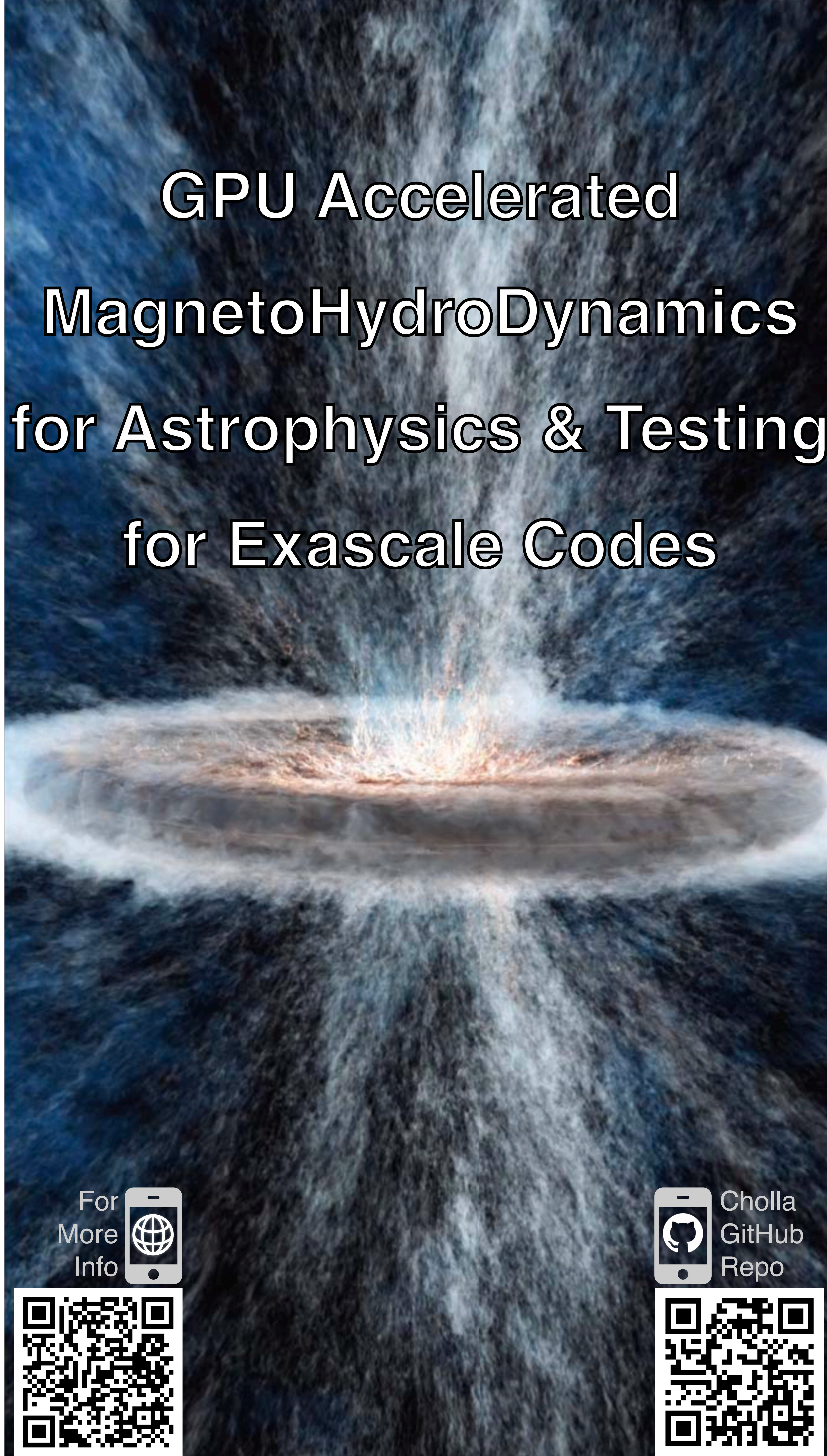
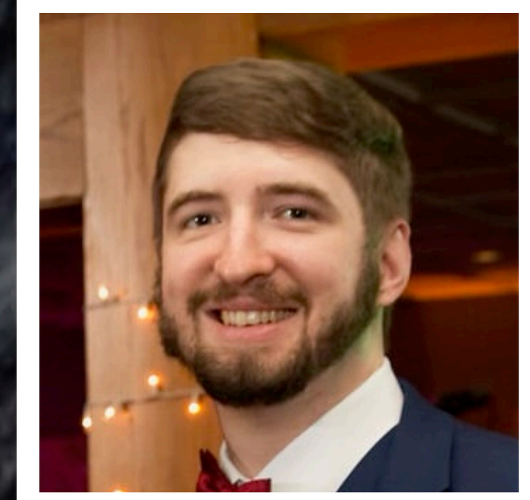


