Preface to the Second Edition

The first edition of this book was issued by 2005, with the objective of providing basic tools for beginning graduate students interested in numerical relativity research. The size of the numerical relativity community has experienced a significant increase since then, due to the scientific breakthroughs in binary black hole simulations which started precisely by autumn 2005 with the famous Pretorius work. Perhaps this has contributed to exhaust the first printed edition in a couple of years.

This second edition provides the opportunity to include important new developments that have arisen since 2005, which we detail below. It will also be the opportunity to respond to the continuing shift in the community scientific objectives, by incorporating a new chapter on relativistic hydrodynamics and magnetohydrodynamics. We have tried to keep the focus on basic tools and formalisms, with most numerical applications being able to run in a single PC. But proper reference is also made to more advanced developments, requiring much larger computational resources.

Here is the list of the main changes and additions:

- In the first edition, there was no description of any harmonic formalism whatsoever. It was justified because this approach was not a mainstream one in 3D numerical relativity applications at that time. But things changed suddenly when Pretorius result happened to be precisely in a generalized harmonic formulation. The leading groups immediately tried to follow the same way, with diverse results. Today, both BSSN and generalized harmonic formulations are first-rank options in current binary black hole simulations. This material has been added as a new section at the end of the first chapter, dealing with the structure of the field equations. The important point of the mutual relationship between the harmonic and Z4 evolution formalisms is discussed in the third chapter, in a new section dealing with covariant formulations. Moreover, it has been possible recently to match numerical results with analytical approximations (in harmonic coordinates) for black hole simulations. This is why we include also at the end of the first chapter a concise account of approximate solution methods, which were just mentioned in the first edition.

- The Z4 formalism was used for deriving by mid-2005 (when the first edition was yet in print) some convenient damping terms for the energy–momentum constraints, together with their translation into the generalized harmonic framework. These new damping terms, which were actually incorporated in Pretorius work, are properly introduced in Chap. 3. Also, the ordering constraints arising in the passage from a second-order to a first-order (in space) system deserve a enhanced discussion in Chap. 4, in particular, the ordering constraints related with the shift derivatives, which were overlooked in the first edition. They have later shown their importance in the passage from the second-order generalized harmonic formalisms to their first-order version, with the inclusion of specific damping terms.
- We have added a new chapter dealing with non-vacuum spacetimes. It starts with the scalar field case, which has been considered as a candidate for modeling dark matter. Then we follow with sections on electromagnetic fields and on relativistic hydrodynamics. This sets the basis for the magnetohydrodynamics section, where we consider the general case, even beyond the ideal MHD one. This is a deliberate choice, as we feel that new important developments will come precisely in this area, contributing to the full explanation of many puzzling astrophysical observations.
- Concerning numerical tools, finite-volume methods should be still considered, with a view on hydrodynamical simulations. In the first edition, however, an upwind-biased variant was proposed, which required using the full eigenvector decomposition. This is not the mainstream practice today, specially in MHD applications, where the expressions for the eigenvectors get really complicated. The community is rather moving toward centered flux formulae, much more cost-efficient. In the case of the spacetime evolution, where just smooth solutions are expected, some finite-differences versions of these methods can be used with a minimal computational cost, keeping most of the robustness of the original finite-volume algorithms. Numerical methods are now included in a new specific chapter. These new tools allow for long-term black hole simulations even in normal coordinates, as described in Chap. 6.

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