Observing supernova neutrino light curve in future dark matter detectors

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The possibility of observing supernova (SN) neutrinos through the process of coherent elastic neutrino-nucleus scattering (CENNS) in future ton scale detectors designed primarily for direct detection of dark matter is investigated. In particular, we focus on the possibility of distinguishing the various phases of the SN neutrino emission. The neutrino emission rates from the recent long term Basel/Darmstadt simulations are used to calculate the expected event rates. The recent state-of-the-art SN simulations predict closer fluxes among different neutrino flavors and lower average energies compared to the earlier simulation models. We find that our estimated total event rates are typically a factor of two lower than those predicted using older simulation models. We further find that, with optimistic assumptions on the detector’s time resolution (∼ 10 ms) and energy threshold (∼ 0.1 keV), the neutrinos associated with the accretion phase of the SN can in principle be demarcated out with, for example, a 10-ton Xe detector, although distinguishing the neutrinos associated with the neutronization burst phase of the explosion would typically require several tens of ton detectors. We also comment on the possibility of studying the properties of non-electron flavor neutrinos from the CENNS of SN neutrinos.

I. INTRODUCTION

The possibilities of studying the properties of neutrinos and extracting conditions inside a supernova (SN) progenitor star before and during its explosion, through observation of the neutrinos emitted from the SN, have been extensively investigated in the past two decades following the observation of neutrinos from SN1987A [1, 2]. Most of these investigations focused on neutrino detection using charged current (CC) processes on water and other detector materials [3, 4], though process of inelastic neutral current scattering on, for example, oxygen [5], deuterium [6], and carbon [7] were also studied.

In the last ten years or so, processes like neutrino-proton [8] and neutrino-nucleus [9, 10] elastic scattering have also been looked at in detail. In particular, as pointed out long ago [12, 13], there can be the process of coherent elastic neutrino-nucleus scattering (CENNS), for which there is a significant enhancement in the predicted number of events, increasing approximately as the square of the number of neutrons constituting the nuclei of the detector material. However, the typical kinetic energies of the recoil nuclei in the elastic neutrino-nucleus scattering are expected to be rather small, requiring detectors with low energy thresholds in the range of few keV to few tens of keV. No conventional neutrino detectors have such low thresholds. However, the detectors used in dark matter (DM) direct detection (DD) experiments designed for the weakly interacting massive particle (WIMP) candidates of DM through nuclear recoil signals associated with WIMP-nucleus scattering may have sufficiently low thresholds so as to be sensitive enough to detect the low energy nuclear recoil events associated with SN neutrinos [10]. However, the presently operating DM detectors are not large enough to detect such neutrino events. Only in context of planned future large ton scale detectors such possibilities would be viable. In the previous studies [14, 15] investigating the possibility of observing the CENNS using various astrophysical neutrino sources and geoneutrinos predict interesting prospects. Indeed, it is now well recognized that these CENNS events due to astrophysical and terrestrial neutrinos can be a major source of background in DM search experiments [14, 16, 17].

The detectors for DM DD, which are currently in operation or are under consideration, use a variety of different target materials. In order to optimize the possibility of detecting SN neutrinos using such detectors, it is important to study the process of coherent elastic scattering of ∼ MeV energy neutrinos on various different target nuclei. For supernova neutrino detection the DM detectors may be particularly useful as the coherent elastic scattering is caused by all neutrino/antineutrino flavors as opposed to only the electron flavor neutrinos in CC processes [10, 18]. Such coherent scatterings will give rise to a few events per ton of detector material for a galactic (10 kpc) SN event compared to some hundreds of $\bar{\nu}_e$ events per kiloton in CC based detectors. So with an order of magnitude increase in the number of events spread over only about 10 seconds, this needs serious consideration particularly for the future ton/multi-ton detectors.

An important consideration for using DM detectors for SN neutrino detection is the excellent time resolutions of the DM detectors which can be in the region of ∼ 10 ns. This offers the interesting possibility of studying the temporal structure of the neutrino emission from the SN. Indeed, measuring the SN neutrino light curve will allow
one to probe the standard SN model, which predicts three main phases of neutrino emission, namely, the neutronization burst phase, the accretion phase and the cooling phase. Clear demarcation of these phases is extremely important as the flux and average energy of the emitted neutrinos are very different in these different phases. Since the CENNS process is flavor blind, the DM detectors can measure the total SN neutrino light curve, and thus will be complementary to the light curves of oscillated $\nu_e, \bar{\nu}_e$ flavors detected by other detectors through CC interactions.

