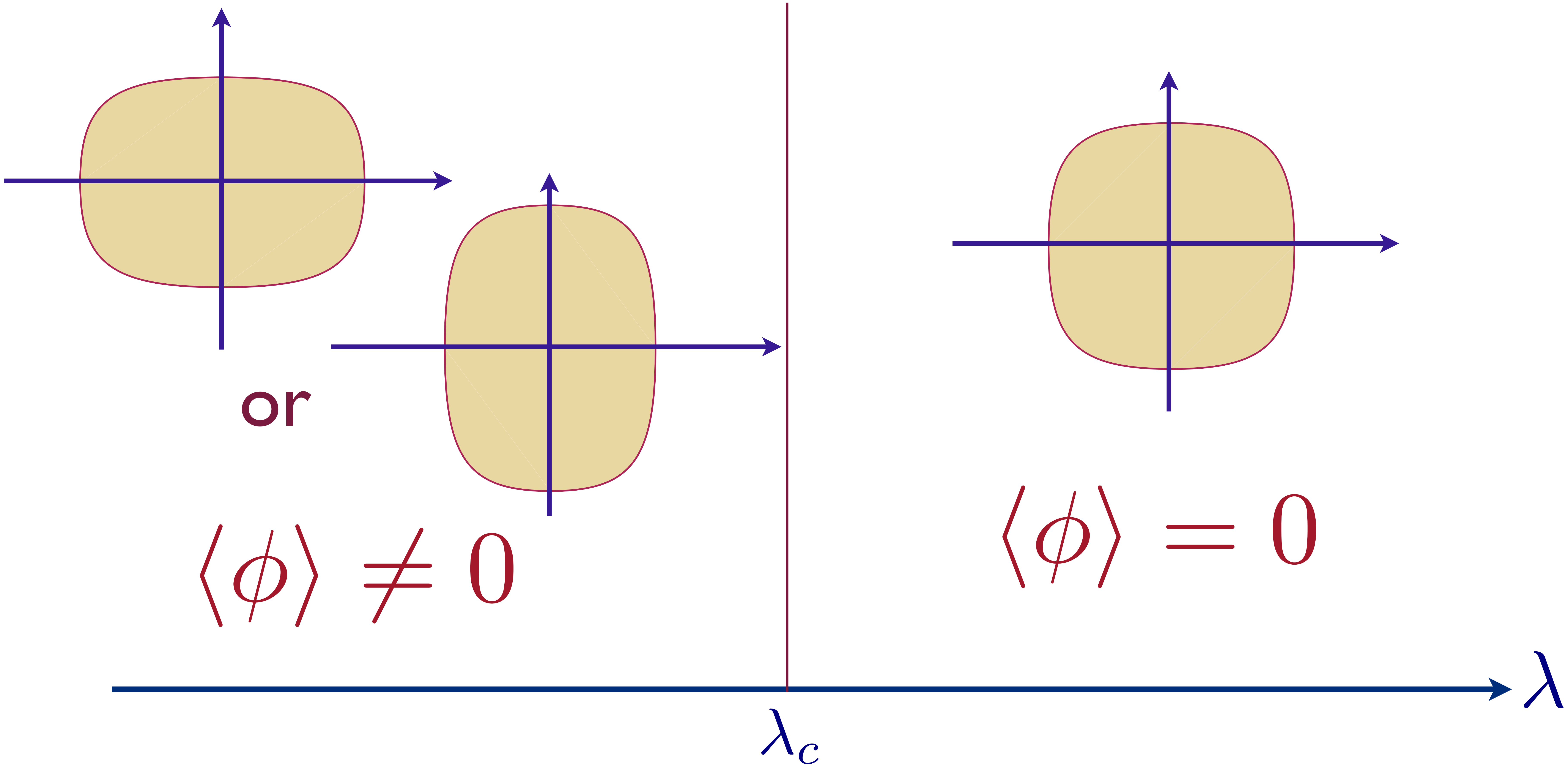
Non-Fermi liquids
vs.
Strange Metals
vs.
Bad Metals

Gordon Research Conference, Mt. Holyoke, June 29, 2022
Subir Sachdev

D. Chowdhury, A. Georges, O. Parcollet, S. Sachdev,
arXiv: 2109.05037, Reviews of Modern Physics

Quantum criticality of Ising-nematic ordering in a metal



Pomeranchuk instability as a function of coupling λ

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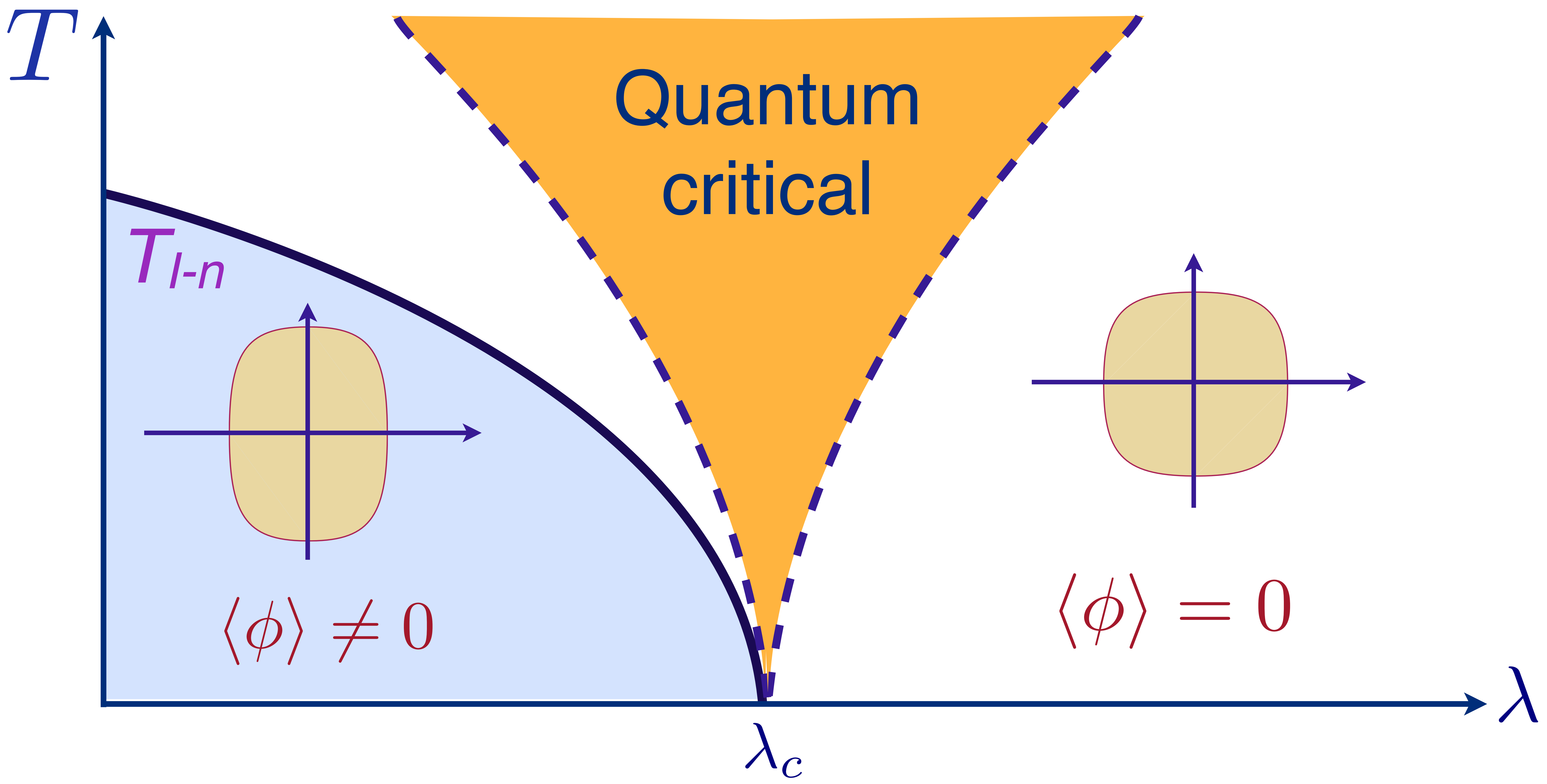

