The Radio Neutrino Observatory in Greenland:

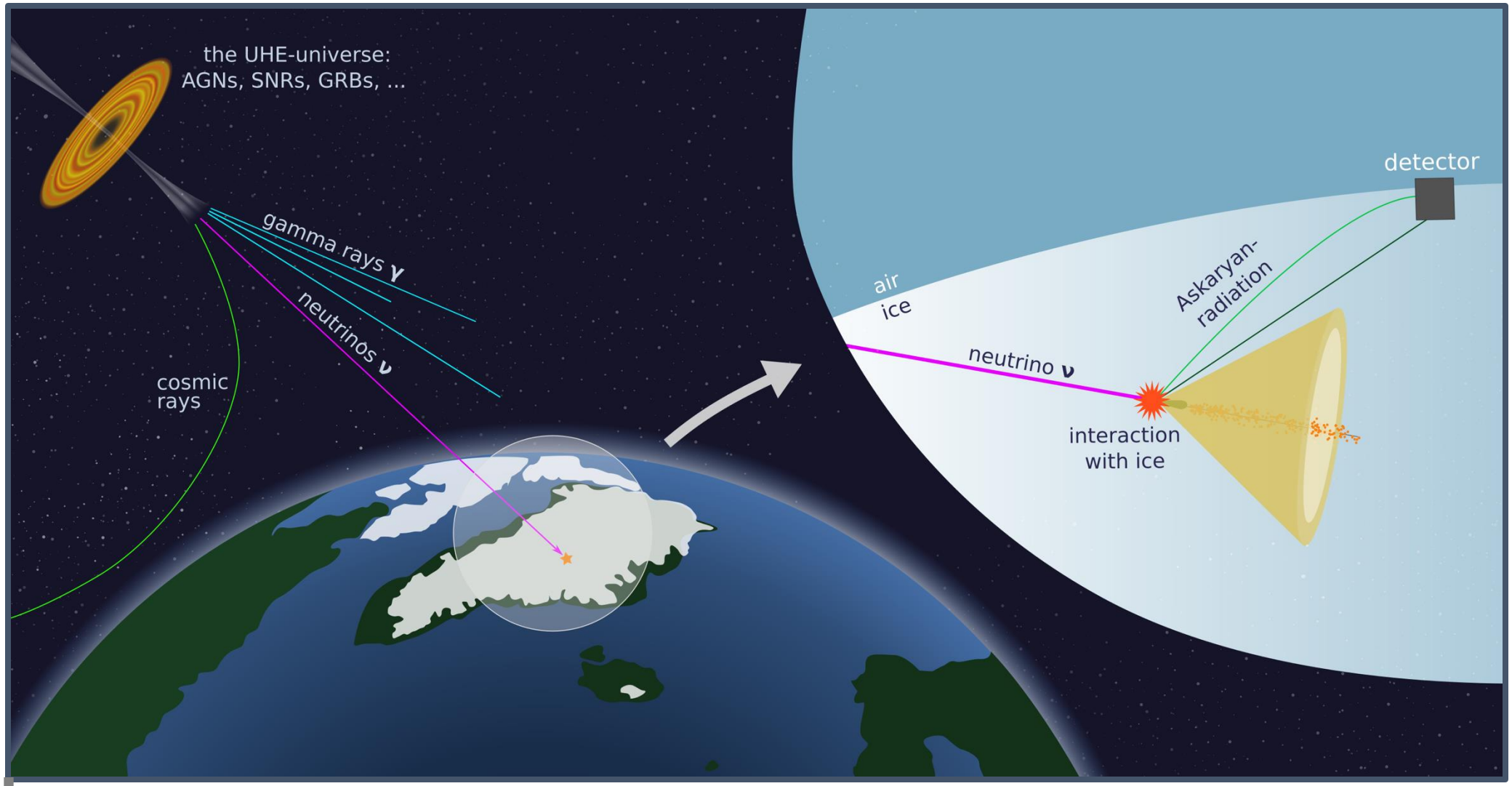
A Path Towards IceCube-Gen2

Nils Heyer for the RNO-G collaboration

21.10.2024, Partikeldagarna

UPPSALA UNIVERSITET

Detecting Cosmic Neutrinos with Radio



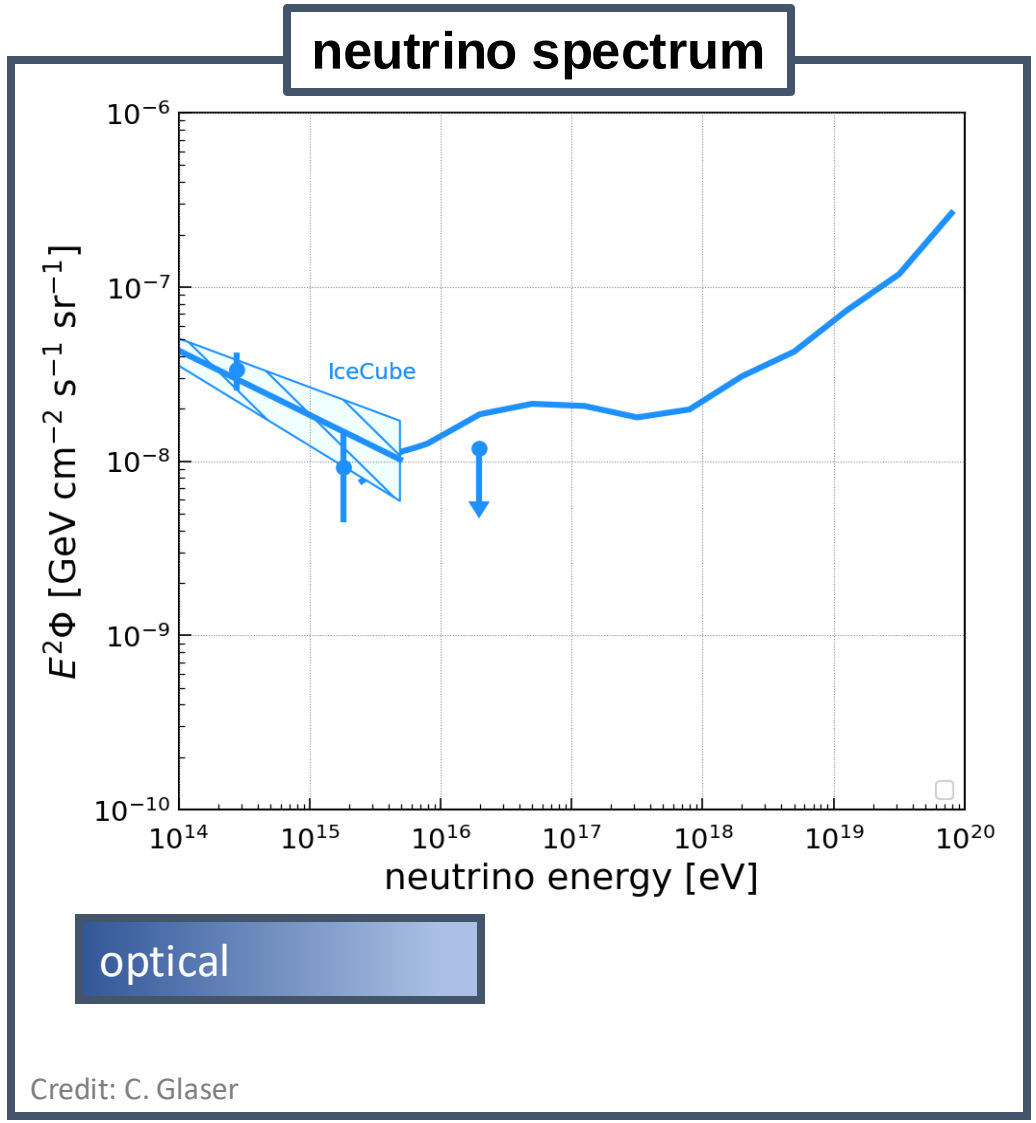
Credit: The RNO-G Collaboration

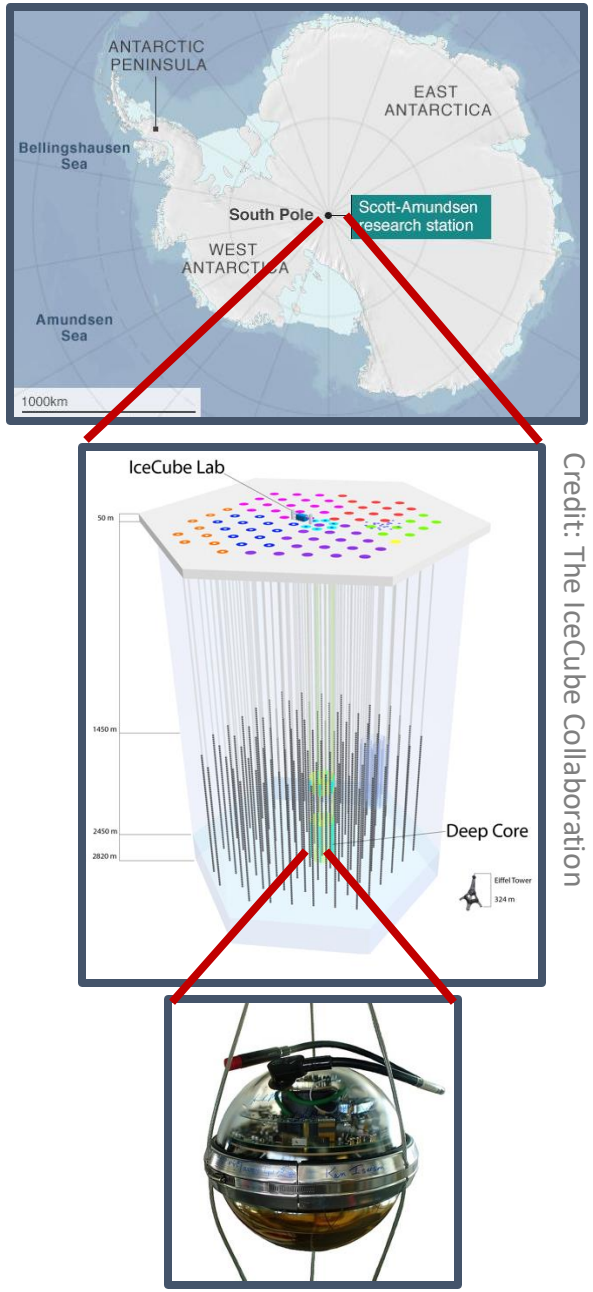
Cosmic neutrinos reach the earth and interact in the ice sheet.