In order to derive realistic estimates of the expected number of SN $\nu$ events in a typical DM detector, it is important to use a reliable SN model that incorporates as much realistic physics of SN explosion and associated neutrino emission as possible. In this paper, we use the results from the Basel/Darmstadt simulations \cite{19} to study the detectability of SN neutrinos in DM detectors employing various different detector materials, and also study the possibility of demarcating the different phases of the neutrino emission from the SN using these detectors.

It may be mentioned here that the average energies of the emitted neutrinos given by the Basel/Darmstadt simulations are typically lower than those given by earlier simulations (see, e.g., \cite{20, 21}). Consequently, we find somewhat lower (by about a factor of 2) number of events compared to earlier estimates \cite{10}.

This paper is organized as follows: In section \textsection II we briefly review the CENNS process. There, for the purpose of illustration, we also calculate the expected event rates in DM detectors with different target materials, for the case of a guaranteed source of astrophysical neutrinos, namely, the $^8\text{B}$ solar neutrinos. Section \textsection III contains the main new results of this paper, where we estimate the expected number of events from a future Galactic SN in DM detectors with different target materials and discuss the possibility of detecting the different phases of the neutrino emission. We further discuss the possibility of extracting the temperature of the non electron neutrinos in the SN neutrino flux. Finally, section \textsection IV summarizes the main results of this paper.

\section{Coherent Elastic Neutrino-Nucleus Scattering}

The differential cross section for the process of coherent elastic neutrino-nucleus scattering is given by \cite{11, 13}

$$\frac{d\sigma(E_\nu, E_k)}{dE_k} = \frac{G_F^2}{4\pi} Q_W^2 M F^2(Q^2) \left( 1 - \frac{M E_k}{2E_{\nu}^2} \right), \quad (1)$$

where $E_\nu$ is the neutrino energy, $E_k$ is the recoil nucleus kinetic energy, $Q_W = N - (1 - 4\sin^2 \theta_W)Z$ is the weak nuclear charge for a nucleus with $N$ neutrons and $Z$ protons, $M(= AM_N)$ is the mass of the nucleus with mass number $A(= N + Z)$ and $M_N = 931 \text{MeV}$ is the average nucleon mass. The form factor, $F(Q^2)$ (with normalization $F(Q^2 = 0) = 1$, $Q$ being the 4-momentum transfer to the nucleus), represents the loss of coherence at high recoil energies when $qR \gtrsim 1$, $q = (2M E_k)^{1/2}$ being the magnitude of the 3-momentum transfer, and $R$ the radius of the nucleus. The maximum kinetic energy of the recoil nucleus is $E_{k,\text{max}} = 2E_\nu^2/M \approx (2/A)(E_\nu/\text{MeV})^2\text{keV}$ for $M \gg E_\nu$. In the limit of complete coherence ($qR \to 0$), the cross section \cite{11} varies approximately as the square of the number of neutrons in the nucleus. In the following analysis, for $F(Q^2)$ we use the Helm form factor with the parametrization given in \cite{11}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.pdf}
\caption{Left: Recoil energy spectra (differential event rate as a function of recoil nucleus kinetic energy) for $^8\text{B}$ solar neutrinos in a dark matter detector with three different target materials, namely, $^{19}\text{F}, ^{28}\text{Si}$ and $^{131}\text{Xe}$. Right: The integral recoil energy spectra (total event rate above a threshold recoil energy) as a function of the threshold recoil energy of the detector.}
\end{figure}
The differential nuclear recoil event rate is given by

\[
\frac{dN(E_k)}{dE_k} = \int_{E_{\text{inmin}}}^{\infty} \frac{dN_{\nu}}{dE_\nu} \sigma(E_\nu, E_k) dE_\nu,
\]

where \(\frac{dN}{dE_k}\) is the differential neutrino flux incident on the detector and \(E_{\text{inmin}} = (M E_k/2)^{1/2}\) is the minimum neutrino energy required to give a recoil kinetic energy of \(E_k\) to the nucleus.

The CENNS process has not yet been observed. To illustrate the kind of event rates one may expect in typical DM detectors, with astrophysical sources of neutrinos, we display in Figure 1 the expected event rates as a function of the recoil energy (i.e., the recoil energy spectrum) for the case of a guaranteed source of astrophysical neutrinos, namely, the solar \(8B\) neutrinos, and for three different target nuclei constituting the detector material, namely, \(^{19}F, ^{28}Si\) and \(^{131}Xe\).

