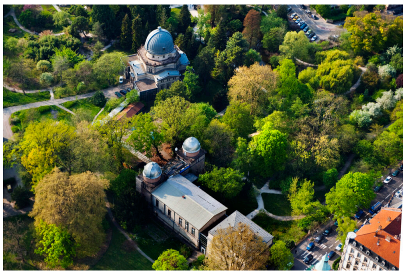

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Well-balanced central WENO Finite Differences and ADER Discontinuous Galerkin schemes for a first-order hyperbolic generalized harmonic formulation of the Einstein-Euler equations

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We present a study on the application of two high-order numerical methods for solving the first-order hyperbolic generalized harmonic (GH) formulation of the vacuum Einstein equations of general relativity, introduced in [1], coupled with the Euler equations for matter variables. More precisely, we consider the central WENO Finite Differences method on 3D Cartesian grids, and the ADER discontinuous Galerkin (DG) method on 2D unstructured polygonal meshes [2]. Both schemes are designed to be well-balanced with respect to arbitrary but a priori known equilibria. The numerical tests successfully reproduce standard vacuum test cases of numerical relativity, such as the robust stability test and the gauge wave (even at large amplitudes), as well as long-term stable evolutions of stationary black holes, including Kerr black holes with extreme spin. We validate the well-balancing property of the schemes by introducing a perturbation to the initial data and verifying that the system relaxes back to the equilibrium configuration with accuracy up to machine precision. Concerning the coupling with matter, besides performing the Michel spherical accretion test, we are able to evolve a perturbed Tolman-Oppenheimer-Volkoff (TOV) star in pure vacuum without introducing any artificial atmosphere, thanks to the filter in the conversion from the conserved to the primitive variables proposed in [3]. These results provide a solid foundation for addressing more complex and challenging simulations, including those of binary systems. References [1] L. Lindblom, M. A. Scheel, L. E. Kidder, R. Owen, and O. Rinne, "A new generalized harmonic evolution system,"Classical and Quantum Gravity, vol. 23, no. 16, S447, 2006. [2] E. Gaburro, W. Boscheri, S. Chiocchetti, C. Klingenberg, V. Springel, and M. Dumbser, "High order direct arbitrary-lagrangian-eulerian schemes on moving voronoi meshes with topology changes,"Journal of Computational Physics, vol. 407, p. 109 167, 2020. [3] M. Dumbser, O. Zanotti, E. Gaburro, and I. Peshkov, "A well-balanced discontinuous galerkin method for the first–order z4 formulation of the einstein–euler system," Journal of Computational Physics, vol. 504,p. 112 875, 2024.

Presenter: MUZZOLON, Stefano