### Advancing gravitational wave predictions from cosmological first-order phase transitions



# **Report of Contributions**

https://indico.cern.ch/e/1511688

Welcome & coffee

Contribution ID: 1

Type: not specified

### Welcome & coffee

Monday 25 August 2025 10:00 (30 minutes)

An effective-theory perspective o ...

Contribution ID: 2

Type: not specified

### An effective-theory perspective on bubble nucleation and growth

Monday 25 August 2025 14:15 (45 minutes)

Certain aspects of phase transition dynamics, at least the initial nucleations and subsequent growth, can be described within the framework of fluctuating hydrodynamics, extended by a scalar order parameter. A strength of this formulation is that the contributions of small and large momenta can be factorized. We describe the ideas and limitations behind this approach, and how it can be used for determining the small-gradient limit of the friction term that appears in the equation of motion of the Higgs field.

Authors: ERIKSSON, Magdalena; LAINE, Mikko Sakari (Universitaet Bern (CH))
 Presenter: LAINE, Mikko Sakari (Universitaet Bern (CH))
 Session Classification: Microscopic scales

Track Classification: Microscopic scales

Type: not specified

### Higher-order-operator corrections to phase transitions parameters in dimensional reduction

The construction of 3D EFTs for phase transition (PT) computations has been taken to unprecedented levels of precision in the recent years, considering effects up to 3-loop order. However, the contributions from higher-dimensional effective operators (EO) that arise at the same order in the power counting have been generally neglected in the literature.

In this talk, we will analyze the effect of these EO in a model resembling the Higgs sector of the SMEFT up to dimension 6, in the strong transition regime. Finally, we will highlight the challenges to overcome to extend these computations to more complex models.

**Authors:** GIL, Luis (Universidad de Granada); CHALA, Mikael (Universidad de Granada); REN, Zhe (The high-energy physics group (FTAE) of the University of Granada)

Presenter: GIL, Luis (Universidad de Granada)

Type: not specified

### The complicated story of Primordial Black Holes production in cosmological Phase Transitions

In this talk, I will investigate the formation of Primordial Black Holes as the result of the collapse of energy density fluctuations originating from supercooled first-order phase transitions. I will present the results of a simplified approach, where the energy density fluctuations are evolved within the limit of flat FRW Universe. I will show how energy density fluctuations modify the Gravitational Wave signals as the production of secondary Gravitational Waves is induced. Finally, we will discuss the full covariant formalism of cosmological perturbation and show how it impacts the production of Primordial Black Holes and Gravitational Waves.

Author: TOCZEK, Piotr (University of Warsaw)

Co-authors: Dr LEWICKI, Marek (University of Warsaw); Dr VASKONEN, Ville

Presenter: TOCZEK, Piotr (University of Warsaw)

Type: not specified

#### **Bubble wall velocity from hydrodynamics**

Terminal velocity of bubble walls in cosmological first-order phase transitions is a key parameter affecting both the primordial gravitational wave signal and baryon asymmetry production in electroweak baryogenesis. In this talk, I present recent results showing that, under local thermal equilibrium, pure hydrodynamic backreaction can lead to steady-state expansion, as confirmed by numerical simulations. However, this is not generic. Runaways are more common, as bubble walls often reach supersonic velocities before the fluid shell forms. To capture this effect, we extend analytical methods beyond local equilibrium and provide a criterion to identify physical detonations, with important consequences for cosmological observables.

**Authors:** NAŁĘCZ, Ignacy (University of Warsaw); Dr LEWICKI, Marek (University of Warsaw); ZYCH, Mateusz (University of Warsaw); KRAJEWSKI, Tomasz (Nicolaus Copernicus Astronomical Center)

Presenter: ZYCH, Mateusz (University of Warsaw)

Type: not specified

### Limits of EFTs at finite temperature for strong phase transitions

Phase transitions are violent and interesting phenomena that could have occurred in the early universe. Possible techniques to study these phenomena can be used in the presence of a hierarchy of scales, leading to the construction of finite temperature Effective Field Theories by integrating out heavier scales. These EFTs are reliable when the dynamics are mainly encoded in the most relevant operators. I will discuss the limits of such EFTs, showing how higher-dimensional operators affect the prediction of stronger transitions, including those detectable by LISA. These considerations impact the applicability of effective theory techniques, including their use in lattice studies.