The IceCube Neutrino Observatory

- Instruments a cubic kilometre of ice
- Successfully measured the cosmic neutrino flux in the TeV-PeV range
- Detected point sources of neutrinos (NGC1068, TXS 0506+056, galactic plane) -> see Jakobs' talk

But there is more…





Credit: The IceCube Collaboration

IceCube-Gen2 Radio

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- Successfully measured the cosmic neutrino flux in the TeV-PeV range
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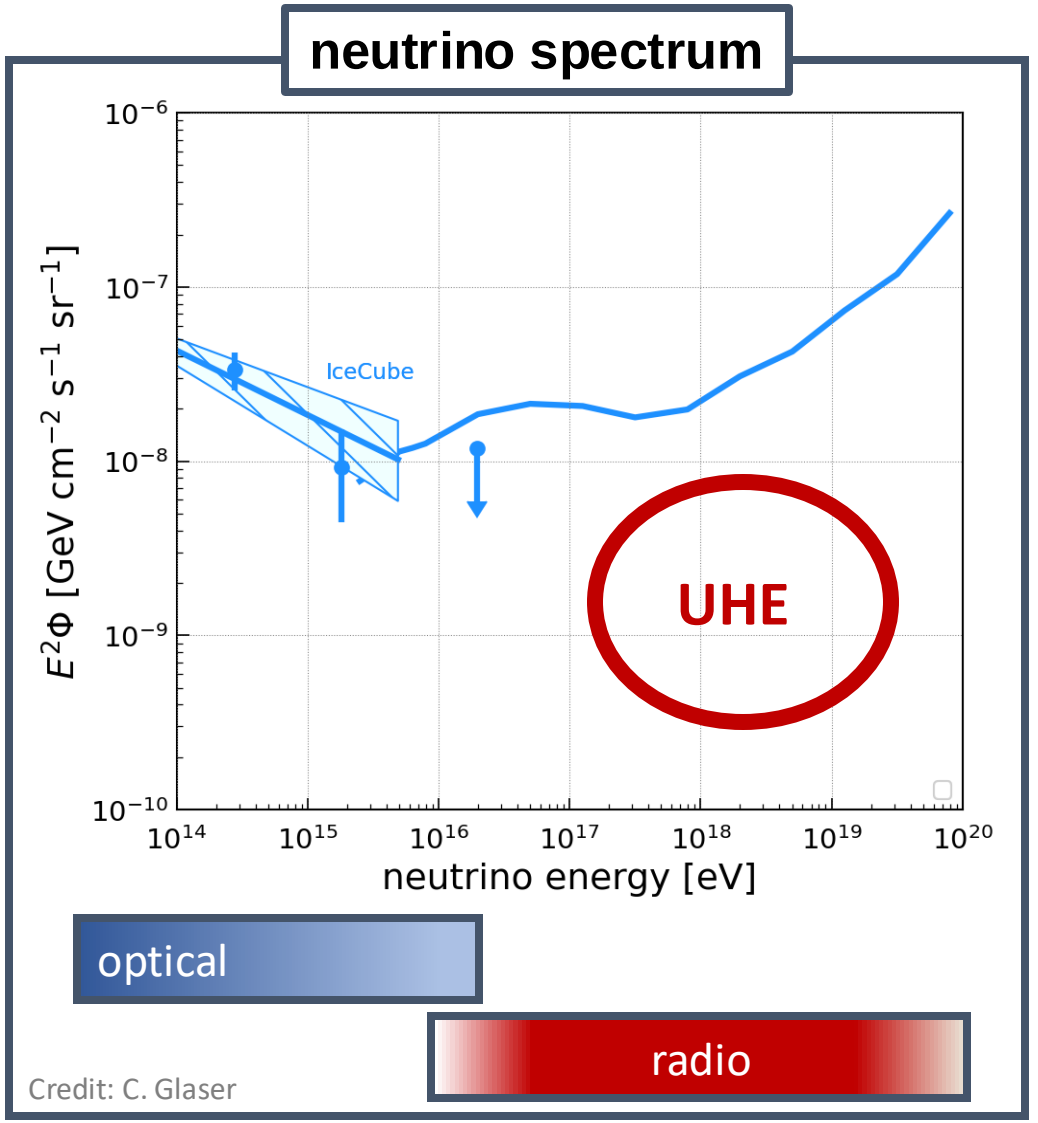
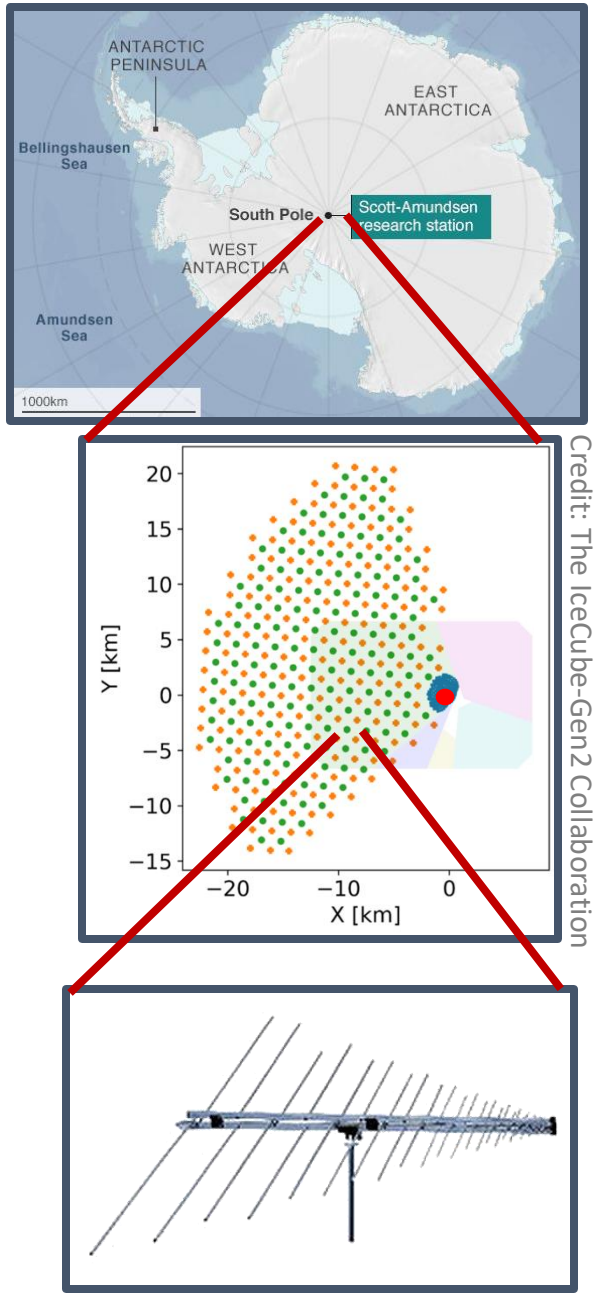
But there is more…

- Radio neutrino detection extends the reach into the EeV range
- Can cost-effectively instrument hundreds of cubic kilometres of ice

