

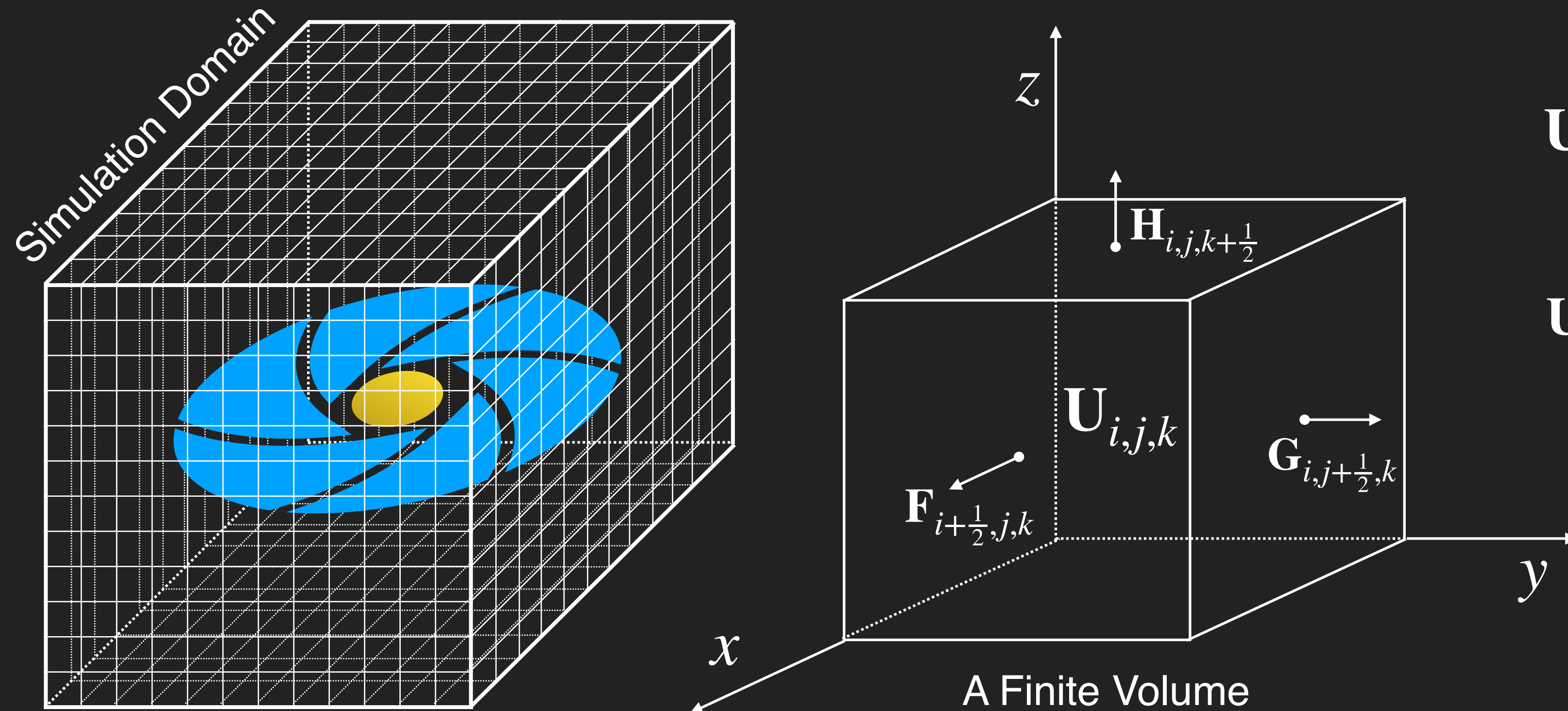
EXASCALE MHD SIMULATIONS WITH

Cholla

ROBERT CADDY

JSI WORKSHOP OCT. 11, 2023

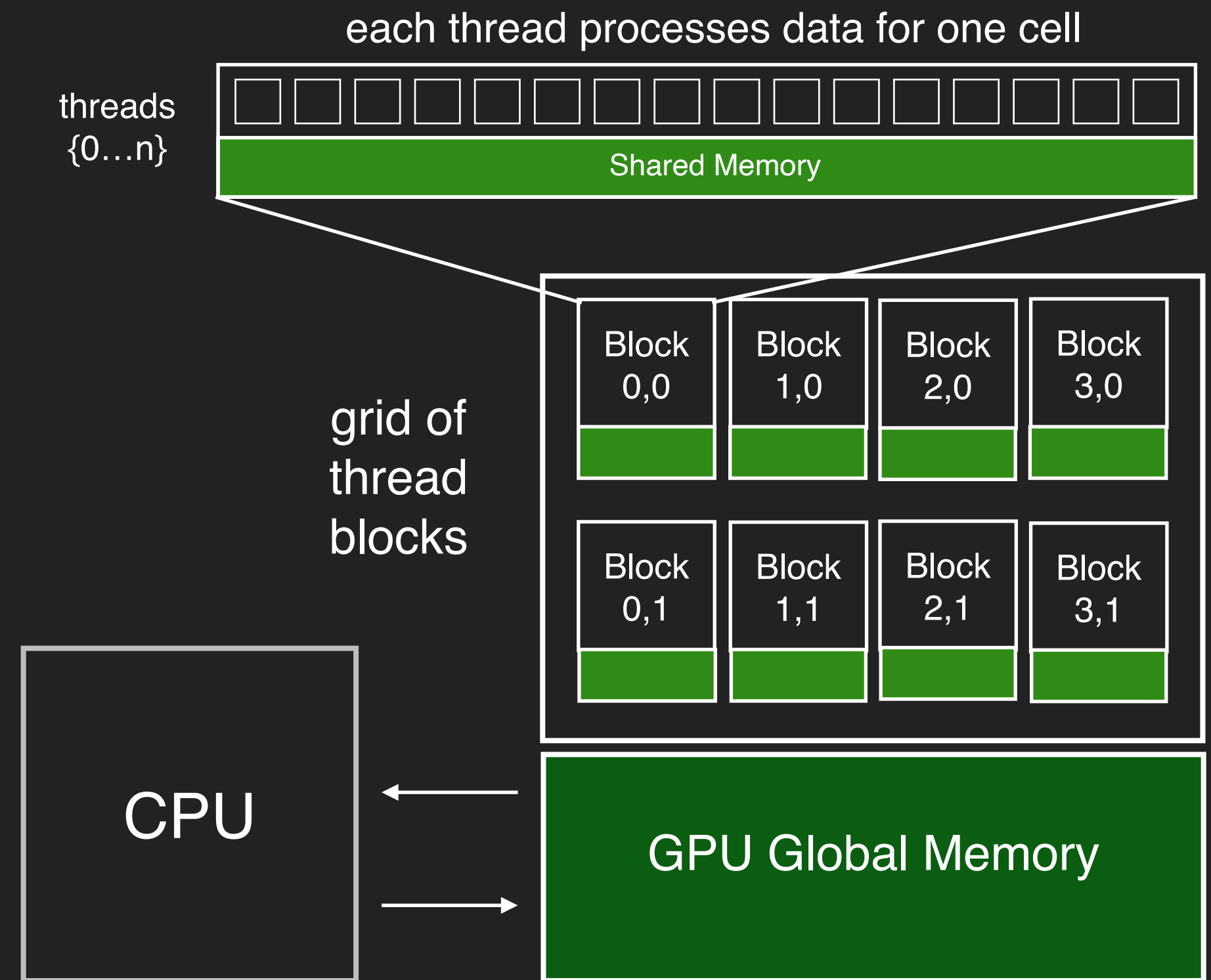
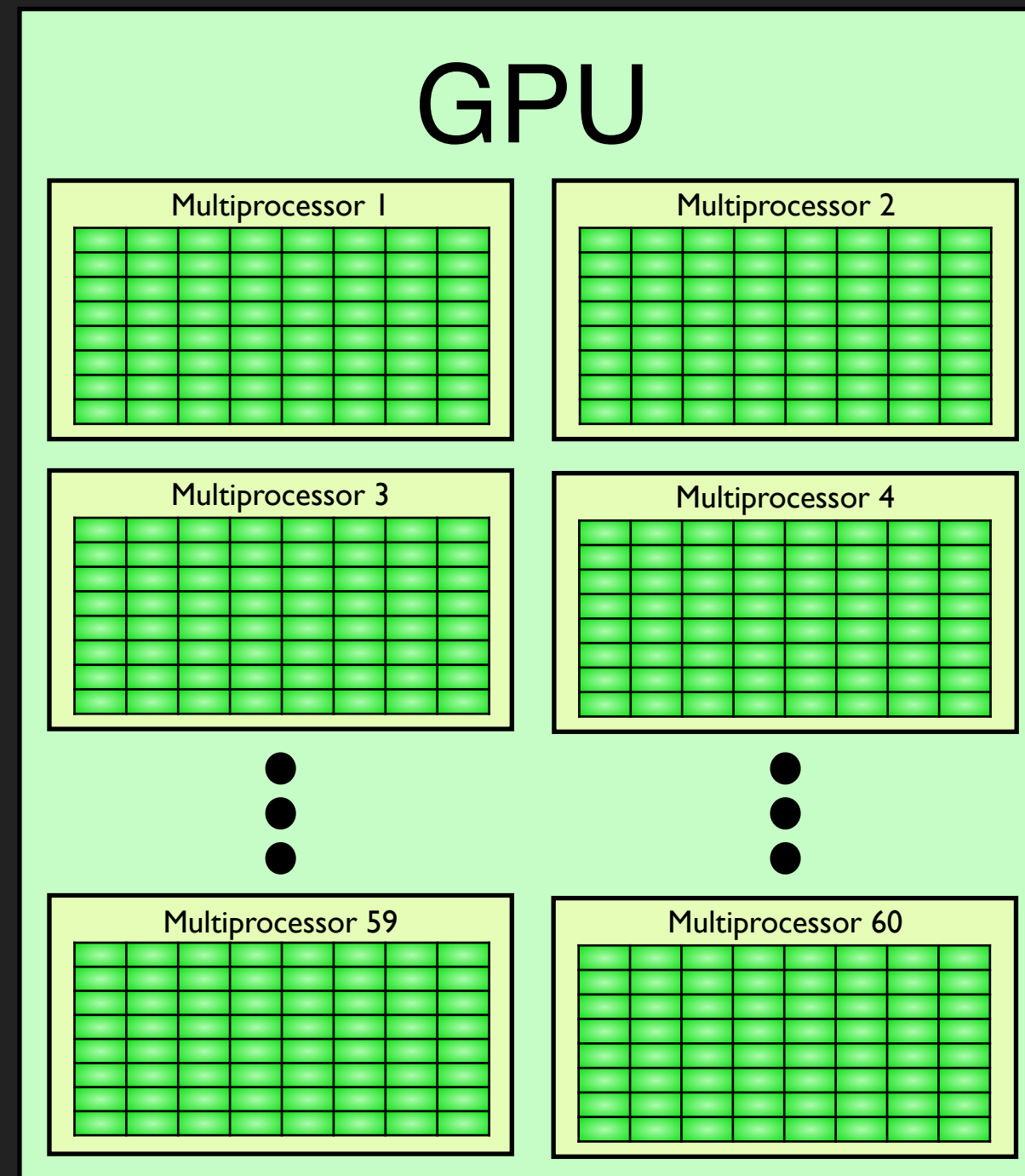
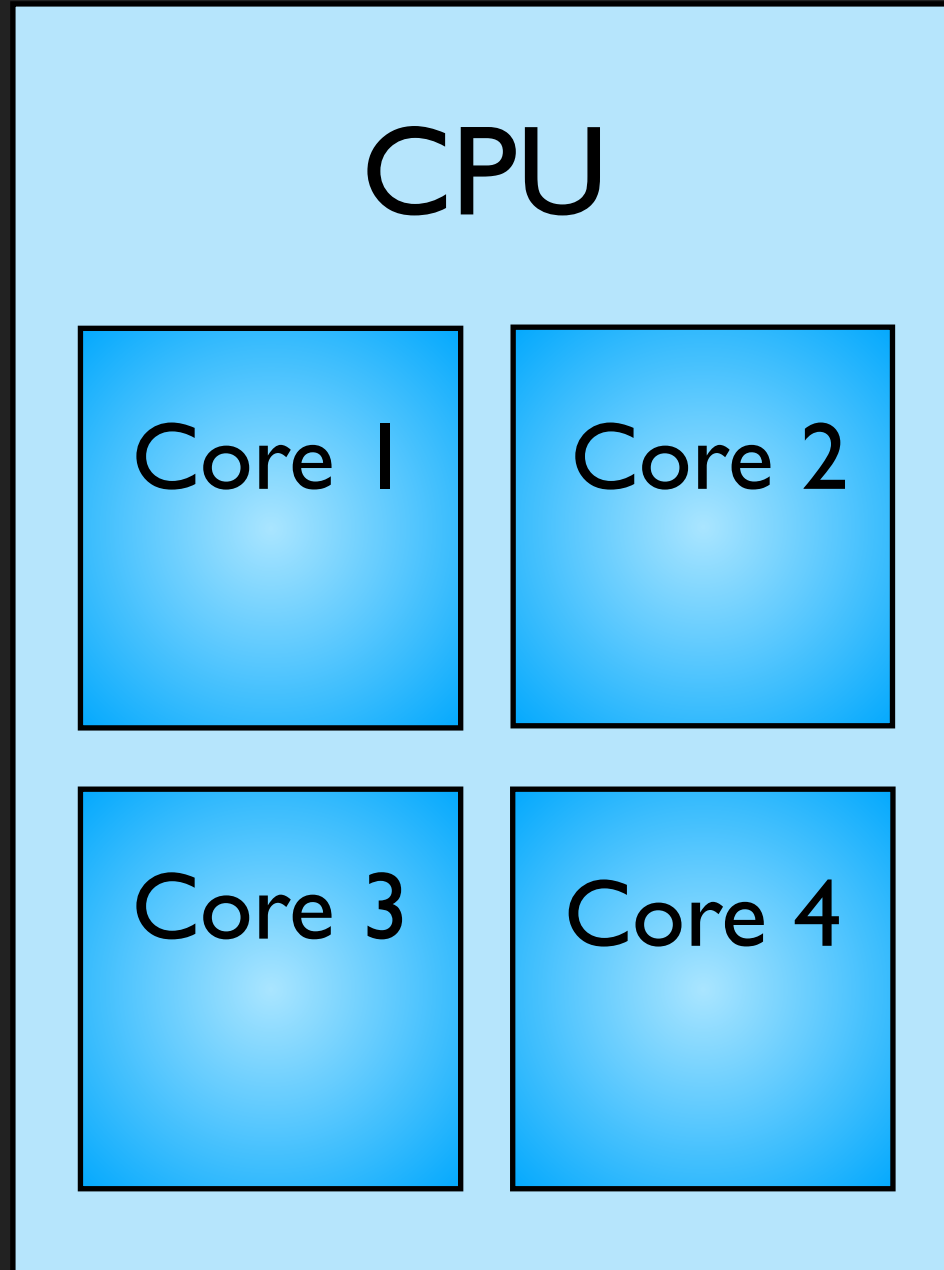
Cholla is a GPU-native, massively-parallel, **finite-volume** hydrodynamics code developed for astrophysics simulations.



