P02

超新星シミュレーションで探るアクシオン様粒子
Exploring Axion-like Particles with Supernova Simulations

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1. Introduction

Axion-like particles (**ALPs**) are hypothetical bosons which can interact with photons and electrons. The interaction between ALPs and the electromagnetic field is described by the Lagrangian

$$\mathcal{L}_{a\gamma\gamma} = -\frac{1}{4} g_{a\gamma} a \tilde{F}^{\mu\nu} F_{\mu\nu}$$

where $g_{a\gamma}$ is the coupling constant, a is the ALP field, and $F_{\mu\nu}$ is the electromagnetic tensor.

The coupling $g_{a\gamma}$ have been investigated by experimental and astrophysical ways. In particular, the nearby supernova (SN) 1987A gives tight constraints. However, **the previous works** [e.g. 1] **ignore the backreaction of the ALP emission on the SN dynamics**.

In the era of multi-messenger astronomy, it is desirable to predict the signature of ALPs in neutrino and gravitational wave signals. For this purpose, **we are constructing SN models coupled with ALPs**. In this poster, **we show preliminary results obtained by post-processing** and discuss future prospect.

2. Supernova Model

In this study, we use a core-collapse SN simulation code **3DnSNe-IDSA** [2] to produce a $20M_\odot$ SN model. Fig. 1 shows the temperature and density profiles of the model.

