Atomtronics: computing with neutral atoms

Sandro Wimberger

Complex Dynamics in Quantum Systems

Dipartimento di Fisica – Parma University

ITP – Heidelberg University

ADVERTISEMENT

MANY THANKS TO

Georgios Kordas

Urs Waldmann (FR)

Collaborators

- Andreas Buchleitner (Freiburg, T)
- Andreas Komnik (Heidelberg, T)
- Herwig Ott (Kaiserslautern, E)
- Gil Summy (Stillwater, E)

Program

1. Motivation
2. Entanglement in Open Bose-Einstein condensates
3. Creation of steady state atomtronic currents
4. Atomtronic transport blockade
5. Perspectives

Program

1. Motivation
2. Entanglement in Open Bose-Einstein condensates
3. Creation of steady state atomtronic currents
4. Atomtronic transport blockade
5. Perspectives

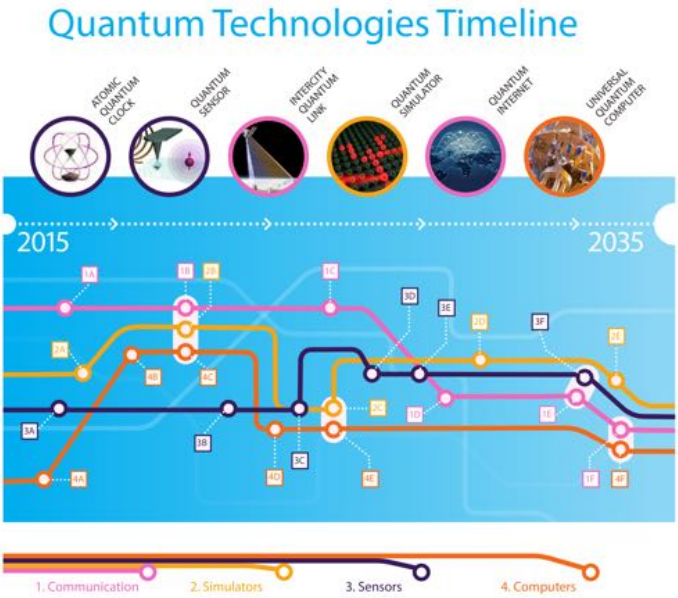
European Flagship Project


Science Home News Journals Topics Careers

SHARE

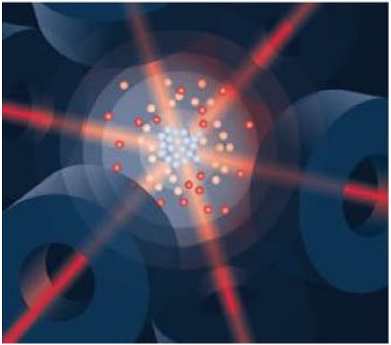
Europe to bet up to €1 billion on quantum technology

By Kai Kupferschmidt | Apr. 22, 2016 , 4:15 PM



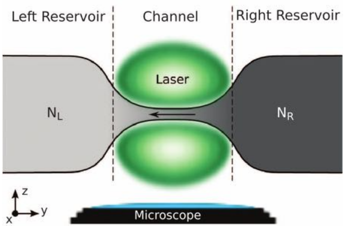
Quantum Technologies Timeline
ATOMIC QUANTUM CLOCK
QUANTUM SENSOR
INTERCITY QUANTUM LINK
QUANTUM SIMULATOR
QUANTUM INTERNET
UNIVERSAL QUANTUM COMPUTER
2015
2035
1A
1B
2B
1C
3D
3E
2D
3F
2E
2A
4B
4C
3A
3B
3C
2C
1D
1E
4A
4D
4E
1F
4F
1. Communication
2. Simulators
3. Sensors
4. Computers

- Simulation of motion of electrons in materials
- Development and design of new complex materials
- Quantum simulator of quantum magnetism and electricity
- Simulators of quantum dynamics of chemical reactions



