Ocean Bottom Detector : Towards direct measurement of mantle geo-neutrino

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1. Motivation to observe mantle geo-neutrinos

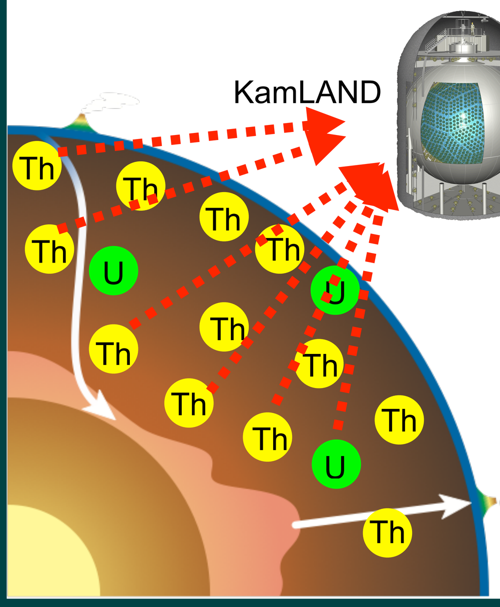
Geo-neutrino

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

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

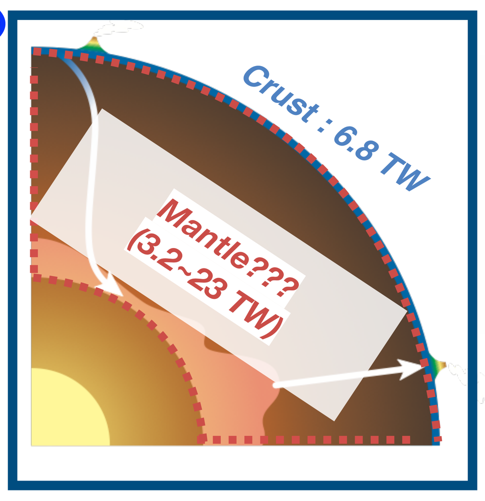
$^{40}K \rightarrow ^{40}Ca + e^- + \bar{\nu}_e + 1.311\,MeV\ (89.28\%)$

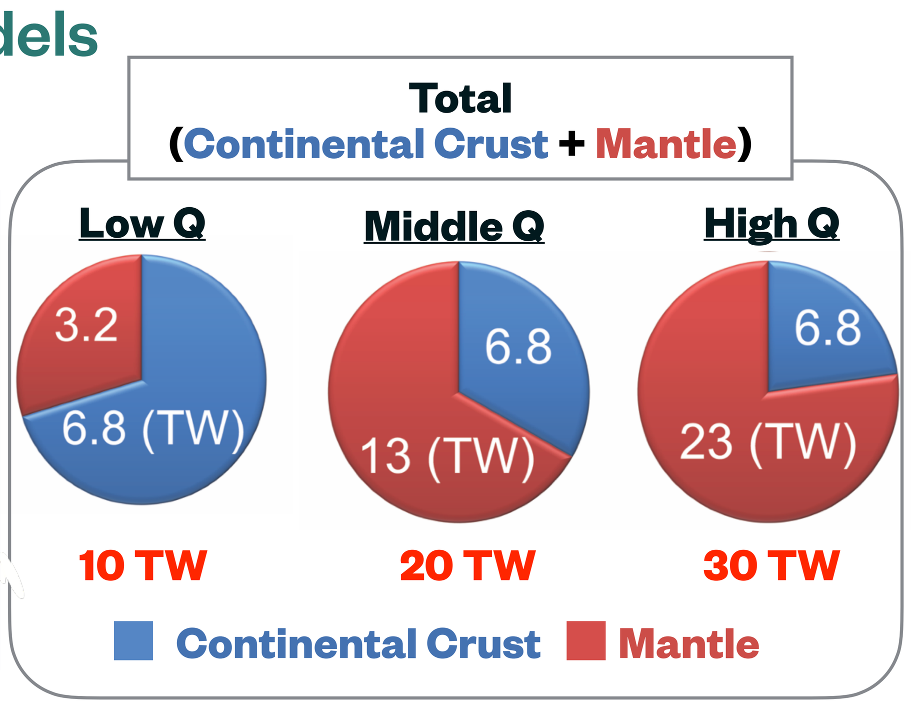
The number of observed geo-neutrino can be converted to the amount of radiogenic heat of the Earth.



