Acoustic detection of Ultra High Energy Neutrinos

The Stanford years

Giorgio Gratta
Stanford University

A little experiment, done by a few intrepid explorers, with very limited resources…
…observing 1500 km3 of ocean with 130 days livetime and still owning the best flux limit with this technique.

Men wanted for hazardous journey. Small wages, bitter cold, long months of complete darkness, constant danger, safe return doubtful. Honour and recognition in case of success.

Sir Ernest Shackleton

Quite a few publications:

Naoko Kurahashi, Justin Vandenbroucke and GG Phys Rev D 82 (2010) 073006.

Naoko Kurahashi and GG, Phys Rev D 78 (2008) 092001.

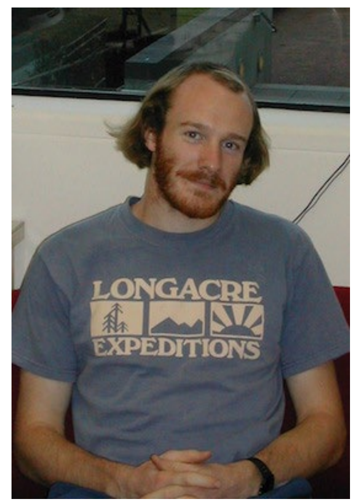
Justin Vandenbroucke and GG, ApJ 621 (2005) 301.

Nikolai G. Lehtinen, Shaffique Adam, GG (Stanford), Thomas K. Berger, Michael J. Buckingham (Scripps/UCSD), Astrop Phys 17 (2002) 279.

And, the alumni did quite well:

S. Adam
Prof. Physics Dept
U Washington S. Louis

N. Lehtinen
Sr. Scientist
University of Bergen



J. Vandenbroucke
Prof. Physics Dept.
U of Wisconsin, Madison

N.Kurahashi-Neilson
Prof. Physics Dept
Drexel University

But, unbeknownst to me at the time,
the origins go back to a couple of other guys:

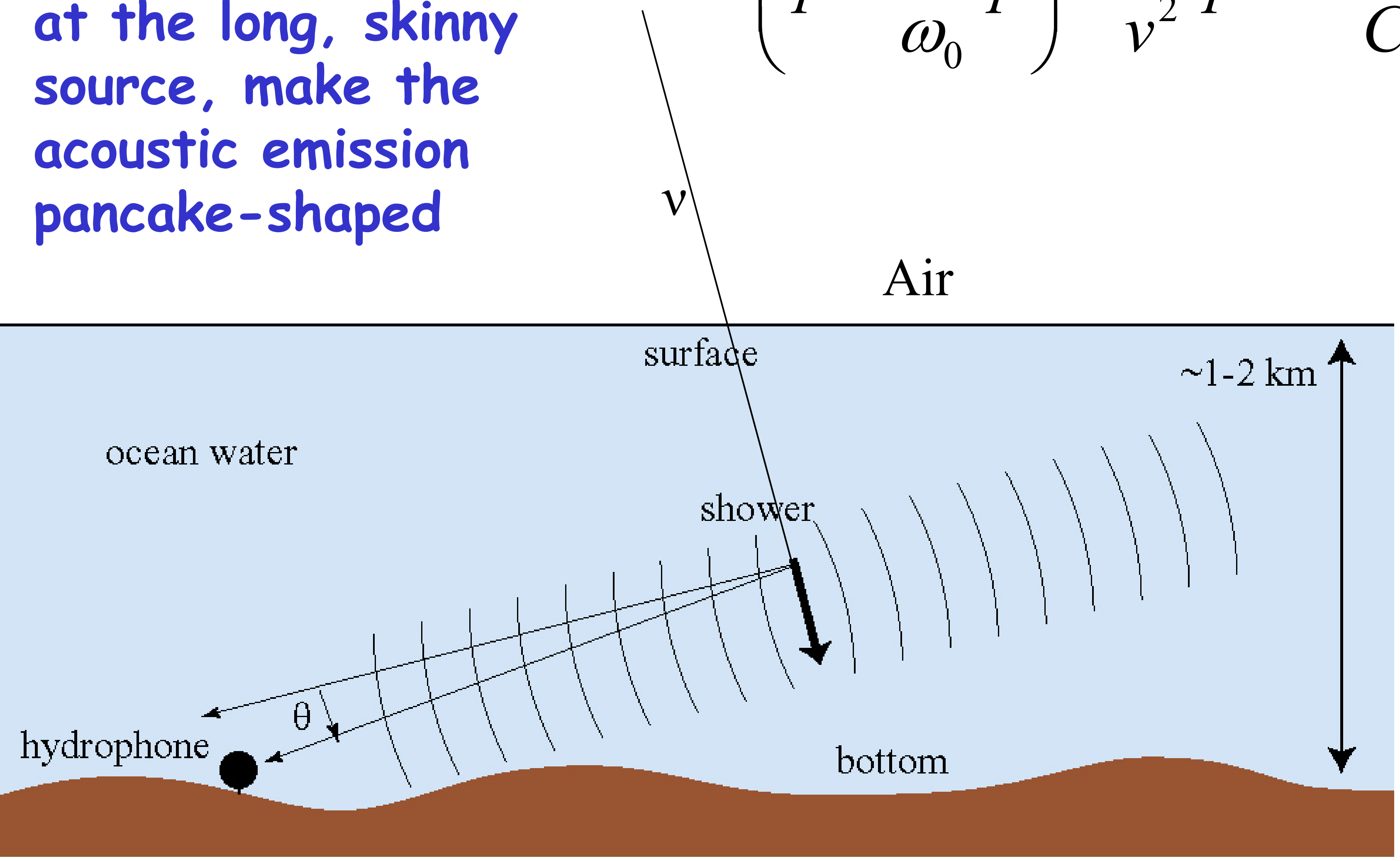
Gurgen Askar'yan
Sov J At En 3 (1957) 921

John Learned
Phys Rev D 19 (1979) 3293

The energy dumped in the string-like shower heats the water that expands, producing a bipolar acoustic pulse

Interference effects at the long, skinny source, make the acoustic emission pancake-shaped

$$\nabla^2\left(p+\frac{1}{\omega_0}\dot{p}\right)-\frac{1}{v^2}\ddot{p}=-\frac{\beta}{C_p}\frac{\partial E}{\partial t}$$



Energy conversion in Ocean, Ice and Salt compared

	Ocean 15°C	Ice -51°C	NaCl 30°C
v_L (m/s)	1530	3920	4560
v_S (m/s)	-	1995	2610
β (m^3 m^{-3} K^{-1})	$2.55 \cdot 10^{-4}$	$1.25 \cdot 10^{-4}$	$1.16 \cdot 10^{-4}$
C_P (J kg^{-1} K^{-1})	3900	1720	839
$v_L^2 \beta / C_P$	0.153	1.12	2.87
$L \sim 3 X_0 \ln(E_0/E_C)^{1/2}$ (m)	10.3	10.3	3.43
$d \sim R_{Moliere}$ (m)	0.1	0.1	0.05
$f_{peak} \sim v_L/2d$ (kHz)	7.7	20	42
Pancake opening: d/L (°)	0.5	0.5	1

