Neutrino mass bound in the standard scenario for supernova electronic antineutrino emission

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Abstract

Based on recent improvements of the supernova electron antineutrino emission model, we update the limit on neutrino mass from the SN1987A data collected by Kamiokande-II, IMB and Baksan. We derive the limit of 5.8 eV at 95% CL, that we show to be remarkably insensitive to the astrophysical uncertainties. Also we evaluate the ultimate mass sensitivity of this method for a detector like Super-Kamiokande. We find that the bound lies in the sub-eV region, 0.8 eV at 95 % CL being a typical outcome, competitive with the values that are presently probed in laboratory. However, this bound is subject to strong statistical fluctuations, correlated to the characteristics of the first few events detected. We briefly comment on the prospects offered by future detectors.

1. Introduction

The interest in measuring the, presently unknown, absolute mass scale of neutrinos has been renewed by the experimental evidences of neutrino

oscillation [1, 2].

It is known since long [3] that neutrinos from supernova can contribute valuable information on the mass of neutrinos. In fact, the stringent limit of $m_\nu < 5.7$ eV at 95 % CL has been obtained by Loredo and Lamb [4] using SN1987A neutrinos [5, 6, 7]; another important result in this connection is the one obtained by Nardi and Zuluaga, who argue that future supernova will permit us to probe the sub-eV region [8, 9, 10].

In the present paper, we aim at updating both these results: namely, we improve the bound on neutrinos from SN1987A and we evaluate the ultimate sensitivity of the method to probe neutrino masses introduced by Zatsepin.

2. The limit from SN1987A

2.1. The reasons of an updated analysis

The limit from SN1987A [4] is quoted in the PDG report but it is considered *"no longer comparable with the limits from tritium beta decay"* [11]. In fact, in the 3 neutrino context it can be compared with the limit obtained in laboratory [12, 13]; the value of the latter is 2 eV, about three times tighter than the former.

Nevertheless, the analysis on neutrino mass of Lamb and Loredo [4] maintains a big methodological merit, being the only one based on a theoretically motivated model for the emission of neutrinos. Their model is capable of reproducing the expected (main) features of neutrino emission and, in particular, it includes an initial phase of intense luminosity. This phase, called accretion, is the crucial ingredient for theories that attempt to explain the explosion of the star, based on the "delayed scenario" [14, 15]–see [16] for a review. As we will show in the following, this phase is the theoretical ingredient that allowed to obtain the comparably strong limit on the mass recalled previously.

There are two specific considerations that make a reanalysis necessary: 1) it has been noted that the likelihood function adopted by Lamb and Loredo has a statistical bias [17]; 2) in addition, an improved model for the emission of neutrinos (which overcomes certain shortcomings and involves significant changes in the astrophysical parameters resulting from SN1987A data analysis) has been recently introduced in the scientific literature [18, 19].

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2.2. Procedure of analysis

The method used in this paper to investigate the neutrino mass is based on punctual comparison between the features of the collected data [5, 6, 7] and the expectations resulting from a specific theoretical model [18, 19]. This model describes the expected flux of electron antineutrinos, taking into account that the main reaction leading to observable events is $\bar{\nu}_e p \rightarrow e^+ n$ both in water Cherenkov than in scintillator detectors.

We assume that the shape of the flux is known up to nine free parameters that are obtained fitting the data. Let us explain their meaning: The first six parameters belong to two emission phases (accretion and cooling) and are used to take into account the large astrophysical uncertainties. Each emission phase is characterized by its intensity, its duration and the average energy of the emitted neutrinos. The three parameters of the accretion phase are the initial mass (M_a), the time scale (τ_a) and the initial temperature (T_a); those of the cooling phase are the radius (R_c), the time scale (τ_c) and the initial temperature (T_c). For details and analytical expressions see [18, 19]. The other three parameters are called "offset times"; each one of them is the absolute delay of the first observed event in each detector, more explicitly described below. We need to include three different offset times because the clocks of Kamiokande-II, IMB and Baksan were not synchronized [5, 7].

