Overview of Results from the ANTARES Neutrino Telescope

Sara Rebecca Gozzini

on behalf of the ANTARES Collaboration

INSTITUT DE FÍSICA CORPUSCULAR

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CSIC
Consejo Superior de Investigaciones Científicas

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

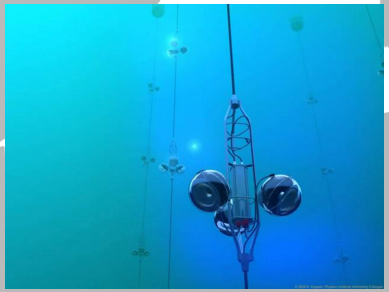
GENERALITAT VALENCIANA

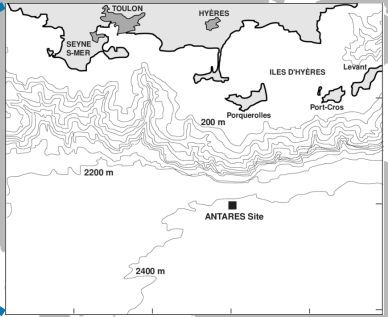
Neutrino detectors in the Mediterranean Sea

ex ANTARES site

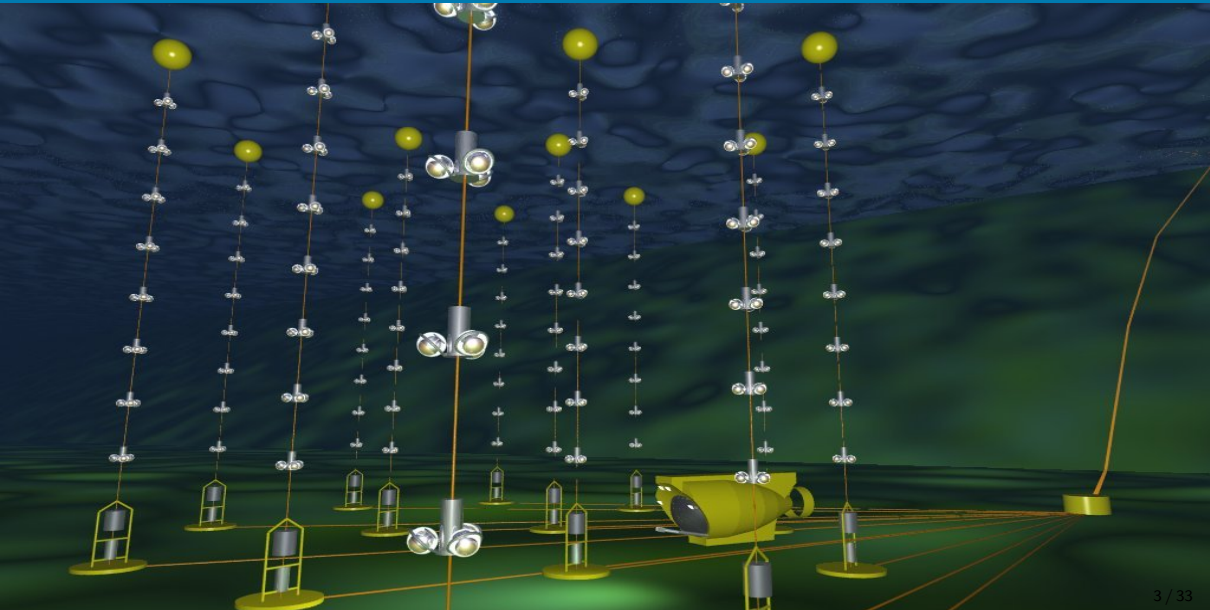
KM3NeT/ORCA

KM3NeT/ARCA





ANTARES: 15 years of data taking 2008-2022

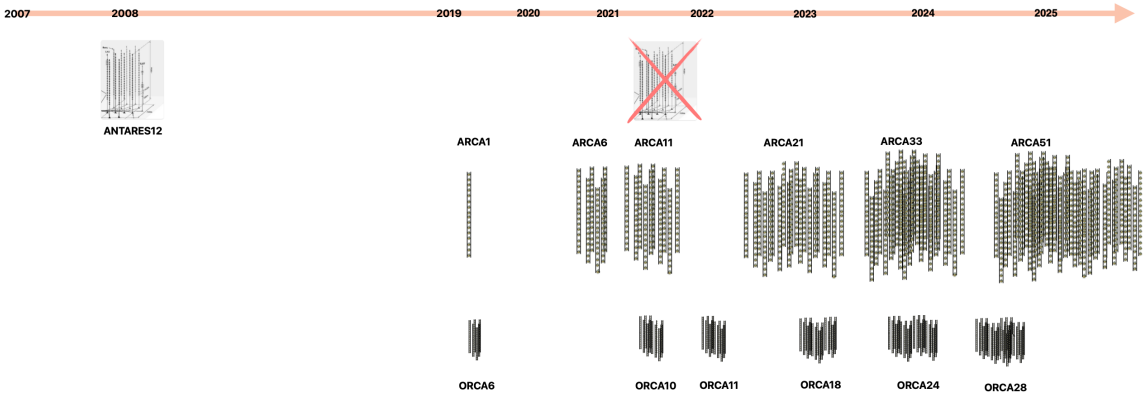


ANTARES: layout

First large-volume Cherenkov detector operating in water

- 12 lines of 885 PMTs instrumenting $\sim$0.015 km^3
- 40 km offshore, cabled to La Seyne/Toulon (France)
- 2500 m below the surface of the Mediterranean Sea
- Completed in 2008, decommissioned in 2022
- Galactic centre visibility 70% of the time

ANTARES: timeline



ANTARES: from prototypal construction to rich physics case

