GR 13: Numerical Relativity

Time: Wednesday 17:30–18:30 Location: HBR 14: HS 2

GR 13.1 Wed 17:30 HBR 14: HS 2

Divergence-Free Constraint Treatment in General-Relativistic Magneto-Hydrodynamic Simulations — •Anna Neuweiler — Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476, Potsdam, Germany

Magnetic fields have a significant impact on the post-merger dynamics of binary neutron star systems, as they influence the lifetime of the remnant as well as the outflow of matter. Their inclusion in numerical relativity is however not trivial since additional equations have to be solved and constraints have to be fulfilled, in particular the divergence-free constraint. We have recently enabled our numerical-relativity code BAM to perform general relativistic magneto-hydrodynamic simulations with hyperbolic divergence-cleaning, which introduces a new variable to damp the divergence. Although this method is simpler than other schemes used in the literature, one advantage is that higher-order reconstruction schemes can be used straightforward. To evaluate the impact, we compare our results for simple tests with other codes using different divergence-free constraint treatments. Finally, we perform binary neutron star simulations and analyze the differences.

GR 13.2 Wed 17:50 HBR 14: HS 2

GR-Athena++: General-relativistic magnetohydrodynamics simulations of neutron star spacetimes — •William Cook — Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743, Jena, Germany

We present the extension of GR-Athena++ to general-relativistic magnetohydrodynamics (GRMHD) for applications to neutron star spacetimes. This couples the constrained transport implementation of Athena++ to the Z4c formulation of the Einstein equations to simulate dynamical spacetimes with GRMHD using oct-tree adaptive mesh refinement (AMR). We consider benchmark problems for isolated and binary neutron star spacetimes demonstrating stable and convergent results at relatively low resolutions and without grid symmetries imposed. The code correctly captures magnetic field instabilities in non-rotating stars with total relative violation of the divergence-free constraint of 10^{-16}. It handles evolutions with a microphysical equation of state and black hole formation in the gravitational collapse of a rapidly rotating star. For binaries, we demonstrate correctness of the evolution under the gravitational radiation reaction and show convergence of gravitational waveforms. We showcase the use of AMR to resolve the Kelvin-Helmholtz instability at the collisional interface in a merger of magnetised binary neutron stars. GR-Athena++ shows strong scaling efficiencies above 80% in excess of 10^5CPU cores and excellent weak scaling is shown up to $\sim 5 \times 10^5$ CPU cores in a realistic production setup. GR-Athena++ allows for the robust simulation of GRMHD flows in strong and dynamical gravity with exascale computers.

GR 13.3 Wed 18:10 HBR 14: HS 2

Spectrally-tuned compact finite-difference schemes with domain decomposition and applications to numerical relativity — •Boris Daszuta — Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743, Jena, Germany

Compact finite-difference (FD) schemes specify derivative approximations implicitly, thus to achieve parallelism with domain-decomposition suitable partitioning of linear systems is required. Consistent order of accuracy, dispersion, and dissipation is crucial to maintain in wave propagation problems such that deformation of the associated spectra of the discretized problems is not too severe. In this work we consider numerically tuning spectral error, at fixed formal order of accuracy to automatically devise new compact FD schemes. Grid convergence tests indicate error reduction of at least an order of magnitude over standard FD. A proposed hybrid matching-communication strategy maintains the aforementioned properties under domain-decomposition. Under evolution of linear wave-propagation problems utilizing exponential integration or explicit Runge-Kutta methods improvement is found to remain robust. A first demonstration that compact FD methods may be applied to the Z4c formulation of numerical relativity is provided where we couple our header-only, templated C++ implementation to the highly performant GR-Athena++ code. Evolving Z4c on test-bed problems shows at least an order in magnitude reduction in phase error compared to FD for propagated metric components. Stable binary-black-hole evolution utilizing compact FD together with improved convergence is also demonstrated.