

January 01, 1998

## Electron neutrino sources from the core of the earth

A. Widom  
*Northeastern University*

E. Sassaroli  
*Northeastern University*

Y. N. Srivastava  
*University of Perugia, Italy*

---

### Recommended Citation

Widom, A.; Sassaroli, E.; and Srivastava, Y. N., "Electron neutrino sources from the core of the earth" (1998). *Physics Faculty Publications*. Paper 166. <http://hdl.handle.net/2047/d20000777>

# Electron Neutrino Sources from the Core of the Earth

A. Widom and E. Sassaroli

Physics Department, Northeastern University, Boston, Massachusetts, U.S.A

Y.N. Srivastava

Physics Department & INFN, University of Perugia, Perugia, Italy

The physical interpretation of extensive measurements of electron neutrinos (in laboratories located on or somewhat below the Earth's surface) often require geophysical notions concerning the possible neutrino sources. Here, we discuss the notion that the Earth's core is a substantial source of low energy electron neutrinos.

PACS: 96.40.T, 14.60.L, 91.65

Our knowledge about the internal geophysical structure of the Earth has been summarized in the classic work of Jeffreys [1]. In his work can be found the basic physics of how the structured spherical shells of our planet have been deduced. One employs the measured sound wave propagation due to the seismic crunching and crackling of Earth quakes. The standard geophysical model [2,3] of the Earth is pictured (approximately to scale) below in Fig.1.

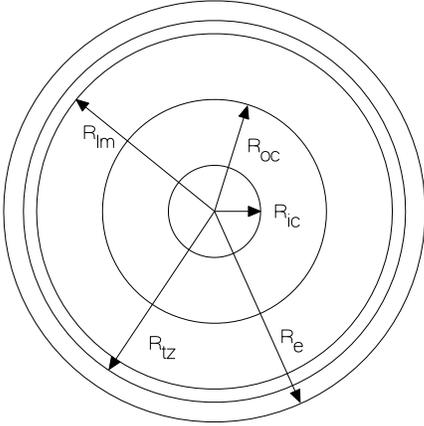


FIG. 1. The shell structure of the Earth includes an inner core with radius  $R_{ic}$ , an outer core with radius  $R_{oc}$ , a lower mantle with radius  $R_{lm}$ , a transition zone with radius  $R_{tz}$  and a thin crust to the surface at radius  $R_e$ .

Less well developed are our notions of radioactive processes within the core and shell structure of the Earth. Early discussions on the nature of nuclear physics within the Earth are due to Darwin [4] and Rutherford [5]. Later Jeffreys states [6] "... it would be interesting to consider what would happen if the present radioactive elements,

with their quantities adapted to  $4 \times 10^9$  years ago, were uniformly distributed ..., it is quite possible that radioactive heating could produce fusion in a fraction of the age of the Earth."

Just as the solar neutrino flux [7] constitutes *direct evidence* of nuclear reactions within the Sun, an observed geophysical neutrino flux would constitute *direct evidence* of nuclear reactions within the Earth. Experimental geophysical data will exist in laboratories located on or somewhat below the Earth's surface with large fiducial volume neutrino detectors. The idea is to measure the differential neutrino flux  $d^2\Phi$  (per unit time per unit area) within a neutrino energy interval  $dE$  and incident from a solid angle direction within  $d\Omega$ . If  $\theta$  is the angle between a line drawn from the laboratory to the center of the earth and the direction of the solid angle  $d\Omega$ , and if there exist spherically symmetric sources, then the differential flux has the functional form

$$\left(\frac{d^2\Phi}{dE d\Omega}\right) = \mathcal{F}(E, \cos \theta). \quad (1)$$

If  $\eta_e(r, E)d^3\mathbf{r}$  denotes the number of neutrinos produced within an earth volume  $d^3\mathbf{r}$  per unit time with an energy less than  $E$ , then the flux of geophysical neutrinos seen in a laboratory located on the Earth's surface is described (in an angular range  $0 < \theta < \pi/2$ ) by

$$\mathcal{F}_e(E, \cos \theta) = R_e \int_0^{2 \cos \theta} \left(\frac{d\eta_e(r = R_e \sqrt{1+x^2-2x \cos \theta}, E)}{dE}\right) dx. \quad (2)$$

Under the assumption that  $\eta_e(r, E)$  is proportional to the mass density  $\rho_e(r)$  in the Earth, it is possible to plot numerically the angular distribution of geophysical neutrinos ( $d\Phi_e/d\Omega$ ). We have carried out such a calculation as shown in Fig.2 below. The mass density in the numerical integrals are taken from tables provided by Birch [8]. For the purpose of conversion into a neutrino flux, we have assumed one part per million of the nuclei  $\beta$ -decay with a mean life-time of  $4 \times 10^9$  years. These nuclear physics numbers are in reasonable agreement with the estimates of Jeffreys.

We find (using the above estimates) that in an Earth bound laboratory the total geophysical electron neutrino flux is at least comparable to the total solar electron neutrino flux. The theoretical angular distribution of the geophysical neutrino flux is (of course) broader. Nevertheless, the magnitudes are sufficient to imply some periodic modulations in what has previously been regarded

as a purely solar neutrino flux. Modulations will occur whenever the neutrino beam from the Sun is parallel (or anti parallel) to the neutrino beam from the Earth's core.

