# Measuring Geo-Neutrinos

NIKOLAI TOLICH
UNIVERSITY OF WASHINGTON

# Earth



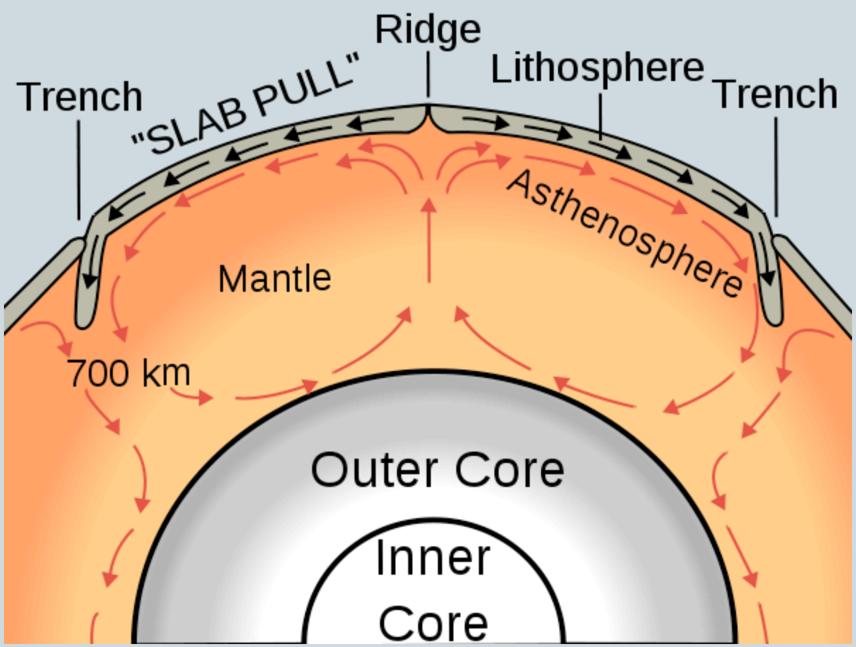



Image: by Surachit, http://en.wikipedia.org/wiki/File:Oceanic_spreading.svg

- Seismic data splits Earth into 5 basic regions:
  - inner core
  - outer core
  - mantle
  - oceanic crust
  - continental crust
- All these regions are solid except the outer core.
- The mantle convects even though it is solid.
- Oceanic crust is being renewed at mid-ocean ridges and recycled at trenches.

# Radioactivity in the earth



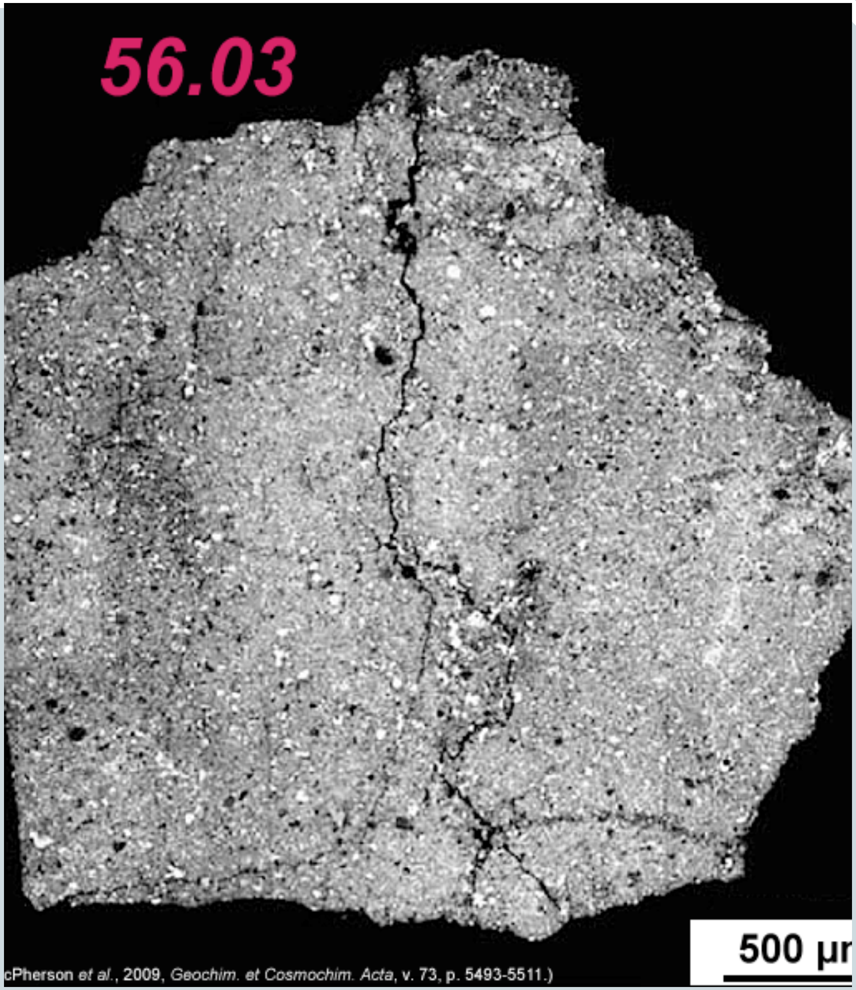



Image: http://www.psrd.hawaii.edu/

- Based on carbonaceous chondrites Lyubetskaya & Korenaga (2007) predict the following concentrations of radioactive isotopes in the earth's primitive mantle and crust
  - U (17±3) ng/g
  - Th (63±11) ng/g
  - K (23±5) $\mu$ g/g
- The resulting heat production rate is $(16\pm3)\times10^{12}$ W

