DQMP Department of Quantum Matter Physics

Quantum transport in (1D) cold atomic systems

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FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

Science to shape the future of the Army
Army Research Office
1951

MaNEP SWITZERLAND

Theory:

A.-M. Visuri

M. Filippone





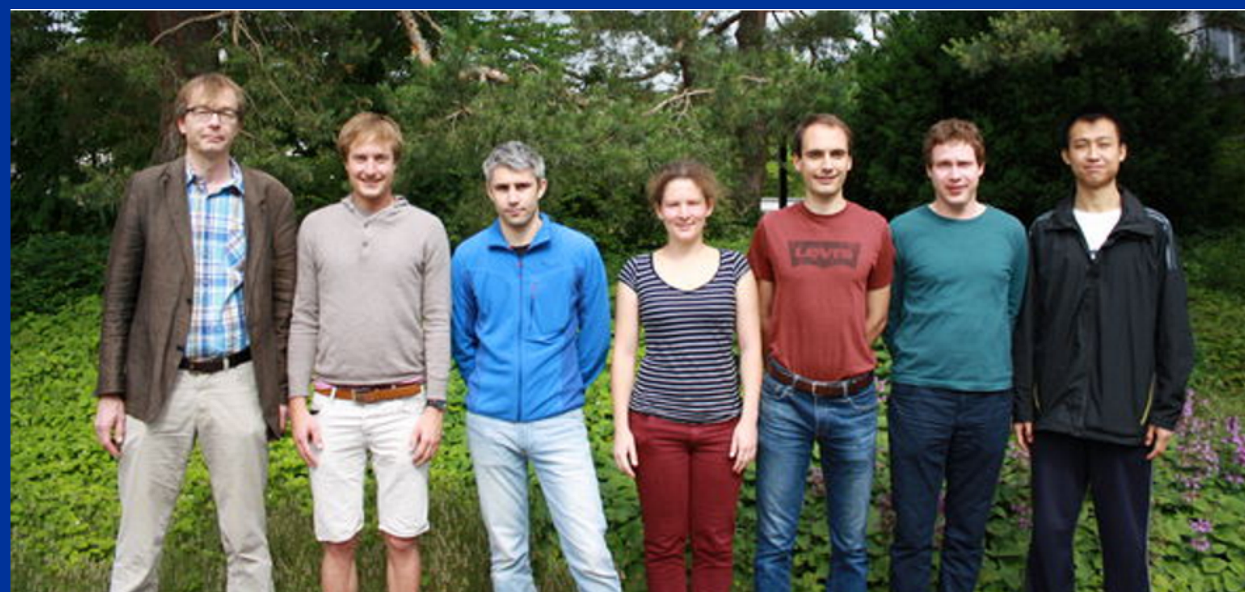

S. Uchino
Waseda U.

P. Grisins
X-rite

S. Greschner

C. Bardyn

Experiments:
Esslinger's
Brantut's
Groups
(ETHZ/EPFL)



From left to right: Tilman Esslinger, Dominik Husmann, Jean-Philippe Brantut, Laura Corman, Martin Lebrat, Samuel Häusler, Muqing Xu

Equilibrium vs Non equilibrium

- Well equipped to deal with equilibrium

$$Z = Tr[e^{-\beta H} \ldots]$$

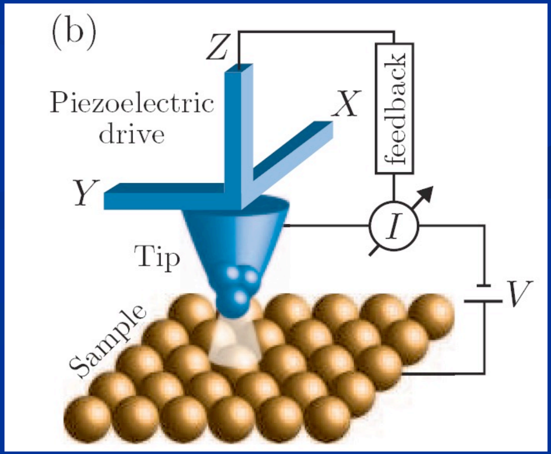
- Non eq: Methods ? / Concepts ?? (temperature, etc.)

- Linear response

$$I = GV$$

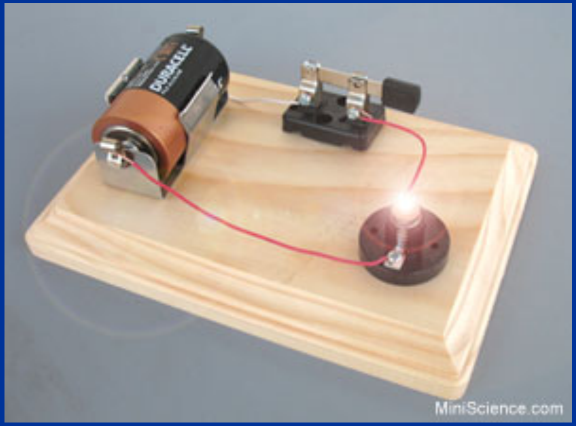
G computed from equilibrium

Not always possible



Should we bother

- Condensed matter
- Rapid (?) relaxation… but pump/probe exp.
- Steady state situations, or weird systems (glasses)

