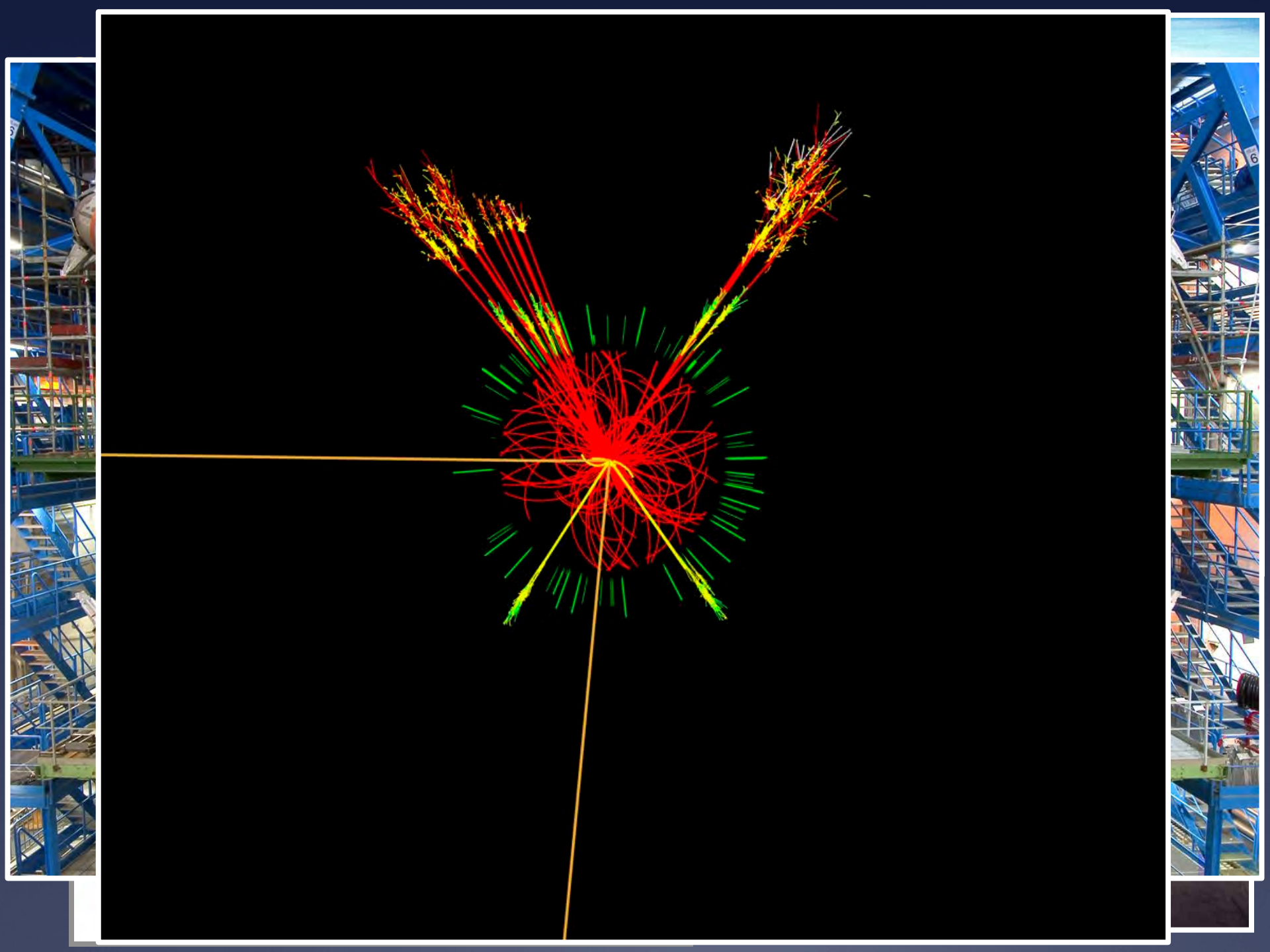
Listening for Neutrinos – from Astrophysics to the Deep Sea

Lee F. Thompson
University of Sheffield

Cetacean echolation and Outer Space Neutrinos
ERICE, Sicily, Italy
18th – 22nd October 2013

The University Of Sheffield.



astro(particle)physics [my view]

- particle
  terrestri
- for exar
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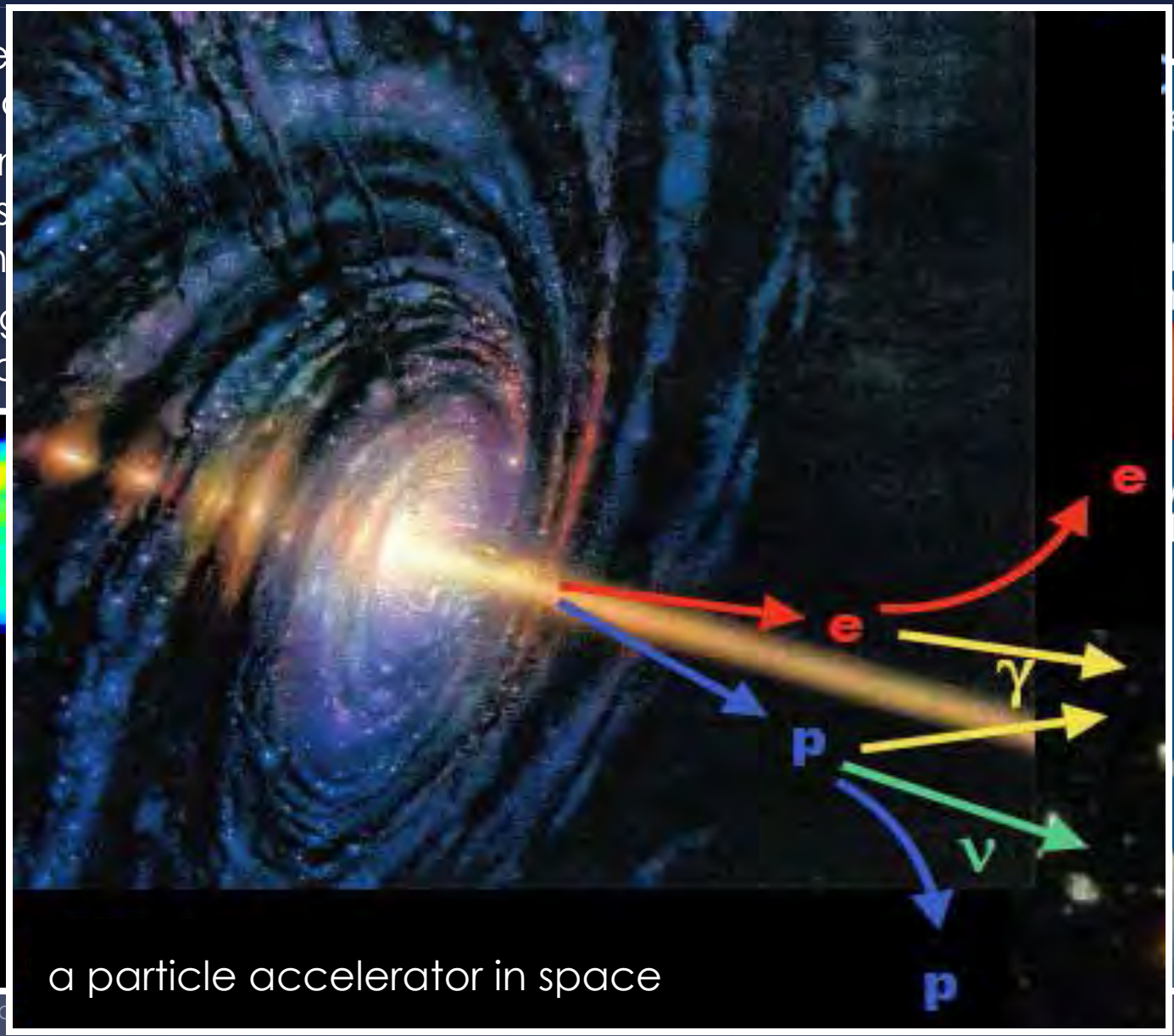
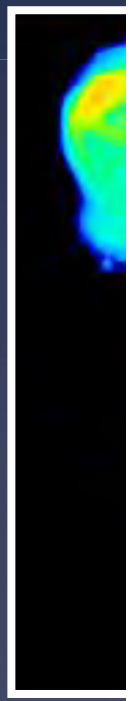
- also, e.g
  supern



a particle accelerator in space

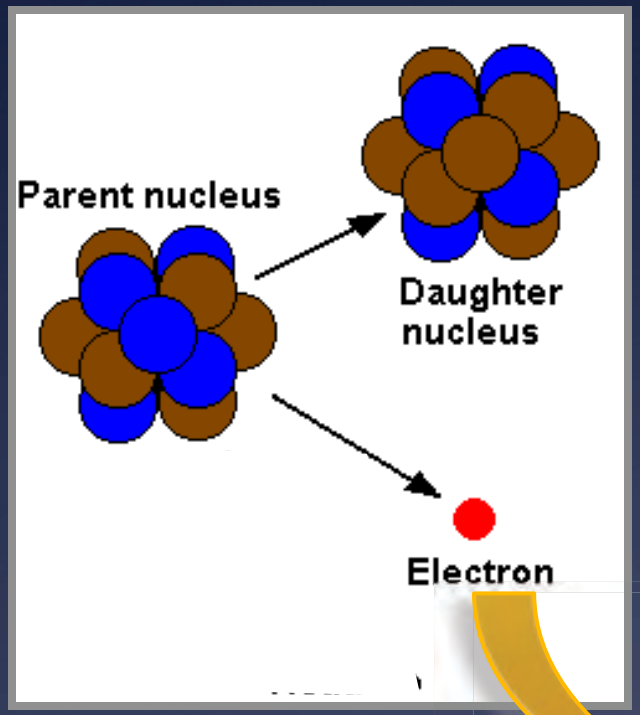


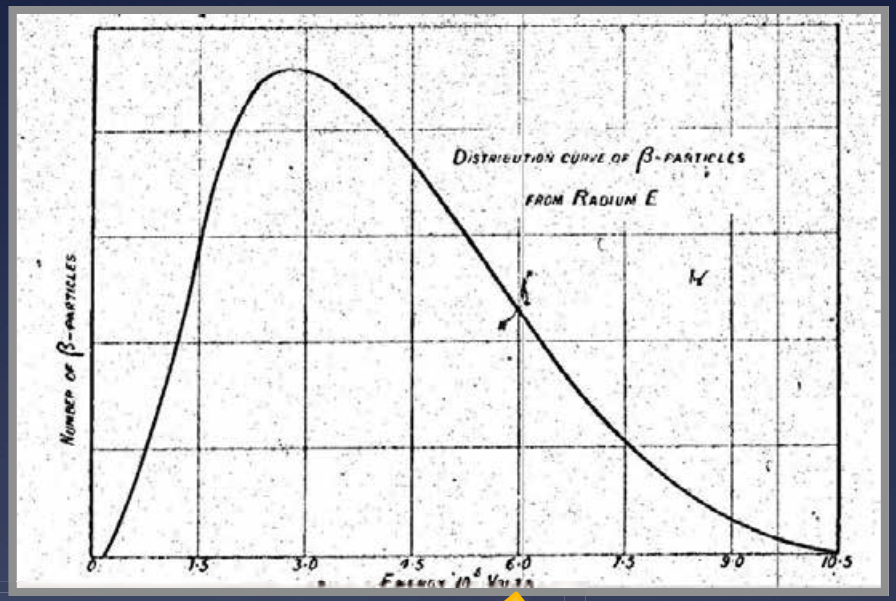
[I ragazzi di Via Panisperna]

Edoardo Amaldi, Emilio Segrè, Franco Rasetti, Ettore Majorana, Enrico Fermi, Bruno Pontecorvo

- Fermi: 1939 Nobel Prize for Physics: "for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons"
- Segrè: 1959 Nobel Prize for Physics: discovery of the anti-proton

