MHD studies towards simulating White Dwarf Mergers using Castro

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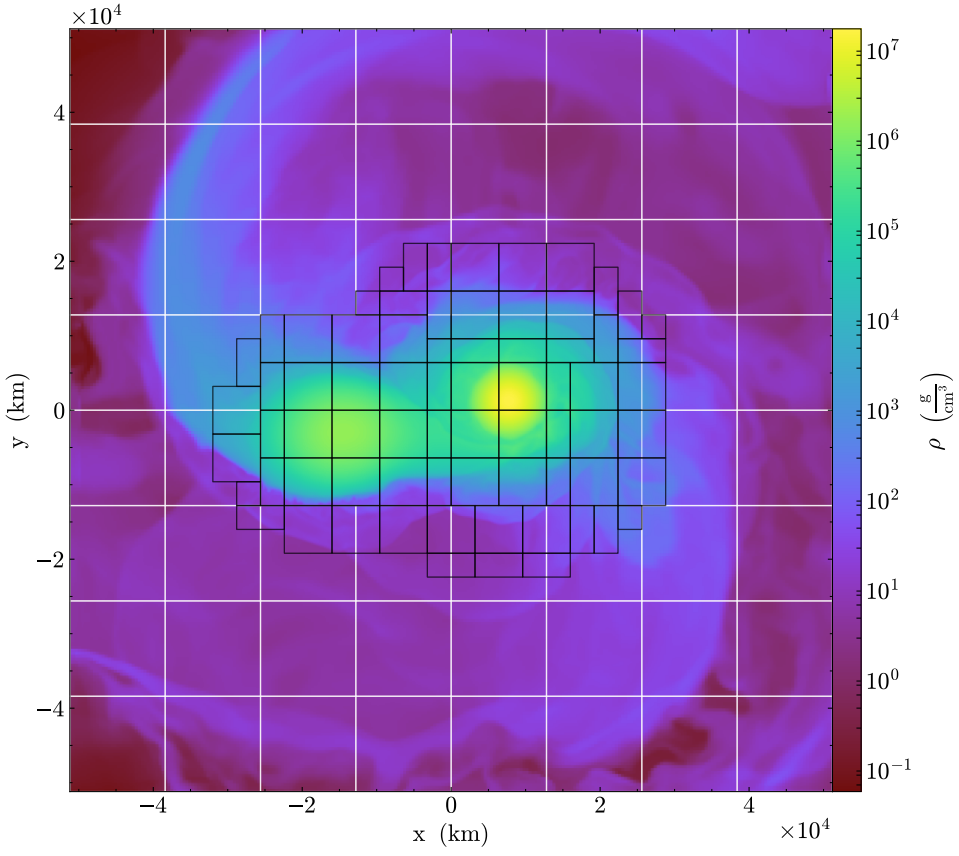
Castro

- Castro is an AMR code that solves the compressible hydrodynamic equations for astrophysical flows
  - conservation of mass $\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \boldsymbol{u}) + S_{ext,\rho}$
  - conservation of momentum $\frac{\partial (\rho \boldsymbol{u})}{\partial t} = -\nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u}) - \nabla p + \rho \boldsymbol{g} + S_{ext,\rho \boldsymbol{u}}$
  - conservation of total energy $\frac{\partial (\rho E)}{\partial t} = -\nabla \cdot (\rho \boldsymbol{u} E + p \boldsymbol{u}) + \rho H_{nuc} + \rho \boldsymbol{u} \cdot \boldsymbol{g} + S_{ext,\rho E}$
- User can supply EOS and reaction networks
- Self gravity
- Radiation, gray and multigroup FLD
- Supports 1-d, 2-d and 3-d

Castro

Zingale et al. 2017



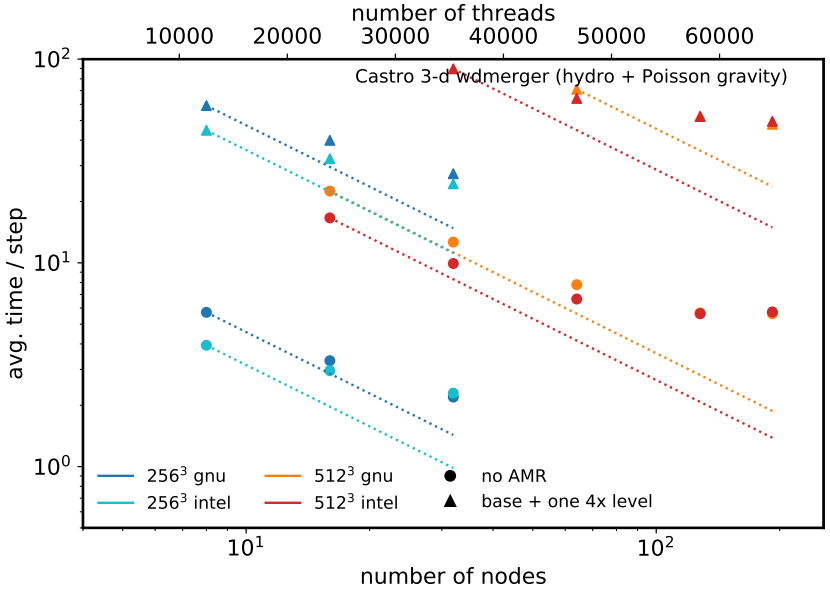
WD merger showing 2-level grid structure

