THE DIFFUSE SUPERNova NeUTRiNO BACKGROUND

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Multi-Messenger Astrophysics began with the detection of 25 neutrinos from SN1987A (Hirata et al. 1987; Bionta et al. 1987; Alekseev et al. 1987). Their distribution in time and energy confirmed the paradigm of the formation of a hot proto-neutron star (PNS) in a core collapse Supernova (ccSN) Janka et al. (2007). To reveal the dynamics of these environments, time-resolved spectroscopy with high count rates is required, which is possible when a ccSN occurs in the Milky Way (MW), at a low rate of ≤3 per century (Adams et al. 2013). However, advances in technology point to ccSN ν-detections in the local volume (DLV = 10 Mpc), at a rate of ∼1 yr−1 (Anandagoda 2019; Ando et al. 2005), and existing detectors offer an independent route to probe ccSNe through the Diffuse Supernova Neutrino Background (DSNB; e.g., Beacom, 2010). The DSNB in the MeV regime represents the cumulative cosmic neutrino emission, predominantly due to ccSNe. Estimates of the DSNB flux found values of 0.2 ± 0.1 cm−2 s−1 (Hartmann & Woosley 1997), 0.14-0.46 cm−2 s−1 (Eν >19.3 MeV) (Ando & Sato 2004) and ~0.24 cm−2 s−1 in the energy range 19.3-27.3 MeV (Horiuchi et al. 2009). Ongoing observations by Super-Kamiokande report an upper limit of 2.8-3.1 νe cm−2 s−1 (90% C.L) for Eν > 17.3 MeV (Bays & Super-Kamiokande Collaboration 2012).

We estimate the DSNB flux for different Star Formation Rate Density (SFRD) models and find that the DSNB can be used to estimate the SFRD using a method similar to the one employed for the Extragalactic Background Light (EBL) by the Fermi-LAT Collaboration et al. (2018).

The DSNB (in the energy-window (E0,E1)1), for a given SFRD, ψ(z) in units of s−1 cm−2 MeV−1, is given by

$$F_\nu = c \int_{E_0}^{E_1} \int_0^\infty dE_\nu \, dz \, C(z) \times R_{SN}(z) \times \frac{dN_\nu}{dE_\nu}(E'_\nu)$$

where the ccSN rate is $R_{SN} = (\psi(z) / <m>) \times f_{SN} \, \text{year}^{-1} \, \text{Mpc}^{-3}$. The average star mass, $<m>$, and the fraction of stars that produce a ccSN, $f_{SN}$, depend on the Initial Mass Function (IMF). We adopt a flat ΛCDM cosmology where the cosmological factor in Eq.(1) is $C(z) = 1/(H_0 E(z))$ where $E(z) = (\Omega_m (1+z)^3 + \Omega_\Lambda)^{1/2}$. See Ando & Sato (2004).

To model the emergent neutrino spectrum of a single ccSN, given by $dN/dE_\nu(E'_\nu)$, in Eq.(1), we follow Hartmann & Woosley (1997); Beacom (2010). Assuming a Fermi Dirac (FD) distribution of temperature T, zero chemical potential with an average neutrinosphere radius, the $\nu_e$ spectrum is,

$$\frac{dN_\nu}{dE_\nu}(E'_\nu) = E_{\nu,tot} \frac{120}{\pi^2} \frac{T^2}{E'_\nu^2} \left[ T^4 (e^{E'_\nu/T} + 1) \right]^{-1} \quad (\nu \text{MeV}^{-1})$$

where, $E'_\nu=(1+z)E_\nu$ and the total energy released per flavor ($E_{\nu,tot}$) is assumed to be 1/6 of the total Binding energy (BE) (Bar et al. 2019). BE is from equation 36 of Lattimer & Prakash (2001) assuming a neutron star mass and radius of $M_{NS} = 1.4 \, M_\odot$ and $R_{NS} = 11$ km.

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1 Boundaries set by competing solar and atmospheric backgrounds are chosen to be $E_0 = 19.3$ MeV and $E_1 = 40$ MeV.
The SFRD(z) is determined through various tracers (UV,IR continuum, H\textalpha\ line) and source counts as a function of redshift eg: (Madau & Dickinson 2014). Therefore, the SFRD(z) depends on cosmology and the IMF. Modifying the SFRD for different cosmological parameters introduces a factor, H\textsubscript{0} E(z) (Porciani & Madau 2001) that cancels C(z) appearing in Eq.(1), rendering it independent of cosmological changes in SFRD models (see Ando & Sato 2004).

We use three SFRD models: 1. Madau & Dickinson (2014), 2. Madau & Fragos (2017) and 3. Fermi-LAT Collaboration et al. (2018). To compute the DSNB flux (see Figure 1:right), C(z) is established via H\textsubscript{0} = 70 km s\textsuperscript{-1} Mpc\textsuperscript{-1} and \Omega\textsubscript{m} = 0.3 and the antielectron neutrino spectrum is given by Eq.(2) with T= 4.76 MeV (Beacom 2010). The IMFs associated with these models are Salpeter (1955), Kroupa (2001) and Chabrier (2003), respectively. As a benchmark, we select the SFRD(z) of Madau & Fragos (2017) given by

\[
\psi(z) = \frac{(1 + z)^a}{1 + \left(\frac{1+z}{b}\right)^c} \times d \quad (\text{M}_\odot \text{yr}^{-1} \text{Mpc}^{-3})
\]

with parameters: a = 2.6, b = 3.2, c = 6.2 and d = 0.01. The SFRD(z) model estimated by Fermi-LAT Collaboration et al. (2018) has parameters: a = 2.99, b = 2.63, c = 6.19, d = 0.013 (Figure 1:left:blue).

Less than 1% of the DSNB is due to star formation above z \sim 2 since star formation decreases for higher redshifts. Thus uncertainties in the high-z SFRD are not crucial (see Figure 1:right).

![Figure 1](image)

**Figure 1.** Variation of SFRD models with redshift (left) and SFRD model dependence of the DSNB flux (right), keeping all other parameters at their standard values. The Percentage increase of the DSNB flux for different SFRD models relative to the benchmark (red) is indicated.

We assume that the mean ccSN is represented by SN1987A (in regards to its neutrino signature), but variations occur due to changing core collapse outcomes and deviations from a FD spectrum with progenitor mass. The DSNB flux increases significantly \approx 32% for the SFRD from Fermi-LAT Collaboration et al. (2018) relative to the benchmark, F\textsubscript{0} of 0.34 cm\textsuperscript{-2} s\textsuperscript{-1} in the energy window(19.3-40 MeV). Thus detection of the DSNB with advanced detectors like gadolinium enhanced Super-Kamiokande (Beacom, & Vagins 2004) can be utilized to not only probe ccSNe physics (Mathews et al. 2019) but also as a tool to estimate the SFRD.

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\footnote{Derived using EBL intensity measurements}
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