RICAP-24
International Conference
on Astroparticle Physics

23-27 Sep 2024, Frascati (Rome)

ANTARES recent results

G. Ferrara

on behalf of the ANTARES Collaboration

DIPARTIMENTO DI FISICA E ASTRONOMIA "ETTORE MAJORANA"

SICILIAE STVDIVM GENERALE 1434 — UNIVERSITÀ degli STUDI di CATANIA

INFN LNS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

ANTARES

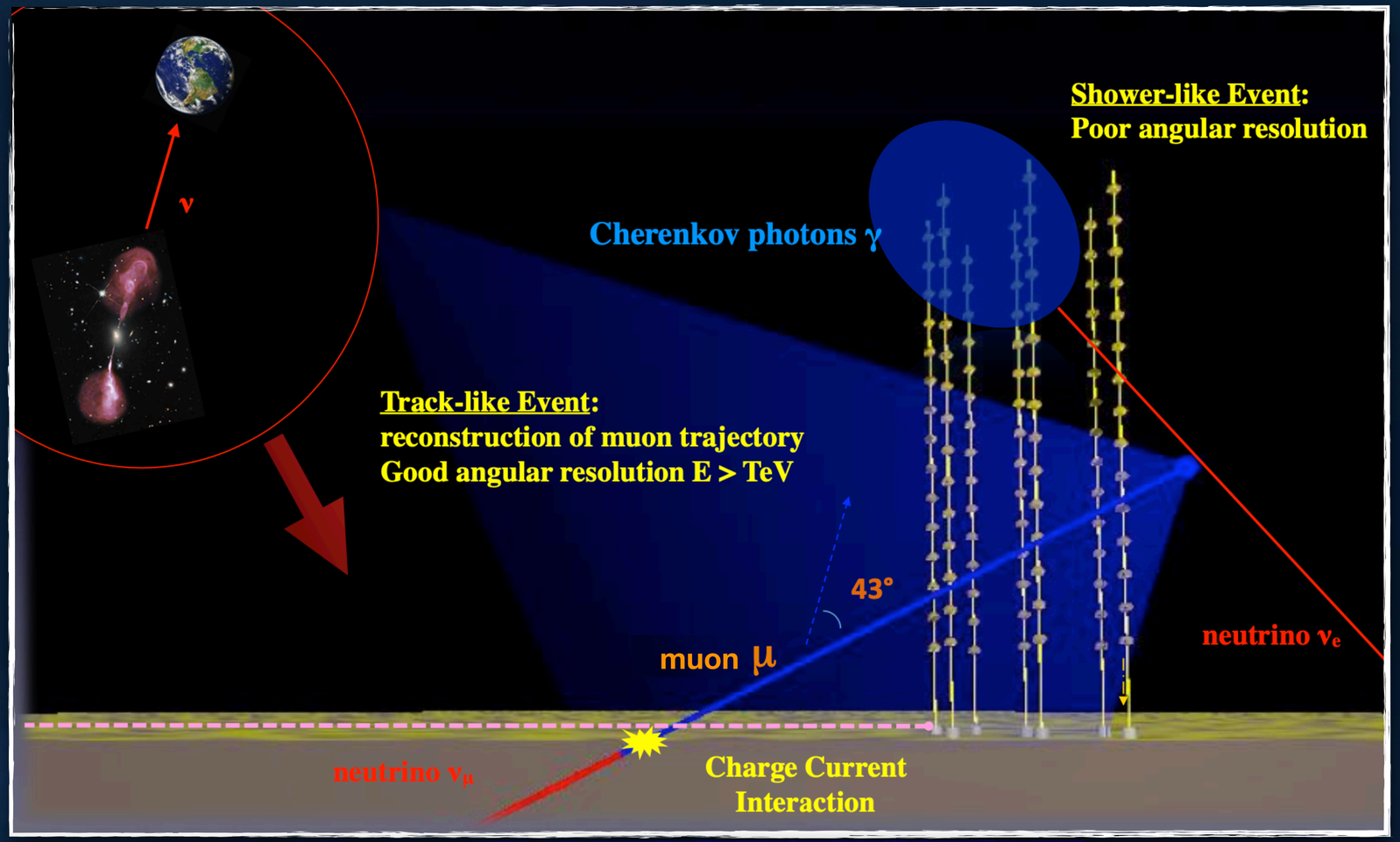
Cosmic neutrino detection principle

- Neutrinos: neutral, stable, weakly interacting

  - not absorbed by background light/CMB (access to cosmological distances)
  - not absorbed by matter (access to dense environments)
  - not deviated by magnetic fields (astronomy over a wide energy range)

- 'Smoking gun' signature for hadronic processes

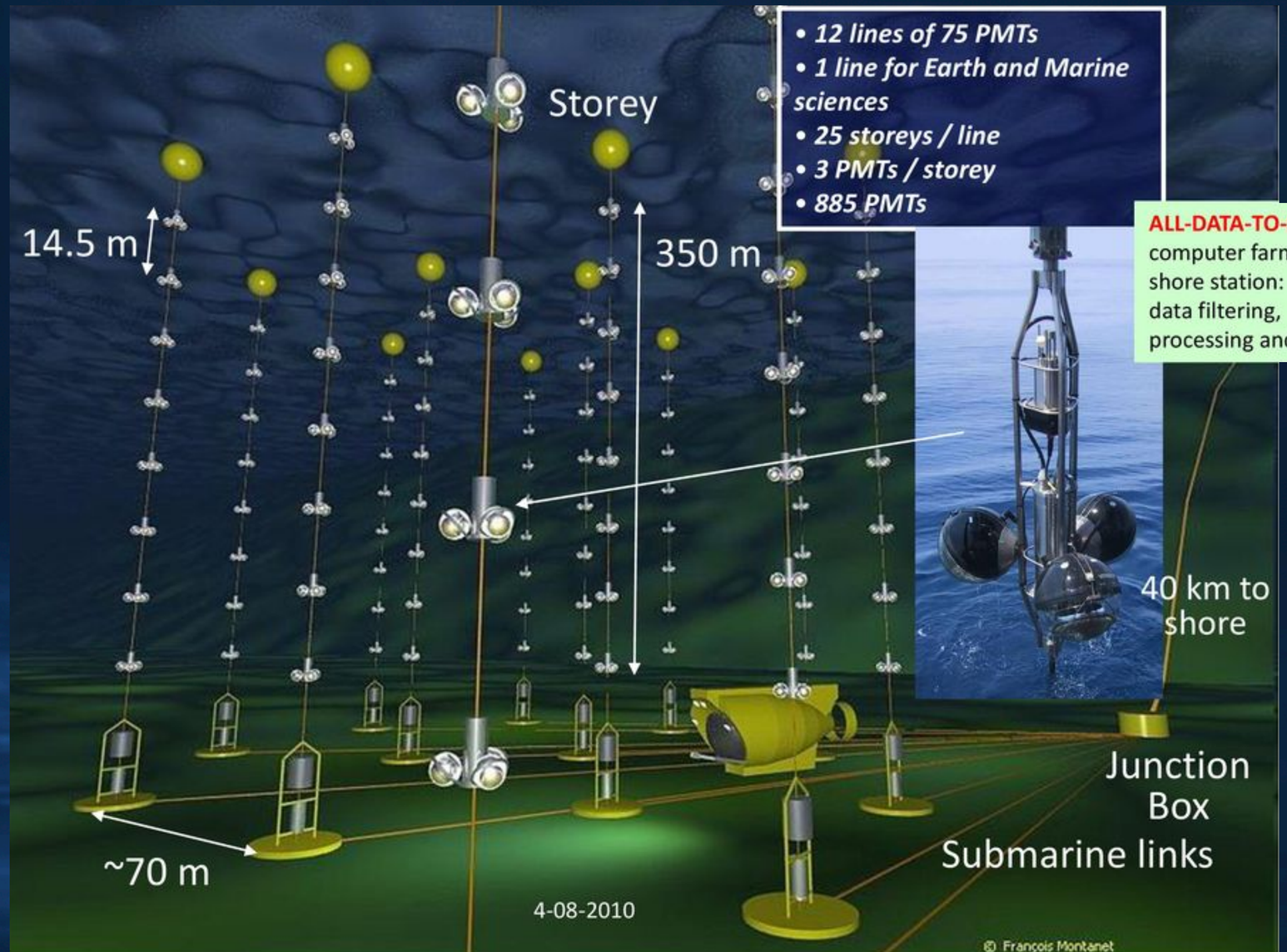
- Correlated in time/direction with electromagnetic and gravitational waves: Multi Messenger Astronomy



- Detection of Cherenkov photons induced by the neutrino interaction products using a 3D array of optical sensors
- Large volume of transparent medium to detect cosmic neutrinos ⟶ water/ice
- Time, position and amplitude of PMT pulses (hits) allow both direction and energy reconstruction

The ANTARES detector

Astronomy with a Neutrino Telescope and Abyss environmental RESearch



Scientific goals:

- *Search for TeV-PeV neutrino sources in the Universe*
- *Dark Matter searches*
- *Multimessenger observations*
- *Neutrino oscillation studies*
- *Beyond the SM: Sterile Neutrinos*
- *Exotic particles*

