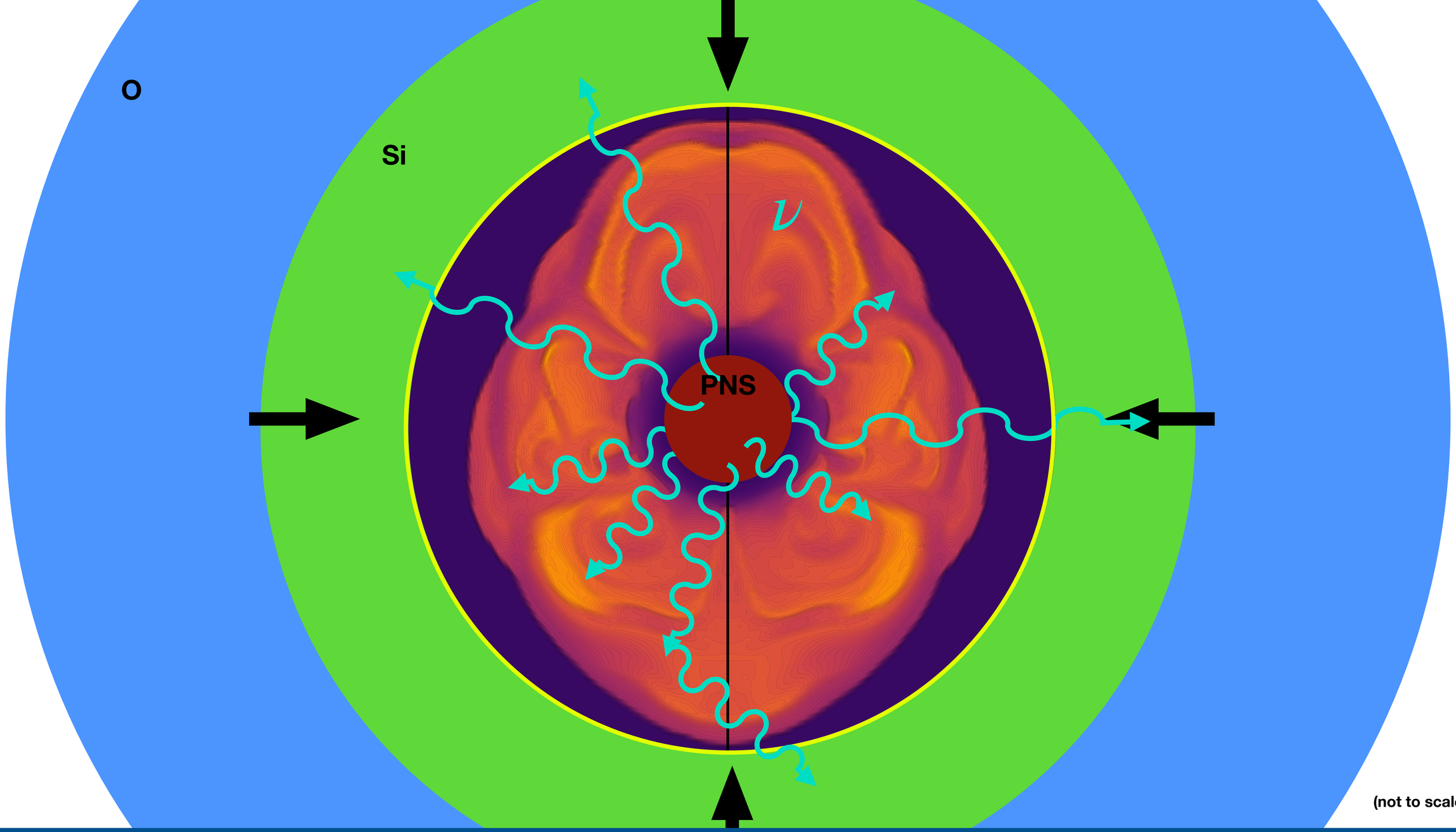
Effects of Neutrino Flavor Conversions in Core-Collapse Supernovae

Multi-Messenger Astrophysics in the Dynamic Universe

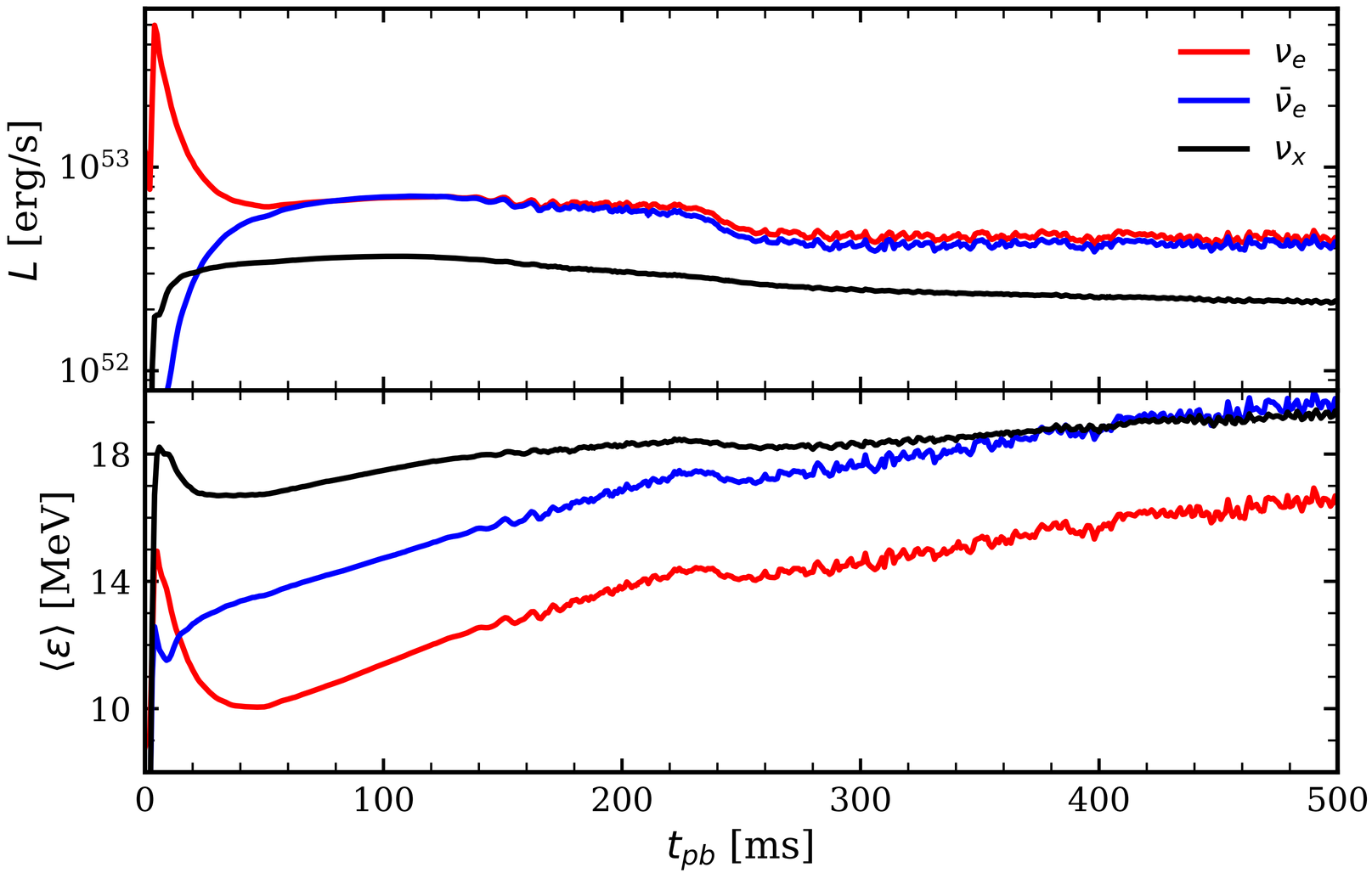
4th February, 2026

Jakob Ehring (Academia Sinica, Institute of Physics)

Accretion phase of core-collapse supernovae


O
Si
ν
PNS
(not to scale)

Neutrino luminosity and mean energy at 400 km



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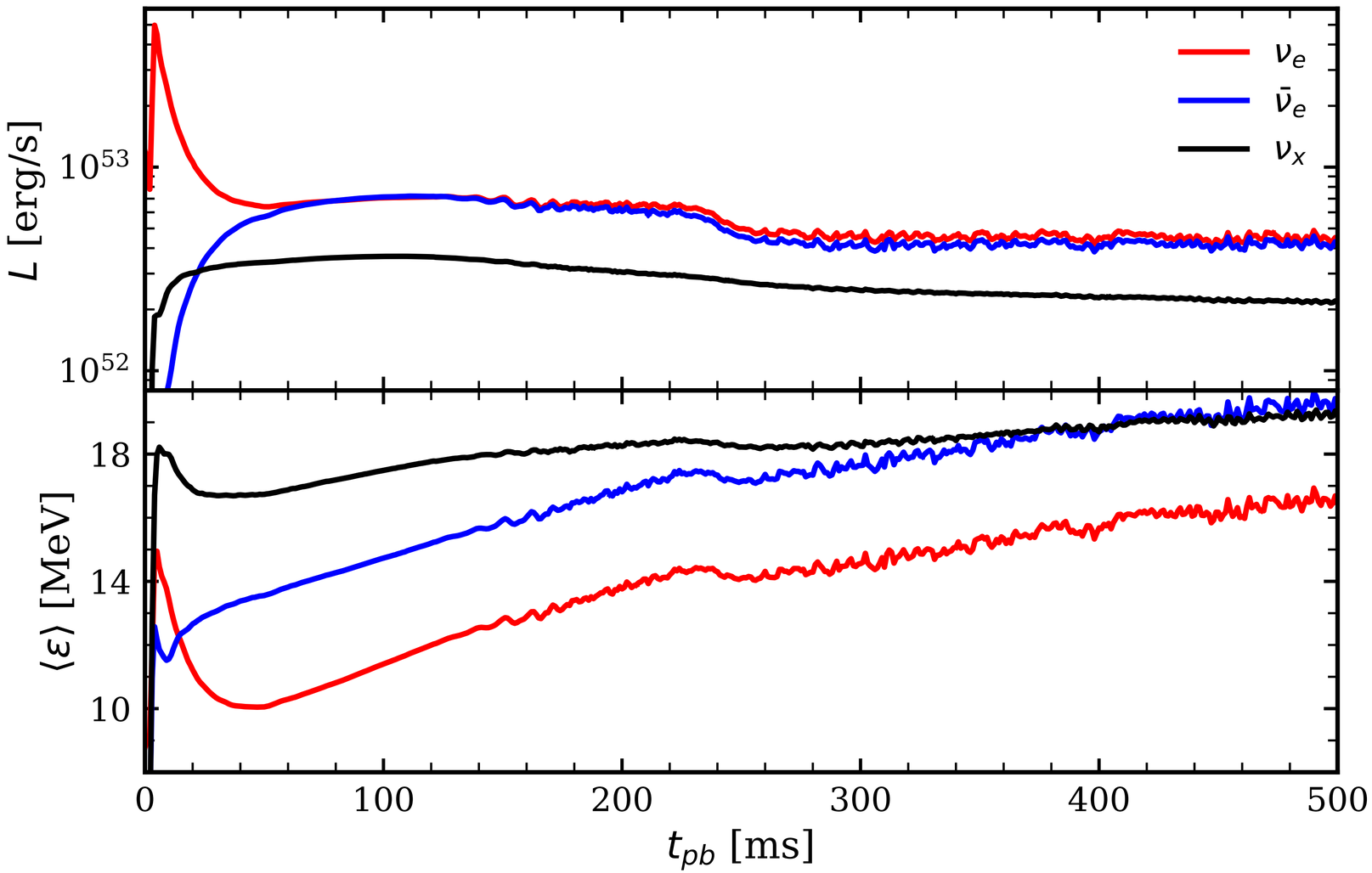


Production (cooling):

Thermal (flavor blind):

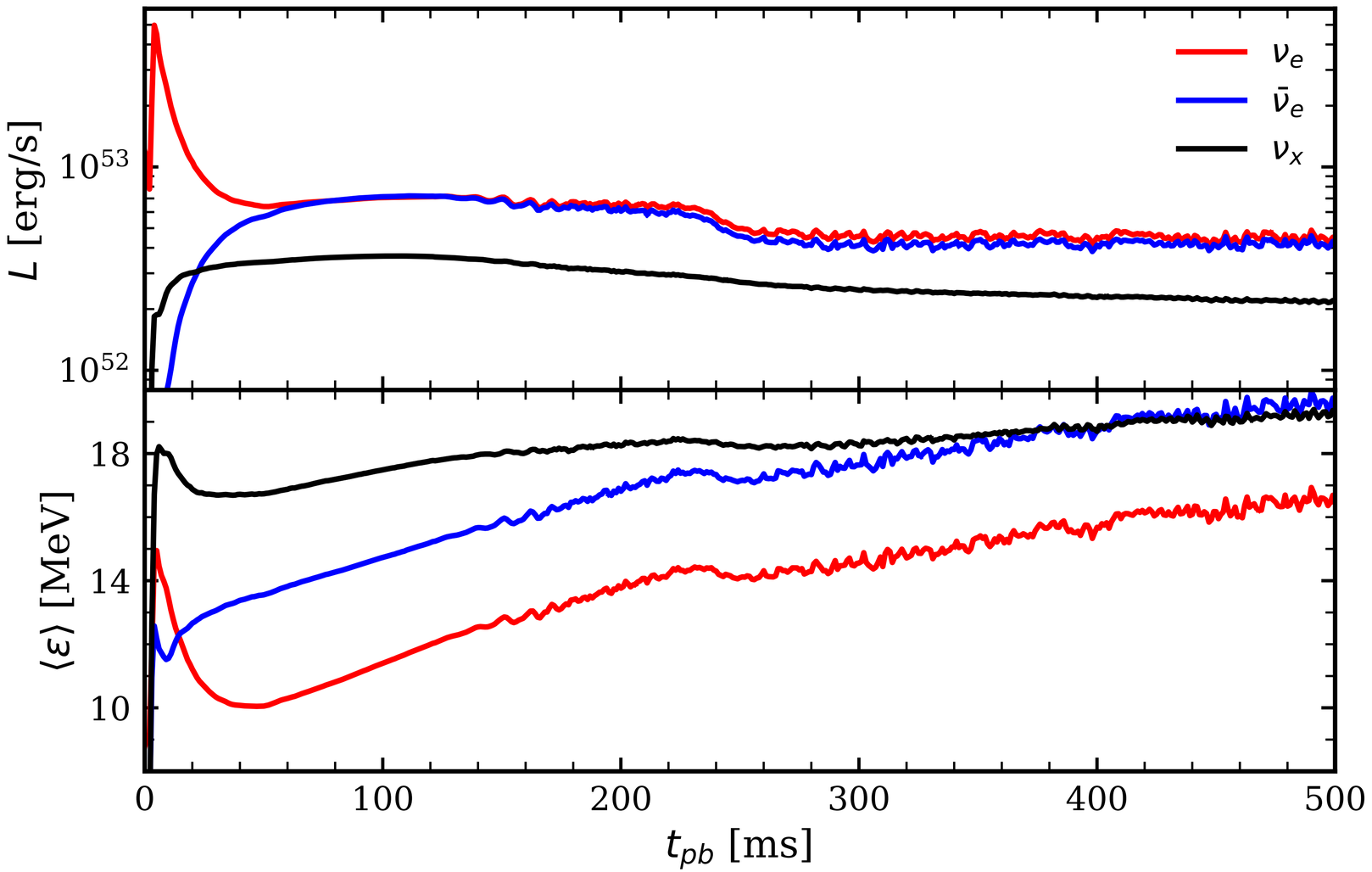
$$N + N \rightarrow N + N + \nu_\alpha + \bar{\nu}_\alpha$$

