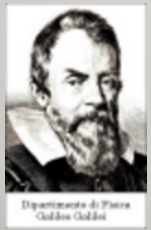

Ministero
Istruzione
Università
Ricerca

Out-Of-Equilibrium States and quasi Many-Body Localization in Polar Lattice Gases

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F I R B
Fondo per gli Investimenti della Ricerca di Base

LB, C. Menotti, A. Recati, L. Santos arXiv:1505.02028

Fondazione
Cassa di Risparmio
di Padova e Rovigo

Plan of the Talk

Introduction (breaf) to repulsive bound atom pairs (only contact intercation)

Introduction (breaf) to dipolar gases

2-body bound states for dipolar particles

2-body dynamics

Many-body dynamics, effective repulsive gas and clusters

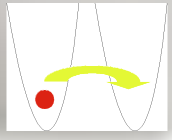
Quasi Many-Body localization

Experimental feasibility and Conclusions

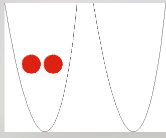
Atoms in Optical Lattice

Neutral Atoms (Bosons) trapped in optical lattice are usually well described by single band Hubbard Models

$$H = -J \sum_{\langle ij \rangle} b_i^\dagger b_j + \frac{U}{2} \sum_i n_i(n_i - 1)$$

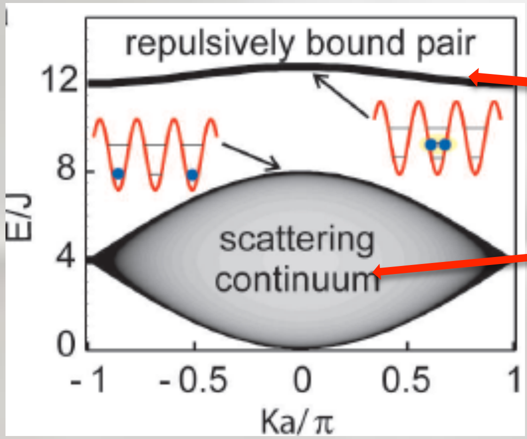


Hopping probability

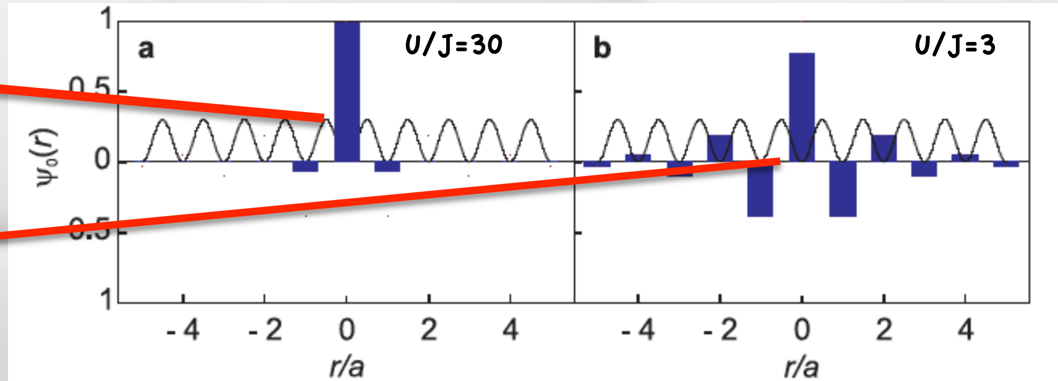


On-site interaction depending by the s-wave scattering lenght a_s

Energy Spectrum



Wave Function



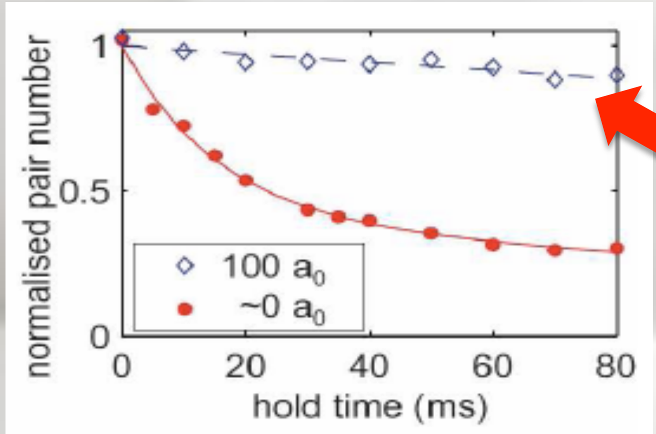
Nature 441, 853 (2006)

