

# Skyradio

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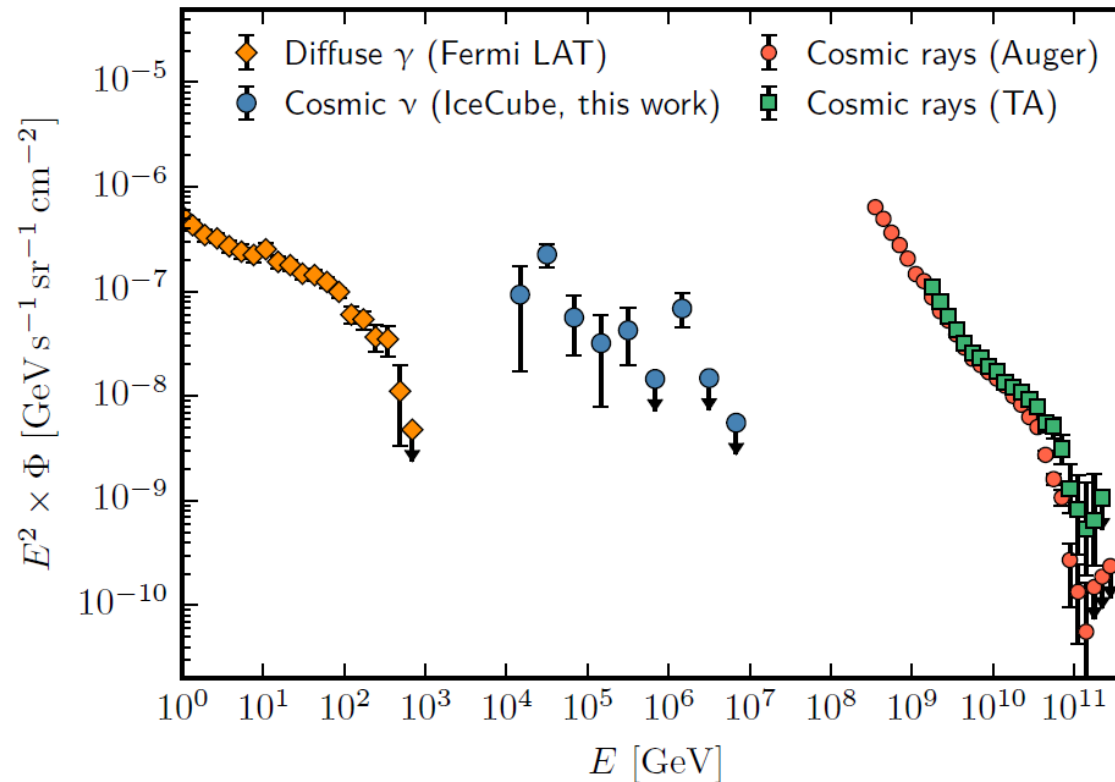
[nick@icecube.wisc.edu](mailto:nick@icecube.wisc.edu)

<http://www.iihe.ac.be>

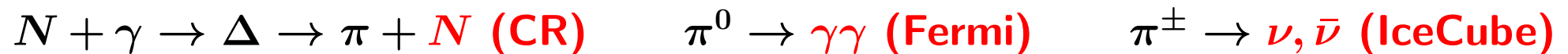


## Overview

The Physics Case	1
Radio Detection	2
Radar Reflection	6
The IceCube High-Energy Extension	8
The Radio Neutrino Observatory Greenland	9
The GRAND project	17
The LOFAR NuMoon project	19
Summary and Outlook	21



- **Common astrophysical sources ?**



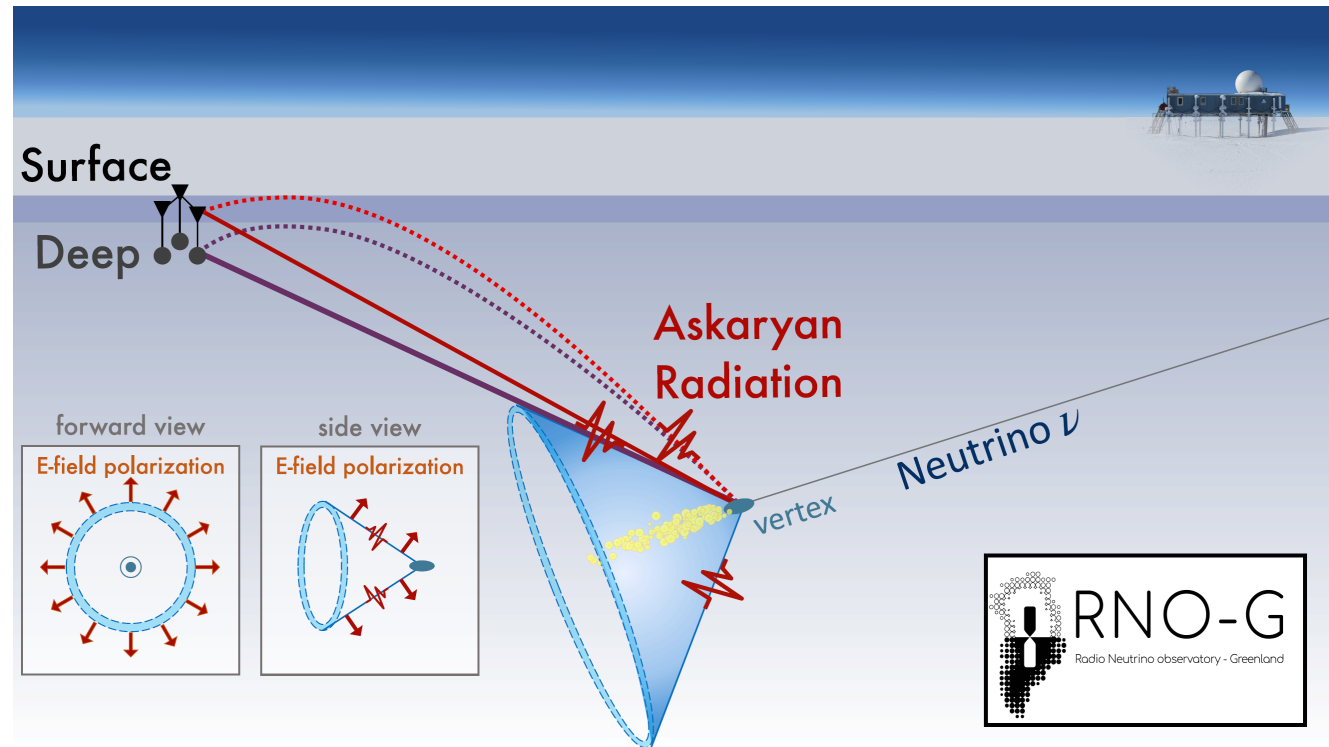
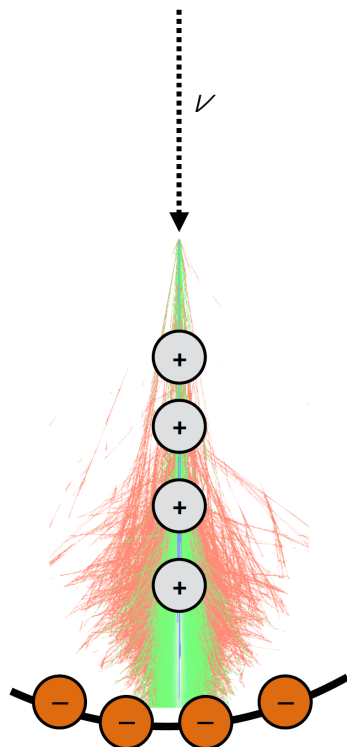
- **Cosmic  $\nu$  spectrum ?  $\rightarrow$  Need more (multi) PeV data**

- **$E_\nu \approx 4\%$  of  $E_N \rightarrow$  Search for  $10^{18}$  eV (GZK) neutrinos**