- Adaptive Mesh Refinement, built on AMReX
- Simultaneous refinement in space and time
- Hybrid parallelism, MPI+OpenMP
- Regression tests
- Ongoing development for GPUs
- Open Source

github.com/AMReX-Astro/Castro

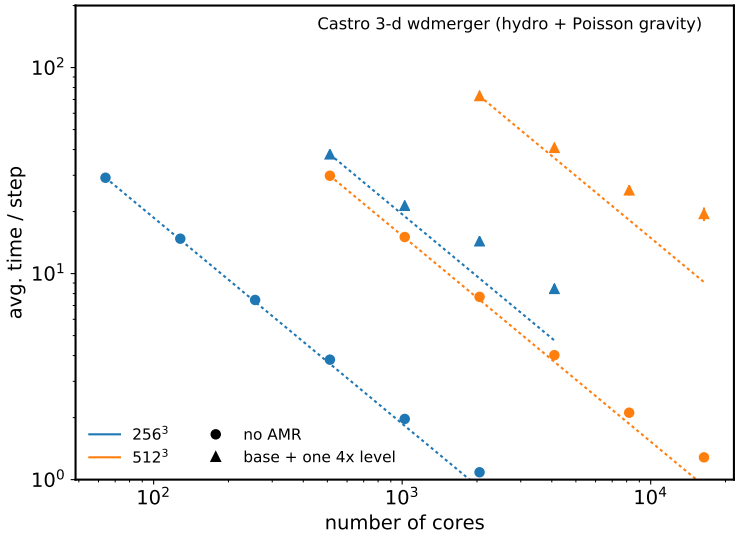
Scaling

