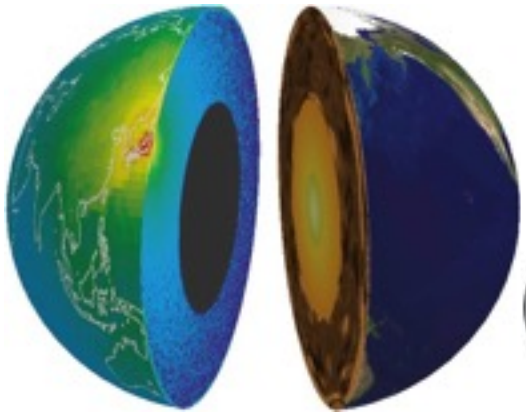
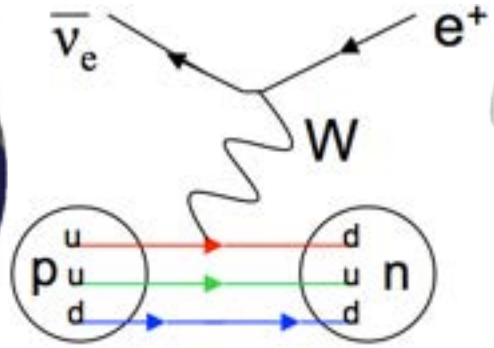

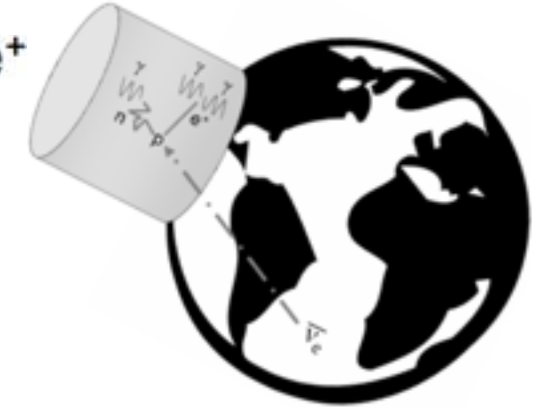
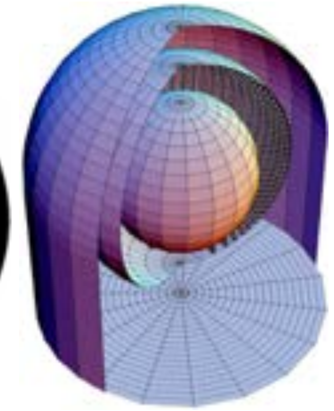
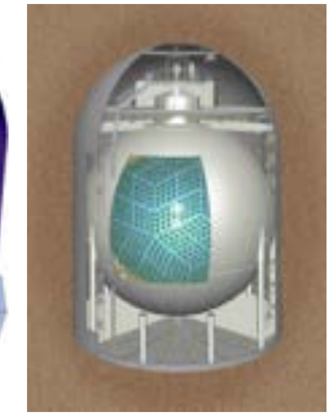
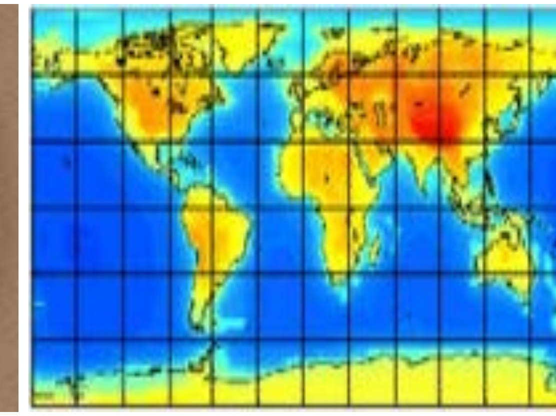

Geoneutrina

Průnik geofyziky a experimentální částicové fyziky

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Spolupracovníci:
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Edwin Kite (Caltech)
Steve Dye (Hawaii Pacific Univ.)
Shijie Zhong (Univ. Colorado Boulder)
John Learned (Univ. Hawaii)

Problémy současné fyziky I, 11. listopadu 2015

Pale Blue Dot
a photograph of Earth taken on 14 Feb 1990, by Voyager 1 from a distance of about 6 billion kilometers

The Blue Marble
a photograph of the
Earth, taken on
7 Dec 1972 from
Apollo 17 at
a distance of
~45,000 kilometers

Geophysics

=

Structure

Composition

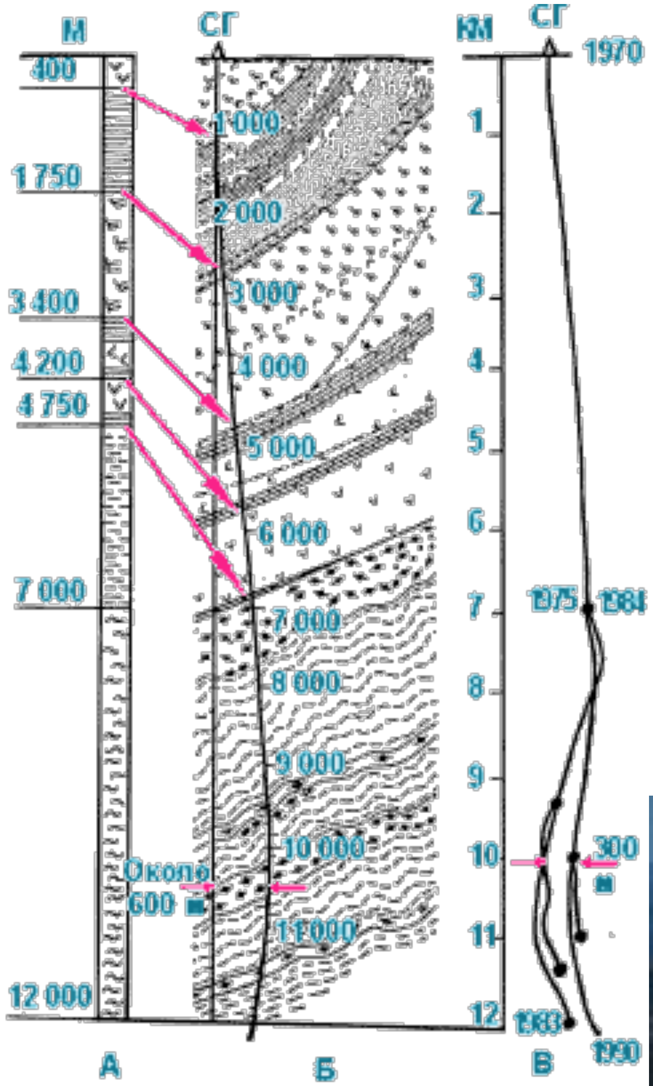
Processes

Origin

Evolution

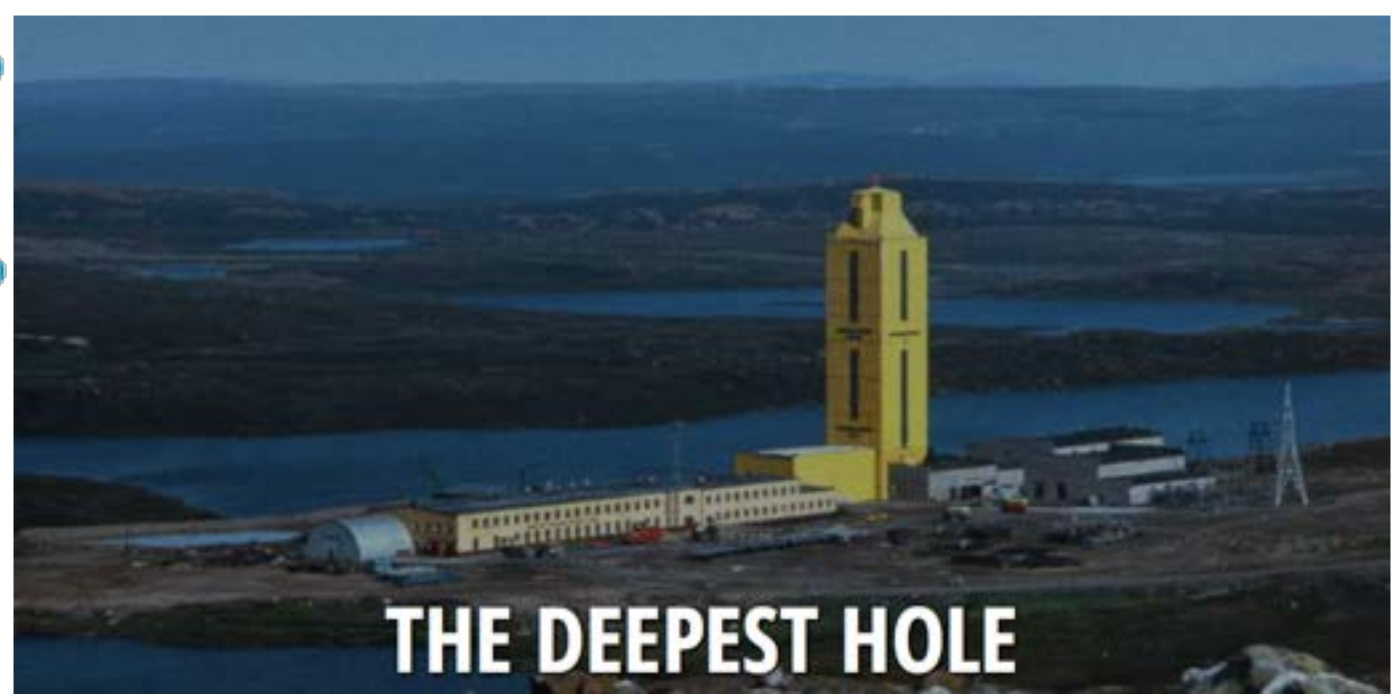
How would you study this apple?

Scientific drilling



Kola Superdeep Borehole
12.262 km deep

compare with Earth radius
~6371 km



Challenges of studying Earth's interior

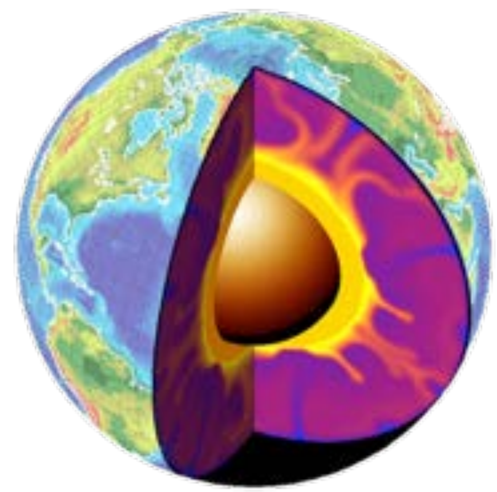
- We cannot examine the interior in-situ
- Indirect evidence
- Size ⇒ Extreme temperatures (7000 K) and pressures (360 GPa)
- Broad range of time scales
- Only one snapshot in time
- Combination of approaches from many different scientific disciplines

Study of (deep) Earth

Observations and sample collections possible at surface

Measurement and analysis of gravity field

Study of earthquakes and propagation of seismic waves



Numerical modeling of dynamic flow in the interior

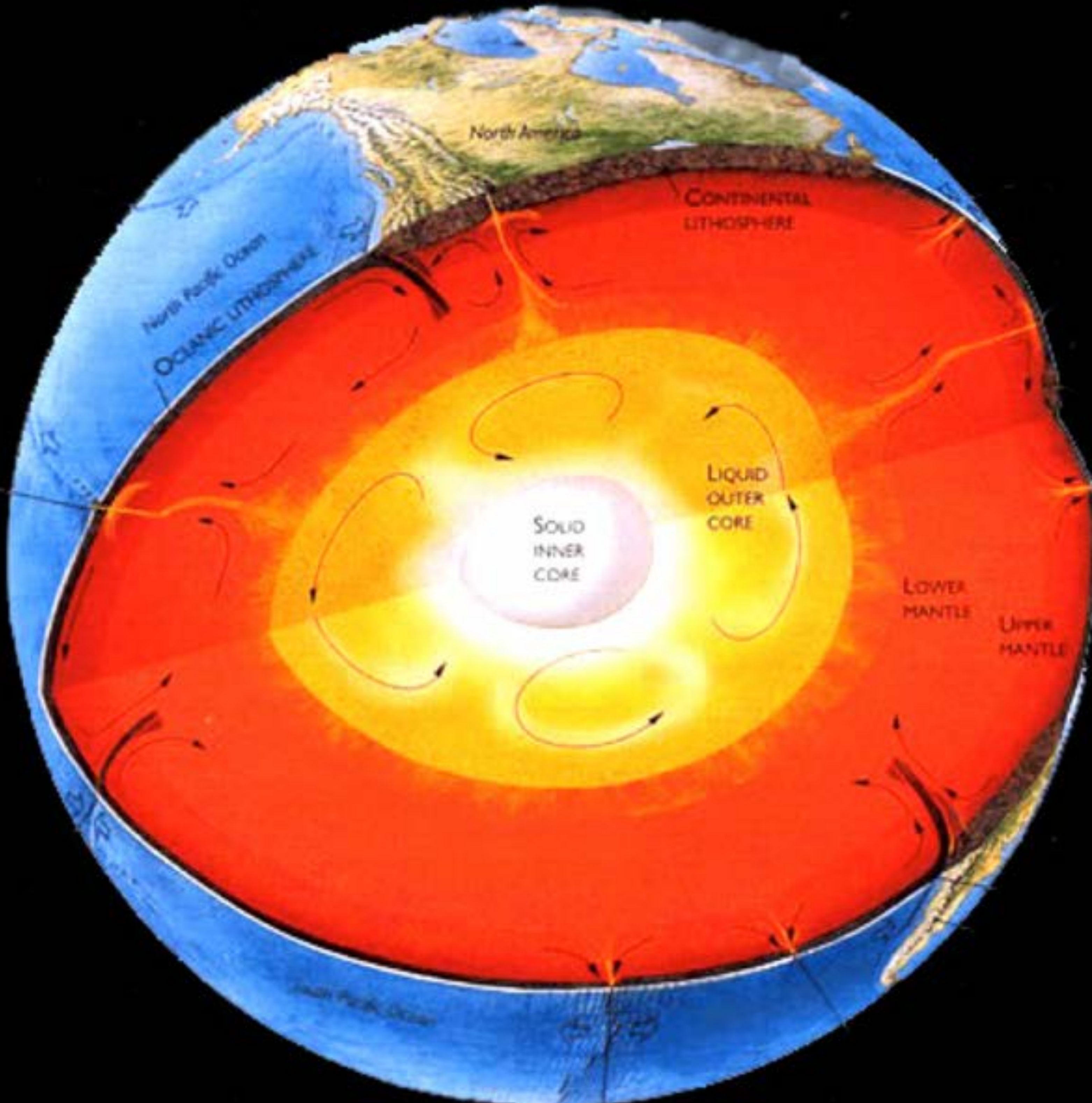
Experiments in minerals at high pressure and temperature

Geochemical analyses of Earth and meteorite samples

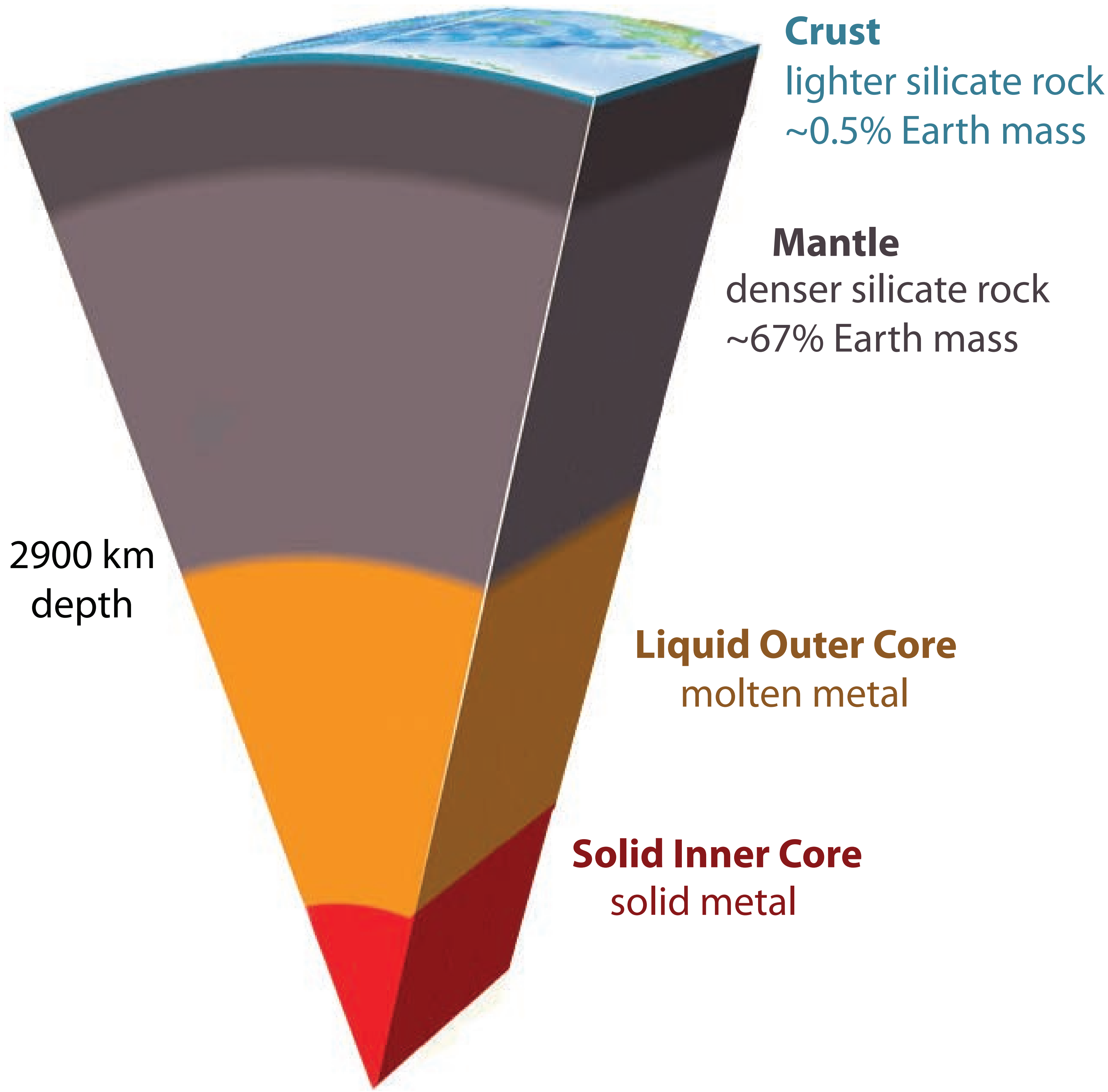
First principles (“ab initio”) calculations of material properties

Fluid mechanics experiments in laboratory

Detection of geoneutrinos, “particle geoscience“



- First order ***compositional*** layering:
  - core
  - mantle
  - crust
- Layering according to ***mechanical properties***:
  - inner core
  - outer core
  - sublithospheric mantle
  - lithosphere

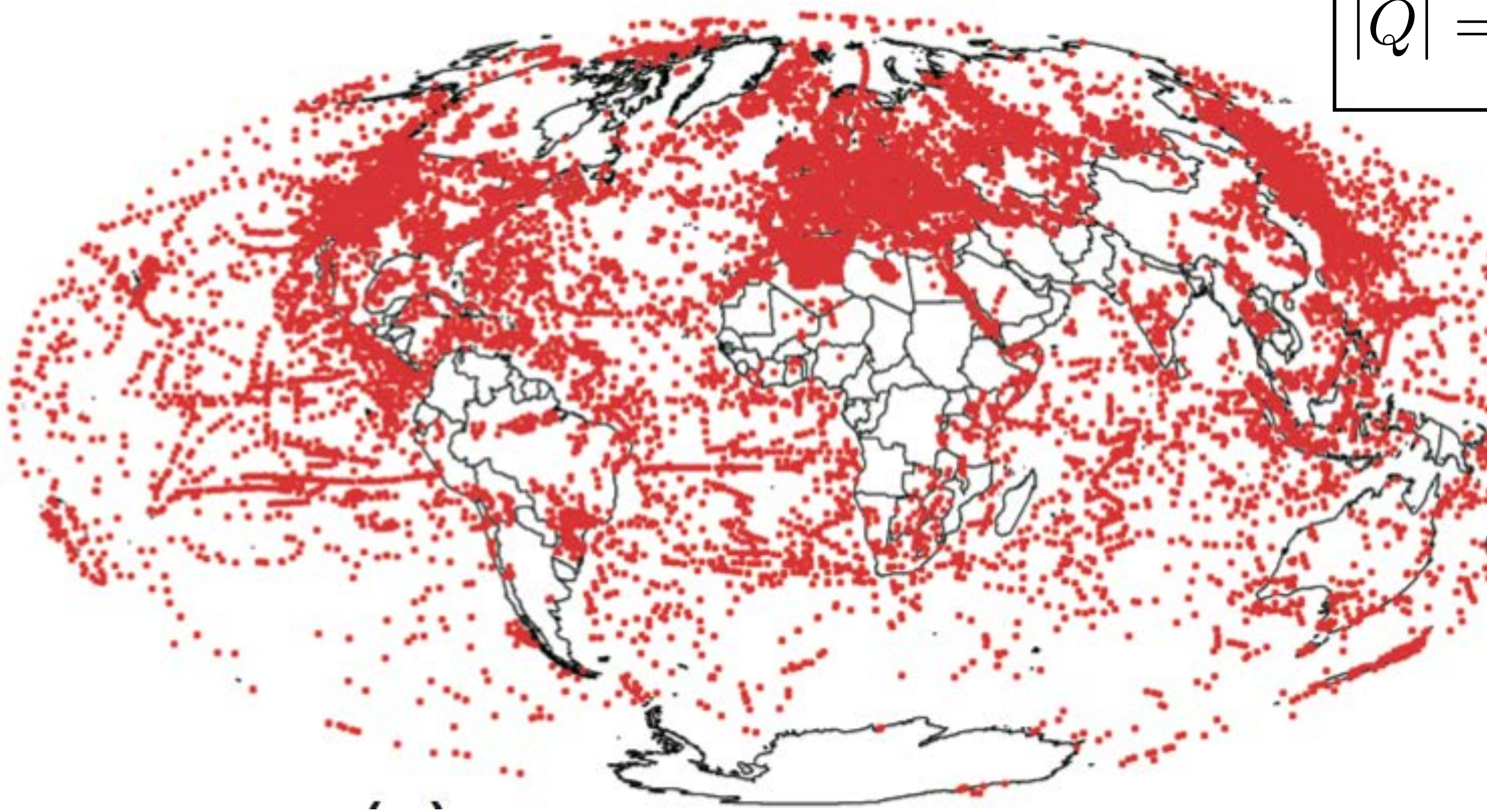

Crust
lighter silicate rock
~0.5% Earth mass
Mantle
denser silicate rock
~67% Earth mass
2900 km
depth
Liquid Outer Core
molten metal
Solid Inner Core
solid metal

Earth loses heat from its interior
Surface heat flow

It is at the surface so we can actually **measure it**...

~38000 measurement sites

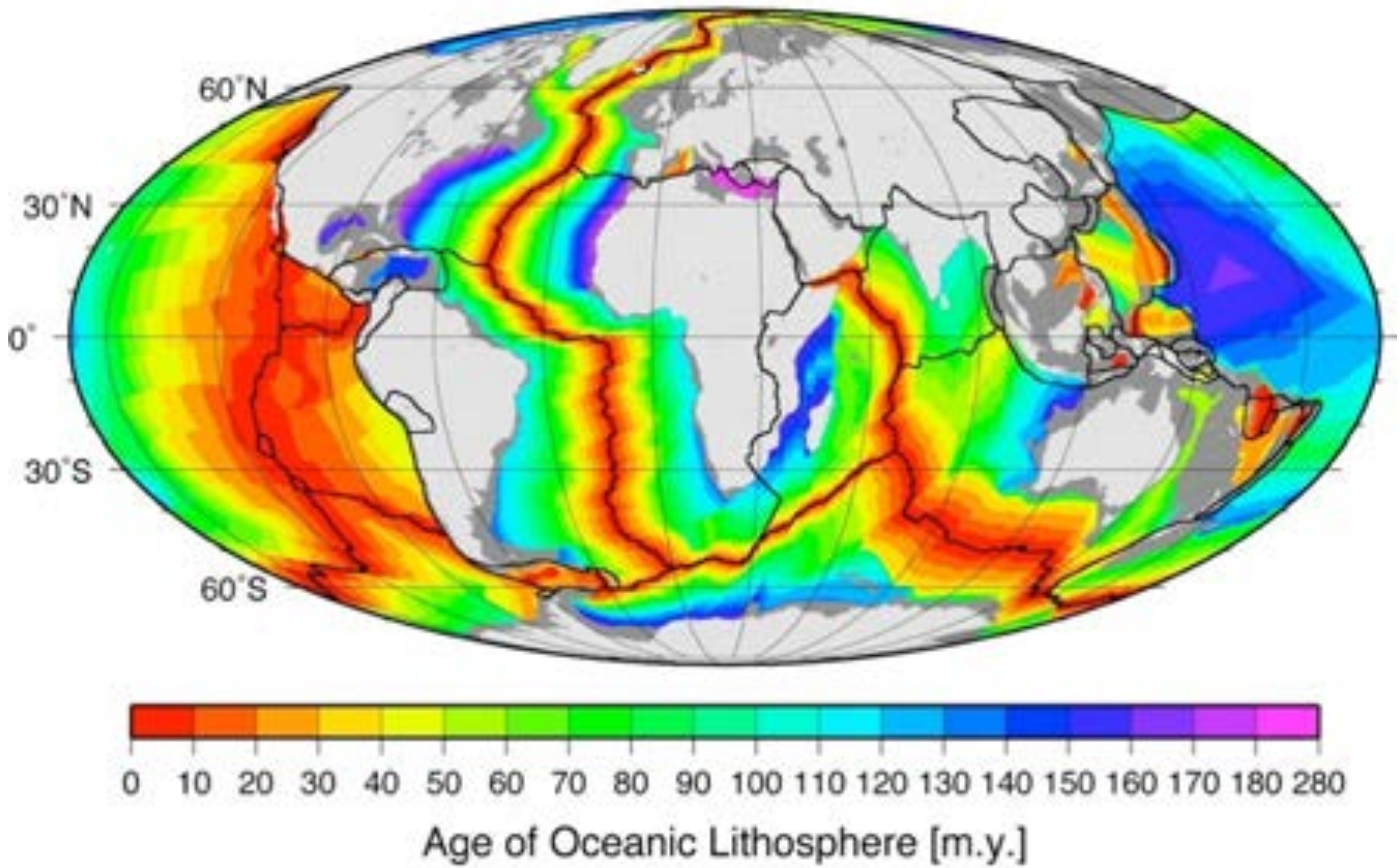
$$|Q| = k\frac{\mathrm{d}T}{\mathrm{d}z}$$



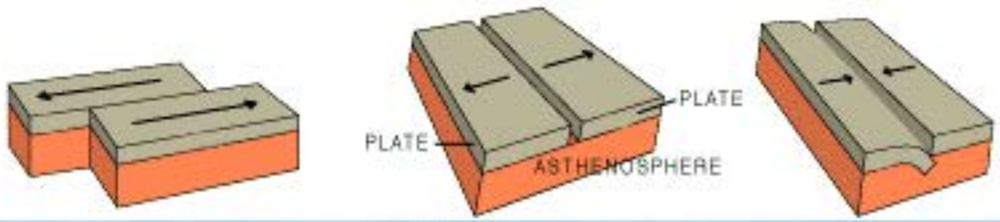
Davies & Davies 2010

Oceanic heat flux

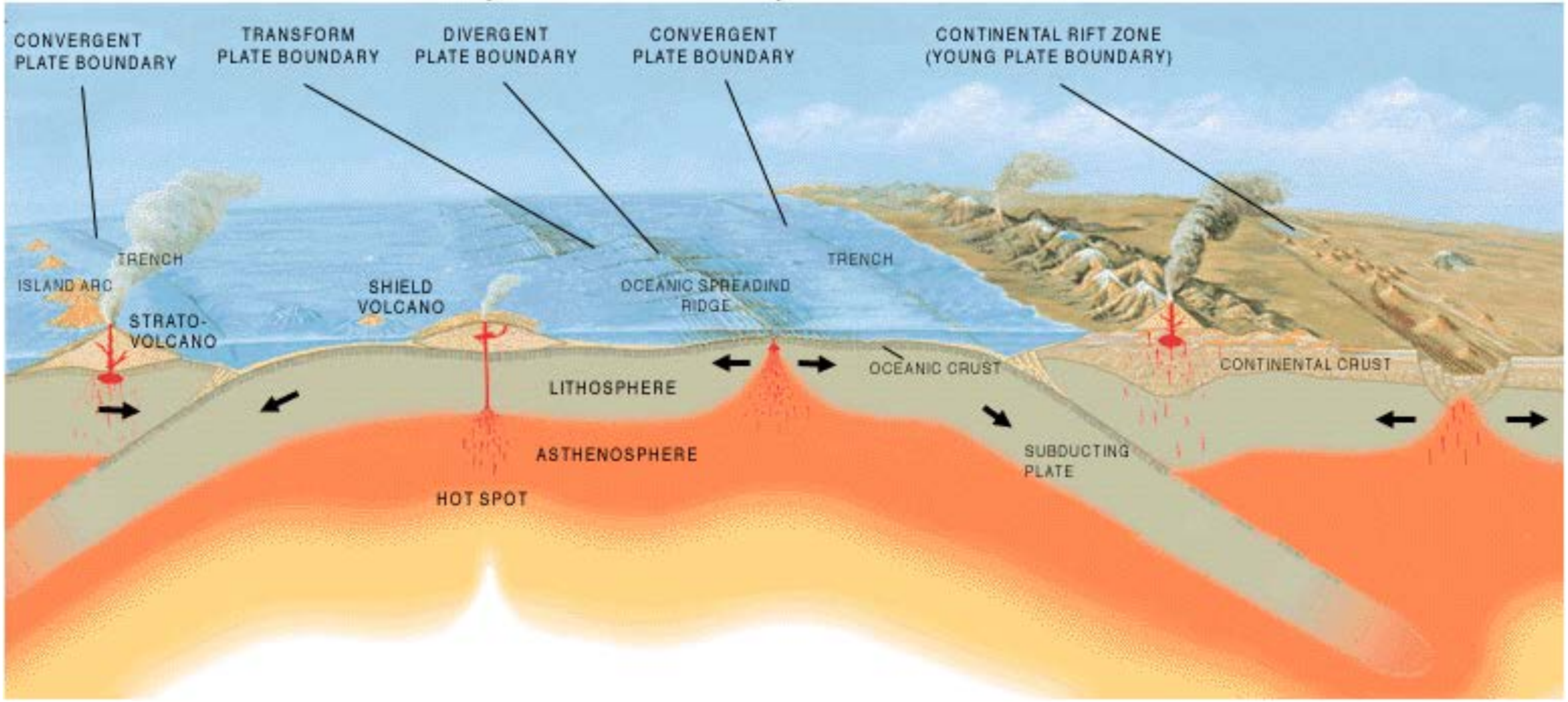
Plate tectonics: oceanic spreading centers



