MICHIGAN STATE UNIVERSITY

Comparing electron-capture rates in CCSNe simulations

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TEAMS SciDAC - 02 Aug 2021

Background

1. Electron-capture
2. Core-collapse
3. Rates

Electron Capture (EC)

$$\mathrm{p}^{+} + \mathrm{e}^{-} \rightarrow \mathrm{n} + \nu_{\mathrm{e}}$$

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- Turns **protons** into **neutrons**
- Produces **neutrinos**
- Removes leptons from the system (**deleptonization**)

Role in CCSNe

- Drives **deleptonization** during collapse

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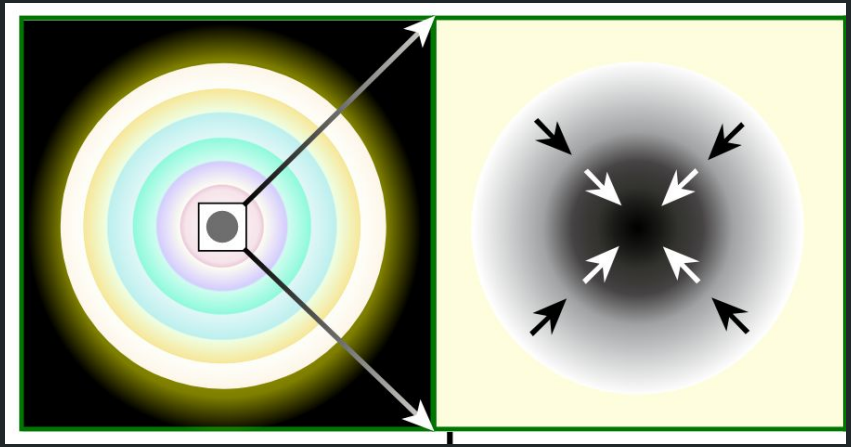
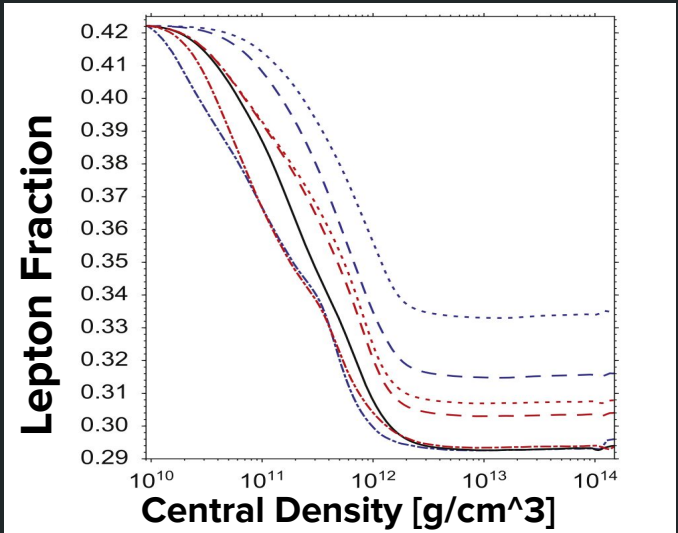


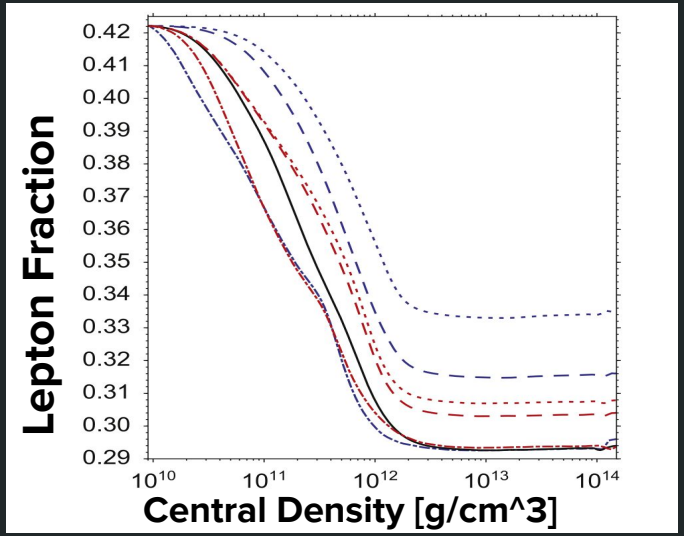
[R. J. Hall]



[Titus+ 2018]

Electron Capture (EC) Rates

- Regulate **deleptonization**



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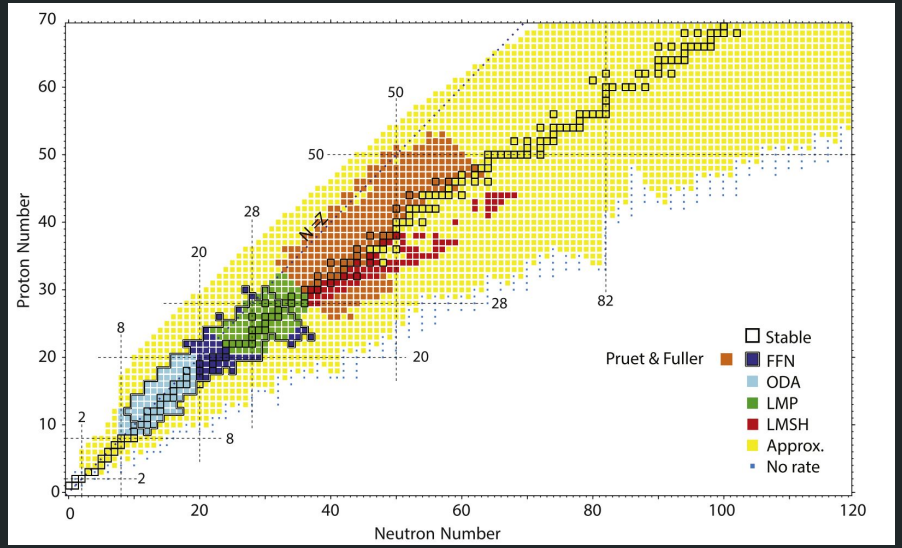

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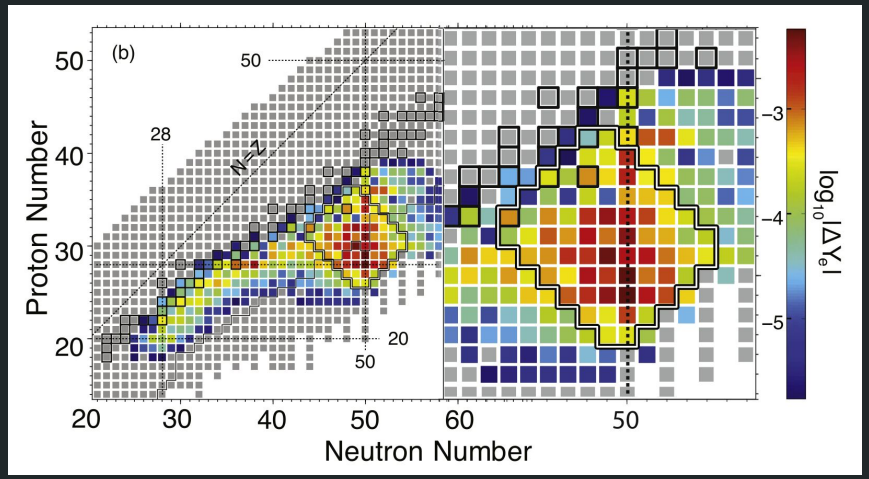

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How do rates impact CCSNe properties?

Methods

1. Rate tables
2. Progenitors
3. Models

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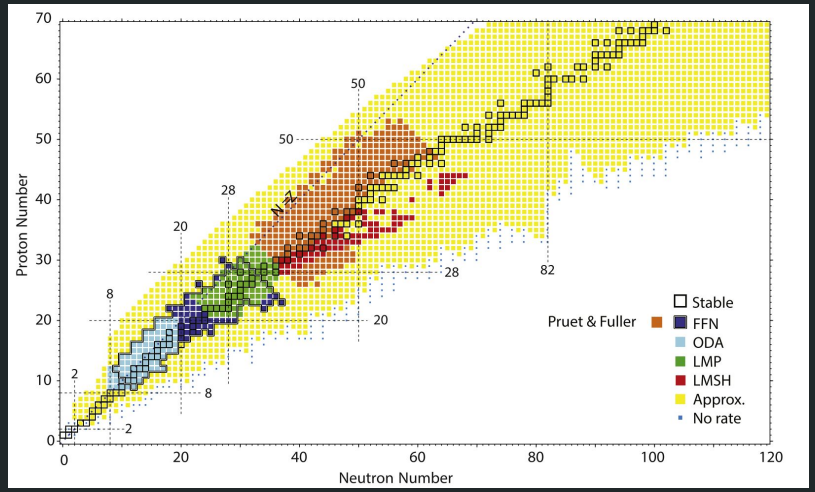

[Titus+ 2016]

EC Rate Tables

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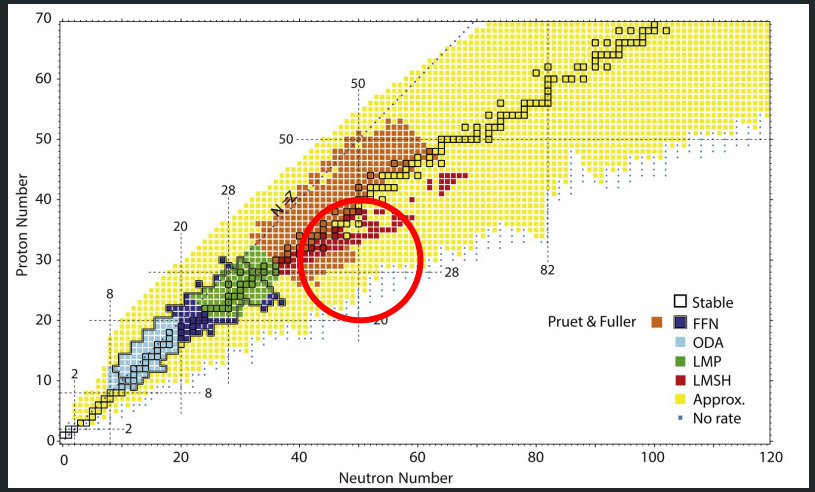
3. **LMP+N50:** updated lab measurements (Titus+ 2019)



[Titus+ 2016]

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- Run for 1 - 5 s

Model Set

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- **200** progenitors: **9 - 120 $M_\odot$**
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  - solar metallicity
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- **200** progenitors: **9 - 120 $M_\odot$**
  - 1D (Sukhbold+ 2016)
  - solar metallicity
  - non-rotating
- Total **600** simulations

