Title: AsterX: a new open-source GPU-accelerated GRMHD code for dynamical spacetimes

Speakers: Liwei Ji

Collection/Series: Magnetic Fields Around Compact Objects Workshop

Subject: Strong Gravity

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Abstract:

With the ongoing transition toward exascale computing to tackle a range of open questions via numerical simulations, the development of GPU-optimized codes has become essential. In this talk, I will highlight the key features of AsterX, a novel open-source, modular, GPU-accelerated general relativistic magnetohydrodynamic (GRMHD) code for fully dynamical spacetimes in 3D Cartesian coordinates. Built for exascale applications, AsterX integrates with CarpetX, the new driver for the Einstein Toolkit, leveraging AMReX for block-structured adaptive mesh refinement (AMR). The code employs the flux-conservative Valencia formulation for GRMHD, and uses high-resolution shock capturing schemes to ensure accurate hydrodynamic modeling. Alongside discussions on the ongoing code development, I will also present the results of comprehensive 1D, 2D, and 3D GRMHD tests conducted on OLCF's Frontier supercomputer, highlighting AsterX's performance gains through subcycling in time and demonstrating its scaling efficiency across thousands of nodes.

AsterX: a new open-source GPU-accelerated GRMHD code for dynamical spacetimes

Liwei Ji
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in collaboration with
J. Kalinani, L. Ennoggi, M. Chabanov, F.G.L. Armengol, L. T. Sanches, A. Wen, B. J. Tsao, S. R. Brandt, M. Campanelli, R. Ciolfi, B. Giacomazzo, R. Haas, E. Schnetter, Y. Zlochower

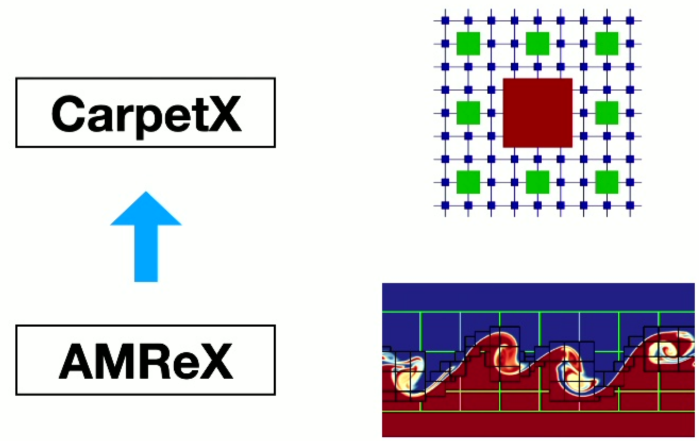
Kalinani et al. 2024, CQG 42 025016, arXiv: 2406.11669

Magnetic fields around compact objects
Perimeter Institute, Mar 26-28 2025

CarpetX: a new driver for the Einstein Toolkit

- Support for cell-centered, face-centered, edge-centered, and nodal data
- Performance portability: parallelization via MPI, OpenMP, hybrid MPI/OpenMP, hybrid MPI/(**CUDA** or **HIP/ROCm** or **SYCL**)
- Adaptive mesh refinement (patch-based)
- Efficient I/O (openPMD, Silo) or ASCII
- Public available at github

  https://github.com/EinsteinToolkit/AsterX
  https://github.com/EinsteinToolkit/CarpetX
  https://github.com/AMReX-Codes/amrex



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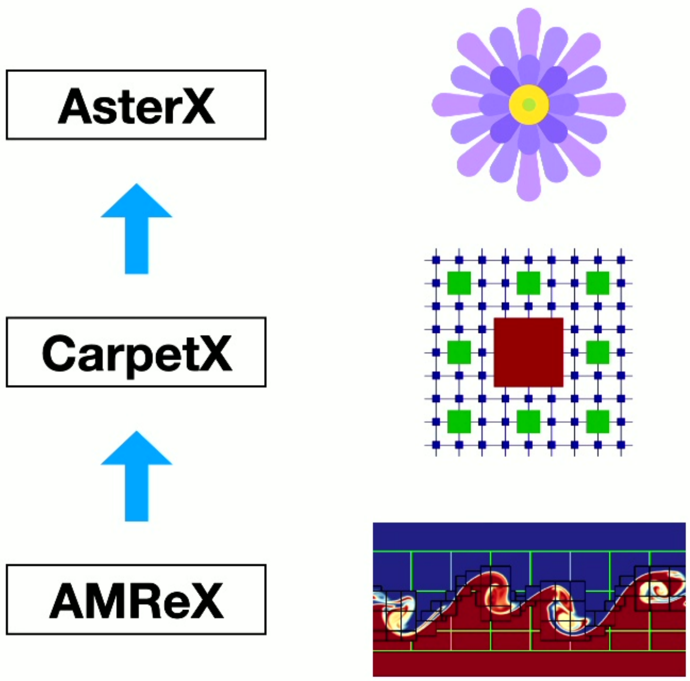