GPU Accelerated MagnetoHydroDynamics for Astrophysics & Testing for Exascale Codes



Robert V. Caddy

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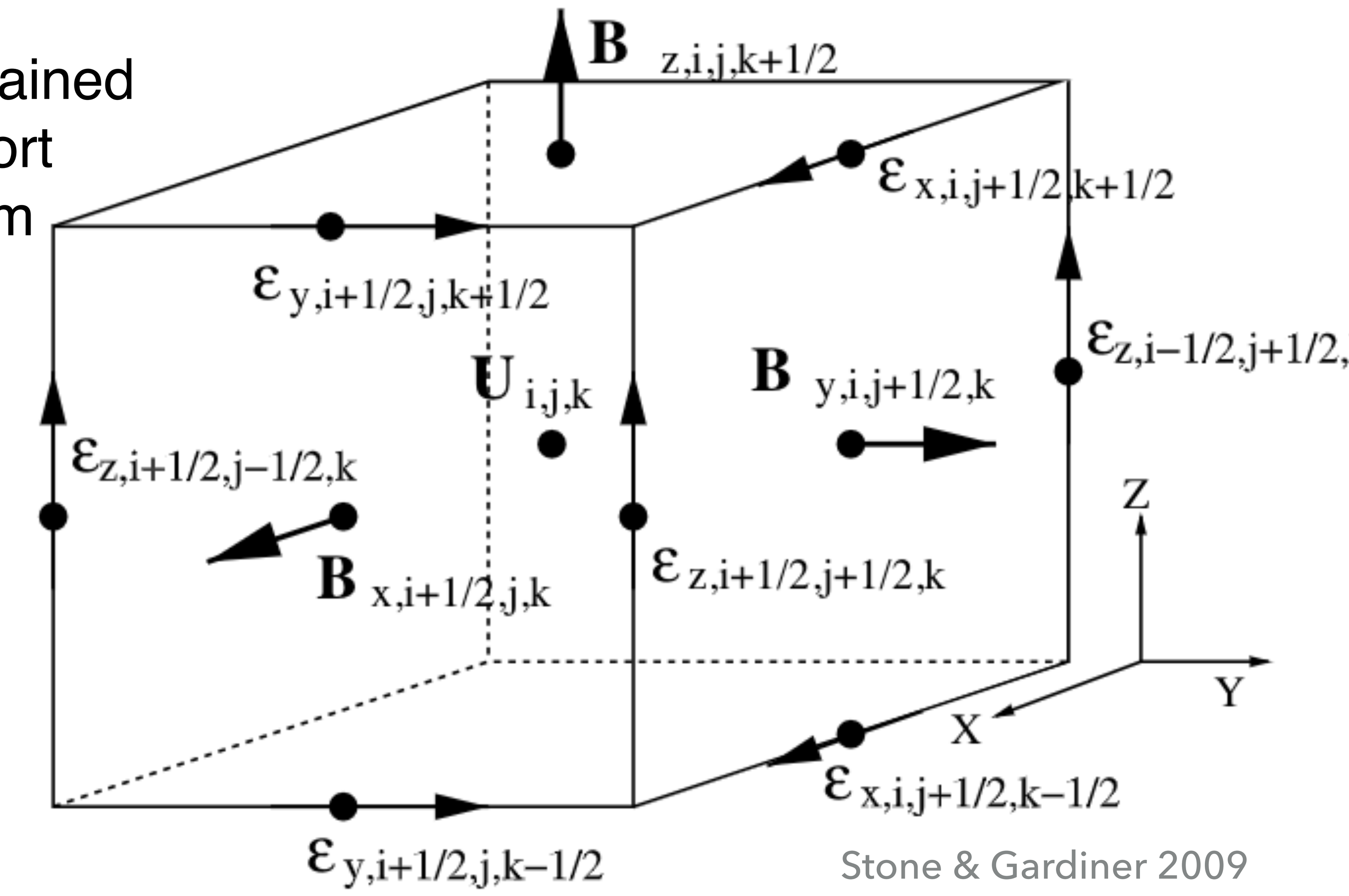
BACKGROUND: Magnetic fields play a significant role in galaxy evolution because they have similar energy densities to the fluid. Magnetic fields would also enable anisotropic conduction and cosmic ray transport to be accurately simulated. Unfortunately, magnetohydrodynamical (MHD) simulations of galaxies are incredibly computationally expensive to run to the point where MHD simulations of entire galaxies have been impossible to perform at high resolution.

