# Status and Future of ν astronomy and the Global Neutrino Network

**October 8, 2020**

Christian Spiering, DESY Zeuthen

# Neutrino Telescopes

## Physics Goals

# Physics with neutrino telescopes

- Search for sources of high-energy cosmic rays
- Dark Matter and Exotic Physics
  - WIMPs
  - Magnetic Monopoles and other superheavies
  - Violation of Lorentz invariance
- Neutrino and Particle Physics
  - Neutrino oscillations
  - Charm physics
  - Cross sections at highest energies
- Supernova Collapse Physics
  - MeV neutrinos in bursts $\rightarrow$ early SN phase, neutrino hierarchy, ...
- Cosmic Ray Physics
  - Spectrum, composition and anisotropies, shadows of moon and Sun

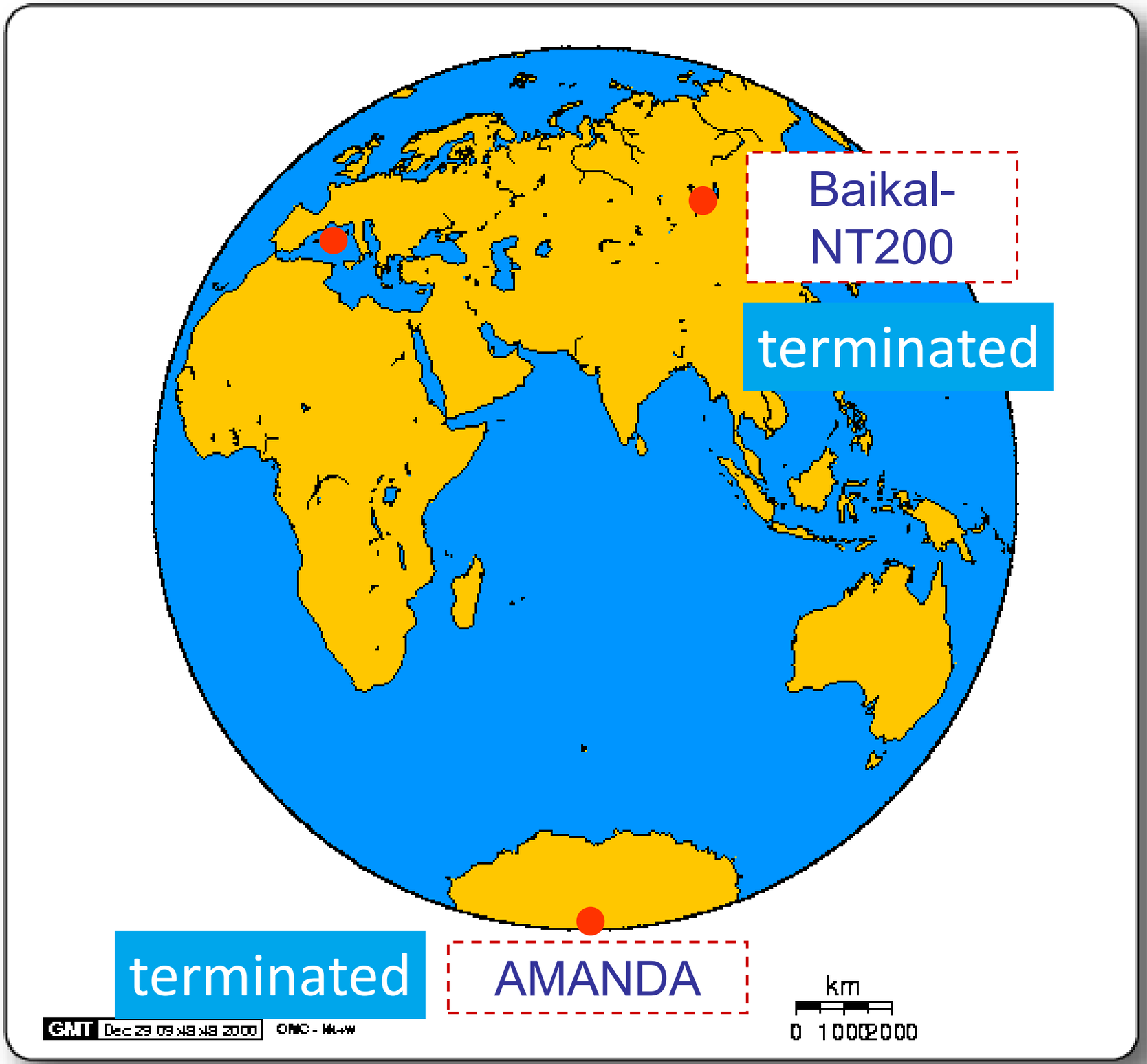
# Physics with neutrino telescopes

- **Search for sources of high-enery cosmic rays** ***Diffuse flux + 1 point source cand.***
- **Dark Matter and Exotic Physics**
  - **WIMPs** ***Upper limits***
  - **Magnetic Monopoles and other superheavies** ***Upper limits***
  - **Violation of Lorentz invariance** ***Upper limits***
- **Neutrino and Particle Physics**
  - **Neutrino oscillations** ***Precision measurements***
  - **Charm physics**
  - **Cross sections at highest energies** ***First data at > 1 TeV***
- **Supernova Collapse Physics** ***Waiting for next galactic SN***
  - **MeV neutrinos in bursts → early SN phase, neutrino hierarchy, ...**
- **Cosmic Ray Physics** ***results add to standard EAS measurements***
  - **Spectrum, composition and anisotropies, shadows of moon and Sun**