The only way to directly measure the amount of radiogenic heat sources

Three heat models





surface heat flow : 47 ± 2 TW

our knowledge of mantle radiogenic heat is uncertain

Mantle geo-neutrino measurement is powerful tool to reveal mantle and its structure

Current status of observations

[Achievement so far]

- Total radiogenic heat the Earth
- Limit on Heat models
- observation- crust model = mantle
- U/Th ratio　Large uncertainty!

[Next target]

Direct measurement of mantle geo-neutrino

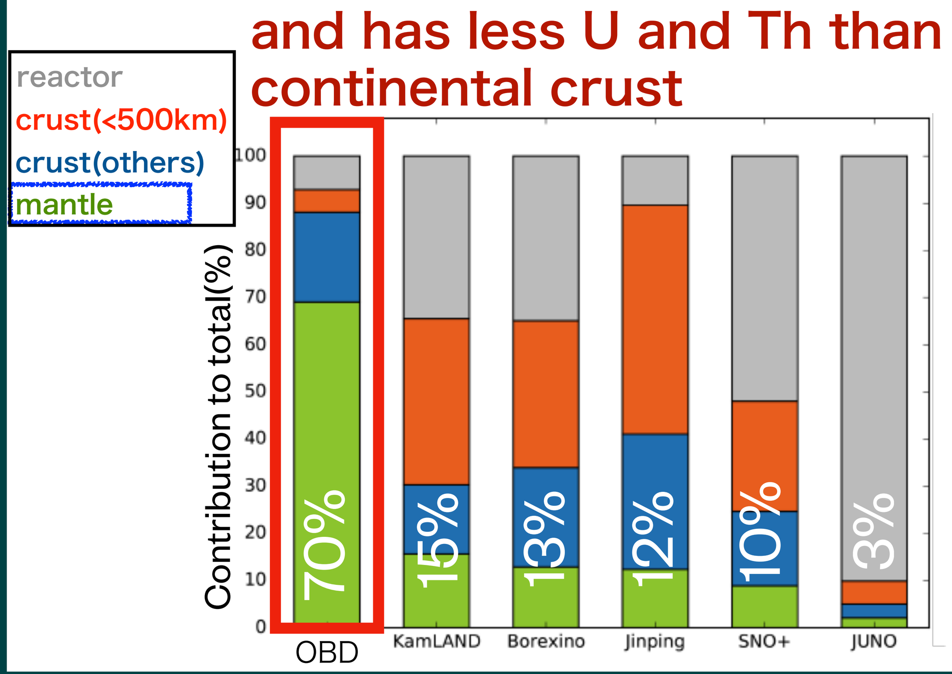
For more accurate observations

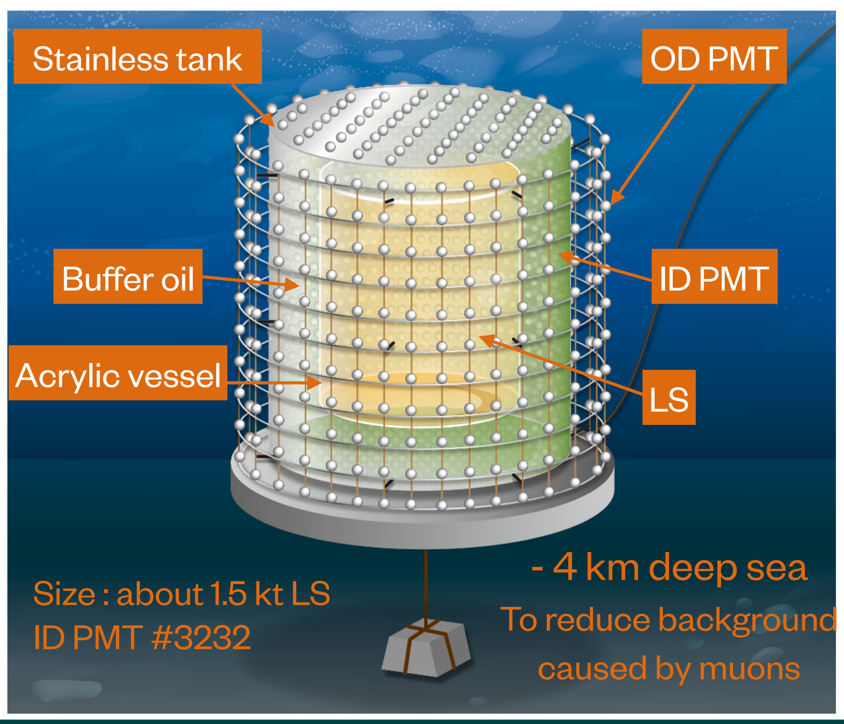
- Better crustal models
- Observe in locations with less crustal influence such as ocean.