Cholla (Computational Hydrodynamics On Parallel Architectures): Cholla is a massively parallel, GPU accelerated, code for modeling astrophysical fluid dynamics. Cholla can harness the incredible power of new GPU accelerated supercomputers like Summit and Frontier to deliver simulations at unprecedented resolutions.

MHD (MagnetoHydroDynamics): My current work is to add magnetic fields to Cholla. Galaxies, and most other systems with plasma, contain significant magnetic fields that may affect their dynamics, so we need to accurately simulate both the magnetic fields and their interaction with matter. Magnetic fields present unique challenges to simulate since they must maintain nearly perfectly zero divergence or the simulation will produce incorrect results, we address this issue using the Constrained Transport algorithm which enforces zero divergence via translating magnetic fluxes to electric fields and then uses those to update the magnetic field.

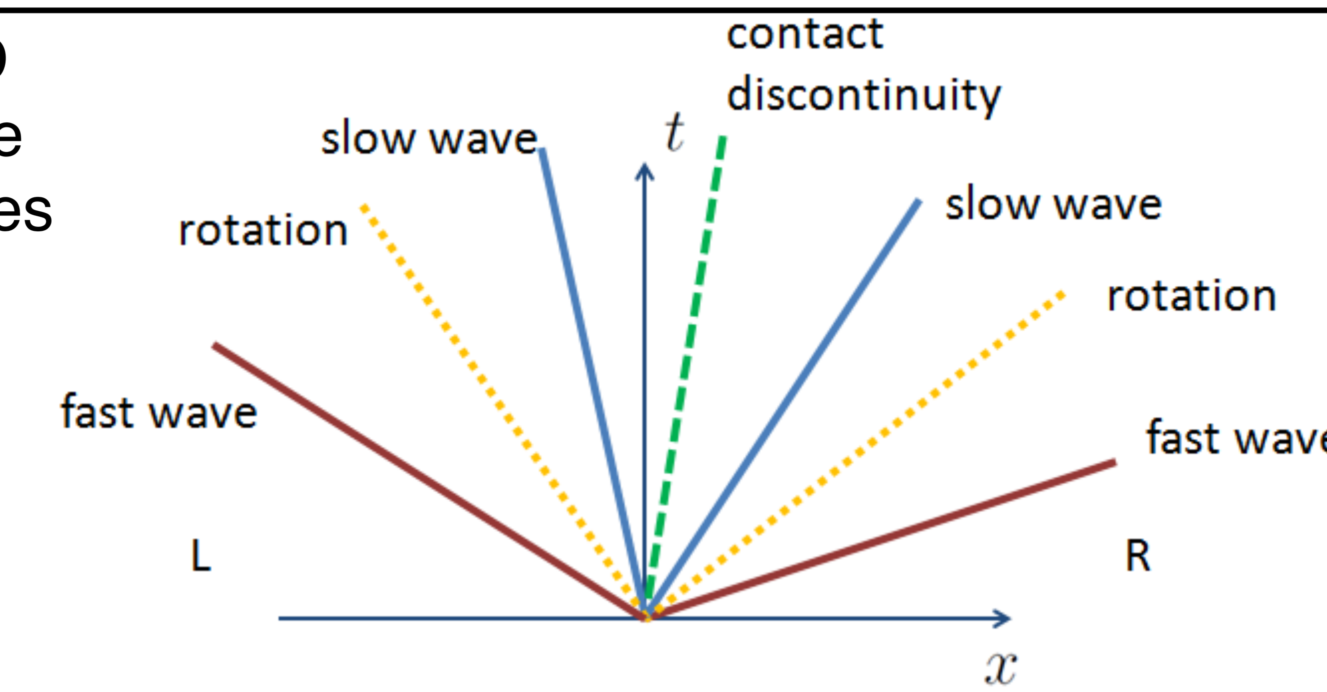
Testing Exascale Codes: A testing framework was required for Cholla as the complexity and number of contributors grew. I built a testing framework for Cholla using a mixture of GoogleTest and custom code. This framework works with both automated testing systems (Jenkins & GitHub Actions) and on any system that Cholla itself will run on, including the Summit supercomputer and testbed systems for Frontier. This new framework has enabled faster and more confident development of Cholla and is designed with exascale code in mind.

