Dynamics of strong and weak localizations in disordered quantum systems

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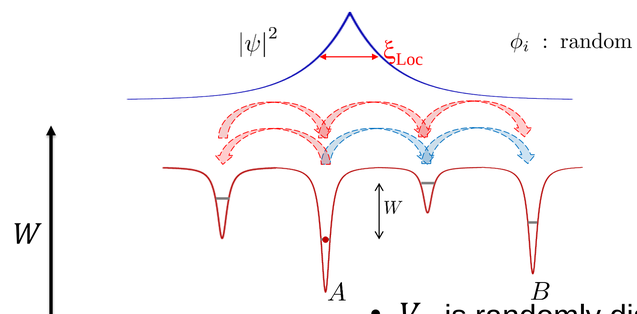
Anderson model [1]

$$Hu_n = V_n u_n - T u_{n+1} - T u_{n-1}$$



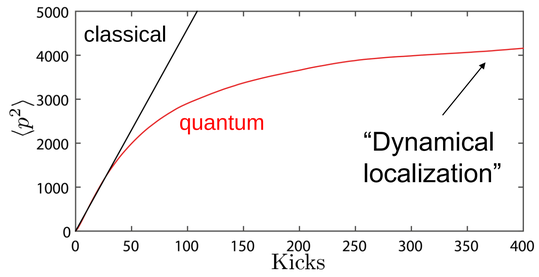
- V_n is randomly distributed over $[\frac{-W}{2},\frac{W}{2}]$

$\frac{w}{T} >> 1$ Localization $\frac{w}{T} << 1$ Diffusive regime

Simulating quantum disordered systems with the Kicked Rotor [2]

$$\hat{H}(x,t) = \frac{\hat{p}^2}{2} + K\cos(\hat{x})\sum_n \delta(t-n)$$

➢ In *momentum space* → mapping on the **Anderson model** :

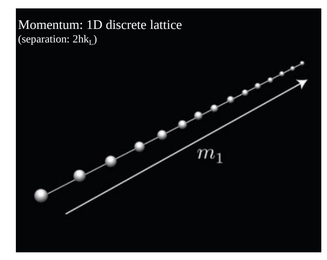


Anderson localization in momentum space

$$t_0 a_m = V_m a_m - \sum_{r\neq 0} t_r a_{m+r}$$

V_m : on-site energies (quasi-random)

t_r : coupling between momentum states



- Anderson transition 3D (2008-2009)
- Observaton of the 2D Anderson localization (2015)
- **Now : controlling the Time Reversal symmetry in disordered (Anderson) systems**

Creation of an artificial gauge field in Floquet systems

Symmetries greatly affect localization dynamics

$$\hat{H}(x,t) = \frac{\hat{p}^2}{2} + K(t)\cos(\hat{x}+a(t))\sum_n \delta(t-n)$$

➢ Mapping (*momentum space)* : **Quasi-1D disordered system + Aharonov-Bohm flux**

Periodic modulations (phase or amplitude)

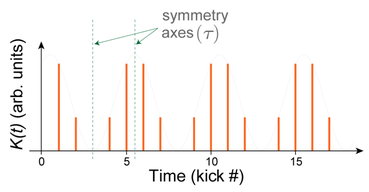
$K(t) = K(t+N)$

$$\mathcal{K}(t) = K\left[1+\cos\left(\frac{2\pi t}{N}+\varphi\right)\right]$$

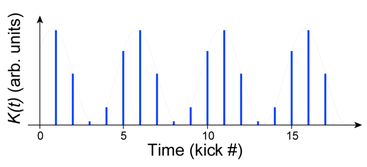
Artificial gauge flux:

$$\Phi_2 = N\varphi$$

$K(t)$: symmetric
$a(t)$: antisymmetric



$K(t)$: random
$a(t)$: random



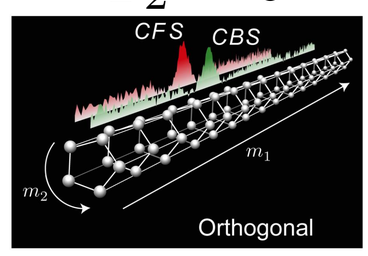
$N\varphi = 0 \pmod{\pi}$: orthogonal class

