Asymmetric transport in a bosonic chain

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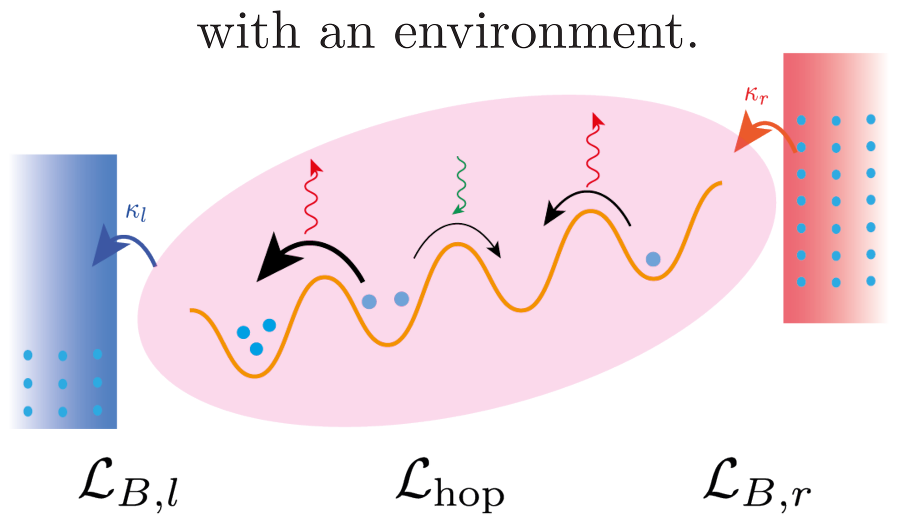
1. Introduction

We propose a minimal model to study **asymmetric** transport in a bosonic chain. This model is a counterpart of the ASEP model for fermions. We find the following properties: (i) the particles pile up on one edge of the chain, an effect we call **bosonic skin effect** (ii) the emergence of a zig-zag phase with **lasing-like** behavior on every other site (iii) a coalescence of dynamical eigenstates, known as an **exceptional point**, at the onset of the zig-zag phase (iv) current fluctuations falling into the **Kardar-Parisi-Zhang (KPZ)** universality class, which describes the growth of interfaces.

2. Model for asymmetric bosonic transport

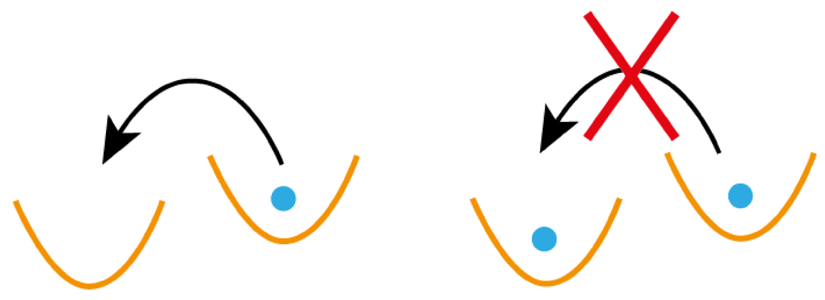
$$\mathcal{L}_{\rm hop}\rho = \sum_{p=1}^{L-1} \Gamma_l \mathcal{D}[a_p^\dagger a_{p+1}]\rho + \Gamma_r \mathcal{D}[a_{p+1}^\dagger a_p]\rho$$

Ex: boosons in an energy gradient interacting with an environment.

