Theia and the Hadean Heralds

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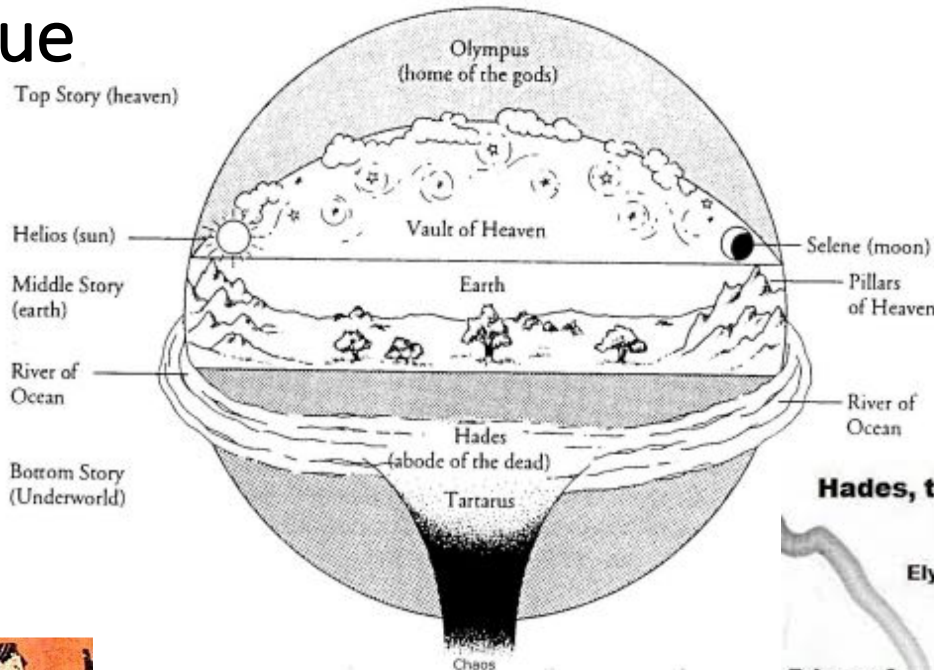
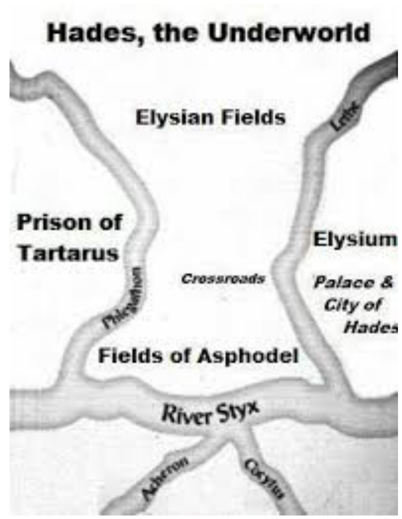
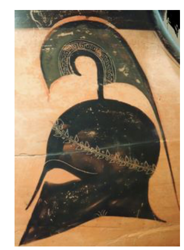
Prologue


Olympus
(home of the gods)
Top Story (heaven)
Vault of Heaven
Helios (sun)
Selene (moon)
Middle Story
(earth)
Earth
Pillars
of Heaven
River of
Ocean
River of
Ocean
Hades
(abode of the dead)
Bottom Story
(Underworld)
Tartarus
Chaos


Hades, the Underworld
Elysian Fields
Lethe
Prison of
Tartarus
Elysium
Crossroads
Palace &
City of
Hades
Phlegethon
Fields of Asphodel
River Styx
Acheron
Cocytus



