

1. Light Sterile Neutrinos



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$$\begin{aligned}\nu_e &= \cos \theta \nu_1 + \sin \theta \nu_2 \\ \nu_s &= -\sin \theta \nu_1 + \cos \theta \nu_2\end{aligned}$$

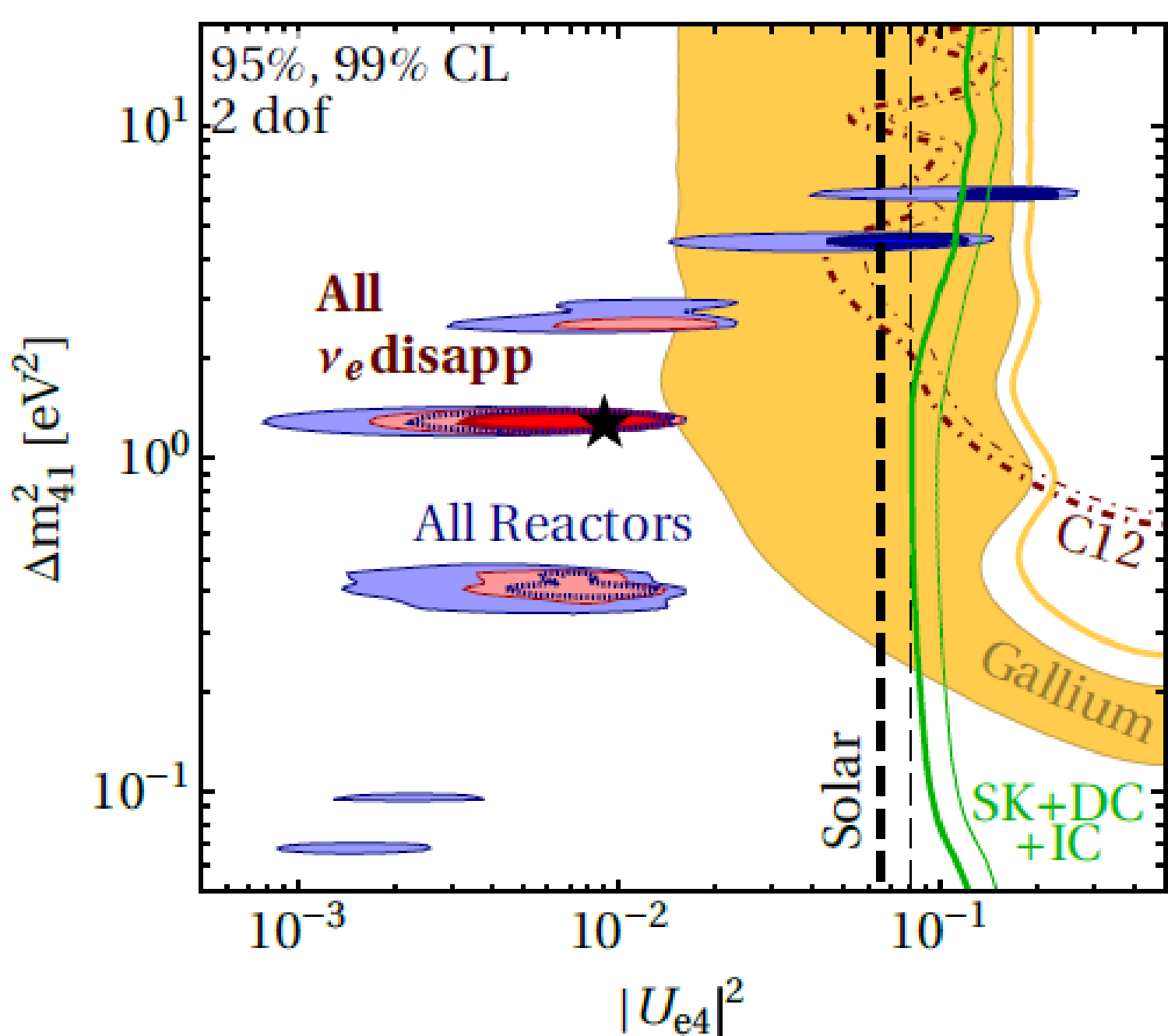


Fig. 1: The parameter space for sterile neutrinos [1]. The red islands show the preferred regions indicated by experiments.

