What we found with KamLAND

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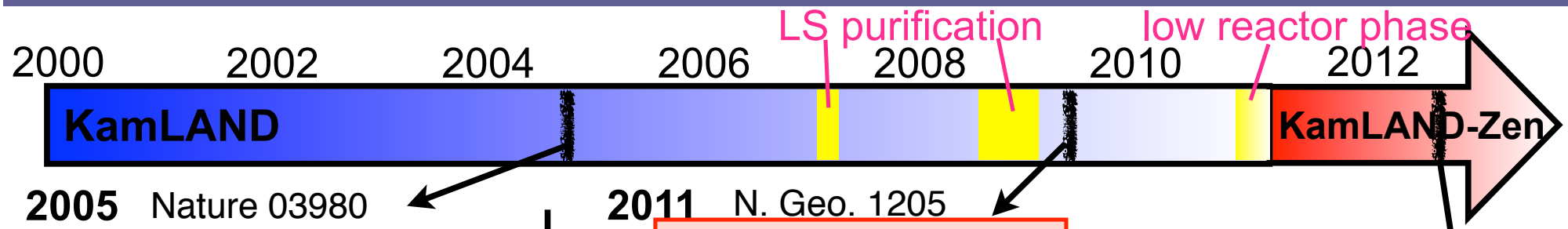
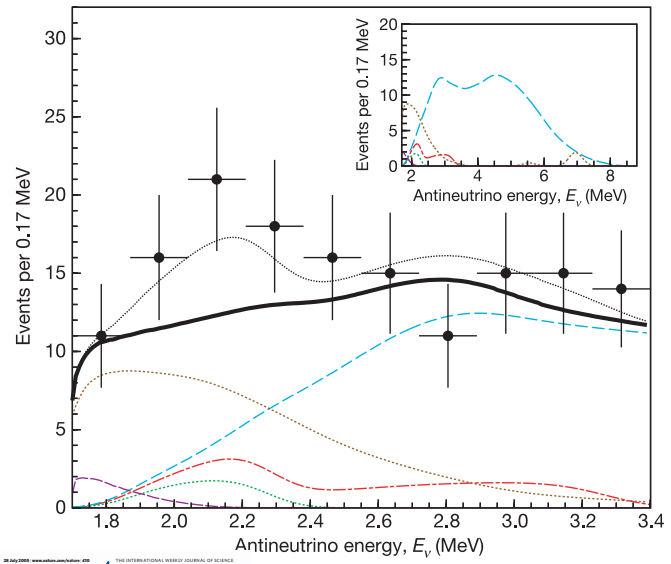
Geo-neutrino Measurement at KamLAND



