ANTARES and KM3NeT:
Latest results of the neutrino telescopes in the Mediterranean

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on behalf of ANTARES and KM3NeT collaborations
ANTARES and KM3NeT:
Latest results of the neutrino telescopes in the Mediterranean

• Neutrino astronomy
• ANTARES and KM3NeT detectors
• Detector performances
• ANTARES latest results
• KM3NeT status and expected results
• Conclusions
Neutrino astrophysics

Charged Cosmic Rays
✔ Copiously produced
✘ Directions scrambled by magnetic fields

High Energy Gamma Rays
✔ Produced both by hadronic and leptonic mechanisms
✘ Absorbed on dust and radiation

UltraHigh Energy Cosmic Rays
✔ Not strongly deflected by magnetic field
✘ Limited by GZK cut-off

Neutrinos
✔ Not affected by magnetic fields and radiation, not absorbed by matter
✘ Very low interaction cross section
Neutrino detection principle

An array of PMT detects the Cherenkov light induced by the particles produced in the neutrino interaction.

The measurement of position and time of the detected photon allows the reconstruction of the direction and the energy of the event.
The ANTARES detector

- Completed 2008
- 2450m depth
- 12 lines
- 25 storeys/line
- 3x10-inch PMTs/storey
- 885 10” PMTs
- ~15 Mton instrumented
The KM3NeT detector

- 31 3”-PMTs in one digital optical module (DOM)
- 18 DOMs per string (Detection Unit, DU)
- 115 DUs per building block
KM3NeT ARCA & ORCA

**ARCA**
Astroparticle Research with Cosmics in the Abyss
Line distance = 90 m
Vertical DOM dist. = 36 m

**ORCA**
Oscillation Research with Cosmics in the Abyss
Line distance = 20 m
Vertical DOM dist. = 9 m

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Phase I (fully funded)

Phase 2 partially funded

ANTARES & KM3NeT collaborations

• since April 2017: Perth
• since May 2018: Sydney

~40 institutes
14 countries

2 sites:
- Toulon, FR
  ANTARES
  KM3NeT/ORCA
- Capo Passero, IT
  KM3NeT/ARCA

3d site under study
(Pylos, GR)
ANTARES vs KM3NeT-ARCA performances

**Tracks:**
- $\nu_\mu$ CC

**Showers:**
- $\nu_e$ CC, $\nu_{\text{all}}$ NC

**Angular Resolution:**
- ANTARES:
  - $\angle < 0.4$ deg @ $E_\nu > 10$ TeV
  - $\angle < 0.1$ deg @ $E_\nu > 100$ TeV

- KM3NeT:
  - $\angle < 3$ deg
  - $\angle < 2$ deg
KM3NeT-ORCA performance

Tracks

- Muon energy accuracy: $\Delta(\log_{10} E)=0.25-0.3$ @ $E > 10$ TeV
- Shower energy accuracy: 5-10% at $E >$ some 10 TeV
- Very good angular resolution helps enormously in source associations and enhances S/N ratio especially in point source analysis

Showers

$\nu_e$ CC events with containment cut

Angular resolution $\nu_e$ CC events with containment cut
Latest results from ANTARES

- Diffuse flux search
- Point-source search
- Galactic plane
- Multi-messenger strategies
  - Gravitational waves
  - Fast Radio Burst (FRB)
  - Bright Gamma Ray Burst (GRB)
- Moon shadow
Diffuse flux search

All-sky / All-flavor neutrino search (years 2007-2015)

Reconstructed events after quality cuts:

<table>
<thead>
<tr>
<th>Events per bin (2007 - 2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
</tr>
</tbody>
</table>

Bkg expectation | Signal expectation | N events measured

- **Tracks**:
  - 13.5+/−4
  - 3-3.5
  - 19

- **Showers**:
  - 10.5+/−4
  - 3-3.5
  - 14

Results compatible with IceCube diffuse flux:

- 1.6 σ excess
- Null cosmic neutrino contribution rejected at 85% CL

Most of the galactic gamma ray sources are in the southern sky

Best pointing from a N-Hemisphere telescope

Searches:
- Full-sky
- Candidate list
- Galactic centre
**Point-source flux search**

All-flavor neutrino search (years 2007-2015): 7622 track-like + 180 shower-like events

**Sensitivities and upper limits (90% C.L.)**

Most sensitive limits for a large fraction of Southern sky, especially at $E < 100$ TeV


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“KRA Gamma model” has been introduced recently to explain the high-energy gamma ray diffuse Galactic emission. This model reproduces Fermi & Milagro data.


Combined U.L. (ANTARES+ IceCube) excludes the diffuse Galactic neutrino emission as the major cause of the “spectral anomaly” between the two hemispheres measured by IceCube.

