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Quantum quenches and competing orders: I. Time-dependent Hartree-Fock+BCS theory

Wenbo Fu, Ling-Yan Hung, Subir Sachdev

(Submitted on 29 Jan 2014)

We study the non-equlibrium dynamics of an electronic model of competing bond density wave order and d-wave superconductivity. In a time-dependent Hartree-Fock+BCS approximation, the dynamics reduces to the equations of motion of operators realizing the generators of SU(4) at each pair of momenta, $(\mathbf{k}, -\mathbf{k})$, in the Brillouin zone. We compare the results of numerical studies of our model with recent picosecond optical experiments.

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Quantum quenches and competing orders: II. quantum non-linear sigma model

Ling-Yan Hung, Wenbo Fu, Subir Sachdev

(Submitted on 4 Feb 2014)

We study the non-equilibrium dynamics of a quantum generalization of a O(6) non-linear sigma model of competing orders in the underdoped cuprates (Hayward {\em et al.}, arXiv:1309.6639). We obtain results, in the large N limit of a O(N) model, on the time-dependence of correlation functions following a pulse disturbance. We find that the oscillatory responses share various qualitative features with recent optical experiments.

Transport near the quantum critical point of the Bose-Hubbard model: Quantum Monte Carlo and Holography

M.I.T.
May 8, 2014

Subir Sachdev

Talk online: sachdev.physics.harvard.edu

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The dynamics of quantum criticality revealed by quantum Monte Carlo and holography

William Witczak-Krempa
Perimeter

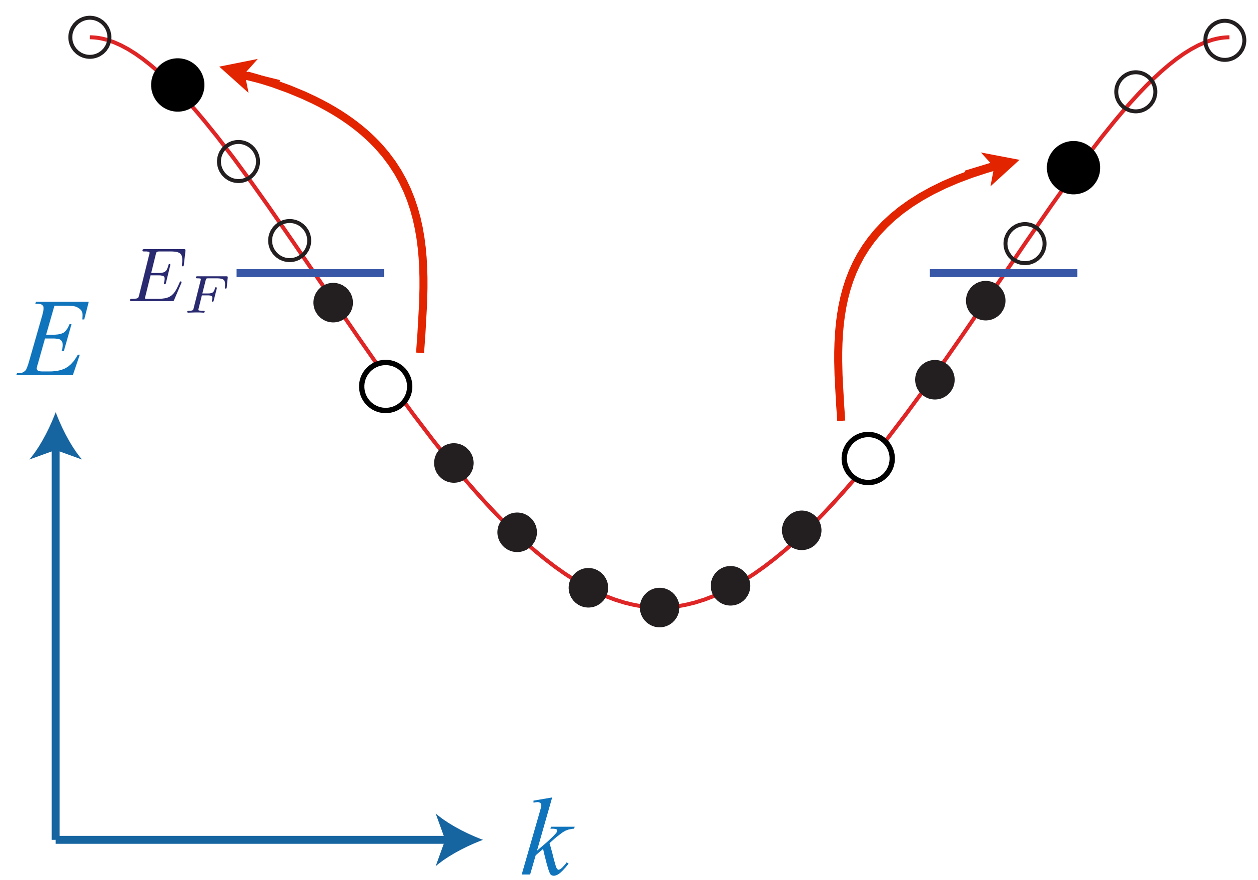
Erik Sorensen
McMaster

Foundations of quantum many body theory:

1. Ground states connected adiabatically to independent electron states

2. Boltzmann-Landau theory of quasiparticles

Metals



Modern phases of quantum matter:

1. Ground states disconnected from independent electron states: many-particle entanglement

2. Boltzmann-Landau theory of quasiparticles

Famous examples:

The fractional quantum Hall effect of electrons in two dimensions (e.g. in graphene) in the presence of a strong magnetic field. The ground state is described by Laughlin's wavefunction, and the excitations are *quasiparticles* which carry fractional charge.