- Hypothetical neutrinos that do not participate in the weak interaction
- A possible solution to the **reactor antineutrino anomaly** [2]

Background: A previous study [3] suggested that **supernova explosions can be hindered by the active-sterile neutrino oscillations**. However, self-consistent simulations are necessary to predict supernova explodability.

What we did: We performed **2D supernova simulations coupled with sterile neutrinos** to verify their idea.

2. Stellar Core-collapse Simulations

Code: 3DnSNe-IDSA [4]

Dimension: 2D (axisymmetric)

EoS: Lattimer-Swesty ($K = 220$ MeV) [5]

Progenitor: $14+9M_{\odot}$ merger model for the SN 1987A progenitor [6]

Model	δm_s^2 [eV ²]	$\sin^2 2\theta$	Shock revival?
NoSterile		0	Yes
A	3.90	0.040	No
B	1.30	0.120	No
C	1.30	0.040	Yes
D	1.30	0.013	Yes
E	0.43	0.040	Yes

3. Active-Sterile Neutrino Oscillations

- MSW resonance condition [3]:

$$\frac{\delta m_s^2}{2E} \cos \theta = \frac{3\sqrt{2}}{2} G_F n_b \left(Y_e - \frac{1}{3} \right)$$

δm_s : ν_s mass
 θ : ν_e - ν_s mixing angle
 G_F : Fermi coupling
 Y_e : electron fraction
 n_b : baryon number density

