Friedrich-Alexander-Universität
Erlangen-Nürnberg

RNO-G
Radio Neutrino Observatory - Greenland

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

The Radio Neutrino Observatory Greenland (RNO-G)

Karen Terveer
Karlsruhe, 26.11.2022

The Ultra-High-Energy Universe

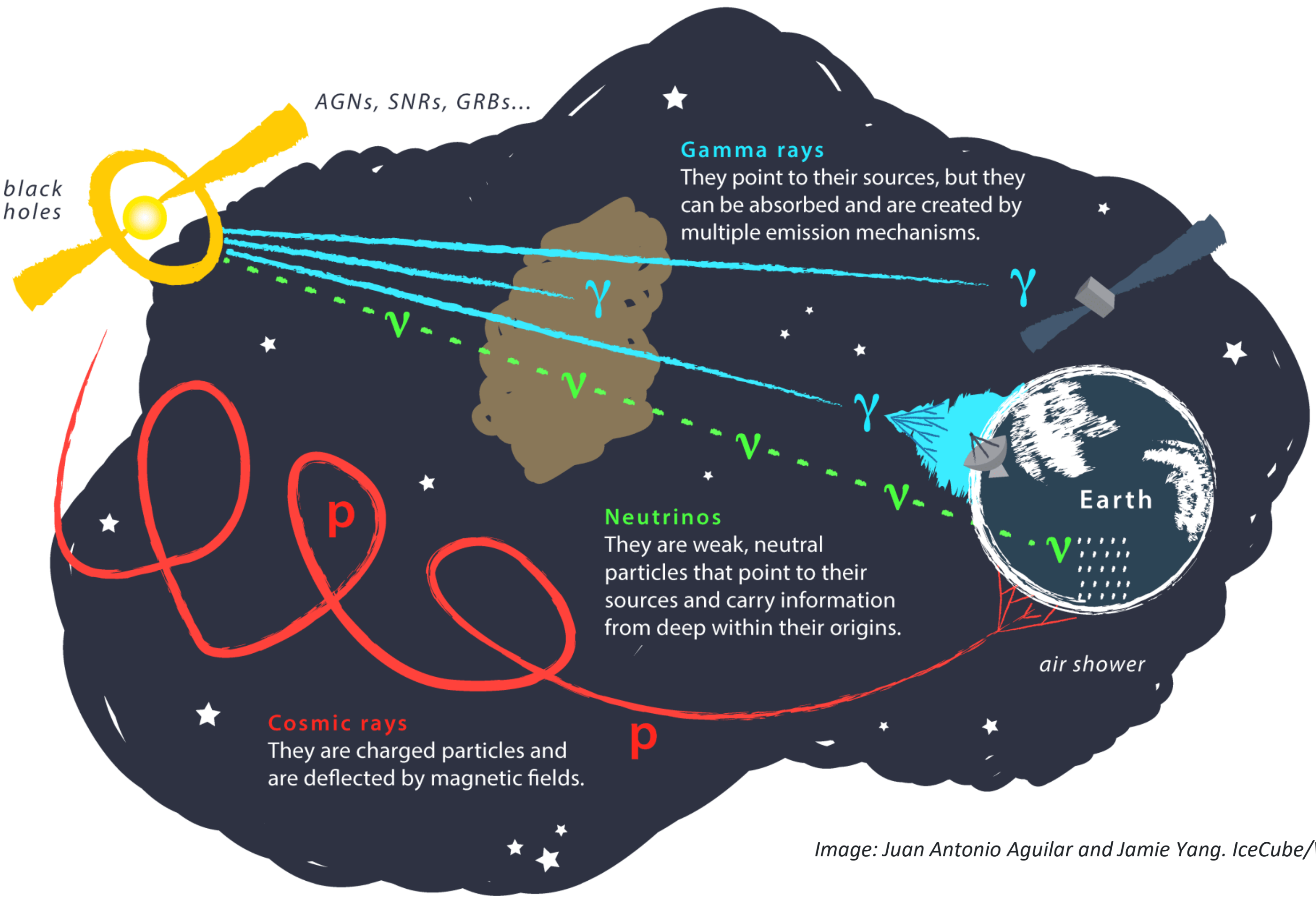


Image: Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC

Neutrinos as messenger particles

- Unlike cosmic rays, neutrinos point back to their sources
- Provide a key piece of the astronomical puzzle
- directly from sources (astrophysical neutrinos) or from interaction of ultra-high energy cosmic rays with photon backgrounds (cosmogenic neutrinos)

Neutrino detection

Neutrinos have low cross section

→ large detector volumes needed to maximise detection probability

Naturally occurring detector materials (water or ice):

- Large volume
- Few instrumentation needed
- Existing neutrino observatories (e.g. IceCube, KM3Net, Baikal-GVD) utilise Cherenkov effect
  - measure resulting radiation with photomultiplier tubes

Image: Felipe Pedreros, IceCube/NSF

Neutrino detection

- IceCube has measured neutrinos below 10 PeV
  - First point sources have been discovered (e.g. NGC 1068, TXS 0506+056)
- Several models predict astrophysical neutrinos up to ultra high energies
- From cosmic ray flux expected are also cosmogenic neutrinos
- Neutrino sky above 10 PeV is yet unknown.

