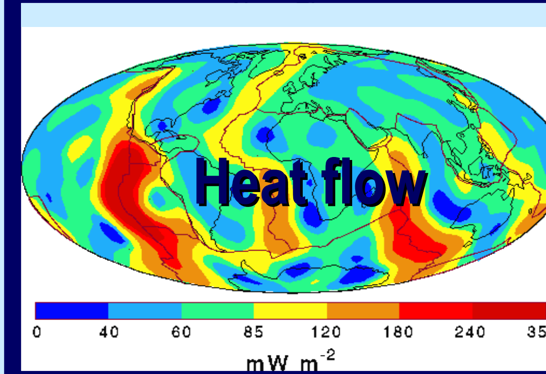
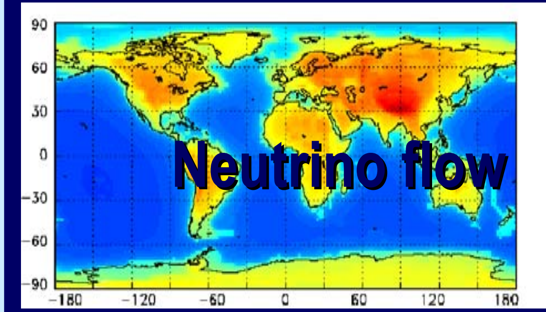
gianni fiorentini, ferrara univ. @ ν_{2004}

Geo-Neutrinos : a new probe of Earth’s interior

- Determine the radiogenic contribution to terrestrial heat flow
- Test a fundamental geochemical paradigm about Earh’s origin: the **B**ulk **S**ylicate **E**arth
- Test un-orthodox / heretical models of Earth’s interior (K in the core, Herndon giant reactor)
- A new era of applied neutrino physics ?





**based on work with Carmignani, Lasserre, Lissia Mantovani Ricci Schoenert Vannucci*

A few references*

G.Eder, Nuc. Phys. 1966
G Marx Czech J. Phys. 1969,PR ‘81
Krauss Glashow, Schramm, Nature ‘84
Kobayashi Fukao Geoph. Res. Lett ‘91
Raghavan Schoenert Suzuki PRL ‘98
Rotschild Chen Calaprice, ‘98

Fiorentini et al PL 2002
Kamland coll, PRL Dec.2002
Raghavan 2002
Carmignani et al PR 2003
Nunokawa et al JHEP 2003
Mitsui ICRC 2003
Miramonti 2003
Mikaelyan et al 2003
McKeown Vogel, 2004
Fields, Hochmuth 2004
Fogli et al 2004

-Geo-neutrinos were introduced by G Eder and first discussed by G Marx
-More refs in the last 2 years than in previous 30.
-Most in the list are theoreticians, experimentalists added recently.

*Apologize for missing refs.

Geoneutrinos: anti-neutrinos from the Earth

- Uranium, Thorium and Potassium in the Earth release heat together with anti-neutrinos, in a well fixed ratio:

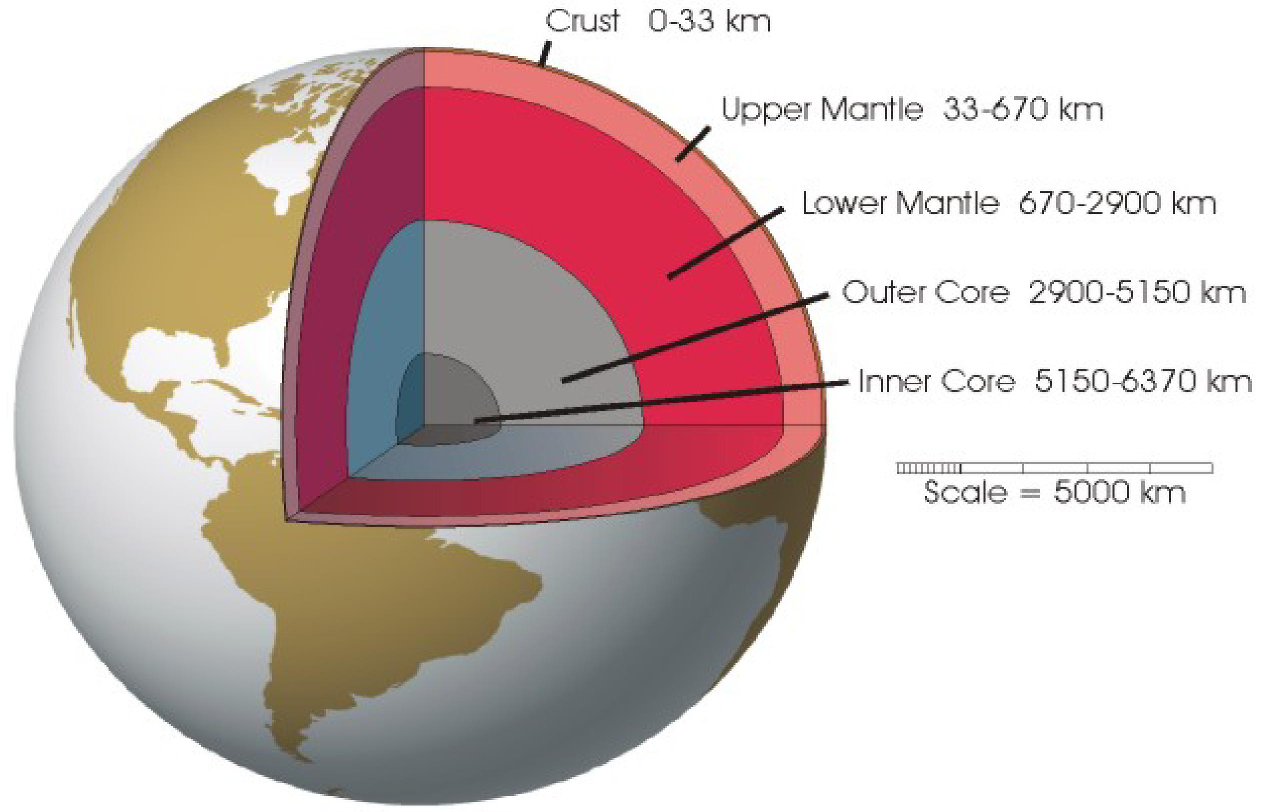
Decay	Q [MeV]	$\tau_{1/2}$ [10^9 yr]	E_{max} [MeV]	ε_H [W/kg]	$\varepsilon_{\bar{\nu}}$ [$kg^{-1}s^{-1}$]
$^{238}U \rightarrow {}^{206}Pb + 8\,{}^4He + 6e + 6\bar{\nu}$	51.7	4.47	3.26	$0.95\cdot10^{-4}$	$7.41\cdot10^{7}$
$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^4He + 4e + 4\bar{\nu}$	42.8	14.0	2.25	$0.27\cdot10^{-4}$	$1.63\cdot10^{7}$
$^{40}K \rightarrow {}^{40}Ca + e + \bar{\nu}$	1.32	1.28	1.31	$0.36\cdot10^{-8}$	$2.69\cdot10^{4}$