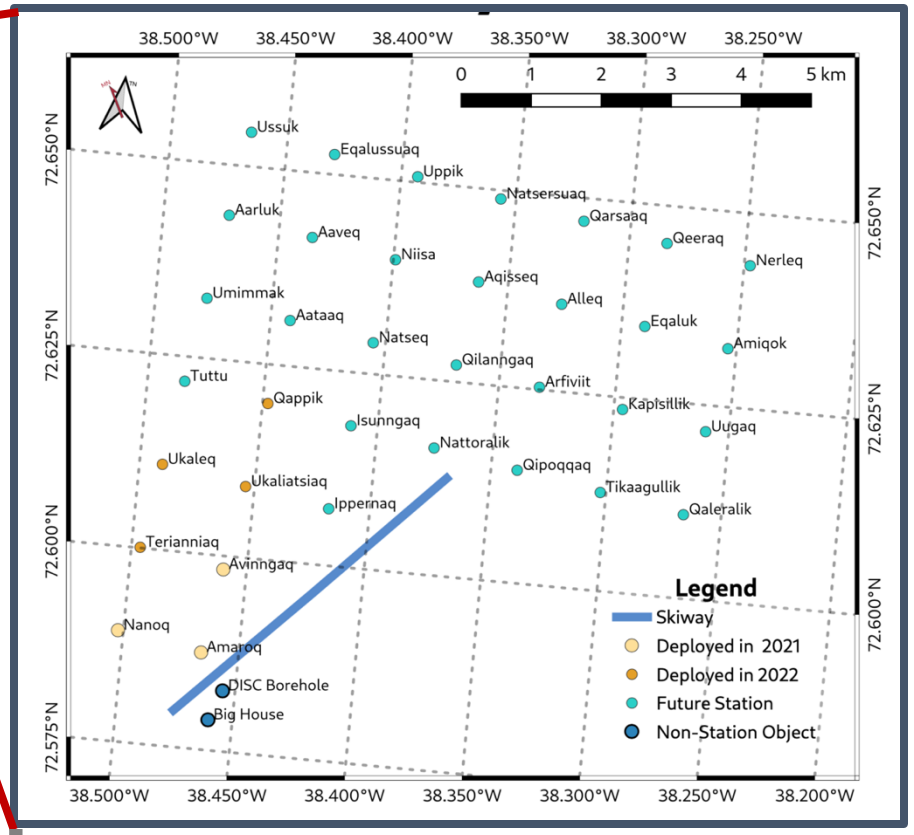




RNO-G

- Located in central Greenland

RNO-G

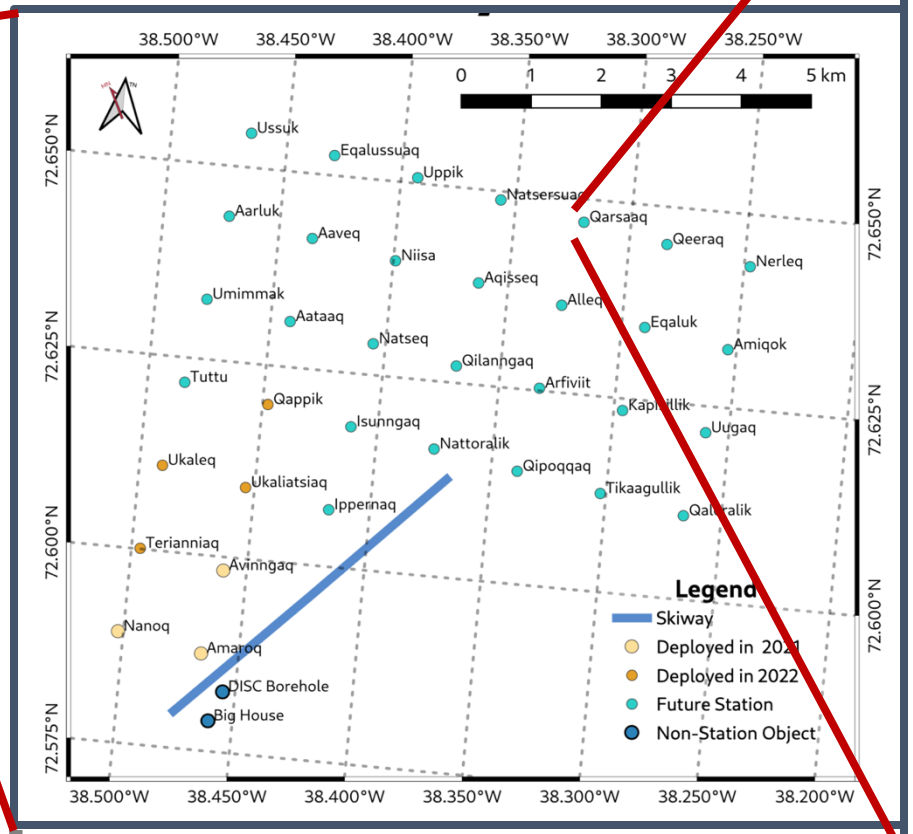


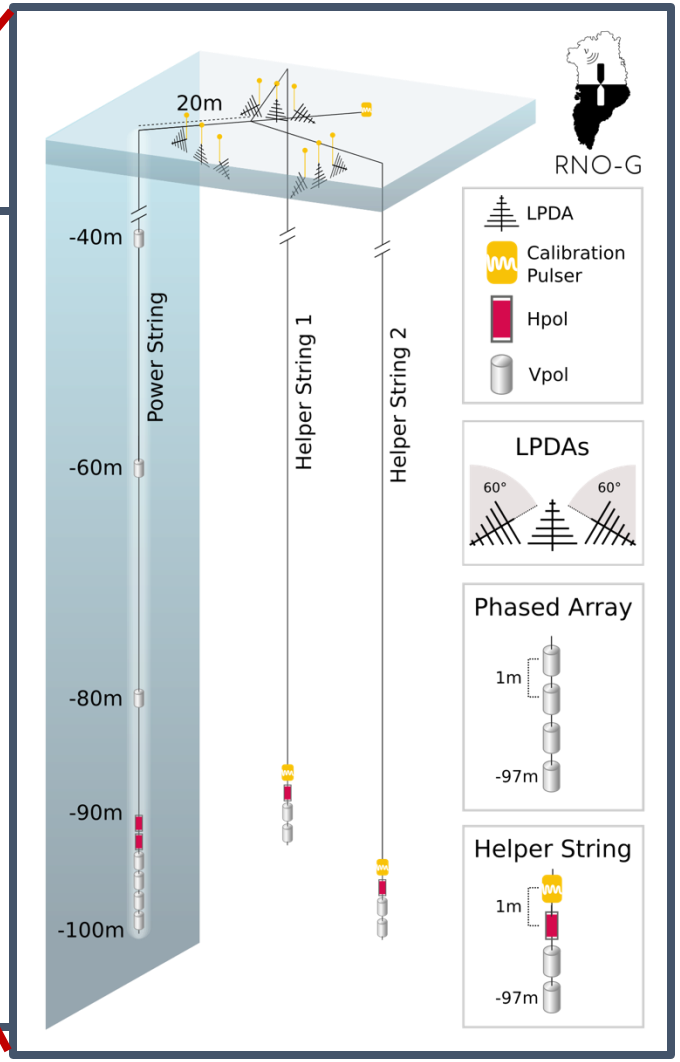
- Located in central Greenland
- 35 stations funded, with 8 stations completed

The layout of the RNO-G experiment.

NSF, GEOSummit, 2022
RNO-G, PoS (ARENA2022) 005, 2022
RNO-G, *JINST* **16** P03025, 2021

RNO-G





- Located in central Greenland
- 35 stations funded, with 8 stations completed
- Combines surface and deep antennas (24 in total) in a hybrid station design

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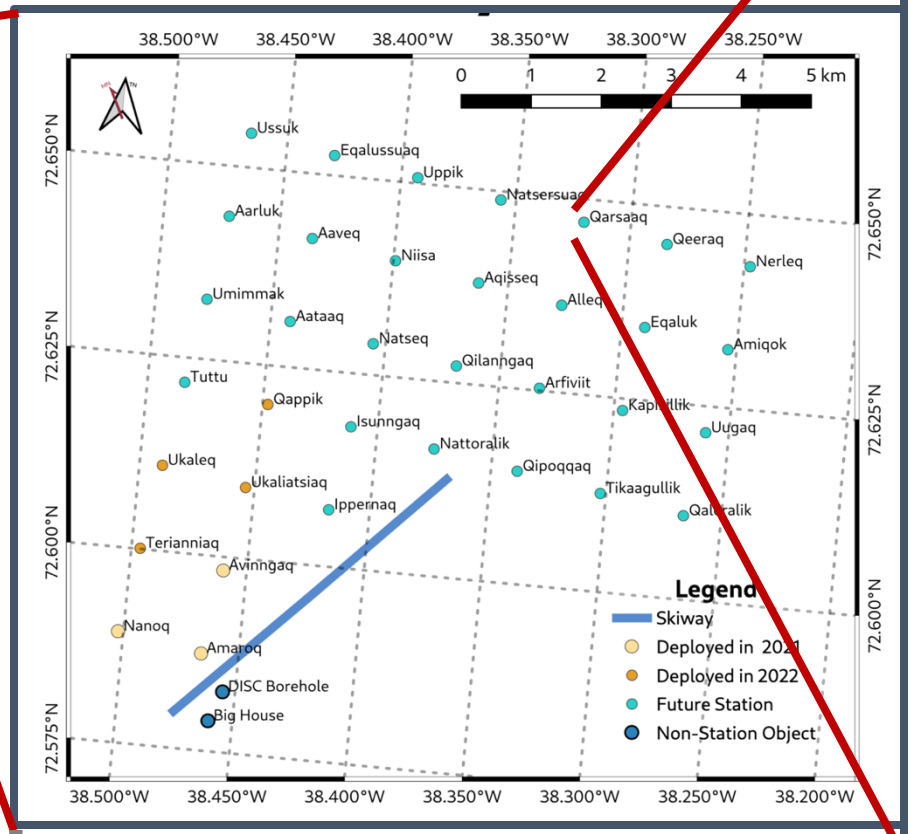
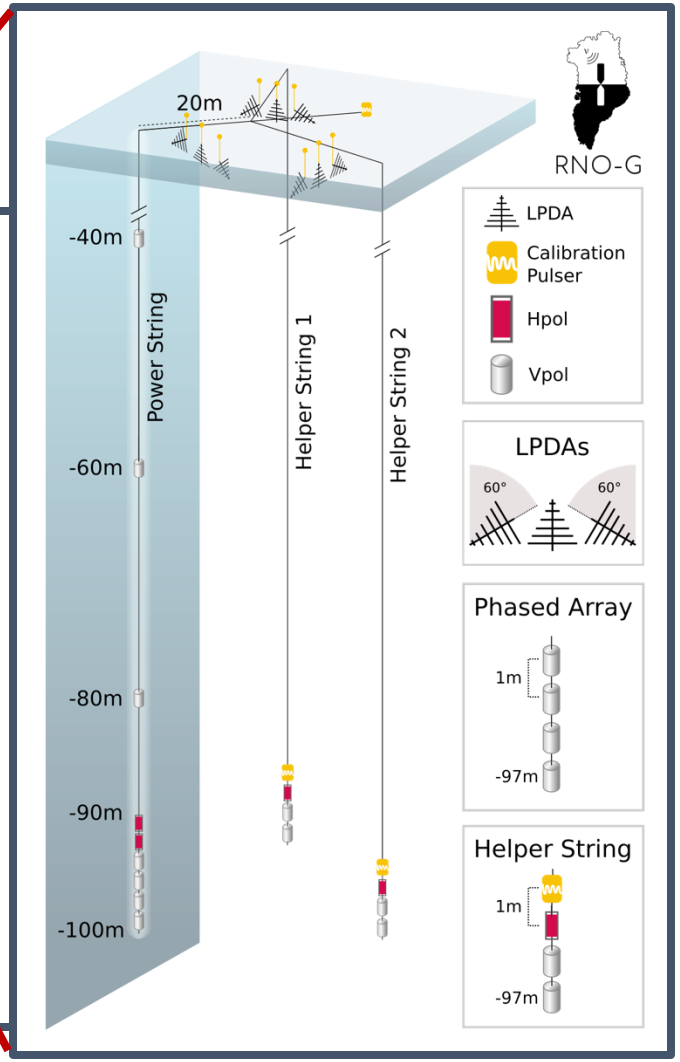