  → Radio detection

Image: A. van der Hoeven, NASA/ESA

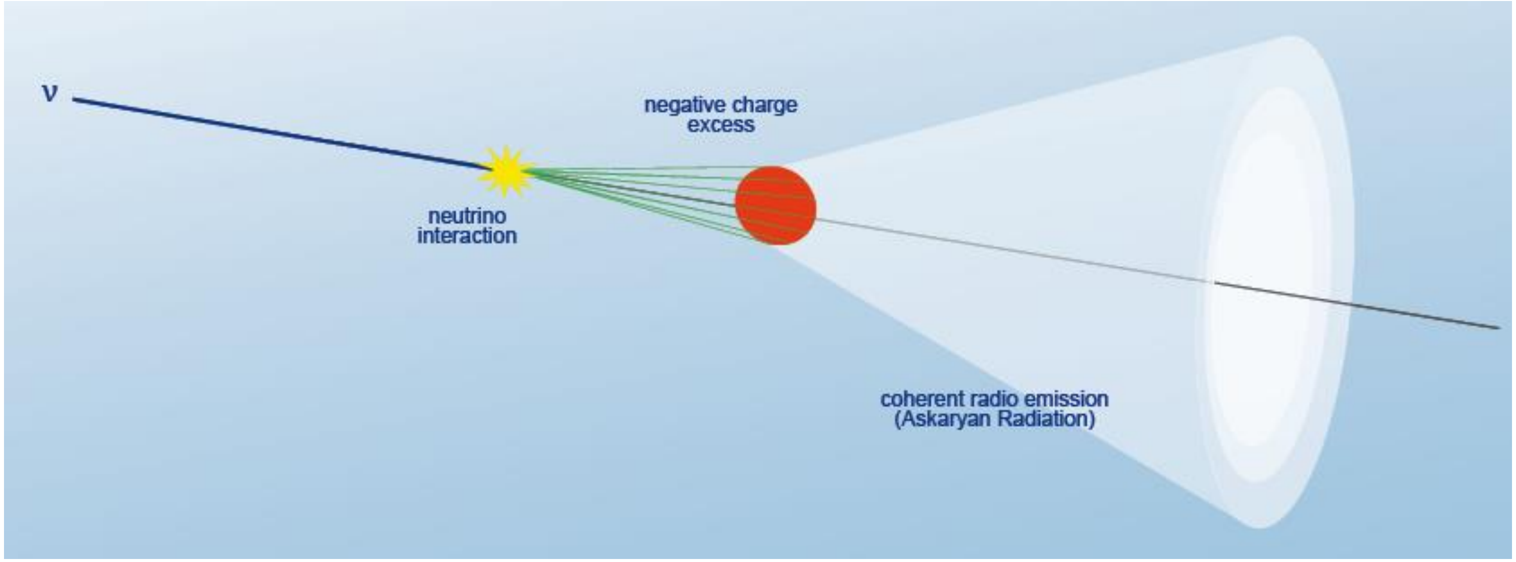
Radio Neutrino detection

- Measuring radio waves from neutrino interactions in ice extends the detection energy range to neutrino energies beyond the PeV scale
- Radio attenuation length in ice is $\sim 1\mathrm{km}$
  - → allows large effective detector volumes at 10 PeV to beyond 100 EeV, an energy range in which neutrinos have not yet been measured

Image: RNO-G, Cosmin Deaconu

Askaryan Effect

- After interaction, neutrino produces secondary particles
- Negative charge excess in particle shower $\mathcal{O}(20\%)$ moving faster than speed of light in ice



- Radio signals can then be detected by antennas

RNO-G

RNO-G

Aims

- Detecting neutrinos in the energy range of 10PeV to 100EeV will allow studies of ultra high-energy neutrino production mechanisms
  - Some sources still unknown
- Allows continuation of measurement of the IceCube flux
  - Sensitive enough to detect first ultra high energy neutrino

Image: RNO-G, Cosmin Deaconu

RNO-G Layout

Image: RNO-G, Cosmin Deaconu

- Experimental site is at Summit Station, Greenland
- Ideal due to low background noise from human activity

