Hanohano
Hawaii Anti-Neutrino Observatory

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Outline

- Project overview
- Geo-neutrino sensitivity
  - Observation of geo-nu flux
  - Measurement of mantle flux
  - Estimating global U and Th content
- Geo-reactor sensitivity
- Summary

Hanohano- Deep Ocean Anti-Neutrino Observatory

Presented by
S.T. Dye
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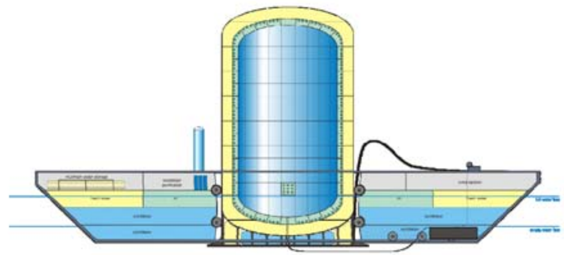
With lots of help from colleagues- several here at Nu08

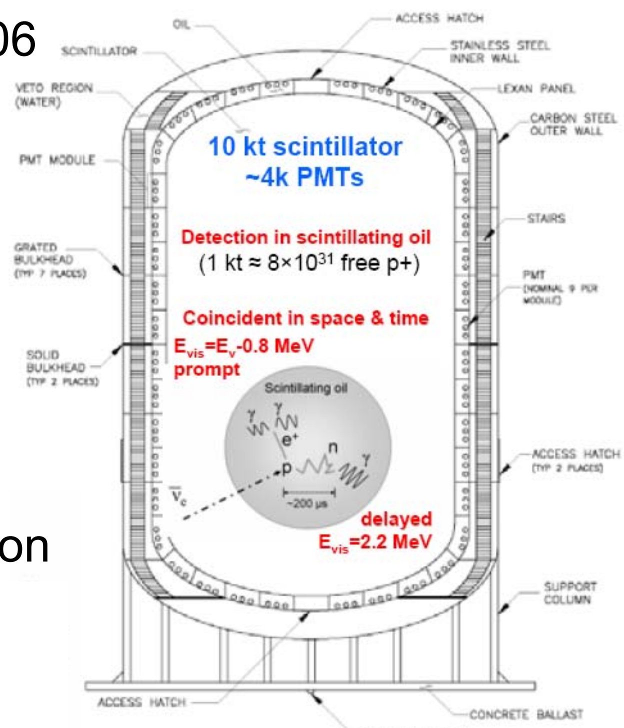


Project Overview

- portable 10 kt scintillator
- deploy and recover
- site determines science
- project cost >$100M, operate >10y
- international collaboration of ~100
- design study completed 2006

Detector Design

- 10-kt scintillator
- inverse-beta coincidence
- 2-m H_2O veto,1-m oil buffer
- 10” PMTs in glass spheres
- carbon steel outer tank
- SS inner tank
- volume change compensation
- power <5 kW
- data rate few Gb/s



Custom Barge

- tow to any ocean
- 10m draft, fits harbors
- onboard
  - oil purification
  - RO water
  - detector support
- detector to 100 kt
- 9 kt max to fit Panama

Deployment/Recovery

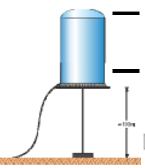
- tow to site, transfer fluids
- lower anchor, pass cable
- release anchor, fill hoses
- descent rate ~100 m/min
- take data for year or more
- max depth 6700 m
- release anchor to recover
- ascent rate ~100 m/min

Hanohano- Particle Physics & Geo/Astro Studies

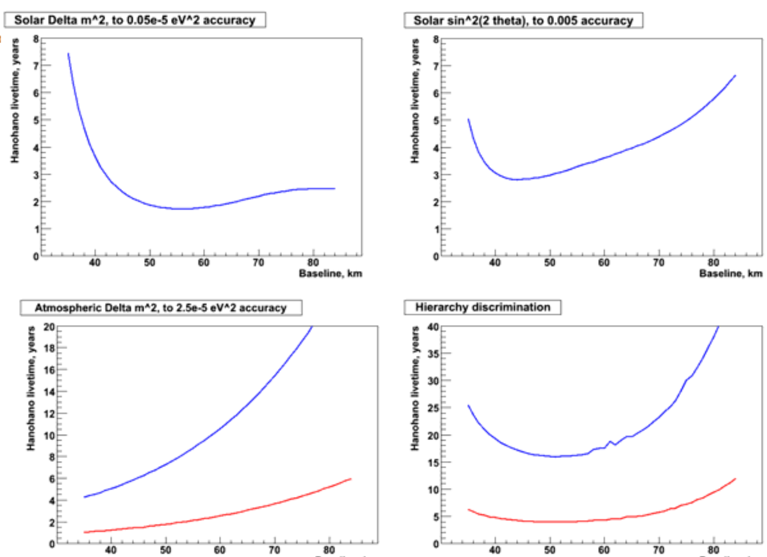
Reactor Site: Neutrino Parameters

Precision measurements in several years!

- optimum baseline ~50-60 km
- 5-6 GW sites available with 1-3 km depth
- need study of overburden requirement
- analysis w/ systematics- M. Batygov (UH)
- solar- Δm^2_{21}, $\sin^2(2\theta_{12})$ to ~1% in 2y, 4y
- if $\sin^2(2\theta_{13})>0.05$, then
  - Δm^2_{31} to ~1% in 2y
  - mass hierarchy in 5y



P=5 GW, $\delta E=2.5\%/\sqrt{E}$



Plots by M. Batygov, UH

Deep Ocean Site: Geo-nu & Solar-nu

Geo-neutrino measurements

- study origin, composition, distribution P_{earth}
- 3-4 km depth to filter cosmic ray muons
- measure mantle geo-nus to 25% in 1y
- synergy with continental observations
- sensitive test of geo-reactor hypothesis

Solar-neutrino measurements

- *pep* and CNO solar neutrinos
  - >4 km depth for signal/noise>1
  - 55,000 events/y
  - probe vacuum/matter transition, NSI

All Sites: SN and proton decay search

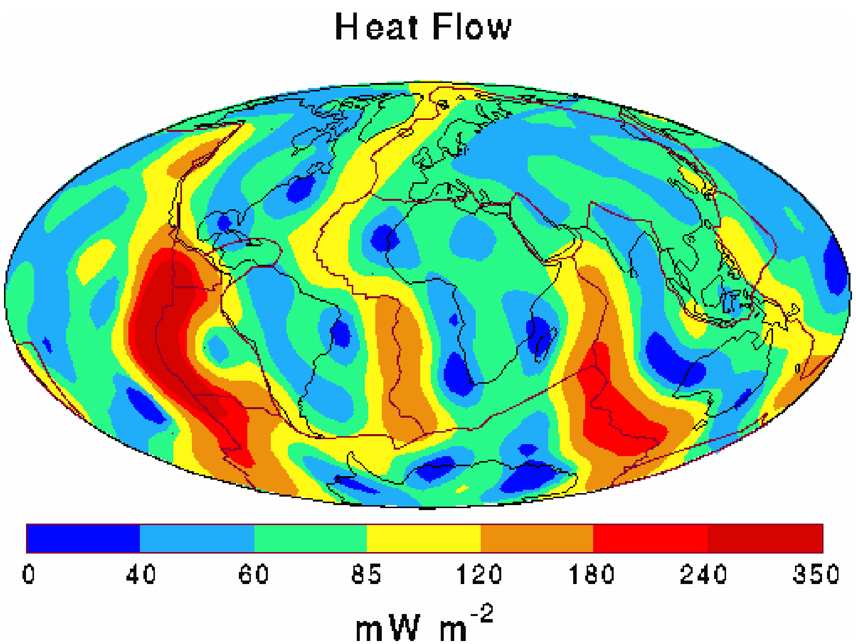
Supernova neutrino measurements

- standard galactic core collapse SN
  - ~5000 CC & NC events in 10 s
  - measure SN & neutrino parameters
- observe relic SN neutrinos 1-4/y (DSNB)

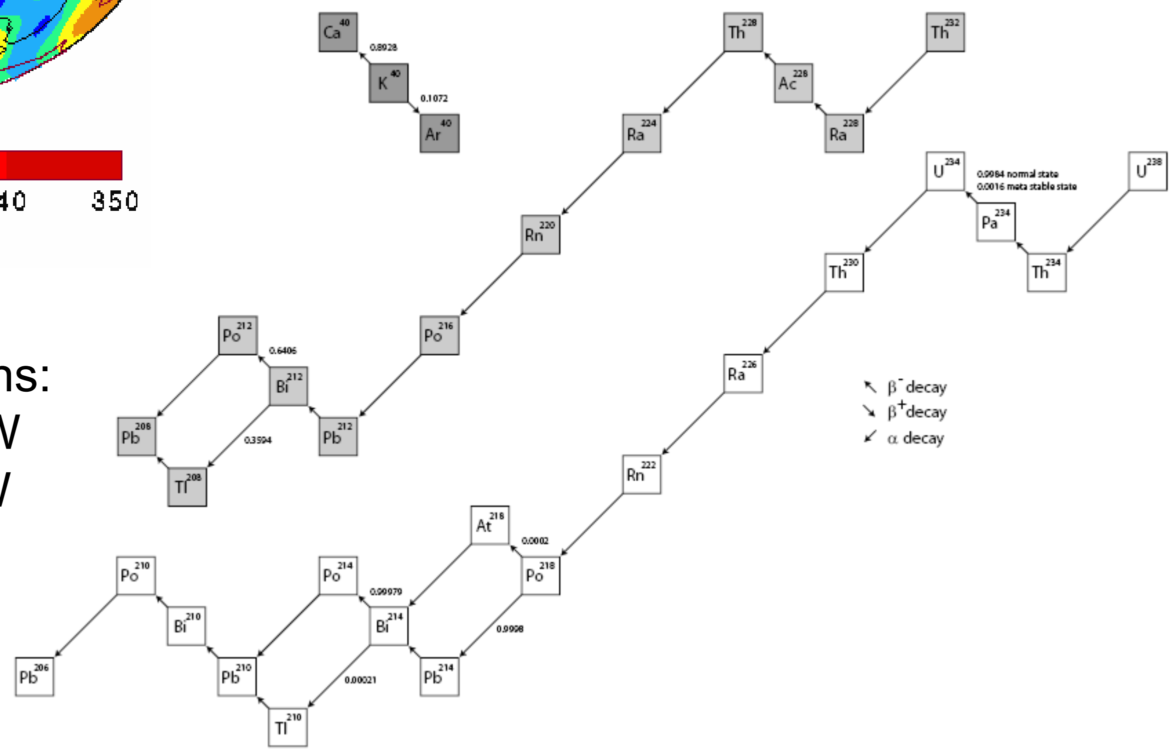
SUSY proton decay search- GUT test

- $p\rightarrow\nu K^+$, $\tau/B>10^{34}$y w/ 10-y exposure

Radiogenic contribution to heat flow

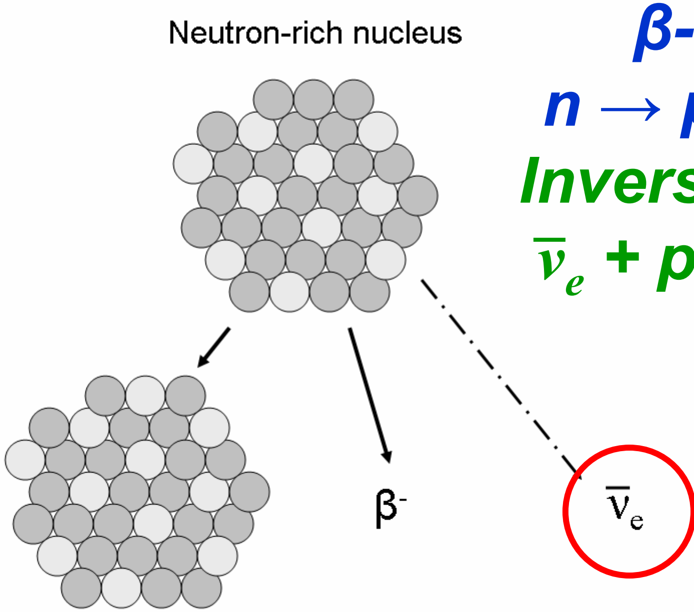


Current geological estimate
Uranium-238 → 8 TW
Thorium-232 → 8 TW
Potassium-40 → 3 TW
Total



