NEMO
a status report

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Laboratori Nazionali del Sud

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Outline

- R&D activities
  - Site exploration
  - Preliminary design of a km3 detector
- NEMO Phase-1
  - Aims and objectives of the project
  - Results and lessons learned
- NEMO Phase-2
  - The Capo Passero shore and deep-sea infrastructures
  - Developments of the technologies for the telescope construction
- Conclusions and prospects
  - The contribution of NEMO to the KM3NeT European consortium
NEMO: a brief history

- R&D activity towards the km$^3$ started in 1998
- Search and characterization of an optimal deep-sea site
- Feasibility study and definition of a preliminary project of the km$^3$
- Development of innovative technological solutions for the km$^3$
  - Low power electronics
  - Directional PMTs
- Advanced R&D activities to validate the proposed technologies
  - Phase-1 and Phase-2 projects
The NEMO collaboration

**INFN**
Bari, Bologna, Catania, Genova, LNF, LNS, Napoli, Pisa, Roma
Università
Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma “La Sapienza”

**CNR**
Istituto di Oceanografia Fisica, La Spezia
Istituto di Biologia del Mare, Venezia
Istituto Sperimentale Talassografico, Messina

**INGV**
Istituto Nazionale di Geofisica e Vulcanologia (INGV)

**OGS**
Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS)

**ISCTI**
Istituto Superiore delle Comunicazioni e delle Tecnologie dell’Informazione (ISCTI)

More than 80 researchers from INFN and other italian institutes
The Capo Passero deep-sea site has been proposed in January 2003 to ApPEC as a candidate for the km3 installation.

- Depths of more than 3500 m are reached at about 100 km distance from the shore.
- Water optical properties are the best observed in the studied sites ($L_a \approx 70$ m @ $\lambda = 440$ nm).
- Optical background from bioluminescence is extremely low.
- Stable water characteristics.
- Deep sea water currents are low and stable (3 cm/s avg., 10 cm/s peak).
- Wide abyssal plain, far from the shelf break, allows for possible reconfigurations of the detector layout.
Seasonal dependence of optical properties

Absorption and attenuation lengths
(for $\lambda=440$ nm)

- $L_a = 66.3$ m
- $L_t = 55.5$ m

Average values $2850\div3250$ m

Absorption length values are compatible with optically pure sea water

Optical background

Data taken in collaboration with ANTARES

- PMT: 10"
- Thres: ~.5 SPE

Dead time: Fraction of time with rate > 200 kHz

The measured value of 30 kHz is compatible with pure $^{40}$K background

No seasonal dependence observed
km3 architecture: the NEMO proposal

- Detector based on tower-like structures with horizontal extent
- Non homogenous distribution of sensors
- Vertical sequence of “storeys”
- Structure packable for integration and deployment
Several different seafloor layouts have been considered and simulated.
Sensitivity to a point like source (\( \alpha = -2 \) and declination -60°) as a function of observation time


<table>
<thead>
<tr>
<th>years</th>
<th>Ratio IceCube/127 torri</th>
<th>Ratio IceCube/91torri</th>
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<tbody>
<tr>
<td>1</td>
<td>2.7</td>
<td>1.9</td>
</tr>
<tr>
<td>3</td>
<td>3.1</td>
<td>2.2</td>
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<tr>
<td>5</td>
<td>3.5</td>
<td>2.4</td>
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NEMO Phase-1
P. Piattelli

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NEMO Fase-1

Shore laboratory, Port of Catania

25 km E offshore Catania
2000 m depth

TSS Frame
Buoy
Junction Box
e.o. connection
e.o. cable from shore
10 optical fibre, 6 conductors

NEMO mini-tower
(4 floors, 16 OM)

Junction Box

Mini-Tower unfurled

Mini-Tower compacted

03 04

300 m
Deployment and connection

Phase-1
installed in
december
2006 at the
Catania
Test Site
(2000 m
depth)
- Fully operative for 6 months (commissioning and data taking)
- Many critical items and solutions validated
  - Concept of “tower” with horizontal extent
  - Deployment of a compact structure with unfurling on the seabed
  - Double containment pressure vessels
  - “All-data-to-shore” synchronous acquisition
  - Low power electronics
  - Calibration (time and position) techniques
- Some technical problems encountered
  - Loss of buoyancy in the tower
  - Electro-optical penetrators in the Junction Box
- JB problems solved by replacing the defective components
- JB redeployed in 2008 and presently working
- Five months of data analysed
- “Lessons learned” fundamental for further developments
Scheme of the prototype tower

- **Fours floors**
  - Length 15 m
  - Vertical spacing 40 m
- **16 Optical Modules with 10” PMT**
- **Acoustic Positioning**
  - 2 hydrophones per floor
  - 1 beacon on the tower base
- **Environmental instrumentation**
  - 1 compass + tiltmeter in each Floor
  - Control Module
  - CTD (Conductivity-Temperature-Depth) probe on floor 1
  - C* (attenuation length meter) on floor 2
  - ADCP (Acoustic Doppler Profiler (including compass) on floor 4
Acoustic positioning system

Distance H0-H1 measured on floor 2 during 6 hours (1 Feb h.17-23)

Each point is averaged in 300 s

Construction
14.25±0.01

AP measure
14.24±0.06

Accuracy better than the required 10 cm
The instantaneous rate value is calculated by the Front-End board of the PMT averaging, in a time window of 1 µs, all the hits whose amplitude exceeds a given threshold equivalent to 0.3 spe.

