Far-from-equilibrium dynamics in quantum lattice models

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Why studying far-from-equilibrium dynamics in low-energy physics ?

Far-from-equilibrium dynamics ?

- **No effective theory**
- Fundamental problem (impact on the emerging quantum technologies) :
  1. **Transport of matter (motion of quasiparticles) : correlations** $\langle \Psi(t) | \hat{A}_0 \hat{A}_r | \Psi(t) \rangle$
  2. Transport of quantum information (quantum entanglement) : Von Neumann entropy $S_{L|R}\left(|\Psi(t)\rangle\right)$
  3. Thermalization (thermodynamic equilibrium) : Density matrix $\hat{\rho}(t)$

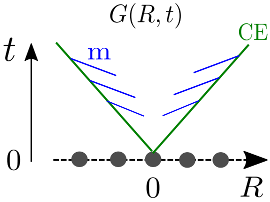
Renewed interest due to ultracold atoms

- Enable to simulate different Hamiltonians (bosonic, fermionic and spin lattice systems)
- No defects (impurities), no vibrational excitations (phononic modes)
- Possibility to control in time the parameters of the Hamiltonian : **quench dynamics !**

Theory on correlation spreading (short-range interactions)

Context

- Global quench confined into the same phase
- Correlation function such that :
- $G_1(R,t) = \langle \hat{a}_R^\dagger(t)\hat{a}_0(t)\rangle - \langle \hat{a}_R^\dagger(0)\hat{a}_0(0)\rangle$
- $G_2(R,t) \sim \langle \hat{n}_R(t)\hat{n}_0(t)\rangle - \langle \hat{n}_R(t)\rangle\langle \hat{n}_0(t)\rangle$



Generic form [1] of $G_1(R,t)$ and $G_2(R,t)$

$$G\left(R,t\right) \propto \int_{\mathcal{B}} \frac{\mathrm{d}k}{2\pi} \mathcal{F}\left(k\right) \frac{e^{i\left(kR+2E_k^{\mathrm{f}}t\right)} + e^{i\left(kR-2E_k^{\mathrm{f}}t\right)}}{2}$$

- Motion of free counter-propagating quasiparticle pairs
- Twofold structure of the correlation cone :
  - **Correlation edge (CE)** : $2V_g(k^*) = 2\max\left(\partial_k E_k^{\mathrm{f}}\right)$
  - **Series of local maxima (m)** : $2V_\varphi(k^*) = 2E_k^{\mathrm{f},*}/k^*$

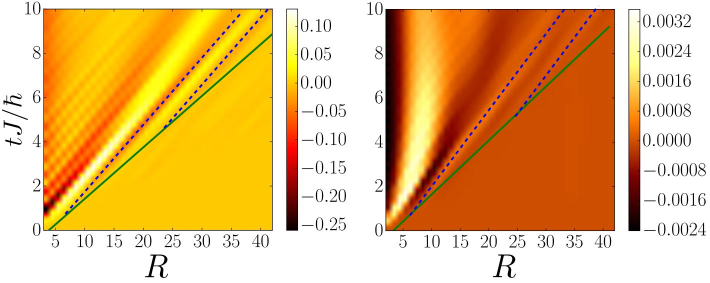
1. *Universal Scaling Laws for Correlation Spreading in Quantum Systems with Short- and Long-Range Interactions* - L.Cevolani, **J.Despres** et al., PRB 98, 024302 (2018) - Editors' suggestions.

t-MPS (tensor networks) results on correlation spreading

Why using this numerical technique ? Why doing numerics ?

- To go beyond the analytical approach of non-interacting quasi-particles
- To consider regimes where the Hamiltonian cannot be diagonalized (no analytical solution)

1D Bose-Hubbard model - quenches confined in the superfluid phase (SF)



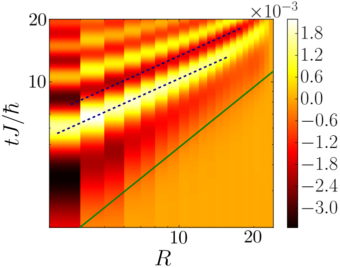
- *Left panel* : meanfield regime ($\bar{n} = 5$, $U/J = 0.2$)
- *Right panel* : strongly-interacting regime ($\bar{n} = 0.1$, $U/J = 10$)

2. *Twofold Spreading of Correlations in a Strongly-Correlated Lattice Bose Gas* - **J.Despres** et al. – soon on ArXiv

Ongoing work : TDVP (tensor networks) results on correlation spreading

1D LRXXZ model - quench confined in the ferromagnetic phase along the x-axis

- Double structure : CE (green) + maxima (blue)
- log-log scale : scaling laws are not ballistic (short-range case)
- *Gapless phase* : CE : sub-ballistic / maxima : super-ballistic



Preliminary results

- Numerical proofs for the theory on correlation spreading (long-range interactions case)
- Crossing critical lines
- Dependence of the scaling laws with respect to the power-law ($1/R^{\alpha}$)