# Heat flow

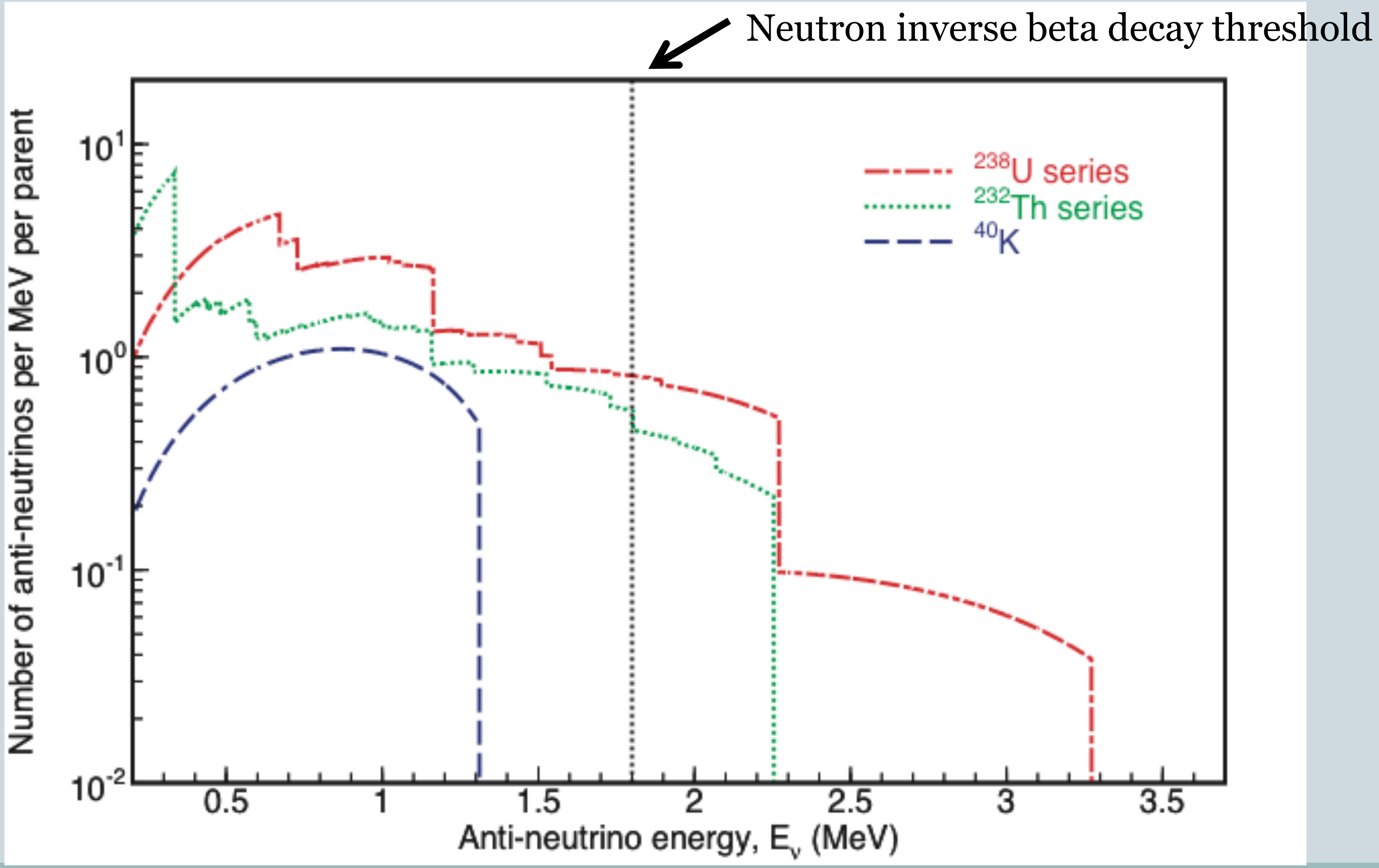


| | |
|---|---|
| Total heat loss | 46 ± 3 TW |
| Total radiogenic heat production | 16 ± 3 TW |
| Crust + lithosphere heat production | 4.9-8.8 TW |
| Present Urey ratio | 0.11 - 0.34 |

- Mantle convection models suggest Urey ratios (ratio of heat production to dissipation in the mantle) greater than 0.7
- Problem with
  - Mantle convection model?
  - Total heat loss measured?
  - Estimated radiogenic heat production rate?
- Geo-neutrinos can cross-check the radiogenic heat production.

