Highlights of the ANTARES Neutrino Telescope

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on behalf of the ANTARES collaboration

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ANTARES: the largest Northern neutrino telescope

Scientific goals

• Neutrino astrophysics
• Multi-messenger studies
• Dark matter searches
• Atmospheric neutrinos
• Exotic particles search: nuclearites, monopoles
• Acoustic neutrino detection
• Earth and Sea sciences

Not discussed today
The ANTARES site

Institut M. Pacha
control room

La Seyne-sur-Mer

Electro-optical Cable of 40 km

Site ANTARES
42° 50' N, 6° 10' E

depth ~ 2500 m

2500 m under s.l.
The telescope: full configuration since 2008

- 12 lines of 75 PMTs
- 1 line for Earth and Marine sciences
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

ALL-DATA-TO-SHORE: computer farm @ the shore station: data filtering, processing and storage.

Submarine links

Junction Box

40 km to shore

Storey

14.5 m

350 m

\~70 m

40 km to shore

\~70 m
How does a neutrino telescope work?

- Muon neutrino, CC only (track reconstruction)
- Neutrino or charged lepton
- Atmospheric muon
- All neutrino flavours, CC & NC (shower reconstruction)
**ANTARES performances**

**Tracks** ($\nu_\mu$ CC) ideal tool for astronomy
- Median <0.4° above 10 TeV
- 90% purity

**Upgoing cascade events** ($\nu_e$ CC, NC)
- Angular resolution ≈ 3°
- Shower confined within ≈ 10 m \(\Rightarrow\) contained events
- Good estimate of the $\nu$ energy, better than 10%
ANTARES searches for neutrino flux

1. Searches for a diffuse flux
2. Searches for point-like sources
3. Searches for diffuse flux with reduced search window
4. Transient/multimessenger studies
1. Diffuse flux search

- Search for excess of **reconstructed** HE events over the expected atmospheric background
- Optimization based on IC best fit flux (spectral index $\Gamma = 2$ and 2.5)
- Variables checked with burn sample (‘0’ ending runs)
1. ANTARES diffuse flux

**TRACKS**

Data: 2007-2015 (2451 livedays)

Above $E_{\text{cut}}$: Bkg: 13.5 ± 3 evts  
IC-like signal: 3 evts  
Observed: 19 evts

**SHOWERS**

Data: 2007-2013 (1405 livedays)

Above $E_{\text{cut}}$: Bkg: 5 ± 2 evts  
IC-like signal: 1.5 evts  
Observed: 7 evts
1. ANTARES diffuse flux

**TRACKS**
Data: 2007-2015 (**2451 livedays**) 

Above $E_{cut}$: 
- Bkg: 13.5 ± 3 evts
- IC-like signal: 3 evts

**SHOWERS**

Above $E_{cut}$: 
- Bkg: 19 evts
- IC-like signal: 3 evts

**ANTARES combined upper limits and sensitivities**
(2007-2015) tracks + showers

- **$\Gamma = 2.5$**
- **$\Gamma = 2$**

**Preliminary**
2. Point sources

2007-2013: 1690 days
(+2014-2015 next weeks)

6490 tracks, 172 cascades

Unbinned all-sky search

54 candidate sources + 8 HESE μ

Best limit for E<100 TeV
2. Joined ANTARES-IceCube PS searches

- Combined 90% CL sensitivities (green line) and limits (points) for $E^{-2}$ spectrum.
- Blue (Red) curves/points indicate ANTARES (IceCube) sensitivities/limits.
2. What about the IC signal? Hidden PS producing $n_p$ HESE?

- A Point Source with $\Phi_0 E^{-\gamma}$ can produce some of the HESE?
- The ANTARES 90% C.L. upper limit excludes that a single point-like source produces $n_p > 6$ HESE, assuming $\gamma = 2.0$.
- A single point-like source yielding $n_p > 3$ is excluded for $\gamma = 2.3$
3. “Enhanced” diffuse flux?

ICECUBE PRELIMINARY

3.

"Enhanced" diffuse flux?

