The sound of neutrinos

ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

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Friedrich-Alexander-Universität
Erlangen-Nürnberg

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Outline

- Motivation
- Comparison of acoustic to optical detection
- Sound generation
- Experiments
  - Background and medium properties
  - Direction and source position reconstruction
  - Flux - upper limit
- Summary

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Astro-particle physics with neutrinos

Neutrino Oscillations:
Direction, Energy, Flavor

Dark matter search (WIMPs):
Direction, Energy

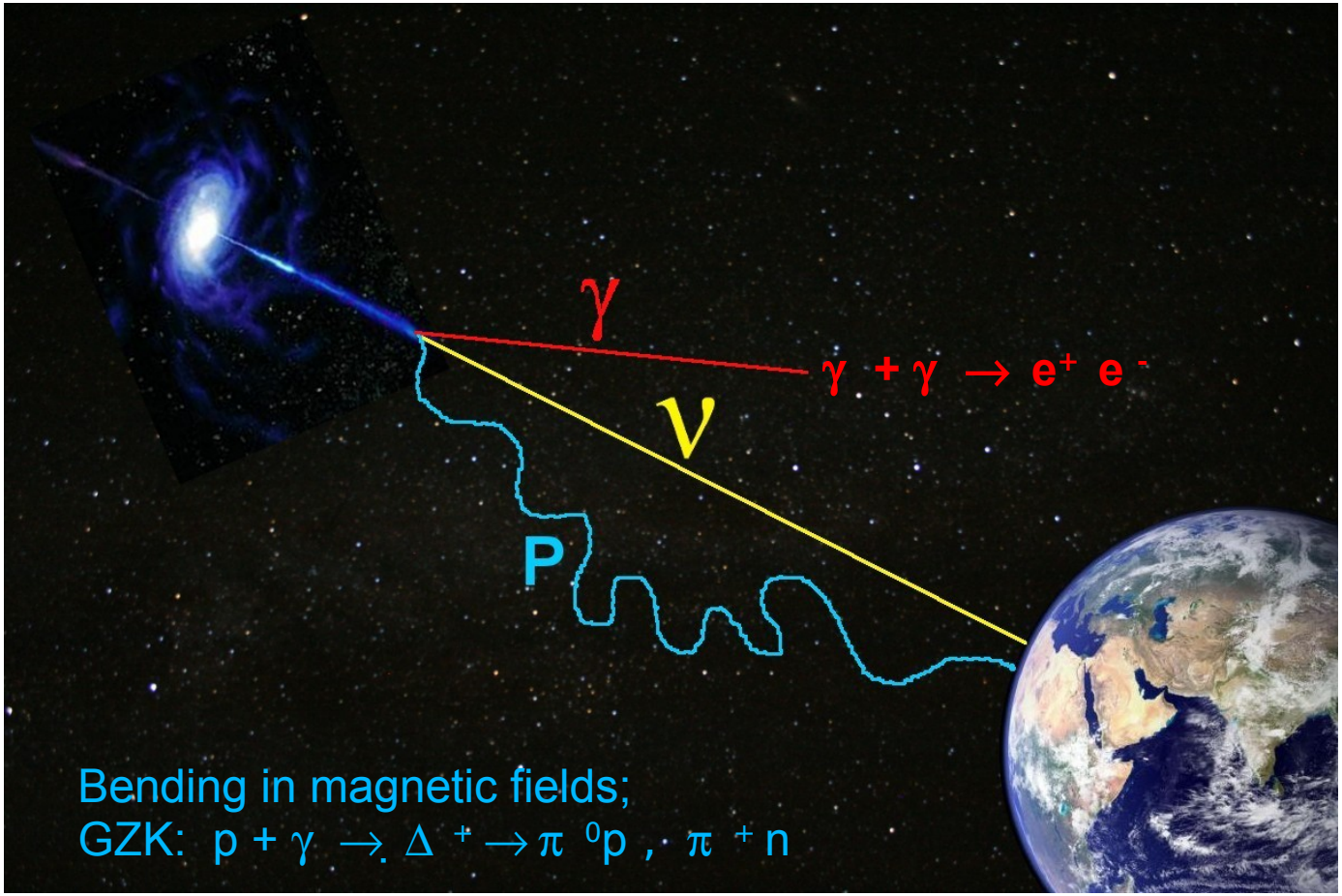
Astrophysical point sources:
Direction, (Energy), Time

Diffuse cosmic neutrino flux:
(Direction), Energy

Low-energy limit:
- detector sensitivity
- background

High-energy limit:
- neutrino flux decreases like E^{-n} ($n \approx 2$)
- large detection volume needed

Why neutrinos?



Neutrinos, unlike protons, are not deflected by magnetic fields
Track points back to source

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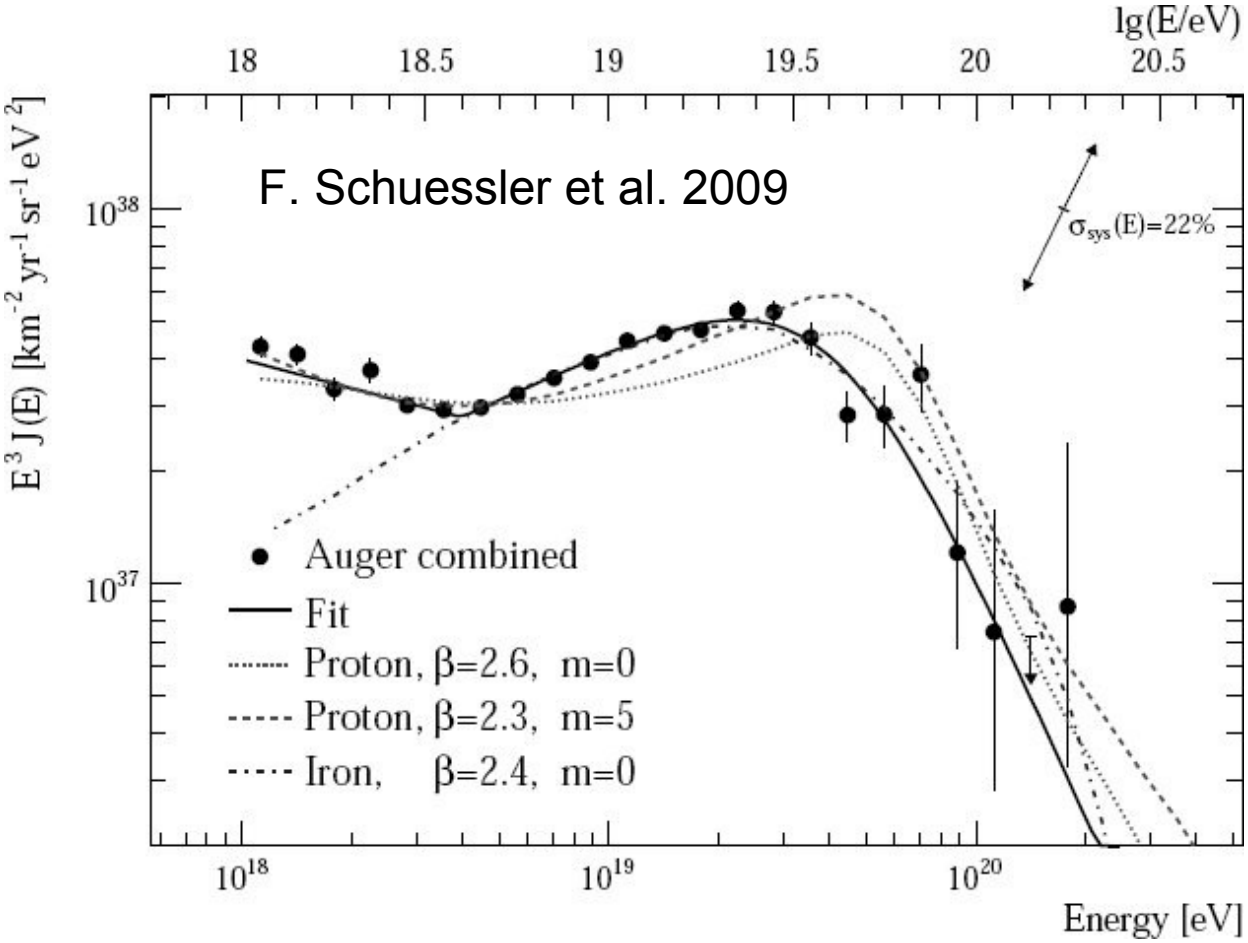
Ultra high energy cosmic rays



Neutrinos from GZK cutoff should exit
Low Flux → large detector volumes

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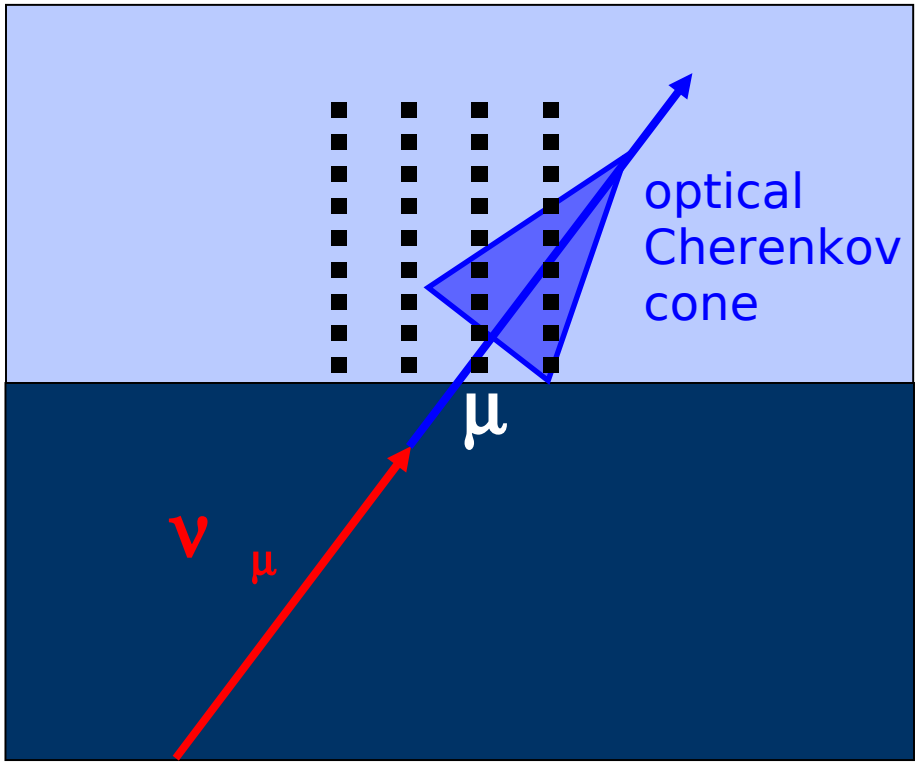
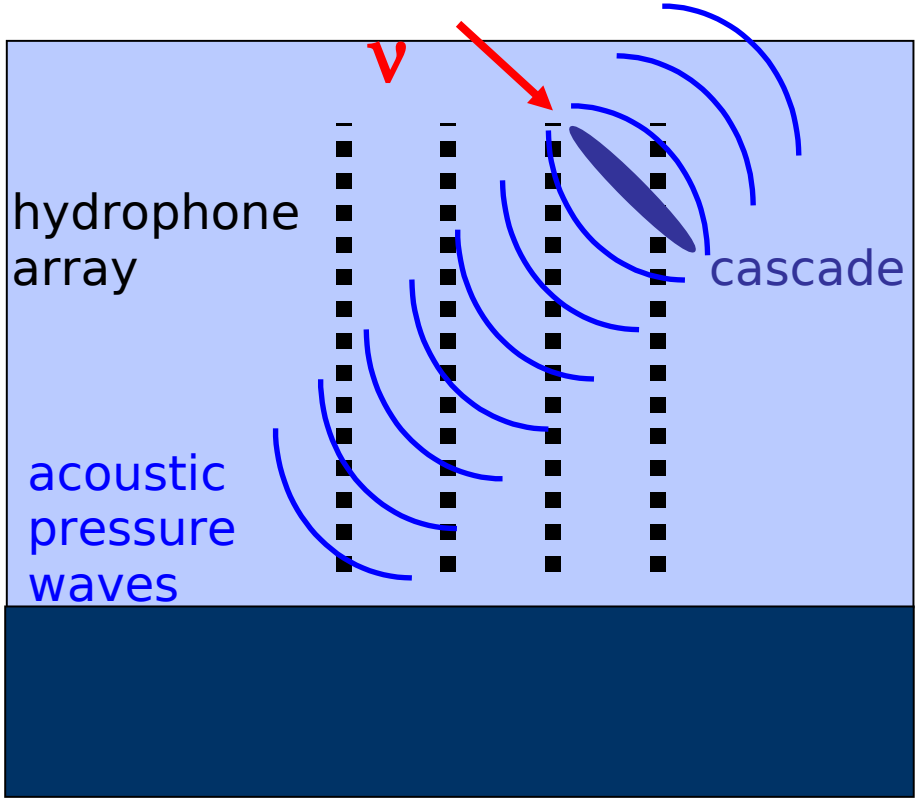
Differences of optical and acoustic neutrino detection