# Geo-neutrino energy spectrum





# Where do the neutrinos come from?



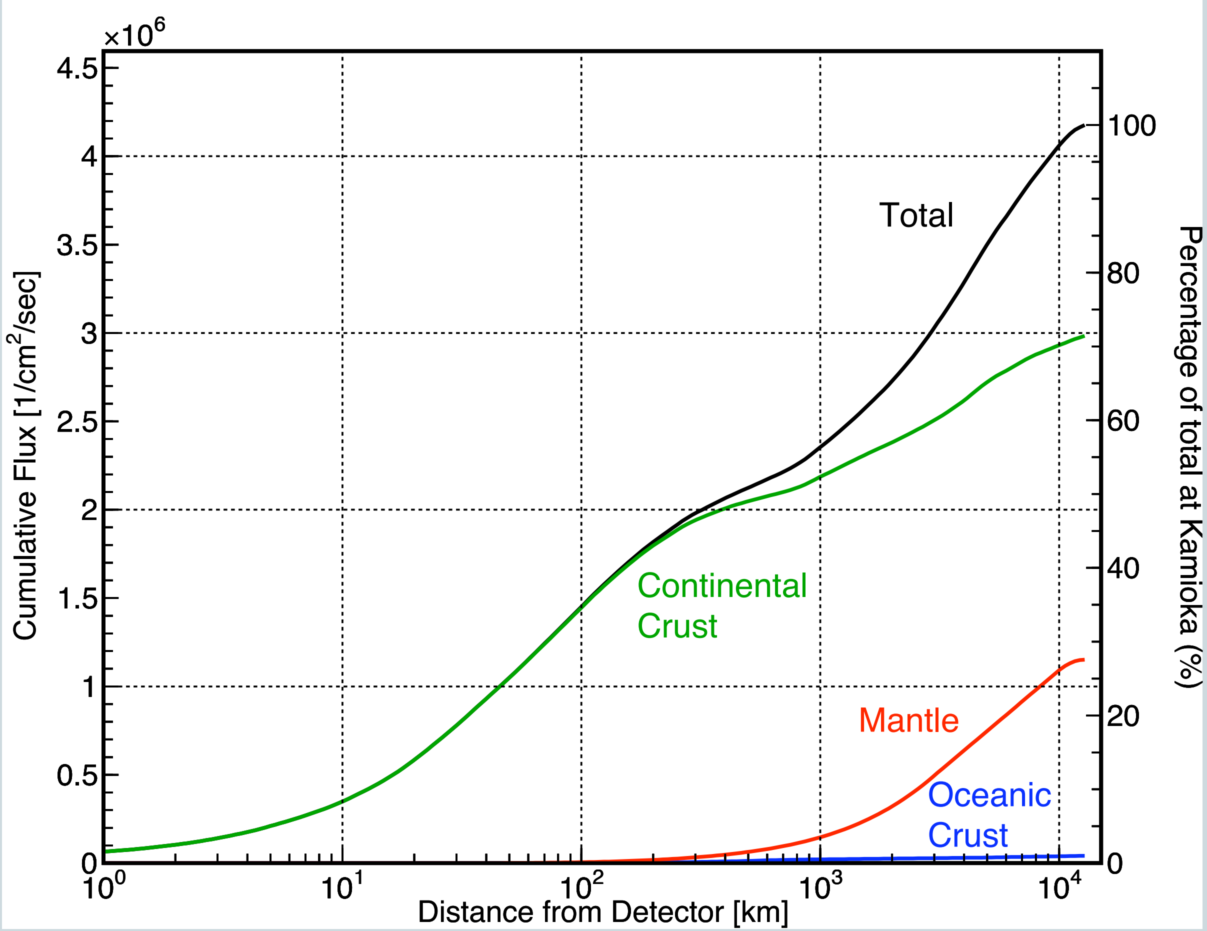



Image: S. Enomoto

# Signal-to-noise ratio



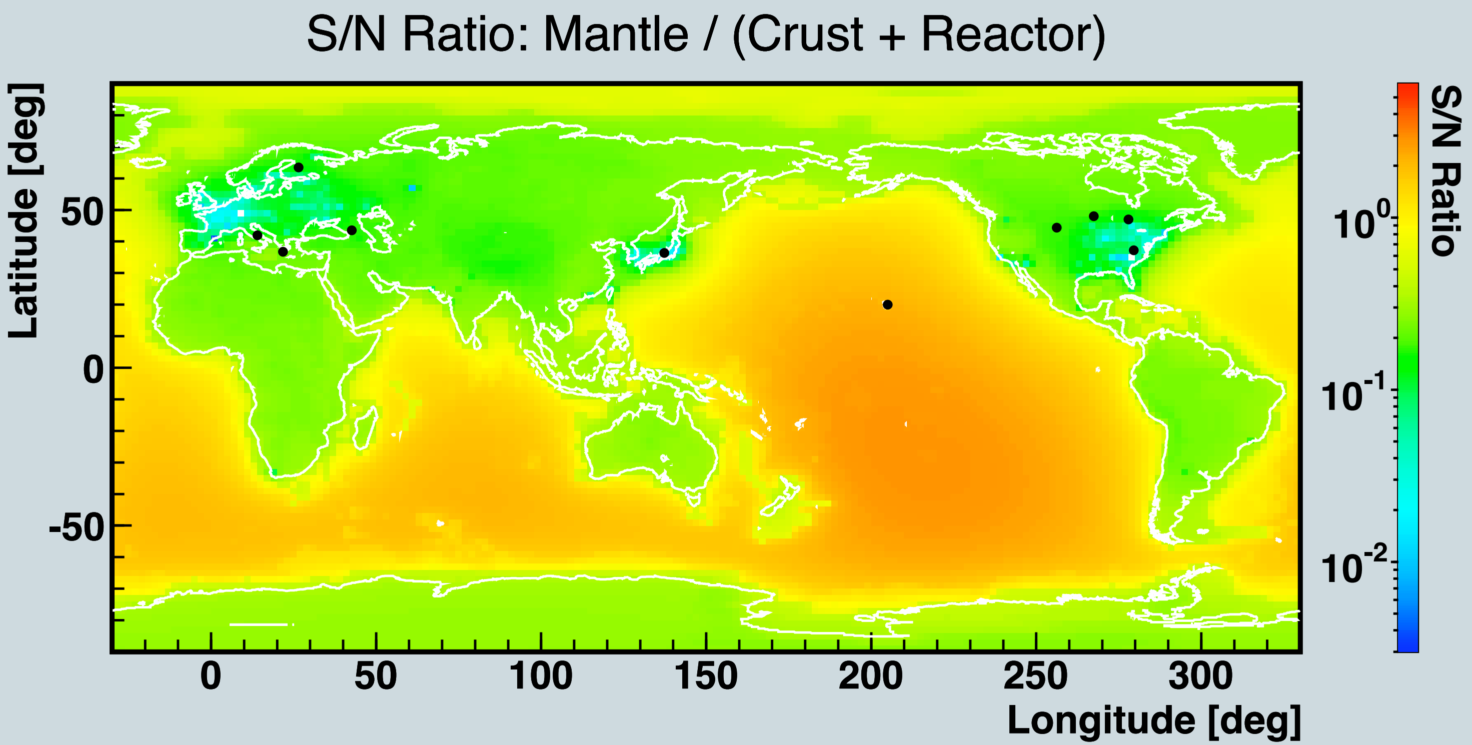


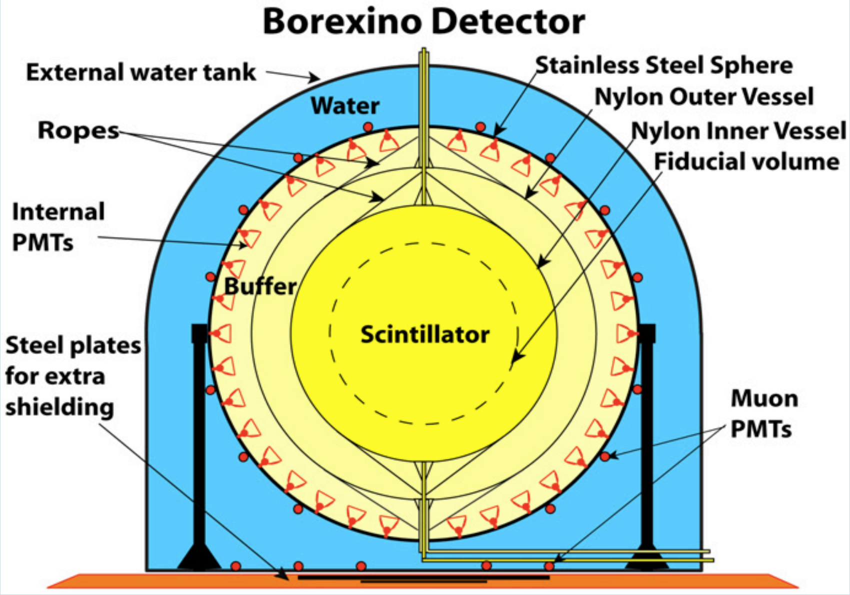

Image: S. Enomoto

