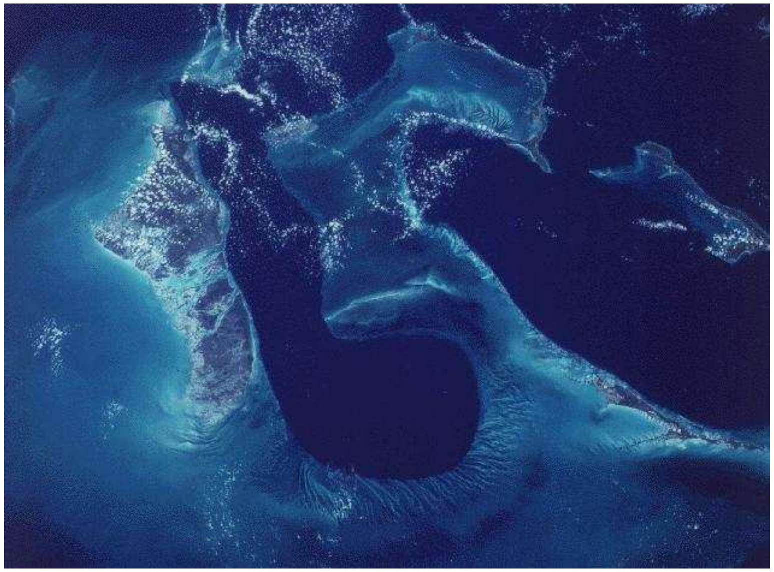
Acoustic UHE Neutrino Detection in Water: Lessons from SAUND

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



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AMANDA/IceCube Collaboration Meeting
Bartol Research Institute, University of Delaware
March 24, 2004

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

Thanks to my SAUND collaborators:

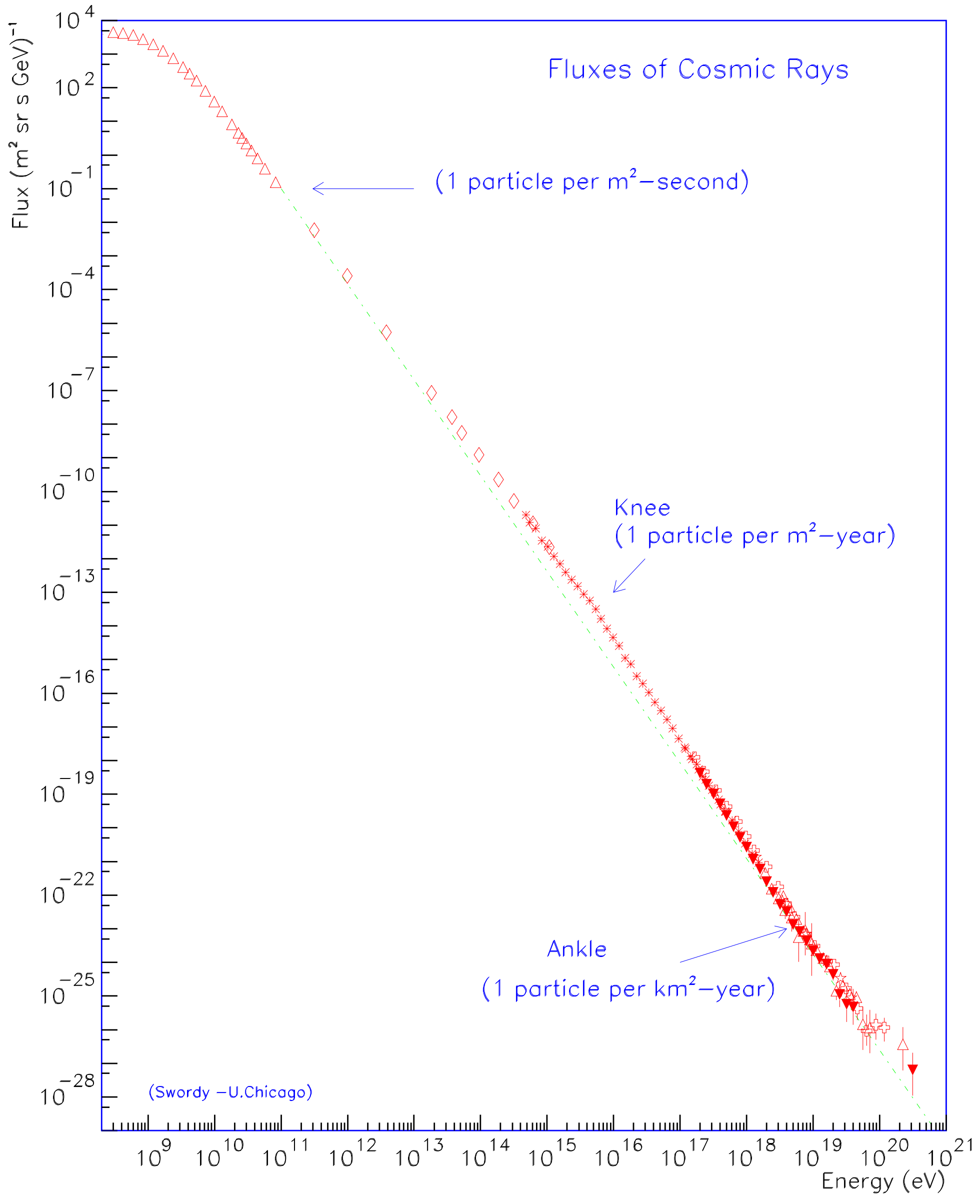
Current:
G. Gratta (Stanford)
N. Kurahashi (Stanford)
M. Buckingham (Scripps)

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

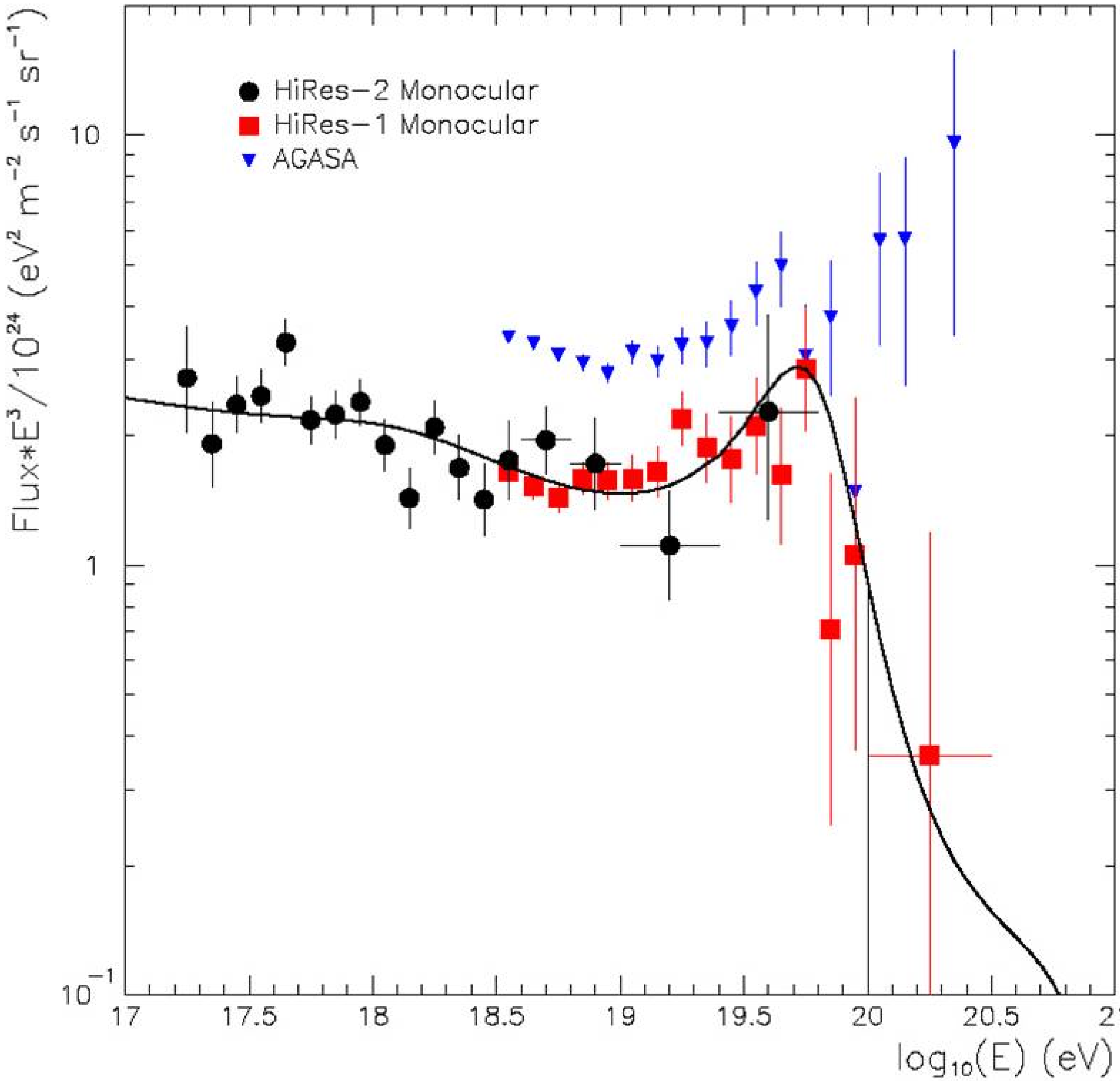
And to AUTEC and the U. S. Navy:

D. Belasco
D. Deveau
T. Kelly-Bissonnette
J. Cecil
D. Kapolka

Cosmic ray spectrum



The Greisen-Zatsepin-Kuzmin (GZK) cutoff



1 event / km^2 / century → detector innovation key!

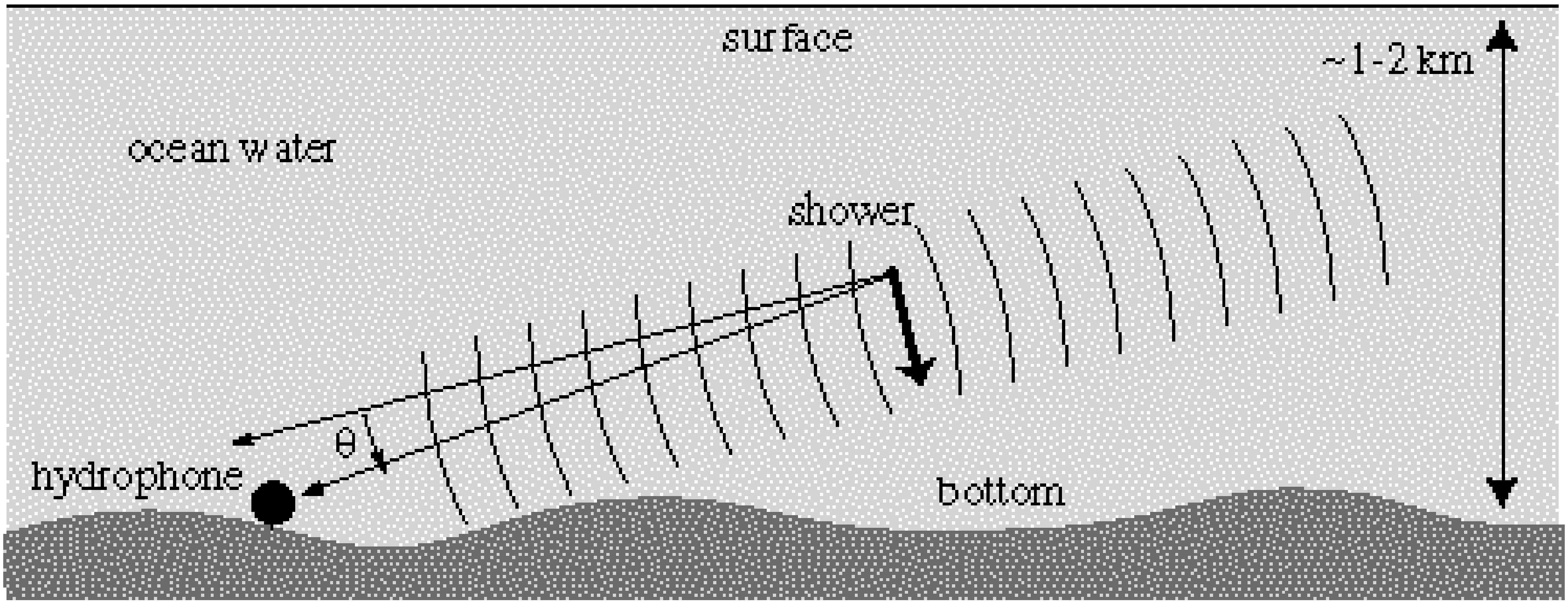
GZK: So what?

