GEONeutrinos

Whole Earth GeoScience

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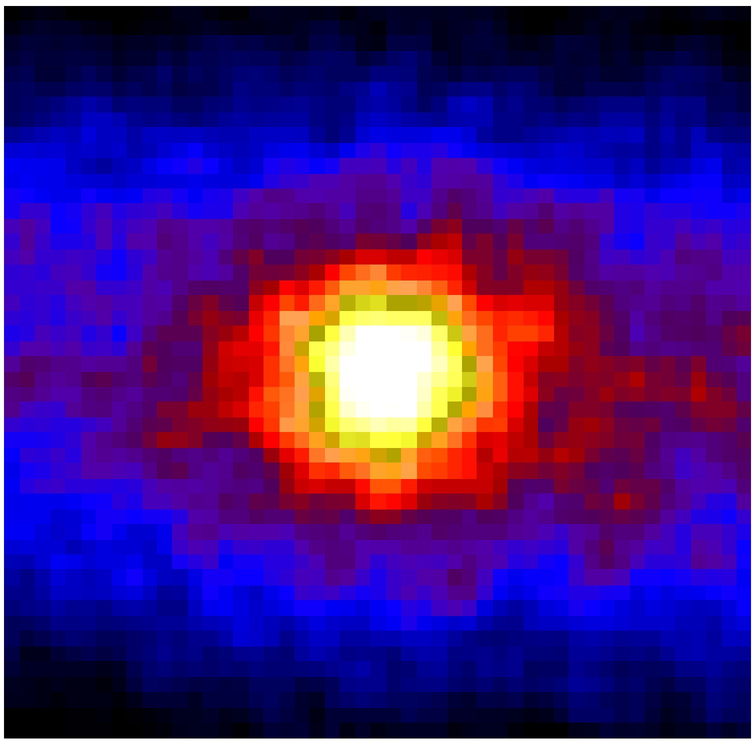
Geo Neutrino Science
—the immediate and larger context

Direct: Radioactivity and Heat flow in earth
Influence on Earth's magnetism
Context Evolution of the Earth
Planetary structures and science
Evolution of the Solar System

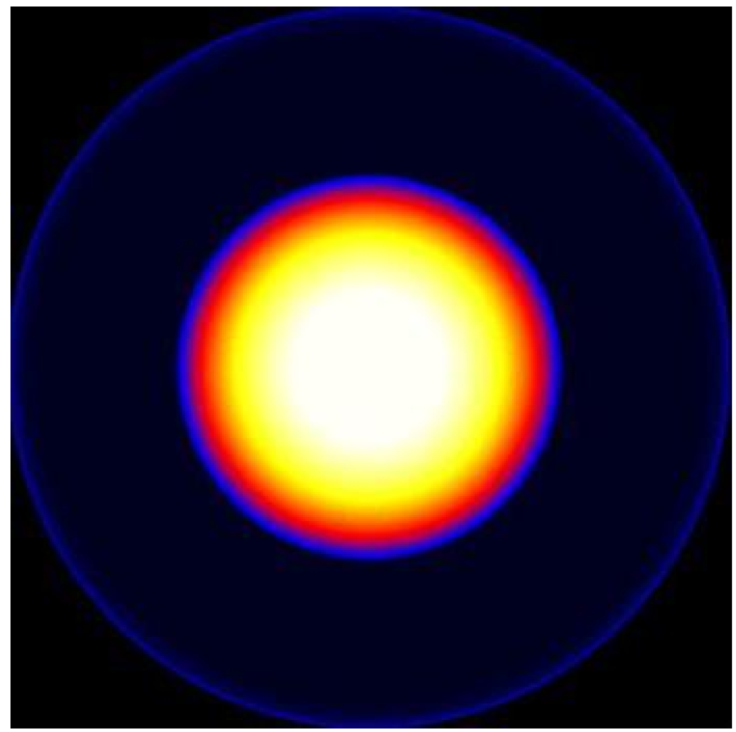
Solar System Neutrino Astronomy

Sun- SK



SK

Earth--?



R. SVOBODA

Neutrino Geophysics—New Science Now

TERRESTRIAL RADIOGENIC SOURCES

1) Radioactivity of U and Th (and others)	Earth's Crust, Mantle
2) Fission Reactor ??	Inner Core
3) Man-made Power Reactors	Surface

ALL ABOVE SOURCES EMIT ANTINEUTRINOS

- **ANTINEUTRINO SPECTROSCOPY CAN PROBE THE EARTH**
- **Just as neutrino spectroscopy has probed the Sun**
- **TECHNOLGY MATURE AND AVAILABLE**
- **PARASITIC MEASUREMENT IN DETECTORS FOR OTHER PHYSICS**

Long Literature: Problem: G. Elders (1966) G. Marx (1969)
Detection methods; Krauss et al Nature 310 191 (1964) and references theirin
Spectroscopy & Specific Model Tests: Raghavan et al PRL 80 635 1998
Rotschild et al Geophys . Res. Lett 25 1083 1998

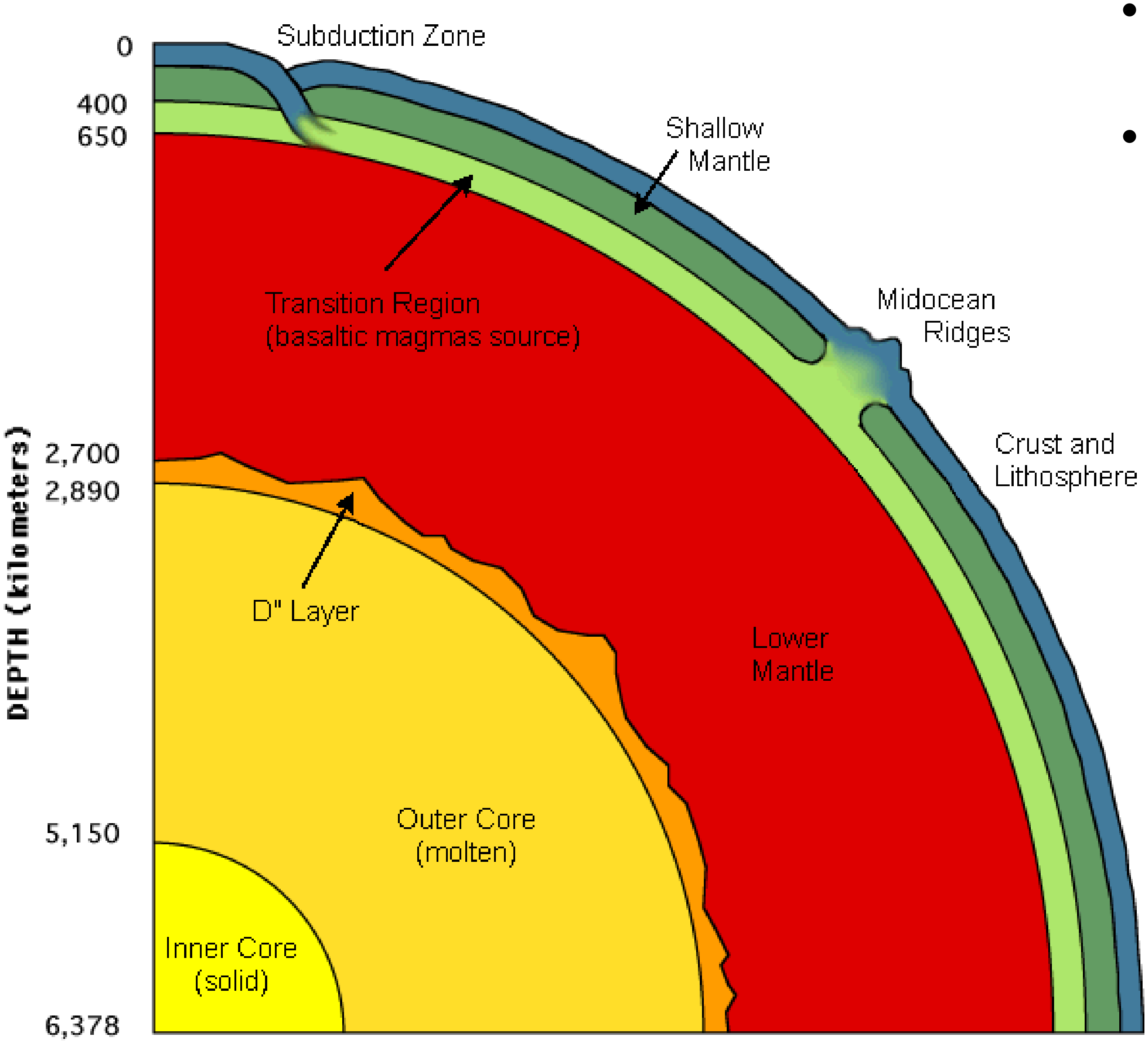
Geo Neutrino Science

Snapshot of Developments and Outlook

- Scientific Motivation & Background Long Delineated
- Triumphal Success of the Solar Neutrino Experience
- March of Detector Technology
- Preliminary GeoNeutrino Detection at Kamland

- Interaction with Geoscience community and their enthusiastic support
- Highlight-- Hawaii Meeting on Neutrino Geoscience
- Marching orders for forging ahead

Inside the Earth-The Present View



Geophysical Models from

- Density profile (seismic data
- Field probes (10 km/ magma outflows)
- Geochemistry (field samples meteoric samples)

Bulk Silicate Earth Model

Preliminary Reference Earth Model

Laboratory Experiments suggesting potassium-iron alloys in the core

Geo Neutrino Mission Whole Earth Data on Radioactivity

Geo Neutrino Mission Goals

- Whole Earth Analytical Chemistry—
  U/Th ratio
- Whole Earth Data on distribution of
  terrestrial Radioactivity
- Whole earth distribution of terrestrial
  Heat Flow
- Check present “Standard Earth Models”
- Discovery of non-standard features
  Fission Reactor in Core?