# Geo-neutrino experiments

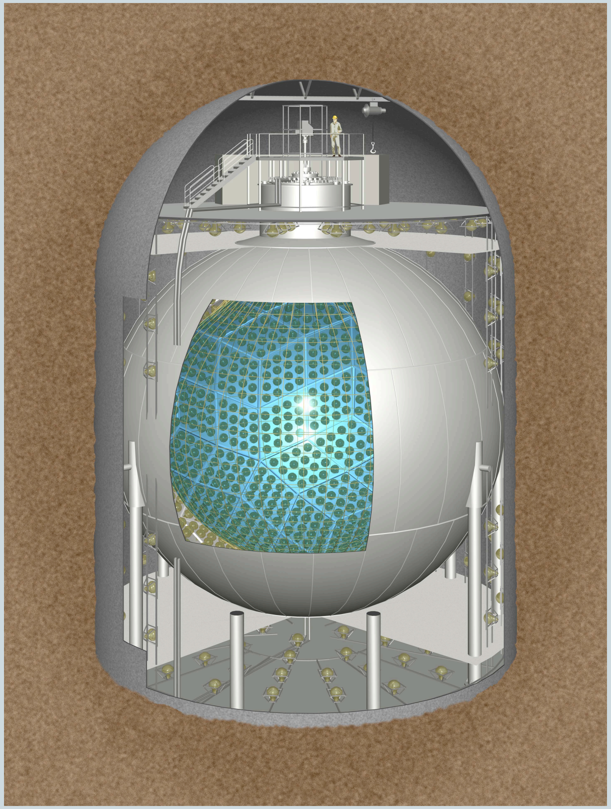
# Experiments



**Borexino**
**300 ton, Italy**



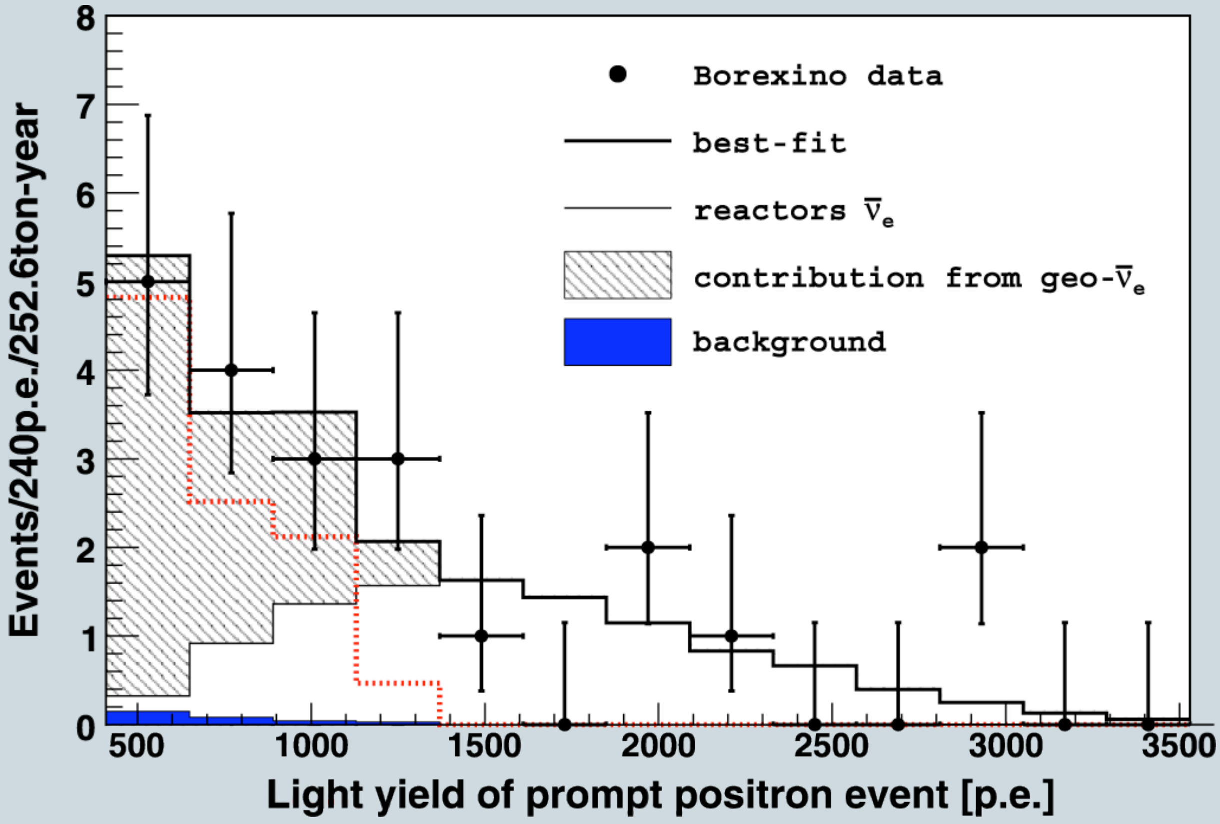

**KamLAND**
**1000 ton, Japan**



# Borexino results



~0.25 ×10$^{32}$ proton.years

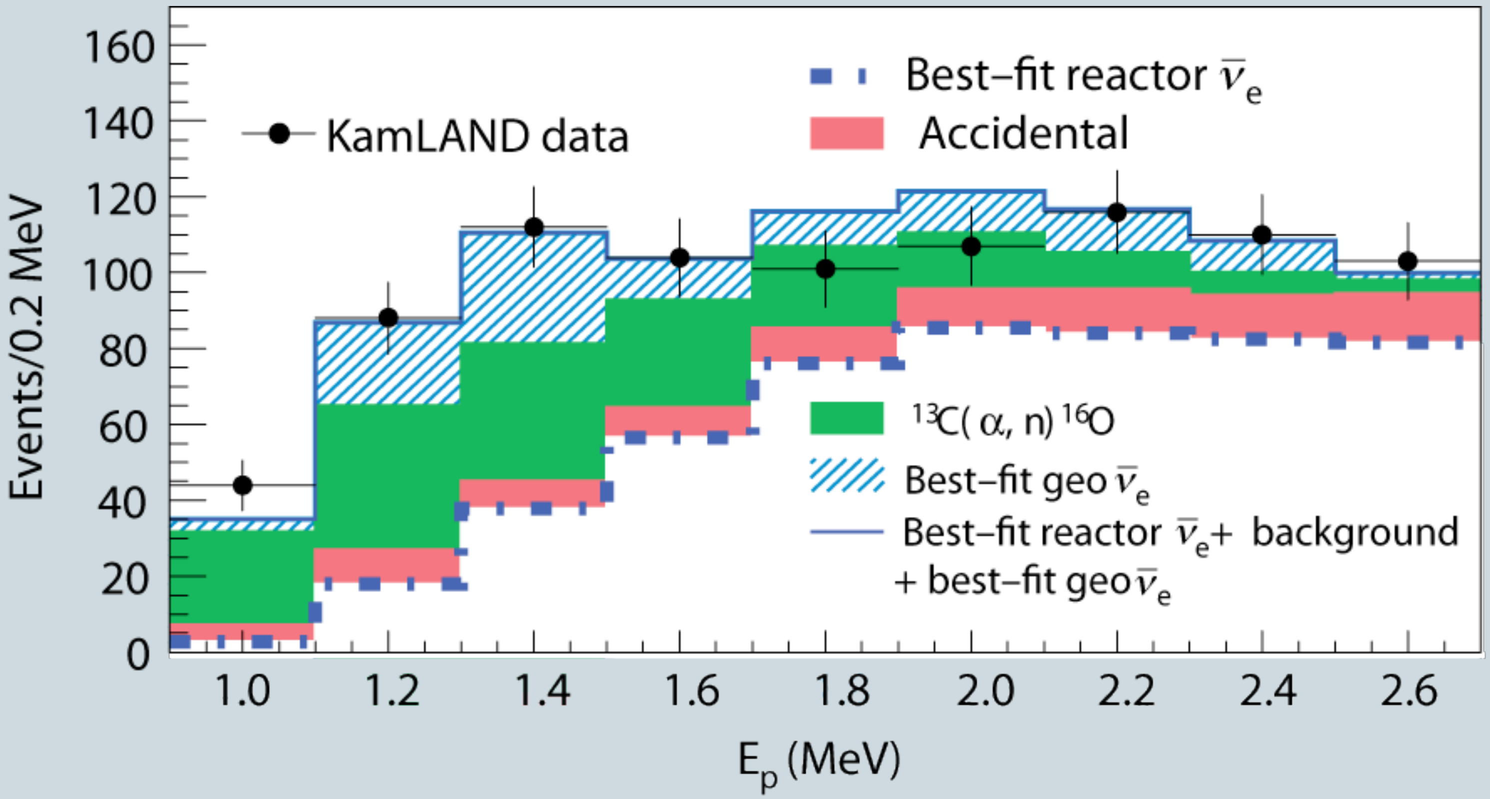



Phys. Lett. B **687** 299, 2010

