Probing Pair-Instability Supernovae via 56Ni Decay Signatures

arXiv:2503.21744

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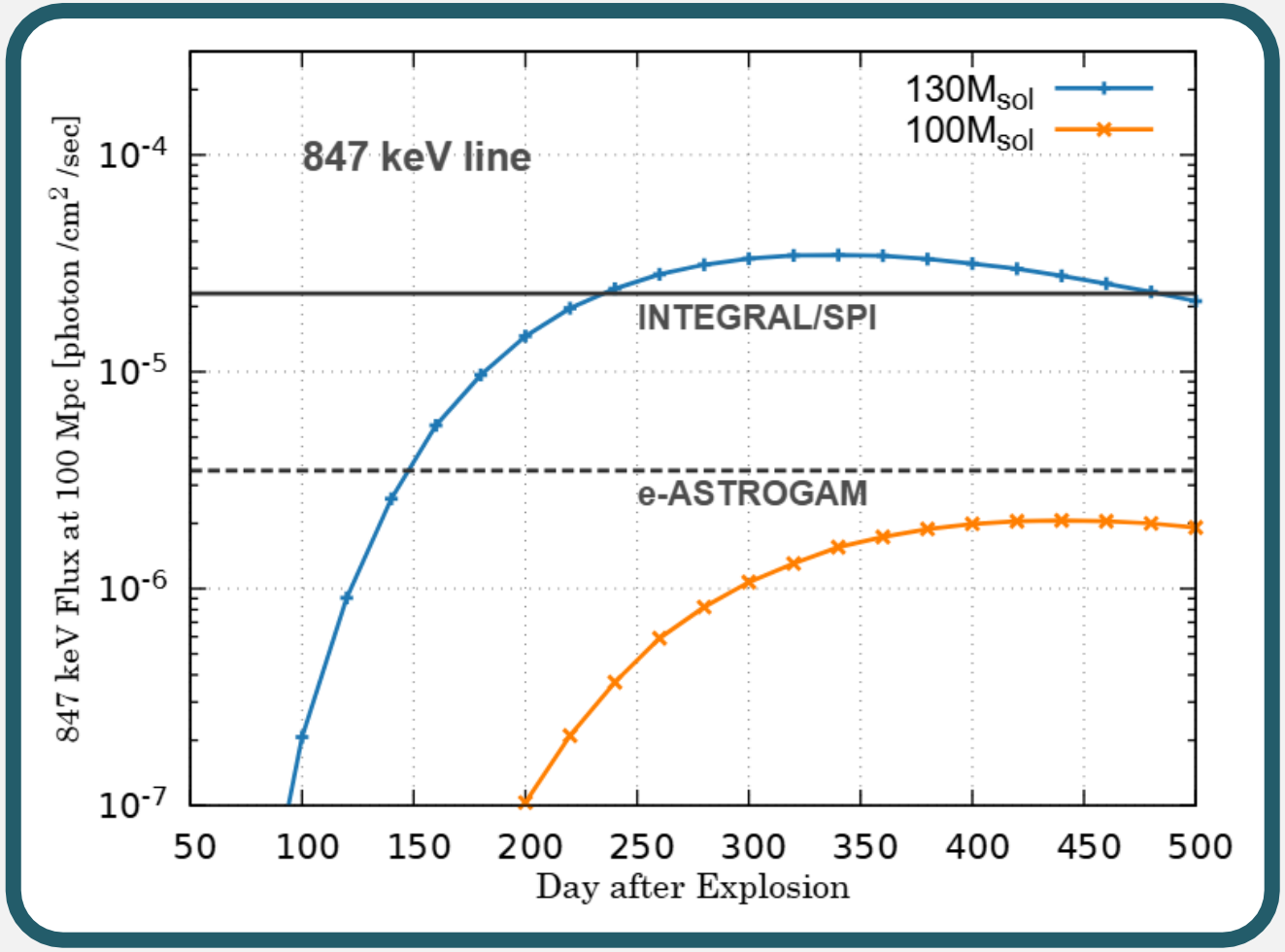
[Result]

The next-generation telescope

will be able to observe the 847 keV line

from PISN at d<300Mpc.



What is Pair-instability supernova (PISN)?

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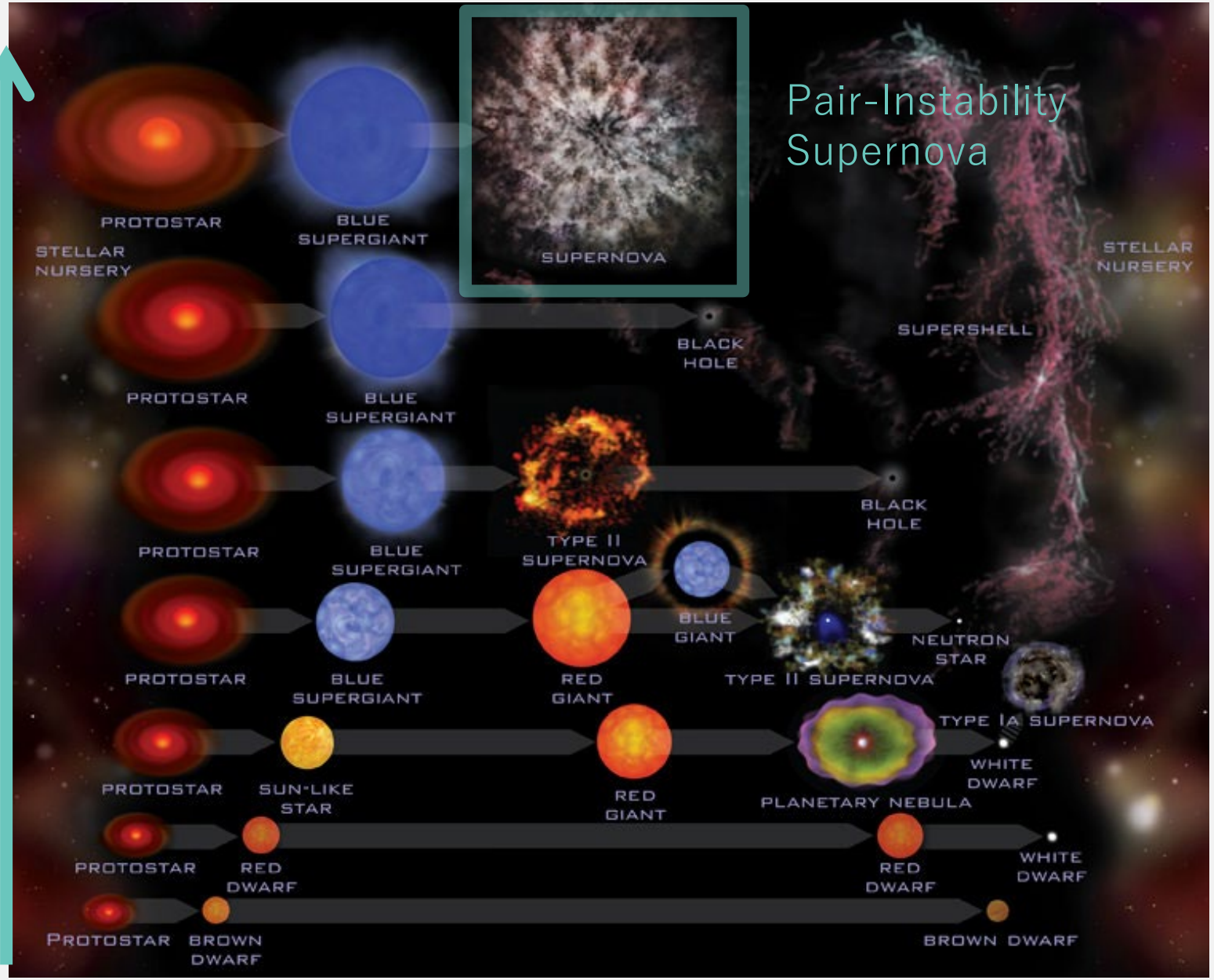

Very massive star ($\gtrsim$ **100 $M_\odot$) cause a thermonuclear explosion** (e.g., Barkat et al., 1967).

PISN explosion synthesizes a large amount of 56Ni (up to 60$M_\odot$!!!).

Why is it interesting to observe PISNe?