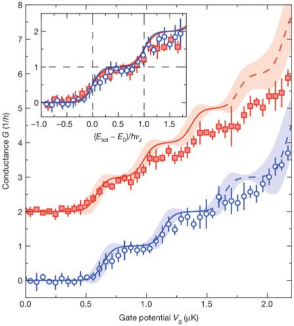
Atomtronics

Fermionic junction



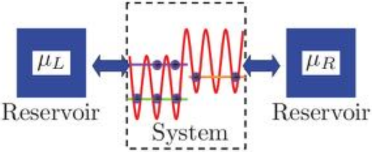
Esslinger, Science 2012

Single atom transport



Esslinger, Nature 2015

Transport cross array of quantum dots



Pepino et al., PRA 2010

Program

- Controlling quantum dynamics in experiments by

  periodic potential (discreteness), interactions & coupling to environment.

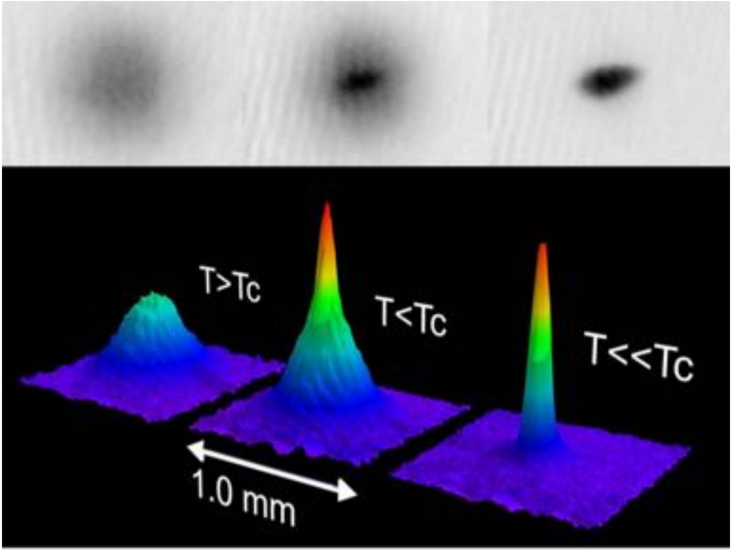
- Controlling quantum dynamics in experiments by

  periodic potential (discreteness), interactions & coupling to environment.

⇒ Atomtronic realizations of

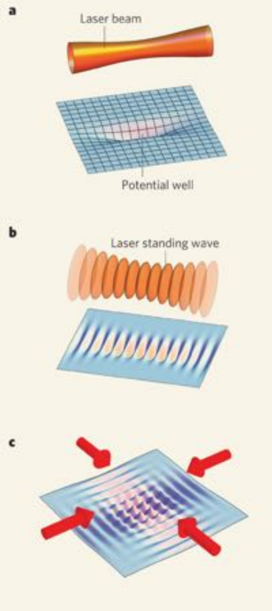
- blockade effects for transport control
- neutral atom transistors
- logic gates for quantum computing!

Bose-Einstein condensate

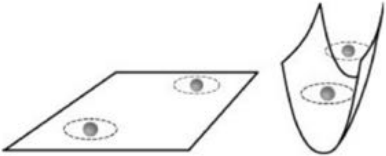


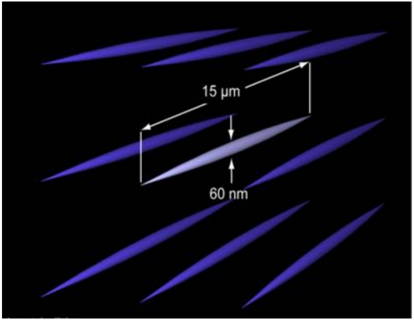
Bose-Einstein condensate

How to create an optical lattice?

