炭素「余熱」効果が対不安定型超新星に与える影響

初代星・初代銀河研究会2023
@北海道大学札幌キャンパス 2023/11/20

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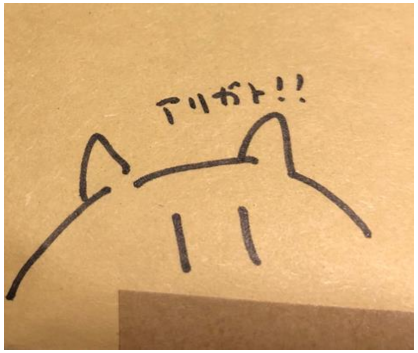

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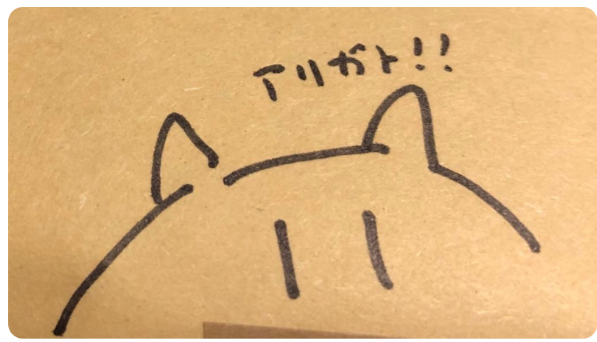
ホームページ作りました

h-Kawashimo.net



Home　Profile　Works　Debate　Link

これは川下大響のホームページです。天体物理の大学院生をしています。

This is Hiroki Kawashimo's Homepage. HK is a graduate school student researching in Astrophysics.

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お知らせ

2023/09/21　川下は11月20日から札幌で開催される初代星・初代銀河研究会2023に参加します。

HK will attend to 初代星・初代銀河研究会2023 in Sapporo.

論文出しました

https://arxiv.org/abs/2306.01682

MNRAS **000**, 1–16 (2023) Preprint 6 June 2023 Compiled using MNRAS LaTeX style file v3.0

Impacts of the $^{12}C(\alpha,\gamma)^{16}O$ reaction rate on ^{56}Ni nucleosynthesis in pair-instability supernovae

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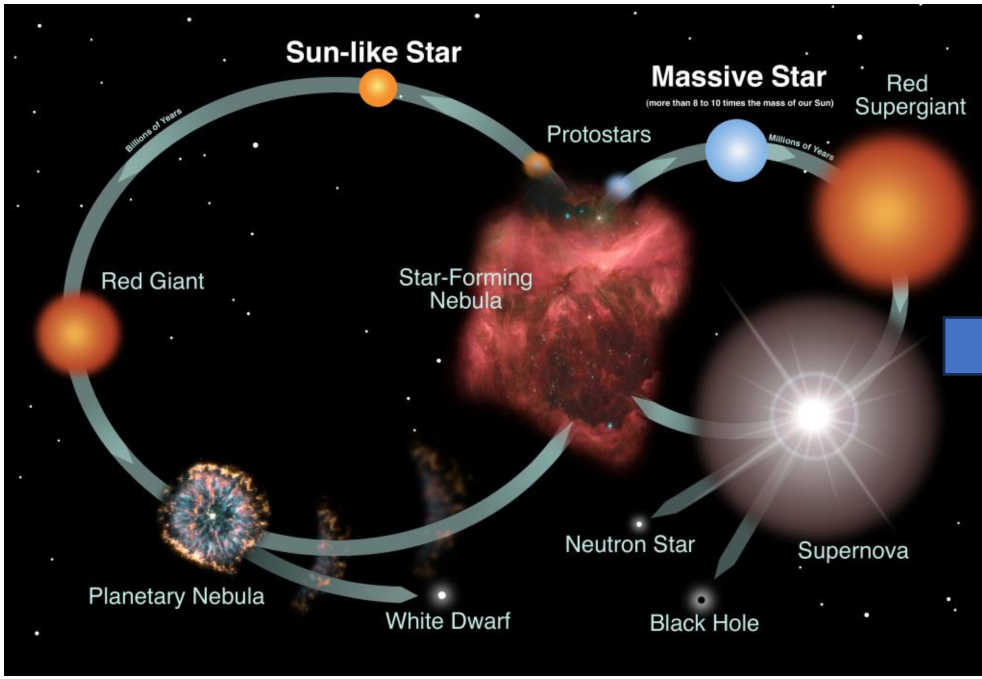
Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

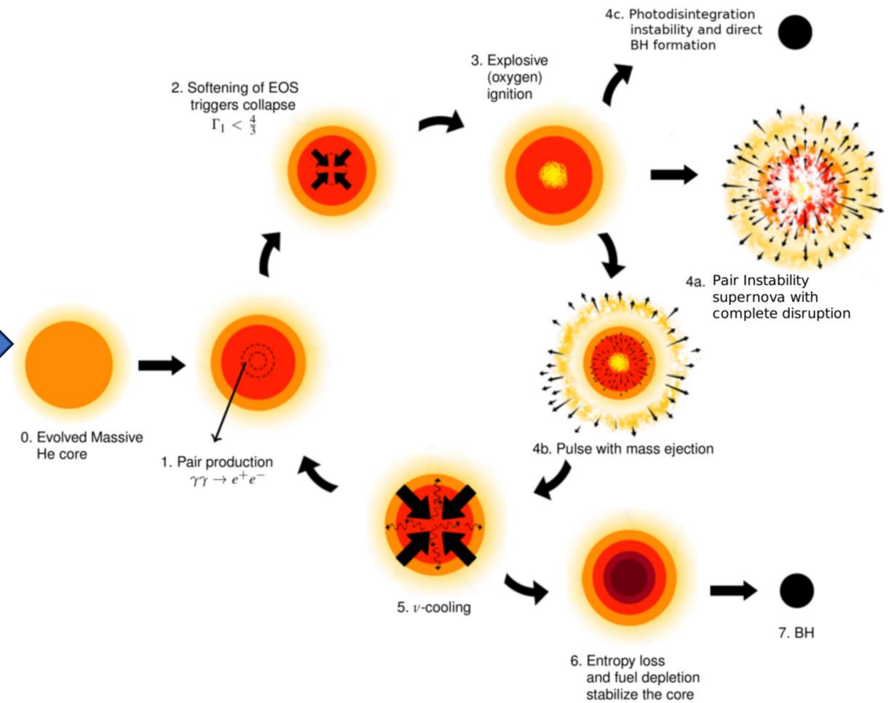
Nuclear reactions are key to our understanding of stellar evolution, particularly the $^{12}C(\alpha,\gamma)^{16}O$ rate, which is known to significantly influence the lower and upper ends of the black hole (BH) mass distribution due to pair-instability supernovae (PISNe). However, these reaction rates have not been sufficiently determined. We use the MESA stellar evolution code to explore the impact of uncertainty in the $^{12}C(\alpha,\gamma)^{16}O$ rate on PISN explosions, focusing on nucleosynthesis and explosion energy by considering the high resolution of the initial mass. Our findings show that the mass of synthesized radioactive nickel (^{56}Ni) and the explosion energy increase with $^{12}C(\alpha,\gamma)^{16}O$ rate for the same initial mass, except in the high-mass edge region. With a high (about twice the STARLIB standard value) rate, the maximum amount of nickel produced falls below 70 $M_\odot$, while with a low rate (about half of the standard value) it increases up to 83.9 $M_\odot$. These results highlight that carbon burning plays a crucial role in PISNe by determining when a star initiates expansion. The initiation of expansion competes with collapse caused by helium photodisintegration, and the maximum mass that can lead to an explosion depends on the $^{12}C(\alpha,\gamma)^{16}O$ reaction rate.

Key words: stars: massive – supernovae: general – stars: evolution – nuclear reactions, nucleosynthesis, abundances