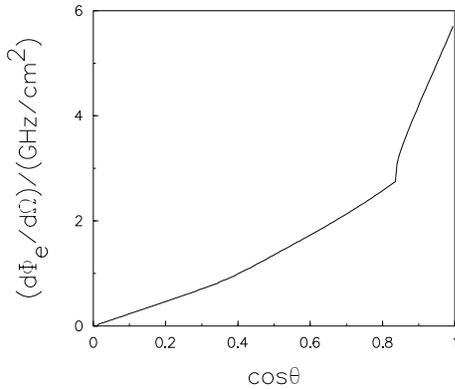


FIG. 2. The angular distribution of geophysical neutrinos in a model in which the source intensity of neutrino production is proportional to the mass density. The geophysical mass density used is due to Birch[8].

The peak in  $(d\Phi_e/d\Omega)$  as  $\cos\theta \rightarrow 1$  is due to the fact that the core of the Earth contains roughly half of the Earth's mass and thereby half of the Earth's neutrino sources in the model under consideration. The discontinuity of the mass density at the core radius  $R_{oc}$  is clearly visible from the structure of the peak.

While the nuclear physics estimates within the core of the Earth are not as accurate as the nuclear physics estimates within the core of the Sun, the above considerations may be valid at least in order of magnitude, and are surely worthy of further study. Recent geophysical investigations [9] indicate a substantial concentration of Uranium (and other radio active nuclei) in the Earth's core, since Uranium is totally miscible at the elevated temperatures of the Earth's core material. This recent geophysical work supersedes an earlier miscibility gap argument for the bulk of nuclear reactions to occur in the mantle and/or above the mantle. Further discussions may be found in the literature [10]. Given that nuclear reactions take place in both the core and mantle, as well as on the surface of the Earth, it should be of no surprise that *nature* and *not nuclear physicists* built the first nuclear reactors. These naturally occurring nuclear reactors have been relatively recently discovered [11].

Atmospheric neutrinos also require geophysical reasoning to trace their source. It has been assumed that cosmic ray protons first produce pions which then decay via

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu, \quad (3)$$

or

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \rightarrow e^- + \bar{\nu}_e + \nu_\mu + \bar{\nu}_\mu. \quad (4)$$

From Eqs.(2) and (3), and in the absence of neutrino oscillations, one expects [12] from atmospheric neutrinos a ratio of

$$\left( \frac{\Phi_a(\nu_\mu + \bar{\nu}_\mu)}{\Phi_a(\nu_e + \bar{\nu}_e)} \right) \approx 2. \quad (5)$$

Initial atmospheric neutrino experiments [13,14] were aimed at deducing neutrino oscillation magnitudes via deviations from Eq.(5).

The notion of geophysical neutrino sources within the Earth's core was ignored in these experiments. However, an "excess" (above and beyond the factor of two) of low energy electron neutrinos heading upward from the earth has been observed. In the most recent Super Kamiokande [15] experiments, the electron neutrino excess was quite pronounced. Note, in this regard, that our  $\theta$  is related to  $\theta_{SK}$  used in the Super Kamiokande experiment by  $\theta = \pi - \theta_{SK}$ ; i.e.

$$\cos\theta = -\cos\theta_{SK}. \quad (6)$$

If we consider neutrinos with energy  $E < 0.4\text{GeV}$ , then we estimate (from the excess electron neutrino data at angles  $0.6 < \cos\theta = (-\cos\theta_{SK}) < 1.0$ ) the ratio

$$\left( \frac{\Phi_e(\nu_e, \cos\theta > 0.6, E < 0.4\text{GeV})}{\Phi_a(\nu_e, \cos\theta > 0.6, E < 0.4\text{GeV})} \right) \approx 0.3, \quad (7)$$

wherein the excess electron neutrinos are here presumed to be of geophysical origin from within the Earth's core.

We hope that the hypotheses (and the experimental data) discussed here concerning geophysical electron neutrino sources within the Earth's core, will inspire future investigations. It appears within current neutrino detection technology to map, via Eqs.(1) and (2), geophysical nuclear reaction sources inside the Earth's core. Such a technique appears presently as a unique probe of such distributions.

- 
- [1] H. Jeffreys, *The Earth*, 6th edition, Cambridge University Press, Cambridge (1976).
  - [2] K. E. Bullen, *The Earth's Density*, Chapman and Hall, London (1975).
  - [3] A. E. Ringwood, in *The Earth, Its Origin, Structure and Evolution*, 1, edited by M. W. McElhinny, Academia Press, London. (1979).
  - [4] G. H. Darwin, *Scientific Papers* Vol. 4, 547, Cambridge University Press, Cambridge (1905).
  - [5] Lord Rutherford and B. B. Boltwood, *Am. J. Sci* **22**, 1, (1906).
  - [6] H. Jeffreys, op. cit. page 428.

- [7] J. N. Bahcall, R. Davis, P. Parker, A. Smirnov and R. Ulrich; Editors *Solar Neutrinos: The first Thirty Years*, Addison-Wesley Publishing Company, Reading MA (1995).
- [8] F. Birch *Journ. Geo. Res.* **69**, 4377 (1964).
- [9] R. C. Feber, T. C. Wallace, and L. M. Libby, *Eos* **65**, 785, (1984).
- [10] E. M. Durrance, *Radioactivity in Geology: Principles and Applications*, John Wiley & Sons, New York (1986).
- [11] G. Boubin, C. Blain, R. Hagemann, M. Kremer, M. Lucas, L. Merlivat, R. Molina, G. Nieff, F. Prost Marechal, F. Regnaud and E. Roth, *C.R. Acad. Sci.* **275**, 2291, (1973).
- [12] T. K. Gaisser, *Cosmic Rays and Particle Physics*, Cambridge University Press, Cambridge (1990).
- [13] J. M. LoSecco, et. al., *Phys. Rev. Lett.* **54**, 2299 (1985).
- [14] S. Hirata, et. al., *Phys. Lett.* **B 205**, 416 (1988).
- [15] Y. Fakuda et. al., hep-ex/9807003 v2 (1998).