Table 4.1 Estimated concentrations of radioactive elements in different regions of the earth

Region	Total mass $[10^{21}$ kg]	Concentration U[ppb]	Th[ppb]	K[ppm]
Oceanic crust[7]	6	100	220	1250
Continental crust[8]	19	1400	5600	15600
Mantle	3985	13.6	53.0	165
BSE[9]	4010	20.3	79.5	240

Table 4.2 Radiogenic heat production rates in different regions of the earth

Region	U [TW]	Th [TW]	K [TW]	Total [TW]
Oceanic crust	0.06	0.03	0.03	0.12
Continental crust	2.61	2.81	1.04	6.46
Mantle	5.32	5.57	2.30	13.19
BSE	7.99	8.42	3.37	19.78

Table 4.3 Crustal conductive heat dissipation rates

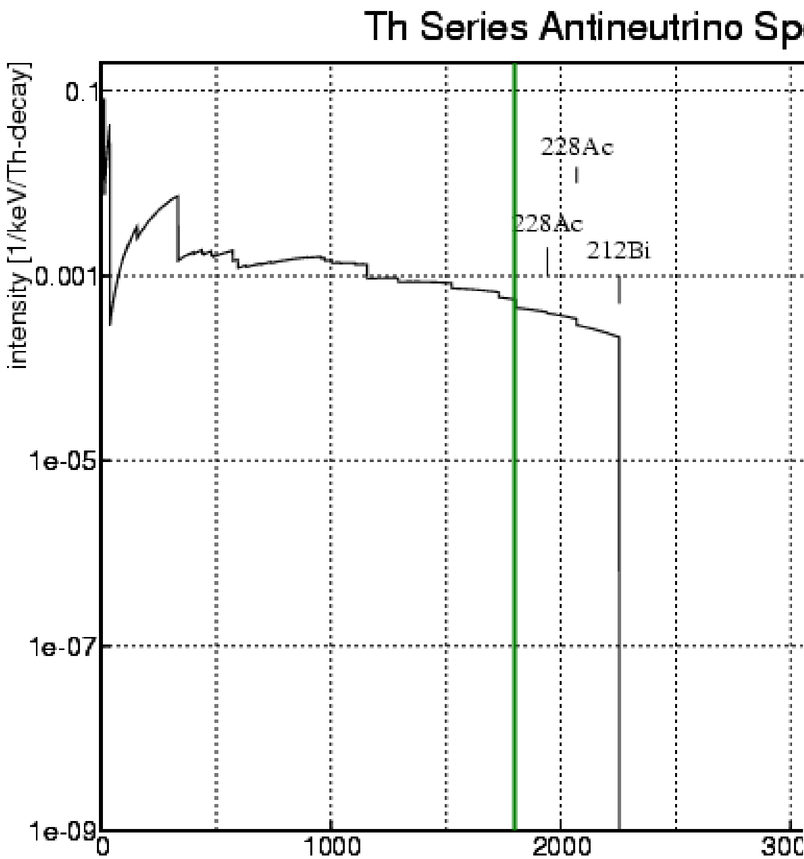
Region	Heat Dissipation Rate $[\mathrm{W\,m^{-2}}]$	Area $[\mathrm{m}^2]$	Global Heat Dissipation Rate [TW]
Oceanic crust	$101 \pm 2.2 \times 10^{-3}$	3.1×10^{14}	31.2 ± 0.7
Continental crust	$65 \pm 1.6 \times 10^{-3}$	2.0×10^{14}	13.0 ± 0.3
Whole Earth	$87 \pm 2.0 \times 10^{-3}$	5.1×10^{14}	44.2 ± 1.0

Principal Origins of Geoneutrinos

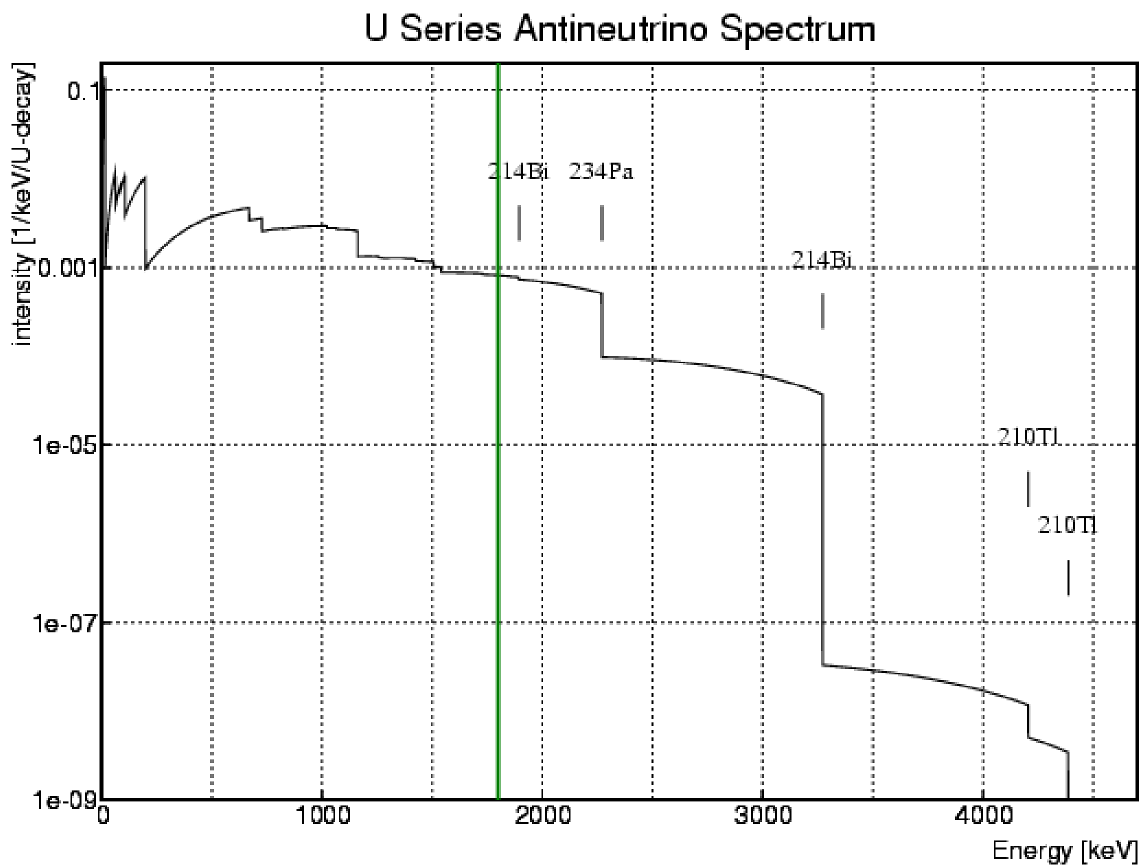
- The Continental Crust 4
- The Oceanic Crust/Mantle 1
- Core? >0?