2005 Nature 03980

geo-neutrino first measurement



749 days

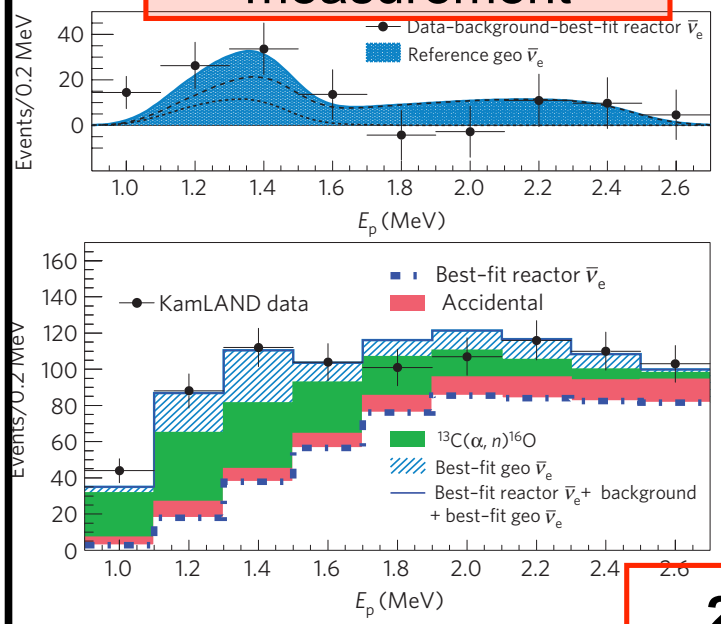
0.71×10^{32} proton-year

geo-nu event

$28.0^{+15.6}_{-14.6}$ ev

2011 N. Geo. 1205

radiogenic heat direct measurement

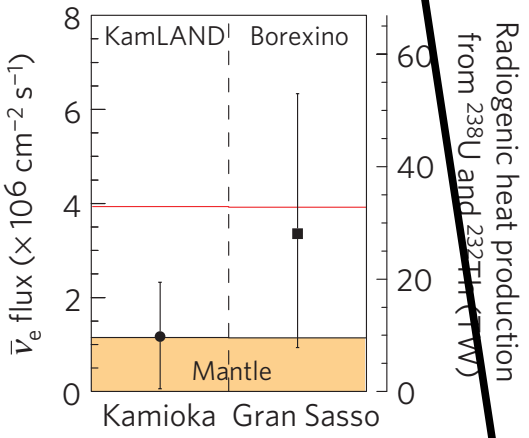


2135 days

3.49×10^{32} proton-year

geo-nu event

106^{+29}_{-28} ev



radiogenic heat

21±9 TW

2013 arXiv:1303.4667

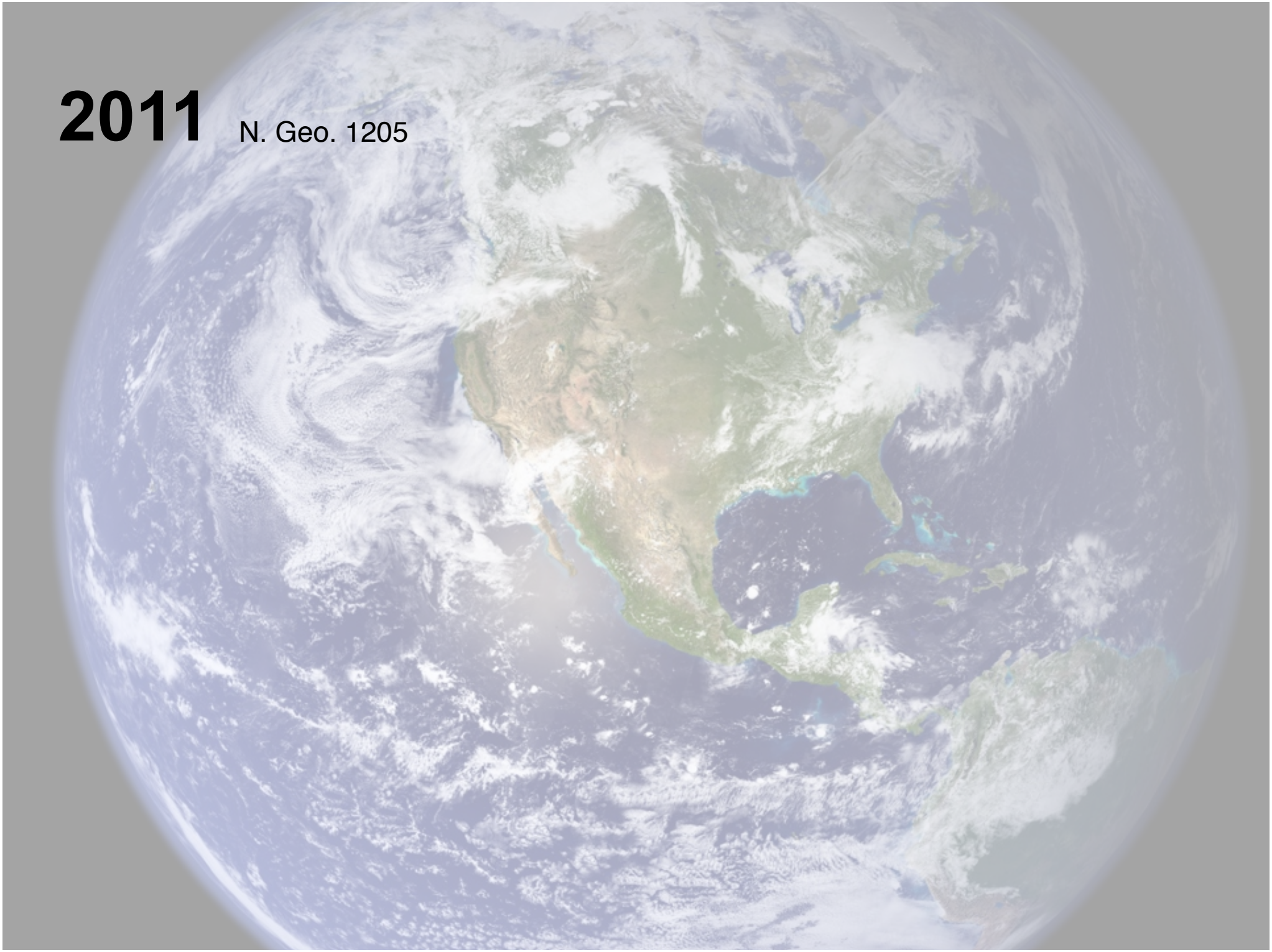
include low reactor phase data

2991 days

4.90×10^{32} proton-year

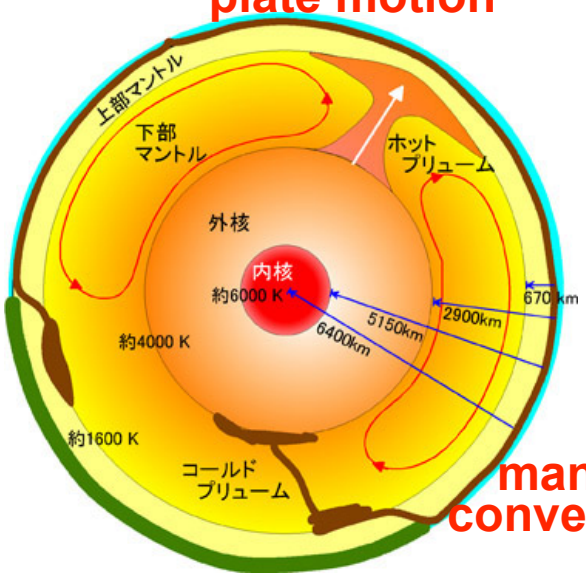
geo-nu event 116^{+28}_{-27} ev

2011 N. Geo. 1205

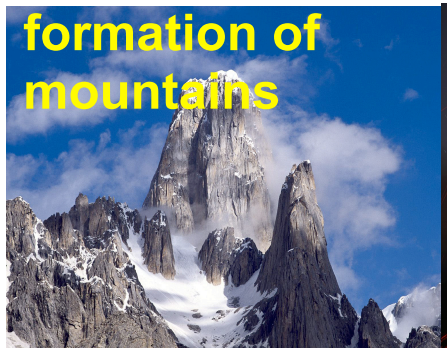


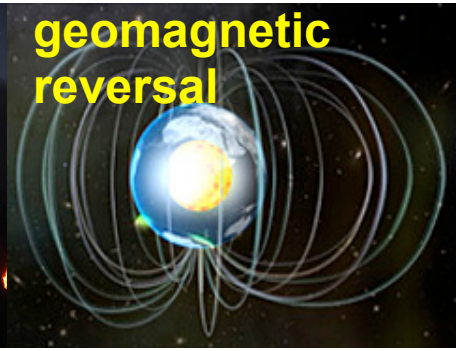
Terrestrial Heat - Geophysical Activity

plate motion



mantle convection





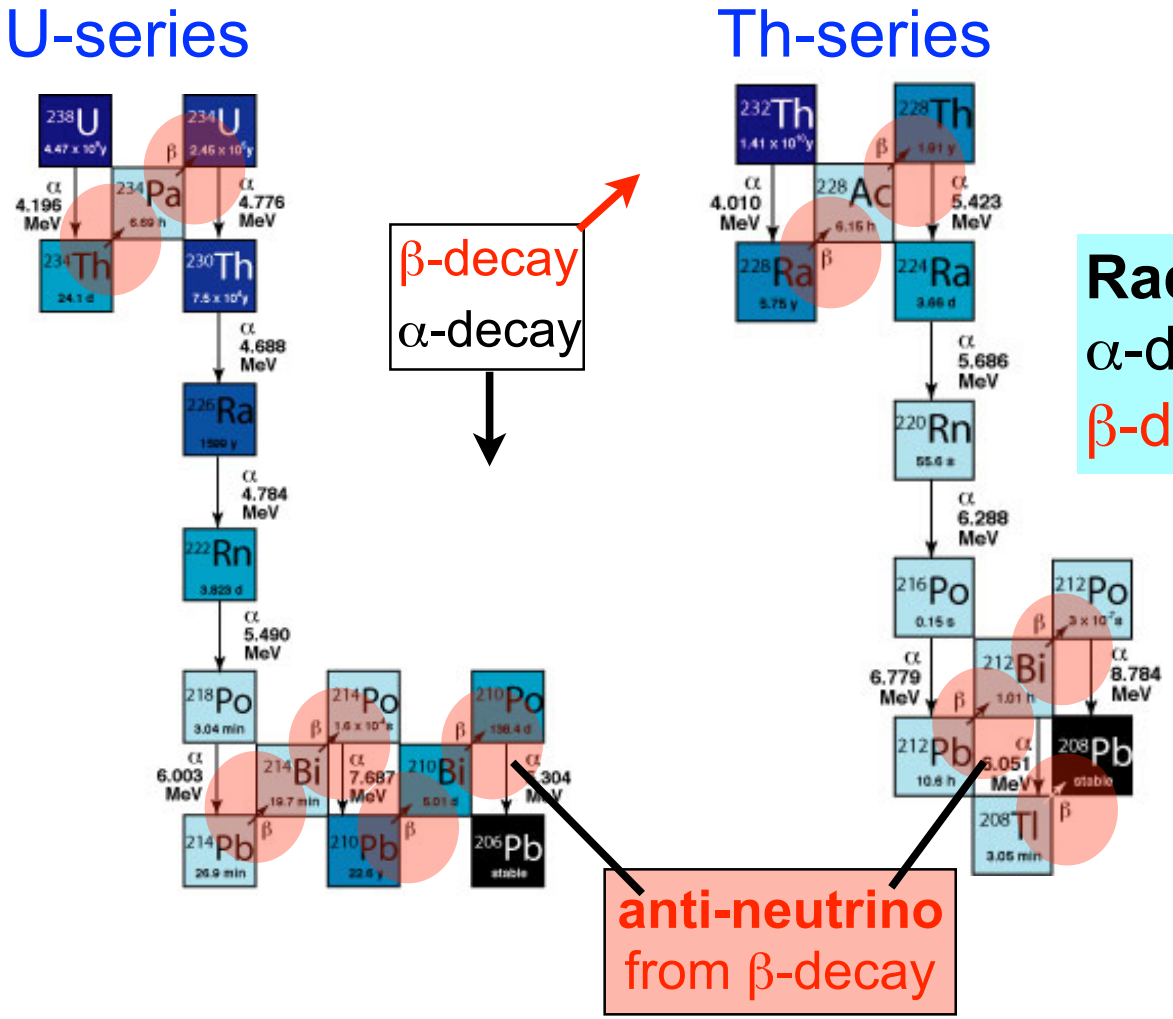
Question on geophysical activity

- What are energy sources? How much energy?