1997 Proposal

2001 Main Electro-Optical Cable deposition

2002 Junction box deployment

2003 Prototype Sector Line - First data

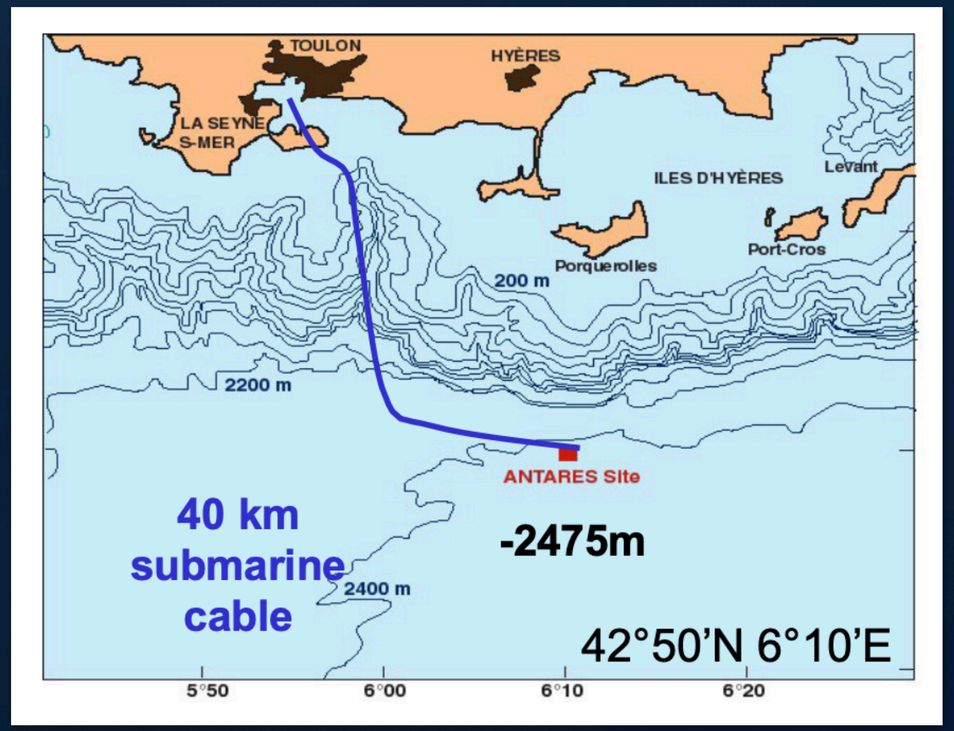
2005 Mini Instrumentation Line with OMs - environmental data

2006 First complete detector line

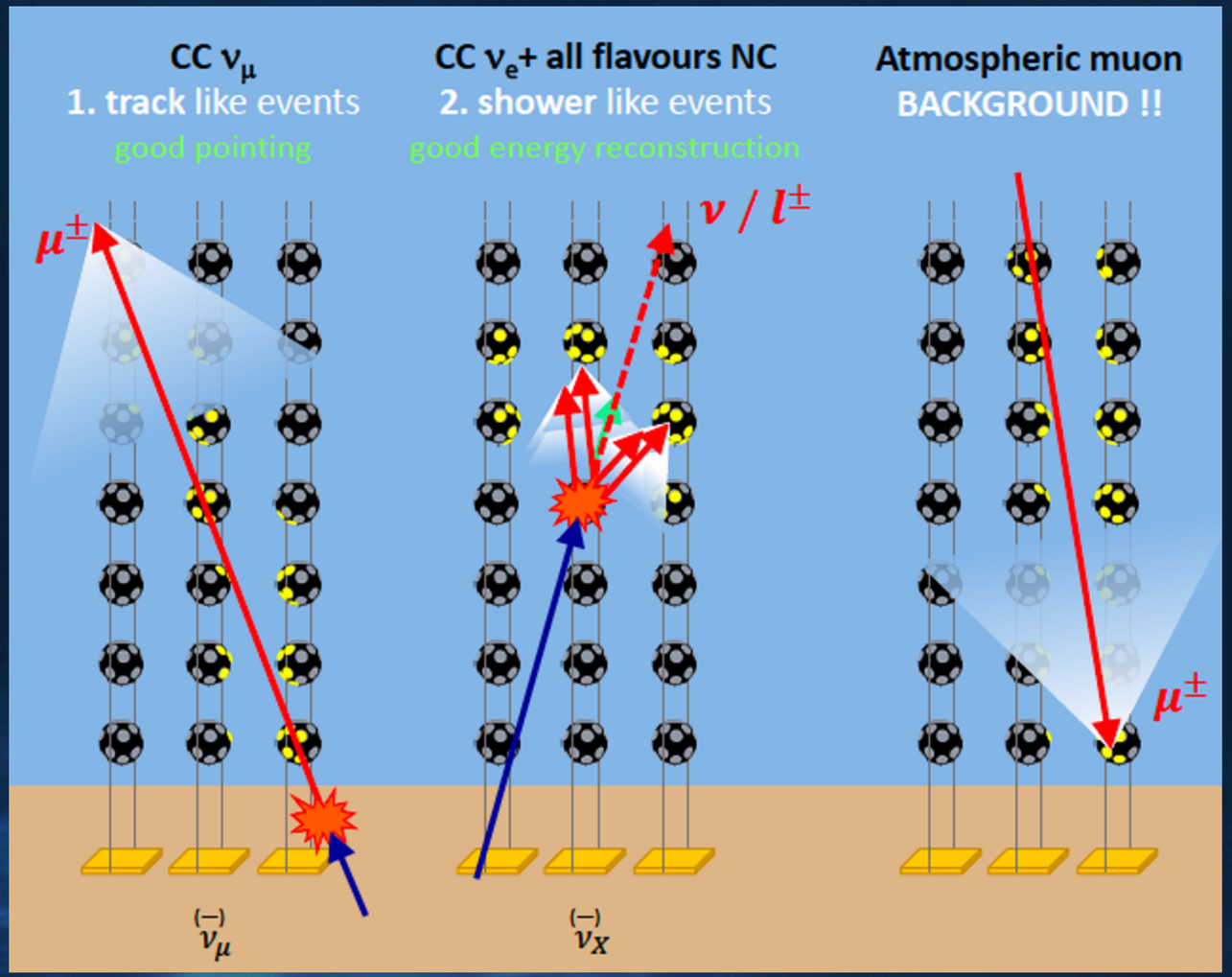
2008 Detector with 12 lines completed - complete configuration

February 2022 Data taking terminated

The ANTARES site



Event topologies and reconstruction performances

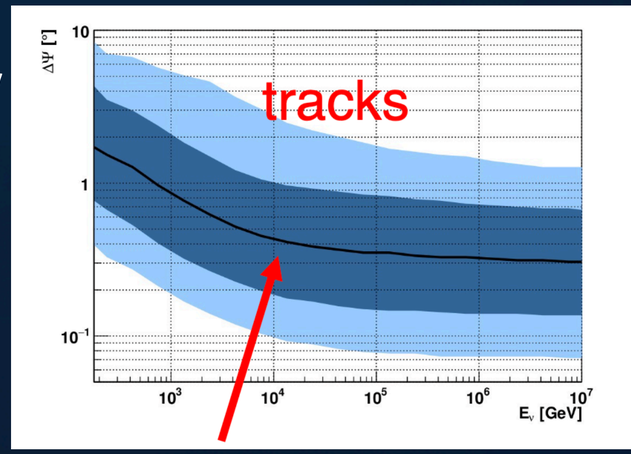


▸ ***track channel*: the golden channel for source identification**

Upgoing track events ($\nu_\mu CC$)

Angular resolution < 0.4° for E > 10 TeV

Energy resolution ~ factor 2



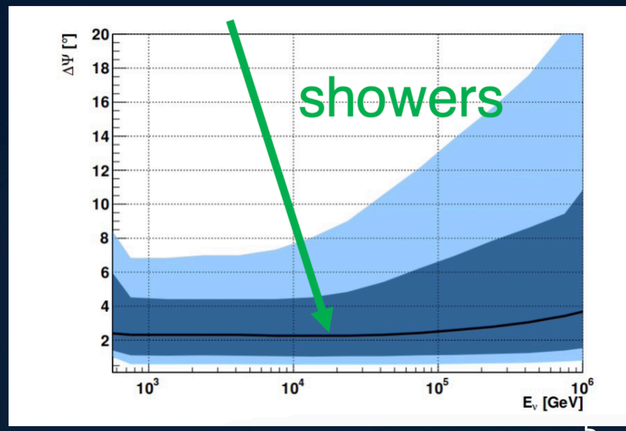
Median resolution

▸ ***shower channel*: good energy resolution**

Upgoing shower events ($\nu_{e,\tau} CC, NC$)

