

Superconductivity and Mottness: Exact Results

Nature Physics, vol.16, 1175-1180 (2020);
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Luke Yeo



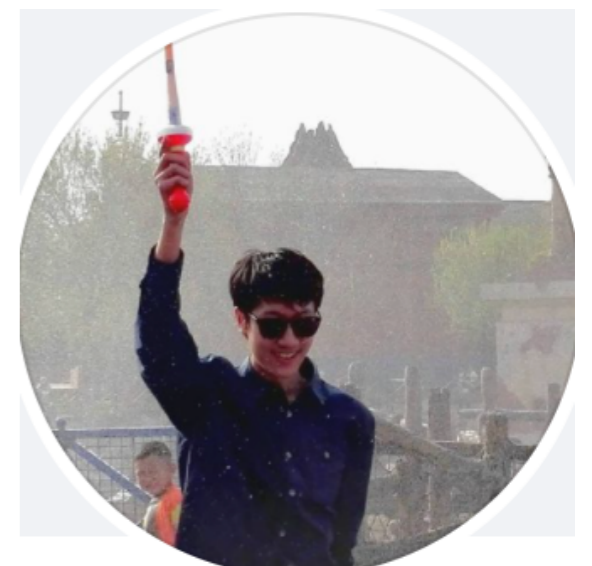
Edwin Huang



G. La Nave



Jinchao Z.



Exempt ArriveCAN Receipt

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This ArriveCAN receipt is confirmation that you have successfully submitted your information in ArriveCAN. You can also see your receipt in the ArriveCAN mobile app or by signing in online.

- If you're entering Canada by air, show this receipt prior to boarding your flight.
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The Canada Border Services Officer may determine that your travel is not exempt and require you to create a new receipt as well as meet other entry requirements. Bring relevant documentation with you to ensure your entry to Canada goes as smoothly as possible.

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Starting a new receipt will cancel this reusable receipt, and you will have to create another one for future use.

2022-07-17



Performance of specific essential services

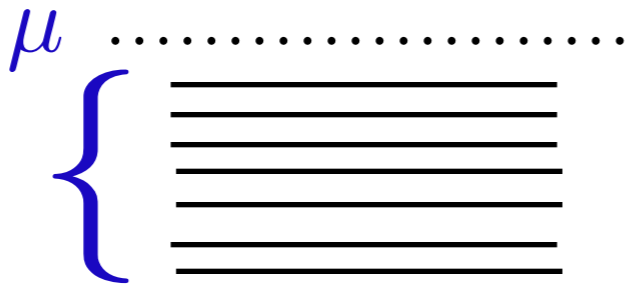
Traveller: philip phillips

Travel Document Type: Passport

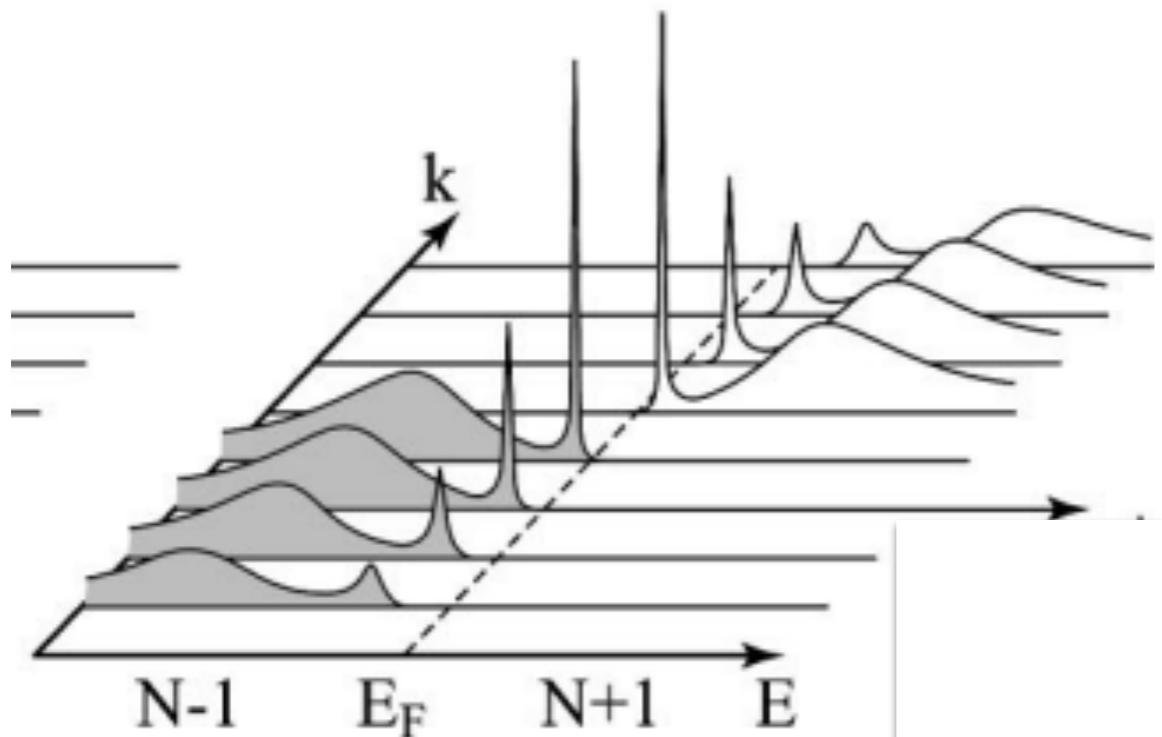
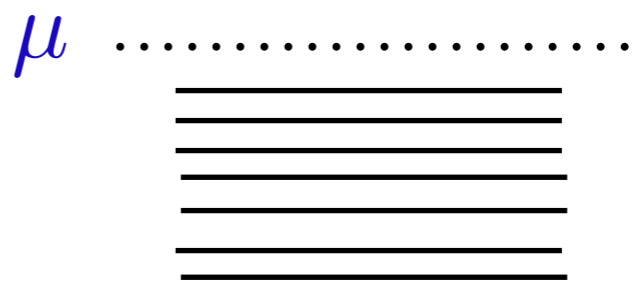
Fermi liquids

NFL

doubly occupied



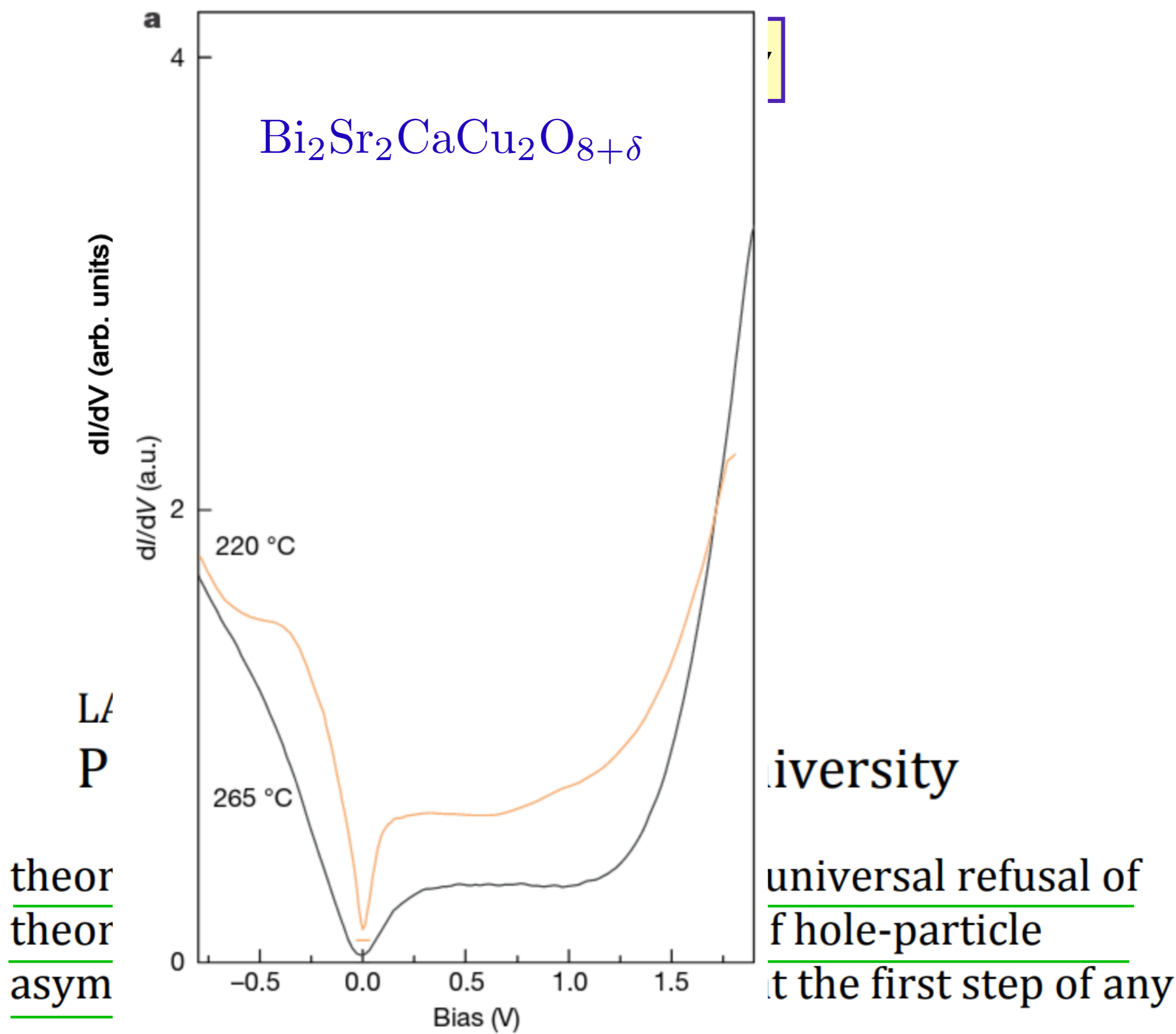
Is single occupancy below chemical potential possible?



Fermi-liquid system

p-h symmetry

with time-reversal symmetry intact?



single
occupancy

?

particle-hole
asymmetry



Anderson
Haldane
2000

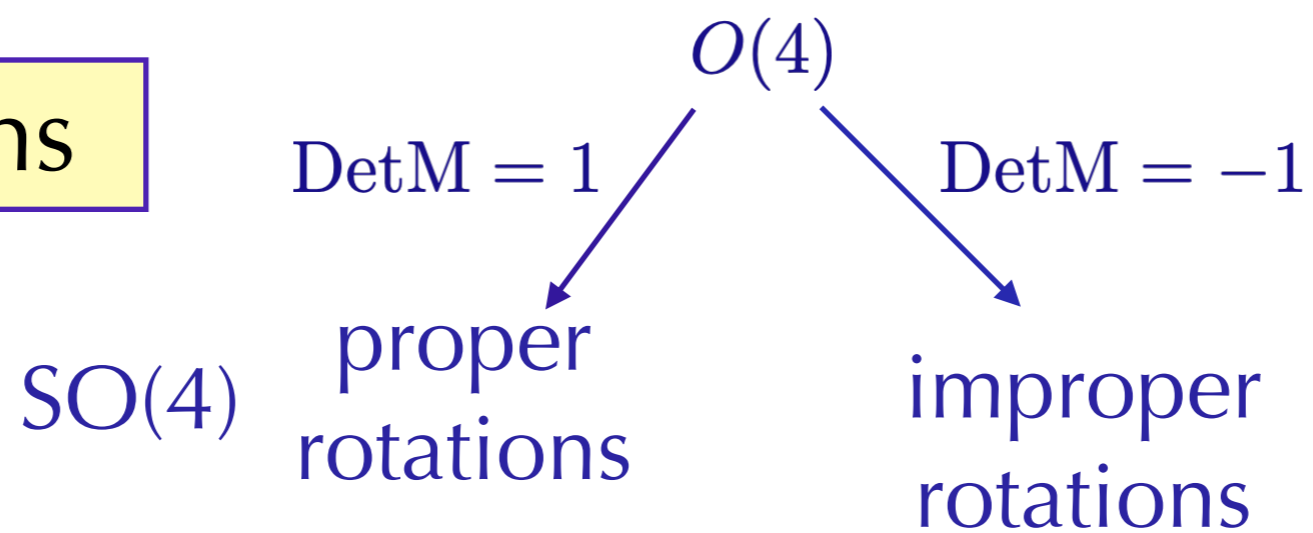
3 citations

Fermi liquids

$$H = \sum_{p,\sigma} (\epsilon(p) - \epsilon_F) n_{p\sigma} + \dots \rightarrow 0$$

