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Ladder top-quark condensation imprints in supercooled electroweak phase transition

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The electroweak (EW) phase transition in the early Universe might be supercooled due to the presence of the classical scale invariance involving Beyond the Standard Model (BSM) sectors and the supercooling could persist down till a later epoch around which the QCD chiral phase transition is supposed to take place. Since this supercooling period keeps masslessness for all the six SM quarks, it has simply been argued that the QCD phase transition is the first order, and so is the EW one. However, not only the QCD coupling but also the top Yukawa and the Higgs quartic couplings get strong at around the QCD scale due to the renormalization group running, hence this scenario is potentially subject to a rigorous nonperturbative analysis. In this work, we employ the ladder Schwinger-Dyson (LSD) analysis based on the Cornwall-Jackiw-Tomboulis formalism at the two-loop level in such a gauge-Higgs-Yukawa system. We show that the chiral broken QCD vacuum emerges with the nonperturbative top condensate and the lightness of all six quarks is guaranteed due to the accidental U(1) axial symmetry presented in the top-Higgs sector. We employ a quark-meson model-like description in the mean field approximation to address the impact on the EW phase transition arising due to the top quark condensation at the QCD phase transition epoch. In the model, the LSD results are encoded to constrain the model parameter space. We then observe the cosmological phase transition of the first-order type and discuss the induced gravitational wave (GW) productions. We find that in addition to the conventional GW signals sourced from an expected BSM at around or over the TeV scale, the dynamical topponium-Higgs system can yield another power spectrum sensitive to the BBO, LISA, and DECIGO, etc.

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