THE OHIO STATE UNIVERSITY

UHE neutrino radio detection, status, and perspectives

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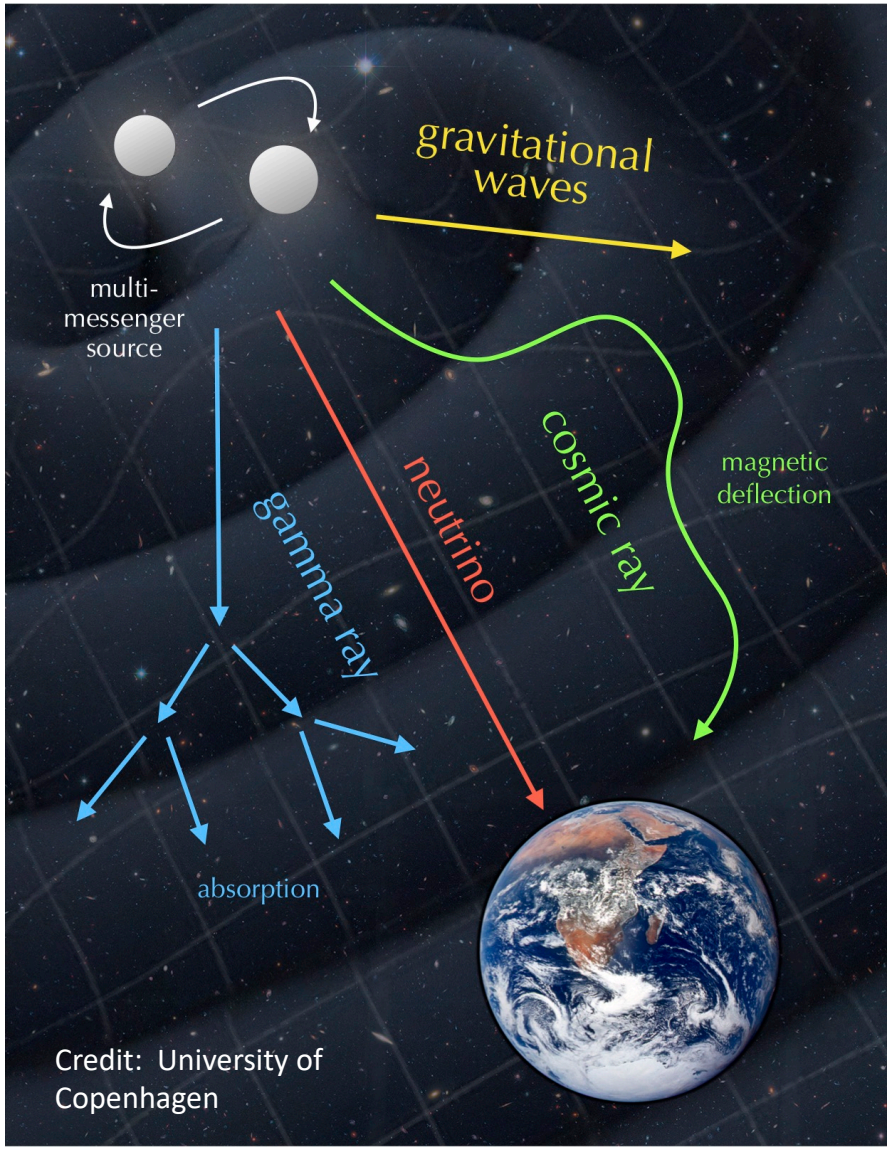
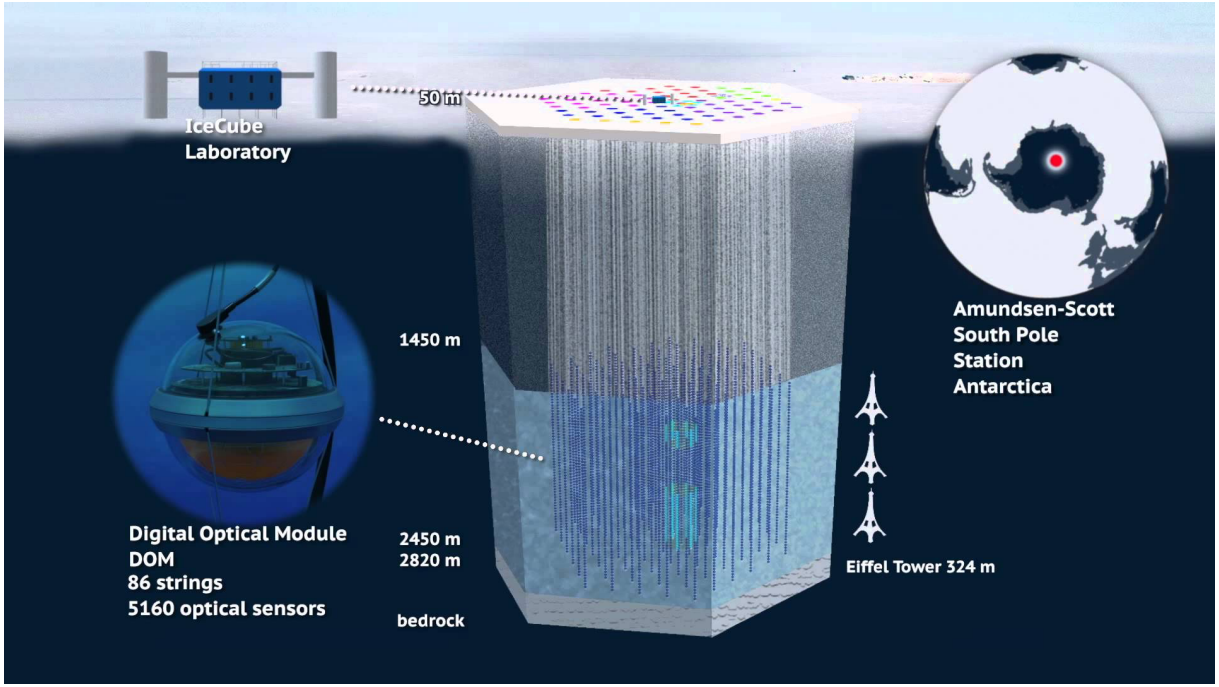
UHE neutrinos - motivation

