# The Radio Neutrino Observatory in Greenland (RNO-G)

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For the RNO-G Collaboration

[XX International Workshop on Neutrino Telescopes](#)
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RNO-G
Radio Neutrino Observatory - Greenland

WISCONSIN
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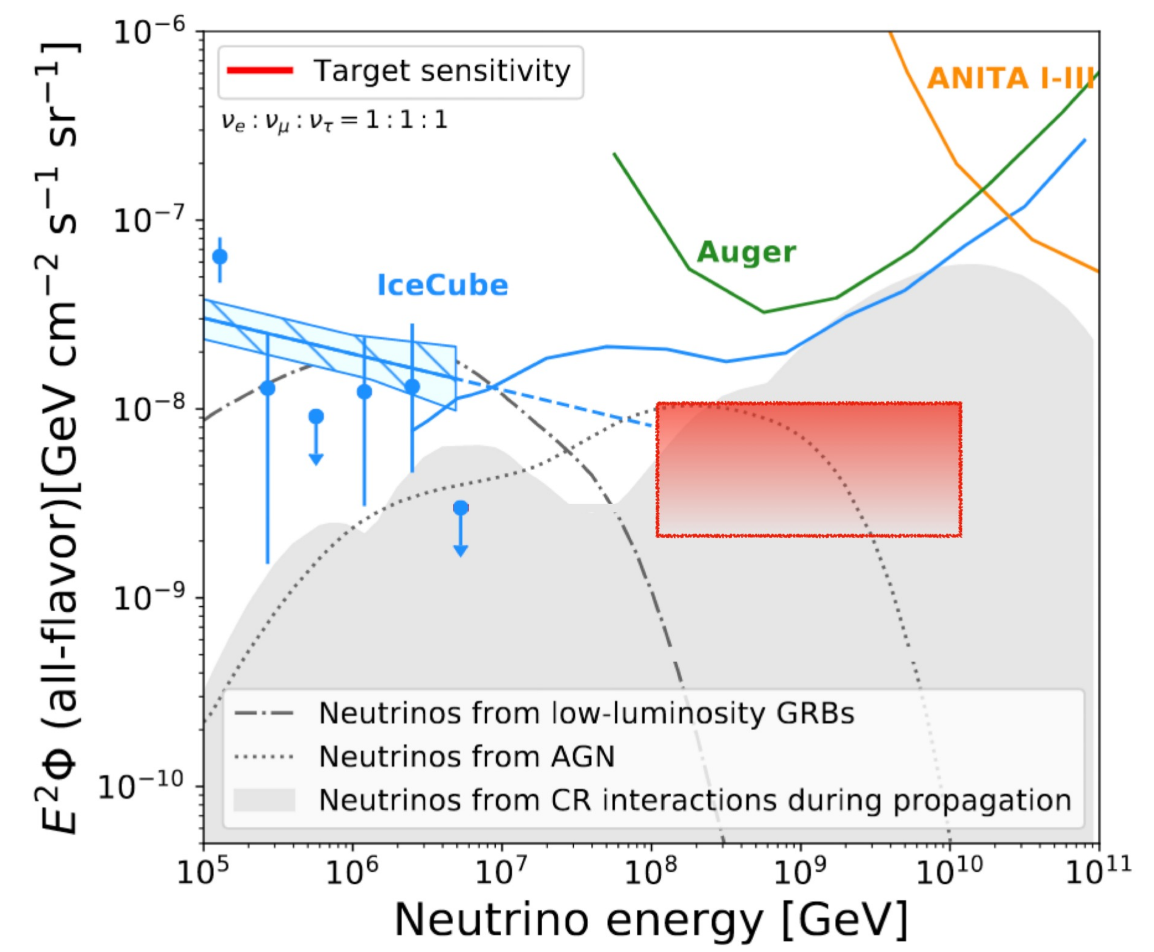
# Hunting for ultra-high energy neutrinos

- Neutrino flux decreases steeply with increasing energy
- ≥10 PeV  we expect O(1/km$^2$/year) neutrinos
- No neutrinos detected at these energies
- Measuring the flux of ultra high energy neutrinos requires detectors with volumes much larger than IceCube & other currently operating neutrino detectors
- Optical detection over such a large volume is cost prohibitive

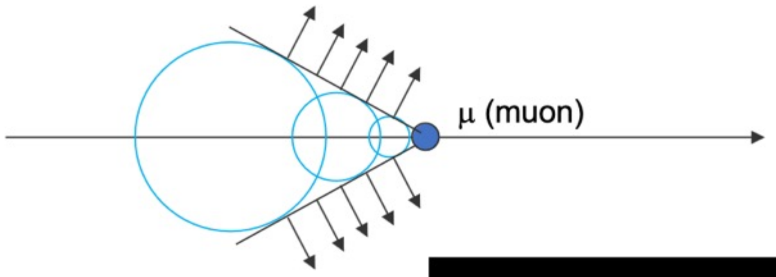


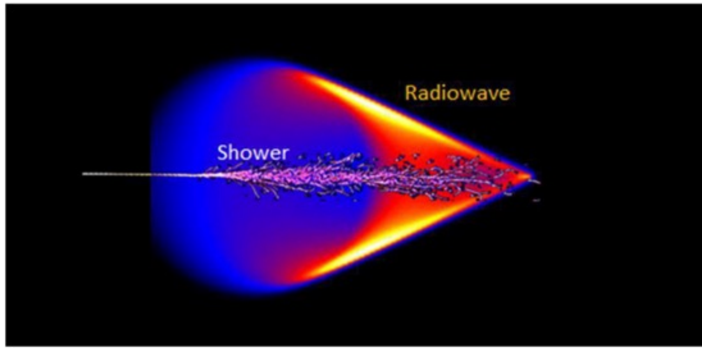

Astro2020 White Paper, arXiv:1903.04334 (modified)

# The Askaryan Emission

*More details in the next talk*
*by Felix Schlüter*

- Cherenkov radiation is generated by particles moving faster than the light speed in medium
- Effect commonly used for particle detection and reconstruction, in experiments in water and ice




*https://lecospa.ntu.edu.tw/experiment-2/experiment-i-ultra-high-energy-neutrinos-and-cosmic-rays/*

- At very high energy, the radiation is boosted
- Electrons/Positrons are created in the particle shower; the positrons annihilate with matter, creating a charge anisotropy
- Charge anisotropy propagates in a dielectric medium creating Cherenkov radiation that sums coherently in the radio bandwidth (“Askaryan radiation”)
- Demonstrated at SLAC national lab in 2006

*https://arxiv.org/pdf/hep-ex/0611008.pdf*

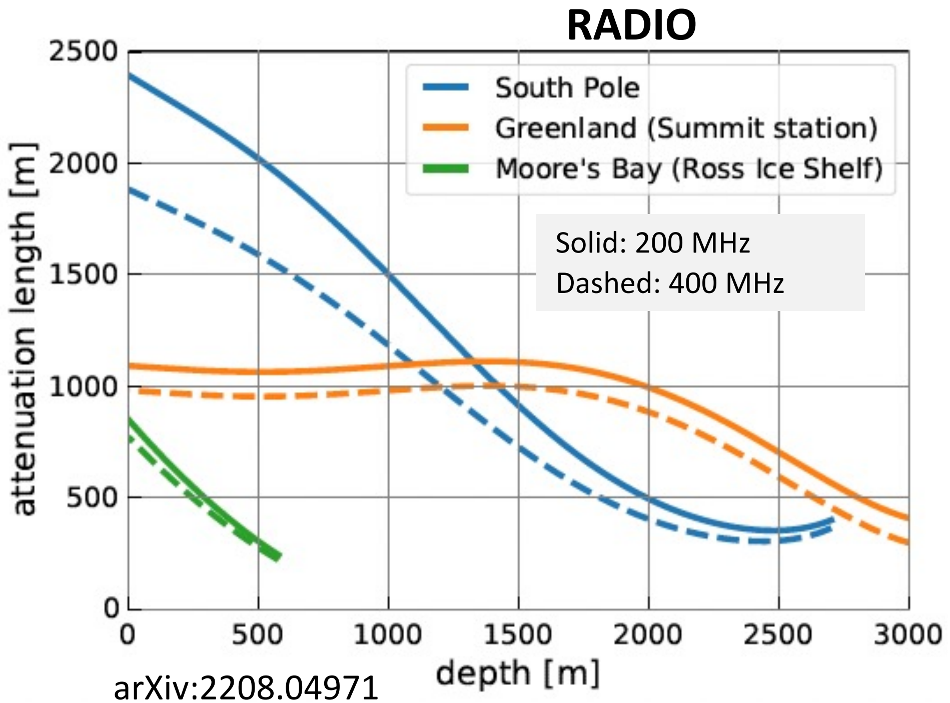
# Absorption

Ice is transparent to electromagnetic waves, in the optical and even better in the radio range