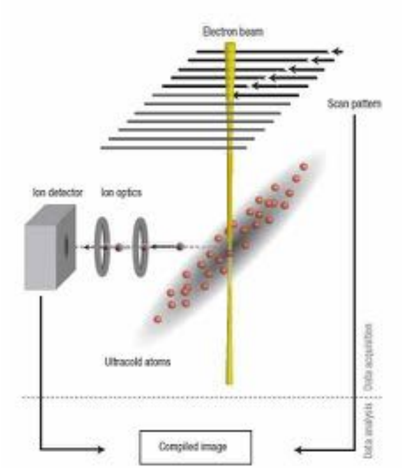


QUASI-1D STRUCTURES

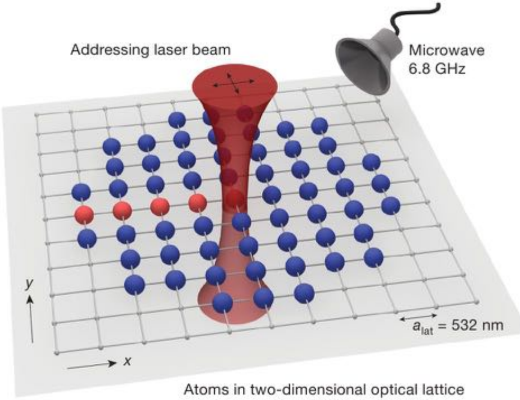




H. Ott (Kaiserslautern)



I. Bloch (Garching)



review: Kordas et al. EPJ ST 2015

Physics

Physics **2**, 23 (2009)

Viewpoint

Order out of noise

Fabio Marchesoni
Dipartimento di Fisica, Università di Camerino, I-62032 Camerino, Italy

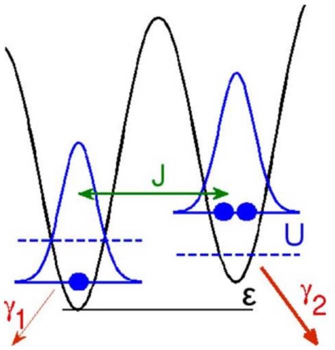
Published March 23, 2009

Subject Areas: Atomic and Molecular Physics, Interdisciplinary Physics

A Viewpoint on:

Optomechanical stochastic resonance in a macroscopic torsion oscillator
F. Mueller, S. Heugel and L. J. Wang
Phys. Rev. A **79**, 031804 (2009) – Published March 23, 2009

Dissipation-induced coherence and stochastic resonance of an open two-mode Bose-Einstein condensate
D. Witthaut, F. Trimborn and S. Wimberger
Phys. Rev. A **79**, 033621 (2009) – Published March 23, 2009



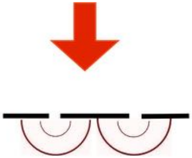
Two-mode Hubbard model:

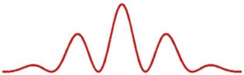
$$\hat{H} = -\frac{\mathbf{J}}{2}\left(\hat{a}_1^\dagger \hat{a}_2 + \hat{a}_2^\dagger \hat{a}_1\right) + \frac{\mathbf{U}}{2}\left[\hat{n}_1(\hat{n}_1 - 1) + \hat{n}_2(\hat{n}_2 - 1)\right]$$

with additional particle loss rates for the two sites:

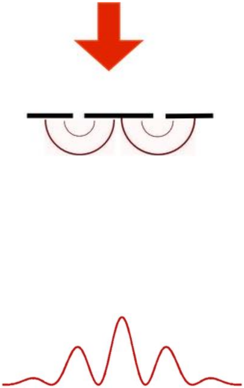
$$\gamma_1, \gamma_2 \longrightarrow \gamma_2 - \gamma_1 \, .$$

INTERFERENCE CONTRAST BETWEEN THE TWO WELLS





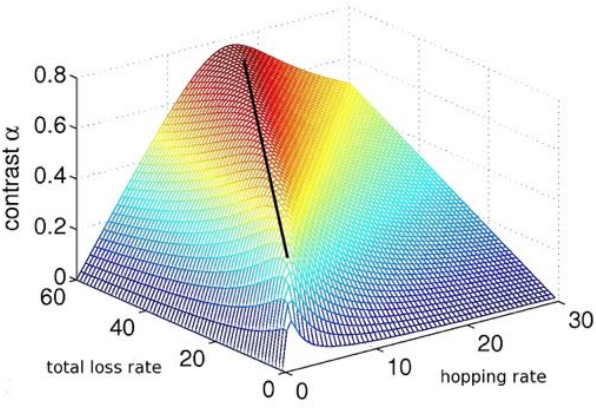
INTERFERENCE CONTRAST BETWEEN THE TWO WELLS



fringe contrast

$$\alpha = \frac{2|\langle \hat{a}_1^\dagger \hat{a}_2 \rangle|}{\langle \hat{n}_1 + \hat{n}_2 \rangle}$$

