2D Electron Transport in Complex Geometries

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University of Colorado **Boulder**

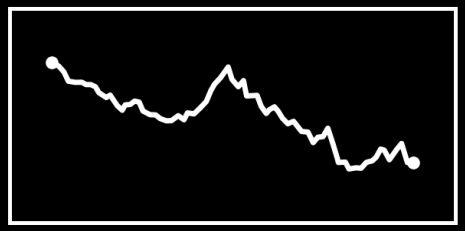
Acknowledgments

Andy Lucas
(Advisor)

Rogue
(Cat)

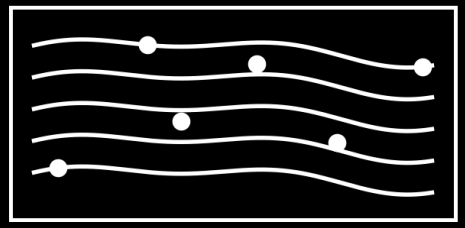
Overview

- Electrons moving in 2D materials have different properties depending on the device characteristics



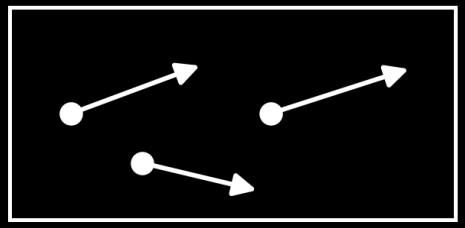
Ohmic

$\gamma_{mr} \gg \gamma_{mc}$



Hydrodynamic

$\gamma_{mr} \ll \gamma_{mc}$



Ballistic

$\gamma_{mr} = \gamma_{mc} = 0$

- But realistic devices explore intermediate regimes

Today's Punchline: a linear transport cartoon reveals how to distinguish this regimes and measure these phenomological parameters γ_{mc}, γ_{mr} with **or without** space-resolved imaging

A toy kinetic theory

- consider a single band of fermions with circular Fermi surface $\varepsilon(|p|) = \epsilon_F$

$$\partial_t f + \mathbf{v}(\mathbf{p}) \cdot \nabla f = C[f]$$

- Then parameterize deviation from equilibrium

$$\delta f = \phi(\mathbf{x}, \mathrm{t}, \theta)\, \delta(\epsilon_F - \varepsilon)$$

$$\phi(\mathbf{x}, \mathrm{t}, \theta) = \frac{a_0}{2} + \sum_n [a_n \cos n\theta + b_n \sin n\theta]$$

- Boltzmann becomes a tower of coupled PDEs

$$\partial_t a_0 + v_F(\partial_x a_1 + \partial_y b_1) = 0$$

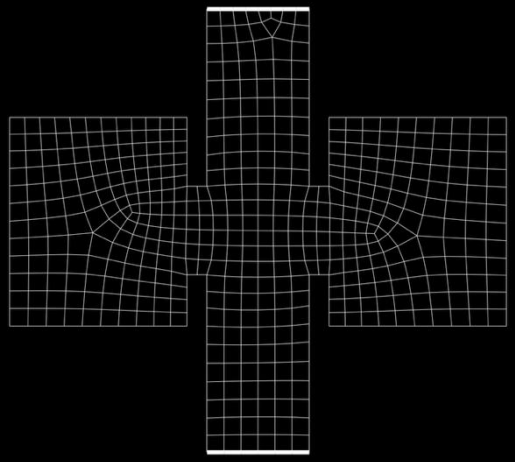
$$\partial_t a_1 + \frac{v_F}{2}\left(\partial_x(a_2 + a_0) + \partial_y(b_2 - b_0)\right) = -\gamma_{\mathrm{mr}}\, a_1$$

$$\partial_t a_n + \frac{v_F}{2}\left(\partial_x(a_{n+1} + a_{n-1}) + \partial_y(b_{n-1} - b_{n+1})\right) = -(\gamma_{\mathrm{mr}} + \gamma_{\mathrm{mc}})\, a_n$$

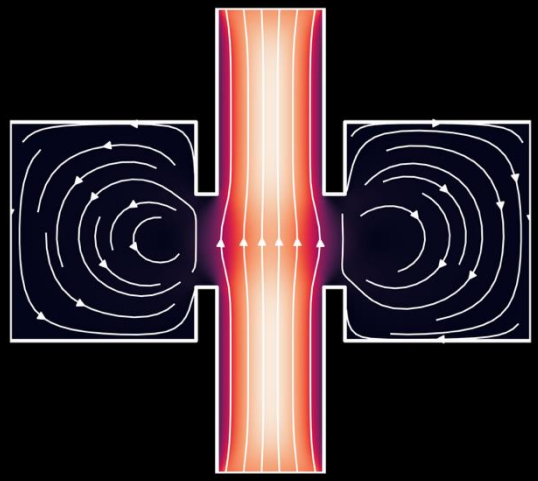
Solve numerically in any geometry you want!