Multi-messenger astrophysics



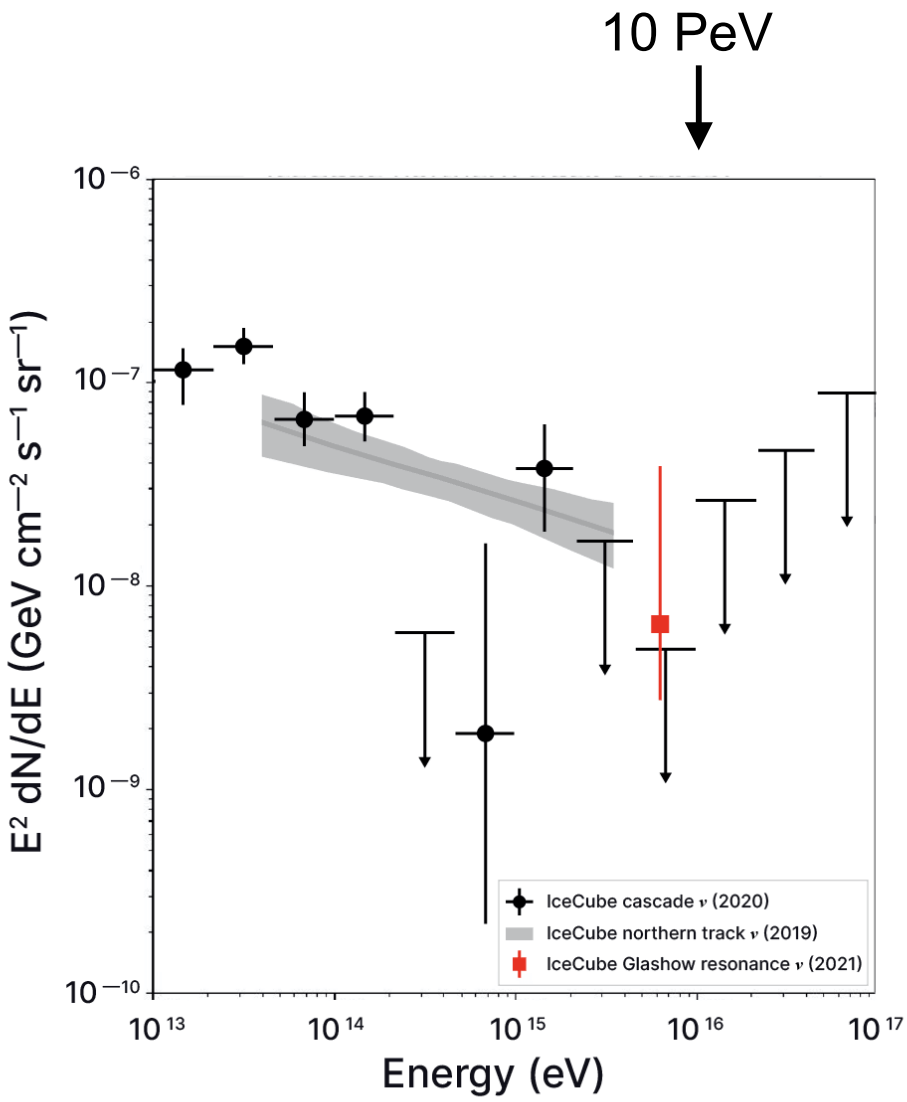
Astrophysical neutrinos

- IceCube observes astrophysical neutrino flux up to O(10 PeV=10^{16} eV)
- Excesses in the direction of three active galaxies