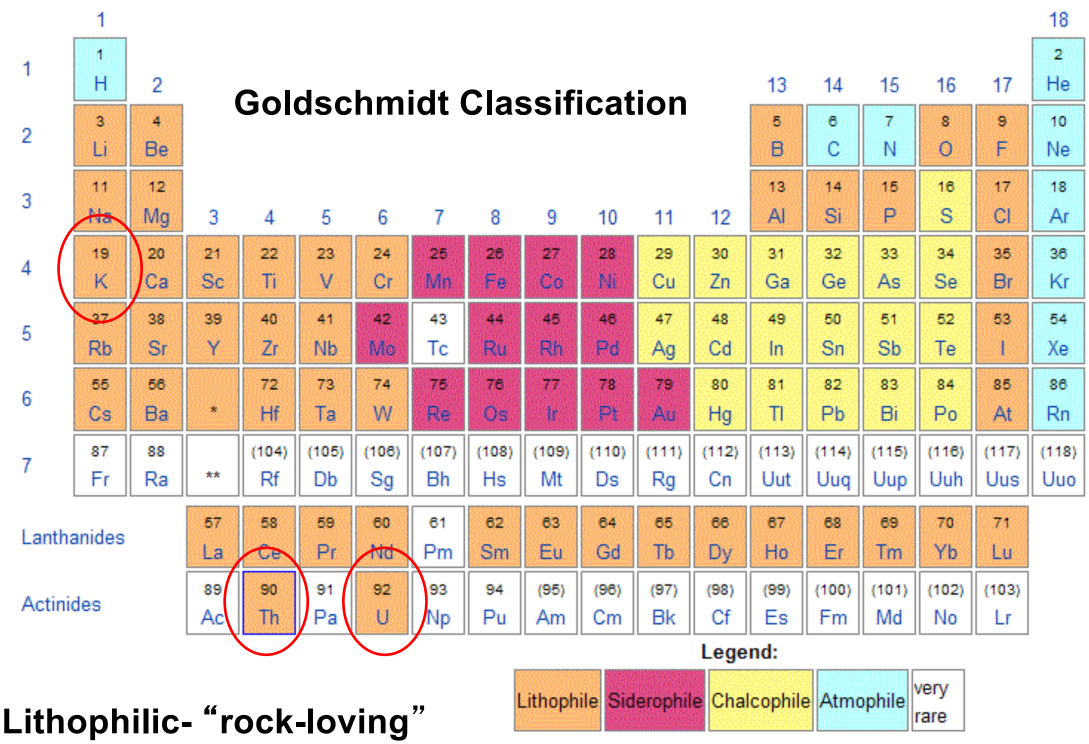
Geo-neutrino Primer

- Terminology
  - DM (depleted mantle not dark matter)
  - CMB (core-mantle boundary not cosmic microwave background)
  - BSE (bulk silicate Earth)
  - HPE (heat-producing element: U, Th, K)
  - Lithophile- "rock-loving"
- Unit
  - Rate: TNU (**T**errestrial anti**N**eutrino **U**nit: 1 event per 10^{32} free proton targets per year ≈ 1.5 / (kT y)
  - Exposure: TNU^{-1}

Overview

- Introduction
- Geological antineutrinos
- Model-dependent results
- Model-independent measurements
- Opportunities for Theia
- Conclusions