$(n_{p\uparrow}, n_{p\downarrow})$ conserved currents

$(c_{p\uparrow}, c_{p\downarrow}, \text{h.c.})$ 4 objects



$$\text{Det}M = \pm 1 \implies Z_2 = O(4) \div SO(4)$$

Improper Rotations

Majorana basis

$$\begin{pmatrix} c_{p\uparrow} \\ c_{p\uparrow}^\dagger \\ c_{p\downarrow} \\ c_{p\downarrow}^\dagger \end{pmatrix} \longrightarrow \begin{pmatrix} c_{p\uparrow} + c_{p\uparrow}^\dagger \\ i(c_{p\uparrow} - c_{p\uparrow}^\dagger) \\ c_{p\downarrow} + c_{p\downarrow}^\dagger \\ i(c_{p\downarrow} - c_{p\downarrow}^\dagger) \end{pmatrix}$$

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} c_{p\uparrow} + c_{p\uparrow}^\dagger \\ i(c_{p\uparrow} - c_{p\uparrow}^\dagger) \\ c_{p\downarrow} + c_{p\downarrow}^\dagger \\ i(c_{p\downarrow} - c_{p\downarrow}^\dagger) \end{pmatrix} \longrightarrow c_{p\downarrow} \rightarrow c_{p\downarrow}^\dagger$$

p-h transformation

$$\epsilon(p) = \epsilon_F$$

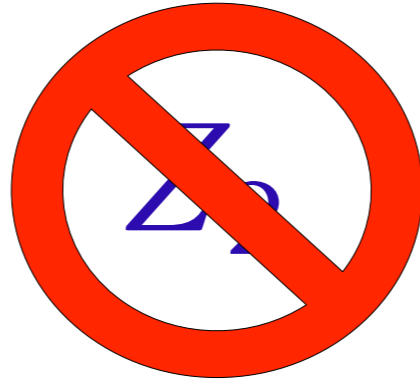
Fermi
Surface

$$H = 0$$



$$\left. \begin{array}{l} n_{p\uparrow} \rightarrow 1 - n_{p\uparrow} \\ n_{p\downarrow} \rightarrow n_{p\downarrow} \end{array} \right\} \mathbb{Z}_2 \text{ at Fermi surface only}$$

How to destroy Fermi liquids?



$$H = \sum_{p,\sigma} (\epsilon(p) - \epsilon_F) n_{p\sigma} + U n_{p\uparrow} n_{p\downarrow}$$

odd
under Z_2

scaling dimension

$$[n_{p\uparrow} n_{p\downarrow}] = -2$$

relevant
interaction

New fixed point!

Hatsugai-Kohmoto
model

Hubbard
not
necessary!

General HK Model

$$\sum_k (\xi_k (n_{k\uparrow} + n_{k\downarrow}) + U n_{k\uparrow} n_{k\downarrow})$$

Solvable Mott transition: $U > W$

$$G_{k\sigma}(i\omega_n \rightarrow z) = \frac{1 - \langle n_{k\bar{\sigma}} \rangle}{z - \xi_k} + \frac{\langle n_{k\bar{\sigma}} \rangle}{z - (\xi_k + U)} \neq \frac{1}{z - \omega_k}$$

