Angle-resolved transport non-reciprocity and spontaneous symmetry breaking in multilayer graphene

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The identification and characterization of spontaneous symmetry breaking is central to our understanding of strongly correlated two-dimensional materials. In this work, we utilize a new scheme of angle-resolved transport measurements to investigate spontaneous symmetry breaking in different multilayer graphene structures, including magic-angle twisted trilayer graphene and Bernal-stacked bilayer graphene [1]. Based on an analytical model [2], we extract all parameters of the conductivity tensor that describes both linear and nonlinear transport responses. This allows us to identify the symmetry axis [1], as well as the Fermi surface shape associated with the underlying electronic order. We report that a hysteretic rotation in the mirror axis can be induced by thermal cycles and a large current bias, supporting the spontaneous breaking of rotational symmetry. Moreover, the onset of non-reciprocity with decreasing temperature coincides with the emergence of orbital ferromagnetism. Combined with the angular dependence of the superconducting diode effect, our findings uncover a direct link between rotational and time-reversal symmetry breaking. These symmetry requirements point towards exchange-driven instabilities in momentum space as a possible origin for transport non-reciprocity in multilayer graphene.

References

[1] Naiyuan J. Zhang, et. al. Nature Materials, in press, (2024).
[2] Oskar Vafek, Phys. Rev. Applied **20**, 064008 (2023).

Figures

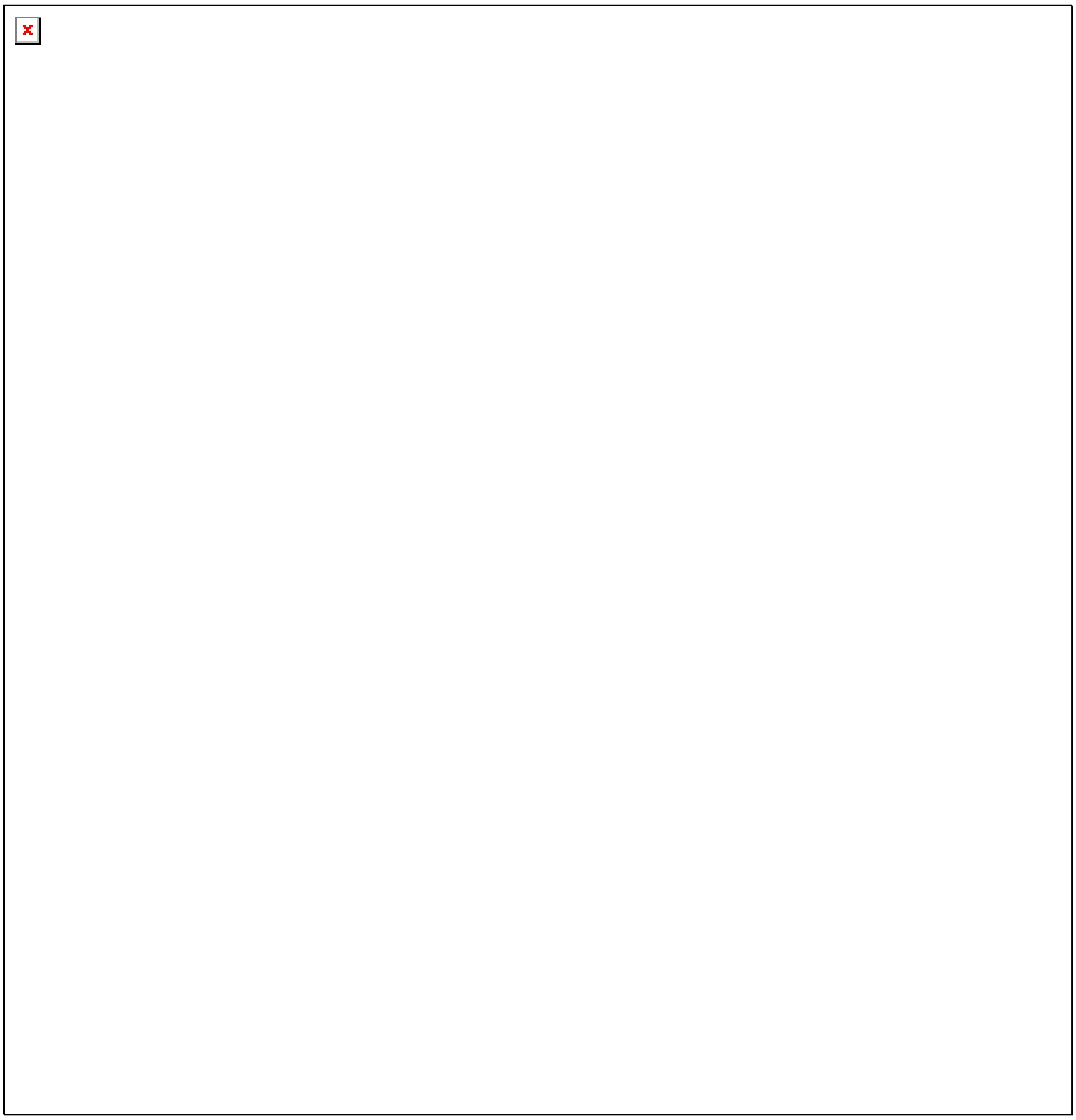

Figure 1: (a-c) Schematic diagram of Fermi surface contour with different angular symmetries. Black arrows mark the azimuth direction of the mirror axis. (d-f) Expected angular dependence in the transport response when the underlying electronic state is described by (d) two, (e) one, and (f) three mirror axes. Left (right) panels show the same angular dependence in the Cartesian (Polar) coordinate. Panel (d) plots the angular dependence of longitudinal and transverse resistance, $R_{//}$ and $R_{\perp}$, which are measured with a small DC current bias. panel (e) and (f) represents the angular dependence of transport nonreciprocity. (g) Schematic diagram of the ``sunflower'' shaped sample and the ARNTM setup.