Země jako „antineutrinová hvězda“

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Den otevřených dveří MFF UK, 26. 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

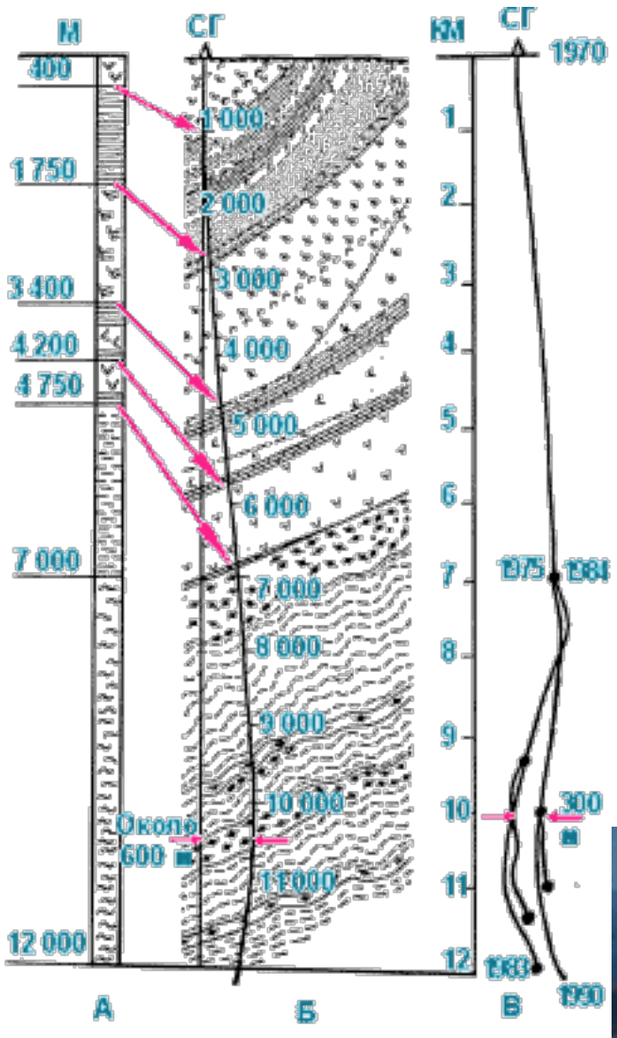
Processes

Origin

Evolution

How would you study this apple?

Scientific drilling



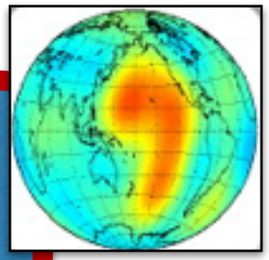
Kola Superdeep Borehole
12.262 km deep

compare with Earth radius
~6371 km

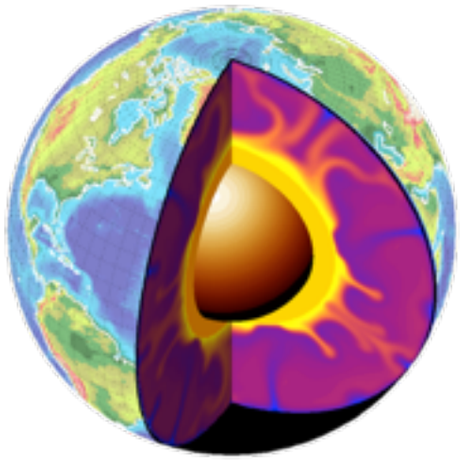
Study of (deep) Earth

Observations and sample collections possible at surface

Measurement and analysis of gravity field, magnetic field



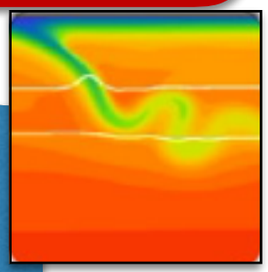
Study of earthquakes and propagation of seismic waves



Geochemical analyses of rock and meteorite samples

Experiments in minerals at high pressure and temperature

Numerical modeling of dynamic flow and deformation in the interior

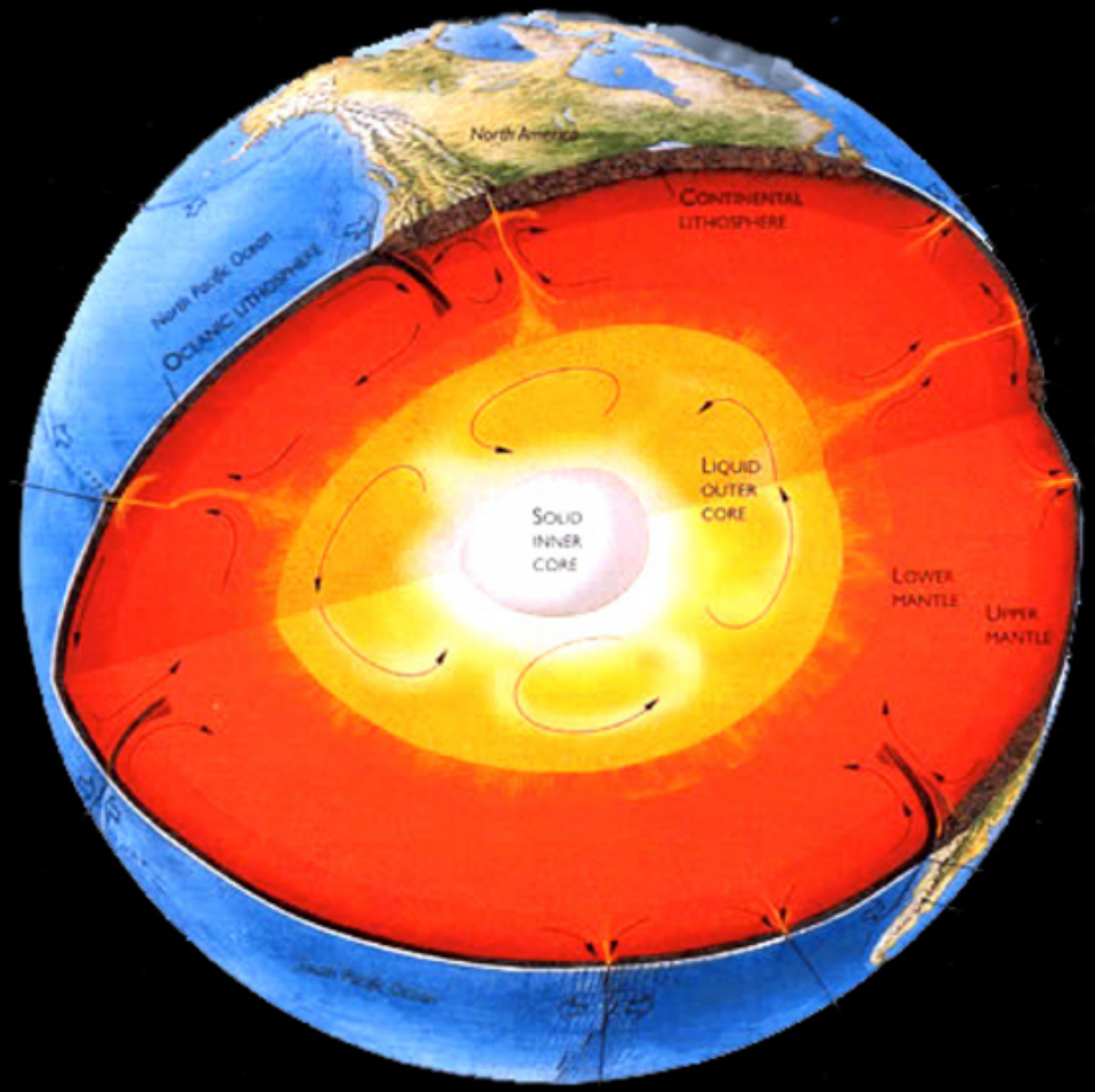


First principles ("ab initio") calculations of material properties

Fluid mechanics experiments in laboratory

Detection of **geoneutrinos**, "particle geoscience"

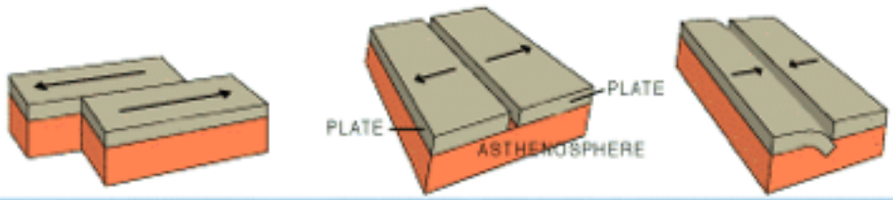
Layered Earth



- ***Compositional*** layering:
  - core
  - mantle
  - crust

- Layering according to ***mechanical properties***:
  - inner core
  - outer core
  - sublithospheric mantle
  - lithosphere

Plate tectonics, motion in Earth interior



theory developed in late 1960's and 1970's

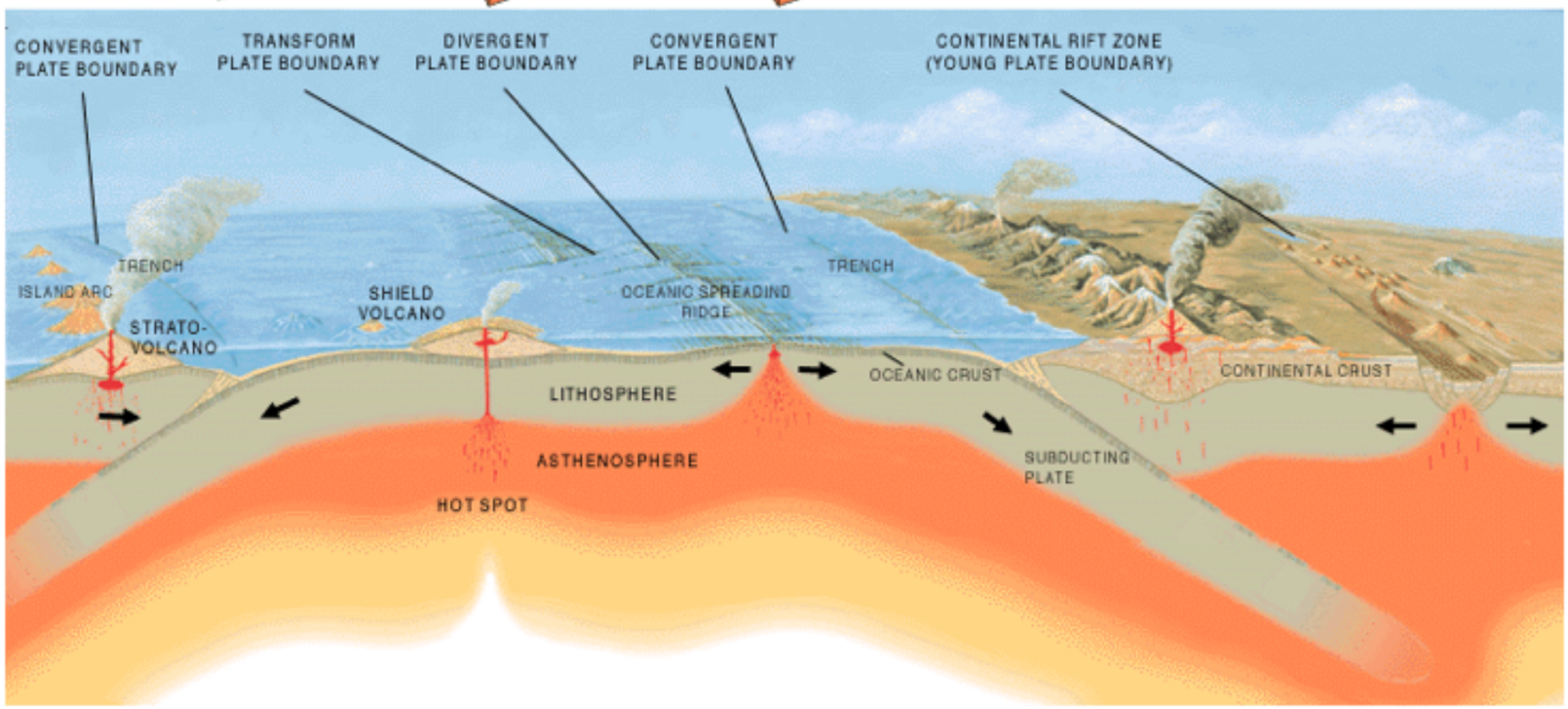
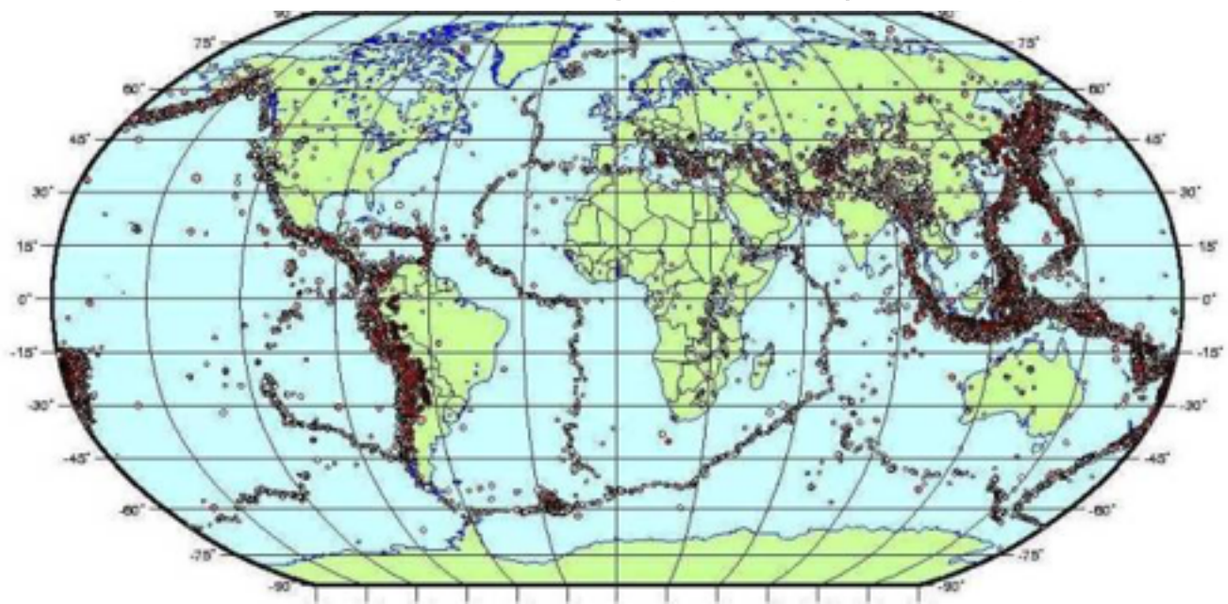