Constrained transport diagram

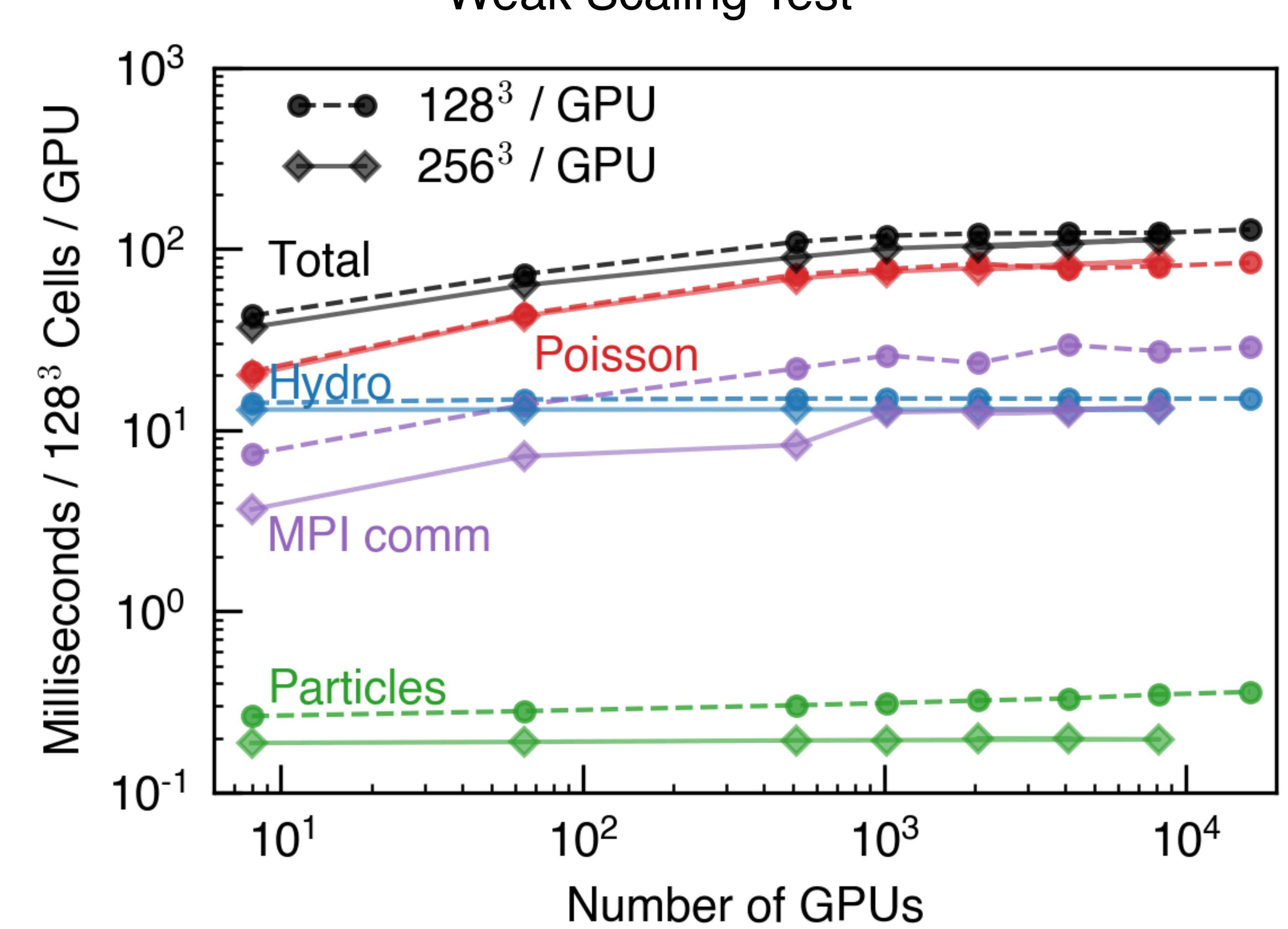


Stone & Gardiner 2009

MHD Wave Modes



