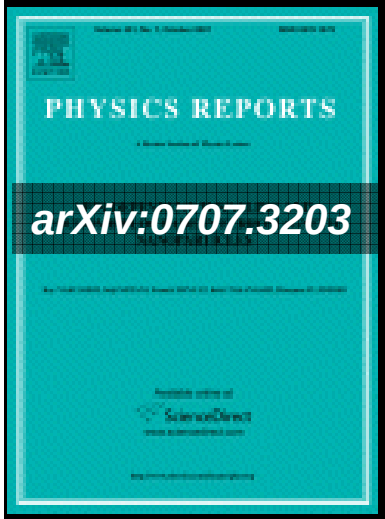
Young Investigators Symposium

Oak Ridge National Laboratory

13-15 October 2008

Geo-neutrinos: a new probe of Earth's interior



Fiorentini G., Lissia M, Mantovani F.

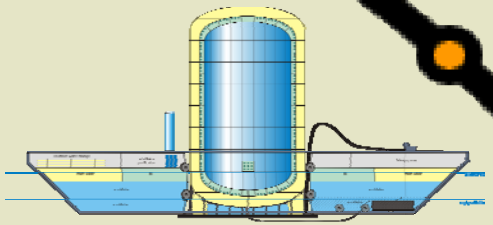
Fabio Mantovani

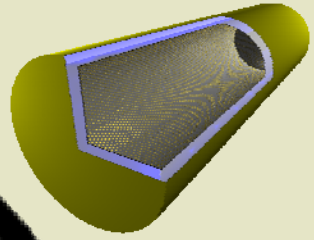
Center of GeoTechnologies

Siena University (Italy)

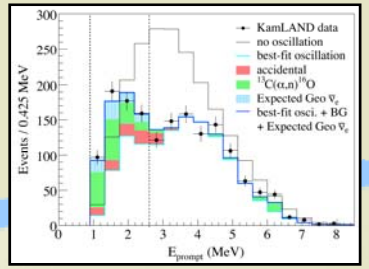
Summary

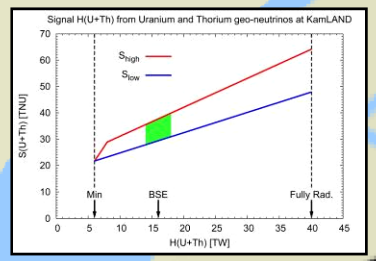
- What are geo-neutrinos?
- Open questions about radioactivity in the Earth
- The impact of KamLAND experiment
- The potential of future experiments
- What's next?

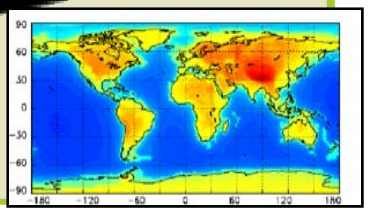




You are here







Geo-neutrinos: anti-neutrinos from the Earth

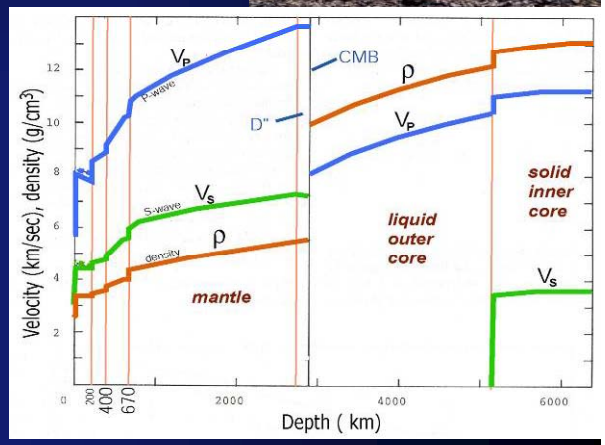
U, Th and ^{40}K in the Earth release heat together with anti-neutrinos, in a well fixed ratio:

Decay	$T_{1/2}$ [10^9 yr]	E_{max} [MeV]	Q [MeV]	$\varepsilon_{\bar{\nu}}$ [$kg^{-1}s^{-1}$]	ε_H [W/kg]
$^{238}U \rightarrow {}^{206}Pb + 8\,{}^4He + 6e + 6\bar{\nu}$	4.47	3.26	51.7	7.46×10^7	0.95×10^{-4}
$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^4He + 4e + 4\bar{\nu}$	14.0	2.25	42.7	1.62×10^7	0.27×10^{-4}
$^{40}K \rightarrow {}^{40}Ca + e + \bar{\nu}$ (89%)	1.28	1.311	1.311	2.32×10^8	0.22×10^{-4}

- Earth emits (mainly) antineutrinos $\Phi_{\bar{\nu}} \sim 10^6\,cm^{-2}s^{-1}$ whereas Sun shines in neutrinos.
- A fraction of geo-neutrinos from U and Th (not from ^{40}K) are above threshold for inverse β on protons: $\bar{\nu} + p \rightarrow e^+ + n - 1.8\ MeV$
- Different components can be distinguished due to different energy spectra: e. g. anti-ν with highest energy are from Uranium.

Probes of the Earth's interior

- Deepest hole is about 12 km
- Samples from the crust (and the upper portion of mantle) are available for geochemical analysis.
- Seismology reconstructs density profile (not composition) throughout all Earth.



Geo-neutrinos: a new probe of Earth's interior

✓ They escape freely and instantaneously from Earth's interior.