Repulsive Bound Atom Pairs

$$H = -J \sum_{\langle ij \rangle} b_i^\dagger b_j + \frac{U}{2} \sum_i n_i(n_i - 1)$$

Grimm's group ^{87}Rb
Nature 441, 853 (2006)

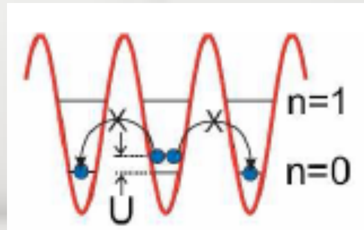
The sample is initially prepared with only pairs and empty sites

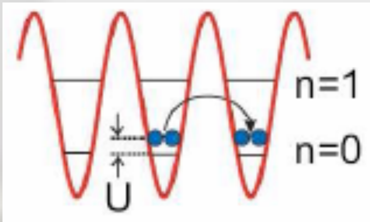


The Number of pairs is conderved!!!

ABSENCE OF DISSIPATION

BAND STRUCTURE



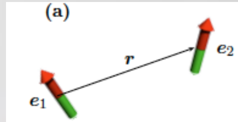


Analogously if initially the sample is composed only by singlons and empty sites, pair formation is forbidden even for strong attractive U, see

Nagerl's group PRL 108, 215302 (2012)

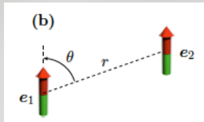
Systems with Dipolar Interaction

Dipolar 2-body interaction $U_{dd}(\mathbf{r}) = \frac{C_{dd}}{4\pi}\frac{(\mathbf{e}_1\cdot\mathbf{e}_2)r^2 - 3(\mathbf{e}_1\cdot\mathbf{r})(\mathbf{e}_2\cdot\mathbf{r})}{\mathbf{r}^5}$

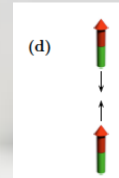


external field

$$U_{dd}(\mathbf{r}-\mathbf{r'}) = \frac{C_{dd}}{4\pi}\frac{1-3\cos^2\theta}{|\mathbf{r}-\mathbf{r'}|^3}$$



attractive



repulsive

1D optical lattice

Peculiar Dipolar Contribute

$$H = J\sum_{<ij>} b_i^\dagger b_j + \frac{U}{2}\sum_i n_i(n_i-1) + V\sum_{i<j}\frac{n_i n_j}{r_{ij}^3}$$