Now we include the effects of neutrino mass. The antineutrino flux, $\Phi_{\bar{\nu}_e}(t, E_\nu)$, is a parametric function that depends on the time of emission (t) and on the energy of the antineutrino (E_ν), see in particular Eqs. 10, 13, 19 and 20 in reference [18]. Of course this function must vanish for $t \leq 0$. Using the same notation of ref. [18] (see in particular Eq. 8 there) we can write the emission time for the i-th event as follow:

$$t_i = \delta t_i + t^{\text{off}} - \Delta t_i. \tag{1}$$

The first term in the right hand side, δt_i, is the relative time between the i-th and the first observed event in the considered detector, which is known directly from the data without significant error. The second one, t^{off}, is the offset time parameter which is the sum of the emission time of the first neutrino detected, t_1, and of its delay due to the velocity of propagation,

Δt_1, namely $t^{\mathrm{off}} = t_1 + \Delta t_1$. Finally, the last term,

$$\Delta t_i = \frac{D}{2c}\left(\frac{m_\nu}{E_{\nu,i}}\right)^2, \tag{2}$$

is the delay of the neutrino due to a non-zero mass [3], where D is the distance of propagation. The neutrino energy $E_{\nu,i}$ of the i-th event can be reconstructed from the measured energy of the positron, E_i, which is known up to its error, δE_i. The numerical value of the delay when $D = 50$ kpc (as for SN1987A), $E_\nu = 10$ MeV (a typical value) and $m_\nu = 10$ eV is $\Delta t = 2.6$ s, which is five times longer than the duration of the phase of accretion.

The scope of the statistical analysis is to extract from the fit t^{off} and m_ν at the same time. It is quite evident that these two terms work in opposite sense, see Eq. (1) and recall the condition $t_i \geq 0$. This makes the extraction of these two parameters more difficult, especially in the case of SN1987A, when the number of observed events is small. We adopt the same likelihood function $\mathcal{L}$ constructed in [18] including in it the expression for the times t_i given in Eq. (1). This is a function of 10 parameters, namely the nine parameters previously discussed plus the neutrino mass.

2.3. Results and remarks

Using the definition $\mathcal{L} = \exp(-\chi^2/2)$ we obtain the function that allows us to estimate the neutrino mass

$$\Delta\chi^2(m_\nu) = \chi^2(m_\nu) - \chi^2_{\mathrm{best\ fit}}, \tag{3}$$

This function is plotted in Fig. 1. The two continuous curves show the results of SN1987A data analysis. The thick line is obtained, for any fixed value of the neutrino mass, maximizing the likelihood with respect to the other 9 free parameters. The curve is somewhat bumpy, reflecting the presence of multiple maxima that compete in the likelihood with similar height. The existence of these maxima has been already remarked in [18] and causes numerical difficulties. To avoid these problems we bound the mass of accreting material M_a, which regulates the intensity of neutrinos emission in the accretion phase, to be lower than 0.6 $M_\odot$ [4, 18]. The thin line, instead, arises when the 6 astrophysical parameters are set to the best-fit values obtained in [18]. In this case only the 3 offset times are allowed to fluctuate freely to maximize the likelihood. The comparison of the two curves reveals some interesting features:
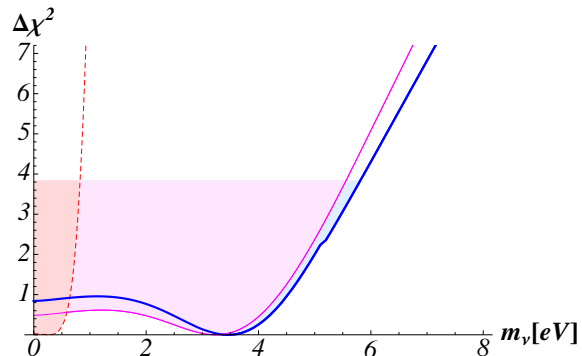
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Figure 1: *The curves show various $\Delta\chi^2(m_\nu)$ obtained by analyzing supernova neutrino data as a function of the neutrino mass. The two continuous curves are obtained from SN1987A data; the thick one includes the astrophysical uncertainties, the thin one assumes instead that the astrophysical parameters of neutrino emission are known. For comparison, we include the result of the analysis of simulated data set, collected in a detector a la Super-Kamiokande (SK), for a future supernova exploding at 10 kpc from us (leftmost dashed curve). This curve, discussed in detail later, illustrates the ultimate sensitivity of the method.*