A crossroads of exciting physics

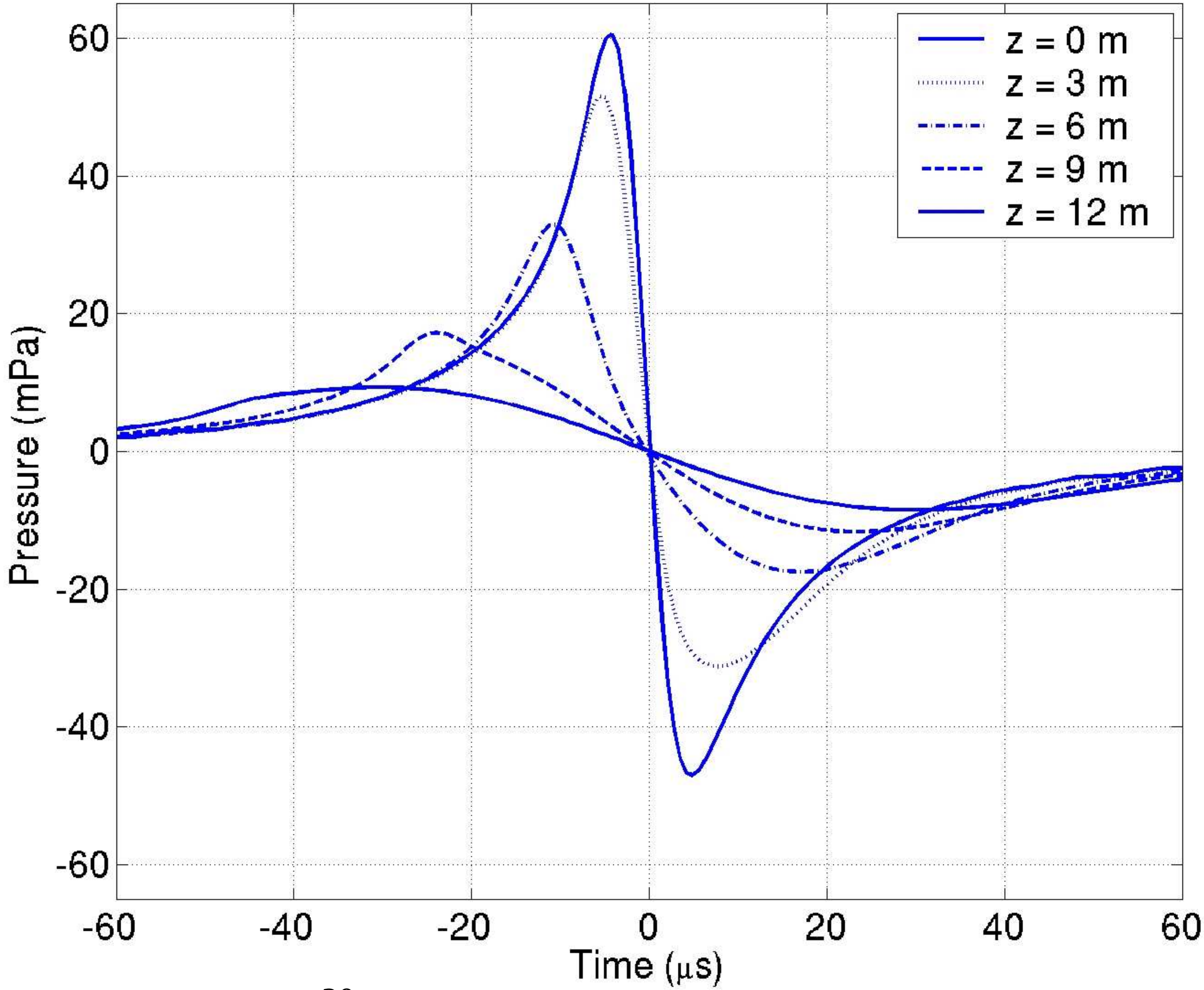
- active galactic nuclei
- gamma ray bursts
- grand unified theories
- topological defects (magnetic monopoles, cosmic strings, domain walls
- supersymmetry
- dark matter
- Lorentz invariance violation
- extra dimensions
- gravity at a TeV
- relic neutrinos

All important topics in our understanding of the universe!

The ocean as a particle detector

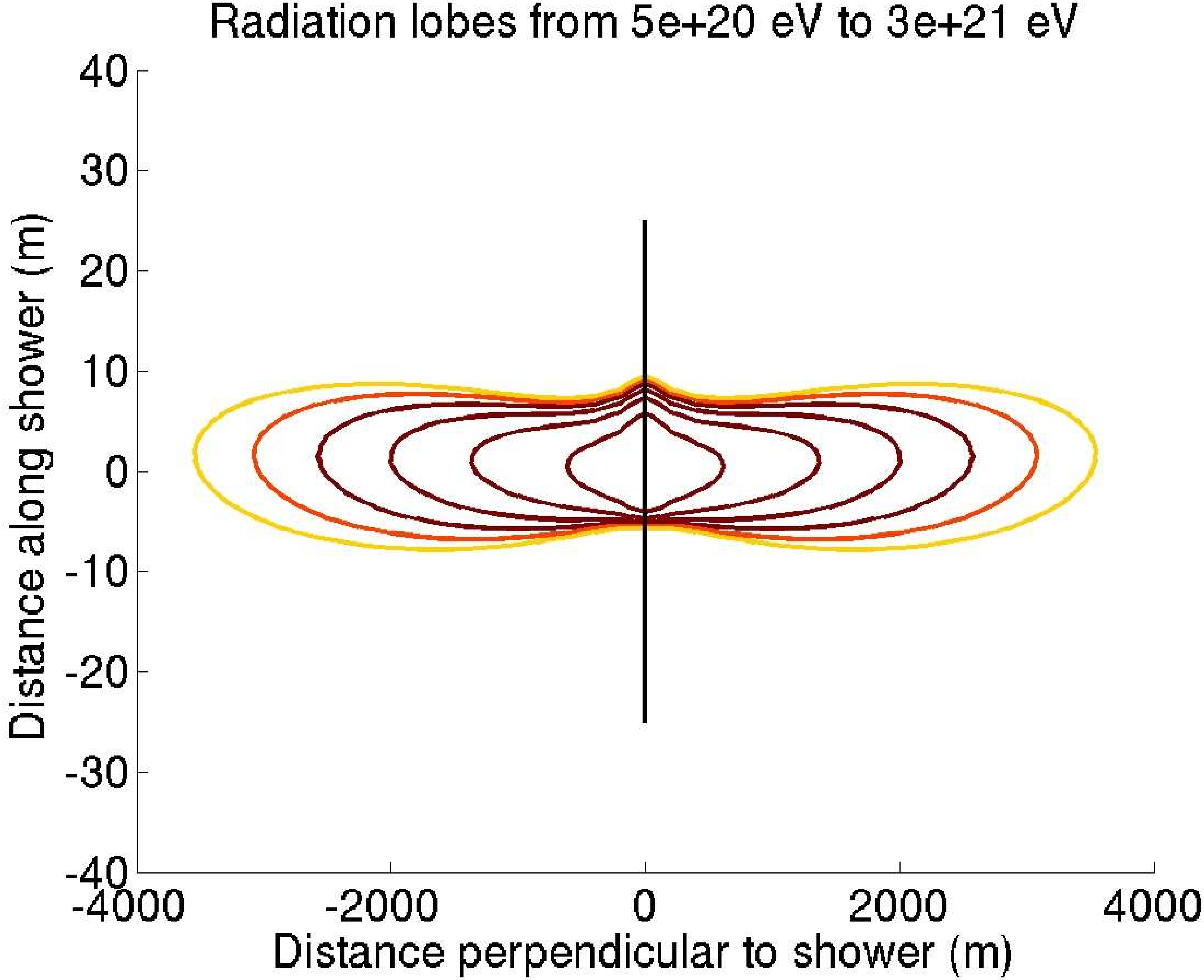


Simulated acoustic neutrino pulse



10^{20} eV hadronic shower @ 1 km

Extreme pancakes



Sound from charged particles in liquids: some background

- first discussion of the idea
  G. A. Askaryan Sov. J. Atom. Energy 3 (1957) 921

- extensive theoretical analysis
  J. G. Learned Phys. Rev. D 19 (1979) 3293

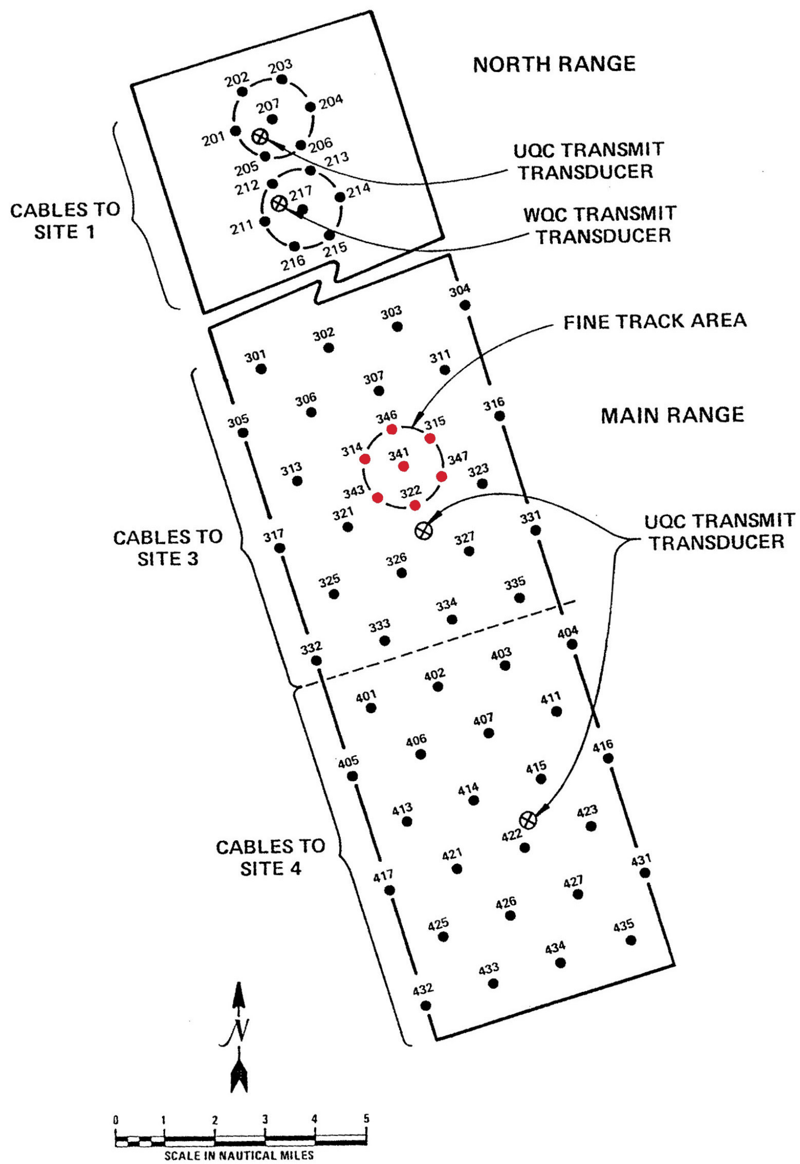
- experimental confirmation
  L. Sulak et al. NIM 161 (1979) 203