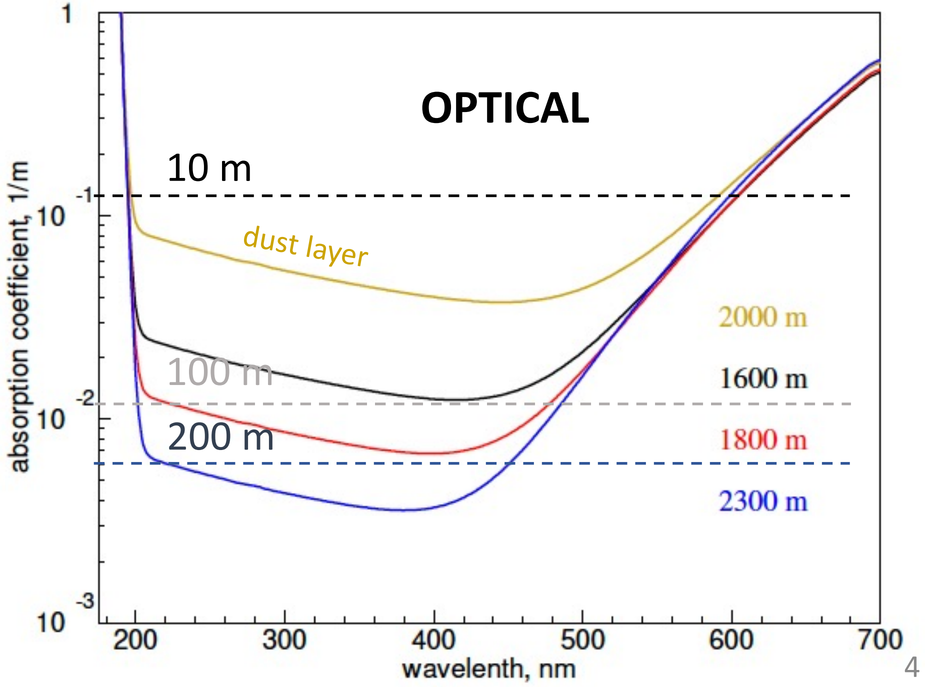
- In radio, the attenuation length is O(1-2 km) at shallow depths in the relevant frequencies, just below the firn (depends on temperature and chemical composition)
  - A radio detector can be "shallow", and the instrumentation can be spaced O(1-2km)

In comparison:

- The absorption coefficient in the UV is O(100-200m) at 2km depth in South Pole ice
  - At shallower depths, bubbles increase scattering/absorption considerably
  - An optical detector needs to be deep, and instrumentation needs to be spaced O(100-200m)