Phase diagram as a function of T and λ

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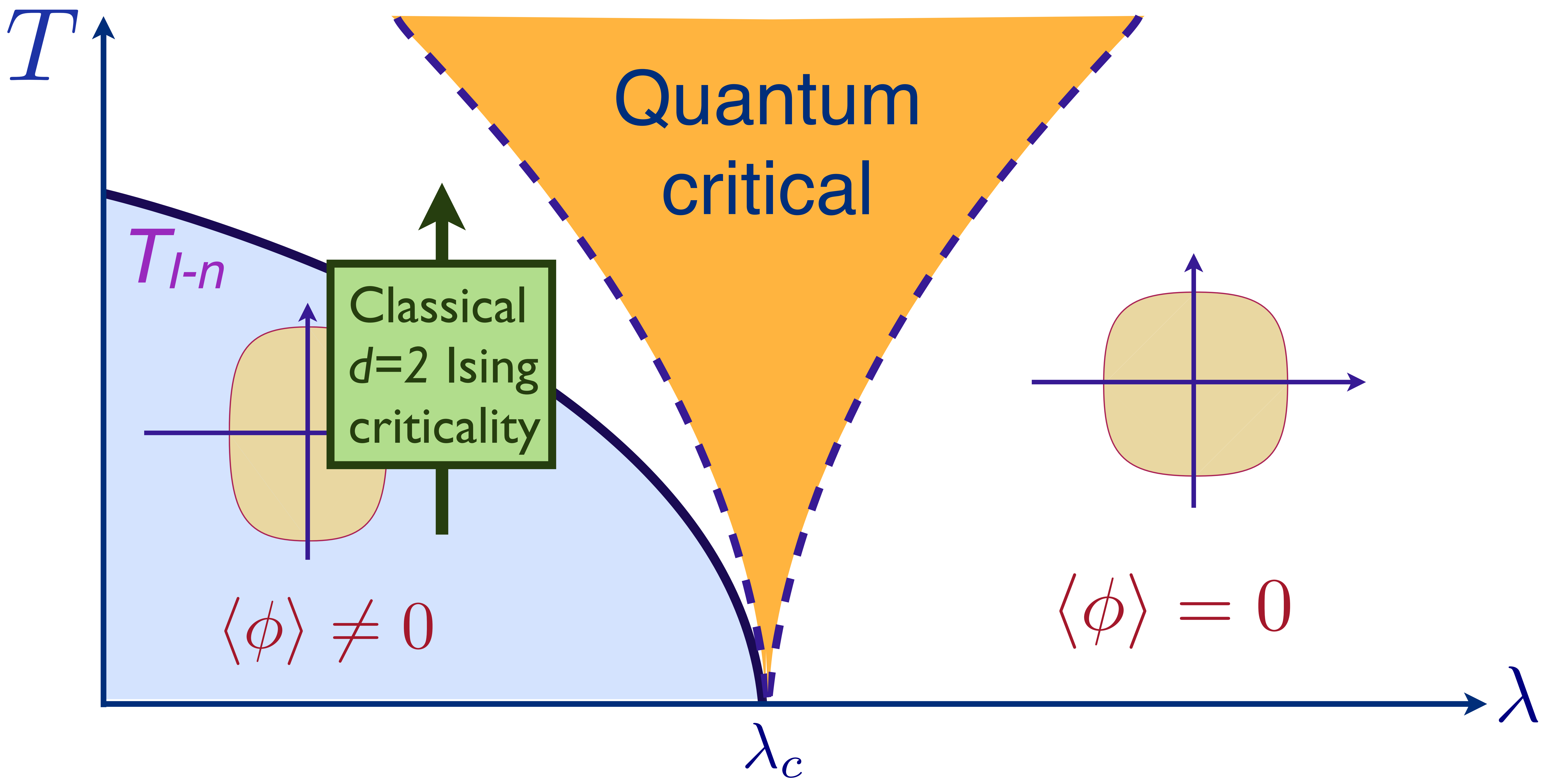

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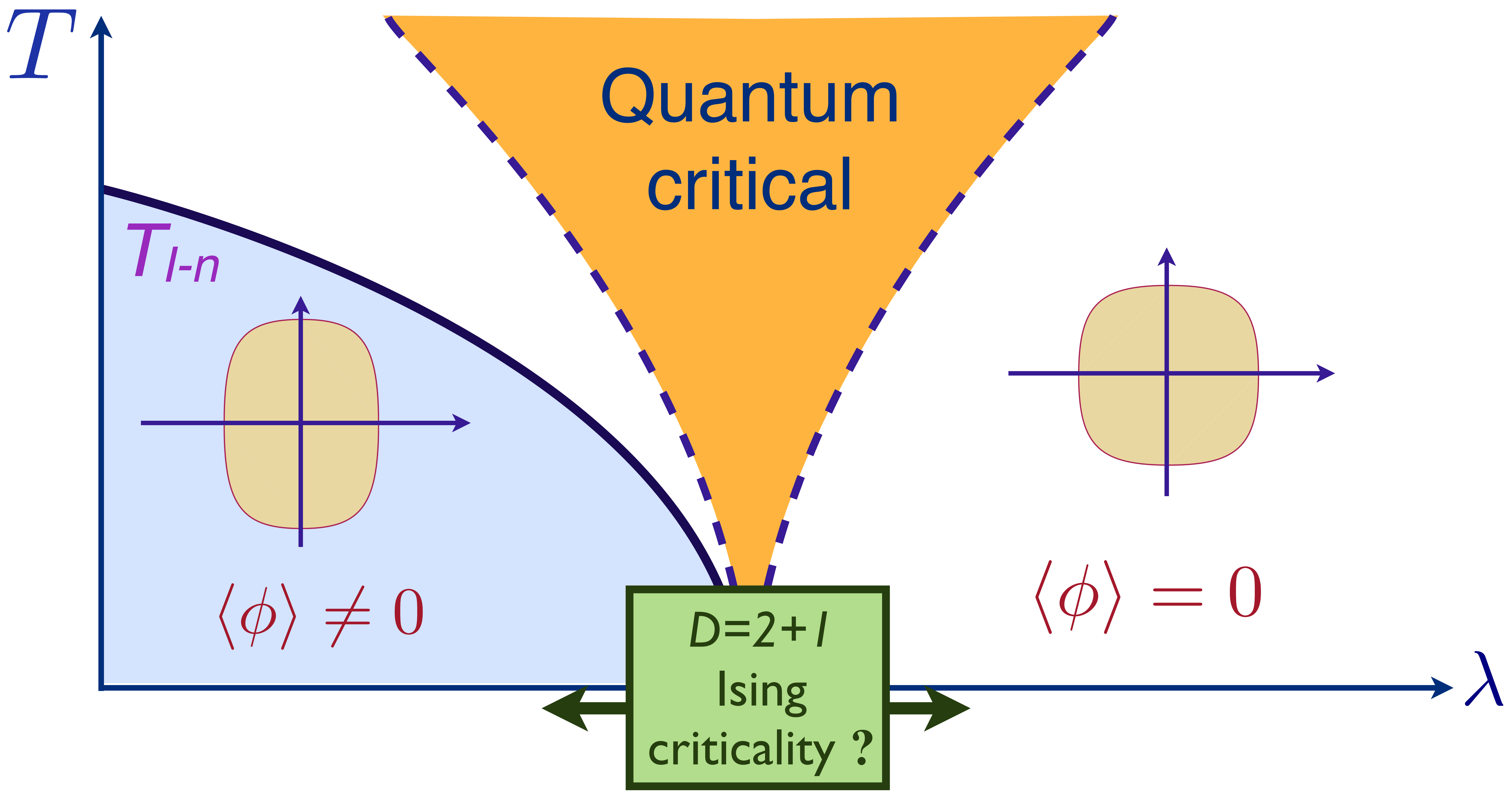