Surface heat flow interpretations:
Conventional view- 46 ± 3 TW
Recent challenge- 33 ± 1 TW

Making and detecting geo-neutrinos



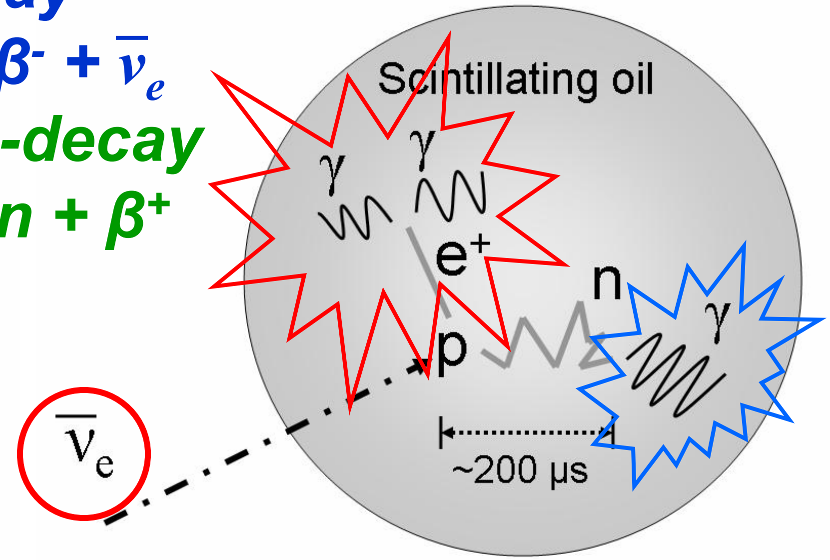
Nucleus with one more proton and one less neutron

β-decay

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

Inverse β-decay

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



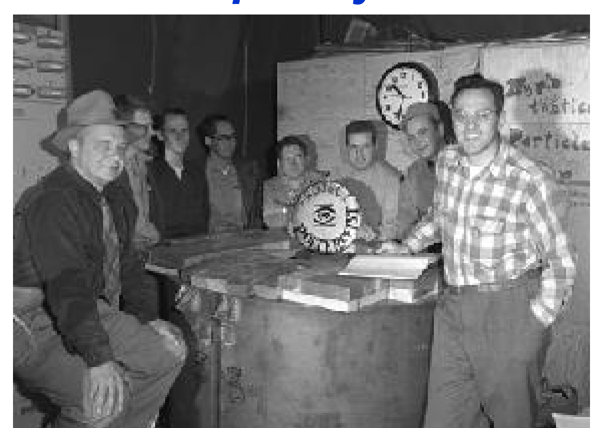
Flux and spectrum only direction poorly resolved

Long-lived terrestrial isotopes

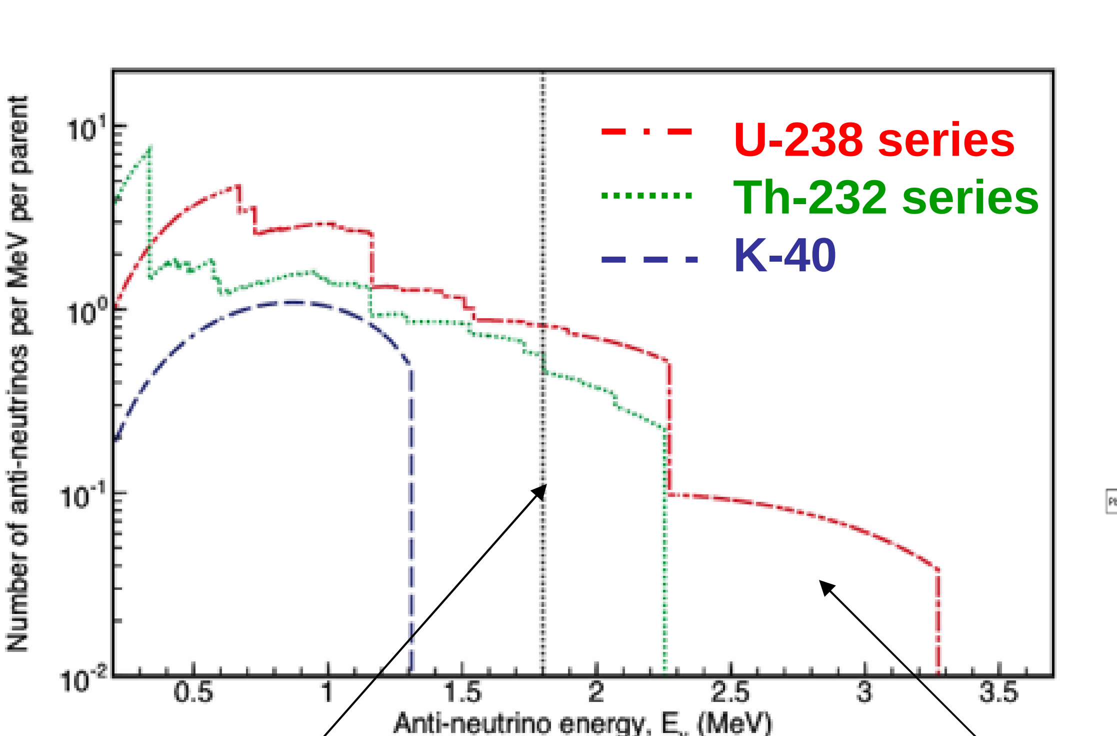
$^{238}U \rightarrow {}^{206}Pb + 8\alpha + 6\beta^- + 6\bar{\nu}_e$

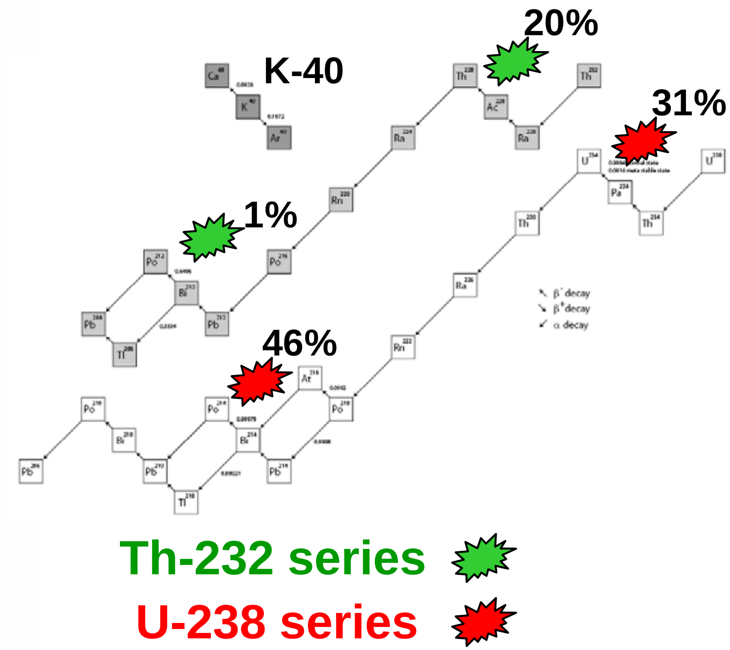
$^{232}Th \rightarrow {}^{208}Pb + 6\alpha + 4\beta^- + 4\bar{\nu}_e$

$^{40}K \rightarrow {}^{40}Ca + \beta^- + \bar{\nu}_e$



Terrestrial antineutrino spectrum





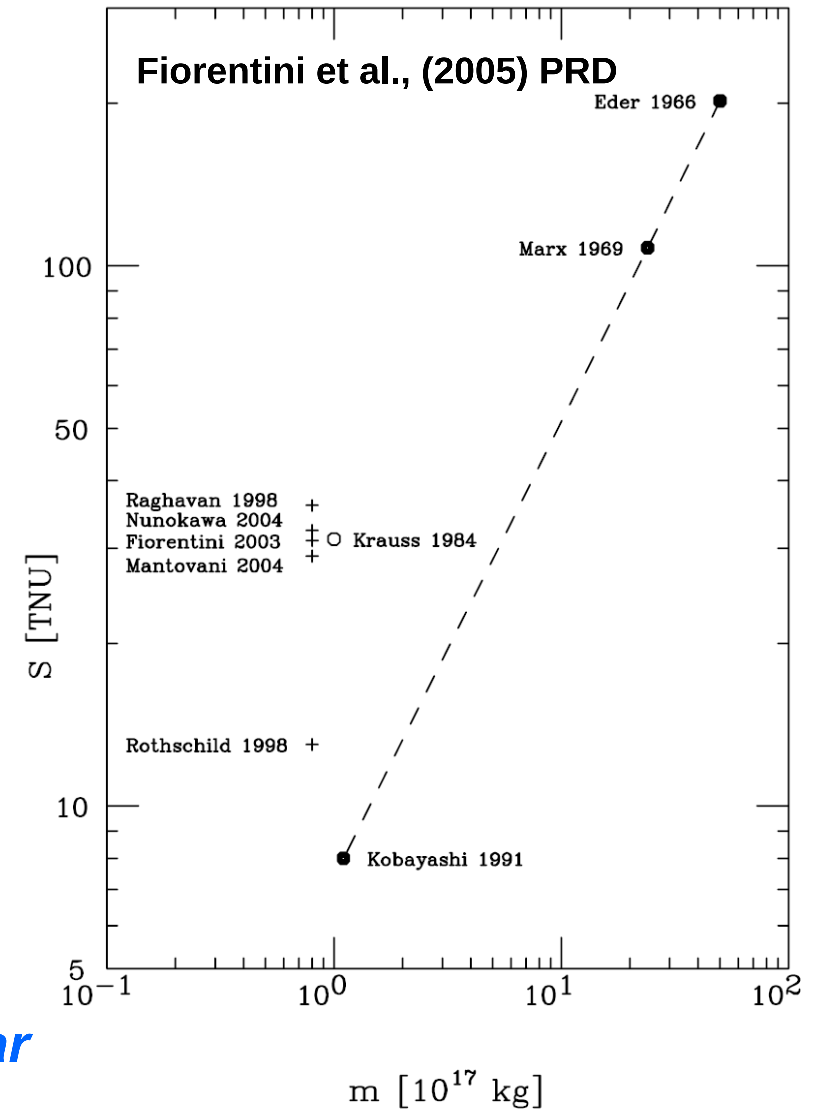
1.8 MeV threshold

Key spectral feature: E_ν > 2.3 MeV due to U-238 series only, allowing separate measurement of Φ_U and Φ_{Th}

