The geo-neutrino study at JUNO

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Outline

- What can JUNO geo-neutrino help geoscience
  - Improve the crust models with particle physics point of view
  - Estimate the radioactive heat from U+Th by JUNO geo-ν
  - Measure Th/U ratio through JUNO geo-ν
  - Evaluate mantle structure using JUNO geo-ν
  - Discuss other potential geo-scientific goal

New Method

New Tools

- How can build community between particle physicists and geo scientist
  - Experience from SNO+ in Canada
  - Experience from KamLAND in Japan
  - Start from the local refined geology model(3D/4D model)

What is Geo-ν and JUNO ability

$$^{238}\mathrm{U} \longrightarrow {}^{206}\mathrm{Pb} + 8\,\alpha + 6\,\mathrm{e}^- + 6\,\bar{\nu}_e \quad + 51.698\mathrm{MeV}$$

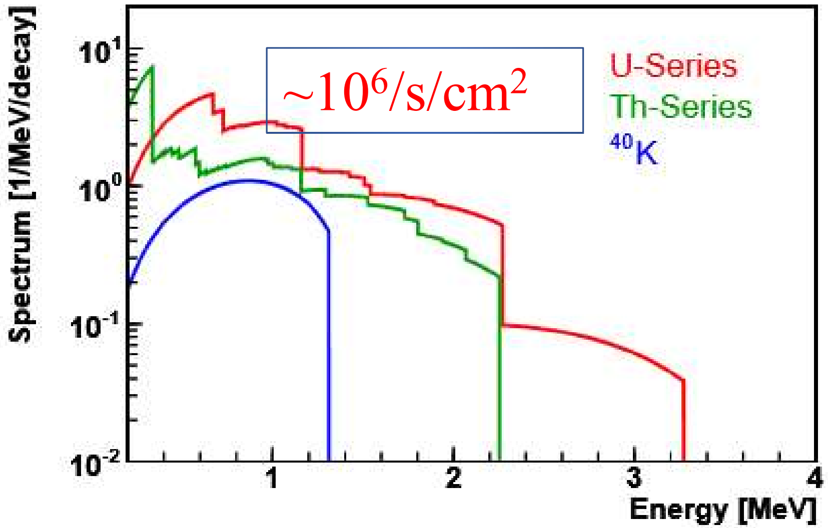
$$^{232}\mathrm{Th} \longrightarrow {}^{208}\mathrm{Pb} + 6\,\alpha + 4\,\mathrm{e}^- + 4\,\bar{\nu}_e \quad + 42.652\mathrm{MeV}$$

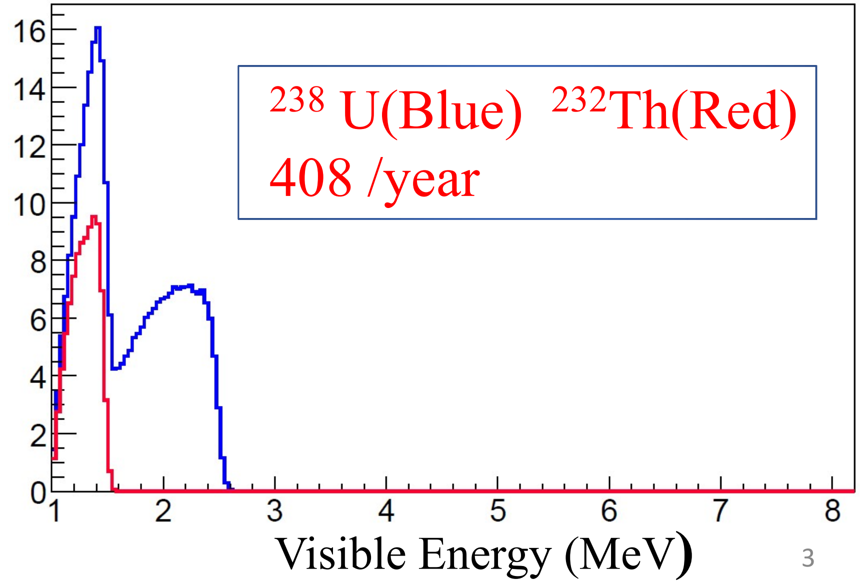
$$^{40}\mathrm{K} \xrightarrow{89.3\%} {}^{40}\mathrm{Ca} + \mathrm{e}^- + \bar{\nu}_e \quad + 1.311\mathrm{MeV}$$

$$^{40}\mathrm{K} + \mathrm{e}^- \xrightarrow{10.7\%} {}^{40}\mathrm{Ar} + \nu_e \quad + 1.505\mathrm{MeV}$$

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

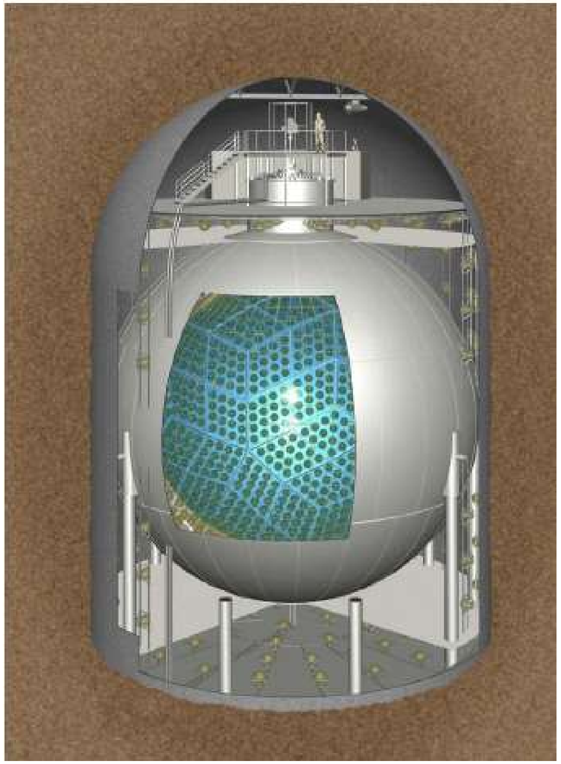
- 1.8 MeV Energy Threshold
- 20 kton LS target
- 3% Energy Resolution





The Existing Geo-ν Experiments

KamLAND, Japan (1kt)



$N_{geo} = 116 \pm 28$ **(8.9y)**

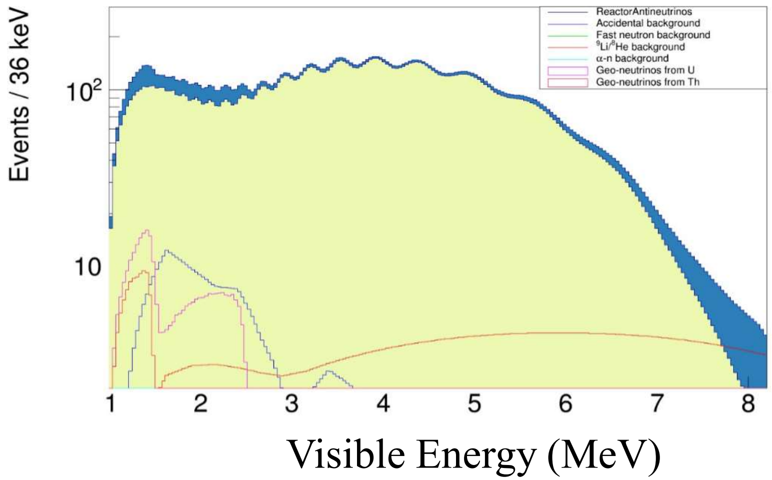
Borexino, Italy (0.6kt)

