Advancing gravitational wave predictions from cosmological first-order phase transitions

Monday 25 August 2025 - Friday 29 August 2025

CERN

Scientific Programme

Gravitational wave (GW) experiments offer a groundbreaking avenue for probing physics beyond the Standard Model (BSM). In particular, the Pulsar Timing Array collaborations reported recently significant evidence for a stochastic GW background and upcoming space-based detectors, like the Laser Interferometer Space Antenna (LISA), and next-generation ground-based detectors (Einstein Telescope and Cosmic Explorer) in the 2030s, are designed to facilitate the detection of early universe signals.
Among potential BSM sources of GWs in the early universe, first-order phase transitions (FOPTs) are particularly promising in signal amplitude and frequency window. Moreover, detecting signatures of cosmological FOPTs might offer tests of several BSM models for, e.g., baryogenesis, dark matter, and electroweak hierarchy solutions.
Since the stochastic GW background of cosmological origin is likely to be a superposition of contributions from various sources, the parameter estimation of the different underlying physical models is challenged by data analysis restrictions. For instance, in LISA, the disentanglement from instrumental noise and several astrophysical foregrounds requires highly reliable predictions for the shape and features of the GW spectrum.
The GW spectrum resulting from a FOPT depends on phase transition parameters such as the temperature, the bubble nucleation rate, the duration, and the energy released. Their detailed knowledge is therefore crucial. This involves understanding the dynamics that drive the phase transition within a specific model at microscopic scales, as well as the evolution of broken-phase bubbles at intermediate scales and their collisions at larger scales.
Although substantial progress has been made at all levels in recent years, multiple uncertainties remain unquantified and affect the predictions of the GW spectral parameters.

The workshop will cover a range of topics essential to understanding gravitational waves from first-order phase transitions. They are organized in three sessions according to the physical length scales characterizing the different processes.

Microscopic scales

We will explore the uncertainties in non-perturbative lattice simulations and perturbation theory. To analyze the convergence of perturbative methods, it is important to benchmark against non-perturbative input. Such analyses are relevant both, for understanding better the infrared behavior of the phase-transition thermodynamics, and the nucleation rate of bubbles. Additionally, the session will address the impact of higher-order corrections on the effective potential in wall speed calculations.

Intermediate scales

Understanding the bubble wall velocity is crucial for accurate predictions of gravitational wave spectra from first-order phase transitions. This session will explore the factors influencing wall velocity, including microphysical interactions between the scalar field and the surrounding plasma. Connections to electroweak baryogenesis and the dynamics of strongly coupled phase transitions will also be discussed.

Macroscopic scales

Gravitational waves are produced in different regimes – from bubble collisions to sound waves and magnetohydrodynamic turbulence. In particular, we will review the associated time scales and the parameters that determine the GW background resulting from each of these sourcing processes, and compare the efficiency of the various sources. We will also discuss scenarios where linear perturbation theory does not capture the evolution of significant velocity perturbations, and interplay between hydrodynamic simulations and analytical models. Finally, we want to discuss extreme regimes, such as transitions with high latent heat release or slow bubble nucleation rates.