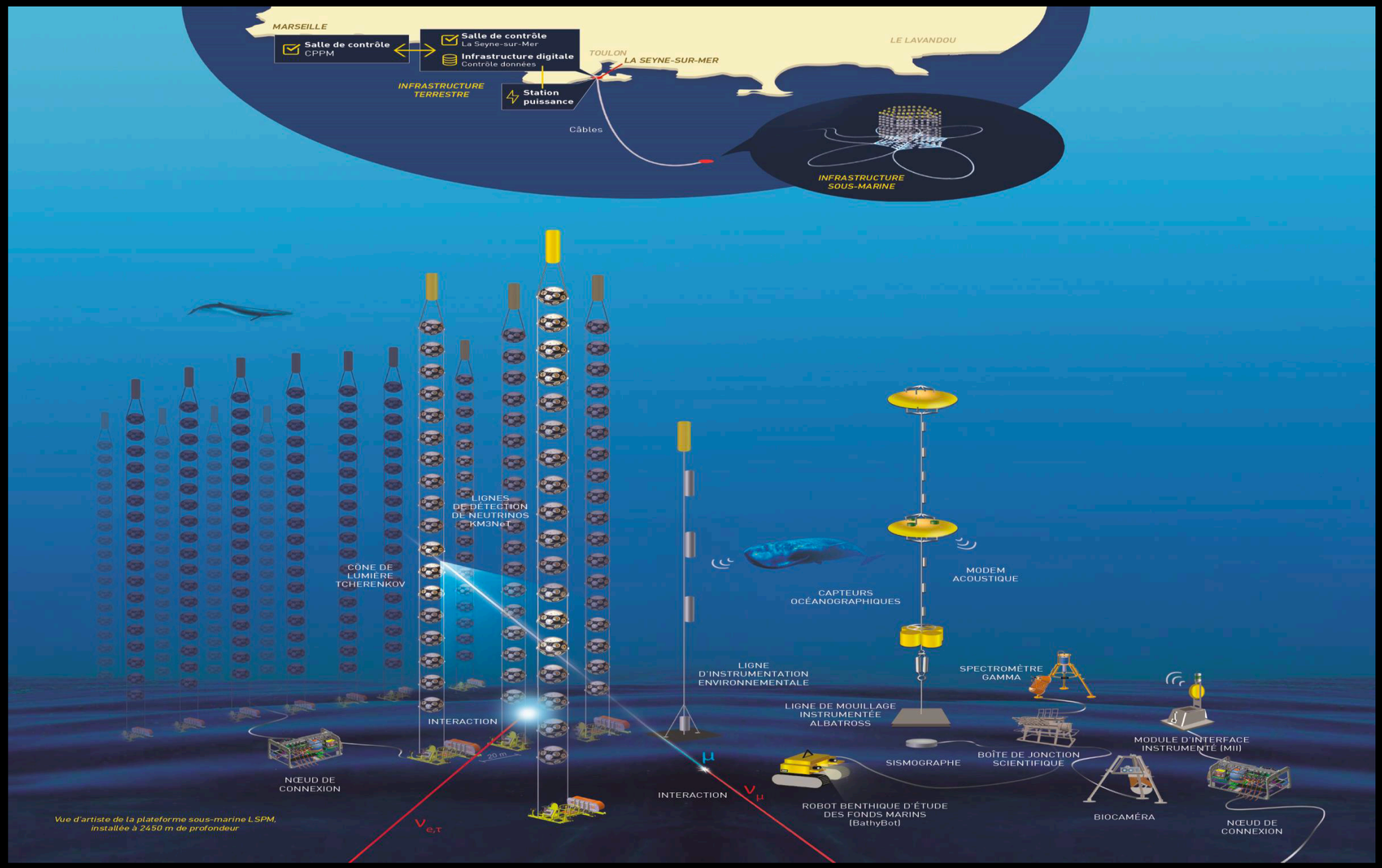
KM3NeT

Multi-purpose Mediterranean Sea Neutrino detectors



Damien Dornic on behalf the KM3NeT Collaboration

Nordic-Baltic Astro Days- 29/05/2026

NEUTRINOS

MESSENGERS OF THE UNIVERSE

The link between astroparticles and astronomy

ASTROPARTICLES
(particle physics in the Universe)

ASTROPHYSICAL SOURCES
Cosmic accelerators

ACTIVE GALACTIC NUCLEI
Supermassive black holes and jets

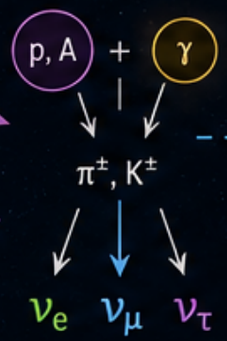
GAMMA-RAY BURSTS
Explosive events at cosmological distances

SUPERNOVA REMNANTS
Shock waves accelerating cosmic rays

NEUTRON STAR MERGERS
Merging compact objects (kilonovae)

NEUTRINO PRODUCTION

Cosmic rays (protons, nuclei) interact with matter or radiation near the sources



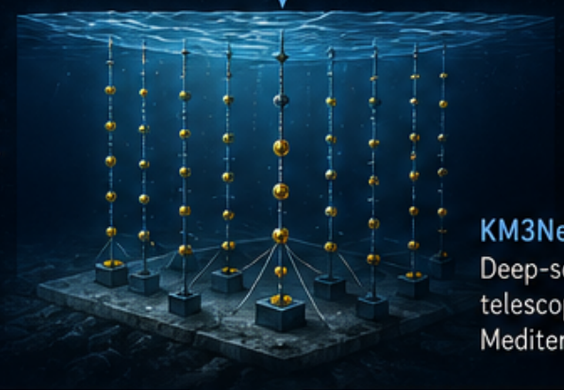
Neutrinos of all flavors are produced

NEUTRINO PROPAGATION

Neutrinos travel cosmic distances without being deflected and with very weak interactions

NEUTRINO DETECTION

Neutrinos interact in a detector, producing charged particles that emit light.



KM3NeT
Deep-sea neutrino telescope in the Mediterranean Sea

ASTRONOMY
(observing the Universe)

MULTI-MESSENGER ASTRONOMY

Neutrinos provide unique and complementary information

GAMMA RAYS
(Fermi, H.E.S.S., ...)
High-energy processes

X-RAYS
(Chandra, XMM-Newton, ...)
Hot and energetic regions

VISIBLE LIGHT
(Optical telescopes)
Stars, galaxies, jets

RADIO WAVES
(Radio telescopes)
Jets, magnetic fields, cosmic structures

GRAVITATIONAL WAVES
(LIGO, Virgo, KAGRA)
Merging compact objects

- ν_e electron neutrino
- ν_μ muon neutrino
- ν_τ tau neutrino

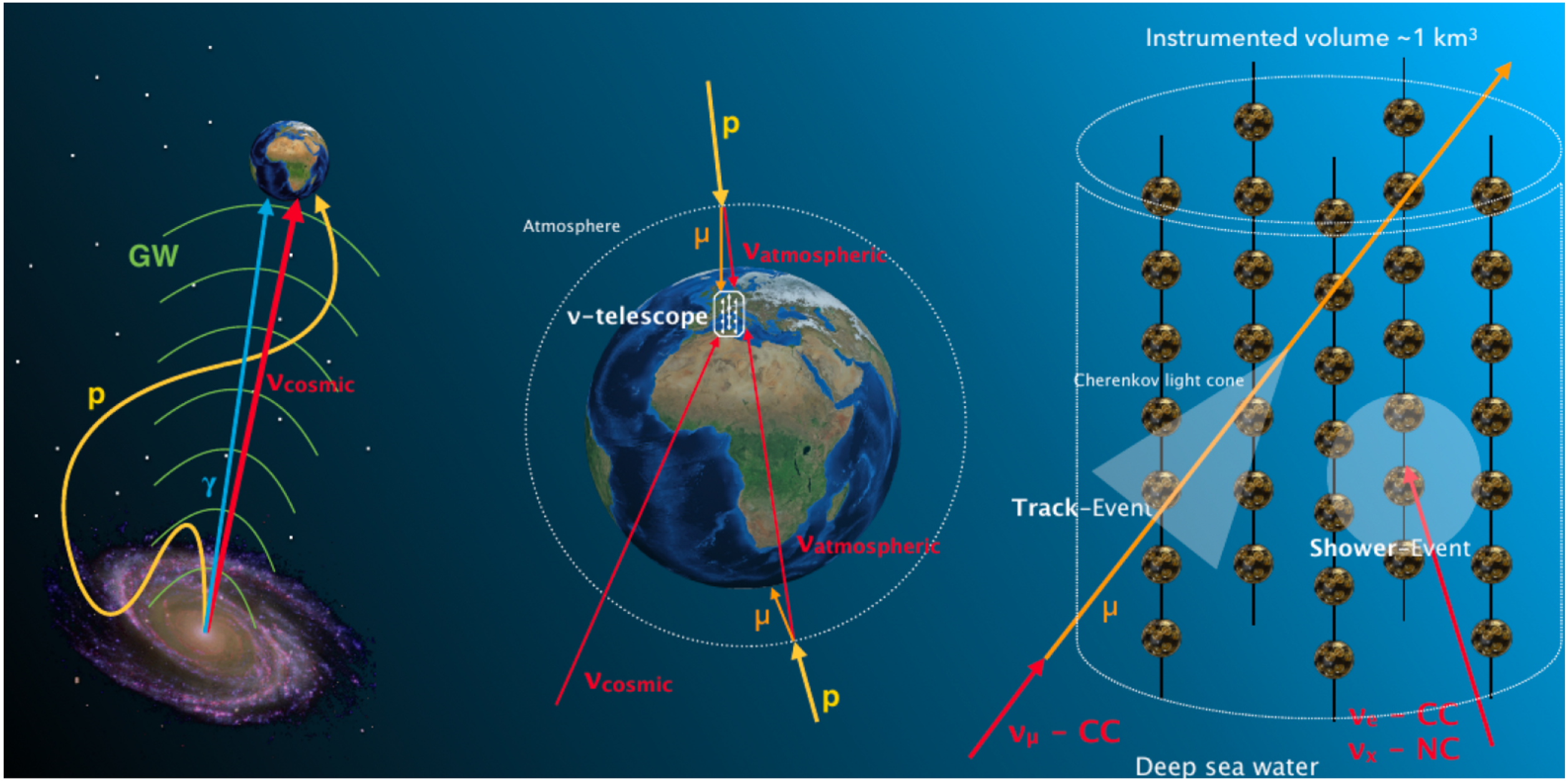
Neutrinos allow us to explore the most violent and distant phenomena in the Universe, inaccessible to other messengers.

Astroparticles
understand the physical mechanisms

Astronomy
observe and understand the cosmos

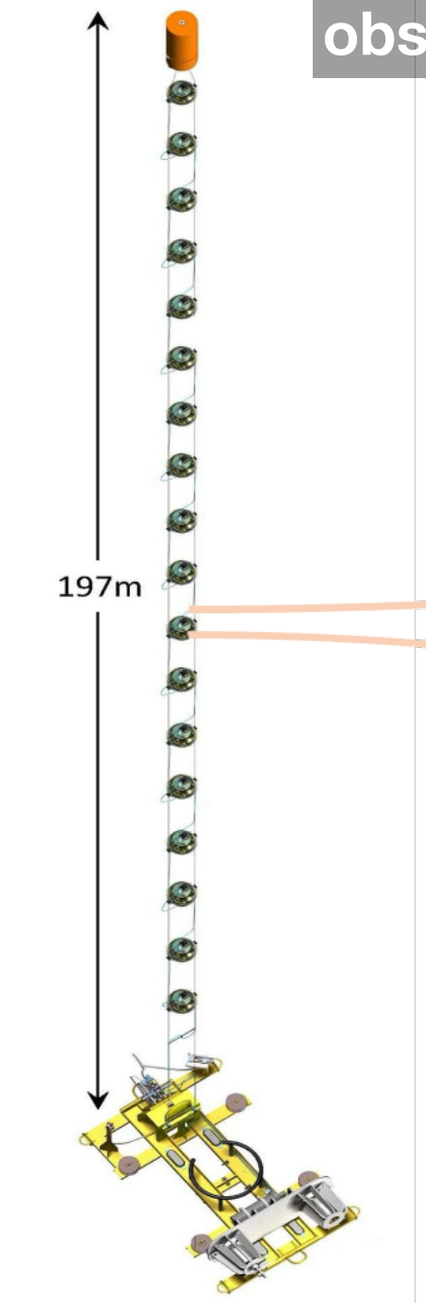
TWO COMPLEMENTARY APPROACHES TO UNDERSTAND THE UNIVERSE

Neutrino detection in KM3NeT



KM3NeT Technologies

The KM3NeT digital optical modules are the eyes of the experiment observing the light around it



KM3NeT Digital Optical Modules

31 PMT assembled in a presure resistant glass sphere

18 DOMs mounted on a mouring line anchored on the sea bed

Inspired several experiments

HyperK

IceCube

KM3NeT, J.Phys.G 43 (2016) 8, 084001

KM3NeT Technologies

Deployment

Line are furled onto a launcher to be deployed

Once at the bottom of the sea, they are unfurled.