**Authors:** BERNARDO, Fabio; Dr KLOSE, Philipp; Dr SCHICHO, Philipp; Dr TENKANEN, Tuomas

Presenter: BERNARDO, Fabio

Bubble wall dynamics and the ele …

Contribution ID: 8

Type: not specified

### Bubble wall dynamics and the electroweak phase transition

Wednesday 27 August 2025 09:15 (45 minutes)

The dynamics of of the electroweak phase transition has profound implications for cosmology and particle physics, and is governed by the density perturbations generated by the expanding bubble. A precise determination of this dynamics, and in particular of the bubble wall velocity, is crucial to assess the experimental signatures of the transition. In this talk, I will report on recent advances in the quantitative theoretical description of bubble dynamics, and, adopting typical benchmark models, present numerical results for the wall velocity and the profiles that describe the phase transition dynamics. A near-universal behaviour across models will emerge and be discussed.

Author: BRANCHINA, Carlo (Università della Calabria)

**Co-authors:** CONACI, Angela; DELLE ROSE, Luigi (Università della Calabria); DE CURTIS, Stefania (Universita e INFN, Firenze (IT))

Presenter: BRANCHINA, Carlo (Università della Calabria)

Session Classification: Intermediate scales

From symmetries to gravitational ····

Contribution ID: 9

Type: not specified

### From symmetries to gravitational waves: a self-consistent calculation

Wednesday 27 August 2025 11:15 (45 minutes)

Predicting the gravitational wave spectrum from symmetry breaking in the early universe during first-order phase transitions is key to understanding these symmetries. In this talk I present our recent advancements in developing a self-consistent framework for predicting such gravitational wave spectra. Our approach enhances existing calculations by providing a more comprehensive treatment of the underlying physics, from the particle physics model to the hydrodynamic evolution of bubbles and the resulting gravitational wave production. The talk will emphasize how this self-consistency refines gravitational wave predictions and explore its implications for understanding early universe cosmology.

**Authors:** TIAN, Chi (Anhui University); BALAZS, Csaba (Monash University); WANG, Xiao (Monash University)

Presenter: BALAZS, Csaba (Monash University)

Session Classification: Intermediate scales

Track Classification: Intermediate scales

Type: not specified

### Finite-temperature bubble-nucleation with shifting scale hierarchies

Focusing on supercooled PTs in models with classical scale symmetry, we investigate the limitations of derivative expansions in constructing a thermal EFT description for bubble nucleation. We show that derivative expansion for gauge field fluctuations diverges because the gauge field mass varies strongly between the high- and low-temperature phases. By computing the gauge fluctuation determinant, we show that these effects can be captured while accounting for large explicit logarithms at two loops. We show how this construction can improve nucleation rate calculations, providing a more robust framework for describing GW from supercooled PT in models like 4the SU(2)cSM.

Author: KIERKLA, Maciek

**Co-authors:** SWIEZEWSKA, Bogumila; VAN DE VIS, Jorinde (CERN); SCHICHO, Philipp (University of Geneva); TENKANEN, Tuomas

**Presenter:** KIERKLA, Maciek

Type: not specified

#### **Examples of GW from FOPT and WallGo**

Examples of GW from FOPT in BSM models and WallGo: I present three examples of BSM producing GW: one from SO(10) from the breaking chain  $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ (2506.07182), another from a first-order phase transition of the inflaton coupled to a dark sector (2412.17278) and the third one from reheating through particle production. As we know, uncertainties in the fundamental parameters affect the phase transition observables. I will present how predictions drastically change in these scenarios taking into account these uncertainties. I will present some results using WallGo and the limitations we have found using it.

Author: VELASCO-SEVILLA, Liliana (Sogang University, South Korea)

**Presenter:** VELASCO-SEVILLA, Liliana (Sogang University, South Korea)

Type: not specified

#### **GW fingerprints of inverse FOPTs**

Building upon the recently proposed concept of inverse FOPT, we investigate their GW signatures. We outline how these transitions differ thermodynamically and hydrodynamically from standard ones and analyse the resulting GW emission from the plasma.