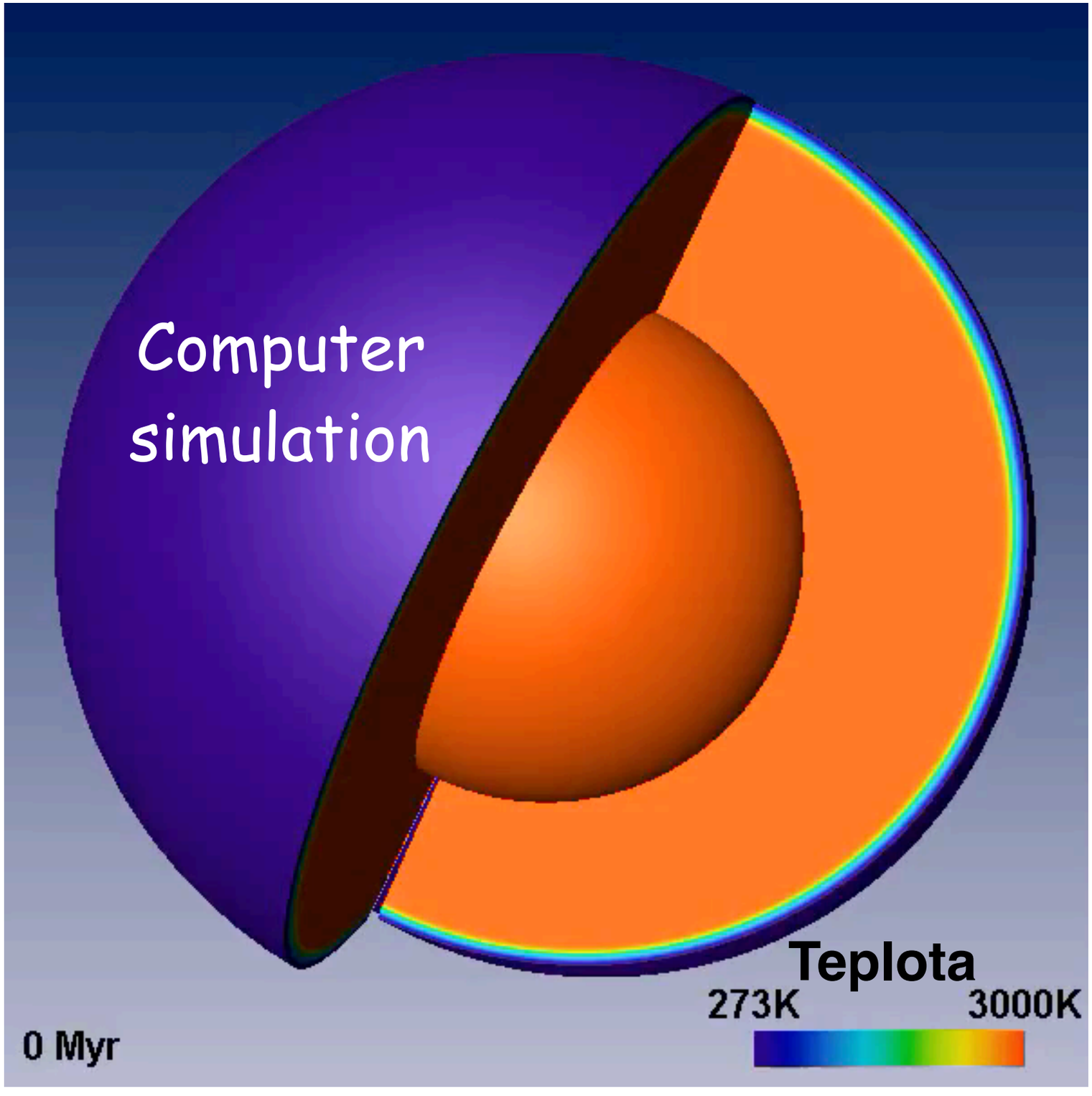
plate velocities ~ few cm/year

Tectonic plates

World seismicity (earthquakes)



Numerical modeling of "mantle convection"



From Hana Čížková, Katedra geofyziky

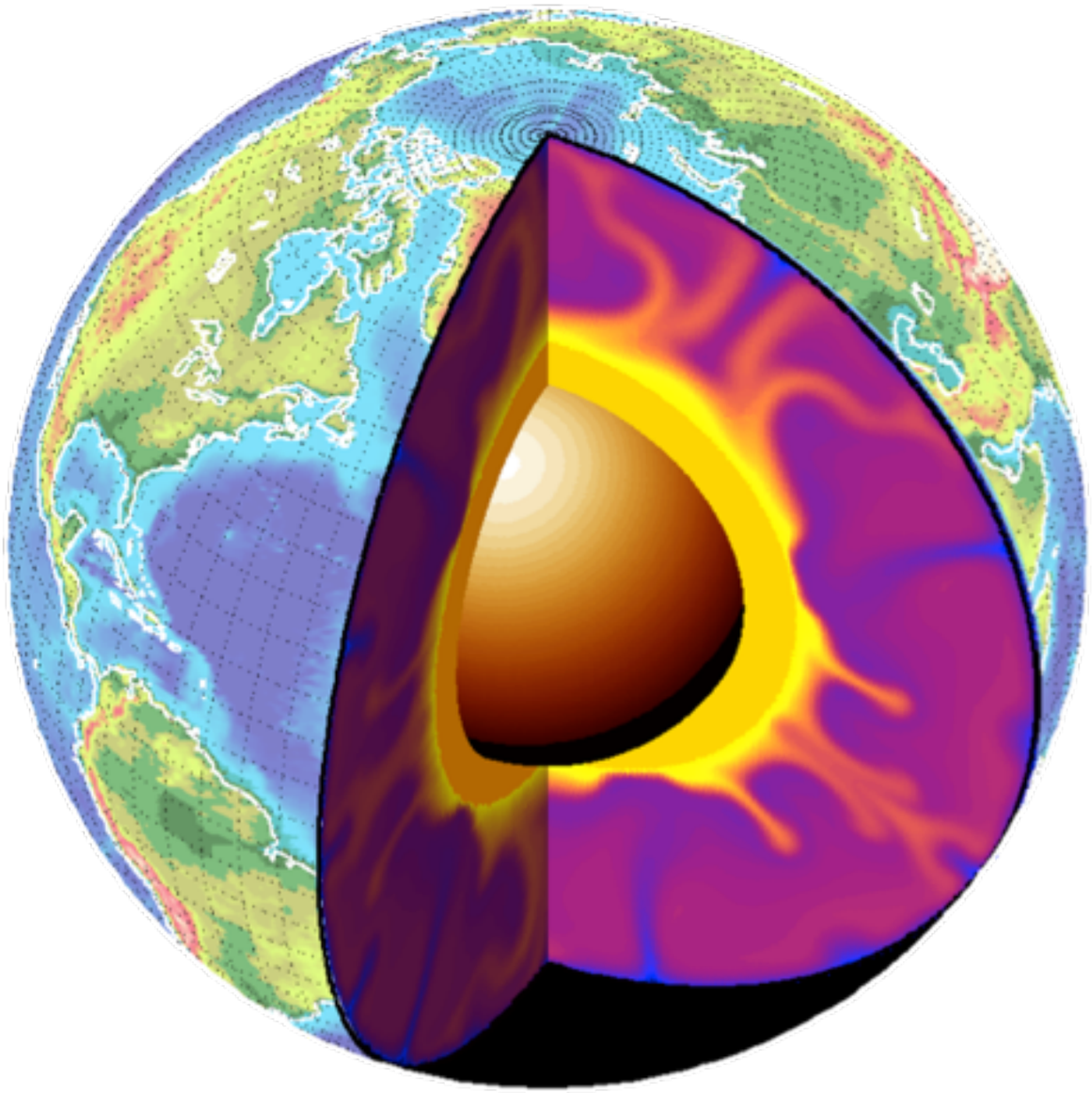
Thermal convection:
hot material rises
cold material sinks

Solving equations of
conservation laws
using computer

Mantle convection, plate tectonics

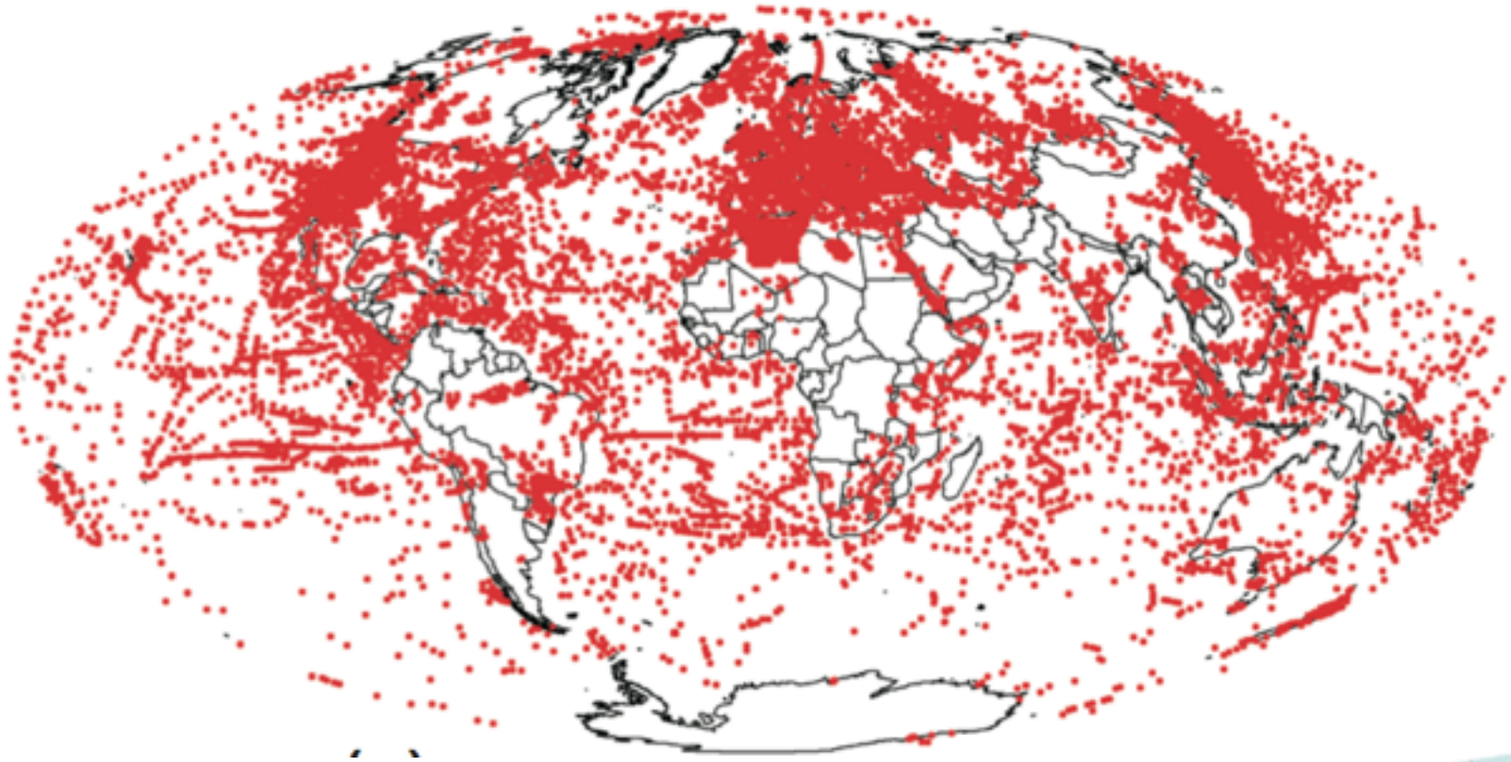
From BBC documentary film “**Earth: The Power Of The Planet**” (youtu.be/ryrXAGY1dmE)

Energy source for convective motions ??