Handles for sorting out

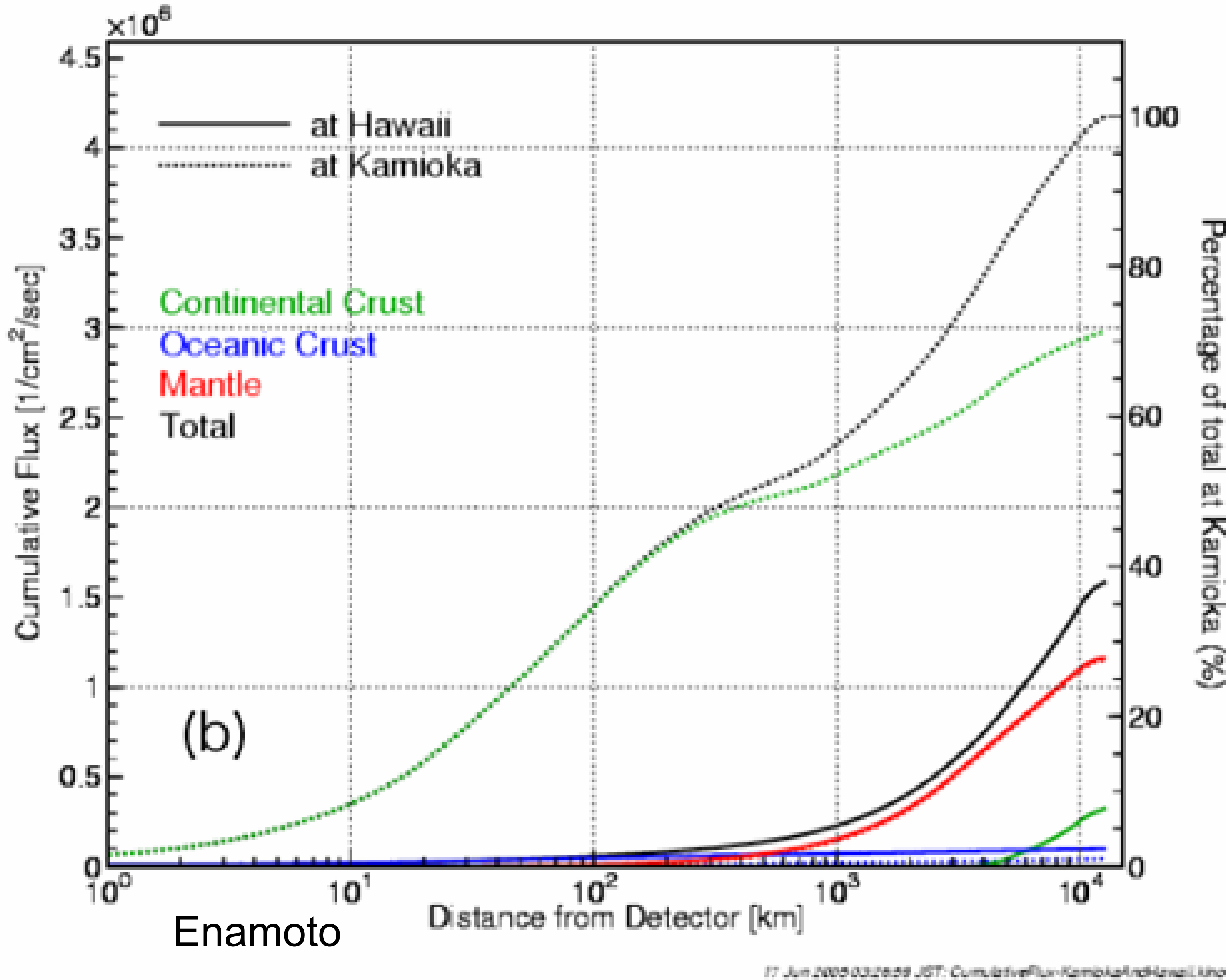
Geo graphical Location of detecto
Directionality of antineutrinos
(separate surface crustal and deeper origins)



A;ntineutrino Spectra from\
The Earth's Interior



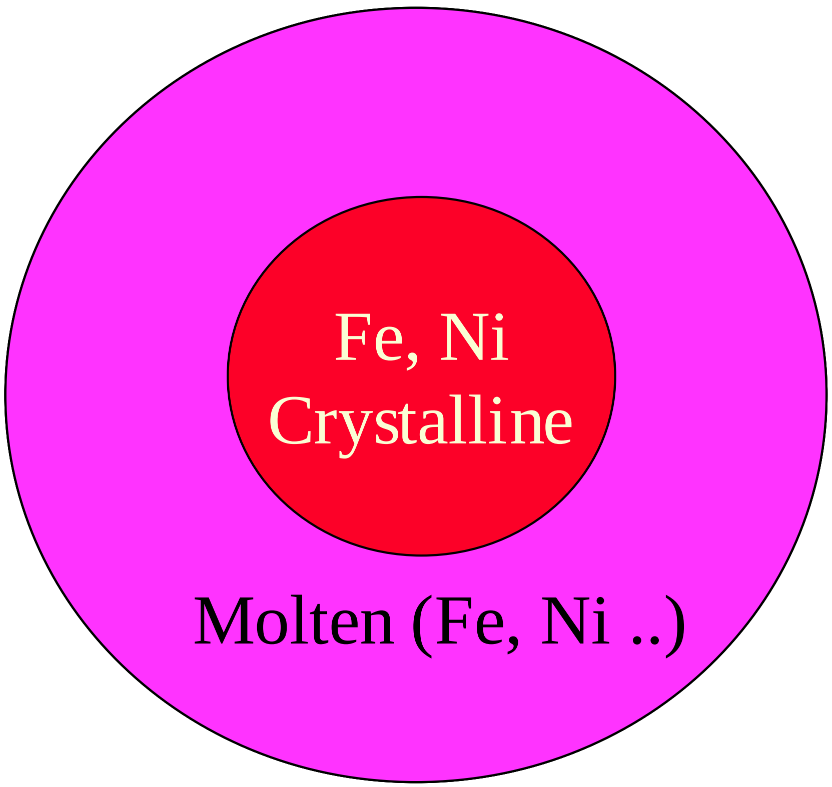
Source discrimination by geographical location of detector



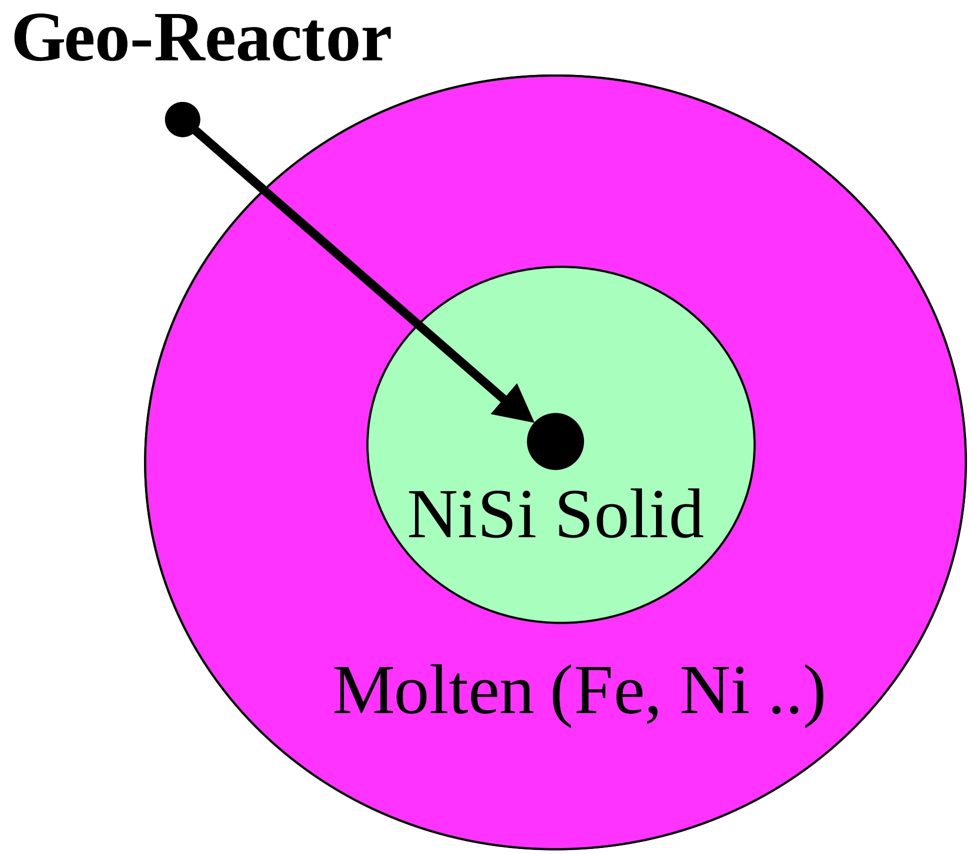
Enamoto

Something rotten in the Core?

Core—Present Model



Core-New Model



Fission Reactor at Center of the Earth ?

Herndon, PNAS 93 646 (1996)
Hollenbach and Herndon PNAS 98 11085 2001

Controversial!