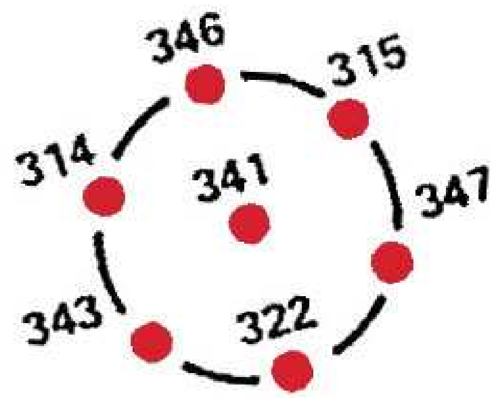
- sensitivity studies for neutrino detection
  N. Lehtinen et al. Astroparticle Physics 17 (2002) 279—292

- growing interest in acoustic arrays
  Stanford workshop on acoustic cosmic ray and neutrino detection, September 2003 http://hep.stanford.edu/neutrino/SAUND/workshop

The Atlantic Undersea Test and Evaluation Center (AUTEC)

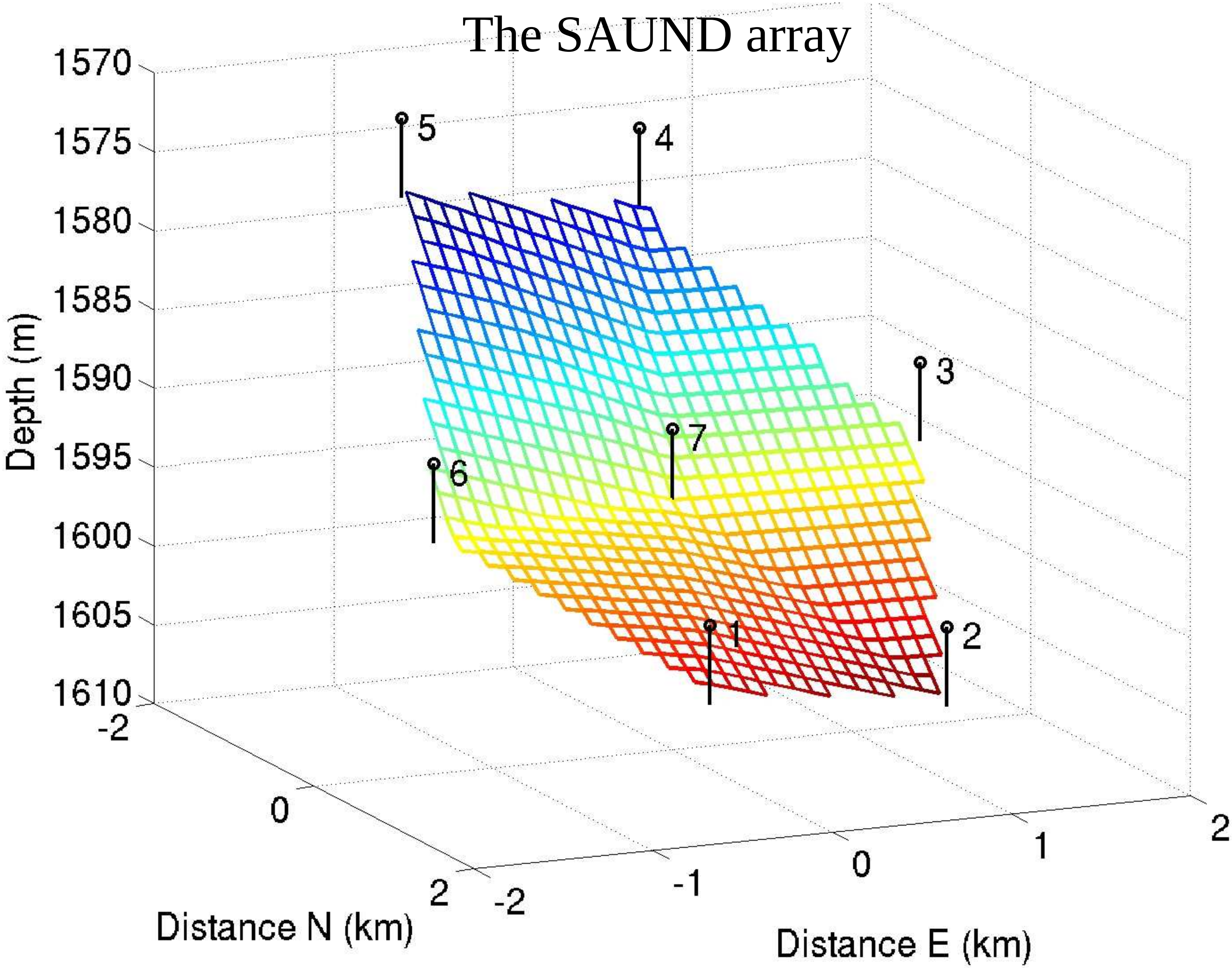
AUTEC hydrophones





SAUND
7 km^2

The SAUND array



Site 3

DAQ

DAQ

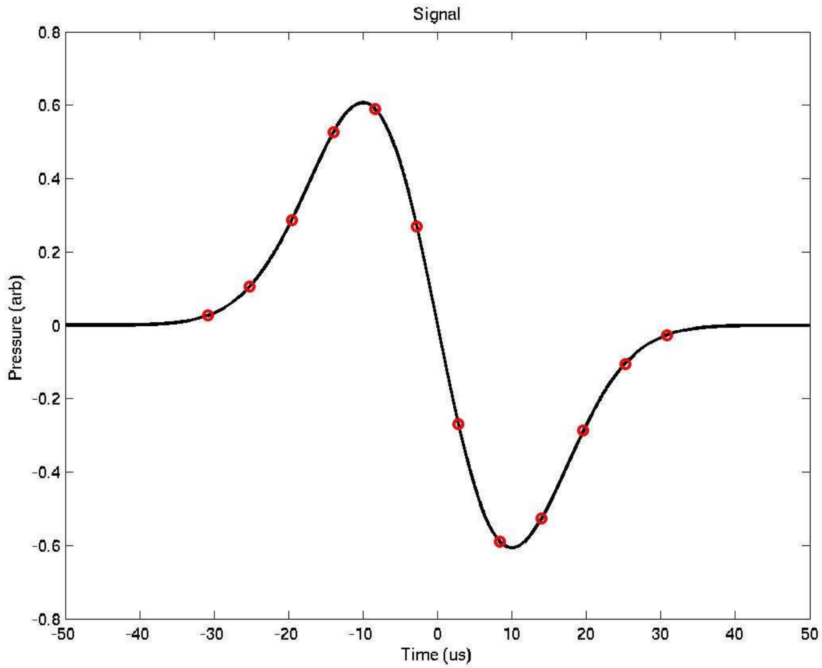
Software

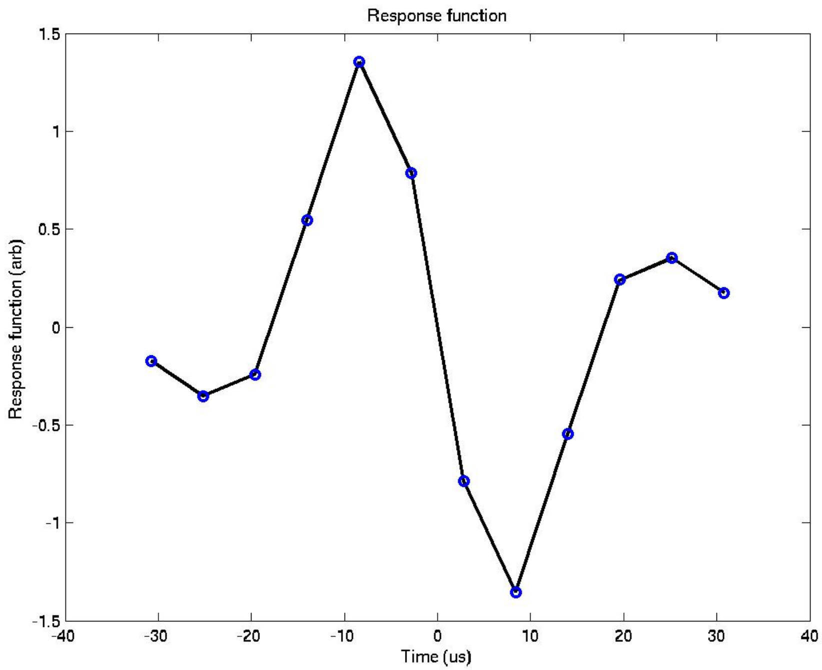
- 179 kHz sampling
- digital matched filter
- variable threshold
- 60 events/minute target
- 1-2 GB / 24 hrs