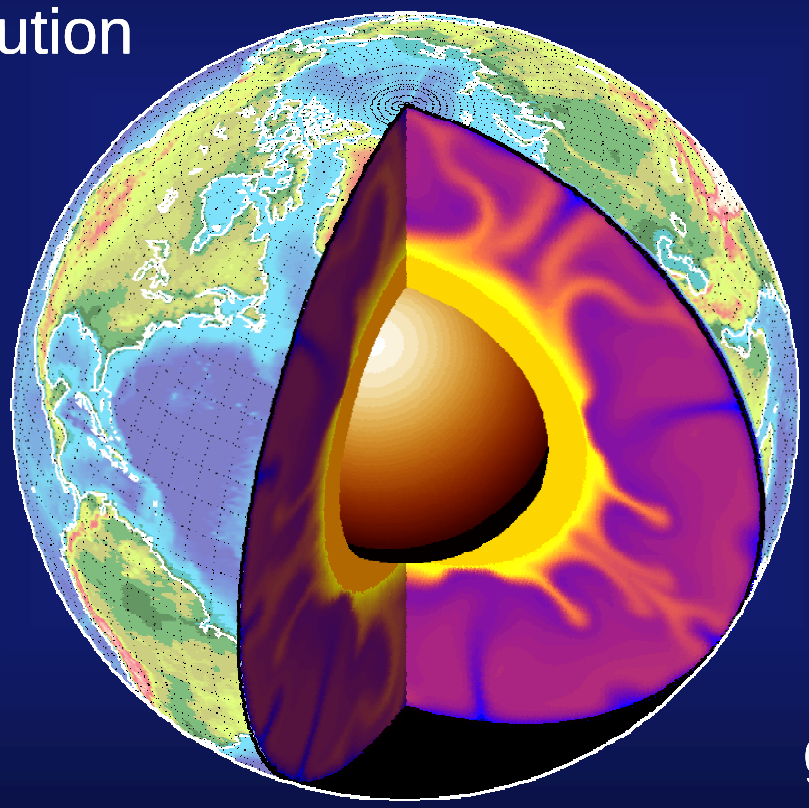
✓ They bring to Earth's surface information about the chemical composition of the whole planet.

Open questions about natural radioactivity in the Earth

1 - What is the radiogenic contribution to terrestrial heat production?

2 - How much U and Th in the crust?

3 - How much U and Th in the mantle?



4 - What is hidden in the Earth's core? (geo-reactor, ^{40}K, …)

5 - Is the standard geochemical model (BSE) consistent with geo-neutrino data?

“Energetics of the Earth and the missing heat source mistery” *

- Heat flow from the Earth is the equivalent of some 10000 nuclear power plants

$$H_{Earth} = (30 - 44)TW$$

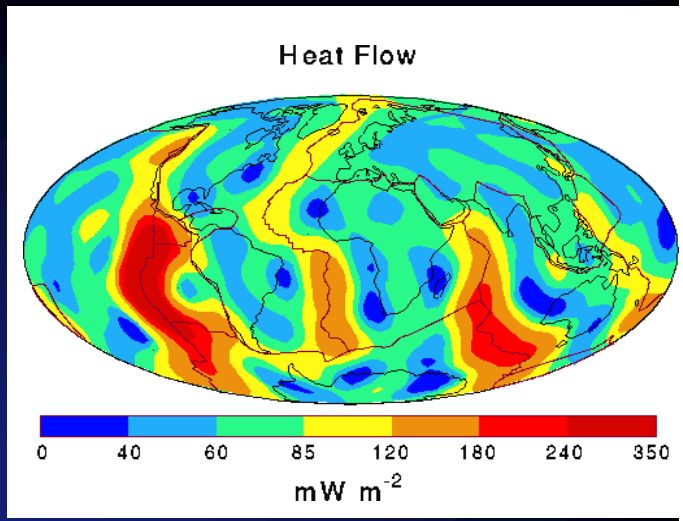
- The BSE canonical model, based on **cosmochemical** arguments, predicts a radiogenic heat production ~ 19 TW:

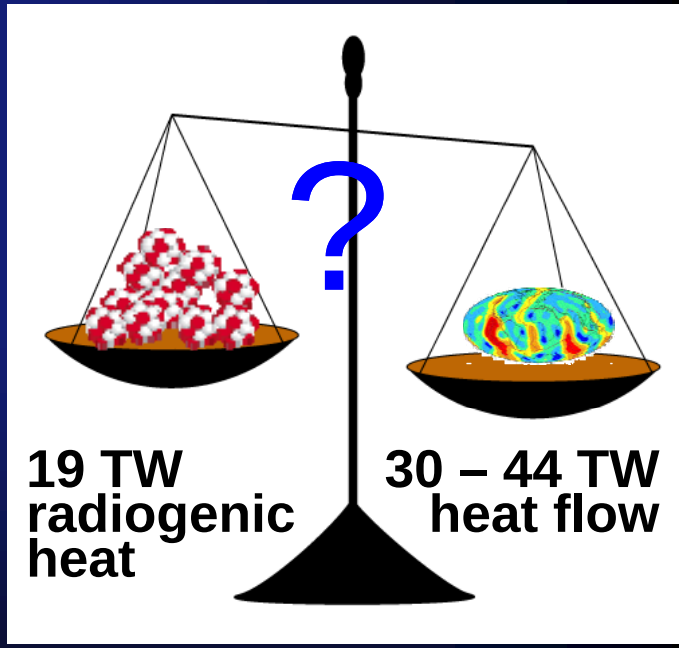
~ 9 TW **estimated** from radioactivity in the (continental) crust

