強結合フェルミ気体におけるメゾスコピックスピン輸送

YS, H. Tajima, & S. Uchino, Phys. Rev. Research 2, 023152 (2020)

講演番号02

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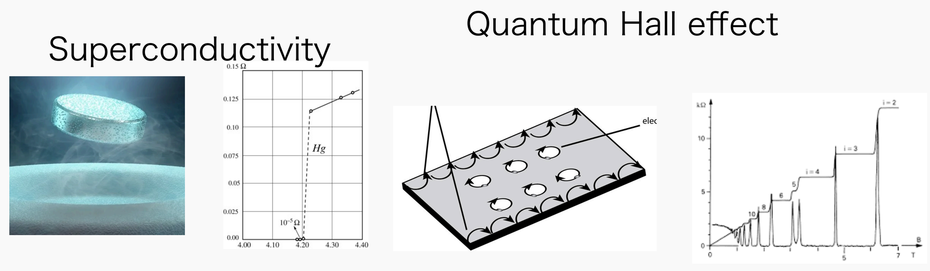
YouTube (By Tajima-san) https://www.youtube.com/watch?v=vIhdQN7ttWE

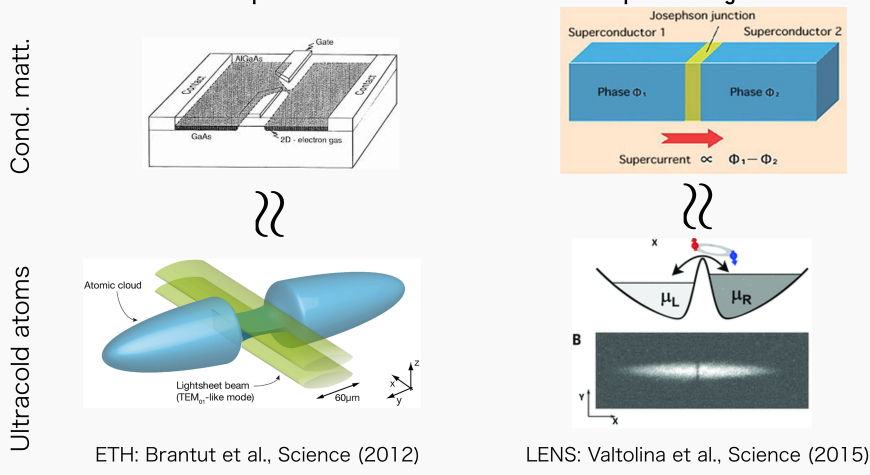
Introduction

1. Quantum Transport

In a bulk



B/w bulks

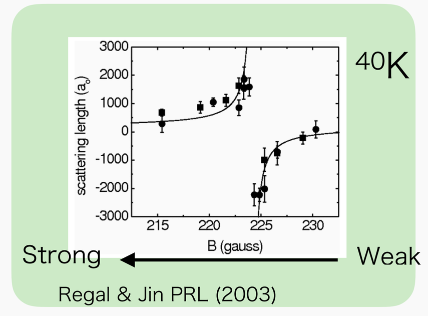


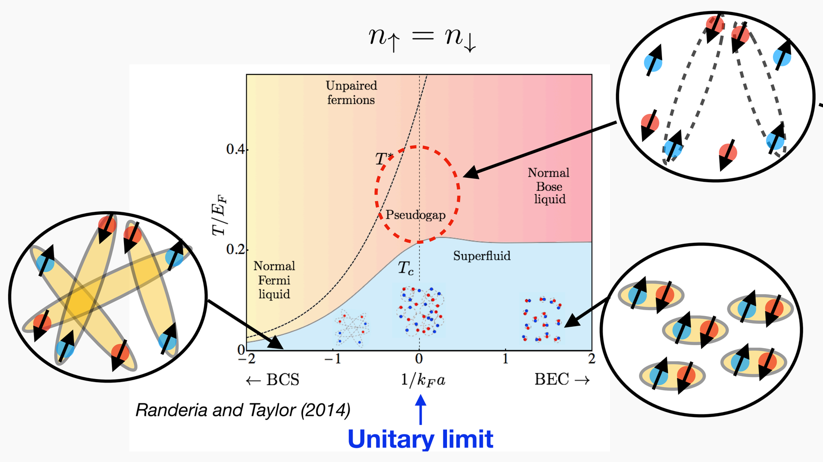
2. Ultracold Fermi gas

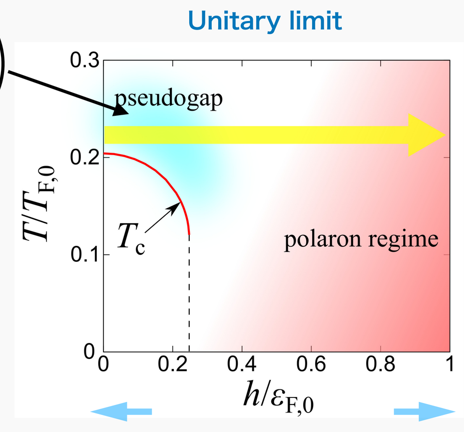