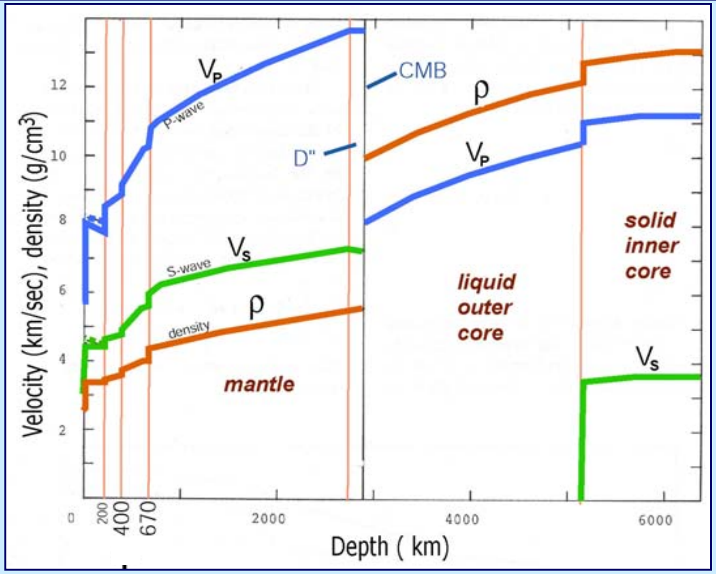
- Earth emits (mainly) antineutrinos, Sun shines in neutrinos.
- Different components can be distinguished due to different energy spectra.
- Geoneutrinos from U and Th (not from K) are above treshold for inverse β on protons:

$$\bar{\nu} + p \rightarrow e^+ + n - 1.8 MeV$$

Probes of the Earth's interior

- Deepest hole is about 10 km.
- The Crust (and the Upper Mantle only) are directly accessible to geochemical analysis.
- Seismology reconstructs density profile (not composition) throughout all earth.





•Geo-neutrinos can bring information about the chemical composition (U,Th and K) of the whole Earth.

The role of geoneutrinos

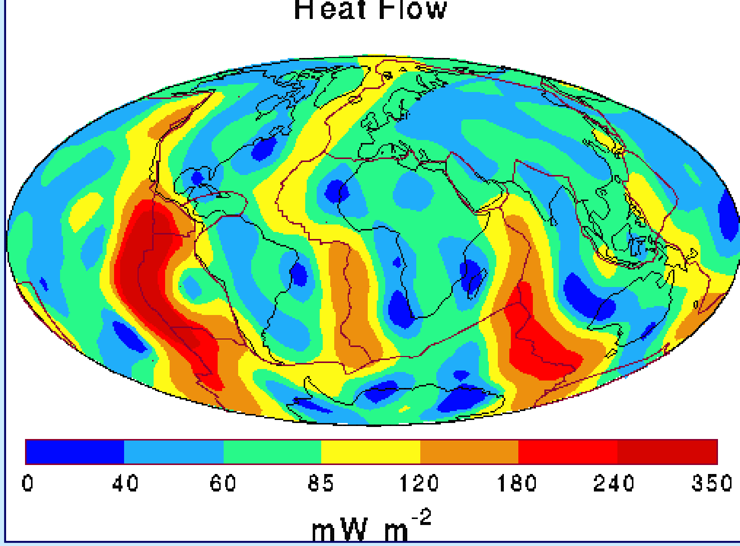
•What is the content of long lived radioactive nuclei inside Earth?

•Detection of (anti) **neutrinos produced in the Earth's interior is the way** for measuring Earth's radioactivity.

•The determination of the radiogenic contribution to Earth energetics is an important and so far unanswered scientific question.

•The origins of the Earth can be tested by measuring U, Th (and K) contents in the Earth with geo-neutrinos.

The connection between radiogenic heat and geo-eutrinos



•For each elements there is a well fixed ratio of heat to anti-neutrinos:

$$H_R = 9.5\ M(U) + 2.7\ M(Th) + 3.6\ M(^{40}K)$$

$$L_\nu = 7.4\ M(U) + 1.6\ M(Th) + 27\ M(^{40}K)$$

•where units are: H [TW] ; M [10^{17}kg] ; L_ν[10^{24} particles /s]

•Everything is fixed in terms of 3 numbers: M(U), M(Th) and M(K)

• With geo-neutrinos one measures the mass and released heat from radiogenic nuclei in the Earth.

Heat released from the Earth

•There is a tiny flux of heat coming from the Earth.

