Acoustic Neutrino Detection In a Adriatic Multidisciplinary Observatory (ANDIAMO)

Antonio Marinelli
(Università Federico II & INFN Napoli)
antonio.marinelli@na.infn.it

in collaboration with
P.Migliozzi and A.Simonelli (INFN Napoli)

27 th European Cosmic Ray Symposium 25-29/07/2022

Askaryan Effect appears on 1957

HYDRODYNAMIC RADIATION FROM THE TRACKS OF IONIZING PARTICLES IN STABLE LIQUIDS

G. A. Askaryan

When ionizing particles pass through liquids the molecules of the medium are entrained by singly-charged ion aggregates which are pushed apart; in addition, small micro-explosions, due to localized heating, occur close to the tracks of the particles. These processes can lead to the formation of localized cavities and nuclei or "seeds" at which the transition to the vapor or gas phase is possible. (The development of these nuclei into bubbles of visible dimensions, which takes place if the liquid is sufficiently unstable, is used in new devices for studying ionizing radiation -- so-called "vapor" and "gas" bubble chambers [1-3].)

The sudden motion of the ion-complexes, the micro-explosive production of the nuclei, the further expansion and contraction and subsequent disappearance or rapid growth (depending on the initial local factors, the properties and state of the medium) should be accompanied by intense localized pulses of radiation of supersonic waves which, in the initial stage, should be quasi-microspherical shock waves. The intensity of this radiation should depend on the properties of the medium which determine the effectiveness of bubble initiation and the dynamics of bubble development (surface tension, stability of the liquid state, etc). It should be noted that similar radiation will occur in solid bodies and compressed gases but its intensity will be considerably smaller than that found in liquids.

First ideas to build a acoustic array for neutrinos in:

G. A. Askaryan and B.Dolgoshein, JETP Lett. 25 (1977) 213
T.Bowen, Proc. 15th ICRC, Plovdiv, 1977, V6, p. 277

Acoustic Signal Propagation

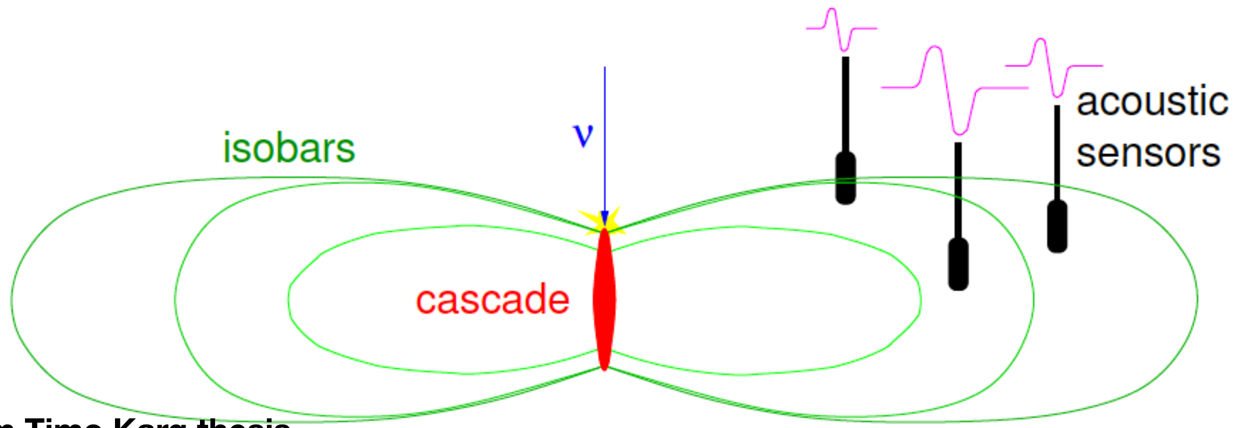
Inhomogeneous wave equation

The sound wave can be described by a pressure field $p(\vec{r},t)$ related to the energy density $\varepsilon(\vec{r},t)$ deposited in the medium though this equation:

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

solution assuming instantaneous energy deposition

α = **bulk expansion coefficient** C_p = **specific heat capacity** c = **sound speed (in w 1500 m/s)**

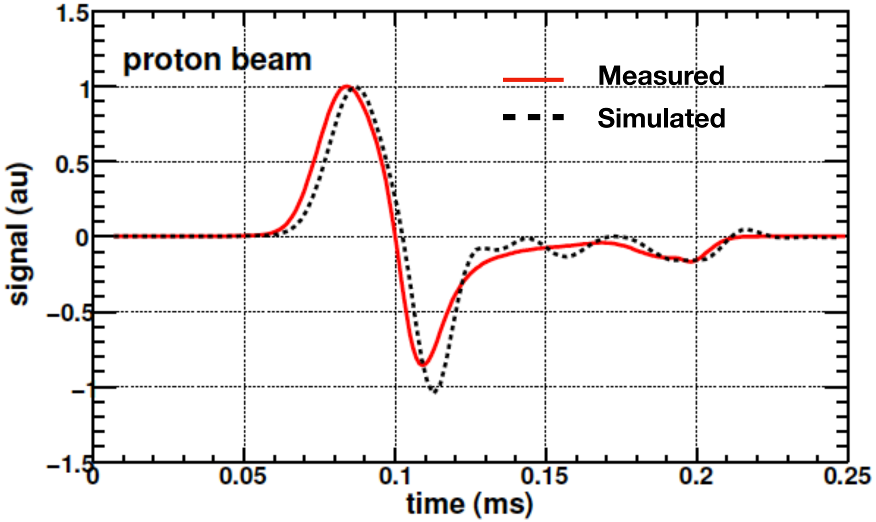


from Timo Karg thesis

"pancake" like signal propagation

In water absorption length of sound wave ~ Km

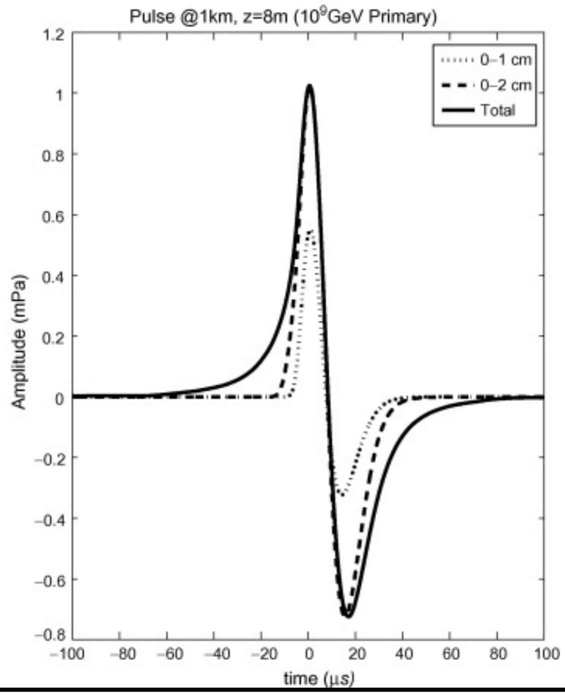
Bipolar signal measurements/simulation



Astroparticle Physics
Volume 65, May 2015, Pages 69-79
R.Lahmann et al.

