# KM3NeT

## Multi-purpose Mediterranean Sea Neutrino detectors



Damien Dornic - CS-IN2P3 - 02/03/2026

# Neutrino detection in KM3NeT

# KM3NeT detector scales

230 detection units

4140 optical modules
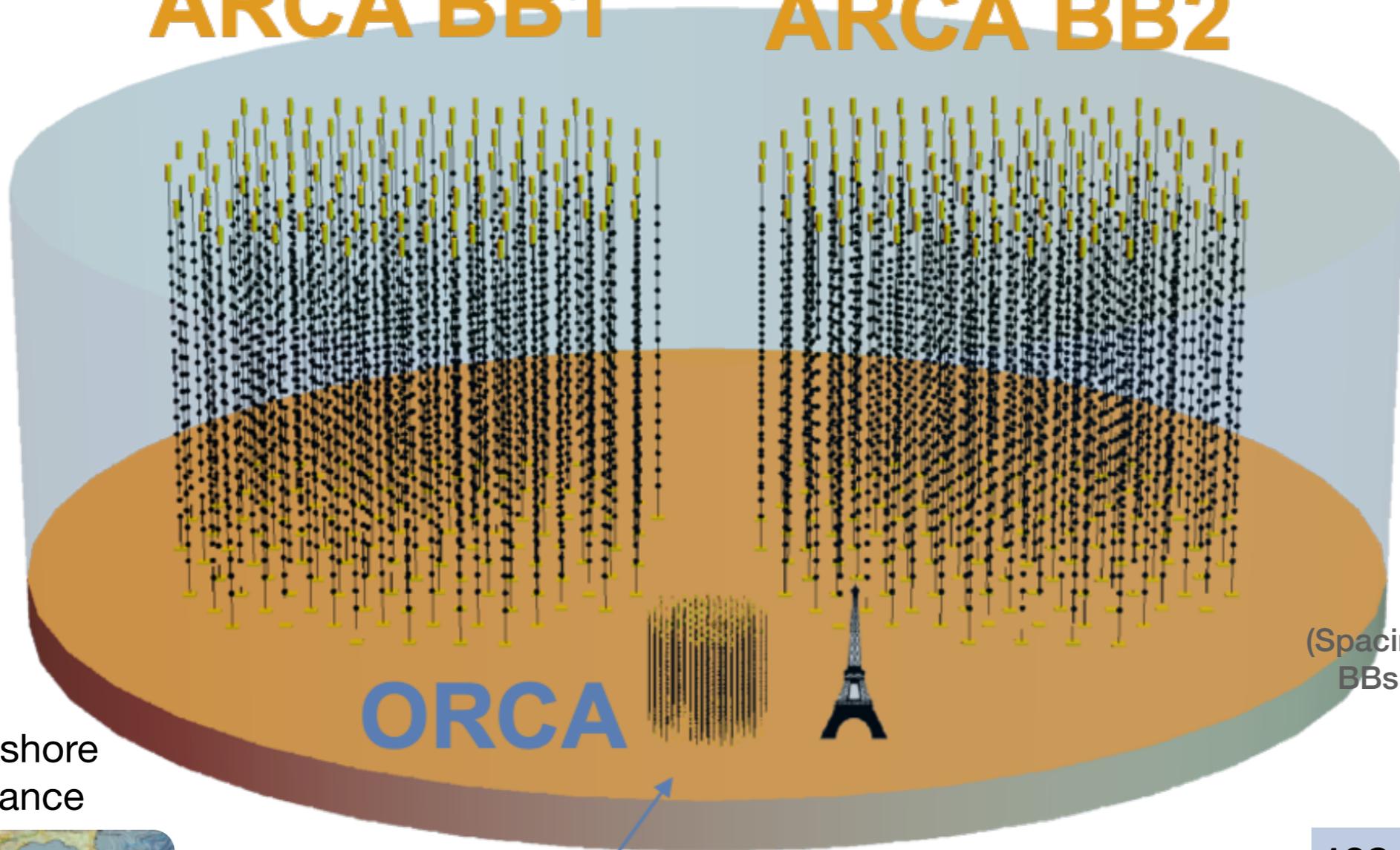
128340 PMTs

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

**ARCA BB1**   **ARCA BB2**

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

ARCA: off shore
Capo Passero, Italy

3400m   ARCA

**ORCA**

(Spacing between the 2 BBs is not at scale)

**O**scillation
**R**esearch
with **C**osmics
In the **A**byss

ORCA: off shore
Toulon, France

2475m   ORCA

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

108 detection units

1944 optical modules

60264 PMTs

# KM3NeT Technologies

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



197m

**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 Technologies



**Deployment**

Line are furled onto a launcher to be deployed

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

# 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**



KM3NeT Infrastructure

- 3 Installation sites
- 2 PMT preparation sites
- 8 DOM integration sites
- 9 base module integration sites
- 5 DU integration sites (DOM to VEOC)
- 3 DU test and preparation to deployment sites
- 4 electronic test & calibration centers

| 27-Jan-26 | ARCA | | | 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% |

# Some pictures

# Some pictures

# Some key numbers…

**Eléments**

- **ORCA:**
  - 108 DUs
  - ~2000DOMs
  - 4 Nodes
- **ARCA:**
  - 230 DUs
  - ~4100 DOMs
  - 17 Nodes
- 200 000 PMT
- ~1Millon de composants
- ~300 transports/an