potassium geo-neutrinos require new technique

Geo-neutrinos: a brief history

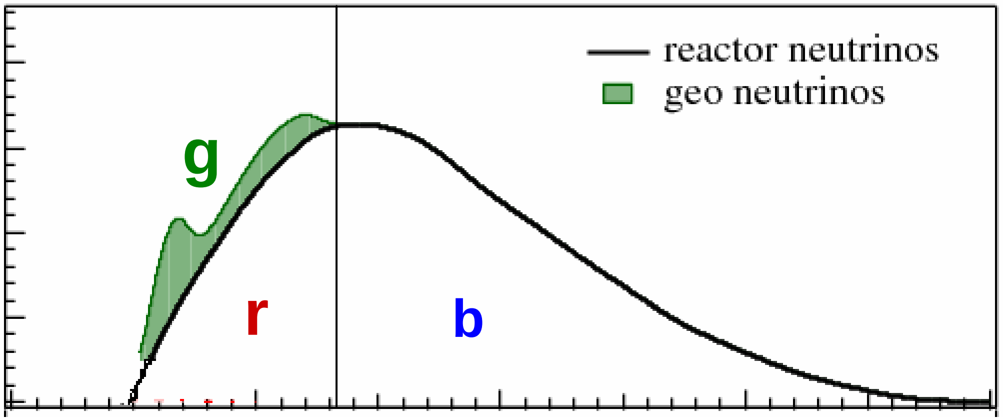
Predictions	Observations
1954 Gamow, Reines	2002 KamLAND
1966 Eder	2007 Borexino
1969 Marx	2010? SNO+
1984 Krauss et al.	201? Hanohano
1991 Kobayashi	201? Homestake
1998 Raghavan et al.	201? Baksan
1998 Rothschild et al.	202? LENA
2003 Fiorentini et al.	20?? EARTH
2003 Nunokawa et al.	
2004 Mantovani et al.	
2007 Enomoto et al.	



1 TNU = 1 event per 10^{32} protons per year

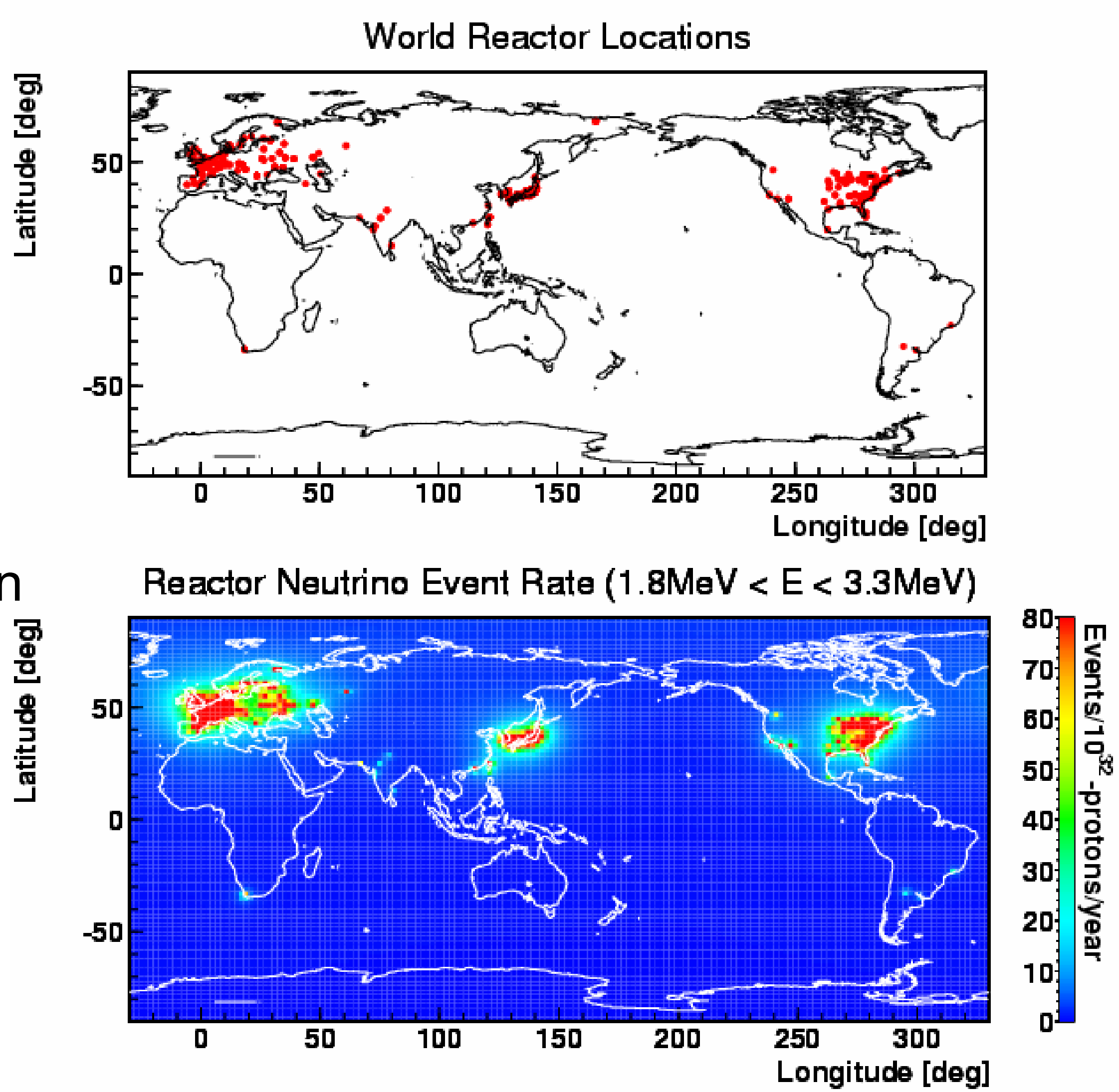
Geo-neutrino flux sensitivity

- Signal from U-series, Th-series, **g**
- Background only from reactors, **r**
  - No accidentals, α,n, cosmogenics
- Measure event total
  - $\mathbf{n}=\mathbf{g}+\mathbf{r}$
- Poisson statistics
- Signal uncertainty
  - $\delta\mathbf{g}=\sqrt{[(\delta\mathbf{n})^2+(\delta\mathbf{r})^2]}$
    $=\sqrt{[\mathbf{g}+\mathbf{r}(1+f)]}$
- $f \approx 0.35$



Reactor antineutrino background

- Energy spectrum overlaps geo-neutrinos
- Flux can be minimized but not eliminated
  - Location-location-location
- Can only to grow as more and more nuclear power plants operate

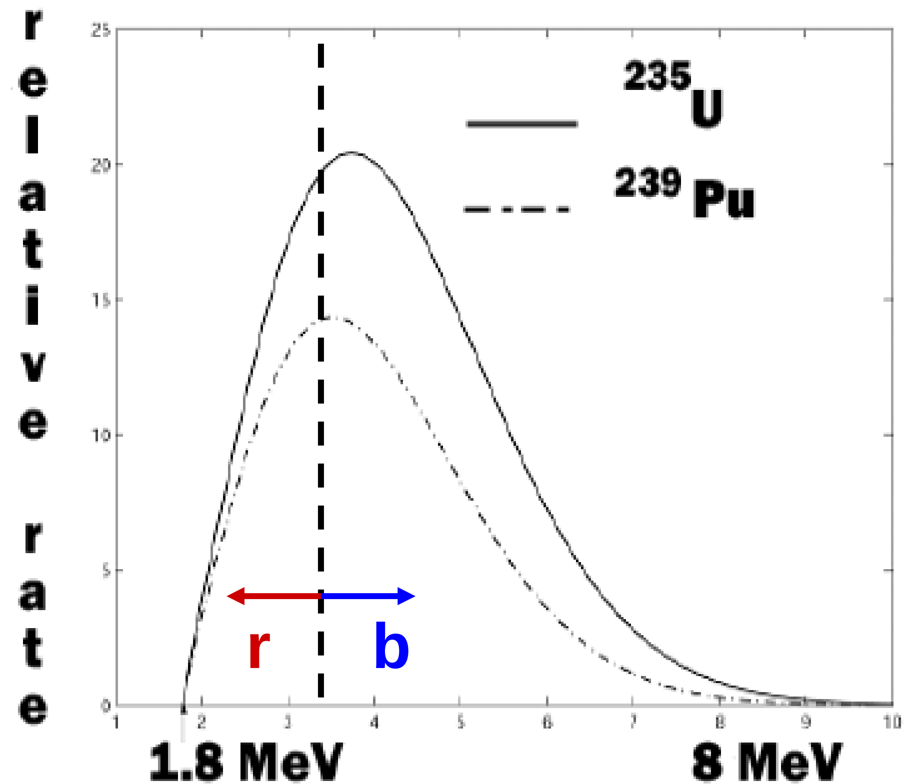


Enomoto plots- Neutrino Sciences 2007

Background from reactors

- Total number of background events is N_r = **r**+**b**
- Estimate number events (**r**) with $1.8 < E_\nu < 3.3$ MeV from number events (**b**) with $E_\nu > 3.3$ MeV
- **r** ≈ 0.35**b**, δ**r** = 0.35√**b**
- Oscillations distort this event ratio only for nearby reactors- not a problem for Hanohano
- Need more careful calculation for SNO+, KL

