What can the CNO neutrinos flux measurement done by Borexino say about $^{40}$K geoneutrino flux?

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Abstract. Borexino collaboration announced the observation of CNO neutrinos flux. Its value appeared larger than expected in case of the Sun high metallicity model. This could be regarded as evidence of large potassium content inside the Earth. The potassium abundance can reach $(1.5 \pm 1.0)\%$ in the whole Earth and the Earth heat flux can be at the level of 200-300 TW. To resolve the problem a new experiment is demanded with a detector similar to Borexino one but better in backgrounds or a detector with another techniques of neutrino measurement, for example on base of $^{115}$In.

1. Introduction

Solar neutrino fluxes from CNO cycle and the antineutrino flux from the Earth generated by the $^{40}$K isotope are in the same energy window [1]. Therefore, when using the elastic neutrino scattering reaction on an electron to detect neutrinos, these fluxes will overlap and distort the spectra of each other. To separate the neutrino spectra of the CNO cycle and the $^{40}$K antineutrino, one needs to know exactly the spectrum of one of the sources.

Recently the Borexino collaboration reported the results of first detection of solar neutrinos from CNO cycle [2]. Two types of analysis were presented. Counting Analysis (CA) uses data in energy window $0.74 - 0.85$ MeV and operates with values of counting rates in this window from four sources: $^{210}$Bi, pep-neutrinos, other backgrounds and CNO-neutrinos. Multivariate Fit (MF) uses data in wide energy region $0.3 - 2.6$ MeV and spectral fit of data. In both analyses were observed values of CNO spectrum integral higher than expected one for the high metallicity solar model. CA gives $5.6 \pm 1.6$ cpd/100t and MF $7.2 (-1.7 + 3.0)$ cpd/100t. Expected value for the high multiplicity Sun is $4.9$ cpd/100t.

Observed excess in 2 cpd/100t could be regarded as a new neutrino source that was not taken into account in Borexino analysis. We suppose this could be an evidence for registration of $^{40}$K antineutrino flux by Borexino.

The excess in future observation of the spectrum from CNO events was predicted in [3] before the Borexino publication on CNO neutrinos registration. This prediction was made on base of calculation $^{40}$K antineutrino flux with high potassium abundance in the Earth.

2. Input of $^{40}$K in total Earth heat flow

The question of the Earth heat flow value is still open. Most popular value is from [4] where the value of flow in $47 \pm 3$ TW is established. This flow includes only half of total flux associated
with radioactive isotopes of uranium, thorium and potassium, which are located in the crust and mantle of the Earth. Another half of flux is regarded due to residual heat, crystallization of the core and other geological reasons. According to modern conception, there are no radioactive elements in the Earth’s core and small abundant in the mantle. However, there is evidence of much larger heat flux of the Earth (200-300 TW) based on the world ocean heating [5] and on observation of the Moon heat flux (assuming the same element content in the Moon and the Earth). Estimations of high heat flux value can be found in [6].

To understand if potassium can give a sufficient input in Earth heat flux we need to estimate correctly potassium abundance in the Earth.

One estimation is based on assumption that all potassium is concentrated mainly in the crust [7]. In the crust we know potassium abundance is 1.5–2.5%. If to calculate potassium mass and divide by the Earth mass we get 0.024%.

The other estimation can be done by analysing the $^{40}$Ar amount in the atmosphere. Total argon abundance in atmosphere is 0.934%. 99.6% of all argon belongs to $^{40}$Ar isotope and only 0.4% to other isotopes $^{36}$Ar (0.34%) and $^{38}$Ar (0.06%). We could associate all $^{40}$Ar with decays of $^{40}$K during the all Earth History. It is necessary only to understand if all argon went out from the Earth interior. This estimation gives abundance at level from 0.01 to 1% depending on assumption of what part of $^{40}$Ar left from the Earth’s interior.

The heat produced by $^{40}$K goes mainly through beta-decay (89% of all decays) and estimated as 0.65 MeV per decay. One can calculate that 1% potassium abundance in the Earth produce 200 TW of heat. At figure 1 one can see the decay scheme of $^{40}$K. It decays to $^{40}$Ca with probability 89% and to $^{40}$Ar with probability 11%. The heat is produced by beta-particles with spectrum boarder energy $E_0 = 1.311$ MeV and gamma-quanta with energy $E_\gamma = 1.46$ MeV.

Most common argument in favor of small potassium abundance is that the Earth would still be liquid until now in case of the abundance value higher than 0.5%. It is not like this because there is efficient way of cooling inner parts of the Earth is case of extra heating – this is hydrogen and hydrogen containing gazes which can transfer energy from inner parts to the surface. At figure 2 the temperature evolution in the Earth centre during its history is shown for 1% of potassium in our days. Clearly seen that in presence of gaz cooling the temperature can be lower than we think now. In the same case surface temperature appeared the same for both scenarios.
Figure 2. Earth temperature evolution in the centre with potassium abundance 1% in our days. Black curve — no cooling mechanism (energy transfers to the surface only by thermoconductive way), red line — with cooling mechanism (Hydrogen and other gases emission).

