

# Ocean Bottom Detector

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**for the OBD working group\***

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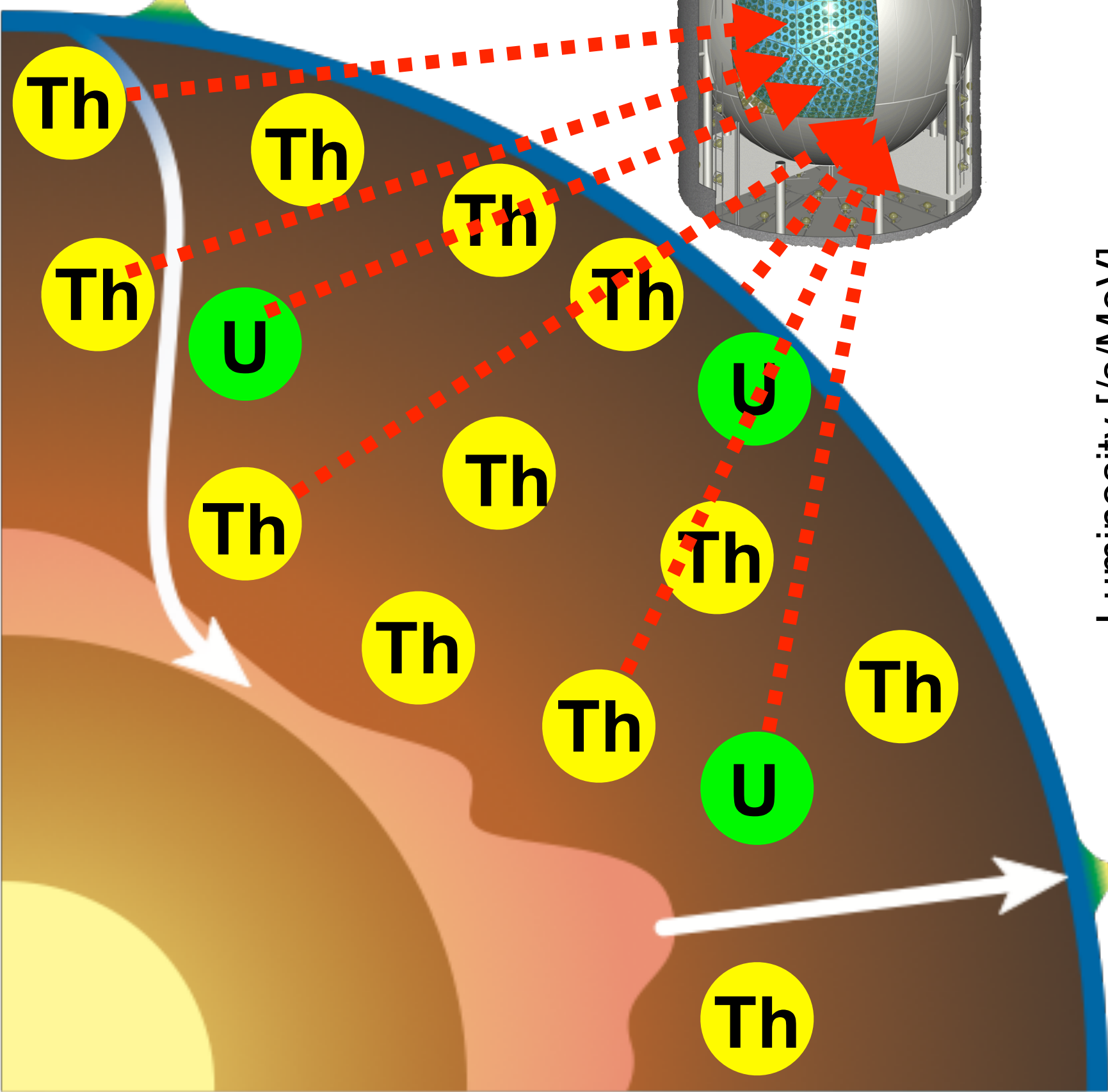
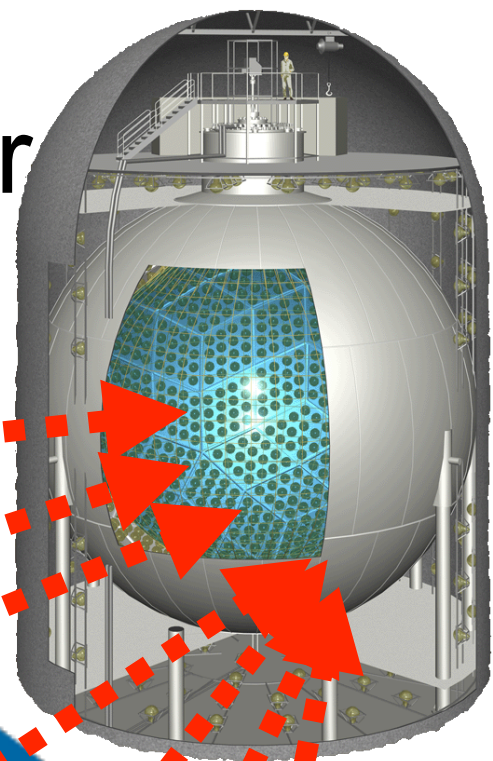
\* K. Inoue<sup>1</sup>, T. Sakai<sup>1</sup>, H. Watanabe<sup>1</sup>, W. F. McDonough<sup>1,2,3</sup>, K. Ueki<sup>4</sup>, N. Abe<sup>4</sup>, M. Kyo<sup>4</sup>, N. Sakurai<sup>4</sup>, E. Araki<sup>4</sup>, T. Kasaya<sup>4</sup>, H. Yoshida<sup>4</sup>

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

## Electron-antineutrinos from natural radioactive decays

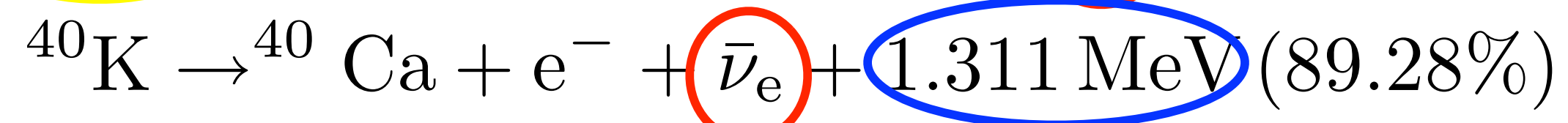
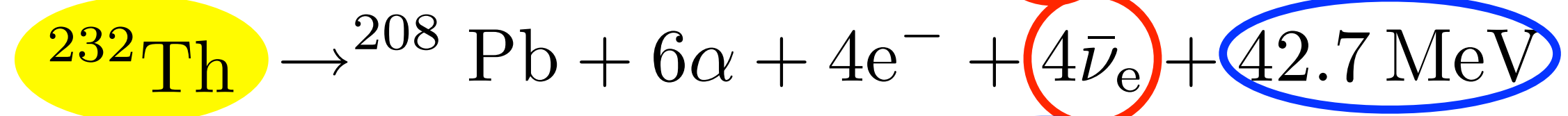
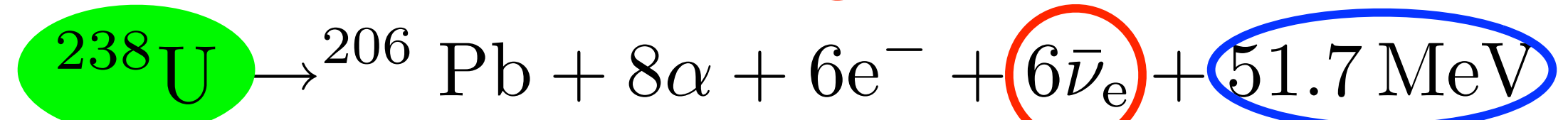
$$\bar{\nu}_e \ 4.1 \times 10^6 / \text{cm}^2 / \text{sec}$$

Anti-neutrino Detector  
(e.g. KamLAND)

