Ocean Bottom Detector: frontier of technology for understanding the Mantle by geoneutrinos

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

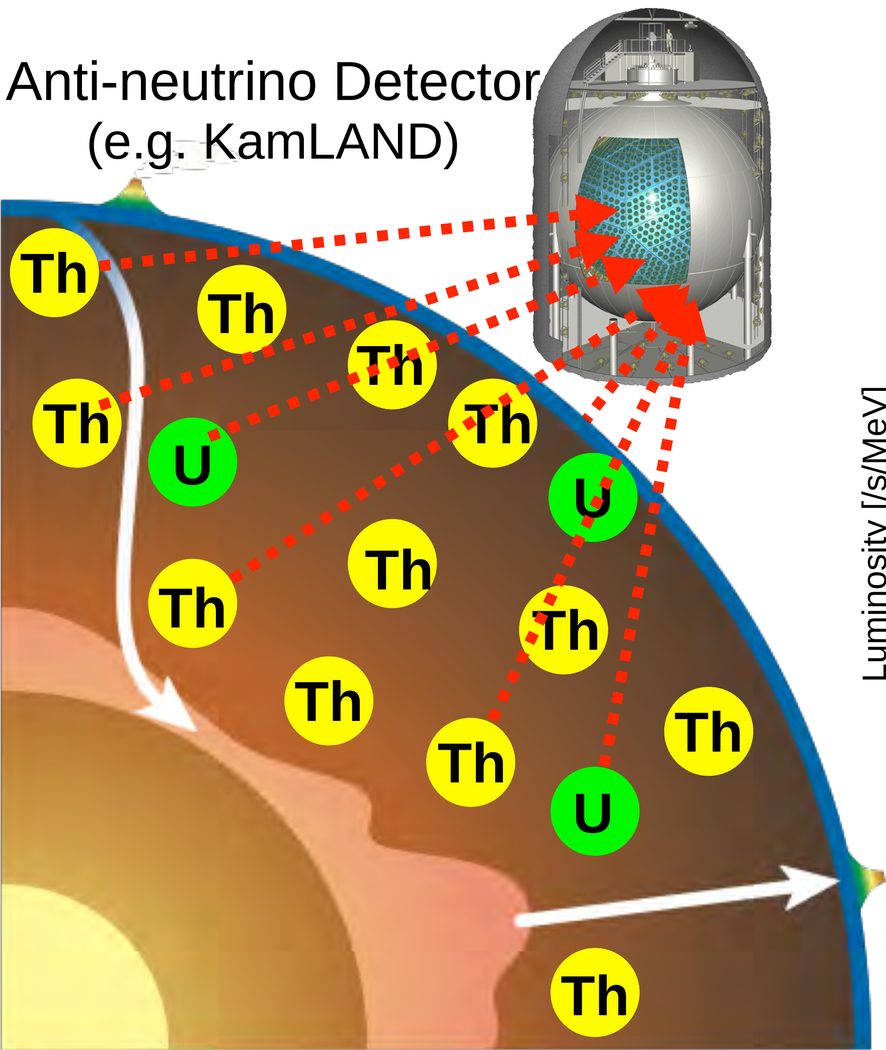
* K. Inoue[1], T. Sakai[1], H. Watanabe[1], W. F. McDonough[1,2,3], K. Ueki[4], N. Abe[4], M. Kyo[4], N. Sakurai[4], E. Araki[4], T. Kasaya[4], H. Yoshida[4]

1. Research Center for Neutrino Science, Tohoku University
2. Department of Earth Science, Tohoku University
3. Department of Geology, University of Maryland
4. JAMSTEC (Japan Agency for Marine-Earth Science and Technology)

Geoneutrinos

Electron-antineutrinos from natural radioactive decays

$\bar{\nu}_e$ $4.1 \times 10^6/\mathrm{cm}^2/\mathrm{sec}$



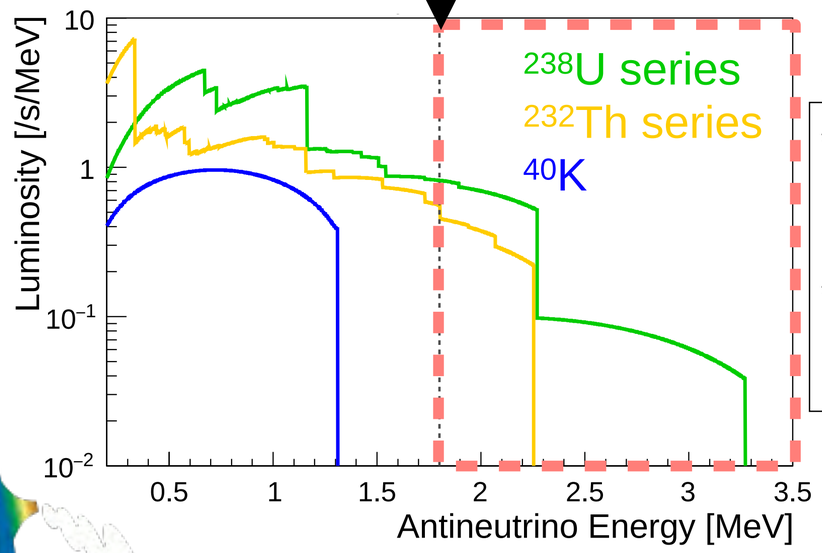
β-decay geo-neutrinos

$$^{238}\mathrm{U} \rightarrow ^{206}\mathrm{Pb} + 8\alpha + 6\mathrm{e}^- + 6\bar{\nu}_\mathrm{e} + 51.7\,\mathrm{MeV}$$

$$^{232}\mathrm{Th} \rightarrow ^{208}\mathrm{Pb} + 6\alpha + 4\mathrm{e}^- + 4\bar{\nu}_\mathrm{e} + 42.7\,\mathrm{MeV}$$

$$^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} + 1.311\,\mathrm{MeV}\,(89.28\%)$$

Energy threshold, 1.8 MeV



inverse β-decay

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

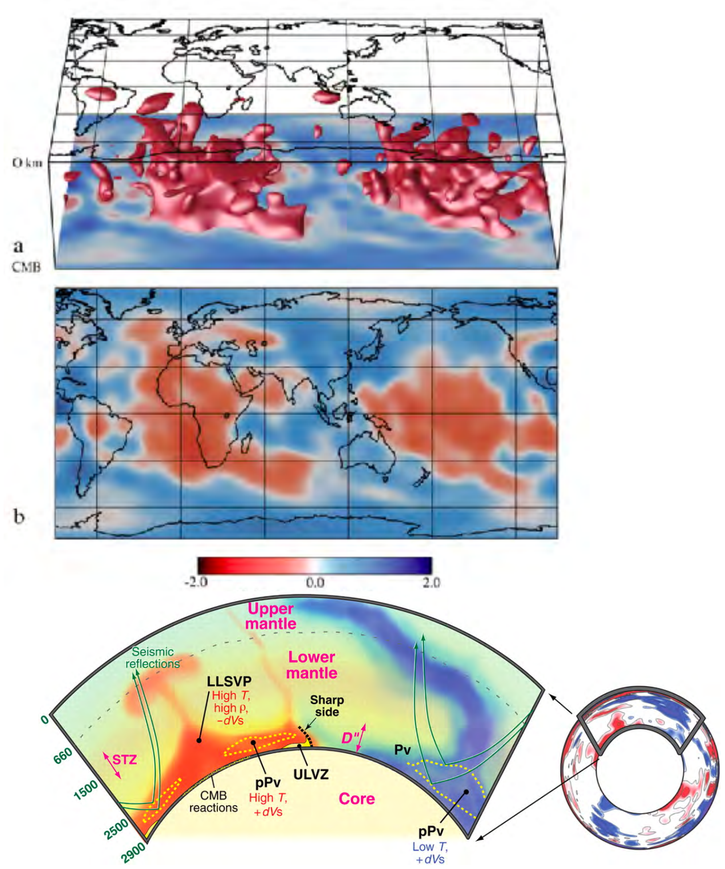
* Only geo-neutrinos from U and Th are detectable right now
* ^{40}K geo-neutrino detection needs another technology.