From P.B.Price, Berkeley

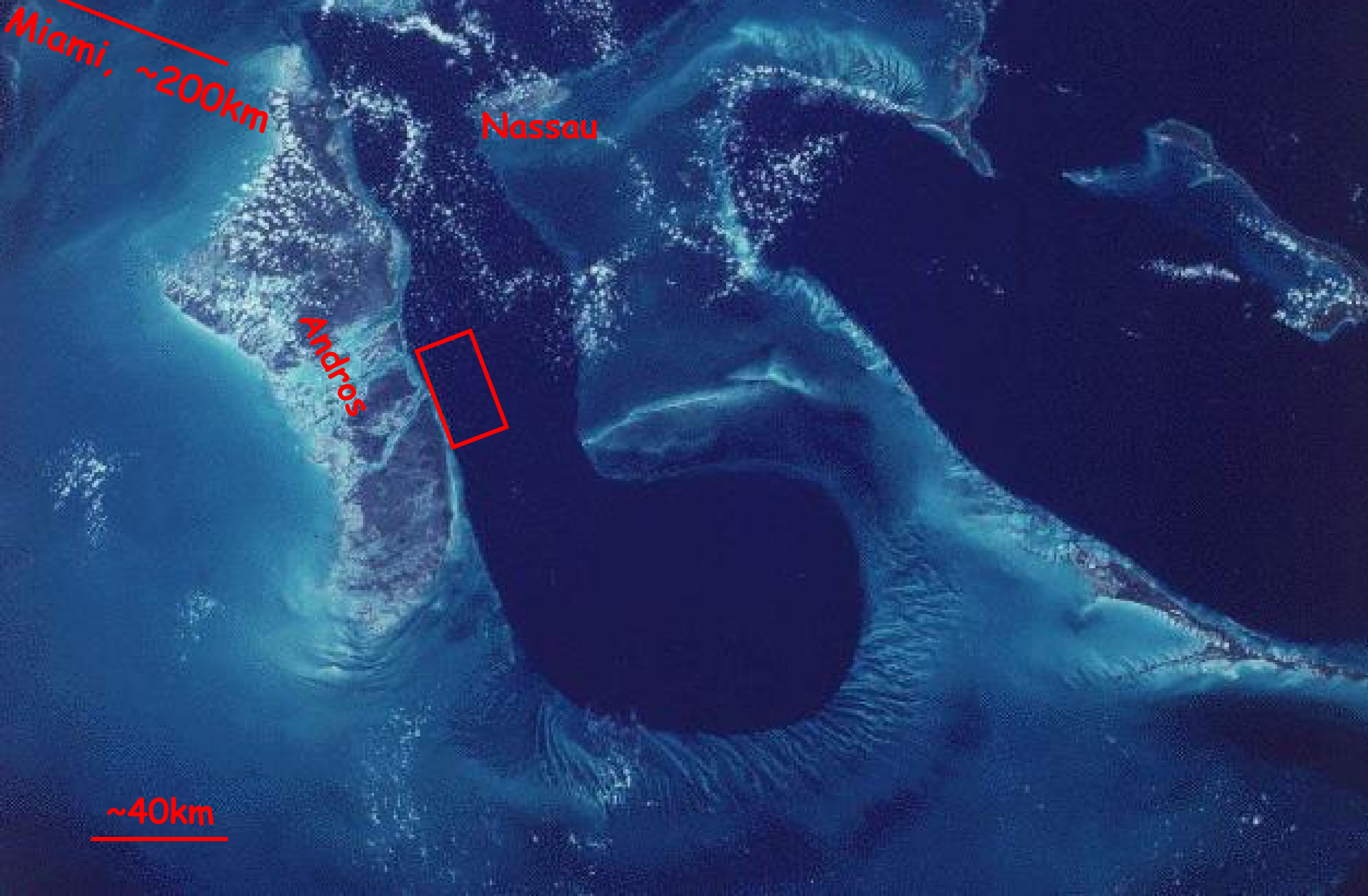
Acoustic detection in water/ice/salt
is only sensitive to νs (and showering μs)
→ atmosphere stops all other species
(shower tails don't produce detectable signals)

- Particle ID is automatic (very large column density compared to atmosphere)
- Truly calorimetric (this is probably not as good as it sounds: calibration is non-trivial)
- L_{att} for sound at ~10kHz ~1km,

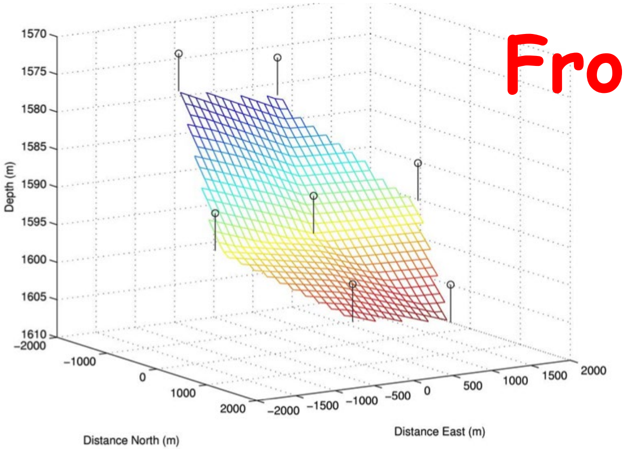
  longer than for Cerenkov light

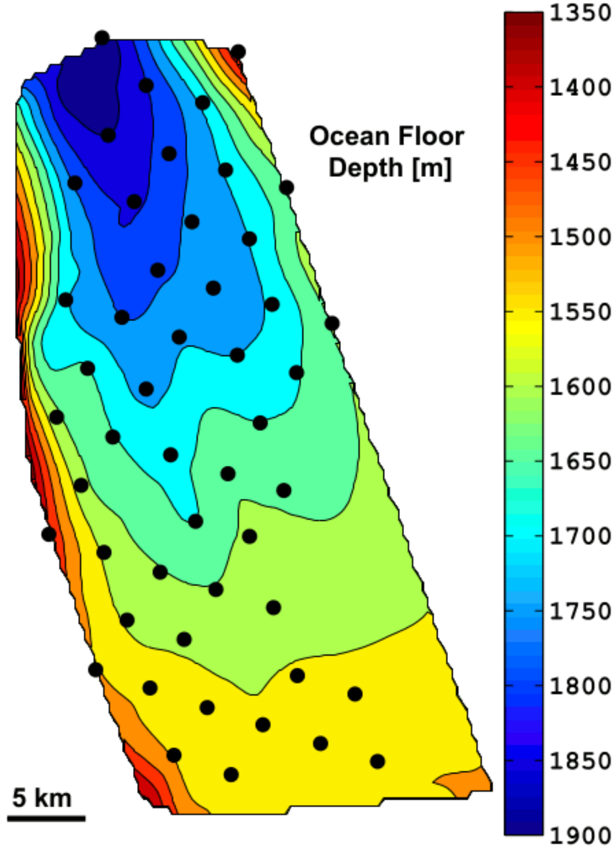
  → Need large area & volume to be sensitive to a flux «1 km^{-2} yr^{-1}
- Salt supports acoustic and radio detection
  Water supports acoustics and optical
  Ice supports acoustics, radio and optical