$$\mathbf{U} = [\rho, \rho u, \rho v, \rho w, E]^T$$

$$\mathbf{U}_{i,j,k}^{n+1} = \mathbf{U}_{i,j,k}^n - \frac{\delta t}{\delta x} \left(\mathbf{F}_{i+\frac{1}{2},j,k} - \mathbf{F}_{i-\frac{1}{2},j,k} \right) - \frac{\delta t}{\delta y} \left(\mathbf{G}_{i,j+\frac{1}{2},k} - \mathbf{G}_{i,j-\frac{1}{2},k} \right) - \frac{\delta t}{\delta z} \left(\mathbf{H}_{i,j,k+\frac{1}{2}} - \mathbf{H}_{i,j,k-\frac{1}{2}} \right)$$

WHY GPUS?



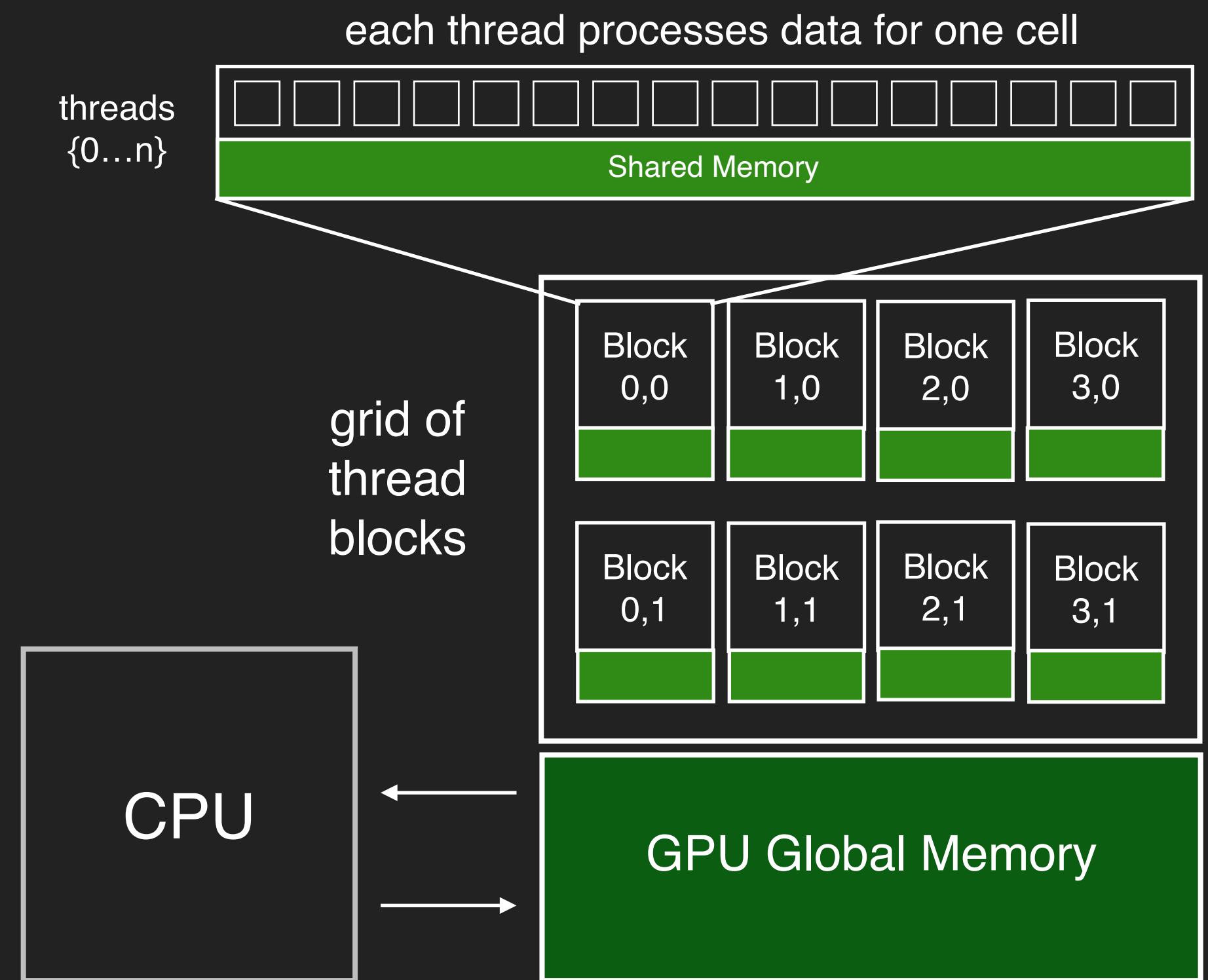
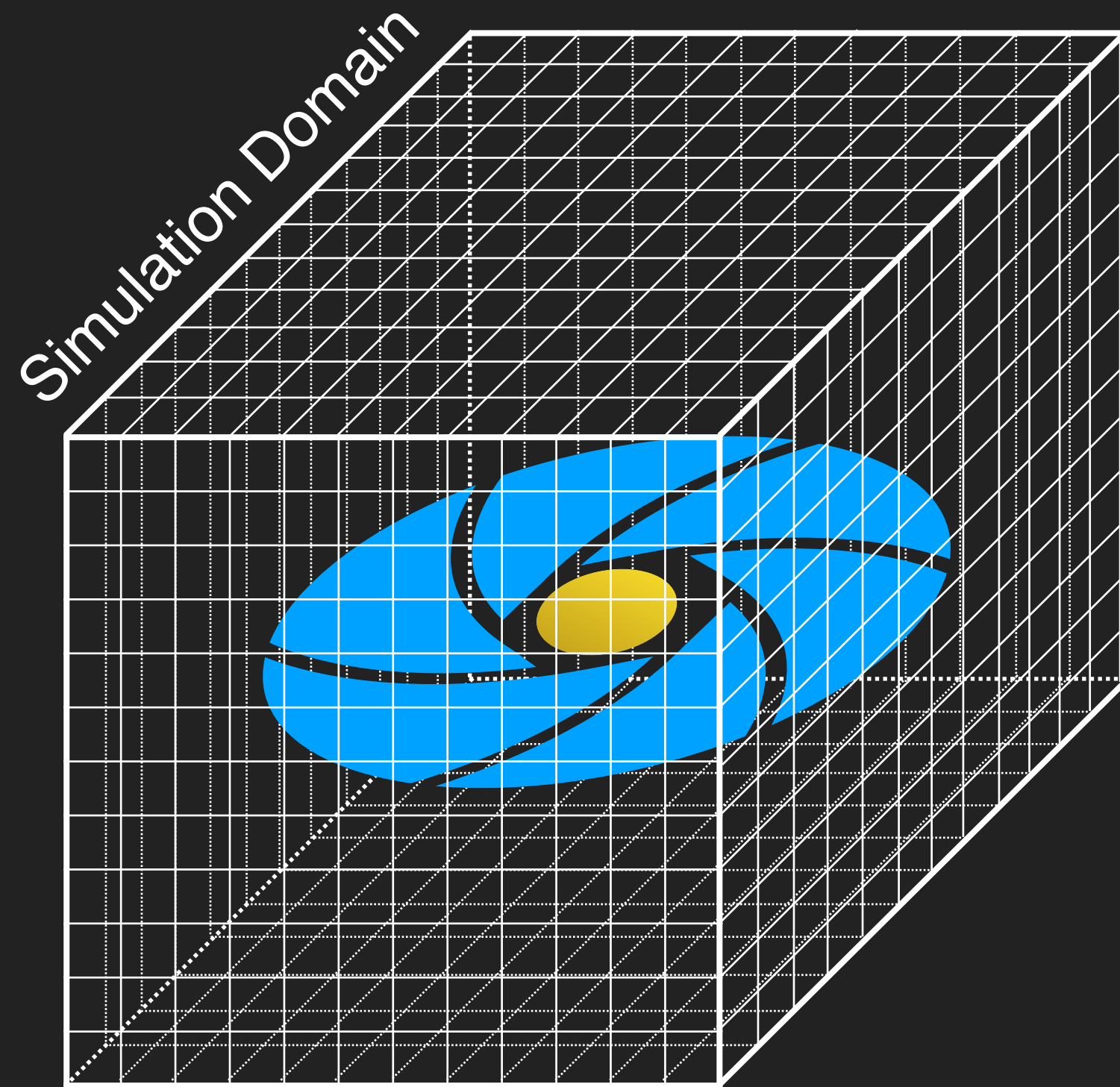
Optimized for Serial Tasks

- ~1-2 TFLOPS
- ≤128 cores
- ~4 GFLOPS/Watt

Optimized for Parallel Tasks

- ~30 TFLOPS
- >7,500 cores
- ~50 GFLOPS/Watt

WHY GPUs?