arXiv:2208.04971

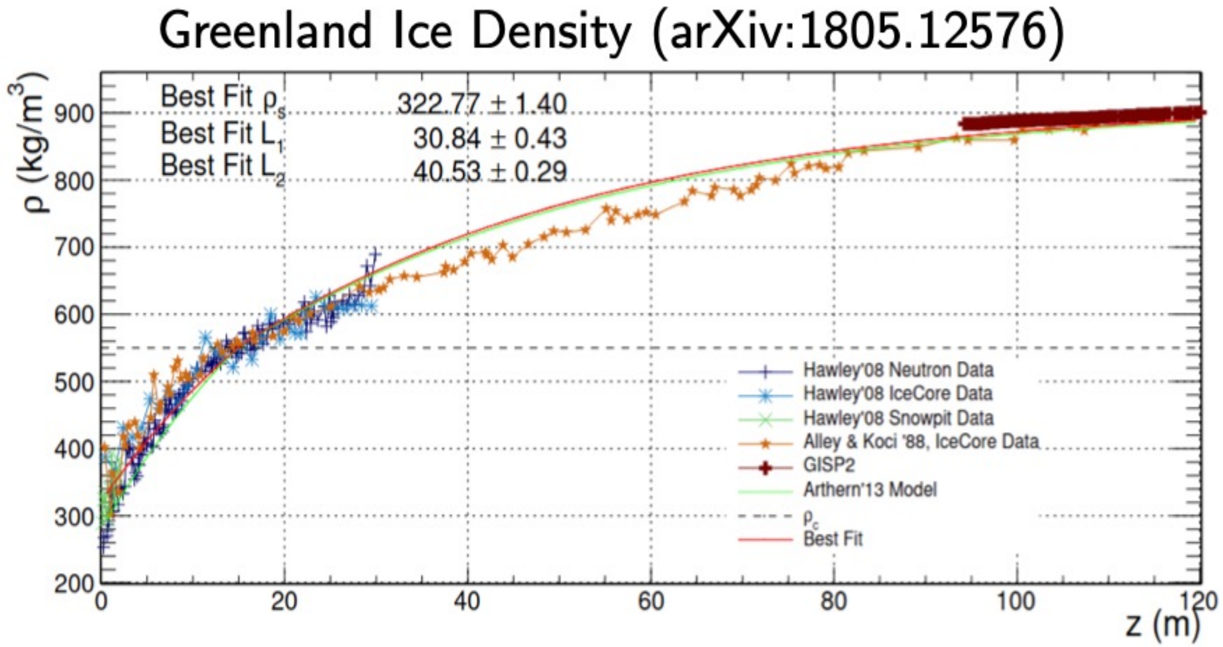


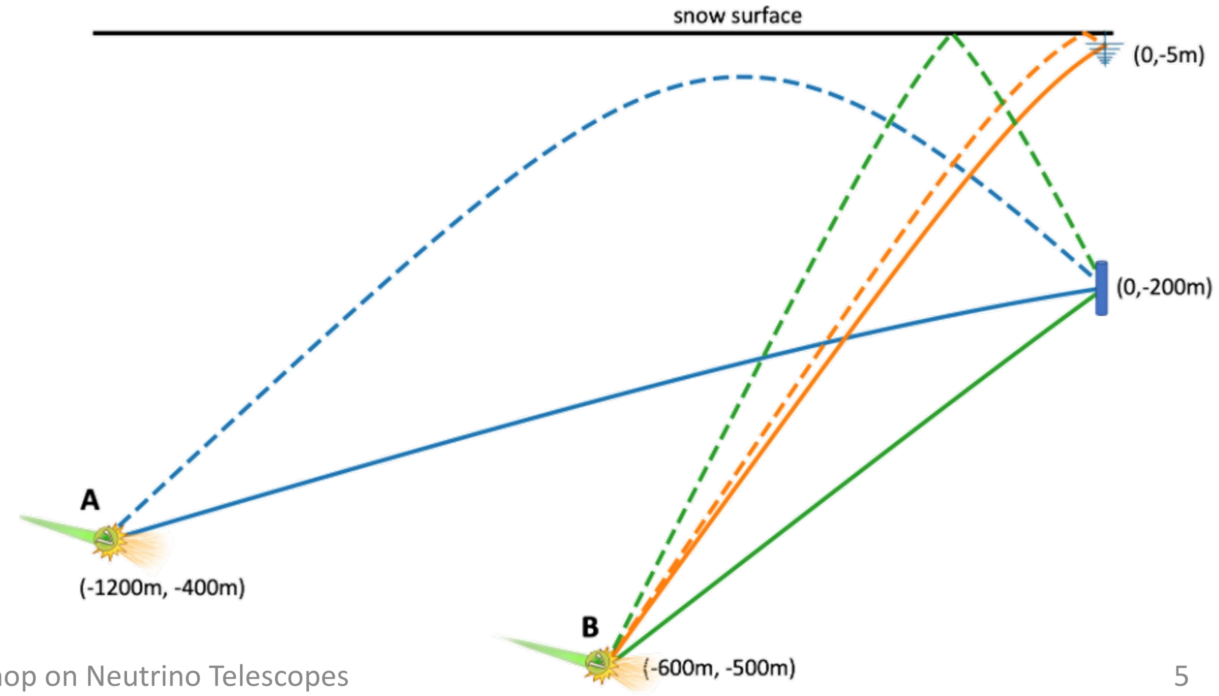
# Index of refraction

- Index of refraction at large depths approximately constant; near surface, in the "firn" region, it follows the density
- Change in index of refraction causes ray bending due to Fresnel refraction

This results in the following:

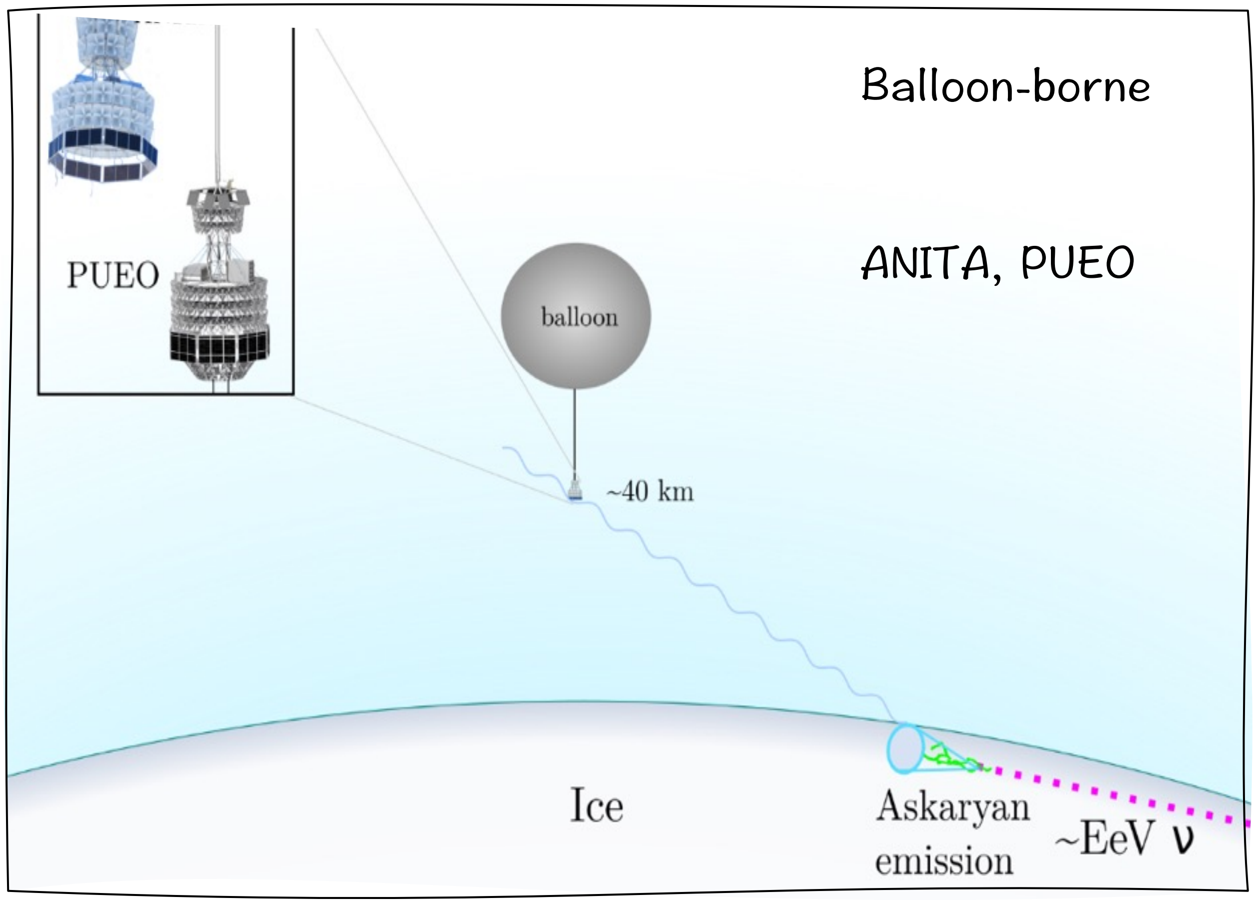
- Antennas below the firn layer capture signals from larger volume
  - Firn depth: O(100 m) in Greenland, O(150-200 m) at South Pole
- Detecting direct, refracted and reflected signals helps reconstruction



# Balloon-borne radio detectors:

- Observe the target medium from afar
  - Large field of view
  - Short flight period
- Antarctic Impulsive Transient Antenna (ANITA)
  - 4 missions
- Future: PUEO (2025/2026)