- In spite of the really different assumptions, namely the complete knowledge of the supernova $\bar{\nu}_e$ emitted flux or only of its shape (up to 6 parameters), the two curves are quite similar. This shows that the large uncertainties in the astrophysics of the emission *are not* the main limitation in this type of analysis.

- In both curves, the minimum is located at $m_\nu \neq 0$, however, this is not statistically significant.[1] This is linked to a clustering of the events #1,2,4,6 of Kamiokande-II for $m_\nu \sim 3.5$ eV, already remarked by several authors, e.g., [21].

From our statistical analysis, we obtain as limit on neutrino mass from SN1987A data the value

$$m_\nu < 5.8 \text{ eV at 95\% CL.} \tag{4}$$

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[1]We note that the presentation using m_ν rather than m_ν^2–which is the quantity that is actually probed, see Eq. (1)–emphasizes somewhat artificially the region close to $m_\nu \sim 0$.

As already noted, this does not change much if we assume that the astrophysics of the emission is perfectly known; in this case, in fact, the limit becomes $m_\nu < 5.6$ eV at 95% CL: see Fig. 1.

From Eqs. (1) and (2) and from the previous discussion, it is quite evident that the information on the presence of the neutrino mass is mainly contained in the earlier events and, in particular, in those with low energy. These considerations select, as the most relevant data, the six events collected by Kamiokande-II in the first second [5], that incidentally, are also the most relevant ones to determine the presence of an accretion phase [4, 18].

3. The sensitivity of the method

These findings led us to the question of evaluating the ultimate sensitivity of this method for a future galactic supernova event. For this aim, we will analyze in this section simulated data, extracted from the generator described in [19] upgraded to describe the propagation of massive neutrinos, focussing mostly on the possibilities of the existing detectors. We will introduce and critically examine the assumptions used to derive the bound, comment on their statistical meaning, and overview the prospects offered by future detectors.

3.1. Statistical procedure

The expected counting rate of the signal is a function of the emission time t, neutrino energy E_ν, detector mass M_d, distance of the supernova D and of the astrophysical parameters that describe the electron antineutrino emission, namely

$$R(t, E_\nu) = 6.7 \times 10^{31} \frac{M_d}{1 \text{ kton}} \sigma_{\bar{\nu}_e p}(E_\nu) \tilde{\Phi}_{\bar{\nu}_e}(t, E_\nu) \epsilon(E_{e+}), \qquad (5)$$

that depends on the supernova distance through the electron antineutrino flux, i.e., $\Phi_{\bar{\nu}_e} \propto 1/D^2$. We will consider a SN exploding at a distance of $D = 10$ kpc, typical of a galactic event [22, 23]. Here, $\sigma_{\bar{\nu}_e p}(E_\nu)$ is the cross section of the interaction process [24]; the function $\epsilon(E_{e+})$ is the detector efficiency that we set to 98% above a threshold of 6.5 MeV; we approximate $E_e = E_\nu - \Delta$ with $\Delta = 1.293$ MeV.
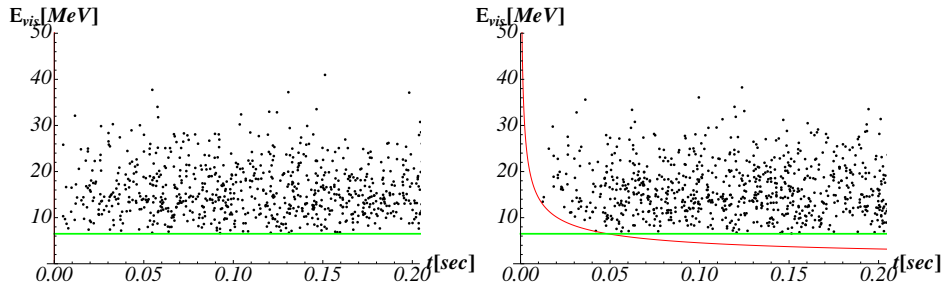
Figure 2: *Positron energy versus the emission time for two samples of simulated events for Super-Kamiokande detector. The neutrino mass is set to zero in the left panel and to the bound from tritium decay, $m_\nu = 2$ eV in the right one. The green line is the threshold of the detector and the red curve is the expected delay due to the neutrino mass, Eq.(2).*