3. Measurement of CNO cycle solar neutrinos with background of $^{40}$K antineutrinos

It turned out that the spectrum of antineutrinos from $^{40}$K is similar to the spectrum of one component of the CNO neutrino, namely spectrum of $^{13}$N. At figure 3 the spectra of all CNO neutrino components in 100 t of the Boreksino target are shown in comparison with the $^{40}$K spectrum under the condition that the potassium content in the Earth is 1%. The CNO components of the $^{13}$N and $^{15}$O isotopes neutrinos are interconnected, and by measuring one of the components, the other one can be easily calculated. The $^{40}$K spectrum almost coincides with the $^{13}$N spectrum. The difference between the experimental spectrum and the shape of the CNO neutrino spectrum will signal the presence of a spectrum from $^{40}$K.

If to summarize all CNO components spectra from figure 3, there appear an inflection in the region of 1 MeV, where the superposition of the $^{13}$N spectrum on the $^{15}$O spectrum begins. In the presence of the $^{40}$K spectrum, the inflection point shifts towards higher energies (up to 1.1 MeV). With a good energy resolution, one could determine the inflection point and solve the problem of $^{40}$K spectrum presence. With small experimental statistics, one can check the ratio of the low-energy part of the experimental spectrum ($E < 1$ MeV) to the high-energy in the window between 0.8 MeV and 1.2 MeV (between the $^{7}$Be and $^{11}$C spectra).

Borexino collaboration has presented the measurement of CNO neutrinos flux [2] this summer. They stabilized temperature of the detector vessel and stopped seasonal fluctuations of main background $^{210}$Bi. This gave opportunity to make accurate measurement of CNO neutrinos. They presented results of two analysis (CA and MF) and we can regard these data as spectrum measured at two effective energies.

We did calculations of observable spectrum of recoil electrons in detector Borexino produced by CNO spectrum and the one mixed with the spectrum of $^{40}$K at different potassium abundance in the Earth. The result is presented at figure 4. At the plot we placed two points on spectra recalculated from the Borexino measurement. It is seen that the experiment satisfies better the curve with 1.5% of potassium abundance than pure CNO spectrum. One can conclude that
Figure 3. Recoil electron spectra in liquid scintillator detector caused by neutrinos from components of CNO spectrum and by antineutrinos from $^{40}\text{K}$ spectrum.

Figure 4. Differential energy spectra of recoil electrons from solar CNO neutrino scattering by scintillator electrons in 100 tons of scintillator (red curve) and the sum of the recoil electron spectra from the scattering of solar CNO neutrino and from the scattering of $^{40}\text{K}$ geo-antineutrino for the concentration of potassium in the modern Earth 1% and 2% of the Earth mass. The oscillations were taken into account. Black points - Borexino measurement at two effective energies.
Borexino observations allows high potassium abundance in the Earth at the level \((1.5 \pm 1.0)\%\). We obtained similar result by the other method in [8].

4. Conclusion

The measured by Borexino CNO neutrino flux can contain some input from \(^{40}\text{K}\) flux produced inside the Earth’s interior. Allowed value of \(^{40}\text{K}\) flux gives potassium abundance \((1.5 \pm 1.0)\%\).

High (1-2\%) potassium abundance can exist if there is an efficient mechanism of Earth cooling inside. We observe this mechanism as gas emission from the Earth surface and the world ocean heating during last 20 years.

To resolve the problem of potassium abundance a new detector is needed with characteristics better than Borexino ones. Also it might be desirable to make independent measurement of CNO neutrinos flux by another detector method. There was done a proposal of so kind detector by R. Raghavan in [9] and [10] on base of scintillator doped with \(^{115}\text{In}\). The detector can be made using new technologies appeared after Raghavan’s proposal to avoid the background from self radioactivity of \(^{115}\text{In}\).

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References

[1] Sinev V V, Bezrukov I B, Litvinovich E A, Machulin I N and Skorokhvatov M D 2015 Phys. Part. Nucl. 46 186

[2] Ranucci G et al. (Borexino collaboration) 2020 Proc. Int. Conf. on Neutrino Physics and Astrophysics;

[3] Bezrukov L B, Karpikov I S, Kurlovich A S, Mezhokh A K, Silaeva S V, Sinev V V and Zavarzina V P 2020 On the contribution of the \(^{40}\text{K}\) geo-antineutrino to single Borexino events Preprint hep-ex/2004.02533

[4] Davies J H and Davies D R 2010 Solid Earth 1 5

[5] Riser S C, Freeland H J, Roemmich D et al. 2016 Nature Clim. Change 6 145

[6] Bezrukov L B, Kurlovich A S, Lubsandorzhiev B K, Mezhokh A K, Morgalyuk V P, Sinev V V and Zavarzina V P 2017 J. Phys.: Conf. Series 934 012011

[7] McDonough W F 2003 Compositional models for the Earth’s core 2 (Oxford: Elsevier-Pergamon)

[8] Bezrukov L B, Karpikov I S, Kurlovich A S, Mezhokh A K, Silaeva S V, Sinev V V and Zavarzina V P 2020 On first detection of solar neutrinos from CNO cycle with Borexino Preprint/hep-ex 2007.07371

[9] Raghavan R S 1976 Phys. Rev. Lett. 37 259

[10] Grieb C, Link J M and Raghavan R S 2007 Phys. Rev. D 75 093006