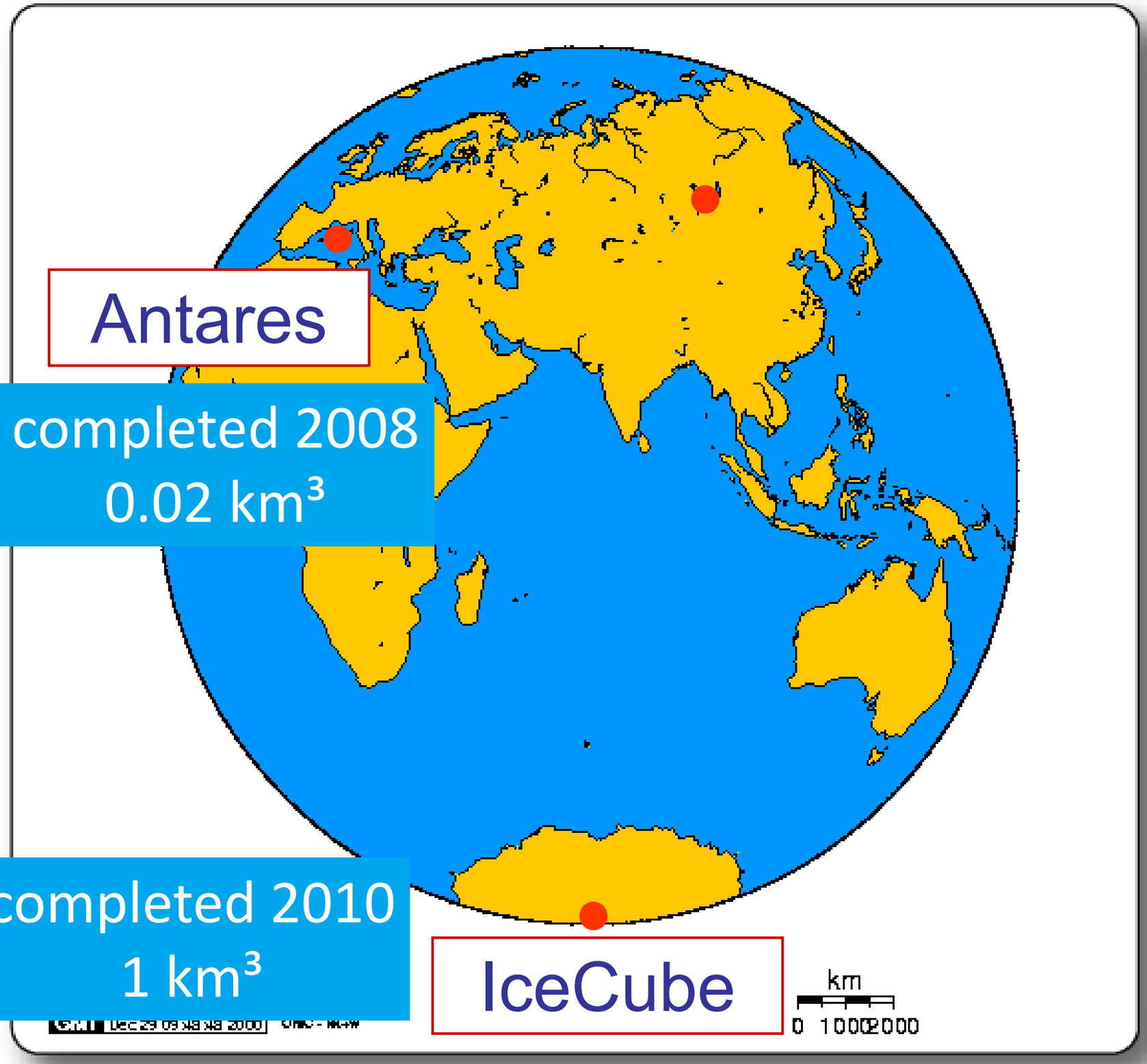
# Neutrino Telescopes

## The Detectors

# Pioneers completed in the 1990s

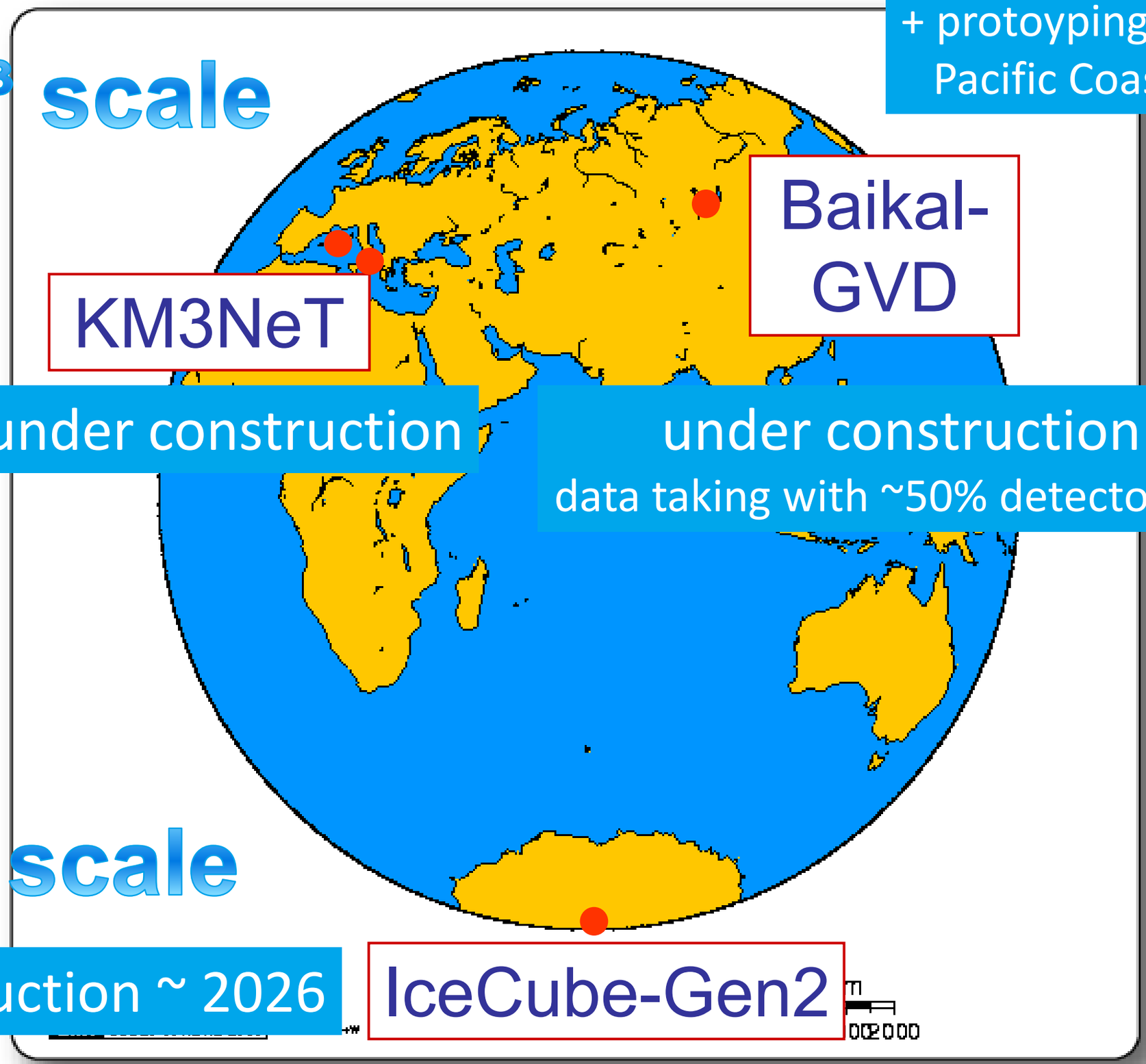


# Completed and Operating



# Under Construction or planned

## ~ 1 km³ scale




+ protoyping for P-ONE, Pacific Coast Canada

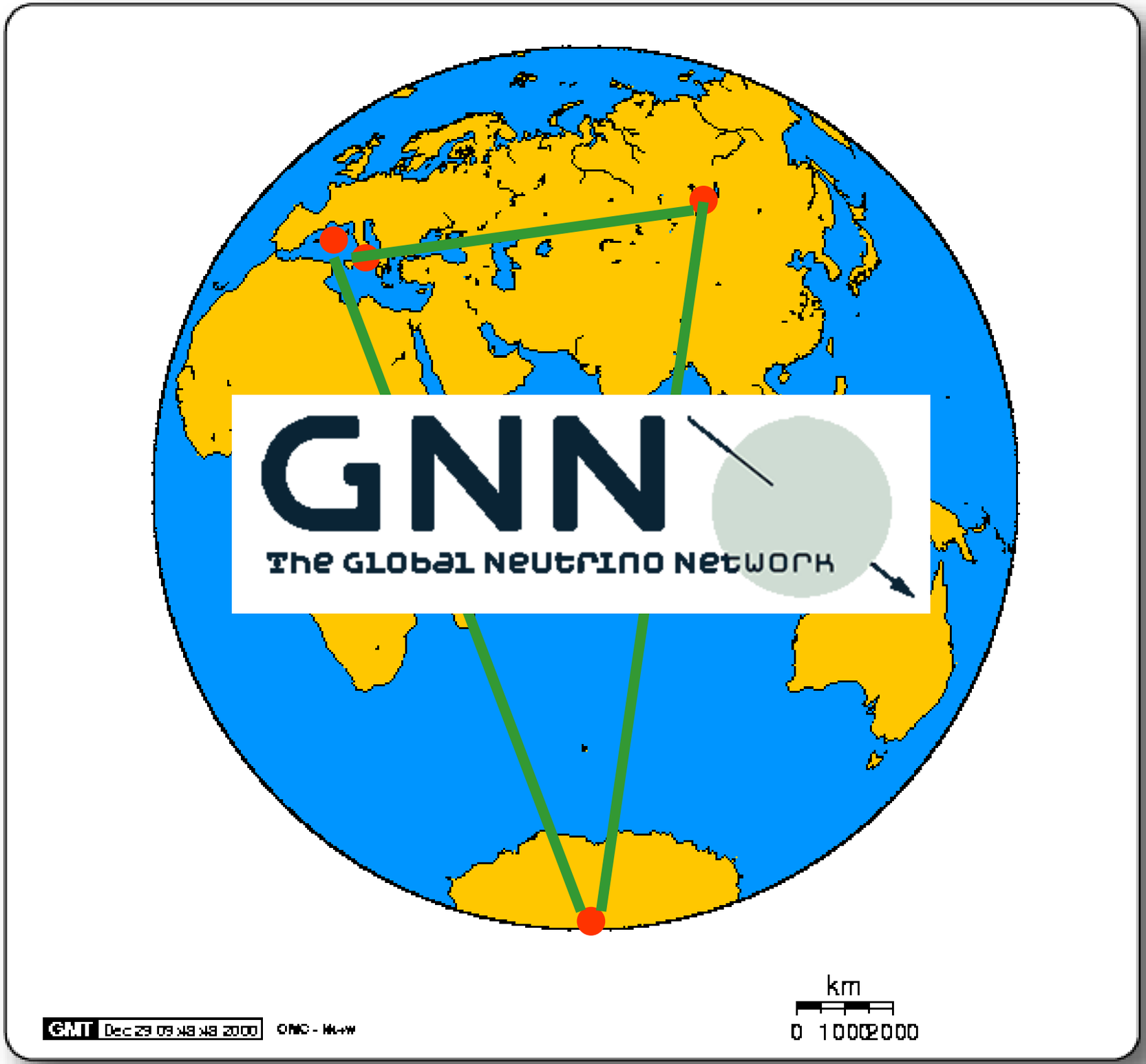
under construction

under construction
data taking with ~50% detector size

## 10 km³ scale

Start construction ~ 2026

# Worldwide Common Effort



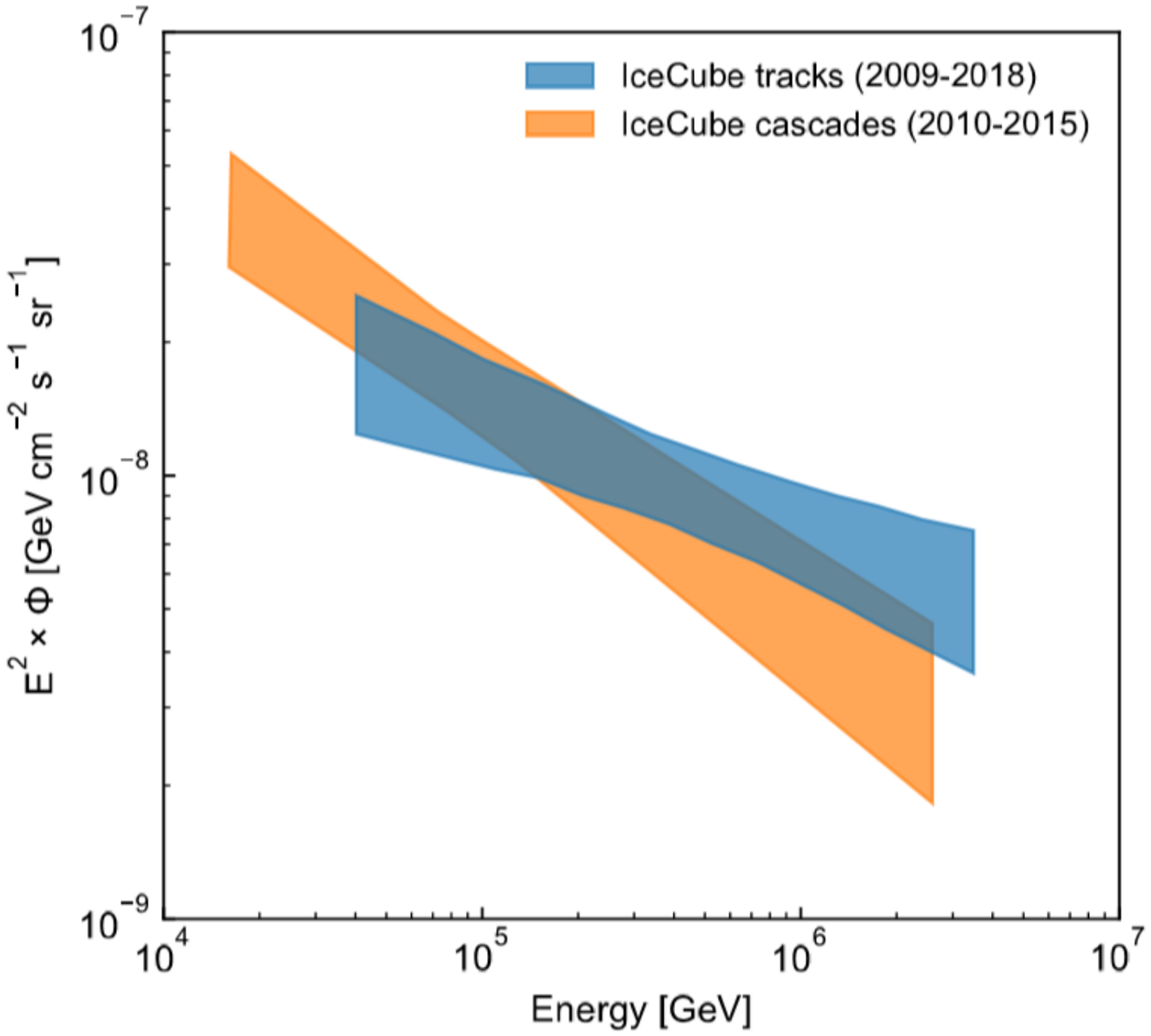
# Worldwide Common Effort

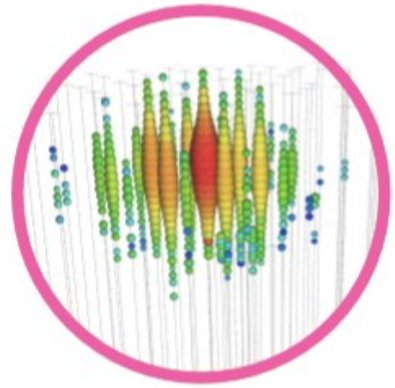
GNN
The Global Neutrino Network

- Exchange knowledge, software, people
- Develop common strategy
- Combine data  (skymaps, ..)
- Cross check of results
- Cooperate in multimessenger and alert programs
- Topical Workshops
- Monthly Newsletter

