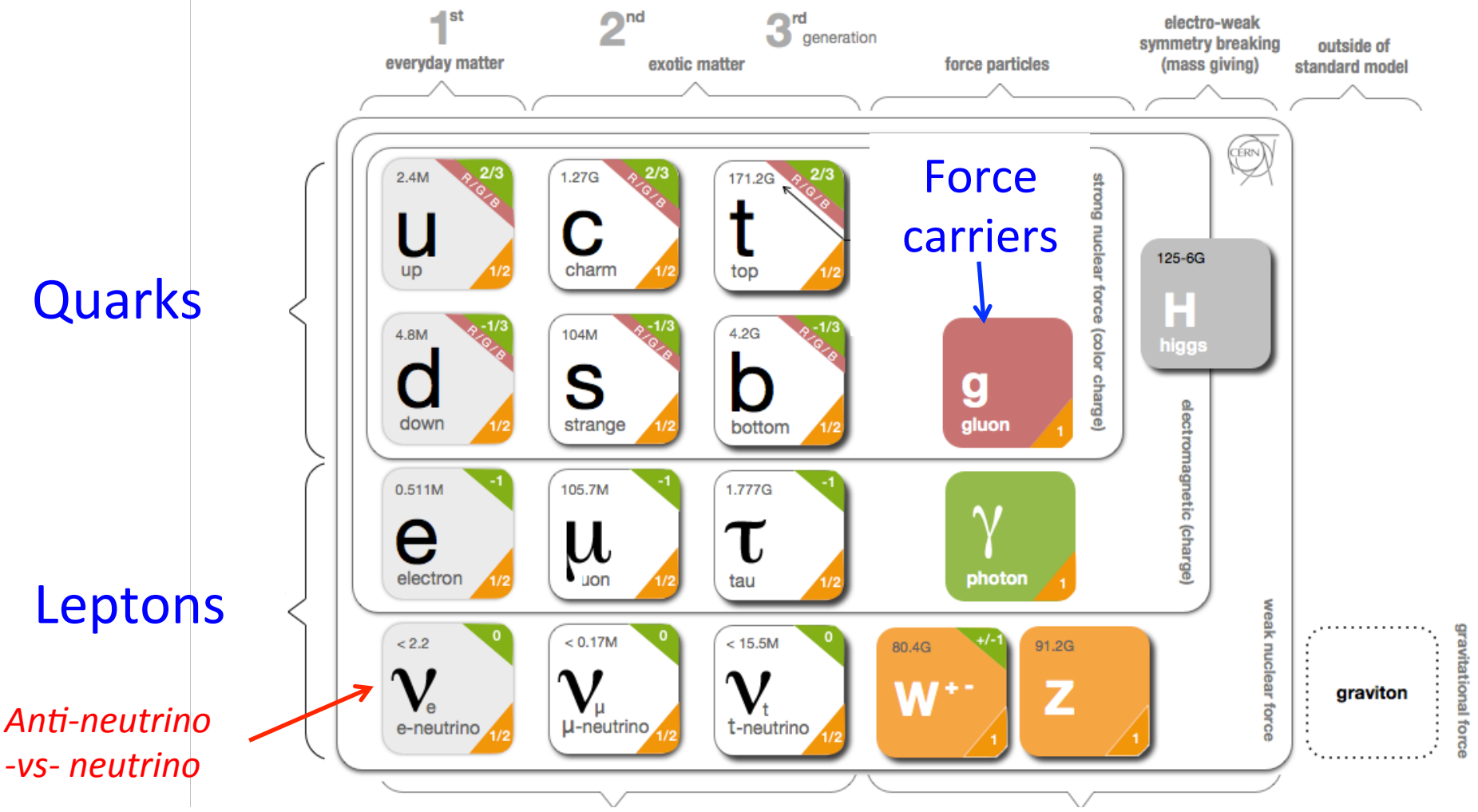
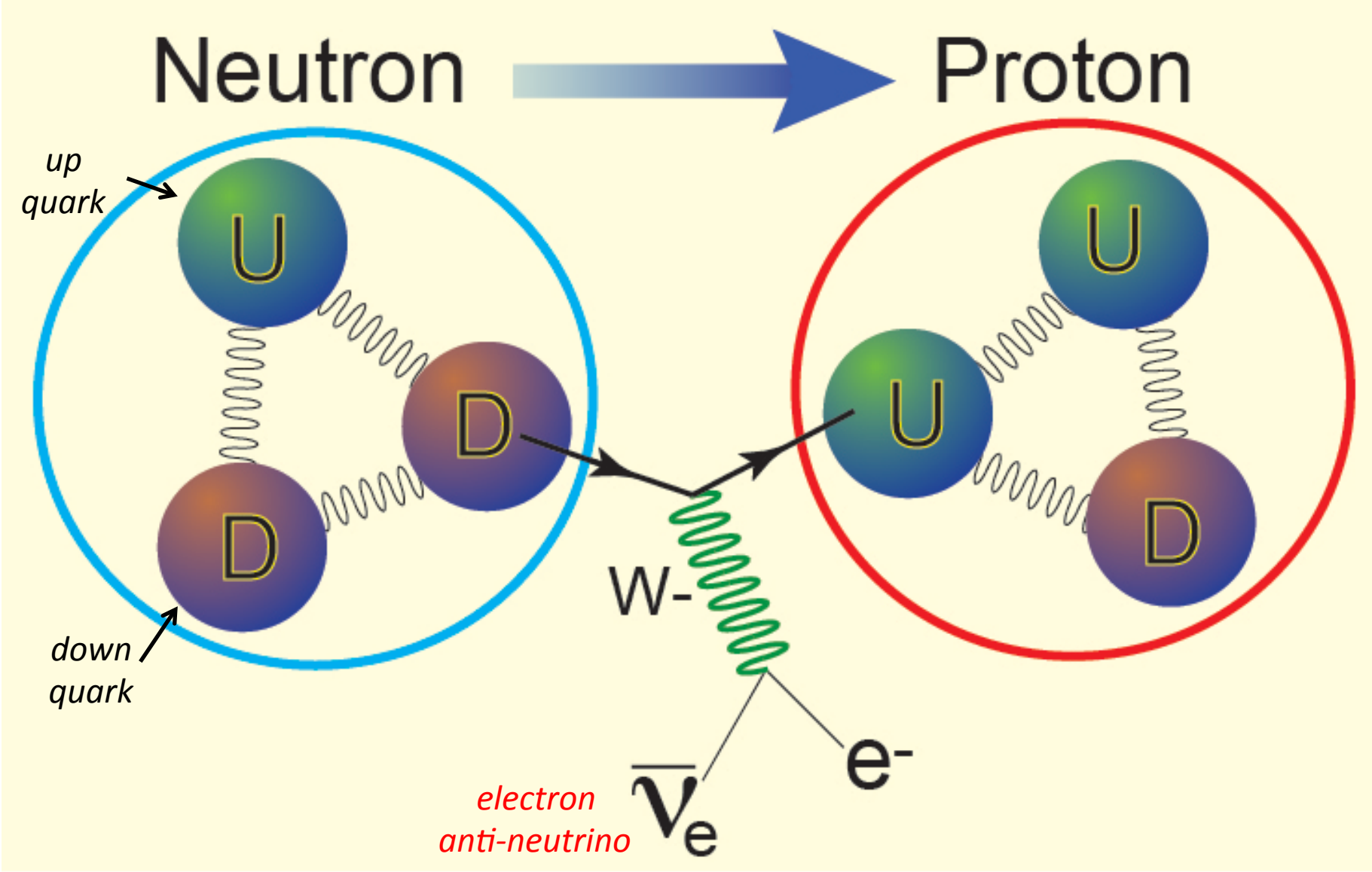
What are Geoneutrinos?

electron anti-neutrinos from the Earth, products of natural radioactivity

Geoneutrino flux
- typical flux $6*10^6$ cm^{-2} s^{-1}



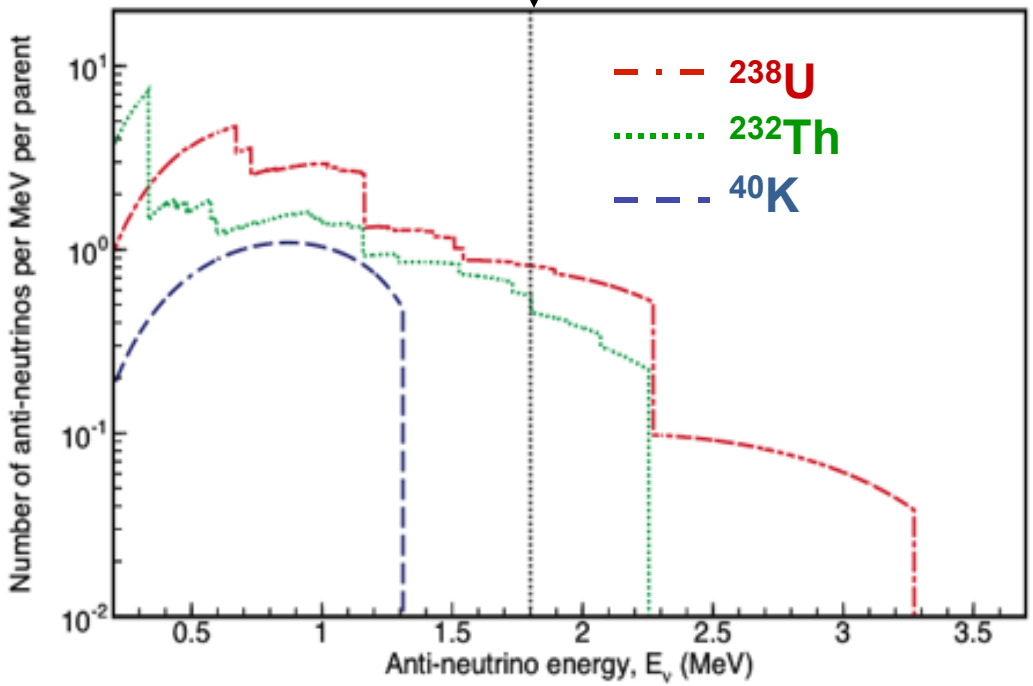
β^- decay process (e.g., U, Th, K, Re, Lu, Rb)