The event rates shown in Figure 1 do not take into account the energy resolution of the detector. To illustrate the dependence on the threshold recoil energy of the detector, the right panel of Figure 1 shows the integral recoil energy spectra above a threshold recoil energy as a function of the recoil energy. It is clear that future ton-scale DM detectors have good prospects for detecting a neutrino source such as the \(8B\) solar neutrinos through neutrino-nucleus elastic scattering in a few years of running.

### III. Supernova Neutrinos and Their Detection in Dark Matter Detectors

Detection of neutrinos from SN 1987A \(^{22,24}\) established beyond doubt that some supernova explosions are associated with emission of large number of neutrinos. According to the present understanding of core collapse supernovae, as the core of a large star starts to collapse after the nuclear fuel gets exhausted, the density in the inner core region at some point goes beyond the nuclear matter density. In the earlier stages of the collapse, the neutronization of matter produces \(\nu_e\)'s, but later at very large densities both neutrinos and antineutrinos of all three flavors (i.e., \(\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu, \nu_\tau\) and \(\bar{\nu}_\tau\)) get produced in much larger numbers. Almost all the enormous energy released in the gravitational contraction, roughly a few times \(10^{53}\) ergs, comes out through the emission of these neutrinos over a timescale of \(\sim 10\) seconds.

As already mentioned, the CENNS process being flavor blind will be sensitive to \(\nu_\mu\), \(\bar{\nu}_\mu\) and \(\nu_\tau\) (hereafter collectively referred to as \(\nu_s\)) in addition to \(\nu_e\) and \(\bar{\nu}_e\). This will allow a direct estimation of the total energy emitted in neutrinos in the SN process. Combined with information about \(\nu_e\) and/or \(\bar{\nu}_e\) event rates for the same SN event in other (conventional CC) detectors, this would then allow one to estimate the average \(\nu_e\) energies emitted in the SN event.

![Figure 2: Temporal profile of the neutrino luminosity (upper three panels) and average energy of the neutrinos (lower three panels) for different neutrino flavors corresponding to the neutronization phase, accretion phase and cooling phase (from left to right, respectively), for the Basel/Darmstadt simulation of a 18 \(M_\odot\) progenitor SN.](image)

While exploring these possibilities one has to be careful, however, as the SN neutrino properties like average energy, luminosity and energy distribution change with the post-bounce time. There are three important stages of neutrino emission in SN: the neutronization burst phase, the accretion phase and the cooling phase. In Figure 2 the luminosities and average energies of different neutrino flavors for the different phases are shown for the Basel/Darmstadt simulation. The neutronization burst phase, which is associated with the deleptonization of the outer core layers during shock breakout, lasts for about 50 ms post-bounce and is characterized by a sharp peak in the electron neutrino luminosity with little contribution from other flavors. This is followed by the accretion phase which is powered by infalling matter, and lasts for about 0.5 second. During this phase the electron neutrino contribution to luminosity gets reduced and the contributions from other species start building up. Finally, we have the cooling phase, which lasts for about 10 seconds, when all the six species diffuse out of the core. More than 80 percent of the total energy emitted in the SN event comes out during this cooling phase. The luminosities of all the neutrino species in the cooling phase show an approximately exponential decrease with time whereas their average energies show a slow linear decrease.

From the above it is clear that the expected number of events in the different emission phases will be different due to different luminosities of the emitted neutrinos during these phases. Therefore, measuring the temporal structure of the detected events will be crucial for extracting the energy spectra of the emitted neutrinos. Note also that the flavor oscillation properties during the different phases will also be different because of different
physical conditions during the phases.