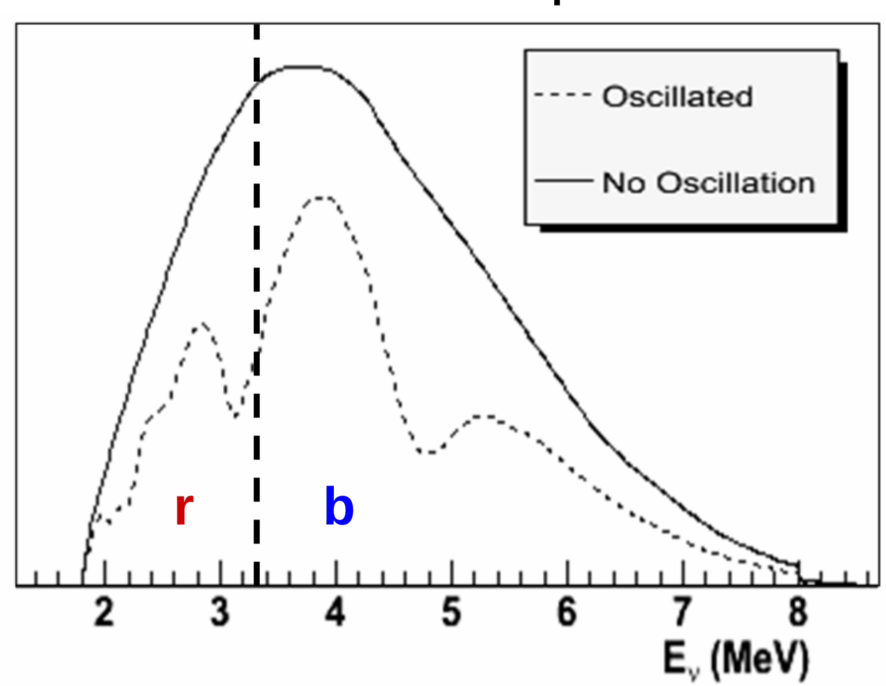
Reactor event spectrum



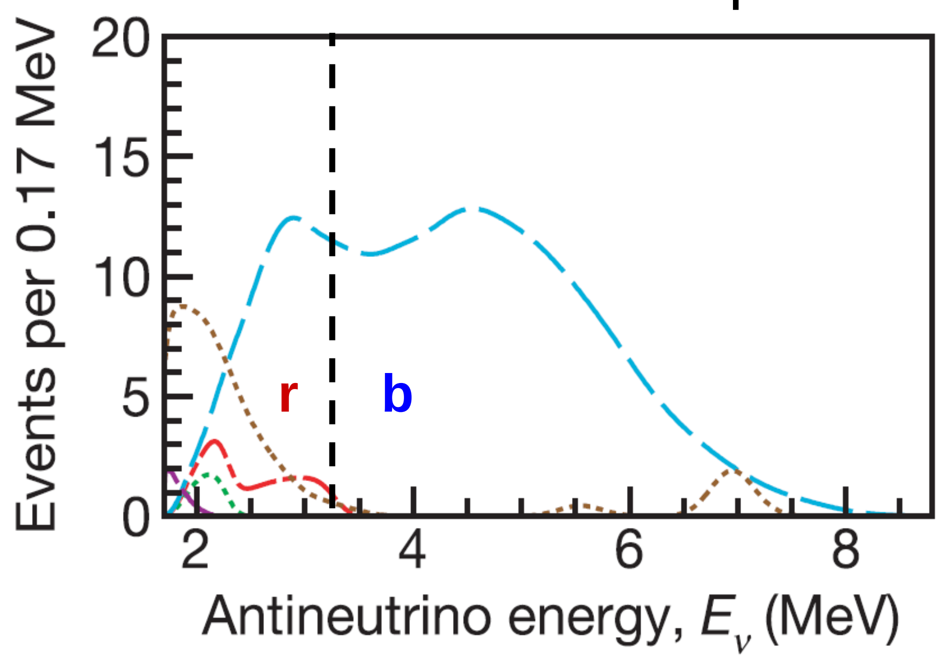
Distortion of reactor spectrum from oscillations

r ~ 0.35b?
Requires confirmation

SNO+ reactor spectrum



KamLAND reactor spectrum



Signal from geo-neutrinos

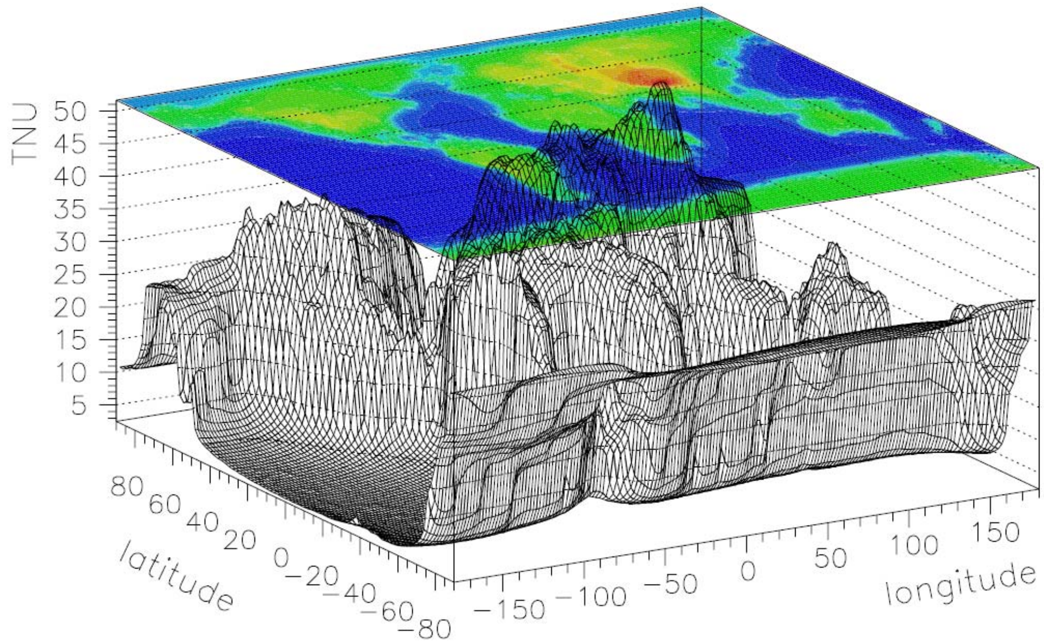
- Crust
  - CRUST 2.0

Bassin, C., Laske, G. and Masters, G., EOS Trans AGU, 81, F897, 2000.

  - U, Th concentrations

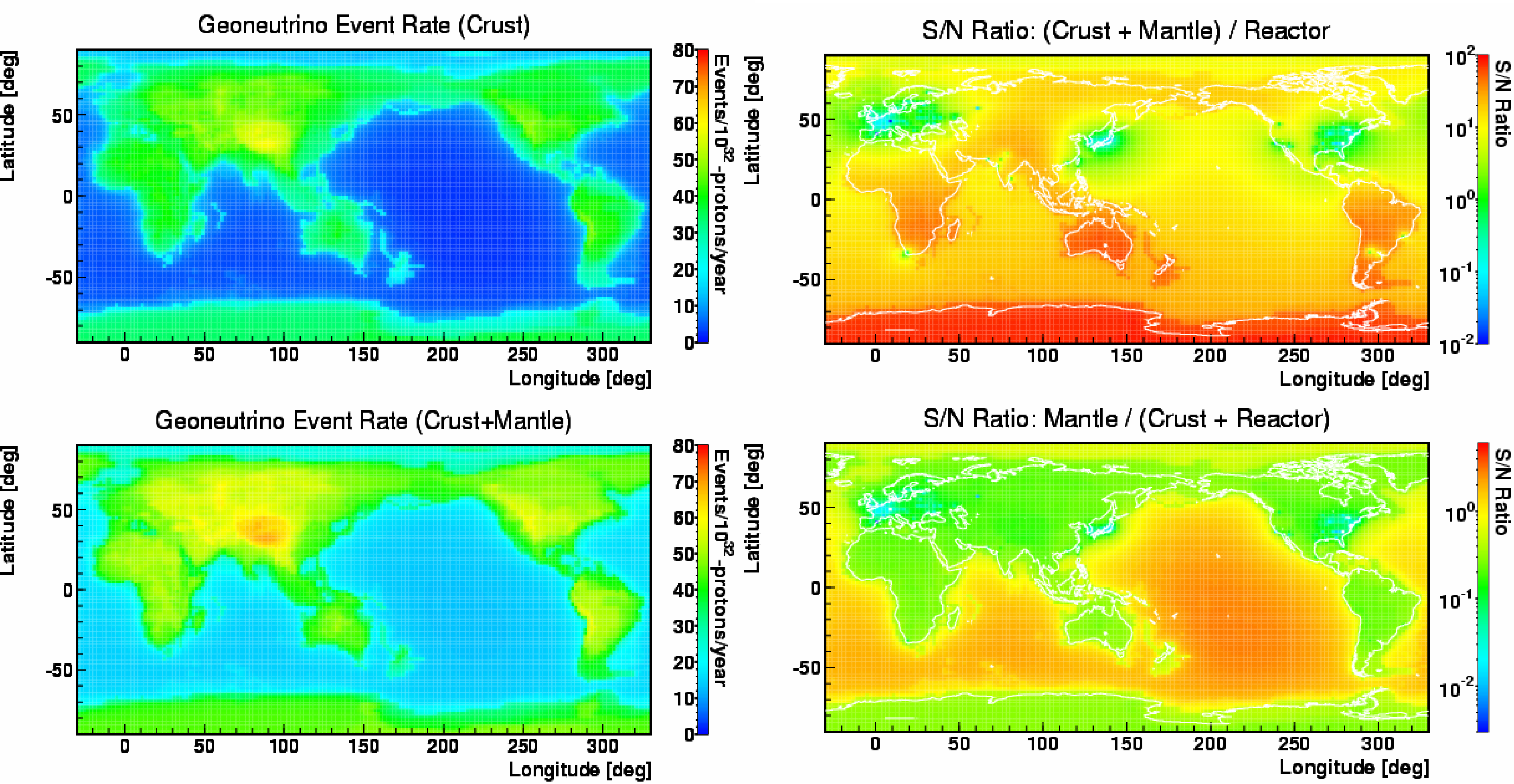
Enomoto, S., et al., EPSL 258 (2007) 147-159.

- Mantle
  - Radial model: 10 TNU
- Total = Mantle + Crust
  - Negligible U, Th in core
  - Neutrino oscillation reduction of 0.57



Geo-neutrino event rate from crust only
1 TNU = 1 event per 10^{32} protons per year

Predicted geo-neutrino rate & S/N



Enomoto model- Neutrino Sciences 2007

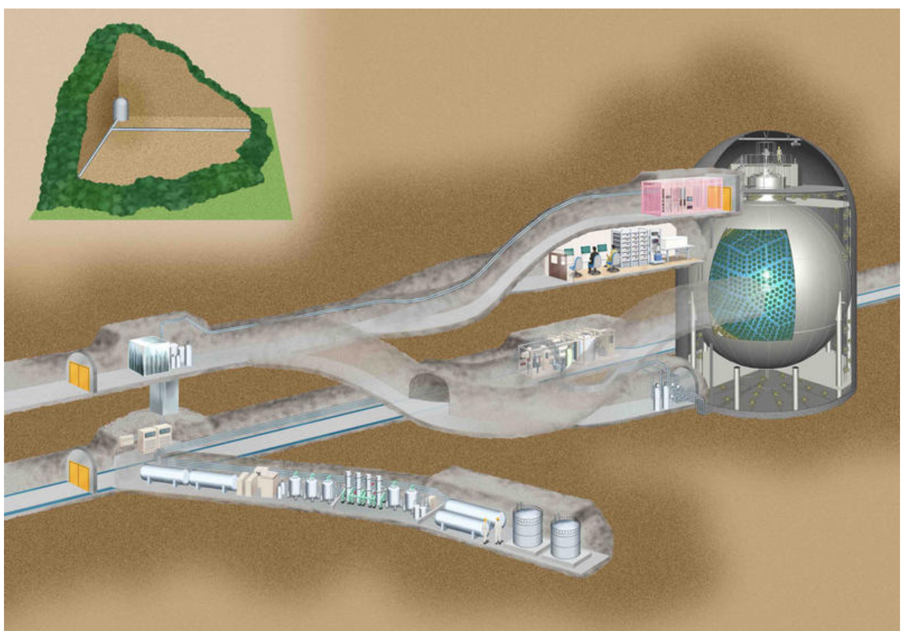
Geo-neutrino detectors- today

KamLAND in Japan

- neutrino oscillations
- operating since March 9, 2002
- 1000 tonnes scintillating liquid
- 1879 photomultiplier tubes, 34%
- Geo-neutrino results 2004, 2008

