Decoherence of Bloch oscillations of cold Fermi atoms

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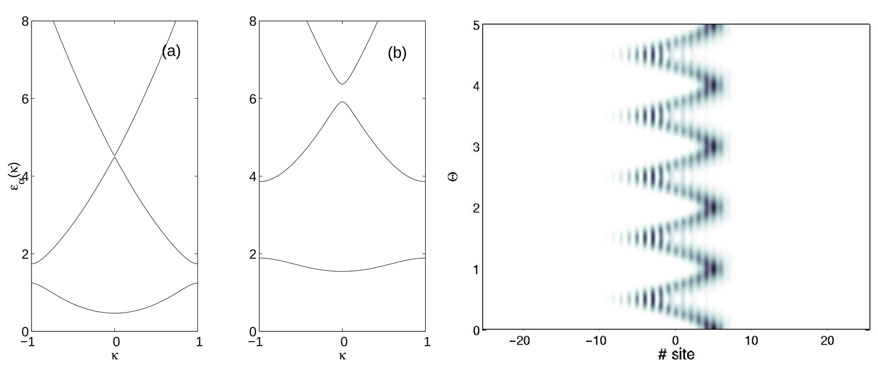
Nonlinear Dynamics in Quantum Systems

INTRODUCTION

BLOCH OSCILLATION



Periodic potential amended by a homogeneous static field:

$$H = H_0 + Fx\,, \quad H_0 = \frac{\hat{p}^2}{2} + V(x)\,, \quad V(x+d) = V(x)$$

Floquet-Bloch solutions:

$$\psi_\kappa(x,t) \sim \psi_{\kappa+Ft/\hbar}(x)$$

$$T_B = 2\pi\hbar/dF \text{ – Bloch period}$$

average momentum $\langle p(t)\rangle$:

$$\langle p(t)\rangle = \int P(p,t)dp = J\sin(\omega_B t)\,, \quad \omega_B = dF/\hbar$$

COLD ATOMS IN OPTICAL LATTICES

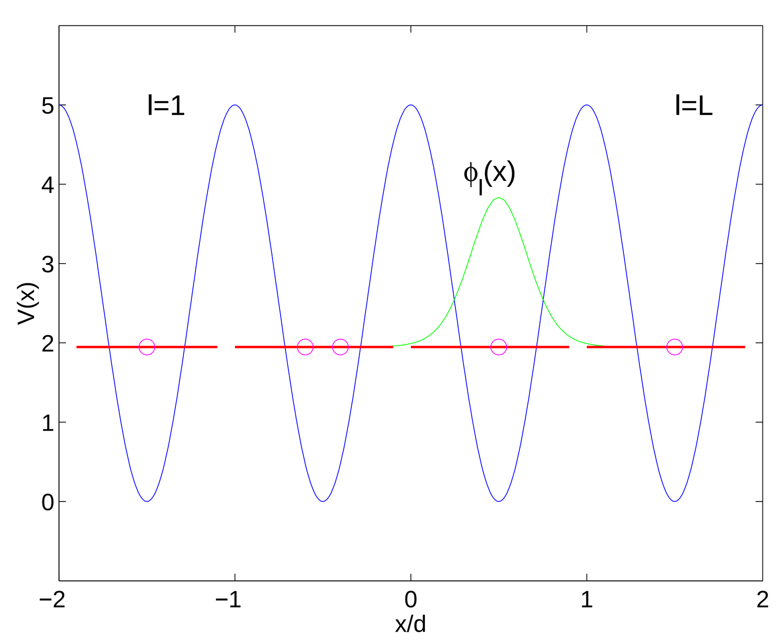
EXPERIMENTAL RESULTS

(1996) BO of non-interacting atoms (dilute gas) $W\bar{n} \ll 1$ [1,2]

Experiments on interacting atoms $W\bar{n} \sim 1$ [3,4]
Bose atoms $\Longrightarrow$ decaying Bloch oscillations (BO) $\sim$ 2-3 T_B
One component Fermi atoms $\Longrightarrow$ non-decaying BO $\sim$ 100 T_B

THIS WORK:
Two components Fermi atoms $\Longrightarrow$ decaying BO $\sim$ 2-3 T_B

MODEL



1D Hubbard Hamiltonian with additional static term:

$$\widehat{H} = \widehat{H}_0 + F\sum_{\ell=1}^{L}\sum_{s=\uparrow\downarrow}\ell\hat{n}_{\ell s}$$

$$\widehat{H}_0 = -\frac{J}{2}\left(\sum_{\ell}\sum_{s=\uparrow\downarrow}\hat{b}^{+}_{\ell,s}\hat{b}_{\ell+1,s} + h.c.\right) + W\sum_{\ell}\hat{n}_{\ell\uparrow}\hat{n}_{\ell\downarrow}$$