[ANTARES: the first undersea neutrino telescope]

Cosmic neutrinos

- Neutrino astronomy / search for sources
- Search for a cosmic component in energy spectrum
- Multi-messenger networking
- Indirect dark matter searches

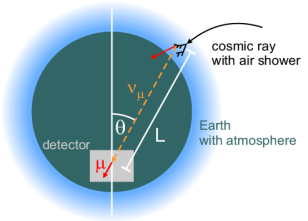
Atmospheric neutrinos

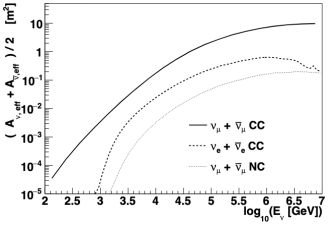
- Flavour oscillations parameters
- New physics signatures: sterile neutrinos, NSI

Multidisciplinary observations

- Marine science, acoustics

Performance: coverage [Phys. Rev. D 96 (2017)]



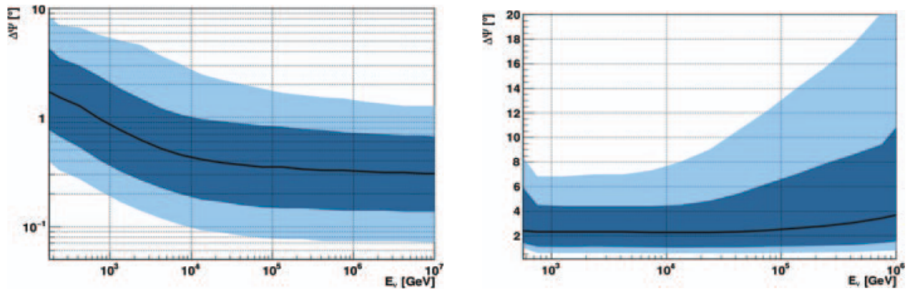


Times and positions of hits	$\rightarrow$	arrival direction coordinates
Number of hits	$\rightarrow$	energy
Shape	$\rightarrow$	flavour of associated lepton

Note: by the time of decommissioning, the collection area of ANTARES was topped by KM3NeT, taking over the prompt astronomy mission.

Performance: pointing [SIF 41C, 134 (2018)]

Excellent optical properties of water (large scattering length) provide good angular resolution.

