Acoustic UHE Neutrino Detection in Water: Lessons from SAUND

http://hep.stanford.edu/neutrino/SAUND

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A Study of Acoustic Ultrahigh-energy Neutrino Detection (SAUND)

Thanks to my SAUND collaborators:

Current:
G. Gratta (Stanford)
N. Kurahashi (Stanford)
M. Buckingham (Scripps)

Past:
N. Lehtinen (Stanford, now at Hawaii)
S. Adam (Stanford, now at Cornell)
Y. Zhao (Stanford)
T. Berger (Scripps)

And to AUTEC and the U. S. Navy:
D. Belasco
D. Deveau
T. Kelly-Bissonnette

J. Cecil
D. Kapolka
Cosmic ray spectrum

![Graph showing the cosmic ray spectrum with flux units in m^-2 s^-1 sr^-1 GeV^-1 and energy in eV. The graph highlights the knee and ankle regions.]
The Greisen-Zatsepin-Kuzmin (GZK) cutoff

1 event / km² / century → detector innovation key!
GZK: So what?

A crossroads of exciting physics
- active galactic nuclei
- gamma ray bursts
- grand unified theories
- topological defects (magnetic monopoles, cosmic strings, domain walls)
- supersymmetry
- dark matter
- Lorentz invariance violation
- extra dimensions
- gravity at a TeV
- relic neutrinos

All important topics in our understanding of the universe!
The ocean as a particle detector
Simulated acoustic neutrino pulse

$10^{20}$ eV hadronic shower @ 1 km

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Extreme pancakes
Radiation lobes from $5 \times 10^{20}$ eV to $3 \times 10^{21}$ eV
Sound from charged particles in liquids: some background

- first discussion of the idea

- extensive theoretical analysis

- experimental confirmation
  L. Sulak et al. NIM 161 (1979) 203

- sensitivity studies for neutrino detection

- growing interest in acoustic arrays
The Atlantic Undersea Test and Evaluation Center (AUTEC)
AUTEC hydrophones

SAUND
7 km²
The SAUND array

Distance N (km)  Distance E (km)
DAQ
**Software**
- 179 kHz sampling
- digital matched filter
- variable threshold
- 60 events/minute target
- 1-2 GB / 24 hrs

\[ \text{signal} : S(t) \propto -\frac{t}{\tau} e^{-t^2/2\tau^2} \]

\[ \text{noise} : N(t) \propto f^{-2} \]

→ **response function**: \( H(t) \propto -\left( \frac{t}{\tau} \right)^3 - 3 \frac{t}{\tau} \) \( e^{-t^2/2\tau^2} \)

**Hardware**
- 1.7 GHz Pentium 4
- ADC card
- 60 GB external hard drive
Adaptive threshold

- **quiet (54 days)**
- **noisy (90 days)**

Cumulative lifetime (days) vs. Threshold

- X-axis: Threshold
- Y-axis: Cumulative lifetime (days)
Calibration sources
One bulb at all 7 hydrophones
Two reflections: sea floor + sea surface

-30
-20
-10
0
10
20
30

Pressure (Pa)

Time (ms)

sea floor ref.
Lightbulb positions reconstructed (zoomed out)
Lightbulb positions reconstructed (zoomed in)
Lightbulb energies reconstructed

<table>
<thead>
<tr>
<th>Bulb</th>
<th>Depth (m)</th>
<th>( P = \rho gh ) (kPa)</th>
<th>( E_0 = PV ) (J)</th>
<th>( E_{rad} ) (J)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>170</td>
<td>1640</td>
<td>250</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>110</td>
<td>1120</td>
<td>170</td>
<td>0.3</td>
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<tr>
<td>3</td>
<td>150</td>
<td>1430</td>
<td>210</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>170</td>
<td>1690</td>
<td>250</td>
<td>2.8</td>
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<tr>
<td>5</td>
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<td>1300</td>
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<td>0.8</td>
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<td>6</td>
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<td>1050</td>
<td>160</td>
<td>0.4</td>
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<td>7</td>
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<tr>
<td>8</td>
<td>140</td>
<td>1380</td>
<td>210</td>
<td>1.9</td>
</tr>
<tr>
<td>9</td>
<td>200</td>
<td>1930</td>
<td>290</td>
<td>1.9</td>
</tr>
<tr>
<td>10</td>
<td>300</td>
<td>2930</td>
<td>440</td>
<td>1.8</td>
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</table>
Data: a large livetime has been integrated

- 200 days livetime
- 25 million events
- 350 GB
- 70% duty cycle
Five-phone coincidence

Require
1) Events obey causality: \( t_{ij} \leq d_{ij} / v_{\text{sound}} \)
2) Geometry consistent with pancake (flat circle!) shape:

accepted:

rejected:
Refracted pancake

- Hydrophone
- Unrefracted pancake
- Refracted pancake
Position reconstruction achieved (10 m resolution)
Radial coordinate vs. depth of reconstructed events

Horizontal distance from central phone (m)
Depth (m)
Background event types

![Graph showing two different waveforms over time](image-url)
Examples of dolphin signals recorded by AUTEC personnel

![Graphs showing dolphin signals over time](image-url)
## Background rejection

<table>
<thead>
<tr>
<th>Cut</th>
<th>Events passing cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Run II, 147 days integrated livetime)</td>
</tr>
</tbody>
</table>

1) Filter trigger 40 million single-phone events
2) Electronic noise 25 million single-phone events
3) 5-phone coincidence 5 million combinations
4) Waveform analysis 3 thousand combinations
   a) Periods < 4
   b) 20 kHz < freq < 40 kHz
   c) Diamond metric < 0.7
5) Threshold <= 0.024
6) 5-phone localization 300 combinations
7) Threshold crossings < 2 a few combinations

(online, offline)
Diffuse neutrino flux

...SAUND measurements coming soon
Conclusions

Lessons and Accomplishments
- Large data set collected (200 days integrated)
- Backgrounds quantified; rejection methods developed
- Refraction significant (esp. beyond 1 km)
  - position + direction reconstruction nontrivial; sea-floor phones bad
- $c_{\text{sound}} = c_{\text{light}} / 200,000$ !! (coincidence not so powerful)
- First-generation threshold: $10^{21}$ eV ($10^{19}$ eV possible?)

Onward and downward (NSF-funded SAUND-II)
- On to more phones (52), area (250 km$^2$), online intelligence (7 CPUs)
- Down to the Gaussian noise floor with advanced online processing
Conclusions

A first effort has been made toward acoustic UHE neutrino detection. The method will be developed more seriously by SAUND-II and tested in a new (better?) medium by IceCube.

3 factors to consider in comparing water to ice:

<table>
<thead>
<tr>
<th></th>
<th>water</th>
<th>ice</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Attenuation length</td>
<td>1-10 km</td>
</tr>
<tr>
<td>2</td>
<td>Signal amplitude (arb. units)</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Background noise</td>
<td>okay</td>
</tr>
</tbody>
</table>

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