the birth of the neutrino

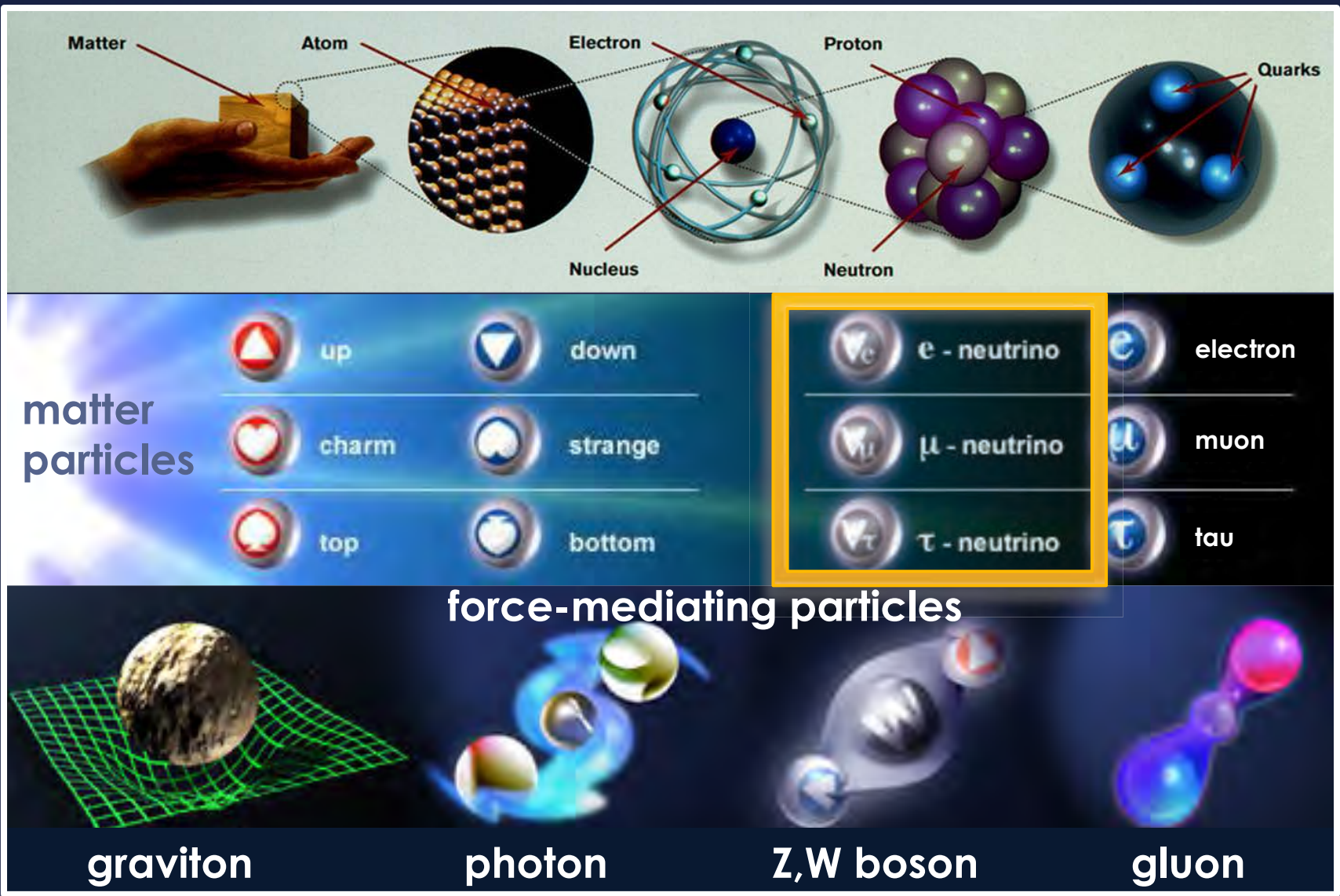




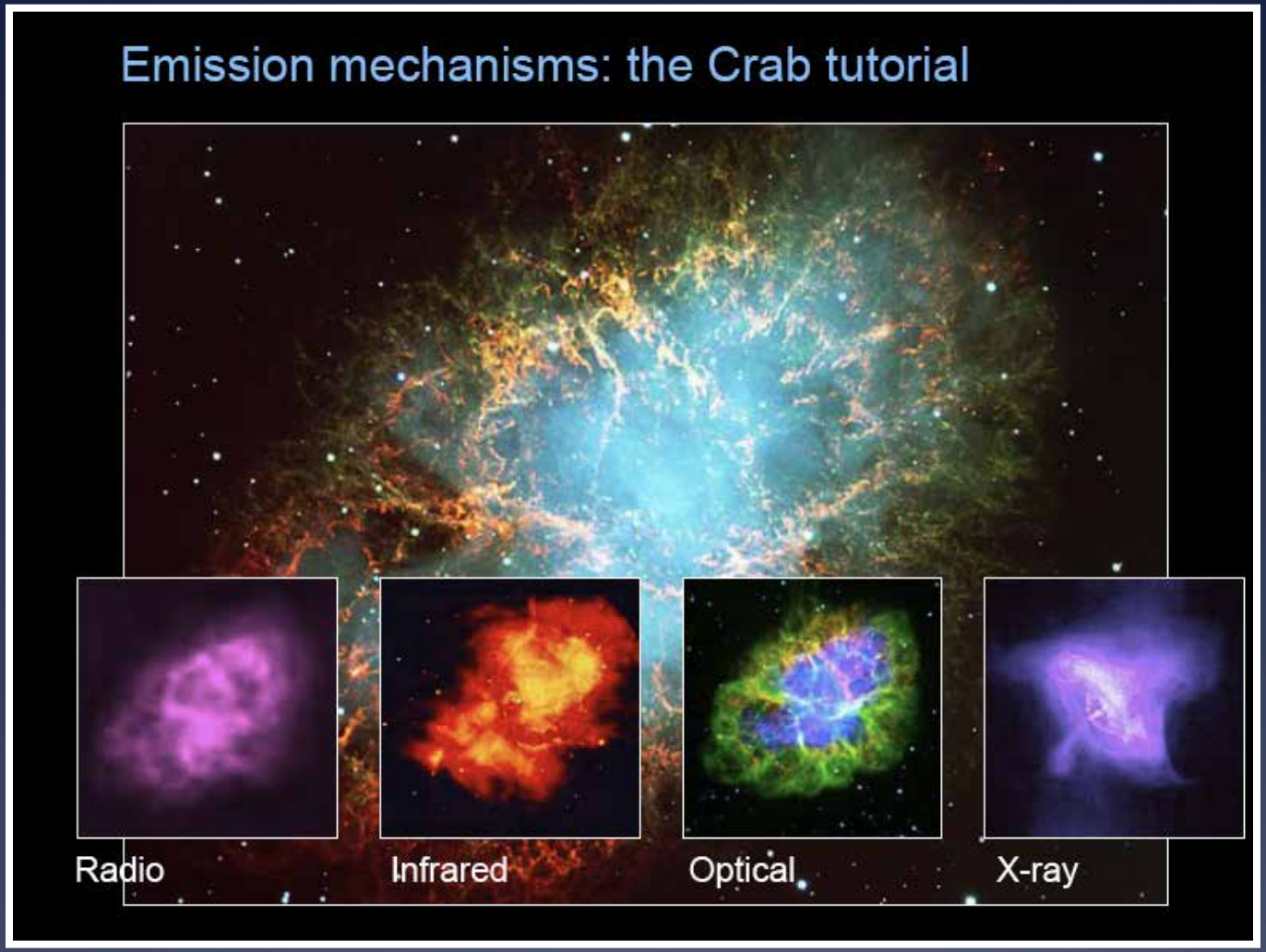
$E = \Delta mc^2$

- Pauli: postulated the existence of the neutrino in 1930 to explain the conservation of energy and momentum in beta decay
- a third particle must be produced, electrically neutral and with very low mass, so not observed
- Fermi: named the particle 'neutrino' in 1933

neutrinos in particle physics

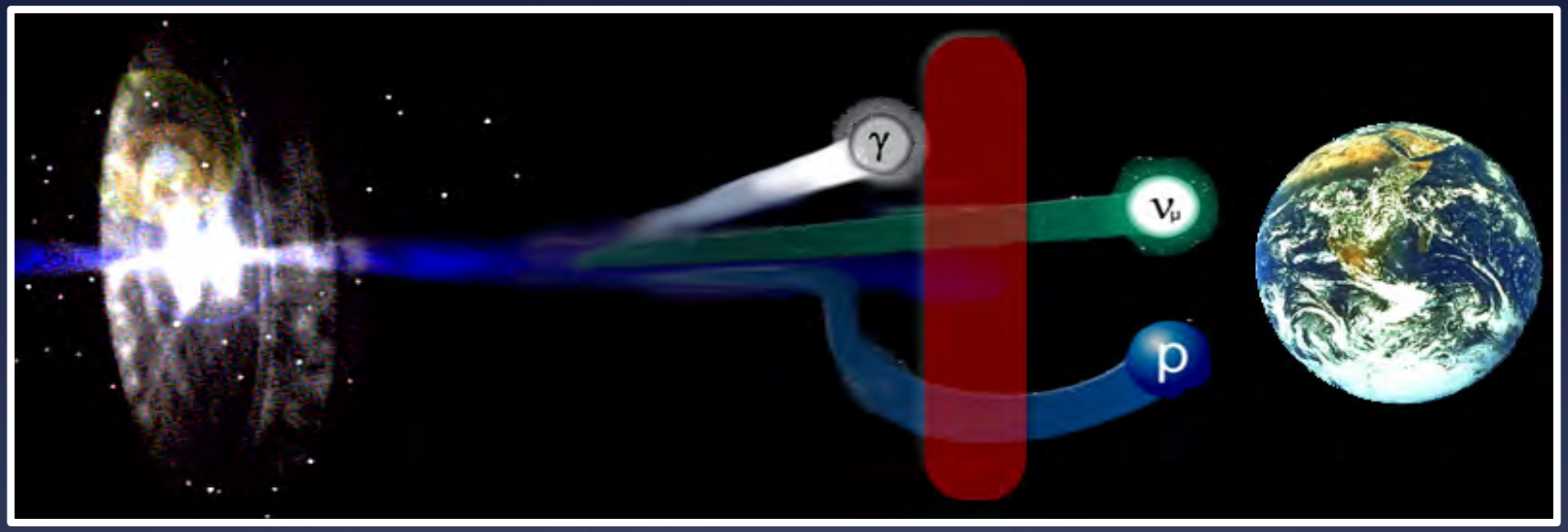


why look for high energy neutrinos?



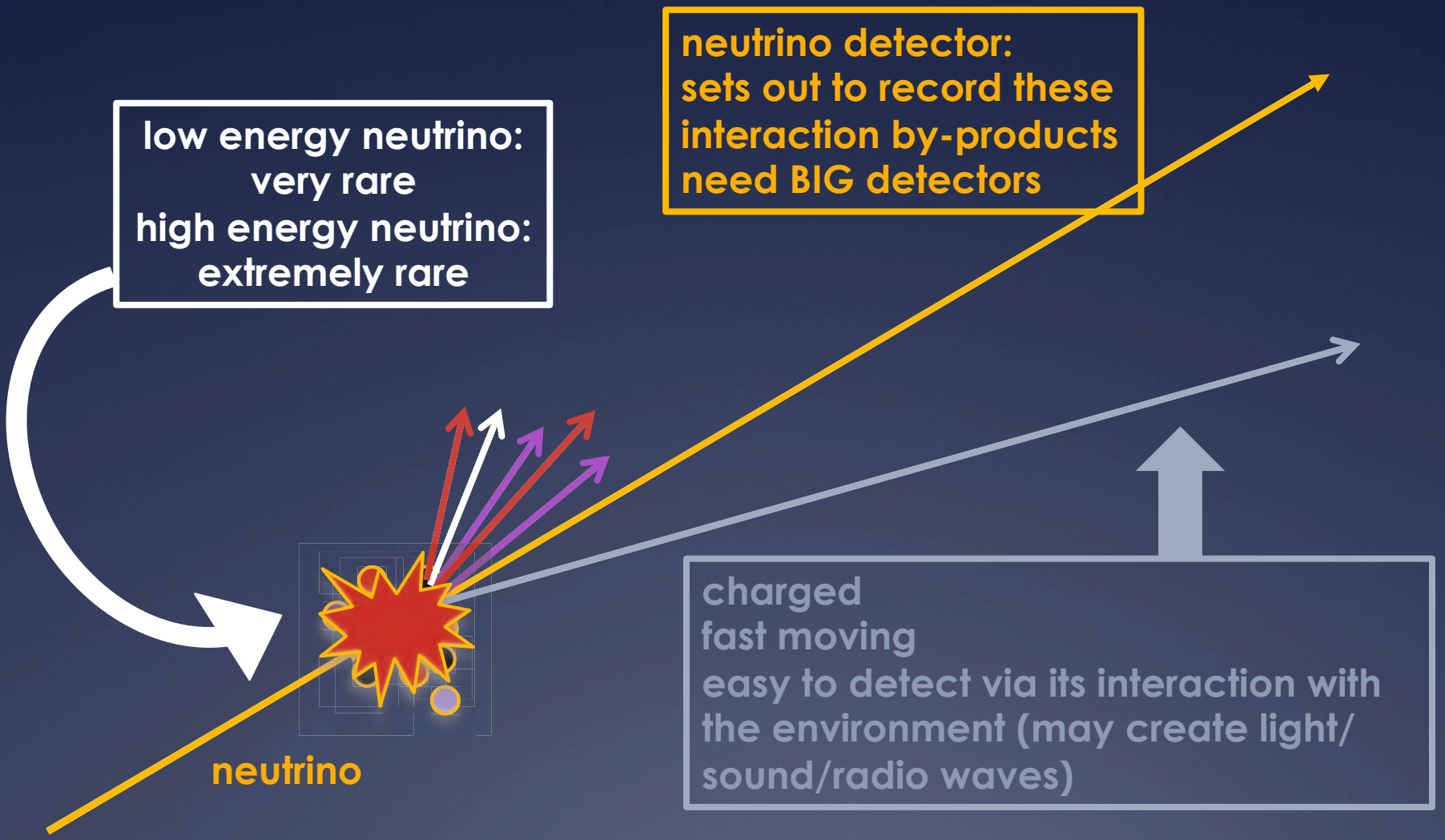
- much of what we know about astrophysical sources involves probes of the electromagnetic spectrum

why look for high energy neutrinos?

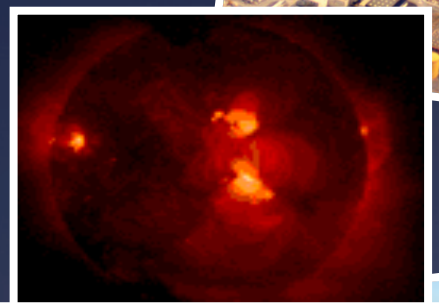


- photons are absorbed in interactions with the interstellar medium
- charged particles may be deviated in (extra-)galactic magnetic fields - loss of information on astrophysical source
- neutrinos open up a "new window on the Universe"

detecting neutrinos [principle]