177 MeV protons beam
distance ~ 20 cm

good match between measured signal and simulated signal (GEANT 4), discrepancy ~10%



Astroparticle Physics
Volume 28, Issue 3, November 2007, Pages 366-379
ACORNE coll

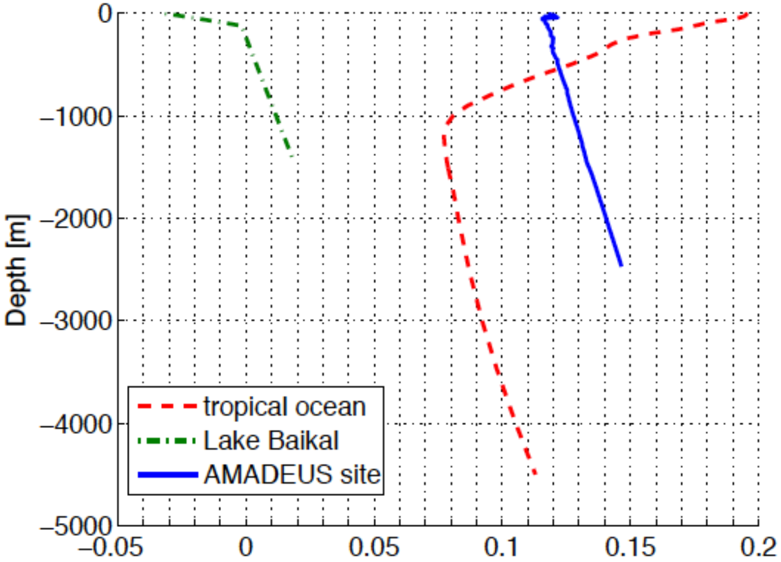
Most of the signal comes from the inner core of the produced shower.

$$P(r = 200\,\mathrm{m}) \approx 10 \times \frac{E_{casc}}{1\,\mathrm{EeV}}\,\mathrm{mPa}$$

Absorption length in the Mediterranean sea

From G.Gratta ICATPP Como 2007

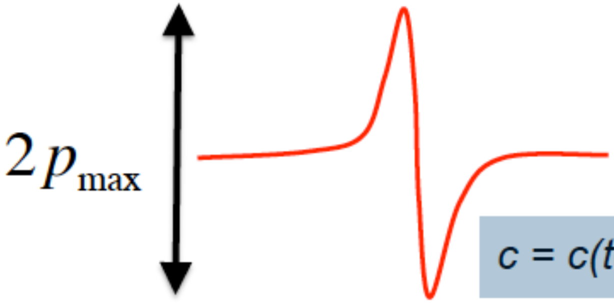
Grüneisen parameter



From R.Lahmann ARENA 2018

Analytical calculation of a signal in the far field for a Gaussian energy density

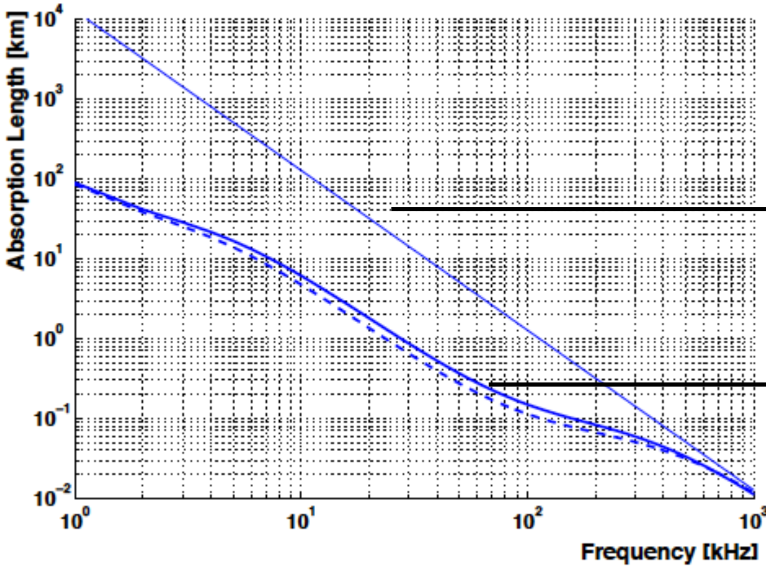
$$p_{\max} \propto \gamma_G \frac{E_0}{\sigma_\rho^2}$$



Grüneisen parameter

$$\gamma_G = \frac{c^2\alpha}{C_P}$$

c = c(temp, pressure, salinity)



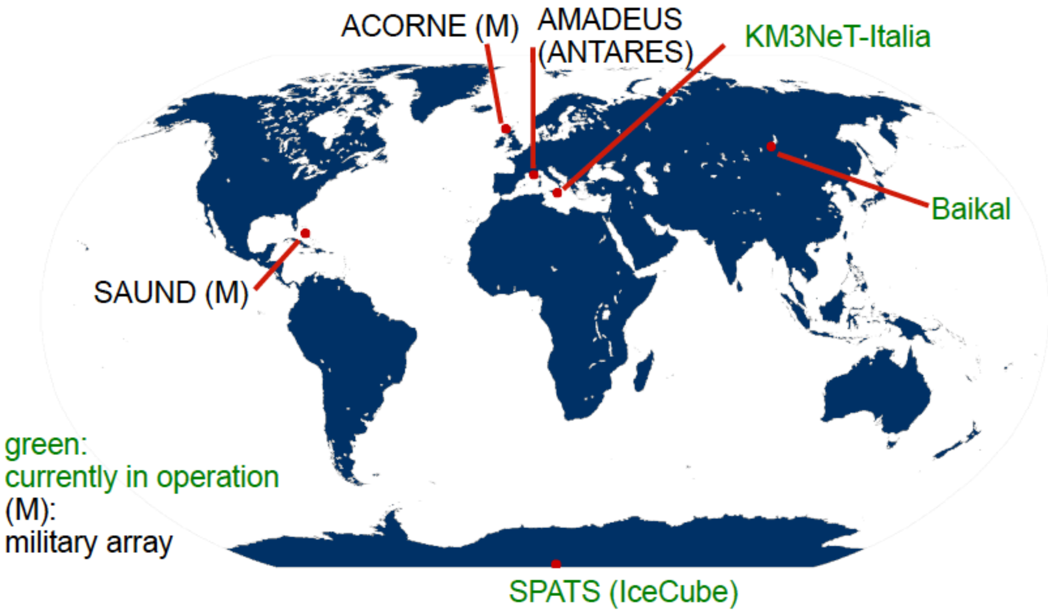
Absorption length for the salinity case of 3.8%

Pure Water case

Solid at 2000 m deep
Dashed at 100 m deep

Previous radio arrays

Test Setups in ice and water *From R.Lahmann ARENA 2018*



Most of the acoustic configuration setups installed up to now were linked to Cherenkov telescopes or to already existing military arrays

A dedicated large volume undersea/ice acoustic neutrino telescope would be preferred

Experiment	Location	Medium	Sensor Channels	Host Experiment
SPATS [19, 20]	South Pole	Ice	80	IceCube
Lake Baikal [7]	Lake Baikal	Fresh Water	4	Baikal Neutrino Telescope
OvDE [21]	Mediterranean Sea (Sicily)	Sea Water	4	NEMO
AMADEUS [22]	Mediterranean Sea (Toulon)	Sea Water	36	ANTARES
ACoRNE [23]	North Sea (Scotland)	Sea Water	8	Rona military array
SAUND [24]	Tongue of the Ocean (Bahamas)	Sea Water	7/49(⋆)	AUTEC military array