Cherenkov detector

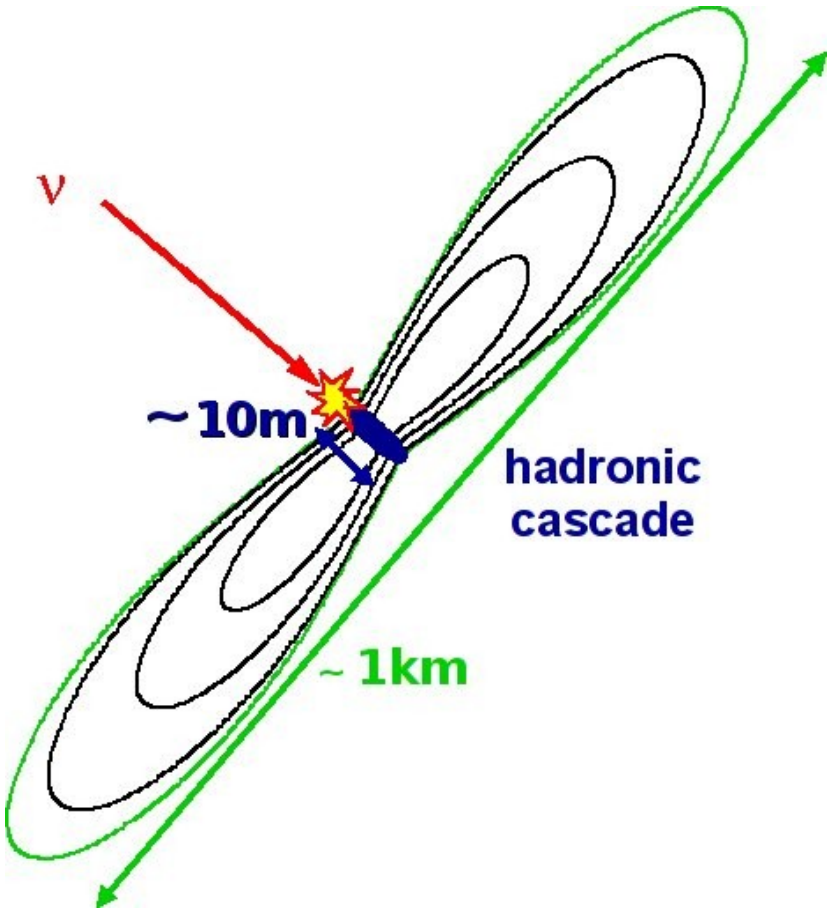
3D Array
60 Meter attenuation length
Medium: water, ice
Energy threshold: > 100 GeV

Acoustic detector

3D Array
1000 Meter attenuation length
Medium: water, ice, salt
Energy threshold: > 2 EeV

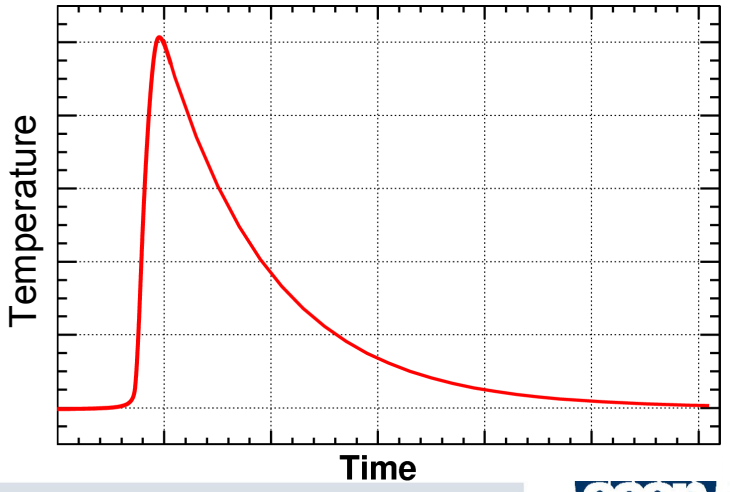
The thermo acoustic model by Askarian

Energy deposition causes local temperature fluctuation resulting in a change in pressure

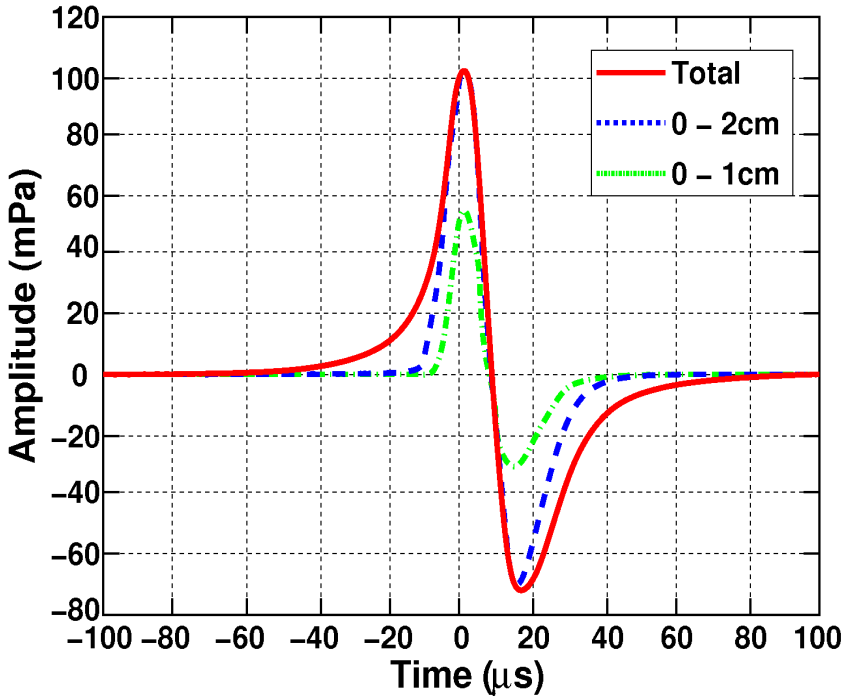


$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = -\frac{\alpha}{C_p}\frac{\partial^2 \varepsilon}{\partial t^2}$$

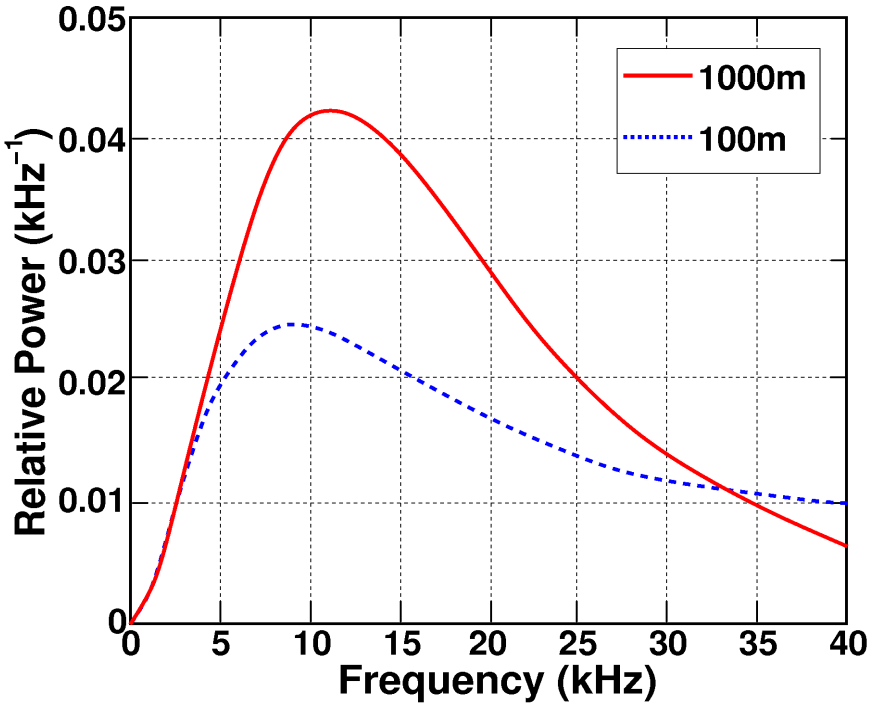
p = pressure
ε = energy density
α = heat expansion coefficient
C_p= spec. heat capacity