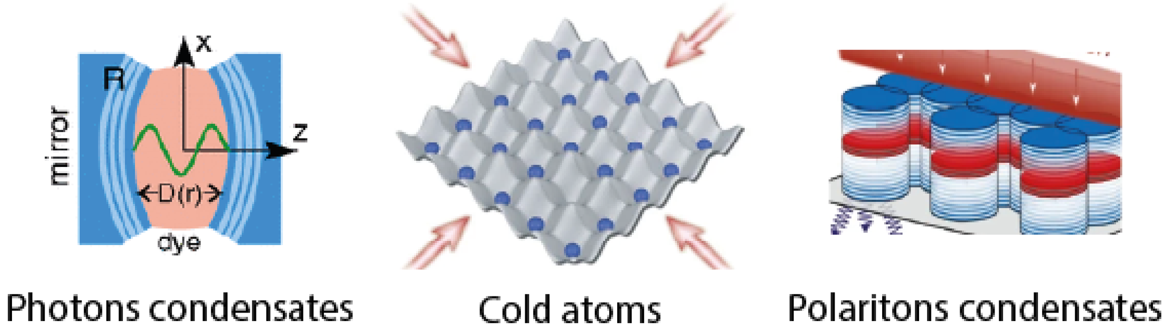


Fermions: $P[p+1 \to p] \propto \Gamma_l(1-n_p)$

Asymmetric Simple **Exclusion** Process (ASEP)



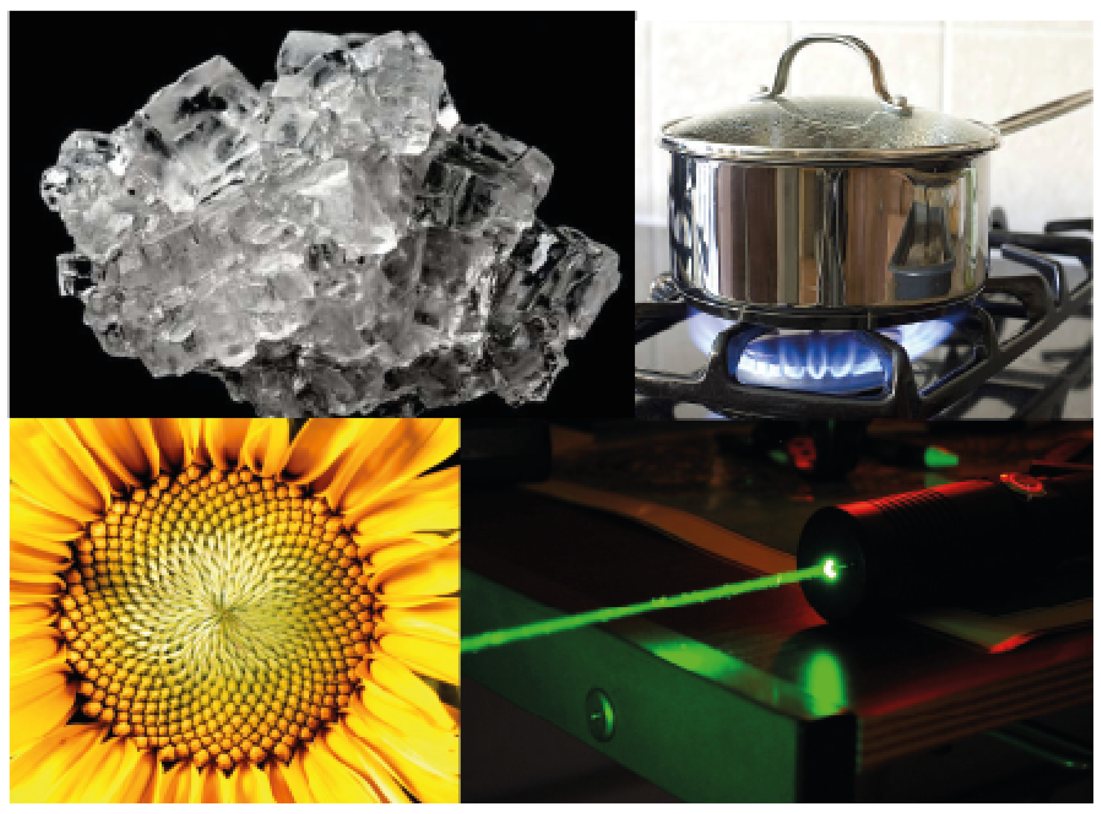
Possible implementations:



Bosons: $P[p+1 \to p] \propto \Gamma_l(1+n_p)$

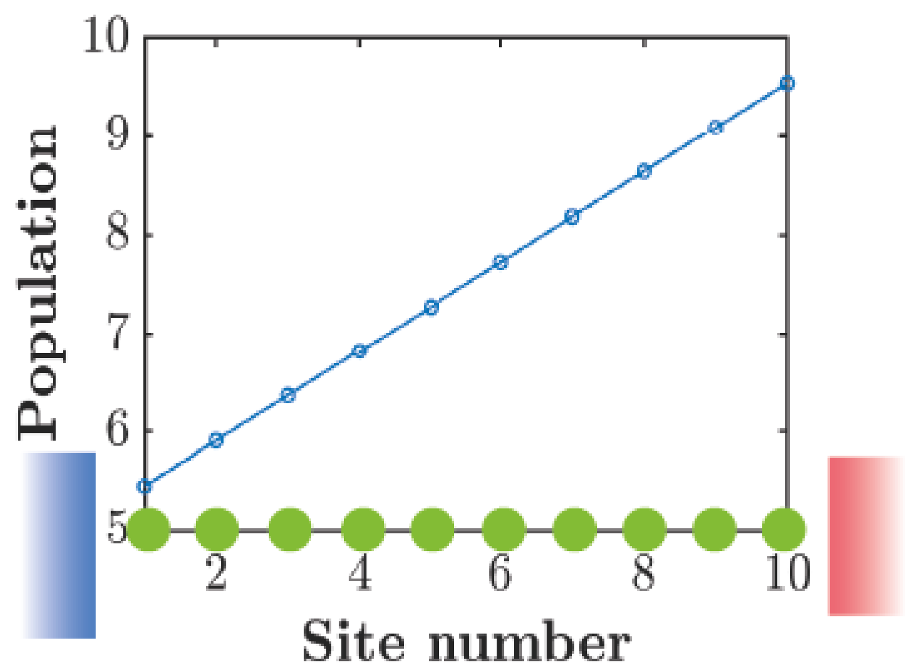
Asymmetric Simple **Inclusion** Process (ASIP)

What is the common point between:

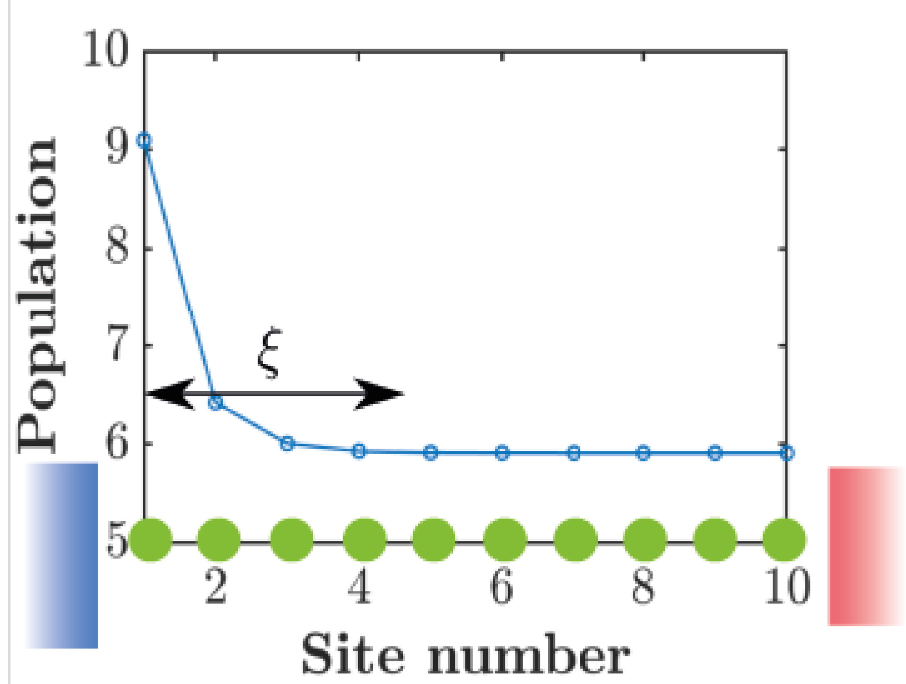


3. Bosonic skin effect

$\Gamma_r = \Gamma_l$: we recover a **diffusive** behavior
Fourier law: $J \propto \frac{\bar{n}_r - \bar{n}_l}{L}$