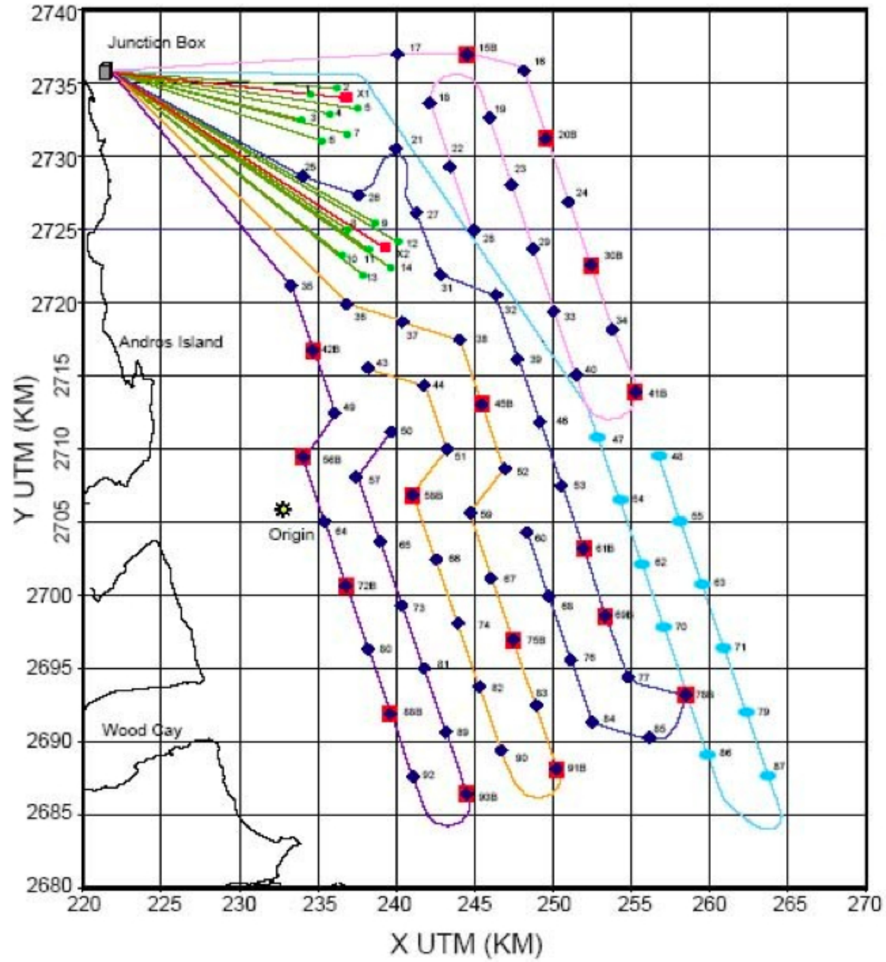
SAUND arrays in the Tongue of the Ocean from space (Atlantic Underwater Test and Evaluation Center)