~ 10 TW **supposed** from radioactivity in the mantle

~ 0 TW **assumed** from the core

- Unorthodox or even heretical models have been advanced…



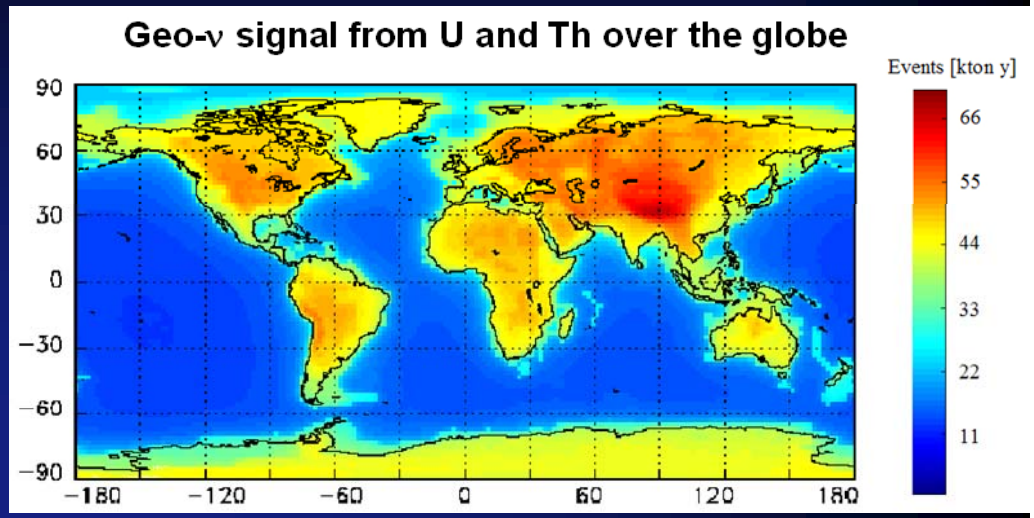


** D. L. Anderson (2005),Technical Report, www.MantlePlume.org*

The World Wide Reference Model*

Geo-ν signals from U and Th over the globe have been calculated by using:

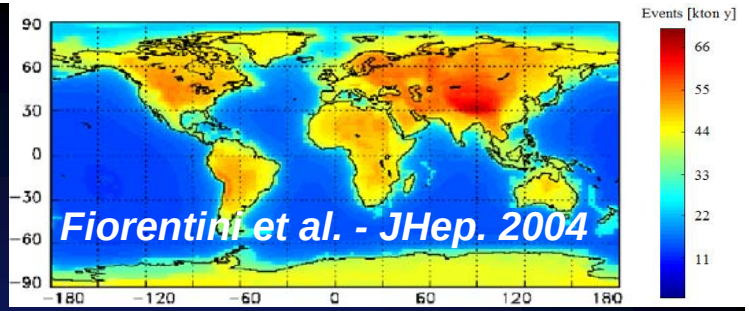
- A 2^ox2^o crustal map (Laske G. – 2001).
- For each of the 16200 tiles density and thickness of sediments, upper, middle and lower crust are given.
- Values of the U and Th mass abundance in each layer taken as mean values of GERM data.
- Spread of GERM data used as indication of uncertainties.



- Mantle is divided into two spherically symmetrical reservoirs (UM and LM).
- For UM measured abundances were used
- For LM the abundances were deduced from BSE mass balance
- No U and Th in the core

** F. Mantovani et al. – Phys. Rev. D 69 – 2004 - hep-ph/0309013*

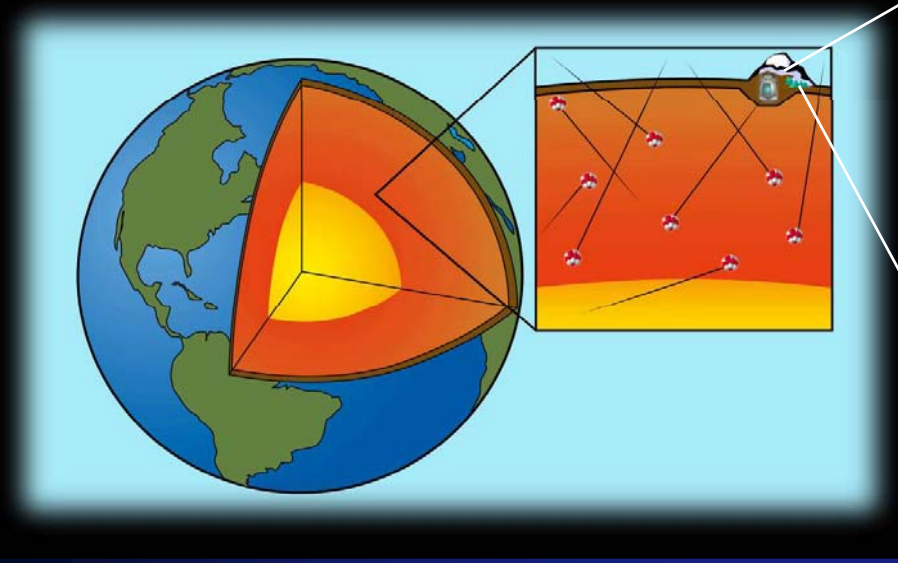
Geo-ν: predictions of the BSE Reference Model

