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COMMENTS ON SUPERNOVA NEUTRINOS AND MAXIMAL 3 NEUTRINO VACUUM OSCILLATIONS

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Due to the expected large difference of energy of ν_μ, $\bar{\nu}_\mu$, ν_τ, $\bar{\nu}_\tau$ compared to ν_e, $\bar{\nu}_e$ from a supernova II we show that it will be straight forward to test the recent proposal by Harrison, et al., that the 3 neutrino mass matrix gives maximal mixing for almost any possible vacuum oscillation mass differences that has been detected in the solar system to date. We show how new detection of supernova neutrinos can completely test this hypothesis provided a full set of detector's exist. We also remark that the 1987A neutrino data do not favor this hypothesis.

1. Comments

In the very interesting paper in Reference 1, the authors suggest that most current neutrino experiments that see a deviation from the expectations of the neutrino flux can be described in a 3 neutrino model with maximal mixing[1]. This idea has partially been discussed before where the simplest model predicted that the 3 neutrino flux should be reduced to 2/3 for say $\nu_e \to \nu_x$ or 1/3 for $\nu_e \to \nu_e$[2]. The major success then was that the Homestake experiment measures something like 0.28 ± 0.3 near 1/3[2,3,4]. The authors accept this but show that there are many other experiments now that are consistent with their hypothesis[1].

In this note we point out another possible way to test the hypothesis of Reference 1, using neutrino (anti-neutrino) bursts from Type II supernova[5,6]. The basic idea is that full 3 neutrino mixing would dramatically change the energy spectrum of the $\bar{\nu}_e$ and ν_e and the $\bar{\nu}_e p \to e^+ n$ ($\nu_e n \to e^- p$) rates of high energy events. The data from SN1987A are in disagreement with the hypothesis of full 3 neutrino mixing.

In the model of Reference 1 there are two neutrino masses $M_1 \sim M_{\lesssim} 3$meV and $M_3 \sim 85 \pm 10 \times 10^{-3}$eV ($\sim 0.1$eV). We assume for simplicity that $\nu_1 = \nu_e$, $\nu_2 = \nu_\mu$, $\nu_3 = \nu_\tau$. In this model the atmospheric neutrino deficit (1) and the solar neutrino puzzle (2) result from

$$\nu_\mu \to \nu_\tau \tag{1}$$

and

$$\nu_e \rightarrow \nu_\tau \tag{2}$$

Since the process $\nu_e \rightleftarrows \nu_\mu$ may not occur due to the small M_1, M_2 mass and mass difference[1]; this leads to the "prediction" that the survival probability for atmospheric ν_μ is[1]

$$P(\nu_\mu \rightarrow \nu_\mu) = 5/9 \tag{3}$$

and for solar neutrinos ν_e[1]

$$P(\nu_e \rightarrow \nu_e) = 5/9 \tag{4}$$

While the former is in good agreement with the Kamiokande and IMB results[7,8] for atmospheric ν_μ, the latter agrees with 3 of the 4 solar neutrino[9,10,11] experiments (being in sharp disagreement with the Homestake results mentioned above)[12]. The case of supernova neutrinos is completely different. In the first place, the likely closest supernova to earth will be at a distance of 10kpc, giving a L/E ratio of $\sim 5 \times 10^{19}$M/MeV and thus vacuum mass difference of $\Delta^2 M \sim 10^{-19}\text{eV}^2$ (we ignore the MSW effect in this paper). Thus, in the maximal mixing model, we may assume that the asymptotic condition for L/E has been reached and therefore

$$P(\nu_i \rightarrow \nu_j) \rightarrow 1/3, \tag{5}$$

$$P(\nu_i \rightarrow \nu_i) \rightarrow 1/3 \tag{6}$$

If the asymptotic conditions do not hold (i.e. $M_1 \equiv M_2$, $\Delta^2 M_{1,2} \equiv 0$) then we obtain the more restricted results in Reference 1

$$P(\nu_{\mu,e} \rightarrow \nu_\tau) = 2/9 \tag{7}$$

$$P(\nu_{\mu,e} \rightarrow \nu_{\mu,e}) = 5/9 \tag{8}$$

We now apply this to the supernova neutrino burst. The important expected features for our arguments are

(1) $F_{\nu_e} \sim F_{\bar{\nu}_e} \sim F_{\nu_\mu} \sim F_{\bar{\nu}_\mu} \sim F_{\nu_\tau} \sim F_{\bar{\nu}_\tau}$

(2) $\langle E_{\nu_e} \rangle < \langle E_{\bar{\nu}_e} \rangle < \langle E_{\nu_x, \bar{\nu}_x} \rangle$. Where F_ν is the neutrino flux, $\langle E_\nu \rangle$ the average neutrino energy[5,6], $\langle E_{\bar{\nu}_{e,\tau,\mu}} \rangle / \langle E_{\bar{\nu}_e} \rangle \sim 2$, and $x = \mu, \nu/$

(3) $\sigma_{(\bar{\nu}_e p \rightarrow e^+ n)} \propto (E_{\bar{\nu}_e})^2$ for most of the energy range covered by the supernova neutrinos for $\bar{\nu}_e + p \rightarrow e^+ + n$.