**Coûts**

- DU:420k€
  - BM:35k€
  - 1xDOM:13k€
- Node:~850k€
- Transports: ~7k€/DU
- Déploiement: ~40k€/DU

**Durées**

- **Durées moyennes d'intégration  <u>par site</u>:**
  - 1xBM: ~1 mois
  - 1xDU: ~1 mois
  - 18xDOM: ~1,2 mois
- **Rythmes d'intégration <u>tout sites compris)</u>:**
  - 1xBM: ~0,5 mois
  - 1xDU: ~1 mois
  - 18xDOM: ~1,2 semaines

# Current situation of ARCA

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

**+ 2 JBs + 14 DUs + 2 replacements DU 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

**33 DUs deployed (1/4 of the full detector)**

**+ 2 sea science instrumented units**

**6 DUs to be deployed in April 2026**

**6 DUs to be deployed in October 2026**



**Current layout (1 building block)**



- **Stable data-taking efficiency ~92%**

- **So far, we have presented results of the ORCA6-11 dataset (~715 kt.yr)**

- **We are finalizing the analyses of ORCA15-18 dataset and prepared the ORCA23-24 dataset.**

# Current situation of ORCA

# LSPM: ORCA sea-floor infrastructure

- **1 shore station in La Seyne sur Mer**
- **1 power hut (1 /2 Power Feeding Equipments)**
- **2 deep-sea cables**
- **2 /4 nodes deployed and in operation**

- **1 Pre-BJS + 1 BJS**
- **Earth and Sea Science Equipments**

**+ strong links with INSU, Ifremer and EMSO**

# Calibration

| Quantity | Target |
|---------:|:-------|
| Position | < 20 cm |
| Orientation | ~ 5° |
| Timing | < 1 ns |
| PMT response | few % |

**Calibration in time, efficiency and position of the 2 detectors is a very challenging task.**

**Calibration is performed in multiple steps:**

- Dark room calibration to get a pre-calibration (with a laser)
- Dynamic orientation and acoustic positioning (acoustic emitters, compass/tilt)
- Inter-DOM and inter-DU time calibration (40K, atmospheric muons, nano beacons, laser)
- PMT gain and efficiencies (40K)
- Absolute pointing (Moon/Sun shadow, external acoustic source)

**Comparison static/dynamical positioning**

KM3NeT/ARCA30, preliminary



**Time calibration in dark box**

# Absolute pointing calibration

## Box-in method with RoV or vessel



- **Absolute positioning of reference beacons <1m**

- **Standard acoustic positioning calibration procedure**

## Moon/sun shadows





**ORCA6**

| Parameters | Moon 2D | Sun 2D |
|---|---|---|
| $\sigma_{res}$ | $0.49° \pm 0.15°$ | $0.65° \pm 0.13°$ |
| $A$ | $0.71 \pm 0.27$ | $1.31 \pm 0.34$ |
| $\Delta\chi^2_{H1/H0}$ | -21.3 | -43.0 |
| Significance | $4.2\sigma$ | $6.2\sigma$ |
| Events/$deg^2$ | 2892 | 3161 |

# KM3NeT Collaboration

**France**
- Centre de Physique des Particules de Marseille, Aix-Marseille Université, CNRS
- Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, CNRS
- Laboratoire Astroparticules et Cosmologie, CNRS, Université Paris Cité
- Laboratoire d'Astrophysique de Marseille, AMU, CNES, CNRS
- Laboratoire de Physique Corpusculaire de Caen, CNRS, Université de Caen
- Laboratoire Univers et Particules de Montpellier, CNRS, Université de Montpellier
- Institut Méditerranéen d'Océanologie, amU, CNRS, IRD, Marseille
- Université de Toulon, Chaire IA ADSIL, CIAN, CNRS
- Subatech, CNRS, IMT Atlantique, Nantes Université

**United Kingdom**
- University of Hull

**The Netherlands**
- NIOZ, Texel
- NWO-I, Nikhef, Amsterdam
- Universiteit van Amsterdam
- Universiteit Leiden

**Belgium**
- UCLouvain, Louvain-La-Neuve
- Université Libre de Bruxelles

**Germany**
- Friedrich-Alexander-Universität Erlangen-Nürnberg
- Max-Planck-Institut für Radioastronomie, Bonn
- Technische Universität München
- Universität Erlangen, Remeis Sternwarte, Bamberg
- Universität Würzburg
- Ruhr-Universität Bochum

**Italy**
- INFN Laboratori Nazionali del Sud
- INFN Sezione di Bari and Politecnico di Bari
- INFN Sezione di Bologna, Università di Bologna
- INFN Sezione di Catania, Università di Catania
- INFN Sezione di Firenze, Università di Firenze
- INFN Sezione di Genova, Università di Genova
- INFN Sezione di Napoli, Università di Napoli Federico II
- INFN Sezione di Padova, Università di Padova
- INFN Sezione di Roma, Sapienza Università di Roma
- Università della Campania L. Vanvitelli
- Università degli Studi di Salerno and INFN Gruppo Collegato di Salerno

**Norway**
- Norwegian University of Science and Technology in Trondheim

**Czech Republic**
- Czech Technical University in Prague, Institute of Experimental and Applied Physics

**Poland**
- AGH University of Krakow
- Nicolaus Copernicus Astronomical Center, Particle Astrophysics Science and Technology Centre, Warsaw

