Deep-sea neutrino telescopes: oportunities for Earh and Sea Siences

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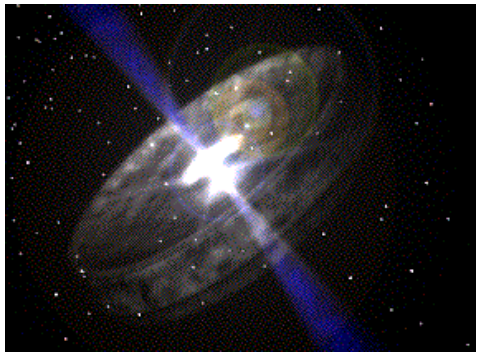
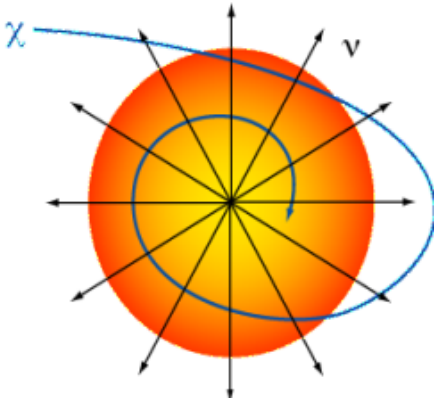
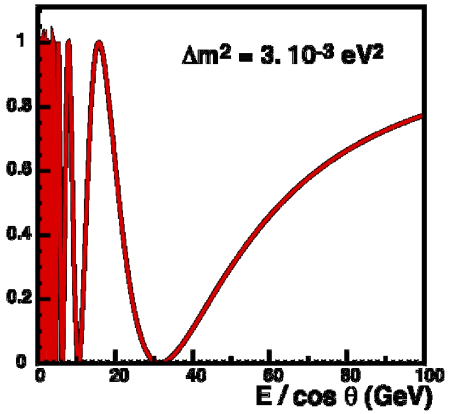
Neutrino telescopes: science scope







High Energy	Medium Energy	Low Energy
E_ν > 1 TeV	10 GeV < E_ν < 1 TeV	10 GeV < E_ν < 100 GeV

ν from extra-terrestrial sources

Origin and production mechanism of HE CR

↓

Primary goal

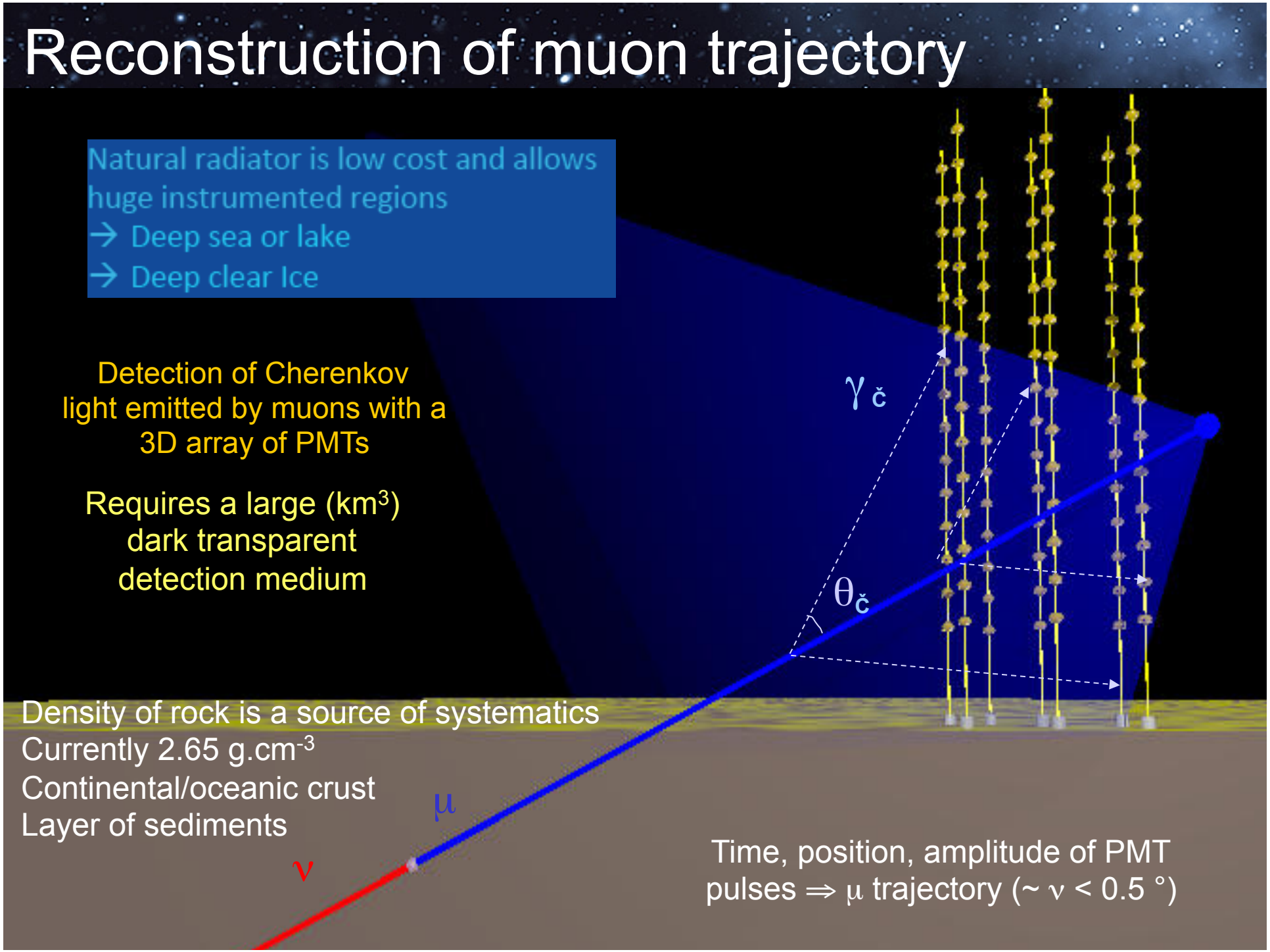
Dark matter search

ν oscillations

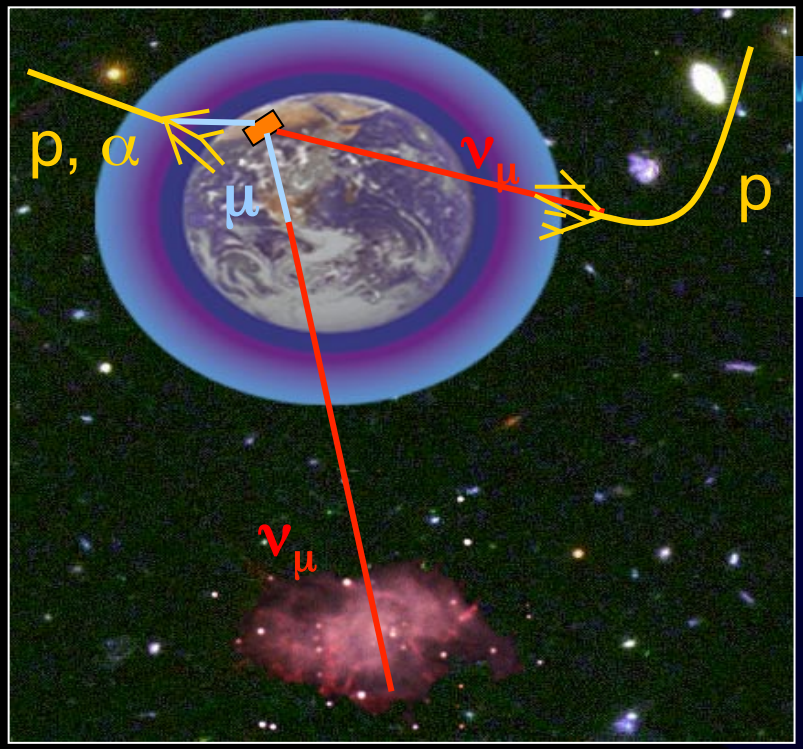
Exotic particle physics
Monopoles, nuclearites,…