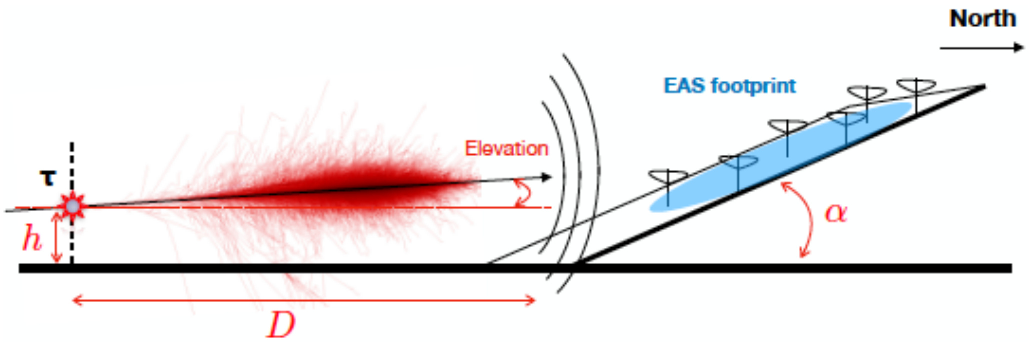
(⋆) The number of hydrophones was increased from 7 in SAUND-I to 49 in SAUND-II

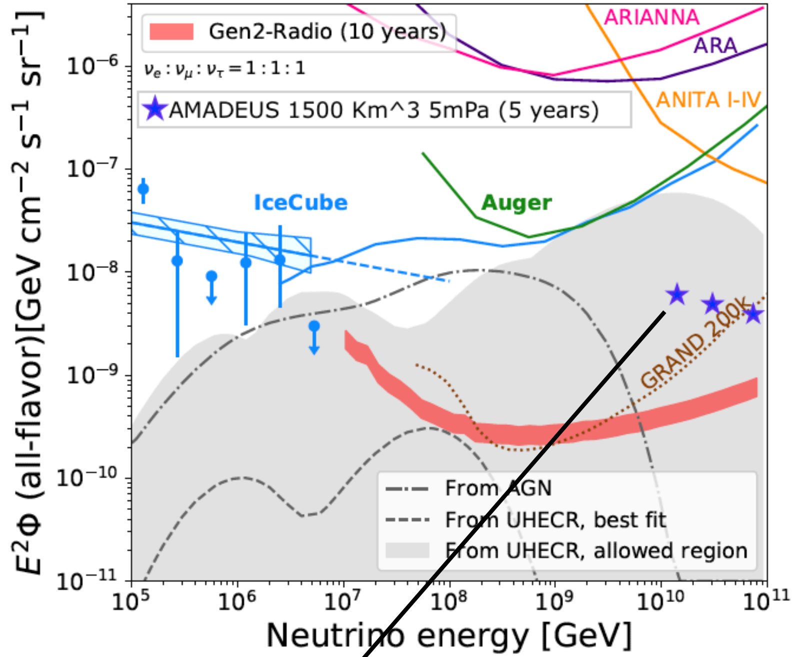
Complementarity with radio arrays

Decoene V. et al.
NIM Vol. 986 2021

Aartsen et al.J.Phys.G 48 (2021)

AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.

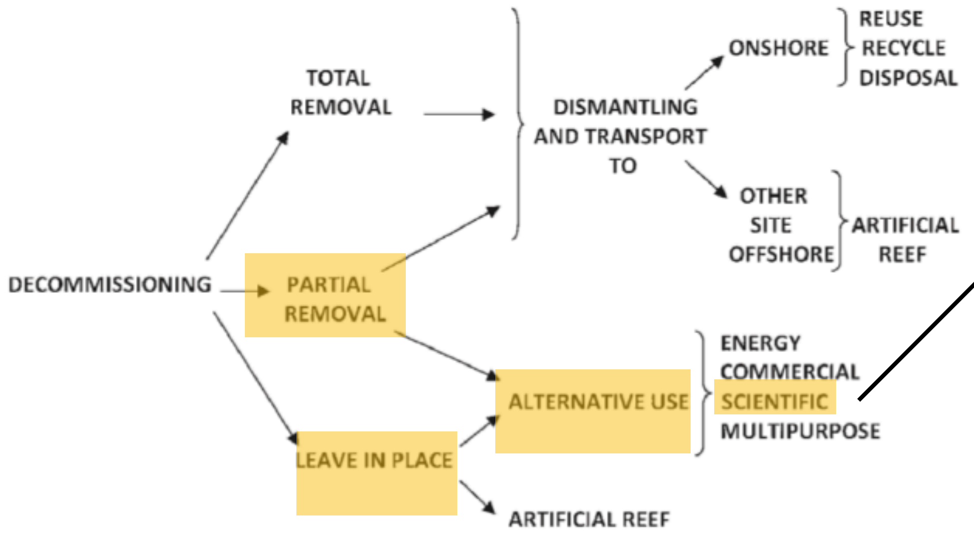




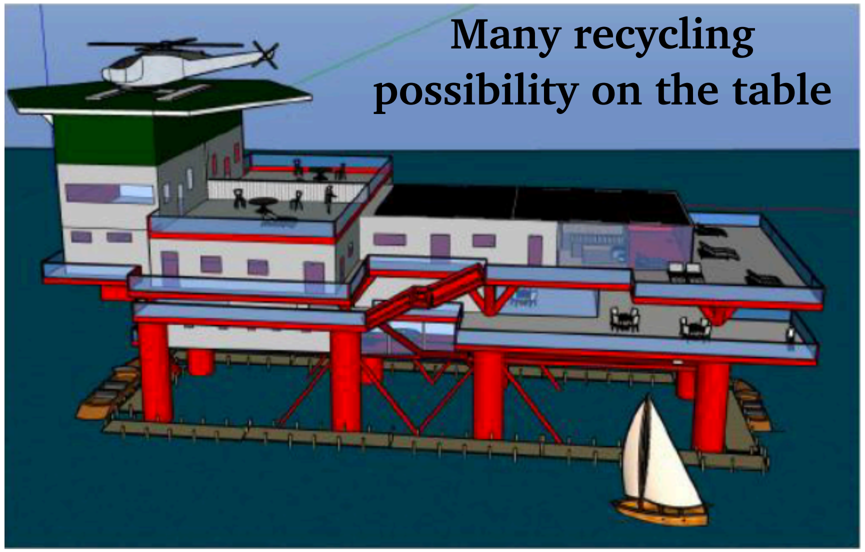
A MC simulation of a cylindrical volume of 44 Km of diameter and a high of 1Km, hydrophone density (200 AM/Km^3) (T.Karg Thesis)

A new dedicated acoustic undersea array looking for down-going events would be complementary to most of the radio arrays and air shower arrays focused on near horizontal or earth skimming events.