Astrophysical neutrinos

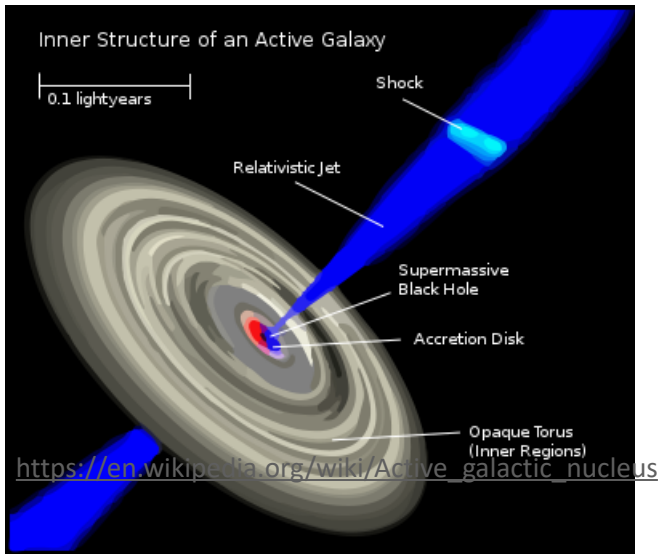
- No neutrinos above ~10 PeV have yet been observed
- Optical technique limits detector scale to O(1 km^3)



https://icecube.wisc.edu/science/research/#neutrinoastronomy

Ultra high energy (>10^{17} eV) neutrinos: candidate sources

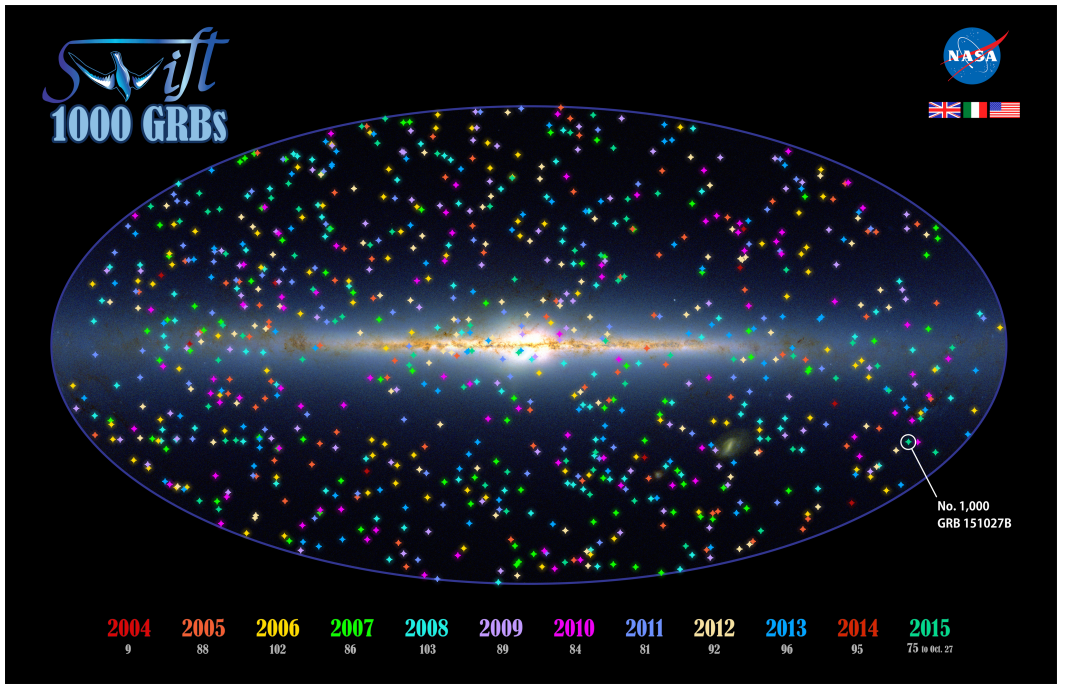
Active Galactic Nuclei (AGN)



- Black hole accreting mass

CRs themselves produce neutrinos *en route*

Gamma Ray Bursts (GRB)



- Star collapse, merger of neutron stars

What can we learn from UHE neutrinos

- UHE neutrinos are the only particles that can reach us with such high energies from cosmic distances
  - What produces them
  - What are the acceleration mechanisms
  - What is the ultimate energy of particles in the universe
- UHE neutrinos probe fundamental physics
  - Test Einstein's equations
  - New physics? ~100 TeV νN interactions

Radio Askaryan emission

- Shower develops 20% charge asymmetry
- Cherenkov-like radiation
- *Coherent* for $\lambda \gg 10$ cm

