## Negative Local Resistance Due To Viscous Electron Backflow In Graphene

## M. $Polini^{l^*}$

<sup>1</sup> Istituto Italiano di Tecnologia, Graphene Labs, Via Morego 30, I-16163 Genova, Italy; email: marco.polini@icloud.com

Graphene sheets encapsulated between thin slabs of boron nitride host a unique electron system that due to weak electron-phonon scattering allows micrometer-scale ballistic transport even at room temperature [1,2,3,4] whereas local equilibrium in the system is provided by frequent electron-electron collisions [5]. Under these conditions, electrons in doped samples behave as a highly viscous liquid and may exhibit hydrodynamic phenomena similar to classical liquids. In this talk I will report on results of combined theoretical and experimental work [6] showing unambiguous evidence for this long-sought transport regime. In particular, graphene exhibits an anomalous (negative) voltage drop near current injection points, which is attributed to the formation of *whirlpools* in the electron flow. Measurements of these nearly local electrical signals enable to extract the value of the kinematic viscosity v of the two-dimensional massless Dirac fermion liquid in graphene, which is found to be an order of magnitude larger than that of honey, in quantitative agreement with many-body theory [7]. Our work shows a possibility to study *solid-state* nearly perfect fluidity [8] and turbulence using high quality graphene.

## References

[1] A.S. Mayorov *et al.*, Nano Lett. **11**, 2396 (2011).

- [2] L. Wang *et al.*, Science **342**, 614 (2013).
- [3] T. Taychatanapat *et al.*, Nature Phys. **9**, 225 (2013).
- [4] A. Woessner *et al.*, Nature Mater. **14**, 421 (2015).

[5] M. Polini and G. Vignale, *The quasiparticle lifetime in a doped graphene sheet*. In *Nononsense physicist: an overview of Gabriele Giuliani's work and life* (eds. M. Polini, G. Vignale, V. Pellegrini, and J.K. Jain) (Edizioni della Normale, Pisa, 2015). Also available as arXiv:1404.5728.

- [6] D. Bandurin *et al.*, to appear on arXiv soon.
- [7] A. Principi, G. Vignale, M. Carrega, and M. Polini, arXiv:1506.06030.
- [8] M. Müller, J. Schmalian, and L. Fritz, Phys. Rev. Lett. **103**, 025301 (2009).

[9] This was done in collaboration with **Iacopo Torre** (NEST, Scuola Normale Superiore, Pisa, Italy), **Andrea Tomadin** (NEST, Istituto Nanoscienze-CNR, Pisa, Italy), **Denis Bandurin** (The University of Manchester, UK), **Roshan K. Kumar** (The University of Manchester, UK), **Moshe B. Shalom** (The University of Manchester, UK), **Leonid A. Ponomarenko** (Lancaster University, UK), and **Andre K. Geim** (The University of Manchester, UK). Marco Polini wishes to thank the PE3 Panel Members of the ERC-2015-CoG call for **NOT** sponsoring this research.