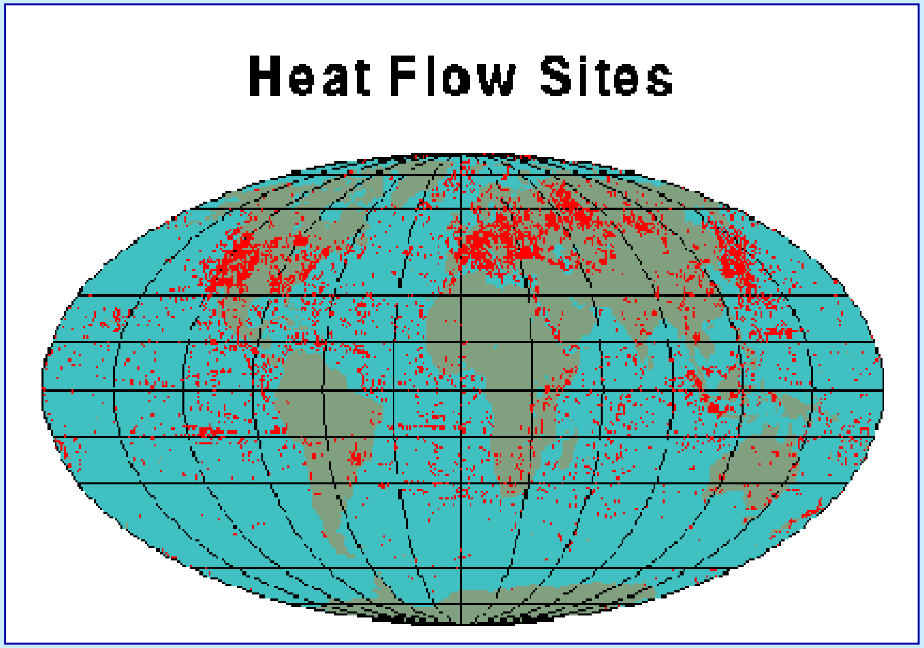
$$\Phi \approx 60\ mW/m^2$$

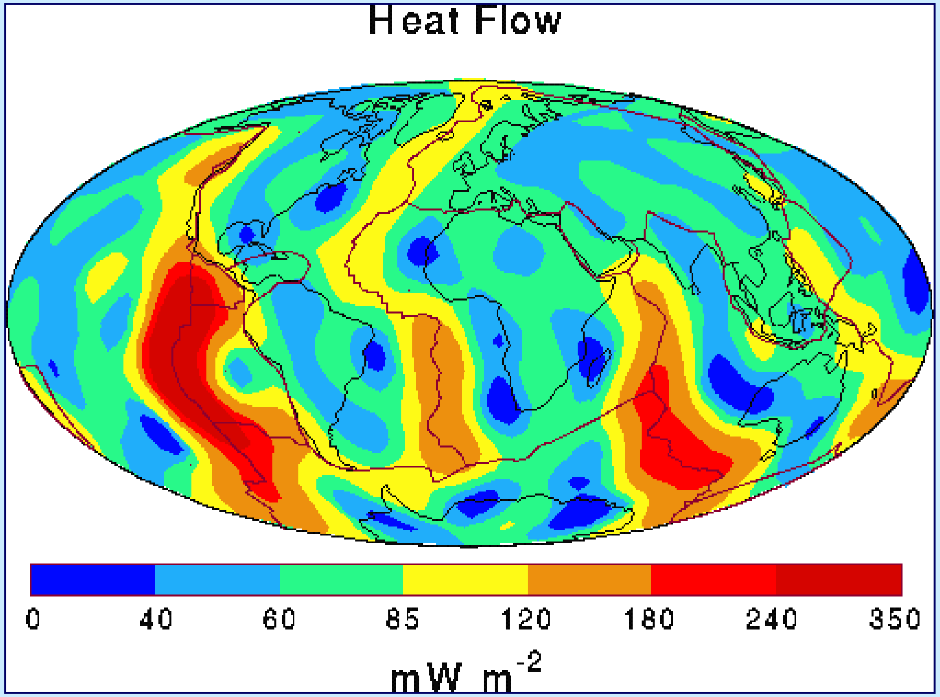
•By integrating the flux one gets the total flow:

$$H_E = (30\text{-}40)TW$$

•It is equivalent to 10^4 nuclear power plants.

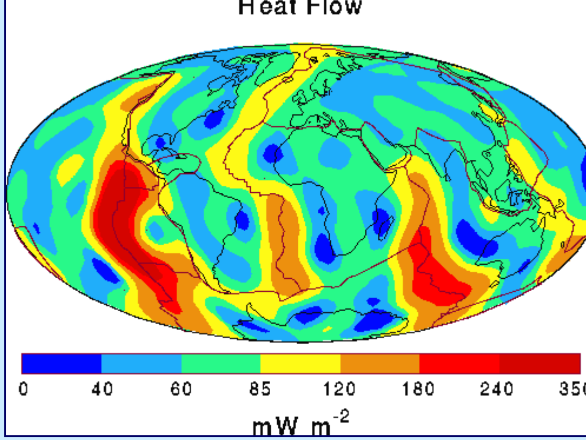
•Warning: the classical 44±1 TW (Pollack 93) recently revised to the "old" 31 ±1 TW (Hofmeister &Criss 04)





What is the source of terrestrial heat?

J Verhoogen, in “Energetics of Earth” **(1980)**



- “…*What emerges from this morass of fragmentary and uncertain data is that **radioactivity** itself could possibly account for at least **60 per cent if not 100** per cent of the Earth’s heat output”.*
- *“If one adds the greater rate of radiogenic heat production in the past, possible release of gravitational energy (original heat, separation of the core…) tidal friction … and possible meteoritic impact … the **total supply** of energy may seem **embarassingly large**…”*

- **Determination of the radiogenic component is important.**

2004

Energetics of the Earth and the Missing Heat Source Mystery

Don L. Anderson

Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125

dla@gps.caltech.edu

BSE

Global heat flow estimates range from 30 to 44 TW … Estimates of the radiogenic contribution ,… based on cosmochemical considerations, vary from 19 to 31 TW. Thus, there is either a good balance between current input and output, as was once believed … or there is a serious missing heat source problem, up to a deficit of 25 TW…

