

# Prediction of the Spectrum of DSNB Using Population Synthesis

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## Abstract

The energy spectrum of the DSNB depends on star formation history, which remains uncertain and leads to multiple predictive models. In this study, we predicted the DSNB spectrum using population synthesis including binary systems, considering distributions of binary periods, mass ratios, and eccentricities. For stellar evolution, we used a code incorporating Müller's 1D SN model into SSE/BSE. We found that the number of stars undergoing core-collapse influences the DSNB spectrum more strongly than the neutrino spectrum of individual supernovae, and that some combinations of star formation history models may be inconsistent with observations.

## 1. Introduction

### Diffuse Supernova Neutrino Background, DSNB

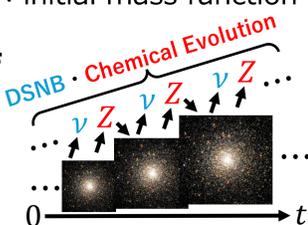
Neutrinos from all past supernovae since the birth of the universe, accumulated throughout the universe. They remain undetected; SK-Gd aim to detect them.

$$\frac{dF_{\nu}(\varepsilon_{\nu}, t_0)}{d\varepsilon_{\nu}} = c \int_0^{t_0} R_{cc}(z) \int_{M_{\min}}^{M_{\max}} N(M, Z(z)) \frac{dN_{\nu}(\varepsilon'_{\nu}, M, Z(z))}{d\varepsilon'_{\nu}} \frac{d\varepsilon'_{\nu}}{d\varepsilon_{\nu}} dM dt$$

$$R_{cc}(z) = \rho_*(z) \frac{\int_{M_{\min}}^{M_{\max}} \phi dM}{\int_{0.08M_{\odot}}^{100M_{\odot}} M \phi dM} \quad \rho_*(z) : \text{star formation rate} \quad \phi : \text{initial mass function}$$

### Objective

- Calculate the energy spectrum of DSNB using Population synthesis
- Investigate the effects of star formation history(SFH) on DSNB



## 2. Method

### Stellar Evolution Code

SSE (Hurley et al. (2000)) · BSE(Hurley et al. (2002)) with improvements based on Müller 1D supernova model (Müller et al. (2016))

### Population synthesis

$$N_s(M)dM = (1 - MF(M))\psi_{IMF}(M) dM$$

$$N_b(M)dM = MF(M)\psi_{IMF}(M) \int_p \int_q \int_e \frac{d^3n}{dpdqde} dpdqde dM$$

### Distributions

- Initial Mass Function, IMF ( $\phi(M) = \frac{dn}{dm}$ )

$$\text{Salpeter IMF } \frac{dn}{dm} \propto m^{-2.35}$$

$$\text{Kroupa IMF } \frac{dn}{dm} \propto \begin{cases} m^{-1.3} & (m < 0.5M_{\odot}) \\ m^{-2.3} & (m > 0.5M_{\odot}) \end{cases}$$

- Multiplicity Frequency, MF ( $MF(M)$ )

flat (single:binary = 1:1)

linear (Duchêne, G., & Kraus, A. (2013) Fig.1)

- Eccentricity Distribution, ED ( $\frac{dn(e)}{de}$ )

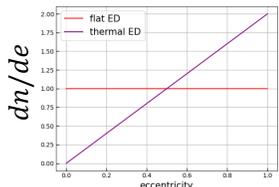
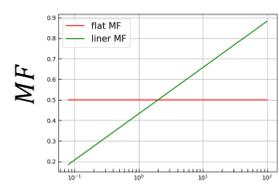
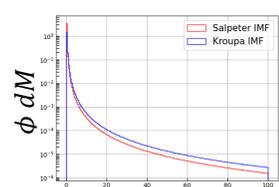
flat ( $\frac{dn}{de} \propto e^0$ ), thermal ( $\frac{dn}{de} \propto e^1$ )

- Star Formation Rate, SFR  $\rho_*(z)$

Madau SFR (MD14), Yuksel SFR (Y08)

- Cosmic Metallicity Evolution  $Z(z)$

i)  $Z(z) = Z_{\odot} \times 10^{-Yz}$  (Langer, N., & Norman, C. A. 2006, ApJ, 638, L63)  
ii) We numerically solved the equations (right) with a RK method to derive the cosmic mean metallicity as a function of time.



