

Recent Results from ANTARES





- First deep-sea neutrino telescope running since 2007
- Excellent view of Galactic center region with high angular resolution
 - → Interesting constraints on the origin of the IceCube signal

Antoine Kouchner Université Paris 7 Diderot AstroParticle and Cosmology APC

Very Large Volume Neutrino Telescope

Dubna, Russia, Oct. 2018

Science scope



ANTARES = multi-disciplinary observatory

Earth and Sea Sciences: oceanography, biology, geology, climate monitoring ...

Connections to Earth and Sea sciences



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

→ Talk by D. Lefevre in environment session

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

CONTRACTOR OF

The ANTARES Collaboration



Nantes

The ANTARES Neutrino Telescope

📖 NIM A 656 (2011) 11-38

2500 m depth

350 m

25 storeys / line
3 PMTs / storey
885 PMTs

Deployed in 2001

40 km

Junction box (since 2002)

Interlink cables

14.5 m

Anchor/line socket

~70 m

100/m

The ANTARES Neutrino Telescope

Julien 31/08/2018 13:42

Tous Médias

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©Montanet

Dur les conditions à l'IMP...

 $\overleftarrow{}$

Basic neutrino detector element: storey



Detector Calibration





Led/laser beacons Intense light: PMT TTS negligible

Timing resolution of electronics ~ 0.5 ns

> Positioning resolution < 10 cm

Reconstruction performances

- Upgoing track events ($v_{\mu}CC$)
- Angular resolution <0.4° for E_v >10 TeV
- 90% purity
- Energy resolution of about a factor 2

- Upgoing cascade events (v_e/v_t CC, NC)
- Angular resolution < 3°
- Energy resolution for $v_e CC$ better than 10%



Absolute Pointing - consistent with expectation



⁴⁰K (long-term) monitoring



11

Updated Oscillation Study

- 9 years of data (2007-2016) 2830 days of lifetime
- 7710 events selected, two reconstruction procedures
- track channel only, E_{reco} from muon range
- A binned likelihood fit (Poisson stat.) is performed in two dimensions ($log_{10}(E_{reco}), cos\theta_{23}^{reco}$)



No-oscillation hypothesis excluded at 4.6σ

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Updated Oscillation Study - sterile

- Same data sample, similar fit
- 3+1 model with $\Delta m_{41}^2 > 0.5 \text{ eV}^2 \rightarrow$ no sensitivity to Δm_{41}^2
- Combination of $|U_{\mu4}|^2\,$ and $|U_{\tau4}|^2\,$ modifies oscillation minimum
- Only few limits on $|U_{\tau4}|^2$ exist so far
- Relevant energy range extended ightarrow good for Antares

Name	Prior	Fit		
N	FREE	0.81 ± 0.09		
θ_{24} [°]	\mathbf{FREE}	0.94 ± 1.84		
θ_{34} [°]	\mathbf{FREE}	24.14 ± 3.88		
δ_{24} [°]	FREE	0 ± 115		
$\Delta m^2_{32} \; [10^{-3} {\rm eV^2}]$	2.46 ± 0.14	2.49 ± 0.13		
$ heta_{23}$ [°]	FREE	48.77 ± 7.03		
$ heta_{13}$ [°]	8.41 ± 0.28	8.41 ± 0.28		
$\Delta\gamma$	0.00 ± 0.05	-0.001 ± 0.035		
$X_{sec} \left[\sigma \right]$	0.0 ± 1.0	0.11 ± 0.99		
$\nu/\overline{\nu}$ [σ]	$0.0{\pm}1.0$	1.09 ± 0.61		



Will soon appear on the arxiv

Indirect Search for Dark Matter



Also DM from the Center of the Earth : 🛄 Physics of the Dark Universe, 16 (2017) 41–48

Indirect Search for Dark Matter



16

Natural scale

M_{WIMP}(GeV)