Relative contribution of ANTARES and IceCube →

stacked histo

stacked histo
Multi-messenger strategies

GeV-TeV γ-rays
Fermi, HESS, HAWC, CTA

neutrinos
IceCube, GVD, SNEWS

UHECR
Auger, TA
only spatial coincidence

Radio/Optic /X-ray
TAROT, MASTER, Swift, INTEGRAL, MWA

Receive alerts
Generate alerts

Gravitational Waves
VIRGO, LIGO

ANTARES

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Gravitational Waves

Recent spotlight on the GW events detected by the Ligo-Virgo Collaboration:
- GW150914 (BBH merger)
- GW151226 (BBH merger)
- LVT151012 (candidate)
- GW170104 (BBH merger)
- GW170817 (NS merger)

Neutrino follow-up on all of them, joint searches with IceCube (and also Pierre Auger Observatory)

So far no coincidences with neutrino from the region of interest at 90% C.L.:
- not so likely for BH-BH merging;
- the jet of the NS-NS event (GW170817) was not aligned to our Line of Sight to provide a visible neutrino signal → upper limit on the neutrino fluence from each events over the whole spectrum

ANTARES and a few KM3NeT lines operational for Virgo/LIGO run 03!
Fast Radio Bursts

- High galactic latitude
- Expected rate: \(\sim 10^3\) FRB/day/all sky

- Green bank
- Arecibo
- GBT
- Parkes
- UTMOST
- ASKAP

FrB 121102

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Fast radio bursts

12 fast radio burst selected for ANTARES analysis

90% C.L. ANTARES upper limits on the neutrino fluence for the power law spectral models with

- $\gamma = 1.0$ (blue)
- $\gamma = 2.0$ (red)
- $\gamma = 2.5$ (black)

for each FRB.
Bright gamma ray burst

4 bright GRB have been selected:
GRB080916C, GRB110918A, GRB130427A and GRB130505A

Upper limits
Two model investigated:
• photospheric
• internal shock

Constraints on baryonic component $f_p$ and Lorentz factor $\Gamma$
• 90% C.L. (solid line)
• 50% C.L. (dashed line)
One possibility to measure the pointing accuracy is to analyse the shadow of the Moon, i.e. the deficit in the atmospheric muon flux in the direction of the Moon induced by absorption of cosmic rays.

Moon shadow significance $3.5 \sigma$; Angular resolution $0.73^\circ \pm 0.14^\circ$

The position of the Moon shadow is consistent with not shifted pointing.
Latest results from KM3NeT

- Status and first detections
- KM3NeT-ARCA
  - Diffuse flux expected performance
  - Point-source expected performance
- KM3NeT-ORCA
  - Neutrino mass hierarchy sensitivity
**Status and first detections**

**ARCA**
- 3 strings deployed Dec 2015 & May 2016
- 2 out of 3 operated, string #3 with short in power system, recovered
- Full restoration of sea-bed network by mid-2019

**ORCA**
- Successful deployment & operation of first string (Sept 2017)
- Cable problem, replacement in summer 2018, resume operations thereafter

DOM and DU assembly proceeding. Deployment after repairs, consistent with schedule.
Diffuse flux performance (KM3NeT-ARCA)

Expected $5\sigma$ significance on diffuse IC flux in < 1 year:
Tracks per year:
• 6 signal
• 4 background
Cascades per years:
• 16 signal
• 9 background

KM3NeT and IceCube are complementarity in their field of view, energy range and flavour coverage

Point source performance (KM3NeT-ARCA)

KM3NeT-ARCA significance for two of the most promising sources. Significant discovery potential for extragalactic sources, complementing IceCube field of view.

Disclaimer: We compare detector sensitivities, not discovery potential at a given time, IceCube will have ~10 years of data when KM3NeT will start operation.
Neutrino Mass Hierarchy (KM3NeT-ORCA)

Signature of the neutrino mass hierarchy → energy-zenith distribution of atmospheric neutrinos

Measurement requires

- best possible resolution in energy and zenith
- separation $\nu_e/\nu_\mu$
- detailed understanding of systematics

Neutrino Mass Hierarchy (KM3NeT-ORCA)

Neutrino mass hierarchy significance


Measurement of $\sin^2 \theta_{23}$ and $\Delta m^2_{32}$

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Conclusions

• **ANTARES**
  - 18/6/18 10 year anniversary of ANTARES completion
  - Solid results from various searches of neutrino emission (point-like, diffuse, ...)
  - Rich multi-messenger program
  - Several combined analyses with IceCube

• **KM3NeT**
  - ARCA: Confirmation of IceCube flux in less than one year
  - ORCA: Competitive with JUNO, determination of neutrino mass hierarchy in ~3 years