Modern phases of quantum matter:

1. Ground states disconnected from independent electron states: many-particle entanglement

2. No quasiparticles

Only 2 examples:

1. Conformal field theories in spatial dimension $d > 1$

2. Quantum critical metals in dimension $d=2$

The Superfluid-Insulator transition

Boson Hubbard model

Degrees of freedom: Bosons, $b_j^\dagger$, hopping between the sites, j, of a lattice, with short-range repulsive interactions.

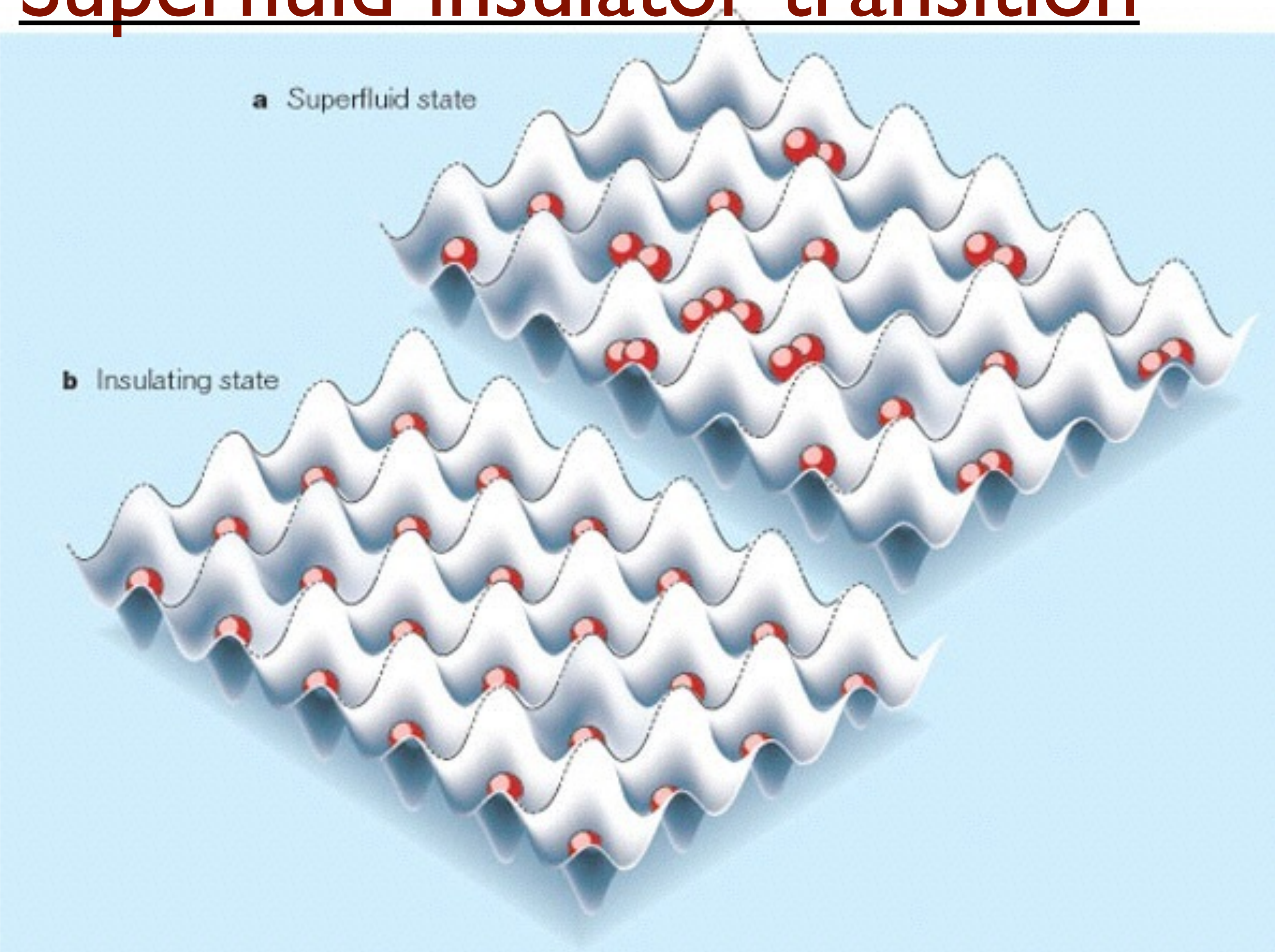
$$H = -t \sum_{\langle ij \rangle} b_i^\dagger b_j - \mu \sum_j n_j + \frac{U}{2} \sum_j n_j (n_j - 1) + \cdots$$

$$n_j \equiv b_j^\dagger b_j$$

$$[b_j, b_k^\dagger] = \delta_{jk}$$

M.P. A. Fisher, P.B. Weichmann, G. Grinstein, and D.S. Fisher, *Phys. Rev. B* **40**, 546 (1989).