Finally, $\tilde{\Phi}_{\bar{\nu}_e}(t, E_\nu)$ in Eq. (5) is the same electron antineutrinos flux used previously, $\Phi_{\bar{\nu}_e}(t, E_\nu)$, improved taking into account the finite rising time of the signal. This is described by an exponential function characterized by a new time scale, $\tau_r > 30$ ms, that we treat as a new parameter of the analysis [19]. With future large statistics we will be able to probe such a small time structure, as argued in [19]. Thus, in our analysis this function depends on 7 astrophysical parameters.

Each event extracted from this function is characterized by its relative detection time δt_i, its positron energy, E_i, and the error on this energy given by the function $\delta E_i/E_i = 0.023 + 0.41\sqrt{\text{MeV}/E_i}$ [25]. We generate the data using the Monte Carlo described in [19] and take into account the effect of neutrino mass by assigning a time delay to each generated event, as prescribed by Eq. (2). Fig. 2 shows two extractions, magnified in the region of the first 200 ms of data taking. Their comparison shows clearly the region where the effect of neutrino mass is most relevant, namely the one with the lowest energies and the smaller detection times.

We studied ten simulated data sets for a detector with a fiducial mass of $M_{SK} = 22.5$ kton as the Super-Kamiokande detector, which corresponds to about 4482 events on average. We also considered two different detector masses: $M_d = M_{SK}/16$, with an average number of events of 280, similar to the ones expected on LVD detector, and also $M_d = M_{SK}/256$, corresponding to an average number of 18 expected events, which resembles the statistics

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collected for SN1987A.

We calculate the bound on the mass by assuming that:

- The astrophysical parameters are precisely known; we use those in ref. [18], that agree with the expectations of a standard collapse and set $\tau_r = 50$ ms.

- The offset time is known without significant error (more discussion later).

These are very optimistic assumptions as appropriate to evaluate the ultimate sensitivity of the method. We discuss the weight of these assumptions in the following and their implications on the understanding of SN1987A results.

We note in passing that the neutrino mass enters the likelihood through Eq. (2), in the form $m_\nu^2 D$; moreover, the interaction rate in Eq. (5) depends on the combination M_d/D^2: thus, the likelihood obeys the exact scaling law

$$\mathcal{L}(M_d, D, m_\nu) = \mathcal{L}(\alpha^2 M_d, \alpha D, m_\nu/\sqrt{\alpha}). \tag{6}$$

This means, e.g., that once we know the value of the neutrino mass bound for $M_d = M_{SK}/16$, we get the bound for $M_d = M_{SK}$ and $D = 40$ kpc simply halving it. From here, we also conclude that the bound on the mass can be written as $m_\nu < f(M_d/D^2)/\sqrt[4]{M_d}$, where the function f depends on the selected statistical level on the adopted test and on the specific data set.

3.2. Results and discussion

The 95% CL neutrino mass bounds, obtained with fixed astrophysical parameters, are reported in Fig. 3 for each analyzed data set.

