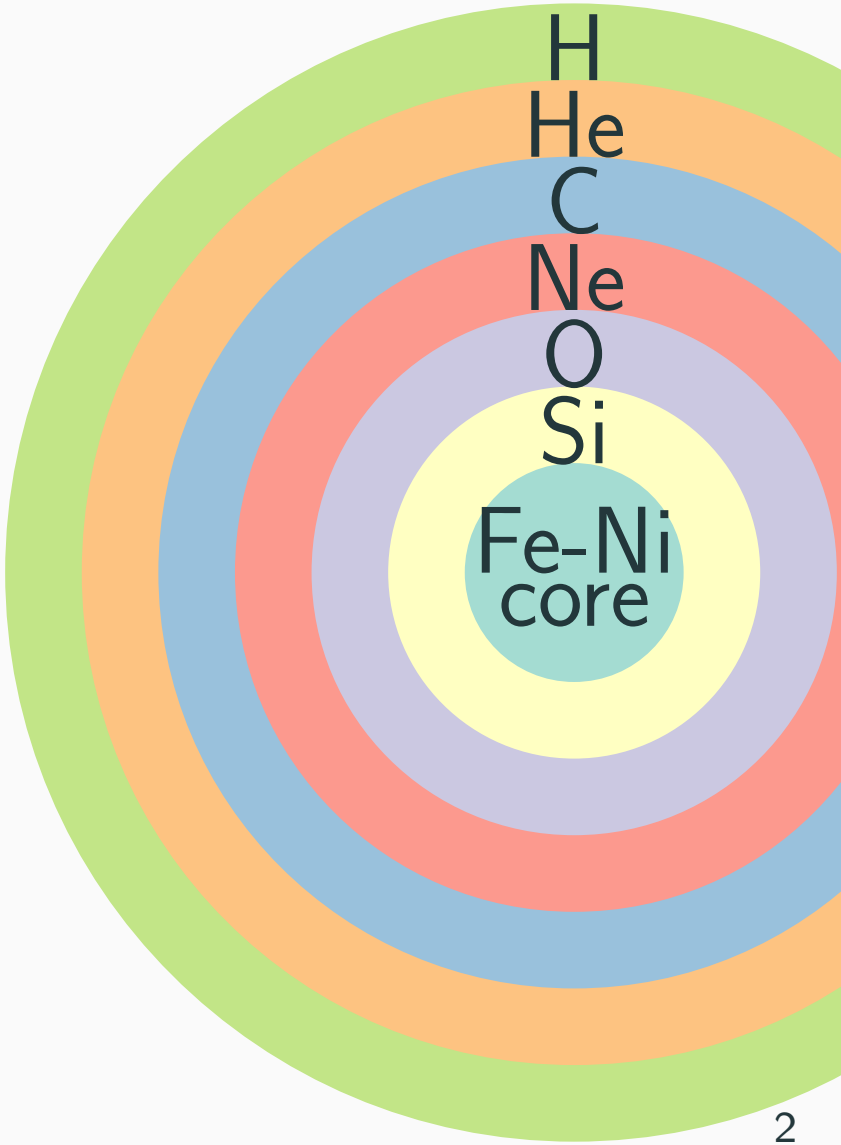
Energy-integrated Neutrino Transport in Core-collapse Supernovae

Haakon Andresen

July 24th 2023

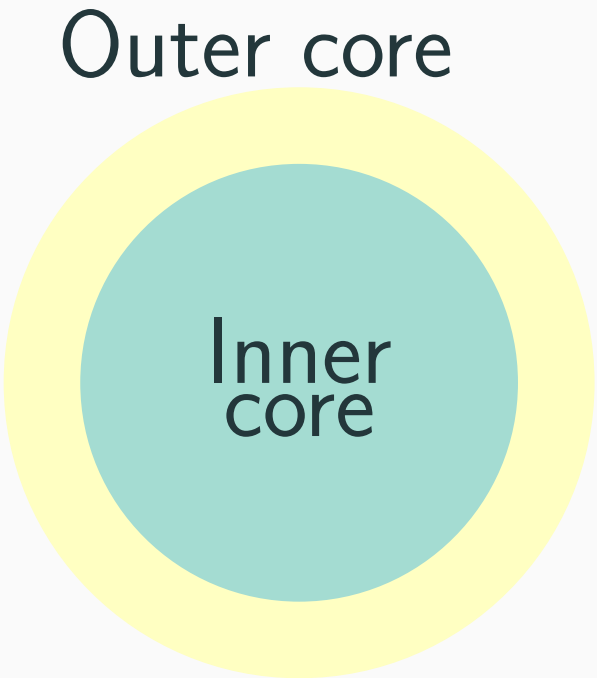
Shell burning

- Iron core
- Eventual collapse



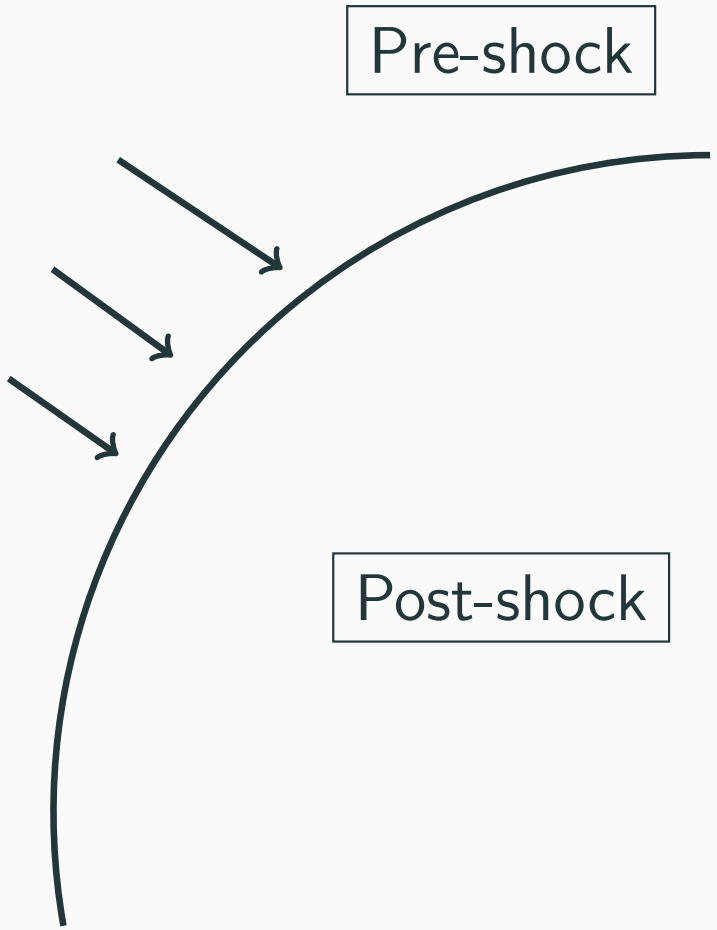
Core Bounce

- Inner core stops contracting
- Supersonically infalling outer core
- Shock wave