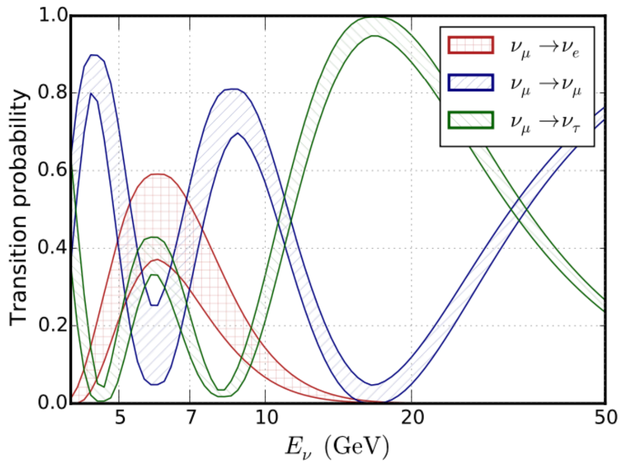
Angular resolution < 4° for E > 10 TeV

Energy resolution better than 10%

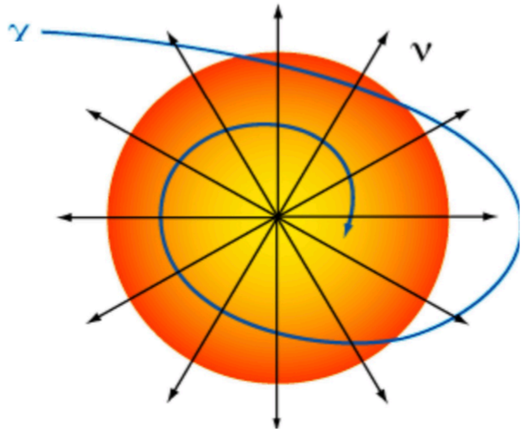


ANTARES science with a multi-energy scale

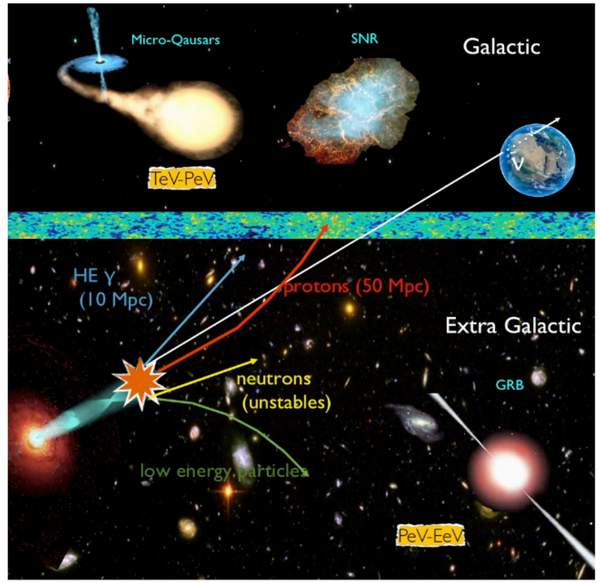
Neutrino: undeflected and unabsorbed ⟶ excellent probes



Low Energy
> 10 GeV



Medium Energy
10 GeV < E_ν < 10 TeV



Galactic → Extragalactic
High Energy, E_ν > TeV → PeV

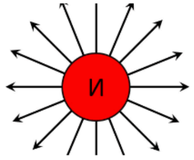
Energy

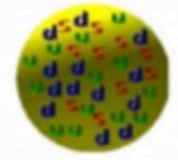
ν Oscillations

Dark matter search

ν from cosmic sources
origin and production
mechanism of HE CRs

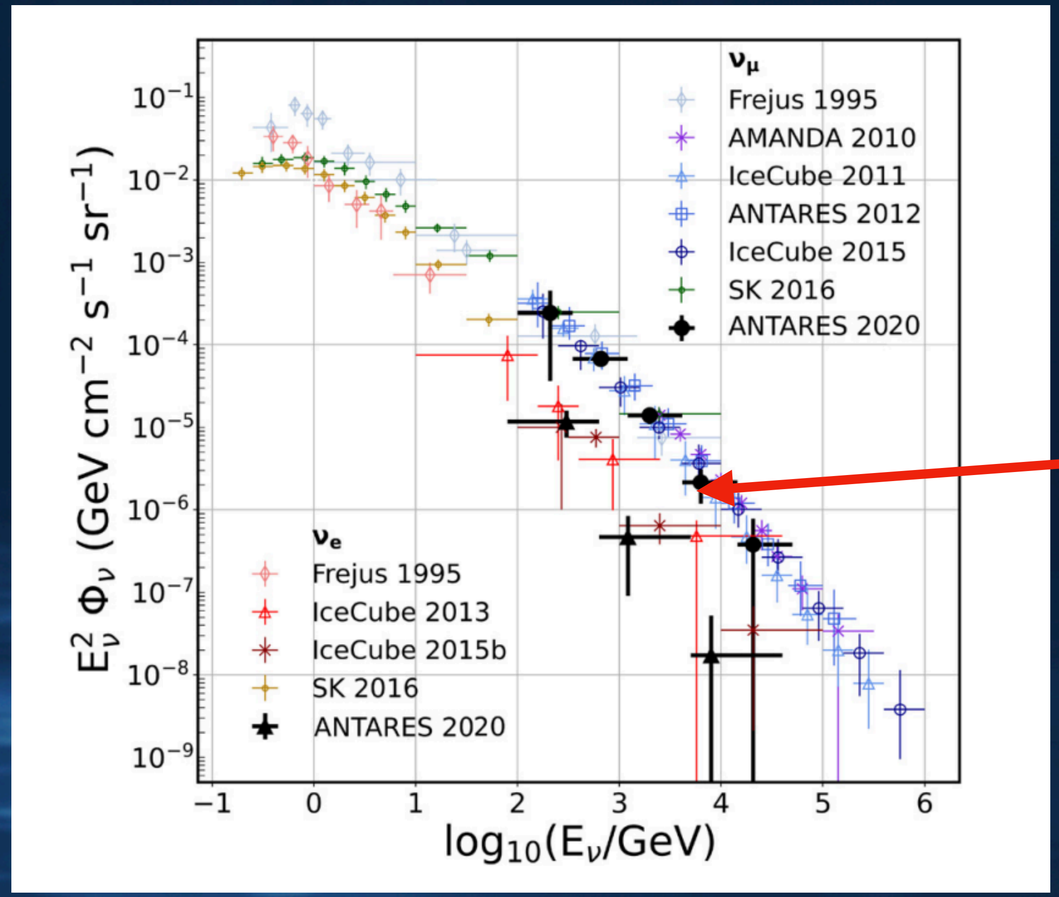
+ Exotic searches - Nuclearites, Magnetic monopoles...