Borexino in Italy

- solar neutrinos
- operating since May 16, 2007
- 300 tonnes scintillating liquid
- 2200 photomultiplier tubes, ~30%
- No geo-neutrino results yet

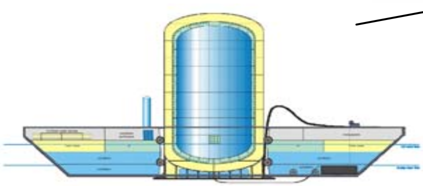


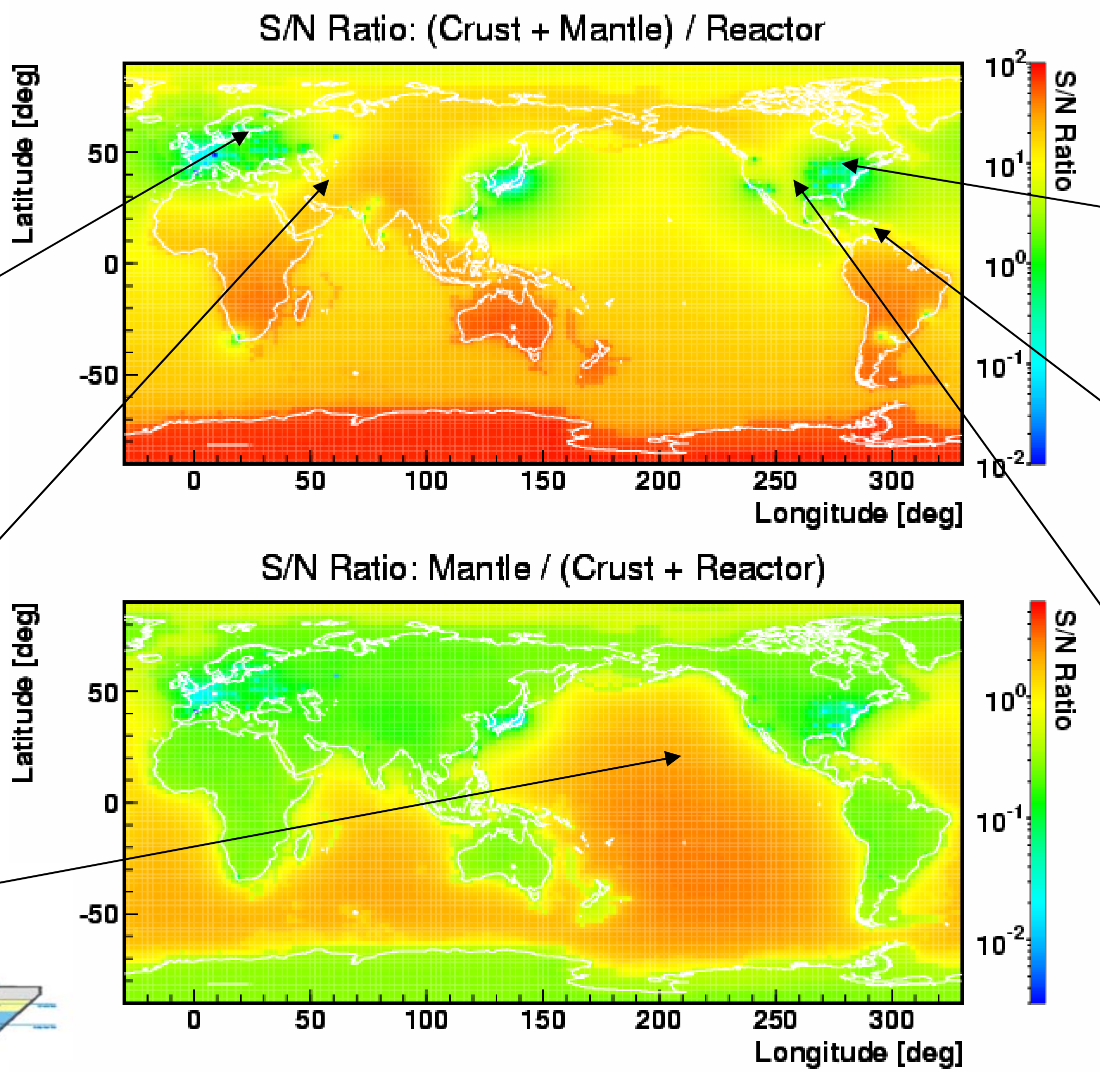
Geo-neutrino detectors- future

LENA

Baksan

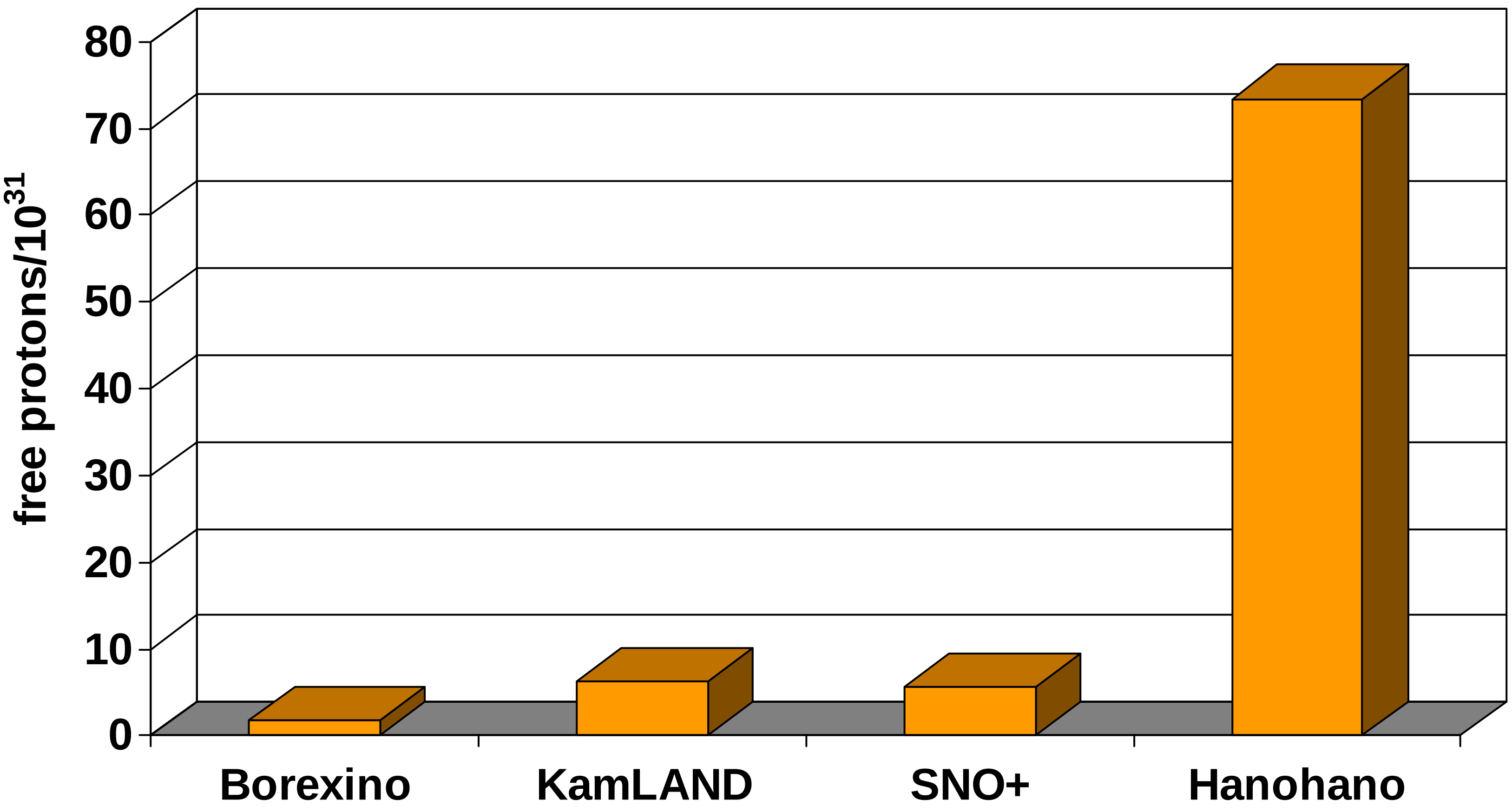
Hanohano



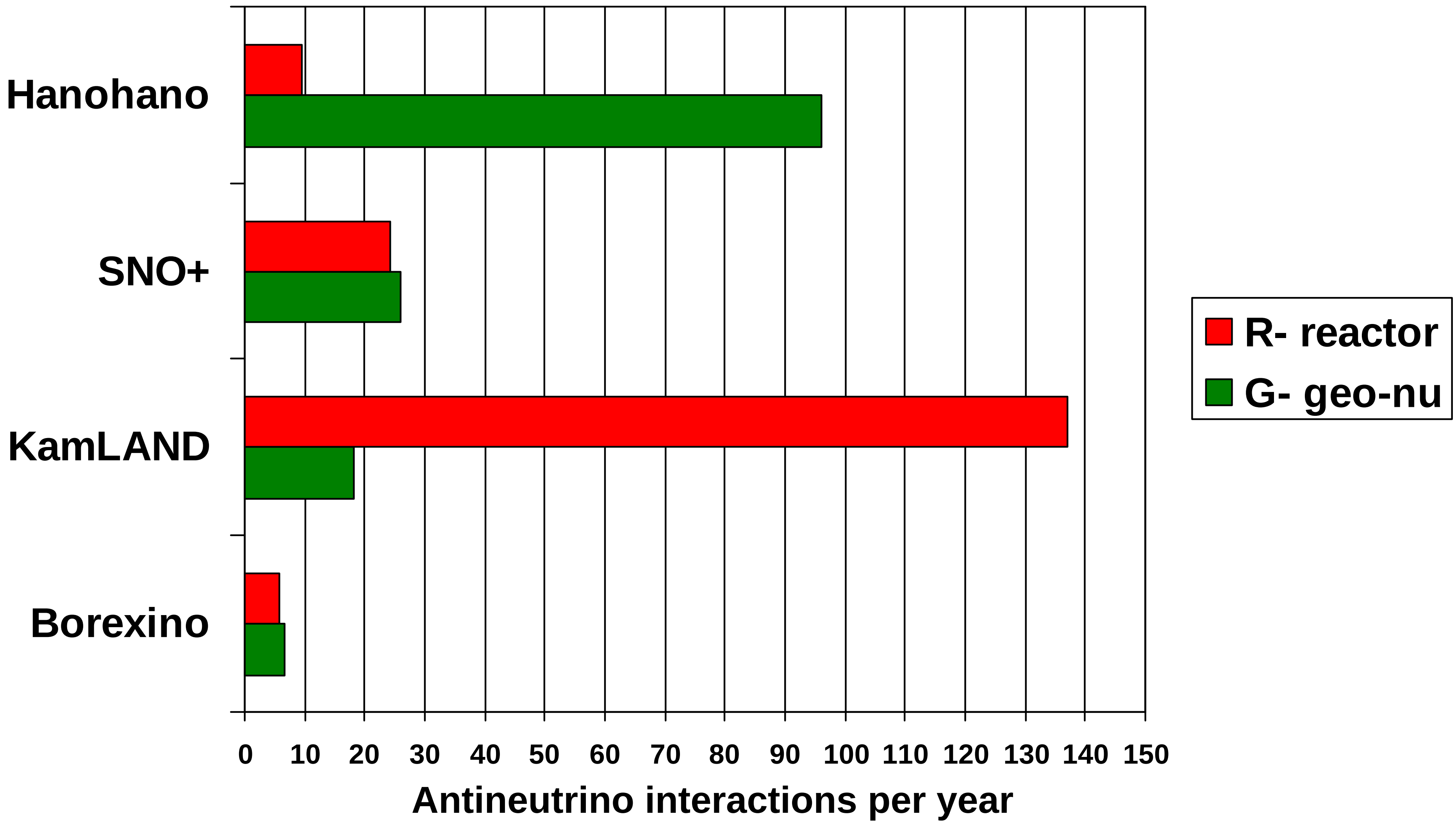