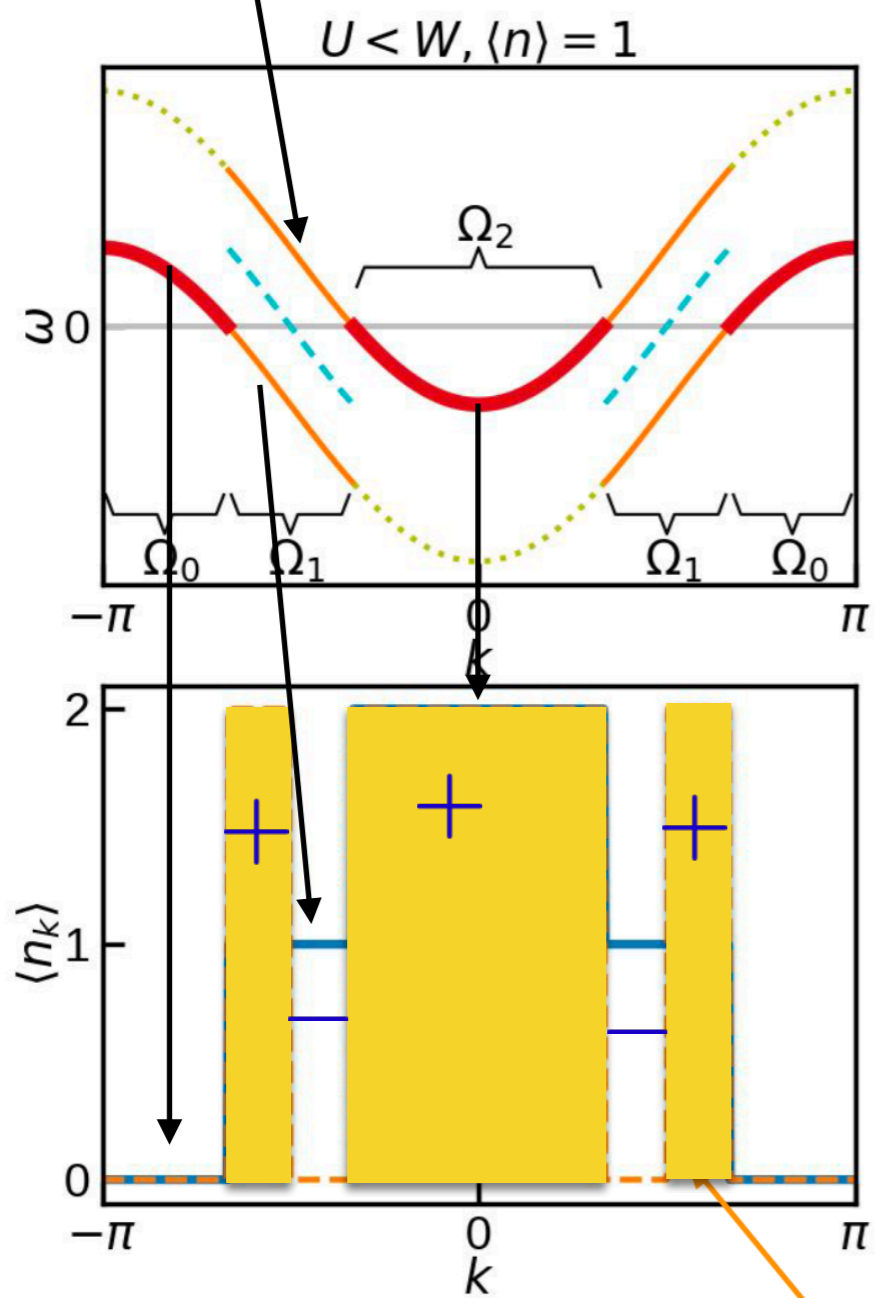
lower Hubbard band

upper Hubbard band

zeros

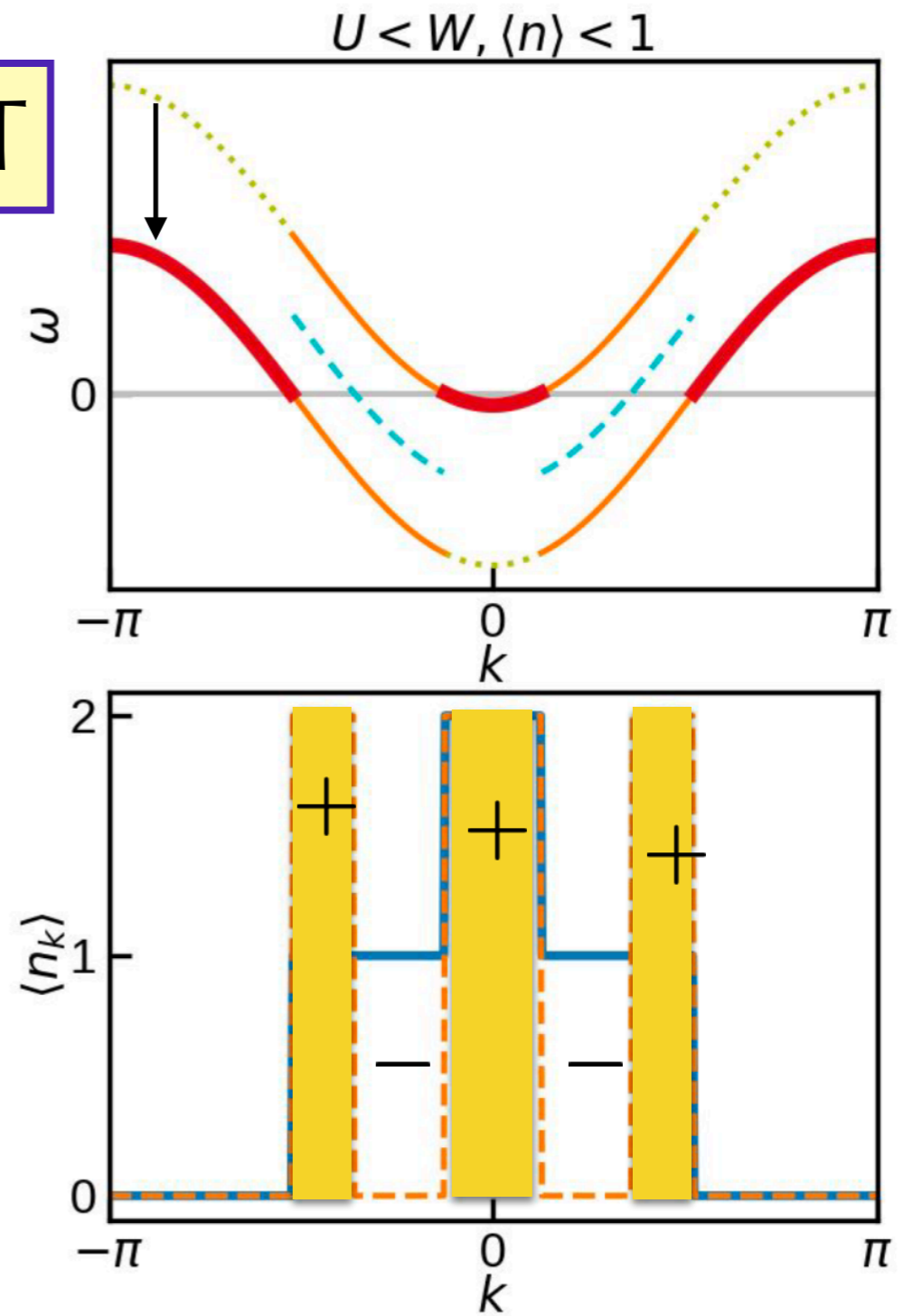
single occupancy

counting charges



$n_{\text{Lutt}} = \langle n \rangle$

SWT



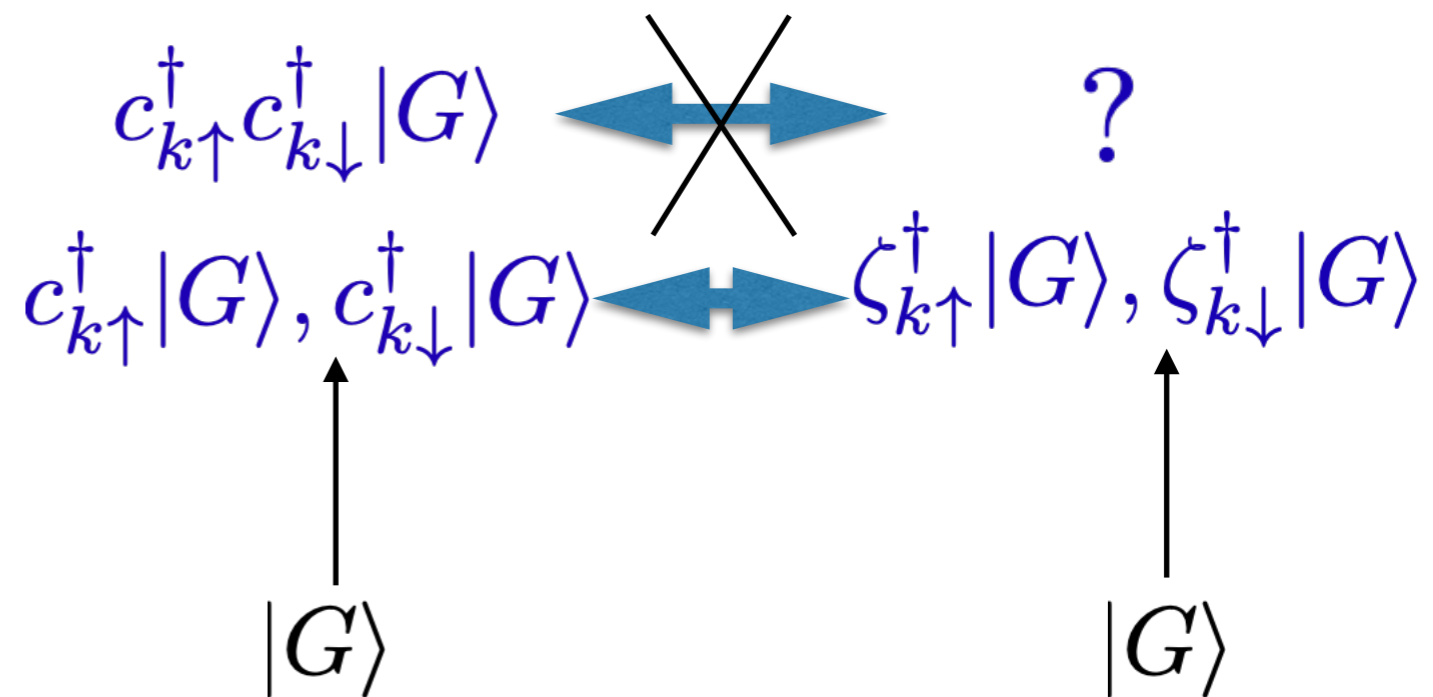
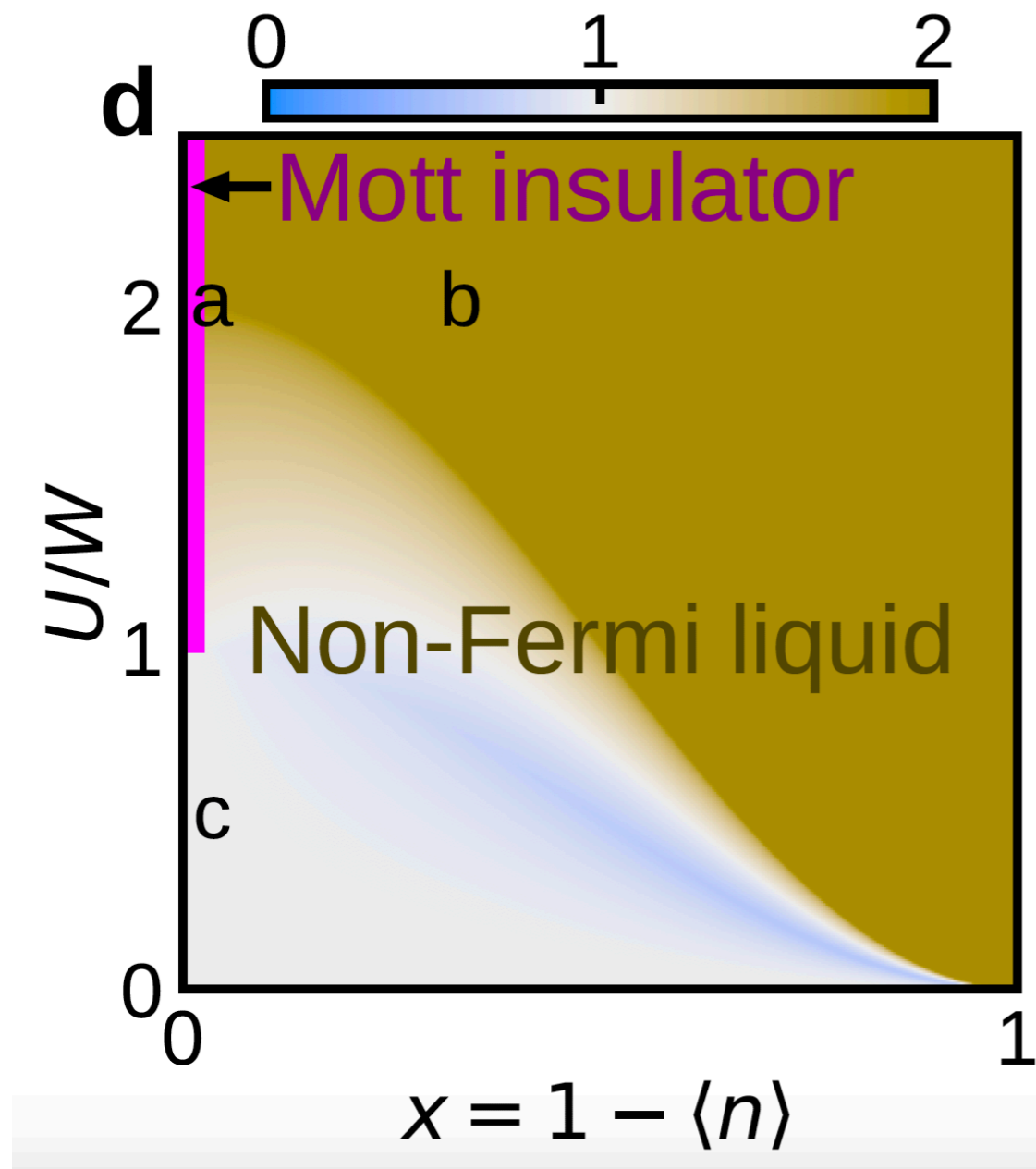
$n_{\text{Lutt}} \neq \langle n \rangle$

zeros \neq particles

Why NFL?

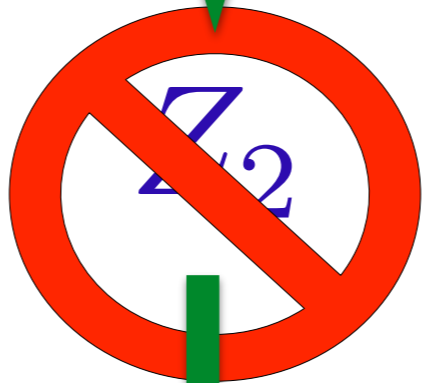
FL

HK
Mottness



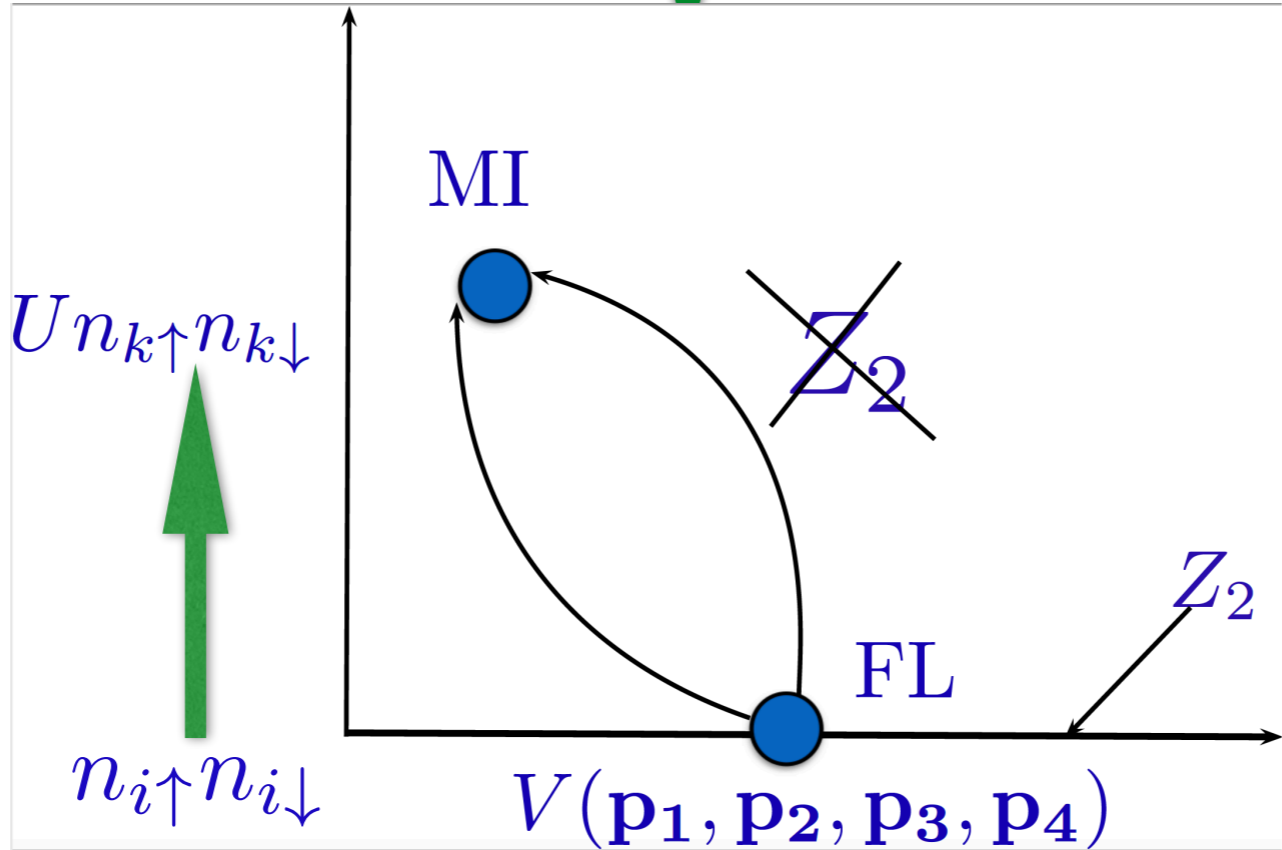
$$\zeta_{k\uparrow}^\dagger \zeta_{k\downarrow}^\dagger |G\rangle = 0$$