**Romania**
- Institute of Space Science - INFLPR Subsidiary, Magurele

**Slovakia**
- Univerzita Komenského v Bratislave
- Slovenská akadémia vied, Kosice

**Greece**
- Institute of Nuclear and Particle Physics, NCSR Demokritos, Athens
- National and Kapodistrian University of Athens

**Spain**
- Centro Oceanográfico de Murcia (IEO-CSIC)
- Instituto de Ciencias del Mar, CSIC, Barcelona
- Instituto de Física Corpuscular, Universitat de València, CSIC
- Laboratori d'Aplicacions Bioacústiques, Universitat Politècnica de Catalunya, Vilanova i la Geltrú
- Universitat Politècnica de València, IGIC, Gandia, València
- Universidad de Granada

**United States of America**
- Princeton University
- Drexel University, Philadelphia
- Harvard University, Cambridge

**Brazil**
- São Paulo State University - UNESP

**Morocco**
- Cadi Ayyad University, Marrakesh
- Mohammed VI Polytechnic University, Ben Guerir
- University Mohammed Ier, Oujda
- University Mohammed V, Rabat

**Finland**
- University of Turku

**China**
- Sun Yat-Sen University, Zhuhai

**Georgia**
- Tbilisi State University
- University of Georgia, Tbilisi

**India**
- Indian Institute of Technology in Mumbai

**Algeria**
- Université Badji Mokhtar, Annaba

**South Africa**
- North-West University, Potchefstroom
- University of Johannesburg
- University of the Witwatersrand, Johannesburg

**United Arab Emirates**
- Khalifa University of Science and Technology, Abu Dhabi
- University of Sharjah

**Australia**
- Western Sydney University

## KM3NeT Collaboration
### 5 continents, 24 countries, 68 institutes

**KM3NeT**

- Full members
- Observer members

# KM3NeT organigram

**Governance & Oversight**

**AISBL Council**
Chair and Director: *N. Leroy*

**Scientific and Technical Advisory Committee**
Chair: *C. Timmermans*

**Institute Board**
Chair: *A. Kouchner*

**Publication Committee:** *A. Margiotta, E. Tzamariudaki*
**Conference Committee:** *C. Markou*
**Outreach Committee:** *M. Circella, TBD*
**Open Science Committee:** *J. Schnabel*
**Early Career Scientists:** *A. Bariego Quintana, TBD*

**Executive Management**

**AISBL Executive Board**

**Management Team**

AISBL Director:
N. Leroy

*Spokesperson/Chair:* P. de Jong
*Deputy Spokesperson:* D. Dornic          *Site Manager KM3NeT-Fr:* N. Lumb
*Technical Project Manager:* A. D'Amico   *Site Manager KM3NeT-It:* R. Cocimano
*Physics & Software Manager:* R. Coniglione  *Site Manager KM3NeT-Gr:* C. Markou

**Equality, Diversity, Inclusion Committee**
*V. Van Elewyck, E. Tzamariudaki*

## Science Steering Committee
**Chair: R. Coniglione**
**Astronomy:** *G. Illuminati, M. Lamoureux, A. Marinelli*
**Calibration:** *V. Pestel*
**Cosmic Rays:** *R. Bruijn, A. Romanov*
**Dark Matter/Exotics:** *A. García-Soto, S. Gozzini*
**Oscillations:** *J. Brunner, V. Carretero Cuenca*
**Processing/Data-Quality:** *F. Badaracco, F. Filippini, C. Lastoria*
**Simulations:** *C. Distefano, L. Fusco,*
**Software/computing:** *L. Aphecetche,*
          *R. Bruno, J. Schnabel*