Theory of plate tectonics

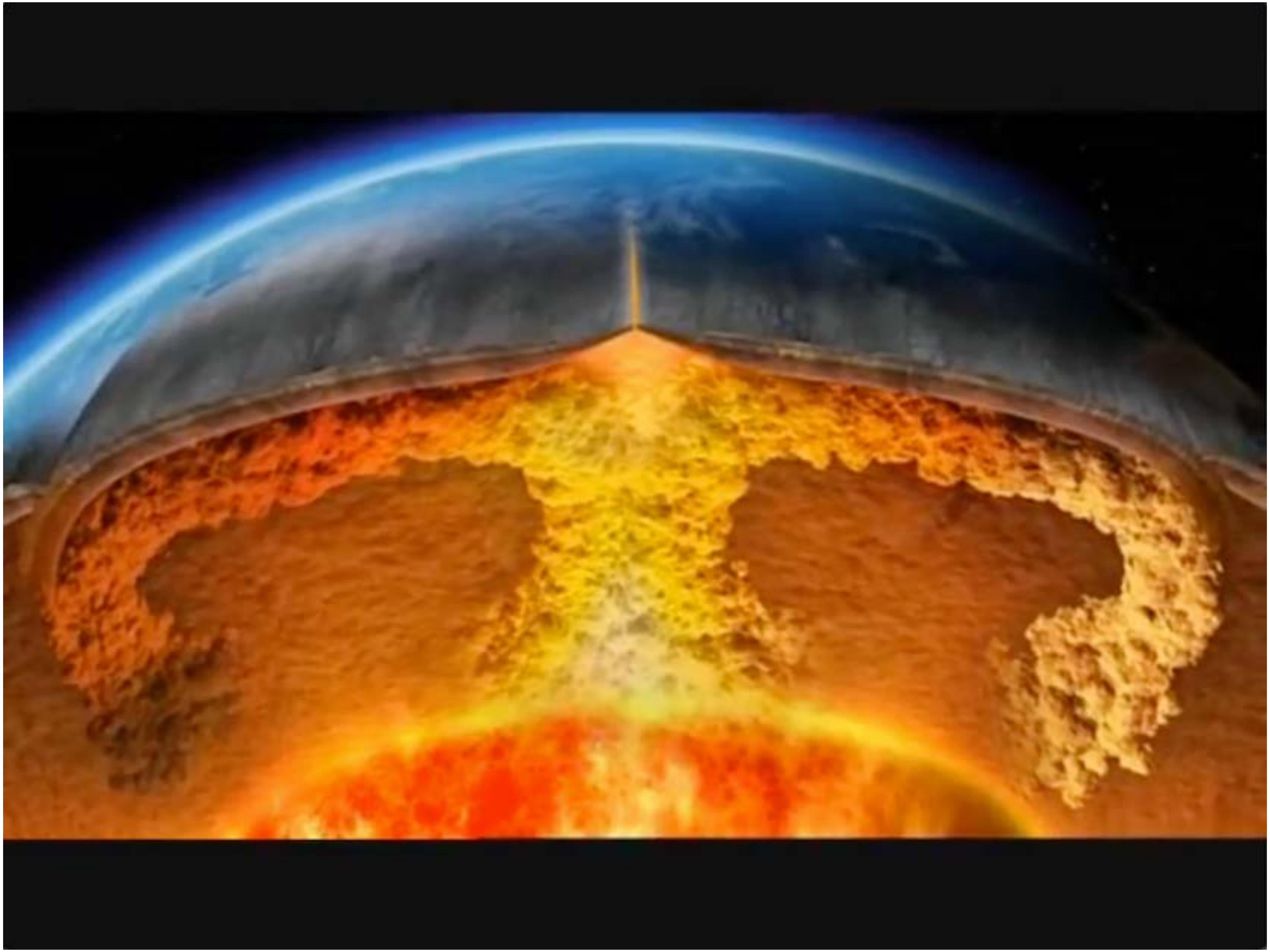


late 1960's and 1970's



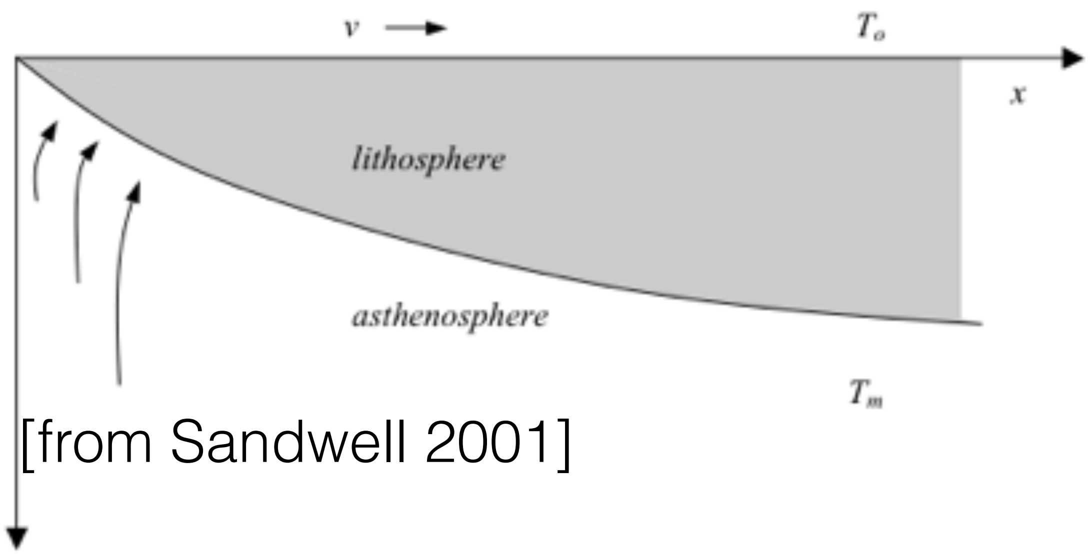
- Tectonic plates
- Plate boundaries … divergent | convergent | transform faults
- Mid-oceanic ridges
- Subduction zones
- Island arcs
- *Hot spots*

Mantle convection, plate tectonics

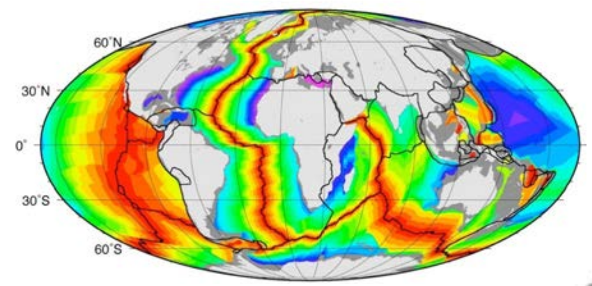


From BBC documentary film "**Earth: The Power Of The Planet**" (youtu.be/ryrXAGY1dmE)

Oceanic heat flux: half-space cooling model



[from Sandwell 2001]

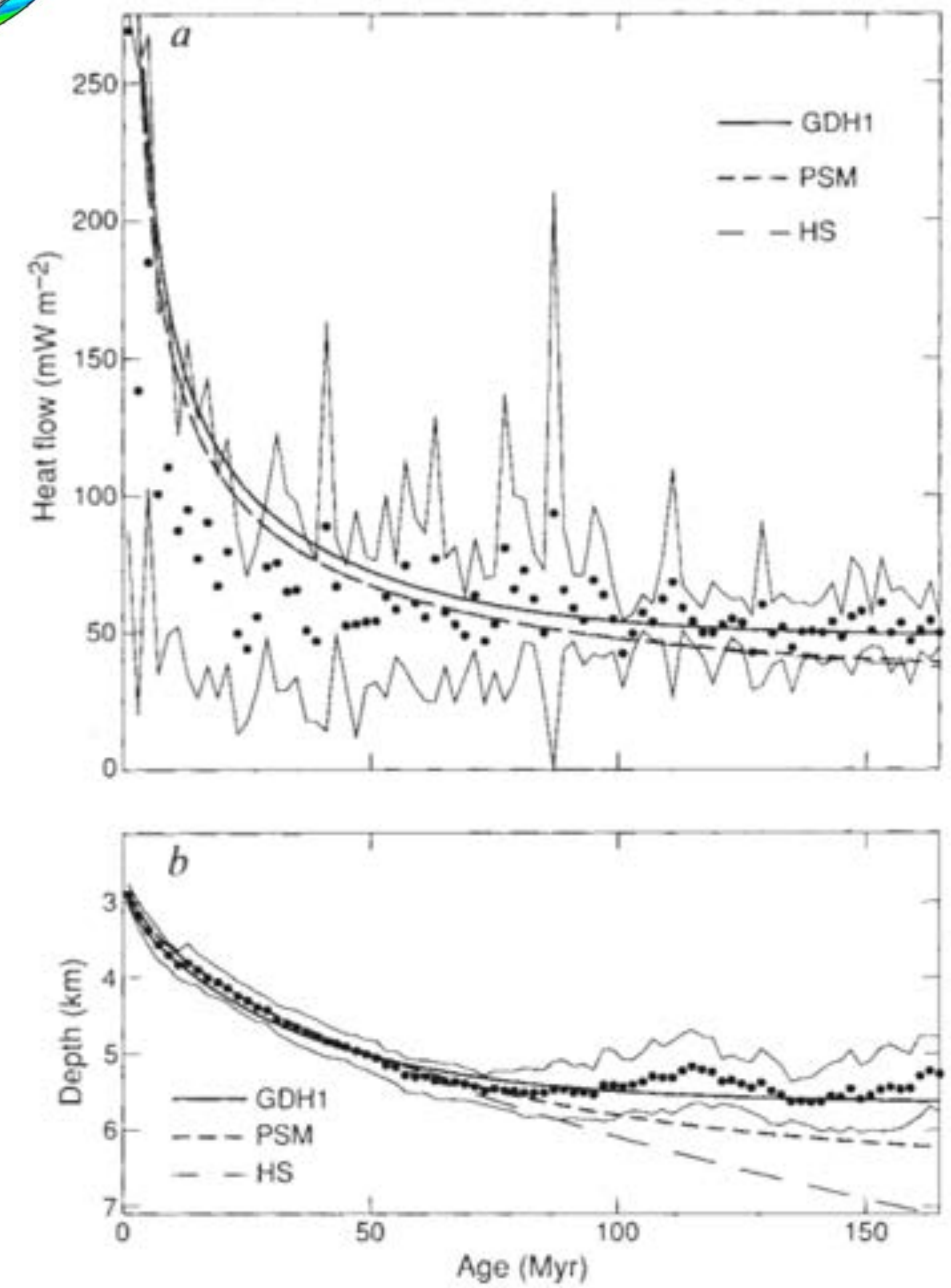


$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}$$

$$T = T_0 + (T_m - T_0)\mathrm{erf}\left(\frac{z}{\sqrt{4\kappa t}}\right)$$

$$\text{heat flow} \propto (\kappa t)^{-1/2}$$

$$\text{ocean depth} \propto (\kappa t)^{1/2}$$



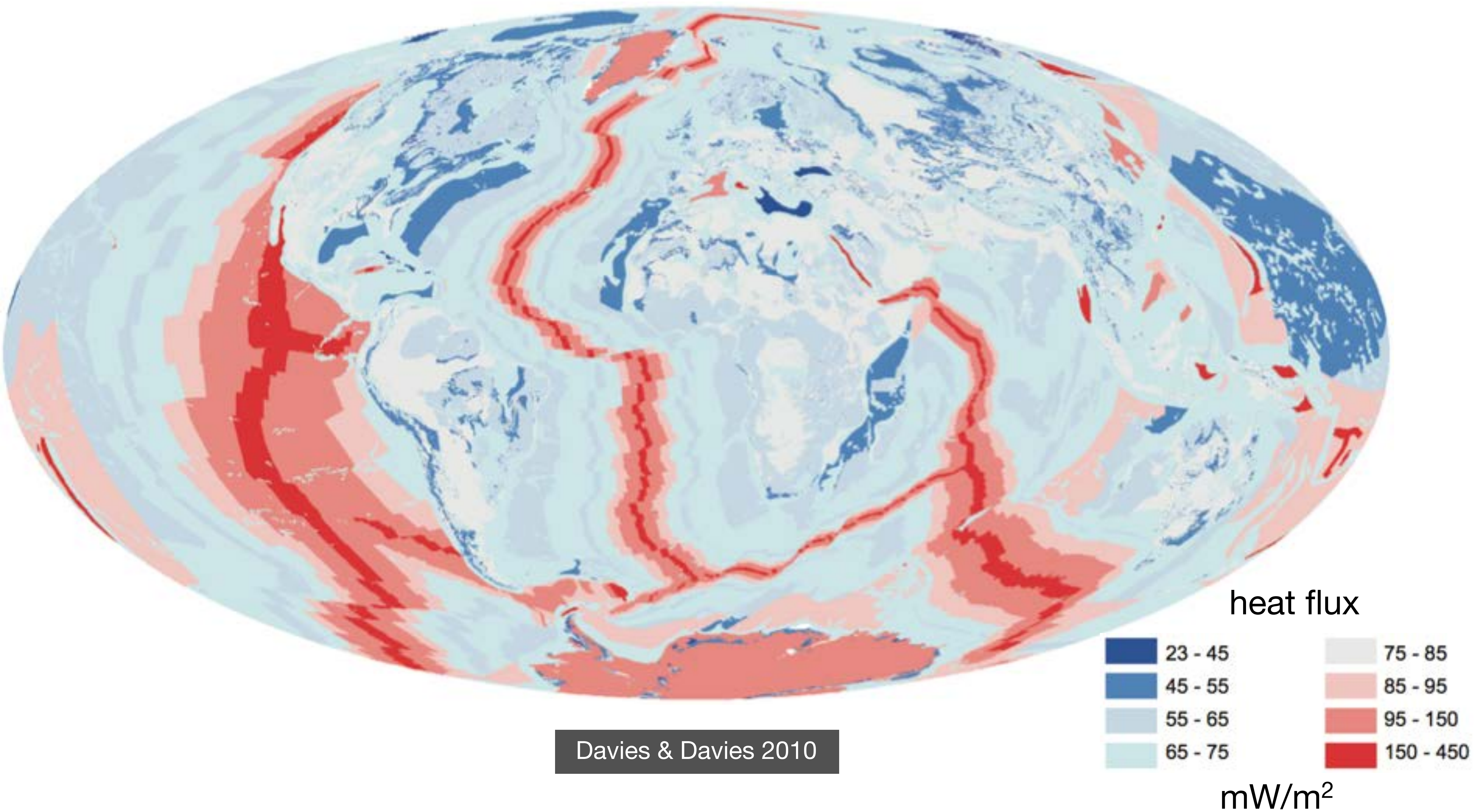
[Stein & Stein 1992]

- explains oceanic heat flow variation with age
- explains ocean depth variation with age

Surface heat flow

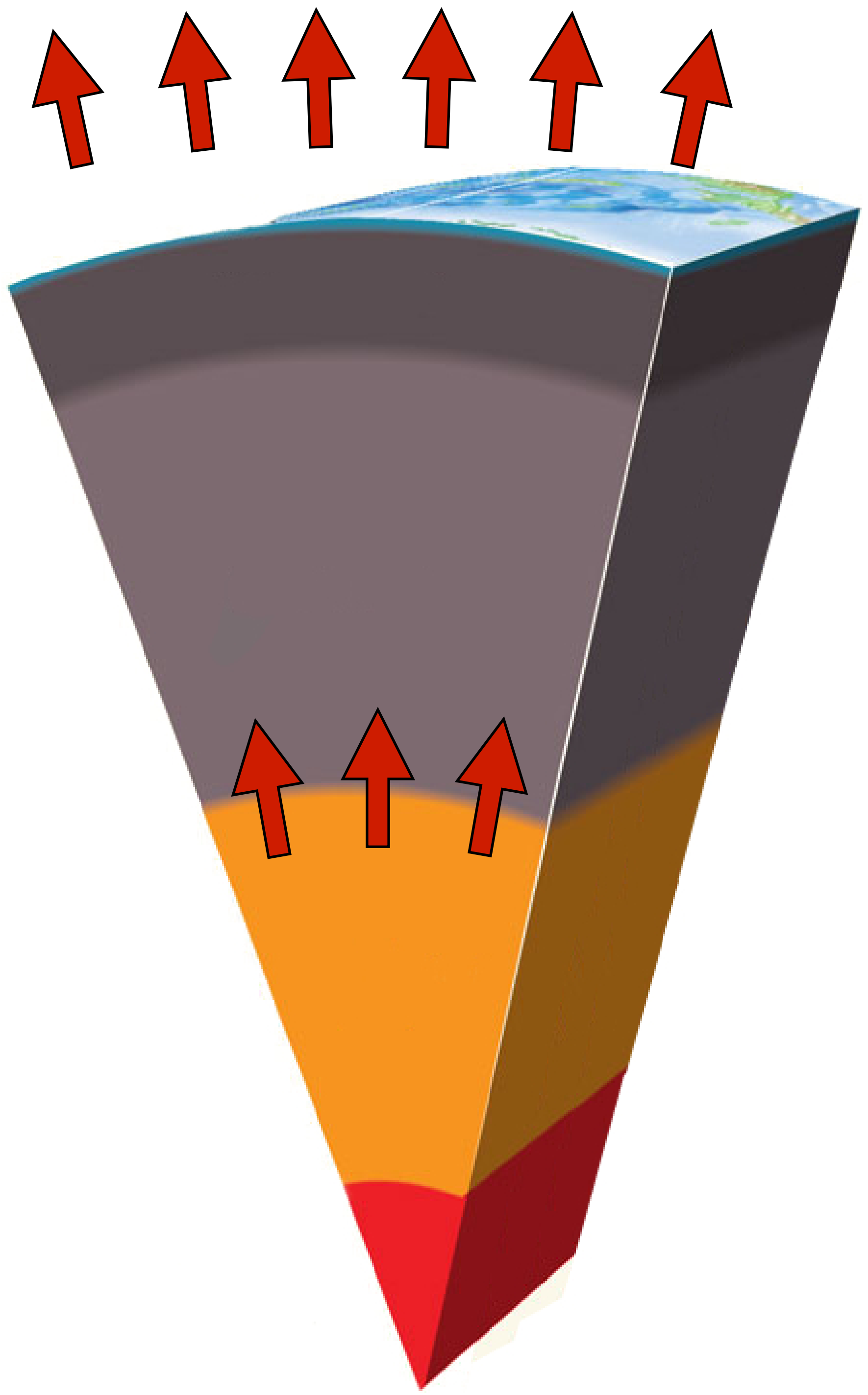
- Young oceans: 128 mW/m^2
- Rest of oceans: 66 mW/m^2
- Continents: 73 mW/m^2

- Pollack et al. (1993): **44 TW**
- Jaupart et al. (2007): **46 ± 3 TW**
- Davies & Davies (2010): **47 ± 1(stat) TW**



Davies & Davies 2010

How come Earth loses heat?



Basic energy balance:

Surface heat flow (46±3 TW)

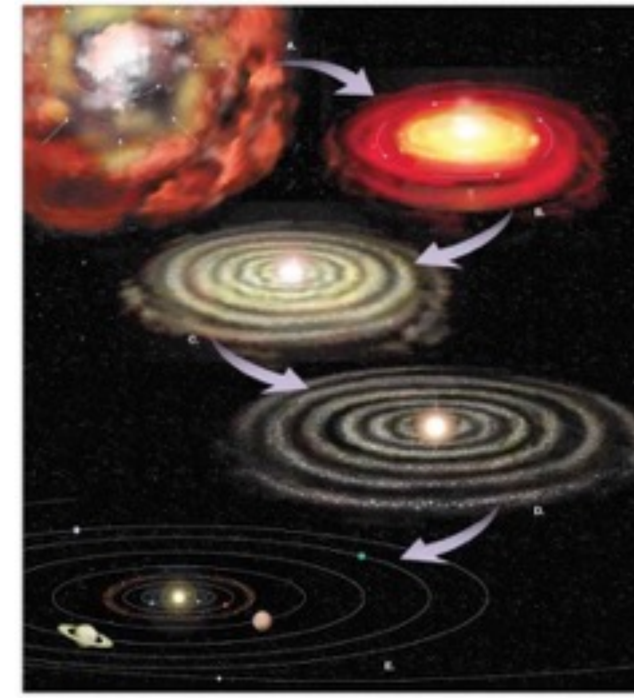
=

Cooling of the interior

+

Heat sources

“Primordial” heat



Planetary formation

Release of gravitational potential energy:

Earth started hot

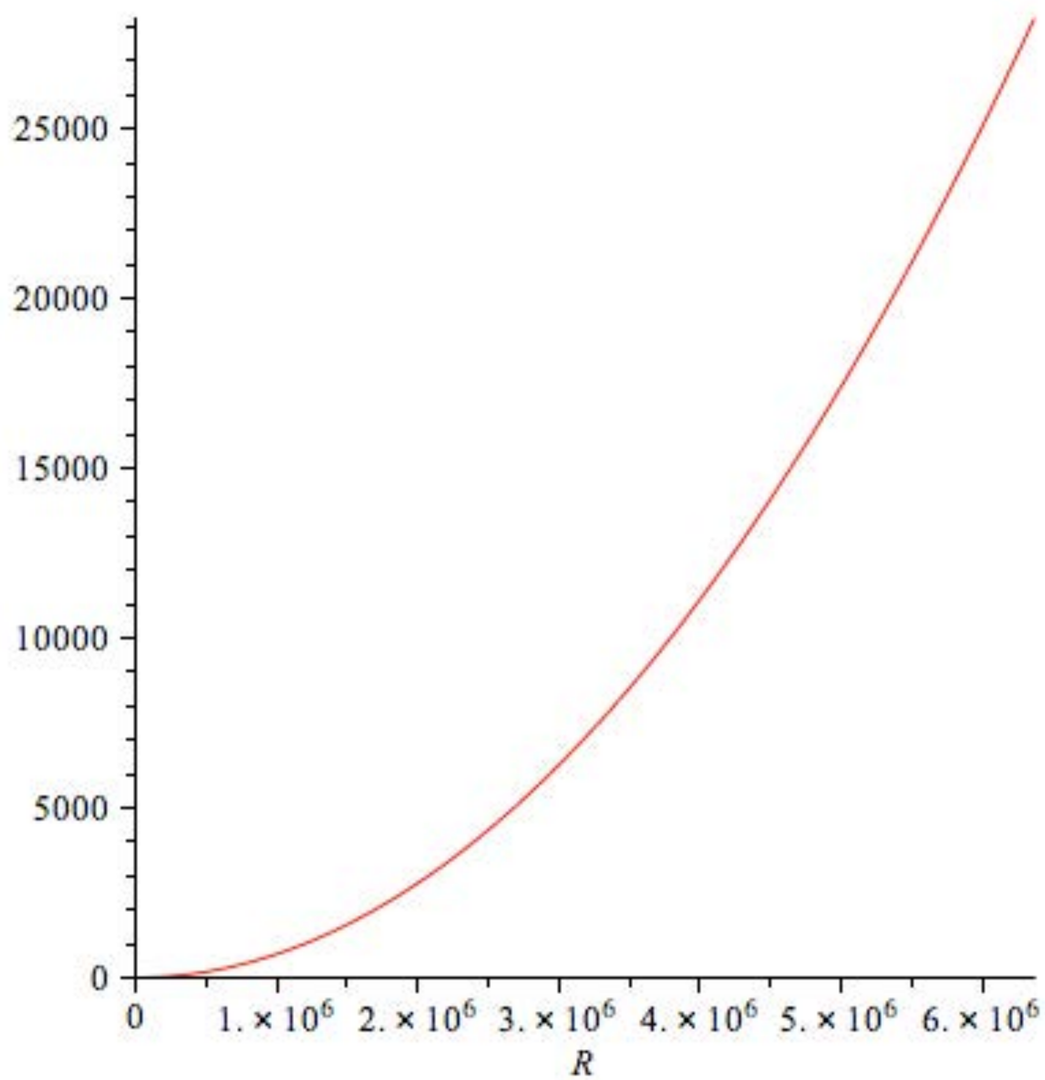
Gravitational binding energy (= −grav. pot. energy)

- Two point masses: $E = G\frac{m_1 m_2}{|\vec{r}_1 - \vec{r}_2|}$
- Number of point masses: $E = \frac{1}{2}\sum_i \sum_{j \neq i} G\frac{m_i m_j}{|\vec{r}_i - \vec{r}_j|}$
- 3-D body: $E = \frac{1}{2}\int\int G\frac{\rho(\vec{r}_1)\rho(\vec{r}_2)}{|\vec{r}_1 - \vec{r}_2|}\mathrm{d}\vec{r}_1\mathrm{d}\vec{r}_2$
- Uniform density sphere:
  - $\mathrm{d}E = G\frac{m_{\mathbf{sphere}}(r)\mathrm{d}m_{\mathbf{shell}}(r)}{r} = \frac{G}{r}\ \frac{4}{3}\pi r^3\rho\ 4\pi r^2\rho\mathrm{d}r = \frac{16}{3}\pi^2 G\rho^2 r^4\mathrm{d}r$
  - $E = \int_0^R \mathrm{d}E = \frac{16}{15}\pi^2 G\rho^2 R^5 = \frac{3GM^2}{5R}$
- Additional binding energy increase due to differentiation, for $\rho_{\text{core}} = c\rho_{\text{mantle}}$, $V_{\text{core}} = b^3 V_{\text{total}}$,
  $\frac{\Delta E}{E_{\text{unif}}} = \frac{1}{2}(c-1)b^3(1-b)\frac{1+b+2b^2(c-1)}{[1+b^3(c-1)]^2}$

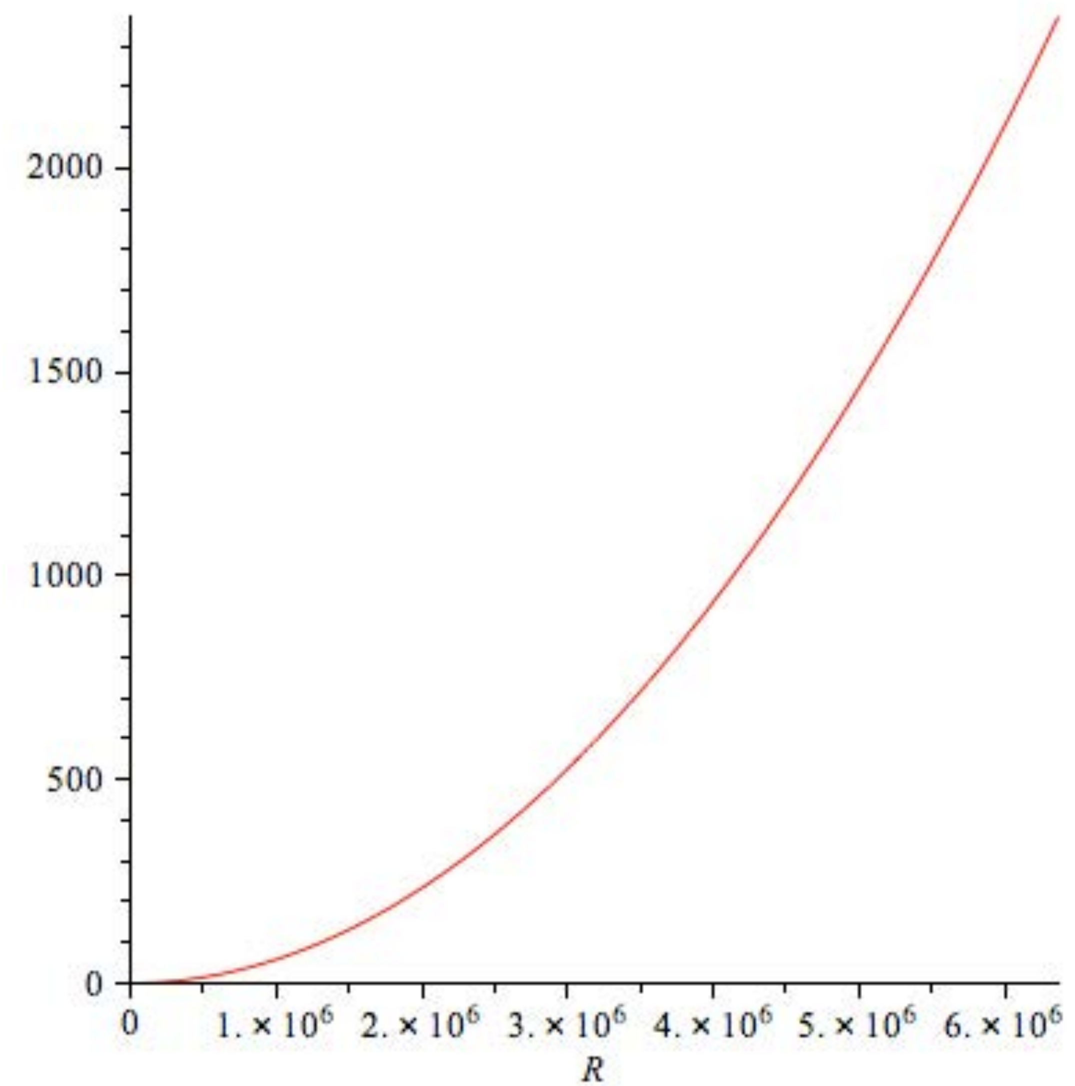
Gravitational binding energy

Equivalent temperature increase (E ~ m C ΔT) to:

Form a uniform planet



Form a dense core



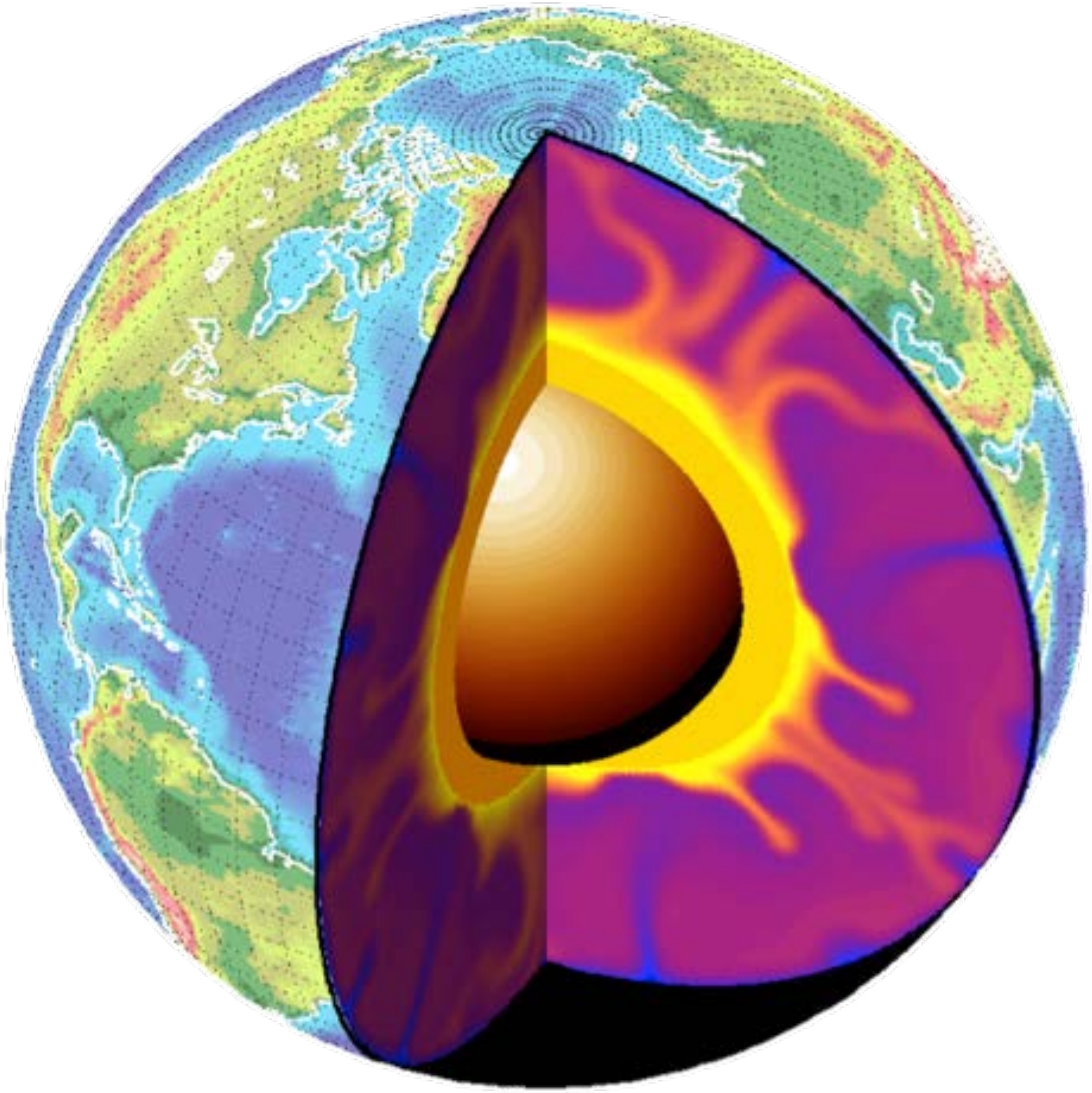
75% rock + 25% metal, densities 3200/7000 kg/m^3, specific heat 1000 J/kg/K

Heat sources in Earth's interior

- Long-lived radioactivity … ***?? TW***
- Continued crust mantle differentiation … **~0.3 TW**
- Tidal heating … **~0.1 TW**
- In the core, related to inner core growth:
    - latent heat
    - compositional energy
    - ohmic dissipation in convecting outer core
    - together with cooling of the core, CMB heat flow **10±5 TW**

Remember: surface heat flow = **46±3 TW**

How much radiogenic heating in the Earth?



What is the Earth made of?

