A global approach to Neutrino Astronomy

Christian Spiering, DESY

1960

Markov proposes underwater neutrino detection

1973

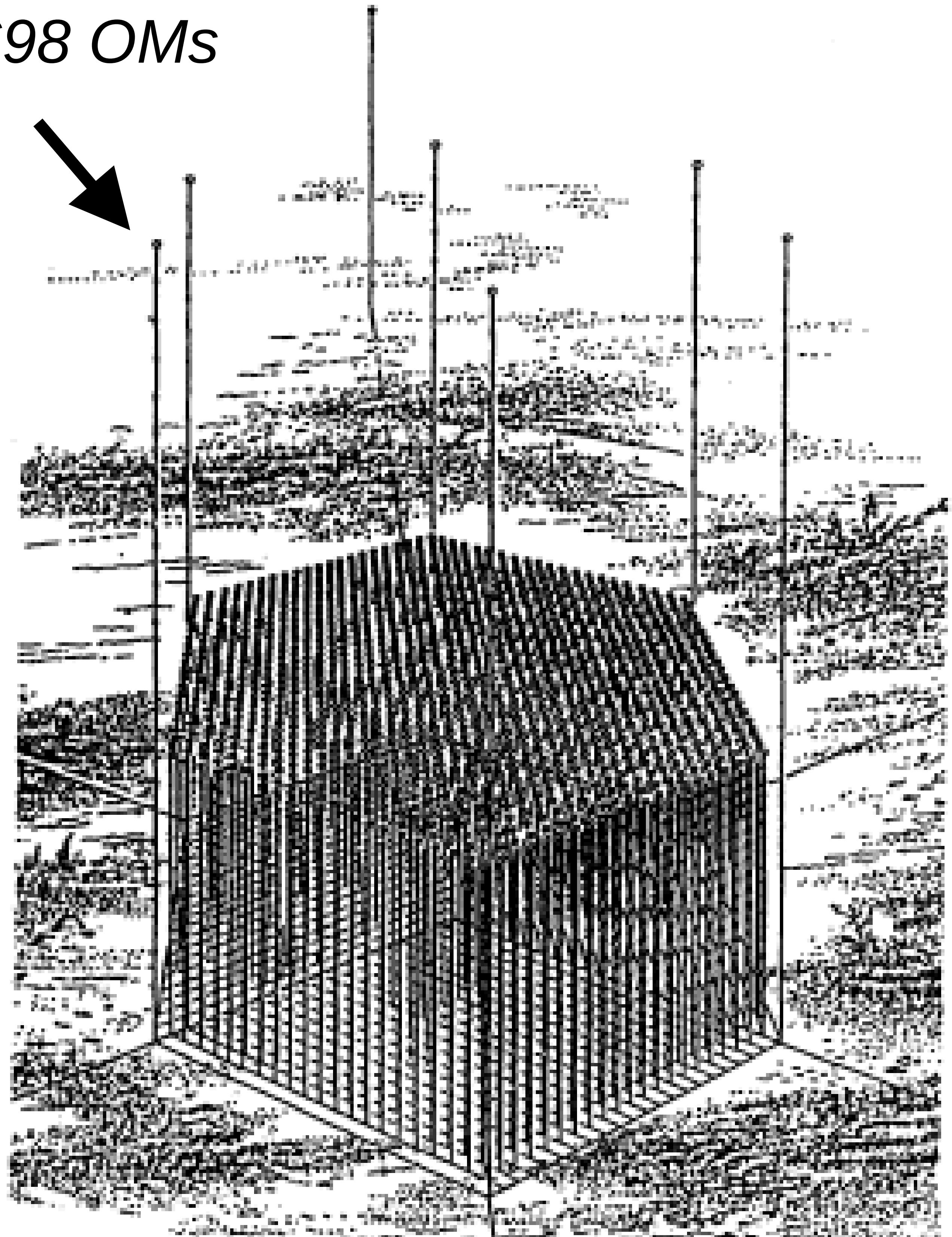
first ideas on

DUMAND

Hawaii

1978: 1.26 km³

22,698 OMs



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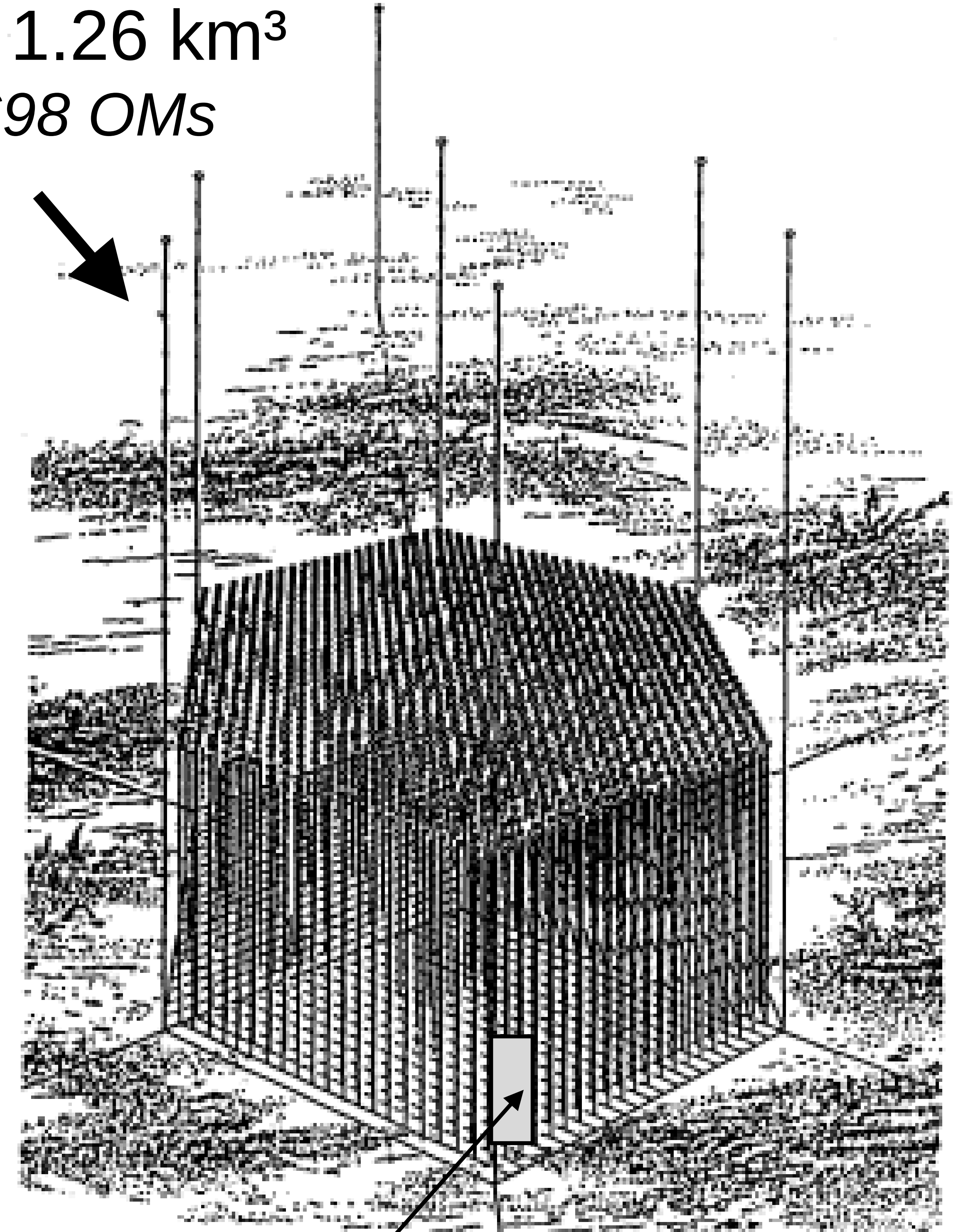

1988: reduced DUMAND design

DUMAND terminated 1996

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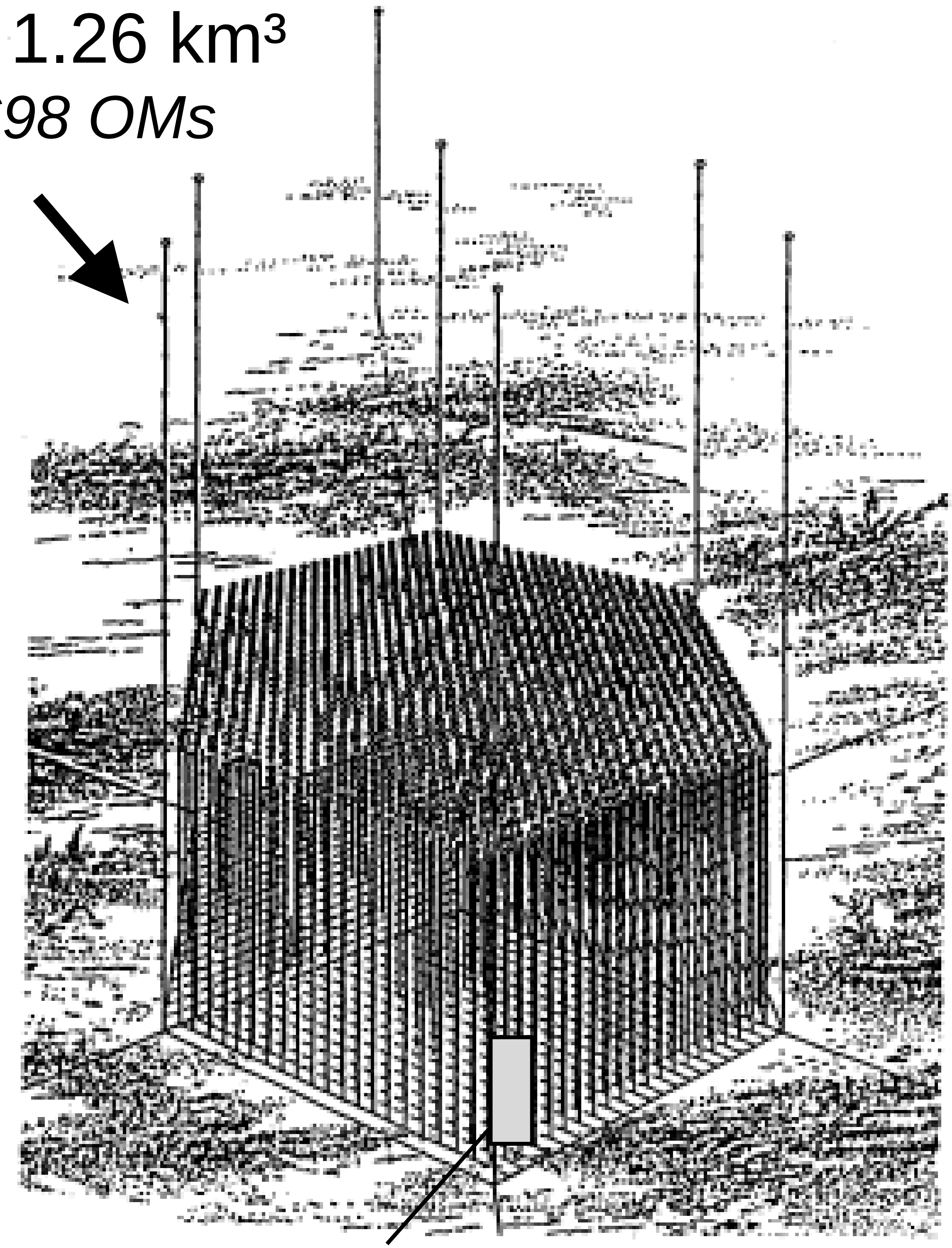

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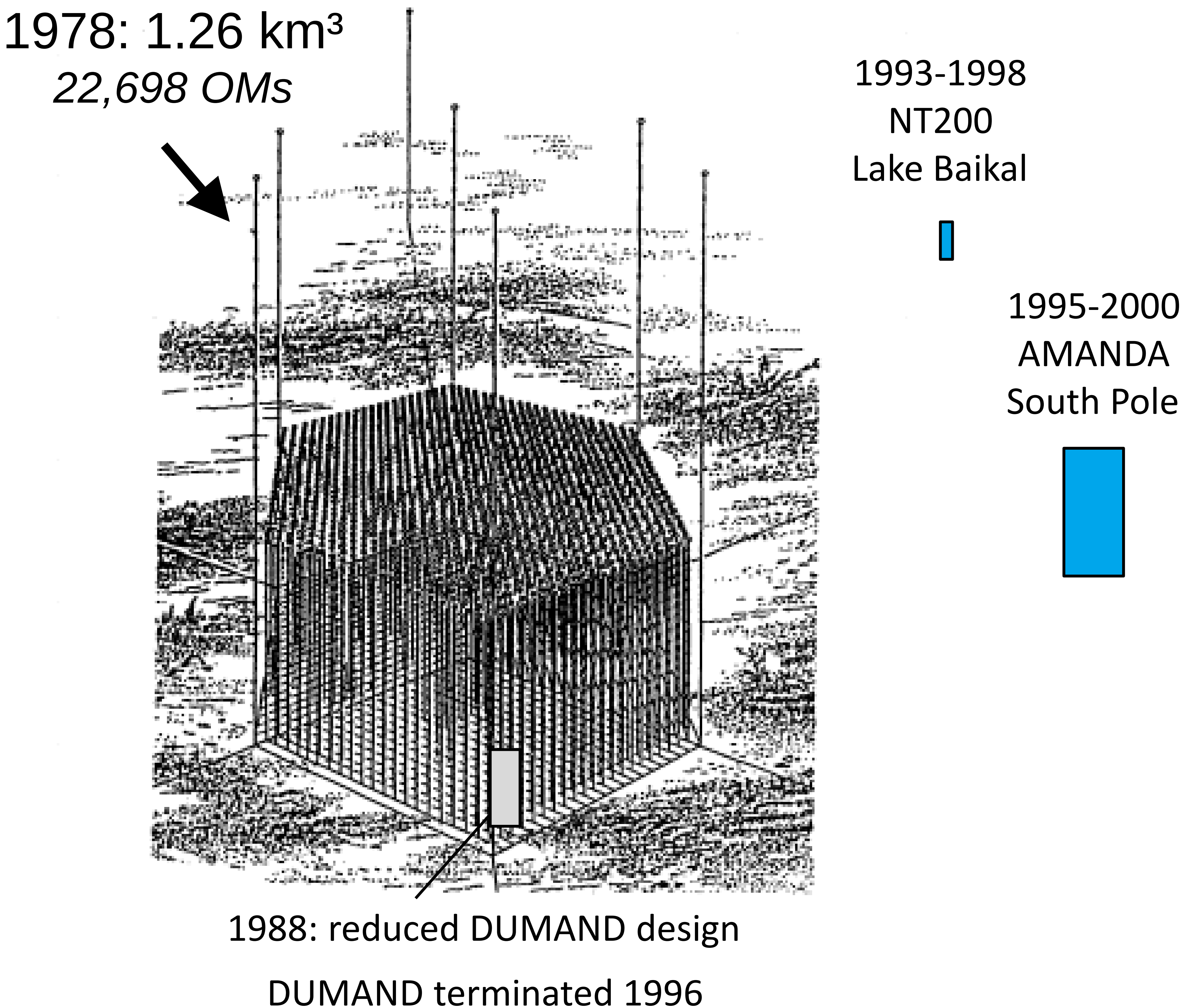
DUMAND terminated 1996