**SN neutrino emission spectra:** For the initial neutrino distribution in energy and time, we use the outputs from the simulation mentioned above [19]. We factorize the time and energy dependence as

\[
F_\nu^0(t, E_\nu) = \frac{L_\nu(t)}{\langle E_\nu \rangle(t)} \varphi(E_\nu, t) \tag{3}
\]

for each flavor \(\nu = \nu_e, \nu_\mu, \nu_\tau\). Here \(\frac{L_\nu(t)}{\langle E_\nu \rangle(t)}\) represents the neutrino emission rate (number of \(\nu\)'s per unit time) with mean neutrino energy \(\langle E_\nu \rangle(t)\). The time variations of the luminosity and the average energy are taken from the simulations. We use the following parametrization of the instantaneous normalized \((\int \varphi(E, t) dE = 1)\) energy spectrum \(\varphi(E, t)\) from Ref. [21]:

\[
\varphi(E, t) = \frac{1}{\langle E_\nu \rangle(t)} \frac{(1 + \alpha(t))^{1+\alpha(t)}}{\Gamma(1 + \alpha(t))} \left( \frac{E}{\langle E_\nu \rangle(t)} \right)^{\alpha(t)} \times \exp \left[ - (1 + \alpha(t)) \left( \frac{E}{\langle E_\nu \rangle(t)} \right) \right]. \tag{4}
\]

Here \(\alpha(t) = \frac{2(E_{\nu_e}^2(t) - E_{\nu_e}^2(t))}{E_{\nu_e}^2(t) - E_{\nu_e}^2(t)}\) is the energy-shape parameter [21] and is also extracted from the simulations. Note that all parameter values used in the present work correspond to the luminosities and average energies of the various neutrino species corresponding to the Basel/Darmstadt simulations for a standard 18 \(M_\odot\) progenitor, as shown in Figure 2.

Having specified the energy and time dependence of the emitted neutrino spectra, we now study the possibility of detecting the neutrinos from the early emission phases in a typical DM detector. For our calculations below we conservatively take the time resolution of the detector to be \(\sim 10\) ms. Typical future DM detectors are expected to have even better time resolution. So our results presented here should be considered as conservative.

**Neutronization Burst:** The SN shock while moving outward through the iron core of the SN dissipates the iron nuclei, thereby producing free protons and neutrons. The subsequent electron capture by nuclei and free protons gives rise to a large \(\nu_e\) flux, which is emitted in a ‘burst’ when the shock breaks out of the neutrinosphere. This deleptonization “neutronizes” the SN environment. The burst peak shown in Figure 2 is fairly independent of the details of the SN models such as electron capture rates, nuclear equation of state and the progenitor mass. In fact, the neutronization burst phase is considered as the “standard neutrino candle” for the core-collapse supernovae scenario, and thus serves as one of the most sensitive probes of the physics of neutrino oscillation [25] and nonstandard physics [26].

Since the \(\nu_e\) burst phase ends within the first 50 ms, with the time resolution of about 10 ms the future DM detectors may have a fair possibility of detecting the neutronization burst phase neutrinos. For illustration, the left panel of Figure 3 shows the expected number of events in 10 ms time bins in Xe detectors of different total target mass assuming a recoil energy threshold of 0.1 keV. The statistical (Poissonian) errors in each bin are also shown. Right: Same for the accretion phase neutrinos in 50 ms time bins.

![Graph showing temporal profile of events](image1)

**Figure 3:** Left: Temporal profile of the number of events in 10 ms time bins, due to the neutronization burst phase neutrinos from a Basel/Darmstadt SN at 10 kpc from earth, in a Xe detector with different total target mass assuming a recoil energy threshold of 0.1 keV. The statistical (Poissonian) errors in each bin are also shown. Right: Same for the accretion phase neutrinos in 50 ms time bins.

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The estimated numbers of events shown in Figure 3 assume a zero background and a small (0.1 keV) threshold recoil energy of the detector. The backgrounds in typical direct DM detectors generally have negligible time variation, and the SN events will arrive in a relatively small time window (~ 10 seconds), like a pile on the near constant background. Moreover, the background from other neutrino sources like the solar and atmospheric neutrinos in this small time window would be negligible compared to the galactic SN neutrino flux. So, the background may not be an issue. However, the threshold recoil energy of the detector will be important for determining the minimum required target mass of the detector for detection of the SN neutrinos. Note also that the estimated number of events are for a SN at a distance of 10 kpc; the numbers will scale as the inverse square of the distance to the SN.