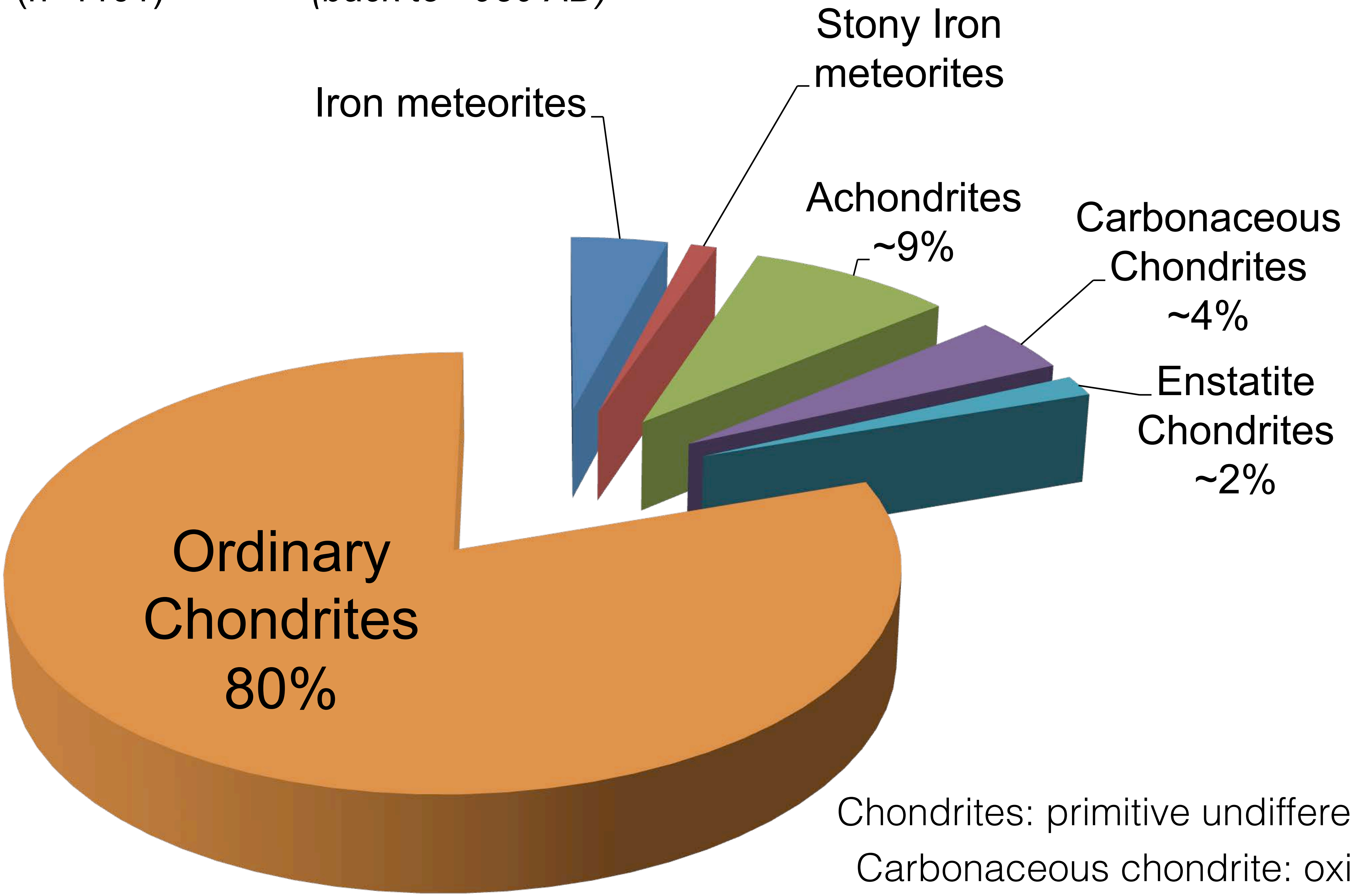
Planetary formation

How to determine composition of a planet without having access for direct sampling?

Clue: Meteorites

Meteorite: Fall statistics

(n=1101) *(back to ~980 AD)*

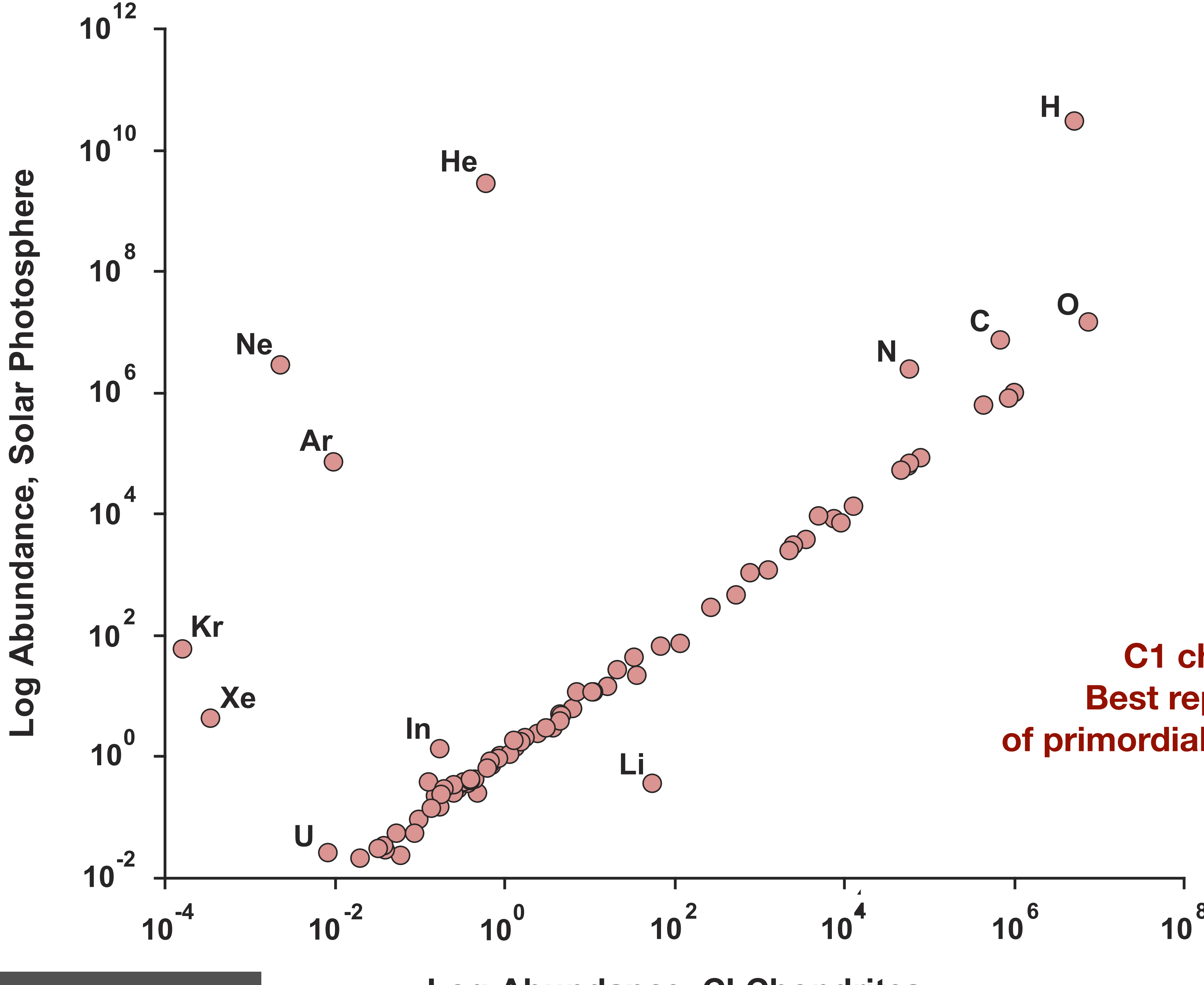


Chondrites: primitive undifferentiated

Carbonaceous chondrite: oxidized

[slide stolen from Bill McDonough]

Composition of C1 chondrites matches solar photospheric abundances



C1 chondrites:
Best representative
of primordial nebular material

from Bill McDonough

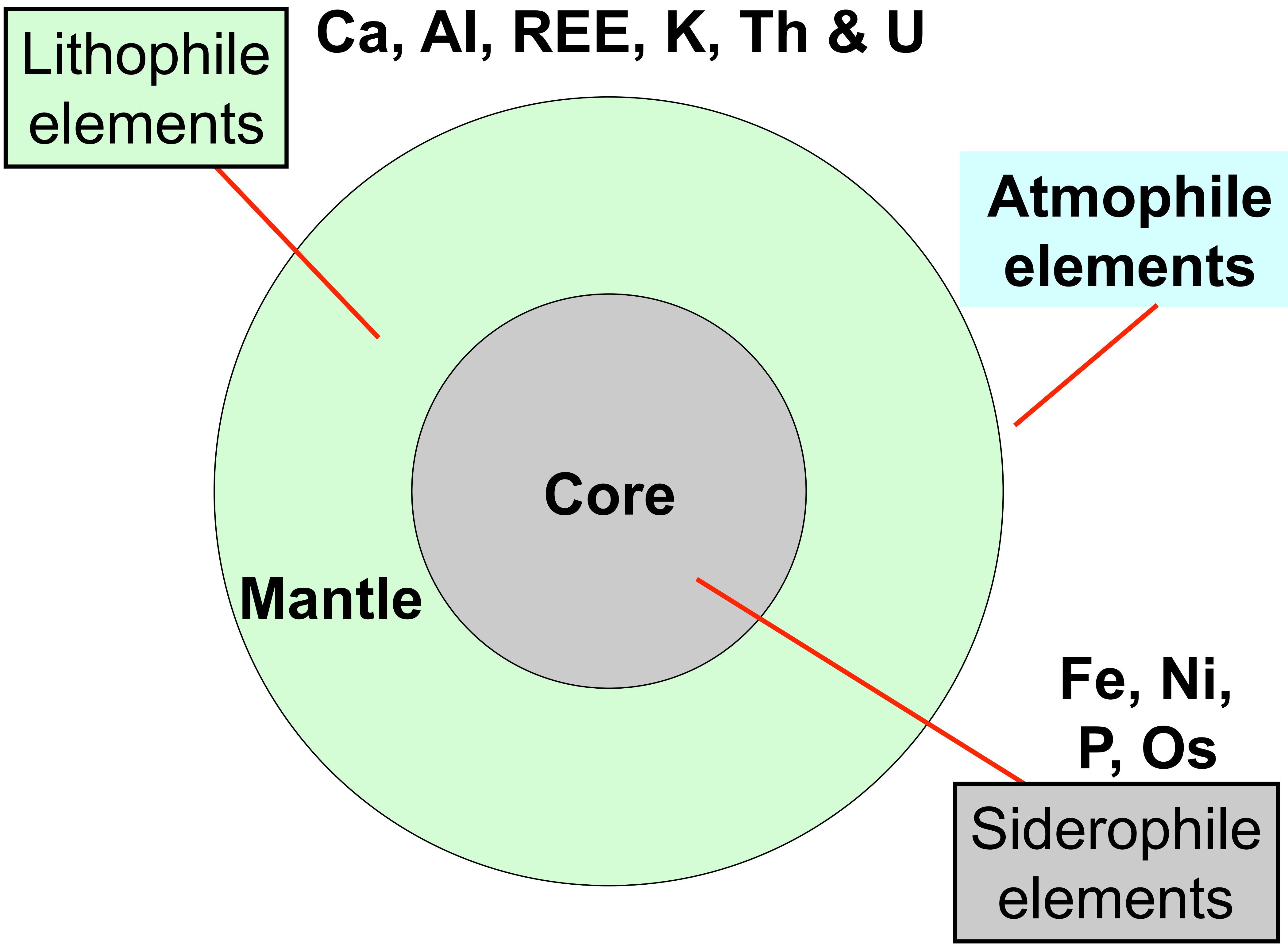
Composition of the Earth

- How does Earth composition relate to C1 chondrites?
- Volatility of elements – refractory (high condensation temperature) vs. volatile (low T_{cond})
- Geochemical behavior of elements
- How are available elements distributed inside the Earth?
    - Core
    - Bulk Silicate Earth = mantle + crust

Constraints

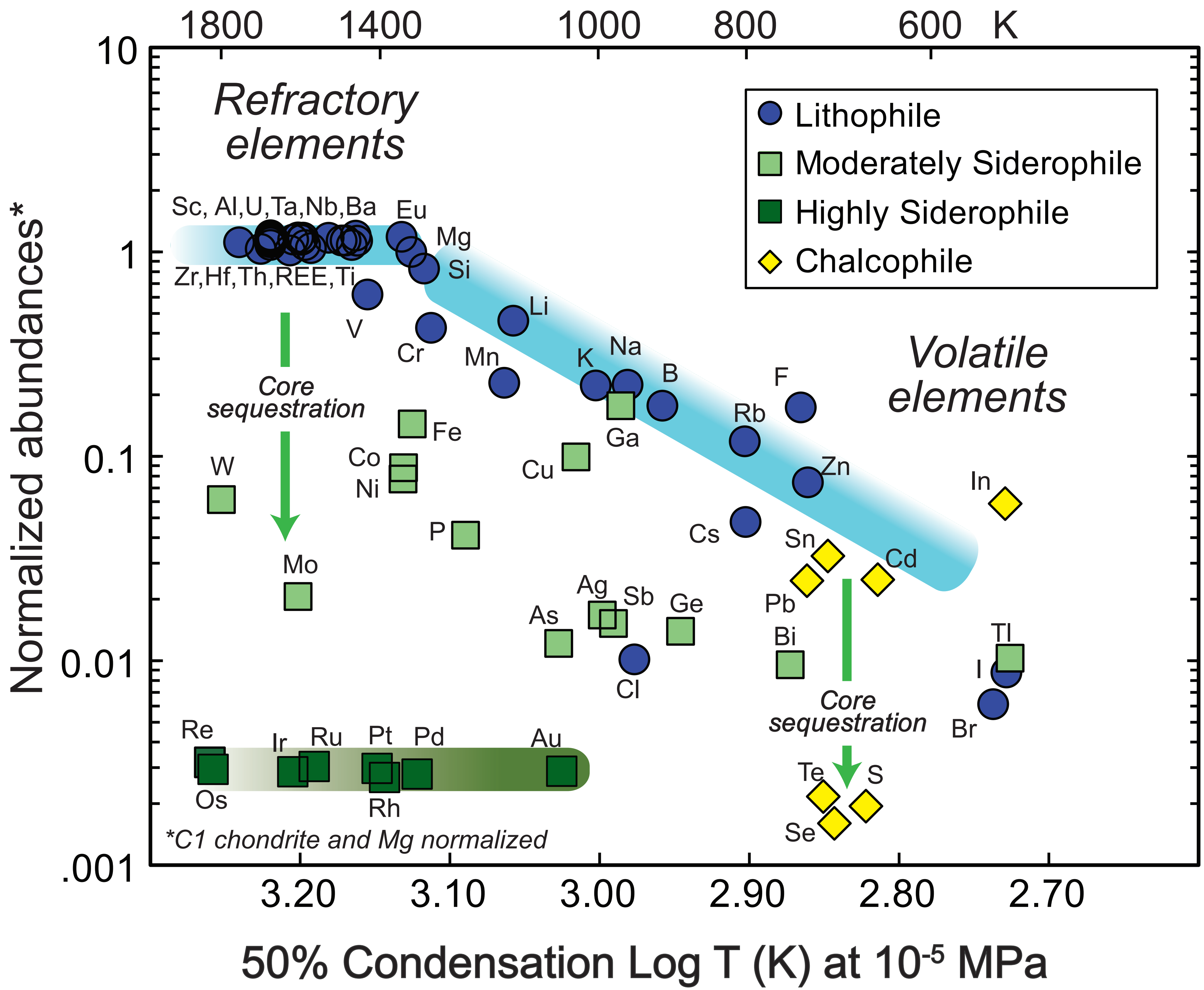
- Mass of the Earth, moment of inertia, gravity analysis
- Seismic imaging (layering, seismic wave speeds)
- Available rock samples
- Constraints from petrology, esp. behavior of elements upon melting

Goldschmidt's Classification of Elements



[slide stolen from Bill McDonough]

Composition of BSE relative to C1 chondrites



Composition of the Earth

- O, Fe, Si, Mg account for 93% of Earth's mass
- + Al, Ca, Ni … 98% of Earth's mass
- minor and trace elements → K Th U
- 20 ppm of U in **Bulk Silicate Earth**
- Th/U ratio of ~4
- K/U ratio of 14000
- **20 TW** of radiogenic heating

^{40}K
^{232}Th
^{238}U

long-lived radioactivity

Alternative compositional estimate

Isotopic similarity between Earth rocks and **enstatite** chondrides

Similarity in oxidation state

Hypothesis: Earth formed from E-chondrite material

Javoy et al. EPSL 2010 ... **12 ppb U** in BSE (Th/U and K/U ratios not so much different)

~11 TW radiogenic power in BSE

Also **"collisional erosion"** model (O'Neill & Palme 2008)

Earth formed with ~20 ppb U in BSE

Differentiated early crust (enriched in U, Th, K)

This crust was lost during a giant impact collision → 10 ppb U in BSE

Yet another estimate of K, Th, U

Caution – oversimplified model

Based on energetics of mantle convection

Parameterized convection models:

heat loss = radiogenic heating + secular cooling

$$Q_s(t) = H_{rad}(t) - C\frac{dT(t)}{dt}$$

Classical scaling between Q_s (Nusselt number) and vigor of convection (Rayleigh number)

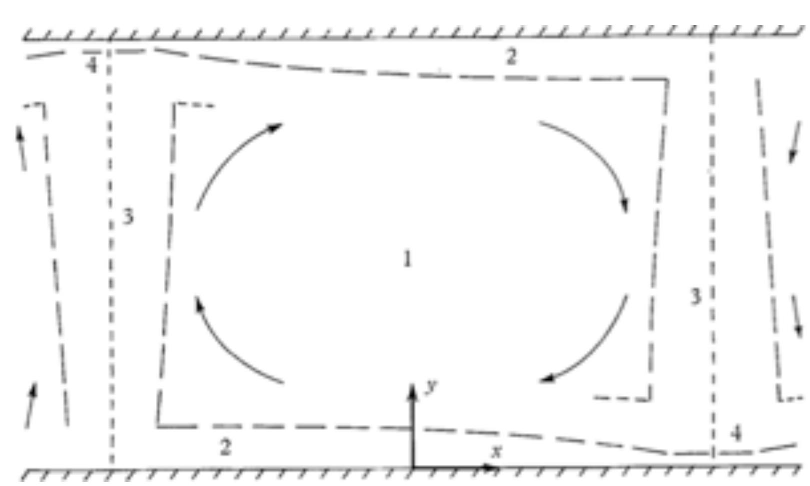
$$Nu \propto Ra(T)^{1/3}$$

Need a large proportion of radiogenic heating to account for mantle heat flow, otherwise “thermal catastrophe” in the Archean

Requires mantle Urey ≥ 0.6 (geochemical = 0.3, cosmochemical = 0.1)

Therefore needs higher abundance of U, Th, K

Radiogenic heating ≥ 30 TW in BSE

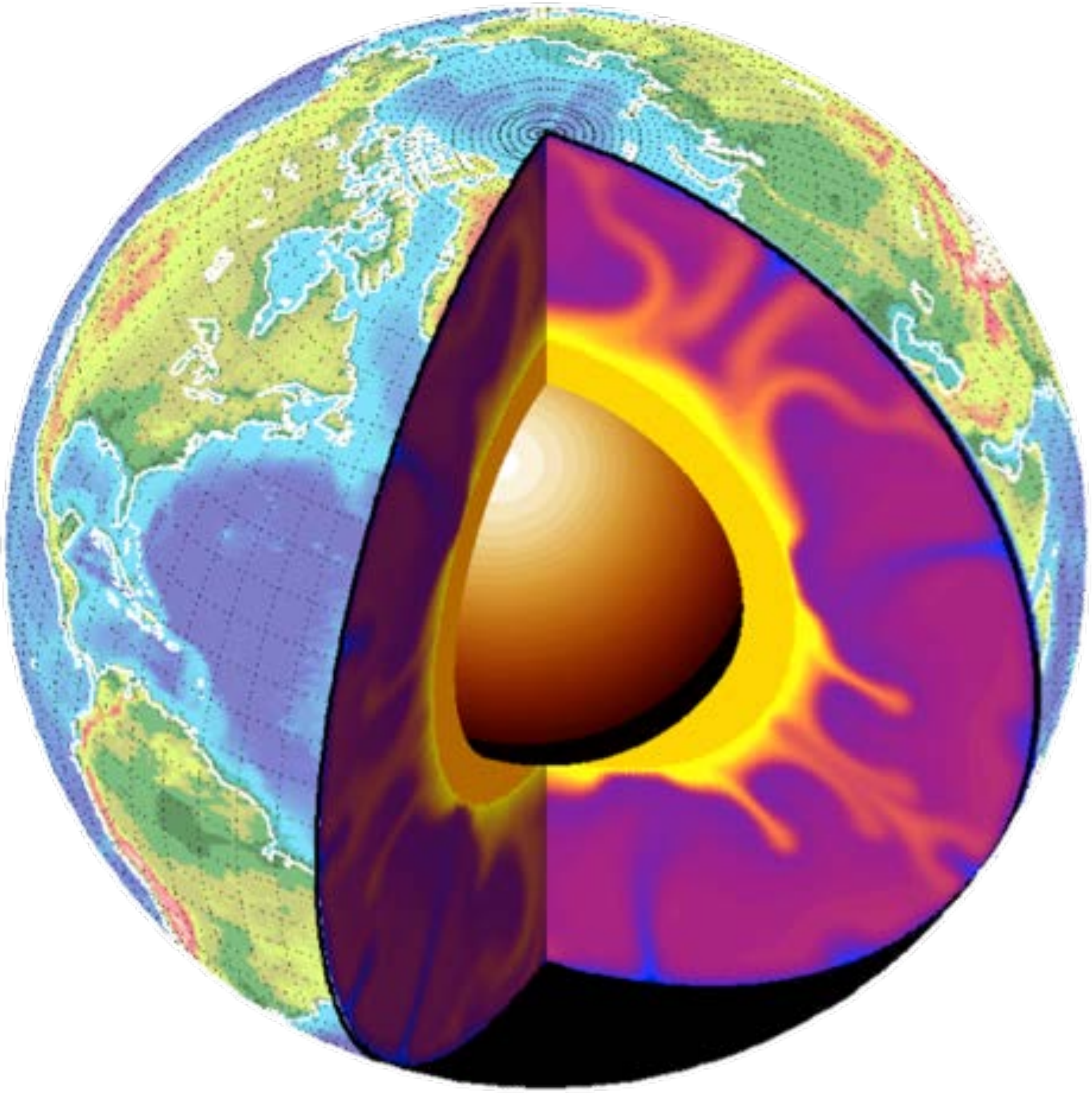


U Th K

Composition of Silicate Earth (BSE)

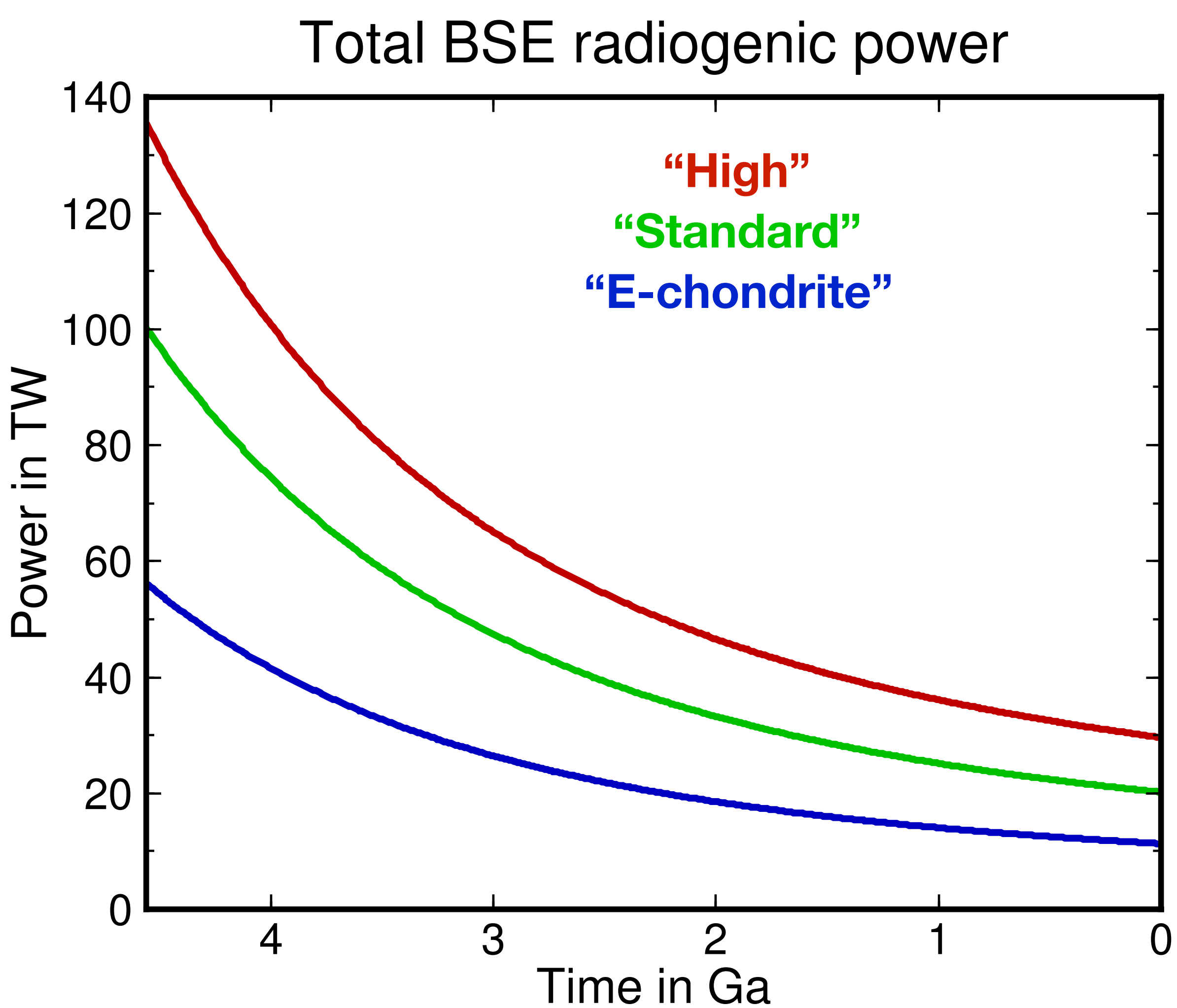
	TW radiogenic power BSE
• **"Standard" estimate** – Ratios of RLE abundances constrained by C1 chondrites – Absolute abundances inferred from Earth rock samples – *McDonough & Sun (1995), Allègre (1995), Hart & Zindler (1986), Palme & O'Neill (2003),* ***Arevalo et al. (2009)***	**20±4**
• **"E-chondrite" estimate** – Isotopic similarity between Earth rocks and E-chondrides – Build the Earth from E-chondrite material – ***Javoy et al. (2010)*** – also "collisional erosion" models (*O'Neill & Palme 2008*)	**11±2**
• **"High" estimate** – Based on a classical parameterized convection model – Requires a high mantle Urey ratio, i.e., high U, Th, K	**33±3**

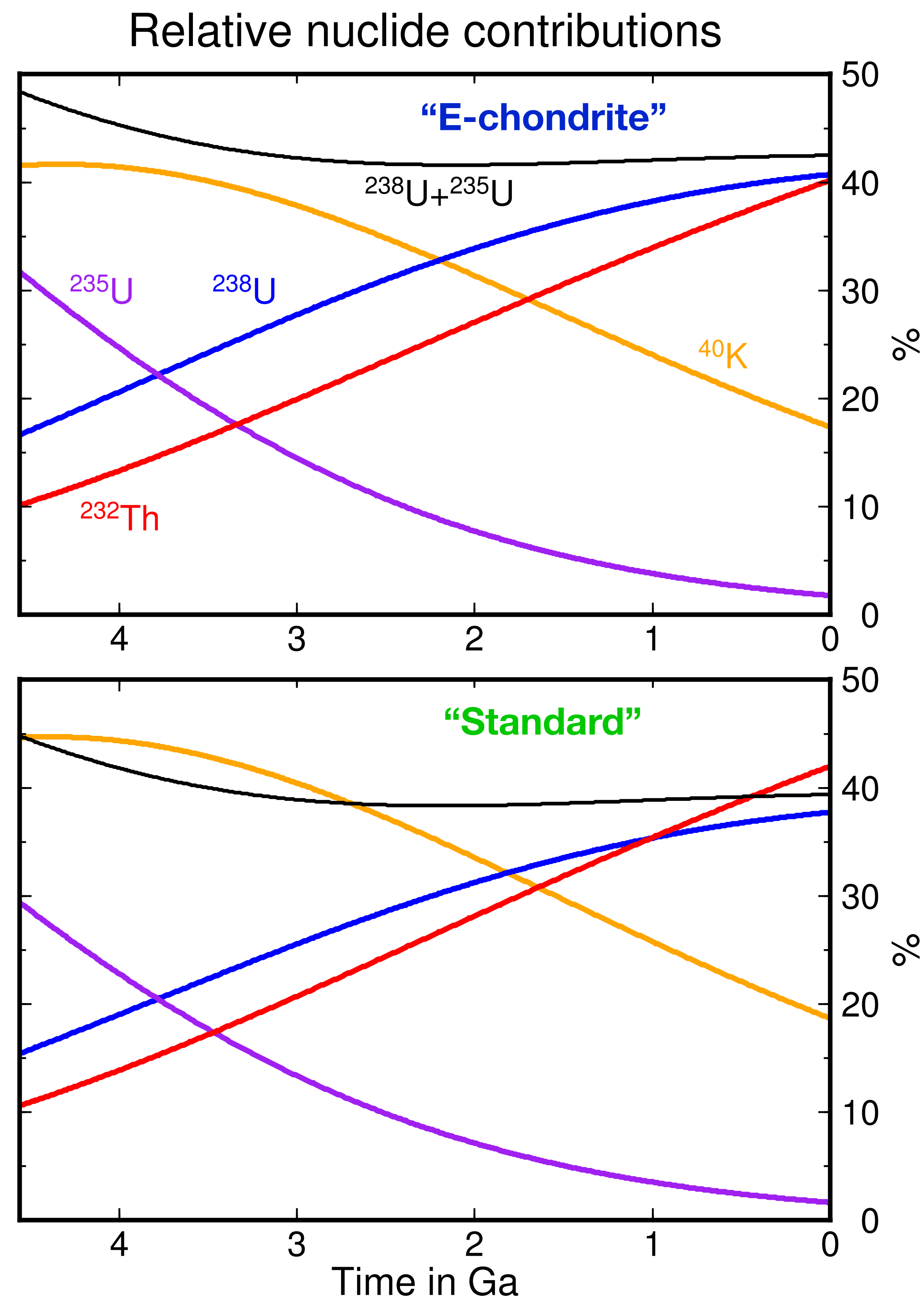
How much radiogenic heating in the Earth?