Proposed as Source of Energy of the Earth's Magnetic field

Caution: Highly Controversial—not accepted by Geochemists

BASIC MODEL:
NiSi INNER CORE OF THE EARTH

•CHEMISTRY of NiSi FORMATION RESULTS IN HIGHLY CONCENTRATED CONDENSATE OF U/Th AT CENTER

•**High 235/238 Isotopic Ratio 5 gY AGO**
Starts Natural Fission Chain Reaction

•FAST NEUTRON BREEDER REACTIONS Sustain fission to the present day

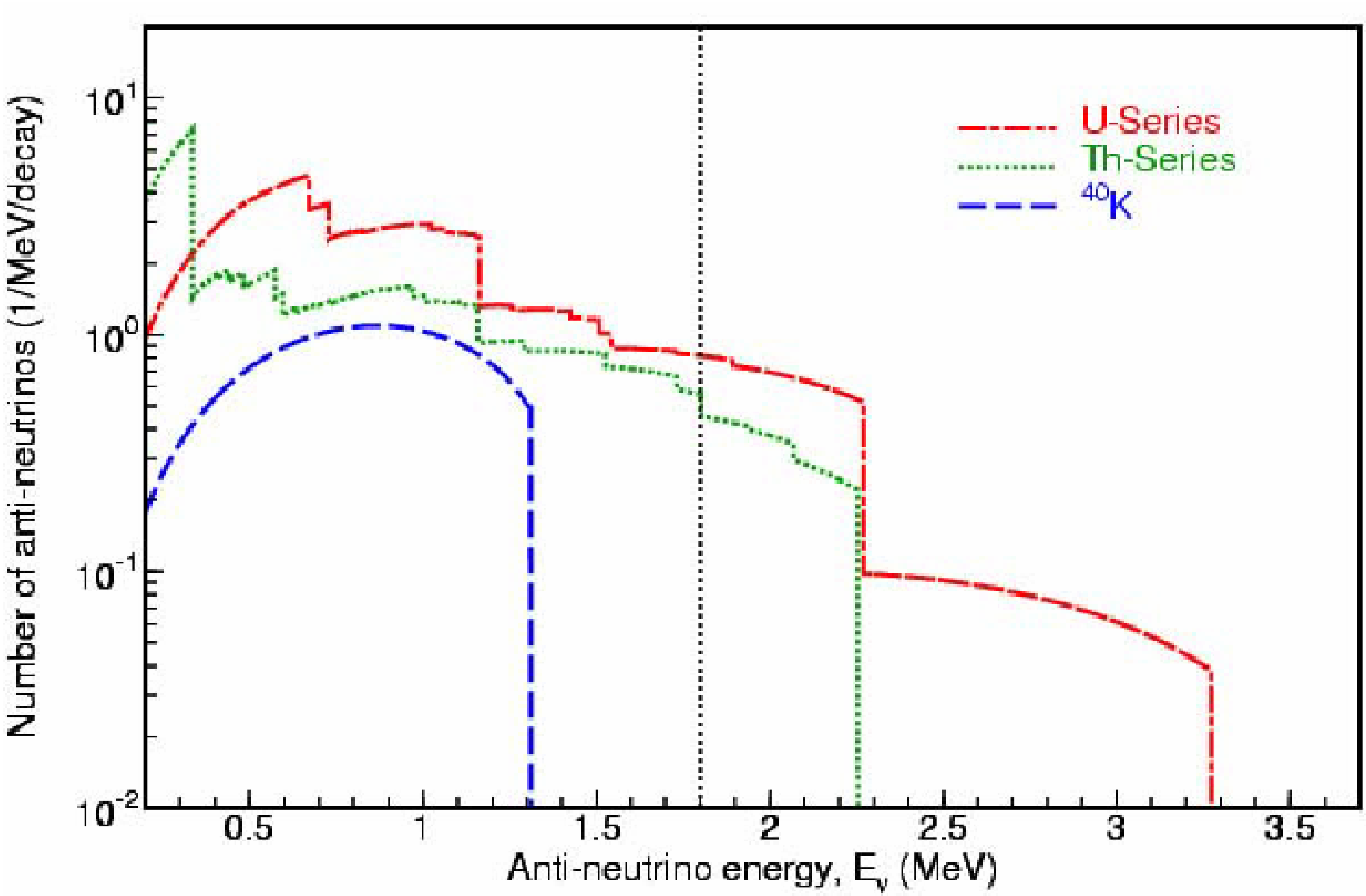
•3-10 TW energy output at present--

•***ONLY WAY TO DIRECTLY TEST MODEL--***
•***DETECT FISSION ANTINEUTRINO SPECTRUM***

What about Potassium—Why important

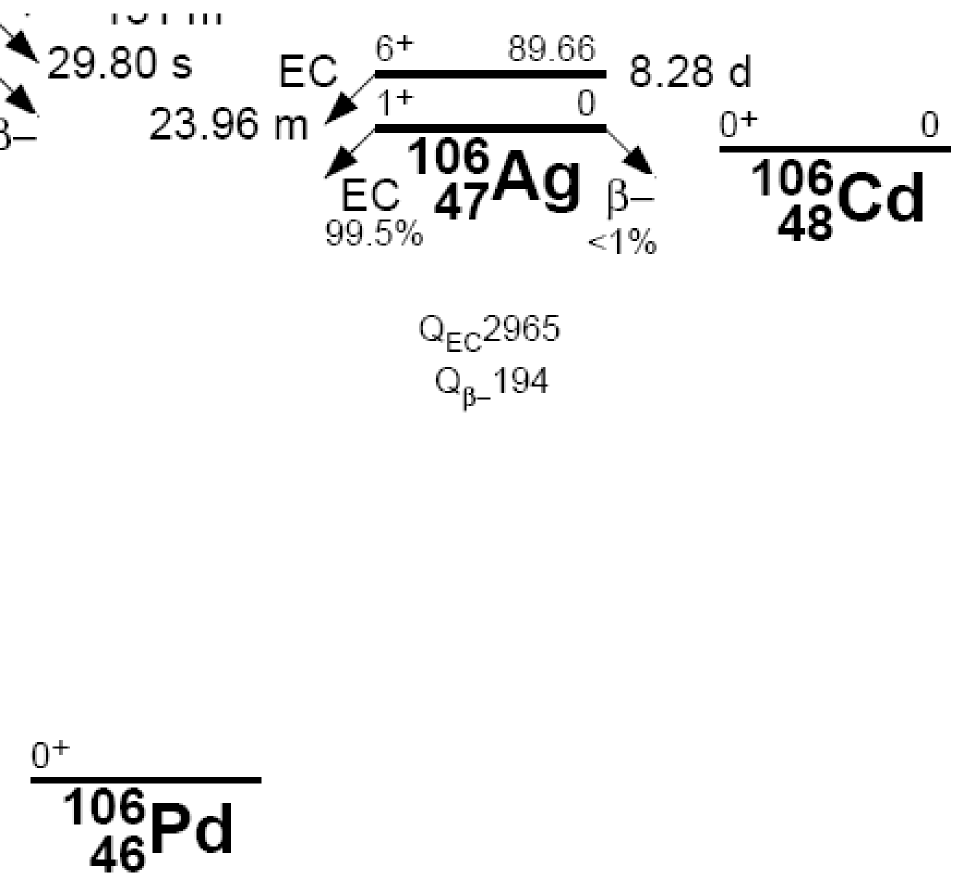
- 16% of the radiogenic heat is from ^{40}K (based upon models)
- largest flux!
- NEW---K may reside in the Earth's core [V. Rama Murthy)
- K/U ratio in chondrites > in the crust
- where is the potassium? do we really know how much there is?