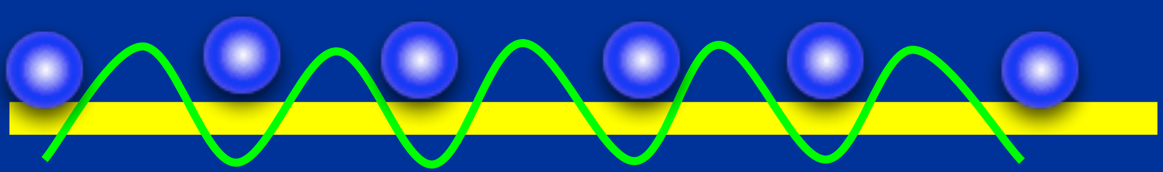


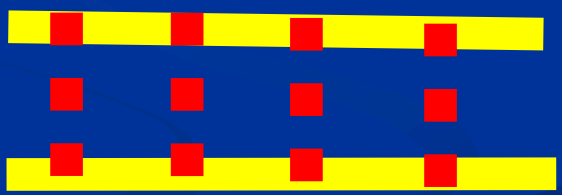
Out of equilibrium situations

- External noise

E. G. Dalla Torre, E. Demler, TG, E. Altman Nat Phys 6 806 (2010); PRB 85 184302 (2012)

- Global quench



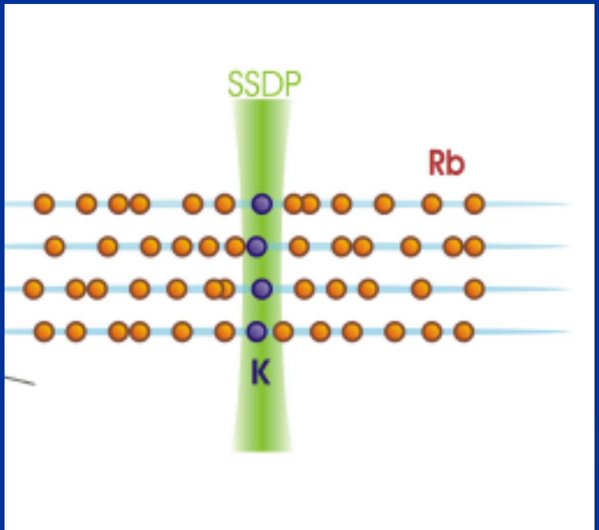


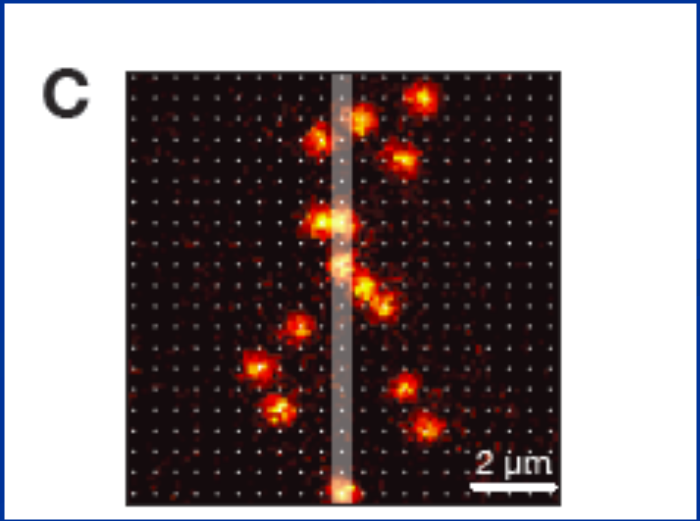
A. Mitra, TG PRL 107 150602 (2011); PRB 85 075117 (2012)
L. Foini, TG PRA 91 023627 (2015)

Out of equilibrium situations

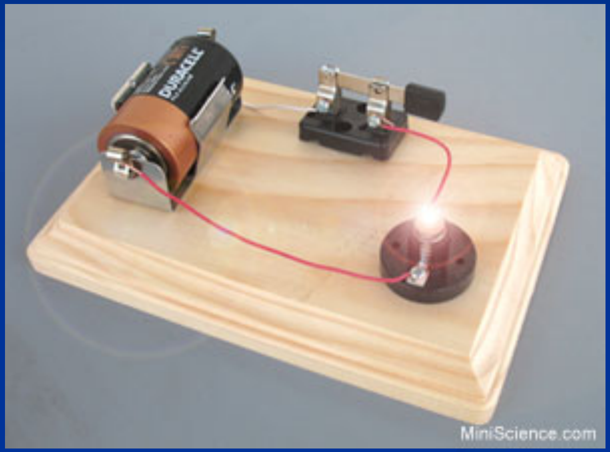
- Local quench (impurity)

M. Zvonarev, V. Cheianov, TG PRL (2007);
J. Catani et al, PRA 85 023623 (2012) ; T. Fukuhara, A. Kantian et al. Nat Phys. (2013)
A. Kantian, U. Schollwoeck, TG PRL 113 070601 (2015)





Steady state Out-of-Equilibrium: Transport



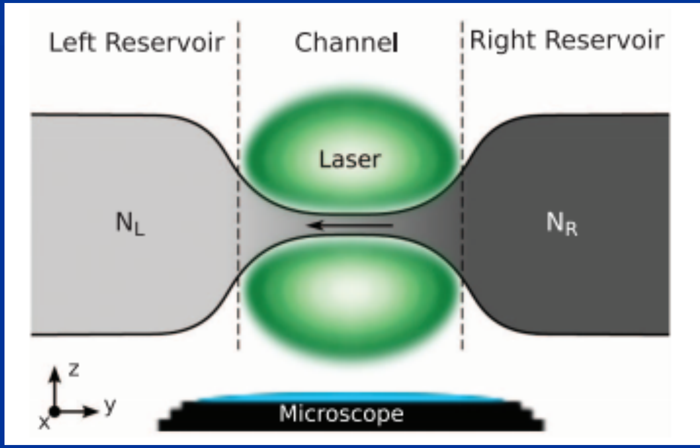
- The simplest form of out of equilibrium
- Reflects the quantum nature of the system (interferences – metal, insulator, etc.)

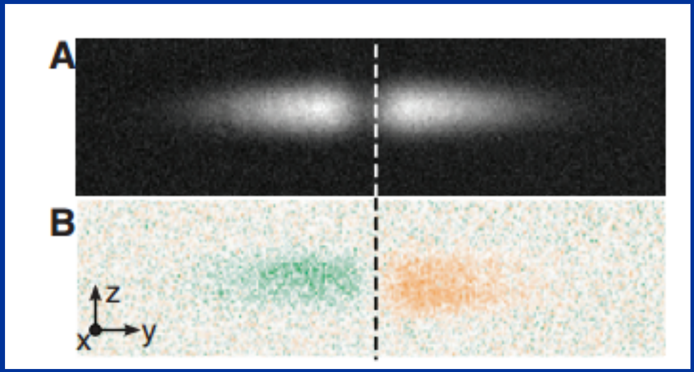
Transport

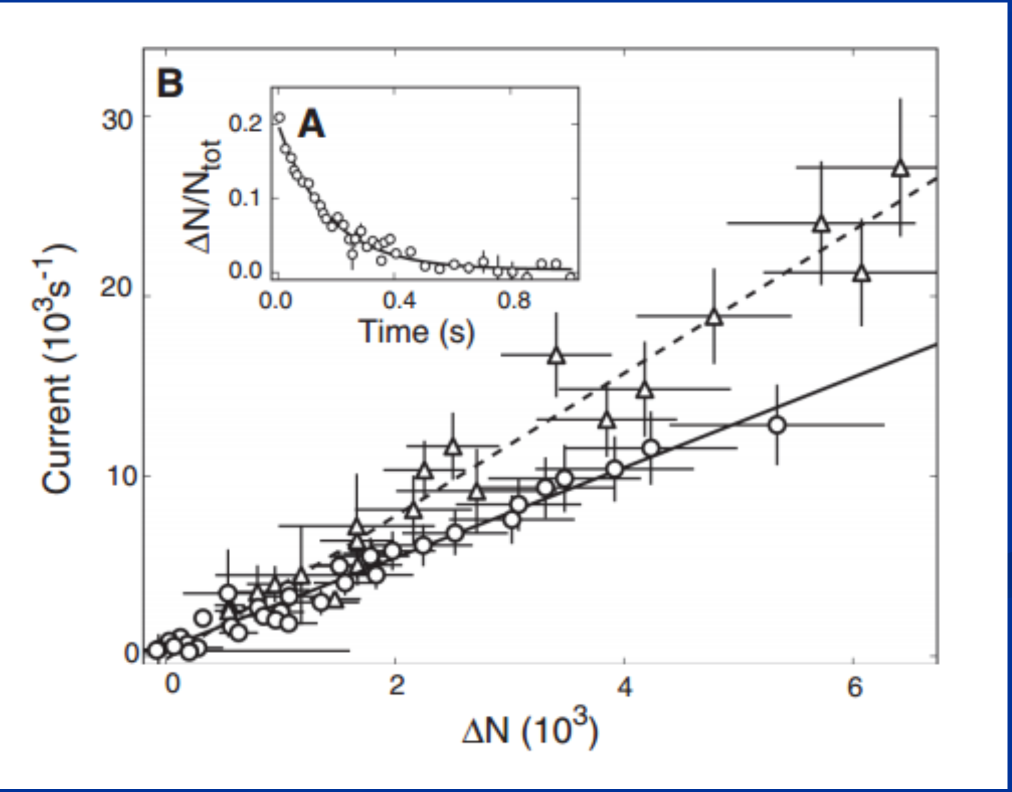
Conduction of Ultracold Fermions Through a Mesoscopic Channel