Measuring Earth's surface heat flow

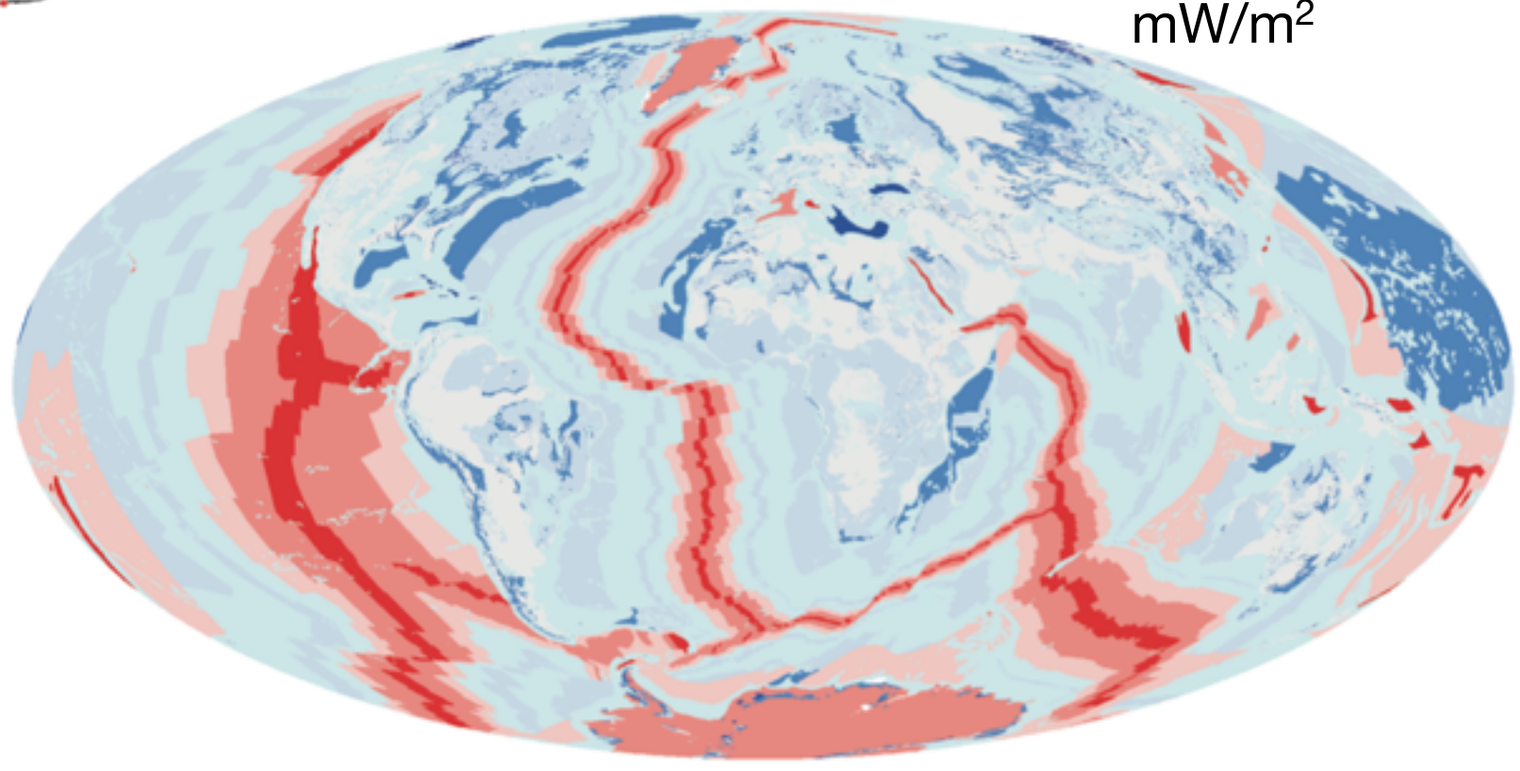
Global heat flow measurement sites



heat flux

23 - 45	75 - 85
45 - 55	85 - 95
55 - 65	95 - 150
65 - 75	150 - 450

mW/m^2



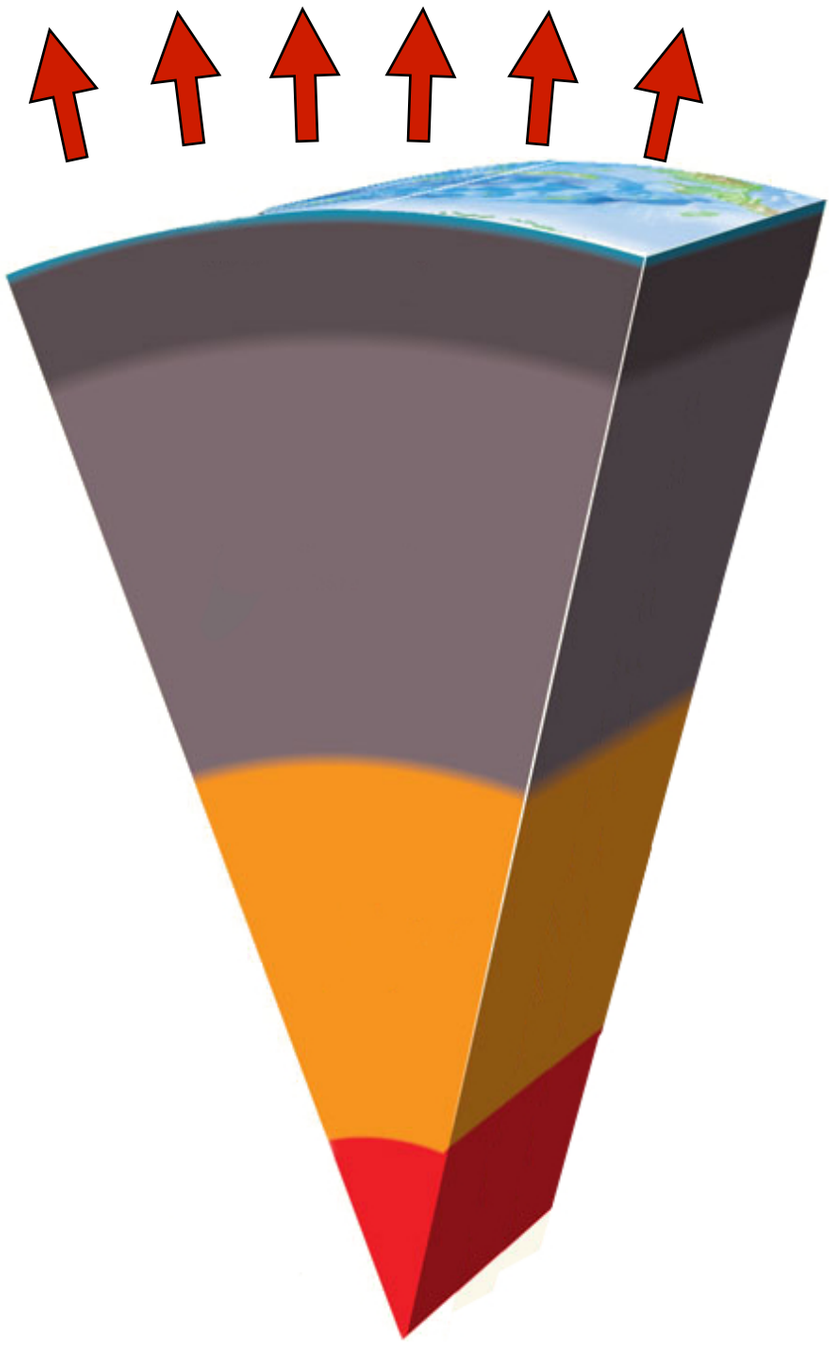
Map of global heat flux

Earth loses
~ 46 TW (terawatts)

From Davies & Davies 2010

Energy source for convective motions ??

What feeds Earth surface heat flow ??



Basic energy balance:

Surface heat flow

=

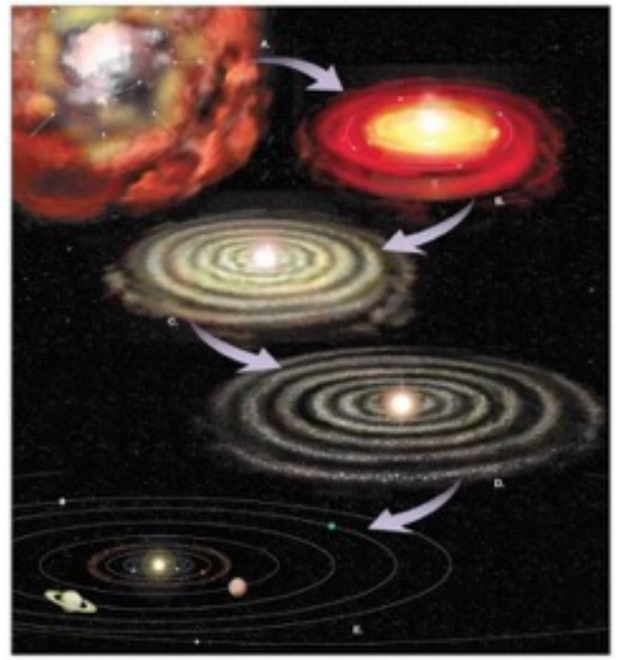
Cooling of the interior

+

Heat sources

"Primordial" heat

Planetary formation



Earth started hot
and has been cooling since

Energy sources in Earth's interior?

Long-lived radioactivity

$^{40}_{19}K$

$^{232}_{90}Th$

$^{238}_{92}U$

C Solid
Hg Liquid
H Gas
Rf Unknown

Metals: Alkali metals; Alkaline earth metals; Lanthanoids; Actinoids; Transition metals; Poor metals
Nonmetals: Other nonmetals; Noble gases

																	2 He Helium 4.002602
												5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3 Li Lithium 6.941	4 Be Beryllium 9.012182											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050																
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57–71	72 Hf Hafniu 178.49	73	74	75 Re Rhenium 186.207	76	77	78	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.9824)	85 At Astatine (209.9871)	86 Rn Radon (222.0176)
87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfo (261)			107 Bh Bohrium (264)				111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Up Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

stable is … er of the isotope with the longest half-life is in parentheses.

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

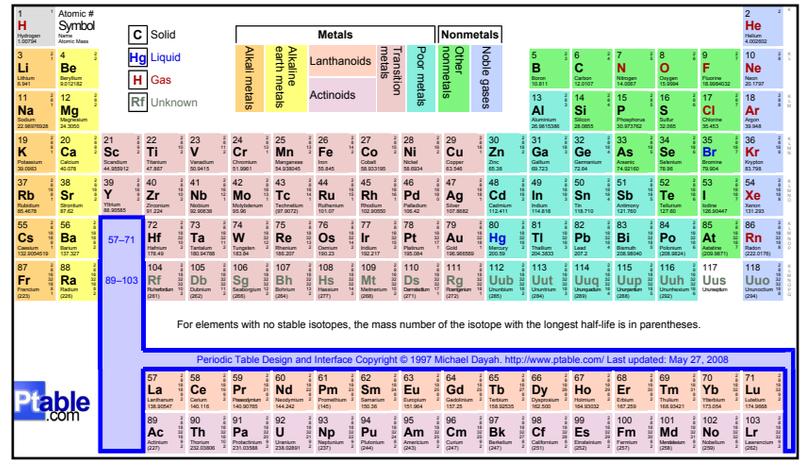
Ptable.com

Chemical composition of the Earth

O, Fe, Si, Mg account for 93% of Earth's mass

+ Al, Ca, Ni … 98% of Earth's mass

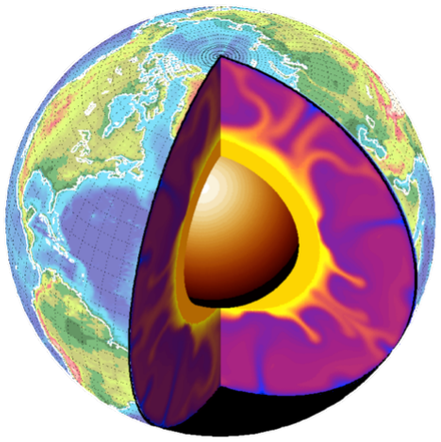
+ other minor and trace elements



~few tens of parts per billion (ppb) of Uranuim (U)

~four times as much Thorium (Th)

~few hundred parts per million (ppm) of Potassium (K)



10–30 TW of radiogenic heating

Could we get a better estimate??

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.

Neutrina na výsluní!