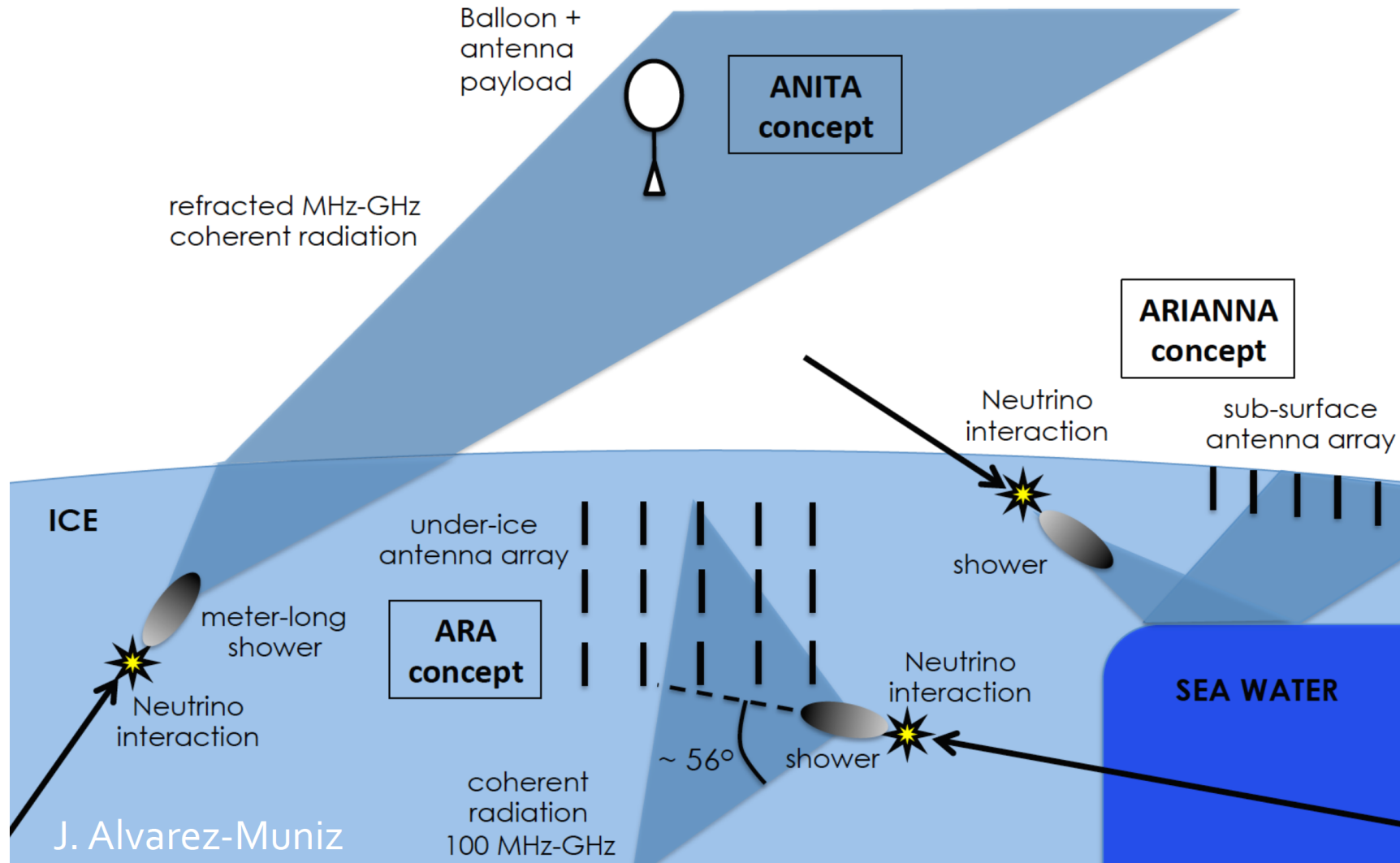
- Current 1 km<sup>2</sup> IceCube detector is too small for the low >PeV fluxes  
 ~5 events ~PeV detected in 10 years → Need >100 times larger detector  
 $\lambda_{att} \sim 200\text{m}$  for light → Amount of light sensors and drilling not feasible

Radio signals of  $\nu$  showers

- Long (km-scale)  $\lambda_{att}$  → Cost effective way to cover large (~500 km<sup>2</sup>) area

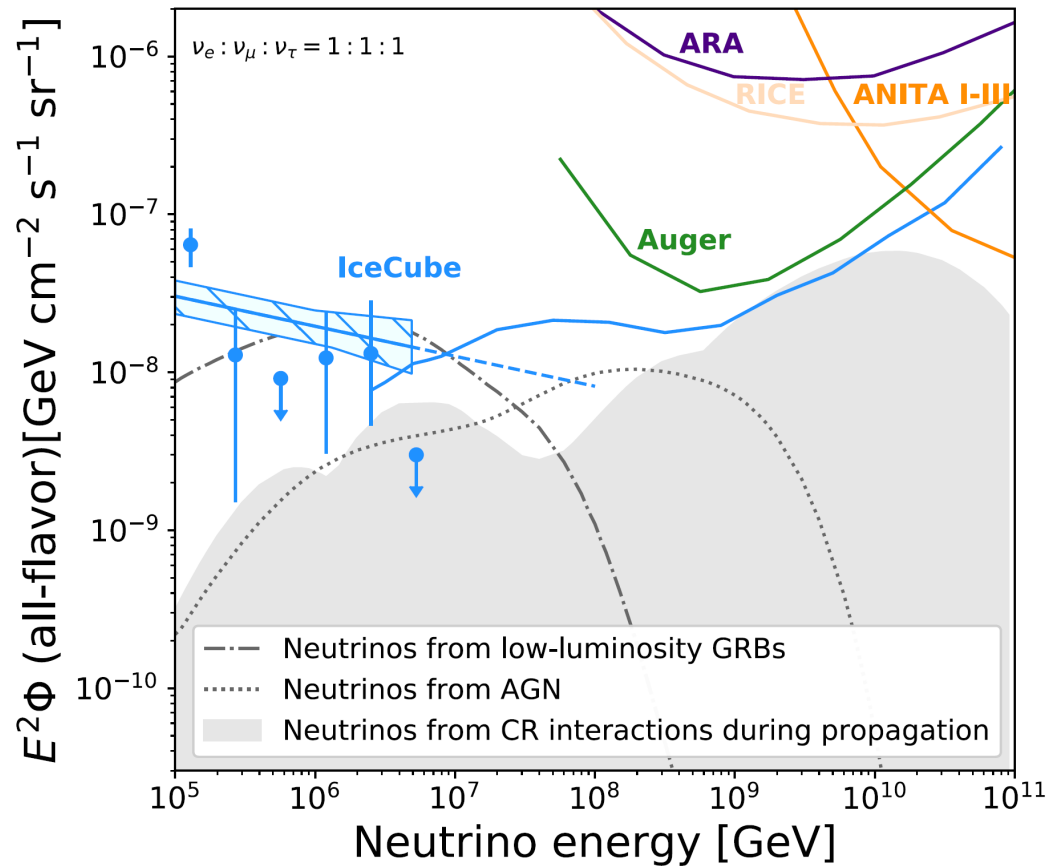


Some early projects : ANITA, ARA and ARIANNA





## The multi-PeV neutrino landscape



### Prospects for radio detection

- Detect events  $> 10^{17}$  eV (100 PeV)

**GZK  $\nu$  : Proof of GZK effect**

or : **Insight in UHECR composition**

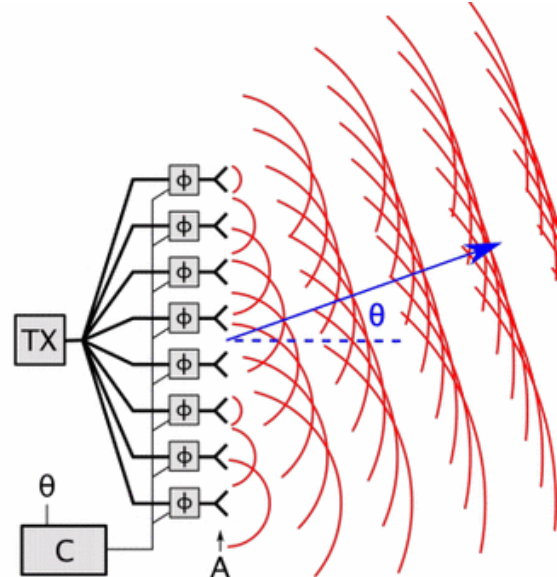
- \* **IceCube-Radio energy gap**

Currently not covered

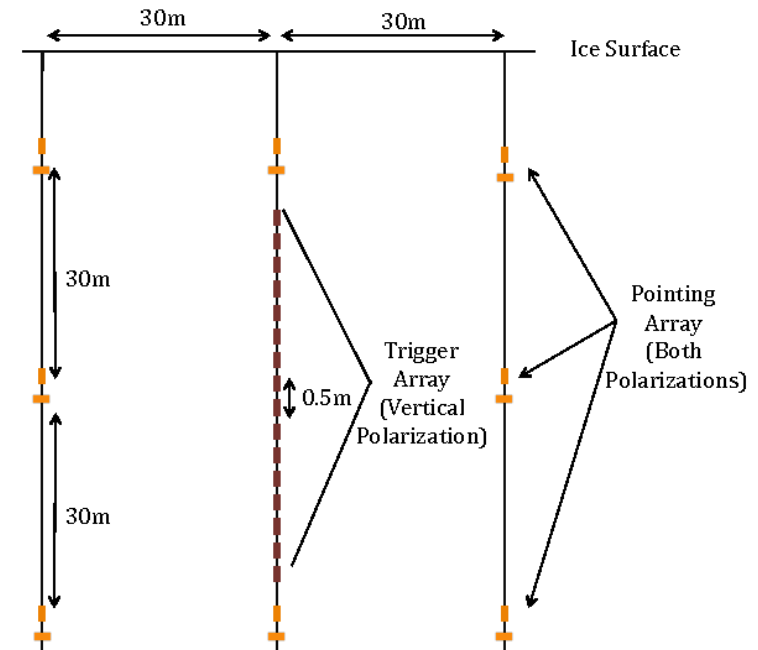
**Try to lower the energy threshold**

The phased array trigger approach

Well known technique



Testbed implemented in ARA

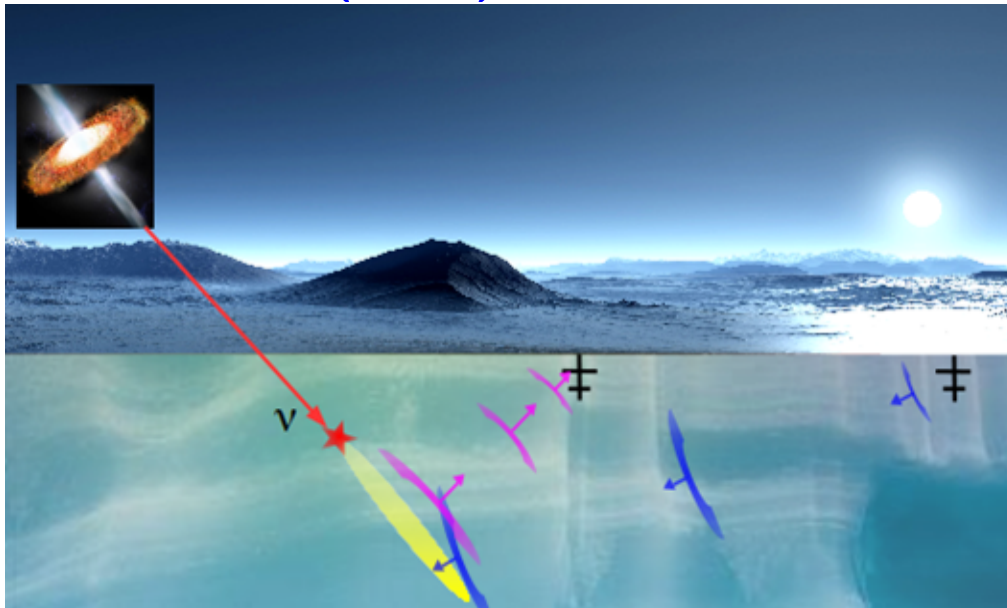


- Similar for receiving signals (e.g. radio astronomy)
- Using multiple beams → Directional sensitivity