The case of low statistics and SN1987A. As first step, we discuss the diamonds points corresponding to a detector with mass $M_d = M_{SK}/256$. The average number of events in this case is very similar to the one observed for SN1987A, so we can explore the fluctuations due to the features of the data in a small data set. The values of the neutrino mass bound fall in the interval of 1.6 eV $< m_\nu <$ 6.4 eV showing that each particular data set contains very different information about the neutrino mass presence.
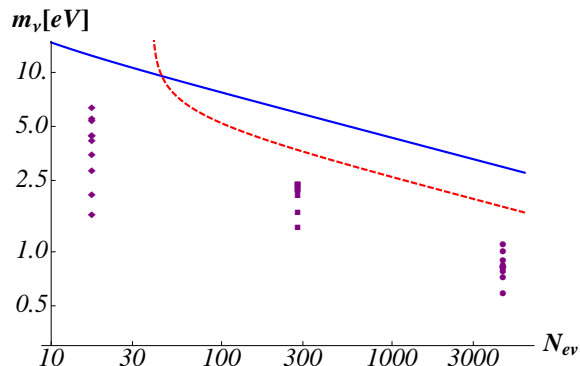
Figure 3: *The dots represent the 95% CL bounds on neutrino mass from the analysis of simulated data; for each of the three value of the average numbers of expected events we extracted and analyzed 10 simulated data set. Circles (dots in the right), squares (center) and diamonds (left) correspond to the results in detectors with masses $M_d = M_{SK}$, $M_{SK}/16$ and $M_{SK}/256$, respectively. The continuous and dashed curves describe the bounds given by Eq. (10) and discussed in the text.*

We used these simulations to investigate the weight of the various assumptions of the analysis on the resulting bound. For a typical simulated data set, we analyzed the data using three different procedures:

1. We suppose to know all the astrophysical parameters without errors and also the offset time. In other words, the only free parameter of the likelihood is the neutrino mass. The resulting 95% CL on neutrino mass in this case is: $m_\nu < 4.4$ eV.

2. We suppose that the offset time is unknown, whereas the 7 astrophysical parameters are known from the theory. Namely, the likelihood is a function of the neutrino mass and of the offset time. The resulting 95% CL on neutrino mass in this case is: $m_\nu < 7.2$ eV.

3. Finally, we suppose that we do not know any of the 9 parameters. Namely, only the shape of the signal in known from the theory and all parameters have to be estimated from the likelihood analysis. The resulting 95% CL on neutrino mass in this case is: $m_\nu < 7.4$ eV.

This study shows that the knowledge of the offset time significantly affects the value of the mass bound. Instead the comparison of the last two results confirms that the knowledge of the astrophysical parameters is less critical for the analysis, in agreement with what we found for SN1987A data analysis.

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We are ready for the comparison with the SN1987A results. This is possible using the scaling relation of Eq. (6). Using $\alpha = 5$, we translate the range $1.6 - 6.4$ eV in the range 0.7 eV $< m_\nu < 2.9$ eV when $D = 50$ kpc and for a detector mass $M_d \simeq M_{KII}$. For a fair comparison, we still need to take into account that the offset times and the astrophysical parameters are unknown in SN1987A analysis. So, comparing $m_\nu < 4.4$ eV and $m_\nu < 7.4$ eV, we multiply this range by the factor $7.4/4.4$ obtaining 1.2 eV $< m_\nu < 4.9$ eV. The bound from SN1987A, $m_\nu < 5.8$ eV, is not far from this range. The residual difference can be attributed to the better performances of the simulated detector. In fact, the improved efficiency implies that more events are collected at low energies; moreover, any misidentification of events is forbidden by constructions, due to the postulated absence of background events above the detection threshold.

The case of high statistics and the ultimate upper limit. Now we discuss the results for high statistic, i.e., the case when $M_d = M_{SK}$, chosen to represent the observation of a future galactic supernova event. A typical simulated data set is the one shown in the left panel of Fig. 2; the resulting $\Delta\chi^2$ is the one given by the dashed line of Fig. 1, that implies:

$$m_\nu < 0.8 \text{ eV at } 95\% \text{ CL} \tag{7}$$

This result confirms the possibility to probe the sub-eV region for neutrino mass using SNe neutrinos, in agreement with the finding of Nardi and Zulu-aga [8, 9, 10]. Also it would be closer to the sensitivity of about 0.2 eV that will be probed by the Katrin experiment [20].