Estimates range from 9 to 36 TW radiogenic power

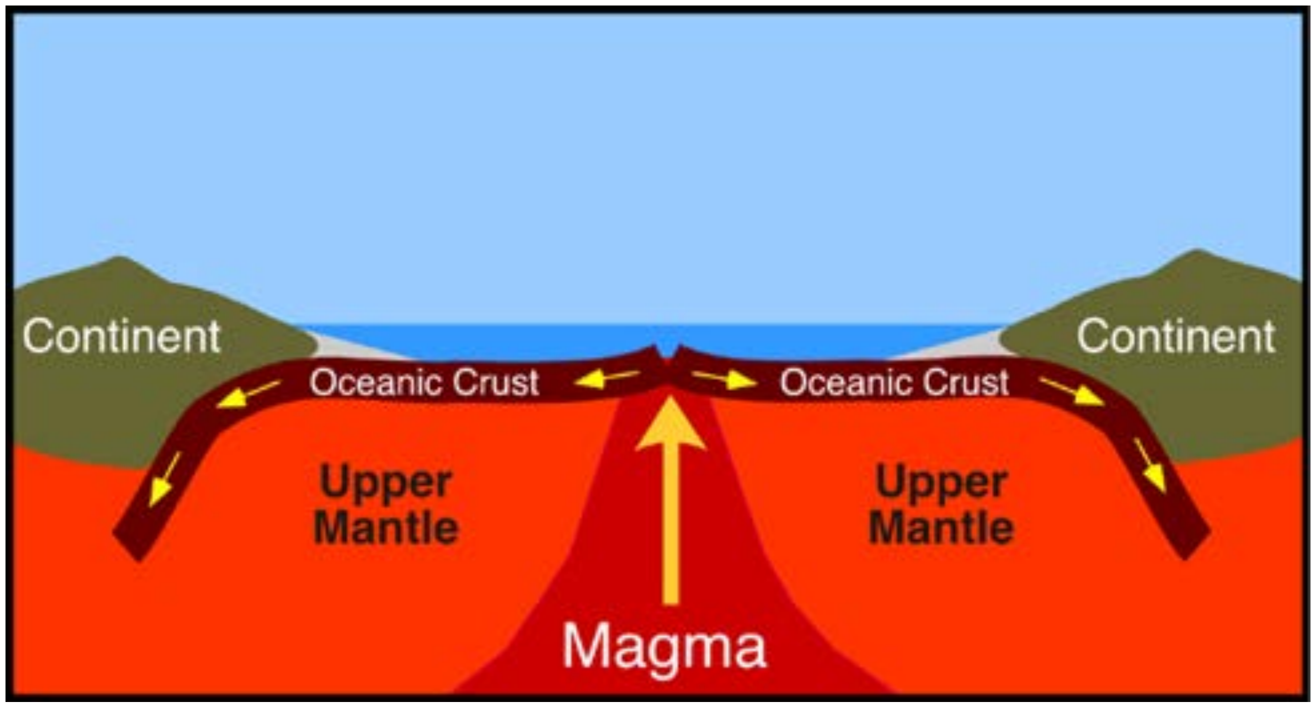
BSE radiogenic power over time

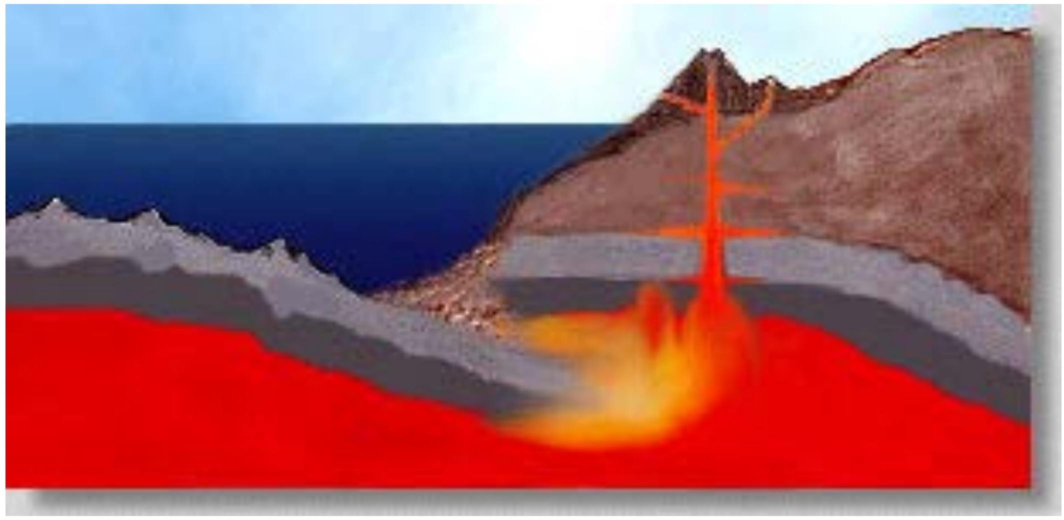




Forming Earth's crust

"Incompatible" elements U, Th, K concentrate in the crust





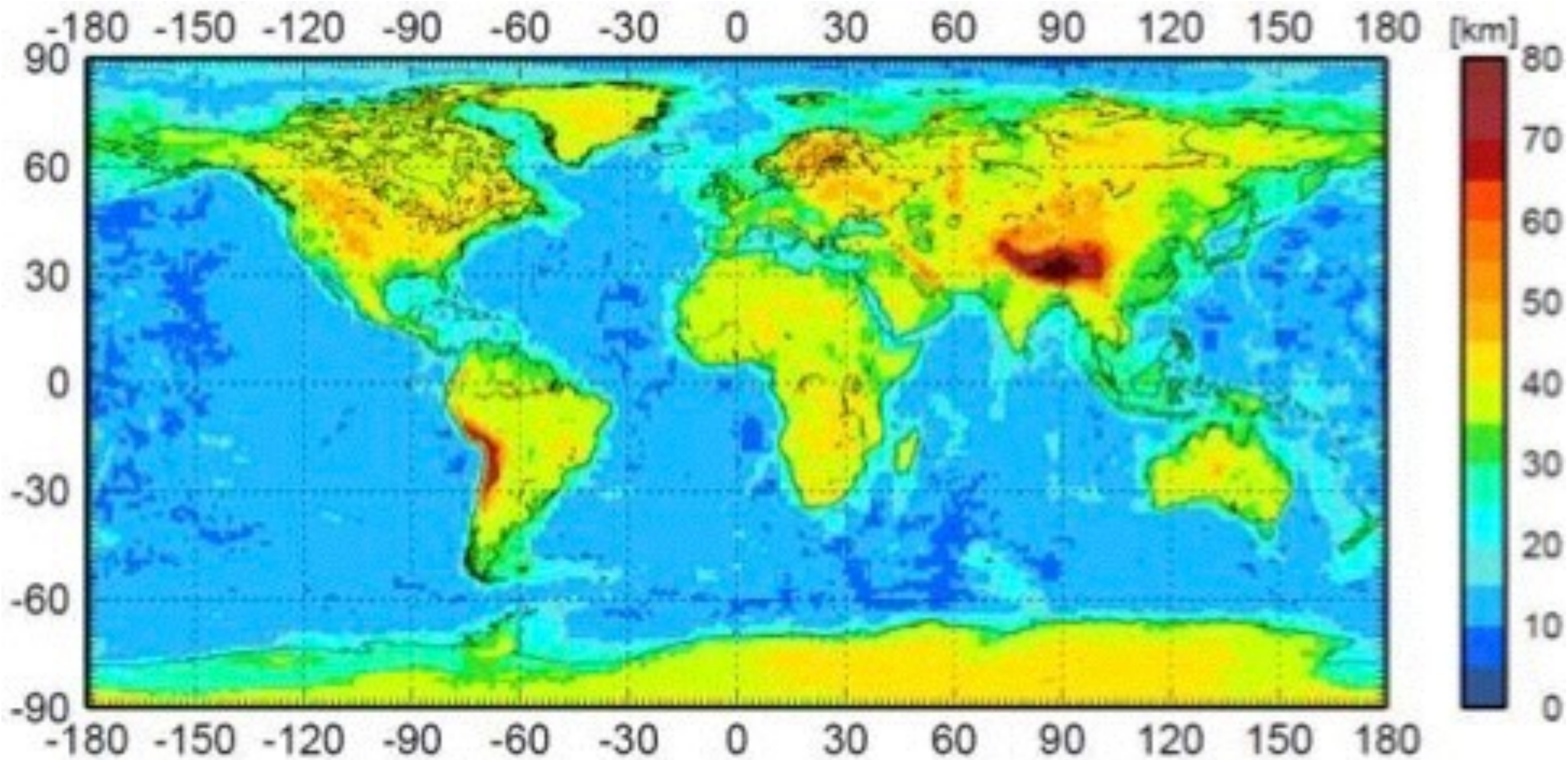
- Some ions do not fit well in the silicate rock crystal structure:
  - "LILE" … large-ion lithophile elements, e.g., **K**
  - "HFSE" … high field strength elements, e.g., **Th, U**
- Upon melting when melt and solid in coexistence, they concentrate in the melt
- Therefore, **crust enriched in K, Th, U**

Crustal heat production

New reference model by Yu Huang et al. (G^3 2013)

Inputs for crustal thickness: CRUST2.0 + CUB2.0 + GEMMA

Inputs for composition: updated and new compositional databases



Continental Crust

6.8 (+1.4/−1.1) TW

Oceanic Crust

0.22 ± 0.03 TW

U Th K

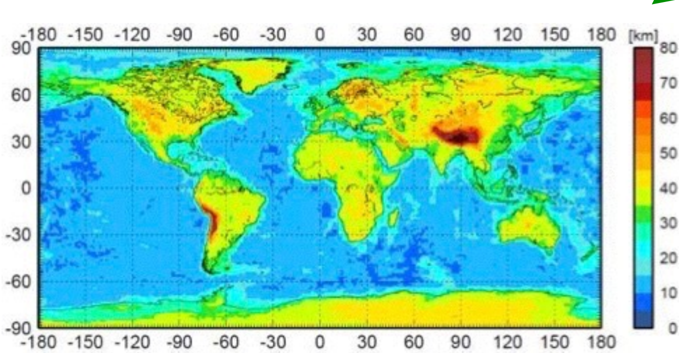
Composition of Silicate Earth (BSE)

- **"Standard"** estimate
  – Ratios of RLE abundances constrained by C1 chondrites
  – Absolute abundances inferred from Earth rock samples
  – *McDonough & Sun (1995), Allègre (1995), Hart & Zindler (1986), Palme & O'Neill (2003),* ***Arevalo et al. (2009)***
- **"E-chondrite"** estimate
  – Isotopic similarity between Earth rocks and E-chondrides
  – Build the Earth from E-chondrite material
  – ***Javoy et al. (2010)***
  – also "collisional erosion" models (*O'Neill & Palme 2008*)
- **"High"** estimate
  – Based on a classical parameterized convection model
  – Requires a high mantle Urey ratio, i.e., high U, Th, K

TW radiogenic power

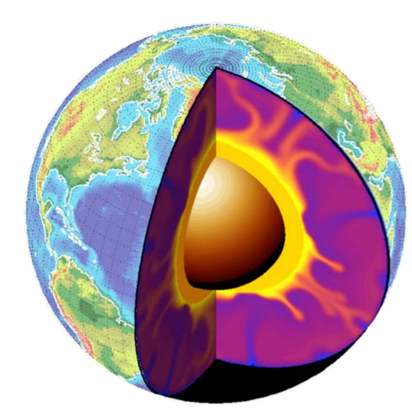
	BSE	Mantle
"Standard"	20±4	13±4
"E-chondrite"	11±2	4±2
"High"	33±3	26±3

BSE = Mantle + Crust

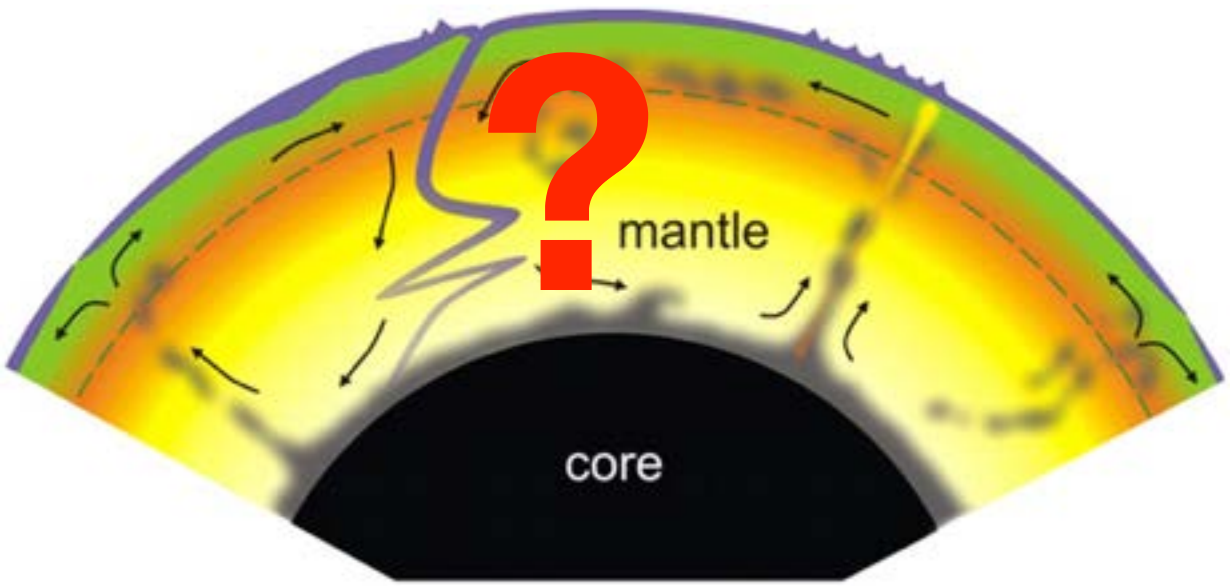


0.22 ± 0.03 TW

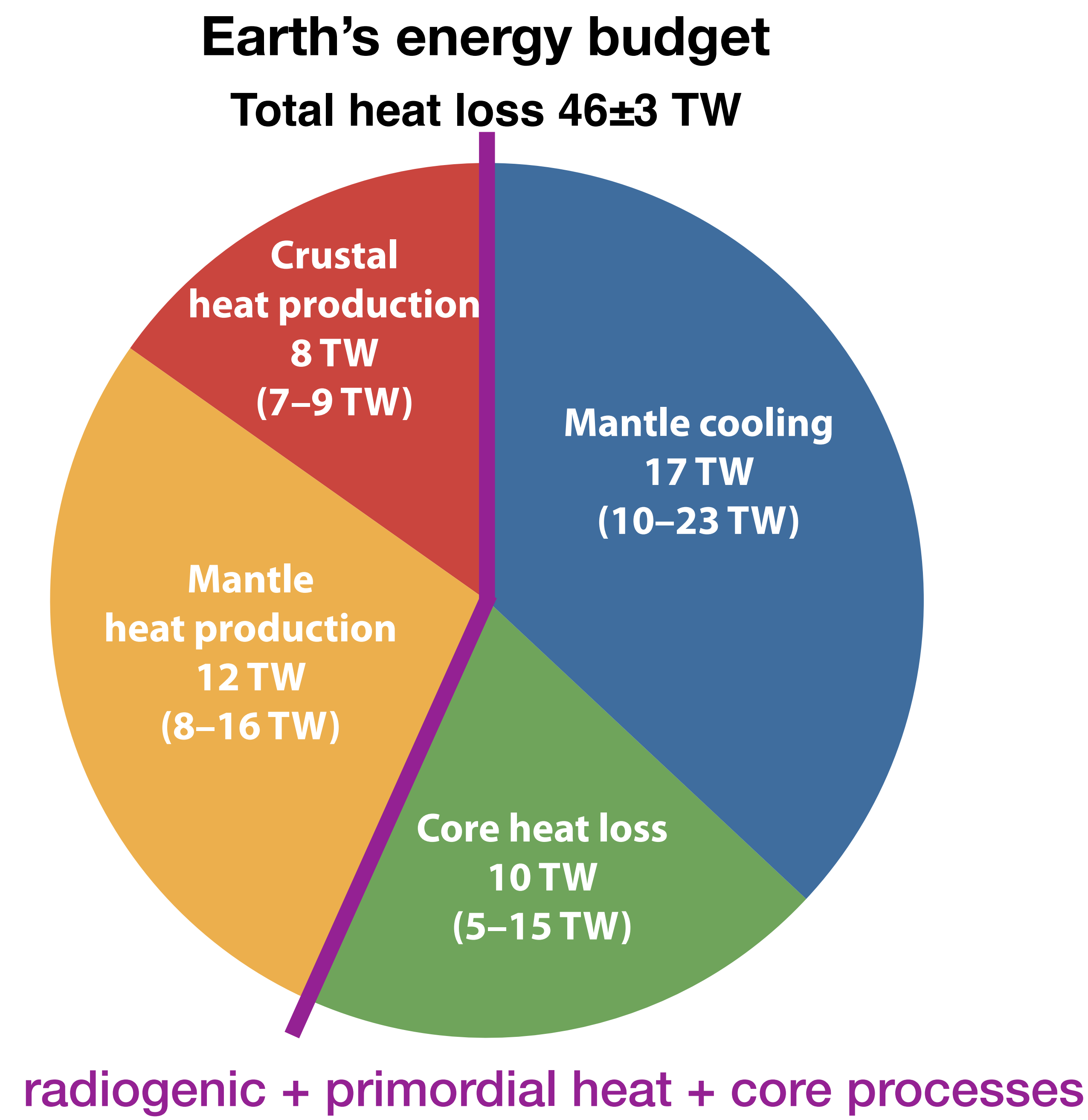
6.8 (+1.4/–1.1) TW



How much radiogenic heating in the mantle to power convection?

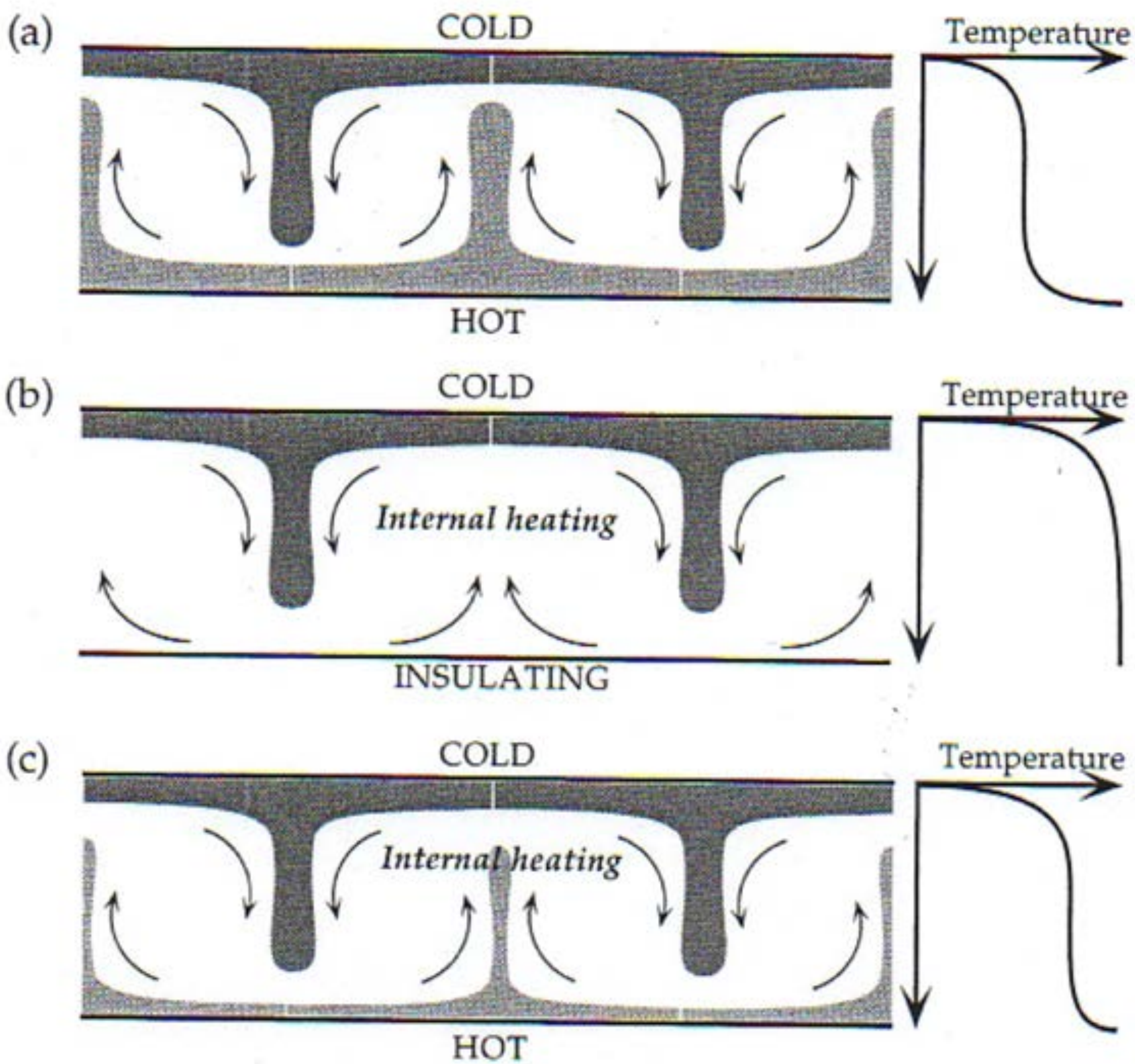


Estimates from 2 to 29 TW radiogenic power in the mantle



How much internal heating in the mantle?

- thermal boundary layers
- upwellings, downwellings
- convection cells

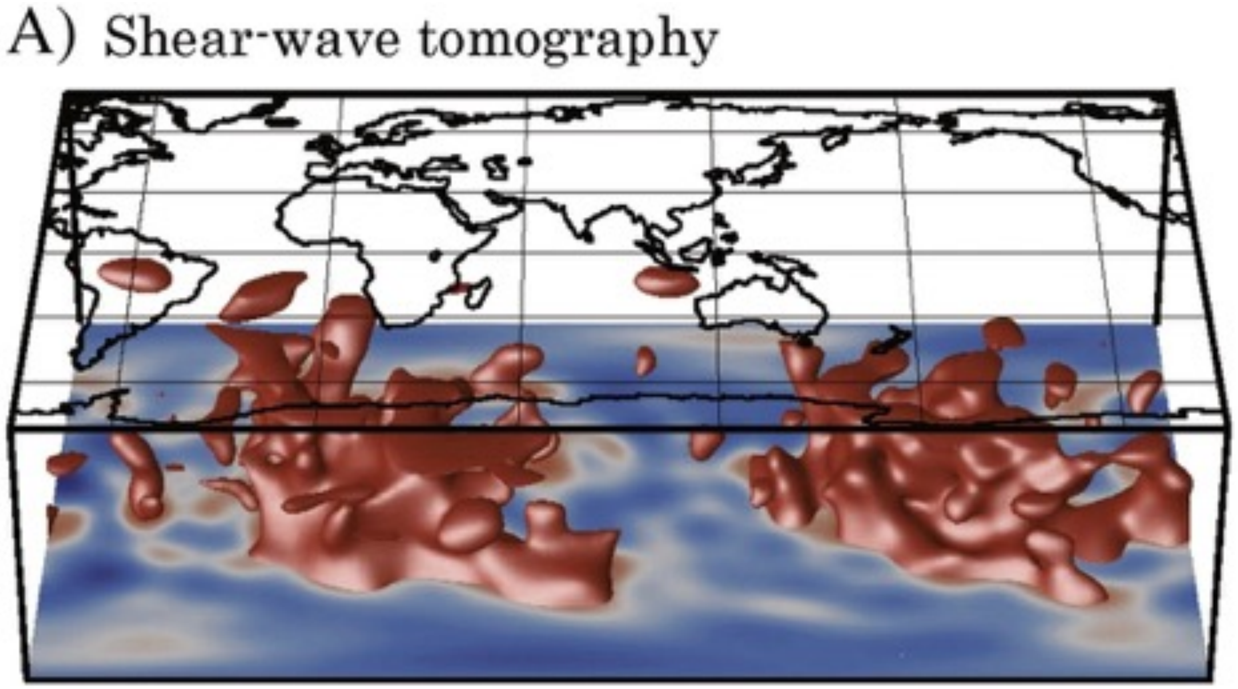


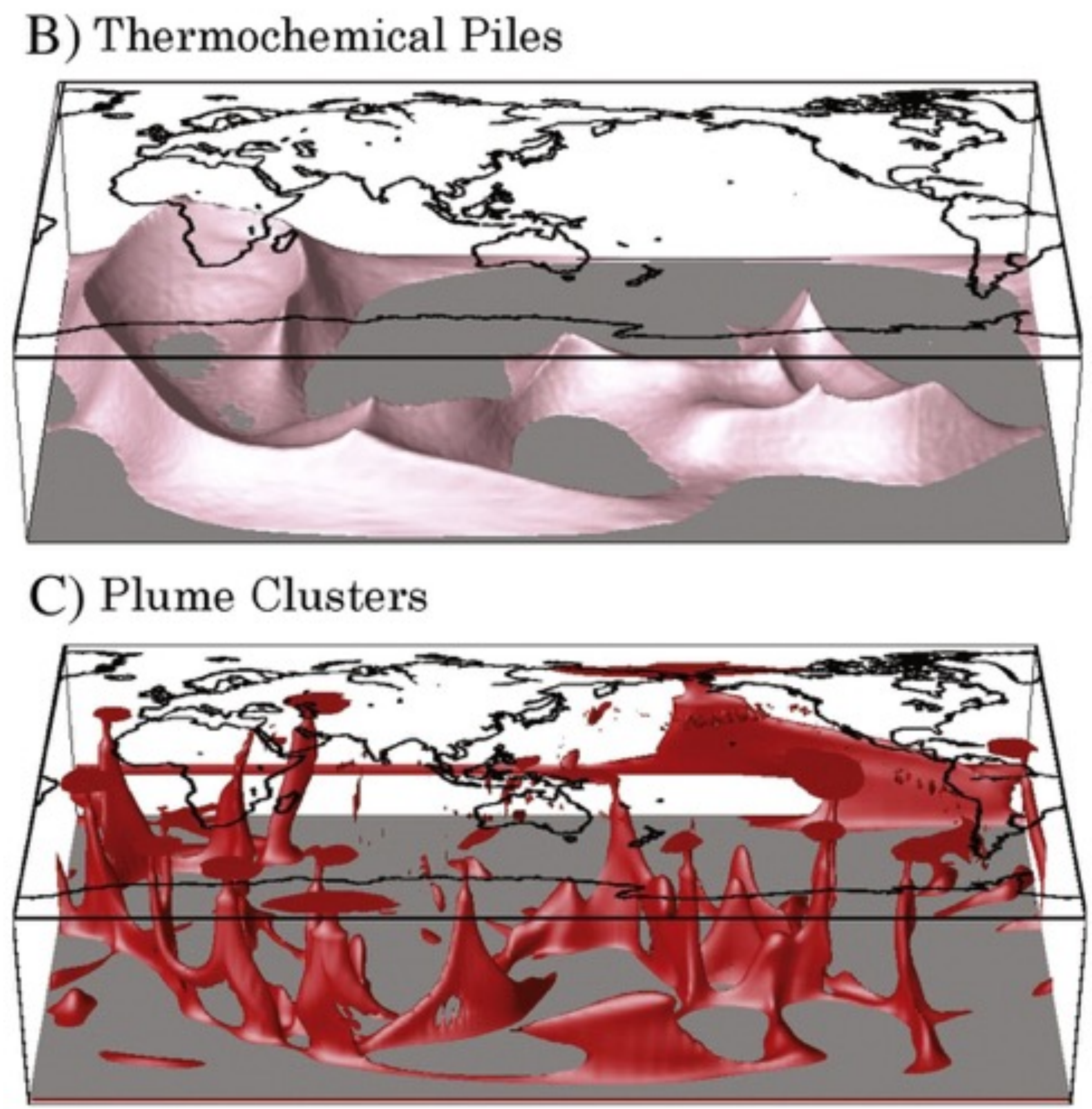
no internal heating

no basal heating

mixed heating ... Earth mantle

Layering, chemical reservoirs in the mantle?





Chemical reservoir enriched
in heat-producing
elements?

Architecture
of the Earth’s mantle...

en.wikipedia.org/wiki/Geoneutrino

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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, the lightest of the known subatomic particles, lack measurable electromagnetic properties and interact only 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 integrated information about the abundances of their radioactive sources inside the Earth. A major objective of the emerging field of **neutrino geophysics** involves extracting geologically useful information (e.g., abundances of individual geoneutrino-producing elements and their spatial distribution in Earth's interior) from geoneutrino measurements.

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 energies above the corresponding threshold (1.8 MeV). In neutrino experiments, large underground liquid scintillator detectors record the flashes of light generated from this interaction. As of 2013 geoneutrino measurements at two sites, as reported by the KamLAND and Borexino collaborations, have begun to place constraints on the amount of radiogenic heating in the Earth's interior. A third detector (SNO+) is expected to start collecting data in 2015. A number of future geoneutrino detectors are being planned.

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2015 Physics Prize

Ill: © Johan Jarnestad/The Royal Swedish Academy of Sciences

2015 Nobel Prize in Physics

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald "for the discovery of neutrino oscillations, which shows that neutrinos have mass".

Takaaki Kajita: "Kind of Unbelievable!"

An interview with Takaaki Kajita immediately following the announcement of the Physics Prize. Hear how he reacted when he got the call that he has been awarded the 2015 Nobel Prize in Physics.

"I Gave My Wife a Hug!"

"It's ironic, in order to observe the sun you have to go kilometers under ground. That's not what you would expect." says Arthur B. McDonald, awarded the 2015 Physics Prize.

→ Interview and transcript

"A Fundamental Discovery in Physics"

The discovery that neutrinos are not massless makes a difference, says Professor Olga Botner, Member of the Nobel Committee for Physics, when interviewed about the importance of this year's Nobel Prize in Physics.

FUNDAMENTAL PHYSICS
BREAKTHROUGH
PRIZE


Kam-Biu Luk and the Daya Bay Collaboration


Yifang Wang and the Daya Bay Collaboration


Koichiro Nishikawa and the K2K and T2K Collaboration


Atsuto Suzuki and the KamLAND Collaboration


Arthur B. McDonald and the SNO Collaboration

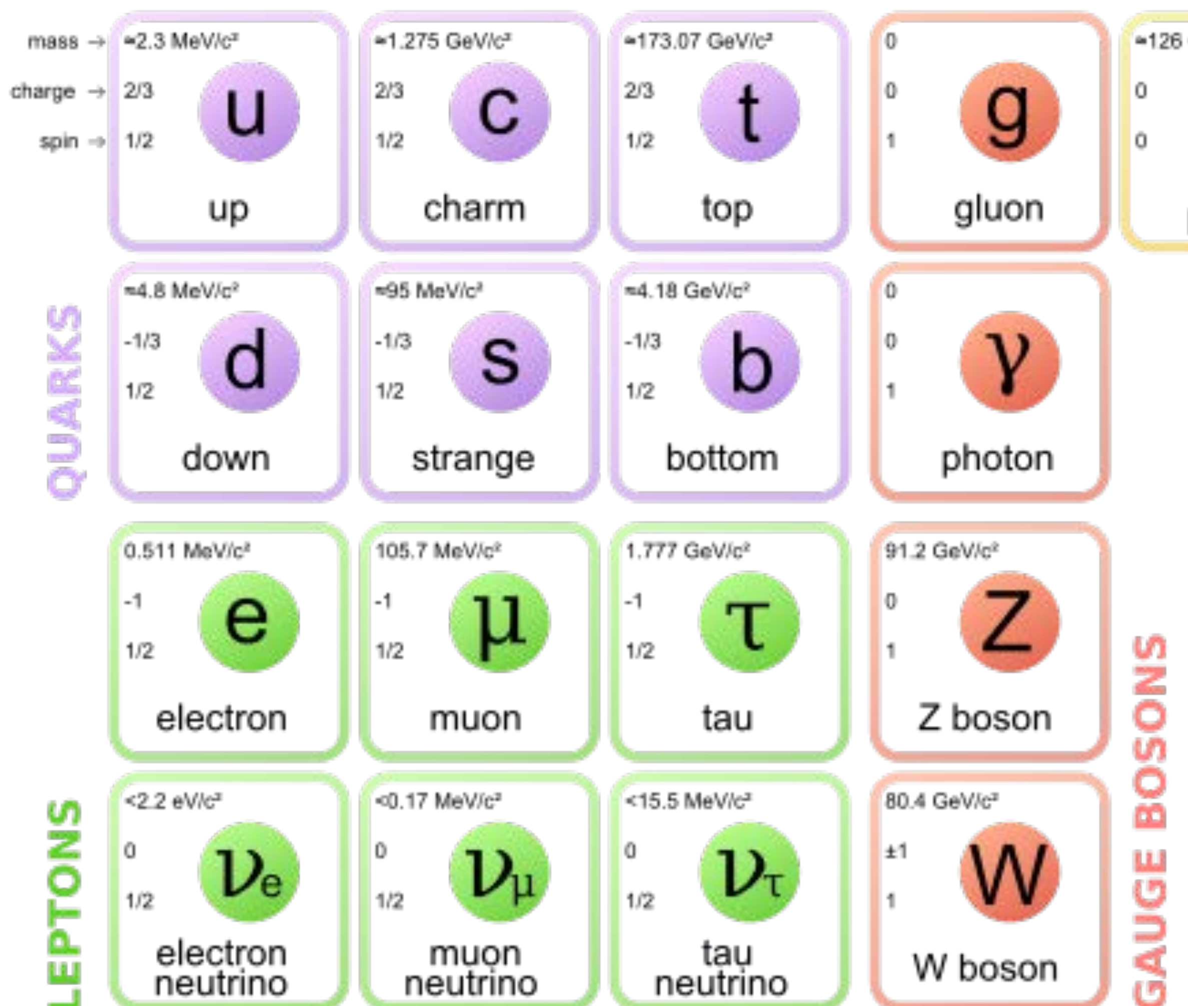

Takaaki Kajita and the Super K Collaboration


Yoichiro Suzuki and the Super K Collaboration

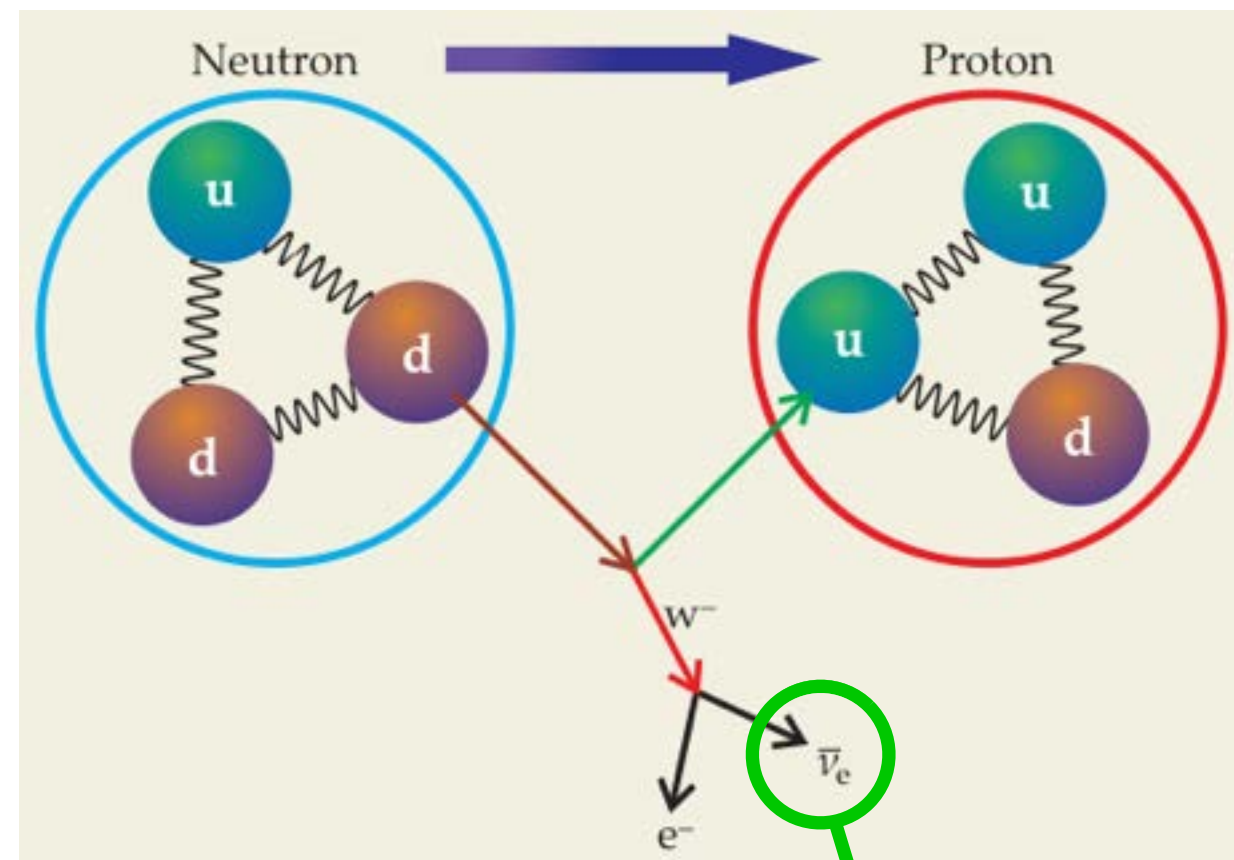
Včetně kolegů z UČJF, členů Daya Bay Collaboration!