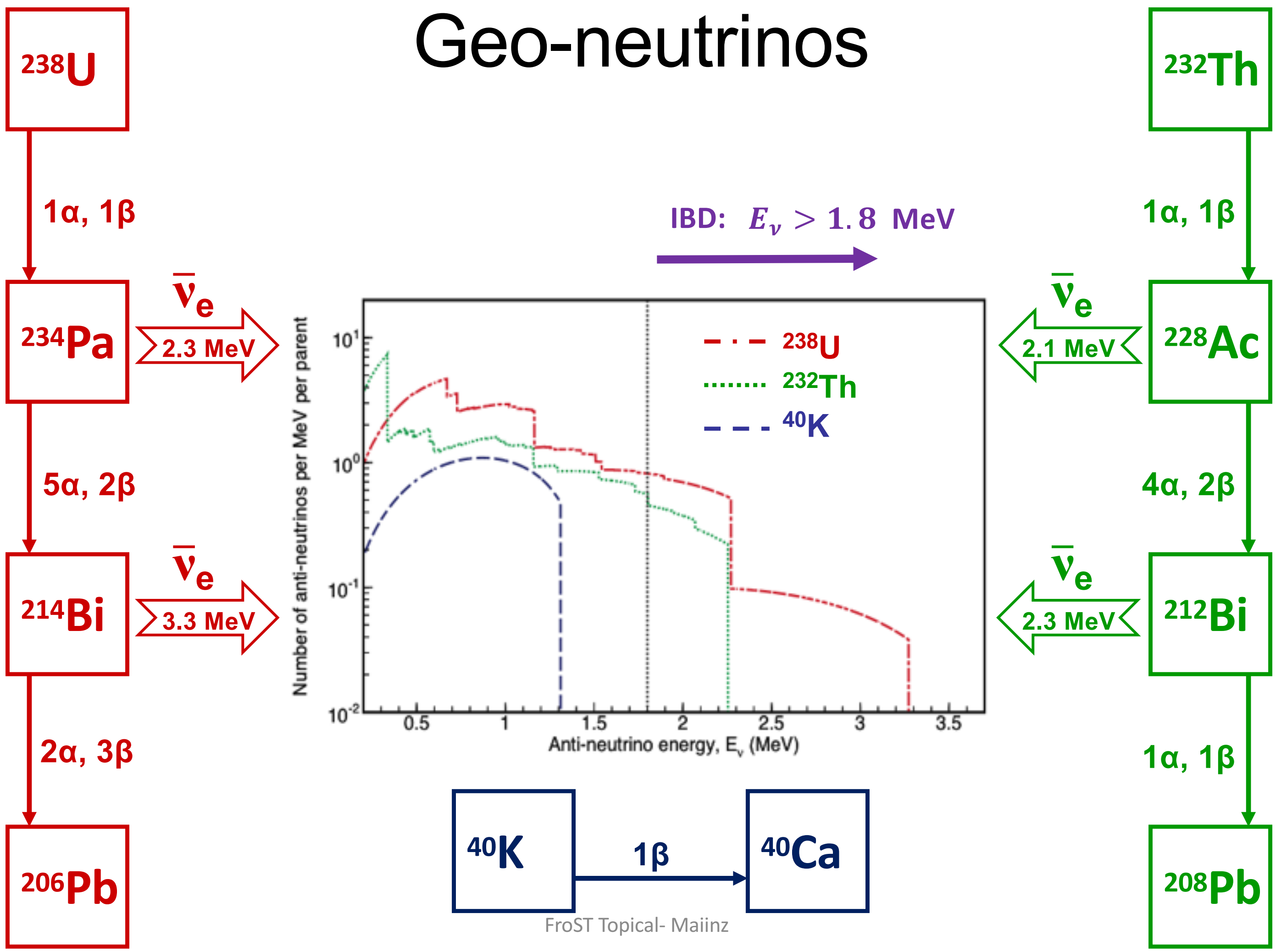
Chemical Affinity of Elements



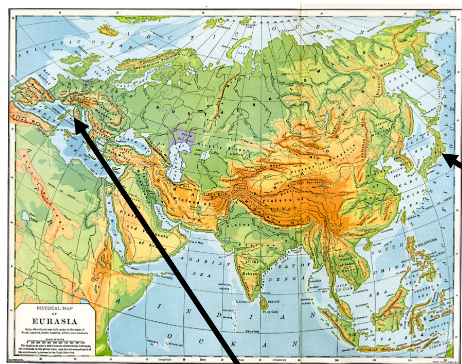
Lithophilic- "rock-loving"