Charged current (e only):

$$p + e^- \rightarrow n + \nu_e$$

$$n + e^+ \rightarrow p + \bar{\nu}_e$$

Neutrino luminosity and mean energy at 400 km



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$$p + e^- \rightarrow n + \nu_e$$

$$n + e^+ \rightarrow p + \bar{\nu}_e$$

Interaction (heating):

All flavors: scattering

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

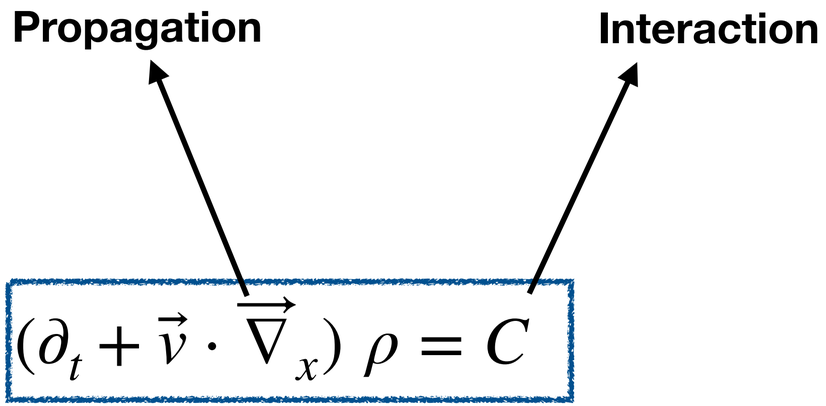
Electron flavor: absorption

$$\nu_e + n \rightarrow e^- + p$$

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

TL;DR

What are neutrino flavor conversions?


Propagation
Interaction
$(\partial_t + \vec{v} \cdot \overrightarrow{\nabla}_x)\ \rho = C$

Neutrinos are quantum particles!

Johan Jarnestad/The Royal Swedish Academy of Sciences, 2015

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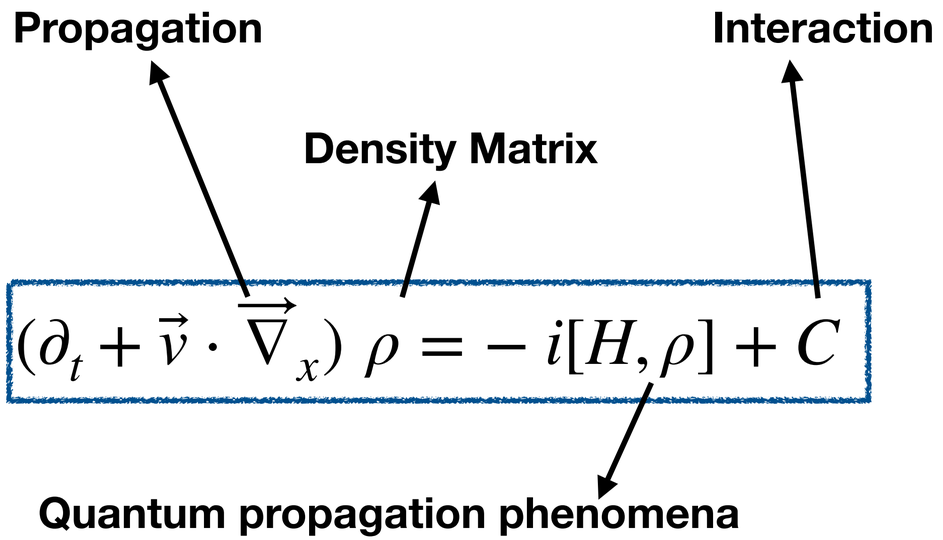


Neutrinos are quantum particles!

Johan Jarnestad/The Royal Swedish Academy of Sciences, 2015

Propagation

Interaction

Density Matrix

$$(\partial_t + \vec{v} \cdot \overrightarrow{\nabla}_x)\ \rho = -\,i[H, \rho] + C$$

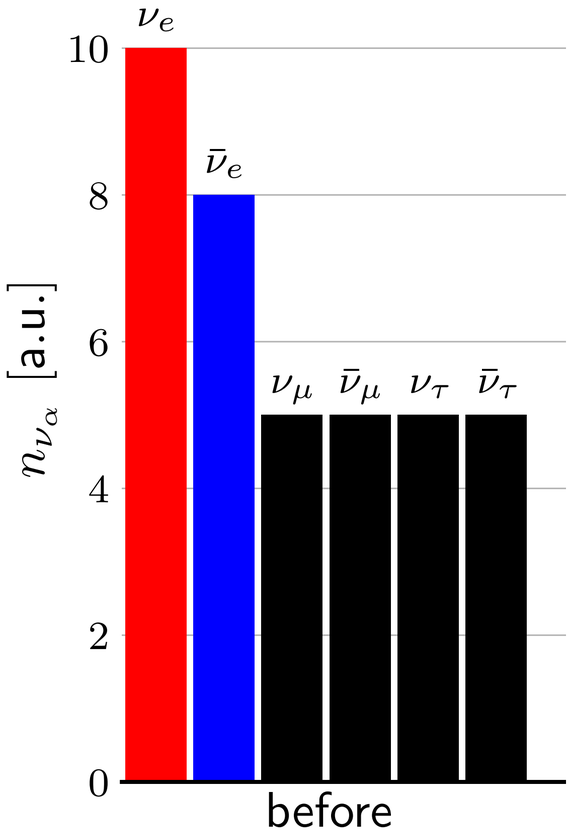
Quantum propagation phenomena

$$H = H_{\text{vac}} + H_{\text{MSW}} + H_{\nu\nu}$$

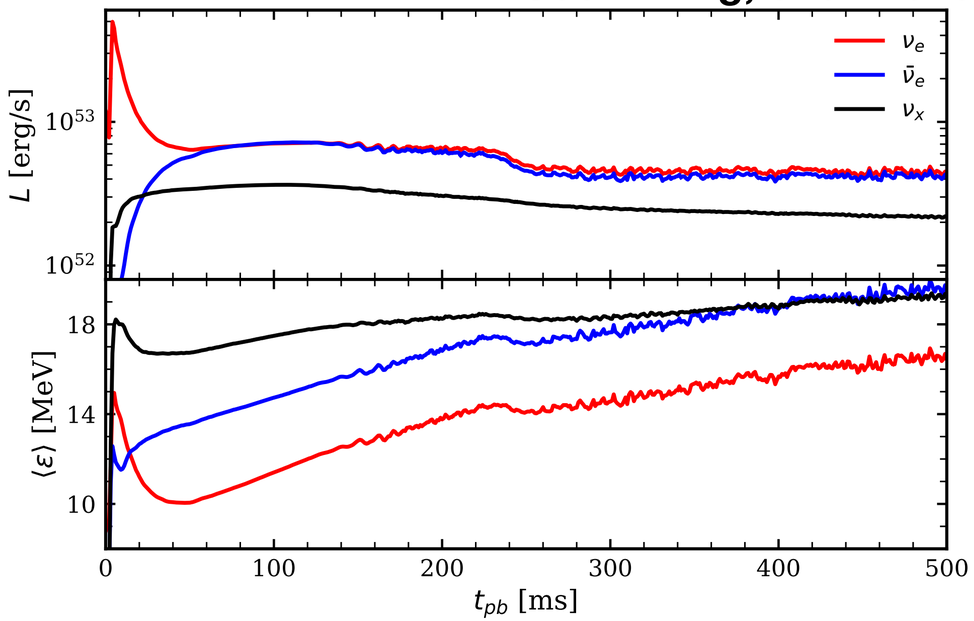
For details see Meng-Ru's talk

A parametric description of flavor conversions in CCSN simulations

Parametrized recipe:



See Ehring, et al. 2023a



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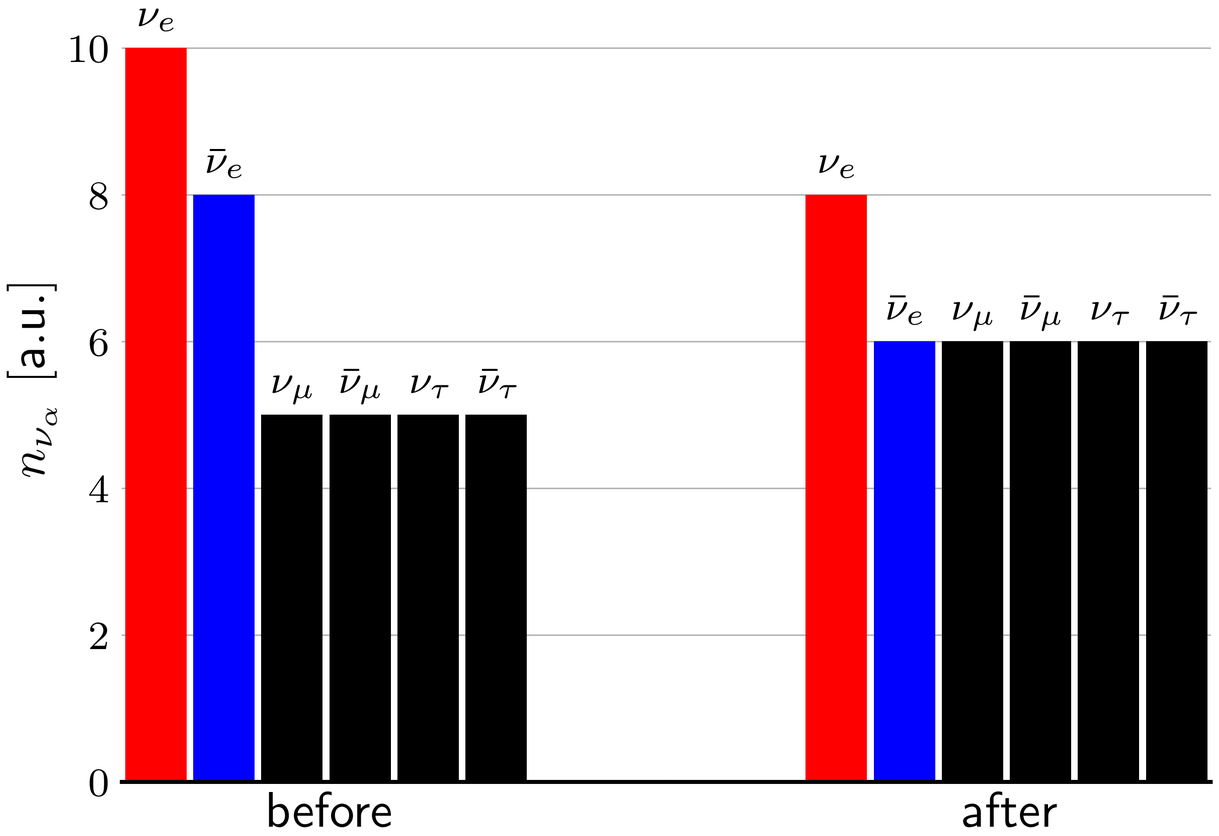

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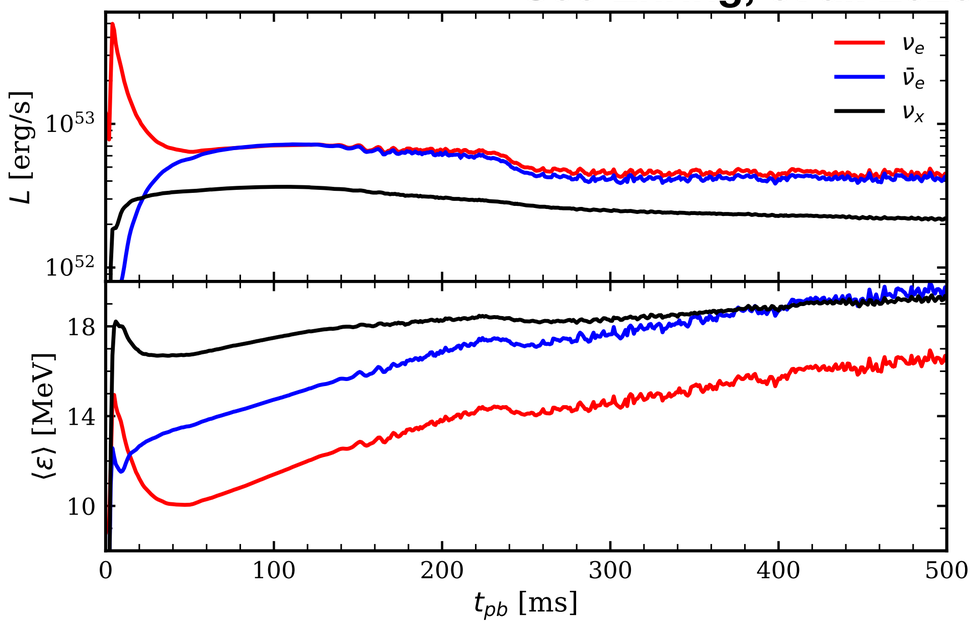

