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Superfluid dynamics of the QCD chiral phase transition

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High-energy heavy-ion collisions create a quark–gluon plasma (QGP) with approximately restored chiral symmetry. Lattice QCD determines the chiral crossover temperature to be $T_c = (156.5 \pm 1.5)\,\mathrm{MeV}$, below which chiral symmetry is spontaneously broken and pions emerge as pseudo–Goldstone bosons. Yet, this chiral transition—second order in the chiral limit—is absent from current hydrodynamic models. We present numerical studies of Model G, the dynamical universality class governing the QCD chiral phase transition. Using scaling arguments and stochastic simulations, we demonstrate a parametric enhancement of long-wavelength Goldstone modes after a quench into the broken phase. The ensuing out-of-equilibrium evolution is effectively captured by a non-abelian pion superfluid description, from which we compute the nonequilibrium pion spectrum. Even with explicit chiral symmetry breaking, soft pion yields remain enhanced over parametrically long times. Coupling this superfluid dynamics to QGP hydrodynamics enables quantitative predictions for signatures of the chiral transition, most notably, enhanced soft pion production in heavy-ion collisions.

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