RNO-G Layout

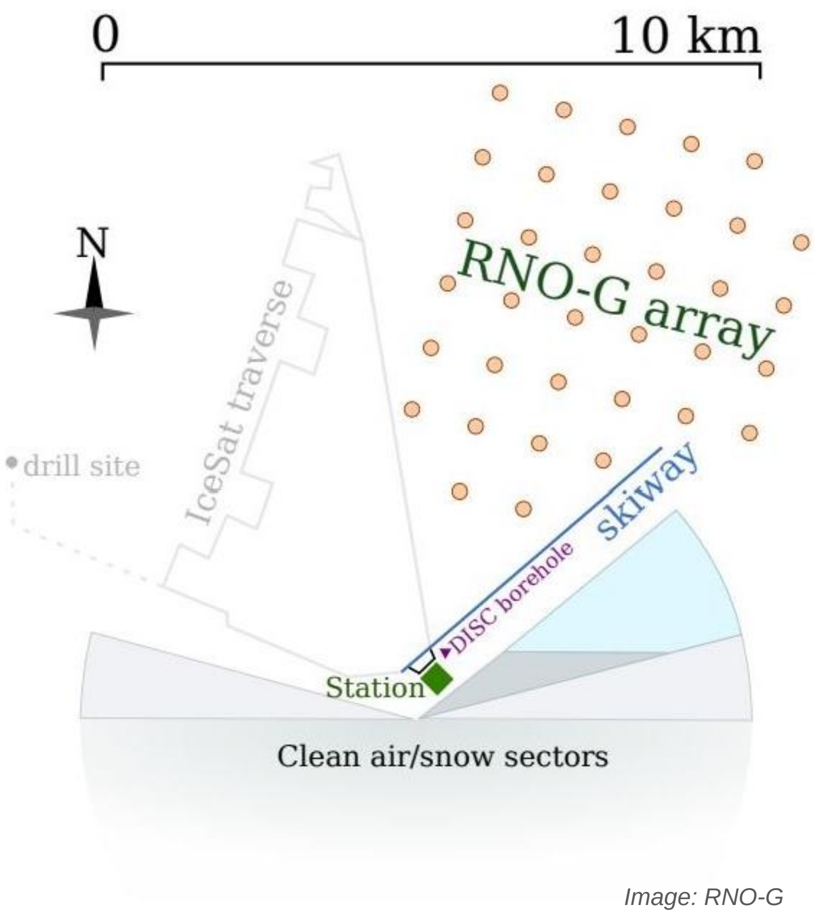


Image: RNO-G

- Experimental site is at Summit Station, Greenland
- Ideal due to low background noise from human activity
- Planned layout:
  - Array of 35 equidistant stations over an area of 5×5 km

RNO-G Station

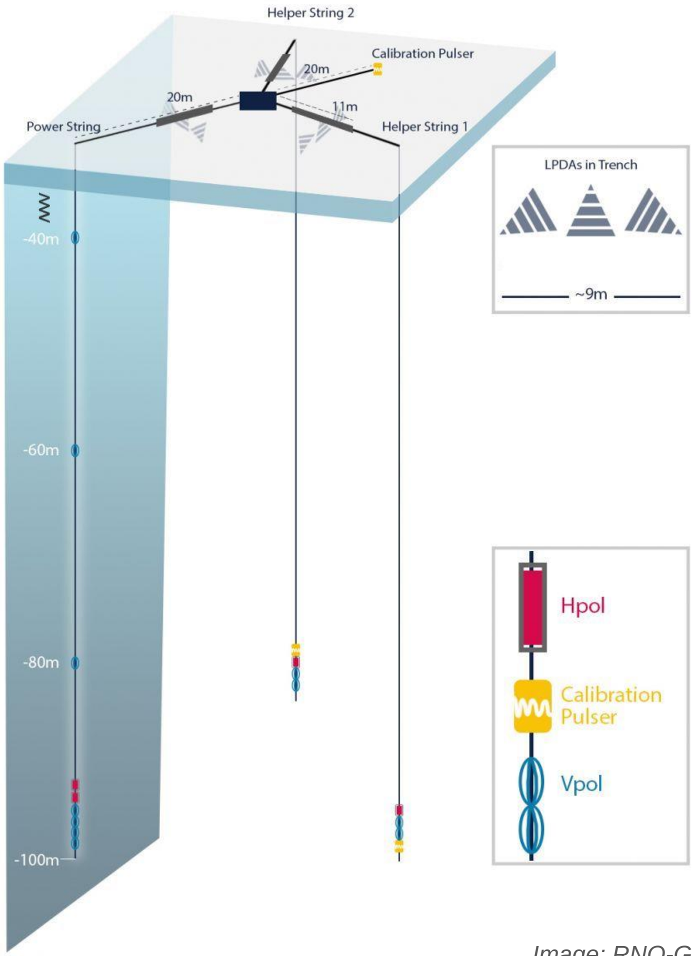


Image: RNO-G

- Station combines **ARIANNA** (shallow) and **ARA** (deep) advantages
  - Consists of deep string antennas and shallow surface antennas