Fermi atoms (6Li, 40K,…) with two hyperfine state

Dilute & cold atomic gas

n = 1013 to 1015 cm-1, T = 1 μK to 10nK



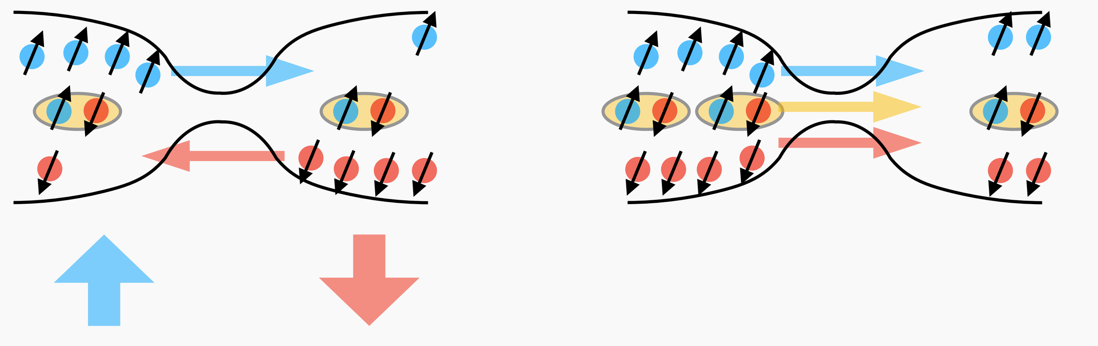




3. Spin vs mass currents

Polarization difference → Spin current

Particle-number difference → Mass current



No contribution from (Spin singlet)

Sensitive to single-particle excitations !!

Excitations of both atoms & pairs

Pair transport:

Multiple Andreev reflection

Husmann, Uchino et al., Science (2015)