Pressure pulse of a neutrino induced cascade



S.Beavon et al.
ArXiv: 0704.1025



S.Beavon et al.
ArXiv: 0704.1025

Energy: 10^{20} eV
Distance: 1000 m

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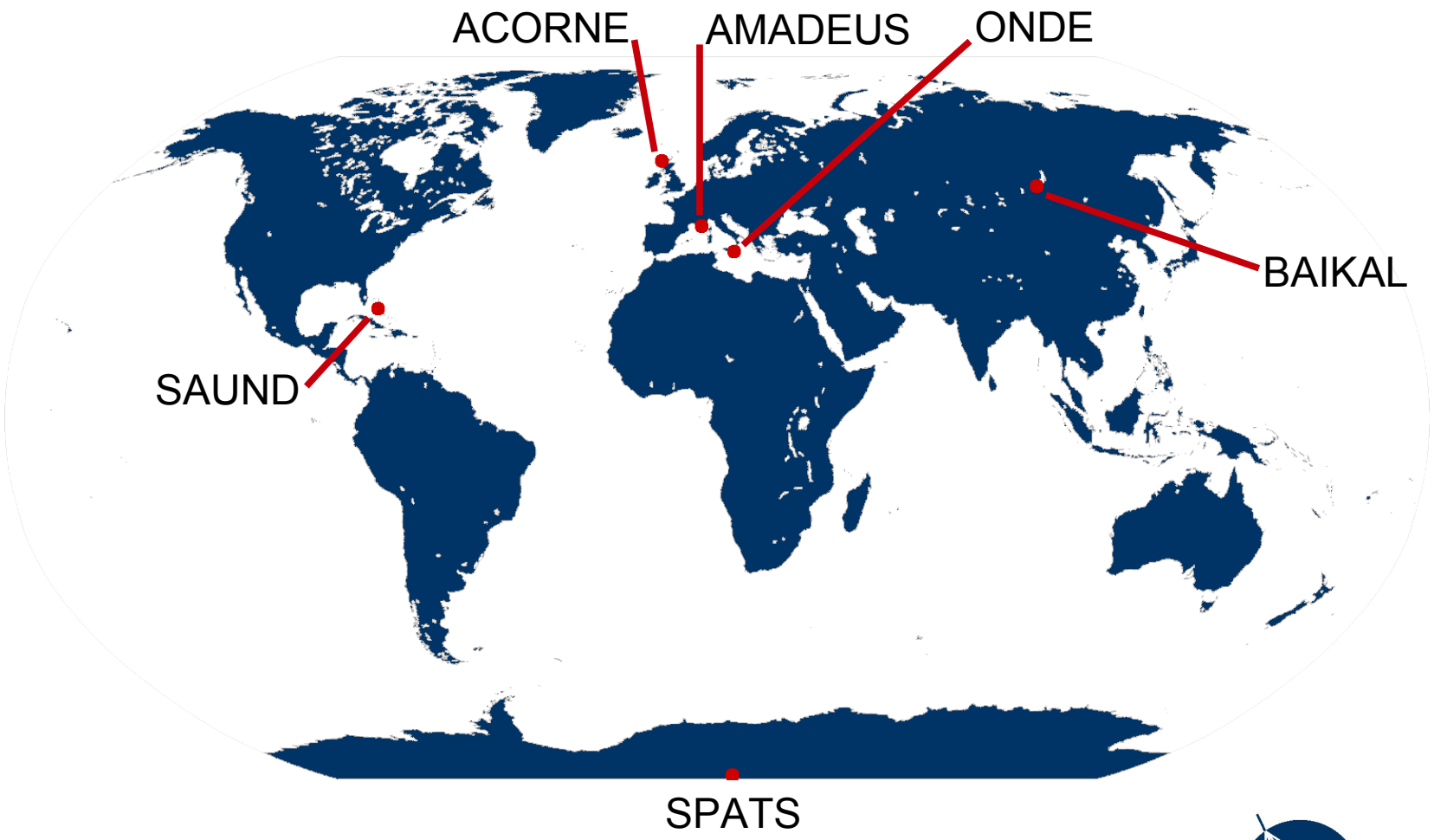
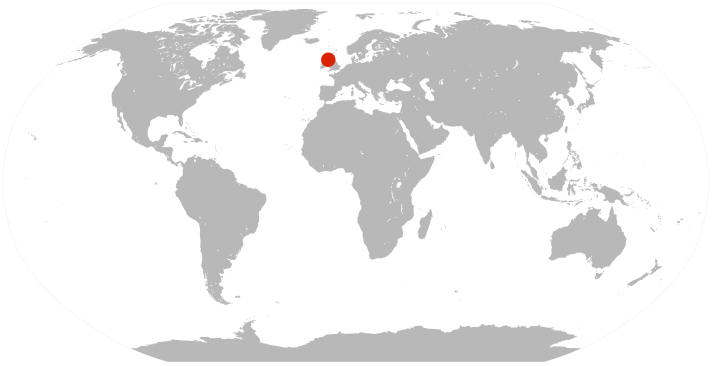
Experiments in ice and water

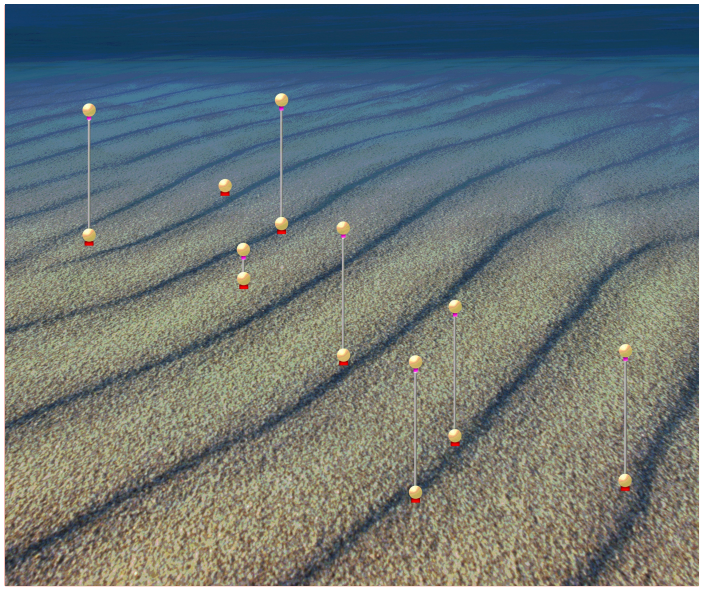


ACORNE

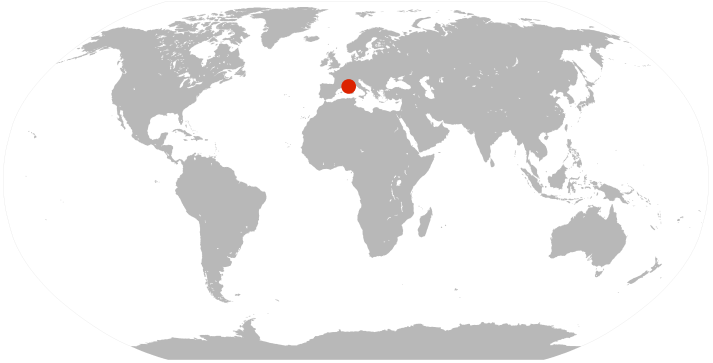


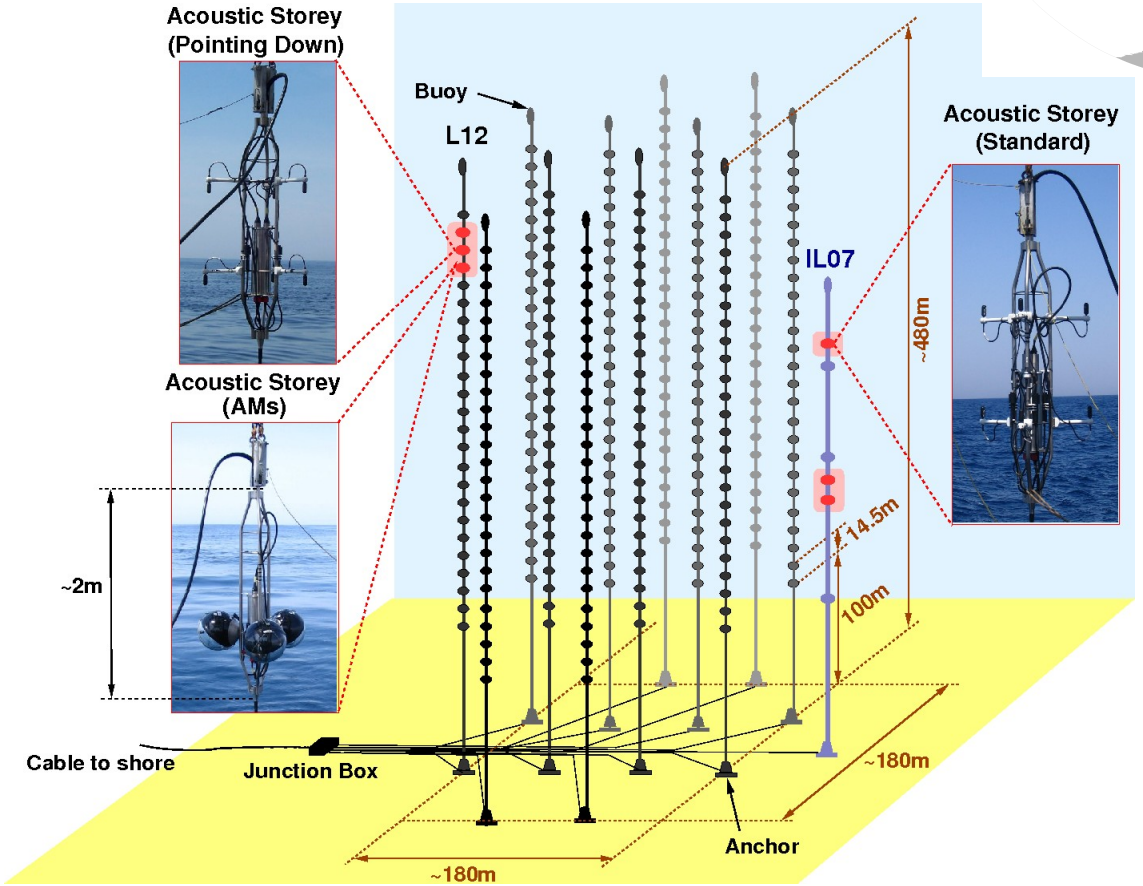
Rona hydrophone array,
a submarine ranging array in North-West Scotland used by the ACORNE experiment

7 hydrophones read out continuously



AMADEUS in ANTARES





36 acoustic sensors on 6 stories

Local clusters for direction reconstruction

Depth 2300 – 2100 m

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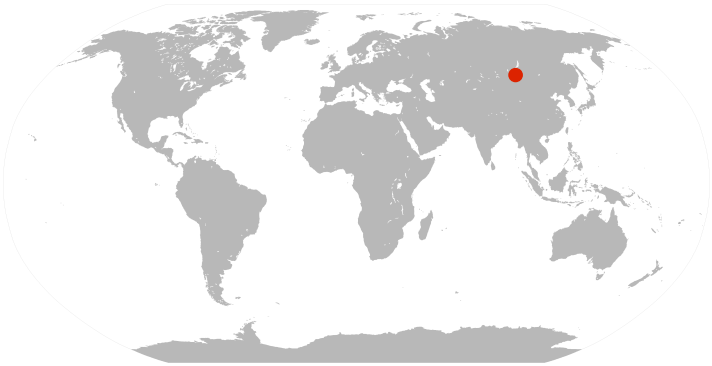
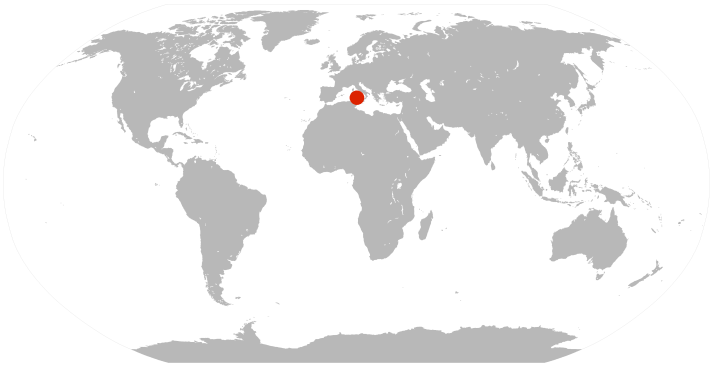
Lake Baikal