Adopting the bag equation of state as a minimal setup, we compute self-similar fluid profiles over a range of wall velocities and transition strengths. We evaluate the GW spectrum from sound waves via the Sound Shell Model, and compare it to analytic fits.

This analysis allows us to probe whether inverse transitions produce distinguishable spectral features, assess their observability with future detectors like LISA.

**Authors:** Dr MADGE PIMENTEL, Eric (IFT-UAM/CSIC); BARNI, GIULIO; VANVLASSELAER, Miguel (VUB); Dr BLASI, Simone (DESY)

**Presenter:** BARNI, GIULIO

Decay of acoustic turbulence and …

Contribution ID: 15

Type: not specified

## Decay of acoustic turbulence and the resulting gravitational wave predictions

Thursday 28 August 2025 14:15 (45 minutes)

For a wide range of scenarios, the generation of gravitational waves (GWs) from cosmological firstorder phase transitions is believed to be dominated by sound waves. Understanding their decay through acoustic turbulence is an important factor in determining the overall intensity of the GW signal. We have simulated acoustic turbulence numerically in three dimensions to study its decay properties and apply them to estimate the resulting GW power spectrum. We find that including the decay leads to shallower power laws in the spectrum, with the predicted steep  $k^9$  power law of the non-decaying case only appearing in the slow decay limit.

Author: DAHL, Jani

**Co-authors:** WEIR, David (University of Helsinki); RUMMUKAINEN, Kari; Prof. HINDMARSH, Mark (University of Helsinki, University of Sussex)

**Presenter:** DAHL, Jani

Session Classification: Macroscopic scales

Track Classification: Macroscopic scales

Thermal nucleation in perturbati ...

Contribution ID: 16

Type: not specified

#### Thermal nucleation in perturbation theory

Monday 25 August 2025 13:30 (45 minutes)

Cosmological first-order phase transitions may have generated an observable gravitational wave background, providing a unique window into physics beyond the Standard Model. A crucial step in predicting this background is the reliable computation of bubble nucleation rates. In this talk, I will discuss how techniques, such as effective field theories, Boltzmann equations and real-time simulations, enhance our understanding of perturbative nucleation rate computations in hightemperature quantum field theories, leading to more robust predictions. I will also highlight remaining challenges in perturbative methods, outlining directions for future progress in this field.

Author: HIRVONEN, Joonas (University of Nottingham)Presenter: HIRVONEN, Joonas (University of Nottingham)Session Classification: Microscopic scales

Track Classification: Microscopic scales

Advancing grav ··· / Report of Contributions

From equations of state to gravit ...

Contribution ID: 17

Type: not specified

#### From equations of state to gravitational wave spectra

The Sound Shell Model provides a computationally efficient way of calculating the gravitational wave spectra of cosmological first-order phase transitions. Based on the Sound Shell Model, we have created the simulation framework PTtools and integrated it with our web-based plotting utility PTPlot.

In this talk I will show how to use PTtools and PTPlot to easily compute Sound Shell Model power spectra for arbitrary equations of state. This is crucial to improving the quality of predictions of stochastic backgrounds of gravitational waves from phase transitions, including equations of state beyond the bag model with temperature- and phase-dependent sound speeds.

Author: Mr MÄKI, Mika

**Co-authors:** WEIR, David (University of Helsinki); Prof. HINDMARSH, Mark (University of Helsinki, University of Sussex)

Presenter: Mr MÄKI, Mika

Type: not specified

# **Exploring Parameter Dependence in the Double-Broken Power Law for GW Signals**

The gravitational wave spectrum from sound wave contributions is typically modeled as a doublebroken power law with fixed spectral slopes. However, the intermediate slope depends on phase transition parameters, which can help resolve degeneracies when reconstructing these parameters. To improve gravitational wave predictions, we provide an analytic form of this parameter dependence, derived via approximations or numerical fits, based on the sound shell model.

