The Radio Neutrino Observatory - Greenland (RNO-G)

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on behalf of the RNO-G Collaboration

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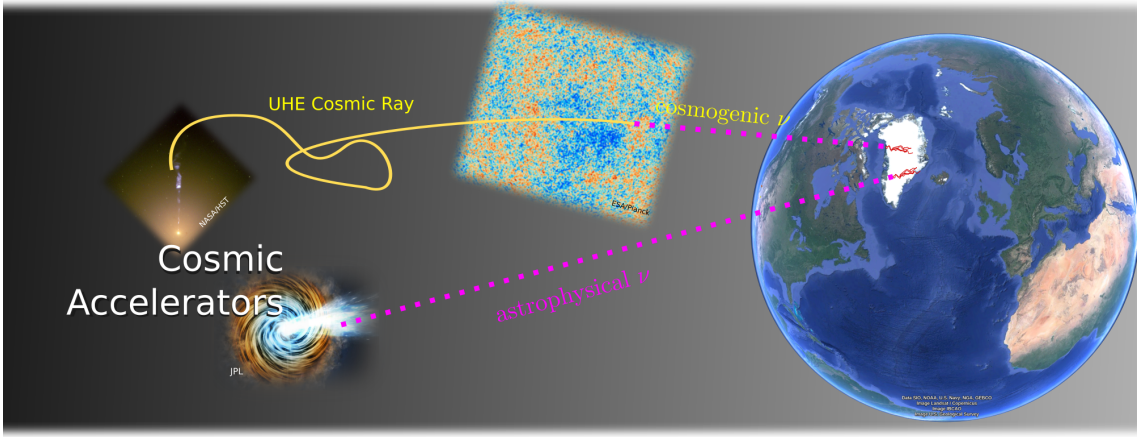
RNO-G Collaboration

The Goal: Detect ultra-high-energy ($\gtrsim$10 PeV) neutrinos

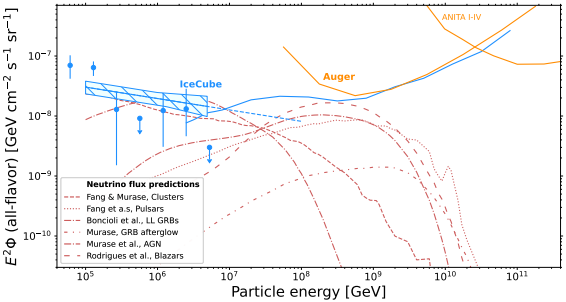
See Abby Vieregg's plenary tomorrow morning for a more detailed treatment!



Neutrinos are the only UHE particle that can travel cosmological distances

Astrophysical Neutrinos

- Neutrinos produced directly in sources
- IceCube has detected a flux up to 10 PeV
  - Source mechanisms still (mostly) unknown
  - May extend up to higher energies
- Plenty of models produce neutrinos at UHE energies



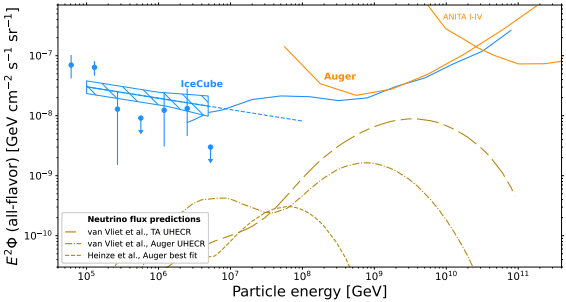
The IceCube data, extrapolated flux, UHE limits, and some astrophysical models (non-exhaustive).