2. Ocean Bottom Detector

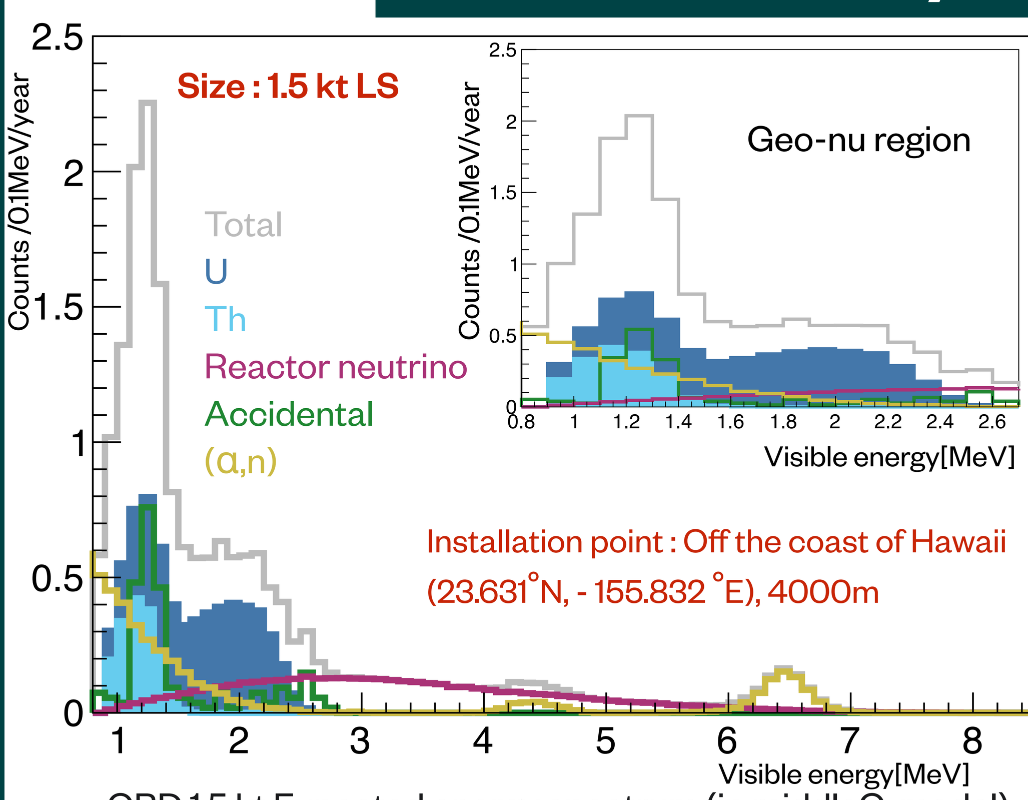
- OBD: New detector for mantle geo-neutrino observation
- Powerful detector for pure physics
  - -Multi baseline measurement of reactor ν
  - -Astro particle physics
  - -Dark matter measurement with less-neutron background
- In 2019, JAMSTEC & Tohoku Univ. joint research has been started.

