Anti-neutrino Directional Measurement

Research Center for Neutrino Science, Tohoku University
Hiroko Watanabe

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Neutrino Geoscience: Current and Future

**what we need**
- improved accuracy of measurement
- modelling
- 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
- detecting K geo-neutrino

**what we learn**

first measurement in **2005**
what we need
improved accuracy of measurement & modelling

directional sensitive detector
detector in the Ocean

new type detector

current generation

what we learn

first measurement in 2005

total radiogenic heat in the Earth

Measuring

Th/U ratio

Measuring

resolving vertical and horizontal flux differences

distinguishing mantle contribution

Measuring

detecting K geo-neutrino

next generation
Neutrino Detectors

- IceCube
- Borexino
- KamLAND
- JUNO
- Daya Bay
- Super Kmiokande
- SNO+
- Double Chooz
- OBD (Hanohano)
- Jinping
- ANDES
- Baksan
Neutrino Detectors: Target

- IceCube
- Borexino
- KamLAND
- JUNO
- Jinping
- Daya Bay
- SNO+
- Double Chooz
- OBD (Hanohano)
- Water/Ice
- Super Kmiokande
- Liquid Scintillator
- ANDES
- Baksan
<table>
<thead>
<tr>
<th>experiments</th>
<th>Water: Super-K (Ice-Cube, etc.)</th>
<th>Liquid Scintillator (LS): KamLAND (Borexino, SNO+, JUNO, etc.)</th>
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<tbody>
<tr>
<td>target volume</td>
<td>50,000 t (larger)</td>
<td>1,000 t</td>
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<td>light</td>
<td>Cherenkov</td>
<td>Scintillation</td>
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<tr>
<td>light yield</td>
<td>6 p.e./MeV</td>
<td>400 p.e./MeV (blighter)</td>
</tr>
<tr>
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## Water vs Liquid Scintillator

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<td>Water</td>
<td>Water-based LS</td>
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5. Summary
1. large size detector (1kt~)

distinguish mantle contribution

separate reactor neutrino background

What We Can Measure?

KamLAND

Borexino
2010 2013 2015 2019

Crust: closest 500 km
Crust: rest of the world

Mantle
High-H
Mid-H
Low-H


What We Can Measure?

1. large size detector (1kt~)

**geo-neutrino**

(1) **distinguish mantle contribution**

(2) separate reactor neutrino background

---

**geo-neutrino angular distribution @Kamioka**

- Upper Continental Crust
- Lower Continental Crust
- Oceanic Crust
- Upper Mantle
- Lower Mantle

---

**crust+mantle**

**crust**

---

simulation

5-years, 50 kt Li-loaded LS detector @Kamioka
What We Can Measure?

1. large size detector (1kt~)
   - **geo-neutrino**
     1. distinguish mantle contribution
     2. separate reactor neutrino background

   ![Graph showing the difference between Geo $\bar{\nu}_e$ and Reactor $\bar{\nu}_e$]

   - Reactor neutrinos: useful for **neutrino property study**
   - Reactor neutrinos are the most significant background for geo-neutrino
2. small size detector (~200 kg) our first target

(1) establishment of new technology using neutrino sources
   sources: reactor neutrino, radioactive neutrino source

(2) application to neutron detector and reactor monitor

What We Can Measure?
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Detection Principle

Problems
- Neutron loses directional information before being captured by proton.
- Delayed signal (2.2 MeV γ-ray) confuses capture point
Reaction in Liquid Scintillator