Number of geo $\bar{\nu}_e \propto$ amount of U Th, **radiogenic heat**

Why geo-neutirno?: Big questions

What is in the mantle?

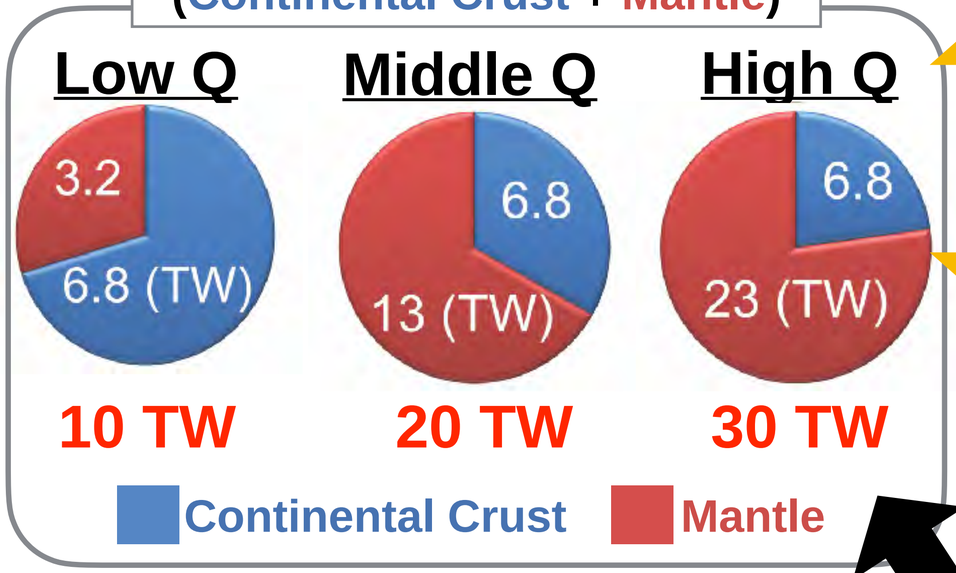
Many seismically imaged structures and chemical heterogeneities in the mantle

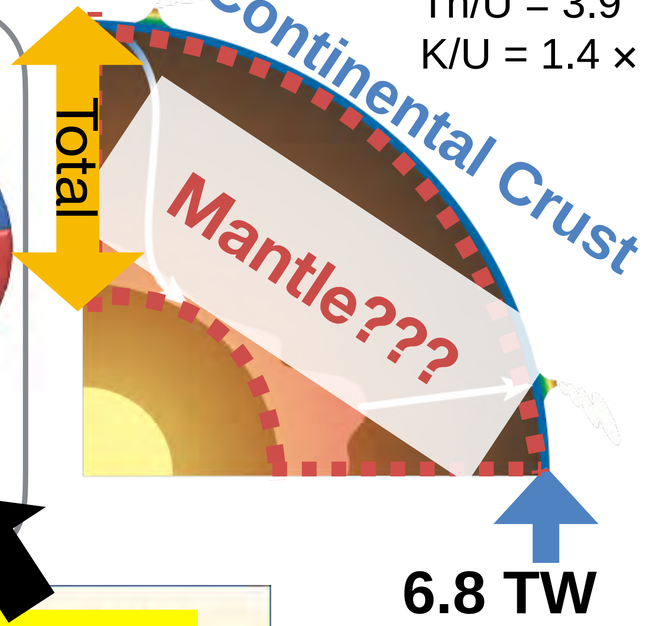


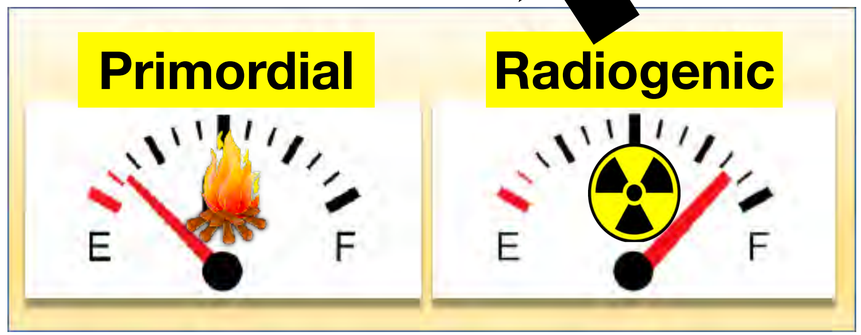
How much fuel is left to drive Plate Tectonics?

Total
(Continental Crust + Mantle)

surface heat flow : 46 ± 3 TW







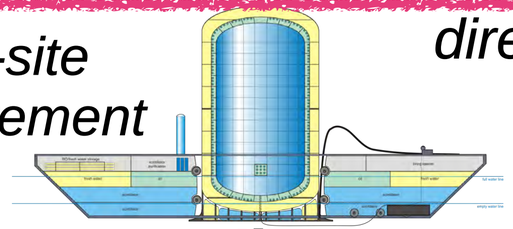
Geo-neutrino can directly define power to drive the Earth's engine