Jean-Philippe Brantut, Jakob Meineke, David Stadler, Sebastian Krinner, Tilman Esslinger*

SCIENCE VOL 337 31 AUGUST 2012

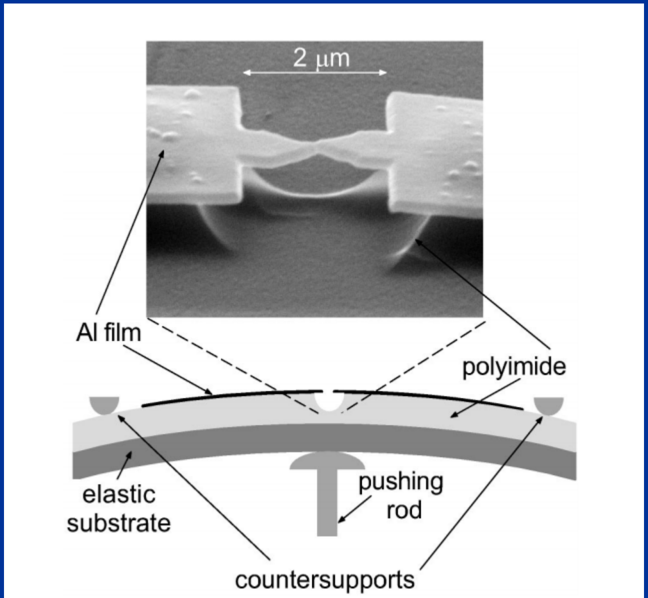


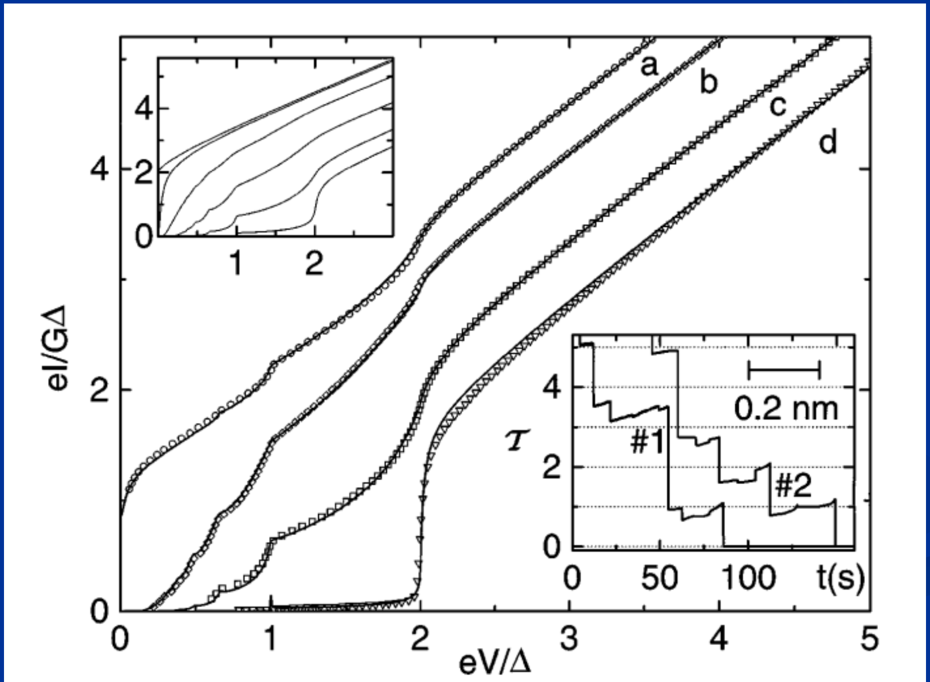




S-S Quantum point contact

- Theory: Blonder, Tinkham, Klapwijk (1982); Averin, Bardas (1995); Cueva, Martin-Rodero, Yetati (1996)

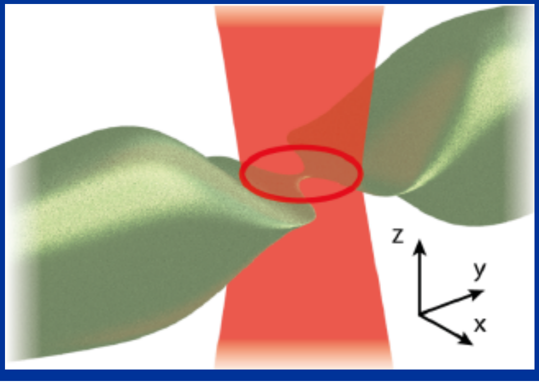


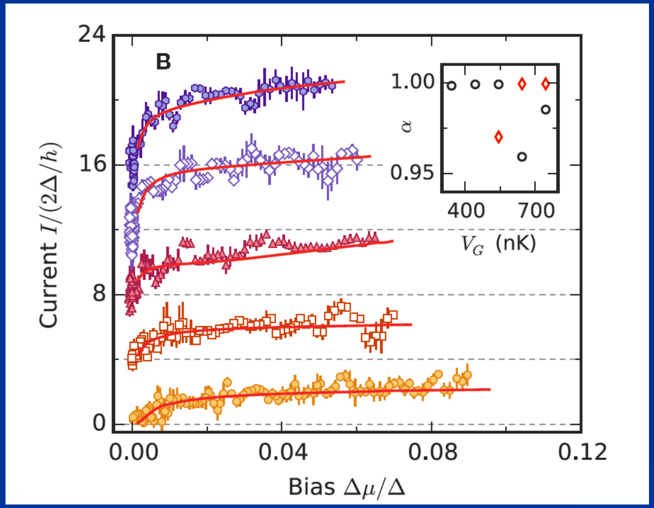


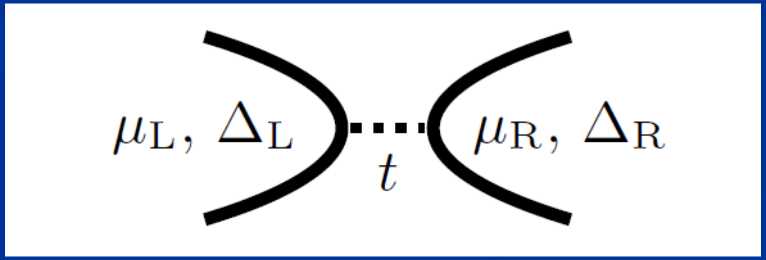
E. Scheer et al. PRL 78 3535 (1997)