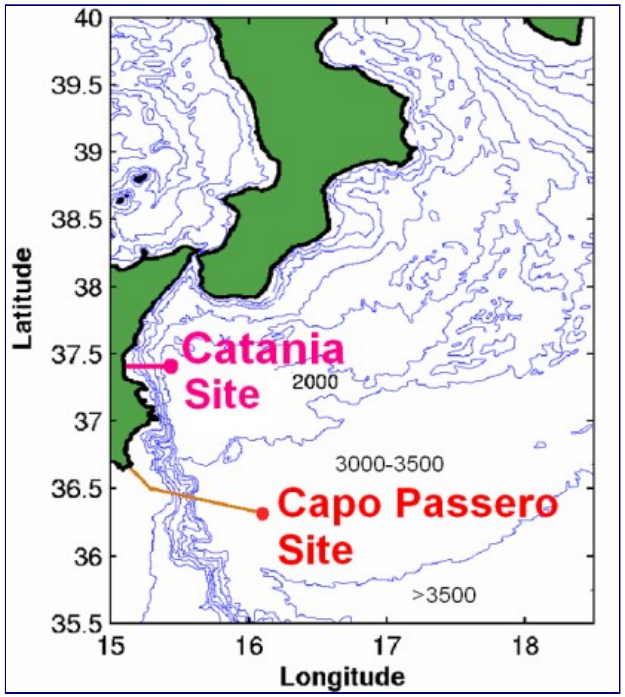


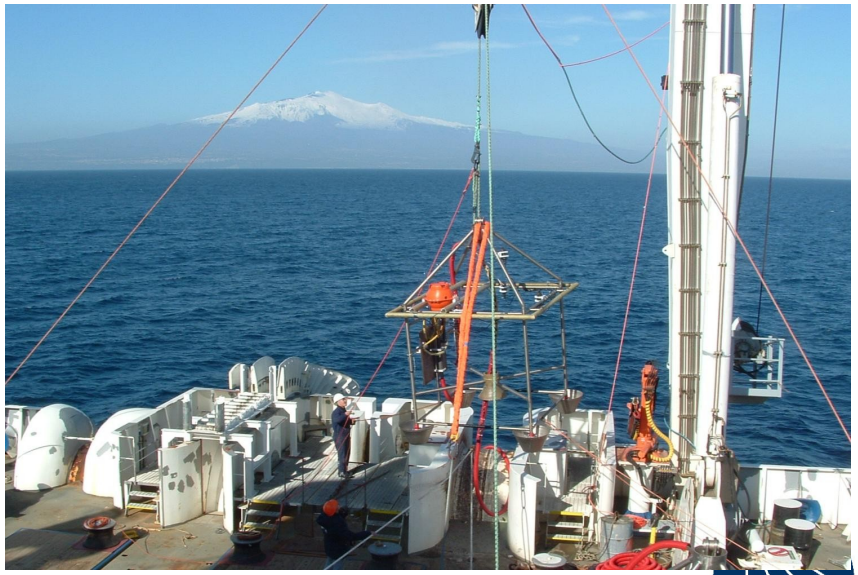
- Tetrahedral antenna
- 4 hydrophones
- 150 meter depth

ONDE

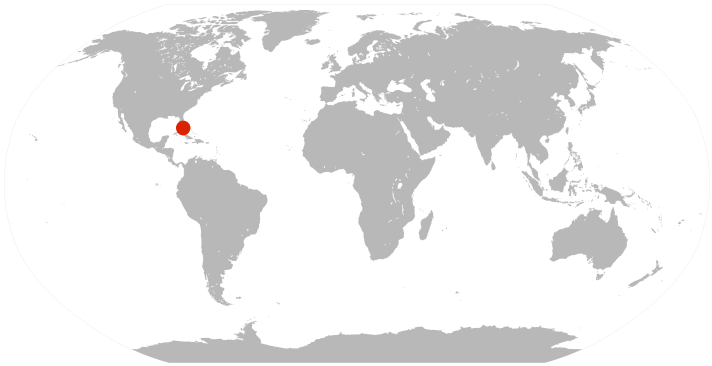


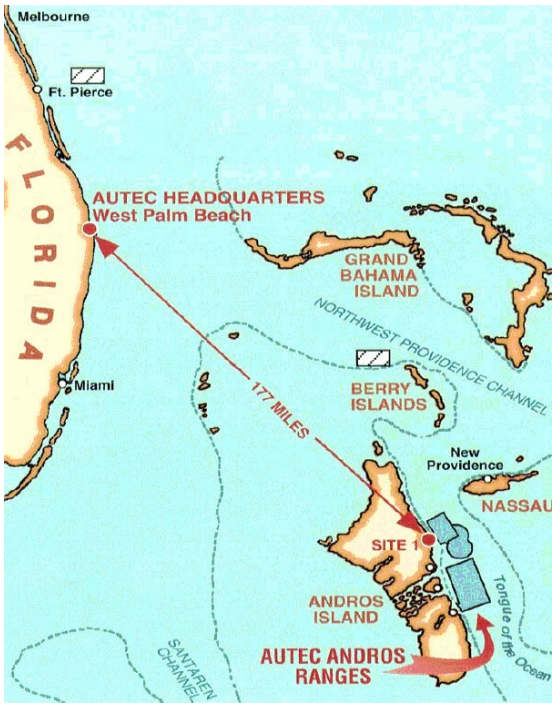
- Test Site at 2000 m depth, 25 km offshore Catania.
- Operation from 2005 -2006
- Recovered in 2008
- 4 hydrophones

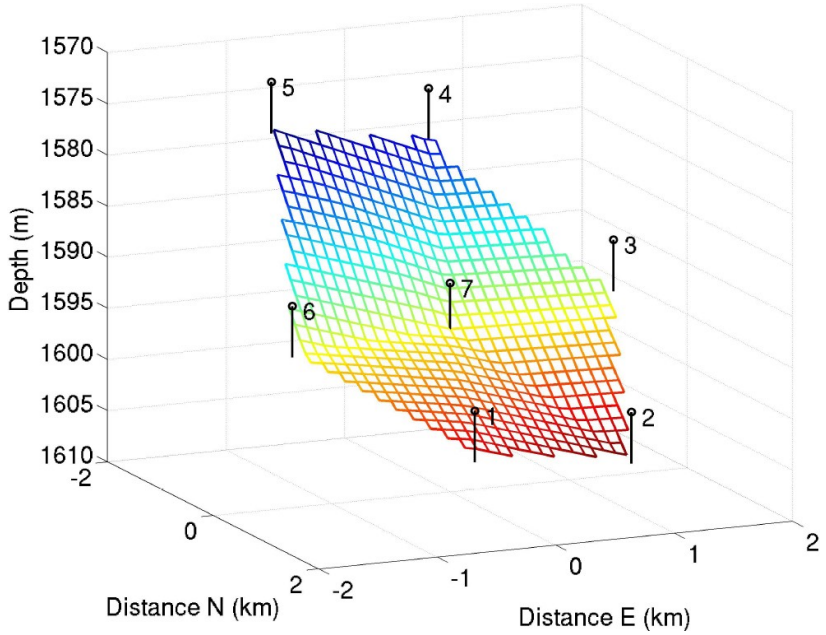




SAUND







SAUND:
7 hydrophones at 1600 m depth
1.5 km spacing

SAUND II:
49 hydrophones
20 km x 50 km area
Spacing of 3 to 5 km

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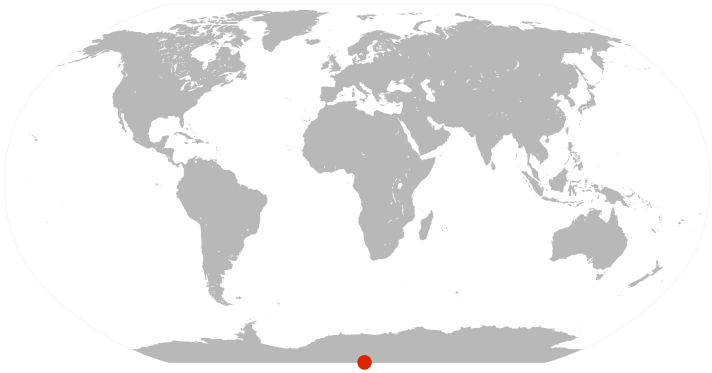
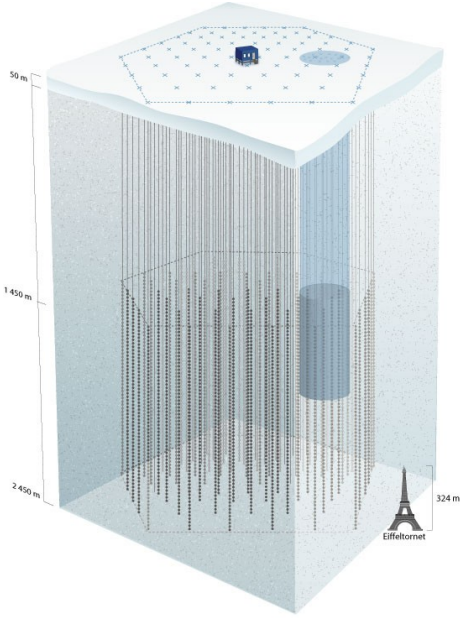
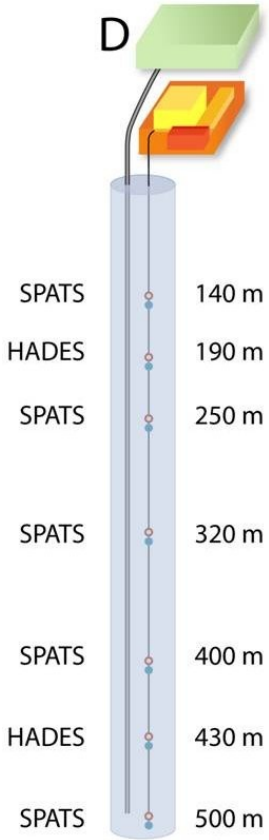
SPATS



Ice as detector medium
4 Strings with 7 “stages” each
A stage consists of a transmitter module and a receiver module





Background and medium properties

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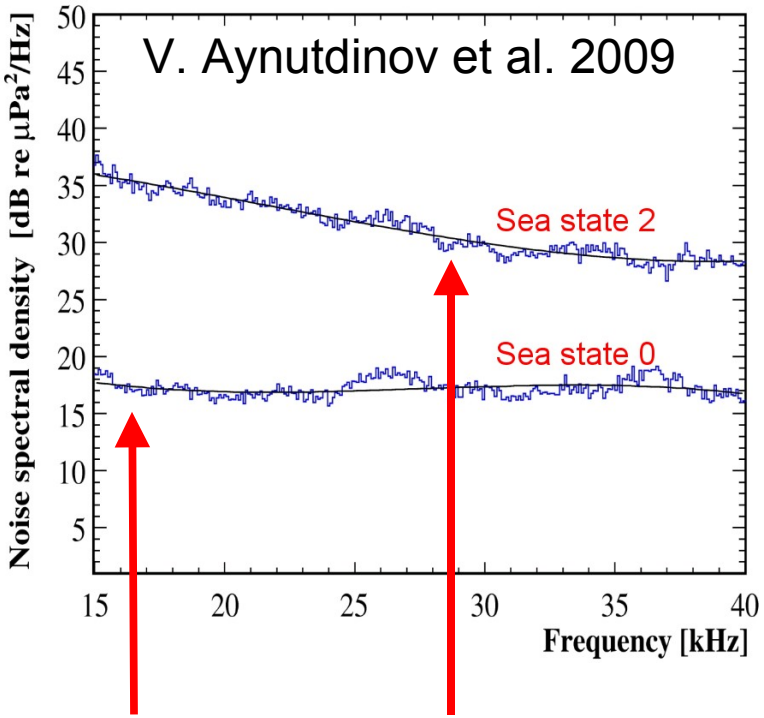
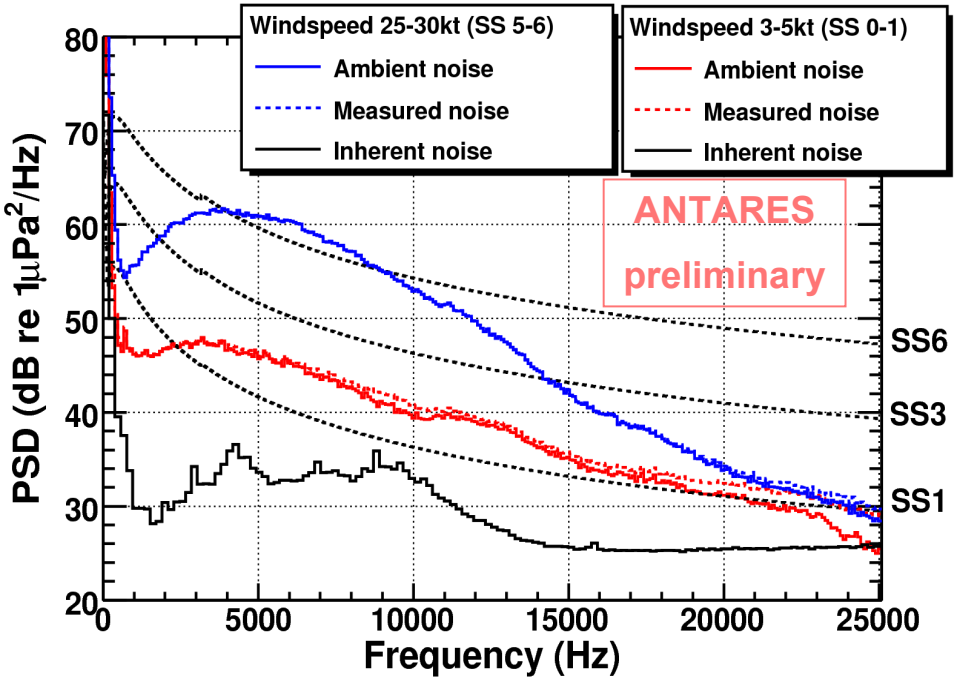
Noise distribution in dependence of wind speed





