Hunting for electron-neutrino lepton number crossings in core-collapse supernovae

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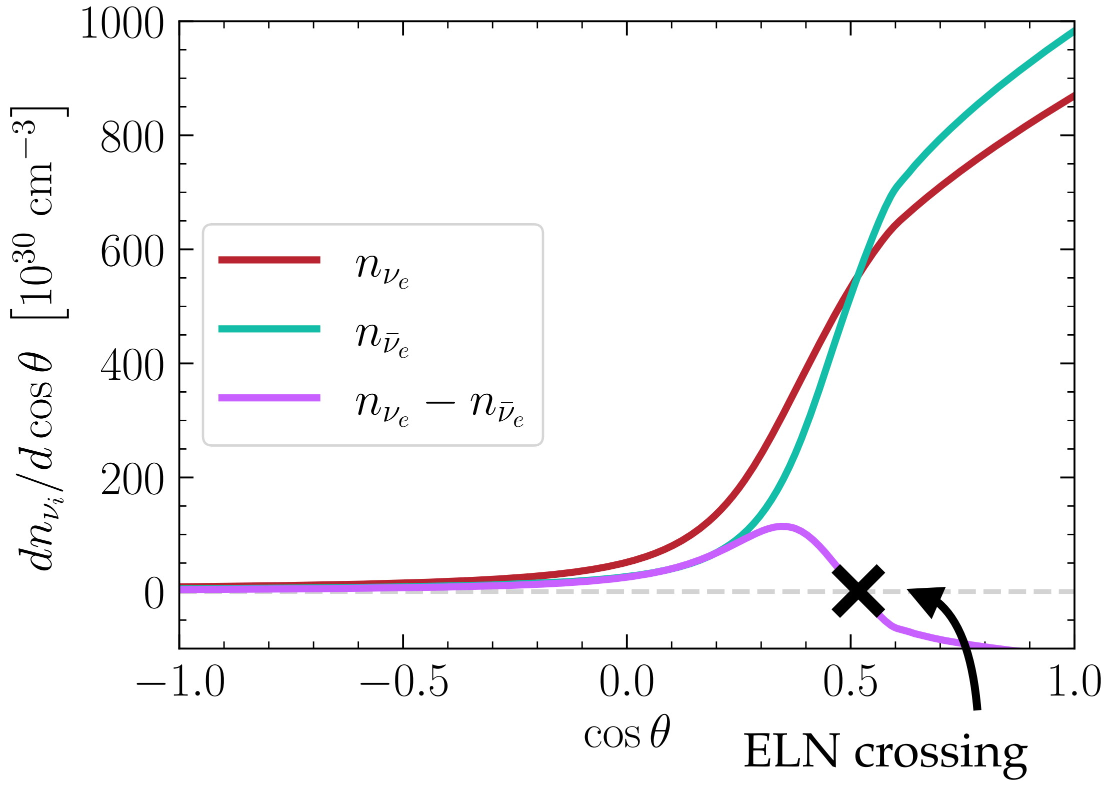
Why look for ELN crossings?

- In core-collapse supernovae (SNe), neutrinos of different flavors decouple at different radii
- This can create electron-neutrino lepton number (ELN) crossings in their angular distributions
- ELN crossings can trigger fast neutrino flavor conversions, potentially affecting the explosion and nucleosynthesis



- It is too expensive to account for flavor conversion directly in supernova hydrodynamic simulations

⇒ First, we should figure out **if the conditions for fast flavor conversions are indeed present:**

1. Do ELN crossings occur in supernovae?
2. Does their existence depend on variations of the physics in the SN core:
   - ✦ Equation of state (EoS)?
   - ✦ Proto-neutron star (PNS) convection?
   - ✦ Muon production?

Supernova models

- 1D spherically symmetric SN models of $18.6M_\odot$ progenitor
- Simulated with the PROMETHEUS-VERTEX code (Garching Core-Collapse SN Archive)

12 model variations:

- ✦ 3 equations of state: LS220, SFHo, DD2
- ✦ With or without PNS convection
- ✦ With or without muon production

Neutrino transport

- State-of-the-art transport methods like moment schemes are in most cases not reliable to compute neutrino angular distributions
- We compute angular distributions in post-processing by solving the Boltzmann equation in the neutrino decoupling region:

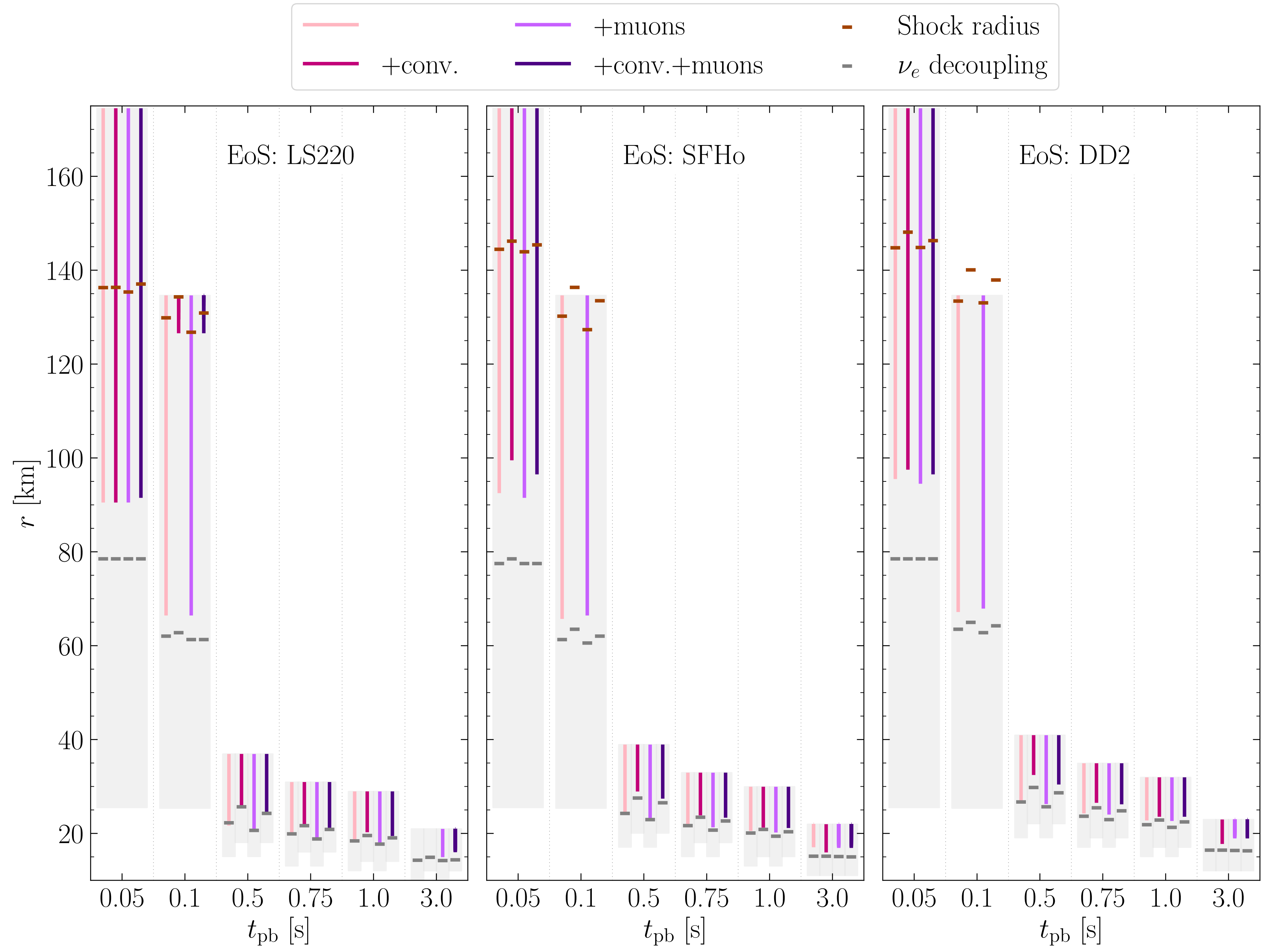
$$\underbrace{\left(\frac{\partial}{\partial t} + \vec{c}\cdot\vec{\nabla}\right)}_{\text{Neutrino propagation}} \underbrace{\rho(r,\cos\theta,E,t)}_{\text{Neutrino field}} = \underbrace{\mathcal{C}[\rho(r,\cos\theta,E,t)]}_{\text{Collision term}}$$

- Input: static fluid profiles (density, Y_e, etc) at selected post-bounce times from SN models
  - We use these profiles to compute neutrino-matter interactions ($\mathcal{C}$)
- We solve the Boltzmann equation for the neutrino field ρ as a function of radius r, propagation angle $\cos\theta(r)$, energy E, and time t

Where and when do ELN crossings occur?

Gray background: radial domain of each simulation

Solid colored lines: radial range where ELN crossings occur for each model



Are the conditions for flavor conversions present?

1. We find ELN crossings in all models at almost all post-bounce times
   - ELN crossings appear after ν_e decoupling (gray mark) and until the maximal radius
   - ELN crossings appear closer and closer to the SN core with time
2. Variations of the physics in the SN core:
   - ✦ EoS: shifts the onset of ELN crossings only slightly
   - ✦ PNS convection: ELN crossings appear at larger radii because the PNS radius increases
   - ✦ Muon production: ELN crossings appear at smaller radii because the PNS contracts faster

Conclusions

- Conditions favorable for the occurrence of flavor conversion are present in the SN core
- The appearance of ELN crossings subtly depends on the SN microphysics and proto-neutron star convection

References

This poster is based on:

- **Marie Cornelius**, I. Tamborra, M. Heinlein, S. Shalgar, H.-T.Janka, arXiv:2507.13429 (PRD 2025, in press)
- **Marie Cornelius**, I. Tamborra, M. Heinlein, H.-T.Janka, arXiv:2506.20723 (PRD 2025, in press)