Results

1. Explosion outcomes
2. Core properties
3. Neutrinos

Explosion Outcomes

- **SNA**: 43 explosions
- **LMP**: 71 explosions
- **LMP+N50**: 73 explosions

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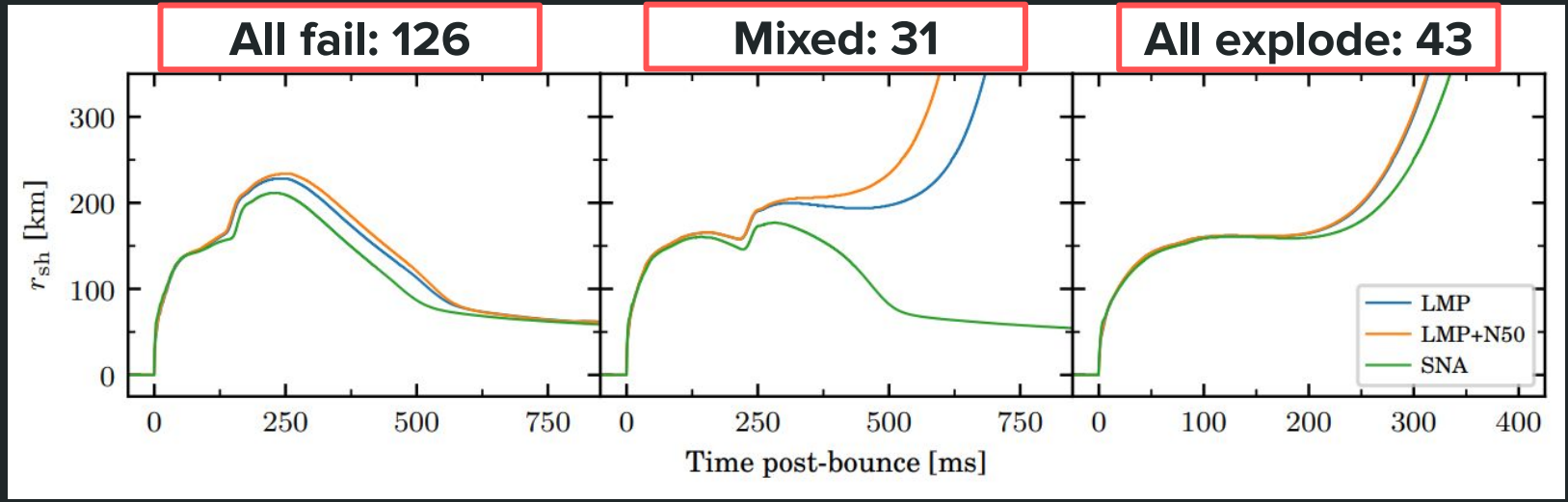
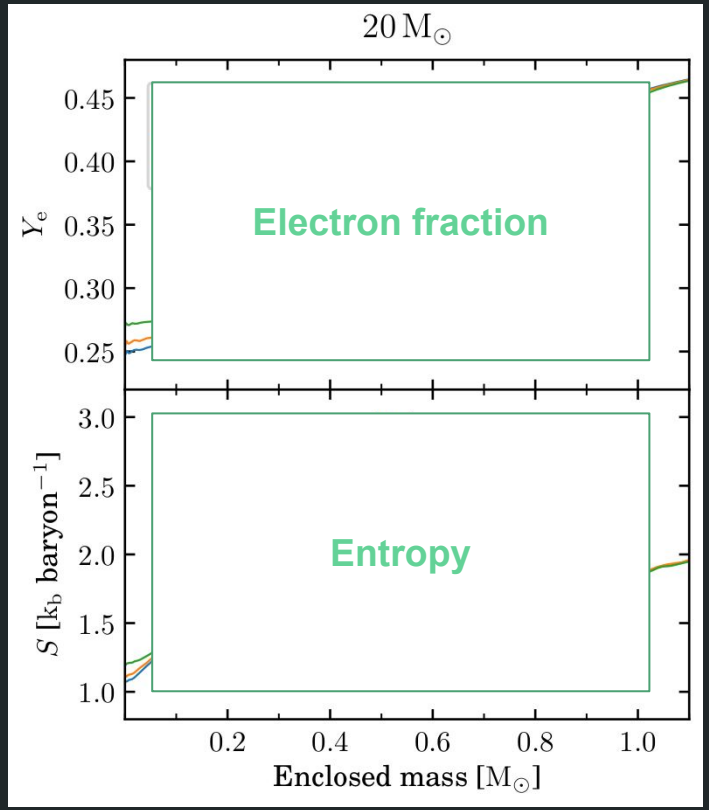
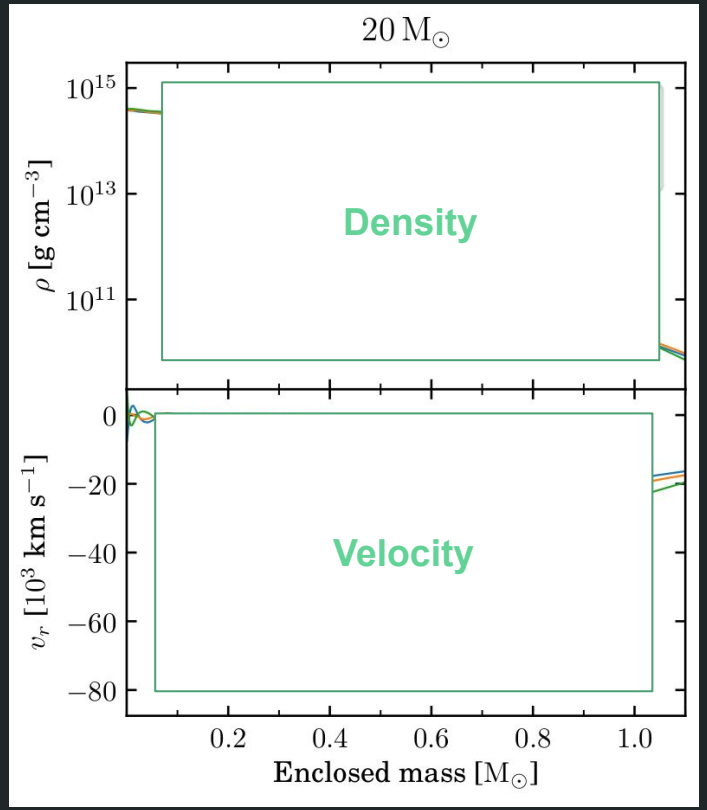


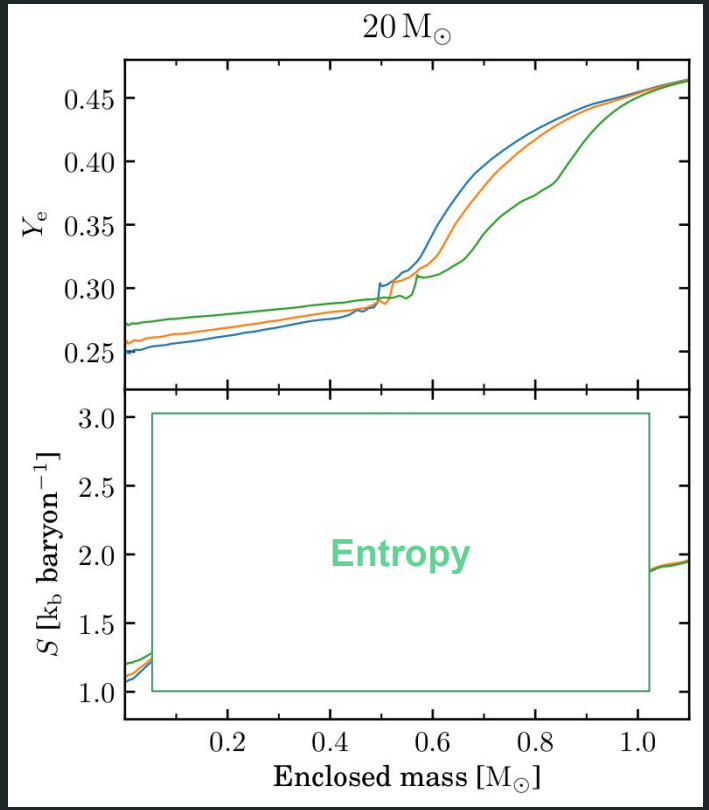
Core Bounce Profiles

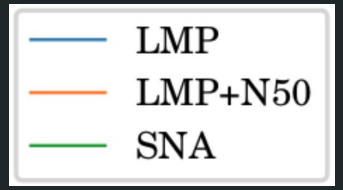


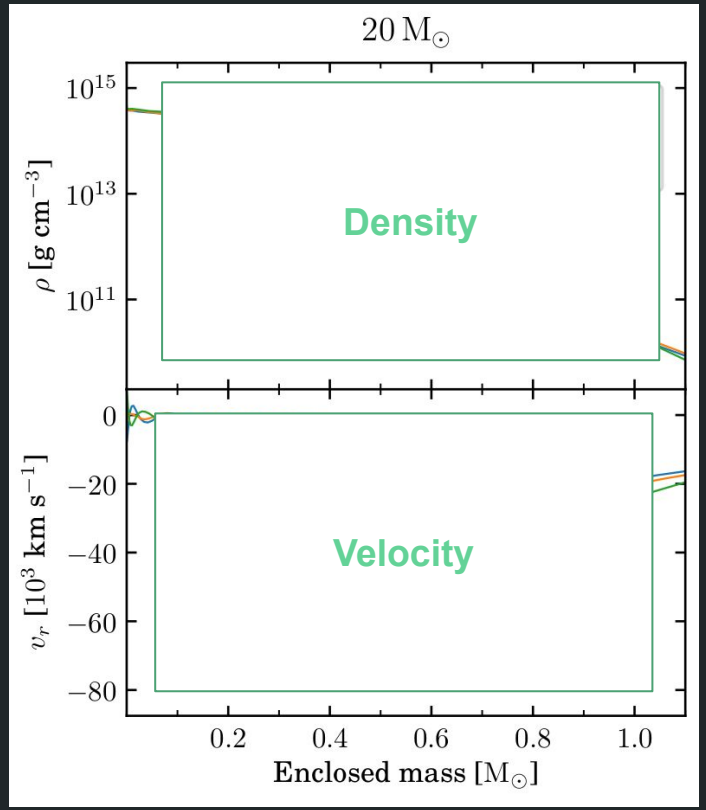


LMP
LMP+N50
SNA

Core Bounce Profiles







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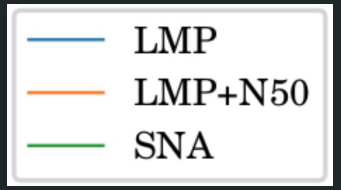