Magnetic Atoms with a permanent magnetic dipol Cr, Er, Dy

(Experiments: Stuttgard, Paris, Innsbruck, Illinois...) $\mu \sim (6-10)\mu_B$

Polar Molecules with electric dipolar momentum RbCs, LiCs, KRb, NaK

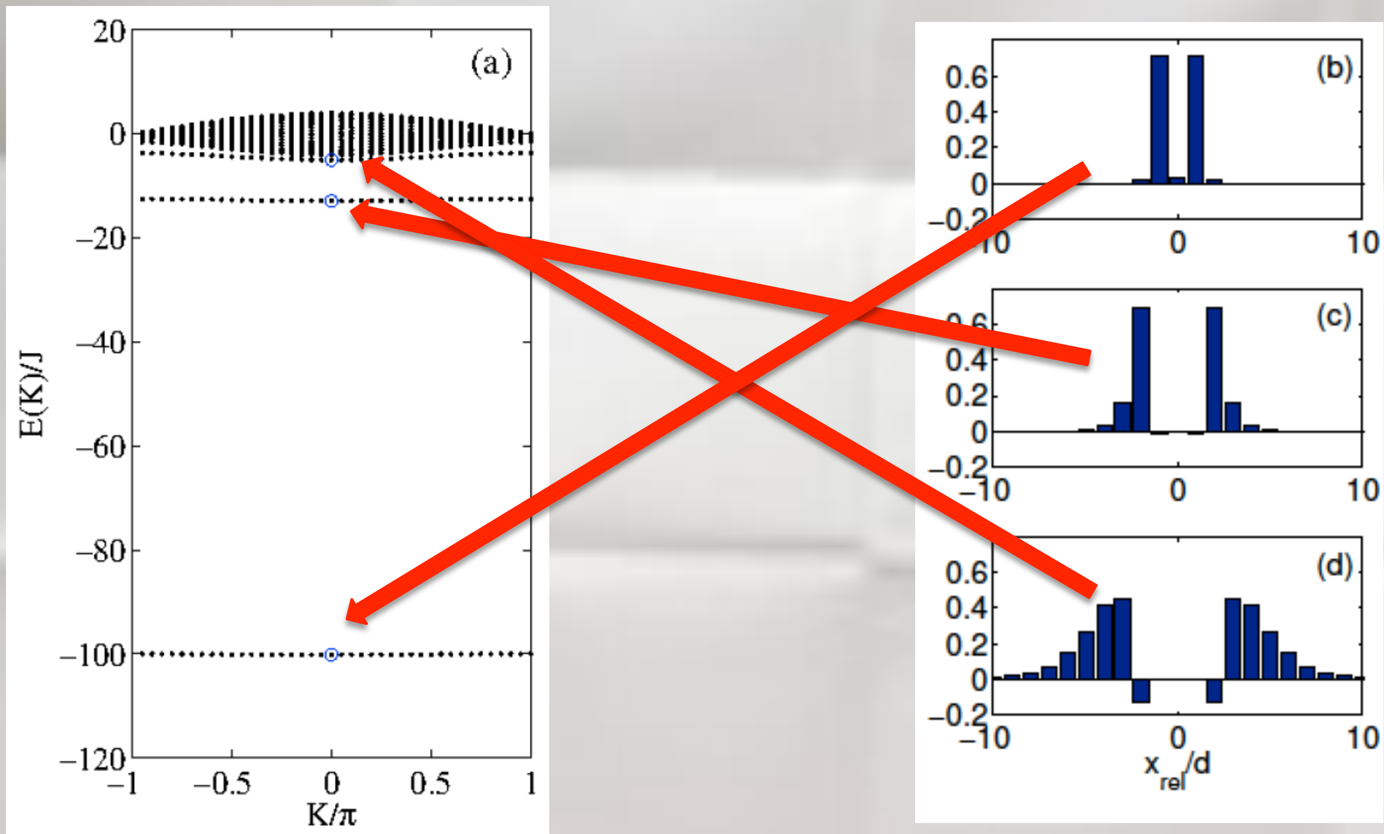
(Experiments: Innsbruck, Jila, Munich, MIT, Trento...) $d \sim (0.5-5.6)D$

2-body bound states with dipolar interaction

$$H = J \sum_{<ij>} b_i^\dagger b_j + \frac{U}{2} \sum_i n_i(n_i - 1) + V \sum_{i<j} \frac{n_i n_j}{r_{ij}^3}$$

2-particles energy spectrum as a function of the center-of-mass quasi-momuntum K, for U=0 and V=-100