U, Th, K in silicate earth- crust and mantle only

Geo-neutrinos



Operating Geo-neutrino Detectors



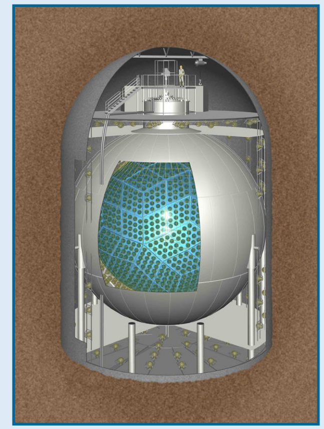
KamLAND- Kamioka, Japan

1 kT LS
80% dodecane
20% PC
w/ 1.36 g/l PPO

~1800 PMTs
34% solid angle

~250 pe/MeV_{vis}

$(5.98\pm0.12)\times10^{31}$ p



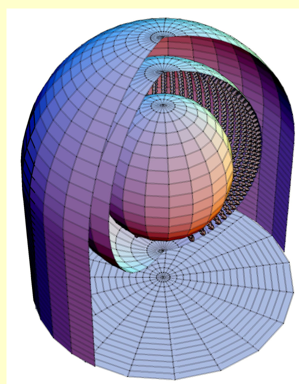
Borexino- Gran Sasso, Italy

0.278 kT PC
w/ 1.5 g/l PPO

2212 8-in PMTs
~30% solid angle

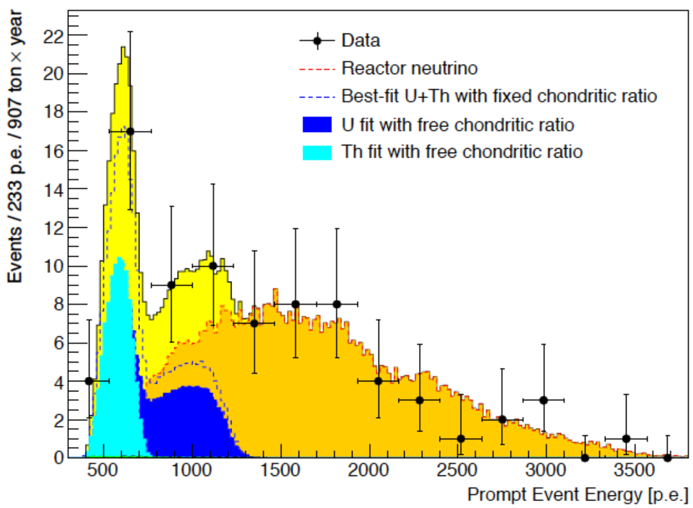
~500 pe/MeV_{vis}

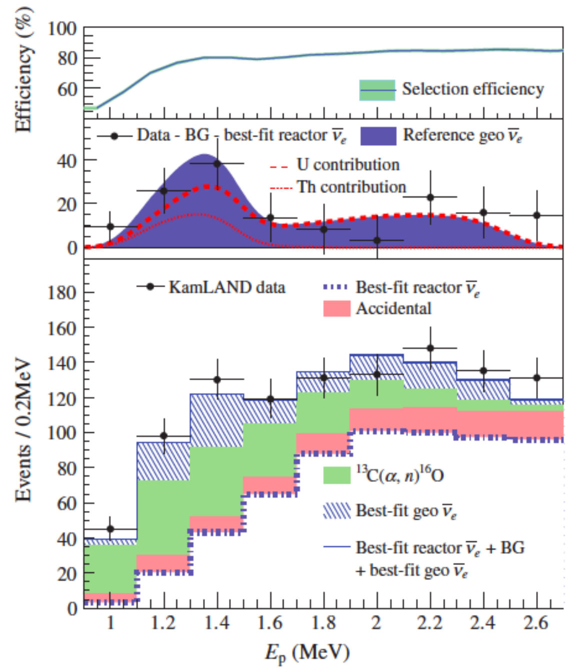
$\sim0.17\times10^{31}$ p



Both existing detectors are in Eurasia at ~40 º N and separated in longitude by ~120 º