Varying noise conditions in dependence of the sea state are seen by all experiments in water

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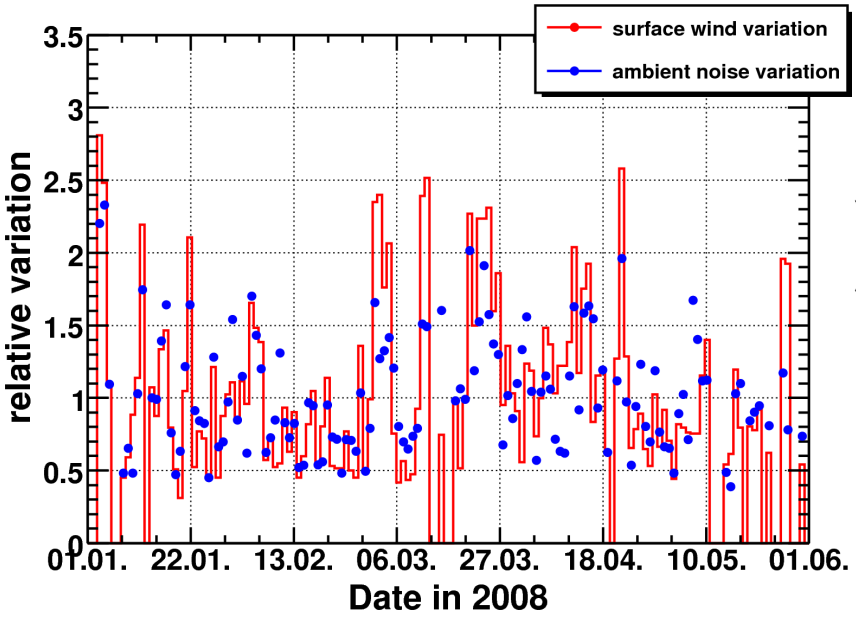
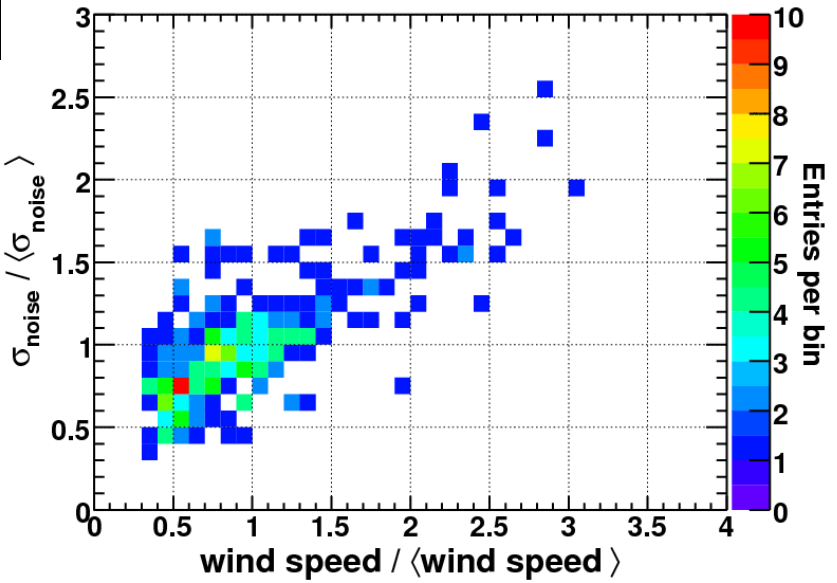
Correlation with Weather Conditions



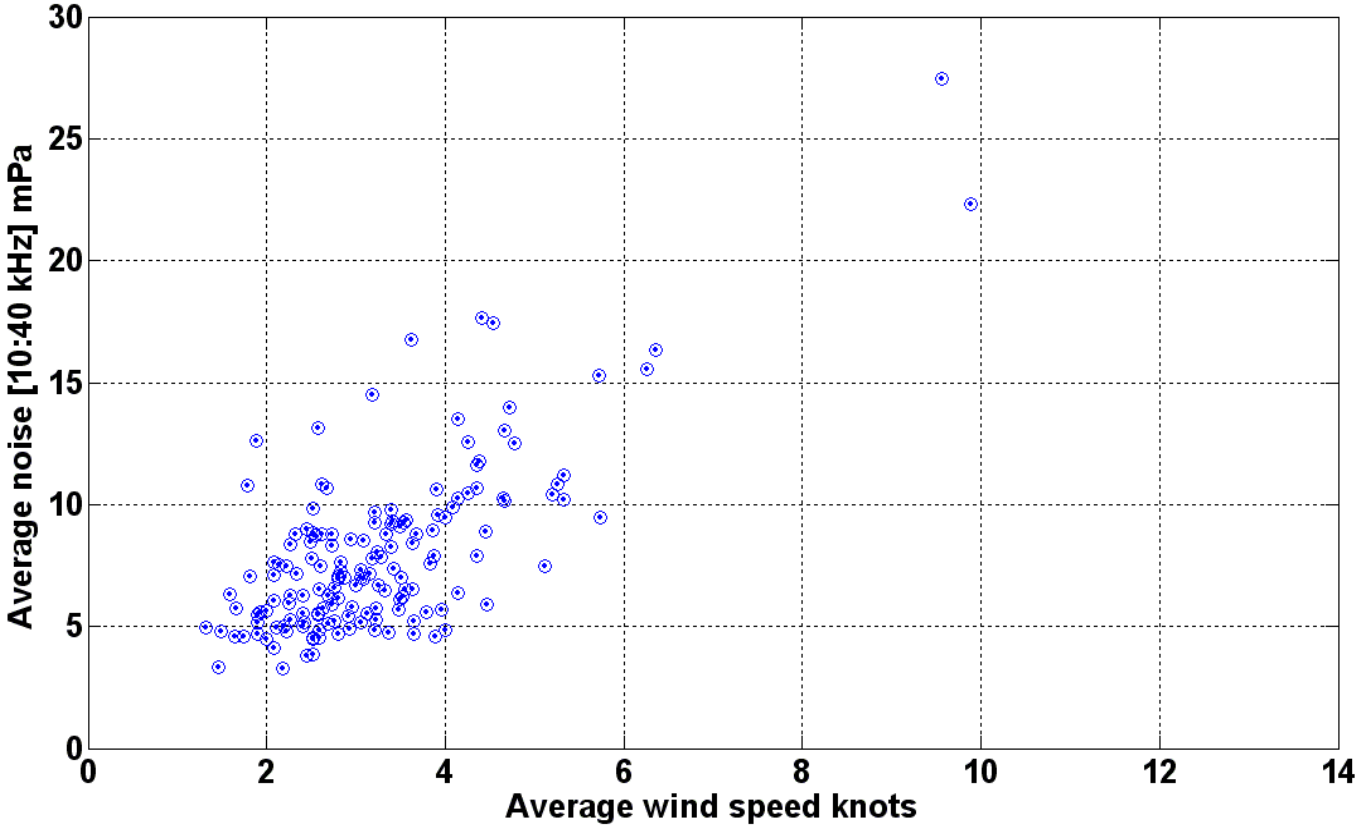


Noise correlation measured by the AMADEUS detector
Weather conditions measured at Hyères airport, about 30km north of ANTARES site

- Correlation coefficient ~ 80%
- Deep-sea noise dominated by sea surface agitation
- Hydrophone noise integrated from 1 to 50 kHz

Correlation with Weather Conditions

Similar behavior seen by the ONDE detector
Wind speed measured 20 km away 155 days (2005, daily average)



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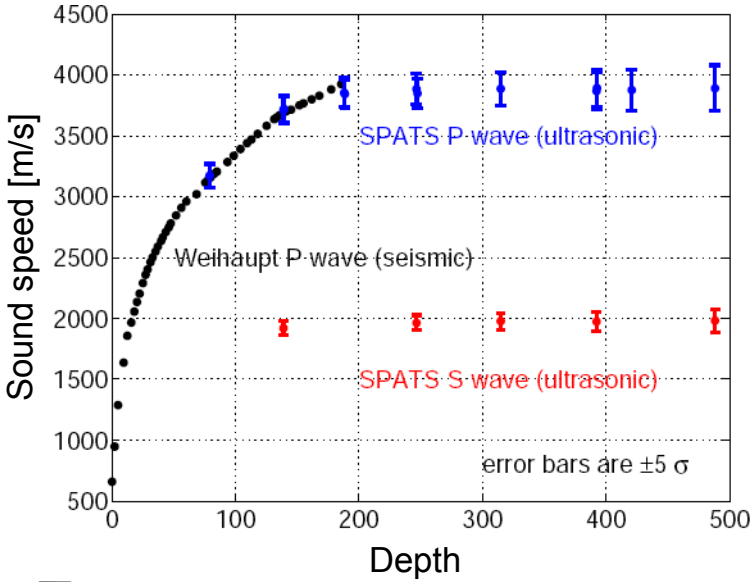
SPATS – speed of sound in ice

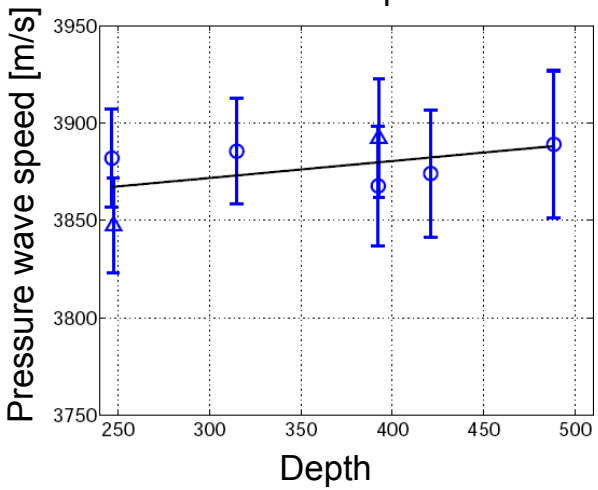


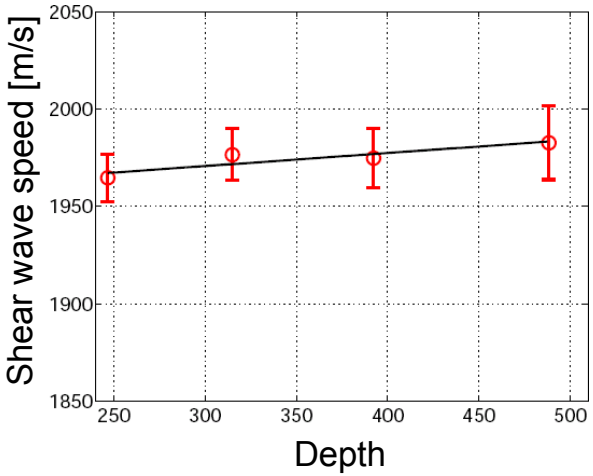
Sound velocity measurements of Pressure and shear waves