- How is the mantle convecting, single or multi-layer convection?
- Why is the frequency of geomagnetic reversals random?

→ It is important to find out the terrestrial heat.

Terrestrial Heat - Heat Sources in the Earth

(1) Radiogenic heat from U, Th, K decay
(2) Release of gravitational energy through accretion or metallic core separation
(3) Latent heat from the growth of inner core



Radiogenic heat :
α-decay or
β-decay emitting “anti-neutrinos”

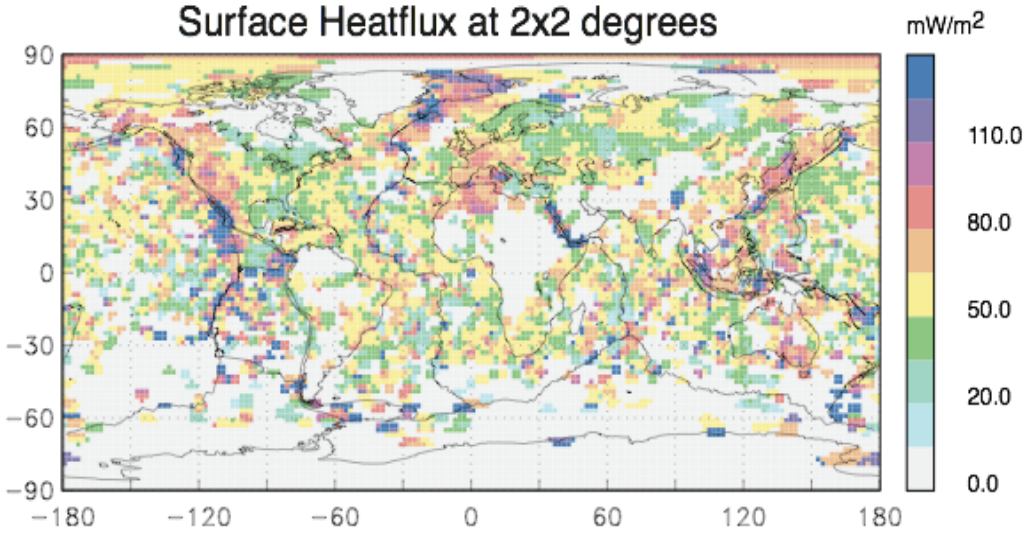
Terrestrial Heat - Heat Balance

☑ Surface heat flow

44.2±1.0 TW

Rev. of Geophys. 31, 267-280 (1993)

crust heat flux measurement & calculation



☑ Radiogenic heat in the Earth

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20 TW

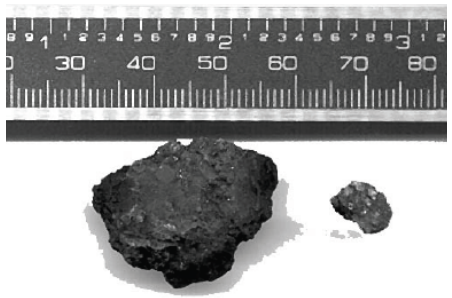
Bulk Silicate Earth (BSE) model

componential analysis of chondrite meteorite

U : 8 TW

Th : 8 TW

K : 3TW



This is not “direct measurement”.