Gati et al. NJP 2006

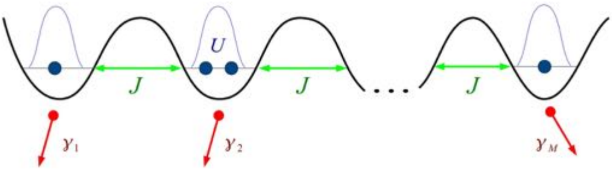


Maximum if external and internal time scales match:

$$\mathbf{J} \approx |\gamma_2 - \gamma_1|$$

Witthaut, Trimborn, SW PRL 2008, PRA 2009

$$\hat{H} = -\frac{\mathbf{J}}{2}\sum_{j=1}^{L-1}\left(\hat{a}^\dagger_{j+1}\hat{a}_j + \hat{a}^\dagger_j\hat{a}_{j+1}\right) + \frac{\mathbf{U}}{2}\sum_{j=1}^{L}\hat{a}^\dagger_j\hat{a}^\dagger_j\hat{a}_j\hat{a}_j.$$



Dissipation: The dynamics is given by the Lindblad equation:

$$\dot{\hat{\rho}} = -i[\hat{H}, \hat{\rho}] + \mathcal{L}\hat{\rho}.$$

review: Kordas et al. EPJ ST 2015

- **Localized single particle loss:**

$$\mathcal{L}_{\text{loss}}\ \hat{\rho} = -\sum_{j=1}^{L} \gamma_{\mathbf{j}} \left(\hat{a}_j^\dagger \hat{a}_j \hat{\rho} + \hat{\rho} \hat{a}_j^\dagger \hat{a}_j - 2\hat{a}_j \hat{\rho} \hat{a}_j^\dagger \right)$$

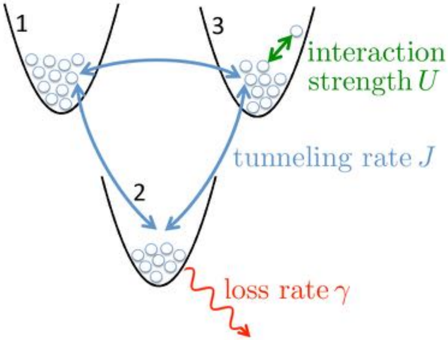
- **Phase noise:**

$$\mathcal{L}_{\text{phase}}\ \hat{\rho} = -\frac{\kappa}{2} \sum_{j=1}^{L} \left(\hat{n}_j^2 \hat{\rho} + \hat{\rho} \hat{n}_j^2 - 2\hat{n}_j \hat{\rho} \hat{n}_j \right)$$

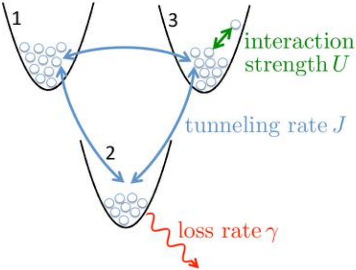
Start: Bose-Einstein condensate with an anti-symmetric wavefunction

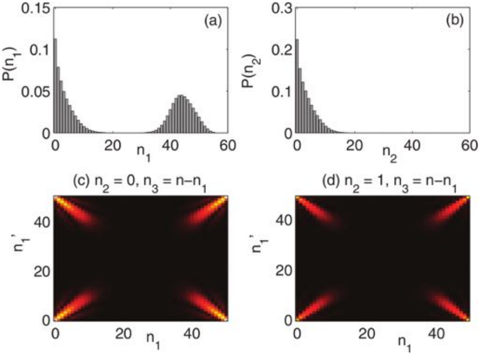
$$|\Psi_-\rangle = \frac{1}{2^N\sqrt{N!}}(\hat{a}_1^\dagger - \hat{a}_3^\dagger)^N|0\rangle$$