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

$$noise: N(t) \propto f^{-2}$$

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

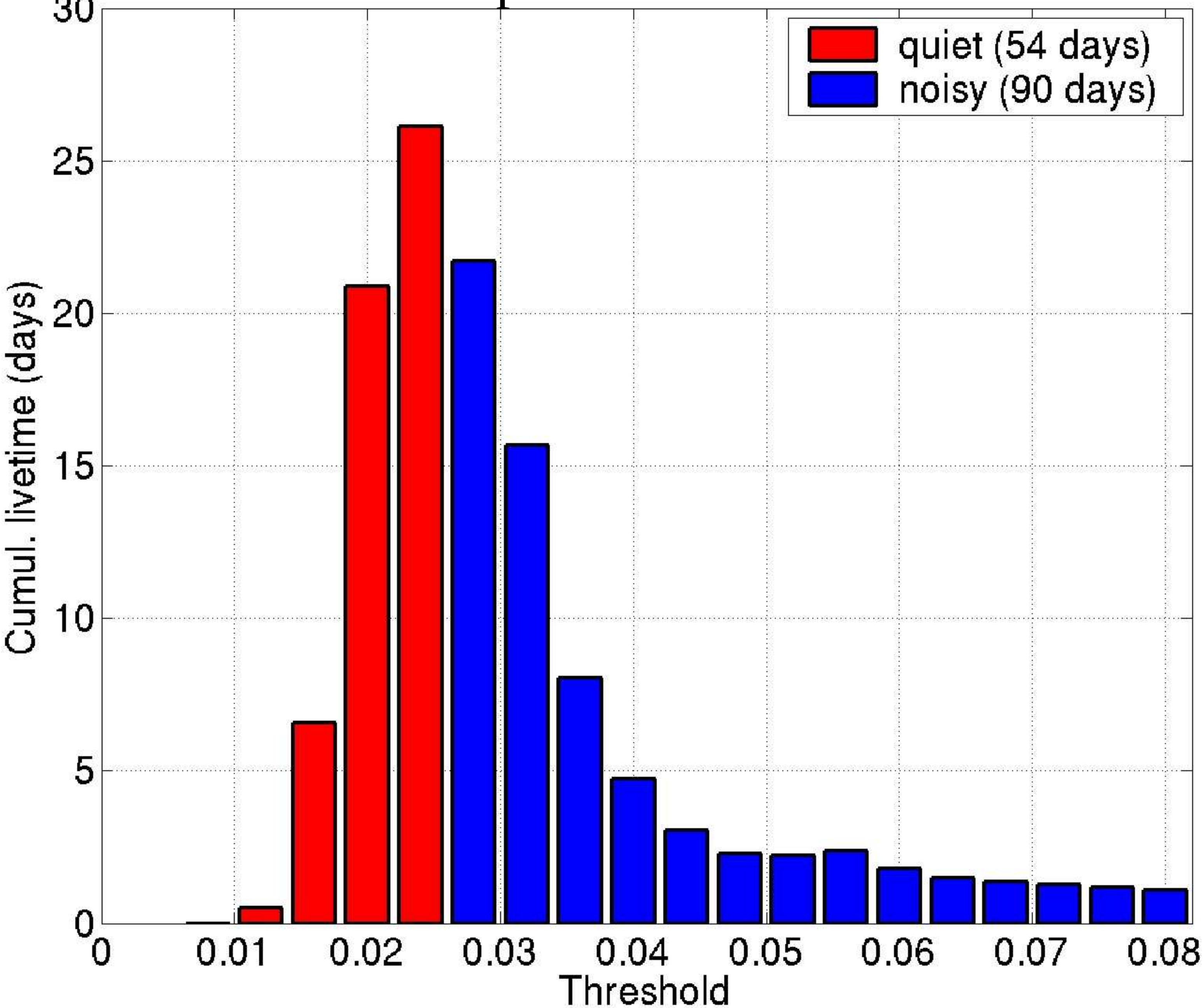




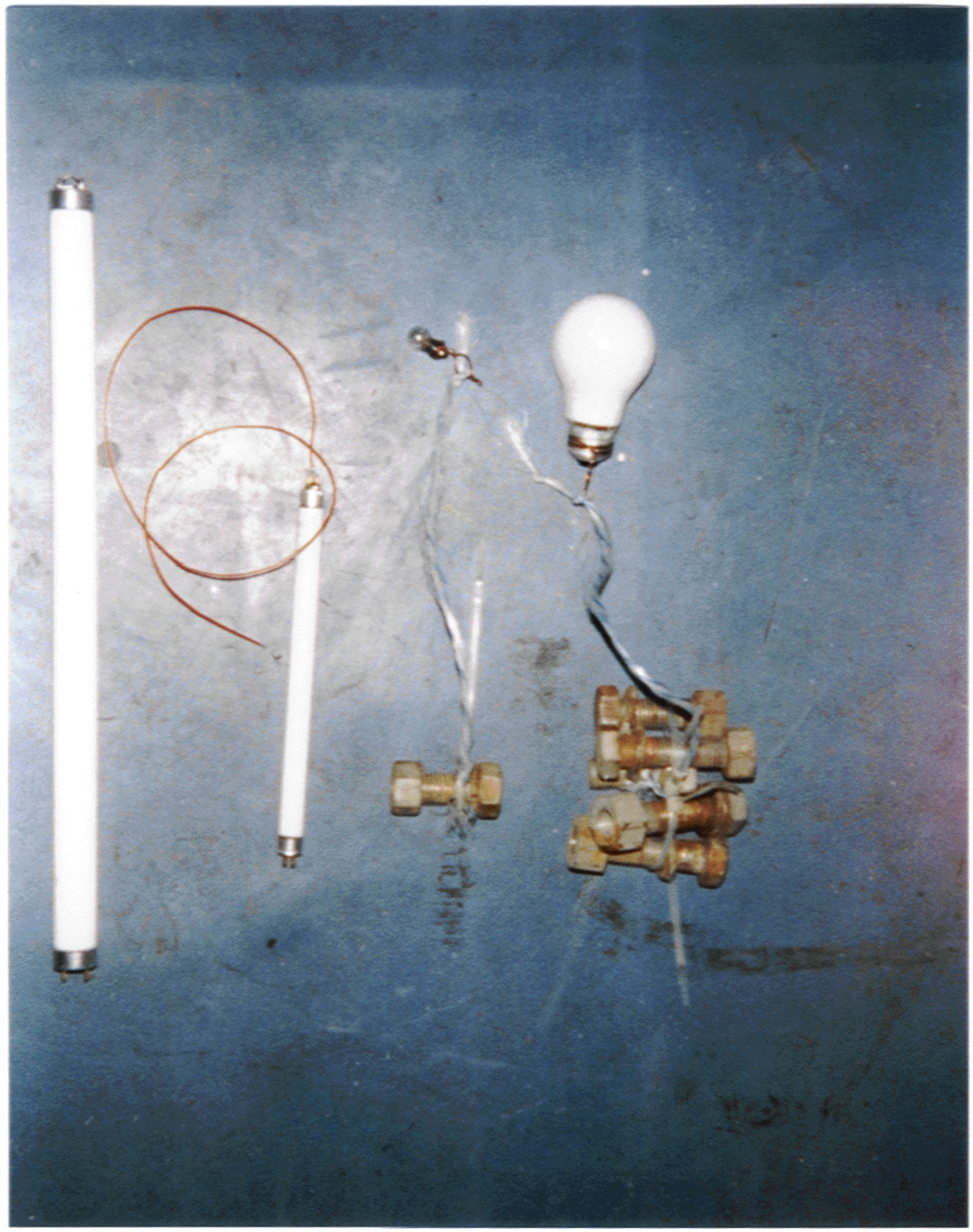
Hardware

- 1.7 GHz Pentium 4
- ADC card
- 60 GB external hard drive

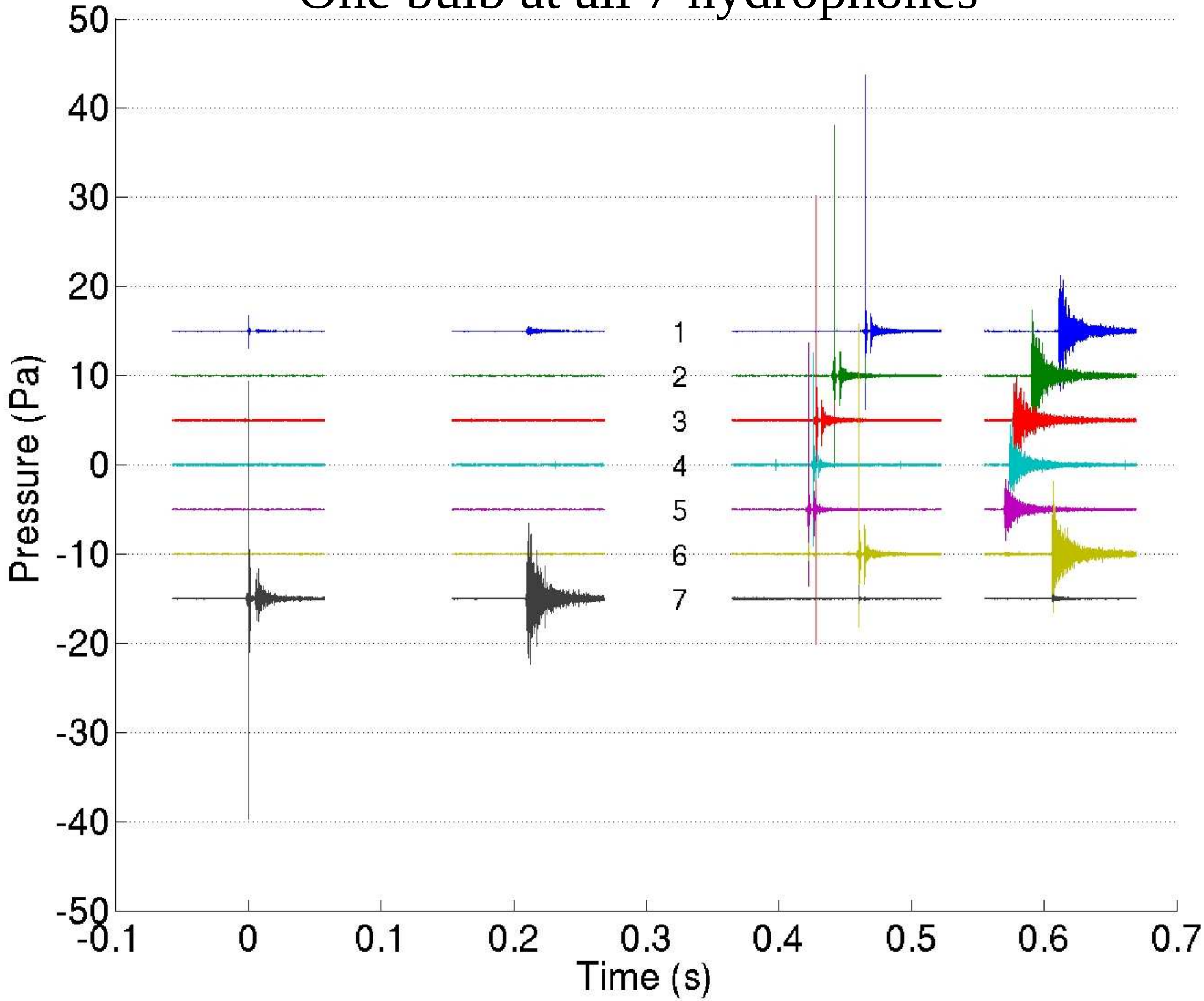
Adaptive threshold