Homestake

Inverse beta reaction targets



Predicted annual event rates



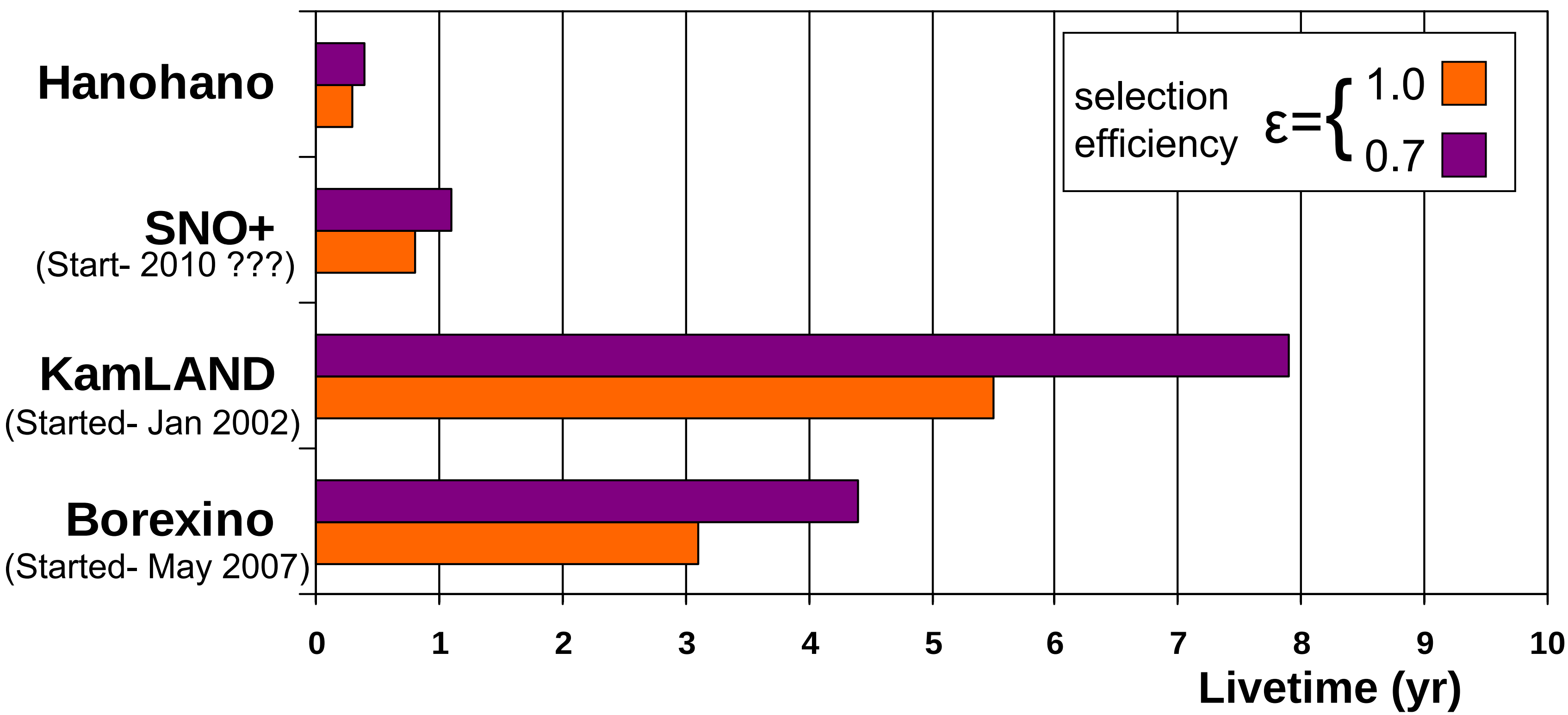
Time for 3σ geo-nu observation

$$g = Gt\varepsilon$$

$$r = Rt\varepsilon$$

$$\delta g / g = \sqrt{G + R(1+f)} / (G\sqrt{t\varepsilon}) = 0.33$$

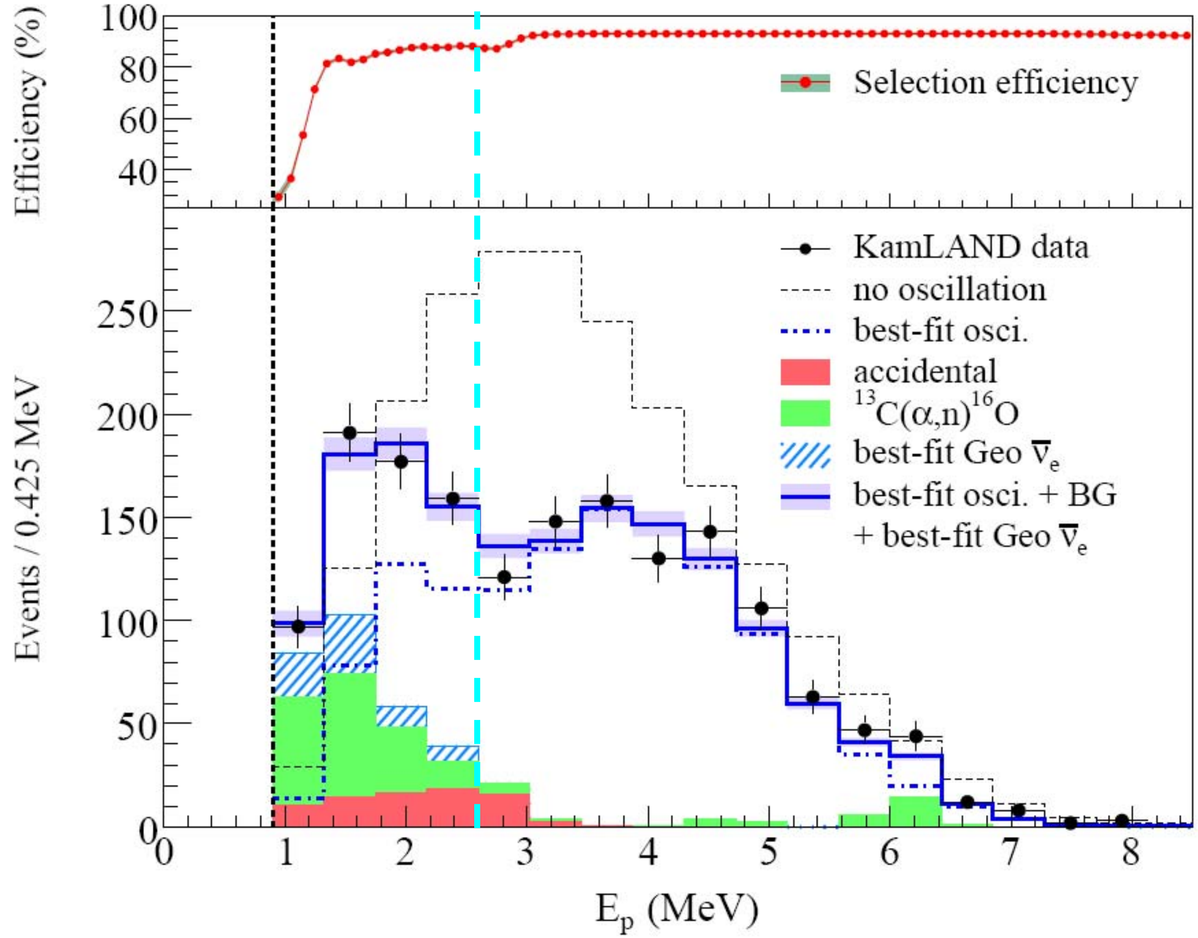
$$t = (G + 1.35R) \big/ (0.11\varepsilon G^2)$$



