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Direct detection of the cosmic neutrino background including light sterile neutrinos

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ABSTRACT

Current cosmological data drop an interesting hint about the existence of sub-eV sterile neutrinos, which should be a part of the cosmic neutrino background (CνB). We point out that such light sterile neutrinos may leave a distinct imprint on the electron energy spectrum in the capture of relic electron neutrinos by means of radioactive beta-decaying nuclei. We examine possible signals of sterile neutrinos relative to active neutrinos, characterized by their masses and sensitive to their number densities, in the reaction $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$ against the corresponding tritium beta decay. We stress that this kind of direct laboratory detection of the CνB and its sterile component might not be hopeless in the long term.

1. As fairly stable and weakly interacting particles, relic neutrinos of the Big Bang must survive today and form a cosmic background similar to the cosmic microwave background (CMB) radiation. This cosmic neutrino background (CνB) played an important role in the evolution of the Universe, and its existence has been indirectly "seen" from current cosmological data on the Big Bang nucleosynthesis (BBN), CMB anisotropies and large-scale structures [1]. How to directly detect the CνB in a laboratory experiment is a great challenge to the present experimental techniques, simply because today's temperature of the CνB is extremely low ($T_\nu \approx 1.945$ K) and thus the average three-momentum of each relic neutrino is very small ($\langle p_\nu \rangle = 3T_\nu \approx 5 \times 10^{-4}$ eV). Among several possibilities for the direct CνB detection [2], the most promising one seems to be the relic neutrino capture experiment by means of radioactive beta-decaying nuclei [3–8]. The point is that a generic neutrino capture reaction $\nu_e + N \to N' + e^-$ will take place with no threshold on the incident neutrino energy, provided N can naturally undergo the beta decay $N \to N' + e^- + \overline{\nu}_e$ with an energy release $Q_\beta = m_N - m_{N'} - m_e$ in the limit of vanishing neutrino masses (i.e., $m_i \to 0$ for $i = 1, 2, \ldots$). The signal of this neutrino capture process is measured by the monoenergetic electron's kinetic energy $Q_\beta + E_{\nu_i} \geqslant Q_\beta + m_i$ for each neutrino mass eigenstate ν_i, as compared with the non-monoenergetic electron's endpoint energy $Q_\beta - m_i$ for each ν_i in the corresponding beta decay. So there is a gap equal to or larger than $2m_i$ between the kinetic energies of the detected electrons in $\nu_e + N \to N' + e^-$ (signal) and $N \to N' + e^- + \overline{\nu}_e$ (background). A measurement of this gap will directly probe relic neutrinos and determine or constrain their masses.

An immediate question is whether the CνB consists of only three active neutrinos (ν_e, ν_μ and ν_τ) or more than three light neutrinos. Using $N_{\rm eff}$ to denote the effective number of thermally excited neutrino species in the early Universe, some authors have recently obtained $N_{\rm eff} = 4.34^{+0.86}_{-0.88}$ at the 68% confidence level from an analysis of the 7-year WMAP data on CMB anisotropies and large-scale structures [9] or $N_{\rm eff} = 4.78^{+1.86}_{-1.79}$ at the 95% confidence level from a similar analysis including the SDSS data on the (DR7) halo power spectrum [10]. Moreover, two independent groups have recently found slightly higher values of the primordial ^{4}He abundance [11], implying the presence of additional radiation or relativistic particles during the BBN epoch. As argued by Hamann et al. in Ref. [12], these results drop an interesting hint that there might exist one or more light sterile neutrinos in the CνB. Their detailed analysis supports this conjecture and is compatible with an interpretation of the LSND [13] and MiniBOONE [14] anomalies in terms of three active neutrinos and two sterile neutrinos [15] if the mass scale of sterile neutrinos lies in the sub-eV range. Although such an interpretation may have severe tension with current disappearance experiments of neutrino oscillations [16], the situation remains so confusing that one might better keep all possibilities open. In particular, current cosmological data cannot be used as an argument against the existence of light sterile neutrinos [12] and the latter might not necessarily be relevant to current neutrino oscillation experiments. This mild standpoint motivates us

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to examine possible effects of light sterile neutrinos in a neutrino capture process to directly detect the CνB.

We find that such light sterile neutrinos can leave a distinct imprint on the electron energy spectrum in the capture of relic electron neutrinos by means of radioactive beta-decaying nuclei. Considering both the $(3+1)$ and $(3+2)$ schemes of neutrino mixing, we calculate possible signals of sterile neutrinos relative to active neutrinos, characterized by their masses and sensitive to their number densities, in the reaction $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$ against the corresponding tritium beta decay. Although our numerical results are just for the purpose of illustration, we stress that this kind of direct laboratory detection of the CνB and its sterile component might not be hopeless in the long term.