From SAUND-I to SAUND-II



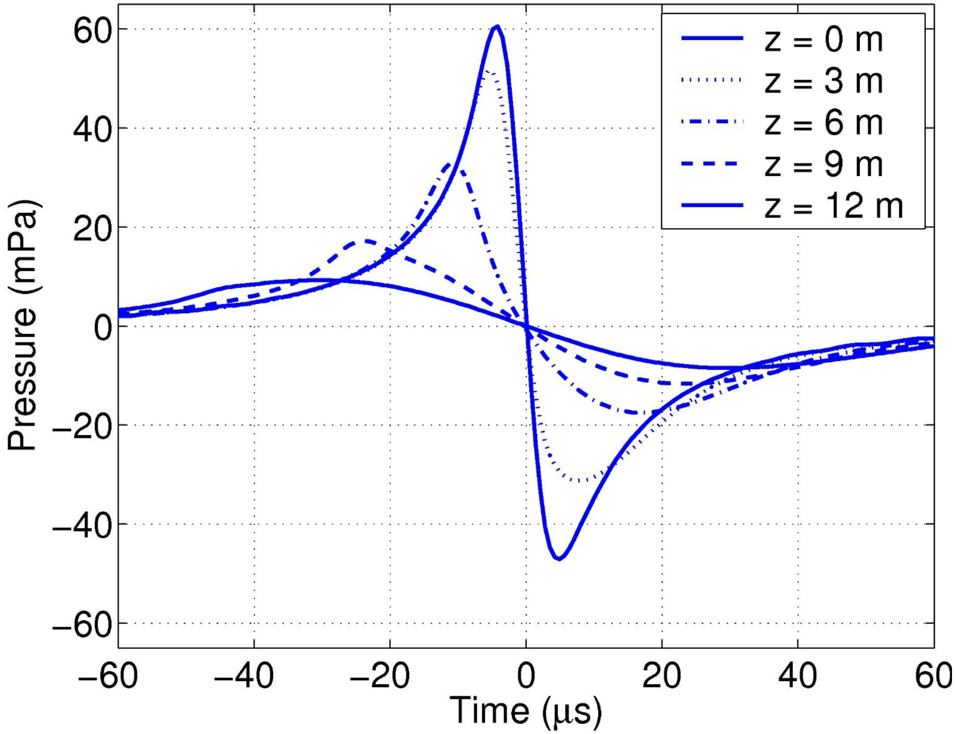




About
1500 km^3

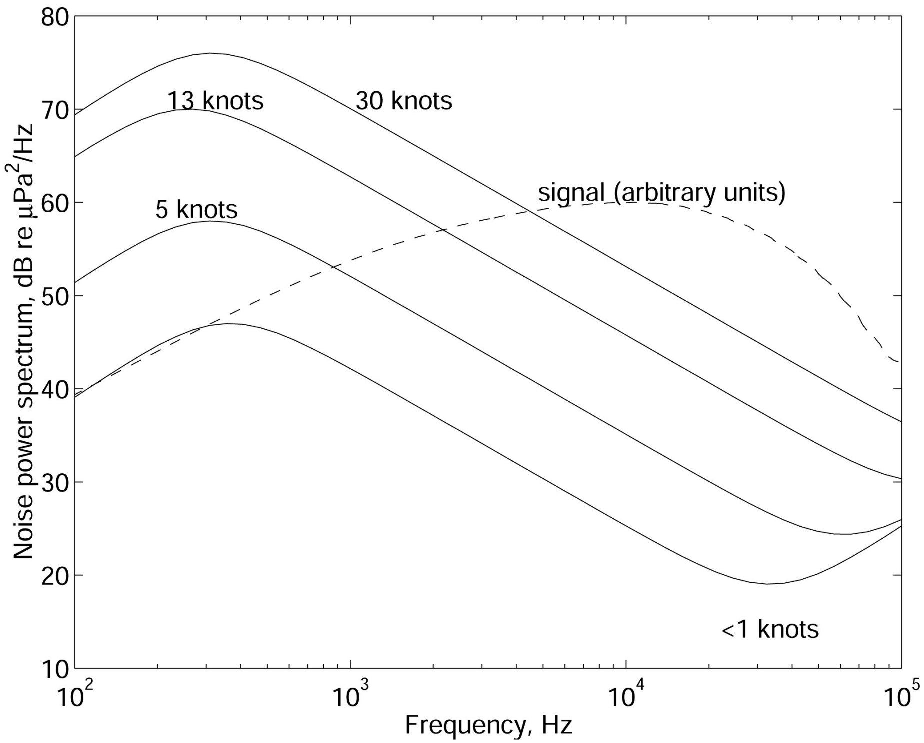
The “Bahamas thing” is not as cool as it sounds…

Autec Site 3

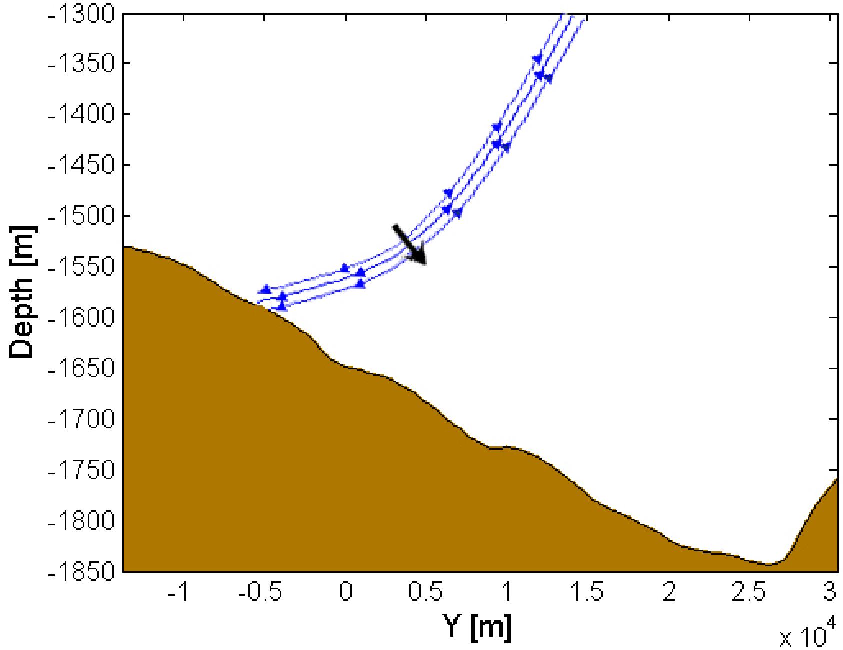


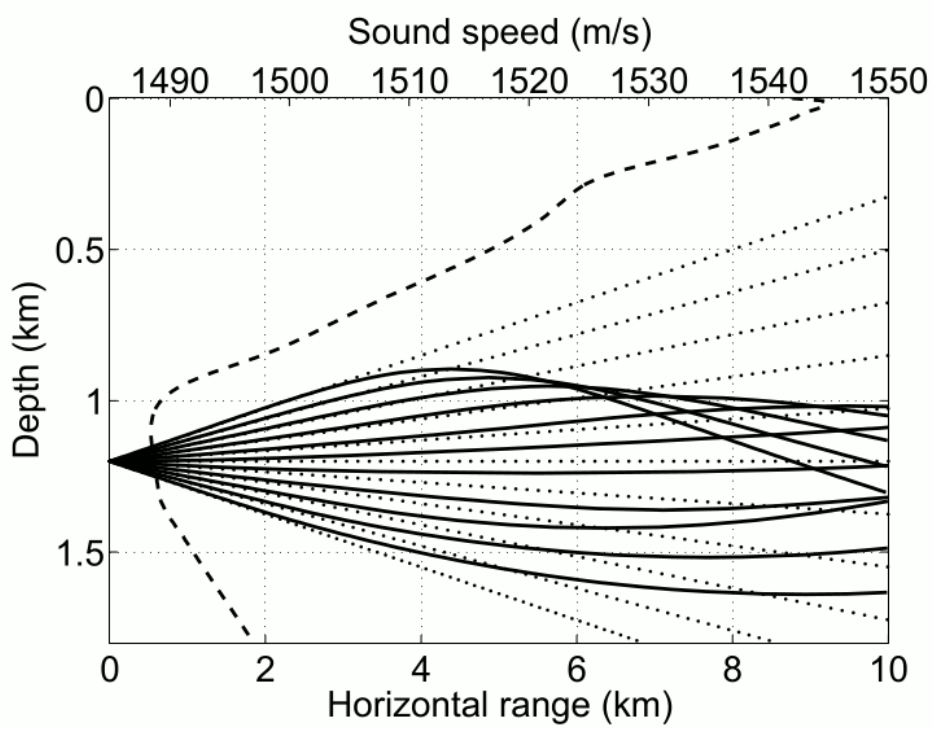
Bipolar pulse has substantial amplitude in the plane of the pancake lobe