Geoneutrinos

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

1.8 MeV Energy Threshold



^{238}U

1α, 1β

^{234}Pa

$\bar{\nu}_e$ 2.3 MeV 31%

5α, 2β

^{214}Bi

$\bar{\nu}_e$ 3.3 MeV 46%

2α, 3β

^{206}Pb

^{232}Th

1α, 1β

^{228}Ac

$\bar{\nu}_e$ 2.1 MeV 1%

4α, 2β

^{212}Bi

$\bar{\nu}_e$ 2.3 MeV 20%

1α, 1β

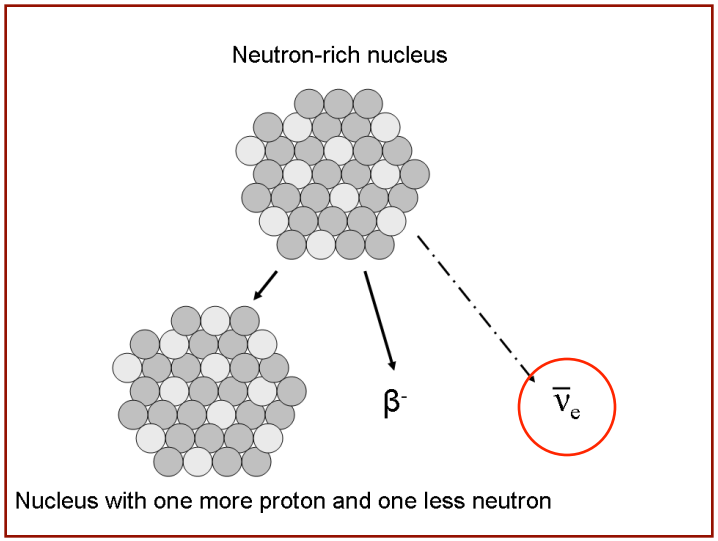
^{208}Pb

^{40}K → 1β → ^{40}Ca

Only **geoneutrinos from U and Th are detectable**

MeV-Scale Electron Anti-Neutrino Detection

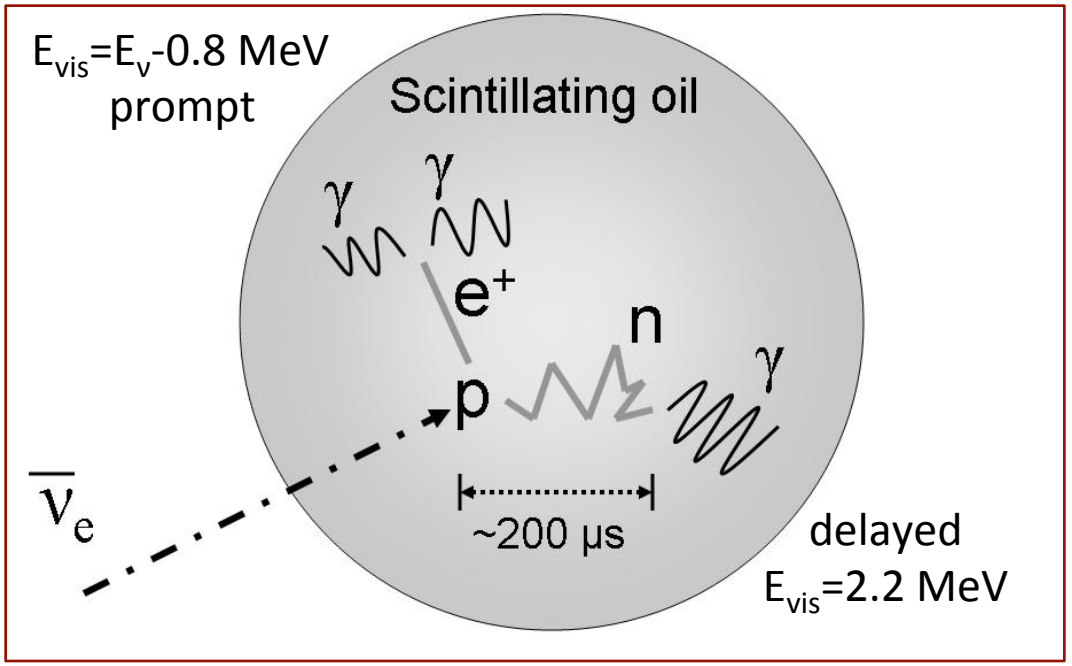
Production in reactors and natural decays



Reines & Cowan

Key: 2 flashes, close in space and time, 2nd of known energy, eliminate background

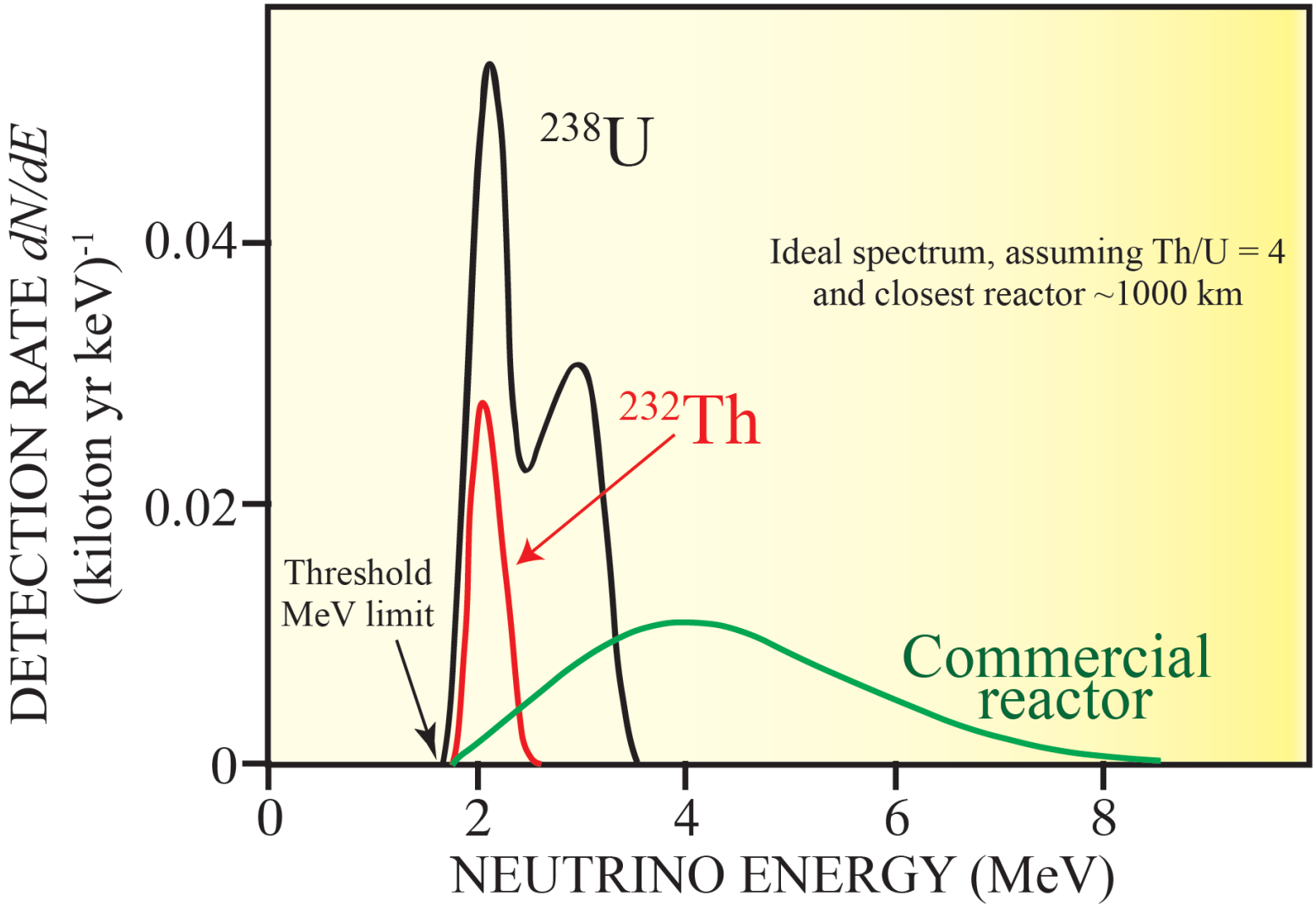
Detection



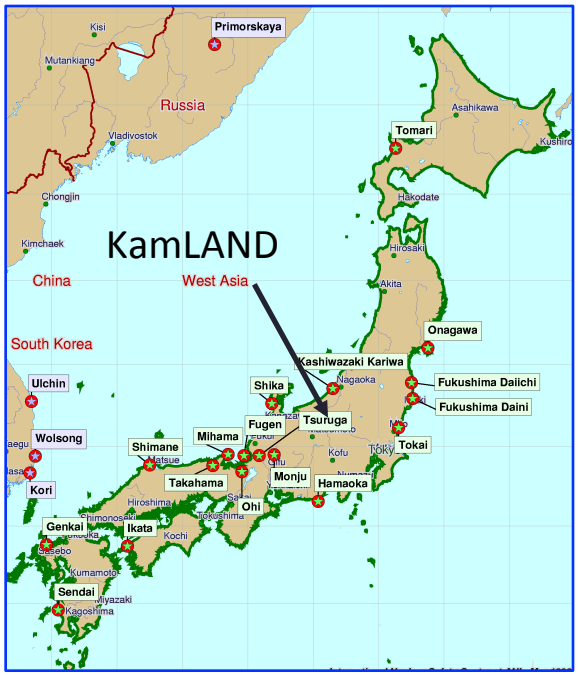
- Standard inverse β-decay coincidence
- $E_\nu > 1.8$ MeV
- Rate and spectrum - no direction