Introduction
Final fates of stars



NASA

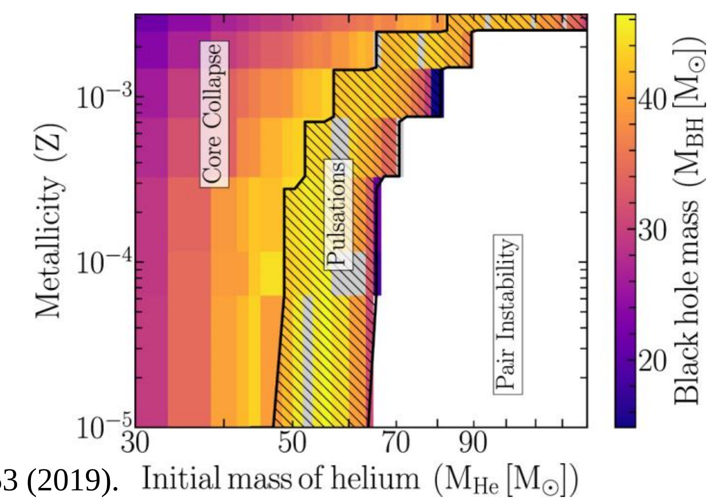


M. Renzo *et al.* A&A **640**, A56 (2020)

Final fate of ZAMS 140-260$M_\odot$ Very massive star

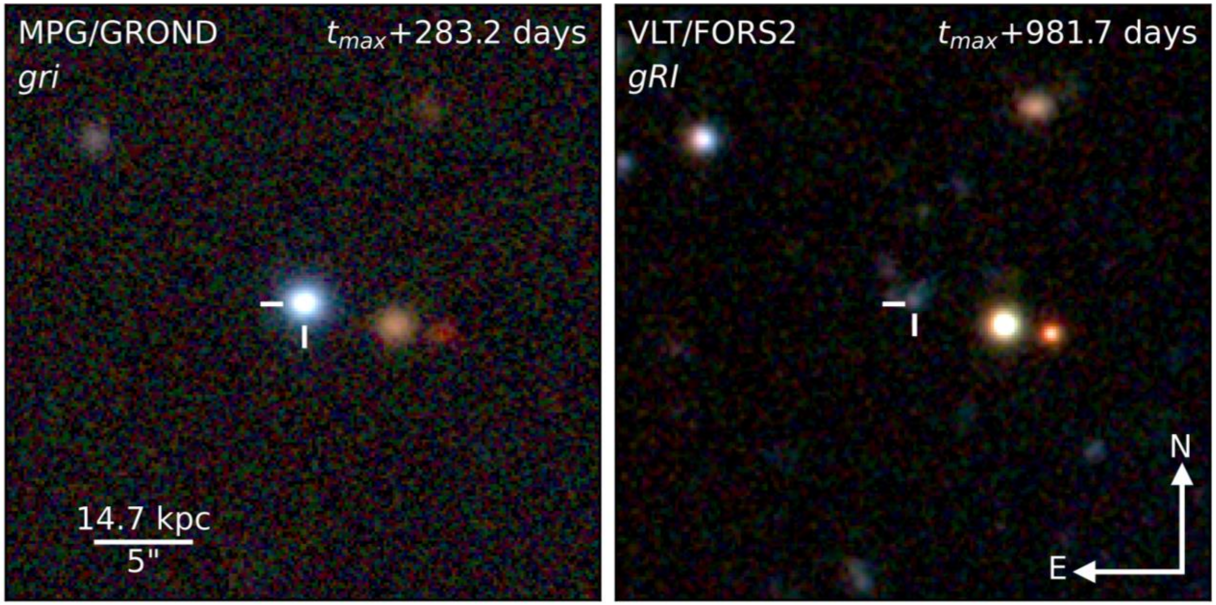
→Pair-instability supernova

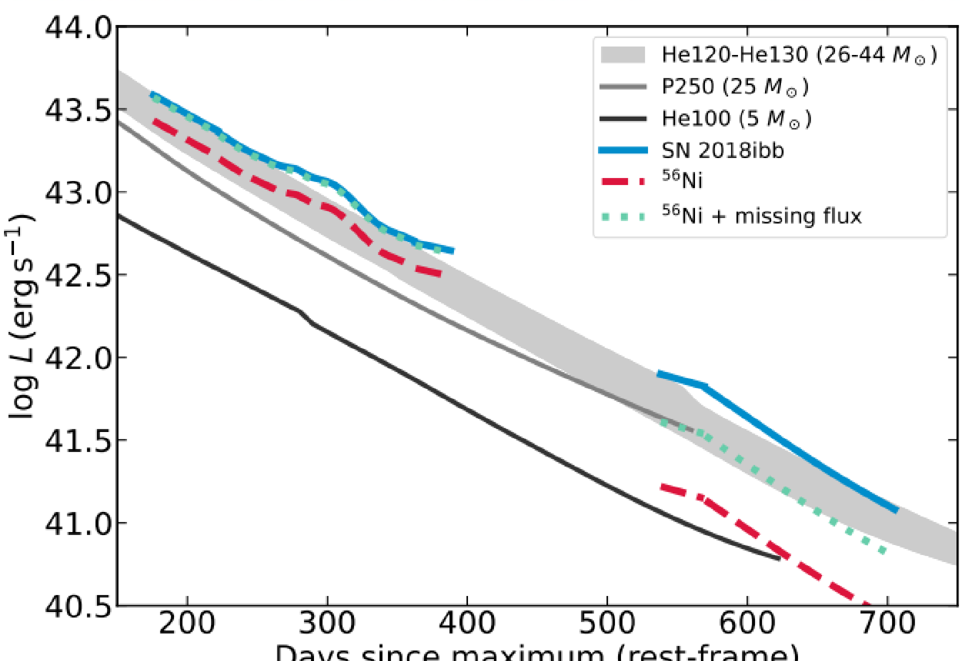
Complete destruction →No compact object (remnant)



R. Farmer *et al.* ApJ. **887**, 53 (2019).

Introduction
PISN best candidate





SN 2018ibb

S. Schulze *et al.* arXiv:2305.05796 (2023).

Astronomy & Astrophysics manuscript no. paper ©ESO 2023
May 11, 2023

1100 Days in the Life of the Supernova 2018ibb — the Best Pair-Instability Supernova Candidate, to date

Steve Schulze[1★], Claes Fransson[2], Alexandra Kozyreva[3], Ting-Wan Chen[4,5,6], Ofer Yaron[7], Anders Jerkstrand[2], Avishay Gal-Yam[7], Jesper Sollerman[2], Lin Yan[8], Tuomas Kangas[9,10], Giorgos Leloudas[11], Conor M. B. Omand[2], Stephen J. Smartt[12,13], Yi Yang (杨轶)[14], Matt Nicholl[15,13], Nikhil Sarin[16,1], Yuhan Yao[17], Thomas G. Brink[14], Amir Sharon[7], Andrea Rossi[18], Ping Chen[7], Zhihao Chen[19], Aleksandar Cikota[20], Kishalay De[★★21], Andrew J. Drake[17], Alexei V. Filippenko[14], Christoffer Fremling[8], Laurane Fréour[22], Johan P. U. Fynbo[23], Anna Y. Q. Ho[24], Cosimo Inserra[25], Ido Irani[7], Hanindyo Kuncarayakti[26,27], Ragnhild Lunnan[2], Paolo Mazzali[28,5], Eran O. Ofek[7], Eliana Palazzi[18], Daniel A. Perley[28], Miika Pursiainen[11], Barry Rothberg[29,30], Luke J. Shingles[31], Ken Smith[13], Kirsty Taggart[32], Leonardo Tartaglia[33,34], WeiKang Zheng[14], Joseph P. Anderson[35,36], Letizia Cassara[37], Eric Christensen[47], S. George Djorgovski[17], Lluís Galbany[38,39], Anamaria Gkini[2], Matthew J. Graham[17], Mariusz Gromadzki[40], Steven L. Groom[41], Daichi Hiramatsu[42,48], D. Andrew Howell[43,44], Mansi M. Kasliwal[17], Curtis McCully[43], Tomás E. Müller-Bravo[38,39], Simona Paiano[37], Emmanouela Paraskeva[45], Priscila J. Pessi[2], David Polishook[7], Arne Rau[6], Mickael Rigault[46], and Ben Rusholme[41]

(Affiliations can be found after the references)

