The KM3NeT deep sea neutrino telescope project

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- Neutrino astronomy: why and how
- The KM3NeT project: physics goals & technical constraints
- Technical design & optimization
- Expected performance
- Timeline and perspectives
Neutrino astronomy: motivations

- **Long-range, deep-source messenger:**
  - no interactions (or weak/gravitational ones) with ambient matter & radiation,
  - no deflection by magnetic fields
  - carry information on the internal processes of the astrophysical engines,
  - unaccessible through photons or hadrons

- **Unique probe of fundamental processes:**
  - origin of UHE cosmic rays?
  - production mechanism of HE gamma-rays (hadronic vs leptonic) ?
  - nature of dark matter?

- **Discovery potential for hidden sources** (not detected through E-M radiation)
Detection principle

Use Earth as a shielding against atmospheric muons

Detector

3D network of photomultipliers

WATER/ICE
(transparent medium)

ROCK

Cherenkov light cone

Time, position & amplitude of hits: allow to reconstruct the arrival direction of the neutrino

golden channel for astronomy (but $\nu_e, \nu_\tau$-induced showers also interesting)
Mediterranean telescopes:

- **ICE CUBE**:
  - 86 strings in 2011
  - ~ 1 km$^3$ instrumented volume
  - IC59 analysis ongoing

- **ANTARES (Toulon)**:
  - 12 lines operating since 2008, ~ 0.015 km$^3$ instrumented volume
  - 2007-2009 data analysis ongoing (5L → 12L)

- **NEMO (Capo Passero, Italy)**
- **NESTOR (Pylos, Greece)**
  - Prototyping phase

- **LAKE BAikal**:
  - NT200+ since 2005
  - Since 2008: 2 prototype strings for a km$^3$-scale detector

- **WORLD MAP OF NEUTRINO TELESCOPES**

Ice Cube: 86 strings in 2011
~ 1 km$^3$ instrumented volume
IC59 analysis ongoing
Ice Cube:
- 79 strings since 2010,
- Completion expected by 2011
- ~1 km$^3$ instrumented volume
- IC59 analysis ongoing

Lake Baikal:
- NT200+ since 2005
- Since 2008: 1 prototype string

ANTARES (Toulon):
- 12 lines operating since 2008, ~0.015 km$^3$
- Instrumented volume
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NEMO (Capo Passero, Italy)
- NESTOR (Pylos, Greece)
- Prototyping phase

**ANTARES + NEMO + NESTOR**

joined efforts to build a (few) km$^3$-sized neutrino telescope in the Mediterranean:

**KM3NeT consortium**

- 40 Institutes from 10 European countries (CY, DE, F, GR, I, IR, NL, RO, ES, UK)
- Mainly Astroparticle Physics, but also several Marine & Earth Science Institutes

**MAIN OBJECTIVES:**

- Neutrino astronomy in the Southern sky
- Exceed IceCube sensitivity by substantial factor
- >10 yr operation without major maintenance
- Provide infrastructure for Marine & Earth Sciences

**OVERALL BUDGET:** ≤ 250 M€
Central physics goal: investigate (extra-)galactic neutrino “point sources” (steady and transients) in the energy regime 1-100 TeV

Exceed IceCube sensitivity: several km$^3$ needed

Complement IceCube field of view

Integrated visibility: $\sim 3.5\pi$ (visibility of individual sources can be < 100% at KM3NeT latitude)

Optimal sensitivity for Galactic sources

(assuming instantaneous $2\pi$ downward coverage)
Other important physics items:
★ High energy diffuse neutrino flux detection
★ GZK neutrinos and link with UHE cosmic rays
★ Indirect search for Dark Matter
★ Neutrino particle physics aspects
★ Exotics (Magnetic Monopoles, Lorentz invariance violation, ...)

Interdisciplinary research
★ marine biology
★ geology/geophysics,
★ oceanography,
★ environmental studies & alerts
Technical constraints

MAIN GOAL: mechanically support a 3D array of optical sensors and connect them to shore (power, slow control, data transmission)

★ Site & environmental constraints:
  - 3–5 km depth tests at 600 bars
  - 40-100 km offshore long-distance data transmission
  - salinity of sea water resistance to chemically aggressive medium
  - sea currents flexible structure
  - optical background from $^{40}$K decay local coincidences required

★ Implementation:
  - construction time < 5 years
  - reliable & efficient deployment strategy
  - operation over at least 10 years without major maintenance

★ Main performance targets:
  - position resolution of optical modules < 40 cm
  - single-photon time resolution < 2 ns
  - dark noise rate < 20% of $^{40}$K rate
  - optical module failure rate < 10% over 10 years
Technical design

Addressed during the **KM3NeT Design Study (DS)** (funded by EC FP6 2006-2009)
- 2008: Conceptual Design Report (CDR)
- 2010: Technical Design Report (TDR)
outlines the main technological options for the construction, deployment and maintenance of a deep-sea neutrino telescope

Research Infrastructure:
**building blocks (BB)** made of **detection units (DU)** made of **storeys**

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**Technical items:**
- Optical Modules
- Front-end electronics
- Readout, data acquisition, data transport
- Mechanical structures, backbone cable
- General deployment strategy
- Sea-bed network: cables, junction boxes
- Calibration devices
- Shore infrastructure
- Assembly, transport, logistics
- Risk analysis and quality control
Optical modules

