What the heck happens when the Universe boils?

Report of Contributions

https://indico.ipmu.jp/e/boilinguniverse

Contribution ID: **1** Type: **not specified**

Jyotirmoy Roy (University of Toronto)

Monday, 5 December 2022 10:00 (1 hour)

Contribution ID: **2** Type: **not specified**

EFT framework for (precision) cosmological phase transition thermodynamics

Monday, 5 December 2022 11:00 (1 hour)

Gauge theories at finite temperature exhibit a rigorous scale hierarchy and their bosonic sector is rendered non-perturbative in the infrared. To reliably describe the thermodynamics of a hot electroweak phase transition both perturbative and non-perturbative methods are needed. At the intersection between these methods, one can construct a three-dimensional effective theory (3d EFT) that systematically includes thermal resummations to all orders. Focusing on generic scalar extensions beyond the Standard Model, I determine their 3d EFT and the corresponding effective potential using the in-house software package DRalgo [1]. Finally, I present a minimal approach [2] that reconciles both gauge invariance and thermal resummation for computing thermodynamics of cosmological first-order phase transitions.

[1] A. Ekstedt, P. Schicho, and T. V. I. Tenkanen, DRalgo: a package for effective field theory approach for thermal phase transitions, [2205.08815]
[2] P. Schicho, T. V. I. Tenkanen, and G. White, Combining thermal resummation and gauge invariance for electroweak phase transition, [2203.04284]

Presenter: PHILIPP SCHICHO (Goethe, Frankfurt)

Contribution ID: **3** Type: **not specified**

Renormalization group improvement for thermally resummed effective potential

Monday, 5 December 2022 15:00 (1 hour)

Effective potential is a standard tool to analyze thermal phase transitions. It is known that perturbative expansion at zero temperature breaks down at high temperature due to infrared divergence. To cure this problem, thermal resummation is indispensable. However, the renormalization group (RG) invariance that is present at zero temperature is lost by such a thermal resummation. In this talk, I will begin by showing the RG non-invariance of resummed effective potential in phi-4 theory up to the 2-loop order, and then propose a scheme in which RG invariance holds order by order in resummed perturbation theory. As an example of first-order phase transition, we consider an extension of the phi-4 theory. Our numerical analysis shows that renormalization scale dependences in our scheme could get milder significantly than those in the MS-bar scheme at 1-loop level, while at the 2-loop level the difference between the two schemes are less pronounced as long as couplings are moderate in magnitude.

Presenter: EIBUN SENAHA (Van Lang University)

Contribution ID: **4** Type: **not specified**

Discussion: Thermal field theory, Tuomas Tenkanen (Nordita and T.D. Lee institute)

Monday, 5 December 2022 16:00 (1 hour)

Contribution ID: **5** Type: **not specified**

Electroweak Bubble Wall Velocity

Tuesday, 6 December 2022 10:00 (1 hour)

It is important to understand the dynamics of Higgs-field bubbles during a cosmological phase transition, as they directly affect the production of various cosmological relics including the matter-antimatter asymmetry, topological defects, primordial magnetic fields, and especially a stochastic background of gravitational wave radiation. In this talk, I will present a recent work where we analyze Higgs condensate bubble expansion during a first-order electroweak phase transition in the early Universe. The interaction of particles with the bubble wall can be accompanied by the emission of multiple soft gauge bosons. When computed at fixed order in perturbation theory, this process exhibits large logarithmic enhancements which must be resummed to all orders when the wall velocity is large. We perform this resummation both analytically and numerically at leading logarithmic accuracy. The numerical simulation is achieved by means of a particle shower in the broken phase of the electroweak theory. The two approaches agree to the 10% level. For fast-moving walls, we find the scaling of the thermal pressure exerted against the wall to be P ~ γ^2T^4, independent of the particle masses, implying a significantly slower terminal velocity than previously suggested, which is especially impactful for the prediction of gravitational wave radiations.

Presenter: Dr YIKUN WANG (Caltech)

Contribution ID: **6** Type: **not specified**

Bubble wall velocities in local thermal equilibrium

Tuesday, 6 December 2022 11:00 (1 hour)

The bubble wall velocity in first-order cosmological phase transitions is crucial for phenomenological studies of, for example, the production of stochastic gravitational waves and electroweak baryogenesis. It is commonly expected that a friction force on the bubble wall can only arise from out-of-equilibrium effects. In this talk, I will discuss the bubble wall motion in local thermal equilibrium. We show that there is a nonvanishing effective friction even in local thermal equilibrium provided that the plasma temperature distribution is inhomogeneous. Further, we propose a new matching condition from local entropy conservation. With this, we are able to determine the bubble velocities in local thermal equilibrium algebraically (with some approximations).