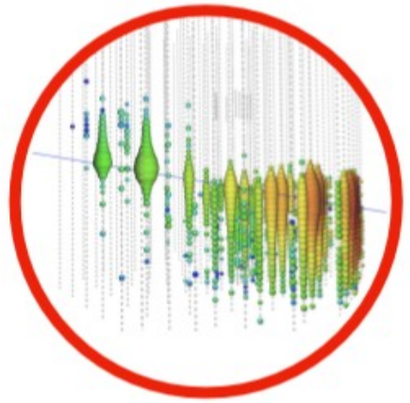
# The Discovery of a Diffuse Cosmic Neutrino Flux

# The Astrophysical Diffuse Neutrino Flux



**High-energy starting events (HESE)**
Interaction vertex in the detector
All flavor, all sky



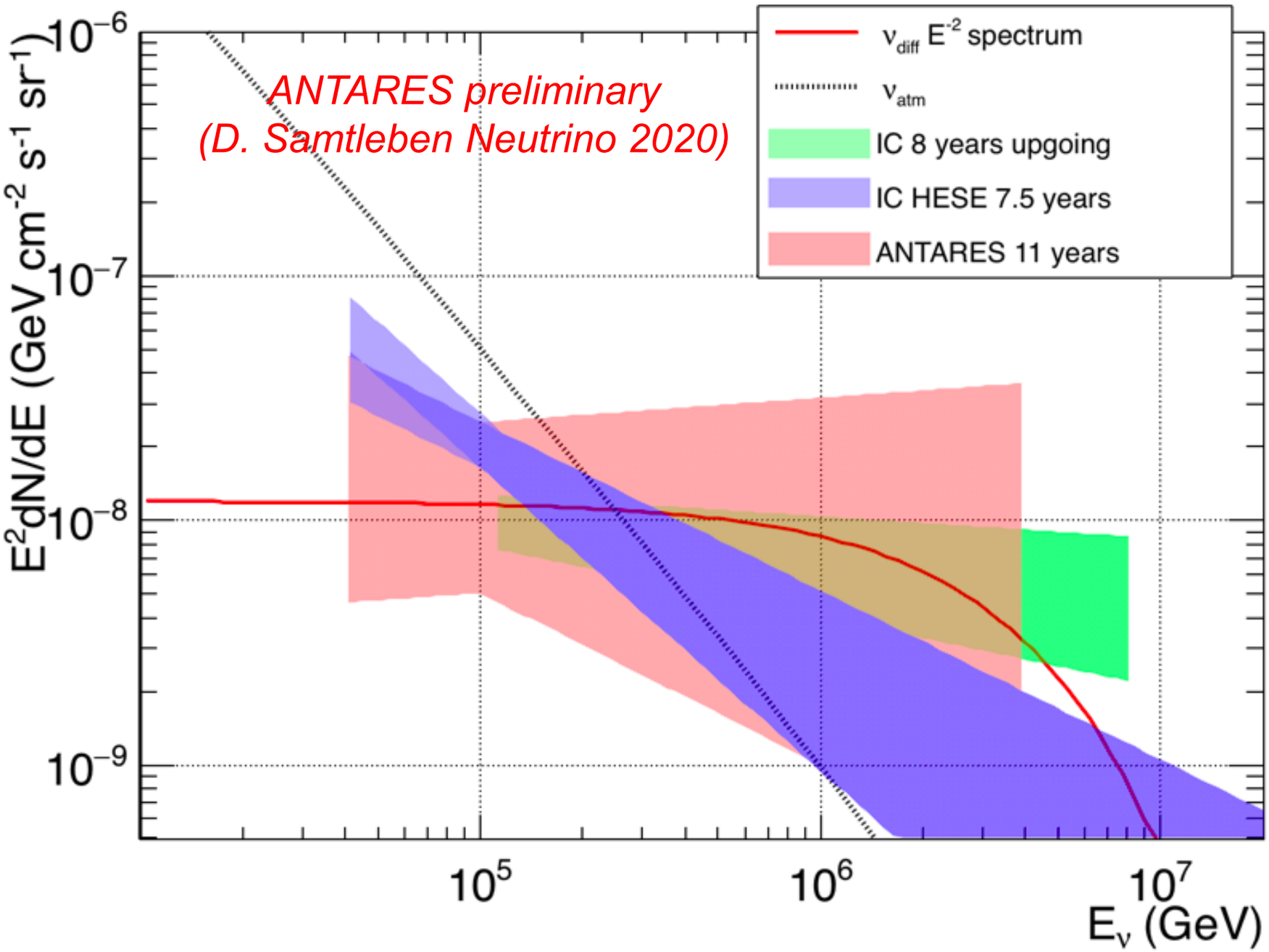
**Up-going tracks**
Muon-dominated
Northern sky

Broken spectrum?

→ Need independent measurements with different systematics: KM3NeT, GVD !

# The Astrophysical Diffuse Neutrino Flux

**Adding ANTARES (1.8 σ excess)**



# Individual Sources and Source Classes

# …. just upper limits

**NO STEADY H.E. NEUTRINO SOURCE DETECTED UP TO NOW**

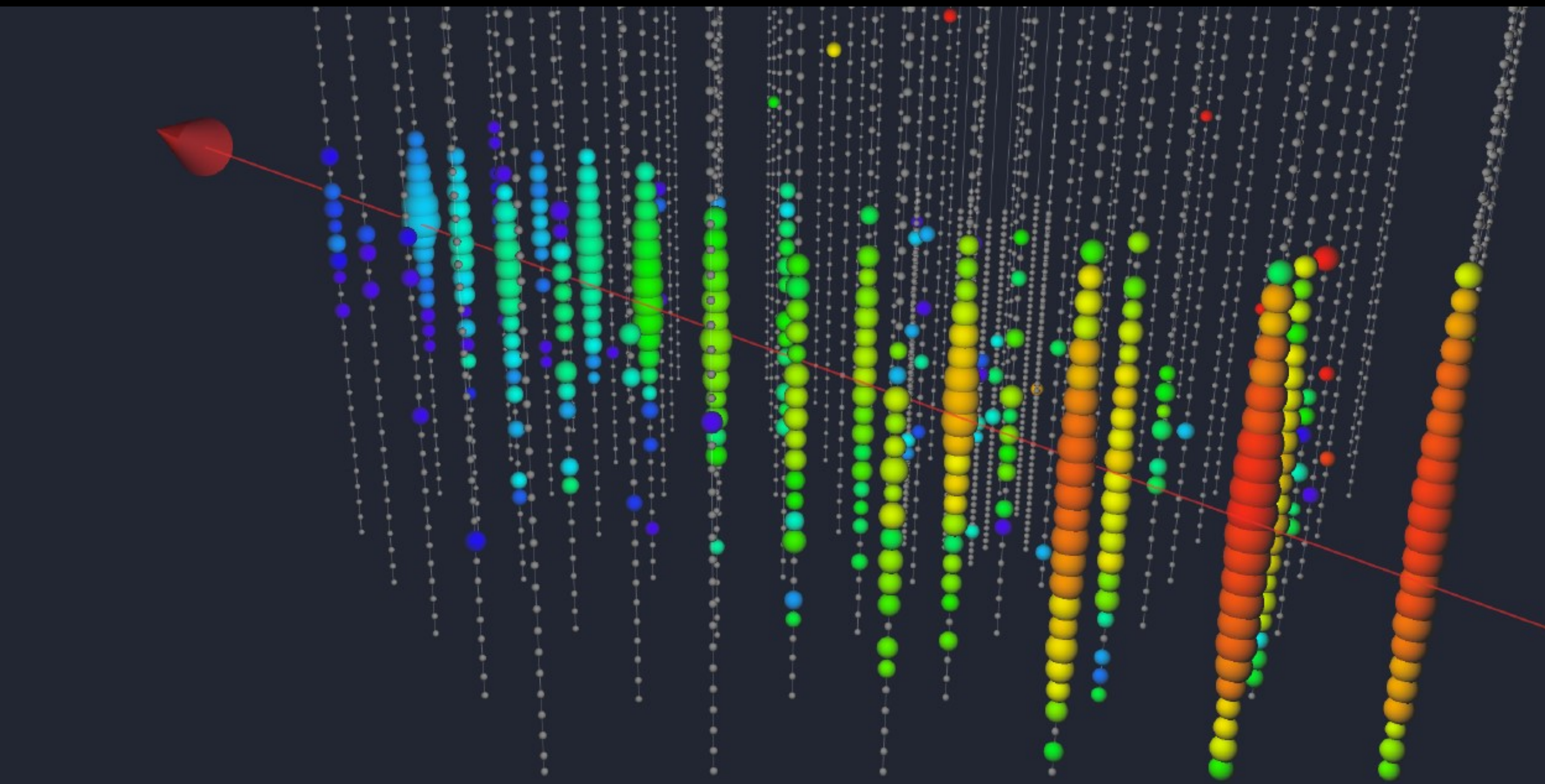
Stacking searches have been performed for

- **GRBs**
- **Gamma-loud blazars**
- **Flat spectrum radio quasars (FSRQs)**
- **…**

with all IceCube and ANTARES searches resulting just in upper limits

# Multi-Messenger Results

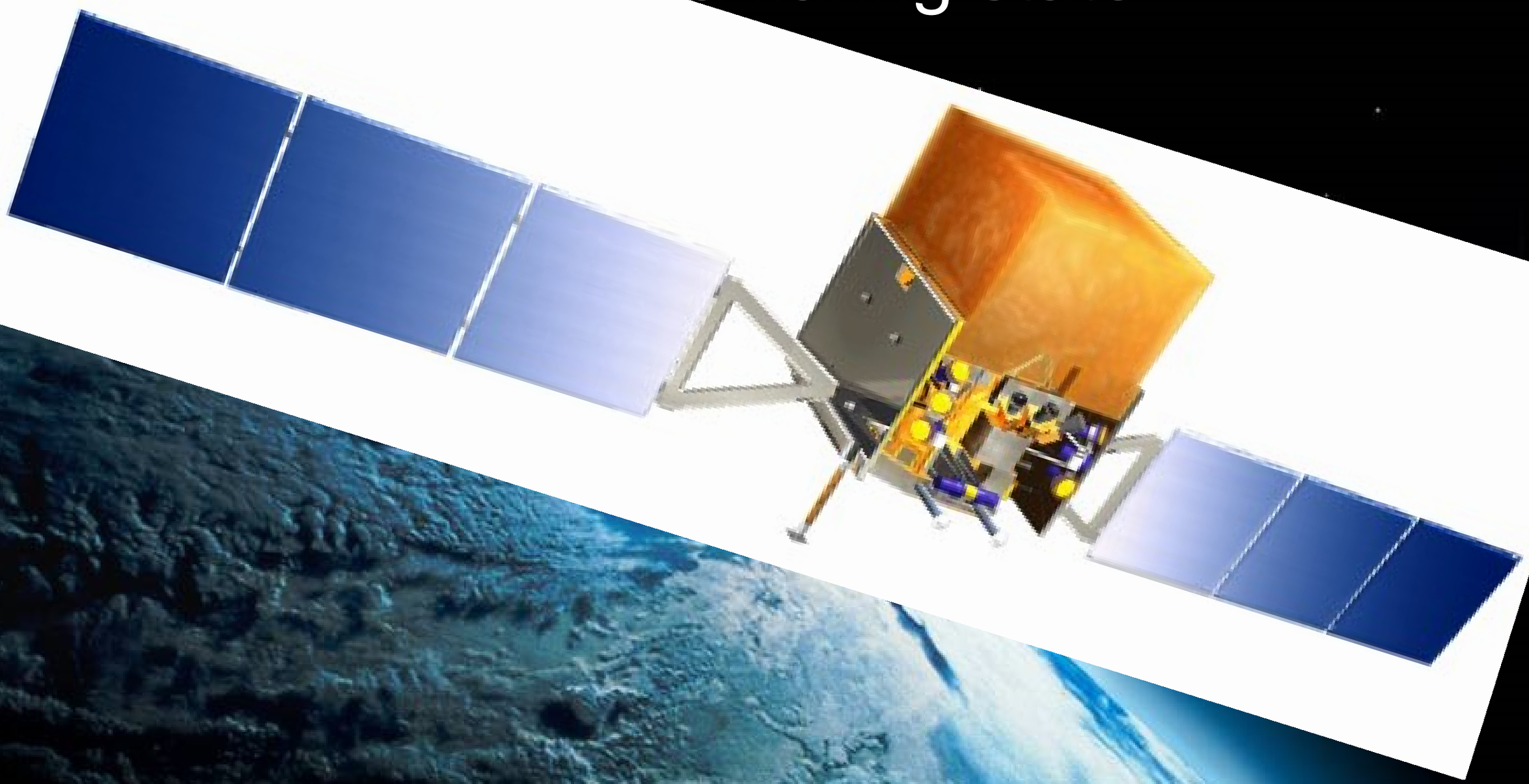
# The first point source candidate



22. September 2017, 20:54 UTC

28. 9. Fermi-Satellite:

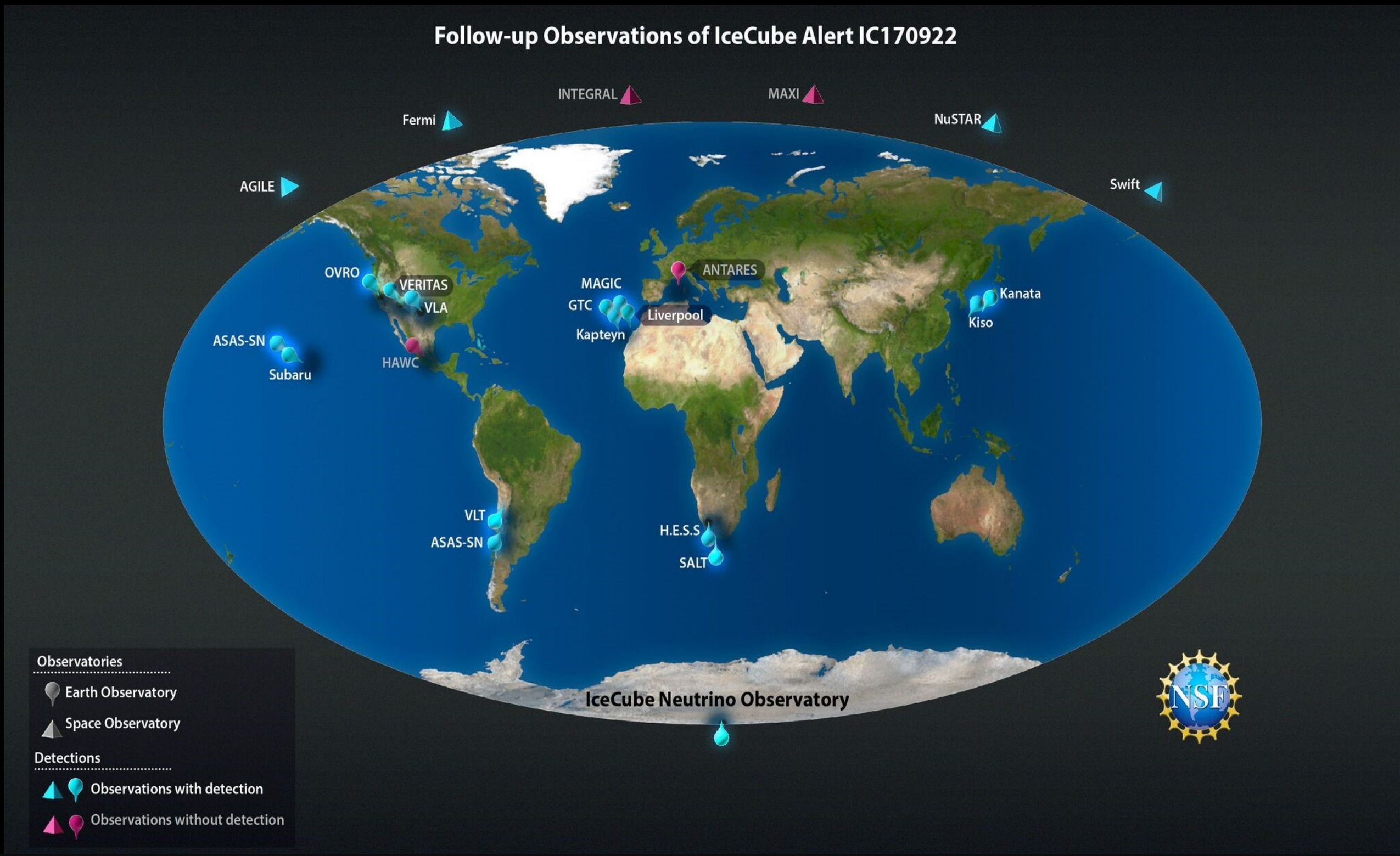
- Source: Active Galaxy TXS 0505+056,
  which is in a flaring state



# From 29.8. on

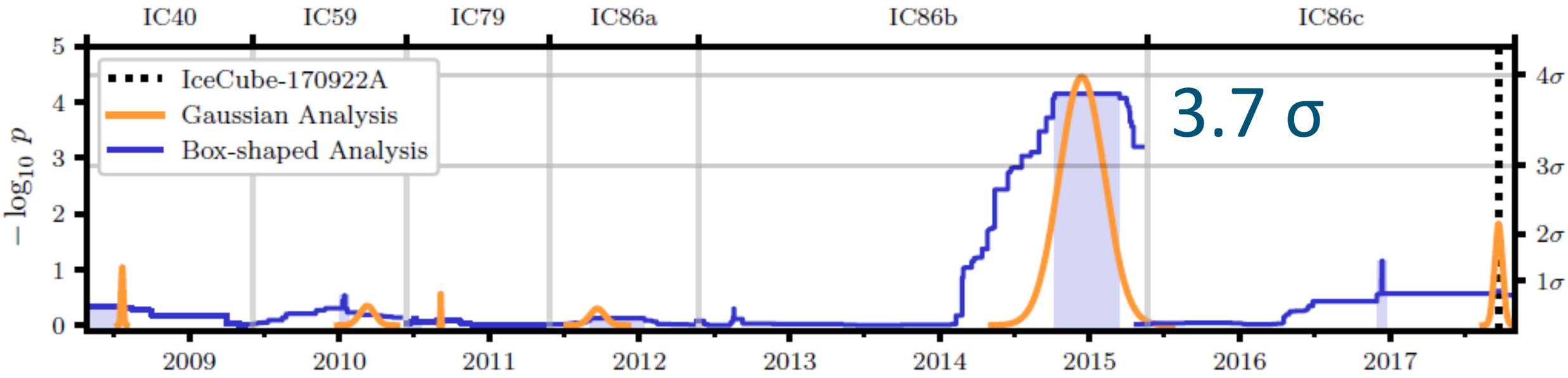
MAGIC: High-ehery gamma rays
TXS 05060+056 is in flaring state

# Follow-up Observations of IceCube Alert IC170922



# Looking back to archival data

Science 361 (2018) 147




Conclusion: Strong evidence (but not yet an undisputable discovery, i.e. an effect of 5 standard deviations), that blazars, especially TXS 0506+056, belong to the sites of very-high-energy cosmic ray acceleration.

**Fantastic demonstration of the potential of multi-messenger observations !**

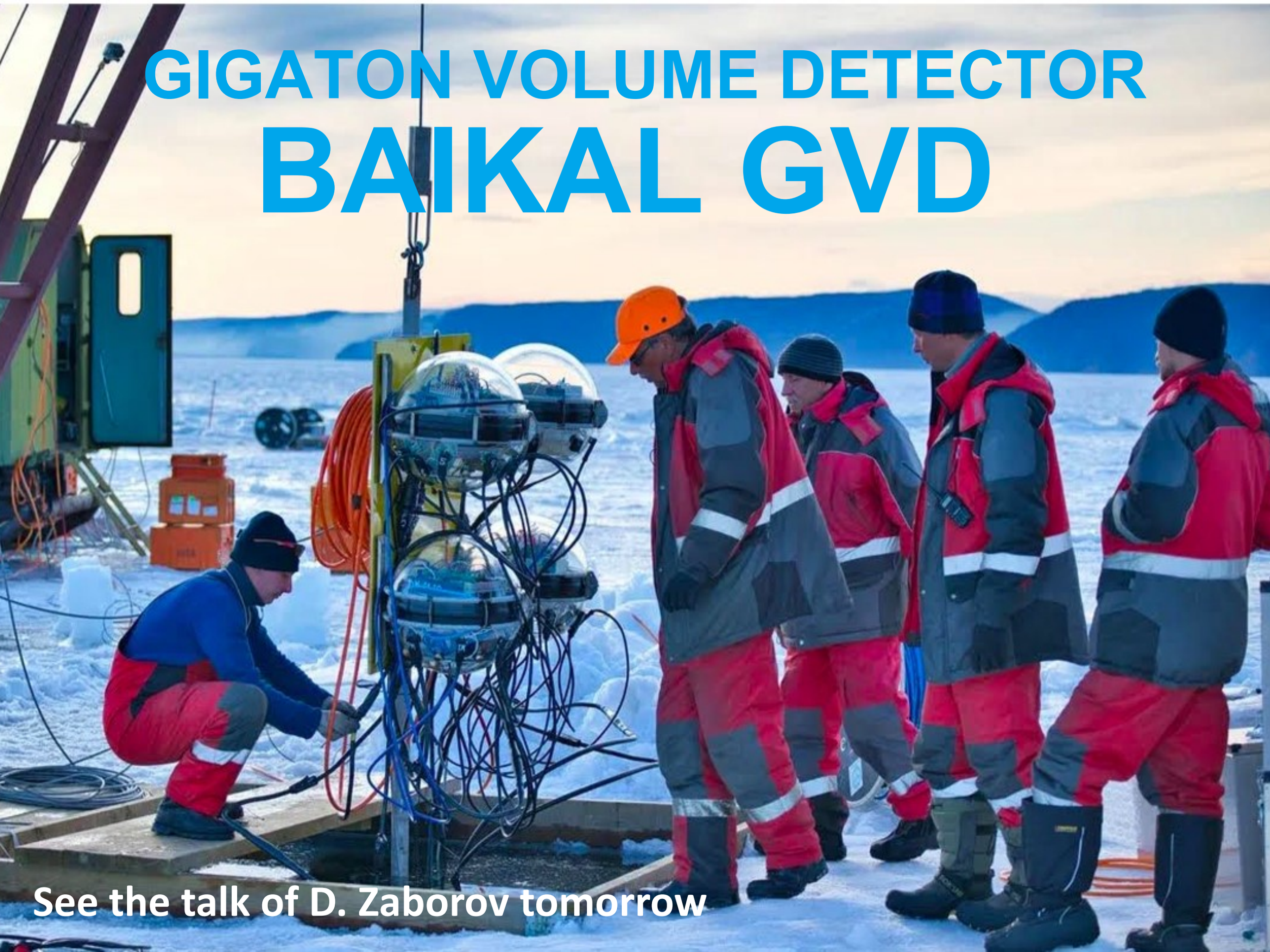
# Summary of where we stand

- **Cosmic high-energy $\nu$ discovered**
- **Opened new window, but landscape not yet charted: no steady point sources identified up to now**
- **Also: remaining uncertainties on spectrum and flavor composition**
- **Some individual sources in reach!**
- **Excluded GRB, Blazars, …. as sole source of HESE events**