## Project Office
**Chair: A. D'Amico**
**Project Control Officer:** *TBD*
**Procurement Manager:** *M. Circella*
**Procurement Officer:** *S. Lancelin*
**QA/QC Manager:** *C. Vérilhac*
**QA/QC Officer:** *L. Morales Gallegos*
**R.A.M.S Manager:** *S. Colonges*
**R.A.M.S Software:** *TBD*
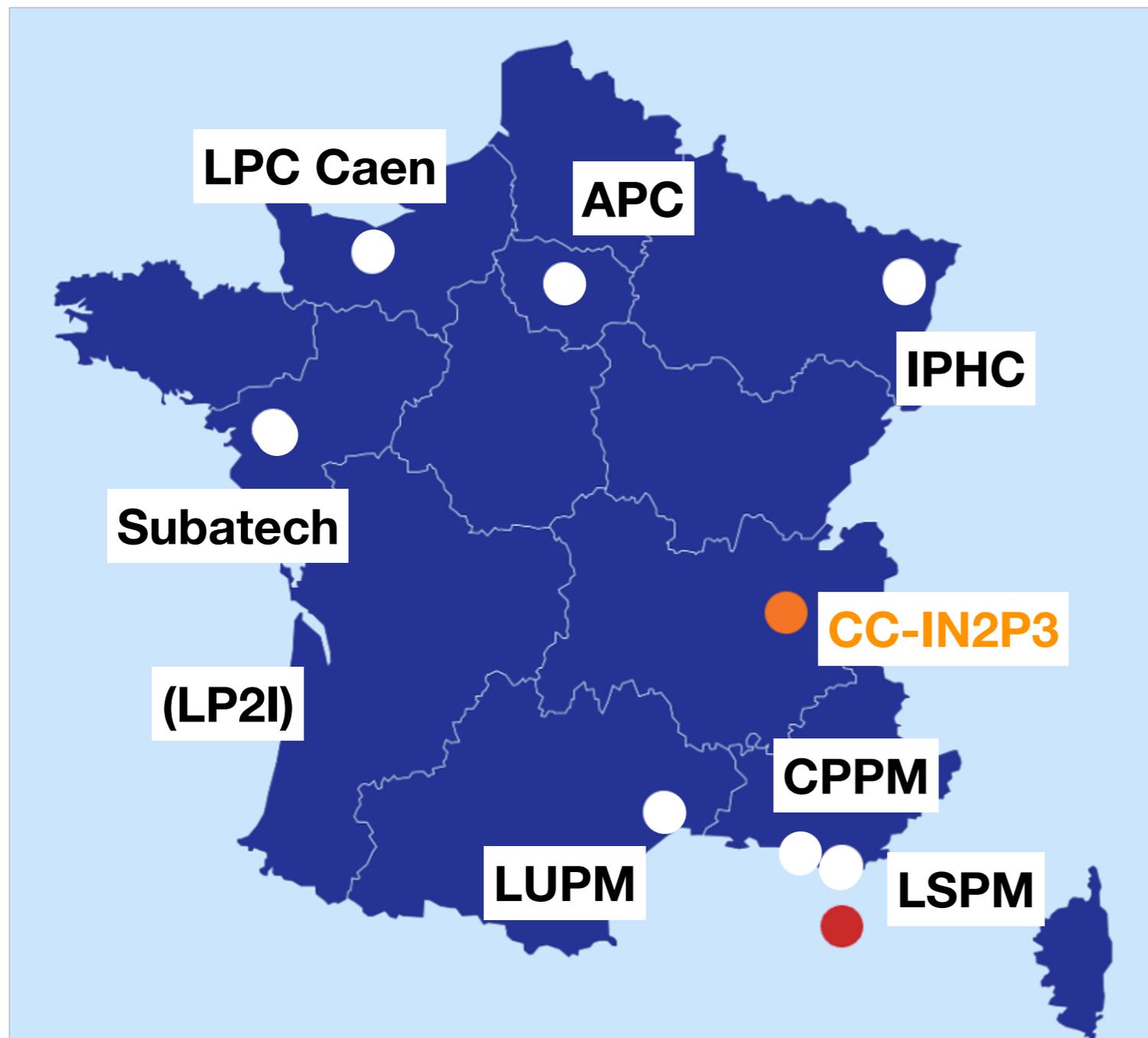**System Engineer:** *S. Henry,*
          *M. Lindsey Clark*

## Technical Steering Committee
**Chair: P. de Jong/A. D'Amico**

| | |
|---|---|
| **Calibration Hardware:** *D. Vivolo* | **BM integration:** *I. Sgura* |
| **DAQ:** *E. Giorgio, F. Benfenati* | **DOM integration:** *E. Leonora,* |
| **Det. operations**: *A. Enzenhöfer, P. Piattelli* | *C. Poiré\*, Y. Roy\** |
| **Electronics**: *D. Calvo, D. Real\** | **DU integration:** *A. Marini, C. Mollo* |
| **Mechanics:** *A. Ilioni, E. Berbee\** | **DB manager:** *C. Bozza* |
| **Optics:** *J-W. Schmelling, S. Pulvirenti\** | |
| **PMT:** *A. Simonelli* | |
| **Power:** *C. Nicolau, D. Bonanno\** | |
| **Software/computing:** *L. Aphecetche,* | |
| *R. Bruno, J. Schnabel* | *\*deputy coordinator* **30/01/2026** |

# KM3NeT France



**LPC Caen**

**APC**

**IPHC**

**Subatech**

**CC-IN2P3**

**(LP2I)**

**CPPM**

**LUPM**

**LSPM**

<u>7 Laboratories @ IN2P3:</u>

**APC, CPPM, IPHC, LPC-Caen, LSPM, LUPM, Subatech (+LP2I)**

**In 2025, 102 persons for 65 ETP**

**~57 scientific persons (34 ETP)**

**~45 technical persons (31 ETP)**


# KM3NeT France responsabilities

| Laboratoire | ETP (S/T) | Technical responsibilities | Scientific responsibilities | Management responsibilities |
|---|---|---|---|---|
| APC | 5.9/3.8 | Mechanics WG convener<br>RAMS Manager<br>System Engineer<br>Calibration Base<br>QA/QC Manager | Astronomy WG convener<br>Oscillation WG convener (former) | ANTARES Spokesperson<br>KM3NeT IB Chair<br>EDI Committee Chair<br>Technical Project Manager (former) |
| CPPM | 3.6/14.2 | Procurement Officer<br>System Engineer<br>Detector Operation Manager ORCA<br>DU Integration WG convener<br>ORCA Marine Operation<br>ORCA seafloor infrastructure<br>ORCA seafloor infrastructure operation<br>ORCA BM integration<br>DU anchor integration<br>Acoustic Positioning<br>ORCA shore station manager<br>Instrument Unit<br>Radioactivity detector<br>MECMA contact person | Oscillation WG convener<br>Astronomy WG convener (former)<br>Online Physics Analysis WG convener | ORCA Site Manager<br>KM3NeT Deputy Spokesperson<br>KM3NeT Spokesperson (former)<br>KM3NeT-Fr Scientific Resp.<br>KM3NeT-Fr Technical Resp.<br>LSPM Director<br>ANTARES Technical Manager<br>CZAR CC-IN2P3 |
| IPHC | 0.8/2.0 | DOM integration | | |
| LPC Caen | 3.0/1.5 | DU integration | Calibration WG convener<br>DPDQ WG convener<br>CR WG convener<br>Software & Computing WG convener (former) | CZAR CC-IN2P3 |
| LUPM | 0.1/1.0 | BM integration | | |
| Subatech | 3.5/3.5 | DOM integration<br>DOM integration WG convener<br>BM integration (until end 2026) | Software & Computing WG convener | |