Presenter: WEN YUAN AI (Kings College London)

Contribution ID: **7** Type: **not specified**

First principles determination of bubble wall velocity

Tuesday, 6 December 2022 13:00 (1 hour)

Presenter: BENOIT LAURENT (McGill)

Contribution ID: **8** Type: **not specified**

Baryogenesis via relativistic bubble walls

Tuesday, 6 December 2022 14:00 (1 hour)

We present a novel mechanism which leads to the baryon asymmetry generation during the strong first order phase transition. If the bubble wall propagates with ultra-relativistic velocities, it has been shown that it can produce states much heavier than the scale of the transition and that those states are then out-of-equilibrium. In this paper, we show that the production mechanism can also induce CP-violation at one-loop level. We calculate those CP violating effects during the heavy particle production and show, that combined with baryon number violating interactions, those can lead to successful baryogenesis. Two models based on this mechanism are constructed and their phenomenology is discussed. Stochastic gravitational wave signals turn out to be generic signatures of this type of models.

Presenter: Dr MIGUEL VANVLASSELAER (SISSA)

Contribution ID: **9** Type: **not specified**

Ultra-relativistic bubbles from the simplest Higgs portal and their cosmological consequences

Tuesday, 6 December 2022 15:00 (1 hour)

We analyze the phase transitions in the minimal extension of the SM with a real singlet scalar field. The novelty of our study is that we identify and analyze in details the region of parameter space where the first order phase transition can occur and in particular when the bubbles with true vacuum can reach relativistic velocities. This region is interesting since it can lead to the new recently discussed baryogenesis and Dark Matter production mechanisms. We fully analyze different models for the production of Dark Matter and baryogenesis as well as the possibilities of discovery at the current and future experiments.

Presenter: Mr GIULO BARNI (SISSA)

Contribution ID: **10** Type: **not specified**

Discussion: bubble wall velocity, Yikun Wang (Caltech)

Tuesday, 6 December 2022 16:00 (1 hour)

Contribution ID: **11** Type: **not specified**

Primordial black hole formation by bubble collisions

Wednesday, 7 December 2022 10:00 (1 hour)

In this talk, I will show that primordial black holes can be formed by bubble collisions if colliding bubbles are super-horizon-sized and not run-away. The PBH abundance can be estimated by counting the number of such collisions of large bubbles for a given first-order phase transition. As a quick example, we use an effective parameters of first-order phase transitions and show that various PBH searches already rule out a part of the reasonable parameter space. In addition, some other choice of parameters can result in PBHs to be the whole dark matter.

Presenter: Dr TAE HYUN JUNG (Korea Institute For Advanced Study)

Contribution ID: **12** Type: **not specified**

Superheavy Dark Matter Production from Symmetry Restoration First-Order Phase Transition During Inflation

Wednesday, 7 December 2022 11:00 (1 hour)

We propose a scenario where superheavy dark matter (DM) can be produced via symmetry restoration first-order phase transition during inflation triggered by the evolution of the inflaton field. The phase transition happens in a spectator sector coupled to the inflaton field. During the phase transition, the spectator field tunnels from a symmetry-broken vacuum to a symmetry-restored vacuum. The massive particles produced after bubble collisions are protected against decaying by the restored symmetry and may serve as a DM candidate in the later evolution of the Universe. We show that the latent heat released during the phase transition can be sufficient to produce the DM relic abundance observed today. In addition, accompanied with the super heavy DM, this first-order phase transition also produces gravitational waves detectable via future gravitational wave detectors.

Presenter: Dr ZHOU, Siyi (Kobe University)

Contribution ID: **13** Type: **not specified**

The role of impurities in first order phase transitions

Wednesday, 7 December 2022 12:00 (1 hour)

First order phase transitions in cosmology are usually assumed to proceed via bubble nucleation in homogeneous spacetime. However, the presence of impurities, or seeds, in the early Universe can provide an additional (catalyzed) channel for the false vacuum decay with enhanced tunneling probability. In this talk we will show how this picture can be realized already in the simplest extension of the SM including a scalar singlet with Z_2 symmetry (xSM), in the case of a two-step electroweak phase transition. The role of impurities is here played by the Z_2 domain walls. We will discuss the various methods and approximations that allow us to evaluate the catalyzed nucleation rate, and show that this is generically faster than the homogeneous one. We will finally comment on the impact of a seeded phase transition in terms of the expected gravitational wave signal.