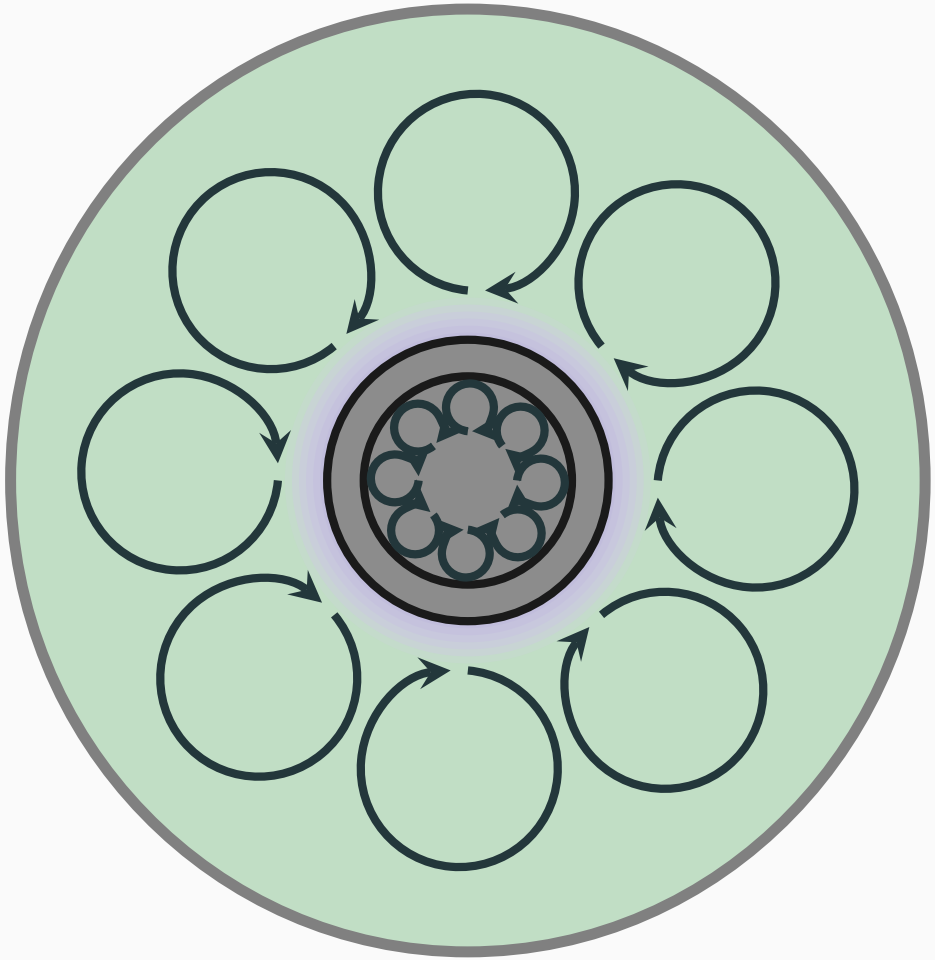
Shock Propagation

- Disintegration of heavy nuclei
- Density decreases
- Neutrino burst

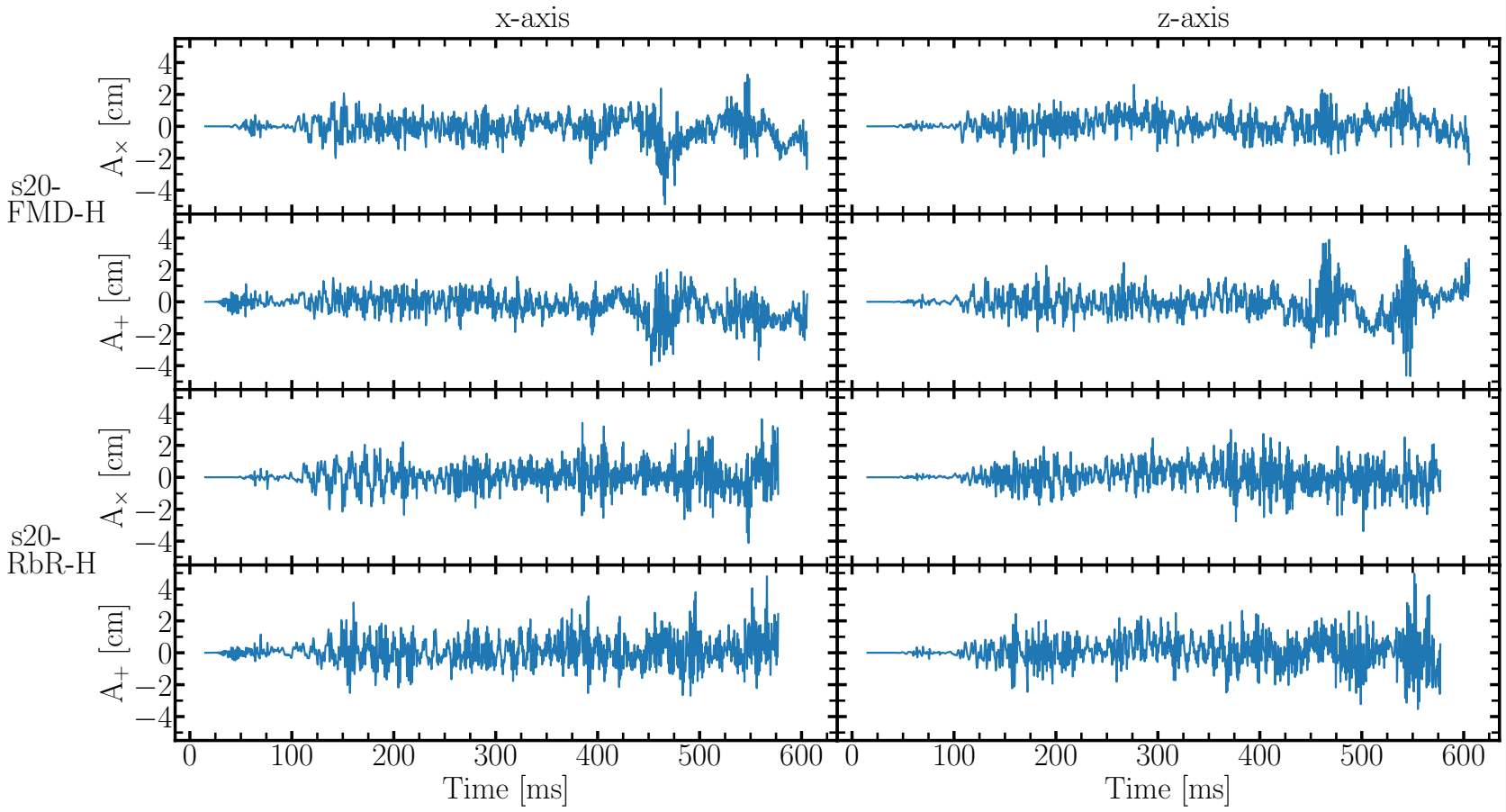


Post bounce

- Heating
- Turbulence
- Gravitational waves