- https://github.com/jackhfarrell/FermiHarmonics
- Use Julia library `Trixi.jl`
- Have studied wall boundary conditions diffuse, specular, or a blend

Drain
$V = 0$



Source
$V = V_S$



$\gamma_{mc} = 30.0$
$\gamma_{mr} = 0.5$

[Zang, Redekop, Stoyanov, **JF**, *et al.* 2603.11175]

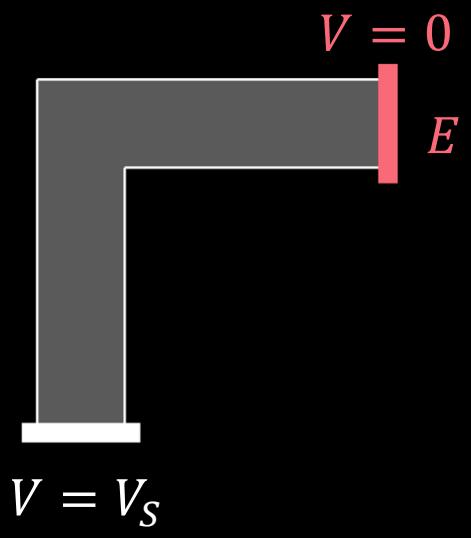
2:12 — 2:24 p.m.
Imaging ballistic and viscous electron flow in dual-gated rhombohedral graphene (Part I)
Canxun Zhang (presenter), Evgeny Redekop, Ludwig Holleis, Hari Stoyanov, Sunghoon Kim, Jack Farrell, David Gong, Aidan Keough, Takashi Taniguchi, Kenji Watanabe, Andrew Lucas, Ania Bleszynski Jayich, Martin Huber, Andrea Young

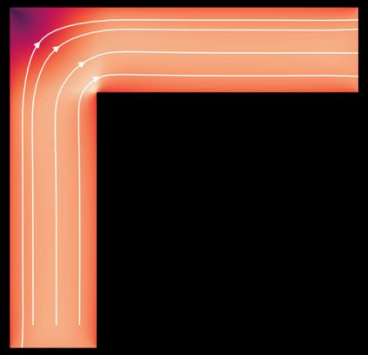
2:24 — 2:36 p.m.
Imaging ballistic and viscous electron flow in dual-gated rhombohedral graphene (Part II)
Evgeny Redekop (presenter), Canxun Zhang, Ludwig Holleis, Hari Stoyanov, Sunghoon Kim, Jack Farrell, David Gong, Aidan Keough, Takashi Taniguchi, Kenji Watanabe, Andrew Lucas, Ania Jayich, Martin Huber, Andrea Young

The Ballistic-Hydrodynamic Crossover

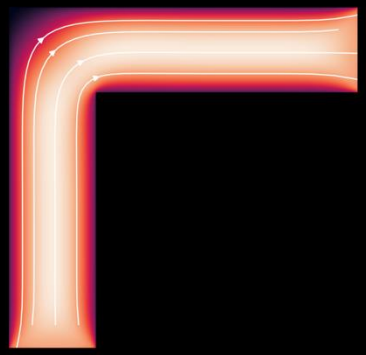
[**JF**, Lucas, *to appear*]

- Space-resolved imaging is quite sophisticated and difficult, what can we say about parameters even without?

