Underwater Neutrino Detection in the Mediterranean Sea: From Presence to Future

Scientific Case: Some highlights

Current Projects: ANTARES, NEMO, NESTOR

The KM3NeT Design Study and Beyond

Conclusions and Outlook
Neutrinos from Astrophysical Point Sources

- Association of neutrinos to specific astrophysical objects.
- Energy spectrum, time structure, multi-messenger observations provide insight into physical processes inside source.
- Measurements profit from very good angular resolution of water Čerenkov telescopes.
- km³ detectors needed to exploit the potential of neutrino astronomy.
High-energy $\gamma$ sources in the Galactic Disk

Update June 2006:

- 6 $\gamma$ sources could be/are associated with SNR, e.g. RX J1713.7-3946;
- 9 are pulsar wind nebulae, typically displaced from the pulsar;
- 2 binary systems (1 H.E.S.S. / 1 MAGIC);
- 6 have no known counterparts.

W. Hofmann, ICRC 2005
Neutrinos from Supernova Remnants

Example: SNR RX J1713.7-3946
(shell-type supernova remnant)

H.E.S.S.: $\gamma = 200$ GeV – 40 TeV

Acceleration beyond 100 TeV.

Power-law energy spectrum, index $\sim 2.1–2.2$.

Spectrum points to hadron acceleration.

$\nu$ flux $\sim \gamma$ flux.

Typical $\nu$ energies: few TeV.

Expected neutrino fluxes: see Felix Aharonian’s talk
Observed sky region in galactic coordinates assuming efficiency for downward hemisphere. 

→ We need ν telescopes in both hemispheres to see the whole sky.
ANTARES: Detector Design

- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking photomultipliers (PMs), axis at $45^\circ$ to vertical;
- 2500 m deep.

Recent ANTARES results: see Vincent Bertin’s talk
• Deployment and operation of several prototype lines in 2003-2005 confirm expected functionality and help to fix last design issues.

• First full line deployed and connected, taking data since March 2, 2006.

• All subsystems operational. Time and position calibration verified.

• First muons reconstructed.

• Detector completion expected by end of 2007.
- Tower based detector (titanium structures).
- Dry connections (recover – connect – redeploy).
- Up- and downward looking PMs (15’’).
- 4000 m deep.
- Test floor (reduced size) deployed & operated in 2003.
- Deployment of 4 floors planned in 2007.

Plan: Tower(s) with 12 floors
- 32 m diameter
- 30 m between floors
- 144 PMs per tower
NESTOR: Data from the Deep Sea

- Background baseline rate of 45-50 kHz per PM
- Bioluminescence bursts correlated with water current, on average 1.1% of the time.

- Trigger rates agree with simulation including background light.
- For 5-fold and higher coincidences, the trigger rate is dominated by atmospheric muons.

Threshold 30mV


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NESTOR: Measurement of the Muon Flux

Atmospheric muon flux determination and parameterisation by

\[ \frac{dN}{d\Omega \cdot dt \cdot ds} = I_0 \cdot \cos^\alpha \theta \]

\(\alpha = 4.7 \pm 0.5\text{(stat.)} \pm 0.2\text{(syst.)}\)

\(I_0 = 9.0 \pm 0.7\text{(stat.)} \pm 0.4\text{(syst.)} \times 10^{-9}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\)

Results agree nicely with previous measurements and with simulations.

The NEMO Project

- Extensive site exploration (Capo Passero near Catania, depth 3500 m);
- R&D towards km$^3$: architecture, mechanical structures, readout, electronics, cables ...;
- Simulation.

**Example: Flexible tower**

- 16 arms per tower, 20 m arm length, arms 40 m apart;
- 64 PMs per tower;
- Underwater connections;
- Up- and downward-looking PMs.
NEMO Phase I: Current Status

January 2005: Deployment of
- 2 cable termination frames (validation of deep-sea wet-mateable connections)
- acoustic detection system (taking data)

Test site at 2000 m depth operational.
Funding ok.
Completion expected by 2006.