Oceanic crust is thinner and has less U and Th than continental crust





3. Sensitivity evaluation



OBD 1.5 kt Expected energy spectrum (in middleQ-model)

Expected num [events/year](in middleQ-model)

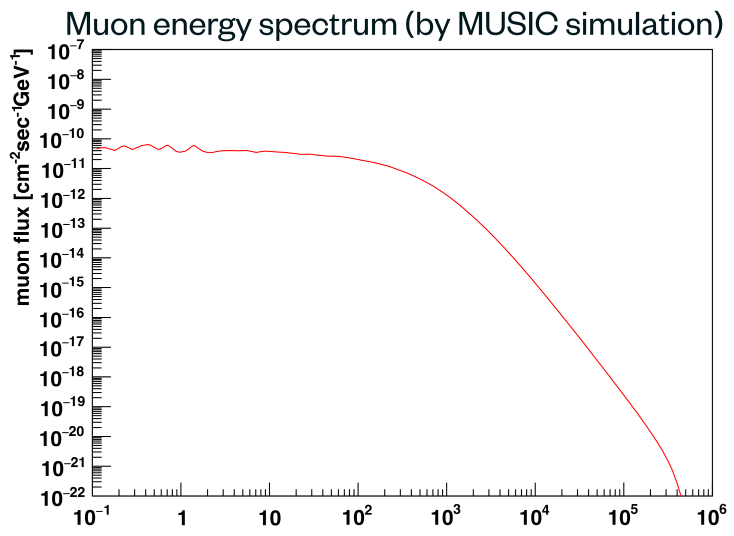
	All-region	Geonu region
U	6.59 (*4.93)	1.64 (*1.23)
Th	1.64 (*1.23)	
Total	8.23 (*6.16)	
Reactor	4.13	1.53
Acci.	1.92	1.90
(α,n)	3.88	2.96
He-Li	0	0
Fast-neutron	< 2.42	< 0.58
Total	9.93	6.39

* mantle geo-neutrino

Expected geo-neutrino number by Dr. Ondřej Šrámek

low-Q	middle-Q	high-Q
6.5(+1.5/-1.3)TNU	12.1(+2.4/-2.6)TNU	21.4±2.3 TNU
- 10 TW	- 20 TW	- 30 TW

Muon energy spectrum (by MUSIC simulation)



Muon Flux= 8.79×10⁻⁹ (cm⁻²s⁻¹)
Average energy = 412 GeV　Low muon rate
Muon Rate = 1.48×10⁻² Hz

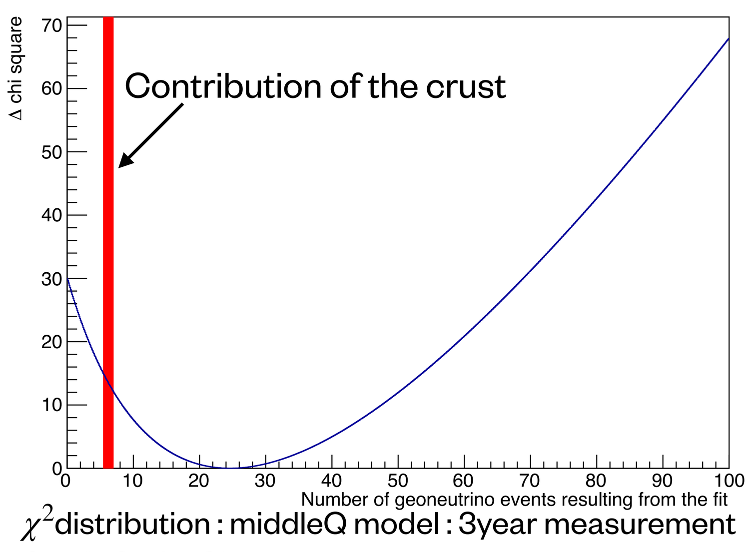
Mantle geo-neutrino observation sensitivity

Make dummy data from expected energy spectrum using Poisson distribution

Fit the dummy data so that χ^2 becomes minimized

$$\chi^2 = \begin{cases} 2\Sigma_i(-(h_i - f_i) + h_i \cdot log\frac{h_i}{f_i})\ (h_i > 0) \\ 2\Sigma_i(-(h_i - f_i)) \end{cases}$$