2. In the presence of N_s species of light sterile neutrinos, the flavor eigenstates of three active neutrinos can be written as

$$|\nu_\alpha\rangle = \sum_i V^*_{\alpha i}|\nu_i\rangle, \tag{1}$$

where α runs over e, μ and τ, ν_i is a mass eigenstate of active (for $1 \leqslant i \leqslant 3$) or sterile (for $4 \leqslant i \leqslant 3 + N_s$) neutrinos, and $V_{\alpha i}$ stands for an element of the $3 \times (3 + N_s)$ neutrino mixing matrix. For simplicity, we assume that the light sterile neutrinos under consideration do not significantly affect the values of two mass-squared differences and three mixing angles of active neutrinos extracted from current experimental data on solar, atmospheric, reactor and accelerator neutrino oscillations [1]. In this assumption we shall use $\Delta m^2_{21} \approx 7.6 \times 10^{-5}\ \mathrm{eV}^2$ and $|\Delta m^2_{31}| \approx 2.4 \times 10^{-3}\ \mathrm{eV}^2$ together with $\theta_{12} \approx 34^\circ$ and $\theta_{13} \approx 10^\circ$ as typical inputs in our numerical estimates. Depending on the sign of Δm^2_{31}, two mass patterns of three active neutrinos are possible:

- the normal hierarchy $m_1 < m_2 = \sqrt{m_1^2 + \Delta m^2_{21}} < m_3 = \sqrt{m_1^2 + |\Delta m^2_{31}|}$;
- the inverted hierarchy $m_3 < m_1 = \sqrt{m_3^2 + |\Delta m^2_{31}|} < m_2 = \sqrt{m_3^2 + |\Delta m^2_{31}| + \Delta m^2_{21}}$.

In either case the absolute mass scale (m_1 or m_3) is unknown, but its upper bound is expected to be of $\mathcal{O}(0.1)$ eV as constrained by current cosmological data [9]. Following Ref. [12], we assume the masses of sterile neutrinos $(m_4, m_5, \ldots)$ to lie in the sub-eV range. Their mixing with active neutrinos is constrained by current neutrino experiments and cosmological data and should be at most of $\mathcal{O}(0.1)$ [15,16]. To illustrate the effect of sterile neutrinos in a neutrino capture process, we shall simply take $\theta_{1i} \approx 10^\circ$ (for $i \geqslant 4$) in our numerical estimates. So we have $|V_{e1}| \approx 0.804$, $|V_{e2}| \approx 0.542$, $|V_{e3}| \approx 0.171$ and $|V_{e4}| \approx 0.174$ in the $(3+1)$ scheme; or $|V_{e1}| \approx 0.792$, $|V_{e2}| \approx 0.534$, $|V_{e3}| \approx 0.168$, $|V_{e4}| \approx 0.171$ and $|V_{e5}| \approx 0.174$ in the $(3+2)$ scheme. We reiterate that these numerical inputs are mainly for the purpose of illustration.

Let us concentrate on the relic neutrino capture reaction $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$, since its corresponding beta decay ${}^3\mathrm{H} \to {}^3\mathrm{He} + e^- + \overline{\nu}_e$ is being precisely measured in the KATRIN experiment [17]. The capture rate for each neutrino mass eigenstate ν_i hidden in the ν_e state is given by [6,7]

$$\mathcal{N}^{(i)}_{\mathrm{C\nu B}} \approx 6.5\zeta_i |V_{ei}|^2\ \mathrm{yr}^{-1}\ \mathrm{MCi}^{-1}, \tag{2}$$

in which $\zeta_i \equiv n_{\nu_i}/\langle n_{\nu_i}\rangle$ denotes the ratio of the number density of relic ν_i neutrinos around the Earth to its average value in the Universe. The standard Big Bang model predicts $\langle n_{\nu_i}\rangle \approx \langle n_{\overline{\nu}_i}\rangle \approx 56\ \mathrm{cm}^{-3}$ today for each species of active neutrinos, and this prediction is also expected to hold for each species of light sterile neutrinos if they could be completely thermalized in the early Universe.[1] Although possible interactions and oscillations in the early Universe could slightly modify the values of $\langle n_{\nu_i}\rangle$ and $\langle n_{\overline{\nu}_i}\rangle$, such corrections are actually unimportant for our numerical estimates [7,19]. In Eq. (2) the unit MCi measures one megacurie source of tritium (about 100 g or 2.1×10^{25} atoms). Note that each ν_i state yields a monoenergetic electron, whose kinetic energy is given by $T_e^i = Q_\beta + E_{\nu_i}$ with $Q_\beta = M_{^3\mathrm{H}} - M_{^3\mathrm{He}} - m_e \approx 18.6$ keV for tritium. Because at least two active neutrinos are already non-relativistic today in the CνB (i.e., their masses are much larger than $T_\nu \approx 1.945$ K or $\langle p_\nu\rangle = 3T_\nu \approx 5 \times 10^{-4}$ eV) and the involved sterile neutrinos are assumed to have masses of $\mathcal{O}(0.1)$ eV, we arrive at $T_e^i \approx Q_\beta + m_i$ as a good approximation. If the mass of the lightest active neutrino is below $\langle p_\nu\rangle$ (i.e., it remains hot or relativistic today), then its energy can be expressed as $E_{\nu_i} \approx \sqrt{\langle p_\nu\rangle^2 + m_i^2}$, which is of $\mathcal{O}(\langle p_\nu\rangle)$ and hence has little effect on the overall electron energy spectrum. Given a finite energy resolution in practice, the ideally discrete energy lines of the electrons emitted from the reaction $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$ must spread and form a continuous spectrum. As usual, we consider a Gaussian energy resolution function defined by