Shore station 2.5 km e.o. Cable with double steel shield
21 km e.o. Cable with single steel shield
5 km e.o. cable

Geoseismic station SN-1 (INGV)

5 km e.o. cable
¾ 10 optical fibres standard ITU-T G-652
¾ 6 electrical conductors Φ 4 mm²
NEMO Phase-1: Next Steps

Deployed January 2005

Summer 2006: Deployment of JB and mini-tower

Junction Box (JB)

TSS Frame

NEMO mini-tower (4 floors, 16 OM)

Mini-tower, compacted

Mini-tower, unfurled

15 m

300 m

Neutrino 2006, 19.06.06
**KM3NeT: Towards a km$^3$ Deep-Sea $\nu$ Telescope**

Existing telescopes “times 30”?
- Too expensive
- Too complicated (production, maintenance)
- Not scalable (readout bandwidth, power, ...)

R&D needed:
- Cost-effective solutions to reduce price/volume by factor $\sim 2$
- Stability goal: maintenance-free detector
- Fast installation time for construction & deployment less than detector life time
- Improved components

**Large volume with same number of PMs?**
- PM distance:
  - given by absorption length in water ($\sim 60$ m) and PM properties
- Efficiency loss for larger spacing

Neutrino 2006, 19.06.06 U. Katz: Underwater Detection
The KM3NeT Design Study

Scope and consortium:

- Design Study supported by the European Union with 9 M€, overall volume ~20 M€.
- Participants: 29 particle/astroparticle physics and 7 sea science & technology institutes from 8 European countries (coordinator: Univ. Erlangen).
- Started on Feb. 1, 2006; will run for 3 years.

Major objectives:

- Conceptual Design Report by summer 2007;
- Technical Design Report by February 2009;
- Limit overall cost to 200 M€ per km³ (excl. personnel).
The KM3NeT Vision

- KM3NeT will be a multidisciplinary research infrastructure:
  - Data will be publicly available;
  - Implementation of specific online filter algorithms will yield particular sensitivity in predefined directions → non-KM3NeT members can apply for observation time;
  - Data will be buffered to respond to GRB alerts etc.
  - Deep-sea access for marine sciences.
- KM3NeT will be a pan-European project
  - 8 European countries involved in Design Study;
  - Substantial funding already now from national agencies.
- KM3NeT will be constructed in time to take data concurrently with IceCube.
- KM3NeT will be extendable.
Some Key Questions

- Which architecture to use? (strings vs. towers vs. new design)
- How to get the data to shore? (optical vs. electric, electronics off-shore or on-shore)
- How to calibrate the detector? (separate calibration and detection units?)
- Design of photo-detection units? (large vs. several small PMs, directionality, ...)
- Deployment technology? (dry vs. wet by ROV/AUV vs. wet from surface)
- And finally: path to site decision.

All these questions are highly interconnected!
Detector Architecture

(D. Zaborov at VLVνT)

Neutrino 2006, 19.06.06  U. Katz: Underwater Detection 18
Sea Operations

- Rigid towers or flexible strings?
- Connection in air (no ROVs) or wet mateable connectors?
- Deployment from platform or boat?
Photo Detection: Options

- Large photocathode area with arrays of small PMs packed into pressure housings – improved timing and amplitude resolution.

- Determination of photon direction, e.g. via multi-anodic PMs plus a matrix of Winston cones.

- But: phase space for developments from scratch is tight.
### KM3NeT: Path to Completion

**Time schedule (partly speculative & optimistic):**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.02.2006</td>
<td>Start of Design Study</td>
</tr>
<tr>
<td>Mid-2007</td>
<td>Conceptual Design Report</td>
</tr>
<tr>
<td>February 2009</td>
<td>Technical Design Report</td>
</tr>
<tr>
<td>2009-2010</td>
<td>Preparation Phase (possibly in FP7)</td>
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<tr>
<td>2010-2012</td>
<td>Construction</td>
</tr>
<tr>
<td>2011-20xx</td>
<td>Data taking</td>
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</tbody>
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Conclusions and Outlook

- The Mediterranean-Sea neutrino telescope projects ANTARES, NEMO and NESTOR have proven the feasibility of large-scale deep-sea neutrino telescopes.

- Exciting data from these experiments can be expected in the near future.

- ANTARES, NEMO and NESTOR have united their efforts to prepare together the future, km$^3$-scale deep-sea detector.

- The EU-funded KM3NeT Design Study (2006-09) provides substantial resources for an intense 3-year R&D phase.