KM3NET/ORCA: PERSPECTIVES AND MULTI-SEARCH POTENTIAL OF AN UNDERWATER NEUTRINO TELESCOPE

VHEPU 2018 - QUY NHON

ALBA DOMI - UNIVERSITÀ DEGLI STUDI DI GENOVA, CPPM MARSEILLE
Neutrino Telescopes: Science Scope

**Low Energy:**
MeV < \( E_\nu < 100 \) GeV

- \( \nu \) oscillations,
- Supernovae...

**Intermediate Energy:**
10 GeV < \( E_\nu < 1 \) TeV

- Dark Matter search,
- Monopoles...

**High Energy:**
\( E_\nu > 1 \) TeV

- \( \nu \) from extra-terrestrial sources...

---

KM3NeT/ORCA
KM3NeT/ORCA+ARCA
KM3NeT/ARCA
NEUTRINO TELESCOPES OVERVIEW

Higher Sensitivity to neutrino sources: “precision frontier”

Present neutrino detectors

Sensitivity at $\geq$EeV: “energy frontier”

KM3NeT

See Talk of Sergio Navas

ARA, ARIANNA, EVA, GRAND

Sensitivity at PeV energies: “intensity frontier”

IceCube gen 2

Credits: M. Ackerman
Why KM3NeT?

Event Topologies

Tracks: $\nu_\mu^\text{CC}, \nu_\tau^\text{CC} (\tau \rightarrow \mu)$

Showers: $\nu_e^\text{CC}, \nu^\text{NC}, \nu_\tau^\text{CC} (\tau \rightarrow e)$

Angular resolution KM3NeT vs IceCube

IceCube through-going mu arXiv: 1609.04981

KM3NeT

ARCA - Tracks

ARCA - Showers

Angle $\nu-\mu$ (intrinsic limit)
Why KM3NeT?
KM3NeT COLLABORATION

KM3NET LOI: DOI: 10.1088/0954-3899/43/8/084001

ORCA
(Oscillation Research with Cosmics in the Abyss)

ARCA
(Astroparticle Research with Cosmics in the Abyss)
DETECTION TECHNOLOGY

3 Building Blocks (BB):
- 115 Detection Units (DUs) per BB
- 18 Digital Optical Modules (DOMs) per DU
- 31 PMTs (3") per DOM (19↓, 12↑)

DOMs
- 18 DU
- 31 DOMs

PMTs
- 43 cm
- 3" PMTs

ARCA - h 700 m
ORCA - h 200 m
ORCA/ARCA DETECTORS

ORCA:
1 Dense building block optimised for intermediate energies (1-100 GeV)
Total of 64170 PMTs

ARCA:
2 Sparse building blocks optimised for high energies (>1 TeV)

<table>
<thead>
<tr>
<th></th>
<th>ORCA</th>
<th>ARCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>String spacing</td>
<td>23 m</td>
<td>90 m</td>
</tr>
<tr>
<td>Vertical spacing</td>
<td>9 m</td>
<td>36 m</td>
</tr>
<tr>
<td>Depth</td>
<td>2470 m</td>
<td>3500 m</td>
</tr>
<tr>
<td>Instrumented mass</td>
<td>1x 8 Mton</td>
<td>2x 0.6 Gton</td>
</tr>
</tbody>
</table>
ORCA: Neutrino Mass Ordering

Impact on:
- Magnitude and nature of neutrino mass.
- Distinguish between different theoretical models.
- Impact on $\beta\beta$ studies.
- Core-collapse supernovae.

Ref: W. Winter, DOI: 10.1063/1.4915577
ORCA: Measuring Mass Ordering with Atmospheric Neutrinos

- Free, Natural Beam of known composition ($\nu_e$, $\nu_\mu$).
- $\nu_e$ interaction with electrons.
- Oscillation pattern distorted by Earth’s matter effects: IO ↔ NO difference.

ORCA: Neutrino Mass Ordering

Approach: measure $E_\nu$ and $\theta_\nu$ of upgoing neutrinos.

$$\chi^2 = (N_{\text{NO}} - N_{\text{IO}})^2 |N_{\text{NO}} - N_{\text{IO}}| / N_{\text{NO}}$$

Ref: S. Bourret, L. Quinn: PoS Neutrino 2018
Tau Neutrino Appearance

- $\nu_\tau$ appearance tests unitarity of $3\nu$ mixing matrix and BSM theories.
- 20% deviation from unitarity can be detected with $5\sigma$ in 5 years.
- $\sim3000 \nu_\tau^{\text{CC}}$ events/year with full ORCA.
- $\nu_\tau$ events predominantly shower-like.