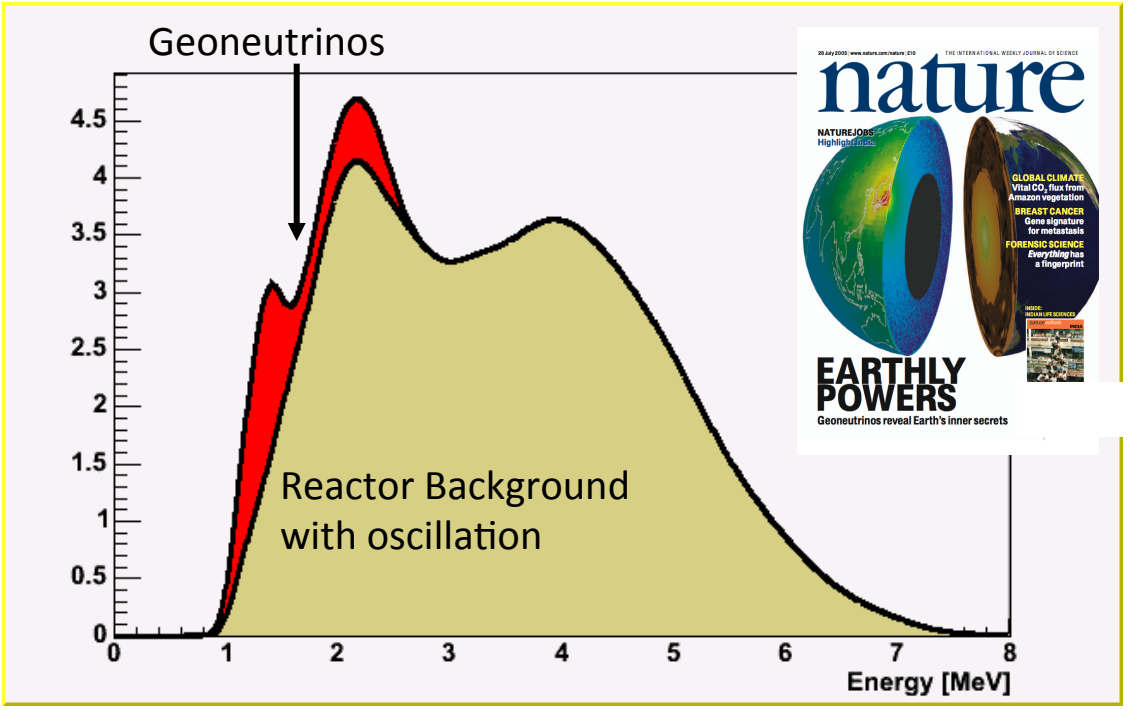
Antineutrinos - Geoneutrinos

$$\overline{\nu}_e + p^+ \longrightarrow n + e^+$$



Reactor and Earth Signal

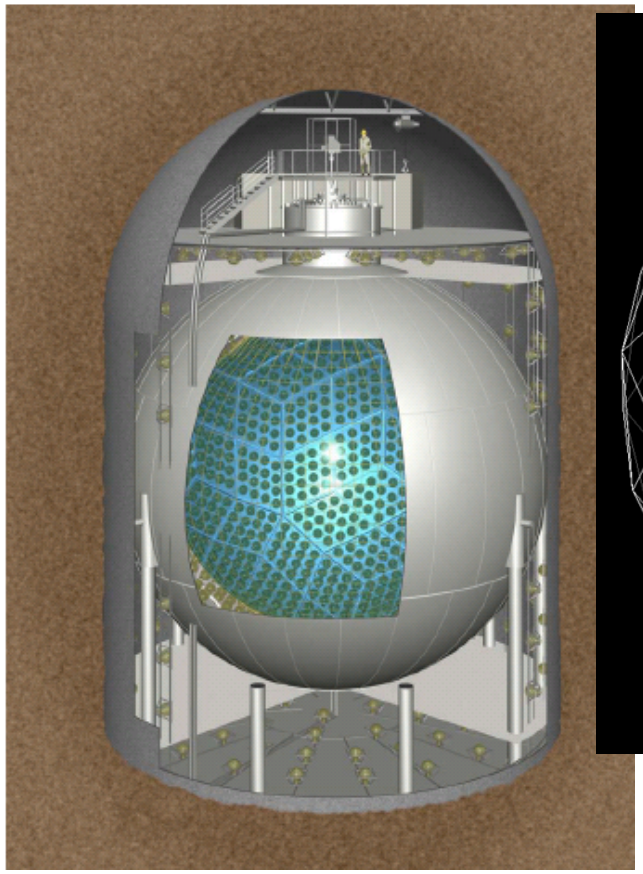




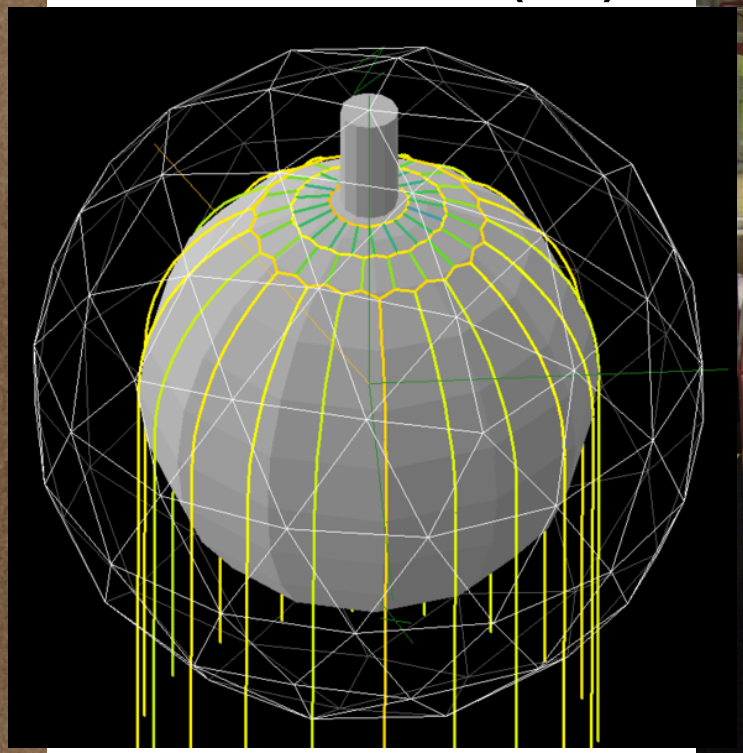
- KamLAND was designed to measure reactor antineutrinos.
- Reactor antineutrinos are the most significant contributor to the total signal.

Present Liquid Scintillator Detectors

KamLAND, Japan (1kt)

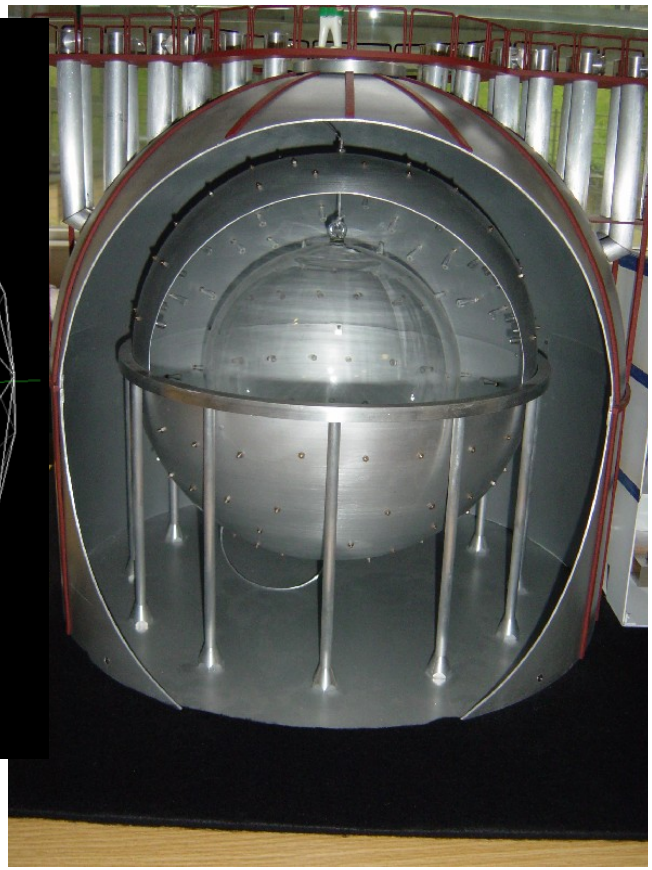


SNO+, Canada (1kt)



under construction
(online 2014?)

Borexino, Italy (0.3kt)