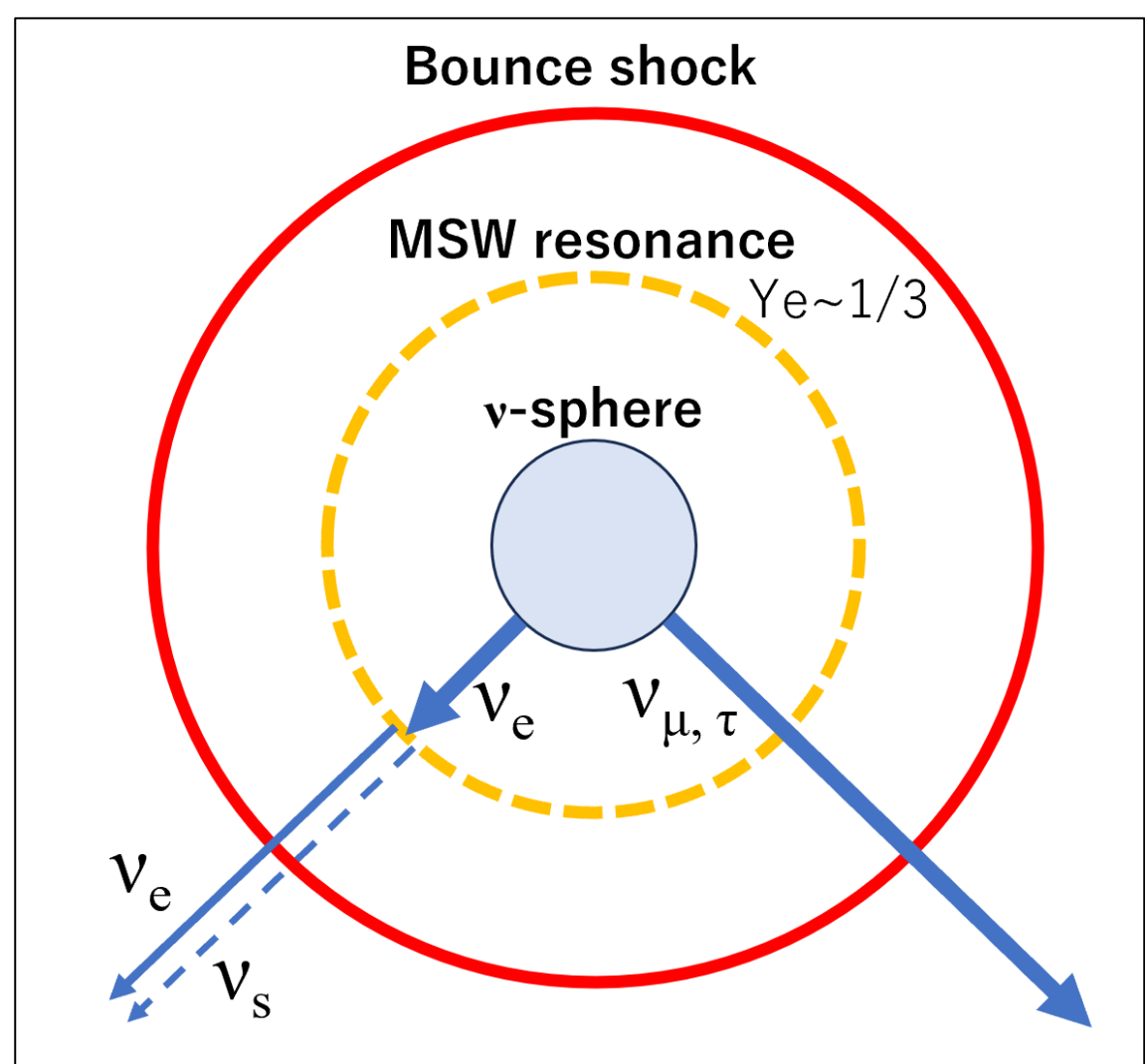


Fig.2: Production of sterile neutrinos in a collapsing star.

- When $Y_e \sim 1/3$, the resonance condition is satisfied

→ **"Disappearance" of ν_e in the gain region**

- The conversion probability is estimated by the Landau-Zener formula:

$$P_{es}(E_{res}) = 1 - \exp\left(-\frac{\pi^2}{2}\gamma\right)$$

$$V_{eff} = \pm \frac{3\sqrt{2}}{2} G_F n_b \left(Y_e - \frac{1}{3} \right)$$

$$\Delta_{res} = \tan 2\theta \left| \frac{dV_{eff}/dr}{V_{eff}} \right|^{-1}$$

$$l_{osc} = (2\pi E_{res}) / (m_s^2 \sin 2\theta)$$

$$\gamma = \Delta_{res} / l_{osc}$$

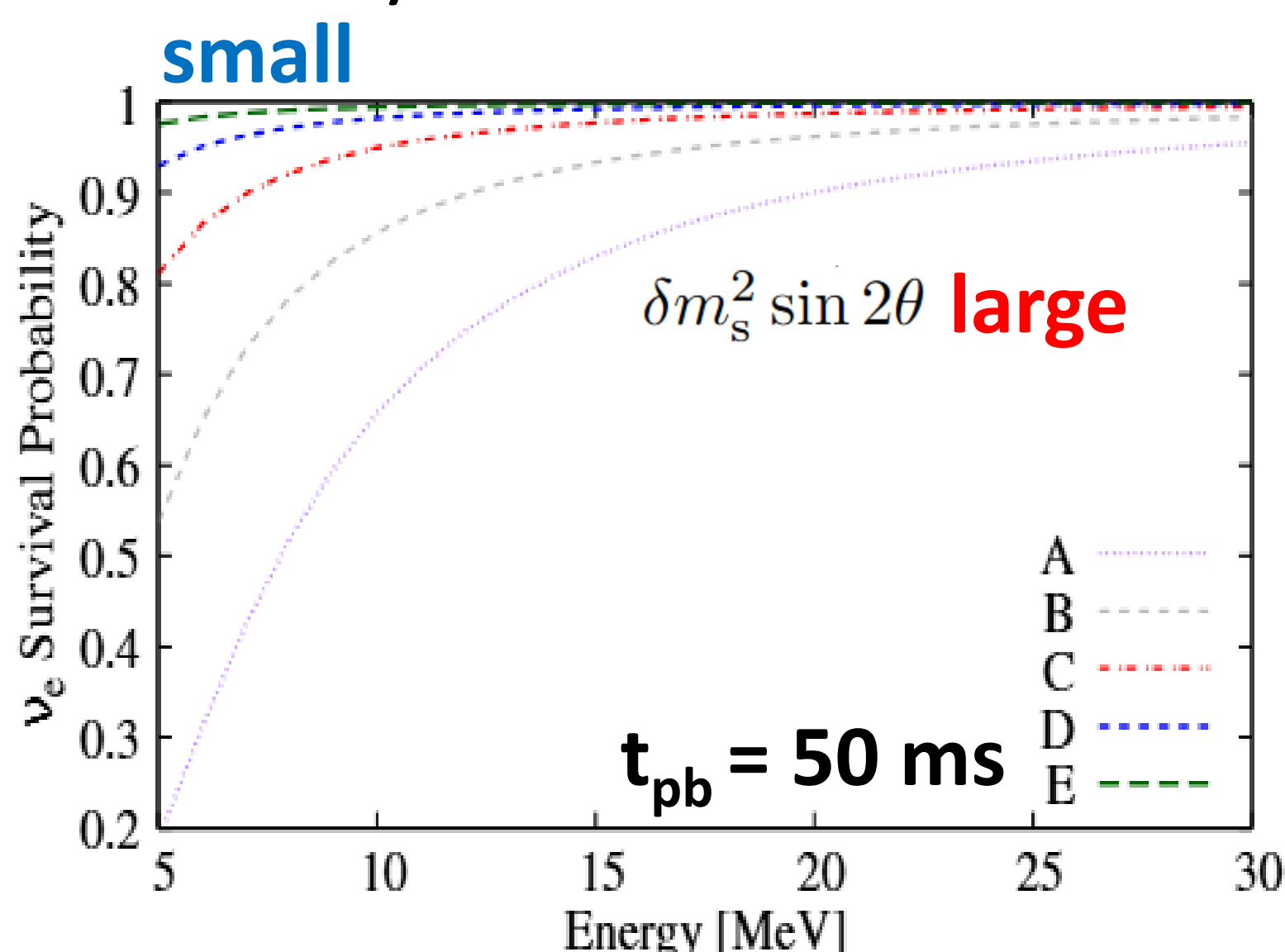


Fig. 3: The ν_e survival probability in the supernova models [7].

The ν_e flux can be reduced by $O(10)$ %!

- ✓ The **neutrino heating rate is suppressed** because of the active-sterile oscillations.
- Hindrance of the shock revival