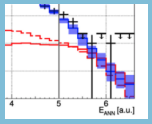


Tracks (left): predominantly $\nu_\mu CC$; angular resolution down to 0.4° at 10 TeV

Cascades (right): predominantly ν_e CC or any NC; angular resolution 4° at 10 TeV

Cosmic neutrinos: search types

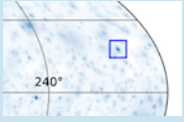
Diffuse excess at high energies without directional information



Multimessenger prompt coincidence upon alert from other experiments

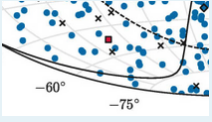
Sources (autocorrelation)

Space (-time) clusters of events, all-sky



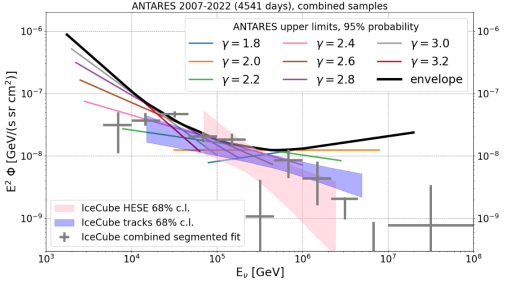
Sources (correlation with catalogue)

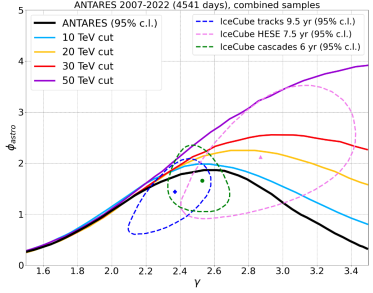
Coincidence with preselected objects



Measurement of diffuse ν flux (all-sky) [JCAP08(2024)038]

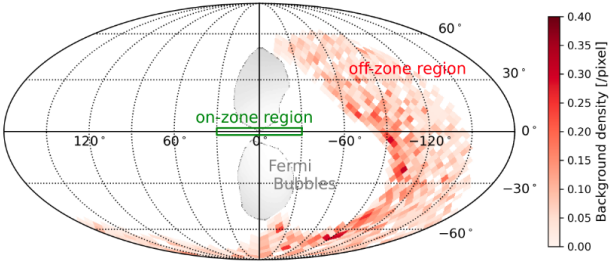
Three events passing signal cuts (one track, two showers), less than 1σ significance.
Upper limits to diffuse flux of astrophysical neutrinos provide best fit parameters $\gamma = 3.35$
$\Phi_{100\mathrm{TeV}} = 0.23 \times 10^{-18}$ GeV^{-1}cm^{-2} s^{-1} sr^{-1}

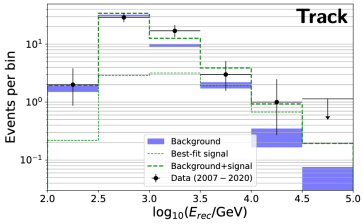




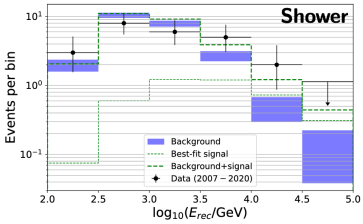
Diffuse Galactic ν flux: Galactic ridge [Phys. Lett. B (2023)]

Hint for a TeV neutrino emission from the central region of the Galaxy $|l| < 30°, |b| < 2°$. Inconsistent with the background-only expectation at 2σ level.





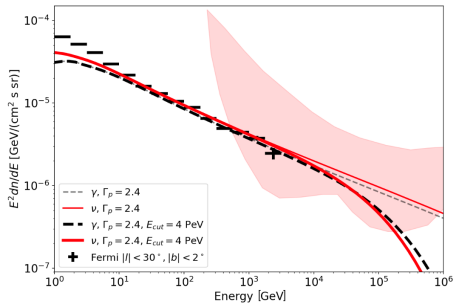
(a) Track-like events



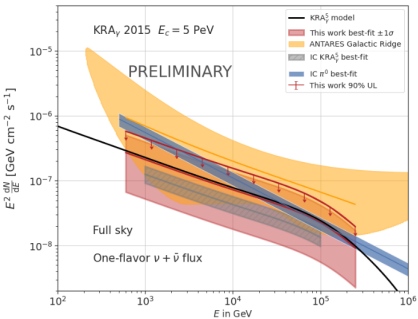
(b) Showering-like events

Diffuse ν flux from Galactic ridge/plane [ICRC2023] [ICRC2025]

Note: thanks to geographical position, search in ANTARES can be run on ON-OFF mode (left), not only benchmarked on π^0 or KRA-γ templates (right) - based on CR propagation optimised on Fermi γ emission data..