What are neutrinos?

Standard Model of elementary particles



β^- decay



electron antineutrino

Geoneutrinos?

Electron anti-neutrinos emitted in β⁻ decays
of naturally occurring radionuclides

$$^{238}_{92}\mathrm{U} \longrightarrow ^{206}_{82}\mathrm{Pb} + 8\alpha + 6e^- + 6\bar{\nu}_e + 51.698\,\mathrm{MeV}$$
$$^{232}_{90}\mathrm{Th} \longrightarrow ^{208}_{82}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.652\,\mathrm{MeV}$$
$$^{40}_{19}\mathrm{K} \xrightarrow{89.3\,\%} ^{40}_{20}\mathrm{Ca} + e^- + \bar{\nu}_e + 1.311\,\mathrm{MeV}$$

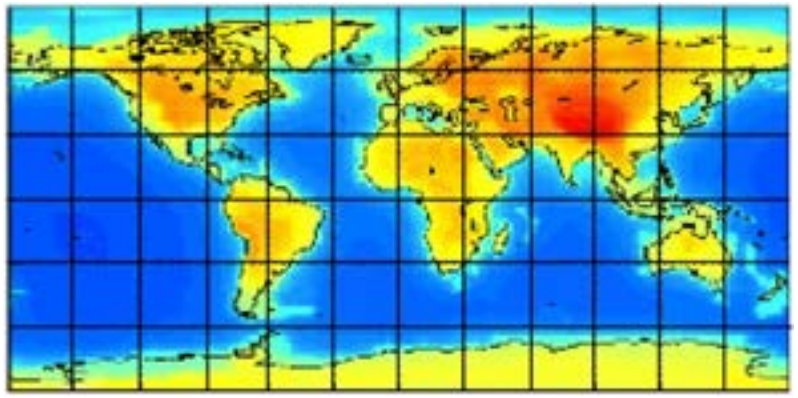
Decay energy
~20% carried away by antineutrinos
~80% heats the Earth's interior

Neutrinos only interact through weak interaction.

Typical geoneutrino flux: 10^7 cm^{-2} s^{-1} at Earth surface,

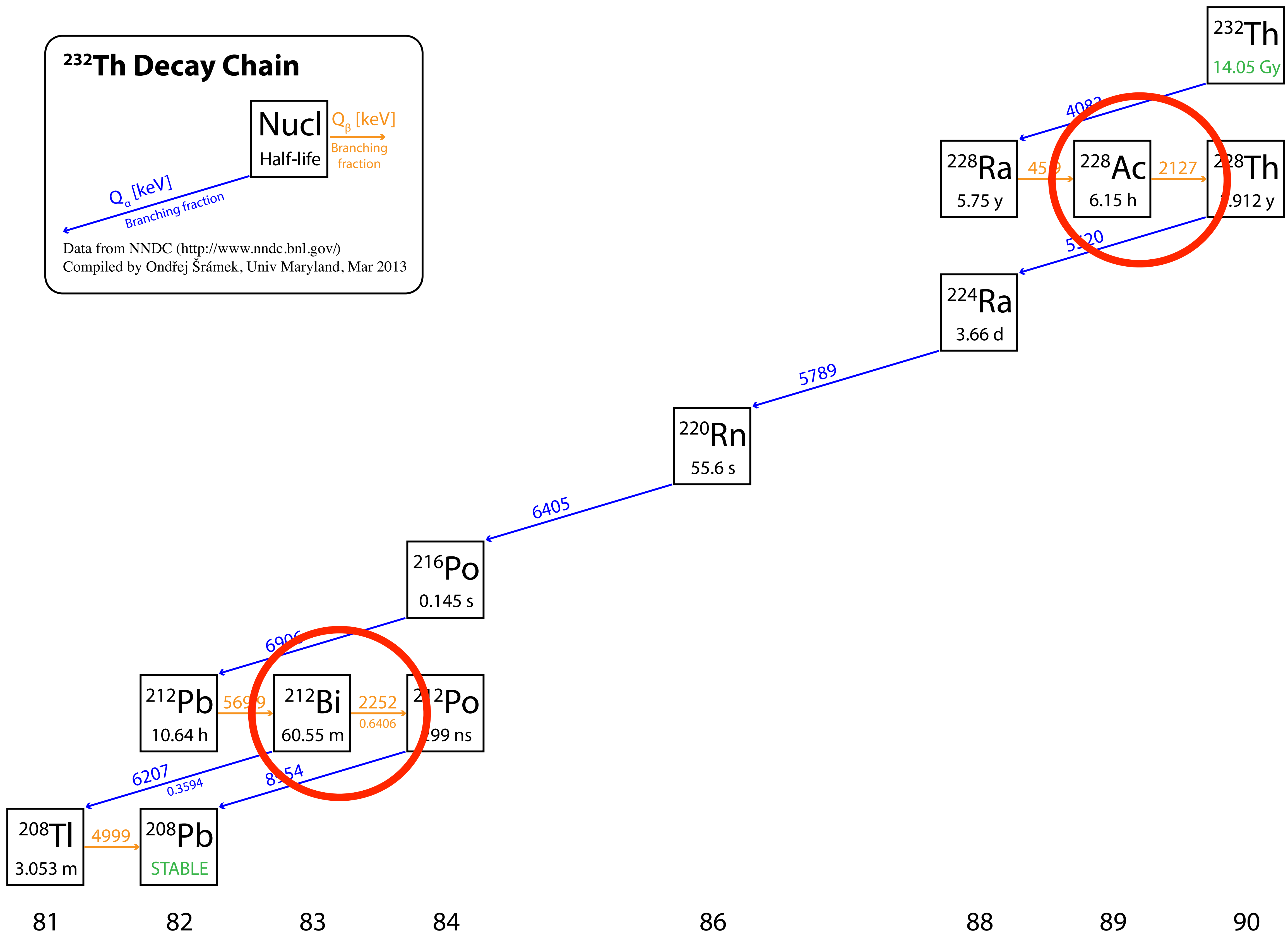
or ~10^{10} flying through each of you every second.

Integrated information about radioactivity inside the Earth.

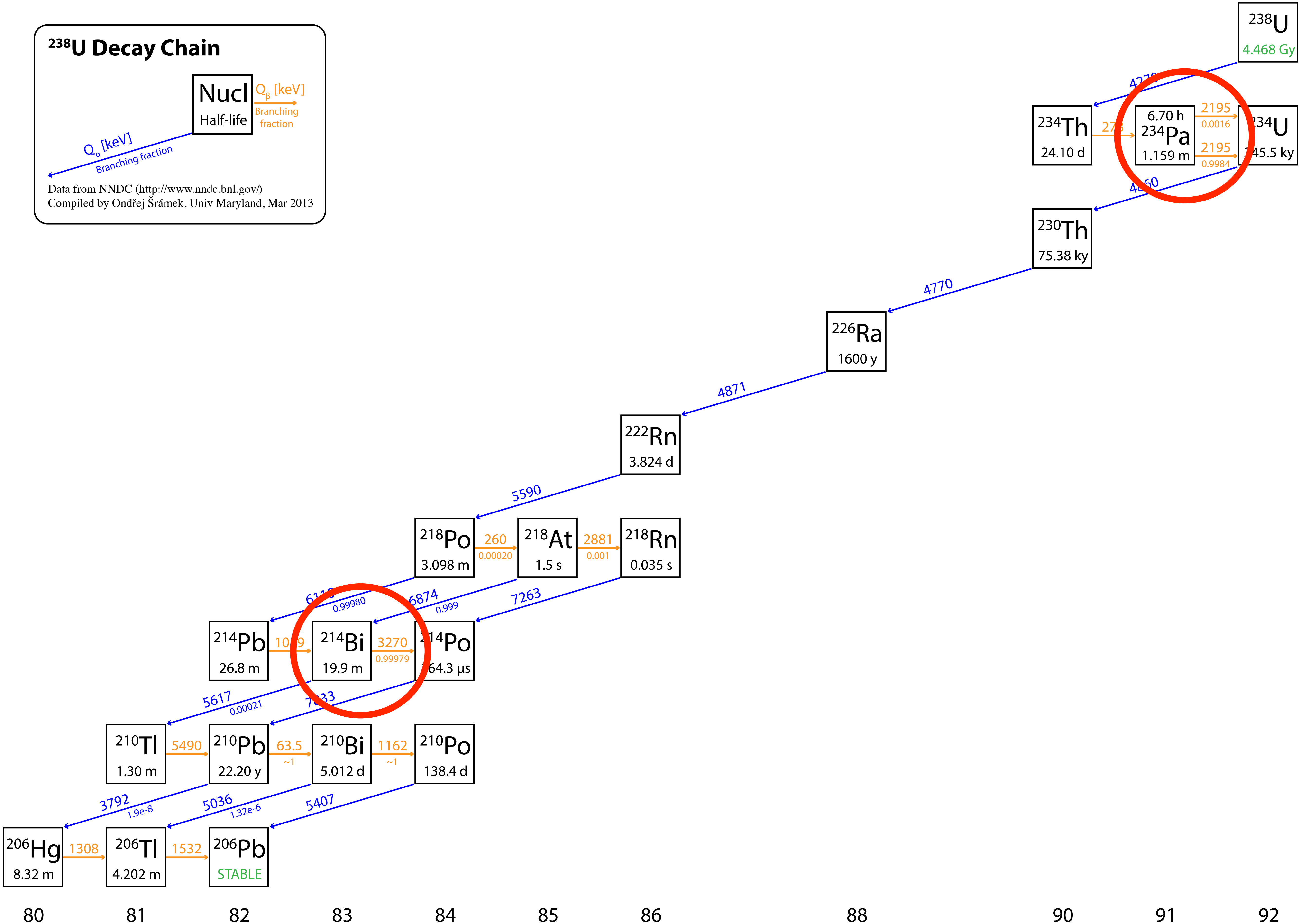


geo-ν's now detectable ... and have been detected

Measuring radioactivity of the Earth!



232Th Decay Chain
Nucl
Half-life
Qβ [keV]
Branching fraction
Qα [keV]
Branching fraction
Data from NNDC (http://www.nndc.bnl.gov/)
Compiled by Ondřej Šrámek, Univ Maryland, Mar 2013
232Th
14.05 Gy
4082
228Ra
5.75 y
228Ac
6.15 h
2127
228Th
5520
224Ra
3.66 d
5789
220Rn
55.6 s
6405
216Po
0.145 s
212Pb
10.64 h
212Bi
60.55 m
2252
0.6406
212Po
6207
0.3594
208Tl
3.053 m
4999
208Pb
STABLE
81
82
83
84
86
88
89
90



238U Decay Chain
Nucl
Half-life
Qβ [keV]
Branching fraction
Qα [keV]
Branching fraction
Data from NNDC (http://www.nndc.bnl.gov/)
Compiled by Ondřej Šrámek, Univ Maryland, Mar 2013
238U 4.468 Gy
234Th 24.10 d
234Pa 6.70 h 1.159 m
234U 245.5 ky
230Th 75.38 ky
226Ra 1600 y
222Rn 3.824 d
218Po 3.098 m
218At 1.5 s
218Rn 0.035 s
214Pb 26.8 m
214Bi 19.9 m
214Po 164.3 μs
210Tl 1.30 m
210Pb 22.20 y
210Bi 5.012 d
210Po 138.4 d
206Hg 8.32 m
206Tl 4.202 m
206Pb STABLE
4270
273
2195 0.0016
2195 0.9984
4860
4770
4871
5590
260 0.00020
2881 0.001
6115 0.99980
6874 0.999
7263
1019
3270 0.99979
5617 0.00021
7833
5490
63.5 ~1
1162 ~1
3792 1.9e-8
5036 1.32e-6
5407
1308
1532
80
81
82
83
84
85
86
88
90
91
92

Brief (geo)ν history

1930: Pauli proposes a new neutral particle to resolve energy conservation problem in β^- decay

1956: Reines & Cowan reported the first electron antineutrino detection (reactor antineutrinos)


NATURE VOL. 310 19 JULY 1984

REVIEW ARTICLE

Antineutrino astronomy and geophysics

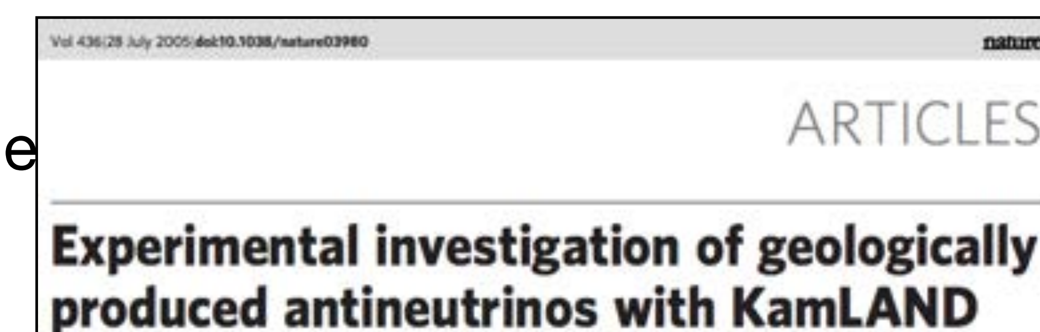
Lawrence M. Krauss*, Sheldon L. Glashow† & David N. Schramm‡

* Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
† Department of Physics, Boston University, Boston, Massachusetts 02215, USA
‡ Department of Physics and Astrophysics, Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA

Radioactive decays inside the Earth produce antineutrinos that may be detectable at the surface. Their flux and spectrum contain important geophysical information. New detectors need to be developed, discriminating between sources of antineutrinos, including the cosmic-background. The latter can be related to the frequency of supernovas.

1984: Krauss, Glashow, Schramm:
Antineutrino astronomy and geophysics

2005: first reported measurement of geone
KamLAND experiment


Vol 436|28 July 2005|doi:10.1038/nature03980 nature

ARTICLES

Experimental investigation of geologically produced antineutrinos with KamLAND

Detection of geoneutrinos

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

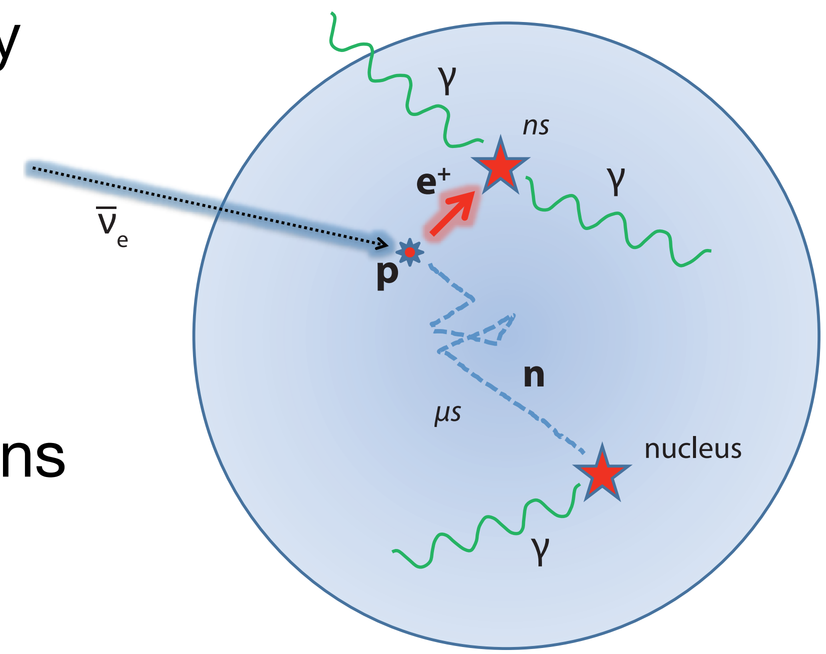
Antineutrino detection mechanism: Inverse beta decay

Energy threshold, only works for ^{232}Th and ^{238}U

Liquid scintillator detectors:

Large ~10^{32} free protons or ~1 kiloton of scintillator

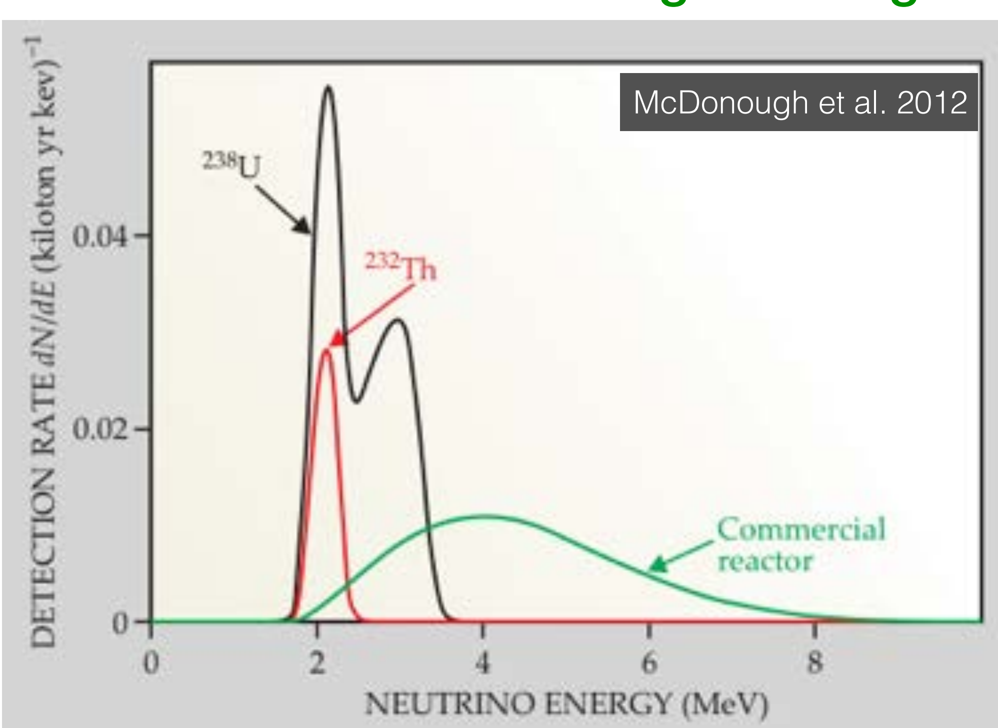
Underground to shield from cosmic ray muon interactions in the atmosphere

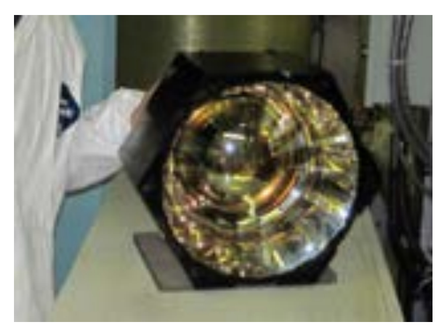


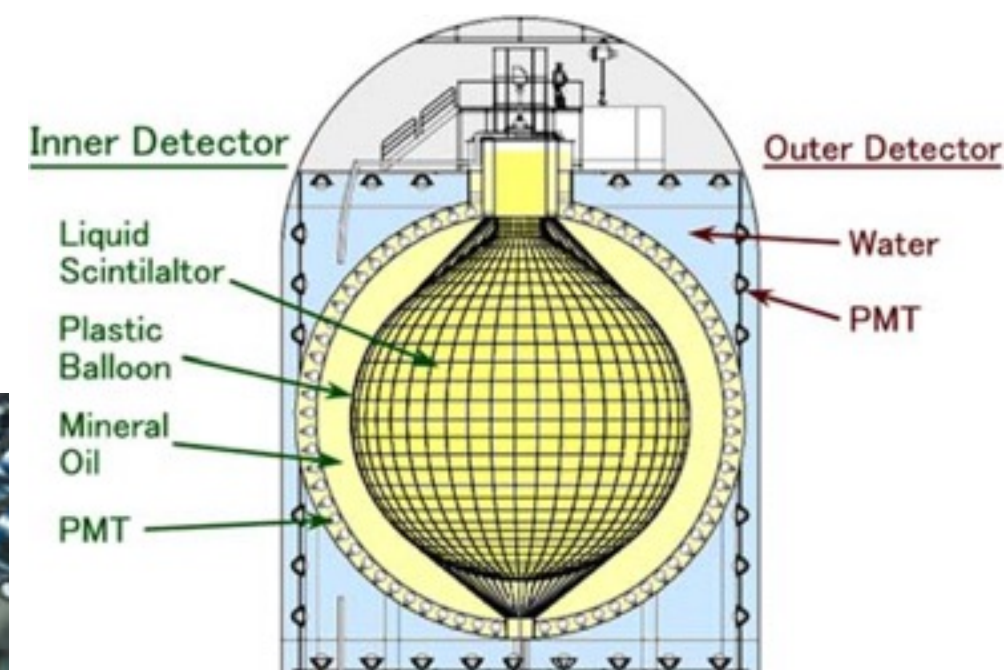
Double-flash coincidence

1 TNU ("Terrestrial Neutrino Unit") =
= 1 event over a year-long fully efficient exposure of 10^{32} protons

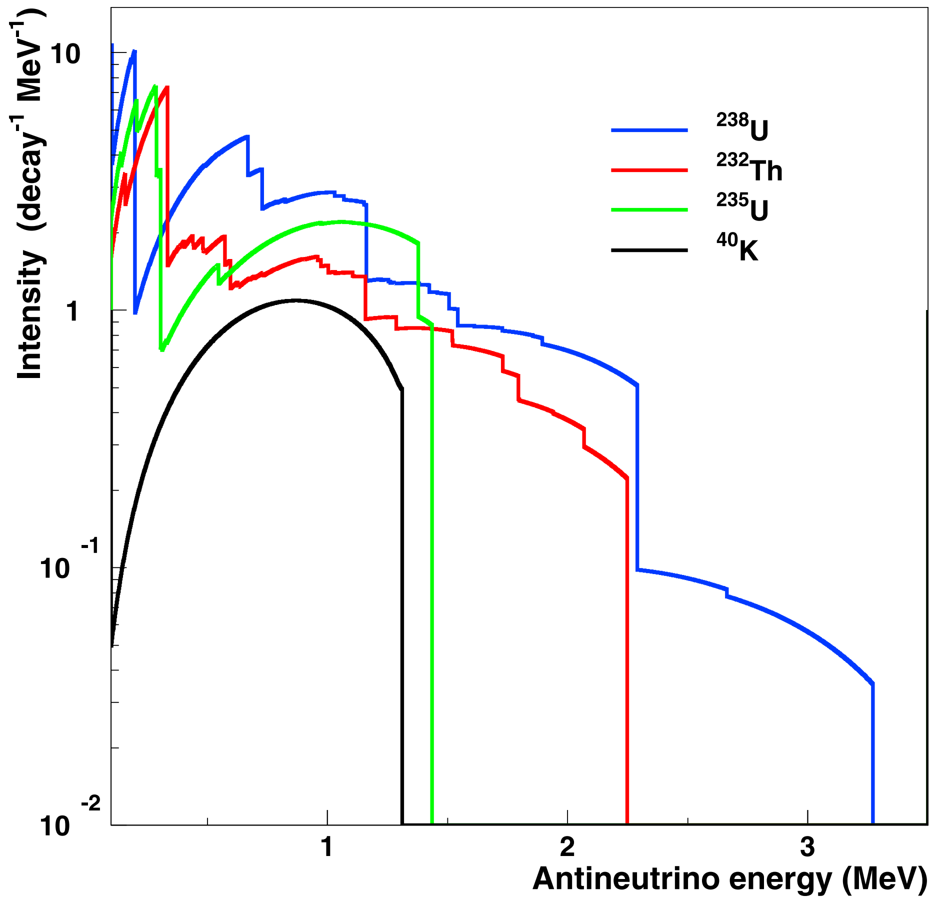
Reactor antineutrino background signal



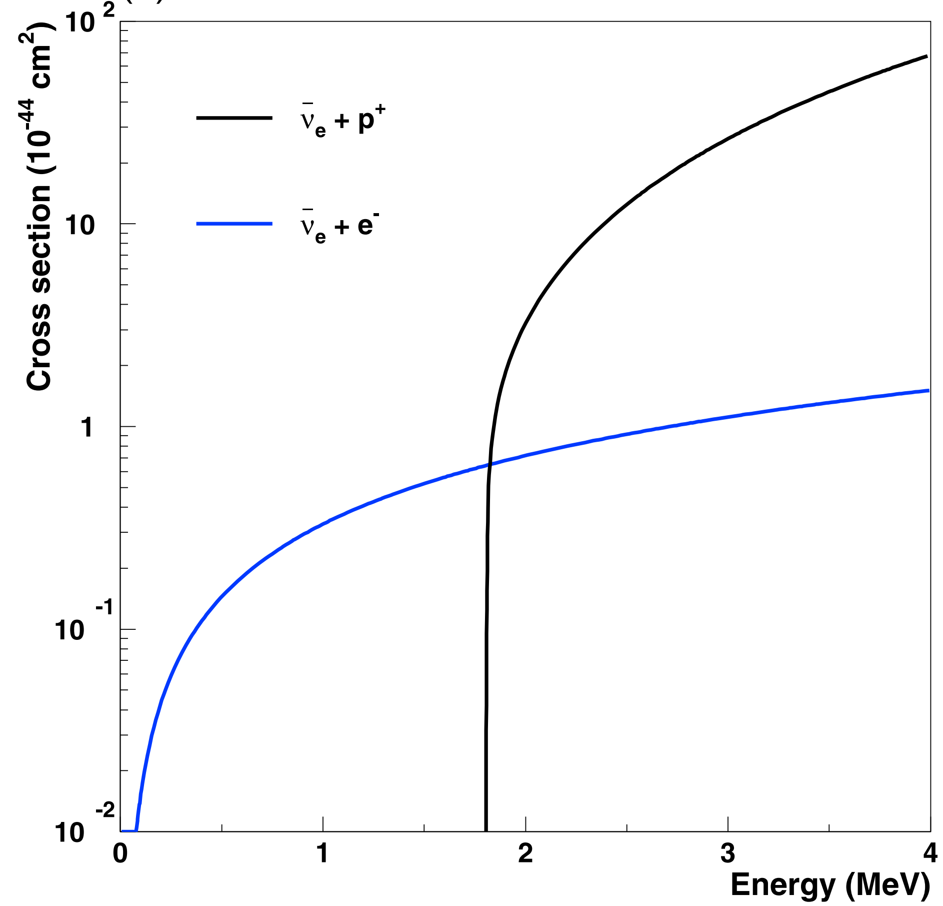




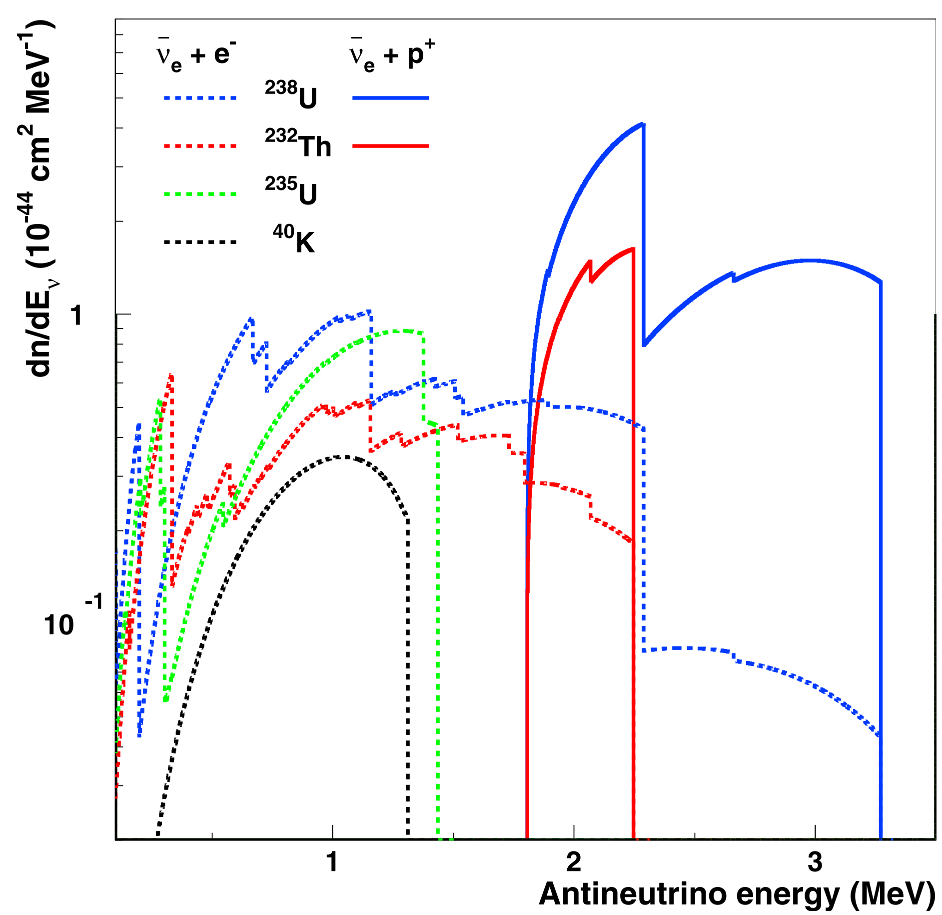
(a) Antineutrino intensity energy spectra



(b) Cross sections



(c) Antineutrino interaction energy spectra



intensity spectrum (a)

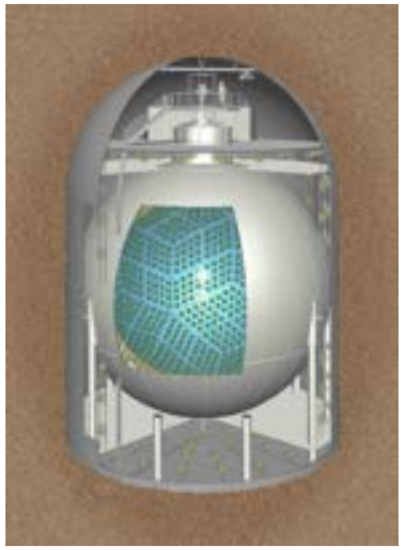
×

cross section (b)

=

interaction spectrum (c)

Dye 2012

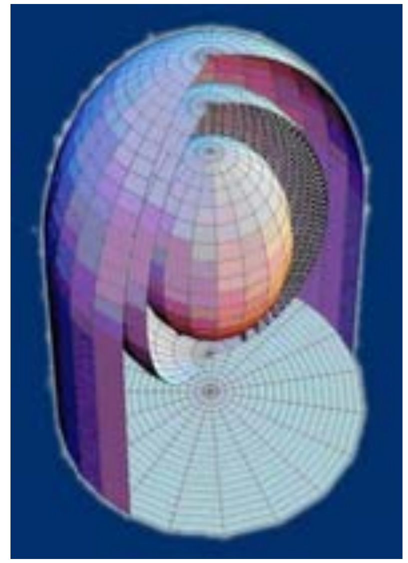


KamLAND
Kamioka, Japan

2005

2011

2013



Borexino
Gran Sasso, Italy

2010

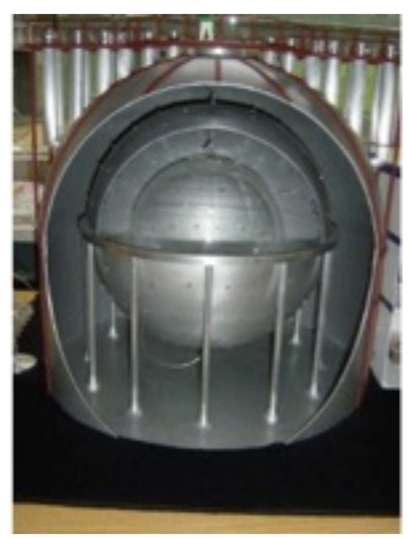
2013

2015

SNO+
Sudbury, Canada

online soon...