Geo-neutrino Observations





Borexino data (2015)
5.9σ detection

KamLAND data (2013)
4.6σ detection

Geo-neutrinos conclusively observed at Japan and Italy

Earth Energy Budget

Terrestrial Power Balance

$P_{surface} \approx P_{rad} + P_{CMB} + P_{man\_cool}$

Present Status

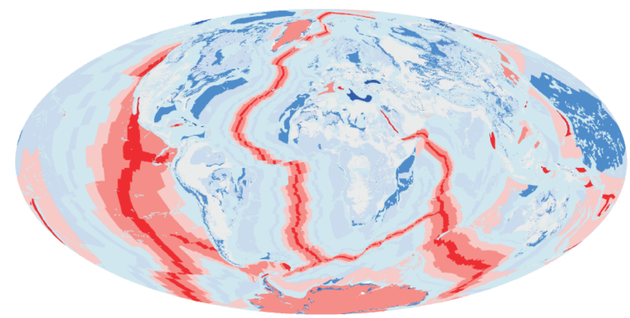
Surface heat flow P_{surf} = 47±3 TW

- Radiogenic heating P_{rad} = 15±10 TW
- Heat flow across CMB P_{CMB} = 13±3 TW

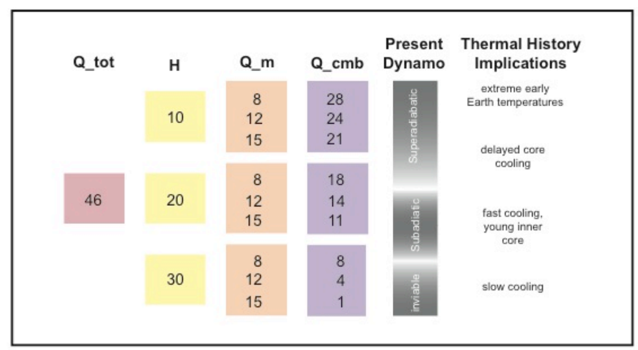
= Rate of mantle cooling P_{man_cool} = 19±11 TW

Constrain thermal evolution

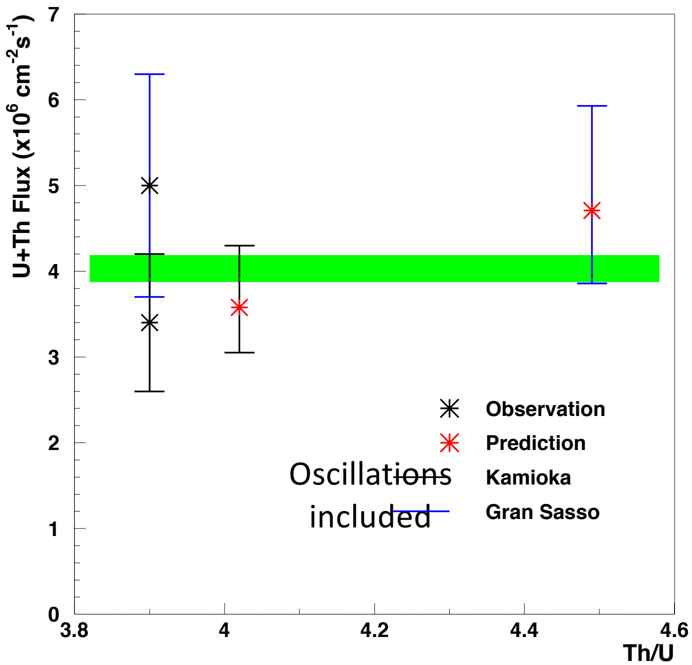
$\partial T/\partial t = Aq/Mc\,(Mh/Aq - 1) = -(50 \text{ to } 150)$ K/Ga

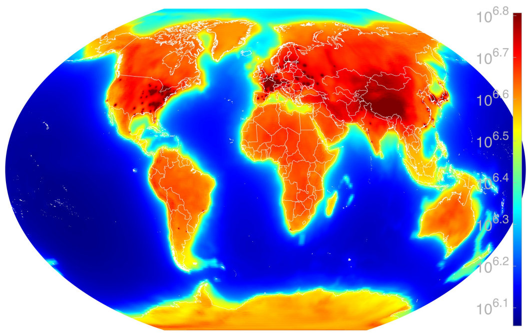


Surface Heat Flux



Geo-neutrino Observations and Predictions





Predicted surface flux variation

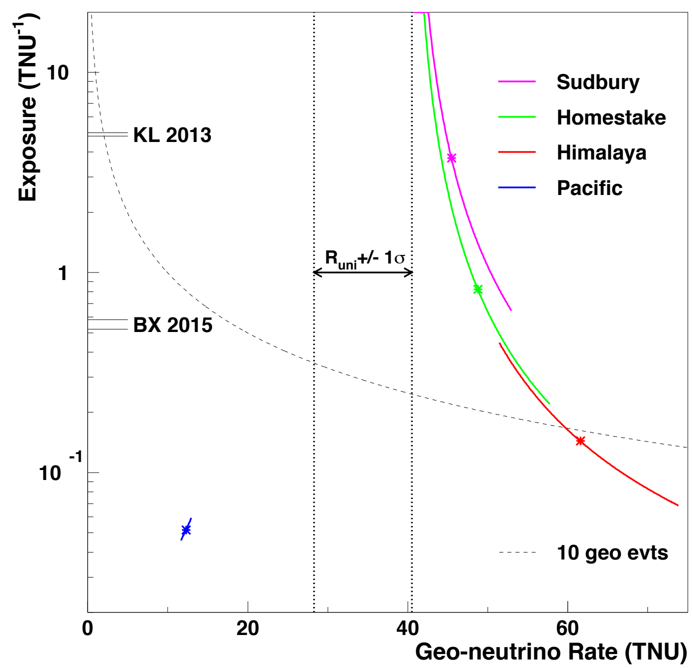
Measurements and predictions are consistent
Surface flux variation not resolved yet