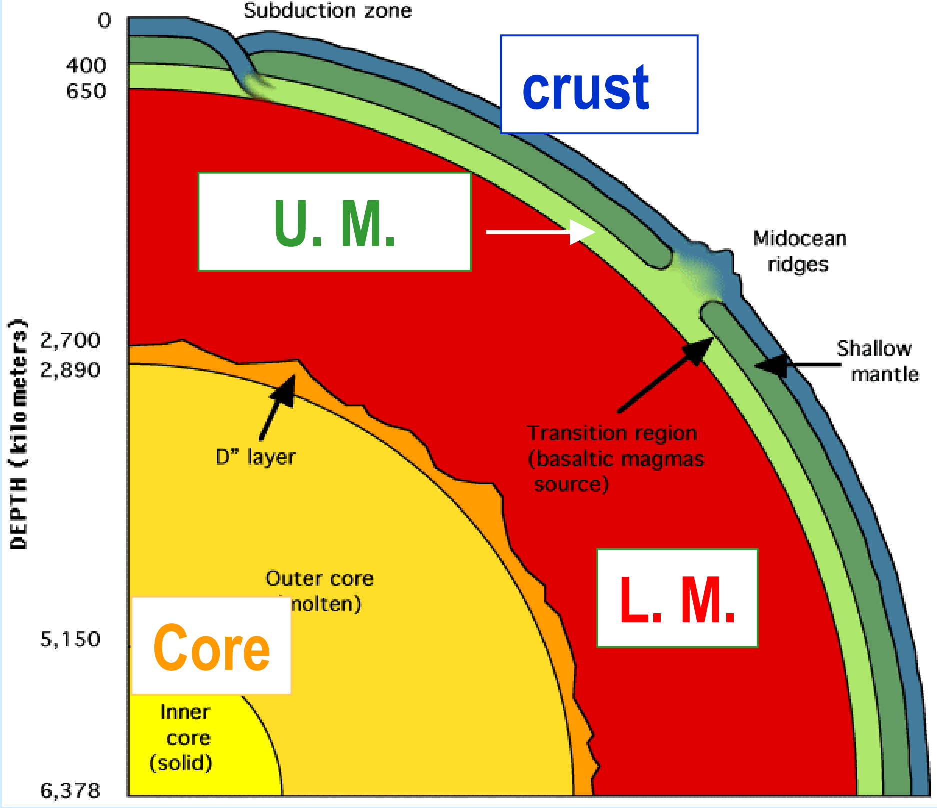
- **Determination of the radiogenic component is important.**

Where are U, Th and K?

- The crust (and the upper mantle only) are directly accessible to geochemical analysis.
- U, K and Th are "lithofile", so they accumulate in the (continental) crust.
- U In the crust is:

  $M_c(U) \approx (0.3\text{-}0.4) 10^{17}$Kg.
- The ≈ 30 Km crust should contains roughly as much as the ≈ 3000 km deep mantle.
- Concerning other elements:

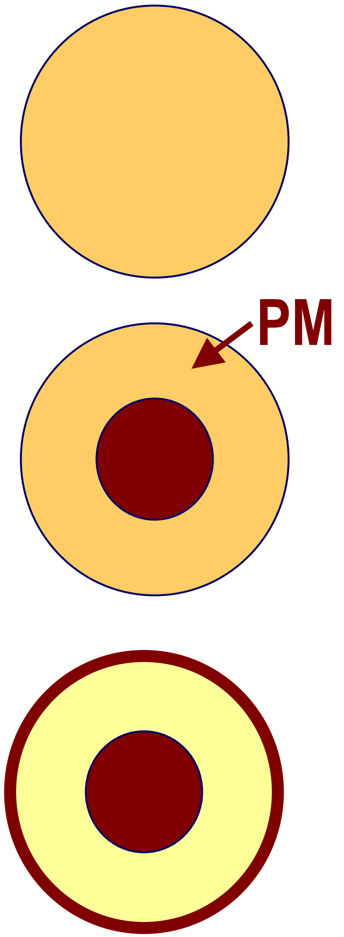
  $Th/U \approx 4^*$ and $^{40}K/U \approx 1$



- For the lower mantle essentially no direct information: one relies on data from meteorites through geo-(cosmo)-chemical (BSE) model…
- According to geochemistry, no U, Th and K should be present in the core.

The canonical Bulk Silicate Earth paradigm

- CI chondritic meteorites are considered as representative of the primitive material of the solar system.
- Earth's global composition is generally estimated from that of CI by using geochemical arguments, which account for loss and fractionation during planet formation.
- In this way the Bulk Silicate Earth (BSE) model is built.
- It describes the "primitive mantle" i.e.:
  - subsequent to core formation.
  - prior to the differentiation between crust and mantle
- It is assumed to describe the present crust plus mantle.
- It is a fundamental geochemical paradigm, consistent with most observations. It should be tested.



U, Th and K according to BSE

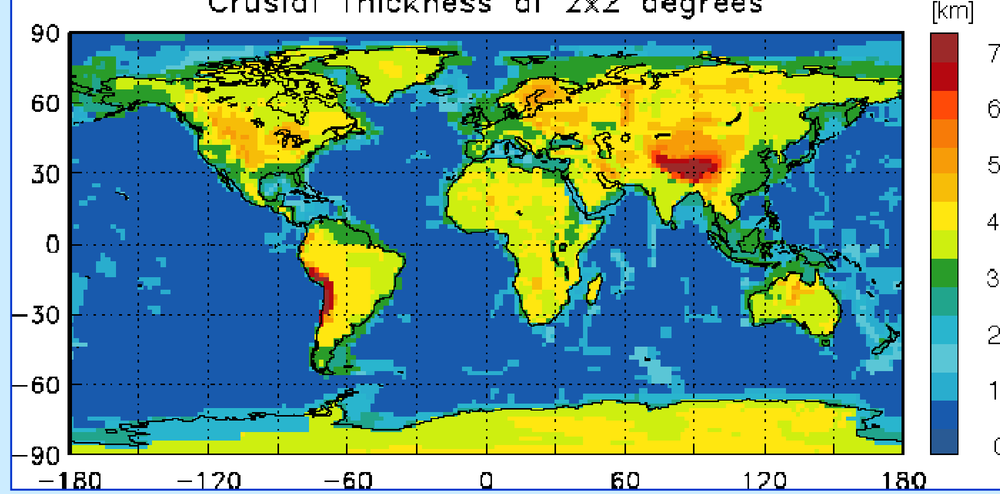
- Global masses of U, Th and K are estimated with accuracy of ±15%
- Radiogenic Heat and neutrino Luminosity can be immediately calculated:

	$M(10^{17}kg)$	$H_R(TW)$	$L_\nu(10^{24}/s)$
U	0.8	7.6	5.9
Th	3.1	8.5	5.0
^{40}K	0.8	3.3	21.6

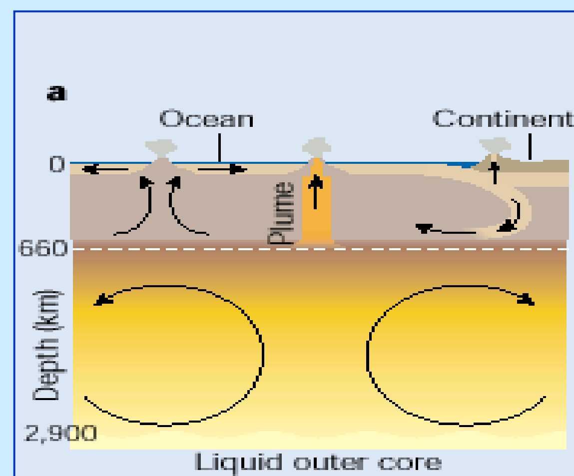
- Amounts U, Th and K inferred for the mantle are comparable to those observed in the crust
- Total radiogenic heat production (19 TW) is about ½ of observed heat flow, with comparable contribution from U and Th.
- Neutrino luminosity is dominated by K. Th and U give comparable contributions.