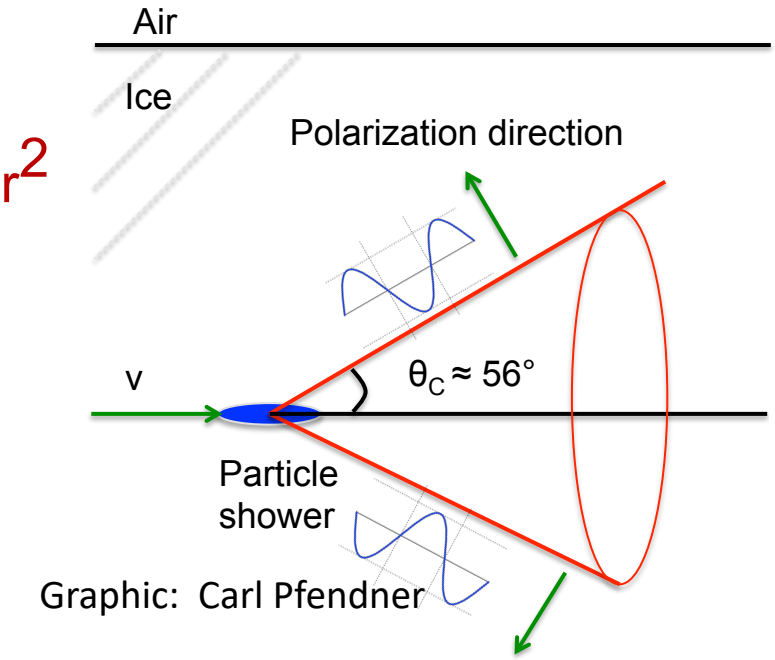
Gurgen Askaryan, 1962

→ **RADIO**

Power$\propto E_{shower}^2$

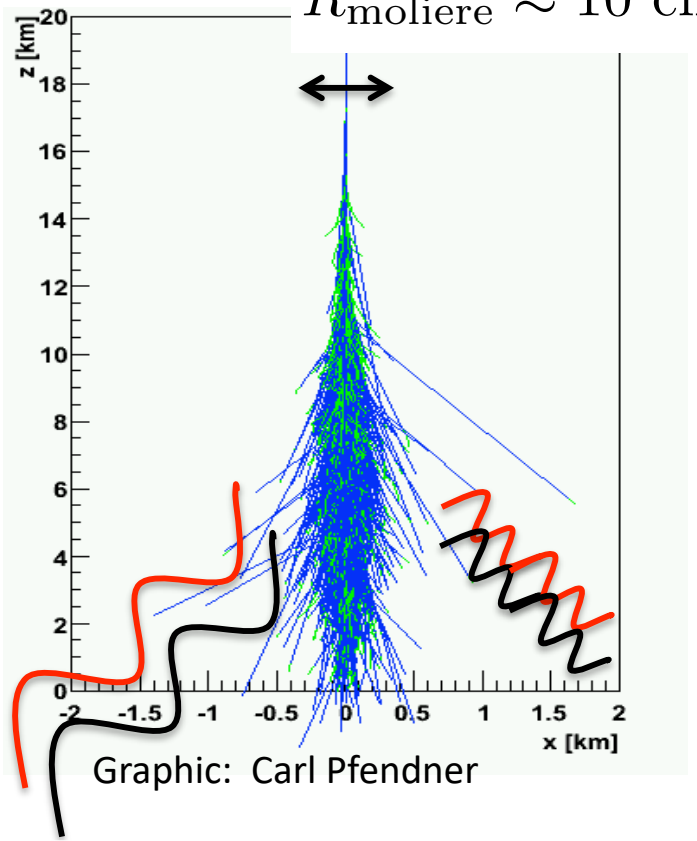
Confirmed experimentally in sand, salt, ice:

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



Graphic: Carl Pfendner

$R_{\text{moliere}} \approx 10$ cm



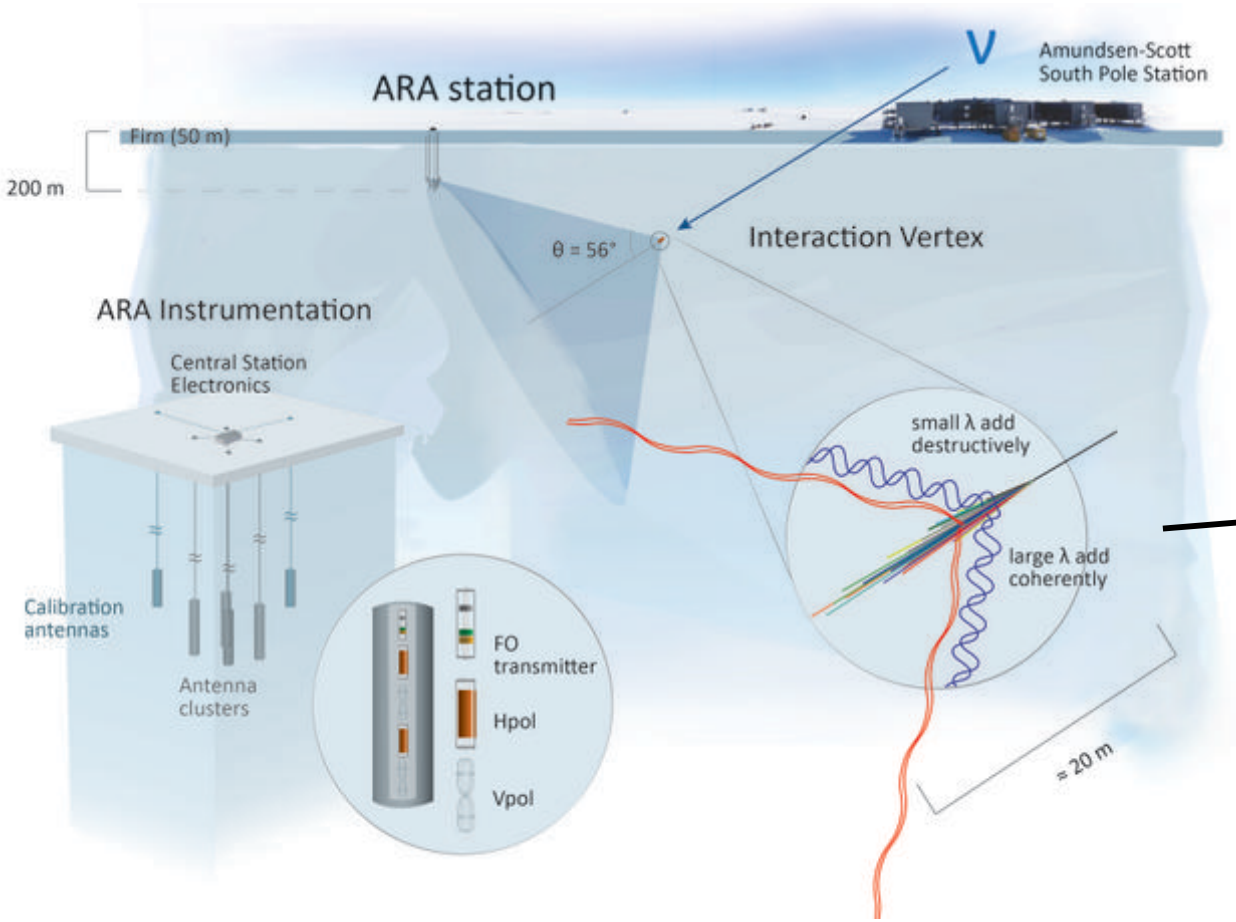
Graphic: Carl Pfendner

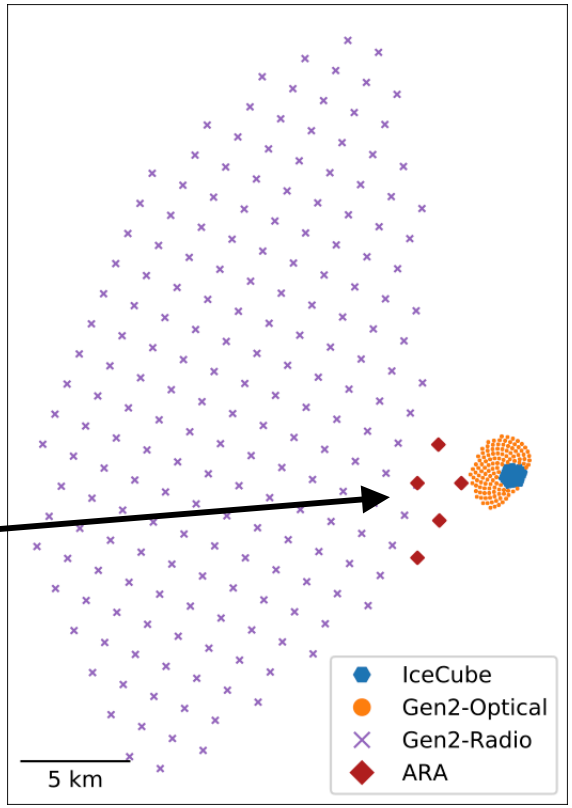
- Pure ice is low-loss for radio: field attenuation lengths ~1 km

UHE neutrino detection strategies

In-Ice Detection Technique

- Close to interactions → low-ish thresholds



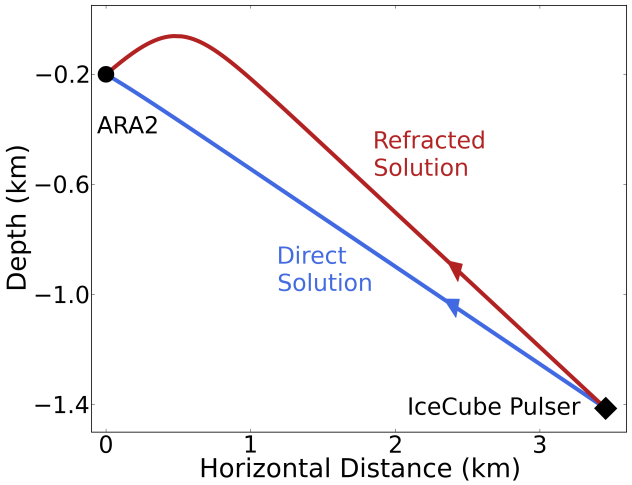


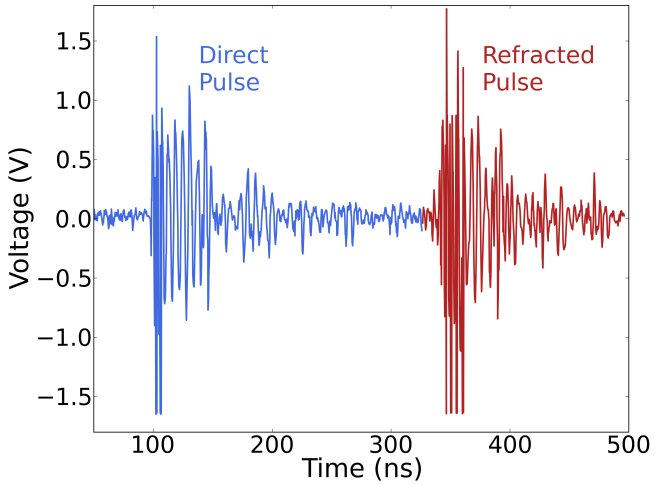
Credit: Brian Clark

ARA - up to 200m depth

ARA

- Neutrino search coming soon - 5-station, >10 years
- Analyzing deep pulses uniquely measured across five stations spanning many km^2 - complexities of ice
- Developing next-generation DAQ ARA-Next
  - RFSoC (radio frequency system-on-a-chip)
  - Many trigger channels