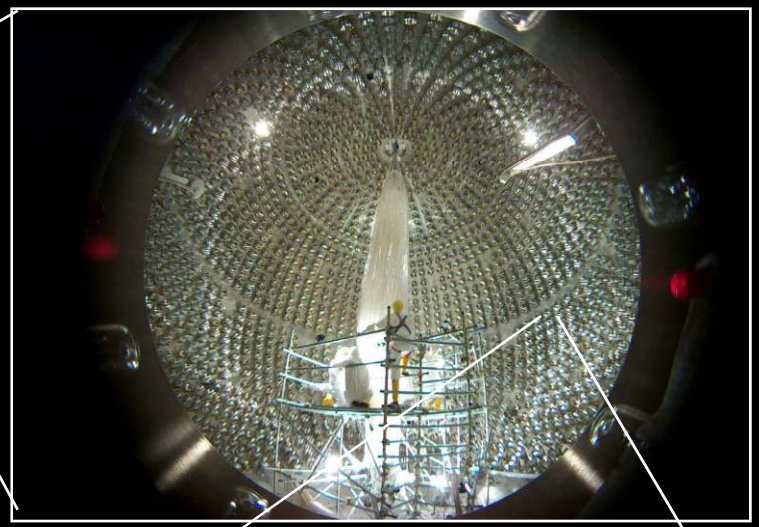


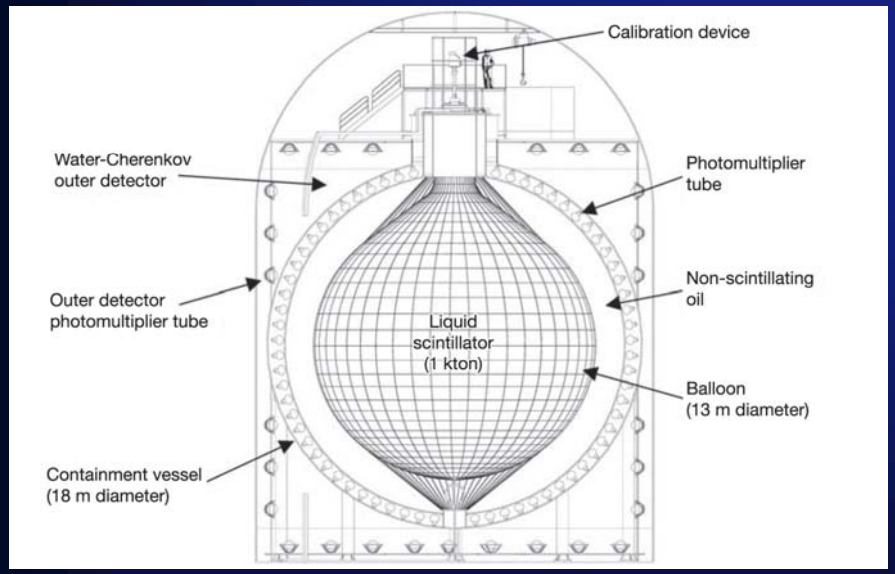
Signal from U+Th [TNU]	Mantovani et al. (2004)	Fogli et al. (2005)	Enomoto et al. (2005)
Pyhasalmi	51.5	49.9	52.4
Homestake	51.3		
Baksan	50.8	50.7	55.0
Sudbury	50.8	47.9	50.4
Gran Sasso	40.7	40.5	43.1
Kamioka	34.5	31.6	36.5
Curacao	32.5		
Hawaii	12.5	13.4	13.4

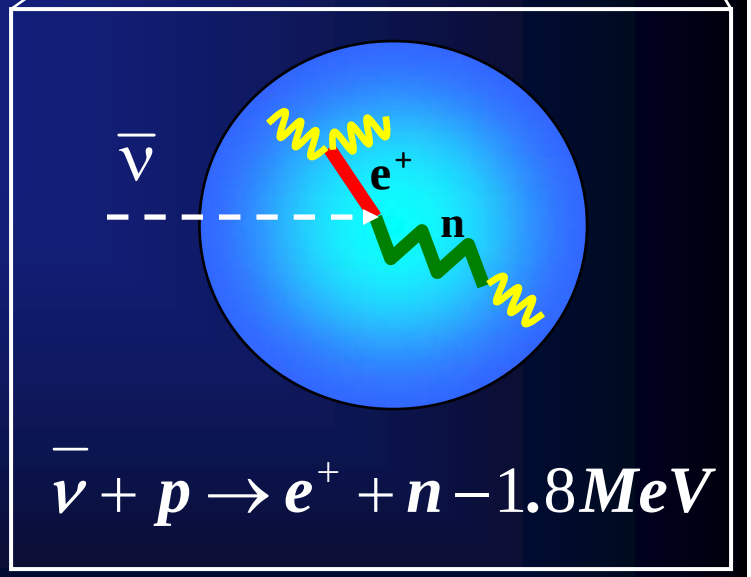
- **1 TNU = one event per 10^{32} free protons per year**
- **All calculations in agreement to the 10% level**
- **Different locations exhibit different contributions of radioactivity from crust and from mantle**

KamLAND experiment









KamLAND experiment consists of 1 Kton Liquid Scintillator, surrounded by 1845 PMT

KamLAND 2002-2007 results on geo-neutrino

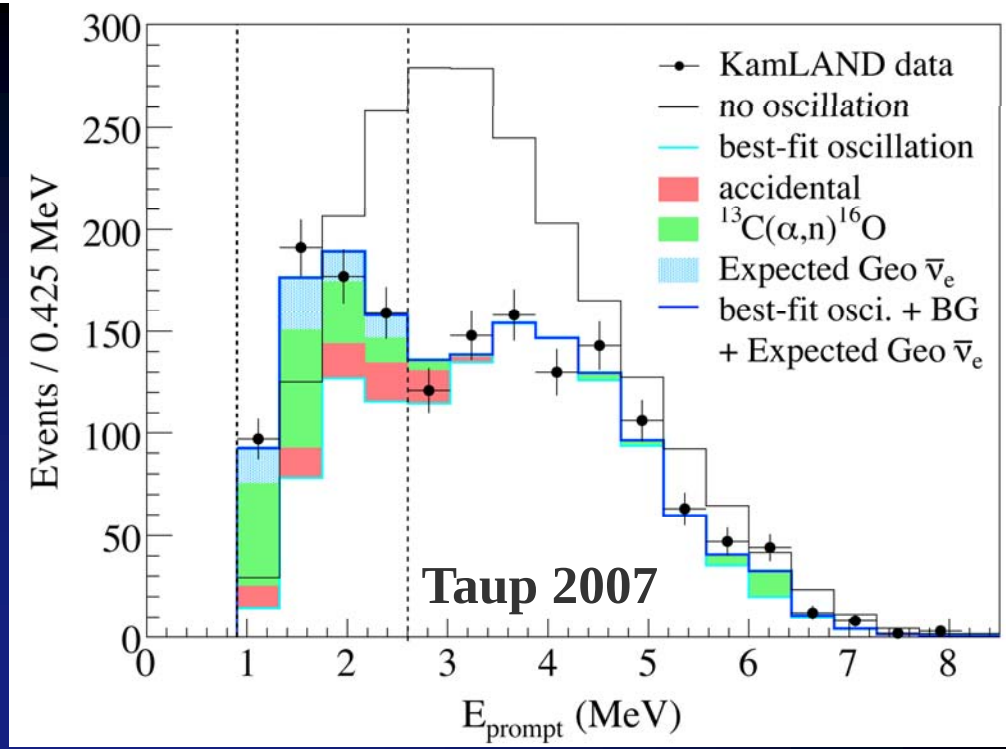
- **In five years data ~ 630 counts in the geo-ν energy range:**

~ 340 reactors antineutrinos

~ 160 fake geo-ν, from $^{13}C(\alpha,n)$

~ 60 random coincidences

~ 70 geo-neutrino events are obtained from subtraction.



