thornado-Hydro (xCFC)

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thornado
https://github.com/endeve/thornado

My Website
https://www.samueljdunham.com

toolkit for high-order neutrino-radiation hydrodynamics

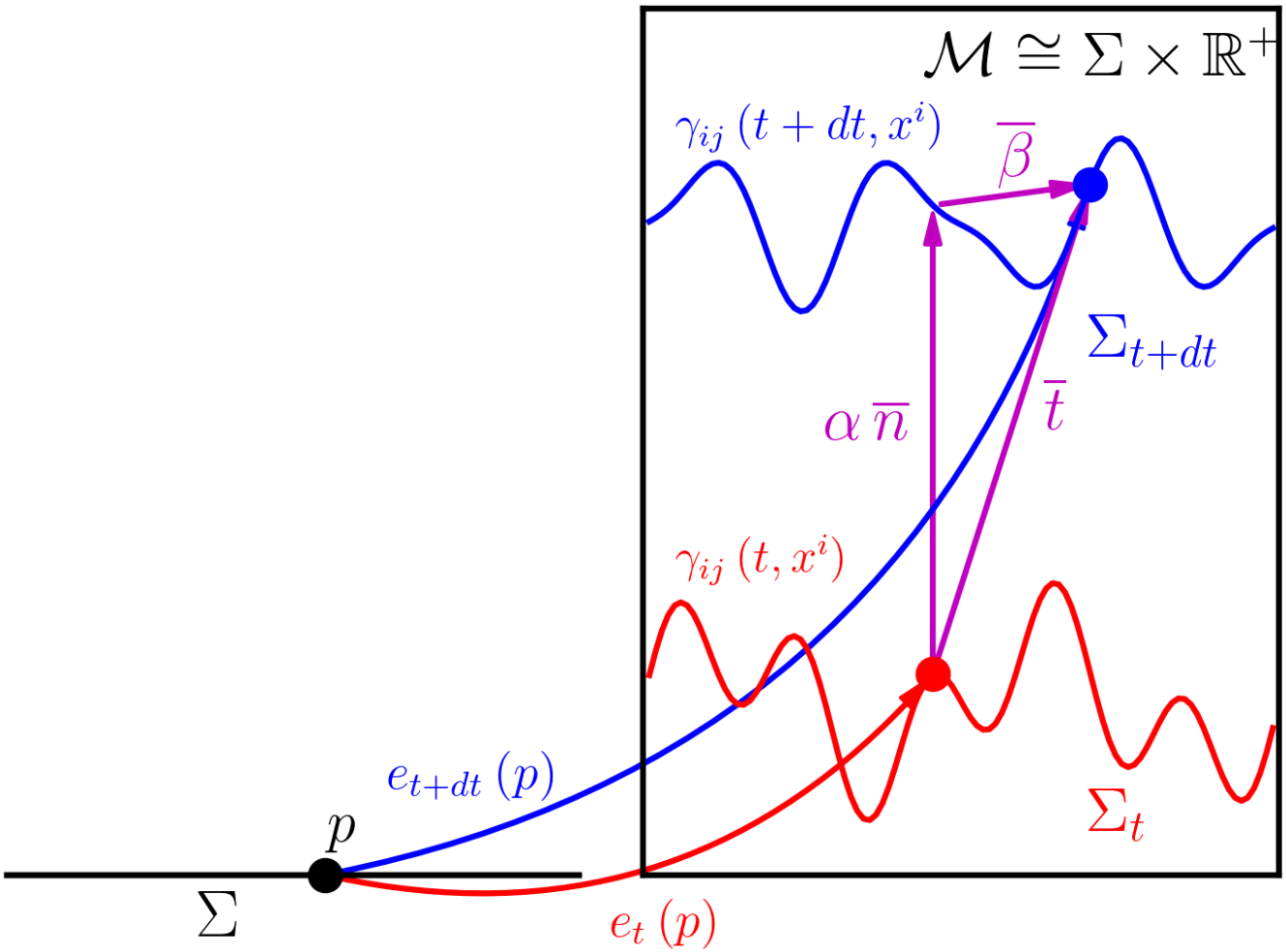
- DG
- SSPRK/IMEX
- GR (xCFC)
- Hydro[a] (Valencia)
- Neutrino transport[b] (M1)
- Interfaces to tabulated EoS/Opacities (weaklib: `https://github.com/starkiller-astro/weaklib`)