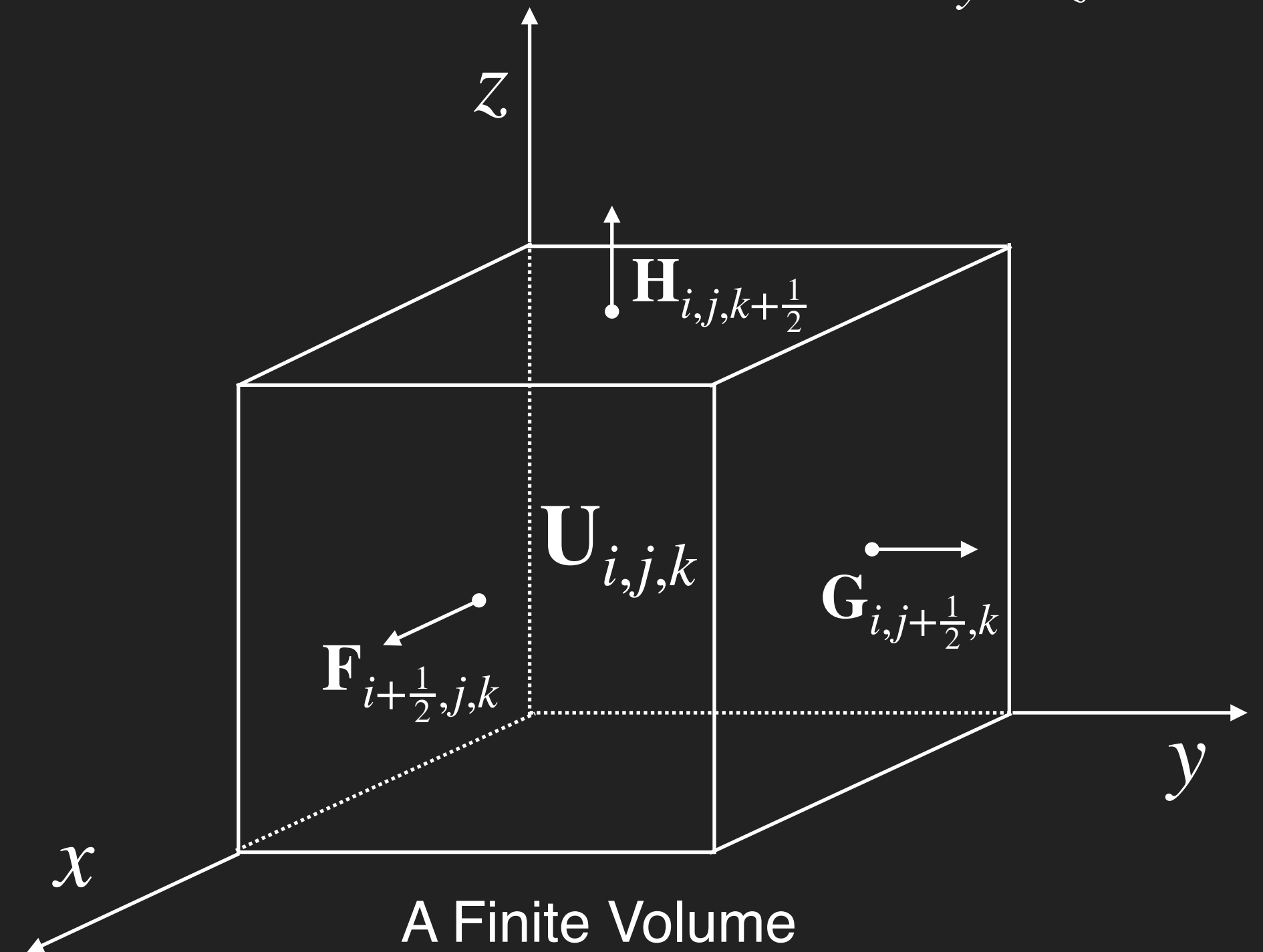
WHY CHOLLA MHD?

- ▶ No consensus on the effect of magnetic fields in galaxies
- ▶ Zero divergence methods are computationally expensive
 - ▶ $\nabla \cdot \vec{B} = 0$, magnetic monopoles shouldn't exist
- ▶ Need ~ 1 pc resolution, impossible before the exascale era
- ▶ Required for anisotropic diffusion & cosmic ray transport
- ▶ Simulation data will be extensive and public

HOW TO REPRESENT THE MAGNETIC FIELD?

- ▶ Option 1:
 - ▶ Problems:
 - ▶ Transform the Induction equation
 - ▶ Non-zero divergence
 - ▶ Solution:
 - ▶ “Divergence Cleaning”, more computation and potentially insufficient

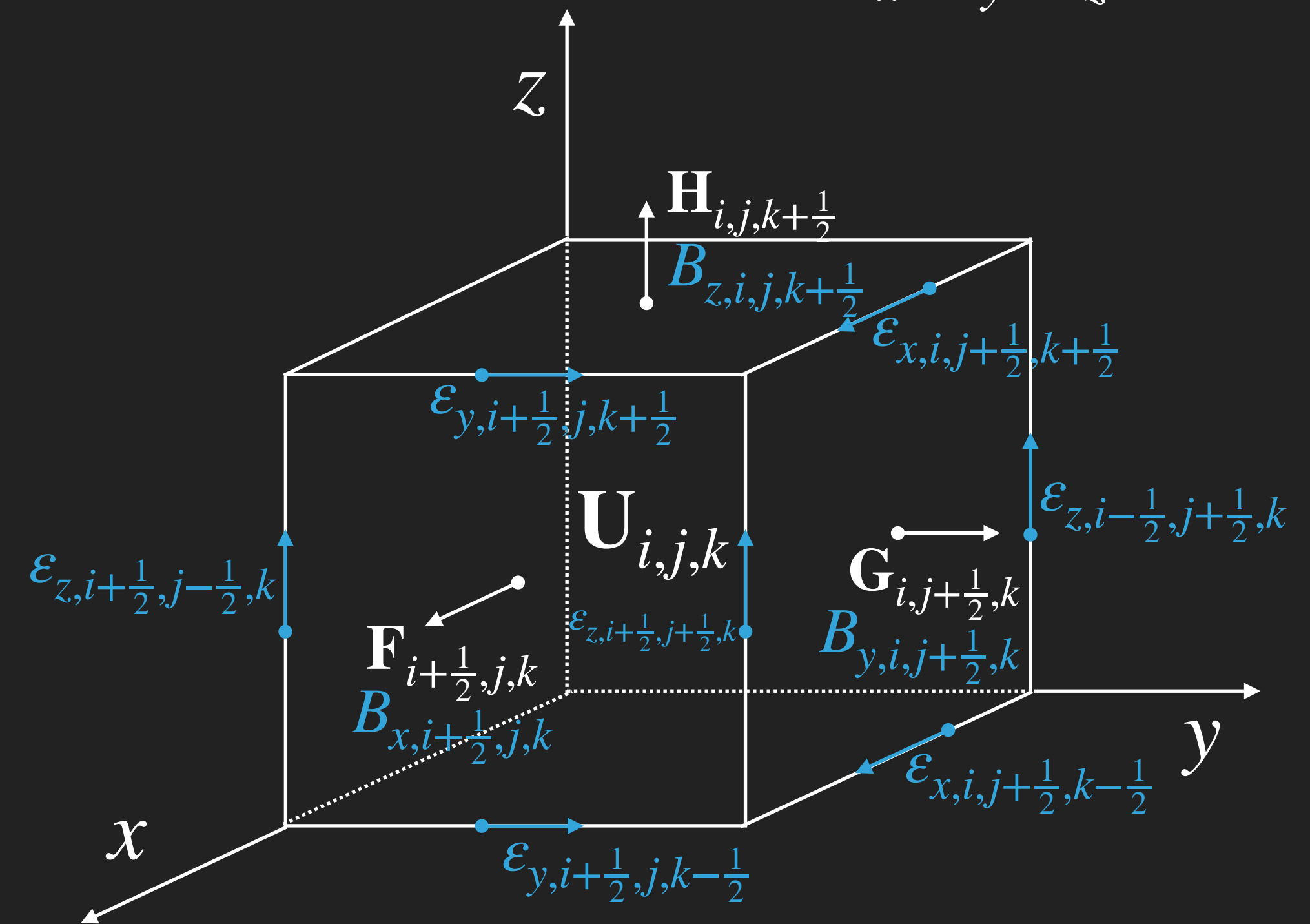
$$\mathbf{U} = [\rho, \rho u, \rho v, \rho w, E, B_x, B_y, B_z]^T$$



HOW TO REPRESENT THE MAGNETIC FIELD?

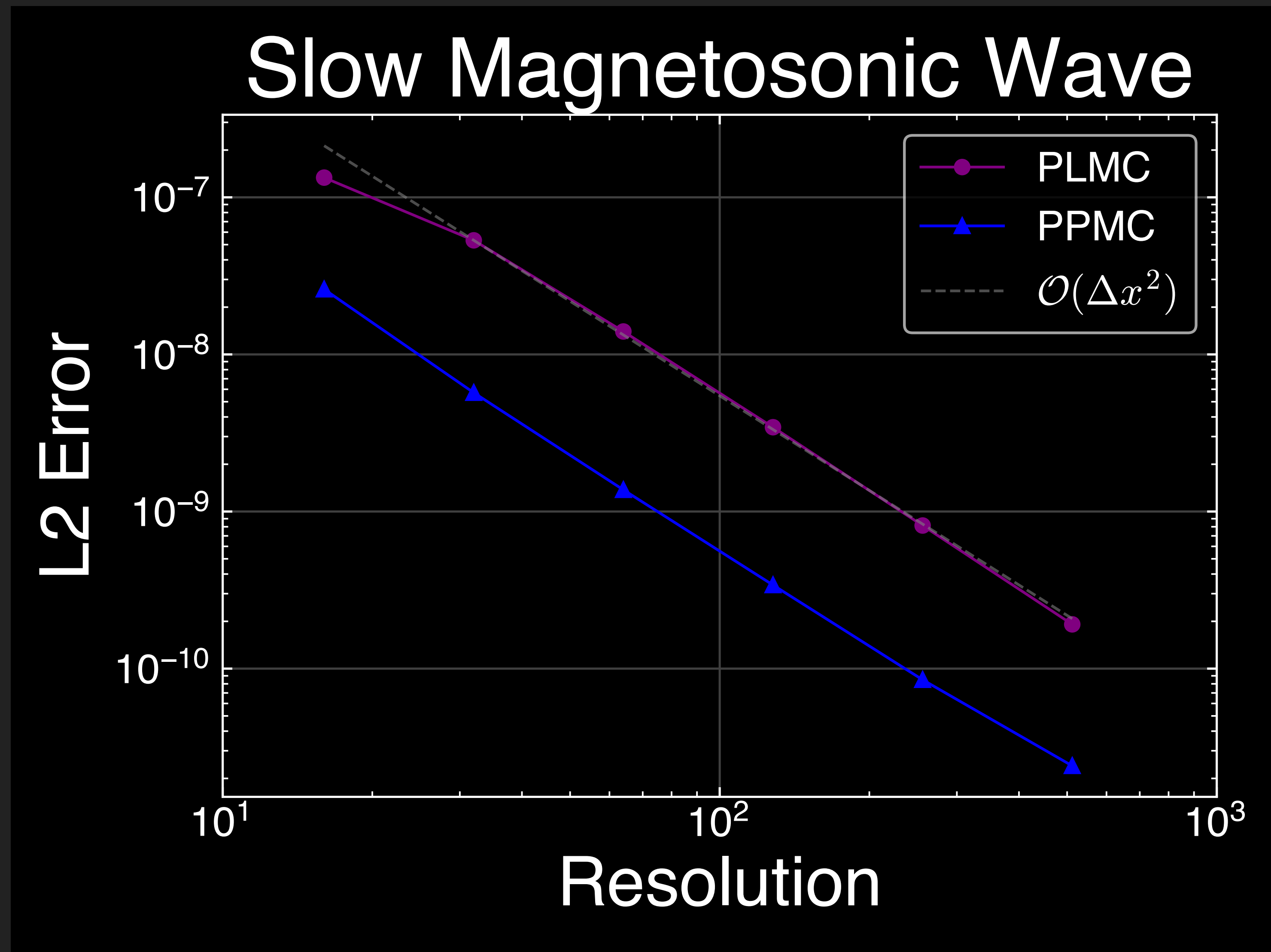
- ▶ Option 2: Constrained Transport
 - ▶ Divergence Free by construction
 - ▶ Computationally expensive
 - ▶ Complex to implement
 - ▶ Requires divergence free initial conditions