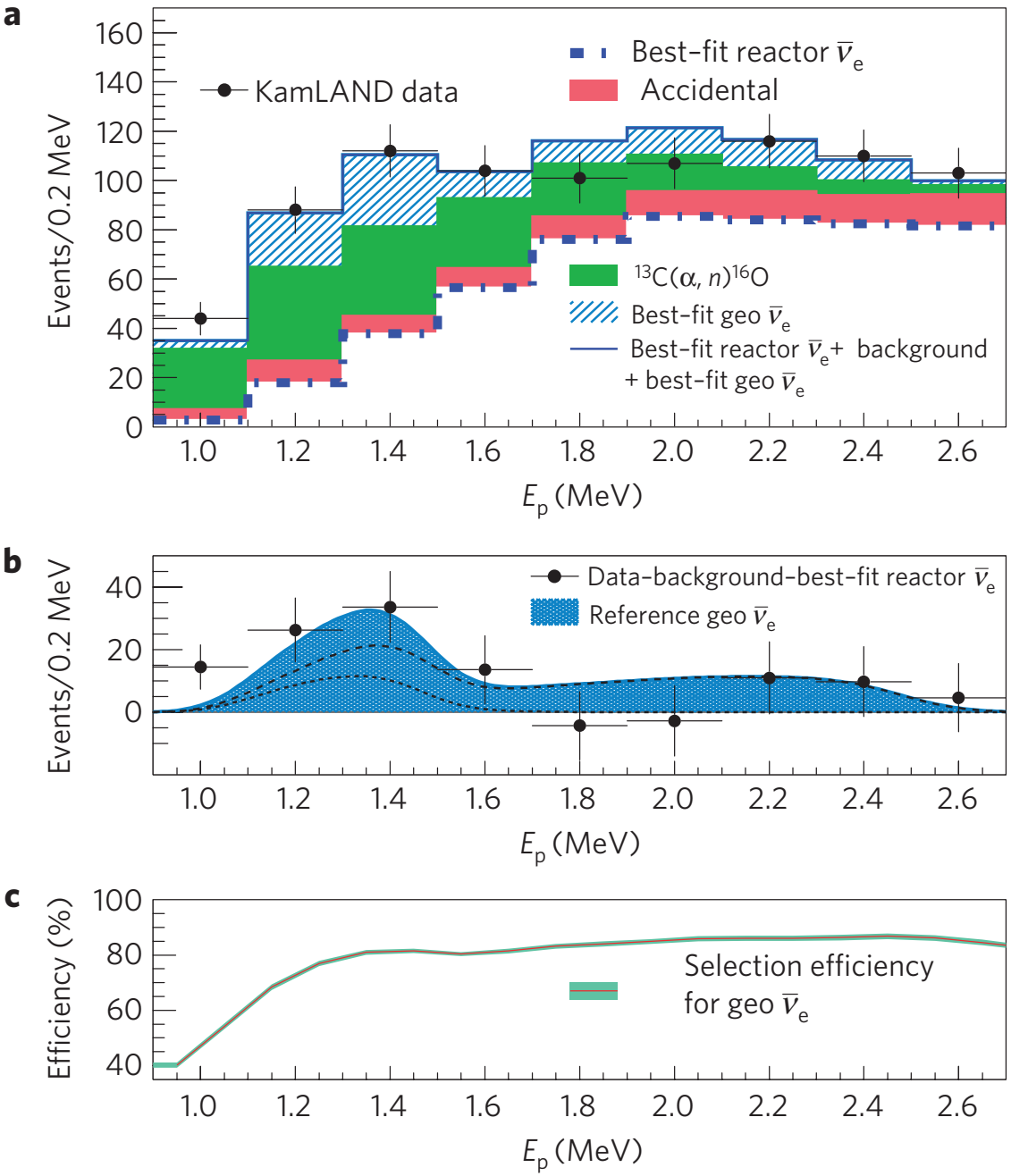
Almost half of radiogenic heat contributes to the surface heat flow.

Why?

↓

Geo-neutrino can directly test radiogenic heat production.

Analysis - Observed Energy Spectrum (0.9-2.6 MeV)