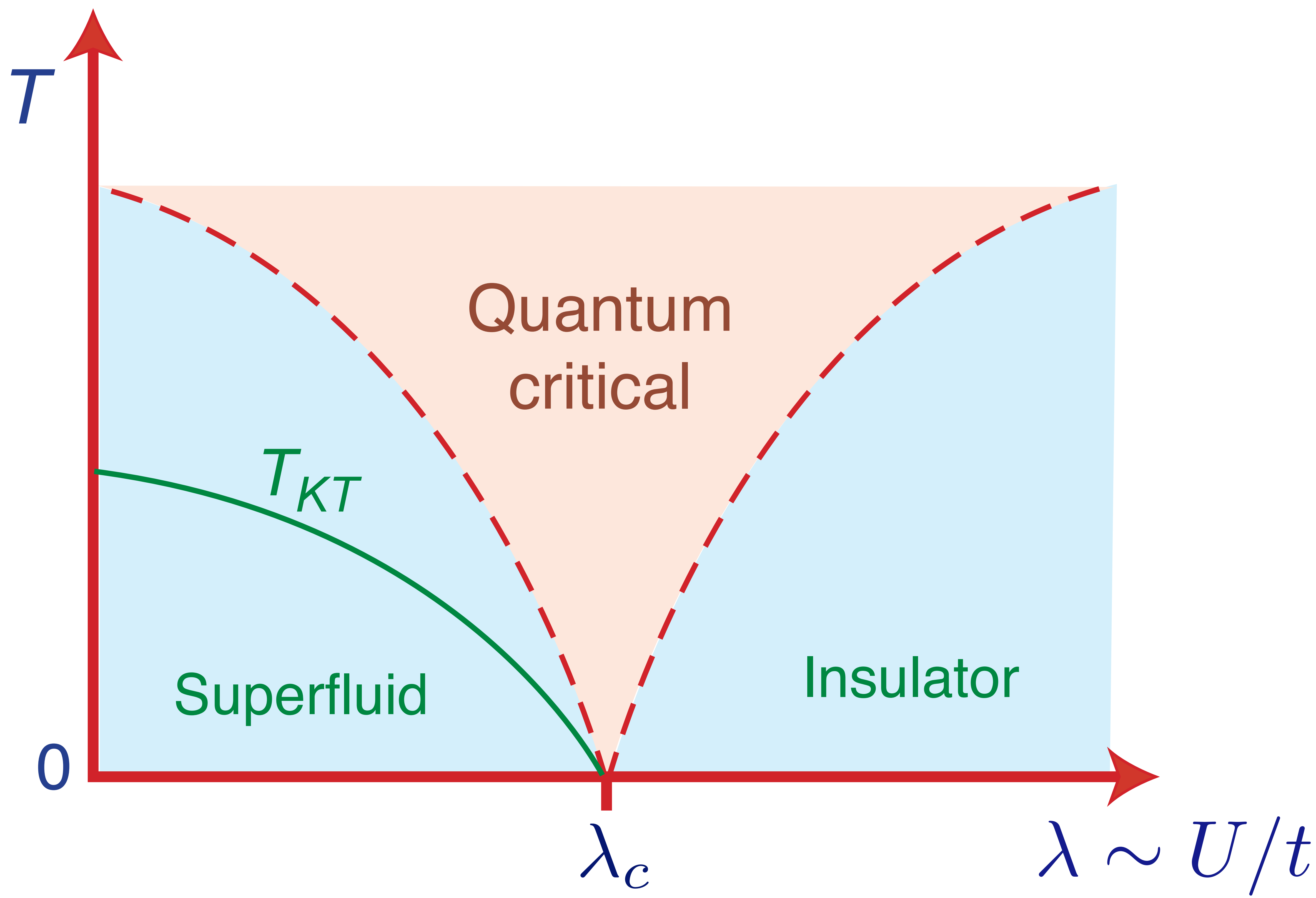
Superfluid-insulator transition

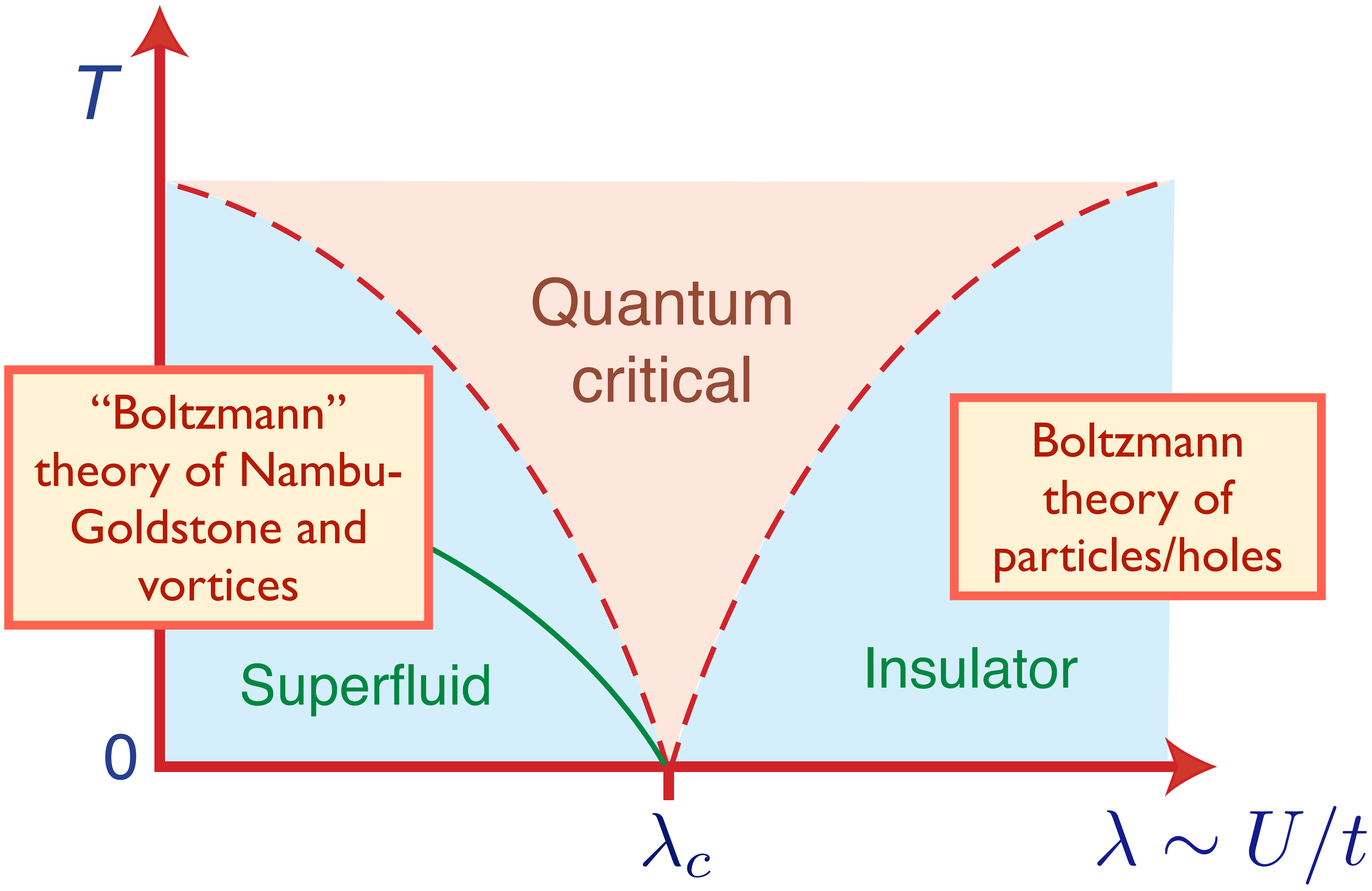