Quantum point contact

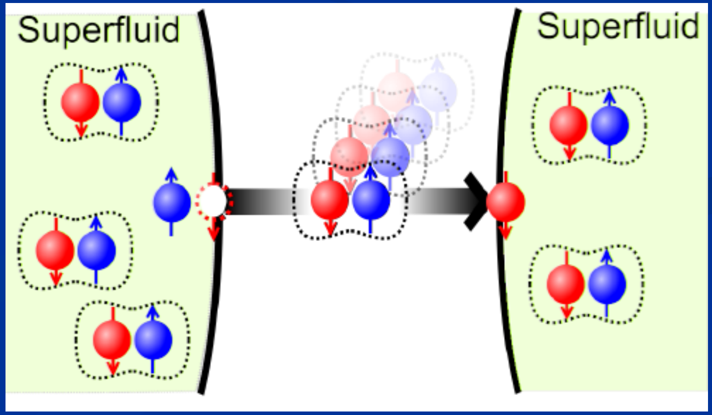
D. Husmann, S. Uchino, et al. Science 350 62667 (2015).







- Quantum point contact: multiple Andreev reflexions



One dimensional structure

Observation of quantized conductance in neutral matter

Sebastian Krinner[1], David Stadler[1], Dominik Husmann[1], Jean-Philippe Brantut[1] & Tilman Esslinger[1]

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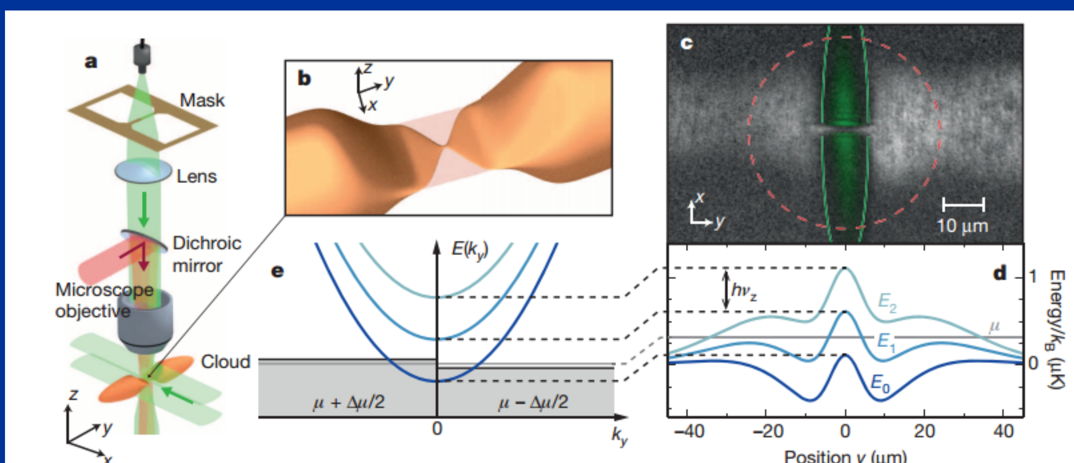
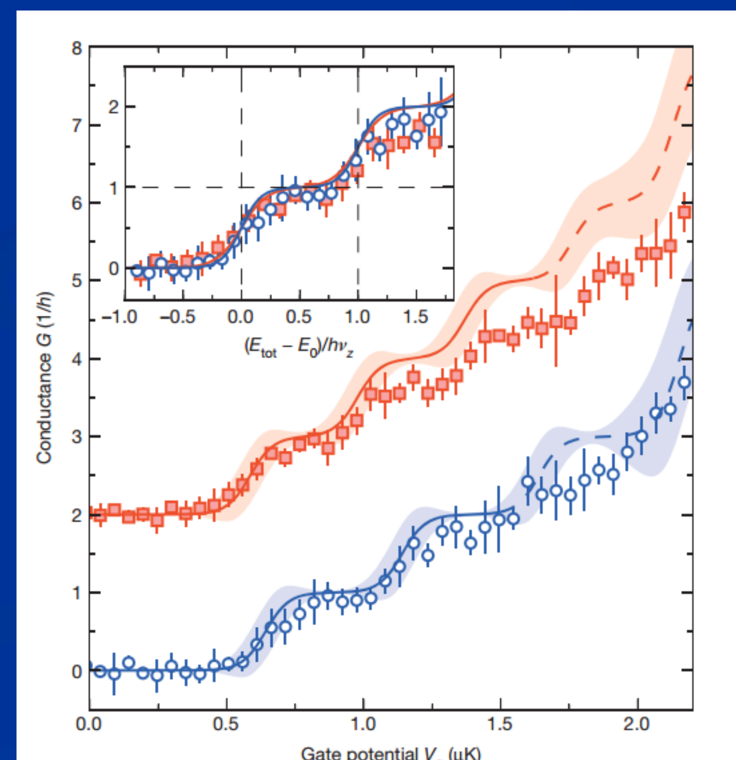




Weak periodic lattice

- Classical: does not do anything
- Non-interacting Quantum system: create bands
- Even a weak lattice leads to a (band) insulator
- What will happen with interactions ?

Attractive interactions and (weak) periodic lattice

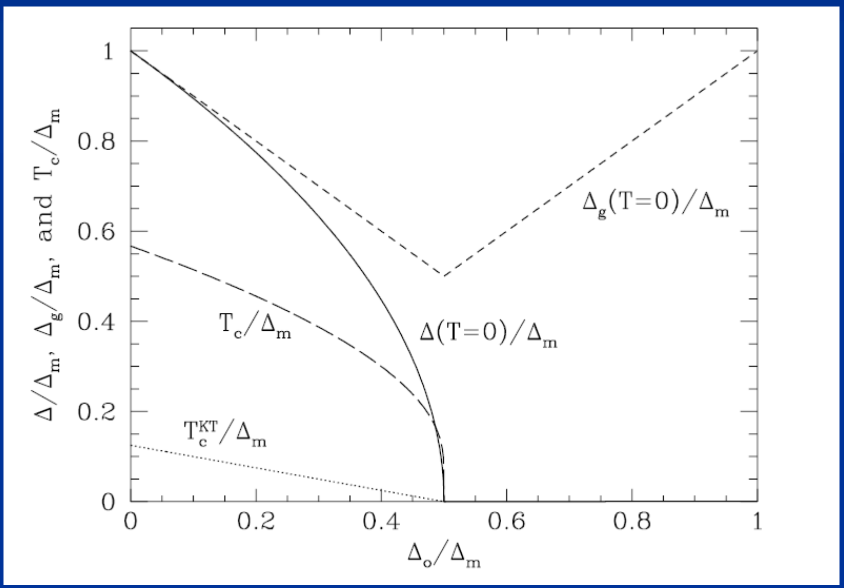
- Attraction: singlet superconductor
- Superconductor resists "scattering" (disorder, potentials, etc.)
- Expect a competition band insulator-superconductivity

Eur. Phys. J. B **10**, 649–662 (1999)