- Provide trigger to ARA antennas  
Directional info → Reduce noise  
Lower ARA threshold for  $\nu$  detection

Radar reflections from the shower plasma

New idea (VUB) for  $E < 10^{17}$  eV

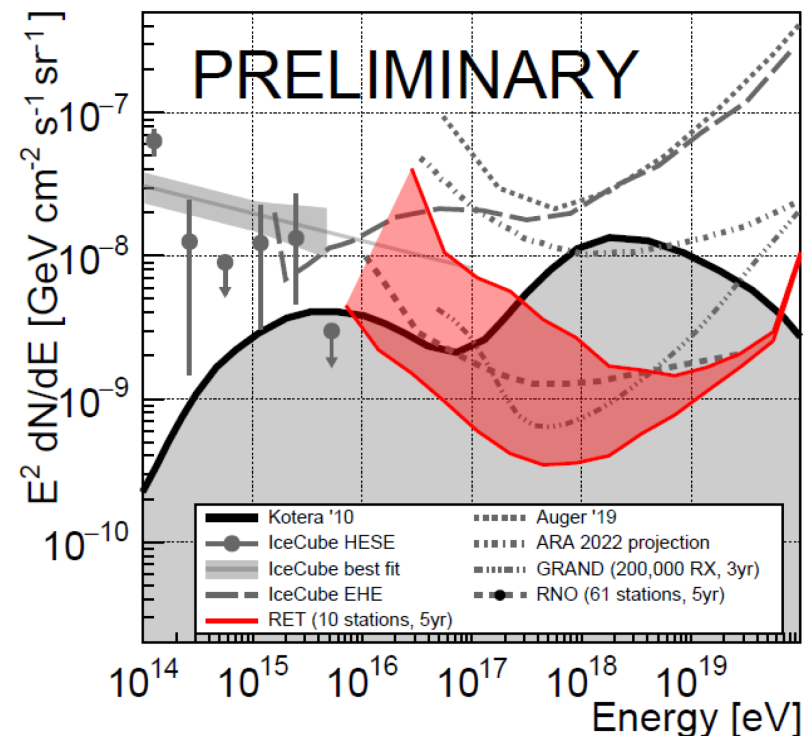


[Credit Krijn de Vries]

- Signal scales with transmit power  
→ Allows low energy threshold
- Beam tests confirmed the principle  
(PRL 124 (2020) 091101)

Simulation results

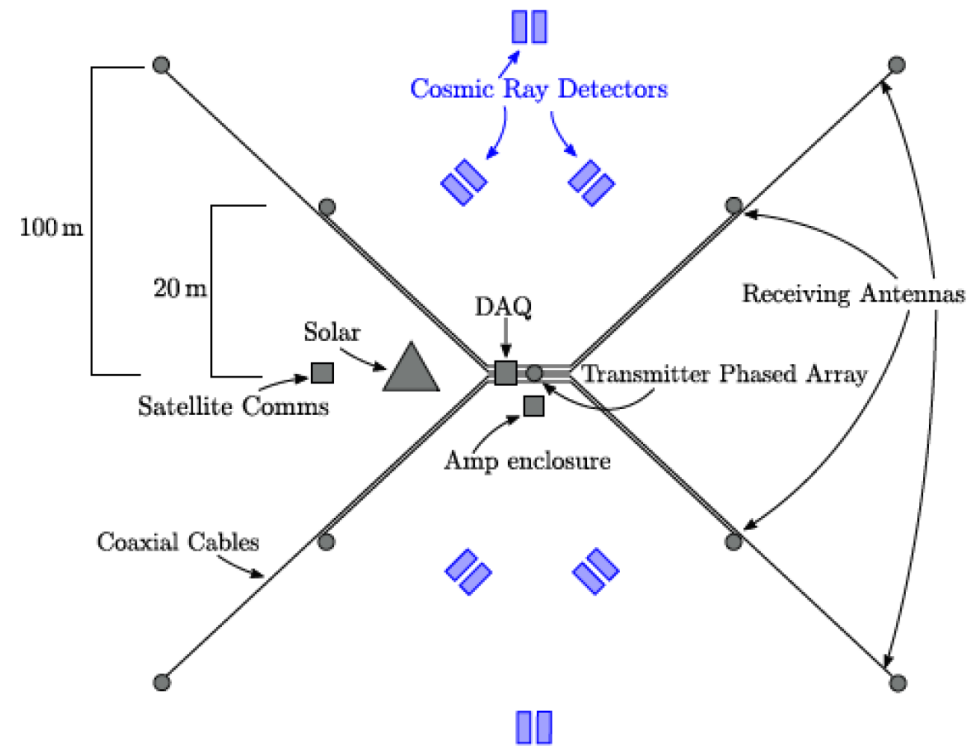
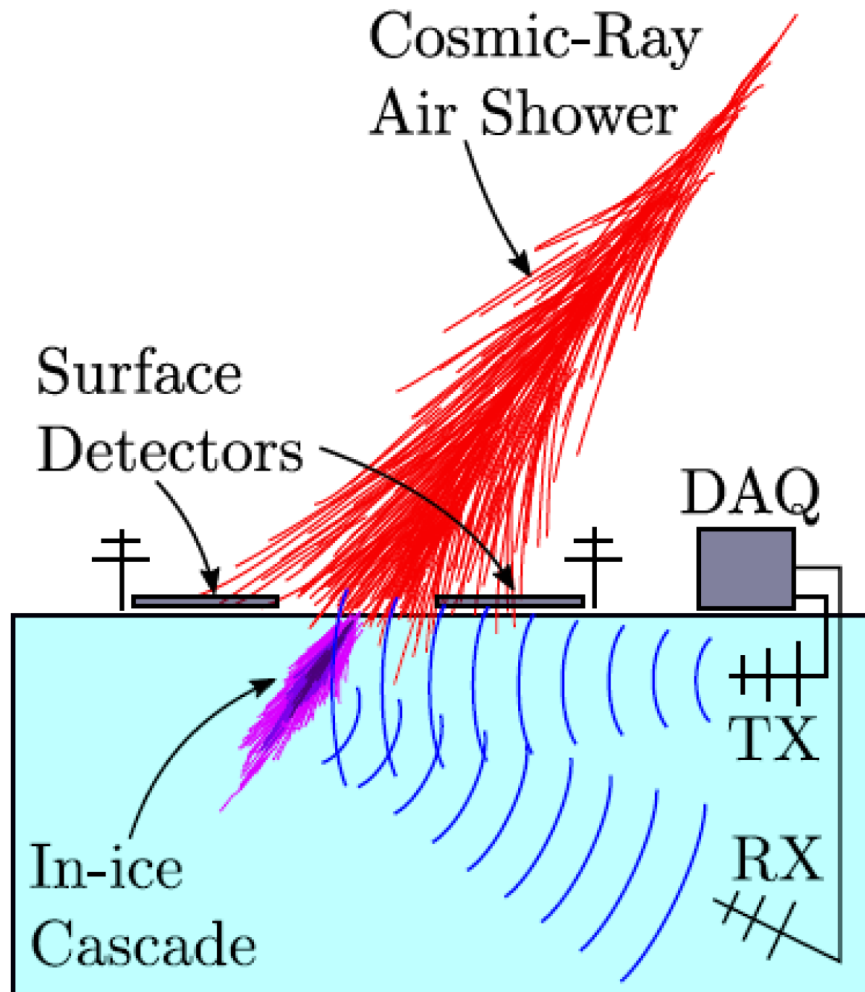
ICRC2021 proceedings