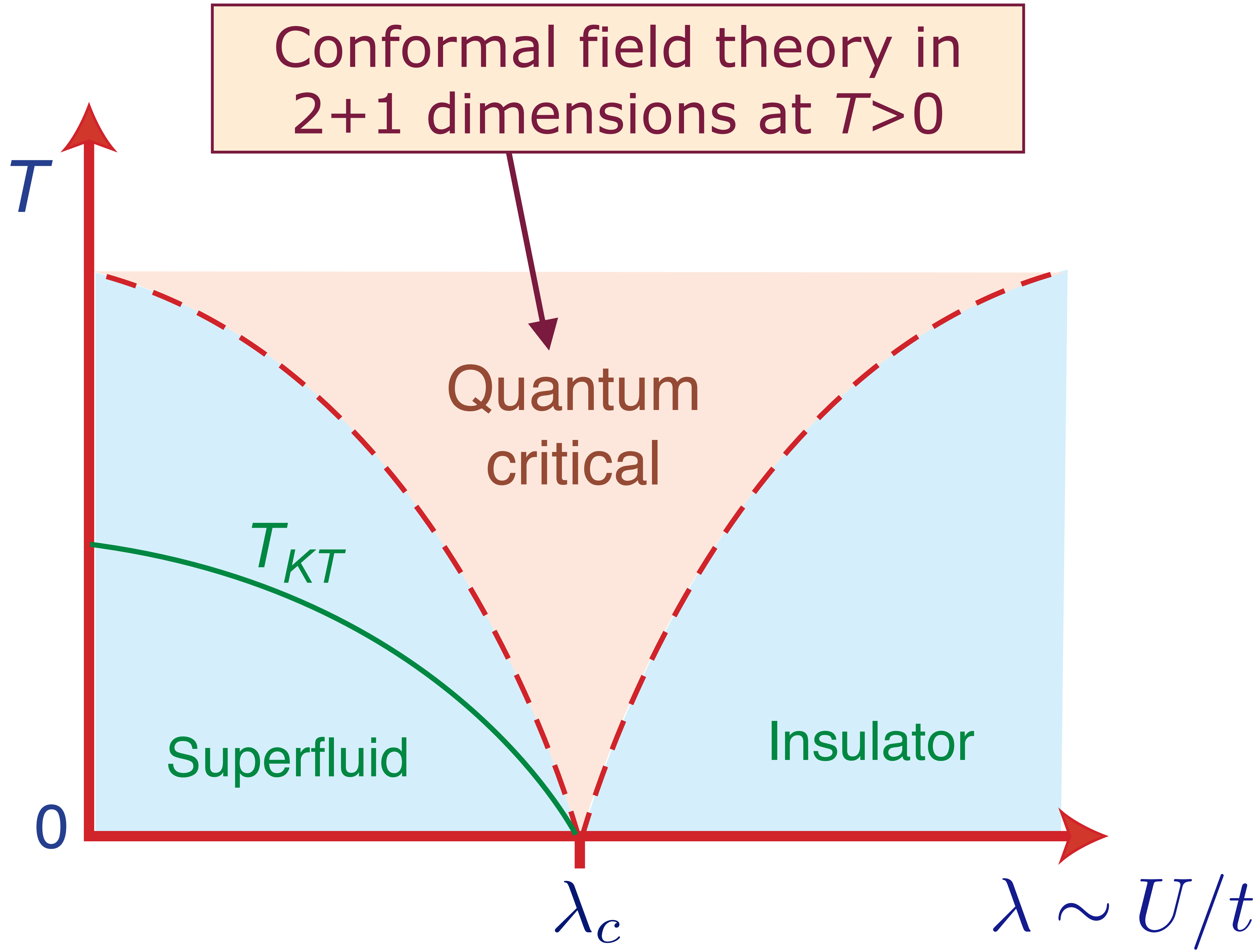
M. Greiner, O. Mandel, T. Esslinger, T. W. Hänsch, and I. Bloch, *Nature* **415**, 39 (2002).