Fermi liquids



$$[U n_{p\uparrow} n_{p\downarrow}] = -2$$

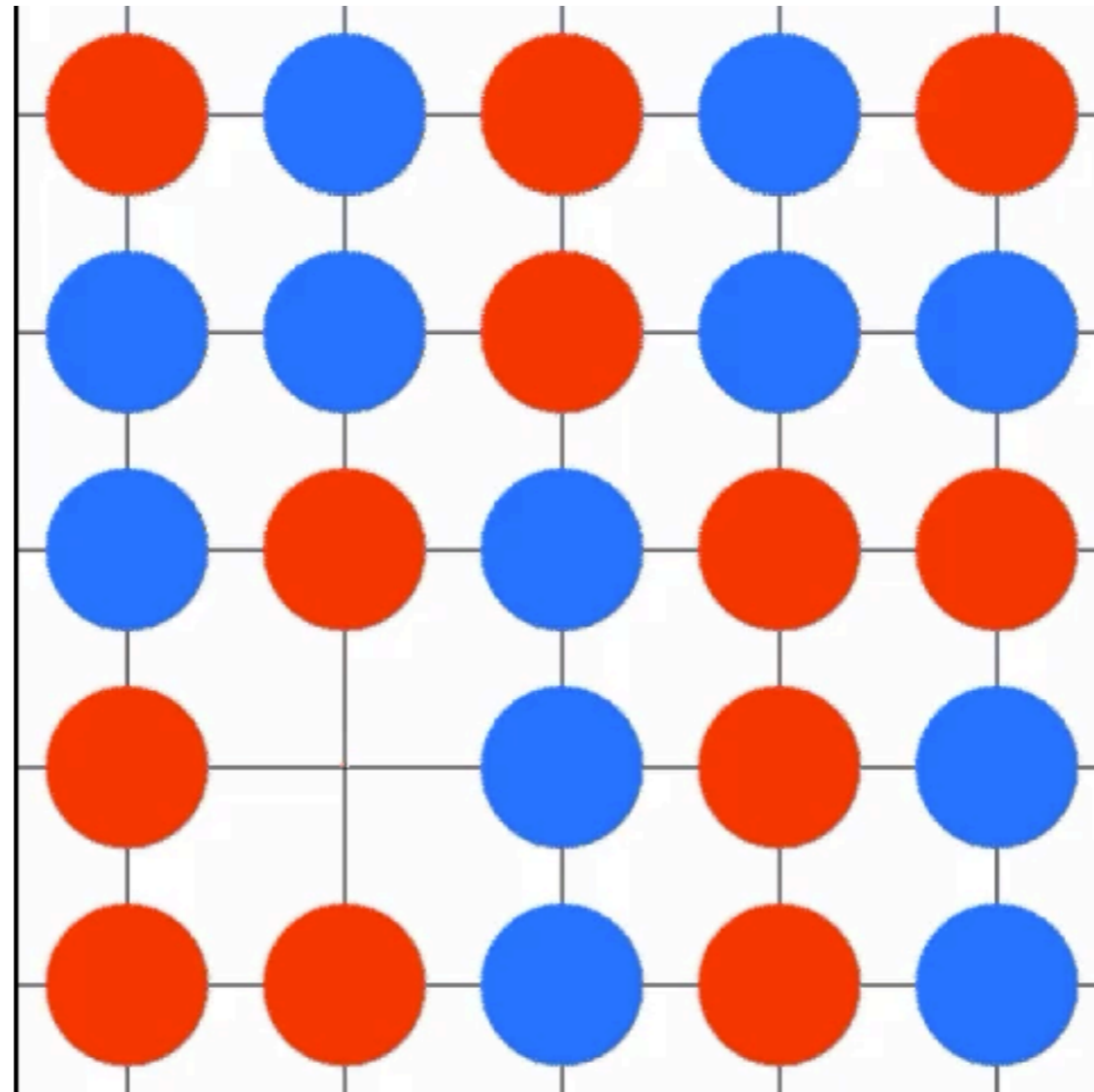
$$\left(\frac{1}{s}\right)^2 \propto \frac{1}{s}$$



Hubbard
not
necessary
(universality
class)

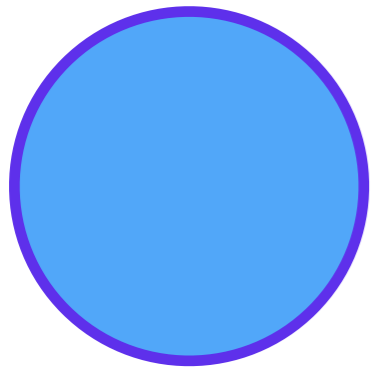
what does the HK model leave out??

$$[H_t, H_U] \neq 0$$

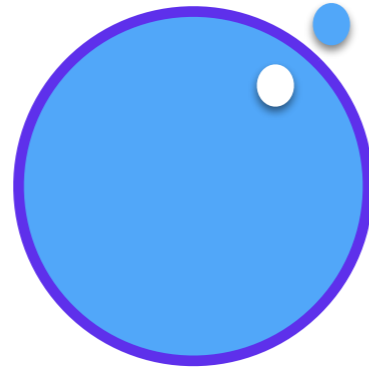


dynamical spectral weight transfer

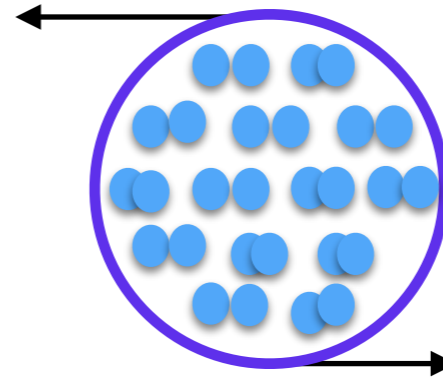
Fermi gas



Fermi liquid



BCS
superconductor



Mottness

2

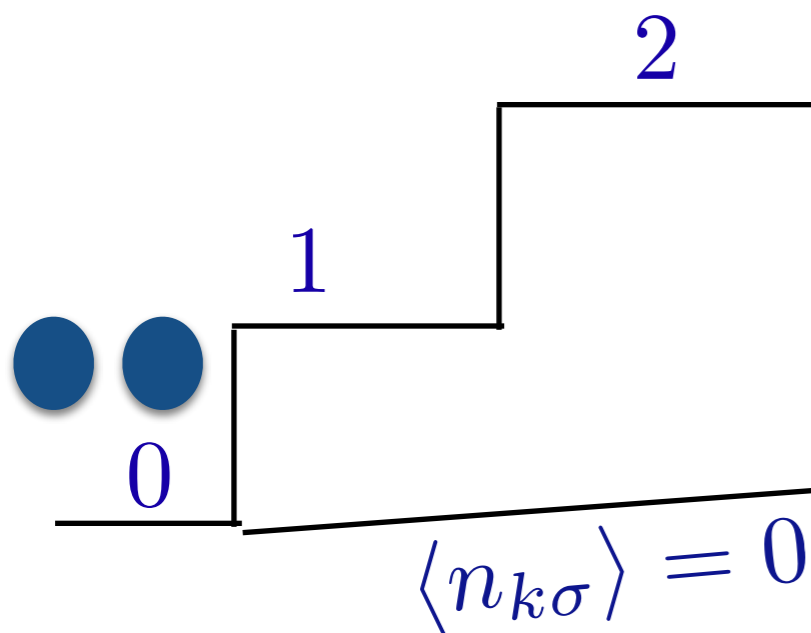
1

0



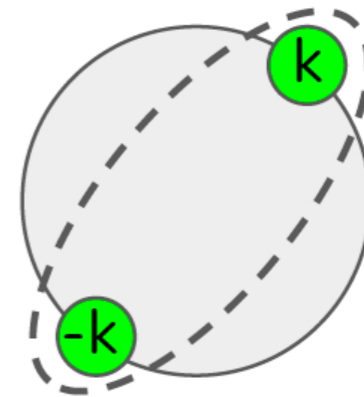
Superconductivity?

Cooper Instability



$$H = H_{\text{HK}} - gH_p$$

$$|\psi\rangle = \sum_{k \in \Omega_0} \alpha_k b_k^\dagger |\text{GS}\rangle$$

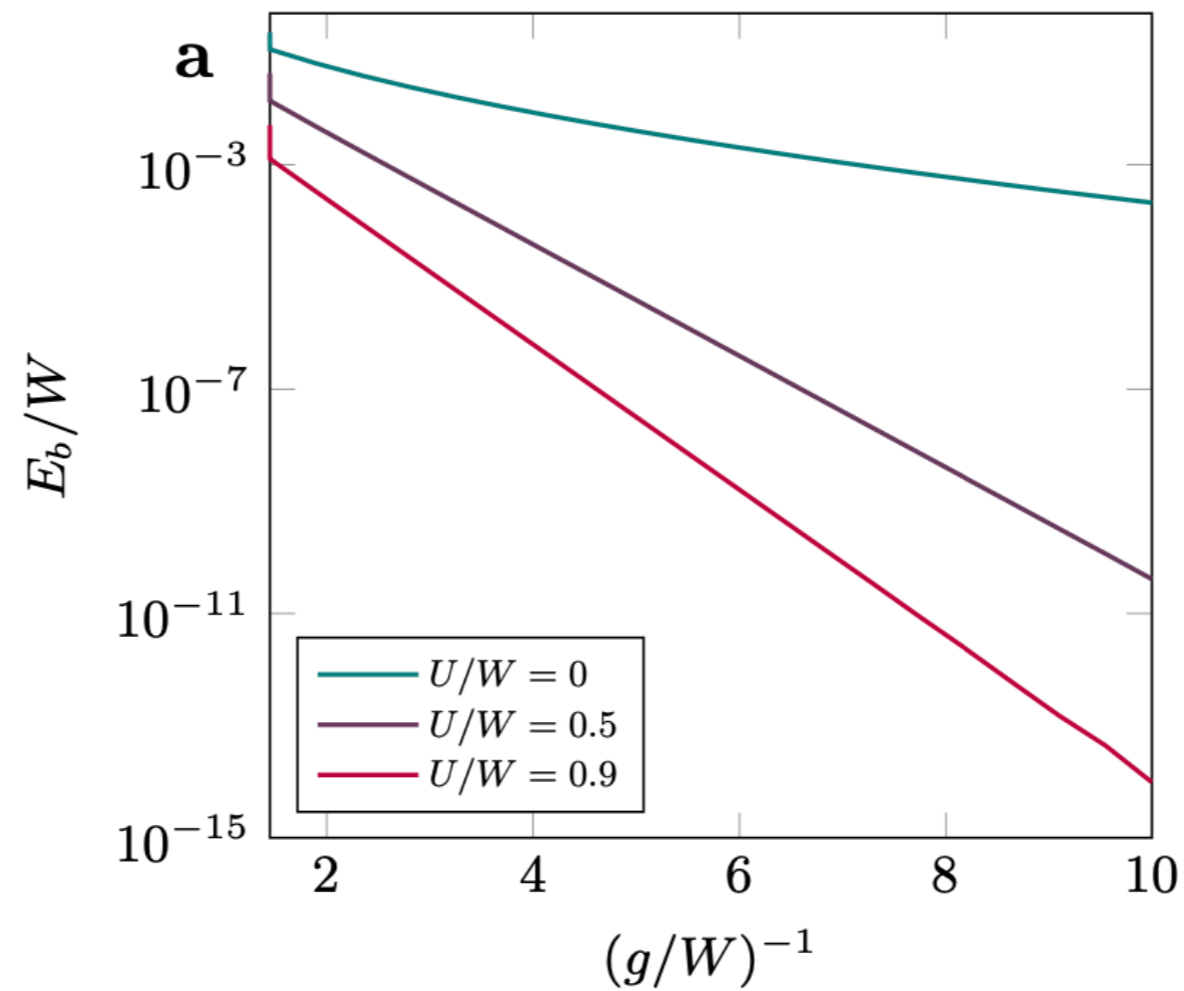


$$= \sum_{k, k'} b_k^\dagger b_{k'}$$

$$E_b = \langle \text{GS} | H | \text{GS} \rangle - \langle \psi | H | \psi \rangle \leq 0$$

Cooper Instability

$$E_b = -E \sim W(1 - (U/W)^2)e^{-\pi W \sqrt{1 - (U/W)^2} / g}$$



Pair Susceptibility

$$\chi(i\nu_n) \equiv \frac{1}{L^d} \int_0^\beta d\tau e^{i\nu_n \tau} \langle T \Delta(\tau) \Delta^\dagger \rangle_g$$