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Highlights of ANTARES - A. Margiotta
3. The Galactic ridge

- $\nu$'s and $\gamma$-rays produced by CR propagation
  \[ p\downarrow CR + p\downarrow ISM \rightarrow \pi^0 \pi^\pm \ldots \]
  \[ \pi^0 \rightarrow \gamma\gamma (EM \text{ cascade}) \]
  \[ \pi^\pm \rightarrow \nu\mu, \nu e \ldots \]
- Search for $\nu_\mu$, data 2007-2013
- Search region \(|l|<30^\circ, |b|<4^\circ\)
- Cuts optimized for $\Gamma=2.4-2.5$
- Counts in the signal/off zones
- No excess in the HE neutrinos
- 90% c.l. upper limits: $3<E_\nu<300$ TeV

PLB 760(2016)143
Simple extrapolation of the *Fermi*-LAT γ-ray measurement to the IC υ flux in the Galactic Plane area excluded

≥ 3 HESE originating in this region excluded at 90% c.l. for Γ = 2.4-2.5
3. $\nu$ from Fermi Bubbles

- $\nu$ can check the hadronic origin of the emission from the bubbles
- $E^{-2}, E^{-2.18}$ spectra [Lunardini et al. PRD92 (2015)] and different cutoff: 50, 100, 500, $\infty$ TeV
- comparison on-zones/off-zones (3) of $\Delta\Omega = 0.66$ sr
- 2008-2015 analyzed (806+366+593 (new) days).
- 28 events observed /19.7 average bkg expected
- Excess of 1.5$\sigma$ (lower than in the previous analysis)

ANTARES EPJ C (2014) 74:2701
4. Multimessenger program

Multi wavelength follow-up of neutrinos

<table>
<thead>
<tr>
<th>Radio</th>
<th>Visible</th>
<th>X-ray</th>
<th>GeV-ray</th>
<th>TeV-ray</th>
<th>GW</th>
<th>ν</th>
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<tr>
<td>MWA</td>
<td>TAROT</td>
<td>Swift</td>
<td>Fermi-LAT</td>
<td>HESS</td>
<td>Ligo</td>
<td>IC</td>
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<tr>
<td>ZADKO</td>
<td>MASTER</td>
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<td>HAWC</td>
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<tr>
<th>Alerts</th>
<th>12/yr</th>
<th>30/yr</th>
<th>6/yr</th>
<th>(Offline)</th>
<th>(1-10/yr)</th>
<th>(Offline)</th>
</tr>
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• better understanding of the related physics mechanisms
• increase of the detector sensitivities thanks to the suppression of the uncorrelated backgrounds
Neutrino follow-up of GW150914

- white line: region of higher sensitivity of ANTARES
- Size of GW150914: 590 deg$^2$ ANTARES resolution: <0.5 deg$^2$
- Limits on total energy radiated in neutrinos: <10% GW
- Future: Receive / send alerts in real time

Phys.Rev. D93 (2016) no.12, 122010
Dark Matter searches
Dark Matter from the Sun and the Galactic Centre

\[ X_{\text{WIMP}} \overline{X}_{\text{WIMP}} \rightarrow \nu \overline{\nu}, \ b\overline{b}, \ W^-W^+, \ \tau^-\tau^+, \ \mu^-\mu^+ \]

- Gravitational trapping and accumulation of DM particles in the centre of astrophysical objects like the Sun and the Galactic centre
- DM annihilation would be produce a HE neutrino flux \( \Rightarrow \text{very clean signature} \)
  \( \text{no significant astrophysical backgrounds expected} \)
- \( \nu_\mu \) spectrum \( \Rightarrow \text{WIMPSIM} \) [Blennow, Edsjö, Ohlsson, arXiv:0709.3898]
- Bkg estimated from time scrambled data.
  \textbf{No excess observed}
The Sun


Limits on neutrino flux transformed in scattering cross section limit
Neutrino telescopes → most restrictive limits for spin-dependent cross section
The Galactic Center

- **Northern** hemisphere: very good visibility of the GC
- Limits on annihilation cross section
- J-factor s calculated with CLUMPY (A.Chardonner et al., Comp.Phys.Comm. 183, 656, 2012)
Summary

• ANTRES → the largest Northern neutrino telescope
• Search for a neutrino flux from the Southern sky: competitive sensitivities and excellent angular resolution in both *track* and *cascade* events
• Significant contribution to understand the origin of cosmic neutrinos observed by IceCube
• Detailed study of *extended* regions (Galactic plane, Fermi Bubbles)
• Huge *multimessenger* effort
  – EM radiation: radio (MWA), optical, X-ray, γ-rays (LAT, IACTs)
  – Gravitational Wave observatories and IceCube
• Important contribution to the indirect searches for *Dark Matter*

The future: KM3NeT