Marine & Earth sciences: oceanography, biology, geology…

Reconstruction of muon trajectory



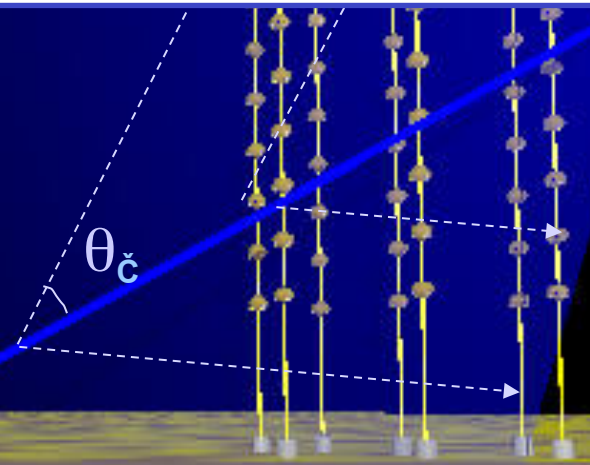
Reconstruction of muon trajectory



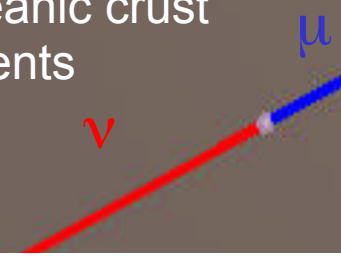
Physical backgrounds:

- ❖ atmospheric neutrinos (irreducible…)
- ❖ atmospheric muons (only down-going)

detectors buried deep
detectors look “downwards”



Density of rock is a source of systematics
Currently 2.65 g.cm^{-3}
Continental/oceanic crust
Layer of sediments

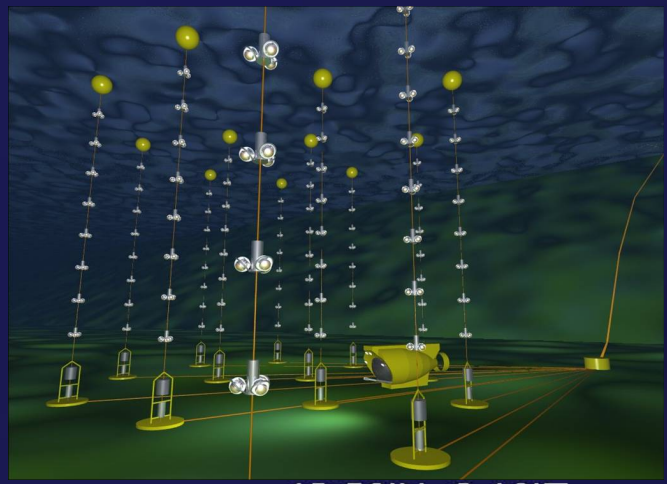


Time, position, amplitude of PMT pulses ⇒ μ trajectory (~ ν < 0.5 °)