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

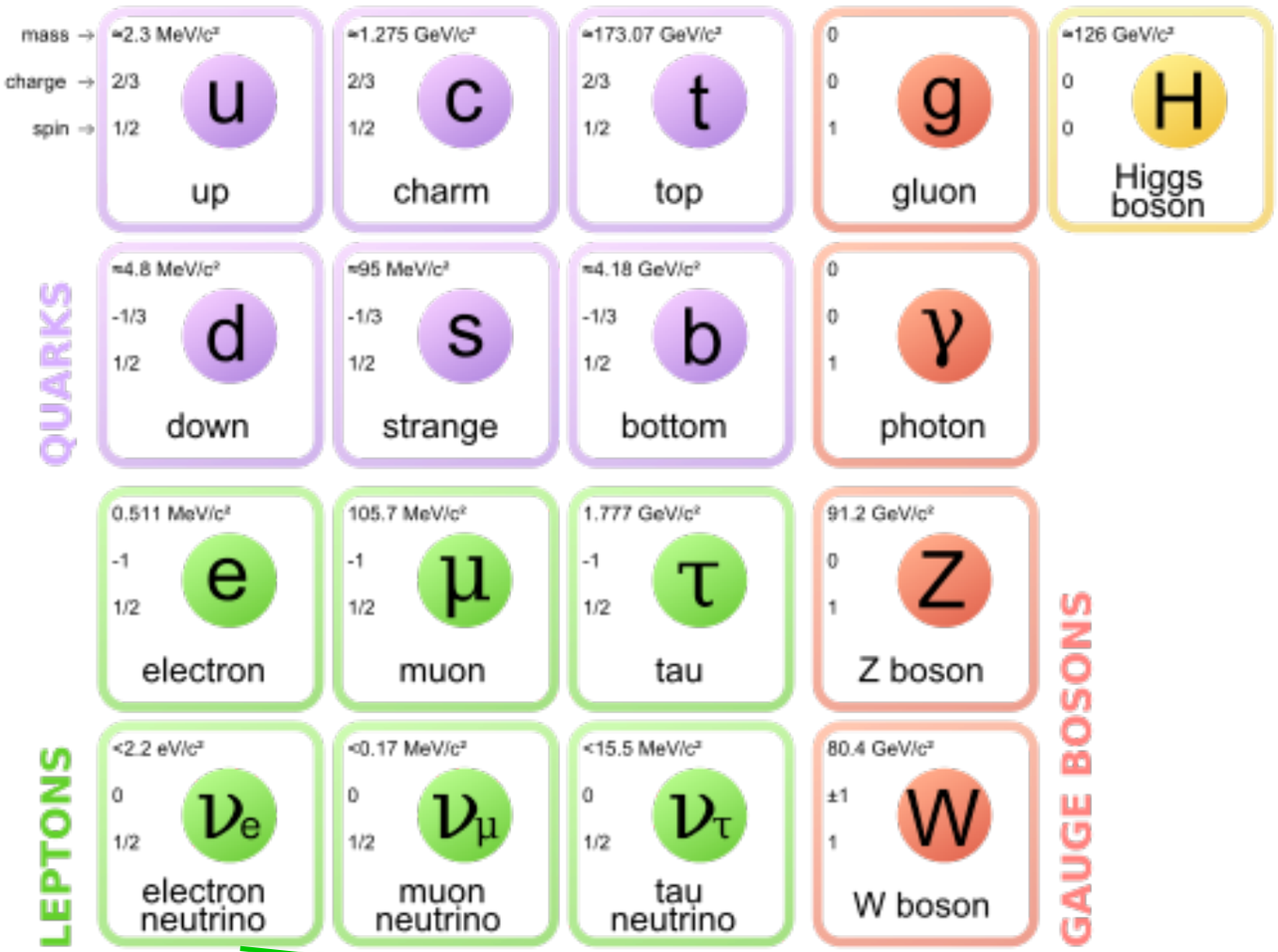

Takaaki Kajita and the Super K Collaboration


Yoichiro Suzuki and the Super K Collaboration

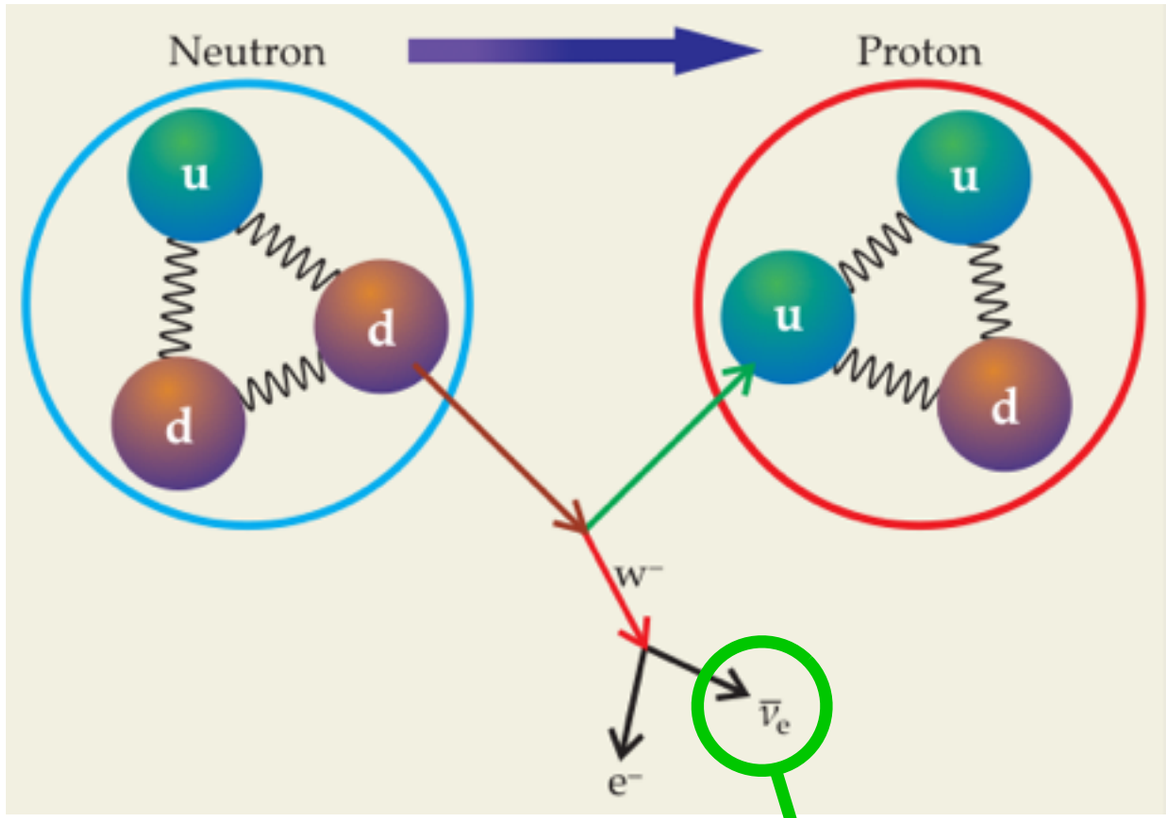
Včetně kolegů z UČJF na MFF UK, členů Daya Bay Collaboration

What are neutrinos?

Standard Model of elementary particles



β^- decay



electron antineutrino

What are geoneutrinos?

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

$$^{238}_{92}\mathrm{U} \longrightarrow ^{206}_{82}\mathrm{Pb} + 8\alpha + 6e^- + 6\bar{\nu}_e + 51.698\,\mathrm{MeV}$$

$$^{232}_{90}\mathrm{Th} \longrightarrow ^{208}_{82}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.652\,\mathrm{MeV}$$

$$^{40}_{19}\mathrm{K} \xrightarrow{89.3\,\%} ^{40}_{20}\mathrm{Ca} + e^- + \bar{\nu}_e + 1.311\,\mathrm{MeV}$$

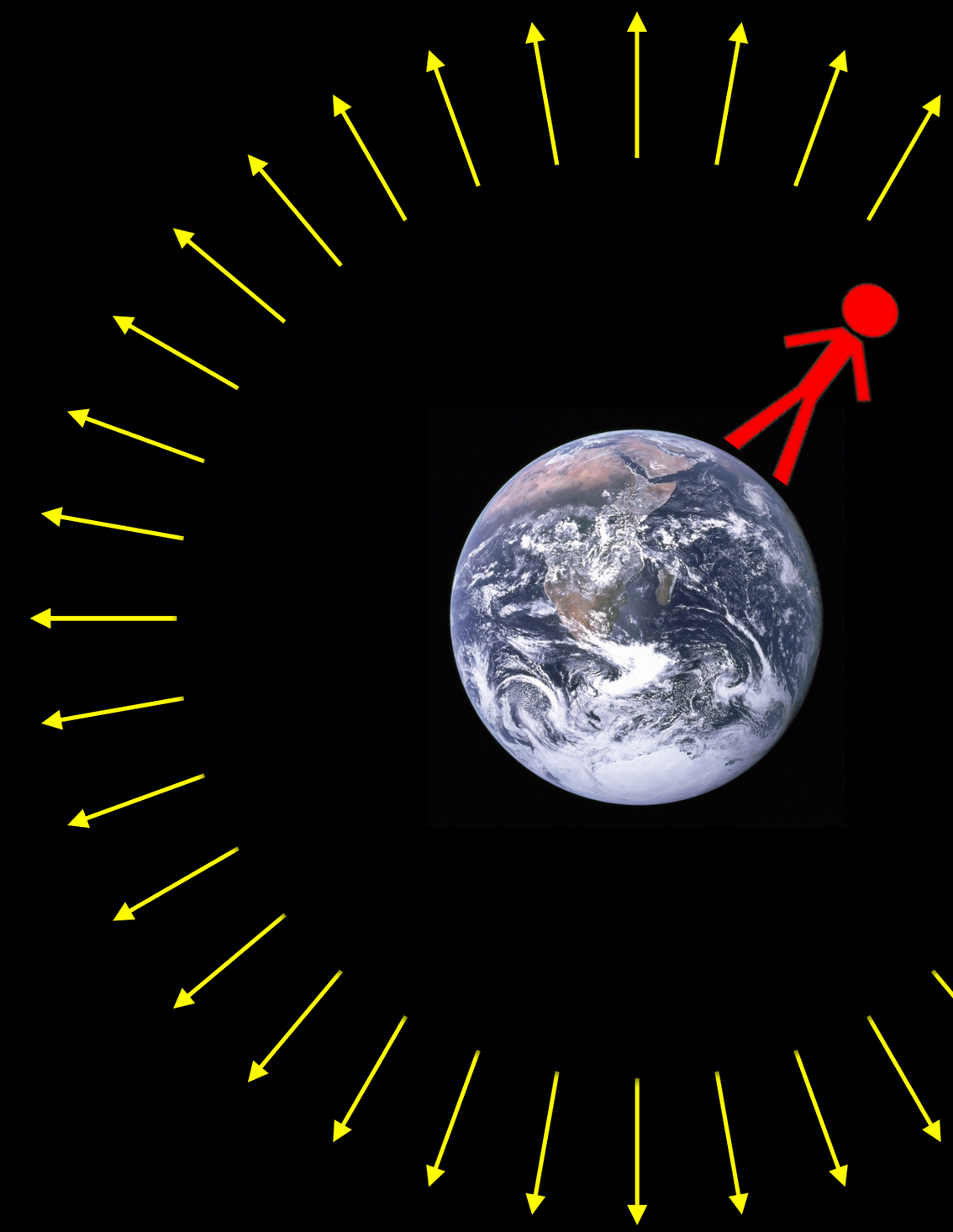
Decay energy
~20% carried away by antineutrinos
~80% heats the Earth's interior

Earth essentially transparent to neutrinos.

They fly out at near-light speed along straight path.