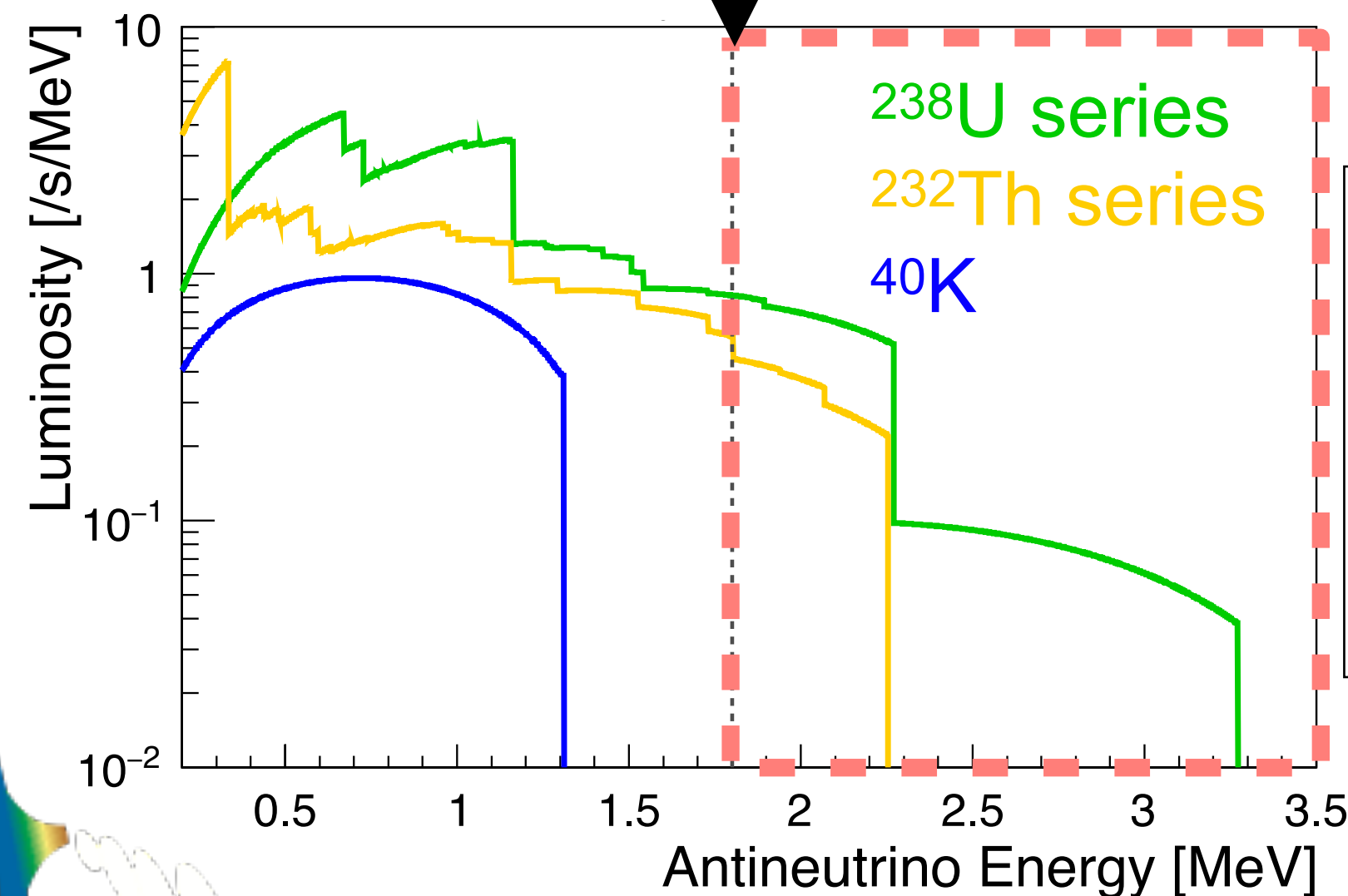


$\beta$ -decay

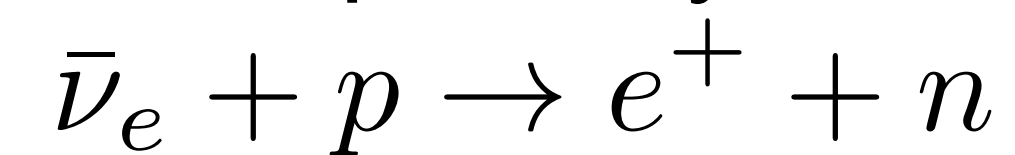
geo-neutrinos



Energy threshold, 1.8 MeV



inverse  $\beta$ -decay



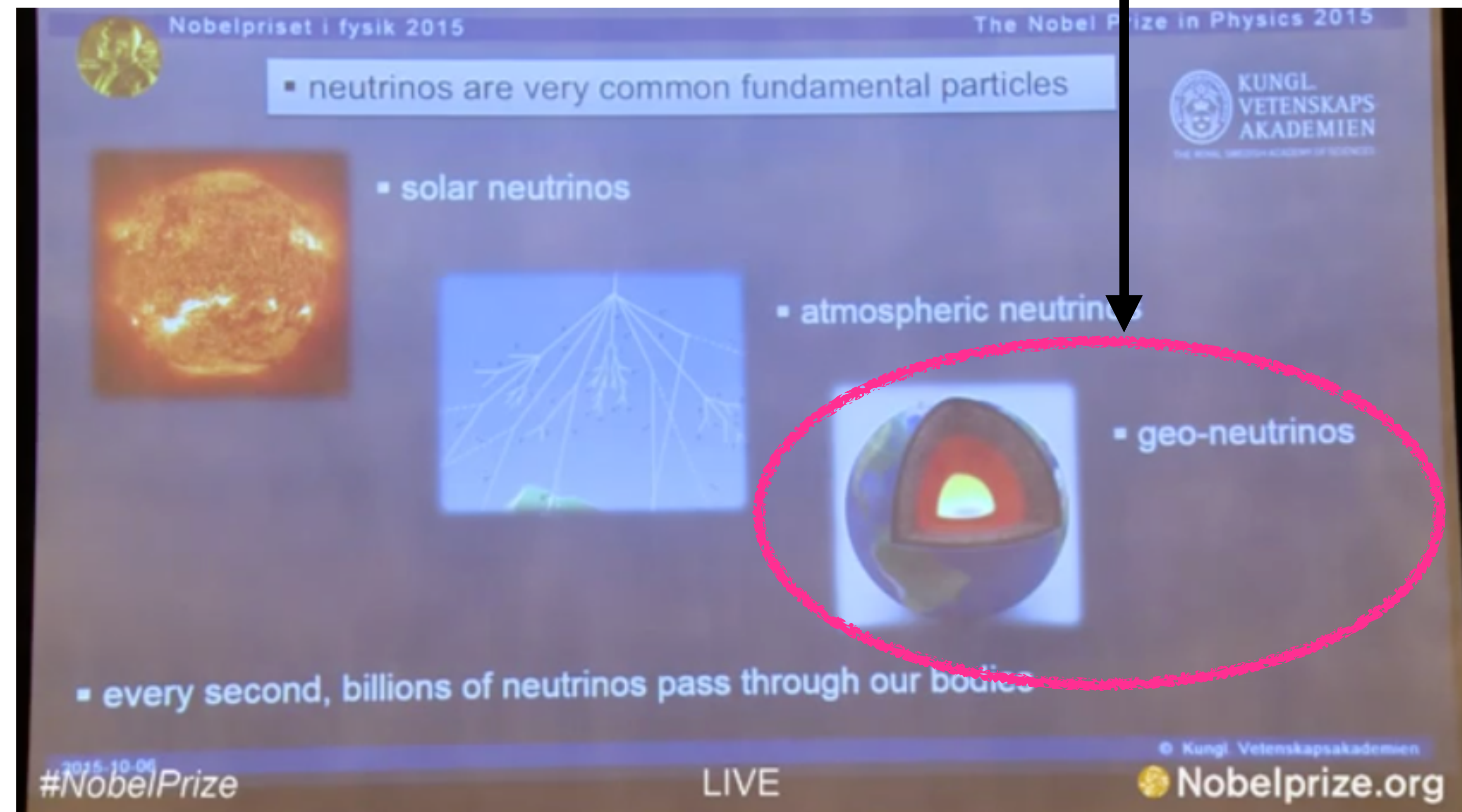
\* Only geo-neutrinos from **U** and **Th** are detectable right now  
\*  $^{40}\text{K}$  geo-neutrino detection needs another technology.

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



Announcement of Nobel Prize in Physics 2015

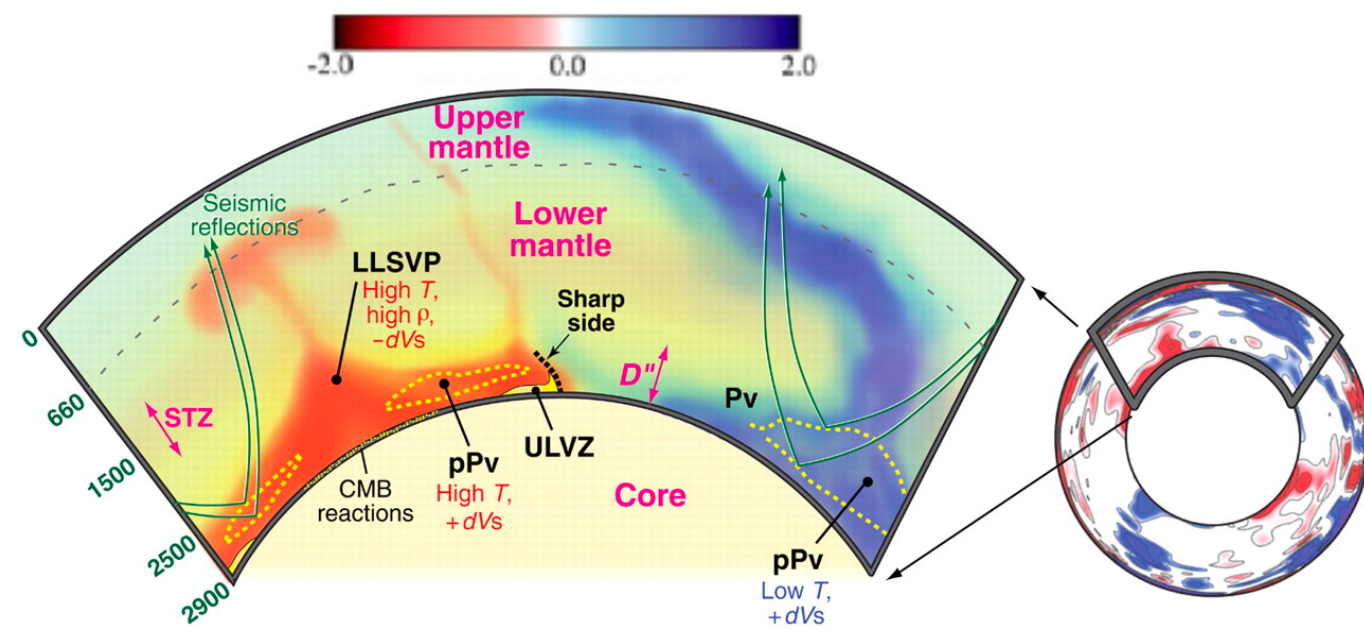
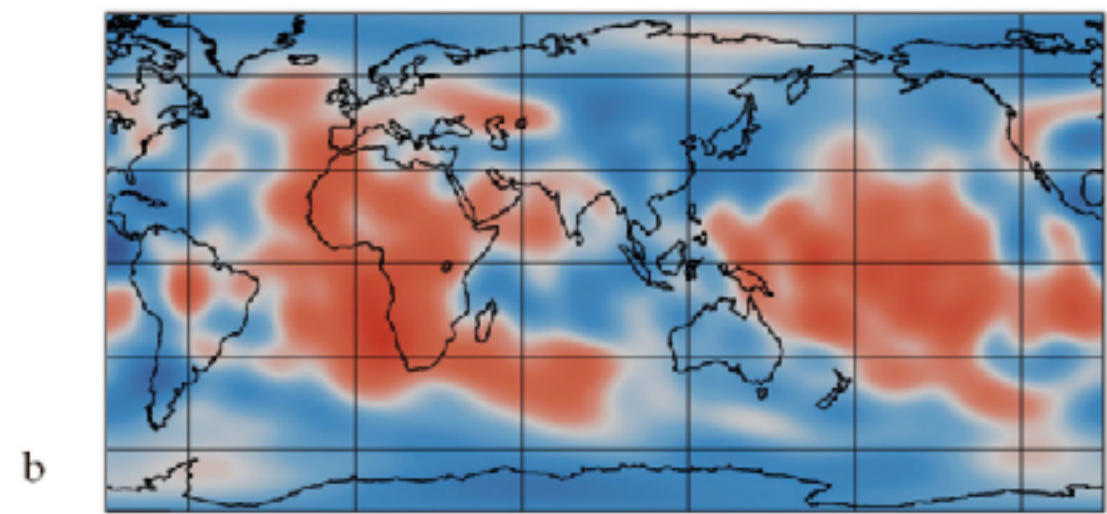
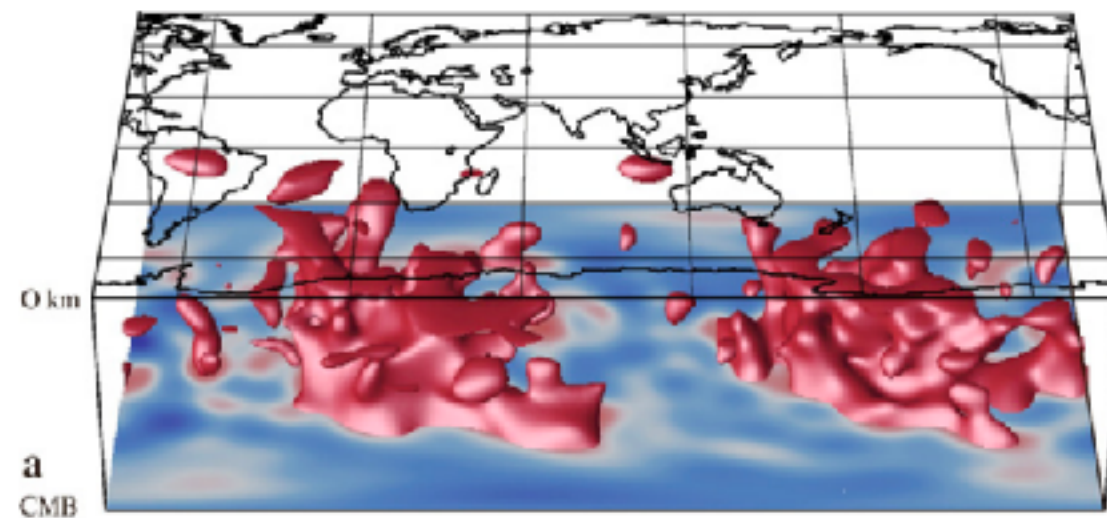
**Geoneutrinos!!!**