Bulk of energy around 10 kHz:
most acoustic surveillance arrays are ill-suited

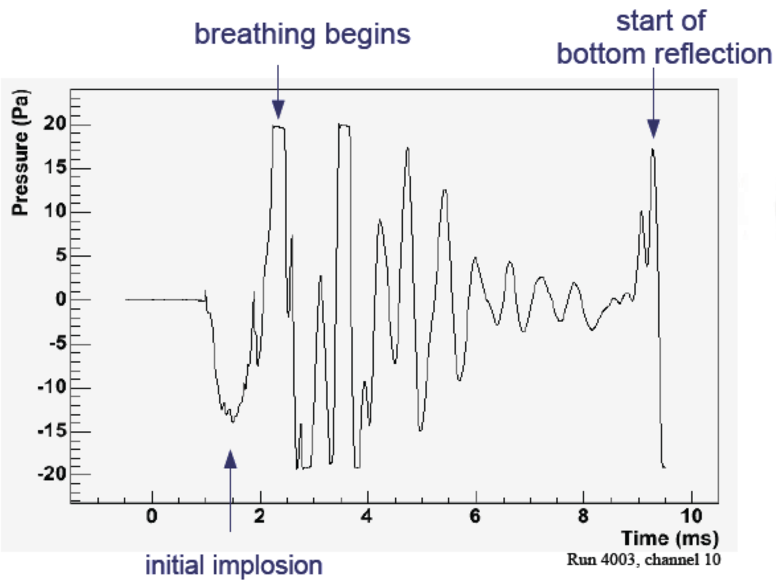


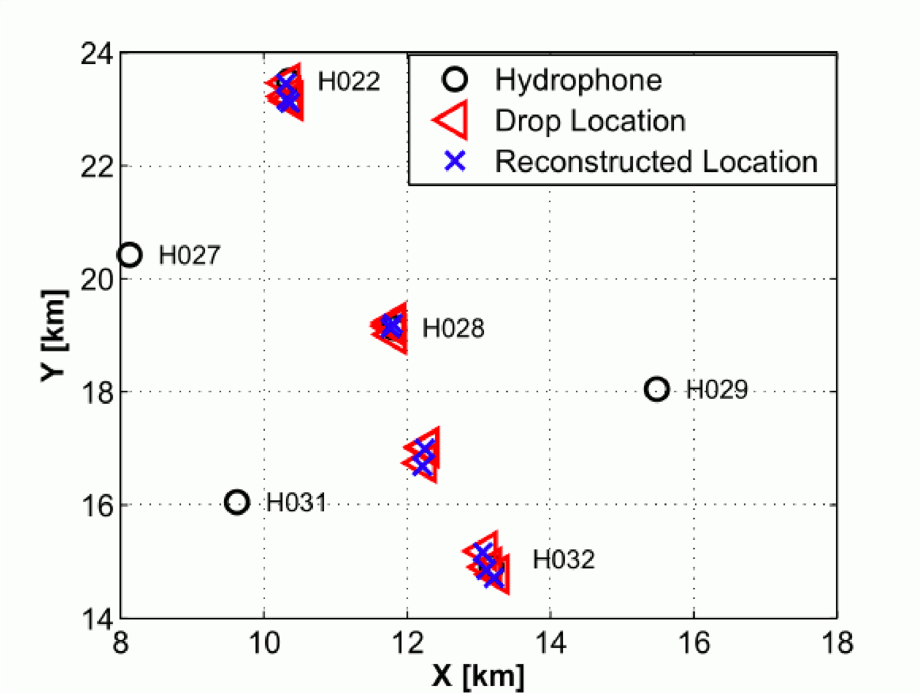
The emission pattern is a pancake, twisted by the variable sound speed





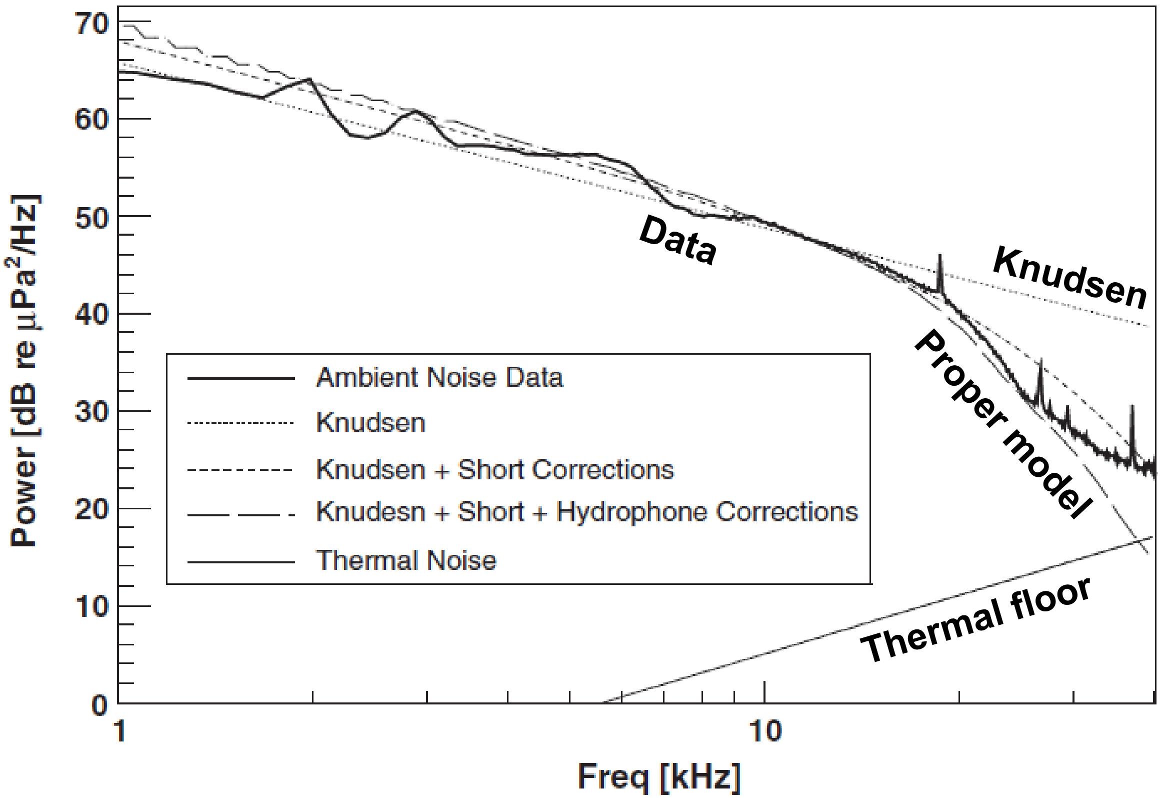
Calibrating the energy and position information



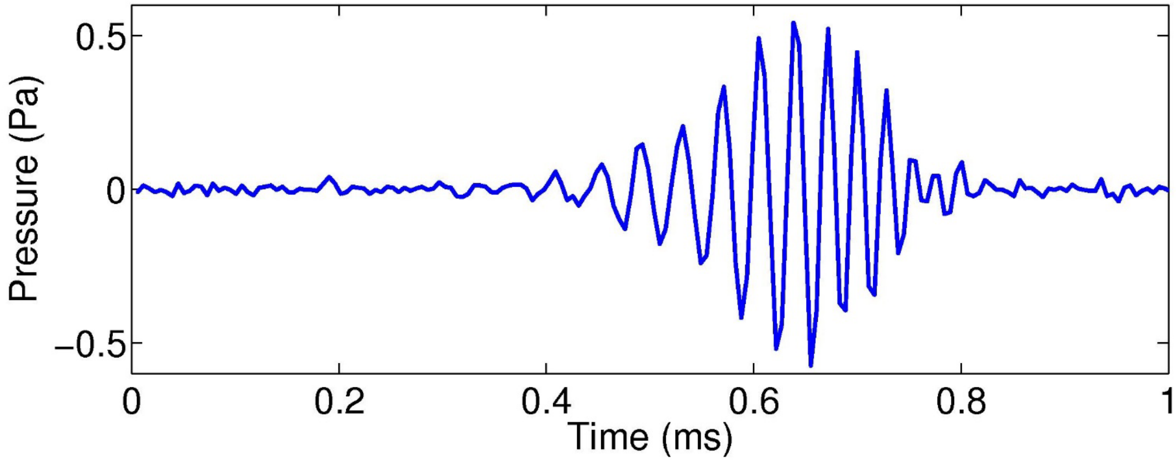


A subtlety on ambient noise:

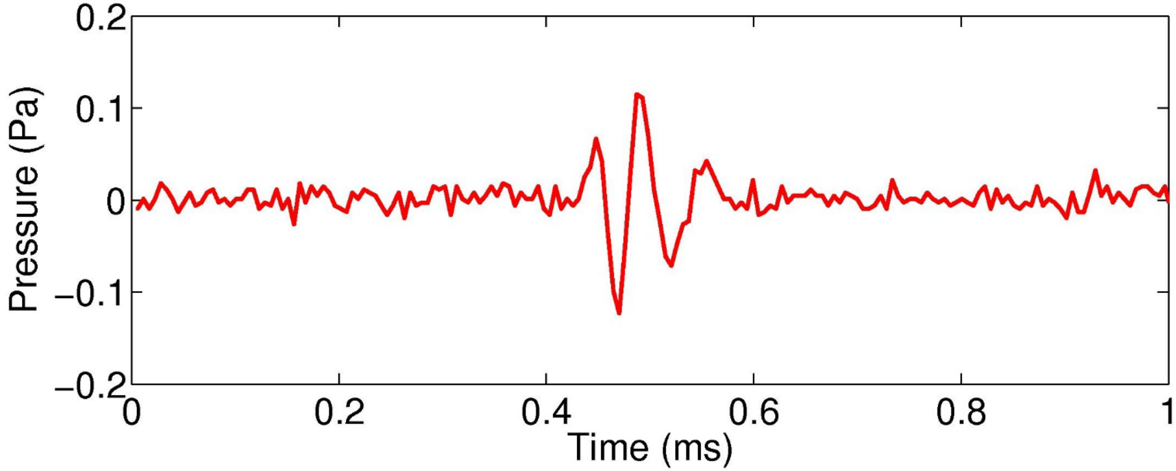
Noise in the water is usually modeled with a "Knudsen spectrum".
This assumes all sources to be on the surface and integrates over a 2D sheet.
At high frequency and large depth, the spectrum is modified by absorption,
something we discovered and we then found was in a Navy classified paper of way back!



Now comes the background



An animal?

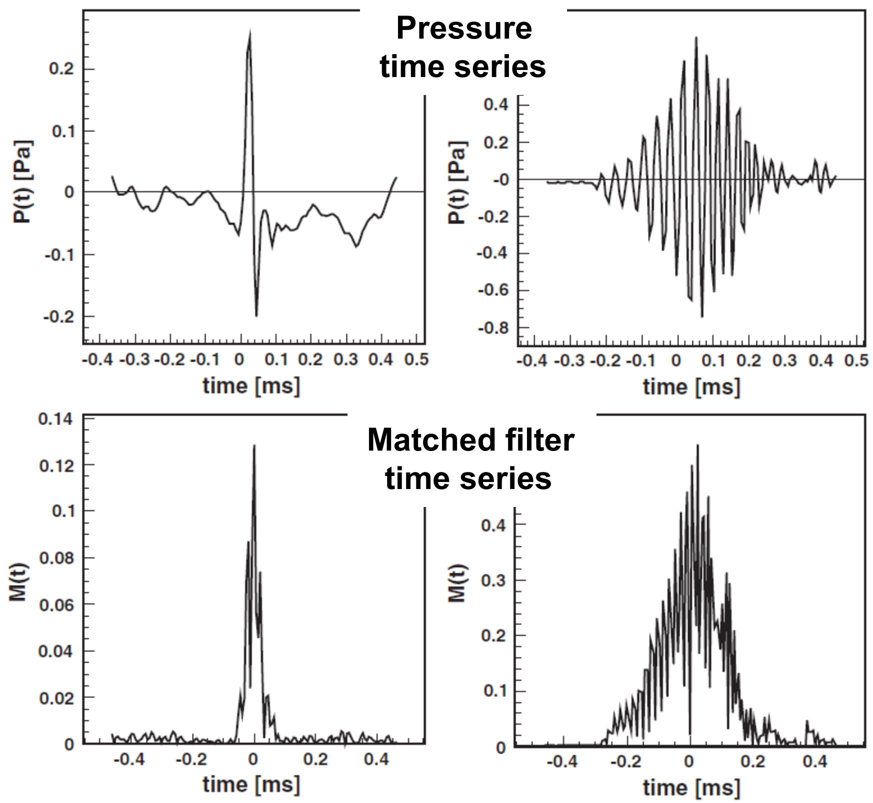


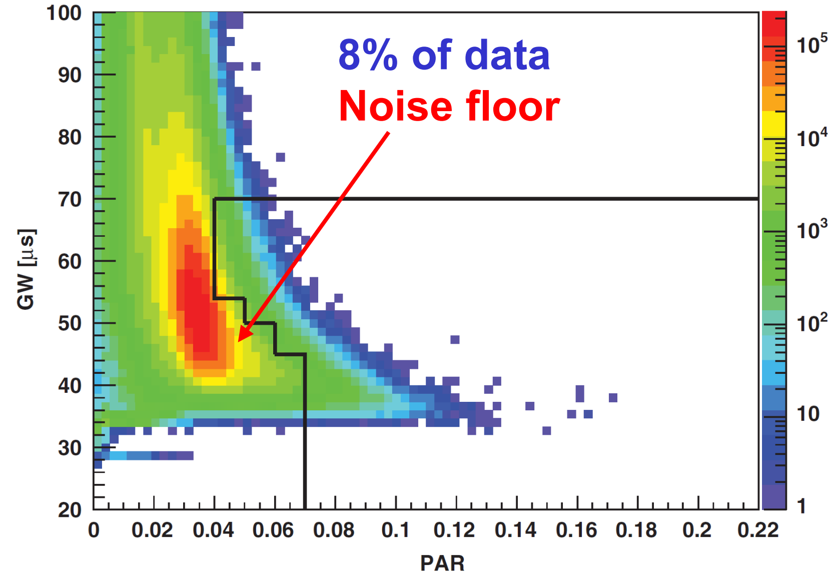
A neutrino?

