HIGH-ENERGY NEUTRINO ASTRONOMY WITH KM3NeT/ARCA

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KM3NeT is a research infrastructure in the Mediterranean Sea hosting neutrino detectors

- **KM3NeT/ARCA** (*Astroparticle Research with Cosmics in the Abyss* this talk)
  
  - discovery and observation of high energy (GeV ÷ PeV) neutrino sources a telescope offshore Capo Passero (Sicily-Italy) is in construction at a depth of 3500m

- **KM3NeT/ORCA** (*Oscillation Research with Cosmics in the Abyss* talk of J. Hofestadt)
  
  - determination of the neutrino mass hierarchy a detector offshore Toulon (France) able to detect neutrinos of tens of GeV is in construction at a depth of 2500m

**ORCA and ARCA same detector technology**

Details on the ARCA and ORCA physics performances and on the technical design in the recently published Letter of Intent

*Letter of intent for KM3NeT 2.0*
The ARCA detector is made of 2 building blocks of 115 Detection Units (DU) each with 90 m DU interspacing (0.5 km³/block).

The DU is a vertical slender string equipped with 18 Digital Optical Modules (DOM) 36 m distant. Each DOM consists of 31 3” PMTs.

- Power and data distributed by a single backbone cable with breakouts at DOMs.
- Sea network of submarine cables and Junction Boxes connected to shore via a main e/o cable.
- All data to shore.

The optical sensor: the Digital Optical Module (DOM)
The DOM is a new design for optical sensors developed in the collaboration. It is a 17” glass sphere with inside:

- 31 3” PMTs (photocathode area $\approx 3 \times 10$” PMTs)
- LED and Piezo
- FPGA readout

Hybrid white rabbit for time synchronization

DWDM for data transmission

The Launcher vehicle (2m diameter)

- rapid deployment
- autonomous unfurling
- recoverable
The DOM Prototype

DOM prototype deployed at Antares site April 2013

Validation of DOM capabilities in situ

Proved that with a single DOM the selection of events from atmospheric muons is possible

THE DU PROTOTYPE
String prototype (3 DOMs) deployed at Capo Passero site May 2014

Time difference between PMTs in the same DOM (2-fold from $^{40}$K)

Proved that the time calibration between PMTs in the same DOM and between DOMs is feasible in a fast and reliable way

## THE KM3NET PHASED IMPLEMENTATION

<table>
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<th>Phase</th>
<th>Building blocks</th>
<th>Number of DUs</th>
<th>Physics goal</th>
<th>Status</th>
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KM3NET-PHASE1: THE FIRST DUS INSTALLED

Two lines in operation at Capo Passero site: the first one deployed in December 2015, the second one in May 2016.

ARCA phase-1 footprint

CTF: Cable Termination (Frame)
- Secondary Junction boxes
- Tower DU
- String DU
- PPM-DU

Junction Box

ARCA DU1 at the sea bottom

Capo Passero shore station

ECRS 2016 - Torino 4-9 September 2016
Comparison of calibration with LED nanobeacons and atmospheric muons in agreement. In situ nanobeacon calibration and on-shore laser calibration agree to $\approx 1$ ns

Rate of high coincidence events in the DOMs reflects the behavior of the atmospheric muon intensity as a function of the depth
THE KM3NET/ARCA PECULIARITIES

Current knowledge:

- Origin of the detected IceCube cosmic flux not yet known. Tension in the energy slope of the measured high energy muon neutrinos from Northern Hemisphere and the full sky all flavour data. Presence of a galactic component not excluded (arXiv:1607.08006)

- High energy neutrinos from known sources not yet observed.

KM3NeT-ARCA can probe the Universe from a different field of view with a better angular resolution

- KM3NeT visibility for up-going muons

- Sea water is a clean and homogeneous medium
THE KM3NET/ARCA LAYOUT

**KM3NeT-ARCA**: two building blocks of 115 DUs (together about 1 km$^3$) being installed at the Italian site at 3500m

- 18 DOM per DU
- Vertical DOM spacing 36 m
- Inter-DU spacing 90 m
THE KM3NET/ARCA RESOLUTION FOR “TRACK-LIKE” EVENTS

“Track-like” events mainly from $\nu_\mu$ CC interactions

Angular resolution better than $0.2^\circ$ for $E_\nu > 10$ TeV and $0.1^\circ$ for $E_\nu > 100$ TeV

Energy resolution better $\approx 20\%$ of the $\log_{10}E_\mu$ for $E_\mu > 10$ TeV
THE KM3NET/ARCA RESOLUTION FOR “CASCADE” EVENTS

“Cascade-like” events mainly from $\nu_e$ CC and NC interactions

Angular resolution better than 2°

Energy resolution better $\approx 5\%$ at 1$\sigma$

ECRS 2016 - Torino 4-9 September 2016
**DIFFUSE FLUX**

Benchmark flux: IceCube flux (isotropic and flavour symmetric)

\[
\Phi(E) = 1.2 \cdot 10^{-8} \left(\frac{E}{1 \text{ GeV}}\right)^{-2} \exp\left(-\frac{E}{3 \text{ PeV}}\right) \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}
\]

- **Track channel**
  Analysis for up-going events based on maximum likelihood of preselected events. Pre-cuts on \(\theta_{\text{zen}} > 80^\circ\), reconstruction quality parameter and \(N_{\text{hit}}\) (proxy for muon energy)

- **Cascade channel**
  Containment cut on reconstructed vertex to remove atmospheric muons (excludes upper 100m layer)
  All sky analysis based on BDT and maximum likelihood.

Discovery at 5\(\sigma\) (50% probability) in less than one year

**DIFFUSE FLUX FROM GALACTIC PLANE**

Benchmark flux from D. Gaggero et al., proceedings ICRC2015. Evaluation of the neutrino flux based on a radially-dependent cosmic-ray transport properties

**Discovery at 5σ (50% probability) in about 5 years**

**GALACTIC SOURCES**

The SNR RXJ1713 and the PWN Vela X

Spectra cutoffs of the order of few tens of TeV

Extension of the sources taken into account (0.6° for RXJ1713 and 0.8° for VelaX)

Assumed Neutrino Spectra


**KM3NeT**

- VelaX
- $\nu_{\text{atm}}$ conventional uncertainty
- RXJ1713.7-3946
- $\nu_{\text{atm}}$ conventional uncertainty

**Observation time [years]**

- 0
- 2
- 4
- 6
- 8
- 10
- 12

**Significance [$\sigma$]**

- 0
- 1
- 2
- 3
- 4
- 5


RXJ1713 ➔ Discovery at 3$\sigma$ (50% probability) in $\approx$ 4 years

VelaX ➔ Discovery at 3$\sigma$ (50% probability) in $\approx$ 2 years

*Results based on the old track reconstruction*
POINT-LIKE SOURCES*

Benchmark flux proportional to $E^{-2}$ flux

Better sensitivity (for equivalent exposure) and better sky coverage than IceCube

KM3NeT will soon take over from ANTARES as the biggest detector in the Northern Hemisphere (KM3NeT phase-1 will be \( \approx 0.1 \text{ km}^3 \))

★ KM3NeT phase-1: 2 DUs of ARCA already installed and fully functioning at the Italian site

★ Following phase KM3NeT 2.0

★ KM3NeT/ARCA (\( \approx 1 \text{ km}^3 \)) will be installed at the Italian node of the KM3NeT distributed infrastructure

★ Exciting physics prospects

★ Investigate the neutrino sky with unprecedented resolution and sky coverage
Back up slides
Total KM3NeT cost: 125M€ (ARCA+ORCA)