Hydrodynamics with fluctuating broken translations

Anna Karlsson
Nordita, 31 August 2018

Work with S. Hartnoll, B. Goutéraux and L. Delacrétaz

1612.04381, 1702.05104, *work in progress*

Institute for Advanced Study,
and Chalmers

Motivation

Metals often display spontaneously
broken symmetries
near quantum critical points

Transport properties
(conductivity etc.) are highly
sensitive to the nature of
broken symmetries

In a tractable limit:
slow flows near a local
equilibrium

$\downarrow$

hydrodynamics

$\tau \gg \tau_{\text{local thermalization}}$

2d examples:
U(1), translations

$\searrow$

stripes/checkerboard
patterns in the charge
density

[Mesaros *et al.* '11]

Edge dislocation
in a stripe pattern

U(1): [Davison, Delacrétaz, Goutéraux and Hartnoll, '16]

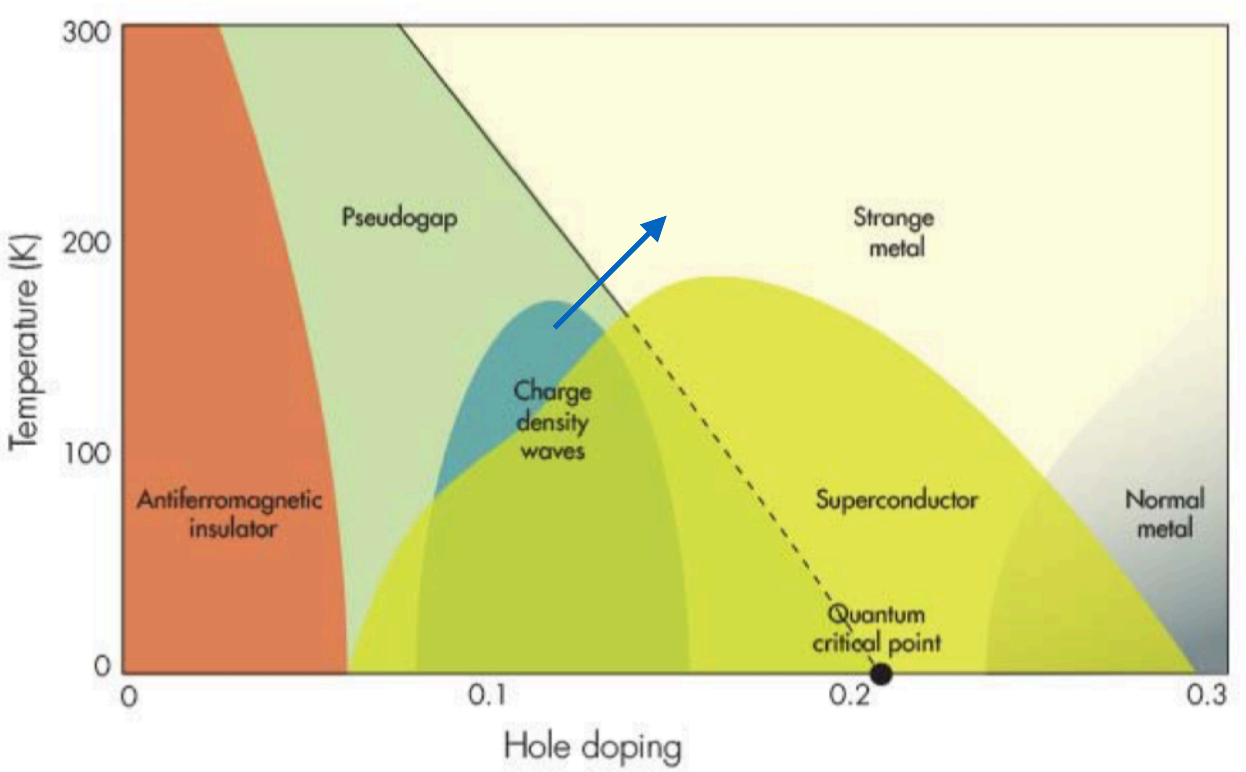
Motivation

In the presence of broken symmetries, hydrodynamics contains additional Goldstone modes

Quantum fluctuations:
mobile topological defects locally restore the symmetry by relaxing phase coherence
(phase relaxations)

what's new

translation symmetries
(observed in the pseudogap region)



1. Qualitative behaviour up to the hydrodynamic limit
2. Evaluation of hydrodynamic coefficients for phase relaxation

Through memory matrix analyses
(see 1702.05104)