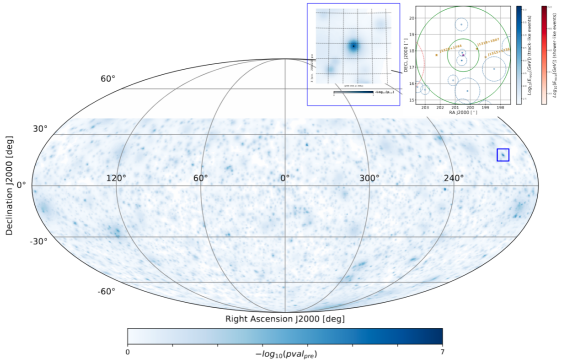
Galactic ridge. Best fit index $\Gamma = 2.45$



Galactic Plane template $< 1.65\sigma$

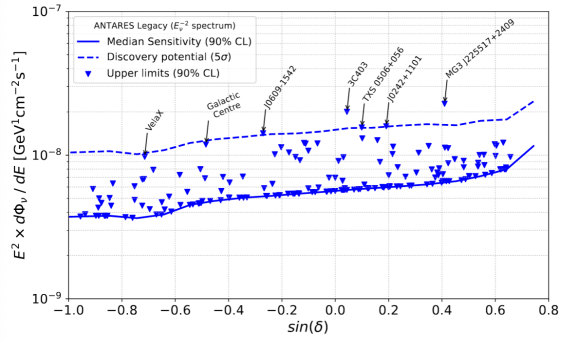
Search for sources (all-sky) [ICRC2025]

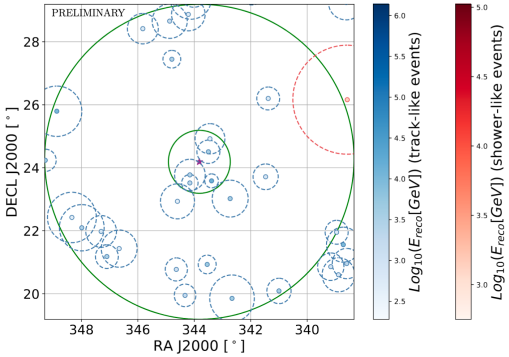
Autocorrelation with $0.11° \times 0.11°$ pixels. Most significant cluster found at (RA, dec) = (200.17°, 17.5°), with 0.38 post-trial significance. Closest objects to the most significant pixel are the radio sources: J1318+1807 (1°), J1315+1736 (1.5°) and J1328+1744 (1.7°).



Search for sources (upon candidate list) [ICRC2025]

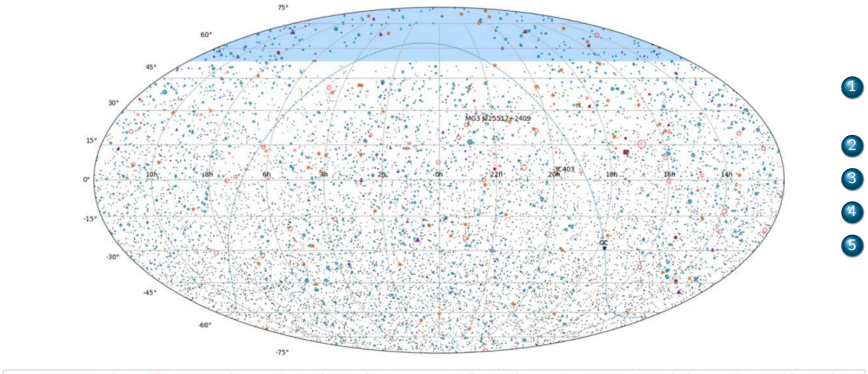
169 targeted sources: 155 point-like and 14 with extended Gaussian morphology. Most significant source: γ-ray blazar MG3 J225517+2409 (2σ post-trial)





Stacking sources [ApJ 911 48 (2021)]

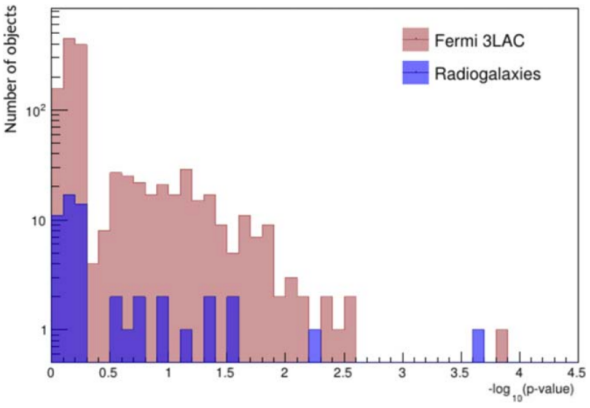
Test correlation with **classes of sources**, rather than with individual objects. Cumulative search for excess sensitive to *individually weak sources*.