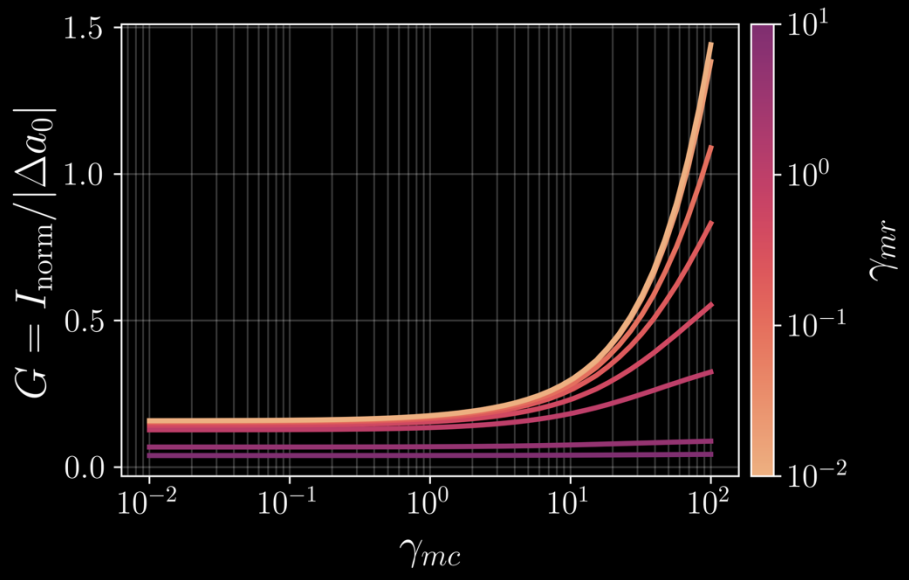




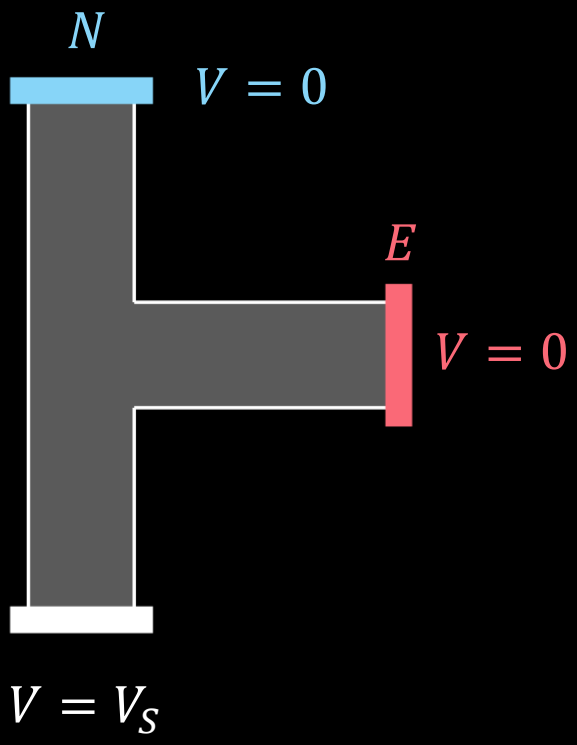
ballistic

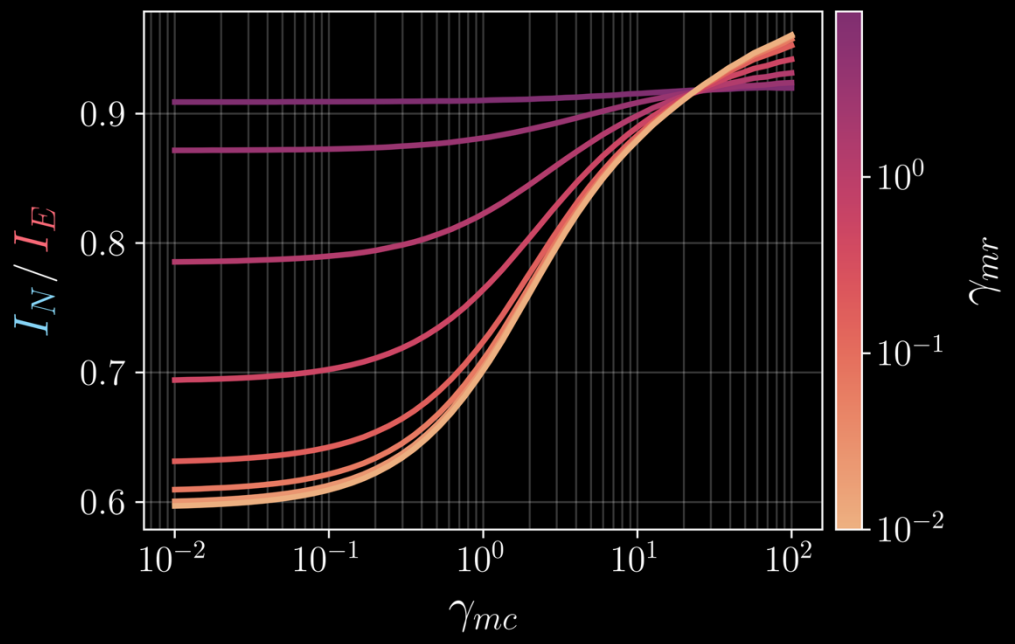


hydrodynamic

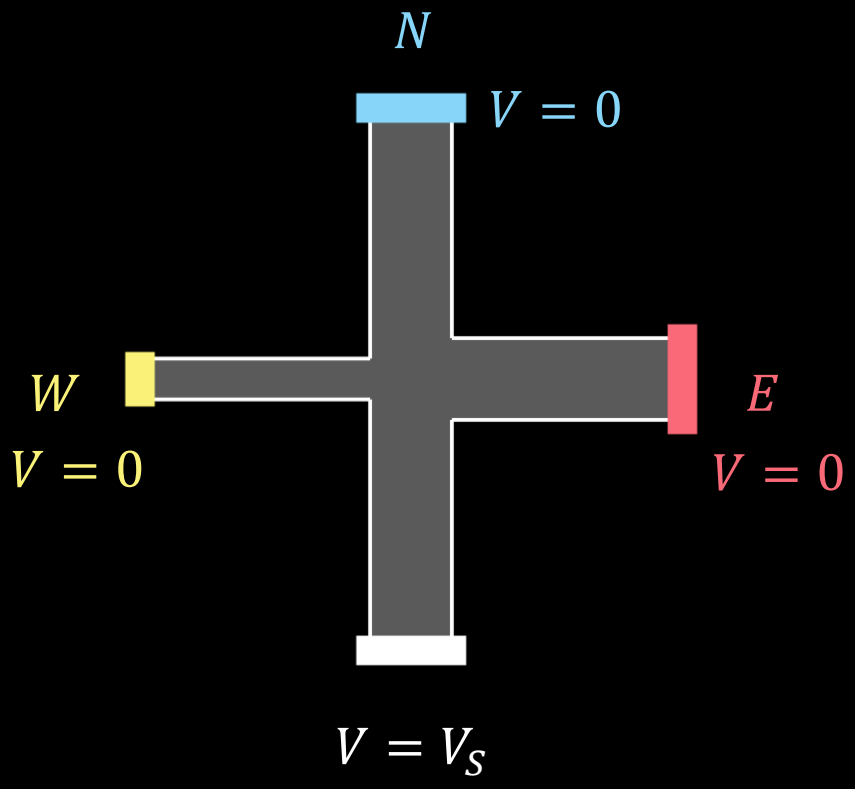


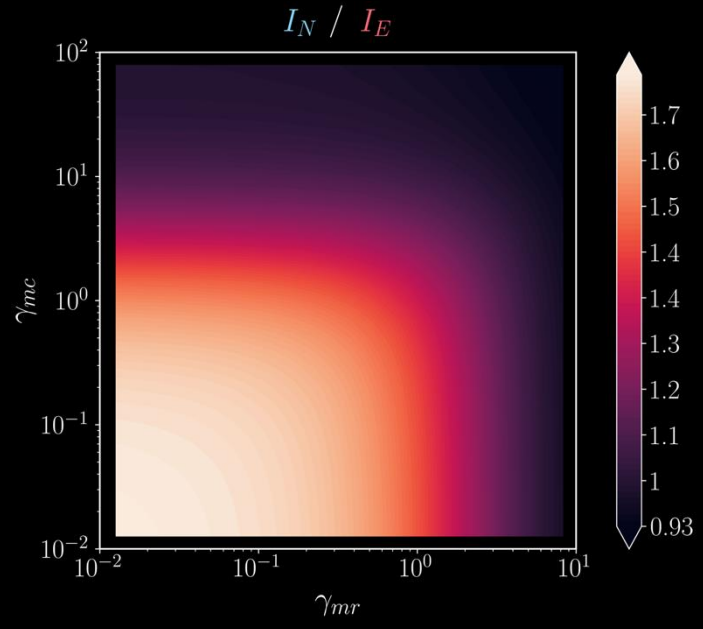
The Ballistic-Hydrodynamic Crossover (II)