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 → **next** generation

total radiogenic heat in the Earth — ☑ Measuring

Th/U ratio — ☑ Measuring

Directly **Next Target!**

distinguishing mantle contribution — ☑ Measuring

resolving vertical and horizontal flux differences

detecting K geo-neutrino

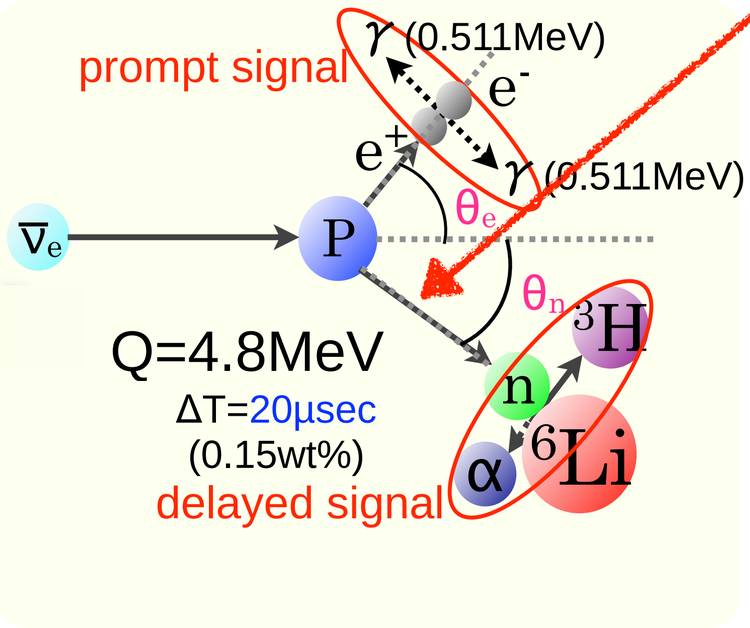
first measurement in **2005**

what we learn

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

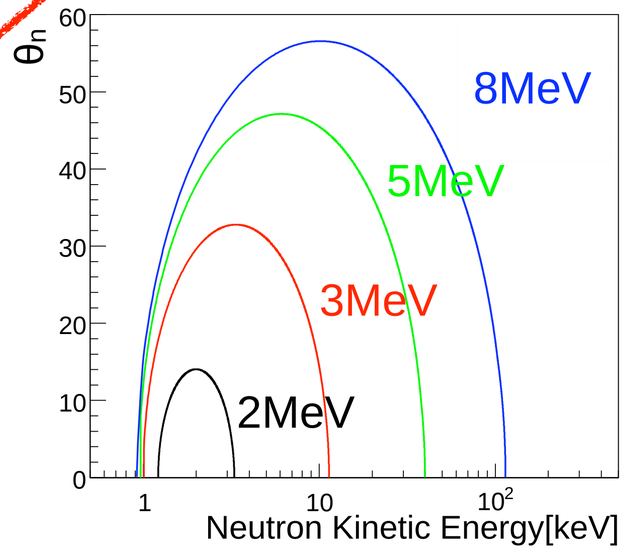
Directionality

Li loaded liquid scintillator



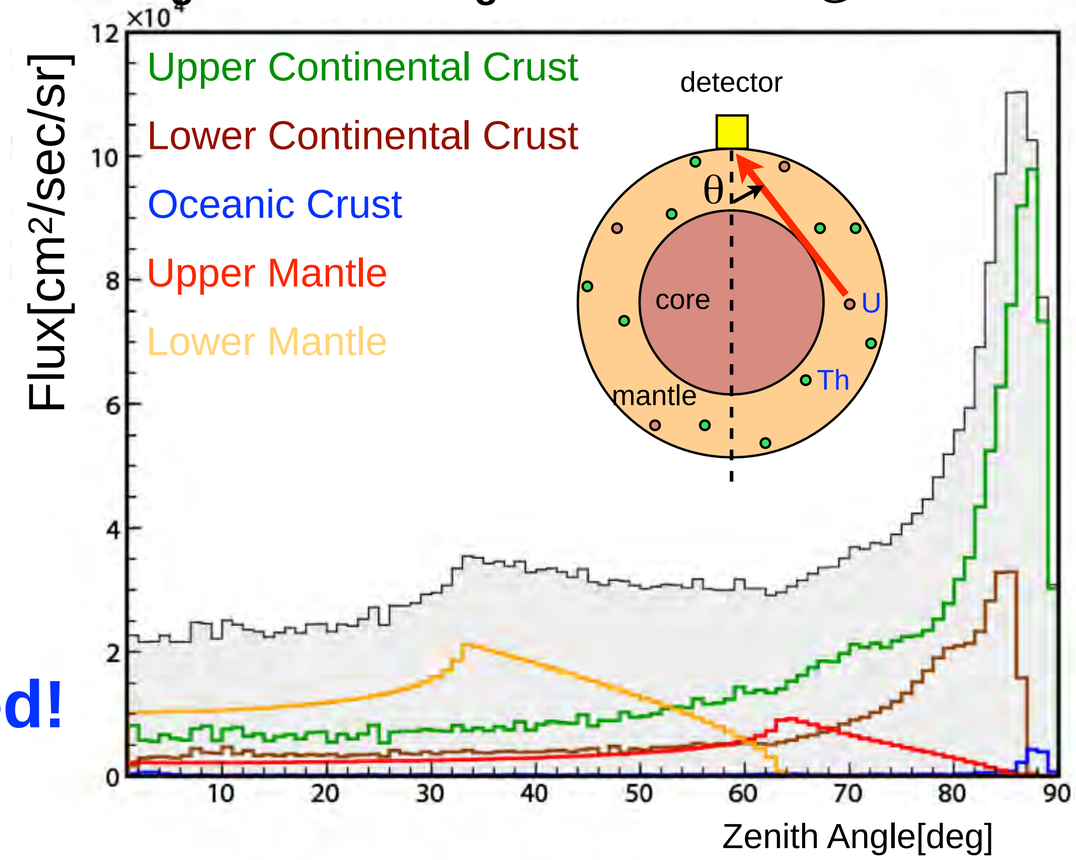
Neutron has directional information of anti-neutrino

PRD 60, 053003 (1999), P. Vogel & J. F. Beacom



$E_{\bar{\nu}e}$ <3MeV→θ_n<35°

geo-neutrino angular distribution @Kamioka

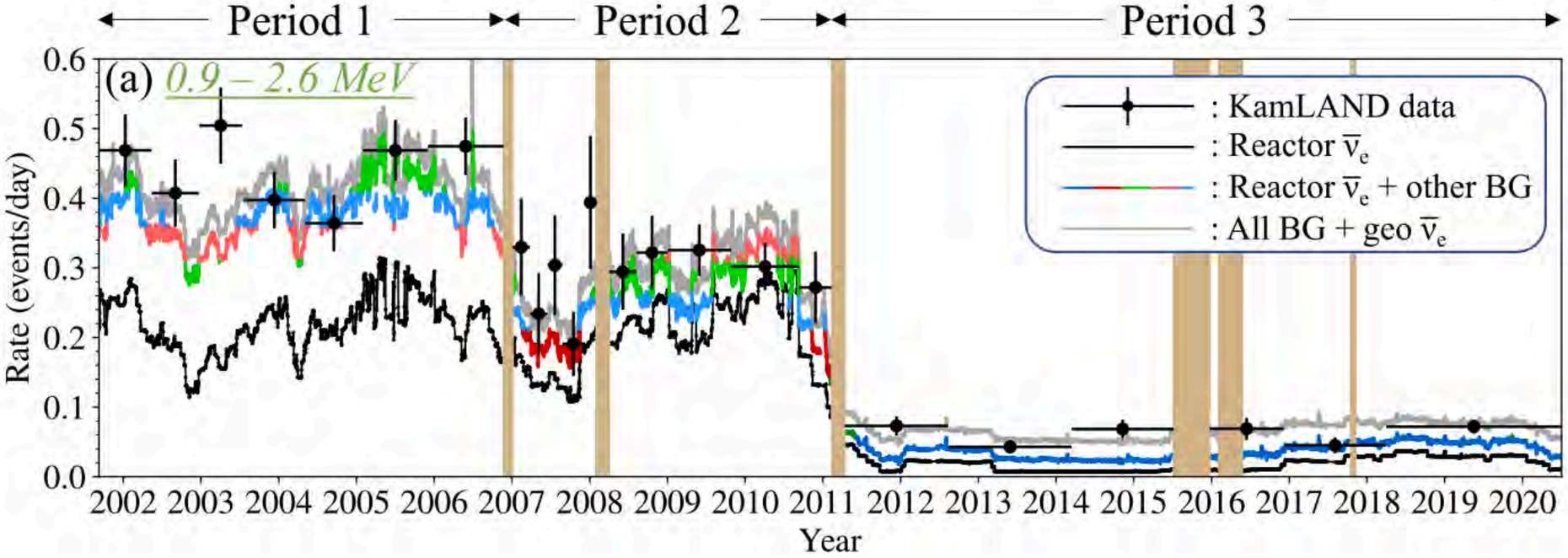


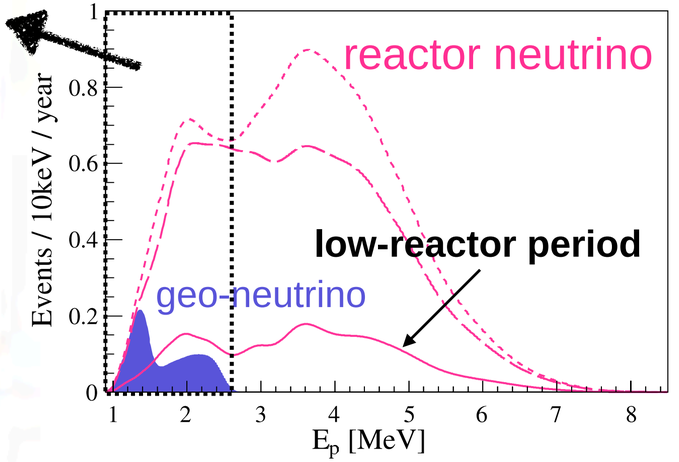
WANTED

- ☑ ^{6}Li loaded liquid scintillator →**completed!**
- ☑ high vertex resolution detector →**ongoing**