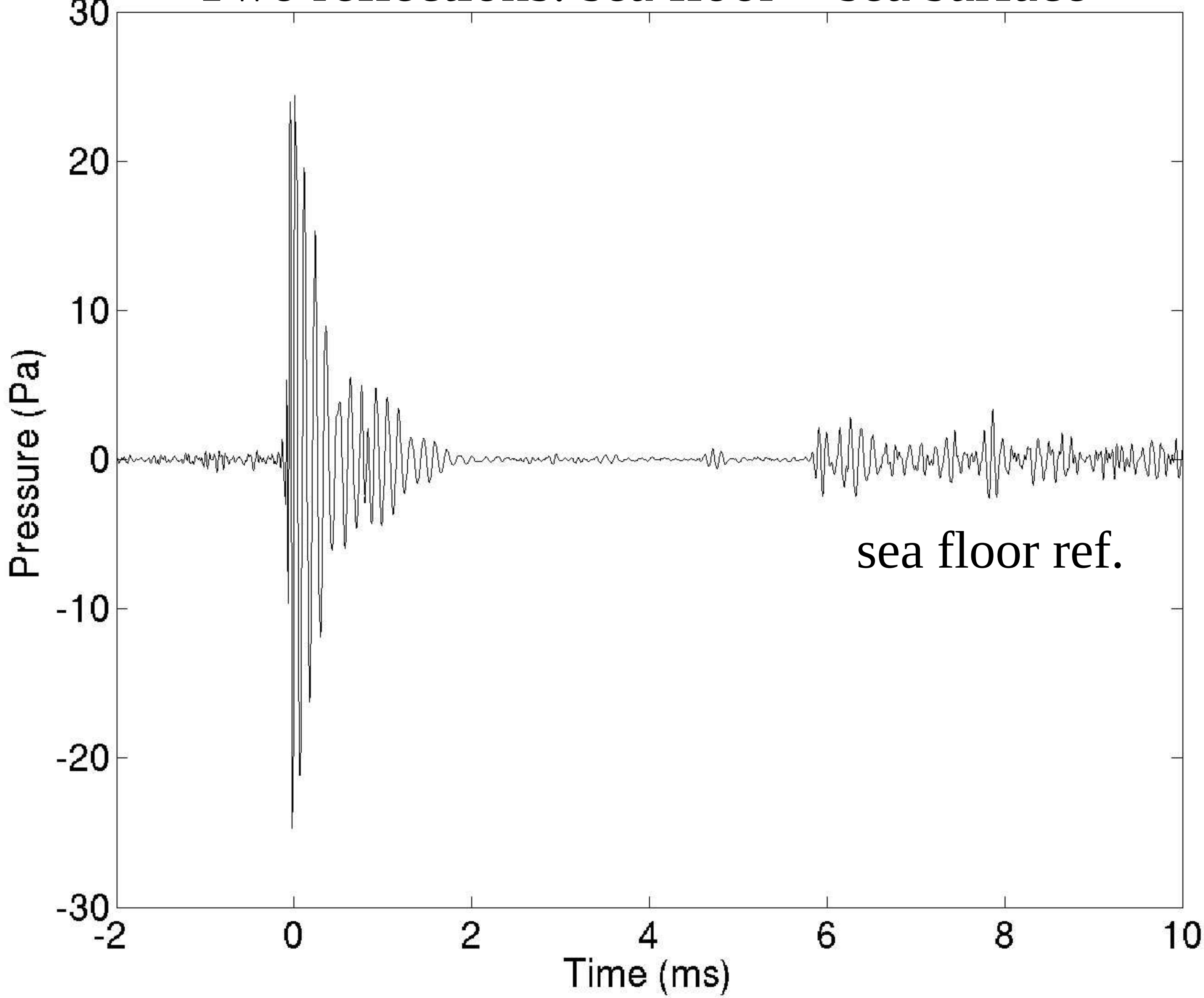
Calibration sources



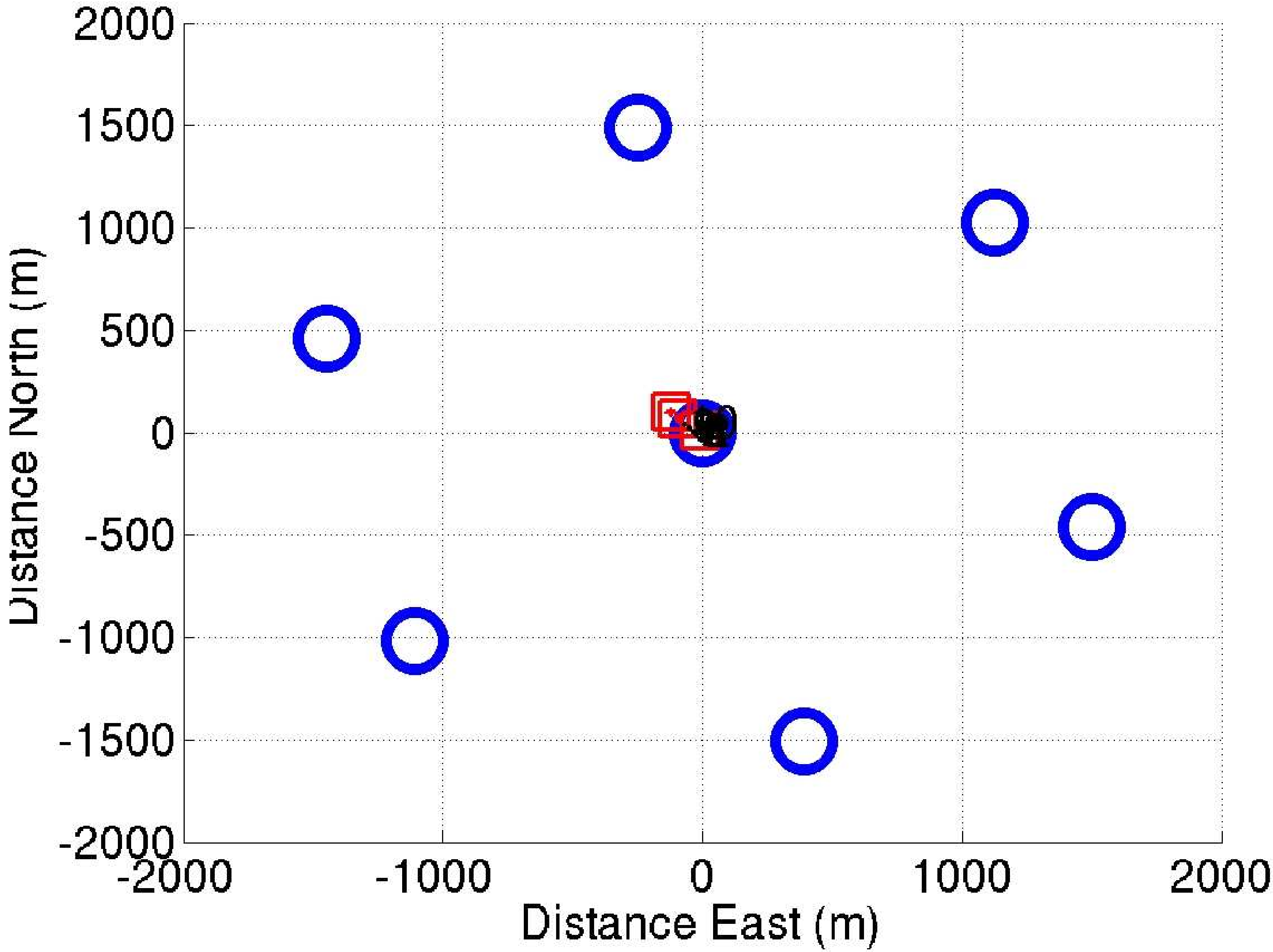
One bulb at all 7 hydrophones



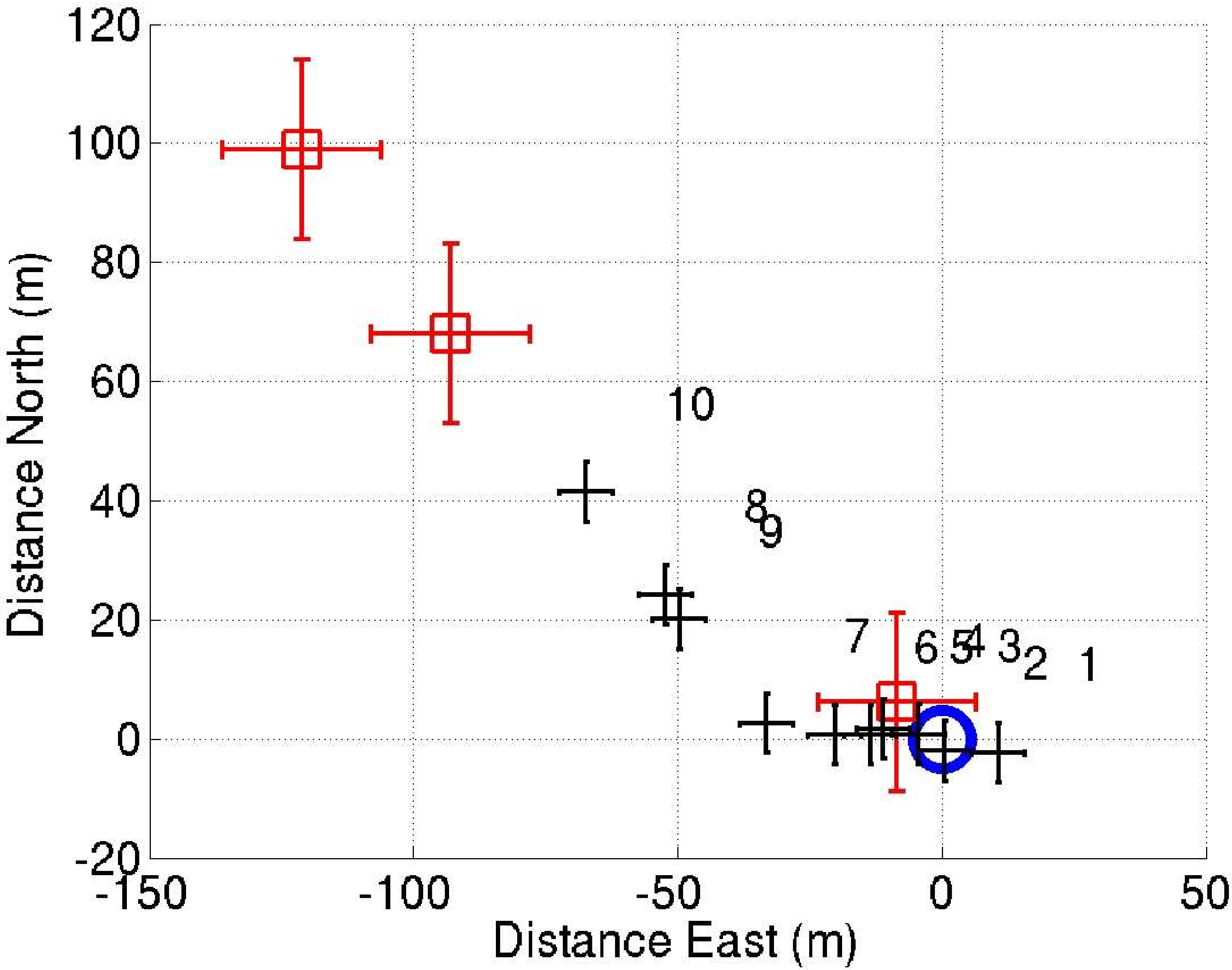
Two reflections: sea floor + sea surface



Lightbulb positions reconstructed (zoomed out)



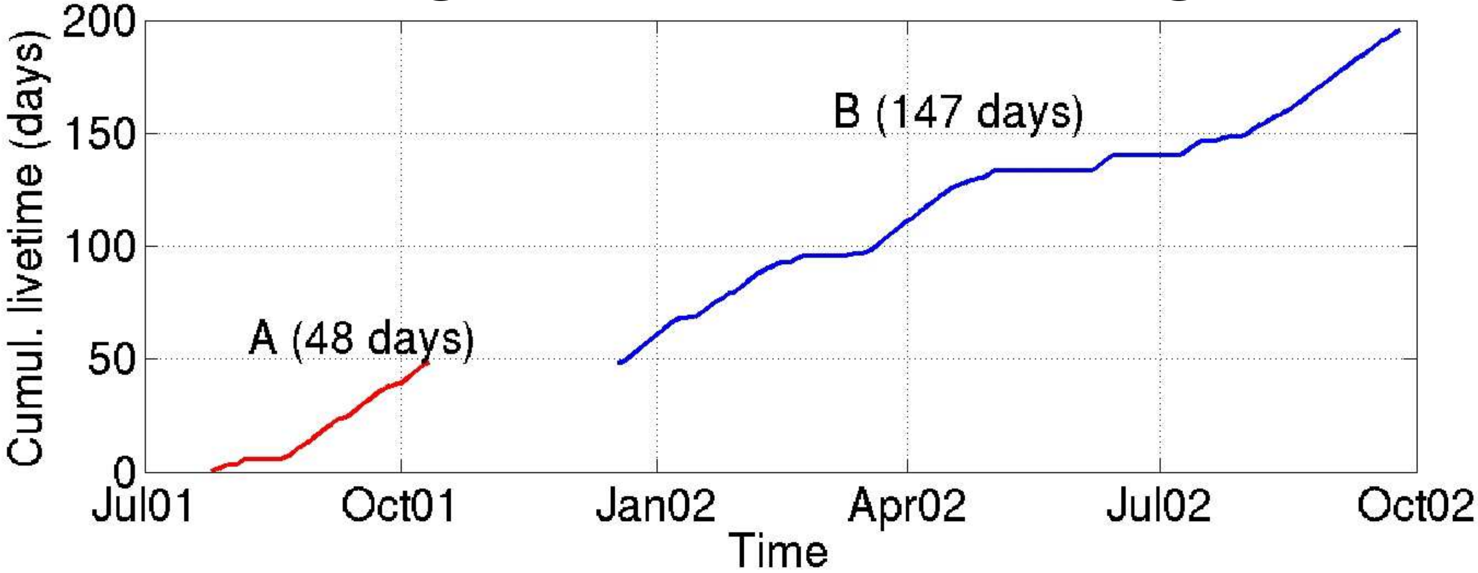
Lightbulb positions reconstructed (zoomed in)