Observation of Quantum Criticality with Ultracold Atoms in Optical Lattices

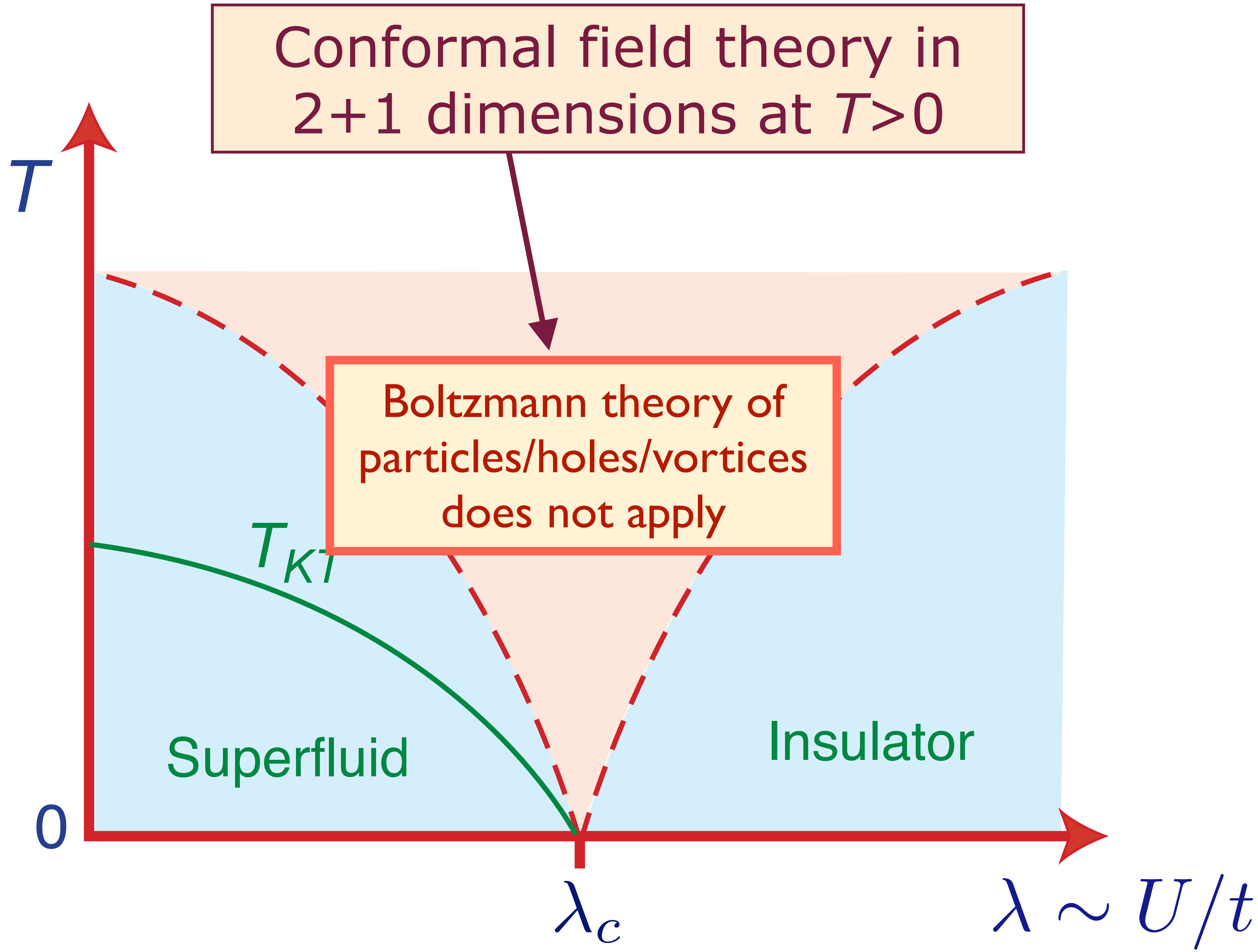
Xibo Zhang,* Chen-Lung Hung, Shih-Kuang Tung, Cheng Chin*   *Science* **335**, 1070 (2012)