$$\mathbf{U} = [\rho, \rho u, \rho v, \rho w, E, B_x, B_y, B_z]^T$$



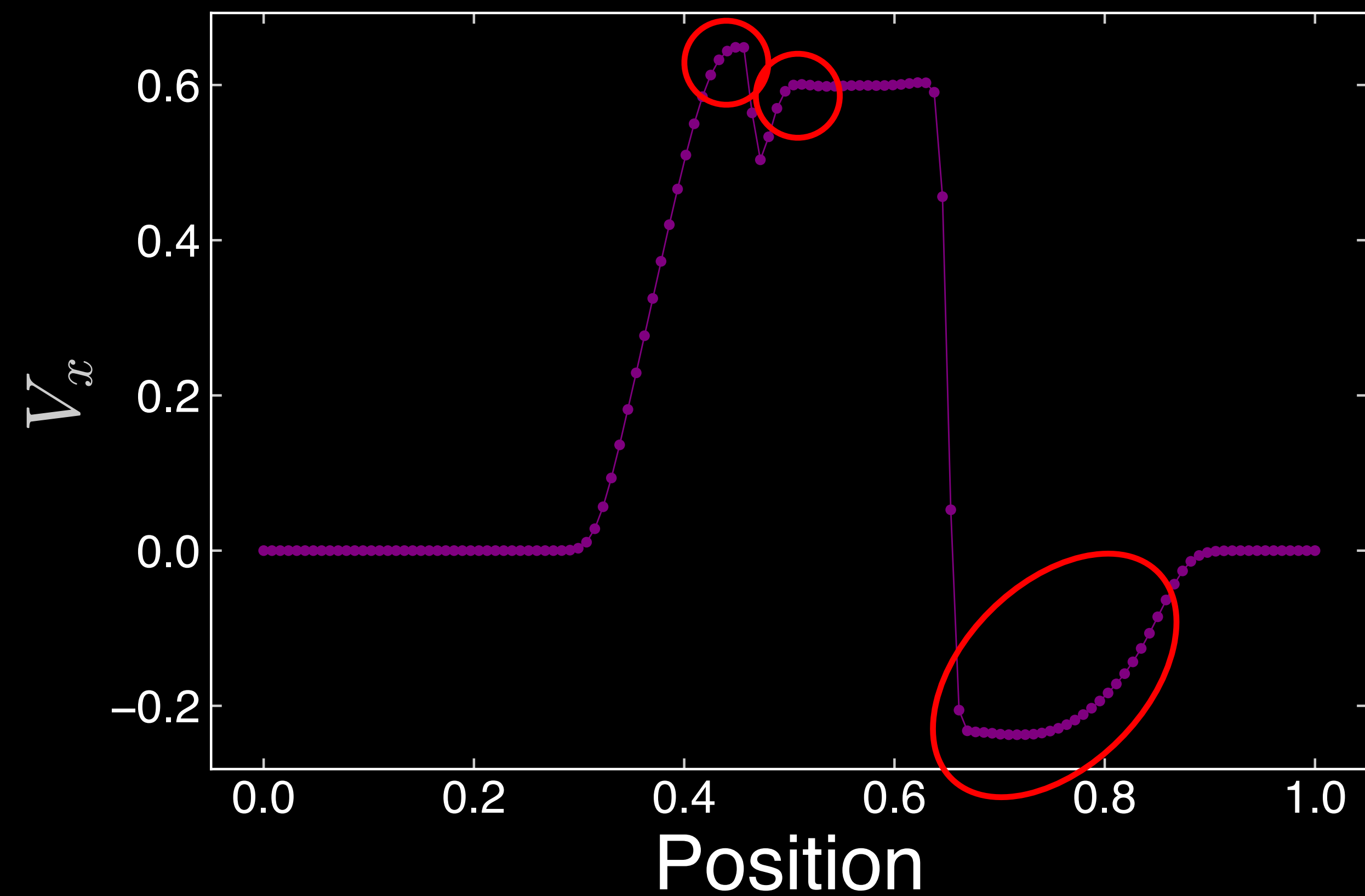
A Finite Volume + Constrained Transport

LINEAR WAVE CONVERGENCE

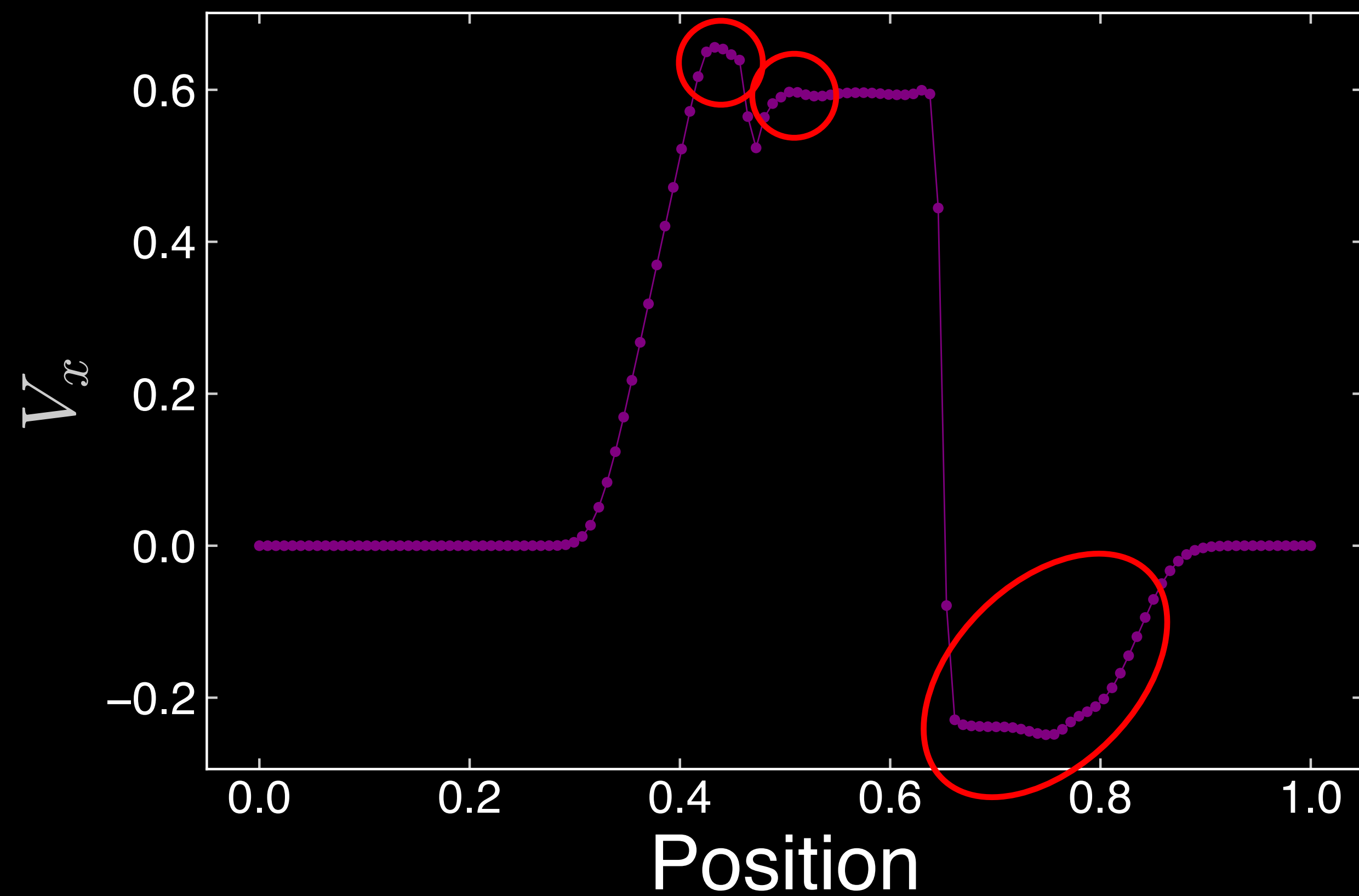


PPMC VS. PLMC - SHOCKS

Brio & Wu PLMC