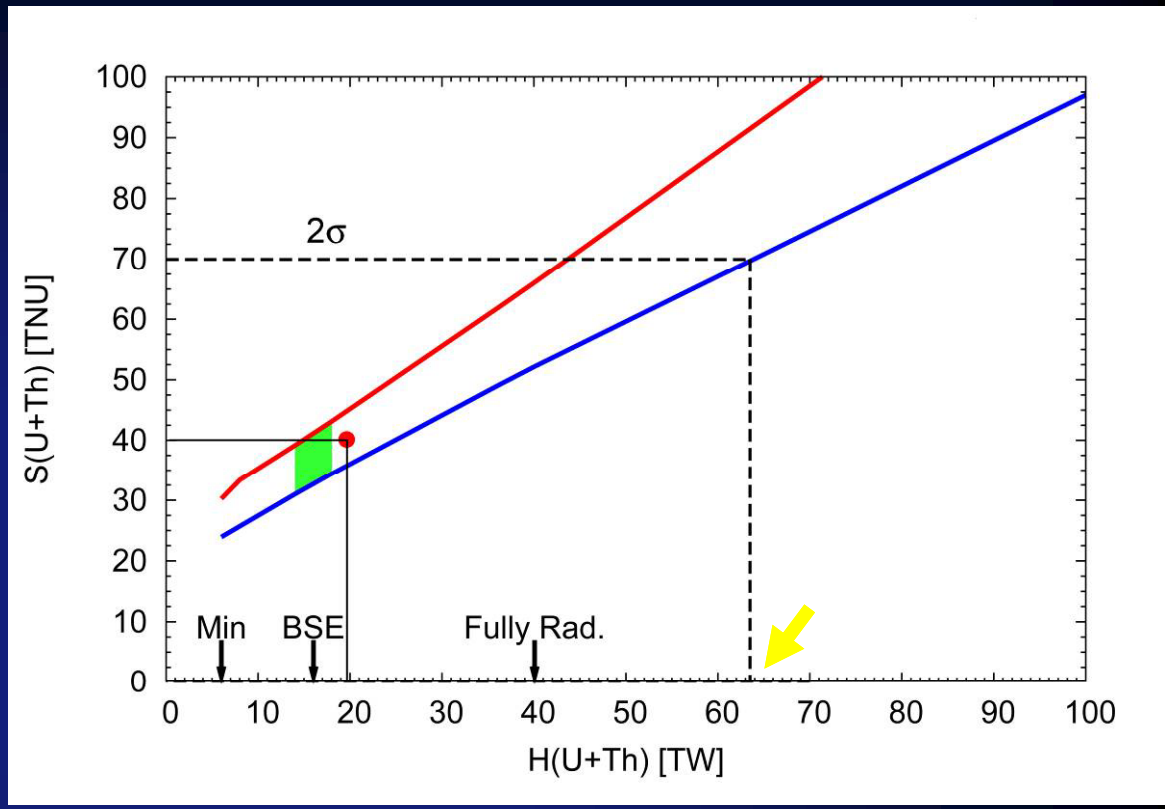
- **Adding the "chondiritic hypothesis" for U/Th:**

$$N_{geo\text{-}\nu}\ (U+Th) = 75 \pm 27$$

- **This pioneering experiment has shown that the technique for identifying geo-neutrinos is now available!!!**

Implications of KamLAND result

- The KamLAND signal **39 ± 15 TNU** is in perfect agreement with BSE prediction **37 ± 6**.



- It is consistent within 1σ with:

- Minimal model

- Fully radiogenic model

- Concerning radiogenic heat, the 95% CL upper bound on geo-signal translates into* **H(U+Th) < 65 TW**

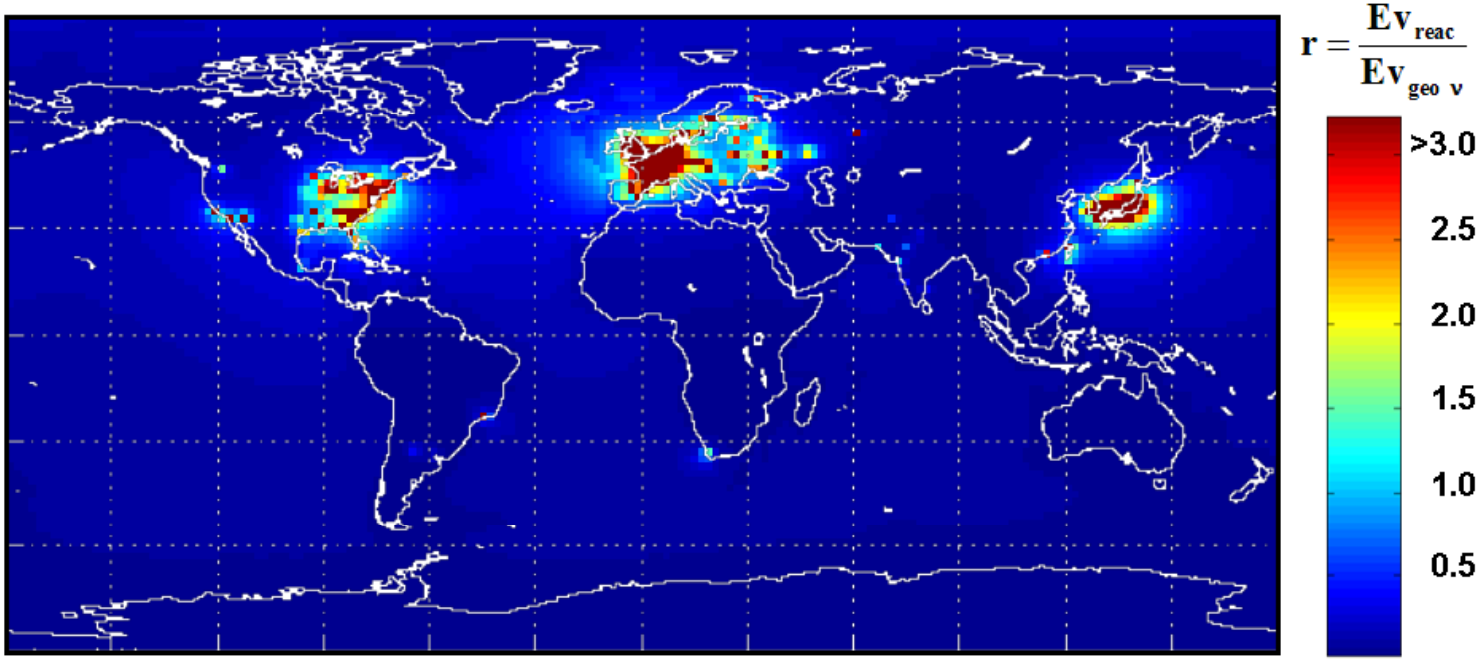
** G. Fiorentini et al. - Phys.Lett. B 629 – 2005 - hep-ph/0508048*