From luminosity to fluxes

- Anti neutrino fluxes are of the order $\Phi \approx L_\nu / S_{Earth} \approx 10^6\ cm^{-2}\ s^{-1}$ [as for solar B-neutrinos].
- The flux at a specific site can be calculated from total amounts of radioactive nuclei and their distribution.
- The crust contribution can be estimated by using geological maps of Earth crust (which distinguish CC from OC and also distinguish several layers in the CC).

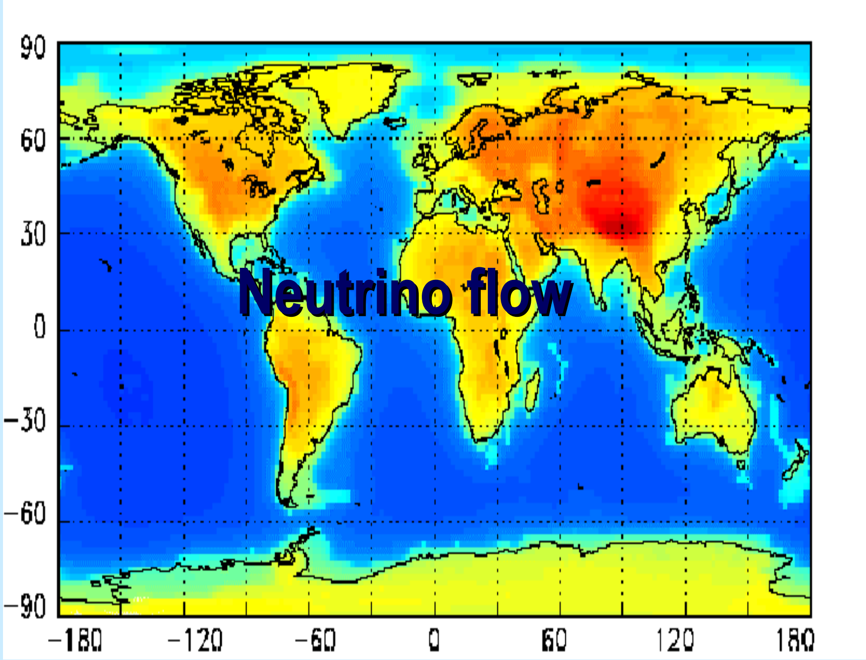


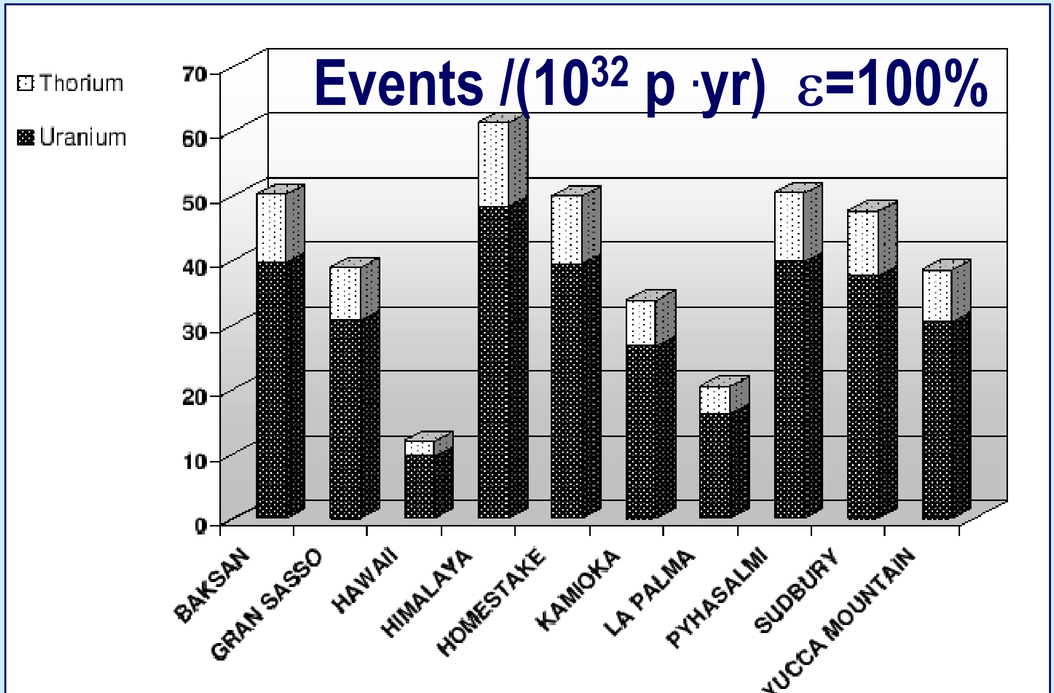
- The geochemist's mantle model is layered, the upper part being impoverished, abundance in the lower part being chosen so as to satisfy BSE mass balance.



