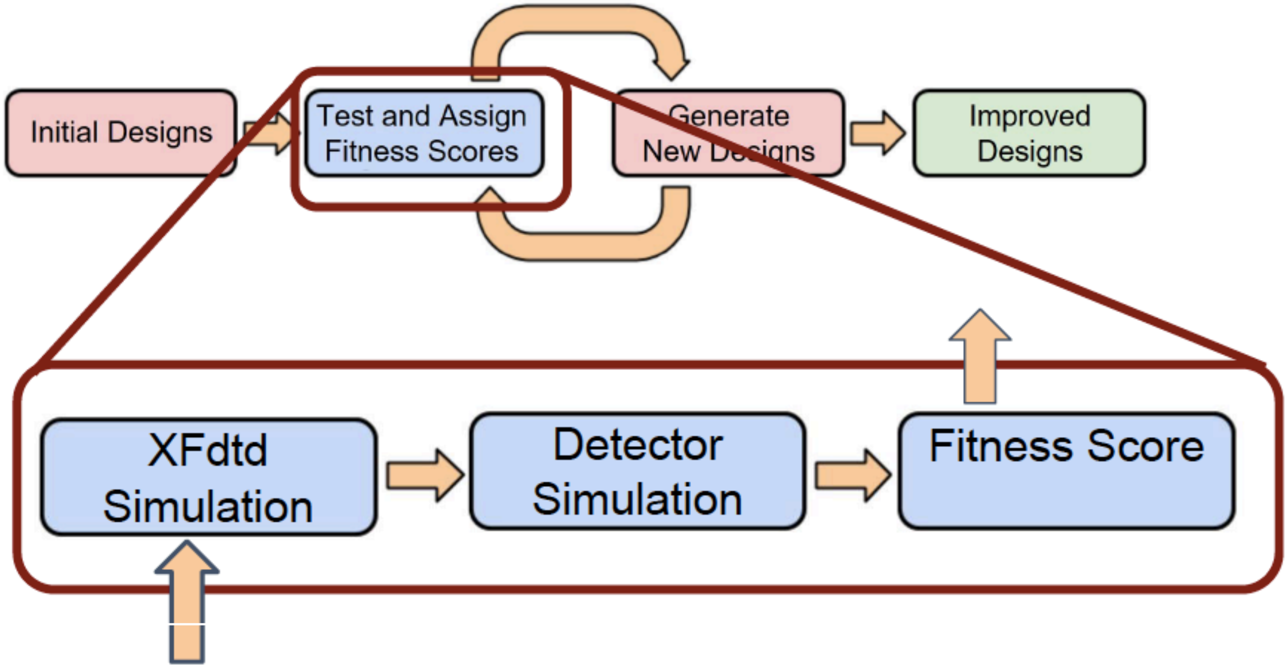
- Lately a growth in genetically evolved antennas (mostly narrow band)


[2]

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

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!

Backup slides