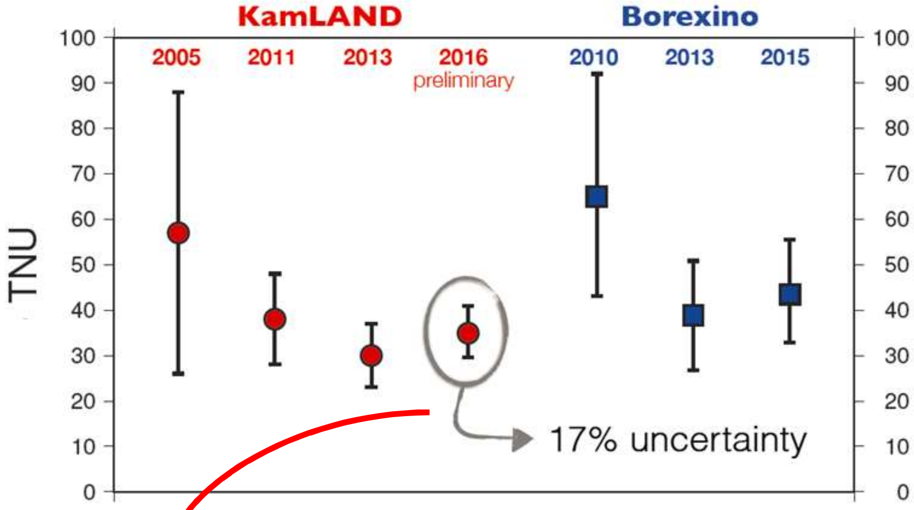
$N_{geo} = 23.7 \pm 6.5$ **(5.7y)**

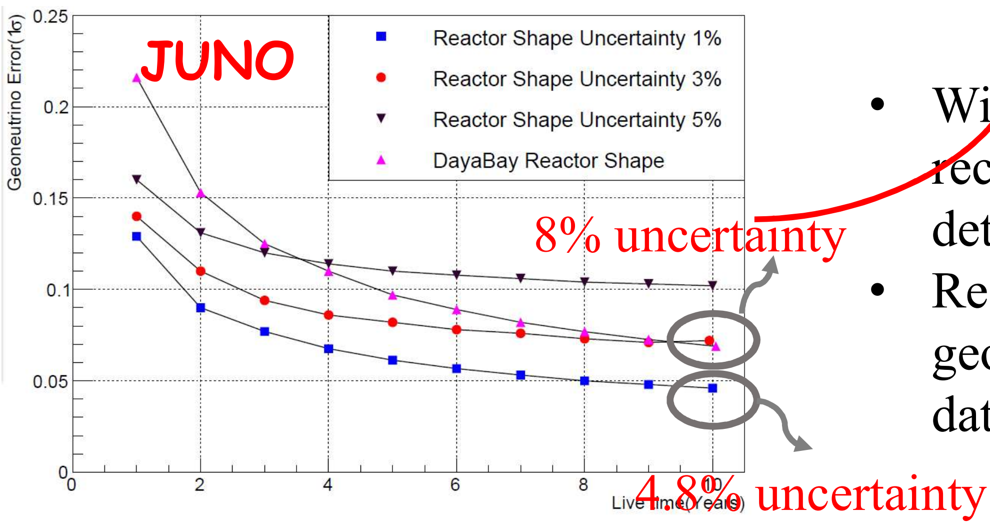
$N_{geo} = 25 \pm 18$

- **408/y** is a huge number, better than all the existing experiments.
- Even with this small number 25, The paper is the cover of nature.

How precise of JUNO Geo-ν measurement







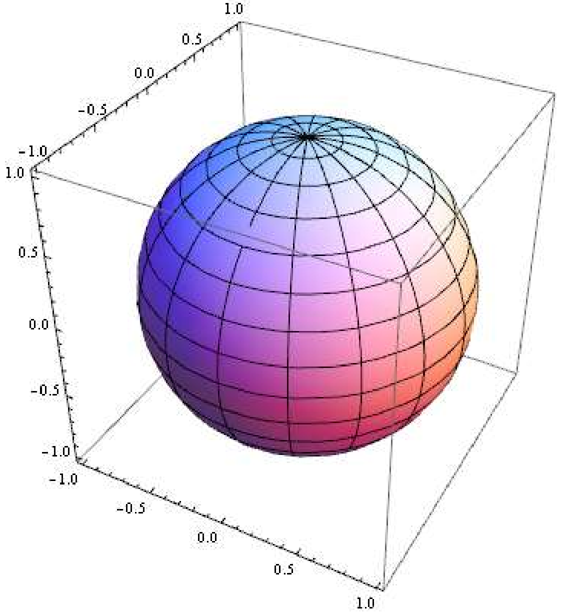
- Within the first year of running, JUNO will record more geo-neutrino events than all other detectors will have.
- Reactor neutrino is the main background for geo-neutrino in JUNO. But still with 10 years data, we can reach high precision.

How we estimate Geo-ν in JUNO ?

Geo-ν flux on the Earth surface + JUNO detect ability

Geo-information + Particle physics/detector

Geo-ν flux



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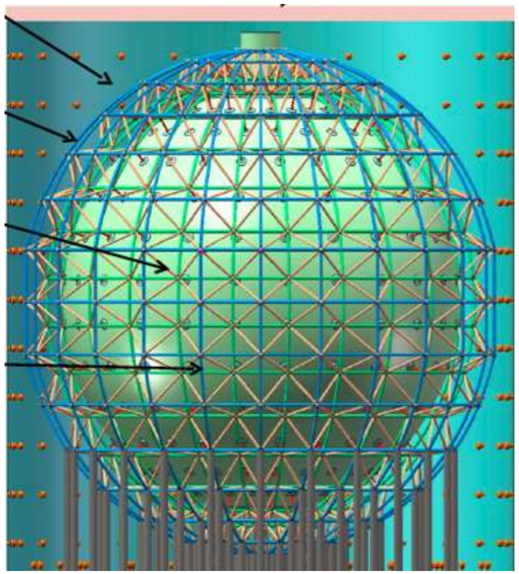

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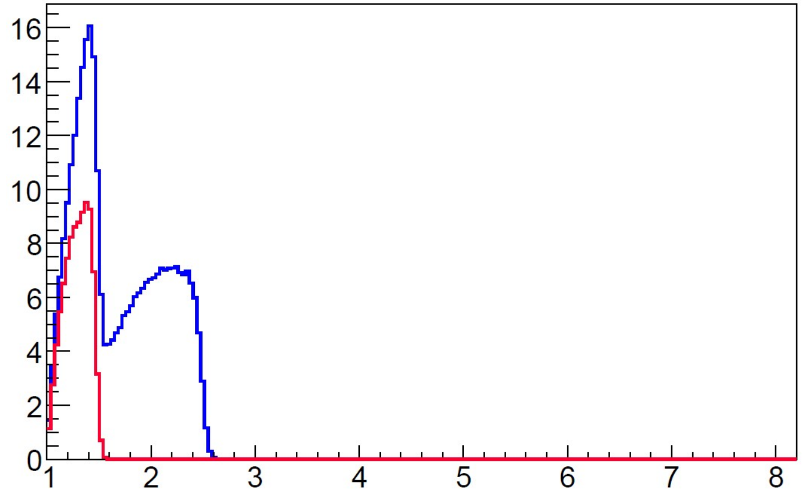