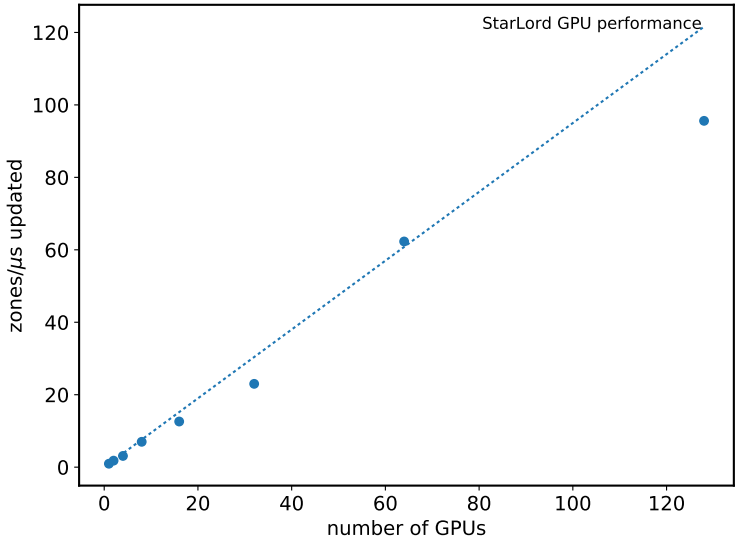
NERSC Cori



Zingale et al. 2017

OLCF Titan



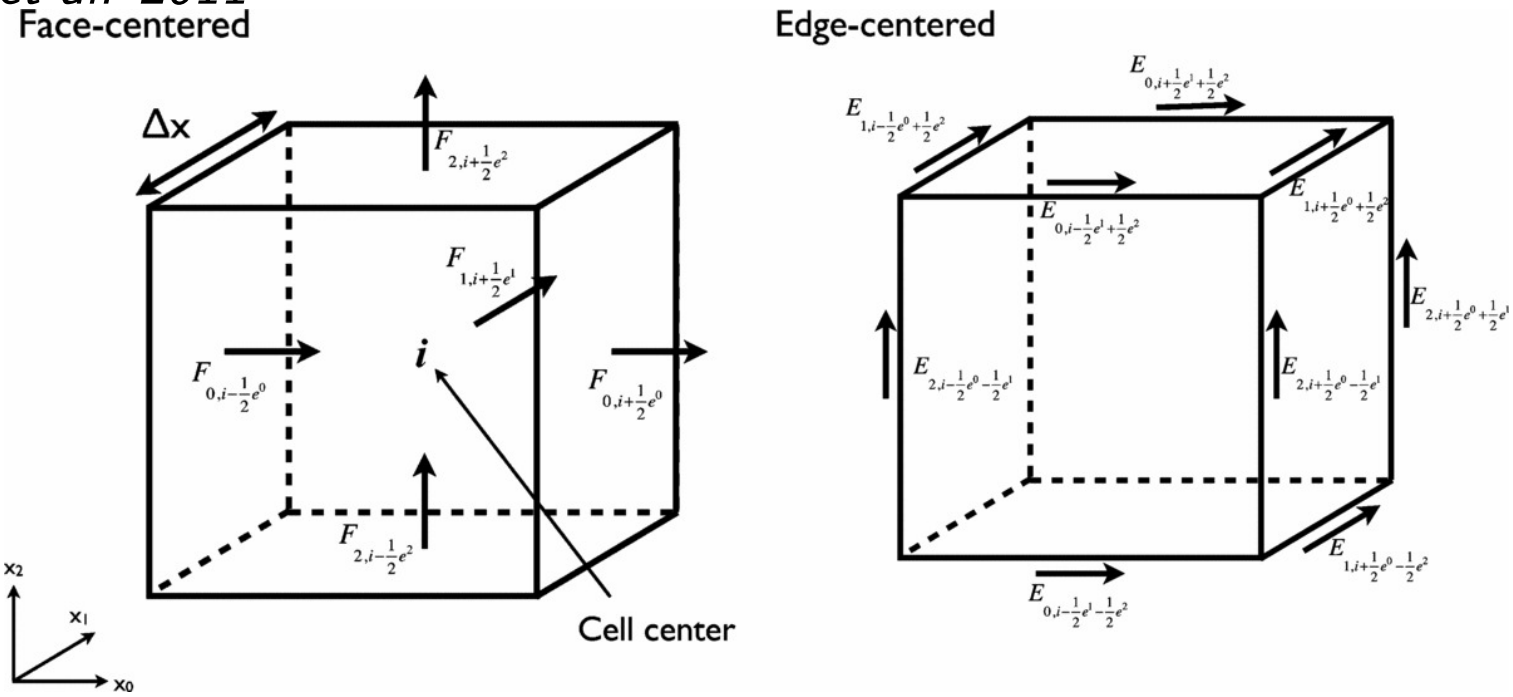


OLCF Summitdev

MHD – Algorithm

- Assumes perfectly conducting fluid
- Only electric fields induced by motion of magnetized fluid