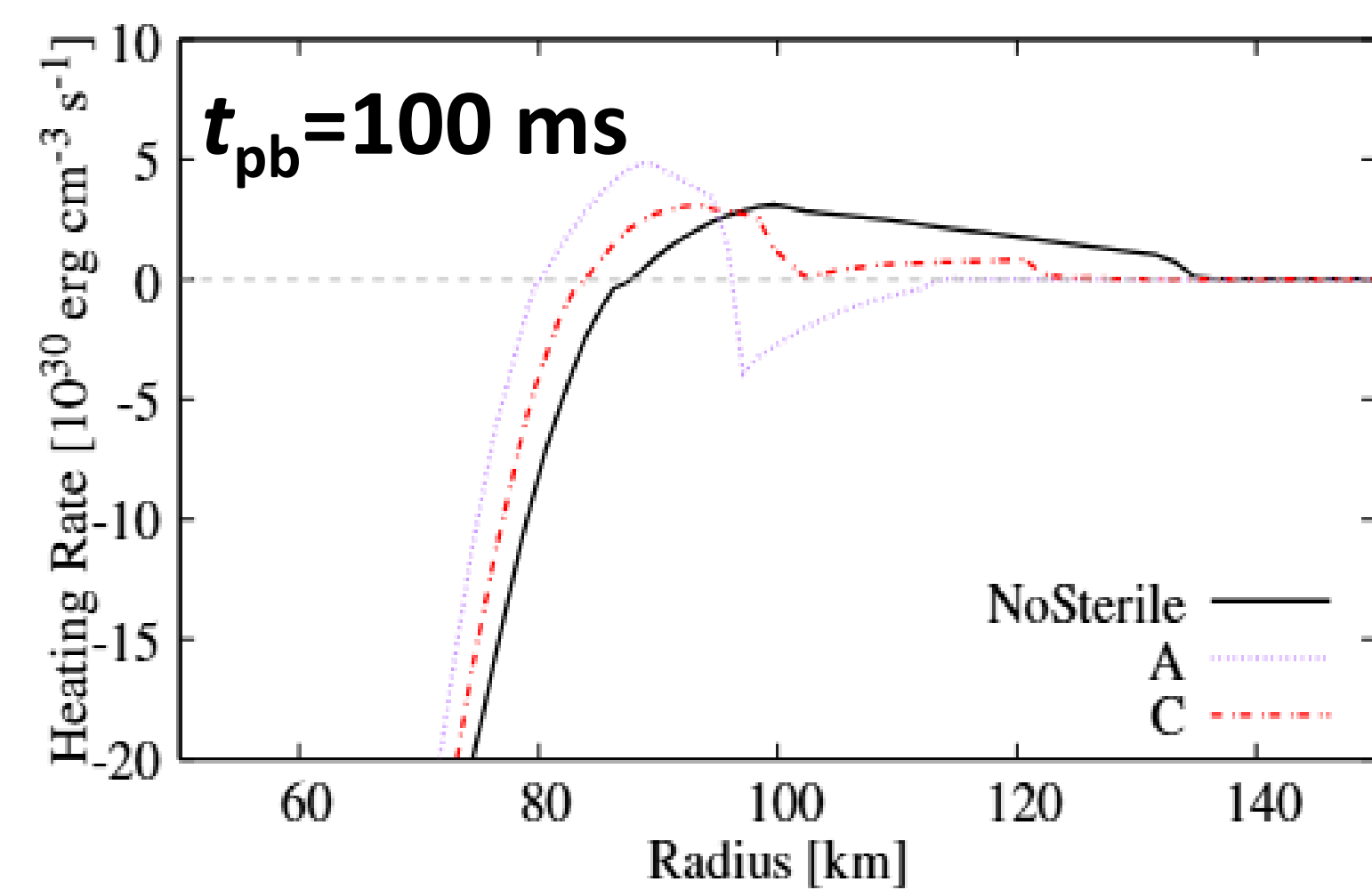


Fig. 4: The radial profile of the neutrino heating rate [7].

4. Failed Supernova Explosions

4-1. Shock Radius

- ✓ When sterile neutrinos are considered, the shock revival is delayed.
- ✓ When the mixing angle is sufficiently large, **the stalled shock is not revived** until the end of the simulations.