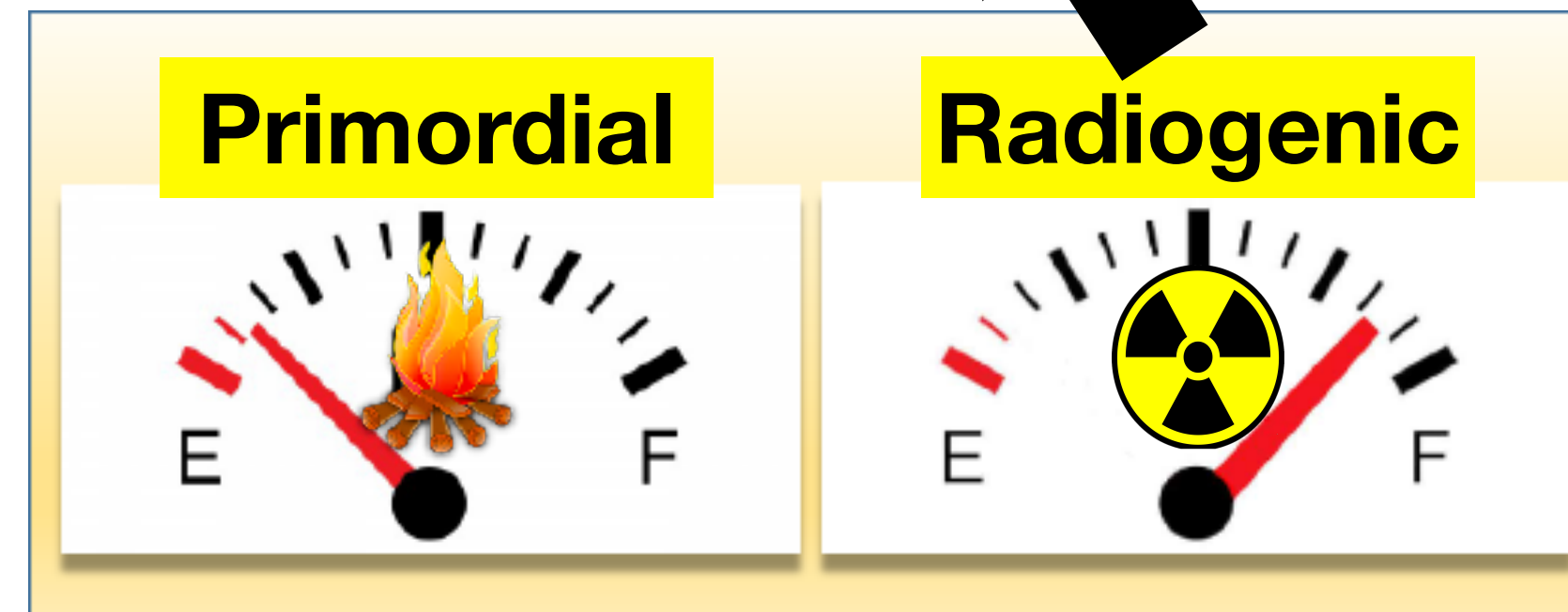
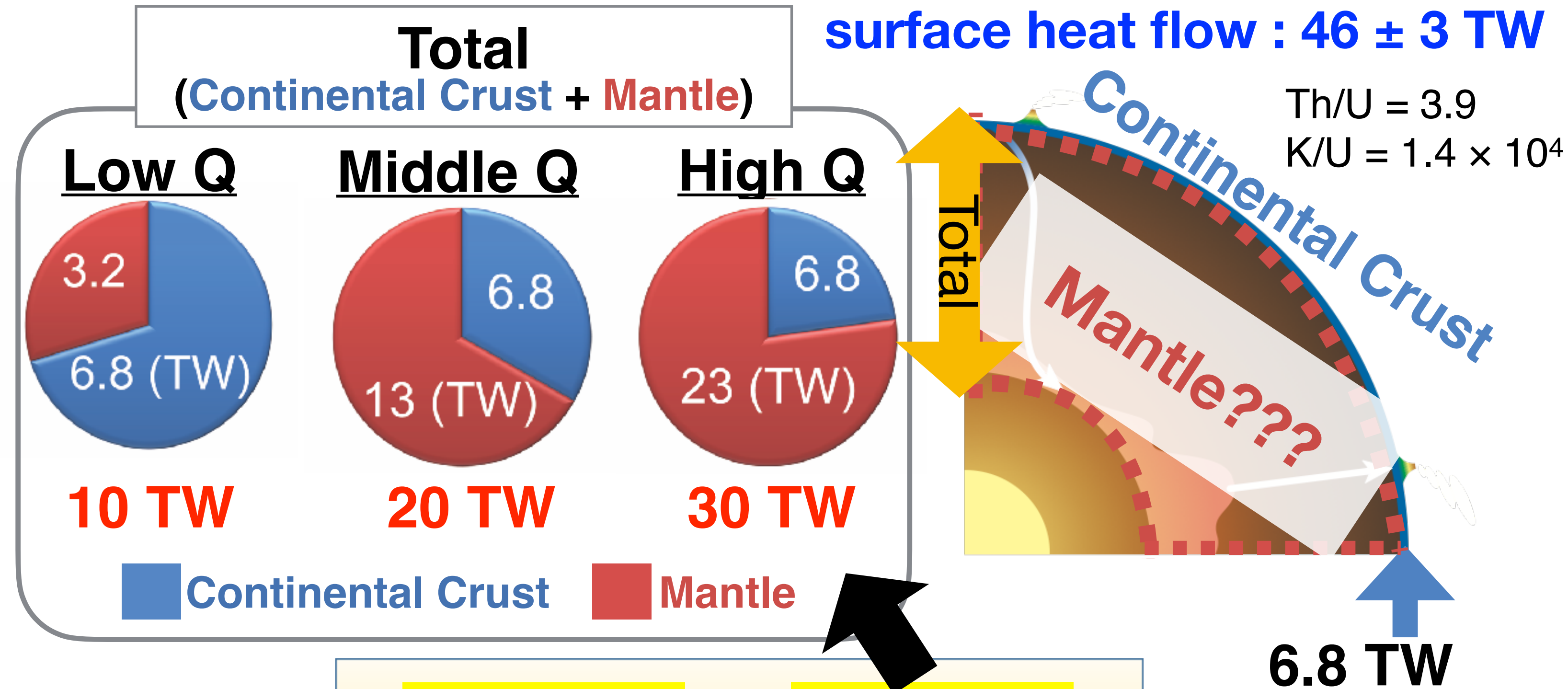
**World Class Science**

## What is in the mantle?

Many seismically imaged structures and chemical heterogeneities in the mantle



## How much fuel is left to drive Plate Tectonics?

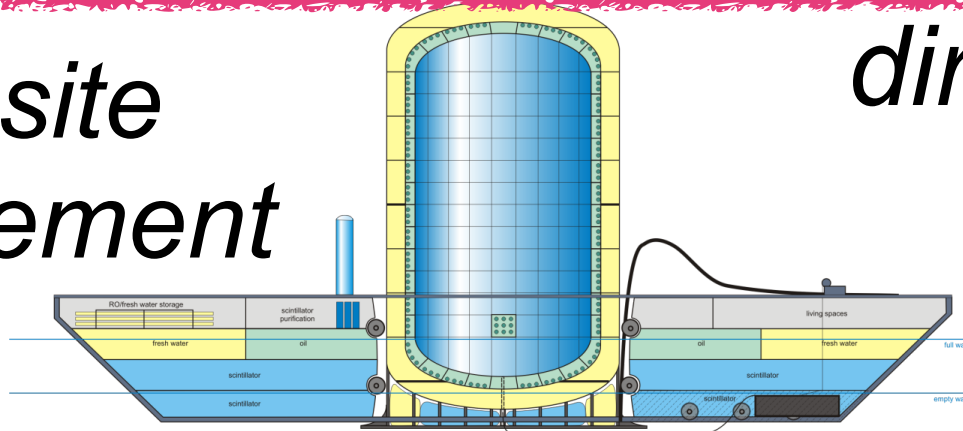


**Geo-neutrino can directly define power to drive the Earth's engine**

## 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

resolving vertical and horizontal flux differences

Th/U ratio

Measuring

Next Target!

distinguishing mantle contribution

Measuring

detecting K geo-neutrino

## what we learn



first measurement in 2005

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

$$\text{Observation} = \text{Crust} + \text{Mantle}$$

(y = x + b)

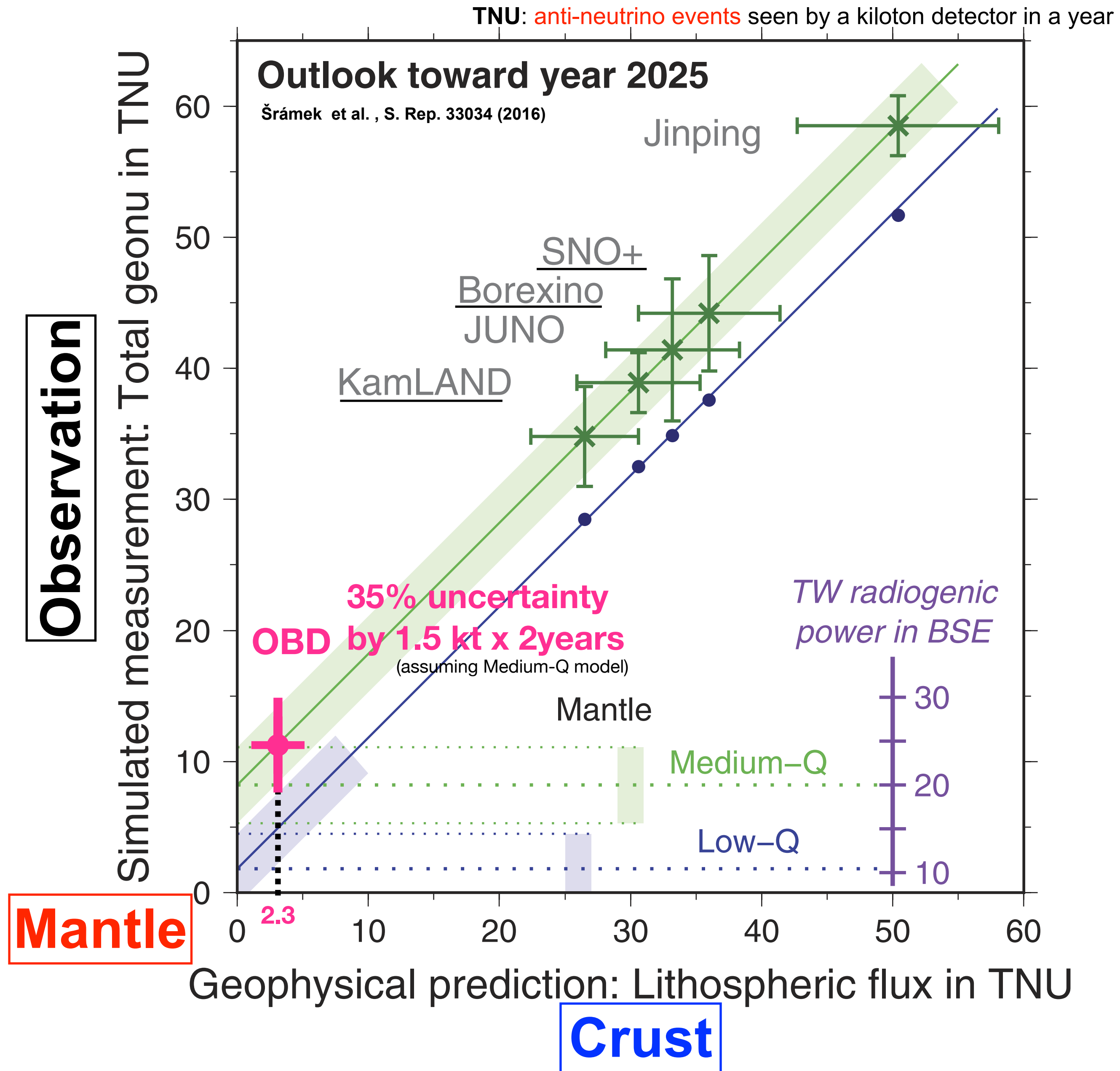
Near Future...