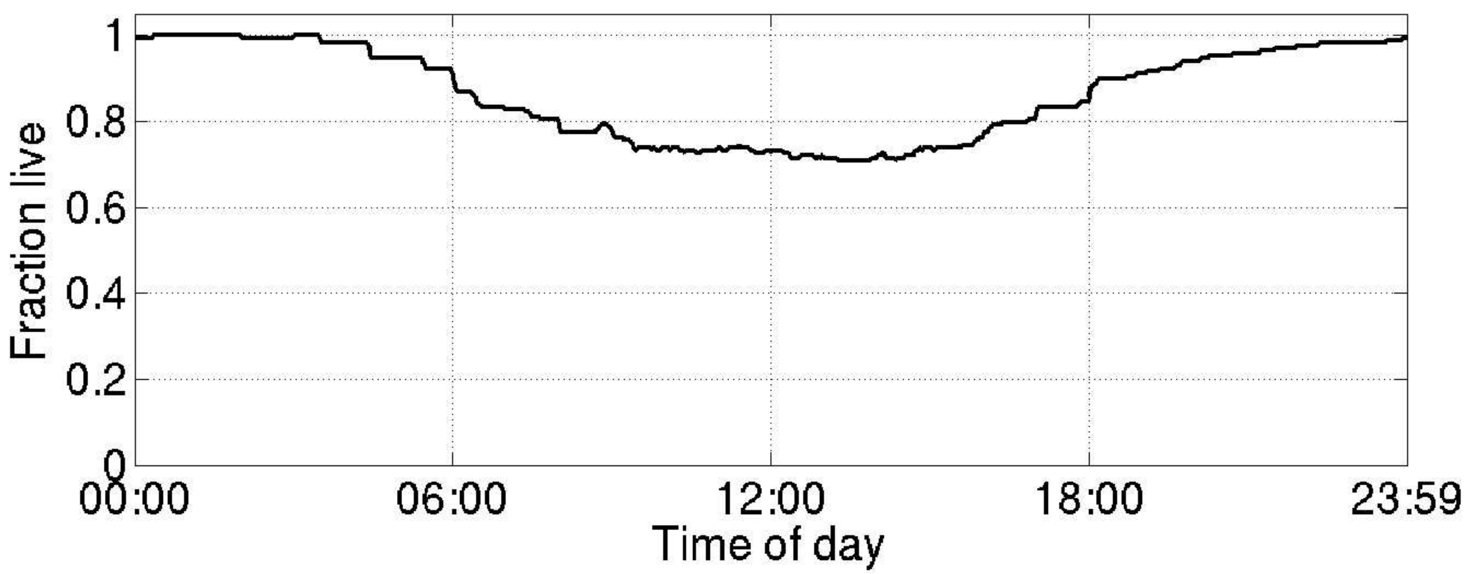


Lightbulb energies reconstructed

Bulb	Depth (m)	P = ρgh (kPa)	E_0 = PV (J)	E_{rad} (J)
1	170	1640	250	1.7
2	110	1120	170	0.3
3	150	1430	210	1.5
4	170	1690	250	2.8
5	130	1300	200	0.8
6	110	1050	160	0.4
7	90	900	140	0.1
8	140	1380	210	1.9
9	200	1930	290	1.9
10	300	2930	440	1.8

Data: a large livetime has been integrated





200 days livetime	25 million events	350 GB	70% duty cycle

Five-phone coincidence

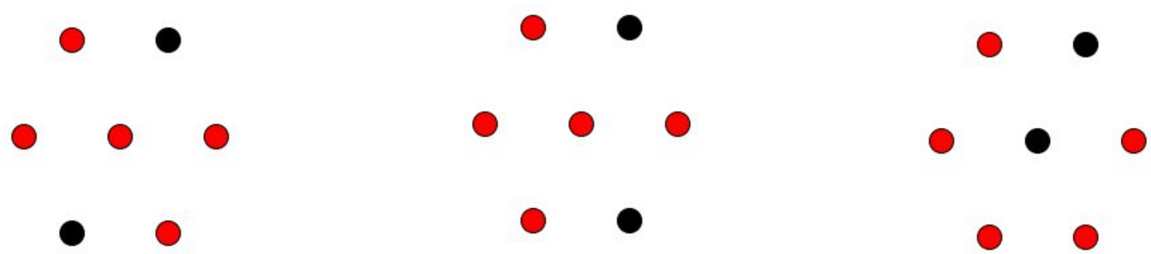
Require

1) Events obey causality: $t_{ij} \leq d_{ij} / v_{sound}$

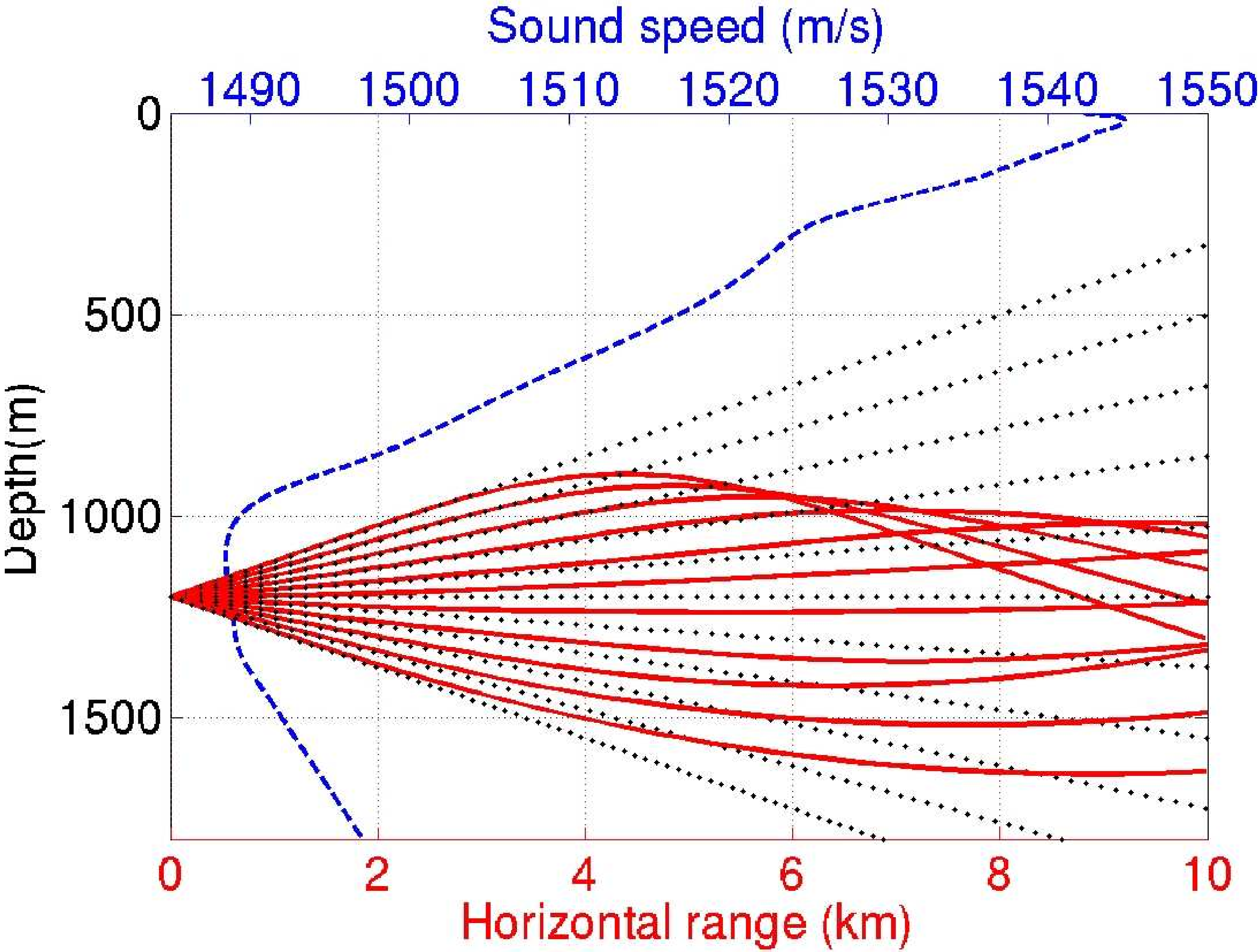
2) Geometry consistent with pancake (flat circle!) shape:

accepted:

rejected:

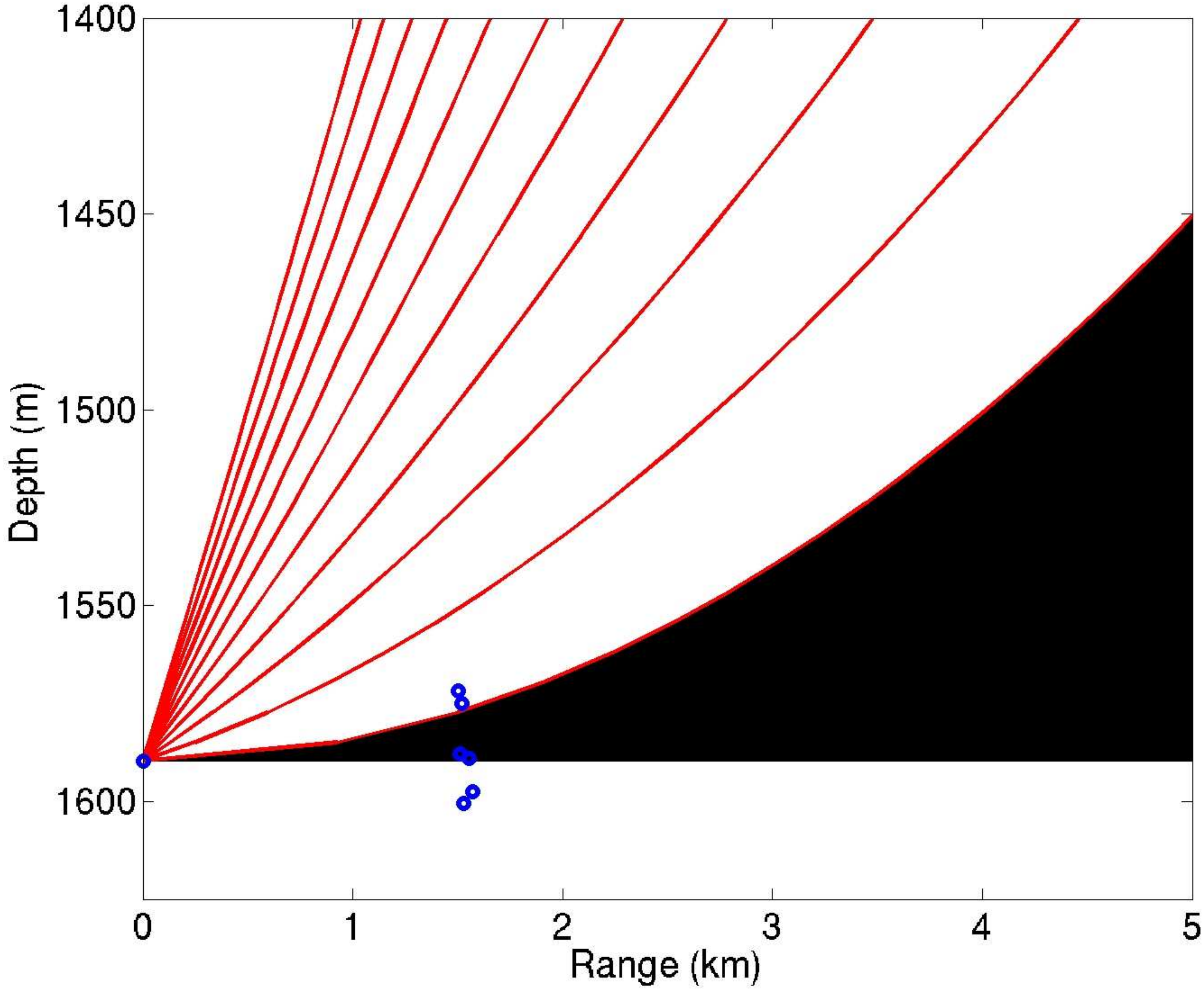


Refraction

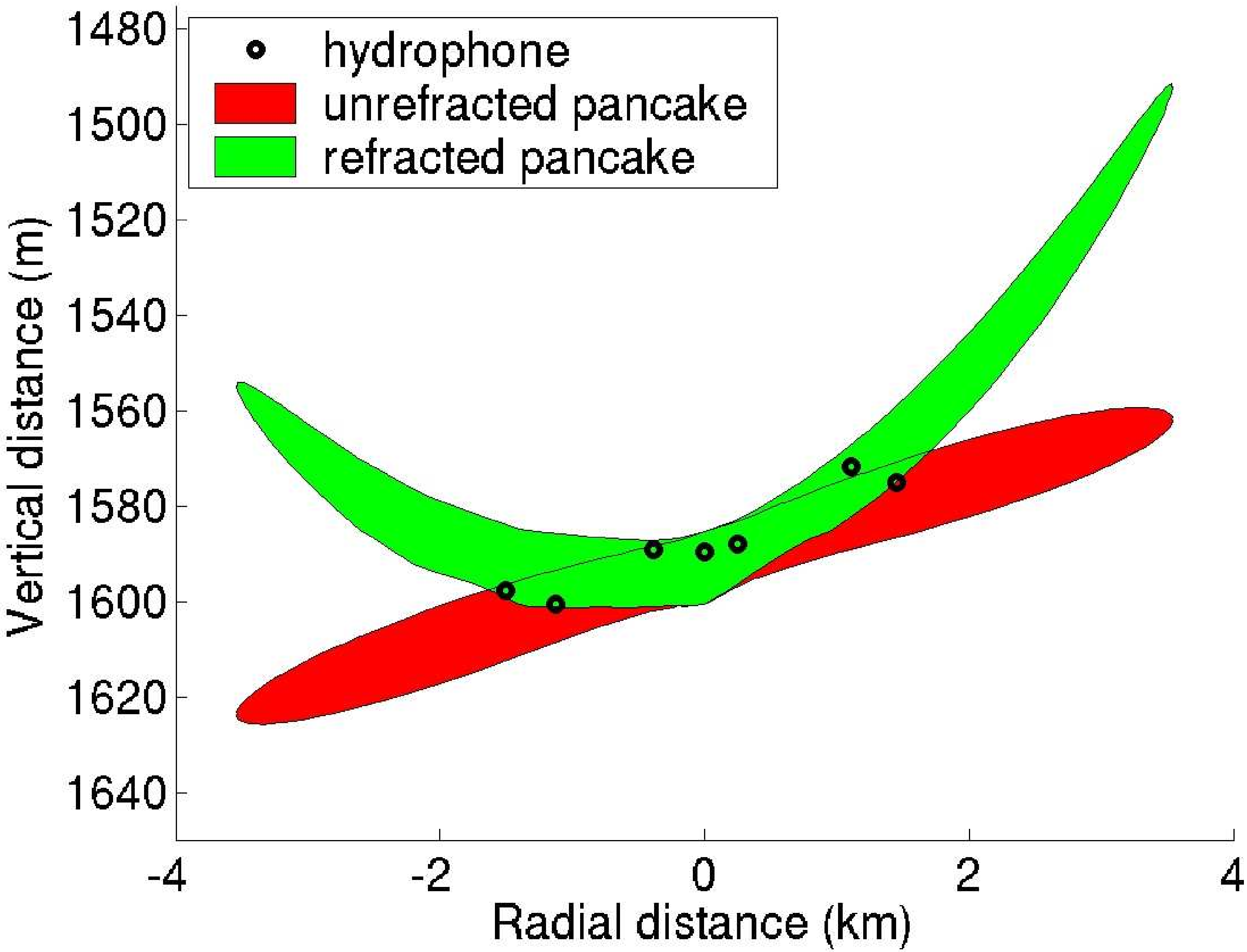


Sound speed (m/s)
1490
1500
1510
1520
1530
1540
1550
0
500
1000
1500
Depth(m)
0
2
4
6
8
10
Horizontal range (km)