Motivation

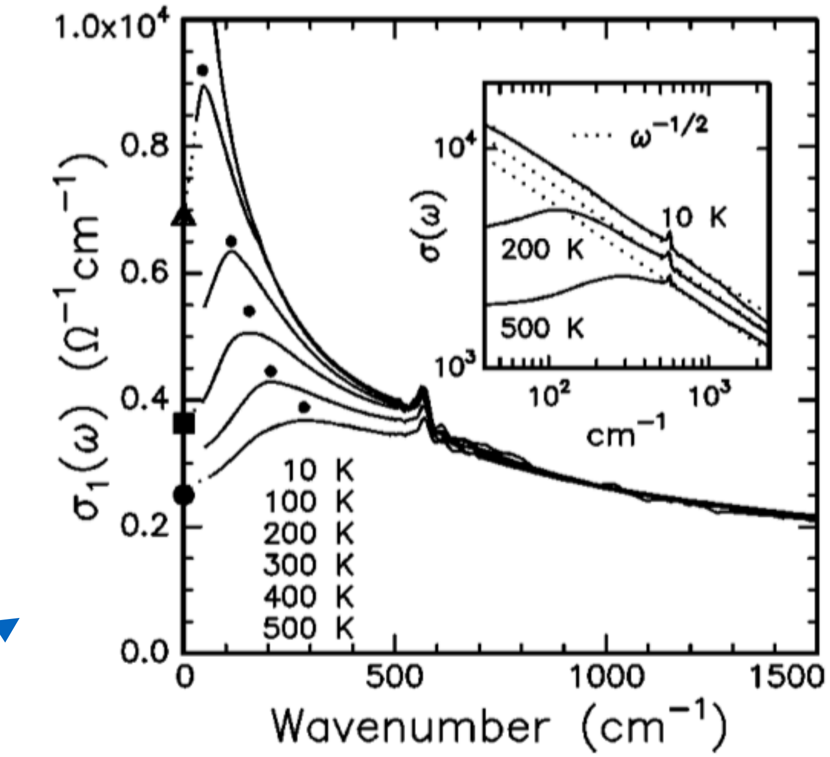
`Strange' features of metals
near quantum critical points

Characteristic features of
the optical conductivity

1. Momentum relaxation broadens the Drude peak
2. Magnetic fields move the Drude peak to nonzero frequency (cyclotron)
3. Spontaneous breaking of translations with mobile dislocations both broadens the peak and moves it out
4. Magnetic fields + the above: finite frequency peak can split

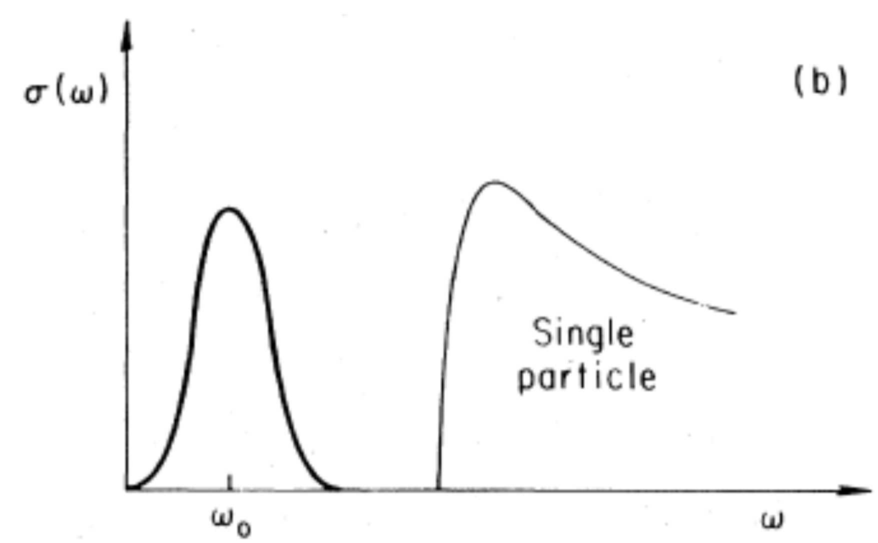
Other effects also exist, e.g. on the viscosity (sound attenuation)

Bad metals



[Lee, Yu, Lee, Noh, Gimm, Choi, Eom, '02]

$CaRuO_3$



[Grüner, '88]

Stripe features

Hydrodynamic formulation

A set of slow modes n, s, π^i — Charge, entropy,
with sources μ_e, T, v^i — momentum densities