# KamLAND results



$3.5\times10^{32}$ proton.years

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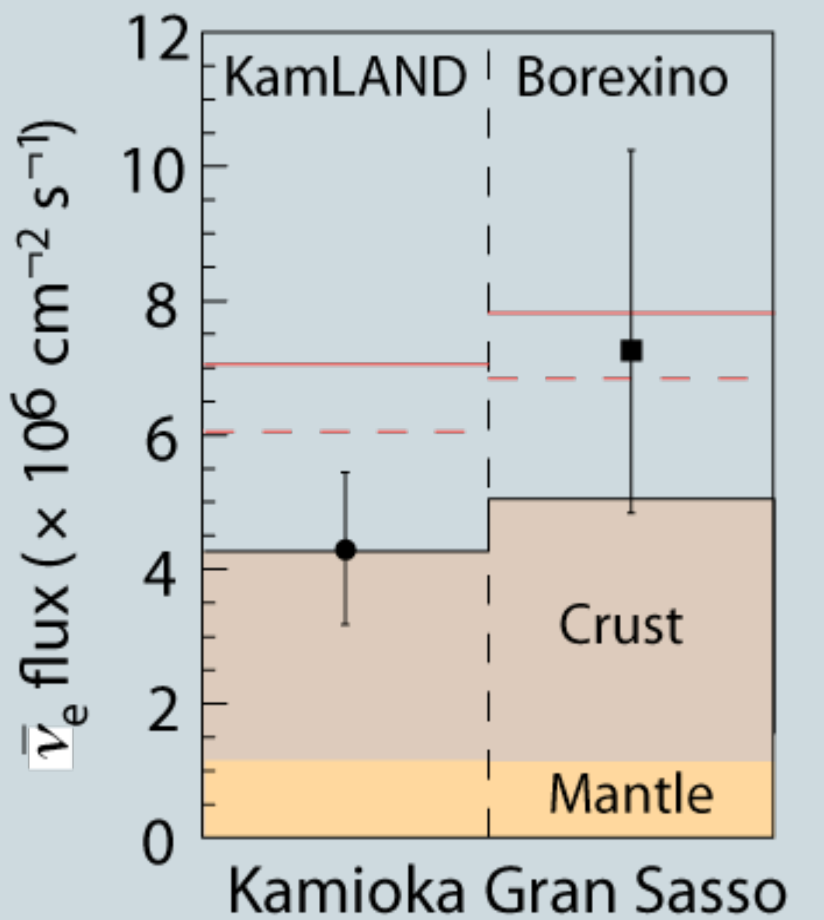
# Comparison to predictions



| | KamLAND [×10⁶ /cm²/sec] | Borexino [×10⁶ /cm²/sec] |
|---|---|---|
| S. Enomoto *et al.* (Total) | 4.4 | 5.2 |