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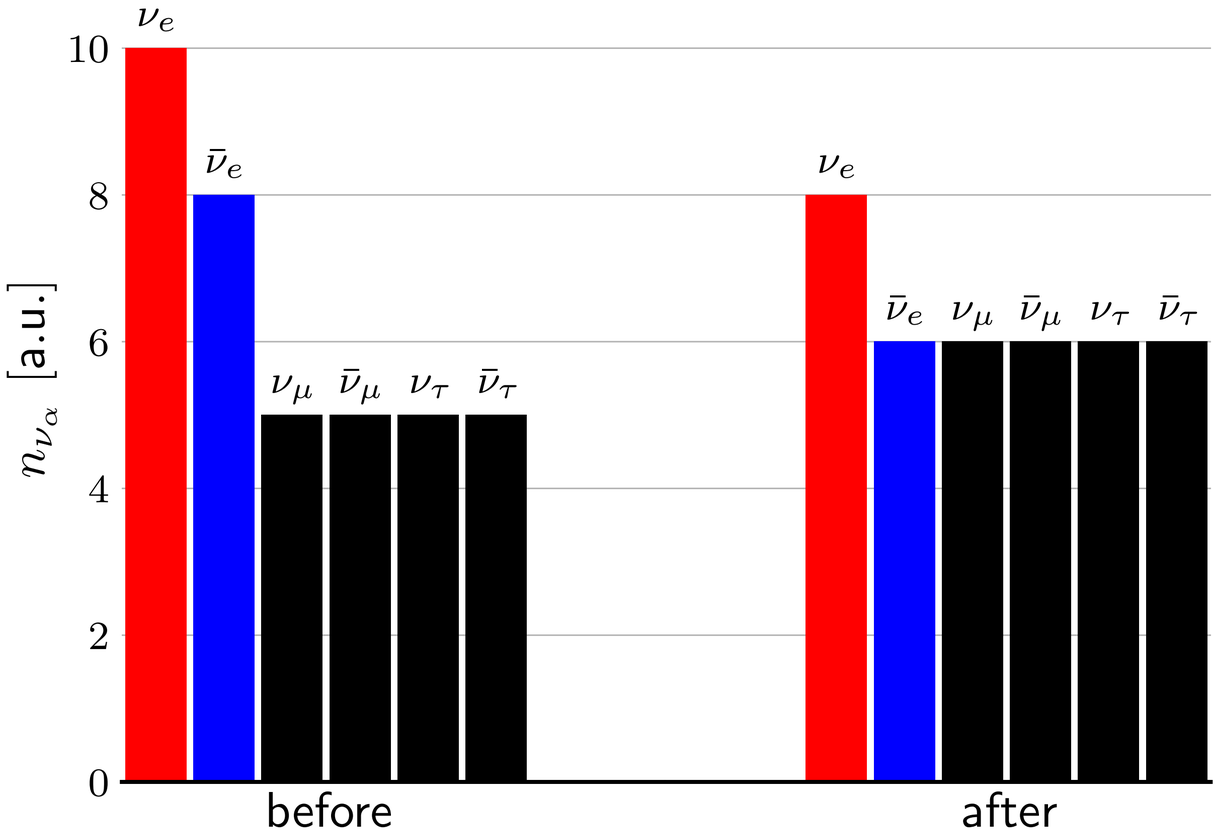
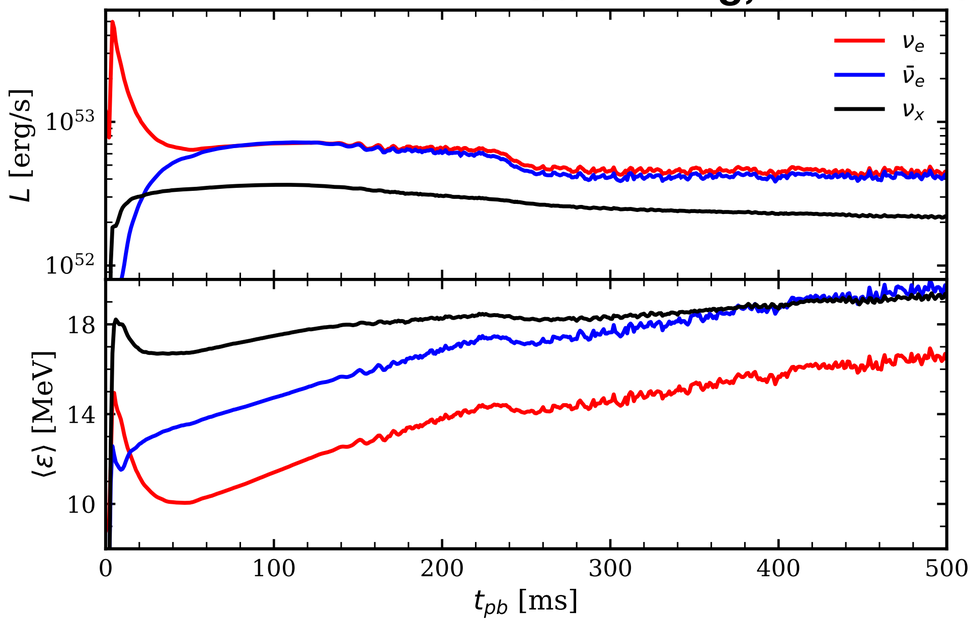


$$\nu_e, \bar{\nu}_e \rightarrow \nu_x, \nu_x$$

See Ehring, et al. 2023a



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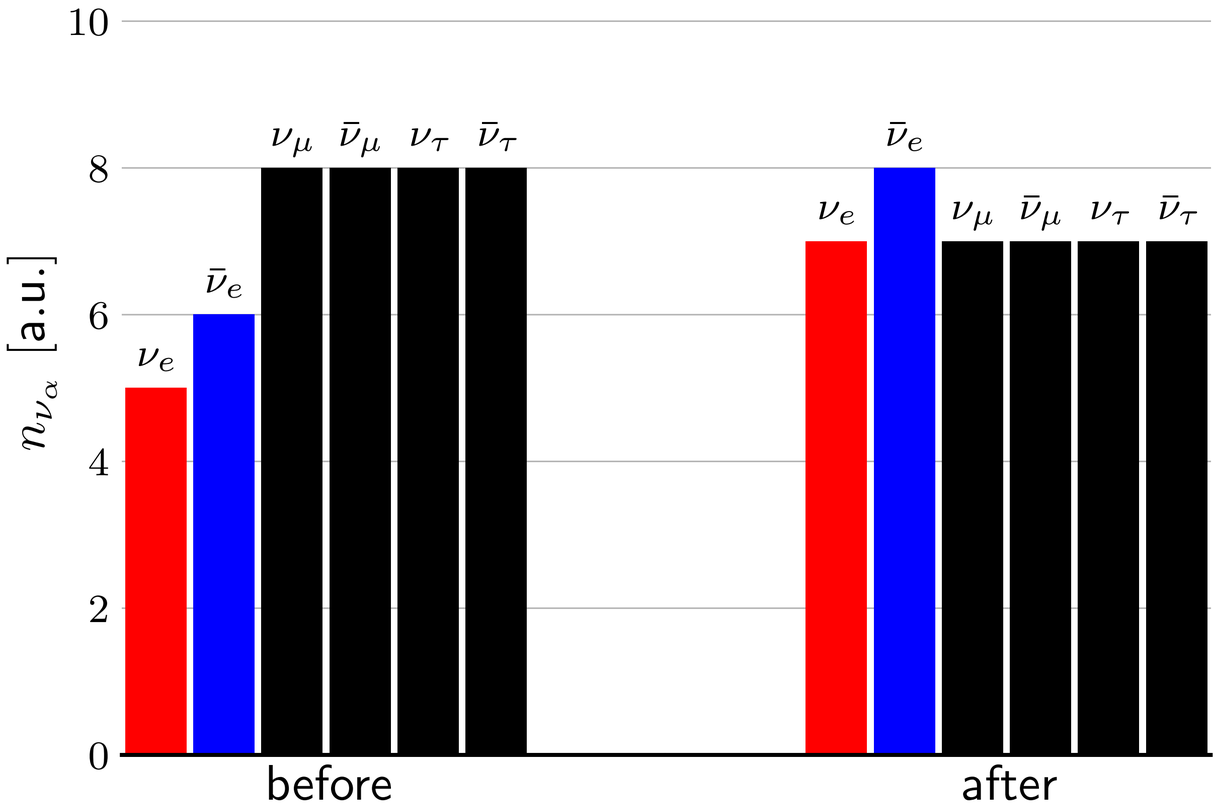
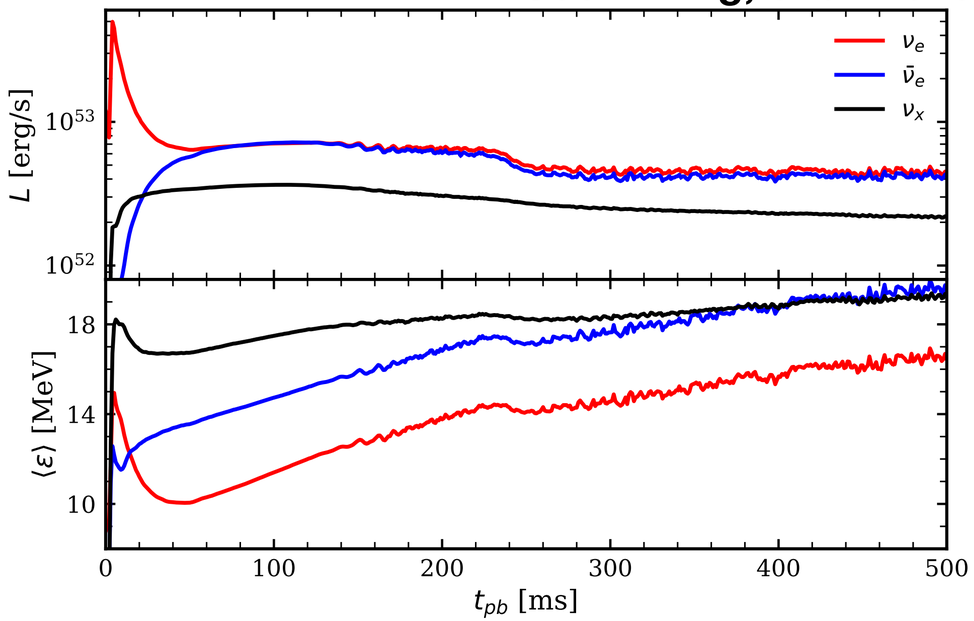


$$\nu_e, \bar{\nu}_e \rightarrow \nu_x, \nu_x$$

At higher energies:

$$\nu_x, \nu_x \rightarrow \nu_e, \bar{\nu}_e$$

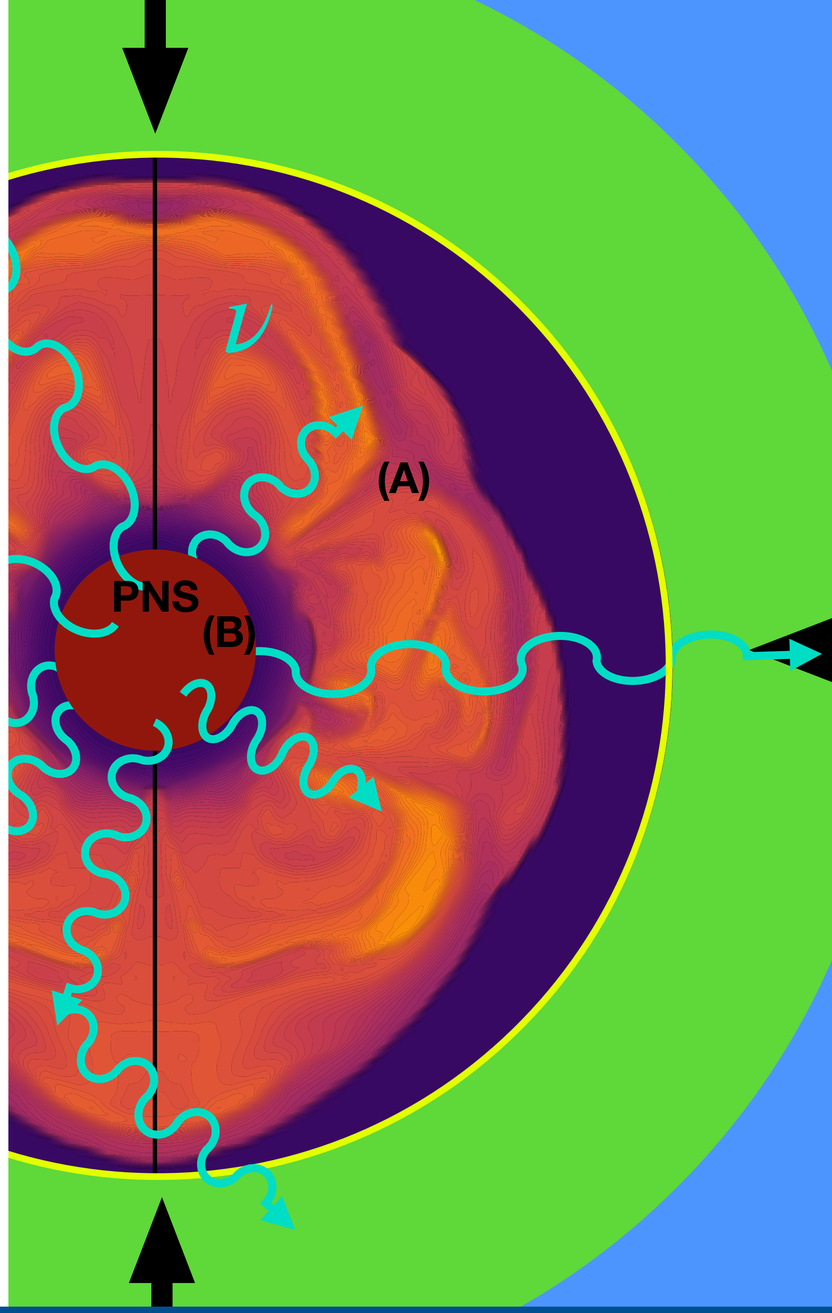
See Ehring, et al. 2023a



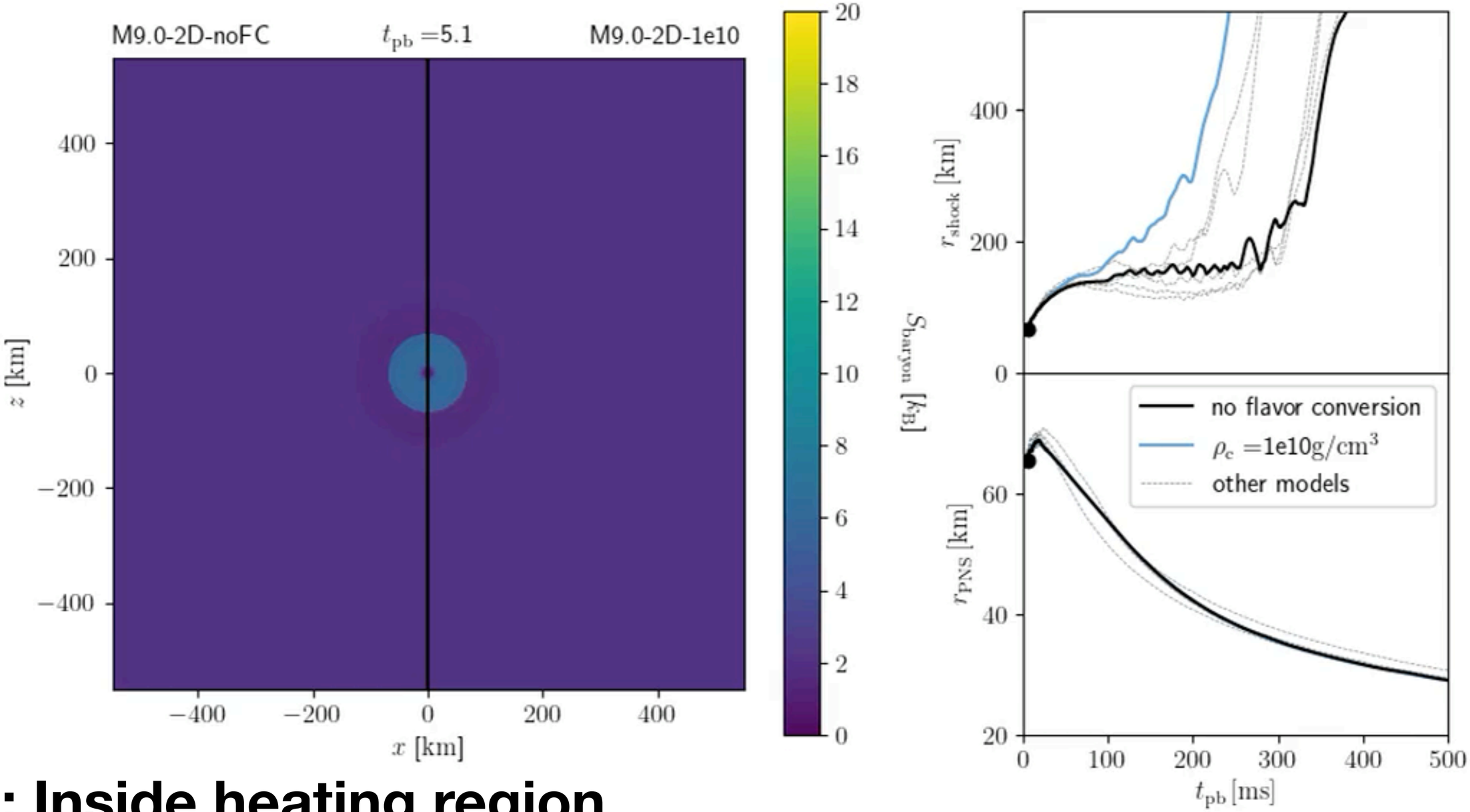
Probe effect in different regions:

Use density to restrict flavor conversions to different regions:

- **Inside Heating Region** $(\rho_{\text{crit}} = 10^{10}\,\text{g/cm}^3)$ **(A)**
- **Inside Cooling Region** $(\rho_{\text{crit}} = 10^{12}\,\text{g/cm}^3)$ **(B)**

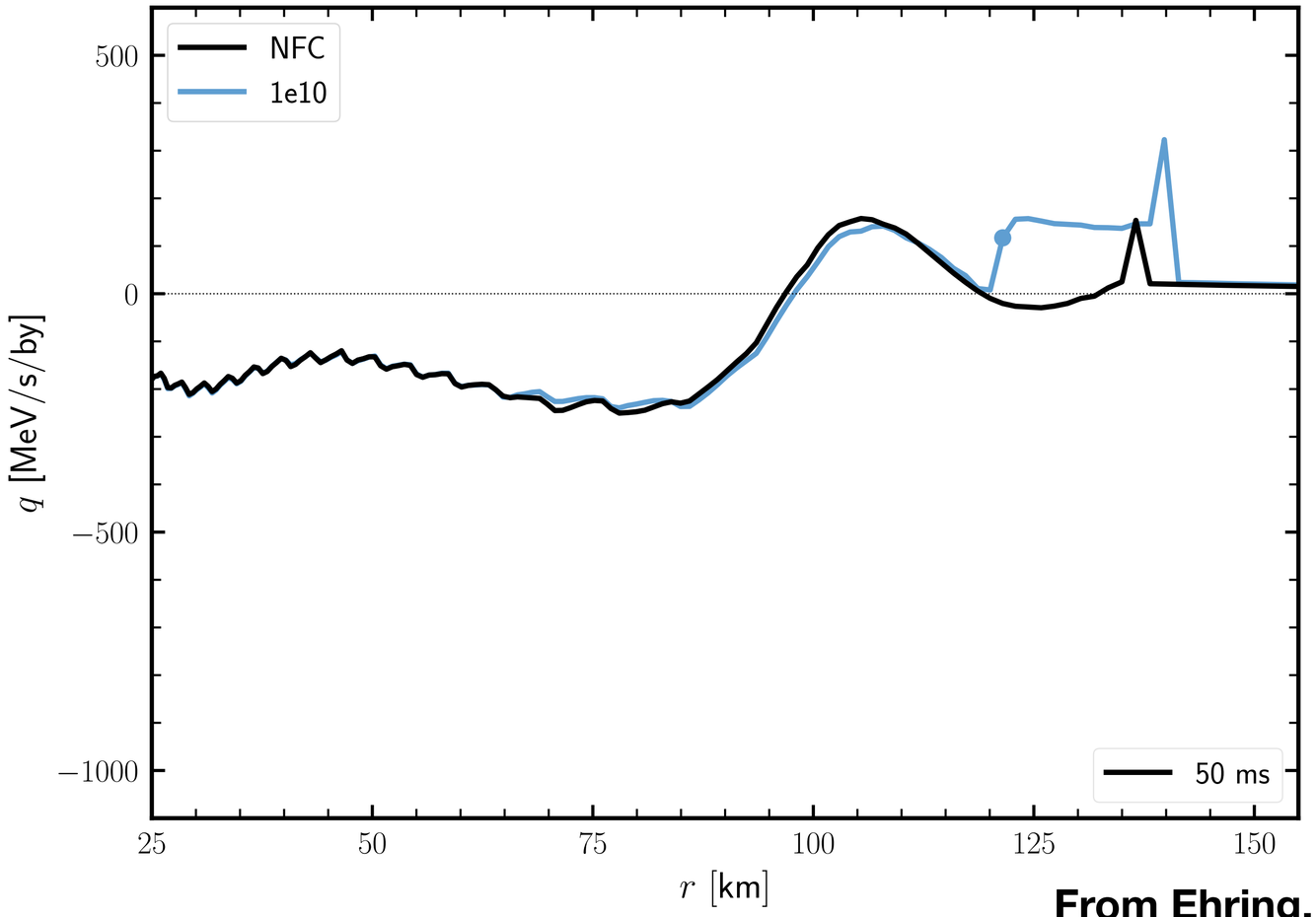


Results from simulations in axial symmetry (2D)