Nuclear reactors: the enemy of geo-neutrinos

$$r = \frac{\text{Events}_{\text{reactors}}}{\text{Events}_{\text{geo } \nu}}$$

In the geo-neutrino energy window

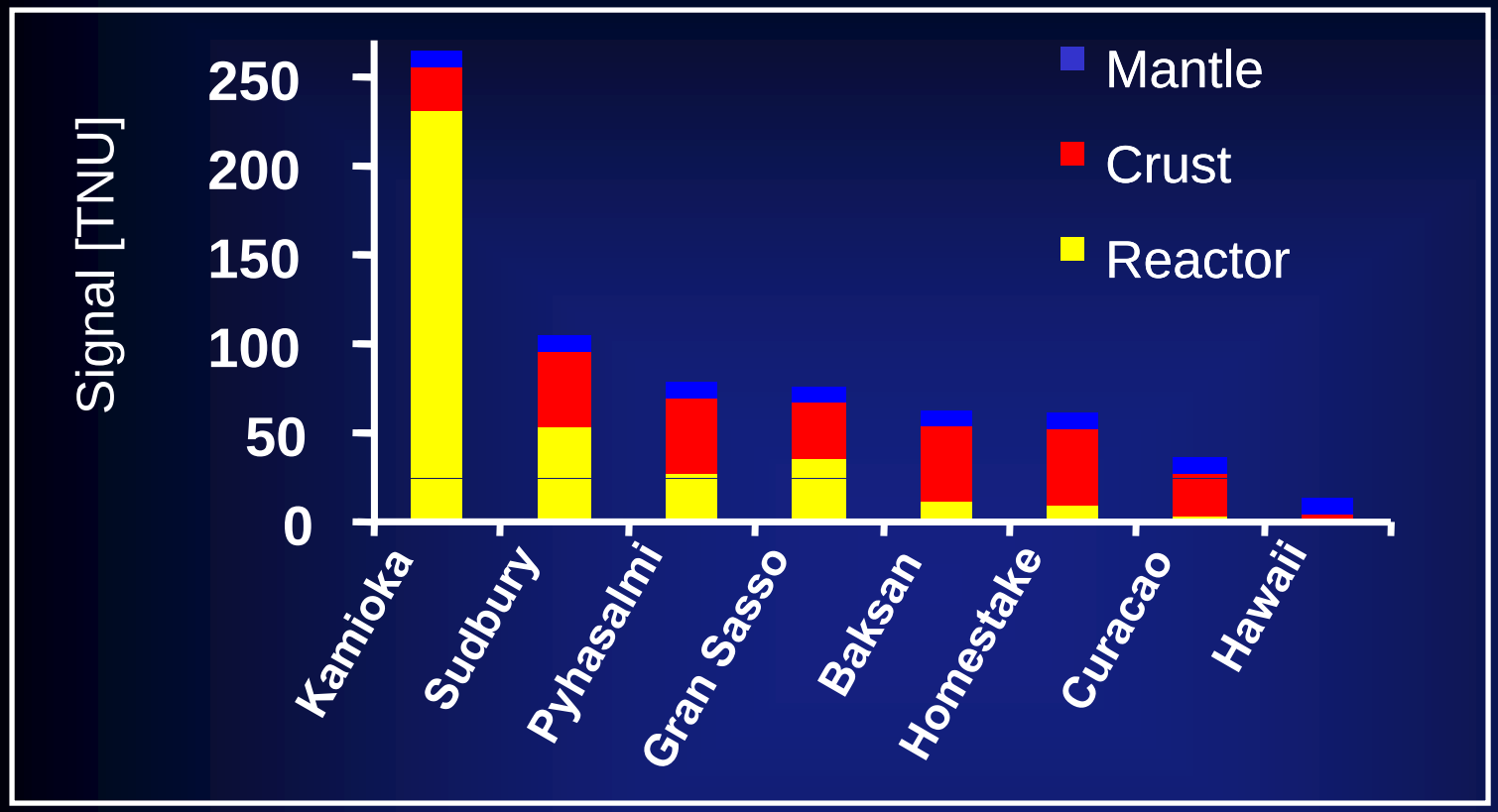
	r
Kamioka	6.7
Sudbury	1.1
Gran Sasso	0.9
Pyhasalmi	0.5
Baksan	0.2
Homestake	0.2
Hawaii	0.1
Curacao	0.1

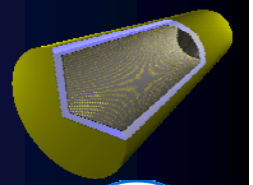


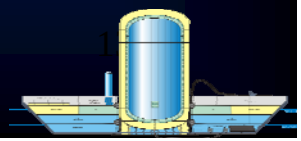
Fiorentini et al. - Earth Moon Planets - 2006