1993-1998

NT200

Lake Baikal



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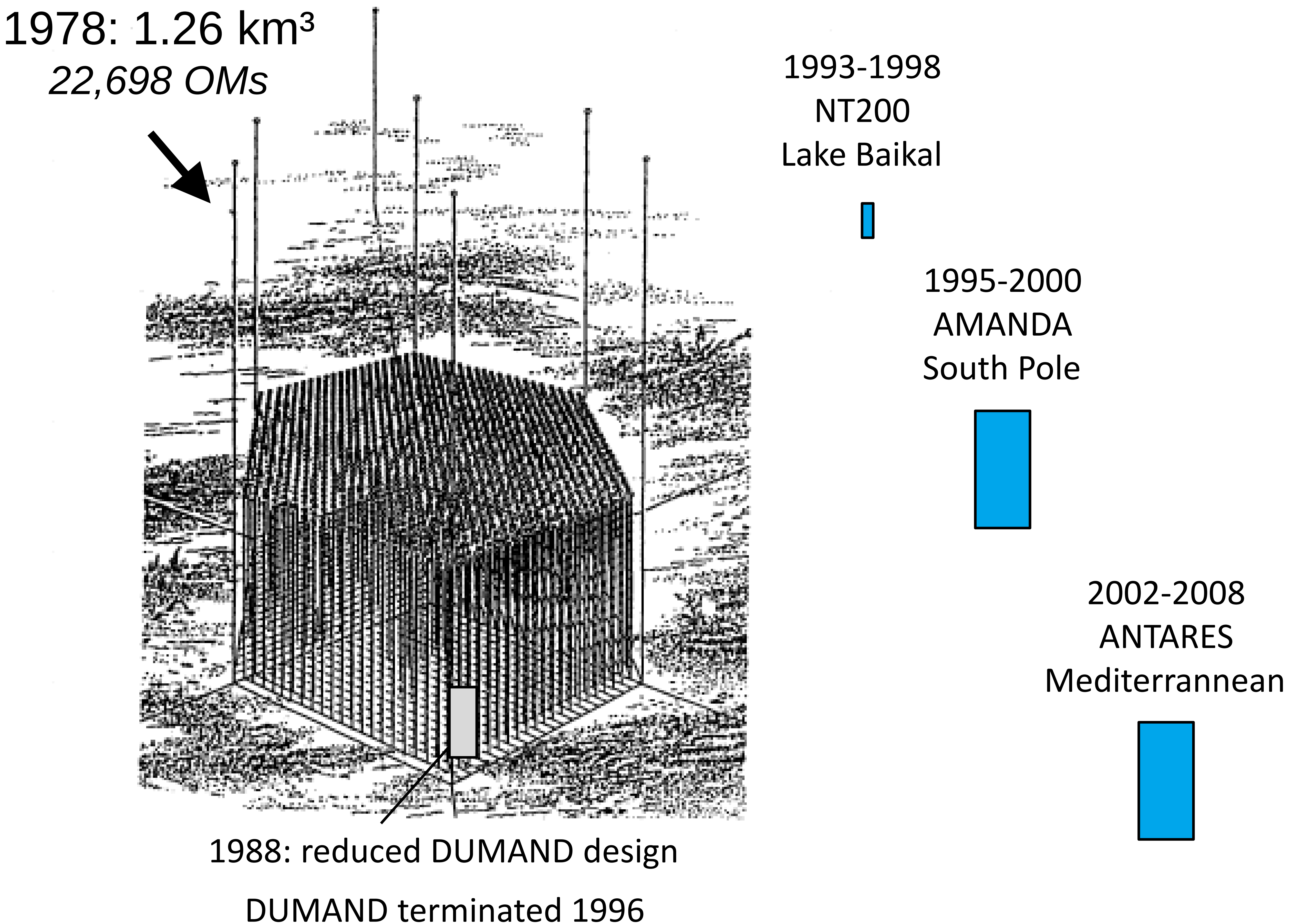
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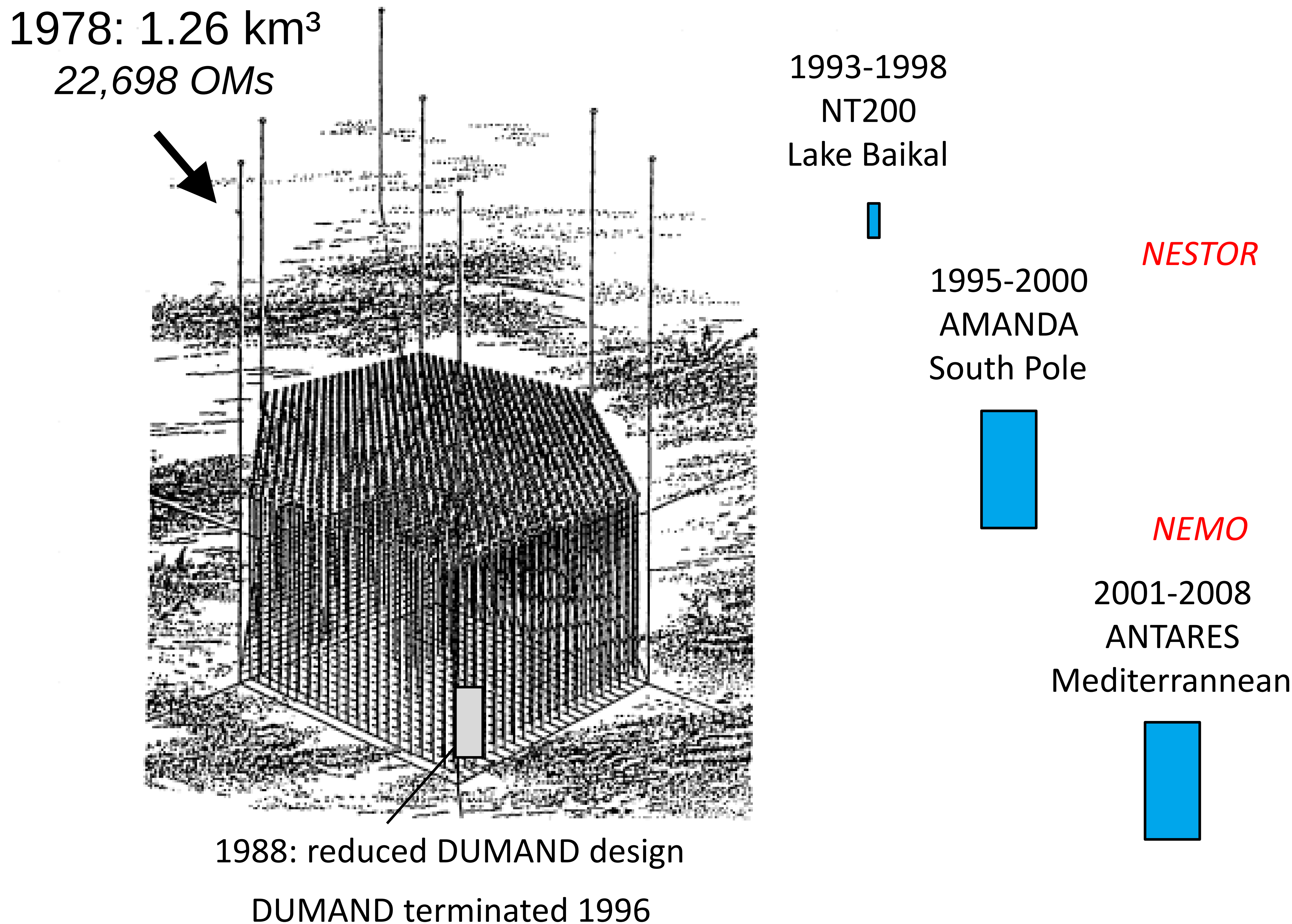
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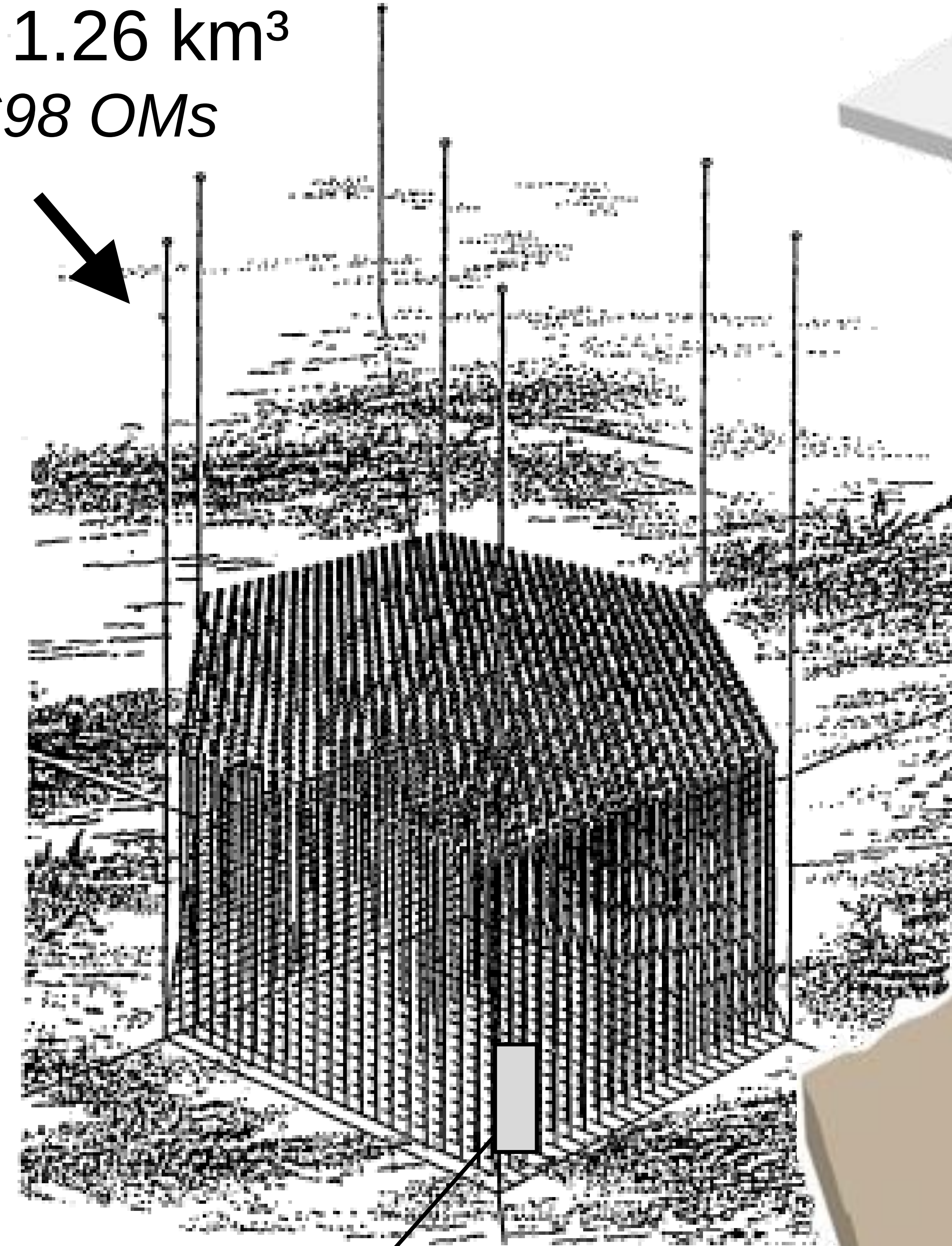
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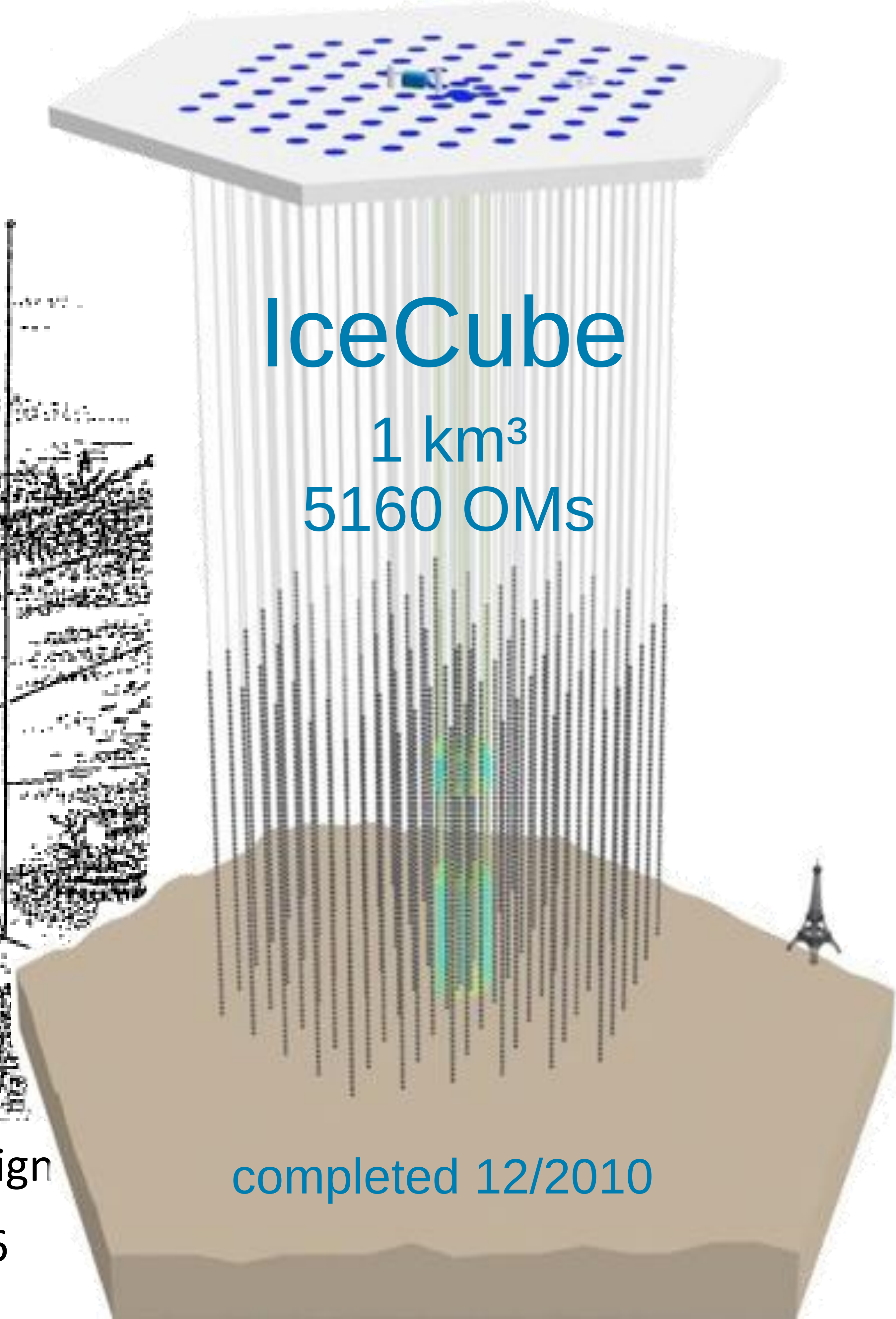
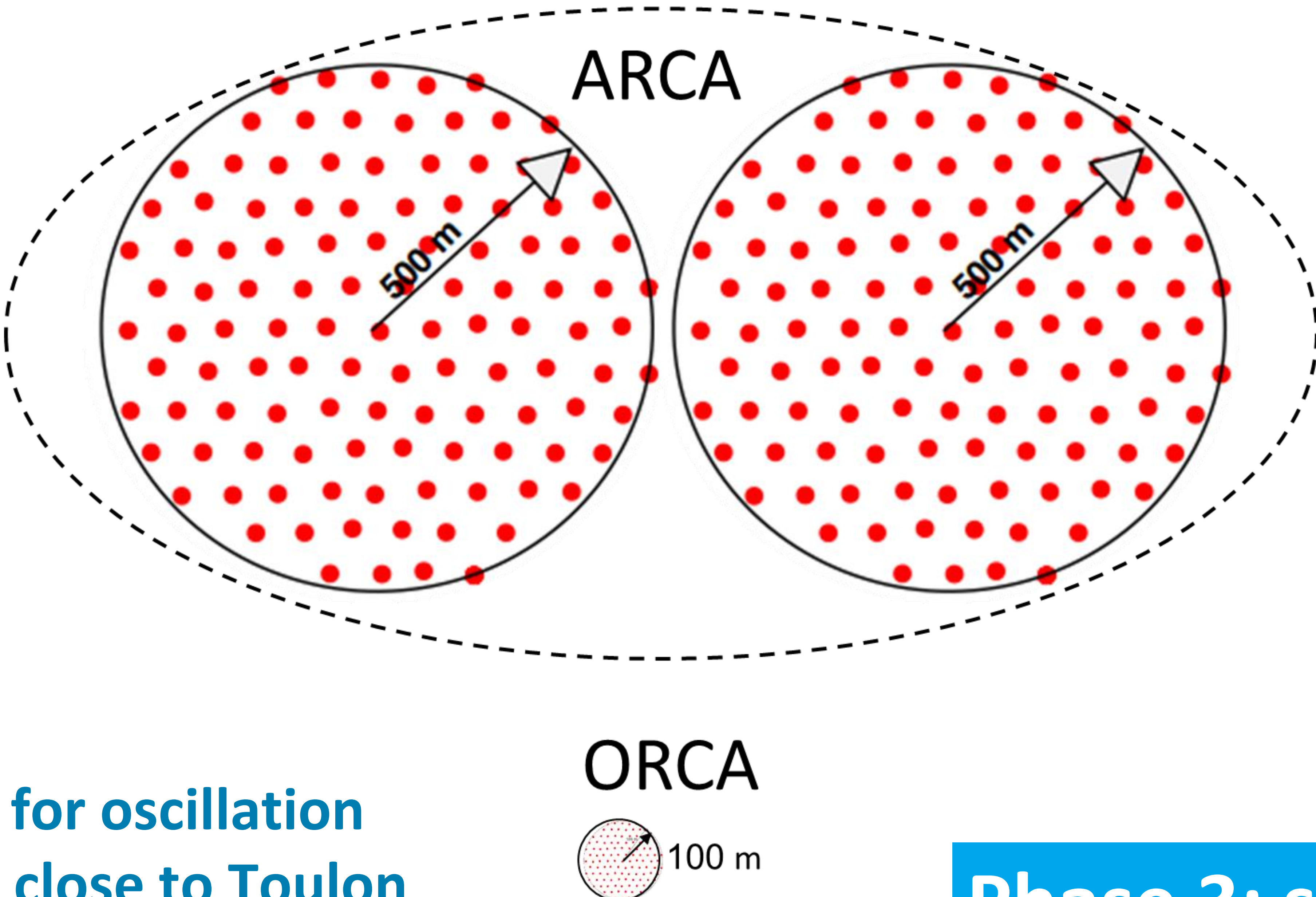

