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Title: Probing Non-Standard Neutrino Interactions with Supernova Neutrinos at Hyper-K

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Referee report

The authors considered non-standard neutrino self interactions (NSSI) for a galactic supernova (SN) neutrinos which, in principle, could be tested at Hyper-Kamiokande (Hyper-K or HK) detector. It seems that the paper contains some new interesting results but before it can be considered for publication, I would like the authors to take into account the following observations.

1) In page 6, in the 2nd paragraph,

The sentence below,

"... when the neutrino density is comparable to or greater than the matter density."

is not very clear or not well written. I think that it is better to write as follows (or something similar),

"... when the neutrino number density is comparable to or greater than the nuleon (or electron) number density."

2) Regarding the results shown in Fig. 3

The authors found that the non-zero values of g_3 tend to delay the onset of collective oscillation effects for the NH case while such effect is small (absent) for the IH case, but they did not provide any physics discussion or explanation why the flavor conserving coupling g_3 induces such effects. If it is possible, it would be better if the authors can give some qualitative/intuitive discussion. Or it is the outcome of the complicated numerical simulations and difficult/impossible to provide some qualitative physics explanation?

3) Regarding the results shown in Fig. 4

Similar comments I made above apply also to the results shown in Fig. 4. It would be nice if the authors can provide some qualitative physics discussion why the presence of the flavor violating coupling g_1 tends to advance the onset of collective oscillations for all the four cases shown in this figure. In addition to this effect, why the $\bar{\nu}_e$ survival probability (at larger r) tend to be larger for larger coupling g_1? Is there any physics explanation?

4) Regarding the results shown in Figs 3 and 4 (about the maximum distance considered)

The authors show the neutrino and anti-neutrino survival probabilities until $r = 300$ km but I understand that the values at this distance are not yet the final survival probabilities to be used to calculate the SN neutrino induced event rates at Hyper-K. In particular, the probabilities shown in the upper left and lower right panels of Figs. 3 and 4 are still changing as a function of distance so it is clear that the values at $r = 300$ km are not yet the final ones. Moreover, I think that at larger distance beyond 300 km (typically $r \sim O(1000)$ km or so) there can be the usual MSW resonance effect which can change dramatically the probabilities. So I think it would be useful to show the probabilities until the distance that they reach some values close to the final survival probabilities to be used to compute the number of events. This can be done either by extending the distance in Figs. 3 and 4 or by providing some other figures with different scales of distance.

5) Regarding the separation of IBD and ES events

It seems that the authors assume that it would be possible to count separately the number of events coming from IBD and ES reactions in the Hyper-Kamiokande detector. However, in a water Cherenkov detector like Hyper-K, in my understanding, it would be impossible to identify (distinguish) event by event, the one induced by IBD reaction and the one by the elastic scattering as it is not distinguish electron and positron. The estimation of number of events can be done only statistically by taking into account the angular dependence of scattered/produced electrons/positrons, namely, the events induced by ES reaction are forward peaked whereas the ones by IBD reactions are almost isotropic. However, if gadolinium is loaded into the HK detector, it would be possible to identify IBD events (see Ref. [22]). It would be better to make some comments on these details.

6) Regarding the results shown in Table 1 (i)

I understand that the authors considered the ratio of the number elastic scattering (ES) events and inverse beta decay (IBD) reactions in order to be more supernova model independent as the ratio depends less on the SN model than the absolute number of events of these reactions, which I agree. However, the uncertainties (errors) shown in the table 1 look too small to me and I would like to understand better how the authors obtained these numbers, and confirm if the ratio is sufficiently robust against the SN model uncertainties. If we look at Table LI of Ref. [22] (Hyper-Kamiokande Design Report) where the number of events of various reactions for a galactic SN (at 10 kpc) induced neutrino events in HK are shown, and simply consider the ratio of the ES and IBD induced events, the variation of the ratio would be significantly larger than the uncertainties/errors indicated in the Table 1. For example, I think that if the average energies of SN neutrinos are somewhat increased or decreased, this will change the ratio since the energy dependence of ES and IBD cross sections are different. Roughly speaking, the ES cross section increases linearly as energy increases whereas the IBD cross section increases quadratically (or it is proportional to the energy squared) for the energy range relevant for SN neutrinos. So if the average energies are increased (decreased) the ratio of ES/IBD would be decreased (increased) and can be confused with the effect coming from NSSI. So I would like the authors to discuss more this kind of potential problem(s) to establish or separate the effect coming from NSSI from that of SN model uncertainties.

7) Regarding the results shown in Table 1 (ii)

It seems that the results shown in Table 1 do not include the uncertainties coming from statistics (which is different from the uncertainties coming from SN model variation). Since the number of ES events are smaller than that coming from IBD one, at first approximation, the statistical errors coming ES events should be the main source of error for the ratio. For 3000 (4000) of ES events, the expected statistical error is $\sim$ 1.8 (1.6) %. It would be better to show also the statistical error in the table. Of course, since this error depend on the distance to the supernova, it can be shown just for the case of 10 kpc SN as a reference.

8) Regarding the event number distribution as a function of the neutrino energy

In order to understand better the results found in this paper, I would like to see also the event number distribution as a function of the neutrino energy, something similar to the one shown in Fig. 177 of Ref. [22] just for the cases of IBD and ES reactions for g_1, $g_3 = 0$ and 0.2, for example, for normal and inverted mass ordering.