Time Reversal Symmetry (TRS) preserved

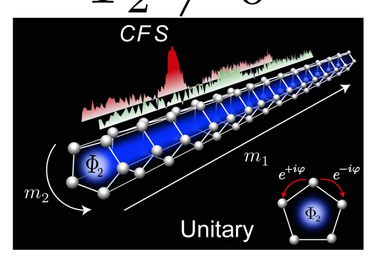
$N\varphi \neq 0 \pmod{\pi}$: unitary class

Time Reversal Symmetry (TRS) broken

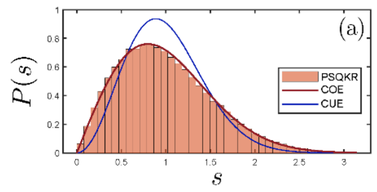
$\Phi_2 = 0$

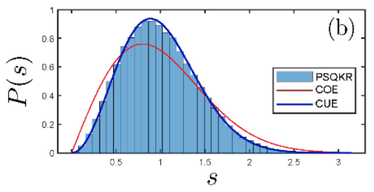


$\Phi_2 \neq 0$



Floquet quasi-energy level statistics



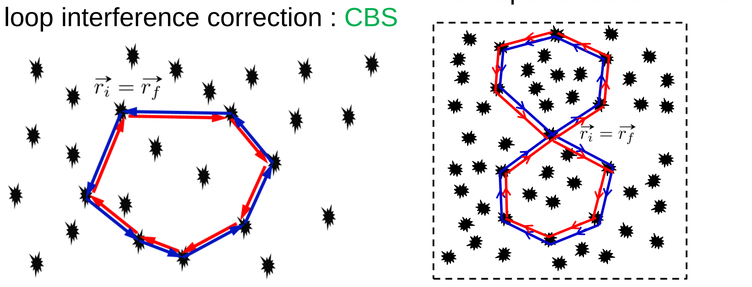


Observation of the Coherent Forward Scattering : a great tool for studying the AL dynamics

Particle scattering in disordered medium

One loop interference correction : CBS

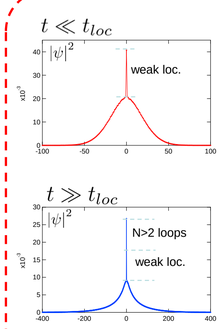
Two loops correction : CFS



If TRS is active $\varphi_+ = \varphi_-$

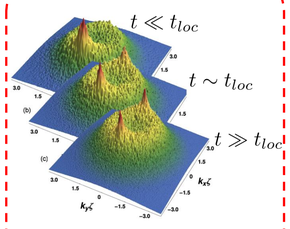
Even If TRS is broken $\varphi_+ = \varphi_-$

In 'direct' space:



Enhanced return(s) to the origin (ERO)

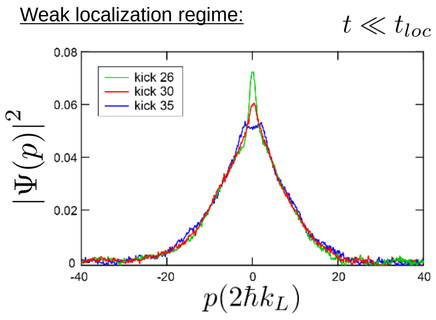
In reciprocal space [3] :



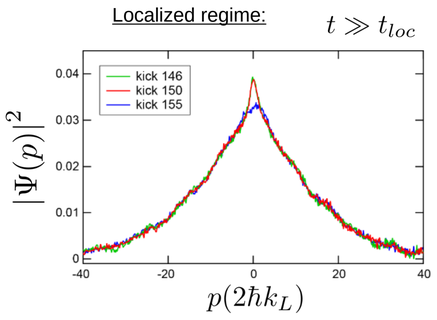
- CBS present at $t<<t_{Loc}$
- CBS vanishes if TRS breaking
- CFS saturates only at $t>t_{Loc}$
- CFS robust toTRS breaking

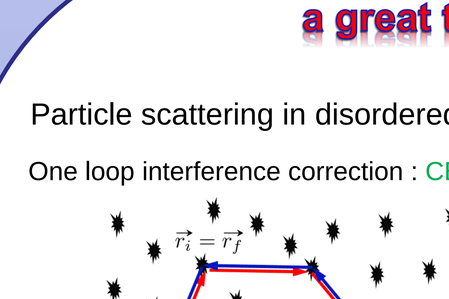
CFS: smoking gun of the Anderson localization