Agreement with previous measurements

New results for greater depths

R. Abbasi et al. 2009





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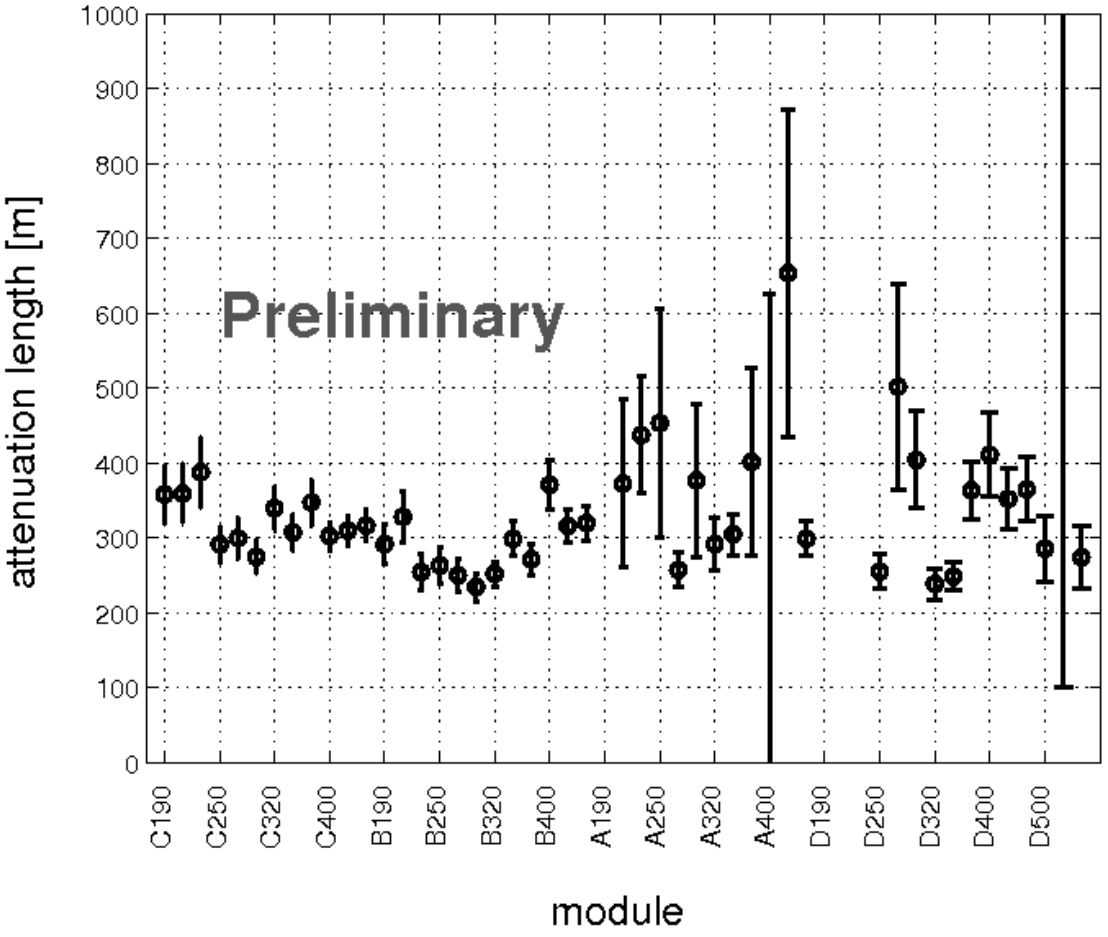
SPATS – attenuation length in ice



Attenuation length about 300 meters in ice

F. Descamps et al. 2009

Direction and source position reconstruction

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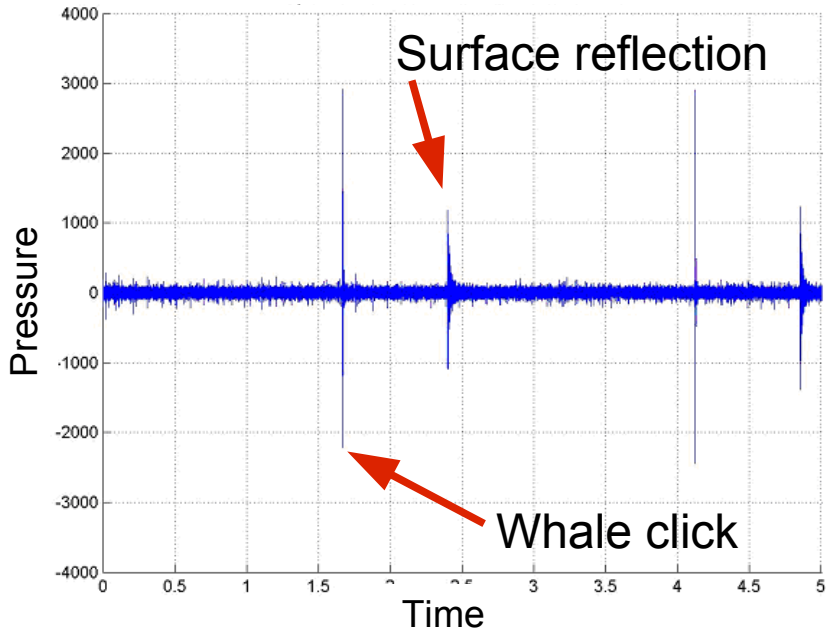
ONDE – sea mammal tracking

- Detection range > 40 km
- Tracking of sperm whales
- Monitor
  - Presence
  - Routes



Direction reconstruction using time delays between hydrophones

Depth reconstruction using reflection on surface

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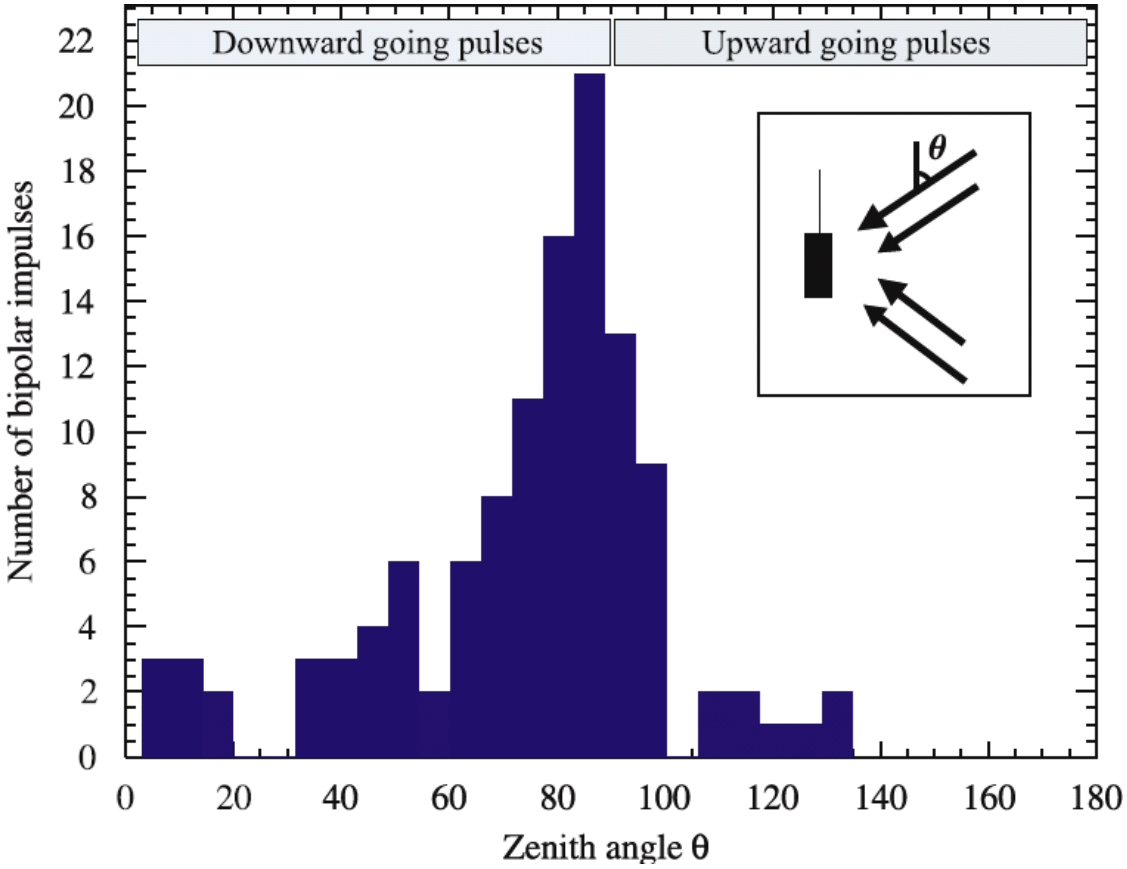
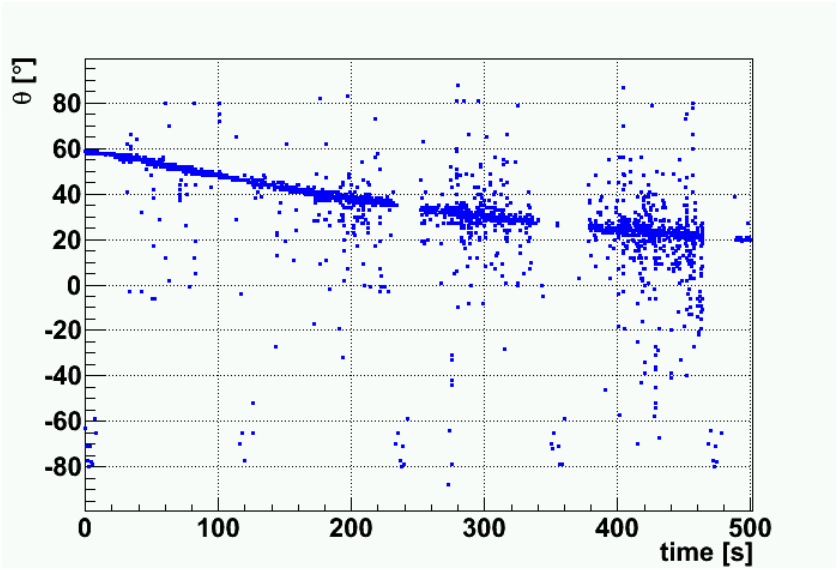
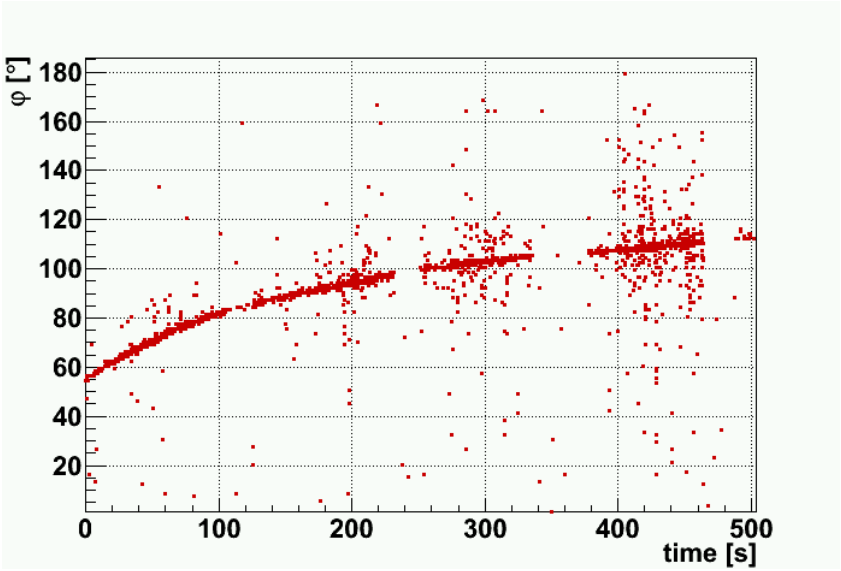
Lake Baikal – detection of neutrino like pulses