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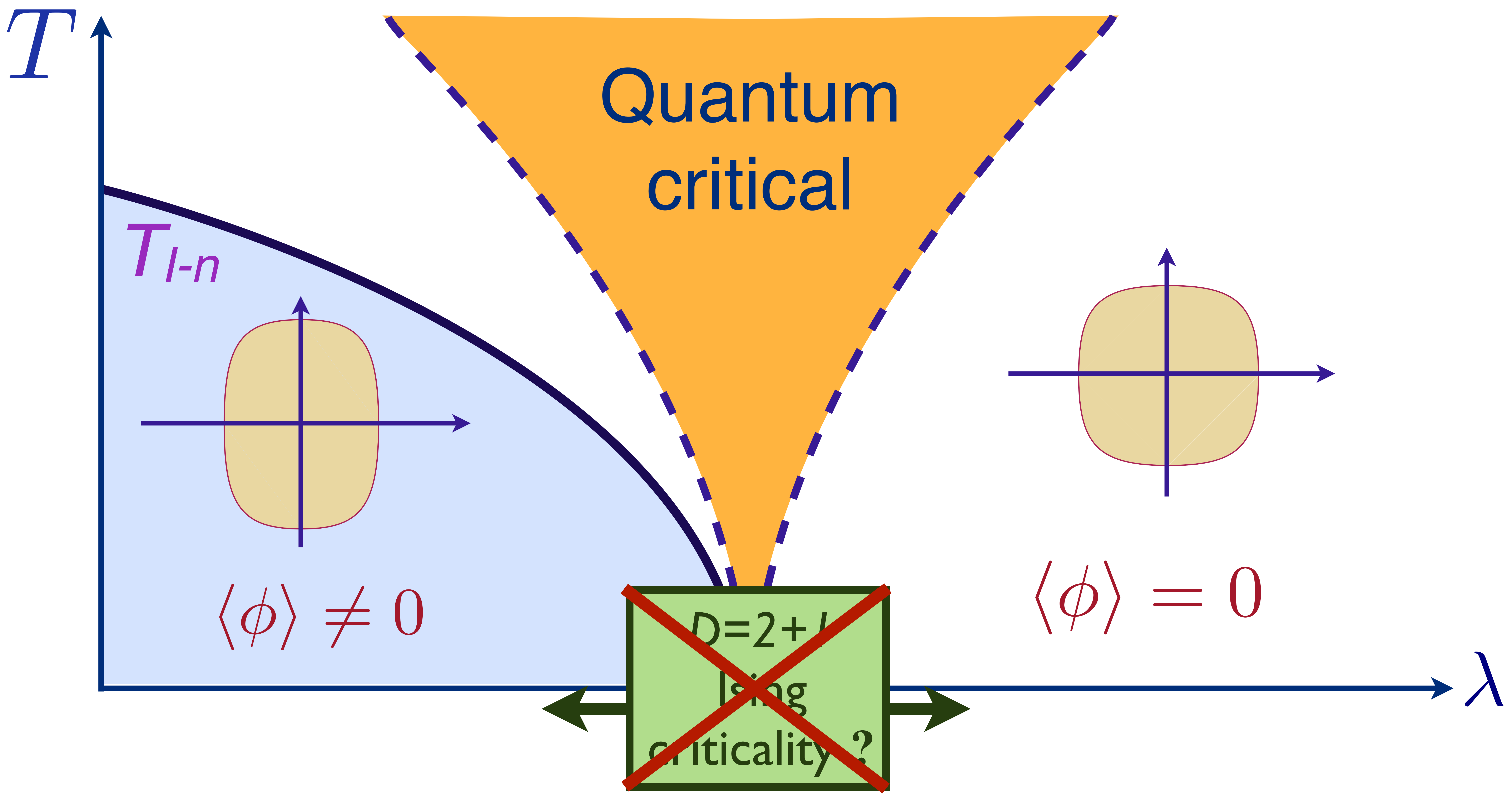

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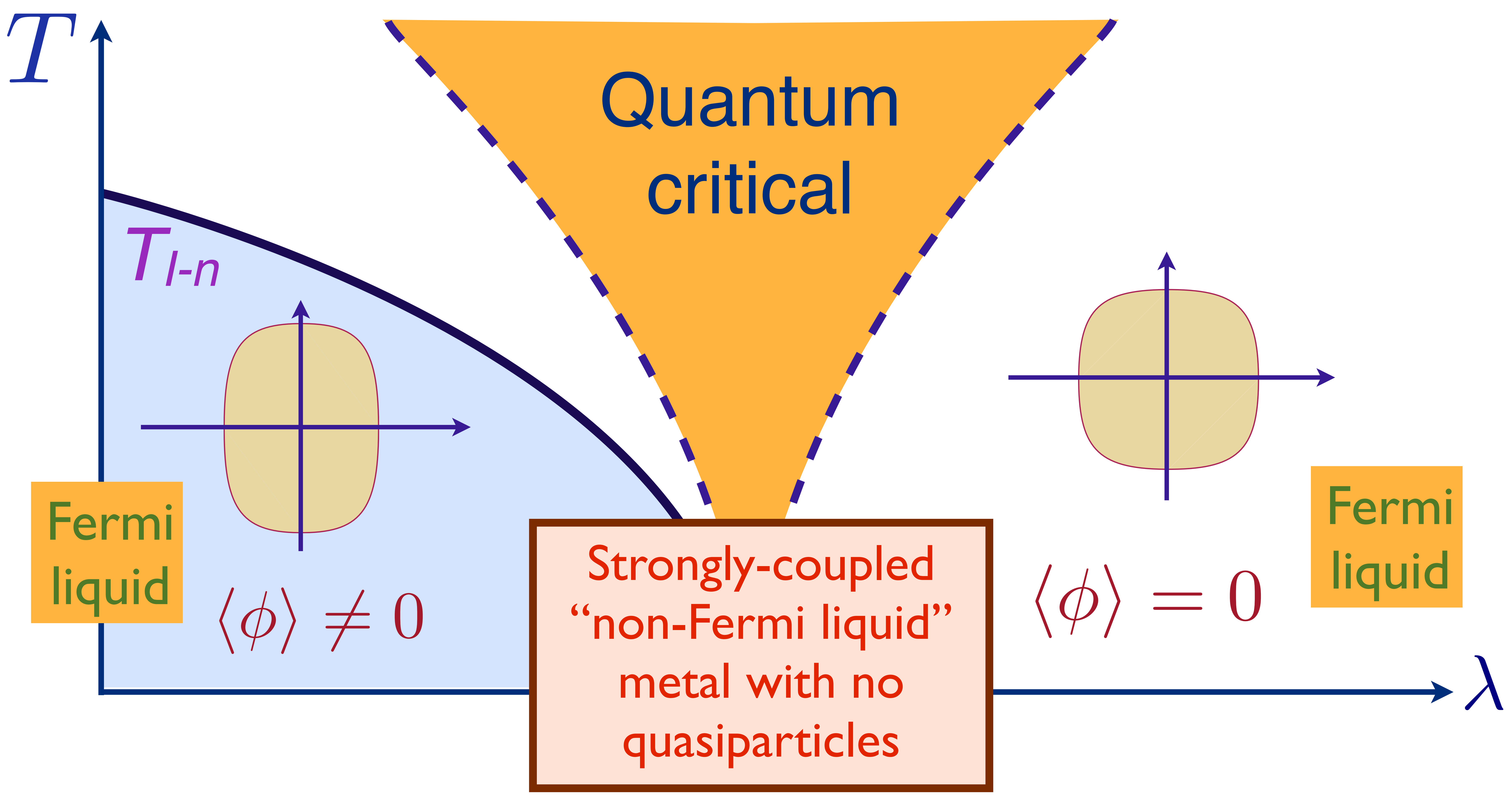