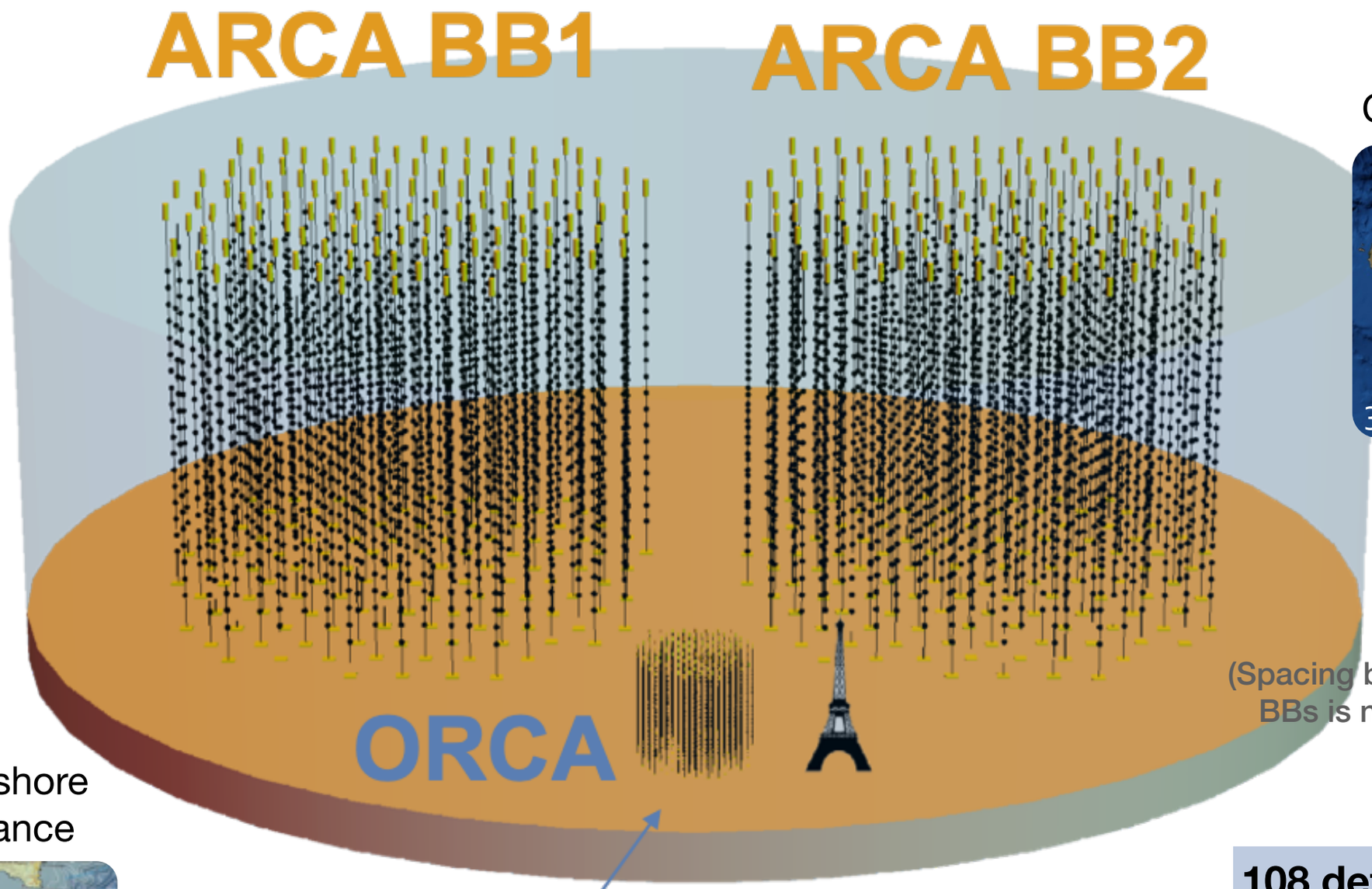
KM3NeT detector scales

230 detection units

4140 optical modules

128340 PMTs

36m vert. x 90m horiz. spacing TeV - PeV



(Spacing between the 2 BBs is not at scale)

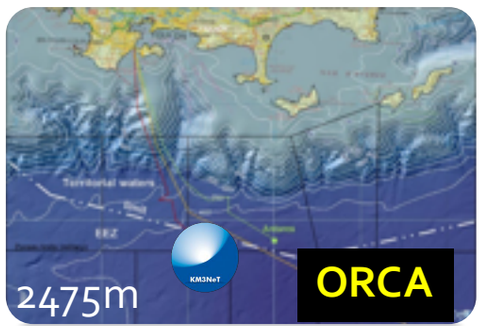
9m vert. x 20m horiz. spacing
GeV - TeV

Astroparticle **R**esearch with **C**osmics In the **A**byss

ARCA: off shore Capo Passero, Italy

Oscillation **R**esearch with **C**osmics In the **A**byss

ORCA: off shore Toulon, France

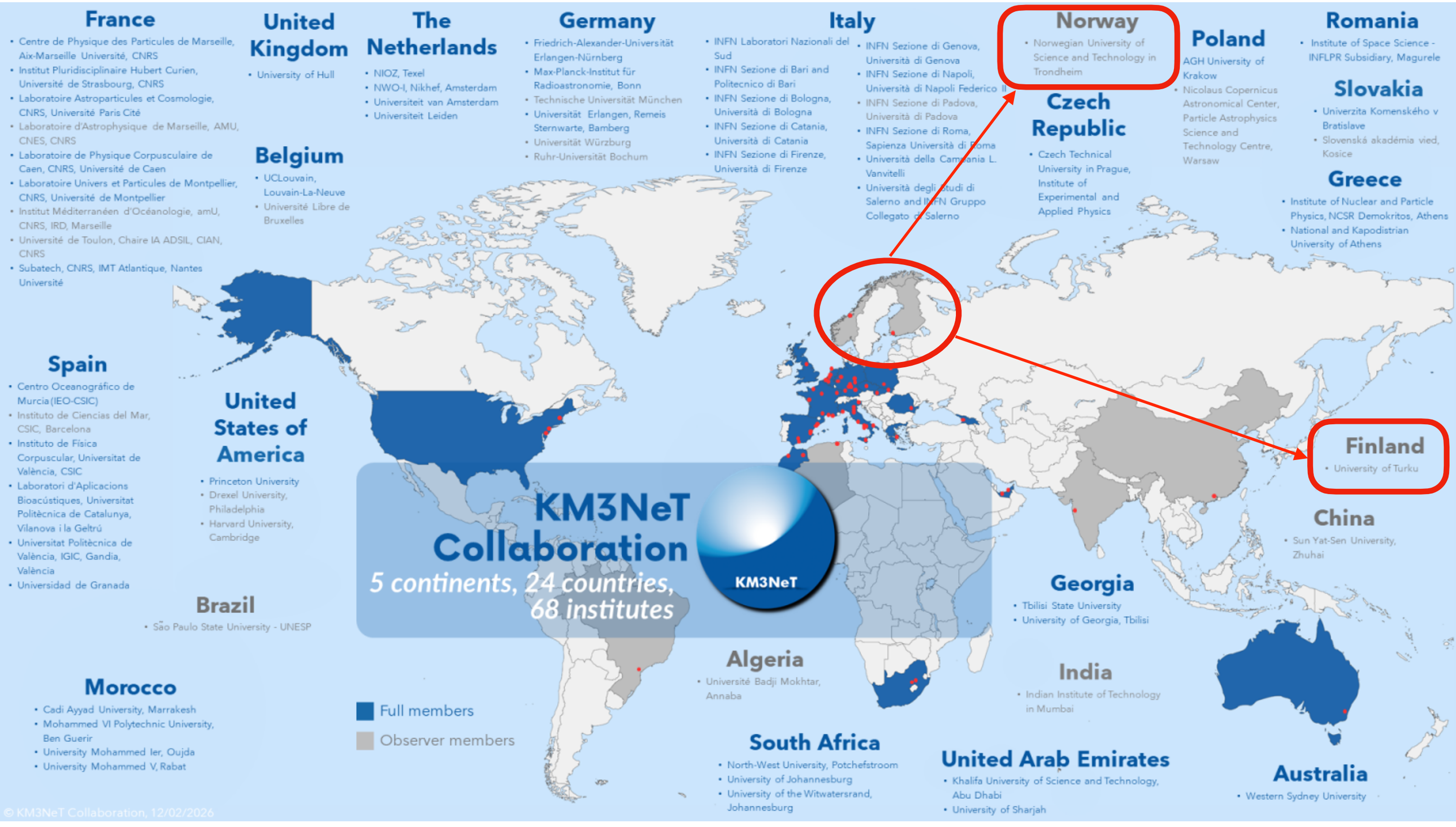


108 detection units

1944 optical modules

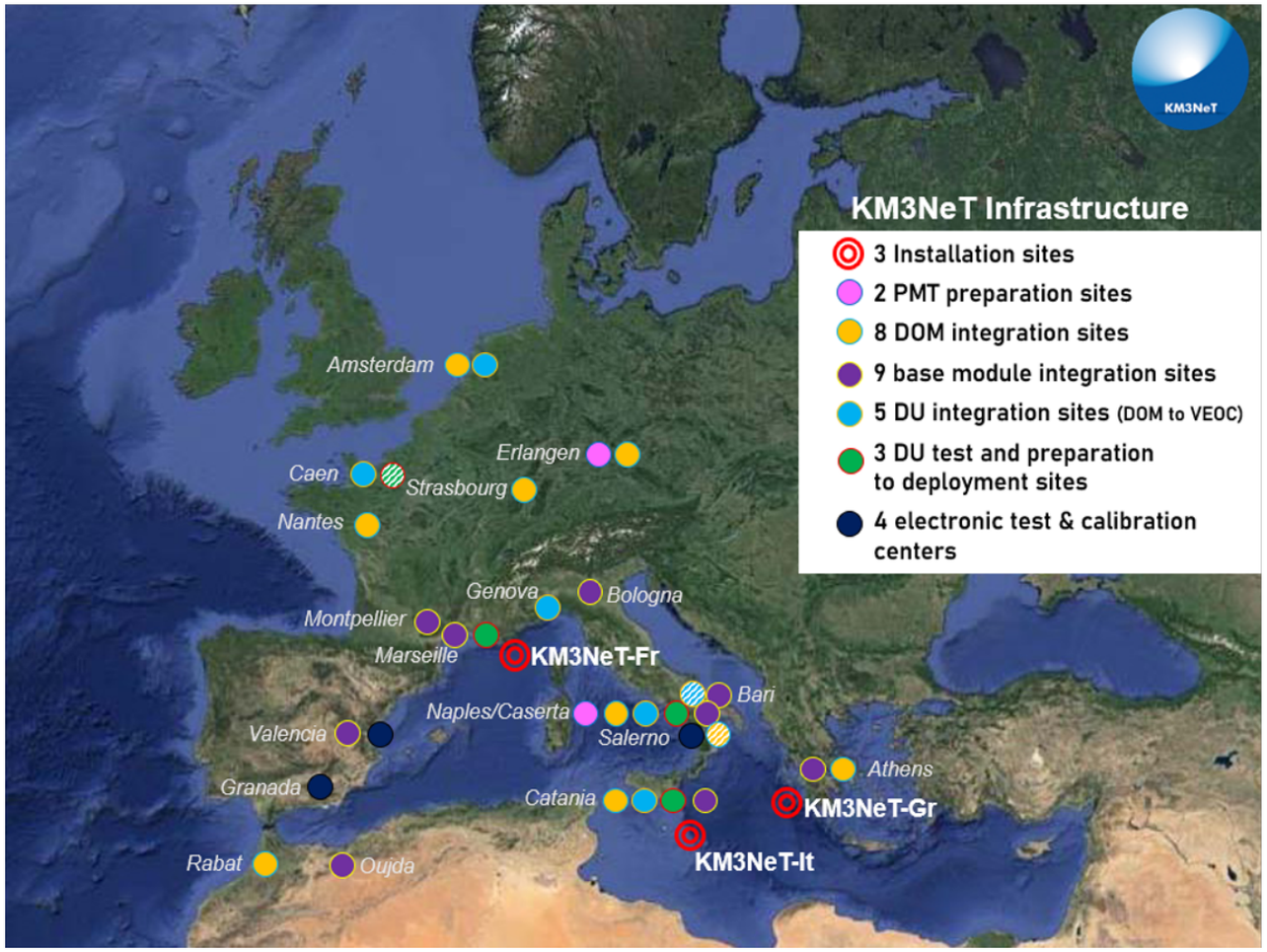
60264 PMTs

KM3NeT Collaboration



Status of the construction

- **Parallel construction of ORCA and ARCA**
- Multiple integration sites across the world: 24 sites on 7 countries
- **~2100 optical modules built**
- **~100 detection units integrated**
- **End of the construction ~2030 for ORCA, ~2032 for ARCA**

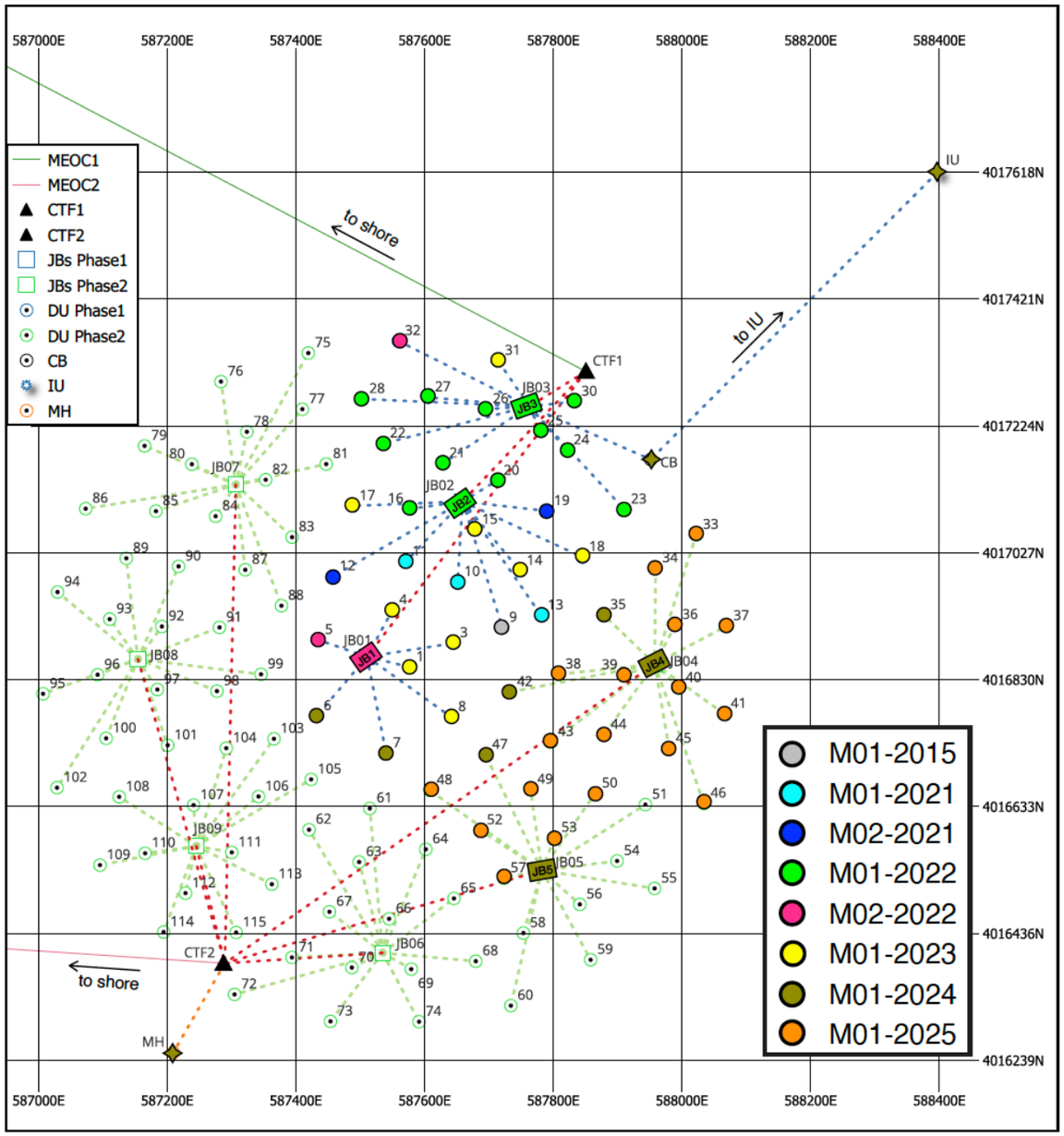


27-Jan-26	ARCA (198)		ORCA (108)	
	quantity	% completed out of total	quantity	% completed out of total
Optical Modules	1206	33,8%	864	44,4%
Base Modules	71	35,9%	47	43,5%
Detection Units	58	29,3%	36	33,3%