Huang et al (2013) G-cubed [***arXiv:1301.0365***](arXiv:1301.0365)

Geo-ν signal on Earth Surface

Geoneutrino signal in TNU

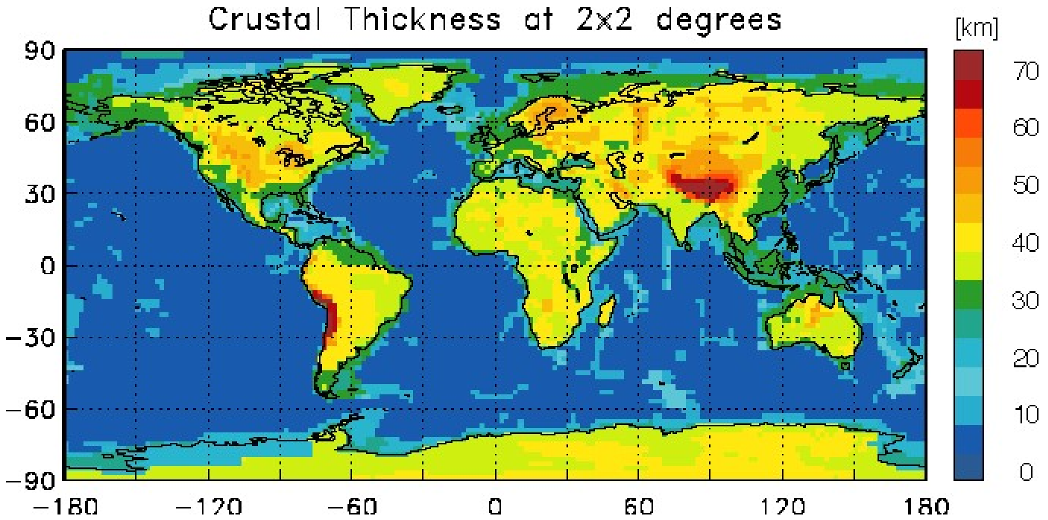
$$\Phi_i = A_i \cdot n_i \cdot P_{\nu_e - \nu_e}(E_\nu, |\vec{L}|) \cdot \int_V \frac{a_i(\vec{L}) \cdot \rho_i(\vec{L})}{4\pi |\vec{L}|^2} \cdot dV$$

- $A_i \cdot n_i$: Activity and number of produced geoneutrinos
- $P_{\nu_e - \nu_e}(E_\nu, |\vec{L}|)$: Survival probability function
- $a_i(\vec{L})$, $\rho_i(\vec{L})$: Abundance and density of the source unit
- $|\vec{L}|$: Distance between source unit and detector
- dV: Volume of source unit

Earth structure (ρ and L) and **chemical composition** (a)

The Earth Structure Models and Chemical Composition Models

Earth Structure Models (ρ and *L*)



Global Models : Crust2.0 Crust1.0 Litho1.0
Chinese Local Models: SUN YS et.al and Huang et.al
From ZHAO Liang

Chemical composition Model (α)

Layers	^{238}U	^{232}Th	
OC Sediment	$1.73 \pm 5\%$	$1.73 \pm 5\%$	Plank,2014
OC Crust	$0.07 \pm 30\%$	$0.21 \pm 30\%$	White and Klein,2014
Sediment	$1.73 \pm 5\%$	$1.73 \pm 5\%$	Plank,2014
Upper Crust	$2.7 \pm 21\%$	$10.5 \pm 10\%$	Rudnick and Gao,2003,2014
Middle Crust	$1.3 \pm 31\%$	$6.5 \pm 8\%$	Rudnick and Gao,2003,2014
Lower Crust	$0.20 \pm 30\%$	$1.2 \pm 30\%$	Rudnick and Gao,2003,2014
CLM	$(33^{+49}_{-20}) \times 10^{-3}$	$(150^{+277}_{-97}) \times 10^{-3}$	Huang,2013

More details see *Ondrej's talk in the afternoon*

Geo-neutrino study can improve the models

Analysis Method is one of the contribution to geo-science

JUNO Geo-ν contribution to geo-science(I)

Improve the quality of geo physical/chemical models!

- Weird points in Litho1.0 Thickness is negative.

	latitude	longitude	thickness	depth to bottom		
1	14.5	-165.5	-4.229	1.694	2551.2	5
2	14.5	-122.5	-1.537	2.393	2422.5	4
3	14.5	-50.5	-0.109	6.27	2422.5	4.
4	14.5	21.5	-3.575	0.543	2014.88	
5	14.5	93.5	-64.25	16.888	318.74	
6	14.5	165.5	-2.949	10.93	2846.77	
7	12.5	-164.5	-0.625	10.025	2004.07	
8	12.5	-92.5	-3.672	-0.438	2213.23	
9	12.5	-51.5	-4.685	3.823	2865.2	5
10	12.5	51.5	-3.064	-21.057	3319.7	

Ondrej/Beda are working on this
see Ondrej's talk

- Huang's model: thickness is an integer, very rough model.

70E-130E, 20N-55N70 130 20 55

55.0N 70.0E 17 0

Thick	Vp	Vs	Poisson	Density	Depth
2.0	5.009	2.892	0.25	2.502	2.0
4.0	5.566	3.214	0.25	2.613	6.0
7.0	5.748	3.319	0.25	2.650	13.0
15.0	6.206	3.583	0.25	2.762	28.0

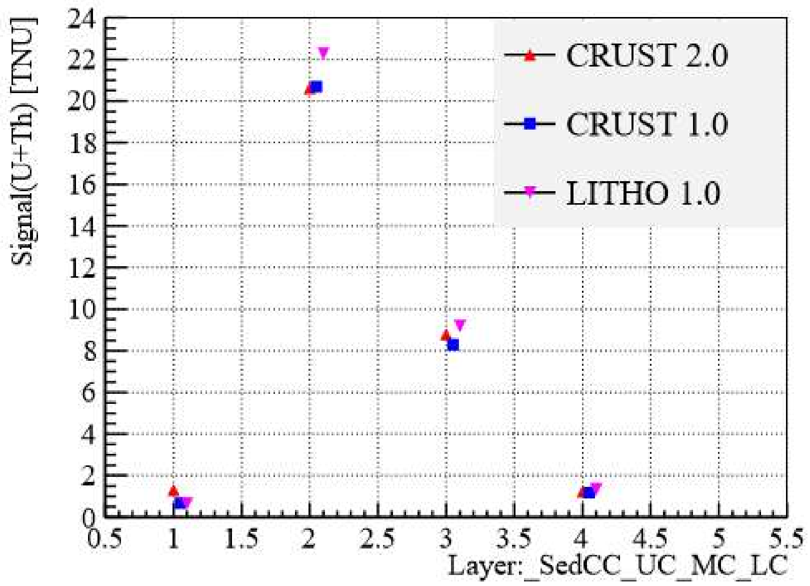
Jincheng combine Litho1.0 to fix this Geophysical model into a Lithology distribution model.