Toulon

M.Pacha

Antares



Electro-optical
Cable of
40 km

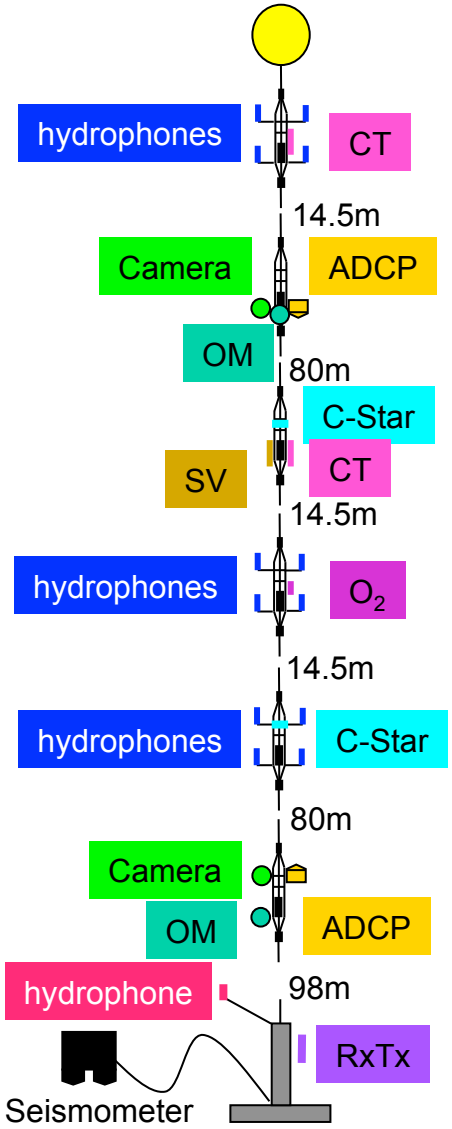
42 50'N, 6 10'E

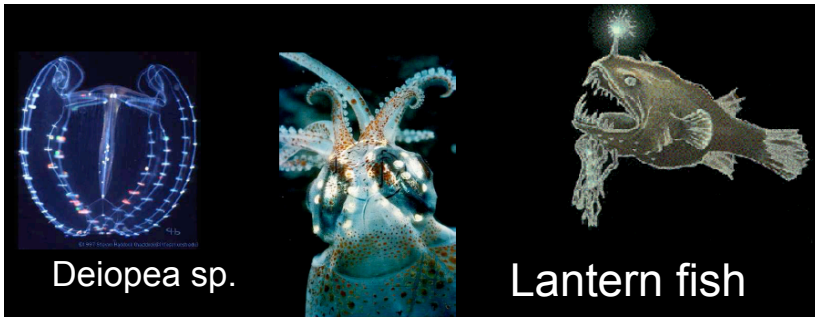
Google

© 2008 Cnes/Spot Image
Image © 2008 DigitalGlobe
Image NASA

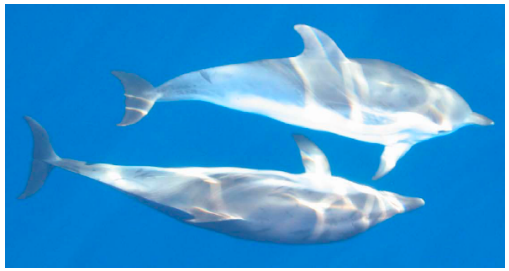
Sea science and Earthquakes

Instrumentation Line



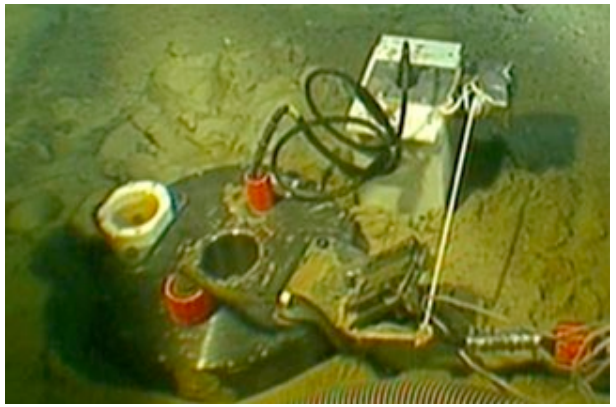


Acoustic noises



http://listentothedeep.org/

seismometer

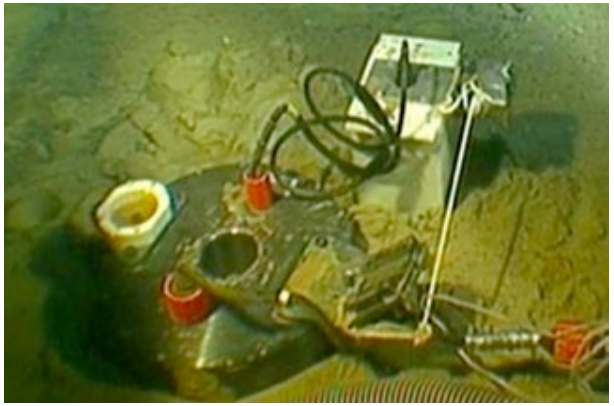


Video-monitoring

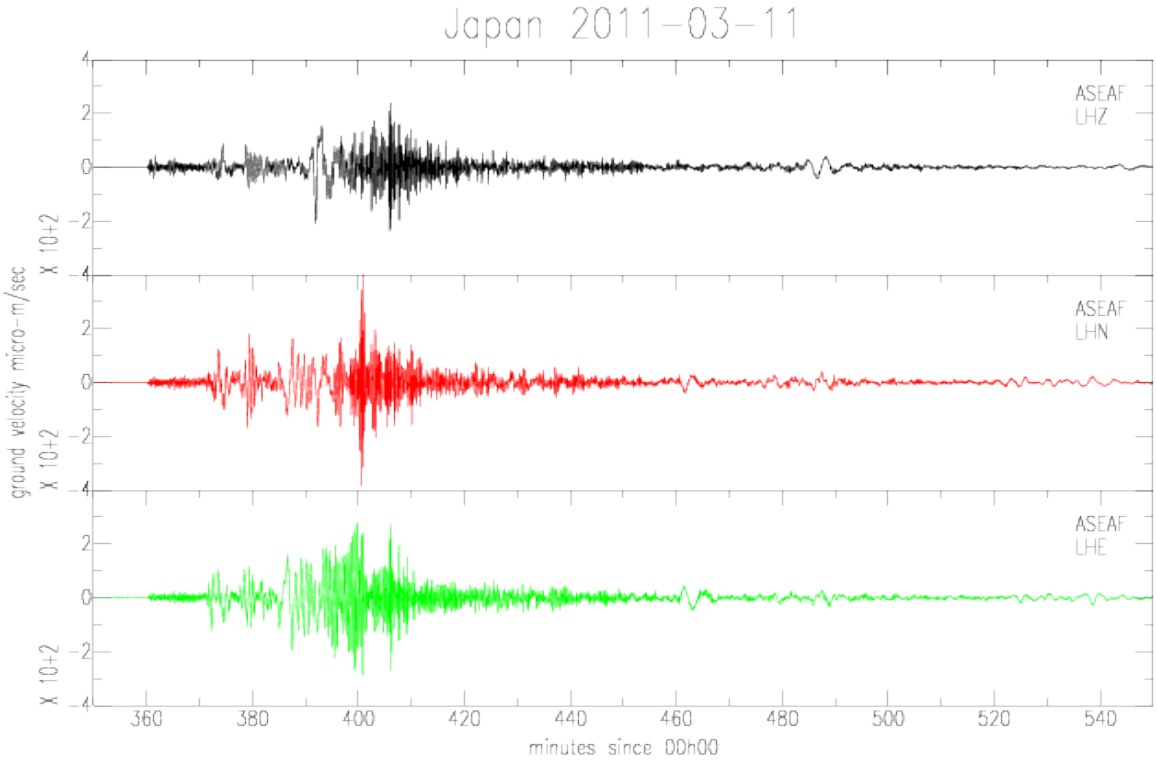
ANTARES is a multidisciplinary observatory

A tragic exemple

Seismometer



Real time monitoring



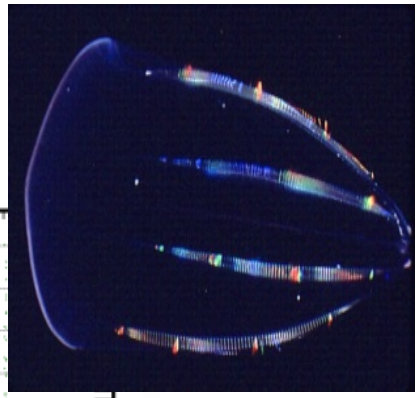
Antares e-log

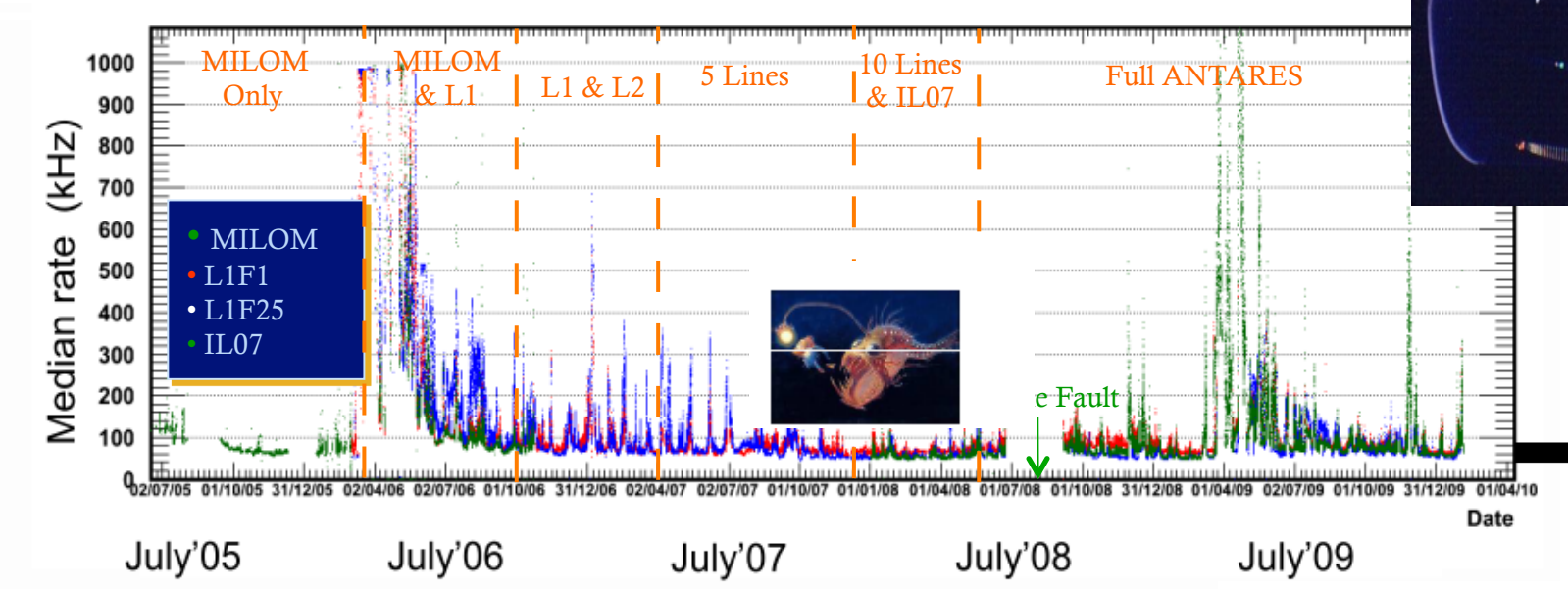
“Japon earthquake offshore of Myiagi Mw 8.9 11/03/2011 05h46UTC

The earthquake took place off shore. The location and the focal solution show that it is related to the subduction zone of the Pacific plate beneath Japon. The generation of a large tsunami is confirmed.”

Optical background

Deep water formation (cold winter) +
Instabilities of local currents due to
surface water



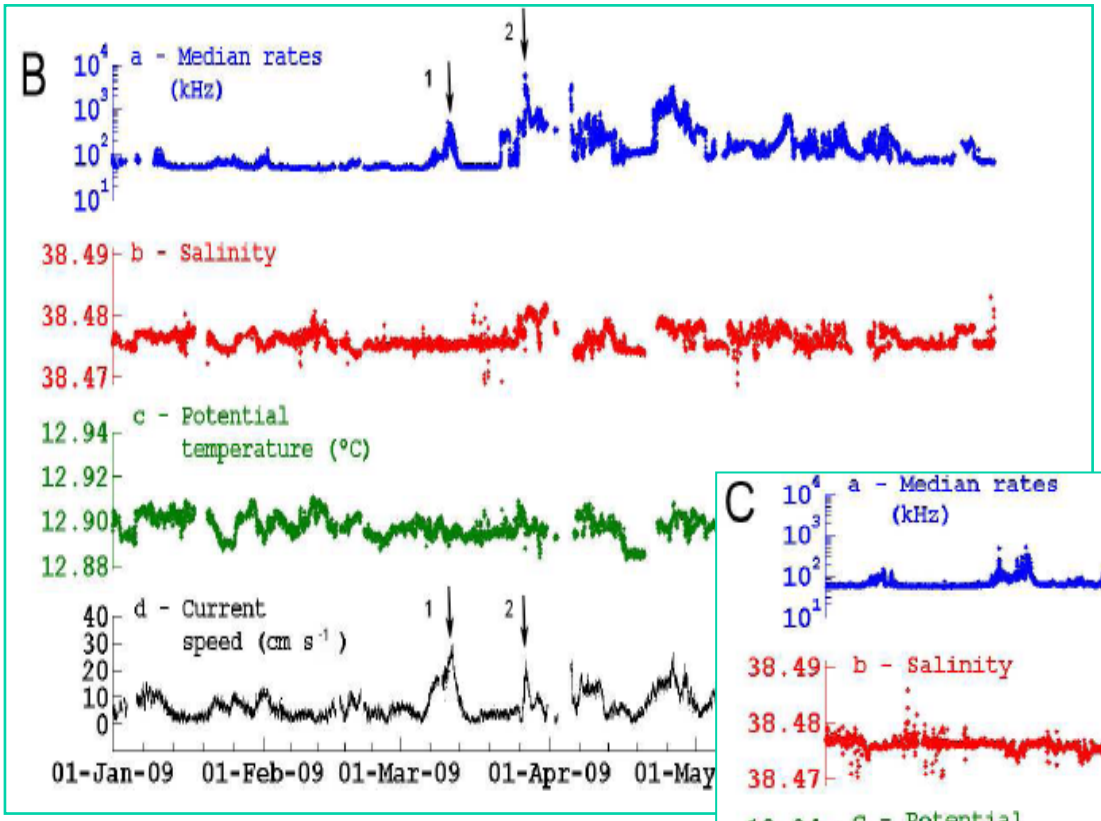


Optical background :