$$R\left(T_e, T_e^i\right) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left[-\frac{(T_e - T_e^i)^2}{2\sigma^2}\right], \tag{3}$$

where T_e is the overall kinetic energy of the electrons detected in the experiment. Using Δ to denote the experimental energy resolution (i.e., the full width at half maximum of a Gaussian energy resolution for the outgoing electrons [6,7]), we have $\Delta = 2\sqrt{2\ln 2}\,\sigma \approx 2.35482\sigma$. Then the overall neutrino capture rate (i.e., the energy spectrum of the detected electrons for the reaction $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$) is given as

$$\begin{aligned}\mathcal{N}_{\mathrm{C\nu B}} &= \sum_i \mathcal{N}^{(i)}_{\mathrm{C\nu B}} R\left(T_e, T_e^i\right) \\ &\approx 6.5 \sum_i \zeta_i |V_{ei}|^2 R\left(T_e, T_e^i\right)\ \mathrm{yr}^{-1}\ \mathrm{MCi}^{-1}.\end{aligned} \tag{4}$$

Taking account of the gravitational clustering of relic non-relativistic neutrinos around the Earth [20], we expect $\zeta_i \geqslant 1$ in general. For simplicity, we shall first assume $\zeta_i = 1$ in our numerical estimates of the capture rate and then illustrate a possible enhancement of the signal due to much larger values of ζ_i.

The main background of the neutrino capture process under consideration is the standard tritium beta decay ${}^3\mathrm{H} \to {}^3\mathrm{He} + e^- + \overline{\nu}_e$. In this process the effect induced by non-zero neutrino masses can show up near the electron's endpoint energy $Q_\beta - \min(m_i)$, where $\min(m_i)$ means the lightest neutrino mass among m_i (for $i = 1, 2, \ldots, 3 + N_s$). The finite energy resolution may push the above endpoint towards a higher energy region, and hence it is likely to mimic the desired signal of the neutrino capture reaction. Given a finite energy resolution described by the Gaussian function in Eq. (3), the energy spectrum of the tritium beta decay can be expressed as

$$\frac{\mathrm{d}\mathcal{N}_\beta}{\mathrm{d}T_e} = \int_0^{Q_\beta - \min(m_i)} \mathrm{d}T'_e \left\{ N_{\mathrm{T}} \frac{G_{\mathrm{F}}^2 \cos^2\theta_{\mathrm{C}}}{2\pi^3} F(Z, E_e) |\mathcal{M}|^2 \times \sqrt{E_e^2 - m_e^2}\, E_e \left(Q_\beta - T'_e\right) \right.$$

[1] The sub-eV sterile neutrinos discussed in Ref. [12] and here should be most likely to stay in full thermal equilibrium in the early Universe, provided their mixing with active neutrinos is not strongly suppressed [18]. We are indebted to S. Hannestad for clarifying this point to us.

$$\times \sum_i \left[|V_{ei}|^2 \sqrt{\left(Q_\beta - T_e'\right)^2 - m_i^2}\, \Theta\left(Q_\beta - T_e' - m_i\right)\right]$$
$$\times R\left(T_e, T_e'\right)\Bigg\}, \qquad (5)$$

where $E_e = T_e' + m_e$ is the electron energy with T_e' being its kinetic component, $N_{\rm T} \approx 2.1 \times 10^{25}$ denotes the target factor whose value is equal to the number of tritium atoms of the target, $F(Z, E_e)$ represents the Fermi function, and $|\mathcal{M}|^2 \approx 5.55$ stands for the dimensionless contribution of relevant nuclear matrix elements [17]. In Eq. (5) the theta function $\Theta(Q_\beta - T_e' - m_i)$ is adopted to ensure the kinematic requirement.