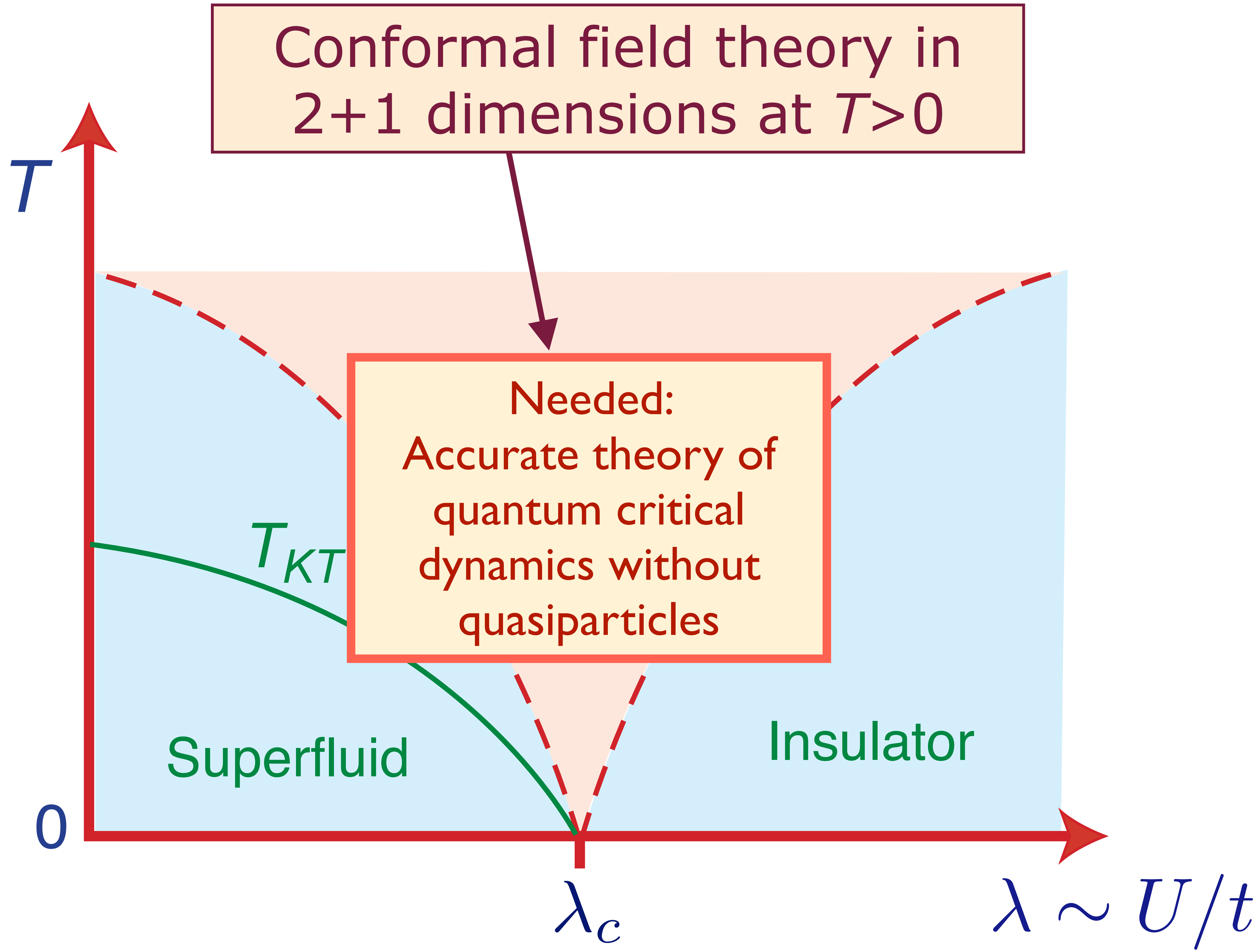

T
Quantum
critical
T_{KT}
Superfluid
Insulator
0
λ_c
$\lambda \sim U/t$


T
0
Quantum
critical
"Boltzmann"
theory of Nambu-
Goldstone and
vortices
Boltzmann
theory of
particles/holes
Superfluid
Insulator
λ_c
$\lambda \sim U/t$