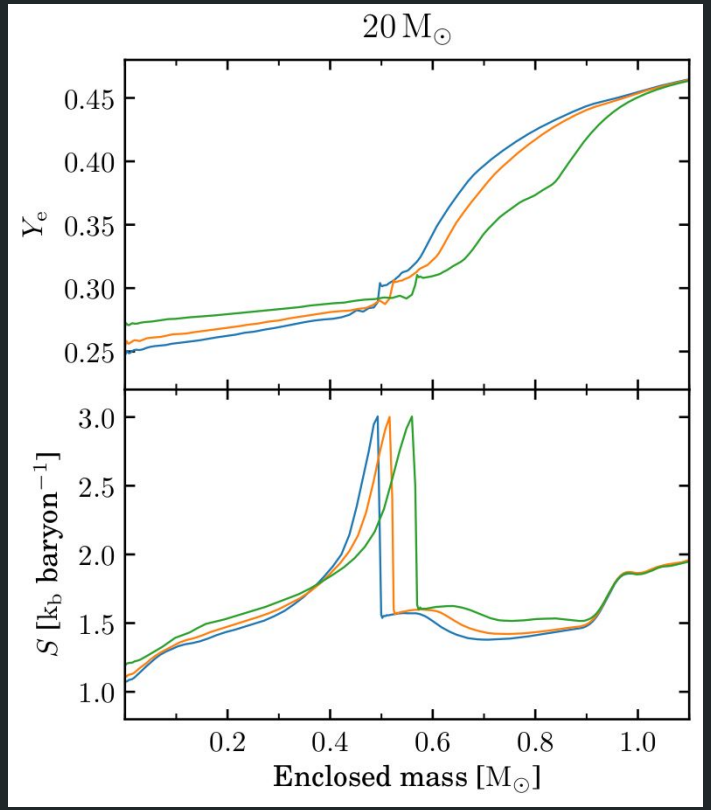

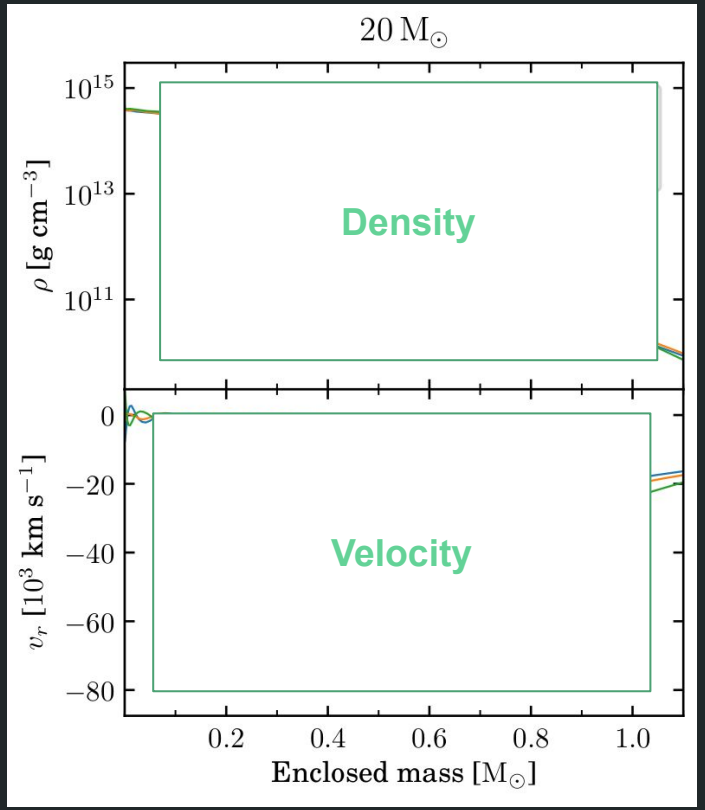

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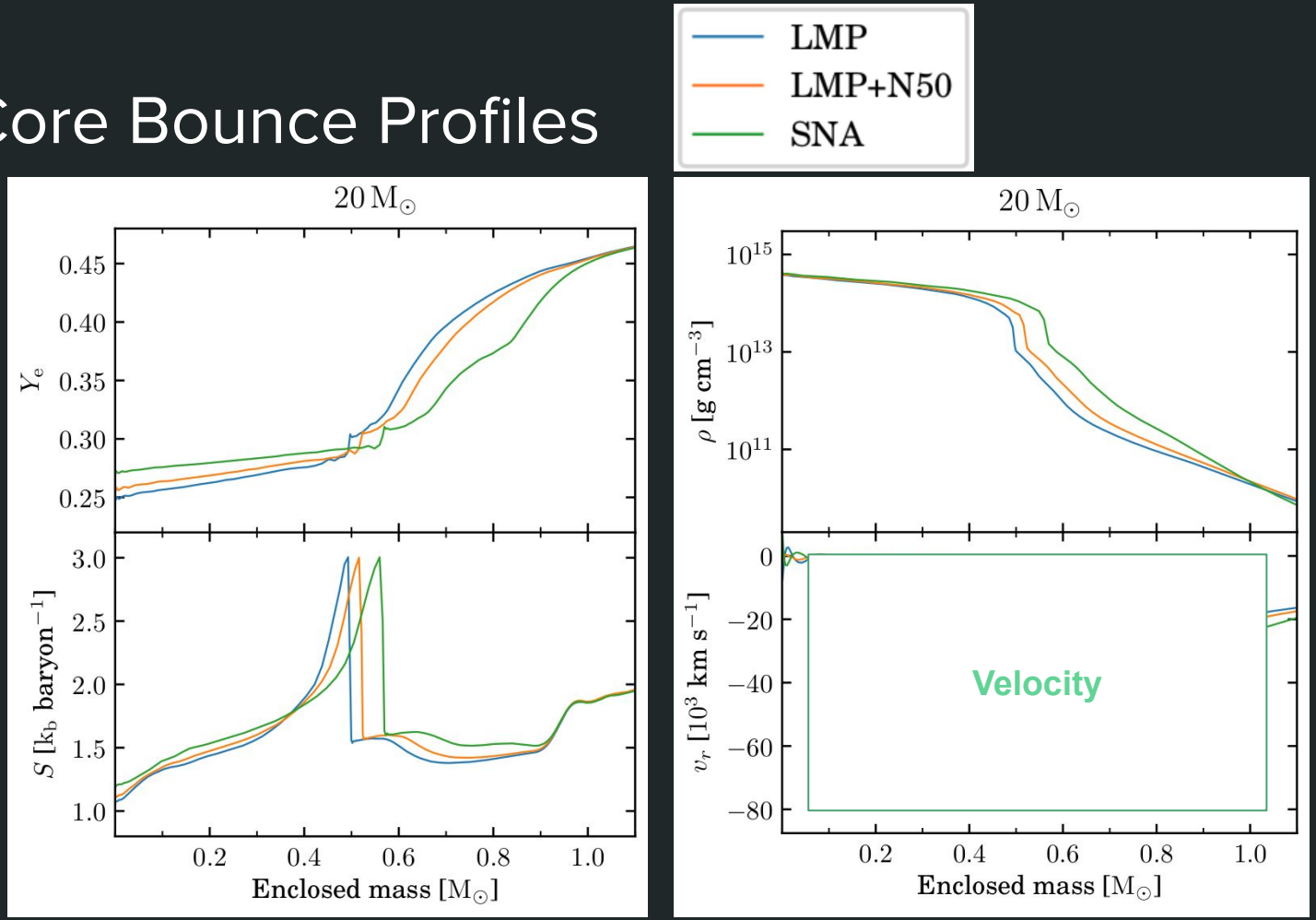

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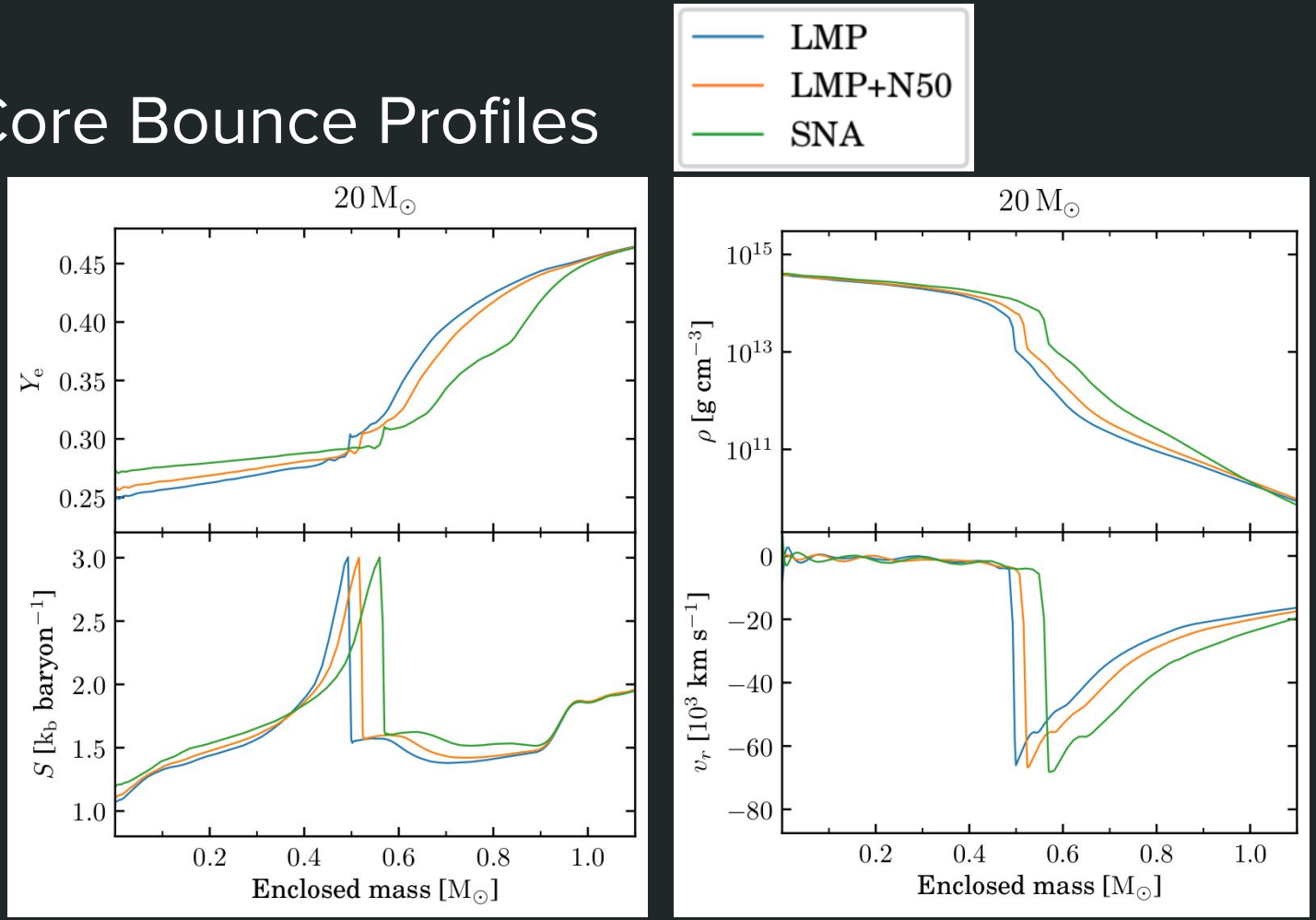
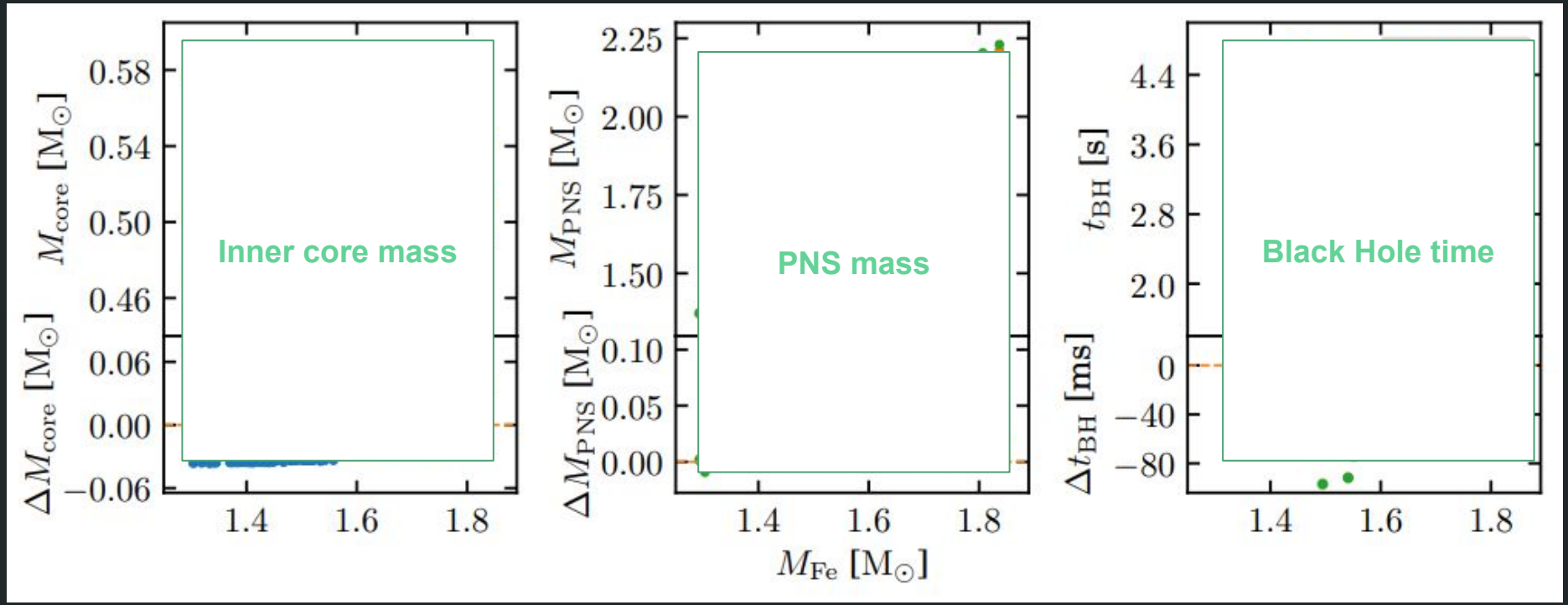


Core Properties



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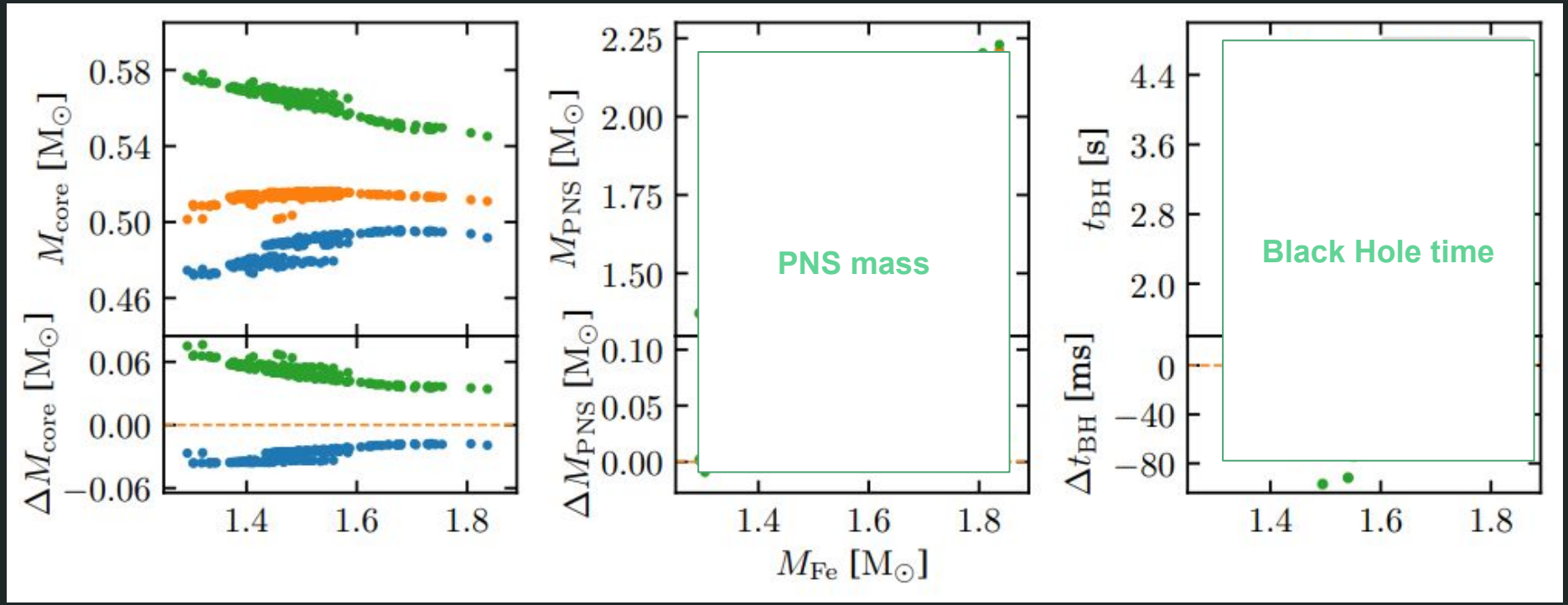