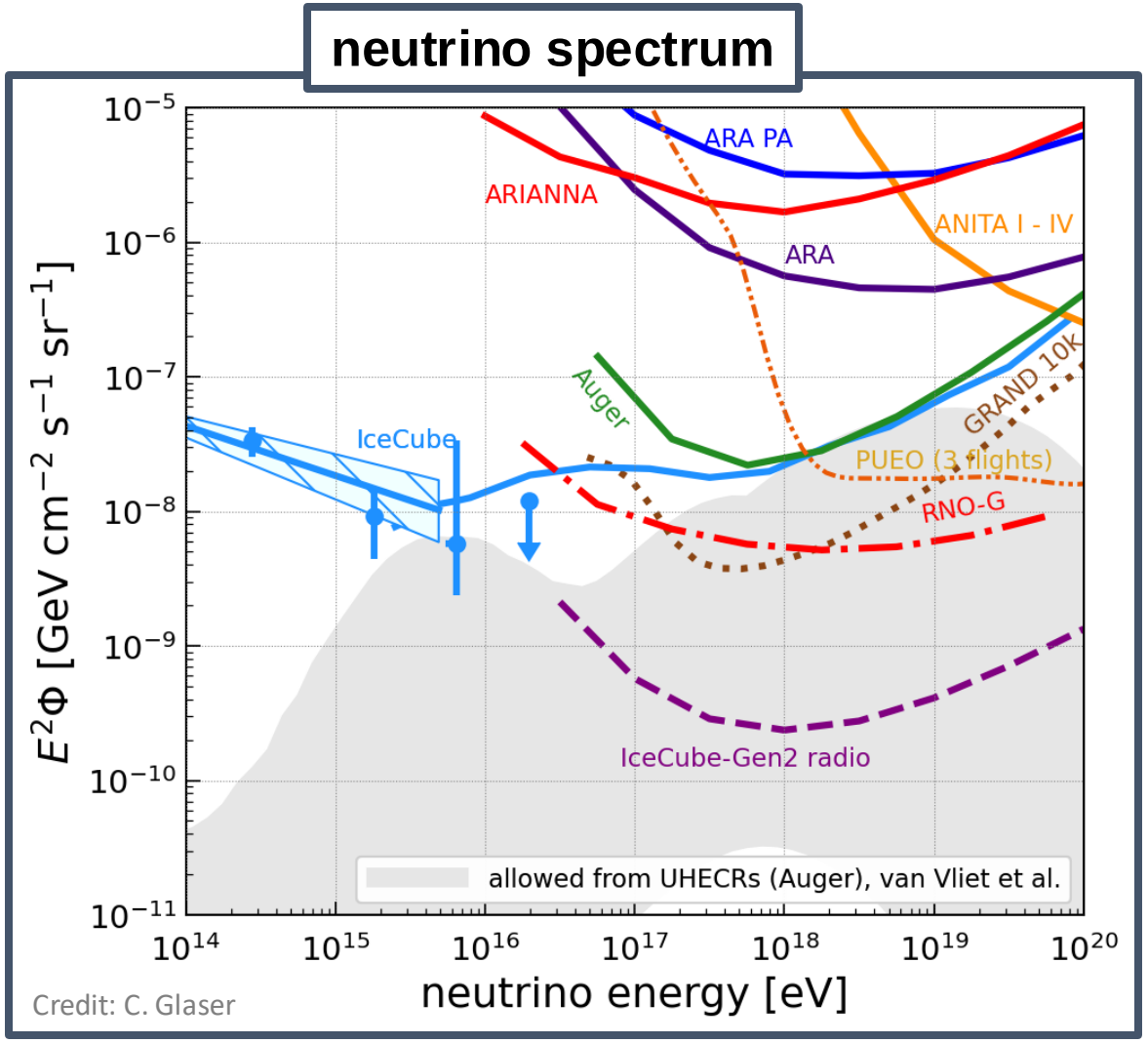
- Located in central Greenland
- 35 stations funded, with 8 stations completed
- Combines surface and deep antennas (24 in total) in a hybrid station design
- Can be used as a test site to prepare for IceCube-Gen2 Radio

The layout of the RNO-G experiment.

NSF, GEOSummit, 2022
RNO-G, PoS (ARENA2022) 005, 2022
RNO-G, *JINST* **16** P03025, 2021

Ultra-High Energy Neutrino Landscape

- Many different source predictions for the UHE flux
- Sources: GZK-neutrinos, AGNs, Pulsars, others?
- IceCube and Auger have set the most competitive limits in this energy region
- RNO-G is the first fully funded experiment big enough to be sensitive to some flux models
- IceCube-Gen2 Radio would be big enough to be sensitive to most flux models



Deployment of RNO-G

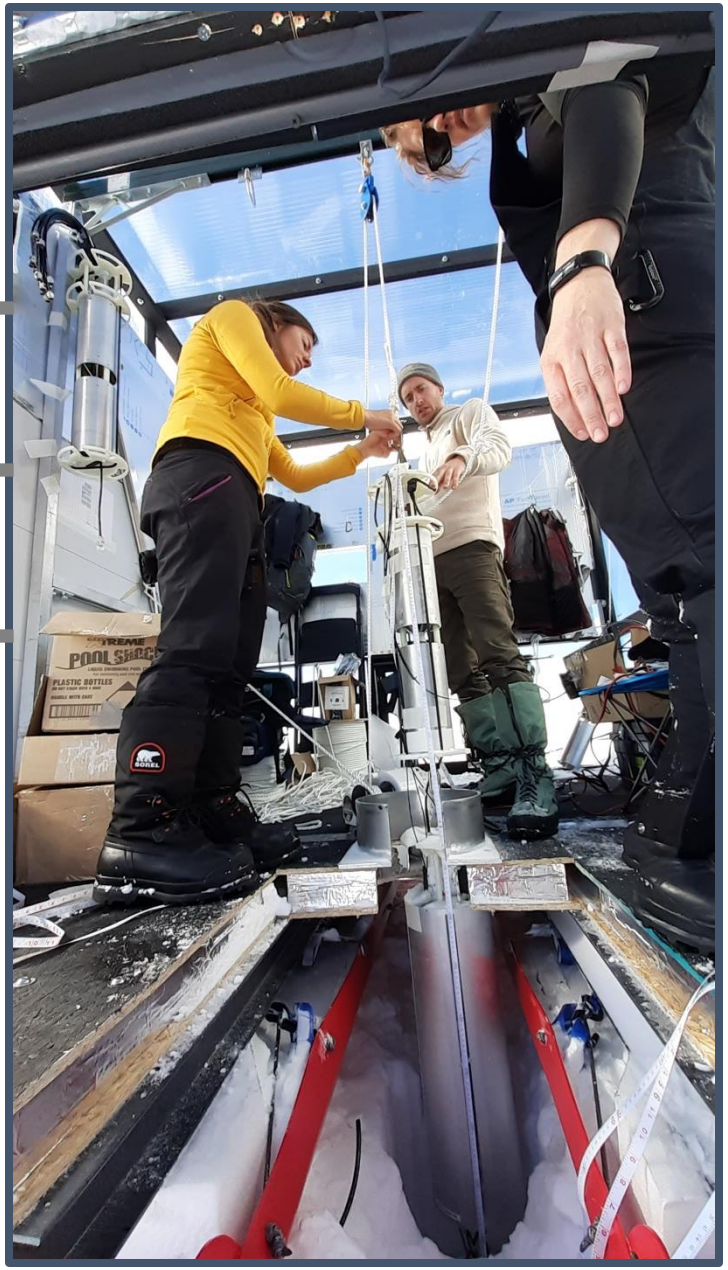
Me digging out a trench for an LPDA antenna.

Credit: The RNO-G Collaboration

Deployment of RNO-G

Me digging out a trench for an LPDA antenna.

Antennas being deployed into a borehole.



Credit: The RNO-G Collaboration

Deployment of RNO-G

Me digging out a trench for an LPDA antenna.

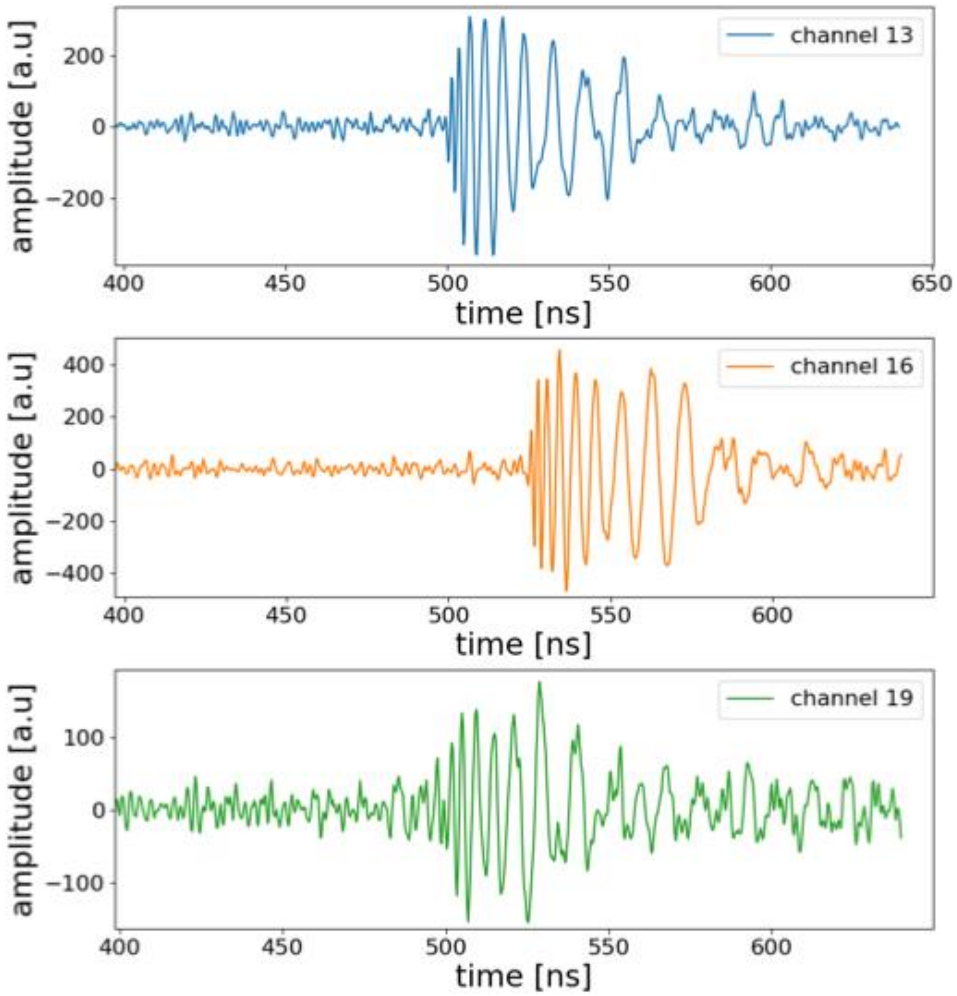
Antennas being deployed into a borehole.