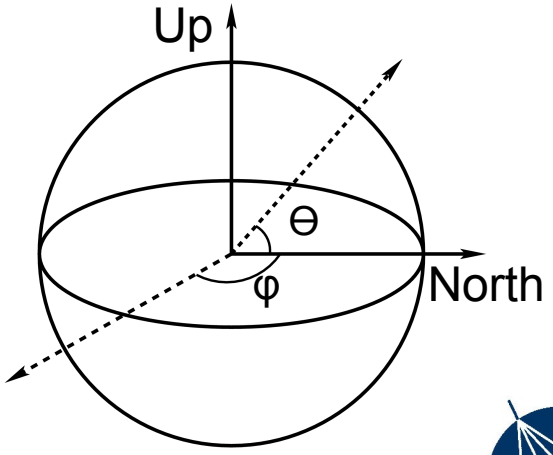
Reconstructed zenith angle for neutrino-like pulses

AMADEUS – source tracking





Sample of a moving emitter track interrupted by ANTARES positioning system



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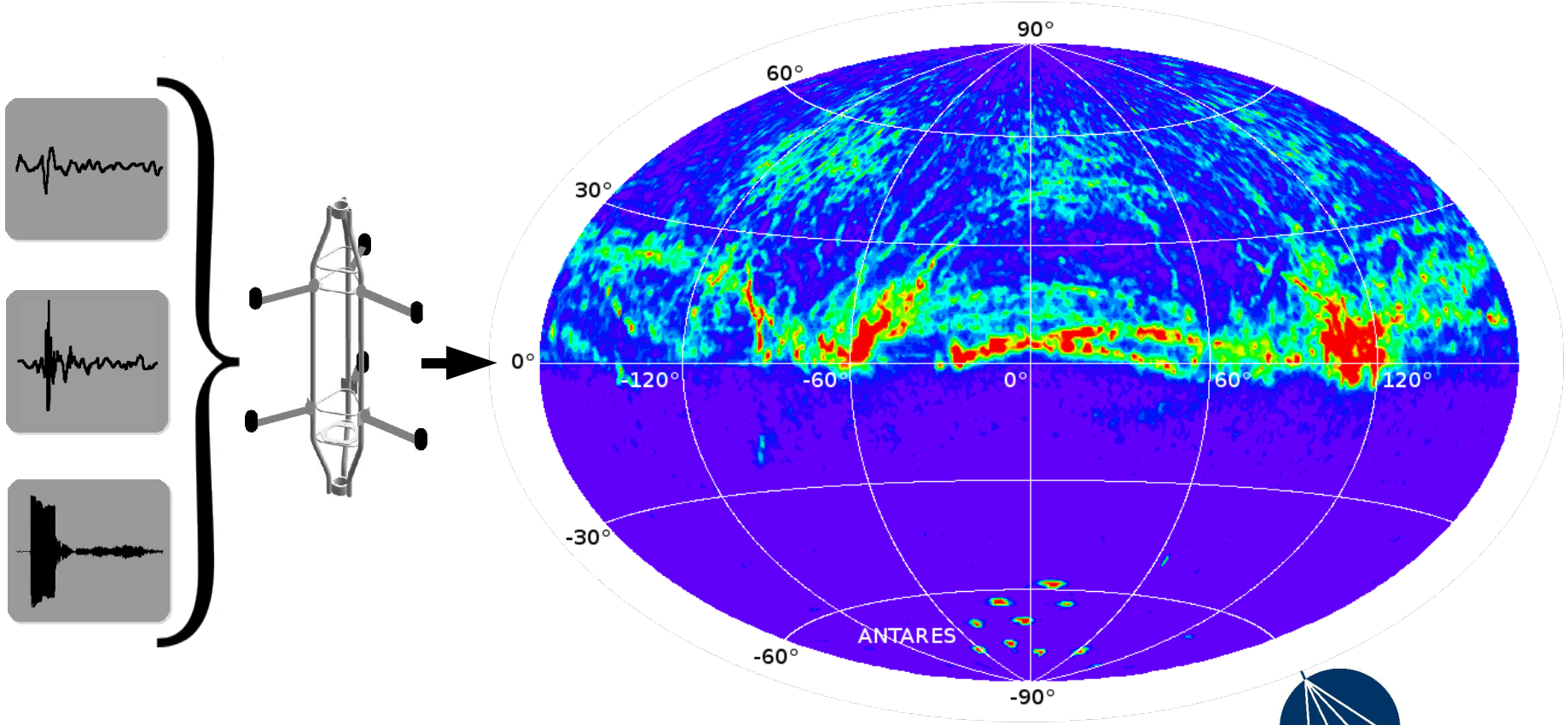
AMADEUS - Source direction distribution

- Direction reconstruction for one story
- All types of transient signals included, sea mammals, ships etc.
- Origin points north to horizon



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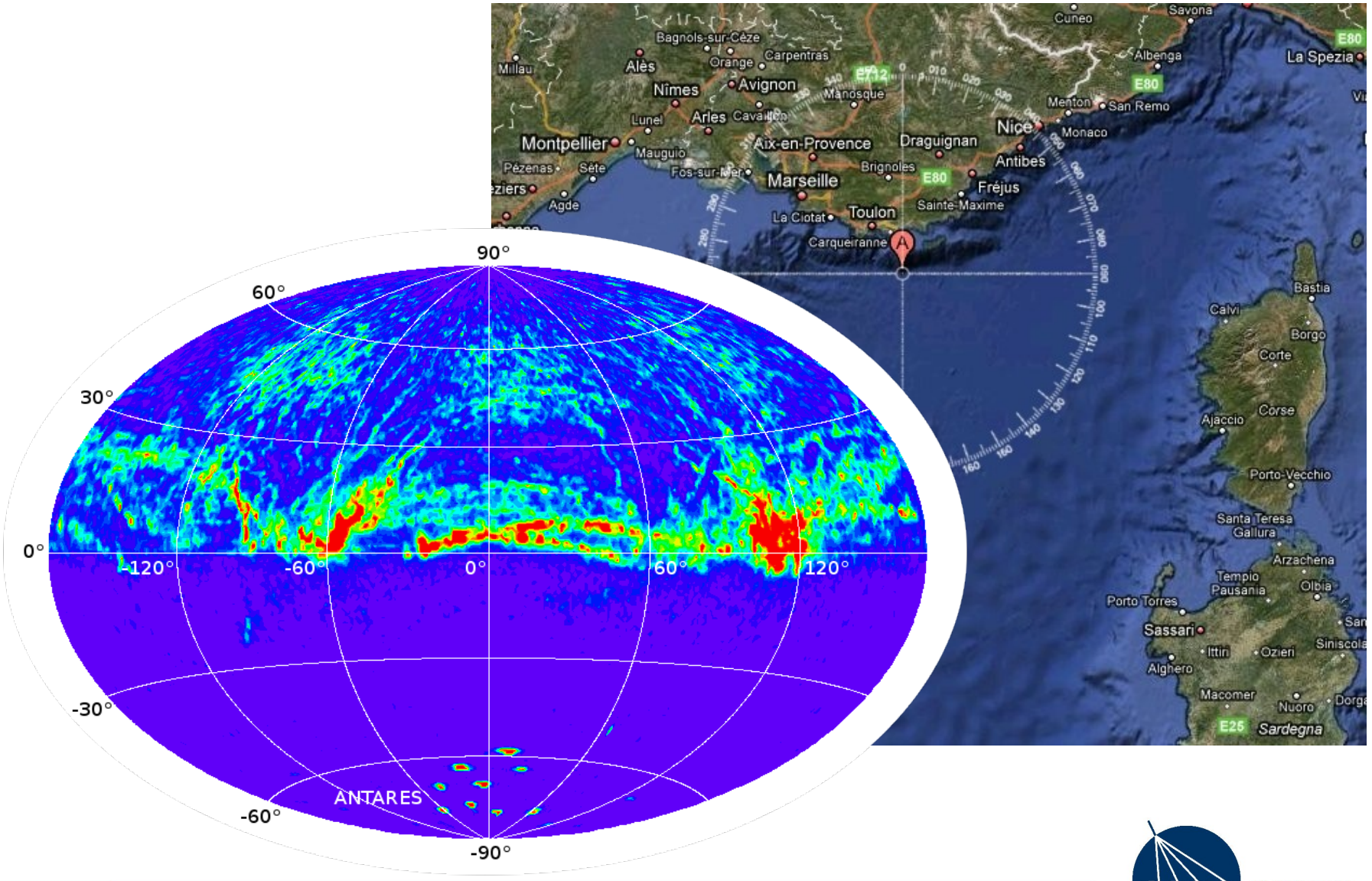
AMADEUS - Source direction distribution



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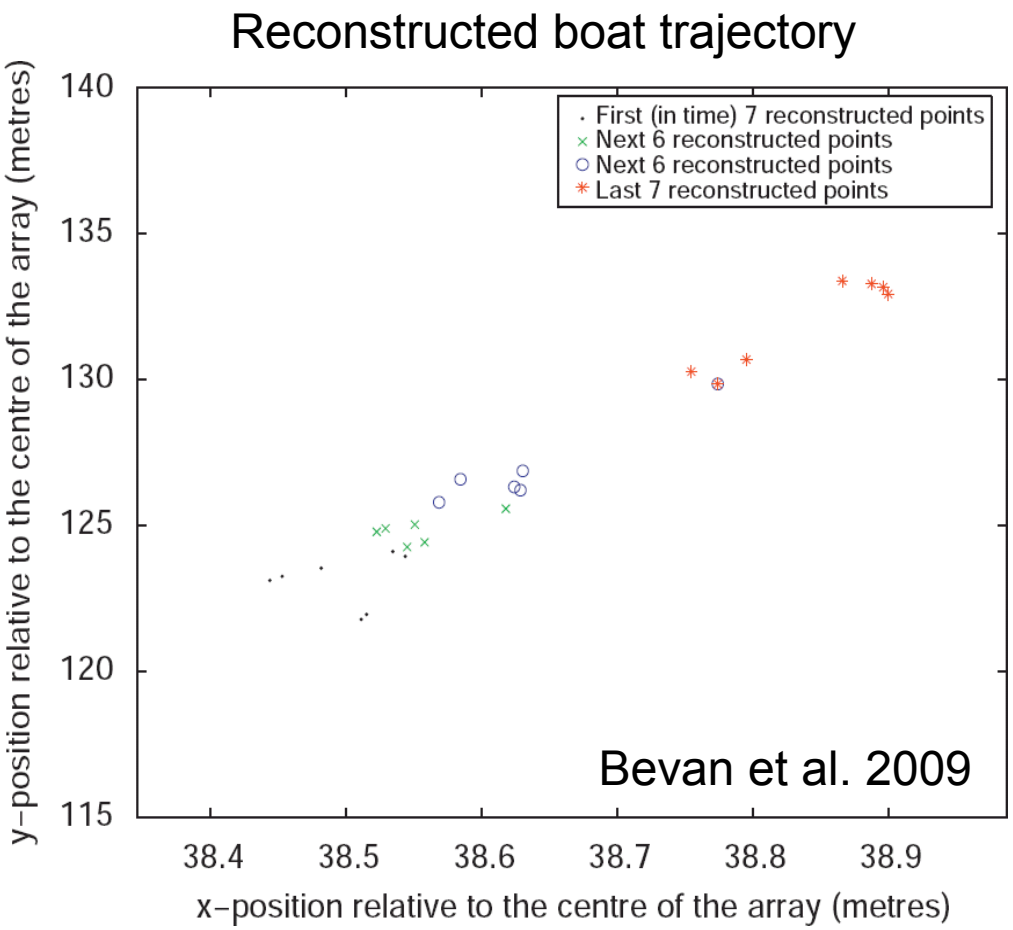
ACORNE – source location reconstruction