| (Crust) | 3.2 | 4.0 |
| (Mantle) | 1.2 | 1.2 |
| F. Mantovani *et al.* (Total) | 4.0 | 4.6 |
| Measured | $4.3^{+1.2}_{-1.1}$ | $7.1^{+2.9}_{-2.4}$ |

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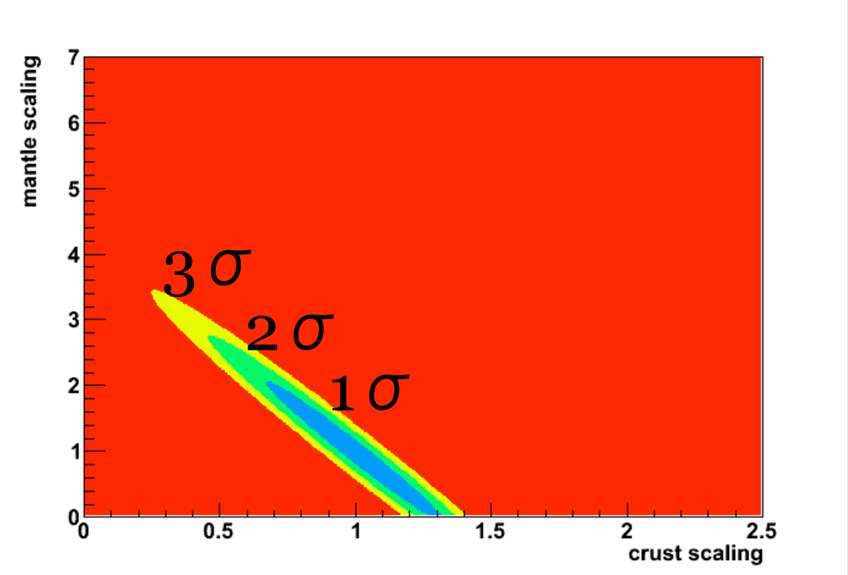
# Need for more detectors