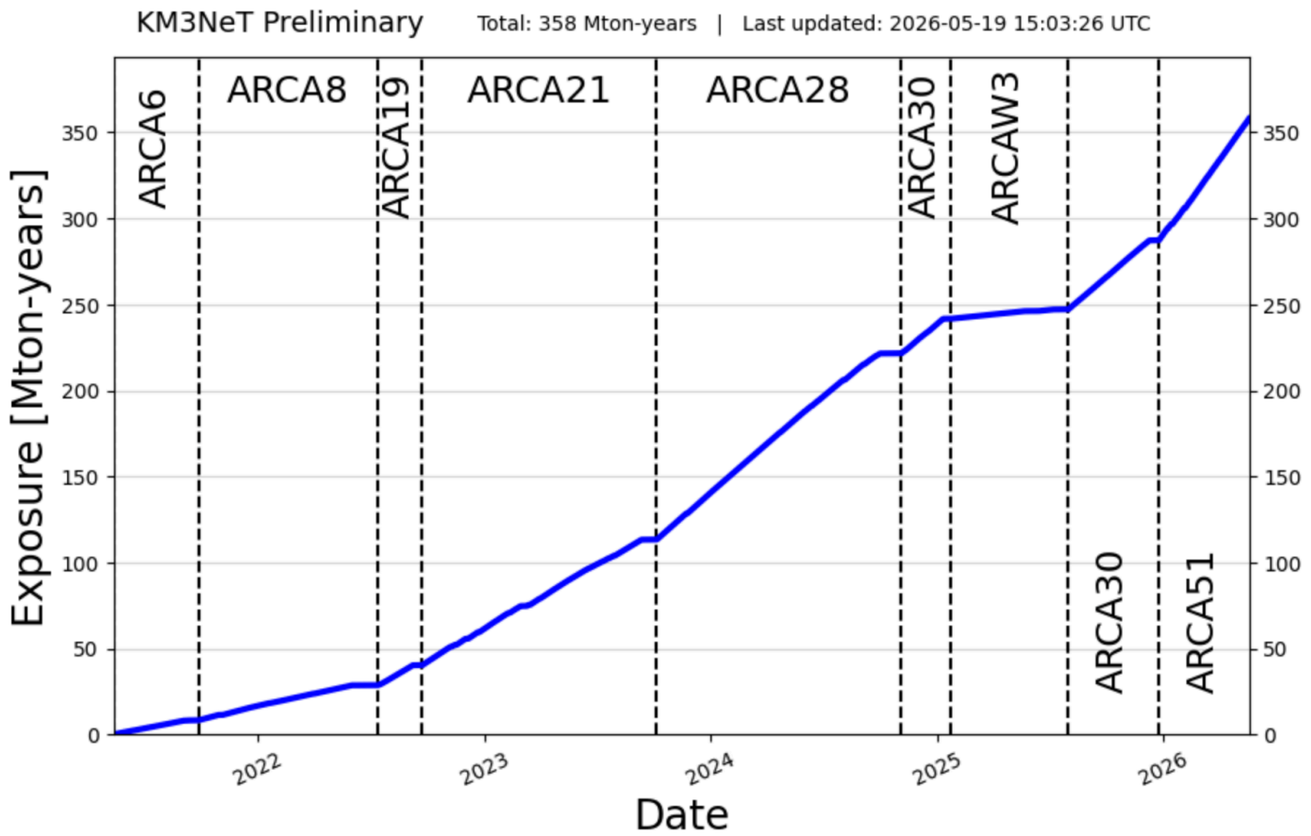
Current situation of ARCA

51 DUs deployed (44 % of the 1st building block)

+ 2 JBs + ~11 DUs + 1 replacements DUs in Summer 2026



Current layout of the 1st building block



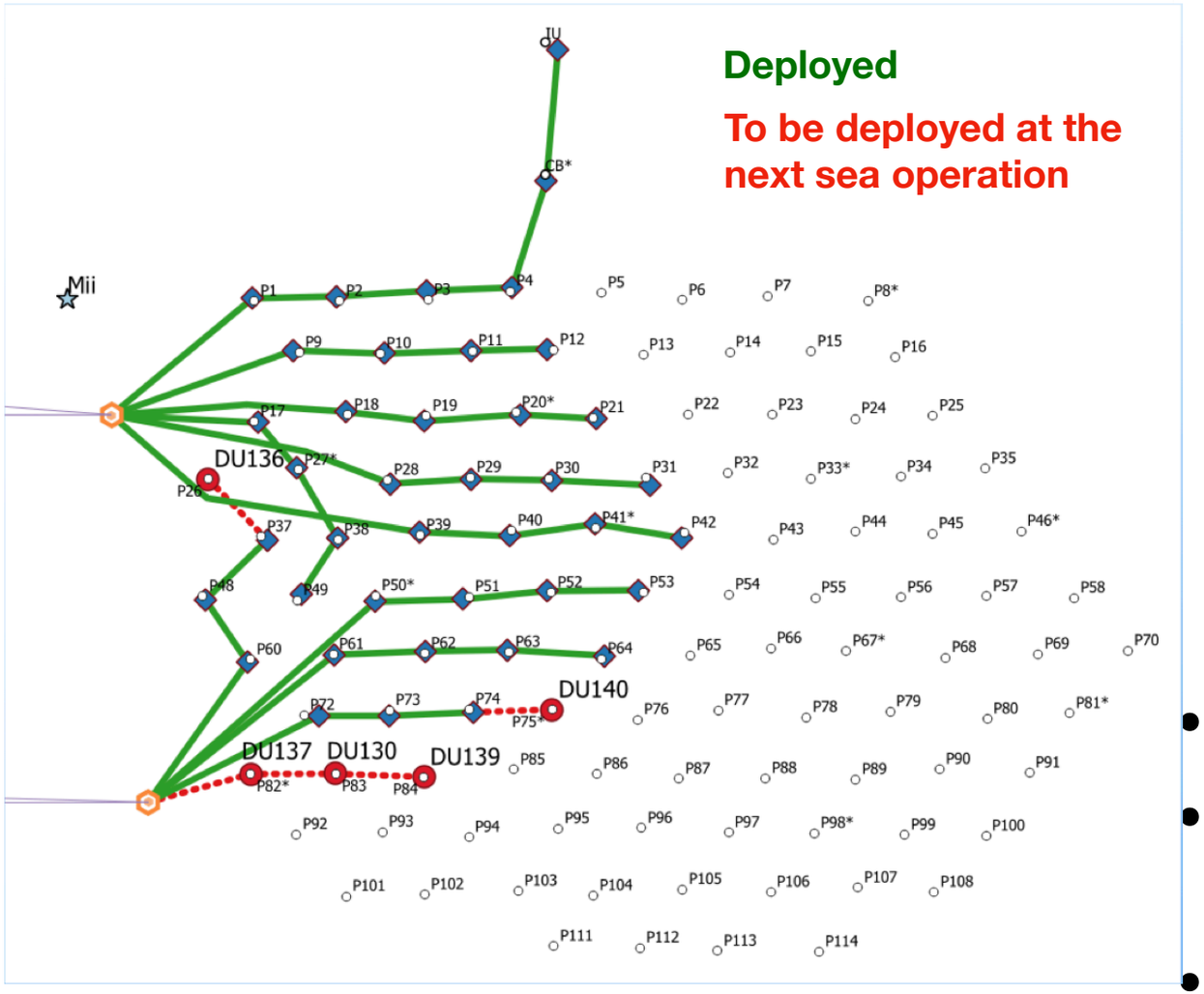
- **Stable data-taking efficiency ~90%**
- **So far, we have presented results of the ARCA6-21 dataset (~130 Mt.yr)**
- **We are finalizing the calibration and processing of ARCA28/30 dataset**

Current situation of ORCA

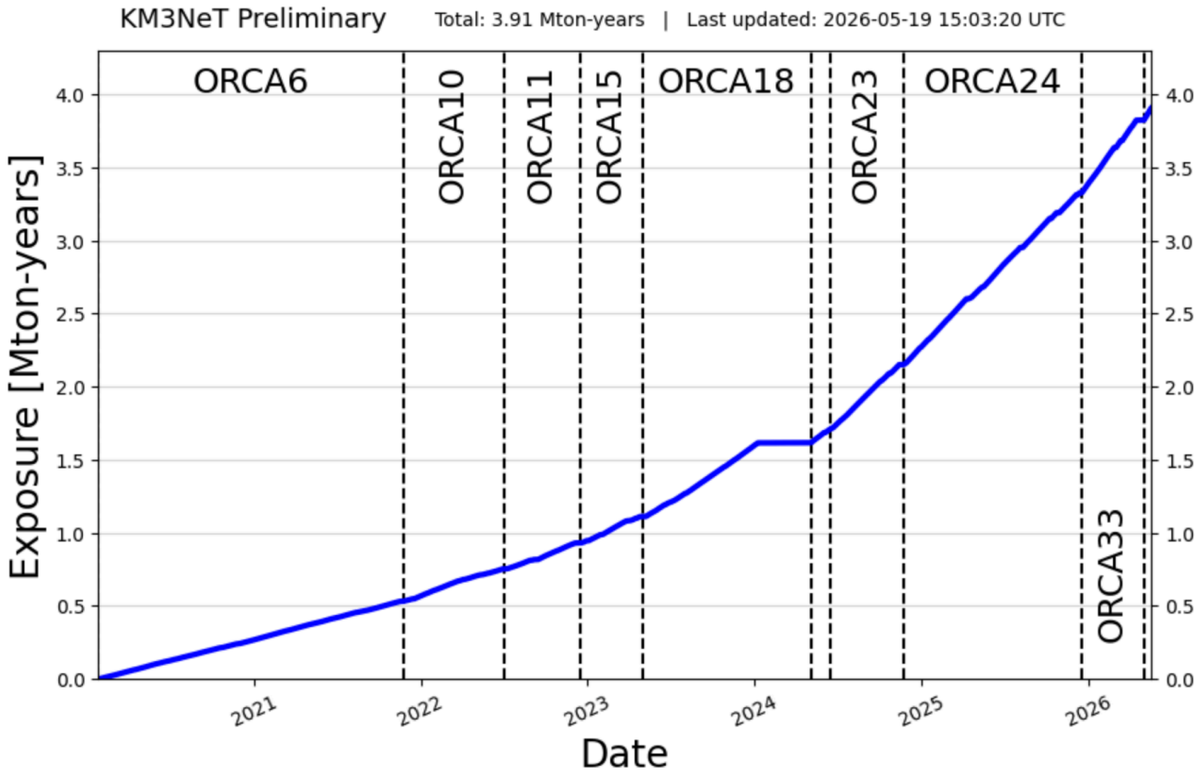
38 DUs deployed (1/4 of the full detector)

+ 2 sea science instrumented units

5+3 DUs to be deployed in July+oct 2026

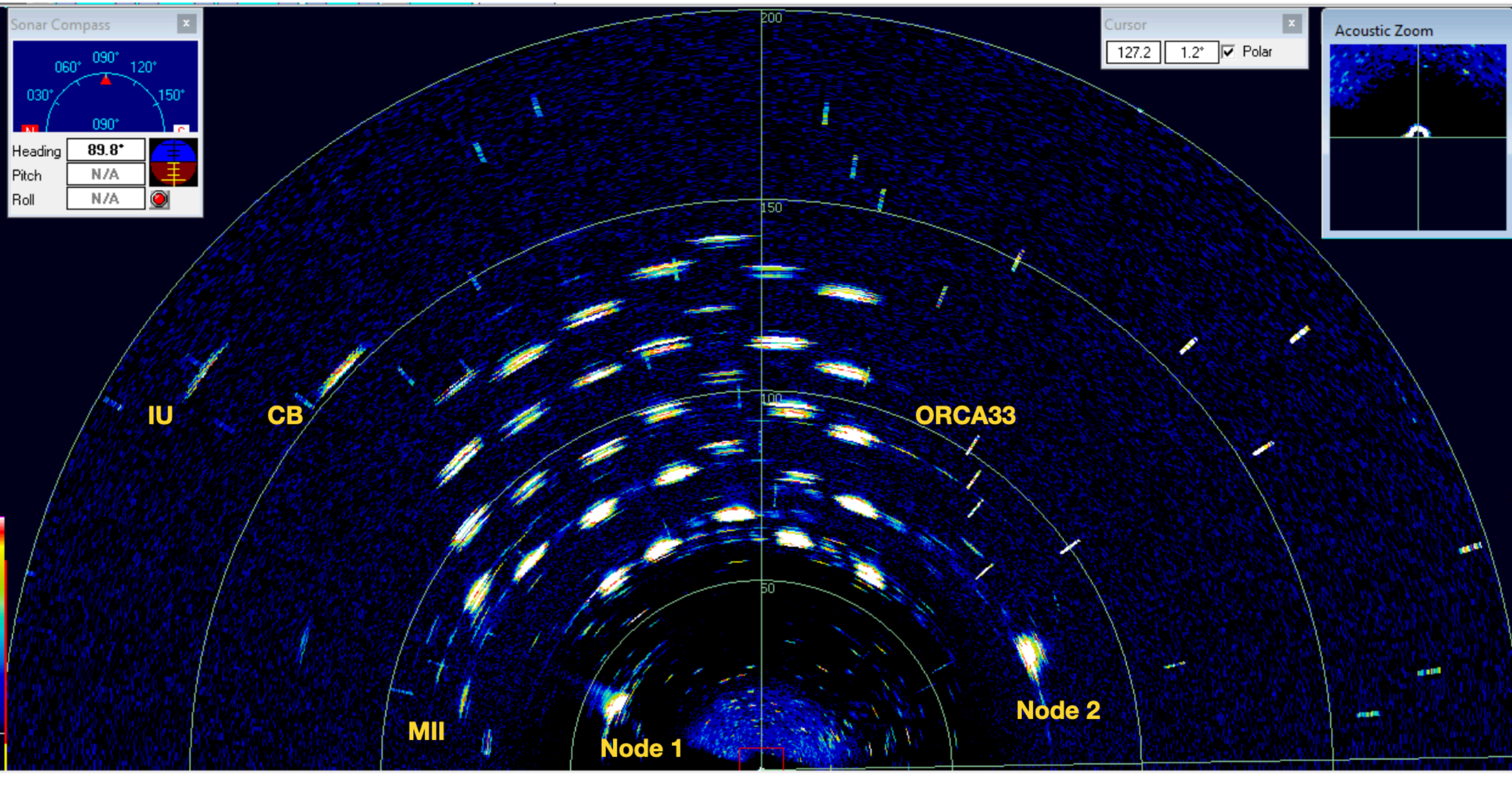


Current layout (1 building block)



