Nuclear Physics in Astrophysics XII (NPA-XII) @ Babeş-Bolyai University, Cluj-Napoca, Romania (2026/09/07-2026/09/11)

The most important temperatures of helium burning reactions in pair-instability supernova nucleosynthesis

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↑My Website

↑arXiv:2605.27264

Introduction / Motivation

Pair-instability supernova (PISN): final fate of ~200$M_\odot$ stars

→ He burning (3α and $^{12}C(\alpha,\gamma)^{16}O$) process is important!

e.g. **BH mass gap shift** (Farmer+ 2019, 2020 etc.)
PISN luminosity (HK+ 2024, Takahashi 2018)

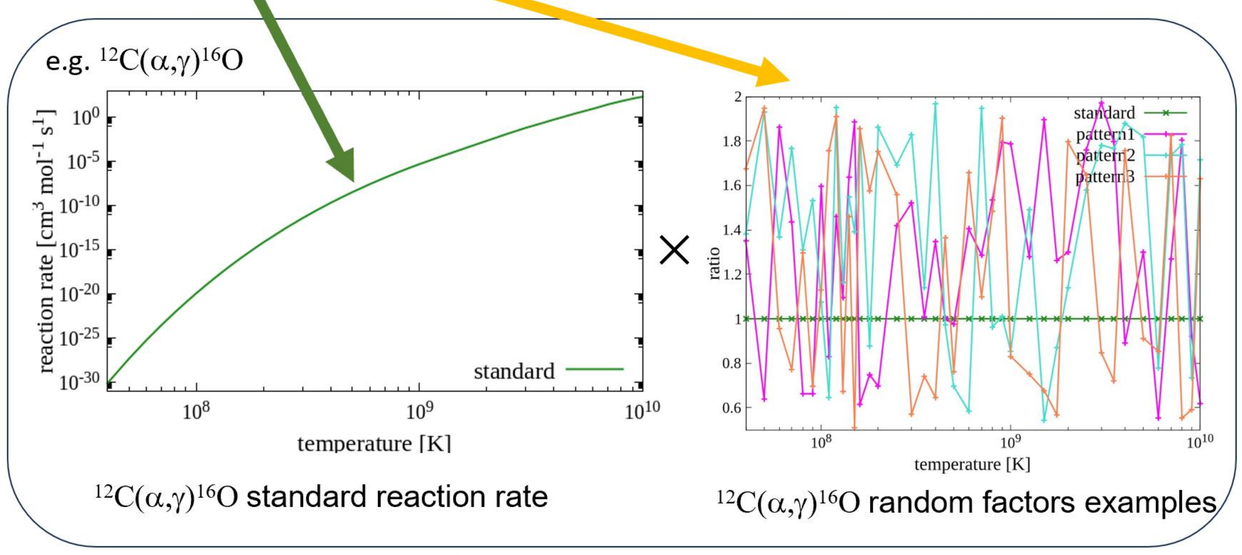
But, these reactions have large uncertainty above stellar evolution environment temperature...

When we observe PISN, what is the reaction rate at **"what temperature"** of this reaction that dominates this observational information?

→ Temperature-resolved Monte Carlo (MC) survey to find the **most important temperature**

Method

Calculate $p_{\rm std}(T)$ × $f_{\rm ptn}(T)$ → Generate randomized reaction rate