Cosmogenic Neutrinos

- Neutrinos produced from interactions of UHE cosmic rays as they move through the universe
  - e.g. GZK process produces ν's one third of the time

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n + \pi^{+} \rightarrow p + \nu's$$

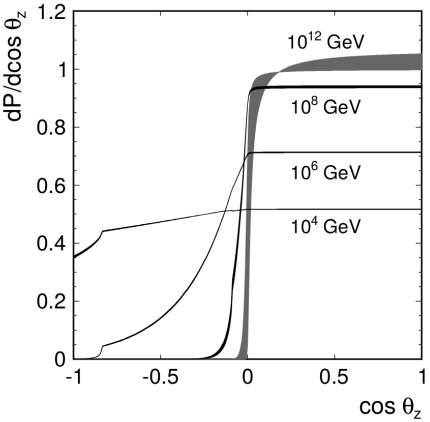
- Must exist, but flux depends on cosmic ray injection spectrum, cosmological evolution of sources, and composition
- UHE Cosmic ray properties (e.g composition) poorly measured and only "locally" (within GZK horizon of ∼100 MPc)



Same as before, but with some cosmogenic models (non-exhaustive)

Particle Physics too?

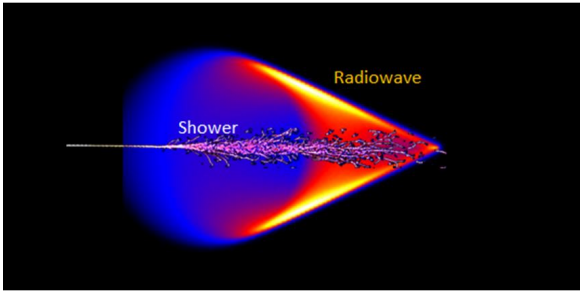
- We can't produce neutrinos at this energy in the lab
- If we detect enough UHE neutrinos, can probe SM in a new regime
  - e.g. can measure cross-section by using earth as spectrometer (since Earth opaque to neutrinos at UHE)

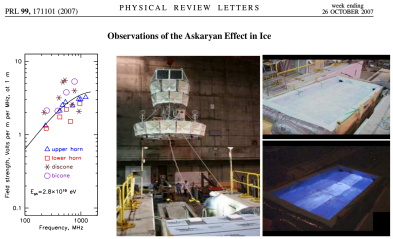


Phys. Rev. D 83, 113009

Enabling Mechanism: Askaryan Radiation

- Natural media optical Cerenkov detectors like IceCube or KM3Net limited by light propagation in media, difficult to scale up
- UHE showers in dense media produce radio emission (Askaryan Effect)
  - Because you have electrons in the media, EM shower develops fast-moving negative charge excess
  - At wavelengths larger than size of the cascade ($\mathcal{O}(10cm)$, i.e. radio) emission becomes coherent!
  - We have (for now) a bountiful natural medium with long radio attenuations lengths (glacial ice)
  - Effect probed in the lab



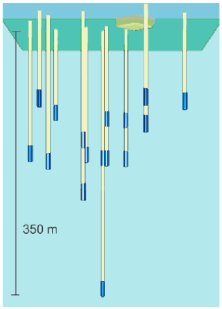


Other ice-based Askaryan ν experiments

ANITA/PUEO*

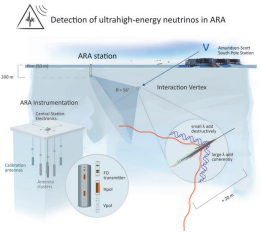
Antennas on a high-altitude balloon over Antarctica.

RICE



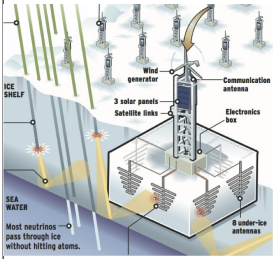
The original in-ice Askaryan experiment (AMANDA piggyback).