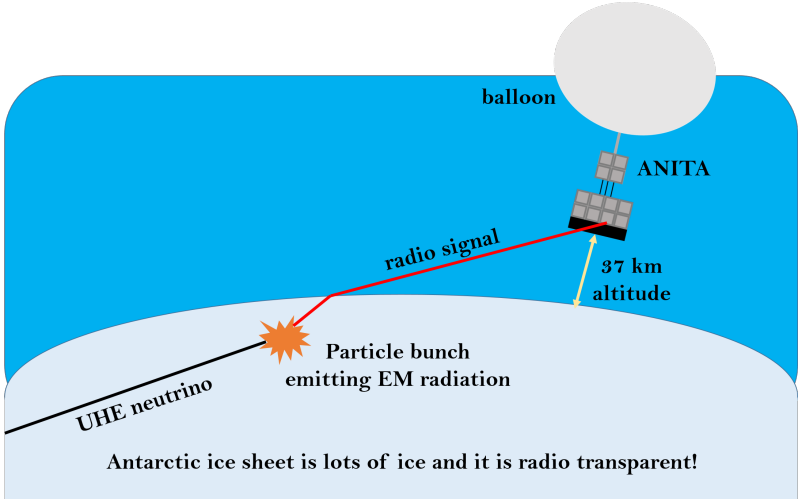
Example signature targeted by ARA-Next trigger

Status and future of in-ice radio projects

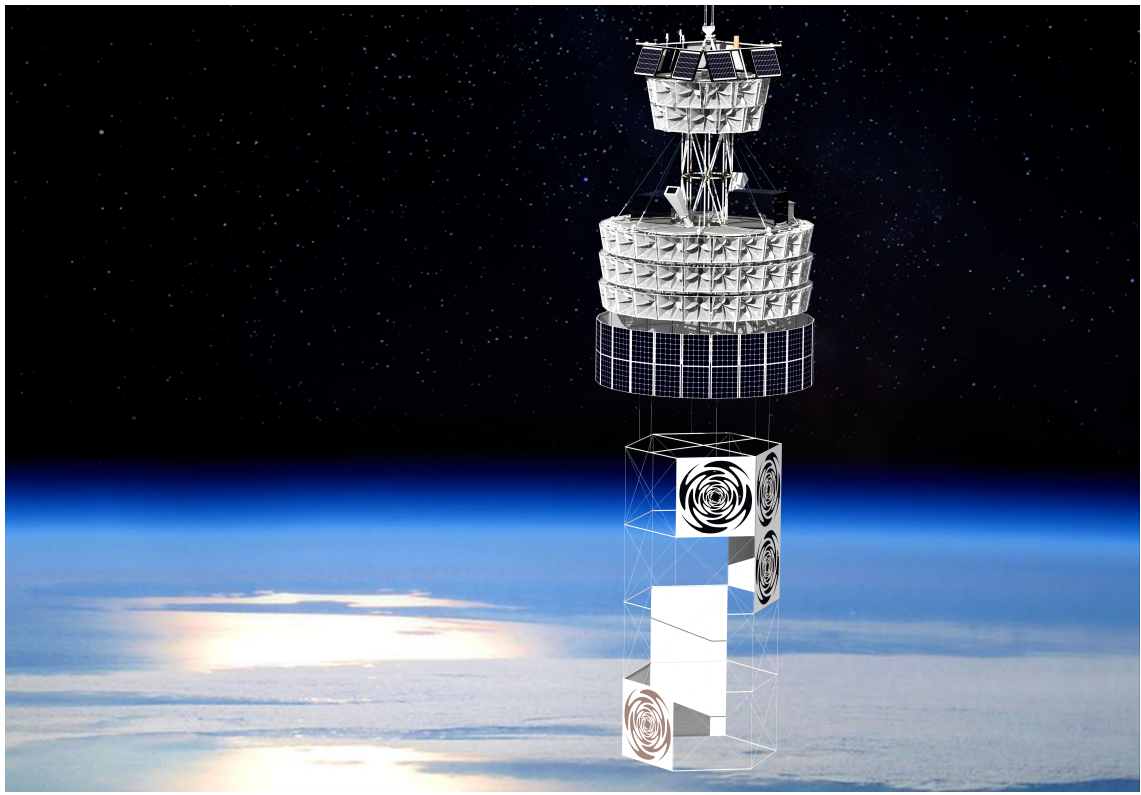
- ARA will continue to play and important role at South Pole
  - World's most sensitive dataset
  - Testbed in South Pole ice
- RNO-G deployed 8 stations so far in Greenland
  - Surface and deep (~100m), different ice
  - View of northern sky
- IceCube-Gen2
  - Next-generation, in planning stages
  - Endorsed by Astro2020 and P5