$^{12}C(\alpha,\gamma)^{16}O$ standard reaction rate

$^{12}C(\alpha,\gamma)^{16}O$ random factors examples

Using synthesized ^{56}Ni mass $M_{\rm 56Ni,ptn}$,

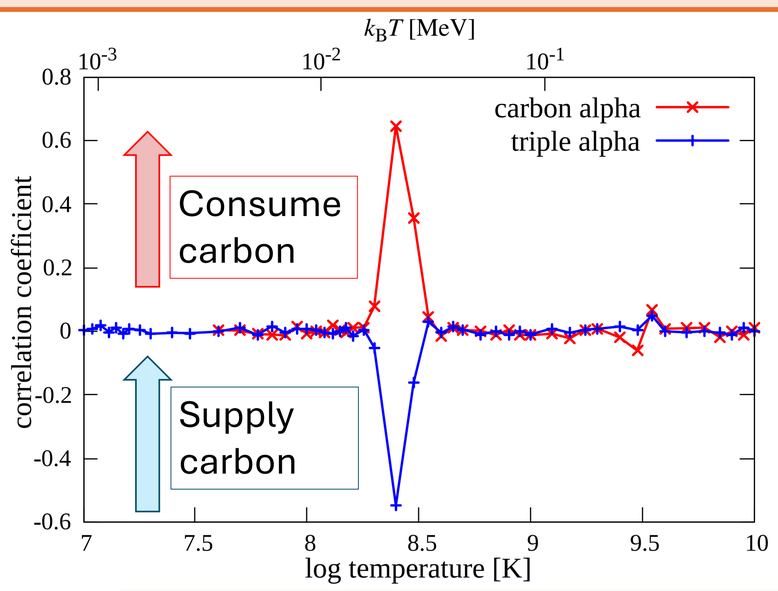
Temperature \ Pattern number	$M_{\rm 56Ni,ptn}$	$M_{\rm 56Ni,1}$	$M_{\rm 56Ni,2}$	$M_{\rm 56Ni,3}$	…
	$f_{\rm ptn}(T_1)$	$f_1(T_1)$	$f_2(T_1)$	$f_3(T_1)$	…
	$f_{\rm ptn}(T_2)$	$f_1(T_2)$	$f_2(T_2)$	$f_3(T_2)$	…
	$f_{\rm ptn}(T_3)$	$f_1(T_3)$	$f_2(T_3)$	$f_3(T_3)$	…
	$f_{\rm ptn}(T_4)$	$f_1(T_4)$	$f_2(T_4)$	$f_3(T_4)$	…
	…	…	…	…	…

We can calculate correlation coefficients $r(T_b)$ between $M_{\rm 56Ni,ptn}$ and each random factors $f_{\rm ptn}$ focusing on T_b as

$$r(T_b)=\frac{\frac{1}{n}\sum_{\rm ptn=1}^{n}\left(M_{\rm 56Ni,ptn}-\overline{M_{\rm 56Ni}}\right)\left(f_{\rm ptn}(T_b)-\overline{f_{\rm ptn}(T_b)}\right)}{\sqrt{\frac{1}{n}\sum_{\rm ptn=1}^{n}\left(M_{\rm 56Ni,ptn}-\overline{M_{\rm 56Ni}}\right)^2}\sqrt{\frac{1}{n}\sum_{\rm ptn=1}^{n}\left(f_{\rm ptn}(T_b)-\overline{f_{\rm ptn}(T_b)}\right)^2}}$$