The average measured rates are about 80 kHz for PMTs on floors 2, 3 and 4 as expected from $^{40}$K decay plus a contribution of diffuse bioluminescence.
Atmospheric muon angular distribution

23-24 January, 2007:

LiveTime: 11.31 hours
OnLine Trigger: $\sim 6 \cdot 10^7$
OffLine Trigger (7 seeds): 184709
Reconstructed tracks: 2260
Selected tracks: 965
Vertical Muon intensity as a function of depth from data recorded on 23-24 Jan, 2007
Compared with the relation from
NEMO Phase-2
STATUS
- 100 km electro-optical cable (>50 kW, 20 fibres) deployed in July 2007
- DC/DC power converter built by Alcatel tested and working; installation in July 2009
- On-shore laboratory (1000 m²) inside the harbour area of Portopalo completed
The Alcatel DC/DC system

System based on an innovative 10 kW DC/DC converter specifically designed by Alcatel for deep-sea applications

A final prototype of the DC/DC converter has been tested at full load in realistic conditions
Test of the DC/DC converter

- **Power Supply**: 10 kW
- **Artificial Line**: 100 km
- **MVC**: 10 kW, 10 kV / 400 V
Upgrades in the tower design

- DC power system to comply with the feeding system provided by Alcatel
- Data transmission system
- Segmented electro-optical backbone
- Acoustic system integrating both positioning and acoustic detection systems
KM3NeT

- European Consortium involving 40 Institutes from 10 countries
- Design Study project (FP6)
  - Define the technologies for the construction of the km3
- Preparatory Phase project (FP7)
  - Define the governance, legal and financial issues and prepare plans for construction of the Research Infrastructure
Convergence in KM3NeT

- Three full designs are presently considered in KM3NeT
- The final choice will be based on detector sensitivity, cost and reliability
- One of the designs, developed by INFN and IN2P3, is largely based on the experience and technical solutions developed in NEMO and ANTARES
  - Tower with horizontal extent
  - Packable structure for integration and deployment with unfurling on the seabed
  - Synchronous all-data-to-shore readout
  - DC power feeding system
New data daisy chain data transmission system

The link is bidirectional with asymmetric data rates:
- Up-going link @163.84 Mb/s for timing and slow control
- Down-going link @1.18 Gb/s for physics data and control

All nodes are identical
The system can be implemented using either a fibre or a copper backbone
“Daisy Chain” connections

Optical modules

Floor electronics module

Optical backbone

Electrical backbone

Optical connector

Electrical connectors

Hidrophone connector

Electrical connector to OM
## Power distribution network

### POWER BUDGET

<table>
<thead>
<tr>
<th></th>
<th>N° DU</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>84</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Power per DU</td>
<td>300 W</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DUs total power</strong></td>
<td>25,2 kW</td>
<td>36 kW</td>
<td></td>
</tr>
<tr>
<td>Cable Losses &lt; 4%</td>
<td>1 kW</td>
<td>1,5 kW</td>
<td></td>
</tr>
<tr>
<td>Cable voltage drops%</td>
<td>&lt; 4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Power off-shore</td>
<td>26,2 kW</td>
<td>37,5 kW</td>
<td></td>
</tr>
<tr>
<td>MVC losses ((\eta=80%))</td>
<td>6,6 kW</td>
<td>9,4 kW</td>
<td></td>
</tr>
<tr>
<td>Main Cable losses</td>
<td>1,7 kW</td>
<td>3,5</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL POWER LOSSES</strong></td>
<td>27%</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td><strong>POWER ON SHORE</strong></td>
<td>34,5 kW</td>
<td>50,4 kW</td>
<td></td>
</tr>
</tbody>
</table>

- Electo-Optical Cable
- 100 Km
- 10 K

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One idea for the seabed layout and cable network
Optical network to shore

- Ring topology based on circulators: doubled offshore and onshore to achieve 100% redundancy;
- 1 ring can support as many DUs as fiber bandwidth allows;
- Standard ITU frequency grids accommodate up to 60 ÷ 132 colors (100 GHz or 50 GHz grid spacing)
- 3 rings are needed to transport 120 DUs;
- 6 fibers of the Main Electro Optical Cable are used to setup the 3 rings between shore and subsea;
Near future plans

- Test of a “mechanical” tower in May-June 2009 to validate the structure and the new buoy design at 3500 m depth

- Building of a fully equipped tower with a reduced number of floors to test the technological solutions proposed in KM3NeT (in collaboration with the IN2P3 groups) to be deployed in spring 2010
Conclusions …

- In a ten year long activity NEMO has provided significant contributions towards the km3 detector
  - Identification of an optimal deep-sea site
  - Development and test of technologies for the telescope construction

- The NEMO collaboration is presently taking part in the KM3NeT EU consortium
... and outlook

- For the construction of the KM3NeT European Research Infrastructure a multi-site option is also being considered.
- This option fits a funding scheme in which most of the funding will come on a regional basis.
- The assessment of the single vs multi-site option will be done within the Preparatory Phase project, but preliminary results indicate that a multi-site telescope has at least the same sensitivity than a single one.
- Initiatives to get fundings are under way in several countries (France, Greece, Italy, The Netherlands).
- In Italy the Sicilian Regional Government has proposed the funding of a km3 size detector on national funds for the less developed regions.