AsterX: General Relativistic MHD code

Heavily adapted from the **Spritz** code

- **ReconX** (TVD, PPM, WENO-Z, MP5)
- **Flux solvers** (LLF, HLLE)
- **Con2PrimFactory** (Noble, Palenzuela, Entropy, RePrimAnd)
- **EOSX** (Idea gas, Polytropic, Hybrid, Finite temperature tabulated)
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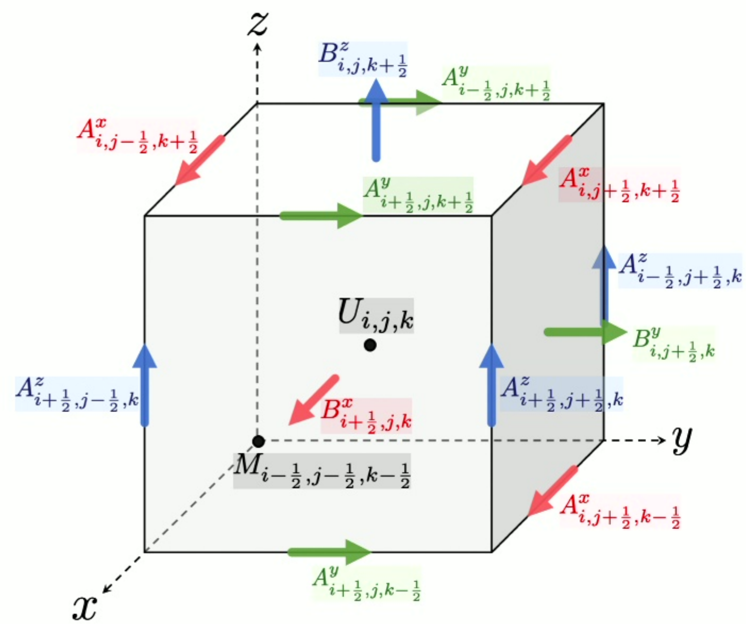
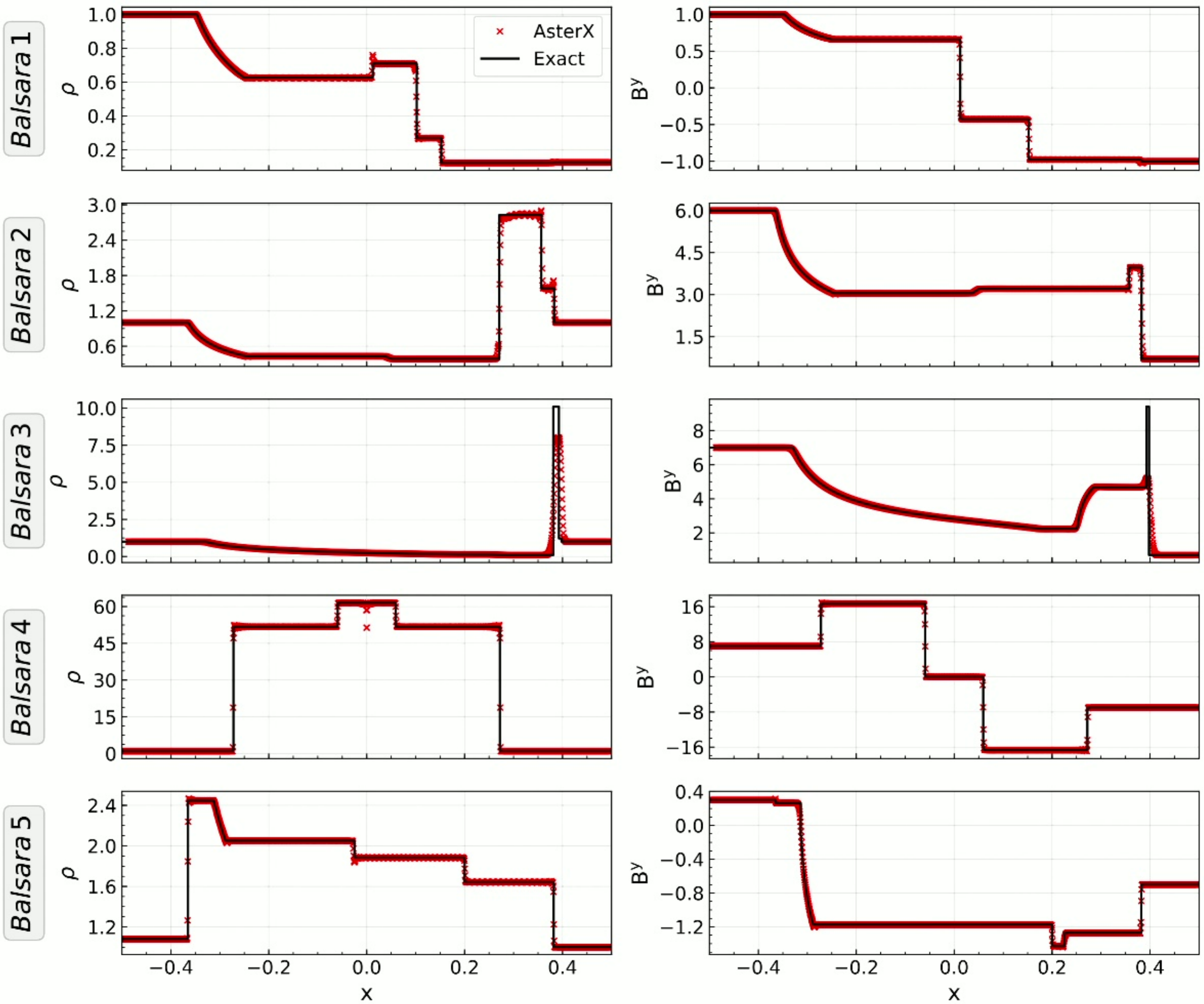
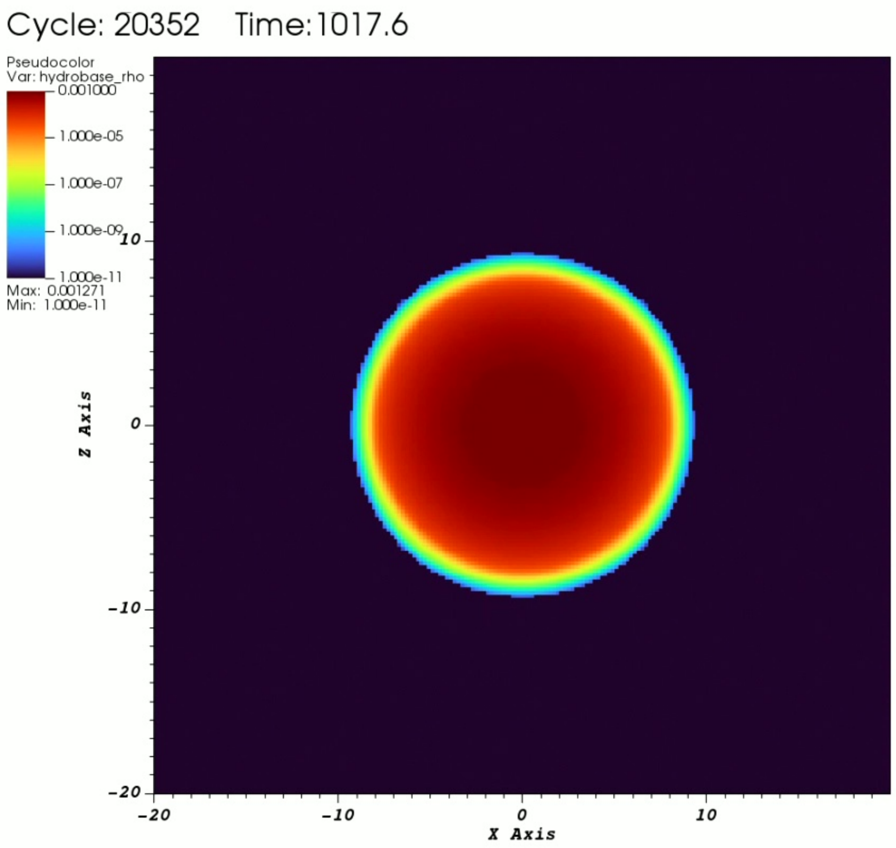
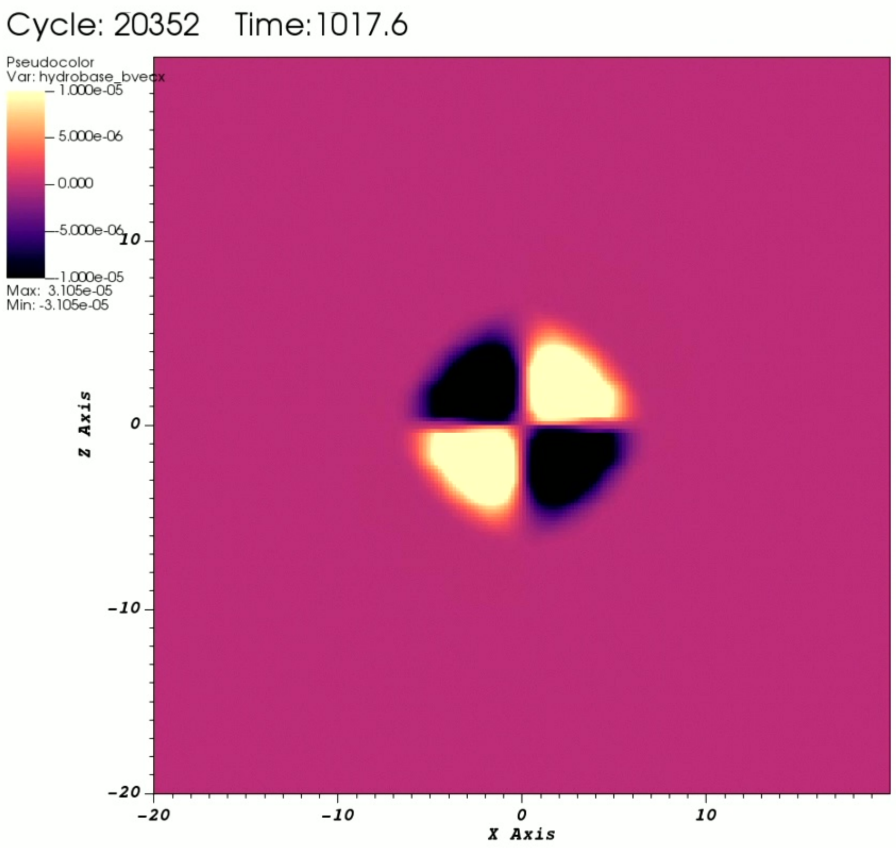