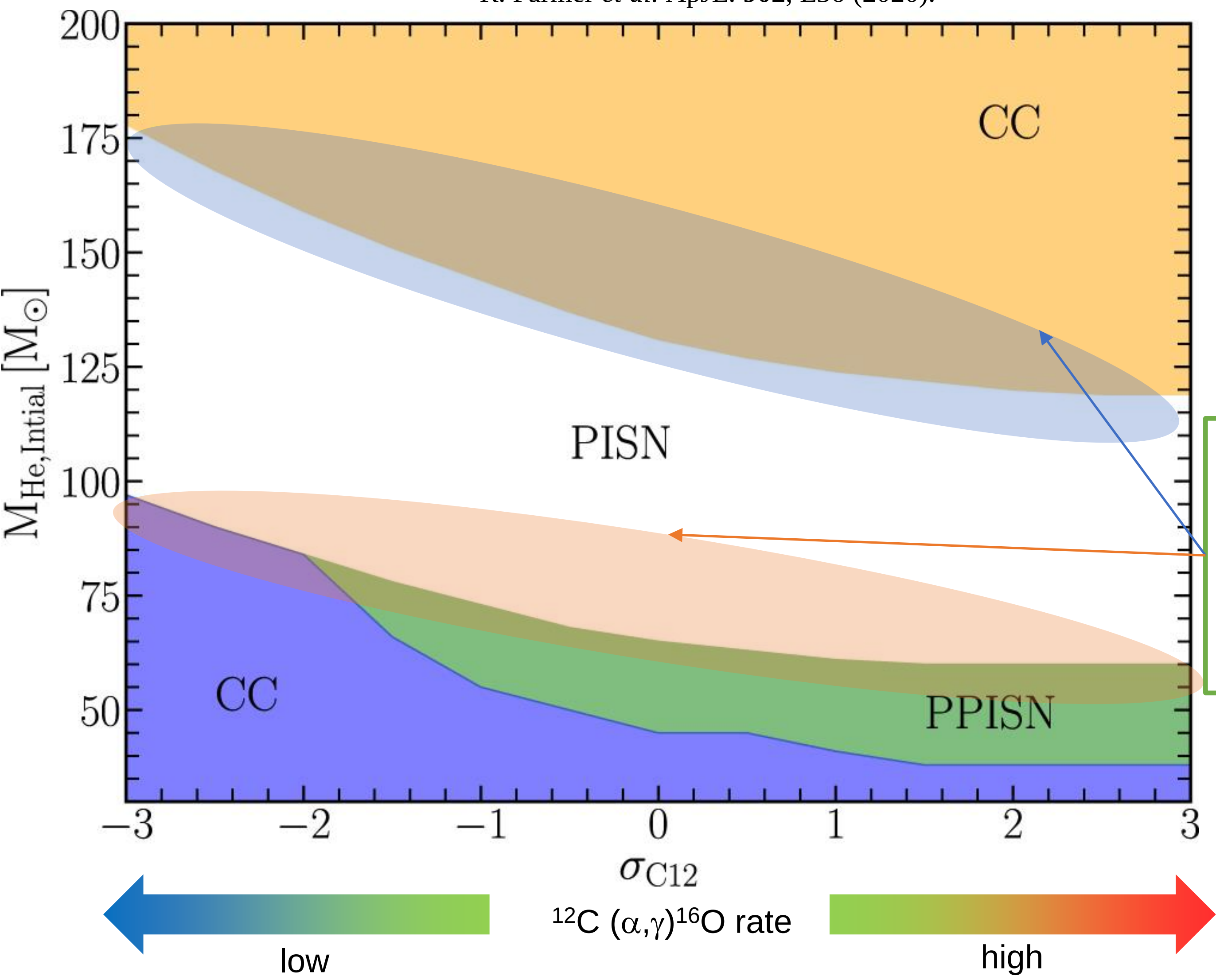
Received XXX; accepted XXX

ABSTRACT

Stars with zero age main sequence masses between 140 and 260 $M_\odot$ are thought to explode as pair-instability supernovae (PISNe). During their thermonuclear runaway, PISNe can produce up to several tens of solar masses of radioactive nickel, resulting in luminous transients similar to some superluminous supernovae (SLSNe). Yet, no unambiguous PISN has been discovered so far. SN 2018ibb is a hydrogen-poor SLSN at z = 0.166 that evolves extremely slowly compared to the hundreds of known SLSNe. Between mid 2018 and early 2022, we monitored its photometric

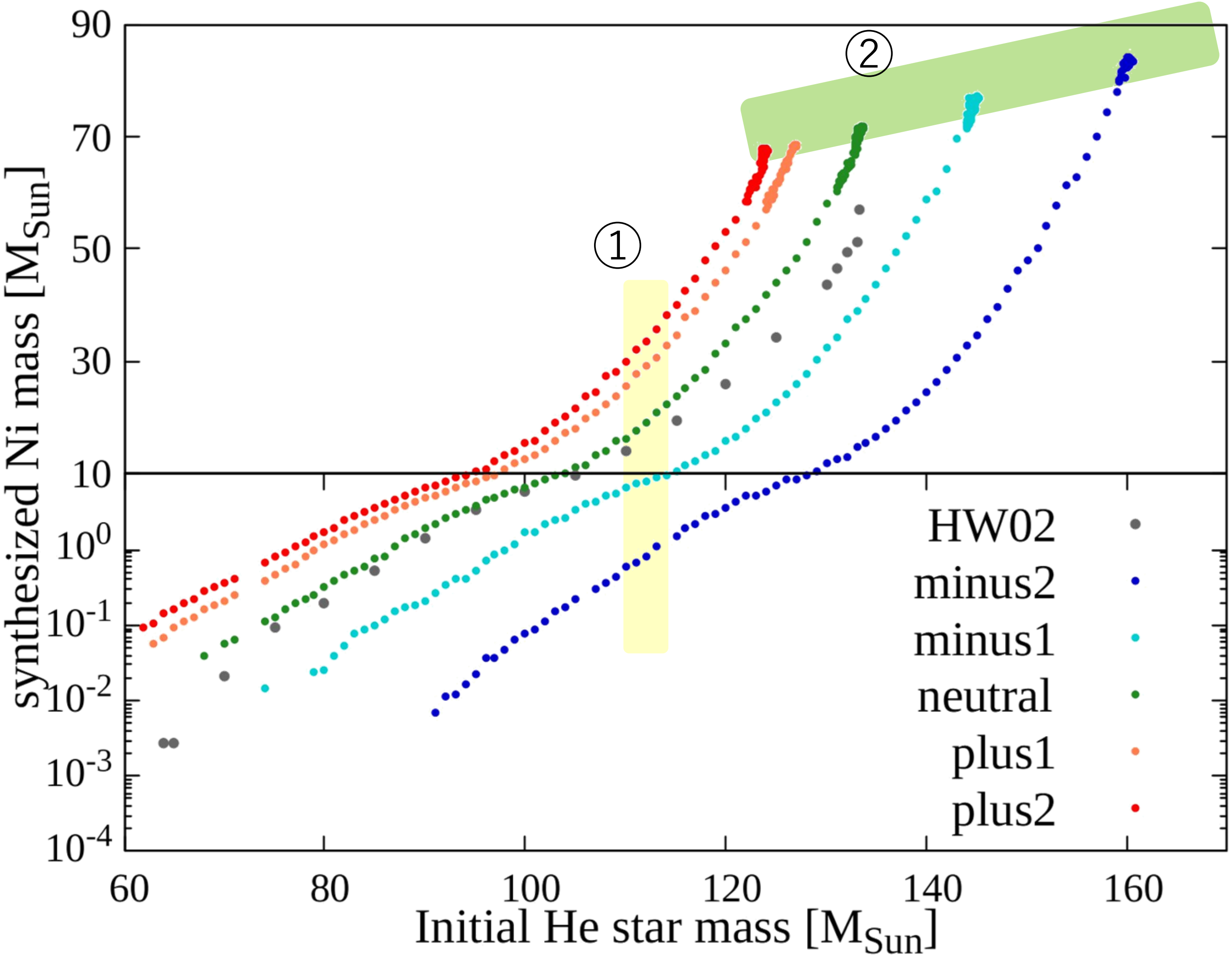
Motivation
PISN upper/lower limits

R. Farmer *et al.* ApJL. **902**, L36 (2020).



なぜこのように反応率に対し傾く応答をする？

Motivation (前回のおさらい)
Ni synthesis



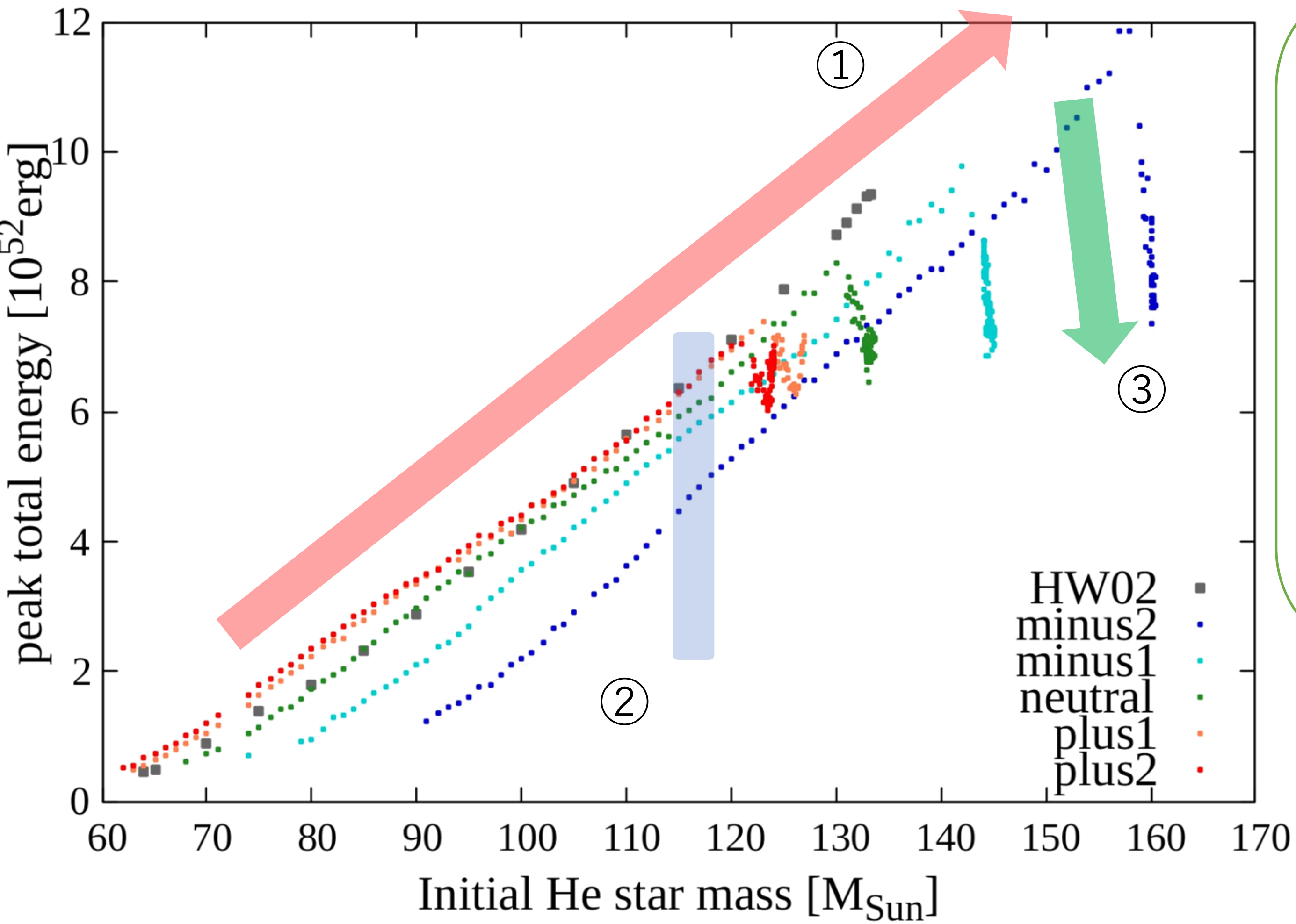
(HW02: A. Heger & S. E. Woosley ApJ. **567**, 532 (2002))

① High reaction rate→more Ni

② Maximum amount is larger for lower rates (Max 84.5$M_\odot$ for the -2σ group!)