Taking advantages of existing infrastructures



Archetti and Paci 2018

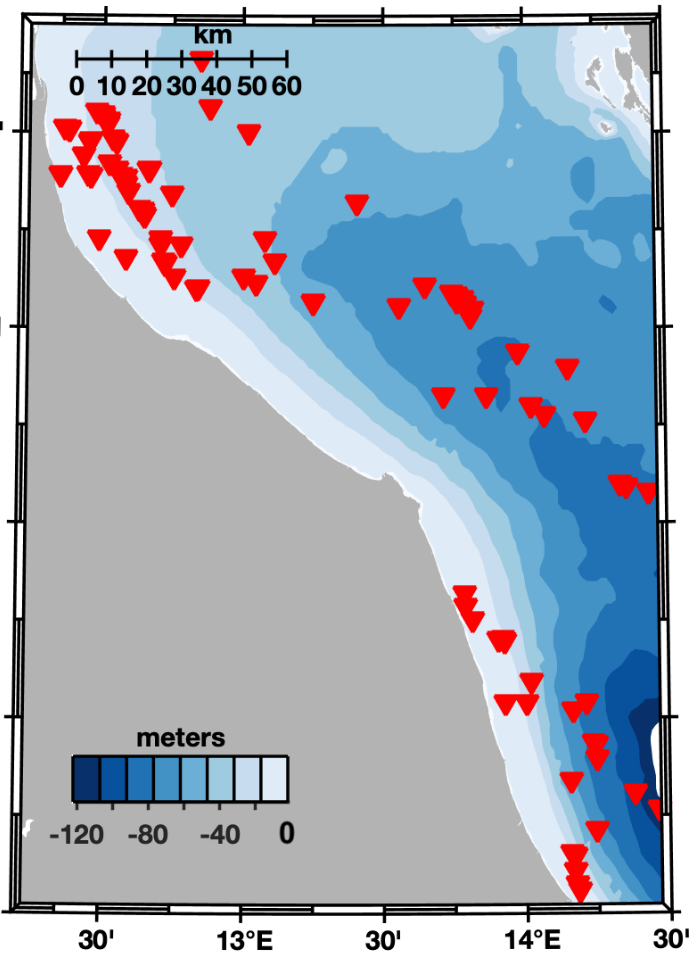


- Very Interesting the case of inactive oil rig platforms in the Adriatic sea.
- Convey with the ENI company and the EU founding agencies about this preferential decommissioning path.
- Build a dedicated acoustic neutrino detector.

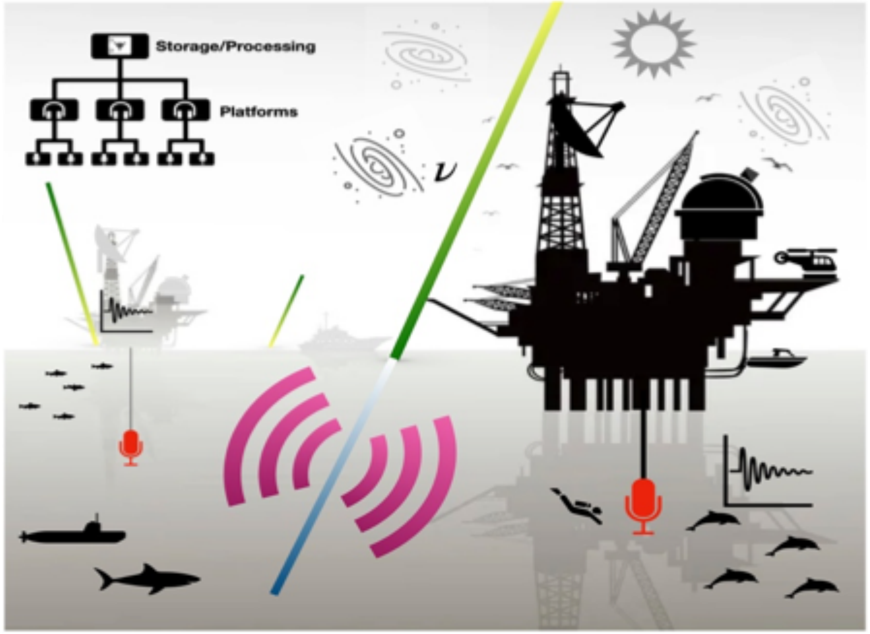
Assomineraria offshore map 2019

ANDIAMO: the concept

AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.



ENI dismissed oil rigs platform
Variable depth from 25 to 80 m



- Reuse the powered ENI oil rig platforms
- Take advantage of the Adriatic favorable temperatures
- Use the ray tracing techniques in a shallow water environment
- Exploit the presence of the SOFAR channel range
- Possibility to reach a instrumented surface ~ 10000 Km^2 and a volume ~ 500 Km^3 with low costs

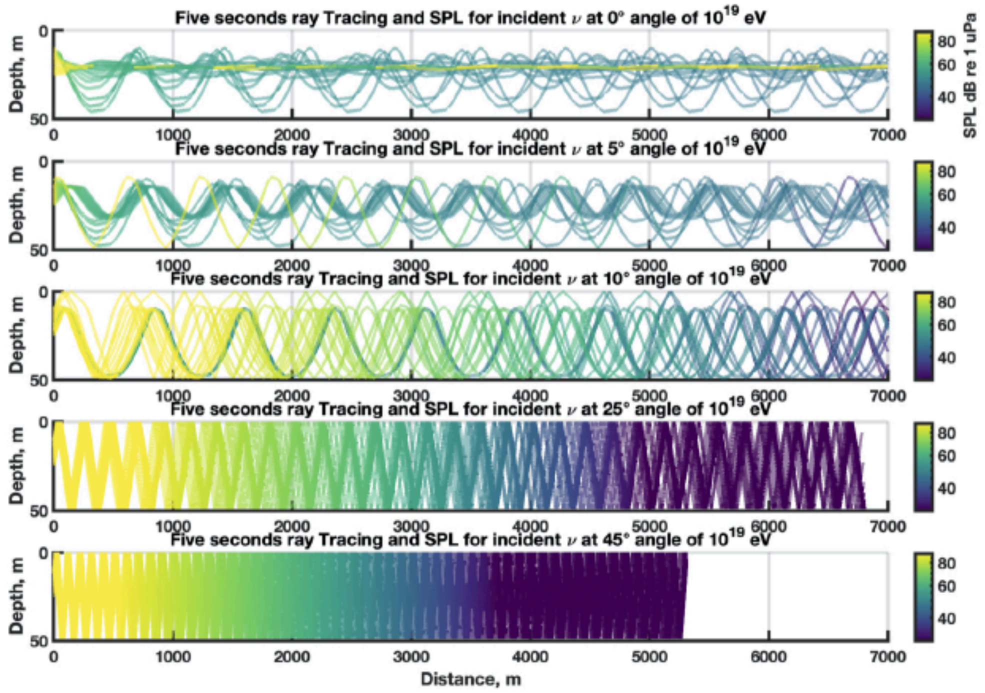
ANDIAMO vs previous undersea acoustic arrays

- Easier DAQ since we don't need any deep based power network.
- Possibility to digitize the signal directly on the powered platforms (small distances to transport the signal).
- Easier expansion of the detector trough buoyant lines , platforms will remain the basement for the DAQ system.
- Have a dedicated hydrophone for the expected signal instead of standard piezo-hydrophones used for calibration on the Cherenkov telescopes.