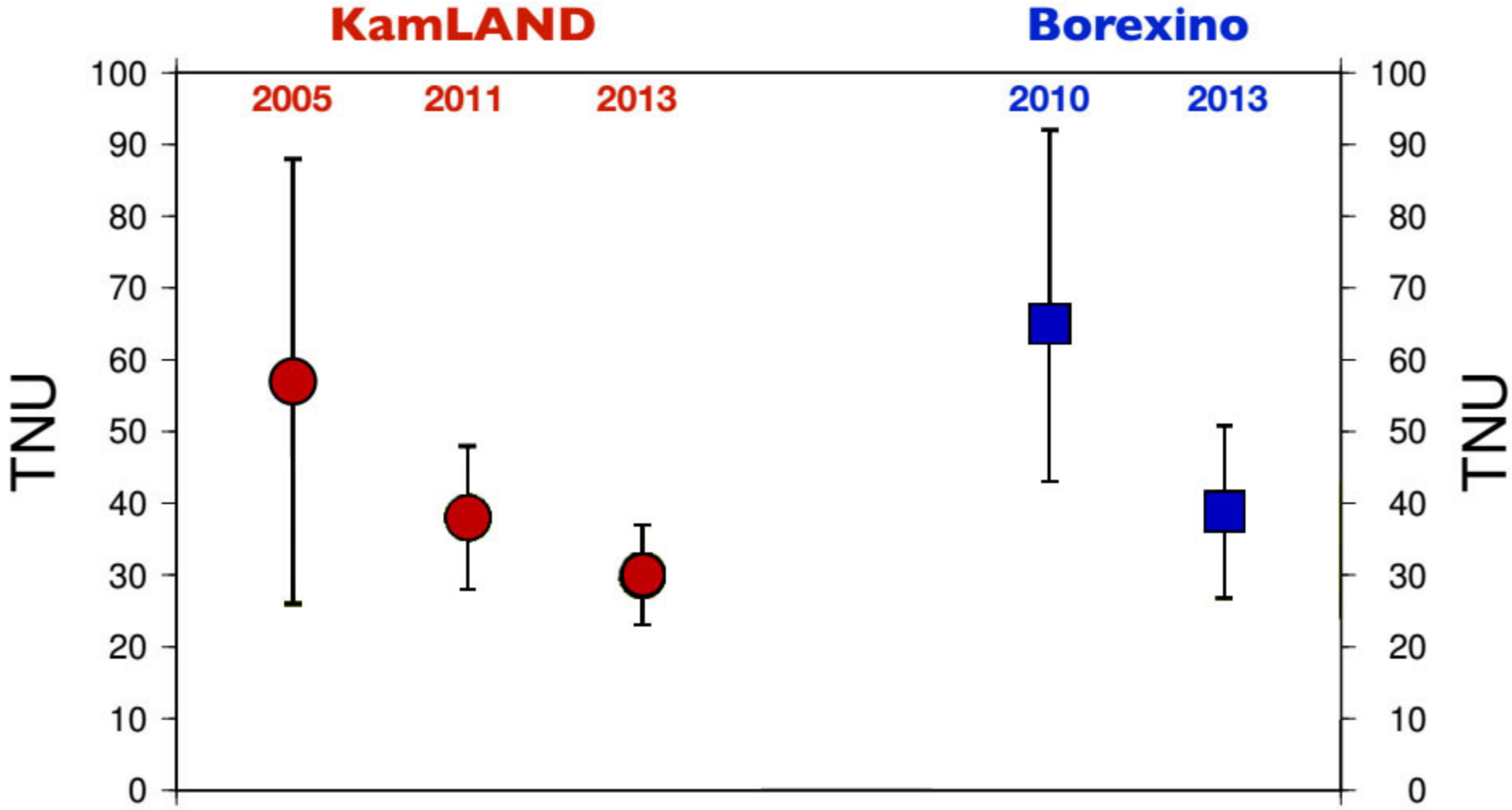
116^{+28}_{-27}

from Mar '02 to Nov '12

14.3 ± 4.4

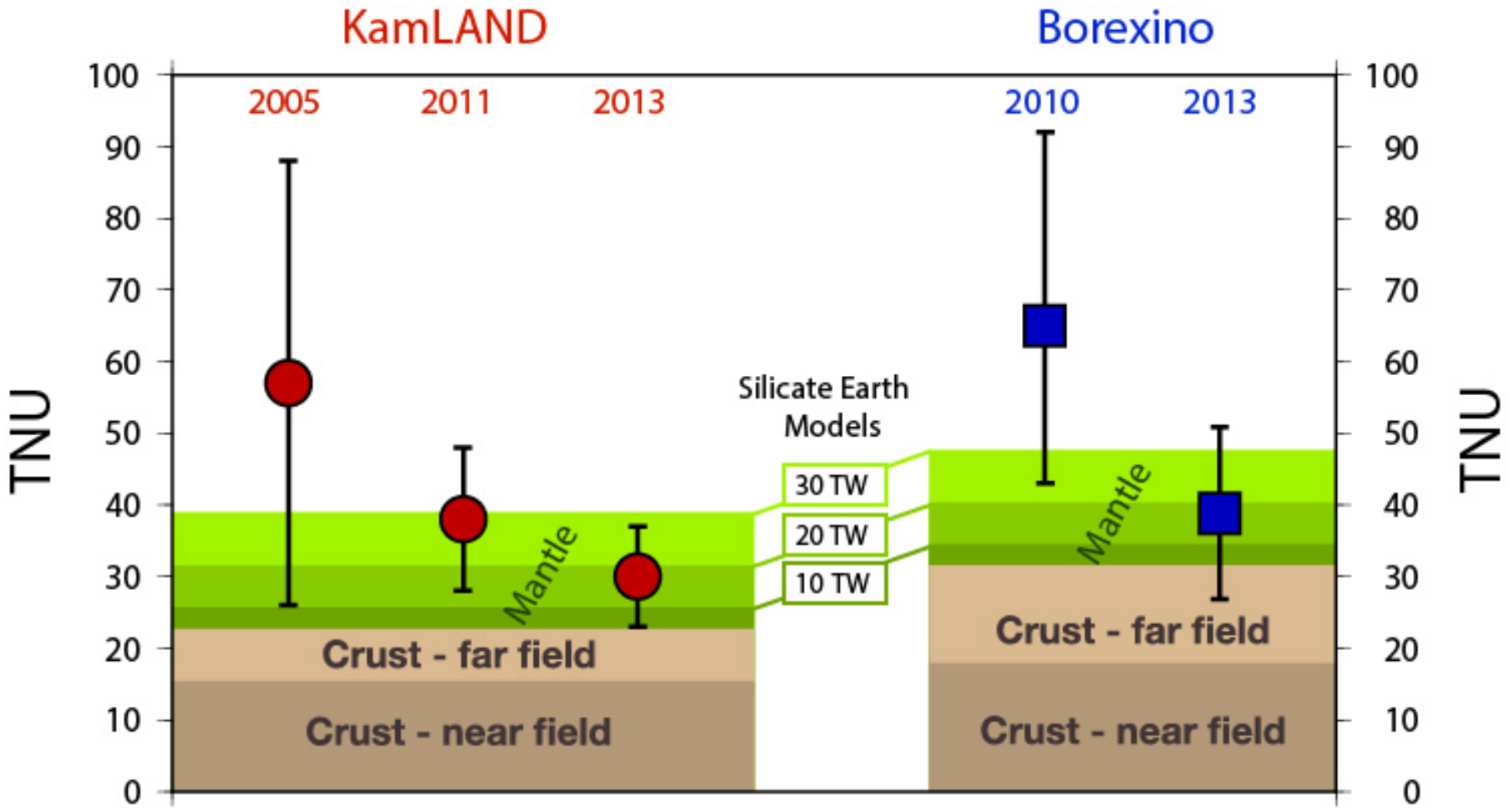
from Dec '07 to Aug '12

Can Physics Help Geoscience?



TNU: geo-n$\bar{\upsilon}$ event seen by a kiloton detector in a year

Summary of geoneutrino results



SILICATE EARTH MODELS

Cosmochemical: uses meteorites – 10 TW

Geochemical: uses terrestrial rocks –20 TW

Geodynamical: parameterized convection – 30 TW

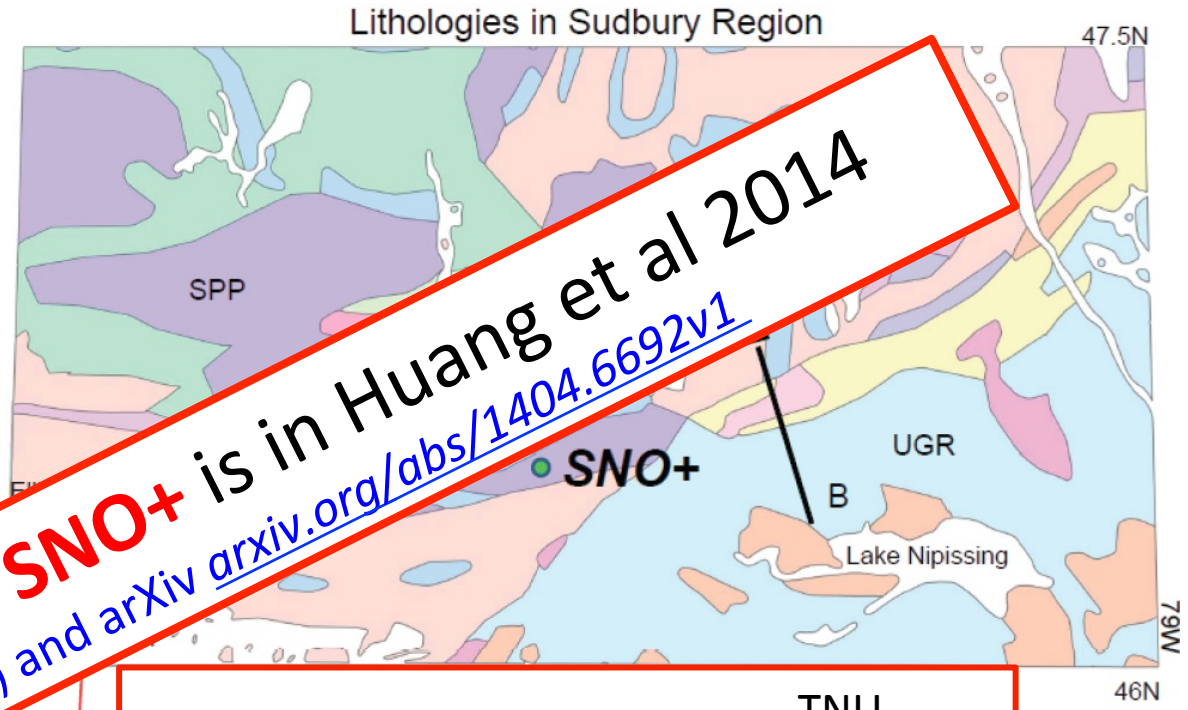
TW scales relative to U

10, 20, 30 TW ≈ 10, 20, 30 ppb

Estimating the geoneutrino flux at SNO+

- Geology
- Geophysi

Our prediction for **SNO+** is in Huang et al 2014 G-cubed (*in review*) and arXiv arxiv.org/abs/1404.6692v1