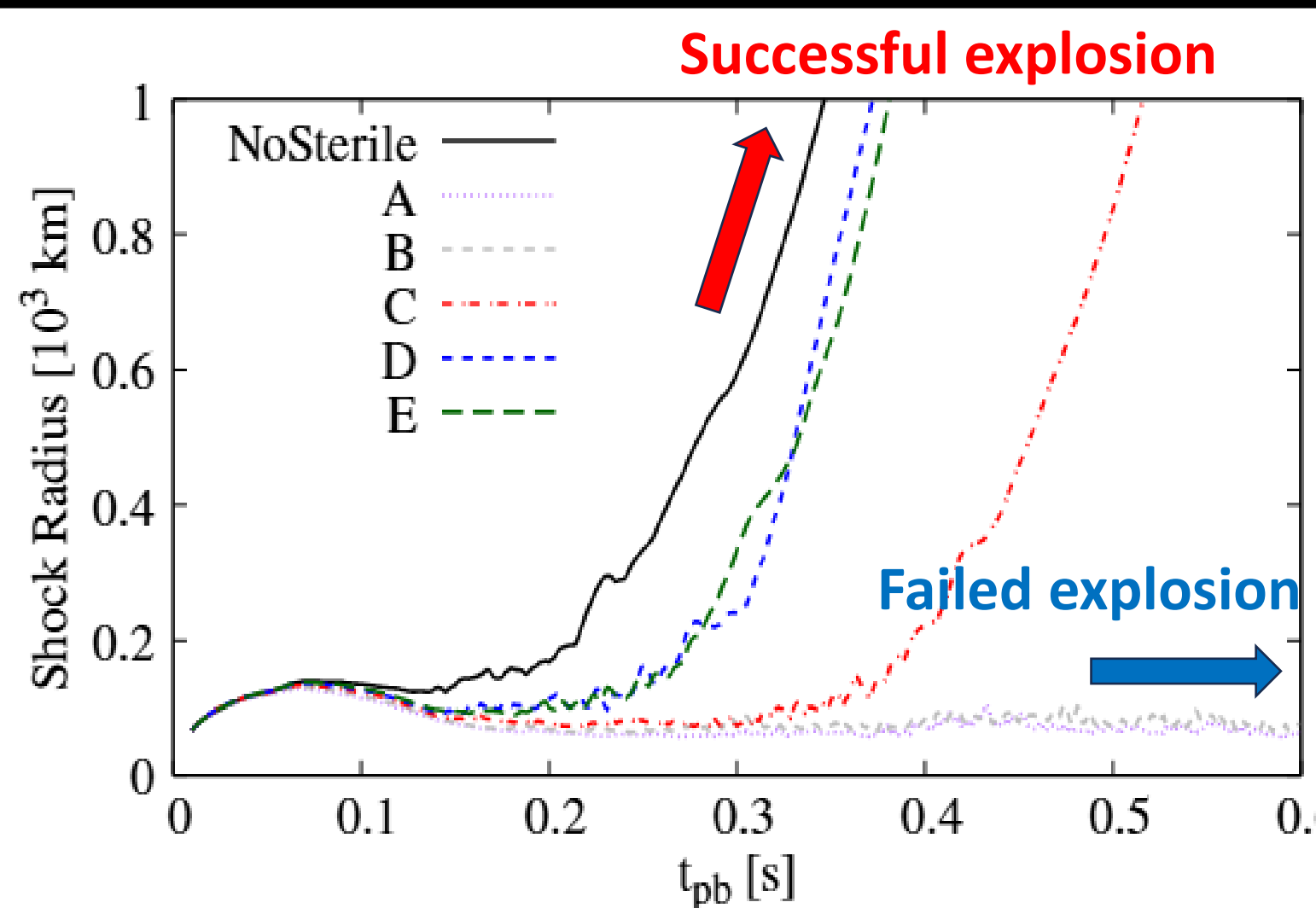


Fig. 5: The radius of the bounce shock [7].

4-2. Explosion Energy

- ✓ When sterile neutrinos are considered, **the explosion energy is reduced**.