Earth, an "antineutrino star"

Emits electron antineutrinos created inside the Earth



Some 10 billion geoneutrinos flying through each of us every second…

$$^{238}_{92}\mathrm{U} \longrightarrow {}^{206}_{82}\mathrm{Pb} + 8\alpha + 6e^- + 6\bar{\nu}_e + 51.698\,\mathrm{MeV}$$

$$^{232}_{90}\mathrm{Th} \longrightarrow {}^{208}_{82}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.652\,\mathrm{MeV}$$

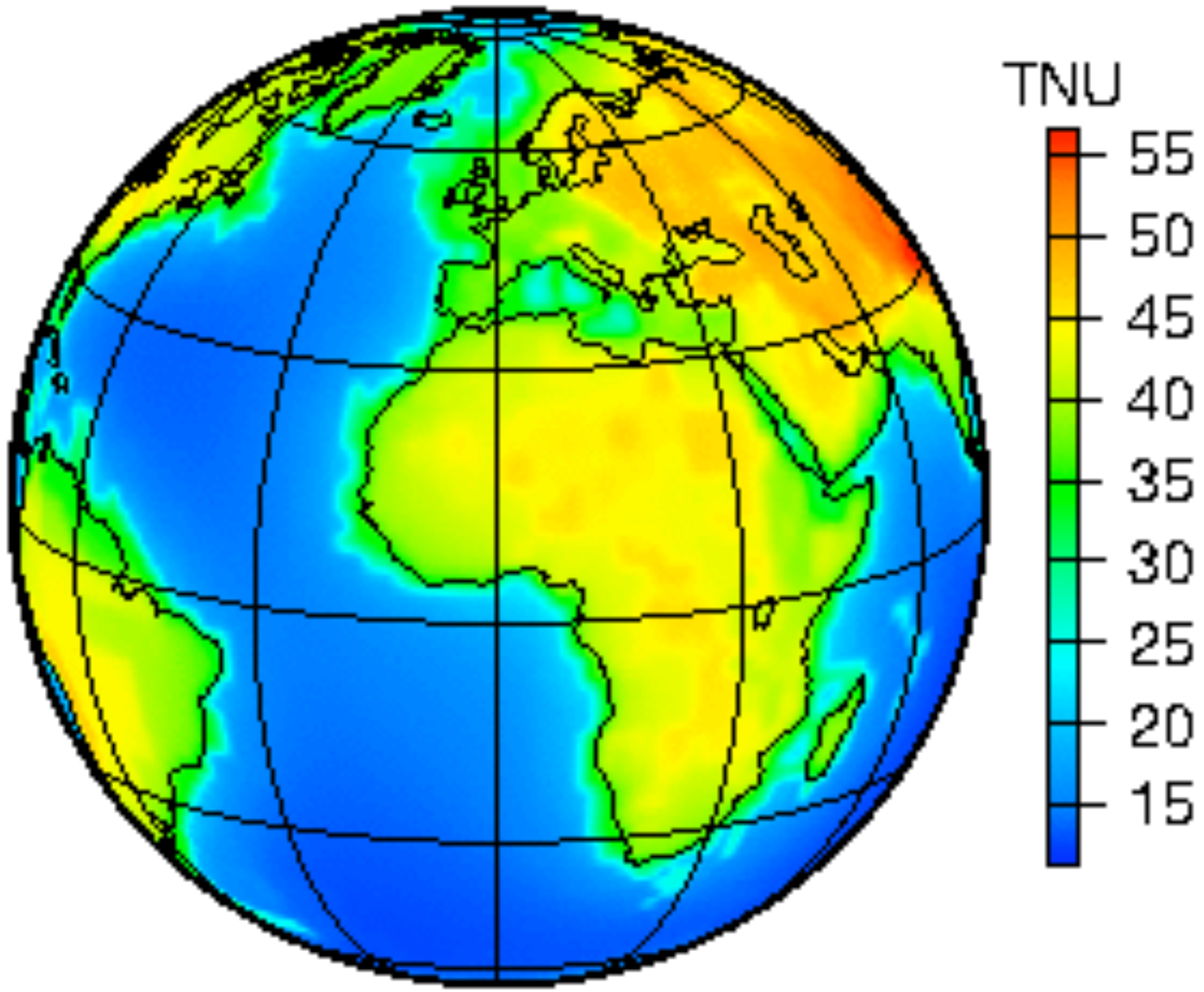
$$^{40}_{19}\mathrm{K} \xrightarrow{89.3\,\%} {}^{40}_{20}\mathrm{Ca} + e^- + \bar{\nu}_e + 1.311\,\mathrm{MeV}$$

~ chemical composition ⟷ ~ geoneutrinos ⟷ ~ radiogenic heating

How much K, Th, U ??

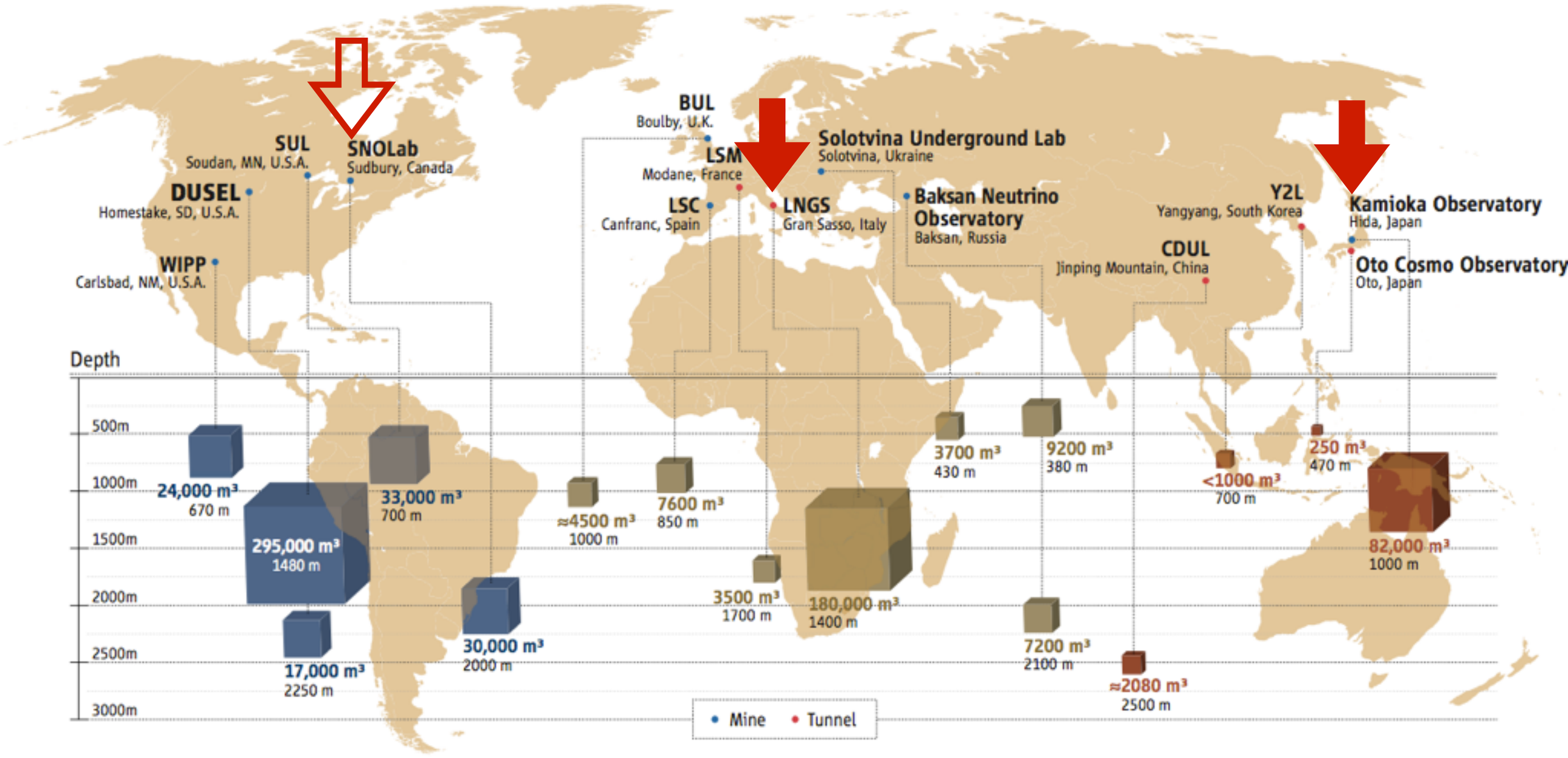
10 or 20 or 30 TW ??

Prediction of geoneutrinos at Earth's surface



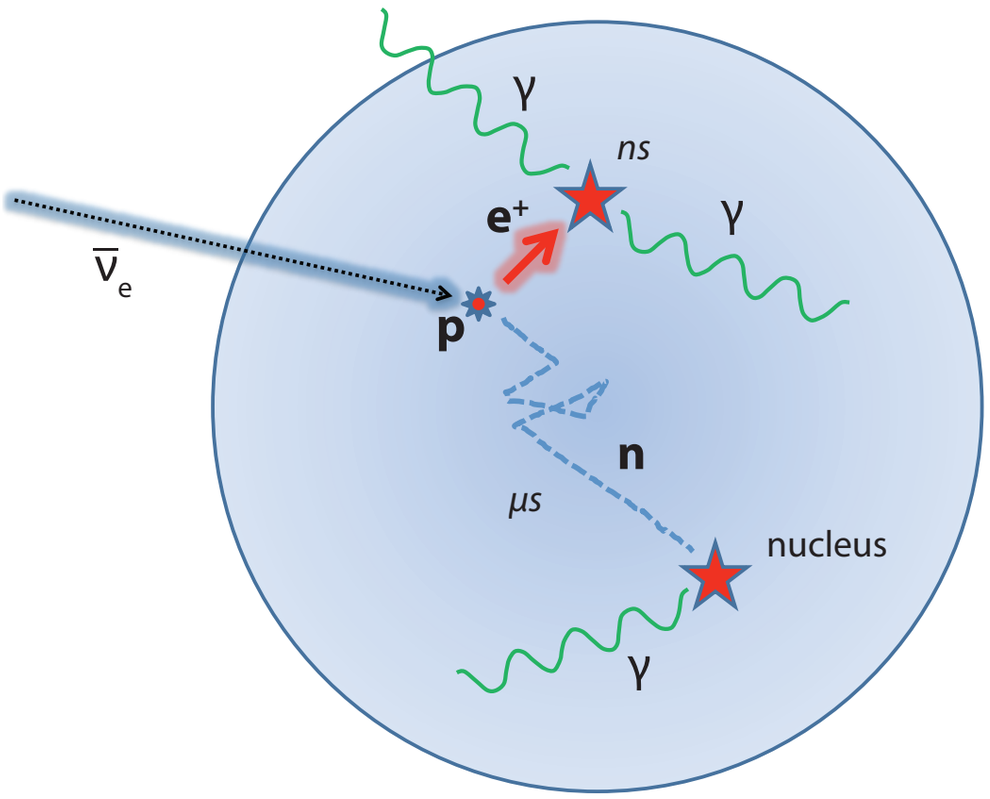
If we could count geoneutrinos…

Geoneutrino-detecting underground physics laboratories



Cho 2010 Science 10.1126/science.330.6006.904

Detecting (geo)neutrinos

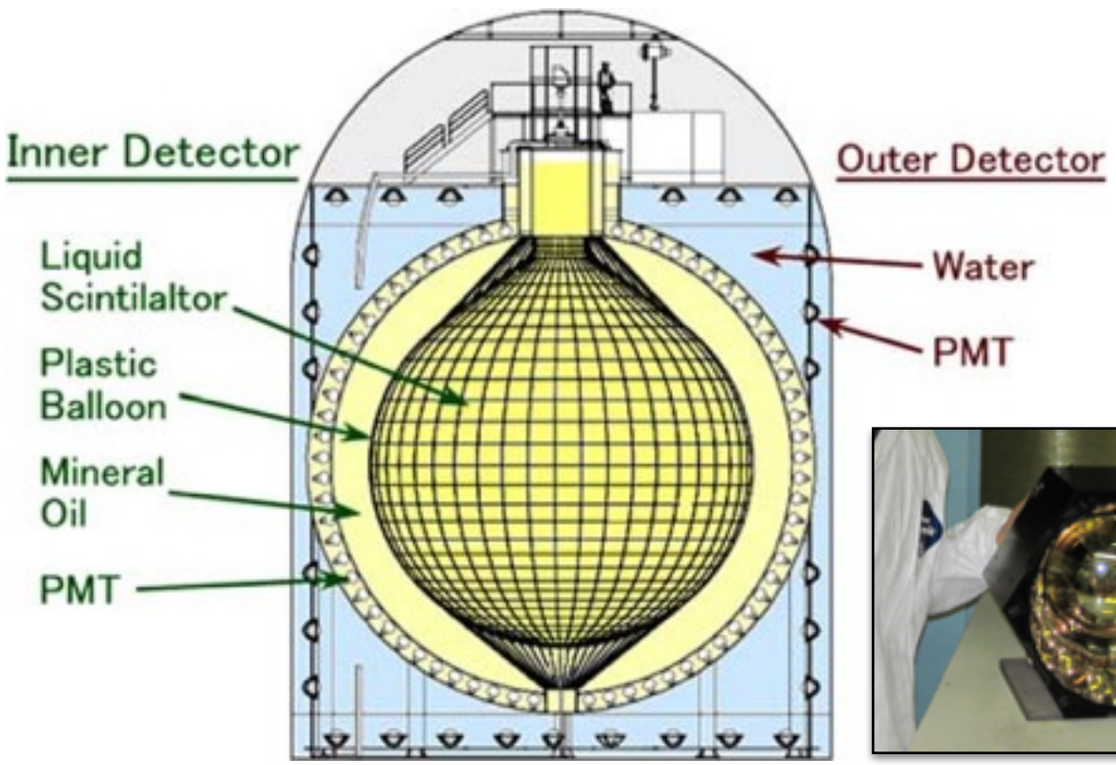


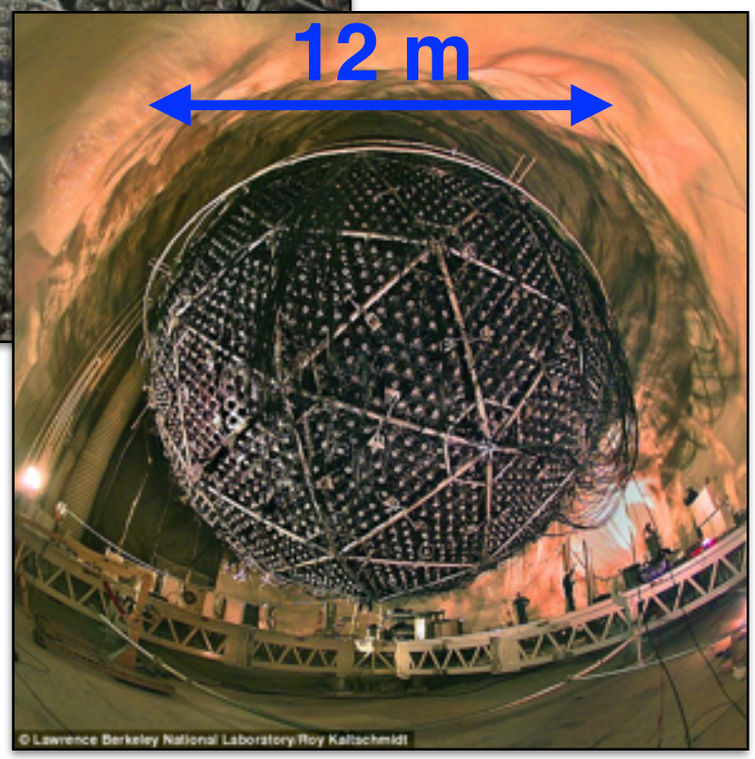
Liquid scintillator detectors:

Large … ~1000 tons

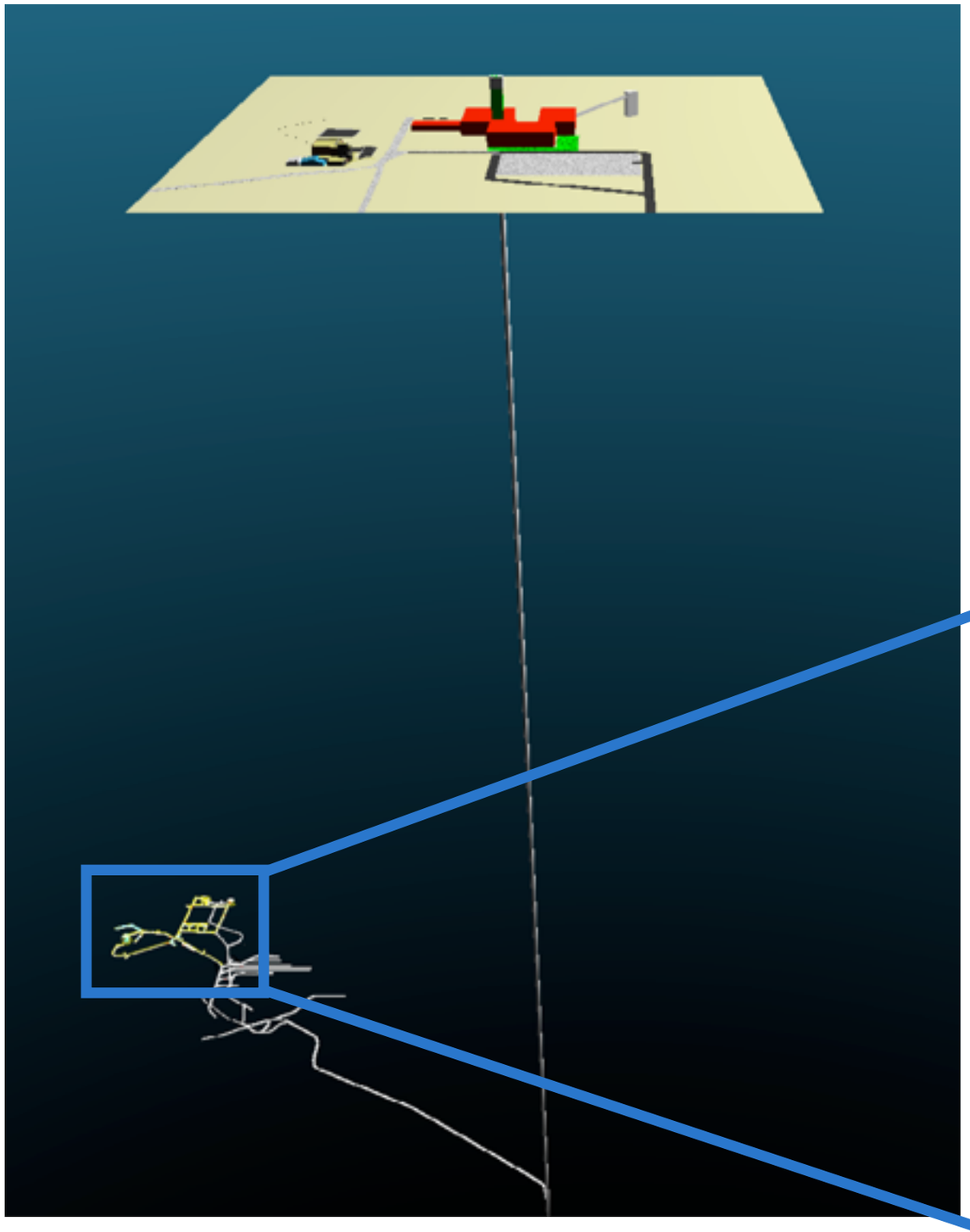
Underground … to shield from cosmic rays

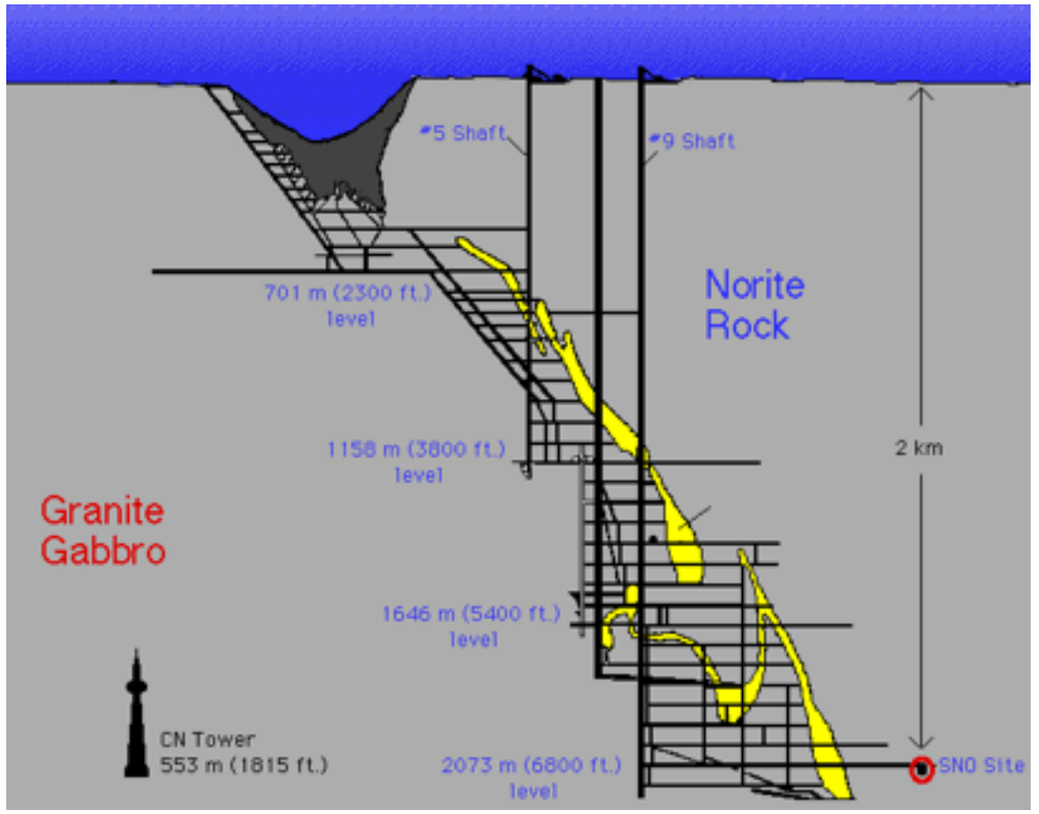
Operation … several years

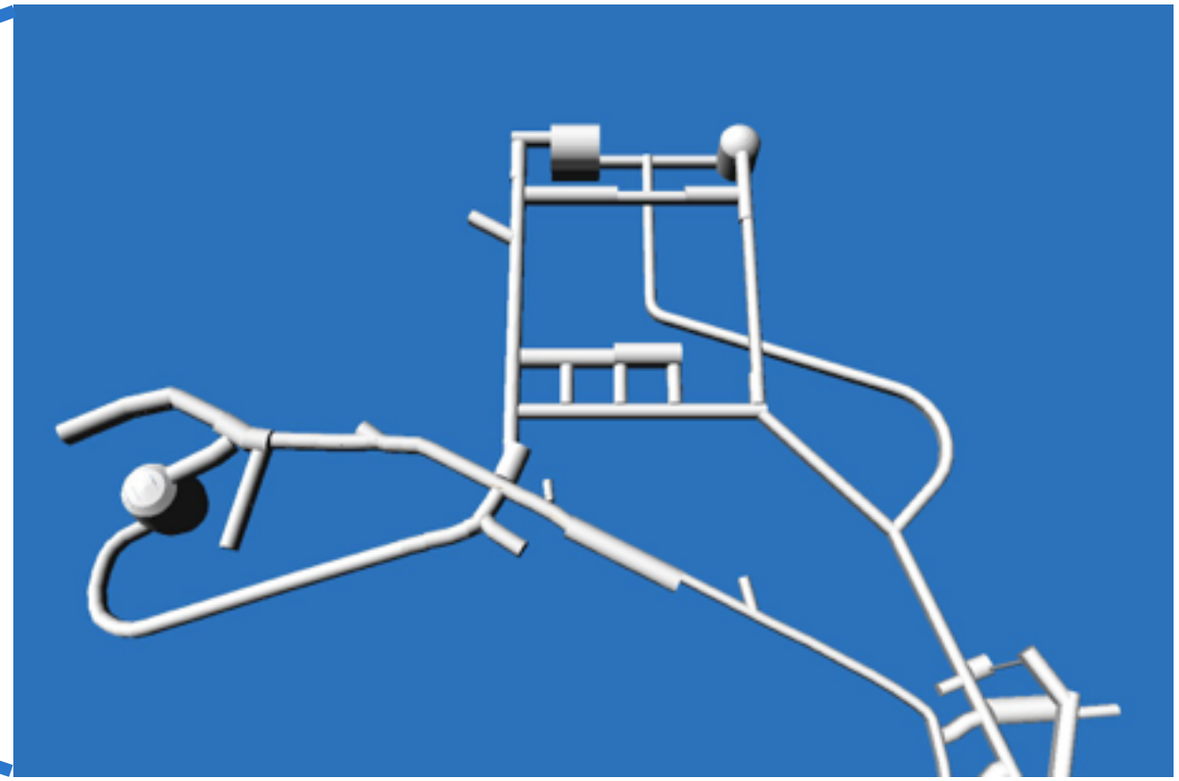




Sudbury, Ontario, Canada








SNOLAB

Brief (geo)neutrino 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 — 195

Antineutrino astronomy and geophysics

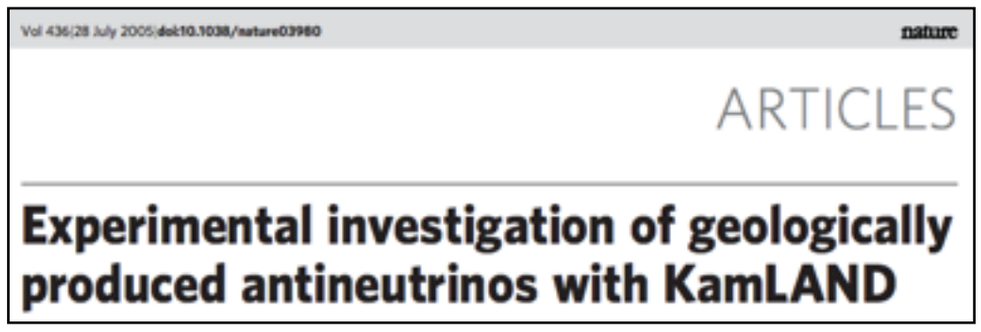
Lawrence M. Krauss*, Sheldon L. Glashow† & David N. Schramm‡

* 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 geoneutrinos at KamLAND experiment



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

ARTICLES

Experimental investigation of geologically produced antineutrinos with KamLAND

This is what a scientific paper looks like...

Antineutrino astronomy and geophysics

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

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IF there are more things in heaven and Earth than are dreamt of in our natural philosophy, it is partly because electromagnetic detection alone is inadequate. For sources which are visually obscured or which emit most of their energy in a form other than photons, new methods of detection must be developed. This has spurred the growth of neutrino astronomy, typified by the detection of neutrinos emitted in the interior of the Sun[1,2] but although the usefulness of the weak interactions in probing astrophysical sources has been recognized, the potential of antineutrino detection has not been widely explored. That is our objective.