Probability of finding 2 particles r sites apart for K=0



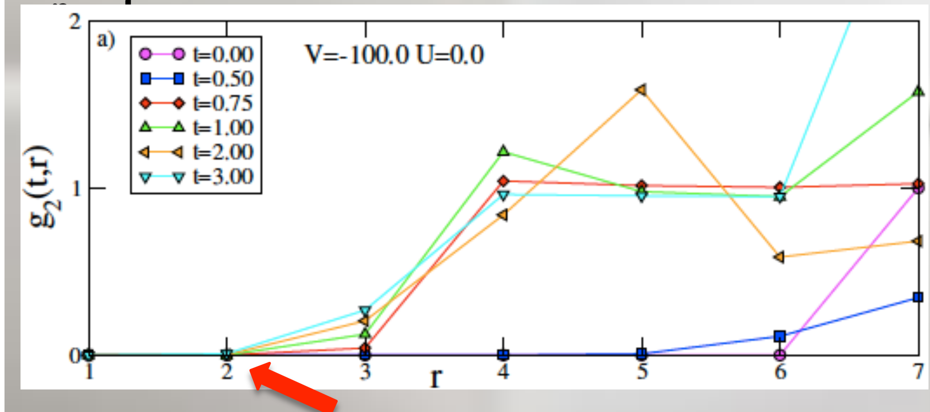
LOCALIZED

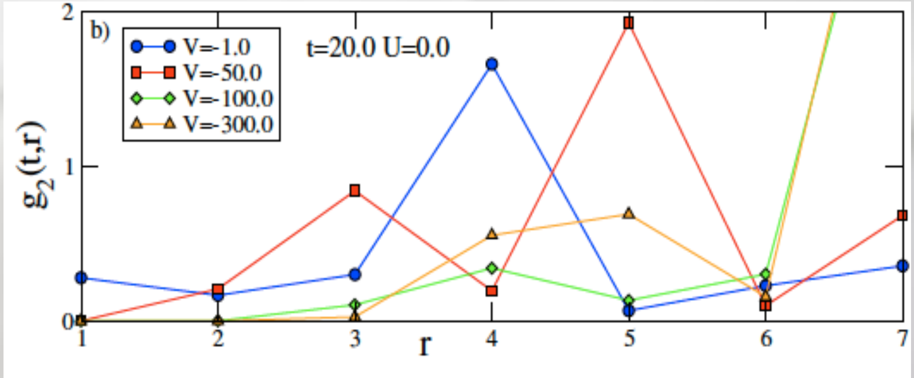
DELOCALIZED

2-body dynamical properties

2 particles at t=0 localized 6 sites

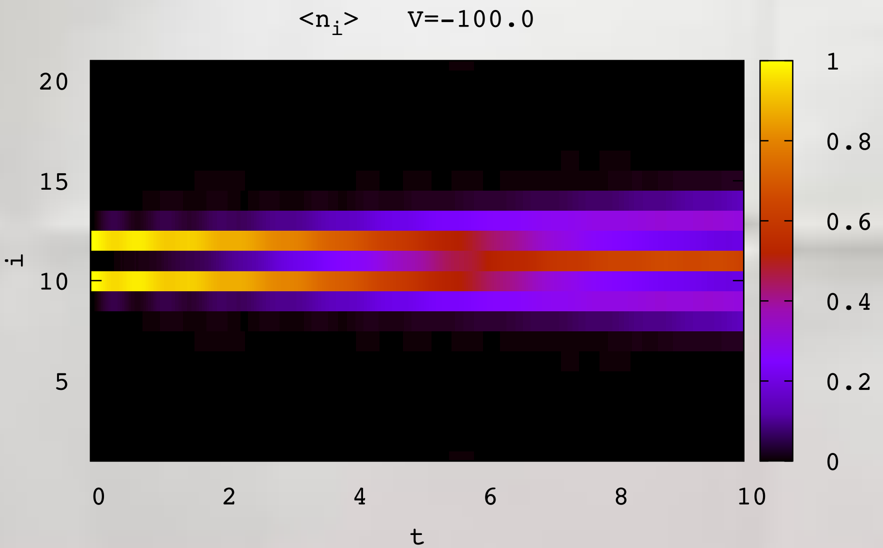
$$g_2(r,t) = \frac{\langle n_i(t) n_{i+r}(t)\rangle}{\langle n_i(t)\rangle\langle n_i + r(t)\rangle}$$