Proposed setup:



Formation of entangled NOON states

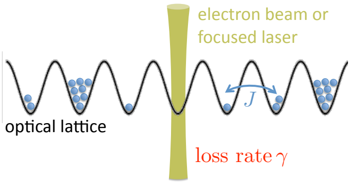


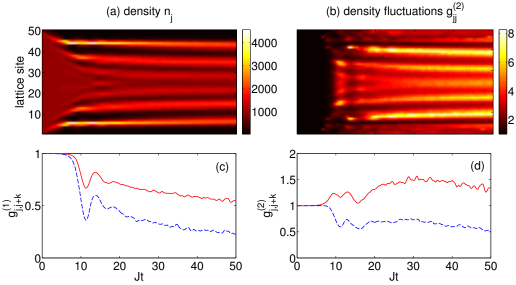


- Formation of robust states: Precision measurements!

  Kordas, SW, Witthaut EPL 2012

- Density matrix projection: Bimodal particle distribution





- Many-body stability of solitonic (very coherent) states!?
- Formation by approach to attractor in open system's dynamics

Kordas, SW, Witthaut PRA 2013

Program

UNIVERSITÀ DEGLI STUDI DI PARMA
DIPARTIMENTO DI FISICA E SCIENZE DELLA TERRA
"MACEDONIO MELLONI"

DIPARTIMENTO DIDATTICA RICERCA SERVIZI

Cerca con Google

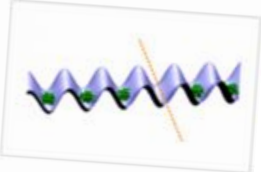
Home

Atomtronica, pubblicato un importante lavoro scientifico del prof. Wimberger

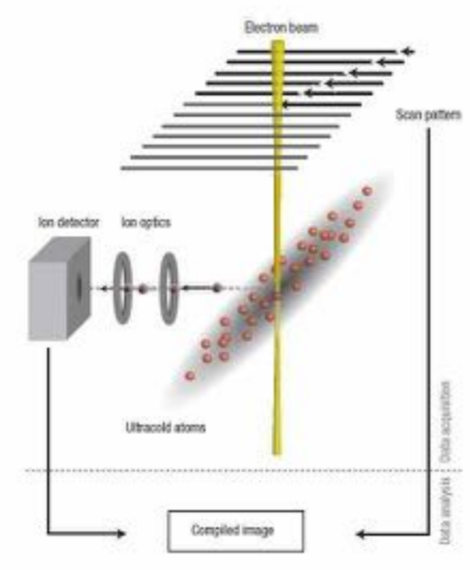
Lo studio del docente del Dipartimento di Fisica è apparso sulla rivista Physical Review Letters

Nel Dipartimento di Fisica e Scienze della Terra "Macedonio Melloni" del nostro Ateneo, il prof. Sandro Wimberger e i suoi collaboratori lavorano sulla **teoria di progettazione di sistemi atomtronici**, operando in un **contesto internazionale**, in cui la parte sperimentale è affidata al **gruppo del prof. Herwig Ott dell'Università tedesca di Kaiserslautern.**

Il primo frutto di questa collaborazione è costituito dal lavoro scientifico Negative differential conductivity in an interacting quantum gas, pubblicato recentemente sull'importante rivista **Physical Review Letters.**