**3 multi-site measurements can constrain mantle contribution.**

Crust estimation needs to be accurate.

+ OBD

**OBD can directly measure mantle contribution.**



• **Direct Measurement of Mantle**

need to be far from crust  
can be far from reactors

• **Multi-site Measurements**

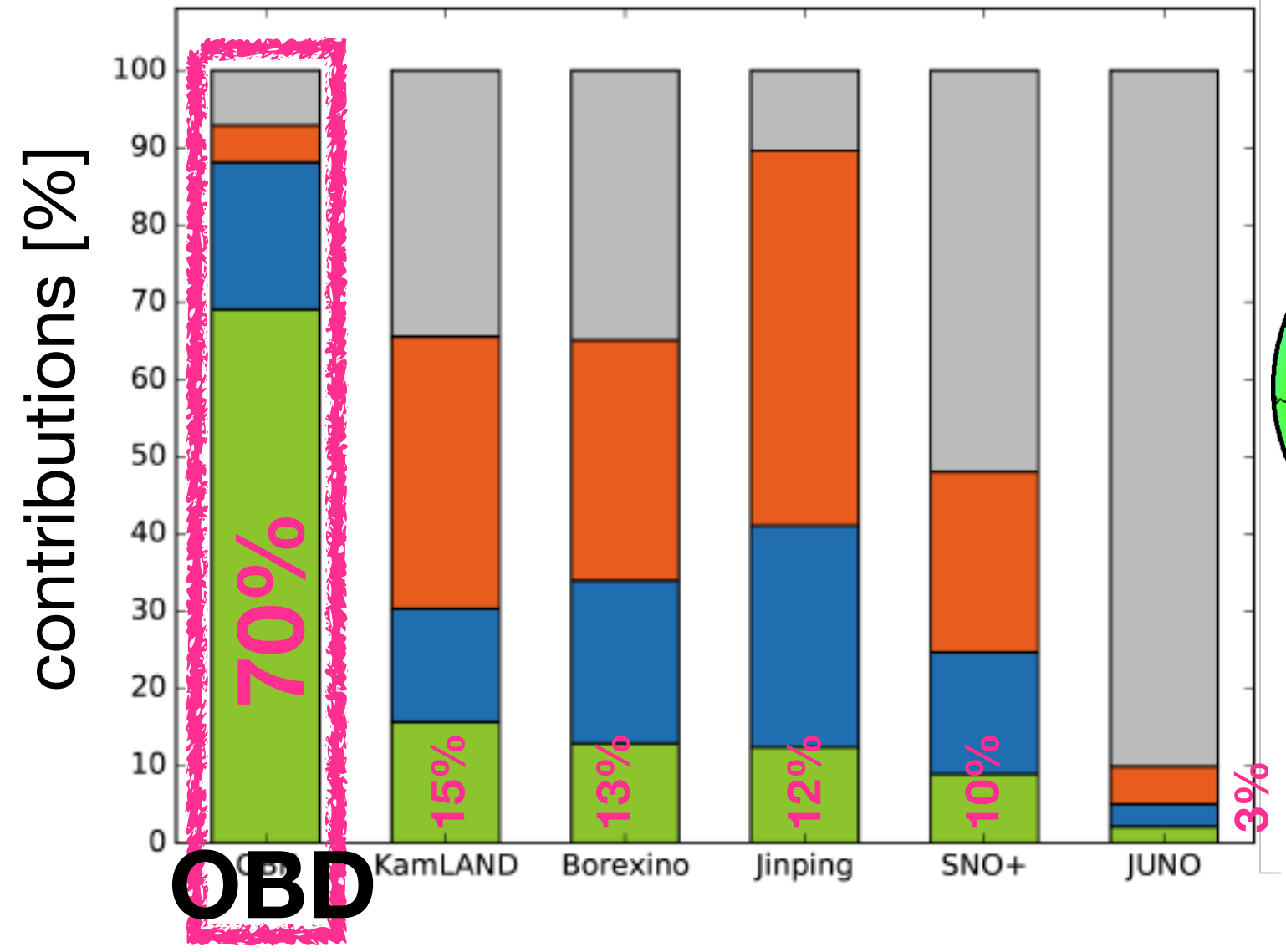
Solve the mystery of deep Earth!

• **Multidisciplinary Detector**

Physics, Geoscience, Mantle drilling, Biology, New technology,...

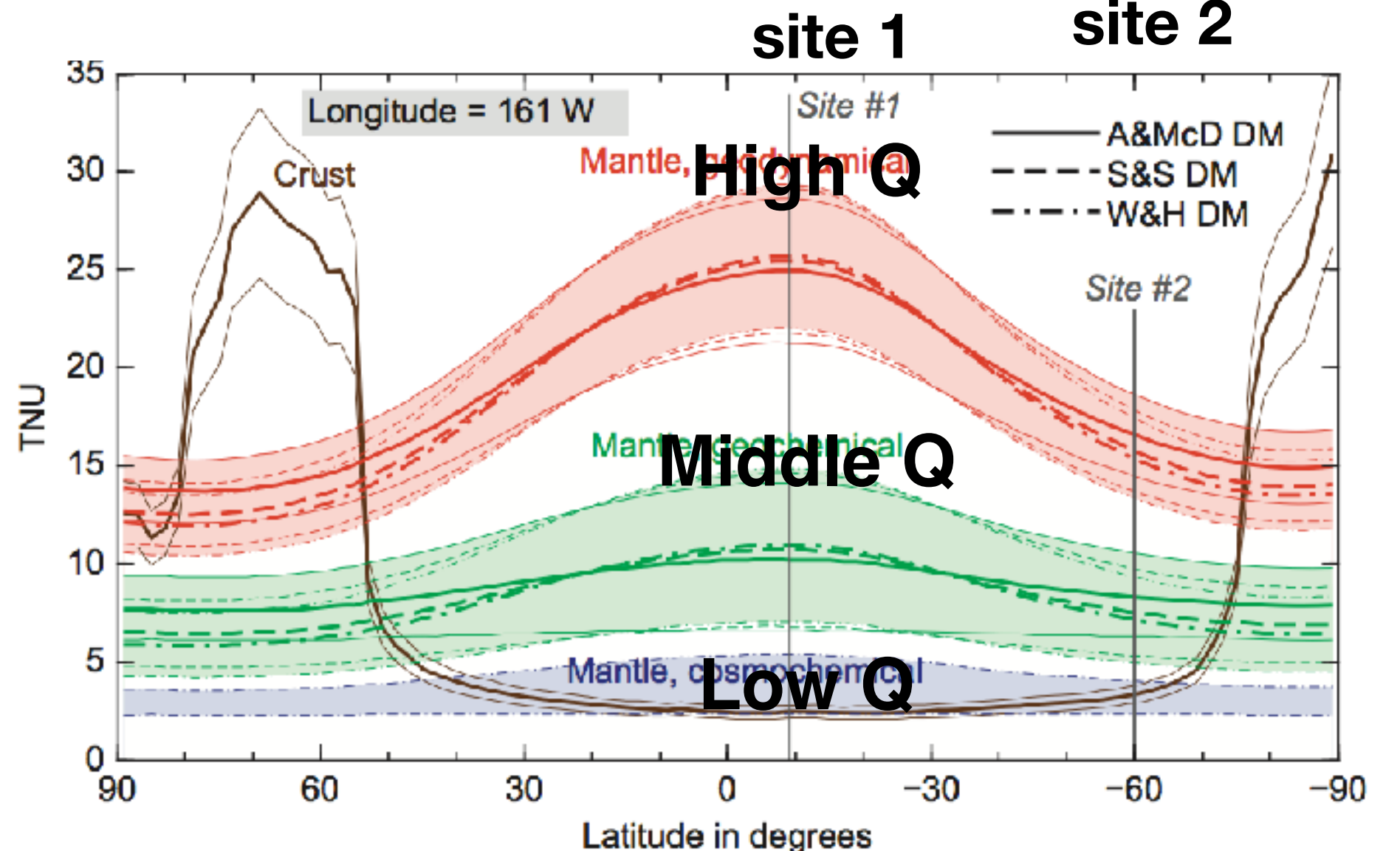
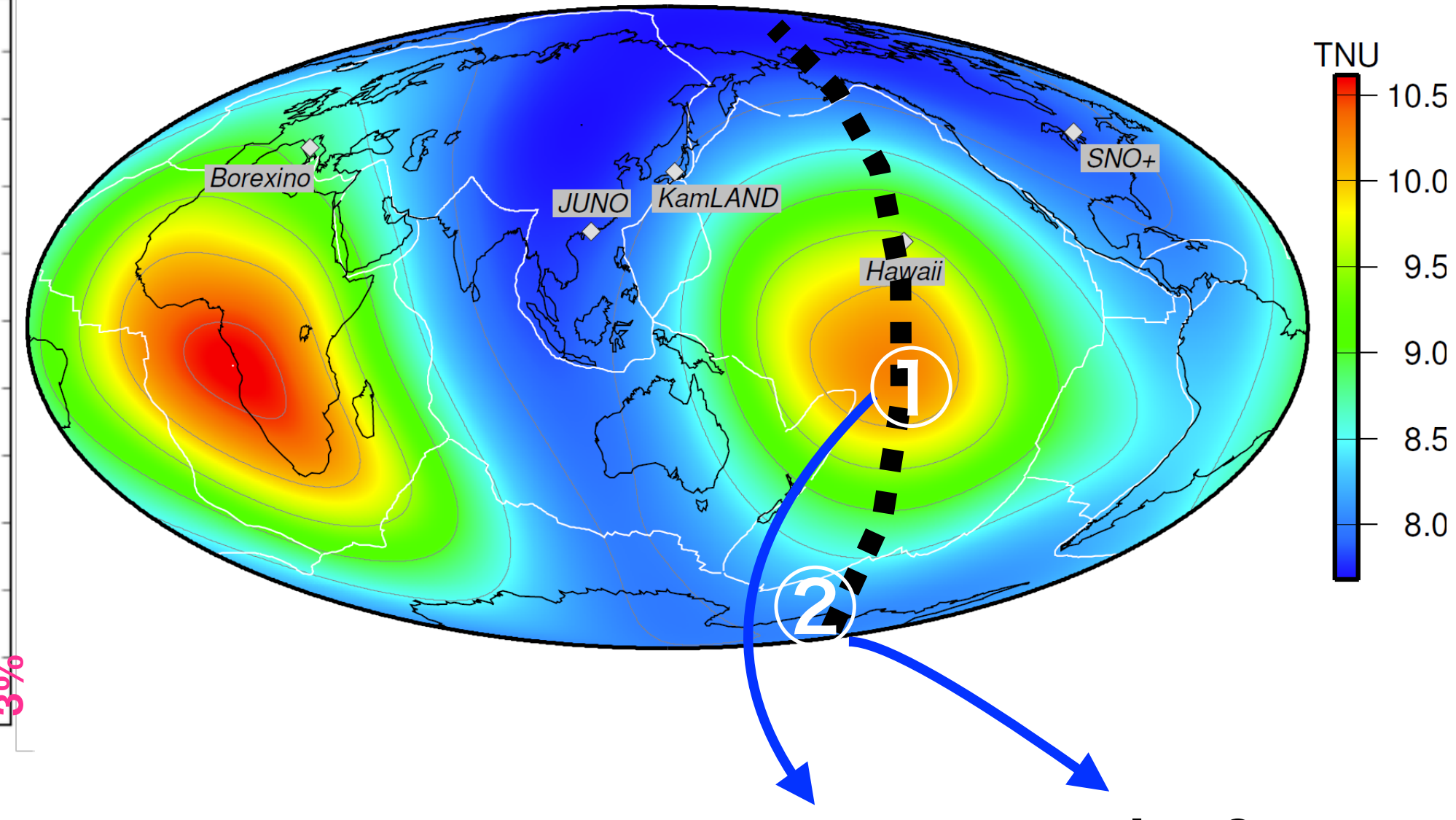
- Physics :
- multi baseline measurement of reactor neutrinos
  - astro particle physics
  - dark matter measurement with less-neutron background etc.