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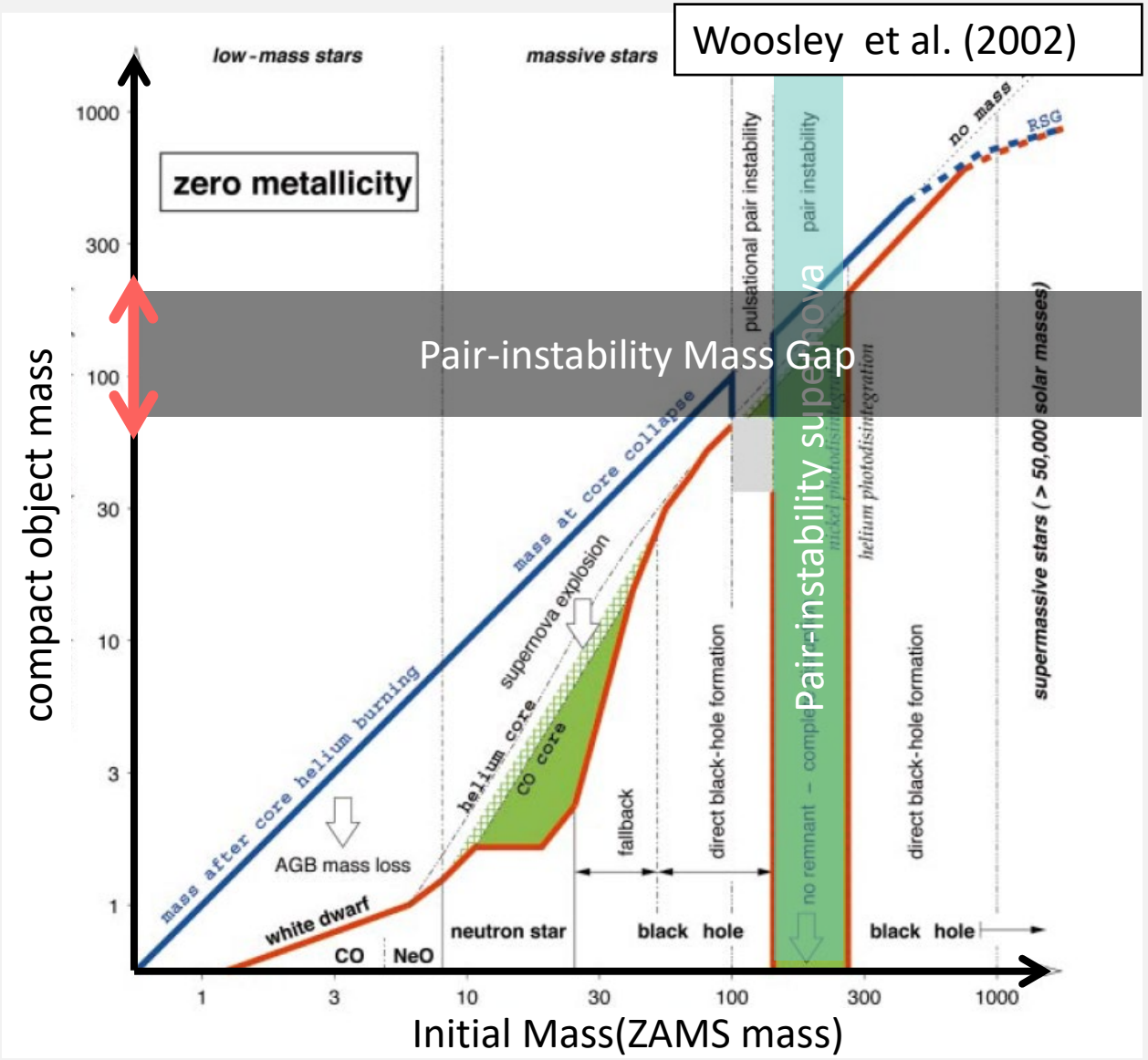
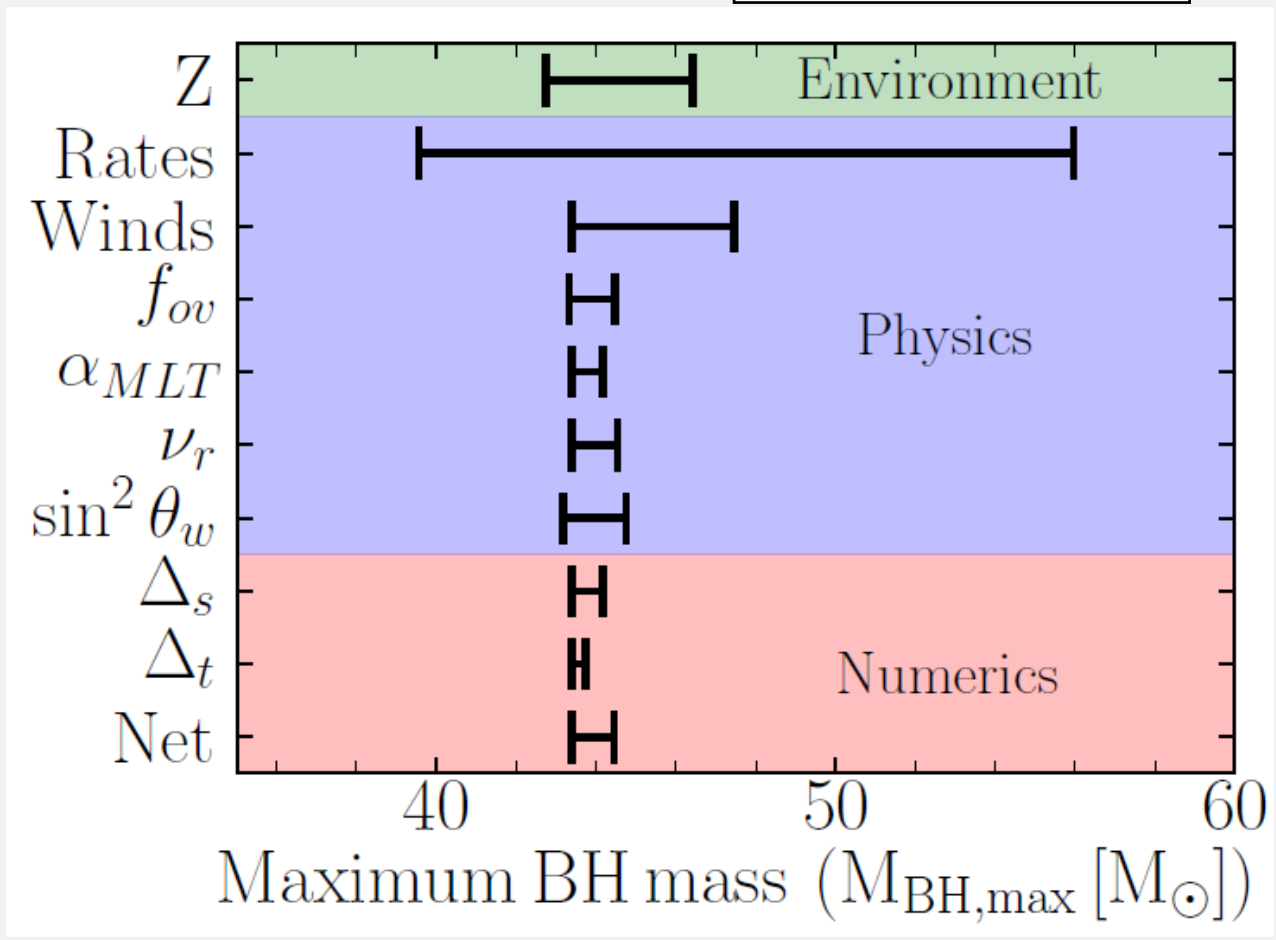
It is known that no compact objects remain after a PISN explosion.

Woosley et al. (2002)



Farmer et al. (2021)



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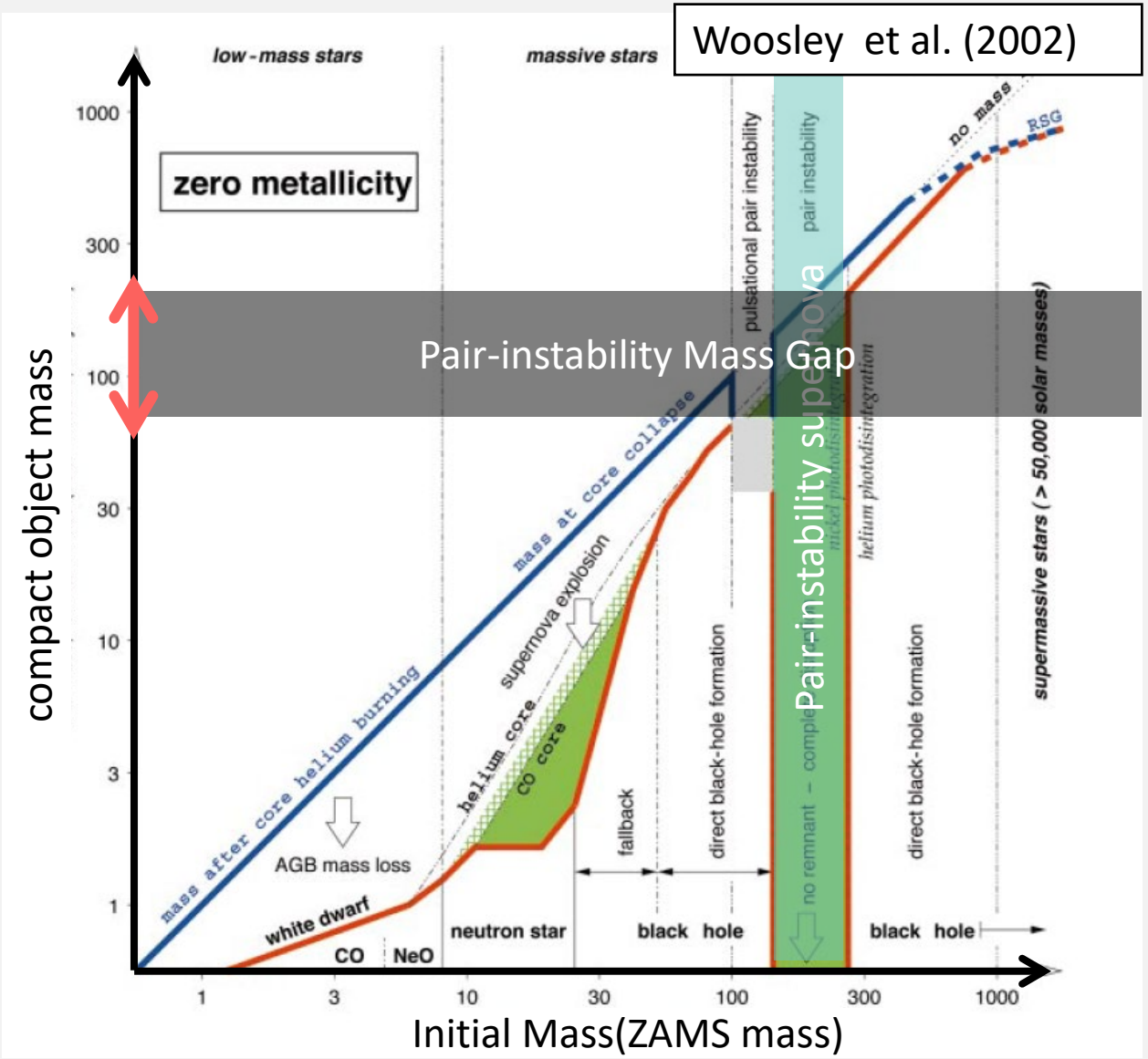