s20 - High Resolution



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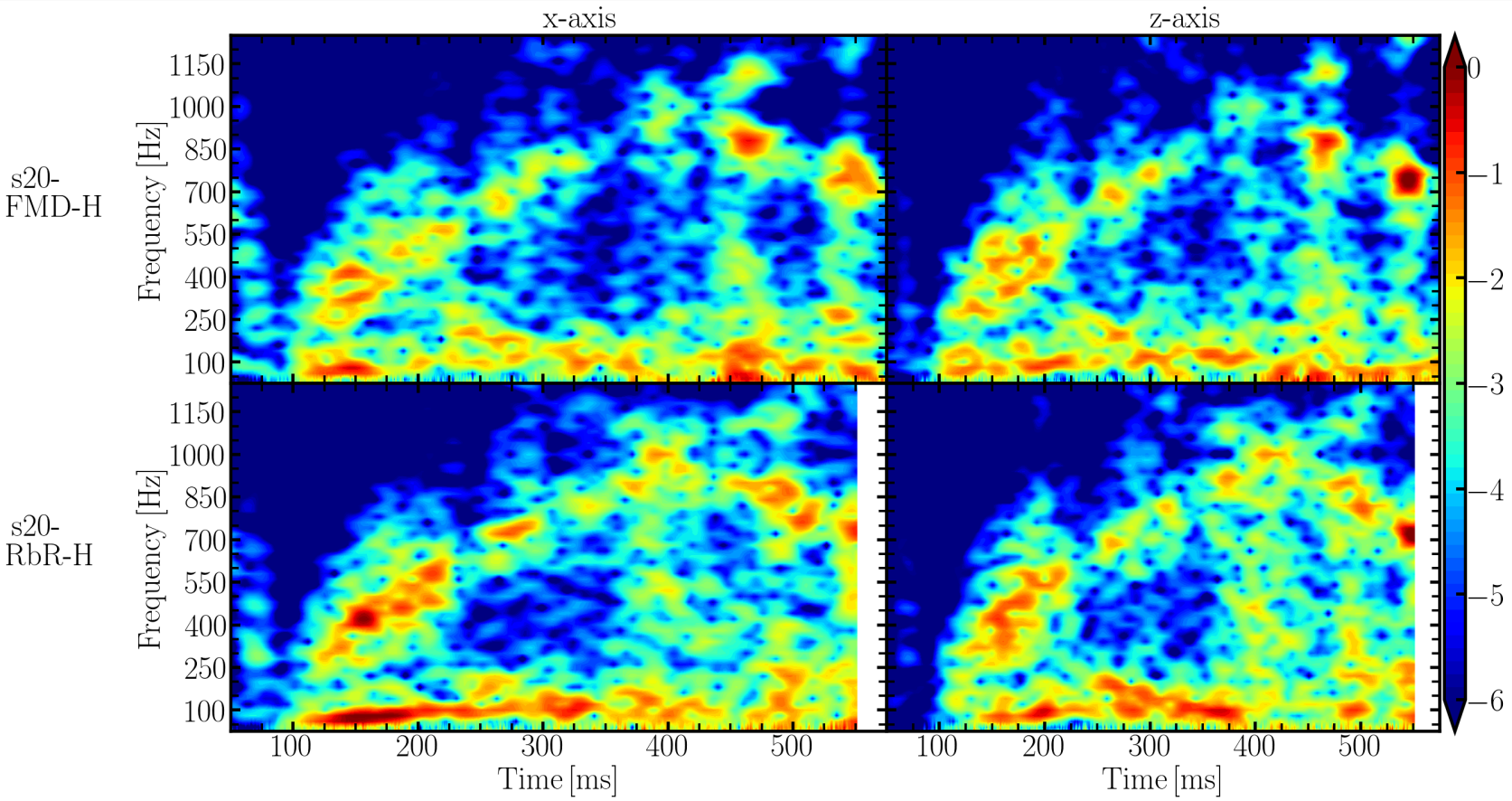


Current Status

- The neutrino-driven mechanism
- Consistent explosions
- Multi-messenger signals