Current : KamLAND Latest Results

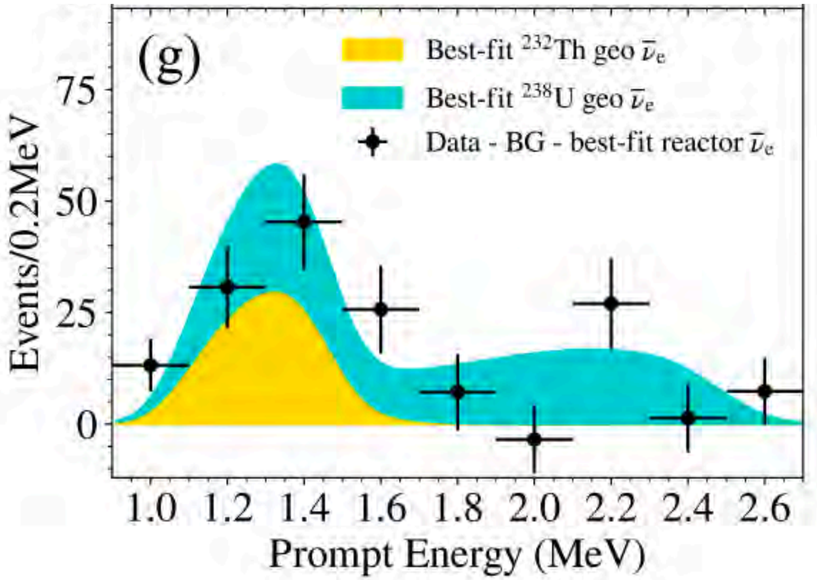
Accepted by GRL, “Abundances of uranium and thorium elements in Earth estimated by geoneutrino spectroscopy” (arXiv link)





Dataset : Mar, 2002-Dec, 2021
Livetime : 5227 days
(low-reactor phase : 2590 days)

☑ **massive dataset of low-reactor period**
→ **precise measurement of U and Th contributions**



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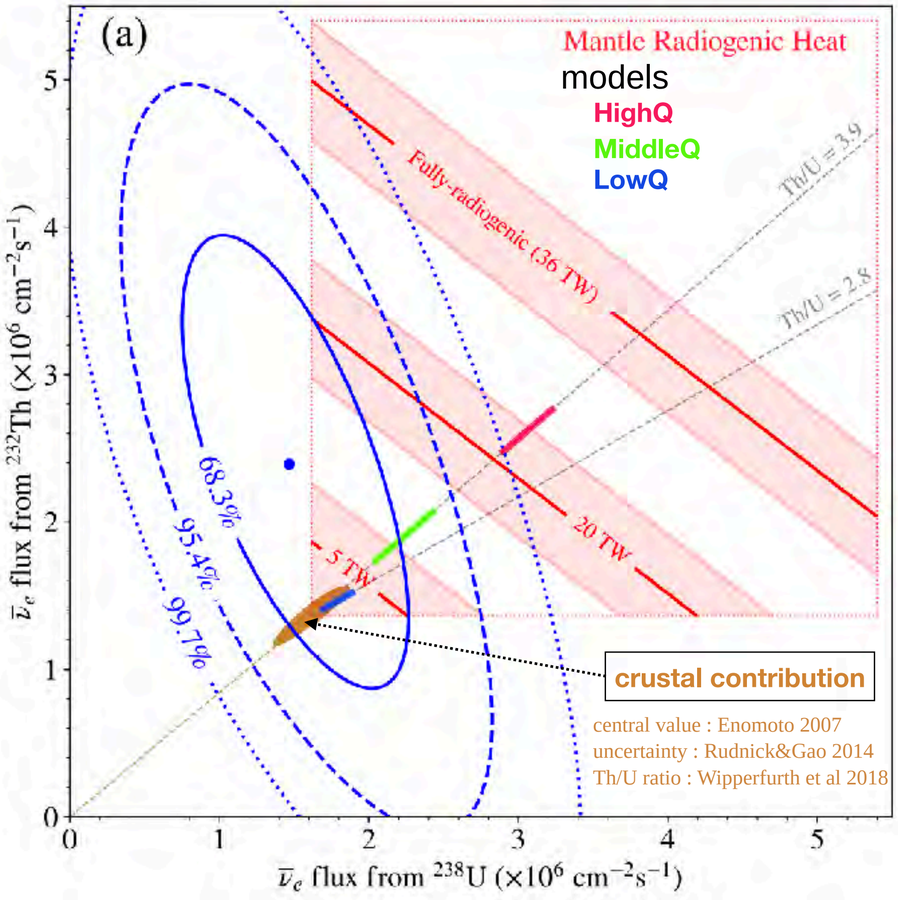
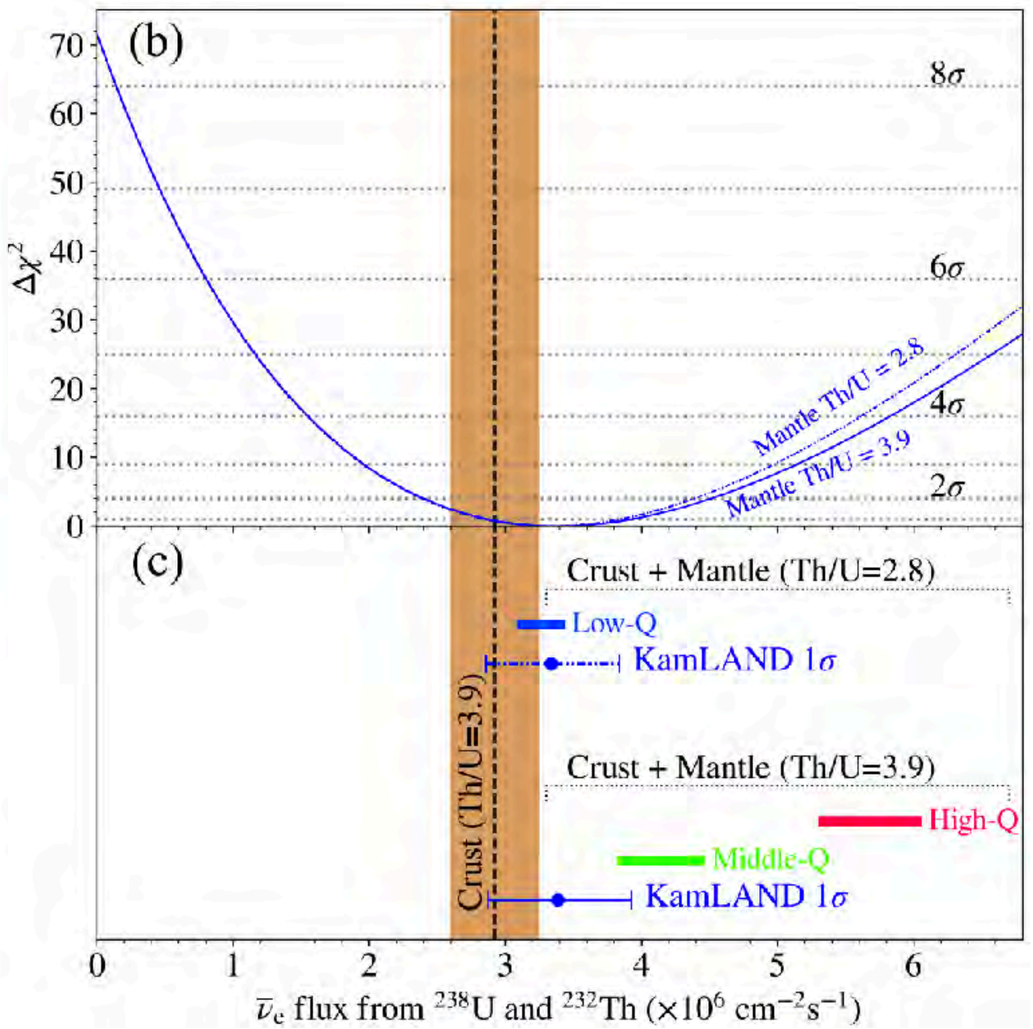