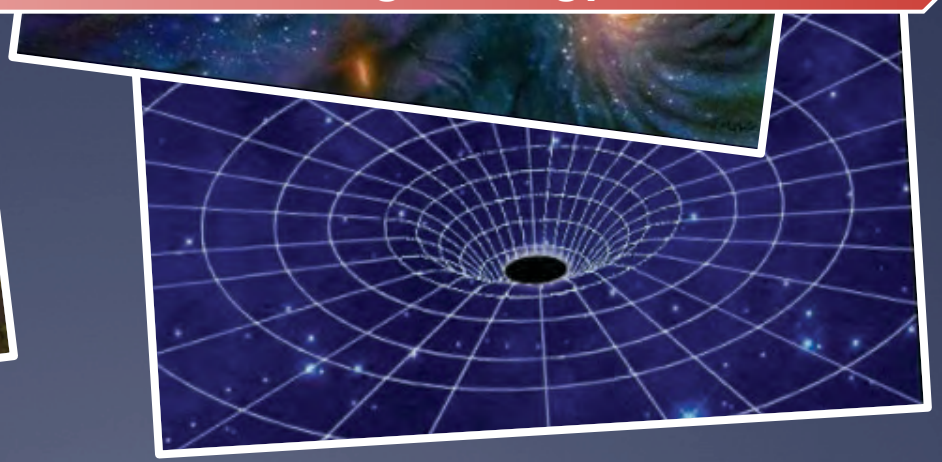


neutrino sources

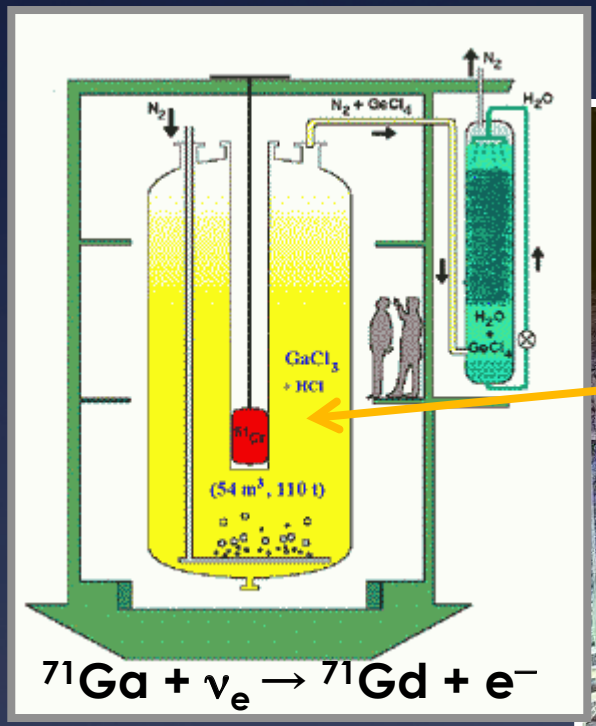


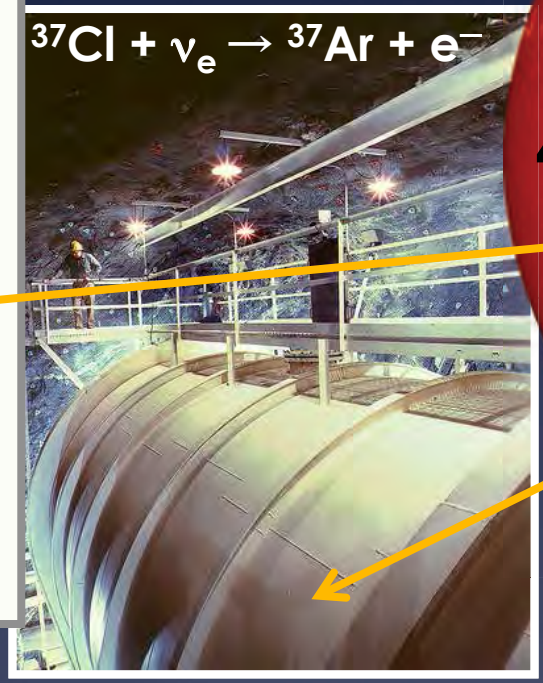
low energy

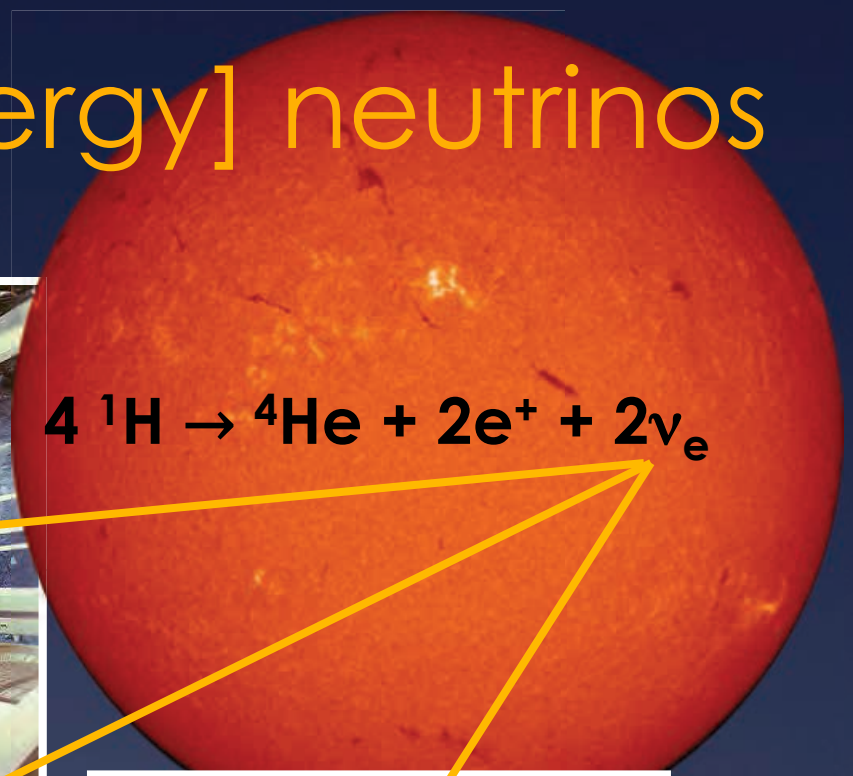
high energy

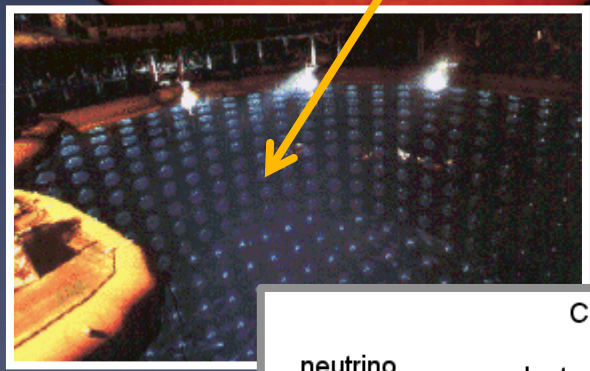


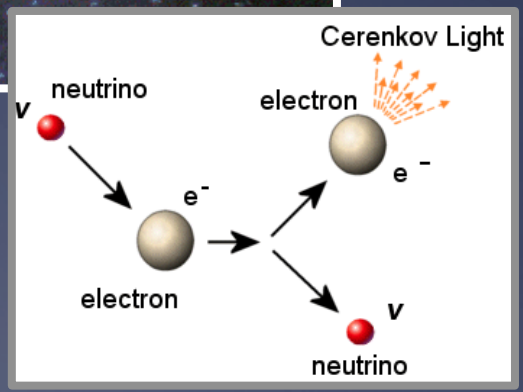
detecting[low energy] neutrinos





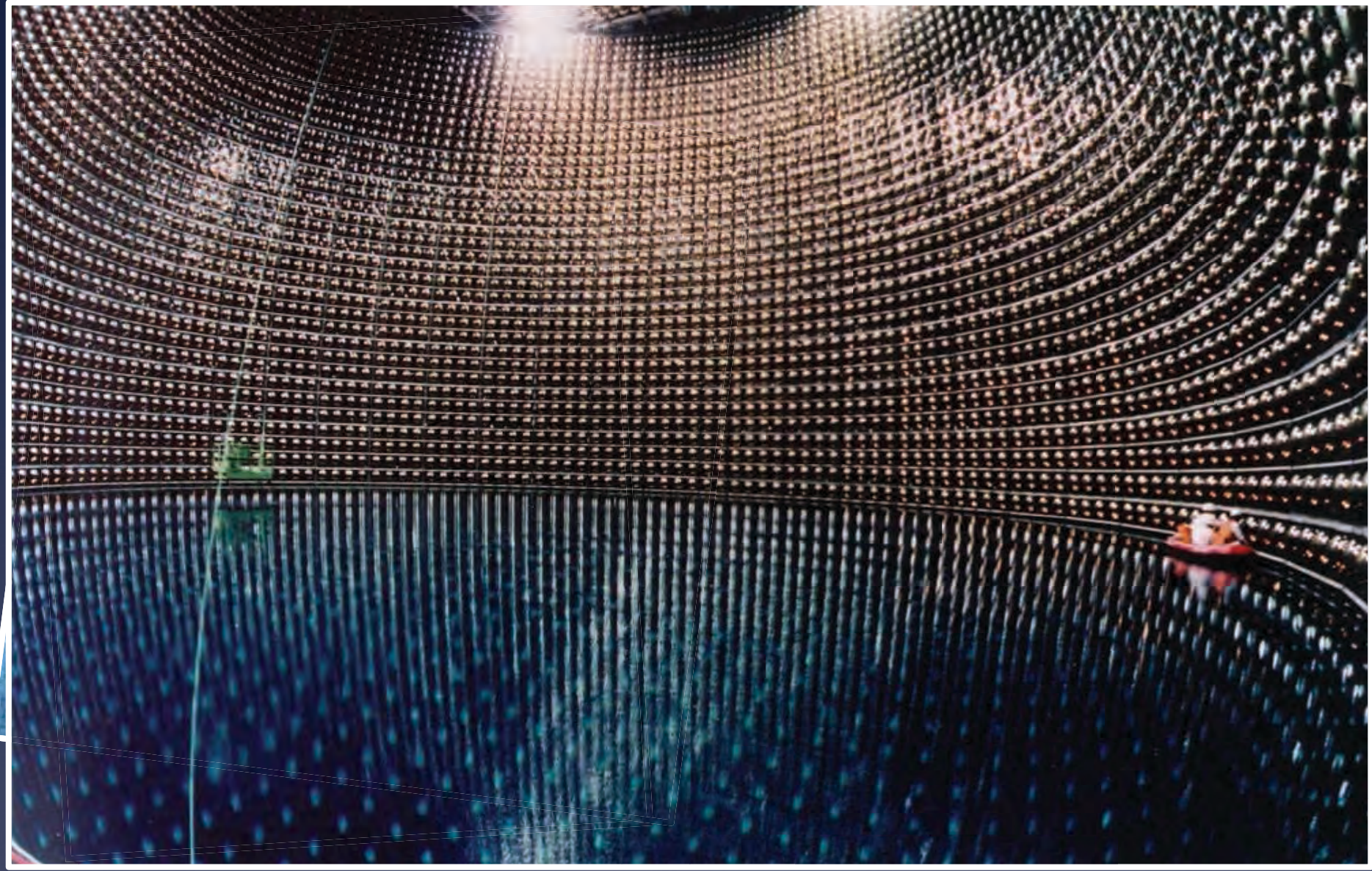






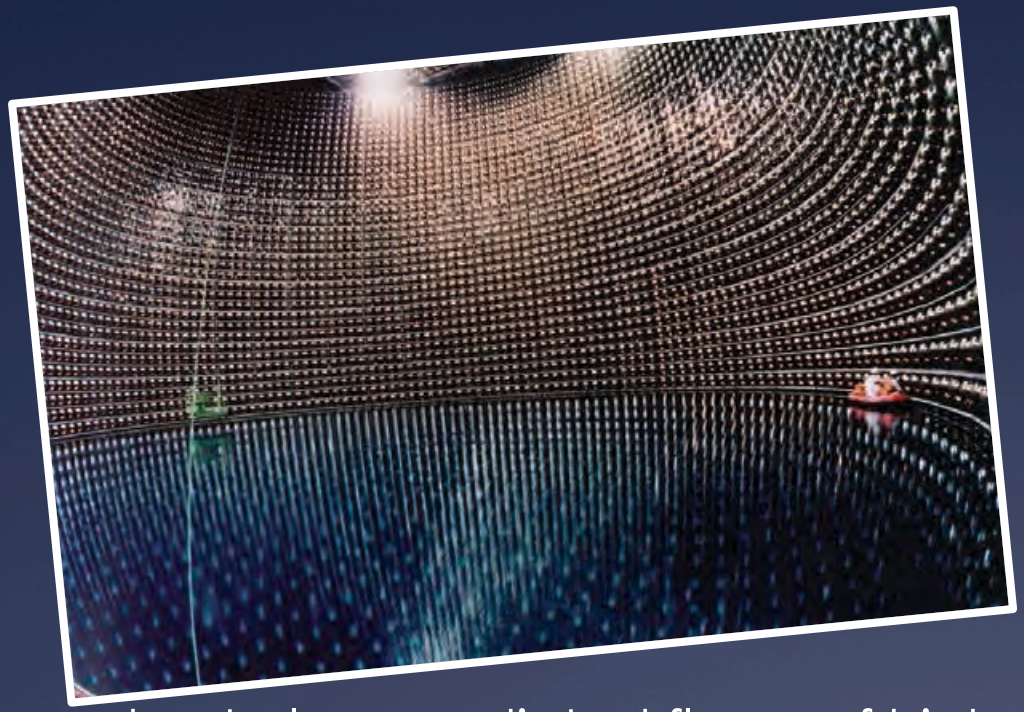
- neutrinos are hard to detect (they hardly ever interact) so we need to build HUGE experiments to detect them
- series of experiments starting in the late 1960s that set out to detect neutrinos from the Sun

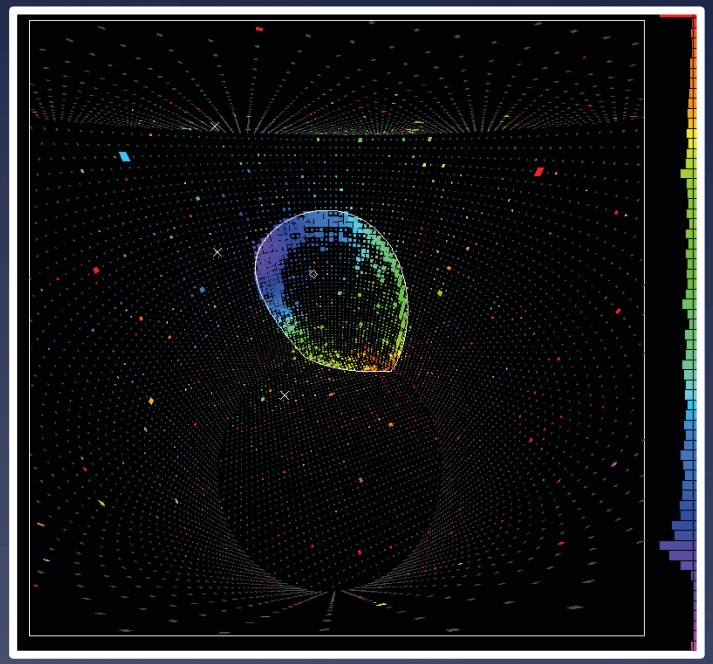
SNO and SuperKamiokande



detecting[high energy] neutrinos

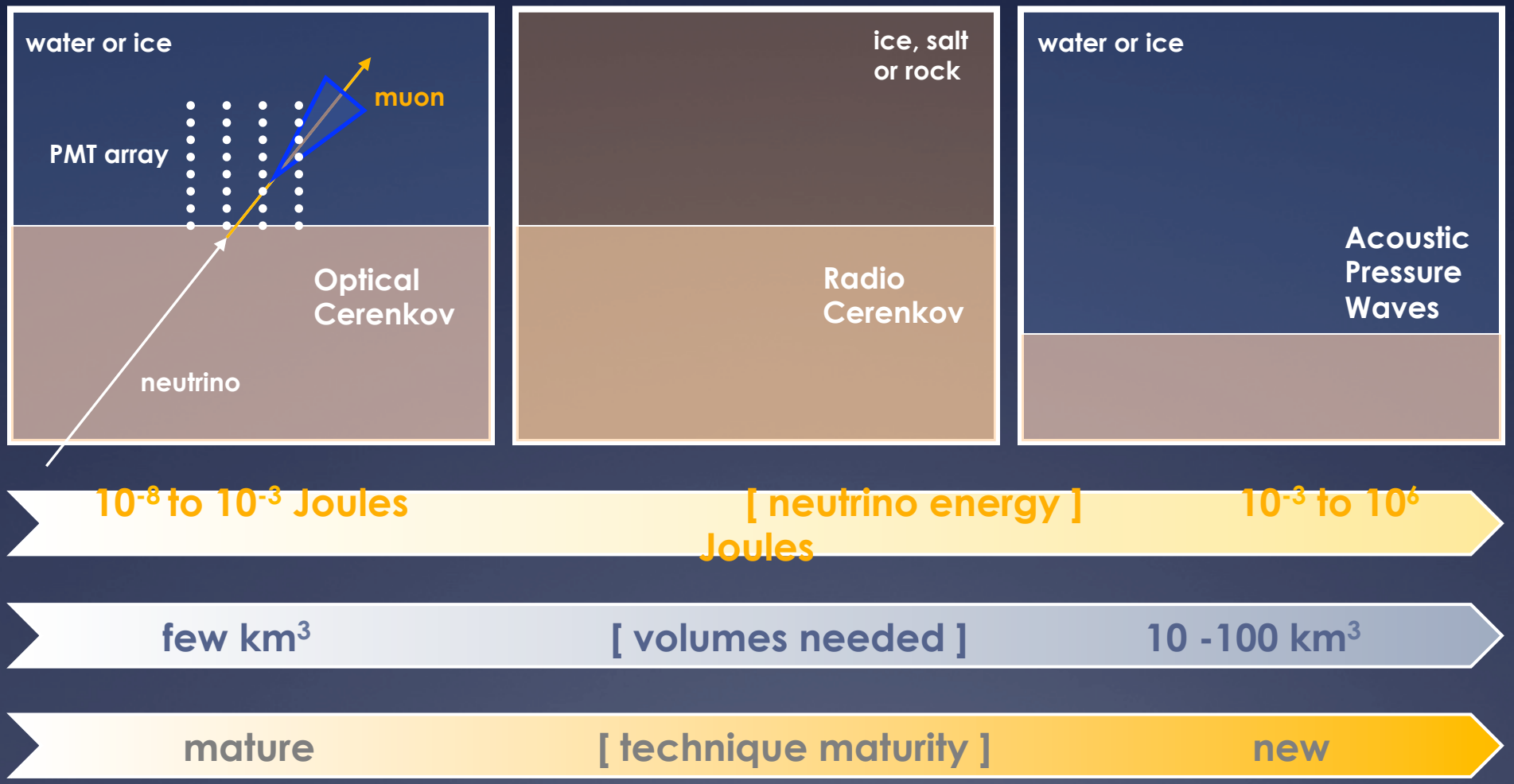
- general principle: detect the results of a neutrino's interaction with its surroundings (charged particle or 'cascade' (shower)



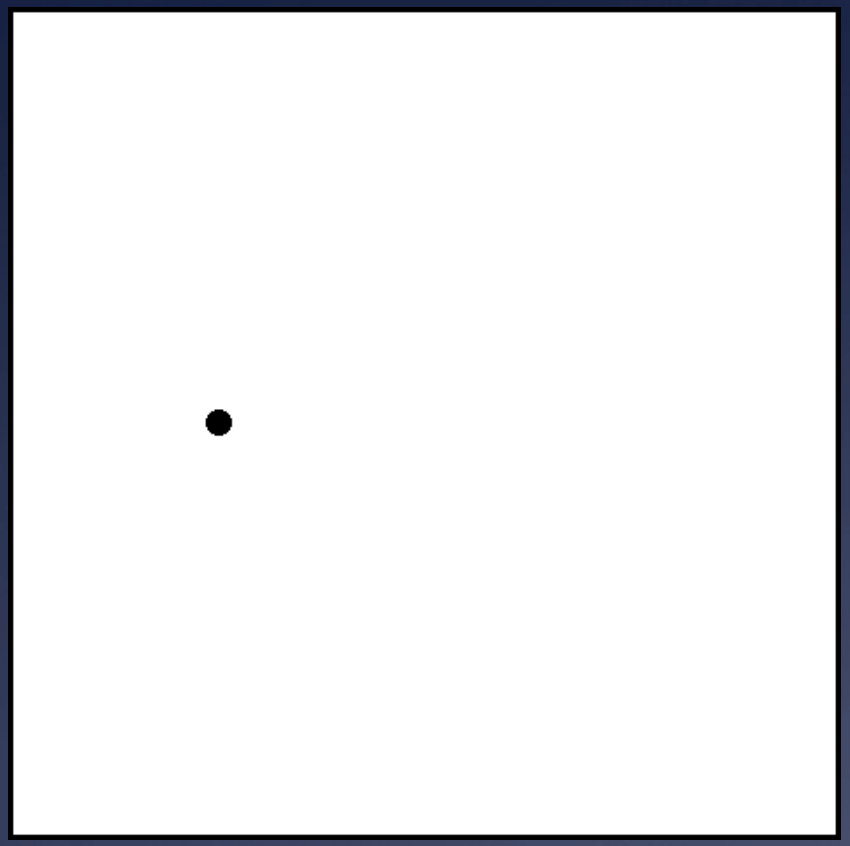


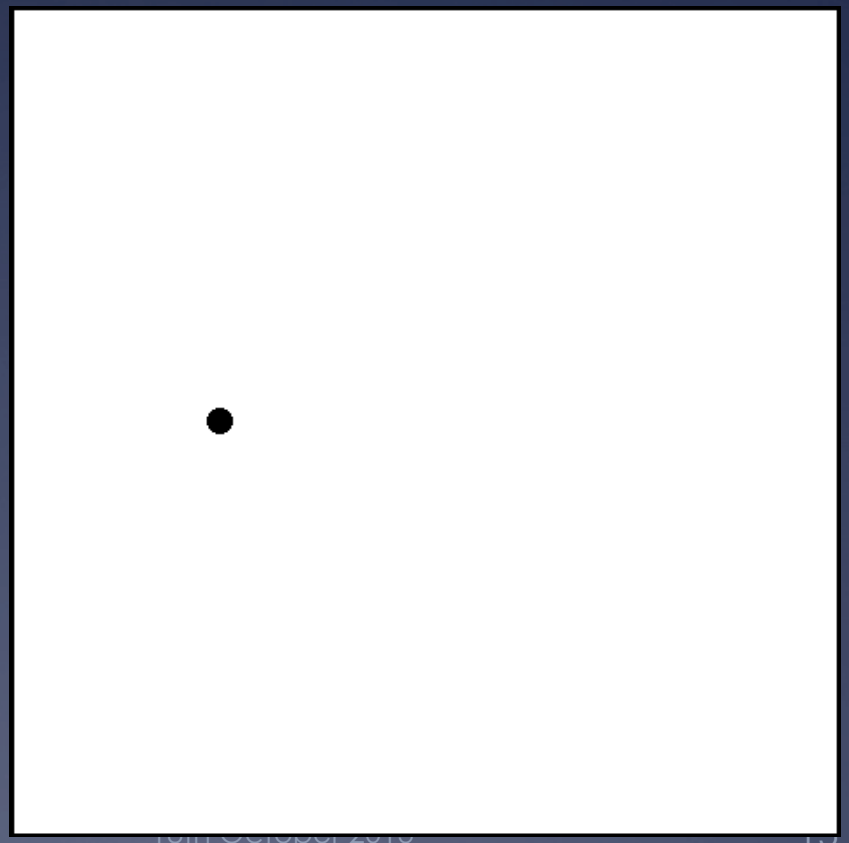
- due to low predicted fluxes of high-energy neutrinos man-made detectors like SuperKamiokande simply aren't big enough!
- need to instrument large volumes of naturally occuring media such as water or ice