Weak Scaling Test



For More Info

Cholla GitHub Repo

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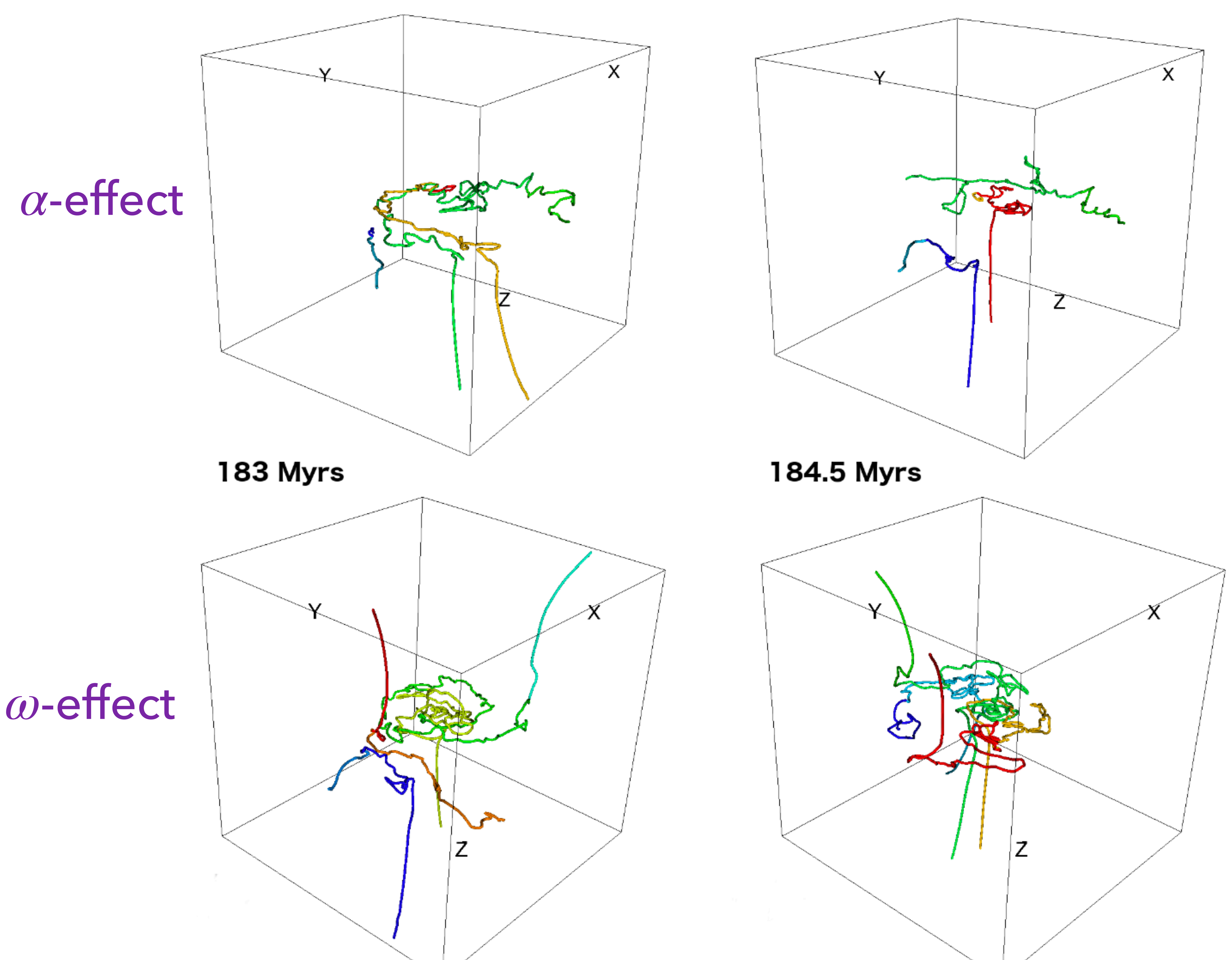
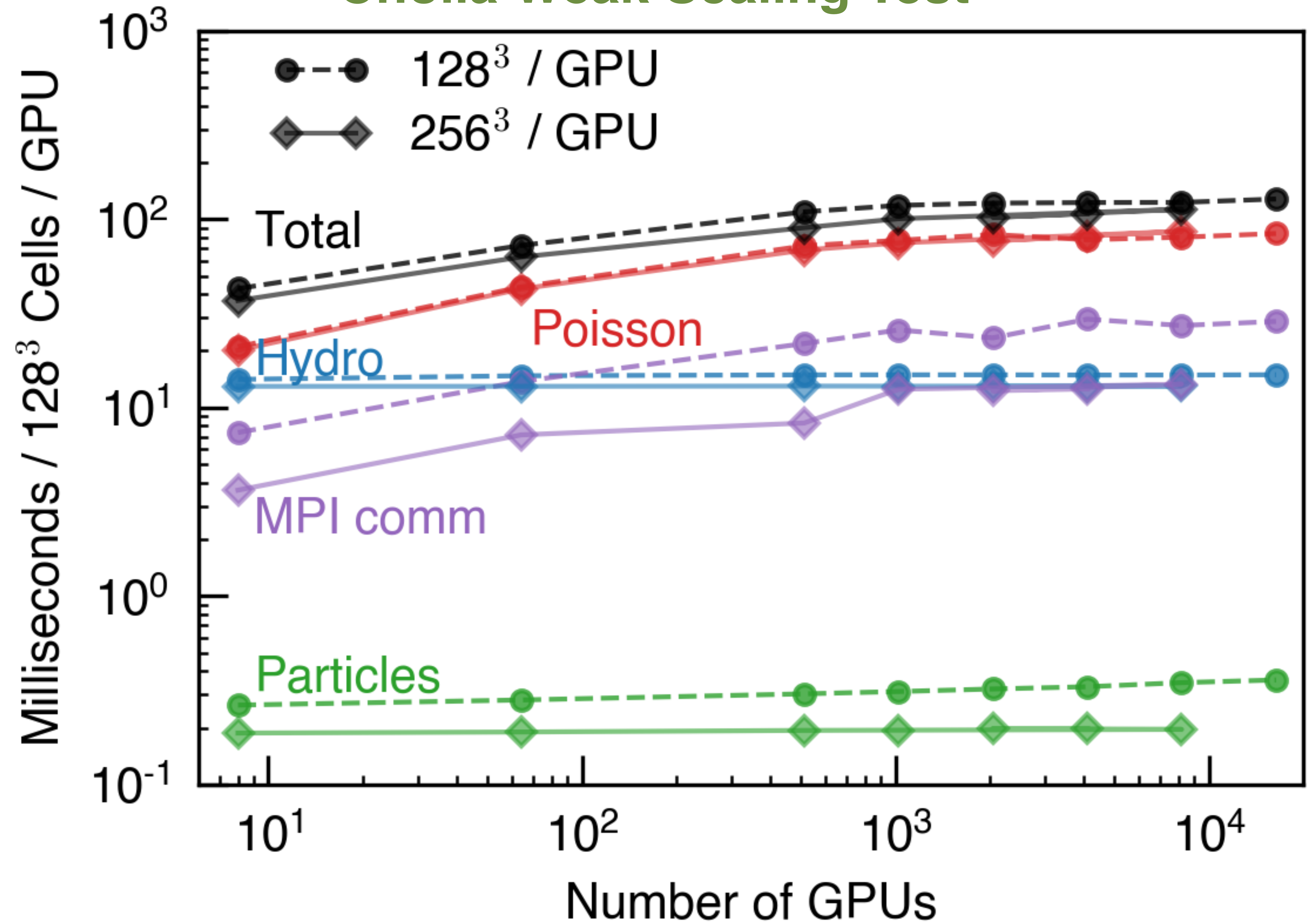
Galactic Magnetic Field Lines (simulated)