3. With the help of Eqs. (4) and (5), one may numerically calculate the relic neutrino capture rate against the corresponding tritium beta decay. Blennow has done such an analysis in the scheme of three active neutrinos by examining the dependence of both the CνB signal and its background on the neutrino mass hierarchy and neutrino mixing angles [7]. Here we focus on the sterile component of the CνB and its possible signals in the neutrino capture reaction $\nu_e + {}^3\text{H} \to {}^3\text{He} + e^-$. As mentioned in Section 2, we are mainly interested the sub-eV sterile neutrinos whose mixing with active neutrinos is of $\mathcal{O}(0.1)$ or somewhat smaller. To be more explicit, we assume that the masses of sterile neutrinos are larger than the absolute mass scale of three active neutrinos. In this case we have the following naive expectations:

- The signal of the sterile component of the CνB is on the right-hand side of the electron energy spectrum as compared with the signal of the active component of the CνB. Their separation is measured by their mass differences.
- The rate of events for the signal of relic sterile neutrinos is crucially dependent on the magnitude of their mixing with active neutrinos. Hence a larger value of $|V_{ei}|$ (for $i \geqslant 4$) leads to a higher rate of signal events.
- Whether a signal can be separated from its background depends on the finite energy resolution Δ in a realistic experiment. In general, $\Delta \leqslant m_i/2$ (for $i = 1, 2, \ldots, 3 + N_s$) is required to detect the CνB via a neutrino capture reaction [6,7].

Let us make some quantitative estimates of the CνB signals in two schemes of neutrino mixing: (a) the $(3+1)$ scheme with one sterile neutrino; and (b) the $(3+2)$ scheme with two sterile neutrinos. In either case the lightest active neutrino mass is typically taken to be 0.0 eV, 0.05 eV or 0.1 eV. We fix $m_4 = 0.3$ eV together with $|V_{e1}| \approx 0.804$, $|V_{e2}| \approx 0.542$, $|V_{e3}| \approx 0.171$ and $|V_{e4}| \approx 0.174$ in the $(3+1)$ scheme; or $m_4 = 0.2$ eV and $m_5 = 0.4$ eV together with $|V_{e1}| \approx 0.792$, $|V_{e2}| \approx 0.534$, $|V_{e3}| \approx 0.168$, $|V_{e4}| \approx 0.171$ and $|V_{e5}| \approx 0.174$ in the $(3+2)$ scheme. The gravitational clustering of relic neutrinos around the Earth is tentatively omitted and will be illustrated later. Our numerical results are presented in Figs. 1–3. Some discussions are in order.

Fig. 1 shows the relic neutrino capture rate as a function of the kinetic energy T_e of electrons in the $(3+1)$ scheme with $\Delta m^2_{31} > 0$ and $m_4 = 0.3$ eV. The value of the finite energy resolution Δ is taken in such a way that only the signal of the sterile neutrino can be seen (left panel) or both the signals of active and sterile neutrinos can be seen (right panel). These simple results confirm the naive expectations given above, especially for the signal of the sterile component of the CνB. We find that it is in principle possible to distinguish the sterile neutrino from the background when Δ is of $\mathcal{O}(0.1)$ eV or much smaller. As the lightest neutrino mass m_1 increases from 0 to 0.1 eV, the signal curve moves towards the higher $T_e - Q_\beta$ region while the background curve moves towards the lower $T_e - Q_\beta$ region. To make a realistic measurement sensitive to the active component of the CνB, one needs a sufficiently good energy resolution. The required energy resolution depends on the mass hierarchy of three active neutrinos, as one can see from Fig. 1 (right panel). Note that the small peak sitting at $T_e - Q_\beta \approx 0.05$ eV in the top right corner of Fig. 1 arises from the contribution of ν_3 with $m_3 \approx 0.05$ eV. It is not seeable in the top left corner of Fig. 1 simply because the resolution is not good enough.

An analogous analysis of the relic neutrino capture rate is carried out in the $(3+1)$ scheme with $\Delta m^2_{31} < 0$ and $m_4 = 0.3$ eV, and the numerical results are given in Fig. 2. We see that this figure is essentially similar to Fig. 1, and the primary difference appears in the signal peaks of active neutrinos in their top right corners. Such a difference can be understood with the help of Eqs. (3) and (4): the central position of a signal peak is approximately determined by $T_e - Q_\beta \approx E_{\nu_i}$ and its height is mainly measured by $|V_{ei}|^2$ for given values of Δ and ζ_i. When the lightest neutrino mass m_3 is extremely small, the main contribution of active neutrinos to the capture rate sits at $T_e - Q_\beta \approx m_1 \approx m_2 \approx 0.05$ eV as shown in the top right corner of Fig. 2. In contrast, the main signal peaks shows up at $T_e - Q_\beta \in \{m_1, m_2\}$ when the lightest neutrino mass m_1 is extremely small (as illustrated in the top right corner of Fig. 1). So it is in practice much easier to detect the active component of the CνB when three active neutrinos have an inverted mass hierarchy or a nearly degenerate mass spectrum.

We illustrate the relic neutrino capture rate in the $(3+2)$ scheme with $\Delta m^2_{31} > 0$ (left panel) or $\Delta m^2_{31} < 0$ (right panel) in Fig. 3, where $m_4 = 0.2$ eV and $m_5 = 0.4$ eV are typically taken. The value of the finite energy resolution Δ is chosen in such a way that only the signals of sterile neutrinos can be seen. If the values of m_4 and m_5 are very close to each other or their difference is much smaller than Δ, it will be very difficult to distinguish between the two signal peaks of sterile neutrinos. When the absolute mass scale of three active neutrinos is very close to the smaller mass of two sterile neutrinos, there may be a mixture between their signals as shown in the bottom left and bottom right corners of Fig. 3. In this case only the heavier sterile neutrino is distinguishable from the signal of active neutrinos.