Radiogenic Heat

Th/U free

Adding heat estimate from crust,
^{238}U : 3.4 TW, ^{232}Th : 3.6 TW

$$Q^{\mathrm{U}} = 3.3^{+3.2}_{-0.8}\ \mathrm{TW}$$
$$Q^{\mathrm{Th}} = 12.1^{+8.3}_{-8.6}\ \mathrm{TW}$$
$$Q^{\mathrm{U}} + Q^{\mathrm{Th}} = 15.4^{+8.3}_{-7.9}\ \mathrm{TW}$$

Model Rejection

HighQ model is rejected at
99.76 % C.L. (homogeneous mantle)
97.9% C.L. (concentrated at CMB)

best-fit

Th/U free

	N of event	0signal rejection
U	117^{+41}_{-39}	3.3σ
Th	58^{+25}_{-24}	2.4σ
U+Th	174^{+29}_{-28}	8.3σ

Improve the distinct spectroscopic contributions of U and Th

Multi-site Measurement + OBD

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

(y = x + b)

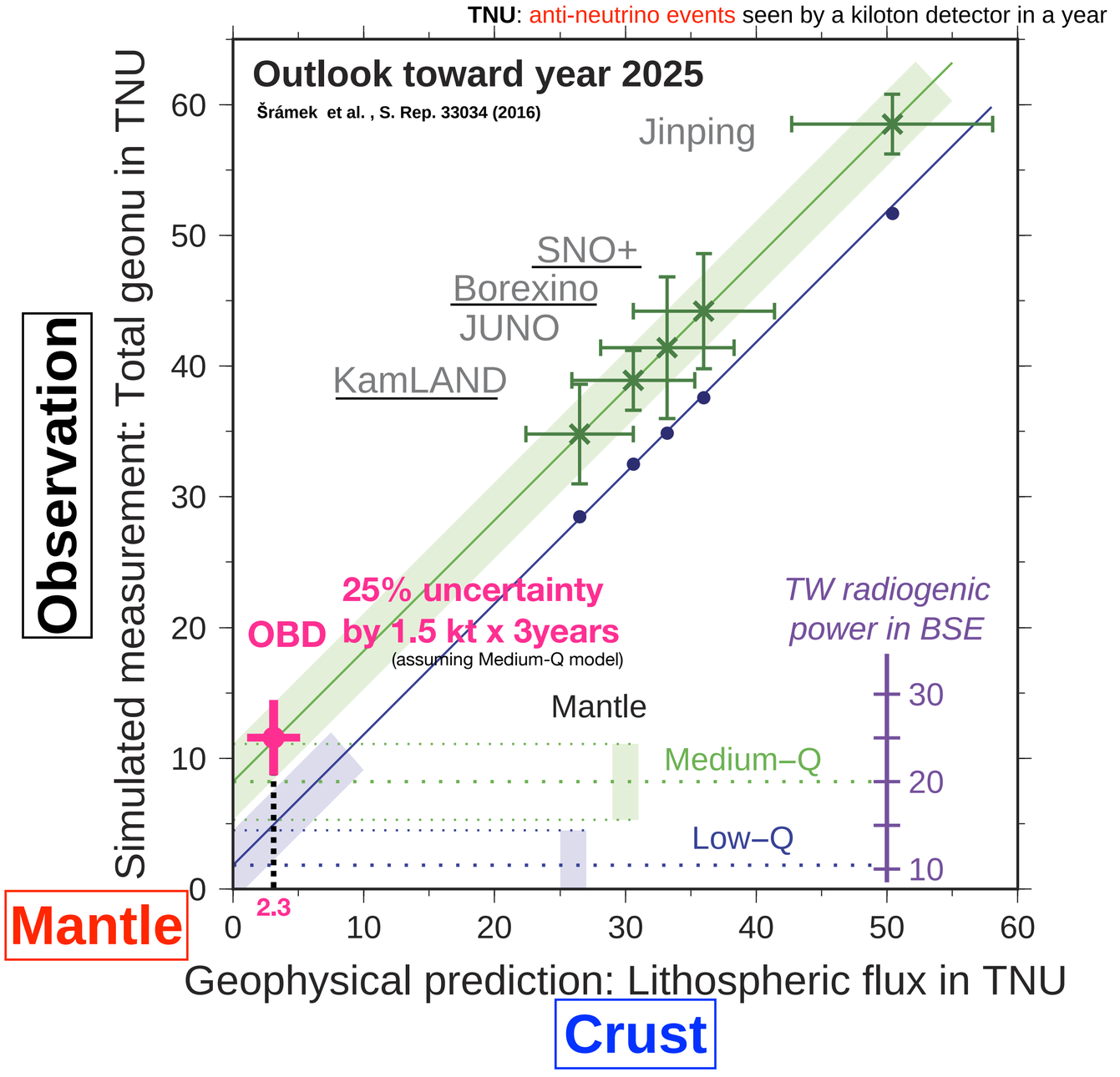
Near Future…

3 multi-site measurements can constrain mantle contribution.

Crust estimation needs to be accurate.

+ OBD

OBD can directly measure mantle contribution.



OBD Motivations

- **Direct Measurement of Mantle**

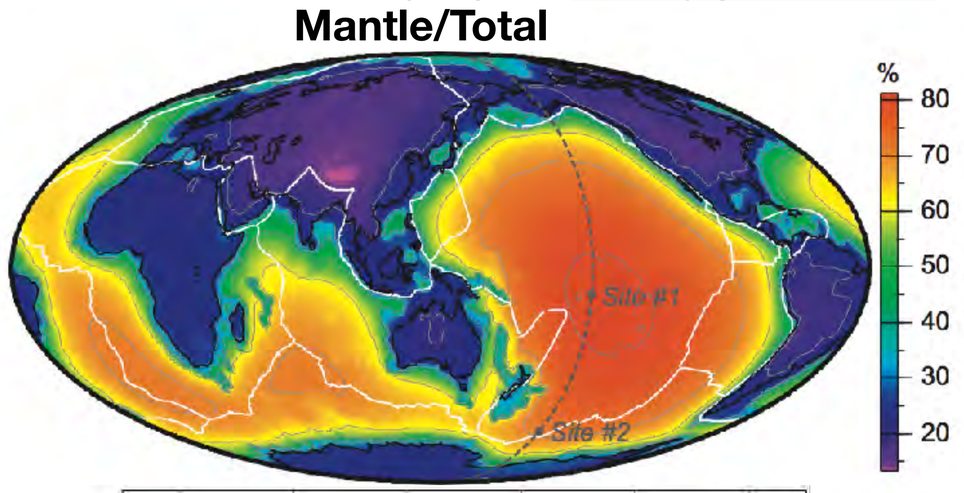
  need to be far from crust
  can be far from reactors