- Fluid self-gravity via Poseidon: `https://github.com/jrober50/Poseidon`
- GPUs via OpenACC or OpenMP pragmas
- MPI parallelism and AMR via AMReX: `https://github.com/AMReX-Codes/amrex`

[a] **???**
[b] **?**

3+1 Decomposition

$$ds^2 = g_{\mu\nu}\, dx^\mu\, dx^\nu = -\alpha^2\, dt^2 + \gamma_{ij}\left(dx^i + \beta^i\, dt\right)\left(dx^j + \beta^j\, dt\right)$$



Conformally-Flat Condition

Developed by **?**, extended by **?**

$$\gamma_{ij}\left(x\right) = \psi^4\left(x\right)\,\overline{\gamma}_{ij}\left(x^i\right)$$
$$K = 0,\ \partial_t\, K = 0$$

- Exact in spherical symmetry!
- Hyperbolic $\rightarrow$ Elliptic equations
- Good for long-time simulations

Special case: Schwarzchild spacetime in isotropic coordinates

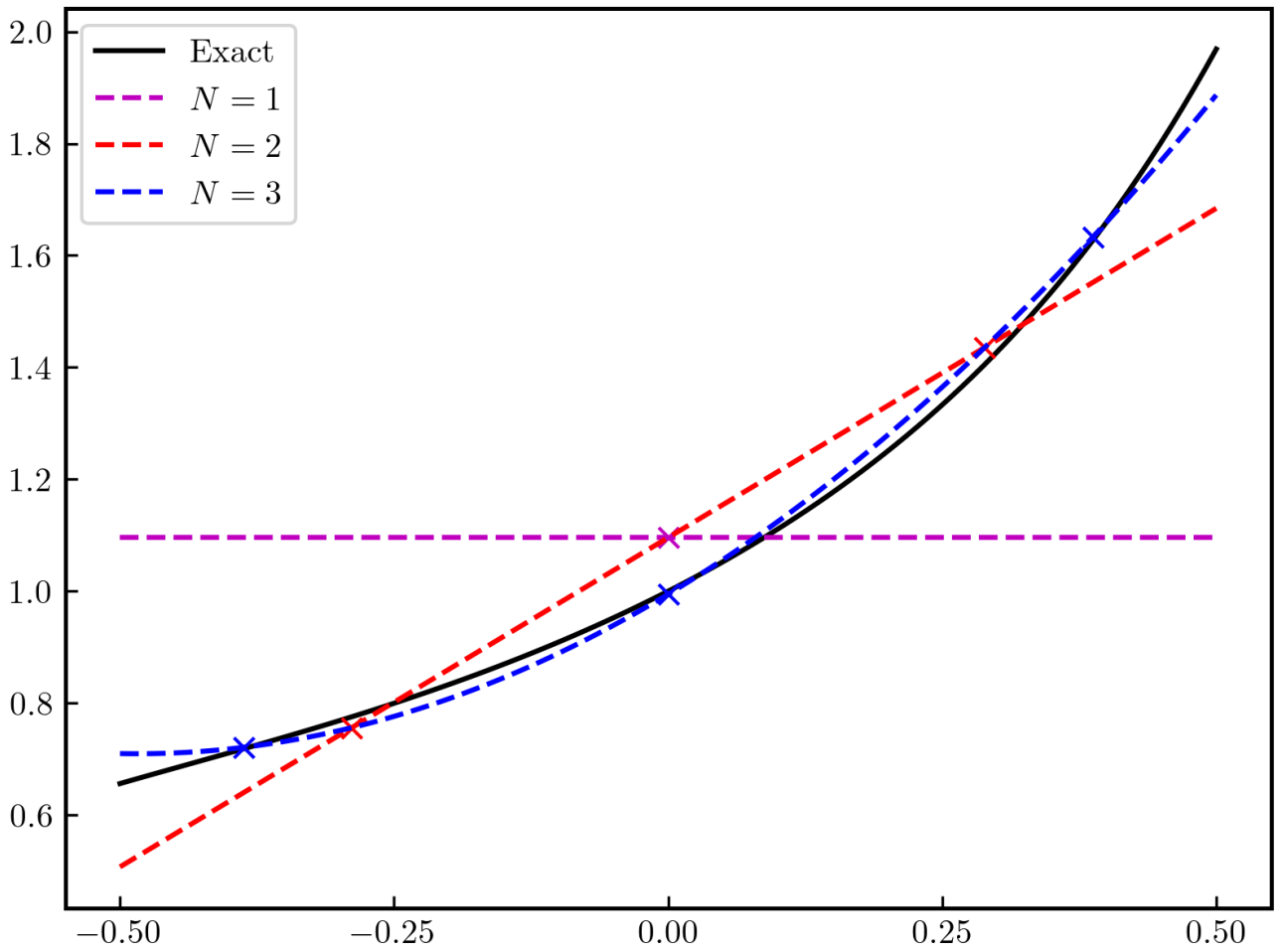
$$\alpha = \left(1 + R_{\rm Sc}/r\right)\left(1 - R_{\rm Sc}/r\right)^{-1}$$
$$\psi = 1 + R_{\rm Sc}/r$$
$$\beta^i = 0,$$