An inspection of Fig. 3 shows also quite clearly that the bounds fluctuate strongly with the individual simulation, even for high statistics. This can be explained as follows. The emission time of each signal event is subject to the condition $t_i > 0$ (see Eq. (1)), which implies the condition on the neutrino mass:

$$m_\nu < m_\nu^* = \text{Min}_i \left\{ E_{\nu,i} \sqrt{\frac{t^{\text{off}} + \delta t_i}{D/(2c)}} \right\}. \tag{8}$$

When we replace $E_{\nu,i} = E_i + \Delta$, namely, neglecting the error in the measurement of the positron energy, we obtain the bound m_ν^* on the neutrino mass

N_{ev}	t^{off}(ms)	m_ν(eV)	m_ν^*(eV)
4328	4.9	0.78	0.94
4479	2.9	0.82	0.68
4497	2.9	0.72	0.76
4473	2.9	1.10	1.10
4492	4.6	0.84	0.77
4464	2.9	0.82	0.73
4488	3.5	0.90	0.72
4412	2.6	0.82	0.65
4412	1.2	0.59	0.52
4399	3.0	1.01	0.77

Table 1: *Number of events in Super-Kamiokande, offset time, statistical bound on the neutrino mass, and neutrino mass bound from Eq. (8) in 10 simulations.*

directly from the data. Typically, the minimum in Eq. (8) corresponds to the first (or the first few) event(s) of the data set; compare, e.g., with Fig. 2. This means that the role of the fluctuations is very important, also for large number of detected events. In other words, the bound m_ν^* depends strongly on the specific data set. We compare this bound with the one obtained by the full analysis of the likelihood function in Tab. 1. Within 25% the two bounds are in agreement. This supports the idea that, in this type of analysis where t^{off} is known, the information on the neutrino mass is mostly contained in the first few events, rather than somewhat distributed in the data set.

An alternative estimator. For comparison, we present also other estimators of neutrino masses that, instead, depend on relatively large numbers of events. We construct them by imposing that the error on a typical time scale of neutrino emission, τ, is larger than the average delay of the events $\langle \Delta t \rangle$:

$$\langle \Delta t \rangle < n_\sigma \cdot \frac{\tau}{\sqrt{N-1}}, \tag{9}$$

where n_σ is the required sensitivity (the number of sigmas); N is the number of detected events in the assigned time scale τ ($N \gg 1$ since we want to determine experimentally the phase of emission); $\langle \Delta t \rangle$, in turn, will be derived from Eq. (2) replacing the neutrino energy with its average value $\langle E_\nu \rangle$. For

a similar proposal, see [26]. Setting $n_\sigma = 2$, we get the following bound on the neutrino mass:

$$m_\nu < \frac{2\langle E_\nu \rangle}{\sqrt[4]{N-1}} \sqrt{\frac{\tau}{D/c}} \qquad (10)$$

We use the value $\langle E_\nu \rangle = 13$ MeV and $D = 10$ kpc for numerical purposes and consider two concrete times scales of emission: the one of the accretion phase, $\tau = \tau_a = 0.55$ s, which corresponds to $N = 0.4 N_{ev}$; the one of the rising function, $\tau = \tau_r = 50$ ms, which corresponds instead to $N = N_{ev}/40$. These lead to the continuous curve and to the dashed curve of Fig. 3, respectively. As soon the expected number of events is large enough ($N \gg 1$), we get a stabler bound on the neutrino mass.[2] However, Fig. 3 shows clearly that these are very conservative upper bounds, when compared with the true bounds from the full likelihood analysis.

