Neutrinos and Axions from Earth

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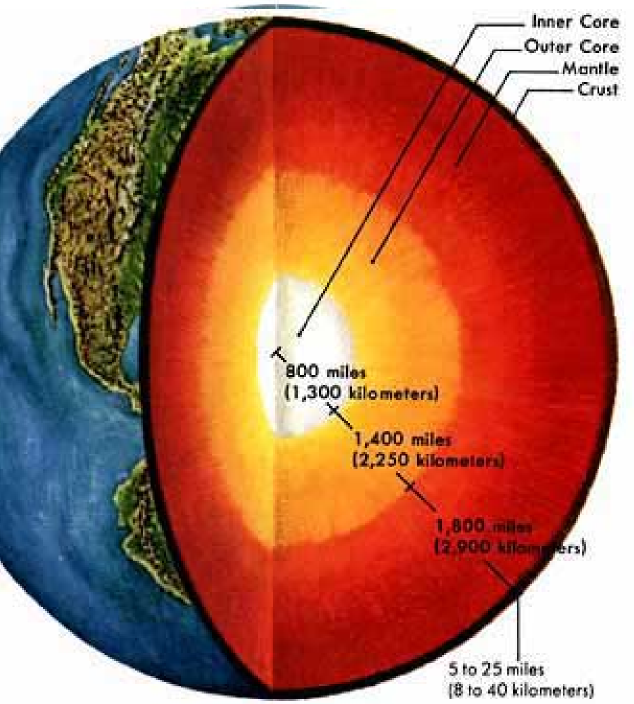
Earth's inner structure and radiogenic heat



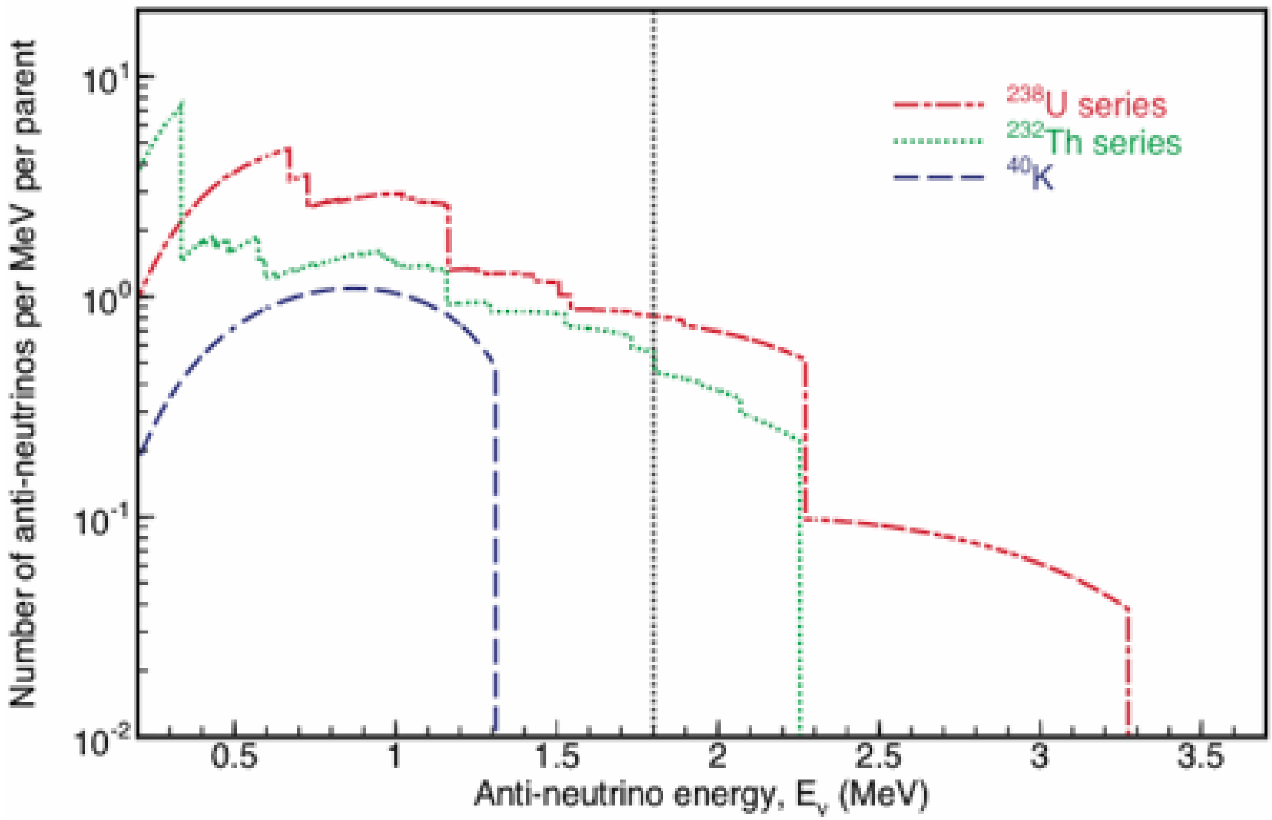
The radioactive isotopes inside the Earth generate **heat**. The decay chains of ^{238}U and ^{232}Th and ^{40}K generate most of the radiogenic heat produced. According to the estimated concentrations of these isotopes, the radiogenic heat production rate is **~19TW**.

As these radioactive isotopes beta-decay, they produce **antineutrinos**. So, measuring these antineutrinos may serve as a crosscheck of the radiogenic heat production-rate.

