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Understanding properties of the Dirac eigenspectrum in QCD and approach to thermalization

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In this work, we study the localization properties of the eigenstates of non-Abelian SU(3) gauge theory both with and without dynamical quark flavors in a gauge invariant manner, using first-principles lattice gauge theory techniques. We use the eigenspectrum of a probe (overlap) Dirac operator to understand the properties of thermal gauge ensembles of 2+1 flavor QCD generated using domain wall fermions as well as pure SU(3) gauge theory. Focusing on the infrared part of eigenspectrum that lie within the non-perturbative magnetic scale, we propose suitable observables that allow us to unambiguously categorize different regions of the eigenspectrum. While most of these so-called magnetic modes are completely delocalized and chaotic, with nearest-neighbor level spacing fluctuations similar to random matrices of a Gaussian unitary ensemble (GUE), few eigenmodes with fractal-like properties start to appear at temperatures just near and above the chiral crossover temperature. We show that their fractal dimensions carry information about the universality class of the chiral transition in QCD.

Having demonstrated that at sufficiently high temperatures, the non-Abelian plasma is gluon dominated with large occupation numbers in the infra-red and exhibits properties similar to a chaotic system, we discuss its consequences for heavy-ion experiments. Starting from a non-equilibrium initial state of SU(3) gluons inspired by the Color
Glass Condensate effective theory, a real-time classical-statistical evolution leads to a self-similar scaling regime where we show that infrared magnetic modes are also over-occupied and chaotic. Thus by matching the evolving magnetic scale in this non-equilibrium scaling regime with that of a typical thermal state of QCD, we estimate a thermalization time of ~ 1.44 fm/c.
Reference: Understanding the approach to thermalization from the eigenspectrum of non-Abelian gauge theories, Harshit Pandey, Ravi Shanker, Sayantan Sharma, arXiv:2407.09253 [hep-lat]

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