Holographic Gravitational Waves

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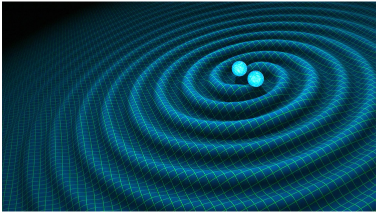
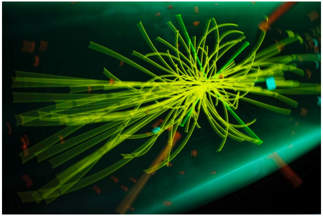
Overview

Motivation





- The detection of Gravitational Waves (GWs) offers new insights in fundamental questions.
- The early universe and the Standard Model (SM) of particle physics.
- Possible phase transitions (PTs) in the early universe could leave an imprint on the GW background, which LISA might be able to detect.
- Extensions of the SM allow these PTs (e.g. at the electroweak scale), providing the opportunity to explore particle physics with GWs.

The Setup

- Primordial PTs driven by the temperature decrease during the expansion of the universe.
- The nature of these PTs depends on the particle theory model and if they are of first-order, they proceed through the nucleation and collision of broken phase bubbles [1].
- This is a violent process capable of sourcing GWs, typically modelled through lattice simulations. Instead, study it using Holography.

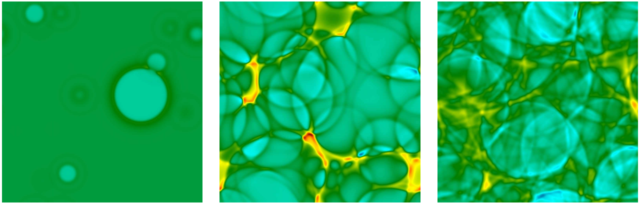


Figure: Bubble collisions (slices of fluid energy density). Picture taken from [2].

[1] P. Binétruy et al. arXiv:1201.0983, [2] M. Hindmarsh et al. arXiv:1511.04527.

Holography (AdS/CFT)

A conjectured duality between a quantum field theory (no gravity) in D-dimensions and a gravitational theory in (D+1)-dimensions and in asymptotically anti-de Sitter (AdS) space [3].

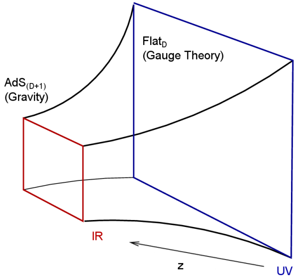


Figure: Schematic picture of the duality.

- The dynamics of a strongly coupled quantum field theory can be mapped to those of classical gravity.
- T_{mn} of the quantum field theory (boundary) $\longleftrightarrow$ $g_{\mu\nu}$ of the gravity side (bulk).
- Use Numerical Relativity (NR) techniques for the dynamical study of $g_{\mu\nu}$.

[3] J. Maldacena, Adv.Theor.Math.Phys.2:231 (1998).

Workplan

1. Model holographically systems with first-order phase transitions that reproduce possible early universe scenarios (e.g. Einstein-Maxwell-scalar theories).
2. Evolve in time the gravitational model, making use of the code of [4]:
   - Adapt the code to spherical coordinates. At the moment it is in Cartesian coordinates and used for Heavy Ion Collisions (HIC).
   - Generalize to 3+1 dimensions. This would allow for evolution of bubble collision.
3. Phenomenology: extract the corresponding GW signature for different models (SM extensions) and/or different stages of the early universe evolution.

[4] M. Attems et al. arXiv:1703.02948.

Workplan

- A 3+1 code would be useful for Quark-Gluon Plasma explorations as well.
- Currently only head-on collisions through a 2+1 code.
- 3+1 version $\rightarrow$ Non-head-on collisions (more realistic).

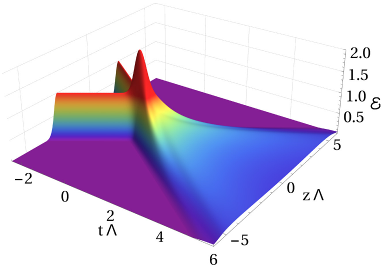


Figure: Holographic HIC. Picture taken from [5].

[5] M. Attems et al. 10.1051/epjconf/201817507030.

Summary

- Find gravitational duals for theories that allow first-order PTs in the early universe.
- Study the dynamical evolution of the gravitational models using Numerical Relativity.
- Map the results back to the 4-D boundary theory and extract the GW stochastic background.
- Possibility to consider different primordial GWs production scenarios (e.g. turbulence after bubble collision or different type of PTs). Improved modelling of HIC.

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Thank you!

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