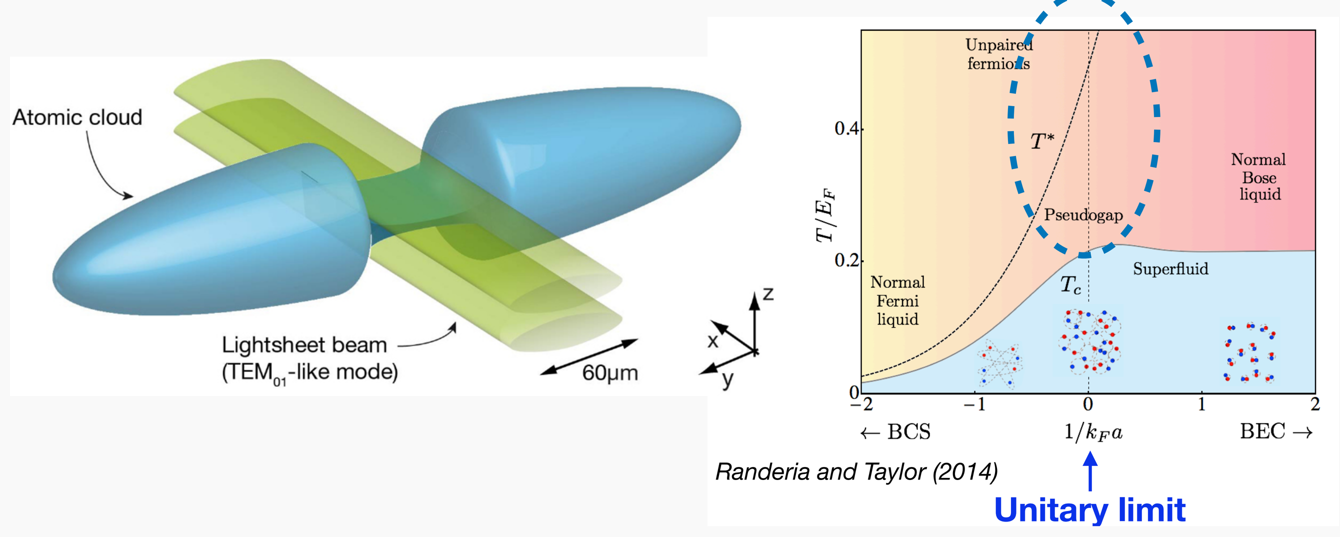
Josephson occillation

Valtolina et al., Science (2015)

Purpose

Understanding of transport properties for strongly interacting Fermi gases

Transport ⟷ Excitation properties in bulks



Here, spin transport in normal phase is focused on

Pseudogap regime

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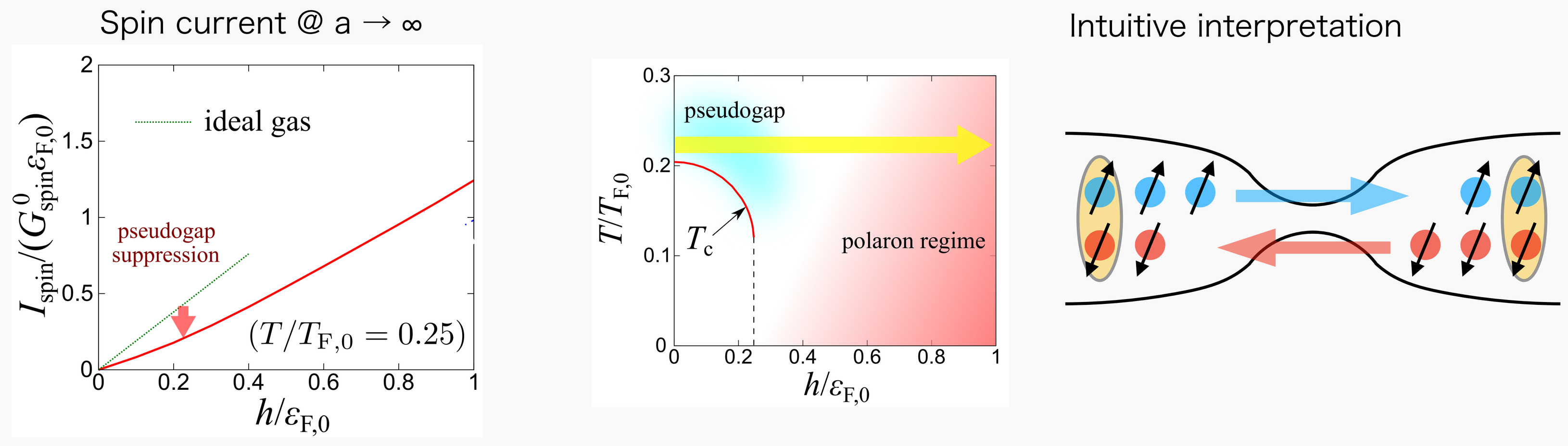
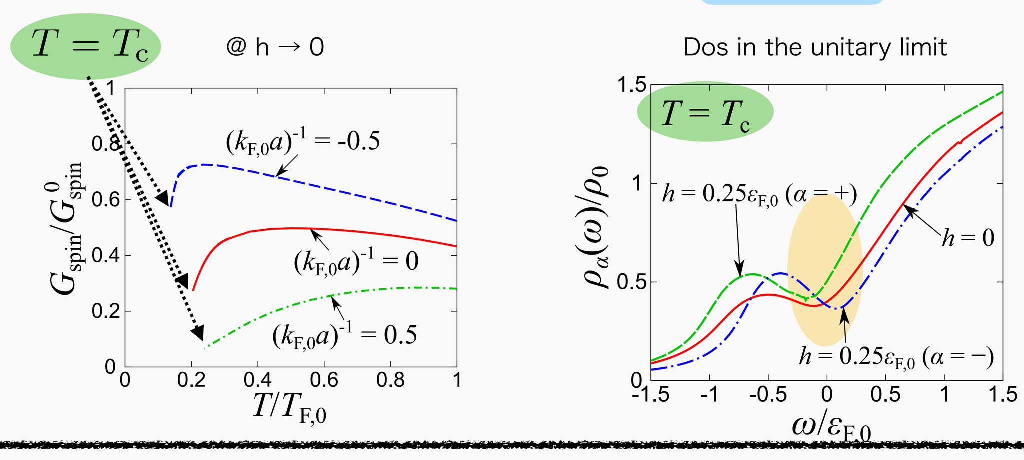