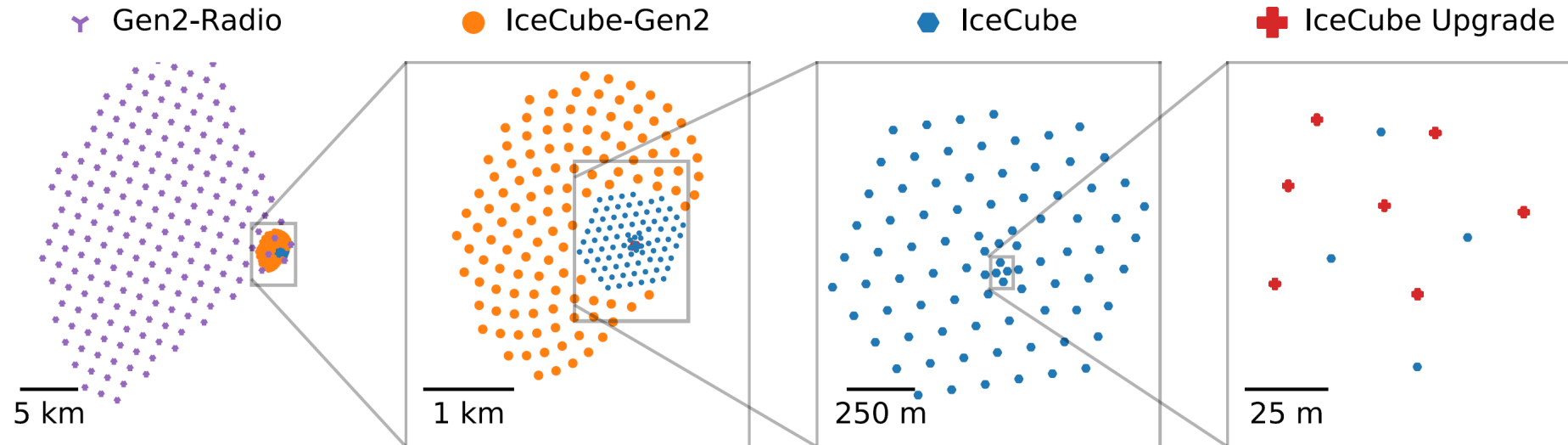
Fills the IceCube-Radio  $E$  gap

→ Possibility for full energy coverage

Towards an in-situ proof of principle at Taylor Dome Antarctica  
(ArXiv:2104.00459)



## The IceCube-Gen2 extended neutrino observatory



- Radio component :  $\sim 200$  stations covering  $\sim 500 \text{ km}^2$
- Autonomous power and communication
- \* **Never been tried before in polar conditions  $\rightarrow$  Need for a pathfinder project**
  - Test autonomous power and communication
  - Test scalability towards  $\sim 200$  stations
  - Provide initial scientific exploration

## The RNO-G radio array

- **Participating institutes**

VUB, ULB, UGent, UChicago, PSU, OSU, UW-Madison, DESY, KU, MSU, Alabama, Uppsala, Erlangen

- **Belgium plays a leading role**

Project fully funded by FWO-IRI

- **Location: Summit station Greenland**

→ Inverted seasons w.r.t. SP

No interference with IC Upgrade

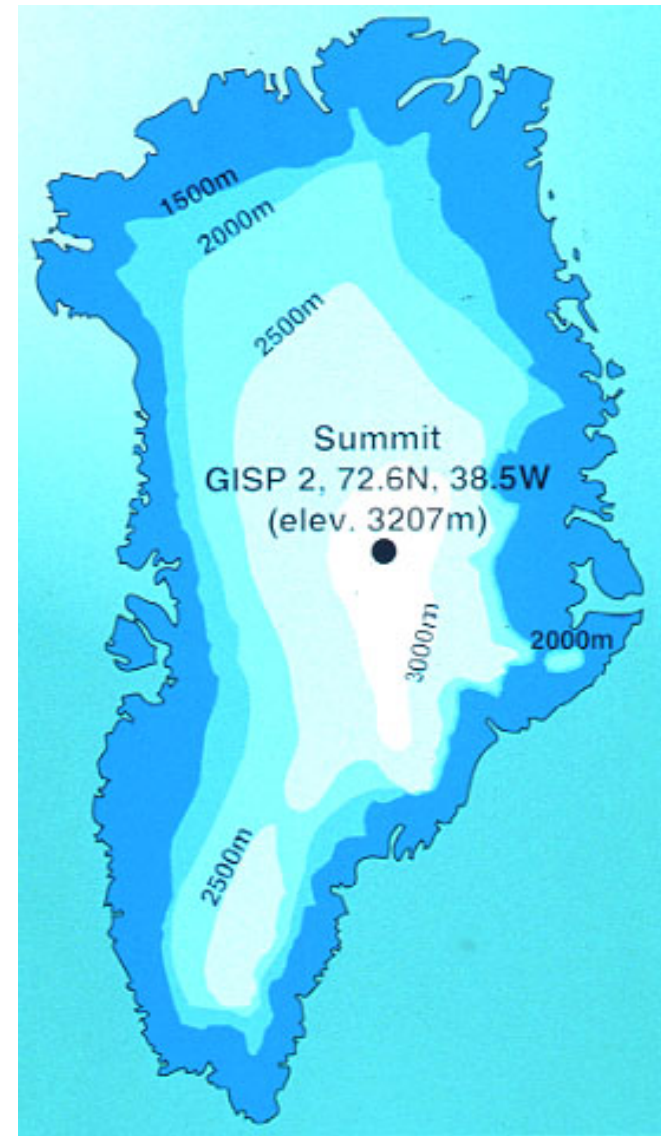
Same NSF cargo planes etc. available

- **35 autonomous stations in 2024**

→  $\sim 50 \text{ km}^2$  array

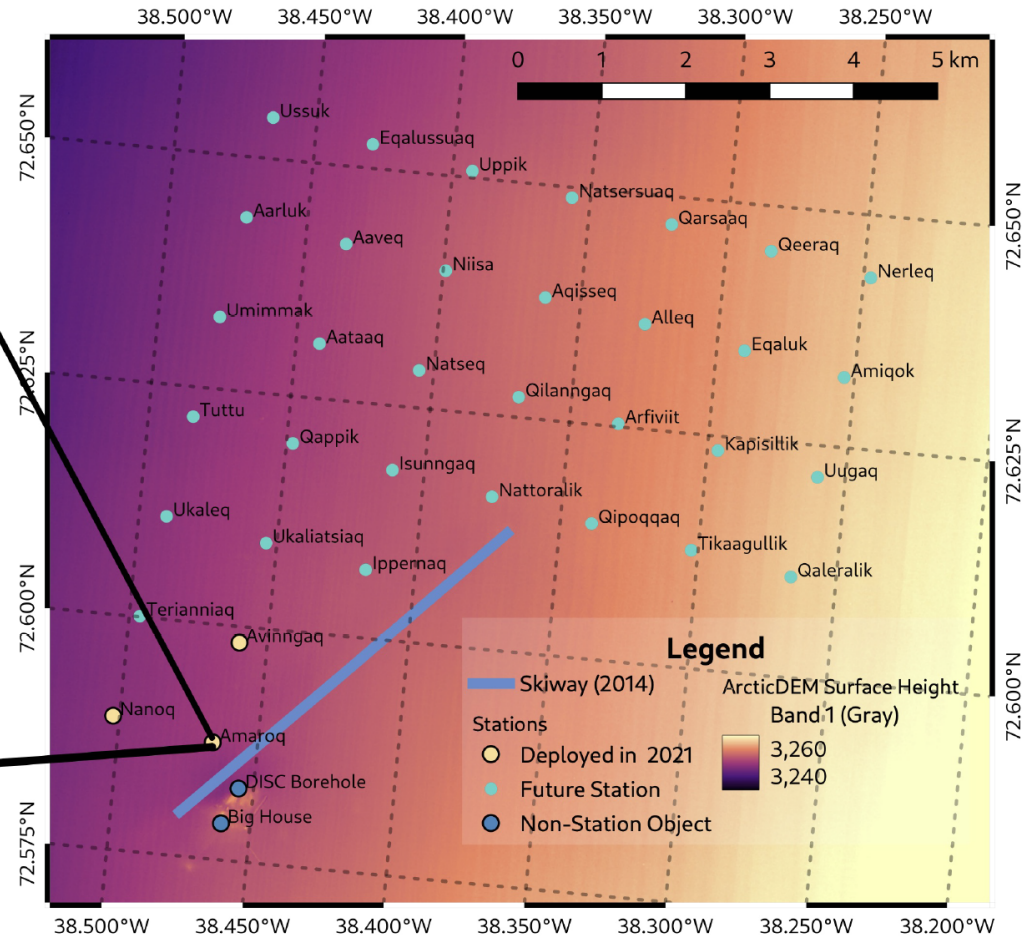
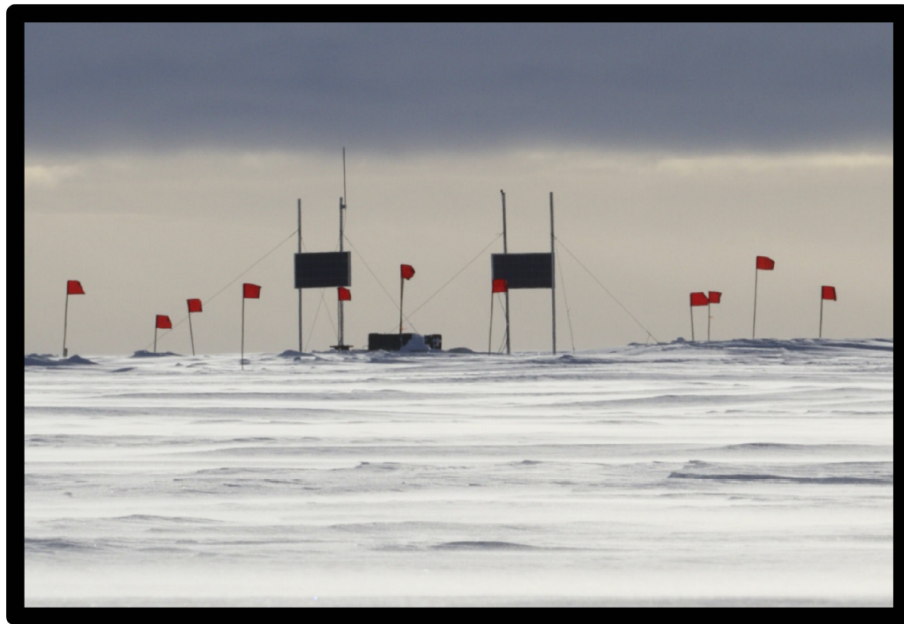
1<sup>st</sup> deployment in 2021 (3 stations)

