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Real-time dynamics of pseudo-Goldstone and critical mode in QCD

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The low energy QCD matter can be effectively desicrbed by O(4) model. the spontaneous breaking of approximate symmetries gives rise to emergent pseudo-Goldstone modes and a radial σ mode. It has been proposed that the damping of pseudo-Goldstone modes at finite temperatures is universally constrained in the way that $\Omega_\varphi/m_\varphi^2 \simeq D_\varphi$ in the broken phase, where Ω_φ and m_φ are the relaxation rate at zero wavenumber and the mass of pseudo-Goldstones, D_φ is the Goldstone diffusivity in the limit of purely spontaneous breaking. We find that, away from the critical temperature, the proposed relation is always valid. When the temperature is very close to the critical value the pseudo-Goldstone damping displays a novel scaling behavior that follows $\Omega_\varphi/m_\varphi^2 \propto m_\varphi^{\Delta_\eta}$ with a correction Δ_η controlled by the critical fluctuations and obeying the critical universalities. Near the critical temperature the radial mode emerges as the critical mode. We analyze the relaxation dynamics by incorporating the effective potential and transport coefficients derived from first-principles fRG-QCD calculations. Our results indicate that once away from the critical point, the relaxation time of the critical mode decreases dramatically. Specifically, along the freeze-out line, the relaxation time remains mild. Consequently, the non-equilibrium dynamics have limited effects on observables along the freeze-out line.

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