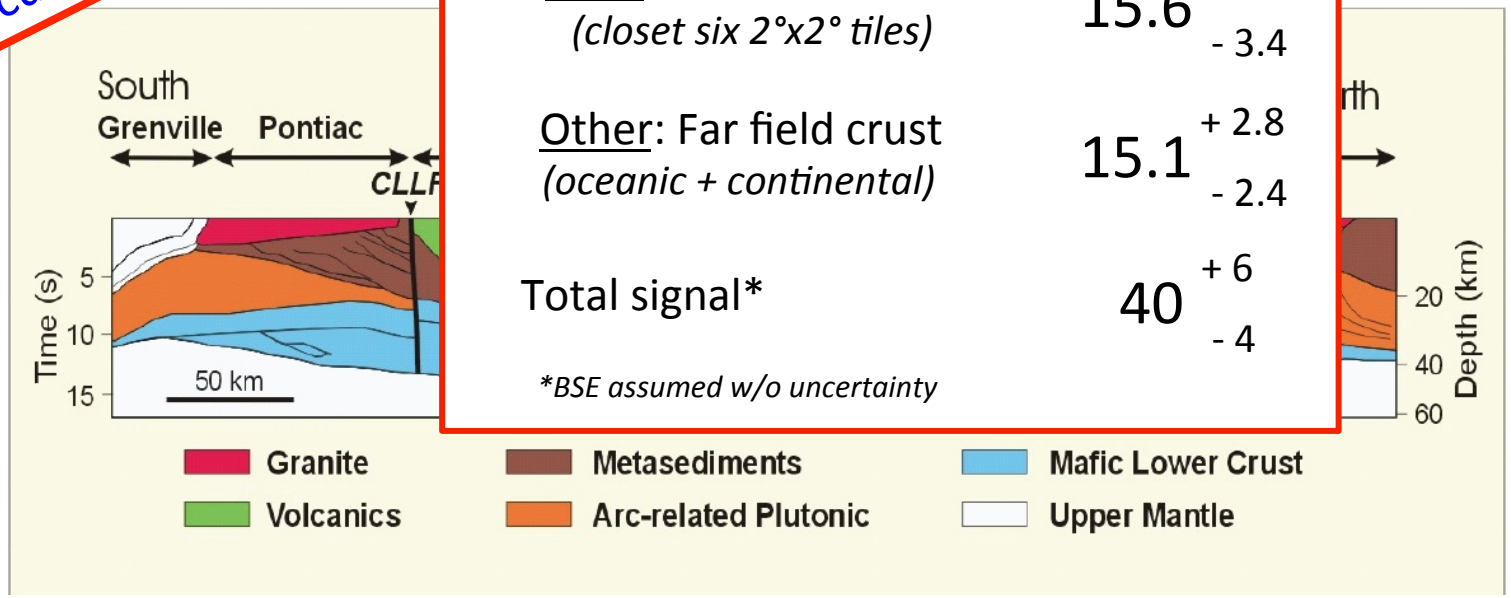


~800 ppm
mines

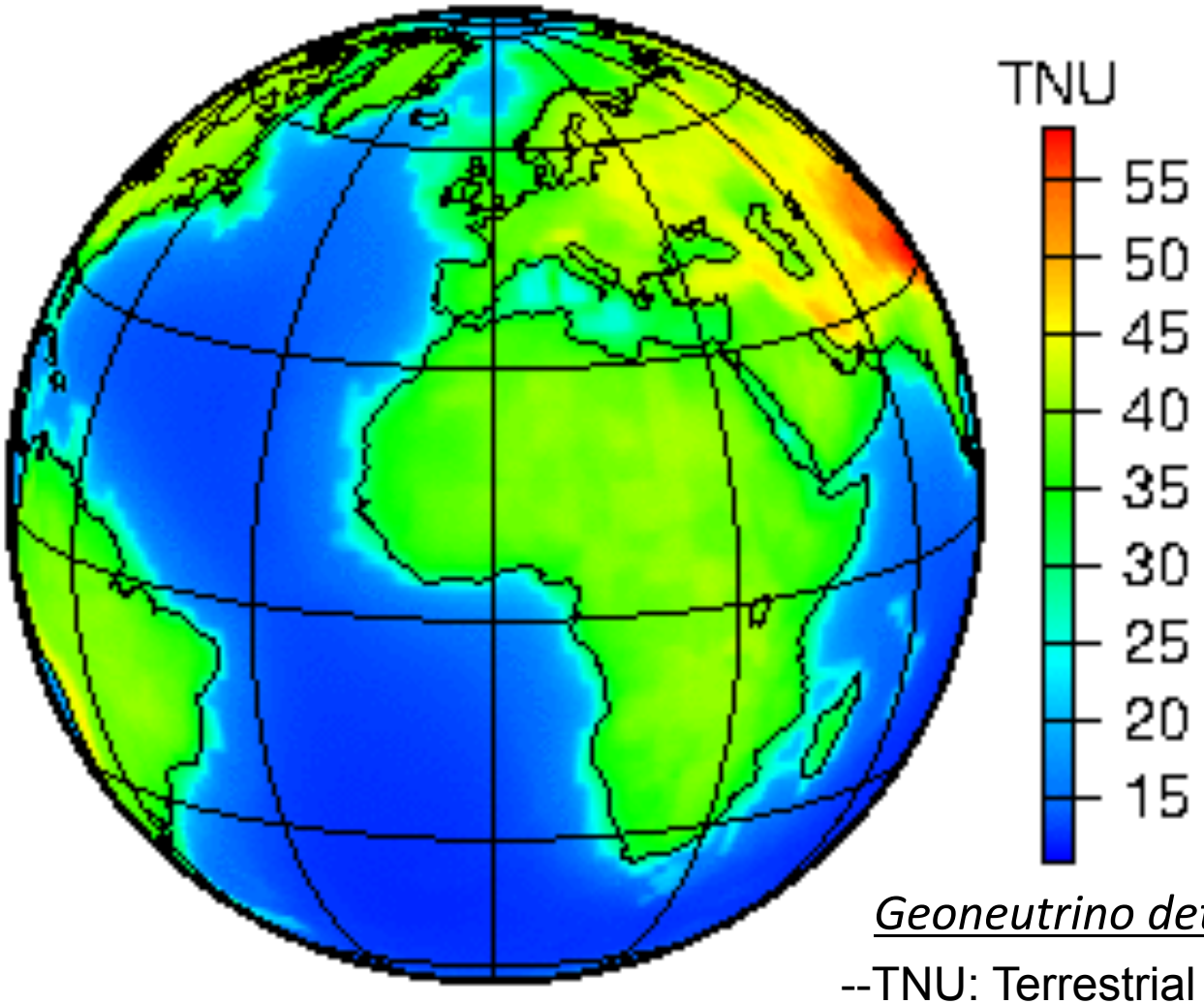
	TNU
Local: Near field crust *(closet six 2°x2° tiles)*	$15.6^{+5.3}_{-3.4}$
Other: Far field crust *(oceanic + continental)*	$15.1^{+2.8}_{-2.4}$
Total signal*	40^{+6}_{-4}

**BSE assumed w/o uncertainty*

seismic x-section



Predicted Global geoneutrino flux based on our new Reference Model

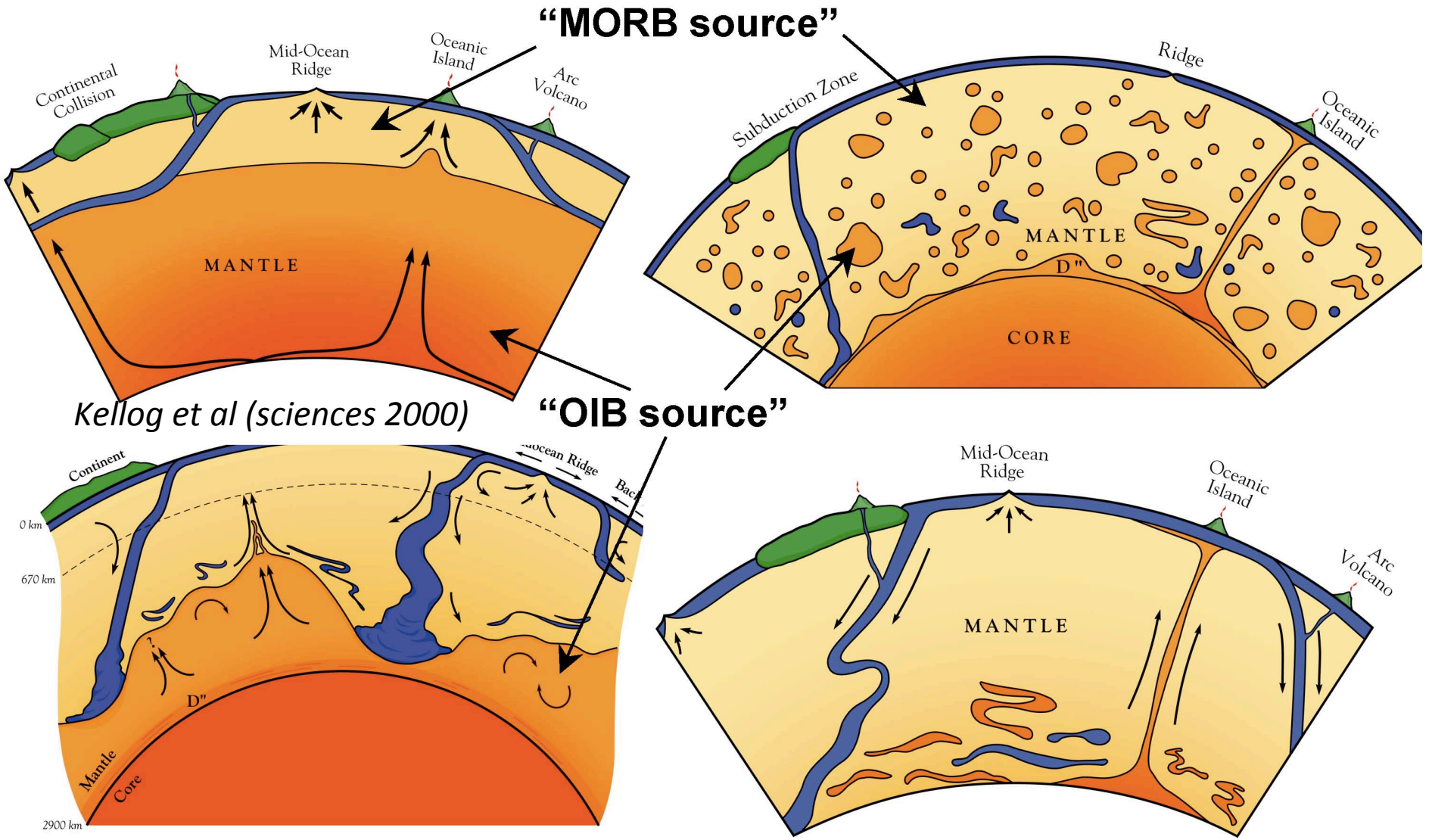


Huang et al (2013) G-cubed
arXiv:1301.0365 10.1002/ggge.20129

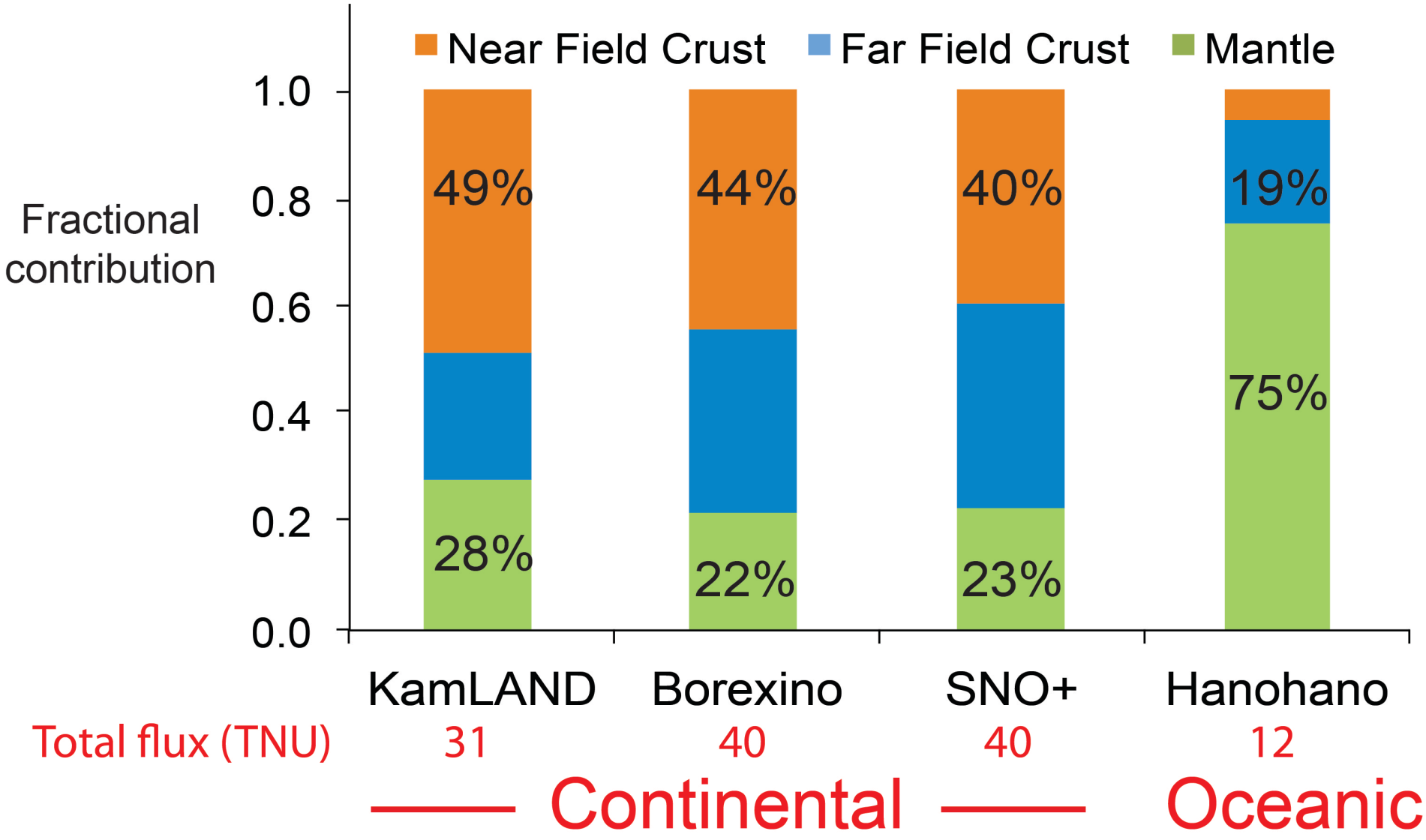
Geoneutrino detection rate

--TNU: Terrestrial Neutrino Unit
-- 1 TNU = one geoneutrino event per 10^{32} free protons per year