 10^{4}

 10^{3}

Also DM from the Center of the Earth : D Physics of the Dark Universe, 16 (2017) 41–48

 10^{-25}

 10^{-26}

 10^{1}

 10^{2}

Diffuse flux (all flavors)

Sample:

- 2007 2015; livetime 2450 days
- All-flavour analysis (track+showers)

Event selection chain + energy-related cut applied to

- obtain a high-purity neutrino sample
- maximise sensitivity

Signal modeled according to the IceCube flux

Result:

33 events (19 tracks + 14 showers) in data **24 ±7 (stat.+syst.) events** background in MC

1.6 excess, null hyp. rejected at 85% CL

🚇 ApJL 853, L7 (2018)



Results not really constraining... but fully compatible with IceCube

Search for diffuse flux from Galactic ridge

Combined U.L. at 90% CL (blue line) on the 3-flavor neutrino flux of the KRA_γ model (5-50 PeV cutoff)



Result: total flux contribution of **diffuse Galactic neutrino** emission <9% of the total diffuse IC astrophysical signal (E_v > 30 TeV)

Phys. Rev. D 96, 062001 (2017)
 ANTARES+IC submit. ApJL

→ Talk by C. Haack HE session

Stacked expected signal vs. δ (top) and energy (bottom). Colors relative contribution to the sensitivity



All flavor point source search

- 2007-2015 (2424 days): ٠ 7629 tracks, 180 cascades
- Unbinned all-sky search •
- 106 Candidate sources • including 13 IceCube HESE tracks and HAWC sources
- No significant excess
- Best limits for part of Southern Hemisphere
- Excellent sensitivity for E_{v} <100 TeV

p = 13%

Phys. Rev. D 96, 082001 (2017)

Most significant cluster in full sky p = 6% (1.9 sigma) $(\alpha, \delta) = (343.8^{\circ}, 23.5^{\circ})$





Special focuses

 IceCube HESE muon tracks Limits (10⁻⁸ GeV cm⁻² s⁻¹)

IceCube event ID	$\alpha[^\circ]$	$\delta[^{\circ}]$	$\beta_{\rm IC}[^\circ]$	$\Phi_0^{90\%}$
3	127.9	-31.2	1.4	2.1
5	110.6	-0.4	1.2	1.5
8	-177.6	-21.2	1.3	1.7
13	67.9	40.3	1.2	2.4
18	-14.4	-24.8	1.3	2.0
23	-151.3	-13.2	1.9	1.7
28	164.8	-71.5	1.3	1.2
37	167.3	20.7	1.2	1.7
38	93.2	14.0	1.2	2.1
43	-153.4	-22.0	1.3	1.3
44	-23.3	0.0	1.2	1.8
45	-141.0	-86.3	1.2	1.2
53	-121.0	-37.7	1.2	1.6
Clu	ster at $(\alpha, \delta) =$	(130.1°, -2	9.8°)	
-26 -26 -28 -28 -28 -28 -28 -28 -28 -28			•	
5.3 sig. events 1.2 σ	(i) 132 1 RA J20	30 128 000 [°]	126	



Combined ANTARES-IceCube PS search

ANTARES 2007-2015 and the IC40, IC59, IC79, IC86 samples for the Southern Hemisphere

Sample	Livetime (days)	Events	
tracks	2415	5807	ANTARES
showers	2415	102	9 years

	Sample	Livetime (days)	Events	
	IC40	376	22779	
Through-going	IC59 IC79 IC86	348	64257	IcoCubo
tracks		316	44771	7 years
		333	74931	/ years
	2012-2015	1058	119231	