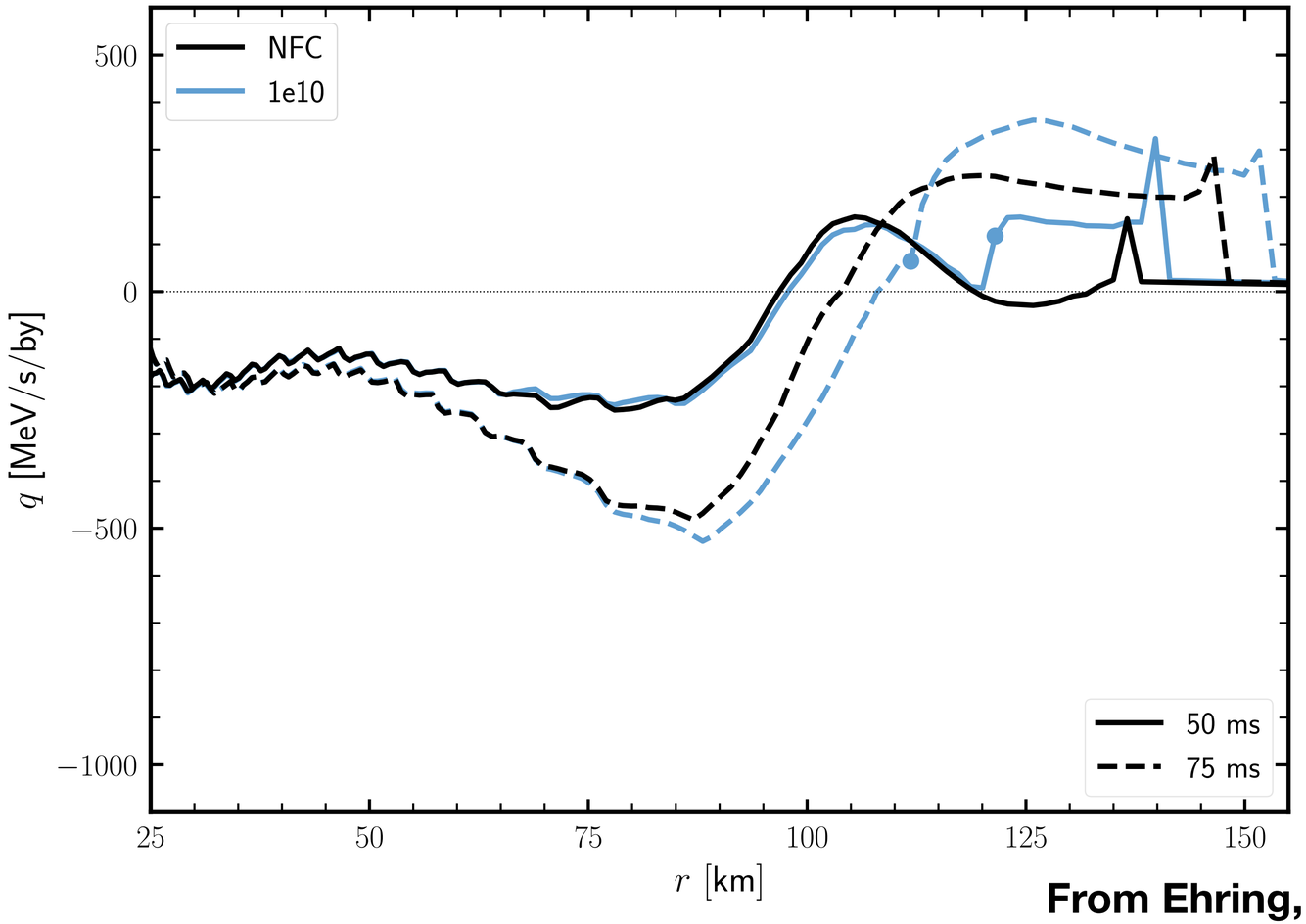
(A): Inside heating region

Local heating



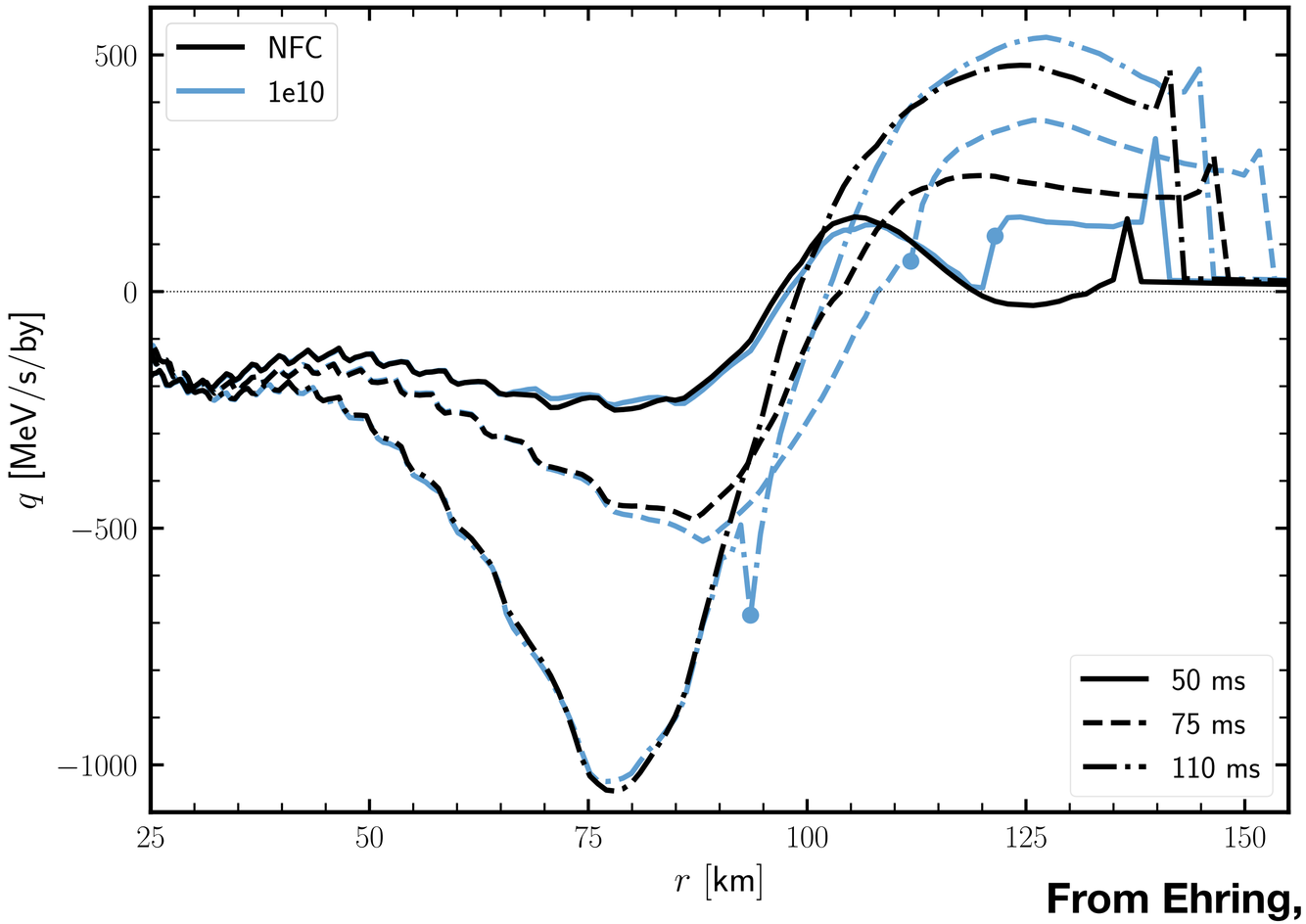
From Ehring, et al. 2023a

Local heating



From Ehring, et al. 2023a

Local heating



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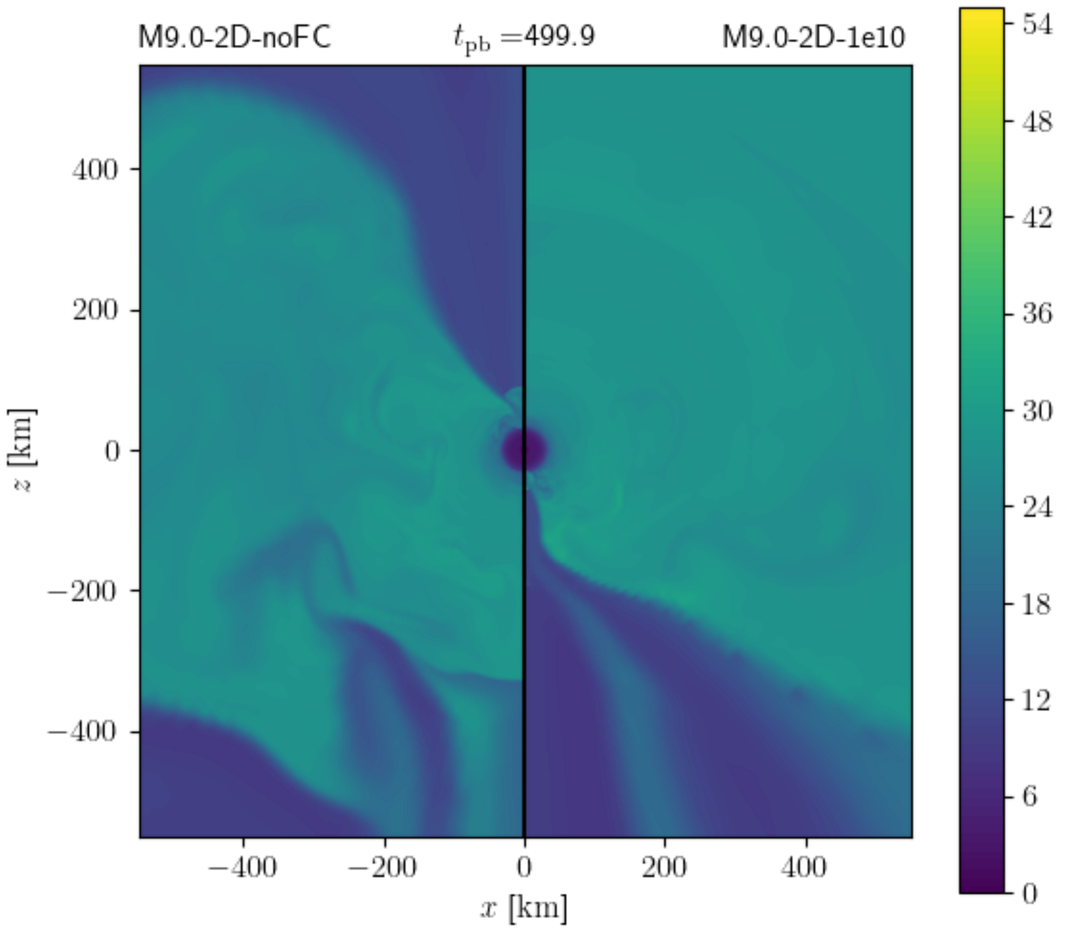
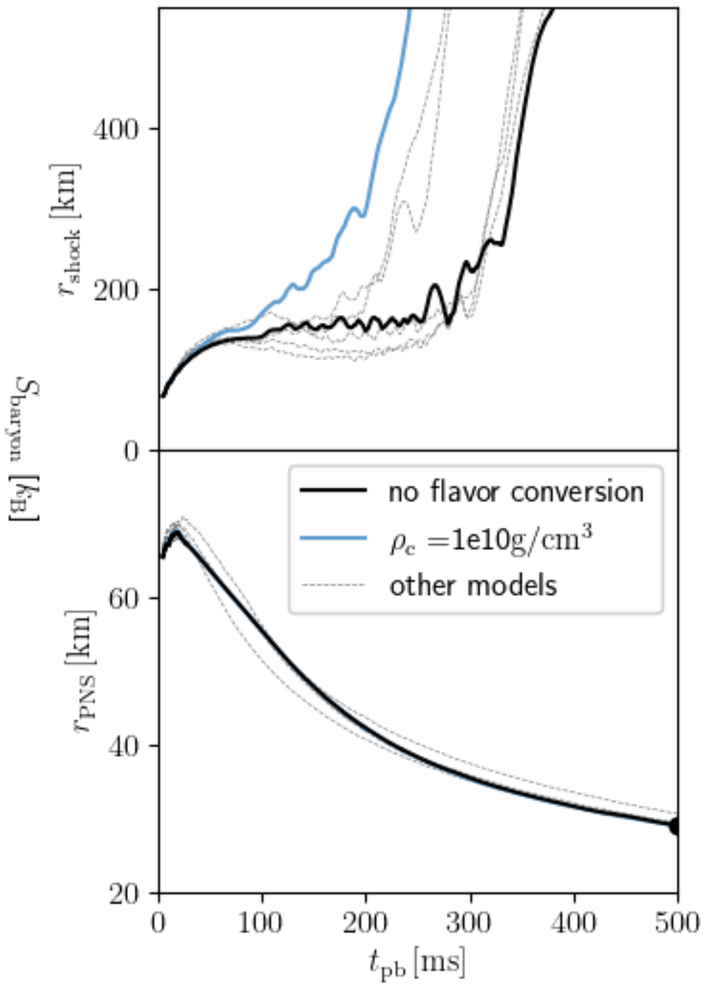
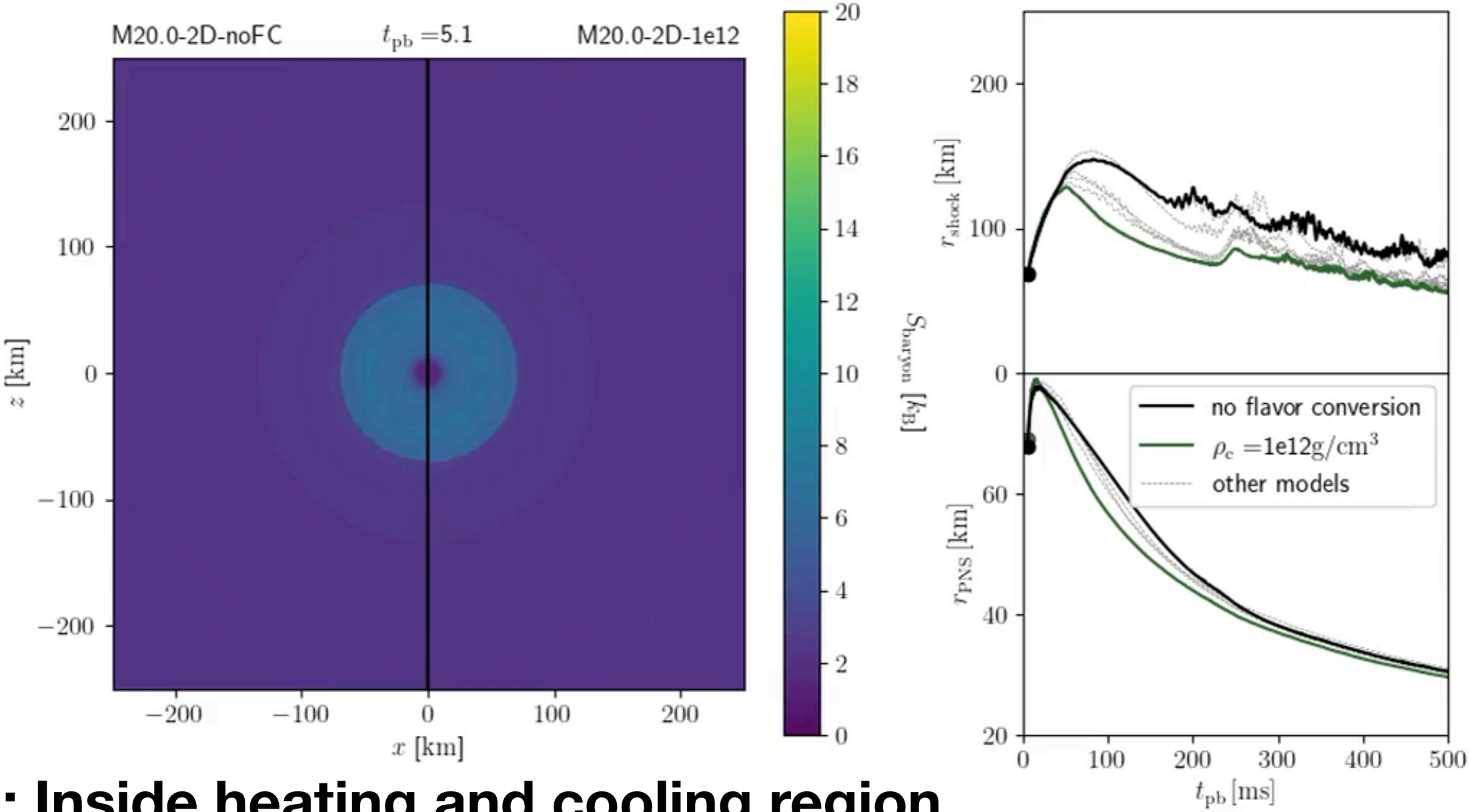


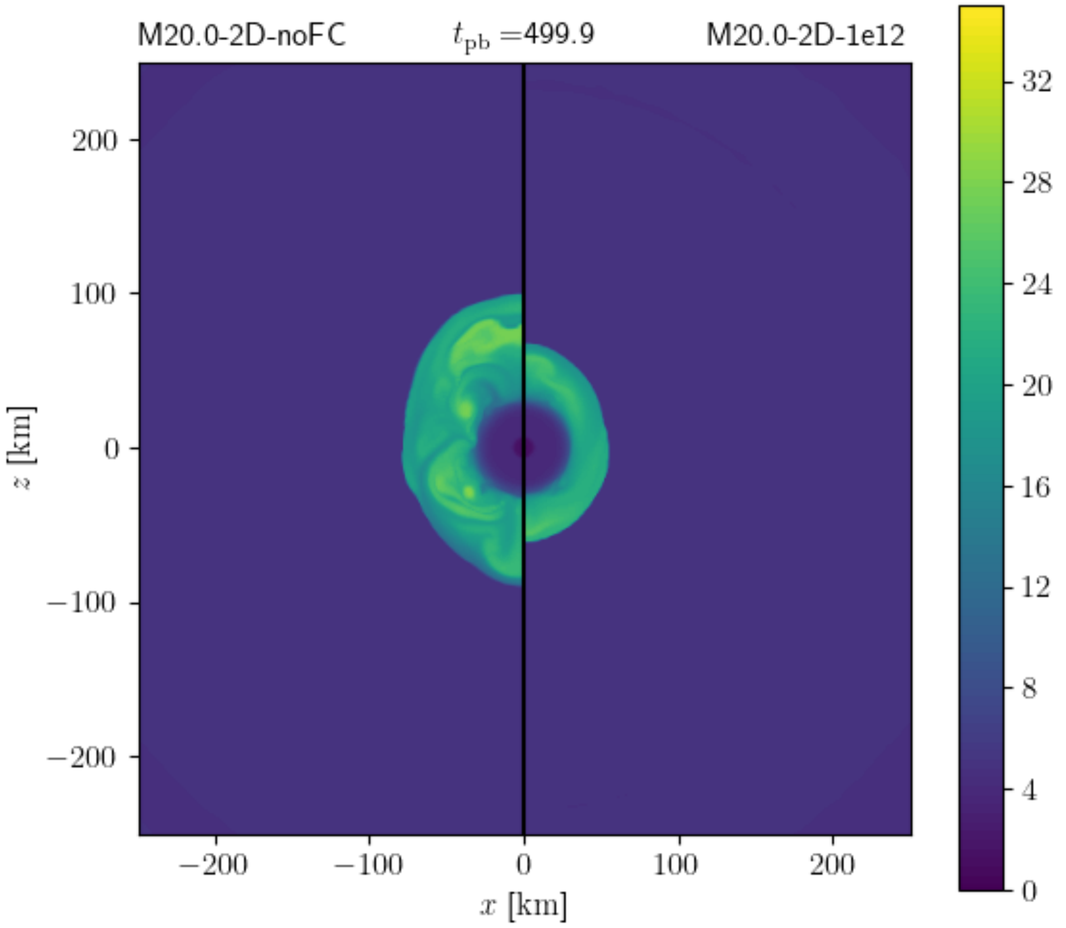


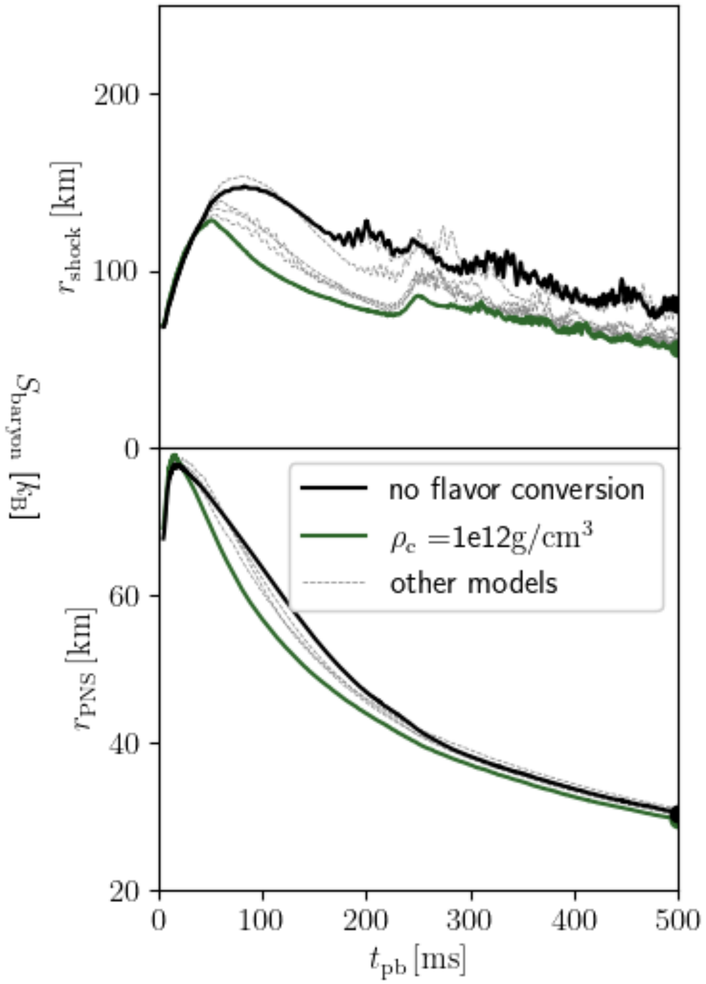
Low mass progenitor system
Conversions in heating region