ARA*



Deep antennas buried in ice near South Pole

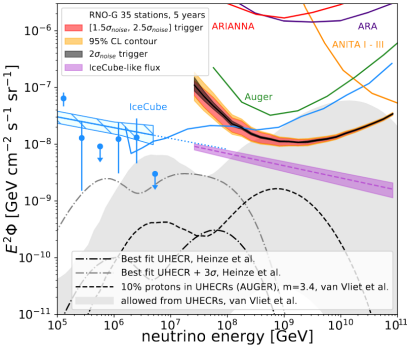
ARIANNA

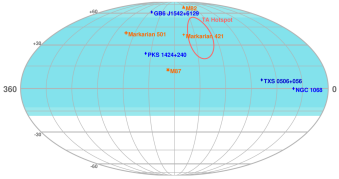


Near-surface antennas on Ross Ice Shelf

*I work on these experiments

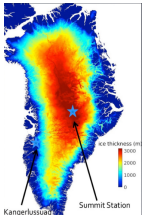
RNO-G Overview

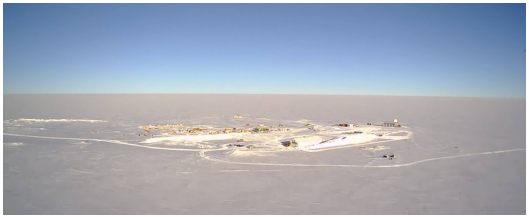




- 35 planned stations near Summit Station, Greenland
  - Deployment began last summer
- RNO-G will soon be the most sensitive UHE Askrayan neutrino detector yet in 100 PeV - 10 EeV
  - Sensitive enough to probe reasonable cosmogenic and astrophysical models
  - The first Askaryan detector in the North (different view of the sky)
- RNO-G is designed to be scalable and to serve as a technology demonstrator for even bigger future experiments (e.g. IceCube-Gen2Radio)

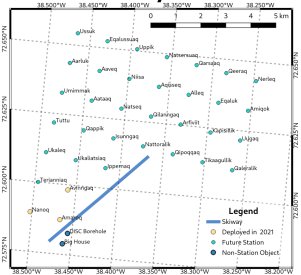
Summit Station site

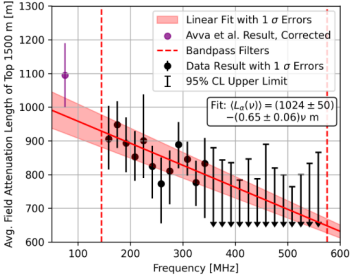




- NSF station at apex of Greenlandic ice sheet
- Ice is over 3 km thick
- First RNO-G result: an updated ice attenuation length measurement!