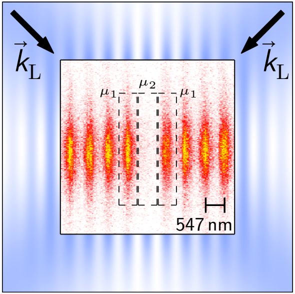
Experimental control of the loss



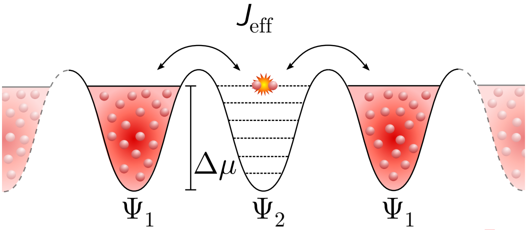
review: Kordas et al. EPJ ST 2015

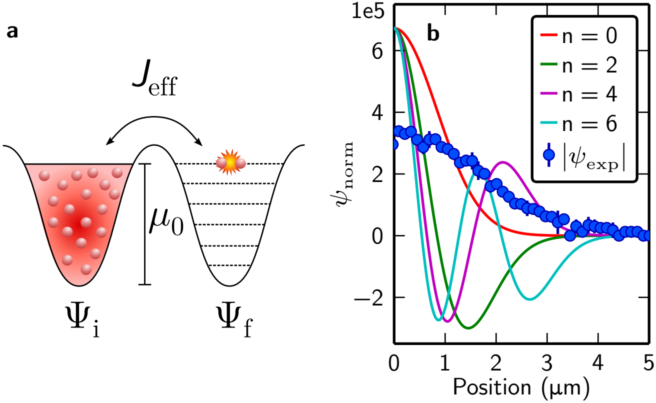
Refilling dynamics of an empty site

(a)



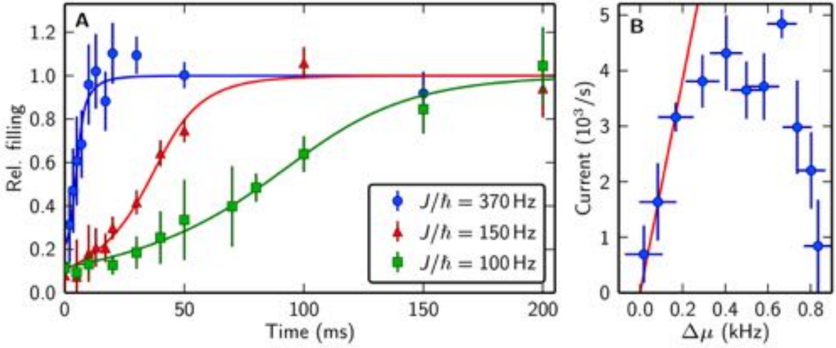
(b)





⟶ Radial tunneling coupling

Labouvie, Santra, Heun, W, Ott, PRL 2015



$\longrightarrow$ Nonlinear current-voltage characteristics!

Labouvie, Santra, Heun, W, Ott, PRL 2015

Effective model for NDC effect

Effective tunneling coupling with nonlinearity and radial coupling:

$$J_{\text{eff}}\left(\Delta\mu\right) = J - \left(1-\eta\right) J \cdot \Delta\mu/\mu_0 \times 1.7\,,$$

and fast local thermalization due to collisions in the initially empty site:

$$i\hbar\partial_t\hat{\rho} = \left[\hat{H}_{\text{eff}}, \hat{\rho}\right] + i\hbar\mathcal{L}\hat{\rho}$$

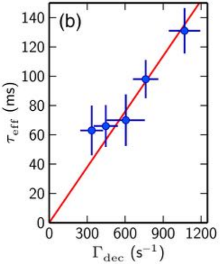
with dephasing model:

$$\mathcal{L}\hat{\rho} = \Gamma_{\text{dec}}\left(2\hat{n}_c\hat{\rho}\hat{n}_c^{\dagger} - \hat{n}_c^2\hat{\rho} - \hat{\rho}\hat{n}_c^2\right)$$

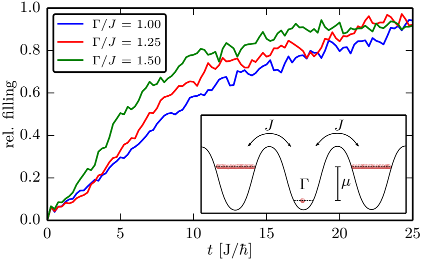
Labouvie, Santra, Heun, W, Ott, PRL 2015

2D EXPERIMENT VS. 1D THEORY

2D experimental Josephson junctions with dephasing:



1D many-body Josephson junctions with dephasing:



PROGRAM

RHEIN-NECKAR-ZEITUNG

Dienstag, 6. Mai 2014 | Heidelberg 22 °C

Immobilienmarkt | Stellen

STARTSEITE POLITIK SPORT WIRTSCHAFT PANORAMA WISSEN KULTUR & TIPPS RATGEBER

Wissenschaft Regional Wissenschaft Computer & Web Medien Region im Netz Campus

Sie sind hier » Startseite » Wissenschaft Regional » Artikel

Empfehlen Tweet +1

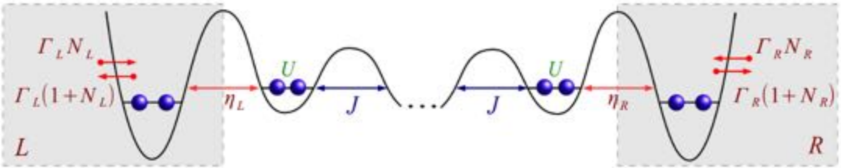
Stromübertragung auf atomarer Ebene

Heidelberger Physiker entwickeln einen neuen Ansatz, Bauteile zur Signalverarbeitung aus einzelnen Atomen herzustellen.

09.04.2014, 06:00

kum/rnz. In einer Studie zum Transport von Atomen in ultrakalten Gasen hat ein Team von Physikern um Dr. Sandro Wimberger einen neuen Ansatz zu der Frage entwickelt, wie sich die Übertragung von Strom auf atomarer Ebene realisieren lässt. Dies könnte für die Herstellung von logischen Bauelementen mit fest definierten Funktionen auf der Basis einzelner Atome von besonderer Bedeutung sein und zum Beispiel in Transistoren oder Dioden Anwendung finden.

THE GENERAL SETUP



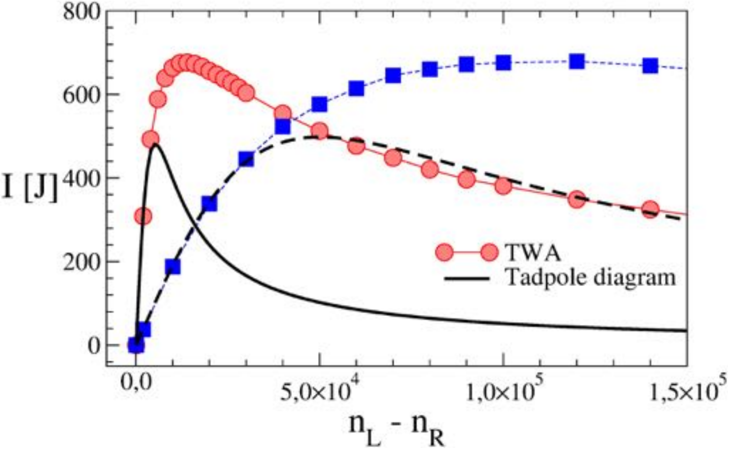
$$\hat{H} = \sum_{j=1}^{M} \epsilon_j \hat{a}_j^\dagger \hat{a}_j - \frac{\mathbf{J}}{2} \sum_{j=1}^{M-1} \left(\hat{a}_{j+1}^\dagger \hat{a}_j + \hat{a}_j^\dagger \hat{a}_{j+1} \right) + \frac{\mathbf{U}}{2} \sum_{j=2}^{M-1} \hat{a}_j^\dagger \hat{a}_j^\dagger \hat{a}_j \hat{a}_j$$

$$+ \sum_k \beta_k \hat{l}_k^\dagger \hat{l}_k + \sum_k \beta_k' \hat{r}_k^\dagger \hat{r}_k$$

$$- \sum_k \eta_{\mathbf{k,L}} \left(\hat{a}_1^\dagger \hat{l}_k + \hat{l}_k^\dagger \hat{a}_1 \right) - \sum_k \eta_{\mathbf{k,R}} \left(\hat{a}_L^\dagger \hat{r}_k + \hat{r}_k^\dagger \hat{a}_L \right)$$