→ **Already > 3x size of IceCube**

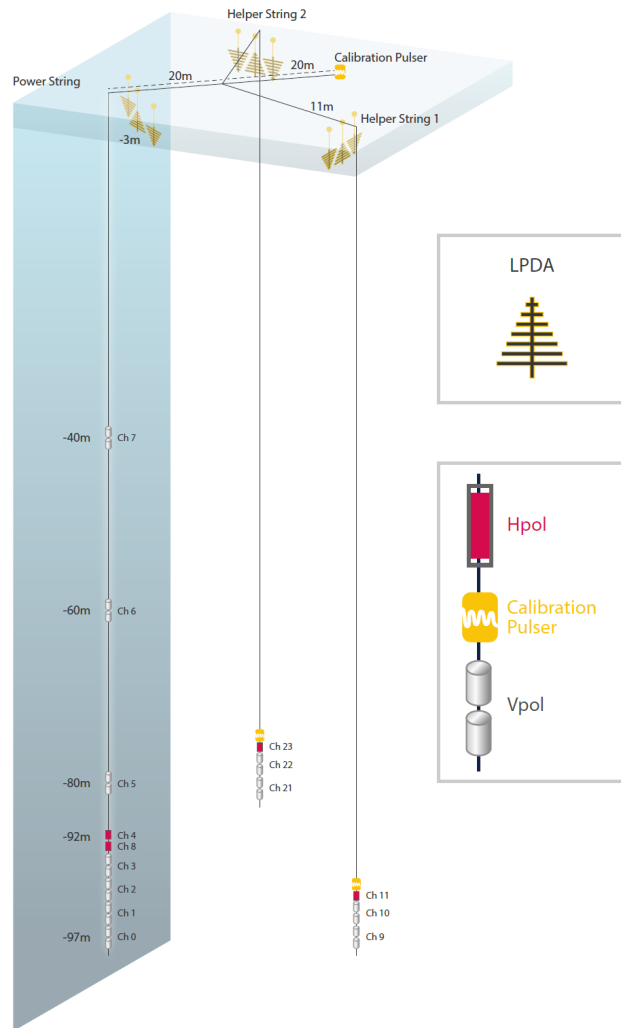




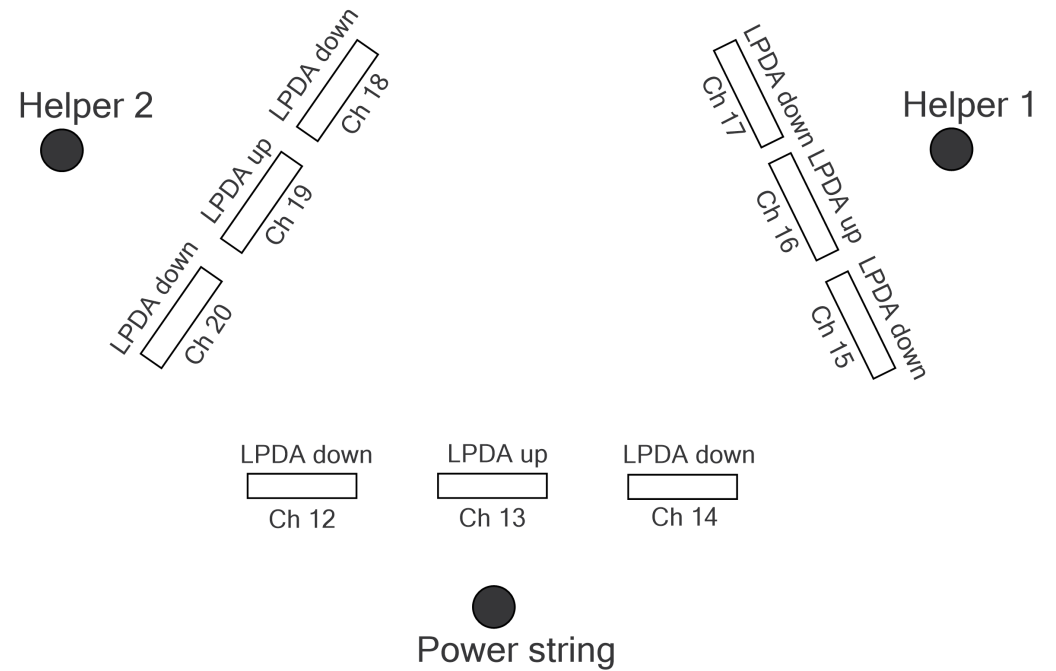
Array geometry



# RNO-G Station layout (JINST 16 (2021) P03025)



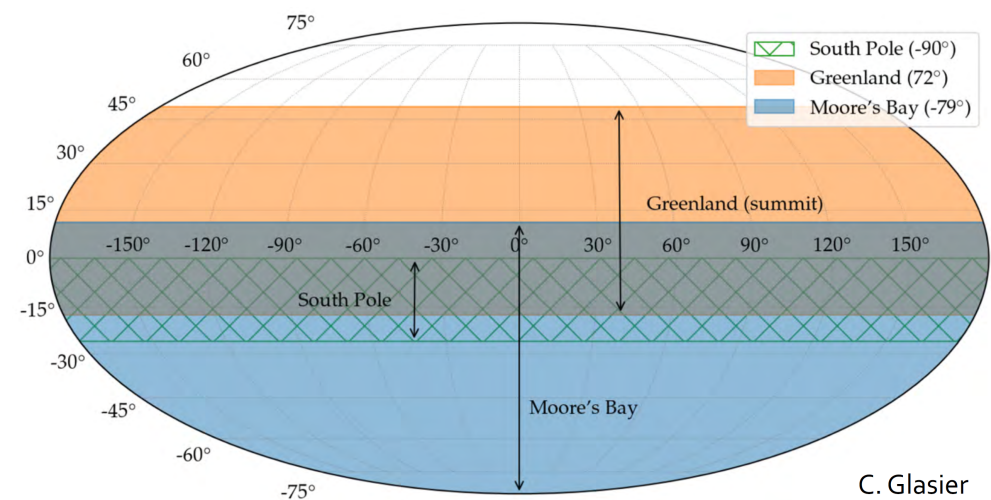
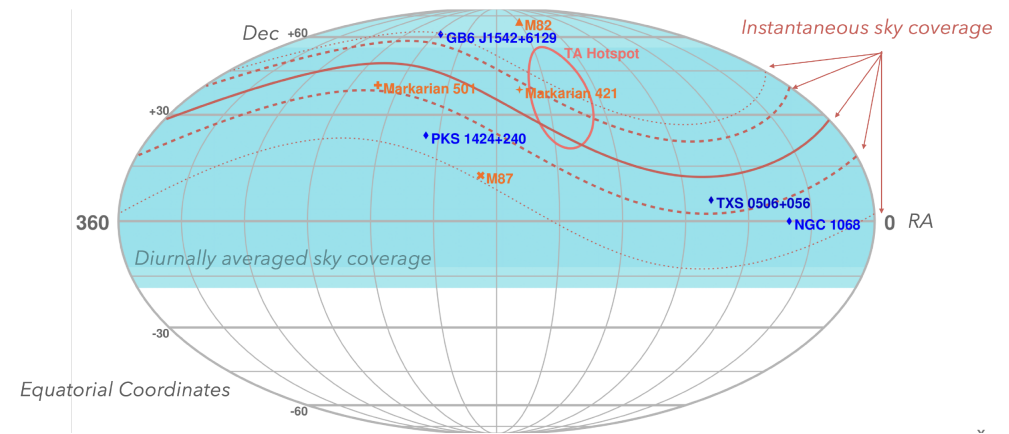
RNO-G Channel Mapping Top View





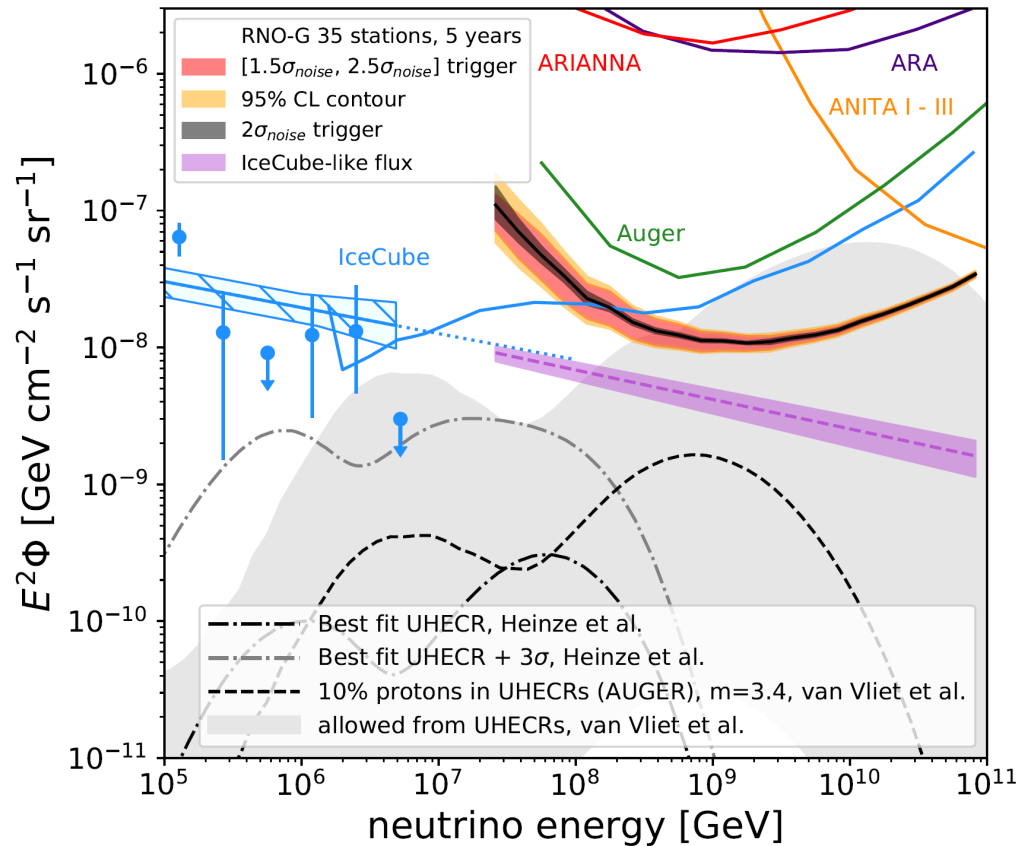
**Strong science case**

- **Overlapping FoV with IC optical**  
Same location seen at PeV and TeV  
→ **Steady sources studies**
- **Complementary FoV to SP radio**  
Earth rotation: Larger sky coverage  
→ **Detection of transients**
- **Join the MM alert system**
- **Develop a real time alert system**  
Focus of the IIHE team