Gauge transformation :

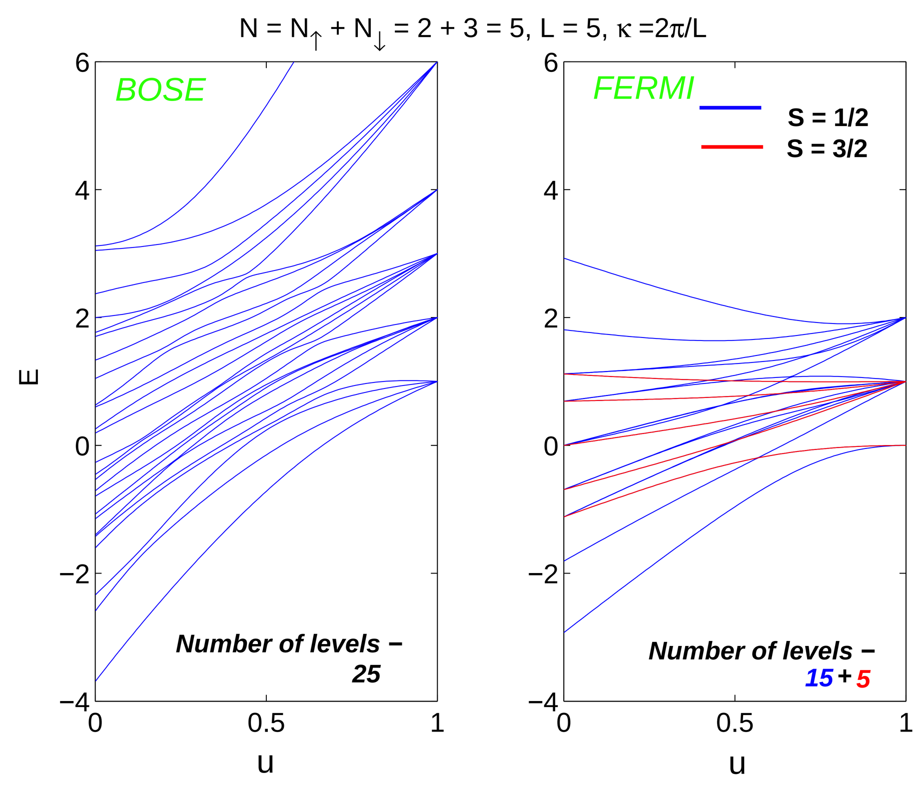
$$\widehat{H} \to \widehat{H}(t) = -\frac{J}{2}\left(e^{-iFt}\sum_{\ell}\sum_{s=\uparrow\downarrow}\hat{b}^{+}_{\ell,s}\hat{b}_{\ell+1,s} + h.c.\right) + W\sum_{\ell}\hat{n}_{\ell\uparrow}\hat{n}_{\ell\downarrow}$$

Factorisation [5]:

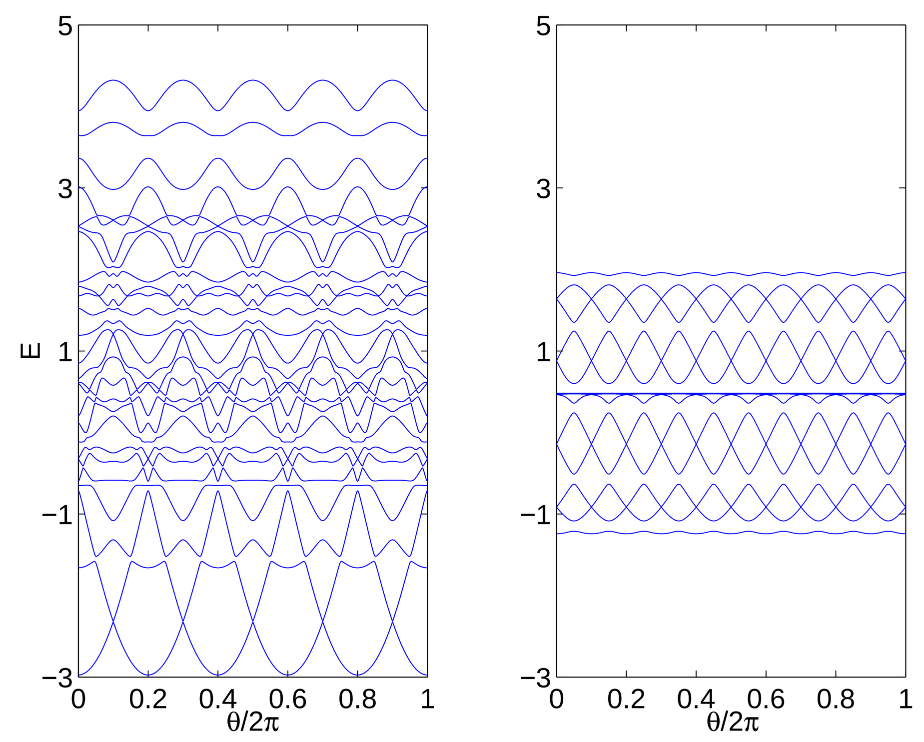
$$H = \bigoplus_{(\kappa,s,s_f)} H^{(\kappa,s,s_f)},$$

where κ - the total quasimomentum, s - the total spin, s_f - the spin flip symmetry quantum number