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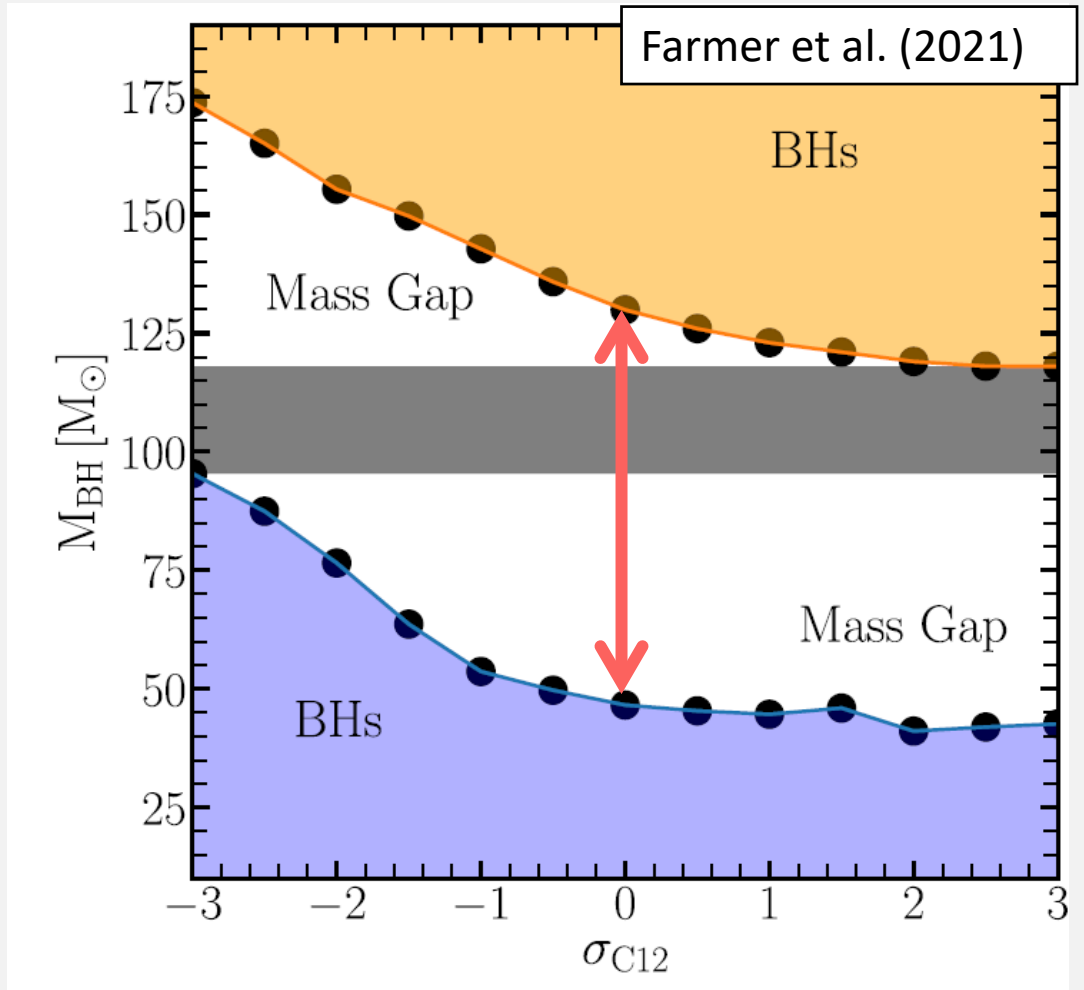

($^{12}C+\alpha \rightarrow {}^{16}O+\gamma$)

why the reaction rate affects the explodability?

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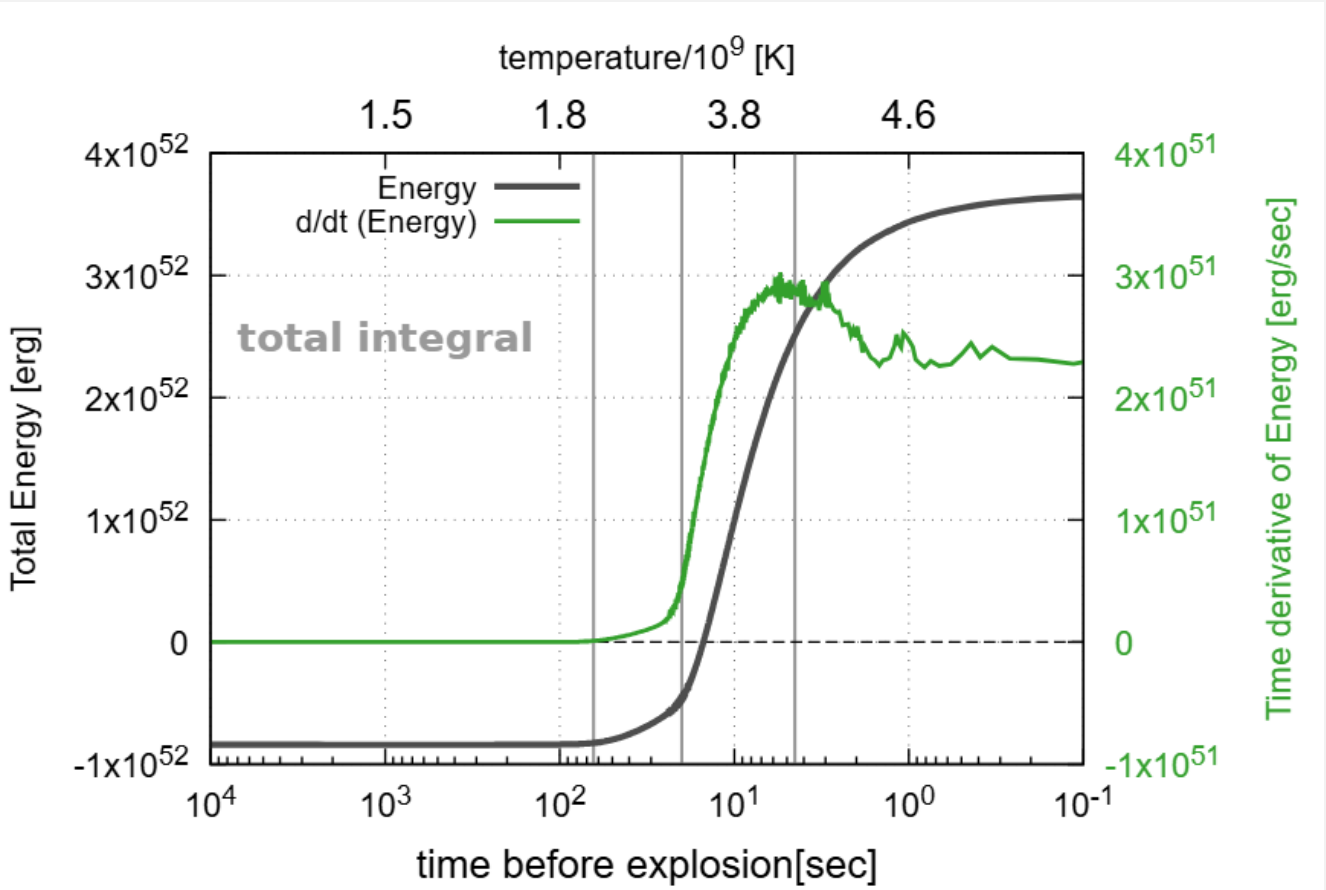