IceCube
1 km³
5160 OMs
completed 12/2010

KM3NeT Phase 2 first cluster to operational 2021/22

- **2 blocks for high-energy neutrino astronomy close to Sicily (~1.2 km³)**

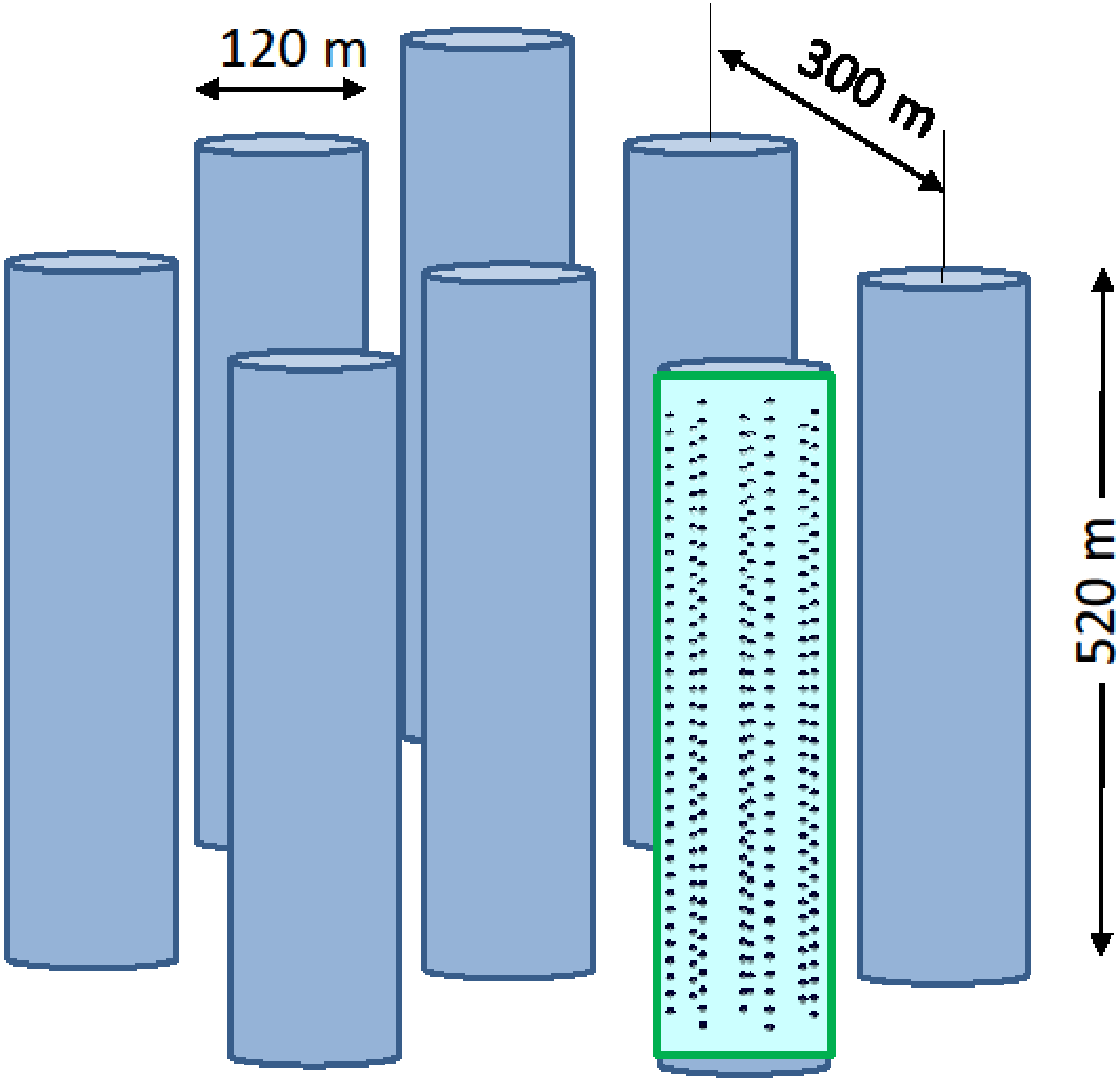


- **1 block for oscillation physics close to Toulon**

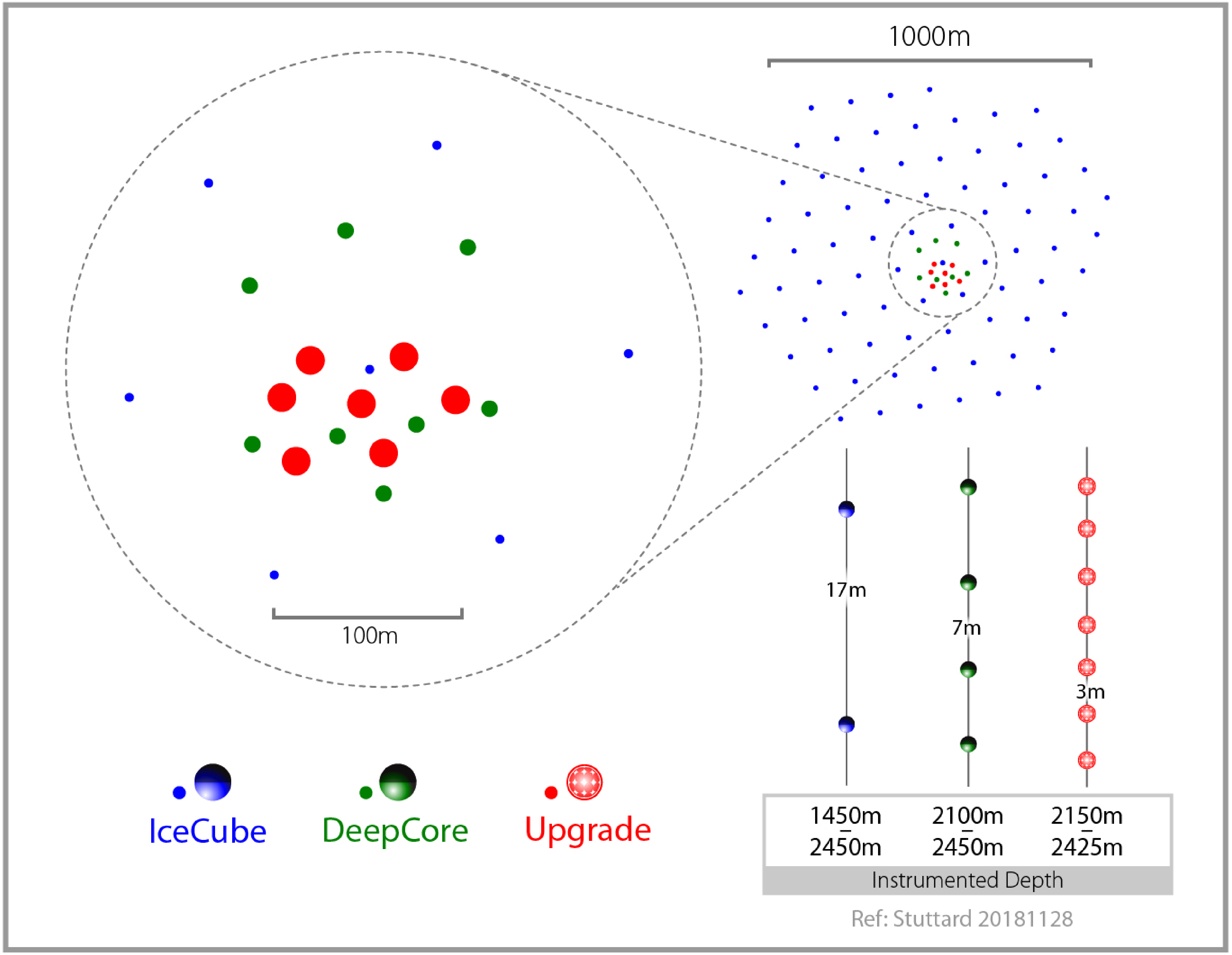
Phase 3: still open
→ ARCA × 2 (or 3)

Baikal GVD Phase 1

- 8 clusters (~0.4 km³)
- 4½ clusters deployed
- Completion 2021
- Later:
  Phase 2 (1.5 km³)