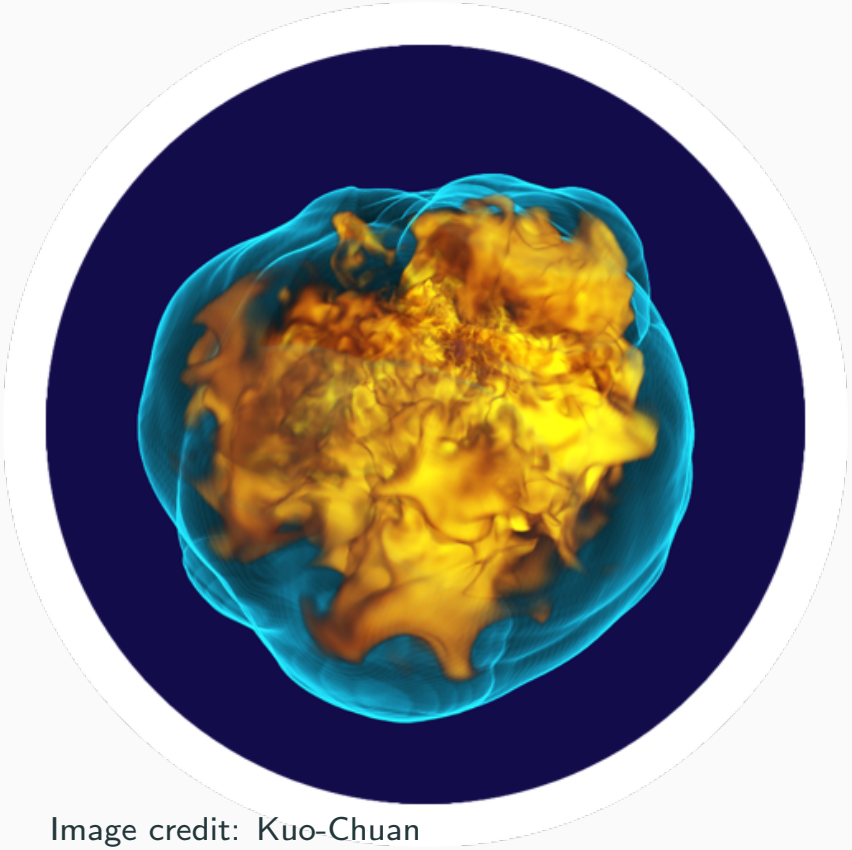


Image credit: Kuo-Chuan

Open Questions

- Late time
- Emission mechanism
- Power gap
- Variation

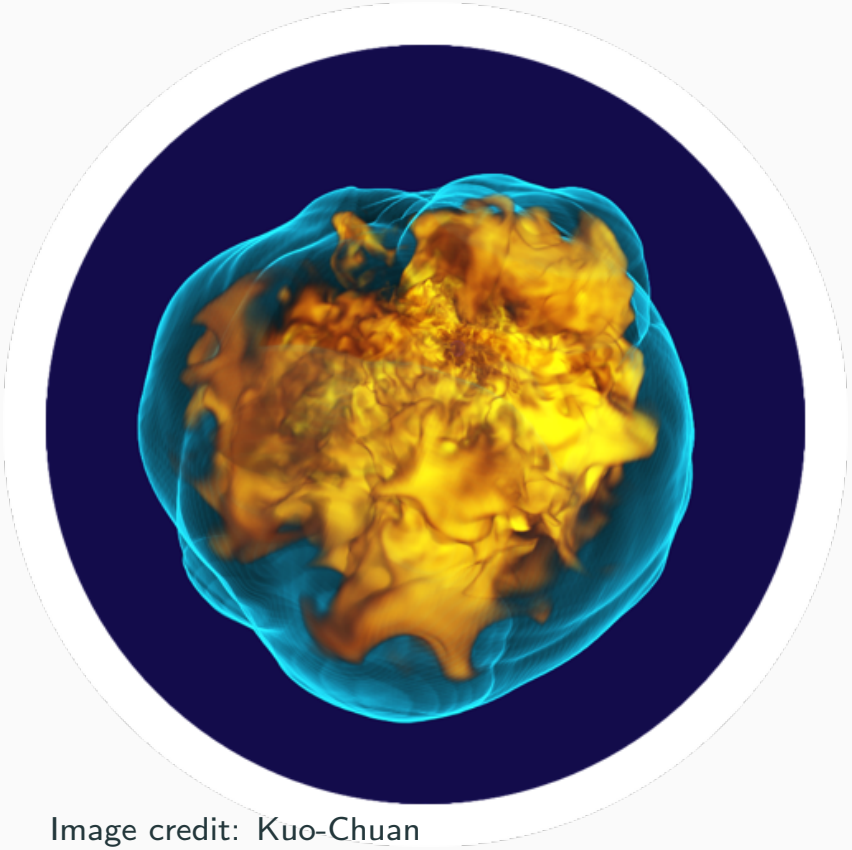
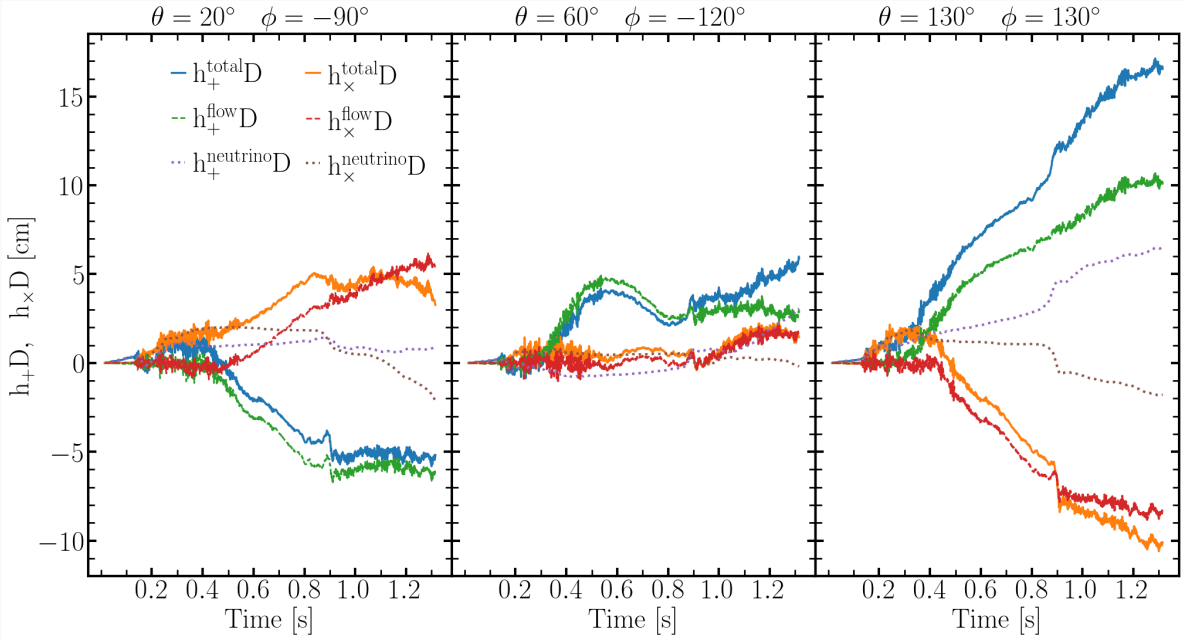


Image credit: Kuo-Chuan

Late-time Signals

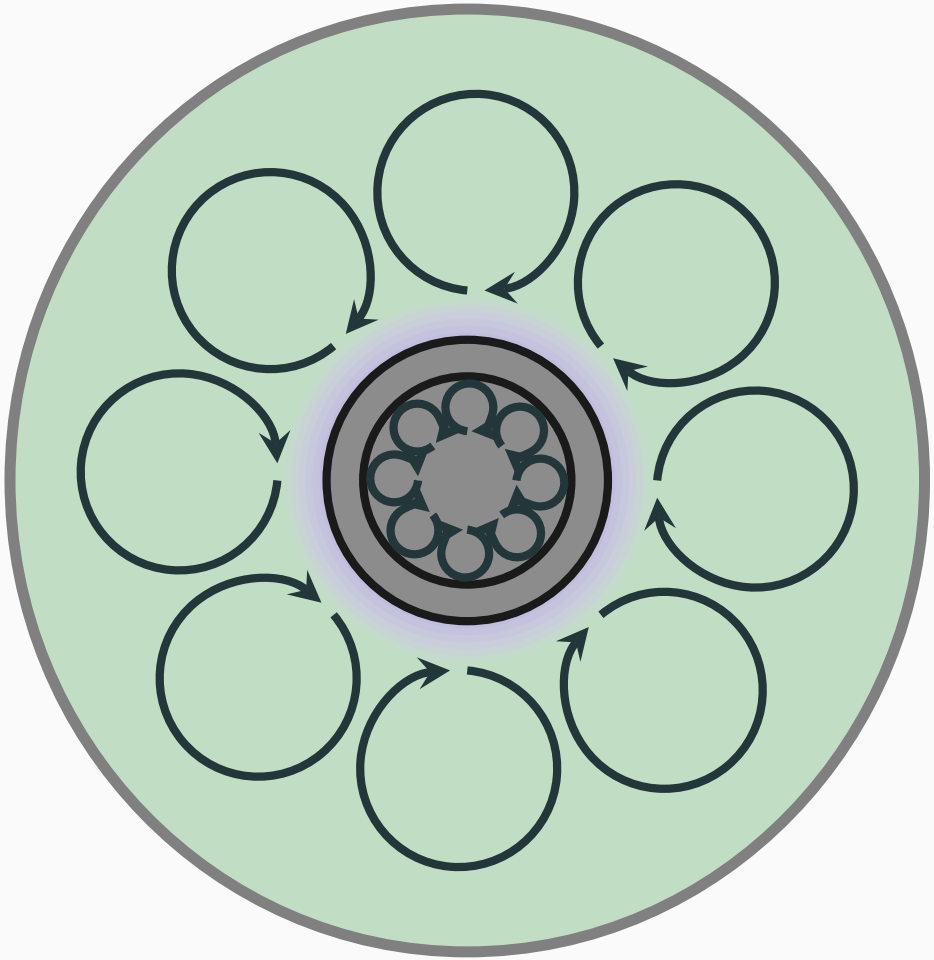
- Neutrinos
- Fallback
- Convection



Richardson+21

Emission Process

- Different results
- Progenitor dependent?
- Are results from 2D applicable?