H. Kawashimo *et al.* arXiv:2306.01682 (2023)

Motivation (前回のおさらい)
explosion energy



(HW02: A. Heger & S. E. Woosley ApJ. **567**, 532 (2002))

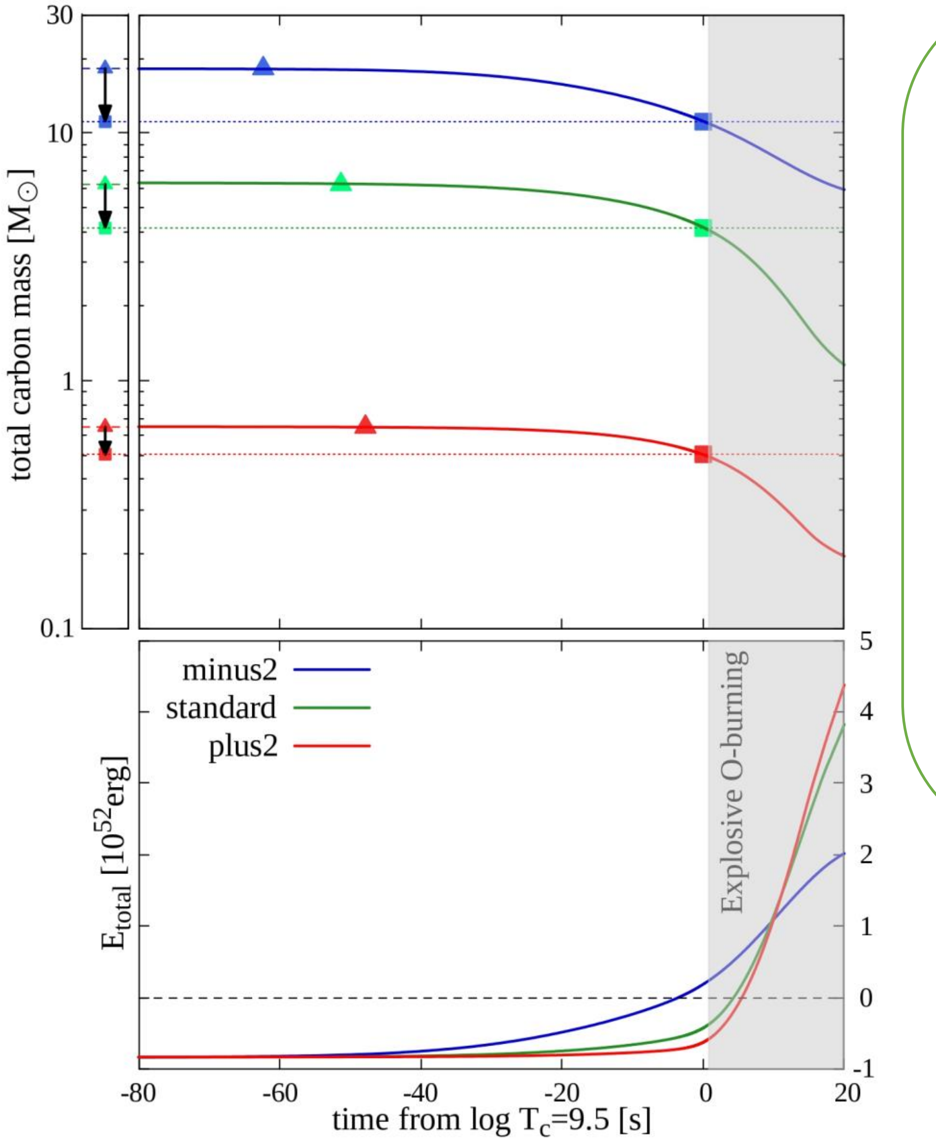
① Expl. energy ∝ Progenitor mass

② High reaction rate →High expl. Energy

③ Energy “dropping” feature in high mass!

H. Kawashimo *et al.* arXiv:2306.01682 (2023)

Motivation (秋天文学会のおさらい)
Carbon "pre-heating"



H. Kawashimo *et al.* arXiv:2306.01682 (2023)

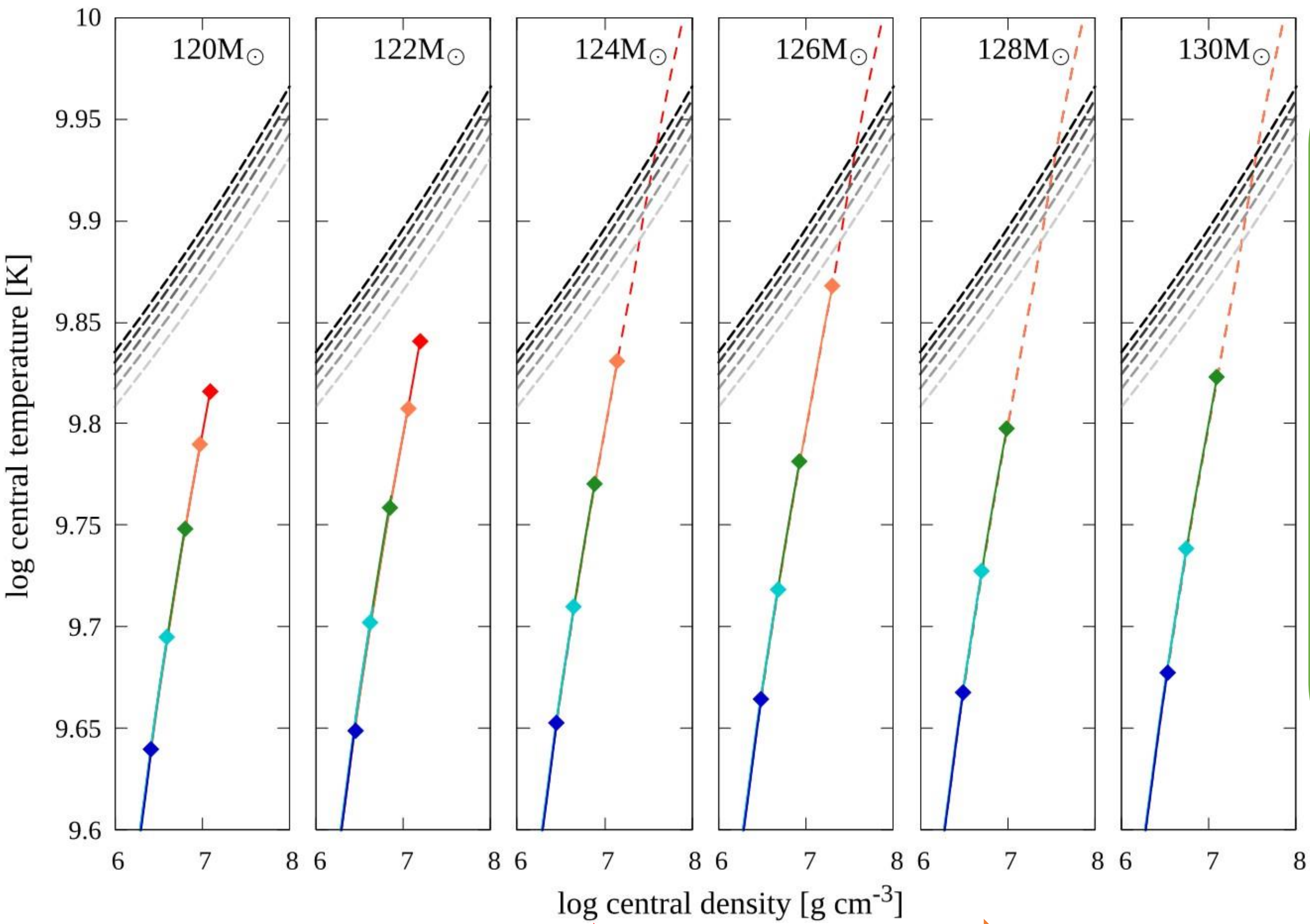
- ▲：start C+C burn, ■: start O+O burn

Upside: carbon remaining

Downside: total energy evolution

- Remain more carbon => gain more energy before O+O main burning!

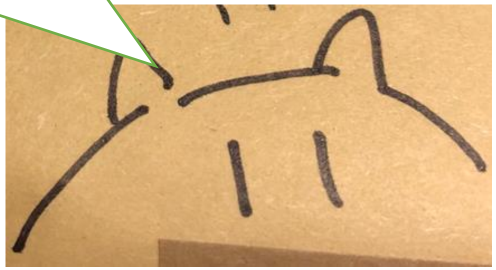
Motivation (秋天文学会のおさらい)
“Pre-heating” shifts limit point



+2σ case killed!

+1σ case killed!