The gravity wave trigger and its limitations. An important remark is in order. We evaluated the ultimate sensitivity of the method with the existing neutrino detectors, assuming that the offset time was known without significant error. How can we achieve this? In principle, we could profit of the detection of gravity waves, assuming they will be seen. However, two additional conditions should be fulfilled: a precise location of the supernova in the sky is needed; the interval of time between the onsets of gravitational and neutrino emissions should be known. The first condition is needed if the detectors of gravity waves and of neutrinos are not in the same location. Elastic scattering neutrino events can provide such an information, but with a uncertainty of several ms [19], while an astronomical identification would make this error negligible. The second condition has at present an associated theoretical 1σ error of about 1 ms [19], which is already limiting the sensitivity of the existing neutrino detectors: see Tab. 1, or consider that IceCUBE uses 2 ms time window. In summary, the key condition for a successful search for neutrino mass by this method is the possibility to implement very precise measurements of the time; however, the previous discussion showed the difficulties to realistically surpass the millisecond time scale. It will be

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[2]Note that in this limit and considering that the number of events scales as $1/D^2$, the bound in Eq. (10) is *independent* from the distance. The same occurs with the bound in Eq. (8) if $t^{\text{off}} + \delta t_i \propto D/\sqrt{M_d}$, that is satisfied for an initial linear rise of the interaction rate, $R(t) \simeq \xi t M_d/D^2$ (which is the quantity that determines the time of the events).

important to take into account these considerations for an analysis of future real data, for instance, taking into account the errors on the measurement of time. Another way to go beyond these limitations would be to rely on larger samples of data; this will be possible by future detectors, which leads us to the last point of the discussion.

Future prospects. Finally, we comment on the prospects to improve the reach of this method to investigate neutrino masses. A straightforward possibility would be to use a bigger detector, say of megaton mass; note incidentally that this is mentioned already in the paper of Zapsepin [3]. For example, with an increase of the number of events expected in Super-Kamiokande (22.5 kton fiducial volume) by a factor of ~ 20 one could expect an improvement on m_ν^2 as the inverse of the square root of this number, thus reaching $m_\nu \leq 0.4$ eV in the most optimistic case. If instead we use the stabler bound of Eq. (10), we find again a value close to the one in Eq. (7).

An alternative possibility would be to identify the very short burst from early neutronization; see [27] for an earlier discussion. Its detection could permit us to investigate neutrino masses of similar size. In the standard scenario of neutrino emission, however, this burst leads to a very small fraction of the total number of events, which leads us again to consider a megaton water Cherenkov detector. In fact, the elastic scattering events are 1/35 of the total sample; the burst comprises some 1/20 of the total energy released in ν_e's, which, when converted in $\nu_{\mu,\tau}$'s by oscillations, have a cross section 6.5 times smaller. Thus, a conservative estimation of the event fraction from the neutronization burst is 1/4500, which means about $N =20$ (=1) events in 450 (22.5) kton of fiducial volume from a supernova at nominal distance of 10 kpc. If used in Eq. (10) with $\tau = 3$ ms, this yields $m_\nu \leq 0.7$ eV, which is again similar to the bound of Eq. (10), but possibly more stable and without resorting to the gravity wave trigger.[3]

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[3]For a more precise bound one should keep into account that the elastic scattering reaction $\nu e \to \nu e$ does not allow to reconstruct the neutrino energy precisely.

4. Summary

The present work, part of a series of papers on supernova neutrinos [17, 18, 19, 22, 24], was devoted to derive and discuss the bound on neutrino mass from supernova electron antineutrinos. Our bound, Eq. (4), agrees well with the one obtained by Lamb and Loredo [4], despite the large number of differences in the procedures of analysis.

We argued that the result from SN1987A is relatively insensitive to the details of the emission model, as soon as the emission resembles the expectations of the standard scenario, that includes an initial phase of intense antineutrino luminosity. We showed that the knowledge of the time when neutrino emission begins ('offset time') has, instead, a significant impact on the bound that the existing detectors can obtain.

We derived the ultimate sensitivity that can be provided by supernova neutrinos with existing detectors. We showed that on average it lies in the interesting sub-eV region. However the key role of the first few detected events also implies a large fluctuation on the mass bounds. A crucial requirement is the need to reach very precise measurements of the offset time; we argued that the detection of a gravity wave burst could permit to reach the sub-eV sensitivity with the existing neutrino detectors. We briefly commented on the prospect to improve the bound using future, megaton class, water Cherenkov detectors.