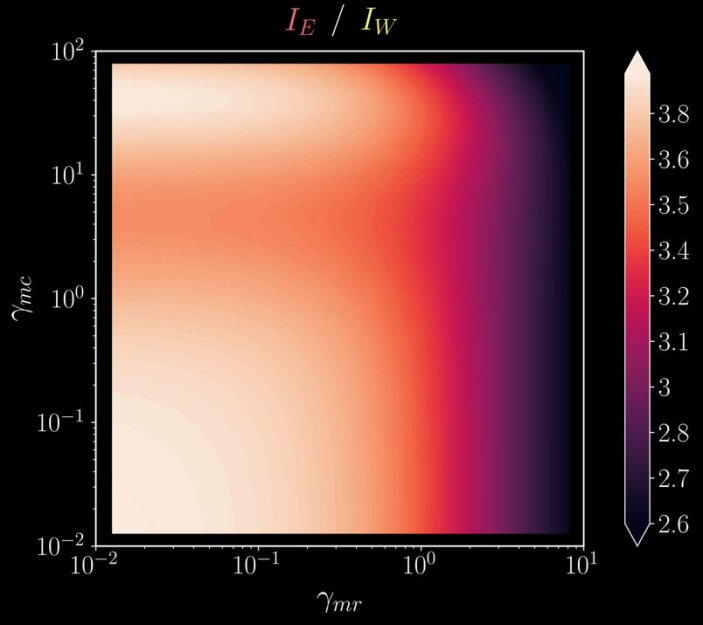




“Measuring” both γ_{mc}, γ_{mr} ?







- These two nice ratios, plus total conductance for example, give three pieces of information from which the two rates could be extracted!

Thanks for your attention! ☺