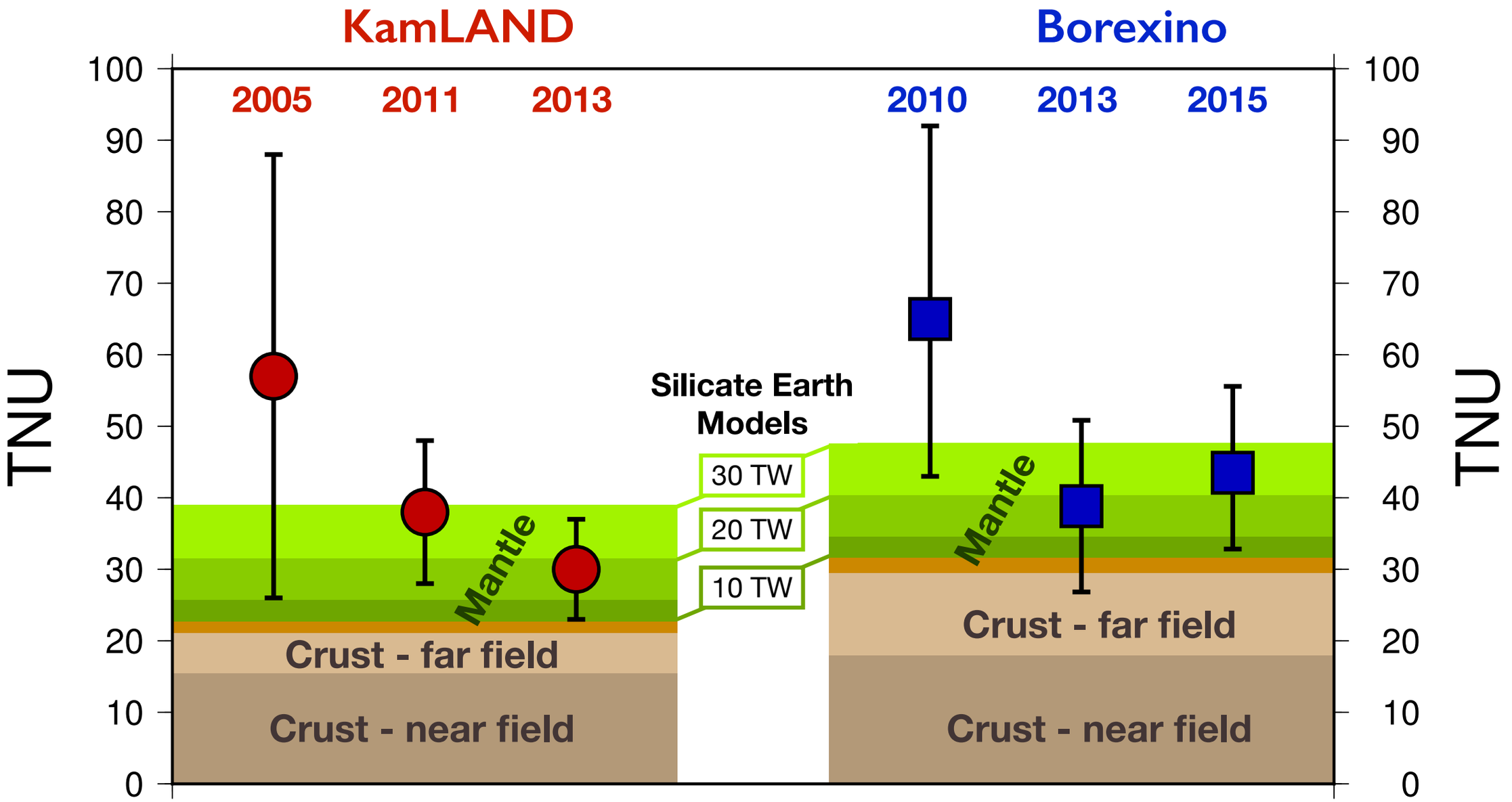
We demonstrate that the Earth is a rich source of antineutrinos whose detection can provide otherwise inaccessible key information on the internal structure and dynamics of the Earth. Moreover, by a consideration of the antineutrino background from other sources, we find that there may be a diffuse background of ~10-MeV antineutrinos from supernovae which, if detected, could yield information on the energy and frequency of supernovae.

flux, centring on the value 40 TW[8–10], were much more accurate, the question of how much of the heat loss arises from production and how much from the fact that the Earth is still hot would remain unresolved. The difficulty is that heating from radioactive sources known in the surface layers is of the same order of magnitude as the total heat flux, so that even small abundances elsewhere would imply that the interior of the Earth is heating, not cooling.

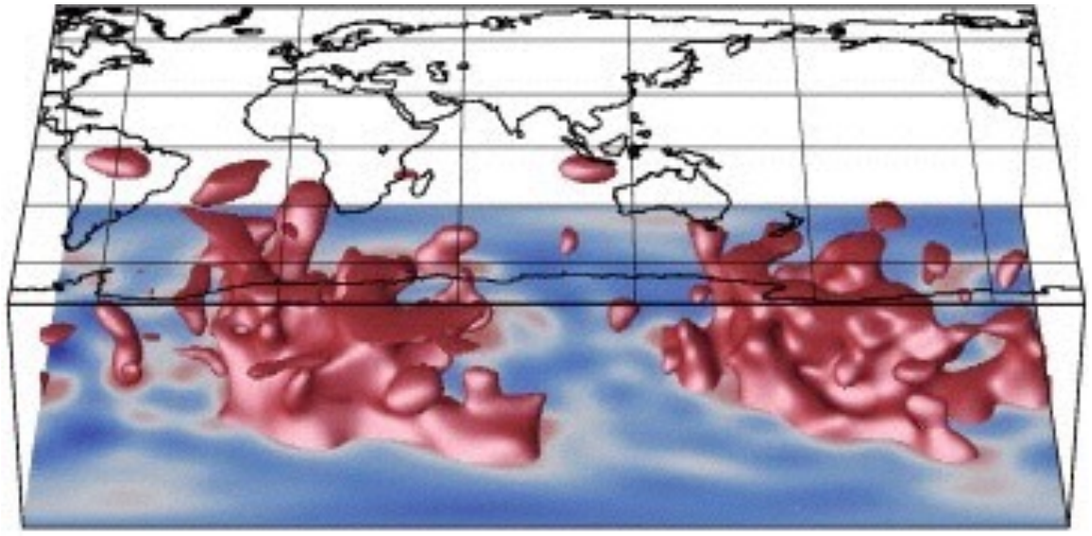
Table 1 gives data for the lithosphere, which we define as the surface layer down to ~100 km depth containing the continental and sub-oceanic plates whose mass of $\sim 2 \times 10^{25}$ comprises about 1/300 of the Earth's total mass[9]. The mean abundances are given in Table 1 for the chief radioactive isotopes ^{40}K, ^{238}U, ^{232}Th, ^{87}Rb (ref. 11); actual abundances depend crucially on rock type and region[8], generally decreasing from granite to basalts to dunites, with ^{238}U and ^{232}Th abundanees varying by factors of 5–10. The abundance of ^{40}K is particularly sensitive to rock type and drops to almost zero in dunites[8].

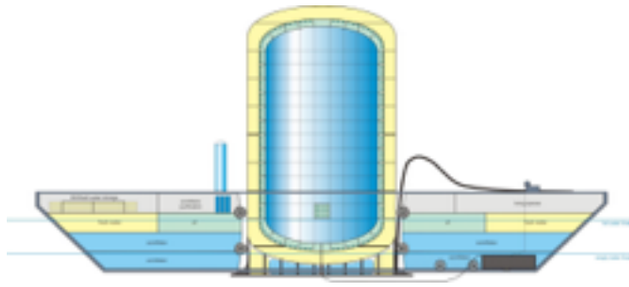
Our first objective is to calculate the spectrum of the anti-

Geoneutrino measurements vs. predictions

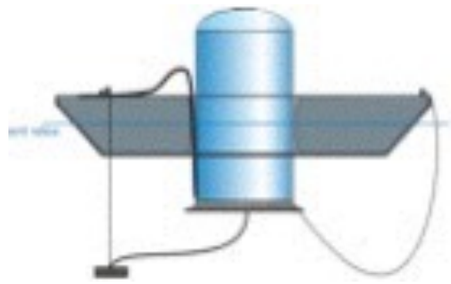


What seismic tomography sees

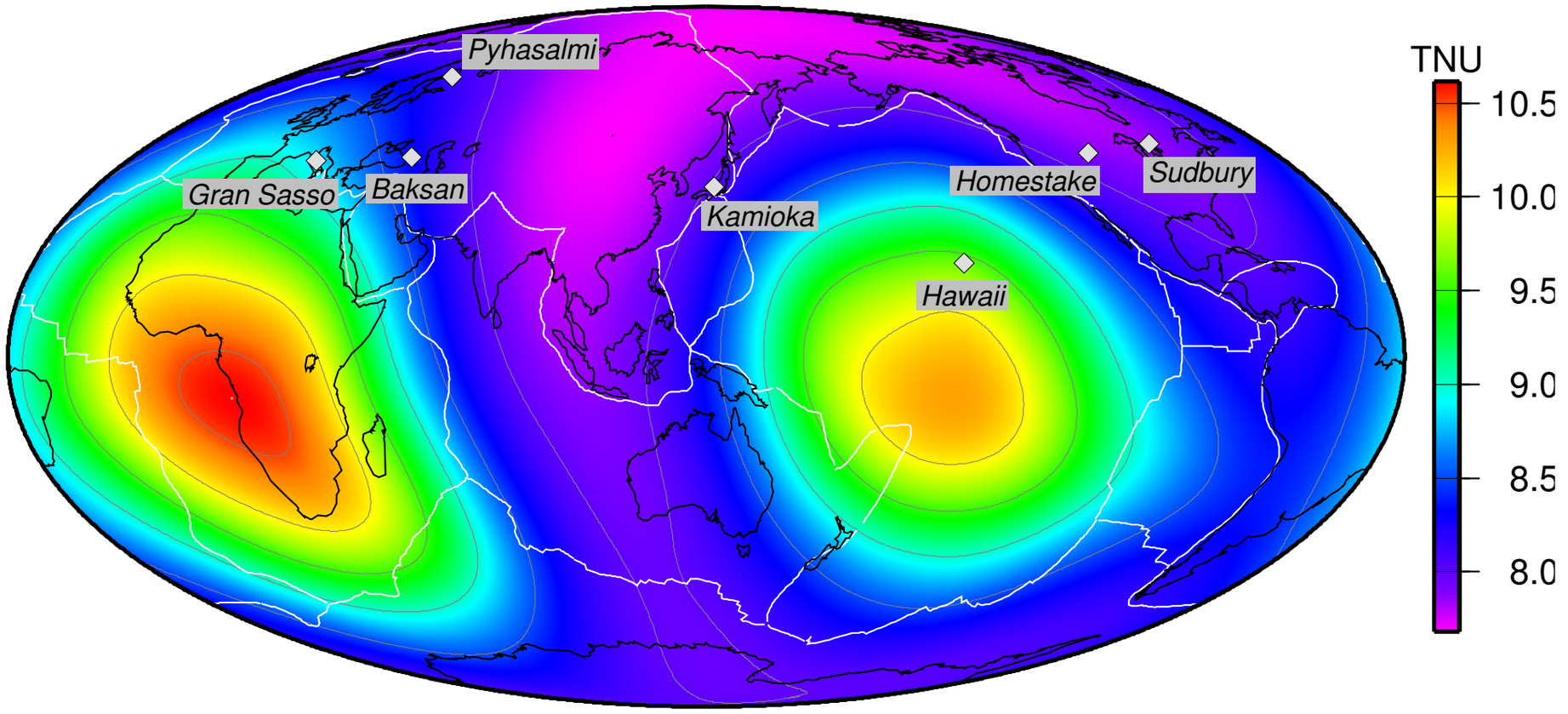


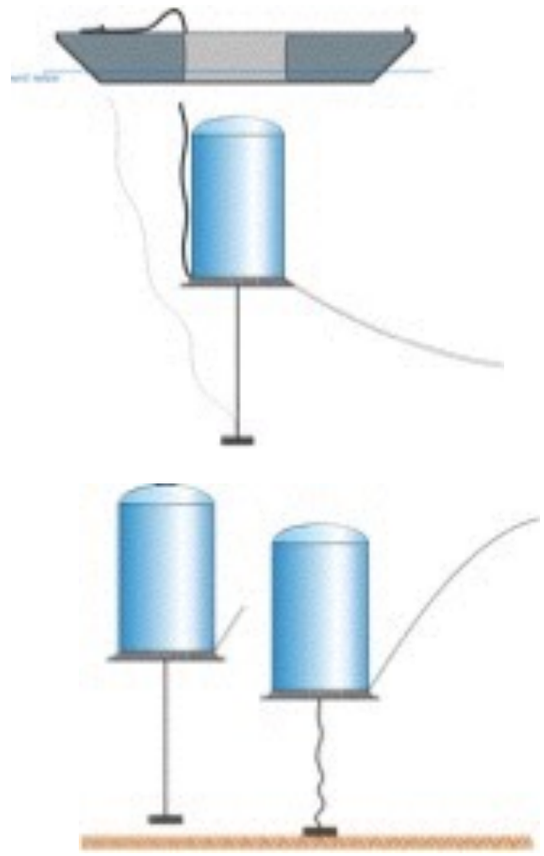


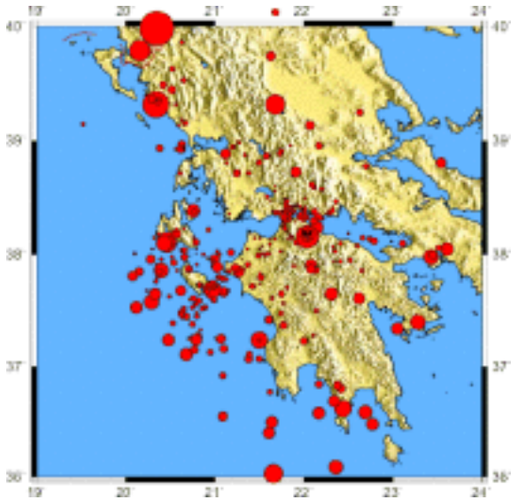
Detect geoneutrinos in the ocean?