# Actual funding situation

**For ORCA:**

* Secured budget for the upgrade of the sea-floor infrastructure (2 nodes + branching unit + upgrade PFE + shore station equipment). CPER NEUMED

* Secured budget for 94/108 detection units (CNRS + NWO + INFN)

**For ARCA:**

* Secured budget for the upgrade of the sea-floor infrastructure: 12/15 nodes + + shore station equipment

* Secured budget for ~150/230 detection units (mostly INFN+regions)

# 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

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

## Atmospheric neutrinos

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

## Cosmic neutrinos

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

# Science cases with KM3NeT



Cosmic Rays

Astrophysics

Neutrino Physics

**KM3NeT**
*Opens a new window on our universe*

Complementarity of ORCA and ARCA
on all topics

Dark Matter

Earth and Sea

# Combinaison ORCA+ARCA

One of the main advantage of KM3NeT is the complementarity between ORCA and ARCA to have the best discovery potential in a very large energy range



| Scientific Topic | ORCA | ARCA |
|---|---|---|
| Cosmic sources | ⭐⭐ | ⭐⭐⭐⭐ |
| CCSN (Core-Collapse Supernovae) | ⭐⭐⭐ | ⭐⭐⭐ |
| Oscillation parameters | ⭐⭐⭐⭐ | ⭐ |
| Mass hierarchy | ⭐⭐⭐⭐ | ⭐ |
| Sterile neutrinos | ⭐⭐⭐ | ⭐⭐ |
| Beyond the Standard Model (BSM) | ⭐⭐ | ⭐⭐⭐ |
| Dark matter | ⭐⭐⭐ | ⭐⭐⭐ |
| Cosmic rays | ⭐⭐ | ⭐⭐⭐ |

# Cosmic rays

**Very large atmospheric muon sample:**

- Atmospheric muon parametrization using the Daemon flux data-driven model
- Measure the water properties with stopping muons
- Prompt component in atmospheric muon analysis
- Measurement of the cosmic rays anisotropy
- Seasonal variation of atmospheric muons
- Measurement of the atmospheric neutrino spectrum

# Dark matter at Galactic Center

**Analysis for WIMP Dark Matter annihilation:**

○ **Competitive upper limits for ARCA19-21**

○ **New sensitivities for ARCA230 (1y and 5 y)**

○ **New sensitivities for ORCA6-11**



WIMP WIMP → $\tau^+ \tau^-$



**KM3NeT Preliminary**

ORCA-6/10/11 (755 days)

ARCA-19/21 (336 days)

ARCA-230 (1 y)

ARCA-230 (5 y)

$\langle \sigma v \rangle$ $[cm^3 s^{-1}]$

$m_{DM}$ $[GeV/c^2]$

Upper Limits:
- H.E.S.S. 2014-2020 (Einasto)
- Fermi-LAT (DSph., NFW)
- MAGIC (DSph., NFW)
- VERITAS (DSph., NFW)
- HAWC (Galactic Halo, Burkert)
- IceCube 5 years (NFW)
- ANTARES (4532 days, NFW)

Sensitivities (90% CL):
- ARCA-19/21 (336 days, NFW)
- ARCA-230 (1 yr, NFW)
- ARCA-230 (5 yrs, NFW)
- ORCA-6/10/11 (755 days, NFW)