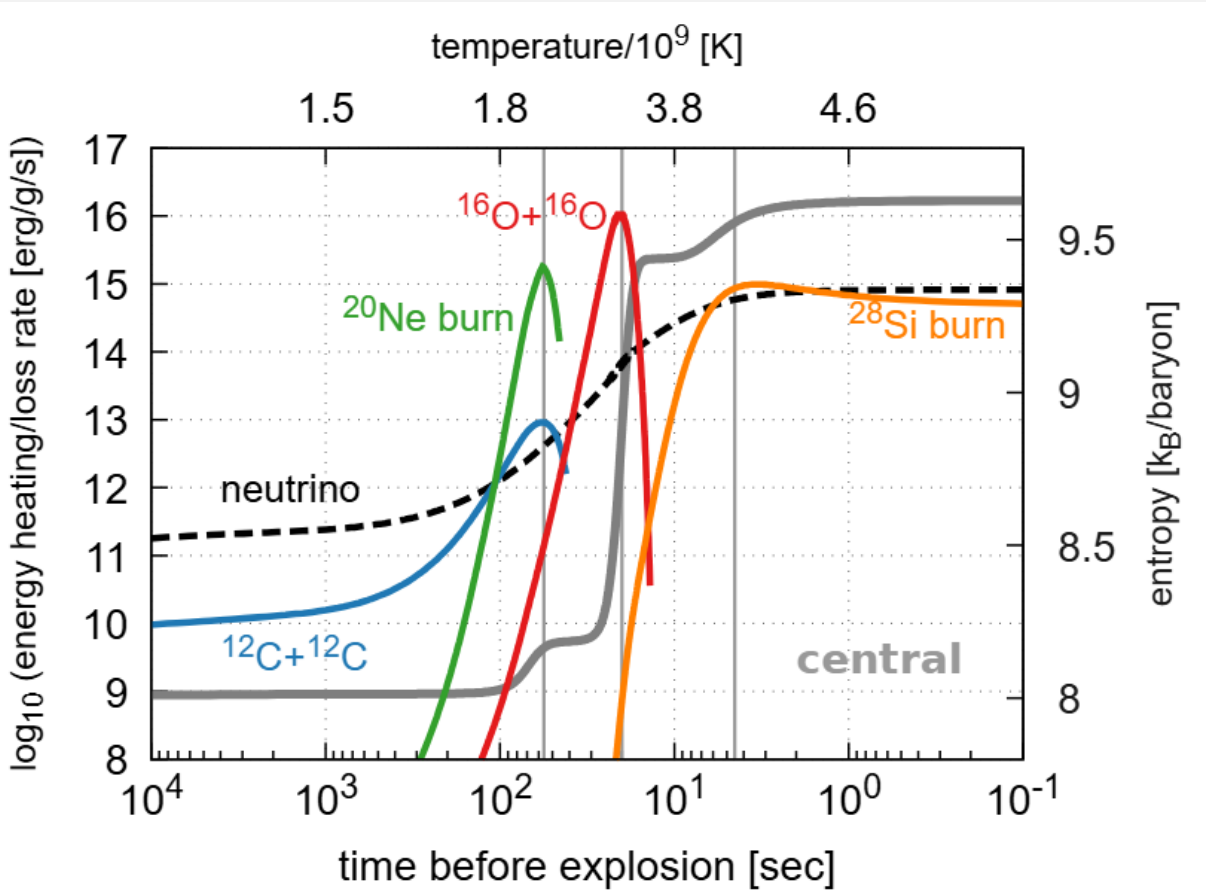

Sawada et al. (in prep)

why the reaction rate affects the explodability?

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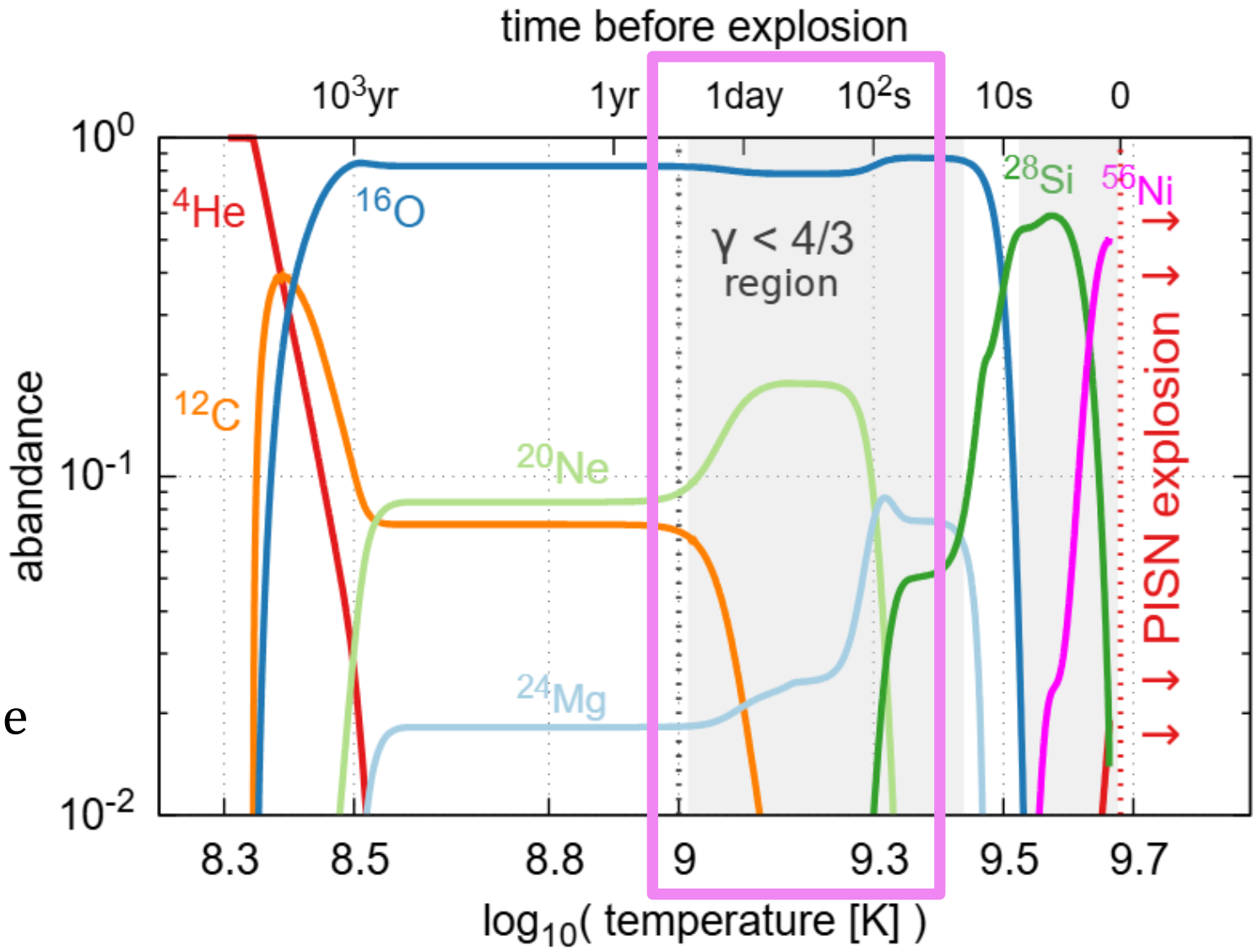
$$^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{24}\mathrm{Mg}^{*} \rightarrow {}^{20}\mathrm{Ne} + {}^{4}\mathrm{He}$$

$$^{16}\mathrm{O} + {}^{4}\mathrm{He} \rightarrow {}^{20}\mathrm{Ne}$$

(∴effectively)

$$2 \cdot {}^{12}\mathrm{C} + {}^{16}\mathrm{O} \rightarrow 2 \cdot {}^{20}\mathrm{Ne}$$



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Prediction of Gamma Ray Emitting from Supernova

