Results from
the ANTARES Neutrino Telescope

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for RICAP-16 on behalf of
the ANTARES Collaboration

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Results from the ANTARES neutrino telescope

ANTARES neutrino telescope
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A. Sánchez Losa (INFN - Sezione di Bari)

RICAP2016
Frascati - 23/Jun/2016
Results from the ANTARES neutrino telescope

- Largest in the Northern Hemisphere
- 12 lines | 25 storeys | 3 OMs
- 885 PMTs in total
- Full configuration since 2008
- Real-time data processing
- Data taking planned until mid-2017
Results from the ANTARES neutrino telescope

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- 12 lines | 25 storeys | 3 OMs
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Fermi 5-year gamma-ray skymap (>1 GeV) combined with ANTARES visibility

- Instantaneous half sky visibility
- Visibility of $\frac{3}{4}$ of the sky: most of the Galactic Plane
Results from the ANTARES neutrino telescope

Detection principle

Neutrino interactions:
- **CC**: $\nu l N \xrightarrow{W} l X$
- **NC**: $\nu N \xrightarrow{Z} \nu N$

Neutrino topologies:
- regarding interaction (CC/NC) and lepton output ($e/\mu/\tau$)
- tracks and showers

![Diagram of neutrino interactions and topologies](image-url)
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ANTARES Track & Shower Performances

- Median angular resolution for tracks below 0.5° above ~10 TeV: 0.4° for $E^{-2}$
- Effective area ~1m² @ 70 TeV

Bottom: performance of the shower energy-direction reconstruction (EM&HS) for contained events. Left, MC–reconstructed angle vs. neutrino energy. Right, MC–reconstructed energy ratio vs. shower energy. Error bars are 25–75%.

IceCube – PhysRevD 91(2015)2,022001
Highlighted topics:

- **Point sources**: First combined analysis
- **Diffuse fluxes**
- **Multi-messenger studies**:
  - Prompt alerts: TAToO, \textbf{GW150914} follow up...
  - Transient gamma & X-ray sources
  - GRBs
- **Dark matter indirect searches**

Also: \textit{(not covered on this talk)}

- Study of: atmospheric neutrinos and oscillations, atmospheric muons, cosmic-ray anisotropy...
- Exotic particles search: nuclearites, monopoles...
- Acoustic neutrino detection techniques
- Earth and Sea sciences
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Point Sources

IceCube–ANTARES combined analysis

- Southern sky muon tracks
  - IC-40: 375 days of livetime with 22779 events
  - IC-59: 348 days of livetime with 64240 events
  - IC-79: 316 days of livetime with 59009 events
  - ANTARES: 1338 days of livetime with 4136 events

Relative number of source events for $\gamma = 2.0$

Relative number of source events for $\gamma = 2.0$, $E_{\text{cut}} = 100$ TeV

Combined acceptance for $E^{-2}$

Combined acceptance for $E^{-2} \exp(-\sqrt{E/100\text{TeV}})$

Muon neutrino effective area for a point source at a declination $\delta = -30^\circ$ (top) and median angular resolution (bottom) for this analysis
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**Point Sources**

*IceCube–ANTARES* combined analysis

- Full sky + 40 sources (17 extra-galactic + 22 galactic + Galactic Centre)
- Upper limits improvement up to a factor $\sim 2$
- No significant cluster found, largest excesses:
  - Full sky search: $0.7\sigma$ significance (post-trial) at $(\text{RA}: 332.8^\circ, \delta: -46.1^\circ)$
  - Candidate list: $1.2\sigma$ significance (post-trial) for HESS J1741.302

### Limits and sensitivities for $\gamma = 2.0$

![Graph showing limits and sensitivities for $\gamma = 2.0$.]

### Combined upper limits for $E^{-2}$

![Graph showing combined upper limits for $E^{-2}$.]

### Limits and sensitivities for $E_{\text{cutoff}} = 100$ TeV

![Graph showing limits and sensitivities for $E_{\text{cutoff}} = 100$ TeV.]