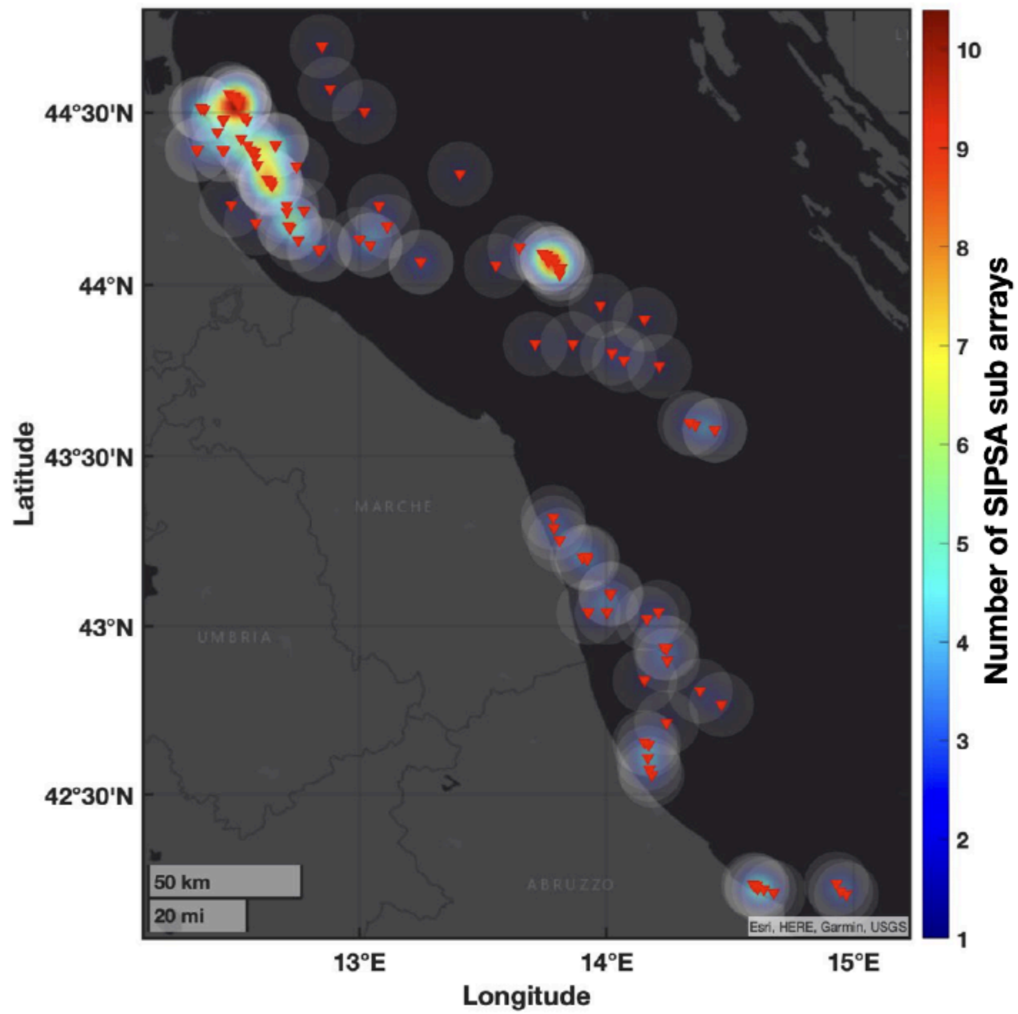
Ray tracing tecnique and surface covered

Importance of signal reflection in a shallow water env.

AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.



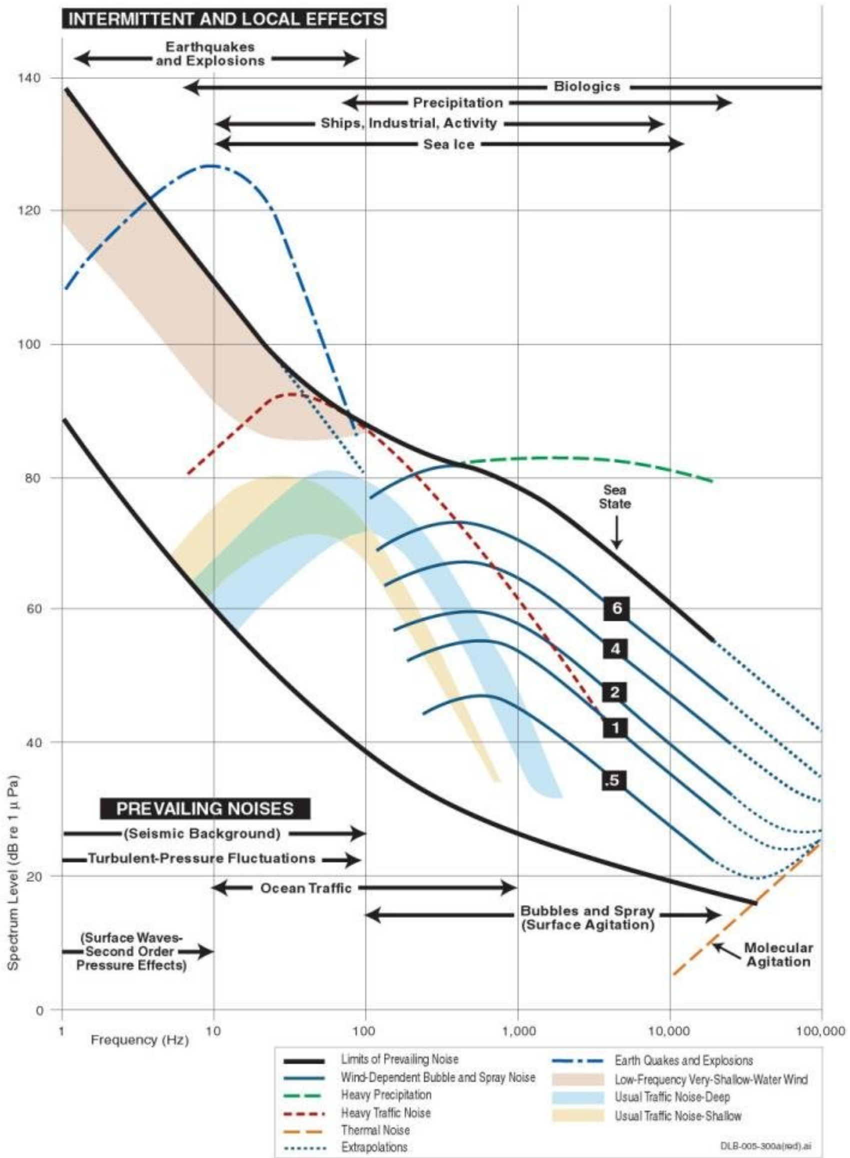
Simulated ray-tracing in the Adriatic shallow water for different neutrino incident angles. Corresponding sensitive area from 2800 Km^2 (45°) to 10000 Km^2 (0°)