RNO-G Planned Layout

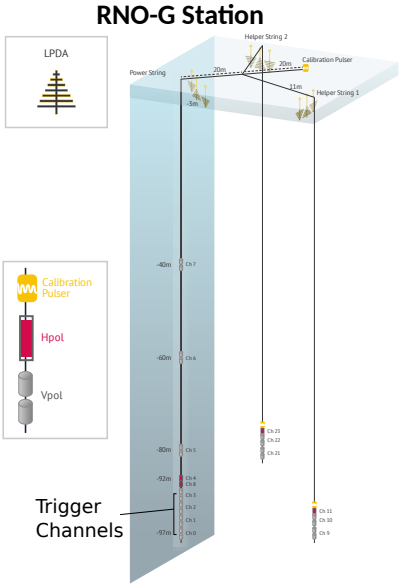




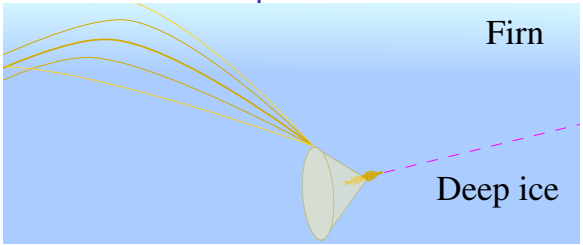
arxiv:2201.07846

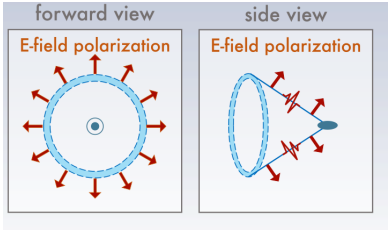
RNO-G Design

- Combination of deep (like ARA) and shallow (like ARIANNA) antennas, 24 ch total
- Key Detector features
  - A deep phased-array trigger used as main neutrino trigger
  - Additional deep antennas to reconstruct events that are triggered
  - A shallow array of antennas. Some are pointing up, as a cosmic ray veto
    - ★ Cosmic-ray air showers also produce impulsive radio emission
- Autonomous power and communication
  - Solar power for now (turning off during polar winter), eventually wind too
  - LTE and LoRaWAN comms (we deployed perhaps the world's most isolated LTE network)



Why Shallow and Deep Antennas?

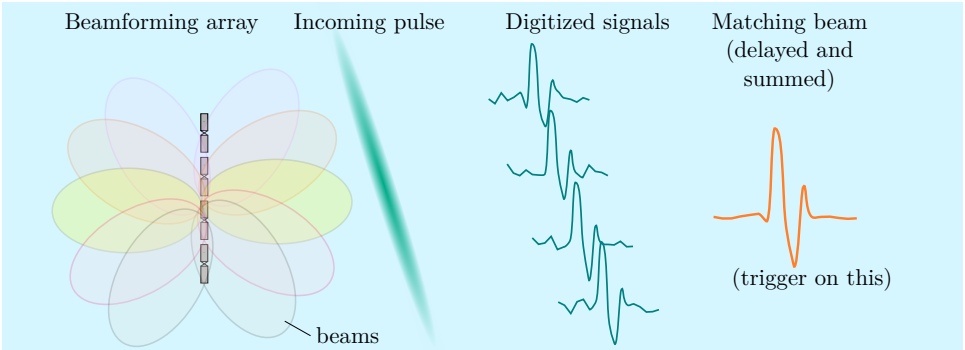




- Deploying antenna near ice surface is simpler, and allows use of higher-gain (more directional) antennas to improve sensitivity
  - And easier to measure multiple polarizations compared to in a borehole due to fewer geometry constraints.
  - Polarization helps reconstruct neutrino direction from emission pattern
- But, the top layer of ice (the "firn") has a density/index of refraction gradient, which shadows the view of much of the ice
- By drilling 100 m to the bottom of the firn, increase the "collecting area"
  - Improved sensitivity and also sky coverage

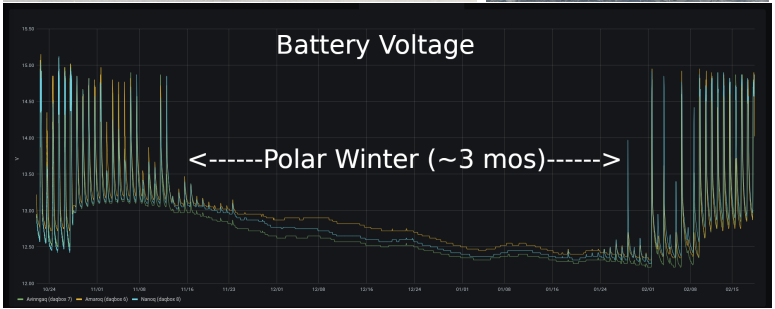
The RNO-G Phased Array Trigger

- We can't fit high-gain antennas down a borehole :(
- But we can synthesize multiple high gain antennas from several low-gain antennas
- Phased array trigger: Take multiple antennas and combine signals with time delays to enhance certain directions (beams), then trigger on the beam
  - Technique demonstrated at South Pole with Askaryan Radio Array (see arXiv:1809.04573, arXiv:2202.07080)
- In RNO-G, the 4 VPols will serve as the primary trigger