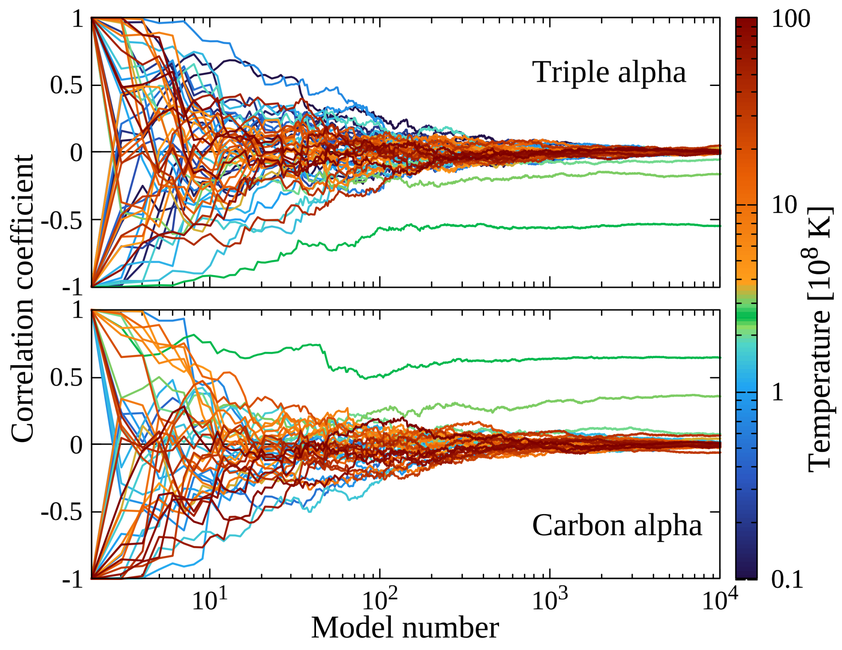
Stellar Evolution
(MESA: Paxton+ 2011 etc.)

Results: correlation coefficient



Correlation at 2.5×10^8 K!
Opposite signs for the two reactions!

Discussions: Convergence

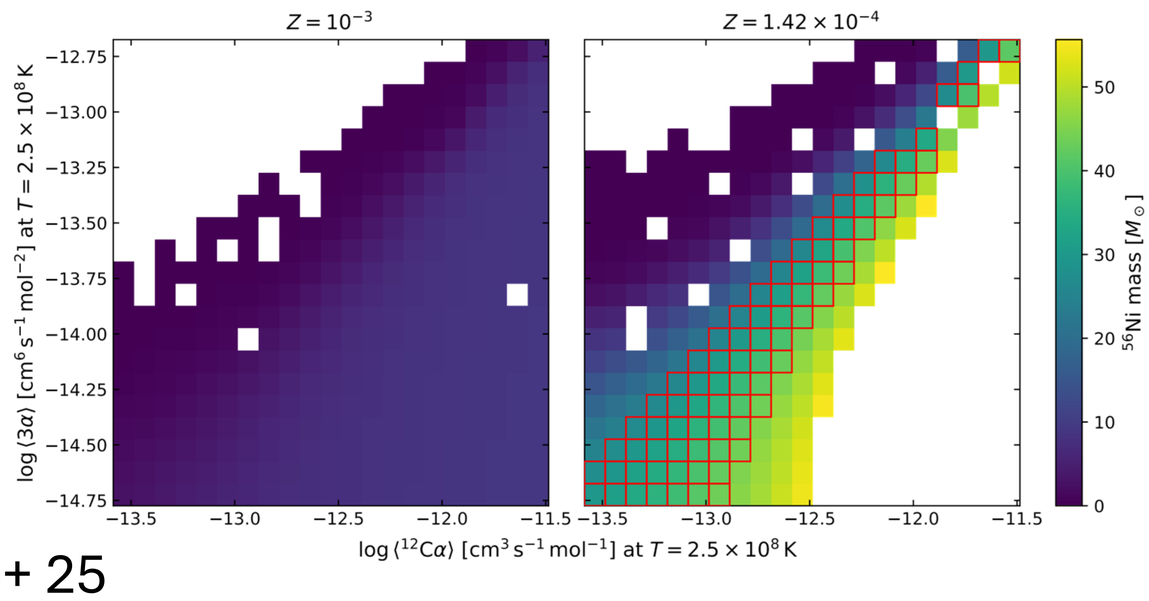


The correlation pattern is already apparent with ~10^2 models.

Discussions: 2018ibb

PISN obs. main contribution will be provided from $Z\sim10^{-3}$

Gabrielli+ 24, Simonato+ 25



SN 2018ibb: PISN strong candidate, 25-44 $M_\odot$ ^{56}Ni

Too large on $Z\sim10^{-3}$ even if considering the He burning reaction
→ SN 2018ibb is a rare case?