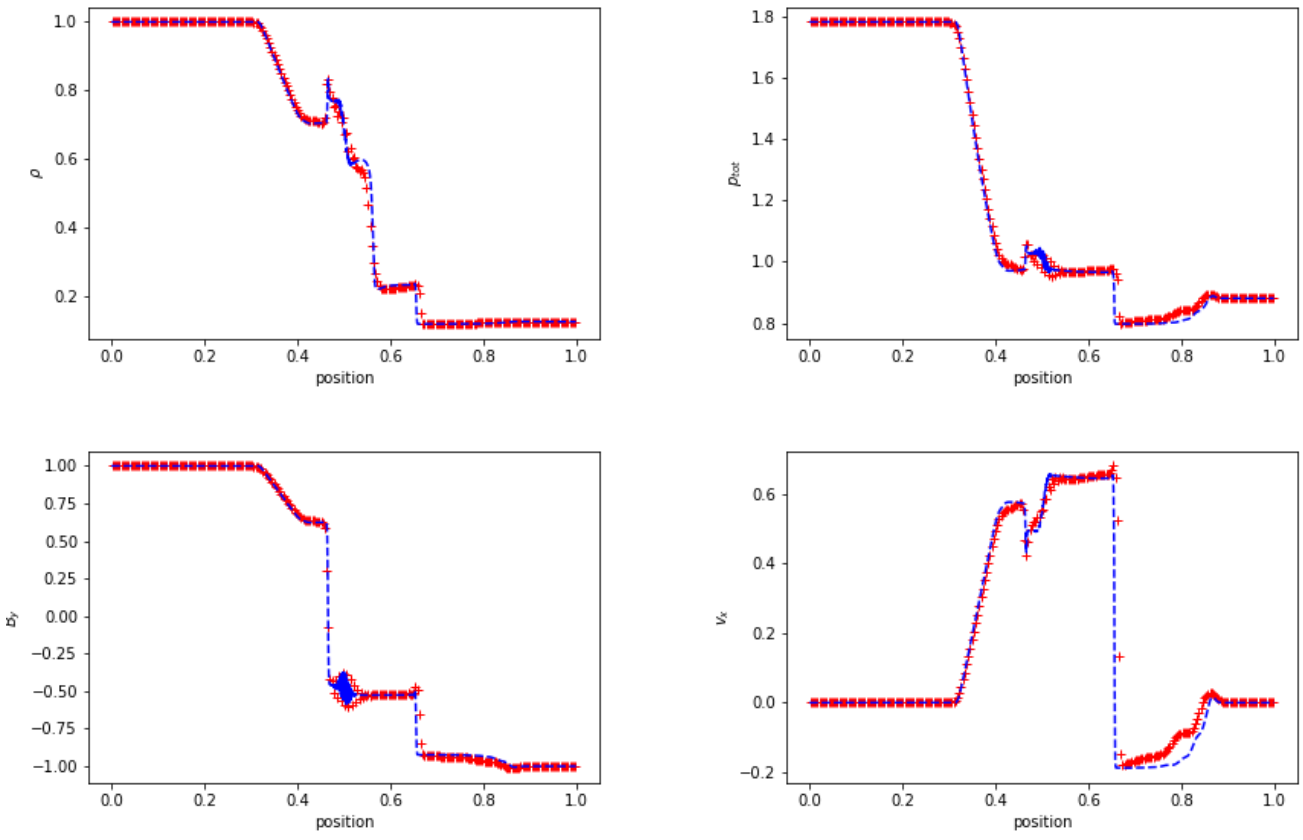
Miniati et al. 2011



- Numerical schemes must ensure $\nabla \cdot \boldsymbol{B} = 0$
- Magnetic field defined at face center
- Electric field at cell edges updates it

MHD port to Castro

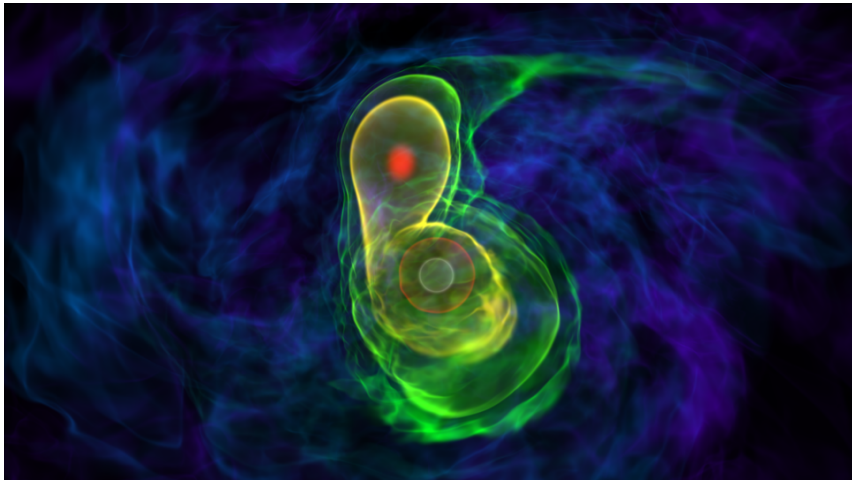
- Integrating MHD solver from Nyx (cosmology code)
- Support general EOS
- Add species
- Coupled with self-gravity conservative form
- Verification



Shock tube test problem solved using 256 and 800 grid cells at t = 0.1 s.

White Dwarf mergers

Katz et. al. 2016



- Presence of magnetic fields and effect on fluid instabilities could drive a hotspot into a detonation
- Include MHD in WD Merger simulation

Continue with WD merger calculations

- Study feasibility of thermonuclear detonation
- Explore different initial models
  - He layer
  - CO + He mergers
- Investigate algorithmic improvements
  - Well-balanced scheme with rotation
  - Self-consistent initial conditions

Timeline for next year

- Sept. 2018 – Verification and optimization of MHD solver
- Oct. 2018 – Explore WD merger initial models
- Jan. 2018 – MHD solver with gravity tested
- Apr. 2019 – WD merger investigation of self-consistent initial conditions
- Summer. 2019 – WD merger simulations with MHD and additional physics

Other work

- Contributing on GPU efforts

Other planned research events

- BNL GPU Hackathon, Sept. 2018
- SIAM CSE Minisymposium presentation, Feb. 2019