What are Geoneutrinos?

Electron anti-neutrinos from the Earth, products of natural radioactivity.

Geoneutrino flux
- typical flux $6 \times 10^6$ cm$^{-2}$ s$^{-1}$

Quarks

Leptons

Anti-neutrino -vs- neutrino
$\beta^-$ decay process (e.g., U, Th, K, Re, Lu, Rb)
Geoneutrinos

$\overline{\nu}_e + p^+ \rightarrow n + e^+$

1.8 MeV Energy Threshold

Only geoneutrinos from $^{238}\text{U}$ and $^{232}\text{Th}$ are detectable
MeV-Scale Electron Anti-Neutrino Detection

Production in reactors and natural decays

Key: 2 flashes, close in space and time, 2nd of known energy, eliminate background

Detection

- Standard inverse β-decay coincidence
- \( E_\nu > 1.8 \text{ MeV} \)
- Rate and spectrum - no direction
Antineutrinos - Geoneutrinos

\[ \bar{\nu}_e + p^+ \rightarrow n + e^+ \]

Ideal spectrum, assuming Th/U = 4 and closest reactor ~1000 km
• **KamLAND** was designed to measure reactor antineutrinos.

• Reactor antineutrinos are the most significant contributor to the total signal.
Present Liquid Scintillator Detectors

KamLAND, Japan (1kt)

SNO+, Canada (1kt)

Borexino, Italy (0.3kt)

from Mar ‘02 to Nov ‘12

116$^{+28}_{-27}$

under construction

(online 2014?)

14.3$^{±4.4}$

from Dec ‘07 to Aug ‘12
Can Physics Help Geoscience?

TNU: geo-ν̅ event seen by a kiloton detector in a year
Summary of geoneutrino results

Silicate Earth Models

Cosmochemical: uses meteorites – 10 TW
Geochemical: uses terrestrial rocks – 20 TW
Geodynamical: parameterized convection – 30 TW

TW scales relative to $U$
$10, 20, 30 \text{ TW} \approx 10, 20, 30 \text{ ppb}$
Estimating the geoneutrino flux at SNO+

- Geology
- Geophysics

Our prediction for SNO+ is in Huang et al 2014

G-cubed (in review) and arXiv arxiv.org/abs/1404.6692v1

<table>
<thead>
<tr>
<th></th>
<th>Local: Near field crust (closest six 2°x2° tiles)</th>
<th>Other: Far field crust (oceanic + continental)</th>
<th>Total signal*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNU</td>
<td>15.6 ± 5.3</td>
<td>15.1 ± 2.4</td>
<td>40 ± 6</td>
</tr>
</tbody>
</table>

*BSE assumed w/o uncertainty
Predicted Global geoneutrino flux based on our new Reference Model

--TNU: Terrestrial Neutrino Unit
--1 TNU = one geoneutrino event per $10^{32}$ free protons per year

Huang et al (2013) G-cubed
arXiv:1301.0365 10.1002/ggge.20129
Early Earth differentiation followed by 4 billion years of plate tectonics

Kellog et al. (sciences 2000)

“MORB source”

“OIB source”
Geoneutrino contributions to detectors

Near Field: six closest $2^\circ \times 2^\circ$ crustal voxels
Far Field = bulk crust – near field crust

<table>
<thead>
<tr>
<th>Total flux (TNU)</th>
<th>Fractional contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>KamLAND 31</td>
<td>49% Near Field Crust, 28% Far Field Crust, 23% Mantle</td>
</tr>
<tr>
<td>Borexino 40</td>
<td>44% Near Field Crust, 22% Far Field Crust, 23% Mantle</td>
</tr>
<tr>
<td>SNO+ 40</td>
<td>40% Near Field Crust, 23% Far Field Crust, 23% Mantle</td>
</tr>
<tr>
<td>Hanohano 12</td>
<td>19% Near Field Crust, 75% Mantle</td>
</tr>
</tbody>
</table>

Continental
Oceanic
**Hanohano International ocean-based (≤50kt)**

**LENAP, EU (50kt)**

**JUNO China (20kt)**

**Future detectors?**

- **CANCELLED?**
Hanohano

A Deep Ocean \( \overline{\nu}_e \) Electron Anti-Neutrino Observatory

Size: scalable from 1 to 50 kT
10-yr cost est: $250M @ 10 kT

- multiple deployments
- deep water cosmic shield
- control-able L/E detection

Descent/ascent 39 min

Deployment Sketch
What’s hidden in the mantle?

Seismically slow “red” regions in the deep mantle

Can we image it with geonous?

Ritsema et al (Science, 1999)
Testing Earth Models

Mantle geoneutrino flux ($^{238}$U & $^{232}$Th)

Predicted geoneutrino flux

Total flux at surface

*dominated by* Continental crust

Mantle flux at the Earth’s surface

*dominated by* deep mantle structures


Ocean based experiment!

- Neutrino Tomography...

- Pacific Transect

- Avoid continents

- 4 km depth deployments

- Map out the Earth’s interior

- Test the models

SUMMARY
Earth’s radiogenic (Th & U) power

\[ 22 \pm 12 \text{ TW} \] - Borexino
\[ 11.2^{+7.9}_{-5.1} \text{ TW} \] - KamLAND

Prediction: models range from 8 to 28 TW (for Th & U)

On-line and next generation experiments:
- SNO+ to come online in 2014 😊
- JUNO: great experiment, big bkgd, geonu application...
- Hanohano: FUNDAMENTAL for geosciences
  
  Geology must participate & contribute to the cost

Future:
- Neutrino Tomography of the Earth’s deep interior 😊
Geoneutrinos: ongoing efforts and wish list

- Directionality
- $^{40}\text{K}$ geonuss
- Detecting hidden objects in the Earth