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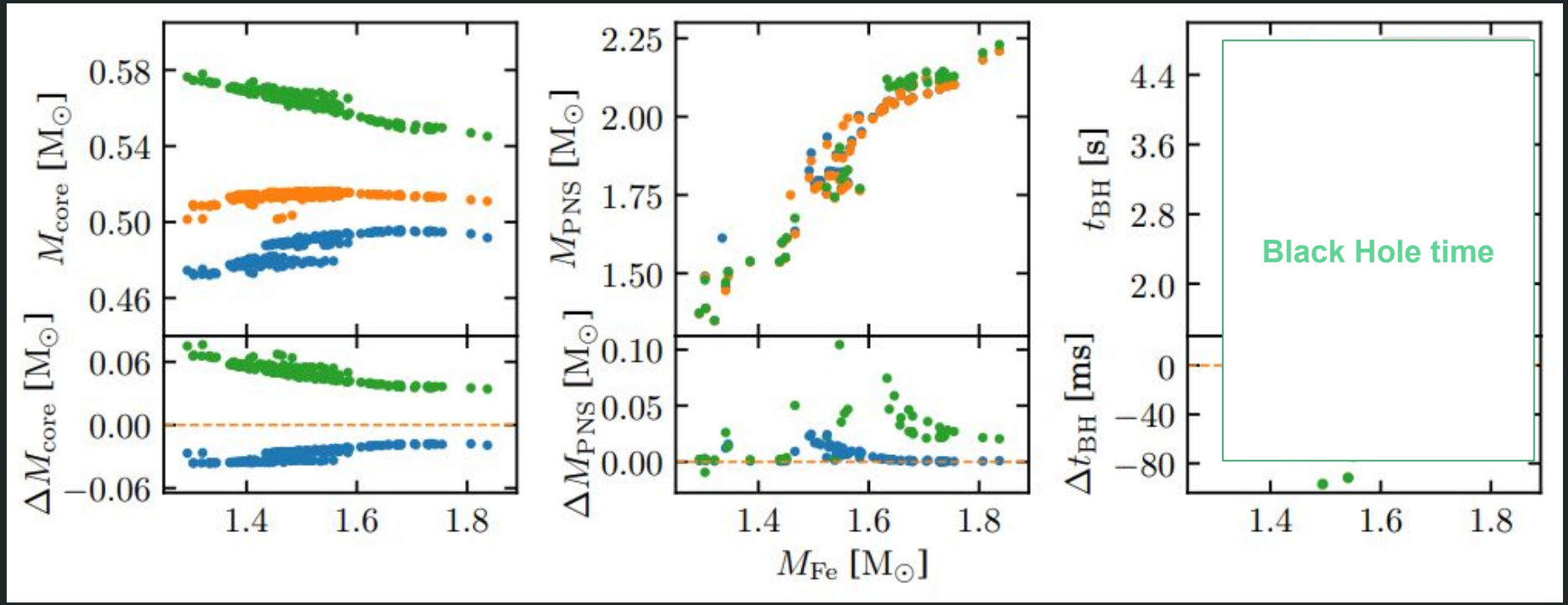

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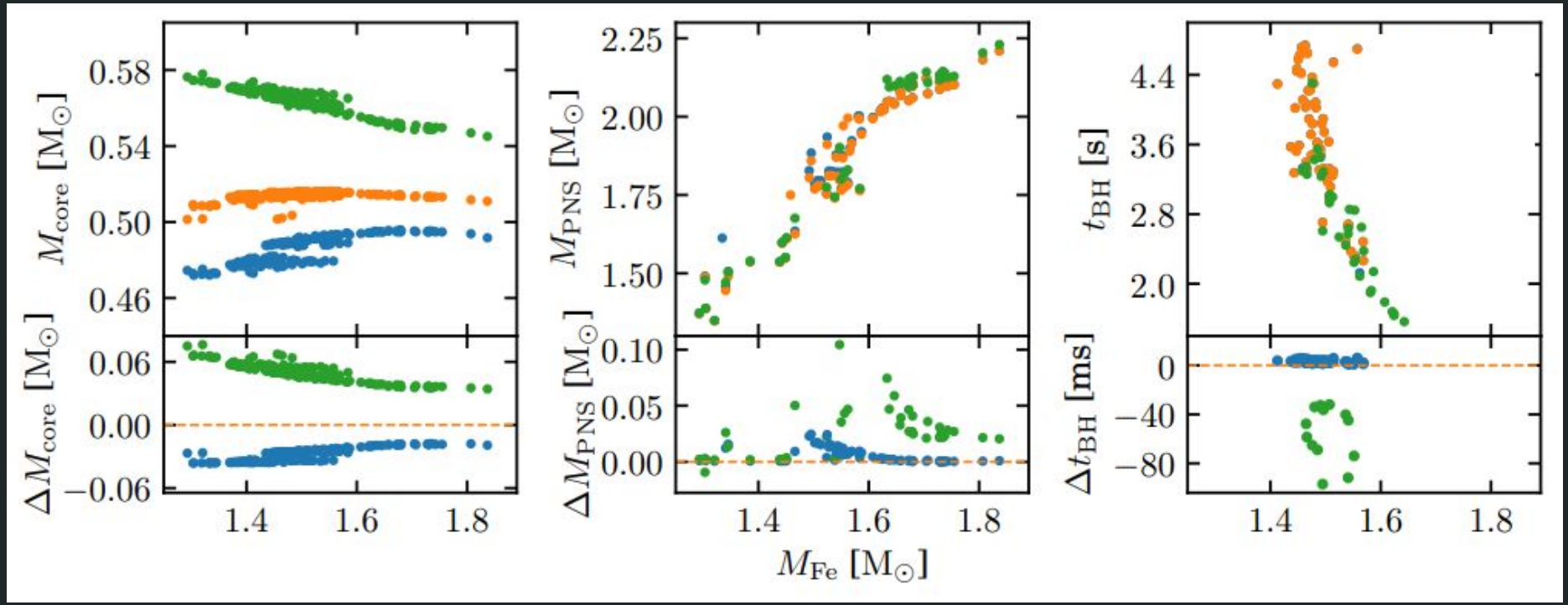
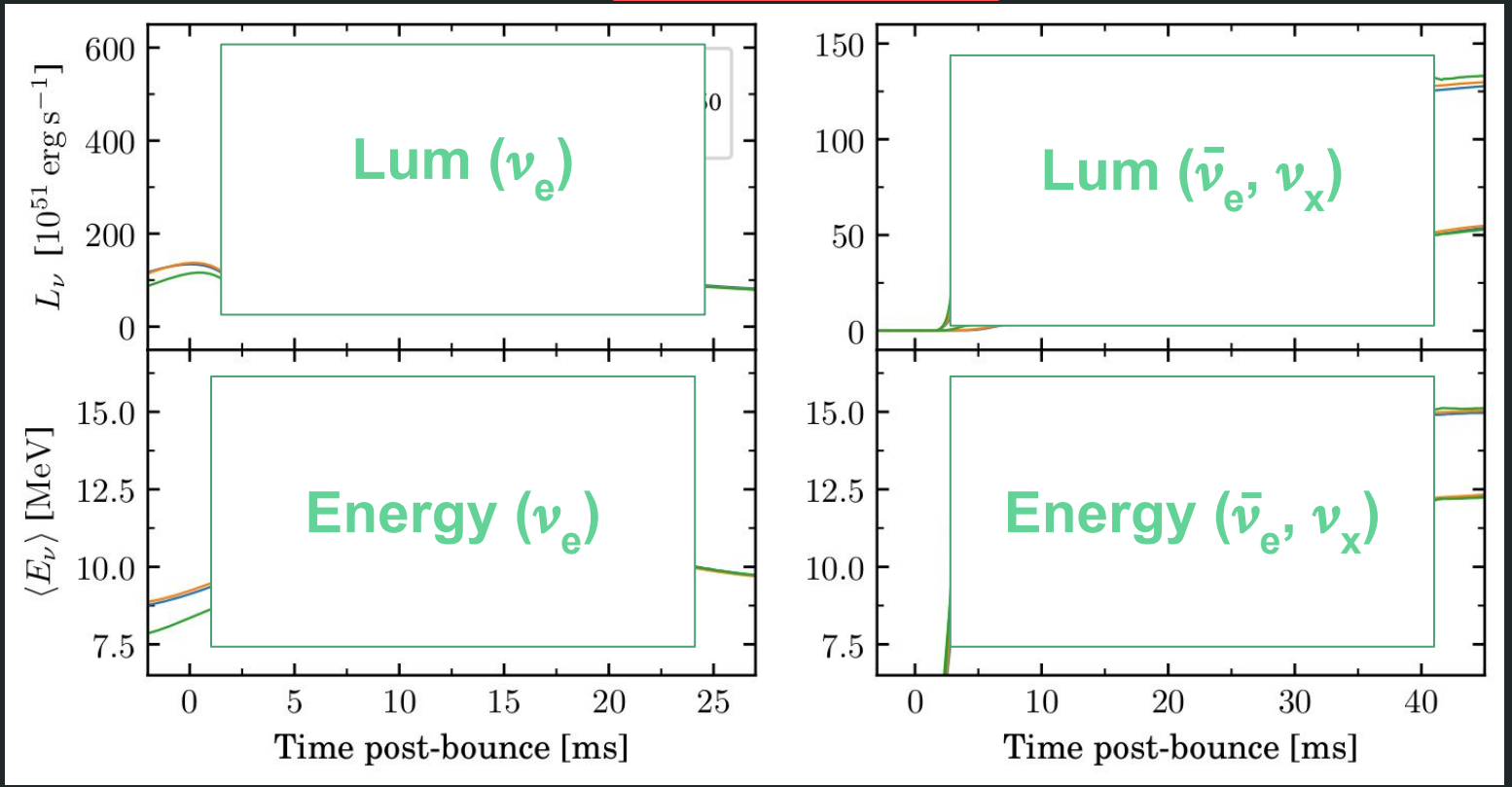