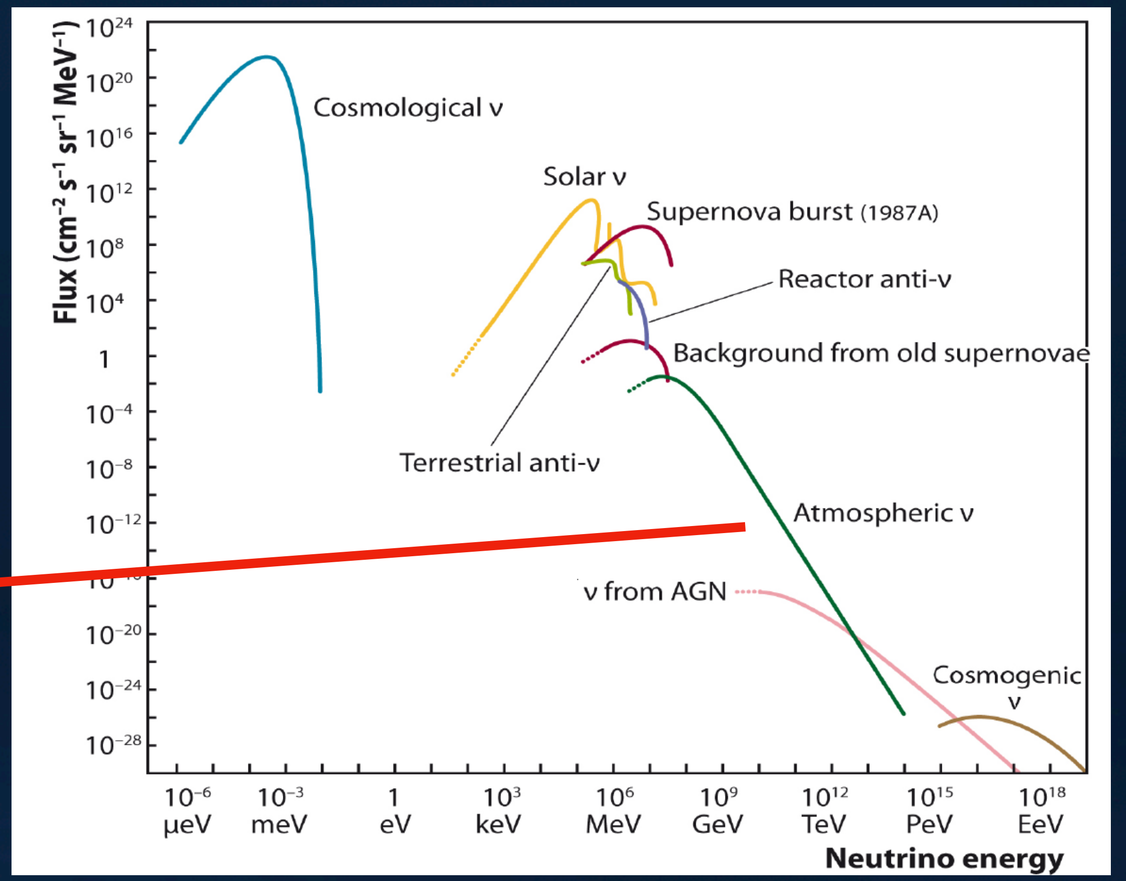


Atmospheric neutrino background

Energy estimator accounts for detector systematics



Atmos-to-Cosmic transition 30-200 TeV



📖EPJ 73: 2606 (2013),

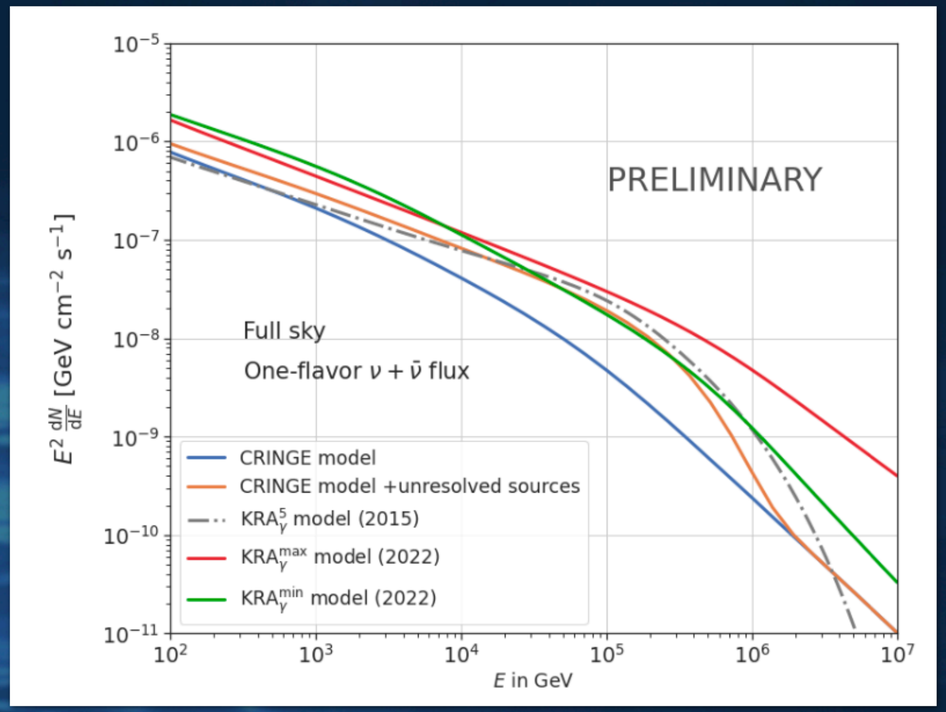
📖PLB 816: 136228 (2021)

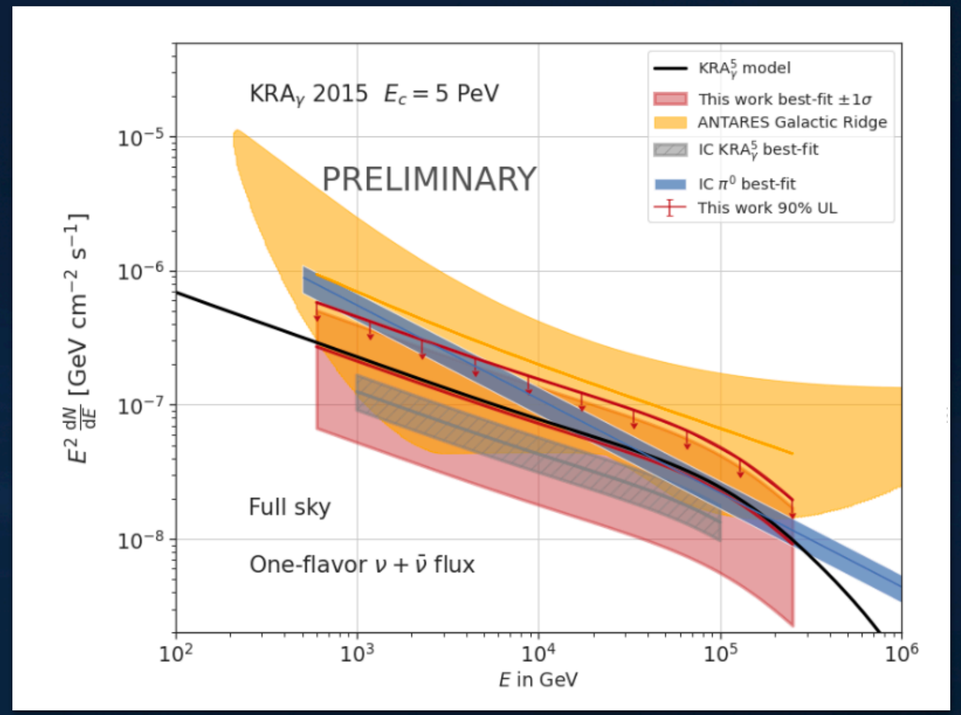
Search for a diffuse neutrino emission from the Milky-Way with ANTARES

(Diffuse flux of cosmic neutrinos see L. Fusco's talk)

- Data sample (2007-2020)
- 7500 track-like and 1145 shower-like events selected (quality cuts /Neural Network and Boosted Decision Tree classifiers)
- Models of neutrino emission, KRAγ / CRINGE
- Unbinned likelihood method
- The higher significance: KRA5γ with a post-trial p-value 1.7 σ

📖 ICRC (PoS(ICRC2023)1084/1103





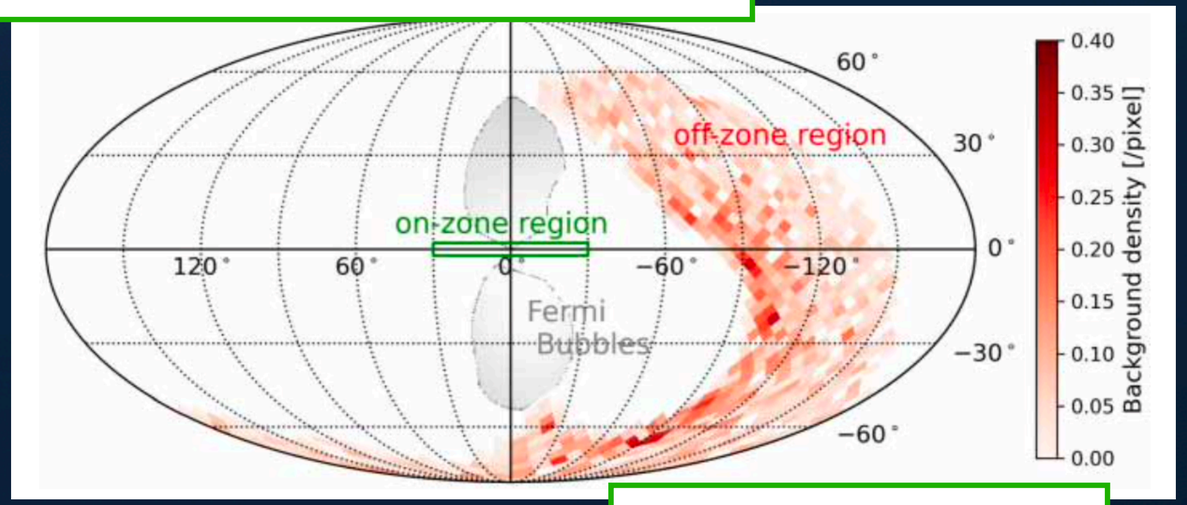
Physics Letters B 841 (2023) 137951

Flux from the Galactic Ridge

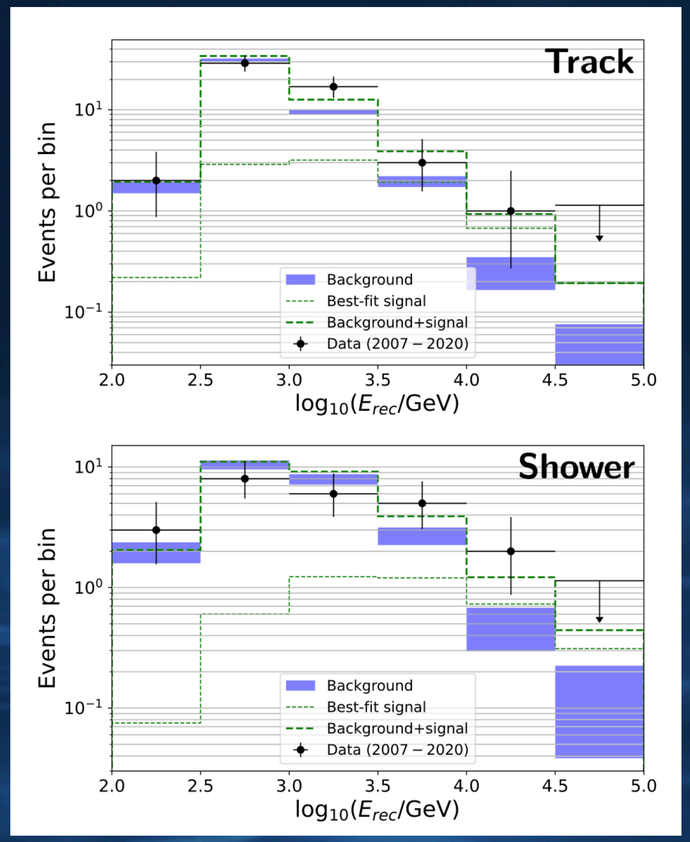
- neutrino signal expected from the Galactic Ridge (1-100 TeV)
- Data sample (2007-2020) 7500 track-like/ 1145 shower-like events selected (quality cuts)
- ON/OFF approach
- ν from a power-law energy spectra with spec. Index in [1, 4]

