

thornado-Hydro (xCFC)

Samuel J. Dunham

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Brandon Barker (MSU/LANL), Jesse Buffaloe (UTK),
SJD (Vanderbilt,UTK), Zack Elledge (UTK),
Eirik Endeve (ORNL/UTK), Anthony Mezzacappa (UTK),
David Pochik (OSU), Nick Roberts (UTK)

thornado

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



My Website

<https://www.samueljdunham.com>





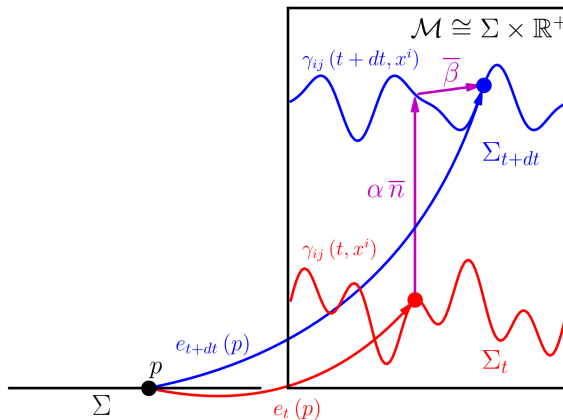
toolkit for high-order neutrino-radiation hydrodynamics

- 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



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

Conformally-Flat Condition

Developed by ?, extended by ?

$$\gamma_{ij}(x) = \psi^4(x) \bar{\gamma}_{ij}(x^i)$$

$$K = 0, \partial_t K = 0$$

(Always and everywhere)

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

Special case: Schwarzschild spacetime
in isotropic coordinates

$$\alpha(r) = (1 + R_{\text{Sc}}/r) (1 - R_{\text{Sc}}/r)^{-1}$$

$$\psi(r) = 1 + R_{\text{Sc}}/r$$

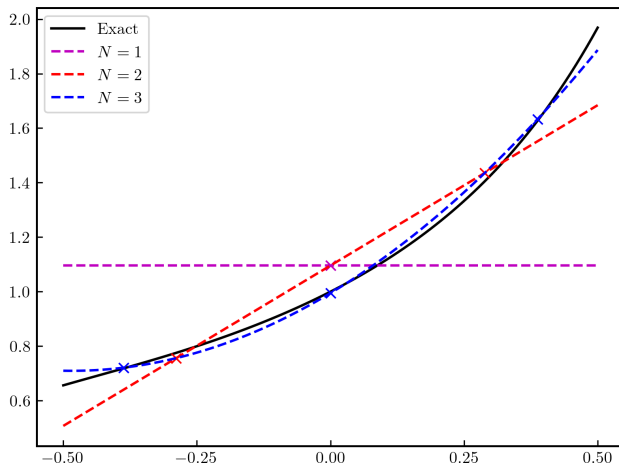
$$\beta^i(r) = 0,$$

with

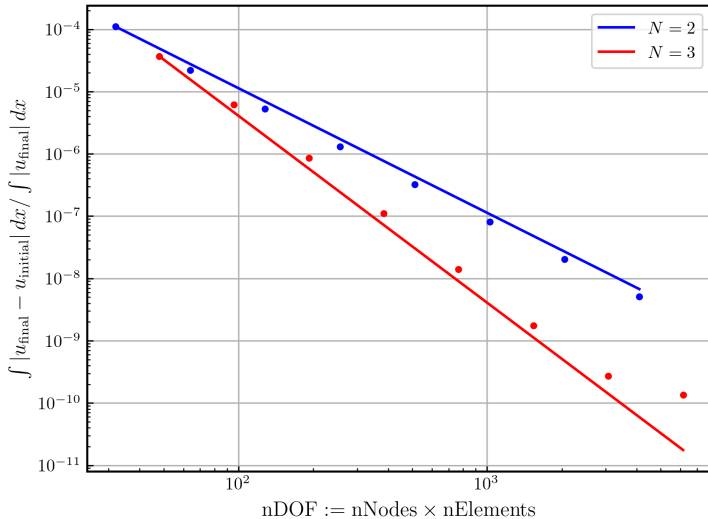
$$r > R_{\text{Sc}} := M/2$$

Discontinuous Galerkin (DG)

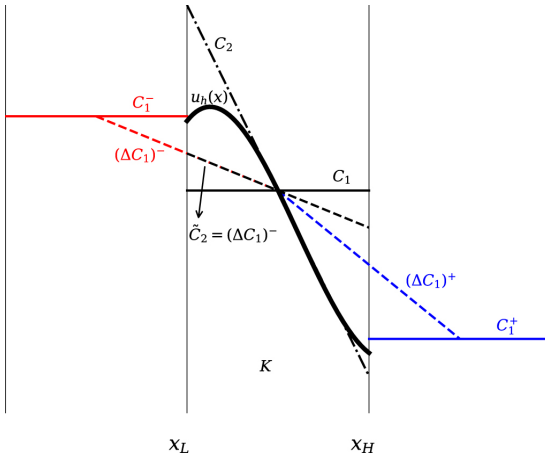
$$u_h(x, t) := \sum_{i=1}^N u_i(t) \ell_i(x)$$