- **Earlier onset of explosion**
- **Increased specific heating**



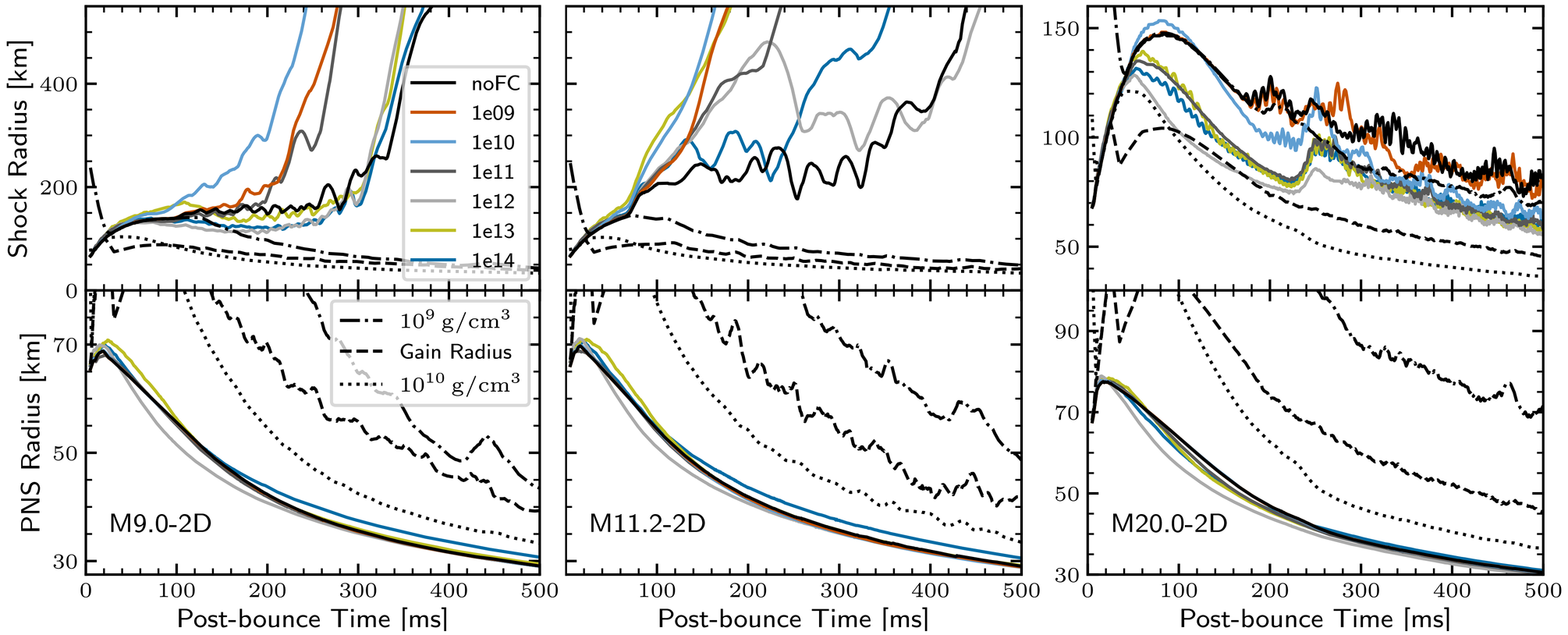
(B): Inside heating and cooling region





Heavy progenitor system
Conversions in heating and cooling region

- **Tendency to black hole formation is increased in all models with flavour conversion**
- **Additionally increased cooling leads to faster PNS contraction**



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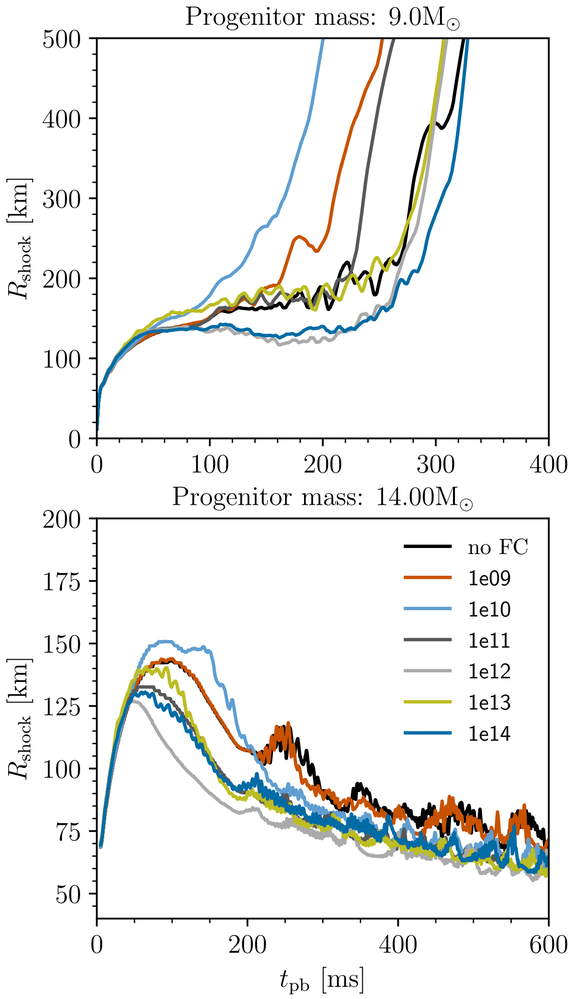
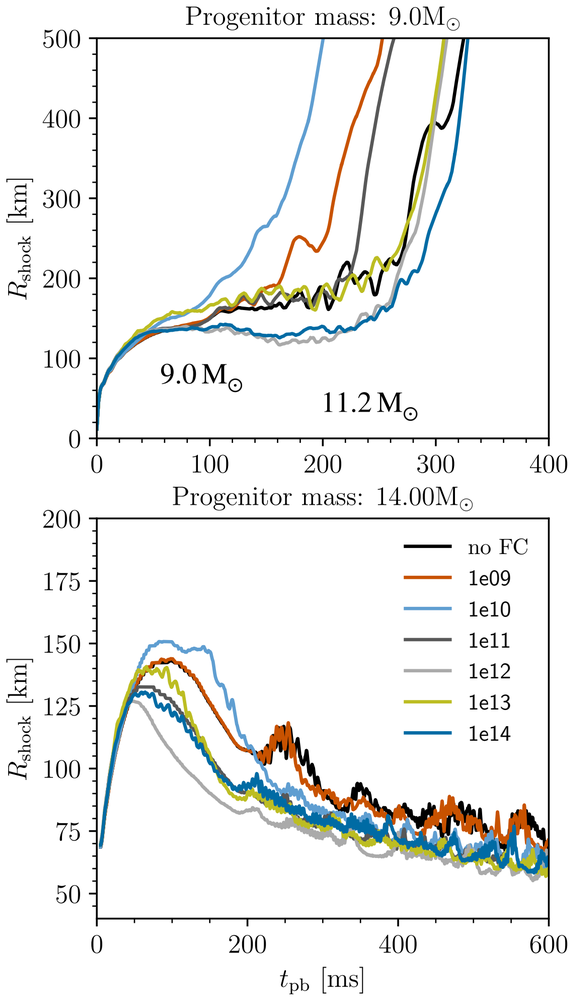


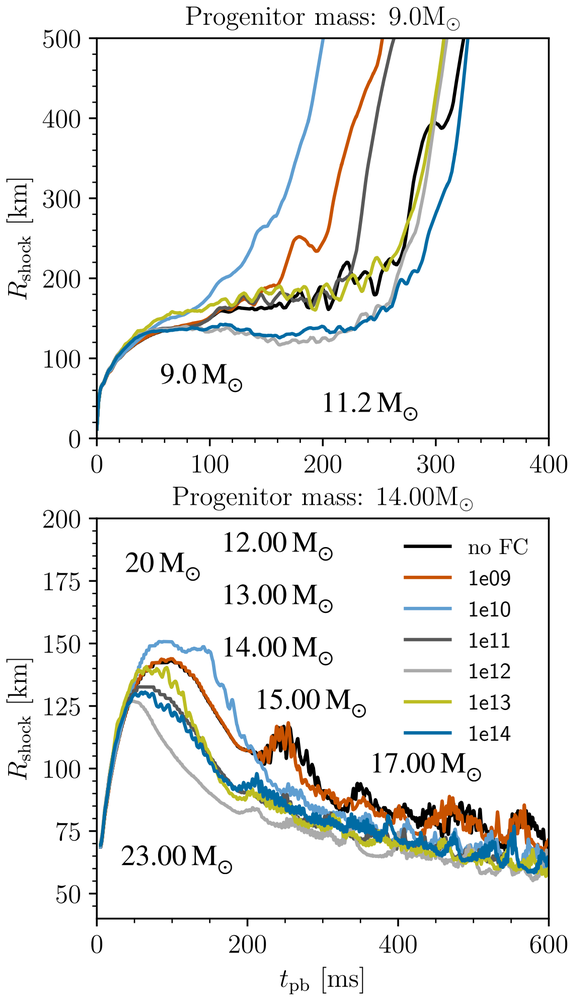
$9.0\,M_\odot$ $11.2\,M_\odot$ $12.00\,M_\odot$ $13.00\,M_\odot$ $14.00\,M_\odot$ $15.00\,M_\odot$ $16.00\,M_\odot$

$17.00\,M_\odot$ $18.00\,M_\odot$ $19.00\,M_\odot$ $20\,M_\odot$ $21.00\,M_\odot$ $23.00\,M_\odot$



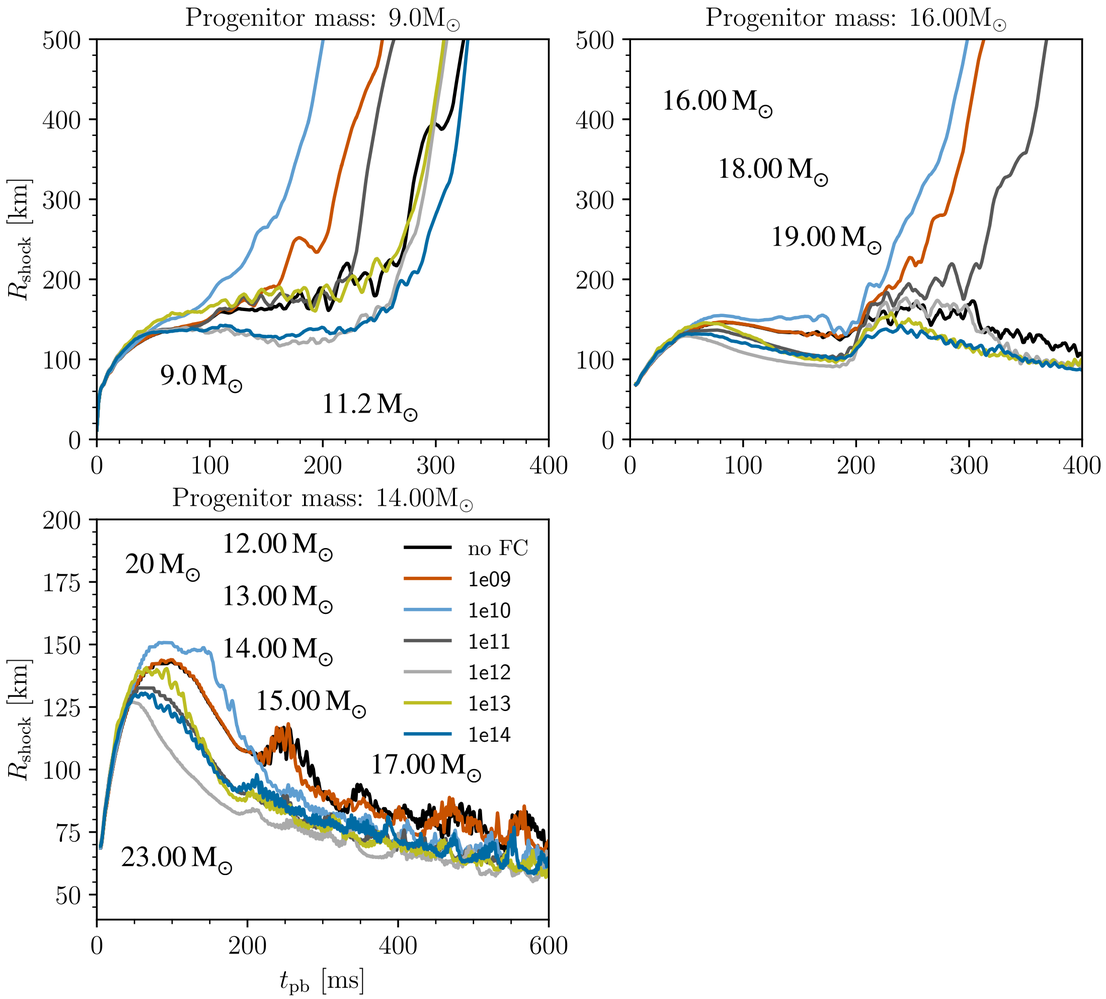
12.00 M⊙ 13.00 M⊙ 14.00 M⊙ 15.00 M⊙ 16.00 M⊙

