MSW effect and (anti)neutrinos from SN1987A

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Abstract

The MSW effect is calculated for ν_e , ν_μ and $\bar{\nu}_e$, $\bar{\nu}_\mu$ from the supernova SN1987A in the Large Magellanic Cloud.

Most of the gravitational energy in a SN explosion is expected to be dissipated as $\nu\bar{\nu}$ pairs with an energy of some tens of MeV [1-3]. The observation of such (anti)neutrinos from the supernova SN1987A [4] has been reported [5-8]. We develop how the MSW effect [9] can modify the expected (anti)neutrino fluxes from SN1987A. More details are given elsewhere [10].

We have used for the ν and $\bar{\nu}$ energy spectra the approximate analytical expression given by Nadezhin et al. [1]. The mean energy of the ν_e is around 10 MeV; the ν_μ are expected to have a mean energy about twice as high because, since their energy is below 106 MeV, they are not subject to charged current interactions and can,therefore, escape more easily the neutron star [3]. The difference in the energy spectrum of the ν_e and ν_μ is essential in our discussion of the MSW effect.

In the core of a supernova, the transformation $\nu_e \rightarrow \nu_2$ and $\nu_\mu \rightarrow \nu_1$ takes place if Δm^2 is in the range $10^6 - 10^{-1}$ eV^2 [11]. This region is essentially ruled out by accelerator and reactor oscillation experiments. The range of Δm^2 for which this transformation occurs in the SN envelope, is more model dependent and can extend up to 10^{-6} eV^2. For small mixing angles the effect of the $\nu_e \rightarrow \nu_2$ and $\nu_\mu \rightarrow \nu_1$ transition is to interchange the ν_μ and ν_e energy spectra. This effect can be observed in a ν_e detector either through a change in the average energy detected or in the total rate if the cross section rises faster than linearly with ν energy.

The supernova SN1987A is in the Large Magellanic Cloud (declination of -70°). As all present neutrino or antineutrino detectors lie at a latitude of $+40 \pm 5^\circ$, the minimum distance in the earth that the (anti)neutrinos have to traverse before reaching a detector is 1.1 earth radius. Then the possible MSW effect in the earth has to be calculated. We have considered two extreme cases: i) (anti)neutrinos leave the supernova without the MSW $\nu_e \rightarrow \nu_2$ and $\nu_\mu \rightarrow \nu_1$ transformation , ii) (anti)neutrinos have been completely transformed in the supernova.

The equations describing the neutrino propagation in the earth are solved according to a numerical program [12]. We define the ratio between the number of events calculated taking into account the MSW effect in the earth and/or in the supernova and the number of events calculated not taking into account the MSW effect anywhere. Figure 1 shows this ratio for neutrinos as a function of $-\Delta m^2$ and for $\sin^2 2\theta = 0.1$. The solid line corresponds to the case i) : the main effect of the earth is an increase in the ν_e counting rate by up to a factor 2, for Δm^2 in the range -10^{-4} to -10^{-5} eV^2. The dashed line corresponds to the case ii) : a large fraction of the ν_μ have been transformed into ν_e inside the SN. Then the expected number of counts at the entrance of the earth is higher than in case i) by a factor up to 3. The

earth effect regenerates ν_μ from ν_e in the same Δm^2 range. Then, the expected counts on the other side of the earth are lower than at the entrance by a factor 1.5 .

If the transition in the supernova is not complete for a given value of Δm^2 , we obtain any intermediate solution between the full curve and the dashed curve. The result in figure 1 ($\sin^2 2\theta$=0.1) is not strongly different for any value between 0.01 and 0.4 . The calculation has also be done when varying the distance traversed by neutrinos in the earth between 1 and 2 earth radius but no significant change has been observed.

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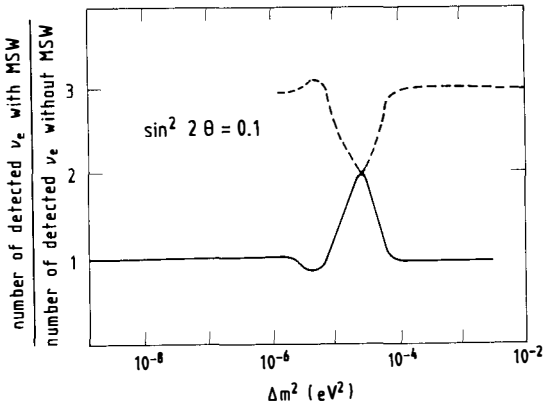

Figure 1 : Ratio between the number of events calculated taking into account the MSW effect and the number of events calculated not taking into account the MSW effect. The solid (dashed) line is for the case where the transformation $\nu_e \rightarrow \nu_2$ and $\nu_\mu \rightarrow \nu_1$ did not (did) take place in the supernova. The enhancement (suppression) around $-\Delta m^2 = 10^{-5} - 10^{-4}$ eV^2 is due to the resonant oscillations in the earth.