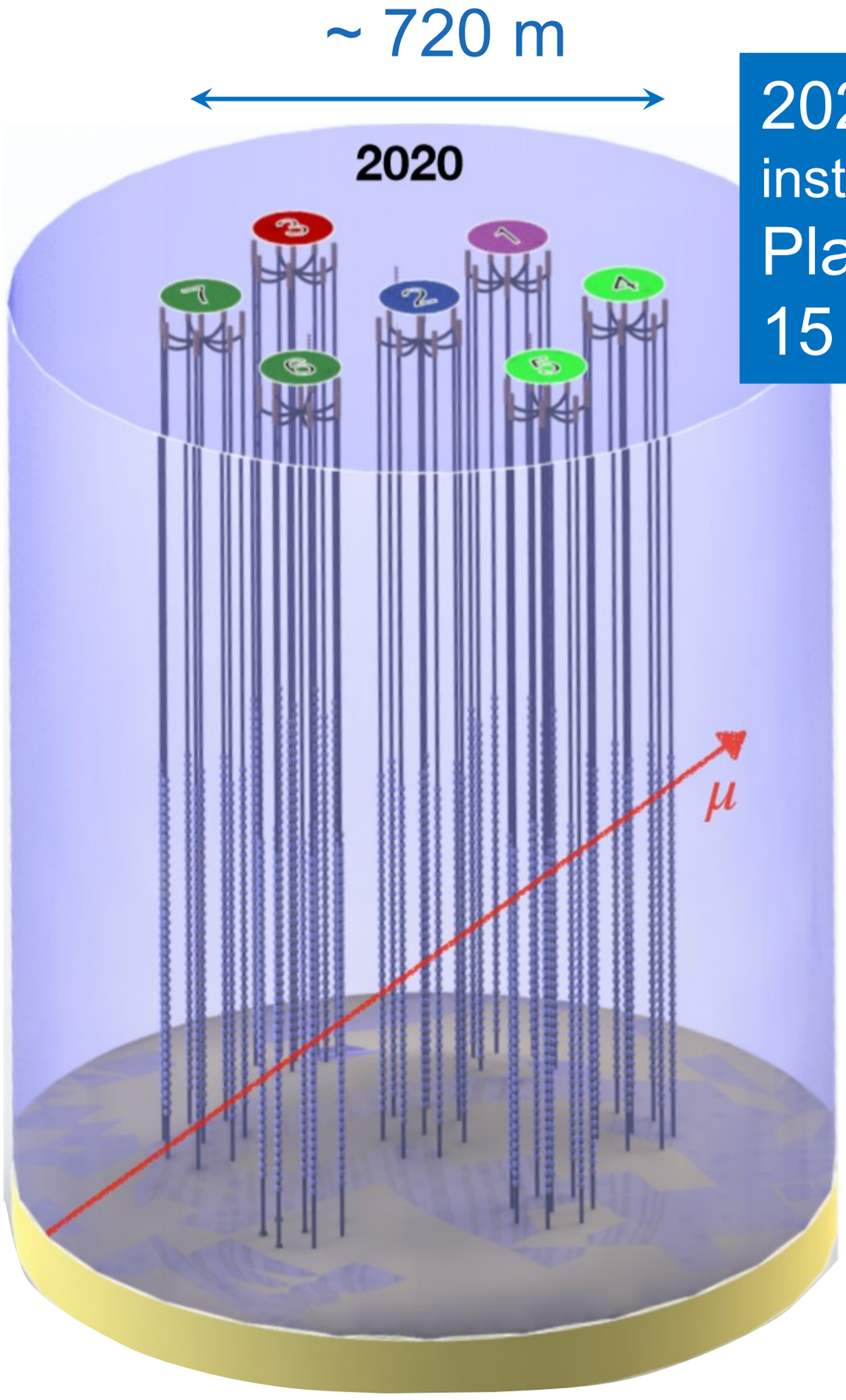
# Where do we go?

# GIGATON VOLUME DETECTOR

# BAIKAL GVD



See the talk of D. Zaborov tomorrow

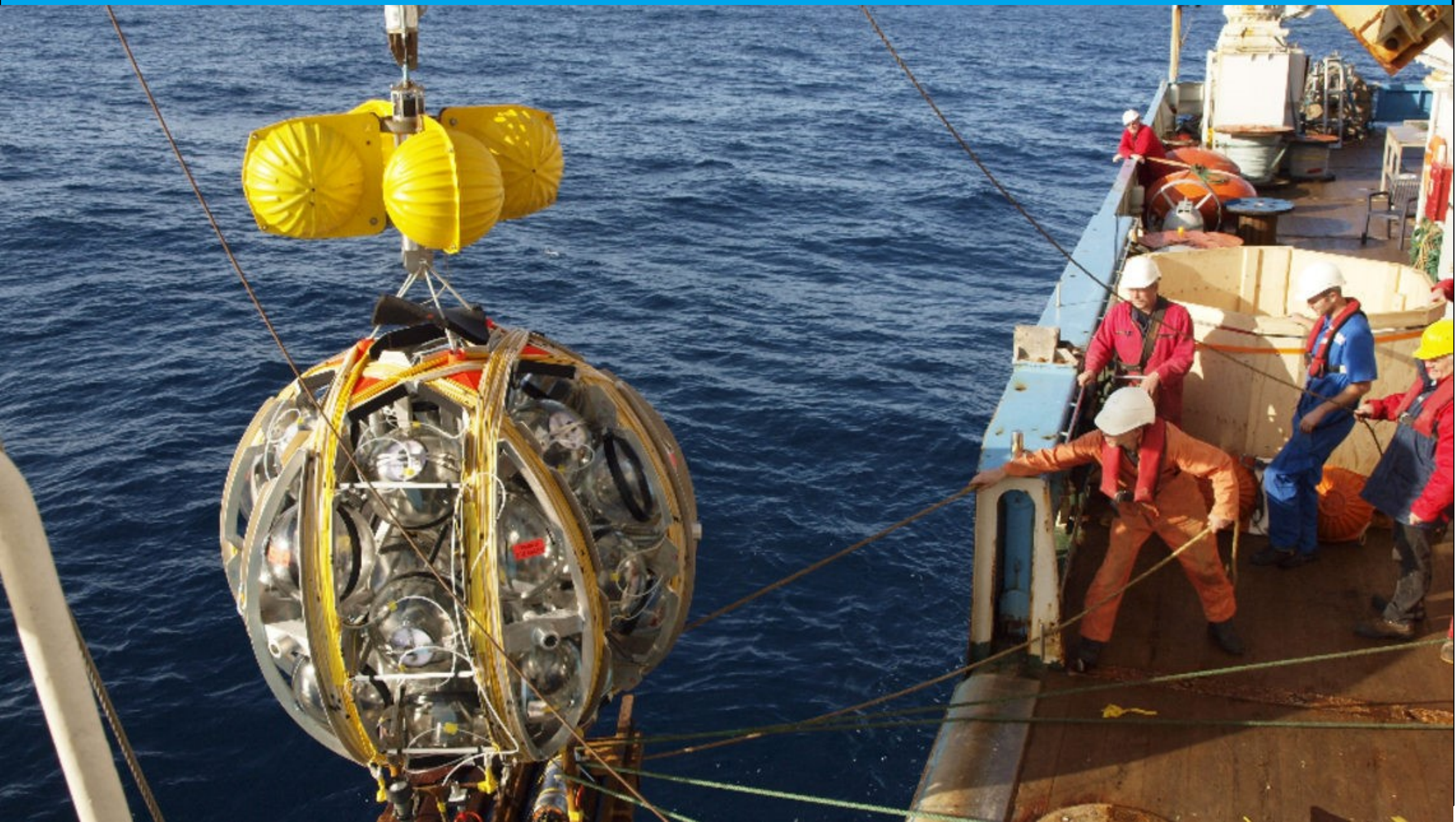



2020: 7 clusters
installed and operating
Planned for 2024:
15 clusters

First results:
See the talk of
D. Zaborov
tomorrow

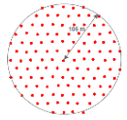
| Year | Total number of clusters | Total number of strings | Number of OMs |
|---|---|---|---|
| 2016 | 1 | 8 | 288 |
| 2017 | 2 | 16 | 576 |
| 2018 | 3 | 24 | 864 |
| 2019 | 5 | 40 | 1440 |
| **2020** | **7** | **56** | **2016** |
| 2021 | 9 | 72 | 2592 |
| 2022 | 11 | 88 | 3168 |
| 2023 | 13 | 104 | 3744 |
| 2024 | 15 | 120 | 4320 |

# KM3NET



# KM3NeT: ORCA and ARCA

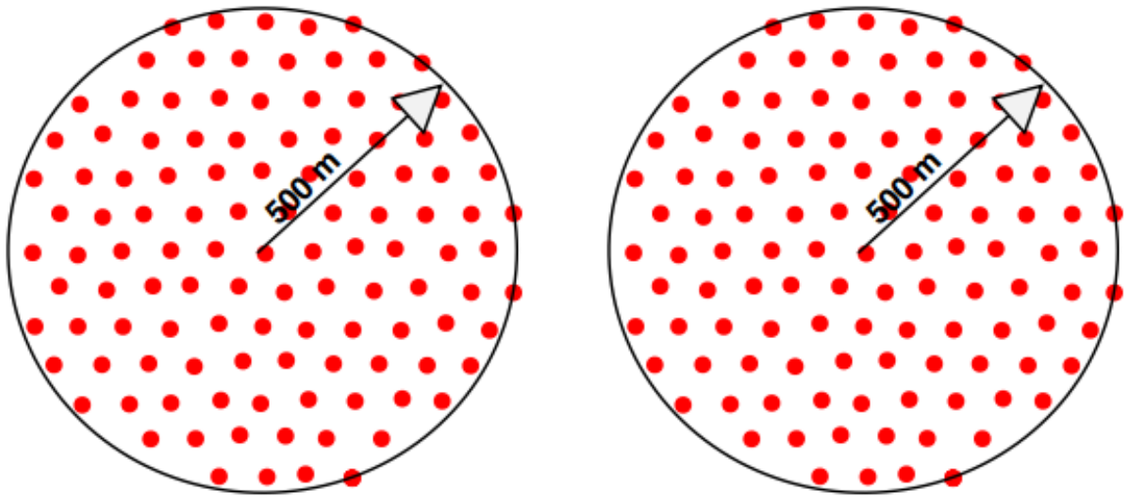
Each block has
115 strings
with 18 Digital
Optical Modules