- Ideally measurement in the ocean to probe the contribution from the mantle.
- Multiple measurements to probe variations.

5% measurement at KamLAND, Borexino, and SNO+

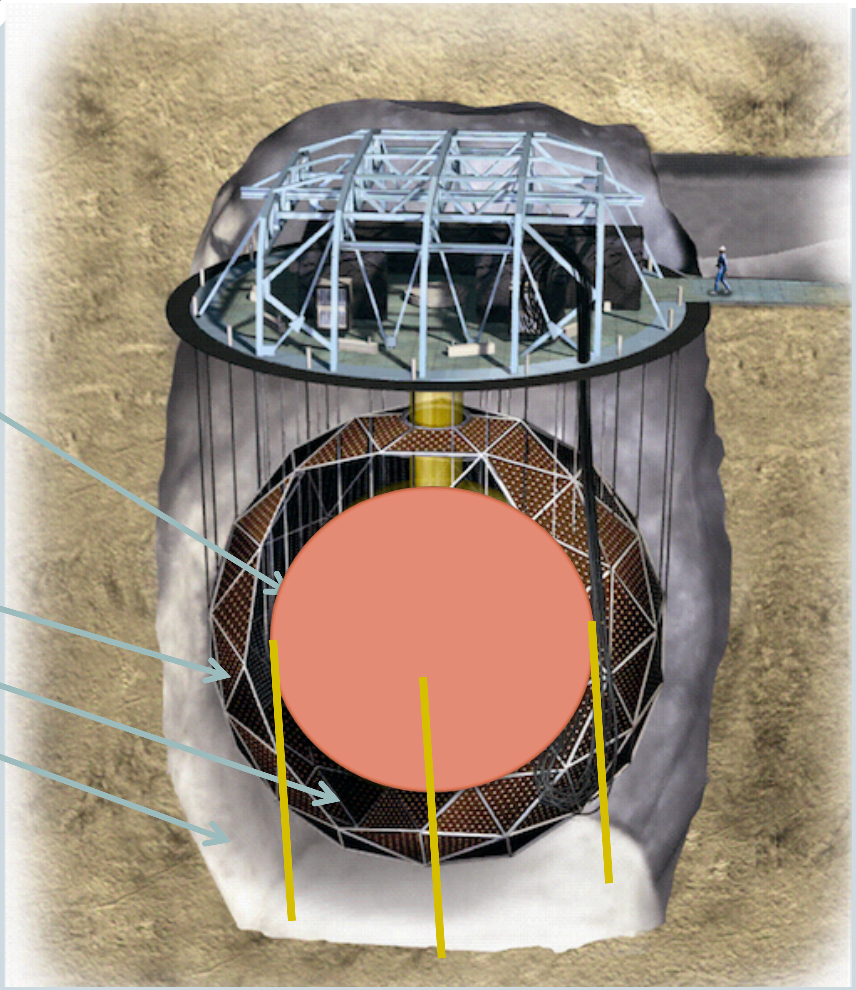



Does not include errors in the model other than scaling the mantle and crust

# SNO+ detector



- Located 2 km underground (~70 muons/day) in the Vale Inco Ltd.  Creighton Mine near Sudbury, Canada
  - 0.8 kton scintillator held in 12 m diameter acrylic vessel
  - 18 m diameter support structure holds 9500 PMTs (~60% photocathode coverage)
  - 1.7 kton inner shielding $H_2O$
  - 5.3 ktons outer shielding $H_2O$