 $\gamma = 2.0$



γ = 2.5

21



The multi-messenger program



Fast Radio Bursts



FRB	ZDM	T ₀ (UTC)	RA (°)	dec (°)	radio telescope
131104	0.59	18:03:59	101.04	-51.28	Parkes
140514	0.44	17:14:09	338.52	-12.31	Parkes
150215	0.55	20:41:41	274.36	-4.90	Parkes
150418	0.49	04:29:04	109.15	-19.01	Parkes
150807	0.59	17:53:55	340.10	-55.27	Parkes
151206	1.385	06:14:56	290.36	-4.13	Parkes
151230	0.76	17:03:26	145.21	-3.45	Parkes
160102	2.13	08:28:38	339.71	-30.18	Parkes
160317	0.70	08:30:58	118.45	-29.61	UTMOST
160410	0.18	08:16:54	130.35	6.08	UTMOST
160608	0.37	03:52:24	114.17	-40.78	UTMOST
170107	0.48	20:05:45	170.79	-5.02	ASKAP

- Jan. 2013 Jan. 2017 analysis.
- 16 FRB (Parkes, UTMOST, ASKAP) → 12 in the FoV during the data taking.
- ± 6h search period in 2°.
- Event selection optimization 1 seen neutrino = 3σ discovery.
- No events found \rightarrow limits set.

A MNRAS 469 (2017) 4465, MNRAS 475 (2018) 1427



Search for neutrinos from TXS 0506+056

Time integrated archival search

- same method as PS searches, +2016/17
- Expected background (3136 days) :
 - 0.23/deg² for track-like
 - 0.005/deg² for shower-like events
- # of events fitting the likelihood signal function a for the source: μ_{sig} = 1.03
- Pre-trial p-value of 3.4% (post-trial 87%)
- 1 track (12/12/2013) 0.3° from the source
- Flux U.L. (@100 TeV) for E⁻²: 1.6x10⁻¹⁸ GeV⁻¹ cm⁻² s⁻¹ in the range [2 TeV-4 PeV]
- In the list of 107 pre-selected sources, only two have a smaller p-value



Distribution of the 13 tracks +1 shower events in the (RA, δ) coordinates around (radius=1° and 5°) the position of TXS 0506+056.

Talk G. Iluminati HE session

ApJL 863, L2 (2018)

Search for neutrinos from TXS 0506+056

Focus on the flare IceCube Flaring period

• We use a time-dependent analysis that reduces by a factor of 2-3 the signal required for a discovery



Results: no events found during flares. Within 2° from the source, 10 background events expected, 13 events found in data. None of them lies in the flaring period.



🚇 ApJL 863, L2 (2018)

25

The multi-messenger program: TATOO

Telescope-Antares Target of Opportunity



TATOO and the GRBs

Radio Optical TeV _y-rays X-ray GeV y-rays MWA TAROT Swift Fermi HESS (12/yr)(offline) (6/yr) ZADKO (2/yr) Integral MASTER HAWC (GWAC) (offline) Talk B. Baret MM session (30/yr)

Triggers:

- Doublet of neutrinos (<3°, <15 min): ~0.04 events/yr</p>
- Single neutrino with direction close to local galaxies:

~1 TeV, ~10 events/ yr

- Single HE neutrinos: ~5 TeV, 20 events/ yr
- Single VHE neutrinos: ~30 TeV, ~3-4 events/ yr

Performances:

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

Sent neutrino alerts (2009-2018)

277 to robotic telescopes+15 to Swift+8 to INTEGRAL



+~22 to MWA +2 to HESS

Summary

Will keep running until 2020 > ANTARES is the largest NT in the Mediterranean Sea. A multi disciplinary observatory (associated sciences).

Competitive physics results.
 Constraints on neutrinos as seen by IceCube.
 Includes cascade-like events various analyses

 Good pointing power

> Extensive multi-messenger program.

> Joint studies with GNN partners very welcome !

> Although technologically challenging ANTARES
is working according to specifications.
 Proves the feasibility of a deep sea Neutrino Telescope.
 → KM3NeT
Thanks for your attention

Thanks for your attention

During operation on the ANTARES/ KM3NeT site