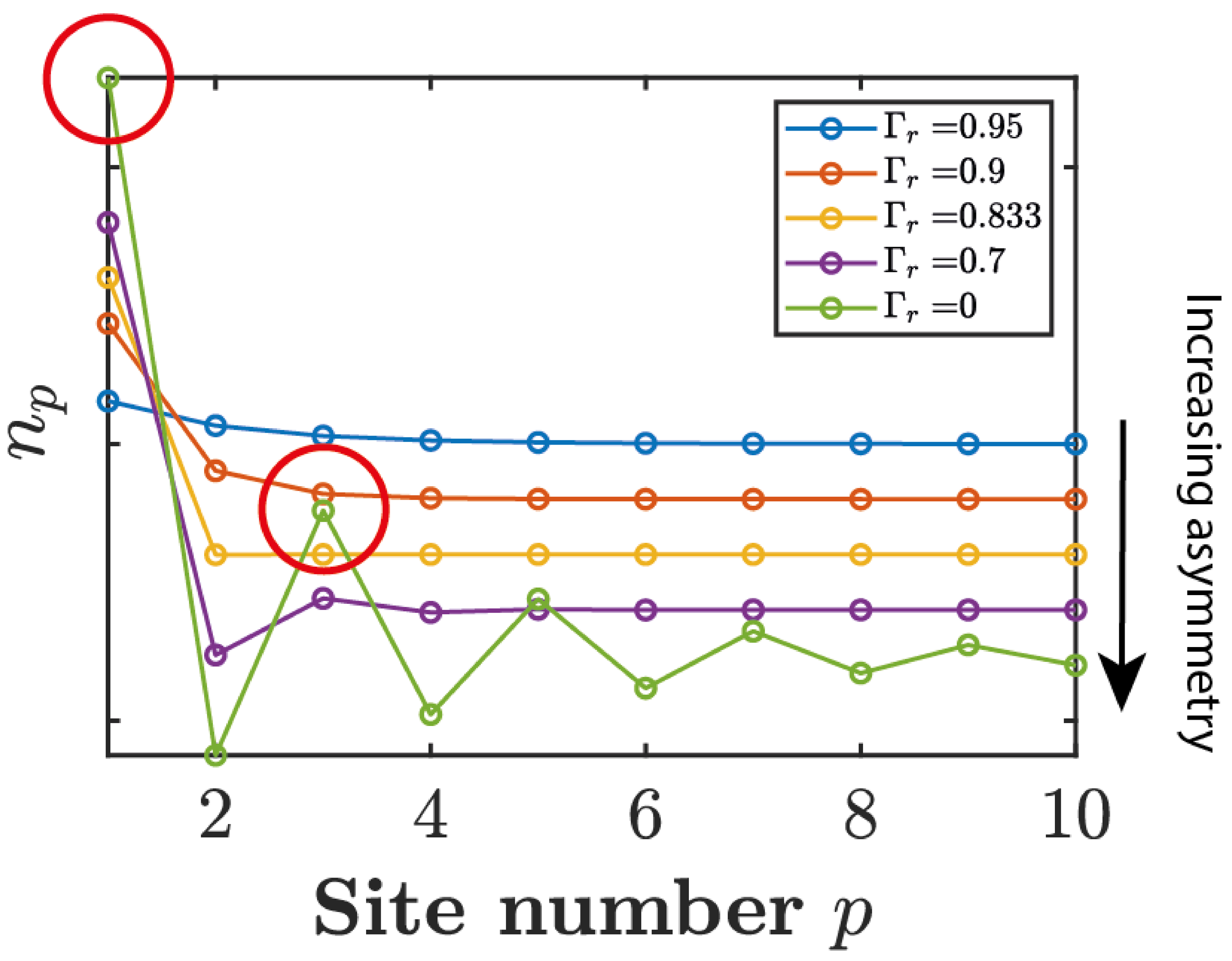


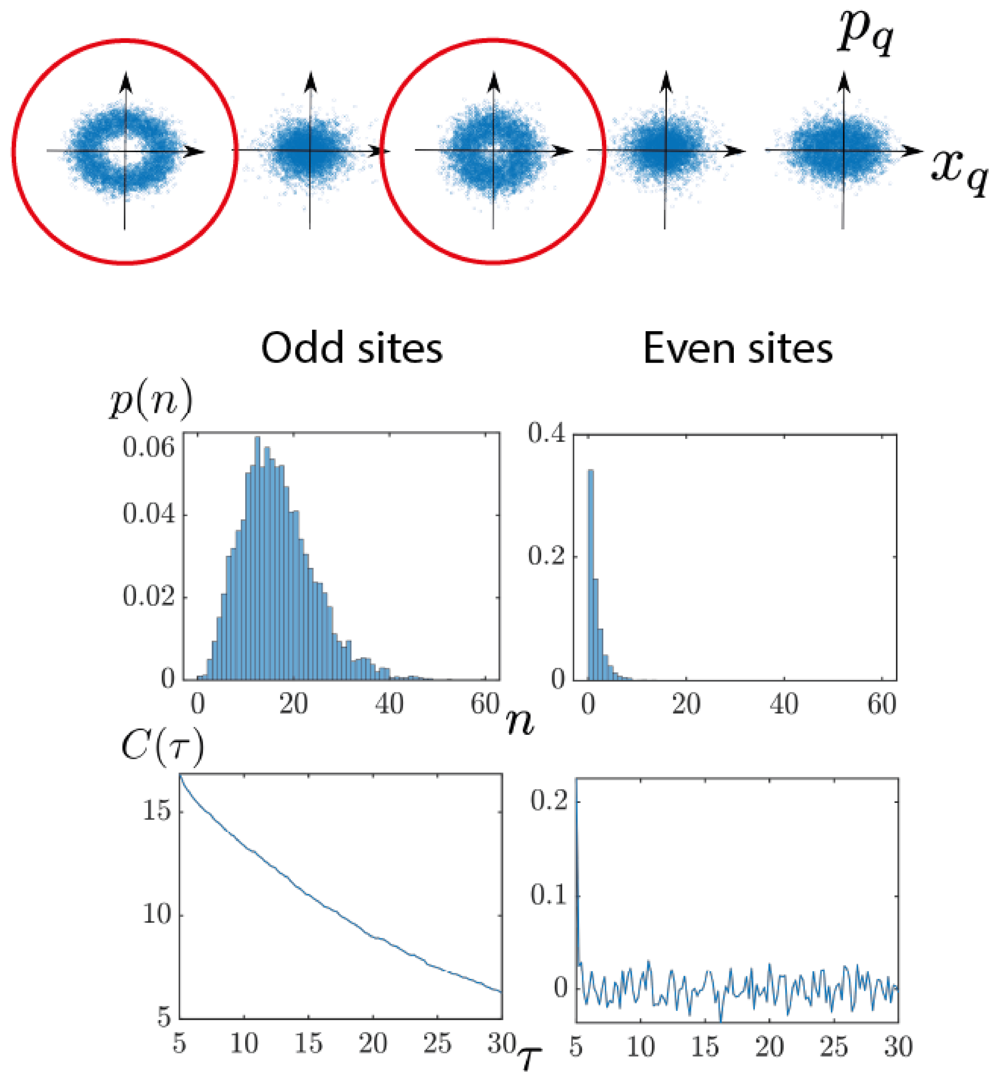
$\Gamma_r = 0.9\Gamma_l$: **pile-up on the edge**
Ballistic current: $J \propto \bar{n}_r$