- **Stable data-taking efficiency ~92%**
- **So far, we have presented results of the ORCA6-11 dataset (~750 kt.yr)**
- **We are finalizing the analyses of ORCA6-18 dataset and preparing the ORCA23-24-33 dataset.**

Current situation of ORCA



Events in KM3NeT

⟹ Optical background light from 40K decay and bioluminescence [easily rejected thanks to the multi-PMT design] ⟹ calibration + ESS
⟹ For physics searches, 3 main event categories are recorded in KM3NeT :

Atmospheric muons

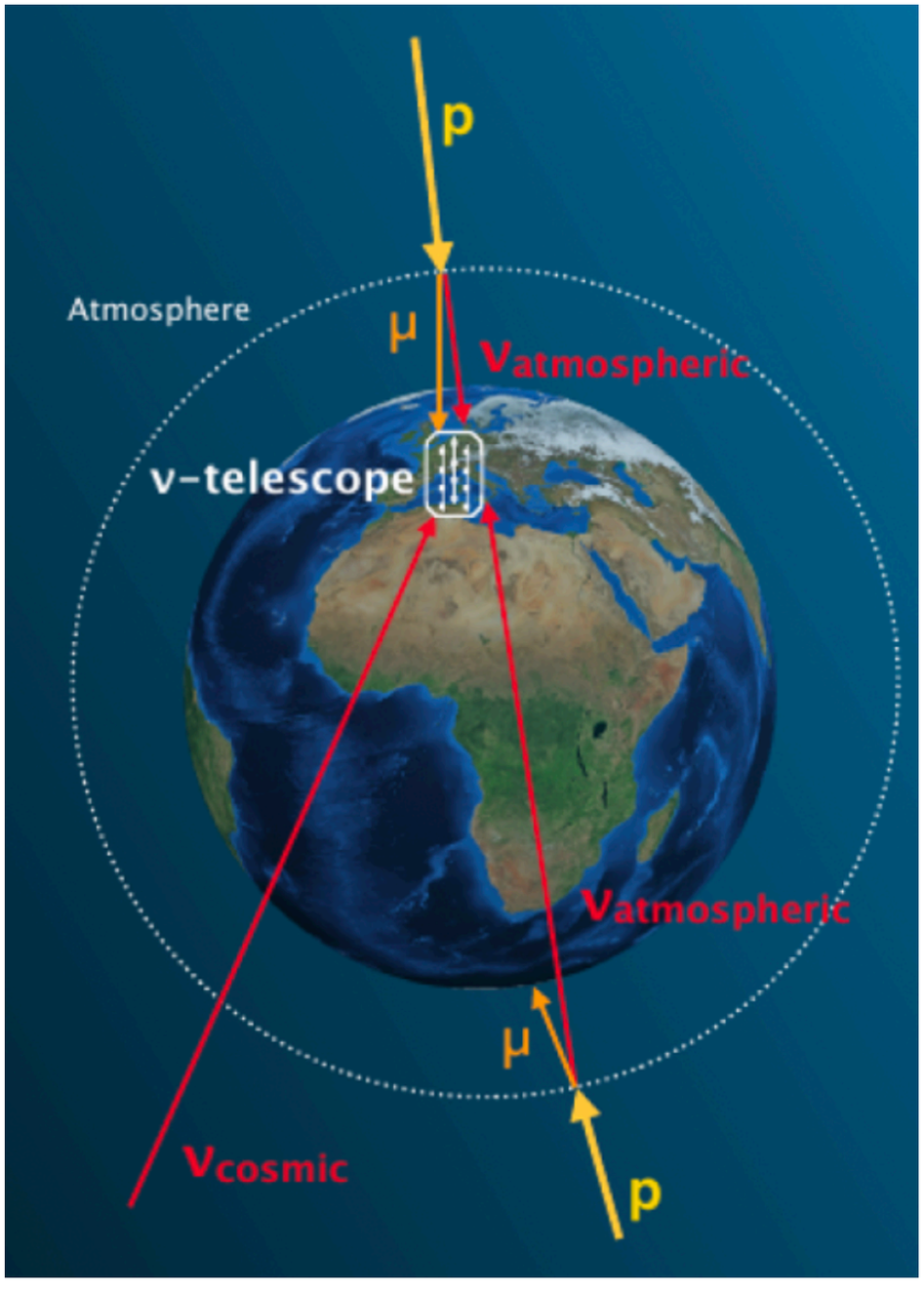
⟹ μ_{atm} ~ 10^8 - 10^{10} /yr [downgoing]
⟹ Calibration
⟹ Cosmic ray physics

Atmospheric neutrinos

⟹ ν_{atm} ~ 10^5 - 10^6 /yr [all-sky]
⟹ Neutrino oscillation
⟹ Beyond standard model

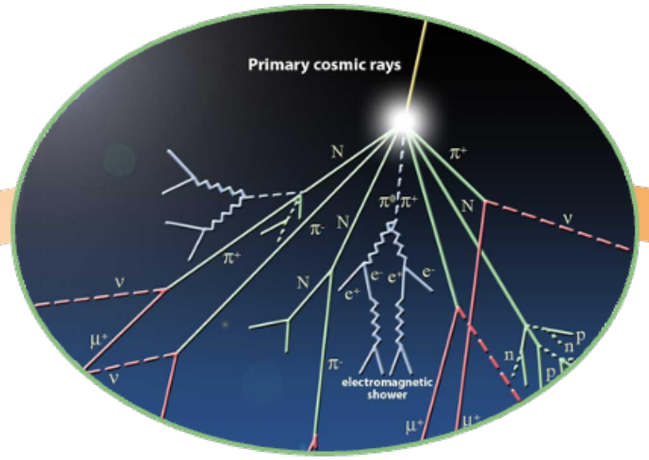
Cosmic neutrinos

⟹ ν_{cosmic} ~ 100 - 500 /yr [all-sky]
⟹ Neutrino astronomy
⟹ Dark matter

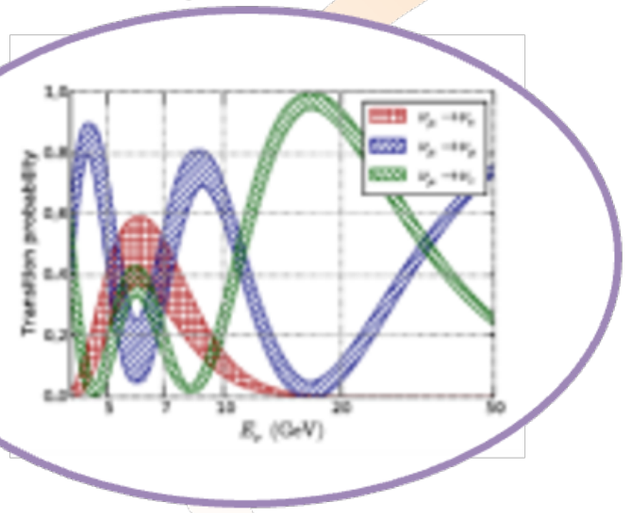


Science cases with KM3NeT

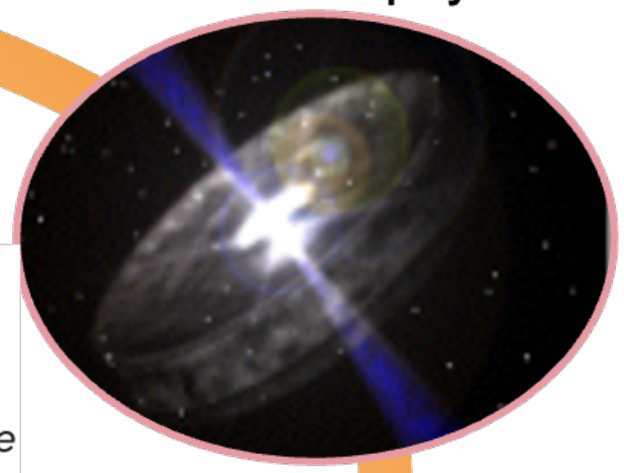
Cosmic Rays



Neutrino Physics



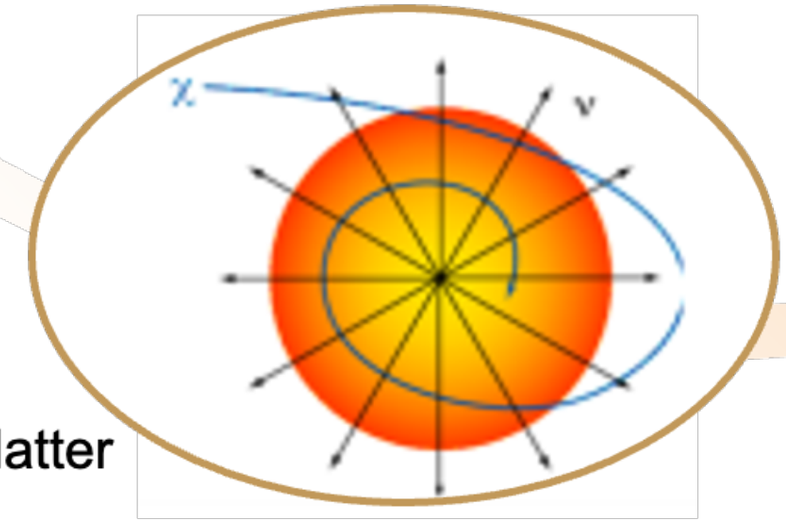
Astrophysics



KM3NeT

Opens a new window on our universe

Complementarity of ORCA and ARCA on all topics



Dark Matter

Earth and Sea

KM3NeT astro analyses

2 detectors ARCA & ORCA: use their complementarity to maximise the energy coverage with the maximum sensitivity

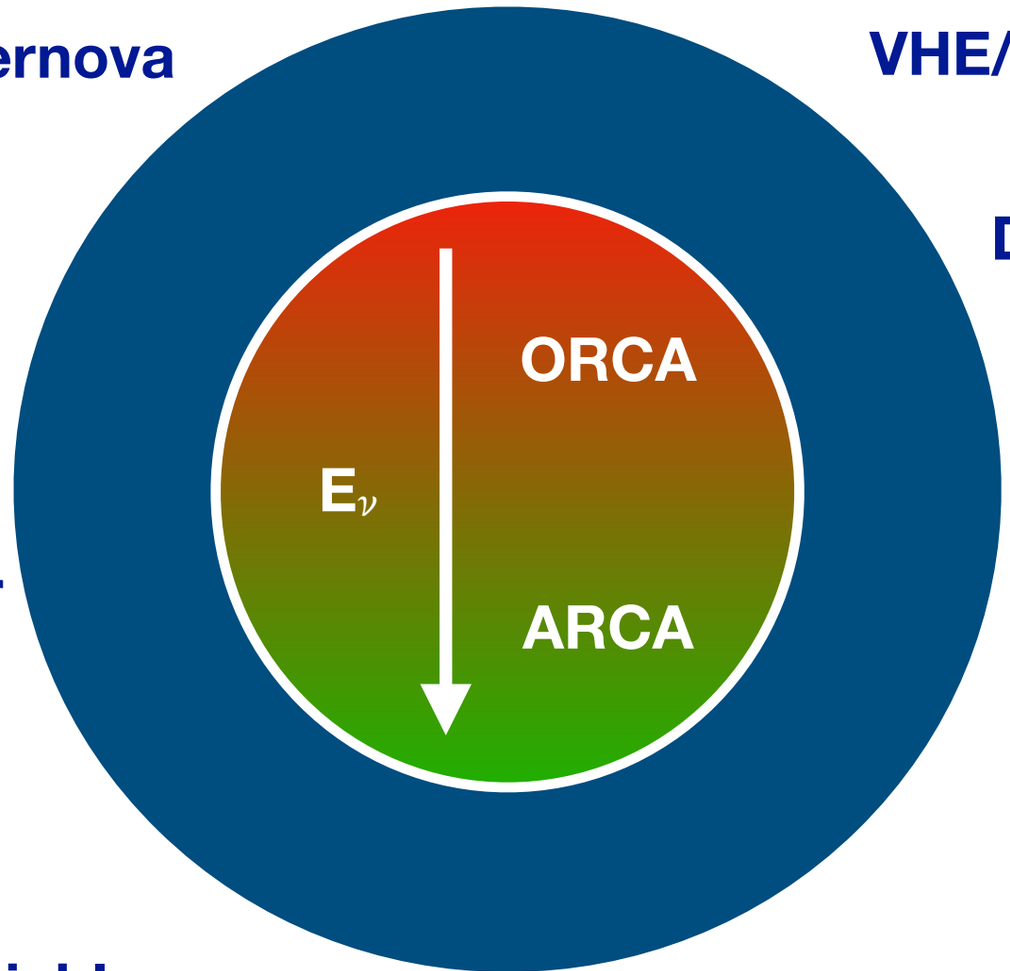
Flavor ratio, tau, Glashow resonance, cross-section