- ◆: start expansion point
- Dashed: PISN failed cases (CC)
- Dashed grey lines: He-pnpn photodisintegration (He 97%-93%)
- “Pre-heating” effect shifts the limit point to the massive side



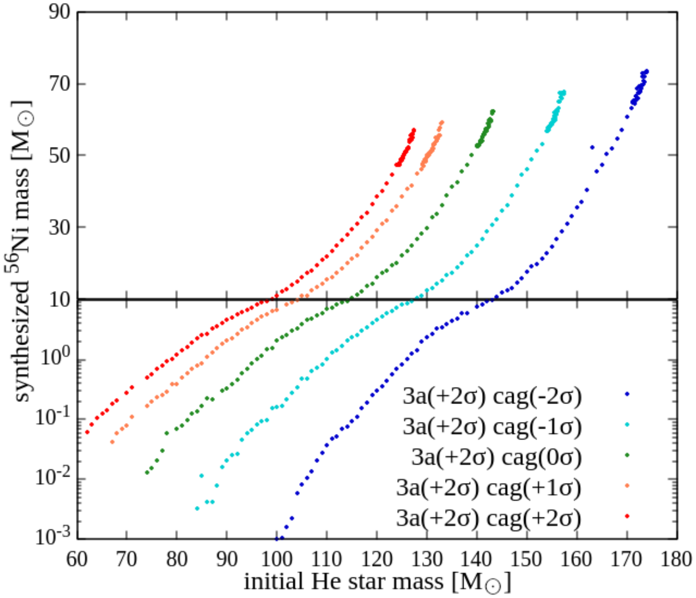
In this work…

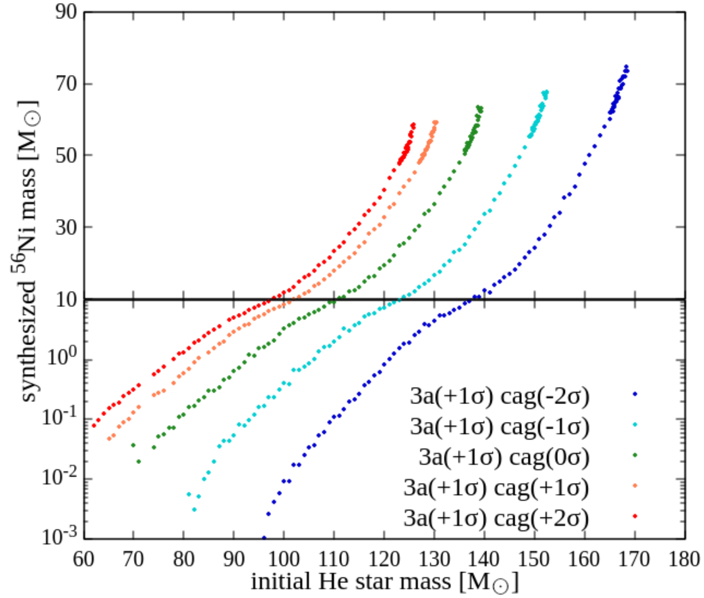
- 3α-> supply ^{12}C (CO core total mass)
- $^{12}C(\alpha,\gamma)^{16}O$-> turn ^{12}C to ^{16}O (C/O ratio)

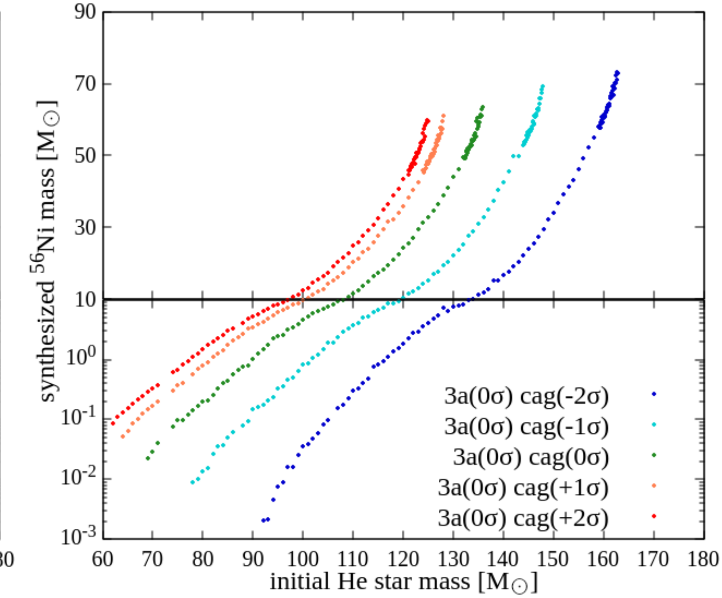
Is 3α rate effective for nickel synthesis?

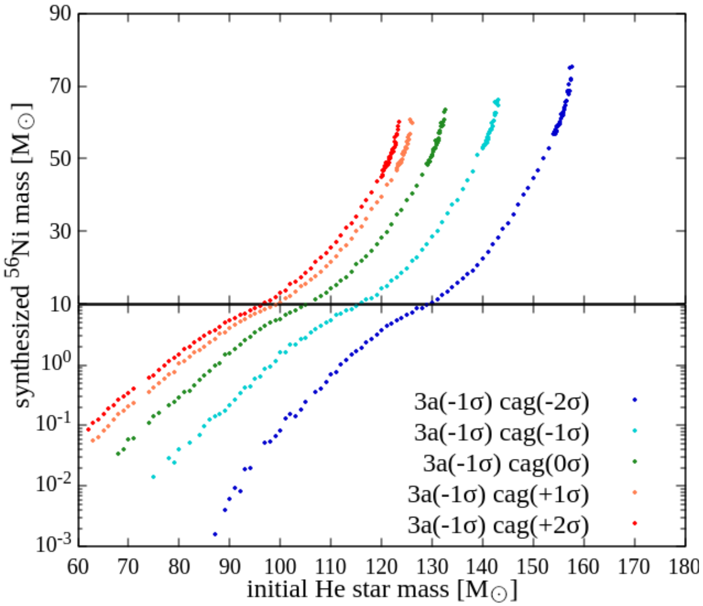
-> Calculation with both 3α and $^{12}C(\alpha,\gamma)^{16}O$ changed

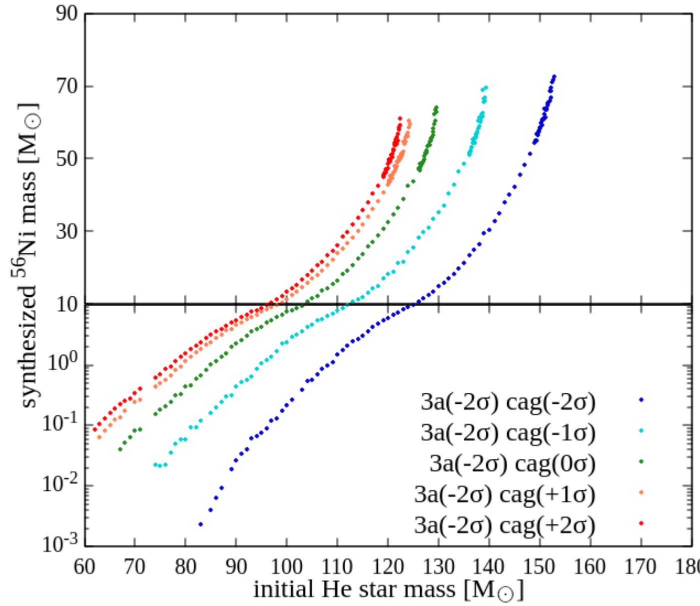
Results
nickel production (3α fixed)