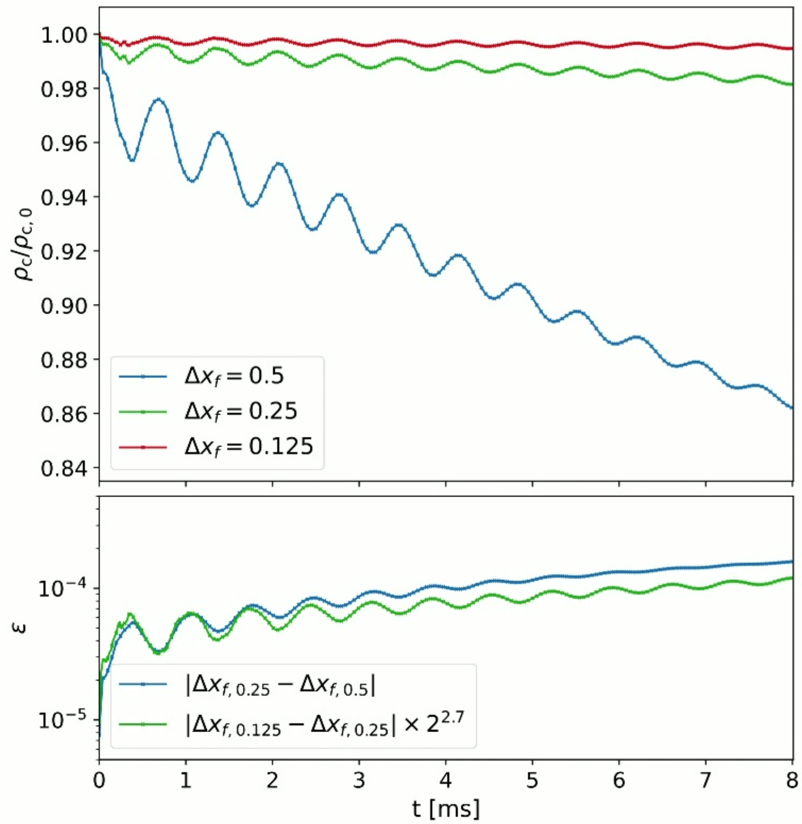

Balsara 1
Balsara 2
Balsara 3
Balsara 4
Balsara 5
AsterX
Exact
ρ
B^y
x

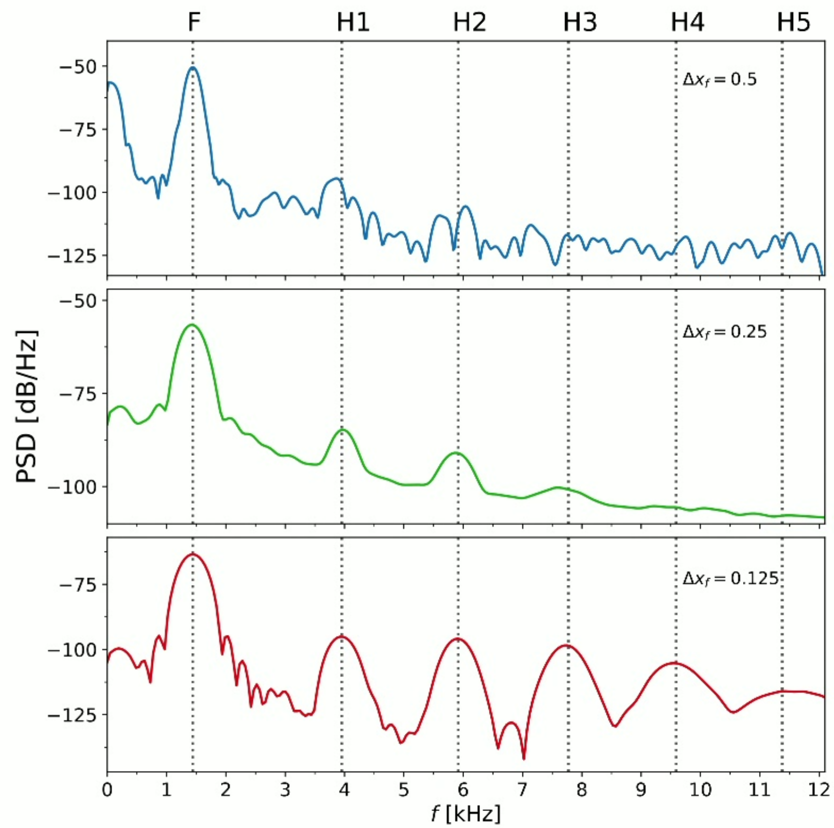
3D Magnetized TOV





3D Magnetized TOV

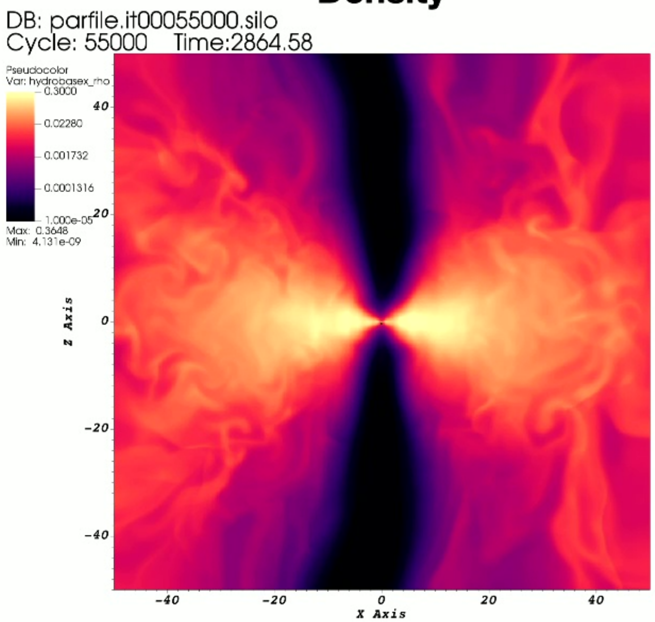