- radioactivity β ^{40}K (35 ±7 kHz)
- bioluminescence :
  - bacteria (continuum)
  - from protista to vertebra (flashs)

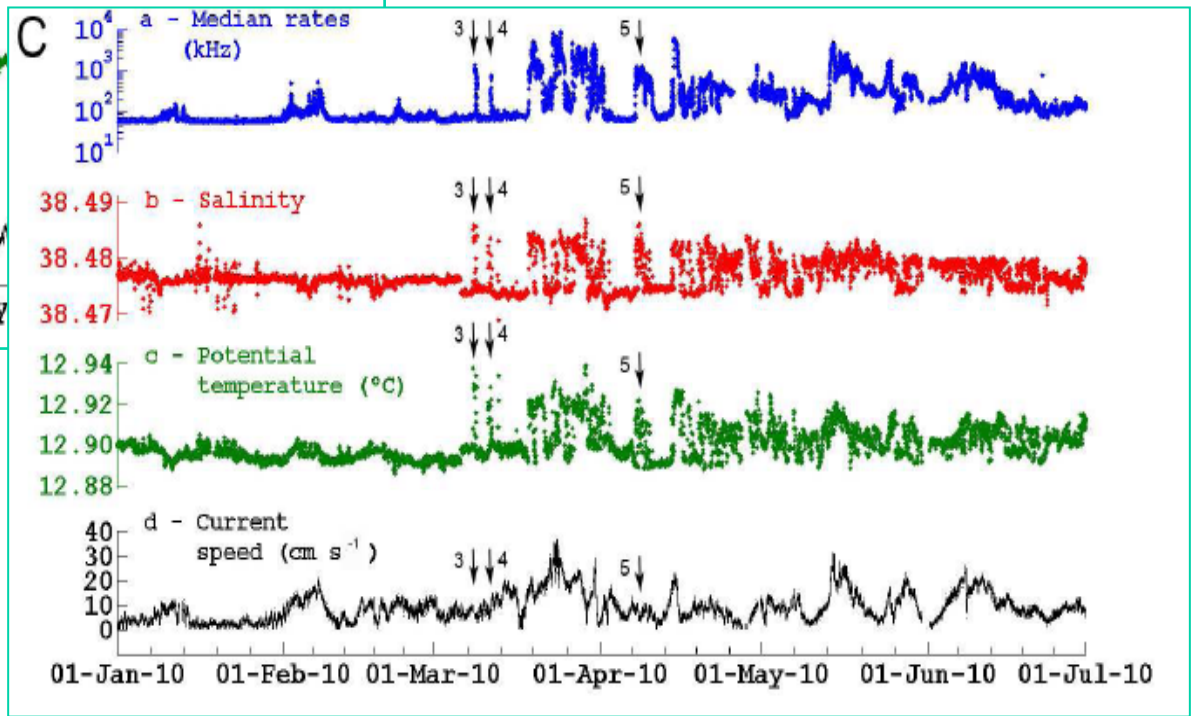
Examples of Correlation studies

2009 : bioluminescence & Sea current

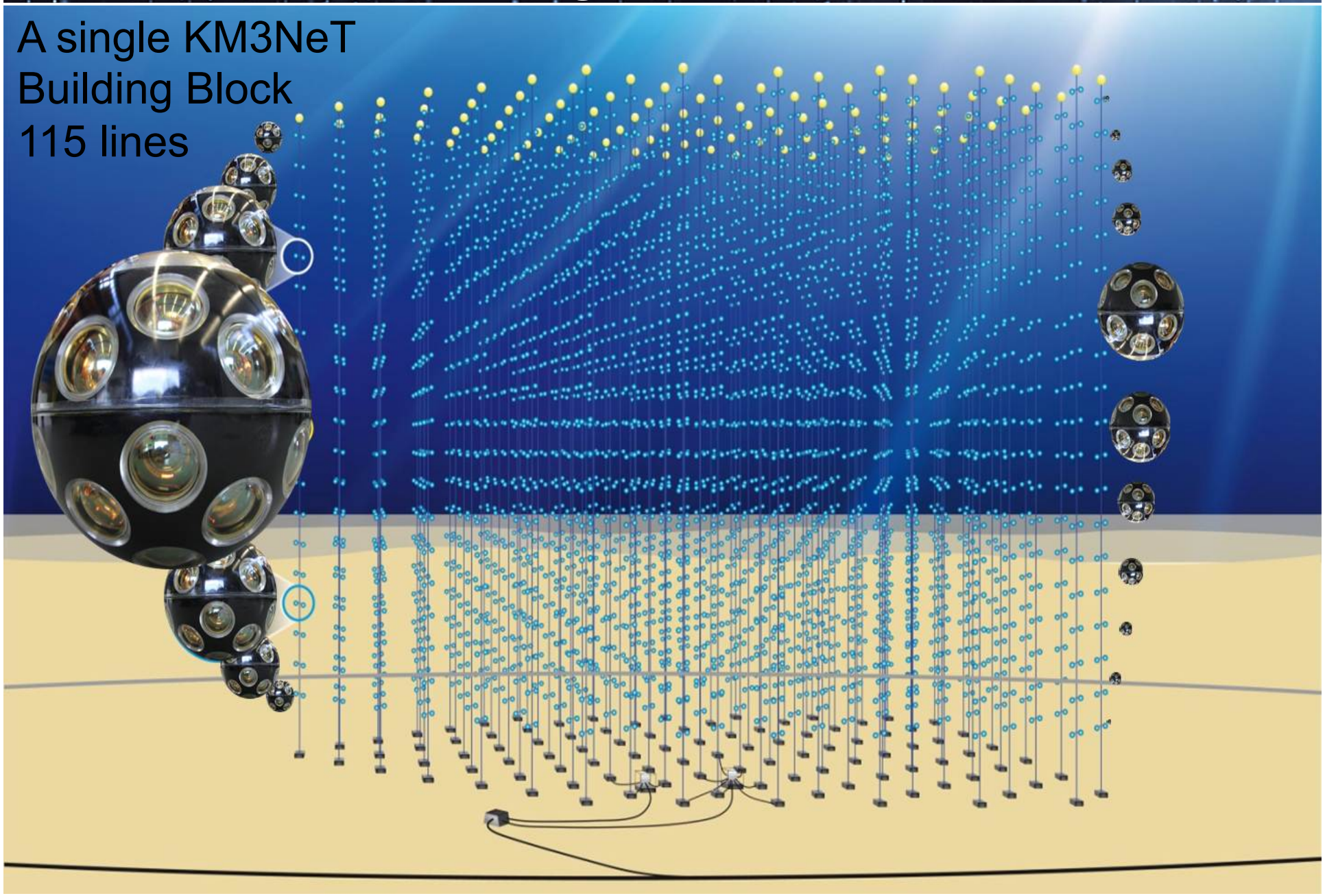


📖 C. Tamburini et al., PLoS ONE 8(7) 2013
📖 H. van Haren et al., Ocean Dynamics, April 2014, Volume 64, Issue 4, pp 507-517