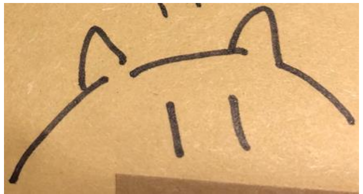






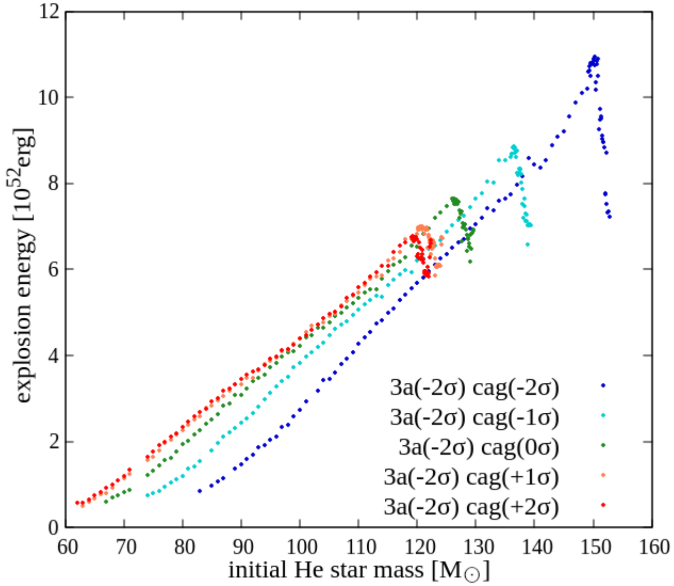


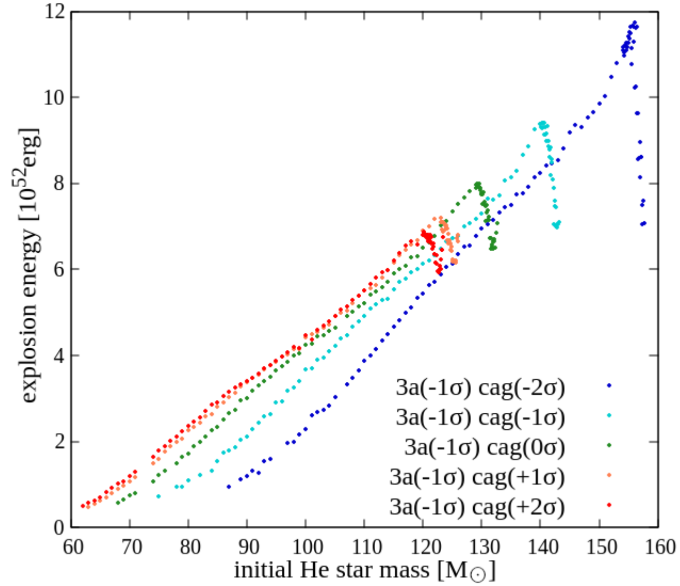
Almost same structure

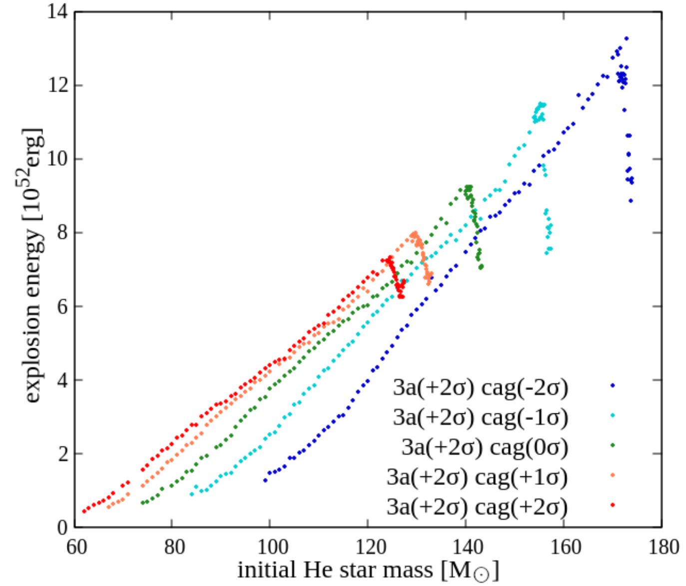


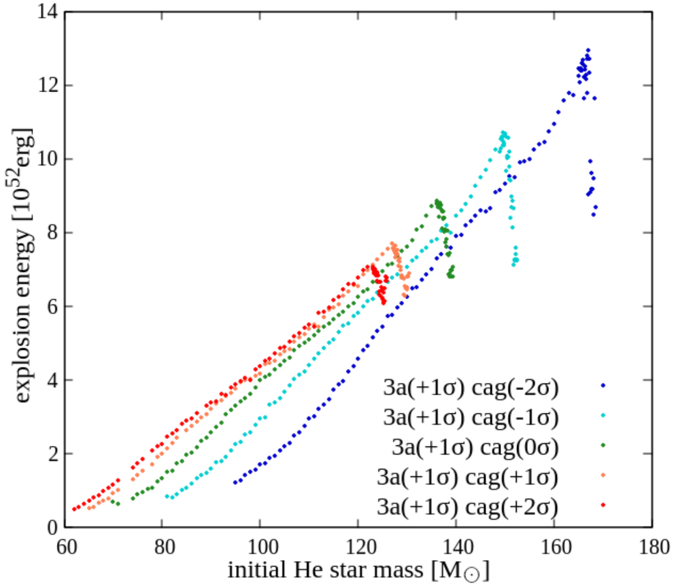
Results

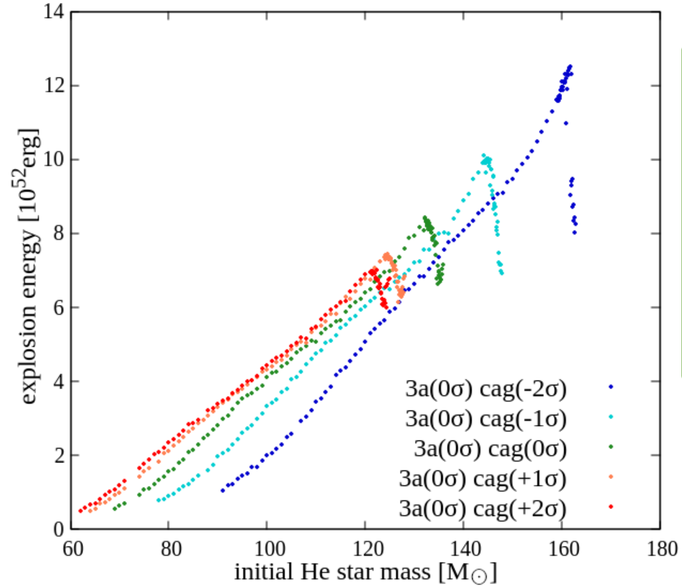
total energy (3α fixed)











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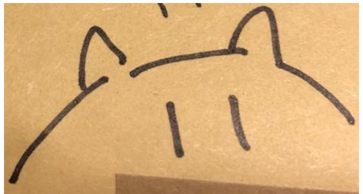
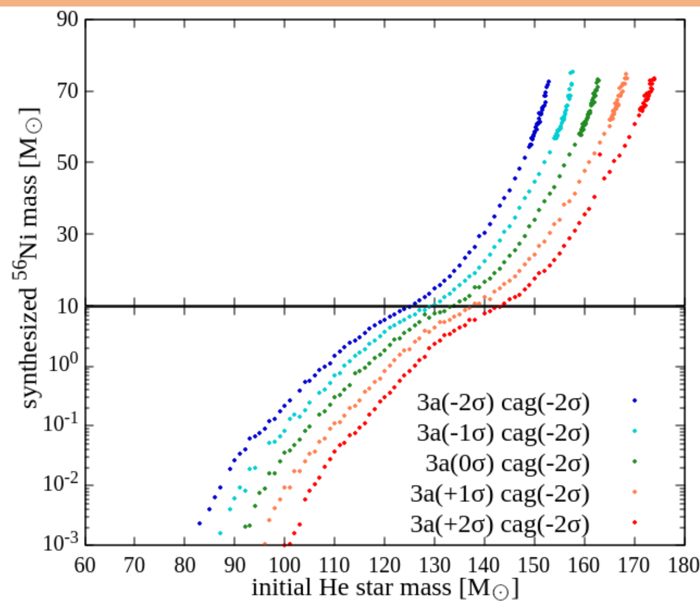
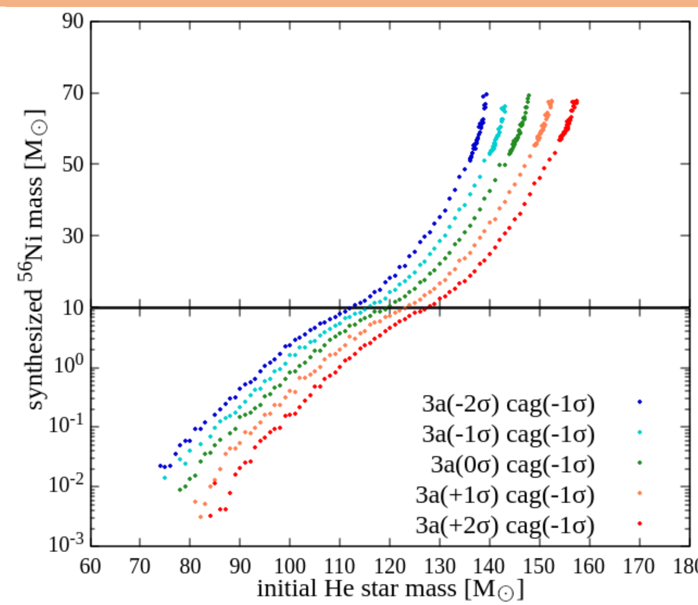
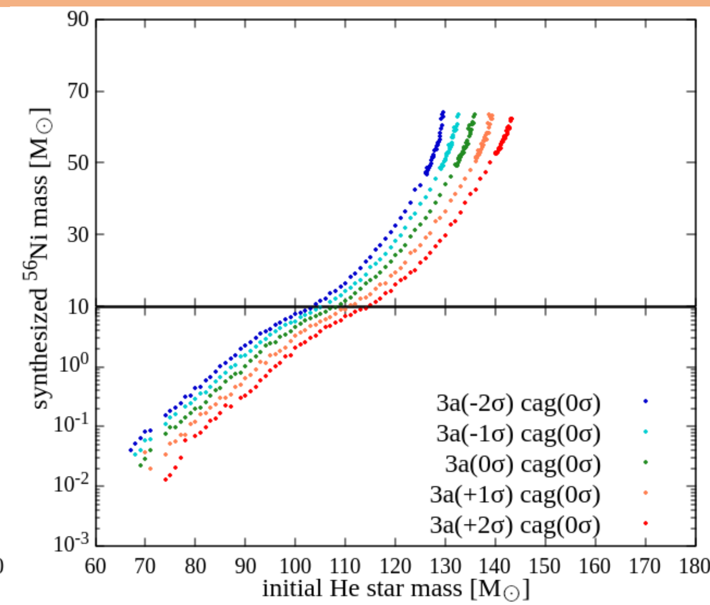