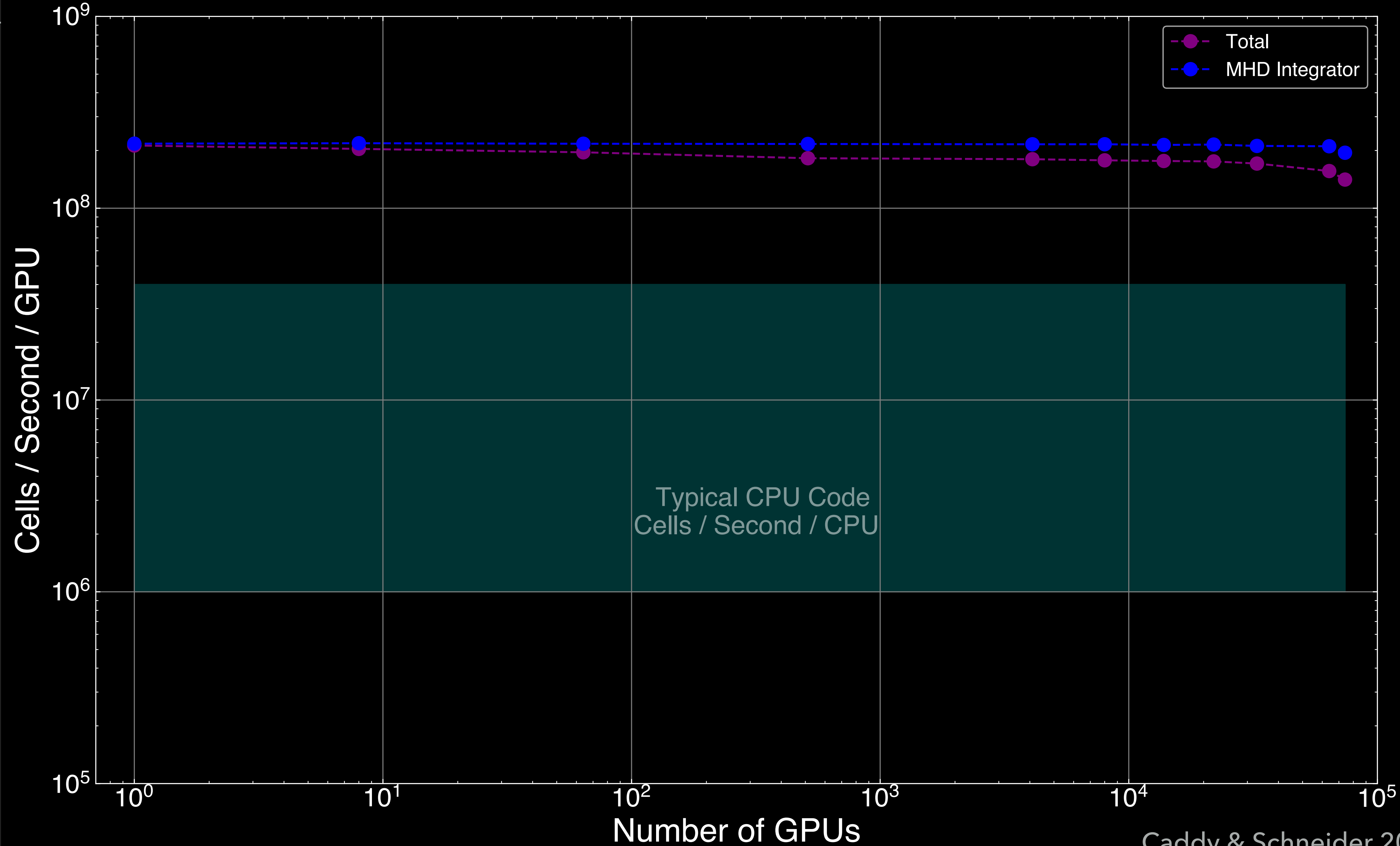
Brio & Wu PPMC

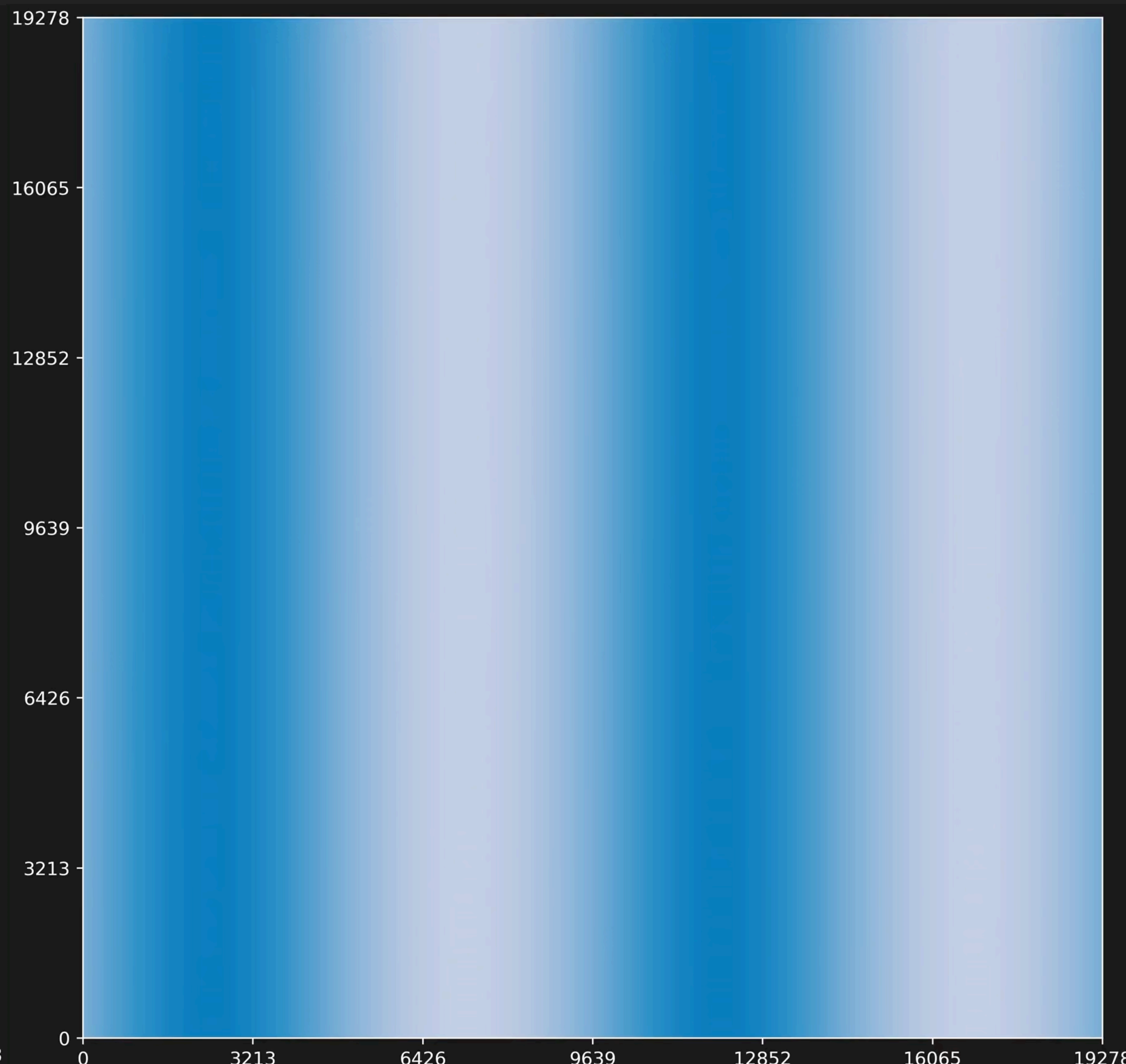
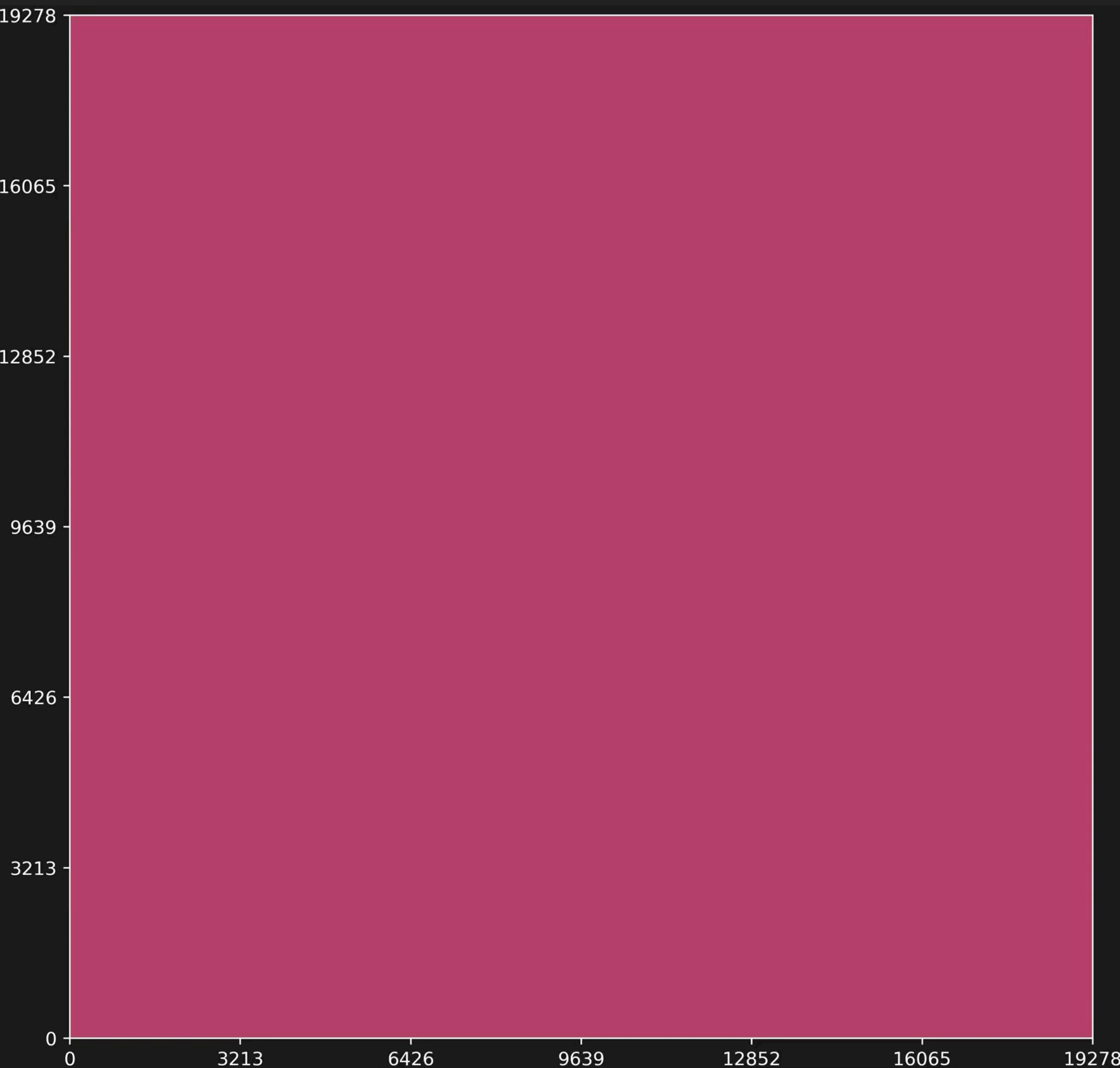


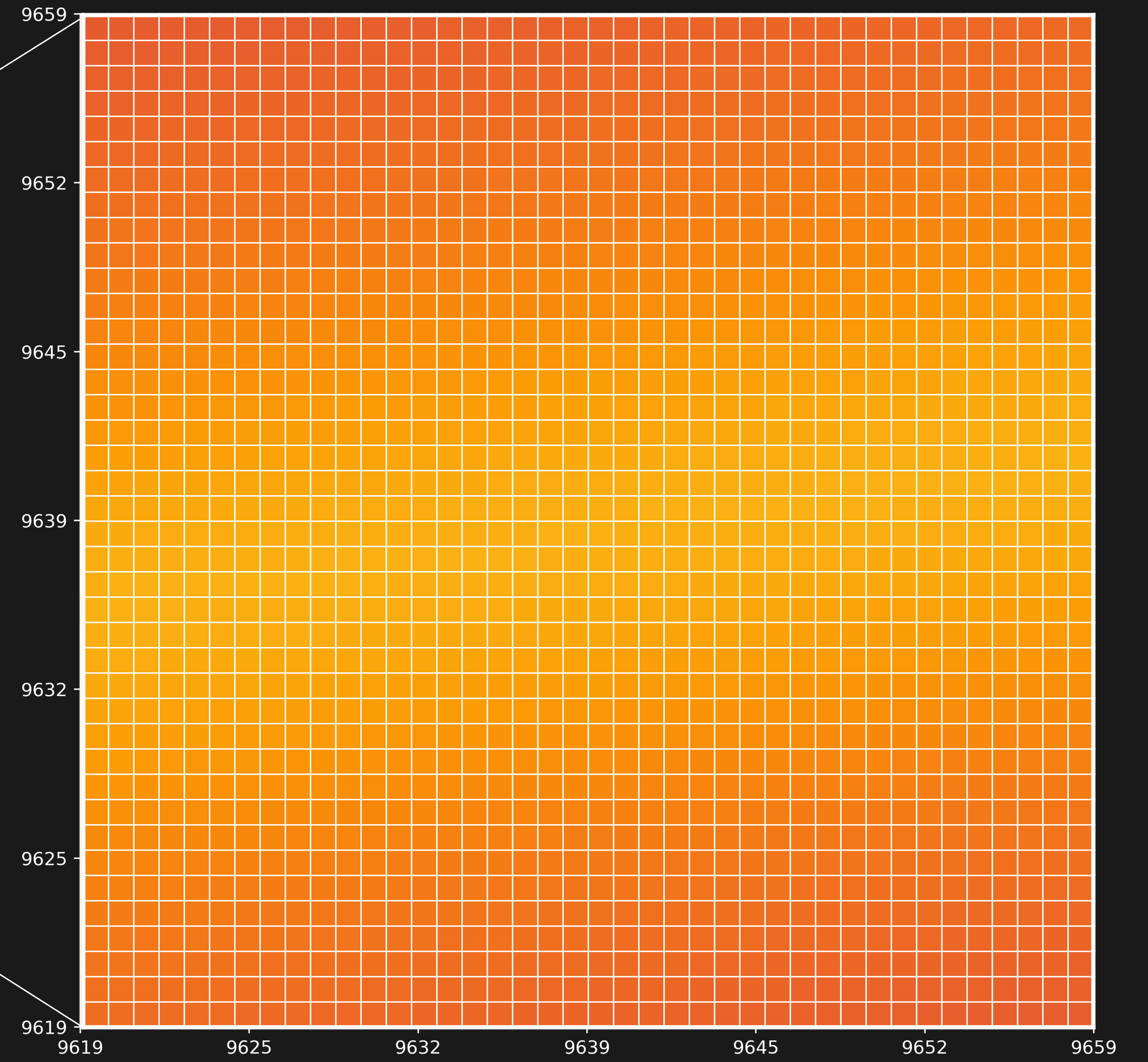
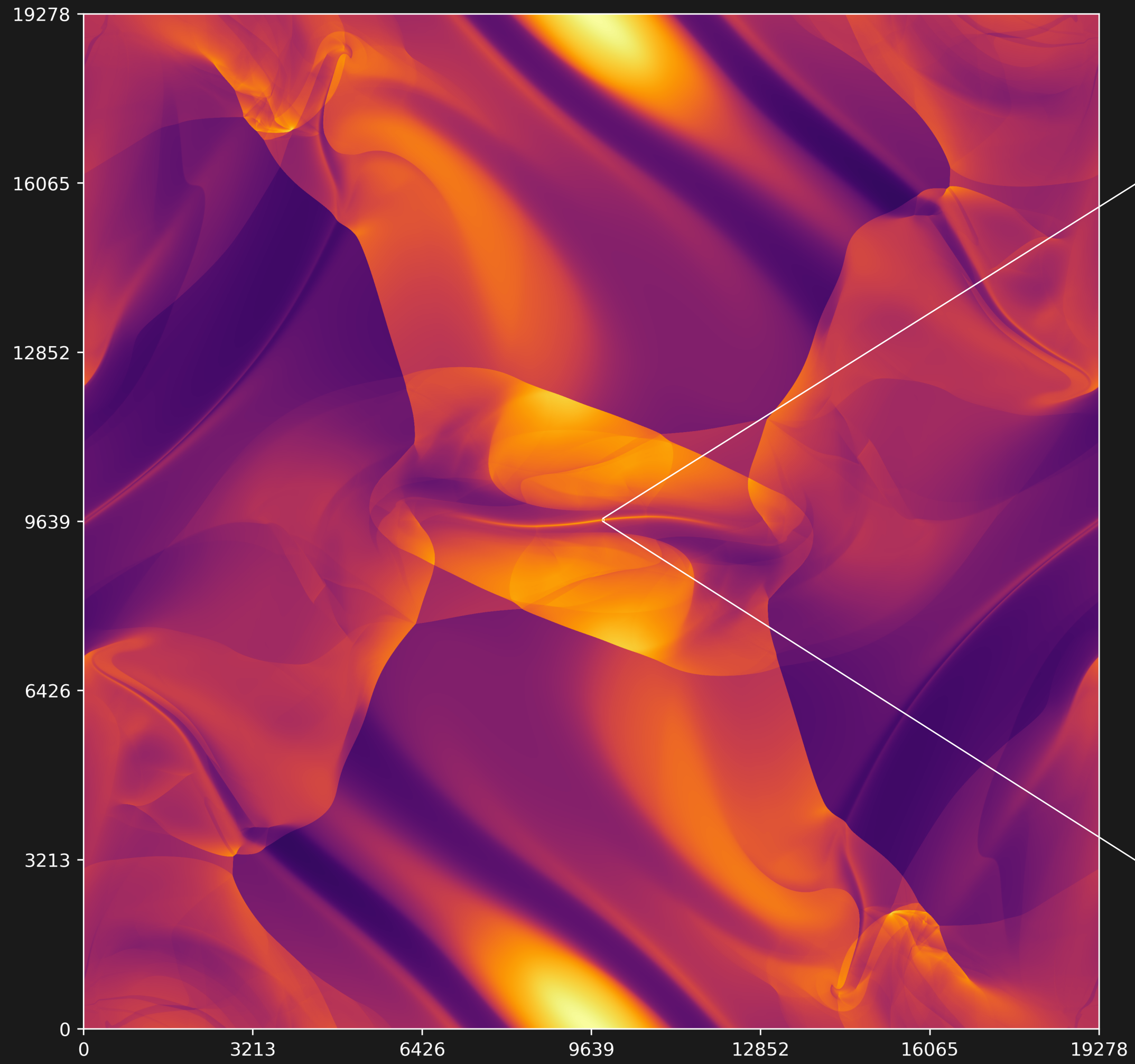
MHD Weak Scaling on Frontier (PLMC)