It is easy to see that the effect of maximal 3 neutrino mixing is to give the flux for high energy $\bar{\nu}_e$ as

$$F^{HE}_{\bar{\nu}_e} = P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)\, F_{\bar{\nu}_\mu} \tag{9}$$

$$P(\bar{\nu}_\tau \rightarrow \bar{\nu}_e)\, F_{\bar{\nu}_\tau} \tag{10}$$

In the asymptotic case $\left(\Delta M_{1,2}^2 > (L/E)^{-1}\right)$ we find

$$F_{\bar{\nu}_e}^{HE} = 2/3 F_{\nu_{e,\mu,\tau}} \tag{11}$$

If we assume that

$$\langle E_{\nu_{\tau,\mu}} \rangle \sim 2\langle E_{\bar{\nu}_e} \rangle \tag{12}$$

we find

$$R_{\bar{\nu}_e}^{HE} = 2/3 \times \left[\frac{\langle E_{\nu_\tau,\bar{\nu}_\mu}\rangle}{\langle E_{\nu_e}\rangle}\right]^2 R_{\bar{\nu}_e}^{LE} \tag{13}$$

$$R_{\bar{\nu}}^{HE} \simeq 8/3\, R_{\bar{\nu}}^{LE} \tag{14}$$

This situation is in clear disagreement with the Kamiokande and Baksan data observed in SN1987A neutrino events (see Figure 1) that are fully consistent with coming from the normal ν_e flux (i.e. have the low energy spectrum)[13]. We use the Kamioka and Baksan experiments which had a higher efficiency for low energy neutrinos than the IMB[14].

In the case $\Delta^2 M_{1,2} \equiv 0$ we would have

$$F_{\bar{\nu}_e}^{HE} = 2/9 F_{\bar{\nu}_e}^{LE} \text{ (from } \bar{\nu}_\tau \to \bar{\nu}_e \text{ oscillations)} \tag{15}$$

and

$$R_{\bar{\nu}_e}^{HE} = 2/9 \times [2]^2\, R_{\bar{\nu}_e}^{LE} \tag{16}$$

$$= 8/9\, R_{\bar{\nu}_e}^{LE} \tag{17}$$

Even this is in mild disagreement with the 1987A data (see Figure 1).

Future SN neutrino observation, including the neutral current channels[5,15] $\nu_x + N \to \nu_x + N'$ combined with observation of $\bar{\nu}_e + p \to e^+ + n$ in Super Kamiokande can fully test this hypothesis. In this case we will be able to relax the theoretical input of the neutrino (anti-neutrino) energy and flux spectrum and test the hypothesis directly using the data from these experiments[5,6,15].

In summary, we have shown that the model of Harrison, Perkins and Scott[1] with one "massive" neutrino (with mass $\sim 0.1eV$) and full mixing is in sharp disagreement with SN1987A data if $\Delta^2 M_{1,2} > 10^{-19}\text{eV}^2$ and mild disagreement if $\Delta^2 M_{1,2} < 10^{-19}\text{eV}^2$. We also have shown how future SN neutrino detection, provided there are both large neutral current and $\bar{\nu}_e$ detectors in operation at the burst time, can fully test this hypothesis[5,6,15].

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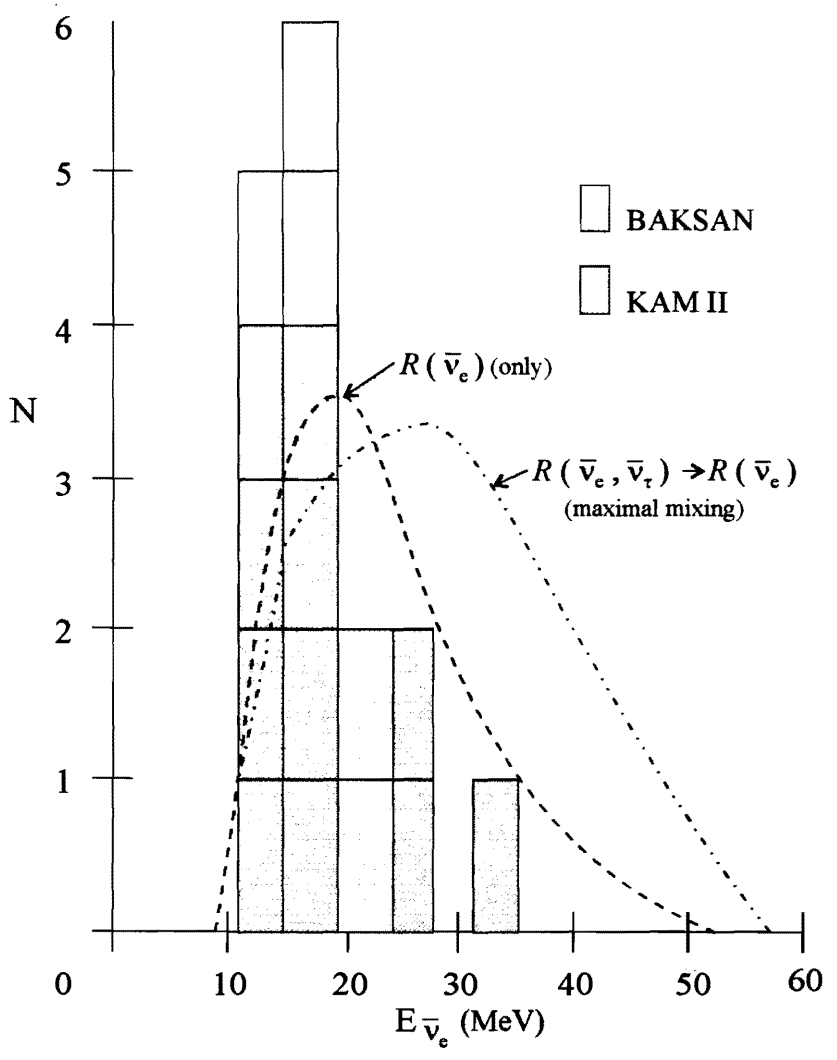

Fig. 1. Plot of $\bar{\nu}_e p \rightarrow e^+ n$ events from Kam II and Baksan as compared to various models for full 3 neutrino mixing. (These data are used since the detectors have relatively high efficiency at low energy.)

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