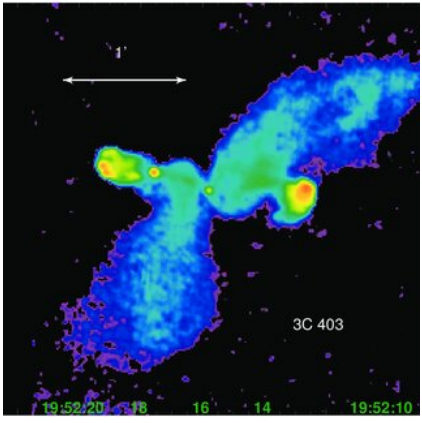


1. Very-high energy IceCube tracks
2. Fermi 3LAC blazars
3. Hard X-ray radio galaxies
4. Star-forming galaxies
5. Jet-obscured AGN

Stacking sources [ApJ 911 48 (2021)]

Best matching catalogue: radio galaxies, 1.6σ post-trial. Best candidate 3C 403 p-value: 2.3×10^{-4}, $N_{sources} = 56 \Rightarrow 2.5\sigma$ [arXiv:2506.21403]

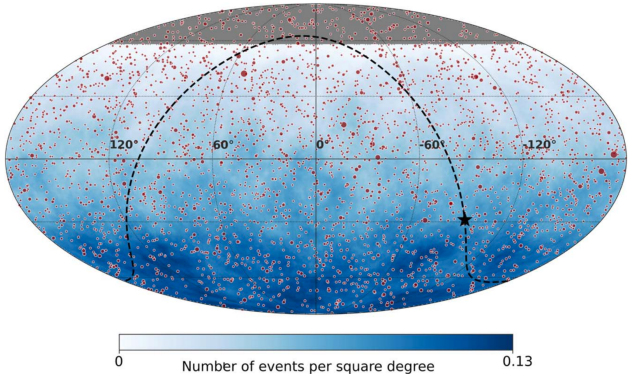




Search for point sources: radio bright blazars [ApJ 964 3 (2024)]

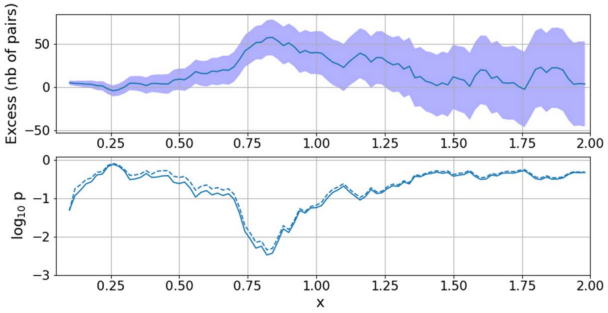
1. Test directional correlation with statistically complete catalogue of blazars
2. Test correlation of ν time clustering with blazar flares.

Hint of association at population level; no conclusive correlation.

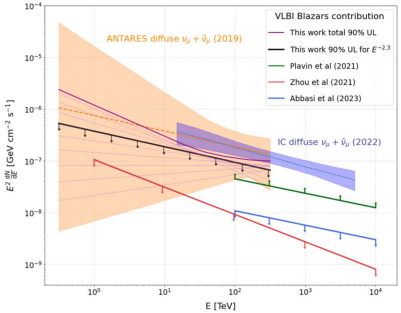


Search for point sources: radio bright blazars [ApJ 964 3 (2024)]

Two complementary search approaches: counting pairs and likelihood-based stacking analysis.



(I) counting blazar-ν pairs



(II) likelihood-based stacking

Search for point sources: radio bright blazars [ApJ 964 3 (2024)]

None of the individual blazars reaches a highly significant correlation. Intriguing time coincidence of ν, radio, and γ-ray flares of J0242+1101 at a $p = 0.5\%$ level.

