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 -- ?
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
• TECHNOLOGY MATURE AND AVAILABLE
• PARASITIC MEASUREMENT IN DETECTORS FOR OTHER PHYSICS

Detection methods; Krauss et al Nature 310 191 (1964) and references therein
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
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

<table>
<thead>
<tr>
<th>Region</th>
<th>Total mass $[10^{21} \text{ kg}]$</th>
<th>U [ppb]</th>
<th>Th [ppb]</th>
<th>K [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceanic crust[7]</td>
<td>6</td>
<td>100</td>
<td>220</td>
<td>1250</td>
</tr>
<tr>
<td>Continental crust[8]</td>
<td>19</td>
<td>1400</td>
<td>5600</td>
<td>15600</td>
</tr>
<tr>
<td>Mantle</td>
<td>3985</td>
<td>13.6</td>
<td>53.0</td>
<td>165</td>
</tr>
<tr>
<td>BSE[9]</td>
<td>4010</td>
<td>20.3</td>
<td>79.5</td>
<td>240</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceanic crust</td>
<td>0.06</td>
<td>0.03</td>
<td>0.03</td>
<td>0.12</td>
</tr>
<tr>
<td>Continental crust</td>
<td>2.61</td>
<td>2.81</td>
<td>1.04</td>
<td>6.46</td>
</tr>
<tr>
<td>Mantle</td>
<td>5.32</td>
<td>2.30</td>
<td>13.19</td>
<td>19.78</td>
</tr>
<tr>
<td>BSE</td>
<td>7.99</td>
<td>3.37</td>
<td>19.78</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 Crustal conductive heat dissipation rates

<table>
<thead>
<tr>
<th>Region</th>
<th>Heat Dissipation Rate $[\text{W m}^{-2}]$</th>
<th>Area $[\text{m}^2]$</th>
<th>Global Heat Dissipation Rate $[\text{TW}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceanic crust</td>
<td>$101 \pm 2.2 \times 10^{-3}$</td>
<td>$3.1 \times 10^{14}$</td>
<td>$31.2 \pm 0.7$</td>
</tr>
<tr>
<td>Continental crust</td>
<td>$65 \pm 1.6 \times 10^{-3}$</td>
<td>$2.0 \times 10^{14}$</td>
<td>$13.0 \pm 0.3$</td>
</tr>
<tr>
<td>Whole Earth</td>
<td>$87 \pm 2.0 \times 10^{-3}$</td>
<td>$5.1 \times 10^{14}$</td>
<td>$44.2 \pm 1.0$</td>
</tr>
</tbody>
</table>

Principal Origins of Geoneutrinos

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

Handles for sorting out Geo graphical Location of detection and Directionality of antineutrinos (separate surface crustal and deeper origins)
A;ntineutrino Spectra from\nThe Earth’s Interior

Th Series Antineutrino Spectrum

U Series Antineutrino Spectrum
Source discrimination by geographical location of detector

(b)

Enamoto
Something rotten in the Core?

Core—Present Model

Fe, Ni Crystalline

Molten (Fe, Ni ..)

Core—New Model

NiSi Solid

Geo-Reactors

Molten (Fe, Ni ..)
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 5gY AGO

  Starts Natural Fission Chain Reaction

• FAST NEUTRON BREEDER REACTIONS Sustain fission to the present $\gamma$

• 3-10 TW energy output at present $\delta$

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

Threshold: $1.8 \text{ MeV} \rightarrow U, \text{ Th visible: } K \text{ is not}$
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….

\[ S = \Phi(\text{TNU}) \times 0.85(kT/\text{TNU}) \]

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>U(ppm) = 0.01</td>
<td>U(ppm) = 0.012</td>
</tr>
<tr>
<td>( \Phi(U) = 7.3 \text{ TNU}^* )</td>
<td>( \Phi(U) = 8.1 \text{ TNU} )</td>
</tr>
<tr>
<td>( \Phi(\text{Th}) = 1.9 \text{ TNU}^* )</td>
<td>( \Phi(\text{Th}) = 2.2 \text{ TNU} )</td>
</tr>
<tr>
<td>( \Phi(\text{tot}) = 9.2 \text{ TNU}^* )</td>
<td>( \Phi(\text{tot}) = 10.3 \text{ TNU} )</td>
</tr>
<tr>
<td>S = 7.9 per kT-y</td>
<td>S = 8.8 per kT-y</td>
</tr>
</tbody>
</table>

\[ S = 7.9 \text{ per kT-y (Mantovani this workshop)} \]
\[ S \sim 8.5 \text{ per kT-y (Lisi this workshop)} \]

* 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): Objective: 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)
Geographical Location and Neutrino Background

Borexino/LNGS

KamLand/Japan

Homestake/Henderson (DUSEL US)

Hanohana (HI US)

SNO+ (Canada)
Geo Neutrinos Science

The hour is at hand
The means will be built

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