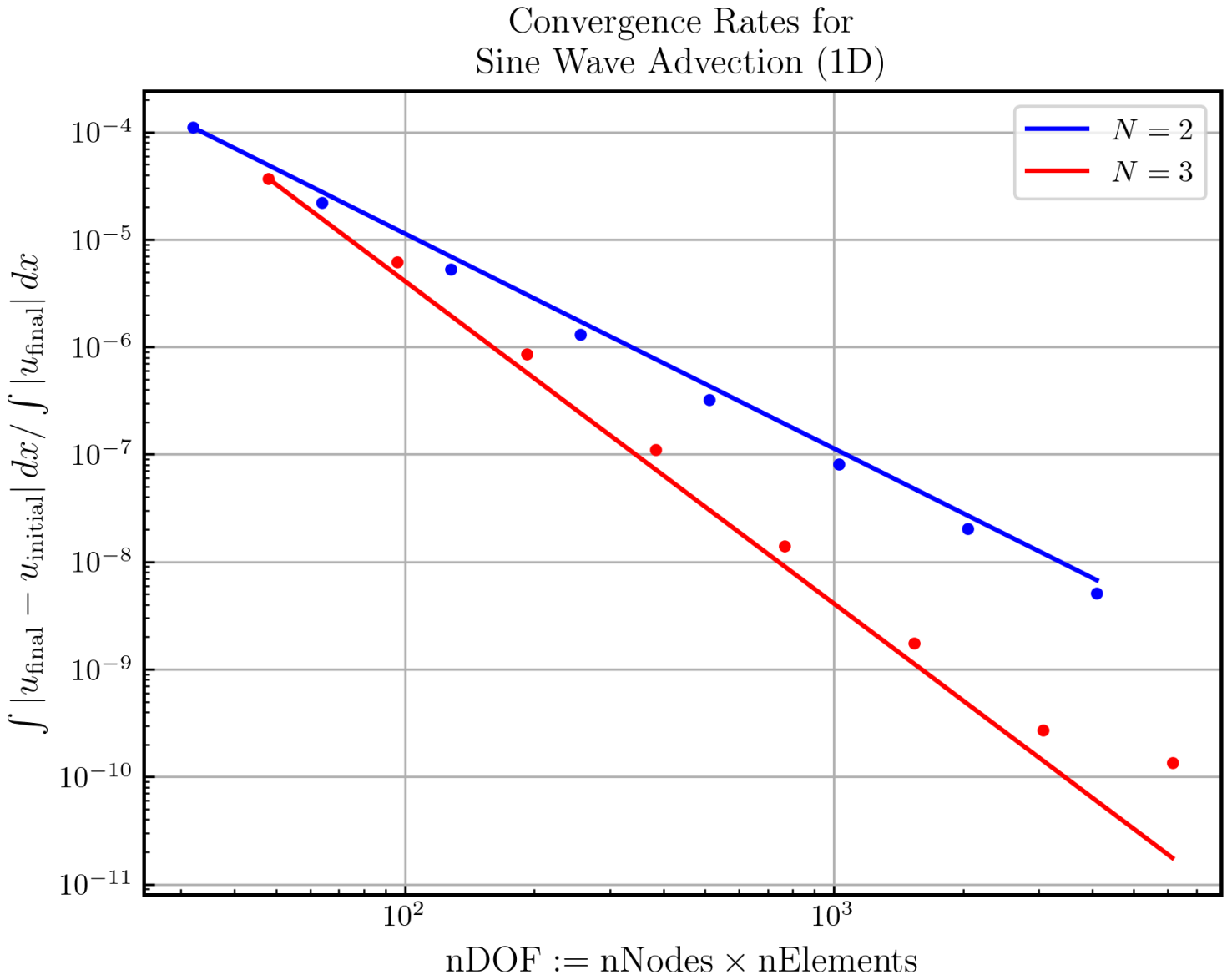
with

$$r > R_{\rm Sc} := M/2$$

Discontinuous Galerkin (DG)