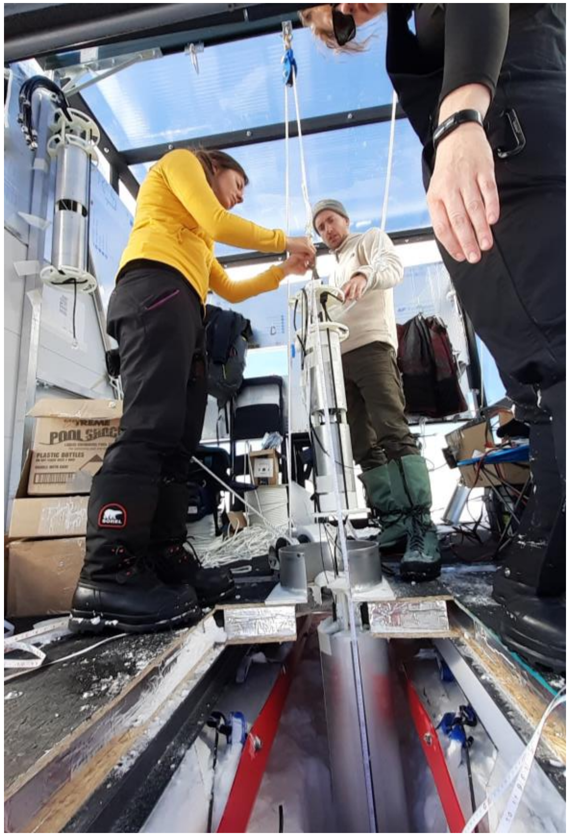
RNO-G Station

Photo of a RNO-G Station

Image: RNO-G

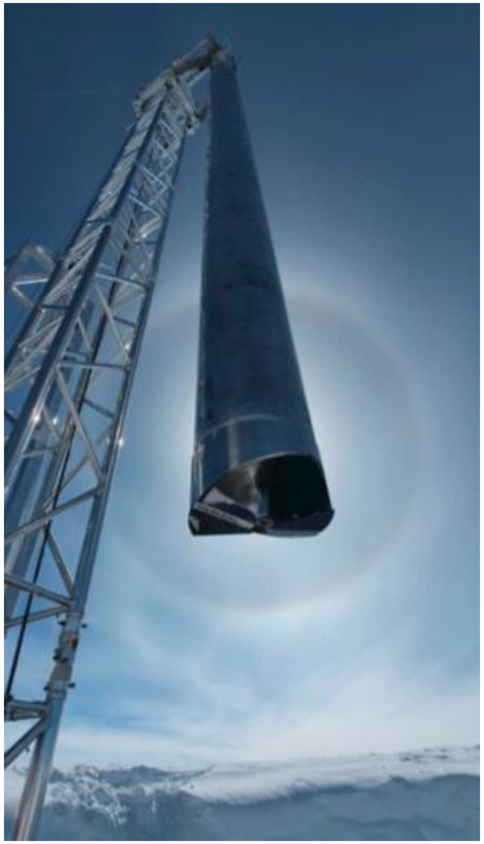
RNO-G Station

- Deployment has begun in 2021.
- Shallow antennas are deployed in shallow trenches, string antennas in deep boreholes