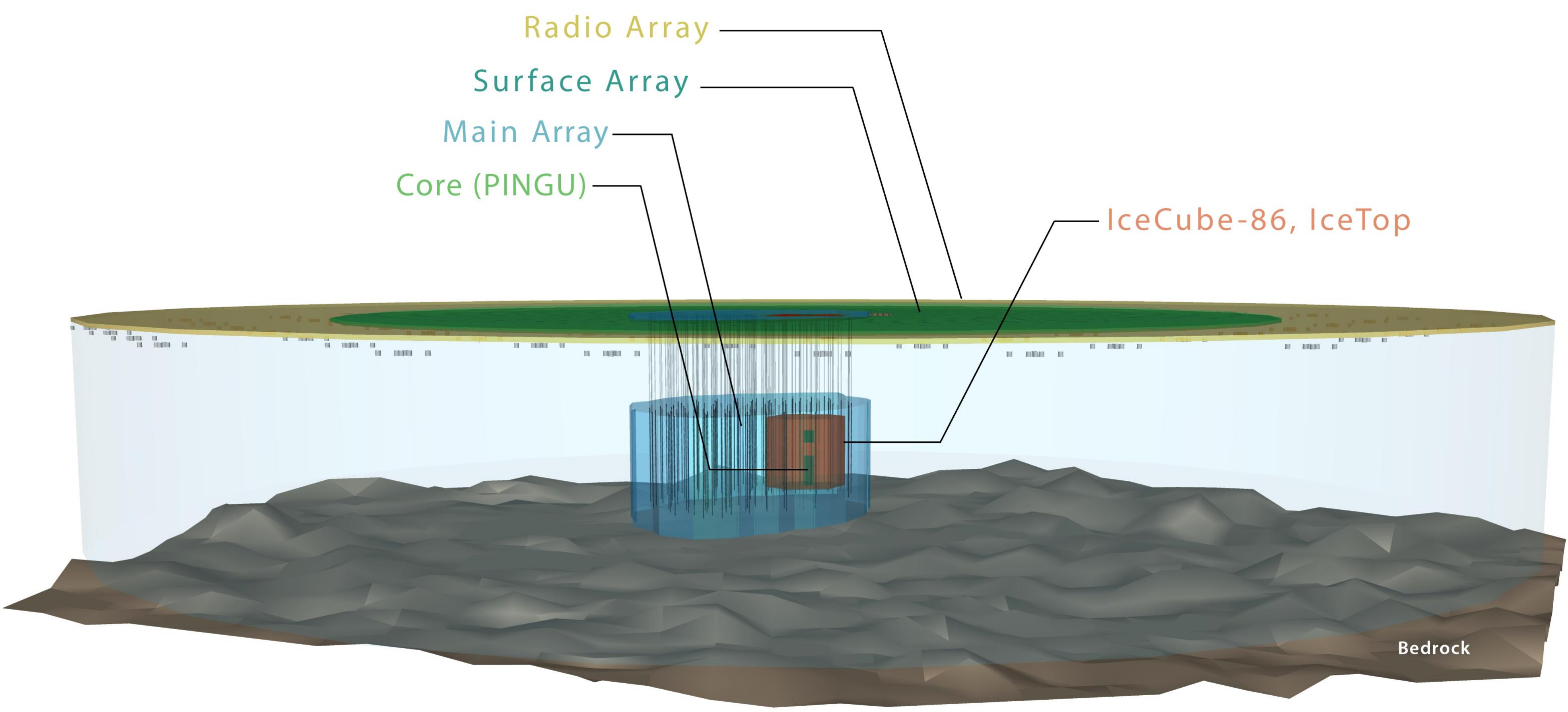


IceCube Upgrade: Deployment 2022/23



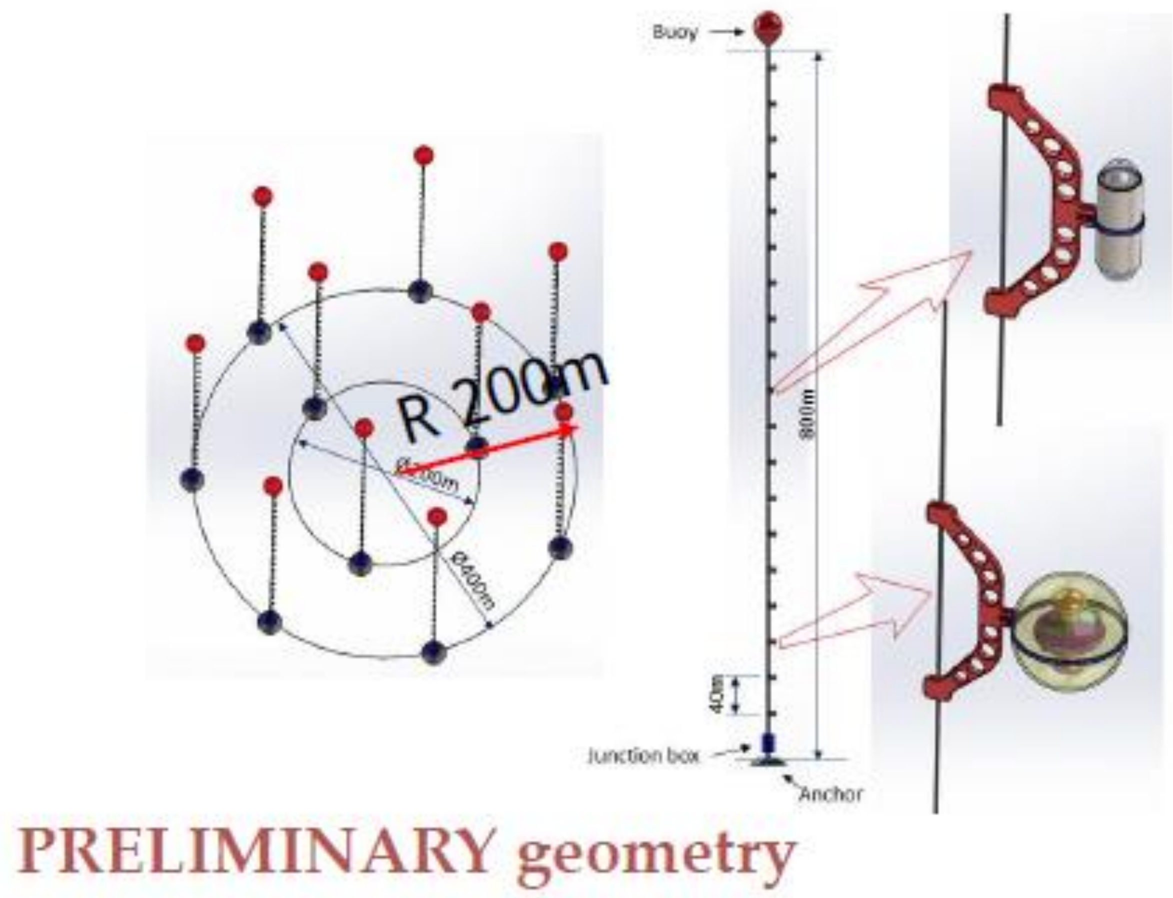
IceCube Gen2

Completion ~2030

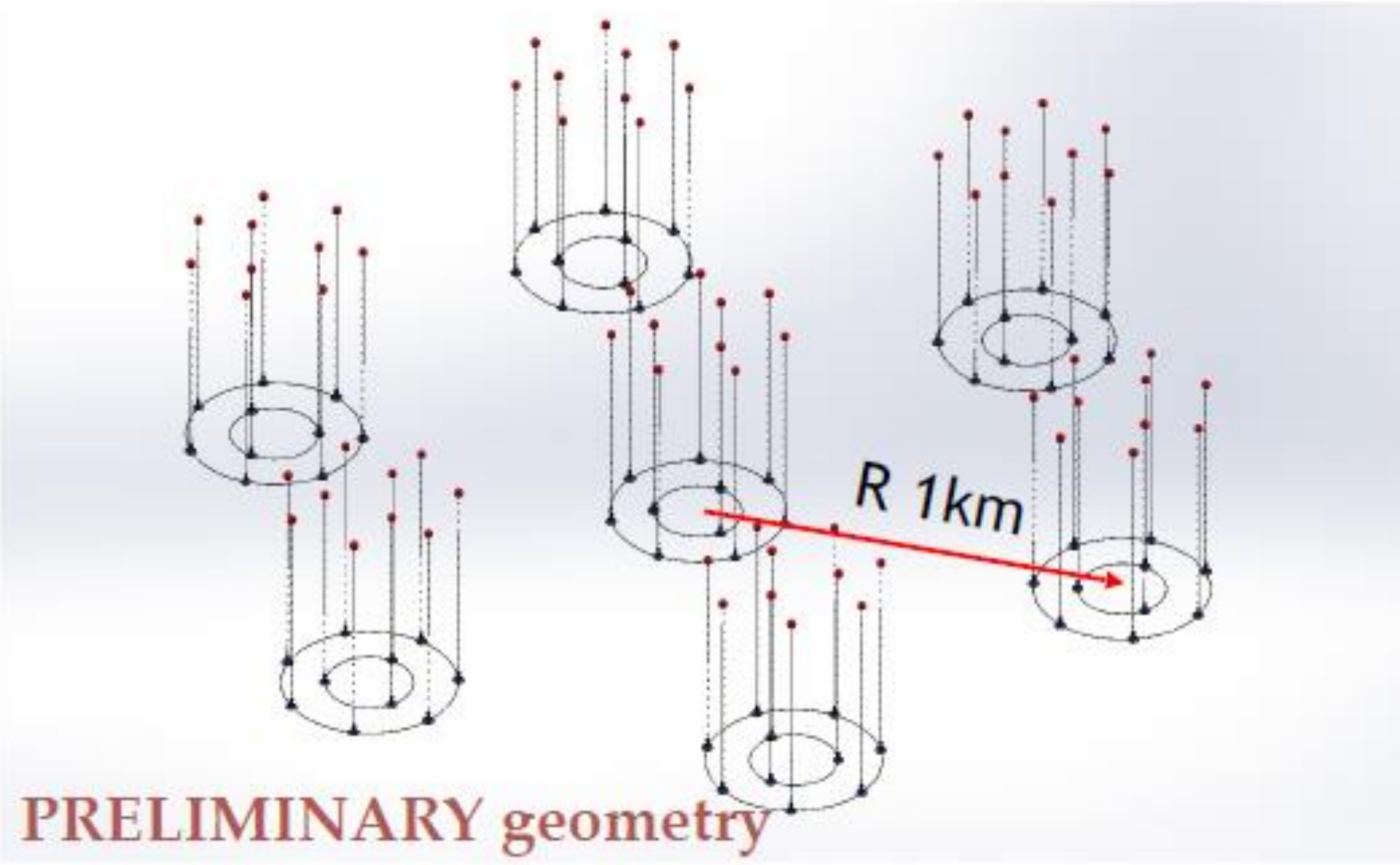


A new potential site: ONC in Canada

10 strings bundle
V = ~0.1km³



70-100 strings
V = ~2km³

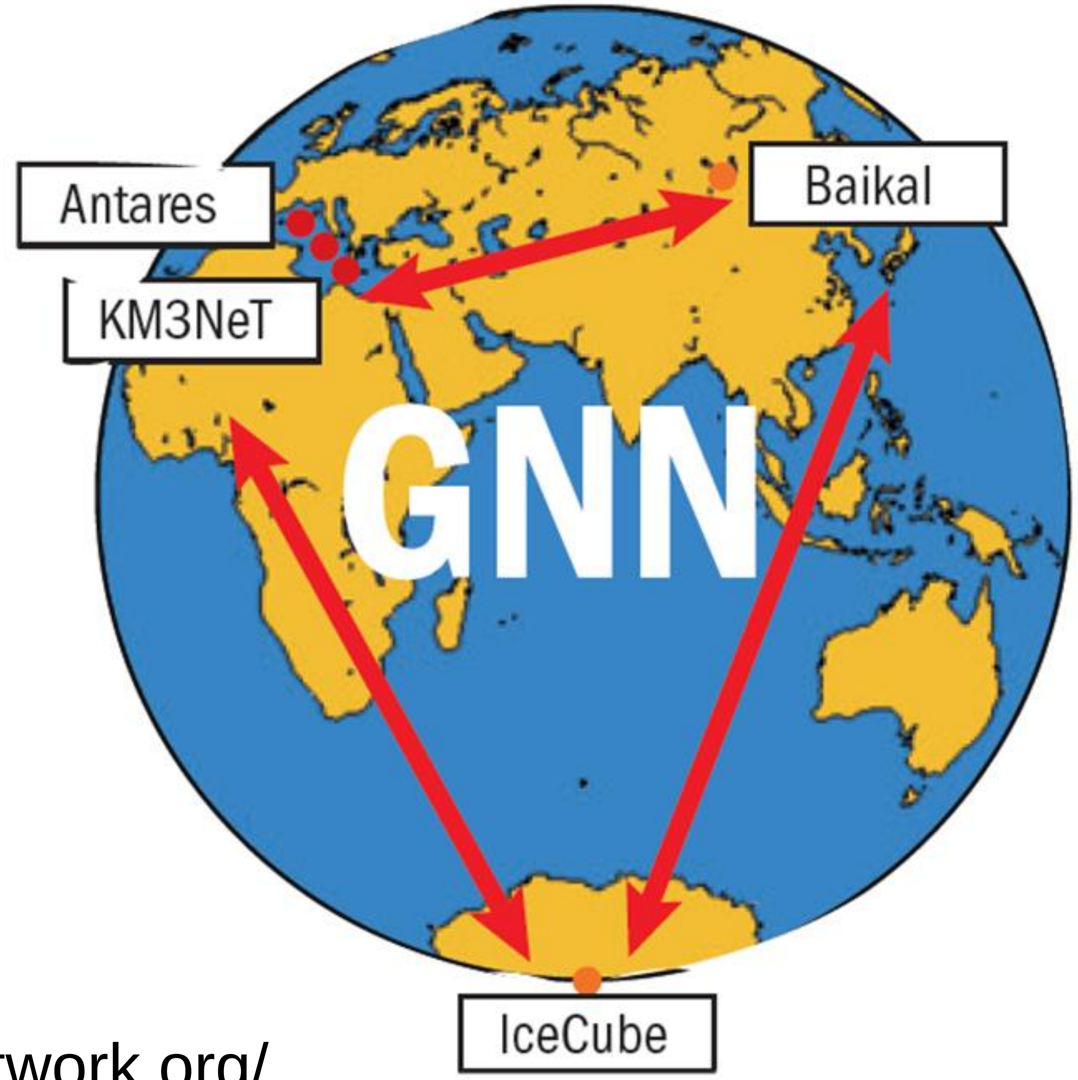


See talk of E. Resconi

Need for coordination:

Formed 2013:

- **ANTARES**
- **Baikal**
- **IceCube**
- **KM3NeT**



https://www.globalneutrinonetwork.org/

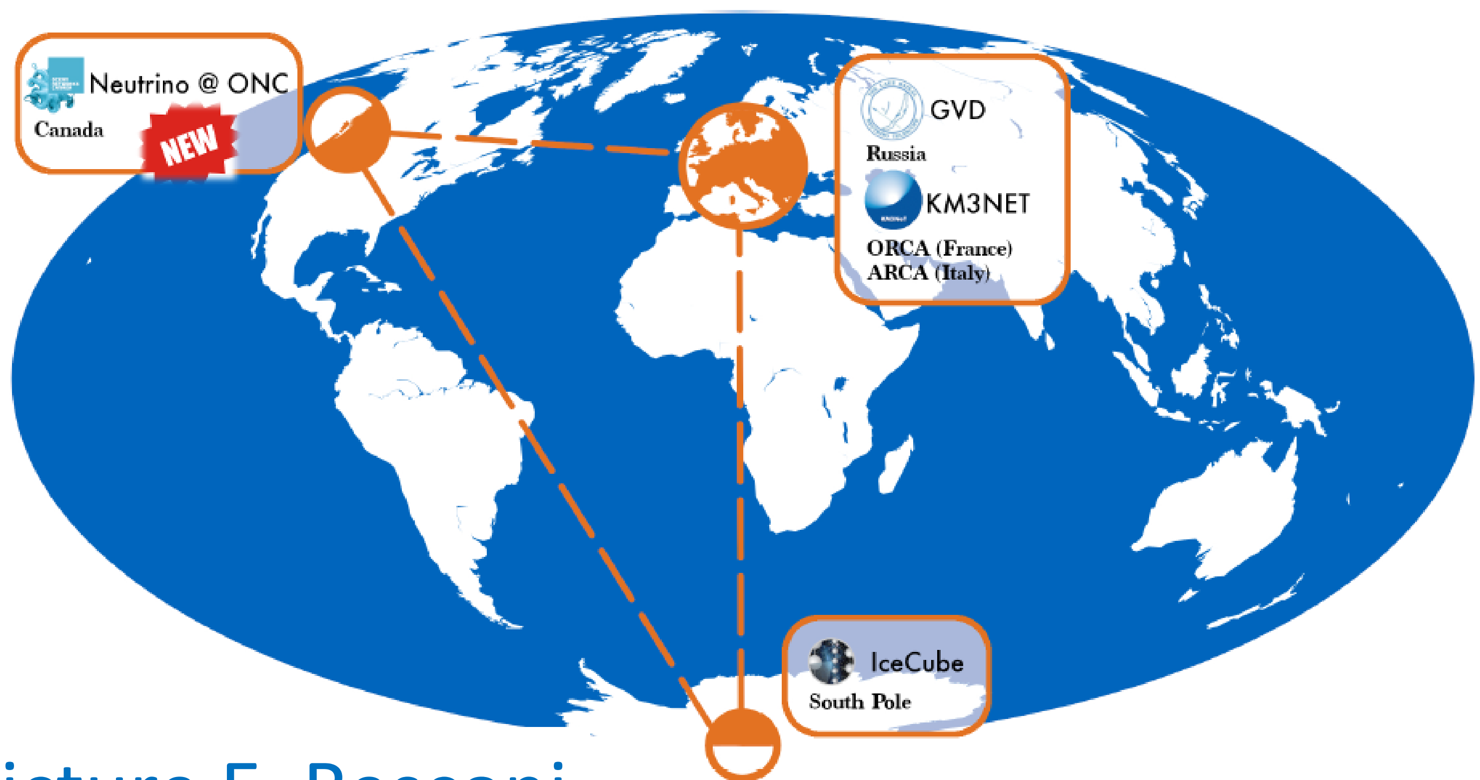
Need for coordination:

GNN
The Global Neutrino Network

Formed 2013:

+ ONC, Canada?

- ANTARES
- Baikal
- IceCube
- KM3NeT



picture E. Resconi

https://www.globalneutrinonetwork.org/

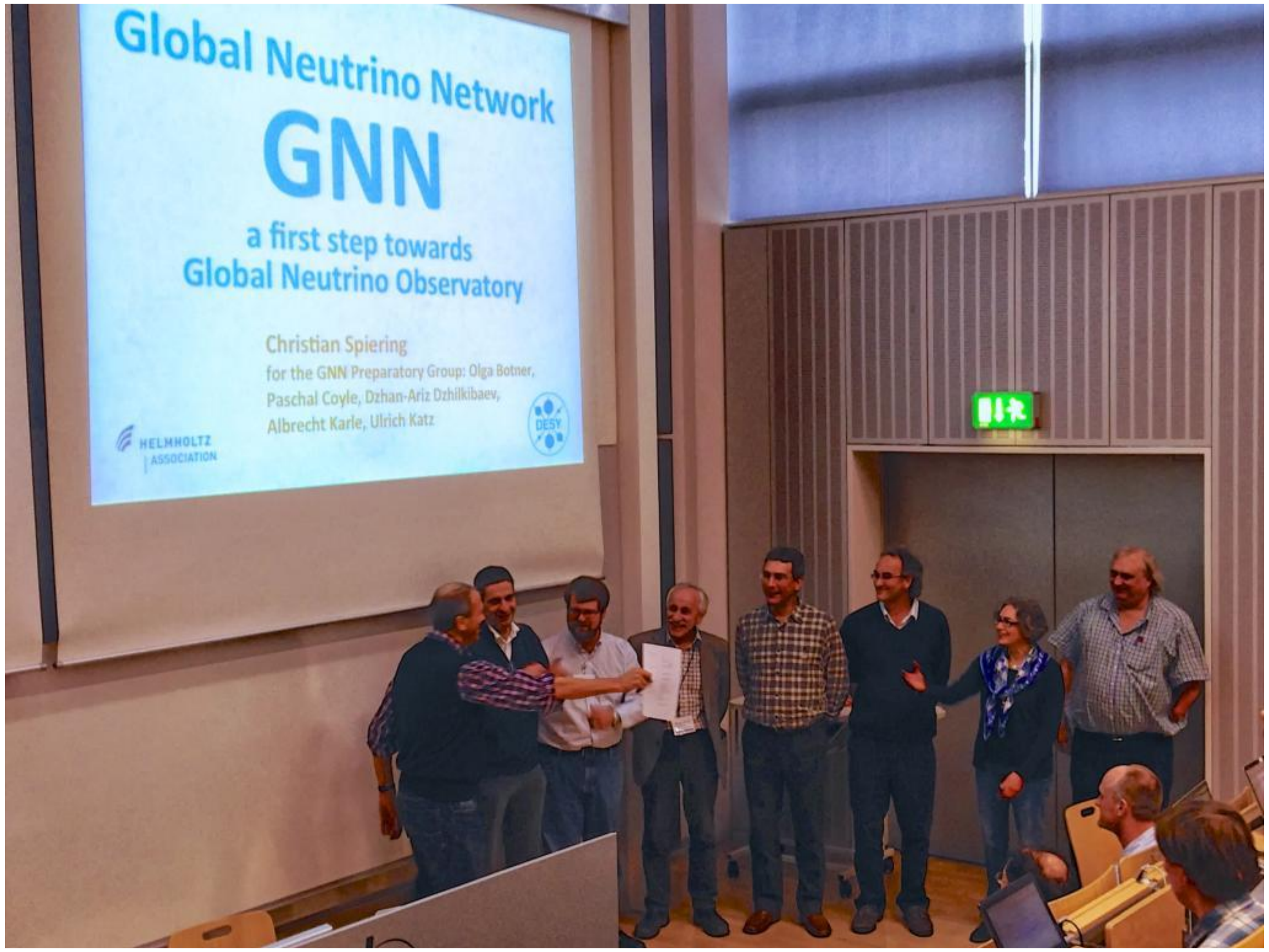
Need for coordination:

GNN

The Global Neutrino Network

After signing the MoU on GNN:

Christian Spiering, Maarten de Jong, Tyce deYoung, Zhan-Arys Dzhilkibaev, Juan-José Hernandez-Rey, Paschal Coyle, Olga Botner, Uli Katz



Need for coordination:

Chair 2013-2017: C.S, since 2017: U. Katz

Present members of GNN Board:

Paschal Coyle (CPPM, Marseille, France)
Zhan Djilkibaev (INR Moscow, Russia)
Grigorij Domogatsky (INR Moscow, Russia)
Darren Grant (University Alberta, Alberta, Canada)
Albrecht Karle (Univ. Wisconsin, Madison)
Uli Katz - chair (ECAP, Univ. Erlangen, Germany)
Antoine Kouchner (APC/University Paris, France)
Christian Spiering (DESY, Zeuthen, Germany)
Maurizio Spurio (Univ. Bologna/INFN, Bologna, Italy)
Mauro Taiuti (Univ. Genova/INFN, Genova, Italy)
Shigeru Yoshida (Chiba University, Chiba, Japan)

Goals of GNN

Develop coherent strategy to maximize the synergistic effects: exchanging information, analysis methods, cross-checking results, defining common ways of presenting data

Work toward framework for coordination of cooperative actions and self-organization of the neutrino astronomy community

Fostering future technological developments

Facilitate preparation of a "Global Neutrino Observatory": future detectors of similar scale in both North and South.

GNN Activities

- Cooperative projects, e.g.

  - Common analyses
  - cross-checks of results with different systematics
  - coordination of alert and multi-messenger policies
  - exchange and mutual checks of software
  - standards for data representation
  - exchange of expertise through mutual working visits of scientists and engineers

- Topical workshops, e.g. MANTS meetings /VLVNT Workshops
- Annual award for an outstanding PhD thesis
- Monthly Newsletter (“GNN Monthly”)

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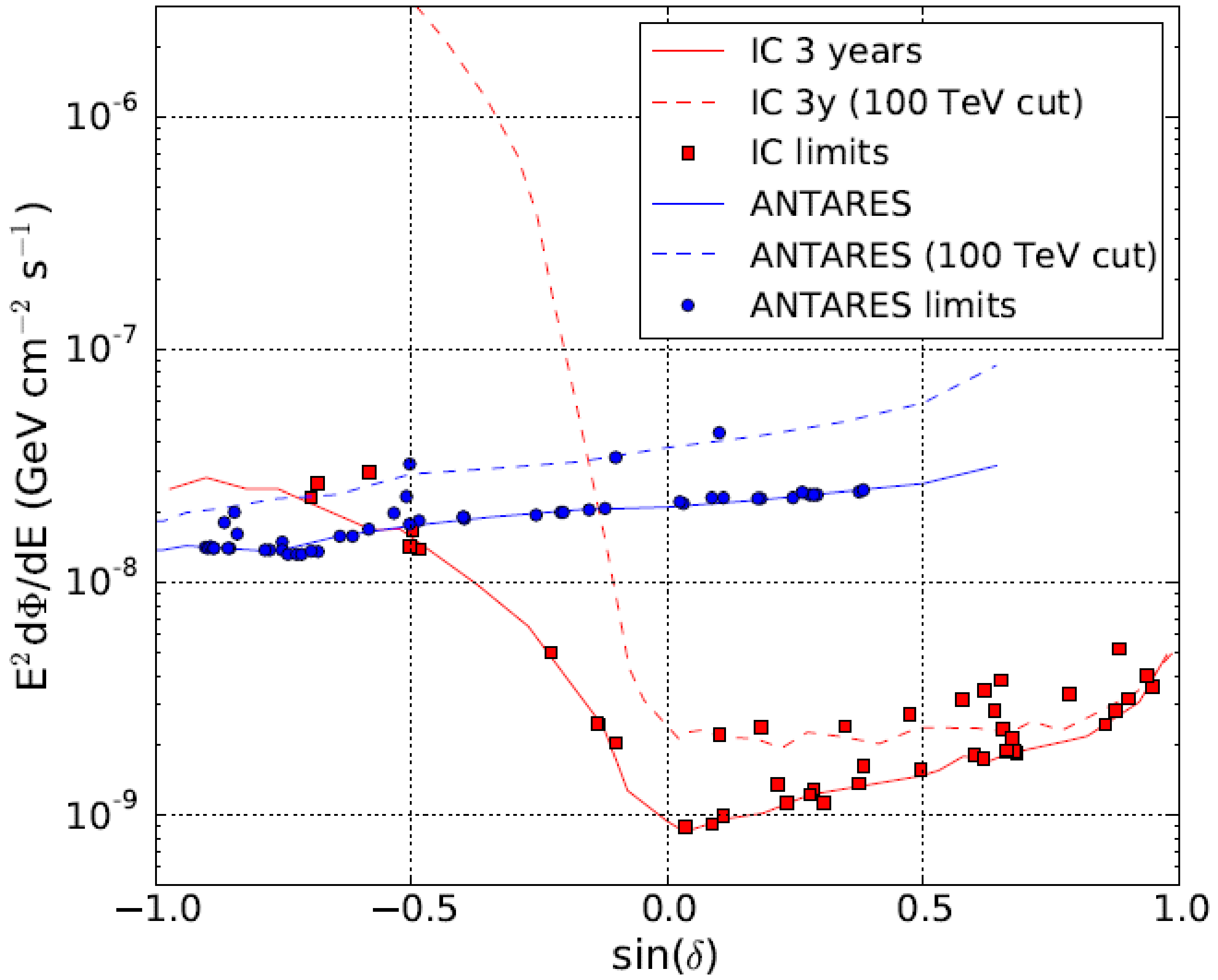
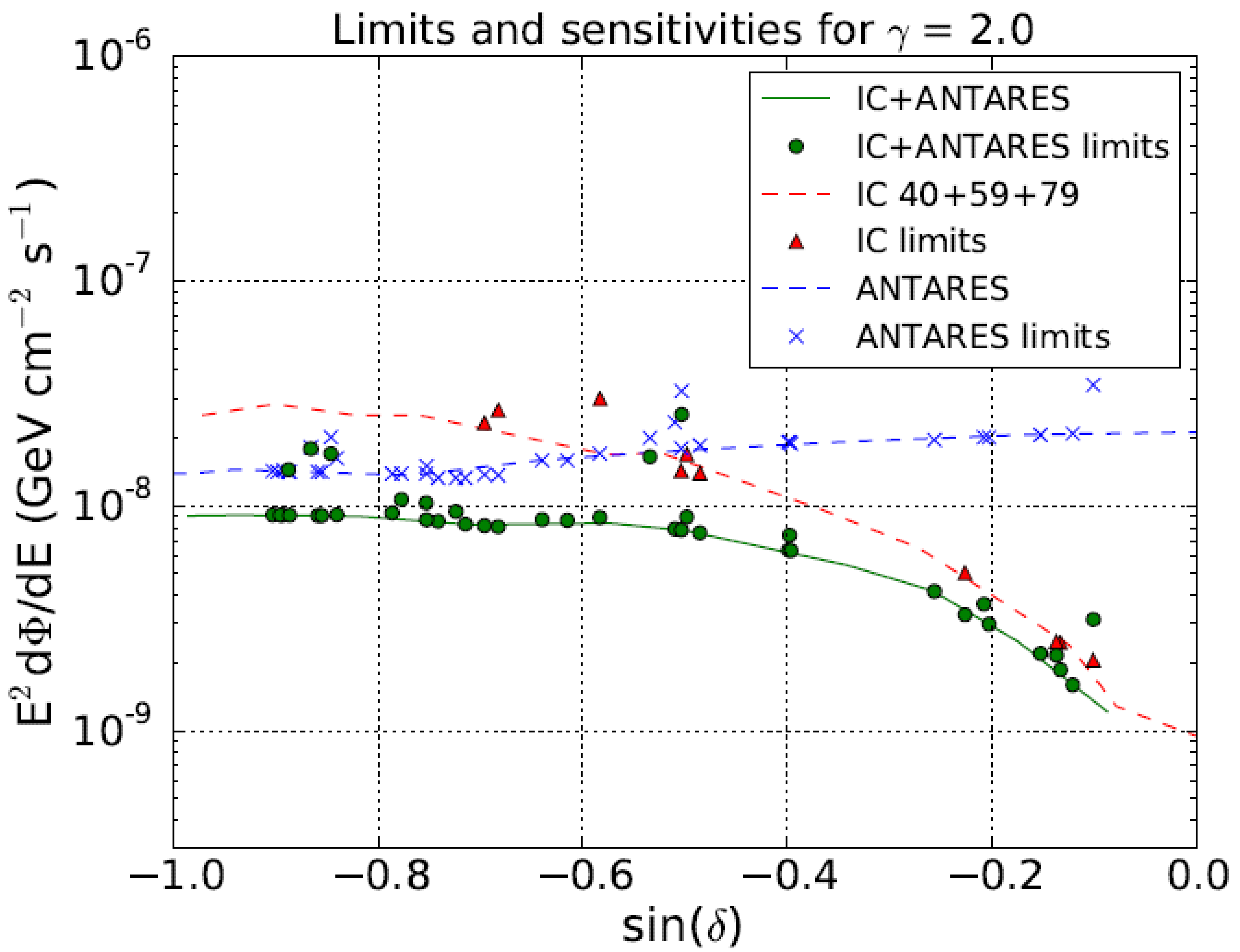
Combination of skymaps: point sources

