

Spin transport in 1D ultracold fermionic gases: Understanding KPZ Superdiffusion

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My PhD investigates quantum magnetism and spin transport in strongly correlated 1D systems using ultracold fermionic ^{40}K atoms. These systems exhibit enhanced quantum fluctuations, emergent collective behavior, and strong correlations absent in higher dimensions. A key feature is their *integrability*, which constrains thermalization processes and leads to nontrivial relaxation dynamics explored in this work both experimentally and theoretically.

My theoretical project investigates the microscopic origin of the so-called *Kardar–Parisi–Zhang (KPZ)* superdiffusive regime—a universal anomalous transport behavior lying between ballistic and diffusive dynamics—recently observed in 1D spin quantum systems, but still poorly understood. Starting from a minimal model—as classical as possible—describing the collision of two opposite-spin fermionic clouds in a 1D harmonic trap and in a strongly repulsive interaction regime, the approach consists in progressively introducing quantum ingredients and characterizing the associated transport regimes, to identify the essential mechanisms leading to KPZ dynamics.

In the minimal model—where particles follow classical trajectories while undergoing quantum-like collisions—the analysis of magnetization scaling and spin currents reveals an anomalous yet subdiffusive transport regime. Building on this characterization, we now incorporate a new quantum ingredient—coherences between particles derived from scattering theory—in order to assess their role in the possible emergence of KPZ superdiffusion.

The emerging theoretical predictions of this work will be confronted with experimental studies using our FermiX experiment, which enables the simulation of quasi-1D fermionic systems; *quantum wires* of ultracold 40K. Moreover, a key feature of the experiment is the precise control of interparticle interactions via Feshbach resonances. Finally, because experimental quantum wires are not perfectly 1D, they exhibit weak integrability breaking, making them a natural platform to study the crossover from integrable to thermalizing dynamics induced by an effective 1D–3D dimensional crossover. This will allow us to test its impact on our observations and on the possible emergence or suppression of KPZ superdiffusive behavior.

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