Geoneutrino Detectors



Future:

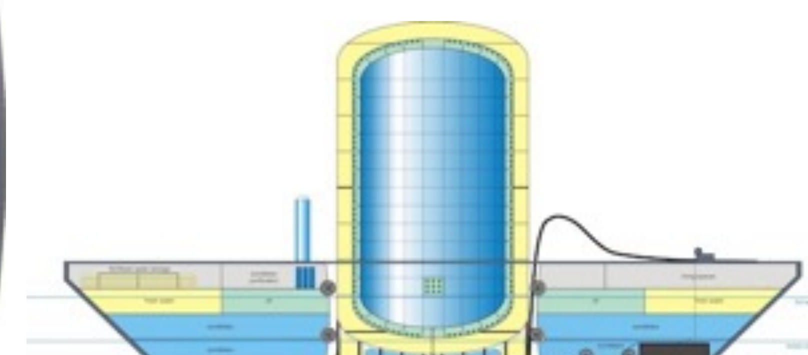
JUNO (China)

CJPLNE (China)

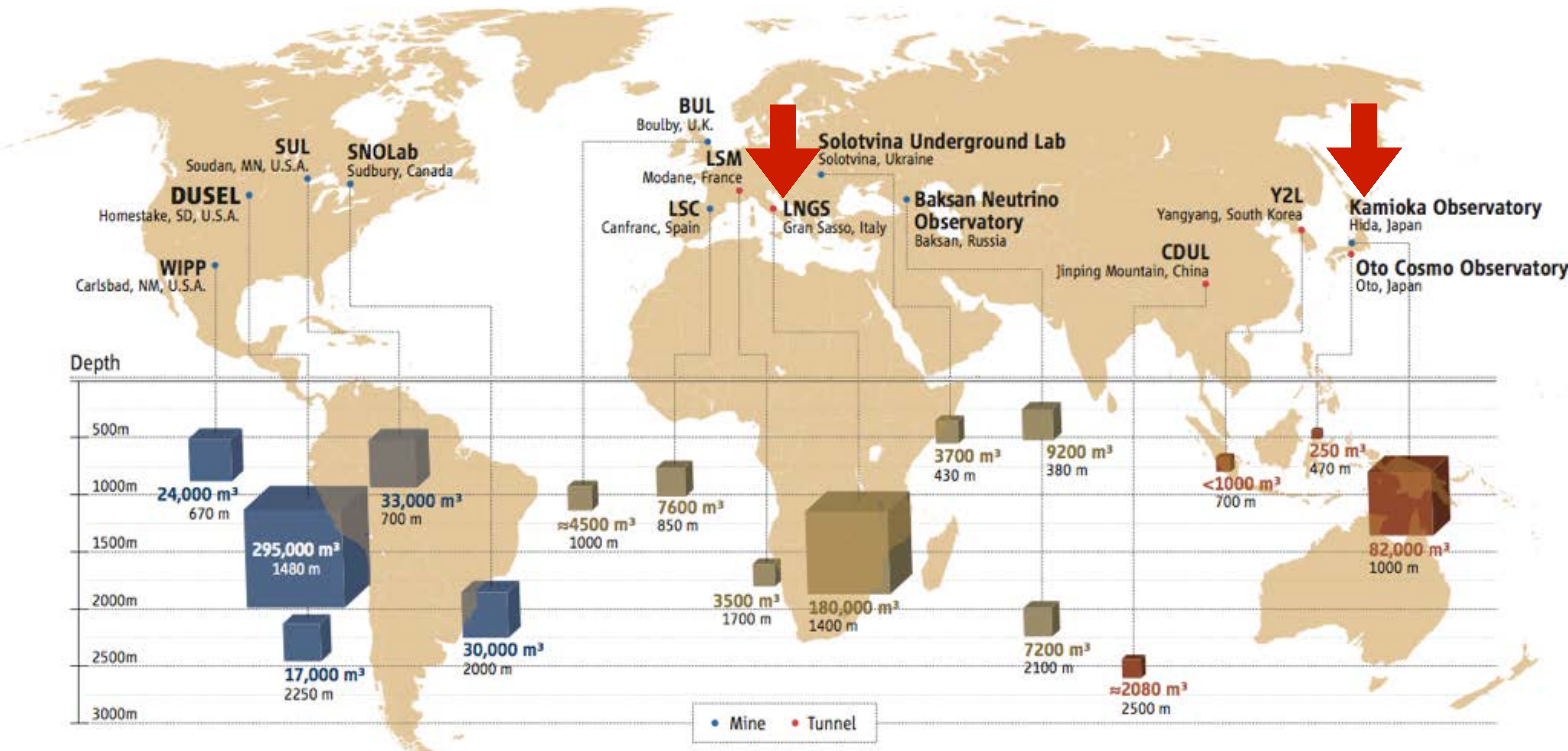
LENA (Europe)

RENO-50 (S.Korea)

Hanohano (USA)

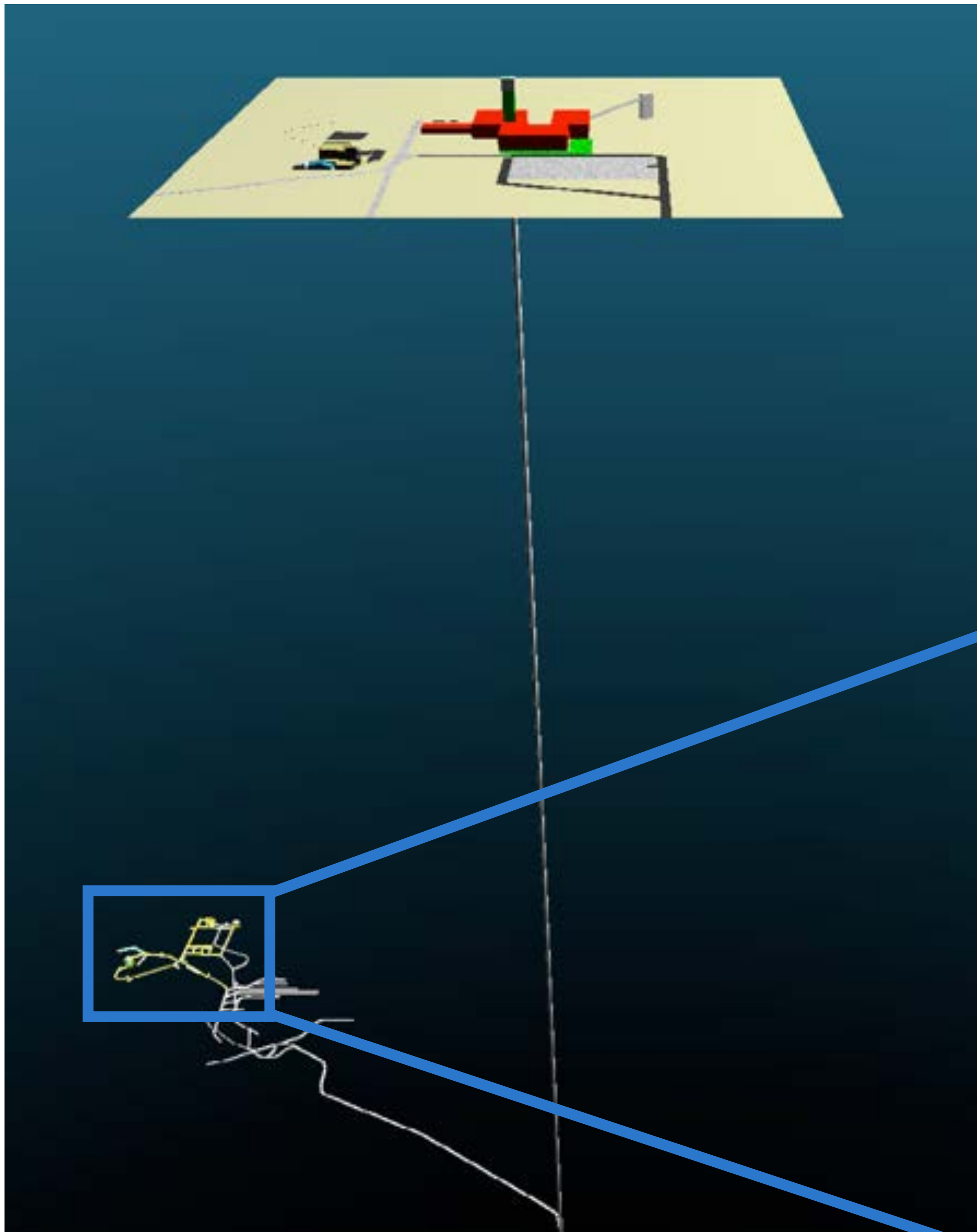


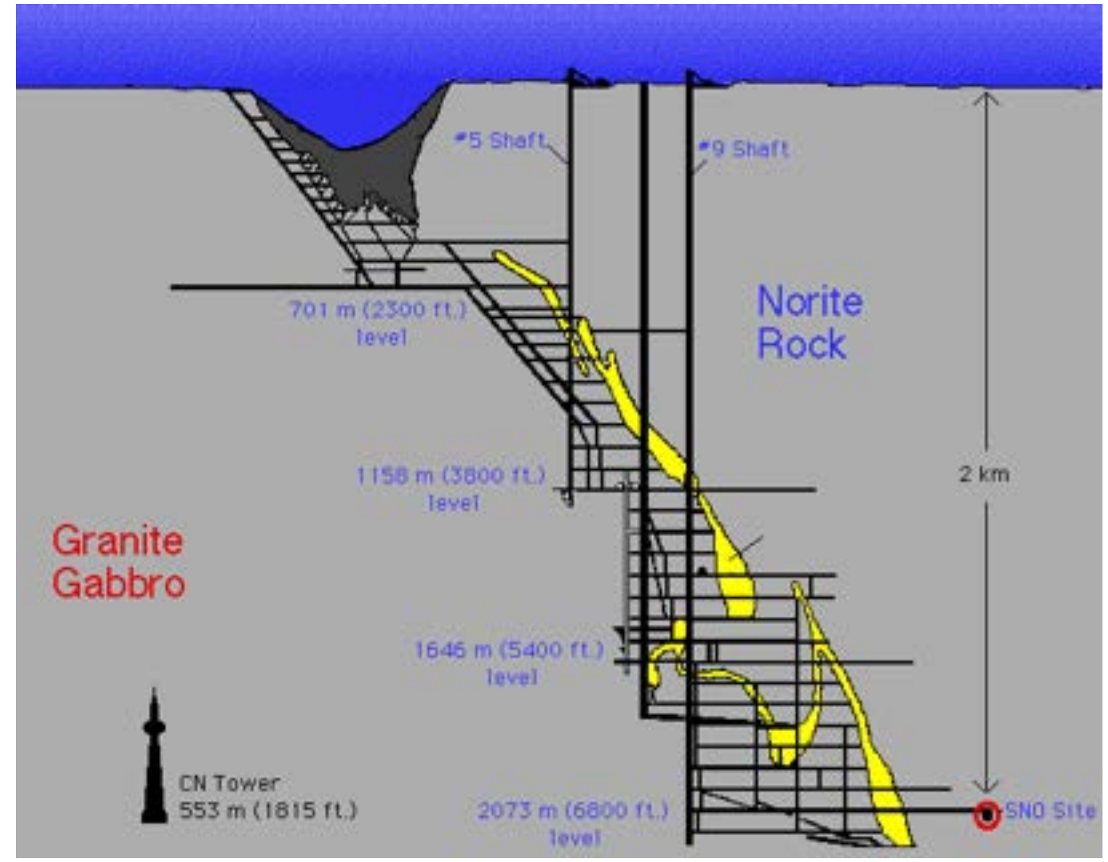
Geoneutrino-detecting underground physics laboratories

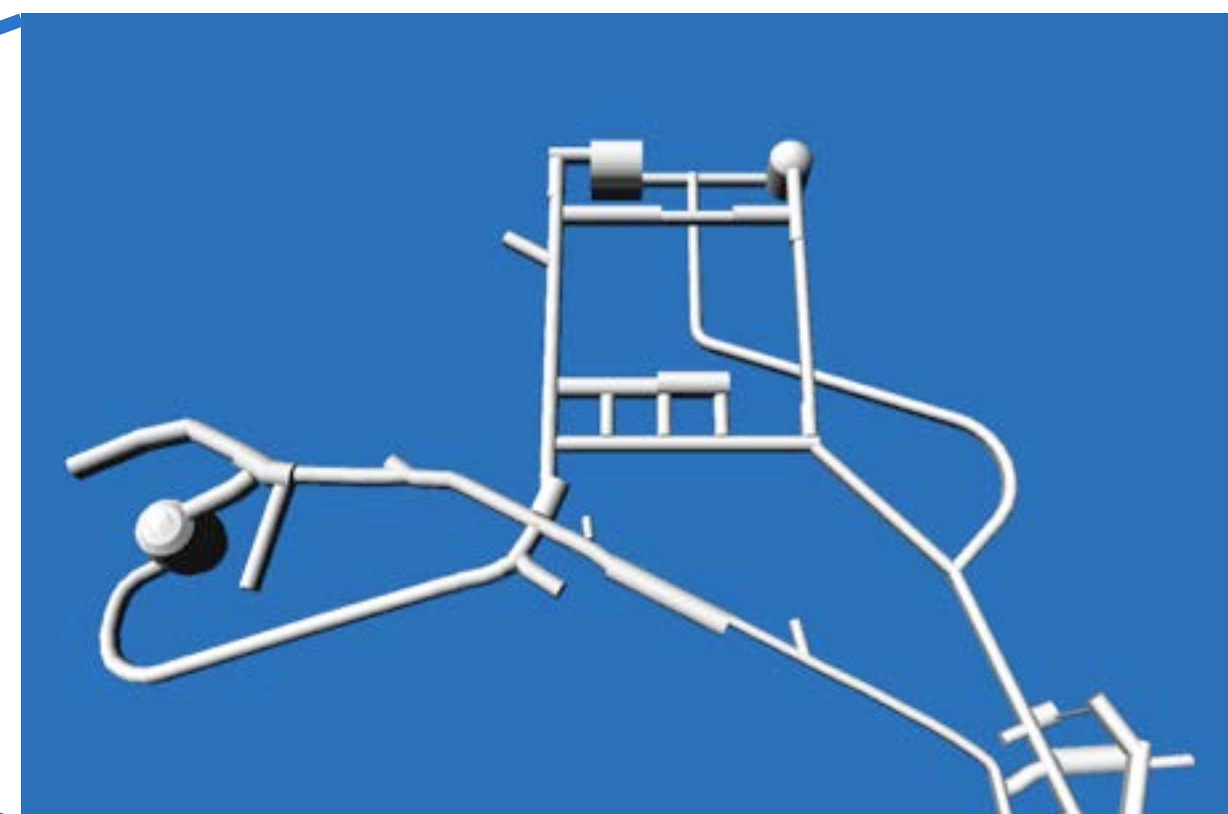


Cho 2010 Science 10.1126/science.330.6006.904

Sudbury, Ontario, Canada





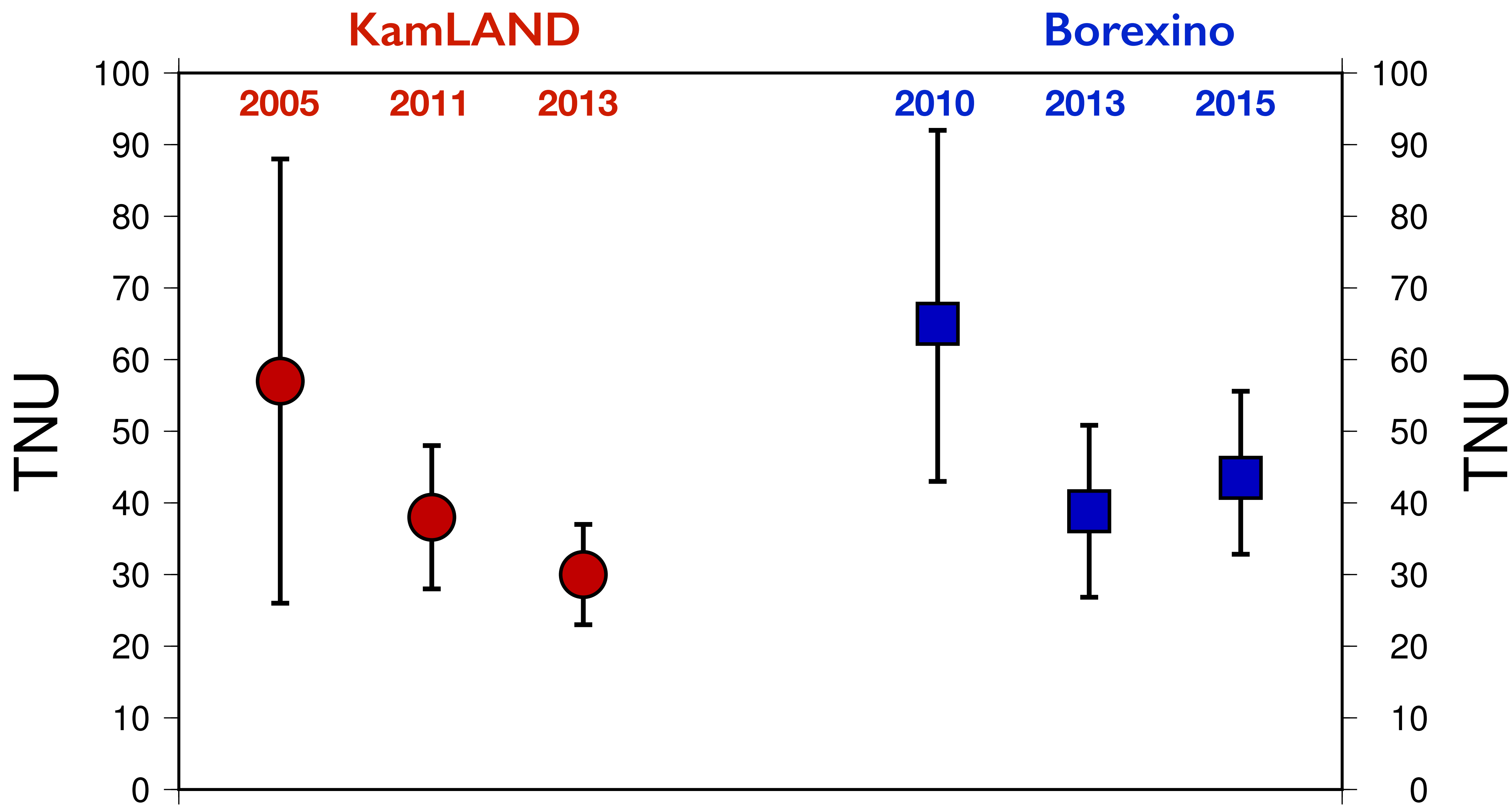



SNOLAB

Geoneutrino measurements

	Study	Reported result	in TNU	events/year
KamLAND	*Araki et al.* (2005)	28 ± 15 events with Th/U=3.9	57 ± 31	14
	Gando et al. (2011)	$106\,^{+29}_{-28}$ events with Th/U=3.9	38 ± 10	
	Gando et al. (2013)	$3.4 \pm 0.8\,\mathrm{cm}^{-2}\,\mu\mathrm{s}^{-1}$ with Th/U=3.9	30 ± 7	14
Borexino	*Bellini et al.* (2010)	$9.9\,^{+4.1}_{-3.4}$ events + Th/U=3.9	$65\,^{+27}_{-22}$	6.7
	Bellini et al. (2013)	with Th/U=3.9	38.8 ± 12.0	3.9
	Agostini et al. (2015)	$23.7^{+6.5}_{-5.7}(\mathrm{stat})^{+0.9}_{-0.6}(\mathrm{sys})$	$43.5^{+11.8}_{-10.4}(\mathrm{stat})^{+2.7}_{-2.4}(\mathrm{sys})$	4.2

Geoneutrino measurements



What does this tell us? ... relation to Earth?

Predicting geoneutrino flux

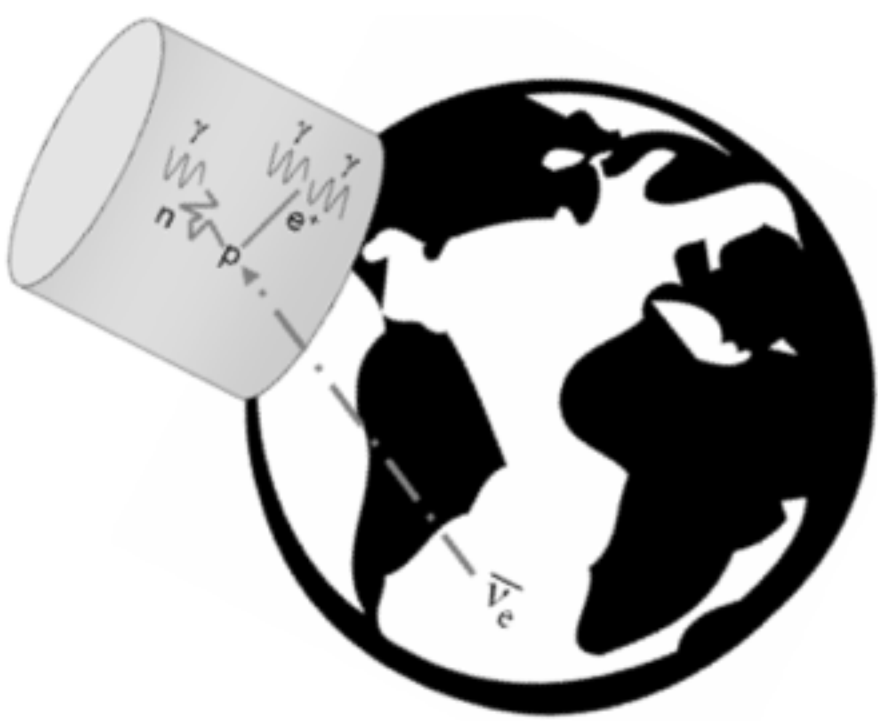
To make sense of geoneutrino measurements.

To motivate new detectors (e.g., where to measure?)

⇒ ***Emission models: Calculate predictions for various compositional estimates & architectures of Earth's interior.***

$$\Phi(\mathbf{r}) = \frac{n_\nu \lambda \langle P \rangle}{4\pi} \int_\Omega \frac{A(\mathbf{r}')\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|^2} \mathrm{d}\mathbf{r}'$$

Flux Φ at position ***r*** from a given radionuclide distributed with abundance *A* in domain *Ω*



inputs from geoscience:

- chemical abundances *A* – **several estimates**
- density *ρ*

inputs from nuclear/particle physics:

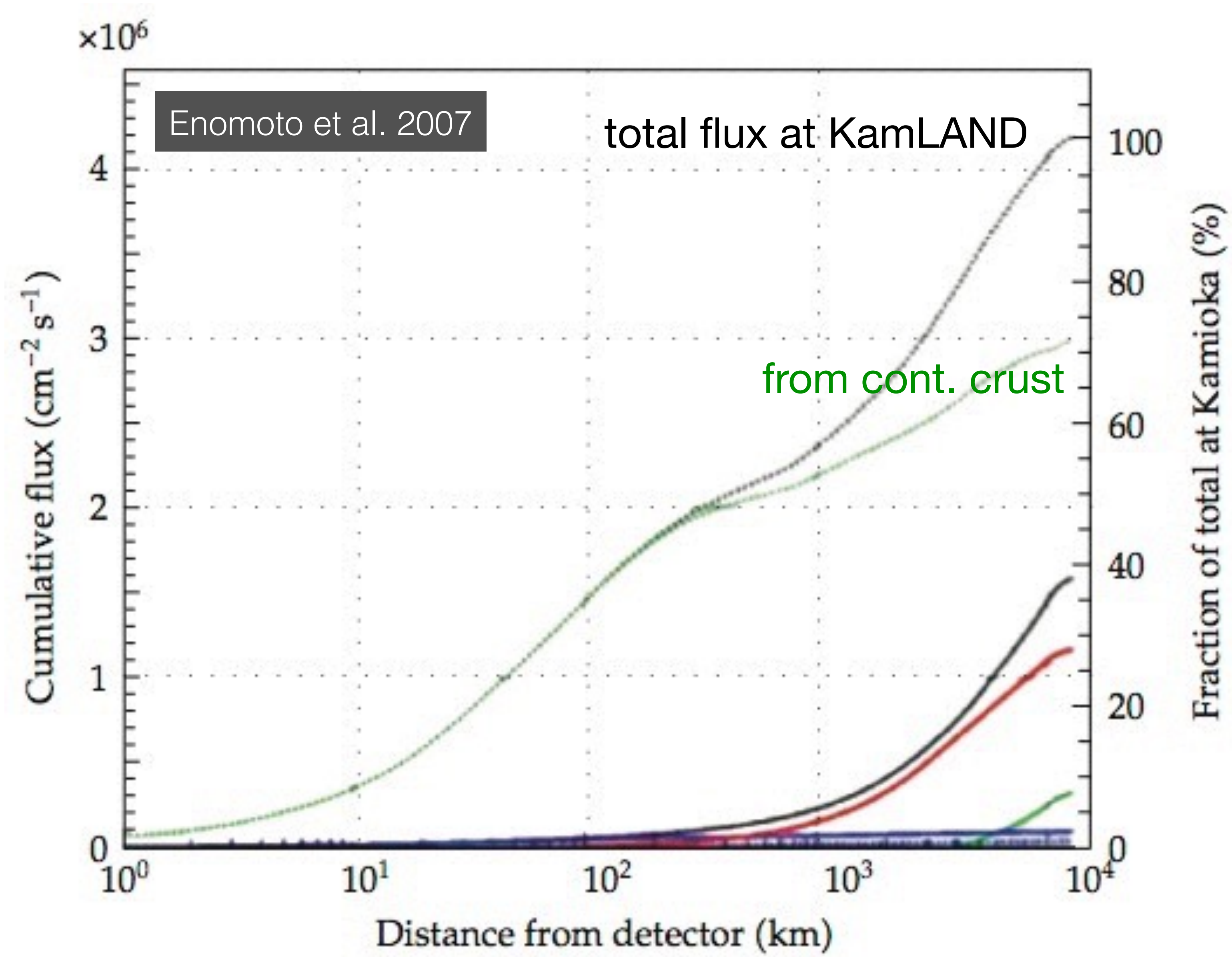
- n_ν, λ, $\langle P \rangle$
- negligible uncertainty