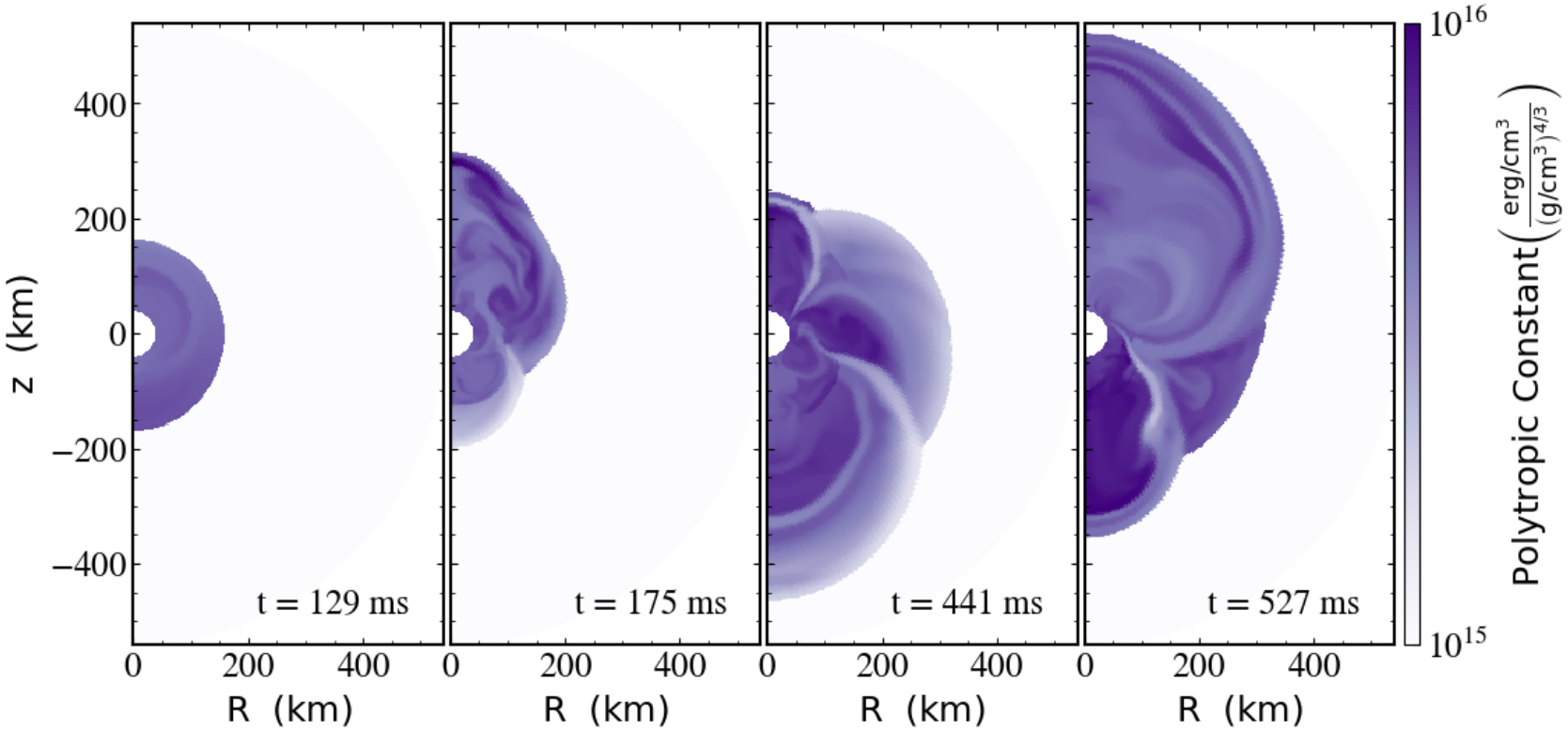
$$u_h(x,t) := \sum_{i=1}^{N} u_i(t)\, \ell_i(x)$$