KL antineutrino energy spectrum

Data: 3/9/02 – 5/12/07; Exposure: 2.44×10^{32} p^+-y

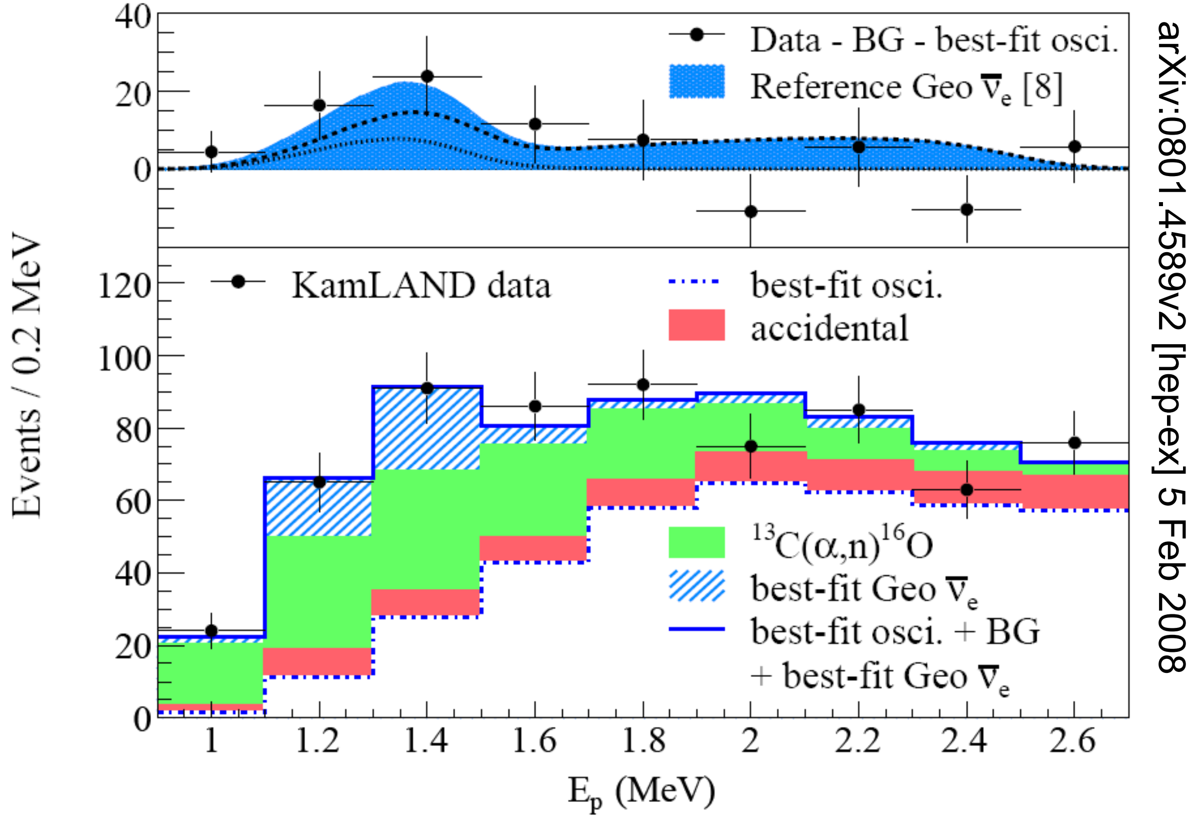
- 2008 results
  - ~4 x exposure
  - radius 5→6m
- Nu-osc result
  - Non-osc spectrum excluded at 5.1σ
- Geo-nu result
  - Reported signal 73±27 (2.7σ)
  - Spectrum fixed to Th/U=3.9



Abe et al. (2008) PRL 100, 221803

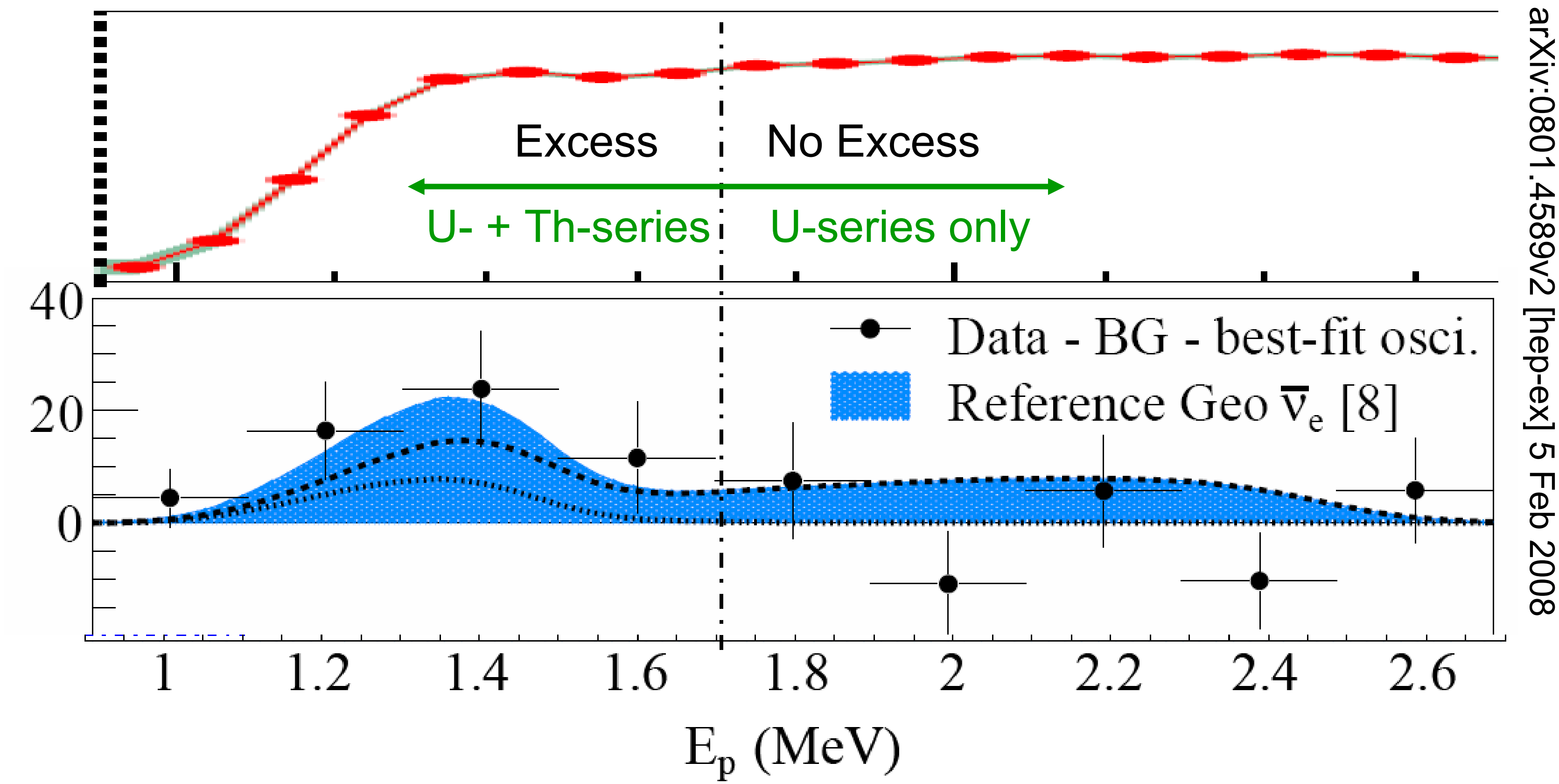
KL low energy spectrum

- KL geo-nu signal
  - Obs ~650 events
  - Exp ~611 bkg events
  - P=5.7% (1.6σ)
  - Excess 39±25
- U-series signal?
  - $1.7<E_p<2.7$ MeV
  - Obs ~384 events
  - Exp ~397 bkg events
  - P=74%
  - Fit to bkg $\chi^2/\mathrm{dof}\approx 0.8$



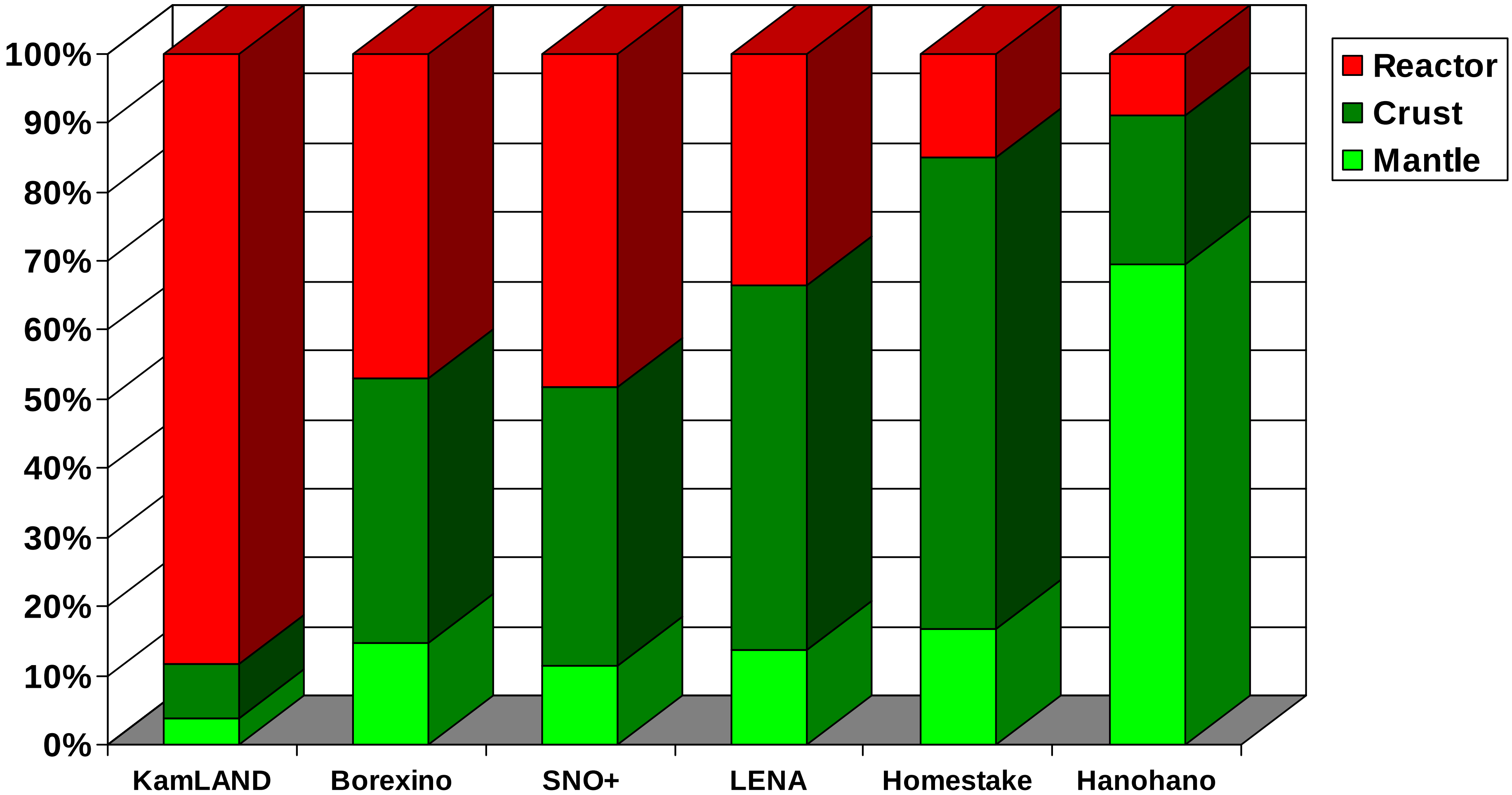
No evidence for U-series geo-nus!!
Observed Th/U very high!!