- CC-SNe （M(^{56}Ni)~0.07M⊙）

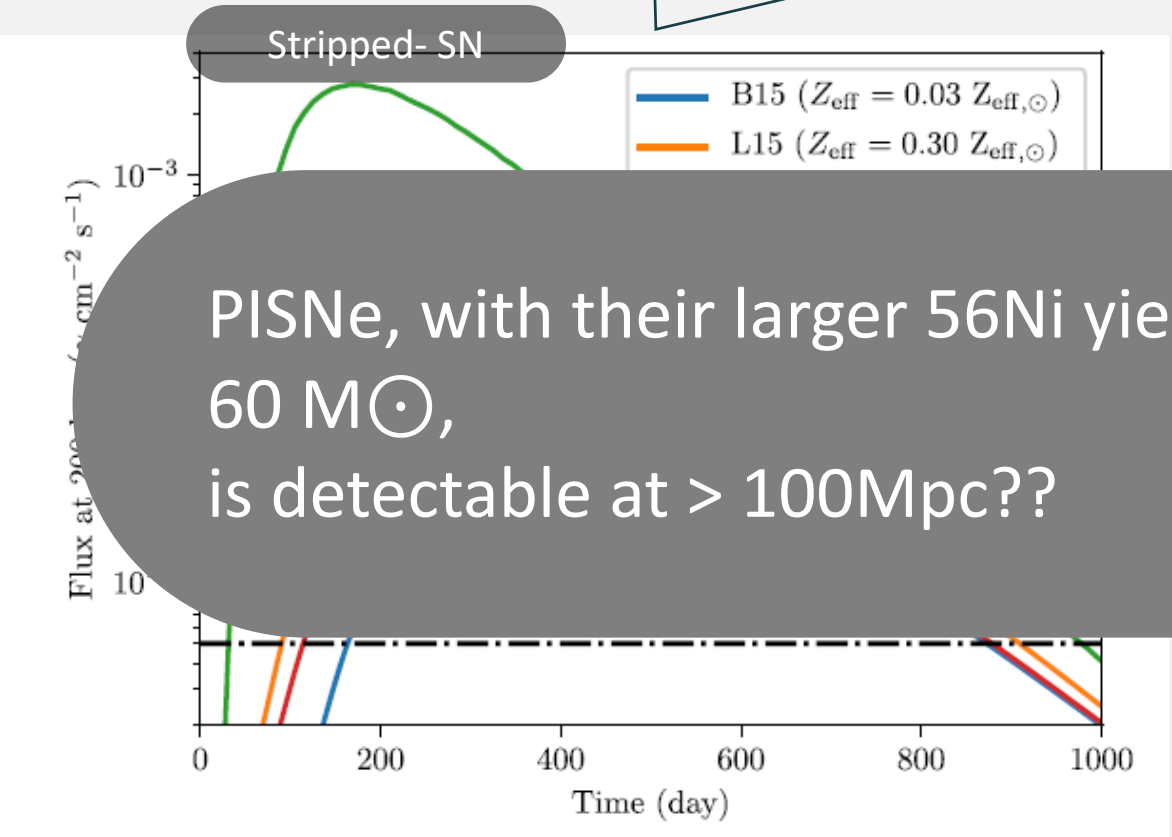
  detection limit ~**2 Mpc**

  by INTEGRAL/SPI. (Alp et al. 2019)

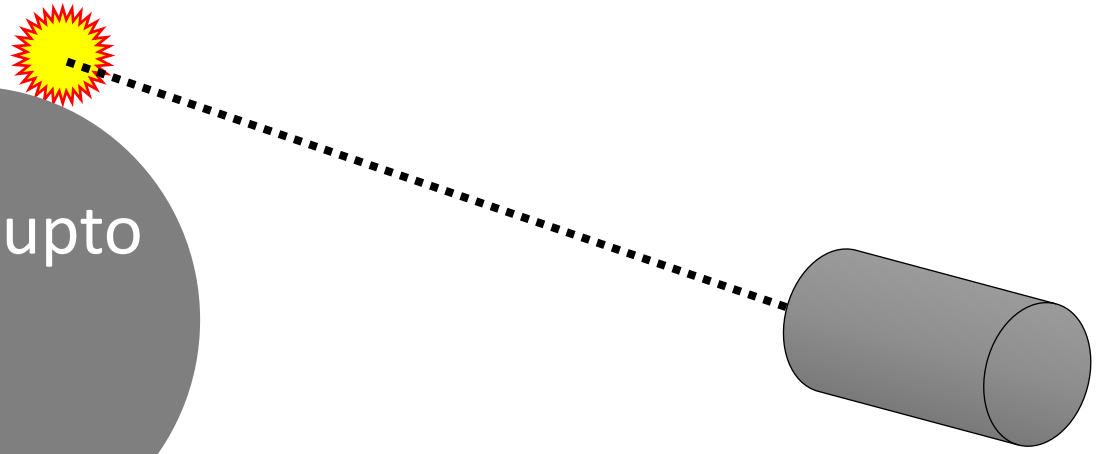
Type Ia SNe （M(^{56}Ni)~0.6M⊙）

detection limit ~**10 Mpc**

by INTEGRAL/SPI. (The & Burrows 2014)



PISNe, with their larger 56Ni yields of upto 60 M⊙,
is detectable at > 100Mpc??



$$F_\gamma \approx \frac{N_A}{4\pi d^2}\frac{X_i}{A}\frac{M(56\mathrm{Ni})}{\tau_i} I_{\gamma,i}\exp\left[-\frac{t}{\tau_i}\right]$$