Reactor  
Mantle  
Crust (<500km)  
Crust (global)



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

Mantle Geoneutrino Flux



2005 No progress...

2019

2020-2022 *funded*

~20 kg

1-10 t

~1.5 kt

10-50 kt

**Maturity of science**

**“Hanohano” 2005**

10~50 kT  
1~5 kmwe  
*movable*

Vessel : 112m x 32m

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

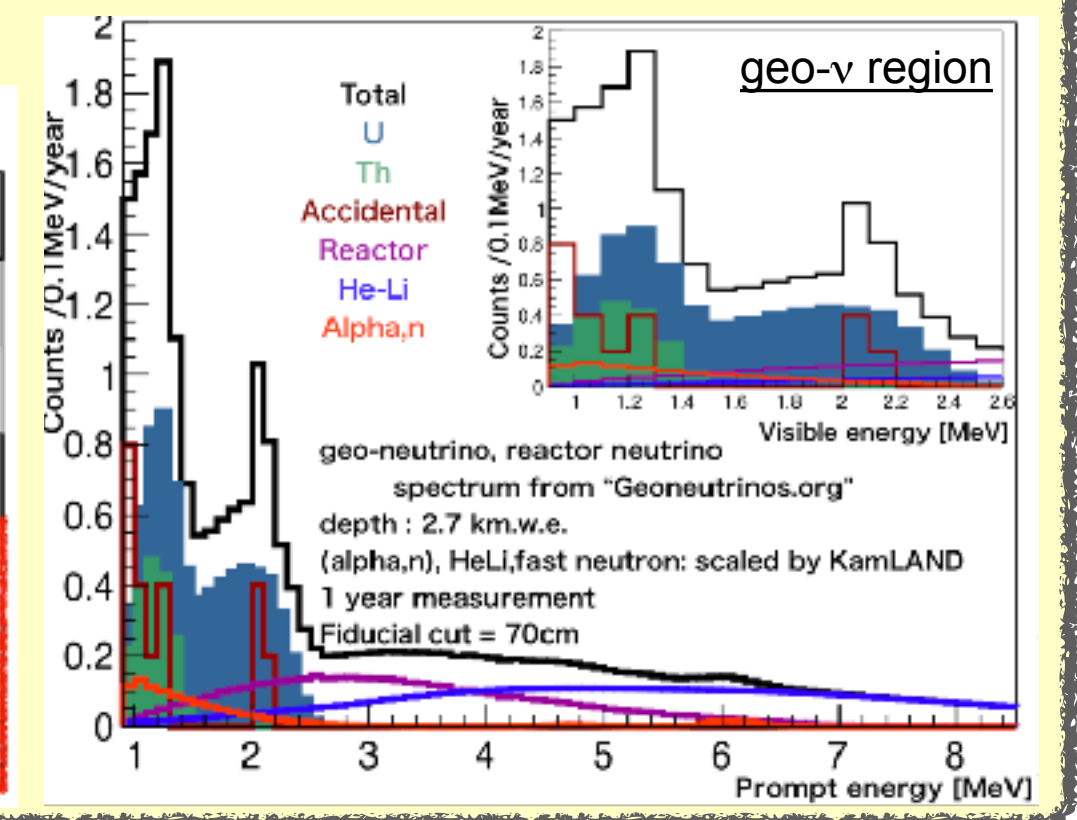
Joint workshop on OBD with Ocean Engineering, Earth Science and Neutrino Physics

**First clear mantle signal**

- \* Detector simulation study is in progress.
- \* Hawaii is possible position.
- \* Sensitivity for mantle geo-neutrino  
1-year : 1.8  $\sigma$   
2-year : 2.6  $\sigma$

More information:  
T. Sakai, Neutrino 2020 (poster #435)

Background			signal	
Source	Events (/year)	geo-nu region	Location: Hawaii	Events (/year)
Reactor	4.5	1.5	U	7.4
Accidental	2.4	2.4	Th	1.8
He-Li	5.8	0.5	<b>Total geo-nu</b>	<b>9.2</b>
alpha,n	1.1	1.0	Mantle U	5.2
Fast neutron	<2.8	<0.6	Mantle Th	1.3
<b>Total</b>	<b>13.8</b>	<b>5.4</b>	<b>Total mantle</b>	<b>6.5</b>

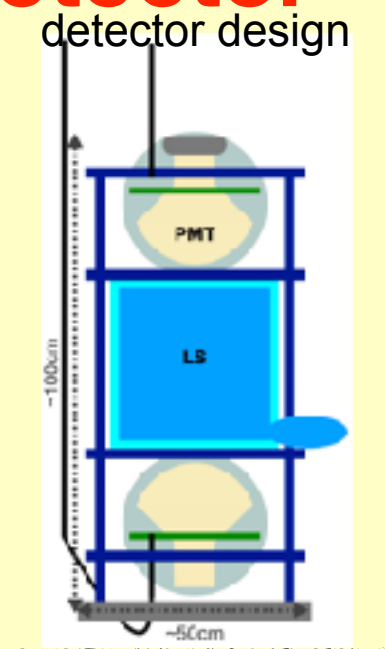
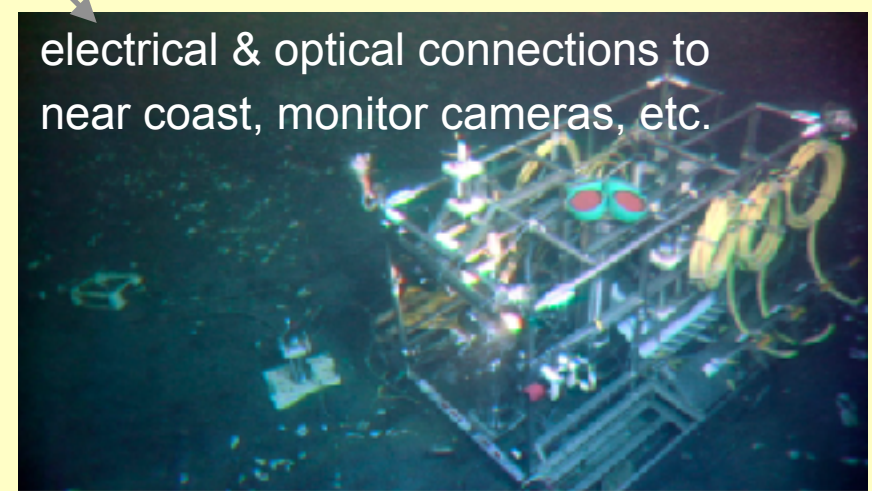


**Technical demonstration & environment measurement in the sea**

deep sea neutrino & muon flux, ocean water density & temperature, radioactivity  
→ input parameters for ~1.5 kt detector design

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

- \* Install detector into ~1km seafloor (JAMSTEC's Hatsushima Observatory)
- \* Technical developments are in progress.
  - \* low-impurity PMT shield
  - \* LS optimization for seafloor environment
  - \* DAQ system & power supply
  - \* deployment, recovery, maintenance, redeploy





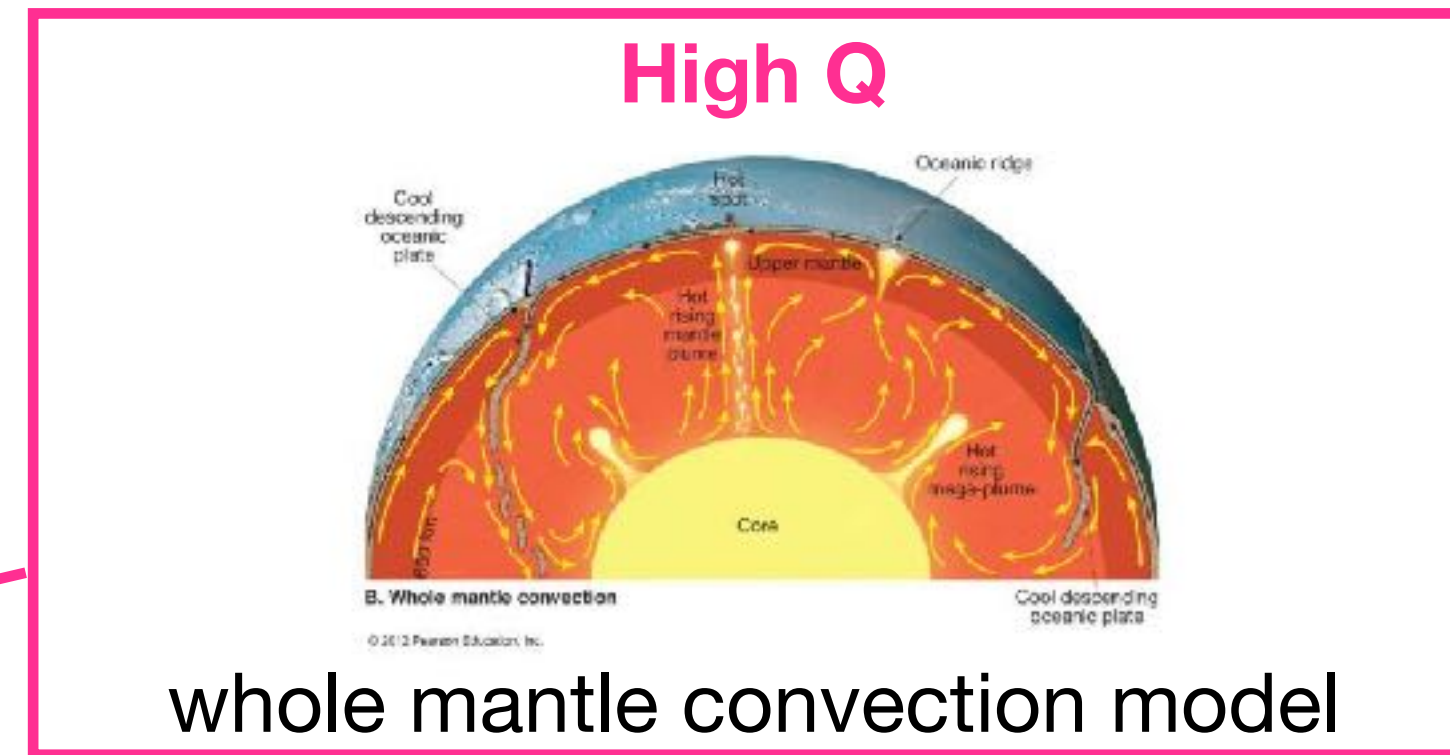
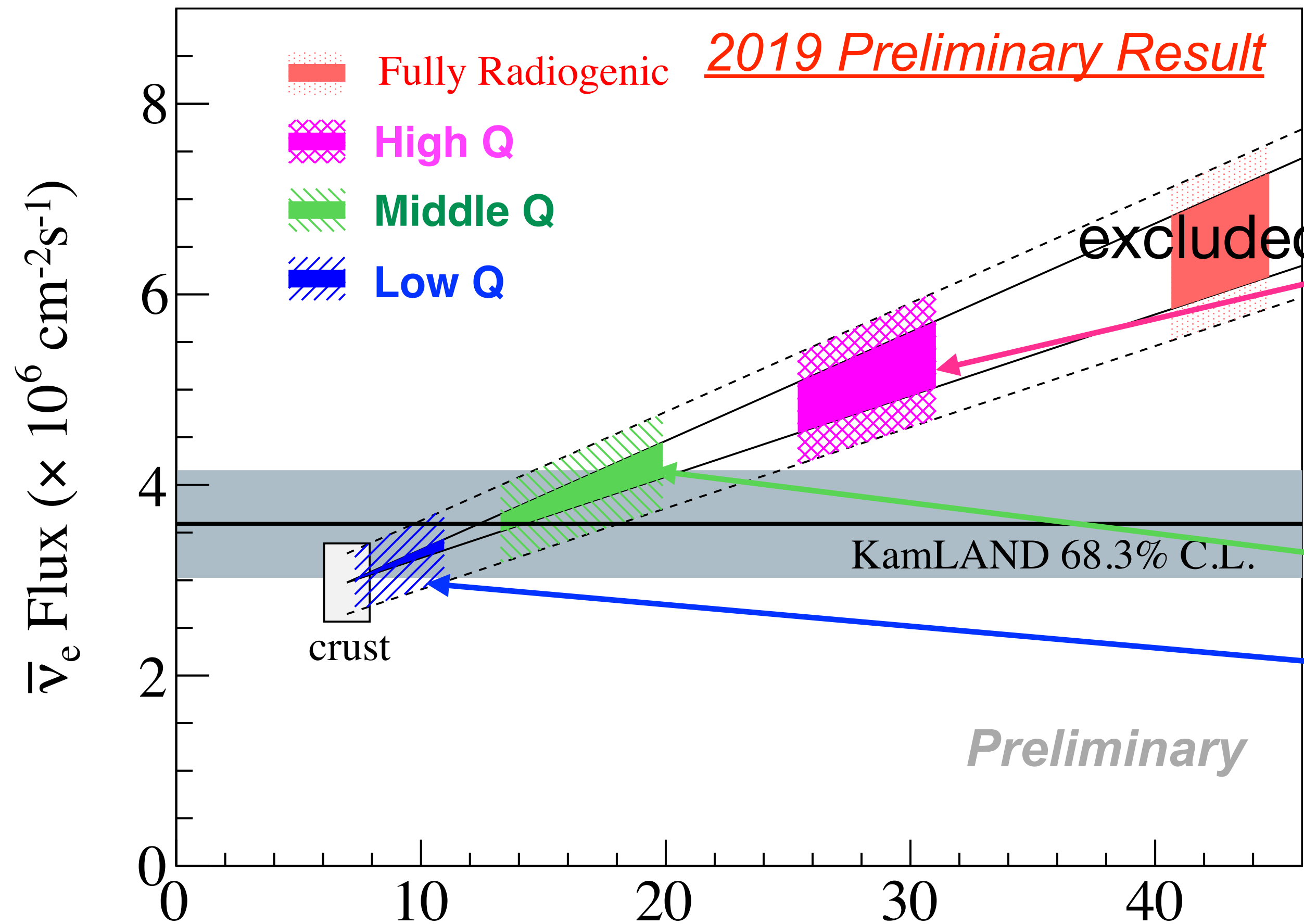
- For two centuries we have asked what is the energy that drives the Earth?
- Geoneutrinos are unique and new tool to measure directly the Earth's interior.
  - ▶ **Only way to measure amount of radioactive elements in the Earth**
- To date, physics experiments have shown the usefulness of geoneutrinos.
  - ▶ **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.**

