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Fermi acceleration induces self-organized critical characteristics to the driven Lorentz channel

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The Lorentz gas (LG) acts in the theory of dynamical systems as a paradigm allowing us to address fundamental issues of statistical mechanics, for instance, transport processes, such as diffusion in the configuration space [1, 2]. The static periodic LG comprises a regular lattice of circular fixed scatterers and an ensemble of non-interacting particles travelling freely between collisions and scattering elastically off the circular obstacles. The transport properties of such a system are determined by the billiard's geometry, that is the specific lattice symmetry and the lattice constant. If the maximum free path length is not bounded from above, then the setup possesses a so-called infinite horizon (IH) and the diffusion in configuration space is anomalous [4, 5]. For a more compact packing of the scatterers, i.e. finite horizon (FH), arbitrarily long flights are not possible and the system exhibits normal diffusion.

Time-dependent generalizations of the original periodic Lorentz gas model have been introduced, in which the scatterers are allowed to oscillate [6, 8], rendering the study of diffusion in momentum space possible. This process is intimately linked to Fermi acceleration [3], which is considered a fundamental acceleration mechanism in many areas of physics. The mechanism consists in the indefinite increase of the mean energy of particles as a result of random collisions with moving scatterers.

In this work [9], we show the emergence of power-law (critical) cross-correlations between non-interacting particles propagating in the driven LG in a channel geometry. To reveal these cross-correlations a spatially coarse-grained description of the dynamics is employed. The dynamically infinite horizon (DIH) is introduced as a property of driven extended billiards for which ballistic corridors open up and close periodically in time, i.e. exist only for certain time intervals. The development of Fermi acceleration then enables the particles to synchronize their motion with the periodic appearance of the ballistic corridors, such that they can perform free flights of arbitrary length, which, in turn, gives rise to intermittent dynamics and the appearance of critical correlations. In this sense, it is shown that Fermi acceleration can act as an effective driving force to steer an ensemble of propagating particles towards a critical state, imparting to the system's dynamics characteristics of self-organized criticality (SOC).

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