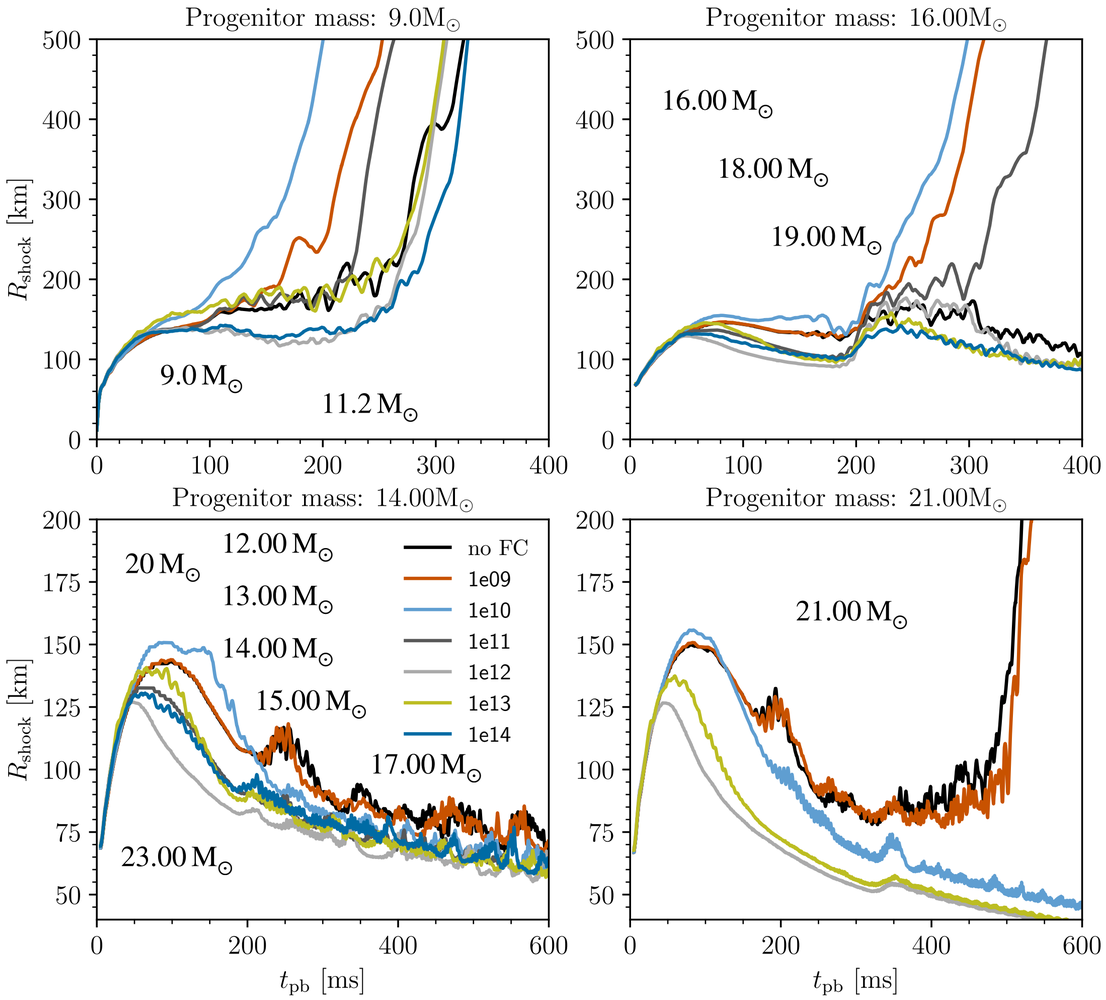
17.00 M⊙ 18.00 M⊙ 19.00 M⊙ 20 M⊙ 21.00 M⊙ 23.00 M⊙



16.00 M⊙

18.00 M⊙ 19.00 M⊙ 21.00 M⊙


Progenitor mass: 9.0M⊙
Progenitor mass: 16.00M⊙
Progenitor mass: 14.00M⊙
$R_{\rm shock}$ [km]
$t_{\rm pb}$ [ms]
9.0 M⊙
11.2 M⊙
16.00 M⊙
18.00 M⊙
19.00 M⊙
20 M⊙
12.00 M⊙
13.00 M⊙
14.00 M⊙
15.00 M⊙
17.00 M⊙
23.00 M⊙
21.00 M⊙
no FC
1e09
1e10
1e11
1e12
1e13
1e14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9.0 M⊙
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16.00 M⊙
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19.00 M⊙
20 M⊙
12.00 M⊙
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no FC
1e09
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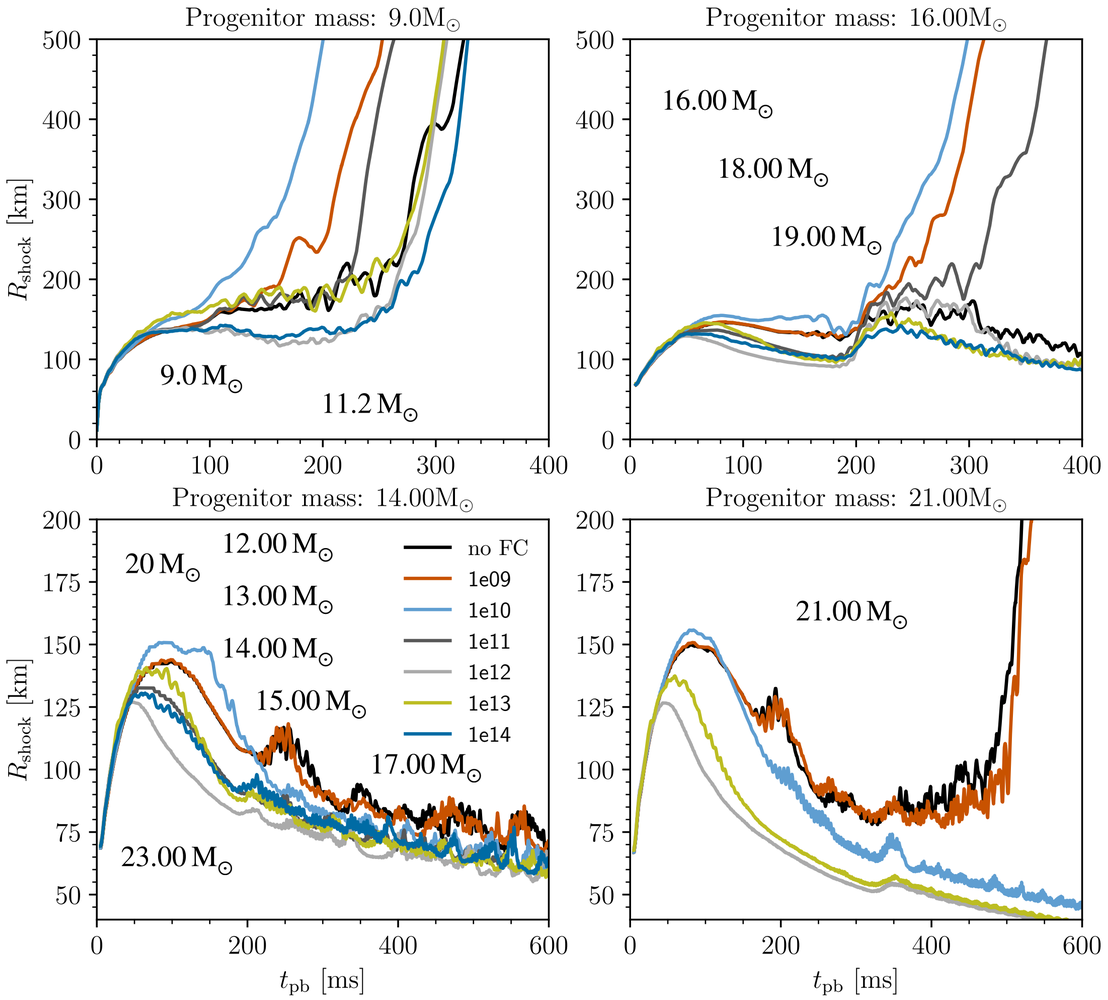
1e13
1e14



low mass ($m \lesssim 12\,\mathrm{M}_\odot$): more vigorous explosions

intermediate mass ($12\,\mathrm{M}_\odot \lesssim m \lesssim 15\,\mathrm{M}_\odot$): faster (?) BH formation

intermediate mass ($16\,\mathrm{M}_\odot \lesssim m \lesssim 19\,\mathrm{M}_\odot$): increased exploadability

higher masses($m \gtrsim 20\,\mathrm{M}_\odot$): prevents (?) explosions

Summary

➡Flavor conversions influence the dynamics

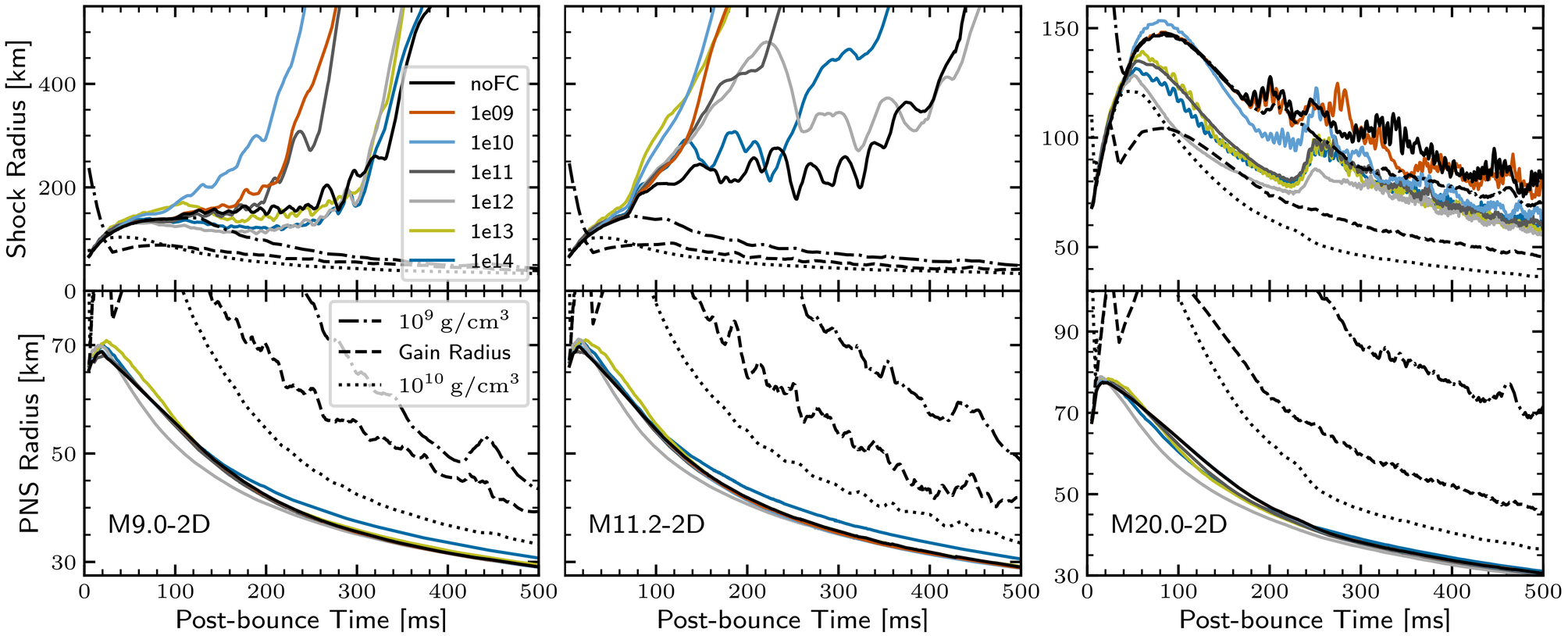
➡They can help AND hinder AND enable AND prevent explosions

➡Flavor conversions enhance
- Heating in gain region
- Cooling in cooling region and PNS mantle

➡Temporal dependence on the effects
- Soon after bounce: largest effect on heating
- At later times: cooling effect remains

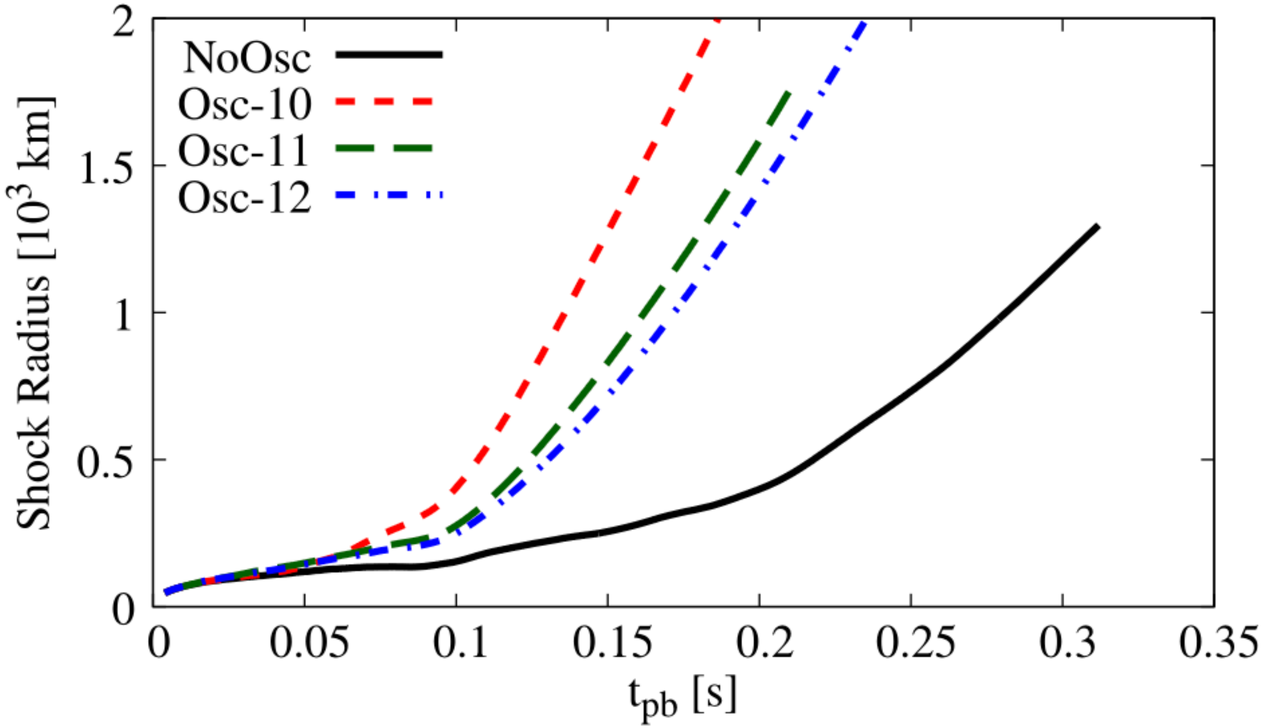
Visit us in Taiwan for a workshop on Neutrino Flavor Conversions
in CCSN and BNSM
23.03.2026 - 27.03.2026