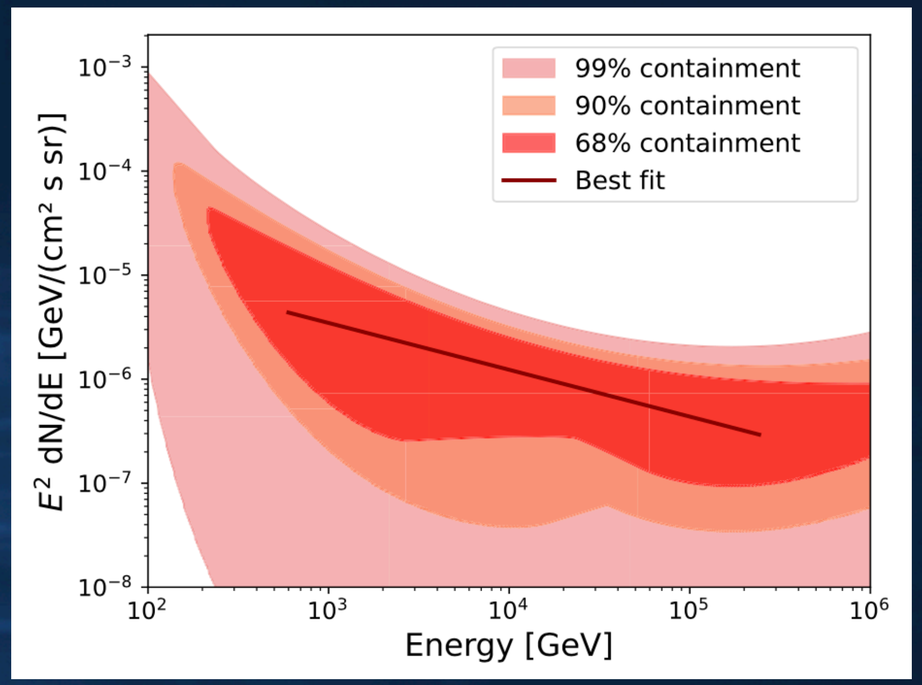
Galactic ridge region:

$|l| < l_{ridge} \approx 30\text{-}40°$ and $|b| < b_{ridge} \approx 2\text{-}3°$



Simple approach ON/OFF





Number of events above 1 TeV: 21 tr (13 sh)

Expected background: 11.7 ± 0.6 (11.2 ± 0.9)

Background rejection significance of 98% (56%)

corresponding to 2.2 σ (0.2 σ) one-tailed excess

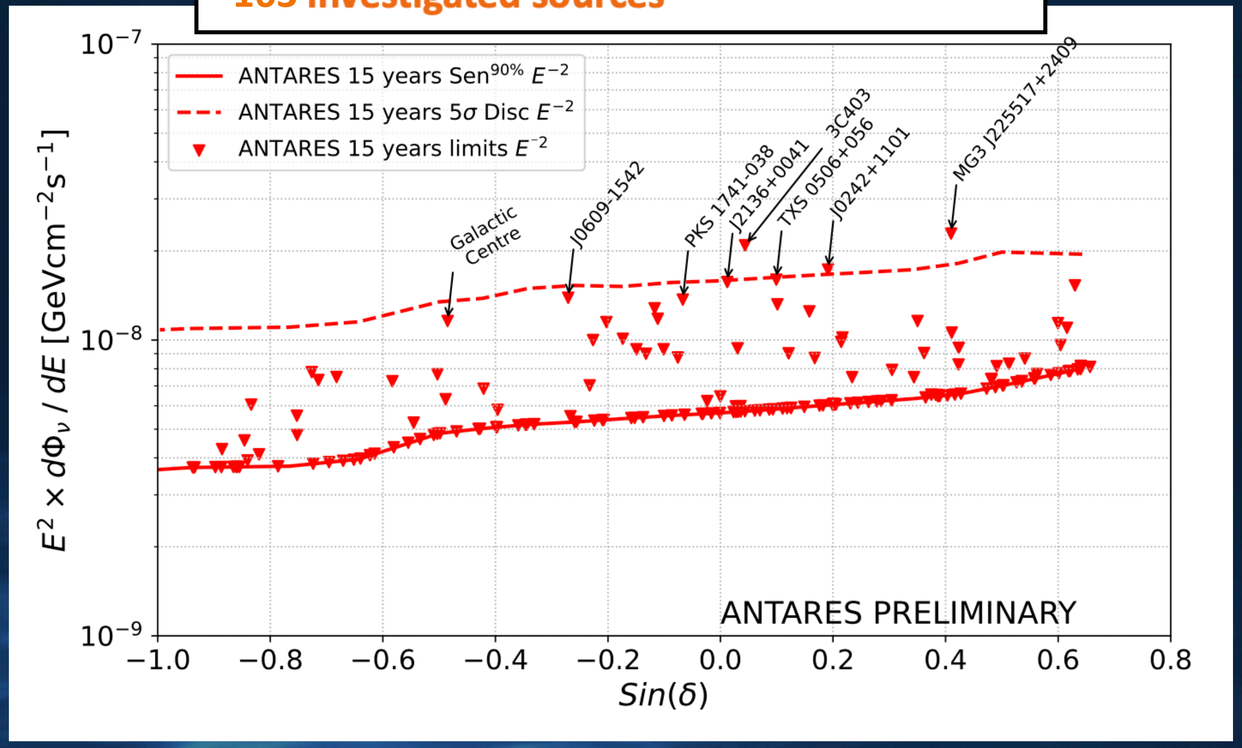
Search for cosmic sources: tracks+cascades

📖 PRD 96, 082001 (2017)
📖 PoS(ICRC2021)1161
📖 PoS(ICRC2023)1128

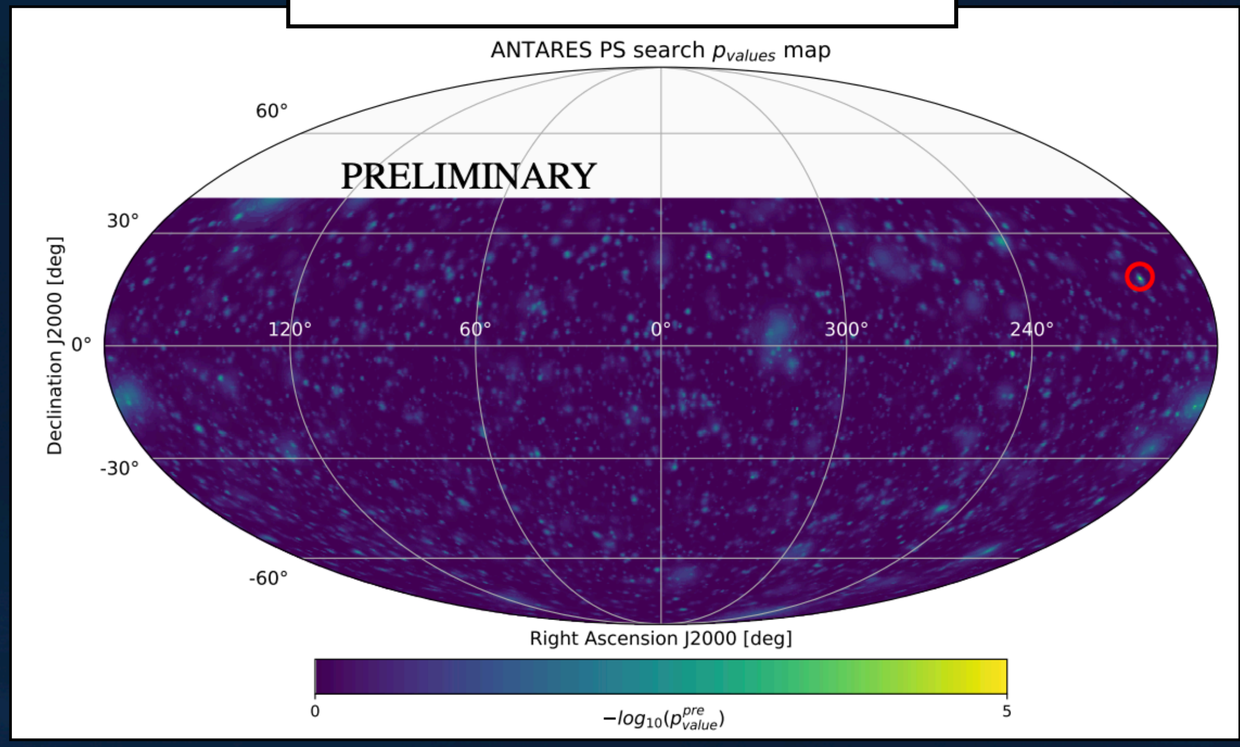
Data set 15 year (from Jan 2007 to Feb 2022); Livetime: 4541 days

Search for an excess of events from a particular sky direction

Using a pre-definite candidate-list search: 163 investigated sources



With a unbinned full-sky search



Most significant source: MG3 J225517+2409

pre-trial significance: 3.4σ; post-trial: 1.7σ

1st significant cluster (α, δ) = (200.5◦ , 17.7◦)

a pre-trial significance 4.0σ; post-trial 1.2σ

Multi-messenger program

Radio	Optical	X-ray	GeV γ-rays	TeV γ-rays
MWA	TAROT ZADKO MASTER GWAC	Swift INTEGRAL	Fermi	HESS HAWC

What triggers an alert:

- Doublet of neutrinos (~0.04 events/yr)
- Single neutrino with direction close to local galaxies (~1 TeV, ~10 events/ yr)
- Single HE neutrinos:
  - HE (~5 TeV, 20 events/ yr)
  - VHE (~30 TeV, ~3-4 events/ yr)

Performances:

- **Time to send an alert: ~5 s**
- **Median angular resolution: ~ 0.4°**

electromagnetic

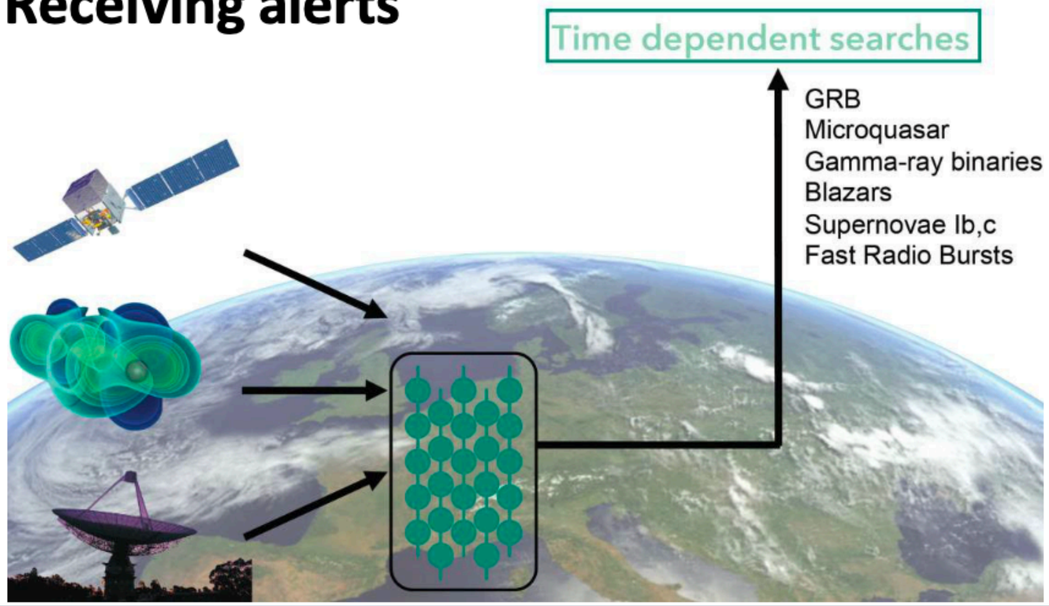
+ LIGO VIRGO

PIERRE AUGER OBSERVATORY

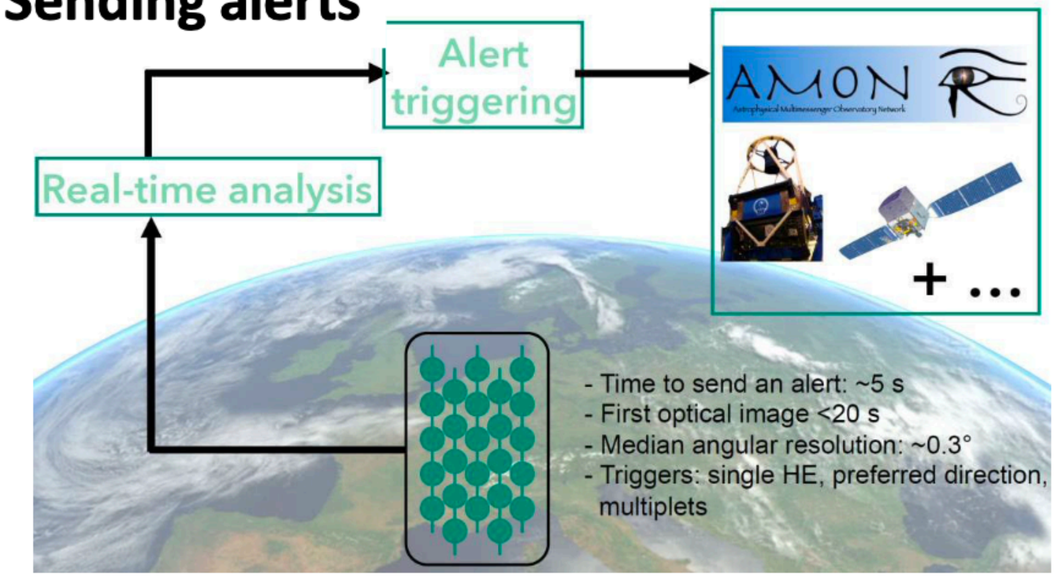
ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

Alert system (**TAToO**: Telescopes and Antares Target of Opportunity)
active since 2009
APP 35 (2012) 530

Receiving alerts



Sending alerts

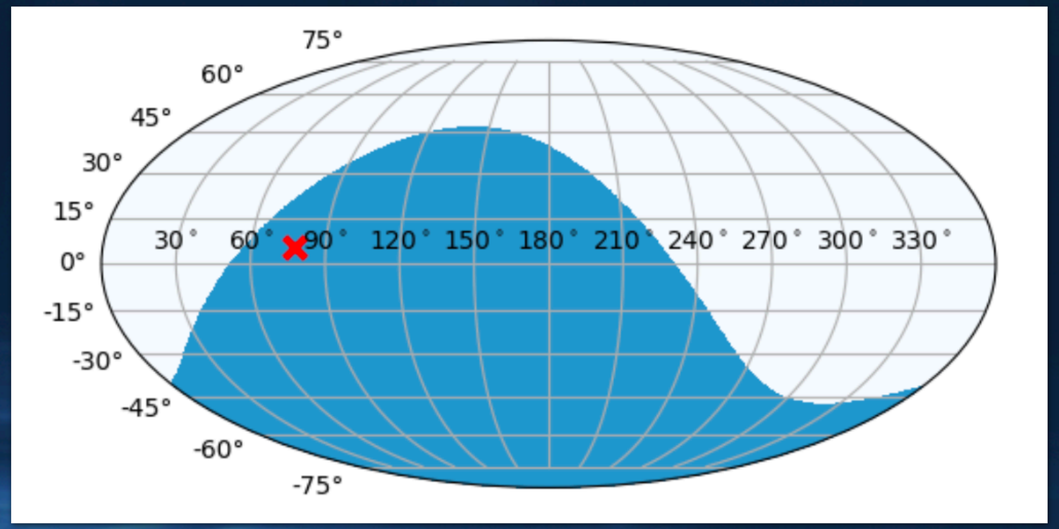


Real-time searches with the ANTARES

Follow-up performed between January 2014 and February 2022

Follow-up of IceCube neutrino alerts

ANTARES followed 37 alerts (7 HESE, 3 EHE, 10 gold and 17 bronze)

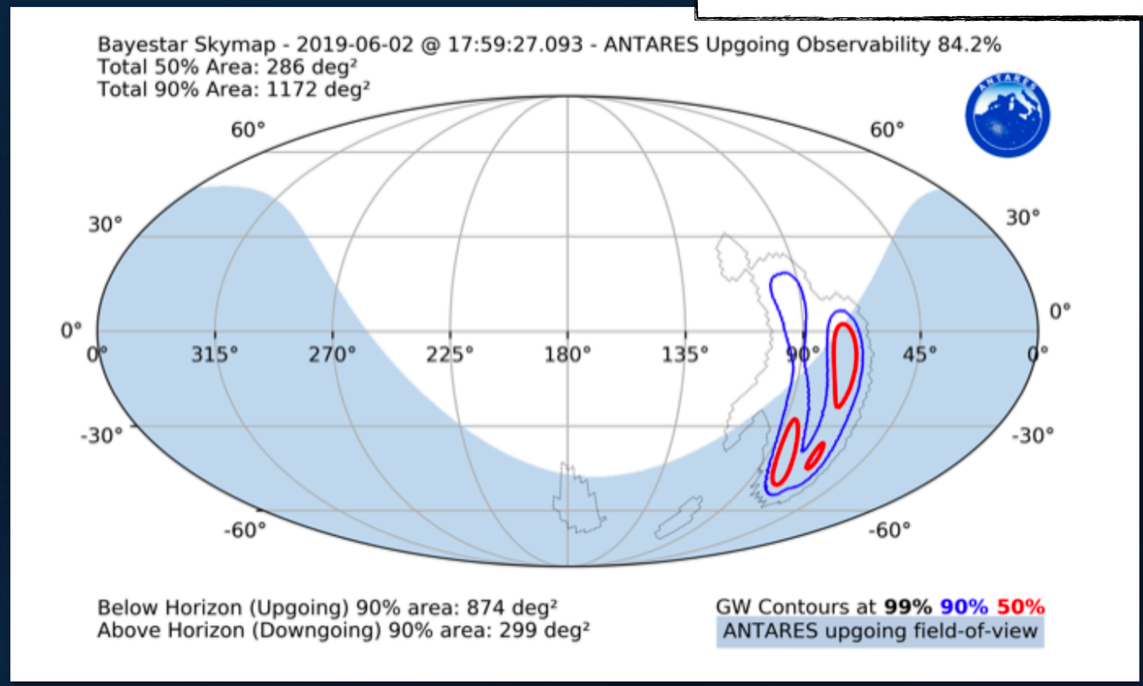


IC170922 and the **ANTARES visibility**

No neutrino candidates found within a cone of 3◦ centred on the IceCube event coordinates and a time window of ±1 hour, further extended to ±1 day.