$\nu_e \rightarrow e^- \theta_e \gamma (0.511 \text{MeV})$

prompt signal

$\nu_e \rightarrow e^+ \theta_e \gamma (0.511 \text{MeV})$

prompt signal

$e^- (0.511 \text{MeV})$

delayed signal

$e^+ (0.511 \text{MeV})$

delayed signal

$\nu_e \rightarrow e^- \theta_e \gamma (0.511 \text{MeV})$

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νe + P → e-γ

Asymmetry = \frac{A_+ - A_-}{A_+ + A_-} 

A_+ 0 \leq \cos \theta \leq 1 
A_- -1 \leq \cos \theta \leq 0

<table>
<thead>
<tr>
<th>Source</th>
<th>Asymmetry</th>
<th>miss-identification rate (θ&gt;90°)</th>
</tr>
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<tbody>
<tr>
<td>$^6$Li LS</td>
<td>0.391</td>
<td>30.4%</td>
</tr>
<tr>
<td>$^{10}$B LS</td>
<td>0.148</td>
<td>42.6%</td>
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<tr>
<td>KamLAND LS</td>
<td>0.079</td>
<td>46%</td>
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Experiment & Idea

Experiment : Double Chooz (2011~, France)
- 8.2 t, Gd-loaded LS
- detectors
  - near : L=400m, 300ν/day
  - far : L=1050m, 40ν/day (L: distance from reactors)

very high statistics of reactor ν

Idea : gaseous time projection chamber


elastic scattering, gas (e.g. CF$_4$) filled chamber

figures from T. Brugière, AAP 2015

~3500 events analysis

500 tonne-years, T > 200 keV

simulation

technically very difficult to construct the detector

$^{40}\text{K geo-ν}$
$^{\text{Solar ν}}$
$^{\text{U,Th geo-ν}}$
$^{\text{Reactor ν}}$
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WANTED

- $^6$Li loaded liquid scintillator \(\rightarrow\) completed!
- high vertex resolution detector \(\rightarrow\) ongoing

This setup is ongoing.

**target:** measure two related events of prompt and delayed events of anti-neutrino measurement
- We need high vertex resolution to separate 2 vertexes.

- required resolution : \(~1.5\text{cm}\)  
  (ref: Photo Multi Plire (PMT) \(~10\text{cm}\))
**High Vertex Resolution Detector**

We designed mirror for 30L detector.

**Vertex Resolution Check**

- Image Size [mm]
- Distance [mm]
- Vertex resolution < 3.2 mm
- (required: < 15 mm)

**Optimize materials**

- Number of detection p.e.
  - 2.6 p.e.
  - (assuming anti-neutrino delayed event)

- Refraction ratio [%]
  - Ar (Cr coat): 45.3%
  - Steel: 55.4%
  - Al: 78.9%
  - Al evaporation on acrylic board: 89.8%
2D photon sensors are tested.

**Multi-Anode PMT**
- Hamamatsu H9500
- 5cm x 5cm
- 256 channels
- Detection of weak signal
- Data readout performance

**Multi-Pixel Photon Counter**
- Detection of weak signal
- Data readout performance
- Lower temperature

**Cooling System**
- Target: <2 MHz
- 95% reduction
Prototype Detector: 30L LiLS + 2 Imaging Detectors

3D images were reconstructed by two imaging detectors.

3D Image measurement

example) muon track

Photon Sensor Data 1

Photon Sensor Data 2

Imaging Detector 1

Imaging Detector 2

Imaging Detector A

Imaging Detector B

30L Li LS
Prototype Detector: 30L LiLS + 2 Imaging Detectors

muon track

We measured 3D images of scintillation light.
Geoneutrinos bring unique and direct information about the Earth’s interior and dynamics.

**Directional sensitivity** will be efficient technology for geo-neutrino measurement.
- Distinguish mantle contribution
- Separate reactor background

New measurement technologies
- $^6$Li loaded liquid scintillator can have good directional sensitivity.
  - We have developed the $^6$Li loaded LS by the original method.
- Imaging detector have designed. It can achieve high vertex resolution.
- Prototype detector : test of detection technology
  - 3D images of muon track and $^{60}$Co γ-ray points have been measured.
  - Next target : 3D image of correlated two events (assuming anti-neutrino signals)