The Radio Neutrino Observatory in Greenland (RNO-G): Prospects and status

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KICP 20th Anniversary
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My Time at KICP

- Graduate Student: 2017-2022
- KICP Associate Fellow: 2022-2022
- I am so grateful for my time here at KICP and it’s great to be back!
The Cosmic Ray Mystery

Cosmic Ray Flux

Energy [eV]

Where are the highest energy cosmic rays coming from?

Cosmic ray challenges:

- They don’t point back to their sources due to magnetic fields
- They may interact as they propagate through the universe
What about neutrinos?

Produced from ultra-high energy sources via cosmic ray interactions (p-p, p-γ)

Produced by interactions between ultra-high energy cosmic rays and cosmic microwave background photons (e.g. GZK Mechanism)

“Ultra-high energy” = 10^{15} eV and above
What about neutrinos?

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**Neutrino Pros:**
- Point directly back at their sources
- Capable of traveling extreme distances without interacting

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What about neutrinos?

**Neutrino Pros:**
- Point directly back at their sources
- Capable of traveling extreme distances without interacting

**Neutrino Cons:**
- Capable of traveling straight through the Earth without interacting

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Produced from ultra-high energy sources via cosmic ray interactions (p-p, p-γ)

Produced by interactions between ultra-high energy cosmic rays and cosmic microwave background photons (e.g. GZK Mechanism)
Neutrinos are expected at higher energies.
We need new strategies to look at higher energies.
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Solutions:
1. Wait decades
2. Build many IceCubes, or
3. Try something else
Instead of Optical, try Radio

**Askaryan Radiation:**

- Shower develops negative charge excess
- Coherent radiation for wavelengths > shower width
- Best in dense, dielectric, radio-clear material
- Ice attenuation: **meters** in optical, **kilometers** in radio

Measured in ice, salt, Sand, Atmosphere

ANITA Collaboration, PRL 2006
Expected Neutrino Signatures
**Expected Neutrino Signatures**

**Neutrino Event Signatures:**
- Impulsive
- MHz-GHz range
- Likely originates from deep ice

![Graphs showing reconstruction channels and phased array](image)
Lots of Radio-Based Experiments

Ice-based radio experiments require less instrumented volume than optical experiments

* I collaborate on these
Where were we 20 years ago?

RICE, GLUE, FORTE had best neutrino limits
The RNO-G Collaboration (2024)
First step: pick a site

• Need somewhere with a lot of radio-clear ice

• South Pole can be logistically hard. Are there other options?

• First tests of radio response of ice in Greenland near Summit Station helped inform future designs- a team with lots of KICP ties!
Second step: prototyping

- Typical triggers had focused on power: looking for coincident power within a given time window on multiple antennas

- Instead, try a trigger with power + direction and a compact antenna design

- Define directions ahead of time and try all directions simultaneously

- Plane wave signals will add coherently -> improved trigger efficiency for smaller signals
Second step: prototyping

Abby testing the first iteration of a phased array trigger - Summit Station, Greenland

Me, at the South Pole testing the South Pole iteration of the phased array trigger
Second step: prototyping

- Farther left = More neutrinos
- Farther up = More neutrinos
Second step: prototyping

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ARA: 8 station-years
ARIANNA: 31 station-years
ARA PA: 7 months!

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Flux $E^2\Phi$ [GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$]

Neutrino Energy [eV]

IceCube

ARA
ARIANNA
ANITA I-IV
Auger

- Cosmogenic: UHECR constraints, van Vliet et al
- Cosmogenic: UHECR + pure proton, Muzio et al
- Astrophysical: MMA constraints, clusters, TDEs
Second step: prototyping

ARA: 8 station-years
ARIANNA: 31 station-years
ARA PA: 7 months!

Scaled up prototype:
35 stations x 5 years

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ARIANNA: 31 station-years
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south Pole Prototype

Flux $E^2\Phi$ [GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$]

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IceCube

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Astrophysical: MMA constraints, clusters, TDEs

Allison et. al. (PRD 2022)
Third Step: try building at scale

- Need lots of individual phased arrays to accumulate enough livetime to see the very faint neutrino signal
- Enter the Radio Neutrino Observatory in Greenland (RNO-G): fully funded (!) to reach 35(+) stations
- Three stations deployed in 2021 and four deployed in 2022: seven total!
- This summer, holes for seven more stations will be drilled
A single RNO-G Station

Bird's Eye View

Surface Channels

Recon Antennas

Phased Array

Downhole View

DAQ

20 m

100 m
A single RNO-G Station

Surface Channels

Phased Array

Recon Antennas

Downhole View

100 m

Different polarizations allow the signal to be reconstructed

Hpol

Calibration Pulser

Vpol
A single RNO-G Station

Recon Antennas

Phased Array

Downhole View

LPDAs in Trench

6.0m (from center)

7.5m

9.0m

Surface antennas used as a cosmic ray veto and additional reconstruction tool
Antennas in Action!

VPol + LPDA

HPol

Antenna in deployment hole
Challenge 1: Drilling

- BigRAID drill: electromechanical, designed specifically for RNO-G

- Drilling holes to 100 m takes time; logistically, it’s very hard to drill fast.

- We are getting better at this! Each year, we are improving (and so is the drill)
Challenge 2: Snow accumulation

RNO-G Station from above

RNO-G Station from above - 2 years after deployment
Challenge 3: Daylight

- RNO-G is solar powered-great for building stations many kms from Summit Station
- Downside: can only take data for ~6 months per year
- Wind power is a possible future option
Challenge 4: Human-made noise

Daily Weather Balloon

Commercial Airplanes

- Station 23
- Station 24
- Station 21
- Station 11
- Station 13

Full Flight Path

Time From First Signal [s]
Challenge 5: Calibration

Need < 5 cm error on antenna locations - and a good ice model!
Building towards the future

- RNO-G is currently being constructed and is carefully building tools needed to conduct a neutrino search.

- Currently using cosmic rays to determine instrument performance.

- Lots of advancements have been needed to make this happen, on every front: drilling, antenna design, hardware/firmware, and calibration.

- 35 stations + 5 years of data will make RNO-G sensitive to most optimistic cosmogenic flux models.