2010 : bioluminescence & salinity & temperature

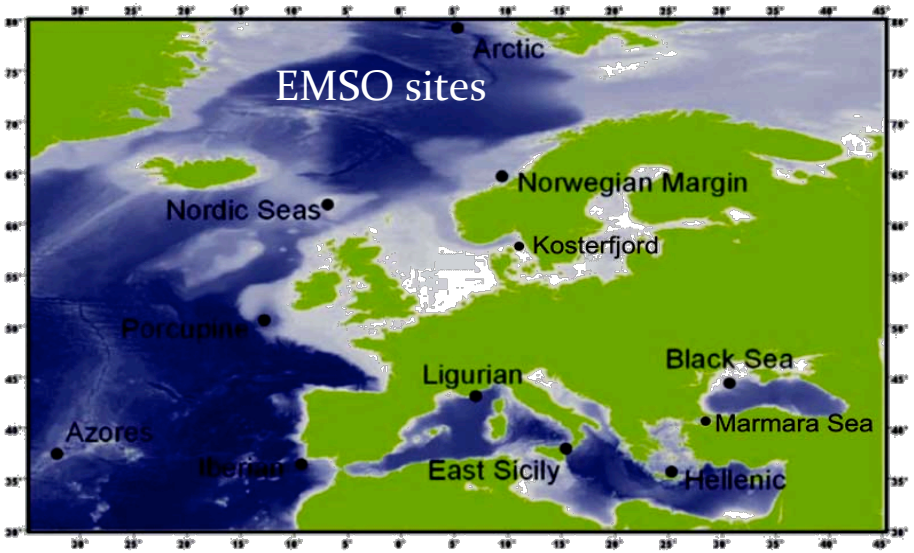


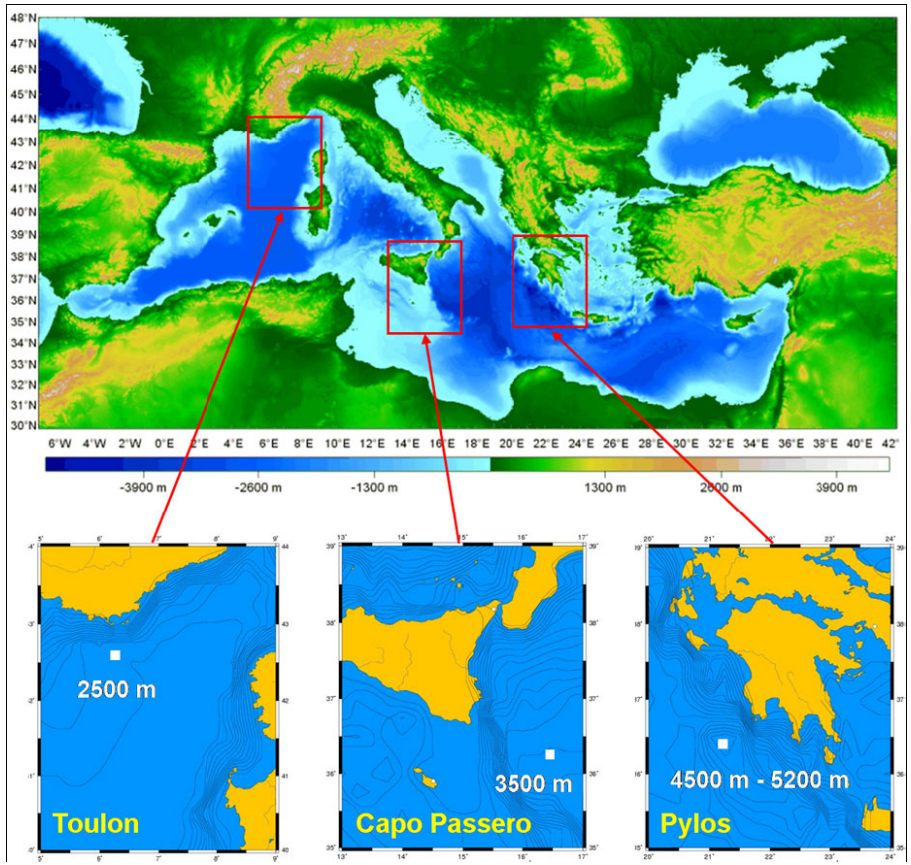
KM3NeT: the next generation telescope



A multi site detector

- Three sites
  - Toulon (France), 2500 m
  - Capo Passero (Italy), 3500 m
  - [Pylos (Greece), 4500-5200 m]
- Earth and Sea science requirements
  - Define the infrastructure needed to implement multidisciplinary science nodes





- EMSO is a ESFRI-PP project aiming at the construction of a European network of seafloor multidisciplinary observatories
- Mediterranean Sea sites and infrastructure technologies are of common interest

France responsible : M. Cannat (IPGP)

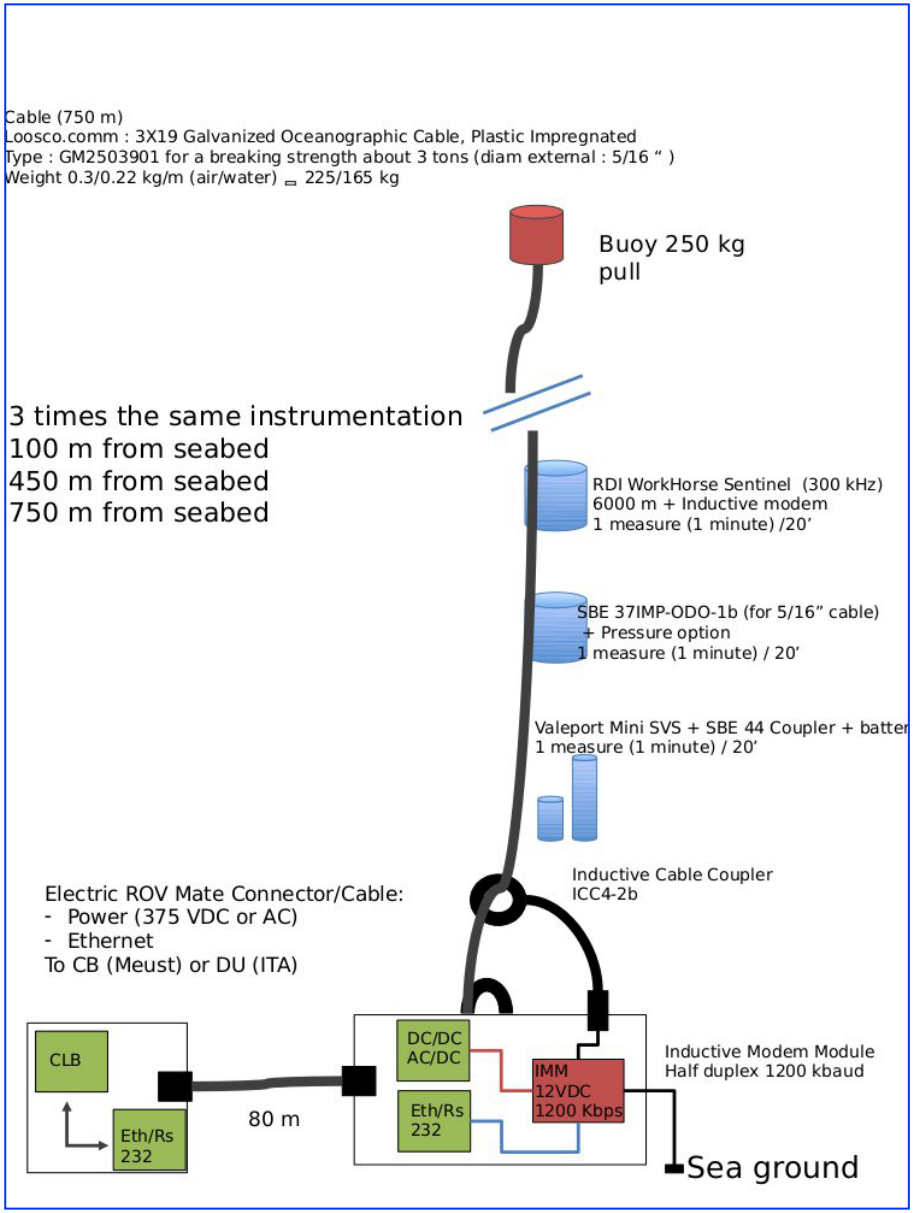
Calibration units

- **Calibration Units (CU):**

detector lines devoted to calibration

and associated sciences

1every 10 detection lines



- **Instrumentation Unit:**

inductive line (+ base) with environmental sensors (temperature, sea current…) and Calibration instruments

(laser, acoustic transducers…)

Anything else?