First combined search for neutrino point-sources in the Southern Hemisphere with the ANTARES and IceCube neutrino telescopes

Astrophys. J. 823:65,2016

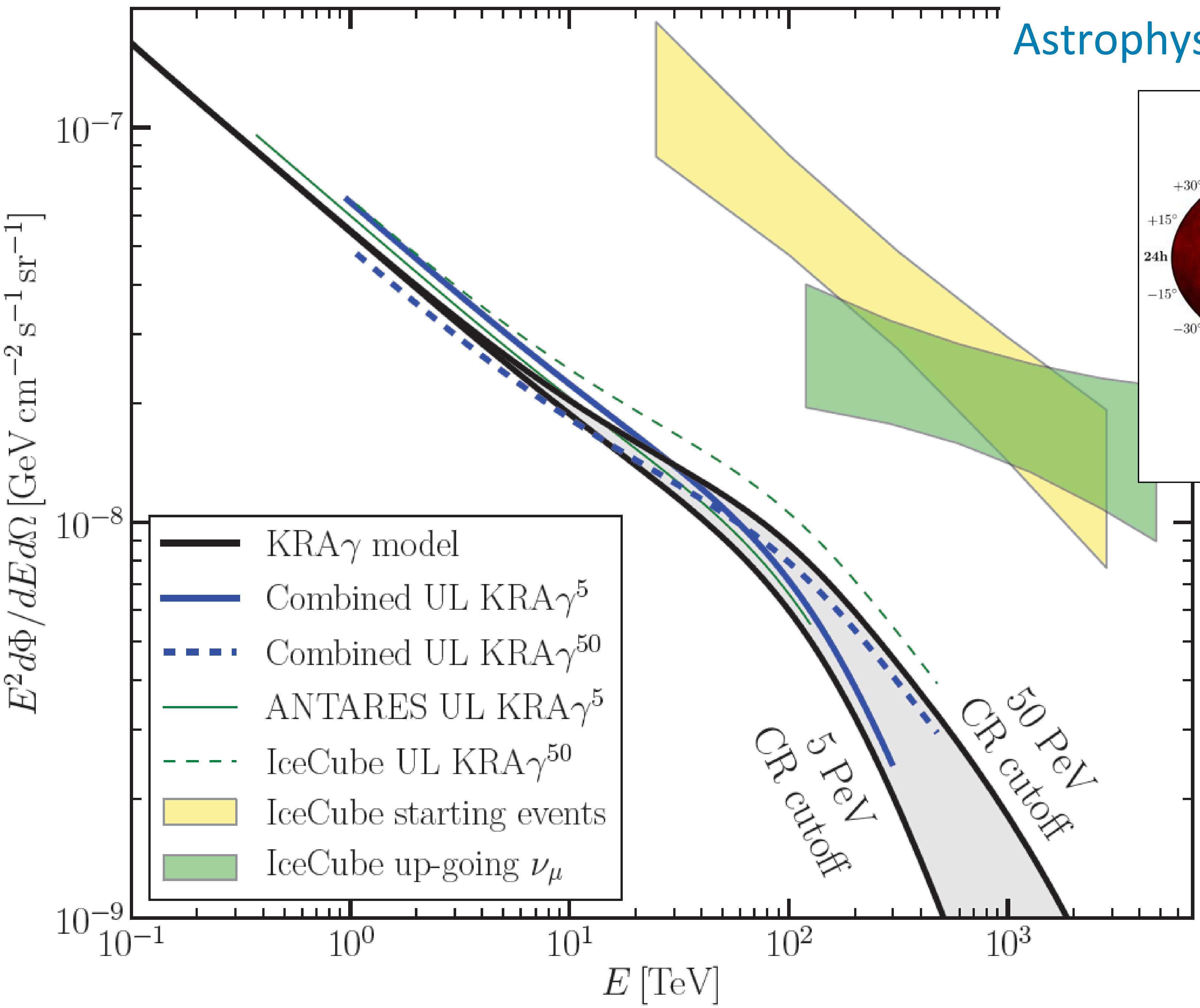


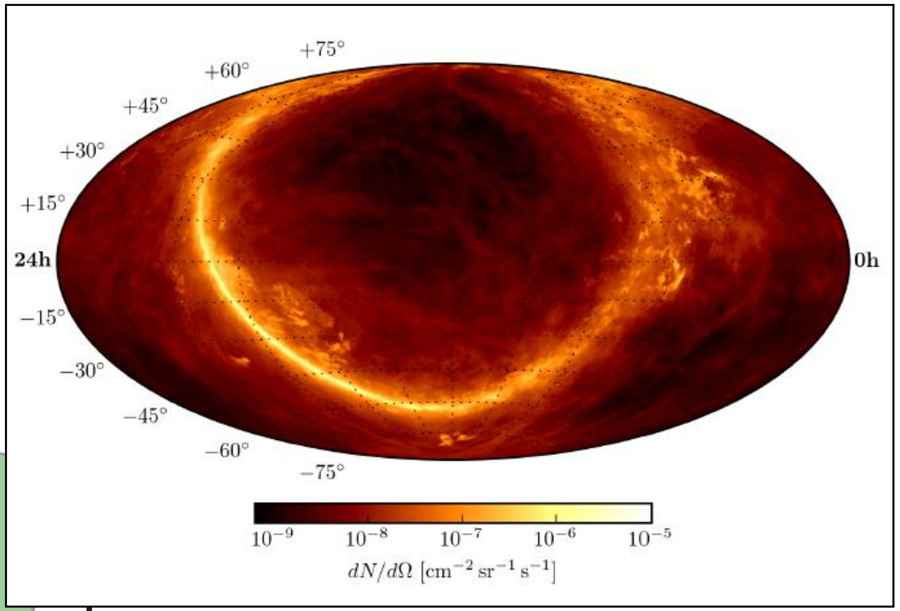


Galactic diffuse emission

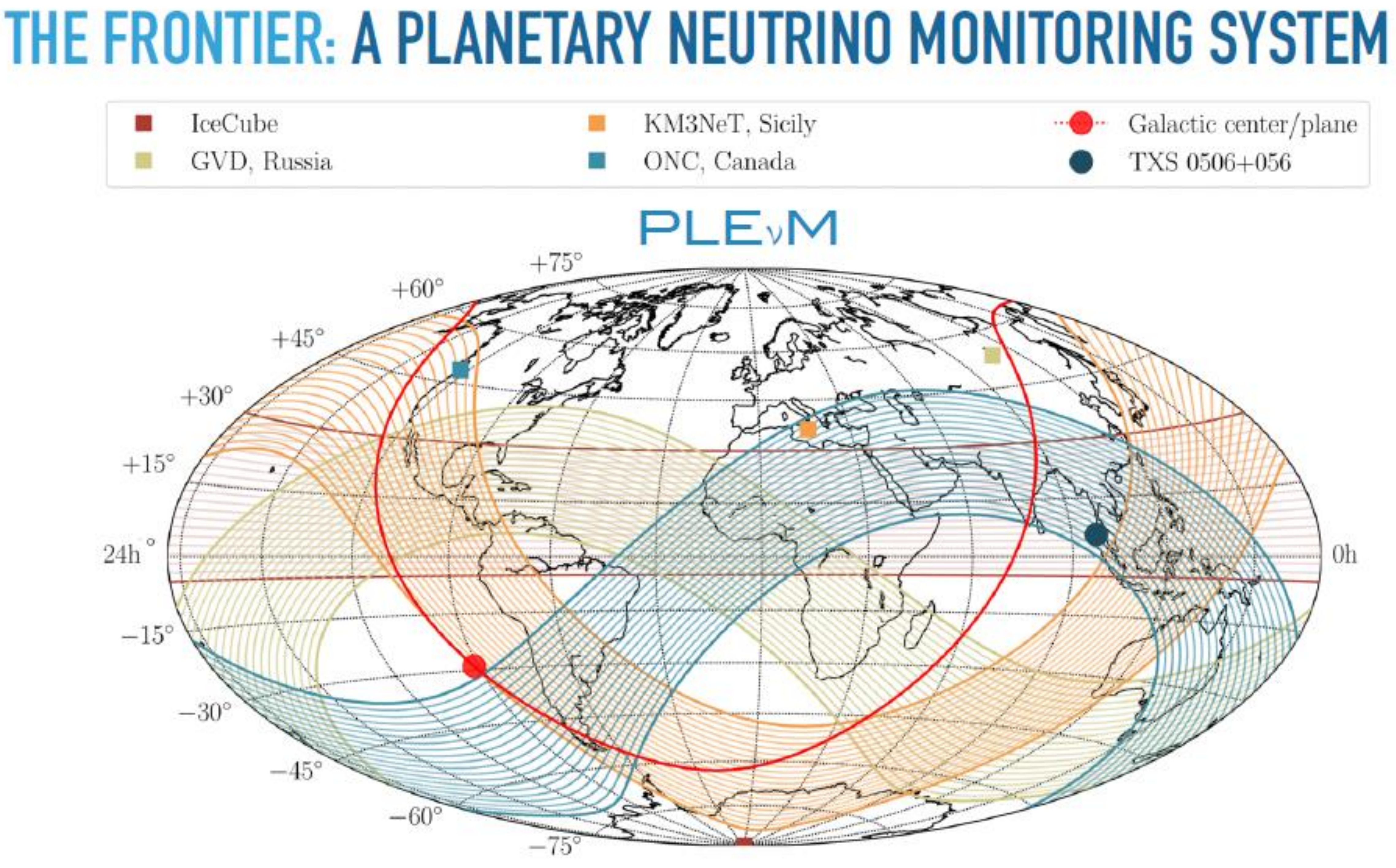
Joint constraints on Galactic diffuse neutrino emission from the ANTARES and IceCube neutrino telescopes