Potassium Spectrum (Krauss et al 1984)

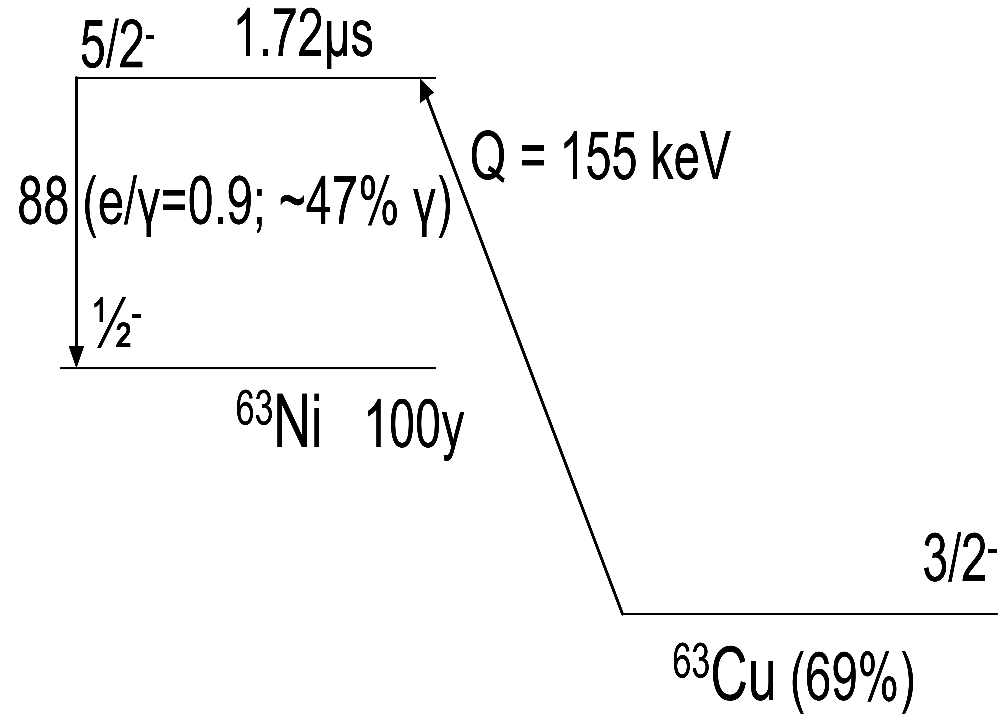


How to detect Potassium from the Earth

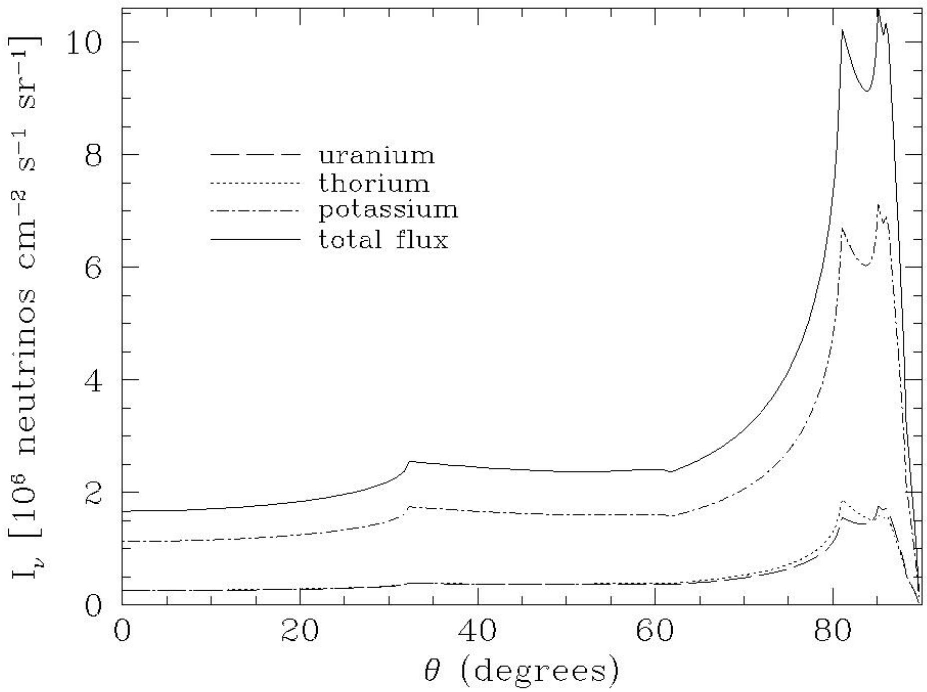
2 ideas after long search

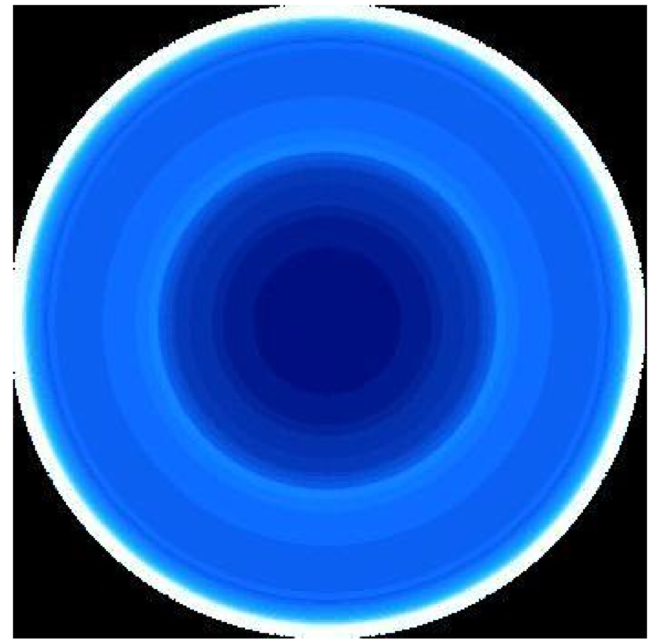


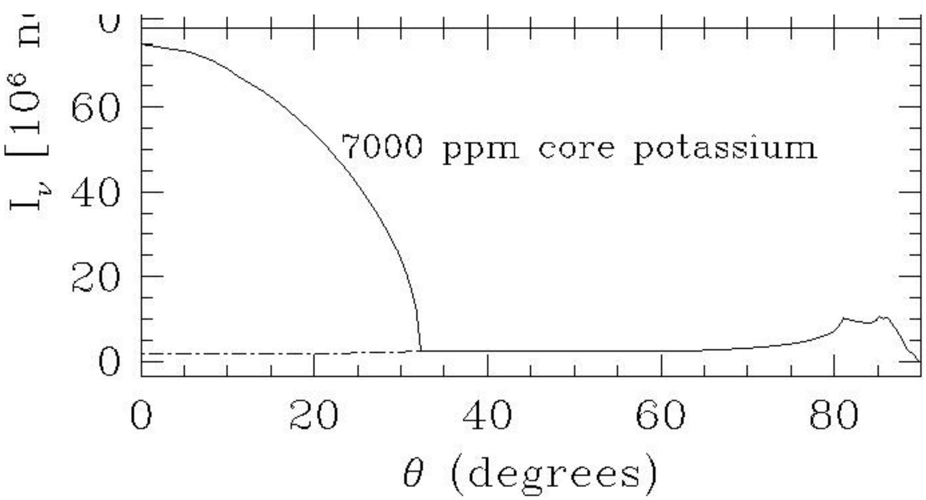
Chen (Hawaii Mtg)

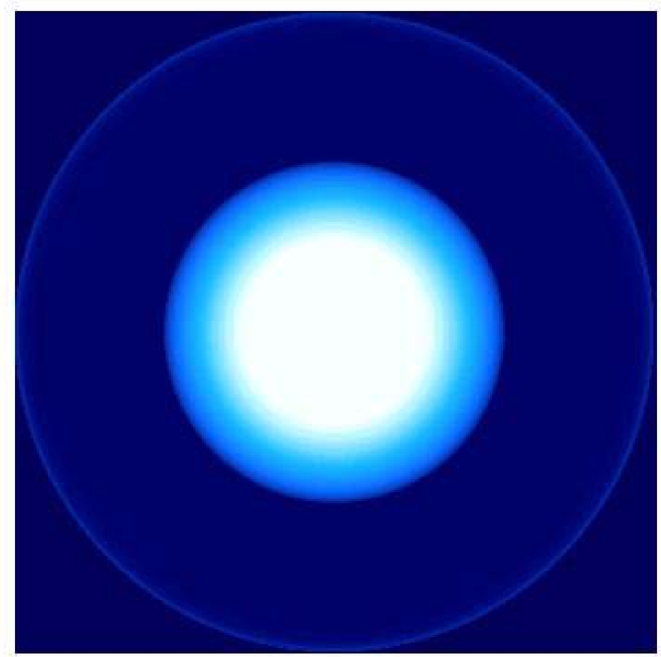


(RSR (unpublished Notes)