ORCA

**France, 40 km from Toulon**

ARCA



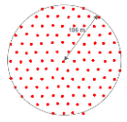

**Italy,**
**100 km from Sicily**

**ORCA:** determination of the Neutrino Mass Hierarchy, precision oscillation physics

**ARCA:** IceCube physics, but with better angular resolution and from the Northern hemisphere

# KM3NeT: ORCA and ARCA

**Each block has 115 strings with 18 Digital Optical Modules**

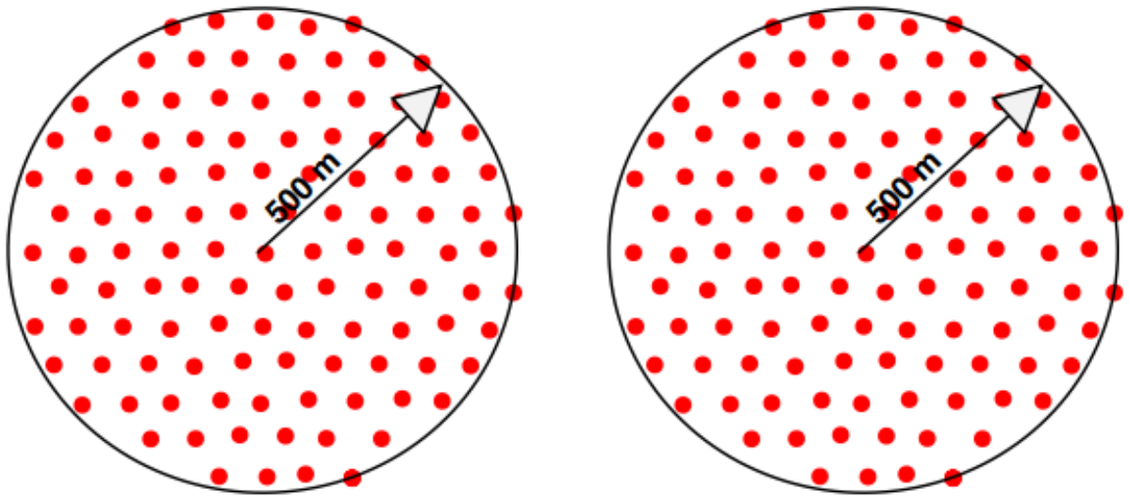


ORCA

## France, 40 km from Toulon

**Completion planned for 2024**
**now operating: 6 strings**

ARCA



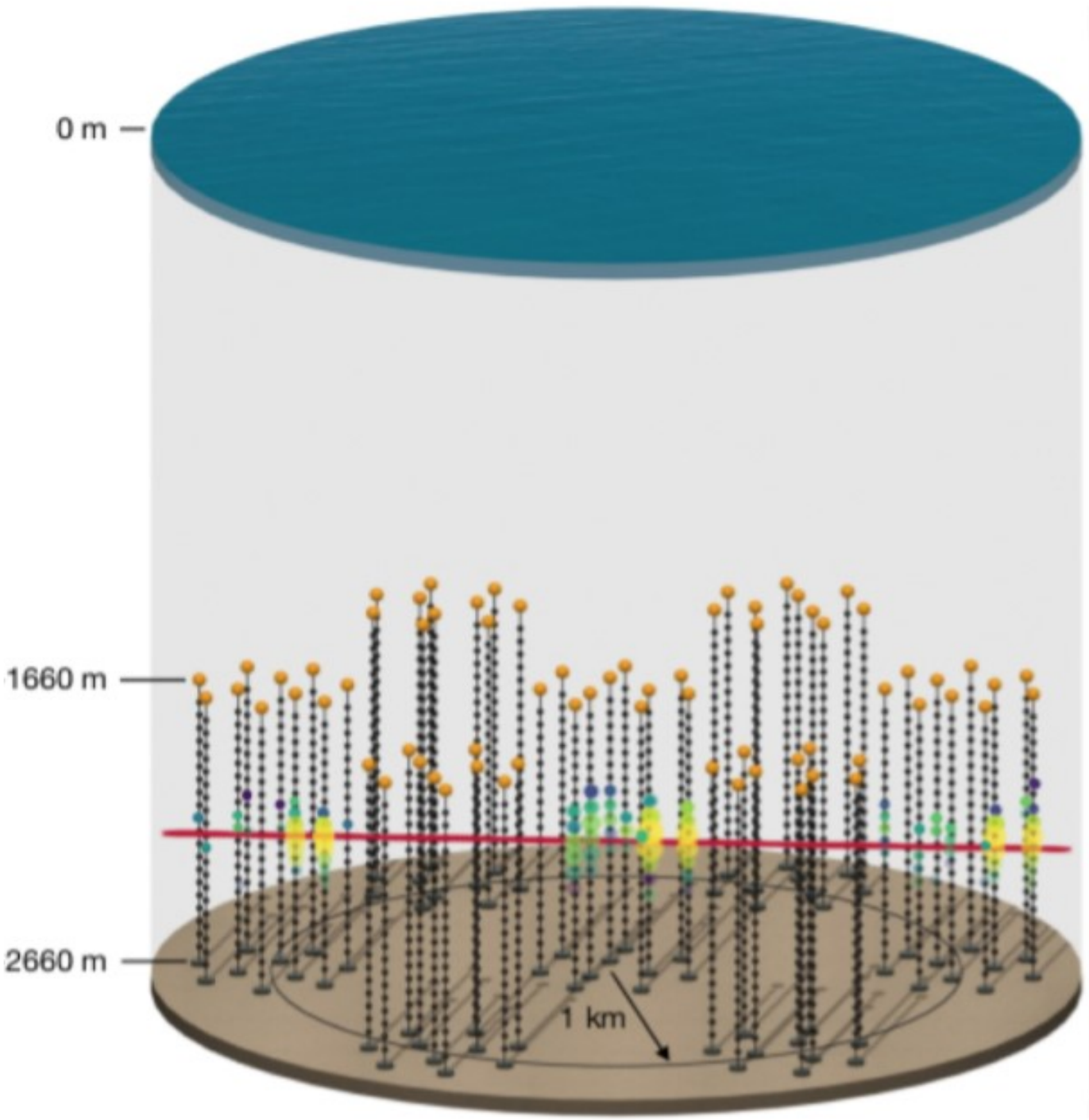

## Italy, 100 km from Sicily

**Completion planned for 2026**
**now operating 1 string**

**ORCA:** determination of the Neutrino Mass Hierarchy, precision oscillation physics

**ARCA:** IceCube physics, but with better angular resolution and from the Northern hemisphere

# The Pacific Ocean Neutrino Experiment




**Prototyping** for a multi-cluster array at the km³ scale (Canadian Pacific coast)

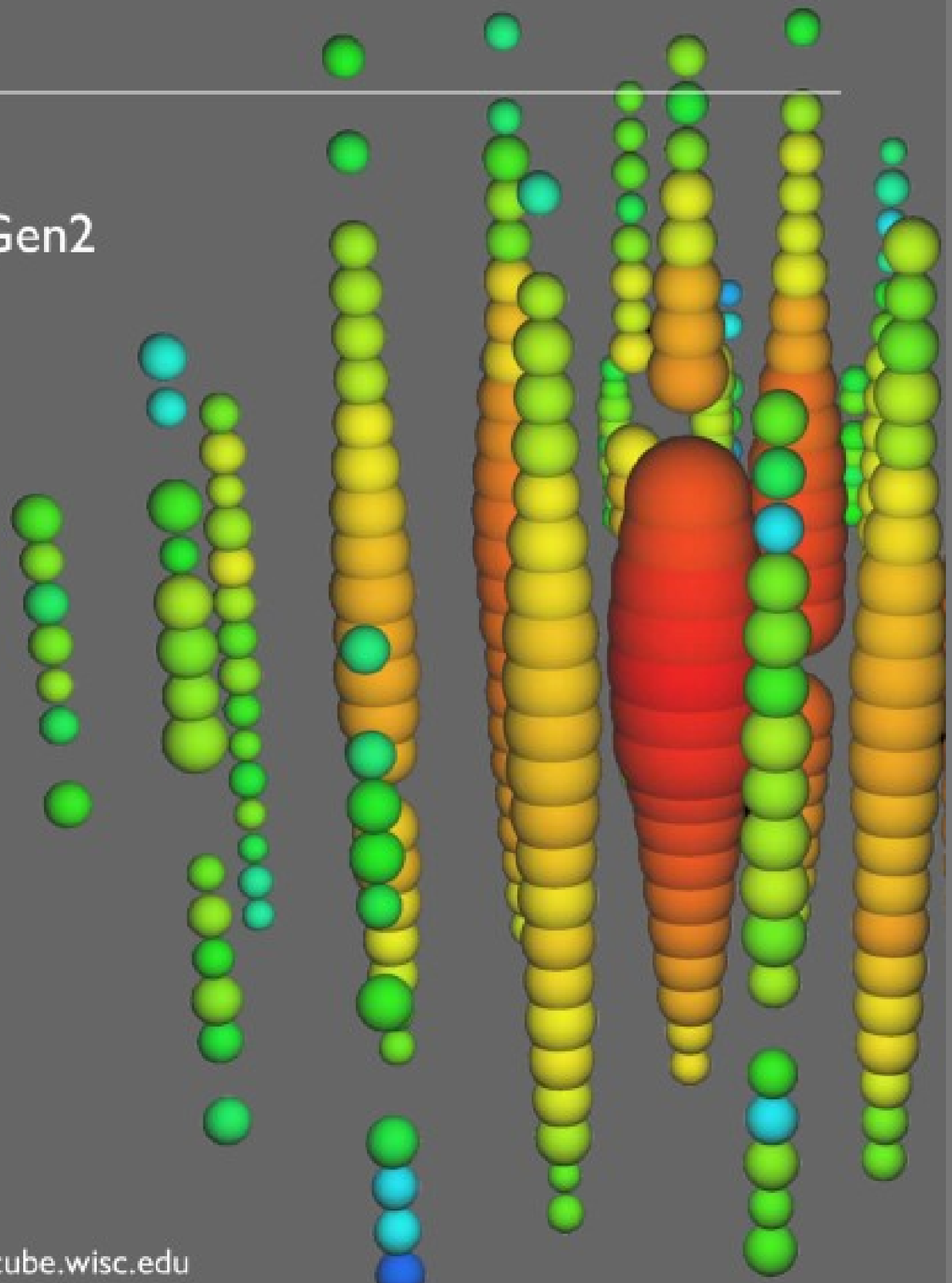
Makes use of existing infrastructure of oceanographers