Triggering SIPSA for near vertical neutrinos

Importance of background sea noise level

Oceanographic Technical report K.Sieger et al. 2013



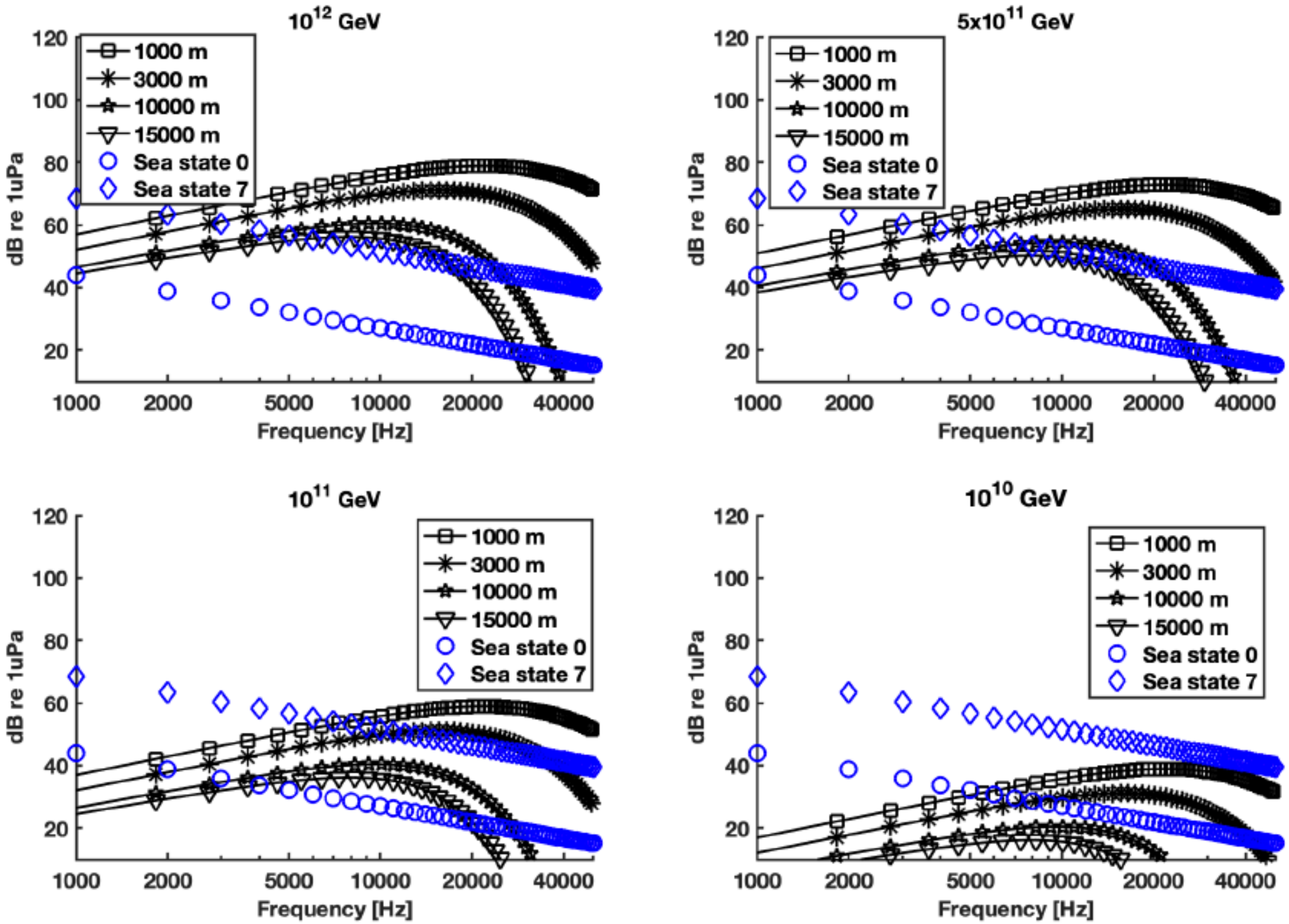
Ambient and human activity contribute to create a background acoustic noise that the neutrino signal should overcome to be observed.

Part of these backgrounds can be variable with time.

The Adriatic sea background level will be studied in details with a dedicated acoustic measurements campaigns.

ANDIAMO observable event energies

AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.

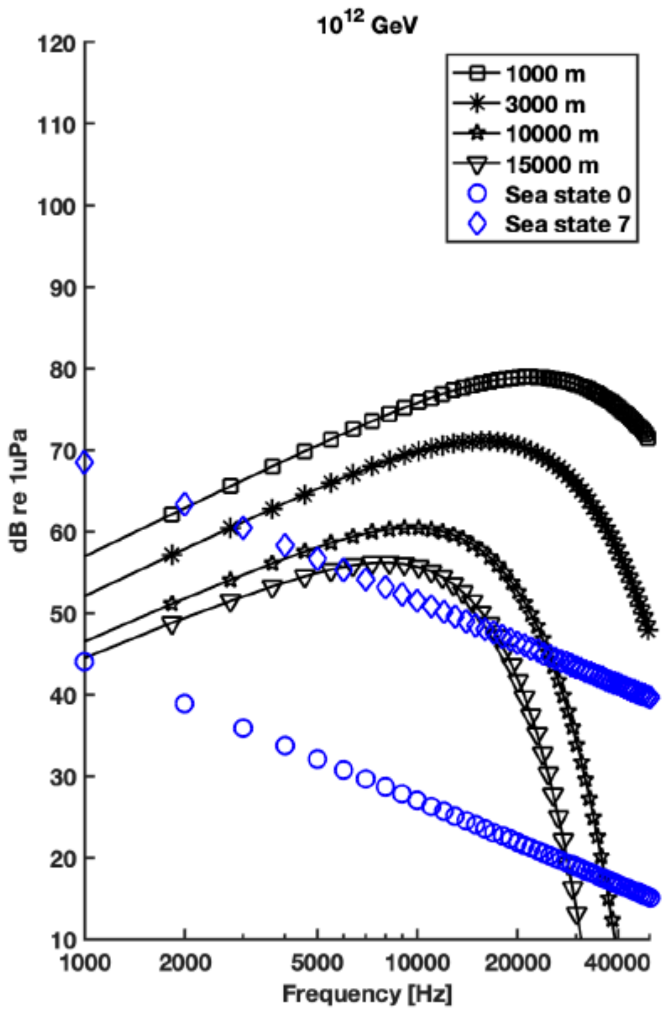


Different energy events simulated

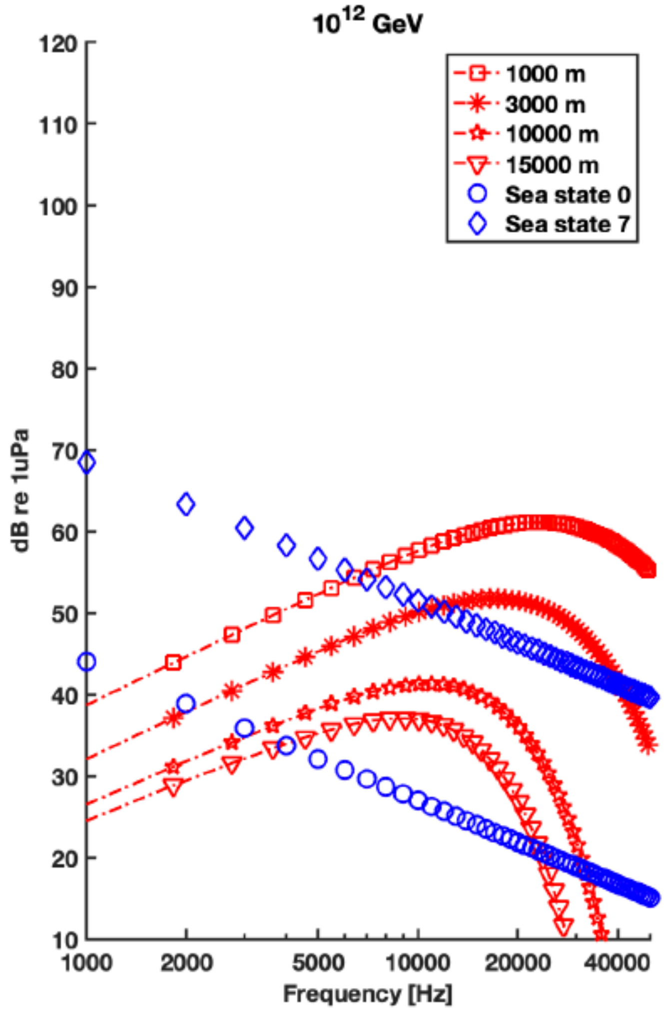
For a low background sea states ANDIAMO could allow the detection of signal even below 10^19 eV

