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Understanding the out-of-equilibrium dynamics near a critical point via a Hydro+ simulation

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Upcoming experimental programs, like the Beam Energy Scan at RHIC, will look for signatures of a possible critical point in the QCD phase diagram in fluctuation observables. To understand and predict these signatures, one must account for the fact that the dynamics of any critical fluctuations must be out-of-equilibrium: because of critical slowing down, the fluctuations cannot stay in equilibrium as the droplet of QGP produced in a collision expands and cools. Furthermore, their out-of-equilibrium dynamics must also influence the hydrodynamic evolution of the cooling droplet. The recently developed Hydro+ formalism allows for a consistent description of both the hydrodynamics and the out-of-equilibrium fluctuations, including the feedback between them. We shall provide the first demonstration of how this works, setting up a Hydro+ simulation in a simplified setting: a rapidity-independent fireball undergoing radial flow with an equation of state in which we imagine a critical point close to the $\mu B = 0$ axis of the phase diagram. Within this setup, we show that we can quantitatively capture non-equilibrium phenomena, including critical fluctuations over a range of scales and memory effects. Furthermore, we show the interplay between the dynamics of the fluctuations and the hydrodynamic flow of the fireball: as the fluid cools and flows, the dynamical fluctuations lag relative to how they would evolve if they stayed in equilibrium; there is then a backreaction on the flow itself due to the out-of-equilibrium fluctuations; and, in addition, the radial flow transports fluctuations outwards by advection.

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