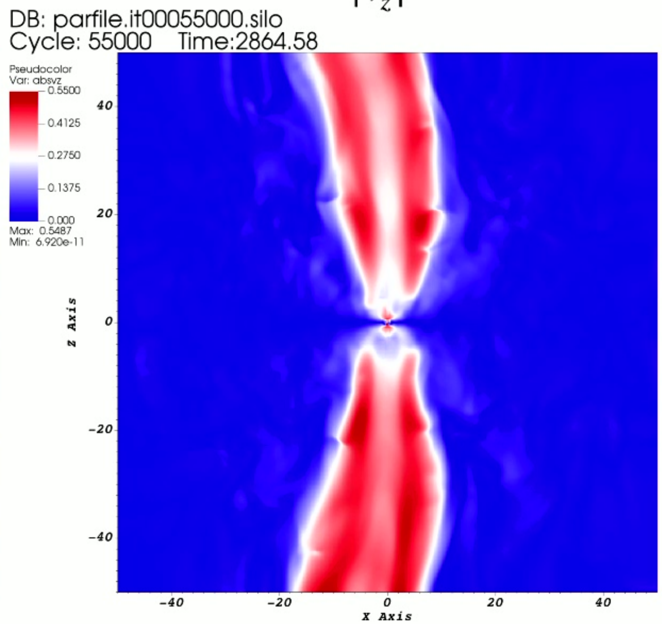
Fishbone-Moncrief disk

M. Chabanov+

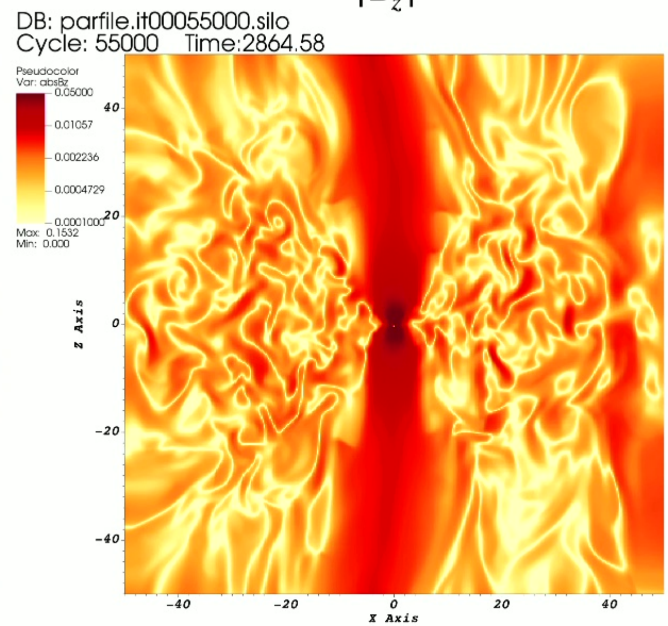
Density



$|v_z|$

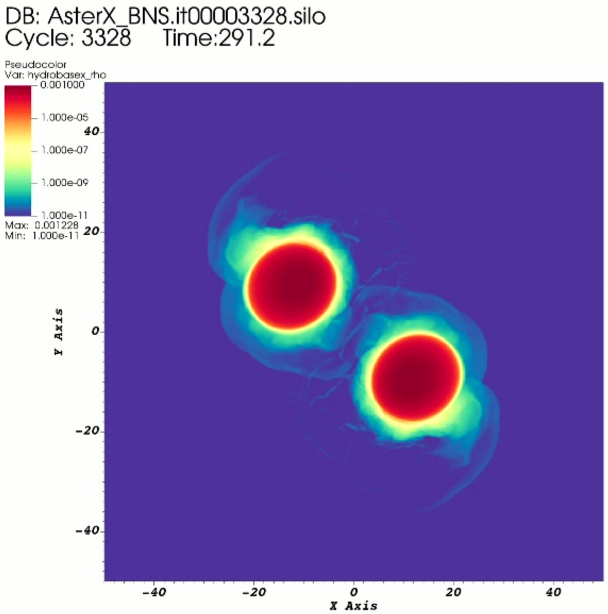


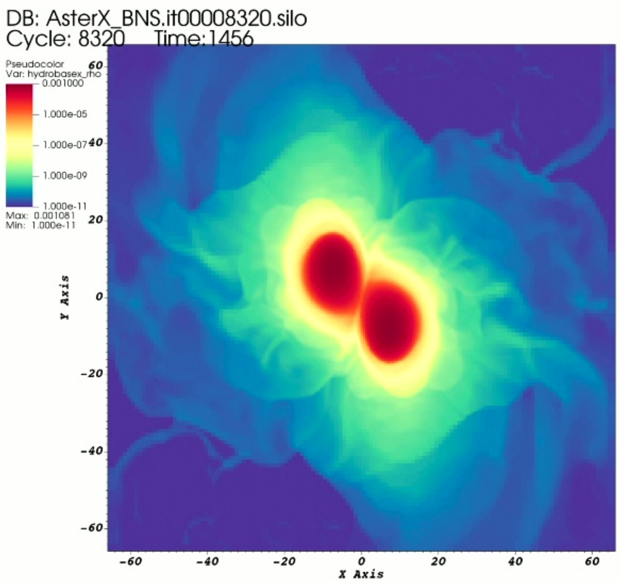
$|B_z|$