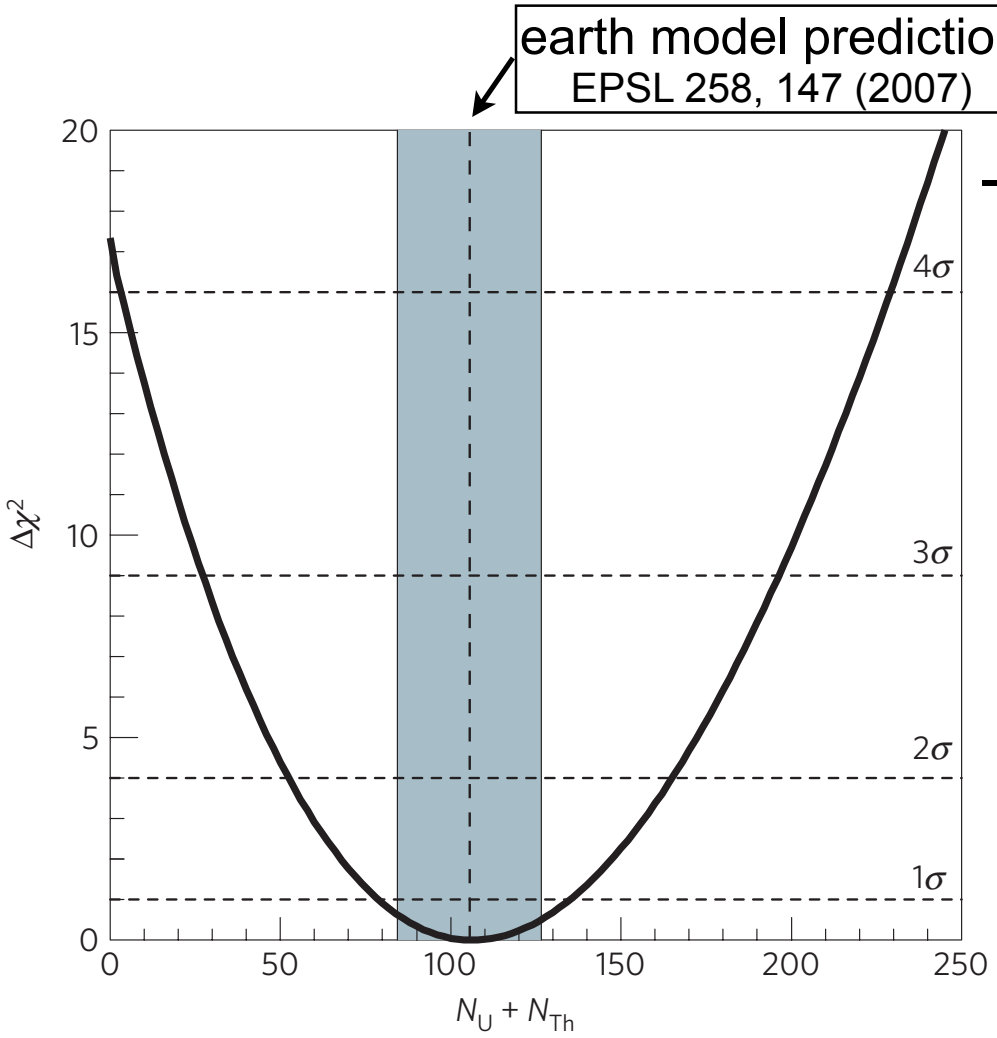


- exposure : 4126 ton-year
  (4.9 times larger the 2005 result)
- result

candidate	841
^{9}Li	2.0 ± 0.1
Accidental	77.4 ± 0.1
Fast neutron	< 2.8
(α, n)	165.3 ± 18.2
Reactor ν	484.7 ± 26.5
BG total	729.4 ± 32.3
excess	111^{+45}_{-45} events

Null signal exclusion (rate)
99.55 % C.L.

Analysis - Rate+Shape+Time Analysis



- U/Th mass ratio fixed (Th/U = 3.9)

$N_{geo} = 106\ ^{+29}_{-28}$ events

$F_{geo} = 4.3\ ^{+1.2}_{-1.1} \times 10^6/cm^2/sec$

$(38.3\ ^{+10.3}_{-9.9}$ TNU)

0 signal rejected at
99.997% C.L.
(> 4σ C.L.)

Analysis - Radiogenic Heat and Flux

fully-radiogenic model
EPSL 258, 147 (2007)

crust (^{238}U, ^{232}Th) 7.0 TW
^{40}K, ^{235}U 4.3 TW
mantle (44.2-7.0-4.3)TW

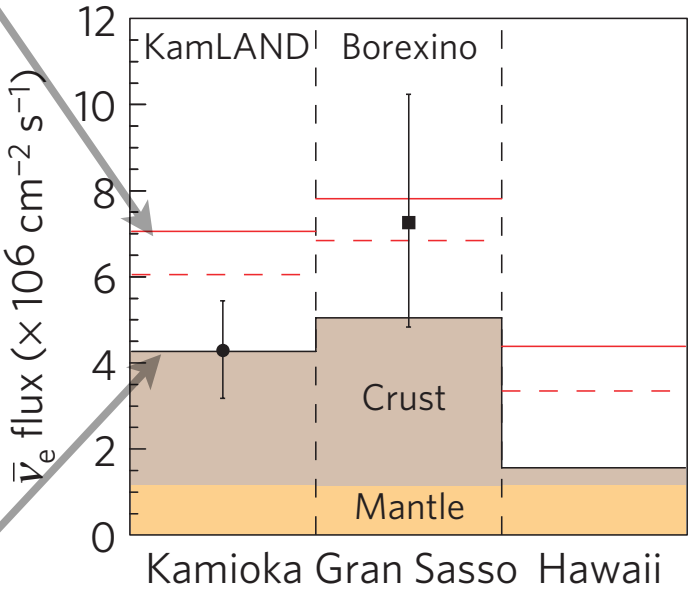
uniform mantle
mantle bottom only

earth model prediction
EPSL 258, 147 (2007)

^{238}U, ^{232}Th 16 TW
^{40}K, ^{235}U 4.3 TW

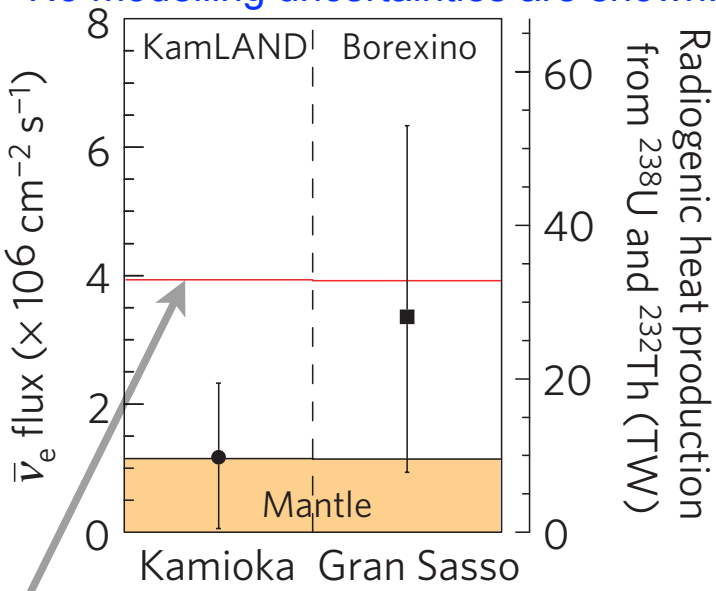
※ assume homogeneous mantle

Mantle+Crust



Mantle

No modelling uncertainties are shown.



total heat flow (44.2 TW)
- crust contribution (7.0 TW)
- other isotopes (4.3 TW)

✓The observed flux is consistent with the 20 TW model

^{238}U+^{232}Th (10±9 TW, KamLAND data) + crust (7.0 TW) + other isotopes (4.3 TW) ~ 21 TW