Early Earth differentiation followed by 4 billion years of plate tectonics



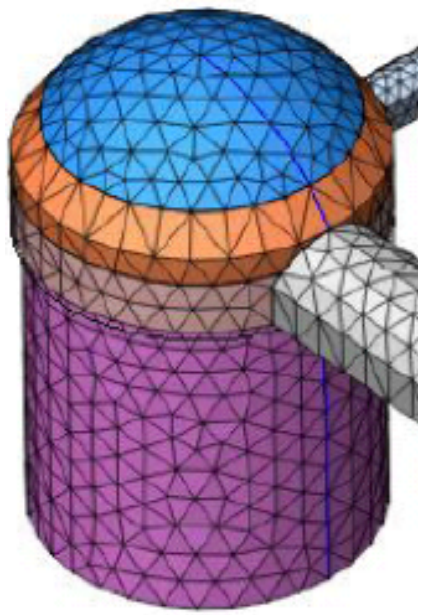
Geoneutrino contributions to detectors



Near Field: six closest 2° × 2° crustal voxels
Far Field = bulk crust – near field crust

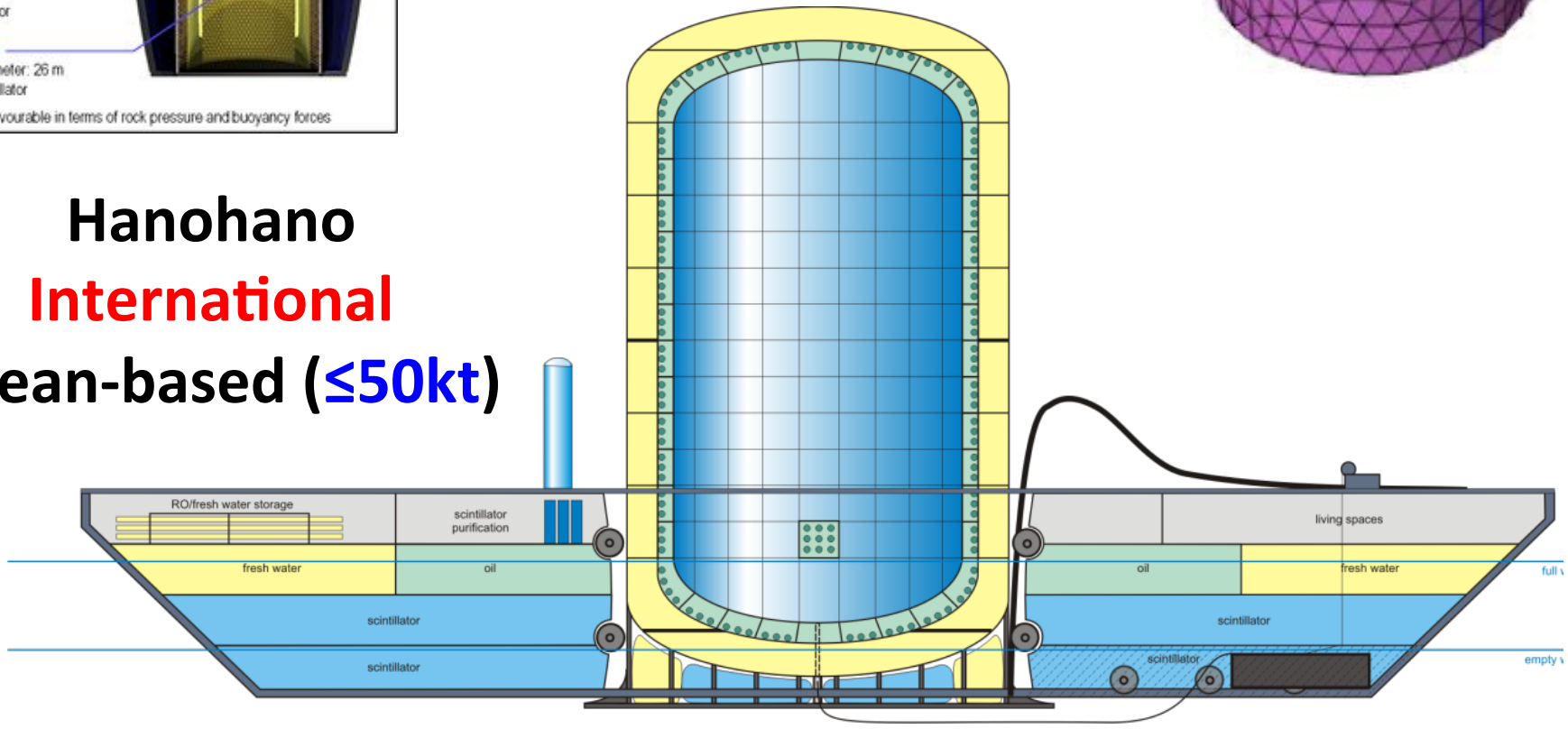
LENA, EU (50kt)

JUNO China (20kt)



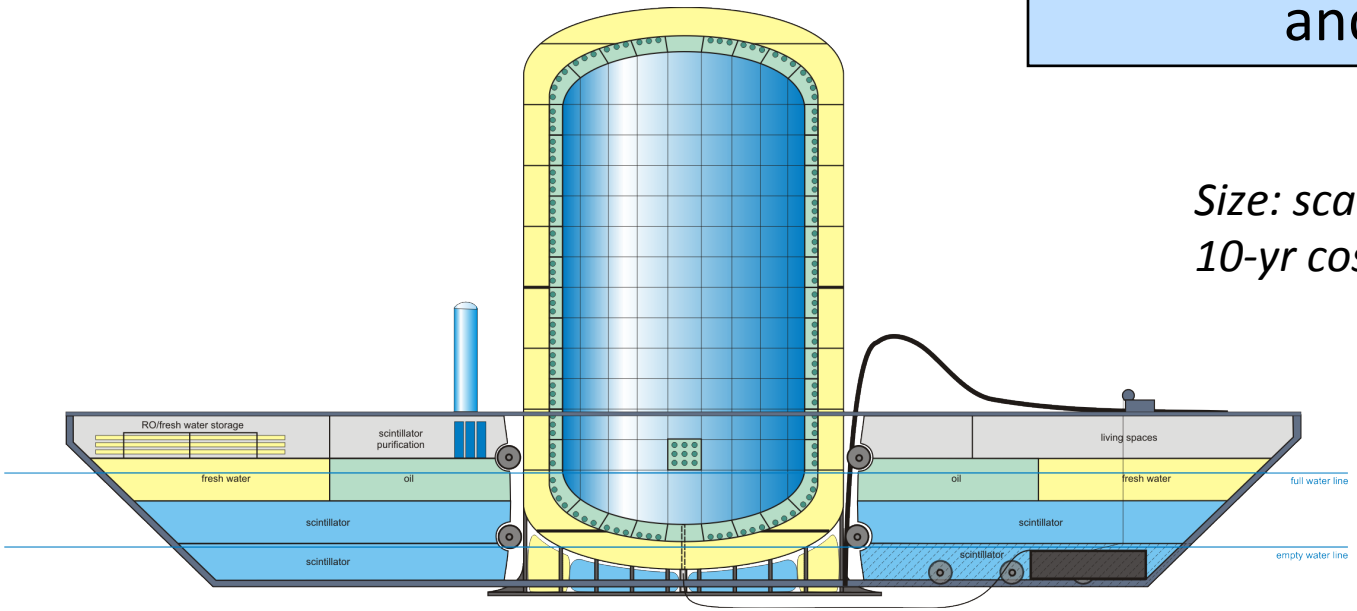
Future detectors?

Hanohano International ocean-based (≤50kt)



