First results of the ANTARES Neutrino Telescope

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32nd International School of Nuclear Physics
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The High-Energy Universe

Supernova remnants  
(SN1006, optical, radio, X-ray)

Active Galactic Nuclei  
(artist’s view)

Microquasars  
(artist’s view)

Gamma-ray Bursts  
(GRB 080319B, X-ray, SWIFT)
Messengers of the High-Energy Universe

Cosmic ray spectrum

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High-energy particle production in the universe

- Accelerator (source)
- Shock fronts (Fermi acceleration)
- Strong magnetic fields up to $10^{15}$ Gauss (pulsars, magnetars)

- Beam dump (secondary particle production)
- Interaction with photon field, matter, interstellar medium
- Protons: pion decay

\[ p + p(\gamma) \rightarrow \pi^{\pm} + X \quad p + p(\gamma) \rightarrow \pi^{0} + X \]

\[ \mu + v_\mu \quad \gamma + \gamma \text{(TeV)} \]

\[ \rightarrow e + v_\mu + v_e \]

- Electrons: inverse Compton-scattering of photons

\[ e^+ \gamma \rightarrow e + \gamma \text{(TeV)} \]
Why neutrino astronomy?

- Neutrinos point back to the source
- Neutrinos travel cosmological distances
- Neutrinos escape from optically thick sources
- Neutrinos are a clear sign for hadron acceleration
- Neutrinos provide complementary information to gamma-rays and protons
Physics with neutrino telescopes

- **Galactic sources**
  (Supernova remnants, Binary systems, Pulsar Wind Nebulae ...)

- **Extra-Galactic sources**
  (Gamma-ray Bursts, Active Galactic Nuclei ...)

- **Dark Matter**
  (WIMPs)

- **Cosmogenic neutrinos**
  (GZK, Top-down, ...)

- Supernovae (MeV neutrinos)

- Neutrino oscillations (atmospheric neutrinos 10 - 100 GeV)

- Cosmic-ray anisotropy (atm. muons)

- Exotic physics
  (Lorentz violation, monopoles, ...)

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Principle of neutrino detection

ANTARES:
Angular resolution
0.3° for $E_{\nu} > 10$ TeV

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Neutrino Candidate

Reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:

Zenith: 34.8°
Fit on 5 line(s)

Run 34927  Frame 7155
Wed Jun 18 00:08:10 2008
Trigger bits 80002020
Line 1-12 Physics Trigger (th)
Sky coverage

ANTARES
- > 75%
- 25% – 75%
- < 25%

TeV γ-Sources
- galactic
- extragalactic

IceCube
- 100%
- 0%

0.5 \( \pi \) sr instantaneous common view
1.5 \( \pi \) sr common view per day

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The ANTARES Collaboration

27 institutes in 7 European countries
ANTARES in the Mediterranean

La Seyne-sur-Mer, near Toulon, France

Main cable (45km)
ANTARES

- 12 Lines (885 PMTs)
- Completion May 2008
- Instrumented volume: \(~0.01\ km^3\)
Calibration
(selection)
Detector positioning

• Acoustic system
  • 1 emitter (+ receiver)
    at each line socket
  • 5 receivers along each line
• Compass and Accelerometer
  • 1 Compass at each storey
  • 1 Acc. at each storey

• Measure every 2 min
  • Acoustics: distance sockets - receivers
  • Compass: heading
  • Accelerometer: tilt

Line shape
Detector positioning

**typical line shape**

\[ r = (az - b \ln(1-cz))v^2 \]

- Example for Sea current
  - \( v = 25 \text{ cm/s} \)
  - \( r_{\text{max}} = 22 \text{ m} \)

**mostly coherent movement of lines**
Position monitoring for PMTs

- Precision of positioning: $\Delta x < 10$ cm
- Monitoring of the positioning with laser pulses

$\rightarrow$ Precision $\sim 0.5$ ns $= 10$ cm
Background
Optical background due to $^{40}$K-decay and bioluminescence:

- Typical rate per PMT 60-120 kHz
- Additional short bursts and periods with higher rates
Bioluminescent Sources

- Bacteria: steady baseline source of light (30kHz in 10'' PMT)
- Macro-organisms: short flashes (up to MHz)

E.g.
large colonial organisms such as pyrosomes (megaplankton)

Size range: 0.2 - 2000 mm
Particle background: atm. muons and neutrinos

- Flux from above dominated by atmospheric muons
- Neutrino telescopes optimised to be sensitive to neutrinos from below
Selected Results
Reconstructed muon tracks: angular distribution

5-line data (May-Dec 2007) + 9-12-line data (2008)

341 days detector live time

1062 neutrino candidates

good agreement with Monte-Carlo expectation:

upward-going: atmospheric neutrinos: 916 (30% syst. error)

atmospheric muons: 40 (50% syst. error)
Muon flux: depth-intensity relation with 5 Lines


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Scrambled sky map of 1000 neutrinos

Galactic coordinate System

Equatorial coordinate System

Scrambled in azimuth

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Point source sensitivity

5-line data 2007, preliminary

Increased sensitivity for full detector
Dark matter search

upper limits from experiments

5-line data 2007
68 days detector live time

Competitive with direct detection for SD cross section
Observation of induced electromagnetic showers from muon tracks

Analysis Technique:

Projection of “late” photons onto reconstructed muon track

preliminary

Rate [Hz]

Data

Monte Carlo

Number of showers

10^5

10^6

10^7

10^8

0 1 2 3 4 5 6

Entries

Cerenkov photons

EM shower

Cerenkov photons

Muon direction

Z-axis

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Energy estimator

\[ R = \frac{\text{Number of prompt and late PMT signals}}{\text{Number of all PMTs contributing to the event}} \]
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\[ E^2 \Phi_{\text{abs}} = 10^7 \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]

\[ E^2 \Phi_{100\% \text{ C.L.}} = 4.5 \times 10^5 \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]
Upper limit on diffuse flux of HE $\nu$

\[ E^2 \frac{dN}{dE} \text{[GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}] \]

\begin{align*}
\text{Frejus} & \quad \text{MACRO} \\
\text{Baikal NT-200} & \quad \text{Amanda-II UHE} \\
\text{Amanda-II $\nu_e$} & \quad \text{Amanda-II $\nu_\mu$} \\
\text{ANTARES-2007-09 $\nu_\mu$} & \quad \text{(W&B)/2} \\
\end{align*}

\[ E^2 \Phi(E)_{90\%\text{CL}} = 4.5^{+2}_{-1} \times 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]

0.83 * 2\pi sr

monitored for
334 days

with
reduced detector setup
during construction phase

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Summary and Outlook

• ANTARES is continuously taking data
• ANTARES complements the sky coverage of IceCube
• ANTARES has a broad physics program
• ANTARES determined sensitive upper limit on HE diffuse $\nu$ flux
• ANTARES paves the way for KM3NeT