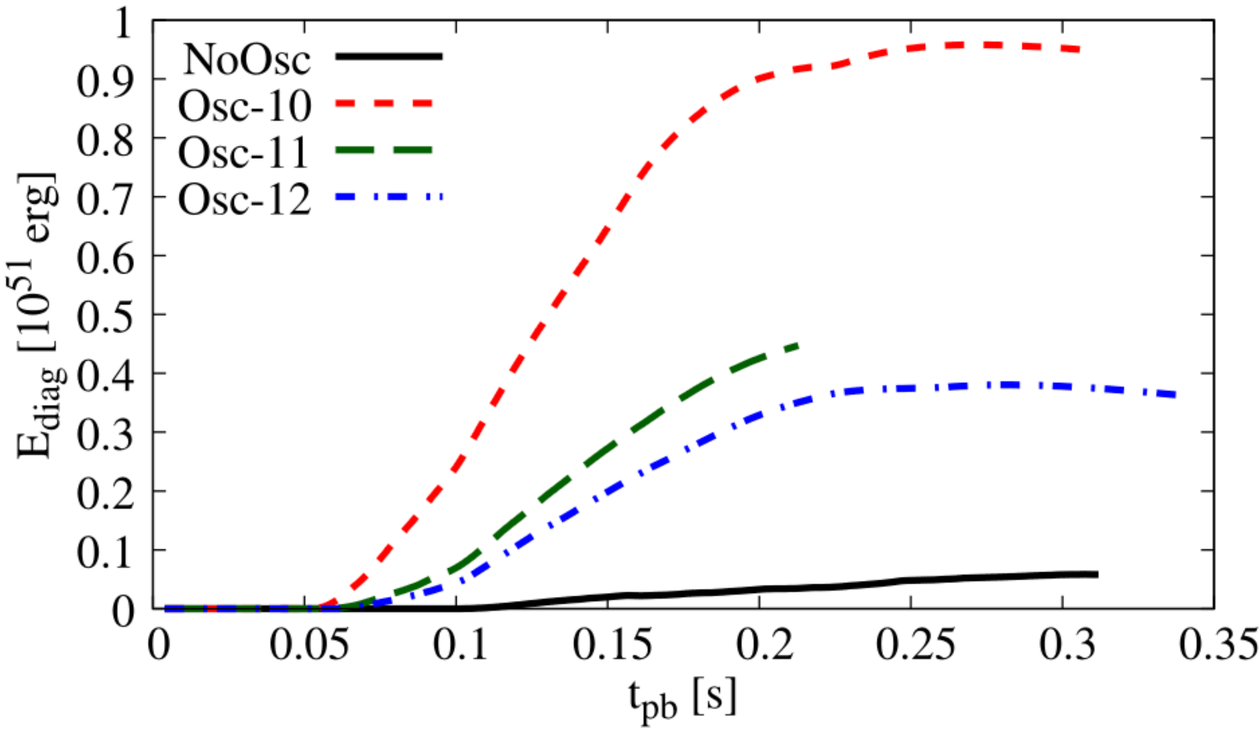
Backup



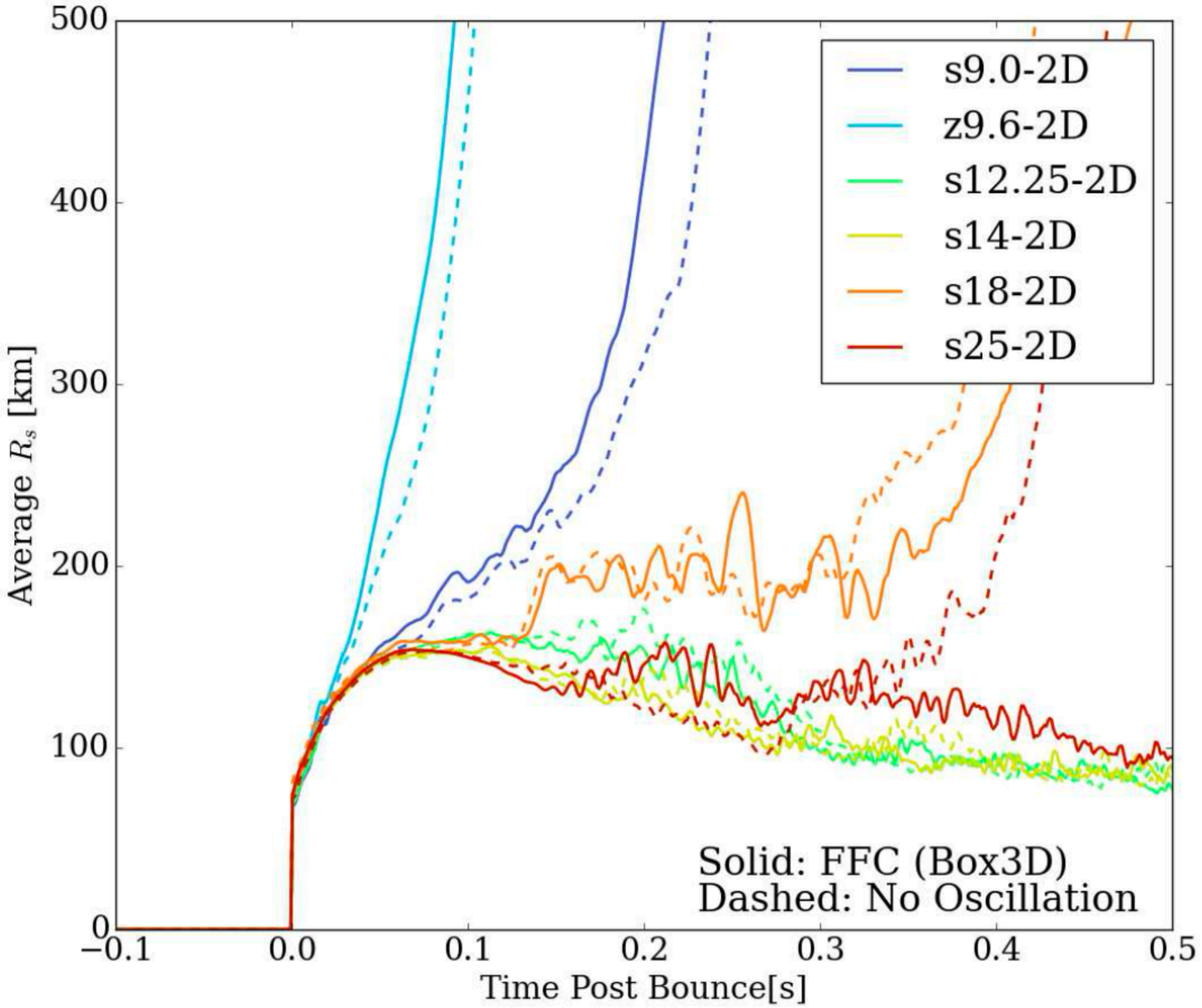
From Ehring, et al. 2023b

11.2 $M_\odot$ - 3D

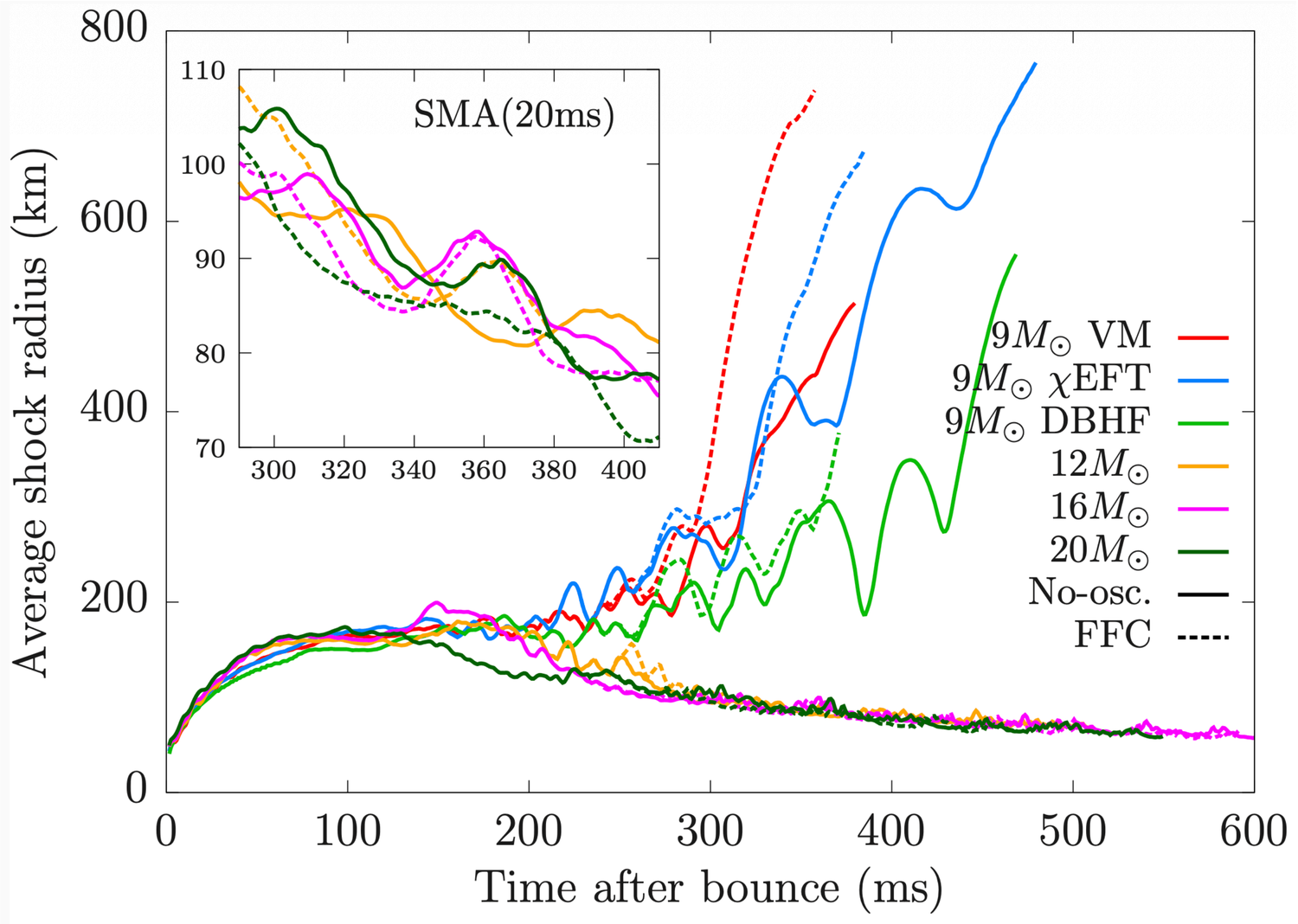




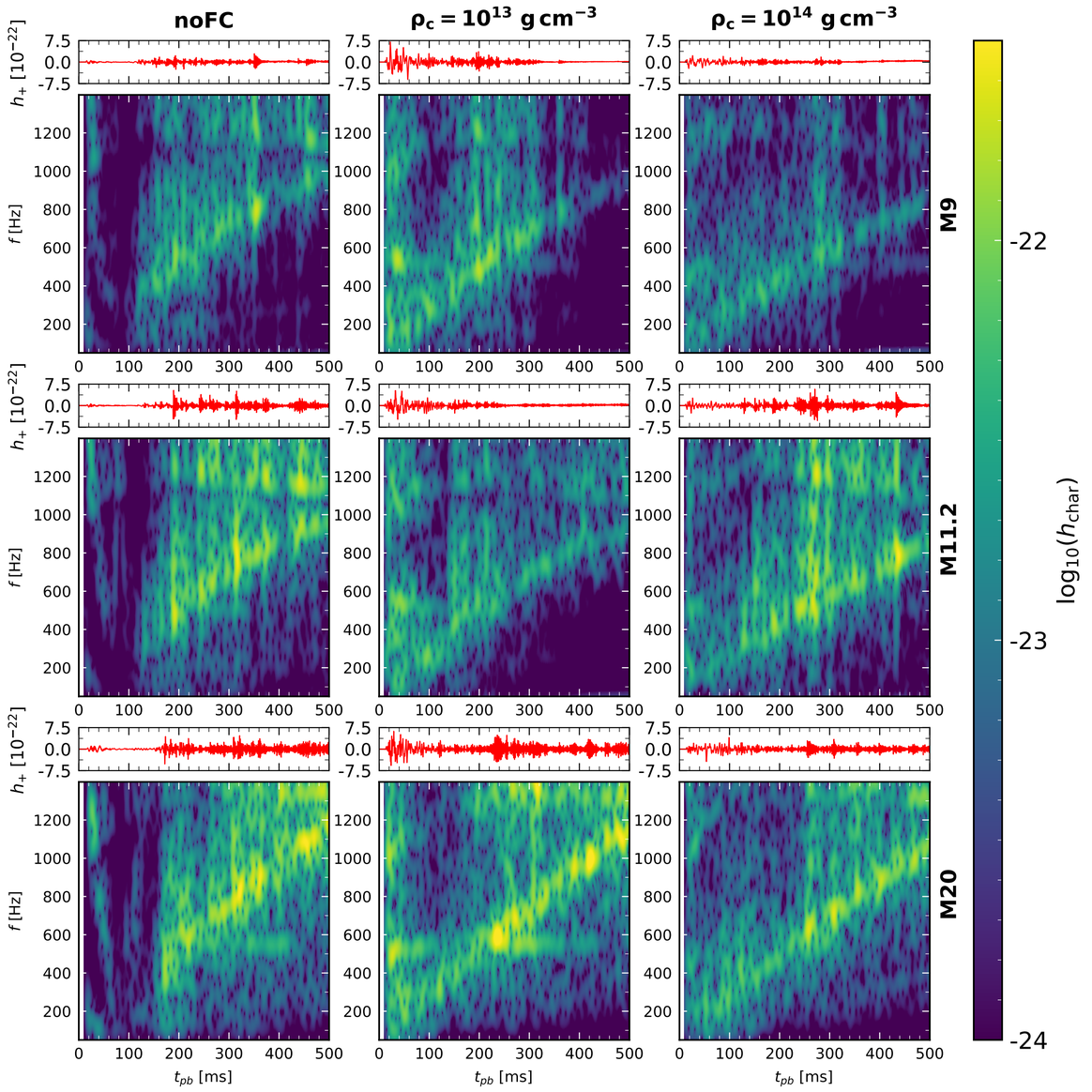
From Mori and Mori 2025



From Wang and Burrows 2025a



From Akako et al 2026


noFC
$\rho_c = 10^{13}$ g cm^{-3}
$\rho_c = 10^{14}$ g cm^{-3}
h_+ [10^{-22}]
f [Hz]
t_{pb} [ms]
M9
M11.2
M20
$\log_{10}(h_{\rm char})$
-22
-23
-24