ANDIAMO: the advantages of shallow water

AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.



30 m deep sea simulated



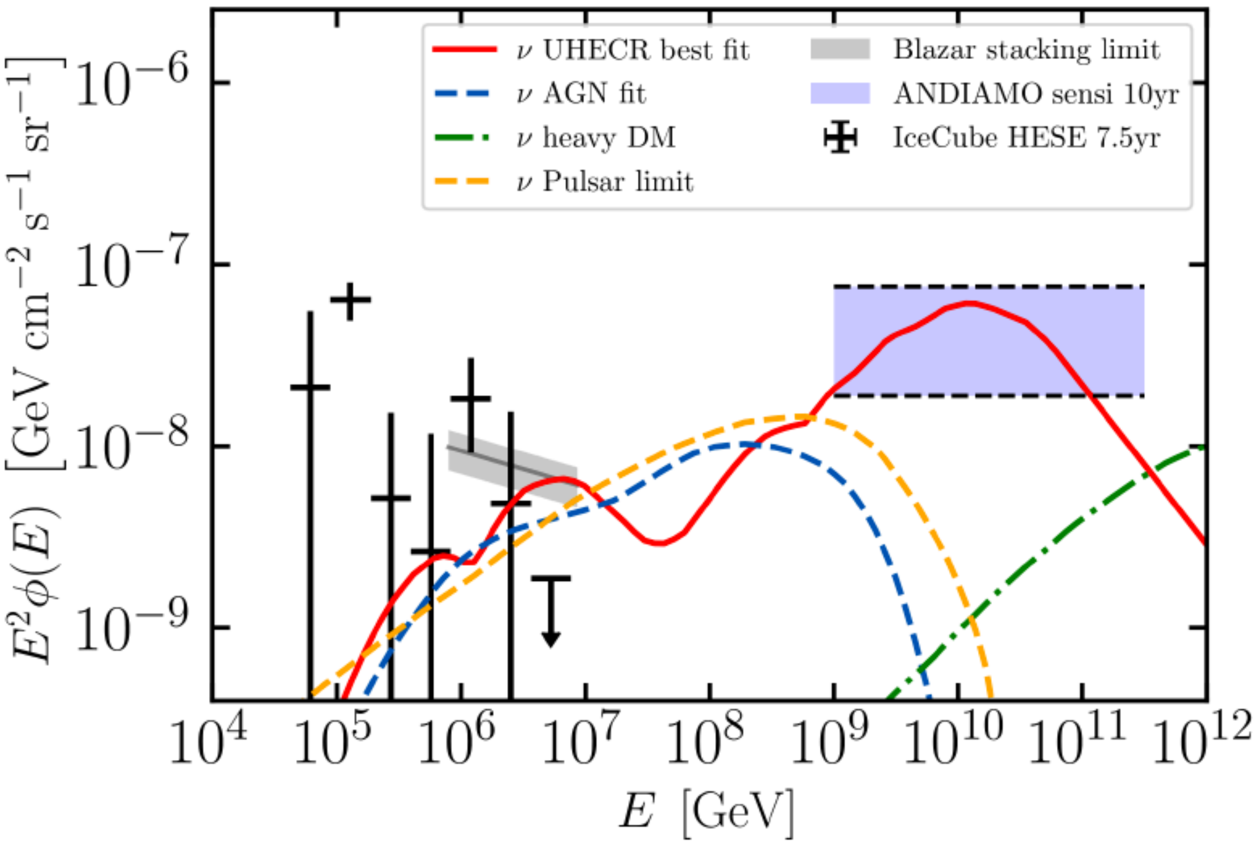
3000 m deep sea simulated

In this plot we can see the advantages of the shallow water environment for a neutrino energy event of 10^21 eV

Easier to see the signal respect to a deep water installation

ANDIAMO: possible sensitivity

AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.



A back-of-the-envelope ANDIAMO sensitive assuming a detection efficiency and a sensitive area and volume linked to the actual platform distribution.

A dedicated Monte Carlo simulation available soon.

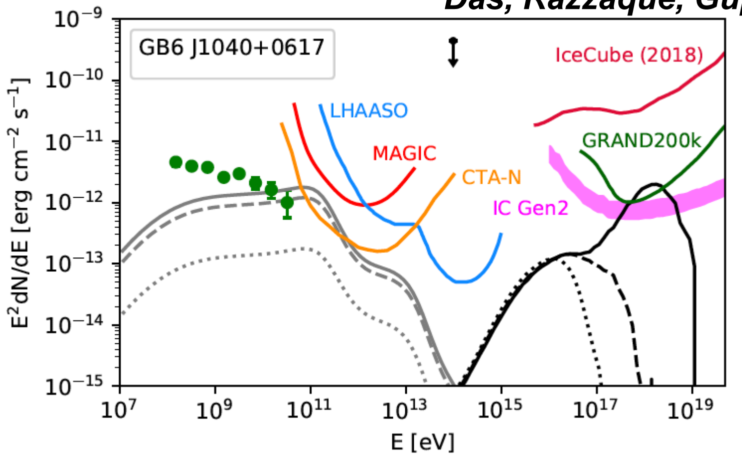
At zero level ANDIAMO sensitivity allows the observation of cosmogenic neutrino flux within a decade of data taking.

ANDIAMO field of view

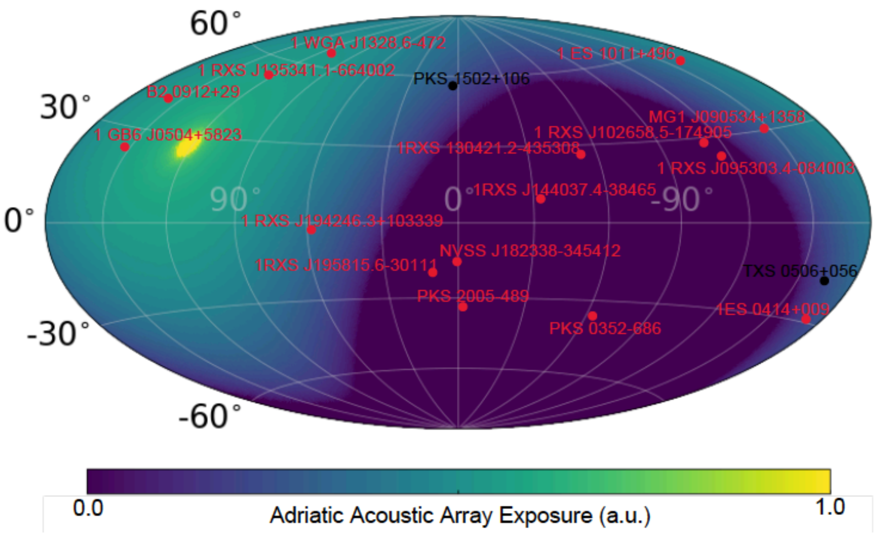
Even though a direct correlation of a UHE neutrino with a known accelerator will be challenging possible extension of ANDIAMO can explore also this possibility

Identify powerful accelerators through the observation of direct UHE neutrino or through the interaction of CR with CMB & EBL for closer ones.