Neutrino Emission

20 Msun



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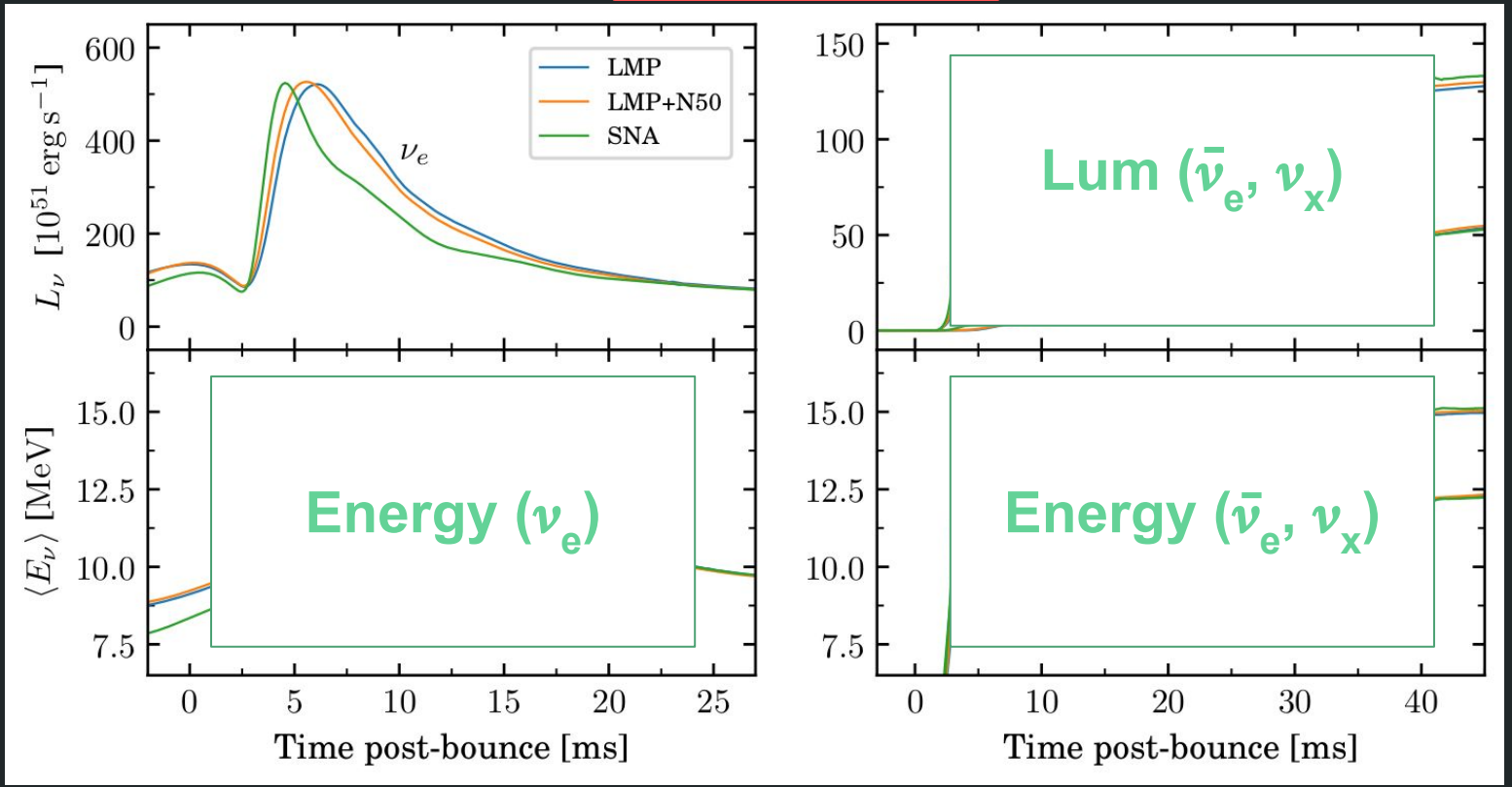

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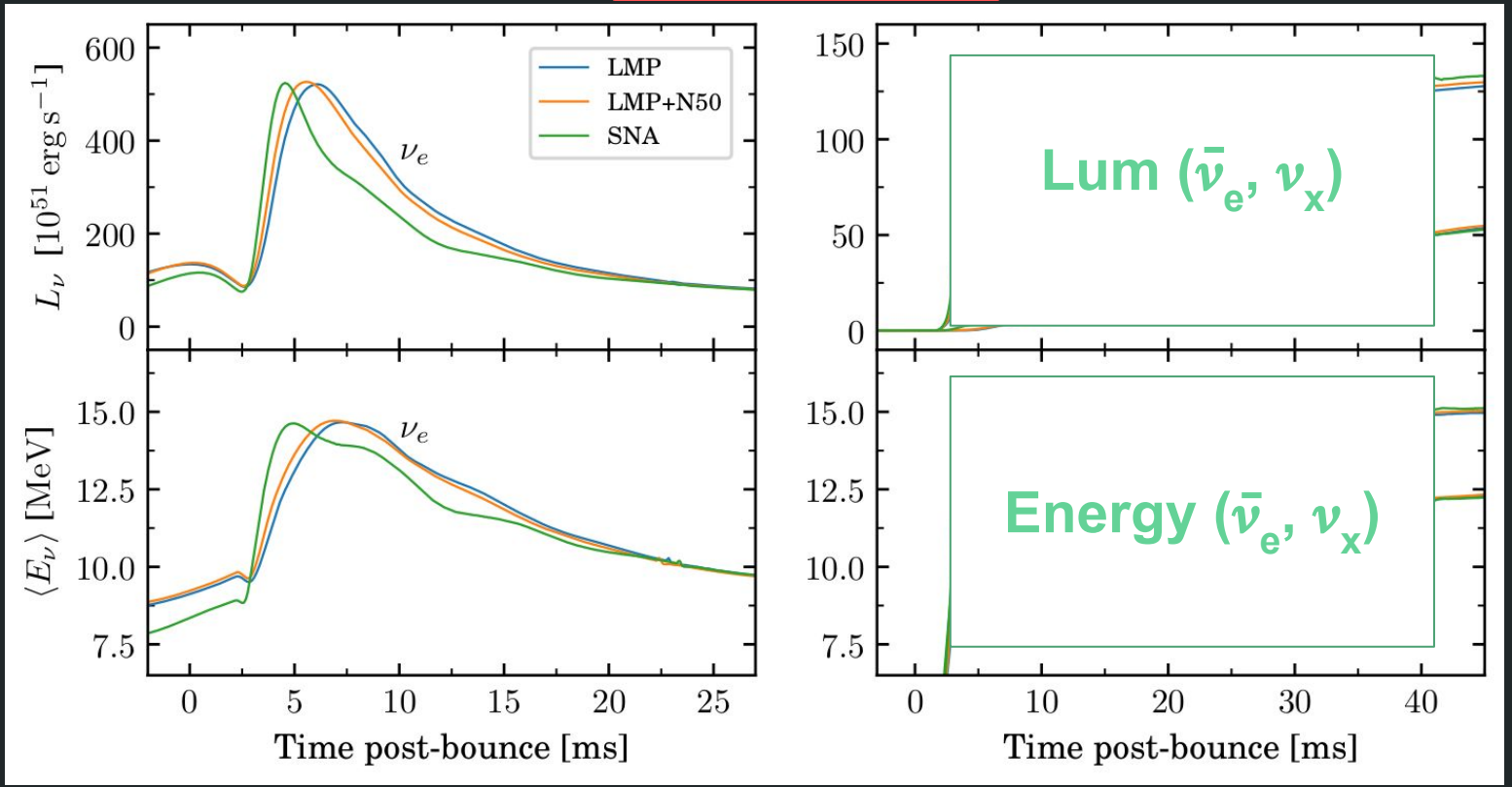

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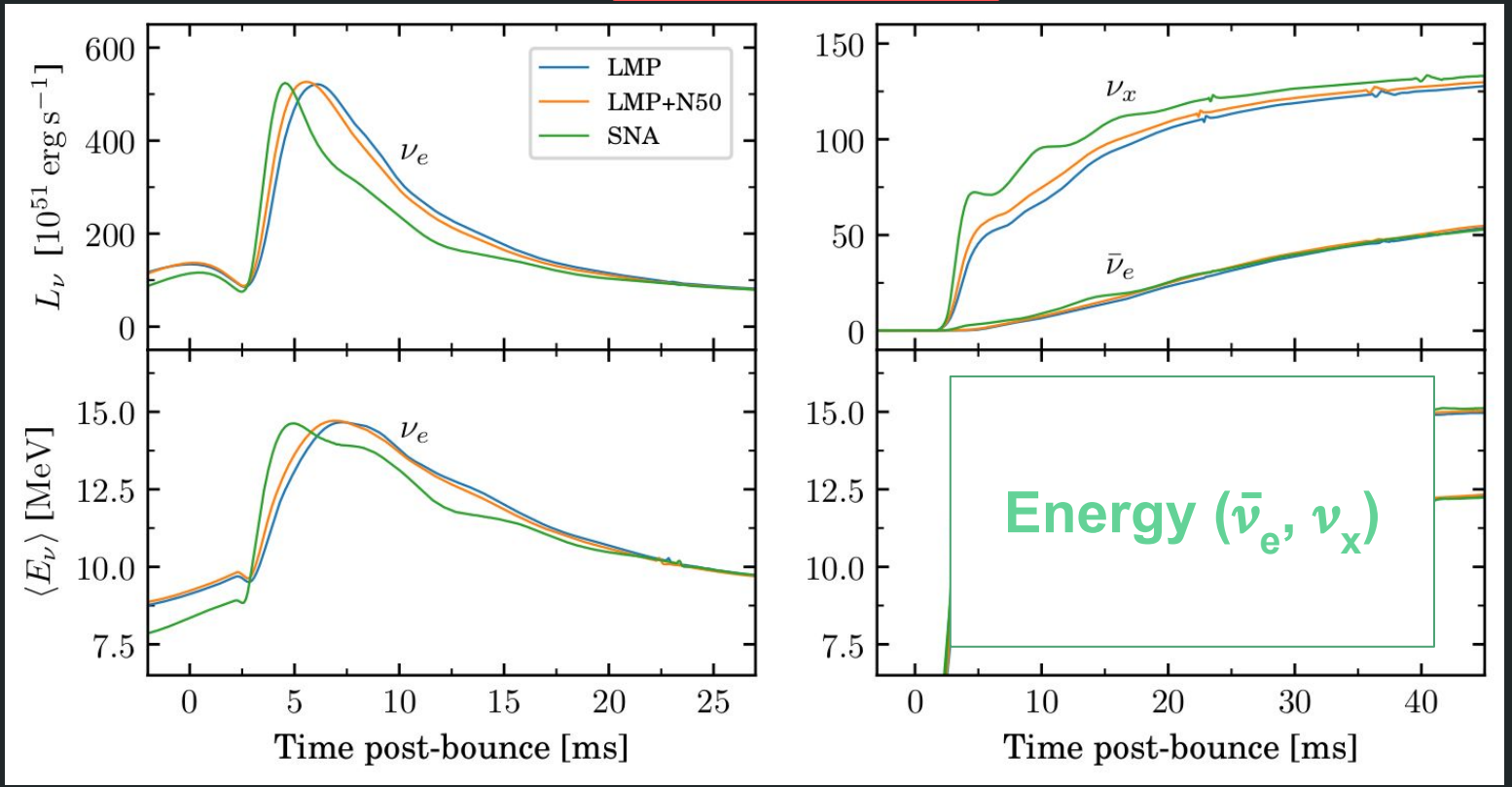

