Recent results from the ANTARES Deep Sea Neutrino Telescope

Vincent BERTIN (CPPM-Marseille) on behalf of the ANTARES Collaboration

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The ANTARES Neutrino Telescope

- Largest underwater neutrino telescope operating for 10 years now (complete in 2008)
- 12 line detector with 885 10” PMTs installed by 2500 m depth off the coast of Provence (France)
- O(11000) neutrinos detected with $E_{\nu} > 10$ GeV

- Excellent view of Galactic Centre region with high angular resolution ($0.3^\circ$-$0.4^\circ$ median)
  → interesting constraint of possible galactic component of the IceCube HE signal

- Real time data processing → generation of alerts (~5s) for multi-messenger searches

Science scope of ANTARES:
- Neutrino astrophysics, search for HE CR origin
- Multi-messenger observations
- Indirect searches for Dark Matter
- Atmospheric neutrinos (oscillations, sterile neutrinos)
- Exotic searches (magnetic monopoles, nuclearites)
- Earth & Sea Sciences, environmental studies

This talk
Reconstruction performances

- **Upgoing track events** ($\nu_\mu$CC)
  - Angular resolution $< 0.4^\circ$ for $E_\nu > 10$ TeV
  - Energy resolution: factor 3
  - 90% purity of neutrinos
  - Large detection volume from $\mu$ range
    → ideal for neutrino astronomy
    → but large atmospheric $\mu$ bkg

- **Upgoing cascade events** ($\nu_e/\nu_\tau$ CC, NC)
  - Angular resolution $< 3^\circ$
  - Energy resolution for $\nu_e$ CC $< 10%$
  - Contained events (small detection volume)
    → almost no atmospheric bkg
Check of Detector Absolute Pointing

Atmospheric shower

Array of 15 scintillator units (0.8 m² each)

Reconstructed track

Moon shadow with 2008-2015 data
(Significance 3.5 σ)

Angular resolution for down-going muons: 0.73° ± 0.15°

Coincidence with Surface Array detector
(2 sea compaines)

PRELIMINARY

POS (ICRC2017) 1053
Search for HE Neutrino Excess (aka ‘Diffuse Flux’)

All sky/all flavour neutrino search with 2007-2015 data (2450 livedays)

Total events above energy thresholds:
- Expected: $24 \pm 7$ bkg, $\sim 8$ from IceCube flux
- Observed: 33

→ Small excess not significant but compatible with IceCube flux

Combined upper limit assuming $E^{-2.5}$ spectrum
Study of Galactic Ridge

- Guaranteed galactic neutrinos from CR interactions with matter
- Does it contribute to IC flux?
- Test ‘KRAγ’ model -> spectrum and morphology reproduce Fermi & Milagro data
- Analysis uses full model morphology and spectrum

New all-flavour analysis:
2007-2015 data, track & cascade events
Likelihood approach probing KRAγ model

Limit at 1.25 x KRAγ model
At most 19% of HESE IC dataset can originate from CR diffusion
⇒ 5.6 out of the 30 HESE with $E_\nu > 60$TeV

Combination with IceCube ongoing

Preliminary arXiv:1705.00497
All flavour point source search with ANTARES

  7629 tracks, 180 cascades

- Search for 106 candidate sources (Pulsars, SNRs,...) and 13 IceCube tracks from the HESE sample

Blue: Tracks
Red: Cascades

Candidate sources
IC HESE tracks

arXiv:1706.01857
All flavour point source search with ANTARES

- Most significant cluster in full sky: $p = 6\% (1.9\,\sigma)$
- Most significant candidate source: HESS J0632+057, $p = 13\% (1.5\,\sigma)$
- Most significant HESE track: $p = 20\% (1.3\,\sigma)$

arXiv:1706.01857
All flavour point source search with ANTARES


- Search for 106 candidate sources (Pulsars, SNRs,...) and 13 IceCube tracks from the HESE sample

- No significant excess found
  - Best limits for part of Southern Hemisphere for $E_\nu < 100$ TeV
  - Relevant energy range for Galactic sources
  - Results to be combined with latest IceCube search

[Graph showing sensitivity and limits]
Send **real-time alerts** (5 s delay, precision 0.3°-0.4°) for neutrinos pairs, single neutrino close to direction local galaxies, single VHE neutrinos

256 alerts sent to robotic optical telescopes, 13 to Swift and a few to MWA & HESS

→ no significant transient associated to neutrinos so far
ANTARES Multi-Messengers Analyses

SWIFT
Ligo
HAWK
Milagro
TA
Auger
MAXI
ANTARES
HESS
IceCube
Fermi
Parkes
MWA
Utmost
# Multi-Messengers / Time Correlation Analyses

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<td>X &amp; Gamma-rays</td>
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<td>Galactic plane</td>
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<td>PLB 760 (2016) 143 arXiv:1705.00497</td>
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Search for Coincidences with Gravitational Waves

- Neutrino follow-up relevant in case of baryonic ejecta (mostly for BH/NS or NS/NS merging)
- Coincident neutrino signal would allow pinpointing the source (< 1°)

- Combined analysis Ligo/Virgo, IceCube and ANTARES (dominates for $E_\nu < 100$ TeV)
- No counterpart observed so far (in ±500 s)
  → Total energy radiated in neutrinos <10%

Now real time follow-up of ongoing science run
Indirect Searches for Dark Matter

Relic WIMPs gravitationally bound / elastic collisions (Sun, Earth, Galactic Centre)

\[ <E_\nu> \sim \frac{M_\chi}{3} \]

Track channel only

Sun analysis

Galactic Centre analysis

Also Secluded DM from the Sun: JCAP 05 (2016) 016
and DM from the centre of the Earth: Physics of the Dark Universe 16 (2017) 41
Oscillations of atmospheric neutrinos

New analysis on-going with dedicated energy reconstruction optimized for low energy events

Sensitivity to neutrino mixing parameters

Data unblinding & results after Summer
Summary & Perspectives

- **ANTARES**, the largest Neutrino Telescope in the Northern Hemisphere, is celebrating **10 years of continuous data taking**
- Cascades events included in analyses with up to **3° angular resolution** → all flavour neutrino searches

- **Strongest limits for galactic point sources** in Southern Hemisphere with $E_\nu < 100$ TeV
- Interesting constraints on **origin of IceCube signal**
- **Small excess of HE neutrinos**, of magnitude expected from IceCube cosmic flux

- **Many multi-messenger analyses** looking for transient sources (Radio, Optical, X/γ-Rays, TeV gammas, GW)
- **Competitive results in Dark Matter searches**

Demonstration of great potential of Deep Sea Neutrino Telescopes

→ **To be exploited with KM3NeT**

(cf talks of P. Sapienza on Tue. 25th & J. Hofestädt on Thu. 27th)