THE EUROPEAN PHYSICAL JOURNAL B
EDP Sciences

From semiconductors to superconductors: a simple model for pseudogaps

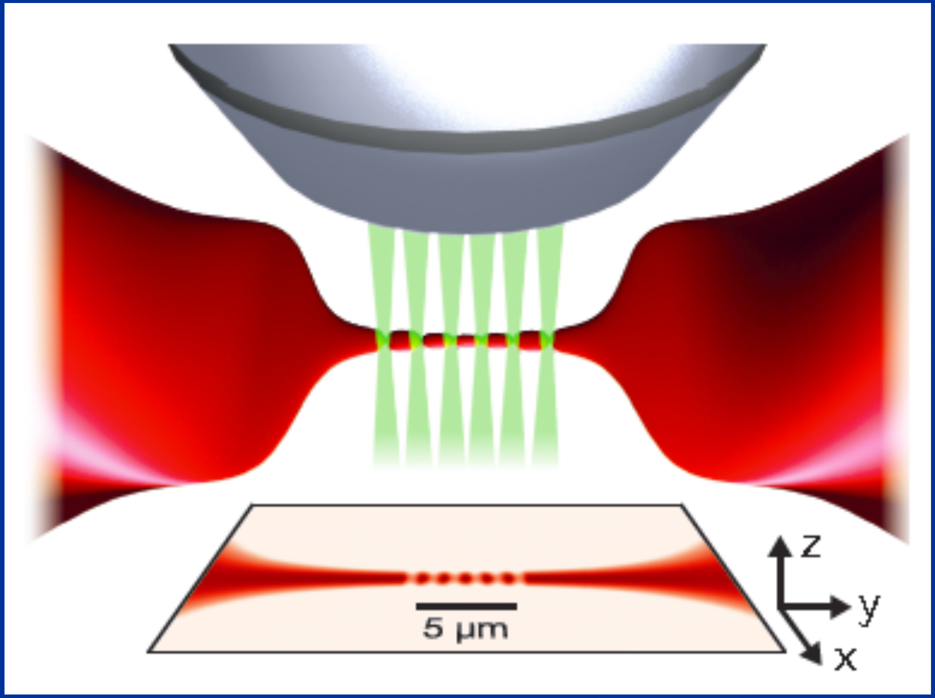
P. Nozières and F. Pistolesi[a]

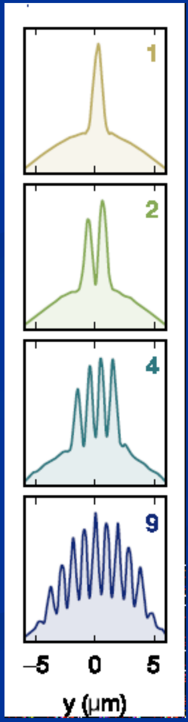


- Mean-Field
- Superconductor-Band insulator transition
- Always true ?
- How to test experimentally ?

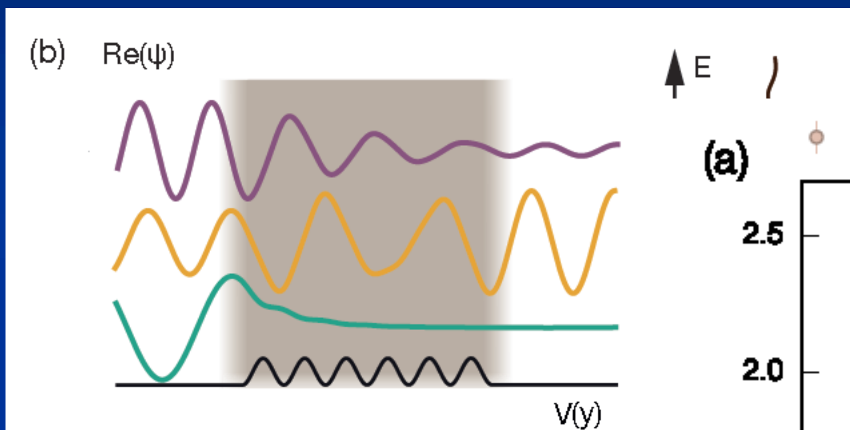
``Atomtronic”