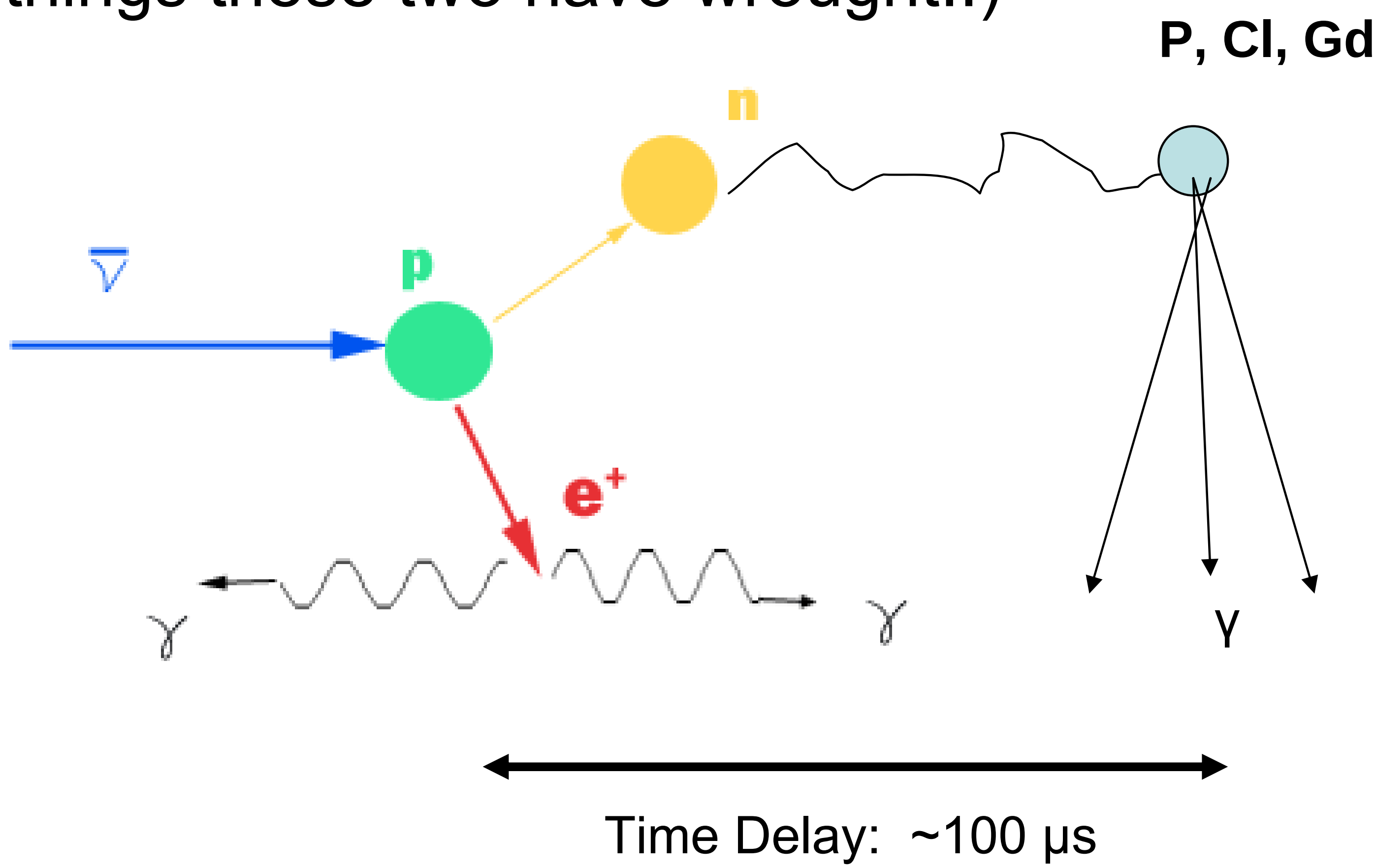




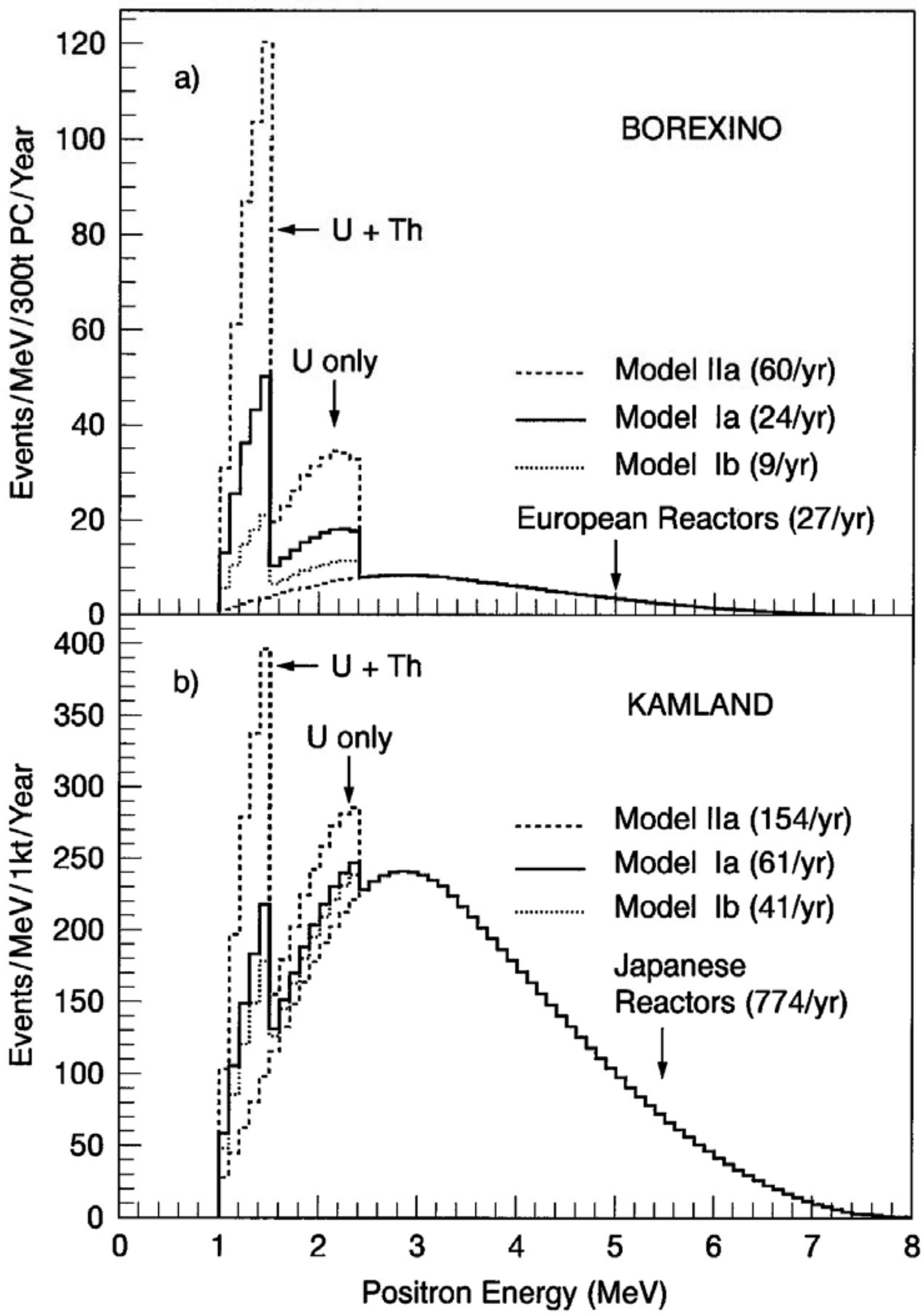


Hochmuth /TUM

Antineutrino Detection:
Classic Reines-Cowan Reaction with Coincidene tag
(The things these two have wrought!!)