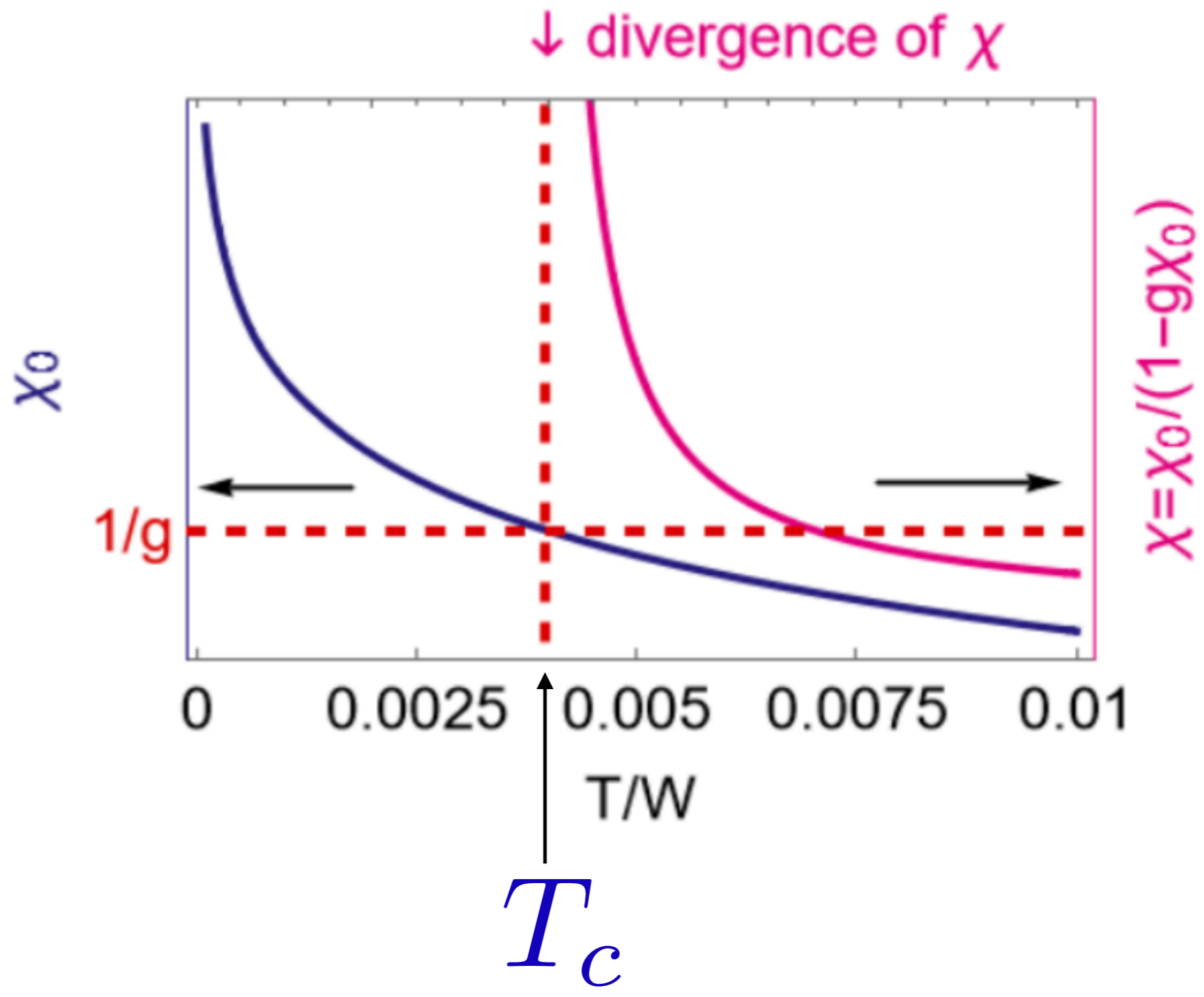


$$= \frac{\chi_0}{1 - g\chi_0}$$



$$g\chi_0 = 1$$

solve for T_c



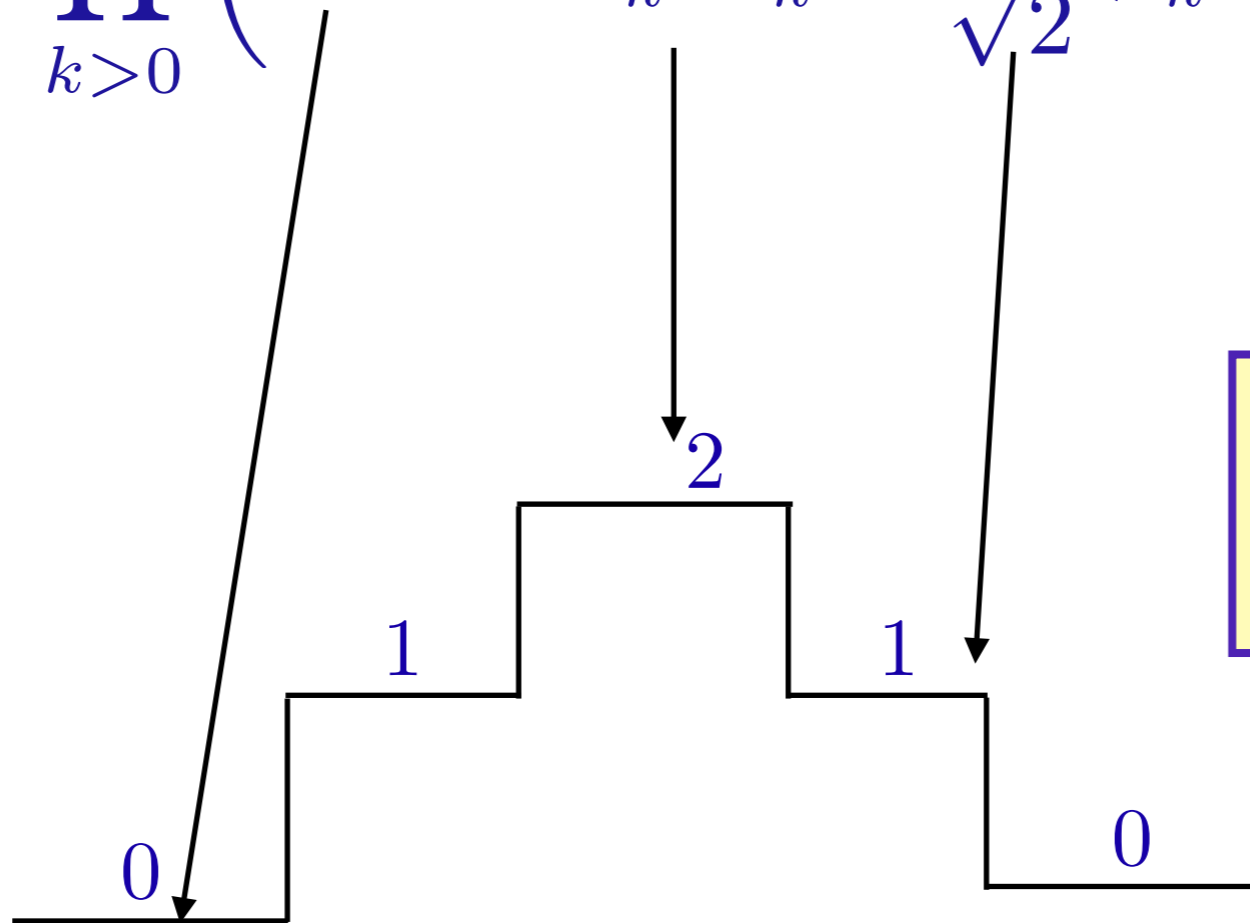
variational wave function

$$|\psi_{\text{BCS}}\rangle = \prod_k (u_k + v_k b_k^\dagger) |0\rangle$$



$$|\psi_{\text{BCS}}\rangle = \prod_{k>0} (u_k^2 + v_k^2 b_k^\dagger b_{-k}^\dagger + u_k v_k (b_k^\dagger + b_{-k}^\dagger)) |0\rangle$$

$$|\psi\rangle = \prod_{k>0} \left(x_k + y_k b_k^\dagger b_{-k}^\dagger + \frac{z_k}{\sqrt{2}} (b_k^\dagger + b_{-k}^\dagger) \right) |0\rangle$$



HK
generalization

three variational parameters

$$|x_k|^2 + |y_k|^2 + |z_k|^2 = 1$$

gap equation


$$\Delta \ll U, W$$

$$\Delta = (W - U)^{1/2} U^{1/2} e^{-\frac{W}{2g}}$$

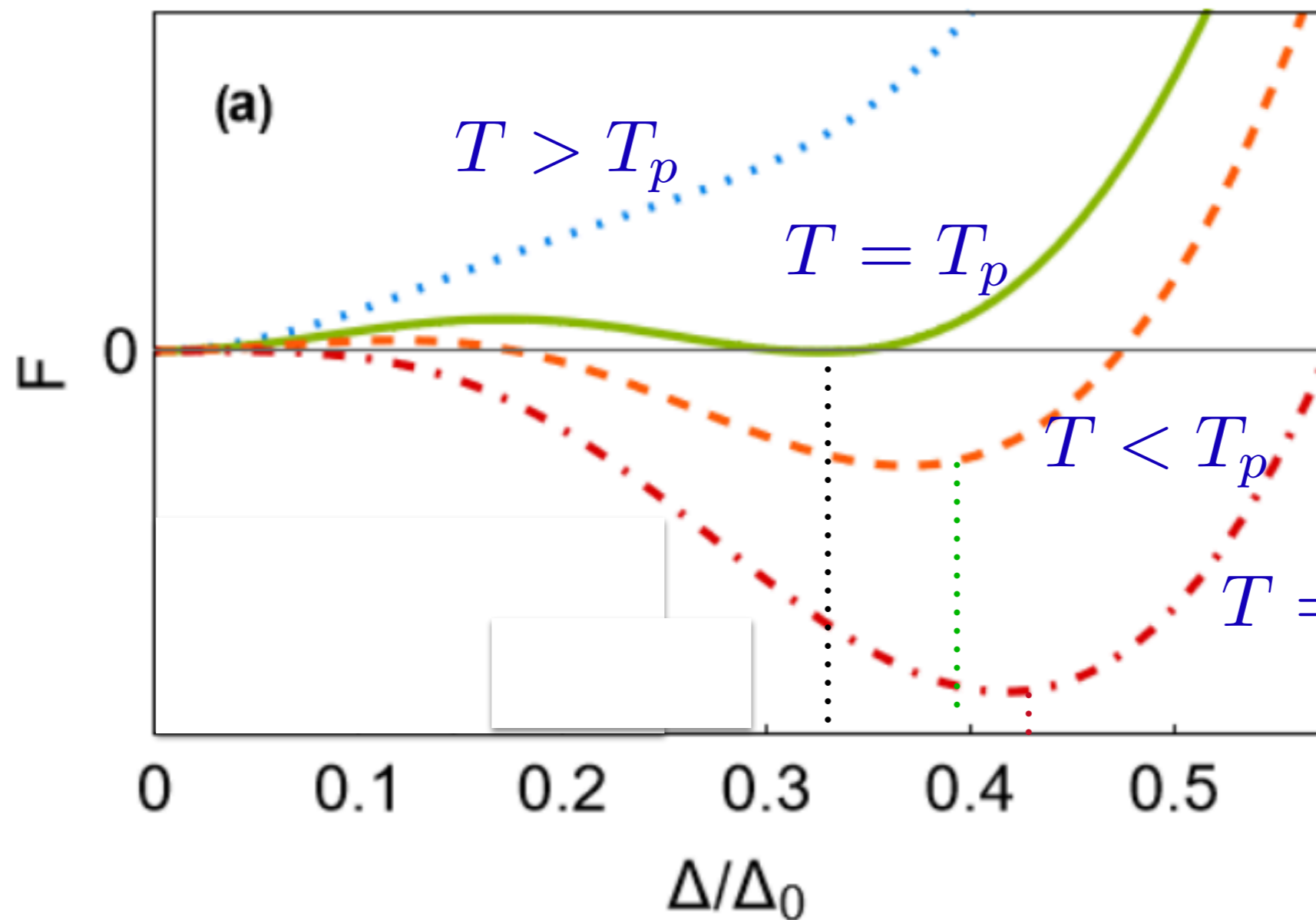
gap/ T_c ratio

$$\Delta = (W - U)^{1/2} U^{1/2} e^{-\frac{W}{2g}}$$

$$T_c = (W - U)^{4/5} U^{1/5} \frac{e^\gamma}{\pi} e^{-\frac{4}{5} \frac{W}{g}}.$$

$$\lim_{g \rightarrow 0} \frac{\Delta}{T_c} \rightarrow \infty$$

non-BCS superconductivity



$t_G \approx 10^{-11}$

MF theory
is accurate!

