Ocean Bottom Detector

Hiroko Watanabe
for the OBD working group*
Research Center for Neutrino Science, Tohoku University, Japan

* K. Inoue¹, T. Sakai¹, H. Watanabe¹, W. F. McDonough¹,²,³, K. Ueki⁴, N. Abe⁴, M. Kyo⁴, N. Sakurai⁴, E. Araki⁴, T. Kasaya⁴, H. Yoshida⁴
Neutrino Geoscience: Current and Future

**what we need**
- improved accuracy of measurement & modelling
- multi-site measurement
- directional sensitive detector
- new type detector

**Detector in the Ocean**

**current generation**
- total radiogenic heat in the Earth
- Th/U ratio

**next generation**
- resolving vertical and horizontal flux differences
- distinguishing mantle contribution

**what we learn**
- detecting K geo-neutrino

**OBD: breakthrough beyond modern land-based detector transforming our vision of deep Earth**

**first measurement in 2005**

**Next Target!**
• **Direct Measurement of Mantle**
  need to be far from crust
  can be far from reactors

• **Multi-site Measurements**
  Solve the mystery of deep Earth!

• **Multidisciplinary Detector**

**Physics, Geoscience, Mantle drilling, Biology, New technology,…**

**Physics**:
- multi baseline measurement of reactor neutrinos
- astro particle physics
- dark matter measurement with less-neutron background etc.
OBD Present & Future

2005: No progress...
2019: 1-10 t
2020-2022: 10-50 kt

“Hanohano”

Vessel: 112m × 32m

10~50 kT
1~5 kmwe
movable

U. Hawaii & Makai Ocean Engineering
Technical tests and detector design

OBD project has started with JAMSTEC & Tohoku U.!

* Japan Agency for Marine-Earth Science and Technology

July 9, 2019

Joint workshop on OBD with Ocean Engineering, Earth Science and Neutrino Physics
Technical test & world’s first measurement in the ocean with LS detector

* Install detector into ~1km seafloor (JAMSTEC’s Hatsushima Observatory), take data for several months
* Technical developments are in progress.
  * low-impurity PMT shield : clean glass or acrylic, strength test will be done on Jan. 2021 at JAMSTEC
  * LS optimization for seafloor environment : experimental device will be ready next week
  * DAQ system & power supply
  * deployment, recovery, maintenance, redeploy
OBD Present & Future

2005
No progress...

2019
2020-2022

~20 kg
1-10 t
~1.5 kt
10-50 kt

2019 funded

Technical demonstration & environment measurement in the sea
deep sea neutrino & muon flux, ocean water density & temperature, radioactivity
→ input parameters for ~1.5 kt detector design

First clear mantle signal
* Detector simulation study is in progress.
* Hawaii is possible position.
* Sensitivity for mantle geo-neutrino
  1-year : 1.8 σ
  3-year : 3.4 σ

<table>
<thead>
<tr>
<th>Signal</th>
<th>rate[event/year]</th>
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<tbody>
<tr>
<td>U</td>
<td>7.4</td>
</tr>
<tr>
<td>Th</td>
<td>1.8</td>
</tr>
<tr>
<td>total geo</td>
<td>9.2</td>
</tr>
<tr>
<td>U mantle</td>
<td>5.5</td>
</tr>
<tr>
<td>Th mantle</td>
<td>1.3</td>
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<tr>
<td>total mantle</td>
<td>6.8</td>
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<table>
<thead>
<tr>
<th>Source</th>
<th>events [year]</th>
<th>Geonu-region</th>
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<tbody>
<tr>
<td>Reactor</td>
<td>4.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Accidental</td>
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<td>1.8</td>
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<tr>
<td>He, Li</td>
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<td>0.6</td>
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<tr>
<td>Alpha, n</td>
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<td>2.6</td>
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<tr>
<td>total</td>
<td>16.1</td>
<td>6.7</td>
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</table>

Visible energy[MeV]

*location: off coast of Hawaii
*depth: 2.7km
*1 year measurement
*geo-neutrino, reactor neutrino flux from "Geoneutrinos.org"
*He-Li scaled by KamLAND data
*Fiducial cut: 72cm

Maturity of science
For two centuries we have asked what is the energy that drives the Earth?

Geoneutrinos are unique and new tool to measure directly the Earth’s interior.
  > Only way to measure amount of radioactive elements in the Earth

To date, physics experiments have shown the usefulness of geoneutrinos.
  > Interdisciplinary community has furthered its connection over these past 15 years.

"Neutrino Science" : collaborations between geology, physics and beyond
  > Ocean Bottom Detector (OBD) = Breakthrough
  > OBD can test fundamental particle physics, reactor baseline studies, etc.

OBD’s Primary Goal:
  • map the mantle
  • constrain the planet’s cooling history
Backup
Why geo-neutrino?: Big questions

What is in the mantle?
Many seismically imaged structures and chemical heterogeneities in the mantle

How much fuel is left to drive Plate Tectonics?

<table>
<thead>
<tr>
<th>Q Level</th>
<th>Total (TW)</th>
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<tbody>
<tr>
<td>Low</td>
<td>3.2</td>
</tr>
<tr>
<td>Middle</td>
<td>6.8</td>
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<tr>
<td>High</td>
<td>6.8</td>
</tr>
<tr>
<td>Total</td>
<td>6.8 TW</td>
</tr>
</tbody>
</table>

Surface heat flow: 46 ± 3 TW
Th/U = 3.9
K/U = 1.4 \times 10^4

Geo-neutrino can directly define power to drive the Earth’s engine
Multi-site Measurement + OBD

Observation = **Crust** + **Mantle**

\( y = x + b \)

Near Future...

3 multi-site measurements can constrain mantle contribution.

Crust estimation needs to be accurate.

OBD can directly measure mantle contribution.

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**Observation**

\( \text{Crust} + \text{Mantle} \)

\( y = x + b \)

**Near Future...**

3 multi-site measurements can constrain mantle contribution.

Crust estimation needs to be accurate.

**OBD** can directly measure mantle contribution.

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**Figure 4.**

Top: Most recent measurement of total geoneutrino flux at KamLAND (KL) and Borexino (BX) vs. lithospheric flux prediction (this study). Best fit of slope 1 line shown as red dashed line, including \( \pm 1\sigma \) uncertainty (red band). The y-intercept reveals signal from the convecting mantle (DM+EM), which scales with radiogenic power in BSE (purple).

Bottom: Simulated measurements in year 2025 vs. lithospheric predictions at geoneutrino detectors KL, JUNO, BX, SNO+Jinping. Assumes that detectors measure the nominal value predicted by the emission model, and measurement uncertainty is assumed to be 11% (KL)\(^52\), 6% (JUNO)\(^53\), 13% (BX), 9% (SNO+)\(^28\), and 4% (JP)\(^28\), respectively. We show results for two BSE compositional estimates, previously termed medium-Q and low-Q models\(^21,58\). The solution of mantle flux for the medium-Q model translates into 12±4 TW of radiogenic power in the mantle.