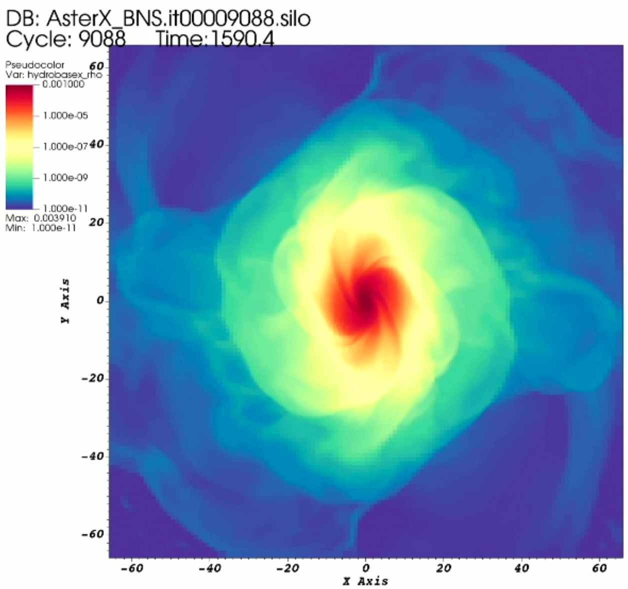


Magnetized BNS mergers: prompt collapse

FUKA Importer by Samuel Tootle

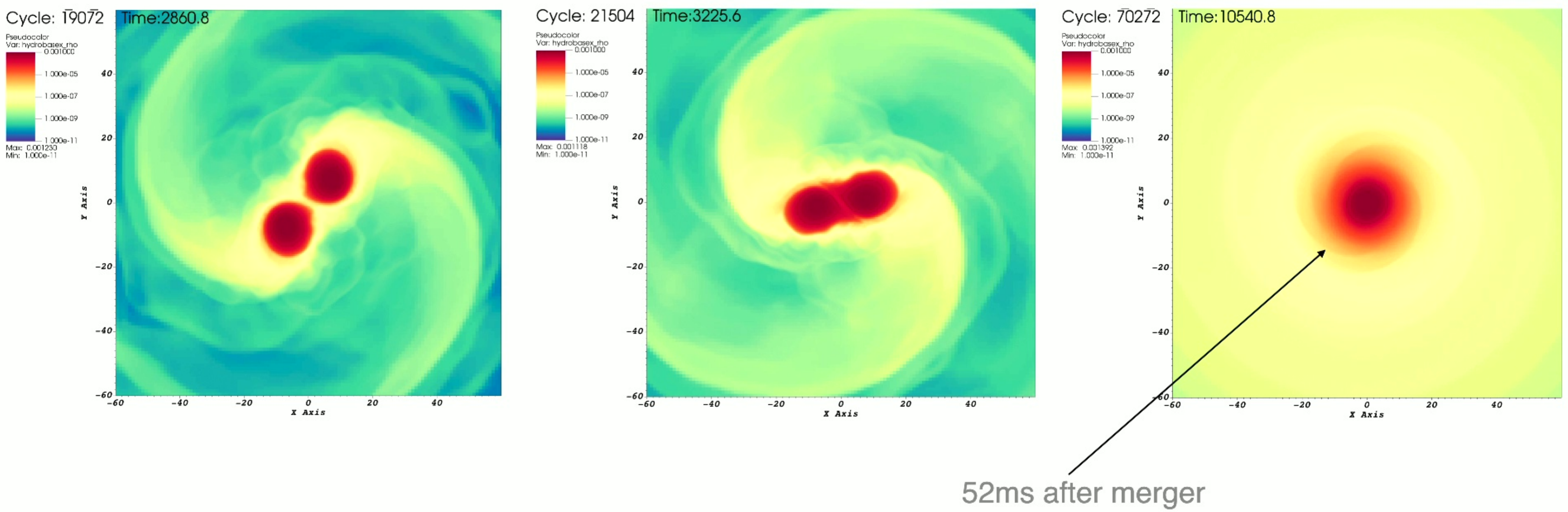






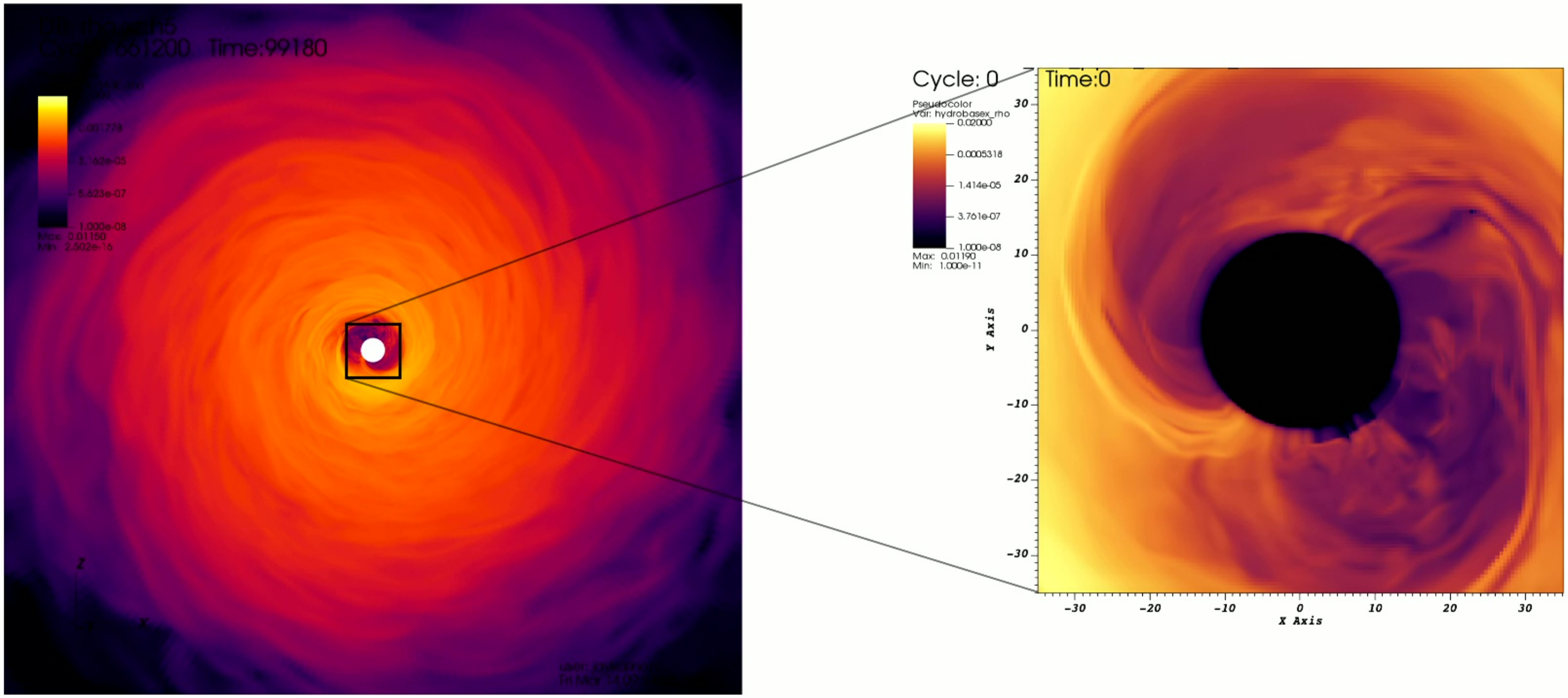
Magnetized BNS mergers: long-lived remnant