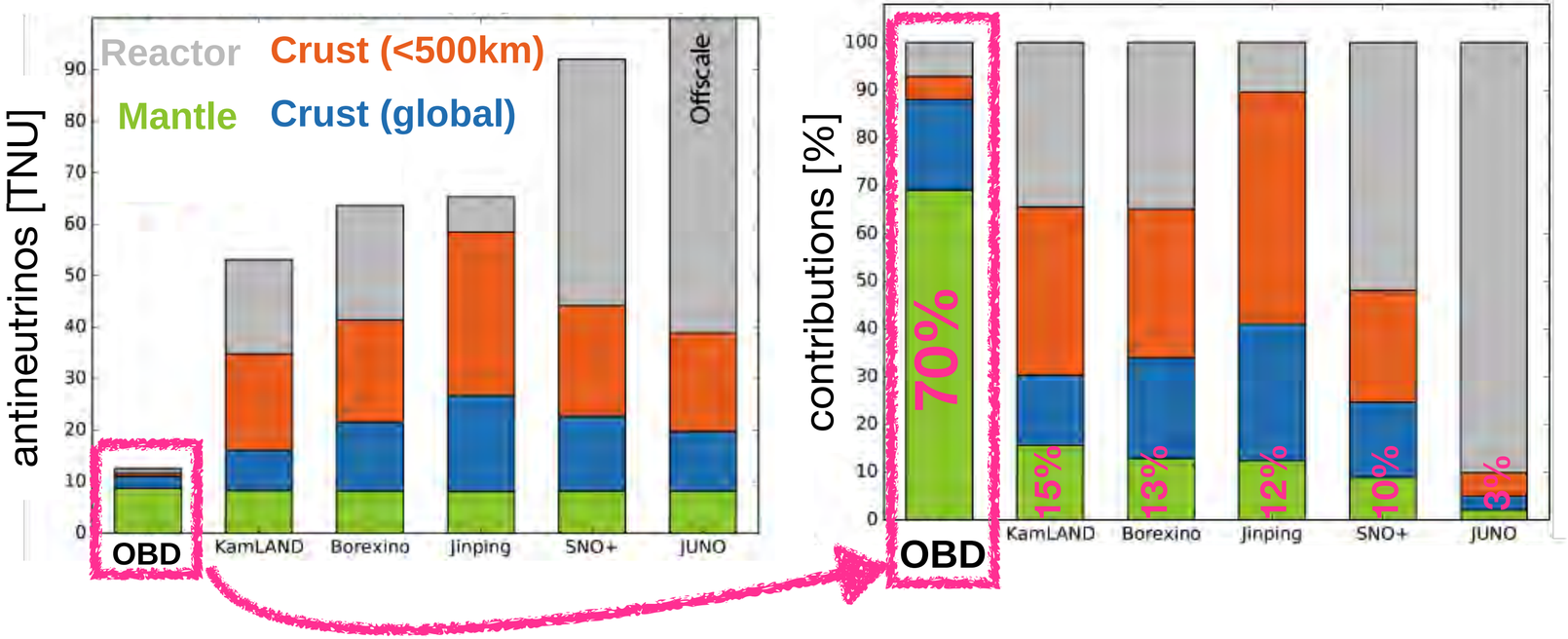
- **Multi-site Measurements**

  Solve the mystery of deep Earth!
  First detector for mapping the inhomogeneous mantle

- **Multidisciplinary Detector**

Šrámek et al (2013) EPS, 10.1016/j.epsl.2012.11.001





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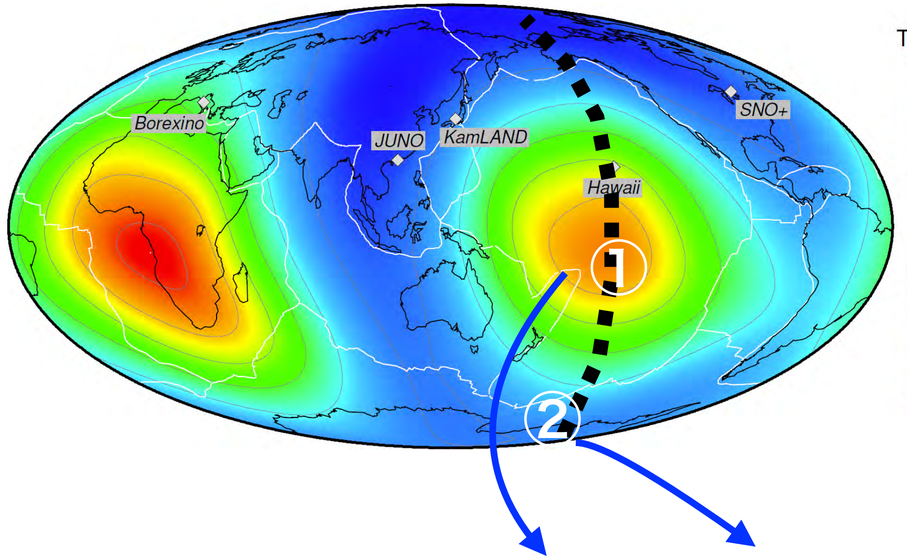
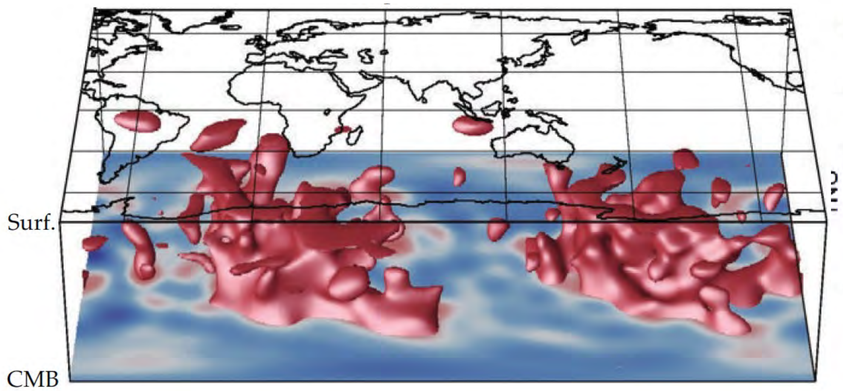
Mantle Geoneutrino Flux

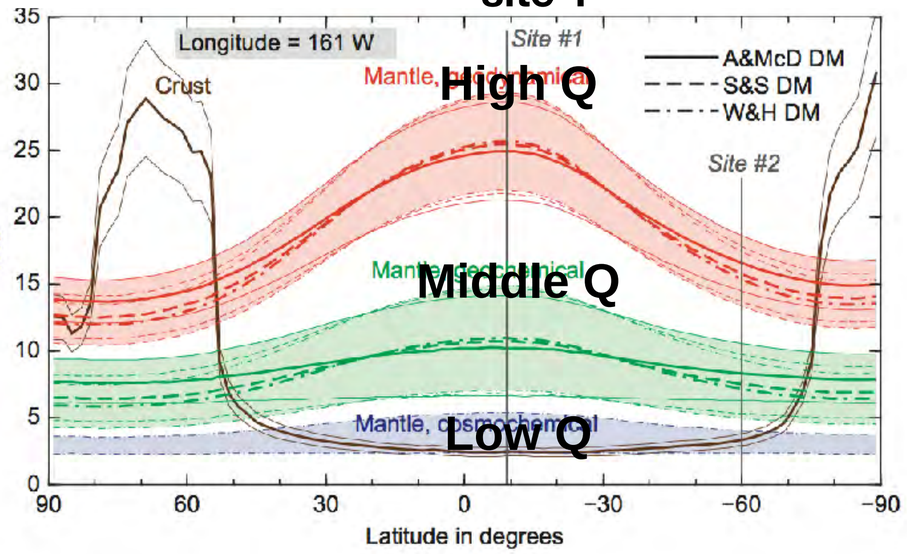


site 1 site 2

Seismically slow "red" regions in the deep mantle



From Alan McNamara after Ritsema et al (Science, 1999)