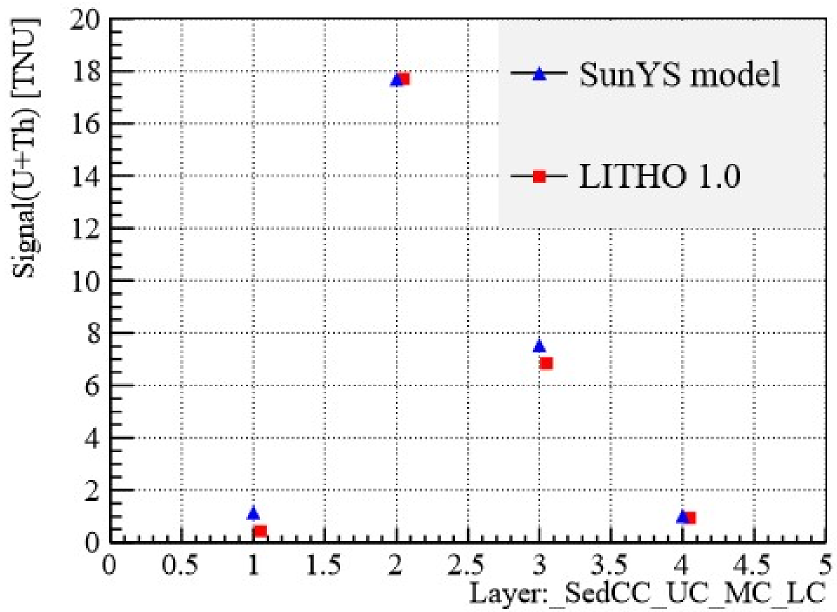
- High uncertainties of chemical composition model

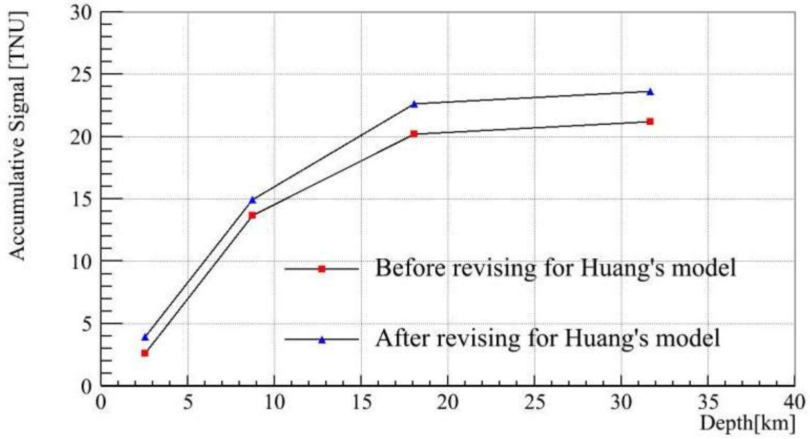
Layers	^{238}U	^{232}Th
OC Sediment	$1.73 \pm 5\%$	$1.73 \pm 5\%$
OC Crust	$0.07 \pm 30\%$	$0.21 \pm 30\%$
Sediment	$1.73 \pm 5\%$	$1.73 \pm 5\%$
Upper Crust	$2.7 \pm 21\%$	$10.5 \pm 10\%$

Yufei and Jincheng collected more samples around JUNO to reduce the uncertainties
See Yufei's talk

JUNO Geo-ν flux with different models

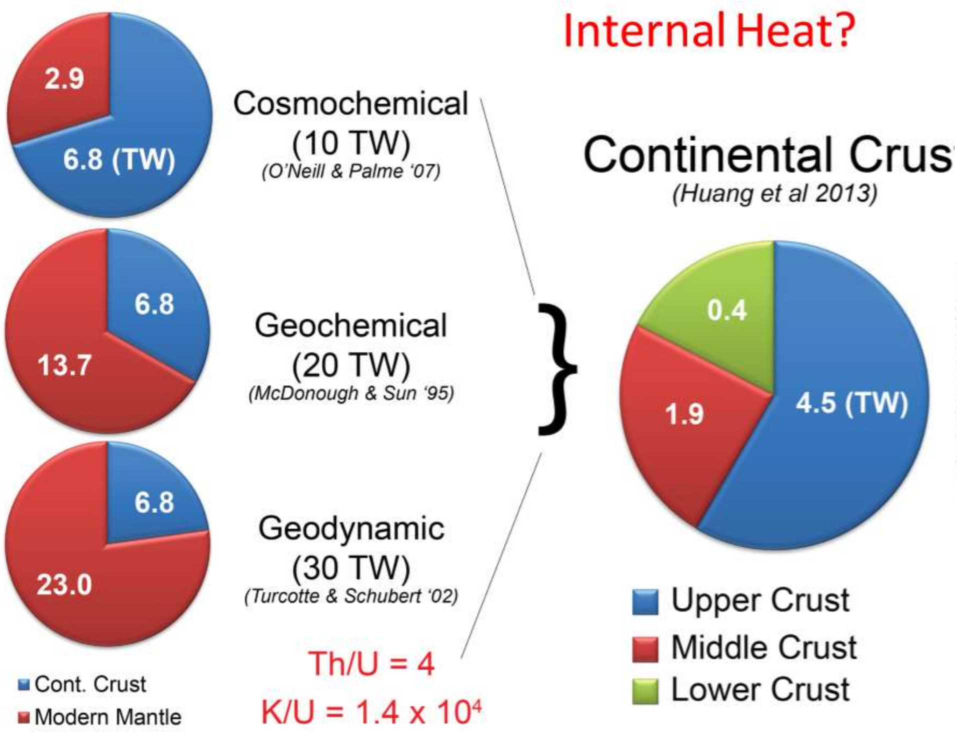


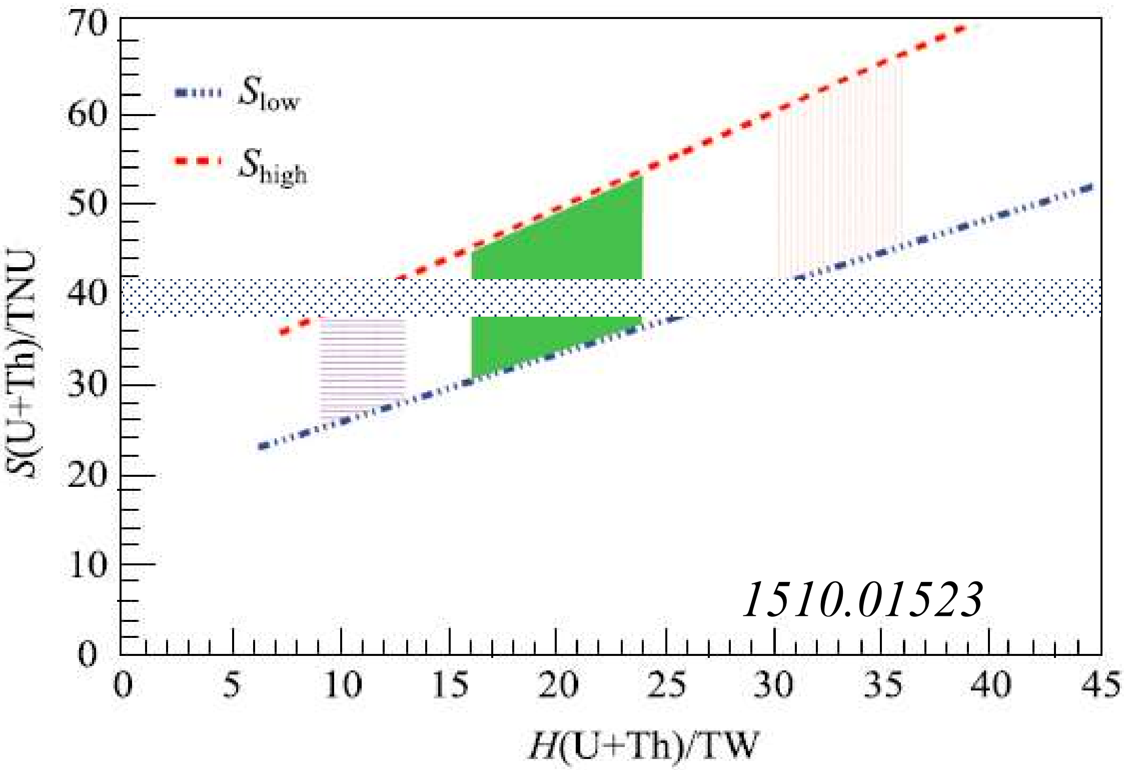




JUNO Geo-ν contribution to geo-science(II)