Borehole drill in operation.

Credit: The RNO-G Collaboration

Physics Results: Cosmic Rays

- Our Antennas are also sensitive to cosmic rays
- The cosmic ray flux is well understood
- Important measurement to understand our detector and its systematics
- We have measured first candidate events, the full analysis is still ongoing



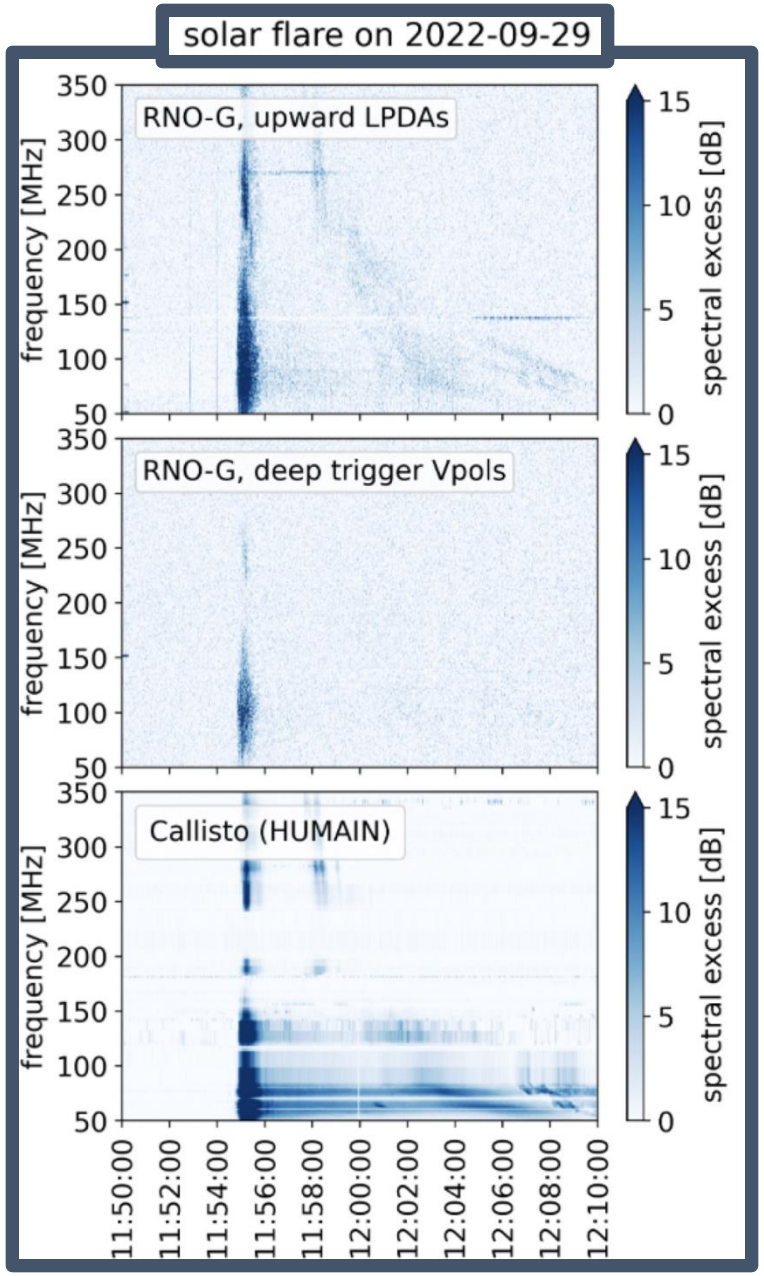
First cosmic ray candidate measured by the RNO-G experiment.
RNO-G, PoS (ICRC2023) 259, 2023

Physics Results: Solar Flares

- Solar flares emit radio signals measurable with our antennas
- Several solar flares have been measured and reconstructed with RNO-G
- We reconstructed the signal arrival direction to sub-degree precision

RNO-G, *AP* **164** 103024, 2024

Spectral excess in the RNO-G detector during a solar flare.



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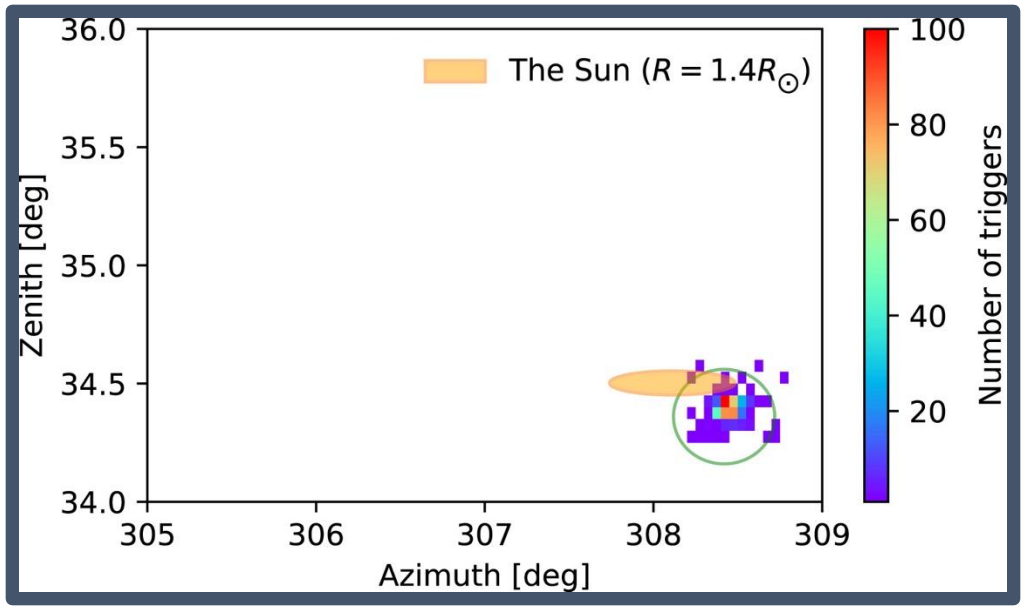

Reconstructed signal arrival direction of the triggered signals.

RNO-G, *AP* **164** 103024, 2024

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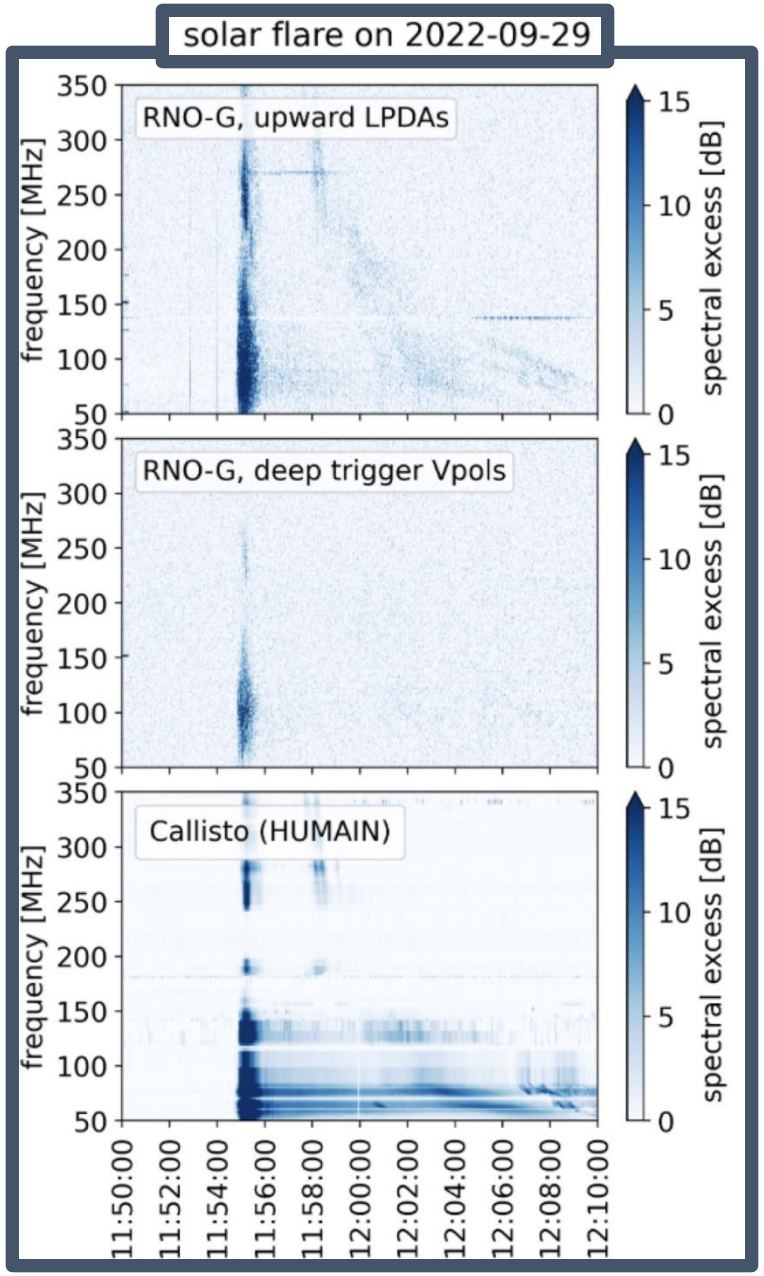
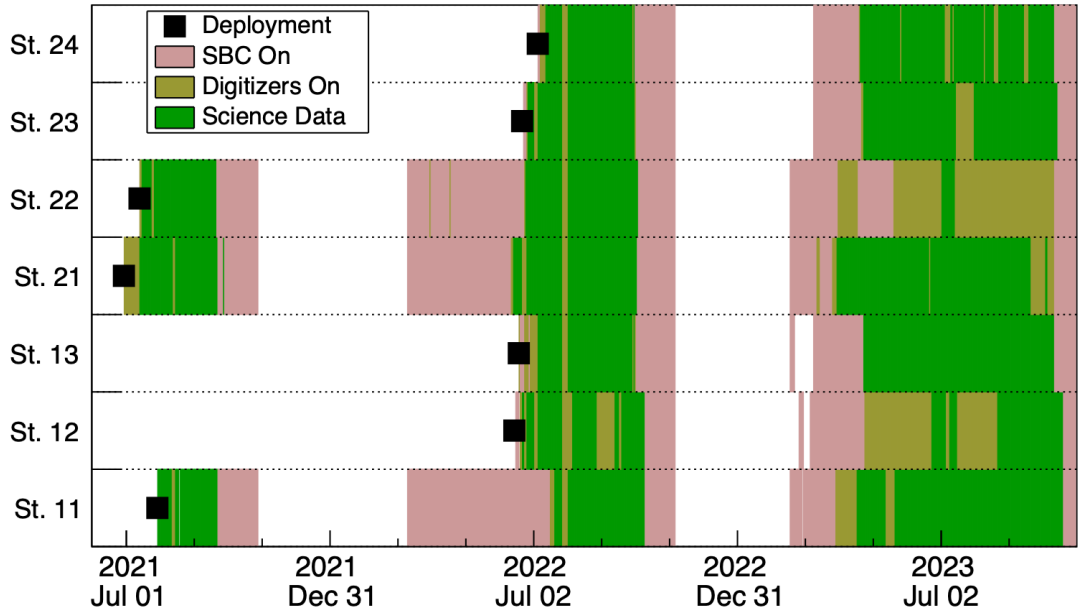