Two-stage superconductivity in the Hatsugai-Kohomoto-BCS model

Yu Li,¹ Vivek Mishra,¹ Yi Zhou,^{2,3,4} and Fu-Chun Zhang^{1,4,*}

¹Kavli Institute for Theoretical Sciences, University of Chinese Academy of Sciences, Beijing 100190, China

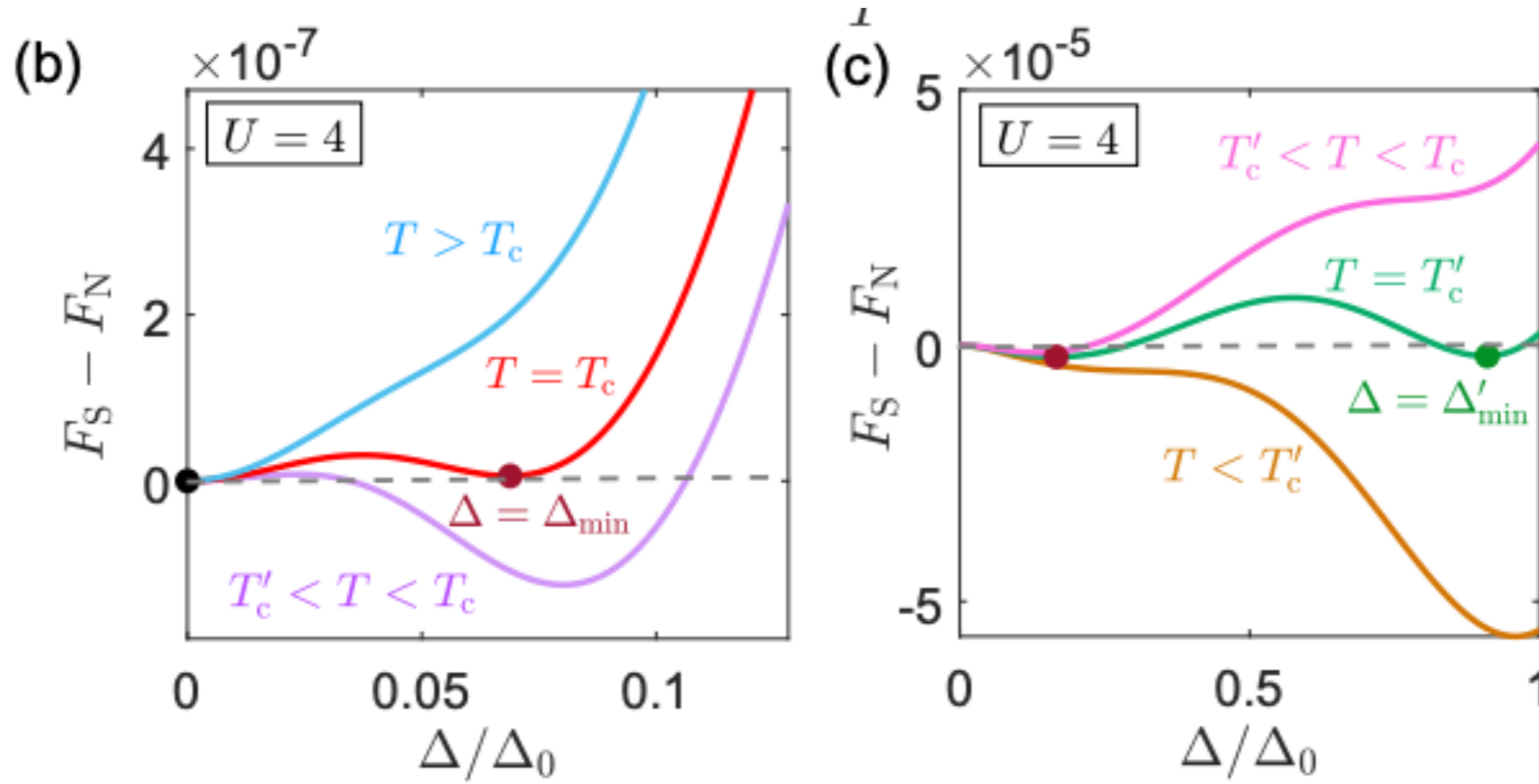
²Beijing National Laboratory for Condensed Matter Physics & Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

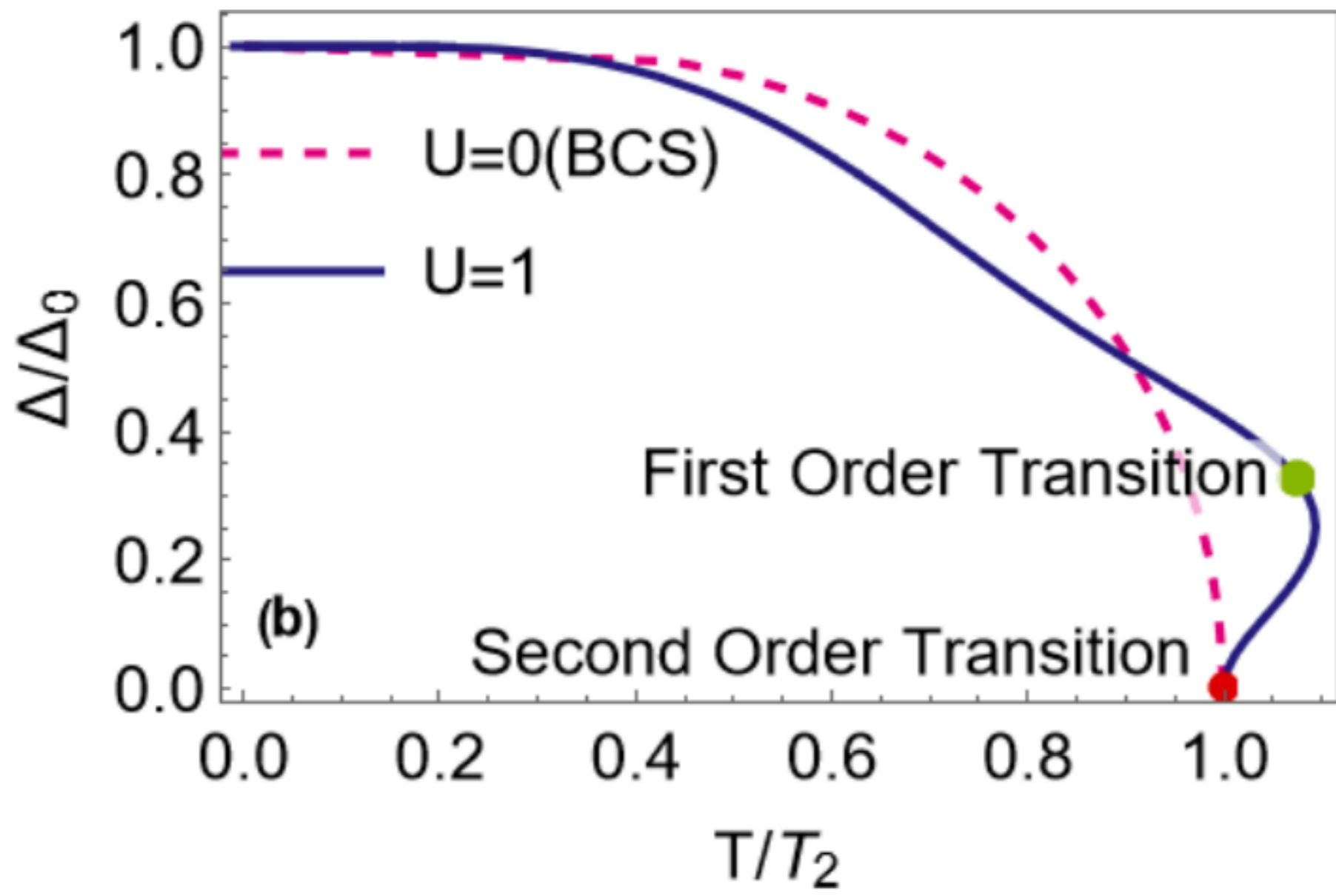
³Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China

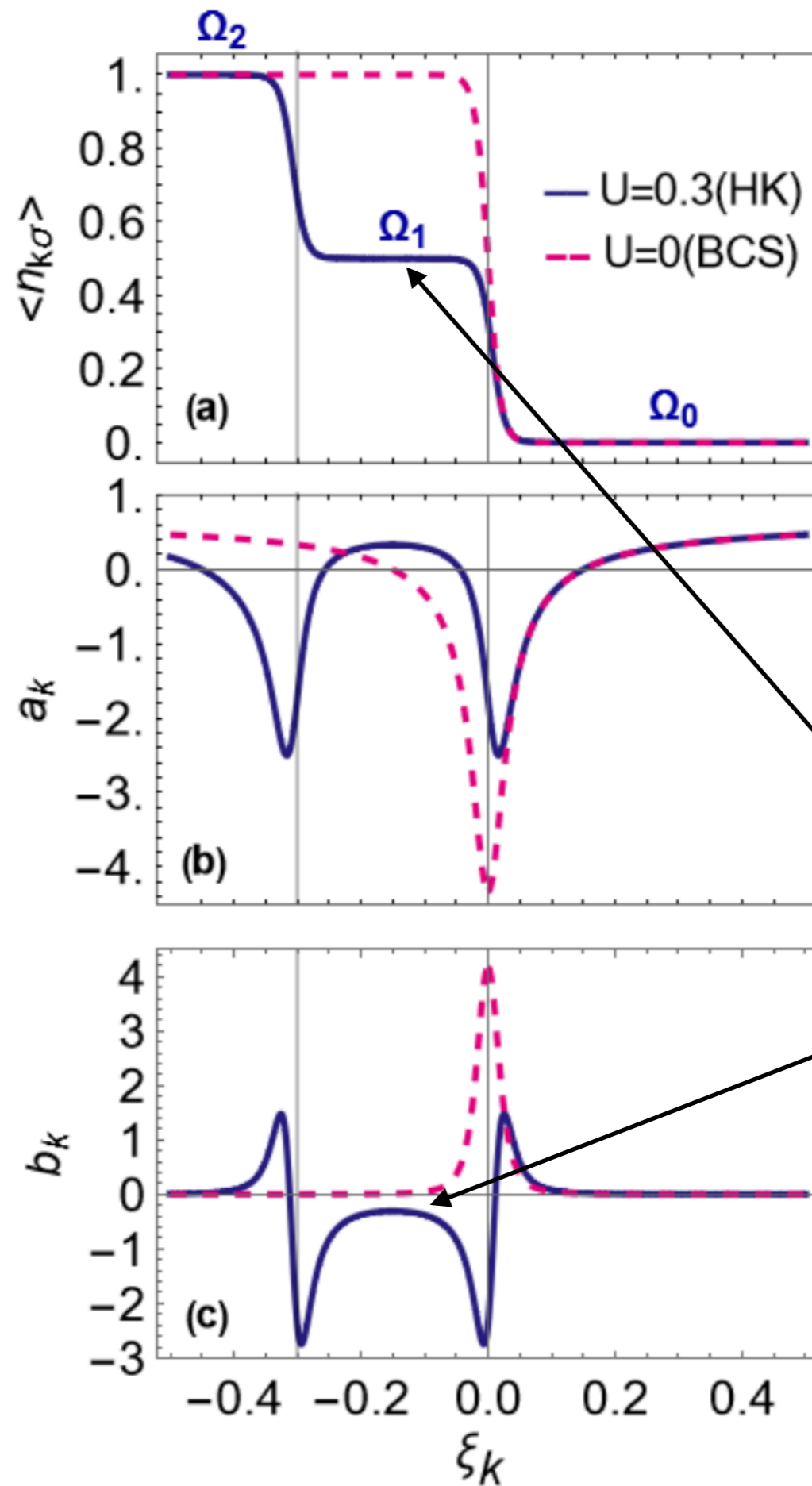
⁴CAS Center for Excellence in Topological Quantum Computation,
University of Chinese Academy of Sciences, Beijing 100190, China

(Dated: July 7, 2022)