Observing Geo-neutrino Signal Rate Variation

KamLAND & Borexino signals are consistent

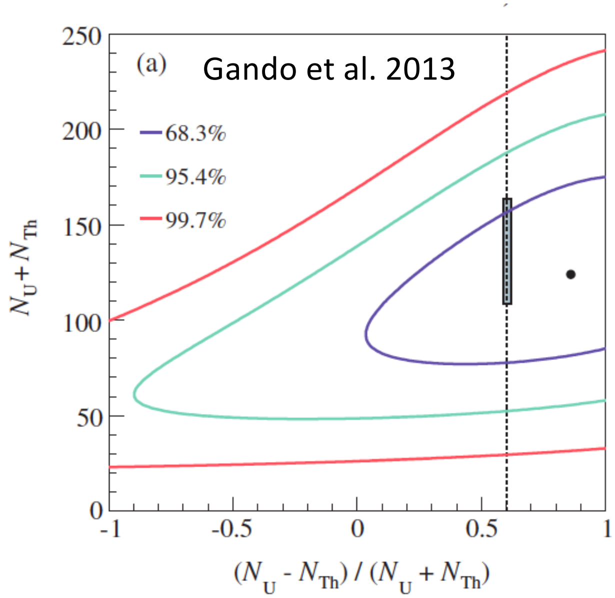
Weighted average gives R_{uni}= 34 ± 6 TNU

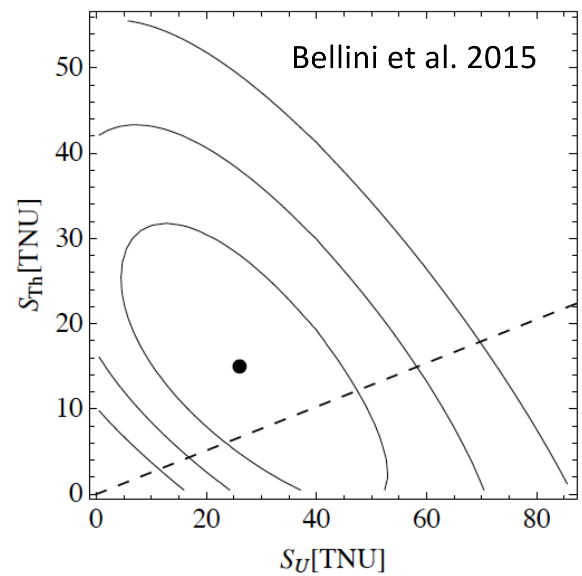
Plot shows exposure needed to observe signal deviation at ± 1σ from R_{uni}



Pacific, Himalaya, Homestake, offer good opportunities (~1 TNU^{-1})