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Properties of a non-Fermi liquid:

- No quasiparticle excitations.
- However, there is a sharp Fermi surface in momentum space, and its enclosed volume obeys the Luttinger relation.
- Relaxational and dissipative phenomena (and OTOCs) are controlled by a 'Planckian' time $\sim \hbar/(k_B T)$, which is independent of the energy scale of the interactions.

Zwierlein

$$G(\omega, \boldsymbol{k}) = \frac{1}{\omega - \varepsilon(\boldsymbol{k}) + iT^{2/3} F\left(\frac{\hbar\omega}{k_B T}\right)}$$

Poster by
M. Tikhanovskaya

S.A. Hartnoll and A.P. MacKenzie, arXiv:2107.07802

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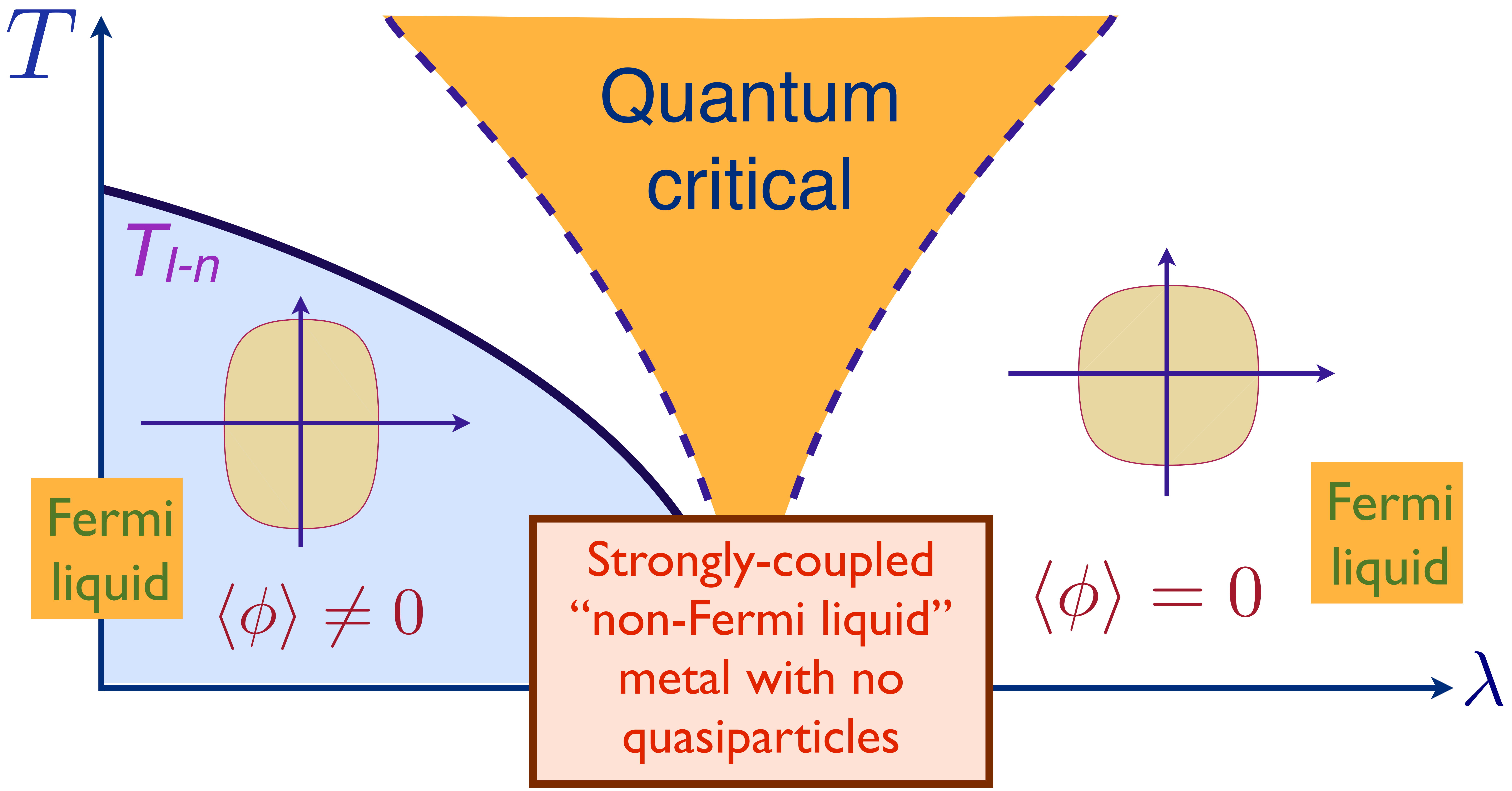