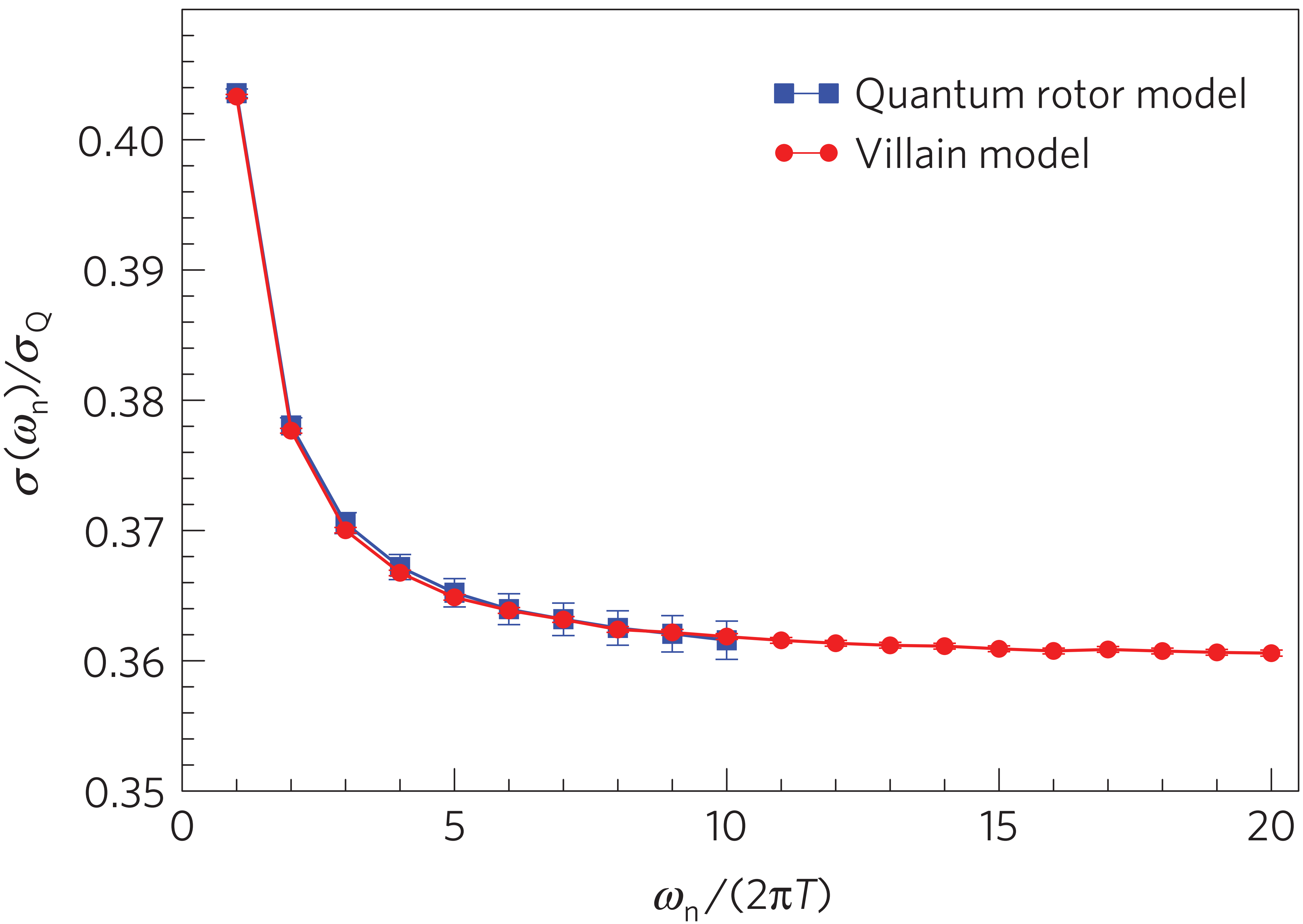


Conformal field theory in 2+1 dimensions at $T>0$
T
Quantum critical
T_{KT}
Superfluid
Insulator
0
λ_c
$\lambda \sim U/t$


Conformal field theory in 2+1 dimensions at T>0
T
Boltzmann theory of particles/holes/vortices does not apply
T_KT
Superfluid
Insulator
0
λ_c
λ ~ U/t

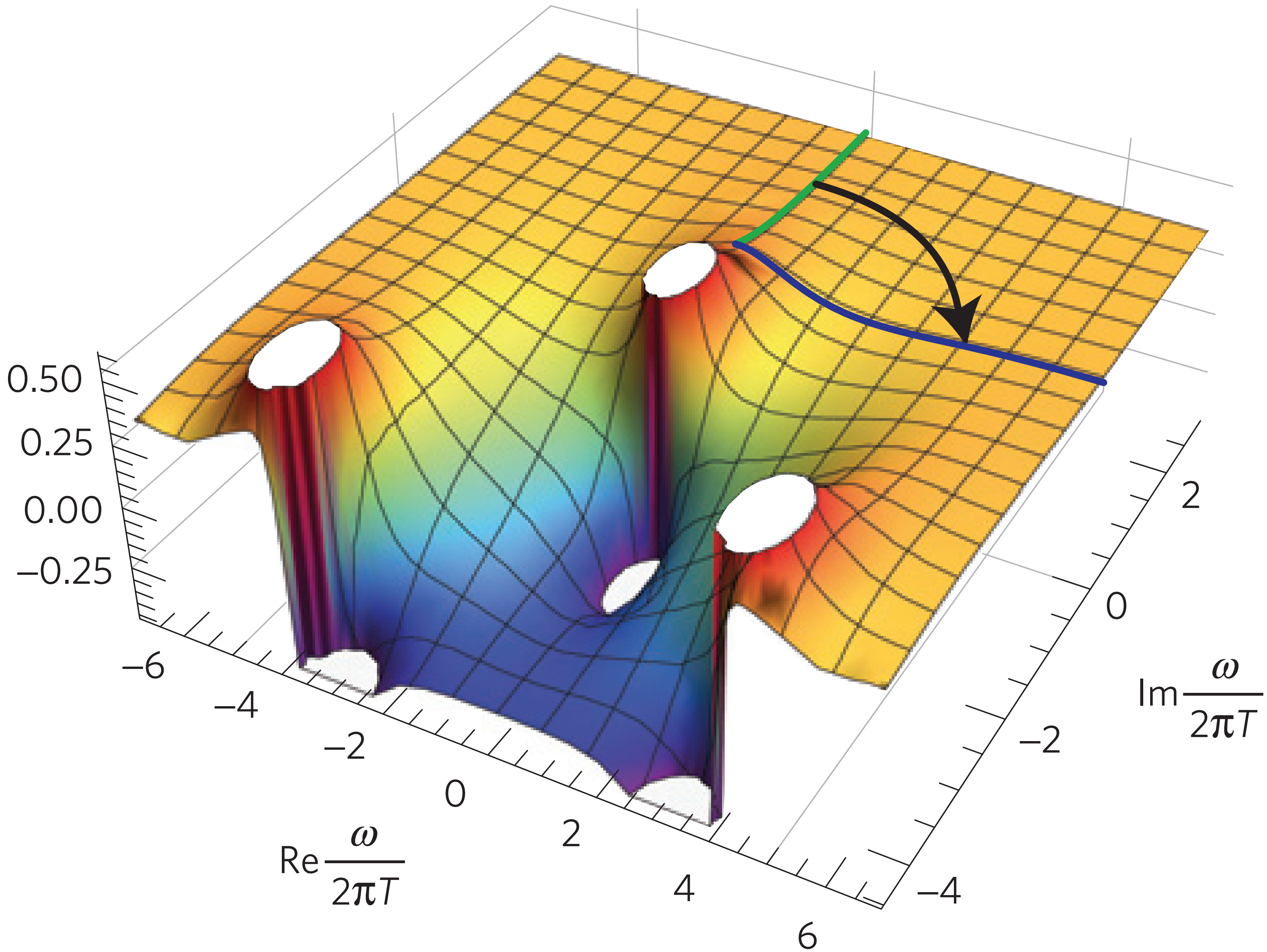

Conformal field theory in 2+1 dimensions at T>0
T
Needed:
Accurate theory of quantum critical dynamics without quasiparticles
T_KT
Superfluid
Insulator
0
λ_c
λ ~ U/t