Convergence Rates for
Sine Wave Advection (1D)
$N = 2$
$N = 3$
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{2}
10^{3}
$\int |u_{\text{final}} - u_{\text{initial}}| \, dx / \int |u_{\text{final}}| \, dx$
nDOF := nNodes × nElements

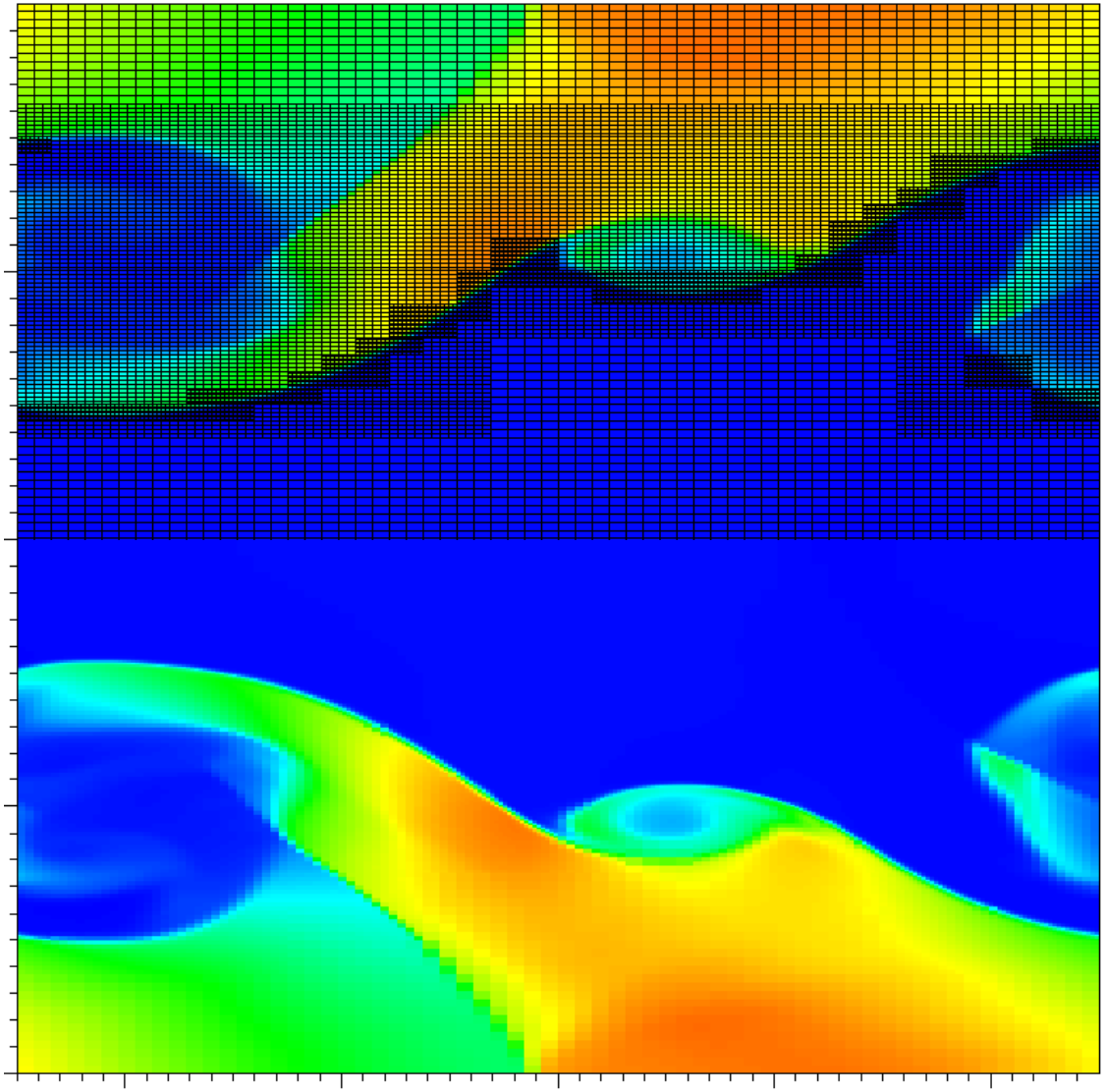
Standing Accretion Shock Instability

Used `thornado` to investigate the role of GR on the SASI[1]