### Combined upper limits for $E^{-2} \exp(-\sqrt{E/100\text{TeV}})$

![Graph showing combined upper limits for $E^{-2} \exp(-\sqrt{E/100\text{TeV}})$.]
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Point Sources

ANTARES 2007–2013 PS update

ANTARES 2007–2013 skymap
- 6490 tracks (median angular res. 0.3°)
- 172 showers (median angular res. 3°)

- Michael, ICRC2015 1078
- 1690 live-time days
- tracks + showers analysis (~10% atmospheric muon contamination)
- Full sky + 54 candidate sources + 8 IceCube μ-tracks
  (Phys Rev Lett 113(2014)101101) + Galactic Centre (as 0°–5° extension)
- No significant cluster found, largest excesses:
  - Full sky search: 1.3σ significance (post-trial) at (RA: 311.7°, δ: -48.3°)
  - Candidate list: 0.75σ significance (post-trial) for HESS J0632+057
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Point Sources

ANTARES 2007–2012 PS about Galactic Centre / IceCube Hot Spot

ANTARES limits (solid lines) on the contribution of point-like sources to the IceCube HESE 3yr sample and the flux required to produce a given expected number of HESE (dashed lines) for source spectra between 2.1 and 2.5 and a source declination of $\delta = -29^\circ$

- Barrios-Martí, ICRC2015 1077
- 1338 live-time days and 5516 tracks ($\sim$10% atmospheric muon contamination)
- No significant result found: point-like sources with spectral index closer to 2.5 are more disfavoured than for values closer to 2.0

ANTARES excludes unique source ($\gamma = 2$, up to $1^\circ$ extension) in a $20^\circ$ cone as origin of the IC cluster (ApJL 786:L5 2014)
TANAMI–ANTARES about IC14 and IC20 events

Relative exposures of the ANTARES candidate list search to a flavour-uniform neutrino flux from the characteristic declinations of the six candidate blazars, and the southern-sky-average of the IceCube HESE 3yr analysis

ANTARES limits on the expected number of IceCube events of blazar origin. “IC 20 TANAMI blazars” corresponds to 0235-618, 0302-623, and 0308-611.

- TANAMI collaboration reported observations of 6 bright blazars locally compatible with the 2 first PeV IceCube events IC14 (Bert) and IC20 (Ernie)
- ANTARES 2007–2012 data
- Relevant constraints on spectral index of potential source
**Results from the ANTARES neutrino telescope**

**Diffuse fluxes**

**ANTARES 2007–2013 diffuse fluxes with showers**

( Nu#2 | L. Fusco)

**PRELIMINARY**

Sensitivity about 1.5 times larger than IceCube best fits (for $\gamma = 2.0$ and $\gamma = 2.5$)

- A first sample of 1405 days (out of 2007–2013 data) has been unblinded for the shower channel
- MC expectations: 5 background events (3 atmospheric muons, 2 atmospheric neutrinos) + 2 signal events (depending on the spectral index, for all flavour)
- 7 events observed in data: Compatible with expectations for background + signal, excess not significant, but more data are being analysed
- Sensitivities computed for 2007–2015 data with tracks and showers (combined $1/S = 1/S_{tr} + 1/S_{sh}$): could reach IC flux?
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Diffuse fluxes

ANTARES 2008–2013 about Fermi bubbles

( Nu#2 | L. Fusco)

- Hallmann, ICRC2015 1059
- Muon tracks in 2008–2013 ANTARES data
- 4 OFF zones selected: same shape, efficiency and coverage than ON zone
- 13 background events expected and 22 events observed in data: \(1.9\sigma\) excess
"Constrains on the neutrino emission from the Galactic Ridge with the ANTARES telescope”, accepted for publication on PhyLettB

Muon tracks in 2007–2013 ANTARES data

9 OFF zones selected: same shape, efficiency and coverage than ON zone

3.7 background events expected and 2 events observed in data: underfluctuation
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Diffuse fluxes

ANTARES May/2010–Nov/2012
time correlation with IceCube HESE 3yr

(ν#2 | L. Fusco)

Upper limits from null observation:
exclude that 2 or more IceCube HESE 3yr originate from the region around the GC for flares ranging from 0.5 to 0.01 days in duration for $E^{-2.5}$ to $E^{-2}$ spectra

- Coleiro, ICRC2015 1073
- Transient source at Sgr A* might be the origin of a few IceCube events (Bai et al. 2014)
- Searched for time correlation between 9 IceCube HESE 3yr and ANTARES events close to the GC
- No significant time correlation was found
Alert triggered by LIGO on 14/SEP/2015: first Gravitational Wave detected


...see GW | A. Coleiro talk a bit later!
Skymap of triggers with (black triangles) and without (red triangles) early optical follow-up.