**Accretion phase:** The SN shock loses energy as it moves outward through the iron core, finally to stall at around few 100 km from the center of the star. At that point, matter starts accreting on to the core, giving increased neutrino emission. This process results in the typical accretion hump in the neutrino luminosity seen in all SN simulations. The infalling material as it accretes onto the core is heated to high temperatures thereby allowing electron-positron annihilation resulting in production of neutrinos of all flavors. Due to high degeneracy of $\bar{\nu}_e$ and electron during deleptonization, the production of $\bar{\nu}_e$ is initially suppressed compared to $\nu_e$. However, the $\bar{\nu}_e$ flux starts growing after the initial deleptonization phase ceases as the CC processes (electron and positron captures on free nucleons) start becoming more efficient. Interestingly, the $\nu_x$, which can be produced only via neutral current processes, can not catch up with the $\bar{\nu}_e$ and $\nu_e$. Moreover, being less strongly coupled with the environment compared to the electron flavors, the $\nu_x$s diffuse out much more swiftly from the SN core than do $\nu_e$ and $\bar{\nu}_e$. Hence, $\nu_x$ luminosities remain lower than those of $\bar{\nu}_e$ and $\nu_e$. This large flux hierarchy between the initial $\nu_e$, $\bar{\nu}_e$ and $\nu_x$ flux provides excellent opportunity for studying oscillation physics with CC based detectors. However, again, the CENNS being flavor blind the detectors will measure the total neutrino flux and should be able to observe the accretion hump independent of the oscillation scenario. Like in the case of the neutronization burst $\nu_x$s, in combination with results from CC based detectors, the detection of the accretion hump neutrinos in a DM detector will offer an important probe of any new physics and also of the standard SN scenario.

The right panel of Figure 3 shows the expected number of events due to accretion phase neutrinos in 50 ms time bins in Xe detectors of different total target mass, again for a SN at a distance of 10 kpc from the earth. As in the case of neutronization burst phase neutrinos, we have assumed zero background and a threshold recoil energy of 0.1 keV for the detector. Evidently, while a 1-ton Xe detector will not be good enough, a 10-ton Xe detector, for example, should be able to pick out the temporal profile of the signal. Obviously, a closer SN offers a better detection possibility. Clearly, more detailed analysis, including proper optimization of the time bin size, threshold recoil energy as well as energy resolution of the detector will be required to have accurate estimation of the required detector mass.

**Different Materials:** Our discussions so far were concerned with Xe as the detector target material. However, DM detectors use a variety of other materials. To study the suitability of relatively lower mass number nuclei for SN $\nu$ detection, below we consider the cases of Fluorine and Silicon, which are also used in
DM DD experiments. Here, again, we use the same Basel/Darmstadt SN neutrino fluxes as described above for a SN at a distance of 10 kpc. We optimize the required detector mass so that the neutronization burst phases events are are detectable. The condition used is that the detector mass should be large enough so that the lower limits of the predicted number of events including the statistical fluctuations are above zero for the first five 10-ms time bins during the neutronization burst. We find that, with this criterion for F and Si, one would require at least 60 and 50 ton mass detectors, respectively, for detecting the neutronization burst phase neutrinos. As expected the required minimum detector masses are larger compared to that for Xe (see Figure 3). A somewhat better prospect for detection is offered by the accretion phase neutrinos, which is shown in Figure 4 assuming, again, zero background and a recoil energy threshold of 0.1 keV. Notice that the accretion hump is visible in both cases.

**Recoil Energy Spectra:** Although demarcation of the temporal profiles (the light curve) of the different neutrino emission phases would, as discussed above, require at least a 10 ton Xe detector, a smaller, 1 ton detector would be good enough to detect a galactic SN event. Figure 5 shows the expected recoil energy spectra (event rate as a function of the recoil energy) in a 1 ton Xe detector for a SN at a distance of 10 kpc. For comparison, in addition to the Basel/Darmstadt SN model considered throughout this paper (see Figure 2), we also show in Figure 5 the event rate expected for a neutrino flux parametrization with average energies of 10, 12 and 18 MeV for $\nu_e$, $\bar{\nu}_e$ and $\nu_x$, respectively, for the entire duration of the SN neutrino emission as used in previous studies (see, e.g., Ref. [10]). Evidently, the larger $\nu_x$ average energy used in earlier studies yielded more expected number of events compared to those for the recent Basel/Darmstadt simulations. The relatively larger average energies quoted in many previous studies represent the early accretion phase of the SN. The average energies in the accretion phase are expected to be larger than those in the cooling phase. Thus, using the larger average energies for the entire SN duration would give larger number of events. We find, for the Basel/Darmstadt SN model, the total number of events are reduced by about a factor of two compared to earlier estimates [10]. Note, the recent results [29] from the same Basel/Darmstadt group shows a larger flux difference of different flavors compare to the their old simulation results [19]. However, even the new differences are way too smaller compared to the very large average energy simulations of [20] and thus the overall results remain robust under the new simulations [29] as well.