Author: Dr MADGE PIMENTEL, Eric (IFT-UAM/CSIC)
Presenter: Dr MADGE PIMENTEL, Eric (IFT-UAM/CSIC)

TBA

Contribution ID: 19

Type: not specified

#### TBA

Monday 25 August 2025 10:30 (45 minutes)

**Presenter:** SWIEZEWSKA, Bogumila (University of Warsaw) **Session Classification:** Microscopic scales

TBA

Contribution ID: 20

Type: not specified

#### TBA

Monday 25 August 2025 11:15 (45 minutes)

**Presenter:** KORMU, Anna

Session Classification: Microscopic scales

TBA

Contribution ID: 21

Type: not specified

#### TBA

Friday 29 August 2025 09:15 (45 minutes)

**Presenter:** JINNO, Ryusuke (Kobe University) **Session Classification:** Macroscopic scales

TBA

Contribution ID: 22

Type: not specified

#### TBA

*Tuesday 26 August 2025 10:30 (45 minutes)* 

**Presenter:** LAURENT, Benoit (CEA / DAM Ile de France (FR)) **Session Classification:** Intermediate scales

TBA

Contribution ID: 23

Type: not specified

#### TBA

Tuesday 26 August 2025 11:15 (45 minutes)

**Presenter:** AI, Wen-Yuan

Session Classification: Intermediate scales

TBA

Contribution ID: 24

Type: not specified

#### TBA

*Tuesday 26 August 2025 13:30 (45 minutes)* 

**Presenter:** Mr DASHKO, Andrii (DESY Theory) **Session Classification:** Intermediate scales

TBA

Contribution ID: 25

Type: not specified

#### TBA

Tuesday 26 August 2025 14:15 (45 minutes)

**Presenter:** LONG, Andrew (Rice University) **Session Classification:** Intermediate scales

TBA

Contribution ID: 26

Type: not specified

#### TBA

Wednesday 27 August 2025 10:30 (45 minutes)

**Presenter:** Dr LEWICKI, Marek (University of Warsaw) **Session Classification:** Intermediate scales

Theory colloquium

Contribution ID: 27

Type: not specified

### Theory colloquium

Wednesday 27 August 2025 13:30 (1h 30m)

**Presenter:** RUMMUKAINEN, Kari

Session Classification: Special contribution

TBA

Contribution ID: 28

Type: not specified

#### TBA

Thursday 28 August 2025 09:15 (45 minutes)

**Presenter:** KONSTANDIN, Thomas

Session Classification: Macroscopic scales

TBA

Contribution ID: 29

Type: not specified

#### TBA

Thursday 28 August 2025 10:30 (45 minutes)

**Presenter:** KAKHNIASHVILI, Tinatin

Session Classification: Macroscopic scales

TBA

Contribution ID: 30

Type: not specified

#### TBA

Thursday 28 August 2025 11:15 (45 minutes)

**Presenter:** MIDIRI, Antonino Salvino (Universite de Geneve (CH)) **Session Classification:** Macroscopic scales

TBA

Contribution ID: 31

Type: not specified

#### TBA

*Tuesday 26 August 2025 09:15 (45 minutes)* 

**Presenter:** Dr JUNG, Taehyun (Institute for Basic Science) **Session Classification:** Microscopic scales

TBA

Contribution ID: 32

Type: not specified

#### TBA

Thursday 28 August 2025 13:30 (45 minutes)

**Presenter:** GIOMBI, Lorenzo (University of Helsinki) **Session Classification:** Macroscopic scales

TBA

Contribution ID: 33

Type: not specified

#### TBA

Friday 29 August 2025 10:30 (45 minutes)

**Presenter:**Prof. HINDMARSH, Mark (University of Helsinki, University of Sussex)**Session Classification:**Special contribution

Type: not specified

### Gravitational wave production: the interplay between vortical and compressional motions

In the early Universe, during a phase transition, the surrounding plasma is subjected to a fluid motion sourcing gravitational waves. This fluid motion can be composed of compressional and vortical motions. Most of the time, they are considered distinct and studied independently. However, by analyzing the UETC of the anisotropic stresses, a mixed term combining vortical and compressional motions leads to another contribution to gravitational wave production. In this presentation, the interplay between the two motions will be at the heart of the discussion.

Author: SALOME, Madeline Clara (Universite de Geneve (CH))

Presenter: SALOME, Madeline Clara (Universite de Geneve (CH))