A reference BSE geo-neutrino model*

- Event yields from U and Th over the globe have been calculated by using:
  - observational data for Crust and UM
  - the BSE constraint for LM
  - best fit ν-oscillation parameters
- Predicted events are about 30 per kiloton·yr, depending on location.
- ¾ originate from U, ¼ from Th decay chains

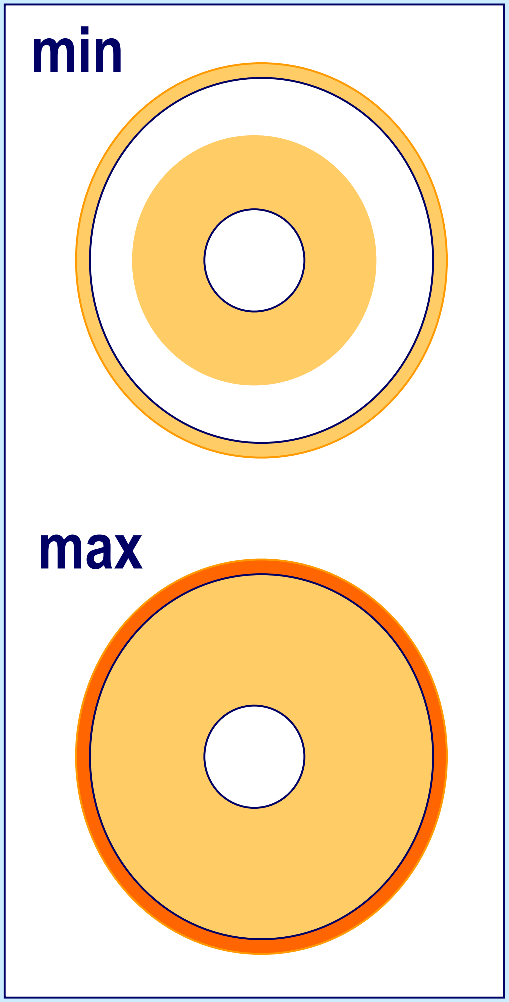




*Mantovani et al PRD-2003

Testing the Bulk Silicate Earth with geo-neutrinos*

- BSE fixes the total U mass (to ±15%)
- The minimal (maximal) flux is obtained by putting the sources as far (as close) as possible.
- The predicted flux contribution from distant sources in the crust and in the mantle is thus fixed within ±20%.
- A detailed investigation of the region near the detector has to be performed, for reducing the uncertainty from fluctuations of the local abundances.
- A five-kton detector operating over four years at a site relatively far from nuclear power plants can measure the geo-neutrino signal with 5% accuracy



It will provide a direct test of a fundamental geochemical paradigm

*Mantovani et al Hep-ph/0401085, JHEP

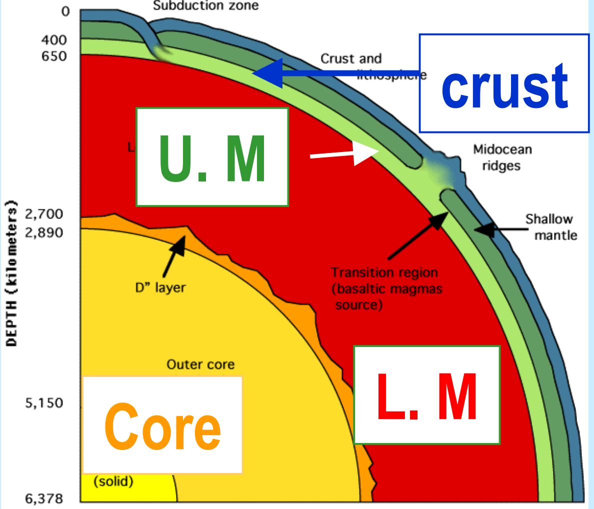
A word of caution

- CI based Bulk Silicate Earth (BSE) is the standard model of geochemists and its geo-neutrino predictions are rather well defined. **It does not mean they are correct.**
- Geo-neutrinos offer a probe for testing these predictions.
- Alternative models can be envisaged.
- A 40 TW (fully) radiogenic model (with ^{40}K:U:Th=1:1:4) at 40 TW is not excluded by observational data.
- It needs M(U, Th,K)=**2x** M_{BSE}(U,Th,K), most being hidden in LM

• Experiments should be designed so as to provide discrimination between BSE and FUL-RAD

Events /(10^{32} p ·yr) ε=100%				
	Hawaii	Kam	GS	Himalaya
BSE	12	33	39	62
Ful-Rad	27	53	58	85

Un-orthodox models: Potassium in the core?



•Earth looks depleted by a factor of seven with respect to CI meteorites.

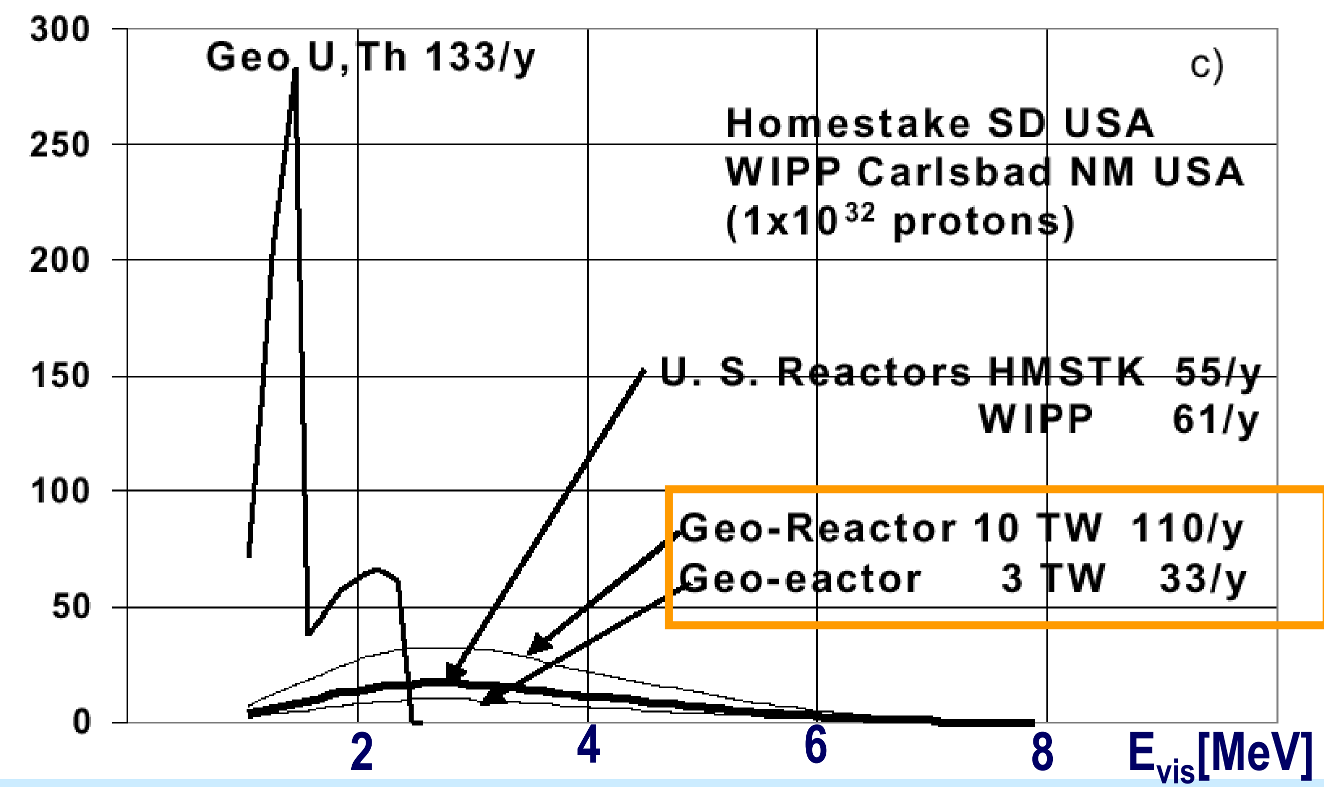
•It has been suggested that missing Potassium might have been buried in the Earth core (although litophile elements are not expected there).