<Transformative insights>

**OBD's Primary Goal :**

- **map the mantle**
- **constrain the planet's cooling history**

Backup



whole mantle convection model

**rejected with  $>2 \sigma$**

**Middle Q** Different types of primordial meteorite  
**Low Q**

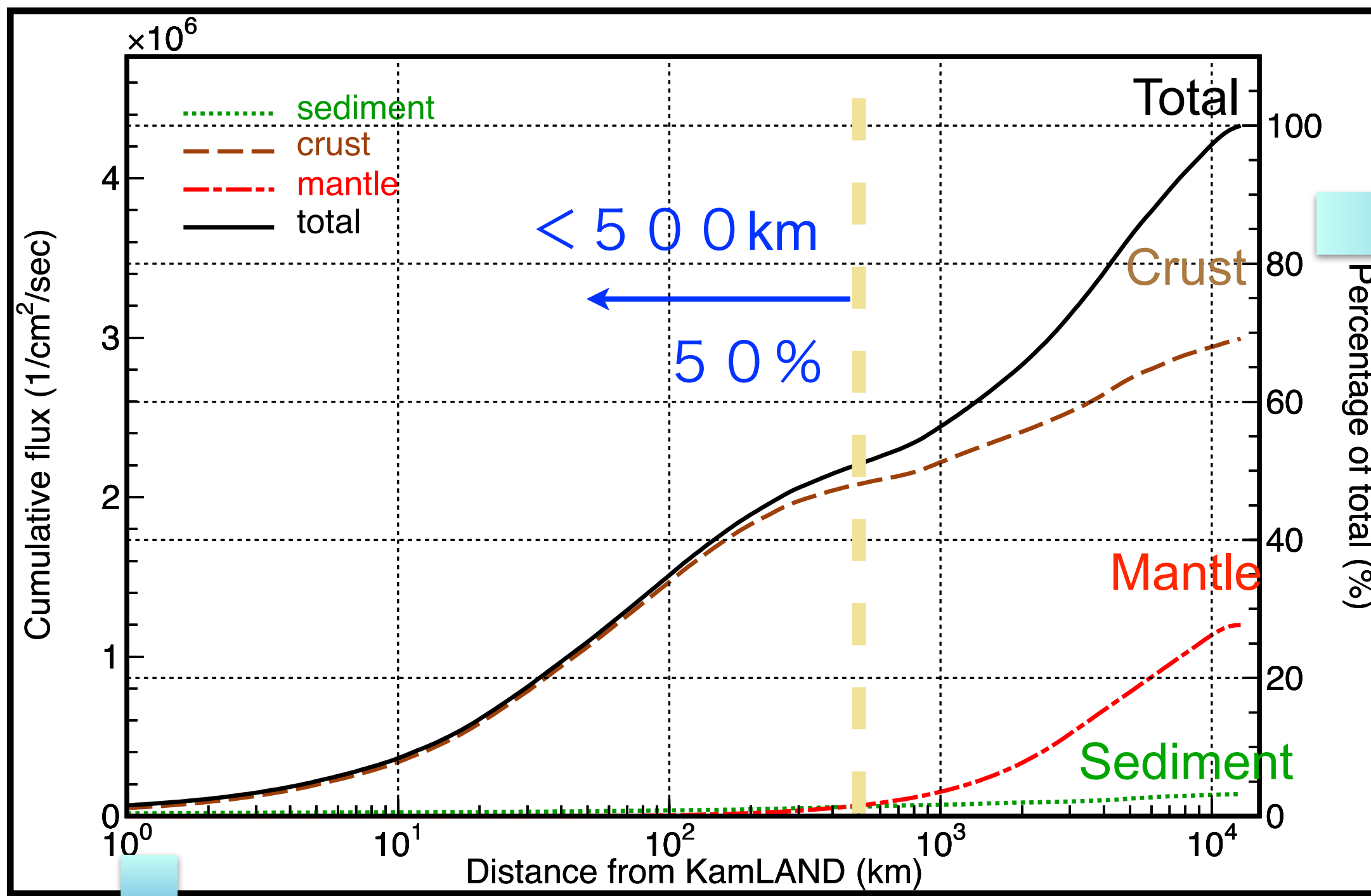
**can be selected by geo-v measurement**

[BSE models]	
<b>High Q</b>	based on balancing mantle viscosity and heat dissipation
<b>Middle Q</b>	based on mantle samples compared with chondrites
<b>Low Q</b>	based on isotope constraints and chondritic models

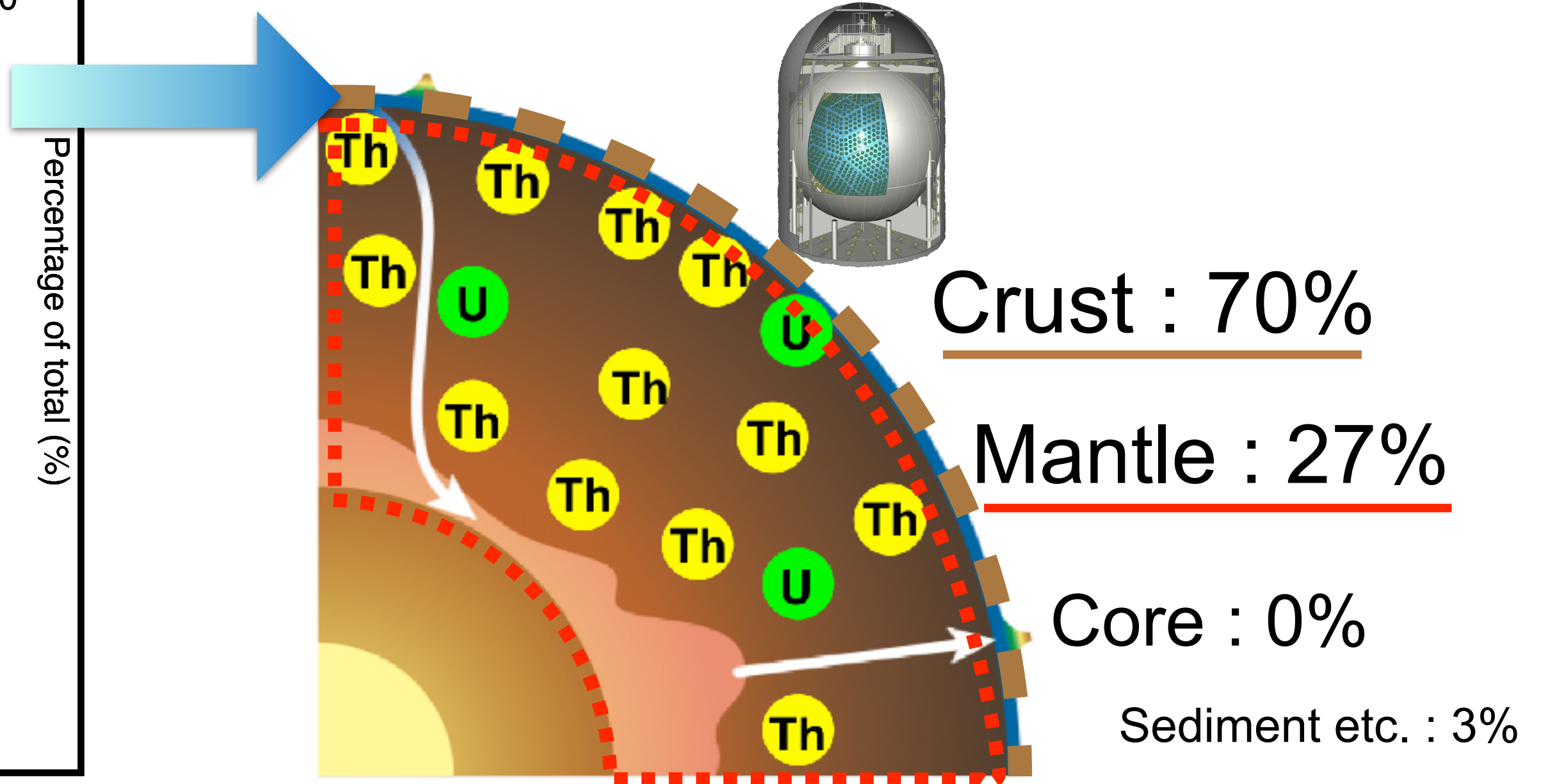
Radiogenic Heat from  $^{238}\text{U} + ^{232}\text{Th}$  (TW)  
 **Radiogenic Heat :  $12.4^{+4.9}_{-4.9}$  TW**  
 (Mantle+Crust, U+Th)

ref) Crust (U+Th)  $\sim 7$  TW Enomoto et al. EPSL 258, 147 (2007)  $\rightarrow$  Mantle (U+Th)  $\sim 5.4$  TW