Constrain the range of radiogenic heat contribution





JUNO Geo-ν contribution to geo-science(III)

Estimate from Th and U concentrations— measured kappa ratio （κ_{meas}）

$$\kappa_{meas} = \frac{^{232}\mathrm{Th}}{^{238}\mathrm{U}}$$

Estimate from lead radiogenic isotope ratio—time integrated kappa ratio(κ_{Pb})

$$\kappa_{Pb} = \frac{\left(\frac{^{208}Pb*}{^{206}Pb*}\right) * (e^{\lambda^{238}T} - 1)}{e^{\lambda^{232}T} - 1}$$

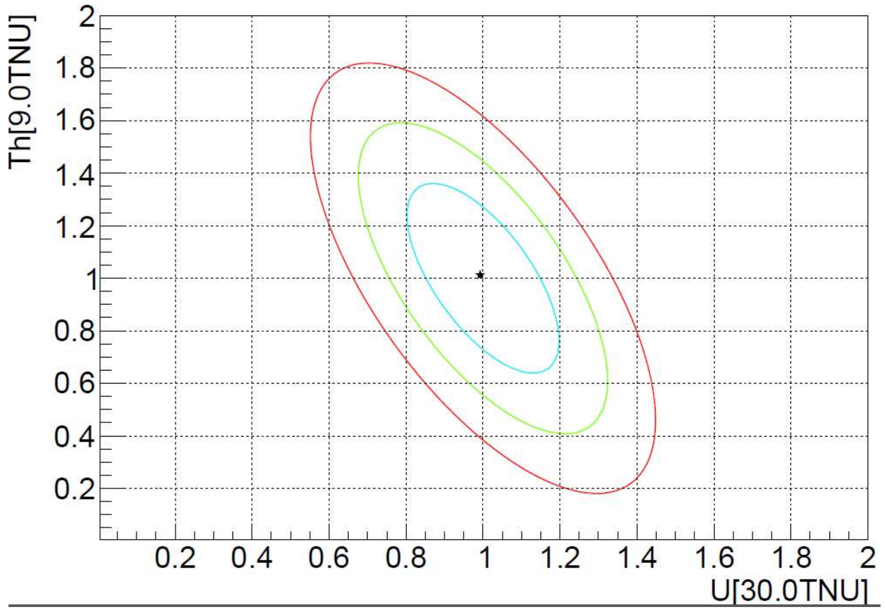
- The difference between κ_{Pb} and κ_{meas} indicates that U6+ recycled back into mantle sometime during the Earth's history
- the BSE κ_{Pb} dictates that Th and U were excluded from the core.
- The small difference between ccKpb and MMKpb indicates that U recycling was a relatively recent process or that limited recycling followed atmospheric oxygenation at 2.4Ga and evolved slowly with time.

See GUO Meng's poster

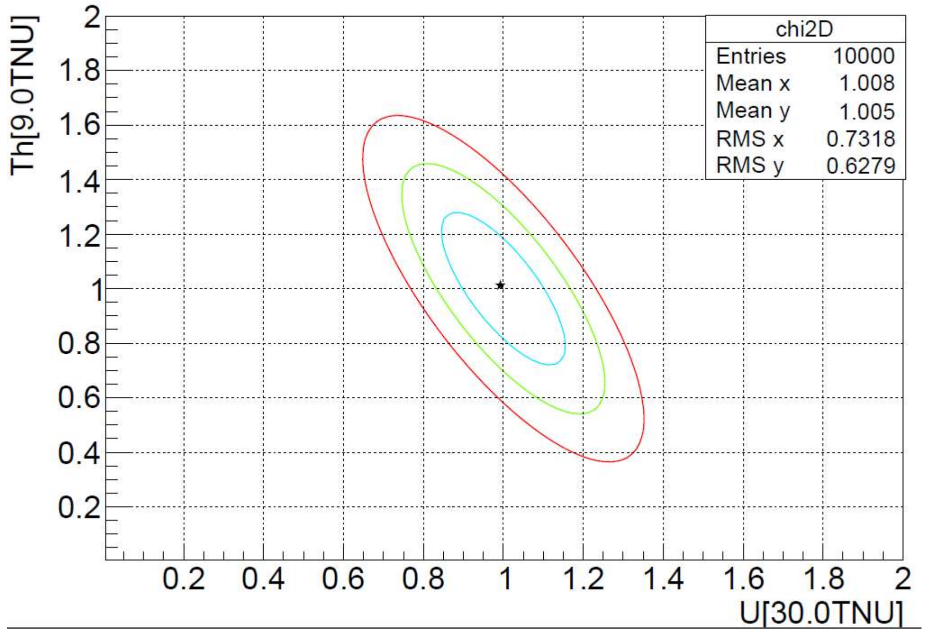
	κ_{meas}		κ_{Pb}	
MORB	n= 2,558	$2.98^{+0.81}_{-0.64}$	n= 936	$3.84^{+0.09}_{-0.09}$
CC	n= 68,886	$3.96^{+5.44}_{-2.04}$	n= 6,247	$4.01^{+0.27}_{-0.25}$
CC (both K's)	n= 9,313	$4.18^{+2.70}_{-1.55}$	n= 9,313	$4.09^{+0.19}_{-0.18}$
OIB	n= 3,496	$3.12^{+2.84}_{-1.54}$	n= 7,690	$3.92^{+0.12}_{-0.12}$

JUNO Geo-ν provide a new way to do Th/U ratio!

The potential of Th/U ratio at JUNO



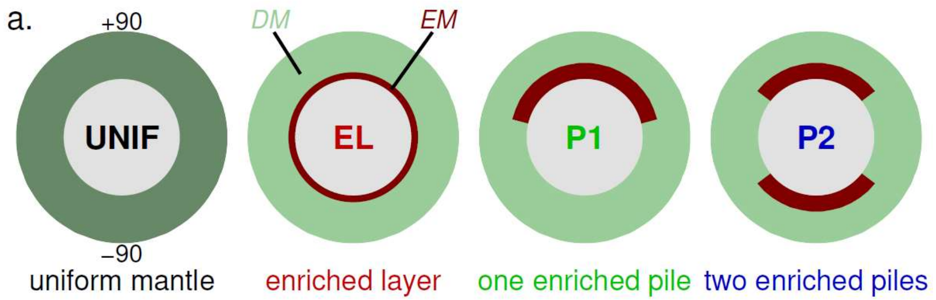
For ten years of running, accuracy of 35% and 20% respectively can be obtained at DYB reactor shape



For ten year of running, accuracy of 30% and 15% respectively can be obtained at 1% reactor shape uncertainty

The uncertainty of Th/U ratio is around 26%

JUNO Geo-ν contribution to geo-science(IV)



Is the mantle compositionally layered or have large structures?