Quantum Monte Carlo for lattice bosons



W. Witczak-Krempa, E. Sorensen, and S. Sachdev, Nature Physics **10**, 361 (2014)
See also K. Chen, L. Liu, Y. Deng, L. Pollet, and N. Prokof'ev, Phys. Rev. Lett. **112**, 030402 (2013)

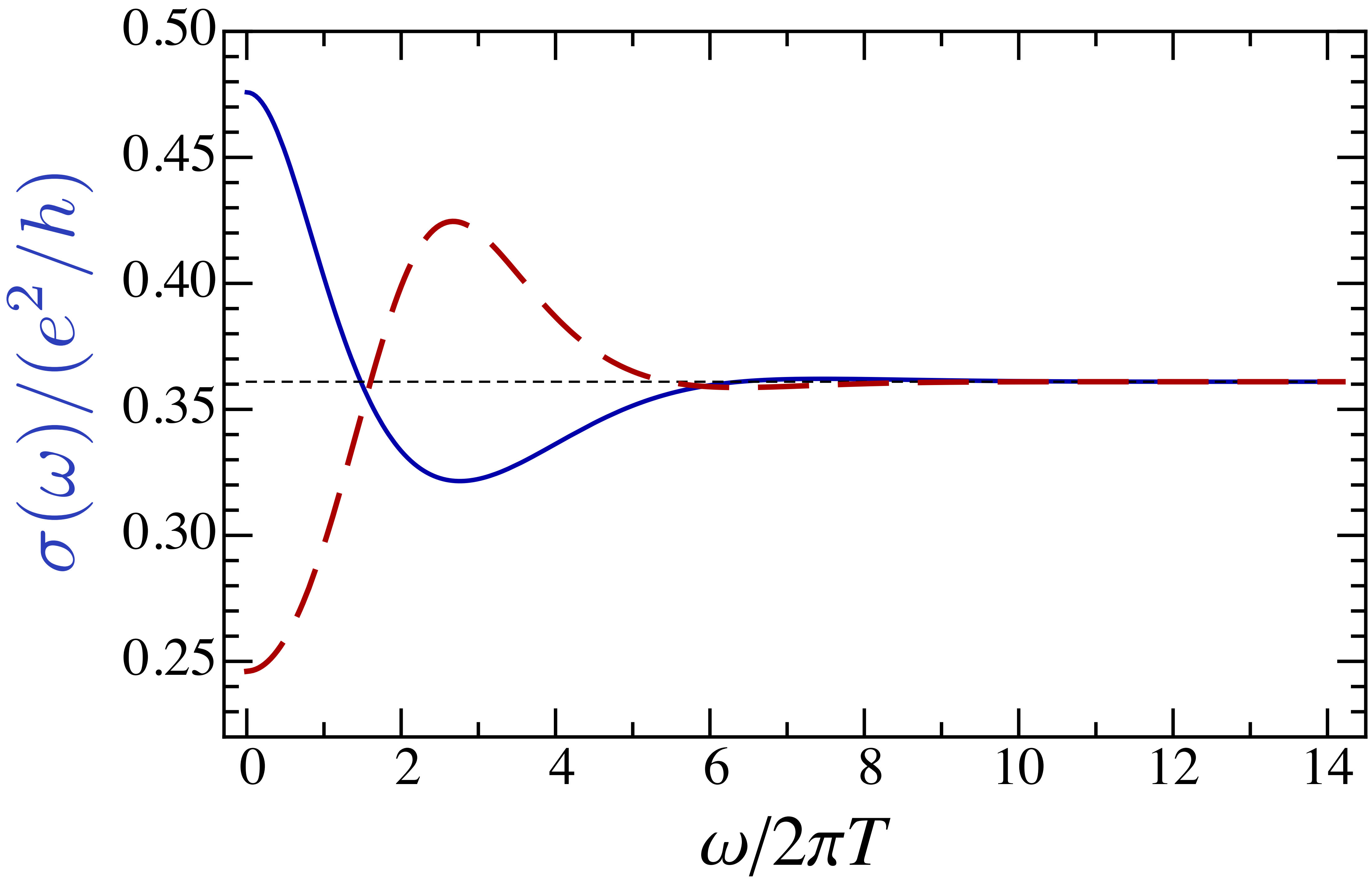
Analytic continuation by a holographic model



Obeys 2 non-trivial sum rules, and all poles and zeros are in the lower-half plane

W. Witczak-Krempa, E. Sorensen, and S. Sachdev, Nature Physics **10**, 361 (2014)
See also K. Chen, L. Liu, Y. Deng, L. Pollet, and N. Prokof'ev, Phys. Rev. Lett. **112**, 030402 (2013)

Transport revealed by QMC and holography



Predictions of holographic theory,
after analytic continuation to real frequencies

W. Witczak-Krempa, E. Sorensen, and S. Sachdev, Nature Physics **10**, 361 (2014)
See also K. Chen, L. Liu, Y. Deng, L. Pollet, and N. Prokof'ev, Phys. Rev. Lett. **112**, 030402 (2013)

Traditional CMT

- Identify quasiparticles and their dispersions

- Compute scattering matrix elements of quasiparticles (or of collective modes)

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Deduce dissipative and dynamic properties at non-zero temperatures	Non-zero T dynamics of CFT maps to dynamics of a "horizon" in (Einstein's) gravitational theory