**Competitive results for the Sun**

# Publications



The international journal of science / 13 February 2025

**nature**

**COSMIC CATCHER**

Deep-sea telescope detects neutrino with highest energy ever recorded
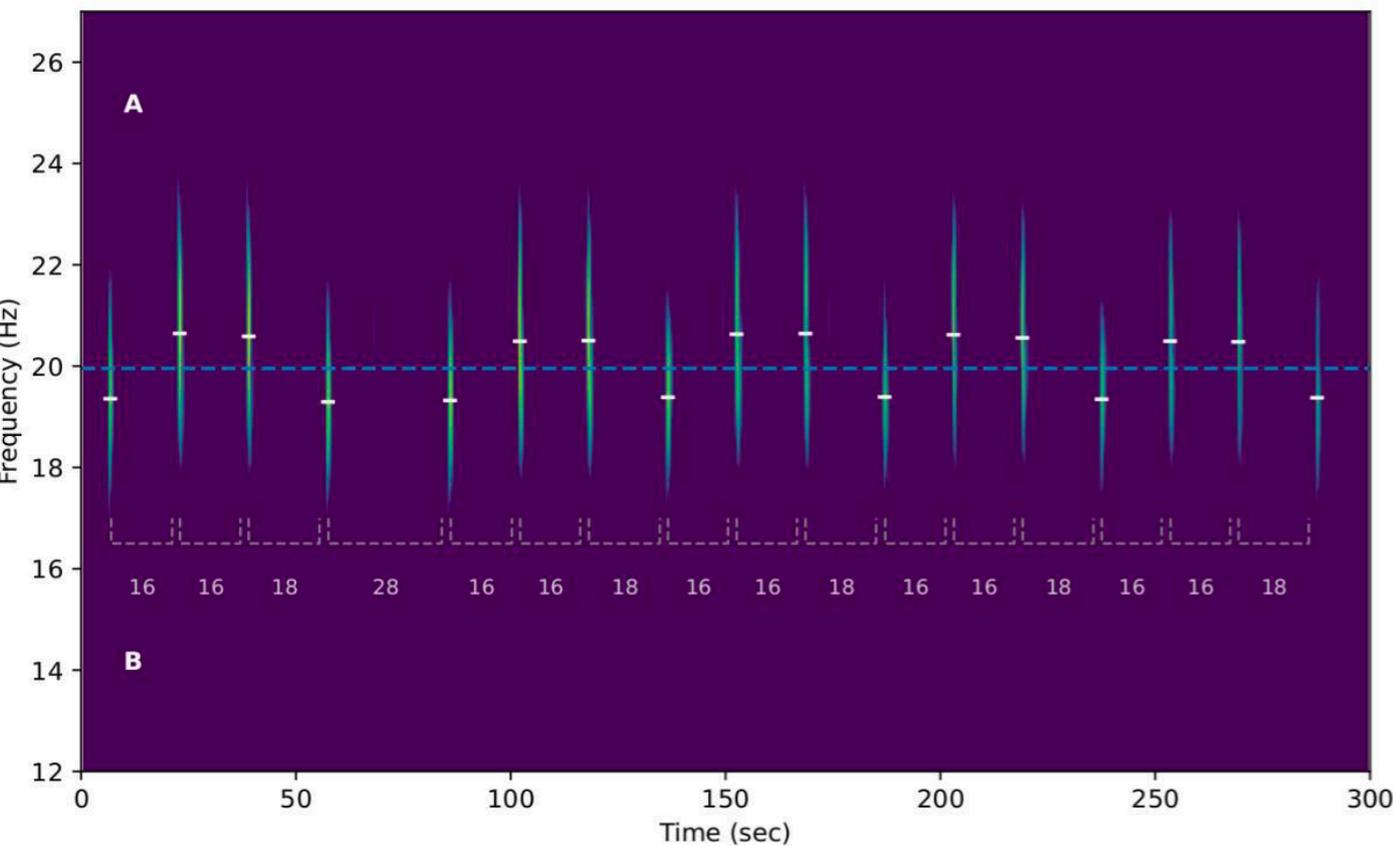
# Earth and Sea Science

**Long-term monitoring of the sea water properties:**

- **M2II (INSU) and IU (CPPM) connected to LSPM**

- **ALBATROSS mooring line (MIO/INSU)**

- **Large array of high precision temperature sensors (NIOZ-Netherlands)**
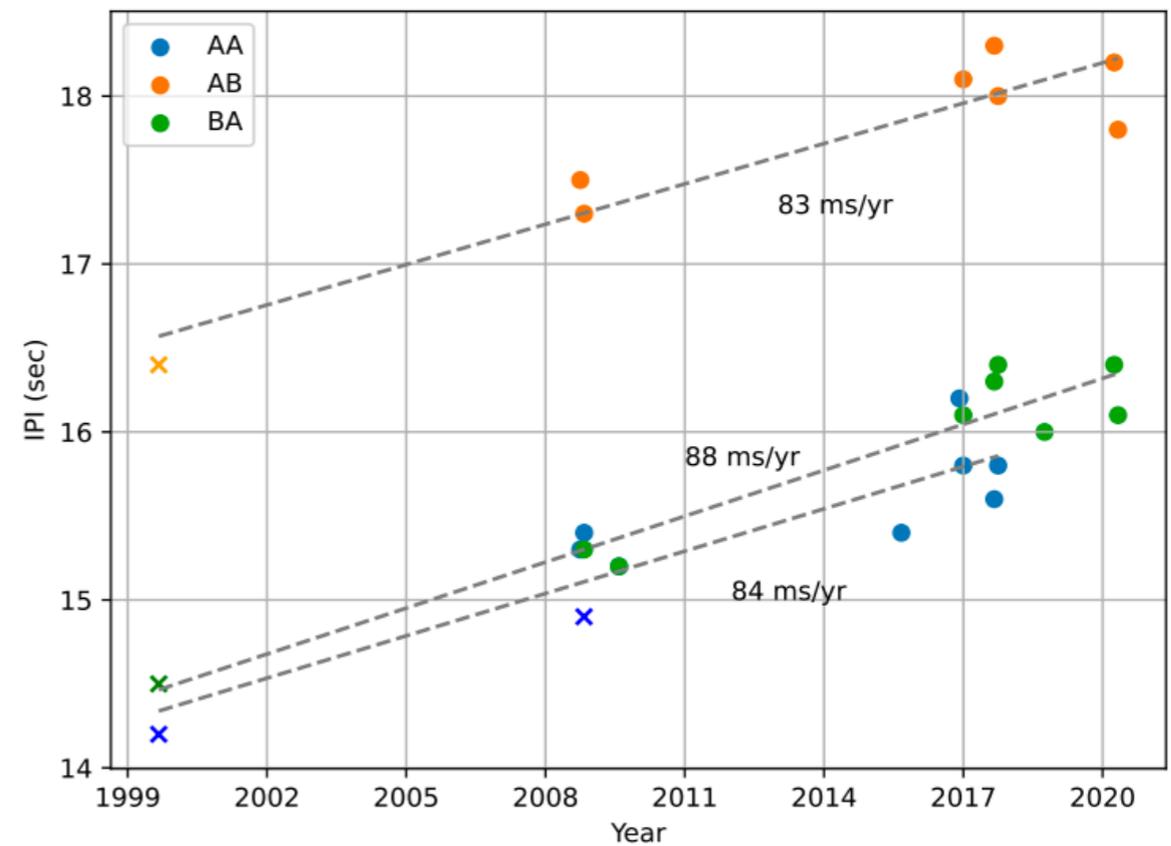
- **Germanium gamma-ray spectrometer (CPPM)**