detecting high energy neutrinos



cerenkov radiation

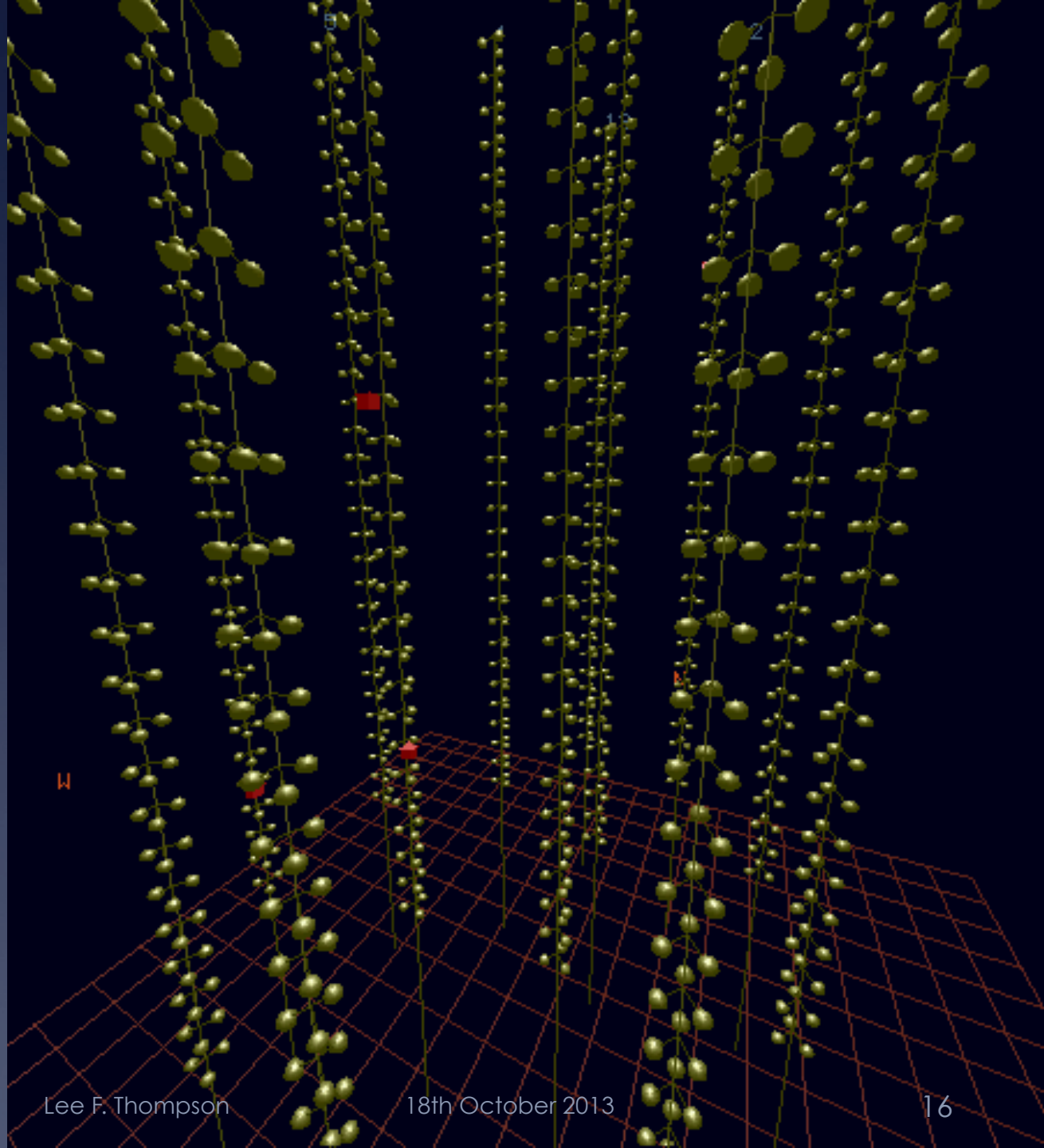




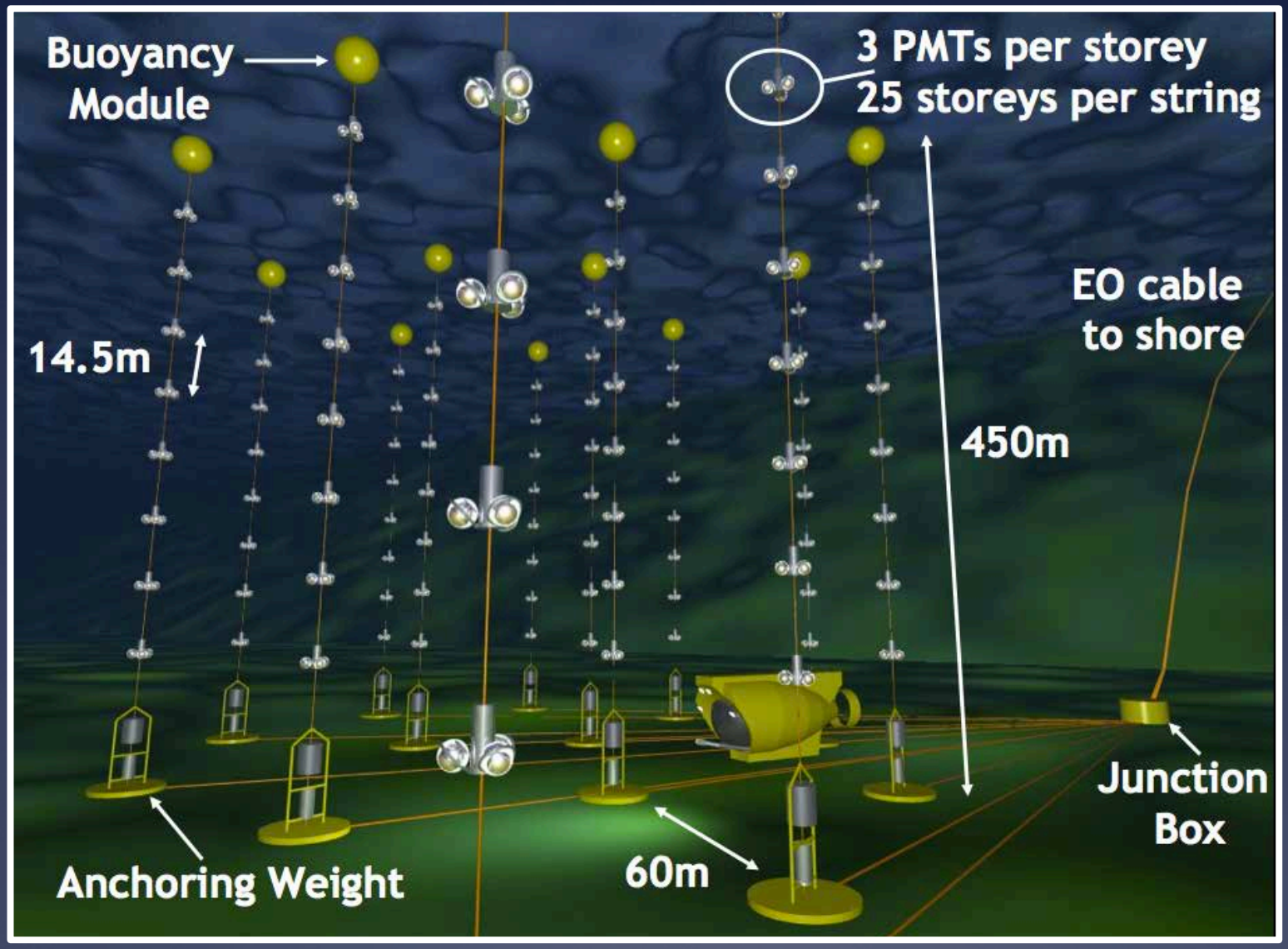
optical Cerenkov neutrino telescope:

the detection concept

a telescope that looks down!

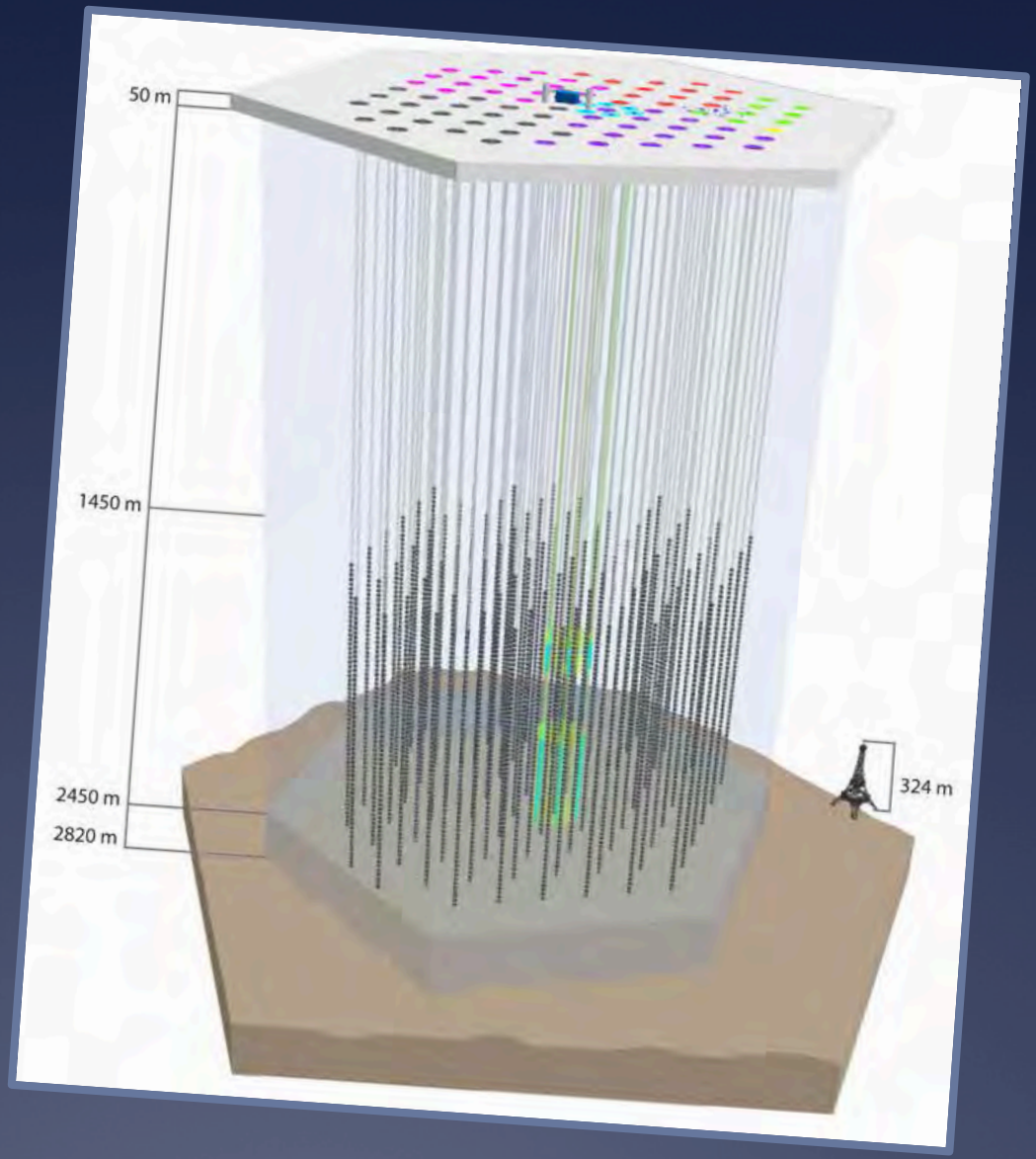


[ANTARES / km3] mediterranean detectors

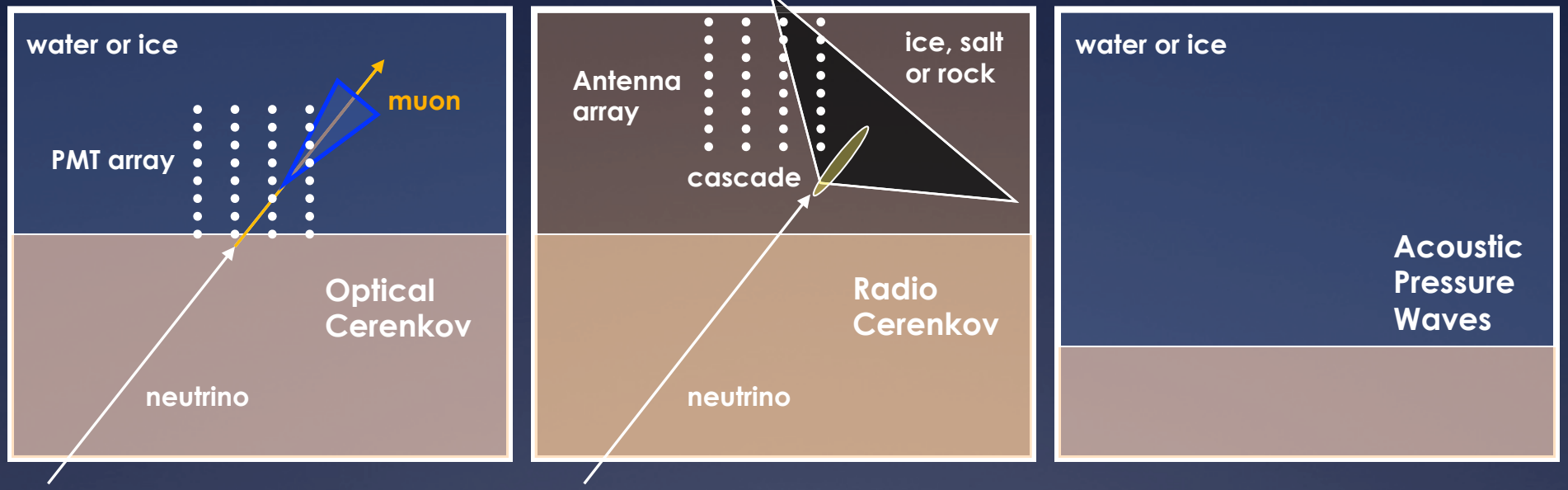


[IceCube] South Pole detector

- IceCube: a cubic kilometre of ice instrumented with almost 5000 (photosensors)
- strings of photosensors deployed in the ice during the Austral summers