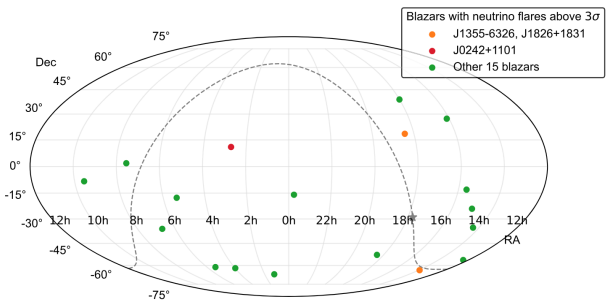
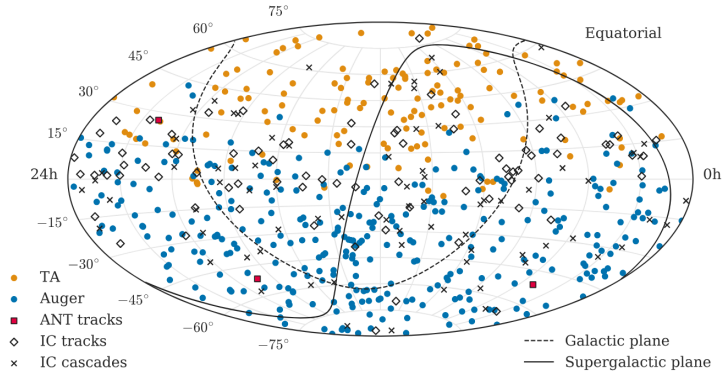


Figure: Sky map in equatorial coordinates showing the positions of the VLBI blazars coincident with the 3σ flares found in ANTARES data.

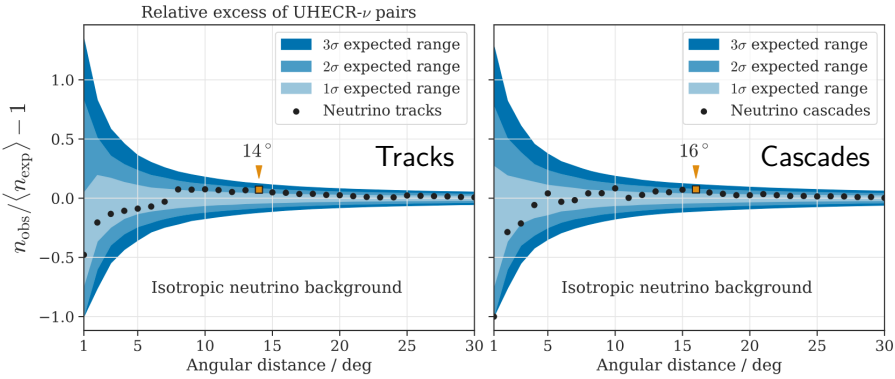
Search for sources: correlation with UHECR [ApJ 934 164 (2022)]

No coincidence found in 3 different analyses testing the correlation of neutrinos (ANTARES high energy tracks and showers, IceCube) with cosmic ray arrival directions.



Search for sources: correlation with UHECR [ApJ 934 164 (2022)]

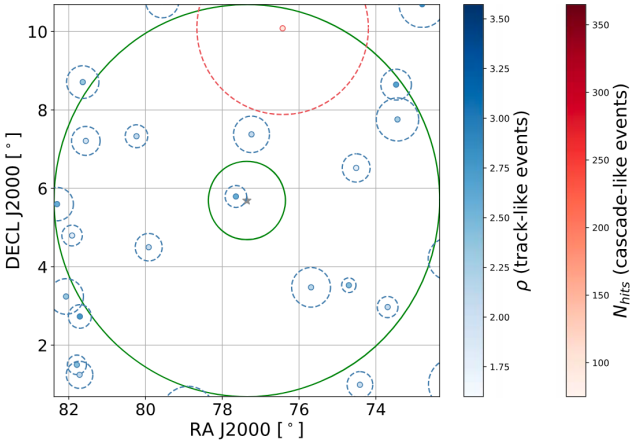
Counting relative excess of neutrino-cosmic ray pairs also shows no correlation signal.