Observing Geo-neutrino Spectrum



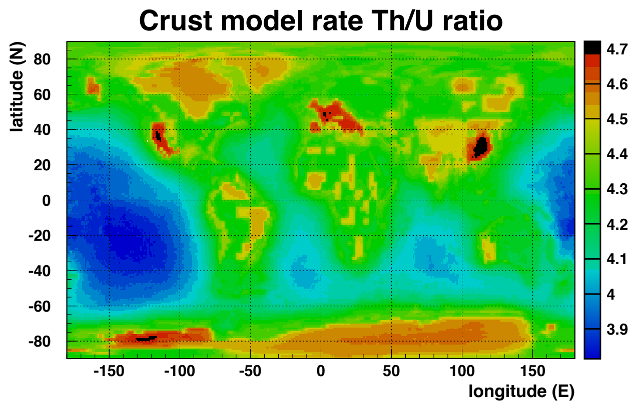


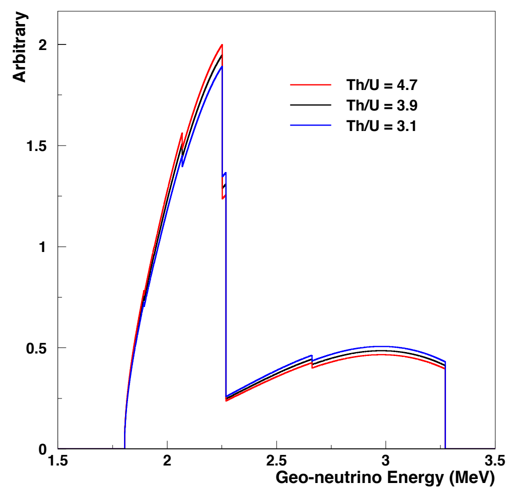
KamLAND data (2013) consistent with $N_{Th} = 0$

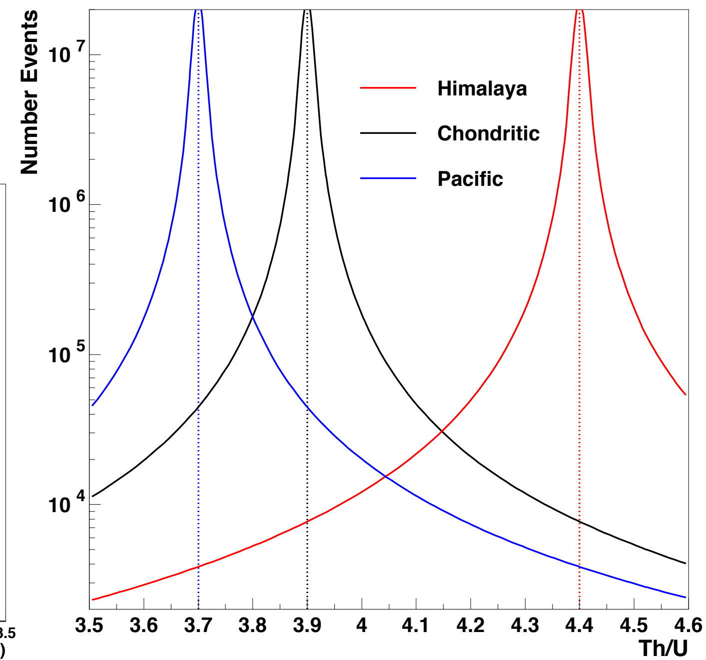
Borexino data (2015) consistent with $S_{Th} = 0$

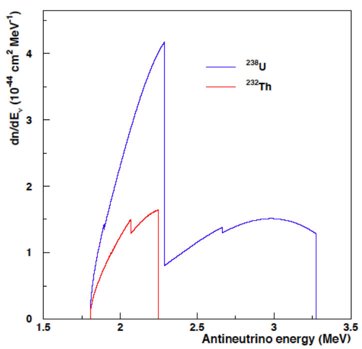
Th geo-neutrinos certainly present but not yet resolved at 1σ