# Geo-neutrino Flux at Kamioka



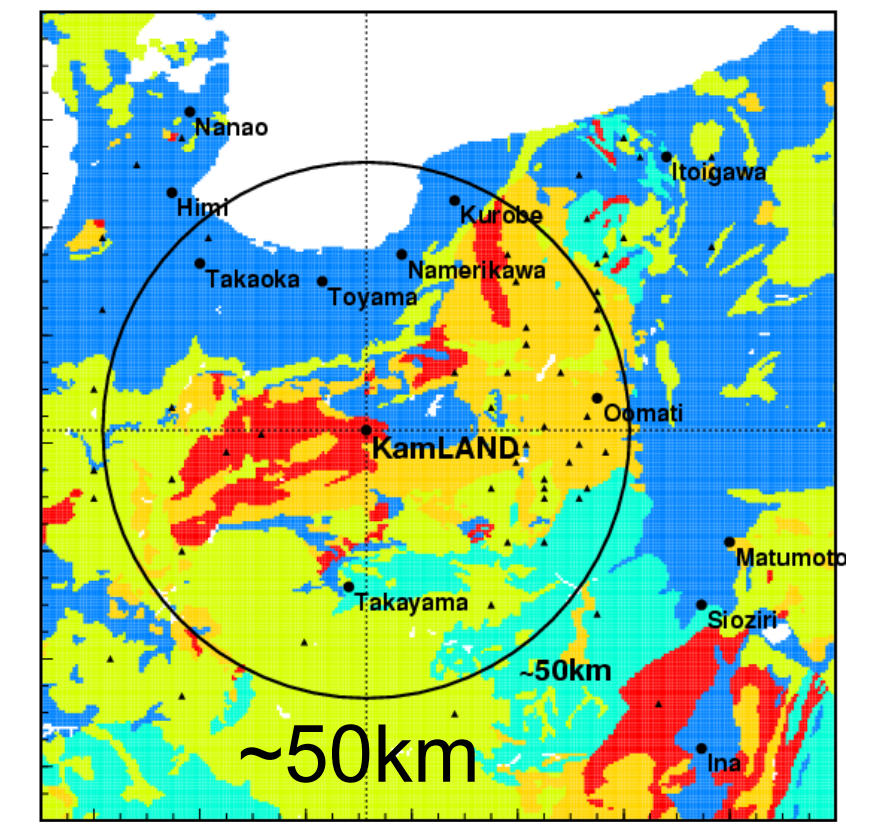
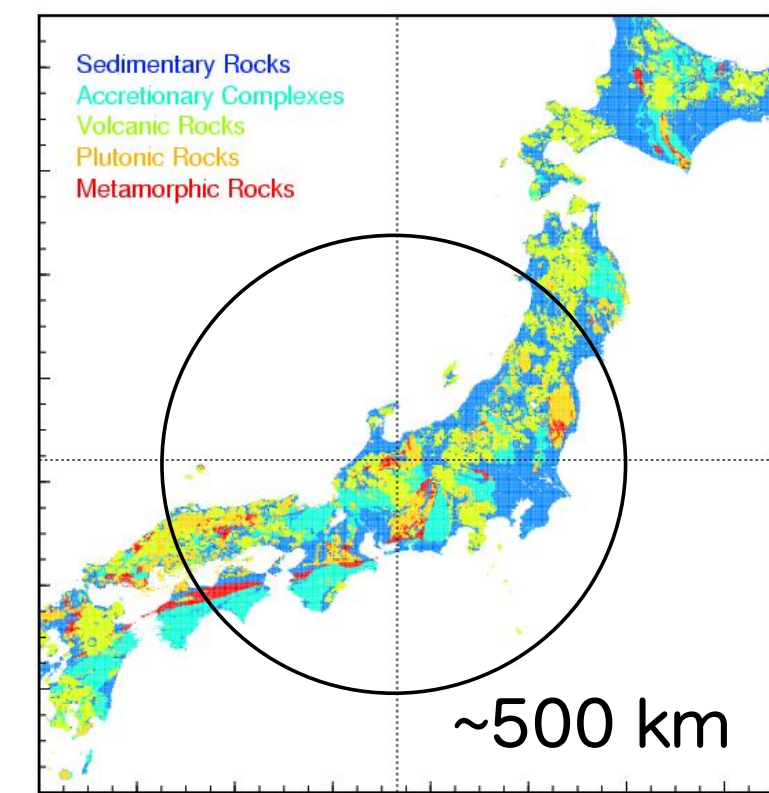
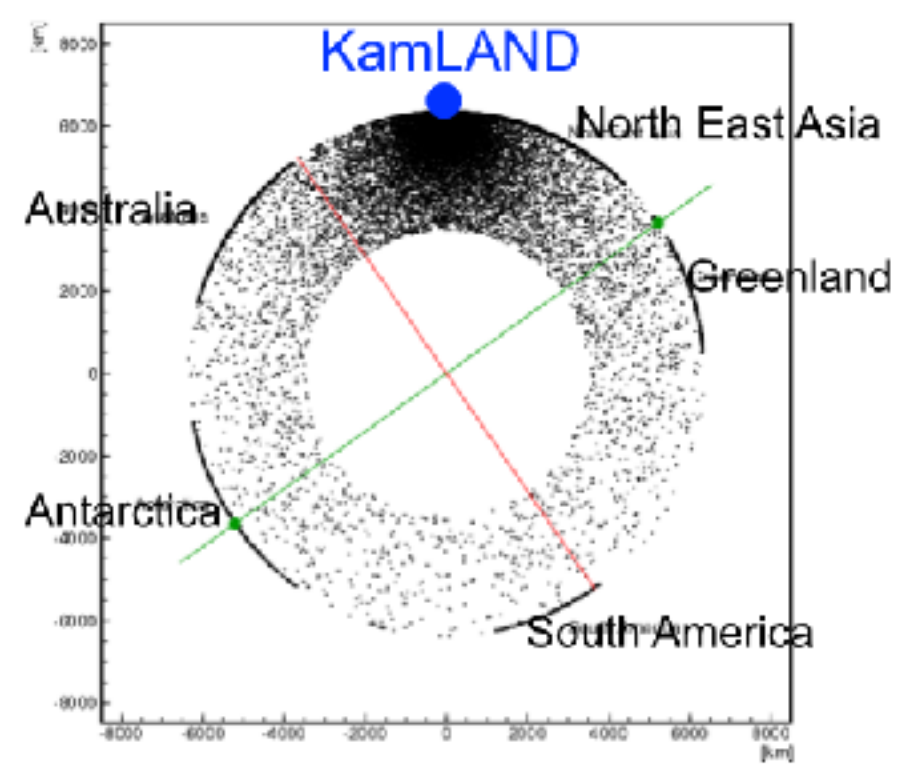
Contributions from each part



Contributions from each area

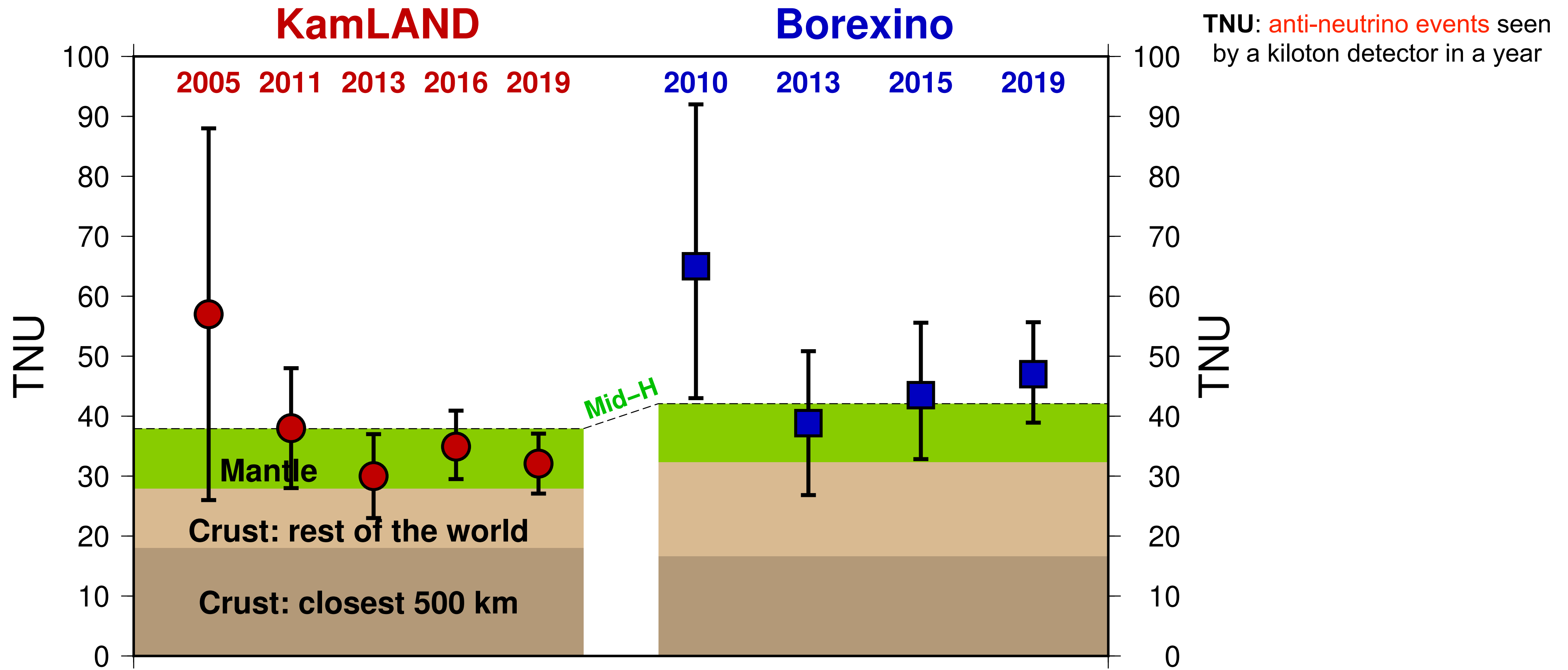
- **50%: distance < 500km**
- 25%: distance < 50km
- 1~2%: from Kamioka mine

**Important to understand local geology**





# KamLAND & Borexino Results



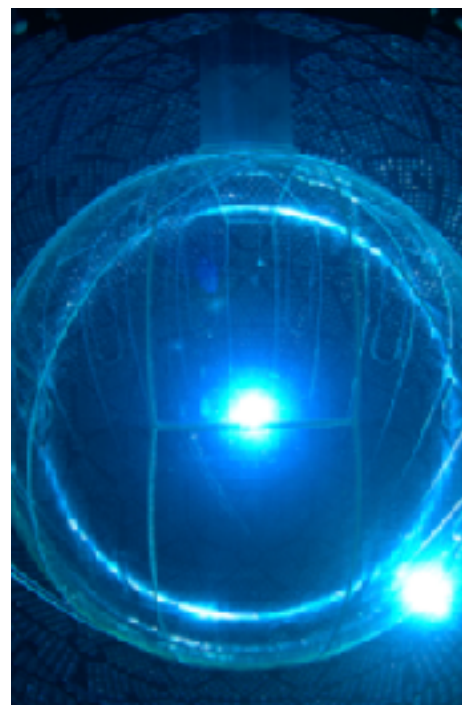
Geoneutrino prediction from Wipperfurth et al. 2020 JGR doi:10.1029/2019JB018433