4. Zig-zag lasing configuration

Asymmetry $\Gamma_r - \Gamma_l$ increases: **zig-zag** configuration described by **Fibonacci-like sequence**. Signatures of **lasing** on odd sites: ring in Wigner distribution, Poisson-like statistics, phase coherence.





5. Exceptional point

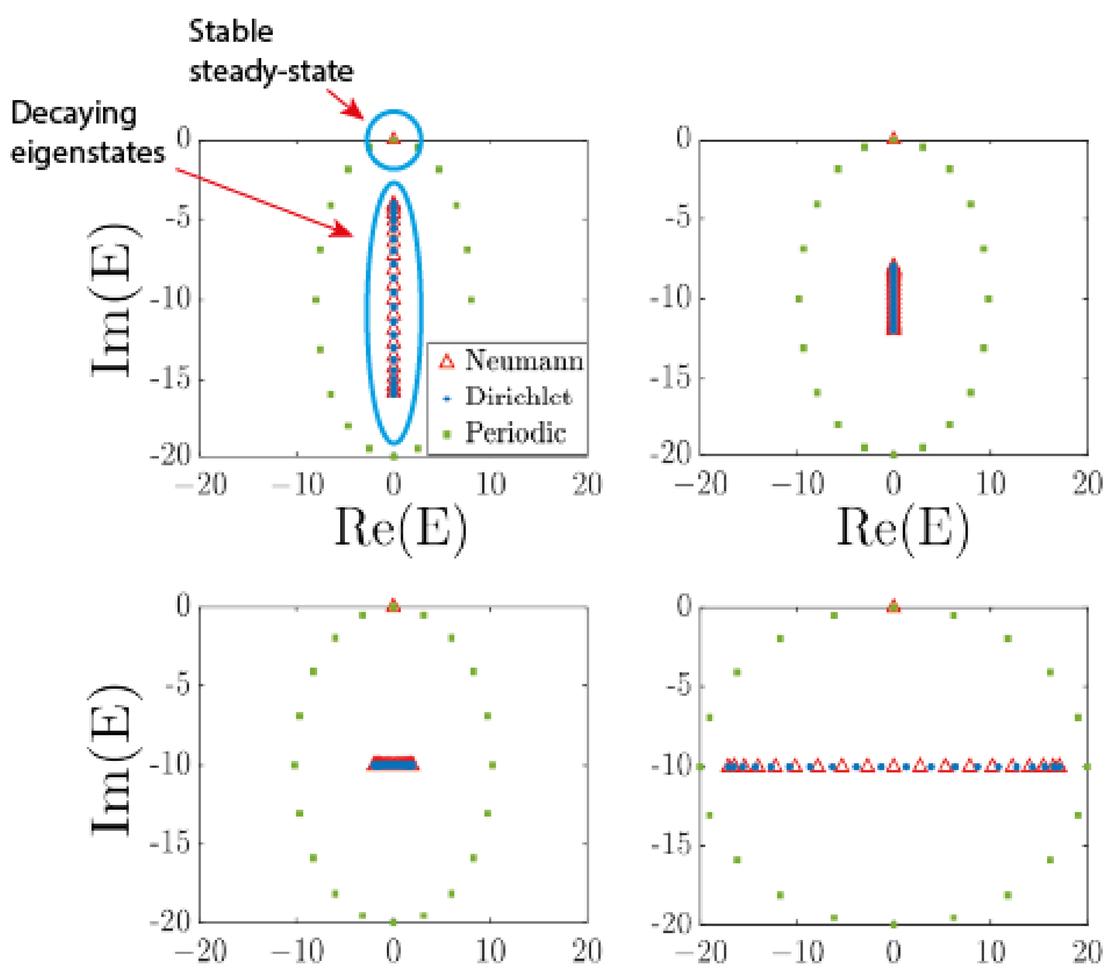
Linearization→ dynamical matrix defines an effective **non-Hermitian Hamiltonian**