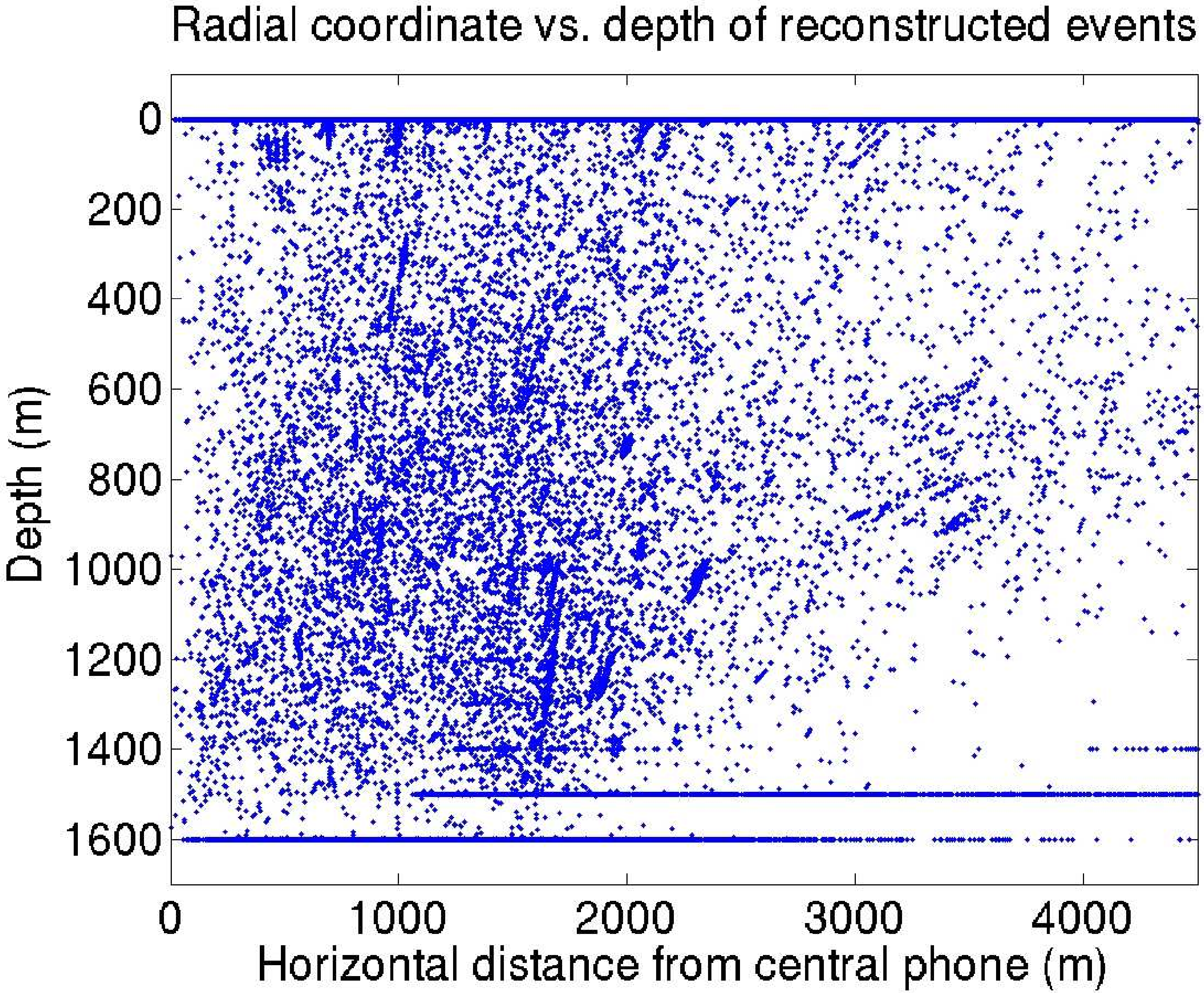
Refraction shadow



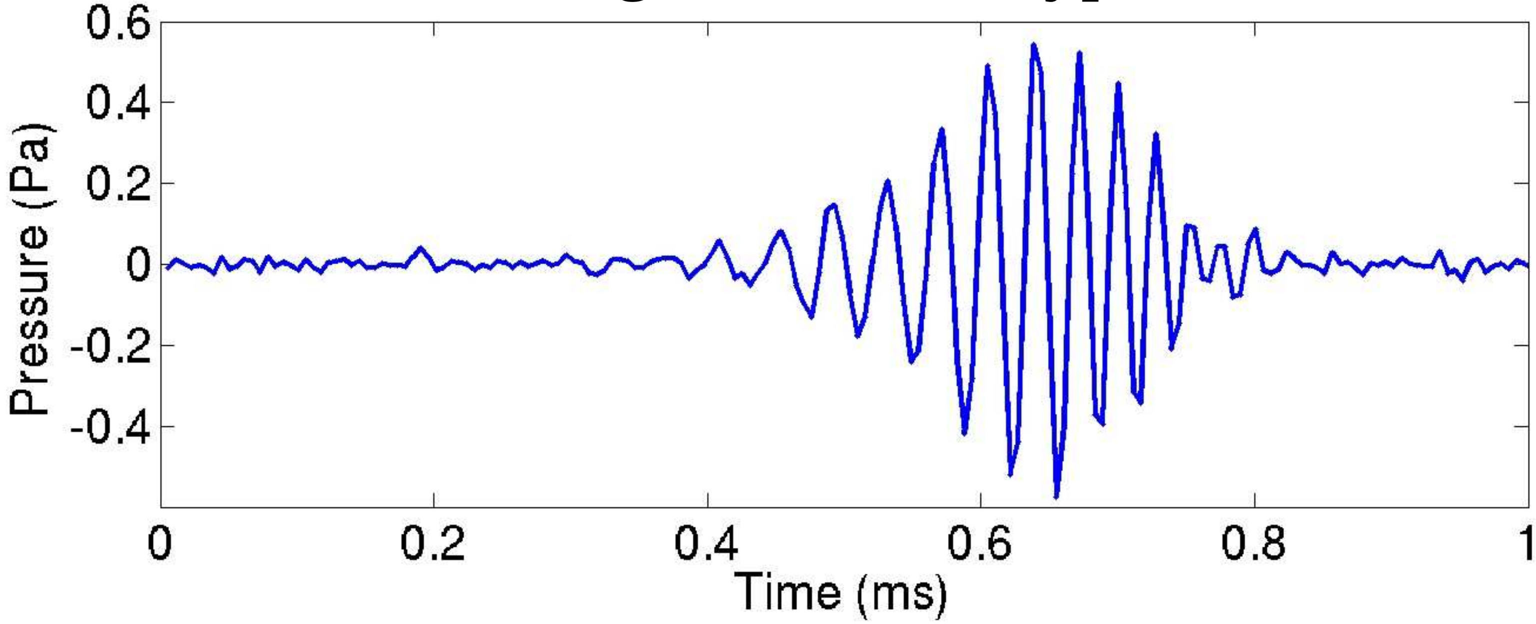
Refracted pancake

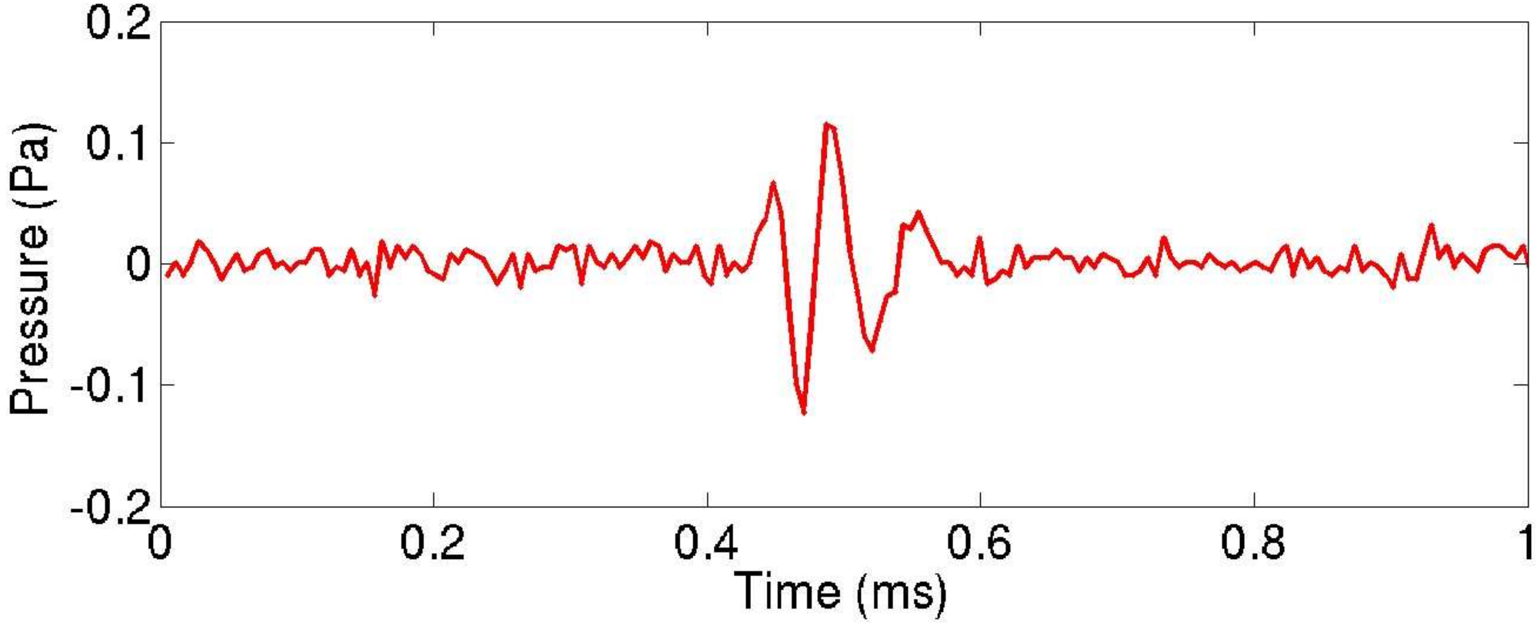


Position reconstruction achieved (10 m resolution)

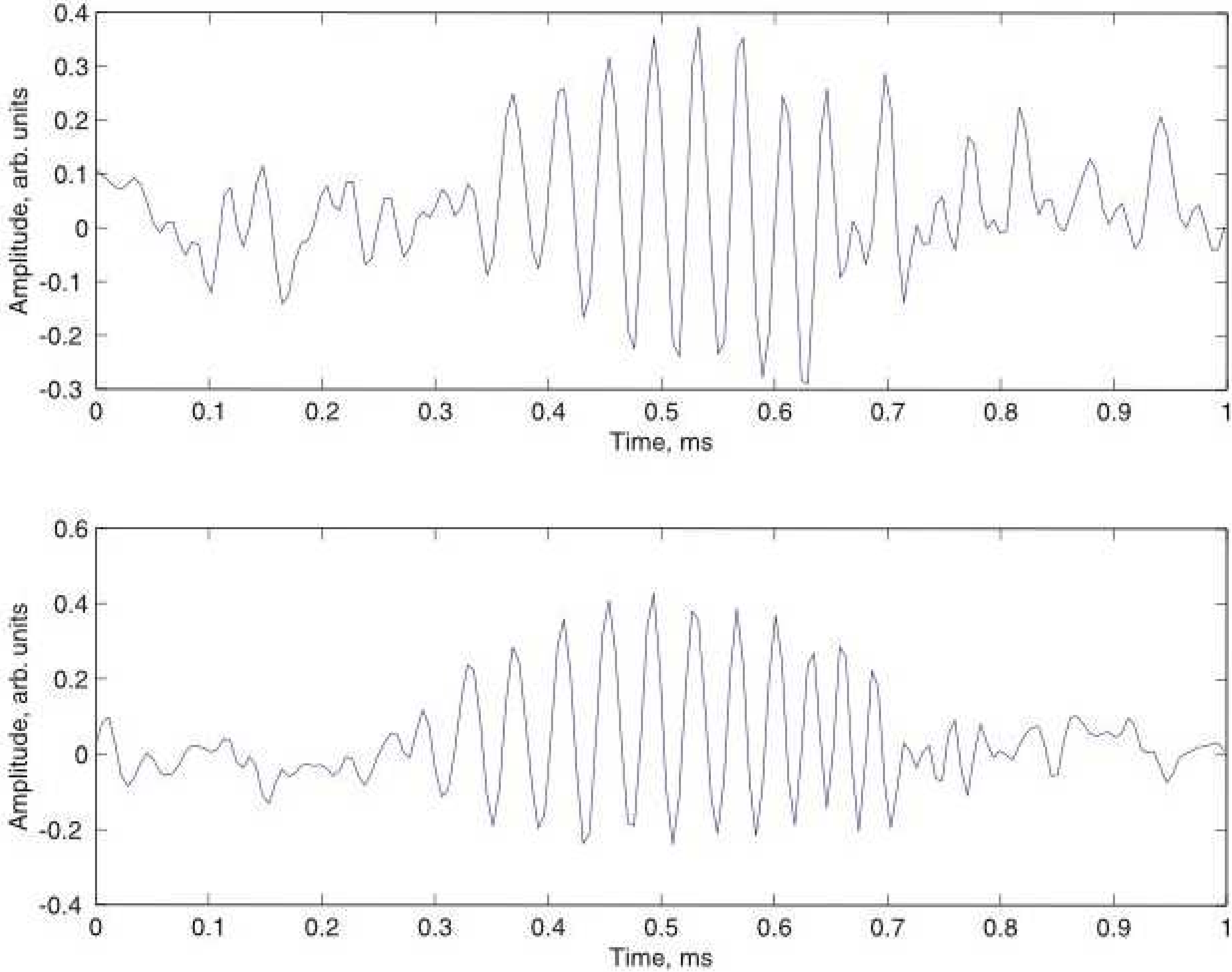


Background event types





Examples of dolphin signals recorded by AUTEC personnel

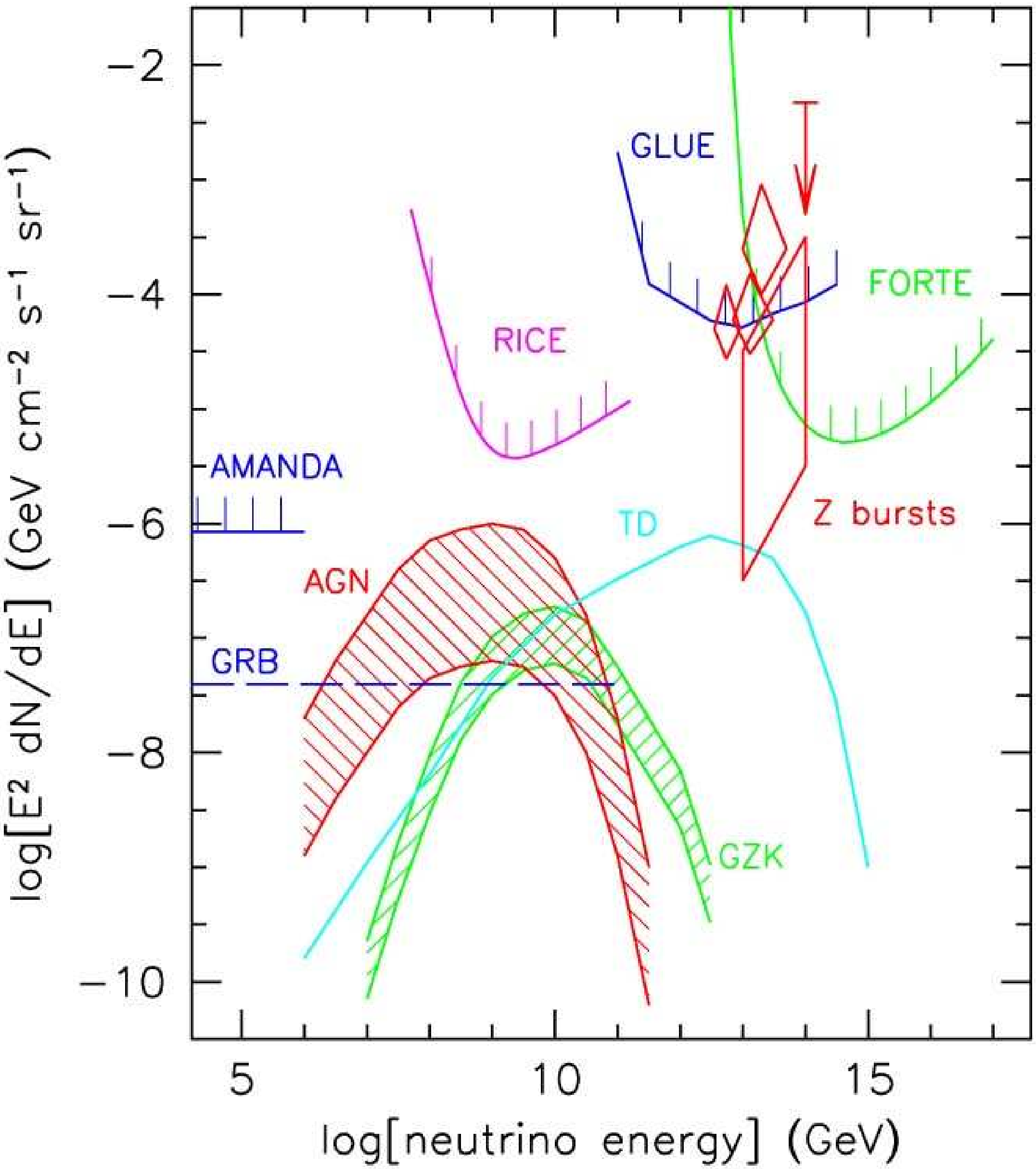


Background rejection

Cut	Events passing cut (Run II, 147 days integrated livetime)	
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



astro-ph
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v2

...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
- $c_{sound} = c_{light}$ / 200,000 !! (coincidence not so powerful)
- First-generation threshold: 10^{21} eV (10^{19} eV possible?)

Onward and downward (NSF-funded ÒSAUND-IIÓ)

- On to more phones (52), area (250 km^2), online intelligence (7 CPUÕs)
- 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:

		water	ice
1	Attenuation length	1-10 km	1-10 km?
2	Signal amplitude (arb. units)	1	10?
3	Background noise	okay	low?

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