Conservation equations $\dot{n} + \nabla \cdot j = 0$

Constitutive relations $j = nv - \sigma_0 \nabla \mu_e - \alpha_0 \nabla T + \dots$ To fist order in derivatives

Addition of Goldstone modes (phases ϕ^i)

- Identification of modes and sources (through the free energy)
- Modified conservation equations and constitutive relations (TR, P)
- Addition of Josephson relations for each Goldstone mode
- Phase relaxation

Limited by time reversal symmetry and parity

$$(\partial_t + \Omega) \nabla \cdot \phi = \nabla \cdot v + \dots$$

Compare U(1): $\nabla \mu_e$

Bad metals

The qualitative features agree:
peak shift and width increase with Ω

$$\sigma(\omega) = \sigma_o + \frac{n^2}{\chi_{\pi\pi}} \frac{\Omega - i\omega}{(\Omega - i\omega)(\Gamma - i\omega) + \omega_o^2}$$

With nearly Galilean invariance,
the hydrodynamical equations give

$$\sigma_{dc} = \frac{ne^2}{m} \frac{\Omega}{\omega_o^2}$$

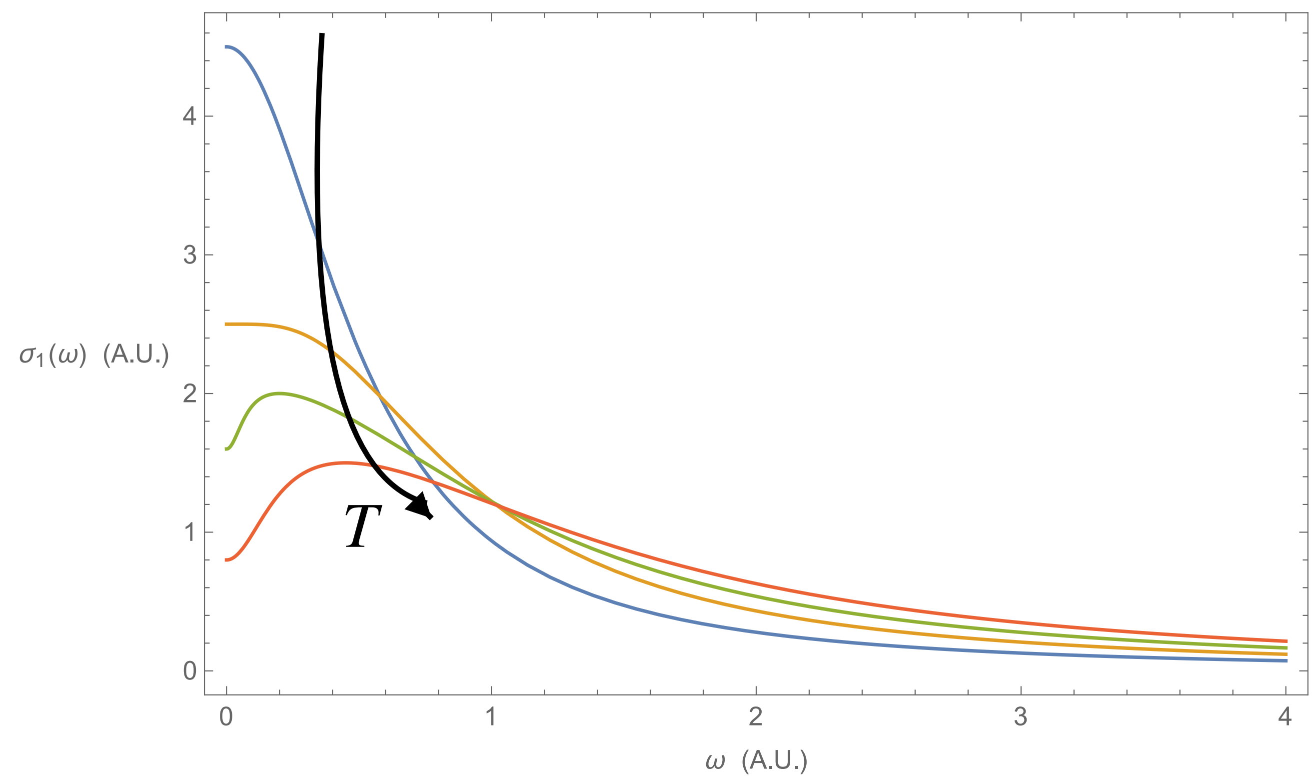


Illustration of bad metal optical conductivity

Peak position and width fits to
behaviour of this kind show

$$\Omega \sim \omega_o \sim k_B T/\hbar$$

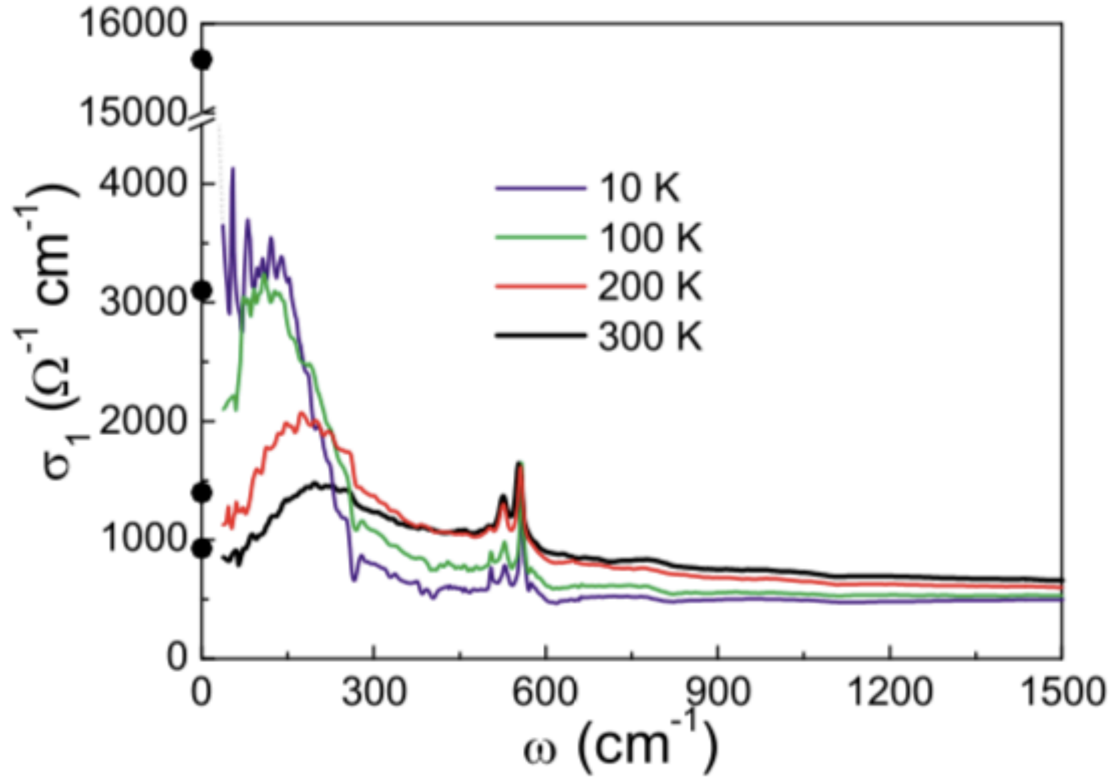
i.e. the typical linear in T resistivity
of bad metals

$$\rho_{\rm dc} = \frac{1}{\sigma_{\rm dc}} \sim \frac{m}{ne^2} \frac{k_B T}{\hbar}$$

at the boundary of hydrodynamical
validity

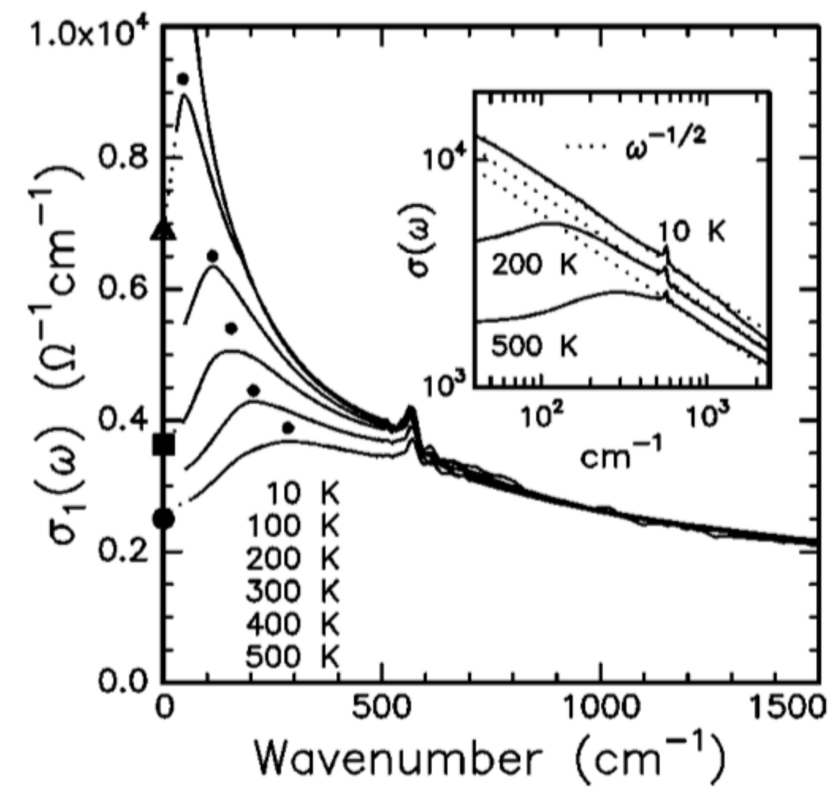
$$\tau \sim 1/T \sim \tau_{\text{local thermalization}}$$