FUKA Importer by Samuel Tootle



SMBBH mergers: Hand-off from SphericalNR

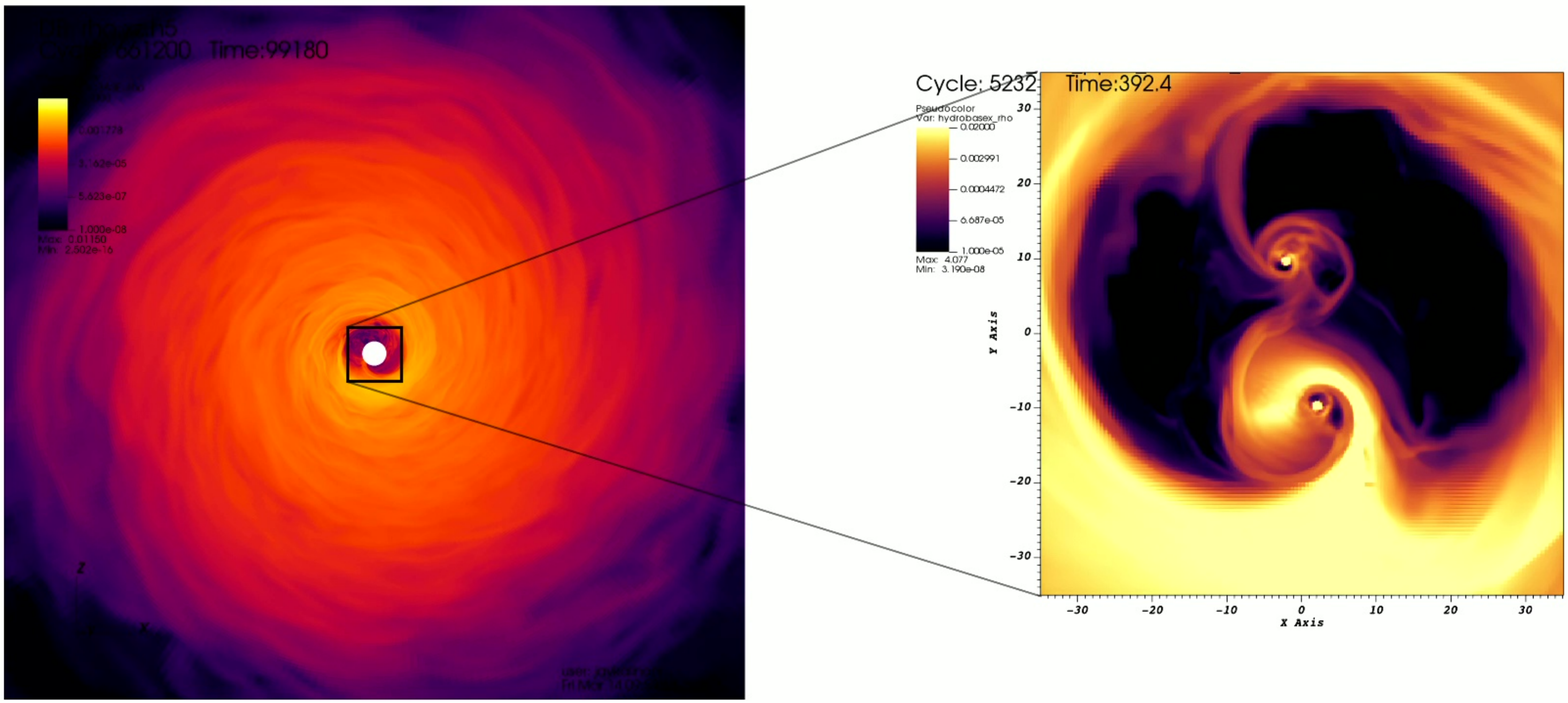
BBHDisk collab. including L. Combi, M.C. de Simone+



CBD equilibrated with SphericalNR (by L. Ennoggi) → Hand-off to AsterX → Initial data with cut-out prescription for cavity

SMBBH mergers: Hand-off from SphericalNR

BBHDisk collab. including L. Combi, M.C. de Simone+



CBD equilibrated with SphericalNR (by L. Ennoggi) → Evolution with AsterX up to ~400 M

SMBBH mergers: Hand-off from SphericalNR

BBHDisk collab. including L. Combi, M.C. de Simone+

See Lorenzo Ennoggi's & Maria Chiara de Simone's talks!

CBD equilibrated with SphericalNR (by L. Ennoggi) → Evolution with AsterX up to ~400 M

Patch-based vs. Octree-based AMR

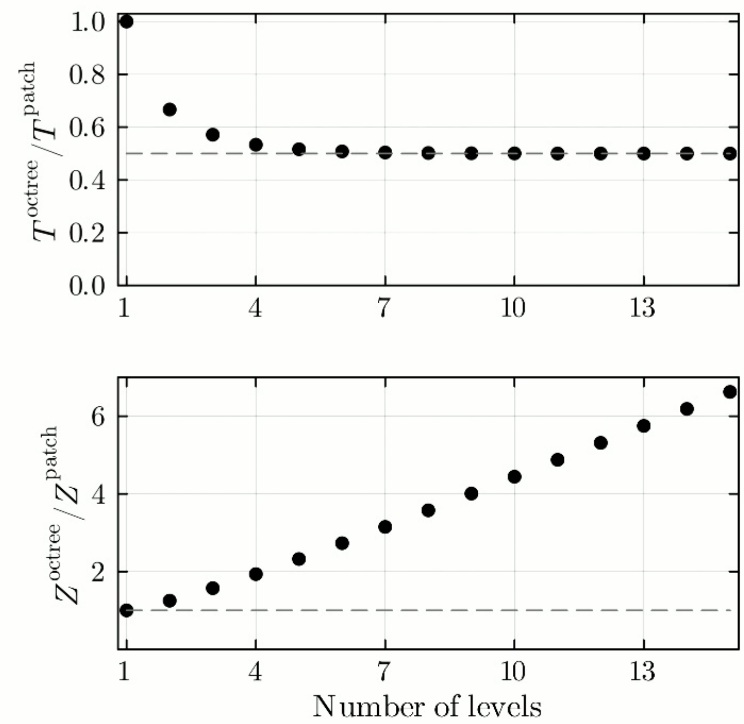
Comparison under equal grid points per level

- Walltime Comparison:

$$\frac{T^{\text{octree}}}{T^{\text{patch}}} = \frac{2^{L-1}}{2^L - 1} \to \frac{1}{2}$$

