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

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

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Current:
- G. Gratta (Stanford)
- M. Buckingham (Scripps)
- J. Vandebrouckk (Stanford, now at Berkeley)

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
- J. Cecil
- D. Deveau
- D. Kapolka
- T. Kelly-Bissonnette
Cosmic ray spectrum

Fluxes of Cosmic Rays

- Knee (1 particle per m$^2$-year)
- Ankle (1 particle per km$^2$-year)

Energy (eV)
The Greisen-Zatsepin-Kuzmin (GZK) cutoff

1 event / km$^2$ / century $\rightarrow$ detector innovation key!
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 key to understanding the universe!
Cosmic ray showers

http://zebu.uoregon.edu/~js/glossary/cosmic_rays.html
The ocean as a particle detector
Simulated neutrino signal

\[ \theta = 8^\circ \]
Extreme pancakes
Radiation lobes from $5 \times 10^{20} \text{ eV}$ to $3 \times 10^{21} \text{ eV}$
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 north (m)  Distance east (m)  Depth (m)
DAQ
**DAQ**

**Software**
- 179 kHz sampling
- digital matched filter
- variable threshold
- 60 events/minute target
- 1-2 GB / 24 hrs

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

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

\[
\rightarrow \text{response function} : H(t) \propto -\left(\frac{t}{\tau}\right)^3 - 3\frac{t}{\tau} e^{-t^2/2\tau^2}
\]

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

Livetime at each threshold (total: 122 days)

Integrated livetime (days)

Threshold

quiet

noisy
Calibration sources
One bulb at all 7 hydrophones

Bulb 1, 30–Jul–2001 09:08:01

Pressure (Pa)

Time (s)
Two reflections!

Bulb 1, 30-Jul-2001 09:08:01

Pressure (Pa) vs. Time (s) graph.
Direct signal

Bulb 1, 30–Jul–2001 09:08:01

Pressure (Pa)

Time (s)
Lightbulb positions reconstructed

Location of boat (GPS) and bulbs (reconstructed)

- hydrophone
- boat
- bulb
Lightbulb energies reconstructed

<table>
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<th>Bulb</th>
<th>Depth (m)</th>
<th>$P = \rho gh$ (kPa)</th>
<th>$E_0 = PV$ (J)</th>
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</table>
Data: a large livetime has been integrated

- 211 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 (2D circle) shape:

accepted:

rejected:
A UTC sound velocity profile (SVP)
Refraction

Ray trace with source at 1200 m depth, from 5 degrees above horizontal to 5 degrees below

unrefracted ray
refracted ray
Refraction shadow
Refracted pancake

Refracted acoustic radiation disk cross section for a $1\times10^{21}$ eV neutrino at zenith 0.5 deg
Position reconstruction achieved (10 m resolution)
Localization → energy reconstruction
Background event type 1
Background event type 2
Examples of dolphin signals recorded by AUTEC personnel

Amplitude, arb. units

Time, ms

Amplitude, arb. units

Time, ms
Background categorization

All Dec01-Sep02 events (31172)

Characteristic number of periods

Characteristic frequency (kHz)

log10(fractional event count)

-1.5

-2

-2.5

-3

-3.5

-4
Monte Carlo neutrinos

Simulated 9508 fake events (thr=0.01)
Background rejection

Cut | Events passing cut
---|---

1) Filter trigger | 40 million single-phone events
2) Electronic noise | 25 million singles
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 | 0 combinations

(online, offline)
Diffuse neutrino flux

...SAUND measurements coming soon
Conclusions

Lessons and Accomplishments
- Large data set collected (211 days integrated)
- Backgrounds determined
- Refraction significant (esp. beyond 1 km)
  - position + direction reconstruction nontrivial; sea-floor phones bad
- $c_{\text{sound}} = c_{\text{light}} / 200,000$ !! (coincidence not as powerful)
- first-generation threshold: $10^{21}$ eV ($10^{19}$ eV possible?)

Upcoming
- Rigorous efficiency checks
- Flux limits

Onward and downward (SAUND-II)
- On to more phones (52), effective area (250 km$^2$), online rejection (7 CPUs)
- Down to the Gaussian floor

A first effort has been made toward acoustic neutrino detection. The method will be fleshed out by SAUND-II and others in the next few years.

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