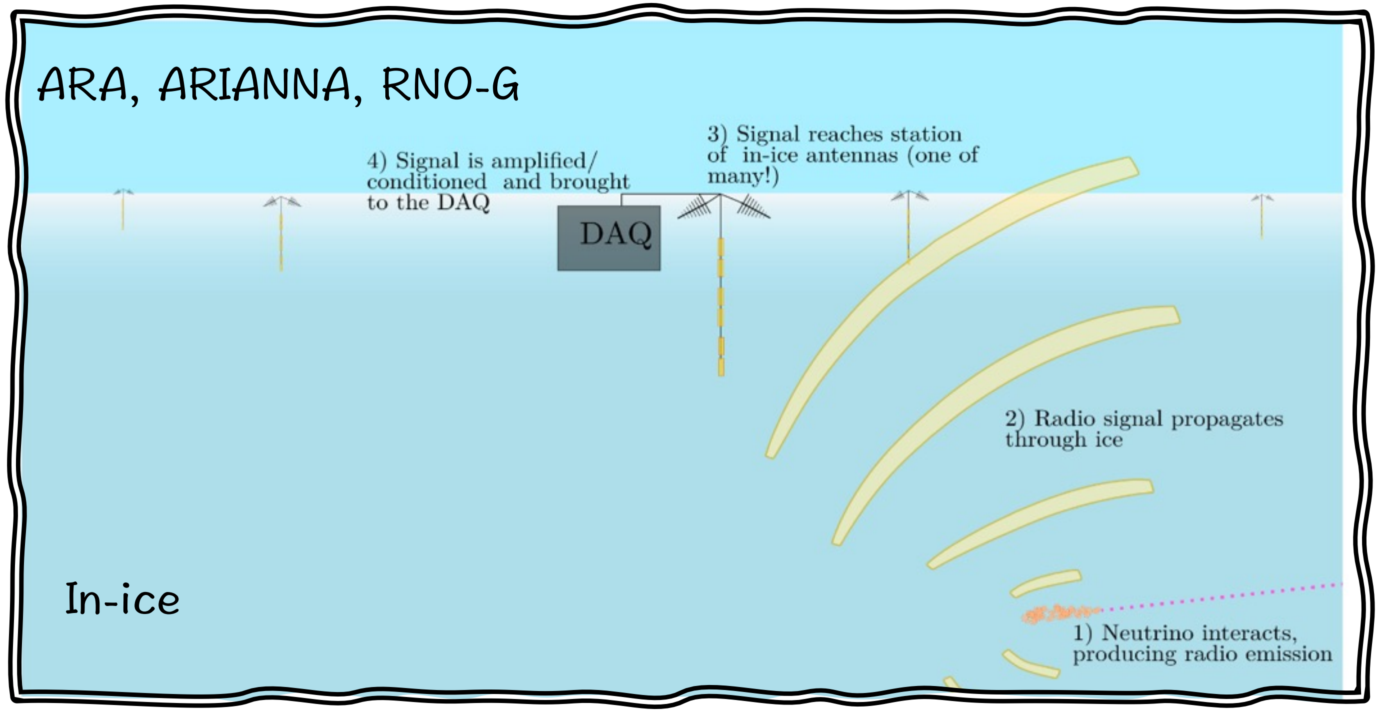



*Illustrations by C. Deaconu, UChicago*

# In-ice radio detectors:

Embed detectors in the target medium:

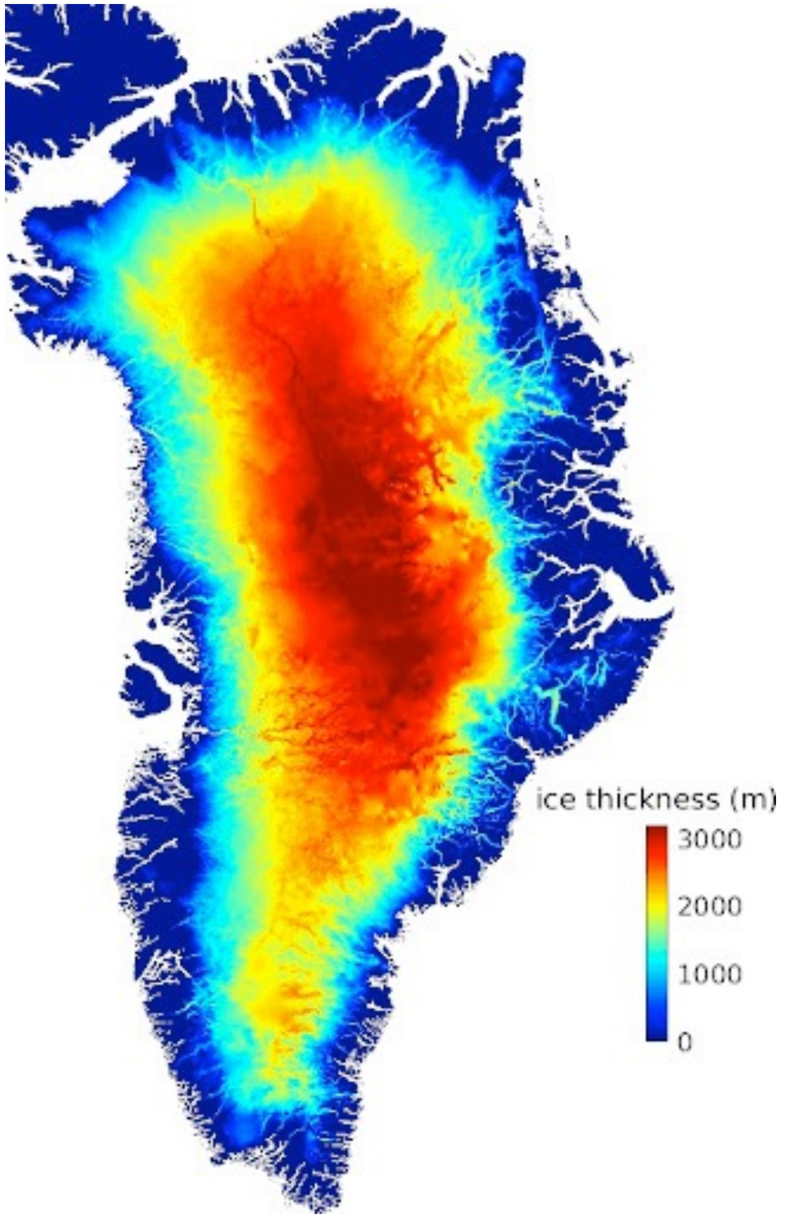
- Radio Ice Cherenkov Experiment (RICE): 1999-2010 @ South Pole
- Askaryan Radio Array (ARA): 2010 @ South Pole
- Antarctic Ross Ice-Shelf ANtenna Neutrino Array (ARIANNA): 2010 @ Ross ice shelf, test @ South Pole