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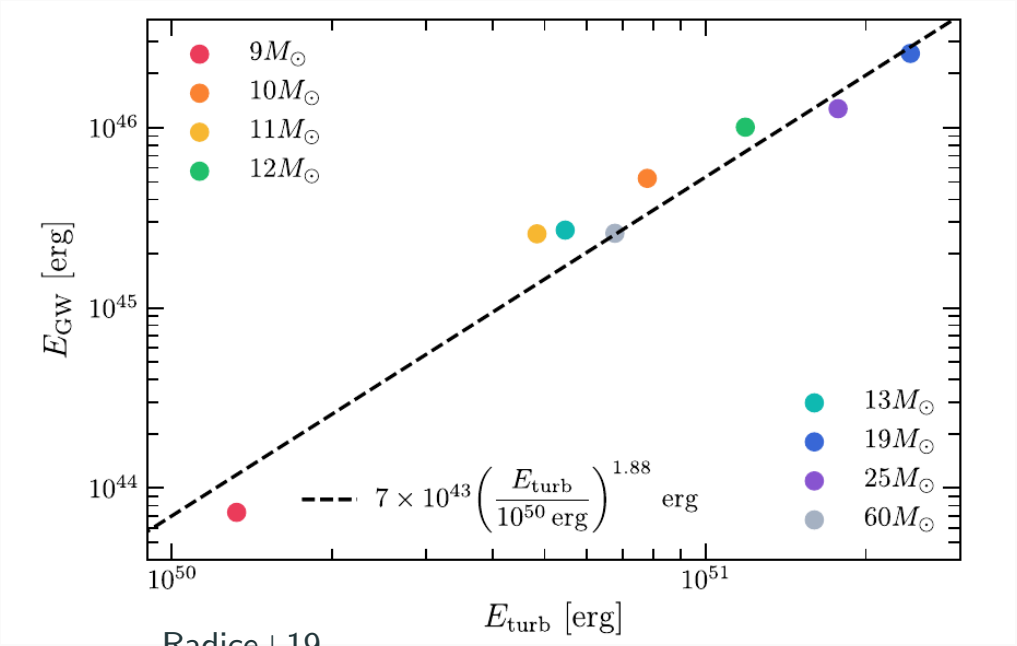
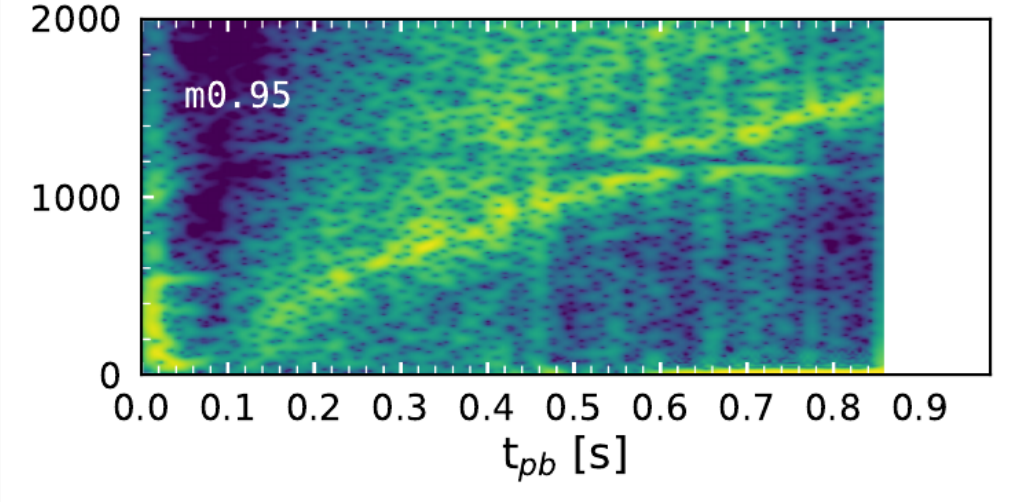


Radice+19

The Power Gap

- Mode crossings
- Central core



Eggenberger-Andersen+21

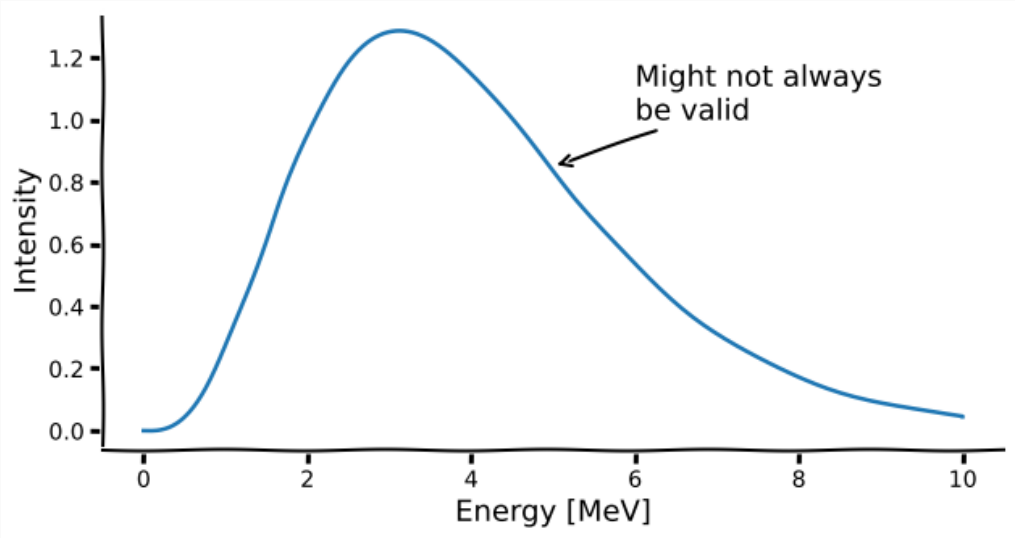
The Way Forward

- Multi-dimensional simulation
- Hydrodynamics, 2D vs 3D
- Neutrino physics

Energy-integrated Neutrino Transport

- FLASH
- Grey M1
- Foucart+15&16

$$f_\nu = \frac{1}{1 + e^{(\varepsilon - \mu)/T}}$$



Energy-integrated Neutrino Transport

$$p^{\alpha}\left(\frac{\partial f_{\nu}}{\partial x^{\alpha}}\right)+(\partial_{t}p^{\alpha})\left(\frac{\partial f_{\nu}}{\partial p^{\alpha}}\right)=\left[\frac{\partial f_{\nu}}{\partial \tau}\right]_{\mathrm{coll}}$$