MHD

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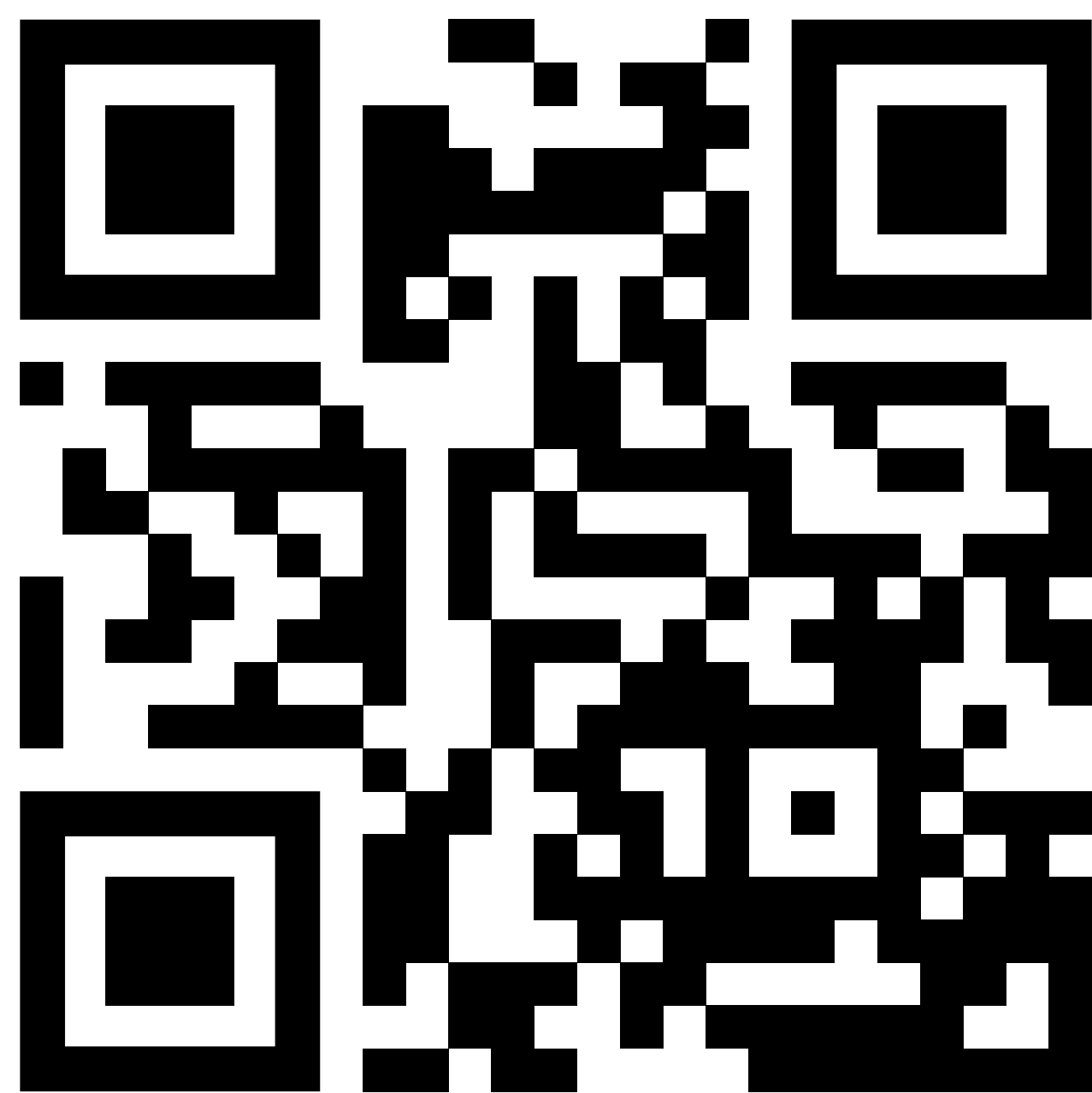
TESTING & CONTINUOUS INTEGRATION (CI)

- ▶ Added a testing framework
- ▶ Tests are easy & fast to run with a single shell command
- ▶ Easy to add and change code confidently
- ▶ Tests are automated and run with each Pull Request (PR)
- ▶ Code formatting & static analysis (clang-tidy) also run on each PR

CONCLUSION

- ▶ Cholla is an exascale capable astrophysical MHD code
- ▶ The MHD module uses constrained transport to maintain zero divergence
- ▶ Includes a testing framework & automated testing/CI of all PRs
- ▶ Details in Caddy & Schneider 2023 in prep
- ▶ Cholla: github.com/cholla-hydro/cholla
- ▶ Resume, CV, etc: robertcaddy.com
- ▶ Talk Repo: github.com/bcaddy/JSI_Workshop_Talk_2023

