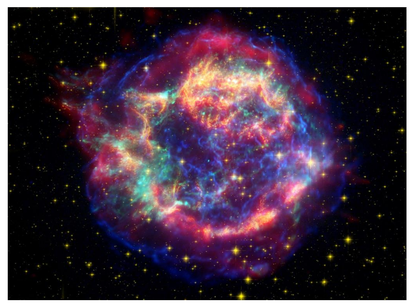
Development of a method for estimating diffuse supernova neutrino background using stellar population synthesis and Müller's one-dimensional supernova model.

Tokyo University of Science, Hiroki Nakamura, Hideyuki Suzuki

Introduction

「birth of a star」 → 「death of a star」(supernova) → emit

repeat for over 13 billion years



©NASA

heavy elements, neutrinos etc.

- heavy elements → chemical evolution of the universe
- neutrinos → accumulate in outer space → diffuse supernova neutrino background (DSNB)
  - expected to be useful in understanding the history of star formation

Purpose

Purpose

Investigating both DSNB and chemical evolution of the universe

I use stellar population synthesis. Below is an image diagram.

individual results (by simplified calculation codes)

	supernova	
single A (M_1, Z_1)	→	ν_1 Z'_1
single B (M_2, Z_2)	→	ν_2 Z'_2
binary C (M_3, M_4, Z_3)	→	ν_3 Z'_3, ν_4 Z'_4

- obtain total amount of neutrinos and heavy elements emitted by star population
- stellar initial mass distribution
- distribution of binary parameters (orbital period, distance etc.)

M :initial mass
Z :initial heavy elements
ν :neutrino emission
Z' :heavy element emission

The SSE and BSE codes of Hurley et al. (2000, 2002) are used as simplified calculation codes, but they cannot estimate the amount of neutrinos and heavy elements released, so improvements are needed.

Method

➢ Relationship between the structure of a progenitor and a supernova

- O'connor & Ott (2011)

$$\xi_M = \left.\frac{M/M_\odot}{R(M_{\rm bary}=M)/1000\ {\rm km}}\right|_{t=t_{\rm bounce}}$$

ξ_M at $M = 2.5M_\odot$ → $\xi_{2.5}$

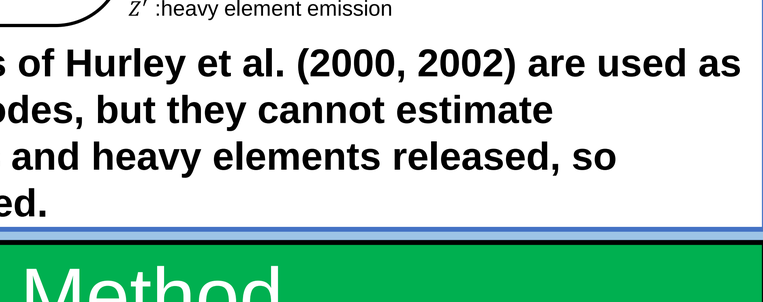
They define compactness parameter ξ_M.
It is said that quantities related to supernova explosions, such as the time until BH formation, can be predicted from $\xi_{2.5}$.

- Sukhbold et al. (2014)

They pointed out the correlation between CO core mass $M_{\rm CO}$ and $\xi_{2.5}$.

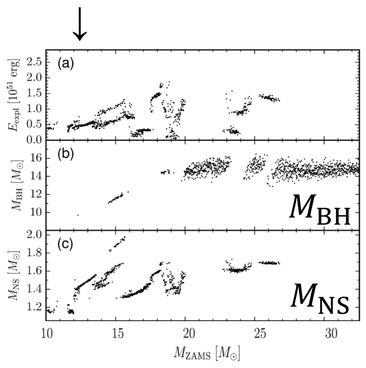
➢ Progenitor models MHLC16

CO core mass $M_{\rm CO}$ and radius $R_{\rm CO}$ of progenitor models available to the public. Created with KEPLER code.

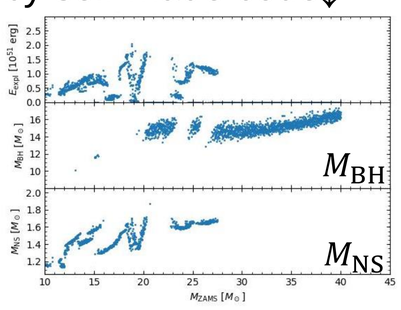


➢ Self-made code based on Müller et al. (2016)