The particles feel an effective repulsion!!!the range of repulsion is r_c

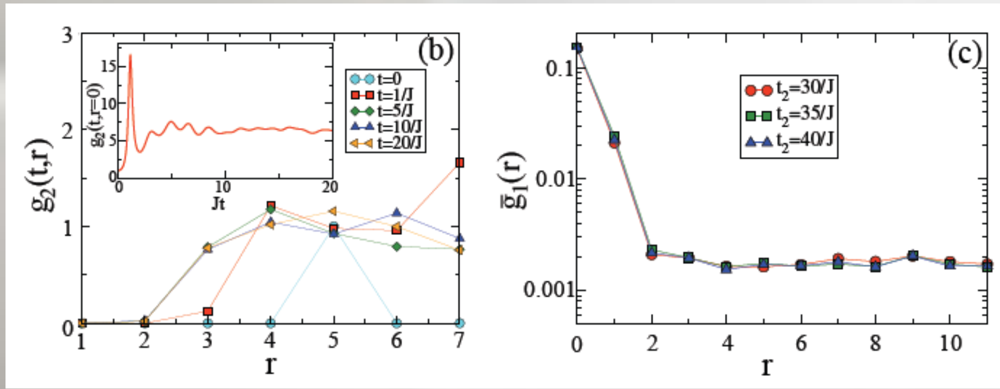
2 particles at t=0 at distance $r<r_c$ and V=-100



The atoms form a pair extended over three sites, and the pair will tunnel with an effective $J_{eff} \approx J^2/V$

Many-Body Dynamics

4 particles at t=0 located at distance $r>r_c$ V=-100

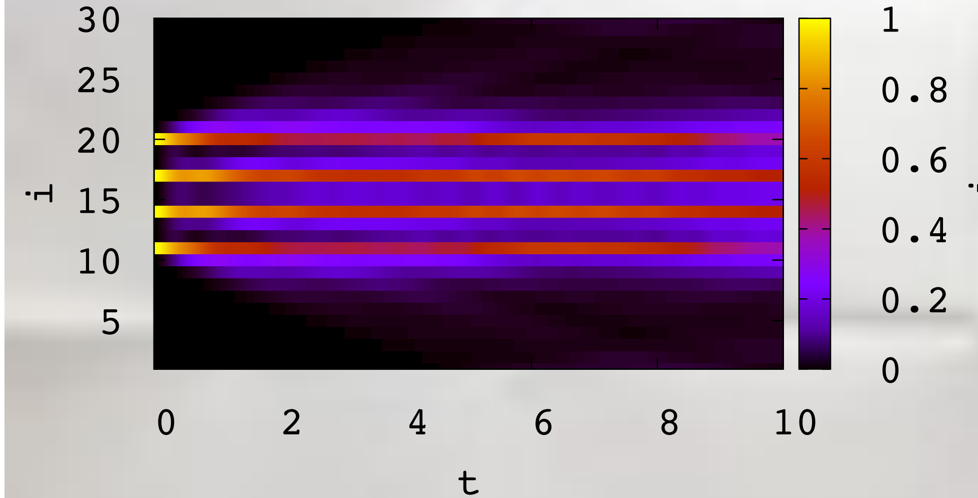


$$\bar{g}_1 = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} dt \langle b_i^\dagger(t) b_{i+r}(t) \rangle \qquad J(t_2 - t_1) = 5$$

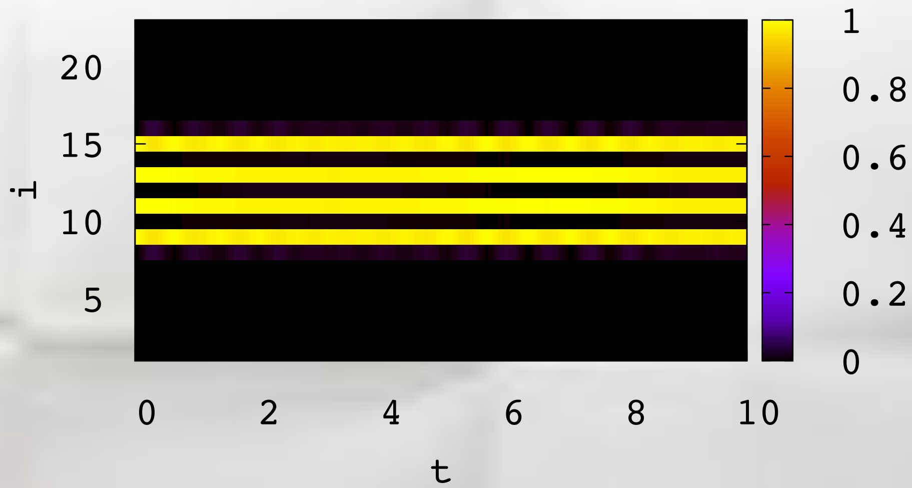
The system equilibrates in an effective repulsive gas!!! (Super-Tonks?)