h_i : observed　f_i : expected



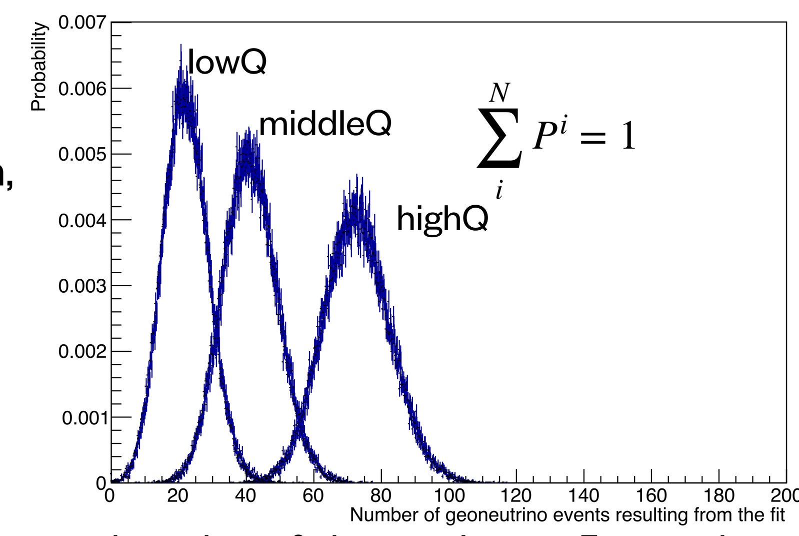
χ^2distribution : middleQ model : 3year measurement 24.7(+6.5/-5.9)events

[mantle geo-neutrino observation sensitivity]

highQ model:　1year → 3.7σ
middleQ model: 3year → 3.5σ
lowQ model:　10year → 2.5σ

Model identification

Using the expected number of observation, I estimated model rejection efficiency



Expected number of observations at 5-year observation

OBD detector is capable of identify the Earth heat models.

Rejection efficiency at 5 year observation

		lowQ	middleQ	highQ
Assumed model	lowQ	\	96.5%	100%
	middleQ	96.5%	\	99.4%
	highQ	100%	99.4%	\

4. Detector development

PMT Shield

PMT Shield : protect PMTs from high pressure (40 MPa at 4km)

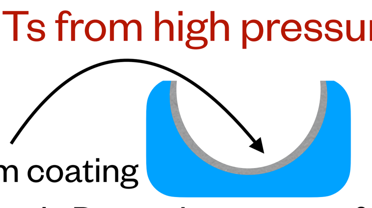
Composition of OKAMOTO's Glass

material name	Weight ratio
High silica	61%
zinc white	3%
Aluminium	4%
Boric acid	3%
5-molecule borax	25%
Sodium Borate	3%
Lithium carbonate	<1%
Sodium	<1%
arsenous acid	<1%

General amount of radioactive substances

	^{238}U	^{232}Th	^{40}K
5-molecule borax	4.3×10⁻⁸g/g	8.6×10⁻⁹g/g	2.8×10⁻⁵g/g

Change the glass material to one with less K.
5-molecule borax has a very large radioactivity

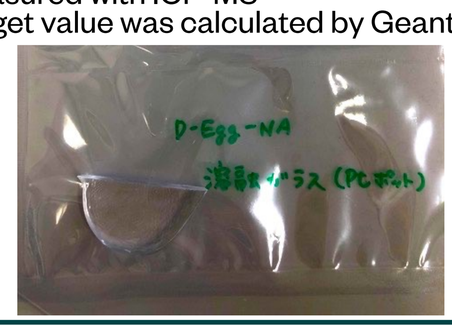


Apply Pt coating to manufacture pot

Result

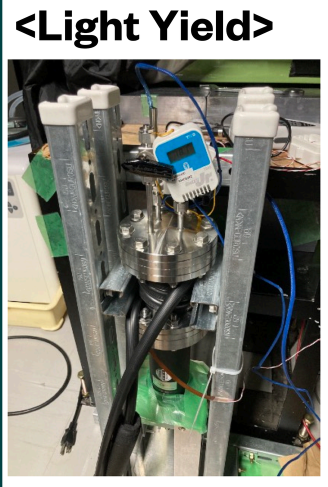
	^{238}U	^{232}Th	^{40}K
w/o coating	2.8×10⁻⁸g/g	3.4×10⁻⁸g/g	1.6×10⁻⁸g/g
w/ coating	1.4×10⁻⁸g/g	<5.0×10⁻⁹g/g	3.4×10⁻⁹g/g
Target value	1×10⁻⁸g/g	1×10⁻⁸g/g	1×10⁻⁸g/g