As clear from the above Figures, the main contribution to the event rates comes from recoil energies below 1 keV. Hence only detectors with relatively low recoil energy threshold $\lesssim 1$ keV will have a reasonable chance of detecting the SN neutrinos. On the optimistic side, however, since the event rates scale as the inverse square of the distance to the SN, some of the potential SN candidates, such as Betelgeuse, Mira Ceti and Antares, which are relatively close by stars (at < 0.2 kpc), offer interesting possibilities for the next generation DM detectors.

**Extracting the $\nu_x$ properties:** Finally, we mention an important by-product of measuring the SN neutrino recoil energy spectrum. For the four non-electron flavor neutrinos/antineutrinos, $\nu_x$, there are two physical quantities of great interest, namely, their time-averaged temperature and the total energy they carry. Whereas the neutral current reactions in conventional neutrino de-
tectors can give information on their total number, measurement of the recoil spectrum for the CENNS events in DM detectors can in principle give information about the energy spectra of the neutrinos. Beacom, Farr and Vogel [9] pointed out in connection with neutrino-proton elastic scattering of SN neutrinos in scintillation detectors like KamLAND that one can get estimates of the total neutrino energy as well as the temperature from the observed proton energy spectra. Though these two observables are strongly correlated, a Monte Carlo simulation procedure as suggested in Ref. [9] may allow one to extract estimates of these two quantities from the observed nuclear recoil spectra in the case of CENNS in DM detectors. Of course, this is possible when the distance of the SN is known independently. Otherwise, like in [9], one can obtain an estimate of the neutrino temperature by marginalizing over the unknown total energy. Since currently there is no observational handle available on the “temperature” of the $\nu_x$ emitted from SNe, the possibility of measuring the SN $\nu_x$ temperature in DM detectors through the CENNS process is certainly worth exploring.

In Figure 6 we plot the flavor composition of the expected recoil energy spectra for the accretion phase neutrinos of a Basel/Darmstadt SN at 10 kpc from earth in a 10 ton Xe detector. The main contribution to the event rate comes from $\nu'x$ as they have larger average energies and also because it is a sum of contributions from four species of neutrinos.

The curves shown in Figure 6 include flavor oscillation which is primarily due to MSW effect since the collective effects are considered matter suppressed [30, 31] during the accretion phase. In the cooling phase more complex scenarios of oscillations may arise which are not very well understood [32] and the flux expressions would be complicated [33]. Hence we focus on the accretion phase where the oscillation scenario seems settled. The flux differences due to different neutrino mass hierarchies are, however, not resolvable even in the multi ton detectors. These curves shown in Figure 6 are for the case of inverted hierarchy.

As already shown in Figure 6 a 10-ton Xe detector should be able to distinguish the accretion phase by measuring the temporal profile of the neutrinos. Thus the measurement of the recoil energy spectrum together with the temporal profile of the events in a 10-ton Xe detector, for example, may indeed allow a measurement of the “temperature” of the bulk of the neutrinos emitted during the main accretion phase of a SN event.

IV. SUMMARY AND CONCLUSION

In this paper we have studied the possibility of observing supernova neutrinos through the process of coherent elastic neutrino-nucleus scattering in next generation detectors for direct detection of dark matter. In doing this we have used the predicted neutrino flux from the recent Basel/Darmstadt simulations, which incorporate more realistic supernova physics than those used in earlier simulation models. We find that our estimated total event rates are typically a factor of 2 lower than those estimated in earlier studies using older simulation models. We have also studied the possibility of distinguishing the various phases of neutrino emission from the supernova through measurement of the temporal profile of the detected events. There we find that, with optimistic assumptions on the detector’s time resolution ($\sim 10$ ms) and energy threshold ($\sim 0.1$ keV), the neutrinos associated with the accretion phase of the SN at 10 kpc from earth can in principle be demarcated out with, for example, a 10-ton Xe detector, although distinguishing the
neutrinos associated with the neutronization burst phase of the explosion would typically require several tens of ton detectors. We also noted that the DM detectors being flavor blind are sensitive to all the neutrino flavors including the non-electron flavor neutrinos, and thus have the potential to constrain possible non-standard physics of neutrino flavor oscillation. Finally, we have explored the possibility of measuring the temperature of the non-electron flavor neutrinos which are inaccessible through other charge current based detectors.

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