- ☑ **Geo-neutrino : measure “Mantle + Crust” contributions**
- ☑ **2019 results have  $>1\sigma$  tension in mantle contribution**
  - affected by **local crust estimation**

# Anti-neutrino Detectors

## SNO+

1 kt, LS+, 5.4 km.w.e.  
**Filling, counting in progress!**

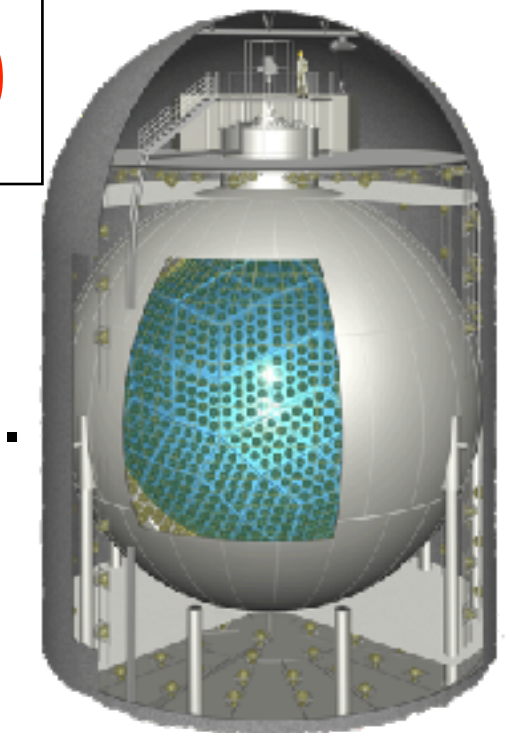


## Baksan

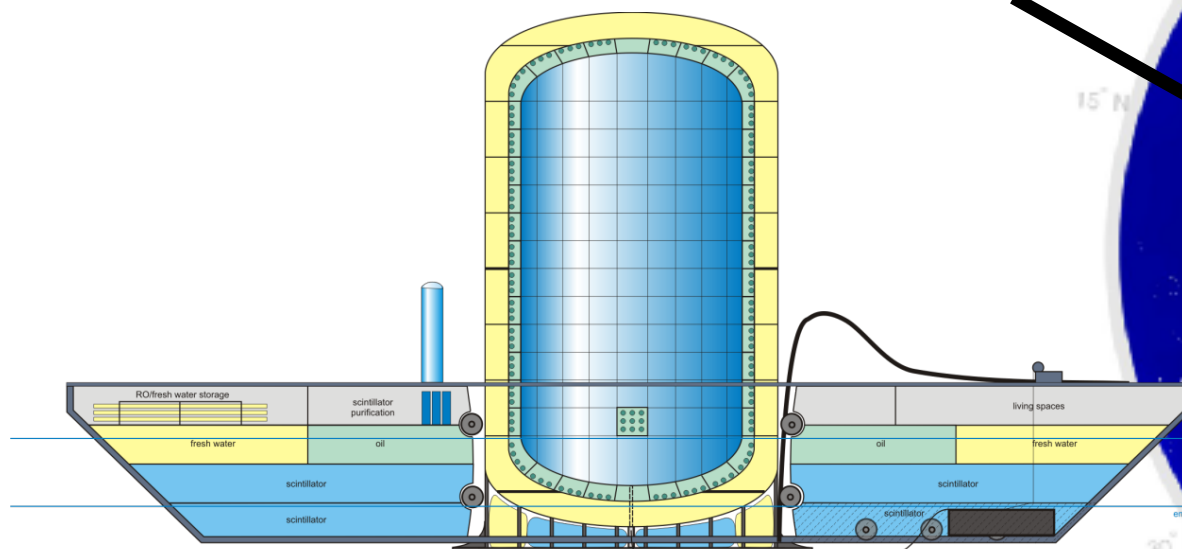
~10 kt, LS  
 4.8 km.w.e.  
 R&D

## KamLAND

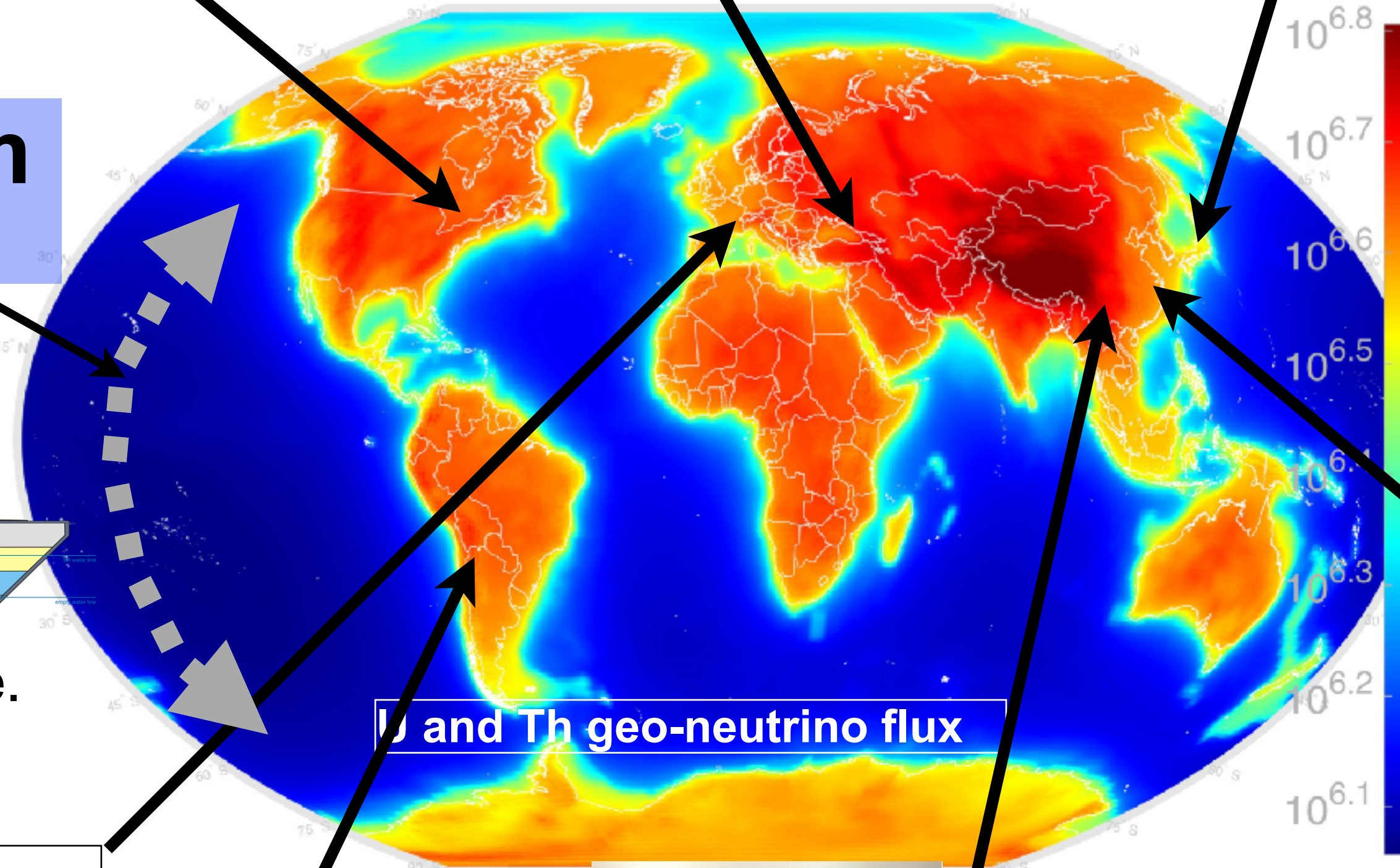
1 kt, LS  
 2.7 km.w.e.  
**running**



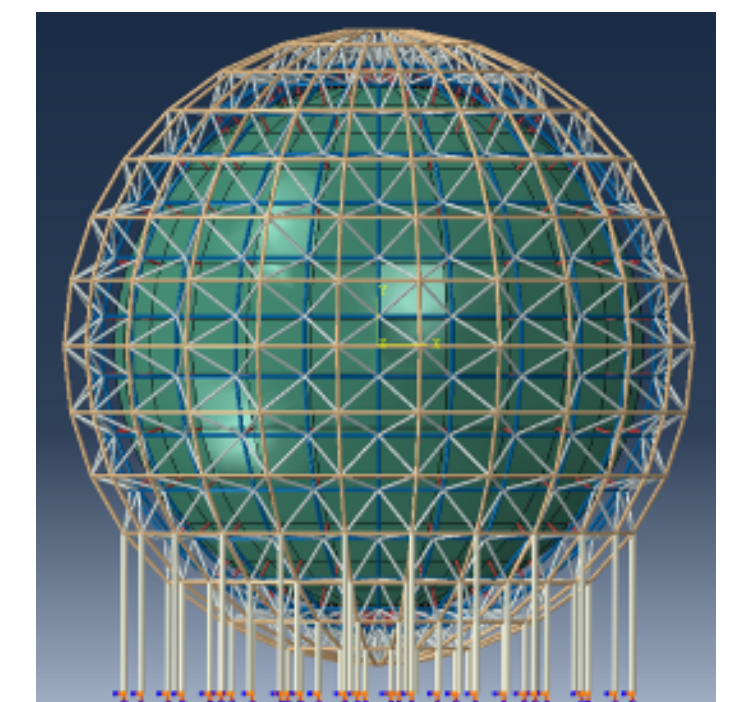
## Ocean Bottom Detector



10-50 kt, LS, ~5 km.w.e.  
**movable**, R&D



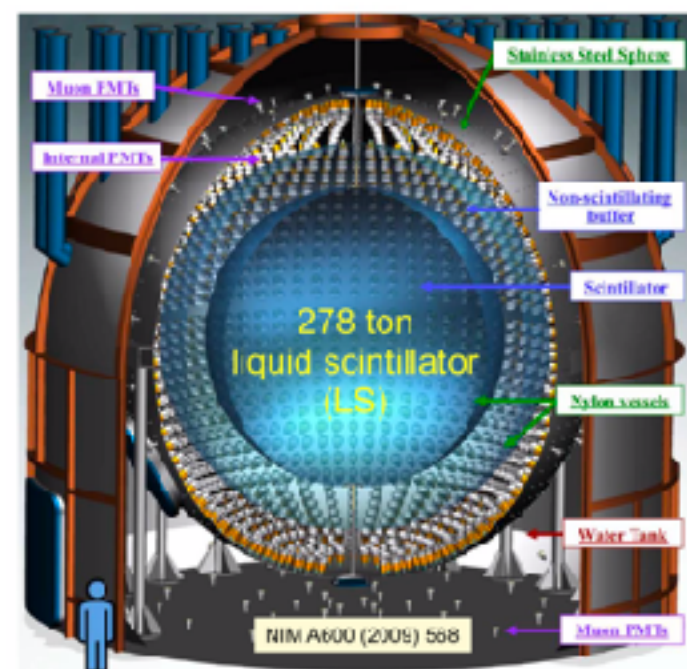
## JUNO



**20 kt**, LS  
 1.5 km.w.e.  
**under construction**  
 (2022~)

## Borexino

0.3 kt, LS  
 3.8 km.w.e.  
**shutdown by the end of 2020**



## ANDES

~3 kt, LS  
 4.5 km.w.e.  
 R&D

## Jinping

1 kt, LS  
**7.5 km.w.e.**  
 Scheduled