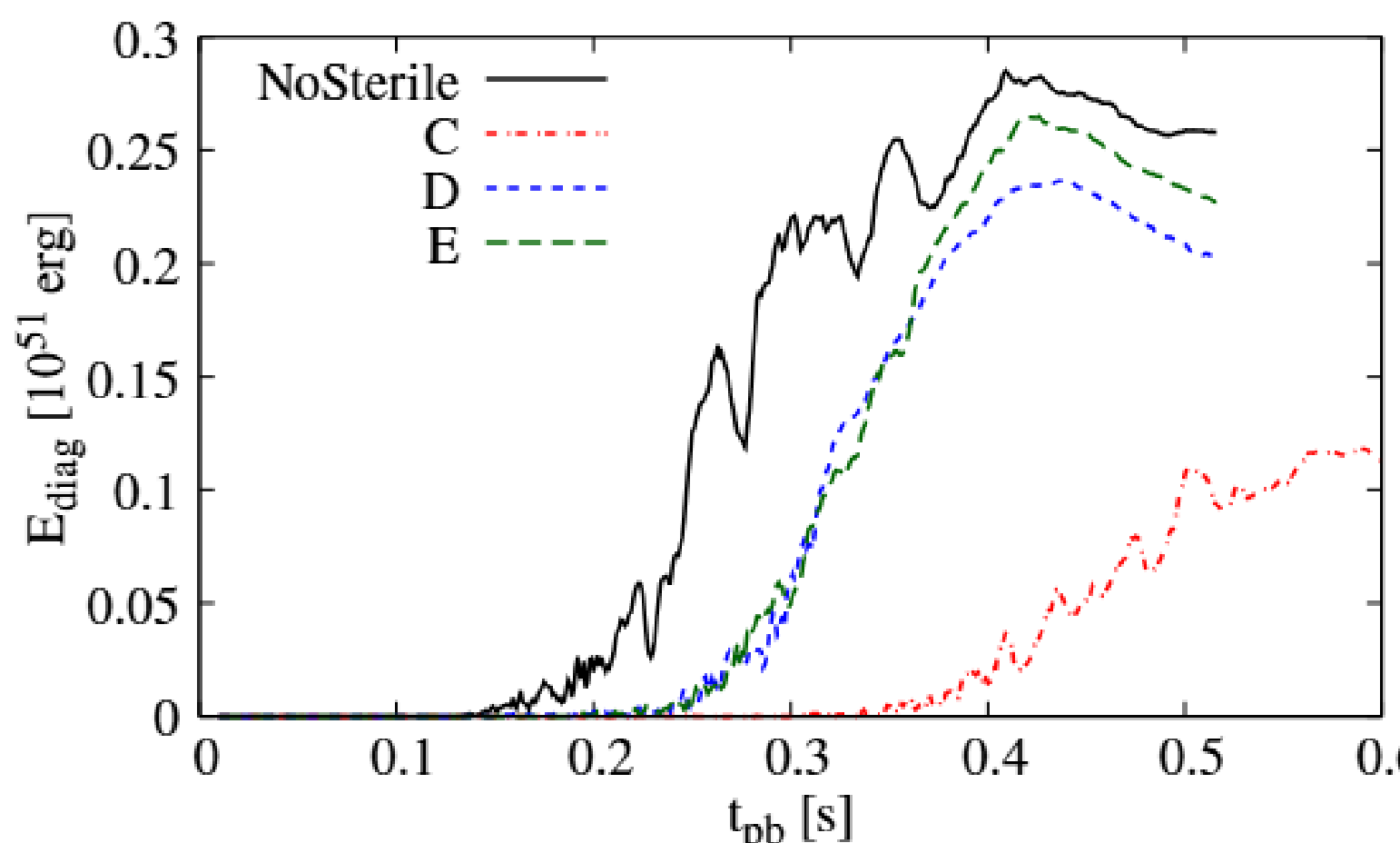


Fig. 6: The diagnostic explosion energy [7].

4-3. SN 1987A Explosion Condition

We can find a condition for successful SN 1987A explosion:

$$\delta m_s^2 \sin 2\theta \lesssim 0.45 \text{ eV}^2$$

- ✓ **SN explodability can provide a new constraint on sterile neutrinos!**

- ✓ A part of the region indicated by the reactor anomaly is excluded.