4 particles at t=0 located at $r \leq r_c$ V=-100

$\langle n_i \rangle (t)$



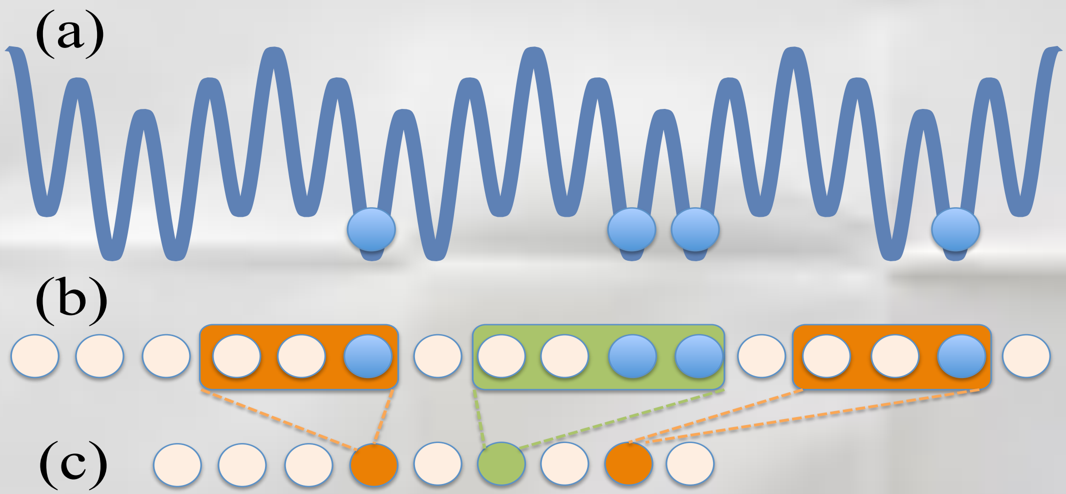
$\langle n_i \rangle (t)$



Particles form a cluster!!!expanding with $J(J/V)^{N-1}$

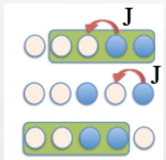
Effective Model

Dimerized Super-Optical Lattice with $V=-100 \rightarrow r_c=2$,

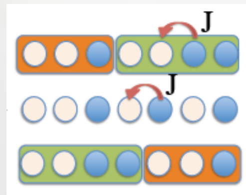


Singlon **S** expanding with J 1°-order processes

Doblon **D** expanding with $J_D=8J^2/7V$ 2°-order processes



Swap **DS**⟷**SD** with $\Omega=4J^2/3V$ 2°-order processes



$$H_{eff} = -\sum_{\langle ij\rangle}(JS_i^\dagger S_j + J_D D_i^\dagger D_j + \Omega D_i^\dagger S_j^\dagger S_i D_j)$$

Mixture of heavy and light particles!!! many-body localization in absence of quenched disorder???