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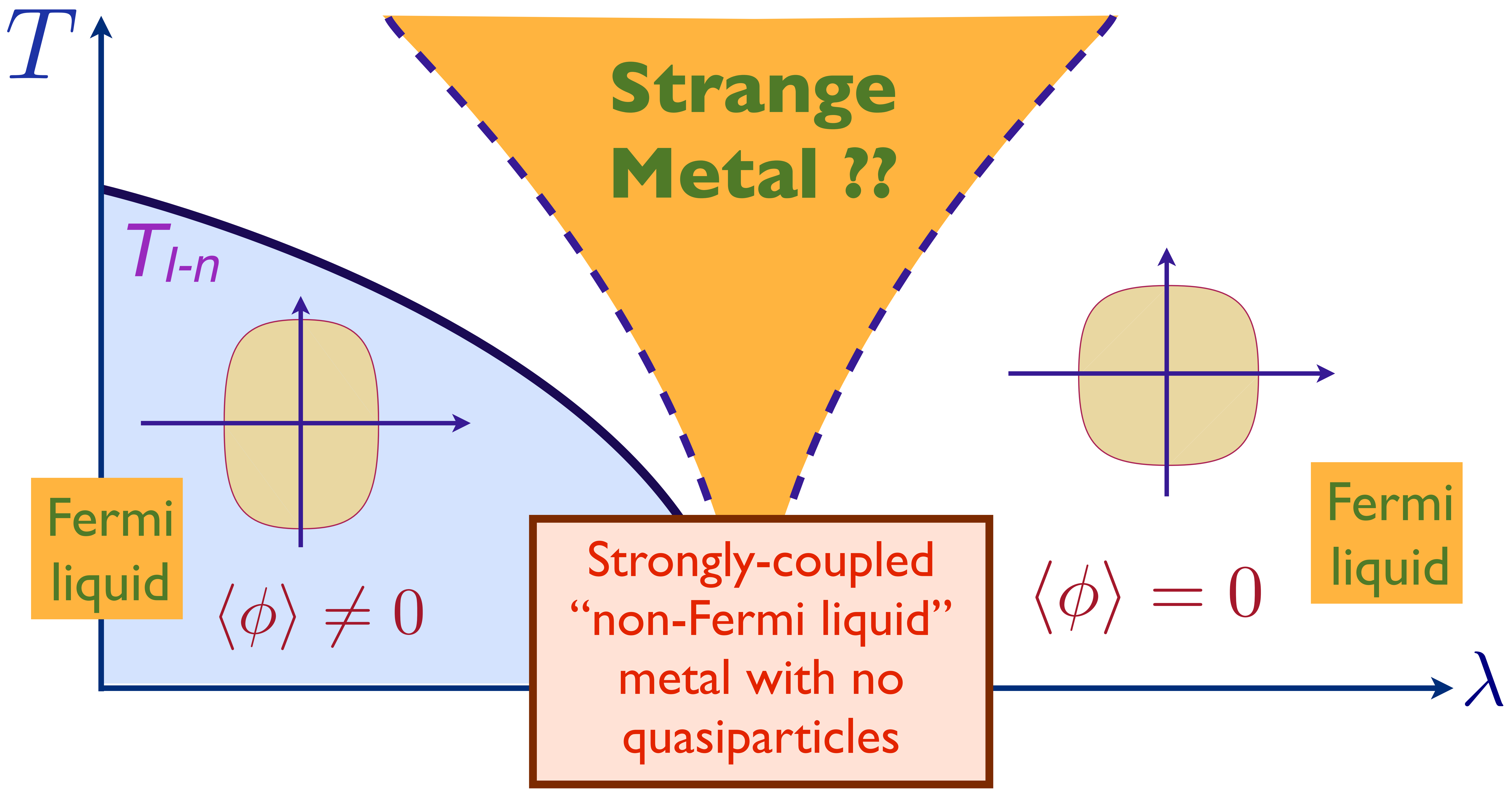