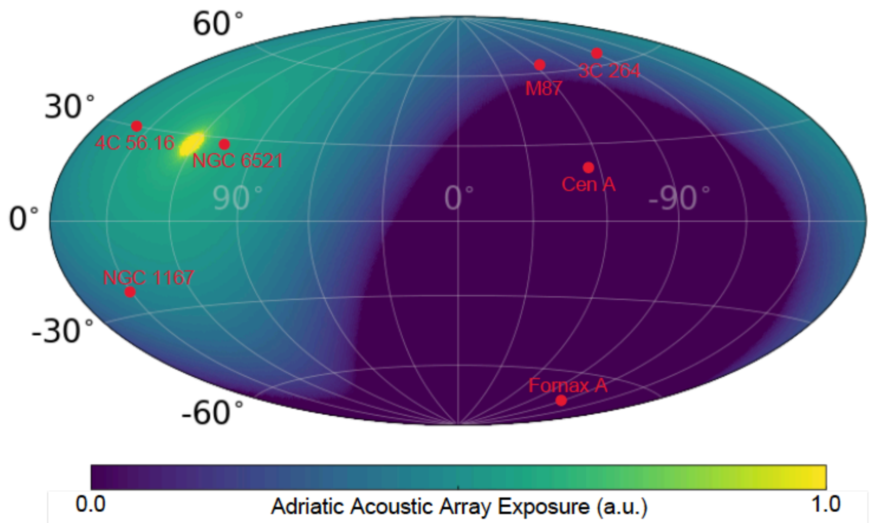
A&A 658, L6 (2022)
Das, Razzaque, Gupta



AstropartPh Volume 143, October 2022, 102760
A.M.,P.Migliozzi, A.Simonelli.

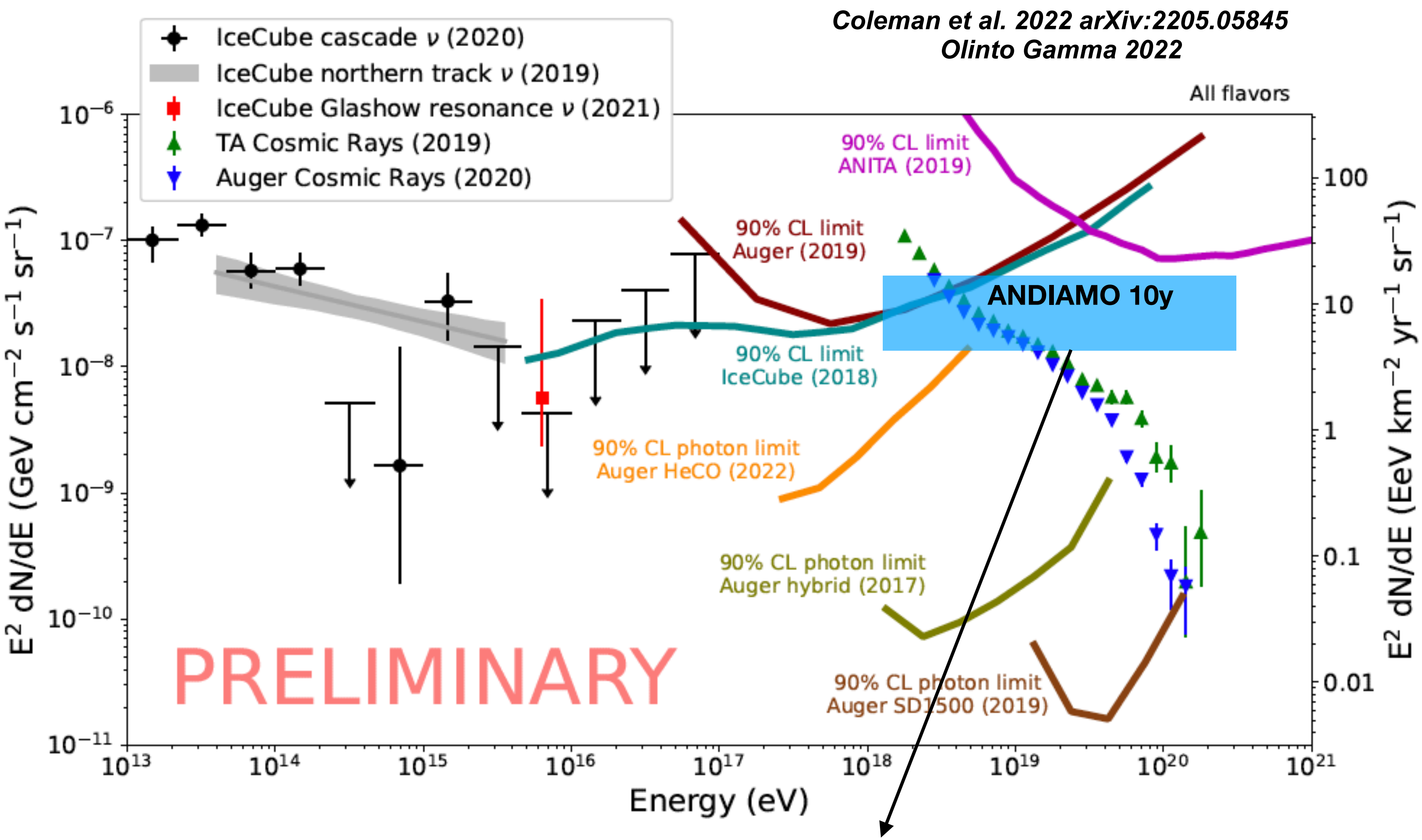


Promising Blazars in the ANDIAMO FoV



Promising Radio galaxies in the ANDIAMO FoV

ANDIAMO discovery potential



The energy region that can be explored by the ANDIAMO array in the next years.
An increased number of hydrophone lines can do even better!

SUMMARY

- Most of the past undersea acoustic neutrino detectors have been based on already placed hydrophone installations (military arrays, acoustic calibration of Cherenkov telescopes…).
- We explore the possibility to build a new dedicated large scale undersea acoustic array (ANDIAMO) taking advantages of already powered non operative oil rigs.
- We show the advantages of the shallow water environment of the Adriatic sea.
- We will proceed now to better define the geometry of the array and obtain a detailed Monte Carlo simulation.
- We will perform in situ measurements as well, for a better understanding of the local background with dedicated hydrophones and a proper DAQ.
- We hope for a positive answer from founding agencies.