- Confirm exclusion of non-appearance (=0) already with 2 months of data

Ref: S. Hallmann PoS (ICRC 2017) 1025
ORCA: STERILE NEUTRINOS

Effects on tracks for both NMH and STERILE NEUTRINO

ORCA Sensitivity to 1 sterile neutrino for 1 year of data taking!
ORCA: Non Standard Interactions (NSI)

- ORCA sensitive to NSI effects of order 10% of the Fermi int.
- Direct bounds are more than 10x larger in some cases.
- ORCA improves over current atmospheric scale bounds.
- Limits competitive with global limits from oscillation.
ORCA: SUPERNOVAE

- Event by event reconstruction impossible due to low energy $\nu$.

- Really high $\nu$ flux from SN $\Rightarrow$ overall rise on PMTs counting rate!

- Background from K40, bioluminescence, muons $\Rightarrow$ cuts on PMTs multiplicities in a DOM + filter between different DOMs.
ORCA: DARK MATTER INDIRECT DETECTION

- DM annihilation in the Sun.
- $\nu$ production ($E > GeV$).
- Constrain DM-DM cross section.

ORCA sensitivity after 3 years of data taking

KM3NeT preliminary
ORCA: EARTH TOMOGRAPHY

- Atmospheric $\nu$ crossing the Earth.
- $E_\nu$ and $\theta_\nu$ of upgoing neutrinos also provide tomographic information complementary to the standard geophysics methods.
- ORCA: sensitive to electron density $N_e$ while geophysics measure $\rho_m$

Ref: V. Van Elewyck, S. Bourret, J. Coelho
PoS(ICRC2017)1020
POSSIBLE EXTENSIONS:
P2O -> Protvino2ORCA Beam

Protvino U70 proton accelerator:
- 2-7 GeV Neutrino Beam (to be constructed).
- Sensitivity to Mass Ordering at least $5\sigma$ after 1 year of beam.
- Sensitivity to measure CP phase.

Ref: Brunner, arXiv:1304.6230
POSSIBLE EXTENSIONS:
Super-ORCA

- Task: Measure $\delta_{CP}$ with atmospheric neutrinos.
  - Possible with $\nu$ energies $\lesssim 3$ GeV → below ORCA's energy threshold!
  - Precise flavour identification, better energy and direction resolution needed.
    → 5-10x denser detector.
    → Assumed ~115k 3” PMTs/Mton
    → ~1% density of SuperK

Ref: J. Hofestädt, T. Eberl, M. Bruchner, Neutrino 2018
**ORCA: CONSTRUCTION STATUS**

- **Main Cable, 2015**
- **1st node: May 2015, Sept 2016**
- **Node deployment: 29 Sept 2016**

- **22 September 2017: First ORCA string**

- **Video:** [https://tiny.cc/OrcaDeployment](https://tiny.cc/OrcaDeployment)

- Data taking currently interrupted: replacement of deep sea part of main cable.
- **Phase 1 (funded):** 7 string array at KM3NeT-France site to demonstrate technology/detection methods in the GeV range ➞ deployment of 4 lines planned after summer 2018!
- **Phase 2:** Deploy 1 building block (115 strings).
ORCA: FIRST EVENTS WITH SINGLE LINE

A Muon Bundle

Upward going neutrino
ORCA: FIRST NEUTRINO ANALYSIS

82 days of data taken with first ORCA line!

KM3NeT Preliminary

<table>
<thead>
<tr>
<th>Events in $\cos(\theta)&lt;0$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>observed:</td>
<td>13</td>
</tr>
<tr>
<td>atm. muon</td>
<td>1</td>
</tr>
<tr>
<td>atm. neutrino</td>
<td>8.33</td>
</tr>
<tr>
<td>- $\nu\mu$</td>
<td>5.44</td>
</tr>
<tr>
<td>- $\nu\bar{e}$</td>
<td>1.36</td>
</tr>
<tr>
<td>- $\nu\tau$</td>
<td>0.96</td>
</tr>
<tr>
<td>- $\nu$ NC</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Atmospheric Muons

Excellent data-MC agreement.

Fewer muons seen at larger depths.
KM3NeT/ORCA intermediate energy neutrino telescope

- Main purpose: NMH determination
- Big multi-search potential in other physics topics: sterile neutrinos, NSI, Dark Matter, Supernovae...
- Construction has started
Thank you!!!
Backup slides
Resolution for ORCA

ORCA Tracks reconstruction performance

ORCA Showers reconstruction performance