Follow-up of LIGO/Virgo gravitational wave alerts

GW event S190602aq



Observing run O1 three GW alerts but only one ANTARES offline analyses

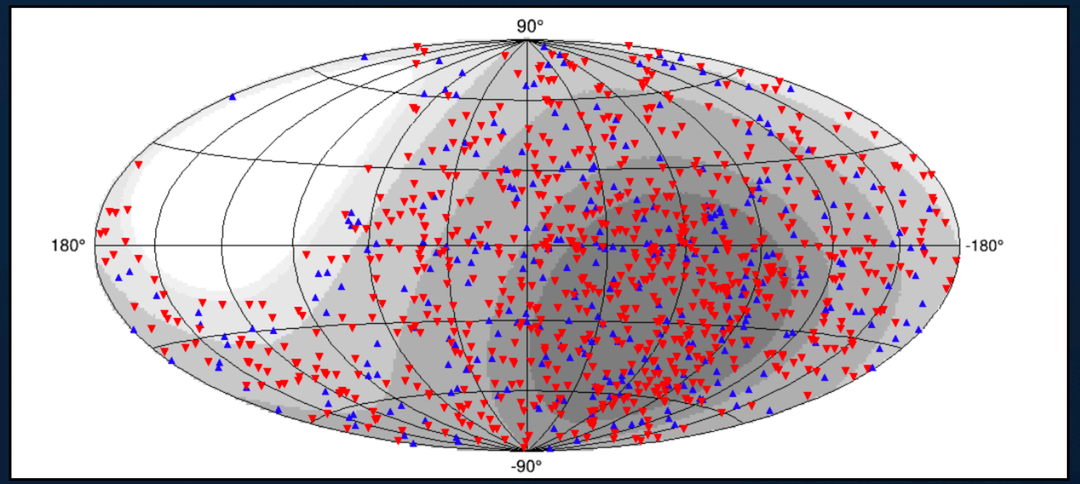
Observing run O2 15 alerts → ANTARES online analyses

Observing run O3: real-time analysis has been performed for 51 GW triggers

Real-time searches with the ANTARES

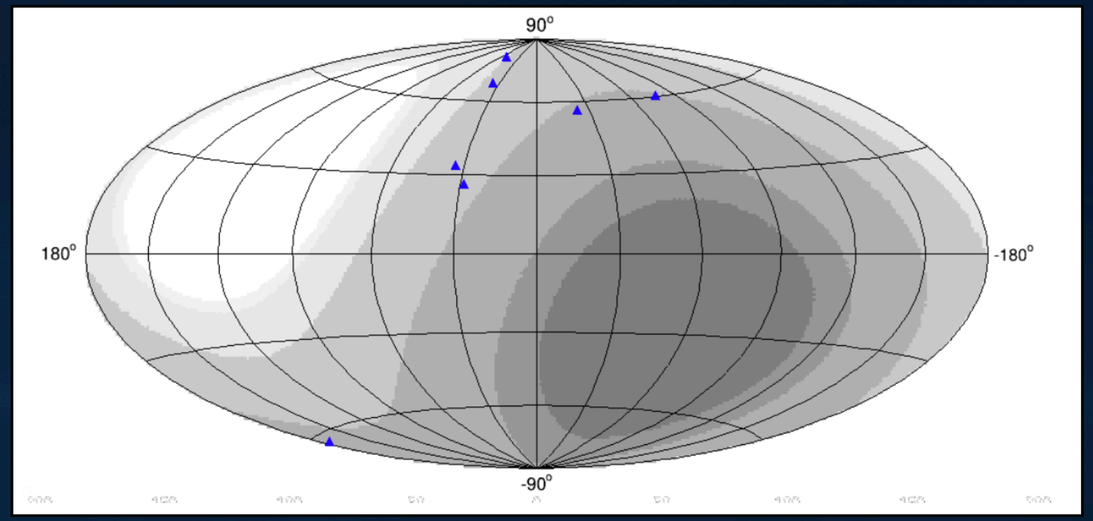
Follow-up of gamma-ray bursts

- Search for neutrino-induced muons in the online data-set performed in real-time within a time window [–250 s; +750 s] around the detection time and in a cone centred on the GRB position
- 317 Swift and 770 Fermi-GBM bursts alerts processed
- No online neutrino signals have been detected



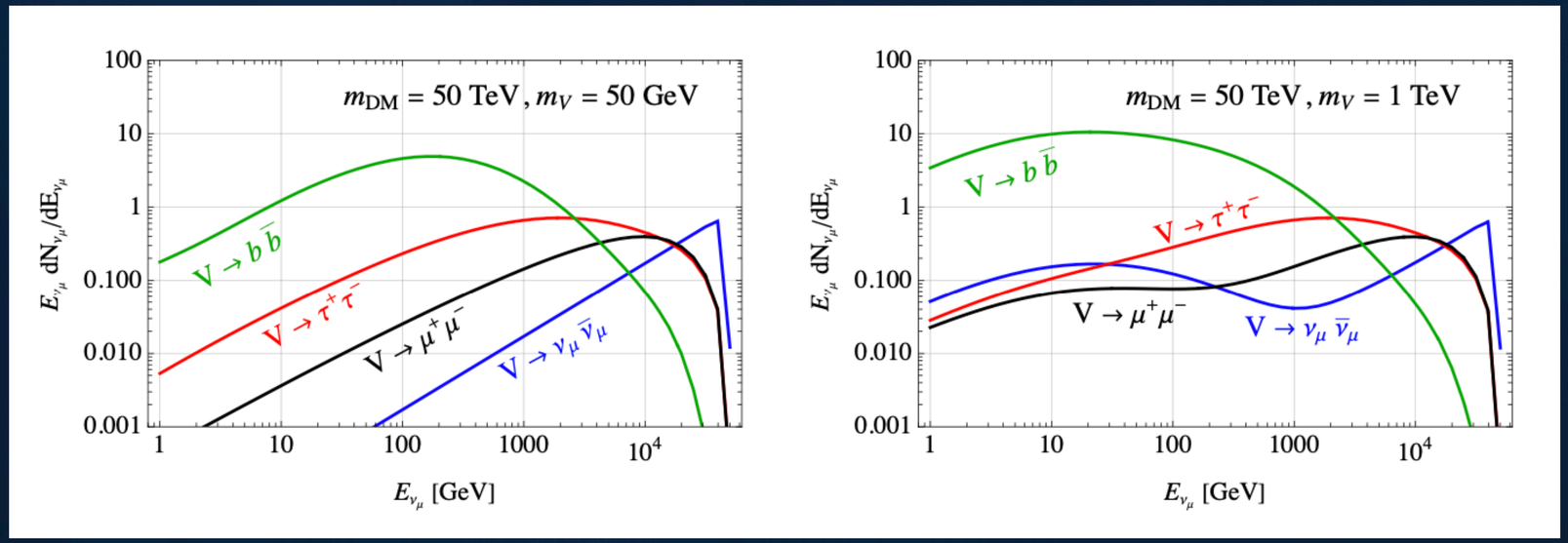
Follow-up of HAWC alerts for transient phenomena

- 22 triggers, 7 of them with a direction within the ANTARES field of view at the time of the alert.
- No online neutrinos have been identified in coincidence with the HAWC transients



📖 JCAP 08 (2023) 072

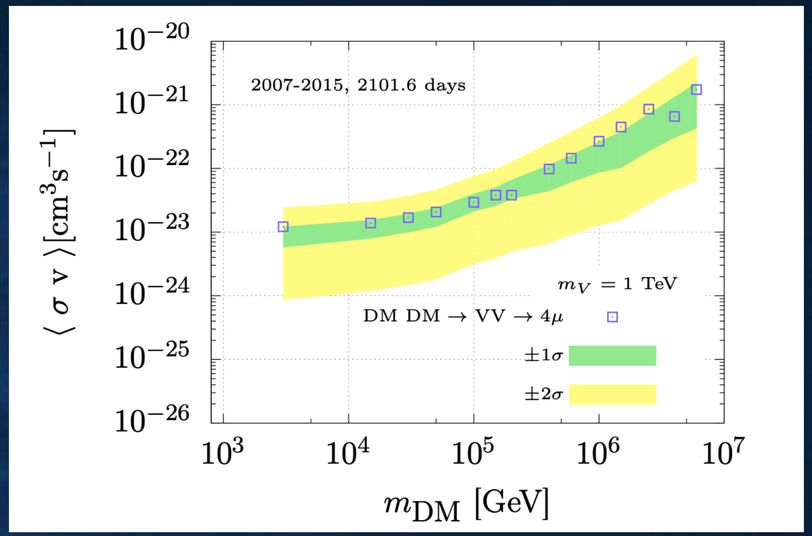
Indirect search for Dark Matter from Galactic Centre