Core-Collapse Supernova

VHE/UHE events

Solar flares

Diffuse all-sky flux



Extended region diffuse flux (Galactic Ridge, Fermi bubble, Cygnus, CMZ…)

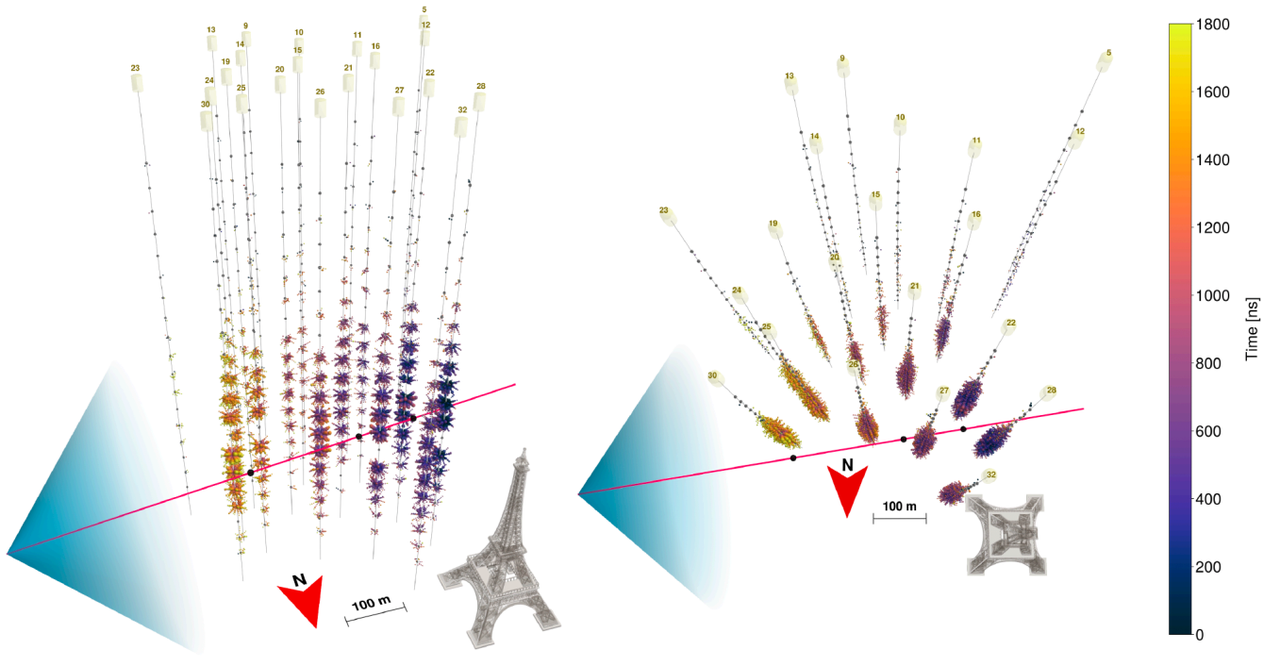
Multi-messenger correlation

Stacking source populations

Transient/variable sources

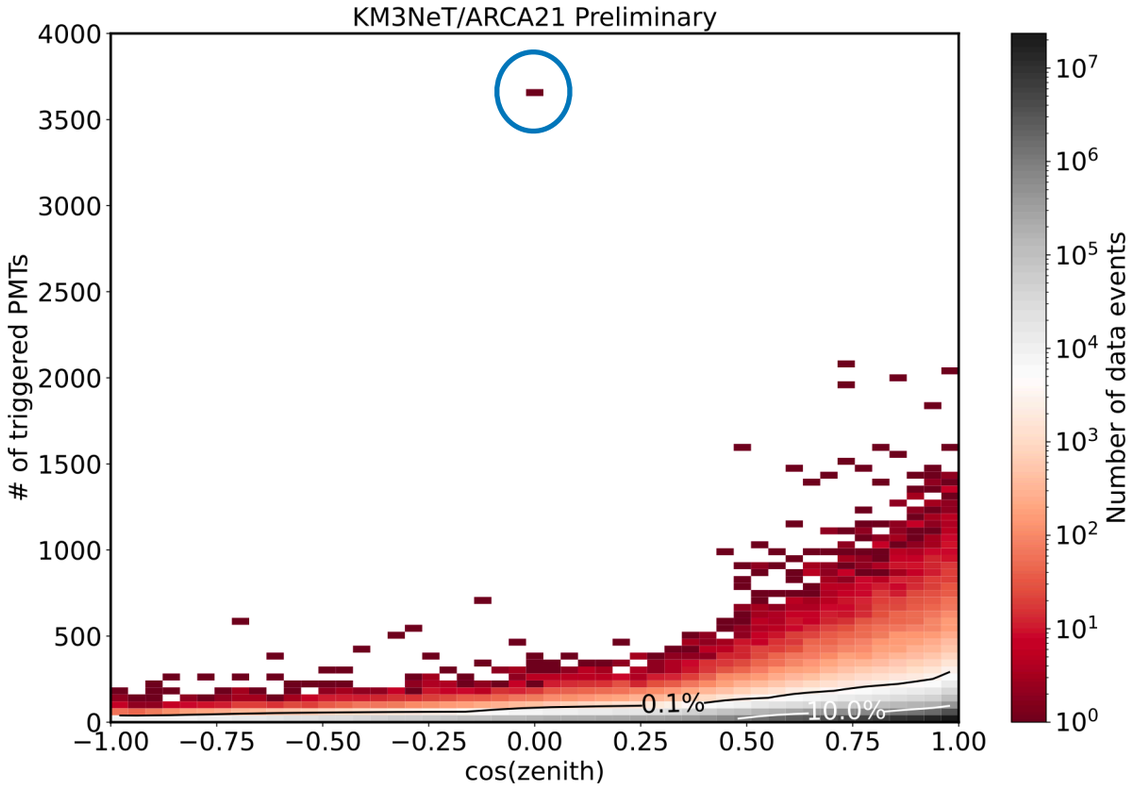
Extended / Point-like sources

KM3-20230213A: 1st UHE neutrino



On February 13th 2023, 01:16:47 UTC, detection of KM3-20230213A :

- **Brightest among 10^8 events collected in the ARCA21 configuration**
- Very horizontal, light deposition in 1/3 of the detector
- Extremely high-quality track reconstruction



It is a COSMIC NEUTRINO !

At the reconstructed direction, and atm. muon could not survive to the detector

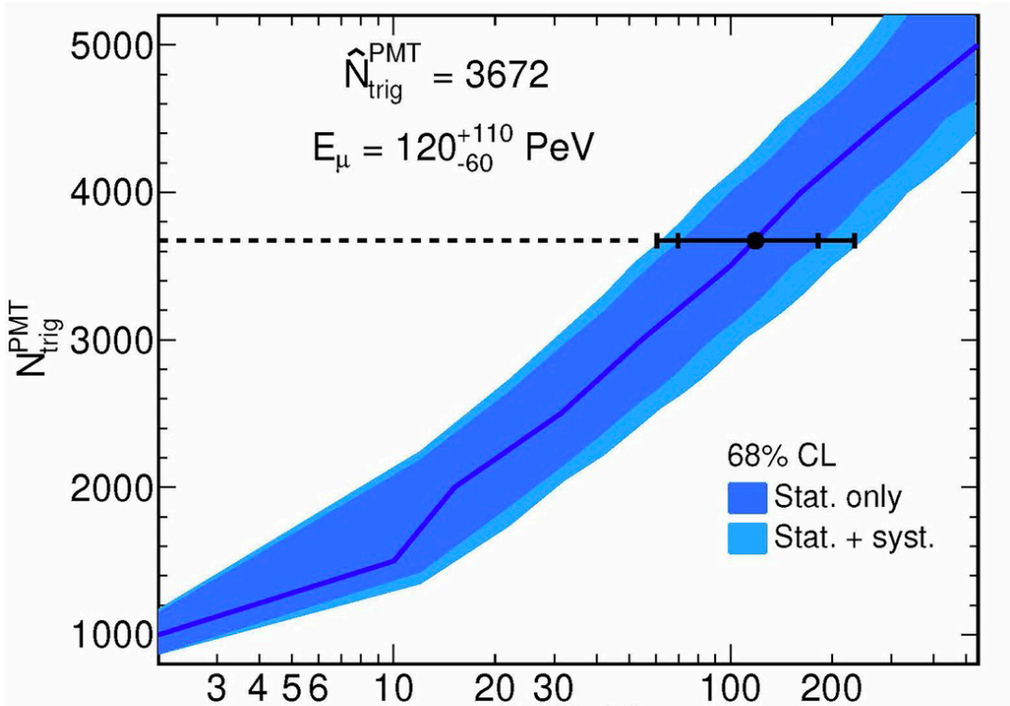
- Atm. muon rate: << 10^{-10} /yr (< 10^{-5} in worse case scenario)
- Muon bundles also unlikely (10^{-3} /yr)
- Atm. neutrinos with such energies ≤10^{-5} /yr

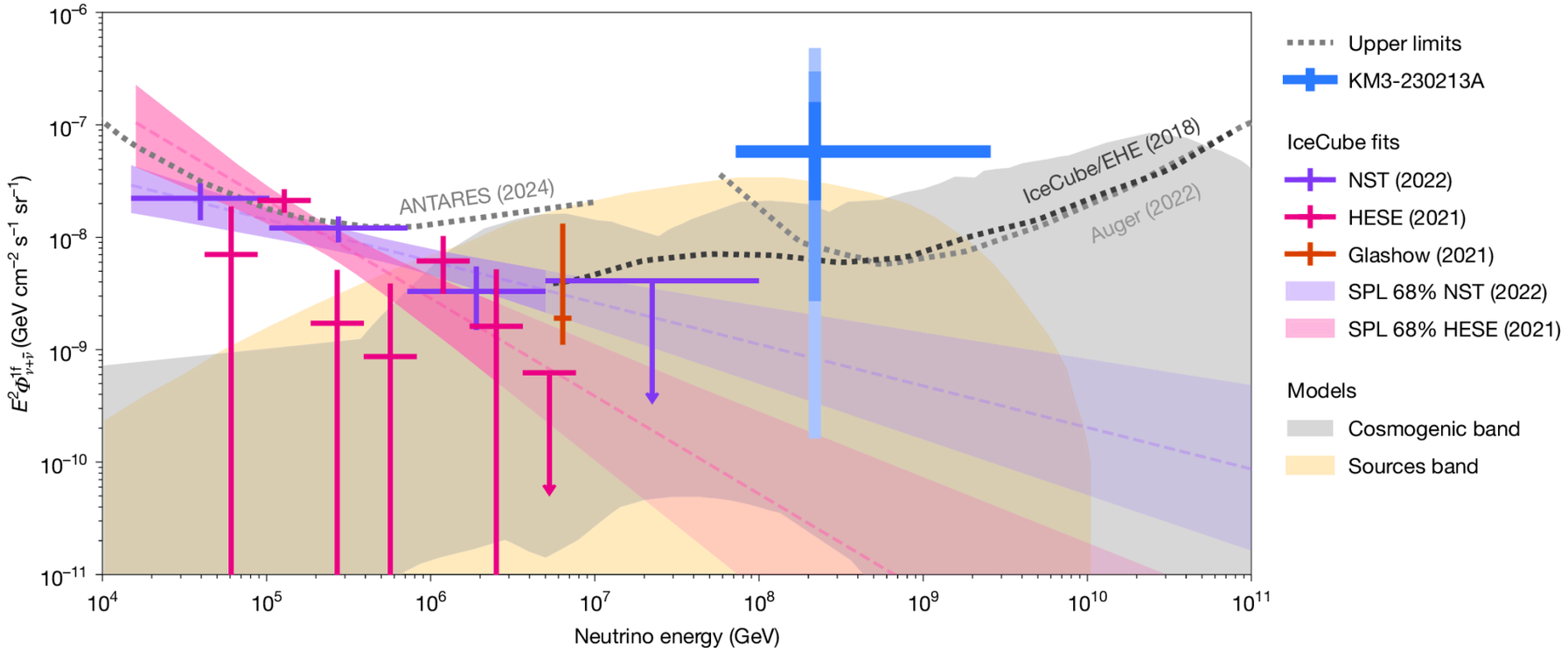
Nature 638, 376–382 (2025)