*Illustrations by C. Deaconu, UChicago*

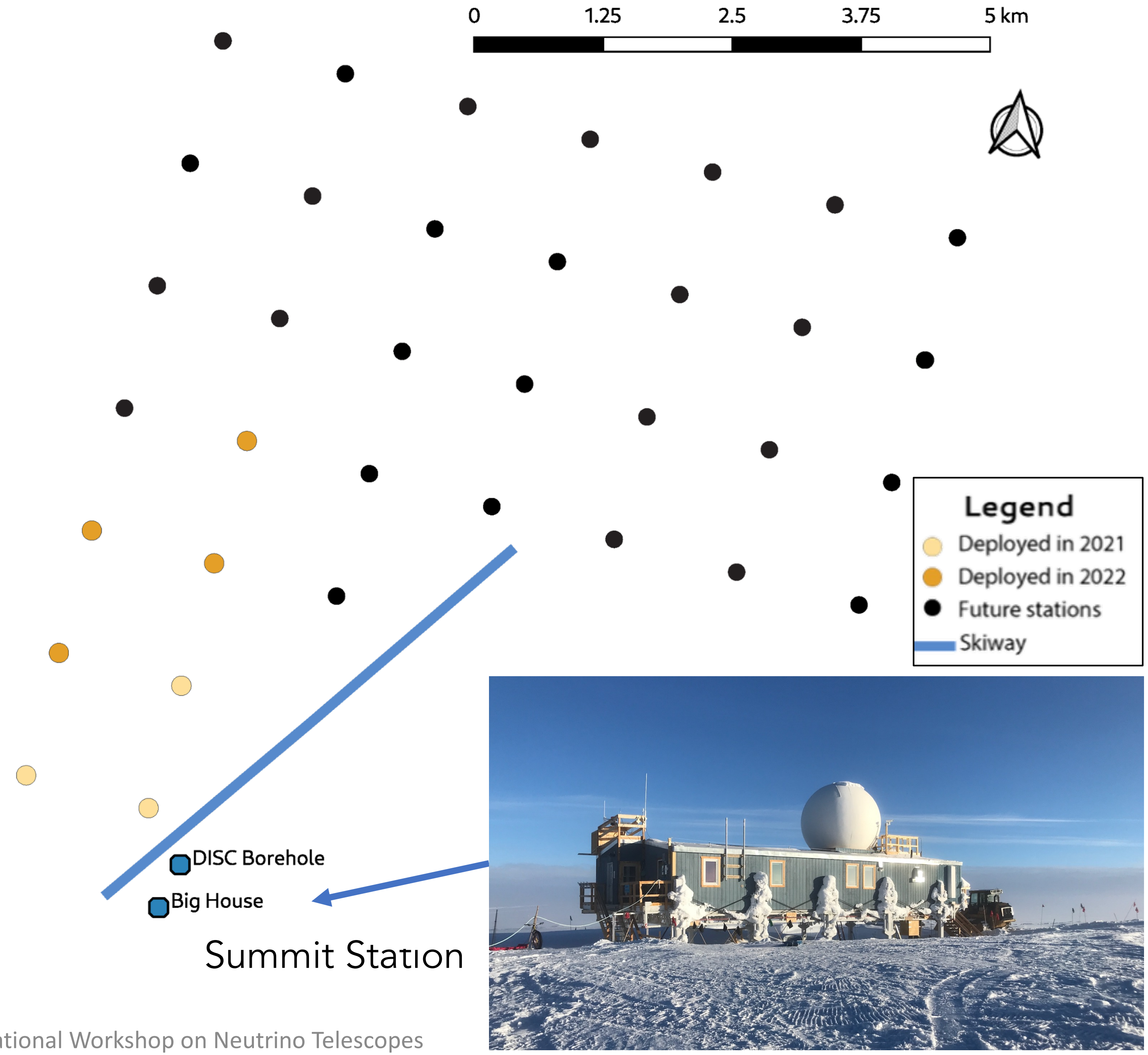
# In-ice radio detection in Greenland

- One of the biggest volume of transparent medium on Earth (the other one is in Antarctica):
- 3km thick ice at Summit Station, with a water layer at bottom.
- Good infrastructure:
  - Summit station NSF-operated
- Northern hemisphere:
  - Inverted season w.r. t. South Pole (May – August)
  - Same cargo planes
- Only radio neutrino detector in this hemisphere
- Sunlight 10 months/year:
  - Solar power
- Firn only about 100 m deep



# RNO-G

- 35 stations spaced 1.25 km apart
- Stations operate independently
- No cables outside the stations
- Autonomous power (25W):
    - batteries
    - solar panels
    - wind turbines *(in development)*
- GPS receiver for timing
- LTE / LoRaWAN communications set up between each station and a base station in the Big House at Summit for data transfer and slow control



# Hybrid station design

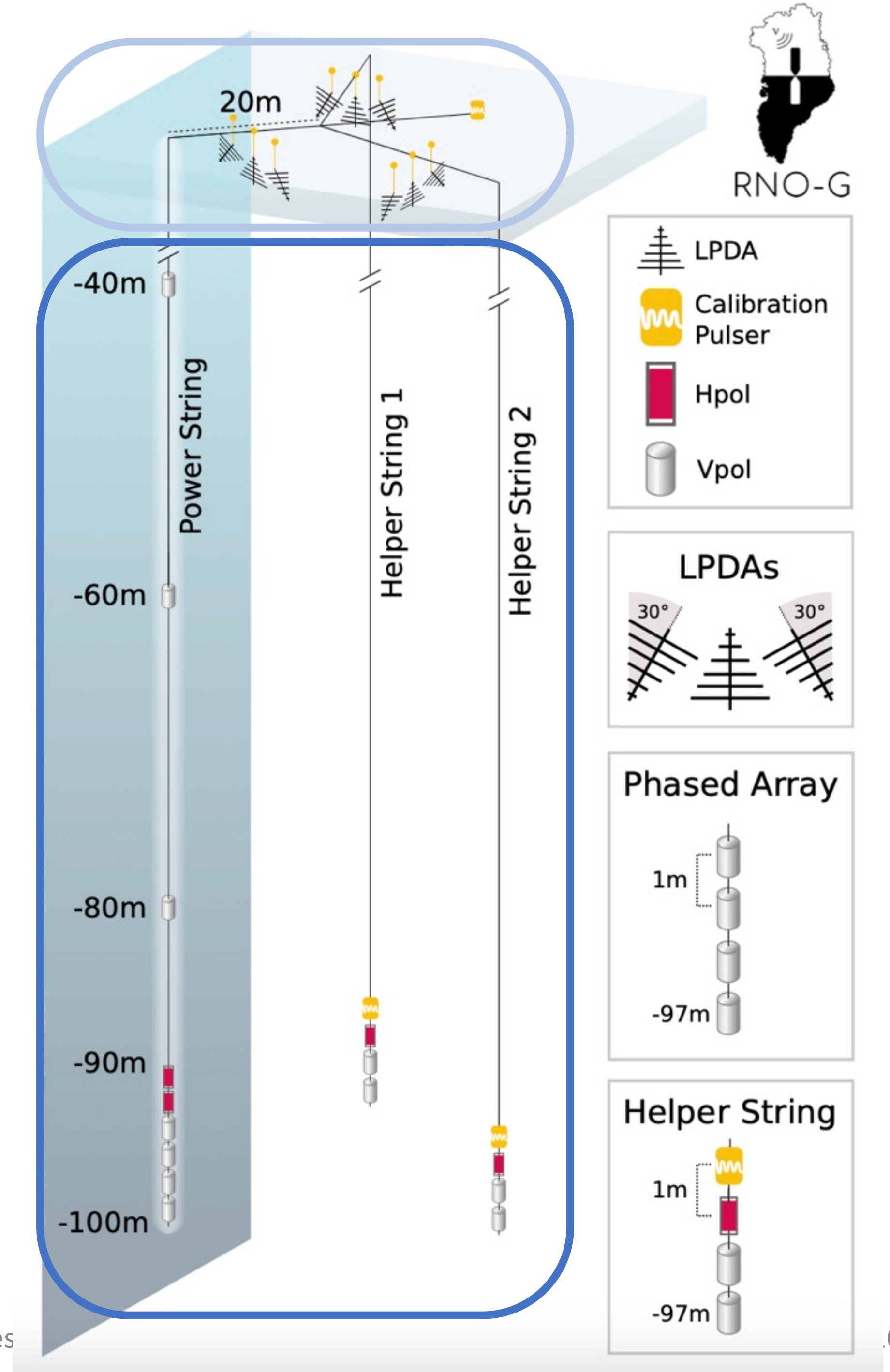
**Shallow component** (~3 m) **(ARIANNA)**

- 9 log-periodic dipole antennas (LPDAs) buried in shallow trenches, facing upward and downward
- Detect cosmic rays and veto RFI from anthropogenic sources and improve reconstruction

**Deep component** (~100 m), 3 strings **(ARA)**

- 11 Vpol deep antennas sensitive to the vertical polarization
  - Provide large fraction of the neutrino effective volume
  - 4 of the Vpol antennas are connected back-to-back in phased array configuration to form a low threshold trigger
- 4 Hpol deep antennas sensitive to horizontal polarization
  - quad slot configuration, constraint by hole size, improve reconstruction