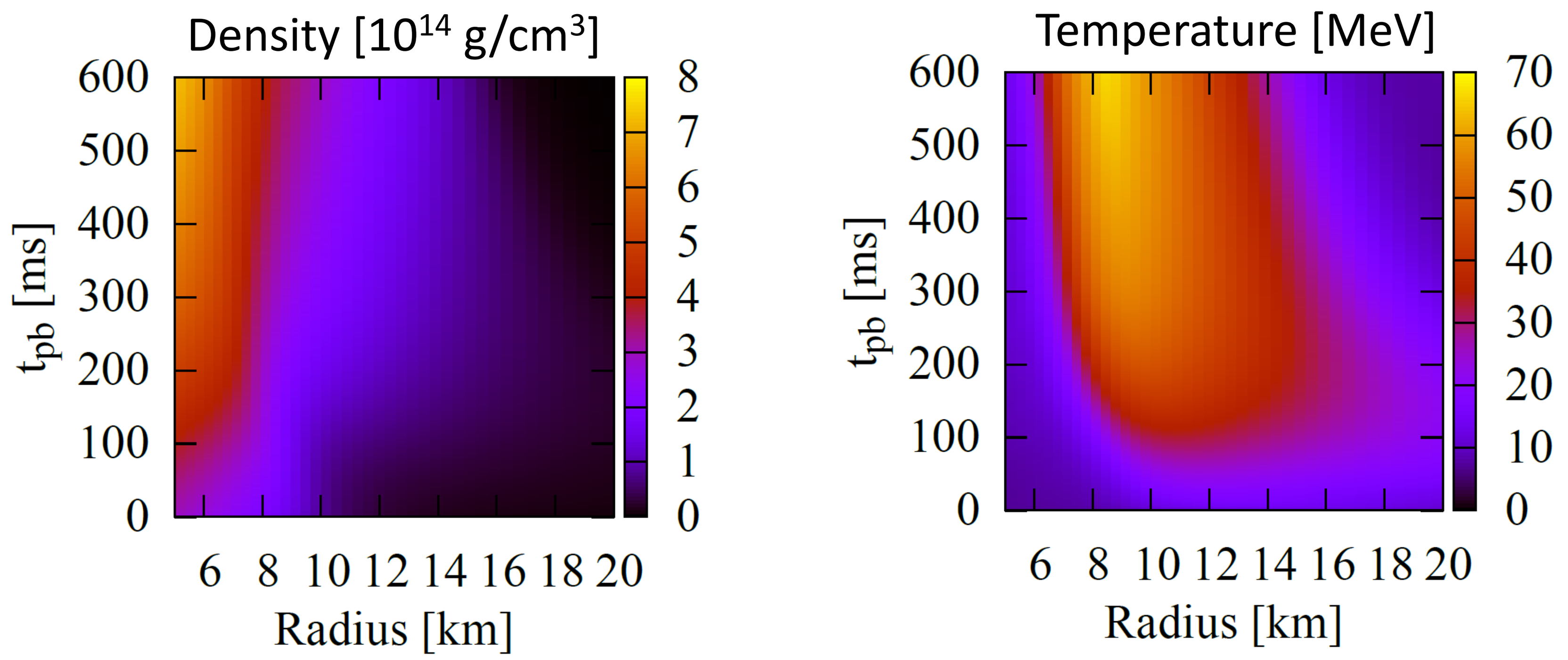

Fig. 1. The density and the temperature profiles of the SN model.

3. Result from the Post-process

In this study, we consider the **Primakoff process** (γ+p→a+p) and **photon coalescence** (γ+γ→a) as processes which produce ALPs.

Fig. 2 shows the ALP luminosity from the SN model. It is seen that the Primakoff process is dominant when ALPs are lighter than ~80 MeV.

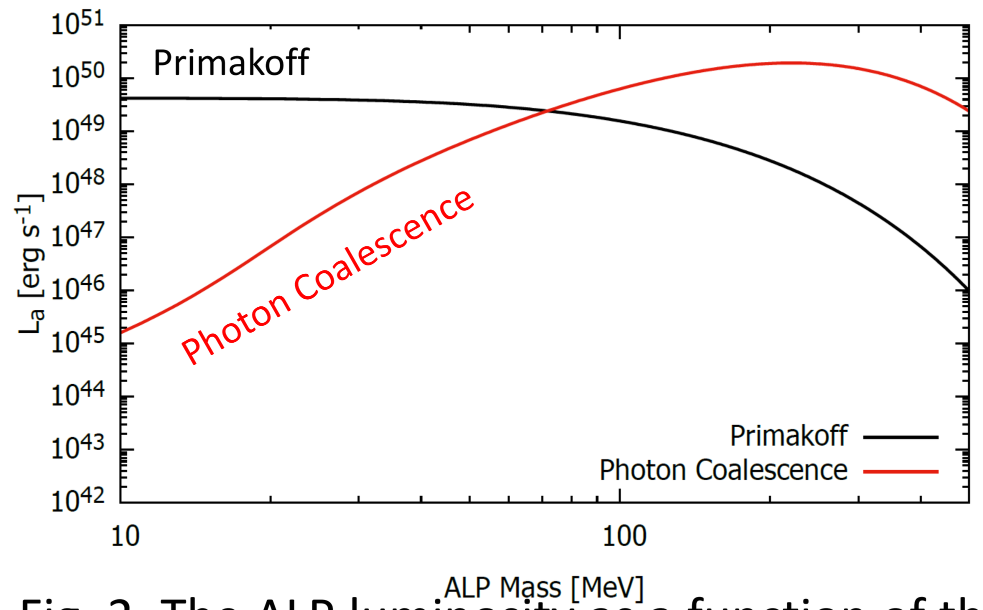

Fig. 2. The ALP luminosity as a function of the ALP mass.

ALPs are absorbed by the SN matter during their propagation. This affects the energy transport in SNe. We consider the **inverse Primakoff process** and the **ALP decay** to simulate the ALP absorption.

We define the "optical depth" of ALPs which are produced at r with energy E and reach R as

$$\tau_a(r,\ R,\ E) = \int_r^R \frac{d\tilde{r}}{\lambda_a(E,\ \tilde{r})}$$

where λ_a is the ALP mean free path. Fig. 3 shows the ALP luminosity with the ALP absorption. It is seen that La is suppressed when the ALP-photon coupling is large.