Critical: Accurate crustal geoneutrino emission model

Cont. crust is enriched in U, Th, K

Geoneutrino flux scales with $1/R^2$

Detectors are located in cont. crust



Need global model

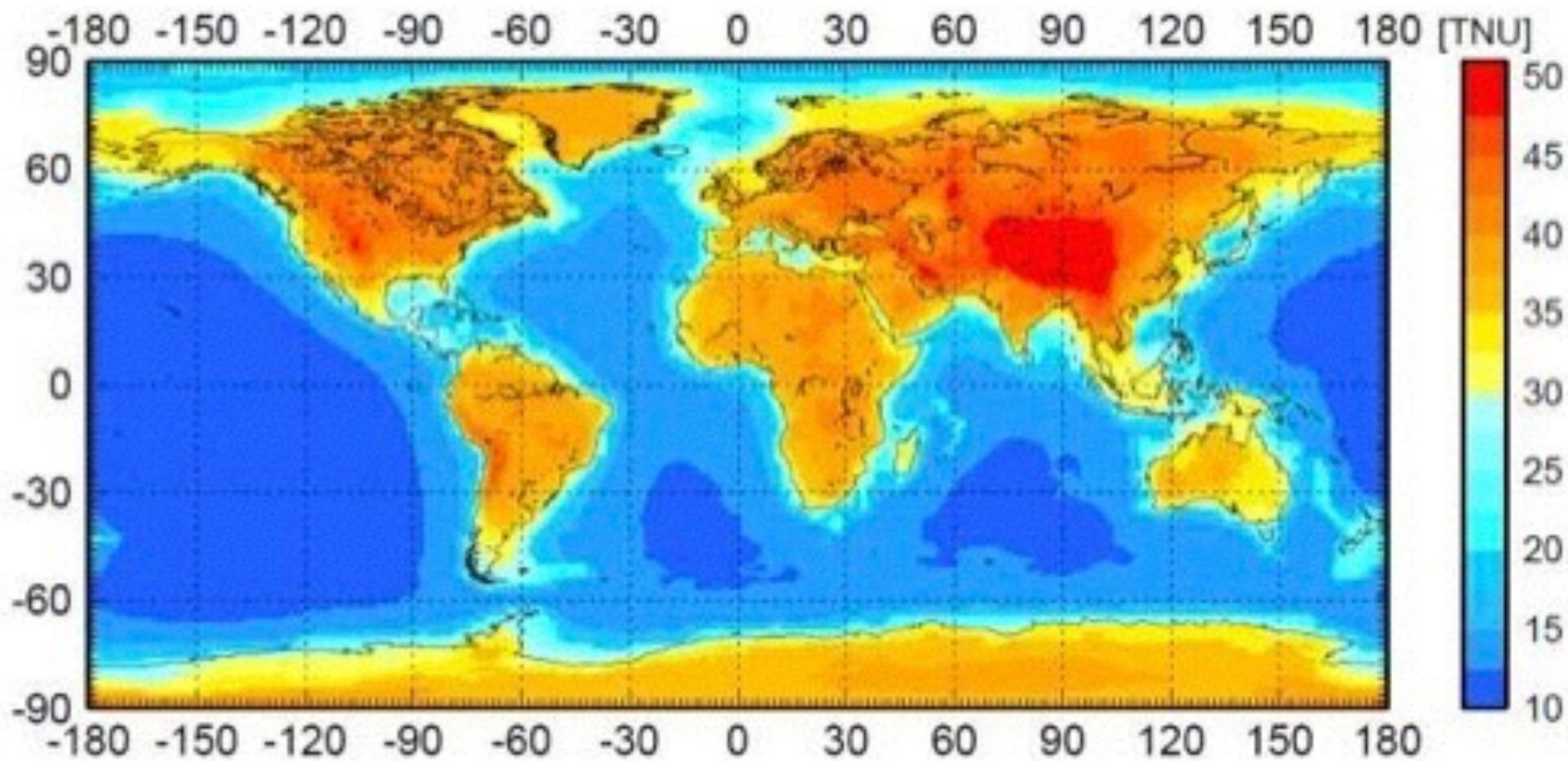
+

local refinement

within few 100 km of

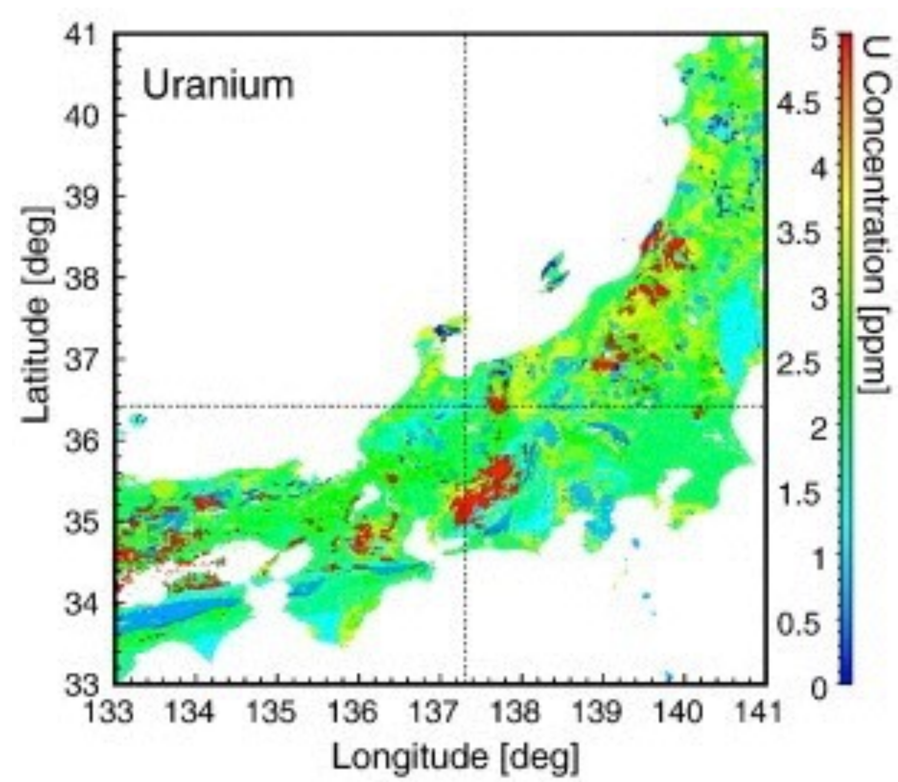
the detector

Critical: Accurate crustal geoneutrino emission model

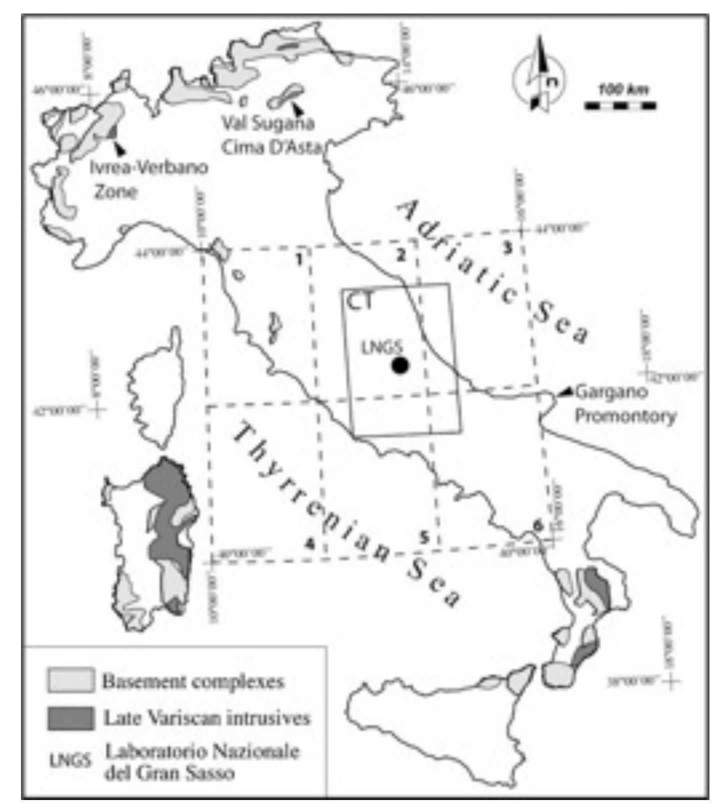


Yu Huang et al.
arXiv: 1301.0365

from Yu Huang

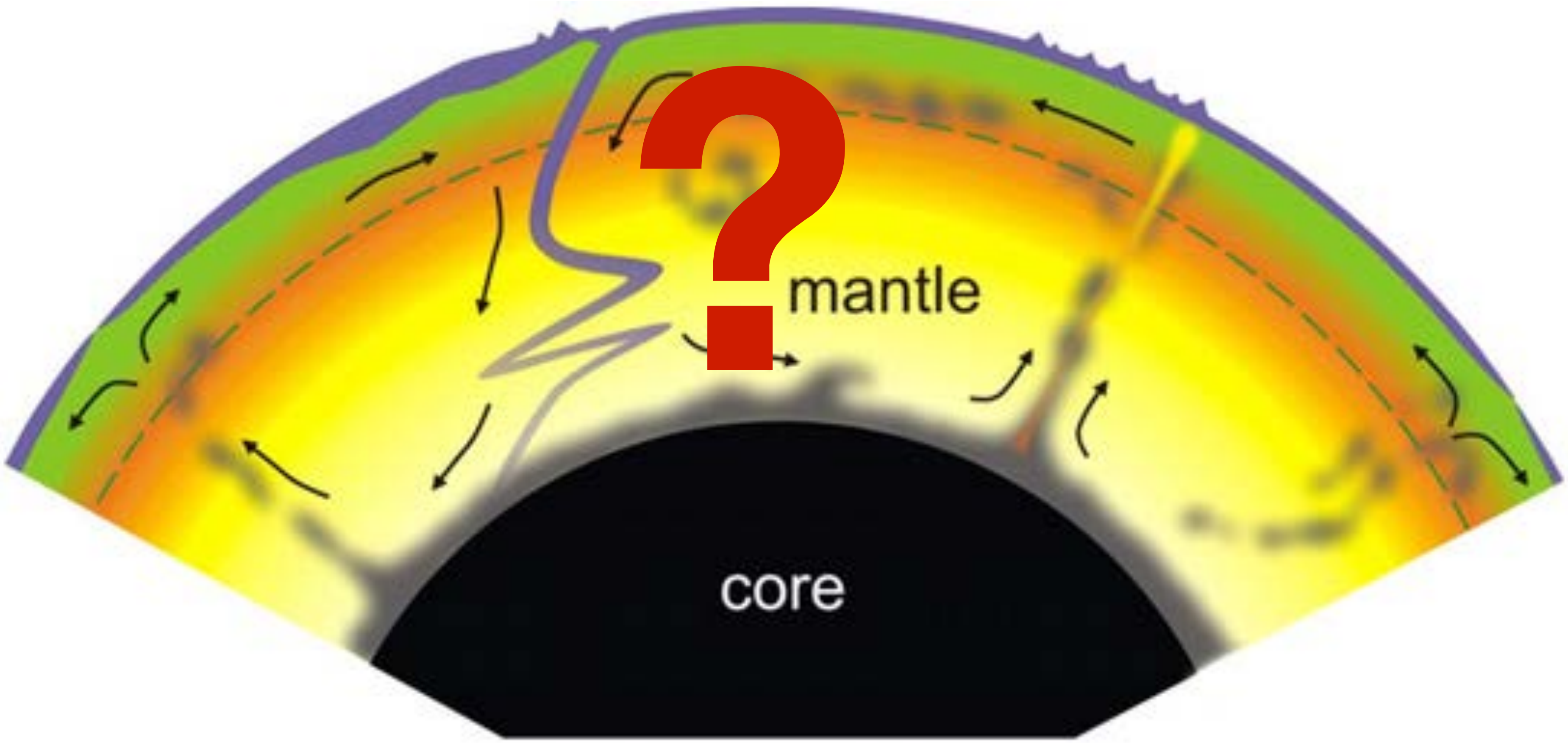


Enomoto et al. 2007



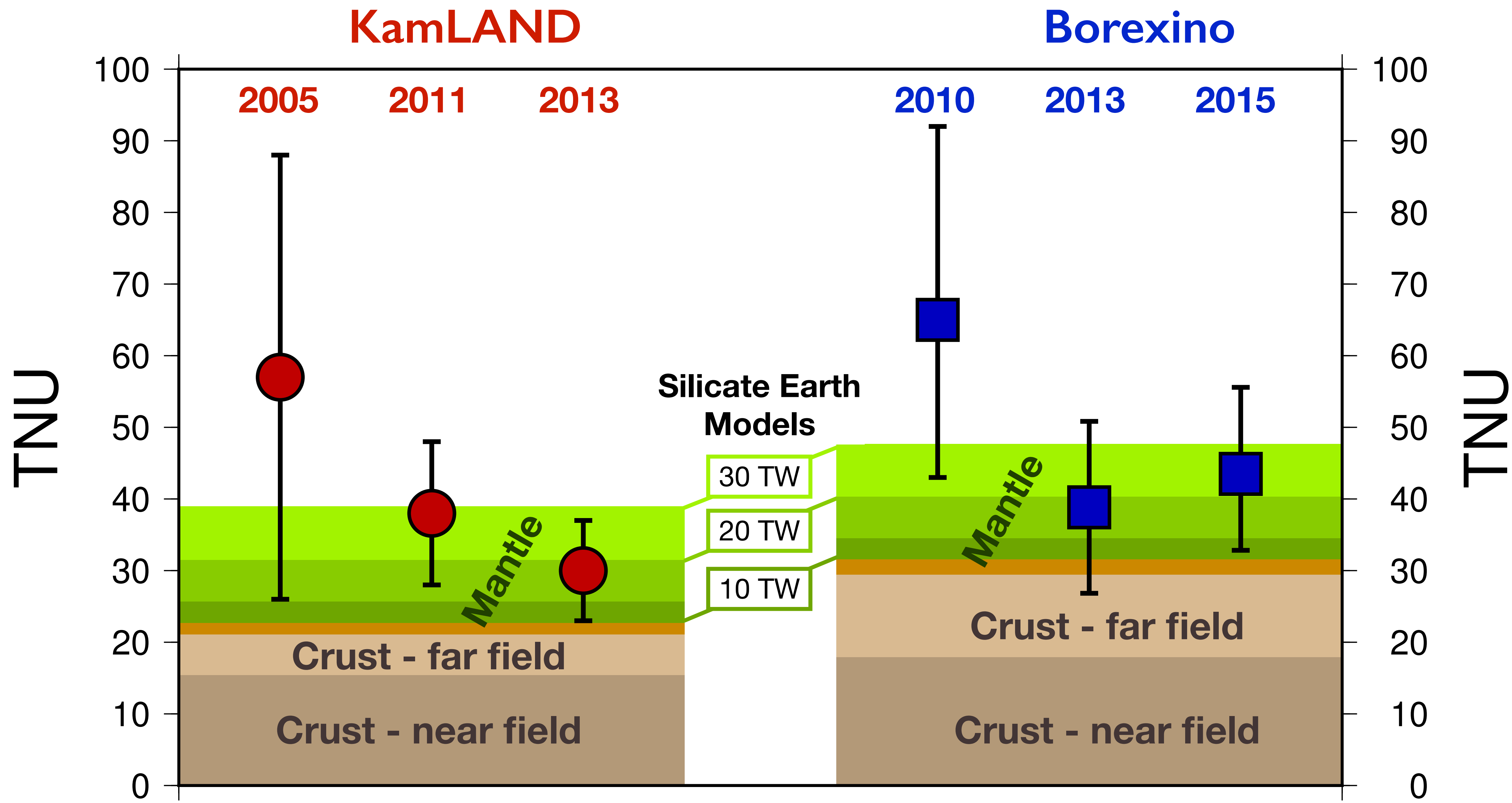
Coltorti et al. 2011

How is radioactivity distributed in the mantle?



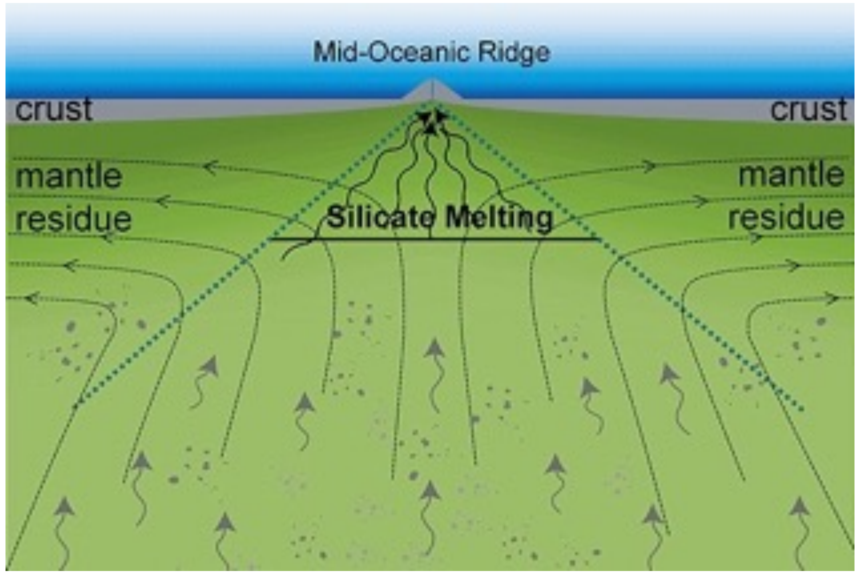
Hypothesis → Geoneutrino flux prediction → Testing with geoneutrino measurement

Geoneutrino measurements vs. predictions

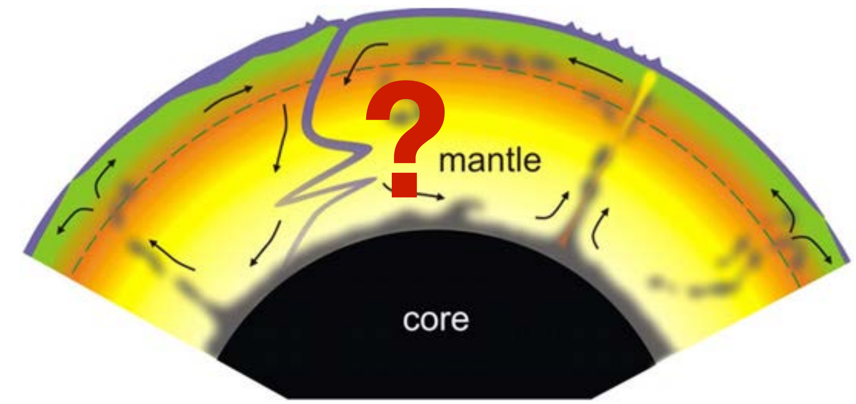


Assumes uniform mantle composition

Shallow mantle composition



Mid-Oceanic Ridge Basalt
composition
→
source rock abundances
in shallow mantle



MORB-source mantle abundance estimates

Workman & Hart (2005)	**2.8 ± 0.4**		
Salters & Stracke (2004)	**4.1 ± 1.2**	**TW**	if occupying entire mantle
Arevalo & McDonough (2010)	**7.5 ± 1.5**		

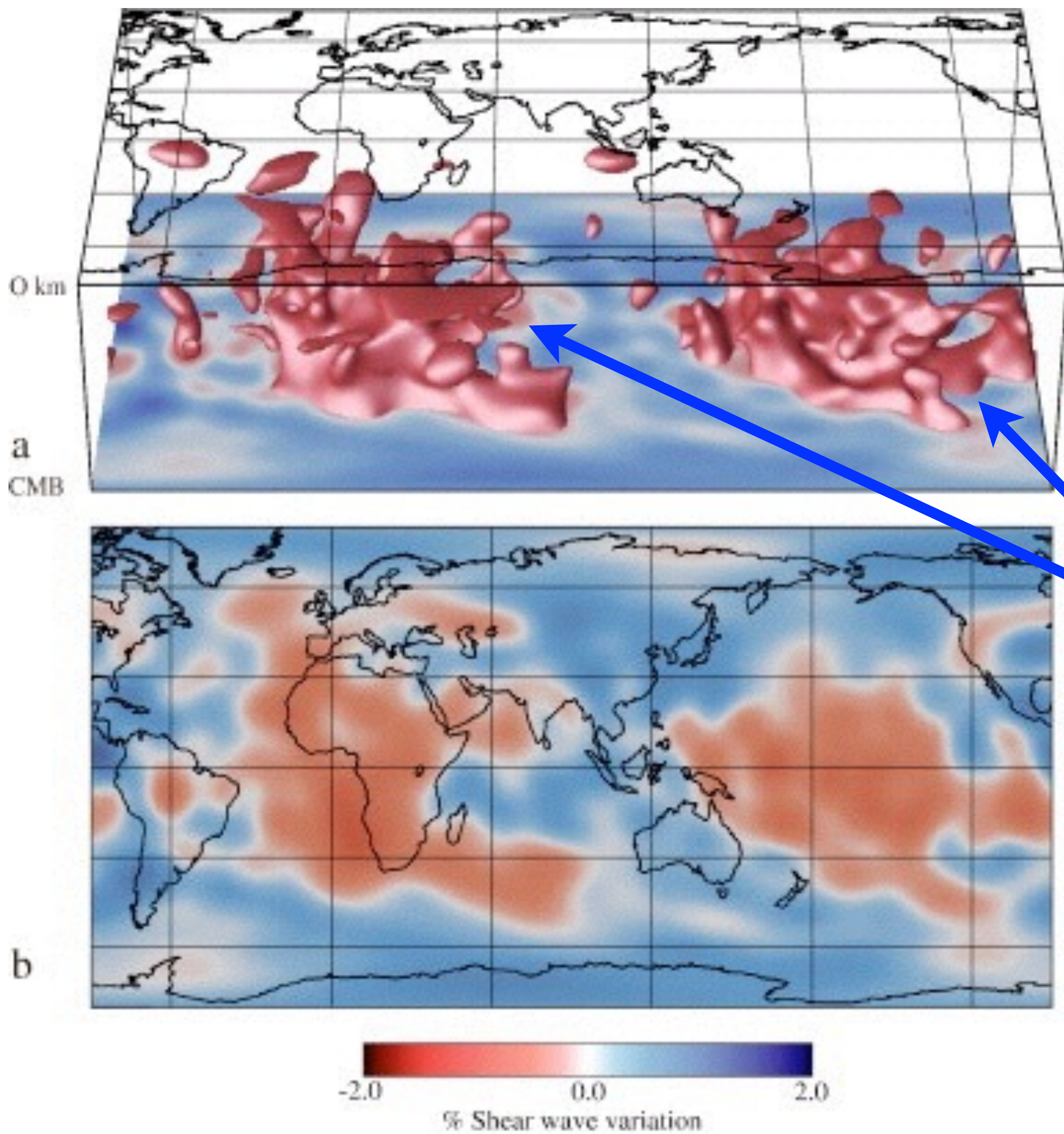
Bulk mantle (=BSE–Crust)

"E-chondrite"	**4.3 ± 2.0**	
"Standard"	**13 ± 4**	**TW**
"High"	**26 ± 3**	

Require enriched material in the mantle

Seismic tomography image of present-day mantle

Seismic shear wave speed anomaly
Tomographic model S20RTS (Ritsema et al.)



Bull et al. EPSL 2009

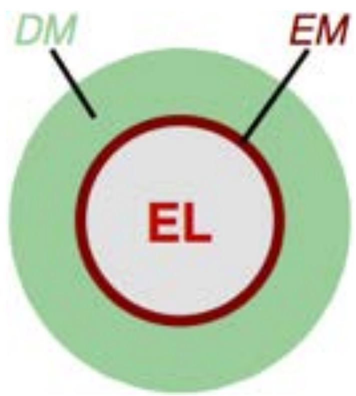
Two large scale seismic speed anomalies – below Africa and below central Pacific

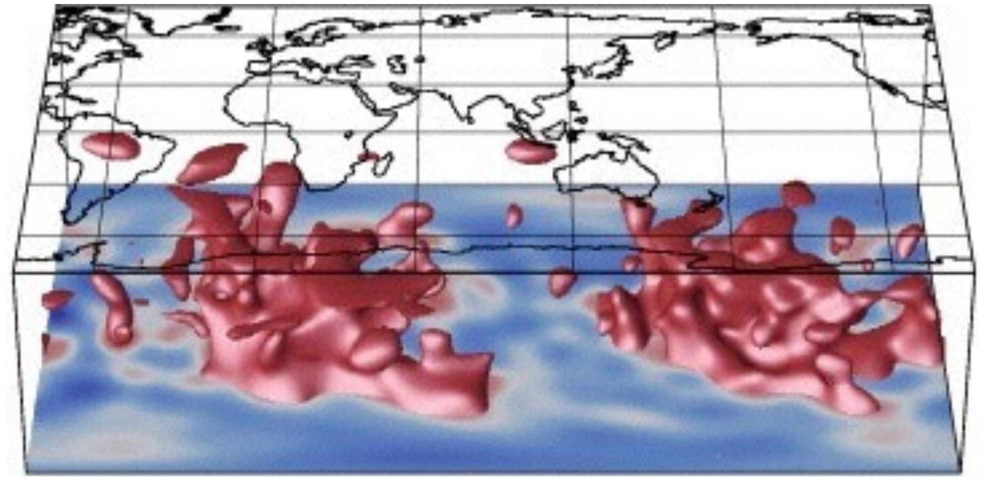
Anti-correlation of shear and sound wavespeeds + sharp velocity gradients suggest a **compositional component**

"**LLSVPs**" or "piles" or "superplumes"

Candidate for a distinct chemical reservoir

Thermochemical piles in deep mantle?

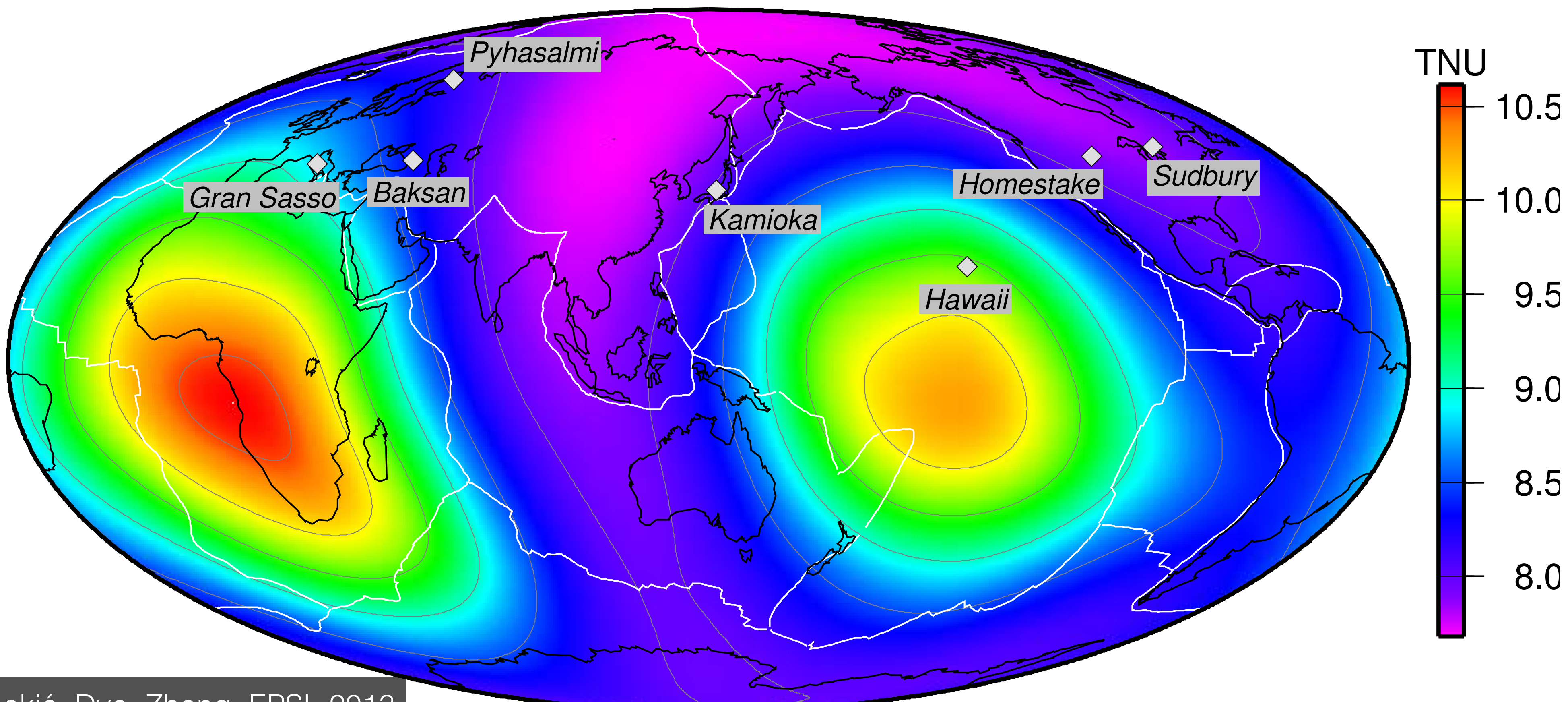




LLSVPs

Assume these piles represent an enriched reservoir.
δlnVs isocontours ⇒ shape

Mantle geoneutrino U+Th signal prediction

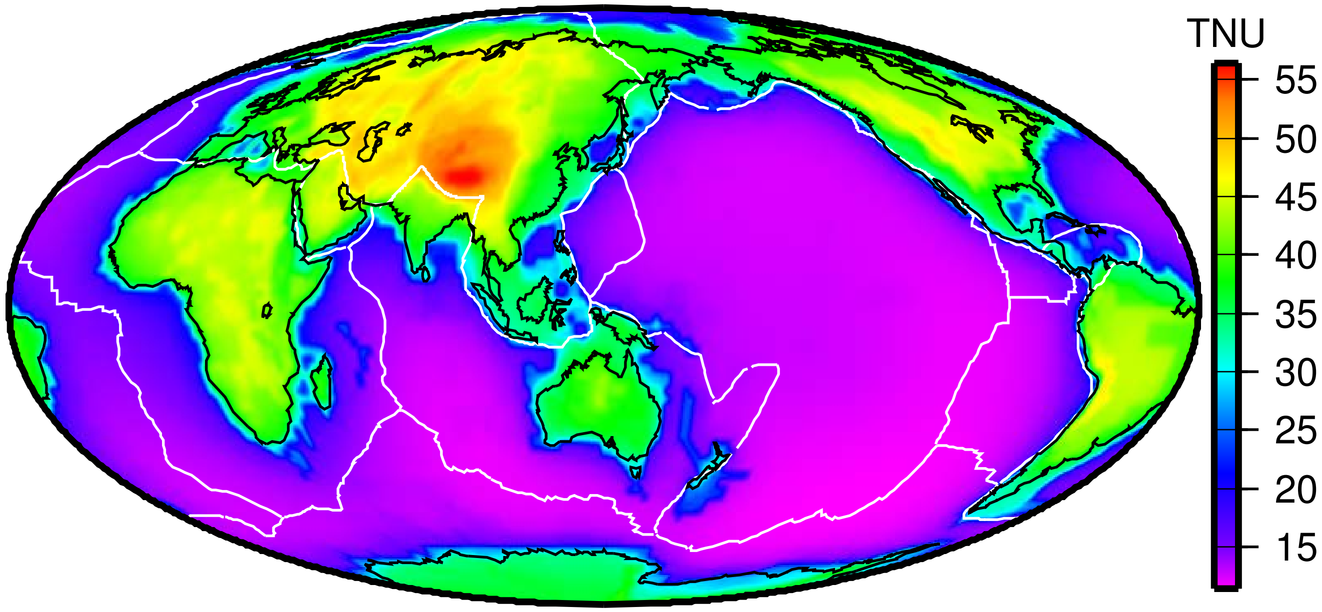


O.Š., McDonough, Kite, Lekić, Dye, Zhong, EPSL 2013

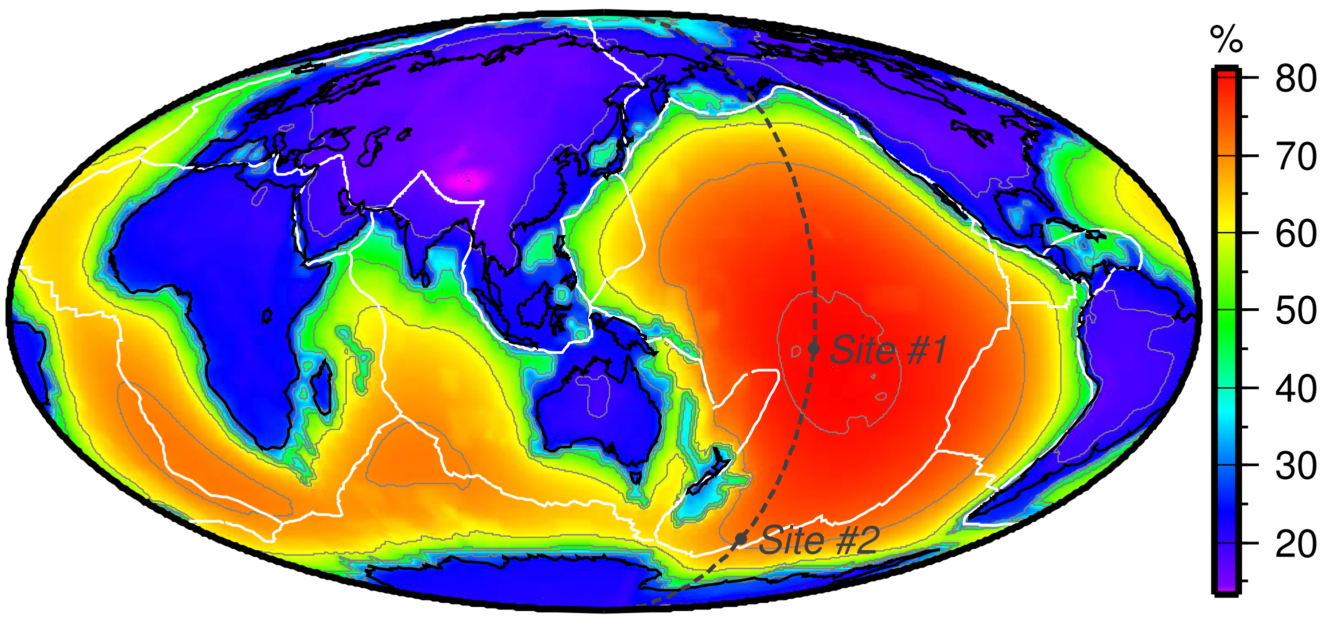
Can we detect such variation in mantle geonu flux?