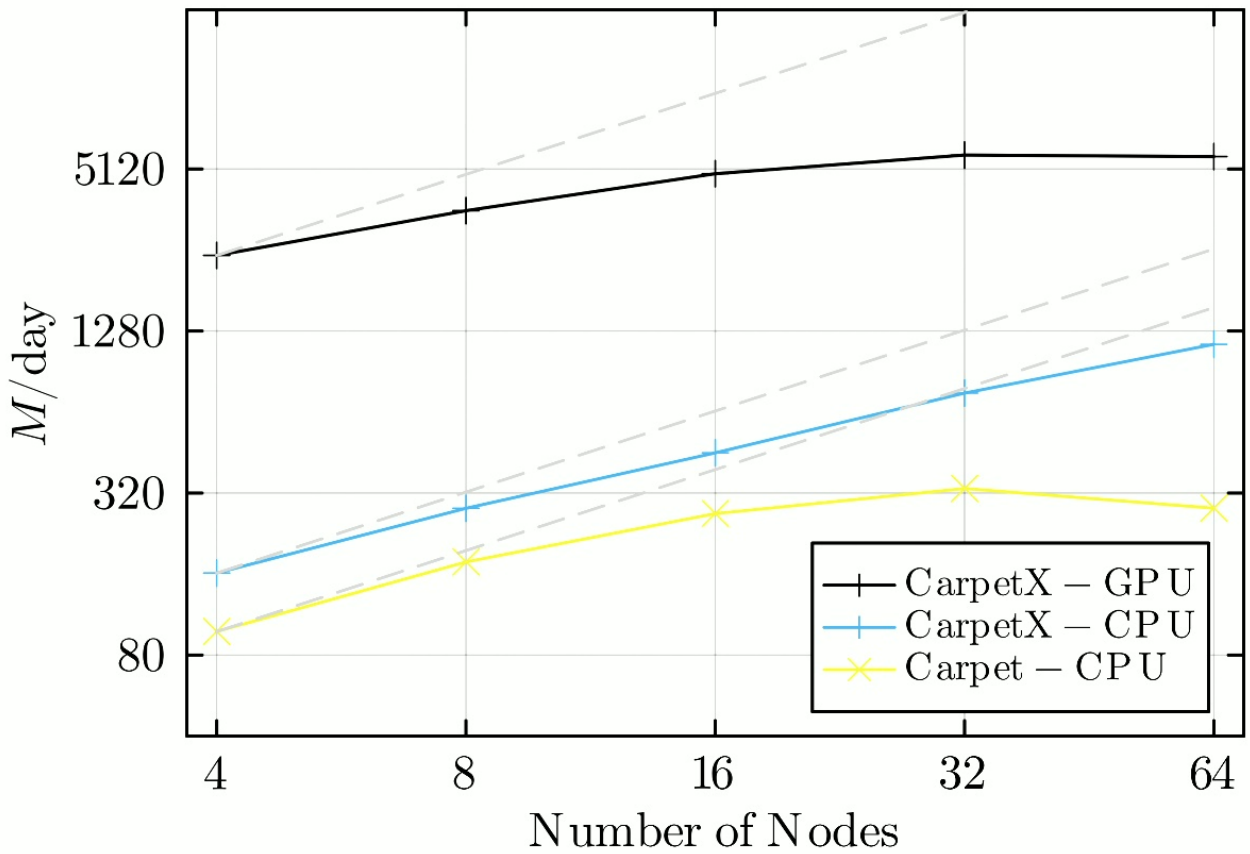
- Computational Resource Comparison:

$$\frac{Z^{\text{octree}}}{Z^{\text{patch}}} = \frac{2^{(L-4)}(1+7L)}{2^L - 1}$$



Strong scaling with subcycling

arXiv:2503.09629



Work in Progress

- Code optimization
- M1 neutrino and radiation transport
- BNS & SMBBH merger simulations

Strong scaling with subcycling

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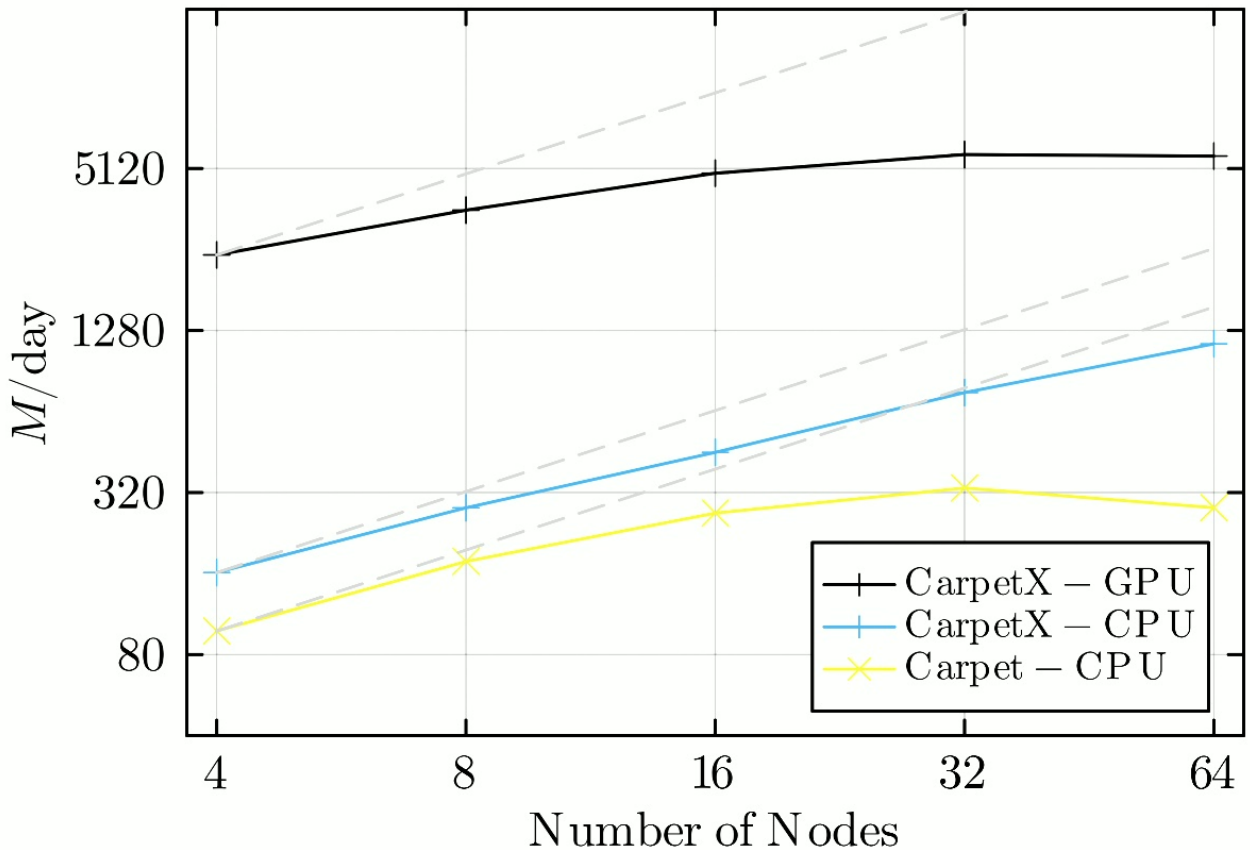

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