Threshold: 1.8 MeV → U, Th visible: K is not



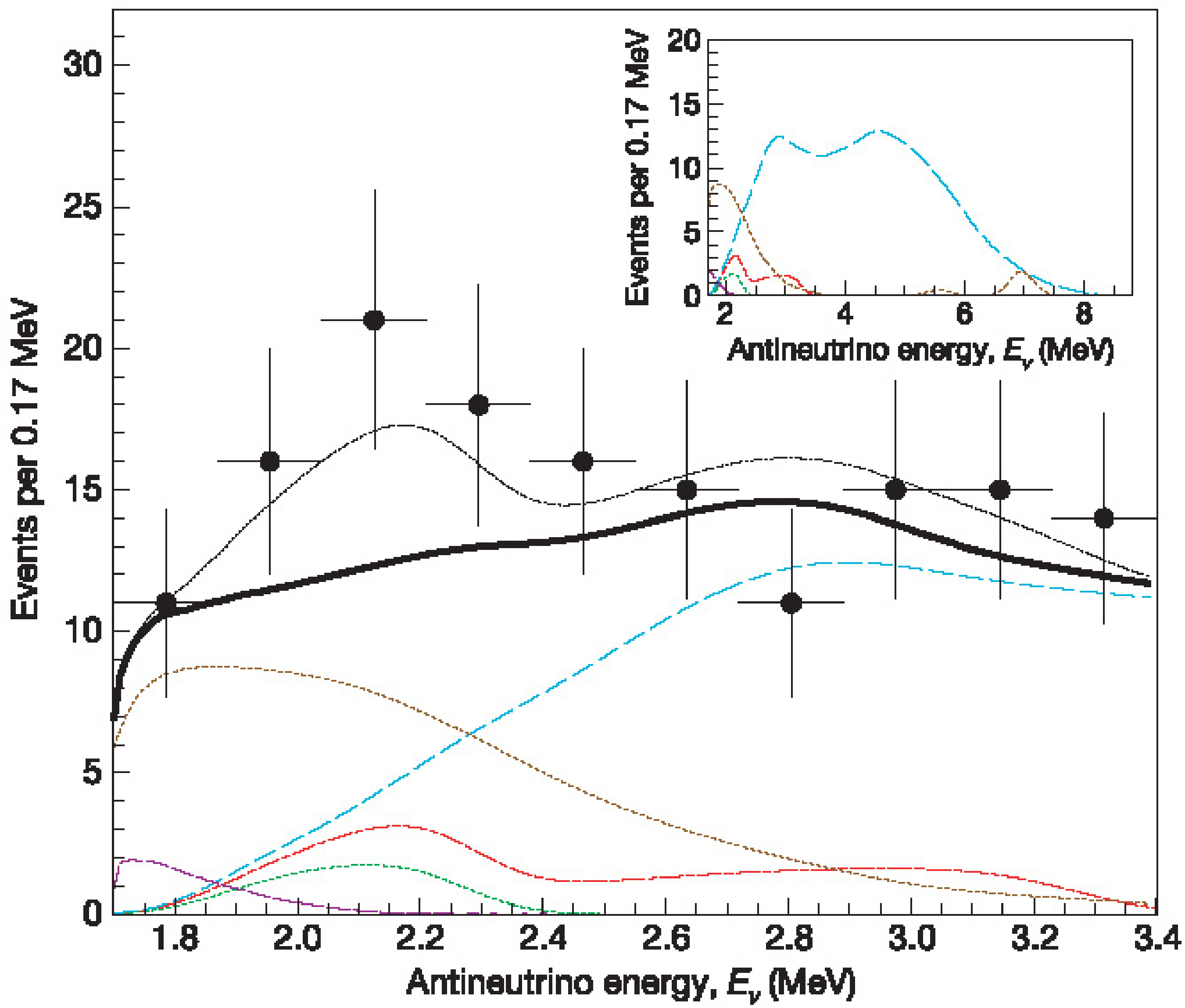
Raghavan et al (1998)

GeoNeutrino Model Predictions

Notable Features:

•U and Th can be separately Measured
•Importance of background from Surface power reactors in the vicinity

The Kamland Result: Birth of geo neutrino Science



Prediction vs Preliminary Result

No Geoneutrino Problem ! So far….

$$S = \Phi(\mathrm{TNU}) \times 0.85(\mathrm{kT/TNU})$$

Raghavan *et al.* (1998)	Enomoto *thesis* (2005)
U(ppm) = 0.01	U(ppm) = 0.012
Φ(U) = 7.3 TNU*	Φ(U) = 8.1 TNU
Φ(Th) = 1.9 TNU*	Φ(Th) = 2.2 TNU
Φ(tot) = 9.2 TNU*	Φ(tot) = 10.3 TNU
S = 7.9 per kT-y	S = 8.8 per kT-y

S = 7.9 per kT-y (*Mantovani this workshop*)
S ~ 8.5 per kT-y (*Lisi this workshop)*

* Corrected for oscillation

S. Dye (HI meeting)

What Next:
International Neutrino Community Enthusiastic About launching vigorous GeoNeutrino Program

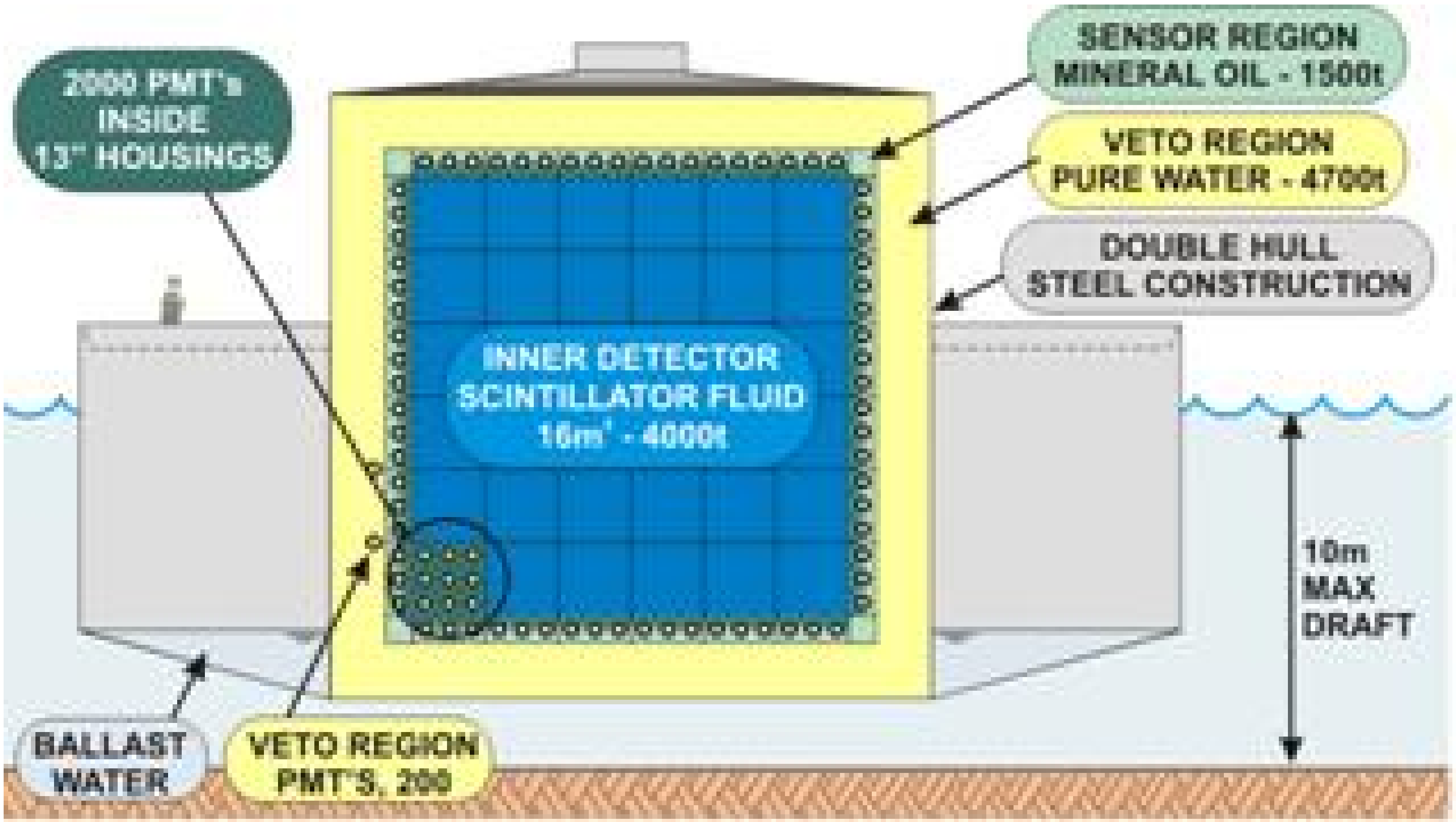
Scintillation Technology

Existing:
BOREXINO
SNO+: Continental Crust

Dedicated New (Typical ~1 kT)
Hanahana (Hawaii): Objedtive: Oceanic/Mantle Sources
DUSEL (Homestake, Henderson): Continental Crust
“Geomanda” : Very Large Scint: South Pole
EARTH (Curcao/ Multilocation)