Crust + Mantle geoneutrino emission

Crust + mantle



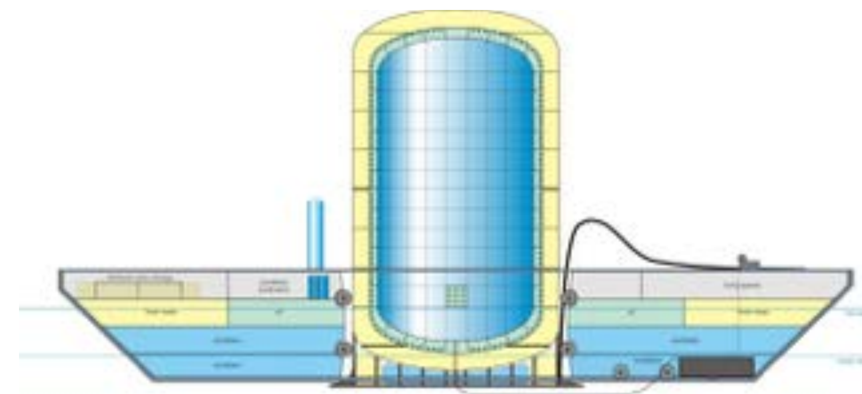
Mantle contribution to total signal



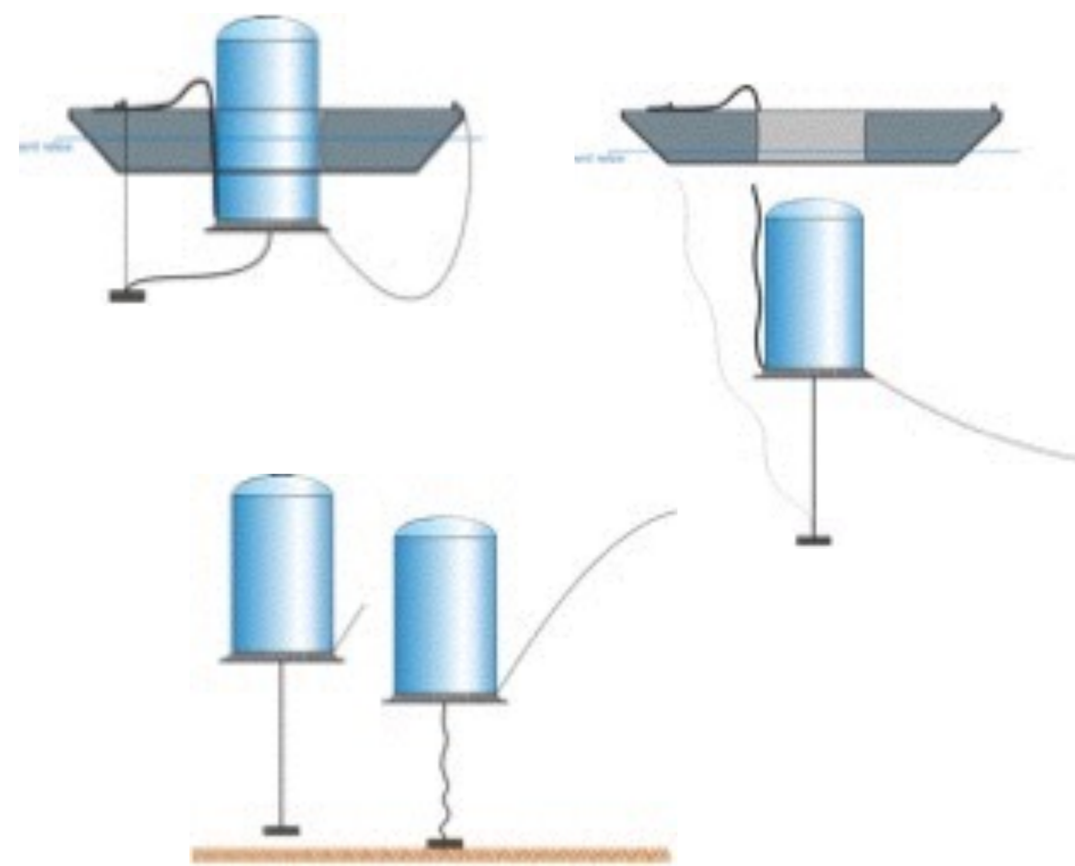
Continental locations: not more than ~25% of geonu signal coming from mantle

O.Š., McDonough, Kite, Lekić, Dye, Zhong, EPSL 2013

To constrain mantle Th, U, we need to measure in the ocean.

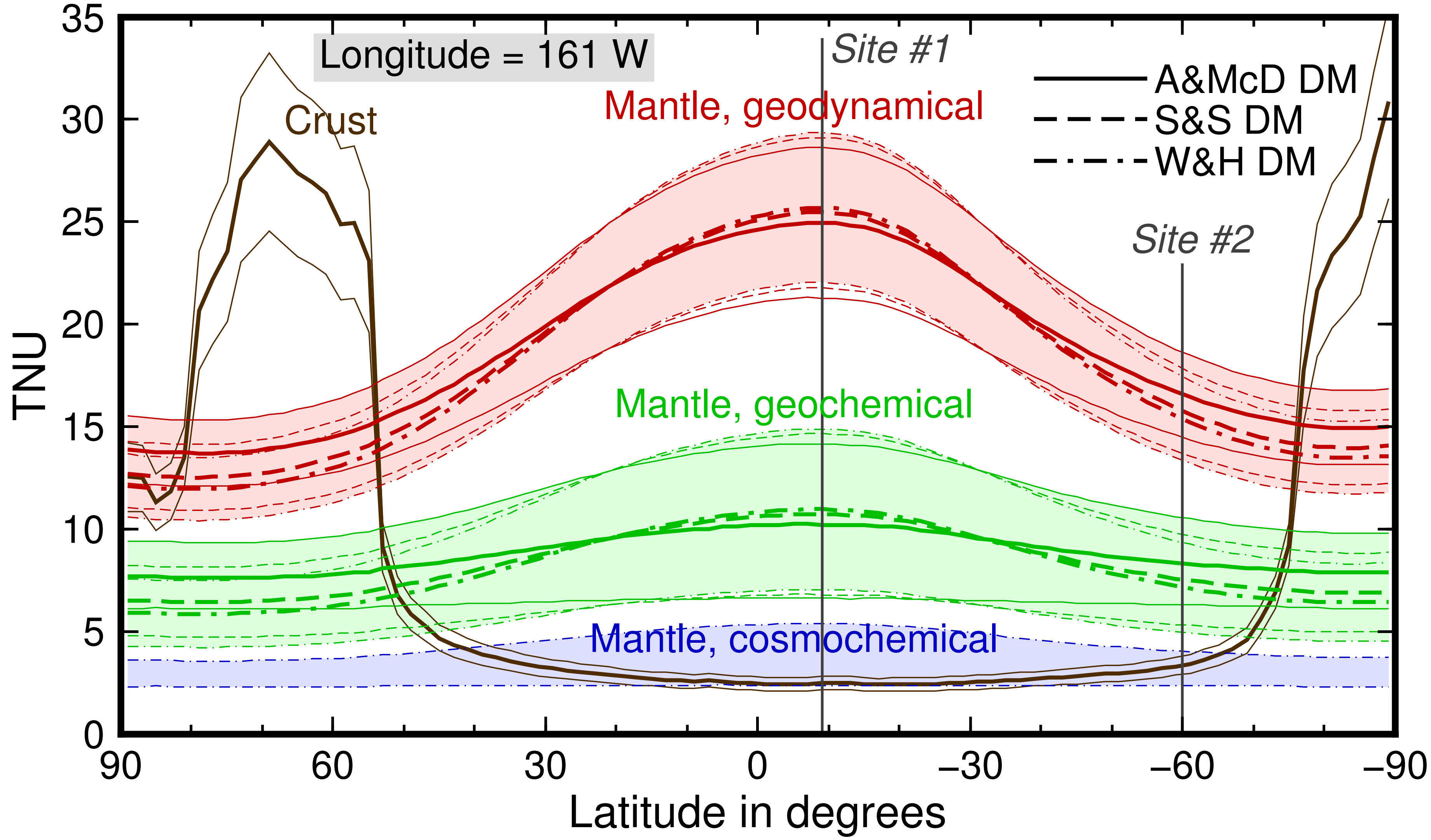


Hanohano (proposed)

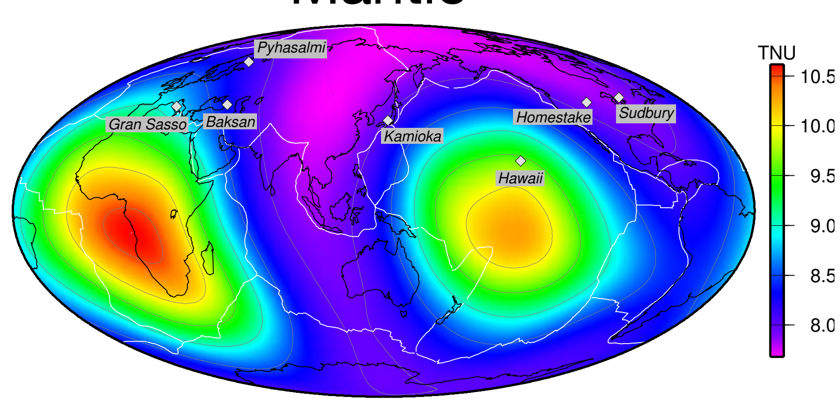


Crust + Mantle geoneutrino emission

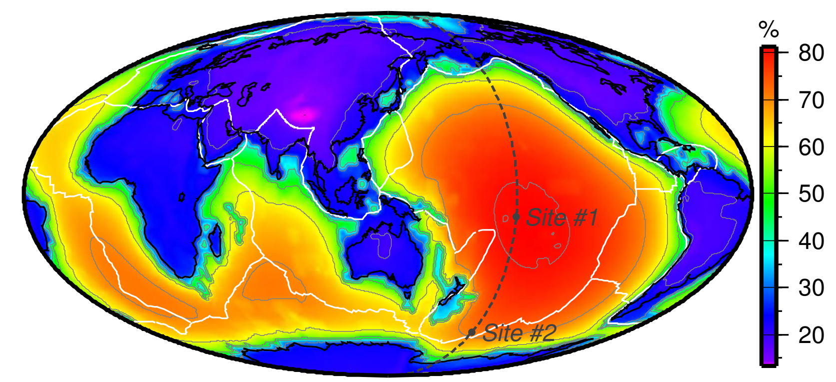
Prediction along 161°W meridian



Mantle

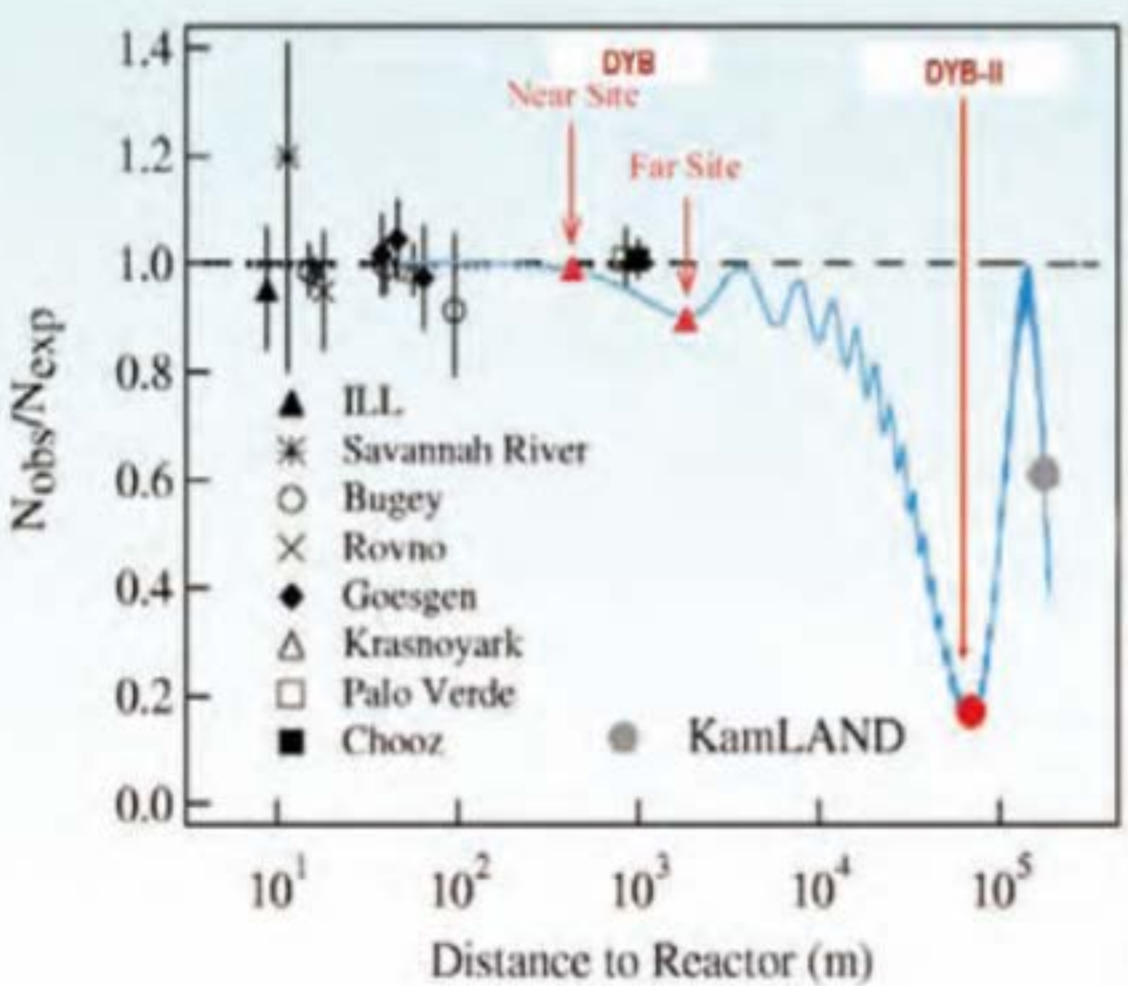


Mantle to total



O.Š., McDonough, Kite, Lekić, Dye, Zhong, EPSL 2013


Contact us | 中文
JUNO
Jiangmen Underground Neutrino Observatory


DYB
Near Site
Far Site
DYB-II
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Nobs/Nexp
ILL
Savannah River
Bugey
Rovno
Goesgen
Krasnoyark
Palo Verde
Chooz
KamLAND
10^1
10^2
10^3
10^4
10^5
Distance to Reactor (m)


Exp. Hall
实验厅
~53km
~53km
台山核电站
Taishan NPP
阳江核电站
Yangjiang NPP

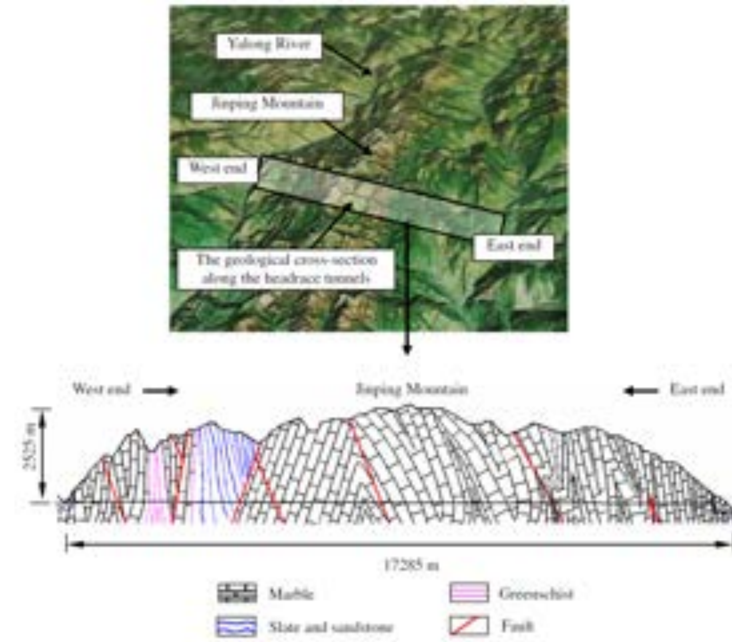
CJPLNE

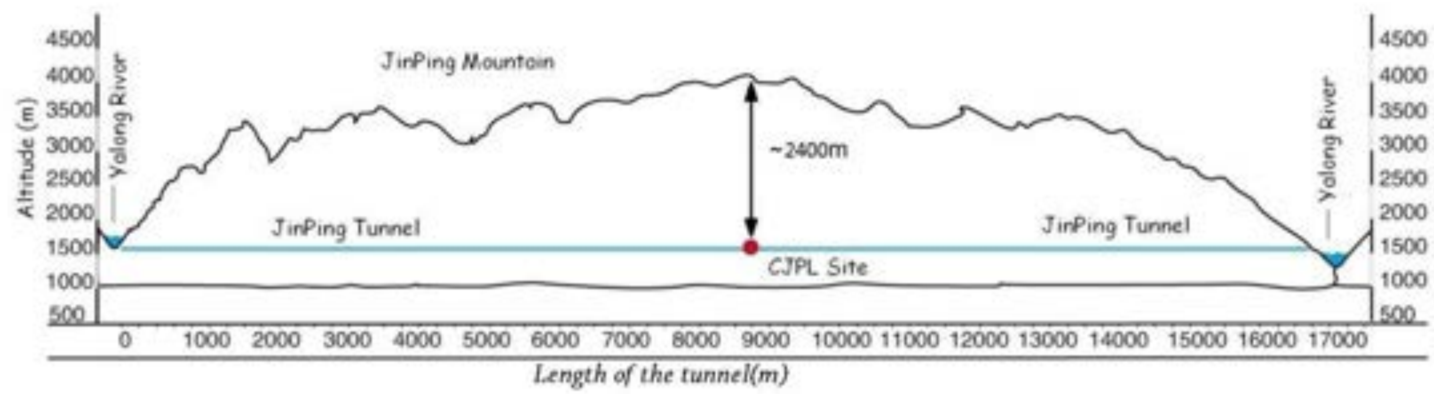
or

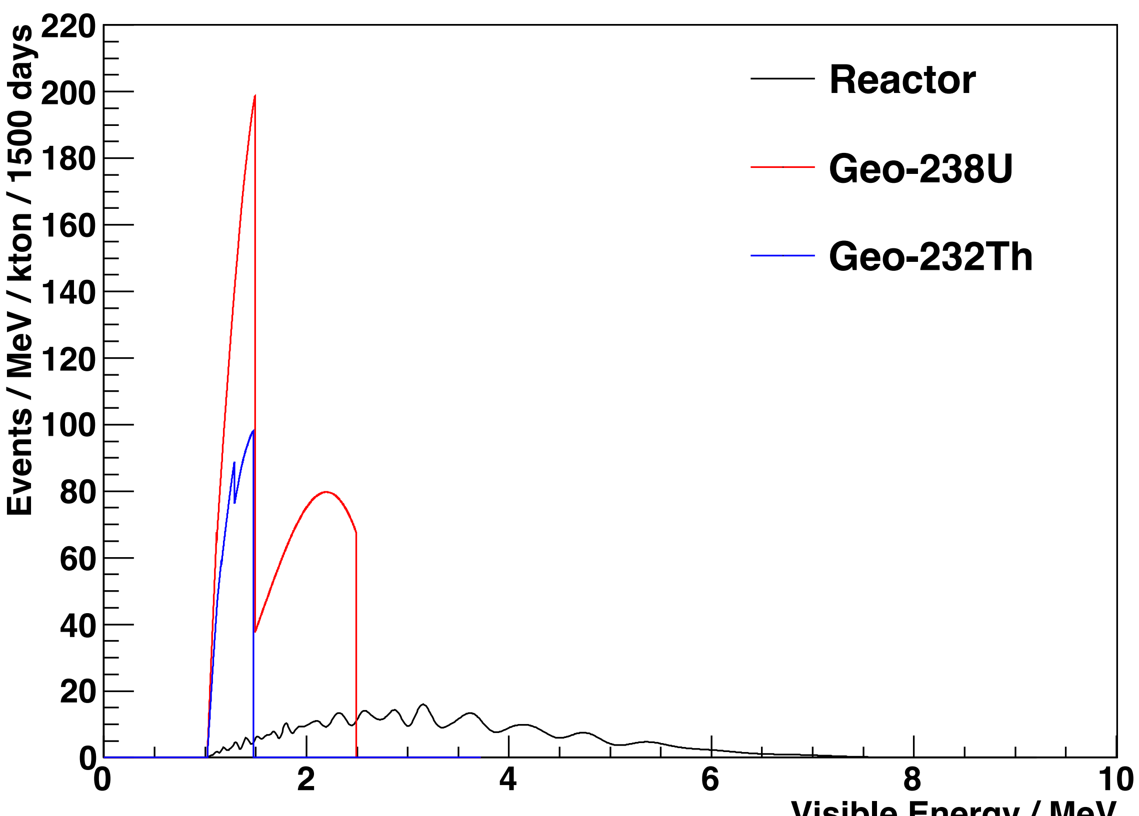
China **J**in**P**ing underground **L**aboratory **N**eutrino **E**xperiment

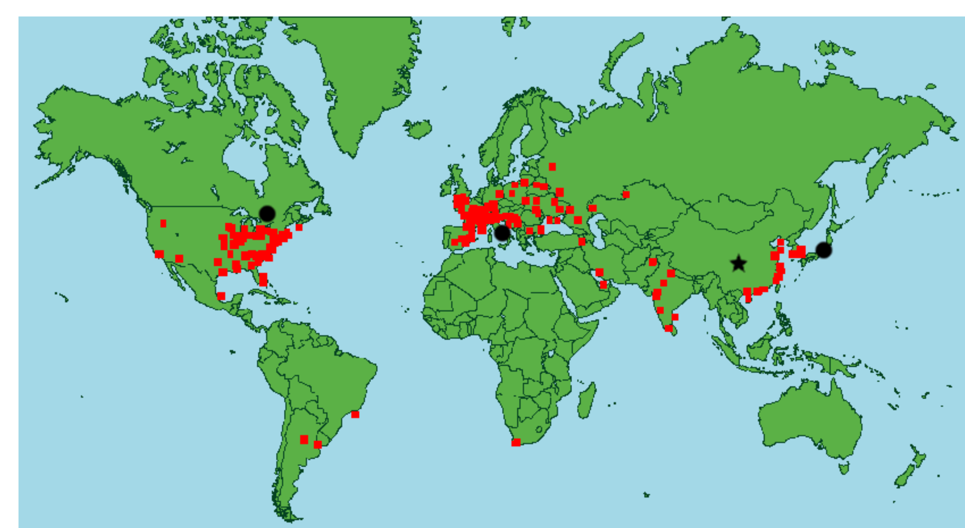
- Website at http://hep.tsinghua.edu.cn/CJPLNE/
- "[Neuntrino opportunities at Jinping](#)" document

PROPOSED





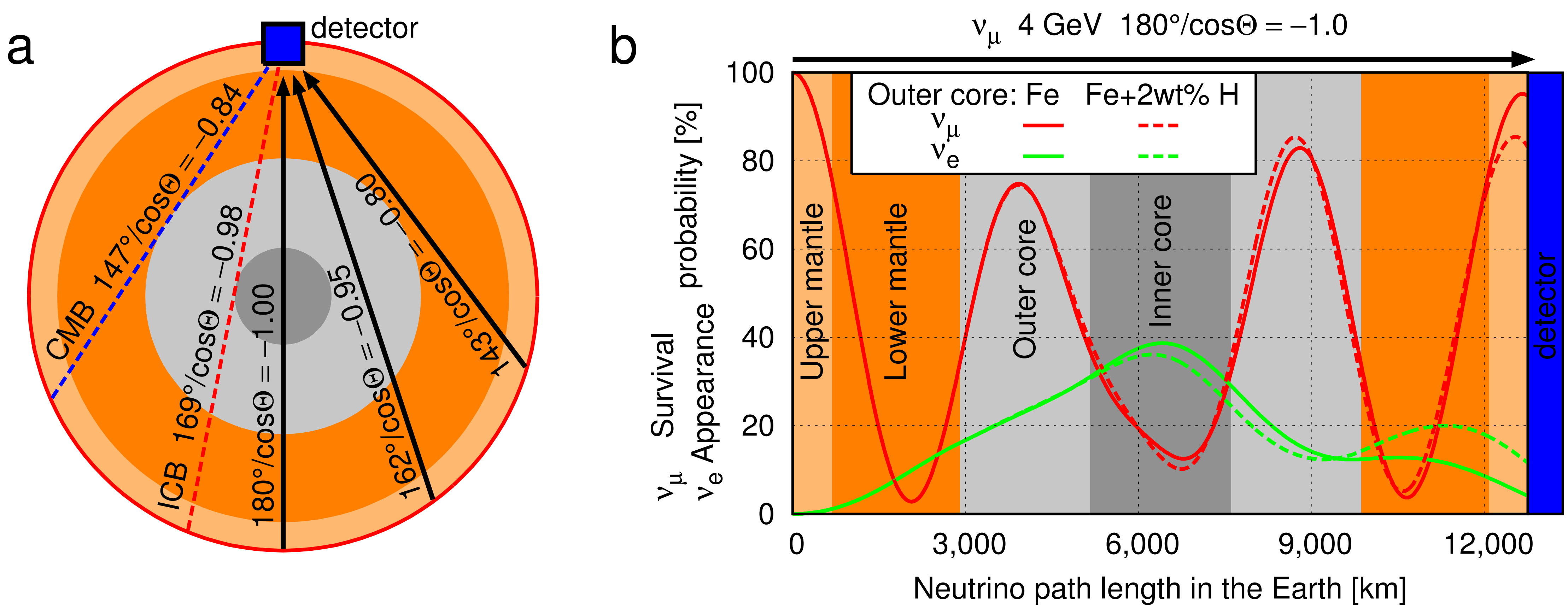


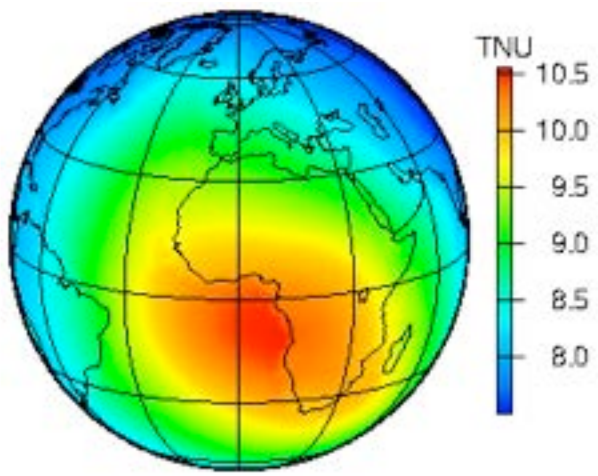


Neutrino geoscience – using neutrinos to measure Earth's properties:

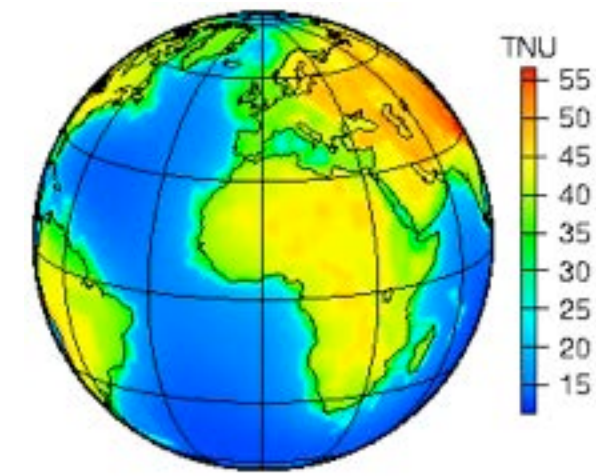
- measuring radioactive nuclei density using geo-neutrinos
- measuring matter density using neutrino absorption
- measuring matter density using neutrino oscillations
- measuring electron density using neutrino oscillations

Rott, Taketa, Bose 2015 doi:[10.1038/srep15225](https://doi.org/10.1038/srep15225) ([arXiv:1502.04930](https://arxiv.org/abs/1502.04930))



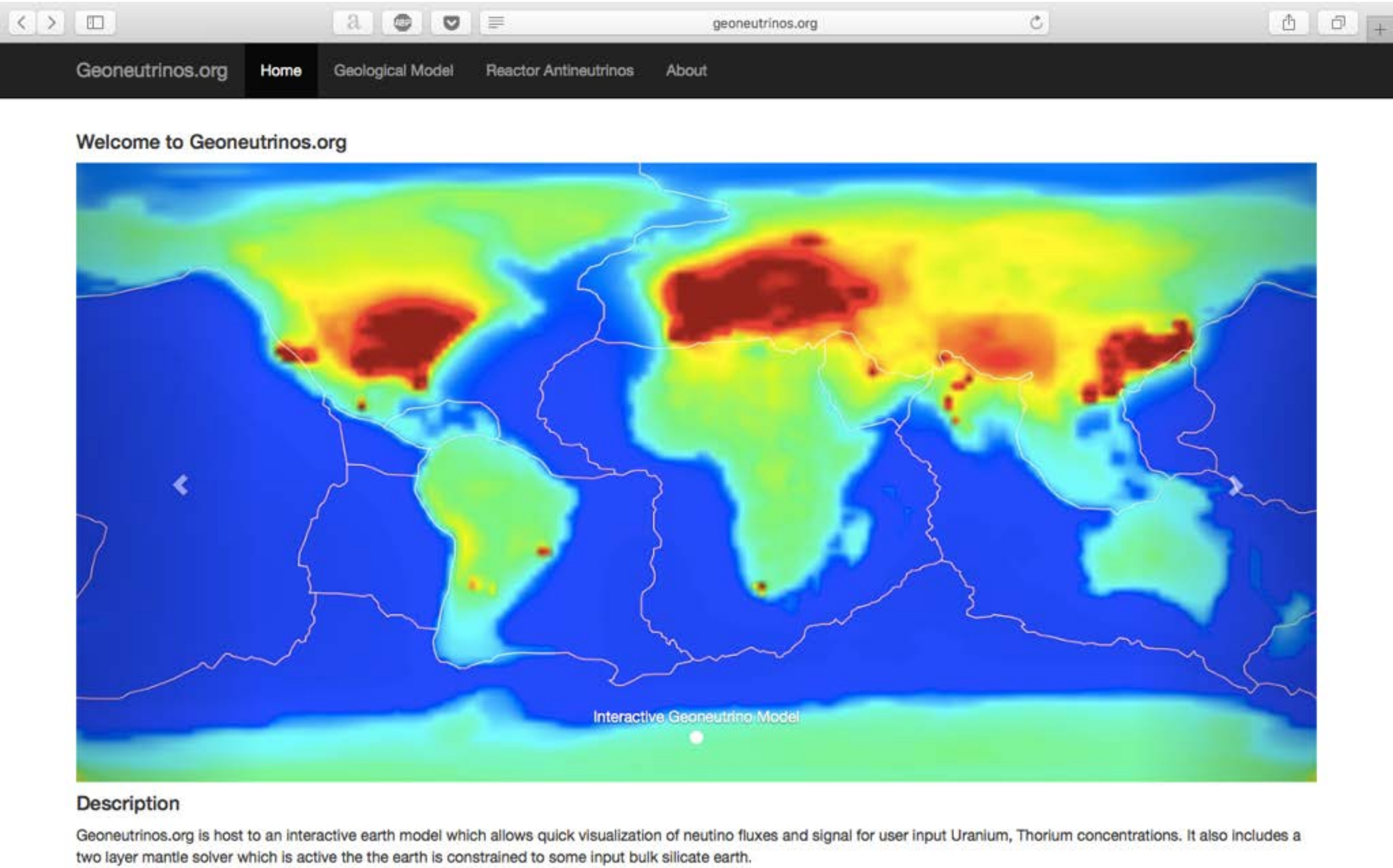


Summary



- Geophysics – diverse research across disciplines
- Still some fundamental unanswered questions
- Emerging field of “particle geophysics” including “neutrino geoscience”
- Geoneutrinos have begun to constrain Earth compositional models

geoneutrinos.org



geo.mff.cuni.cz

KATEDRA GEOFYZIKY

MATEMATICKO-FYZIKÁLNÍ FAKULTA

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Ke Karlovu 3
121 16 Praha 2

- Studium
- Výzkum
- Lidé
- Seismogramy
- Popularizace
- Obhájené práce
- Semináře
- Počítače
- Historie
- Fotogalerie
- Odkazy
- SquirrelMail
- Knihovna KG
- Konzorcium SW3D
- Stanice Praha
- Stanice Řecko

AKTUÁLNĚ

Zajímáte se o studium geofyziky? | Seismogramy Praha | Rozvrh výuky | Geo-dynamický seminář | Seismický seminář | Jiné semináře | G kalendář | guptime

PRO BUDOUCÍ BAKALÁŘE

- Podzimní kolo žádostí o studentské fakultní granty je otevřeno do 15. listopadu. Nahlédněte do naší nabídky témat:
  témata pro bakalářské práce a studentské granty
- Společnost Seismik, s.r.o., vyhlašuje
  soutěž o nejlepší diplomovou a bakalářskou práci – pátý ročník
  v oboru teoretická a užitá geofyzika/seismika.

STANE SE

- 13. 11. seismický seminář J. Vackáře a kol.
- 20. 11. seismický seminář M. Wcisła a L. Eisnera
- 25. 11. geodynamický seminář M. Dostalíka
- 27. 11. seismický seminář P. Bulanta a kol.

STALO SE

- říjen: Tomáš Petrásek publikuje ve Vesmíru
- září/říjen: Julie Nováková bloguje (části 1 a 2) z European Planetary Science

Výpočet elektronové hustoty podél paprsků neutrinových experimentů

Návrh bakalářské práce v oboru “**částicová geofyzika**” na **Katedře geofyziky** ve spolupráci s Ústavem částicové a jaderné fyziky

Kontakt: Ondřej Šrámek
ondrej.sramek@mff.cuni.cz
geo.mff.cuni.cz/~sramek

Mezi vědecké cíle nových neutrinových paprskových experimentů NuMI Off-Axis ν_e Appearance experiment (NOvA) a Deep Underground Neutrino Experiment (DUNE) patří zodpovězení žhavých otázek neutrinové fyziky, souvisejících s oscilací neutrin. Jeden z parametrů potřebných pro analýzu oscilací je elektronová hustota v prostředí, kterým neutrinový paprsek prochází. Cílem práce bude výpočet elektronové hustoty podle paprsku. Tedy, analýza geometrie experimentů, využití existujících modelů struktury zemské kůry, materialové hustoty v kůře a chemického složení hornin kůry, a výpočet elektronové hustoty – počtu elektronů na jednotku objemu – jako funkce dráhy paprsku. Úkol bude řešen na Katedře geofyziky ve spolupráci s Ústavem částicové a jaderné fyziky MFF UK.