Spin conductance $\lim_{h\to 0} G_{\rm spin} = 4\pi t^2 \int d\omega\, [\bar\rho(\omega)]^2 \left(-\frac{\partial f(\omega)}{\partial\omega}\right)$ $\bar\rho(\omega)=\lim_{h\to 0}\rho_\pm(\omega)$ $\propto \cosh^{-2}(\omega/2T)$



Pseudogap formation

Suppression of Gspin

Polaron regime

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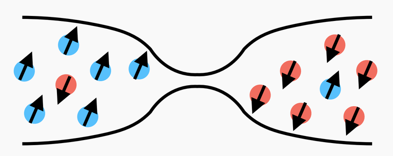
1. Highly polarized gas



Majority atoms form a Fermi sea

Minority atoms behave as Fermi polarons

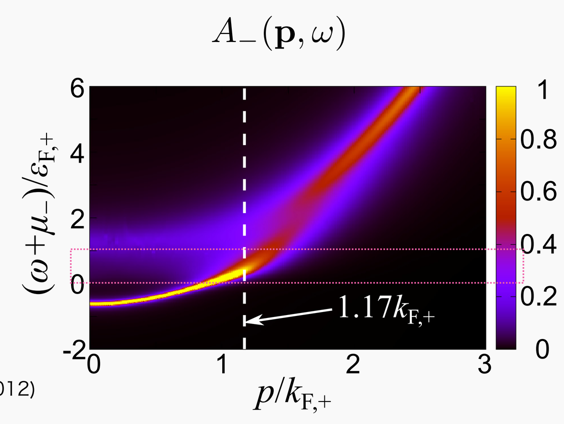
Theory: Chevy PRA (2006); Combescot et al., PRL (2007);…

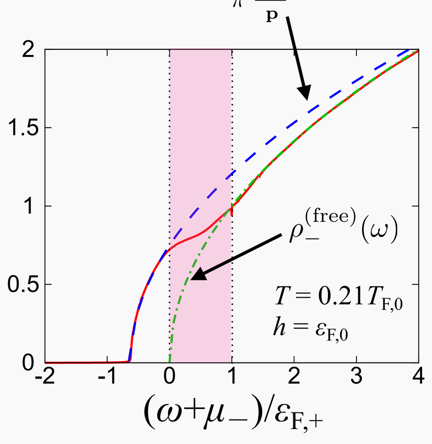
Exp: Schirotzek et al., PRL (2009);

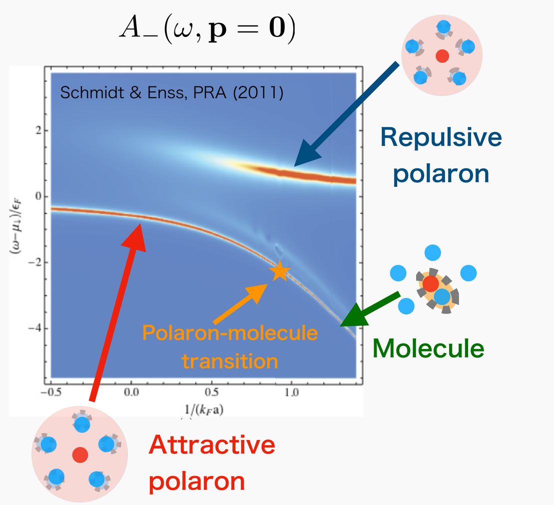
Koschorreck et al., Nature (2012); Kohstall et al., Nature (2012)