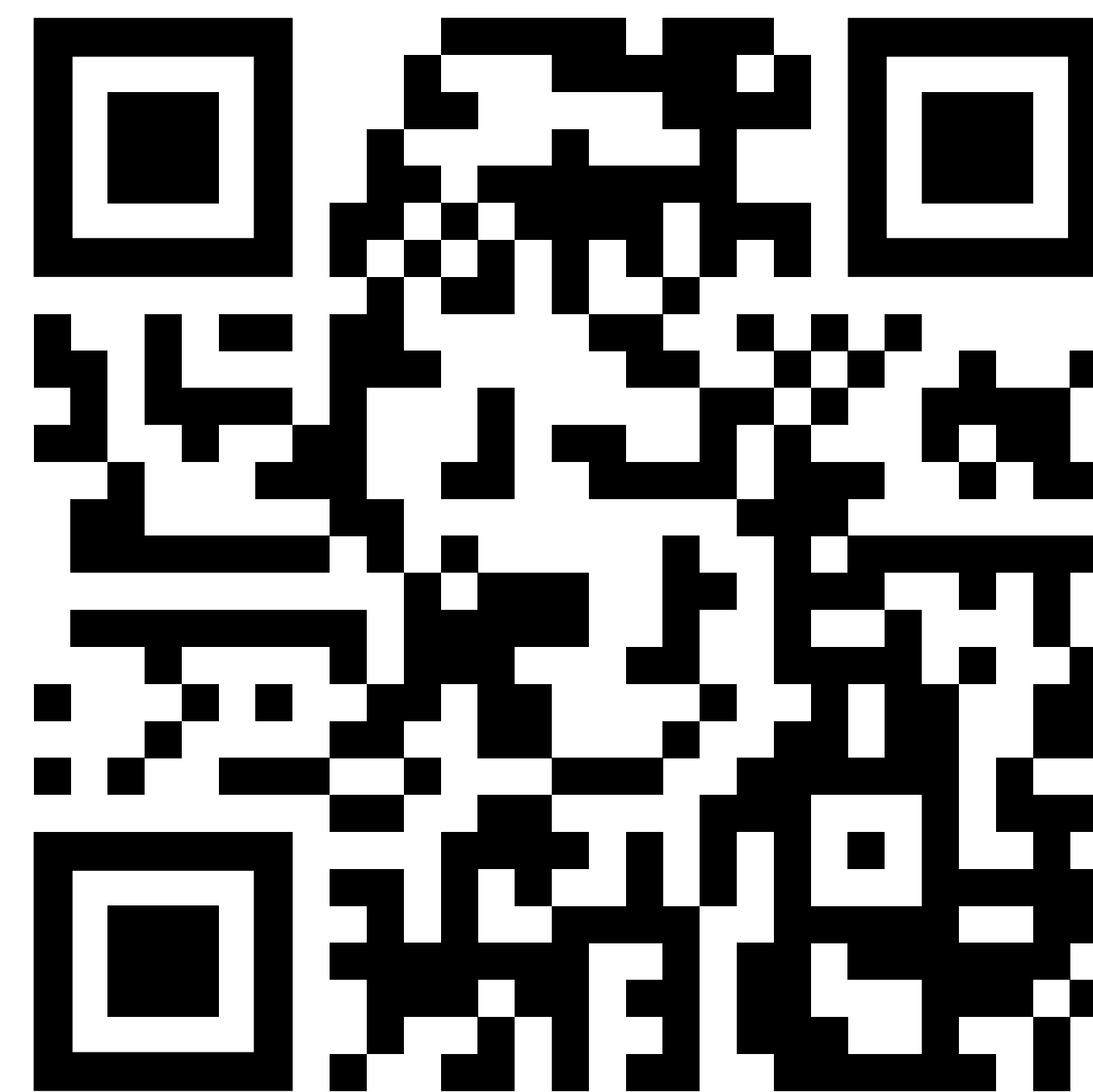
ADDITIONAL SLIDES



robertcaddy.com

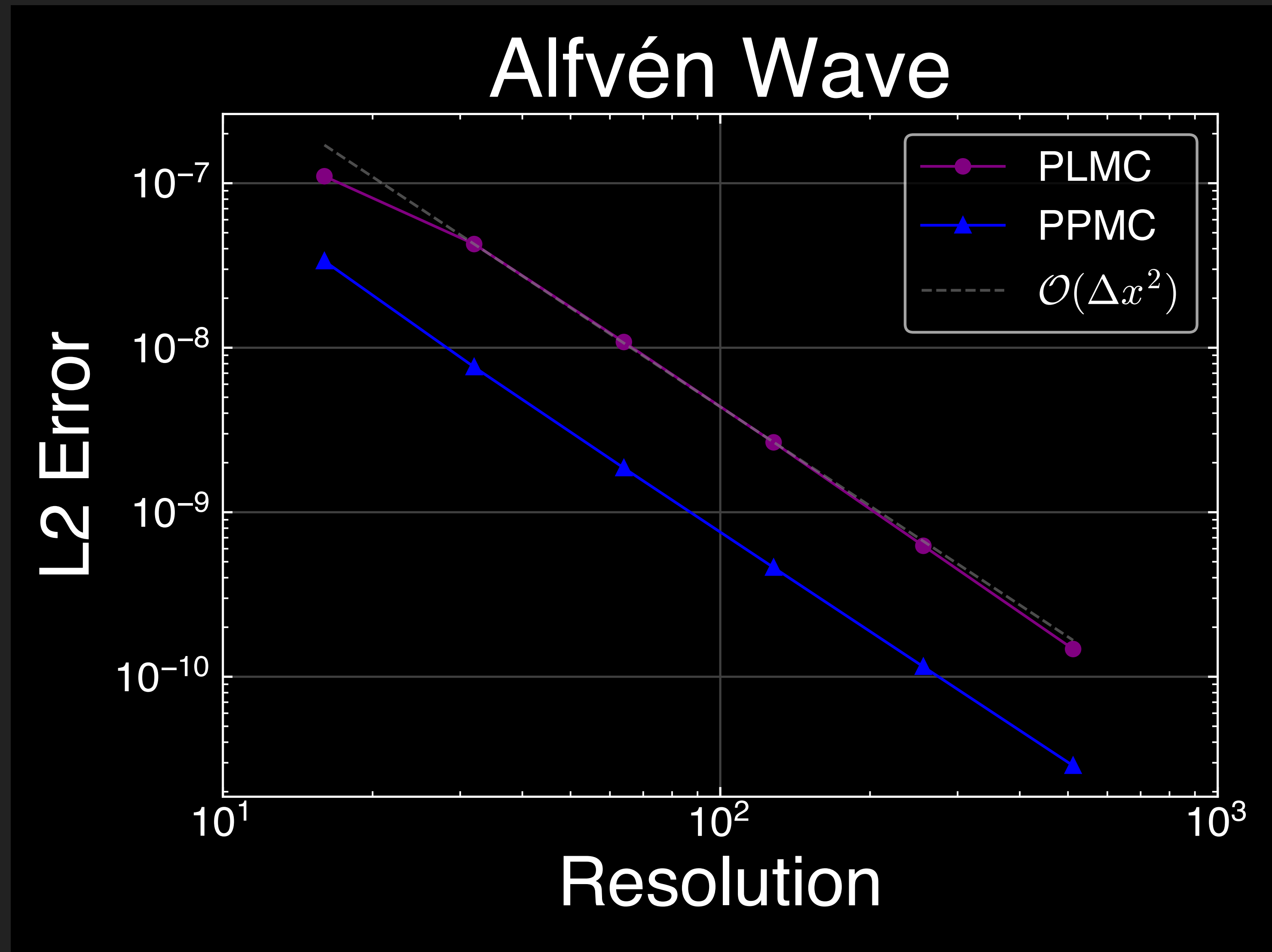


github.com/bcaddy/JSI_Workshop_Talk_2023

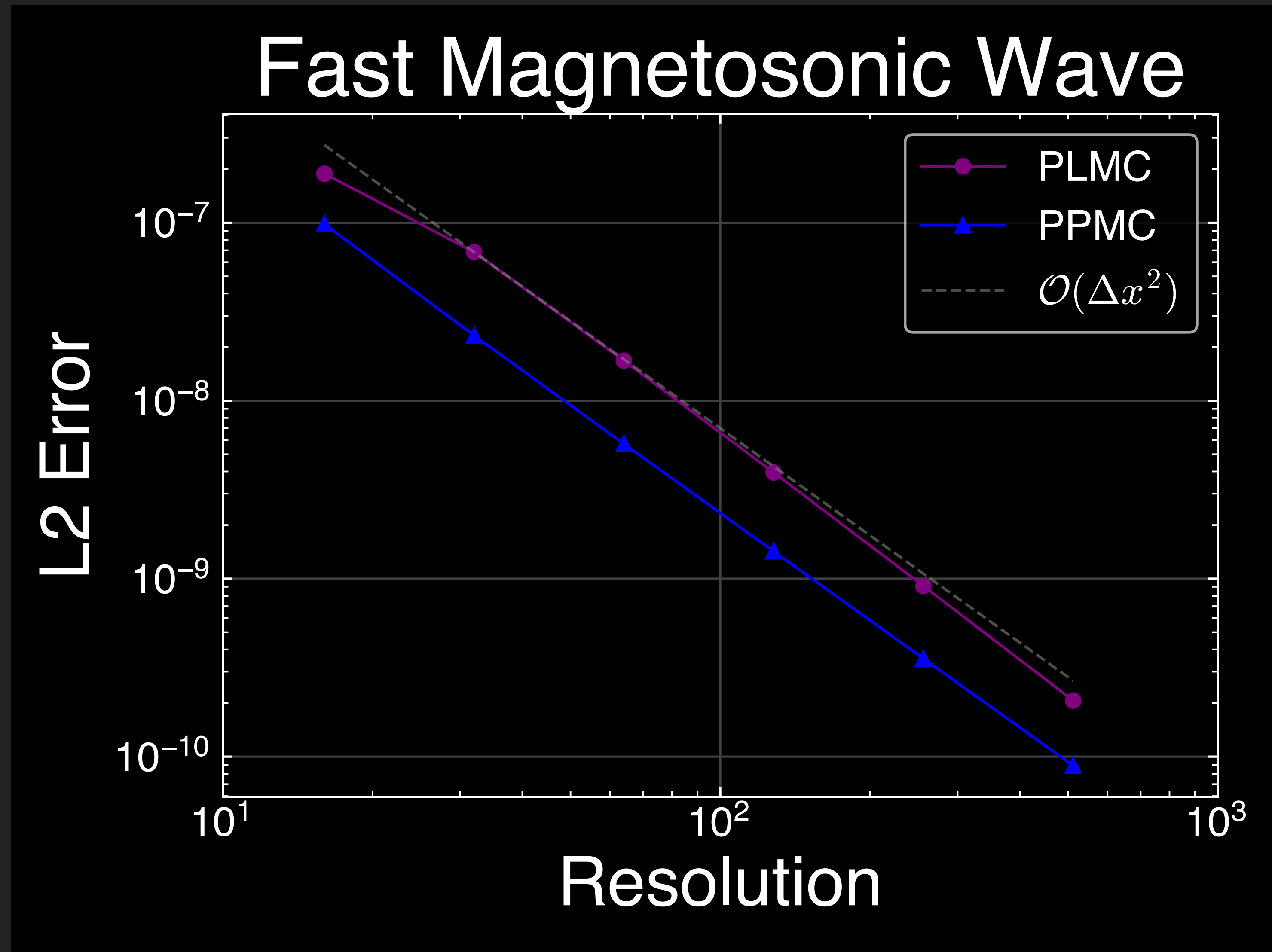


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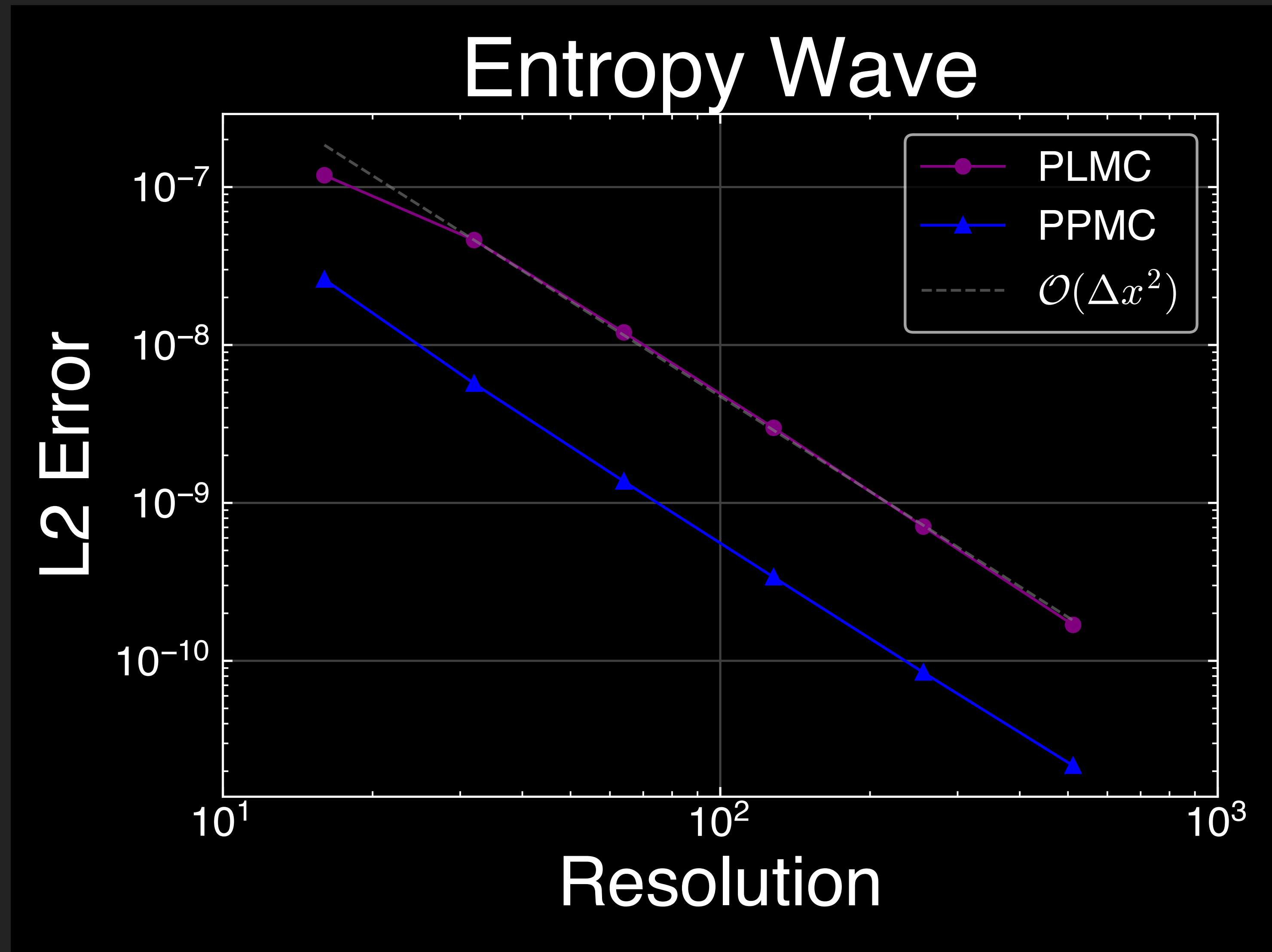
LINEAR WAVE CONVERGENCE



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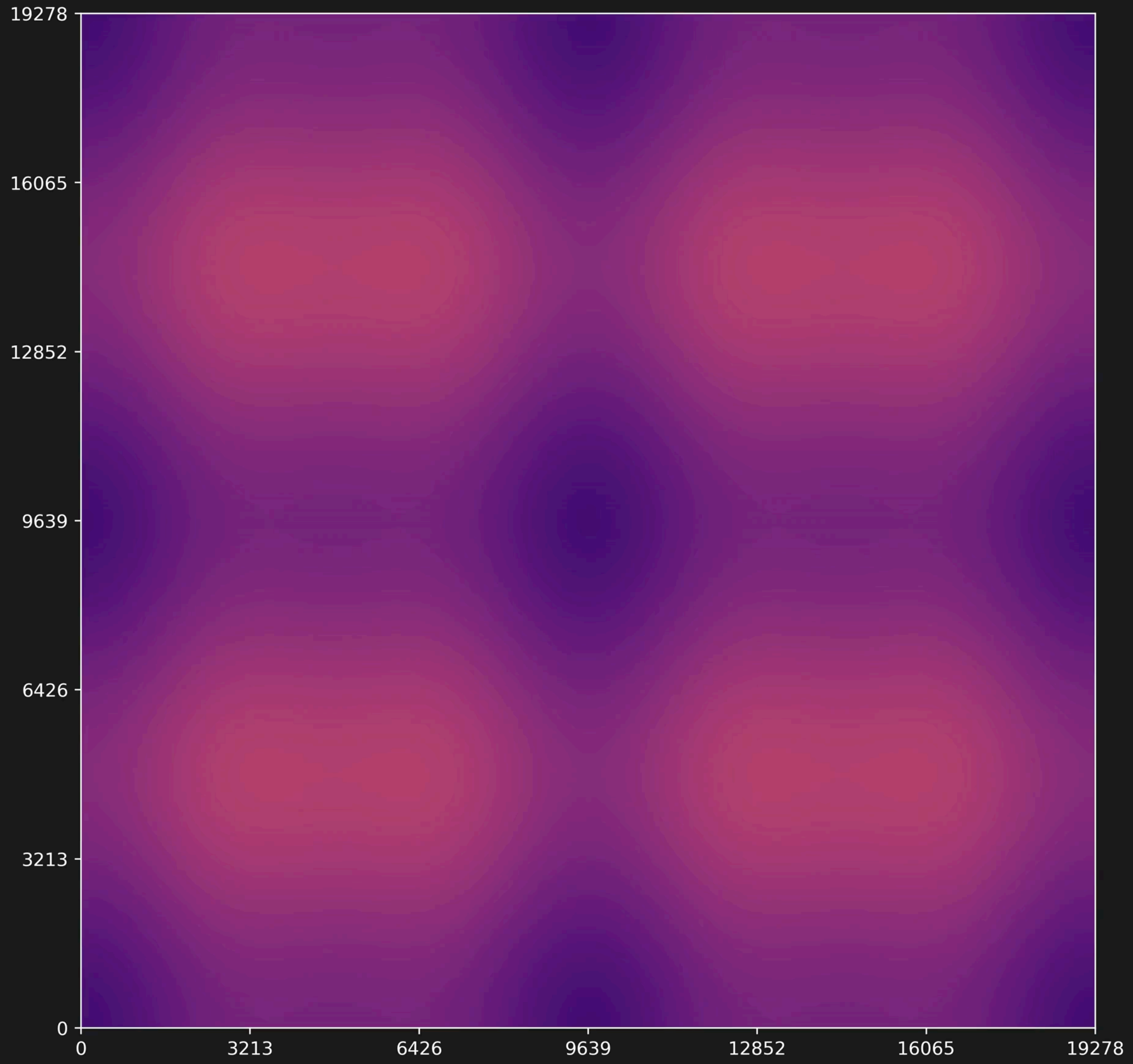