M. Lebrat, P. Grisins et al., arXiv:1708.01250

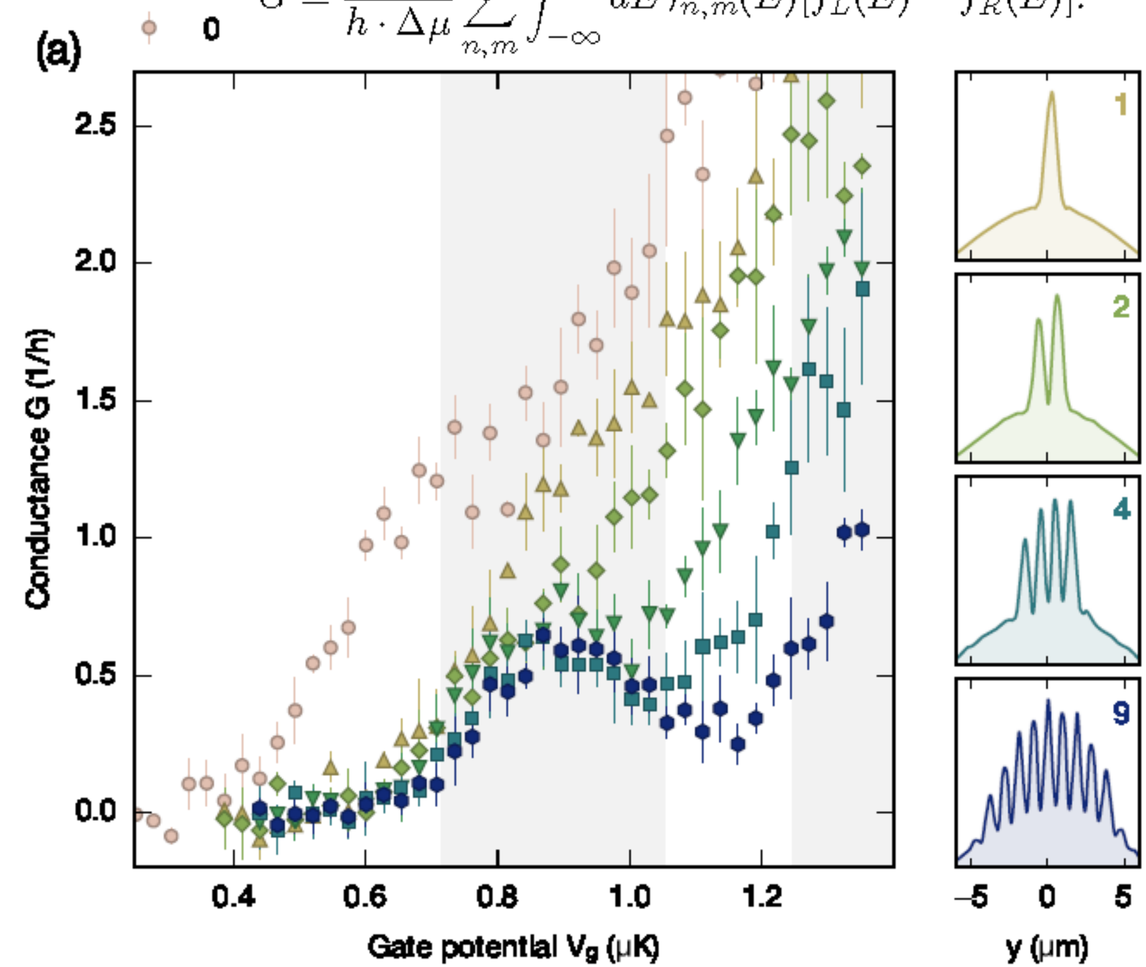


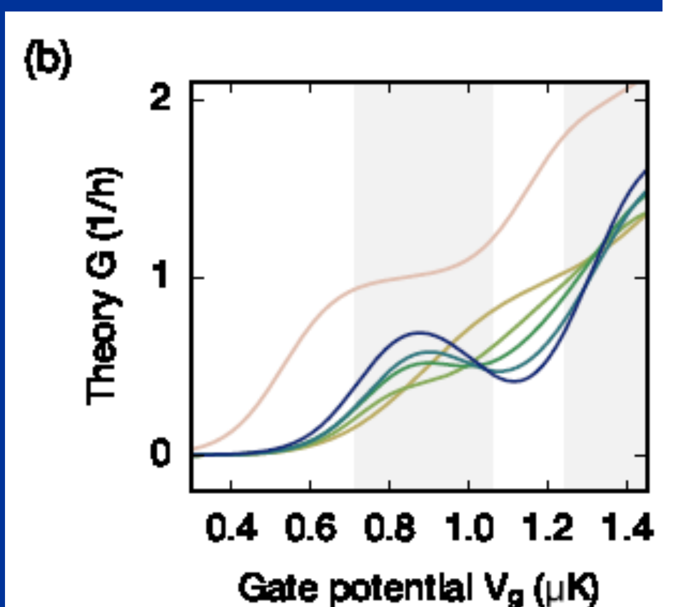


No interactions: band insulator



$$G = \frac{1}{h \cdot \Delta\mu} \sum_{n,m} \int_{-\infty}^{\infty} dE\, \mathcal{T}_{n,m}(E)[f_L(E) - f_R(E)].$$





What happens in with interactions?

$$H = H_{\mathrm{GY}} + H_{\mathrm{lattice}},$$

$$H_{\mathrm{GY}} = -\frac{\hbar^2}{2m}\sum_i \frac{\partial^2}{\partial y_i^2} + g_1 \sum_{i<j} \delta(y_i - y_j),$$

$$H_{\mathrm{lattice}} = \int dy\, V(y)\rho(y),$$

Luther-Emery liquid

- Gap in the spin sector (singlet pairing)

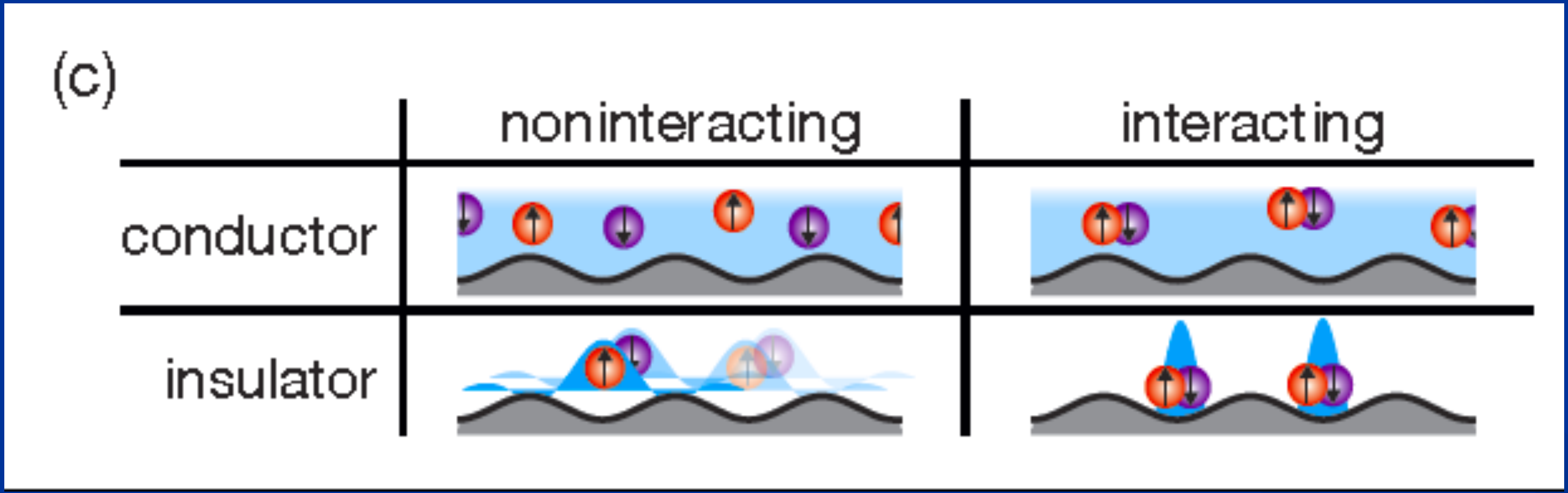
$$\rho(y) = \rho_0 - \frac{\sqrt{2}}{\pi}\nabla\phi_c(y) + 2\rho_0 f_s \cos\left(2k_F y - \sqrt{2}\phi_c(y)\right) + 2C\rho_0 \cos\left(4k_F y - 2\sqrt{2}\phi_c(y)\right),$$