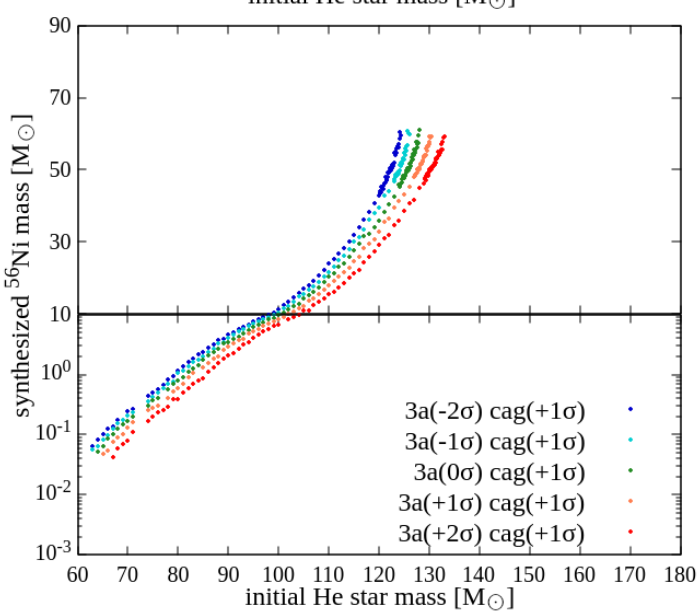
Results

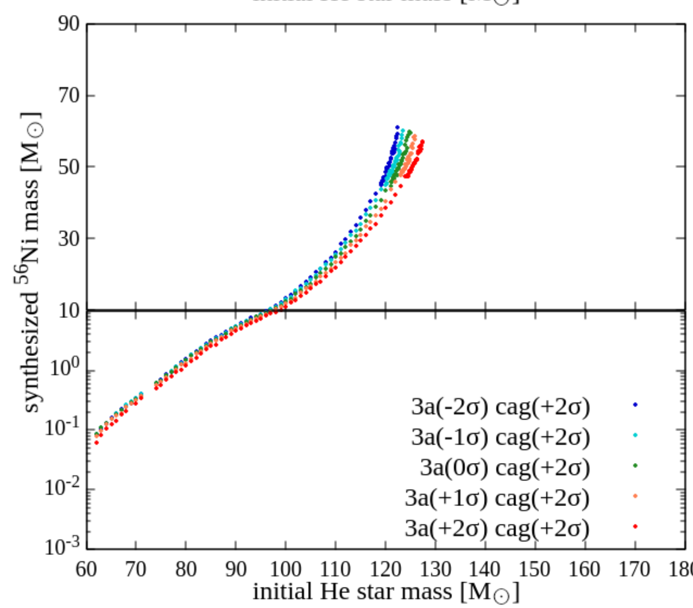
nickel production ($^{12}C(\alpha,\gamma)^{16}O$ fixed)



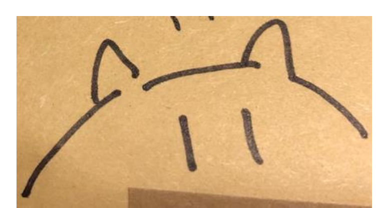






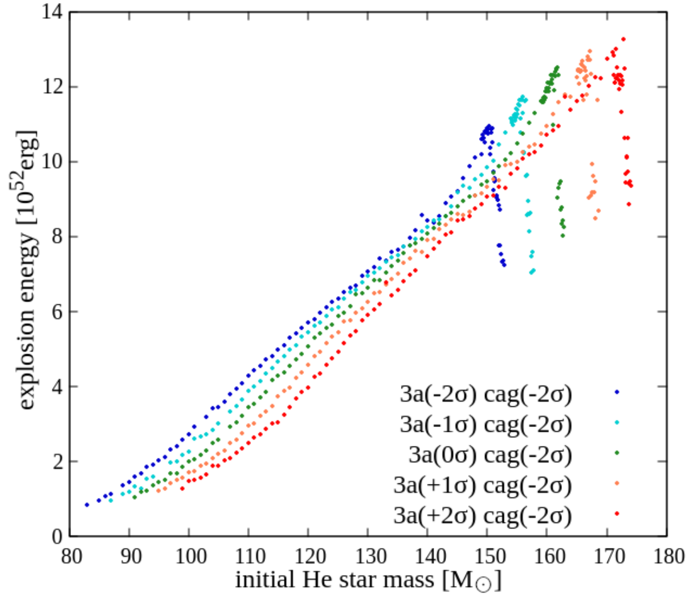


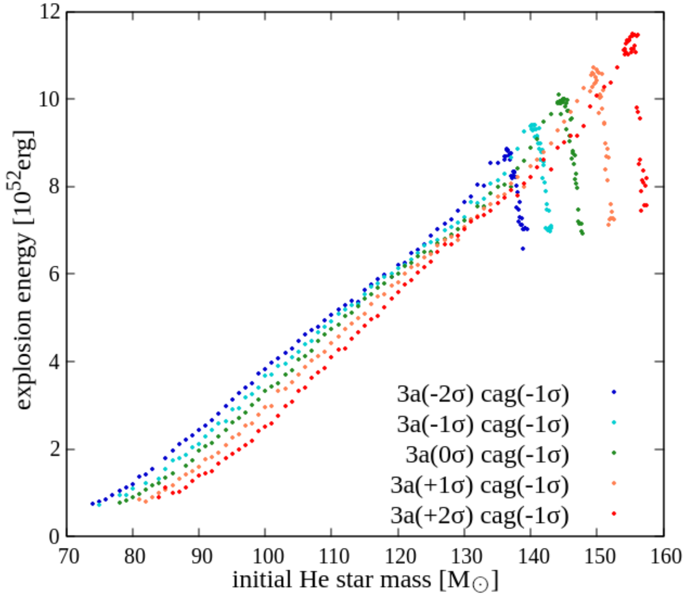
High cag->3α independent!
No hierarchical structure

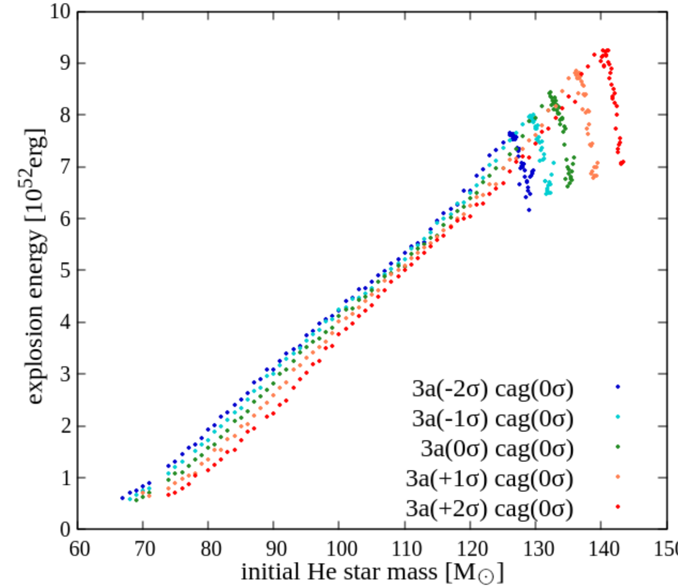


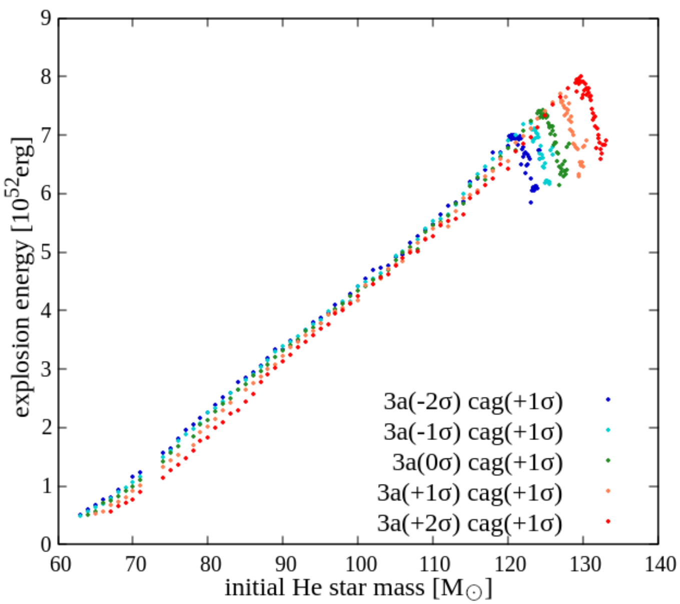
Results

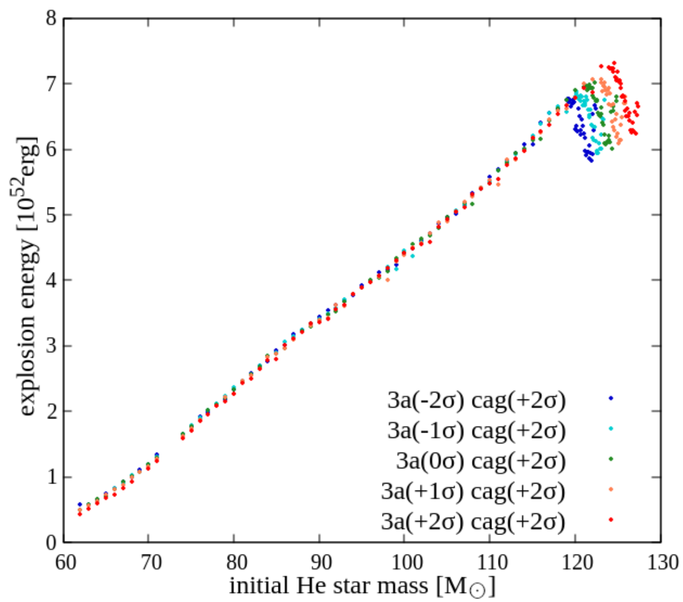
total energy ($^{12}C(\alpha,\gamma)^{16}O$ fixed)