(Equatorial Coordinates)

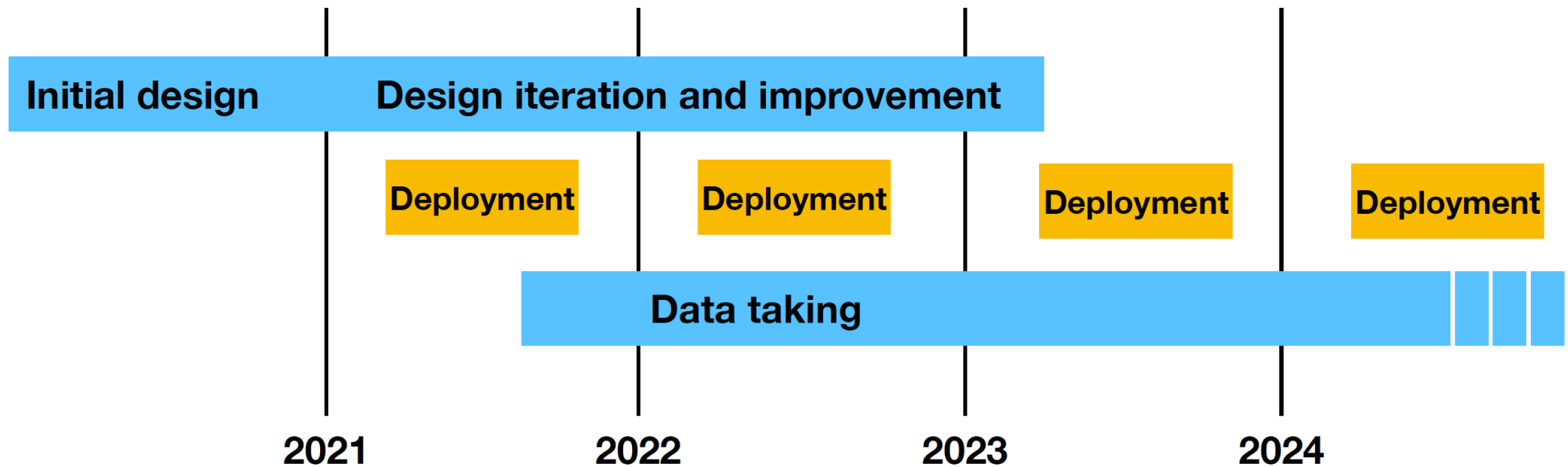
## Sensitivity



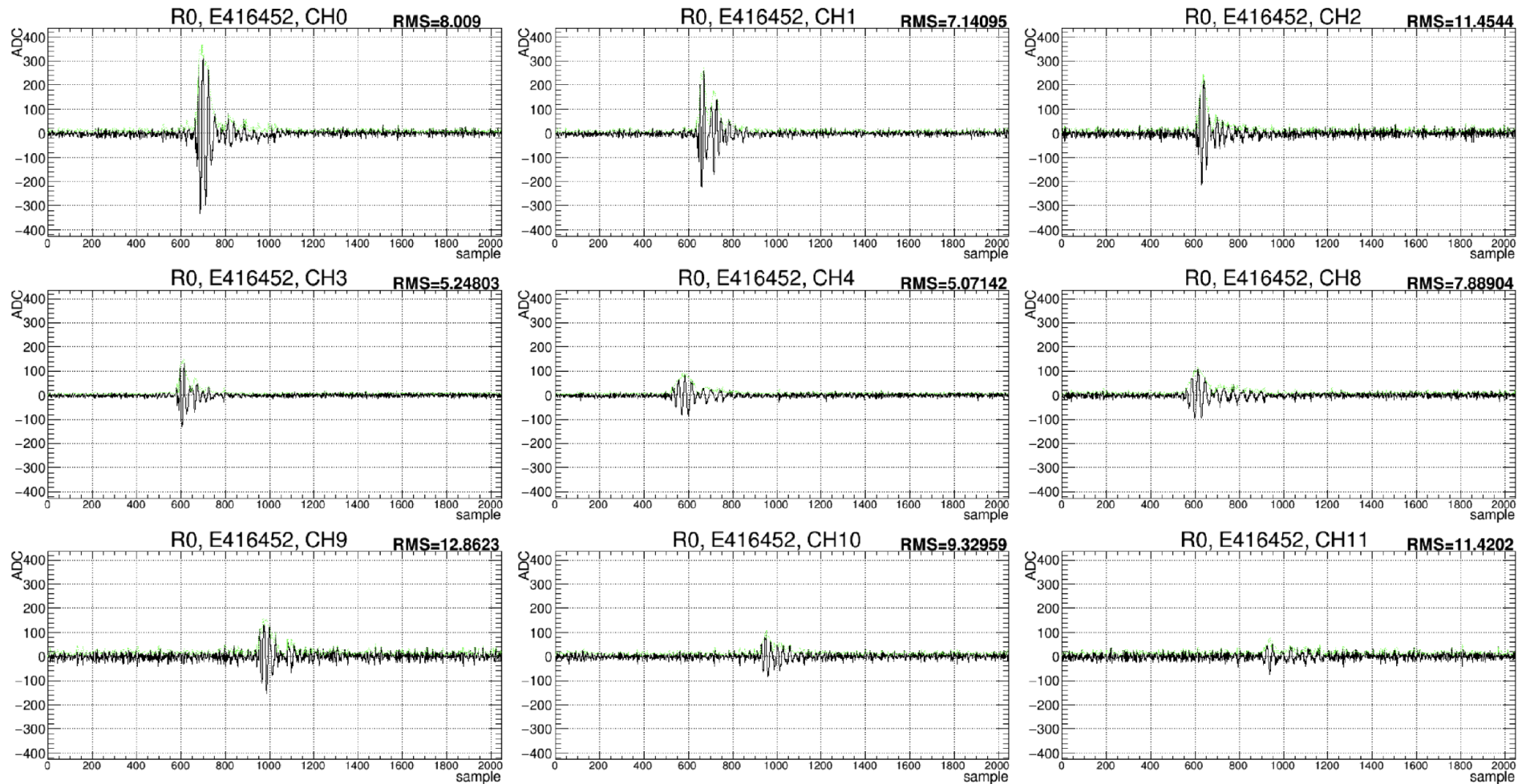
## A real discovery experiment

- First real exploration of GZK regime
- Uncover UHE sources c.q. transients
- Gen2-radio  $\sim 10x$  more sensitive
- Lowering the threshold
- Improve the IceCube optical data