Images: RNO-G

RNO-G Station



British Antarctic Survey's BigRAID auger drill

Borehole

Images: RNO-G

Since 2022, drilling is executed in a drill tent

Image: RNO-G

Current Status

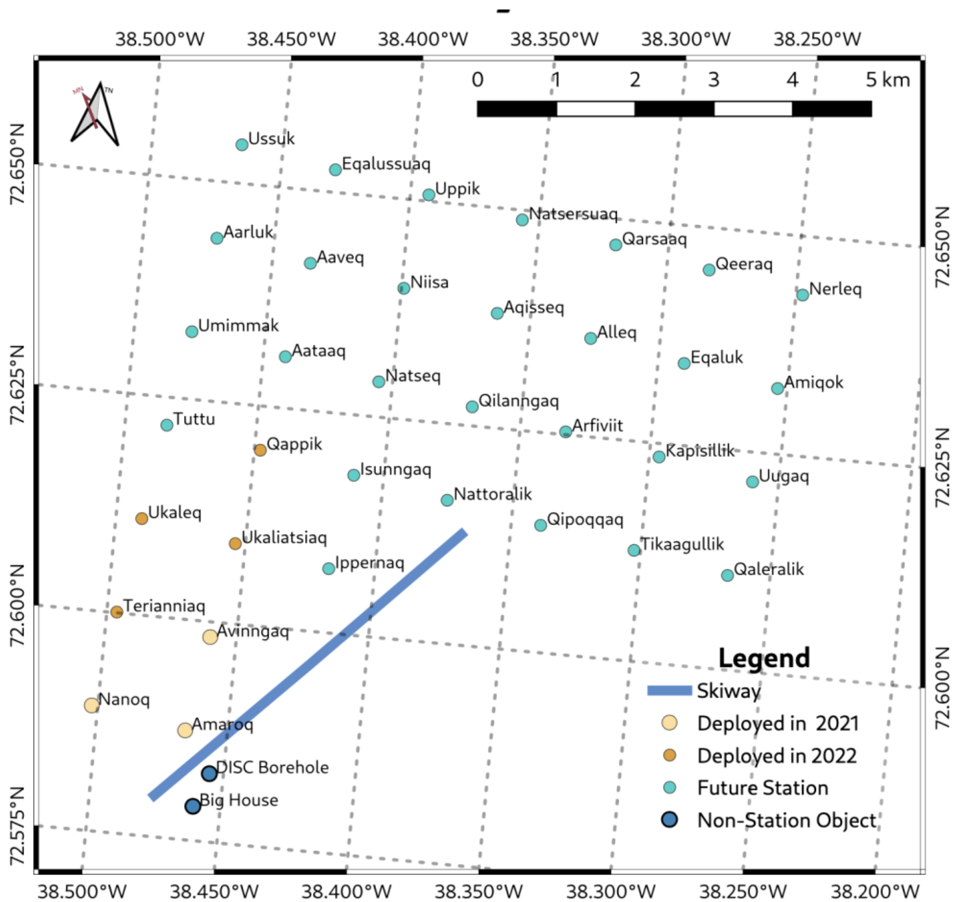


Image: RNO-G

7 stations currently deployed

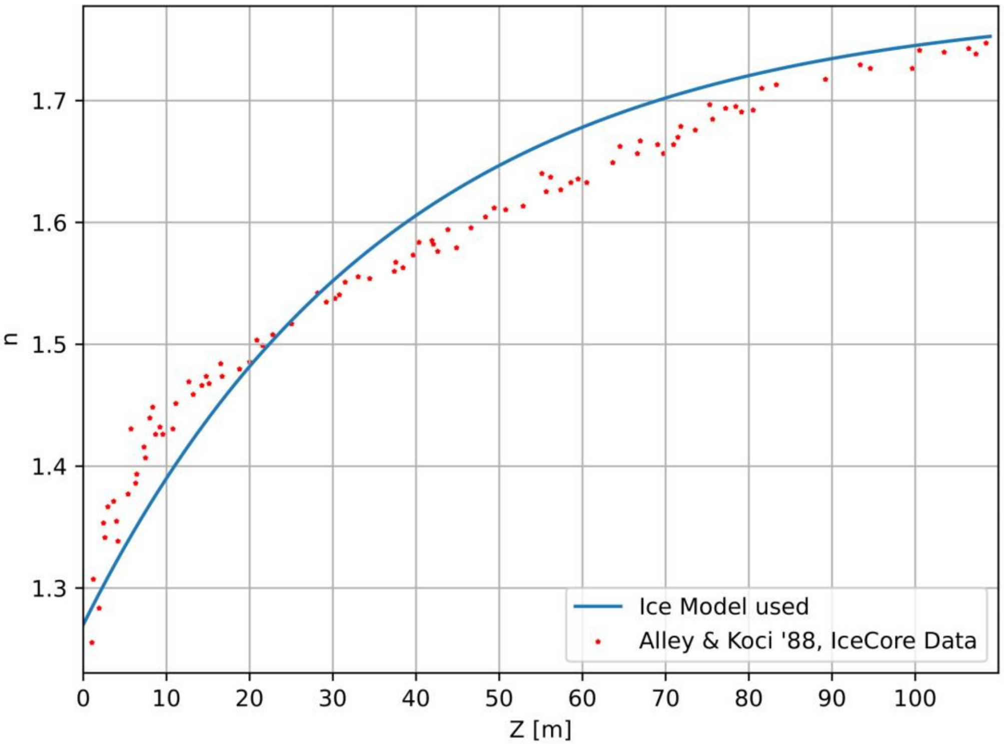
Ice Model
(my work)

Glacial Ice

- On top of the glacial ice, several meters of firn accumulate
- Firn is intermediate stage between snow and ice
- Increasing density with depth due to pressure:

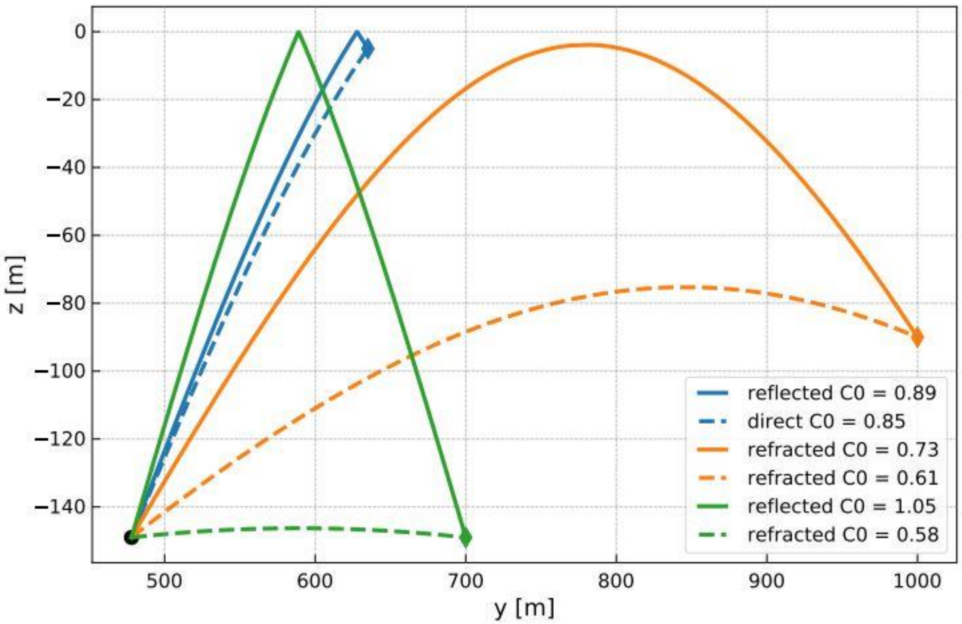
→ Exponential index of refraction profile:

$$n(z) = n_{ice} - \Delta n \, e^{\frac{z}{z_0}}$$

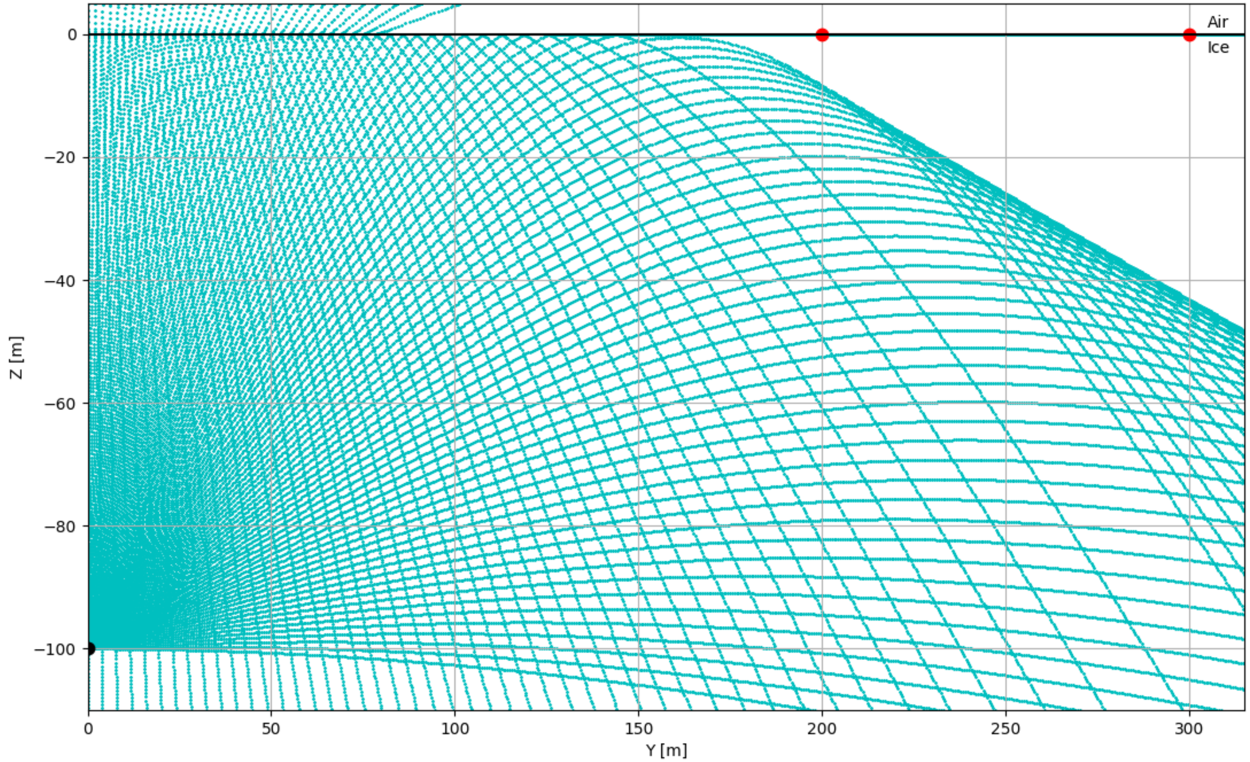


Radio trajectories

- Non-homogenous index of refraction results in curved trajectories
- Each receiver-emitter pair has either one, two or no solutions
- Difference in pulse arrival times can be used to reconstruct neutrino signal



Shadow zone



– Curving of rays leads to refraction zone (receiver-emitter pairs exist) and shadow zone (receiver-emitter pair does not exist)
– No signal expected in shadow zone

Shadow zone signals

- ARIANNA experiment recorded signals in shadow zone
- Propagation times of one of them coincided with a **straight trajectory**