- **KM3NeT optical modules**

# Earth and Sea Science

- **BathyBot/BathyReef benthic crawler (MIO/INSU) to survey the deep-sea marine life**
- **A stereo biocamera system (IP2I-Lyon) to detect faint bioluminescence animals**
- **The KM3NeT acoustic beacons/piezos to detect and monitor the bio-acoustic signals from Cetaceans**
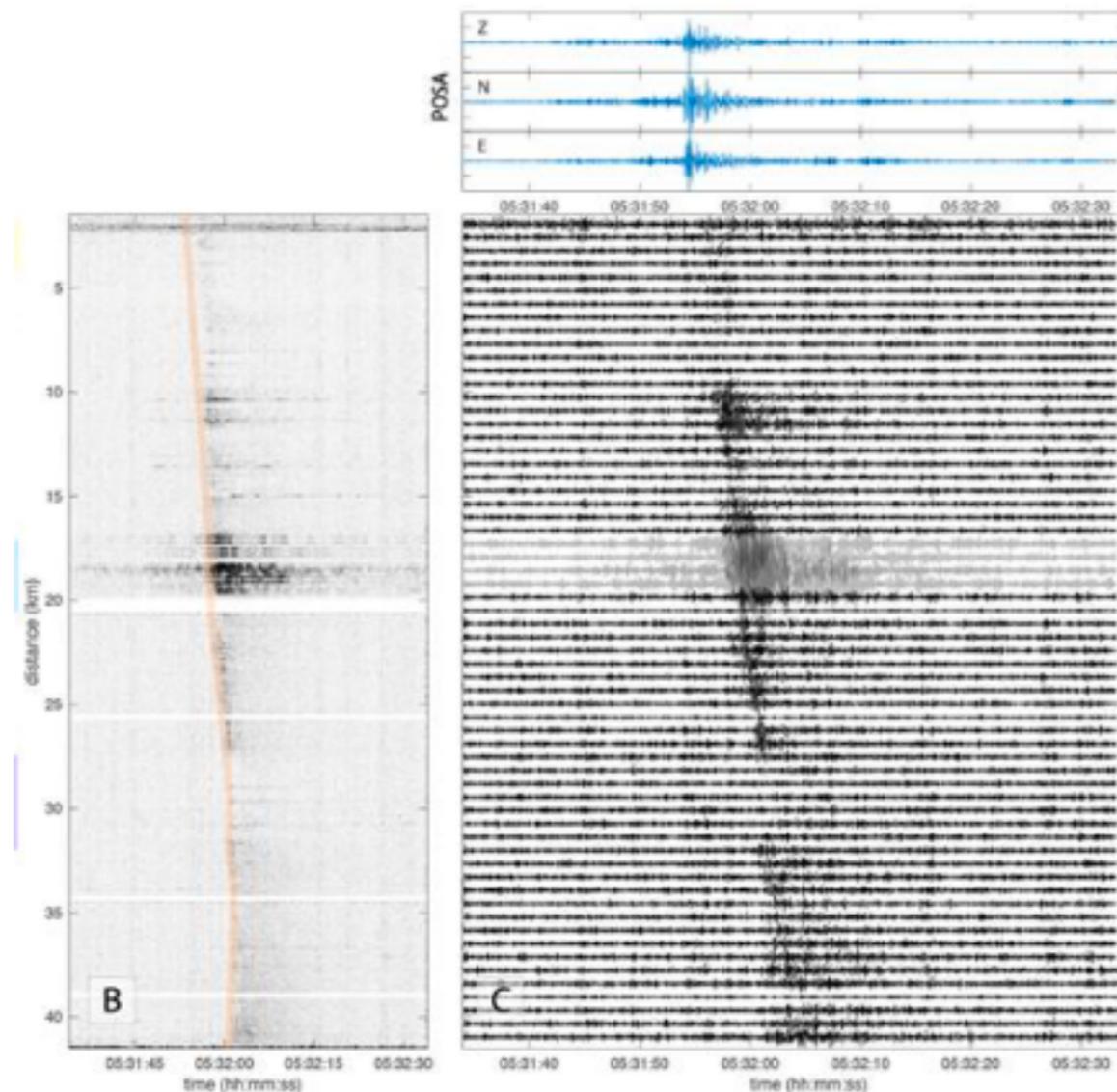