## The Covid-19 corrected RNO-G timeline



### After switching on the first station ...



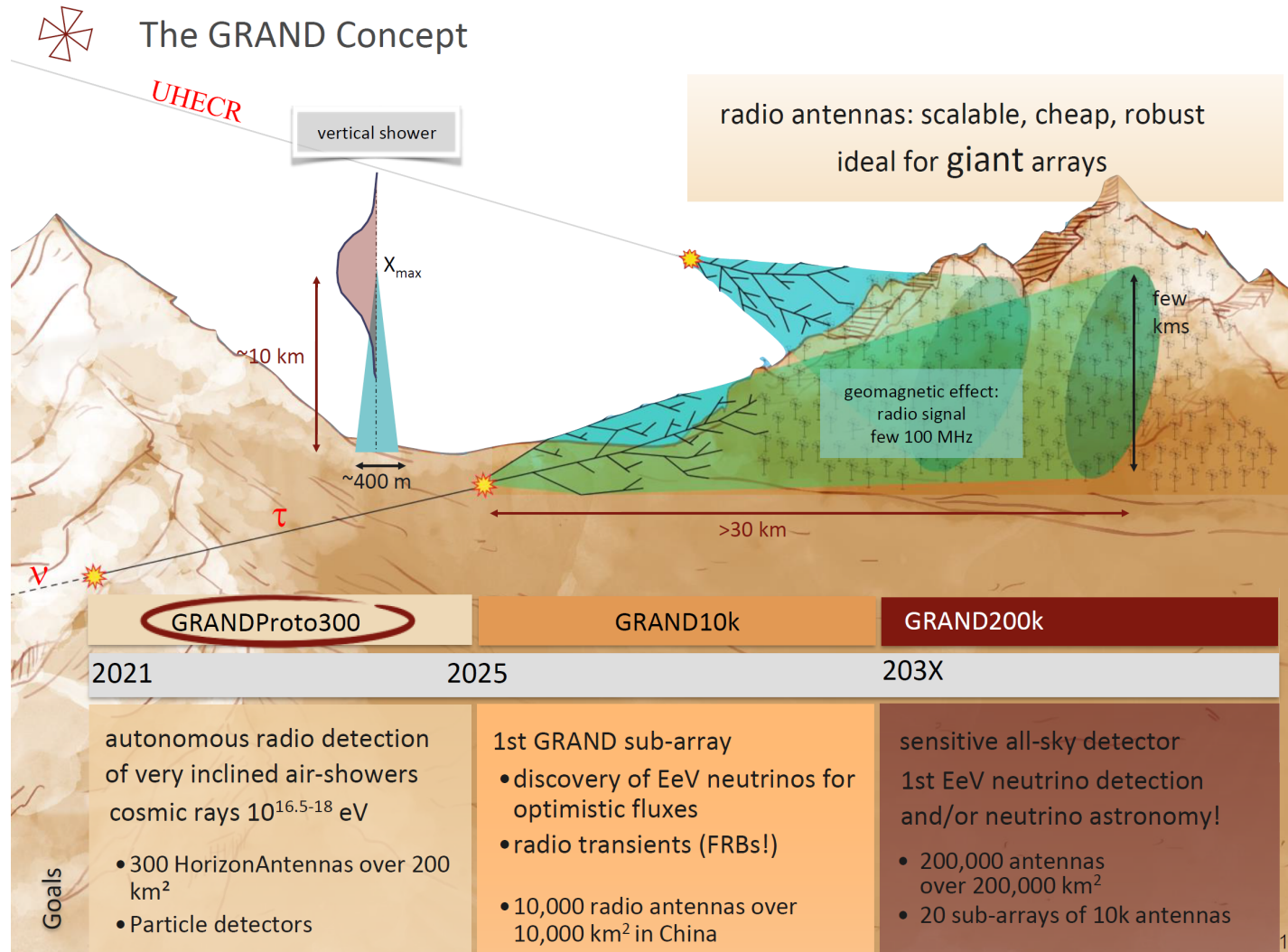
Are we that lucky to see already a neutrino ?



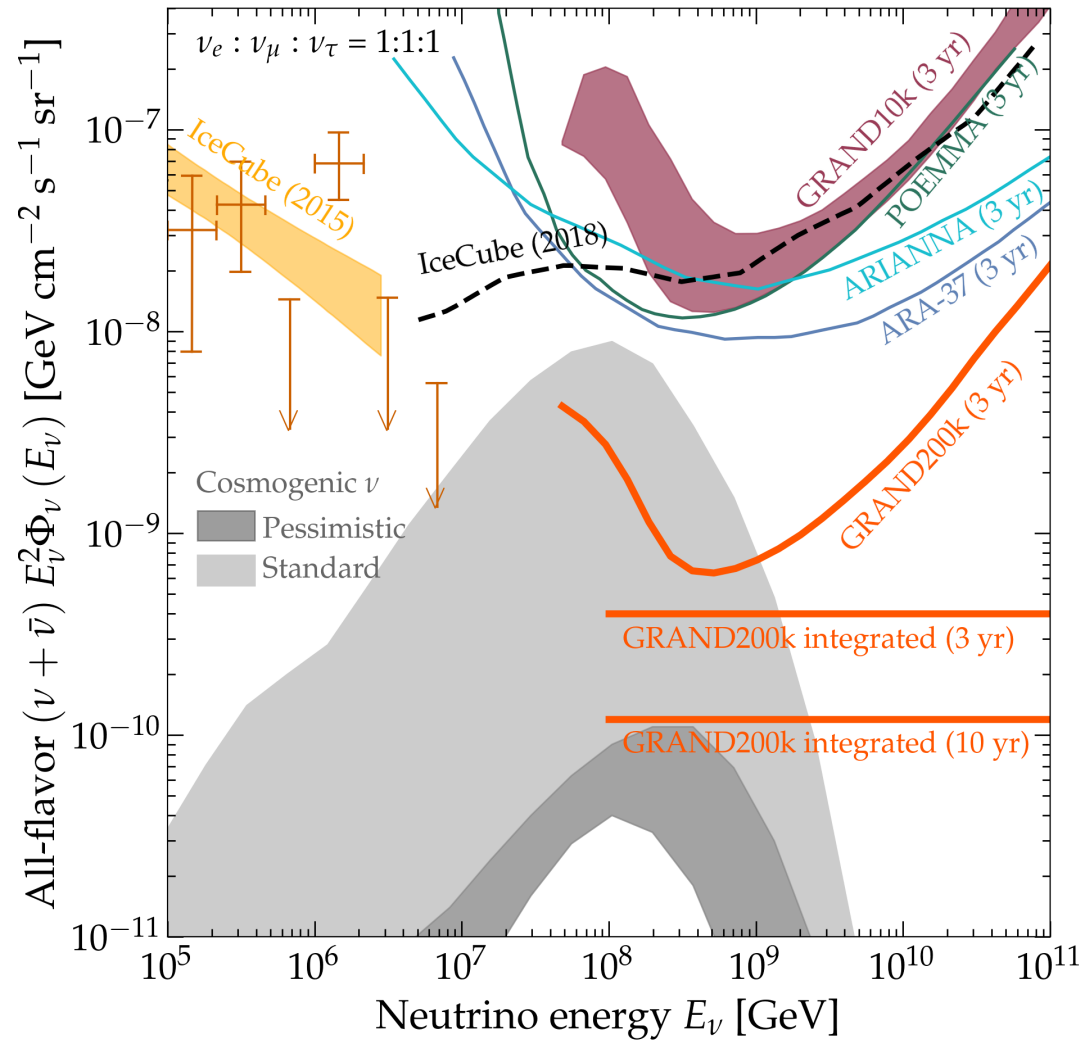
Our signal ...