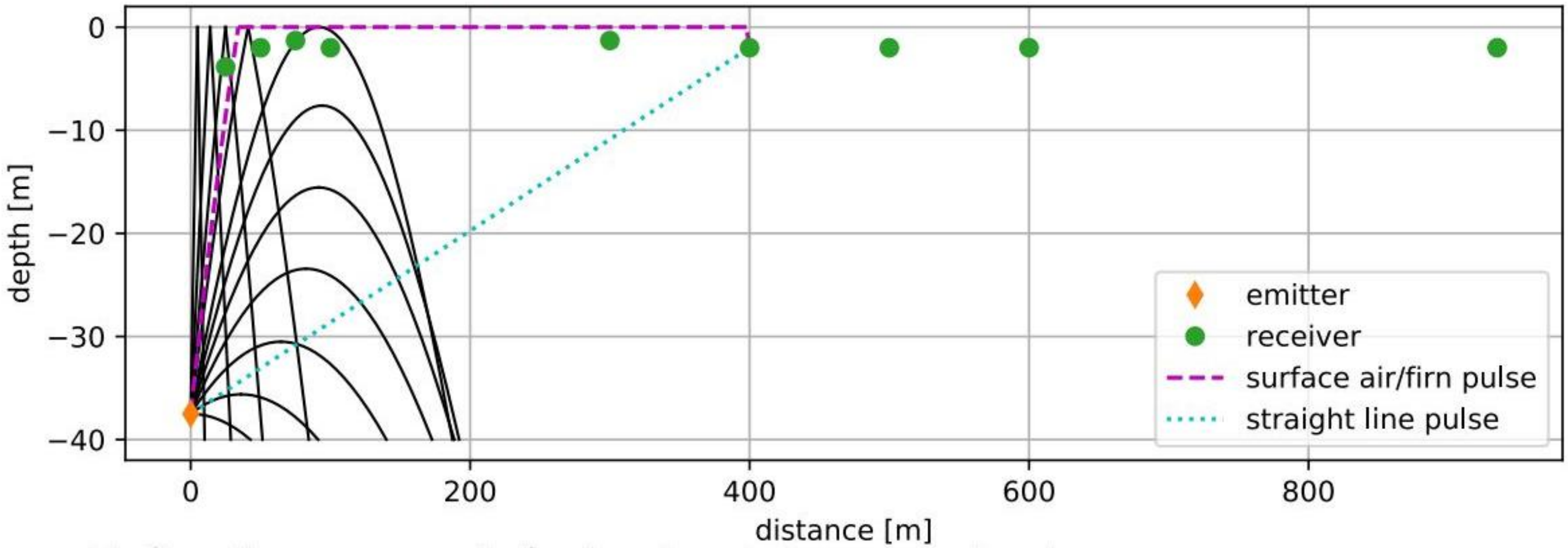


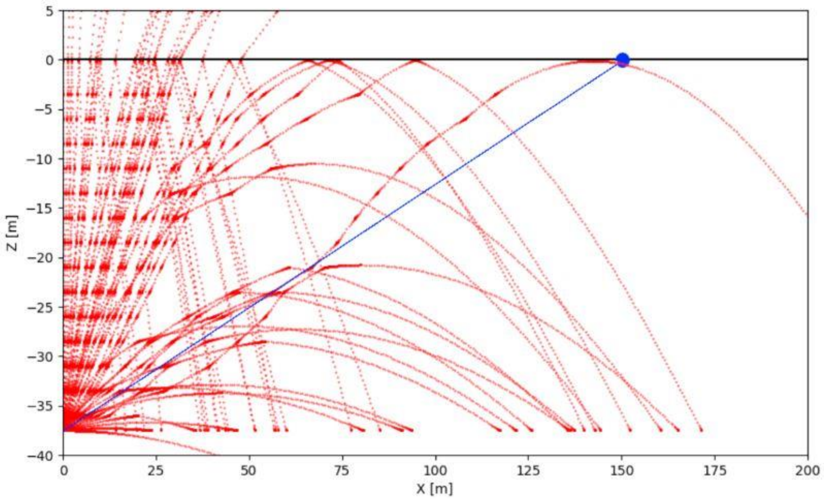
Image: Robert Lahmann, ARIANNA

Shadow zone signals

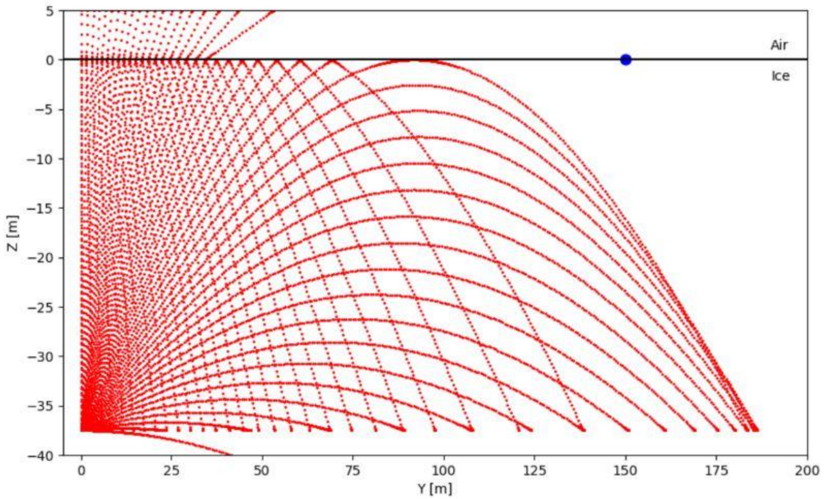
Model assumption:

– Layers in ice (caused by e.g. weather) with local perturbation in index of refraction cause scattering effect:

ice model with layers

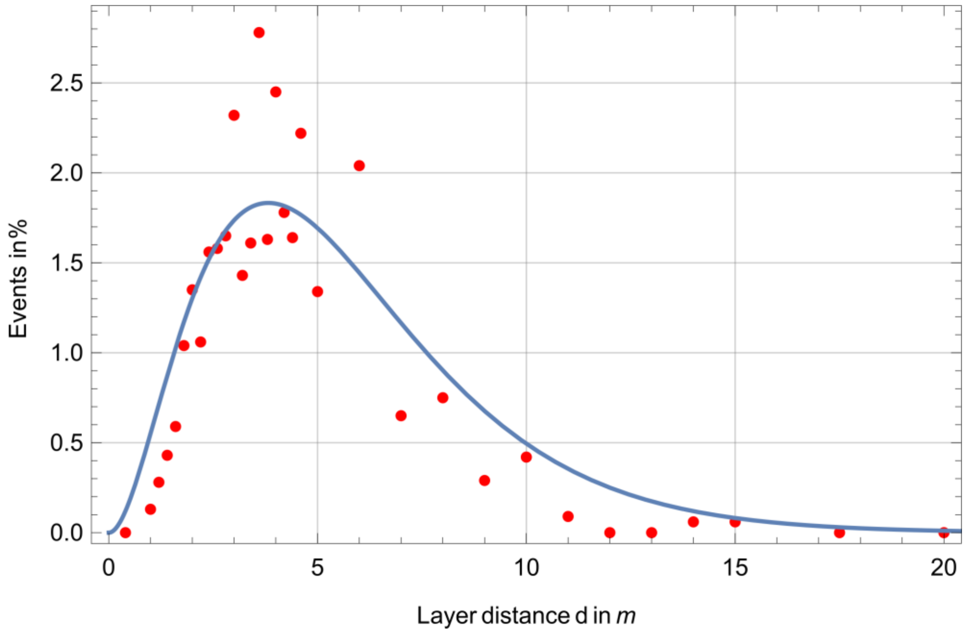


regular ice model



Shadow zone signals

- Series of simulations showed plausibility of the approach
  - various numbers of layers with random perturbation in index of refraction led to shadow zone events
- Incorporating these into simulation frameworks could increase effective volume of detector and aid event reconstruction



Summary

- Radio detection of neutrinos can extend the detectable energy range to above 10 PeV
- RNO-G is expected to detect first ultra-high energy neutrino
- Deployment has begun in 2021
- Non-homogenous ice causes curved radio trajectories, leading to „shadow zone“ where theoretically no signal can be detected
- Shadow zone signals can be phenomenologically explained by scattering layers in ice