So far we have neglected possible gravitational clustering of relic neutrinos in our numerical estimates. To illustrate this effect, we calculate the relic neutrino capture rate in the $(3+2)$ scheme with $m_1 = 0$ or $m_3 = 0$, $m_4 = 0.2$ eV and $m_5 = 0.4$ eV. We assume a larger gravitational clustering effect for a heavier neutrino around the Earth [20]. In this reasonable assumption we typically take $\zeta_1 = \zeta_2 = \zeta_3 = 1$ (without clustering effects for three active neutrinos because their maximal mass is about 0.05 eV in the scenario under discussion) and $\zeta_5 = 2\zeta_4 = 10$ (with mild clustering effects for two sterile neutrinos because their masses are 0.2 eV and 0.4 eV, respectively). The value of the finite energy resolution Δ is chosen in such a way that only the signals of sterile neutrinos can be observed. As shown in Fig. 4, the signals of two sterile neutrinos are obviously enhanced due to $\zeta_4 > 1$ and $\zeta_5 > 1$. If the gravitational clustering of non-relativistic neutrinos is very significant around the Earth, it will be very helpful for us to detect the CνB by means of the neutrino capture processes.

4. Motivated by a mild standpoint that current cosmological data cannot be used as an argument against the existence of light sterile neutrinos and the latter might not necessarily be very relevant to current neutrino oscillation experiments, we have examined possible effects of sub-eV sterile neutrinos in a neutrino