OBD Motivations

• Direct Measurement of Mantle

need to be far from <u>crust</u>
can be far from <u>reactors</u>

• Multi-site Measurements

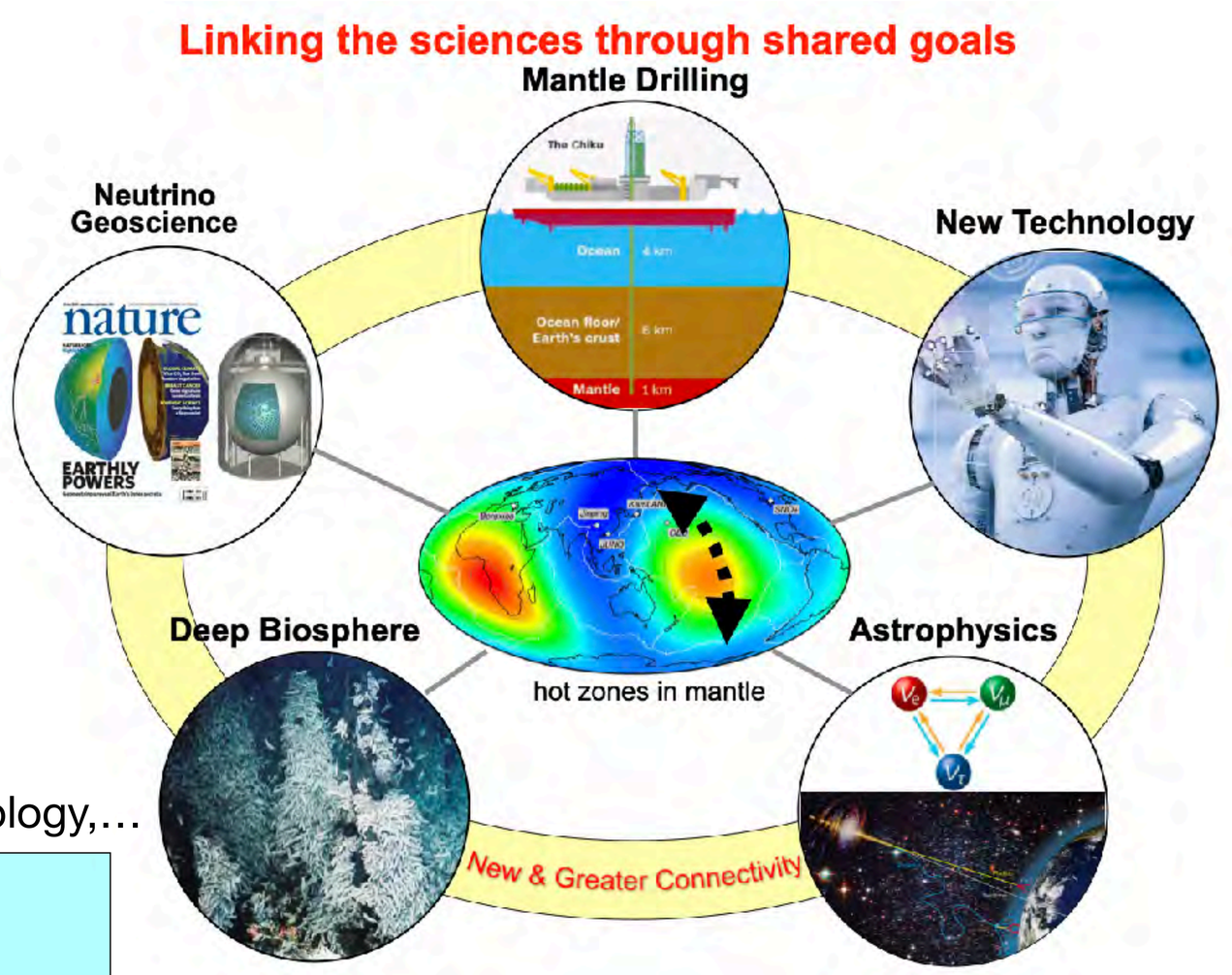
Solve the mystery of deep Earth!
First detector for mapping the inhomogeneous mantle

• Multidisciplinary Detector

<u>Physics</u>, Geoscience, Mantle drilling, Biology, New technology,…

Physics :
- multi baseline measurement of reactor neutrinos
- astro particle physics
- dark matter measurement with less-neutron background

etc.



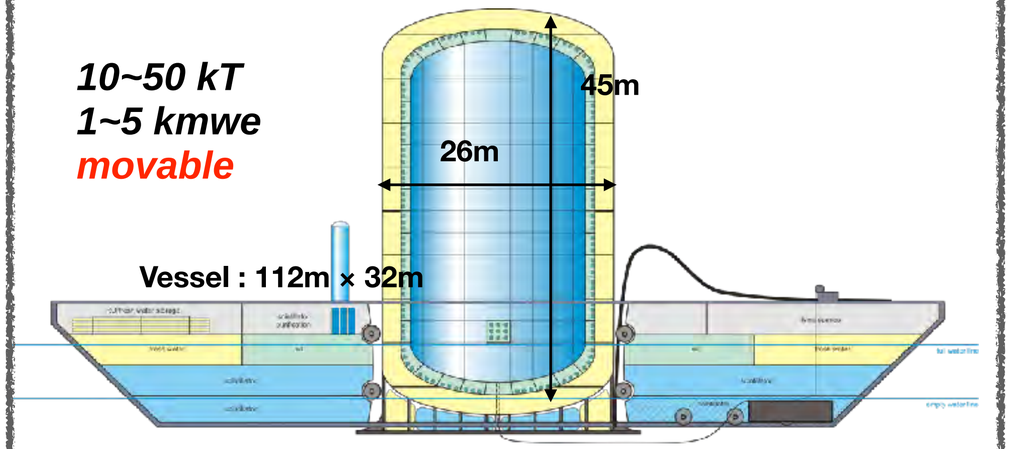
OBD Present & Future

2005 No progress… 2019 we are here 2020-2022 funded

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

“Hanohano” 2005

10~50 kT
1~5 kmwe
movable



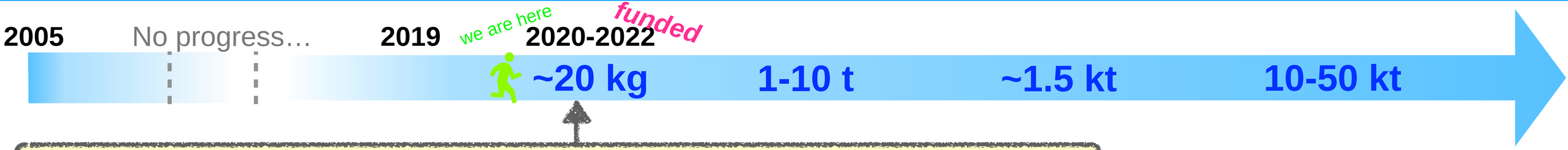
U. Hawaii & Makai Ocean Engineering

Technical tests and detector design

OBD project has started with JAMSTEC* & Tohoku U.!

* Japan Agency for Marine-Earth Science and Technology

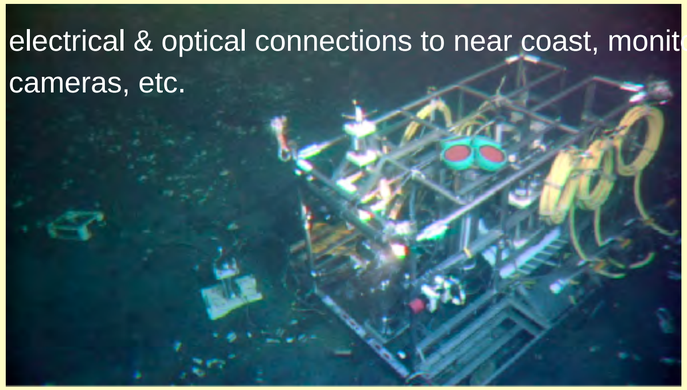
OBD Present & Future



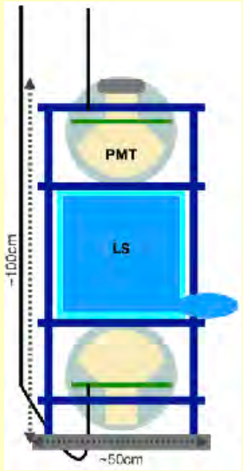
Technical test & world's first measurement in the ocean with LS detector

* Install detector into **~1km seafloor** (JAMSTEC's Hatsushima Observatory), take data for **several months**
* **measure muon late in the sea → input parameter for future large detector**
* Technical developments are in progress.