Energy-integrated Neutrino Transport

$$\partial_t E + \partial_i \left[\alpha F^i\right] + \alpha F^i \partial_i \Phi = \alpha \left(W[\eta - \kappa_a J] - [\kappa_a + \kappa_s] H^t \right)$$

$$\partial_t F^i + \partial_j [\alpha P^{ij}] + \alpha E \partial_i \Phi = \alpha \left(W \left[\eta - \kappa_a J\right] v^i - \left[\kappa_s + \kappa_a\right] H^i \right)$$

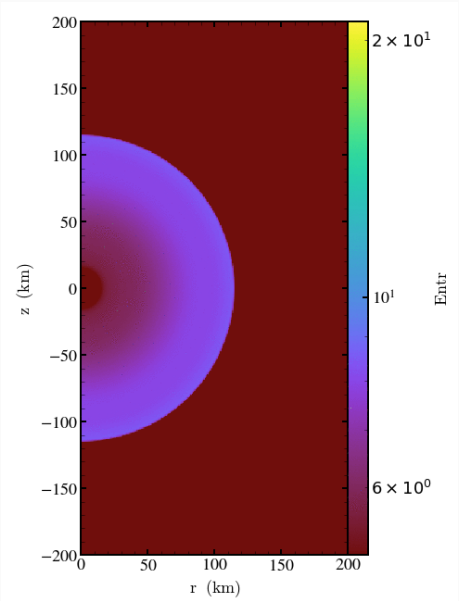
$$\partial_t N + \partial_j (\alpha F_N^j) = \alpha \left(\eta_N - \frac{\kappa_N J N}{W(E - F_i v^i)} \right)$$

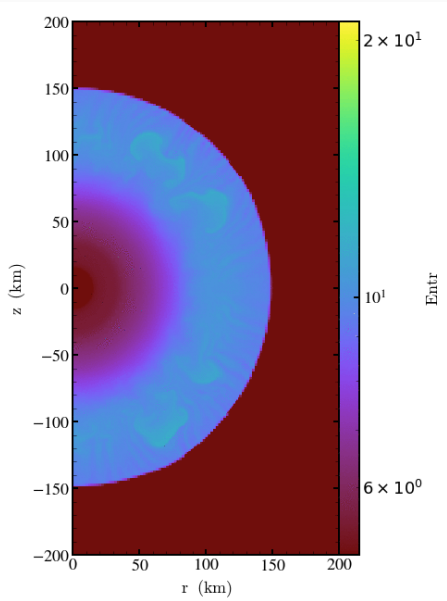
Energy-integrated Neutrino Transport

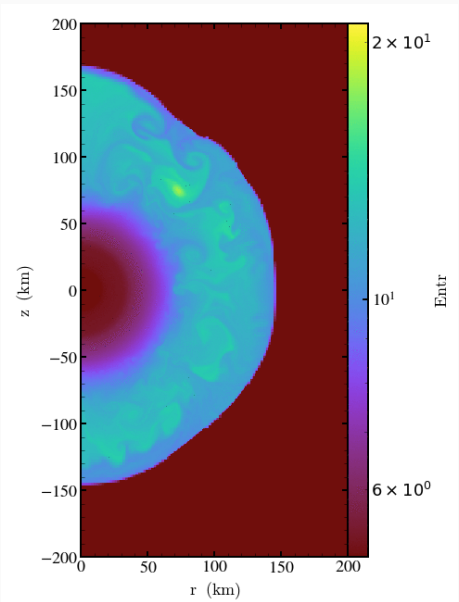
- Three neutrino species
- Neutrino opacities from NuLib
- Post-Newtonian corrections