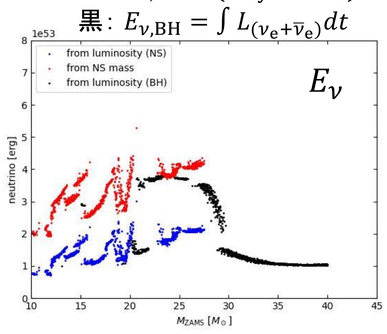
by Müller et al. (2016) ↓



by self-made code↓

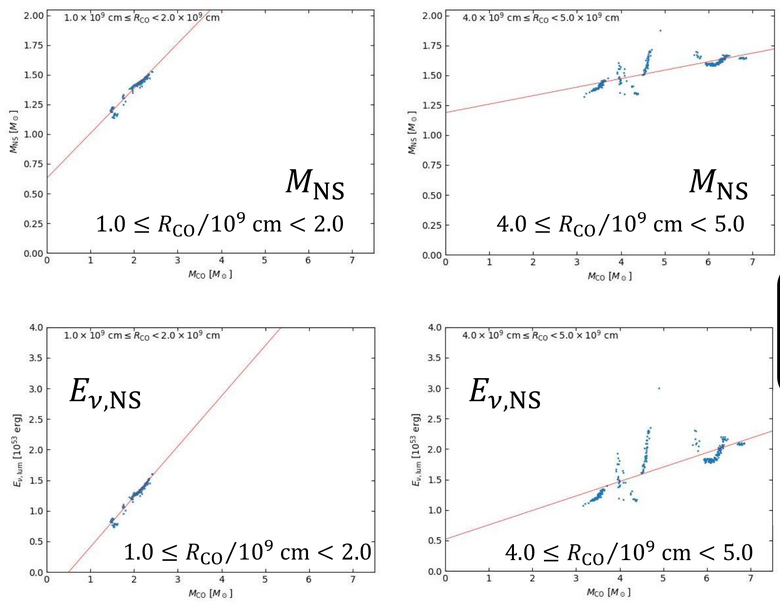


original→
青: $E_{\nu,\rm NS} = \int L_{(\nu_e+\bar{\nu}_e)}dt$
赤: $\mathrm{E}_{\nu,\rm NS} = (M_{\rm by} - M_{\rm NS})c^2$
黒: $E_{\nu,\rm BH} = \int L_{(\nu_e+\bar{\nu}_e)}dt$



Result

➢ Fitting formulae



neutron star mass $M_{\rm NS}$

$$\frac{M_{\rm NS}}{M_\odot} = a_1\left(\frac{M_{\rm CO}}{M_\odot}\right) + b_1$$

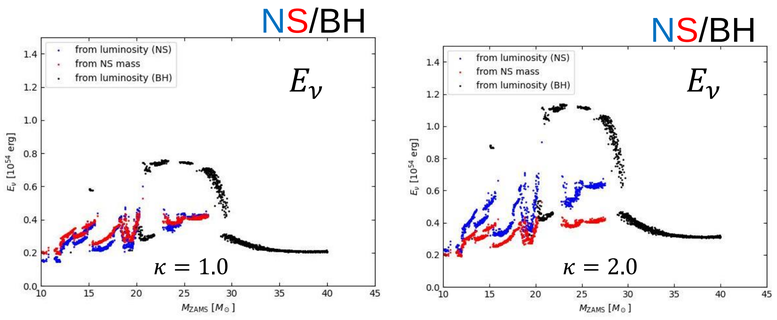
neutrino emission E_ν

$$\frac{E_{\nu,\rm NS}}{10^{53}\ {\rm erg}} = a_2\left(\frac{M_{\rm CO}}{M_\odot}\right) + b_2$$

$$E_{\nu,\rm NS} = \int L_{(\nu_e+\bar{\nu}_e)}dt$$

The fit has some imperfections in accuracy, but this time I prioritized making it possible to handle neutrino and heavy element emissions by supernovae using SSE/BSE.

➢ Response when changing ratio of ν



I investigated the response of E_ν when changing the ratio κ of electronic neutrinos $(\nu_e, \bar{\nu}_e)$ and the others.

$$\left(\kappa = \frac{4\nu_x}{\nu_e + \bar{\nu}_e}\right)$$

When setting $\kappa = 1.0$, the neutrino emissions obtained by the two methods are in some agreement for the case of NS formation.

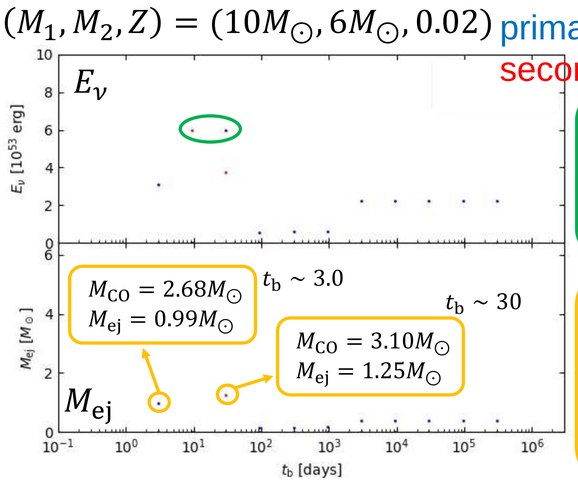
➢ Results of improvement

M_1:initial mass of the primary
M_2:initial mass of the secondary
Z :initial heavy elements

I performed calculations for binary star systems using improved BSE.

$(M_1, M_2, Z) = (10M_\odot, 6M_\odot, 0.02)$ primary/secondary

- initial orbital period $t_{\rm b}: 3.0 \sim 3.0 \times 10^5$ 日



- $t_{\rm b} \sim 10, 30$

BH formation of low-mass stars and massive neutrino emission.

- $t_{\rm b} \sim 3, 30$ $\quad (M_{\rm ej} = M_{\rm CO} - M_{\rm by})$

massive heavy element emission.
This is because mass transport in a close binary star system.

Summary and Future Plan

Summary

- I developed fitting formulae to estimate the amount of supernova neutrinos from the CO core information of the progenitor.
- I investigated the response of neutrino emission when changing the ratio of electronic and non-electronic neutrinos.
- I have made it possible to estimate the amount of supernova neutrinos and heavy elements by simplified calculation codes.
- I investigated the influence of changes in initial orbital period on the final fate and E_ν and $M_{\rm ej}$ of binary star systems.

Future Plan

- To calculate the amount of neutrinos and heavy elements from star populations by combining individual results and distributions.
- To update fitting formulae that constitute codes while examining the influence on predicting DSNB.
- To deepen our knowledge of the abundance ratio of neutrinos depending on their flavor and use this to improve fitting formulae.