KL geo-neutrino signal critique



Excess all at low energy where spectrum dominated by $^{13}C(\alpha,n)^{16}O$, accidentals and detection efficiency not well behaved

Predicted antineutrino source distribution

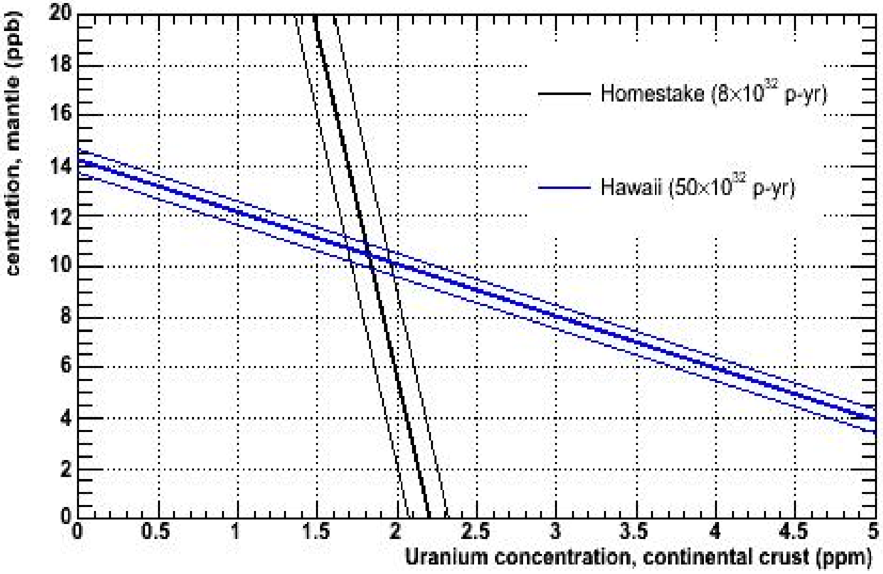


Geology takes two detectors

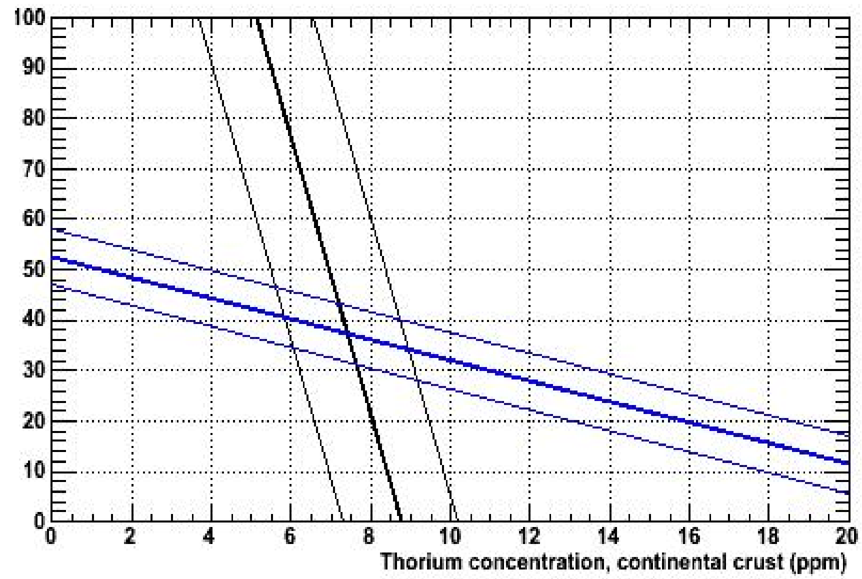
- Earth has two main reservoirs of U & Th
  - Continental crust
  - Mantle
- Land detector

  Mostly CC geo-nus
- Ocean detector

  Mostly Mantle geo-nus
- Together they constrain global U & Th



Dye and Guillian, *Proc. Nat. Acad. Sci.* 105 (2008) 44-47.



Measuring terrestrial uranium and thorium

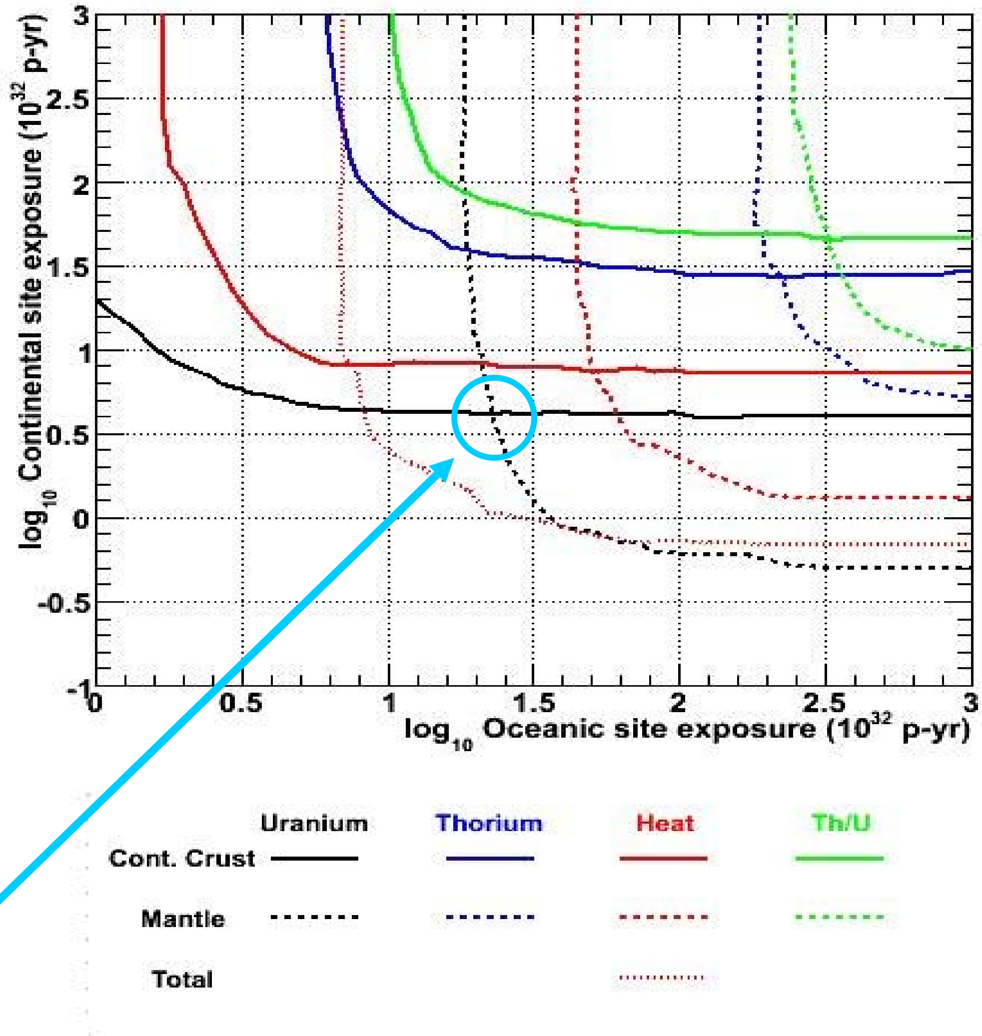
- average concentrations in continental crust and mantle
- requires continental and oceanic detectors

Benchmark exposures

- 20% measurement of U in mantle and continental crust
- Continental site- 4.5e32 p-yr
- Oceanic site- 22.4e32 p-yr

20% precision contours

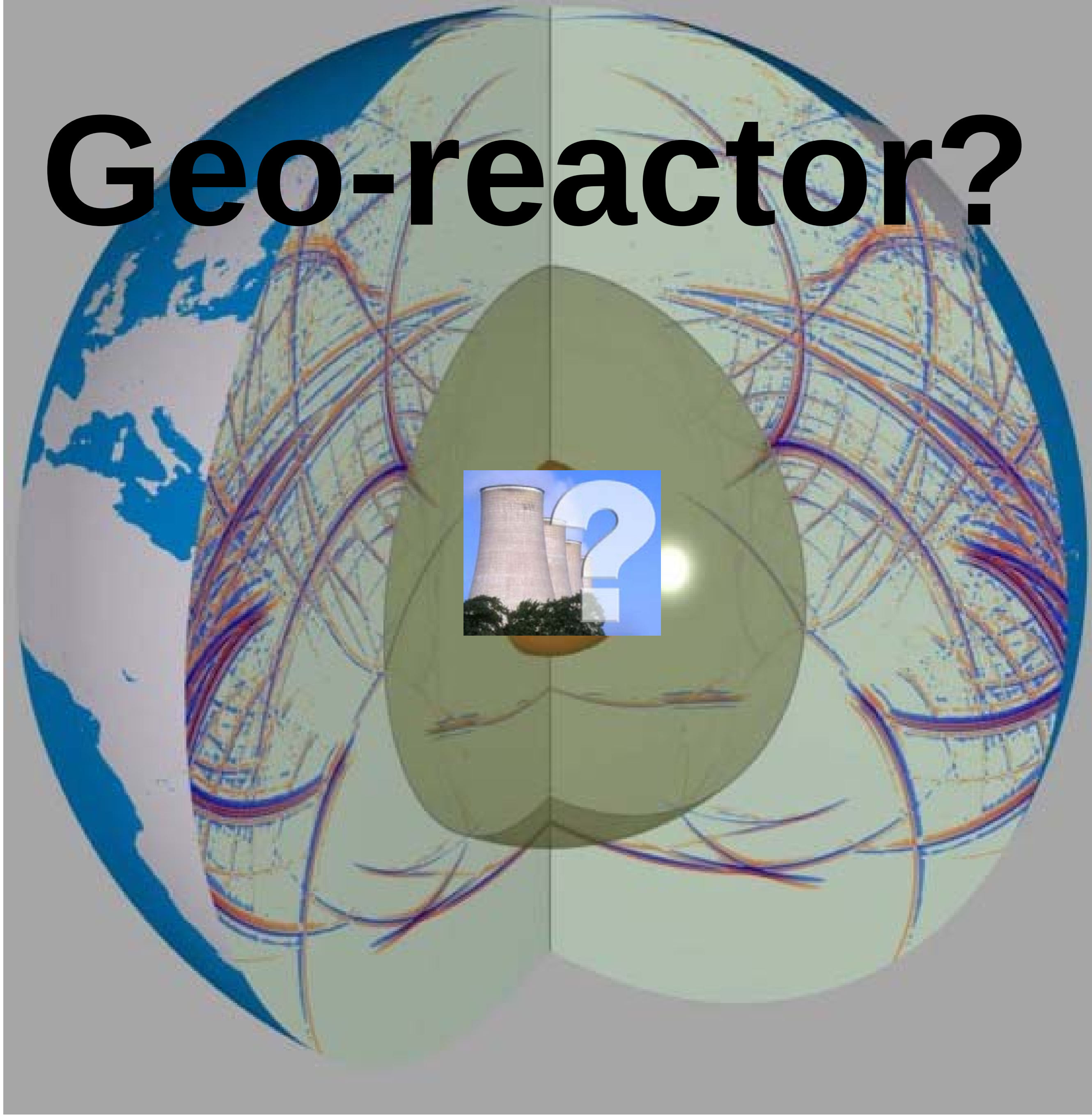
Based on Mantovani et al. model



Dye and Guillian, *Proc. Nat. Acad. Sci.* 105 (2008) 44-47.

Natural fission reactor hypotheses

- Earth-centered
  - 1-10 TW; Herndon (1996)
  - test w/ Hanohano
    P<0.3 TW (90% CL) in 1y
- Boundary b/w inner & outer core
  - 30 TW; Rusov et al. (2007)
  - ruled out by KamLAND
    P<6.2 TW (90% CL)
- Core-mantle boundary
  - de Meijer and van Westrenen (2008)
  - U concentration x20 too low
  - power prediction?



Summary

- Hanohano 10kt oceanic detector
  - Particle physics
  - Neutrino geophysics
- U & Th geo-neutrino studies
  - Conclusive observation in months
  - 25% mantle flux measurement in 1 yr
  - Measure global U & Th w/ continental partner
- Geo-reactor hypothesis testing
  - P<0.3 TW (90% CL) in 1 yr