In-situ calibration via 2 deep pulsers (helper strings) and a shallow pulser



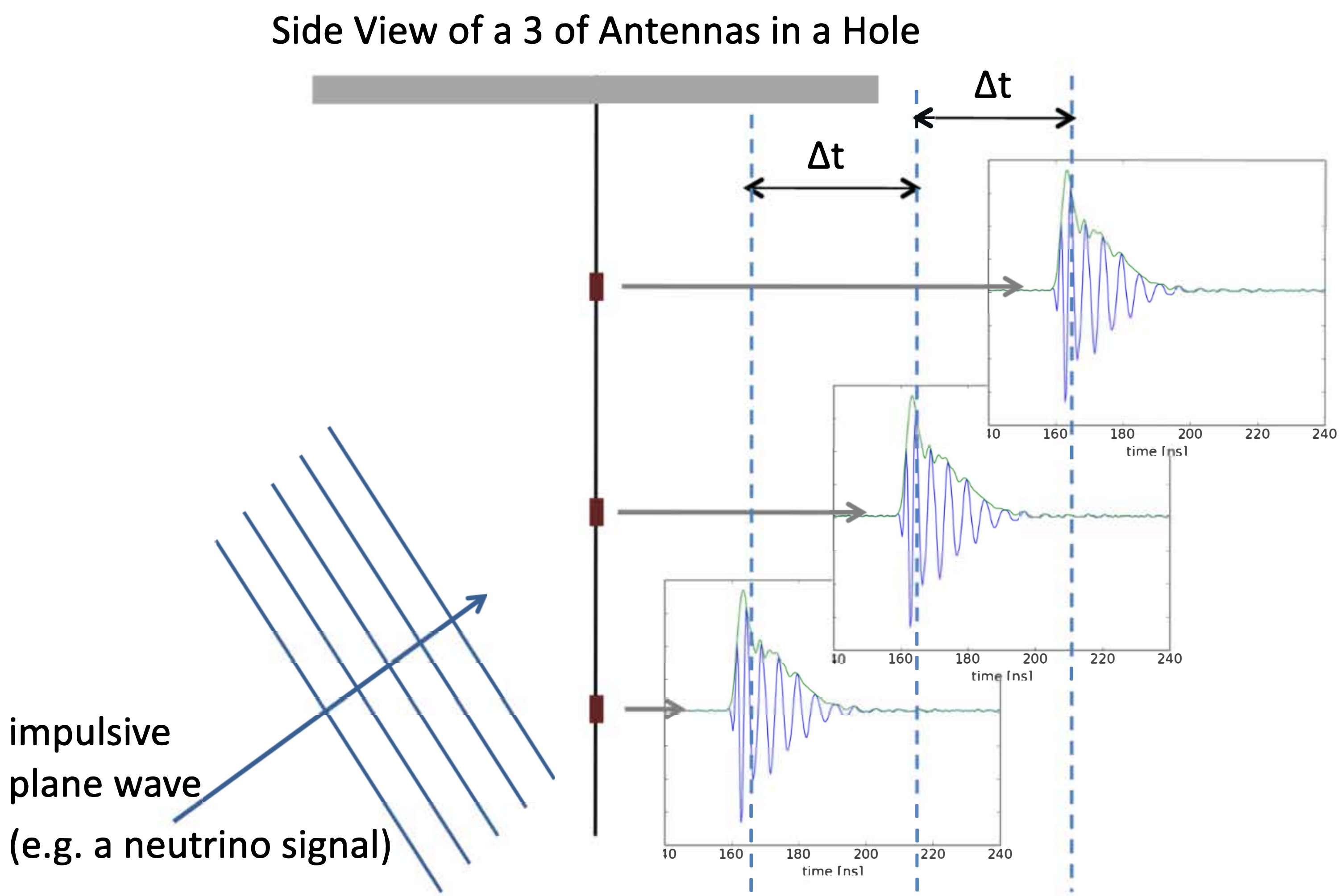
# Phased array trigger

Credit: A. Vieregg

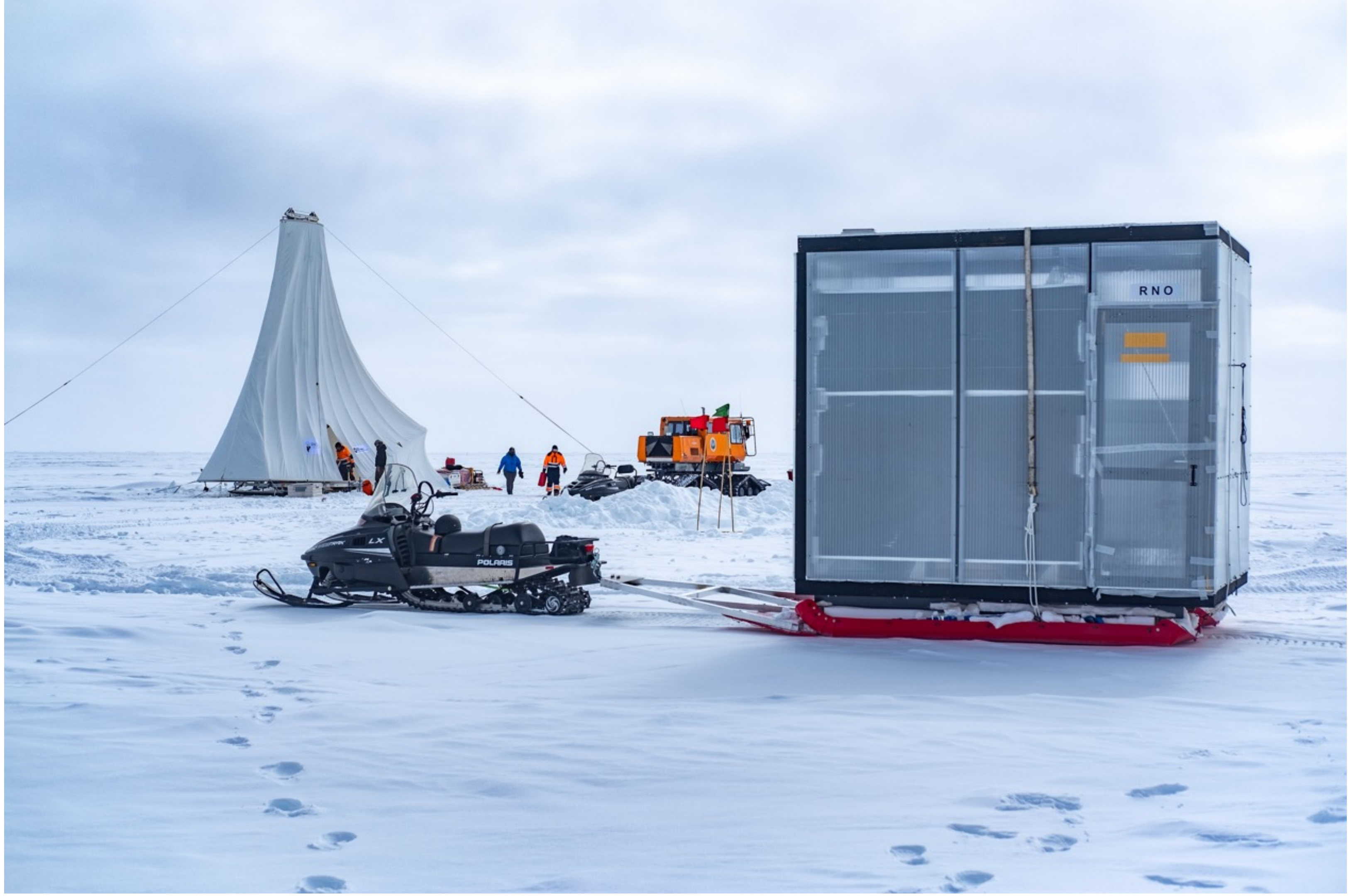
Phased array at trigger level:

- Adds signals together in predetermined directions (beam-forming)
- Plane wave signals add coherently, noise does not
- Trigger threshold is lowered

Phased trigger demonstrated at the South Pole (ARA)