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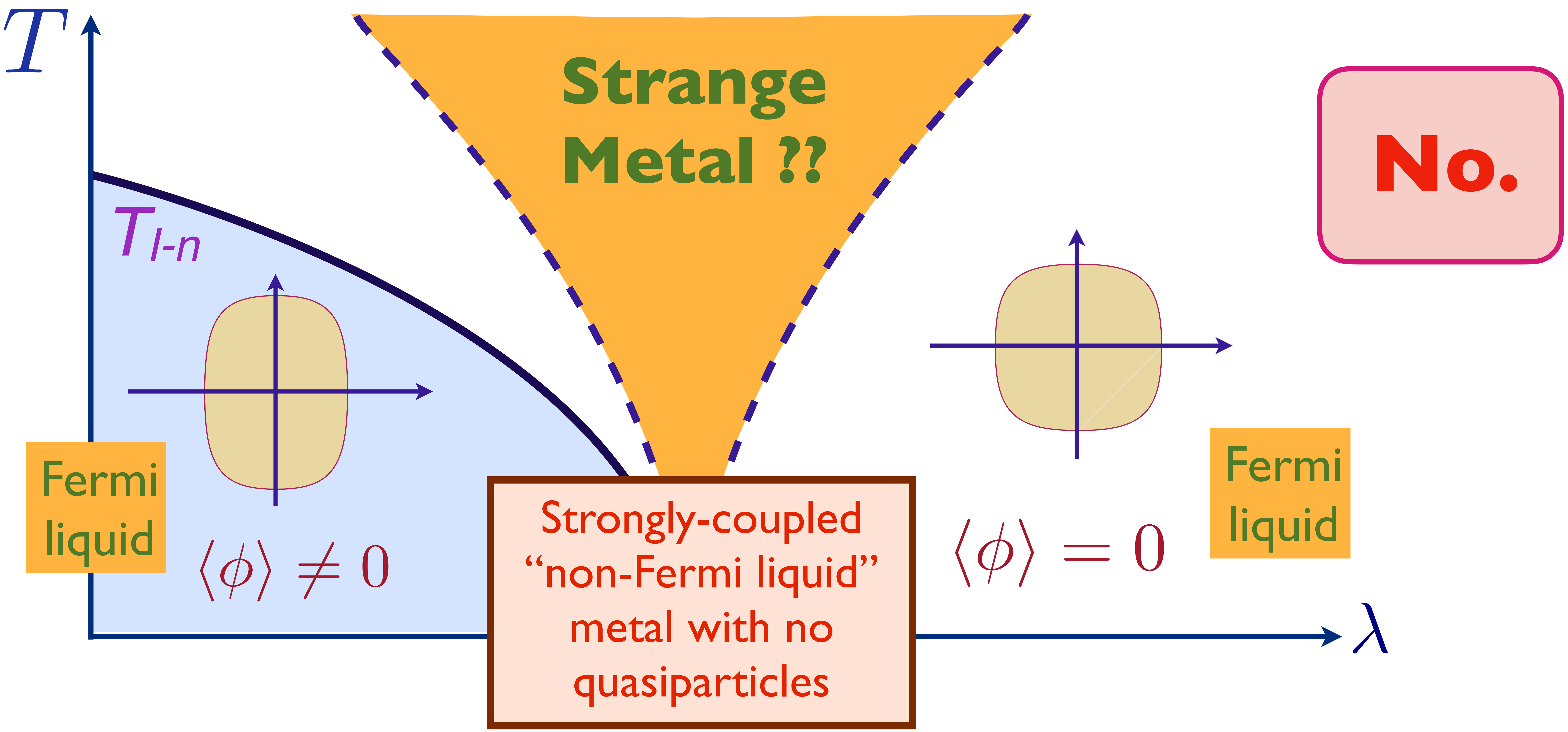
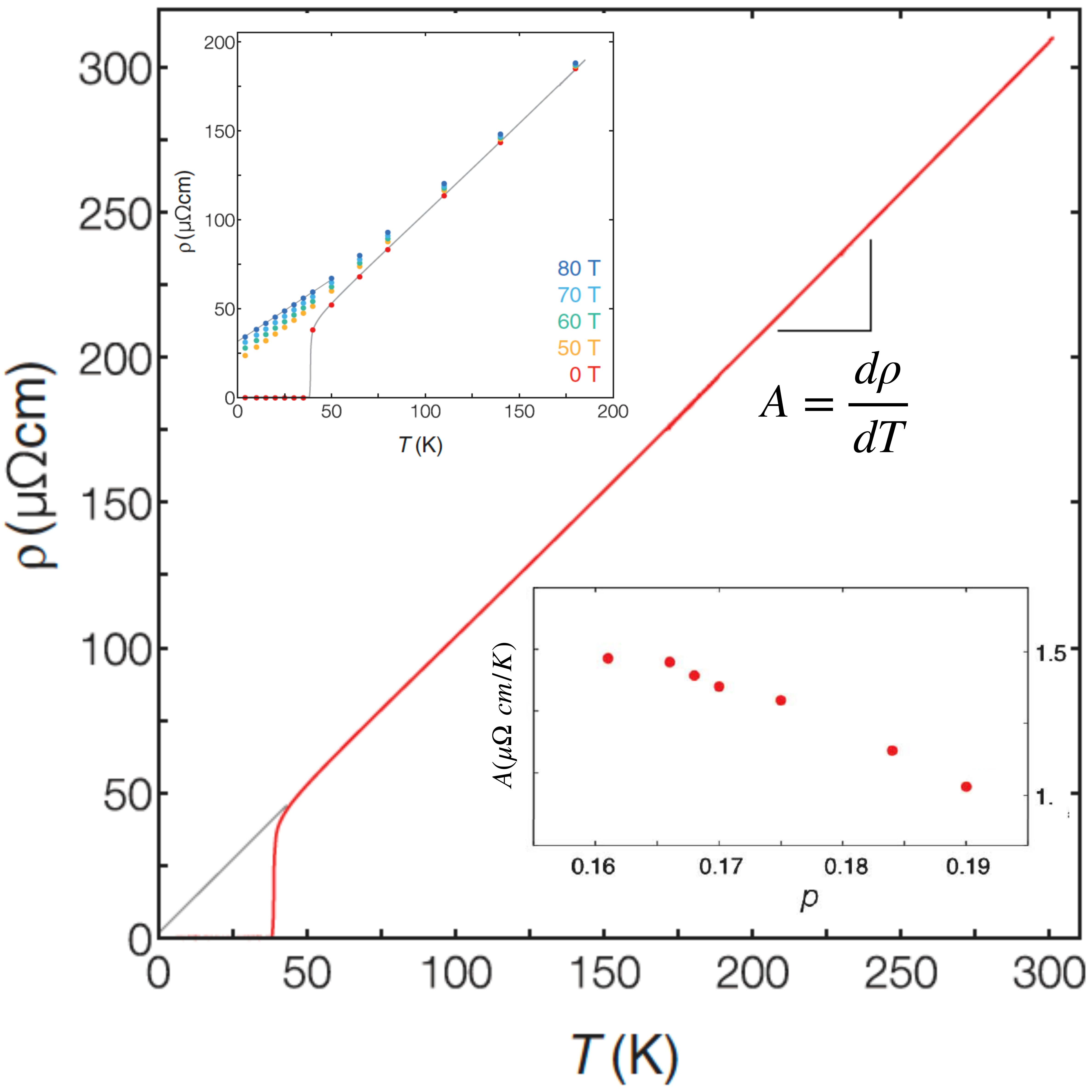
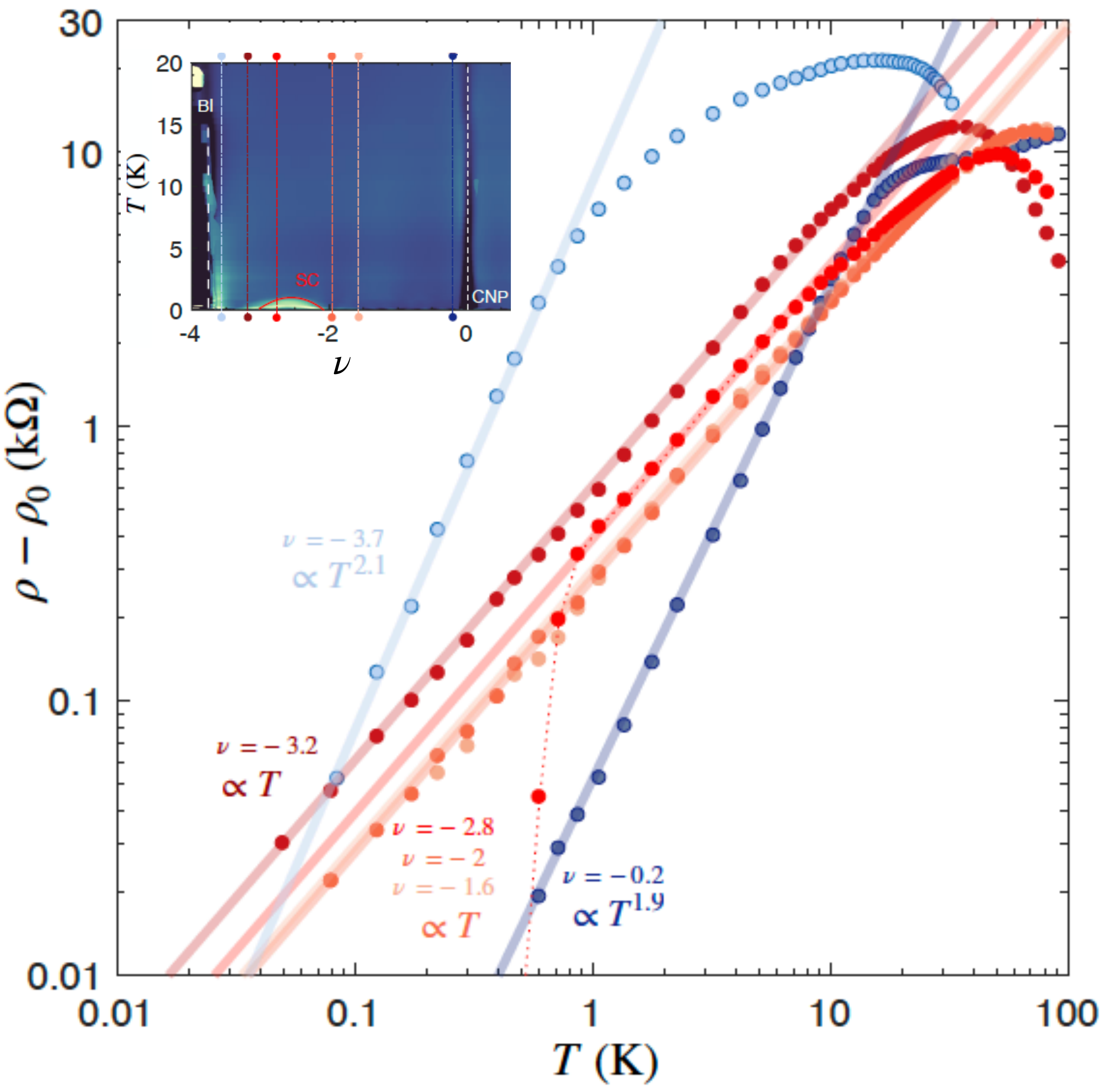


Phase diagram as a function of T and λ

Strange metals



LSCO: Giraldo-Gallo et al. 2018



MATBG: Jaoui et al. 2021

Strange metals

Properties of a strange metal:

- Resitivity $\rho(T) = \rho_0 + AT + \ldots$ as $T \to 0$ and $\rho(T) < h/e^2$ (in $d = 2$).
  Metals with $\rho(T) > h/e^2$ are bad metals.