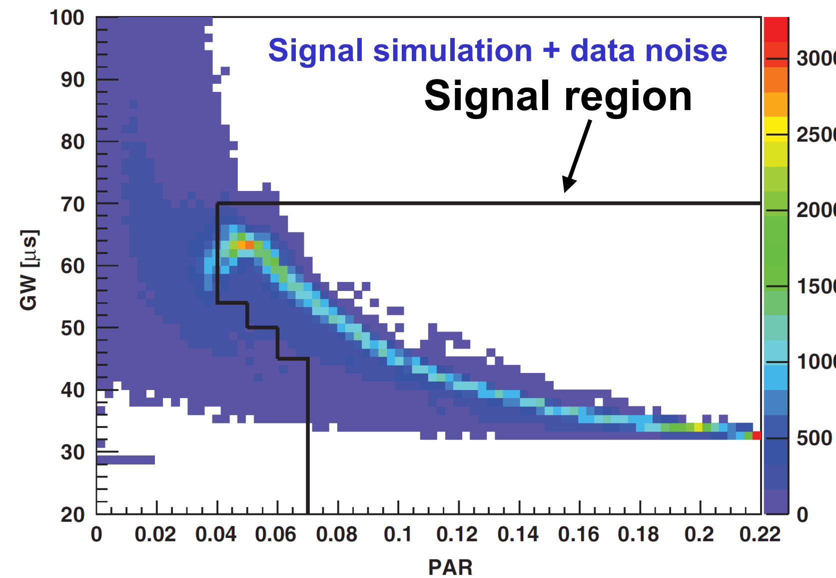
Event selection/reconstruction, out of 130 days live.

Cut	Single phone trigger	Events
Online triggers	327.9M	-
Quality triggers	146.7M	-
Waveform selection	2814545	-
Single phone rate	2562047	-
Triangulation	6605	4995
Isolated events	1227	320
Radiation pattern	8	2

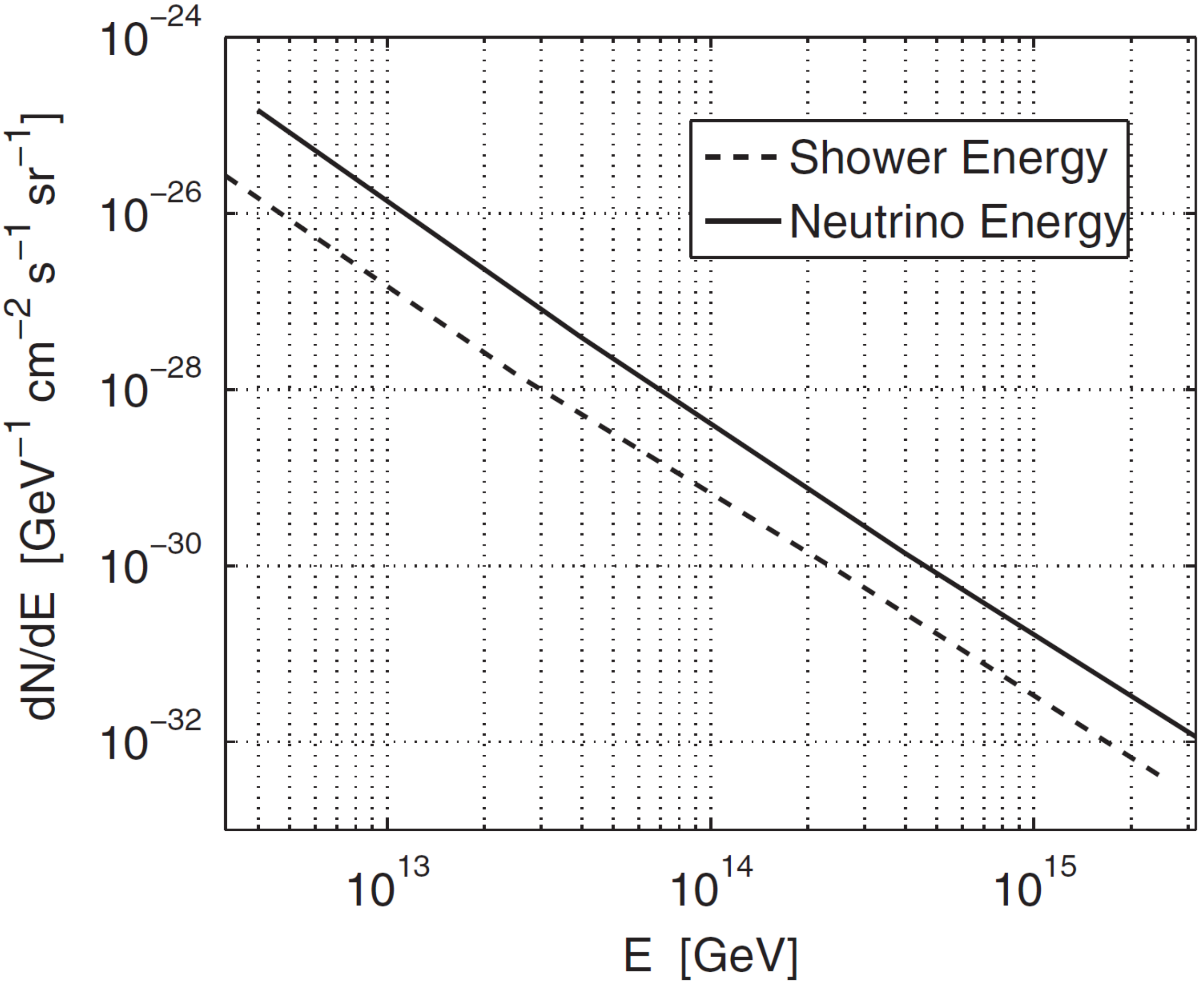
Need a matched filter and an event classifier