Projects in Uppsala: Autonomous Power System

- Arctic conditions make the supply of power difficult (single station uses <30 W)
- Batteries have to survive the cold during night/winter
- Wind turbines can be used to extend the up-time
- Our group in Uppsala tests wind turbines and develops batteries and electronics for this power system

Credit: The RNO-G Collaboration



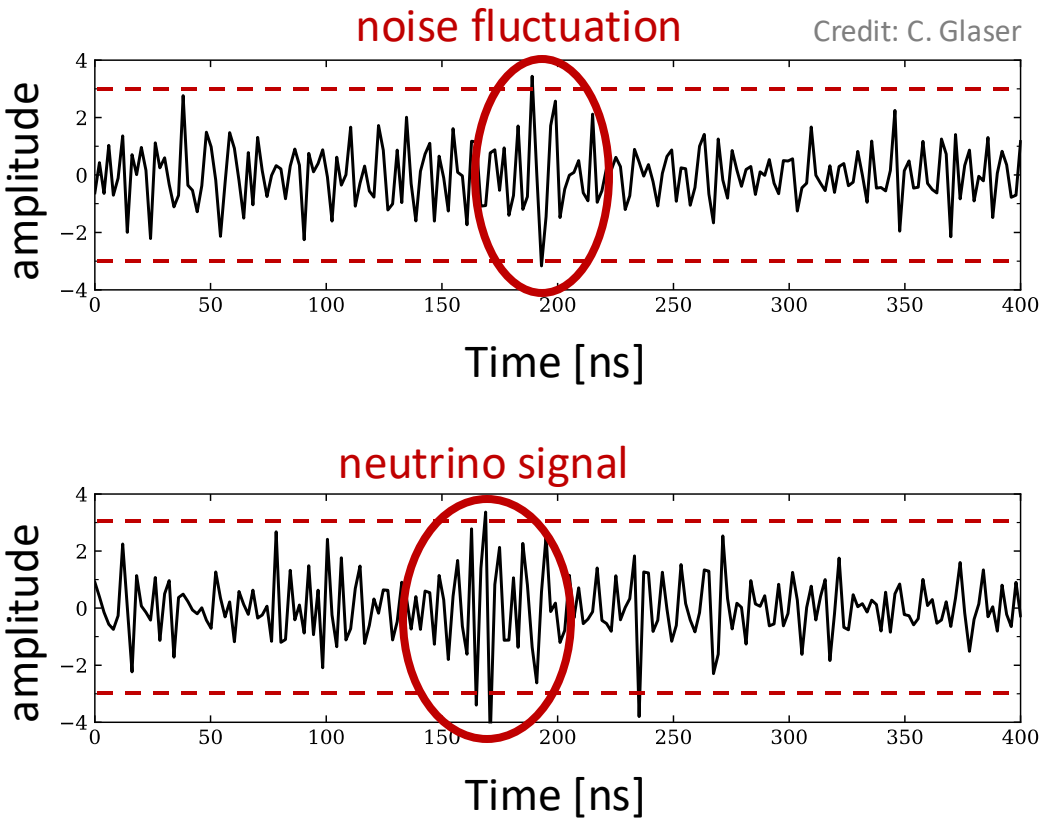
Power system of an RNO-G station. (solar panels, wind turbine and a divert load build in Uppsala)

Current up-time of the RNO-G stations.

Credit: The RNO-G Collaboration

Projects in Uppsala: Deep-Learning Trigger

- Data can't be stored continuously
- Currently, simple threshold triggers are used to record a signal
- The shape of the signal can help significantly in identifying neutrino events
- Our group in Uppsala is developing deep-learning algorithms to identify neutrino signals
- Proof of concept study: RNO-G, PoS (ICRC2023) 1100, 2023



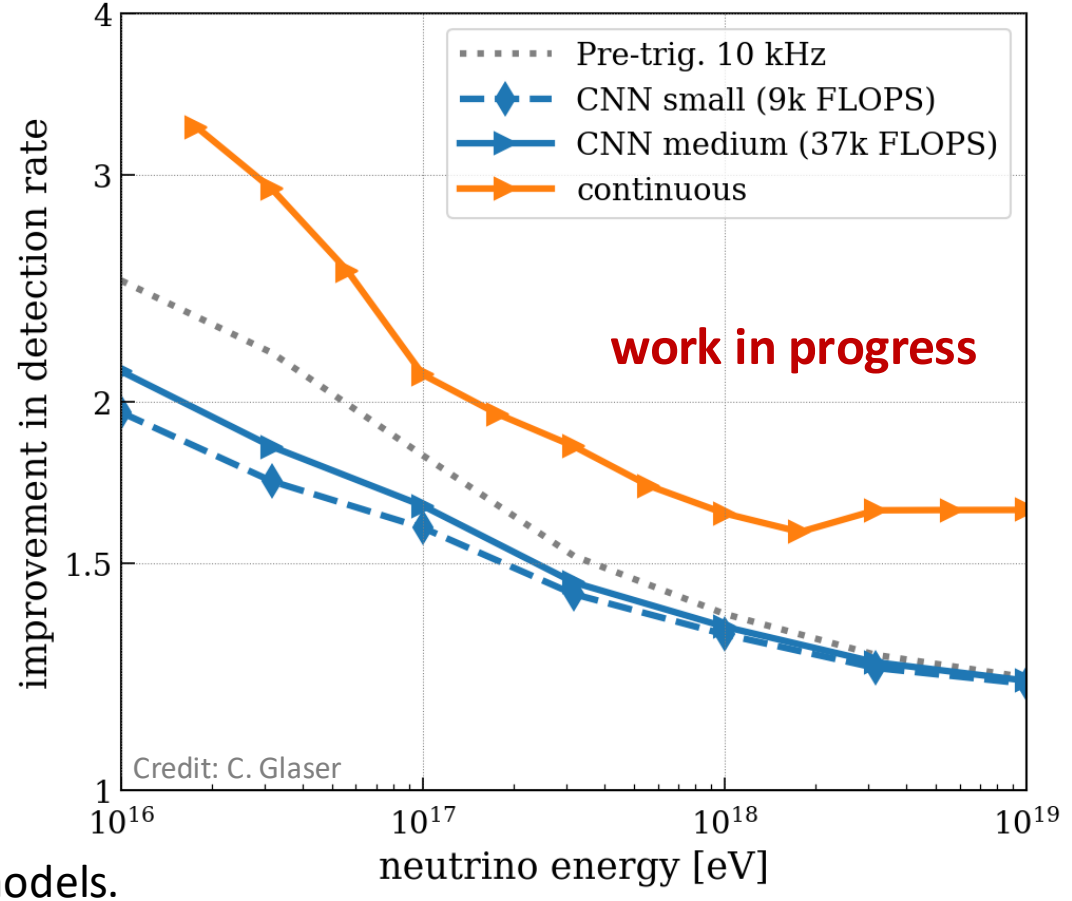
Triggered signal from thermal noise fluctuations and from a neutrino.