- TAROT–ANTARES Target of Opportunity: electromagnetic follow up of neutrino alerts
- Optical (TAROT, ROTSE and MASTER) and X-ray (Swift-BAT) telescopes
- Update of the GRBs limits
- ...also covered on GW | A. Coleiro talk a bit later!
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Multi-messengers

ANTARES 2008–2012 about X-ray binaries

- Sánchez-Losa & Dornic, ICRC2015 1075
- 1044 days of livetime of muon tracks during 2008–2012
- Study of 33 XRBs during X-ray flares, 8 of them also during hardness transition states
- Time signal: X-ray light curves from Swift-BAT, RXTE-ASM and MAXI, transition states from “The Astronomer’s Telegram” alerts
- No significant excess: best post-trial 72% for GX 1+4
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Multi-messengers

ANTARES 2008–2012 about X-ray binaries

- Upper limits on neutrino fluence during studied periods
- Constrains on model parameters
- ...also covered on GW | A. Coleiro talk a bit later!
Brightest GRBs detectable from ANTARES within 2008 and 2013: GRB080916C, GRB110918A, GRB130427A and GRB130505A

Two neutrino production models studied: *internal shock* and *photospheric*

10° around GRB during its detection (7s–100s) ±2s around

No neutrino in coincidence: upper limits and constrains on baryonic loading factor and bulk Lorentz
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**Dark Matter**

**ANTARES 2007–2012 about Dark Matter on the Galactic Center**

(  DM  |  C. Tönnis)

- “Search of Dark Matter Annihilation in the Galactic Centre using the ANTARES Neutrino Telescope”, JCAP10(2015)068
- 1321 days of livetime of muon tracks during 2007–2012
- Competitive results, constraining SUSY dark matter... upcoming new data
Results from the ANTARES neutrino telescope

**Dark Matter**

**ANTARES 2007–2012 about Dark Matter on the Sun**

(\(\text{DM} \mid \text{C. Tönnis}\))

- "Limits on Dark Matter Annihilation in the Sun using the ANTARES Neutrino Telescope", accepted by PhL B (May 6th 2016), arXiv:1603.02228
- 1321 days of livetime of muon tracks during 2007–2012
Results from the ANTARES neutrino telescope

Dark Matter

ANTARES 2007–2012 about Secluded Dark Matter

- “Results of the search for Secluded Dark Matter in the Sun with the ANTARES neutrino telescope”, JCAP05(2016)016
- Dark matter secluded by a mediator: detection by mediator eventually decays in neutrinos
- Sun as the source candidate
- 1321 days of livetime of muon tracks during 2007–2012
- Limits inferred in the absence of excess of signal
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Dark Matter

ANTARES 2007–2012 about Dark Matter search from the Earth

Blue lines: $\tau^+\tau^-$ channel
Magenta lines: $b\bar{b}$ channel
Green lines: $W^+W^-$ channel
Dotted lines: BAKSAN (1978–2009)
Dot-Dashed lines: IceCube (2010–2011)
Black line: XENON100 (2012)
Red line: LUX (2013)

- Gleixner & Tönnis, ICRC2015 1110
- 1191 days of livetime of muon tracks during 2007–2012
- In this search no equilibrium between annihilation and capture can be assumed
1. ANTARES is the biggest neutrino telescope underwater and the biggest in the northern hemisphere
2. High duty cycle and an instantaneous field of view of $2\pi$
3. Good visibility of the GC and most of the GP
4. Presented analysis:
   - First combined IceCube–ANTARES analysis
   - PS update including showers
   - GC/IC-HS PS studies
   - TANAMI–ANTARES about IC HESE
   - Diffuse fluxes with showers
   - Fermi bubbles
   - Galactic Ridge
   - Time correlation with IC HESE
5. Important highlights:
   - First results on diffuse flux with showers in ANTARES
   - IceCube signal confirmation seems around the corner
   - Many promising tracks + showers analysis with data up to 2015 are on going... keep tuned!
   - ...and future is today: see talk on KM3NeT by CR&$\gamma$ | J. Brunner!