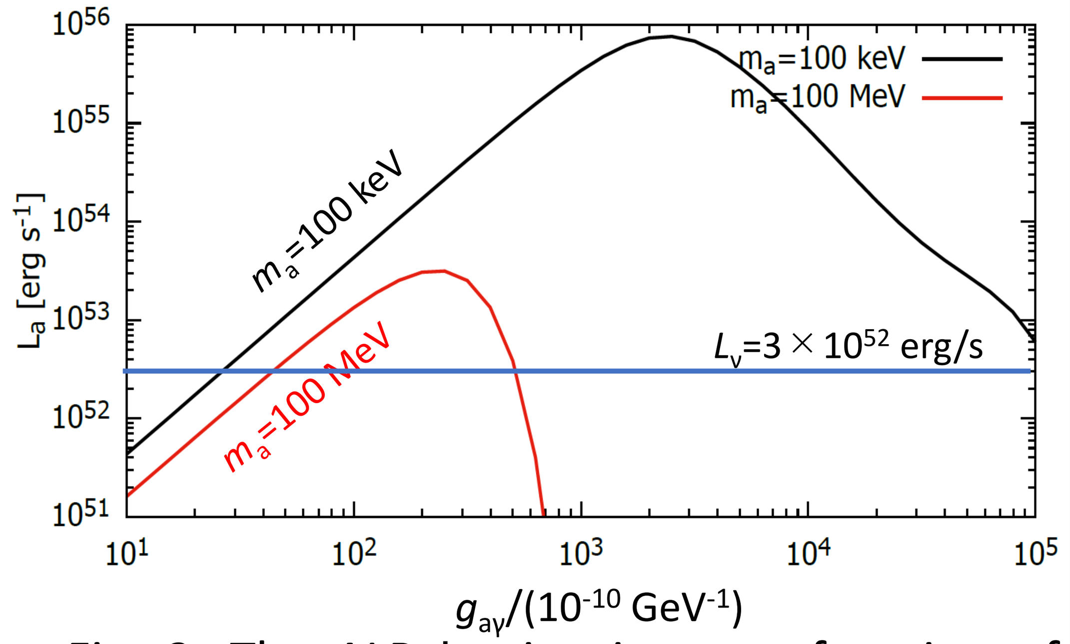

Fig. 3. The ALP luminosity as a function of ALP-photon coupling.

The neutrino burst from SN 1987A reached ~3×10^{52} erg. If L_a exceeds this value, it would have prevented the burst. Fig. 4 shows the limit based on neutrinos from SN 1987A.

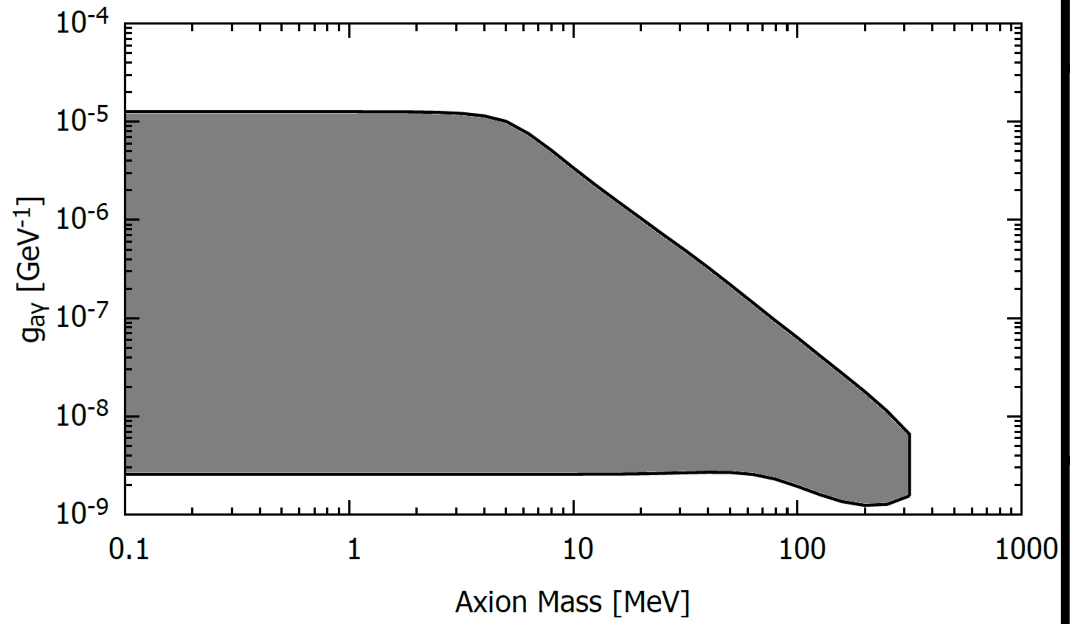

Fig. 4. The SN 1987A limit on the ALP parameters.