•It could provide the energy source of the terrestrial magnetic field and a huge contribution to Earth energetics $H_r(K)=3.3 \times 7=23$ TW, solving the missing heat problem.

• The flux of Anti-ν from ^{40}K at KamLAND would be $10^8 cm^{-2}s^{-1}$, but they are below threshold for inverse β.

•Indirectly, one can learn on K from U and Th geo-neutrinos: if U and Th are found to satisfy energy balance, no place is left for ^{40}K.

Heretical models: a nuclear reactor in the core?



- Herndon proposed that a large fraction of Uranium has been collected at the center of the Earth, forming a natural 3-6 TW (breeder) reactor.
- Fission should provide the energy source for mag. field, a contribution to missing heat, and the source of "high" $^3He/^4He$ flow from Earth.
- Raghavan has considered possible detection by means of "reactor type antineutrinos": a 1Kton detector in US can reach 3σ in one year.
- Time dependence of man made reactor signal could be exploited.

KAMLAND: a first important glimpse

•From six months data ($0.14 \cdot 10^{32}$ p·yr) the KamLAND best fit is

N(U)=4 and N(Th)=5

•This results from 32 counts with P.E.< 2.6 MeV (20 attributed to reactor and 3 to B.G.) .

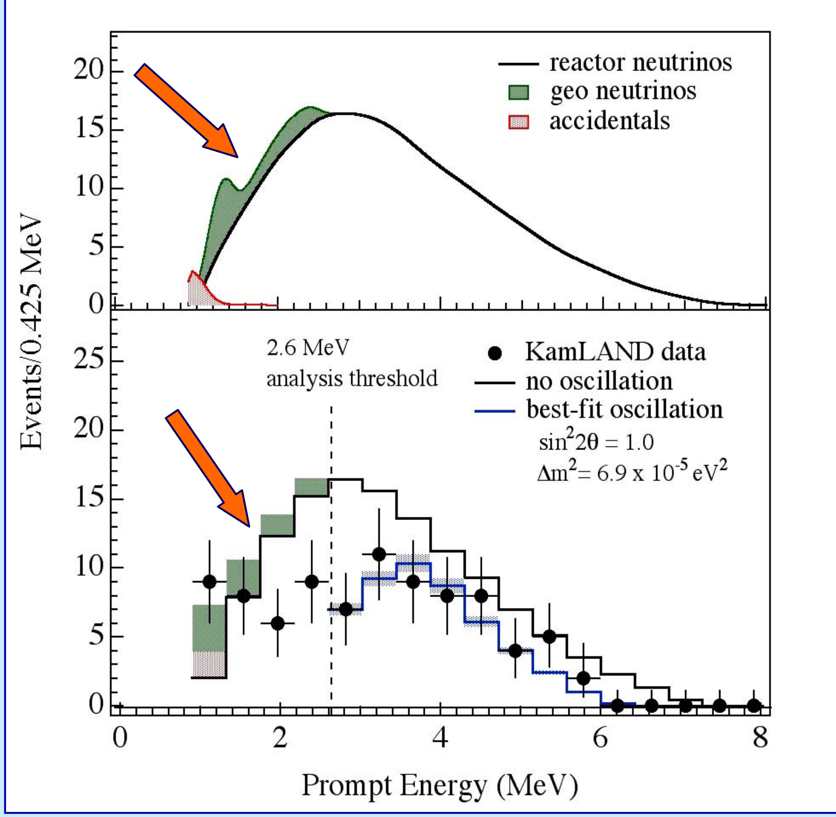
N(Th+U) = 9 ± √ (Counts) = 9 ± 6*

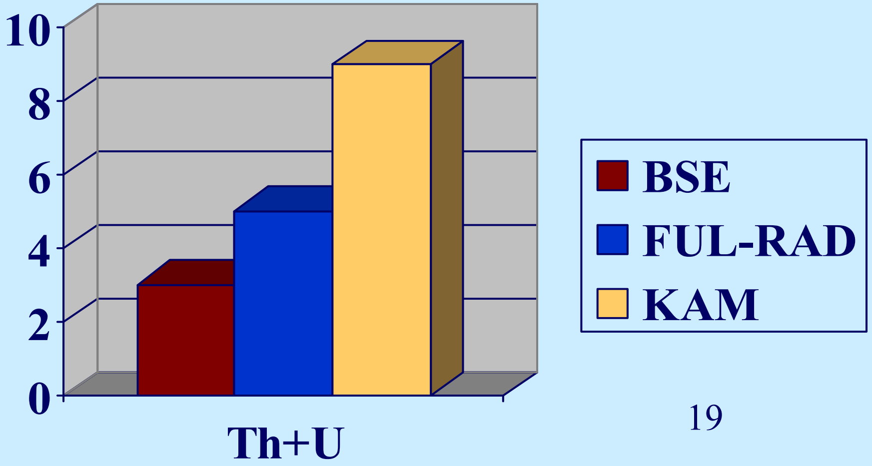
•The error* is dominated by fluctuations of reactor counts.

•The result is essentially consistent with any model , H_r=(0-100 TW).