Search for coincid. with TXS 0506+056 (IC-170922A) [ApJL 863 (2018)]

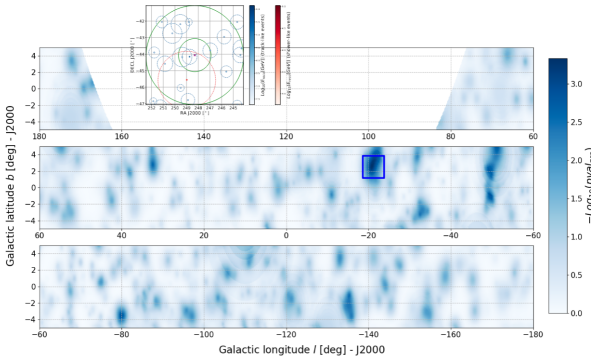
Three searches:

1. online follow-up: no events related to the source
2. time-integrated: 1.03 fitted signal events (p-value $= 3.4\%$). Two astrophysical objects out of 107 candidates with a smaller p-value $\Rightarrow$ 87% chance probability post-trial.
3. time-dependent (burst): no events related to the source



Search for Galactic sources [ICRC2025]

Galactic Plane region: latitude $|b| < 5^\circ$. Each direction is tested for signal assuming a Gaussian with extensions $\sigma_e = 0.5^\circ$, 1°, 1.5° and 2°. Most significant direction at $(l, b) = (-20.7^\circ, 2.6^\circ)$, with post-trial p-value $= 60\%$ to be a background fluctuation.



Multi-messenger networking [Astrop.Phys. 35 (2012)]

Astroparticle has become fully incorporated in time-domain astronomy.

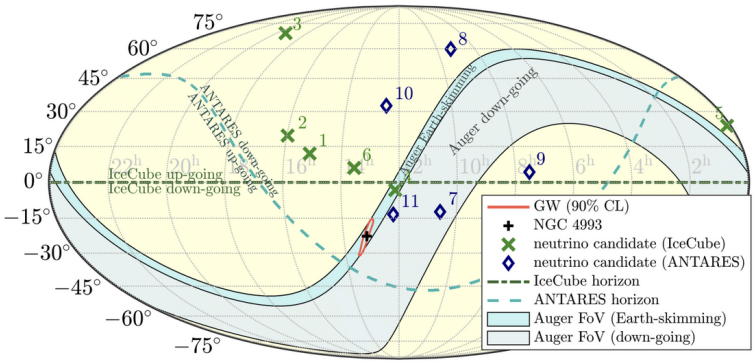
Flares, transients and other sources with time variability (GRBs, gravitational waves, SN)

ANTARES both received and sent alerts. Prompt online reconstruction within $\sim$5 sec (transmits data to shore, filter for physics events, run rapid reconstruction).

- Responded to GCN notices from IceCube, MAGIC, HESS, VERITAS, Fermi, optical or radio instruments, and gravitational wave alerts from VIRGO, LIGO.
- Sent out alert to partners in network (TAToO) triggering on: (I) particular high energy (II) directional coincidence with local Galaxy (III) doublet multiplicity.

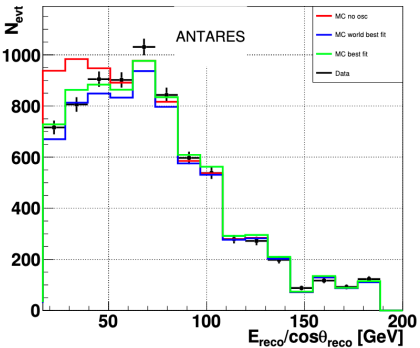
Transient follow-up: grav. waves [JCAP04(2023)004] [ApJL 850 (2017)]

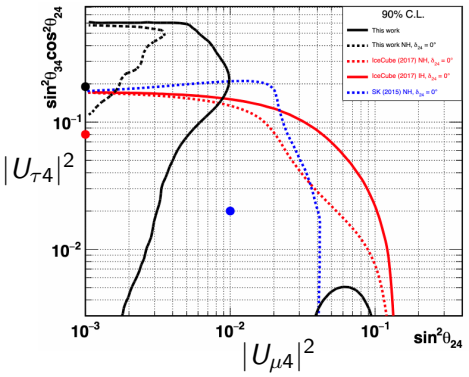
Both online follow-up and offline analysis of GW alerts. Offline follow-up of O1-O2-O3 alerts. GW170817 follow-up. No significant correlation found.