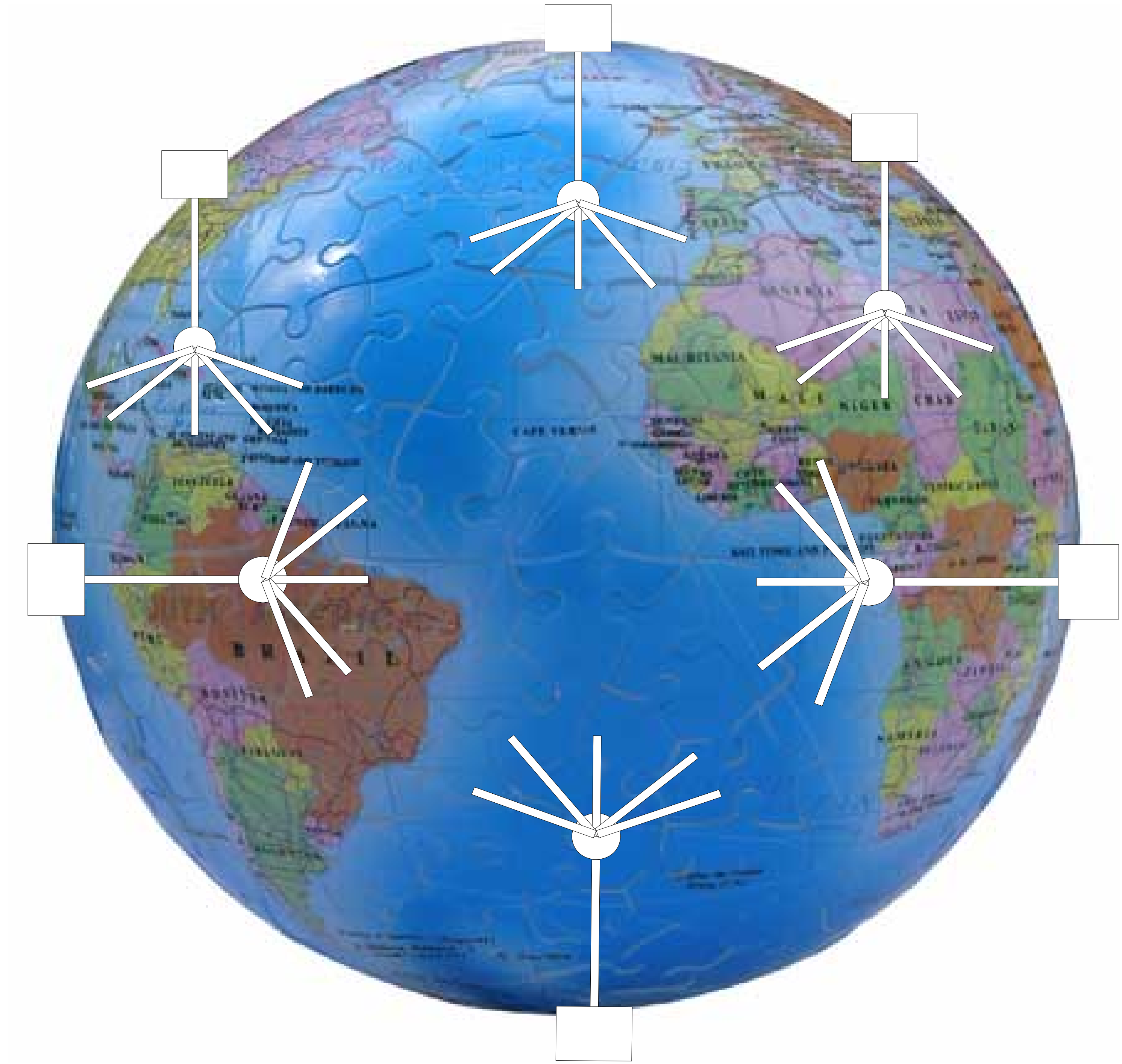
Parasitic New 50 -100 kT multipurpose Detectors
LENA (Europe)
HSD (US)

HANOHANA

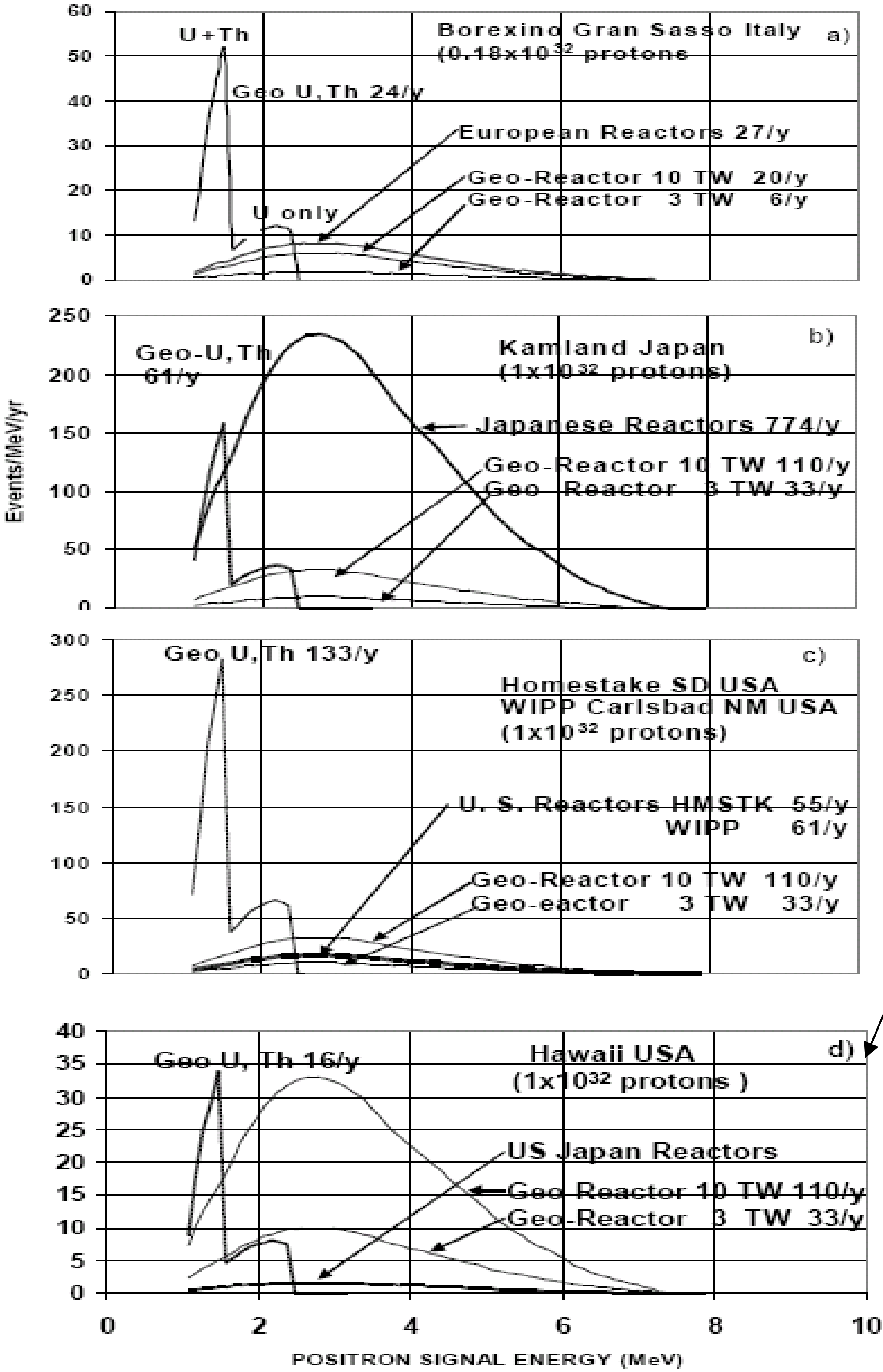


2000 PMT's INSIDE 13" HOUSINGS
SENSOR REGION MINERAL OIL - 1500t
VETO REGION PURE WATER - 4700t
DOUBLE HULL STEEL CONSTRUCTION
INNER DETECTOR SCINTILLATOR FLUID
10m MAX DRAFT
BALLAST WATER
VETO REGION PMT'S, 200

EARTH



Geographical Location and Neutrino Background



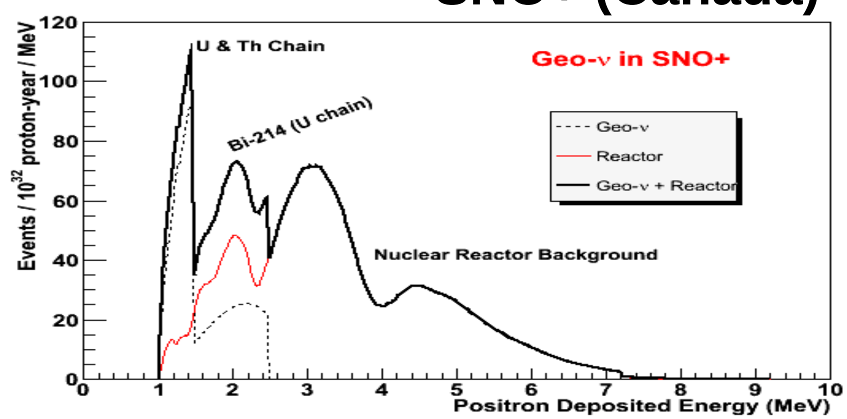
Borexino/LNGS

KamLand/Japan

Homestake/Henderson (DUSEL US)

Hanohana (HI US)

SNO+ (Canada)



Geo Neurtrinos Science

The hour is at hand
The means will be built

The triumph will return
Know the Earth as well as the Sun