Power in the Earth's mantle

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What are geoneutrinos?

Electron antineutrinos from $\beta^-$ decays of natural radionuclides

- Decay energy
  - part carried away by neutrinos
  - part released as heat powering Earth’s dynamics

Geoneutrino spectra

Above 1.8 MeV energy threshold of inverse beta decay reaction:

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

Measuring radiogenic power in the Earth
Geoneutrino detectors

Borexino
0.3 kton
3.7 kmwe
running

KamLAND
1 kton
2.7 kmwe
running

JUNO
20 kton
1.5 kmwe
under constr.
(2020~)

SNO+
1 kton
5.4 kmwe
expected
online 2017

Jinping
4 kton
6.7 kmwe
R&D

Predicted U and Th geoneutrino flux

Usman et al. 2015
Earth models: How much radiogenic heat?

Surface heat flow

46 ± 3 TW

heat flux measurement & calculation

Bulk Silicate Earth (BSE) models

composition of chondrite meteorite

<table>
<thead>
<tr>
<th>Cont. Crust + Modern Mantle</th>
<th>Low Q</th>
<th>Middle Q</th>
<th>High Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 TW</td>
<td>3.2</td>
<td>6.8 (TW)</td>
<td>6.8 (TW)</td>
</tr>
<tr>
<td>20 TW</td>
<td>6.8</td>
<td>13 (TW)</td>
<td>23 (TW)</td>
</tr>
<tr>
<td>30 TW</td>
<td>13.6</td>
<td>26 (TW)</td>
<td>39 (TW)</td>
</tr>
</tbody>
</table>

Th/U = 3.9
K/U = 1.4 × 10⁴

Continental Crust

<table>
<thead>
<tr>
<th>Upper Crust</th>
<th>Middle Crust</th>
<th>Lower Crust</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 (TW)</td>
<td>4.5 (TW)</td>
<td>1.9 (TW)</td>
</tr>
<tr>
<td>6.8 (TW)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Silicate Earth … models vary by a factor of 3
Mantle … models vary by a factor of 20

Crust R* (7 ± 1 TW)
(Rudnick and Gao '03, Huang et al '13)

Mantle R* (13 ± 4 TW)

Core (~9 TW) (4-15 TW)

(0.4 TW) Tidal dissipation
Chemical differentiation

Total R* 20 ± 4

*R radiogenic heat
(after McDonough & Sun '95)

after Jaupart et al 2008 Treatise on Geophysics

Huang et al 2013
Geoneutrinos measurements vs. predictions

1 TNU (Terrestrial Neutrino Unit) = 1 event per year per 1 kton

Silicate Earth models:
High-Q: ~30 TW radiogenic power
Middle-Q: ~20 TW
Low-Q: ~10 TW

modified from McDonough & Šrámek 2014
doi:10.1007/s12665-014-3133-9
Measuring the mantle

Current status – KamLAND and Borexino combined

Measured by physics:

- Total geonu

KamLAND 2016
Borexino 2015 measurements

Fitting line of slope 1:
detectors see the same mantle

Intercept is mantle signal

Result:
Mantle = 8.8 ± 6.4 TNU
(72% rel. uncertainty)

Predicted from geology:
Lithosphere
Emission model
Geoneutrino flux prediction

at 5 detectors

- Crust: closest 500 km
- Crust: rest of the world
- Mantle signal

Šrámek et al 2016 doi:10.1038/srep33034
Measuring the mantle

Future prospect ~2026

Horizontal axis
Geological prediction of crustal emission

Vertical axis
Physics measurement simulated for 2026

Mantle result:
High-Q: $17.7 \pm 3.1$ TNU
Mid-Q: $8.2 \pm 2.9$ TNU
Low-Q: $1.8 \pm 2.7$ TNU

Šránek et al 2016 doi:10.1038/srep33034
Crust + Mantle geoneutrino emission

Ocean-Bottom Detector
R&D
10–50 kt
~5 kmwe movable

Here is where we want to measure mantle

Crust + mantle (TNU)

Mantle contribution to total signal (%)

Crust Mantle, geodynamical
Mantle, geochemical
Mantle, cosmochemical

Site #1
Site #2
A&McD DM
S&S DM
W&H DM

Geochemical BSE

Predicted antineutrino flux (TNU)
in geoneutrino energy window 1.8–3.3 MeV

Relative contributions (%)

Best ratio of mantle signal to background (crust, reactor)
Are LLSVPs enriched in Th, U?

Mantle geoneutrino prediction (excluding crustal signal)

Can we detect such variation in mantle geoneutrino flux?

Thermo-chemical piles?
"Seeing" enriched piles using Ocean Bottom Detector

Prediction along 161°W meridian

Crust + Mantle

Mantle

Mantle to total

Crust Mantle, geodynamical
Mantle, geochemical
Mantle, cosmochemical

Site #1
A&McD DM
S&S DM
W&H DM

Geochemical BSE

Crust + Mantle

North pole
South pole

Latitude in degrees

TNU

Longitude = 161°W

Crust, high-Q
Mantle, middle-Q
Mantle, low-Q

Latitude in degrees

TNU

North pole
South pole

Crust + Mantle

Mantle

Mantle to total

How much radiogenic power in the mantle?

Are LLSVPs enriched in heat-producing elements?

Measuring geoneutrinos will set the limits on the amount of radiogenic power in the Earth.

Thank you.