- Reconstruction by triangulation of signals
- Boat was successfully reconstructed

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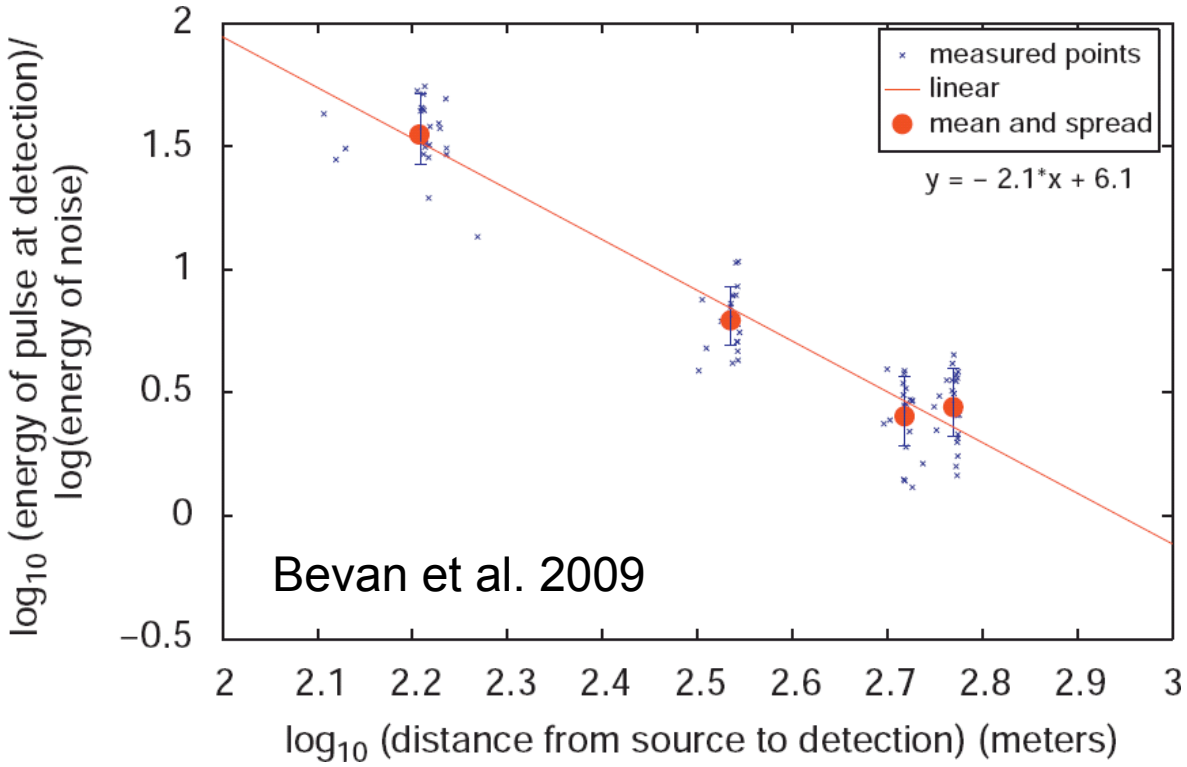
ACORNE – energy dissipation

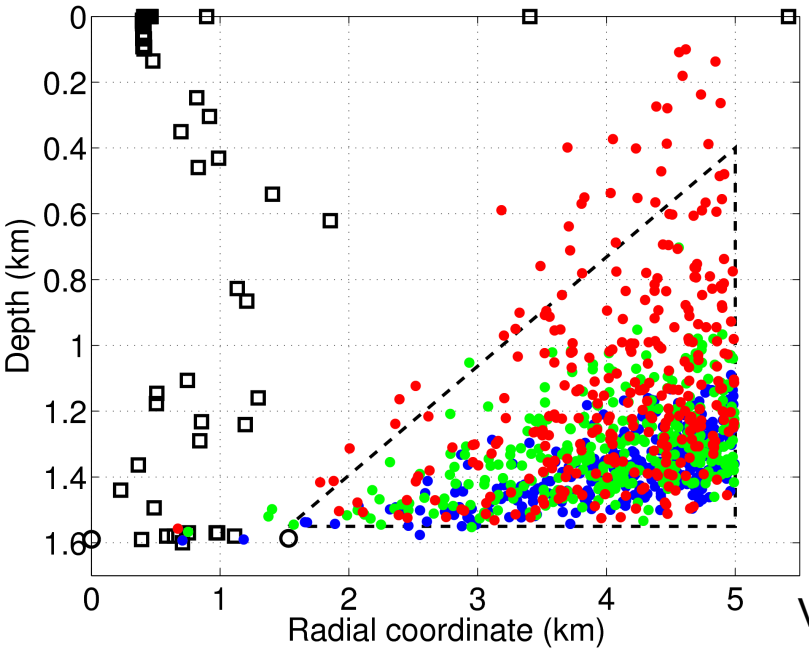
- Signal energy decreases with distance ($1/r^2$)
- slope = -2.1 ± 0.23.

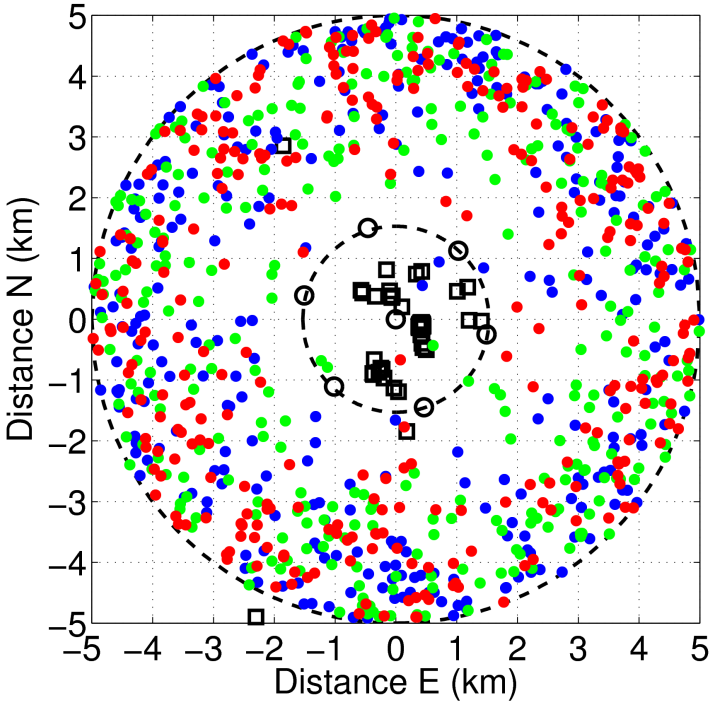


SAUND – detected neutrino like signals

- Reconstructed bipolar and Monte Carlo events
- No events in fiducial volume

- Fiducial volume given by signal geometry





Colors indicate energy
Blue = 10^{14} eV
Green = 10^{15} eV
Red = 10^{16} eV

Vandenbrouke et al. 2004

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Flux upper limit for neutrinos

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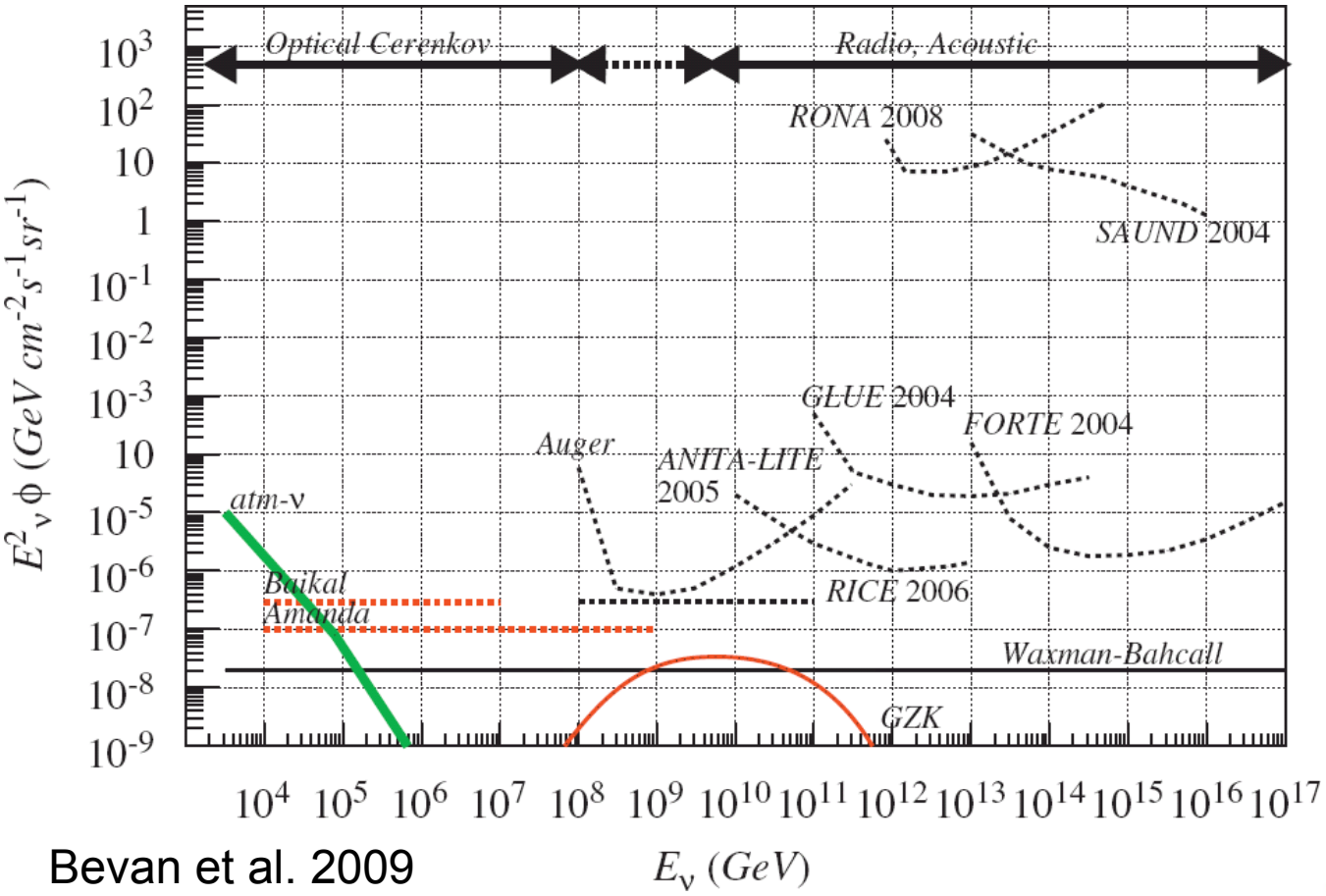
ACORNE (RONA) / SAUND - Upper limit

Upper limits have been calculated for the RONA array and the SAUND detector



Bevan et al. 2009

Summary

- Number of experiments investigating acoustic particle detection
- Background conditions in water correlate with weather
- Direction reconstruction possible using local clusters
- Source location reconstruction possible
- Also applicable for monitoring sea life
- Upper flux limit calculated

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