- Conductance determined by the charge sector

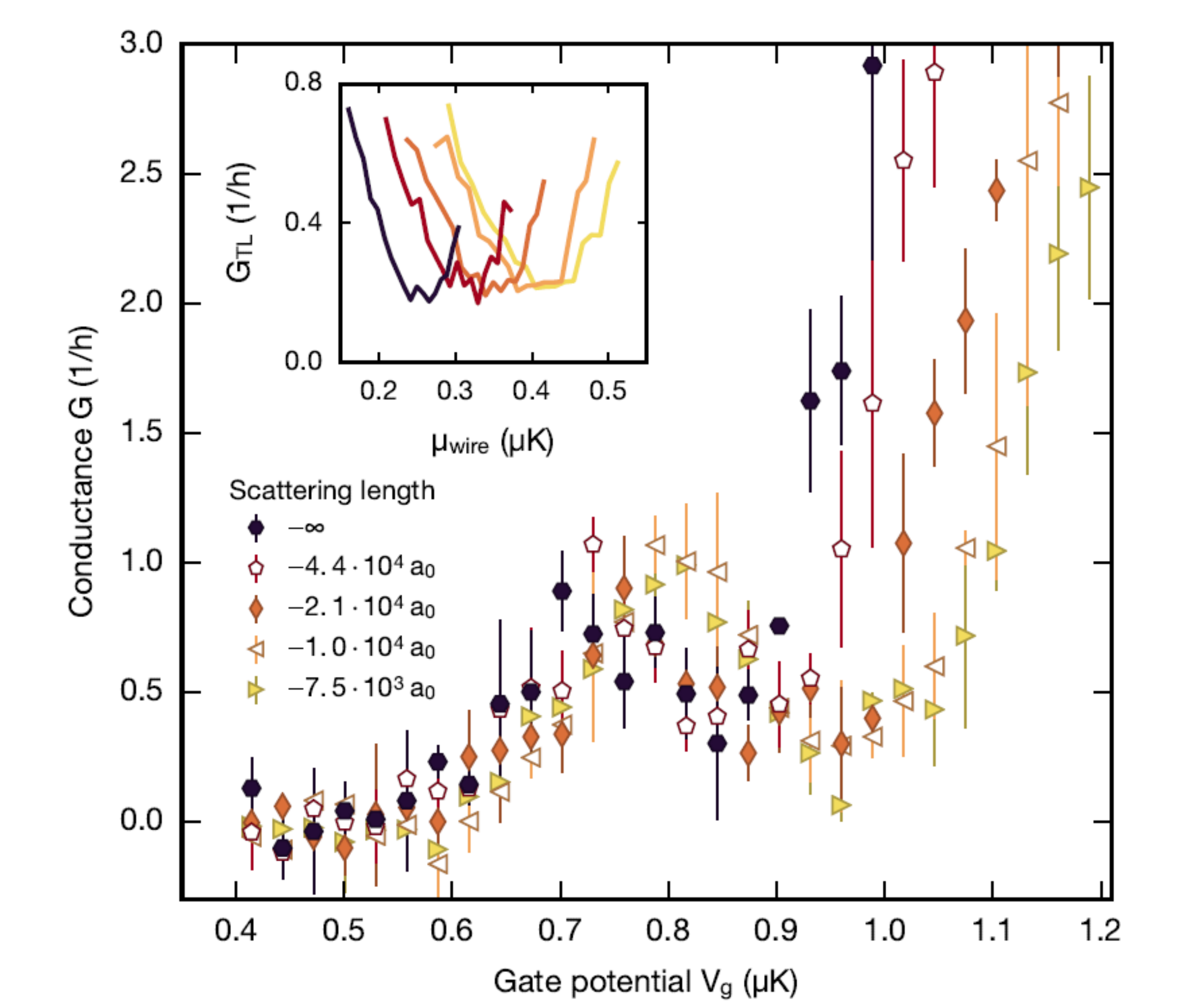
$$\mathcal{H}_\mu(y) = -\mu(y)\rho(y) = \mu(y)\frac{\sqrt{2}}{\pi}\nabla\phi_c,$$

$$I_{\uparrow\downarrow}(y) = \frac{\sqrt{2}}{\pi}\partial_t\phi_c(y,t)$$

Many-body insulator ``pinned" L.E. liquid



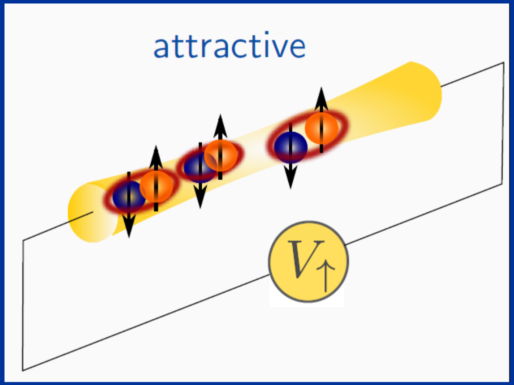
Experimental evidence for L.E. liquid

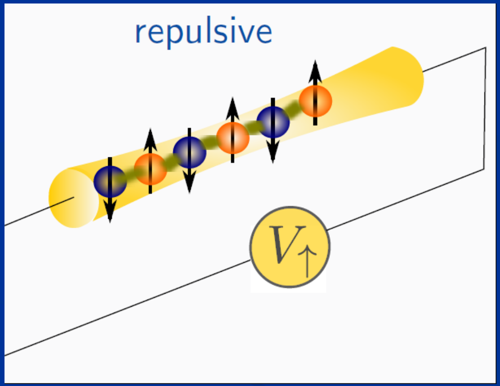


Other transport properties

Spin conductance

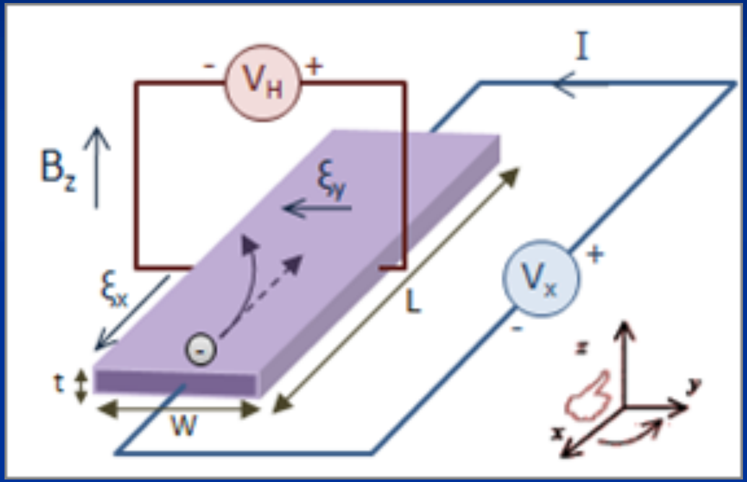
$$J_\sigma = \langle j_\uparrow - j_\downarrow \rangle = G_\sigma(\mu_\uparrow - \mu_\downarrow)$$





Spin Drag: $\Delta\mu_\uparrow$ $\quad J_\downarrow$ $\quad J_\downarrow = D\Delta\mu_\uparrow$

Hall effect



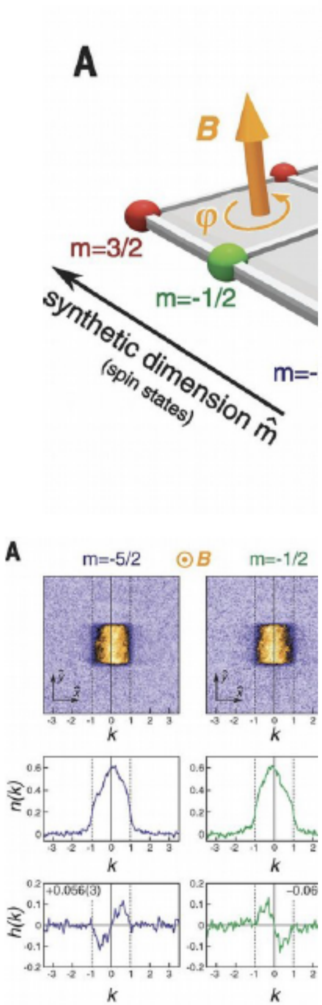
Non interacting ``simple"