✓Fully-radiogenic models are disfavored

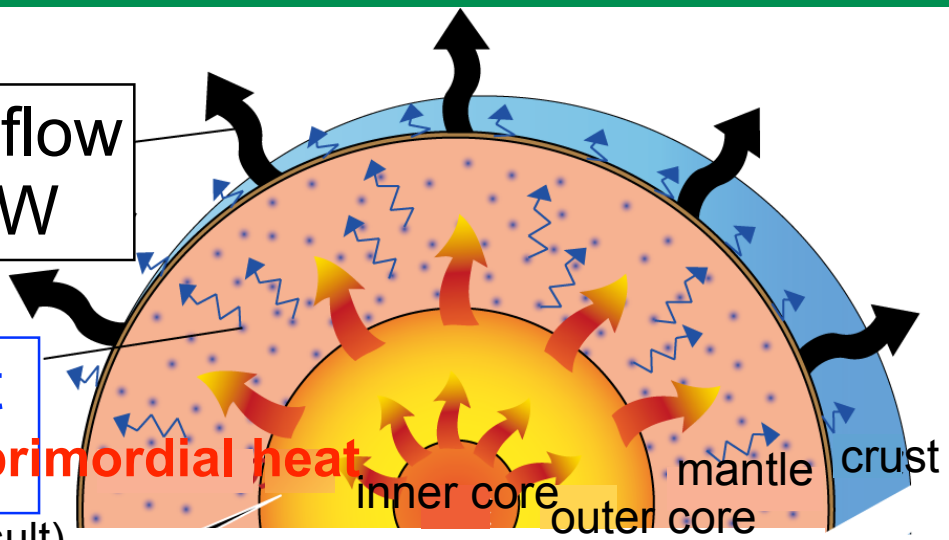
KamLAND only 2.4 σ C.L.
KamLAND + Borexino 2.3 σ C.L.

Analysis - Earth's Primordial Heat

surface heat flow
44.2±1.0 TW

radiogenic heat
~ 21 TW

(based on KamLAND measurement result)