•Wait and see…

* *our estimate*

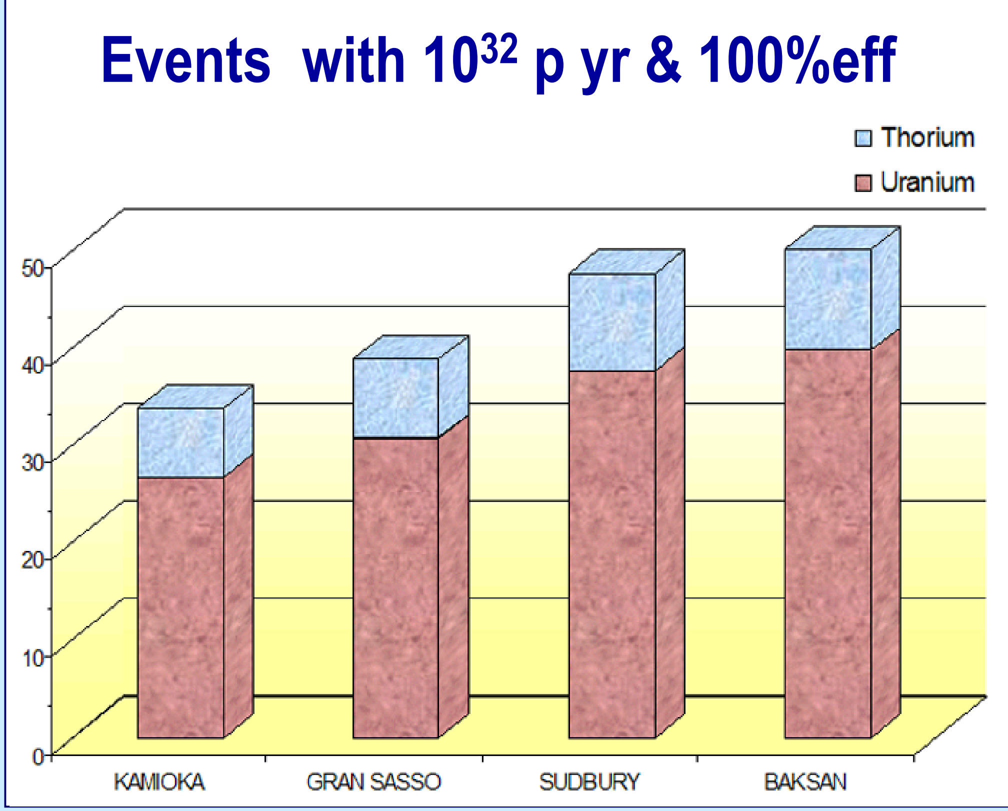




Prospects

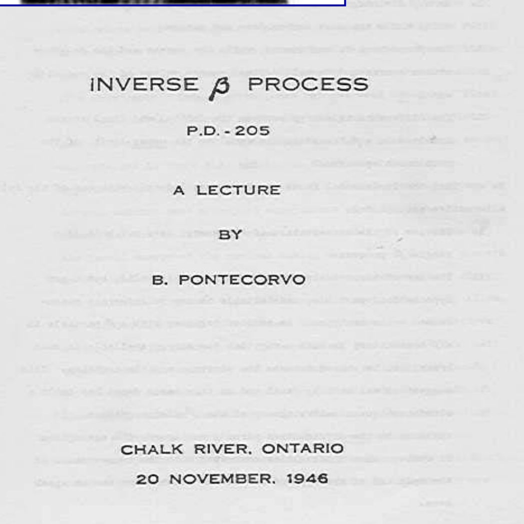
•A 30% uncertainty can be reached at Kamioka with 10 Kton ·yr exposure (or less since some reactor is switched off)

•Same uncertainty at Gran Sasso already with 3 Kton · yr (Reactor Background reduced by factor 6)



•At Baksan Mikaelyan et al. are considering 1Kton detector (R.B. reduced by 10)

•SNO is considering move to liquid scintillator after physics with heavy water is completed. With very low reactor background, well in the middle of Candadian shield (an “easy “geological situation) it will have have **excellent opportunities**.



F CANADA

GY

INVERSE β PROCESS

P.D. - 205

A LECTURE

BY

B. PONTECORVO

CHALK RIVER, ONTARIO

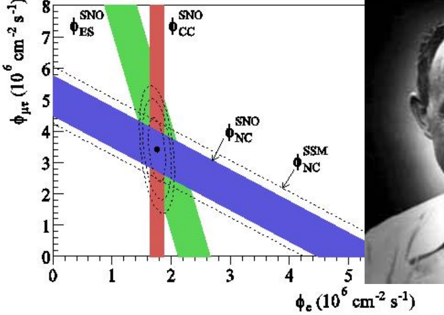
20 NOVEMBER, 1946

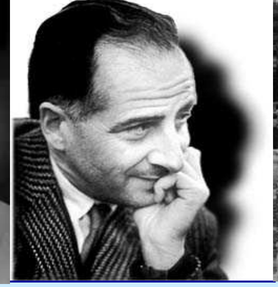
A lesson from Bruno Pontecorvo: from neutrons to neutrinos

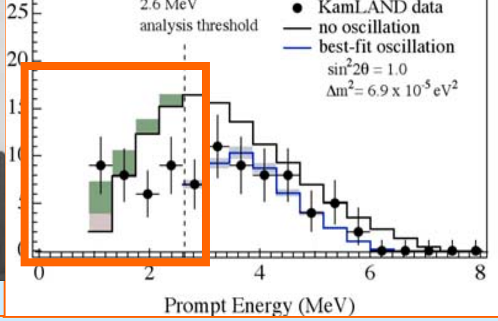
Neutron Well Logging - A New Geological Method Based on Nuclear Physics, Oil and Gas Journal, 1941, vol.40, p.32-33.1942.

- An application of Rome celebrated study on slow neutrons, **the neutron log** is an instrument sensitive to Hydrogen containing substances (=water and hydrocarbons), used for oil and water prospection.

- Now that we know the fate of neutrinos, we can learn a lot <u>from</u> neutrinos.
- The determination of the radiogenic contribution to Earth energetics is an important scientific question, possibily the first fruit we can get from neutrinos.



A new era of neutrino physics ?

• We have still a lot to learn for a precise description of the mass matrix (and other neutrino properties…), however…

• **Now we know the fate of neutrinos and we can learn a lot <u>from</u> neutrinos.**