KM3-230213A: 1st UHE neutrino

- **Muon energy estimate with detailed MC simulation using the best knowledge of the detector performances and detailed muon propagation simulation in water**
- **Using number of triggered PMTs as proxy**
- **Estimation of the neutrino energy:**

$$E_\nu = 220^{+570}_{-110}\ \text{PeV}$$





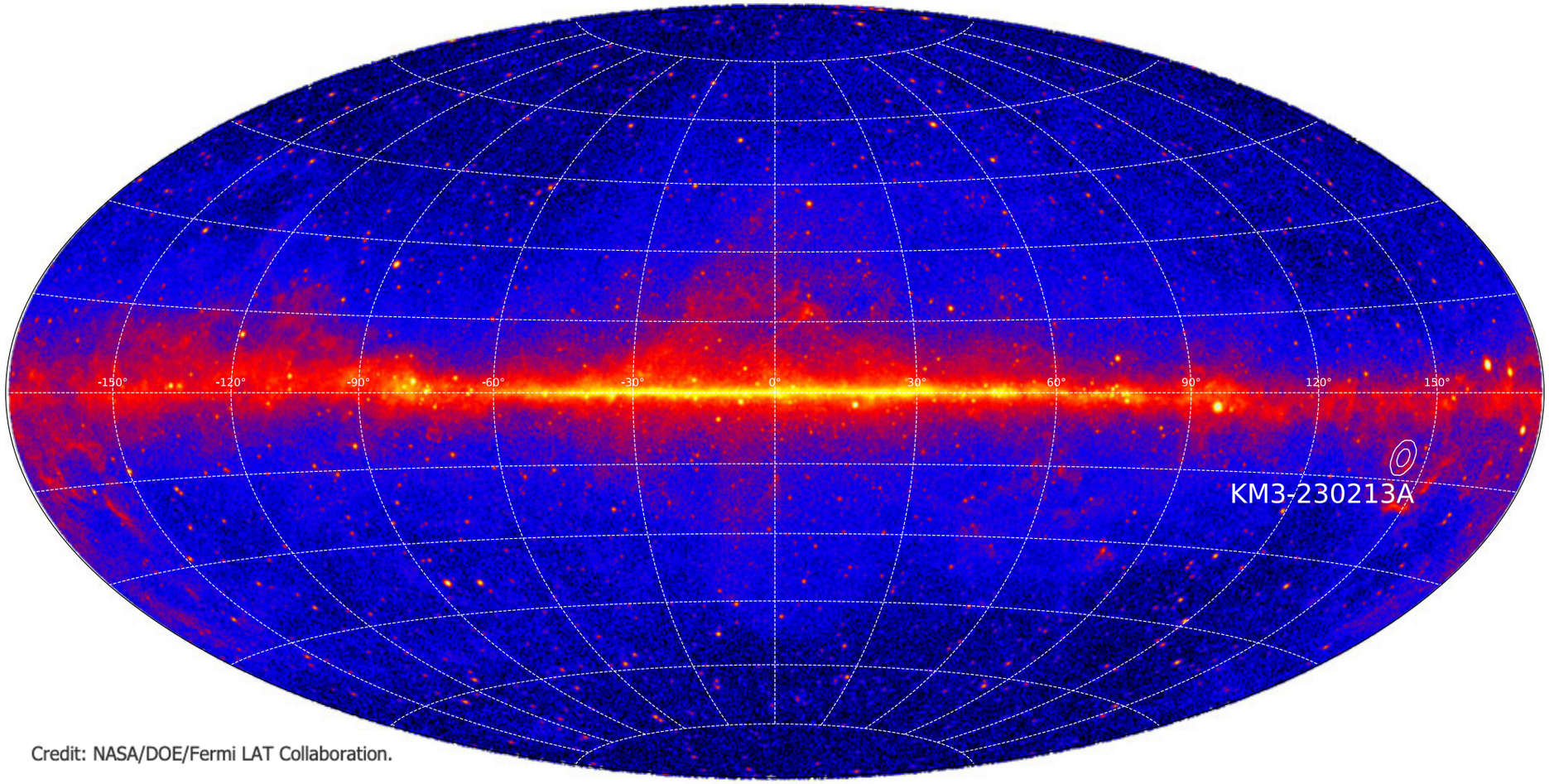
Using single power-law, moderate tension with non-observation by IceCube and Auger (~ 2.5σ)

Nature 638, 376–382 (2025)

KM3-230213A: 1st UHE neutrino

Local coordinates: (zenith, azimuth) = (89.4°, 259.8°):

- **Celestial coordinates: (RA, dec) = (94.3°, –7.8°)**
- R(68%) = 1.5°, R(90%) = 2.2°, R(99%) = 3.0°
- Limited by the absolute positioning of the detection elements (intrinsic reconstruction uncertainty of 0.12°)
- **NEWS: Ongoing campaigns to improve acoustic emitter position accuracy → recalibrate the data and improve pointing/energy estimations**



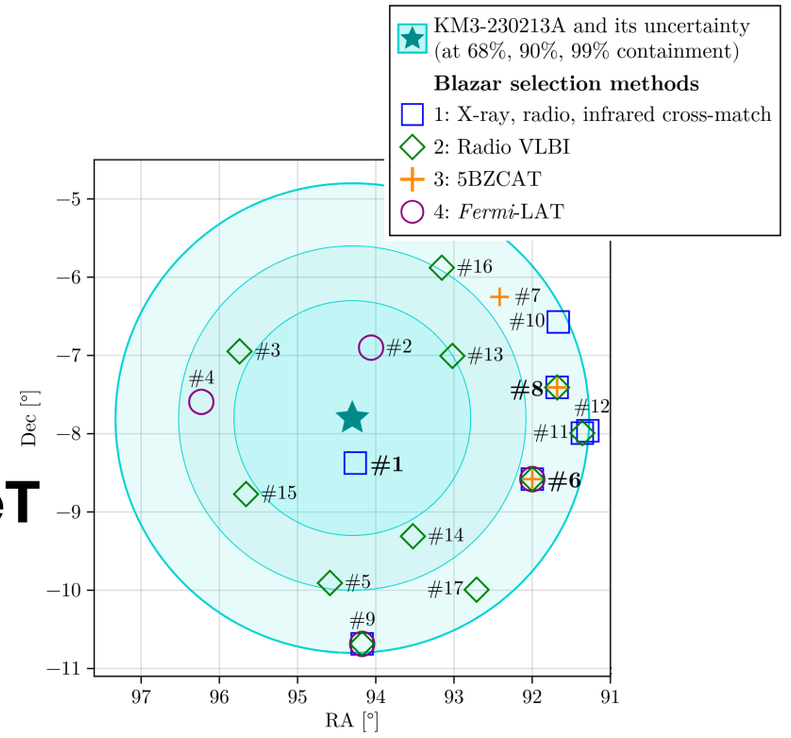
Credit: NASA/DOE/Fermi LAT Collaboration.

Nature 638, 376–382 (2025)

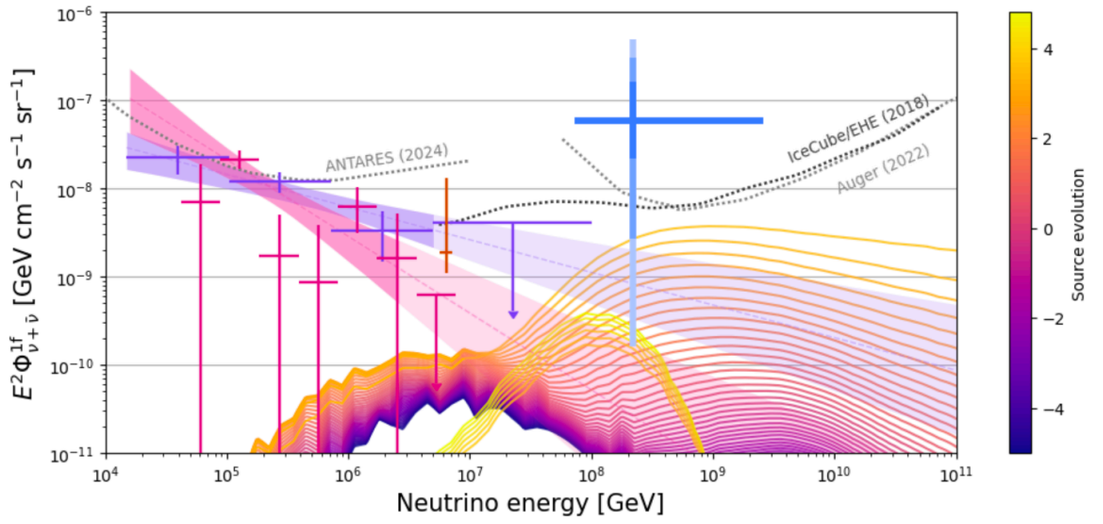
KM3-230213A: 1st UHE neutrino

What do we know on the origin? still unknown

- **Crossmatch with gamma/X/radio catalogs**
  - 17 blazar candidates identified
  - 3 coincidence electromagnetic flares
- **Similar search performed within the Milky Way**
  - 11° below the Galactic Plane
  - No Galactic sources in this direction
- **Search for lower-energy neutrinos with ANTARES / KM3NeT**
  - No significant excess found
- **Consistent with blazar and GRB population studies**



- **Cosmogenic neutrino**
  - Constrain with the Auger+TA UHECR spectrum/composition + EGB Fermi-LAT flux
  - Playing with source evolution and extending $z_{max} \Longrightarrow$ compatibility

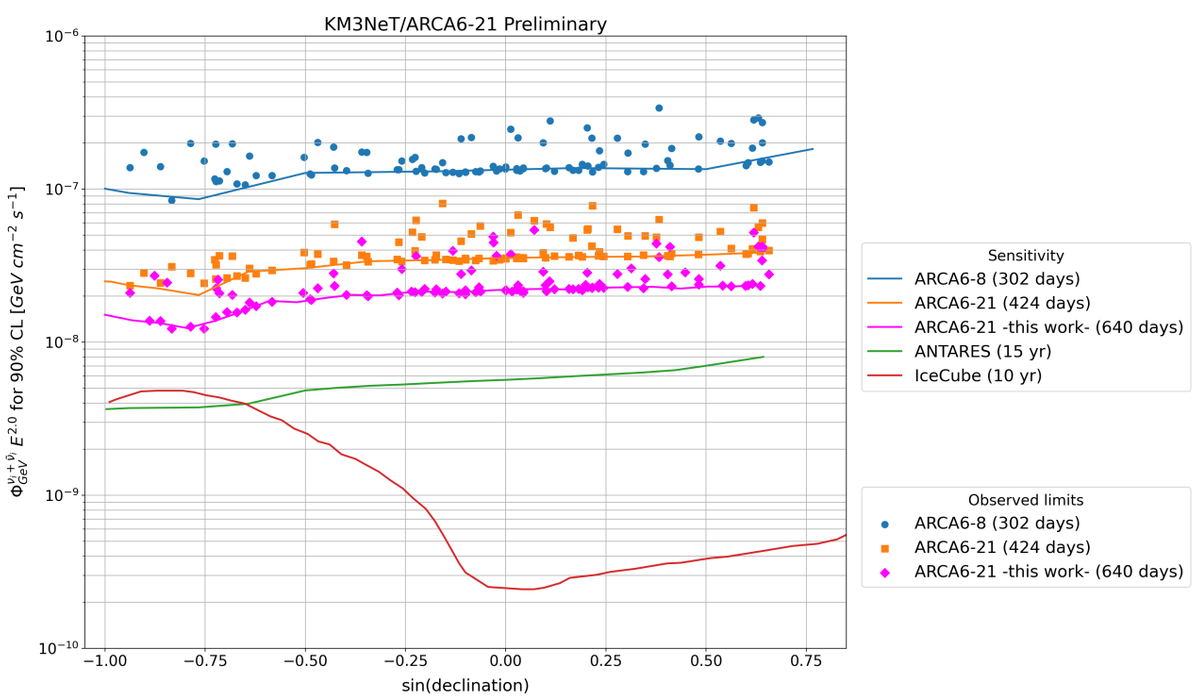


Point-source searches

- **PS results of ARCA 6-21 (640 days)**
- **+ Extension at LE with ORCA6-18 (1200 days)**
- Only the upgoing track channel
- Binned likelihood analysis applied to all-sky scan + 106 selected sources (based on EM properties)
- Only ARCA analysis unblinded

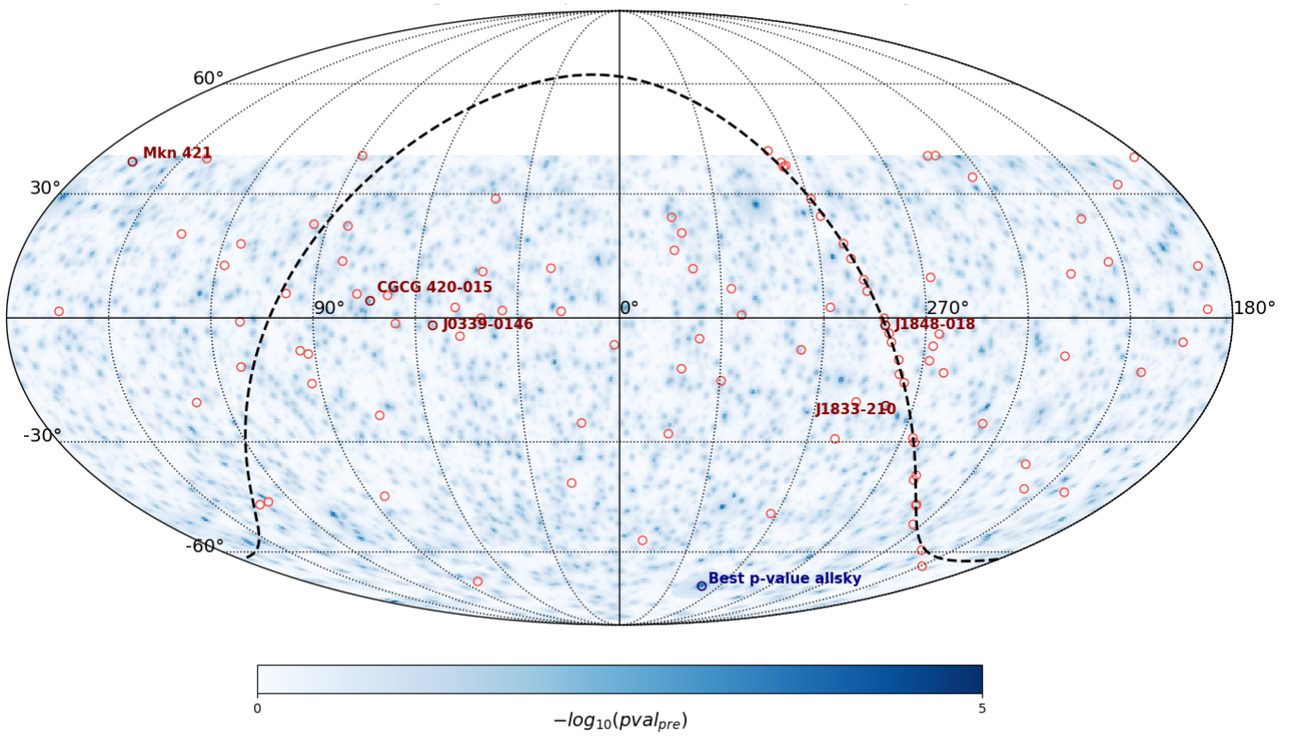
⟹ **No strong neutrino emission observed in line with the background expectation**

Upper-limits assuming E^{-2} spectrum



V. Parisi et al [KM3NeT], Pos (ICRC2025) 1124

Significance map for all-sky search



I. Del Rosso et al [KM3NeT], Pos (ICRC2025) 1026

Source population studies

Stacking search with ARCA6-21 using a binned likelihood framework:

- **Extreme High-frequency-peaked BL Lacs:**
  - 88 selected blazars
  - Neutrino model: LeHAMoC

  ⟹ Results: **p-value=2.6**σ (mainly driven by 1 source 3HSP J204008.3-711459)

- **High-frequency-peaked BL Lacs:**
  - 232 selected blazars from 3HSP cat.
  - Neutrino model: LeHa-Paris (PKS 2155-304 as ref.)