detecting high energy neutrinos

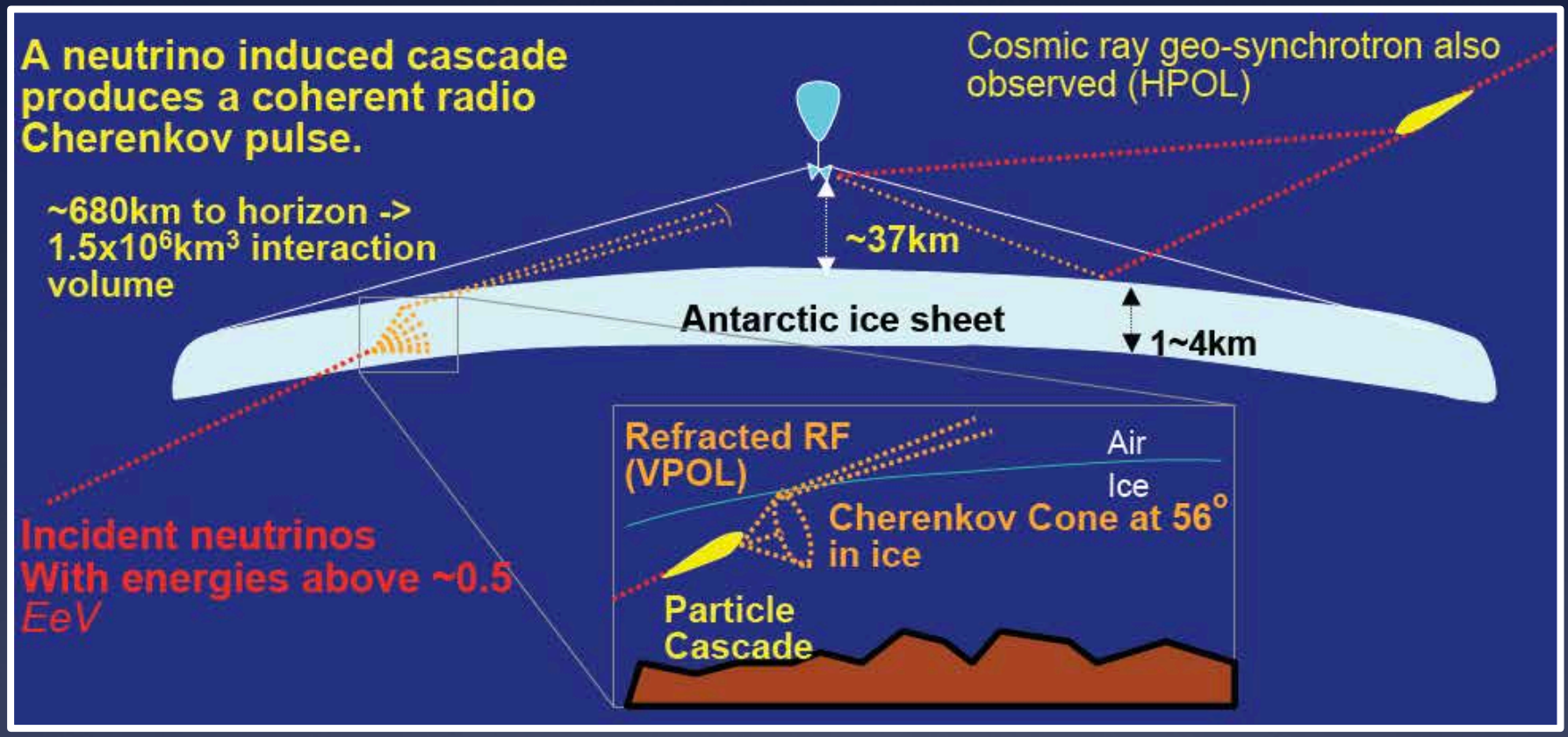


10^{-8} to 10^{-3} Joules [neutrino energy] 10^{-3} to 10^{6} Joules

few km^3 [volumes needed] 10 -100 km^3

mature [technique maturity] new

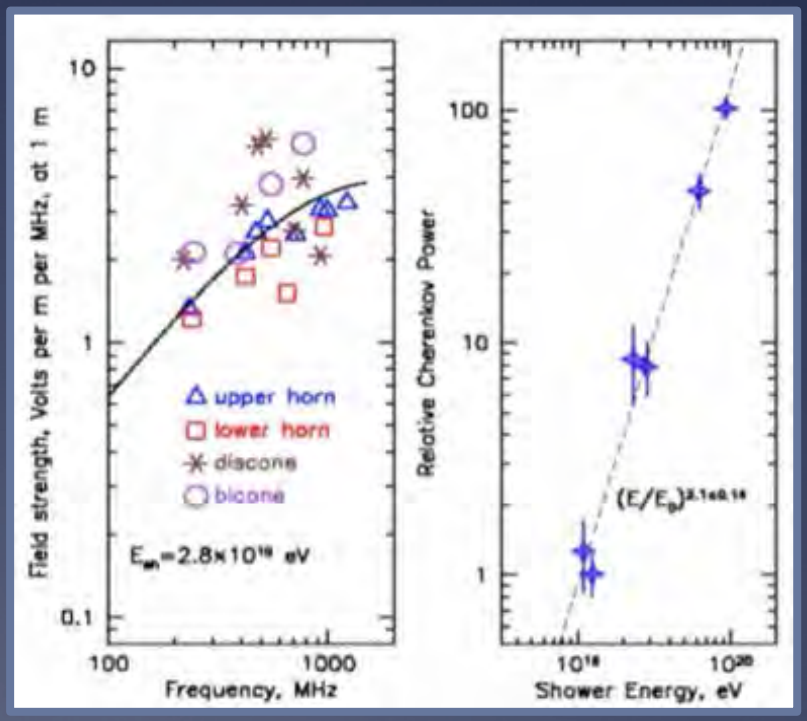
[ANITA] concept



- in this case the radiation caused by the neutrino escapes the medium it is created in i.e. radio waves escape the ice
- don't instrument the - ice fly over it!

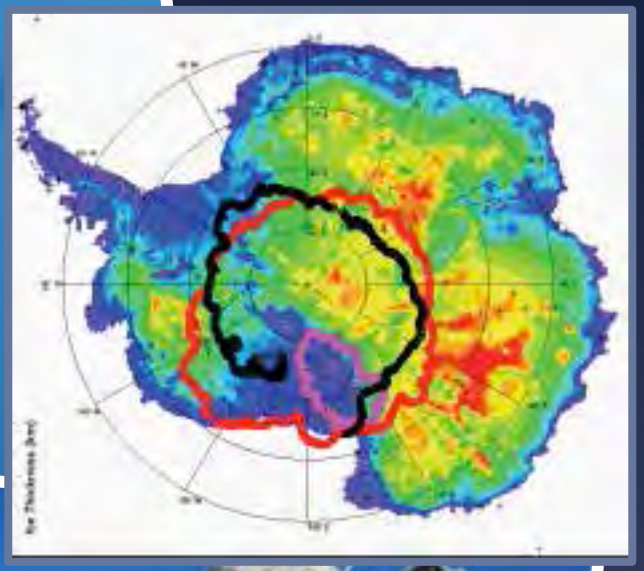
[ANITA] proof of principle

- go to Stanford Linear Accelerator Center
- fire a beam of particles into several tons of ice
- suspend your payload (detectors) above the ice



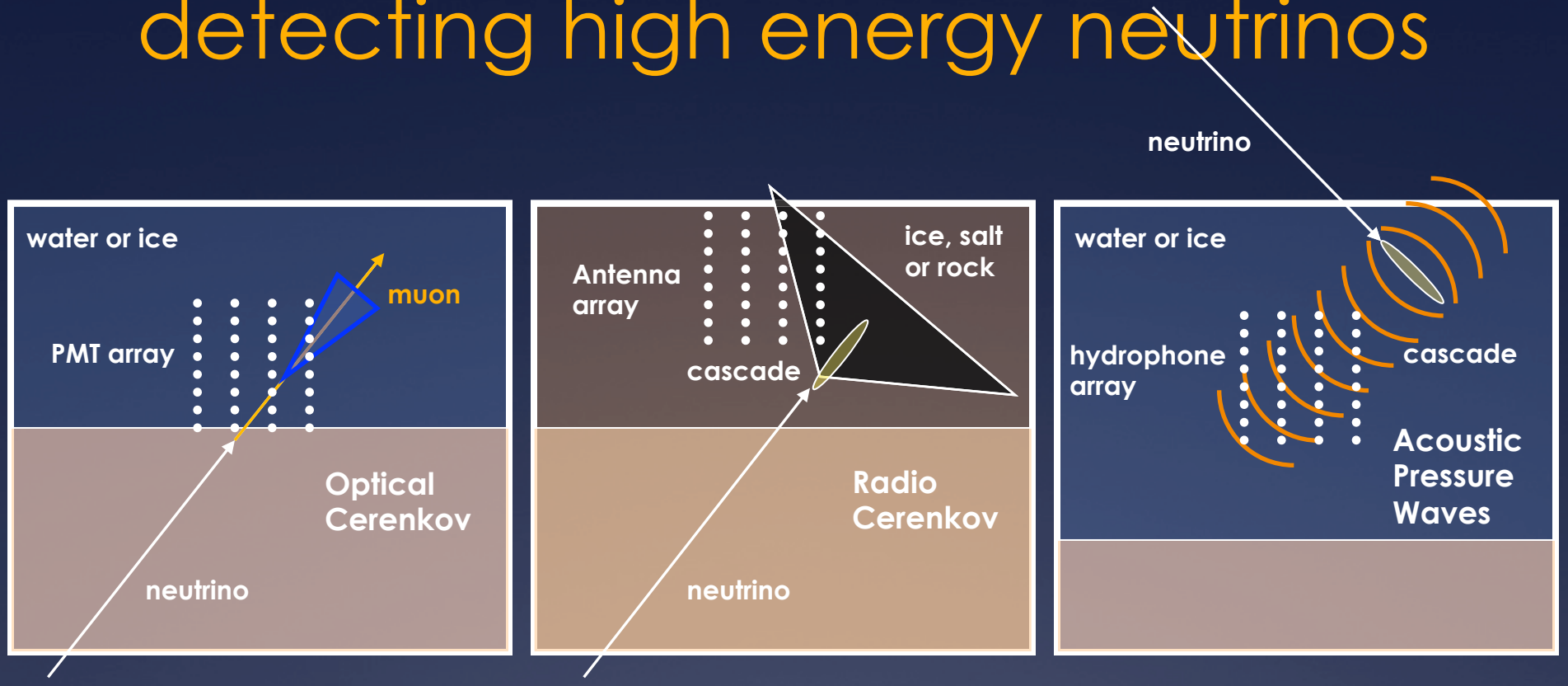
- measure radio frequency signals

[ANITA] flight profile



- circumpolar flight
- typically a month airborne
- huge effective volume observed

detecting high energy neutrinos



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[acoustic pulse] formulation

PHYSICAL REVIEW D VOLUME 19, NUMBER 11 1 JUNE 1979

Acoustic radiation by charged atomic particles in liquids: An analysis

John G. Learned*
University of California, Irvine, Irvine, California 92717
(Received 14 July 1978)

- first journal paper to address the question of the characteristics of an acoustic pulse from a ultra-high energy charged particle
- one of the key equations (of many) in this paper:

$$p(r,t) = \frac{E_0 \beta}{4\pi C_p} \frac{\delta'(r/c - t)}{r}, \qquad (14)$$

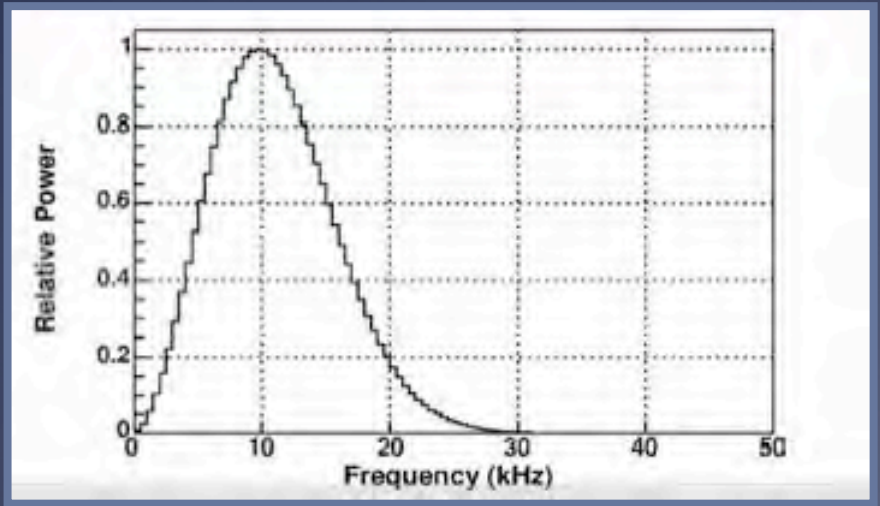
i.e. pulse amplitude goes as the 1st derivative (w.r.t. time) of the heat transfer (delta function) and hence 2nd derivative (w.r.t. time) of the temperature/volume

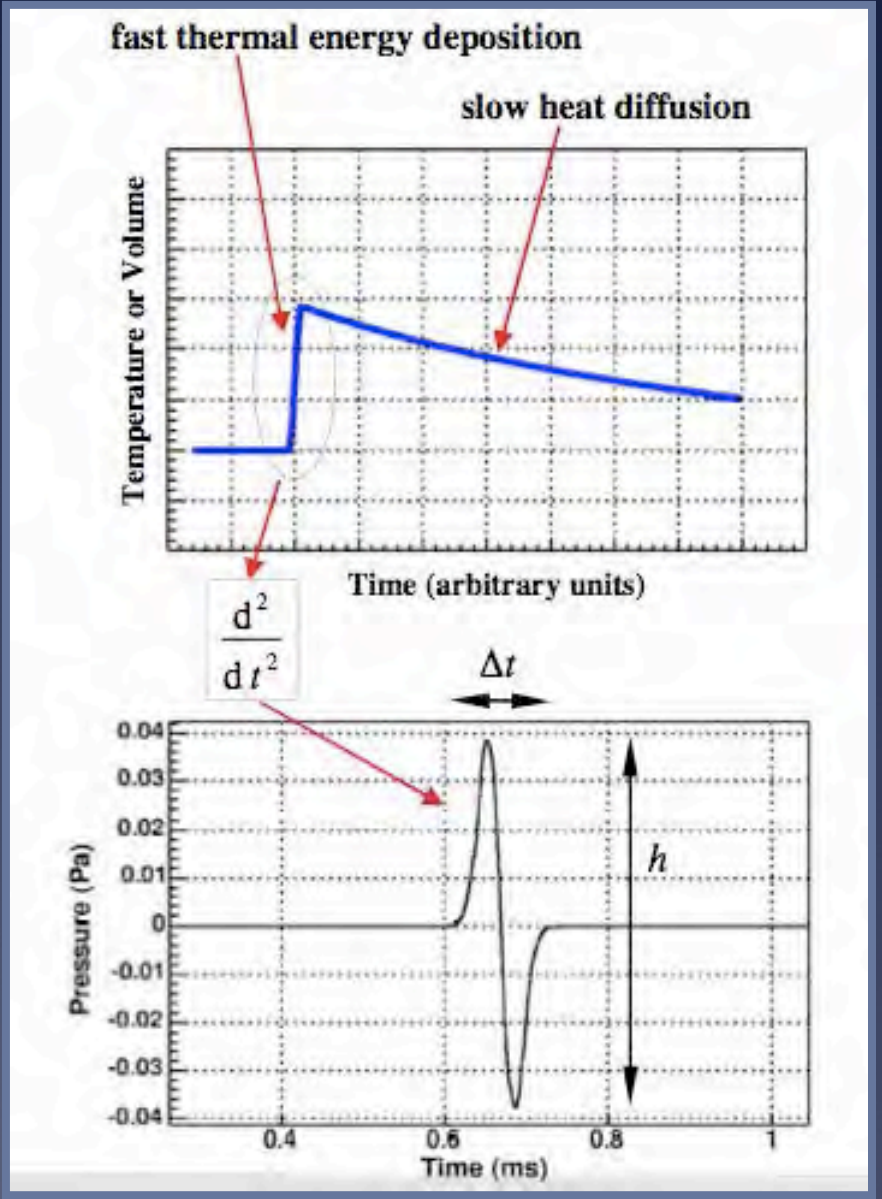
[acoustic pulse] characteristics

- h is proportional to β/C_p where:

  β =coefficient of thermal expansivity (O(10^{-4} K^{-1} for water)

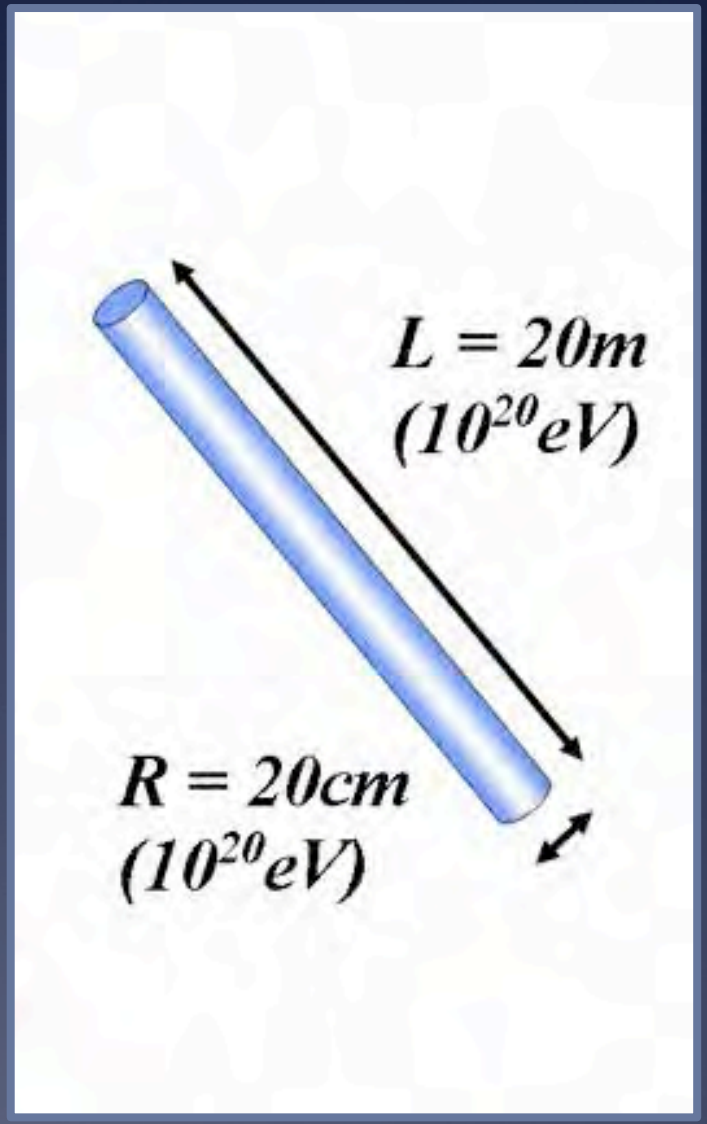
  C_p is the specific heat capacity (3.8×10^3 J kg^{-1} K^{-1} for water)
- Δt is proportional to transverse shower size





