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From microphysics to Gravitational Waves for cosmological phase transitions

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The possibility that future gravitational-wave detectors could observe the relic background from a cosmological phase transition has triggered intense progress in the theoretical description of these events. A detection of such a signal would probe energy scales far beyond those accessible to particle colliders, providing insight into fundamental questions about the early Universe, including the origin of the baryon asymmetry, the nature of dark matter, and the possible existence of exotic relics such as primordial black holes or cosmic strings.

If the transition is first order, it proceeds through the nucleation and expansion of bubbles of the new phase. The resulting gravitational-wave signal is therefore directly determined by microscopic properties of the transition, including the bubble nucleation rate, fluctuation determinants, and the velocity of the expanding bubble walls. Making reliable predictions therefore requires a precise treatment of thermal field theory, out-of-equilibrium dynamics, and the interaction of the bubble wall with the primordial plasma.

To enable systematic studies of models beyond the Standard Model, connecting microphysics to observable signals must be implemented in reliable and automated computational tools. Recent and forthcoming programs for determining bubble fluctuation determinants and bubble-wall velocities represent important steps in this direction. In this talk, I will review recent advances in modelling phase-transition dynamics, discuss the challenges that remain, and outline how improved automation will sharpen gravitational-wave predictions for upcoming experiments.

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