- Based on IAEA Database (2000)
- All reactors at full power

Running and planned experiments







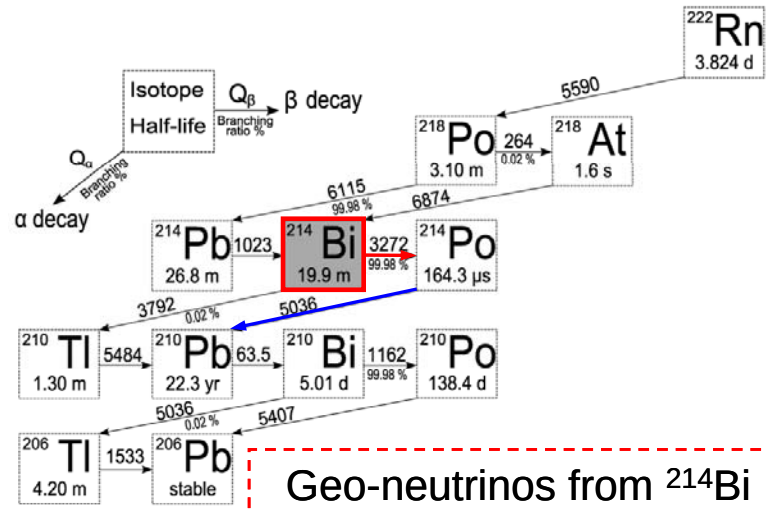
- **Several experiments, either running or under construction or planned, have geo-ν among their goals.**

- **Figure shows the sensitivity to geo-neutrinos from crust and mantle together with reactor background.**

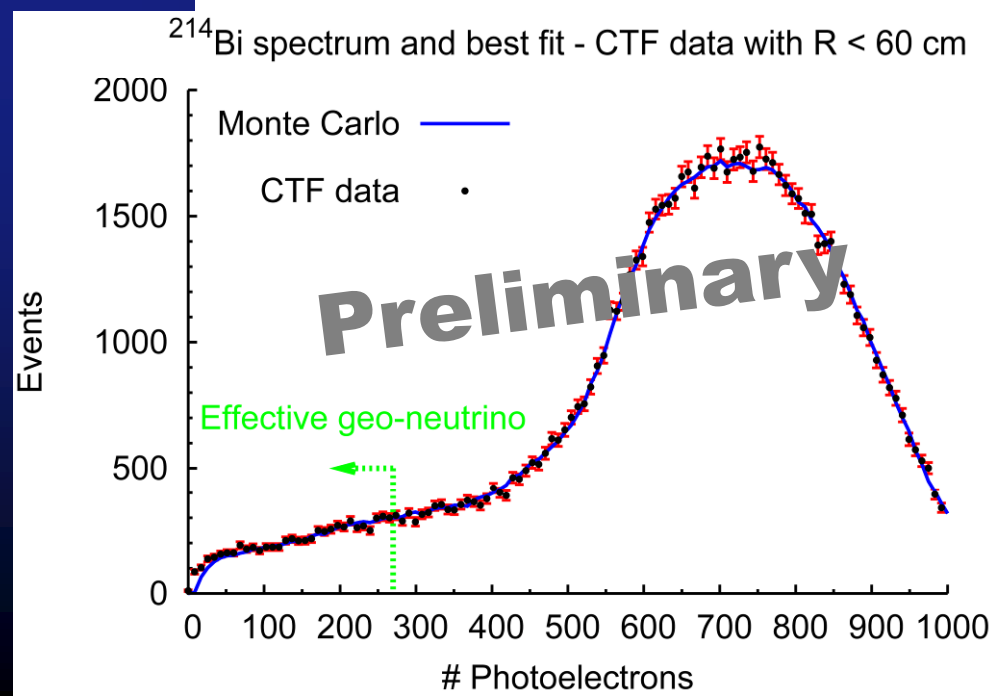
What's next?

1) nuclear physics for geoneutrinos

- The **decay spectra** is necessary for calculating the geo-neutrino signal: they are obtained from **theoretical calculations**, not from direct measurements.
- With CTF @ LNGS a method for **experimental determination** of geo-neutrino spectra has been developed measuring the "prompt energy" of ^{214}Bi decay
- By using the available data from a ^{222}Rn contamination, a fit to the data yields information **consistent and comparable** to that from Table of Isotopes.

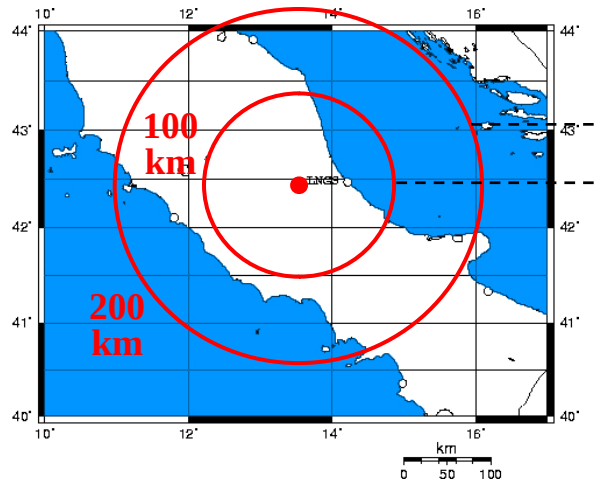


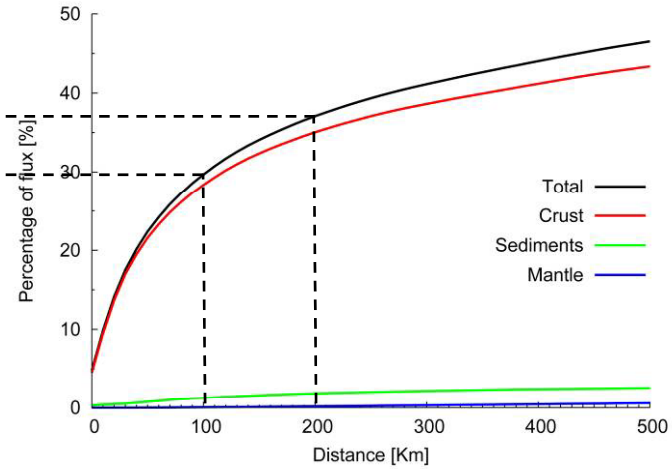
Geo-neutrinos from ^{214}Bi decay provide 46% of the geo-neutrino signal from ^{238}U + ^{232}Th chains!