Convergence Rates for Sine Wave Advection (1D)

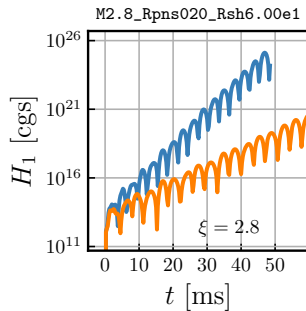
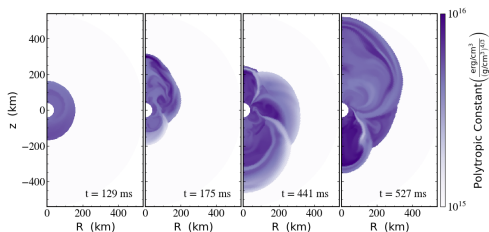


$$u_h(x, t) = \sum_{n=1}^N C_n(t) P_n(x) \implies \tilde{u}_h(x, t) = C_1(t) P_1(x) + \tilde{C}_2(t) P_2(x)$$



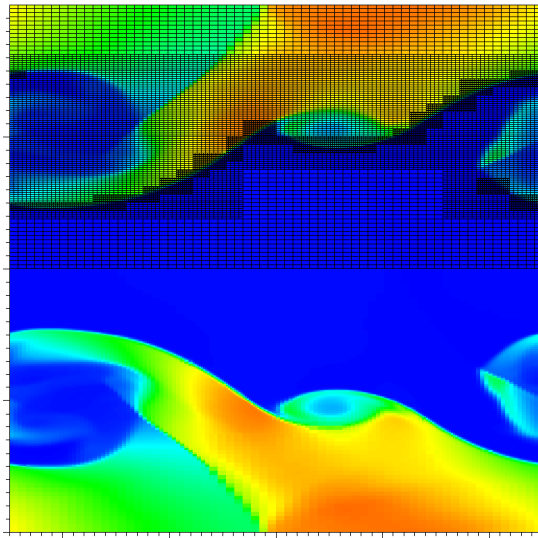
Standing Accretion Shock Instability

Used thornado to investigate the role of GR on the SASI¹



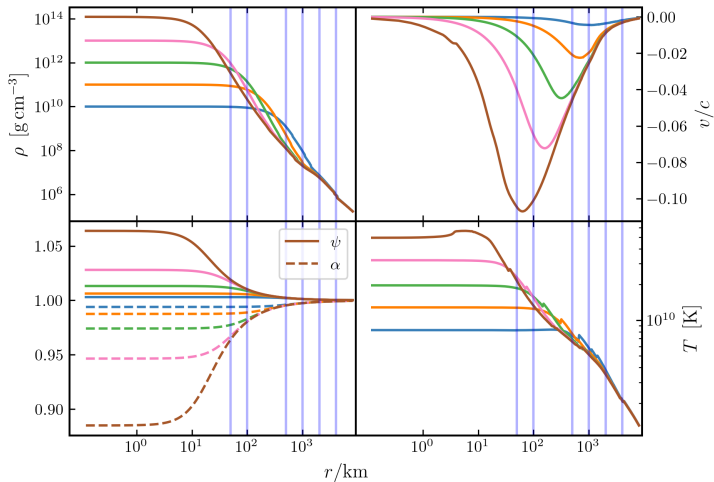
1??

Kelvin–Helmholtz Instability



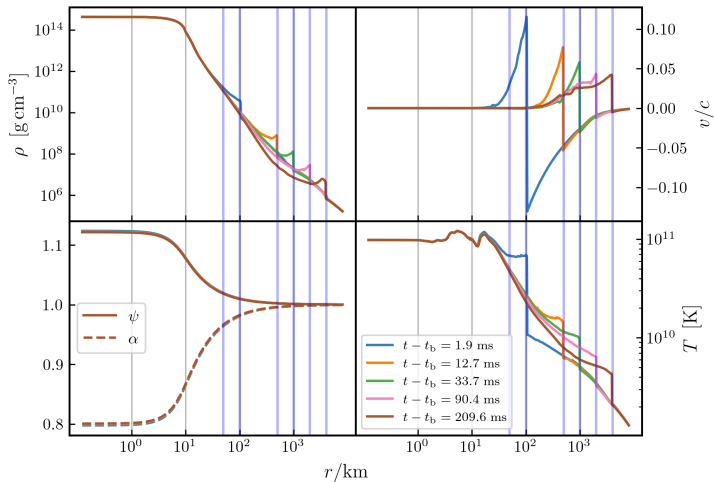
Adiabatic Collapse (SMR)

Adiabatic Collapse, AMReX, Multi-Level,
Collapse Phase



Adiabatic Collapse (SMR)

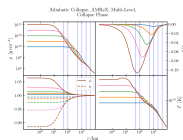
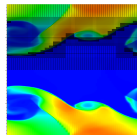
Adiabatic Collapse, AMReX, Multi-Level,
Post-Bounce Phase



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