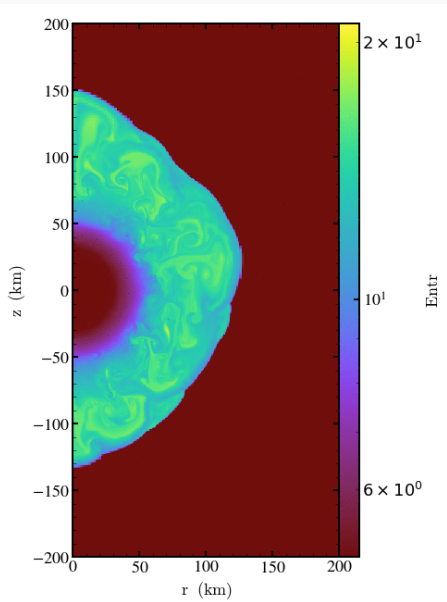
FLASH-Grey

- First 2D test





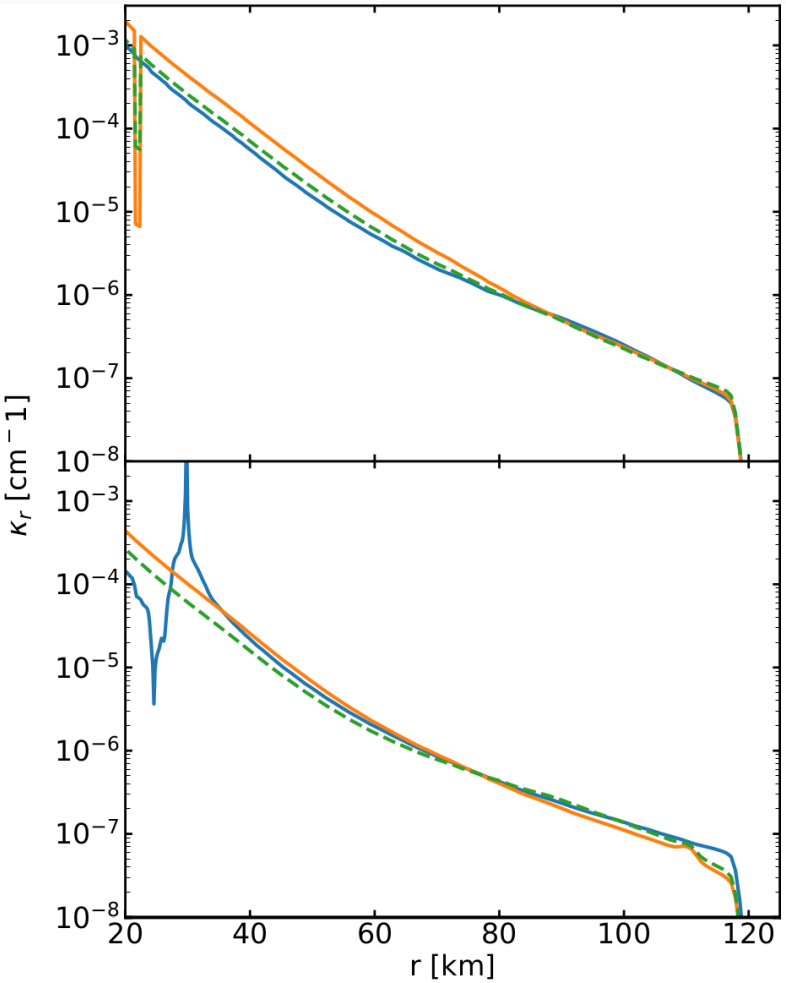


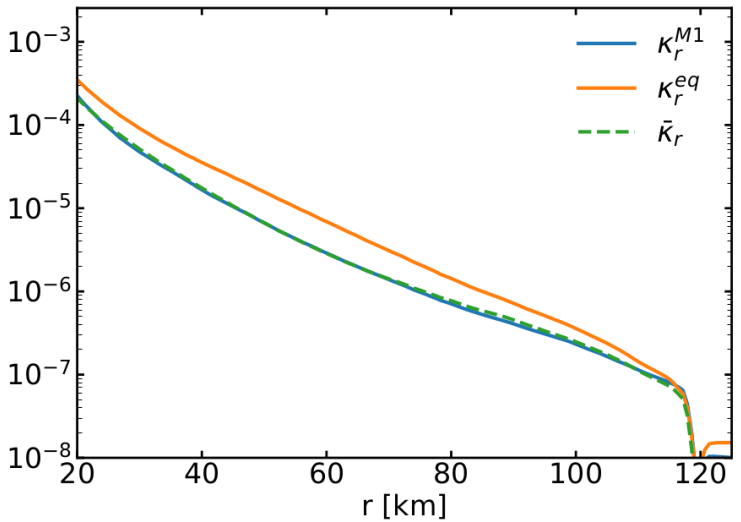


Problems

- Neutrino opacities
- Energy of the flux

2D Comparison





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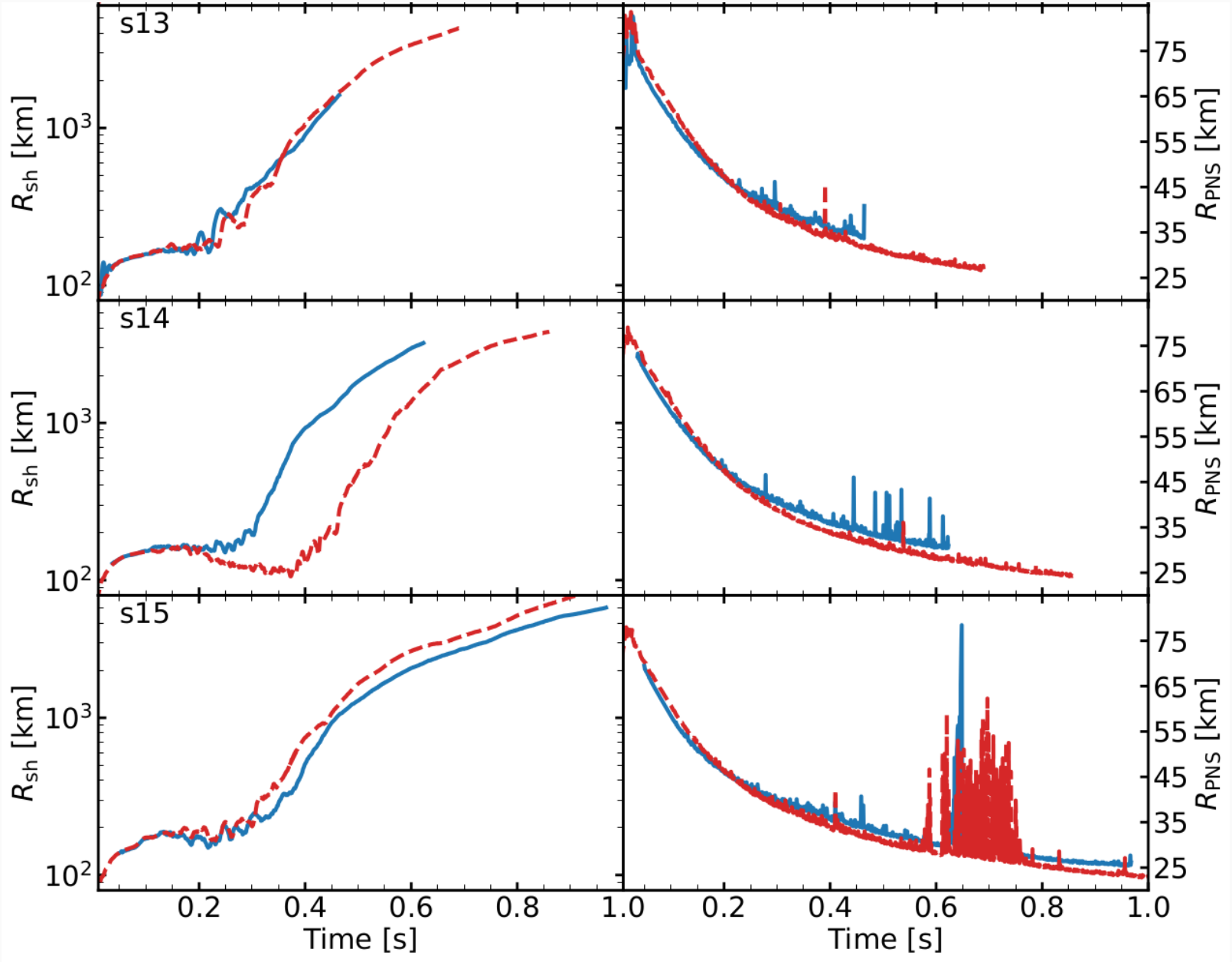