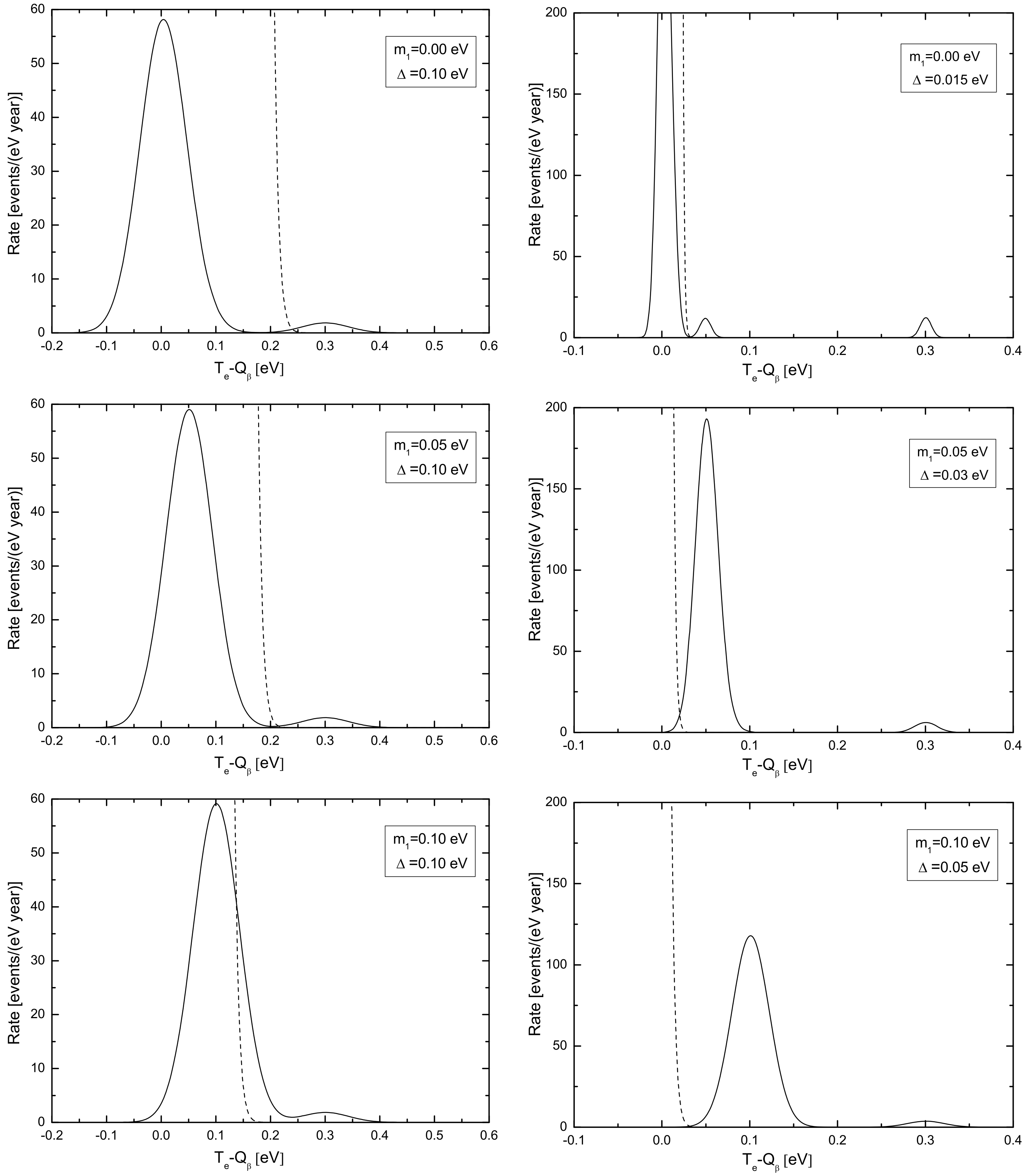

Fig. 1. The relic neutrino capture rate as a function of the kinetic energy T_e of electrons in the $(3+1)$ scheme with $\Delta m^2_{31} > 0$ and $m_4 = 0.3$ eV. The solid and dashed curves represent the CνB signal and its background, respectively. The value of the finite energy resolution Δ is taken in such a way that only the signal of the sterile neutrino can be seen (left panel) or both the signals of active and sterile neutrinos can be seen (right panel). The gravitational clustering of relic neutrinos around the Earth has been omitted.

capture reaction to directly detect the CνB. We find that such light sterile neutrinos can in principle leave a distinct imprint on the electron energy spectrum in the capture of relic electron neutrinos by means of radioactive beta-decaying nuclei. Considering both the $(3+1)$ and $(3+2)$ schemes of neutrino mixing, we have calculated possible signals of sterile neutrinos relative to active