  ⟹ Results: p-value=1.44σ

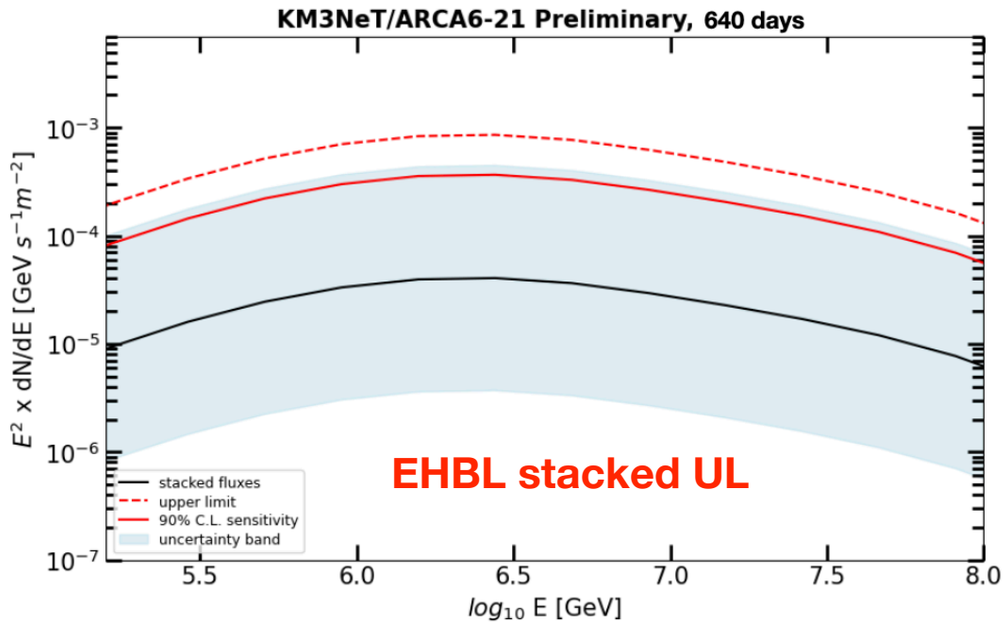
- **Seyfert Hot-Coronae sources:**
  - 32 selected seyferts from BASS cat.

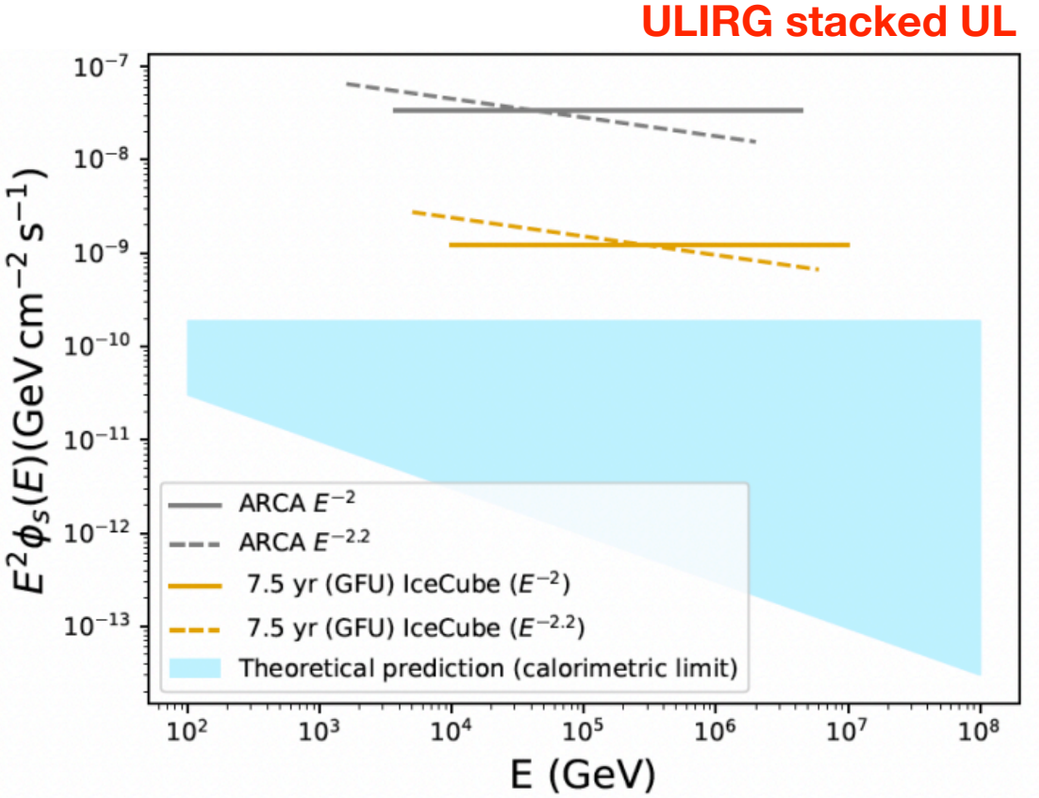
  ⟹ Results: no excess

- **Ultra-luminous infrared galaxies:**
  - 75 selected ULIRGs ($L_{IR} \gtrsim 10^{12}\ L_{\odot}$, $z < 0.13$, $|b| > 5^{o}$)

  ⟹ Results: no excess

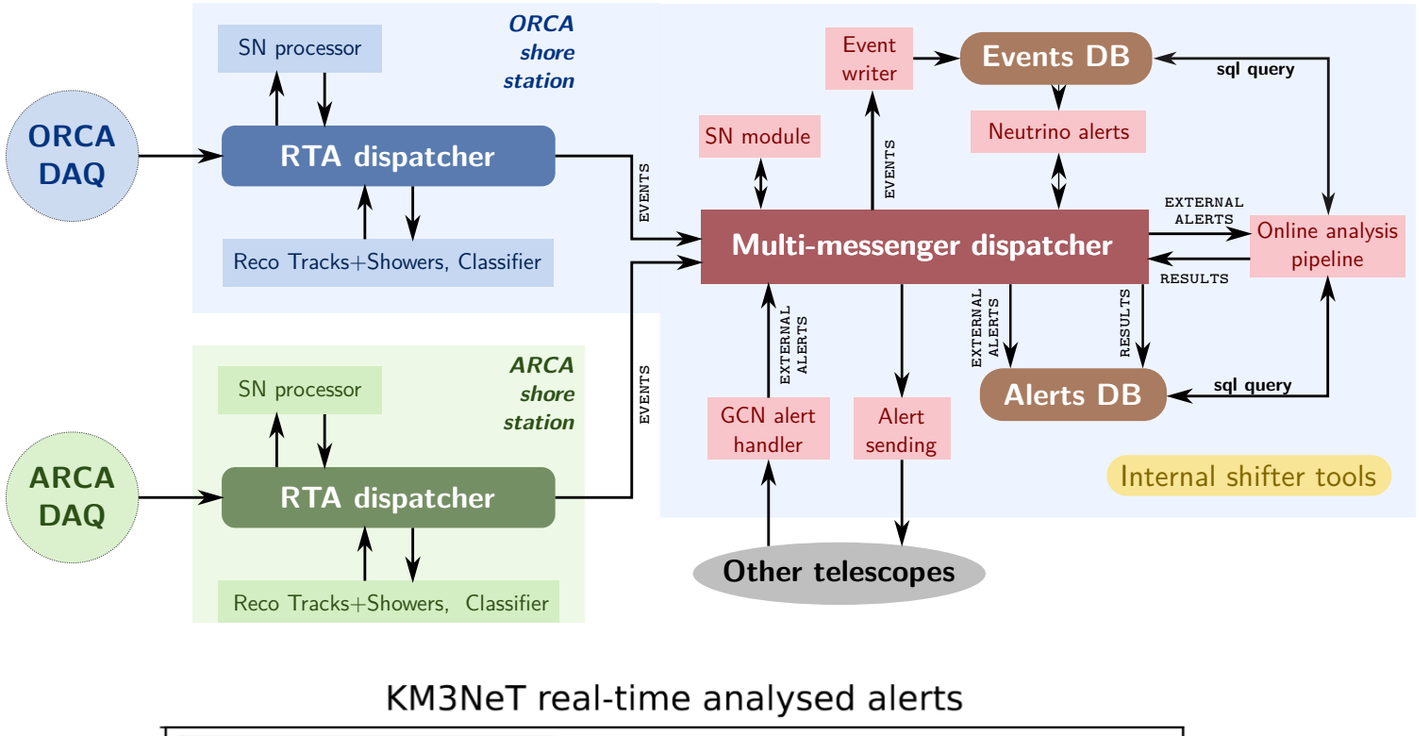
+ GRBs, FRBs, microquasars, GWs



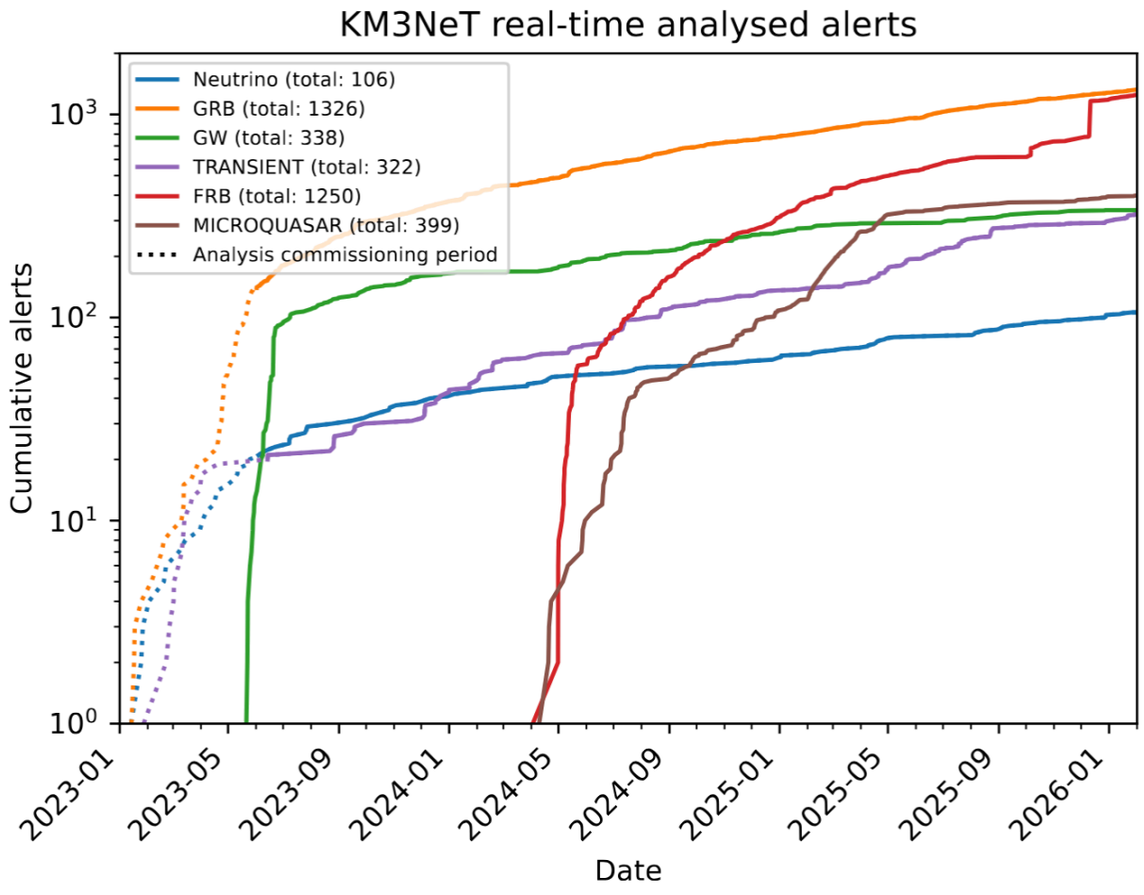


F. Carenini et al, Pos (ICRC2025) 1005 W. Idrissi Ibnsalih et al Pos (ICRC2025) 1065
A. de Benedittis et al, Pos (ICRC2025) 1005 M.R. Musone et al Pos (ICRC2025) 1125

Real-time analysis platform

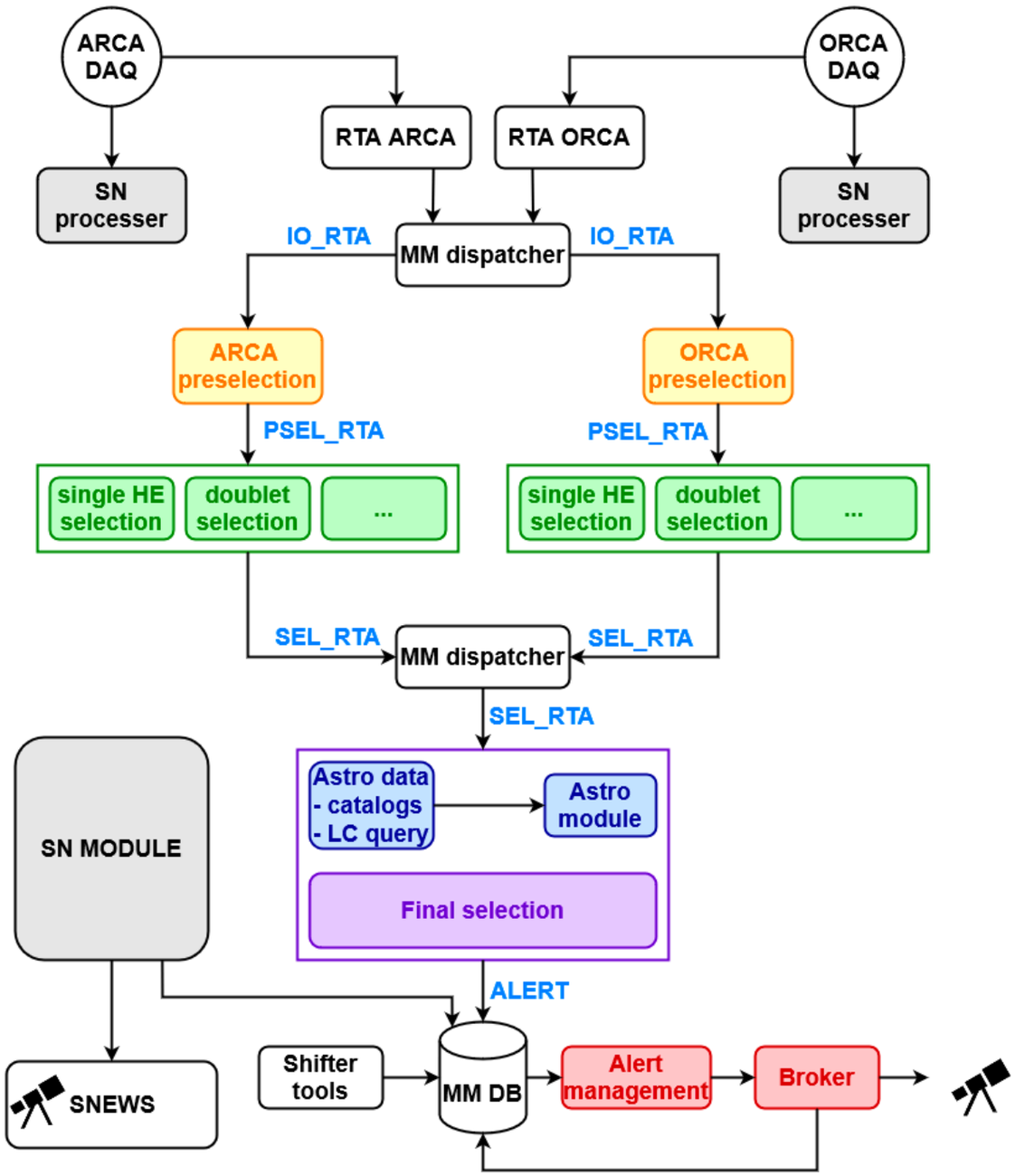


- **From data collection to reconstruction takes about 7 s.**
- **Performing follow-ups of external triggers (GW, transient, IC ν) with KM3NeT**