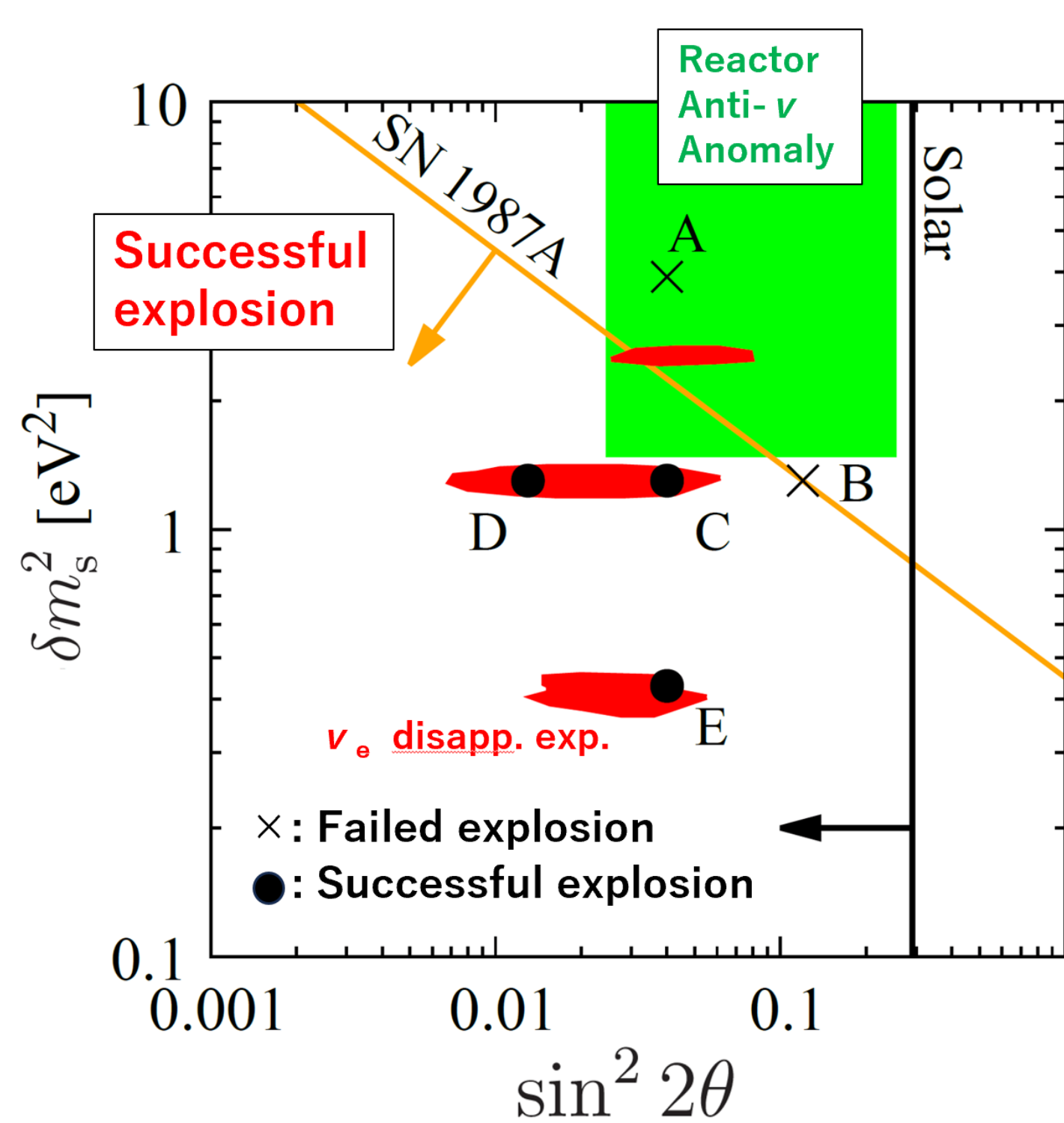


Fig. 7: The parameter space for sterile neutrinos [7]. The points indicate our models and the orange line indicates the constraint obtained in this study.

5. Summary & Future Prospect

5-1. Summary

- Light sterile neutrinos can hinder supernova explosions because active-sterile neutrino oscillations in the gain region suppress heating.
- We performed 2D hydrodynamic simulations for a collapsing star considering the active-sterile neutrino oscillations.
- A new constraint was obtained based on explodability.

5-2. Future Prospect

- A similar argument can be applied to other particle models. For example, we performed simulations coupled with dark photons and found that they hinder supernova explosions as well [8].
- Estimating uncertainties from progenitor models, dimensionality, neutrino transport schemes, ... is also important.

References

- [1] Dentler et al., JHEP 08 (2018) 010. [2] Mention et al., PRD 83 (2011) 073006. [3] Wu et al., PRD 89 (2014) 061303. [4] Takiwaki, Kotake & Suwa MNRAS 461 (2016) L112. [5] Lattimer & Swesty, NPA 535 (1991) 331. [6] Urushibata et al., MNRAS 473 (2018) L101. [7] KM, Takiwaki, Kohri & Nagakura, PRD 111 (2025) 083046. [8] KM, Takiwaki, Kohri, PRD 113 (2026) L041303.