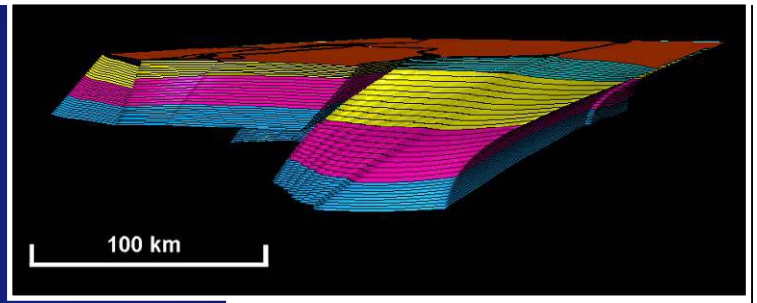


What's next?

2) Local geology relevant for Geoneutrinos in Borexino

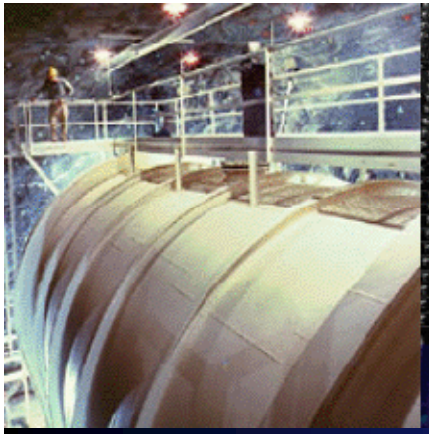


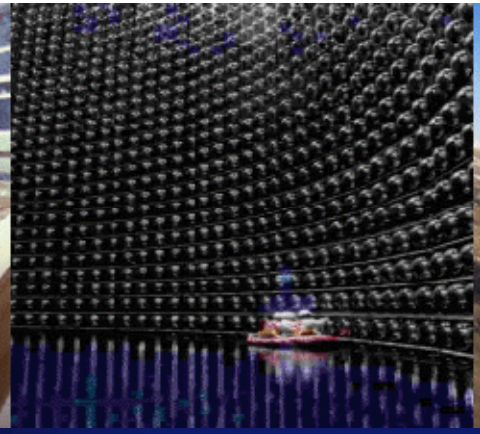


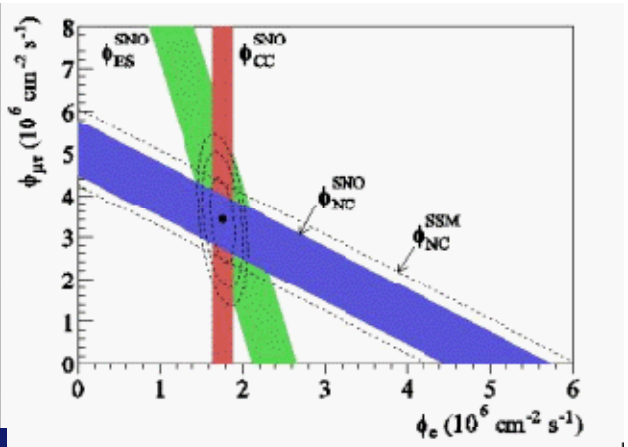


- The regional contribution has to be controlled by study of regional geology, if one wants to extract the global information brought in by geo-ν's
- We performed 3D model of sediments and crust in the region near LNGS, and we measured U and Th content in samples and situ.

- We obtained a **"refined model"** of the local geology: it permits to estimate an expected geoneutrinos signal of **38.6 TNU** (40.7 TNU).
- For 80% eff. and 300 tons C_9H_{12} fiducial mass, we expect **5.5 events/year** in Borexino.

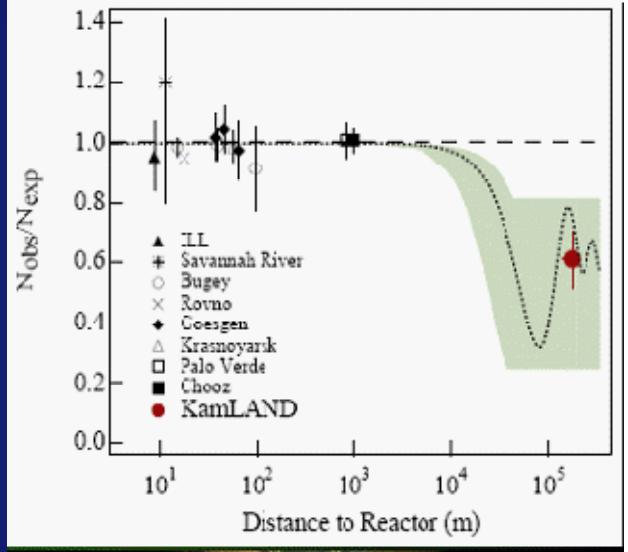


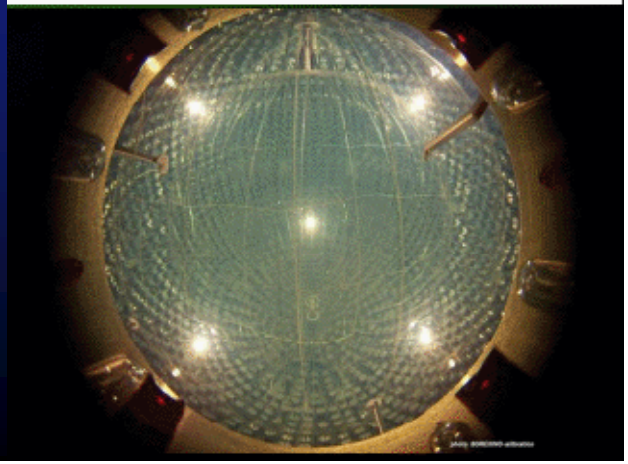




The lesson of solar neutrinos

- ✓ Solar neutrinos started as an investigation of the solar interior for understanding **sun energetics**.
- ✓ A long and fruitful detour lead to the discovery of oscillations.
- ✓ Through several steps, we obtained a direct proof of the solar energy source, experimental solar neutrino spectroscopy, neutrino telescopes.





The study of Earth's energetics with geo-neutrinos will also require several steps and hopefully provide surprises…

KAMLAND 2005
1st evidence of geo-ν

GAMOW 1953
geo-ν were born here