*Spectrum chant sur 20 ans*
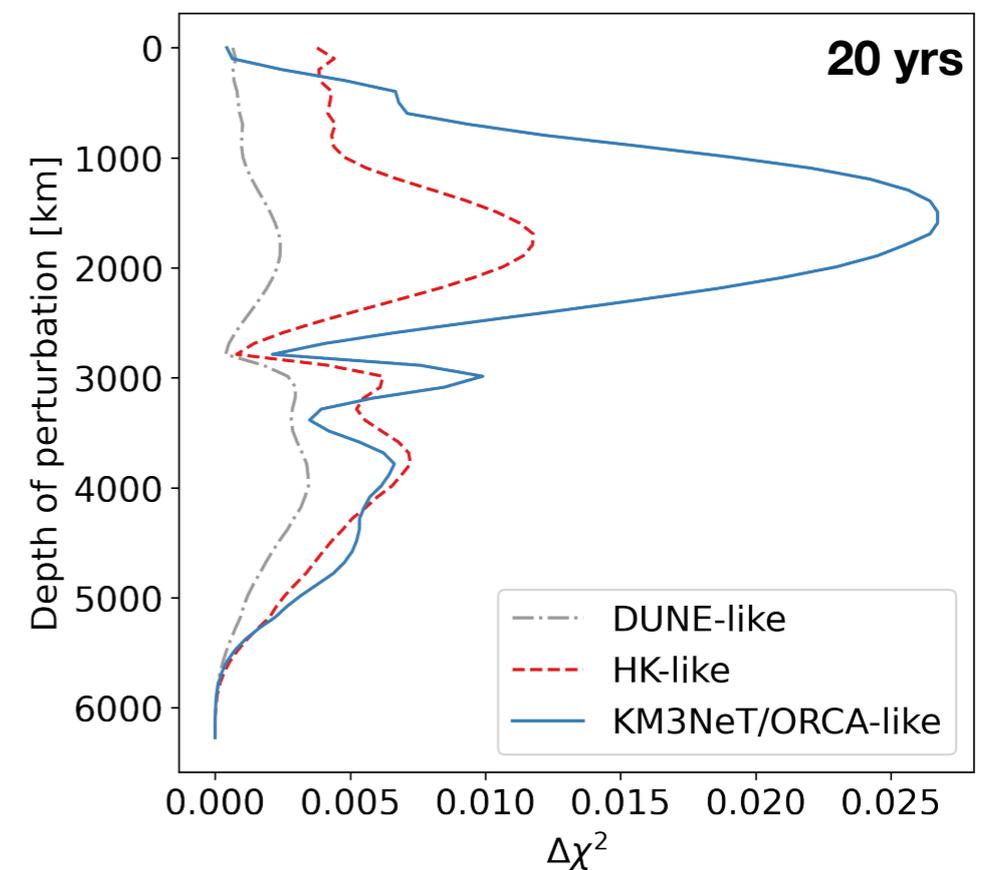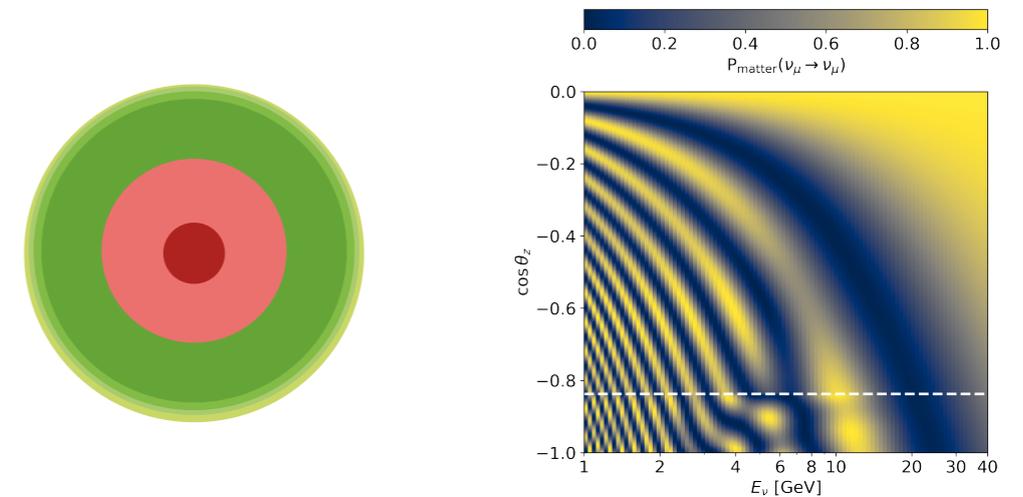
*Evolution du chant sur 20 ans*

# Earth and Sea Science

**Distributed Acoustic Sensing (DAS) laser system, tested on the some unused fibres of main electro-optic cable (with Alcatel and GeoAzur-Nice/INSU)**

**Probing the Earth's interior with neutrino oscillation tomography (APC / IPGP / LGL-TPE / Idaho Univ.)**



*A Magnitude 1.9 earthquake near Frejus (DAS)*

# Summary

**KM3NeT telescope is currently under construction but already taking data with partial configurations. ARCA: 51 lines, ORCA: 28 lines (completion in 2030-32)**

**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 $E_v > 100$ 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 lot of diverse ESS studies