M. Schiulaz, M. Muller AIP Conf. Proc. 1610, 11 (2014); M. Schiulaz, A. Silva, M. Muller PRB 91, 184202 (2015)

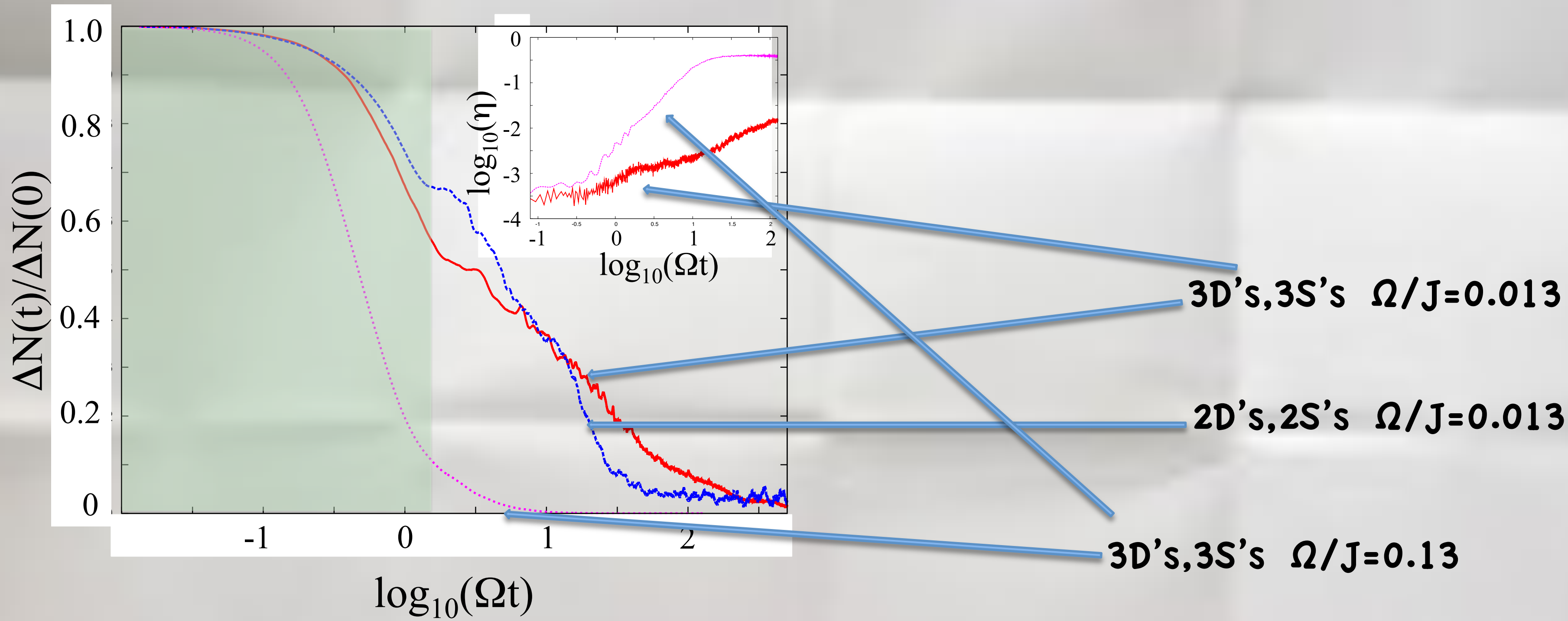
Quasi Many-Body Localization without disorder

MBL:no diffusion and transport, particles explore a small fraction of all possibles states

$N_i = D_i^\dagger D_i \quad \Delta N = \frac{1}{L}\sum_j |\langle\psi(t)|N_j - N_{j+1}|\psi(t)\rangle|$ =0 means perfect homogeneity

n_{max}=many-body Fock states |ν> accounting for all possible distributions of S's and D's

$\eta(t) = \frac{1}{n_{max}}[\sum_\nu |\psi(\nu,t)|^4]^{-1}$ → ≈1 fully delocalized; → ≈$1/n_{max}$ localized



Recent Experiment by Bloch's group [Science 349, 842 (2015)]

Experimental Feasibility and Conclusions

NaK molecules in the lowest ro-vibrational level (MIT,Munich,Trento), partially polarized with d=1D, lattice spacing a=532nm, $V/h \approx 1$KHz, lattice depth 18 E_R, $E_R/h \approx 2.75$kHz, $J/h \approx 10$Hz$=|V|/100$.

Fascinating 2- and many-body dynamics:

Effective repulsive gas
no losses no recombinations

Clusters

MBL in absence of quenched disorder

MBL ARISES NATURALLY DUE TO THE DIPOLAR INTERACTION!!!

THANK YOU