Presenter: Dr SIMONE BLASI (Vrije University)

Contribution ID: **14** Type: **not specified**

Discussion: applications of PTs apart from baryogenesis and gravitational waves

Wednesday, 7 December 2022 16:00 (1 hour)

Contribution ID: **15** Type: **not specified**

Sourcing electroweak baryogenesis

Thursday, 8 December 2022 10:00 (1 hour)

Electroweak baryogenesis requires new physics at the electroweak scale, which can be tested by current and upcoming experiments. Unfortunately, theoretical pedictions for the baryon asymmetry may vary by orders of magnitude, depending on the approximation scheme used. In this talk we revisit how the transport equations are derived in the vev-insertion approximation. A careful and systemetic analysis shows that the leading order contribution to the source terms in the transport equations – which drive the asymmetry – exactly cancel, making this approach much less efficient than previously thought.

Presenter: MARIEKE POSTMA (Nikhef)

Contribution ID: **16** Type: **not specified**

(virtual) CP-violating forces in electroweak baryogenesis: Spinoff from leptogenesis

Thursday, 8 December 2022 15:00 (1 hour)

I will report on a project with Ilyas, Tamarit & White where we calculate the non-collisional source for electroweak baryogenesis from flavour-mixing in a two-fermion system. The equations describing this system have been derived by Konstandin, Prokopec and Schmidt in 2004,5. Here, we aim for an analytic approximation to the solution, that has thus far not been derived. The basic approximation is similar to what has been applied in to the equations for resonant leptogenesis in the Schwinger-Keldys framework.

Presenter: BJORN GARBRECHT (Technical University of Munich)

Contribution ID: **17** Type: **not specified**

Discussion: Charged transport, Marieke Postma (Nikhef)

Thursday, 8 December 2022 16:00 (1 hour)

Contribution ID: **18** Type: **not specified**

Gravitational waves from feebly interacting particles in a first order phase transition

Friday, 9 December 2022 10:00 (1 hour)

In most studies of gravitational waves from first order cosmological phase transitions, it is assumed that the released vacuum energy gets transformed either to bubble wall collisions, or to sound waves in the plasma. In this talk, I consider an alternative possibility that has so far not been considered: the released energy gets transferred primarily to feebly interacting particles that do not admit a fluid description but simply free-stream individually. I will discuss the formalism to study the production of GWs from such configurations, and demonstrate that such GW signals have qualitatively distinct characteristics compared to conventional sources and are potentially observable with near-future GW detectors.

Presenter: JORINDE VAN DE VIS (Utrecht/Desy)

Contribution ID: **19** Type: **not specified**

Cosmological phase transition thermodynamics: pushing perturbation theory to its limits

Friday, 9 December 2022 11:00 (1 hour)

Gravitational waves (GW) from cosmological phase transitions bear huge discovery potential and can be probed by planned future space-based GW observatories. Complementary to current and future collider experiments, such GW signatures can offer a powerful probe for beyond the Standard Model physics. Predictions for stochastic GW spectrum of a cosmological origin are often plagued by large theoretical uncertaintities related to low-order perturbative computation of thermodynamic properties of a phase transition. In this talk, I will discuss how the most accurate predictions to date – that reduce theoretical uncertainties by orders of magnitude – have been obtained, in terms of effective field theory methods in high temperature field theory. Despite these improvements, computation of thermodynamic properties should still be improved in order to make reliable predictions for the GW spectrum. I will discuss pertubative expansion of thermal parameters, and an ambitious task to push perturbation theory to its limits, by computing all first few available orders, before expansion becomes non-perturbative due to the Linde's Infrared Problem.

Presenter: Dr TUOMAS TENKANEN (Nordita and TD Lee, Shanghai)

Contribution ID: **20** Type: **not specified**

Echo of the Dark: Gravitational Waves from Dark SU(3) Yang-Mills Theory

Friday, 9 December 2022 15:00 (1 hour)

We analyze the phase transition in improved holographic QCD to obtain an estimate of the gravitational wave signal emitted in the confinement transition of a pure SU(3) Yang-Mills dark sector. We derive the effective action from holography and show that the energy budget and duration of the phase transition can be calculated with minor errors. These are used as input to obtain a prediction of the gravitational wave signal. To our knowledge, this is the first computation of the gravitational wave signal in a holographic model designated to match lattice data on the thermal properties of pure Yang-Mills.

Presenter: RAMBERG, Niklas (Mainz)

Contribution ID: **21** Type: **not specified**

Discussion: Gravitational waves, Jorinde Van De Vis (Utrecht/Desy)

Friday, 9 December 2022 16:00 (1 hour)