Until now still rather small collaboration

Would add observation power at the Northern Hemisphere

# IceCube-Gen2: The Window to the Extreme Universe

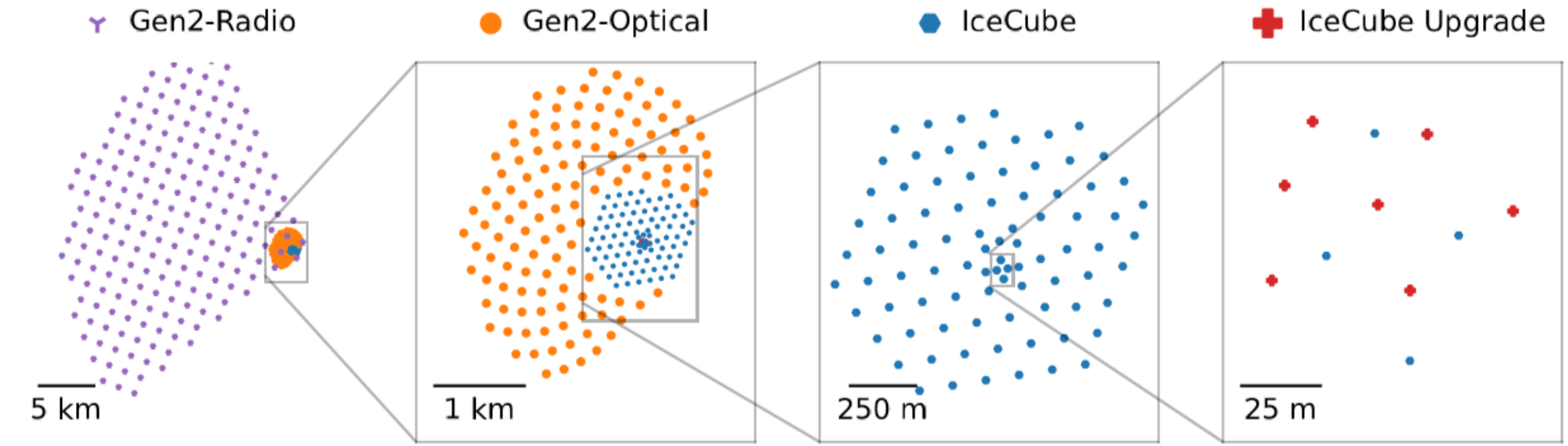
The IceCube-Gen2 Collaboration



August 2020
Contact: analysis@icecube.wisc.edu

arXiv:2008.04323

# IceCube Gen2: from GeV to EeV



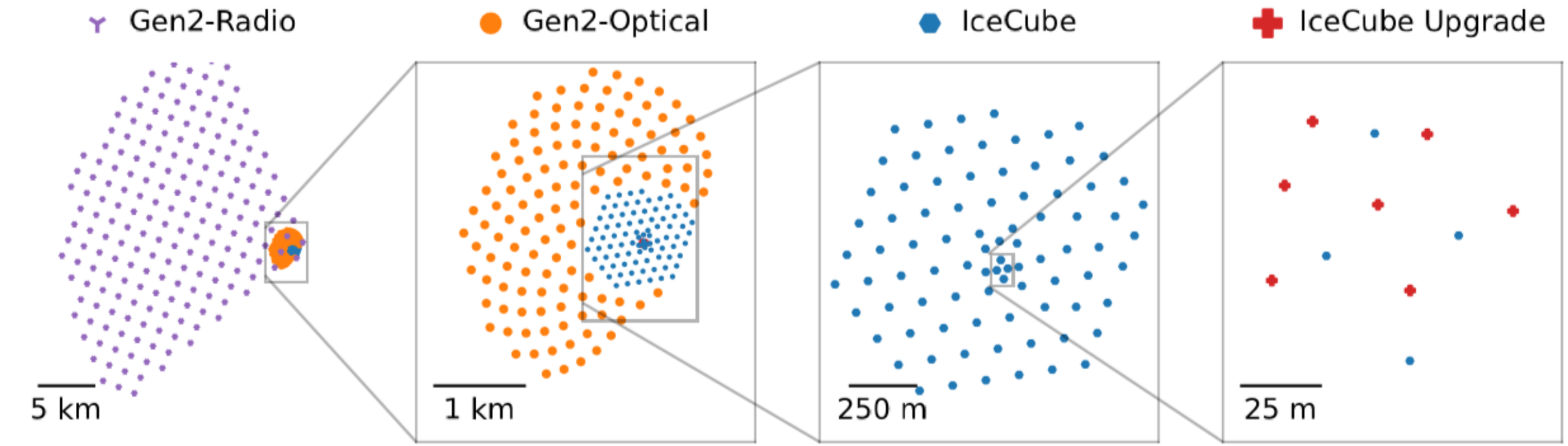

10 PeV to >10 EeV

10 TeV – 50 PeV

100 GeV – 5 PeV

improves DeepCore performance at < 10 GeV

# IceCube Gen2: from GeV to EeV

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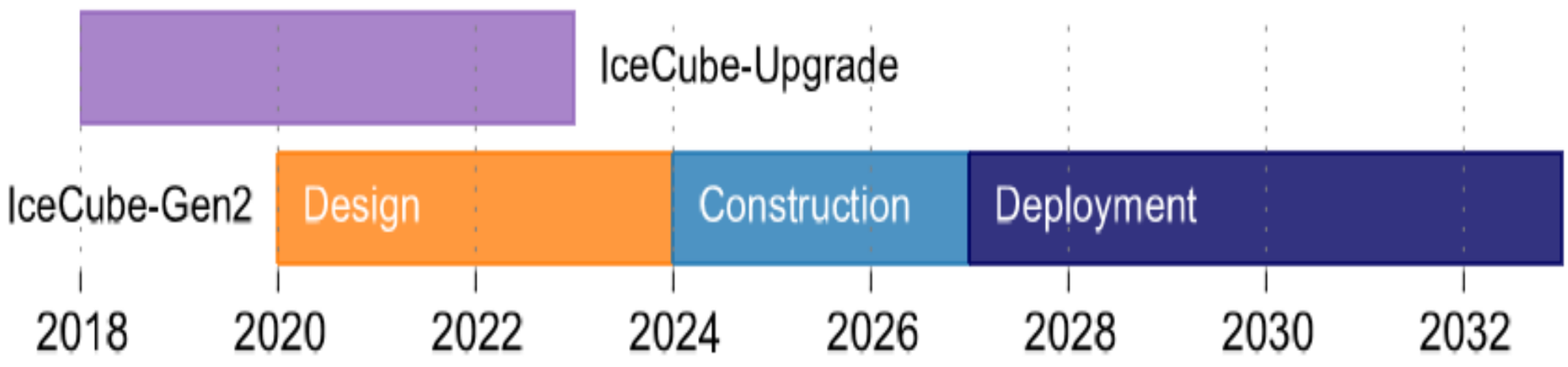
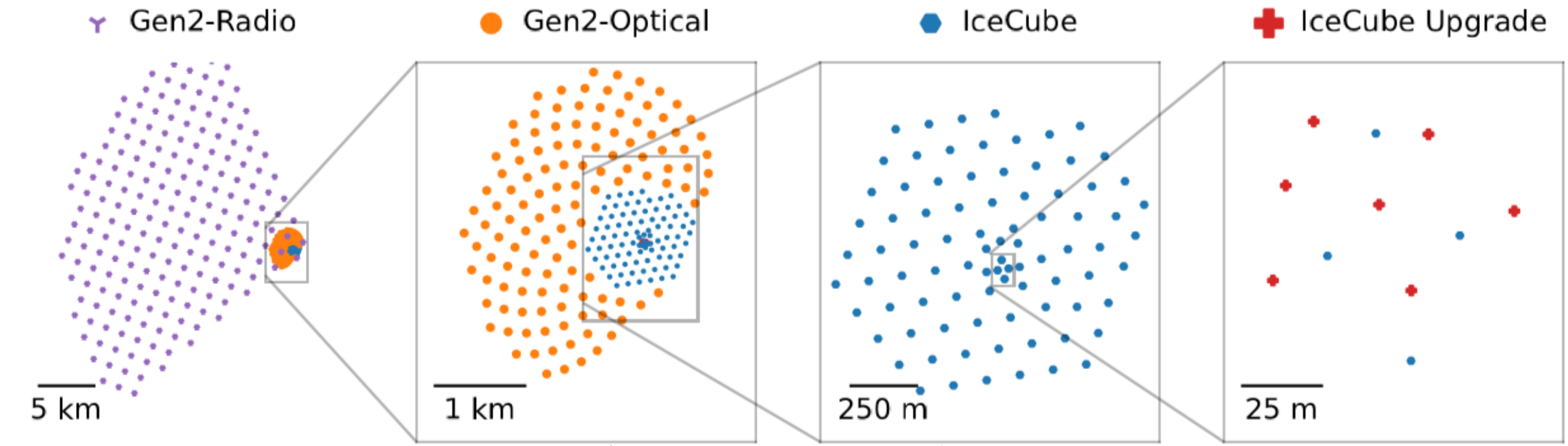