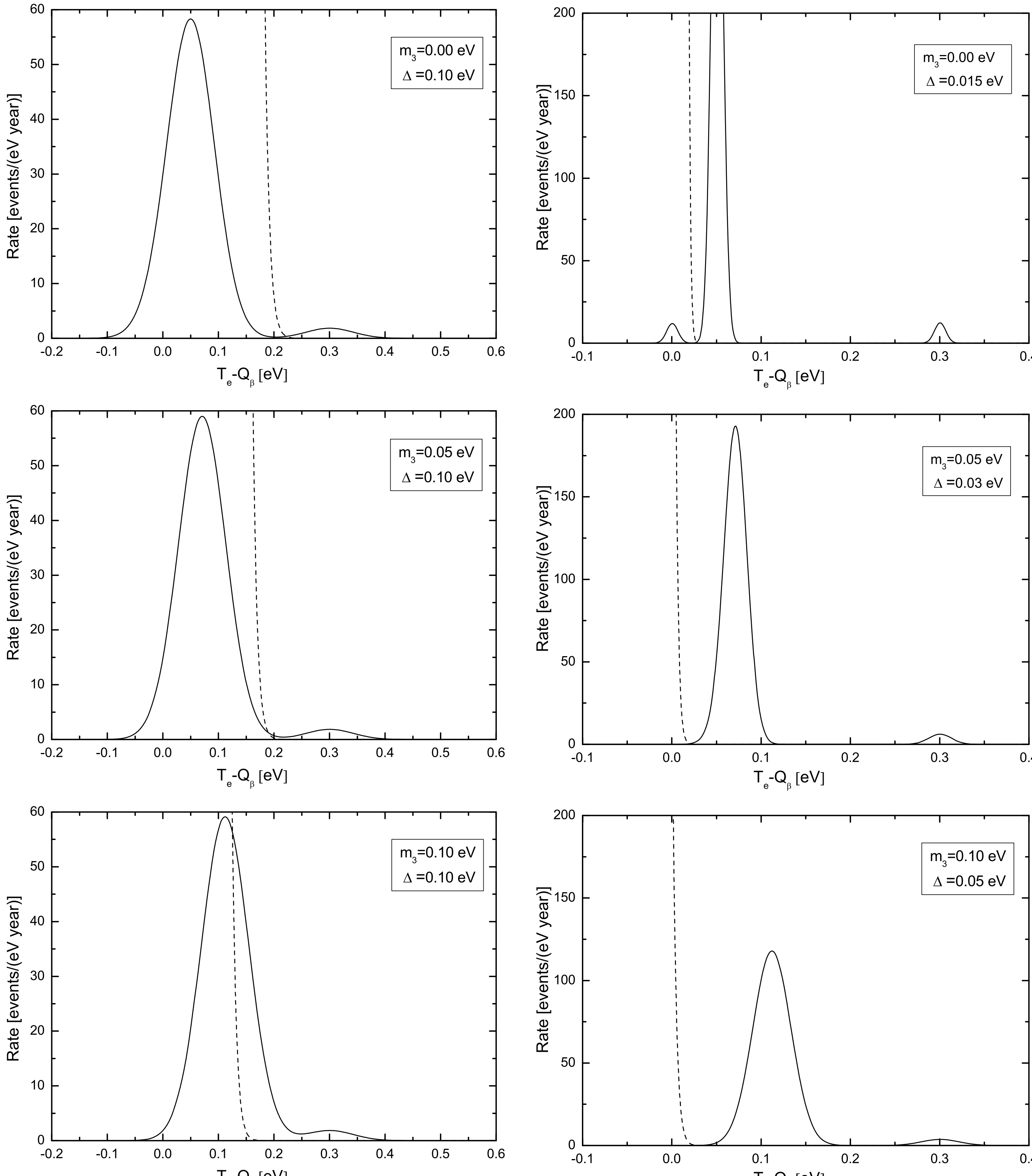

Fig. 2. The relic neutrino capture rate as a function of the kinetic energy T_e of electrons in the $(3+1)$ scheme with $\Delta m^2_{31} < 0$ and $m_4 = 0.3$ eV. The solid and dashed curves represent the CνB signal and its background, respectively. The value of the finite energy resolution Δ is taken in such a way that only the signal of the sterile neutrino can be seen (left panel) or both the signals of active and sterile neutrinos can be seen (right panel). The gravitational clustering of relic neutrinos around the Earth has been omitted.

neutrinos in the neutrino capture process $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$ against the corresponding tritium beta decay. We reiterate that our numerical results are just for the purpose of illustration, but they are useful to show a few salient features of the active and sterile components of the CνB in such neutrino capture processes.