From above: ANITA / PUEO

- Higher energy threshold, enormous ice volume



Graphic: Oindree Banerjee



PUEO: flight 2025-26

- NASA long-duration balloons launch from McMurdo station
- ~30-day flights in stratosphere

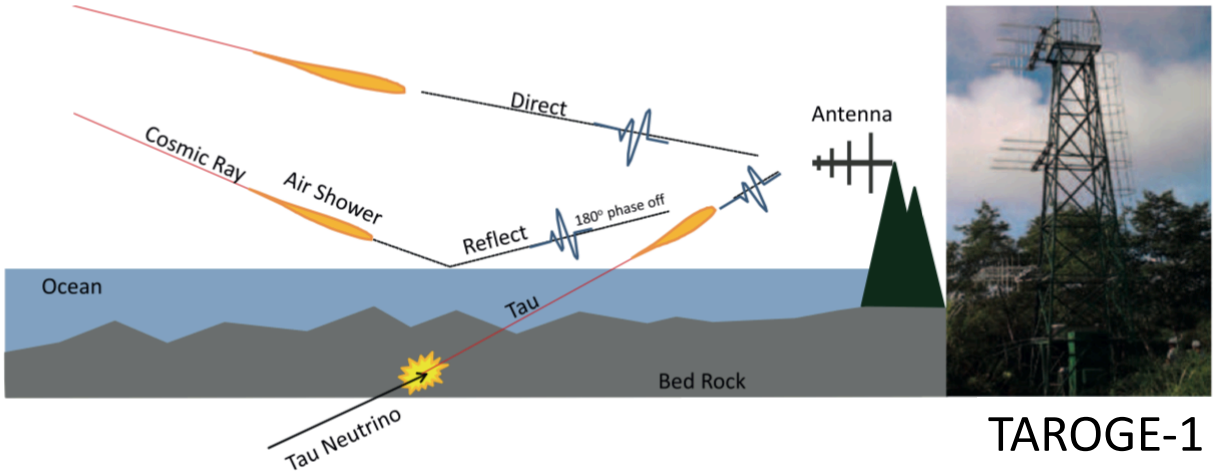
Status and future of balloon

- ANITA four successful flights
  - Established CR radio emission observed from altitude
  - Best constraints on UHE neutrino flux >10^{19} eV
- PUEO 2025-26 Austral summer
  - Threshold-lowering trigger RFSoC-based
  - Low-frequency array dedicated to CR's, ν_τ-induced air showers

Air showers induced by tau neutrinos

- Identifies ν's of one flavor

Particle and Nuclear Physics
93 (2017) 1-68



TAROGE-1

Others -
GRAND
Trinity
TAROGE
TAMBO
EUSO
POEMMA
BEACON

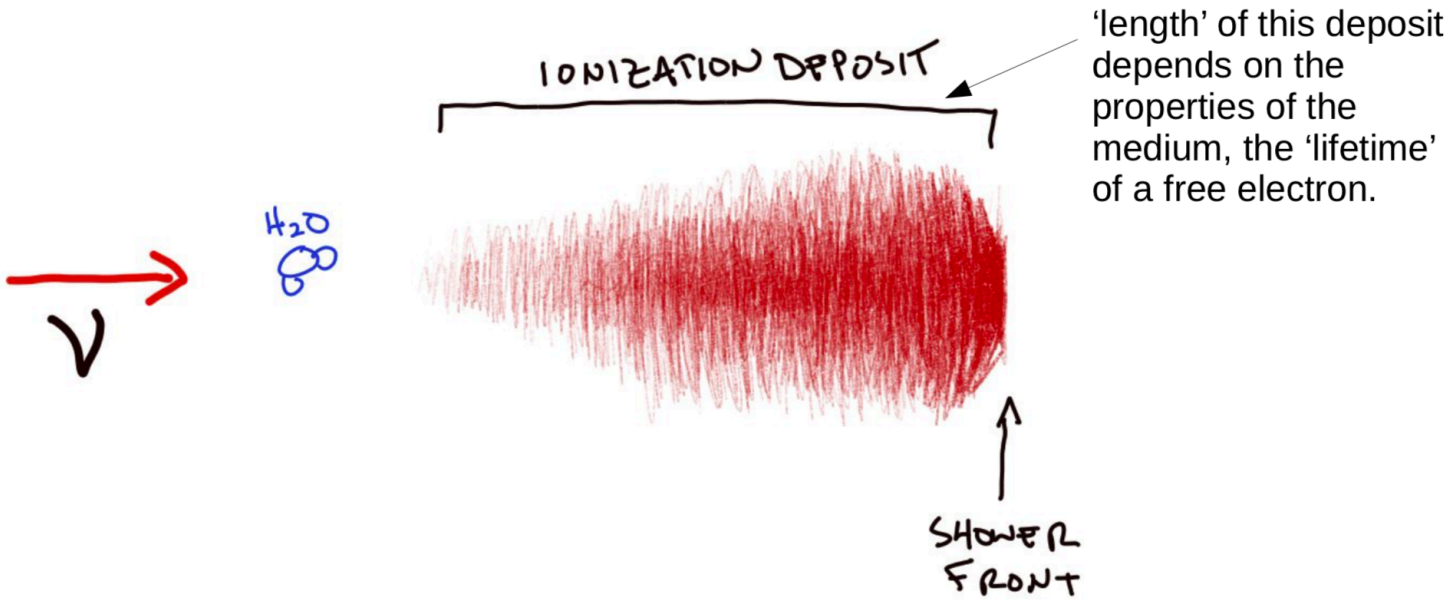
- Auger uses similar mechanism to set strong limits
- ANITA/PUEO also sensitive to this channel