Sramek et.al Earth and Planetary Science Letters 361 (2013) 356–366

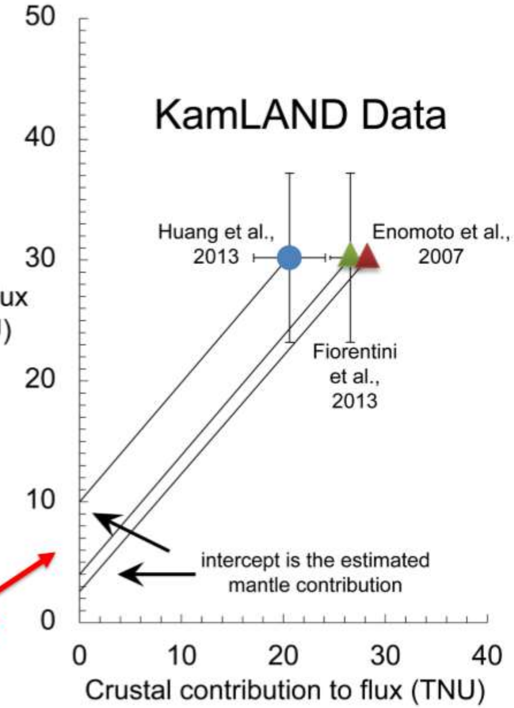
Different Geological models

Y-axis data is strictly from physics

X-axis data is strictly from geology

Intercept is mantle contribution

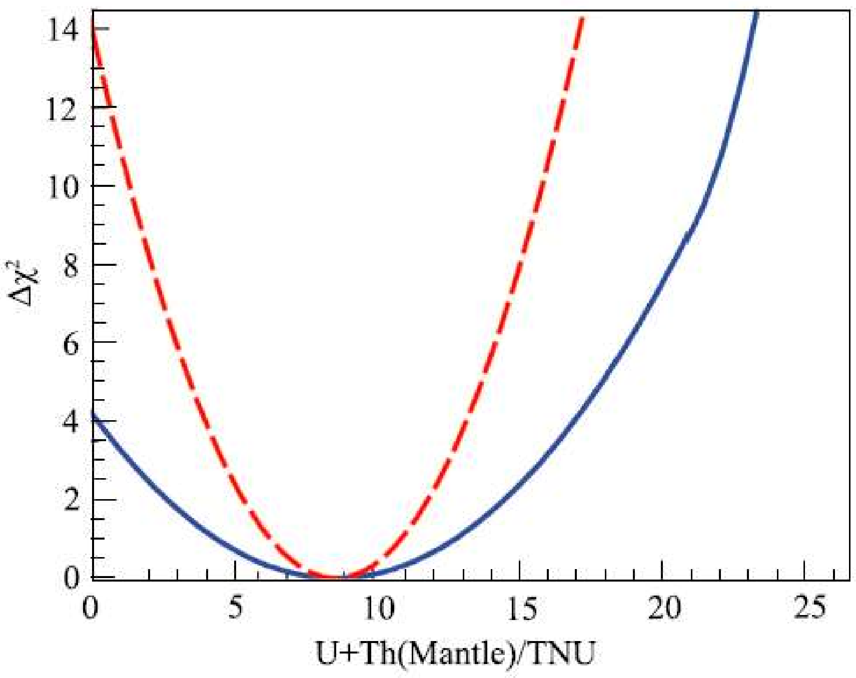
2, 4 and 10 TNU ?



JUNO Geo-ν apply a new way to see deep the Earth ---Mantle

The potential of Mantle measurement at JUNO

R(Mantle)=R(total, exp.)-R(Crust, pred.)



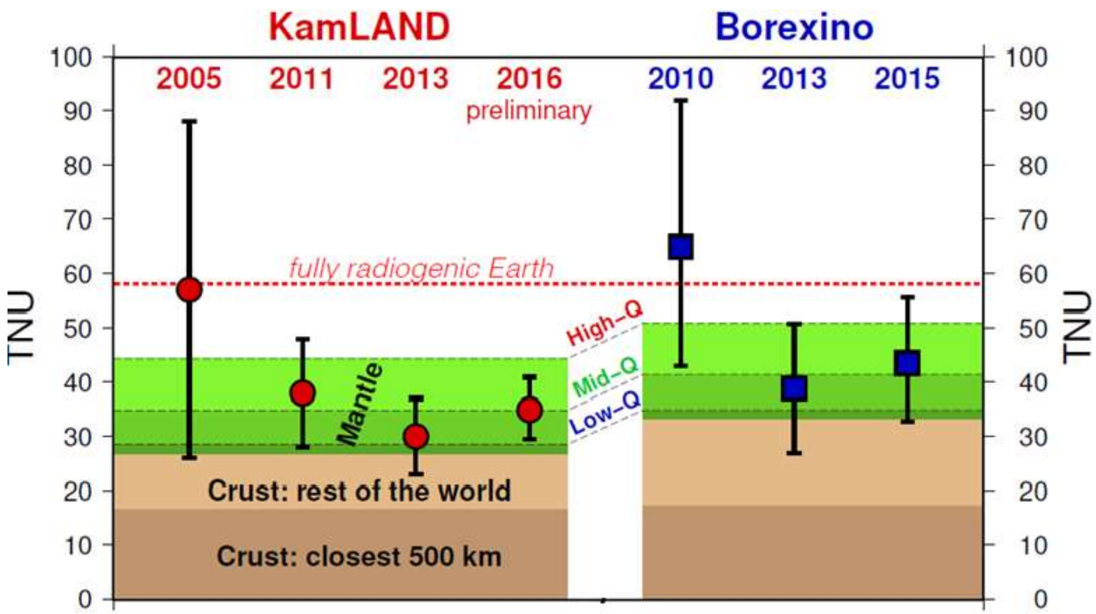
- At 1sigma range mantle: 9 ± 2TNU
- To separate the mantle and curst
  18% crust uncertainty:
  confidence level at **2sigma**
  8% crust uncertainty:
  confidence level at **3.7sigma**

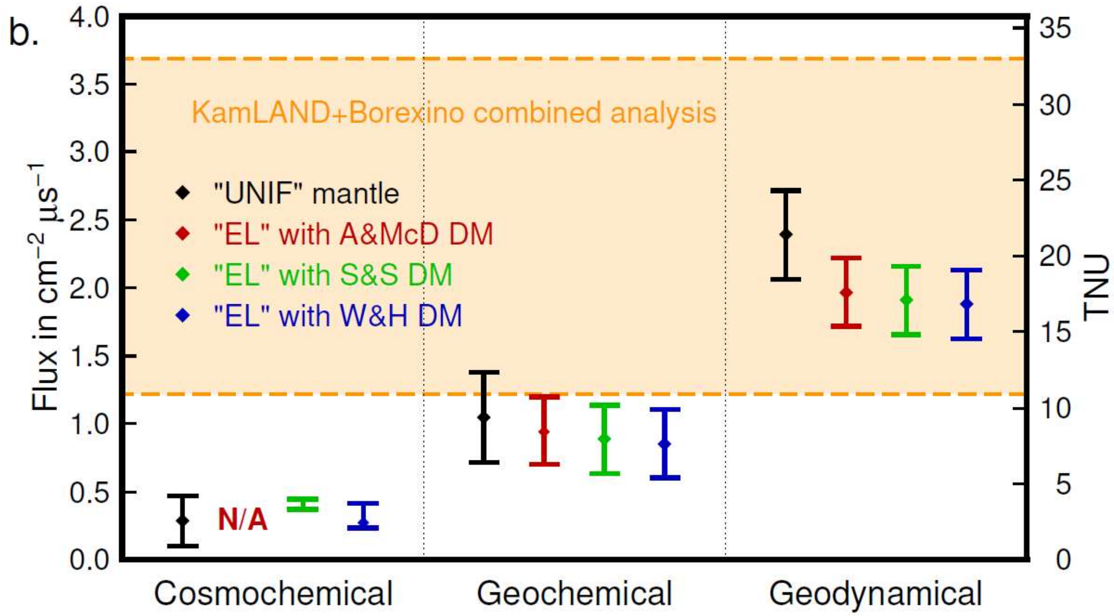
- Refined local model is very important

Comparison of the global reference model(18% crust) and
a benchmark accuracy of the local model (8% curst)