- **Fully automated analysis framework, very versatile and robust**
- Under of the supervision of shifters for external reporting
- **So far, no significant neutrino signal in time/space correlation with the triggers**
- Results to be reported in GCN/ATel asap

Neutrino alert sending



<u>Work in progress (ETA: mid 2026)</u>:

New development of the neutrino alert selection by introducing time/space correlation of potential astro counterpart [« free » data]

➡ Use an hybrid selection: neutrino + astro

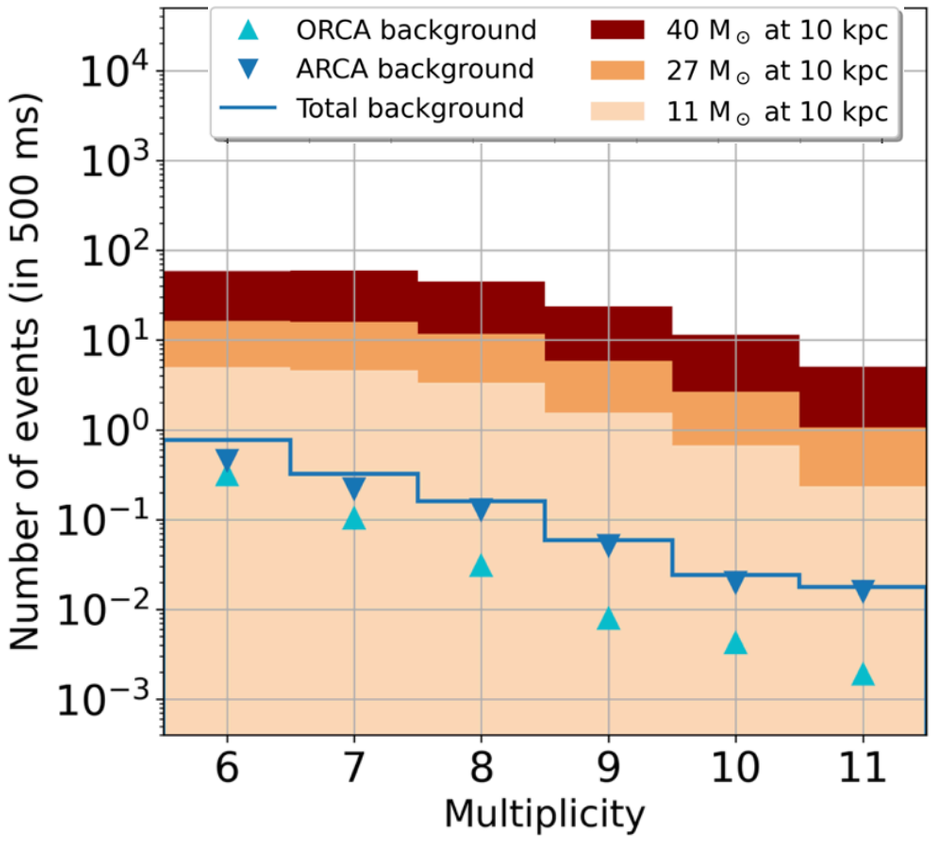
➡ At the end of the module, if one or more interesting sources have been identified, upgrade the candidate alert into a real alert

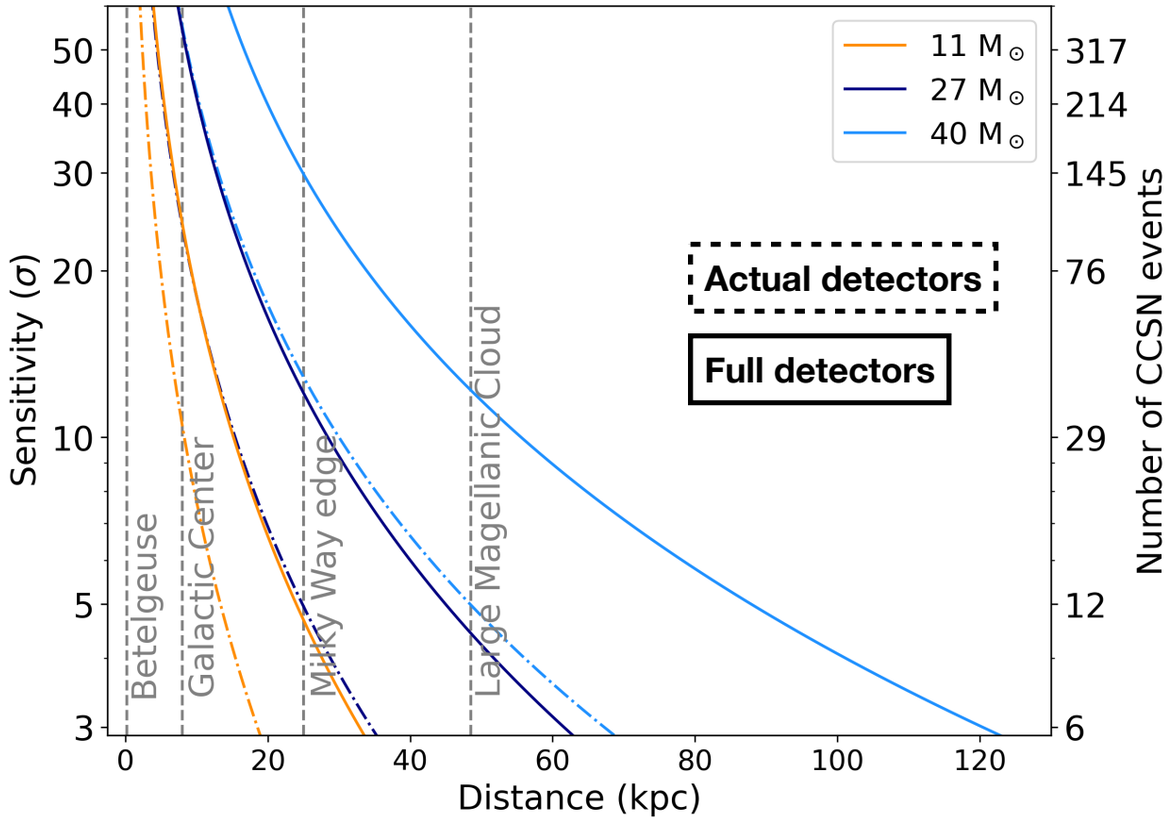
➡ Keep pure neutrino criteria for exceptional characteristics

Core-Collapse supernovae with KM3NeT

CCSN → 99% of the energy in neutrinos o(10 MeV)

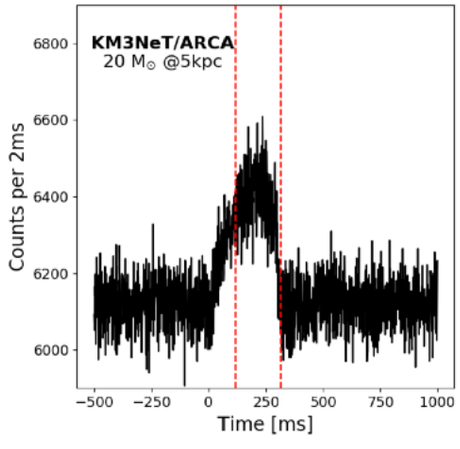
No event-by-event reconstruction ⟹ collective increase of the multiplicity rate on the DOMs



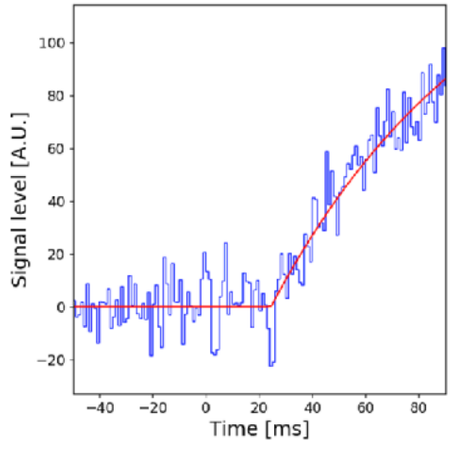


Astrophysical analyses:

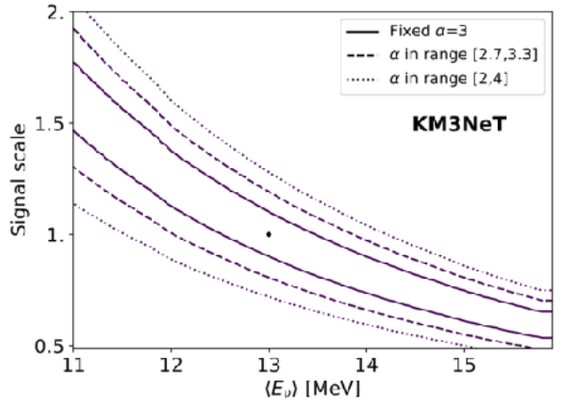
+ connected to SNEWS2.0



Time profile



T_0 estimate



Neutrino spectrum

S. El Hedri et al [KM3NeT], Pos (ICRC2025) 1037

How to have access to KM3NeT data ?

Join the KM3NeT Collaboration

Having access to all KM3NeT data without restriction.

- 2 main status for the Institute: full member / observer

(Observer is a temporary status of 3 years to start in KM3NeT without paying any common fund)

⇒ *It is a very good moment to join the adventure as KM3NeT is still a pretty small collaboration, still in the construction phase, still a lot of place to take*

TNA to KM3NeT

Open call for access to data from KM3NeT → link (deadline 2026-07-20)

Access to expertise in all domains (gamma, X, neutrino, GW, optical/NIR, radio) thanks to:

- Calls for in-person visits (next one in Fall 2026)
- Tutorials
- Dedicated online platform

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Summary

KM3NeT telescope is currently under construction but already taking data with partial configurations. ARCA: 51 lines, ORCA: 38 lines (completion in 2031-2029)

Two sites with complementary energy coverages:

- ORCA from 5 GeV to TeV → optimized for neutrino oscillations but excellent telescope for astronomy
- ARCA from TeV to 100 PeV → optimized for high-energy astrophysical neutrinos

  ⇒ < 0.1° (< 1.5°) for tracks (showers) for E_ν > 100 TeV

- ARCA+ORCA combined detector for MeV

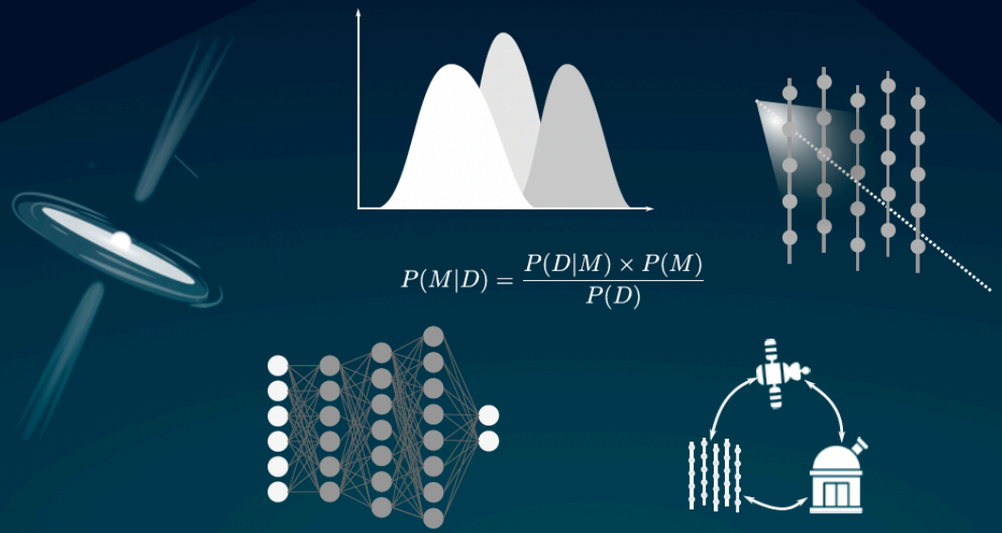
First results:

- With only 5% of the planned exposure, a lot of quite competitive results in oscillation
- KM3-20230213A: first UHE neutrino event
- Diffuse emission and point-source searches: getting close to ANTARES sensitivities
- Multi-messenger online program: started. Soon: sending follow-ups and ν alerts
- Start open science program (public dataset, public alert, transnational access…)
  - A TA open call will be opened very soon to have access to KM3NeT data

ACME Neutrino Astronomy Bootcamp

Nov 29 - Dec 4 2026

Centre Paul-Langevin
Aussois, France



Programme:

- Neutrino sources
- Detection techniques
- Simulation & reconstruction
- Event selection & statistics
- Machine learning & AI
- Hands-on and practical sessions

First circular in the next ACME newsletter!

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