Prediction of Gamma Ray Emitting from PISN

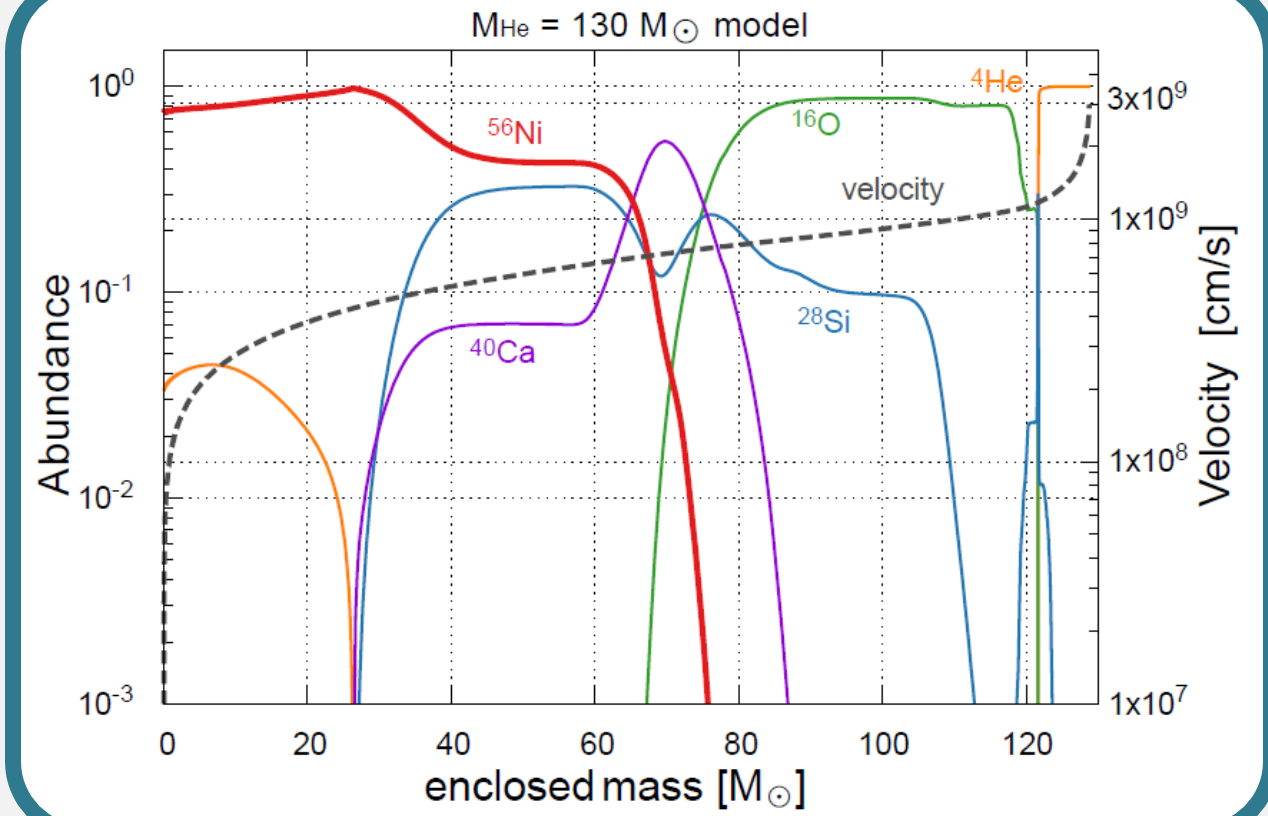
My cal. setup

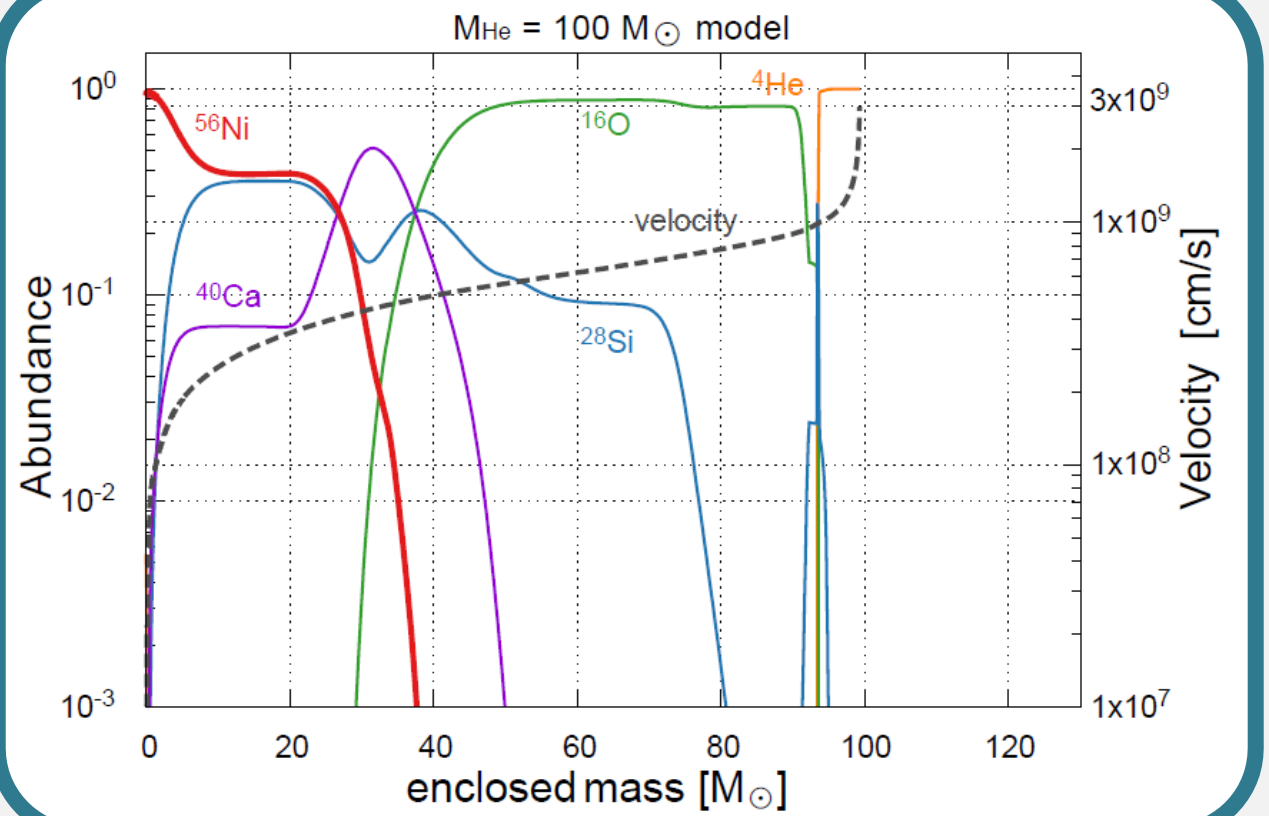
- Cal. code:MESA-r24.08
- Network:128-isotope

- M_{He}=100Msol;

  Eexpl=4 × 10^{52}ergs; ^{56}Ni~10Msol
- M_{He}=130Msol;

  Eexpl=1 × 10^{53}ergs; ^{56}Ni~40Msol



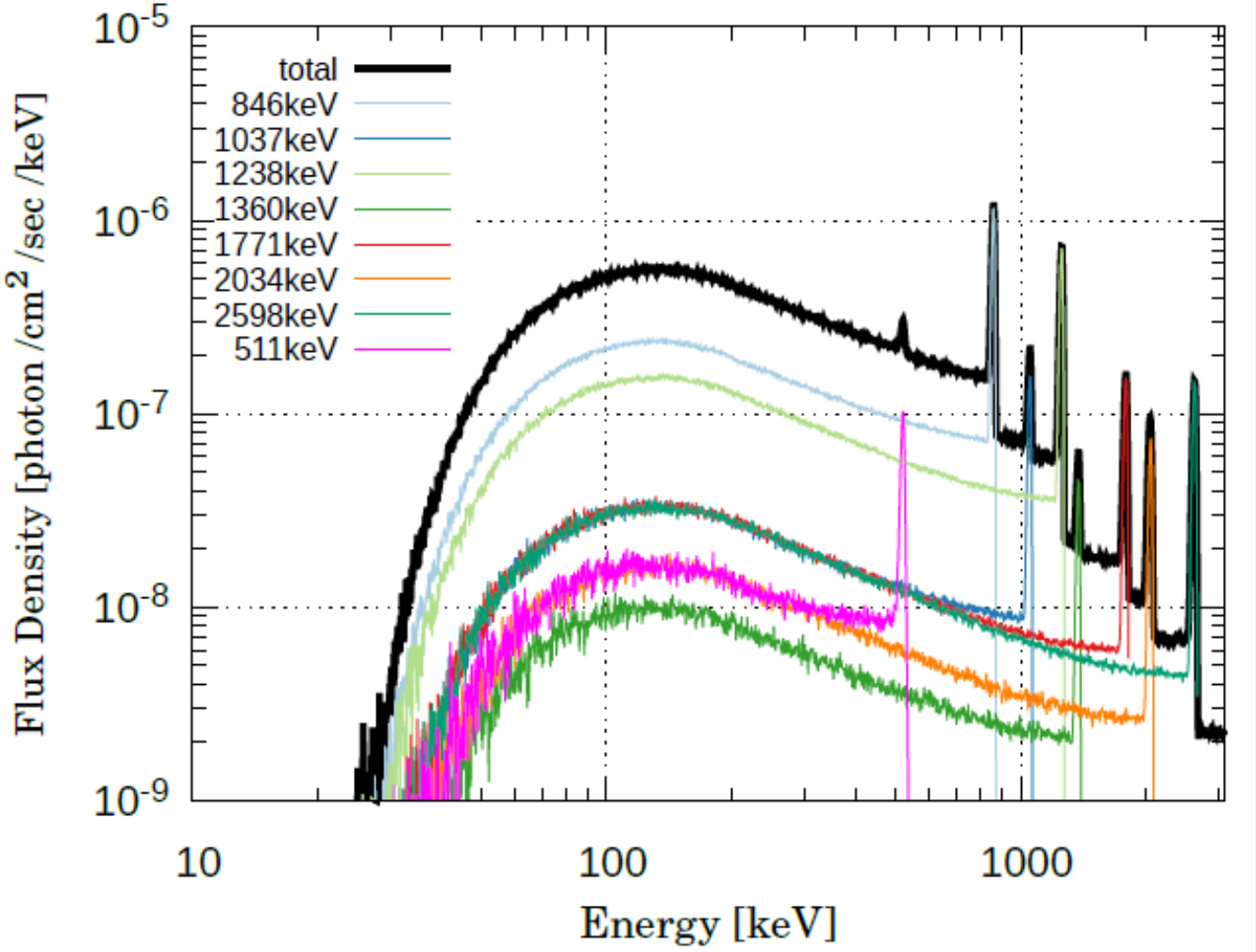


Prediction of Gamma Ray Emitting from PISN

My cal. setup

- Monte Carlo radiative transfer of gamma-ray photons

  (considering pair production, Compton scattering, and photoelectric absorption.)



the model spectrum
at 300 days after the explosion
with helium core 130M
located at a distance of 100 Mpc.

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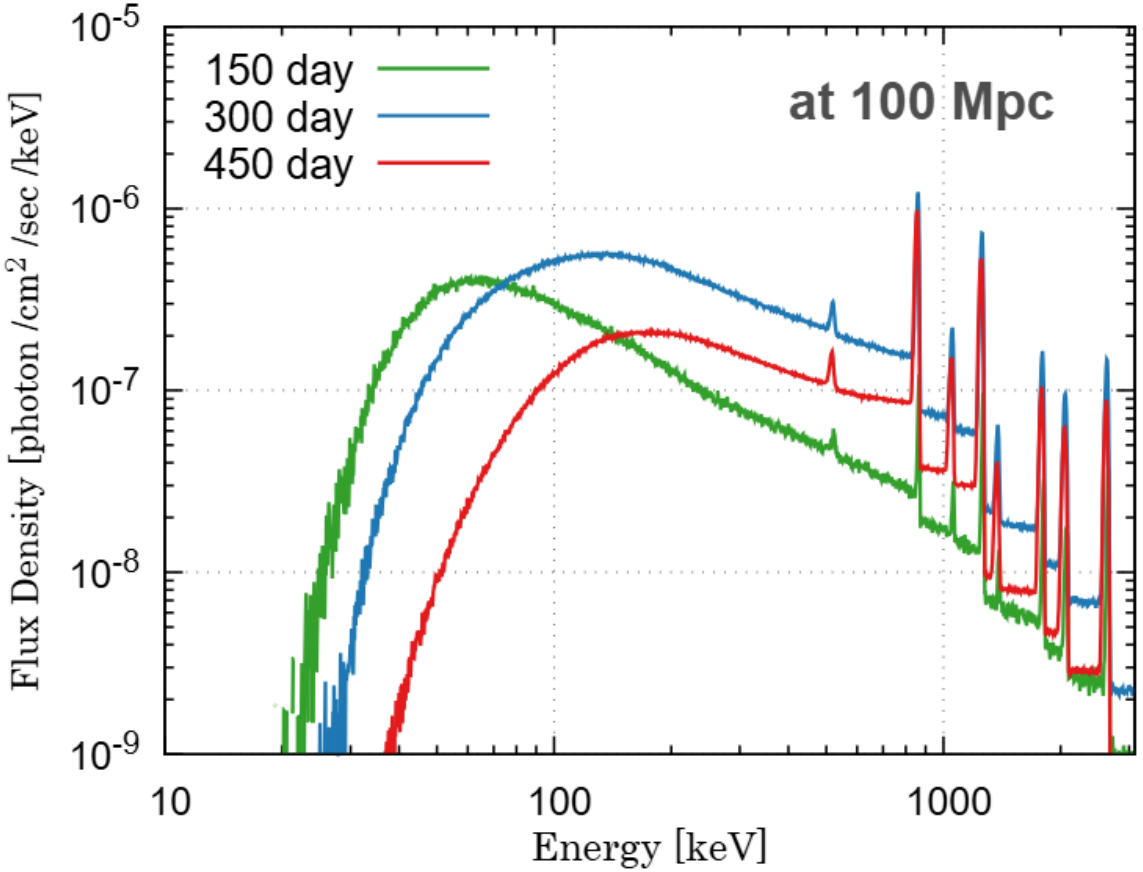