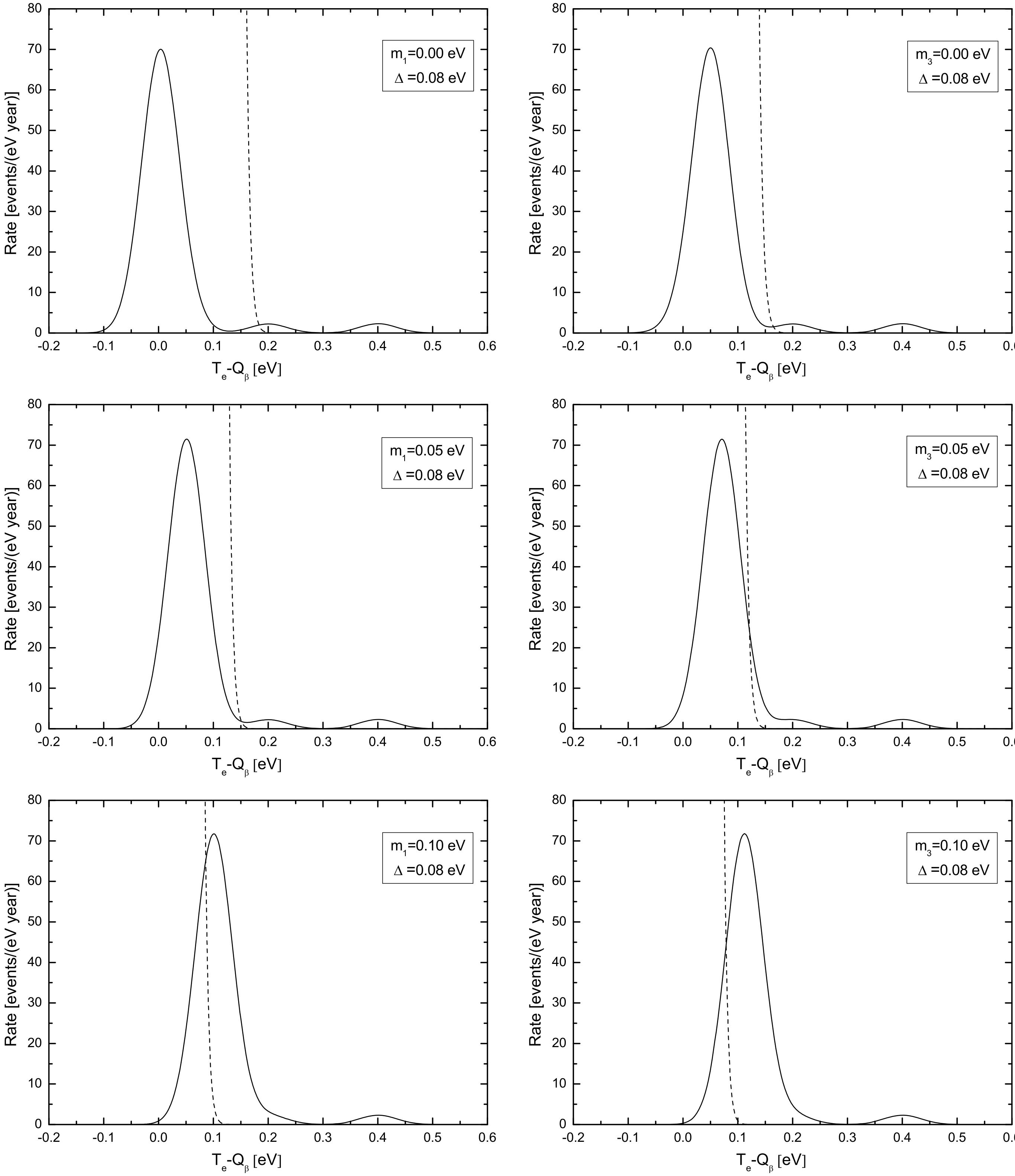

Fig. 3. The relic neutrino capture rate as a function of the kinetic energy T_e of electrons in the $(3+2)$ scheme with $\Delta m^2_{31} > 0$ (left panel) or $\Delta m^2_{31} < 0$ (right panel). In either case $m_4 = 0.2$ eV and $m_5 = 0.4$ eV are typically taken. The solid and dashed curves represent the CνB signal and its background, respectively. The value of the finite energy resolution Δ is taken in such a way that only the signals of sterile neutrinos can be seen. The gravitational clustering of relic neutrinos around the Earth has been omitted.

The major limiting factor of a neutrino capture experiment is its energy resolution. If the energy resolution is gradually improved, it should be possible to establish a signal of the CνB beyond the endpoint of the electron energy spectrum of the beta decay in the future. One might only be able to observe one peak for a given energy resolution, either because the peaks of different

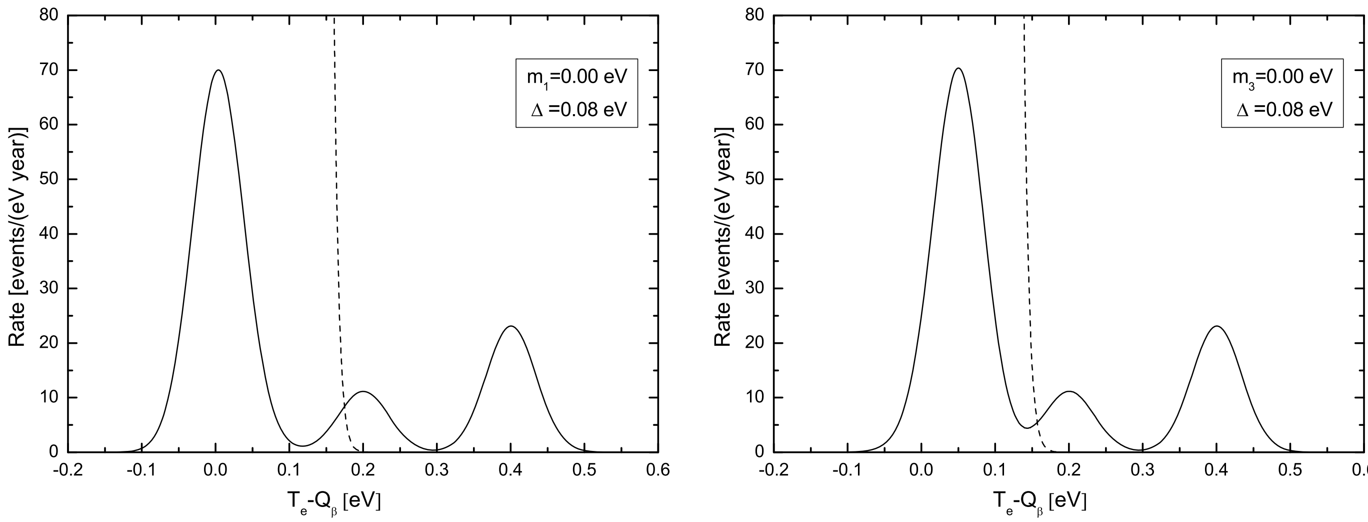

Fig. 4. The relic neutrino capture rate as a function of the kinetic energy T_e of electrons in the $(3+2)$ scheme with $\Delta m^2_{31} > 0$ (left panel) or $\Delta m^2_{31} < 0$ (right panel). In either case $m_4 = 0.2$ eV and $m_5 = 0.4$ eV are typically taken. The solid and dashed curves represent the CνB signal and its background, respectively. The value of the finite energy resolution Δ is taken in such a way that only the signals of sterile neutrinos can be seen. The gravitational clustering of relic sterile neutrinos around the Earth has been illustrated by taking $\zeta_1 = \zeta_2 = \zeta_3 = 1$ and $\zeta_5 = 2\zeta_4 = 10$ for example.

neutrino mass eigenstates merge into a wide one or because the peaks of lighter neutrinos are overwhelmed by the background (or for both reasons). In this case some information on the sterile component of the CνB could be obtained from a combined analysis of the available data from the neutrino capture experiment, neutrino oscillations and cosmological observations. If multiple peaks could finally be seen in the electron energy spectrum with a sufficiently good energy resolution, then they would convincingly indicate the presence of light sterile neutrinos in the CνB.

Needless to say, a direct detection of the CνB in a realistic experiment is very complicated and sophisticated. We admit that current experimental techniques are unable to lead us to a guaranteed detection of the CνB, but more and more efforts have been being made towards this ultimate goal. Whether the neutrino capture experiment (e.g., $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$ under discussion) can win the race or not remains an open question, but it is certainly the most promising horse at present.

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