Projects in Uppsala: Deep-Learning Trigger - Impact

Part of ERC project NuRadioOpt

European Research Council
Established by the European Commission

- Expect a major improvement in the detection rate (up to a factor 3)
- Biggest impact at lower energies -> Trigger is dominated by thermal noise
- Improvements equivalent to building a more than three times larger detector, at essentially no additional costs

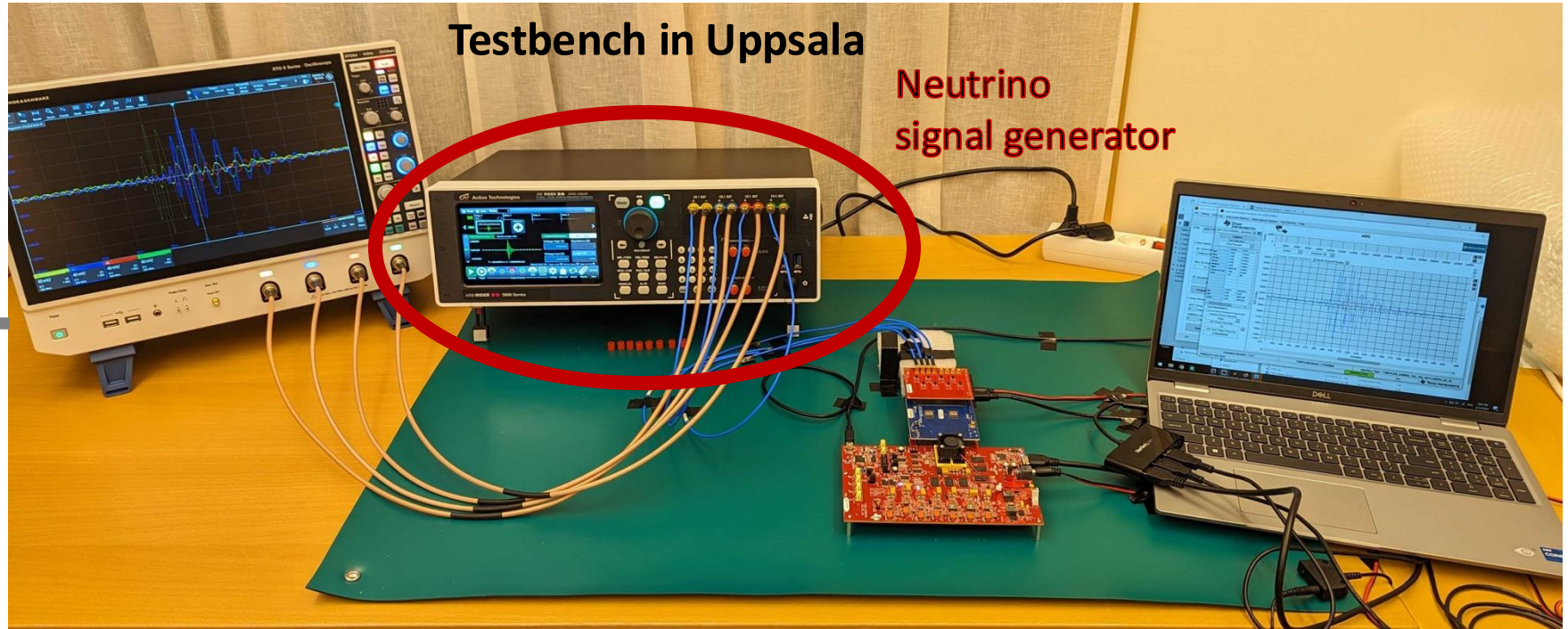


Detector rate improvements with different deep-learning models.

Projects in Uppsala:
New DAQ for Advanced Algorithms

- New ADC generation available (JESD204B interface)
- Better data quality and opportunities for advanced triggers
- High speed and low power (~1GHz, 12bit at 0.5W/channel)
- FPGA engineers from SU and UU work on the implementation

Testbench in Uppsala




Whittier College
Summit Station
Uppsala University
DESY-Zeuthen
FAU-Erlangen
Radboud University
Université Libre de Bruxelles
Vrije Universiteit Brussels
Ghent University
University of Nebraska-Lincoln
University of Kansas
University of Wisconsin-Madison
University of Chicago
The Ohio State University
Pennsylvania State University
University of Alabama
University of Delaware
University of Maryland
RNO-G
Collaboration
April 2024
THE UNIVERSITY OF CHICAGO
WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON
VUB
VRIJE UNIVERSITEIT BRUSSEL
ULB
UNIVERSITÉ LIBRE DE BRUXELLES
DESY.
FAU
Friedrich-Alexander-Universität Erlangen-Nürnberg
KU
THE UNIVERSITY OF KANSAS
PennState
THE OHIO STATE UNIVERSITY
UNIVERSITY OF MARYLAND
THE UNIVERSITY OF ALABAMA
WHITTIER COLLEGE
1887
GHENT UNIVERSITY
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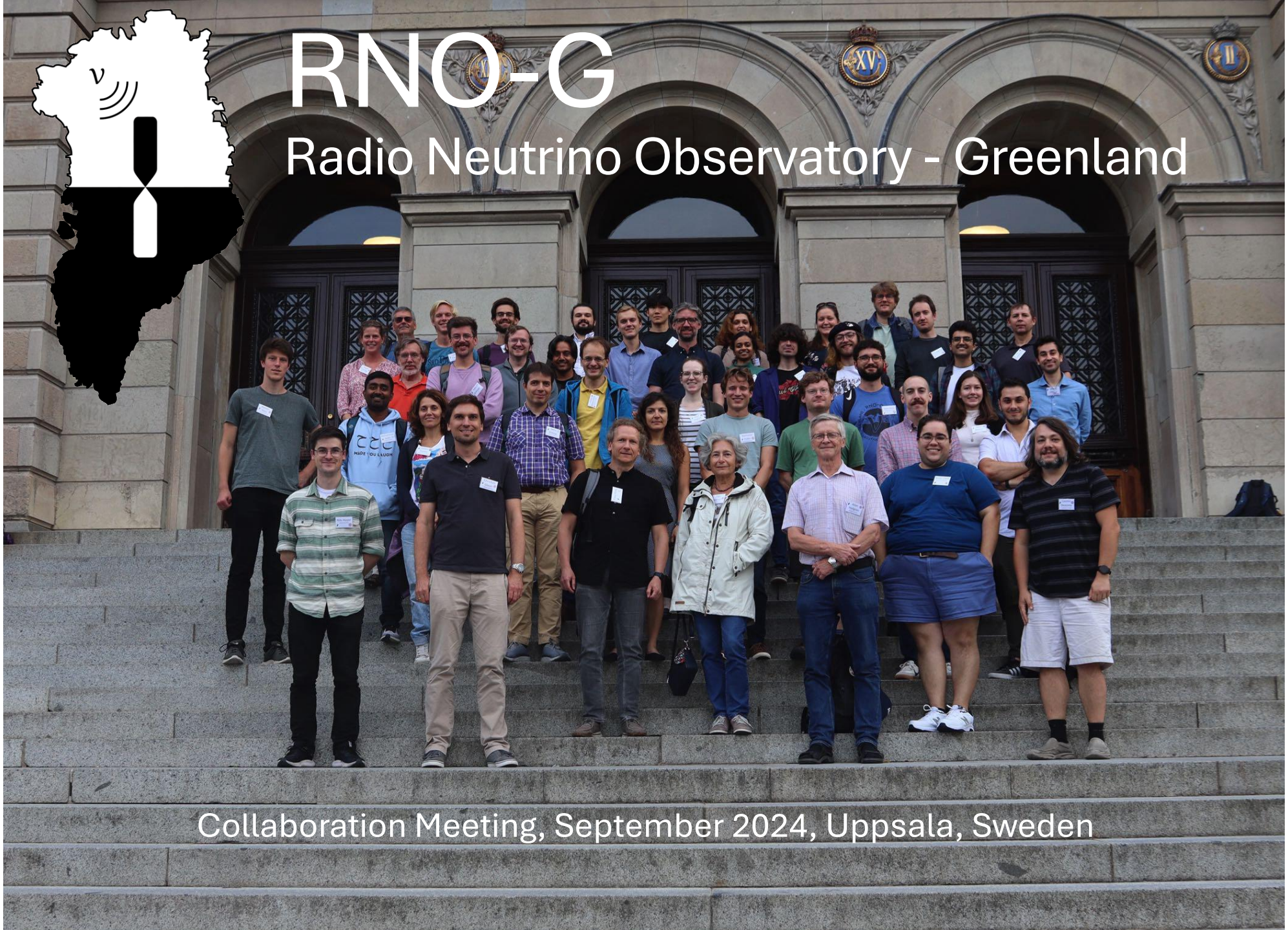
BERGISCHE UNIVERSITÄT WUPPERTAL
UPPSALA UNIVERSITET
Radboud University
UNIVERSITY OF Nebraska Lincoln