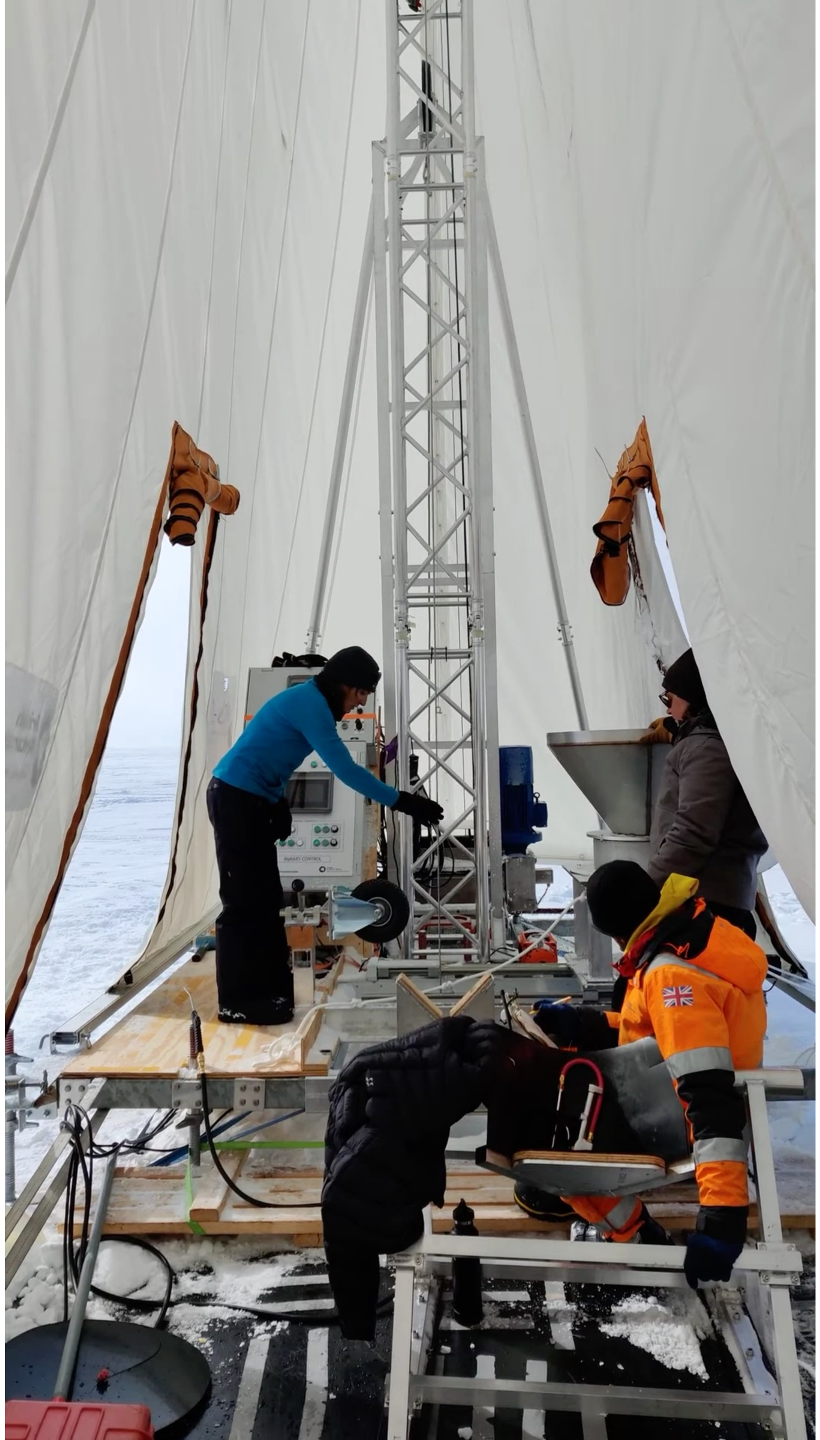
# Drilling & Installation



# RNO-G drill

BigRAID developed by the British Antarctic Survey drilling group

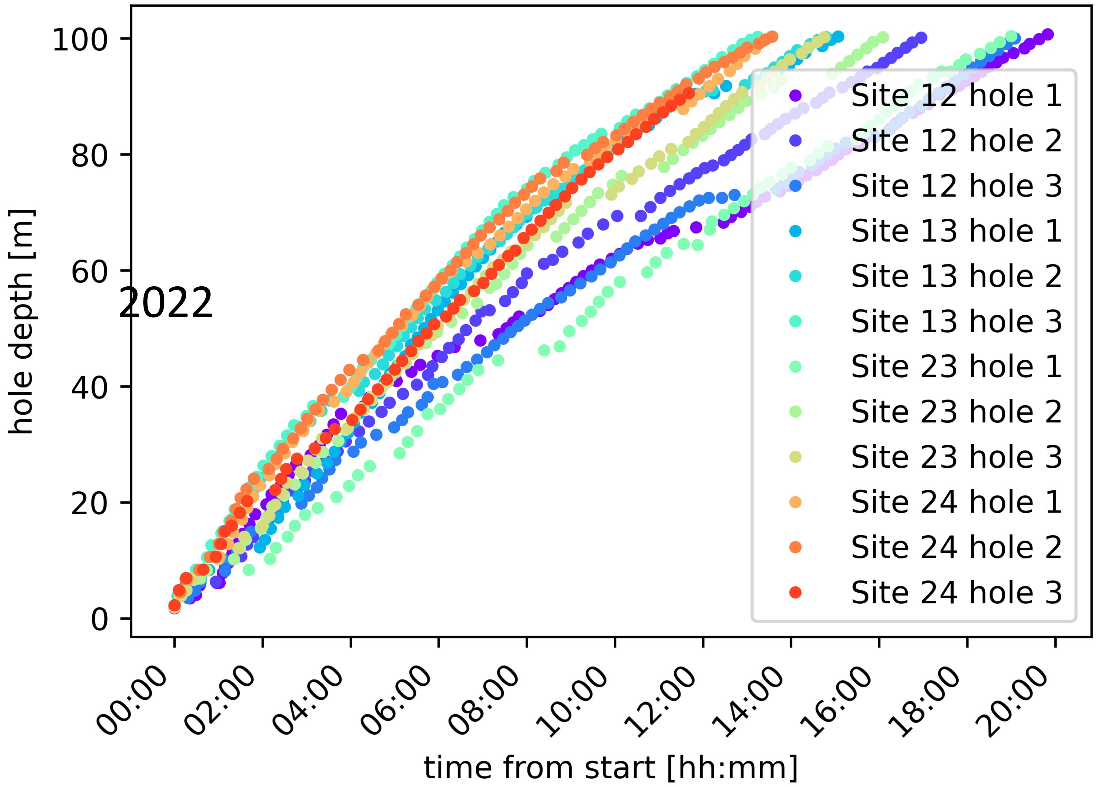
- Auger-type drill, chips are blown and dispersed after every run
- 28cm diameter, 100m dry hole
- Low weight and fuel consumption
- One operator is sufficient for most operations



# Drilling performance

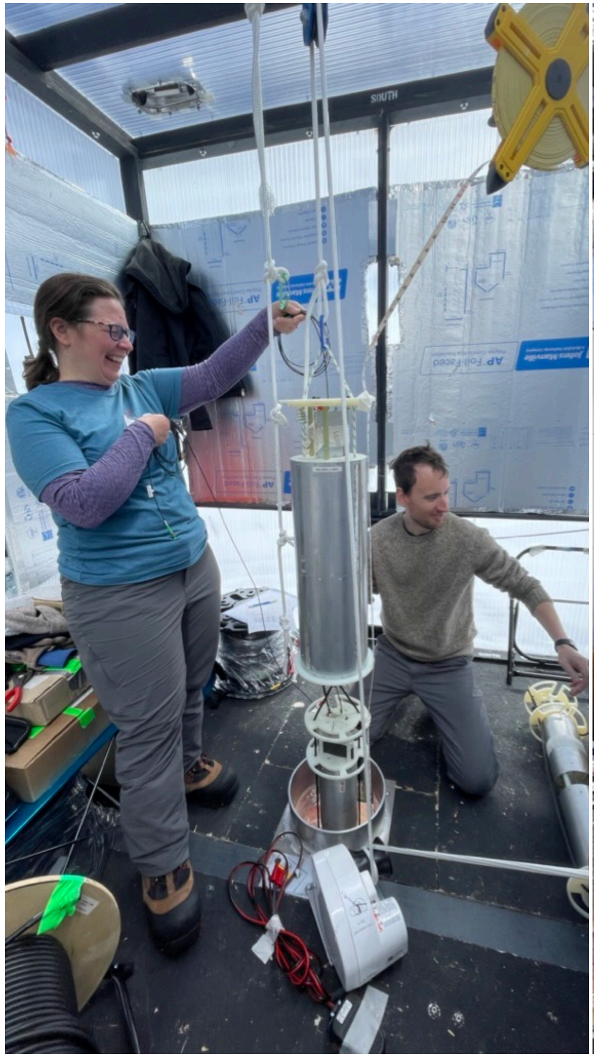
Target drilling is 1x100m hole/day as a benchmark for Gen2 radio drilling