References

[1] Proceedings of the CLXX Enrico Fermi Course *"Measurements of Neutrino Masses"*, eds. C. Brofferio, F. Ferroni, F. Vissani, SIF-IOS, 2009.

[2] A. Strumia and F. Vissani, "Neutrino masses and mixings and...," arXiv:hep-ph/0606054 and subsequent updates; G.L. Fogli, E. Lisi, A. Marrone and A. Palazzo, Prog. Part. Nucl. Phys. **57** (2006) 742; M.C. Gonzalez-Garcia and M. Maltoni, Phys. Rept. **460** (2008) 1.

[3] G.T. Zatsepin, Pisma Zh. Eksp. Teor. Fiz. **8** (1968) 333.

[4] T.J. Loredo and D.Q. Lamb, Phys. Rev. D **65** (2002) 063002.

[5] K.S. Hirata *et al.*, Phys. Rev. D **38** (1988) 448; K. Hirata *et al.* [Kamiokande-II Collaboration], Phys. Rev. Lett. **58** (1987) 1490.

[6] R.M. Bionta *et al.*, Phys. Rev. Lett. **58** (1987) 1494; C.B. Bratton *et al.* [IMB Collaboration], Phys. Rev. D **37** (1988) 3361.

[7] E.N. Alekseev, L.N. Alekseeva, V.I. Volchenko and I.V. Krivosheina, JETP Lett. **45** (1987) 589; E.N. Alekseev, L.N. Alekseeva, I.V. Krivosheina and V.I. Volchenko, Phys. Lett. B **205** (1988) 209.

[8] E. Nardi and J.I. Zuluaga, Phys. Rev. D **69** (2004) 103002.

[9] E. Nardi and J.I. Zuluaga, Nucl. Phys. B **731** (2005) 140.

[10] J.I. Zuluaga, PhD thesis defended on 2005 at the Univ. de Antioquia, Medellin, astro-ph/0511771v2.

[11] C. Amsler *et al.* [Particle Data Group], Phys. Lett. B **667** (2008) 1.

[12] C. Weinheimer *et al.*, Phys. Lett. B **460** (1999) 219.

[13] A.I. Belesev *et al.*, Phys. Lett. B **350** (1995) 263.

[14] D.K. Nadyozhin, Astrophys. Space Sci. **53** (1978) 131.

[15] H.A. Bethe and J.R. Wilson, Astrophys. J. **295** (1985) 14.

[16] H.T. Janka, Astronomy and Astrophysics, **368** (2001) 527; H.T. Janka, K. Langanke, A. Marek, G. Martinez-Pinedo and B. Mueller, Phys. Rept. **442** (2007) 38.

[17] A. Ianni, G. Pagliaroli, A. Strumia, F.R. Torres, F.L. Villante and F. Vissani, Phys. Rev. D **80** (2009) 043007.

[18] G. Pagliaroli, F. Vissani, M.L. Costantini and A. Ianni, Astropart. Phys. **31** (2009) 163.

[19] G. Pagliaroli, F. Vissani, E. Coccia and W. Fulgione, Phys. Rev. Lett. **103** (2009) 031102.

[20] J. Wolf [KATRIN Collaboration], arXiv:0810.3281 [physics.ins-det].

[21] H. Huzita, Mod. Phys. Lett. A **2** (1987) 905.

[22] M.L. Costantini, A. Ianni and F. Vissani, Nucl. Phys. Proc. Suppl. **139** (2005) 27.

[23] A. Mirizzi, G.G. Raffelt and P.D. Serpico, JCAP **0605** (2006) 012.

[24] A. Strumia and F. Vissani, Phys. Lett. B **564** (2003) 42.

[25] M. Nakahata *et al.* [Super-Kamiokande Collaboration], Nucl. Instrum. Meth. A **421** (1999) 113.

[26] J.F. Beacom and P. Vogel, Phys. Rev. D **58** (1998) 093012.

[27] N. Arnaud, M. Barsuglia, M.A. Bizouard, F. Cavalier, M. Davier, P. Hello and T. Pradier, Phys. Rev. D **65** (2002) 033010.