[acoustic pulse] production

- for $E_\nu = 10^{20}$eV 95% of the cascade energy is contained within a cylinder of length 20m and radius 20cm
- the energy deposition can be considered as a continuous distribution of individual heating centres
- radiation is emitted coherently along the cascade axis leading to a confinement of the signal to a narrow pancake due to a superposition of wavelets
- analogous to light diffraction through a slit

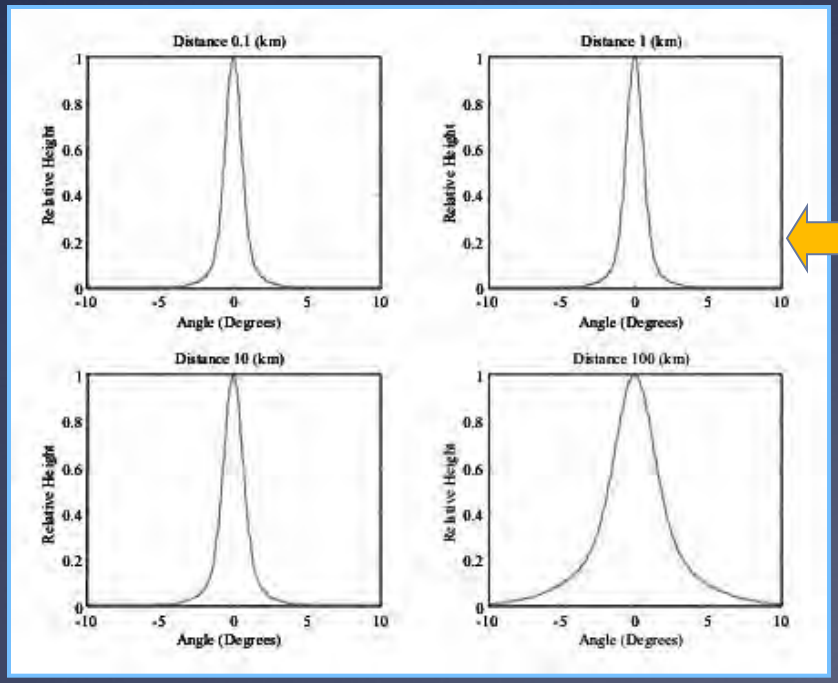


[acoustic pulse] features

- typical cylindrical volume over which the hadronic energy is deposited is ~20m long by a few centimetres wide (95% of energy at 10^{20}eV)
- the energy deposition is instantaneous with respect to the signal propagation
- hence the acoustic signal propagates in a narrow "pancake" perpendicular to the shower direction in analogy with light diffraction through a slit

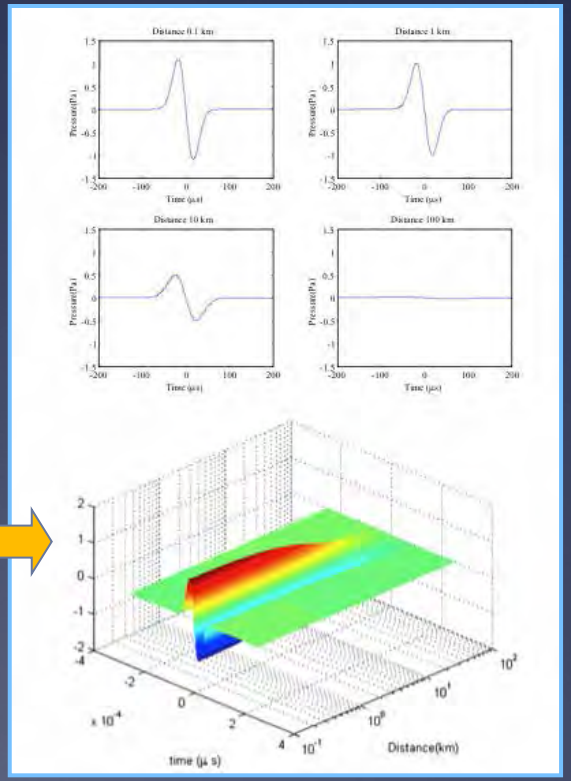
[acoustic pulse] attenuation

- the acoustic signal detected at the hydrophone is modified by 3 factors:
  1. geometric (1/r) attenuation,
  2. angular spread using parametrisations of the modelled spread (using Fraunhofer diffraction theory) fit to 2 Gaussians (hydrophones more than 5 degrees out of the pancake plane are not considered)
  3. attenuation due to the medium - again from studying the acoustic signal as a function of the distance from the source and the water properties. Performed on matched filter output



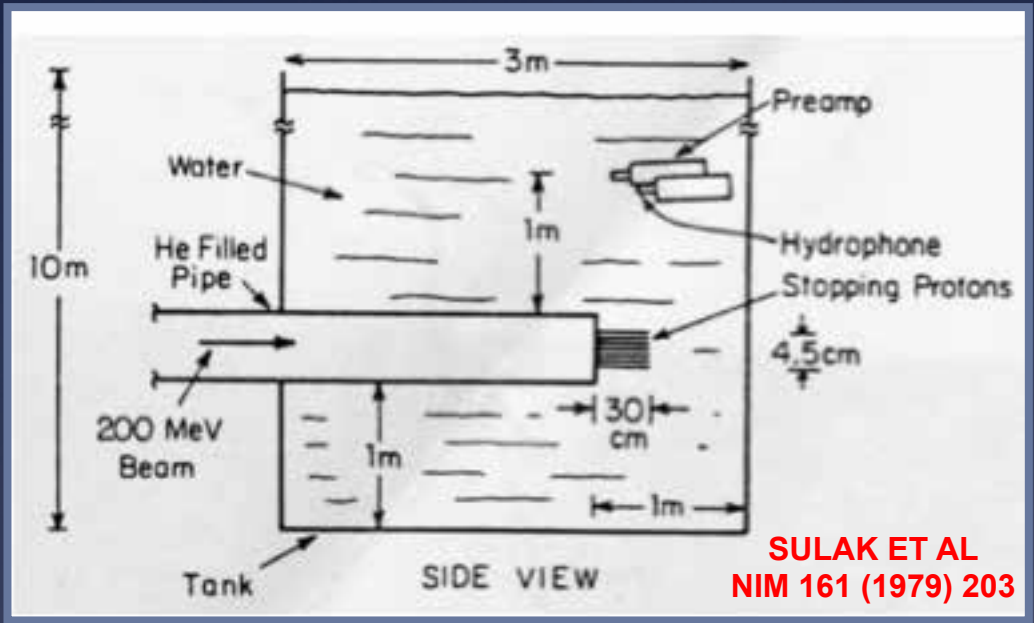
Angular spread

Medium losses

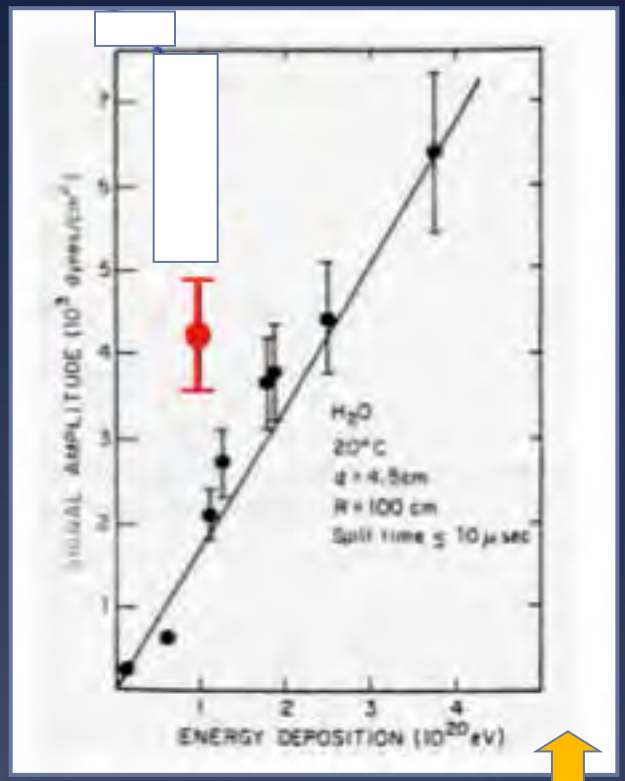


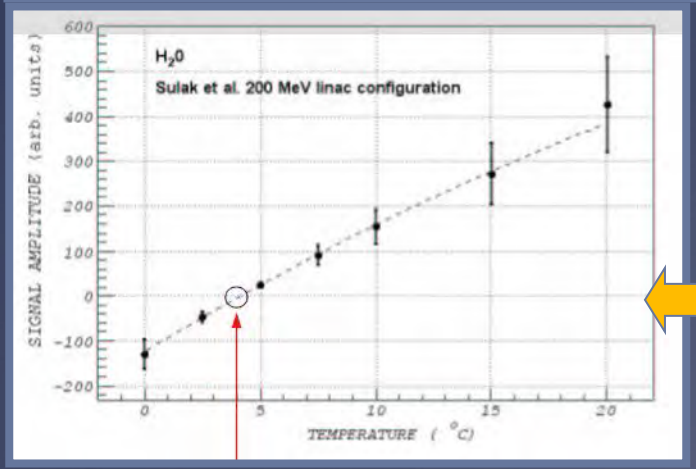
test beam experiments

- results from test beam experiments in late 1970's confirming bi-polar acoustic pulse in a test beam



SULAK ET AL
NIM 161 (1979) 203





- signal amplitude vs. energy deposition along with our prediction from first principle studies
- pressure proportional to Energy - **coherence**
- Signal amplitude vs. water temperature - warmer is better!
- P proportional to β(T) - **thermo-acoustic origin**

[acoustic detection] concept

- neutrino interacts in water/ice causing microscopic expansion
- as a consequence a detectable acoustic signal is produced

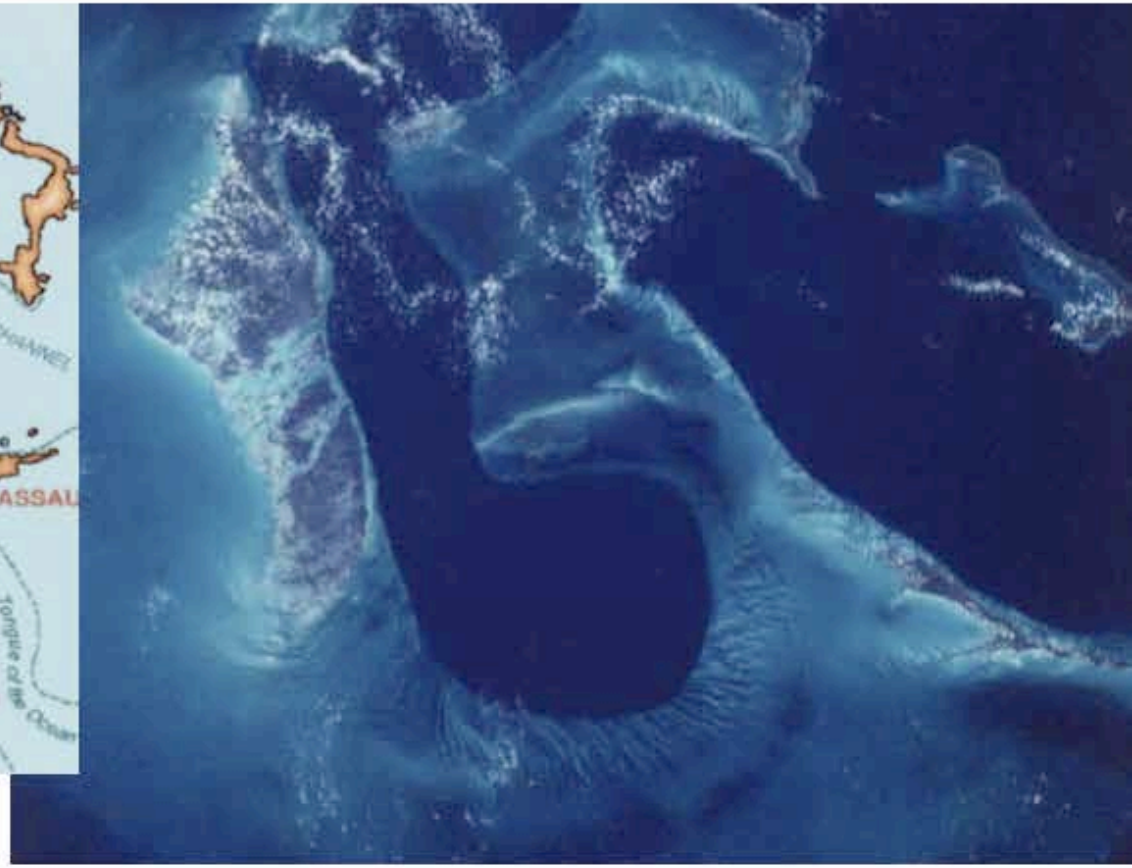
[acoustic detection] projects around the world

- Work done on either existing military arrays or in conjunction with Cerenkov **telescope** deployments

SAUND


NORTH
PACIFIC
OCEAN
UNITED
STATES
NORTH ATLANTIC
OCEAN
Gulf of
Mexico
MEXICO
CUBA
DOMINICAN
REPUBLIC
HAITI
BELIZE
HONDURAS
GUATEMALA
EL SALVADOR
NICARAGUA
Caribbean
Sea
COSTA
RICA
PANAMA
TRINIDAD
and TOBAGO
GUYANA
SURINAME
VENEZUELA
COLOMBIA
Equator
PERU
BRAZIL

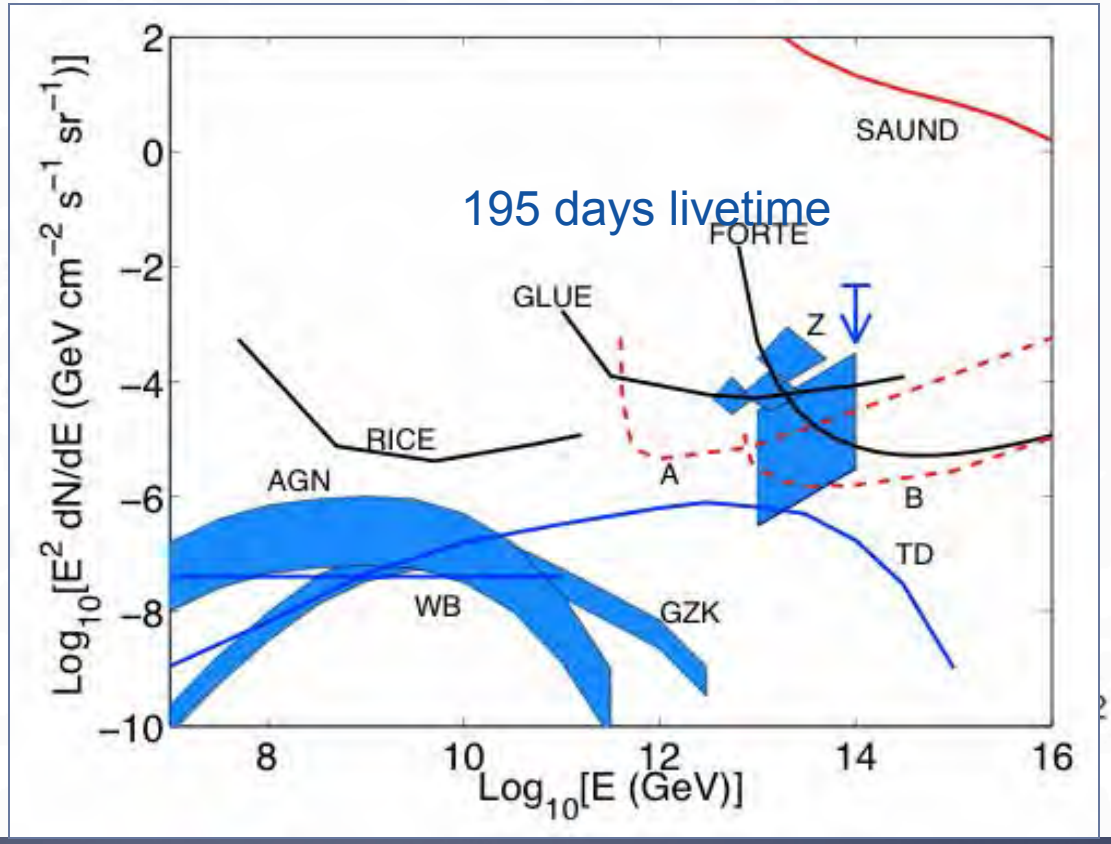
SAUND and AUTEC



History of SAUND

SAUND II based on....
Feasibility and Sensitivity Study
N.G. Lehtinen et al., Astroparticle Physics 17 (2002) 279-292
SAUND I Experiment
J. Vandenbroucke et al., Astrophysical Journal 621 (2005) 301-312