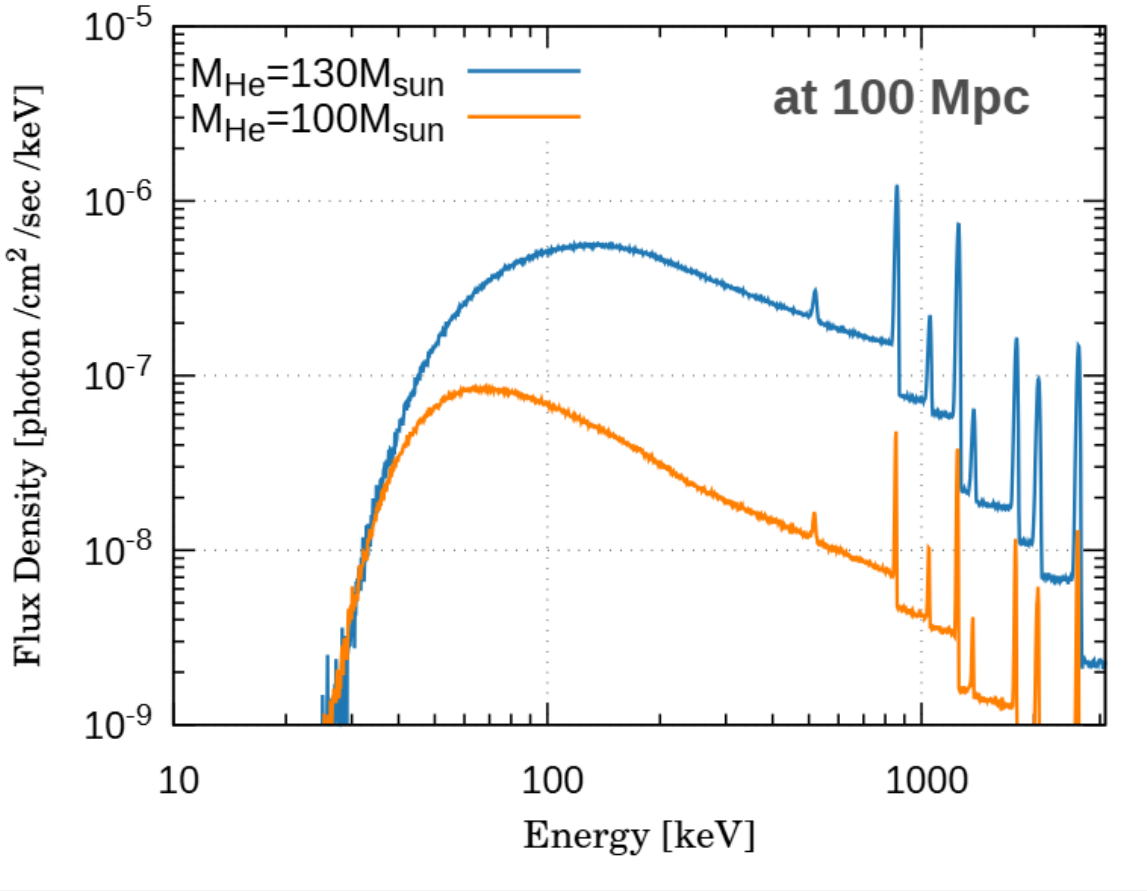

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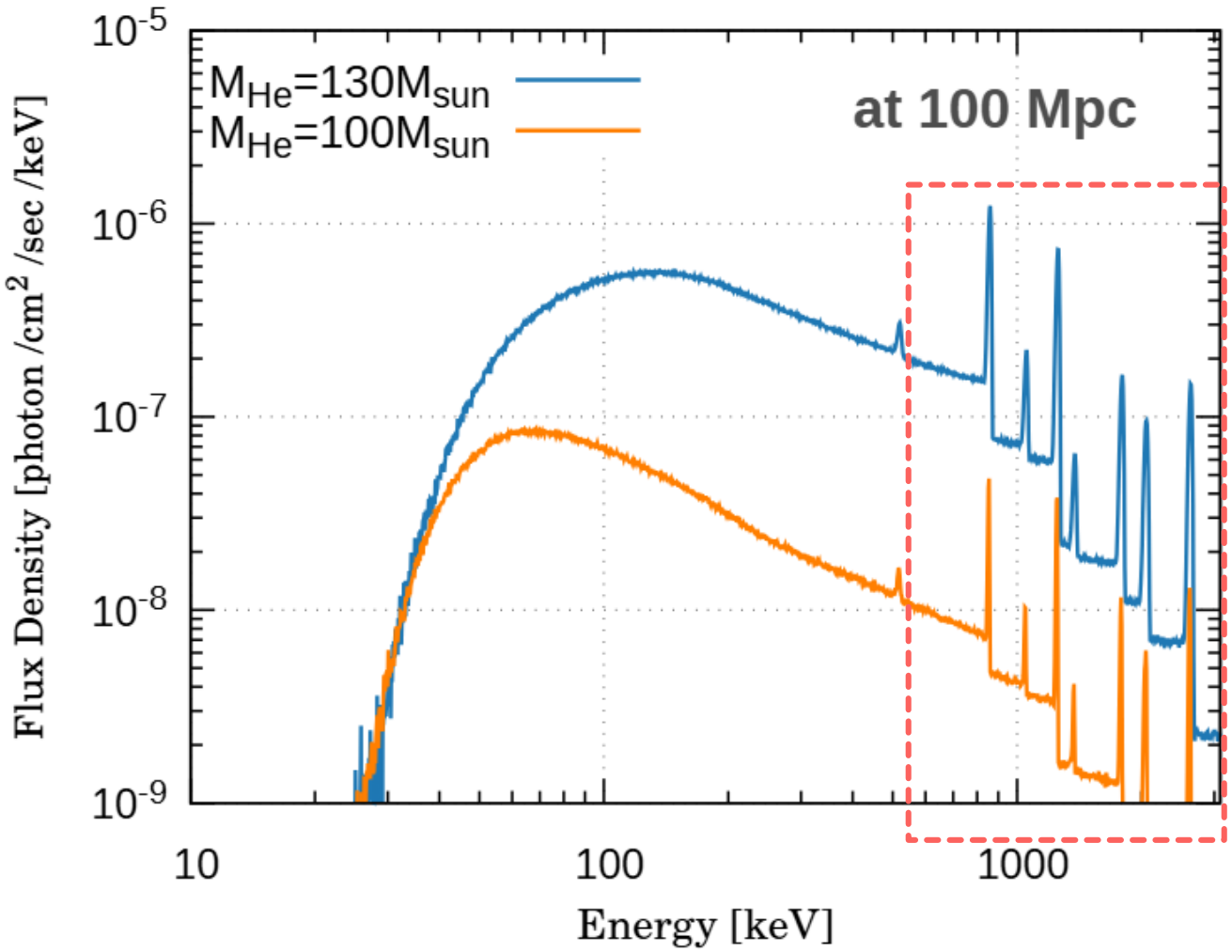