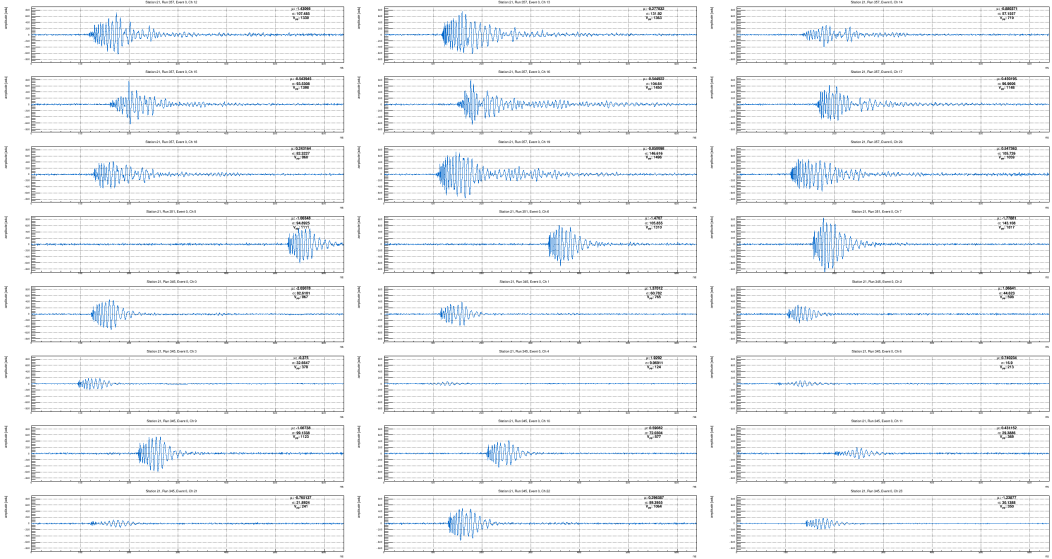


The First Year (2021)

- Deployed the first 3 stations last summer
- Also supporting infrastructure (LTE network, computing, etc.)
- Not competitive for science yet, but learning a lot about how to operate and iterating on some design details
- Stations survived hibernating over winter!

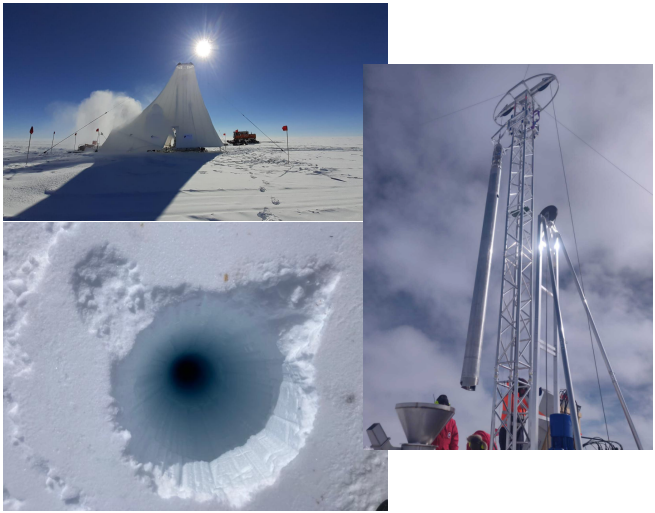


Example Event (surface calibration pulse sent through LPDA)



This Season (2022)

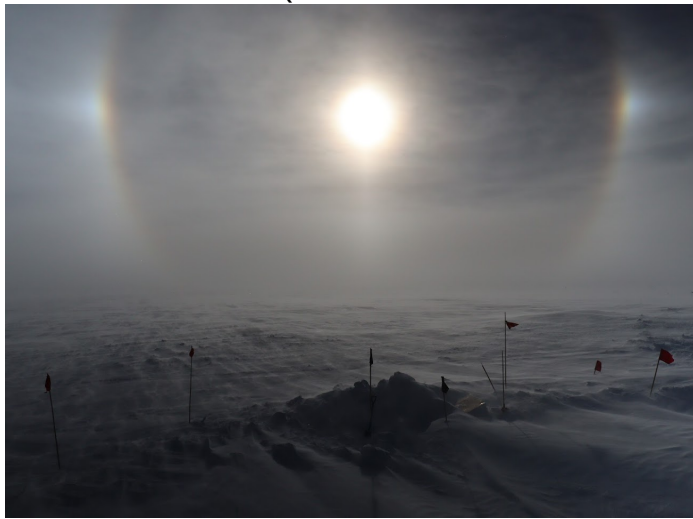
- Drilling team has been at Summit for several weeks to start drilling holes for this season
- Deployment team arriving... today (?)
- Will deploy up to 6 stations this season (depending on weather, etc.)
- Additional ice calibration campaigns