Multi-PMT Optical Module
31 small PMTs (3”) inside a 17” (~ANTARES) glass sphere

- 31 PMT bases (total ~140 mW)
- cooling shield and stem
- single penetrator
- readout electronics inside OM
- total photocathode area equivalent to 3 x 10” PMTs

local coïncidences, directional information

In situ tests on ANTARES Instrumentation Line
In summer 2011
Detector units

Local 3D arrangement of optical modules help resolve ambiguities in the reconstruction of the muon track

Flexible tower with horizontal bars

20 bars equipped with 2 multi-PMT OMs:
Deployment strategy

★ Requirements:
- compact package
- self-unfurling
- connection to seabed network by remotely operated vehicle (ROV):

Packaged bars: unfurling « «from top to bottom »

successfull deployment test in February 2010:
Critical parameters: size and spacing of the detector units

- **Bar length**
  - ratio of effective areas wrt. 3 m bar

- **DU separation**
  - ratio of effective areas wrt. 100 m spacing

### Optimization studies

#### Low energy region
- $100 \text{GeV} < E_\nu < 500 \text{ GeV}$
- Quality cuts applied
  - $\Delta \Omega_{\mu^{-},\text{rec}} \approx 2^\circ$
  - (close to the $\Delta \Omega_{\nu^{-}}$)

#### Point like sources
- $3 \text{ TeV} < E_\nu < 100 \text{ TeV}$
- Quality cuts applied
  - $\Delta \Omega_{\mu^{-},\text{rec}} \approx 0.4^\circ$
  - (close to the search cone radius)

#### Diffuse flux studies & GRB
- $E_\nu > 100 \text{ TeV}$
- No quality cuts applied
  - $\Delta \Omega_{\mu^{-},\text{rec}} \leq 0.9^\circ$
Optimization studies

Critical parameters: size and spacing of the detector units

- Bar length
  - ratio of effective areas wrt. 3 m bar
- DU separation
  - ratio of effective areas wrt. 100 m spacing

Preferred length of the bar: 6m
compromise between physical performance and technical constraints
Optimization studies

Critical parameters: size and spacing of the detector units

Preferred distance between DU: 180 m

(neutrino flux \( \sim E^{-\alpha} \), all energies, no cut-off)

DU separation

ratio of effective areas wrt. 100 m spacing

Bar length

Neutrino flux

DU separation

No quality cuts applied
\( \Delta \Omega_{\mu} \leq 0.9^\circ \)
Angular resolution
(median of $\Delta \Omega \nu-\mu$ rec.)

Dominated by kinematics at low energy

Neutrino effective area

Quality Cuts optimized for point source searches

Loose quality cuts applied
Expected performances

- Sensitivity to neutrino point sources, flux $\sim E^{-2}$

1 year operation

Observed galactic $\text{TeV } \gamma$-ray sources


$\star$: Galactic Center
Expected performances

★ Expected number of events in 5 years observation time for some Galactic sources: (inside optimized cone)

<table>
<thead>
<tr>
<th>Source Name</th>
<th>Source radius (°)</th>
<th>Visibility</th>
<th>Number of events For ( E_\gamma &gt; 5 ) TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Signal ( \nu )</td>
</tr>
<tr>
<td>RX J1713.7–3946</td>
<td>0.7</td>
<td>0.74</td>
<td>4 – 11</td>
</tr>
<tr>
<td>RX J0852.0–4622</td>
<td>1.0</td>
<td>0.84</td>
<td>2 – 6</td>
</tr>
<tr>
<td>HESS J1745–303</td>
<td>0.2</td>
<td>0.66</td>
<td>0 – 22</td>
</tr>
<tr>
<td>HESS J1626–490</td>
<td>&lt; 0.1</td>
<td>0.91</td>
<td>4 – 9</td>
</tr>
<tr>
<td>Vela X</td>
<td>0.4</td>
<td>0.81</td>
<td>4 – 15</td>
</tr>
<tr>
<td>Crab Nebula</td>
<td>&lt; 0.1</td>
<td>0.39</td>
<td>1 – 3</td>
</tr>
</tbody>
</table>

★ Expected number of events for 2 very energetic GRBs detected by Fermi:

<table>
<thead>
<tr>
<th>GRB</th>
<th>Signal</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRB080319B</td>
<td>2.6</td>
<td>( 5 \times 10^{-4} )</td>
</tr>
<tr>
<td>GRB080916C</td>
<td>2.7</td>
<td>( 5 \times 10^{-4} )</td>
</tr>
<tr>
<td>100 typical GRB</td>
<td>12</td>
<td>( 6 \times 10^{-2} )</td>
</tr>
</tbody>
</table>

~ yearly detection rate with future satellites

(With reference Waxman-Bahcall flux)

requiring a time coincidence drastically reduces background
Locations of the 3 pilot projects:
- ANTARES: Toulon (France)
- NEMO: Capo Passero (Sicily, Italy)
- NESTOR: Pylos (Greece)

Long-term measurements performed for site characterization

Main issues for site decision:
- scientific performance
- technological aspects (deployment, maintenance)
- funding opportunities
- political convergence

Final decision to be taken by end 2011
KM3NeT: ~5 km$^3$ neutrino telescope in the Mediterranean, complementing IceCube field of view and substantially surpassing its sensitivity: overall budget needed ~250 M€

Convergence process towards a unique technical design is underway

Readiness for construction expected at the end of Preparatory Phase (March 2012)

Deployment could start in 2013 and data taking soon after