$$R_h = \frac{V_\perp}{I_\parallel B} \propto \frac{1}{n}$$

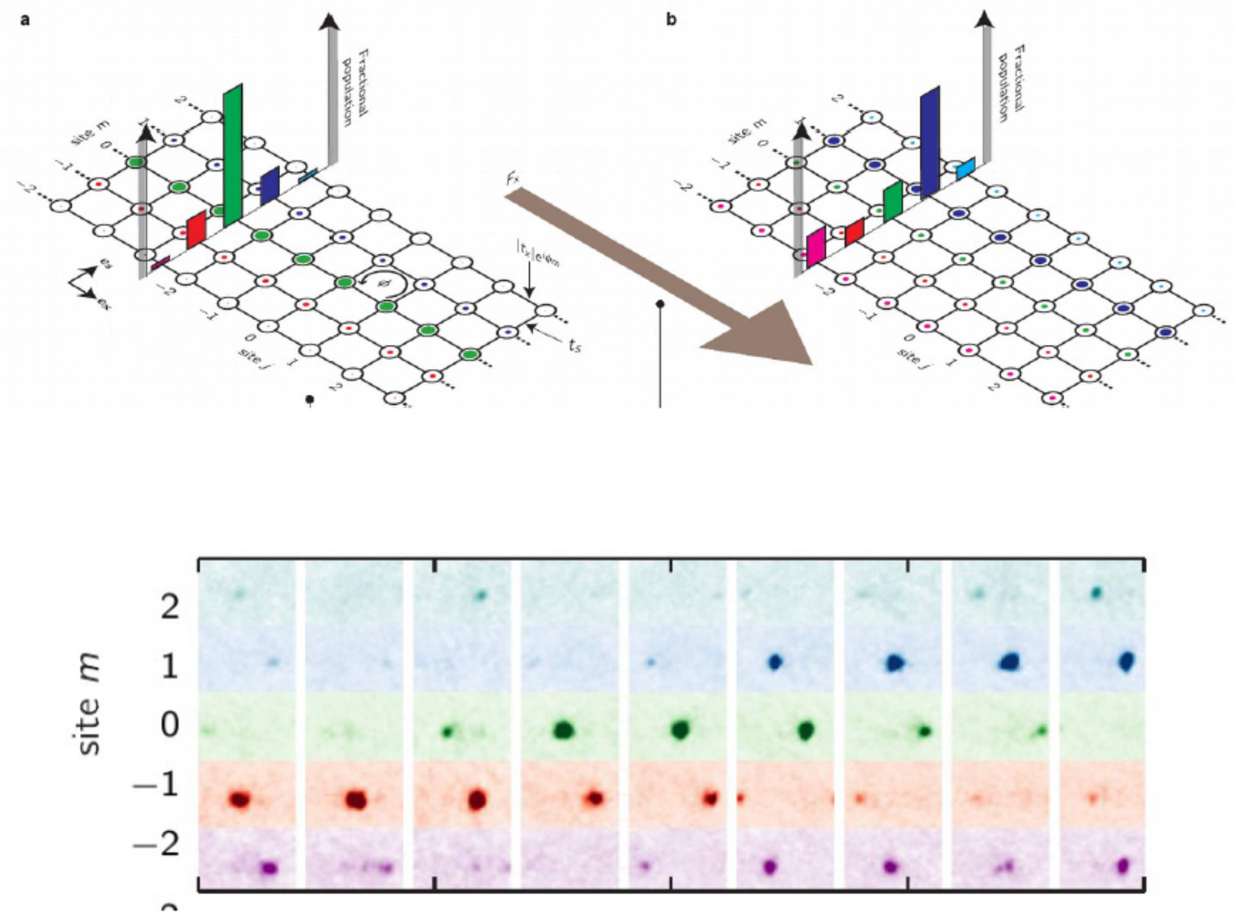
No interactions: curvature of fermi surface - topological formula (Thouless-Kohmoto)

With interactions: open question

Cold atoms



Fallani's group (Florence) **Scien**

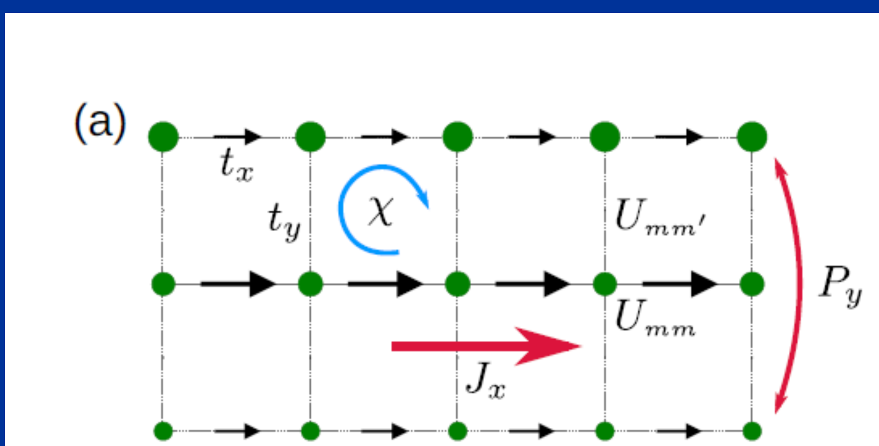


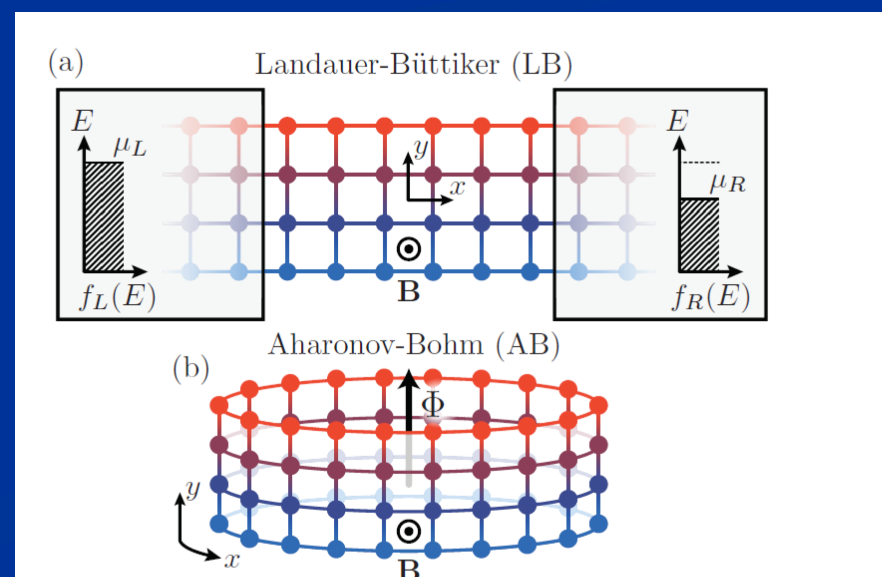
Spielman's group (Maryland) **arXiv:1804.06345**

Hall effect on ladders

S. Greshner, M. Filippone, TG, PRL 122, 083402 (2019)

M. Filippone, C.E. Bardyn, S. Greshner, TG, PRL 123 086803 (2019)





Conclusions/Perspectives

- Calculations and measurements of quantum transport with cold atomic systems
- Novel situations and effects (e.g. proof of existence of Luther-Emery liquid)
- Many exciting possibilities (spin, hall, etc.) and challenging theory questions