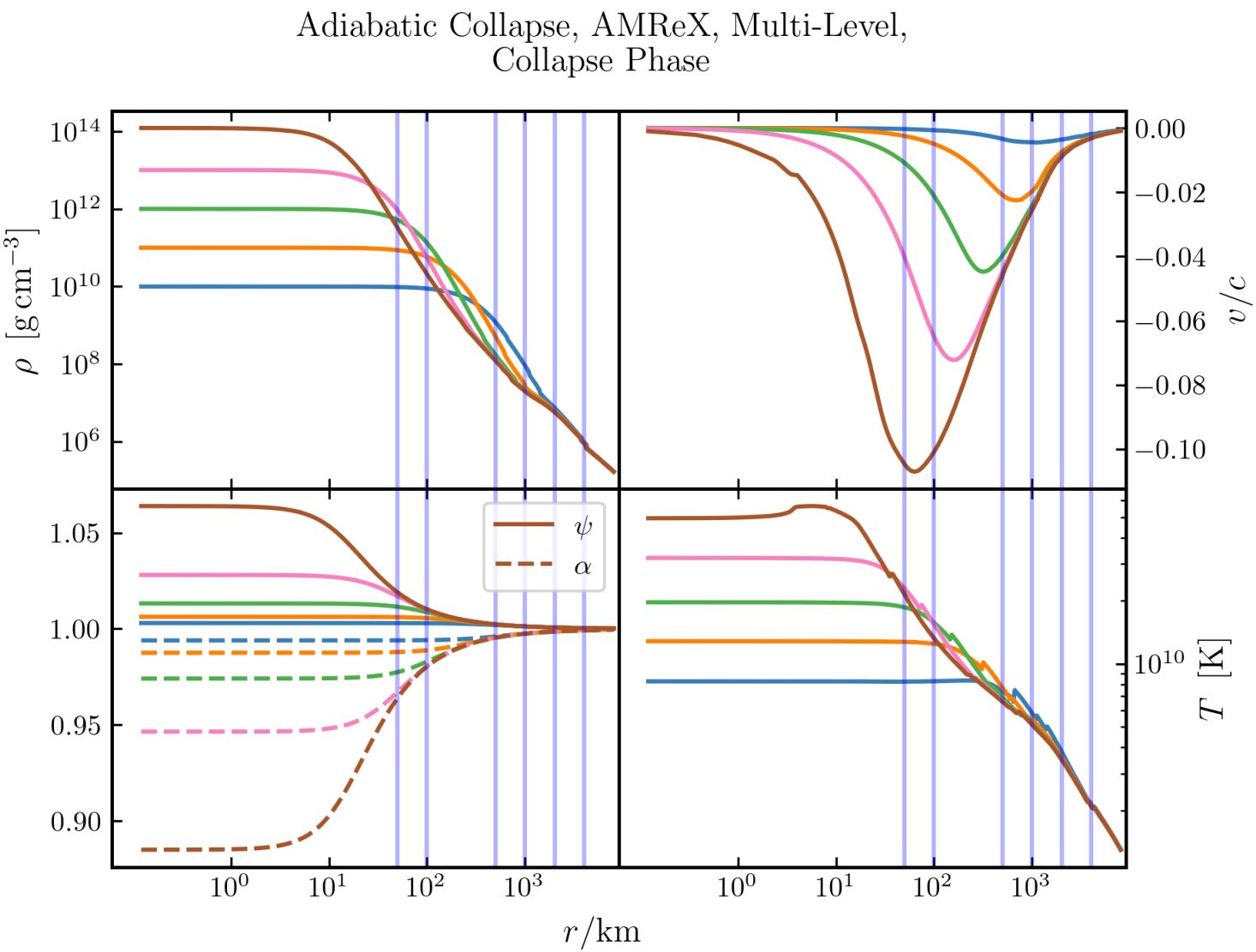


[1] **??**

Kelvin–Helmholtz Instability



Adiabatic Collapse (SMR)