LINEAR WAVE CONVERGENCE



MHD

**ORSZAG-
TANG
VORTEX
ENERGY**

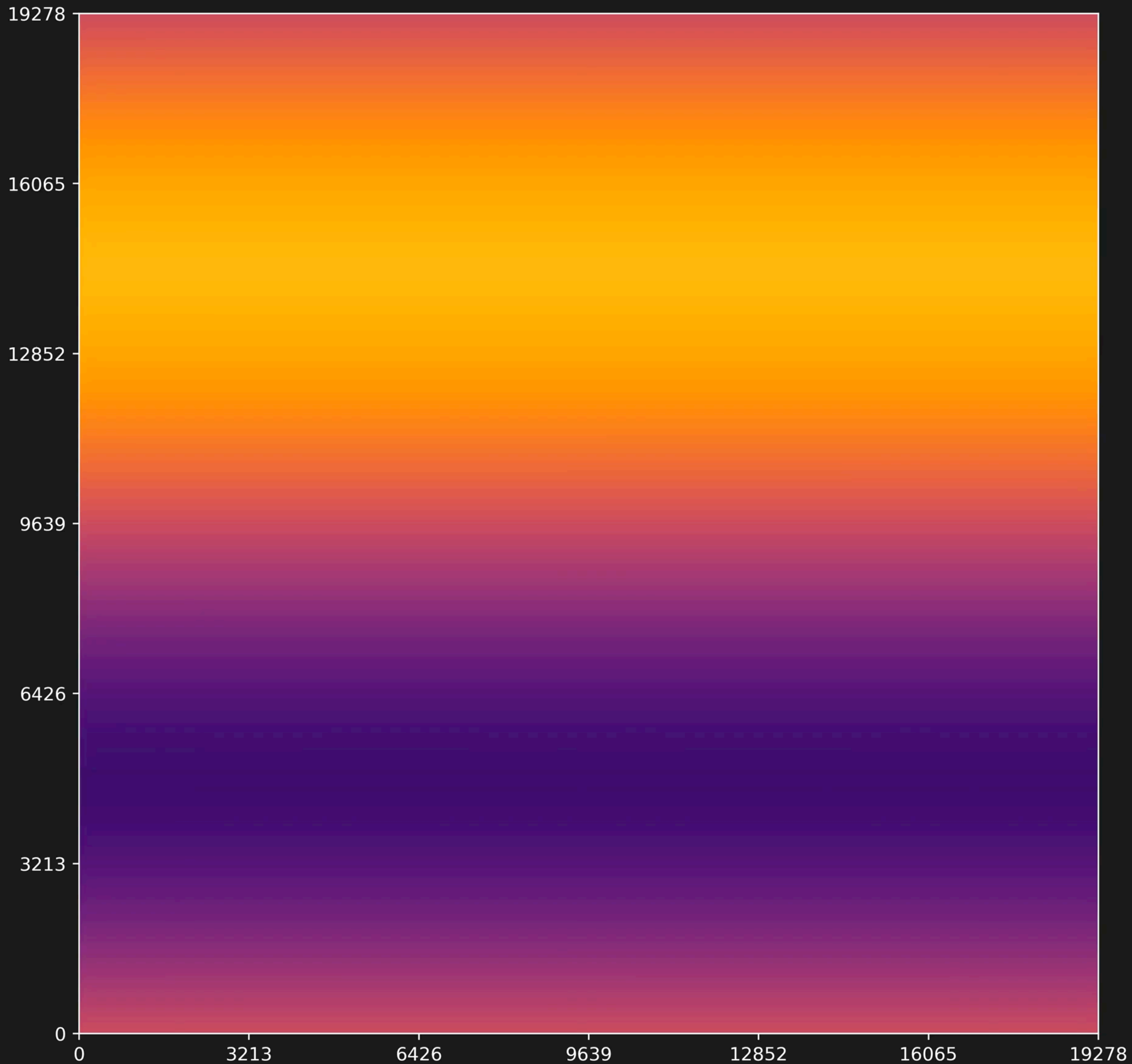


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MHD

ORSZAG- TANG VORTEX

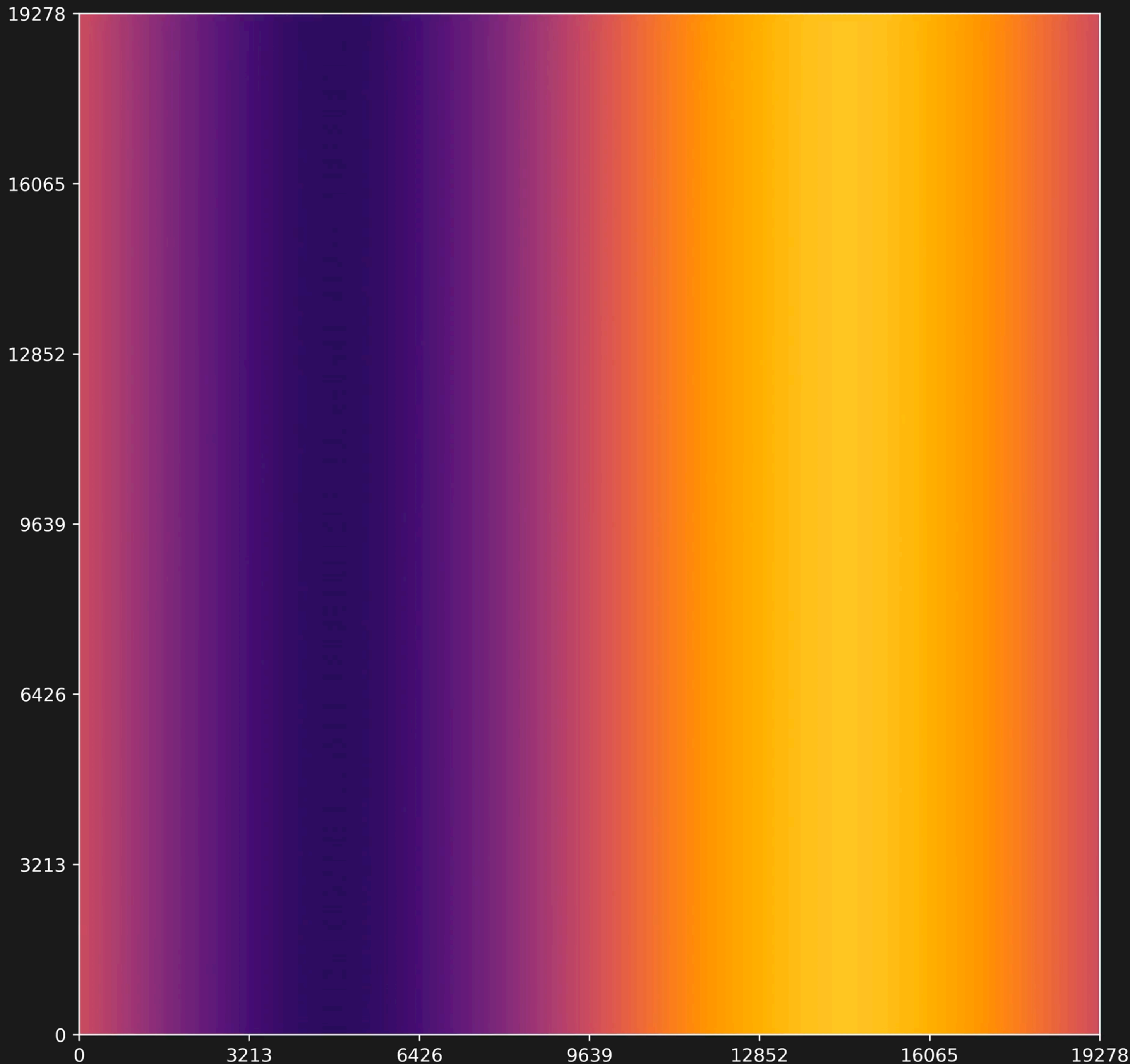
$$P_x$$



MHD

ORSZAG- TANG VORTEX

P_y

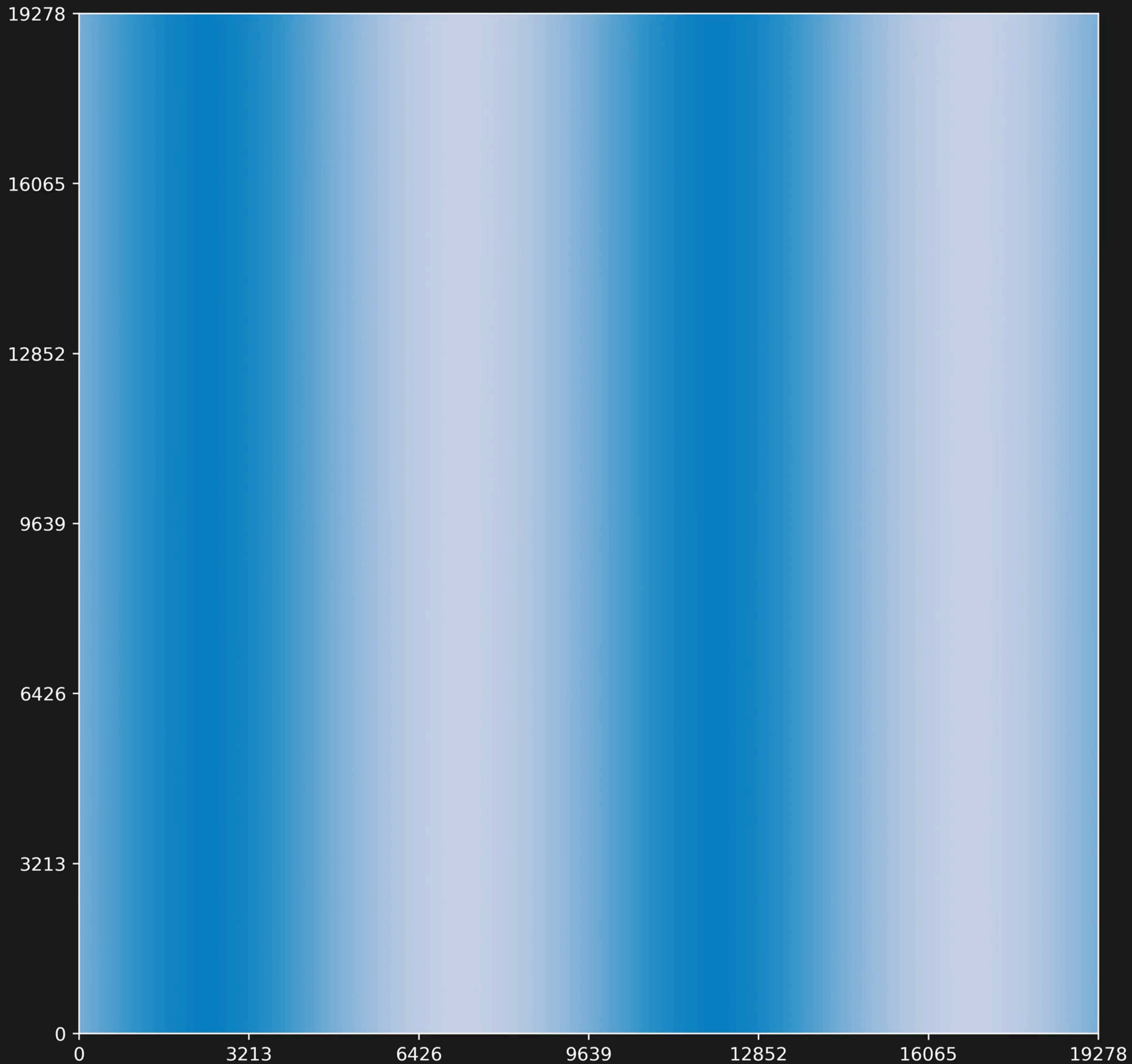


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MHD

ORSZAG- TANG VORTEX

B_y



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