Hanohano

An experiment with joint interests in Physics, Geology, and Security

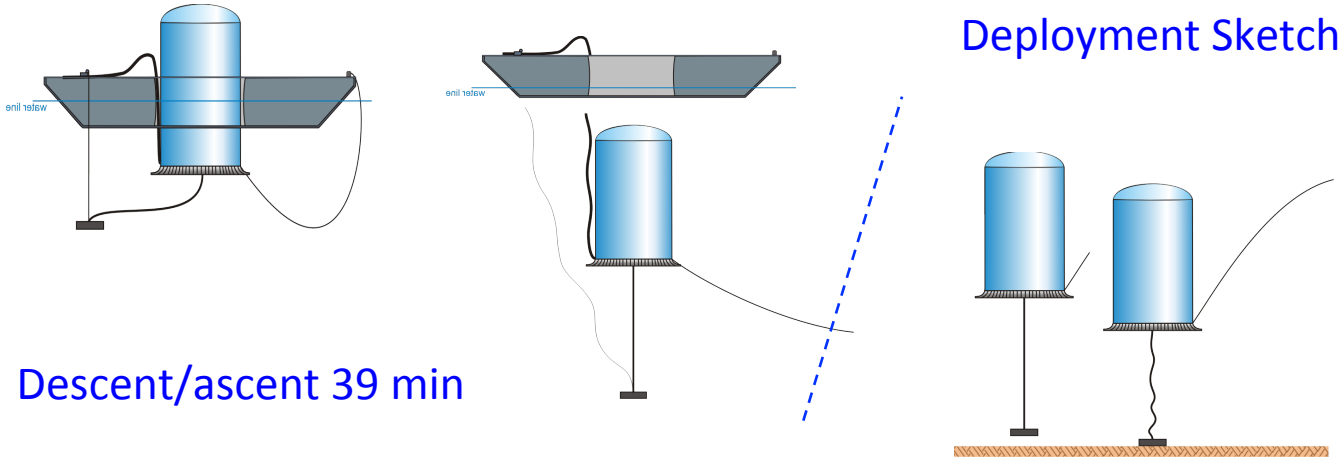


Size: scalable from 1 to 50 kT
10-yr cost est: $250M @ 10 kT

- multiple deployments
- deep water cosmic shield
- control-able L/E detection

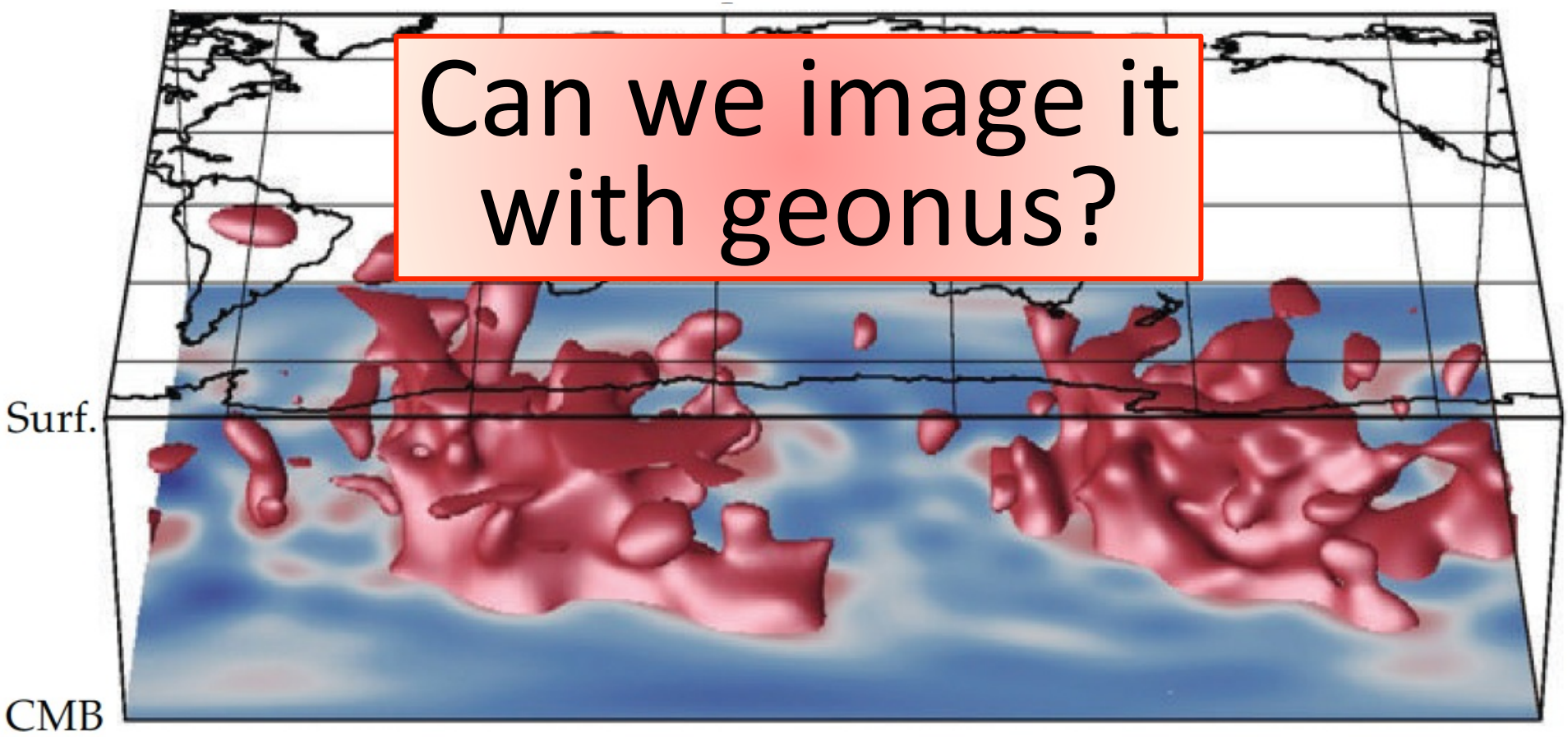
A Deep Ocean

$\overline{\nu}_e$ Electron Anti-Neutrino Observatory



What's hidden in the mantle?

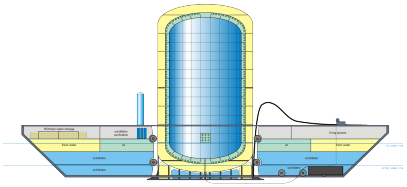
Seismically slow "red" regions in the deep mantle



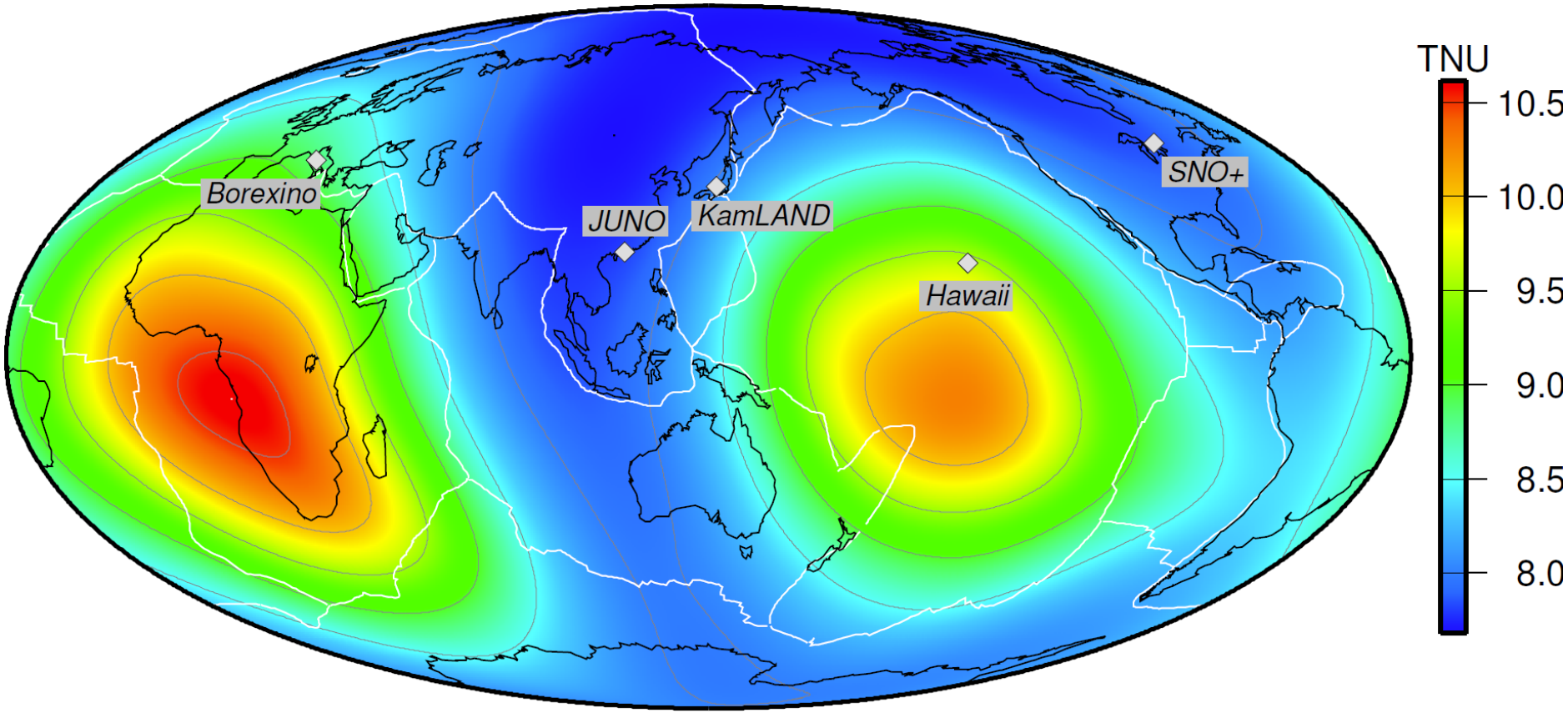
Can we image it with geonus?

Ritsema et al (Science, 1999)

Testing Earth Models

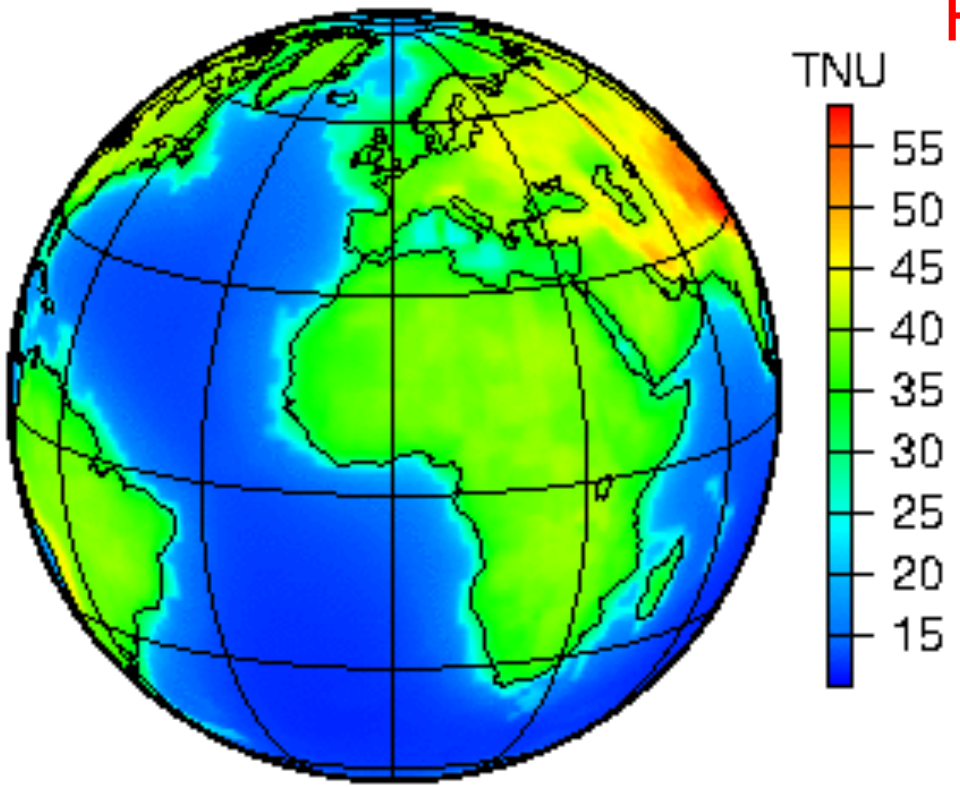


Mantle geoneutrino flux (^{238}U & ^{232}Th)