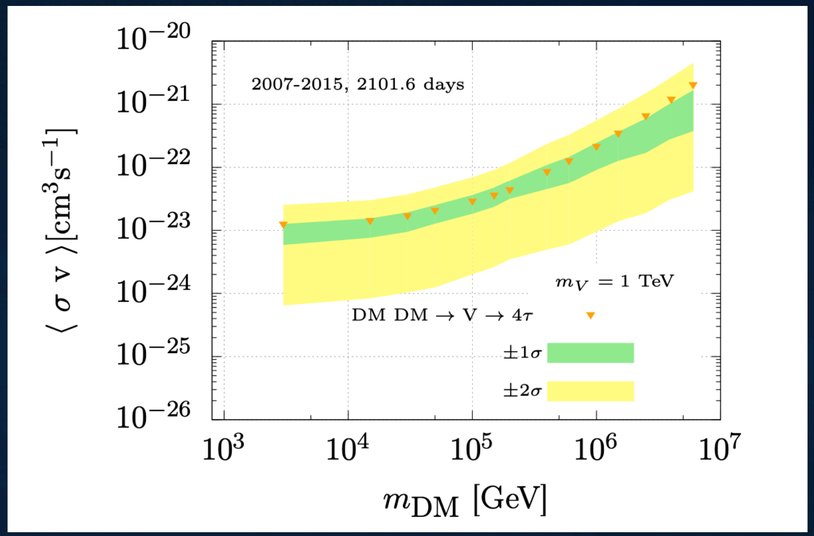


- Data sample (2007-2015)
- muon tracks from upward-going ν_μ charged current (CC) interactions
- 7637 reconstructed tracks recorded over 2101.6 days of effective livetime
- unbinned maximum likelihood method

📖 JCAP06(2022)028

Data consistent with the background-only hypothesis

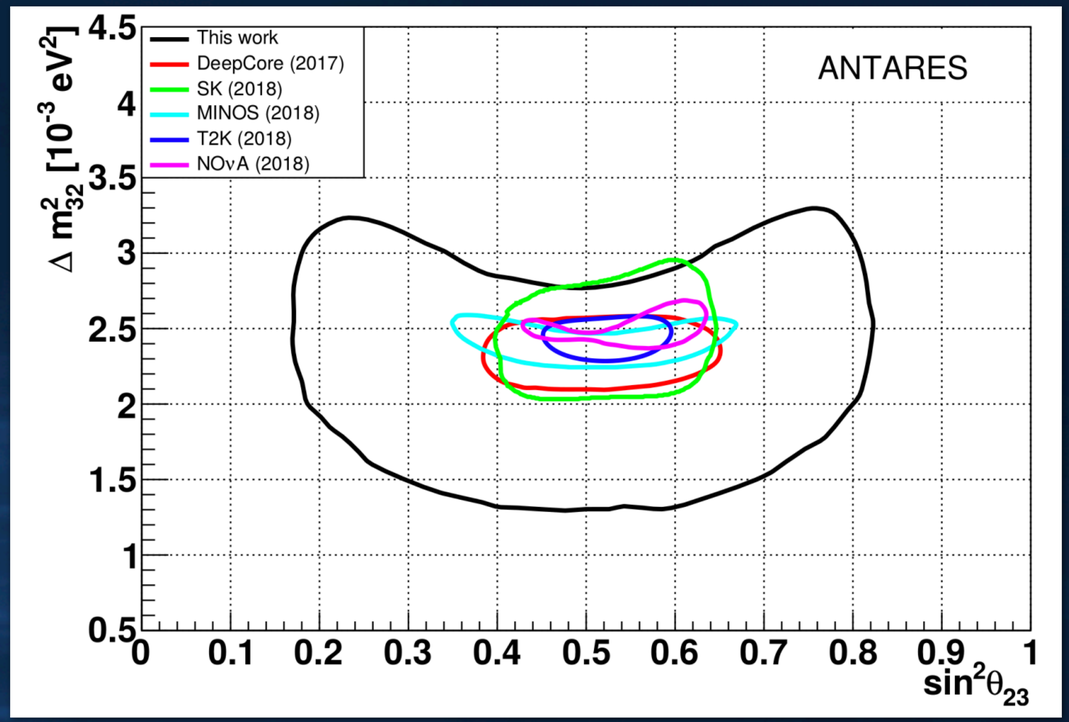




ν - oscillation studies

- Data sample (2007-2016) - 2830 days of lifetime
- 7710 events selected, two reconstruction procedures
- Track channel only, E_{reco} from muon range
- Binned likelihood fit (Poisson stat.) performed in two dimensions ($\log_{10}(E_{reco})$, $\cos\theta_{reco}$)

No-oscillation hypothesis excluded at 4.6σ



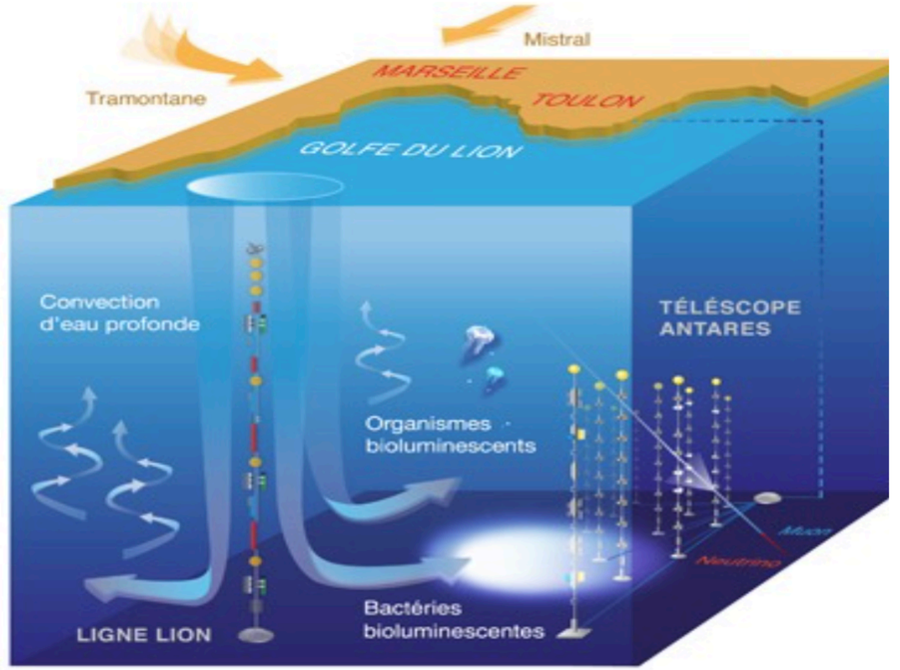
ANTARES: a multidisciplinary observatory

📖 Deep-Sea Research I 58 (2011) 875–884
Acoustic and optical variations during rapid downward motion episodes in the deep North Western Mediterranean

📖 PLoS ONE 8 (7) 2013
Deep-sea bioluminescence blooms after dense water formation at the ocean surface

📖 Ocean Dynamics, April 2014, 64, 4, 507-517
High-frequency internal wave motions at the ANTARES site in the deep Western Mediterranean

📖 *Journal of Geophysical Research: Oceans, Vol 122, 3, 2017*
Deep sediment resuspension and thick nepheloid layer generation by open-ocean convection



📖 *Sci. Rep. 7 (2017) 45517*
Sperm whale diel behaviour revealed by ANTARES, a deep-sea neutrino telescope

📖 https://arxiv.org/abs/2107.08063
Studying Bioluminescence Flashes with the ANTARES Deep Sea Neutrino Telescope

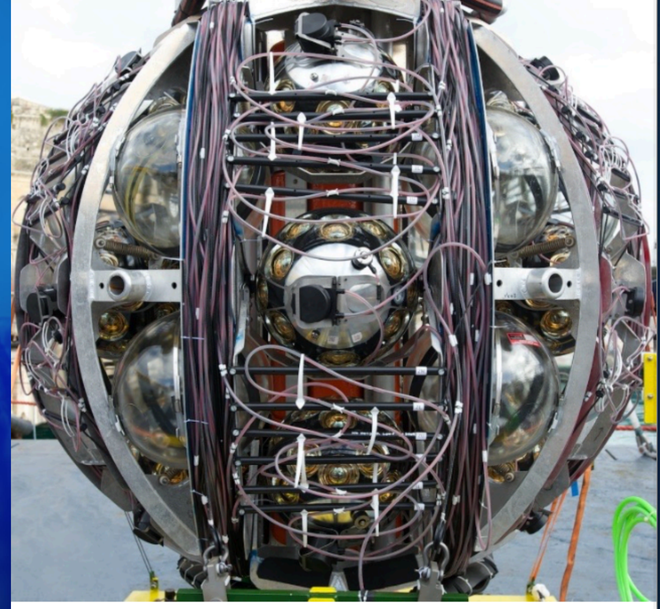
📖 A new paper on pressure measurements at the sea bottom in preparation

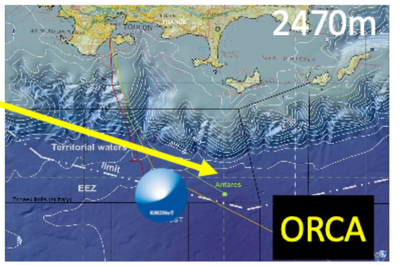
Summary and Outlook

- ANTARES pioneered the field of undersea neutrino telescopes
- The ANTARES experiment has demonstrated the feasibility and reliability of the undersea Cherenkov technique for long-term data acquisition.
- Competitive physics results & intriguing hints
- Constraints on neutrinos as seen by IceCube
- Extensive multi-messenger program
- Multi-disciplinary observatory (Earth and sea sciences)
- Joint studies with several partners
- ANTARES dismantled on February 2022 → KM3NeT infrastructure (*R.Coniglione's talk*)

ANTARES, a truly extraordinary experience…but the adventure is far from over!

Thank you for your attention





Oscillation Research
with Cosmics In the Abyss

Astroparticle Research
with Cosmics in the Abyss

Backup slides