## Detection principle of UHE $\nu_\tau$



GRAND sensitivity



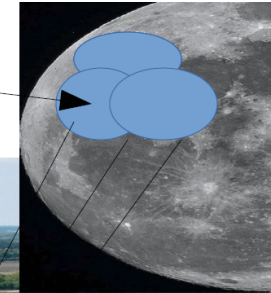


## Use the Moon as a target

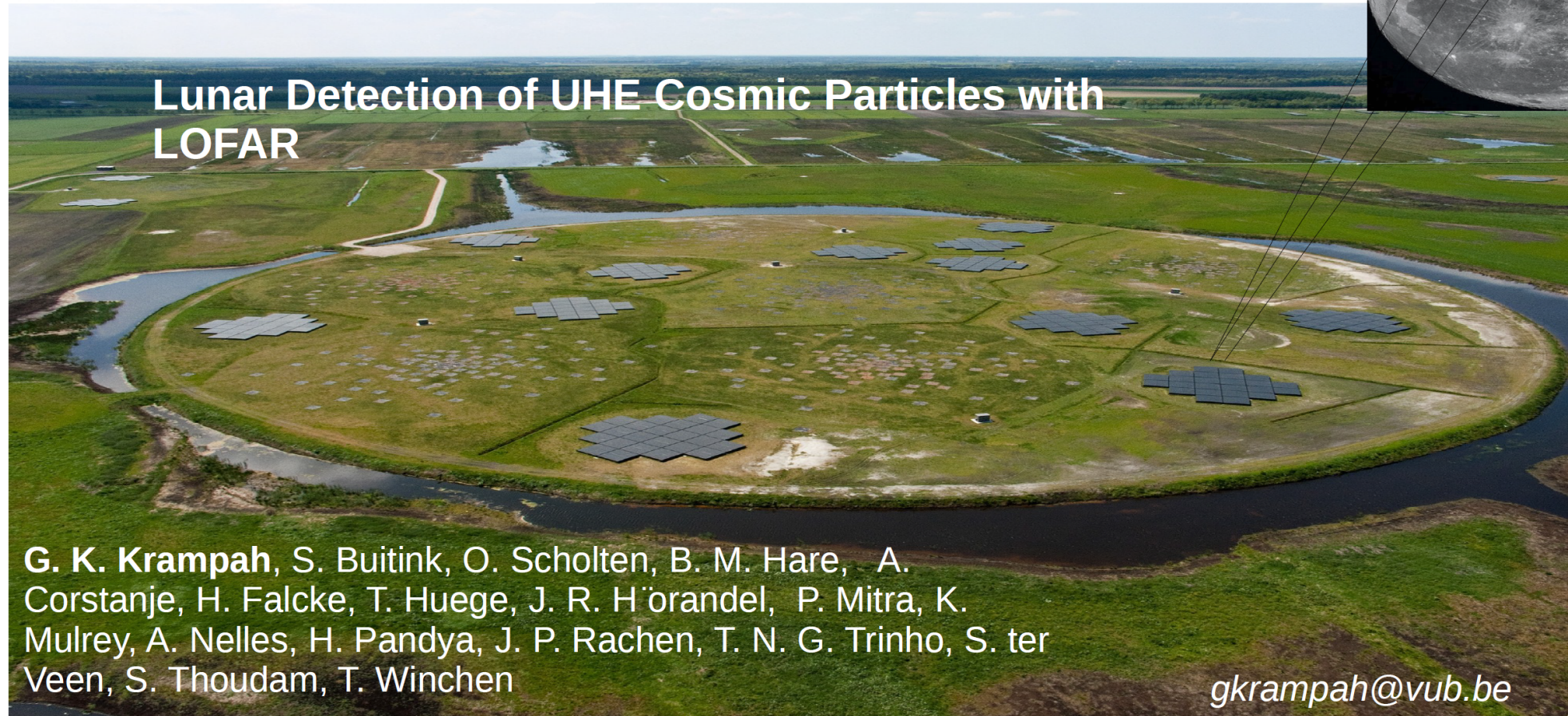


HIGH-ENERGY PHYSICS  
RESEARCH CENTRE

$P, \nu$



## Lunar Detection of UHE Cosmic Particles with LOFAR

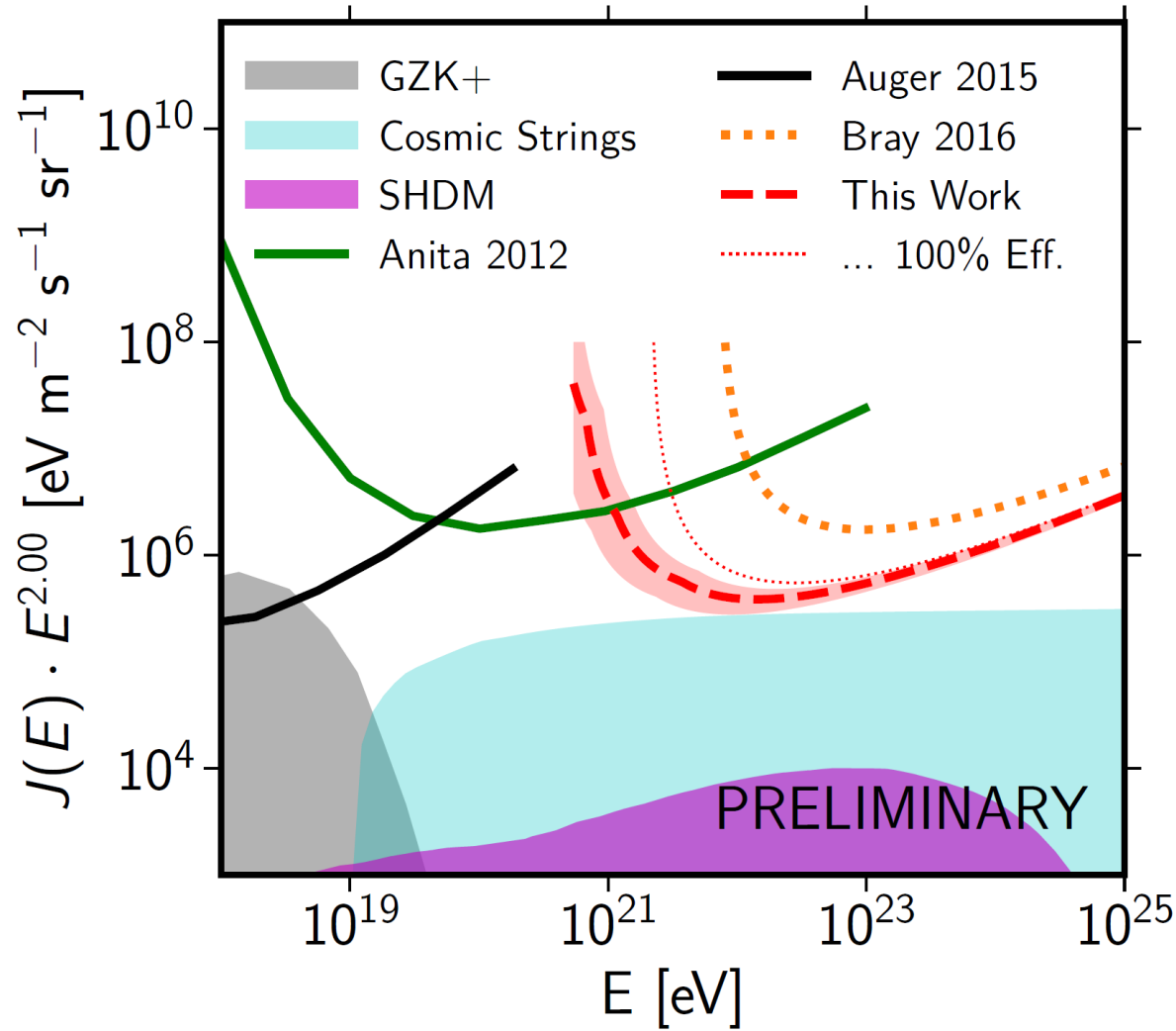


G. K. Krampah, S. Buitink, O. Scholten, B. M. Hare, A. Corstanje, H. Falcke, T. Huege, J. R. Hörandel, P. Mitra, K. Mulrey, A. Nelles, H. Pandya, J. P. Rachen, T. N. G. Trinh, S. ter Veen, S. Thoudam, T. Winchen

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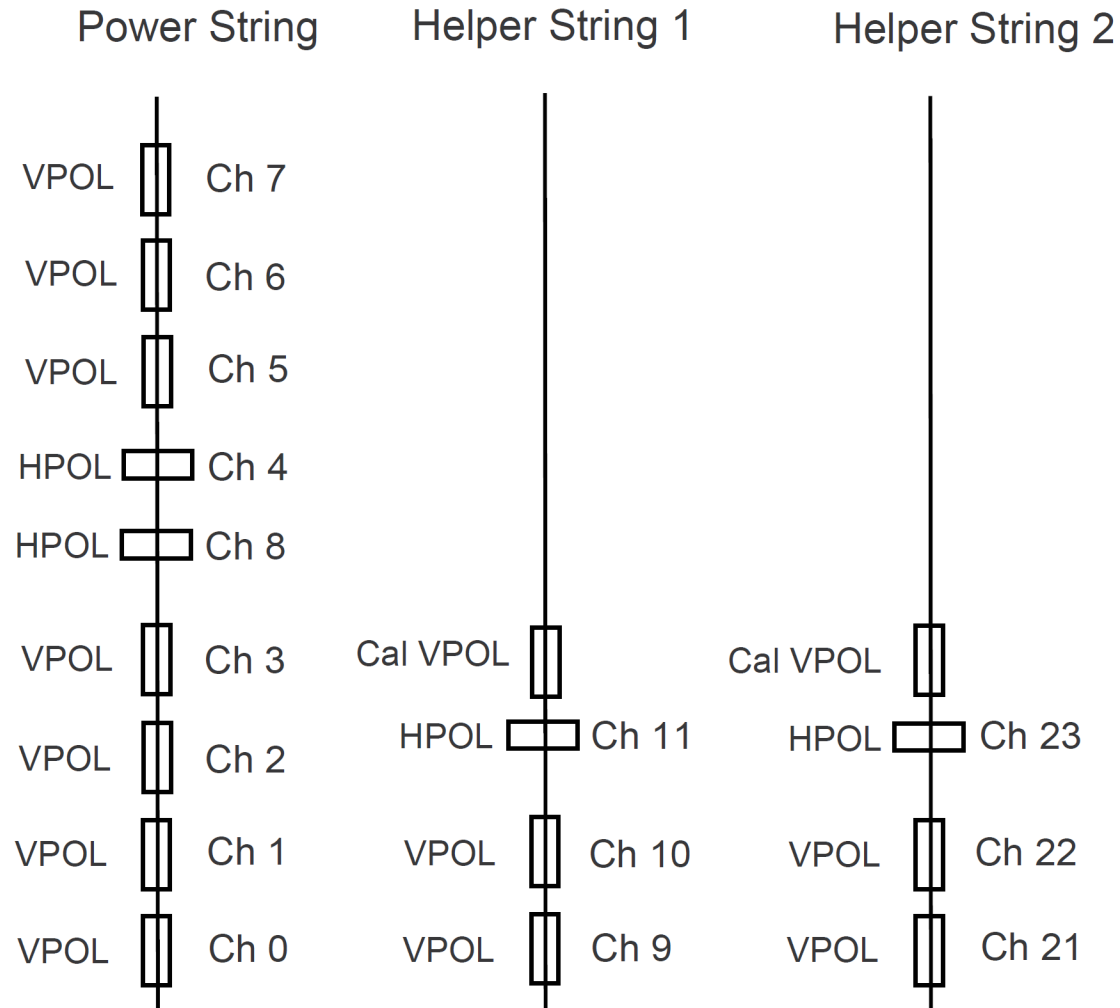
Neutrino sensitivity after 200 hours of observation



- **Need for more statistics of cosmic  $\nu$  at  $>PeV$  energies**
  - Study spectral characteristics of high-energy cosmic  $\nu$
  - Investigate/confirm the GZK effect and UHE  $\nu$  from sources/transients
  - Explore the ZeV arena (LOFAR-NuMoon)
- **Need for  $>100$  times the current IceCube size**
  - **Only feasible with detection via radio signals** ( $\lambda_{att} \sim 1$  km)
  - Radio component of  $\sim 500$  km<sup>2</sup> planned for IceCube-Gen2
- **Deployment has started for a  $\sim 50$  km<sup>2</sup> radio array in Greenland (RNO-G)**
  - Test technical aspects (low threshold, autonomous operation, scalability)
  - First physics exploration of unknown energy regime (GZK neutrinos)  
**Belgium has taken a lead in the RNO-G project (5M FWO-IRI grant)**
  - First deployment of 3 stations in 2021  $\rightarrow$  35 stations in 2024  
**Development of radar reflection technique (2M ERC-StG of Krijn)**
- **"Belgian" people involved** : Katie, Rose, Simona, Paramita, Kumiko, Marine, Pragati, Vesna, Dieder, Enrique, Juanan, Krijn, Olaf, Simon, Stijn, Uzair, Jethro, Tim, Jörg, Godwin, Hershall, Dirk, Bob and Nick

**Backup Slides**

RNO-G Channel Mapping Side View



The RNO-G DAQ system

3 GHz sampling 8-bit ADC Two 2048 sample buffers → ~ 600 ns windows