- **Calibration base (CB):**

Electronic interface

Junction box ←→ instrumentation base

Atmospheric muons/neutrinos and Earth science

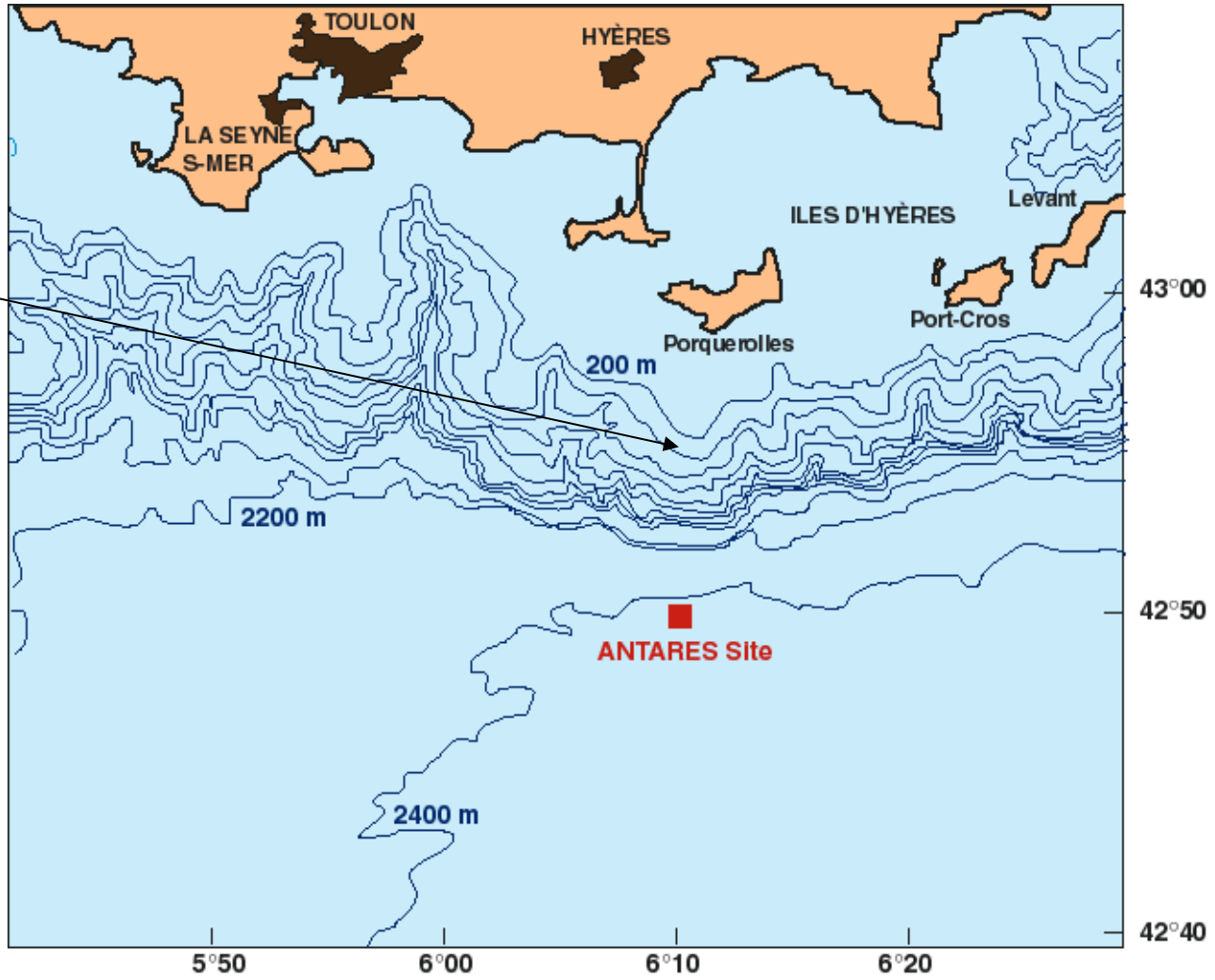
Muons from above: the shadow of the Continental Shelf

1. Is this visible by studying muons ?

2. Can we use to check the detector positioning ?

On going study at APC

Need inputs from specialists



Atmospheric muons/neutrinos and Earth science

ANTARES bathymetric area

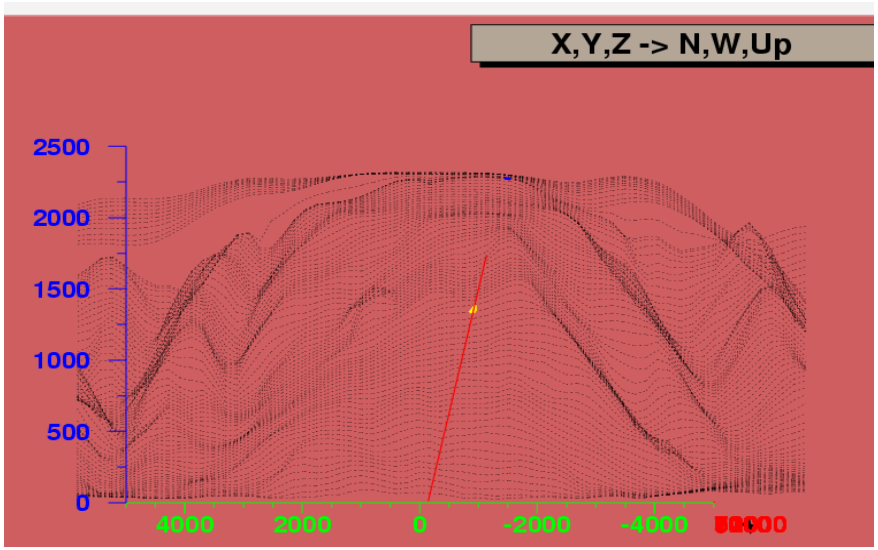
- Covered area

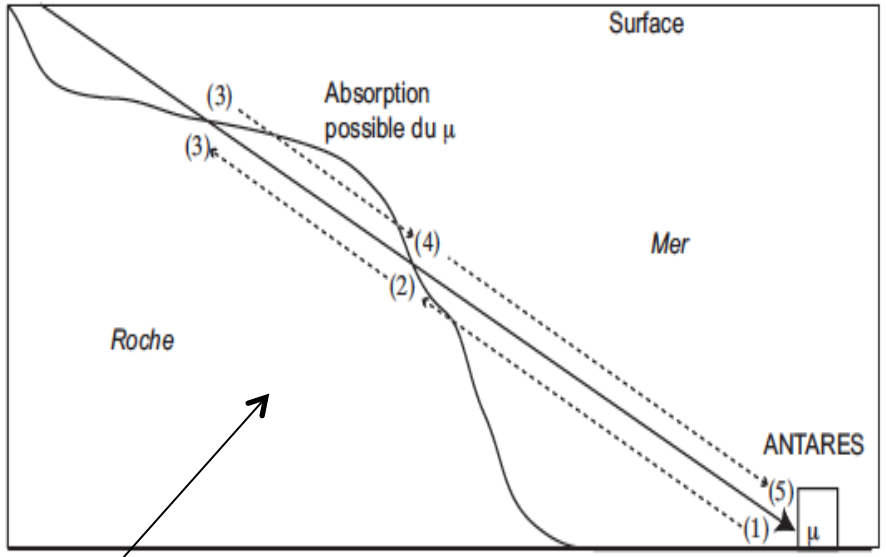
6.0°E-6.25°E / 42.833°N-43°N

- Format

longitude, latitude, depth ~100m x 100m

Relief data originated from SHOM
Restricted

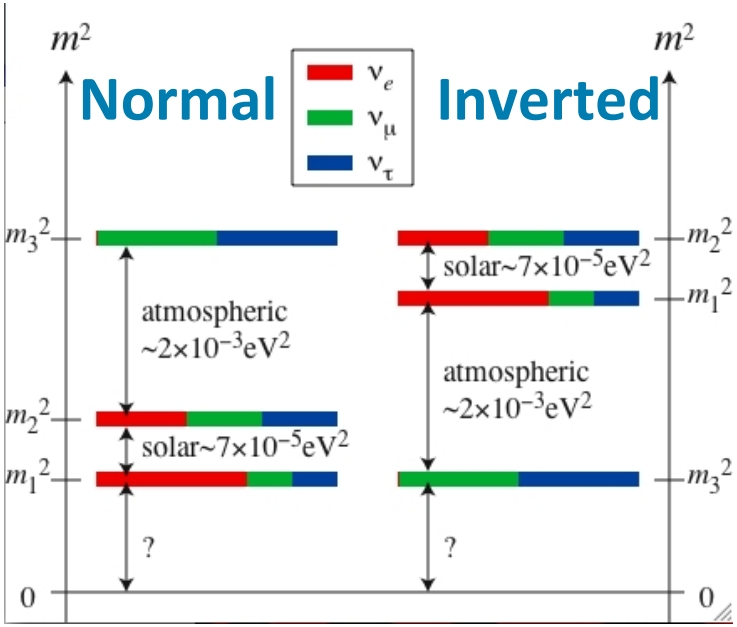




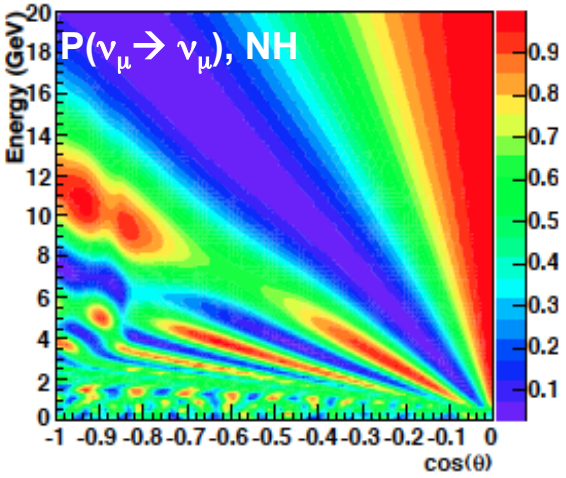
Density / composition of medium unknown?