Astrophys.J. 868 (2018) no.2, L20





New conceptional considerations …



From talk of Elisa Resconi

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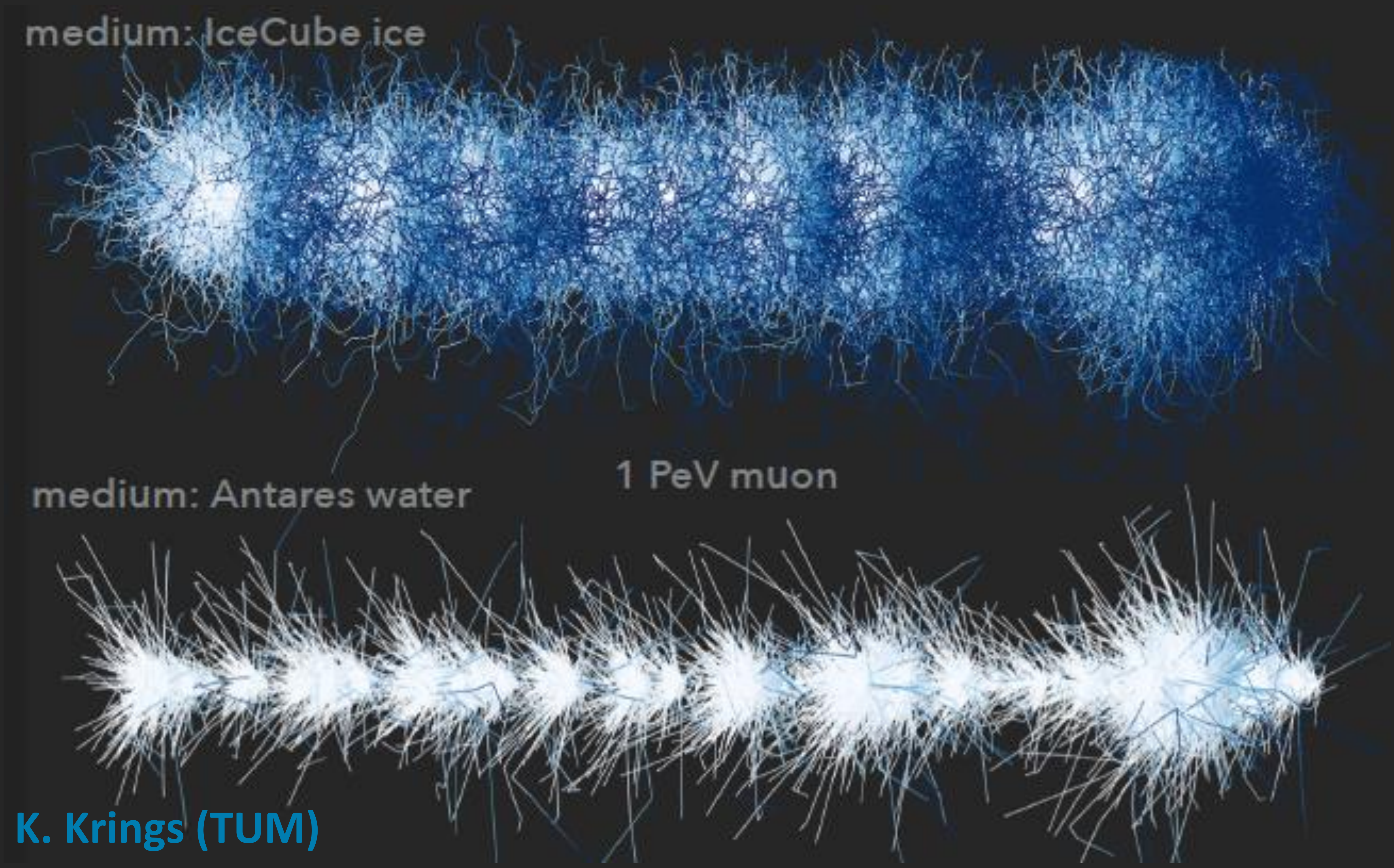
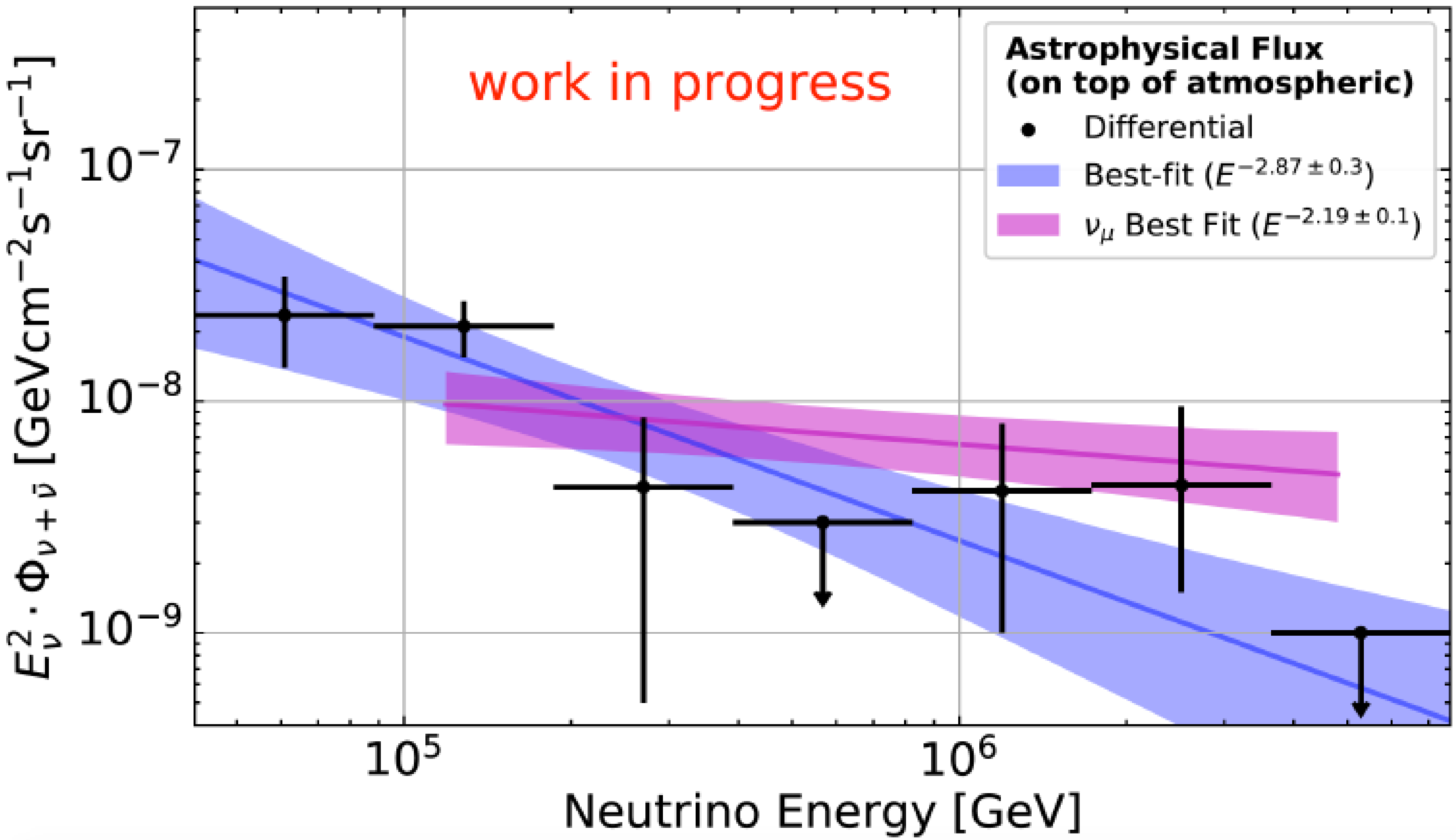
Cross checks with different media



K. Krings (TUM)

Cross checks: spectral shape

Looking forward to similar data from KM3NeT and GVD !

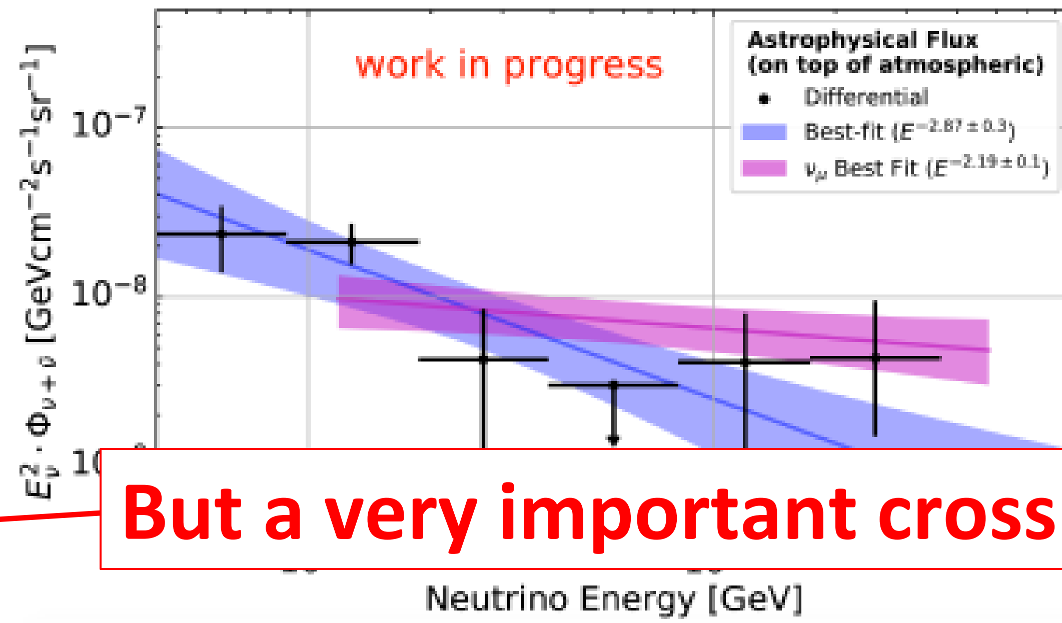


Cross checks: spectral shape

Detecting **cosmic** neutrinos: a threefold way

1. Excess of HE neutrinos over the background of atmospheric events. Estimate of the **neutrino energy (shower-dominated).**

- **No real improvement expected w.r.t. IceCube**



But a very important cross check!

2. Point-like events, excess in the sky map. Rely on the precision of the **neutrino direction (track-dominated)** and background suppression.

- **Unsurpassable sensitivity for Galactic sources for E_ν<100 TeV and part of the Southern sky**

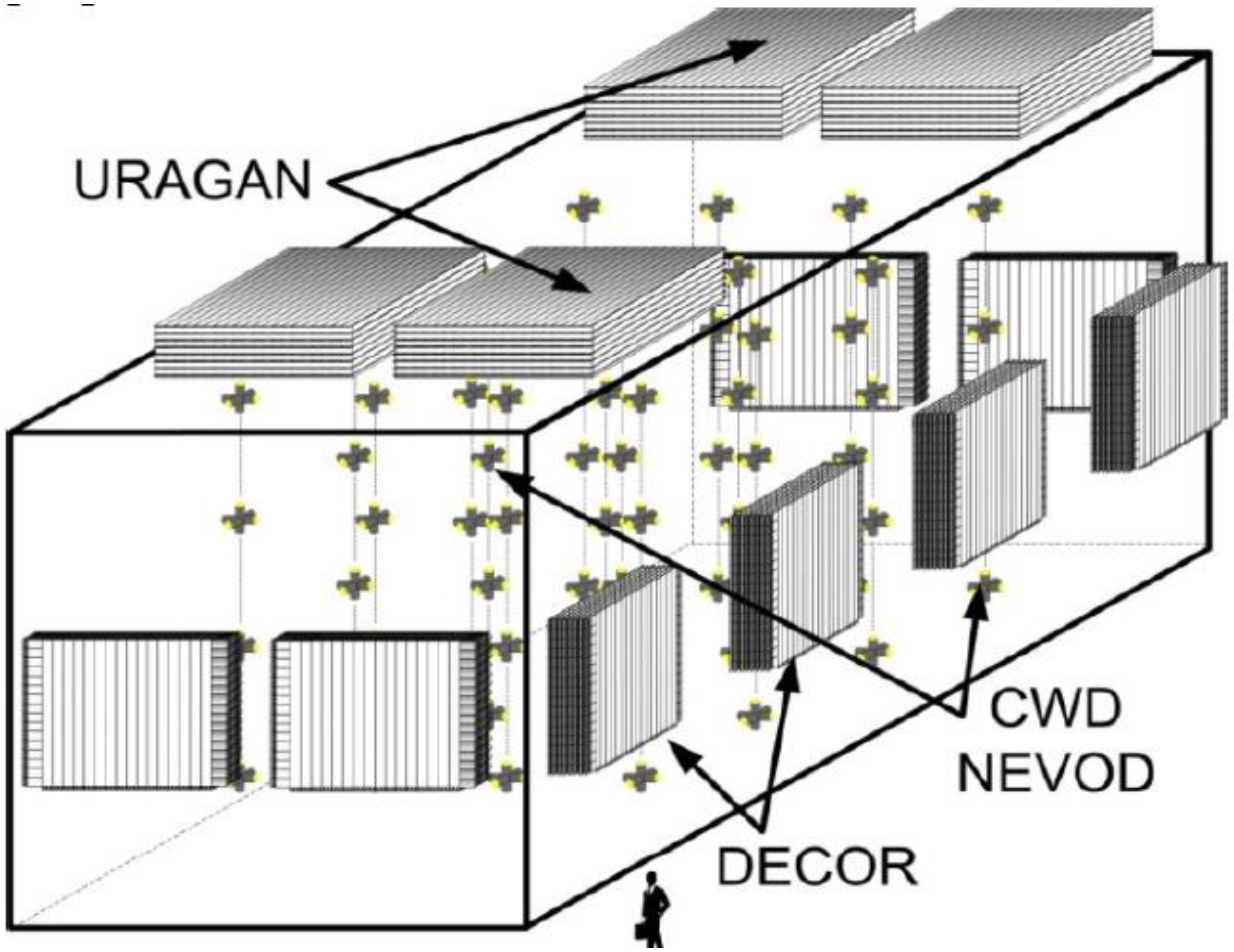
3. Coincident event in a restricted time/direction windows with EM/γ/GW counterparts. Relaxed energy/direction measurement + **transient/ multimessenger** information

- **Real complementarity w.r.t. IceCube**

Slide taken from Maurizio Spurio's talk

Calibration campaigns („technology cross checks")

POCAM's first in site test in Lake Baikal, 2017



NEVOD in Moscow as calibration detector

GNN Activities

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VLVνT (open) and MANTS (internal)

- Amsterdam 2003
- Catania 2005
- Toulon 2008
- Athens 2009
- Erlangen 2011
- Stockholm 2013
- Rome 2015
- Dubna 2018

MANTS Meeting

"**M**editerranean-**A**ntarctic **N**eutrinos **T**elescope**S**"

GNN internal workshop alternating with VLVνT

GNN Activities

- Cooperative projects, e.g.
  - Common analyses
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Monthly newsletter: *GNN Monthly*

GNN MONTHLY

The Global Neutrino Network — 28th Edition — February 28, 2019

News from Baikal

On February 21, a transport with all remaining equipment for the winter expedition left Moscow. With great sadness, however, we had to hear that Andrei Panfilov, one of the very pioneers of the Baikal experiment and also this time already at the Lake, passed away at February 27. Please read the obituary at the end of this newsletter.