Resolving Geo-neutrino Th/U









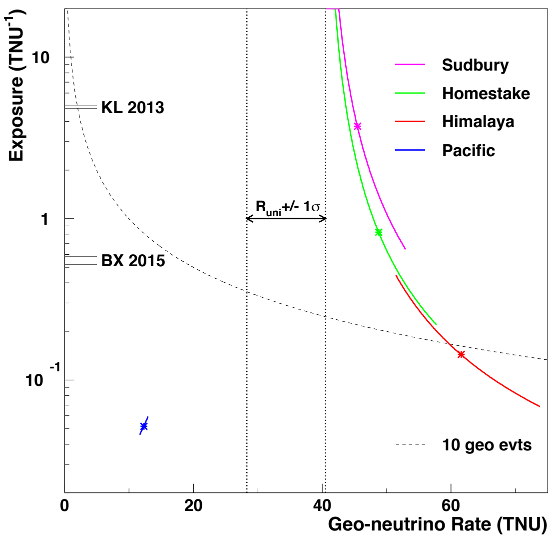
Requires many 1000s of events

Geo-neutrino Observation Status

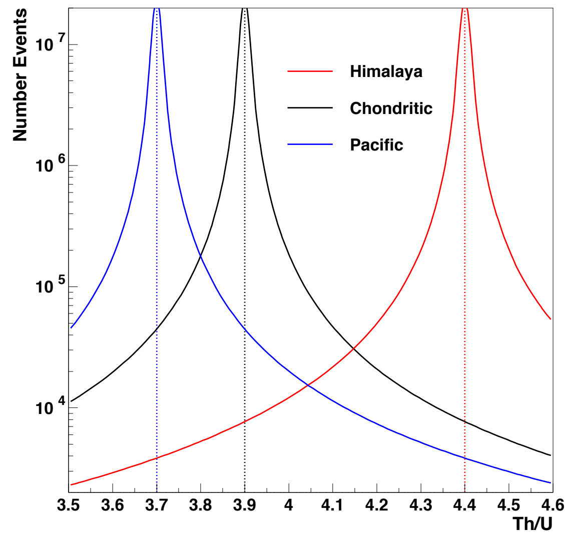
	Rate	Spectrum	Flux	Variation	Power	Dir
U + Th	>5σ	Th/U < 19	Th/U=3.9		model	
K	K/U		K/U		K/U	
Crust	model		model		model	
Mantle	model		model		model	
LLSVP/ULVZ						
Core						

(green)	**Demonstrated/Completed**
(yellow)	**Limit and/or Model-dependent result**
(red)	**Opportunity**

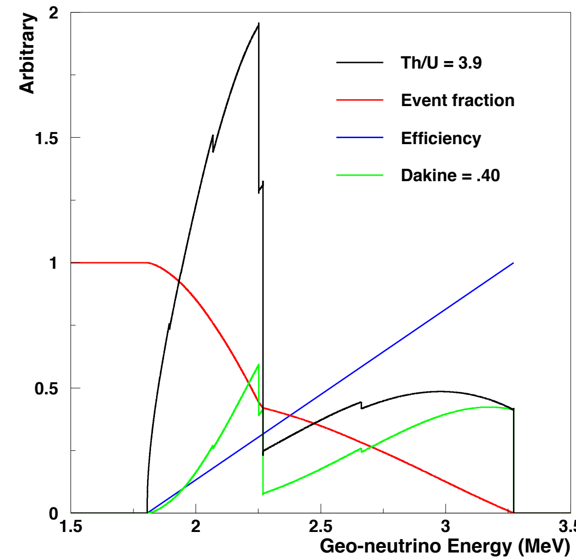
Theia Potential



Requires ~1 TNU^{-1} (ε=1)



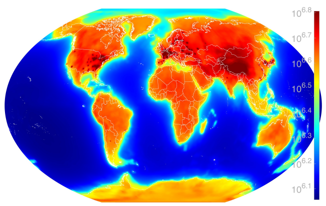
1000s of events

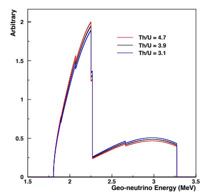


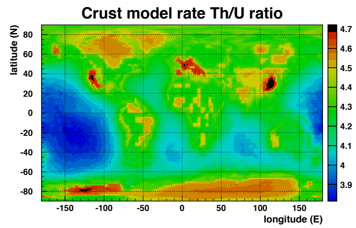
Efficiency is Important

Conclusions

- Geo-neutrinos- low energy $\overline{\nu_e}$ (~MeV)
- Independent verification great hadean trace element partitioning
  - Test constant rate and constant spectral shape hypotheses
  - Confirm variation of surface flux- ~TNU^{-1} (~2 kT-y) exposure
  - Confirm variation of spectral shape- 30 – 100 TNU^{-1} (~50 - 150 kT-y) exposure







- Requirements site dependent
  - Homestake, Pyhasalmi, Korea
- Motivation to push to low energy