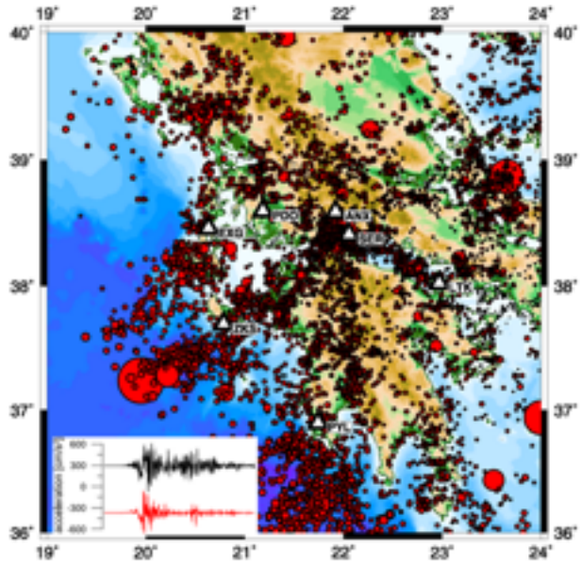


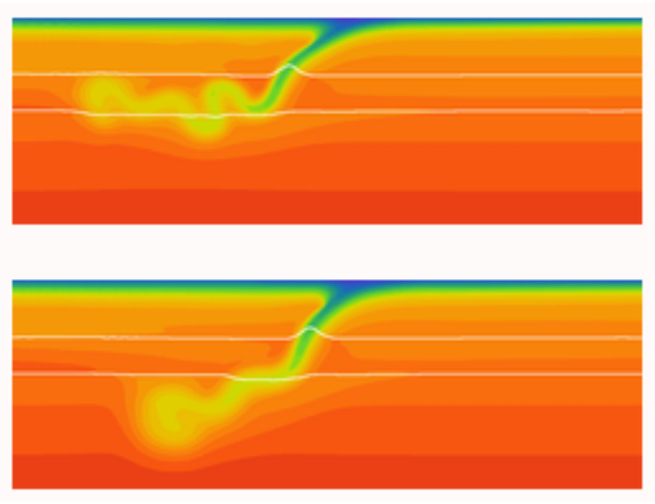
Geoneutrinos from Earth's mantle?



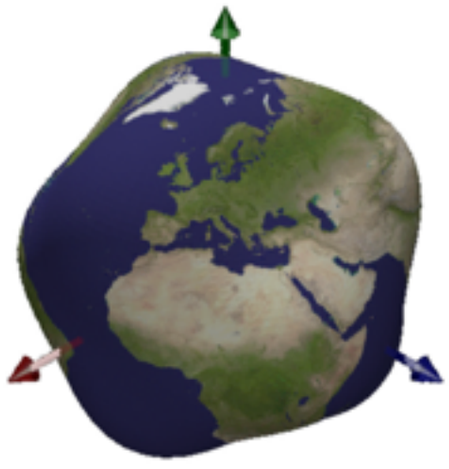


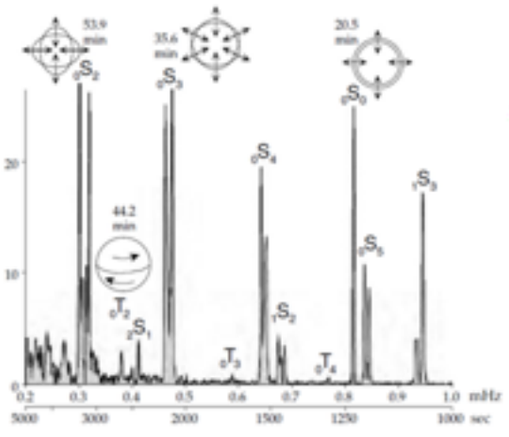


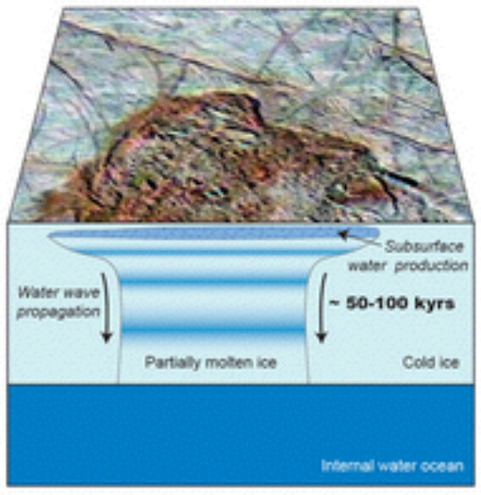


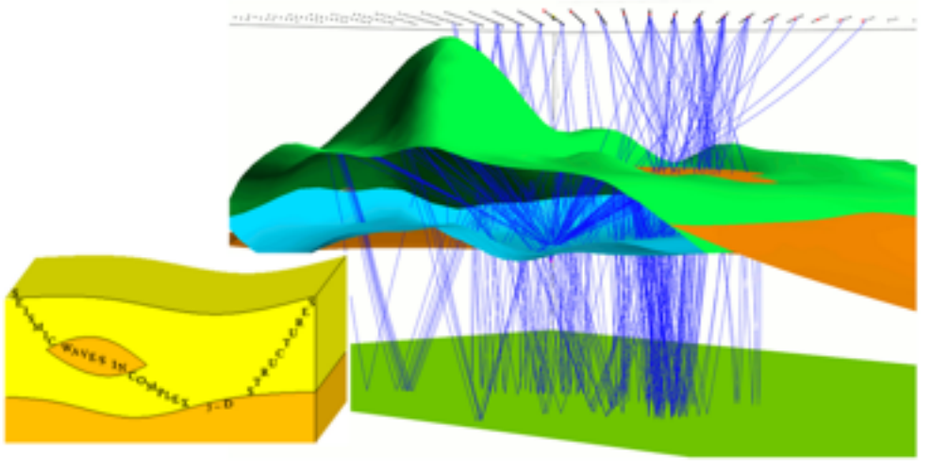


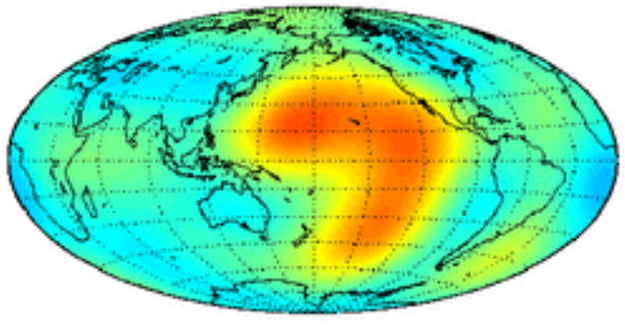
KATEDRA GEOFYZIKY

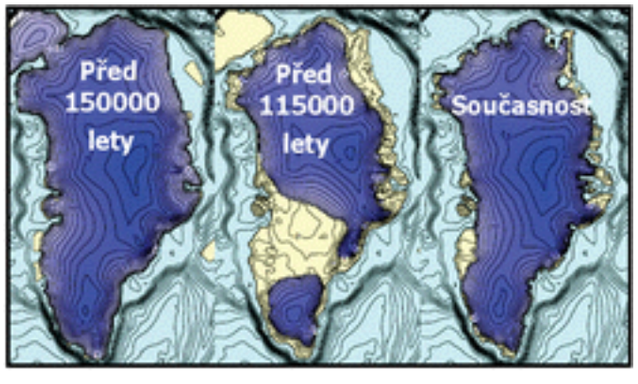


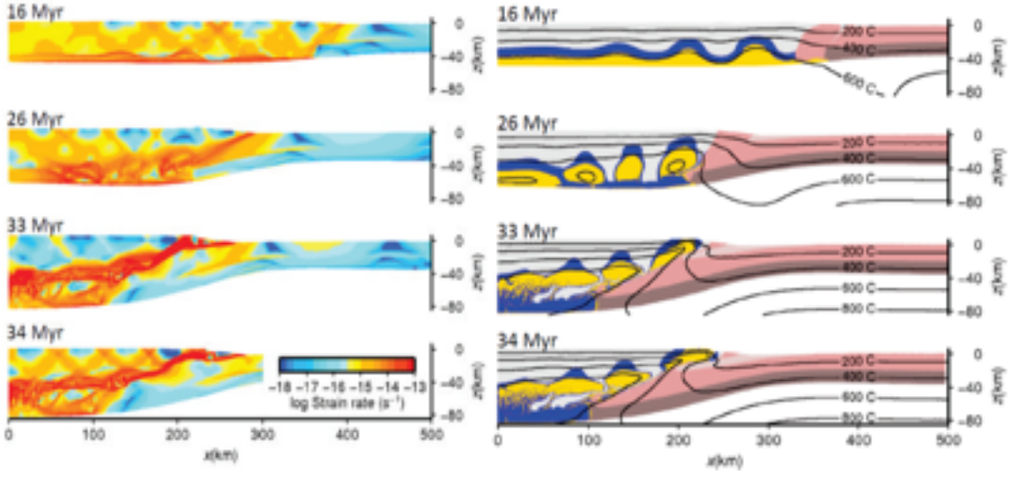


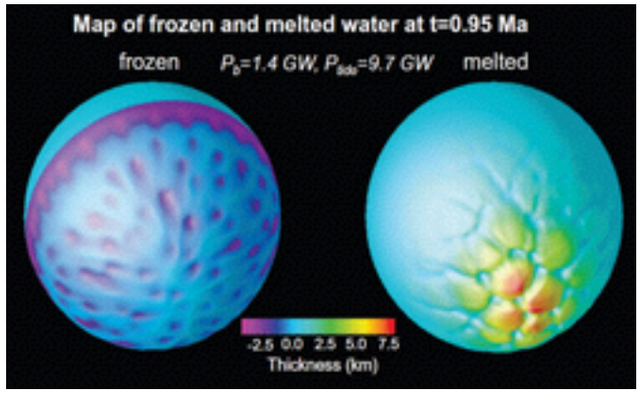


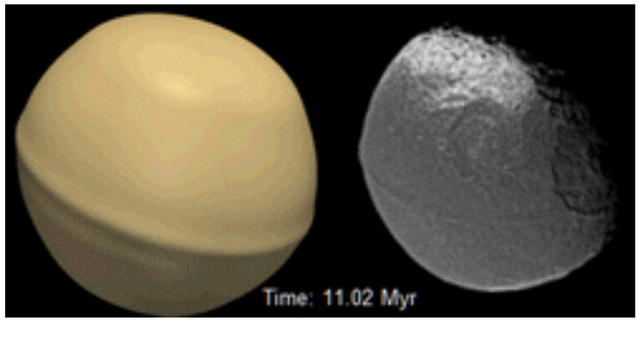












http://geo.mff.cuni.cz

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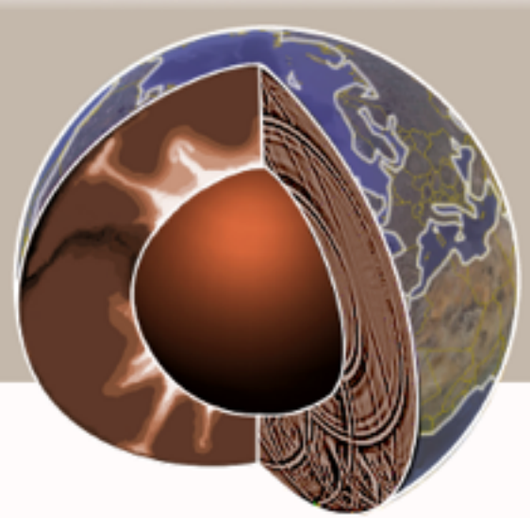
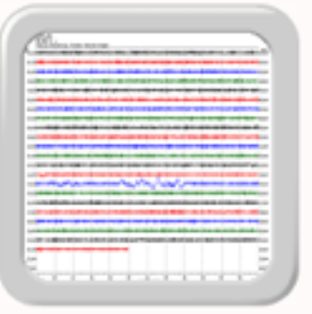


AKTUÁLNĚ

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

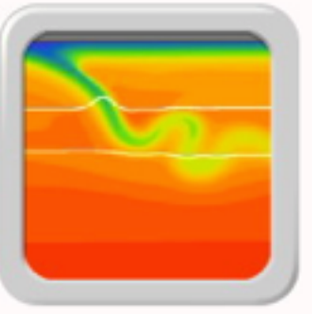
PRO BUDOUCÍ BAKALÁŘE

- 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

Domácí úkol z geofyziky :)

?

voda, $\rho = 1000\ kg/m^3$

skála, $\rho = 3000\ kg/m^3$

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