Earth's mantle and crust contain the main amount of natural radioisotopes ^{238}U, ^{232}Th, ^{40}K.

The core is generally believed to contain negligible amounts of these elements.

Neutrinos from natural radioisotopes



KamLAND and geoneutrinos

Article
Nature **436**, 499-503 (28 July 2005)

Experimental investigation of geologically produced antineutrinos with KamLAND
T.Araki et al.

- KamLAND is the first neutrino detector used to identify and measure geoneutrinos.
- The detector consists of a sphere, 13 meters in diameter, filled with about a kiloton of liquid scintillator. The light flashes are detected by a surrounding array of 1,879 photomultipliers. The photomultipliers are attached to the inner surface of an 18 meters in diameter stainless steel sphere and separated from the weather balloon by a buffering bath of inert oil and water which helps suppress interference from background radiation.

AXIONS from the EARTH

Axions could be produced in Earth's interior via:

- **nuclear de-excitations (attention to nuclear M1 transitions), $N^* \rightarrow N+a$**
- **elastic photon to axion conversion in the presence of a nucleus, $\gamma+N \rightarrow a+N$**
- **Compton scattering, $\gamma+e \rightarrow a+e$**

Axion nuclear deexcitations

It is possible for an excited nuclear state to decay to its ground state via axion emission...

The axion should behave, because it is a pseudoscalar object, as a “magnetic” photon. The allowed values of angular momentum and parity carried away by the axion in such nuclear deexcitation is 0-, 1+, 2-, 3+,…

The dominant multipole is 1+, the axion analog to M1 γ decay.

$$estimation\ of\ \ axion\ to\ M1\,\gamma\ decay: \quad \omega_a \big/ \omega_\gamma^{M1} < 10^{-6}$$

elastic axion to photon conversion

(Creswick et al., Phys.Lett. B 427(1998)235)

Differential cross section for elastic axion to photon conversion in the presence of a nucleus

$$\frac{d\sigma}{d\Omega} = \frac{g_{a\gamma\gamma}^2}{16\pi^2} F_a^2(2\theta)\sin^2 2\theta$$

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z^2 a\hbar^2}{16\pi M^2 c^2}\right)\left(\frac{q^2\left(4k^2 - q^2\right)}{\left(r_0^{-2} + q^2\right)^2}\right)$$

r_0 is the screening length (of the order of 10^{-7} cm for Si, Ge)

$k = 2\pi/\lambda$ is the axion (or photon) momentum, $q = 2k\cdot\sin\theta$ is the momentum exchange, $Mc^2 \equiv 1/g_{a\gamma\gamma}$ is the interaction mass scale almost the same with f, the mass scale of the spontaneous symmetry breaking, Z is the atomic number (charge) of the nucleus.

Axions from Compton scattering

For axion Compton scattering, we suppose that the cross section for $a+e \rightarrow \gamma+e$ (which is the production of gammas from axions, calculated by Donnelly et al., Phys.Rev. D18(1978)1607, is the same as the cross section for $\gamma+e \rightarrow a+e$ (which is the production of axions from gammas) via Compton scattering.

Using the cross section from the paper of Donnelly et al. and an electron density of $3 \cdot 10^{23}$ electrons/cm^3, a number of $7 \cdot 10^{-13}$ axions/cm can be produced per photon of about 1 MeV, passing through the material.

If a material is radioactive and the gammas can travel in this (solid) material a mean free path of about 10 g/cm^2 (which is about 3.6 cm for the rock), we have a production of about $\pi(3.6\text{cm})^3 \cdot A(\text{Bq})/\text{cm}^3$ gammas/sec passing through the material to a mean distance of 3.6 cm.

The axion production by this process must be:

$$\pi(3.6\text{cm})^3 \cdot (A(\text{Bq})/\text{cm}^3) \cdot (7 \cdot 10^{-13} \text{ axions/cm}) \cdot (3.6\text{cm}) = 3.7 \cdot 10^{-10} \text{ axions/Bq.}$$

AXIONS from the EARTH

Axions are produced in Earth's interior mainly via nuclear M1 transitions

Total "geo-axion" production rate: **$2 \cdot 10^{18}$ axions/sec**

With a geometry factor $1/(4\pi r^2) \approx 2{,}5 \cdot 10^{-19}$ cm^{-2},

the flux on Earth's surface is:

0.3 axions cm^{-2} sec^{-1}

*Physics Letters B 645 (*2007) 113-118 , **"Axions from the Earth", Anastasios Liolios**

Search for monoenergetic axions from terrestrial nuclear M1-transitions

e.g. 239 keV (from 212Pb – 232Th)
305 keV (from 206Hg – 238U)
1764 keV (from 214Bi – 238U)

Geoaxion conversion to photons in Earth's magnetic field

- Solar axions passing through the Earth's magnetosphere would give a measurable X-ray flux on the dark side of the Earth
  [papers of Pashos-Zioutas and H.Davoudiasl - P.Huber].

- This idea, in reverse, can also be applied to **axions emitted from Earth** and **passing through the Earth's magnetic field**.

  The magnetic field extends to a distance of some 10^8 m, with strength of the order of $3x10^{-5}$ T at the equator. The long path of geo-axions in the Earth's magnetic field gives an axion conversion to photon probability which is of the same order of magnitude with CAST's conversion probability (i.e. of the order of 10^{-8} for PVLAS derived $g_{a\gamma\gamma}$). With a total geo-axion production rate of $2x10^{18}$ axions/sec, the emission rate of gamma or X-rays beyond the Earth's magnetosphere due to axions would be about 10^{10} photons/sec.