From geo-neutrino to geo-science

Geoneutrino prediction from
Šrámek et al. 2016 doi:10.1038/srep33034

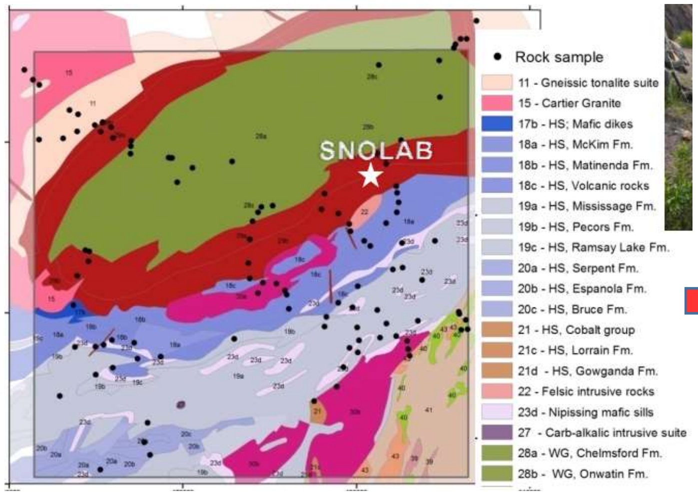


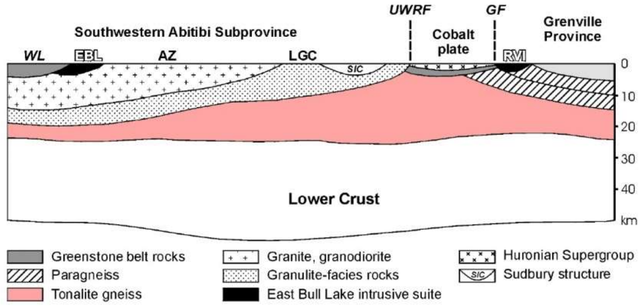


See Beda's talk

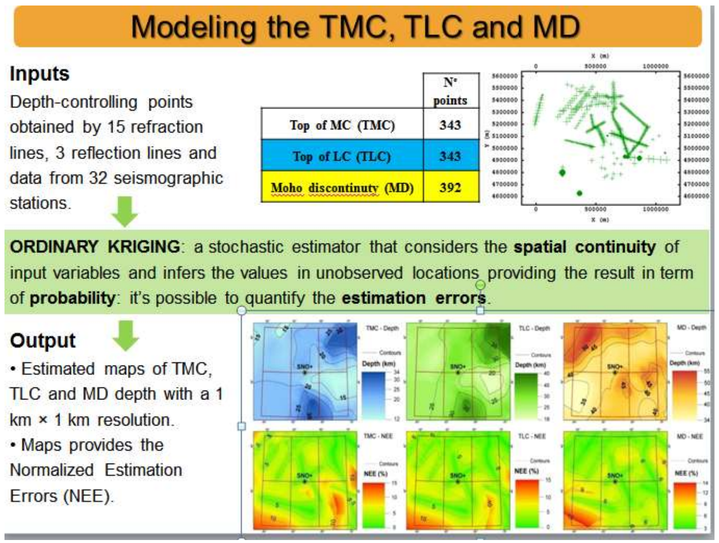
- Using geo-neutrino to solve the geo-problem is not far from us!
- What else can help in geo-science, we can work together to see the possibility!

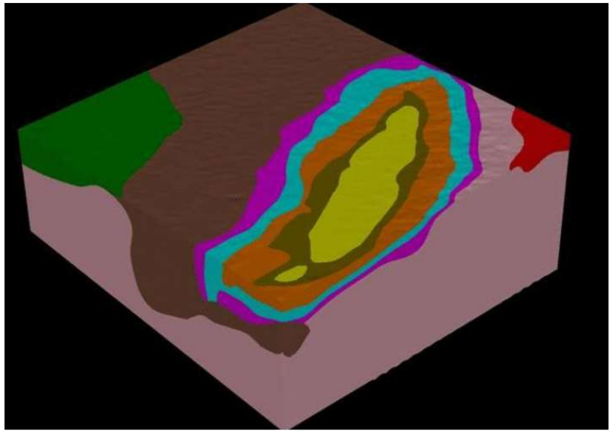
Experience from SNO+ in Canada





Seismology+Geo-physics:
Cross section, seismic data
Give the map with error





Geology: for sample collection
Geochemistry : ICPMS/HPGe
+ Physics abundance analysis

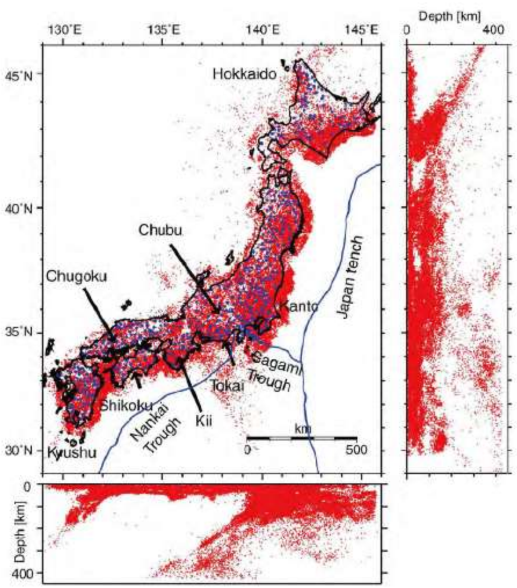
All: interpolation geophysical model to Lithology distribution

Local 3D models

Experience from KamLAND in Japan

Dataset Used for Local Tomography in Japan

Dataset for Local Tomography



red: event, blue: station

Direct P and S waves samples almost all crust in Japan.

Large number of data (> 15 yrs) have been accumulated.

77,730 events 768 stations

3,249,949 P-wave data
2,273,571 S-wave data

Developing a quantitative method for translating a geophysical model (tomography model) into a lithology distribution model

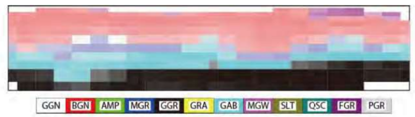
The method can take

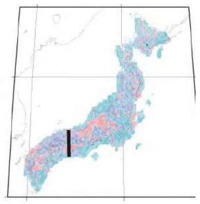
- local features in Japan and
- uncertainties in geophysical models

into account.