Despite a small momentum relaxation Γ



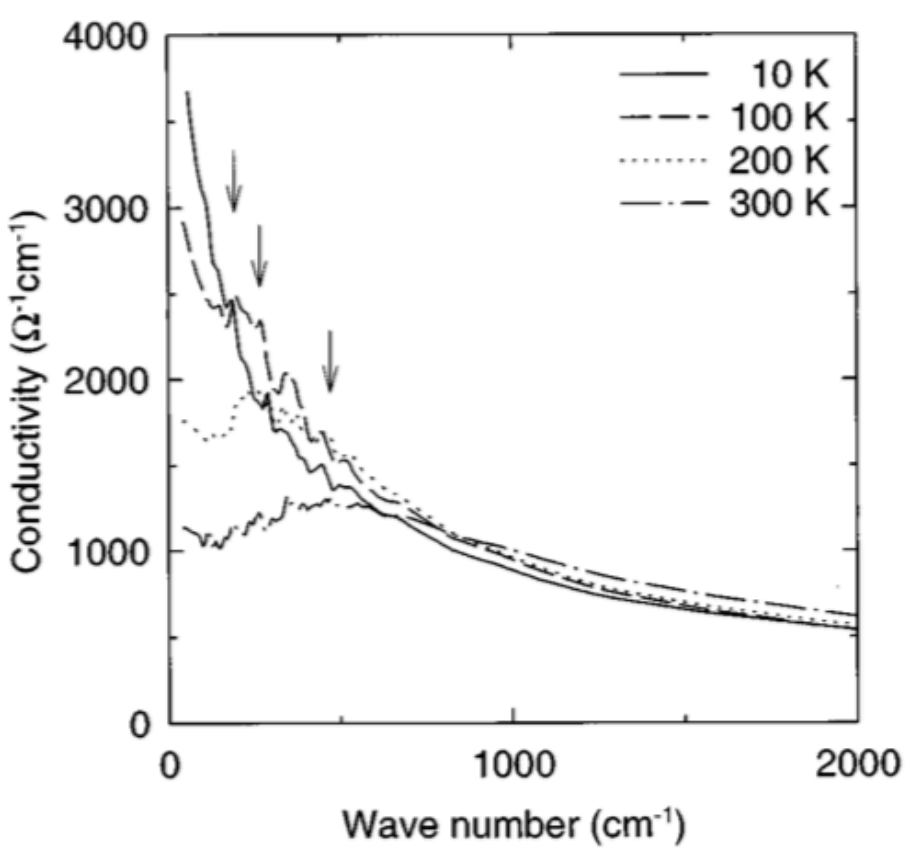
[Wang, Zheng, Wu, Ma, Xiang, Jin, Mandrus, '04]

$Na_{0.7}CoO_2$



[Lee, Yu, Lee, Noh, Gimm, Choi, Eom, '02]

$CaRuO_3$



[Tsvetkov, Schültzmann, Gorina, Kaljushnaia, van der Marel, '97]

$Bi_2Sr_2CuO_6$

Additional features

Apart from indicating that some bad metal behaviour can be connected to fluctuating, spontaneously broken translation symmetries, some additional features include:

- Where vortices in a superfluid causes resistivity, dislocations in a stripe/checkerboard system causes sound attenuation

- In the presence of a magnetic field, the finite frequency peak splits into two (not experimentally observed). At high fields, one peak moves out of the hydrodynamic regime

  The remaining mode is $$\phi^i + \frac{1}{nB}\epsilon^{ij}\pi_j$$

  Work in progress

  and the associated qualitative behaviour of the conductivity, with this mode, is identifiable in Wigner crystal regimes of GaAs

Thank you