7 hydrophones were used at the same site but with different hydrophones and cables

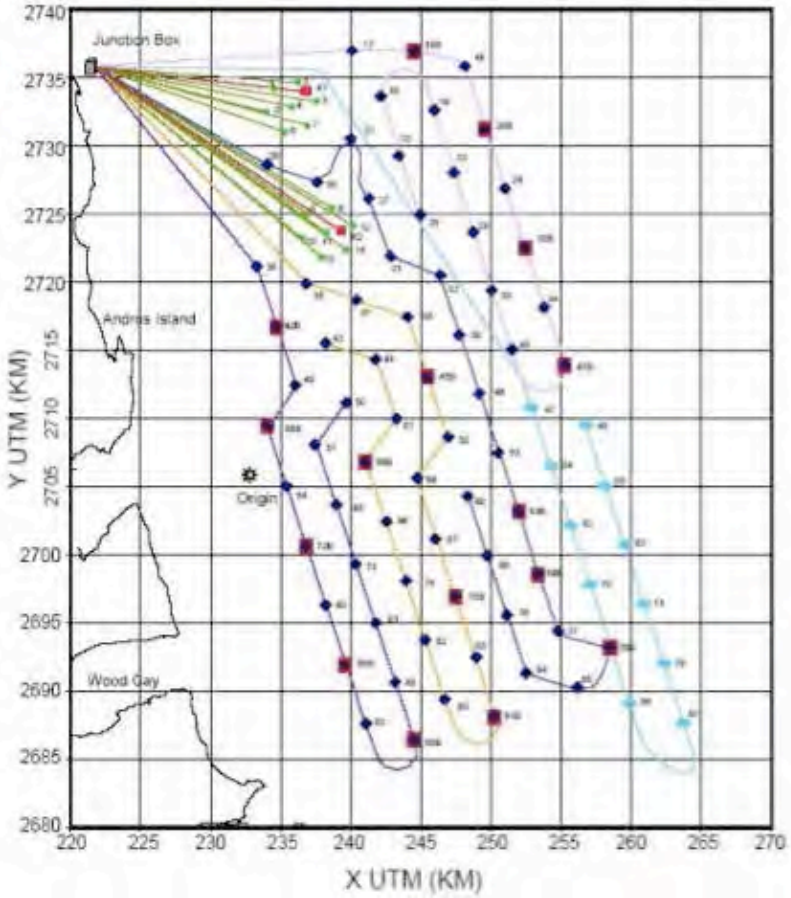


SAUND II Schematics

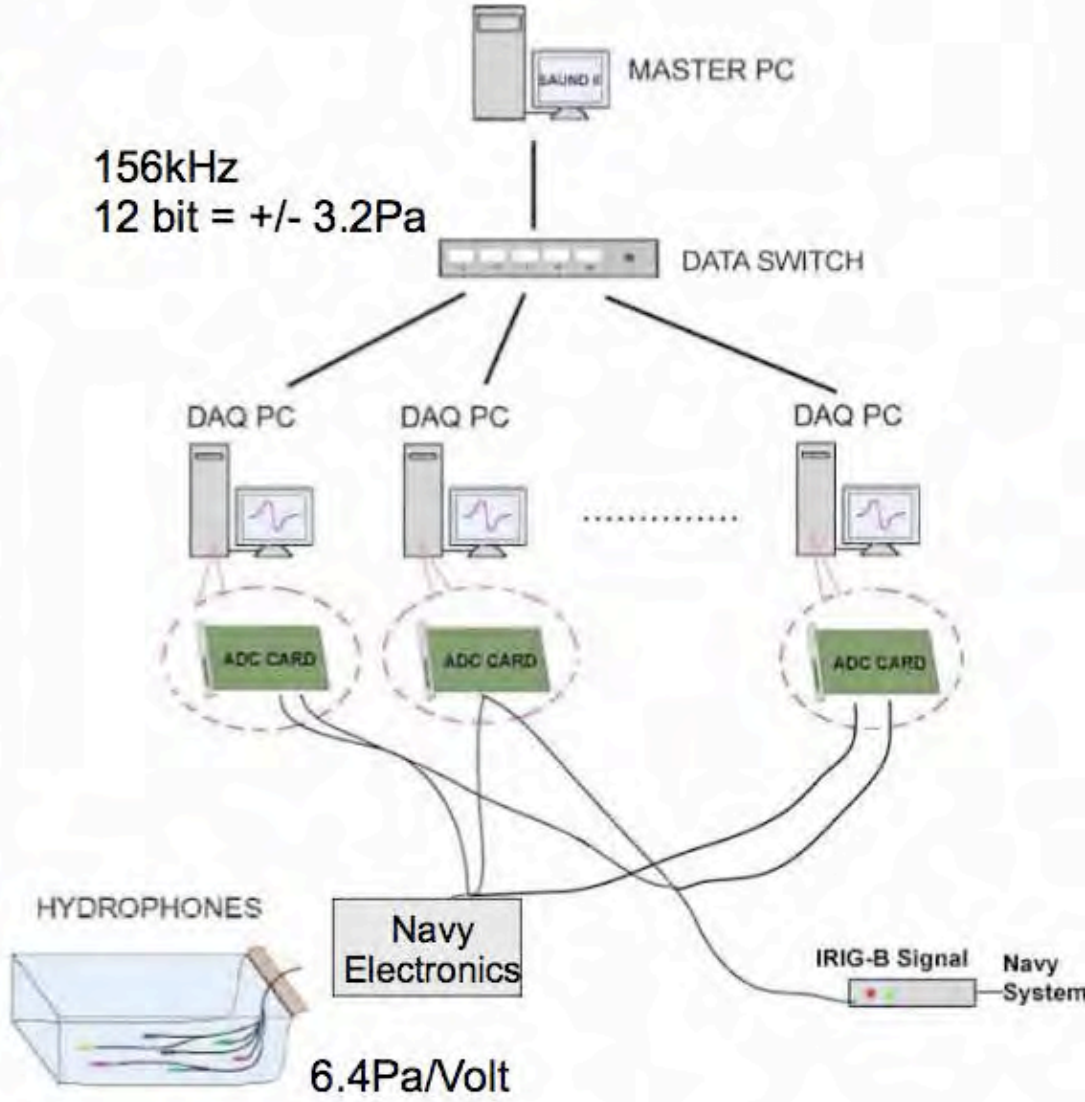
49 Uni-directional Hydrophone readout
20 x 50 km array

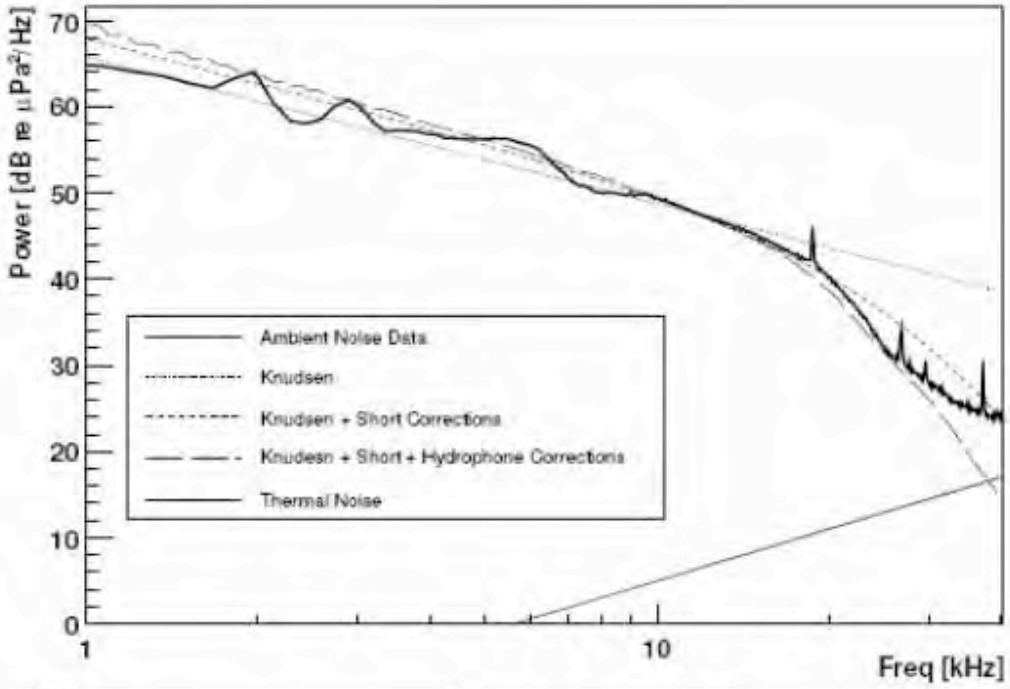
AUTEC HYDROPHONE REPLACEMENT PROGRAM

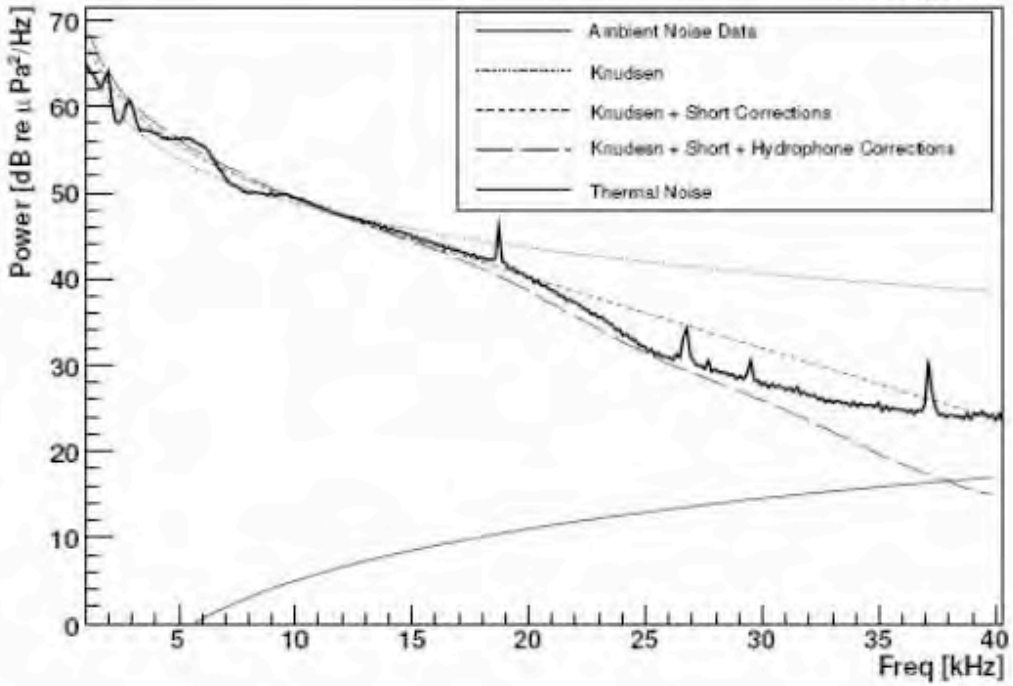
AHRP STRING CONFIGURATION



156kHz
12 bit = +/- 3.2Pa







Results

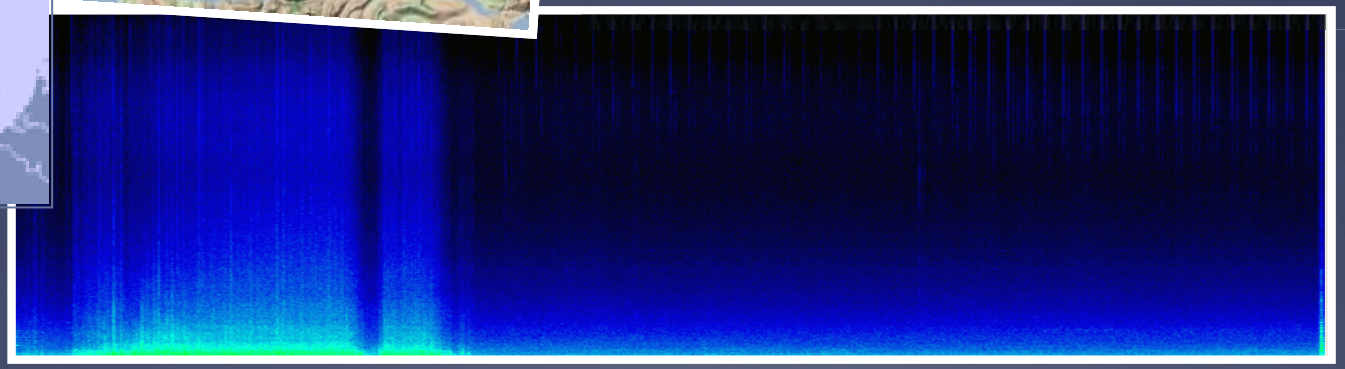
$$J_0(a,h) =$$

$$2\pi J_\infty \int_0^{\pi/-} \cos^{n-1}\theta e^{-ah\sec\theta} g(\theta, f)\sin\theta d\theta$$

Introduce new term
g is the response function of the hydrophone
- not perfectly omnidirectional
- freq response not perferctly flat

Kurahashi and Gratta
arXiv:0712.1833v1 [physics.ao-ph]
Submitted to JASA, Dec 2007

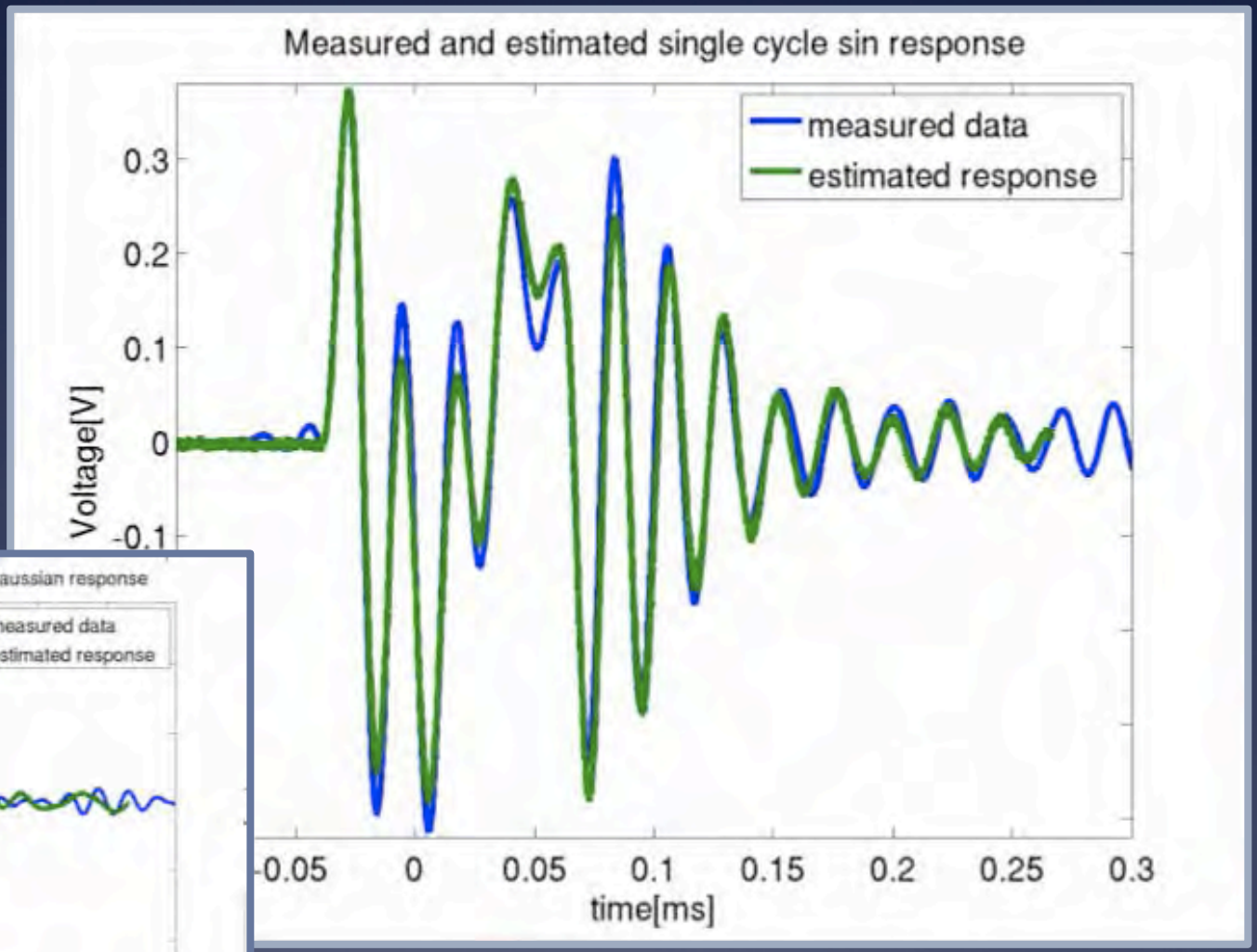
ACORNE

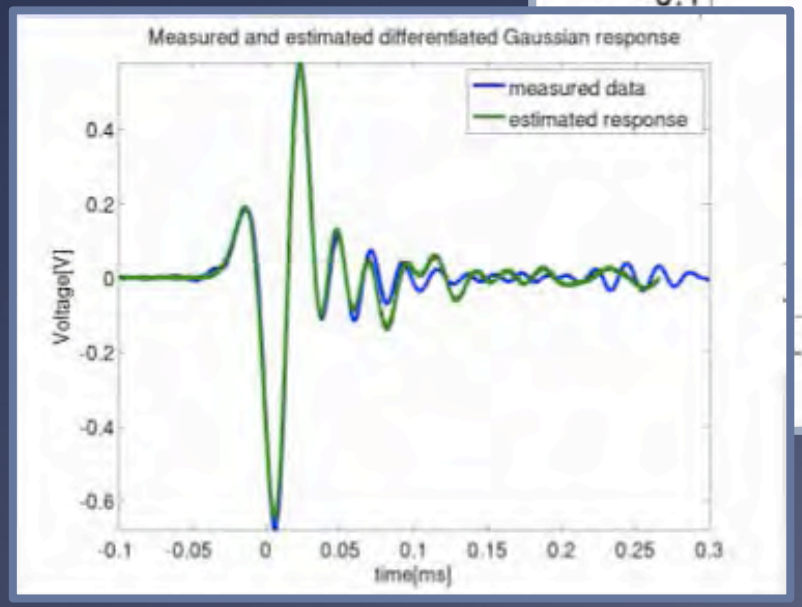


Acoustic **Co**smic **R**ay **N**eutrino **E**xperiment

- Ranging hydrophone array in North West Scotland
- Existing hydrophone array
- Omni-directional hydrophones
- All (unfiltered) data to shore
- Control over DAQ
- No Remote access
- Large dataset available