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- Specific heat $\sim T \ln(1/T)$ as $T \to 0$.

- Optical conductivity

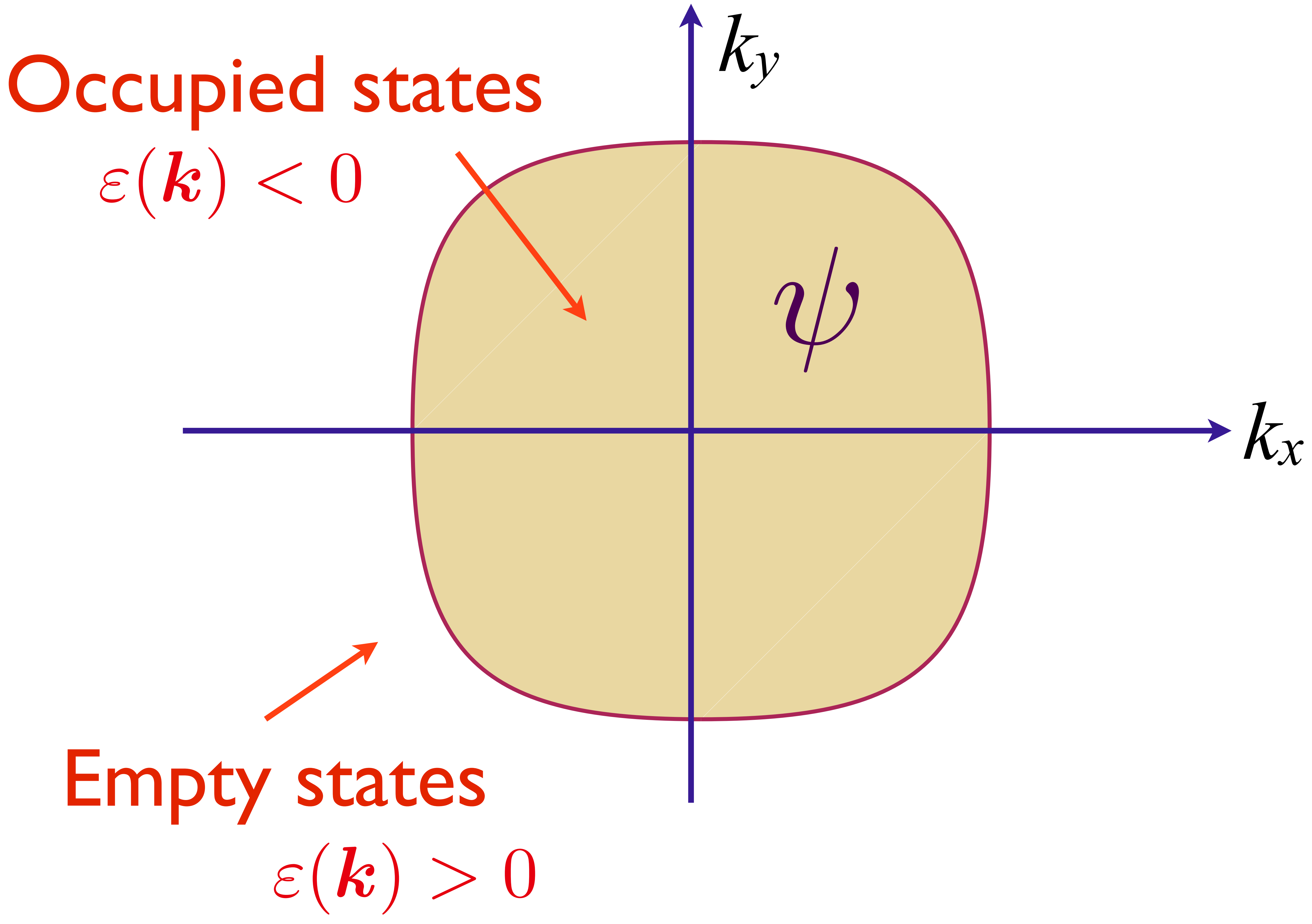
S.A. Hartnoll and A.P. MacKenzie, arXiv:2107.07802

$$\sigma(\omega) = \frac{K}{\dfrac{1}{\tau(\omega)} - i\dfrac{m^*(\omega)}{m}} \quad ; \quad \frac{1}{\tau(\omega)} = T\,G\left(\frac{\hbar\omega}{k_B T}\right)$$

Grissonnanche

B. Michon……A. Georges, arXiv:2205.04030

Fermi surface coupled to a critical boson



+

a critical boson

ϕ

- Nematic order
- Ferromagnetic order
- Transverse component of abelian or non-abelian gauge field
- Antiferromagnetic order...

Boltzmann view of electrical transport:

- Identify charge carriers: electrons near the Fermi surface. Compute the scattering rate of these charged excitations off the ϕ bosons.

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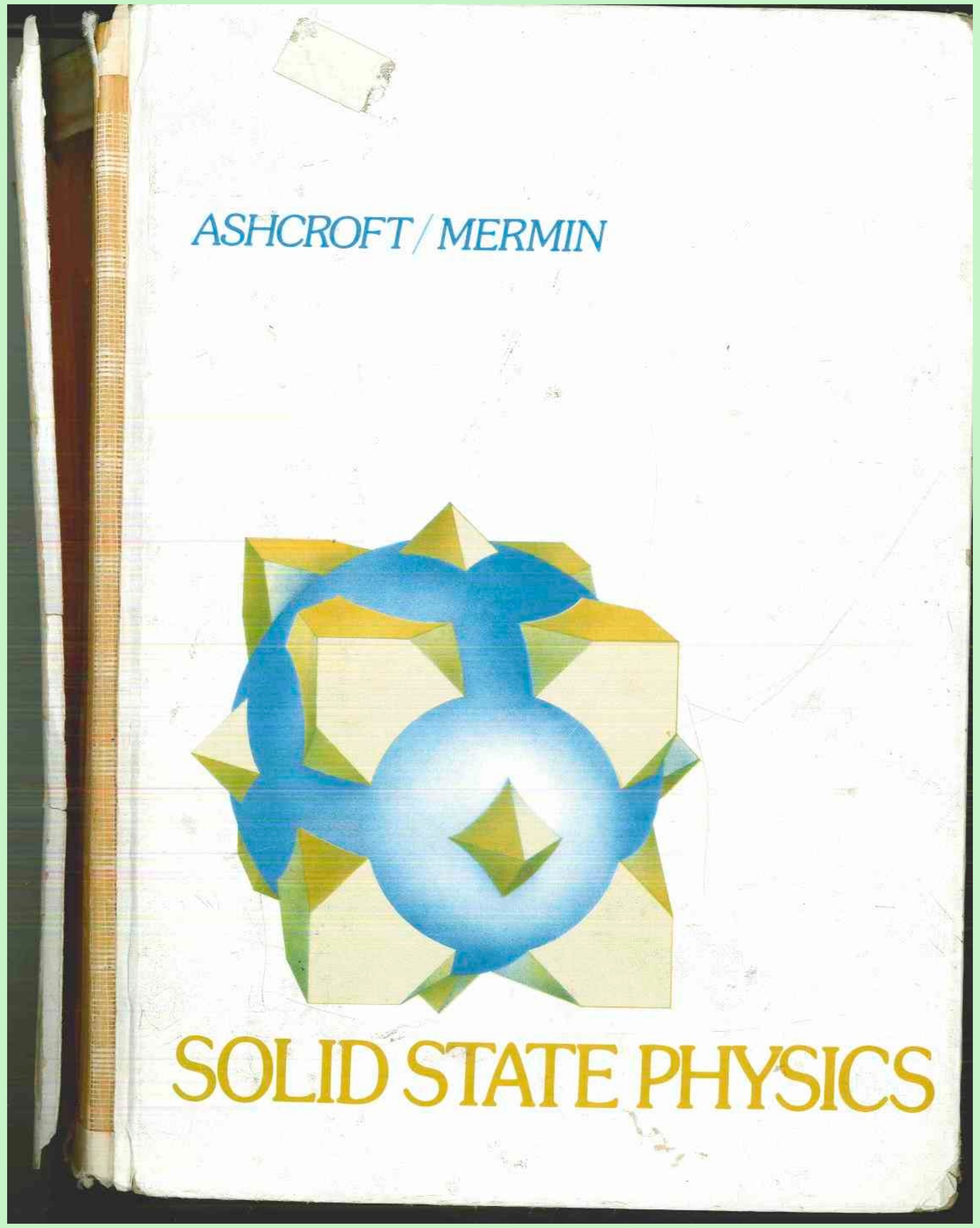