<https://arxiv.org/pdf/2207.01904.pdf>





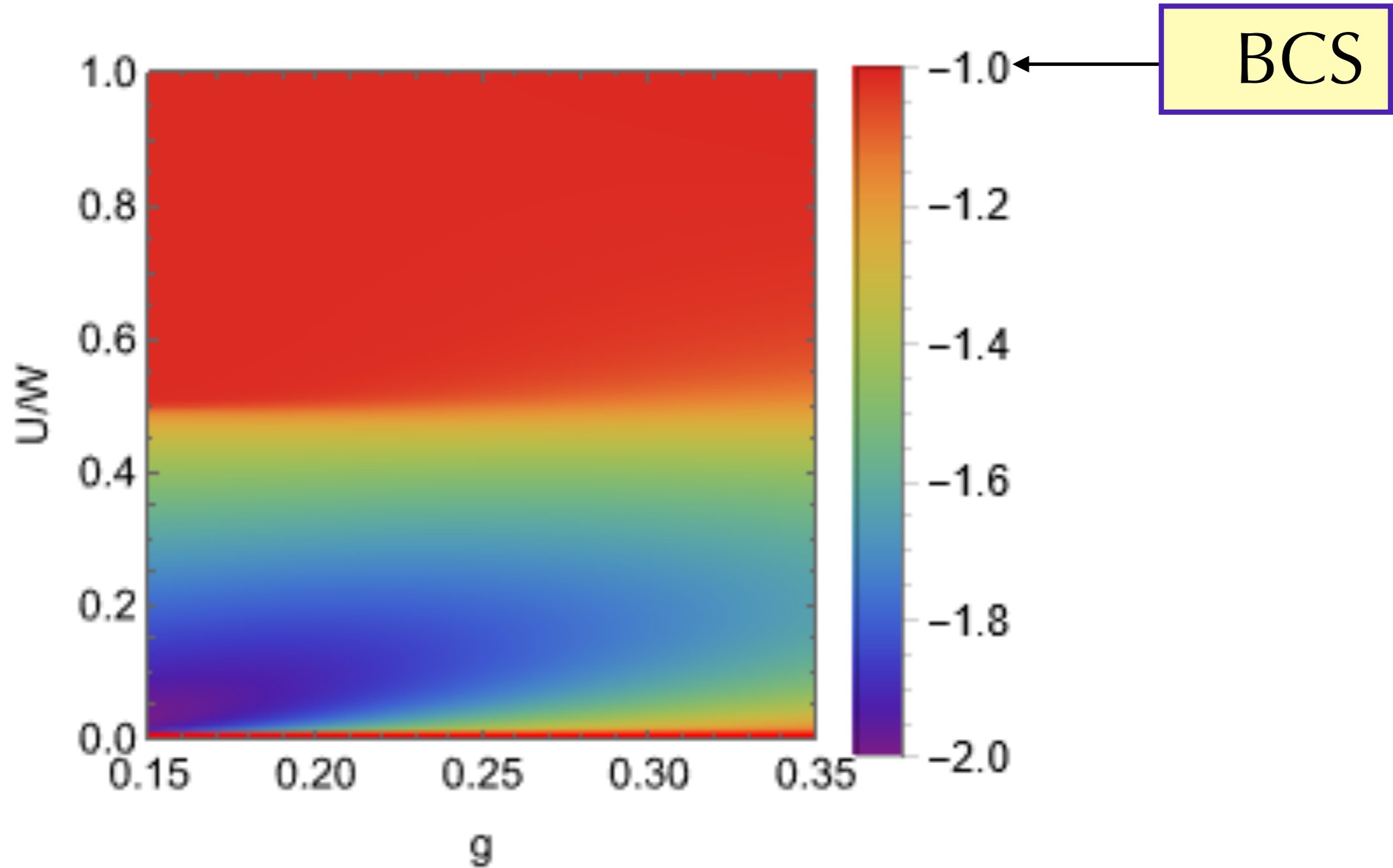


Landau parameters

Mottness

Condensation Energy

$$E_{\text{cond}}/N(0)\Delta^2 < 0$$



Bogoliubov excitations

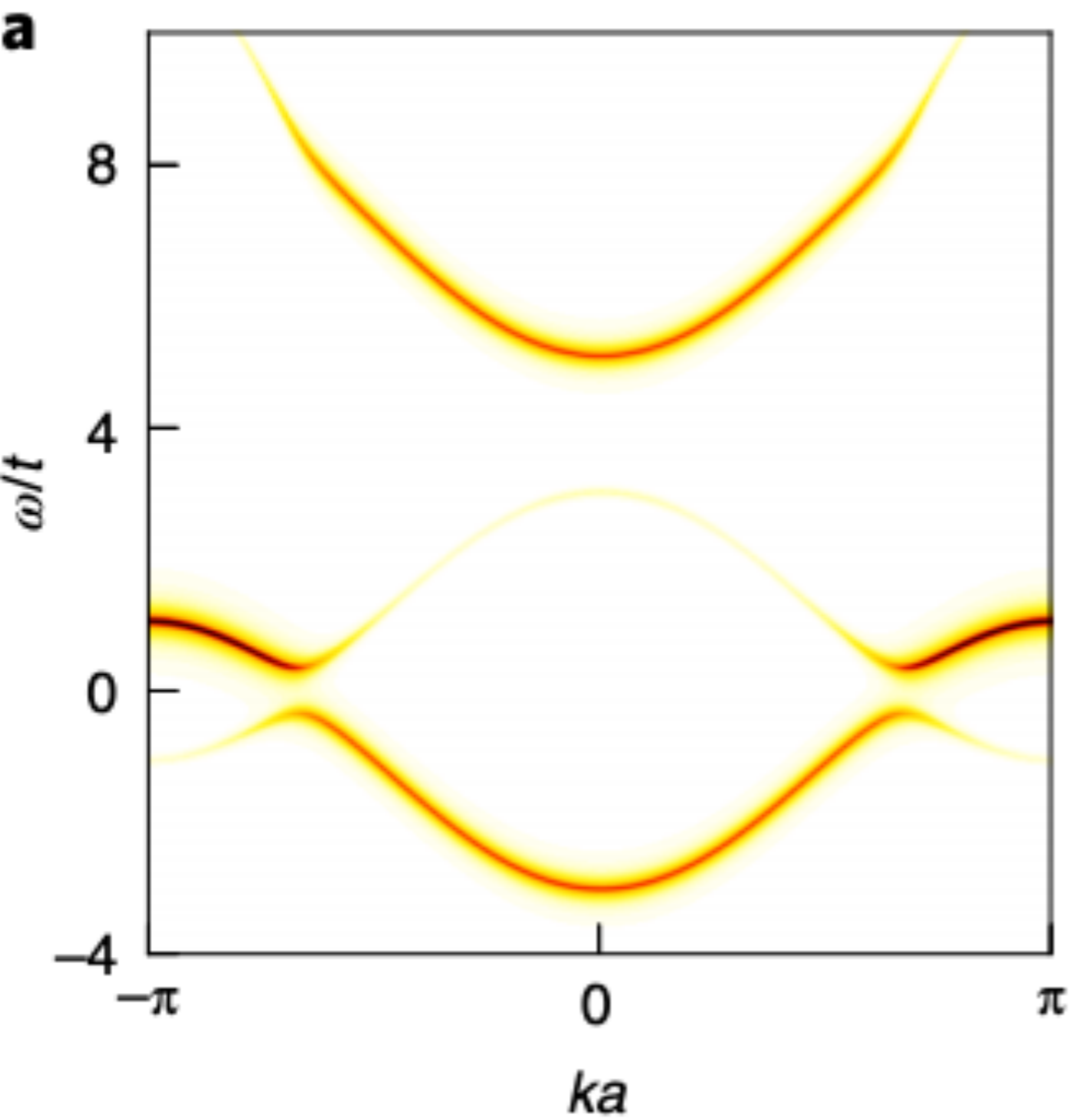
$$\gamma_{k\sigma} |\psi_{\text{BCS}}\rangle = 0$$

$$\gamma_{k\sigma} = u_k c_{k\sigma} - \sigma v_k c_{-k\bar{\sigma}}^\dagger$$


PYHons excitations

$$\gamma_{k\sigma}^l \propto \sqrt{2} x_k \zeta_{k\sigma}^\dagger - \sigma z_k \zeta_{-k\bar{\sigma}}$$

$$\gamma_{k\sigma}^u \propto z_k \eta_{k\sigma}^\dagger - \sigma \sqrt{2} y_k \eta_{-k\bar{\sigma}}$$



PYHon band

can we explain the color change?

REPORT

Superconductivity-Induced Transfer of In-Plane Spectral Weight in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$