Šrámek et al (2013) EPSL 10.1016/j.epsl.2012.11.001; arXiv:1207.0853

Predicted geoneutrino flux



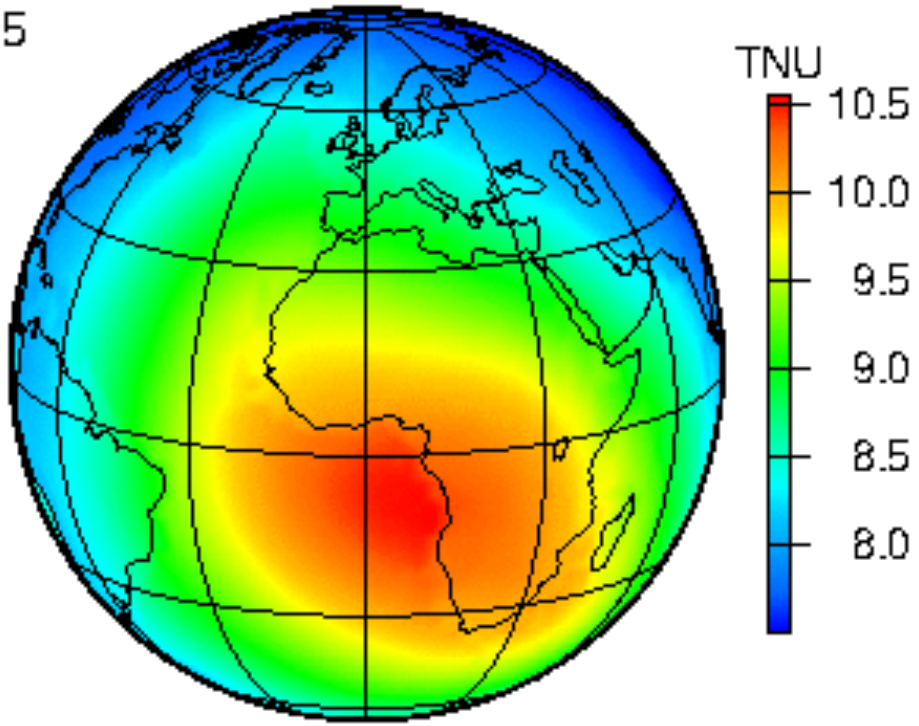
Total flux at surface

dominated by
Continental crust

Yu Huang et al (2013) G-cubed ***arXiv:1301.0365***
10.1002/ggge.20129

Mantle flux at the Earth's surface

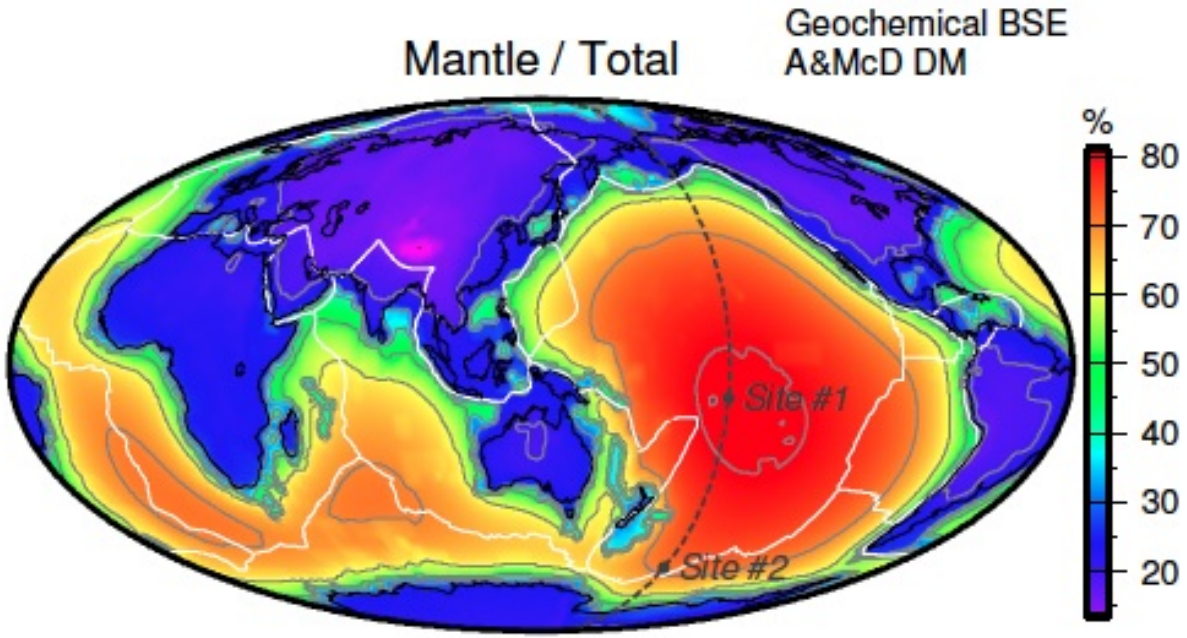
dominated by
deep mantle structures

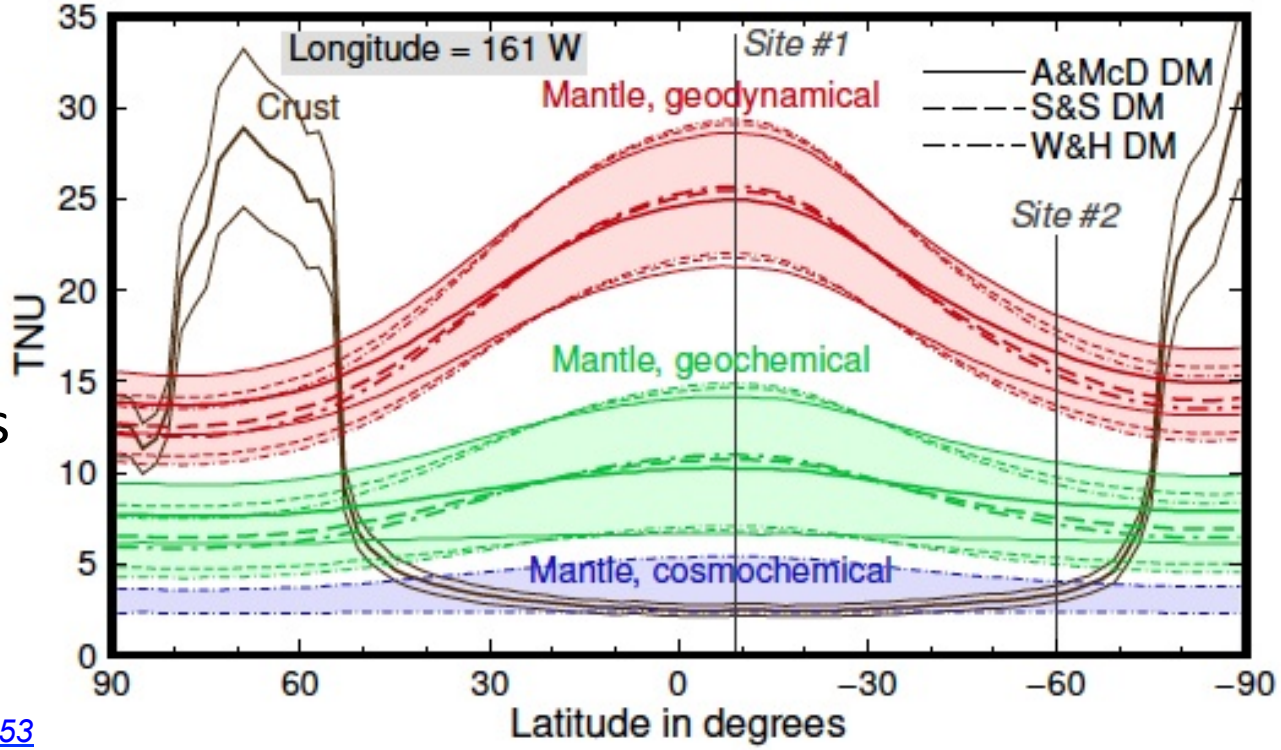


Šrámek et al (2013) EPSL 10.1016/j.epsl.2012.11.001; arXiv:1207.0853

Ocean based experiment!

- Neutrino Tomography… ☺
- Pacific Transect
- Avoid continents
- 4 km depth deployments
- Map out the Earth's interior
- Test the models





Šrámek et al (2013) EPSL arXiv:1207.0853

SUMMARY

Earth's radiogenic (Th & U) power

22 ± 12 TW - Borexino **11.2** $^{+\,7.9}_{-\,5.1}$ **TW** - KamLAND

Prediction: models range from **8 to 28 TW** (for Th & U)

On-line and next generation experiments:

- SNO+ to come online in 2014 ☺
- **JUNO**: great experiment, big bkgd, geonu application…
- Hanohano: **FUNDAMENTAL** for geosciences

Geology must participate & contribute to the cost

Future:

- Neutrino Tomography of the Earth's deep interior ☺

Geoneutrinos: ongoing efforts and wish list

- Directionality
- ^{40}K geonus
- Detecting hidden objects in the Earth

Out-reach efforts

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Geoneutrino

From Wikipedia, the free encyclopedia

Geoneutrino is an electron antineutrino emitted in β^- decay of a radionuclide naturally occurring in the Earth. Neutrinos are the lightest of the known subatomic particles. They lack measurable electromagnetic properties and dominantly interact via the weak nuclear force. Matter is virtually transparent to neutrinos and consequently they travel, unimpeded, at near light speed through the Earth from their point of emission. Collectively geoneutrinos carry the integrated information about the abundances of their radioactive sources inside the Earth. Extracting a geologically useful information (e.g., abundances of individual geoneutrino producing elements and their spatial distribution in Earth's interior) from geoneutrino measurements is a major objective of the emerging field of ***neutrino geophysics***.

Most geoneutrinos originate from β^- decay branches of ^{40}K, ^{232}Th and ^{238}U. Together these decay chains account for more than 99% of the present day radiogenic heat generated inside the Earth. Only geoneutrinos from ^{232}Th and ^{238}U decay chains are detectable by the inverse beta decay mechanism because these have the highest energies, i.e., >1.8 MeV (megaelectronvolts), the energy needed to transform a proton into a neutron and a positron. The flashes of light generated from this interaction are recorded by large underground liquid scintillator detectors of neutrino experiments. To date, geoneutrino measurements at two sites, as reported by the KamLAND and Borexino collaborations, begin to place constraints on the

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Contents
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Random article
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About Wikipedia
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Recent changes
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