surface heat flow
44.2±1.0 TW

−

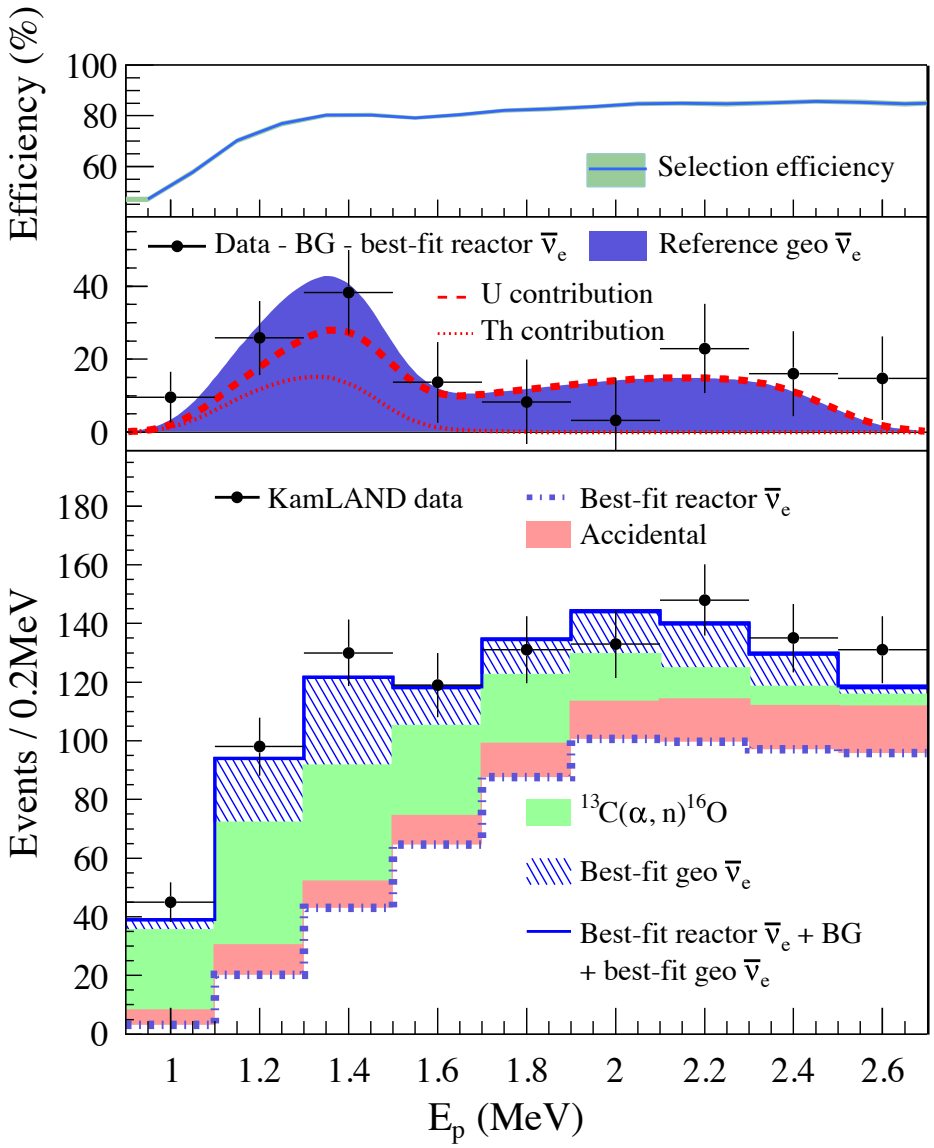
radiogenic heat
~ 21 TW

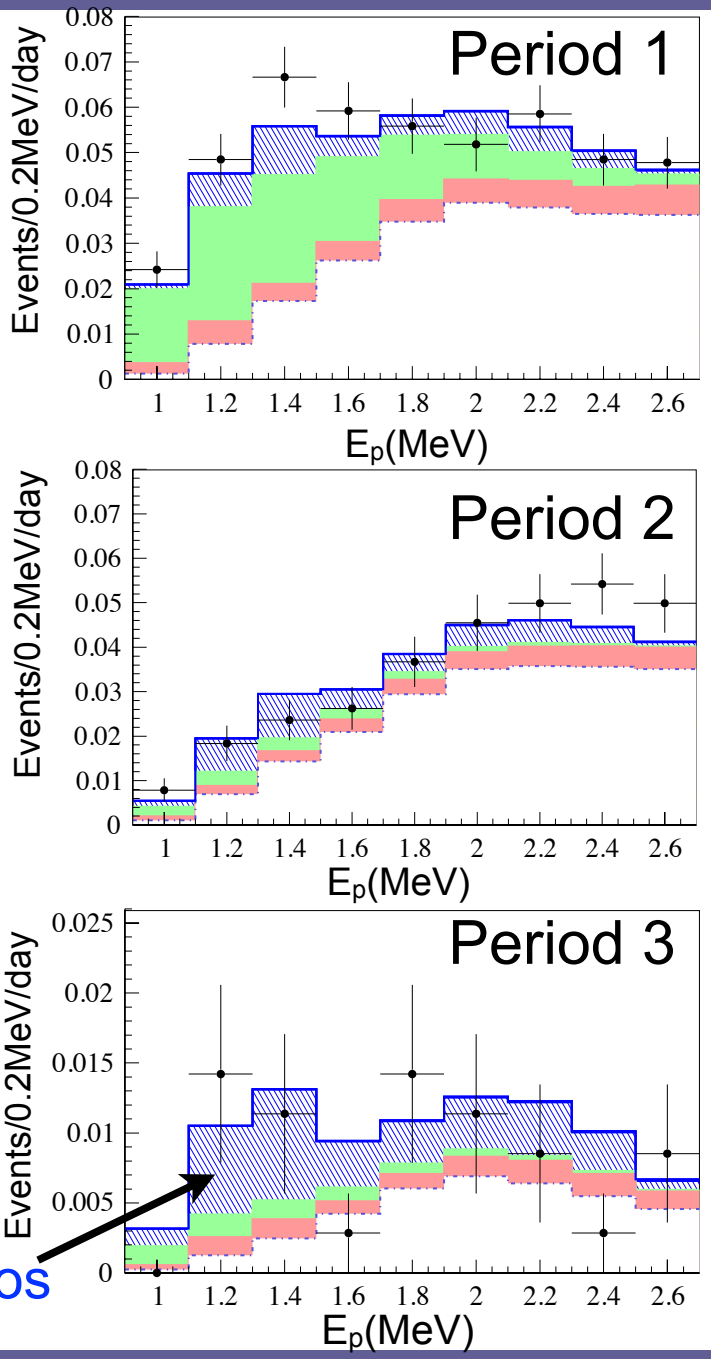
Earth's primordial heat

KamLAND observation shows that heat from radioactive decay contributes about half of Earth's total heat flux.
→ Earth's primordial heat supply has not yet been exhausted.


2013
arXiv:1303.4667

Analysis : Energy Spectrum (0.9-2.6 MeV)



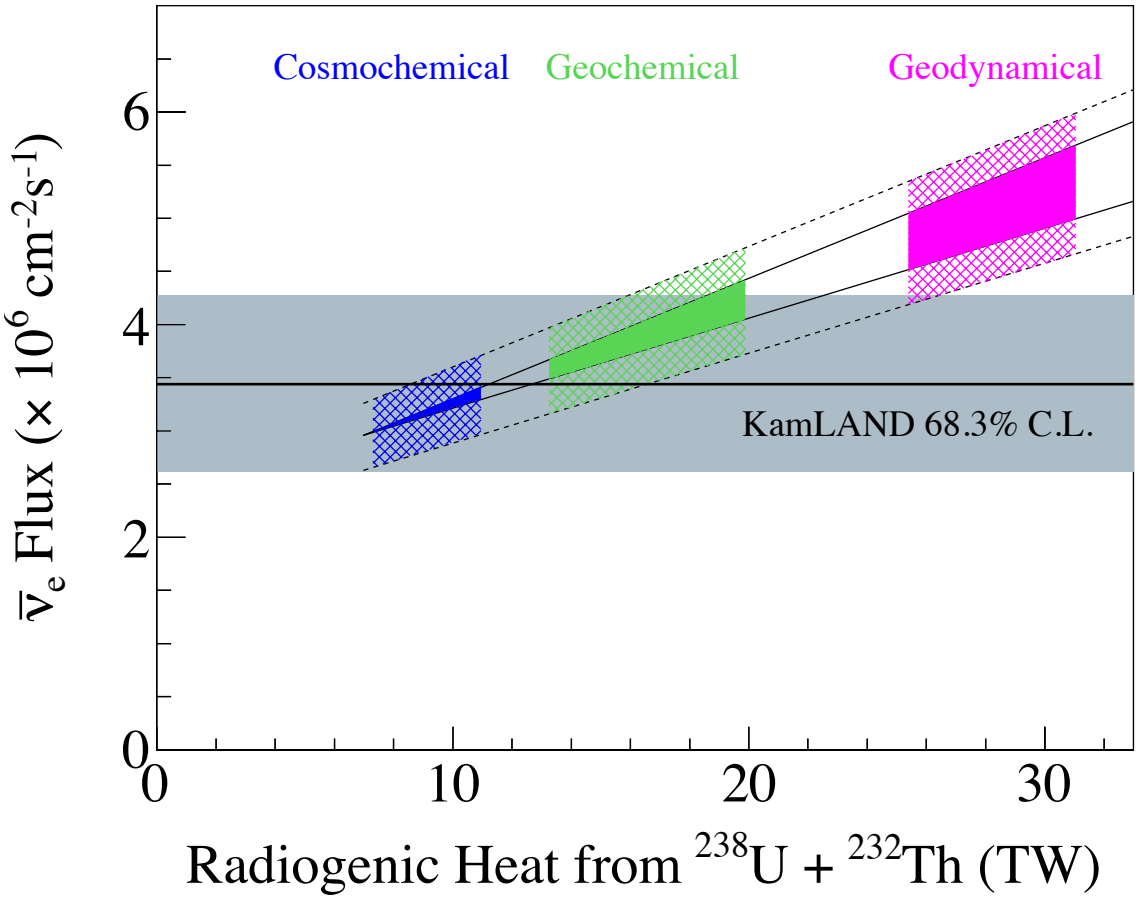


$^{13}C(\alpha, n)^{16}O$ decreased

Reactor-ν decreased

geo-neutrinos

Analysis - Comparison with Models

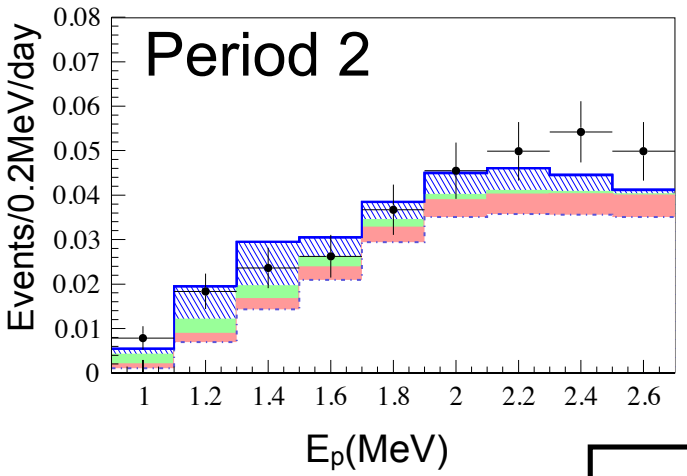


- The measured KamLAND geo-neutrino flux translates to a total radiogenic heat production : 11.2 $^{+7.9}_{-5.1}$ TW
- The geodynamical prediction with the homogeneous hypothesis is disfavored at 89% C.L.
- The BSE composition models are still consistent within ~2 σ.