$$n_p \to n_\infty + \epsilon_p \quad c = (\Gamma_r - \Gamma_l)n_\infty$$

$$\frac{d\vec{\epsilon}}{dt} = -iH_{\rm eff}\vec{\epsilon} \quad \nu = \Gamma_r + \Gamma_l$$

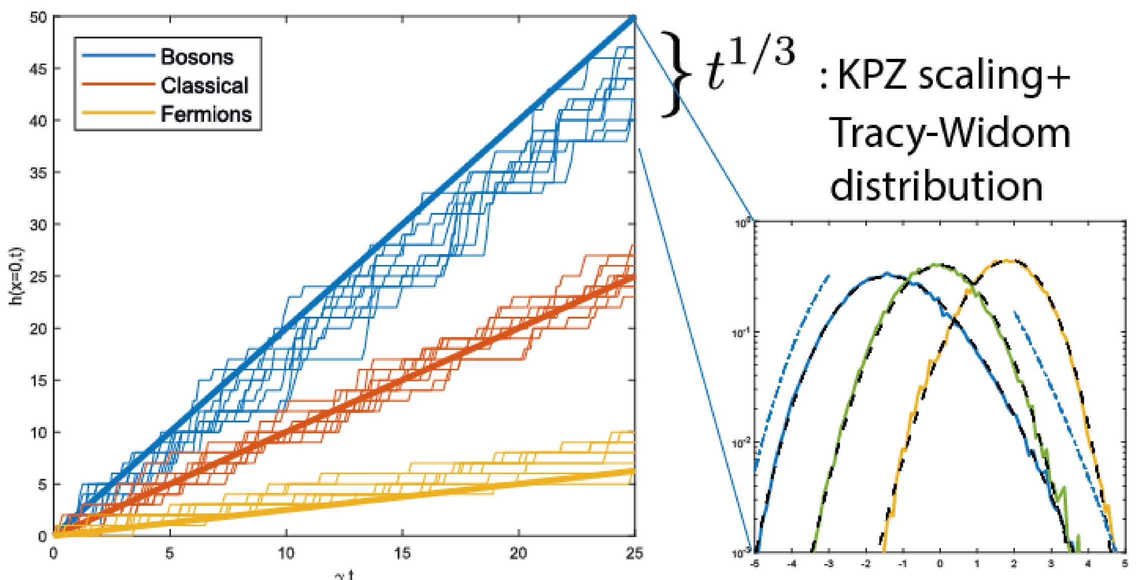
$$H_{\rm eff} = \begin{bmatrix} c+\frac{\nu}{2} & \frac{\nu}{2}+c & 0 & 0 & \dots \\ \frac{\nu}{2}-c & 0 & \frac{\nu}{2}+c & 0 & \dots \\ 0 & \frac{\nu}{2}-c & 0 & \frac{\nu}{2}+c & \dots \\ 0 & 0 & \frac{\nu}{2}-c & 0 & \dots \\ \vdots & \vdots & \vdots & \ddots & \ddots \end{bmatrix} - i\nu$$

Zig-zag transition for $c = \nu/2$. The excited states coalesce → **exceptional point**



6. Connexion to KPZ model

$h(x,t) = \int_0^t j(x,t')dt'$ integrated current
$\to \partial_t h \sim -c(\partial_x h)^2 + \nu\partial_x^2 h + \xi$: **KPZ equation**



7. Conclusion

We have studied a minimal model describing asymmetric hopping in a bosonic chain. This model shows a rich behavior, with unexpected connections to lasing, non-Hermitian dynamics, and interface growth.