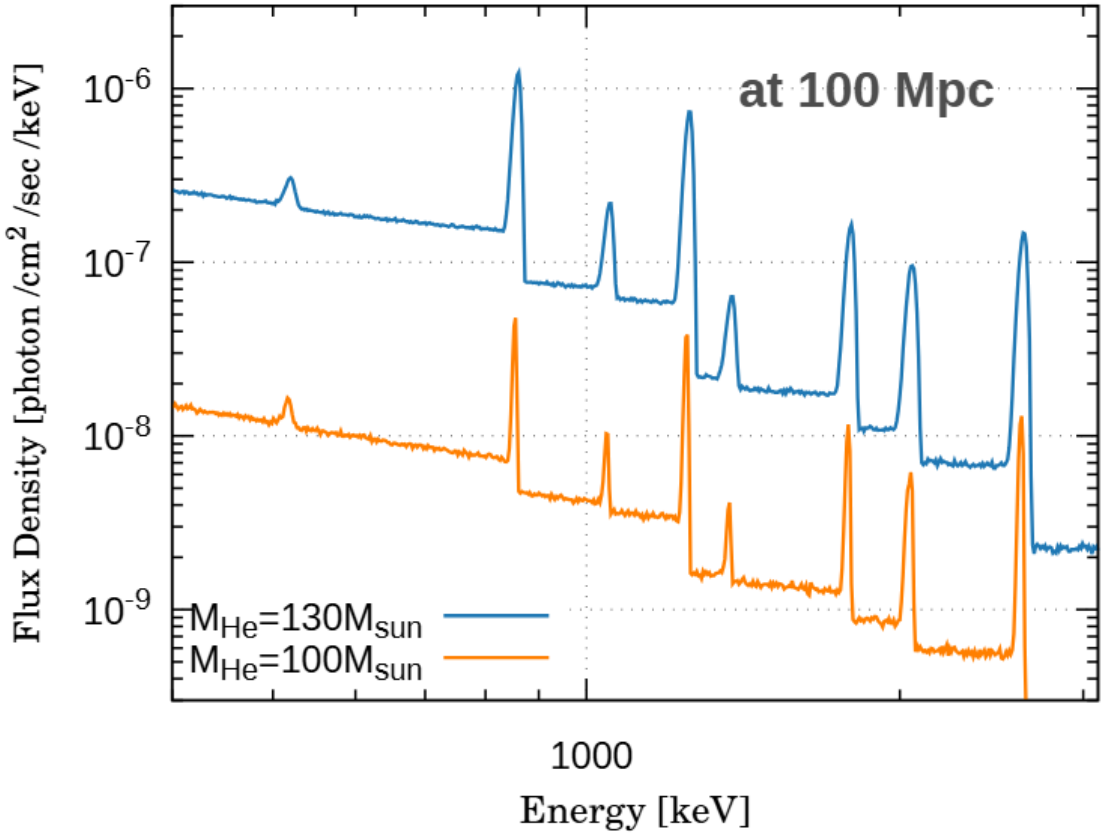

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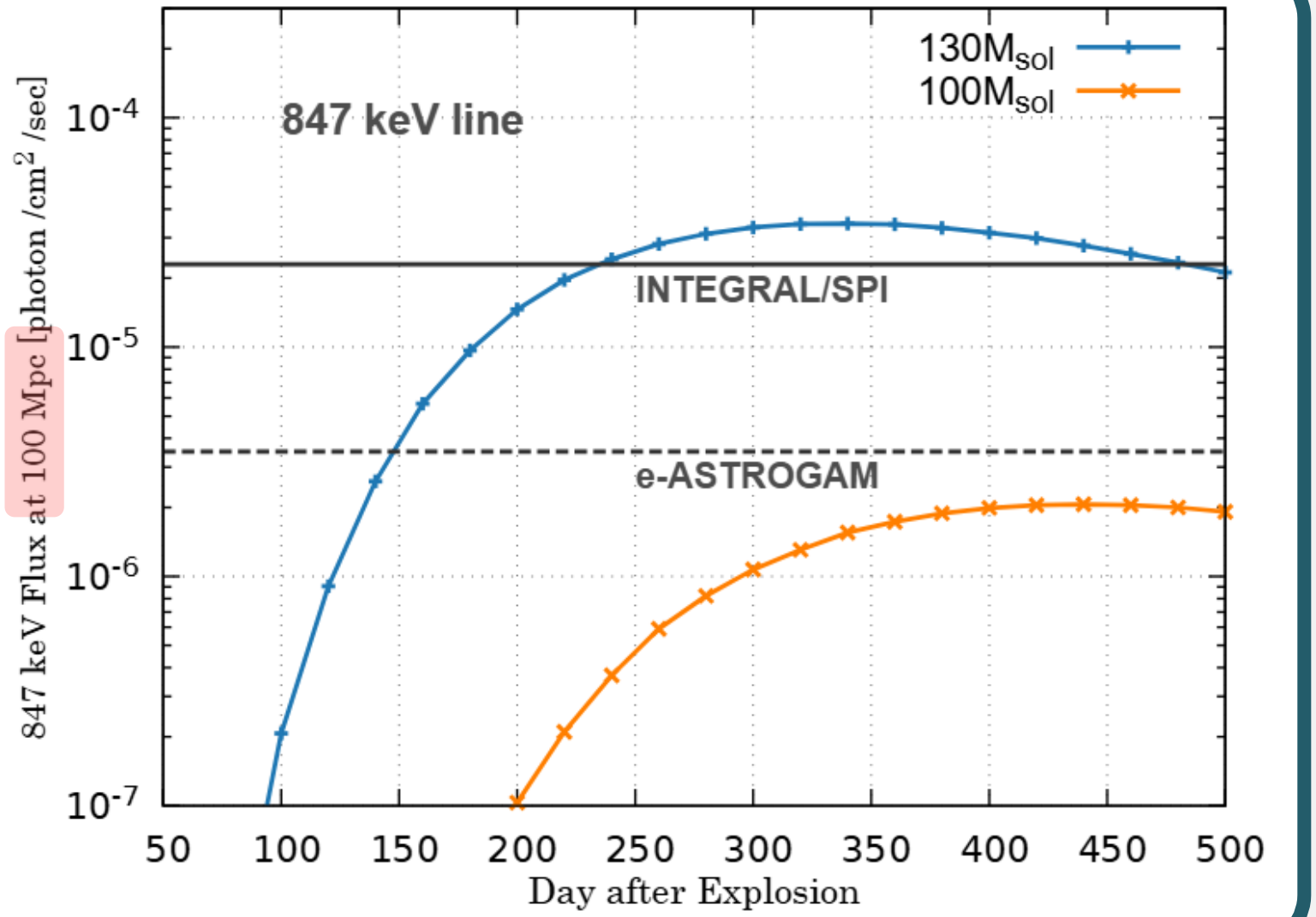

With the M_{He}=130Msol model,

the next-generation telescope will be able to observe

the 847 keV line at d<300Mpc.

Past PISN Candidates:

- SN 2007bi;z=0.128
- SN 2018ibb; z = 0.166

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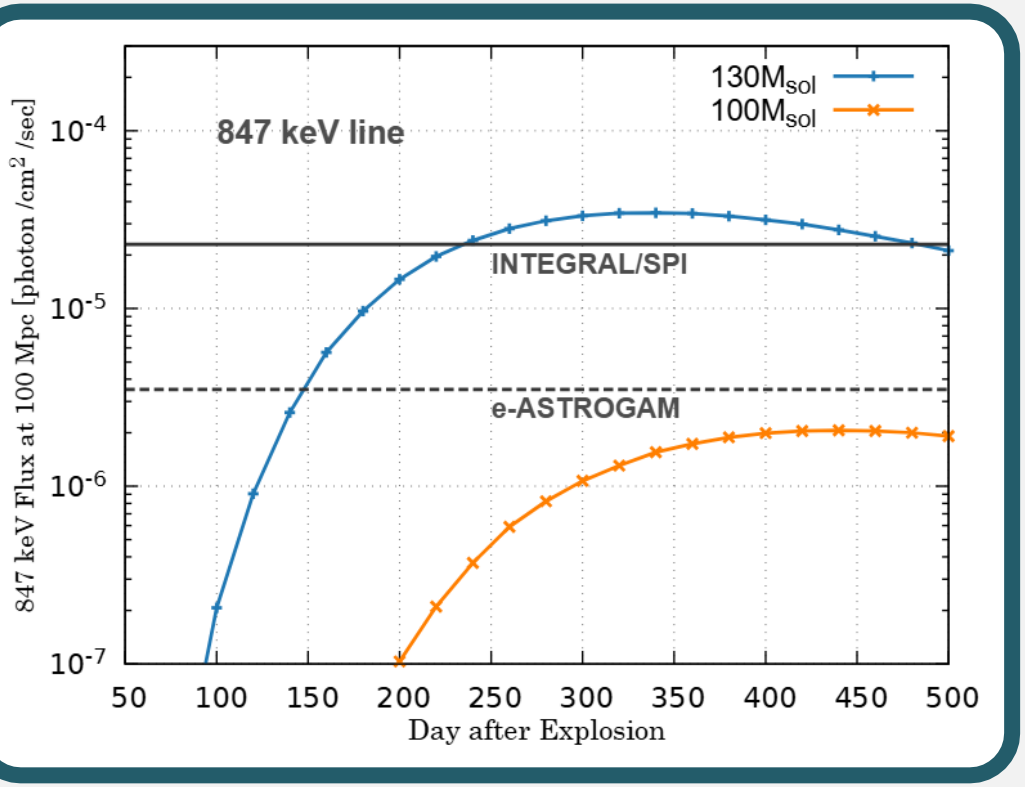

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PISN Event Rate:

- From Super-luminous SN event

  × (PISN fraction : η=1- 10%)

  → 0.01-0.1 events [yr^{-1}]

- From Salpeter IMF; ~1% of core-collapse SN

  →roughly 10 events yr^{-1}.