* Measured with ICP-MS
* Target value was calculated by Geant4

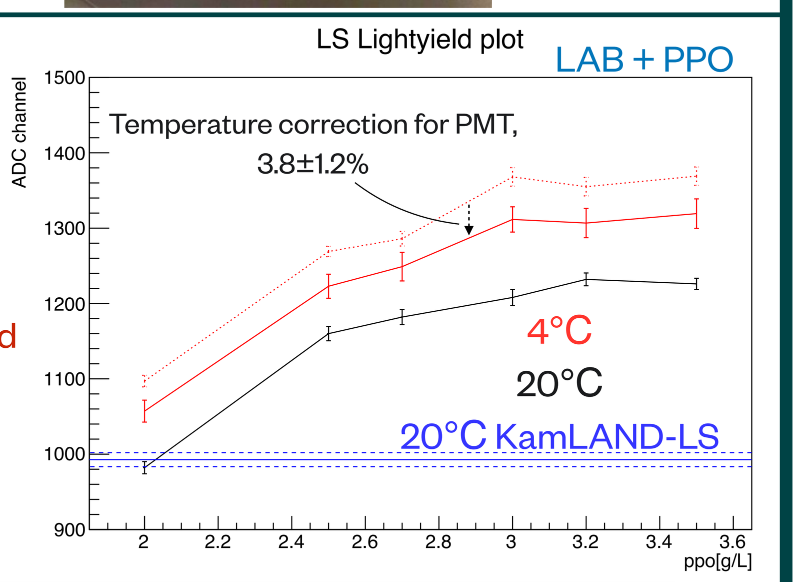


Liquid Scintillator

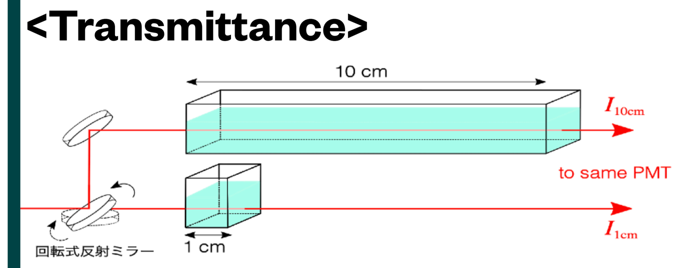
<Light Yield>



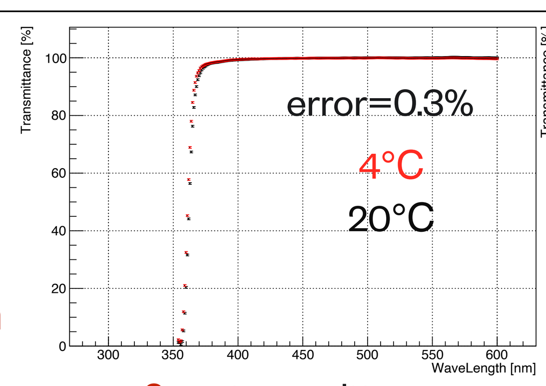
- 4°C and 20 °C
- PPO concentration dependence
- 4°C LAB-LS is 8% brighter than 20°C and 30% brighter than Kam-LS



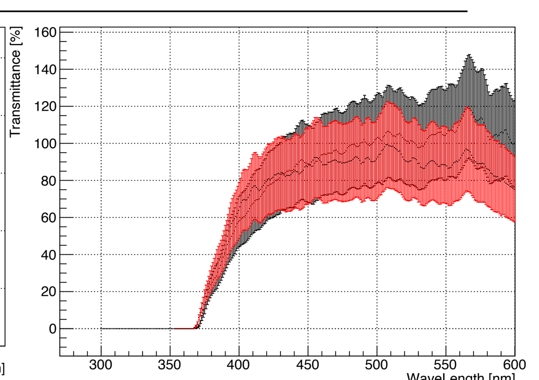
<Transmittance>



There are no difference between 4°C and 20 °C LS



9 cm transmittance



7 m transmittance