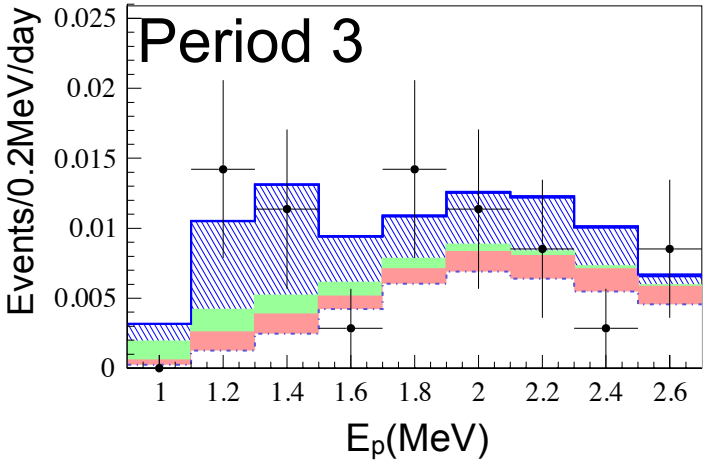
Future

Future Prospects; geo-neutrino uncertainties

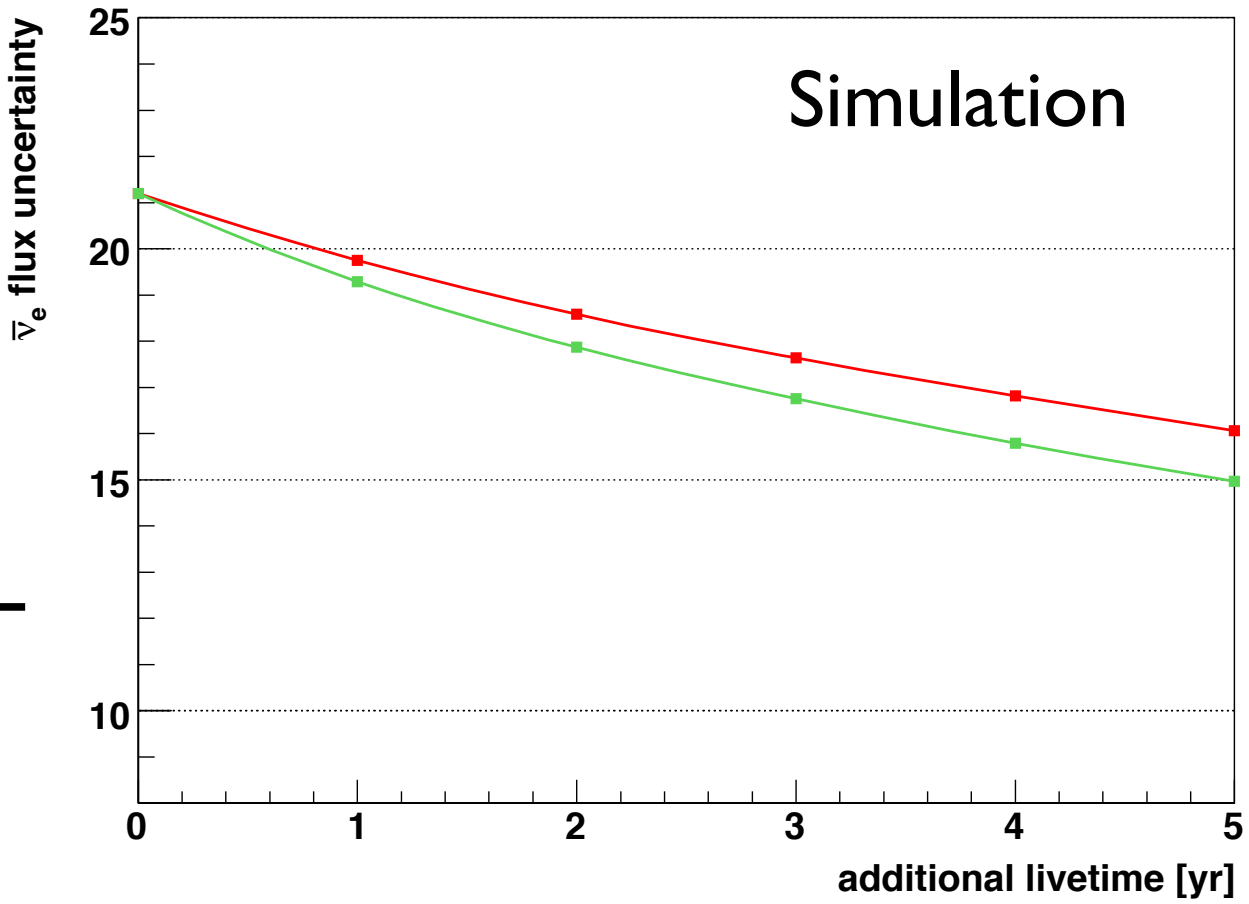
data



low background red



low background
low reactor green



(assuming Earth model)

We will achieve 15~16% uncertainty with additional 5 year measurement.

Summary

- We reported the results of the first study of electron anti-neutrinos produced within the Earth in 2005

- 2011 : radiogenic heat direct measurement
  2013 : low-reactor phase data analysis

- We will achieve 15~16% uncertainty with additional 5 year measurement.

It indicates the ability to discriminate between Earth models

- Future plan at KamLAND
(around 2015) Ce-LAND :
strong neutrino source in outer detector

  * It will be difficult to measure geo-neutrino...
  * It will be good chance to study anti-neutrino directionality at KamLAND

- Next target

Separate measurement of U and Th geo-neutrino
search for geo-reactor
study of the mantle homogeneity

Outer Detector Plan (0.5year)