Research
Journal of
Physics
RJPHY

OPEN ACCESS

News & Comments

The Novel Tool of Numerical Relativity for Basic Cosmology

Fawaz Abdel Razak

Fundamental cosmology, the study of the most fundamental issues underlying the origin, structure, and evolution of our universe, has benefited greatly from the application of high-energy/particle physics methods and tools to the development of cosmological theory. Realizing that cosmic physics falls under the strong-field regime of general relativity is crucial. In particular, the fundamental cosmological problems cannot be approximated by Newtonian gravity and do not occur in the perturbative regime of flat Minkowski space. The exception is when the perturbative approach to cosmology, inspired by particle theory, operates in the strong-field regime. Tools that can handle non-perturbative, non-linear evolution inside or beyond Einstein's gravity are needed to address several unresolved topics.

The goal of the paper was to contrast numerical relativity inflation investigations and make suggestions for further research. Complex computer simulations have been a common and important technique in cosmology for many years. Computing has been crucial in assessing the efficacy of existing theoretical models considering observational data, whether the goal is to explain the CMB or structure development. The diffeomorphism invariance or gauge freedom of general relativity presents a significant computational challenge because most field equation formulations are not suitable for numerical integration. If the underlying system of differential equations can be arranged in such a way that, for given beginning conditions, there exists a single solution that continuously relies on the original conditions, the formulation is said to be "well-posed."

In the framework of particle theory and Effective Field Theory (EFT), the ADM formulation of the field equations makes sense. But for concerns that go beyond perturbation theory, particularly those that can only be answered by numerical integration of the field equations, the ADM form is inadequate. Free evolution techniques, such as those underpinning the simulations included in this paper; simply require the constraints to specify the initial data while numerically integrating the dynamic PDE system. If following suitable rescaling, the two curves computed at finer-grained resolutions lie proportionately closer to one another than the two curves corresponding to coarser-grained resolutions; the code passes the convergence test. Finally, if the unphysical truncation error happens to grow exponentially, a well-posed formulation must be combined with a powerful constraint damping system.

In this Section, recent numerical relativity investigations of two early-universe scenarios, slow contraction, and fast expansion (inflation), are addressed to show the discovery potential of numerical relativity as a tool in fundamental cosmology. Testing the dynamics' sensitivity to cosmic beginning conditions was the main goal of both kinds of experiments. The question of resilience is not covered by the typical textbook explanation for how the cosmos can be smoothed, whether through inflation or steady contraction. Recent investigations have proven the exceptional robustness of slow contraction utilizing the methods and tools of mathematical and numerical relativity. Numerous simulations were used in the analyses, each of which generated the non-linear Einstein-scalar PDE system under a different beginning condition and with a varied shape.

Recently, several non-singular bounce hypotheses and models have been put out using concepts from classical particle physics as inspiration. Numerical relativity simulations will probably be crucial in determining the validity of these hypotheses and differentiating them from one another by extracting their observational predictions.

JOURNAL REFERENCE

Ijjas A. Numerical Relativity as a New Tool for Fundamental Cosmology. Physics. 2022; 4(1):301-314.

KEYWORDS

Slow contraction, inflation, initial conditions, numerical relativity