News from IceCube

The official closing of the South Pole station was already last week. The "snow eagle" (see the picture) was the very last plane to visit the South Pole at February 25. From now on, the winterovers will be left themselves until the end of October.

With an uptime of 99.8% in the first week of isolation, IceCube performed rather pleasantly.

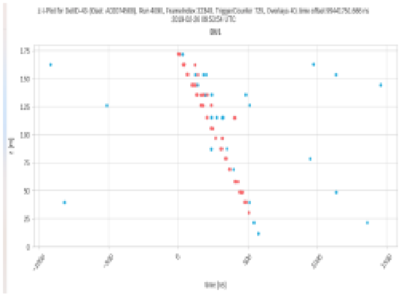
News from ANTARES and KM3NeT

From February 25 to March 1, an ANTARES/KM3NeT Meeting took place in Tbilisi, Georgia. The meeting coincided with the good news that the Tbilisi group o Revaz Shanidze will get financial support.

On February 15/16, after an agonizingly long period o bad weather, the KM3NeT Collaboration successfully deployed and connected the first of the four availabl ORCA detection units (DU) to the refurbished main electro-optic cable. Unfortunately, after the deployment of the first DU, the winch of the heavy li line failed and the other three DUs could not be deployed. The next campaign is planned for mid of April.

Four rolled-up detection units waiting for deployment

All 18 optical modules of the connected detection un are providing good quality data, see the figure on the next page.



Depth versus time plot for a down-going muon recorded with the first ORCA Detection Unit

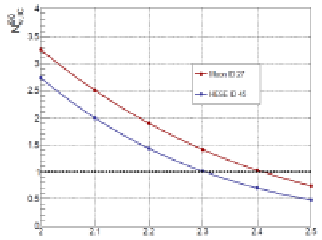
Neutrino Meeting at ONC

On the 19th and 20th of February, Ocean Network Canada (ONC) has hosted a meeting on neutrino telescopes. The existing NEPTUNE infrastructure operated by ONC could in fact host a new telescope. The meeting covered preliminary results from STRAW, the planning of a new mooring line STRAW-b for 2020 and a longer-term construction. A modular approach based on bundle of 10-strings has been discussed and a budget plan has been proposed to finance the first bundle. A conceptual design report is under preparation to cover in details the goal of the new installation. The institutions involved at the moment are ONC-Univ. Victoria, Univ. Alberta, Queens, and TU Munich.

Publications

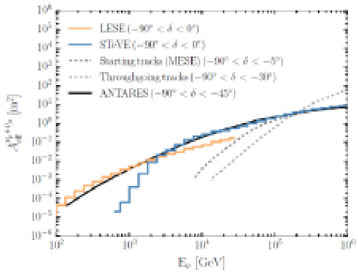
The **ANTARES** Collaboration has posted a paper *ANTARES neutrino search for time and space correlations with IceCube high-energy neutrino events* (https://arxiv.org/abs/1902.09462). Giulia Illuminati (IFIC Valencia) as corresponding author examined arrival time and direction of 6894 track-like and 160 shower-like events recorded by ANTARES over 2346 days of lifetime and looked for coincidences with 54 IceCube high-energy track-like neutrino events (HESE and through-going muons). For steep spectra one may hope for a correlation since for the Southern hemisphere ANTARES is much more effective at lower energies (see, however, the paper below on a lowered threshold for IceCube). She finds no significant correlation and derives upper limits on the one-flavor neutrino fluence from the direction of the IceCube candidates. Special attention is given to the two most energetic IceCube events. The absence of time and space correlation within a time window of 0.1 days between ANTARES events and these two IceCube events constrains the spectral index γ of a possible point-like flaring neutrino source to be harder than -2.3 for the first and -2.4 for the second event, see the figure.

For the two cases of spectral index γ equal to -2.0 and -2.5 respectively, fluence limits for all 54 events are given – about 20/(GeV cm²) for γ = -2.0, slightly dependent of the declination.



90% C.L. upper limits on the expected number of IceCube events originated from a transient $E^{-\gamma}$ point-like source emitting in a time window ≤ 0.1 days as a function of the spectral index γ for the most energetic IceCube events of the through-going muon sample and of the HESE sample, respectively. The dotted line corresponds to the number of events detected by IceCube for each of these directions (i.e. 1).

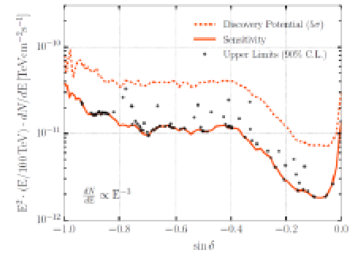
Another low-energy look to the Southern hemisphere is taken by the **IceCube** Collaboration in their paper *Neutrinos below 100 TeV from the southern sky employing refined veto techniques to IceCube data* (https://arxiv.org/abs/1902.05792, submitted to Astroparticle Physics). Every reader of GNN Monthly knows what HESE means: High Energy Starting Events. The domain of HESE is the energy range above several tens of TeV. Three new selection strategies have been developed to improve the sensitivity to track-like events at energies below 100 TeV: MESE (Medium Energy Staring Events), STeVE (Starting TeV Events) and – moving into the region below 1 TeV – LESE (Low Energy Starting Events). Using an online filter which selects track-like events starting inside the detector, plus the two veto-based strategies LESE and STeVE, the atmospheric background could be reduced from order 10^{11} triggered events to a few thousand events per year in the final event samples. The figure below shows the effective areas of the different samples for the Southern hemisphere, compared to the ANTARES effective area. (Note however that the ANTARES angular resolution is about 5 times better at these energies. Therefore IceCube cannot compete with the ANTARES analysis presented above!)



Effective areas of the LESE (light blue) and STeVE (dark blue) selections compared to other IceCube selections using tracks the through-going event selection (dashed light gray) and the starting event selection (MESE) (dashed gray). Also shown is the effective area for ANTARES (black). The effective areas are shown for a neutrino flux ν_μ + anti-ν_μ and averaged over the solid angle in the indicated declination range.

Rickard Ström (Uppsala), David Altmann (Erlangen) and Alexander Kappes (Münster) have used these samples to search for point-like neutrino sources in the southern sky at energies between 100 GeV and several TeV, using four years of IceCube data.

No significant deviations from the background-only hypothesis were found. Upper limits at 90% C.L. were calculated for all 96 sources of a pre-defined list (see the following figure). The most significant source was HESS J1616-508, with a post-trial p-value of 6.1%, again compatible with the background-only hypothesis.



Sensitivity and 5σ discovery potential as functions of declination, with flux upper limits for each object in the source catalog assuming a soft spectrum (spectral index γ = -3).

This analysis is the first of IceCube to search for point-like sources of neutrinos in the track channel at these energies in the southern sky. The samples are also well suited for searches for extended sources or neutrino emission in the Galactic plane (where the drawback of the moderate pointing is less important).

The paper *A search for transient optical counterparts to high-energy IceCube neutrinos with Pan-STARRS1* was submitted to Astronomy and Astrophysics and posted at https://arxiv.org/abs/1901.11080. Pan-STARRS is a 1.8-m telescope located at the Haleakala Observatory in Hawaii. It is equipped with a 1.4 Gigapixel CCD camera with ~ 7 deg² FoV and automatic real time data processing. Anna Franckowiak , Jakob van Santen (both DESY) and Claudio Kopper (Michigan State Univ.) for **IceCube** together with several **Pan-STARRS** scientists have used Pan-STARRS1 to follow-up five of the 2016/17 IceCube alerts to search for any optical transients that may be related to the neutrinos. Typically 10–20 faint extragalactic transients are found within the Pan-STARRS1 footprints and are generally consistent with being unrelated supernovae (SNe) and AGN. The figure shows the landscape of sources around one of the five events.

Long-term vision

~ 2030

- 6-8 km^3 optical detectors both in the South and in the North
  - IceCube Gen2
  - KM3NeT/ARCA + GVD, + …. + Canada ?
- ~100 km^2 radio detector at the South Pole ($RNO_{100\ km^2}$ ~ 2024 ?)

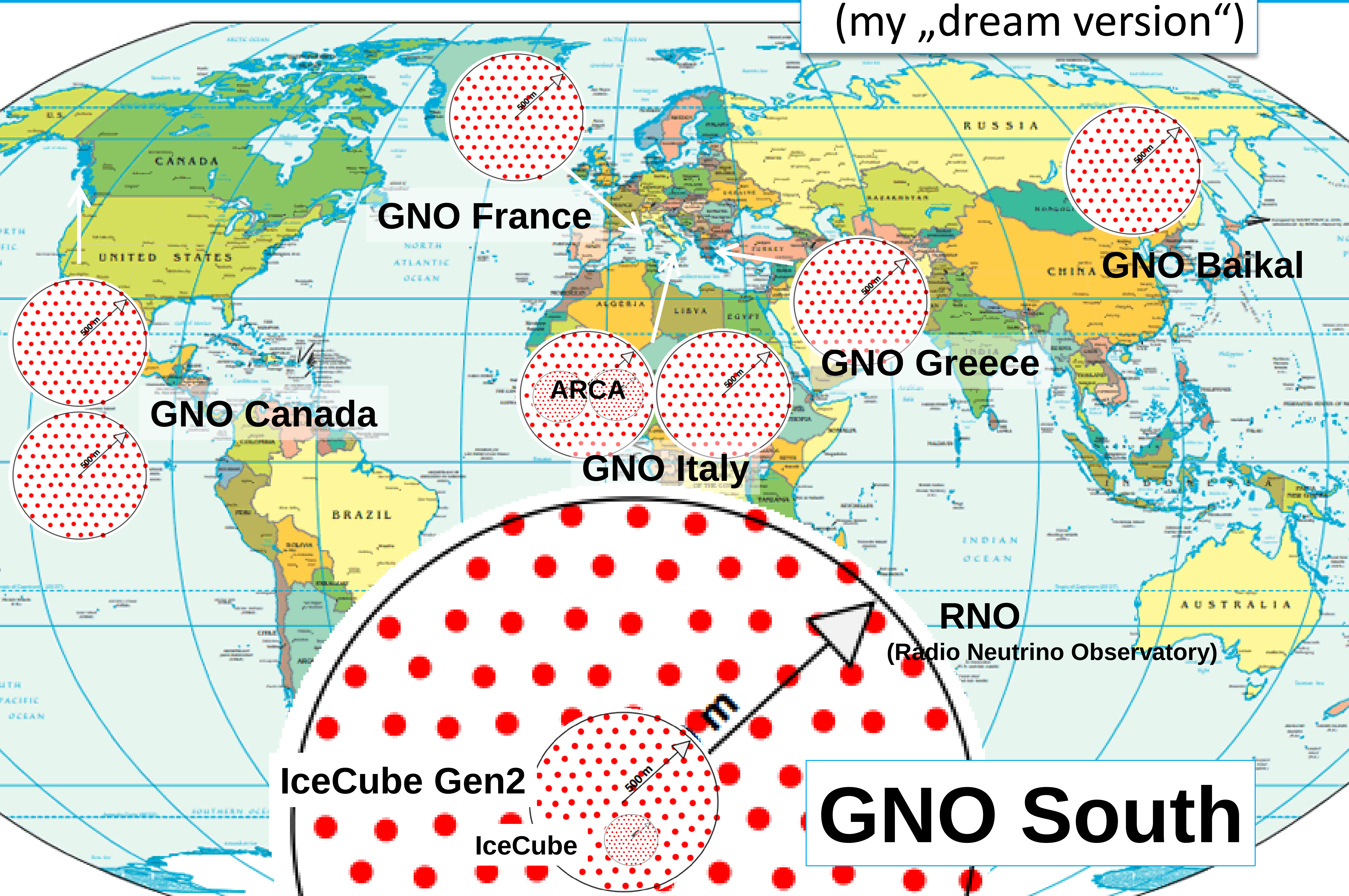
Beyond 2030

(depending on the outcome of the Σ 6-8 km^3 phase !!!)

- > 10 - 1000 km^3 scale
  - Optical ?
  - Radio
  - (Acoustic ?)

Global ν Observatory (Optical: North 7 x 3 km³, South 8 km³, radio: South ≥100 km²)

(my „dream version“)



GNN: strategic considerations

- In the future, big and expensive projects in fundamental science will compete with each other across disciplines, nations and communities : not “IceCube vs. KM3NeT”, but may be astronomy vs. gene technology.
- Need to speak with one common voice (similar to GWIC which was instrumental in steering and synchronising gravitational wave research on a global scale, and with a time horizon of decades)
- A coherent effort including neutrino astronomy as well as neutrino physics may have good prospects in the “global science league”.
- GNN is a good starting point for this coordination process. If used with care and courage, GNN can be the right instrument for building our future strategy.

GNN Input to CERN Strategy Process

18 December 2018

A memorandum by the Global Neutrino Network as input to the update of the European Strategy for Particle Physics

U.F. Katz, Chair, Board of the Global Neutrino Network

Friedrich-Alexander University of Erlangen-Nürnberg
Erlangen Centre for Astroparticle Physics
Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
katz@physik.uni-erlangen.de

The Global Neutrino Network is an association of the neutrino telescope projects targeting the investigation of cosmic and atmospheric neutrinos in the energy range from GeV to beyond PeV. The main scientific objectives are the exploration of high-energy cosmic neutrinos from non-thermal astrophysical sources (neutrino astronomy), the investigation of fundamental questions of particle physics with atmospheric, but also cosmic neutrinos (neutrino physics), and further particle physics topics such as the search for dark matter. In this document we focus on the particle physics aspects and provide information that we consider useful in linking neutrino telescopes to the European Strategy for Particle Physics.

GNN Input to CERN Strategy Process

Conclusions

Given the particle and in particular neutrino physics capabilities of the current and upcoming neutrino telescopes, we suggest to consider these instruments as an element of the future European Particle Physics Strategy and to exploit synergies both on the scientific and instrumental level. In particular, a mutually beneficial cooperation between the neutrino telescope projects and the CERN neutrino platform might be an option to explore. We note that the neutrino telescope community is deeply involved in technology, computing and data science developments which are also relevant for accelerator-based experiments – examples are photo-detection, GPU-based scientific computing and open data provision.