- 2021 (9 weeks): 3 stations
  - 7 + 2 holes, achieved 100m/day for 1 hole
- 2022 (10 weeks): 4 stations
  - 12 + 2 holes, fastest holes in 12.5 hrs
- North winds & bad weather on average 20%
- Up to 1/2 day to dig out the drill after a big storm
- Flexibility on work hours/days from Summit allows for catching up if needed



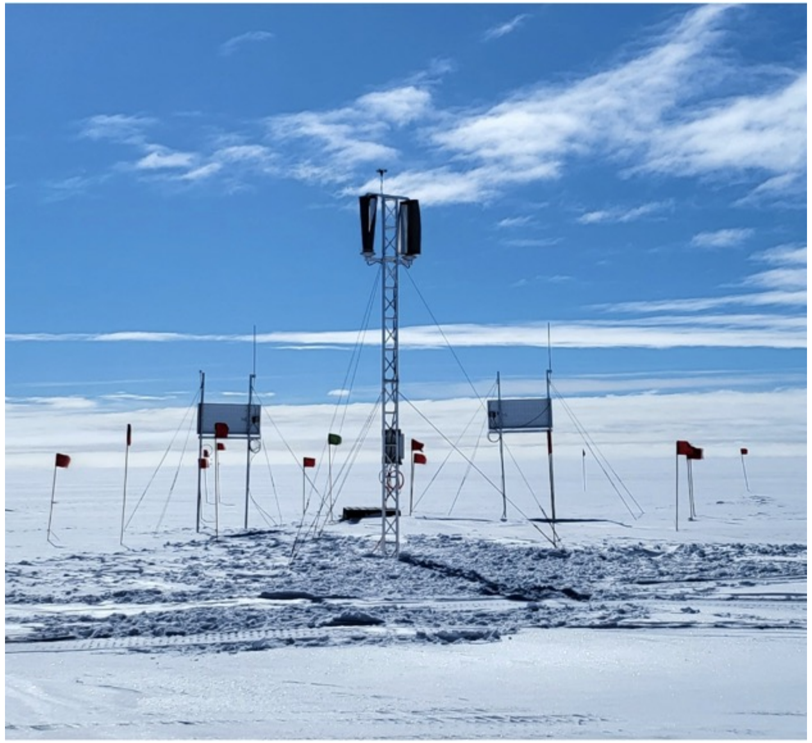

# Installation of deep components

- Custom designed, lightweight deployment sled parked on top of the hole and serves as warming point
- Strings are assembled as they are lowered
- Installation process takes 3-4 people:
    - 6 hours / power string
    - 2-3 hours / helper string

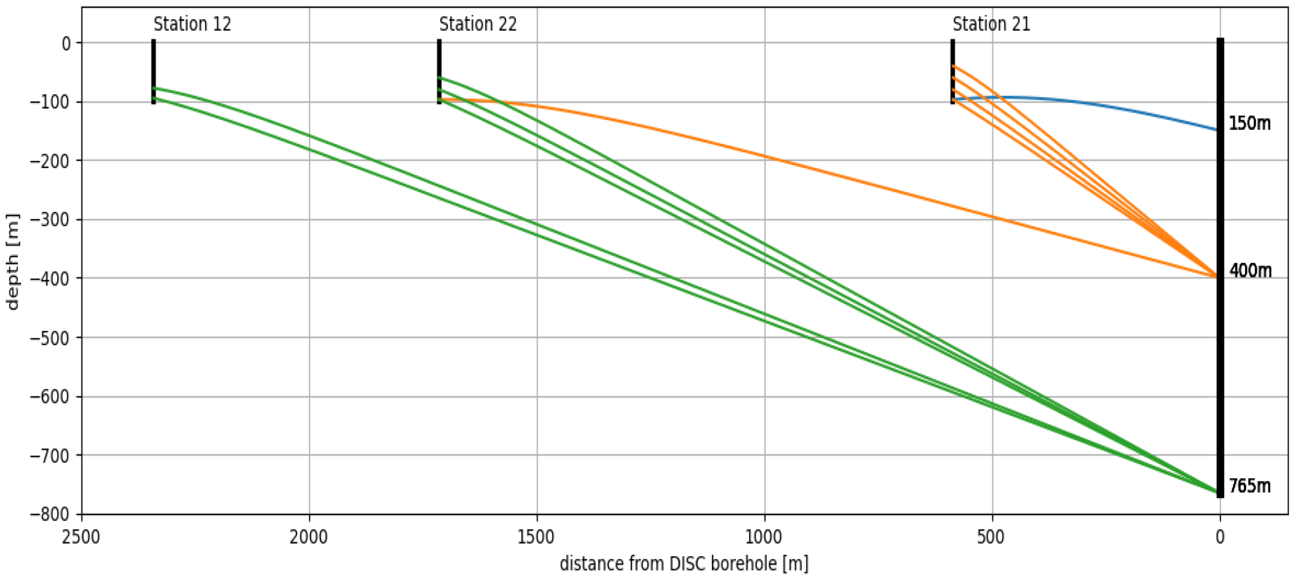
# Installation of surface components

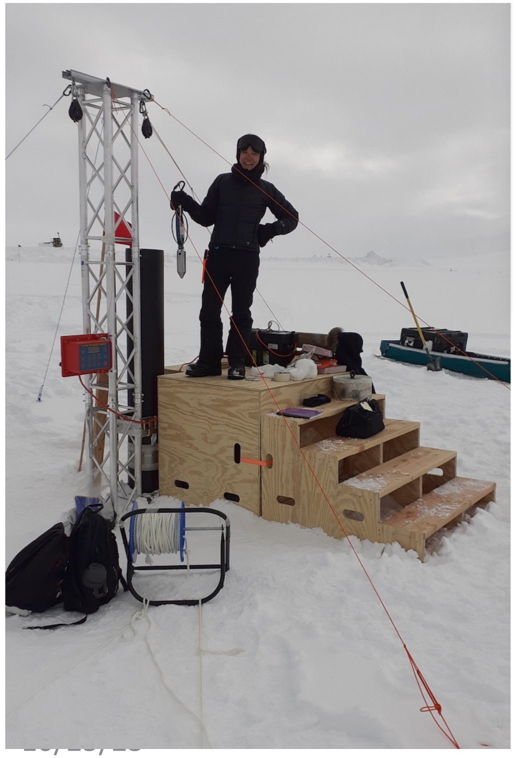
- Three slots perpendicular between strings and DAQ
  - Slots are so far dug by hand, in parallel with string installation
- DAQ, panels and wind turbines at the center
- A full station can be installed in 2.5 days with a team of 4




# Calibration campaigns

- A deep hole (such as DISC) would allow for calibration of more stations with same source
- Surface pulsing, GPR scans, GPS survey, future: neutron density probe
- Auto-melting probes used for 30m cal. holes



# Summary

- RNO-G is the only radio neutrino detector in the northern hemisphere
- Well funded in Europe and in US
- 75 members, 18 institutions, 5 countries
- Currently in expansion!

RNO-G Collaboration June 2022

RNO-G team 2022

- Radiofrequency Ice Dielectric Measurements at Summit Station, Greenland
- Triboelectric Backgrounds to Radio-based Polar UHE Neutrino Experiments
- In situ, broadband measurement of the radio frequency attenuation length at Summit Station, Greenland
- Reconstructing the neutrino energy for in-ice radio detectors
- Design and Sensitivity of the Radio Neutrino Observatory in Greenland (RNO-G)