Hatsushima Observatory



detector design



OBD Present & Future

2005 No progress… 2019 we are here 2020-2022 funded

~20 kg → 1-10 t → ~1.5 kt → 10-50 kt

Maturity of science

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

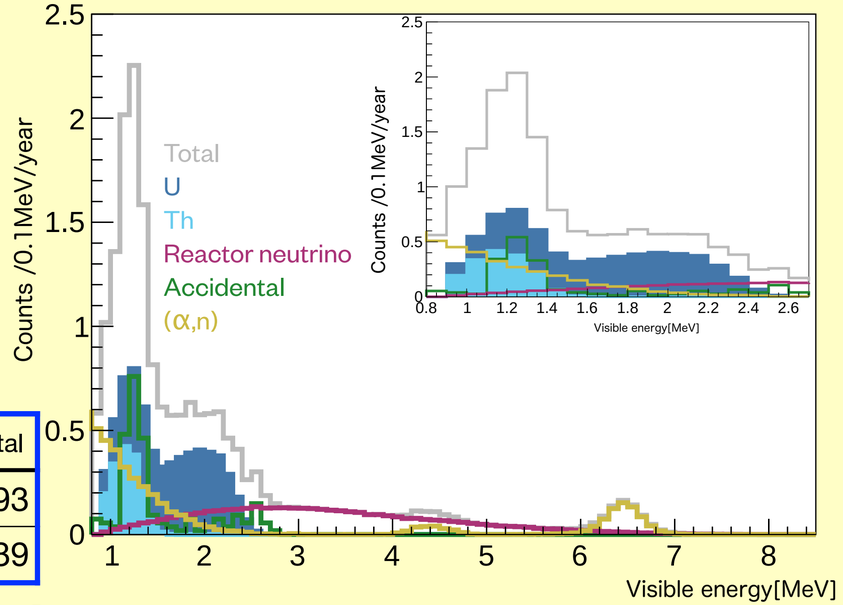
T. Sakai, Poster

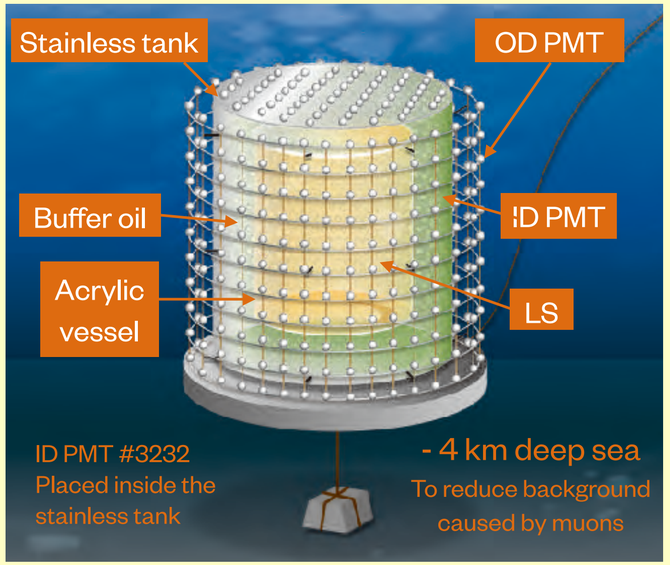
First clear mantle signal

* Detector simulation study is in progress.
* Hawaii is possible position.
* Detector should be installed at **~4km** deep sea to shield muons **Low temperature (2-4℃) high pressure (40MPa)**

	Signal			Backgrounds					
E reagion	U	Th	Total	Reactor	Acci.	(α,n)	He-Li	Fast-neutron	Total
All	6.59 (4.61)	1.64 (1.15)	8.23 (5.76)	4.13	1.92	3.88	0	<2.42	9.93
Geo-nu				1.53	1.90	2.96	0	<0.58	6.39

(mantle) [Events/year]





*** Mantle geoneutrino sensitivity**

highQ model: 1year → 3.7σ

middleQ model: 3year→ 3.5σ

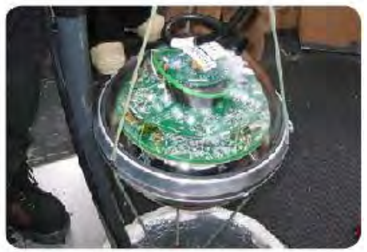
lowQ model: 10year→ 2.5σ

Technical Developments

* PMT shield

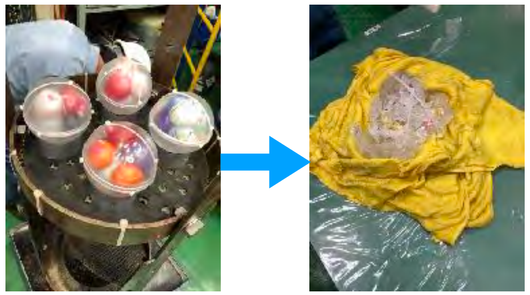
Needs : low background
pressure resistant

ref) IceCube experiment

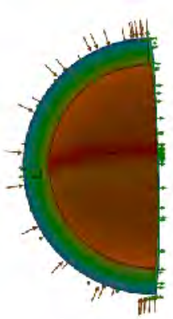


Acrylic

- low background
- pressure resistant : <40MPa broken



Pressure test @JAMSTEC



structural calculation

can not be used

Glass (OKAMOTO Glass Co.)

- pressure resistant
- very high impurities

[g/g]

	^{238}U	^{232}Th	^{40}K
target	1×10^{-8}	1×10^{-8}	1×10^{-8}
normal glass	$\sim1\times10^{-7}$	$\sim1\times10^{-7}$	$\sim1\times10^{-7}$
our work	**1.4×10^{-8}**	**$<5.0\times10^{-9}$**	**3.4×10^{-9}**
reduction	**1/10**	**1/500**	**1/300**

* cleaner material selection
* Pt coating on the melting pot

enhance the size (20 inch)

can be used

* Liquid scintillator

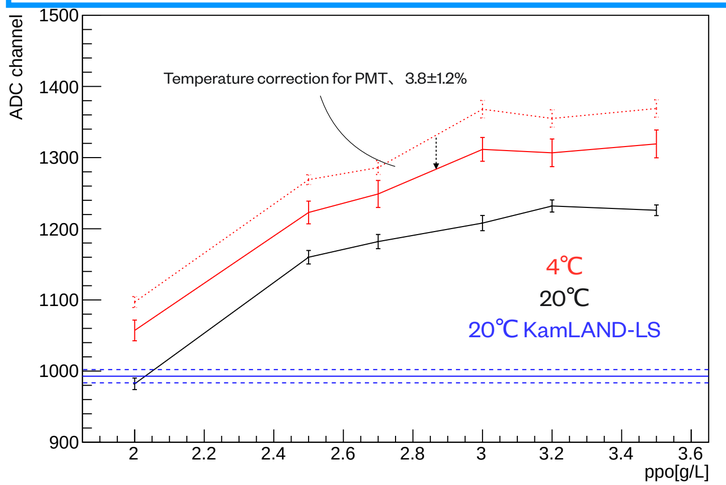
T. Sakai, Poster

LAB(oil) + PPO(fluorescents)

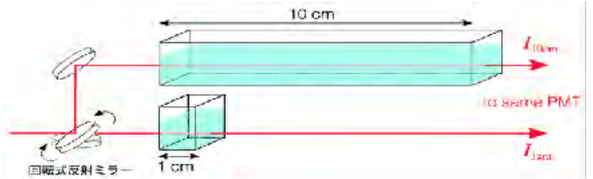
Low temperature

light yield

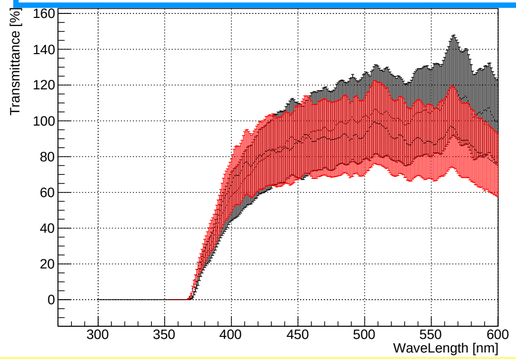
4°C is brighter than 20°C (+9%)



light transition



no temperature affect



Technological development has been started!

Summary

- 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.
  - **Strong way to measure amount of radioactive elements in the**

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

- **"Neutrino Geoscience" : <u>collaborations between geology, physics and beyond</u>**
  - **Ocean Bottom Detector (OBD) = Breakthrough**
  - **OBD has strong power to measure mantle contribution directly**

OBD's Primary Goal :

<Transformative insights>

・map the mantle

・constrain the planet's cooling history