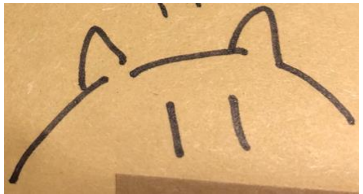




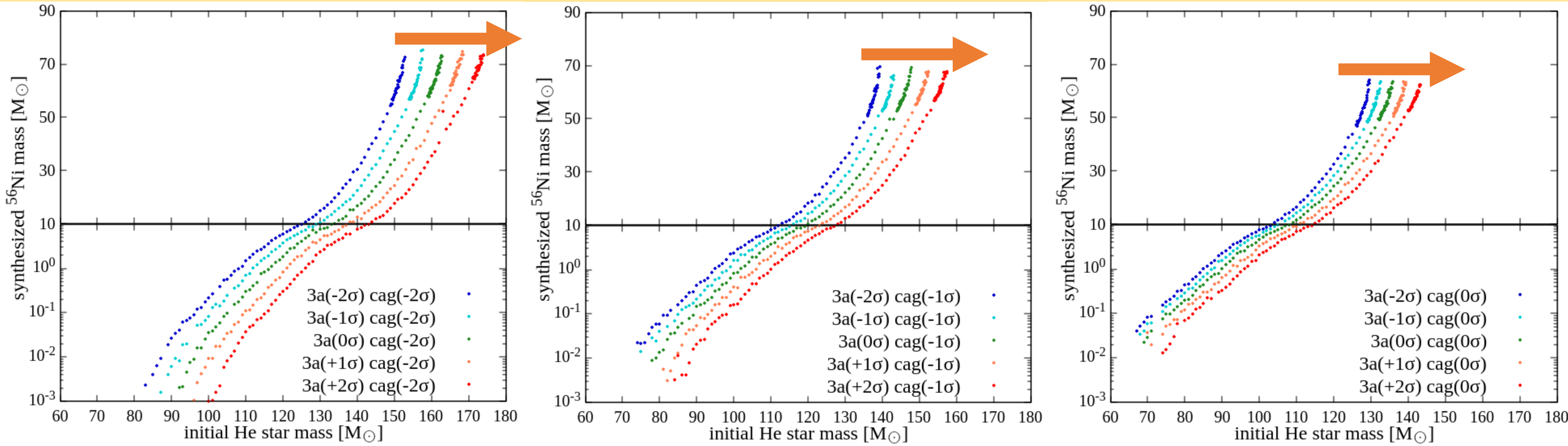


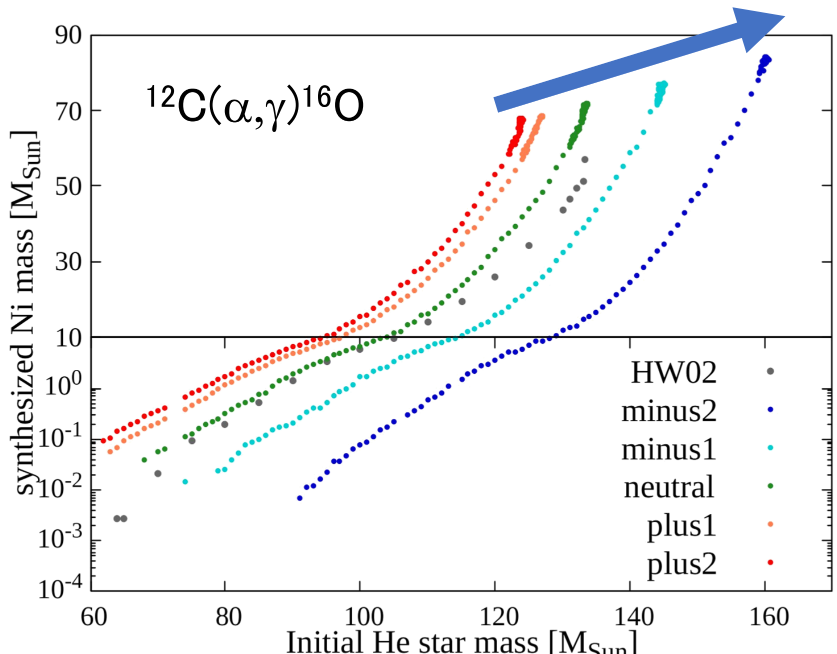


High cag->3α independent
No hierarchical structure



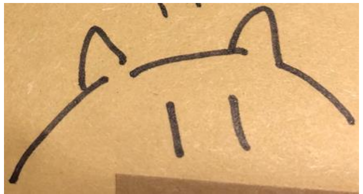
Discussion -1



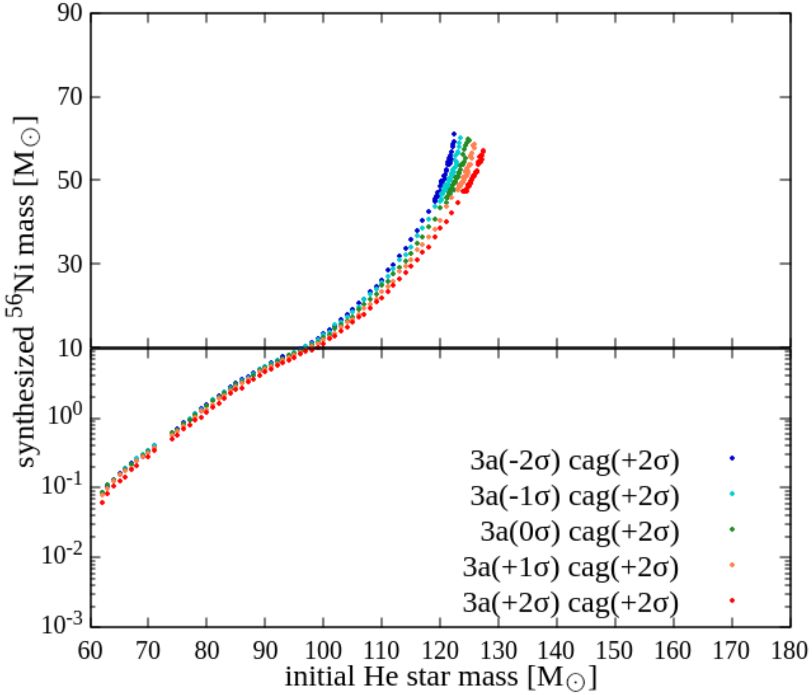


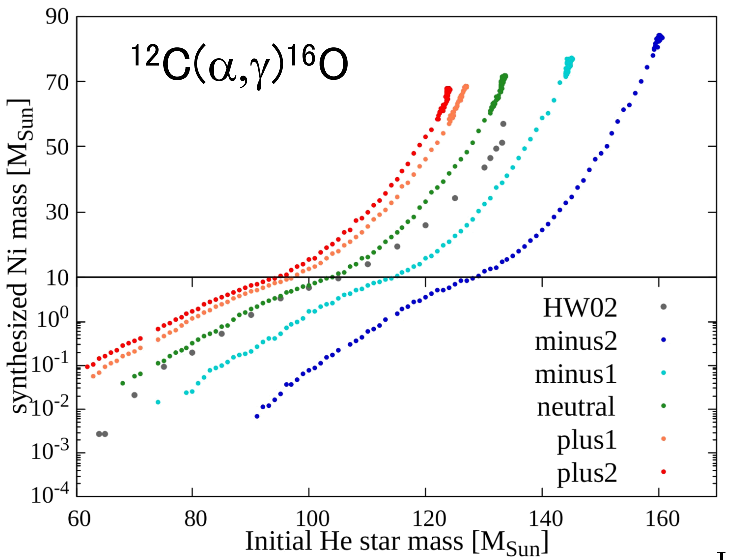
No ↗ feature? (The highest amount of nickel produced in each series)
: ↗ feature is independent from "pre-heating"?

H. Kawashimo *et al.* arXiv:2306.01682 (2023)



Discussion -2





With high $^{12}C(\alpha,\gamma)^{16}O$ rate, all series have same lines.

high $^{12}C(\alpha,\gamma)^{16}O$ rate
➔ Carbon depression?
➔ low "pre-heating"?

However: explodable mass range shift

H. Kawashimo *et al.* arXiv:2306.01682 (2023)

Summary

Motivation

- PISNは$^{12}C(\alpha,\gamma)^{16}O$反応率を振ると爆発範囲やニッケル生成量、爆発エネルギー量に変化

- この原因は炭素「予熱」効果で、$^{12}C(\alpha,\gamma)^{16}O$反応率が低いと炭素が多く残るので、PISNの主エネルギーである酸素より先に燃える

- 炭素量を決定するのは$^{12}C(\alpha,\gamma)^{16}O$のみならず、3$\alpha$も影響。同時に変えたら？

Result and Discussion

- $^{12}C(\alpha,\gamma)^{16}O$が変化する場合、おおかた3$\alpha$によらず同じようなふるまい

- $^{12}C(\alpha,\gamma)^{16}O$が高いとき、3$\alpha$を変化させてもほかでみられるようなhierarchicalな構造がない

- 3αが変化しても、系統ごとの最高生成ニッケル量は影響を受けない