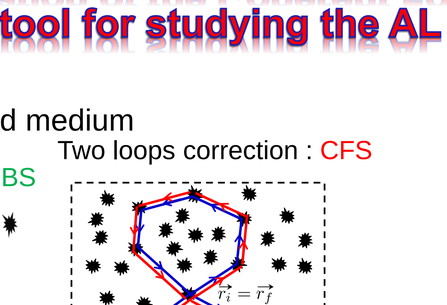
Weak localization regime: $t \ll t_{loc}$



Localized regime: $t \gg t_{loc}$







Effect of temporal gauge field on the dynamics of AL :

- One-parameter fits : decoherence time (CBS) and localization time (CFS)
- The unitary class : AL dynamics is slower (absence of weak-localization loops)
- Very good agreement with supersymmetric theoretical predictions

Measurement of the one-parameter scaling function

$$\beta_O(g) = -1 - \frac{4\sqrt{2}}{3\sqrt{\pi}}\frac{1}{g} + \cdots$$

$$\beta_U(g) = -1 - \frac{1}{2}\frac{1}{g^2} + \cdots$$

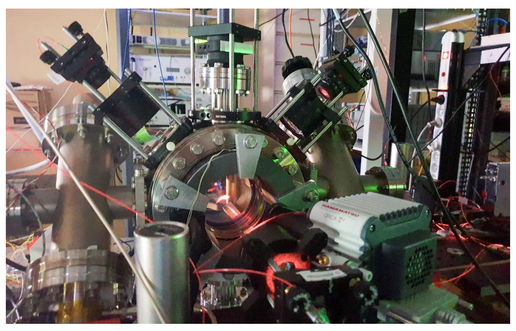
$1/g$ 1st order corrections absent when ~~TRS~~

$1/g^2$ 2nd order corrections survive when ~~TRS~~

"Universality" of the scaling function:

Perspectives :

A potassium BEC apparatus under way



PhD students :
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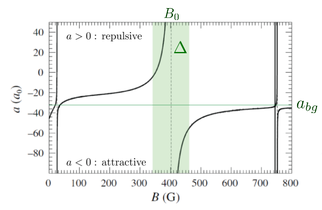
M. Denis

Control interactions *via* Feshbach resonances



^{39}K :

$a_{bg} = -33.48\ a_0$

$B_0 = 403.4$ G

$\Delta = 52$ G

What is the fate of Dynamical localization ? (teaser)

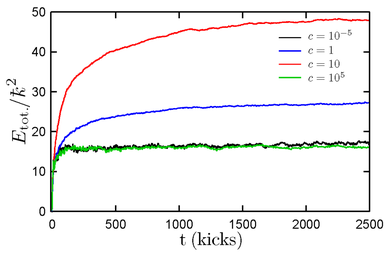
Contact interactions have long been predicted to destroy Dynamical localization

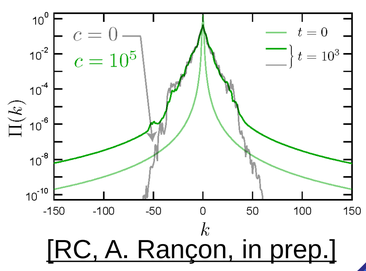
- Short-range in position ⇔ long range in momentum
- Dynamical localization replaced by sub-diffusive behavior

Recent developments : at least one interesting limit :

- Tonks-Girardeau limit (strong interactions, 1D)
- Mapping of the (dynamical) system onto free fermions
- Localization energy still finite !!! [5]

A toy model : 2-boson kicked Lieb-Liniger model on a ring $\hat{H}_{LL} = \frac{\hat{p}_1^2}{2} + \frac{\hat{p}_2^2}{2} + c\,\delta(\hat{x}_1 - \hat{x}_2)$





[RC, A. Rançon, in prep.]

CFS: a promising tool for studying AL with interactions / MBL

Unprecedented control in studying Anderson localization !

C. Hainaut et al., Nat. Commun. **9**, 1382 (2018)

ANR PROJET FINANCÉ PAR L'ANR – PROJECT FUNDED BY THE ANR
CEMPI CENTRE EUROPÉEN POUR LES MATHÉMATIQUES, LA PHYSIQUE ET LEURS INTERACTIONS
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[2] S. Fishman et al.,PRL 49, 509 (1982)
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[5] C. Rylands et al., PRL 124, 155302 (2020)