Ntormousi et al. 2020, figure 10

Cholla Weak Scaling Test



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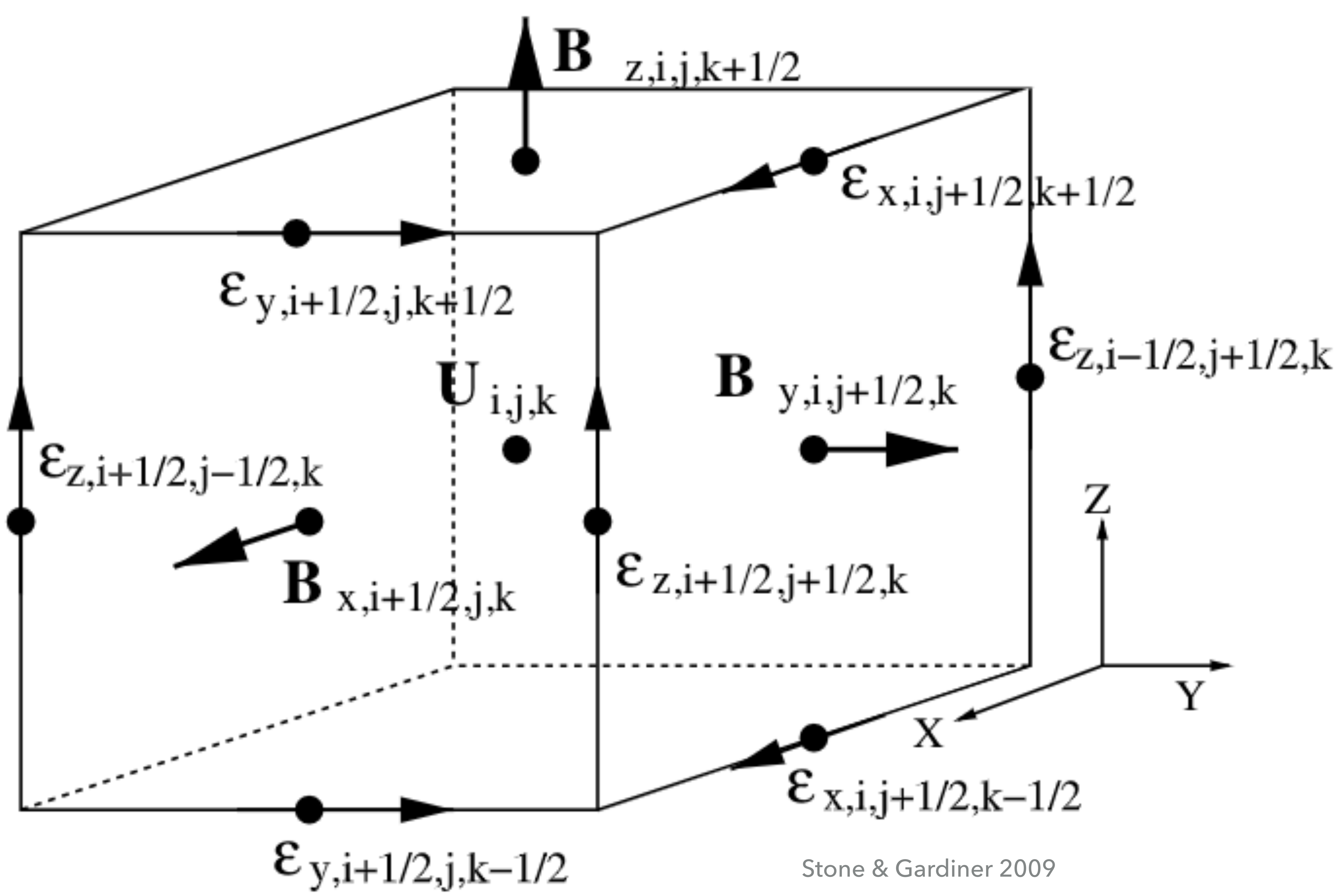
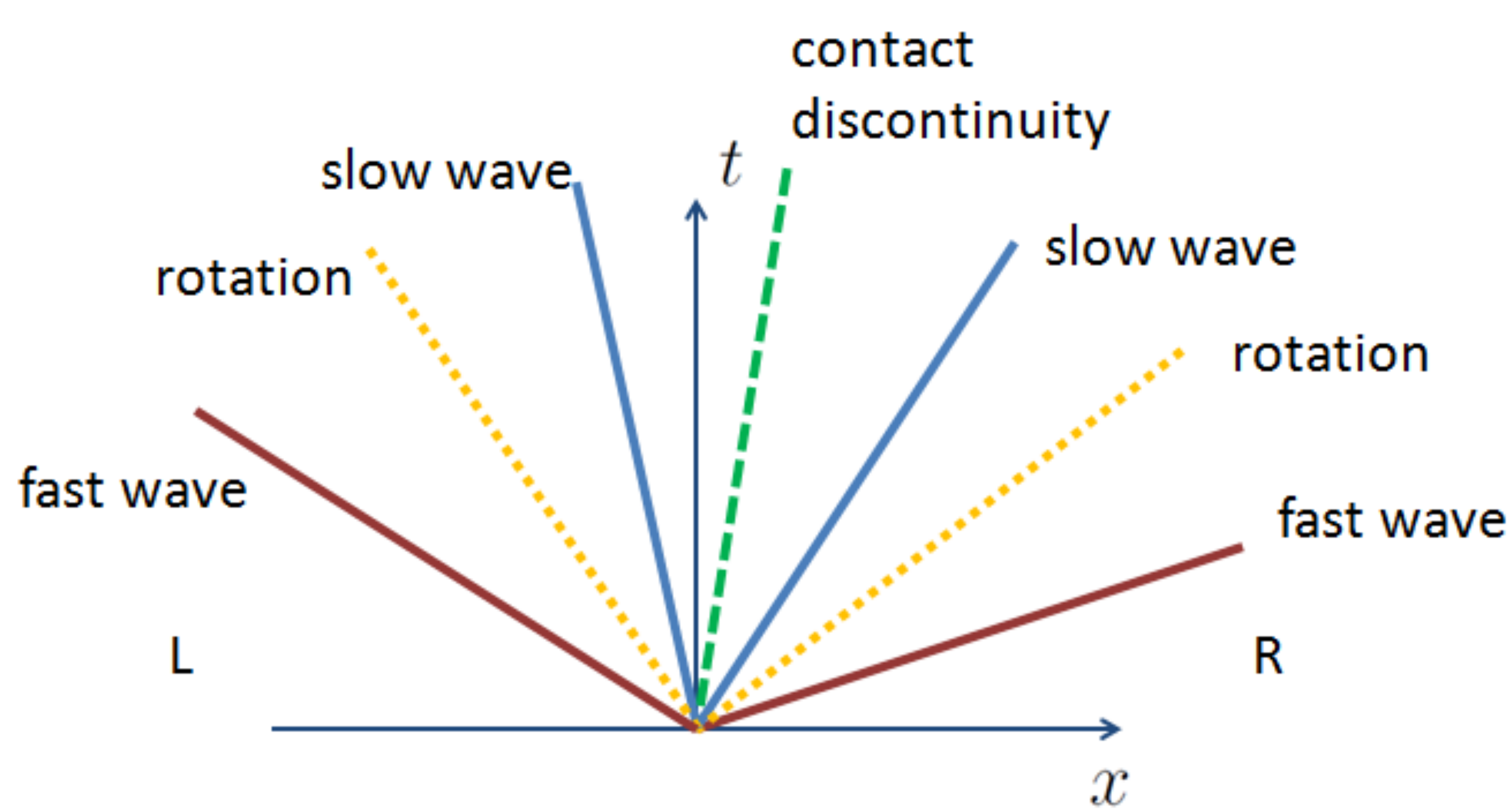
Constrained Transport Diagram



MHD Wave Modes



Progress on MHD:

- Implemented simple 1D Hydro code to help understand principles
- Implemented simple 1D MHD
- Built a testing framework for Cholla with automated builds, fully automated testing is waiting on support from university cluster admins since Cholla needs GPUs to run
- MHD in Cholla is mostly finished and at the bug fixing stage. Currently it only includes first order spatial reconstruction but higher order reconstruction will be added once the rest has all the bugs fixed
- Extremely preliminary performance analysis indicates that MHD takes about 39% longer per time step than a similar pure hydro problem. This is much better than expected since CPU codes typically take ~2.5x times longer with MHD vs hydro (Stone et al. 2020).

Future Work:

- Finish bug hunting in MHD
- Add MHD support to higher order spatial reconstruction implementation
- Run global galaxies simulations with MHD on Frontier
- Publish results, likely both a code paper and a simulation results paper
- Possibly implement anisotropic conduction or cosmic ray transport

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