RADAR Technique: RET

- Active rather than passive approach

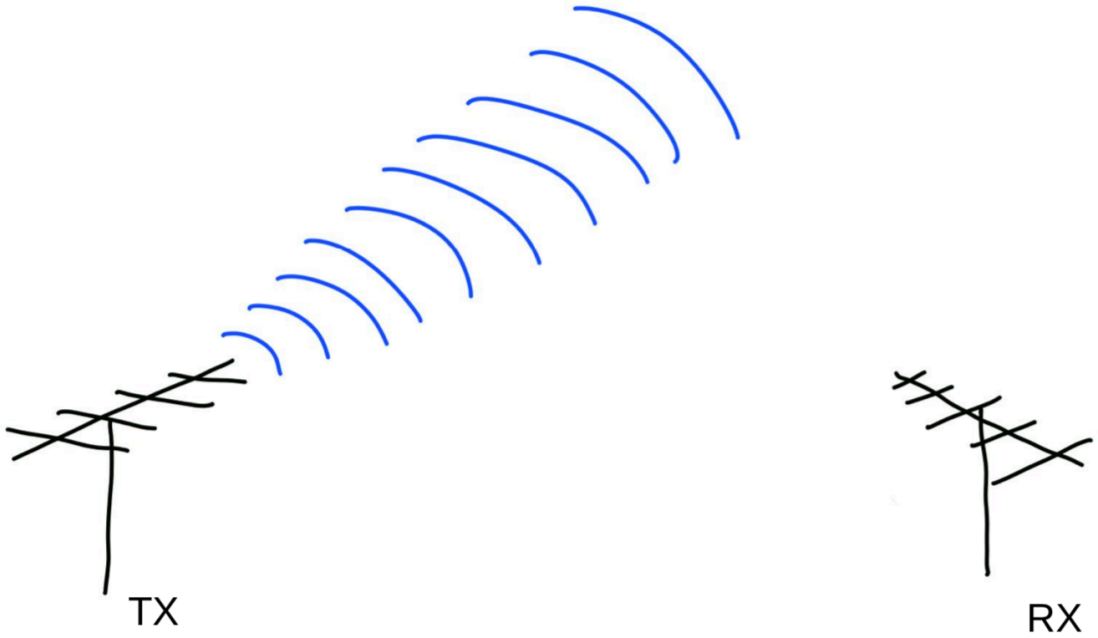
Led by Prof. Steven Prohira, KU
2022 MacArthur Fellow

- high-energy primary interactions create cascades of relativistic particles
- cascade particles *ionize* the material, leaving behind a dense, short-lived cloud of charge



RADAR Technique: RET

Prototype currently being deployed in Greenland

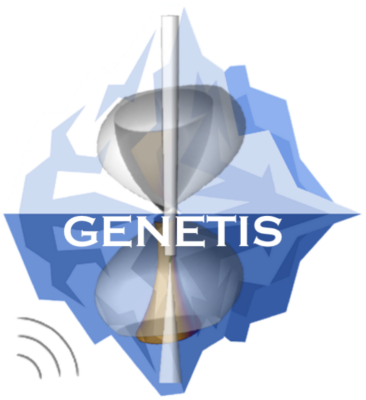


- Transmitter (TX) broadcasts a radio signal into a volume
- receiver(s)(RX) monitor this same volume

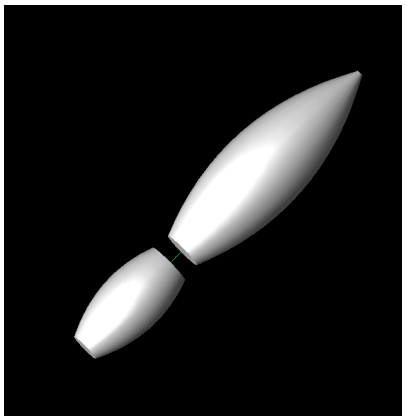
UHE neutrino experiments: summary

- There are many complementary approaches in play for reaching UHE neutrinos
- This strategy is important because
  - UHE neutrinos have not yet been observed
  - Once first UHE neutrino measured, cross-checks and different ways to characterize their properties

Shameless plug - GENETIS



- Growing collaboration using AI for design of instruments for optimal science outcomes
  - Initially using genetic algorithms to design antennas for UHE neutrino experiments
  - Not limited to any of these
- Seeking use cases - array geometries low hanging fruit



An evolved antenna design

J. Rolla et al. [GENETIS Collaboration], Phys.Rev.D 108 (2023) 10, 102002
J. Rolla et al., IPN Report, Volume. 42-237, pp. 1-47, May 15, 2024.

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