Conclusion and Outlook

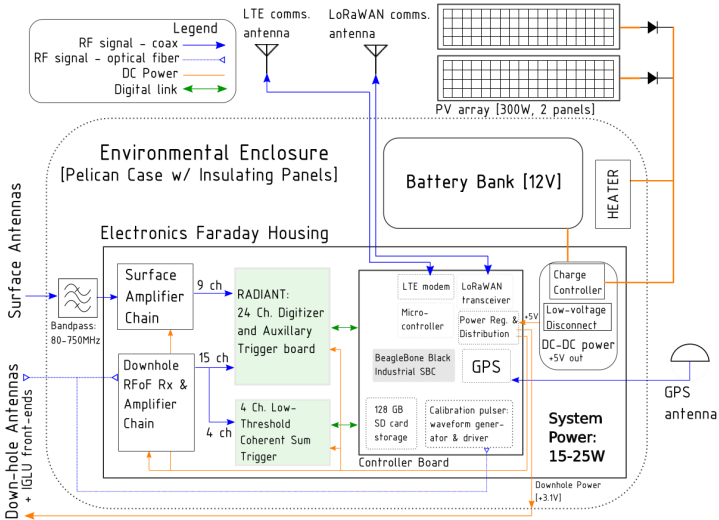
- RNO-G is a new radio array targeting UHE neutrinos being deployed in Greenland
- RNO-G will be the largst and the most sensitive detector in its energy range (100 PeV - 10 EeV).
- Deployment has started, planned full array completion in several years
- RNO-G will also serve as a scalable technology demonstrator for future even larger radio arrays (e.g. IceCube Gen2Radio)

Questions?



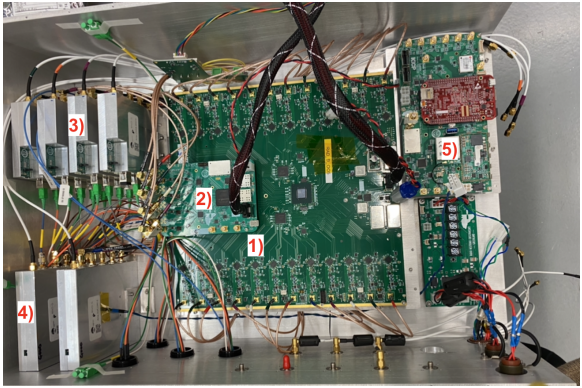
Backup Slides

System Diagram



Station Electronics

- Lots of custom electronics to achieve our goals in a $\sim$ 20W envelope
  1. "RADIANT": 24-channel main digitization board (RNO-G band is 100 MHz-800 MHz) using LAB4d switched-capacitor array digitizers
     - ⋆ Also auxilliary trigger (using diode square-law detector)
  2. "FLOWER": 4-channel streaming digitizer board, used for phased array trigger
  3. RF over fiber receivers for downhole channels
  4. Low-noise Amplifiers for surface channels
  5. Controller board
     - ⋆ Single board computer + control microcontroller + GPS (for timing) + Comms



Antennas

- Shallow: LPDA's in multiple orienattions
- Deep:
  - Fat dipole for Vpol
  - Slot antenna for HPol

VPol + LPDA (+students)

Hpol