H. J. A. Molegraaf¹, C. Presura¹, D. van der Marel^{1,*}, P. H. Kes², M. Li²

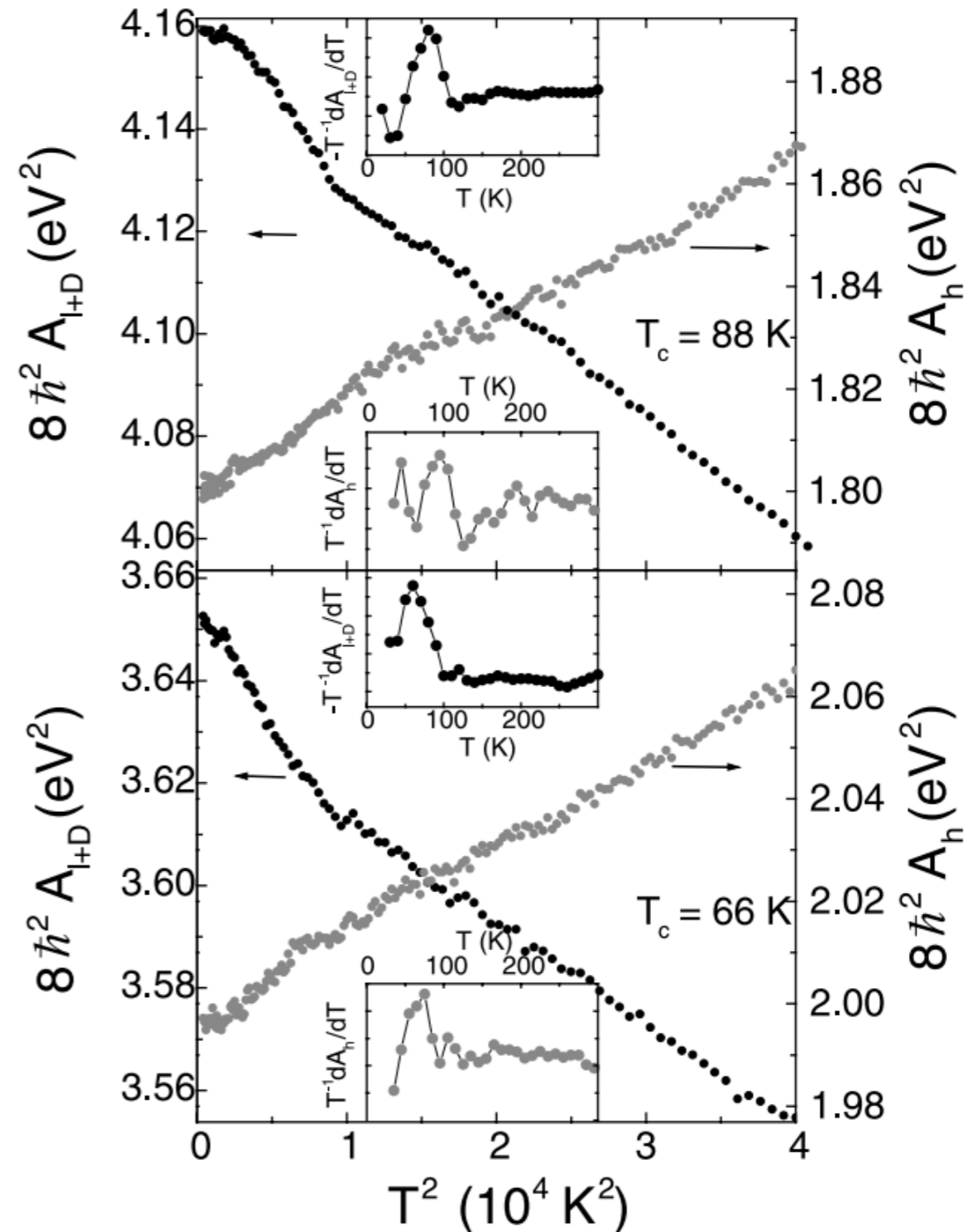
+ See all authors and affiliations

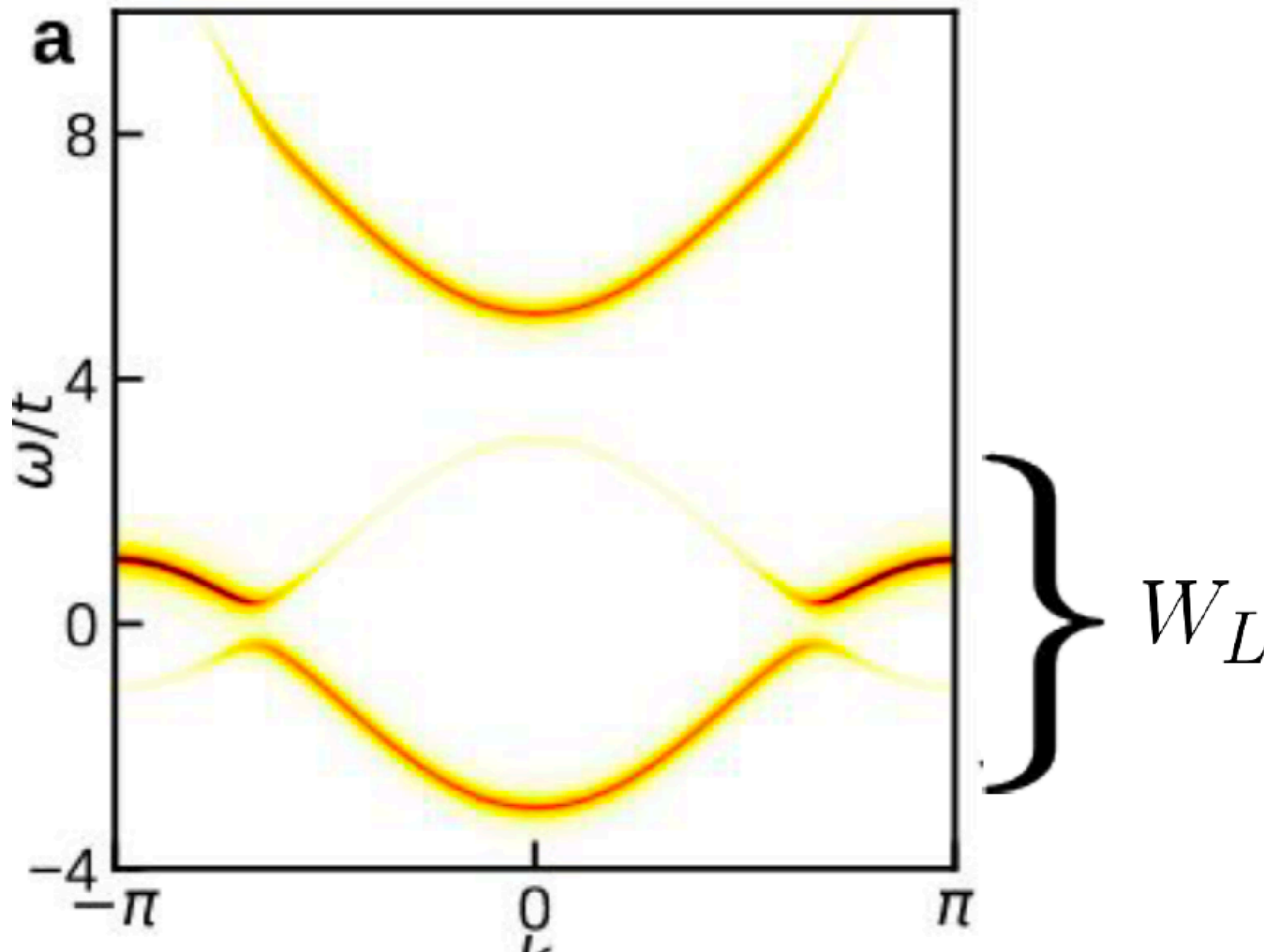
Science 22 Mar 2002:
Vol. 295, Issue 5563, pp. 2239-2241
DOI: 10.1126/science.1069947

$$A_l = \int_0^{\Omega} \sigma(\omega) d\omega \quad \Omega/2\pi c = 10000 \text{ cm}^{-1}$$

$$A_h = \int_{\Omega}^{2\Omega} \sigma(\omega) d\omega \quad \Omega/2\pi c = 10000 \text{ cm}^{-1}$$

$$\frac{\Delta A_l}{A_l} \propto 3\%$$





why?

$$H = H_{\text{HK}} + H_p$$

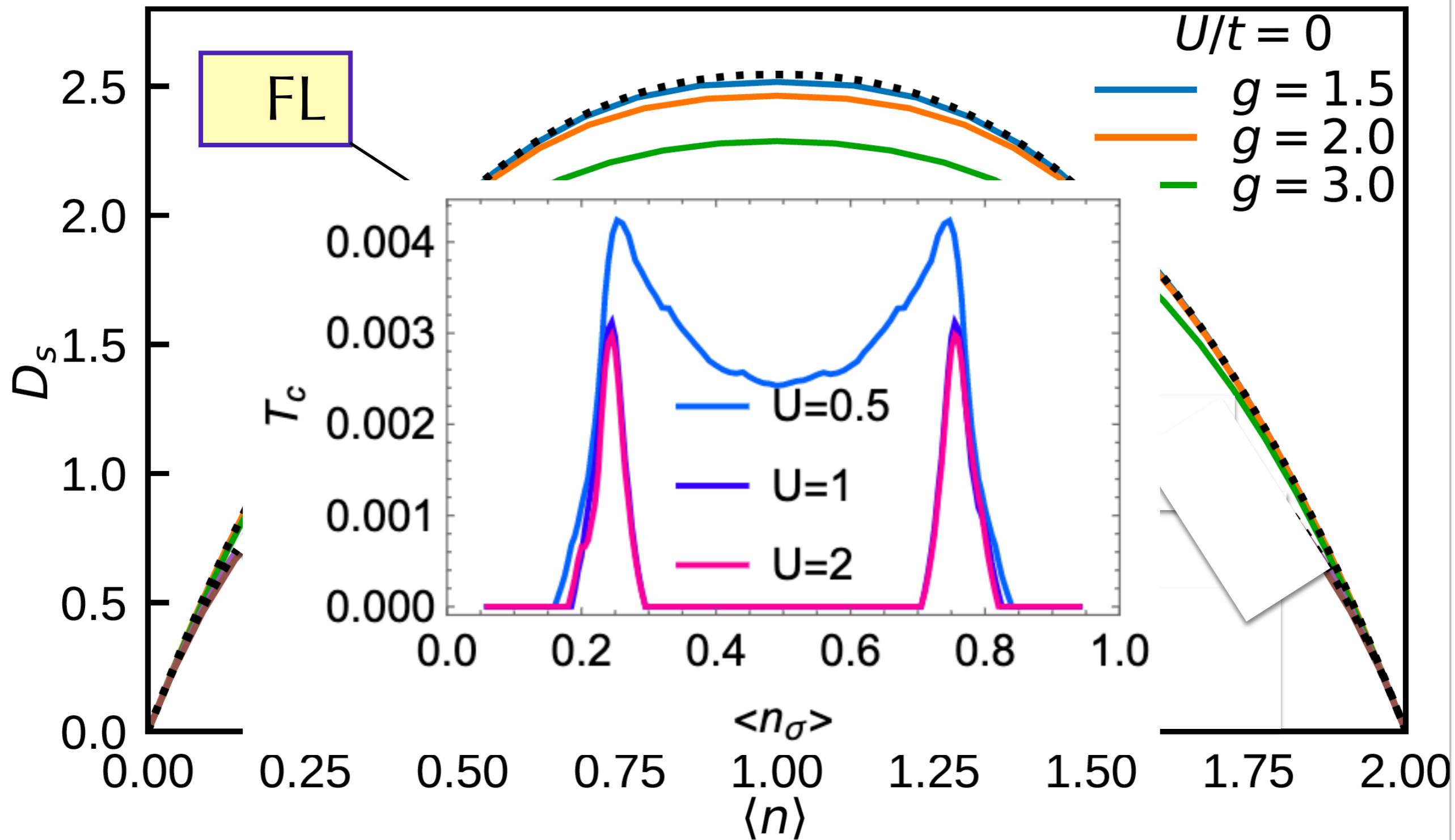
$$[H_{\text{HK}}, H_p] \neq 0$$



dynamical
spectral weight
transfer

Superfluid Density

Mottness-induced suppression



Superconductivity

Mottness

observable

$$\chi \rightarrow \infty$$

$$\Delta \neq 0$$

$$\lim_{g \rightarrow 0} 2\Delta_0/k_B T_c$$

quasi – particles

t_G (Ginzburg)

$$1/TT_1$$

Landau Expansion

$$E_{\text{cond}}/N(0)\Delta^2$$

BCS/FL

$$T_c$$

$$T_c$$

$$3.52$$

Bogoliubons

$$\approx 10^{-12}$$

HS peak

$$a = \alpha t, b > 0$$

$$-1$$

PYHZ/HK

$$T_c (= T_2)$$

$$T_p (> T_2)$$

$$\infty$$

PYHons

$$\approx 10^{-11}$$

no HS peak

$$a = \alpha t, b < 0$$

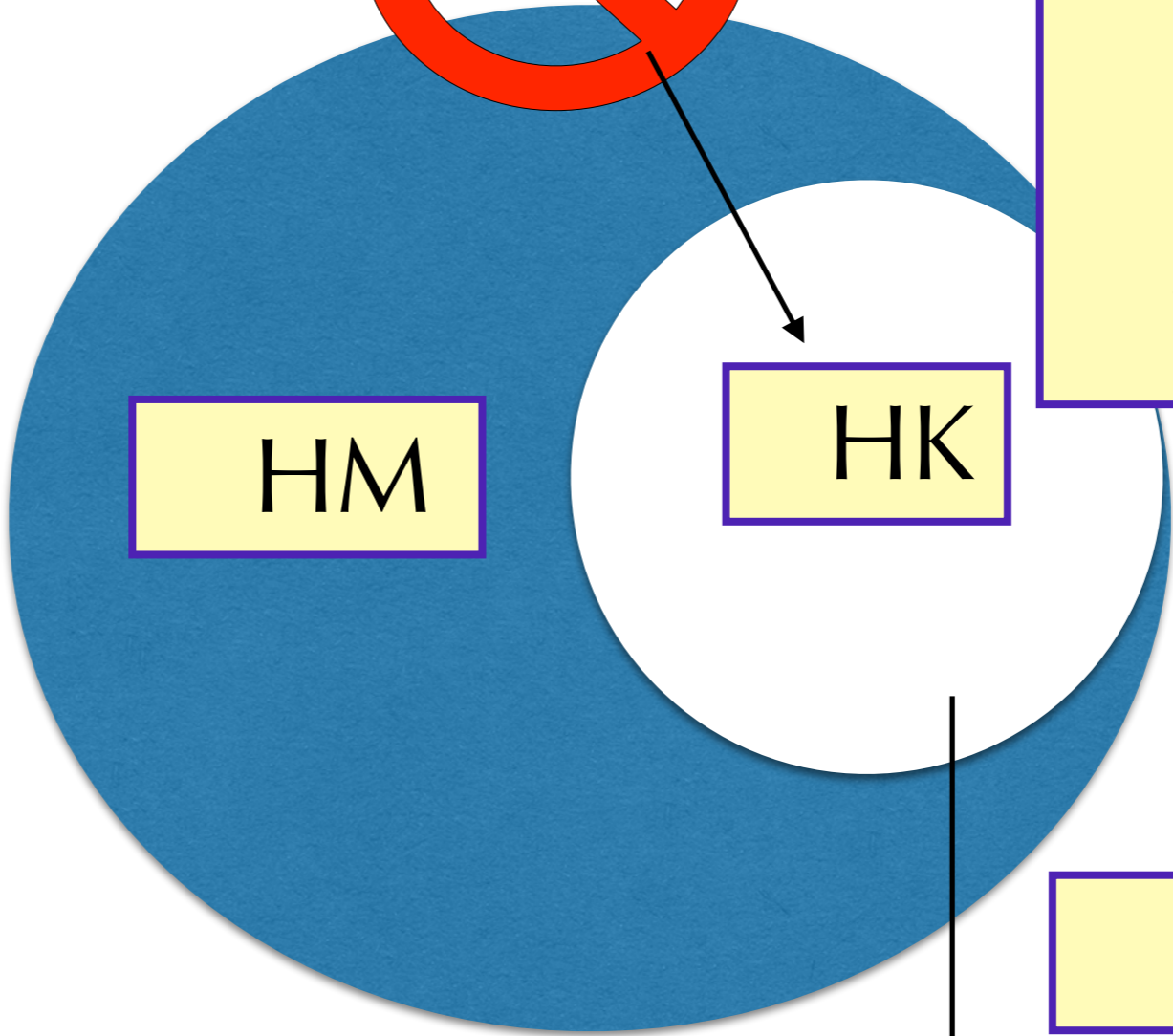
$$c > 0$$

$$[-2, -1]$$

Mottness



most relevant interaction



PYHons

non-BCS superconductivity

violation of Luttinger