Neutrinos from below: matter effects in neutrino oscillations

ORCA: a dense detector to measure the neutrino mass hierarchy with atmospheric neutrinos



- Free 'beam' of neutrinos:
  ν_e/anti ν_e, ν_μ/ anti ν_μ; broad range of baselines (50 → 1250 km) and energies (GeV → PeV)
- ν_e and ν_μ interact differently with matter (electrons)
- Different mass hierarchies (normal/inverted) provide different oscillogram patterns in (energy, zenith):



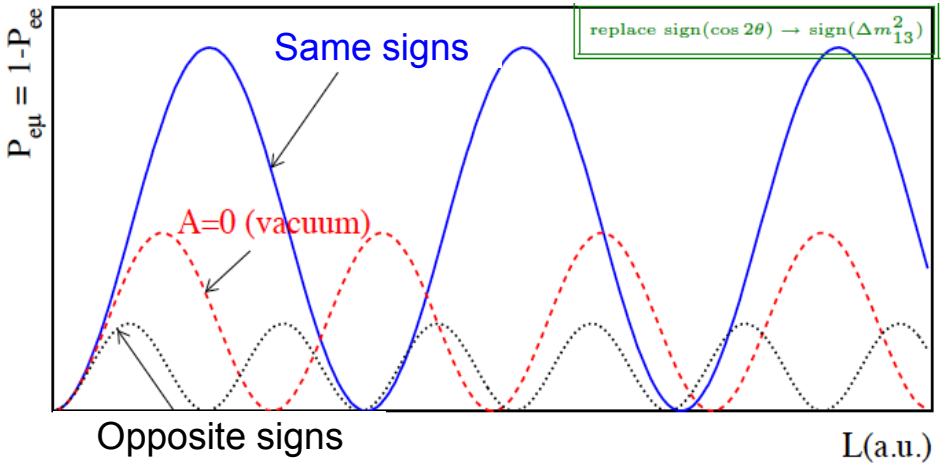
📖 W. Winter : arXiv:1305.5539,
📖 Agarwalla et al. arXiv:1212.2238
📖 Akhmedov et al. JHEP 02 (2013) 082

(Constant Density) Matter Effects

$$P^m_{3\nu}(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\,\sin^2 2\theta^m_{13}\,\sin^2\left(\frac{\Delta^m m^2_{31}\,L}{4E_\nu}\right)$$

$$\sin^2 2\theta^m_{13} \equiv \sin^2 2\theta_{13}\left(\frac{\Delta m^2_{31}}{\Delta^m m^2_{31}}\right)^2$$

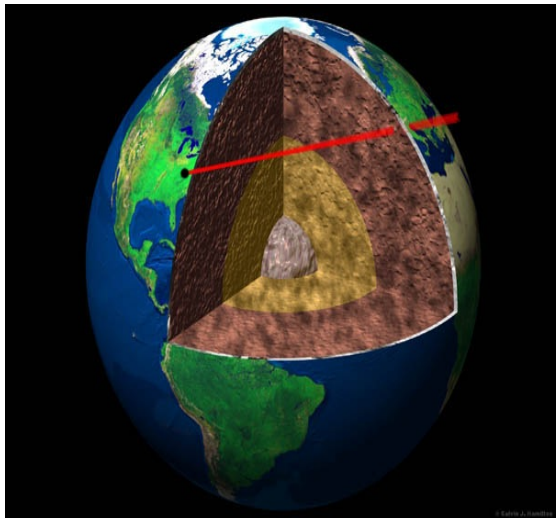
$$\Delta^m m^2_{31} \equiv \sqrt{(\Delta m^2_{31}\cos 2\theta_{13} - 2\,E_\nu\,A)^2 + (\Delta m^2_{31}\sin 2\theta_{13})^2}$$



$$E_{\rm res} \equiv \frac{\Delta m^2_{31}\cos 2\theta_{13}}{2\sqrt{2}\,G_F\,N_e} \simeq 7\,{\rm GeV}\left(\frac{4.5\,{\rm g/cm^3}}{\rho}\right)\left(\frac{\Delta m^2_{31}}{2.4\times 10^{-3}\,{\rm eV}^2}\right)\cos 2\theta_{13}$$

Matter resonance: A ➔ $\Delta_{13}\cos 2\theta_{13}$
- Effective mixing maximal
- Effective osc. frequency minimal

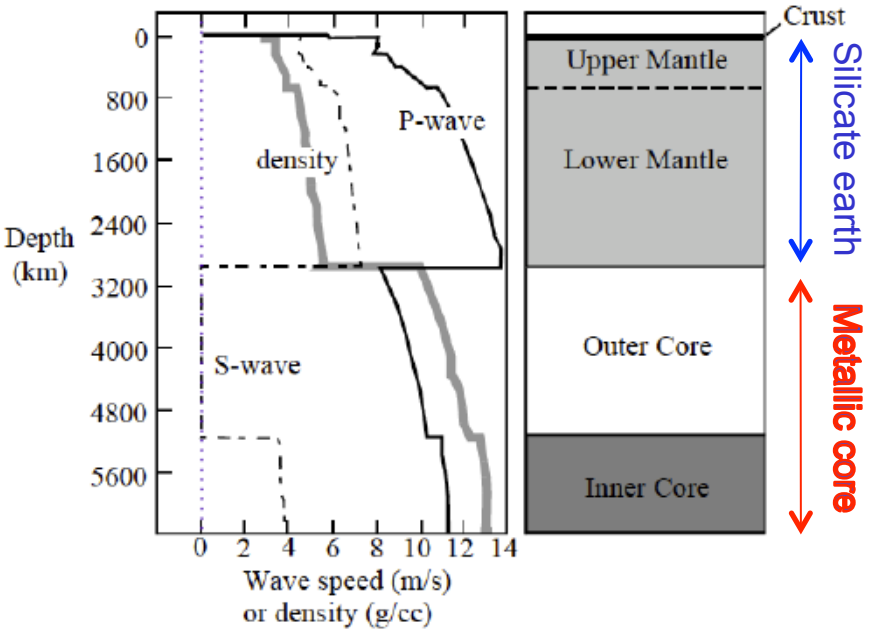
Resonance energy Earth:
- Mantle E_{res} ~ 7 GeV
- Core E_{res} ~ 3 GeV



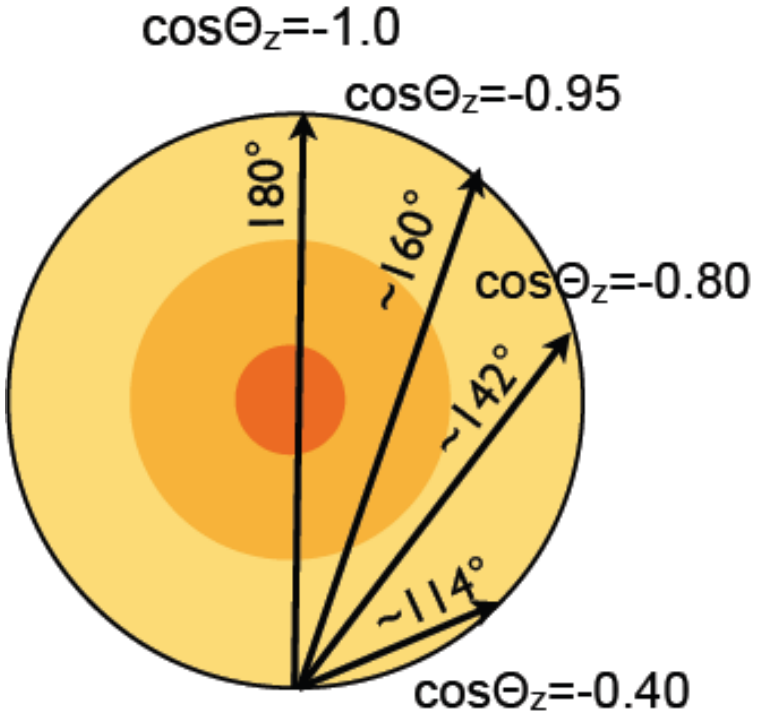
Requirements:
- Δ_{13} ~ A matter potential must be significant but not overwhelming
- L large enough – matter effects are absent near the origin
- Distinction between neutrinos and anti-neutrinos

➔ different flux and cross-sections!