LEVEL DYNAMICS

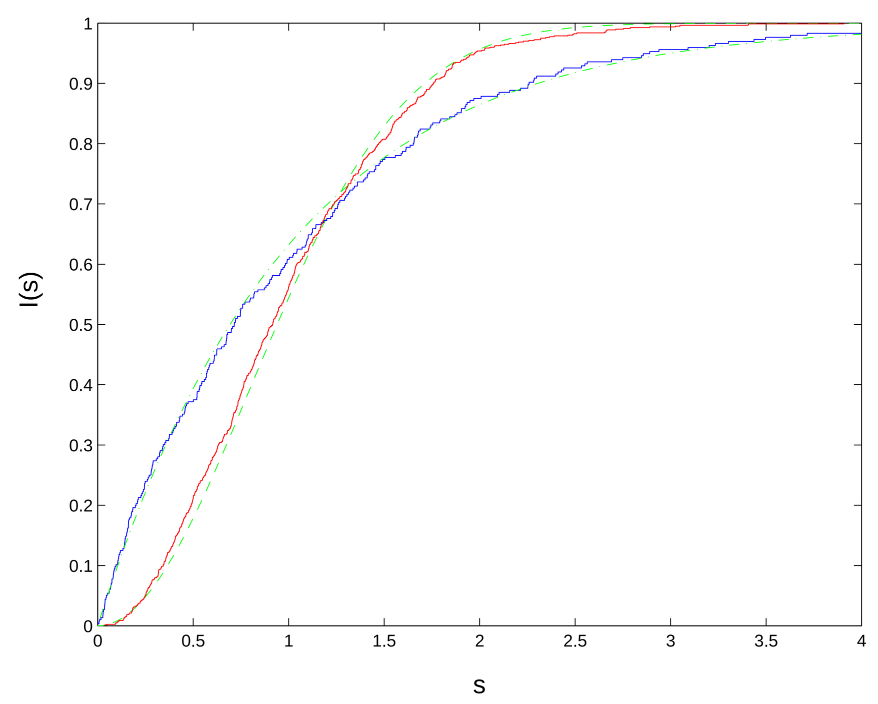


Energy levels of the unperturbed Hubbard Hamiltonian, for bosons (left panel) and fermions (right panel), as a function of the parameter u ($u = W, J = 1 - u$). $N = 5$ ($N_\uparrow = 3$, $N_\downarrow = 2$ for the fermionic case), with periodic boundary conditions. Only the levels of $\kappa = 2\pi/L$ symmetry are shown.



Instantaneous spectrum of $\widehat{H}(t)$ of the Bose (left panel) and of the Fermi problem (right panel), as a function of the parameter $\theta = Ft$. $u = 0.3$, $N = 5$ (Bose), $N = N_\downarrow + N_\uparrow = 3 + 2$ (Fermi), L = 5. Only the levels with $\kappa = 0$ and $S = 1/2$ (for fermions) symmetry are shown.

LEVEL STATISTICS



Integrated level spacing distribution $I(s)$ for the unperturbed system (red solid line - Bose, blue solid line - Fermi), compared to theoretical RMT distributions:

Poisson distribution (dashed-dotted line),

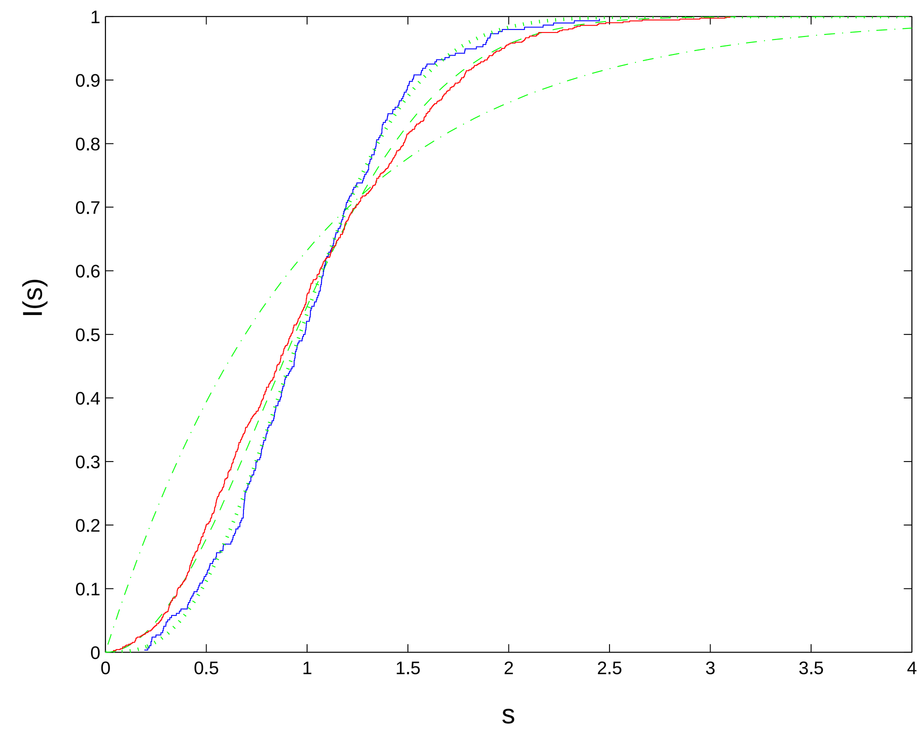
$$I(s) = 1 - \exp(-s)\,, \quad s = \frac{E_{j+1} - E_j}{\langle E_{j+1} - E_j\rangle}$$

Wigner-Dyson distribution (GOE) (dashed line)

$$I(s) = 1 - \exp\left(-\frac{\pi s^2}{4}\right)$$

Integrated level spacing distribution of the Floquet-Bloch operator :

$$\widehat{U}(T_B) = \widehat{exp}\left(-\frac{i}{\hbar}\int_0^{T_B} dt\widehat{H}(t)\right)$$

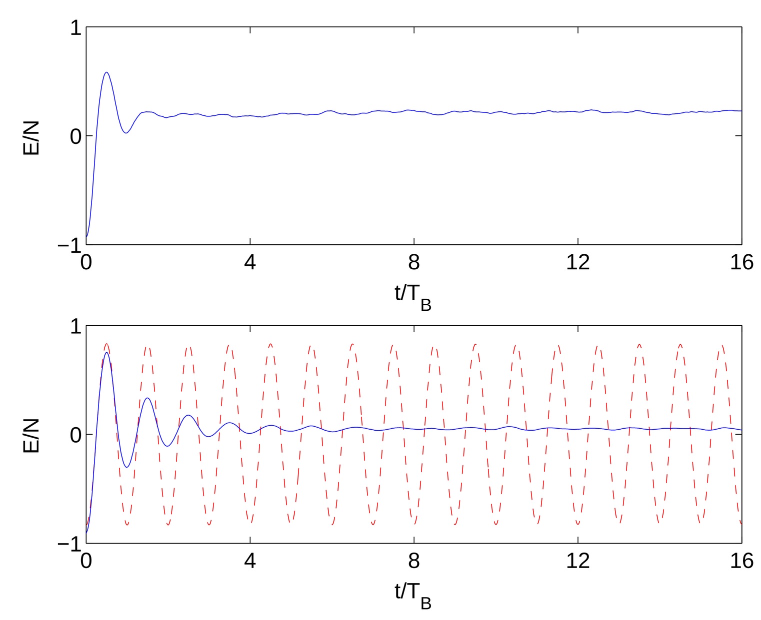


dotted line: CUE statistics,

$$I(s) = \mathrm{erf}\left(\frac{2s}{\sqrt{\pi}}\right) - \frac{4}{\pi}s\exp\left(-\frac{4}{\pi}s^2\right).$$

Bloch oscillation of the average energy

$$E(t) = \langle\Psi(t)|\widehat{H}(t)|\Psi(t)\rangle$$



Bloch oscillations of the average energy for Bose (top) and Fermi (bottom) atoms. $N = 5$, $L = 15$, $J = W = 1$, and $F = 0.2$. Dashed and solid lines in the lower panel correspond to spin-polarised ($N_\uparrow = 5$, $N_\downarrow = 0$) and unpolarised ($N_\uparrow = 3$, $N_\downarrow = 2$) samples, respectively. The system is initially prepared in the ground state of the unperturbed 1D Hubbard Hamiltonian.

RESULTS

- Integrated level spacing distribution of the unperturbed Hamiltonian has Poissonian statistics (as expected for integrable systems)
- A static force breaks reflection (and quasi-spin, not shown here) symmetry of the 1D Hubbard model
- Integrated level spacing distribution of the Floquet-Bloch operator exhibits Wigner-Dyson statistics (CUE)
- Bloch oscillations decay irreversibly, similar to the bosonic case [6]

References

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