$$\frac{d\rho_*}{dt} = (1 - R)\psi$$

$$\frac{d\rho_g}{dt} = -\frac{d\rho_*}{dt}$$

$$\rho_g \frac{dZ}{dt} = y(1 - R)\psi$$

## 3. Result & Discussion

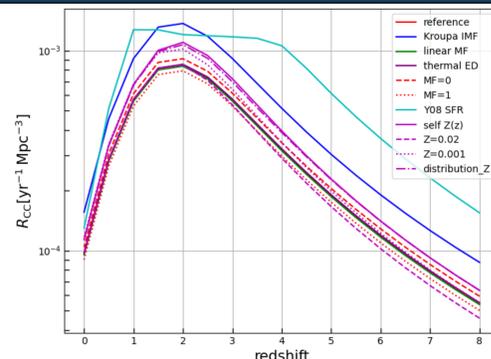


Fig 1 core-collapse rate

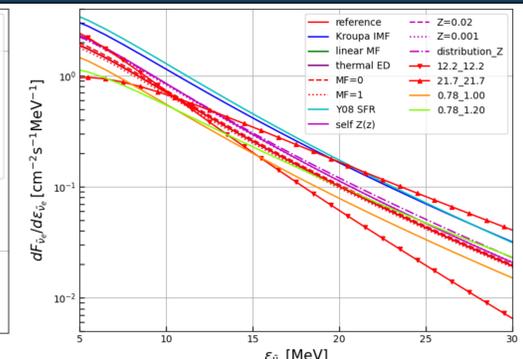


Fig 2 The spectrum of the DSNB

### Effects of Distribution and SFR

Tab 1 relative change

Kroupa IMF formed many massive stars, increasing both  $R_{cc}$  and spectrum.

The number of stars undergoing core-collapse in binary star systems is reduced due to binary interactions.

A linear MF increases the binary fraction without significantly changing the total NS/BH number. However, binaries more frequently form high-mass cores, enhancing high-energy neutrinos and slightly broadening the spectrum.

Y08 SFR is a higher than MD14 SFR, especially at high  $z$ . Because neutrino energies scale as  $1/(1+z)$ , high  $z$  supernovae mainly enhance the low-energy part of the spectrum.

### Effect of Cosmic Metallicity Evolution

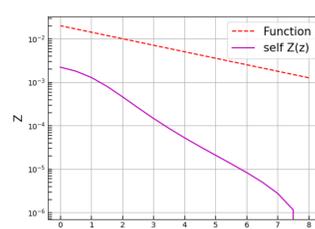


Fig 4 Metallicity Evolution  
Low  $Z \rightarrow N_{cc}$  increase  
 $R_{cc}$  increase  
Flux increase

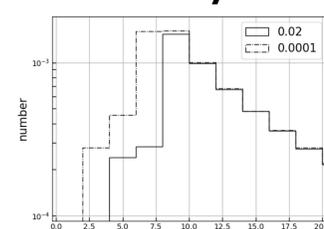


Fig 5 Number of core-collapse stars

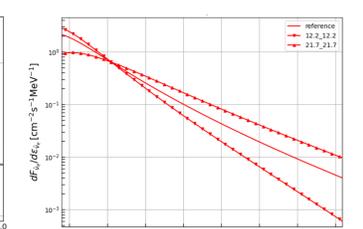


Fig 6 Effect of  $\langle \varepsilon_{\nu} \rangle$  for DSNB

$$\frac{dN_{\nu}}{d\varepsilon_{\nu}} = \frac{1}{E_{\nu}} \left( \frac{\varepsilon_{\nu}}{\langle \varepsilon_{\nu} \rangle} \right)^{\alpha_{\nu}} \exp \left( - \frac{(\alpha_{\nu} + 1) \varepsilon_{\nu}}{\langle \varepsilon_{\nu} \rangle} \right)$$

### Effect of $\langle \varepsilon_{\nu} \rangle$

$\langle \varepsilon_{\nu} \rangle$  was varied depending on the compact remnant formed. Higher  $\langle \varepsilon_{\nu} \rangle$  increases the high-energy neutrino flux and decreases the low-energy flux.

### Comparison with observational constraints

With the Yuksel SFR and Kroupa IMF,  $\langle \varepsilon_{\nu} \rangle = 21.7$  MeV predicts a DSNB flux above current observational limits. These combinations are inconsistent with observations.

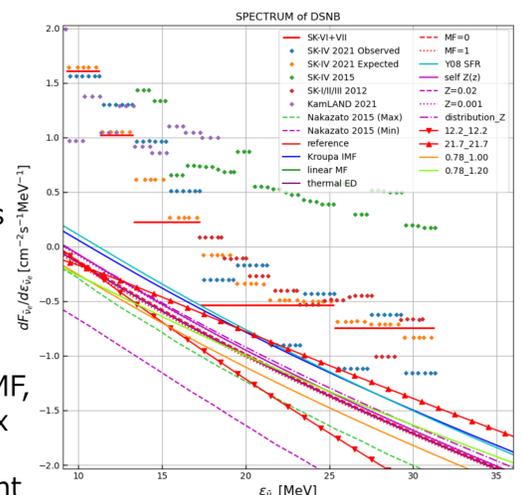


Fig 7 Comparison with observations

## 4. Conclusion and Future Plans

### Conclusion

- We used population synthesis to compute the core-collapse rate and DSNB energy spectrum for several star formation history.
- Both quantities strongly depend on IMF and SFR, which directly set the number of formed stars. Increasing the binary fraction reduces the number of formed NSs and BHs. Comparison with observations shows that three SFH combinations are inconsistent with observations.

### Future Plans

- Introduce progenitor-mass and metallicity dependence of  $\langle \varepsilon_{\nu} \rangle$ .
- Improve chemical evolution modeling and directly compute EMP stars evolution to enhance realism and accuracy.
- This framework can also predict the rates of GW and NSM, and by comparing them with independent observations of DSNBs, it can constrain the SFH.