# Future experiments

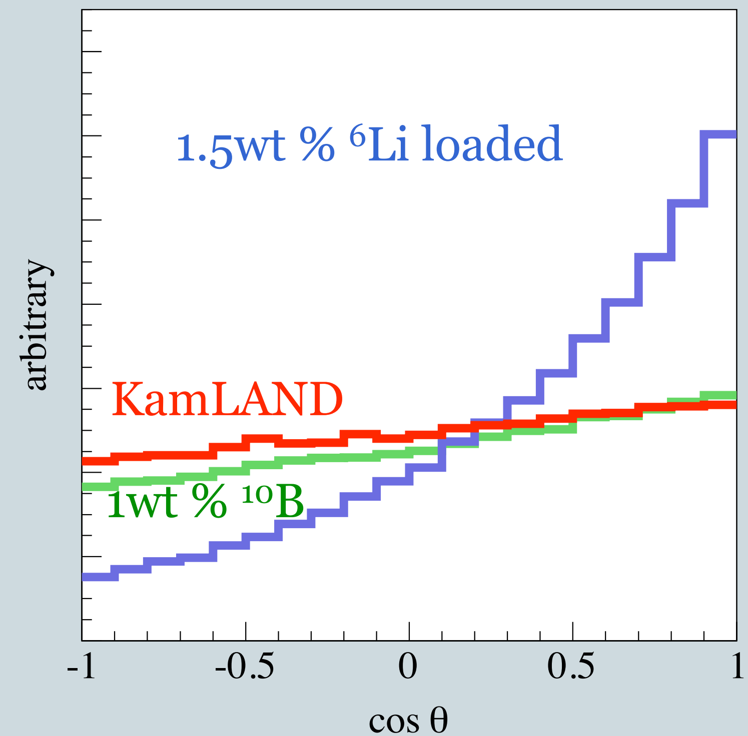


- SNO+ (0.8 kton), currently under construction
- Proposed detectors:
  - LENA (~50 kton), on continental crust
  - HanoHano (~10 kton), on oceanic crust
  - Baksan (~1 kton), on continental crust
  - DUSEL (??), on continental crust
  - EARTH (~1 kton), on oceanic or continental crust

# Directionality and $^{40}K$ detection



- Directionality sensitive detectors could directly determine the U and Th distribution within Earth.
- K detection is also important. Since K is more volatile than U and Th, the absolute amount is less well known. Is there K in the core?

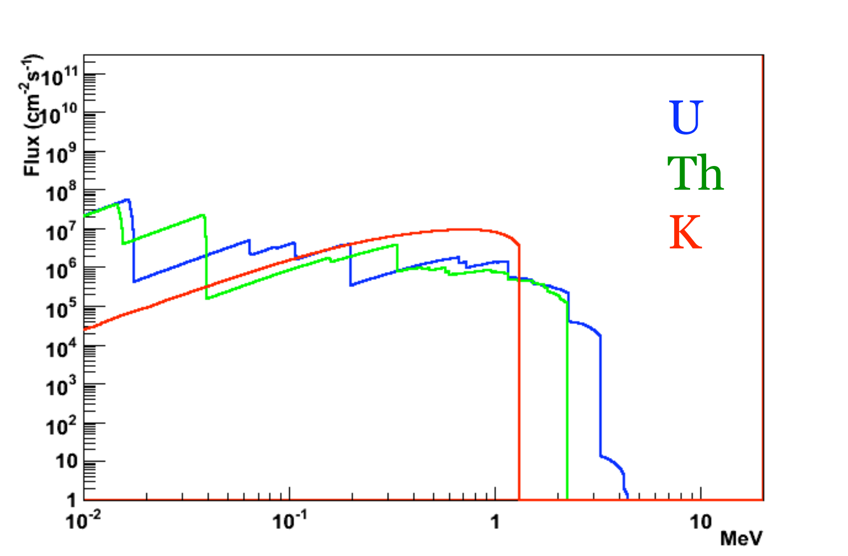



I. Shimizu. Nuclear Physics B (Proc. Suppl.) **168** (2007) 147

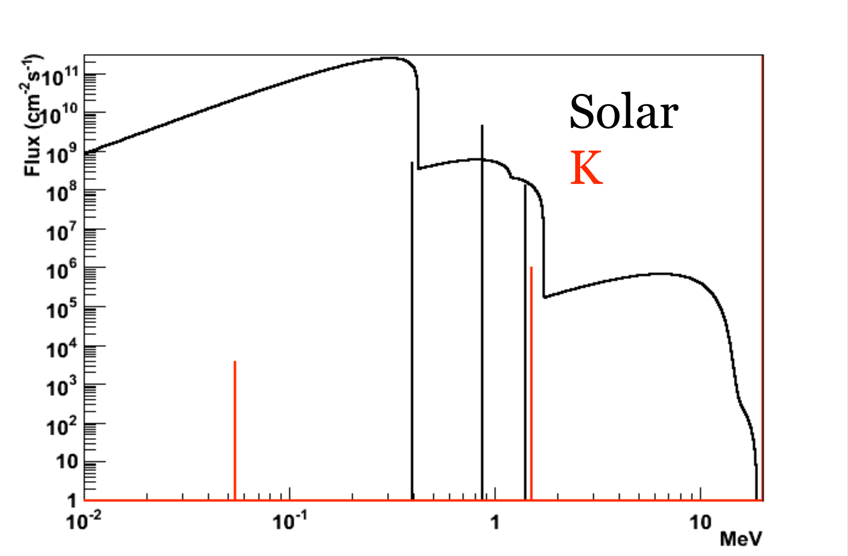
# Solar and geo neutrino signals



## Antineutrinos




## Neutrinos



# Detection requirements



- Need to
  - distinguish electron-antineutrinos from solar electron-neutrinos
  - be sensitive to neutrinos with energies<3.4 MeV geo-neutrinos
  - be sensitive to rates as low as ~20 events/kton/year

# Other detectors



## Liquid Ar

- Elastic scattering:
  - Low cross-section
  - Overwhelmed by solar neutrinos, therefore need good angular resolution
- CC, $\nu_e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$:
  - Threshold too high

## Water Cherenkov

- Detect electron-antineutrinos from neutron inverse beta decay

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

- Not sensitive to geo-neutrinos because they are below the Cherenkov threshold

# Conclusions



- KamLAND and now Borexino have observed geo-neutrinos.
- The reported error is now approaching the level where they could contribute to our knowledge of Earth.
- Need to build more detectors to determine contribution from the mantle in order to help solve problem of mantle convection.