Comparison with Conventional Geological Approach

our model

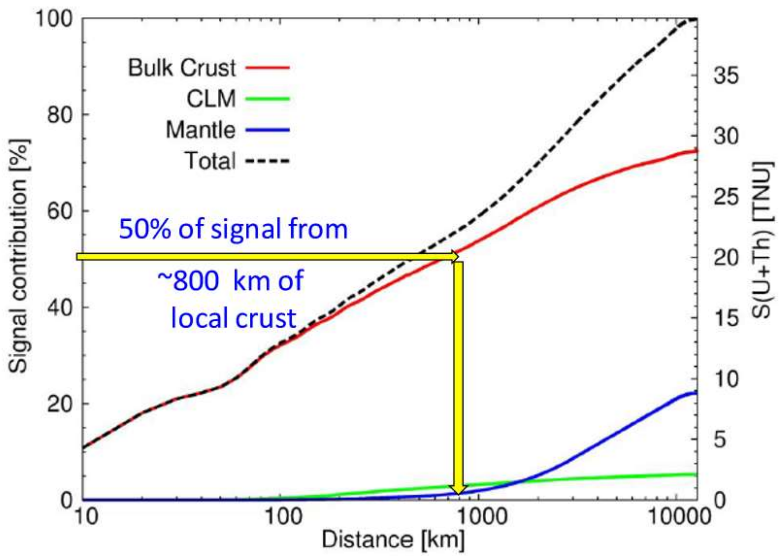


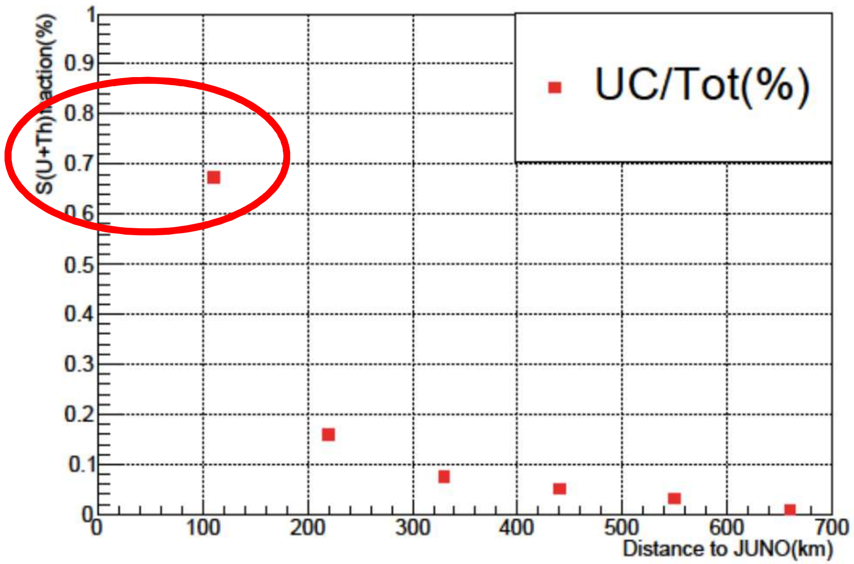


geological insight + reflection survey

Ito and Sato (2010)

The need of refined local(south China)model





Private Advisory Organ -> Working Group

Lessons from KamLAND（Janpan）

N. Takeuchi (seismology)
M. Yamano (heat flow)
T. Iizuka (geochemisty)

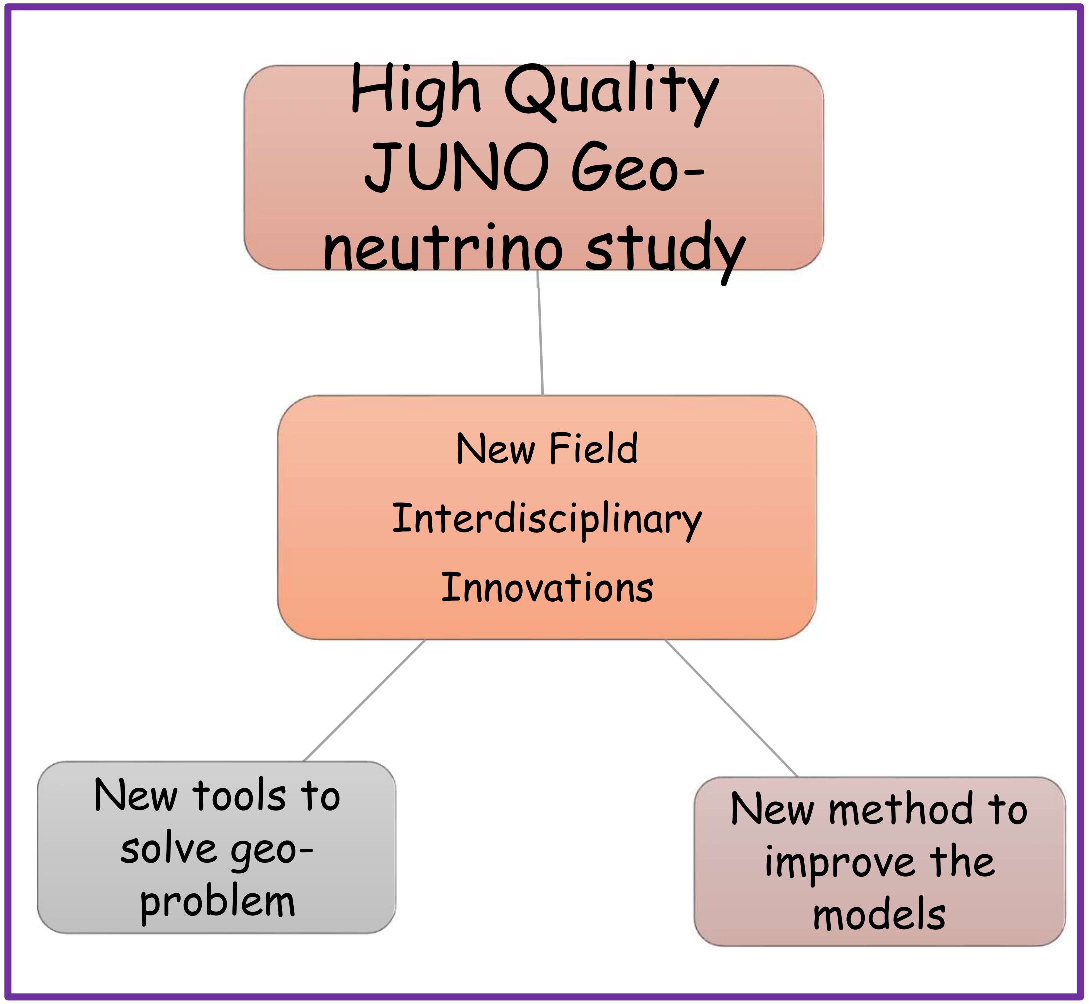
H. Tanaka (physics)
H. Watanabe (physics)
A. Taketa (physics)
Y. Shirahata (physics)
S. Enomoto (physics)

W. Mcdonough (geochemistry)
M. Fabio (physics)
H. Iwamori (petrology)

+ others

Build the geo-science and particle physics Community

Geology
Seismology
Heat flow
Geochemistry
Geophysics
Petrology
Physics …………………



High IF SCI

?

Attractive idea for NSFC application

Let’s start with south China refined 3D model.

geoneutrino community

该二维码7天内(7月28日前)有效，重新进入将更新