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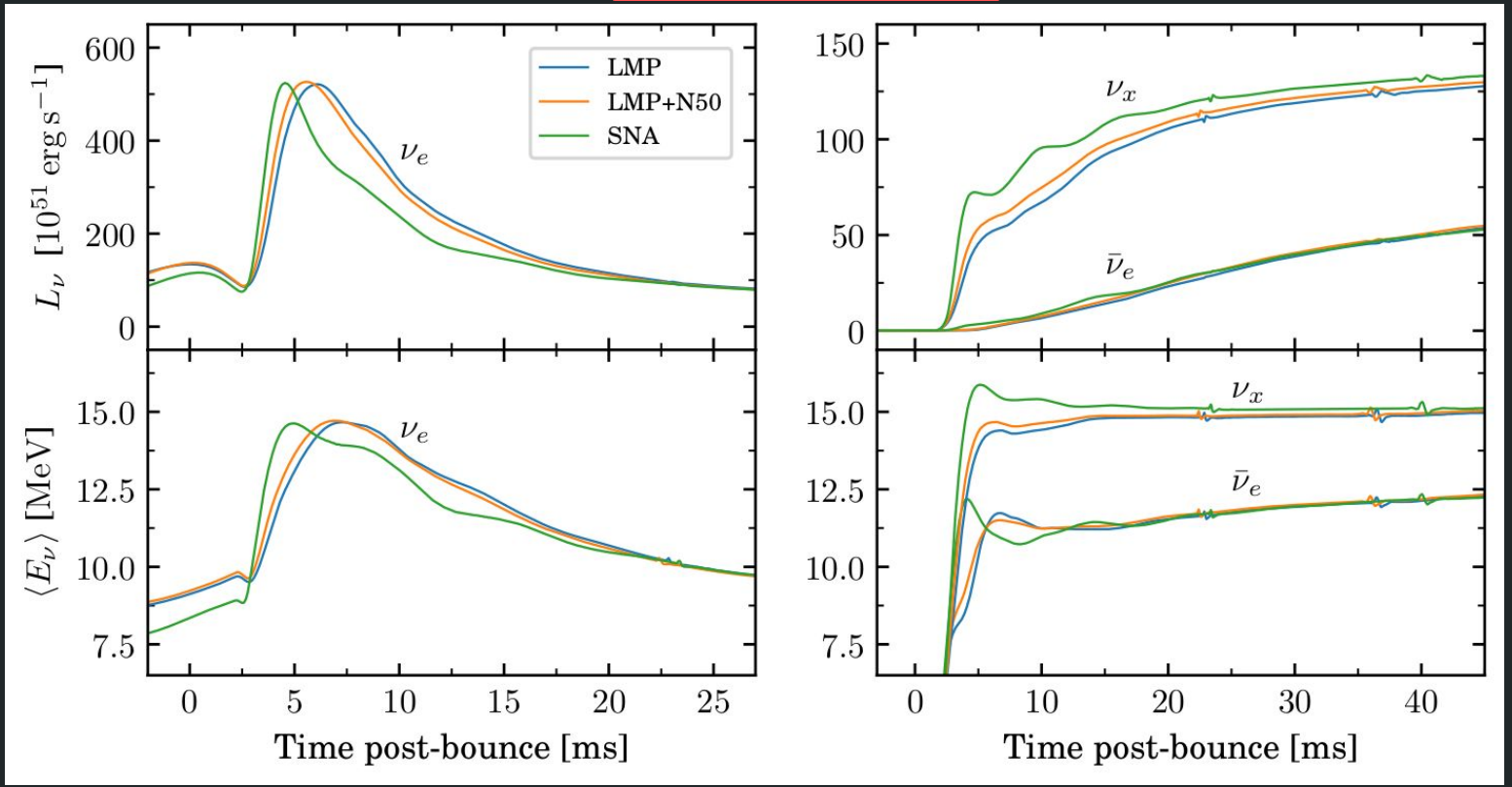
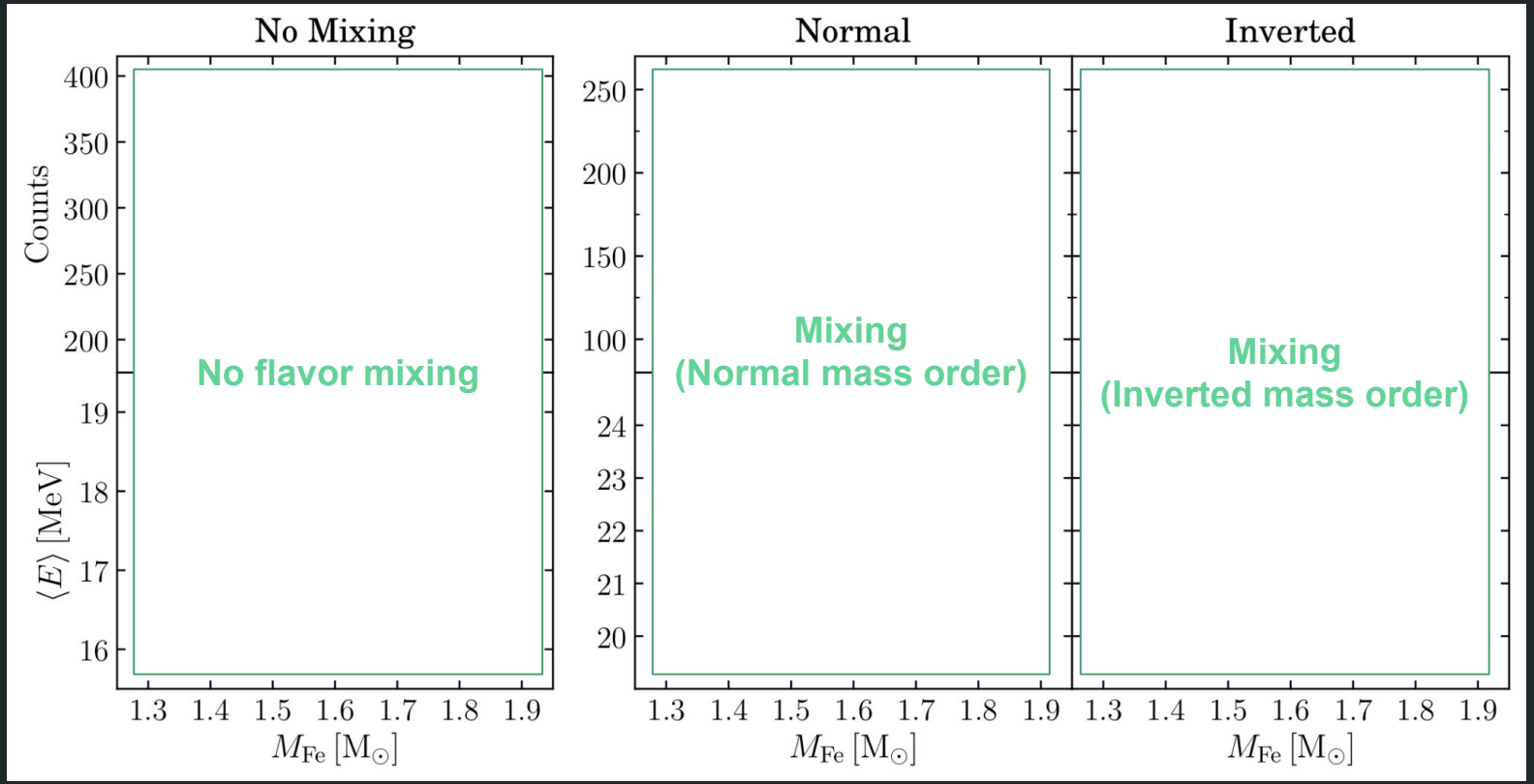


Neutrino Observables

- SNOwGLoBES
- DUNE detector
  - 40 kt liquid-argon
  - Dominant channel: ν_e charged current
- Integrate 100 ms around bounce
- Adiabatic neutrino flavor mixing (normal/inverted)

Neutrino Observables



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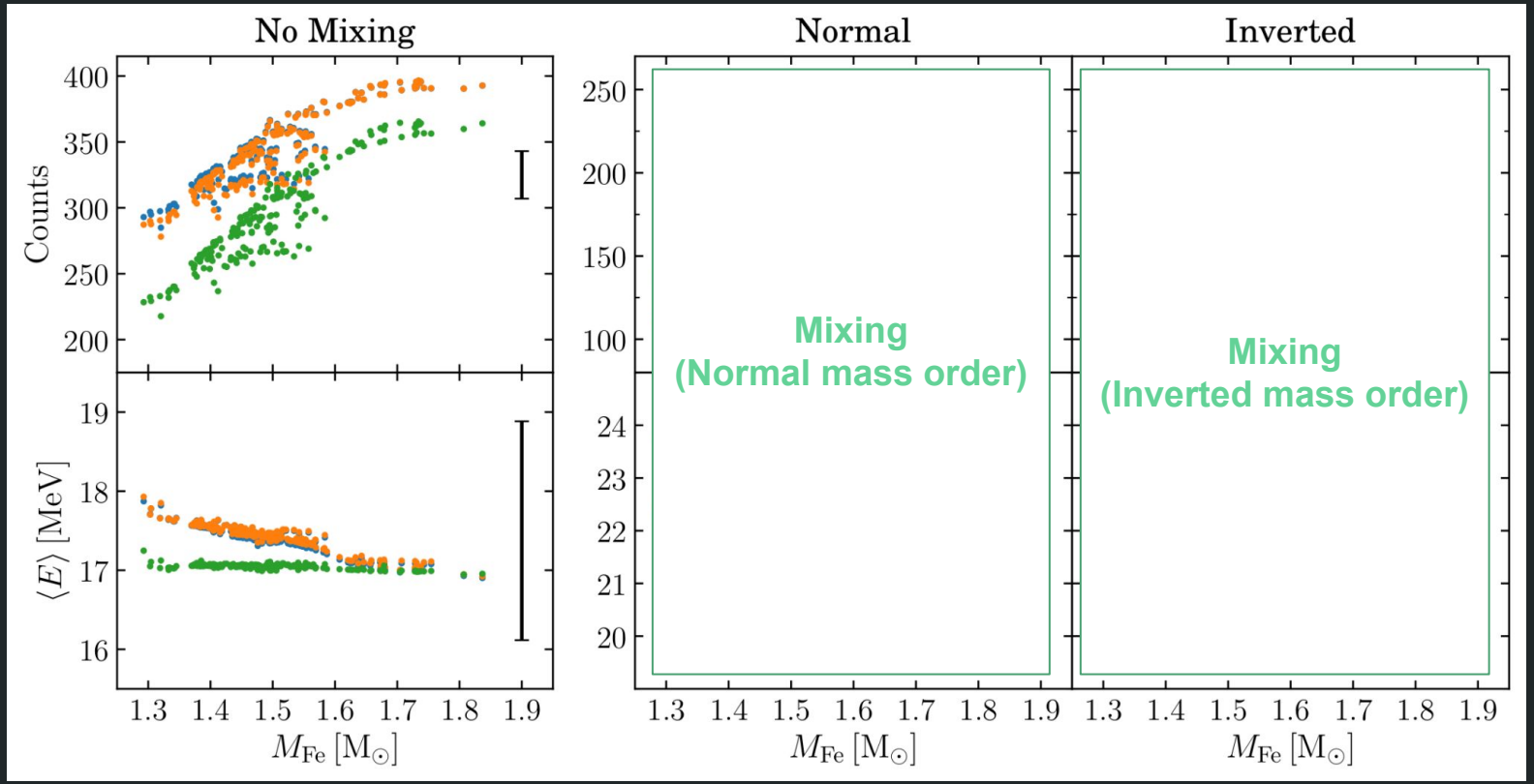

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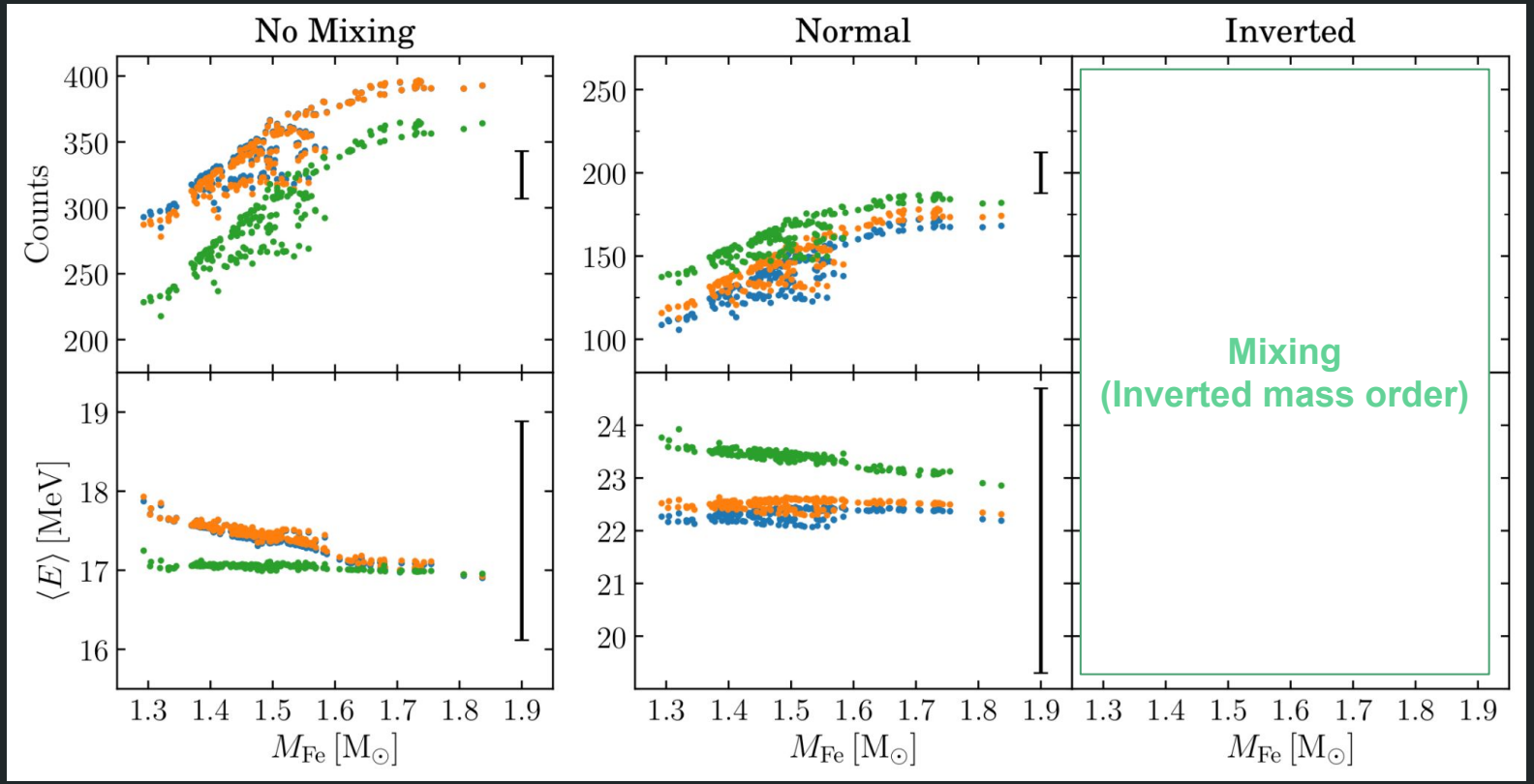