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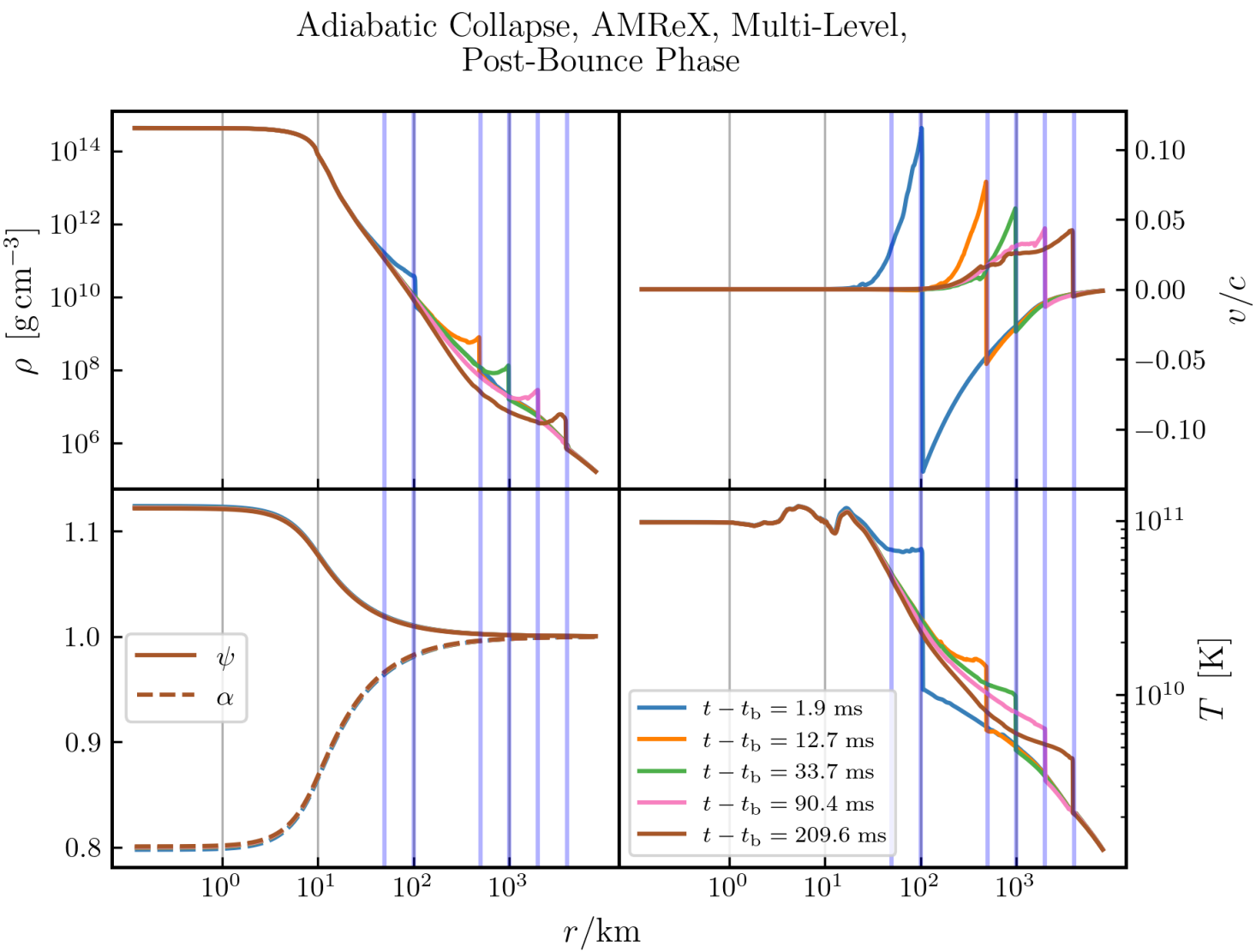
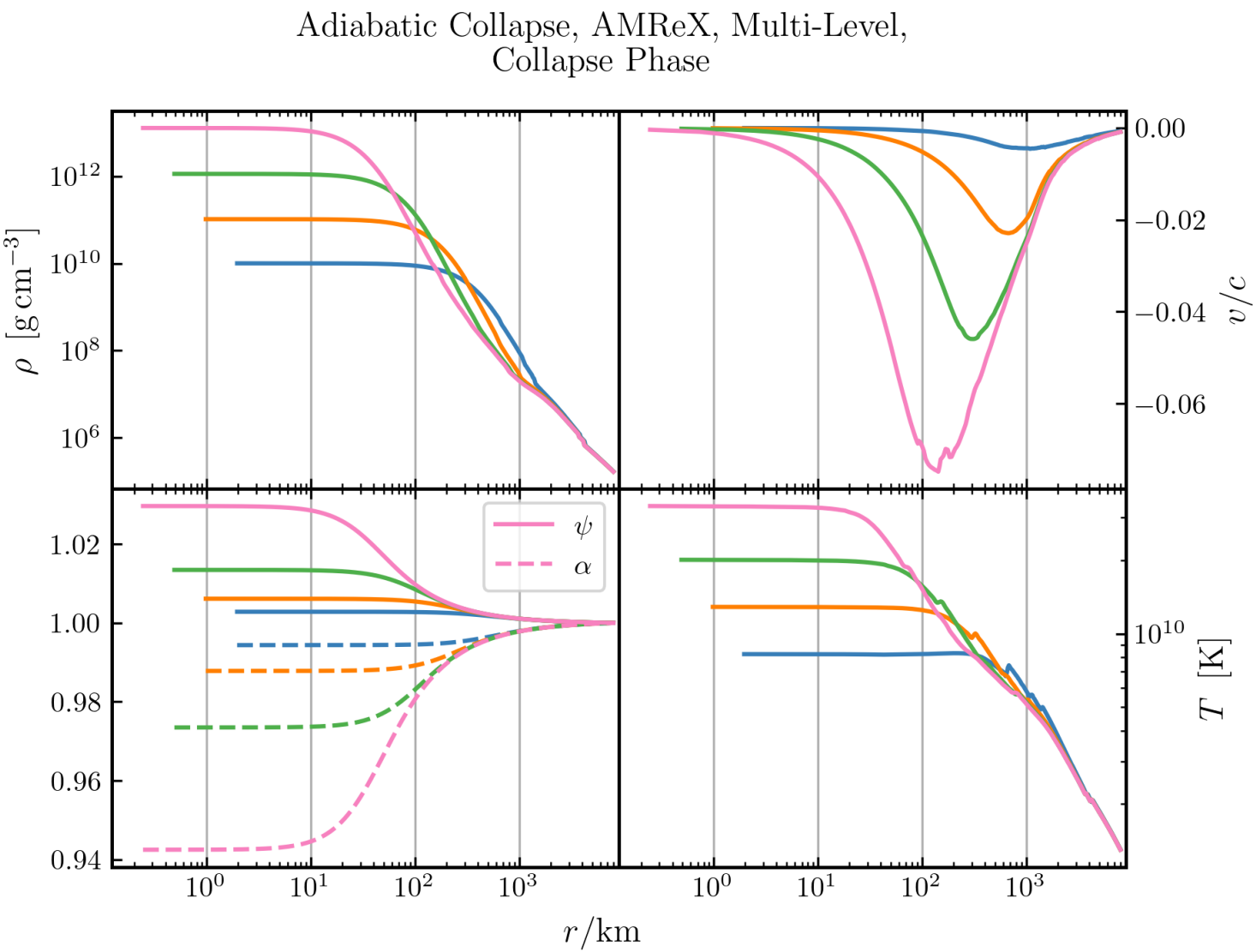


Adiabatic Collapse (AMR)



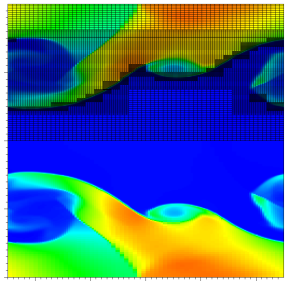
Works in Progress

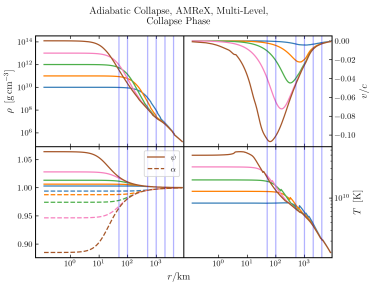
- Finish debugging AMR in hydro+gravity
- Finish testing GR neutrino transport
- Couple GR transport to hydro and gravity
- Add AMR capabilities to transport

Bibliography

Summary

Can run pure hydro problems in GR with AMR





Doing GR, adiabatic collapse simulations with mesh refinement

Working on coupling GR transport to existing hydro+gravity modules