PHONON DRAG

Peierls[28] pointed out a way in which the low temperature resistivity might decline more rapidly than T^5. This behavior has yet to be observed

[28] R. E. Peierls, *Ann. Phys.* (5) **12**, 154 (1932).

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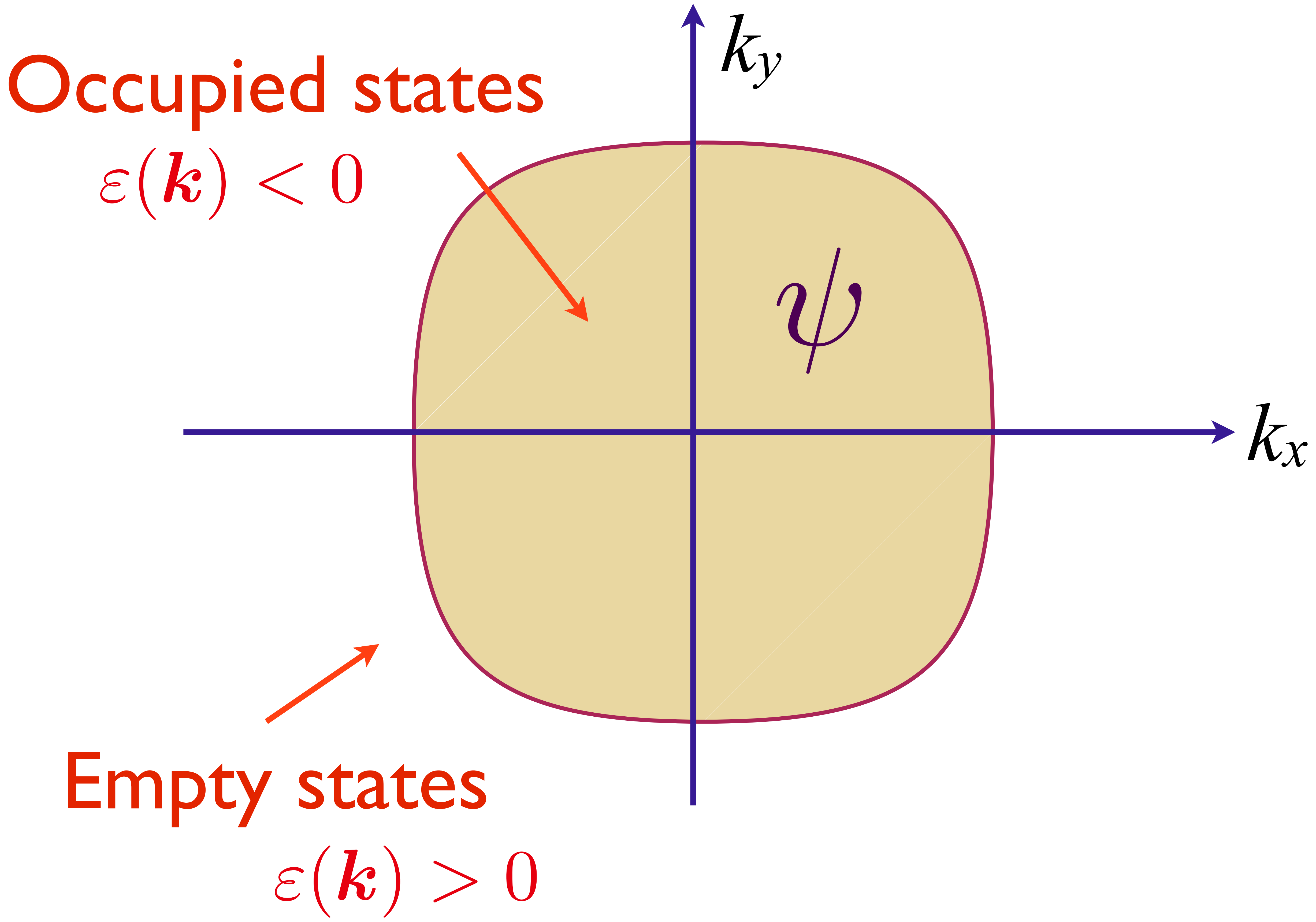
- However, Bloch's law ignores conservation of total momentum, or **phonon drag**.
- **Transport in non-Fermi liquids:**
  We cannot separate the momenta carried by the fermions and the bosons, because neither of them exists at low energies! We must treat the combined system together (*extreme drag*), and conservation of momentum in the low energy theory implies $\rho(T) = 0$. This first became clear from holographic and hydrodynamic approaches, and has now been confirmed in complete diagrammatic/Boltzmann computations.

Lucas

Strange metals



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a critical boson

ϕ

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+ "something else….."

Strange metals

- Umklapp
  X. Wang and E. Berg, Phys. Rev. B **99**, 235136 (2019).
  P. A. Lee, Phys. Rev. B **104**, 035140 (2021).

- t-J model in large dimensions, with random J_{ij}
  Haoyu Guo, Yingfei Gu, and S. Sachdev, Annals of Physics **418**, 168202 (2020)
  P. T. Dumitrescu, N. Wentzell, A. Georges, and O. Parcollet, PRB **105**, L180404 (2022).
  M. Christos, D. G. Joshi, S. Sachdev, and M. Tikhanovskaya, arXiv:2203.16548

- Order parameter with current-like symmetry
  D. V. Else and T. Senthil, Phys. Rev. B **104**, 205132 (2021)
  Zhengyan Darius Shi, Hart Goldman, Dominic V. Else, T. Senthil, arXiv:2204.07585

Posters

- Spatial disorder in fermion-boson Yukawa coupling
  E. E. Aldape, T. Cookmeyer, Aavishkar A. Patel, and E. Altman, PRB **105**, 235111 (2022).
  I. Esterlis, Haoyu Guo, Aavishkar A. Patel, and S. Sachdev, Phys. Rev. B **103**, 235129 (2021)
  Aavishkar A. Patel, Haoyu Guo, I. Esterlis, and S. Sachdev, arXiv:2203.04990.

- Interference of disordered 'diffusons' and critical boson
  Tsz Chun Wu, Yunxiang Liao, and Matthew S. Foster, arXiv:2206.01762