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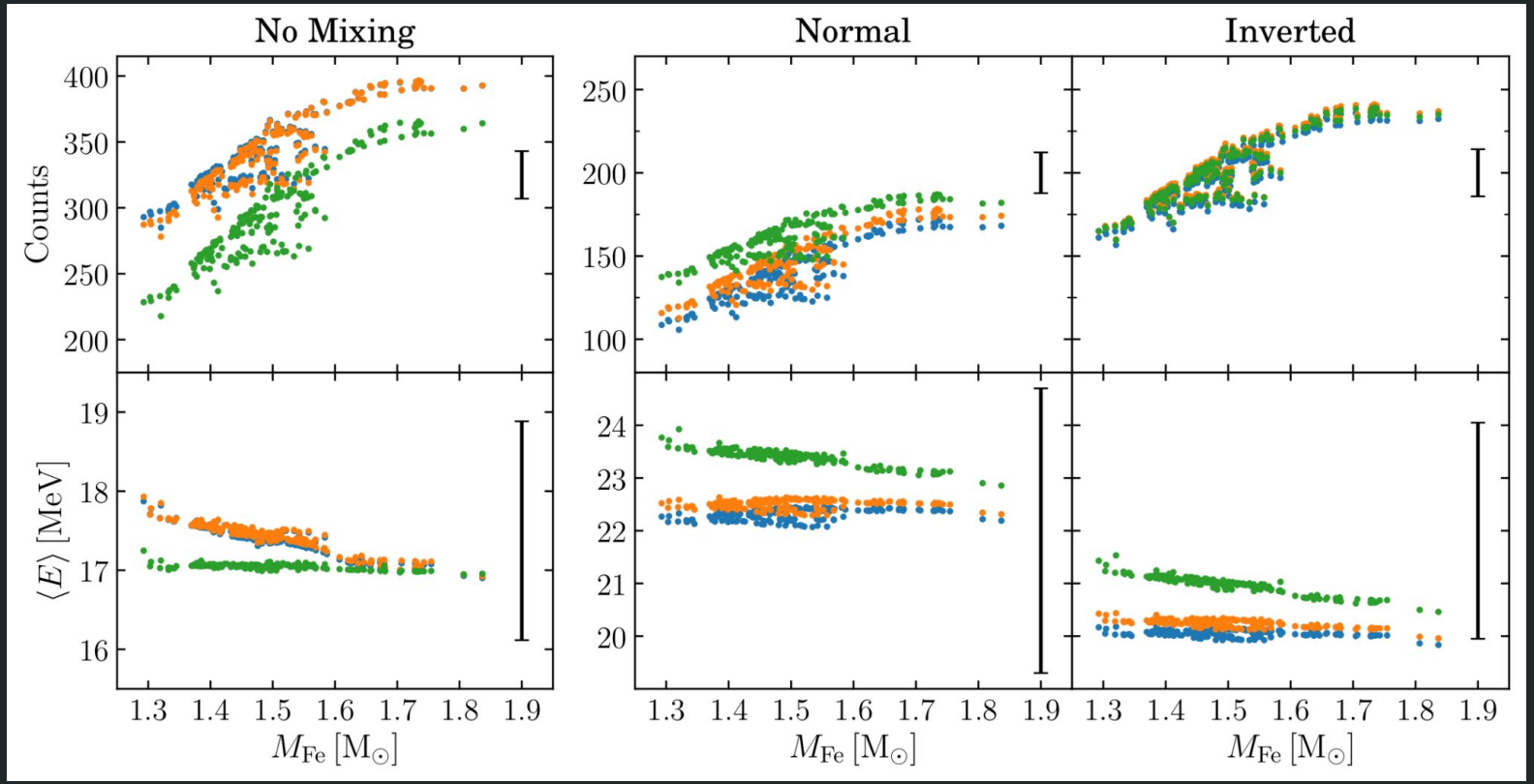

Overall Results

SNA	LMP	LMP+N50
• Higher Y_e (high dens) • Lower Y_e (low dens) • Faster collapse • Larger cores • Least favorable exp.	• Lower Y_e (high dens) • Higher Y_e (low dens) • Slower collapse • Smaller cores • More favorable exp.	• Intermediate • Most favorable (?)

Limitations and Future Work

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  - 1D, solar metallicity, non-rotating, non-magnetic

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- **Models**:
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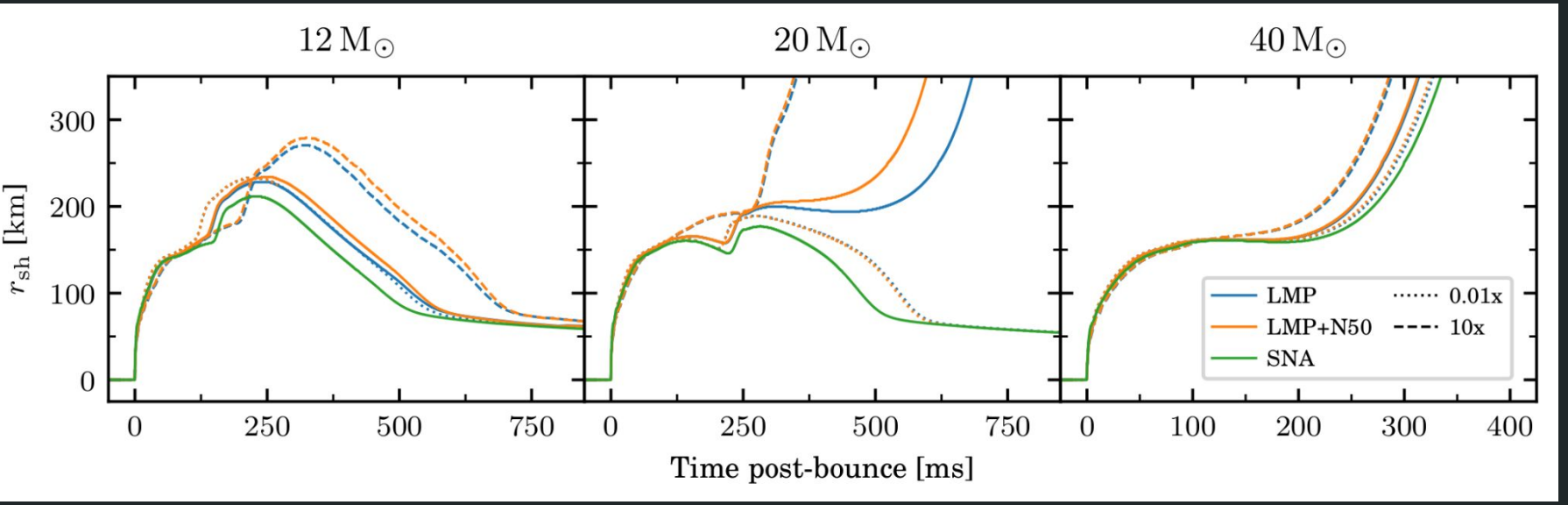
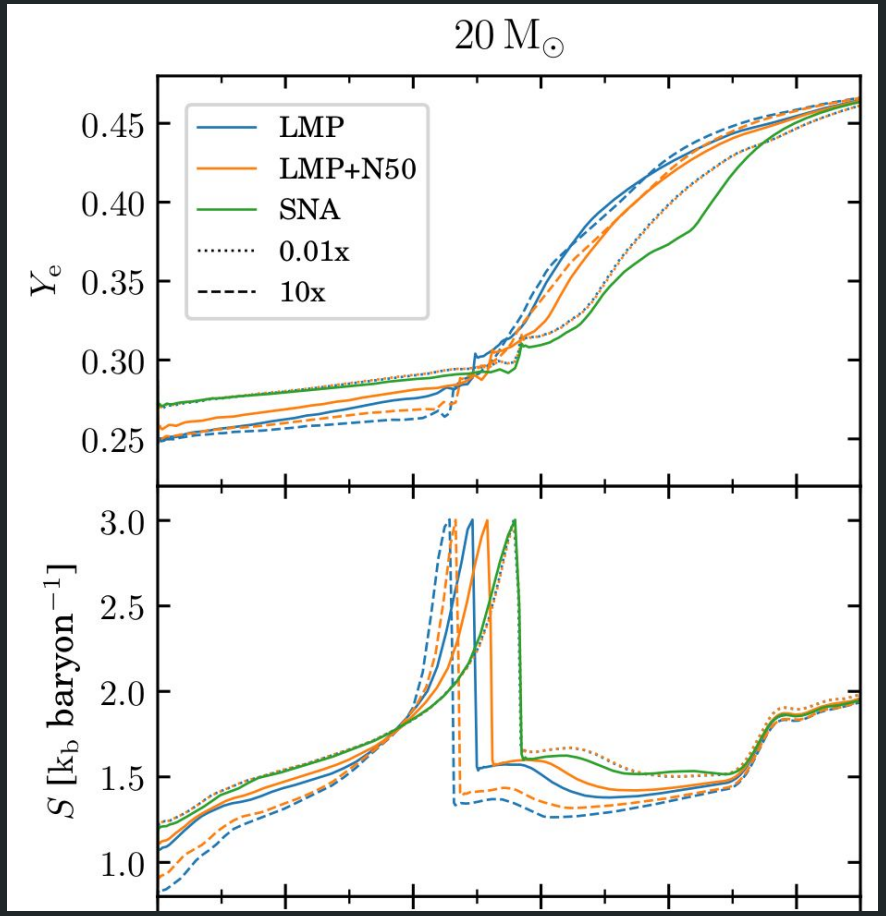
- **Neutrinos**:
  - no in-situ oscillations
  - single detector
- **EC Rates**:
  - Still rely on approximations for many nuclei
  - No temp-dependence effects