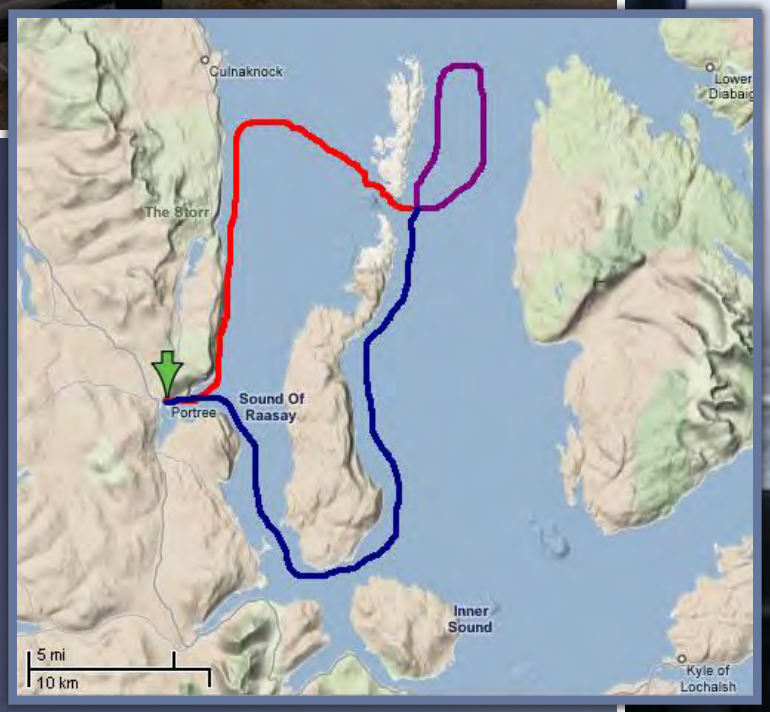
[ACORNE] hydrophone response



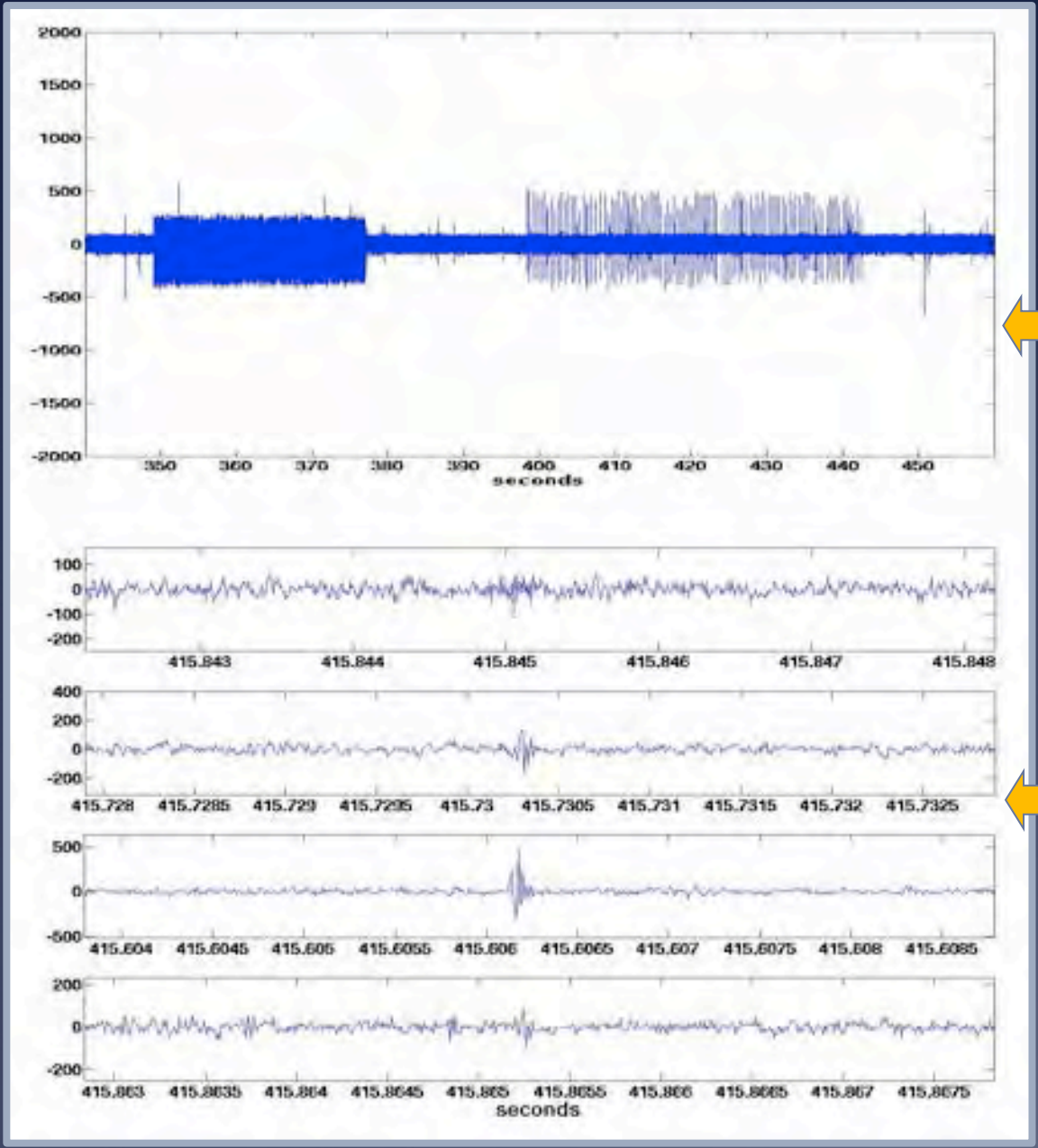


[ACORNE] Rona Field Trips 2007/08

- In August 2007 and September 2008 we injected a number of different pulse types and amplitudes directly above the Rona hydrophone array



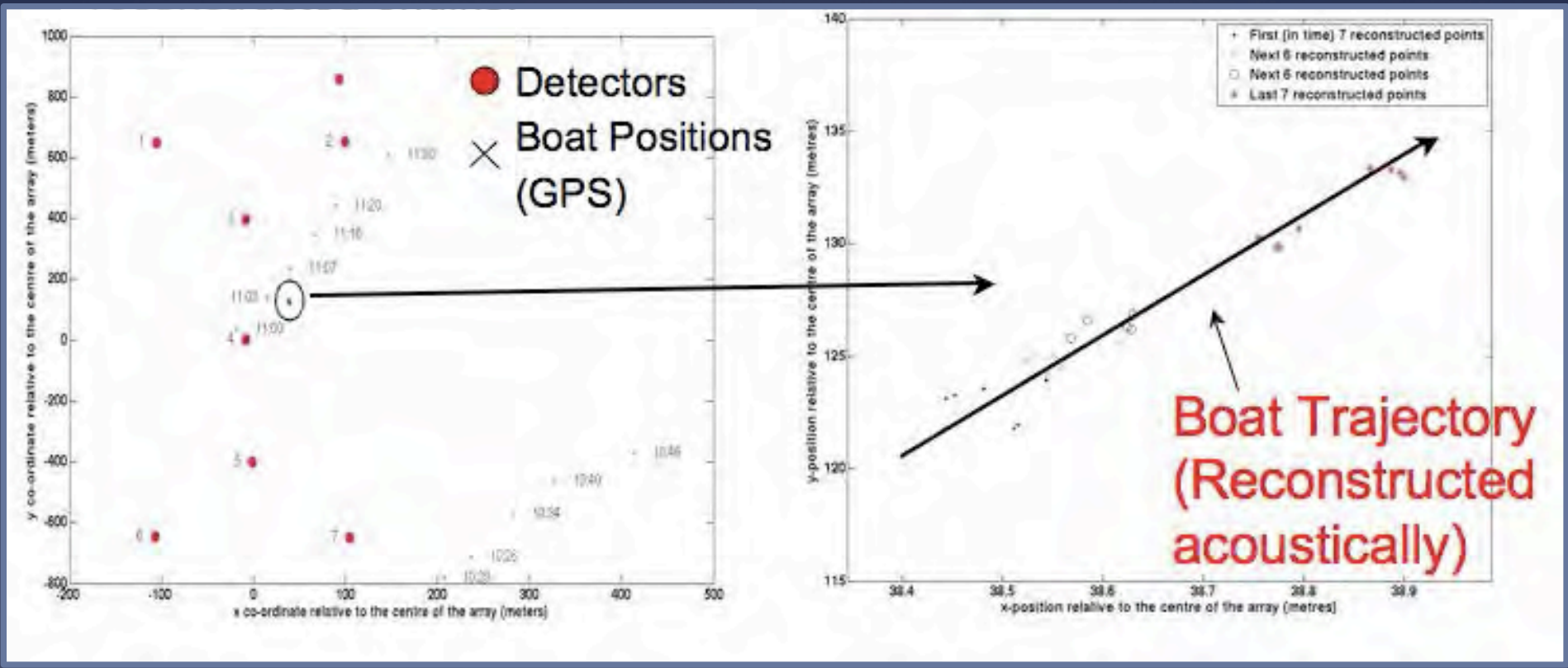
[ACORNE] pulse detection



- Raw data from one hydrophone showing 2 periods of pulse injection
- Zoom in on one of the injected pulses on the four nearest receiving hydrophones
- 25% of injected pulses oberved

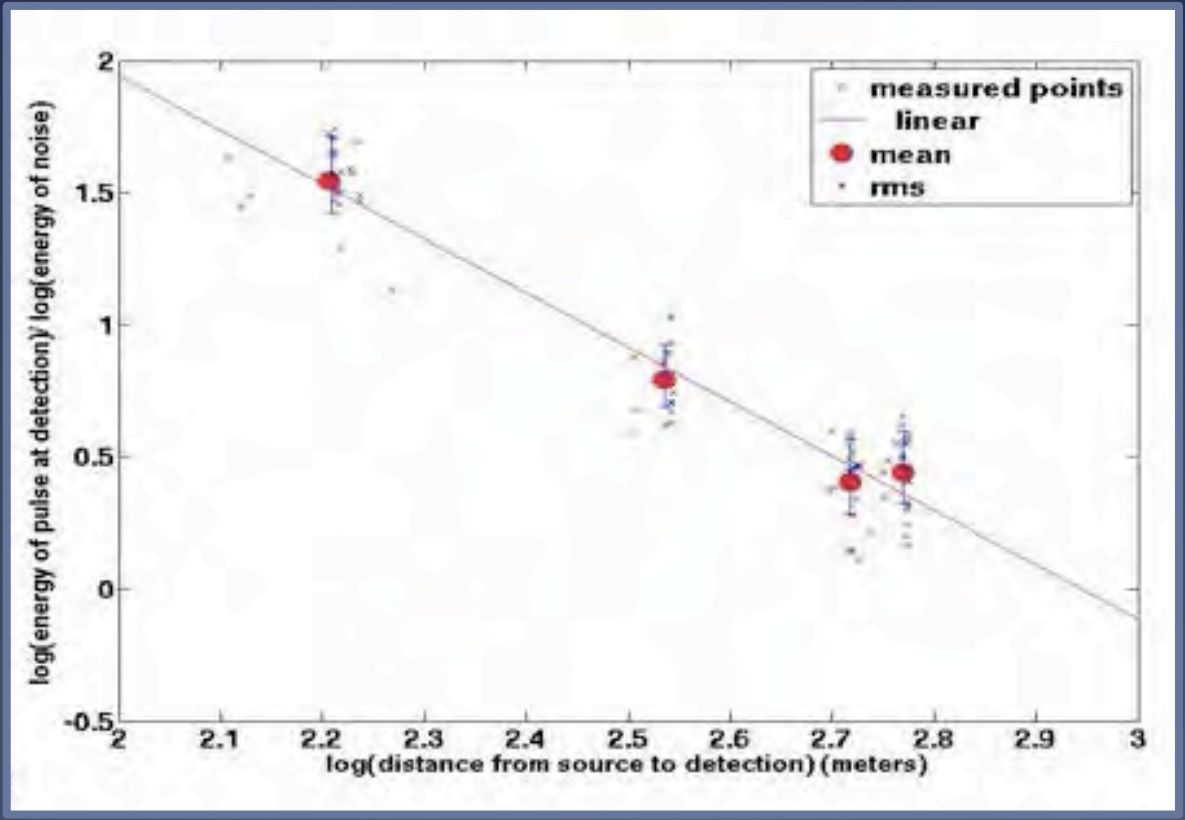
[ACORNE] boat trajectory

- Using the known hydrophone positions and time of arrival of the pulse on each hydrophone the origin of the pulse could be reconstructed (required 4 or more hydrophones to see the pulse)
- The boat and drift were successfully reconstructed when compared against available GPS data



[ACORNE] energy fall-off

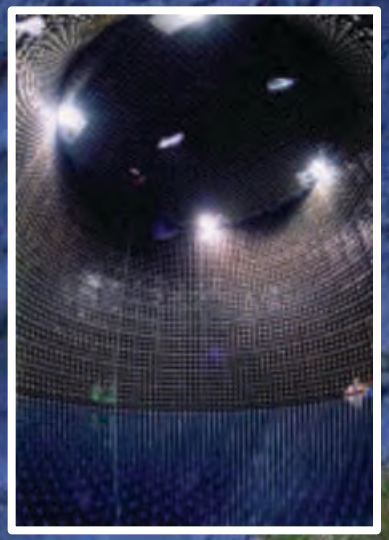
- As another "sanity check" the energy of the reconstructed pulses was plotted as a function of distance to confirm, or otherwise a $1/r^2$ dependence
- Fitted straight line to data gives a gradient of -2.10 ± 0.23



conclusions

- neutrinos are one of the fundamental building blocks of nature
- study of low energy neutrinos has yielded exciting information about the properties of neutrinos
- detecting high energy neutrinos help us to 'look' at the Universe in new ways
- neutrinos rarely interact necessitating huge detectors
- the acoustic detection of neutrinos is still relatively new but is a powerful technique in the hunt for these elusive cosmic particles
- the experimental techniques used lead to great scope and potential for interdisciplinarity with other interests

[multi-disciplinarity] I



295 km

Kamioka

Tokai

[multi-disciplinarity] II

COMMENT

SPACE Curbing Chinese space activity undermines US interests p.444 | BRAIN Conspiracies, religions, coincidences, ghosts and patterns p.446 | HEALTH The rise in height and lifespan during the industrial revolution p.448 | MUSEUM Monaco exhibition showcases marine marvels p.449

H. NEW/REUTERS

The wave that hit Miyako City on Japan's east coast during the 11 March tsunami caught researchers by surprise.

Hidden depths

A staggering lack of undersea data hampers our understanding of earthquakes and tsunamis. Geophysicists must put more instruments offshore, says **Andrew V. Newman**.

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- "But underwater monitoring lags behind"
- "This needs to change. We must improve undersea monitoring and make it cheaper, increasing measurements of the sea floor 100-fold."
- "Geophysicists should be working with government and intergovernmental agencies to develop and test cheaper technologies for tracking continuous, long-term sea-floor strain accumulation. Autonomous systems that can run without human intervention will be much cheaper in the long run. "