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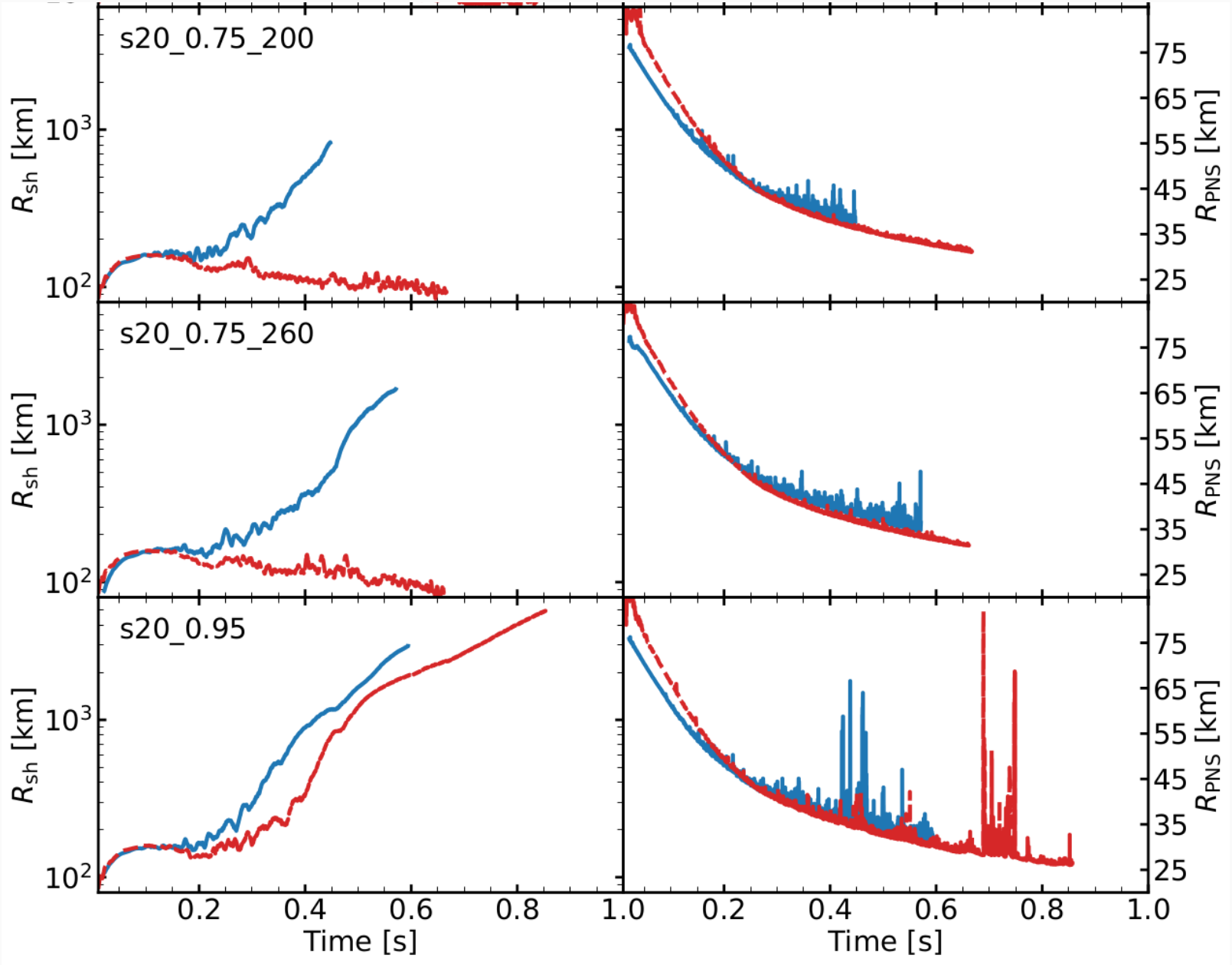

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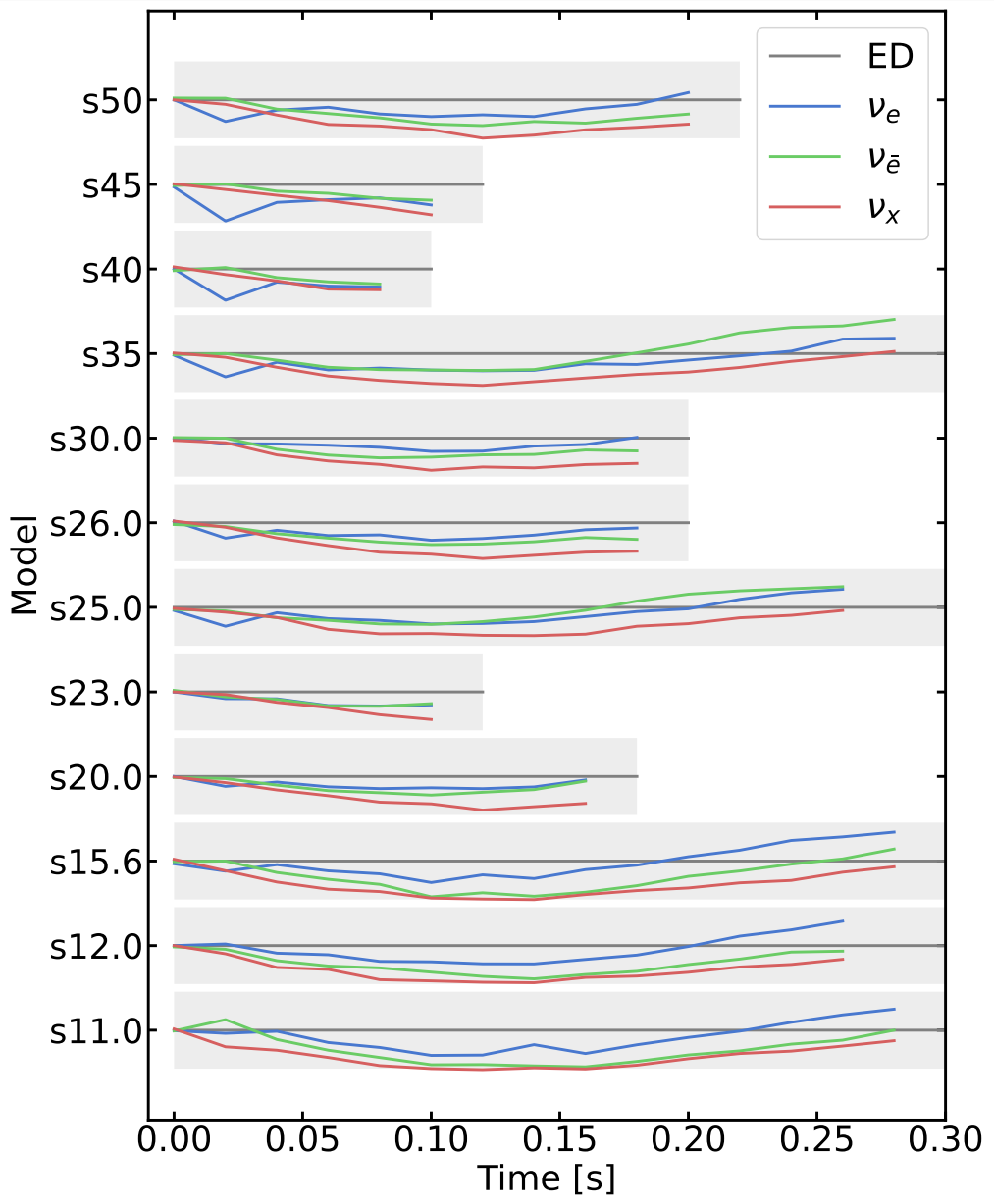

Faster

Category	Min Time (s)	Max Time (s)	Avg Time (s)
RadTrans Grey	102.021	84.587	89.480
RadTrans ED	551.559	518.894	530.380

- 2D simulation
- 3 nodes
- 94 cores

Conclusion and Next Steps

- Matches the energy dependent transport
- Differences in the details and individual models

- Run 2D simulations
- Select models for 3D simulations

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