CENTRAL RESULT – STATIONARY STATE

Current vs. chem. potential: Interaction blockade



Ivanov, Kordas, Komnik, SW EPJ B 2013

NON-INTERACTING LIMIT $U_j = 0 = \epsilon_j$

Mean occupation numbers for $x = J/\Gamma$:

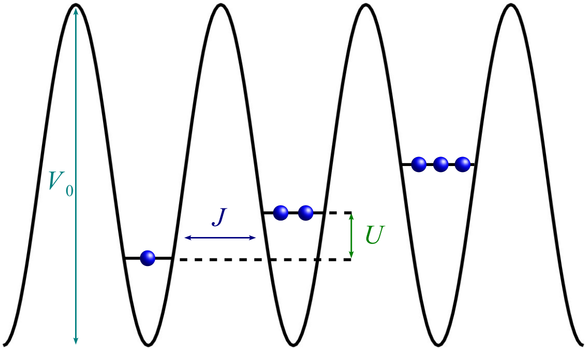
$$n_1 = n_L - \frac{n_L - n_R}{2} \frac{x^2}{1+x^2}$$
$$n_2 = \frac{n_L + n_R}{2}$$
$$n_3 = n_R - \frac{n_R - n_L}{2} \frac{x^2}{1+x^2}$$

Steady-state current:

$$I = J \frac{x}{1+x^2} (n_L - n_R)$$

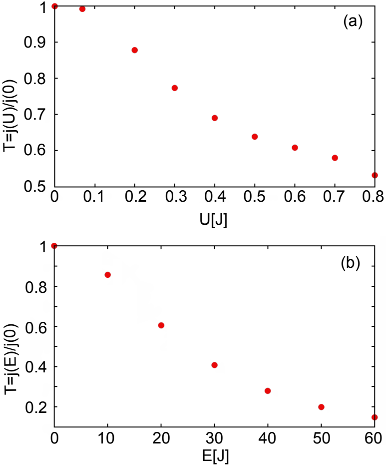
→ Implying an Ohmic behavior!

Steady-state current control: blockade (a) and local level detuning (b)



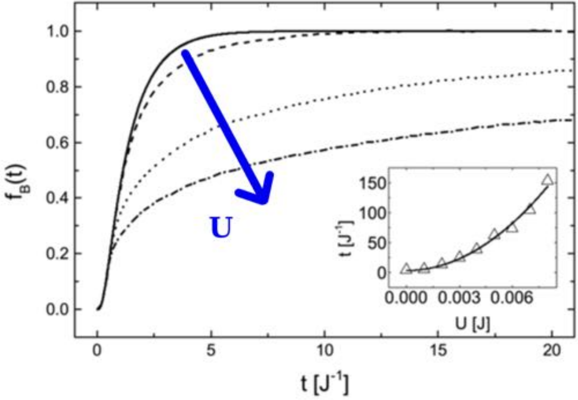
RESONANT TUNNELING VS. INTERACTIONS

Steady-state current control: blockade (a) and local level detuning (b)



c.f. Zenesini/Arimondo et al. NJP 2008; Schlagheck et al. NJP 2010

Time to reach a possible steady state increases with interaction **U**:



Methods for strong interactions and non-Markovian couplings!?

Program

Open questions

- New efficient computational methods for non-equilibirum dynamics of ultracold bosonic systems in the continuum and higher dimensions?

OPEN QUESTIONS

- New efficient computational methods for non-equilibirum dynamics of ultracold bosonic systems in the continuum and higher dimensions?

$\Rightarrow$ Realization of

- quantum transport with neutral interacting atoms!
- transport control: atom blockade effect!
- logic gates for atomtronics!?
- quantum thermalization and/or many-body localization!?

Invitation to Parma

Thank you very much!

- Kordas, Witthaut, SW: EPJ ST **224**, 2127–2171 (2015)
- Ivanov, Kordas, Komnik, SW: EPJ B **86**, 345 (2013)
- Labouvie, Santra, Heun, SW, Ott: PRL **115**, 050601 (2015)