Earth tomography and composition



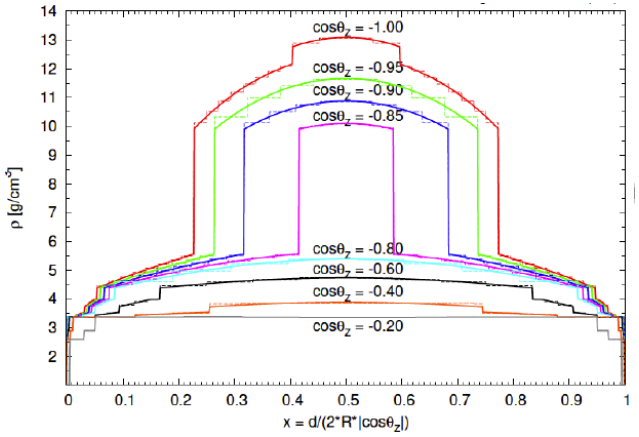
William F. McDonough "The Composition of the Earth"



Earth density relatively well described through seismic measurements (compressional and shear waves): PREM model *(Dziewonski & Anderson, 1981)*

Neutrino absorption/oscillation tomography:

- independent check of density profile
- constraints on core composition

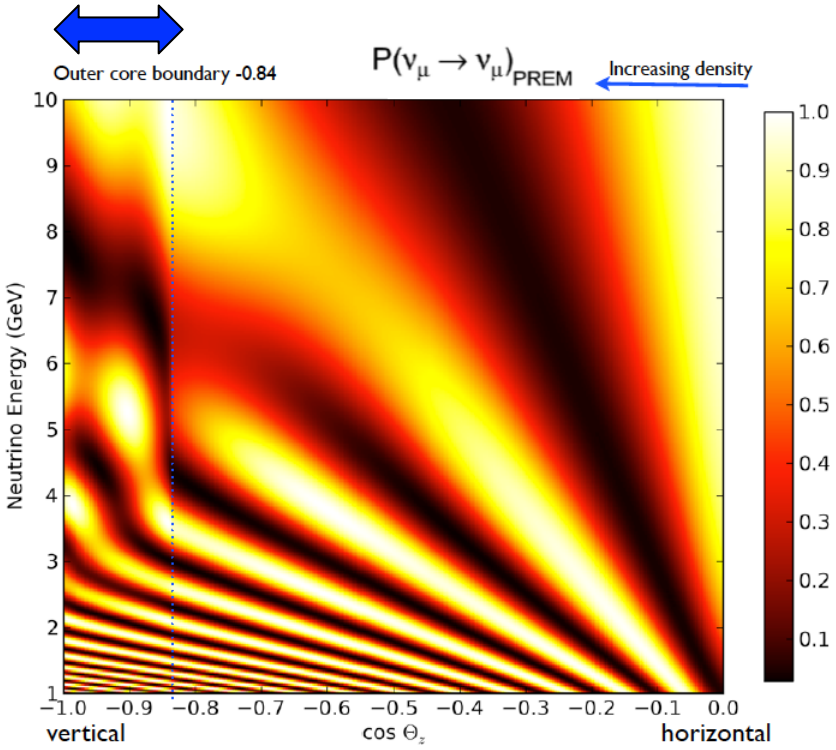


Earth tomography and composition

Matter-induced neutrino oscillation effects depend on electron density

→ constraints on composition: Y=Z/A

CORE



Most sensitive domain:

E ~2 → 10 GeV

cosθ < -0.84(neutrinos traversing the core)

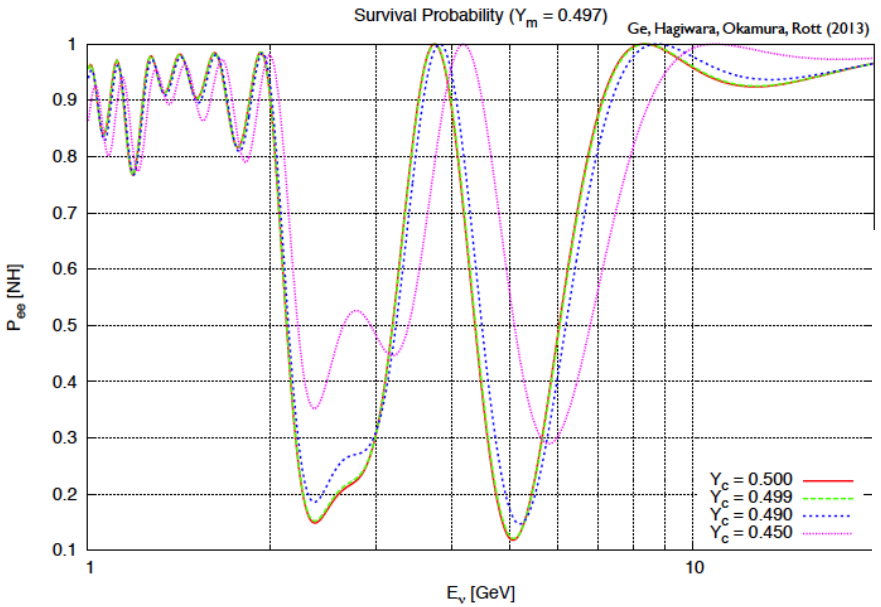
Oscillation parameters fit using information from neutrinos traversing the mantle only

→ constrain Y_{core}

Earth tomography and composition

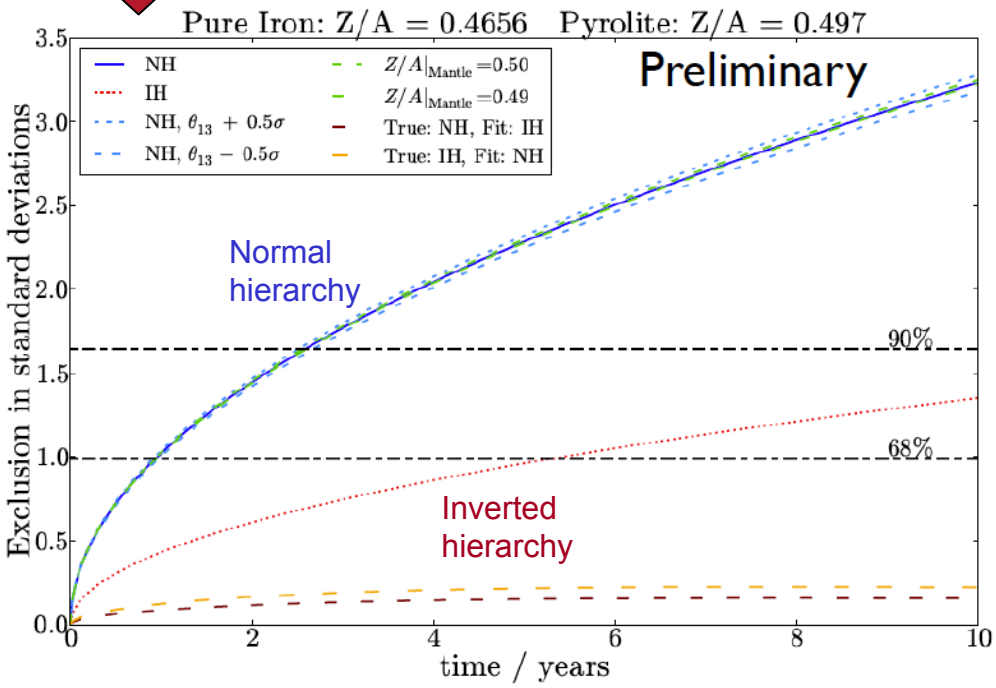
Matter-induced neutrino oscillation effects depend on electron density

→ constraints on composition: Y=Z/A



ν_e survival probability for different electron densities in the core:
Yc 0.45 → 0.5
(Yc uncertainties based on Earth composition: few %)

Example study: extreme cases
- pure iron core (Yc = 0.4656)
- core = mantle (Yc = 0.497)



(here for an in-ice detector)

Conclusions and perspectives

ANTARES, KM3NeT/ORCA:
underwater Cherenkov telescopes for neutrino (astro)physics

- Cabled deep-sea observatories: opportunities for marine and Earth sciences

⇒ long-term monitoring of environmental parameters

⇒ test bench for new instruments (e.g. on calibration lines)

- Atmospheric neutrinos: a background… and a tool to study the Earth

TeV → PeV neutrino absorption tomography:

⇒ Earth density profile

~GeV neutrino oscillation tomography

⇒ Earth composition

sensitivity studies & detector optimisation to be conducted !