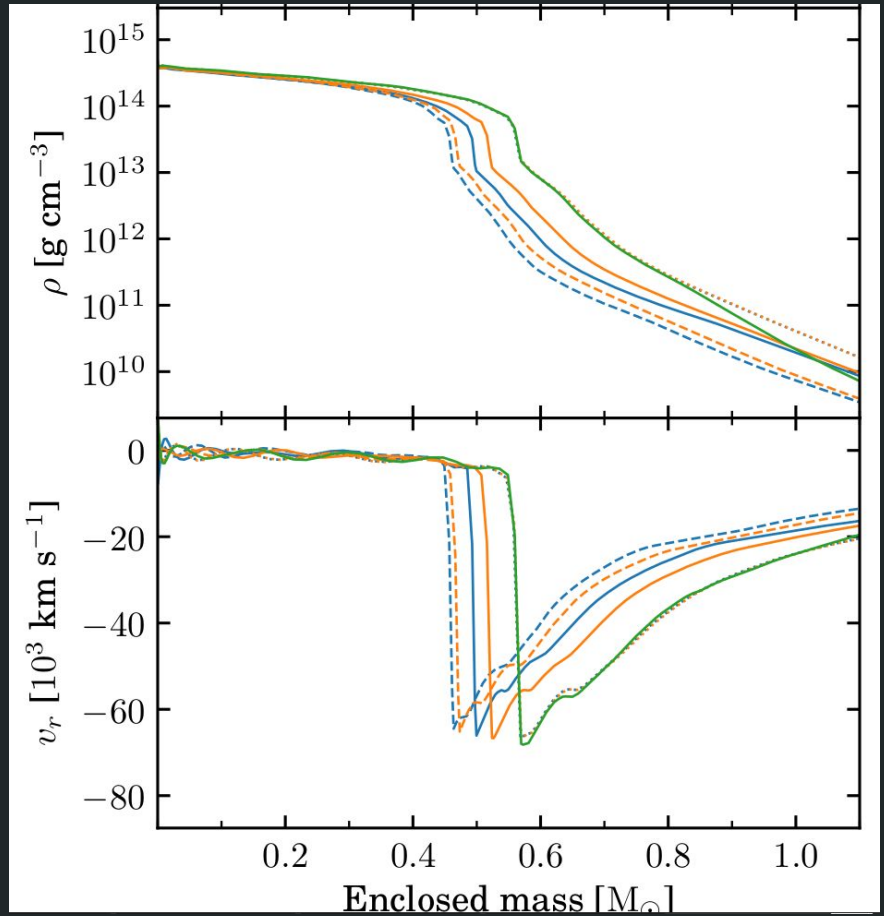
Summary

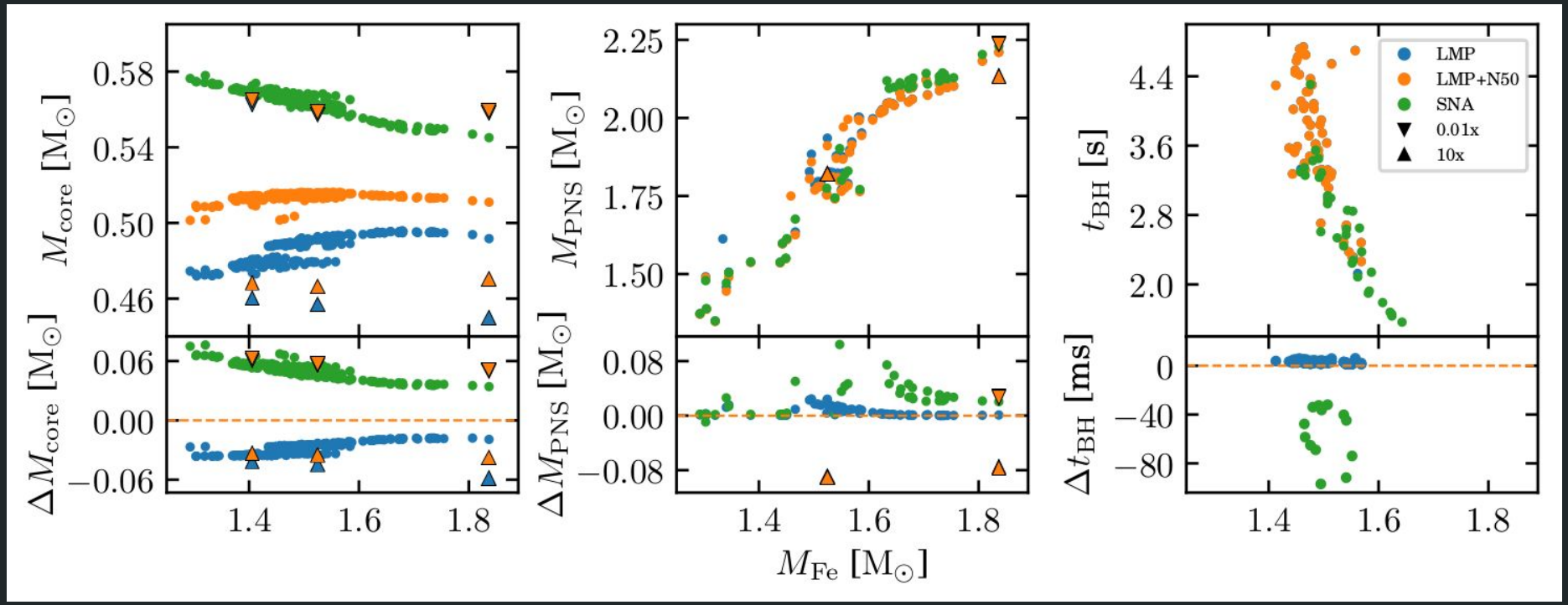
- **3** EC rate tables: SNA, LMP, LMP+N50
- **200** progenitors: 9 - 120 $M_{\odot}$
- Consistent difference in CCSNe properties
- **SNA** least-favorable, **LMP** more, **LMP+N50** most (slightly)
- Neutrino detections (SNOwGLoBES)
- Johnston et al. (2021) in prep.

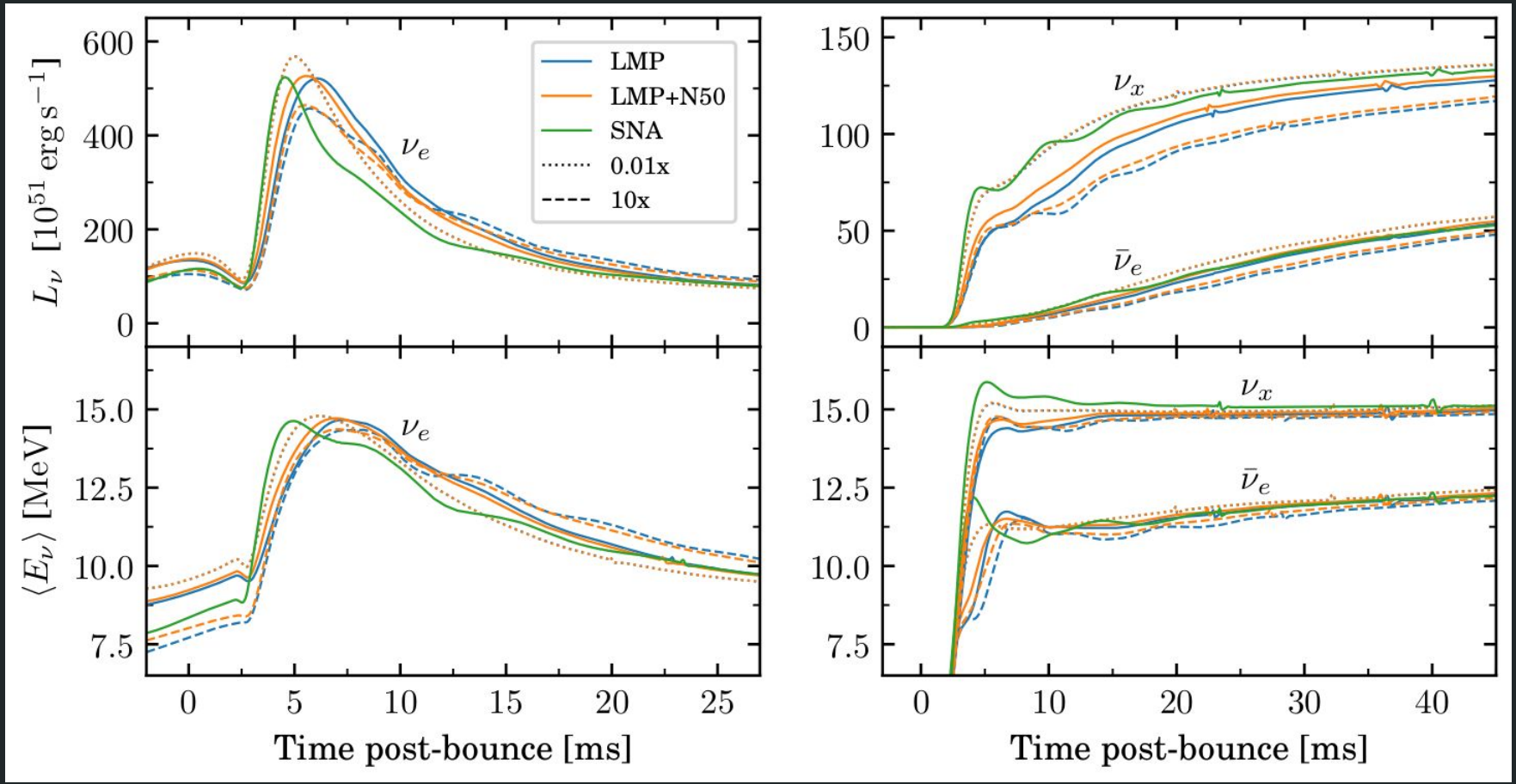
Bonus Slides

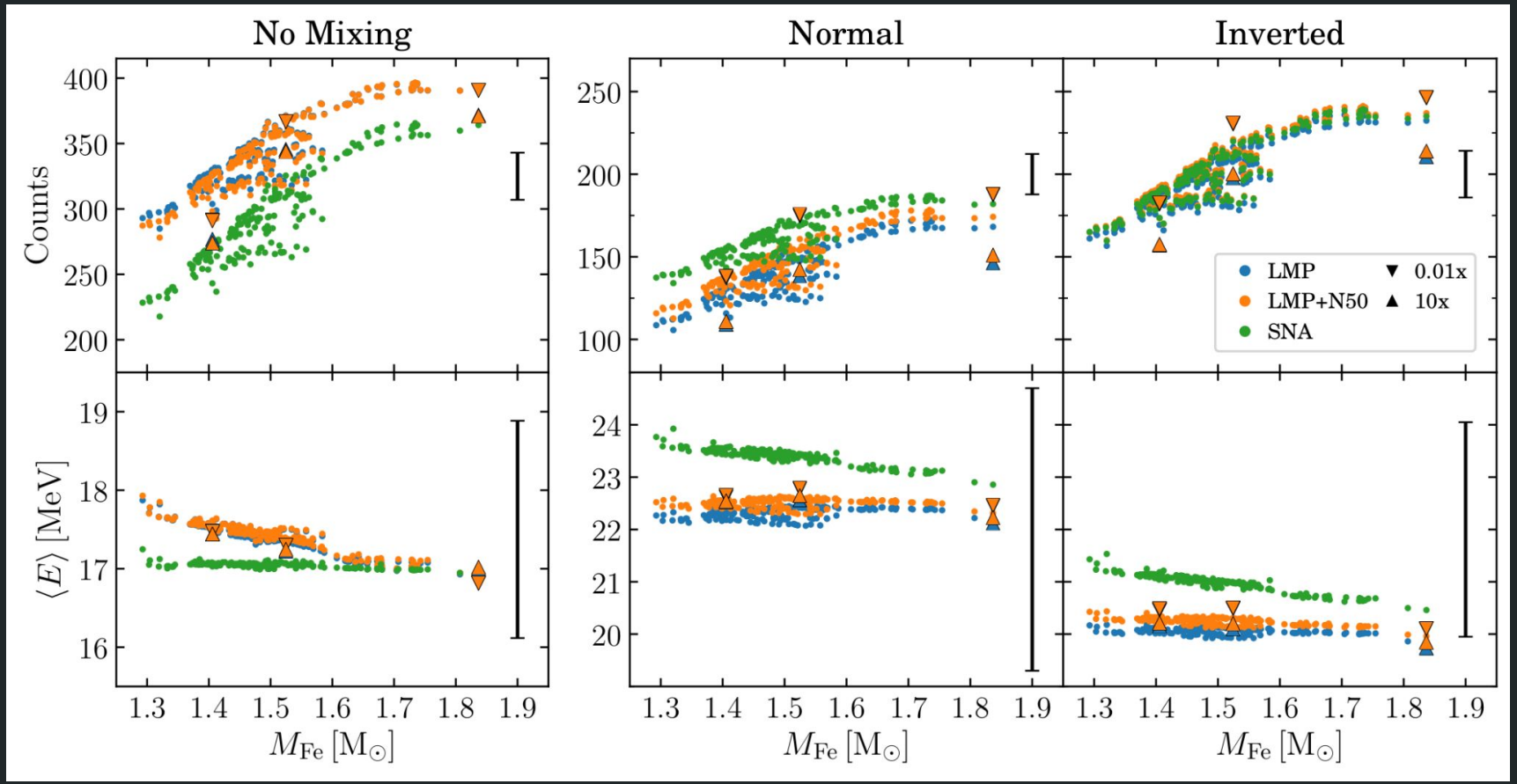

12 M⊙
20 M⊙
40 M⊙
r_{sh} [km]
300
200
100
0
0
250
500
750
0
250
500
750
0
100
200
300
400
Time post-bounce [ms]
LMP
LMP+N50
SNA
0.01x
10x


20 M⊙
LMP
LMP+N50
SNA
0.01x
10x
Y_e
S [k_b baryon^{-1}]


ρ [g cm^{-3}]
v_r [10^3 km s^{-1}]
Enclosed mass [M⊙]


$M_{\rm core}$ [$M_\odot$]
$\Delta M_{\rm core}$ [$M_\odot$]
$M_{\rm PNS}$ [$M_\odot$]
$\Delta M_{\rm PNS}$ [$M_\odot$]
$t_{\rm BH}$ [s]
$\Delta t_{\rm BH}$ [ms]
$M_{\rm Fe}$ [$M_\odot$]
LMP
LMP+N50
SNA
0.01x
10x


LMP
LMP+N50
SNA
0.01x
10x
L_ν [10^{51} erg s^{-1}]
$\langle E_\nu \rangle$ [MeV]
ν_e
ν_x
$\bar{\nu}_e$
Time post-bounce [ms]
Time post-bounce [ms]


No Mixing
Normal
Inverted
Counts
⟨E⟩ [MeV]
M_{Fe} [M$_\odot$]
LMP
LMP+N50
SNA
0.01x
10x