Atmospheric oscillation parameters [JHEP06(2019)113]

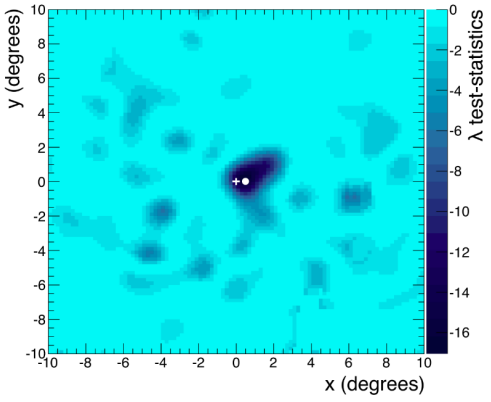
Channel: ν_μ disappearance. Best fit: $\theta_{23} = 45^{+12}_{-11}$ (maximal), $\Delta m^2_{32} = 2.0^{+0.4}_{-0.3} \cdot 10^{-3}\text{eV}^2$. Non-oscillation hypothesis rejected at 4.6σ. Instead no significant preference for 3+1 sterile scenario.





Measurements with atmpospheric muons [Eur. Phys. J. C 78 (2018)]

Moon shadow seen with 3.5 σ significance, corresponding detector angular resolution for downward-going atmospheric muons $0.73^\circ \pm 0.14^\circ$



Indirect dark matter searches [Phys. Lett. B 805 (2020)]

Search for a signal of neutrinos from WIMP annihilation in the Galactic Centre based on maximum likelihood. Data set compatible with background constrains annihilation rate.

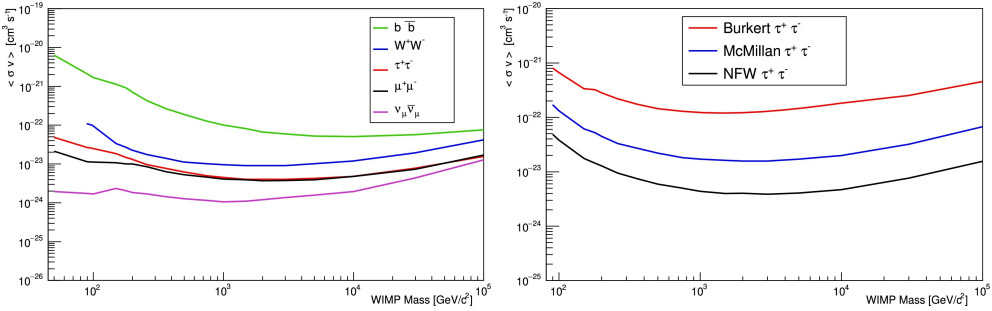


Figure: Upper limits on thermally averaged cross section for WIMP pair annihilation, for five annihilation modes (left) and for channel DM DM $\rightarrow \tau^+\tau^-$ and different halo profiles (right).

Summary

First undersea neutrino telescope, operating for 14 years and opening up the way to KM3NeT detectors, currenly being constructed (see next dedicated talk, M. Circella).

1. Search for cosmic neutrino sources / neutrino astronomy
2. Hint of excess from the inner Galactic region
3. Participation in multi-messenger prompt alert network
4. Measurement of neutrino oscillations and best fit of oscillation parameters
5. Collateral science: oceanology, marine biology, acoustics.

Publicly available data: **https://antares.in2p3.fr/data/**

ANTARES decommissioning

ANTARES decommissioning

ANTARES decommissioning

Main References

[ANTARES: the first undersea neutrino telescope]
[First all-flavour Neutrino Point-like Source Search with the ANTARES Neutrino Telescope]
[ANTARES Search for Point Sources of Neutrinos Using Astrophysical Catalogs: A Likelihood Analysis]
[Constraints on the energy spectrum of the diffuse cosmic neutrino flux from the ANTARES neutrino telescope]
[Search for Spatial Correlations of Neutrinos with Ultra-High-Energy Cosmic Rays]
[Searches for point-like and extended sources of cosmic neutrinos with the complete ANTARES dataset]
[Search for dark matter towards the Galactic Centre with 11 years of ANTARES data]
[Measuring the atmospheric neutrino oscillation parameters and constraining the 3+1 neutrino model with ten years of ANTARES data]
[The Search for Neutrinos from TXS 0506+056 with the ANTARES Telescope]
[First results of the Instrumentation Line for the deep-sea ANTARES neutrino telescope]
[The ANTARES detector: two decades of neutrino searches in the Mediterranean Sea]