RNO-G

Radio Neutrino Observatory - Greenland



Collaboration Meeting, September 2024, Uppsala, Sweden

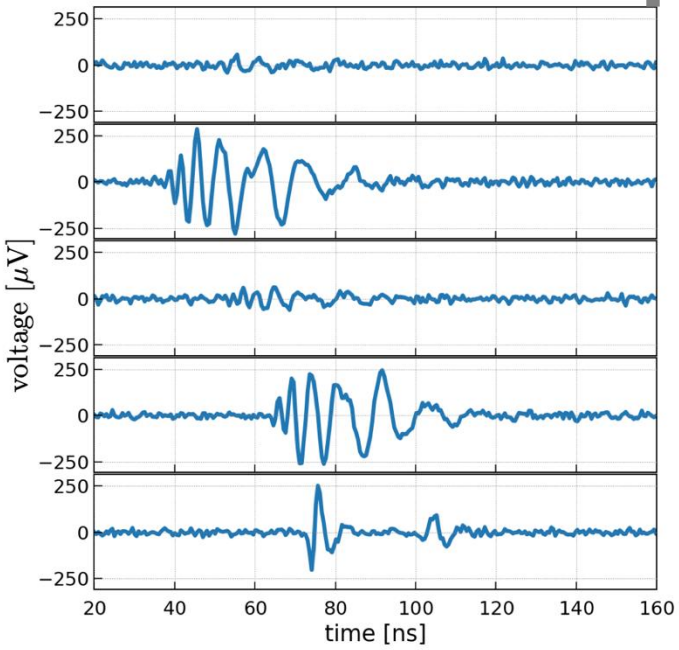
Backup

Usually we attack the science, but sometimes science strikes back

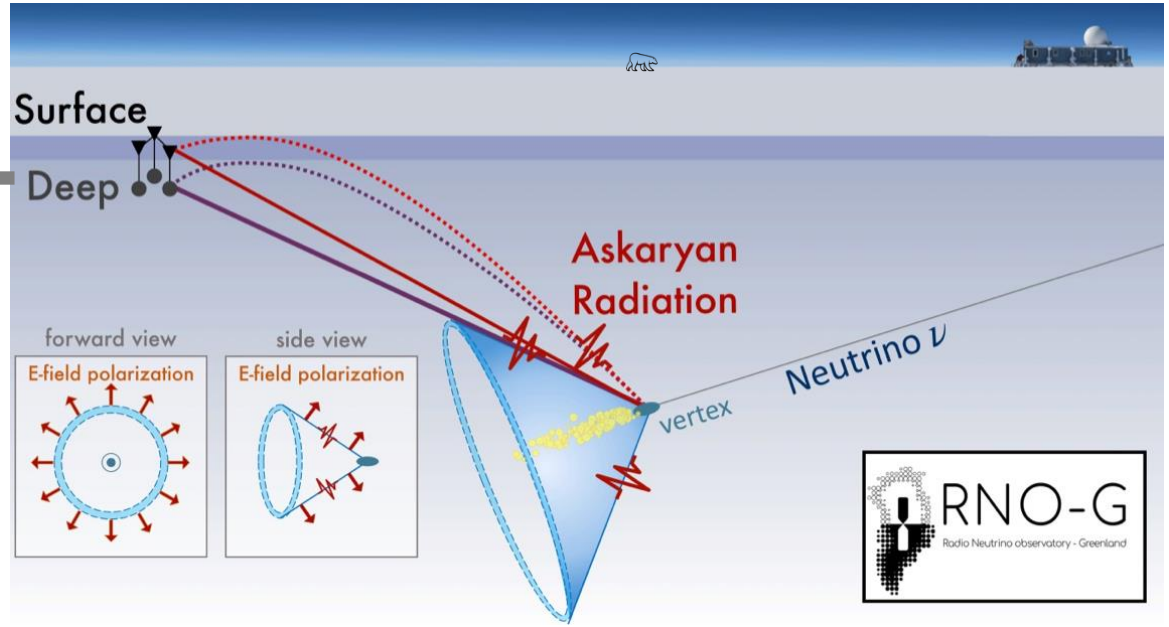
How to Measure Cosmic Neutrinos with Radio?

- The neutrino collides with a nucleus in the ice
- The collision induces a particle shower
- The particle shower creates a radio pulse via Askaryan emission
- The radio pulses propagate through the ice until reaching an antenna
- The pulse is measured by one or multiple radio antennas

Simulated radio pulses in the five surface stations.
(Glaser et al., 2023)

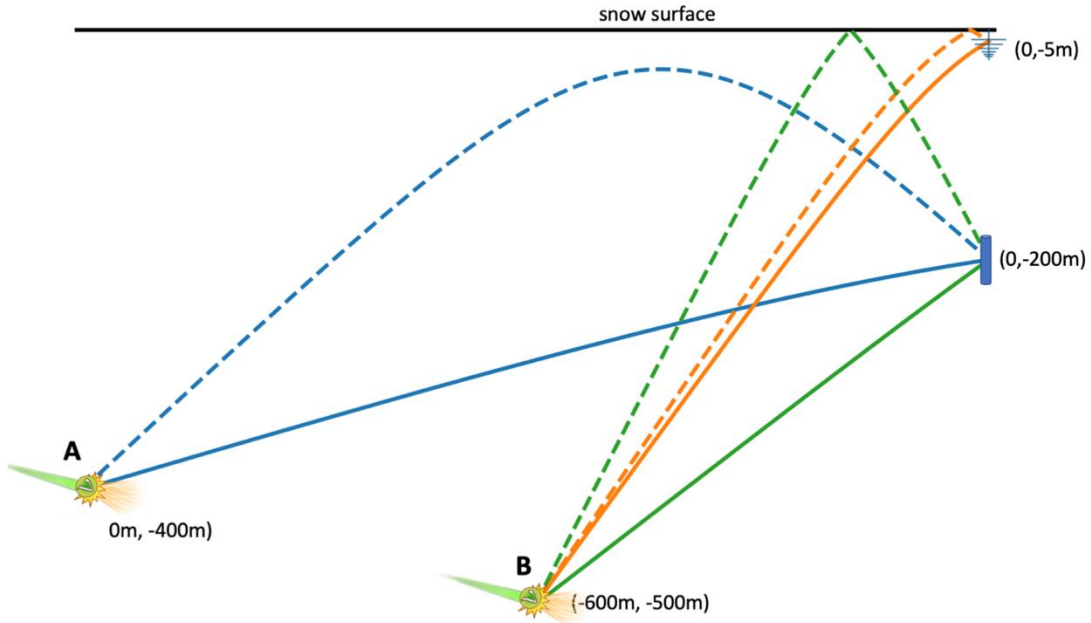


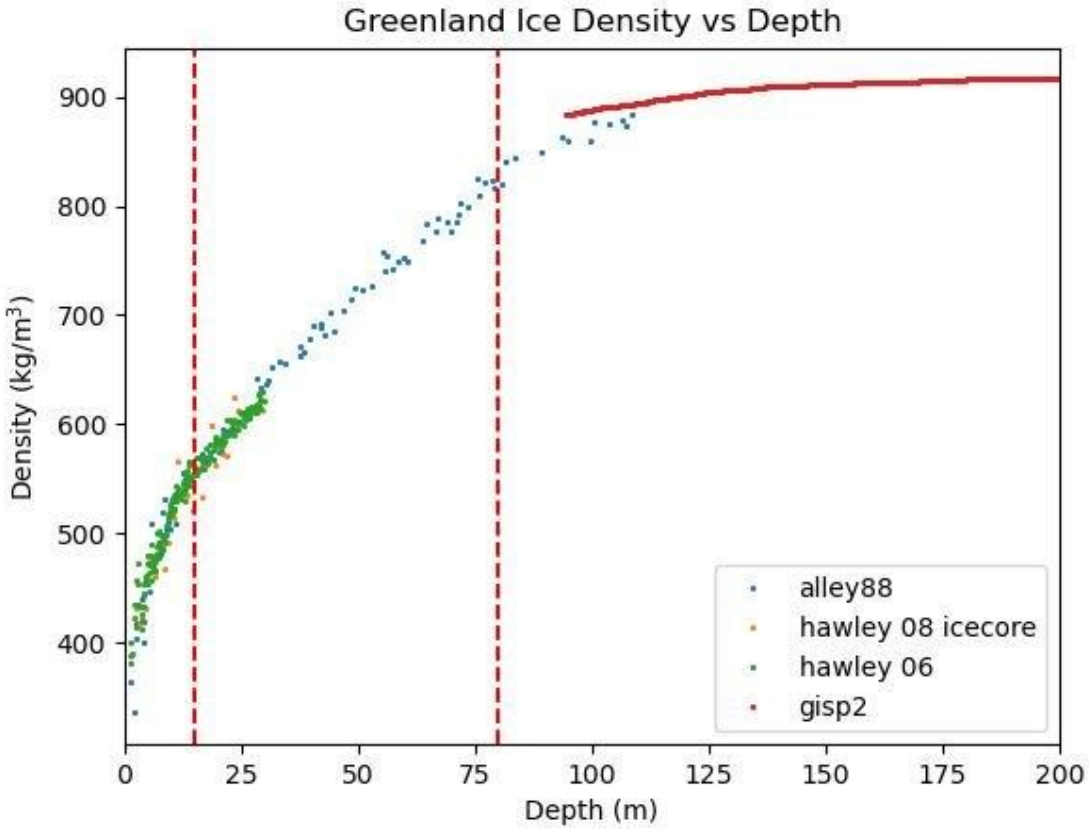
Schematic drawing of the detection principle via Askaryan radiation.
(RNO-G, 2021)

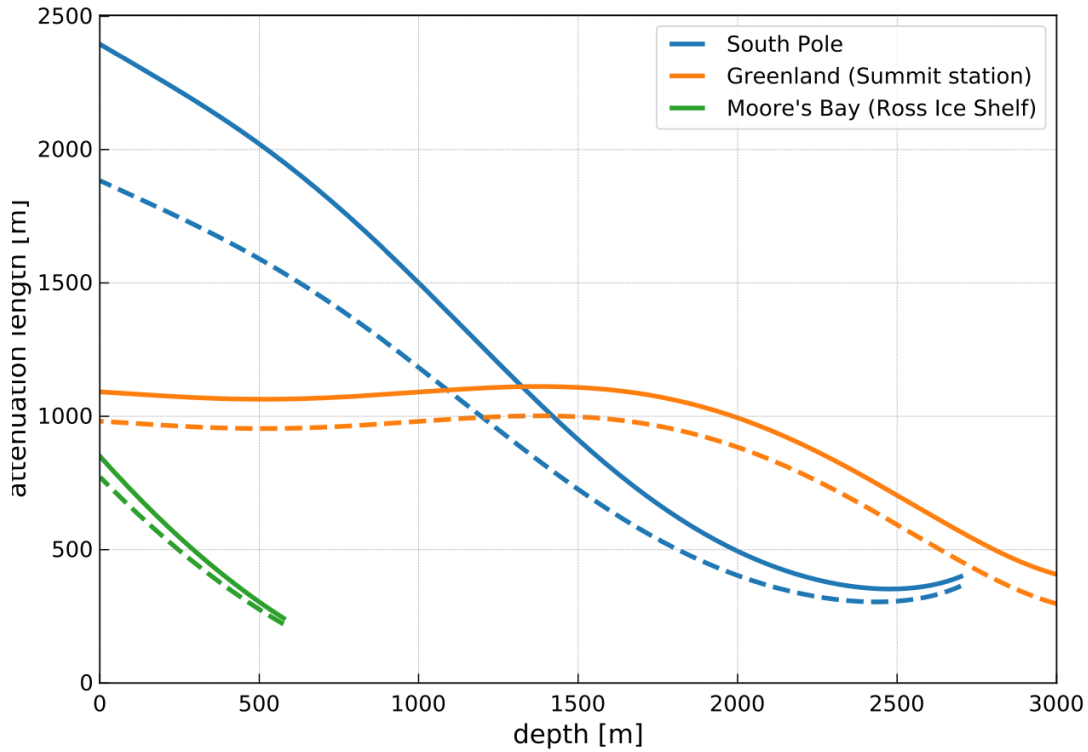


RNO-G: Antennas

Ice effects


snow surface
(0,-5m)
(0,-200m)
A
0m, -400m)
B
(-600m, -500m)


Greenland Ice Density vs Depth
Density (kg/m³)
Depth (m)
alley88
hawley 08 icecore
hawley 06
gisp2


South Pole
Greenland (Summit station)
Moore's Bay (Ross Ice Shelf)
attenuation length [m]
depth [m]

Calibration Measurements