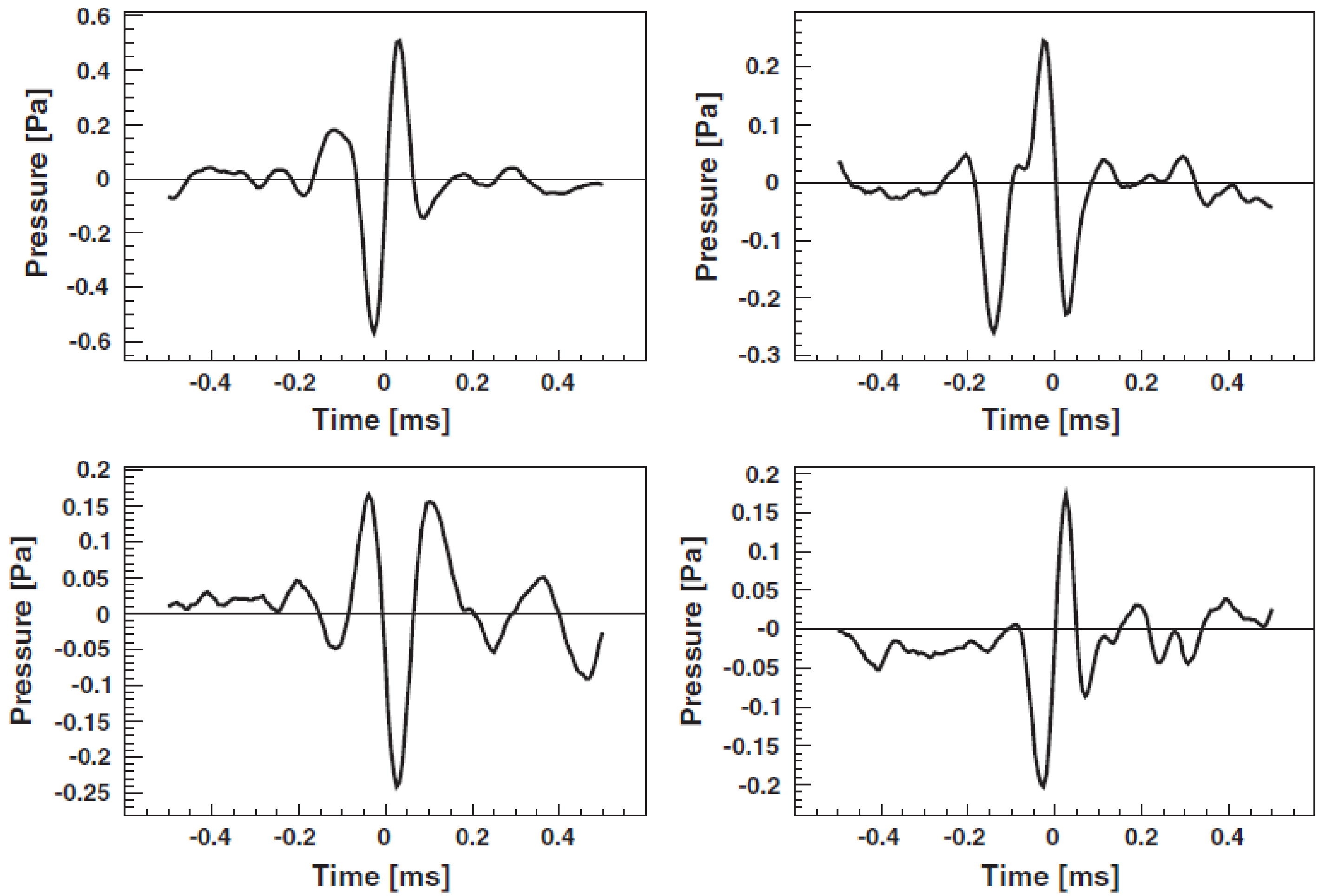


The sensitivity is limited by the fact that there are only phones in one bottom lates (and we had to require a 4-phone coincidence)



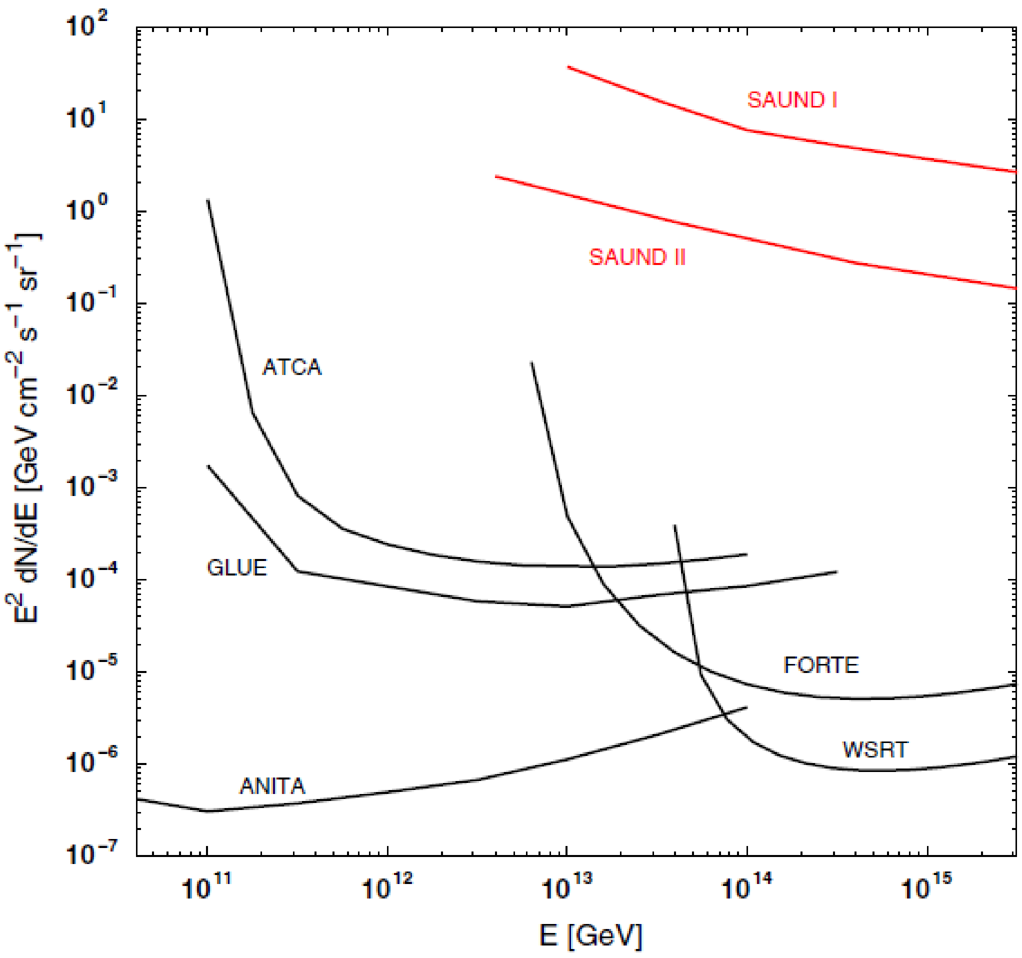
2 events survive all cuts.

The most impressive was on 3 May 2007, 15:01:04.17 UTC



In the end, here is the flux limit, which, as far as I know, is still the best for the technique

(plot is historical, from PRD 82 (2010) 073006, so more modern results are missing)



Conclusions

- Some of the properties of acoustic detection are unique and complementary to those of other techniques
- *"Unambiguous identification of rare UHE neutrinos from either acoustic or radio signal in huge and naturally occurring bodies subject to varying and poorly understood backgrounds is very difficult."**

  * From the conclusions of Kurahashi et al. PRD 82 (2010) 073006
- The next step requires a dedicated array, with phones distributed along the water column. There is now an opportunity with new Cherenkov detectors in seawater.
- Together with radio and optical Cerenkov it may provide the "perfect detector" to explore the unknown.

Work supported by Stanford University and the NSF
(which is perfectly capable to funding exploratory, high risk ideas!)