See the Supplementary Material [3] **for details on formulation.**

4. Future Prospect

The ALP absorption may result in nontrivial effects in SN dynamics. Fig. 5 is a schematic picture on the central part of SNe. The region between the shock and the gain radius is called the gain region. If ALPs decay into photons and deposit their energy in the gain region, they may help the shock revival.

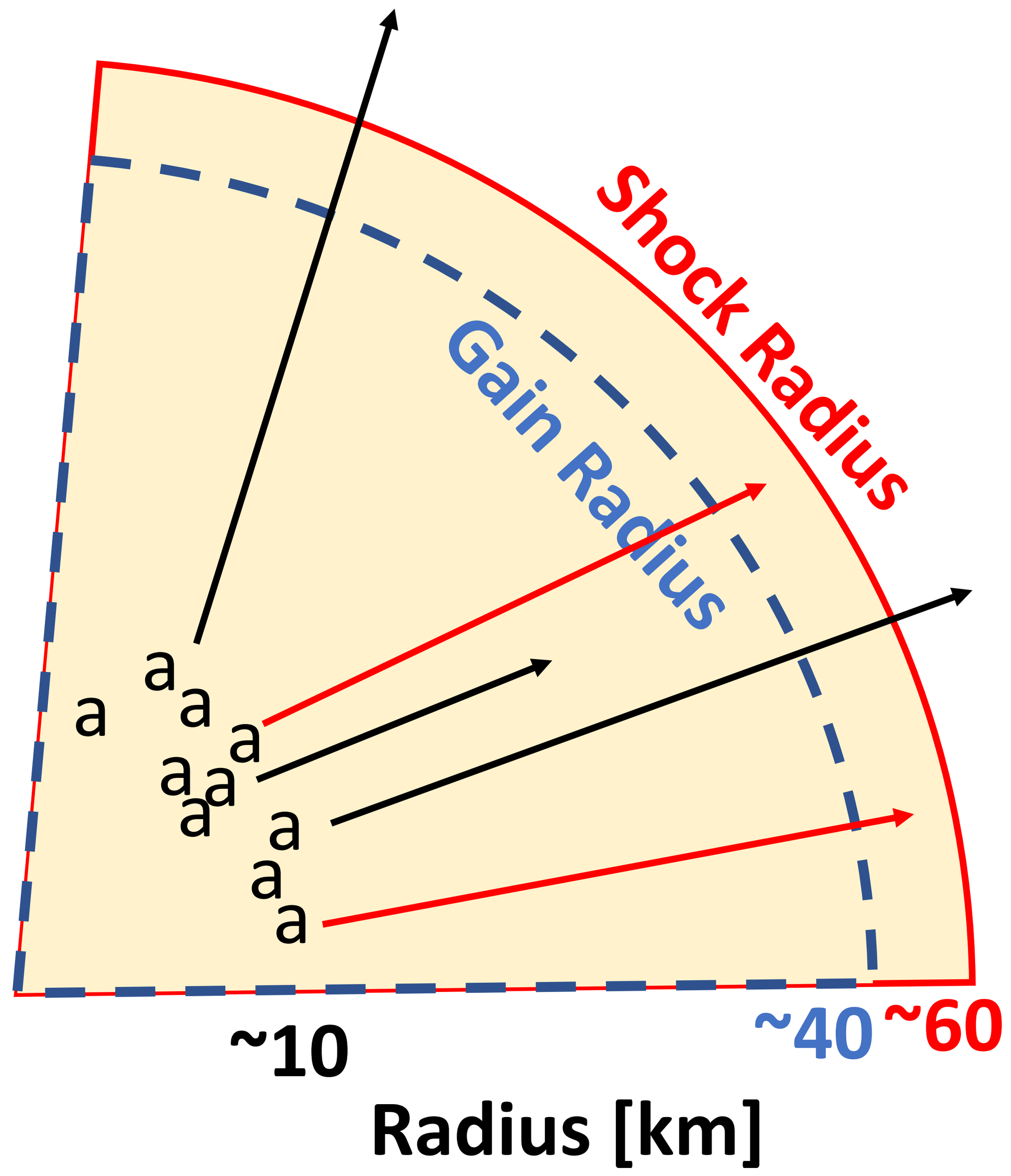

Fig. 5. The schematic picture of the central region of a SN.

Fig. 6 shows the deposited energy L_{gain} in the rain region as a function of the ALP parameters. Since L_{gain} exceeds 10^{51} erg, it may have significant effects on the shock.

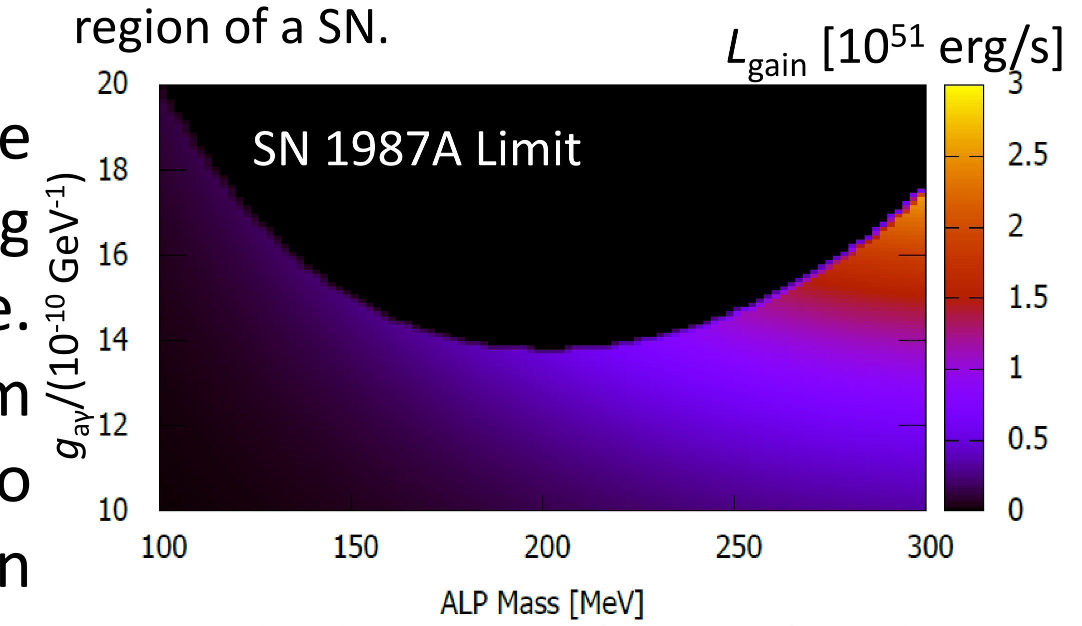

Fig. 6. The luminosity deposited in the gain region by ALPs. The black region shows the SN 1987A limit.

In order to fully discuss the effect of ALP, we are incorporating ALPs in the SN simulation code. We are also planning to perform multi-dimensional simulations to predict the signature of ALPs in neutrino and gravitational wave signals.

5. Summary

We have calculated the ALP luminosity from SNe and constrained the ALP parameters with post-processing. In order to understand the backreaction to SN dynamics and predict multi-messenger signals, we are incorporating ALPs in the SN simulation code.

References

[1] Lucente et al., JCAP 12 (2020) 008.

[2] Takiwaki, Kotake & Suwa, MNRAS 461 (2016) L112.

[3] Mori (2021), http://th.nao.ac.jp/MEMBER/mori/supple.pdf