# IceCube Gen2: from GeV to EeV

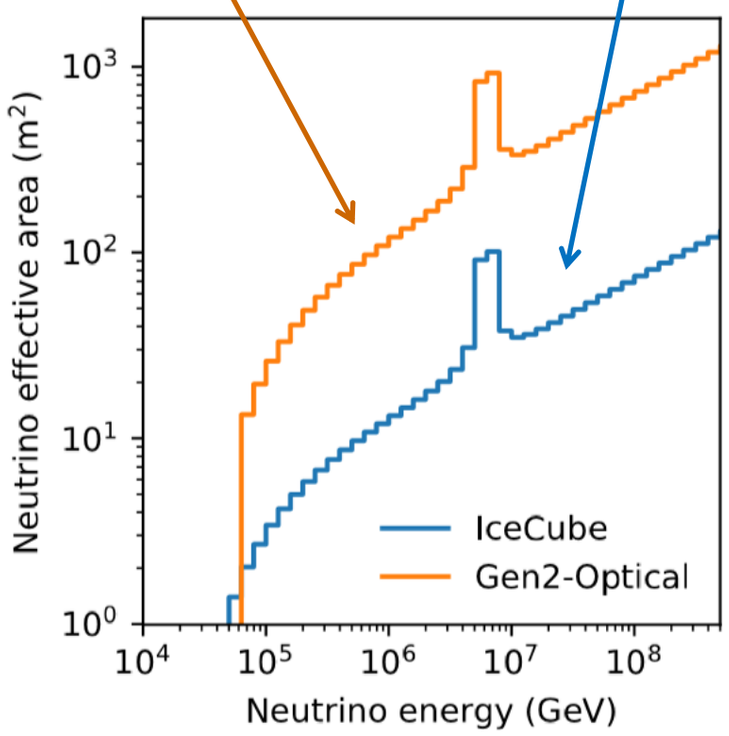



10 PeV to >10 EeV

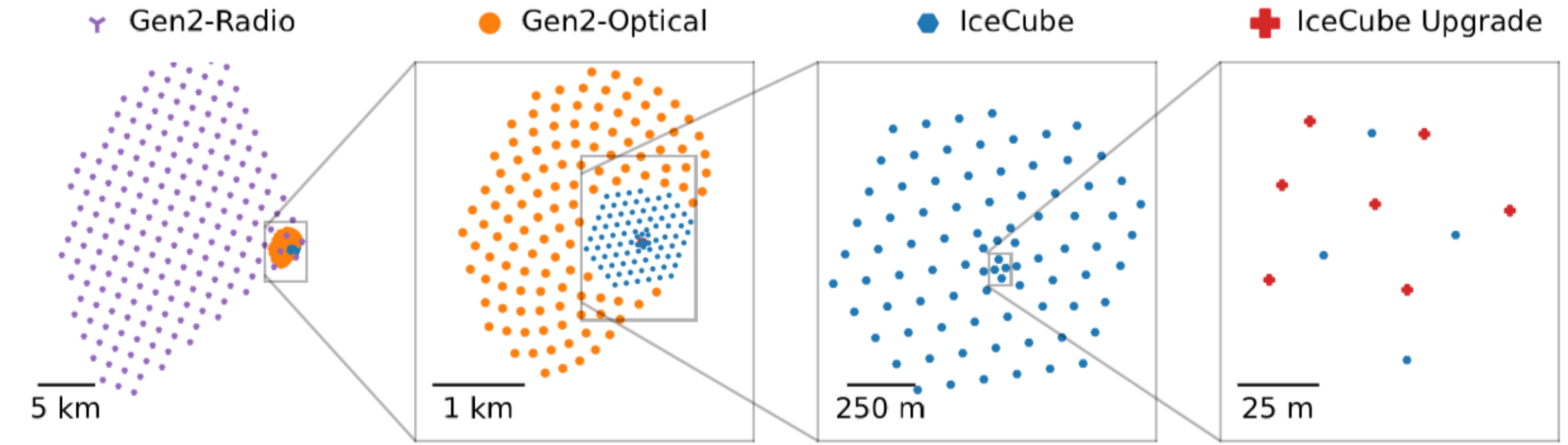
improves DeepCore performance at < 10 GeV

**Neutrino effective area:**

**Gen2 -Optical vs. IceCube**



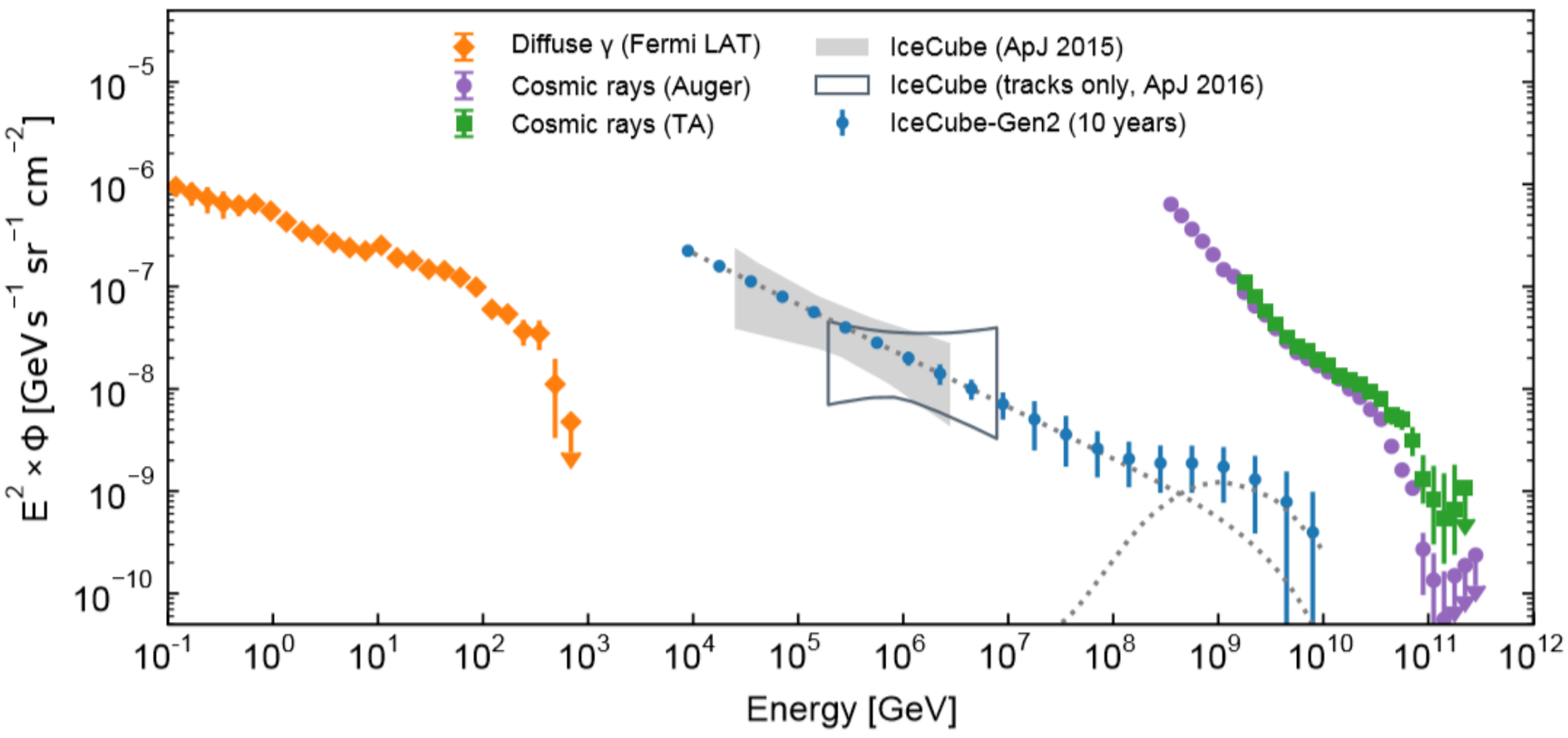
# IceCube Gen2: from GeV to EeV



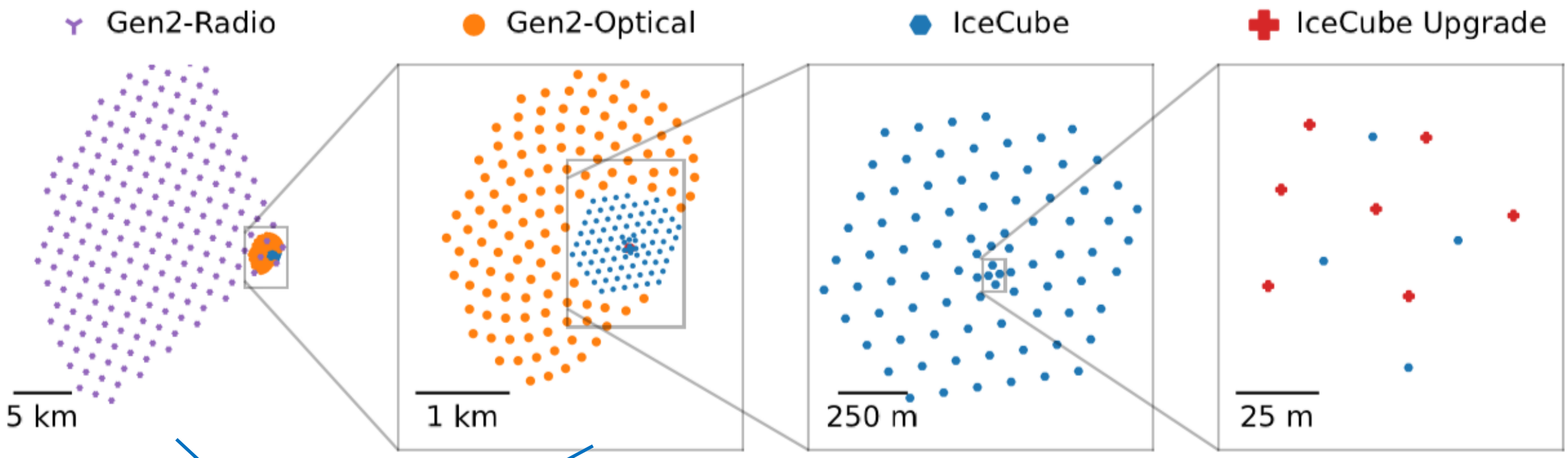

10 PeV to >10 EeV

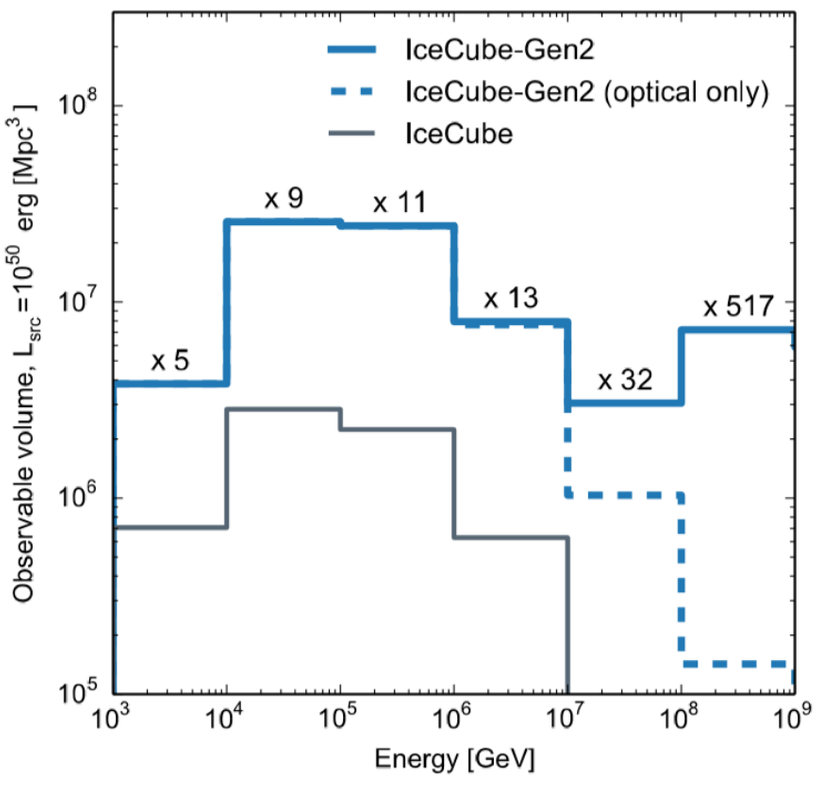
**Spectrum of diffuse flux**

(Gen2 optical and radio)



# IceCube Gen2: from GeV to EeV




Observable volume of IceCube and IceCube-Gen2 for a generic 100 s burst with equivalent isotropic emission of $10^{50}$ erg in neutrinos.

# Conclusions

- **High-energy neutrino window is opened**
- **Extremely dynamical field**
- **Coordination within Global Neutrino Network**
- **Northern hemisphere:**
  **towards cubic kilometer detectors.**
  Baikal-GVD, KM3NeT-ARCA, (PON?)
- **Soon later IceCube towards 10 km³**
- **Mid 2020s and later:**
  **fill landscape of $\nu$ sources with more and more entries. Close-in on cosmic ray sources ! (?)**

# THANK YOU FOR YOUR ATTENTION