2. Minority spectrum & DoS

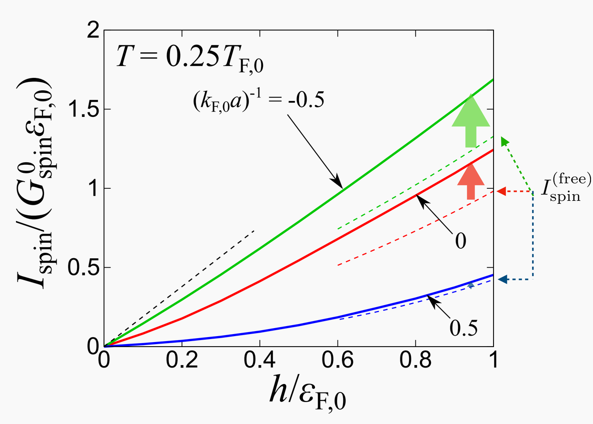
$\rho_-^{\rm (att)}(\omega) = -\frac{1}{\pi}\sum_{\mathbf p} A_-^{\rm (att)}(\mathbf p,\omega)$







4. Spin current



Broad repulsive branch & Broadened attractive polaron

DoS enhancement

$\rho_-(\omega)$ in $0 \lesssim \omega+\mu_- \lesssim \varepsilon_{F,+}$

Increase of the spin current

Model

1. Tunneling Hamiltonian model

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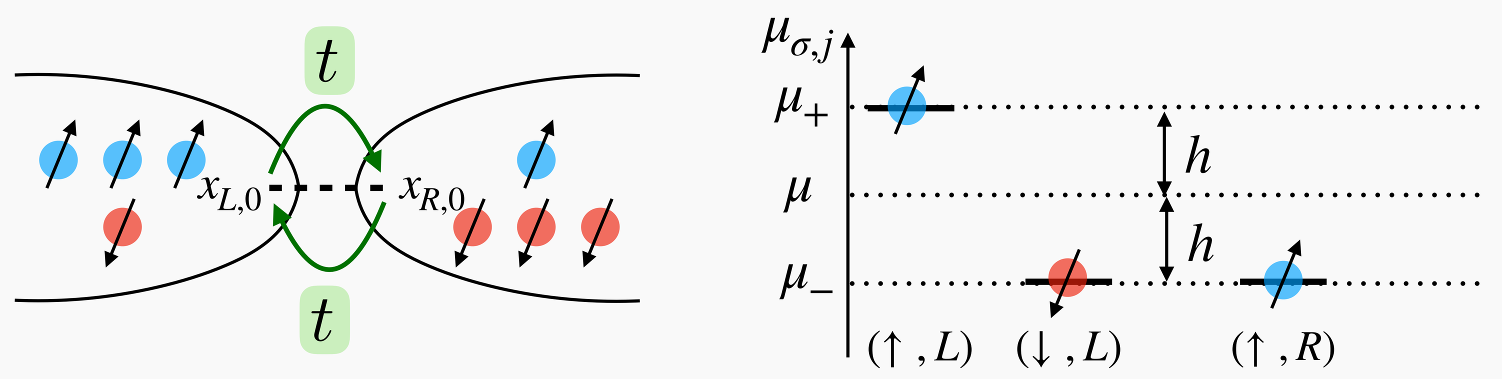


$H = H_R + H_L + H_T,$

Reservoirs:

Majority: $\alpha=+$ Minority:

$$H_j = \sum_{\mathbf p}\sum_{\sigma=\uparrow,\downarrow}\left(\frac{p^2}{2m}-\mu_{\sigma,j}\right)c^\dagger_{\mathbf p,\sigma,j}c_{\mathbf p,\sigma,j} - U\sum_{\mathbf p,\mathbf p',\mathbf q} c^\dagger_{\mathbf p+\mathbf q,\uparrow,j}c^\dagger_{-\mathbf p,\downarrow,j}c_{-\mathbf p',\downarrow,j}c_{\mathbf p'+\mathbf q,\uparrow,j},$$

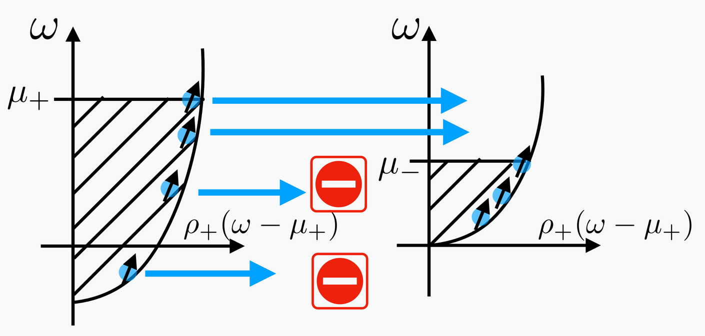
Contact interaction

Tunneling term:

$$H_T = t\sum_{\sigma=\uparrow,\downarrow}\psi^\dagger_{\sigma,L}(x_{L,0})\psi_{\sigma,R}(x_{R,0}) + \text{H.c.} = t\sum_{\sigma=\uparrow,\downarrow}\sum_{\mathbf p,\mathbf p'} c^\dagger_{\mathbf p,\sigma,R}c_{\mathbf p',\sigma,L} + \text{H.c.}$$

2. Kubo formula

$$I_{\rm spin} \equiv -\frac{d(N_{\uparrow,L}-N_{\downarrow,L})}{dt}$$
$$= 4\pi t^2\int d\omega\, \rho_+(\omega-\mu_+)\rho_-(\omega-\mu_-)\left[f(\omega-\mu_+)-f(\omega-\mu_-)\right] + O(t^4)$$



Density of states (DoS):

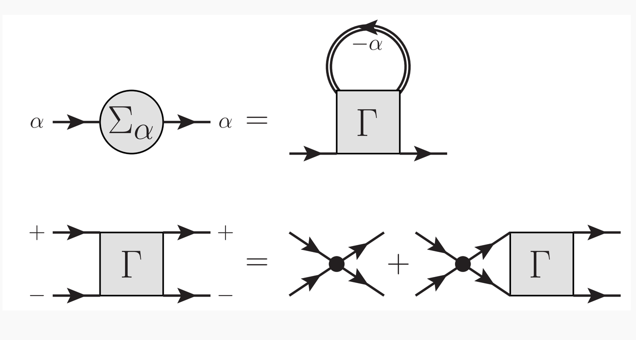
$$\rho_\pm(\omega) = -\frac{1}{\pi}\sum_{\mathbf p}\mathrm{Im}[\mathcal G_\pm(\mathbf p, i\omega_n\to\omega+i\delta)],$$

Fermi distribution func.:

$$f(\omega) = \frac{1}{e^{\omega/T}+1}$$

3. Extended T-matrix approx.(ETMA):

[Kashimura, Watanabe, & Ohashi PRA (2012)]



Double line: $\mathcal G_\pm(\mathbf p, i\omega_n) = \dfrac{1}{i\omega_n - \frac{p^2}{2m}+\mu_\pm-\Sigma_\pm(\mathbf p,i\omega_n)}$

Single line: $\mathcal G_0(\mathbf p, i\omega_n) = \dfrac{1}{i\omega_n - \frac{p^2}{2m}+\mu_\pm}$

Dot: $-U$

Summary

Two-terminal spin transport for strongly interacting Fermi gas

1. Small spin bias: Suppression of $I_{\rm spin}$ due to the pseudogap
2. Large spin bias: Enhancement of $I_{\rm spin}$ due to the polarons

Spin current measurement becomes a sensitive probe to pseudogap & polarons

Future perspective:

Superfluid regime, low-energy polaron current, current noise