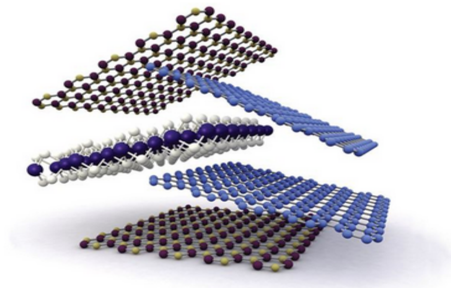
So many possibilities!

http://hqgraphene.com/




HfTe2


PtSe2


TiS2 (1T phase)


As2Te3


Black Phosphorus


Hexagonal Boron Nitride


TiSe2


TiTe2

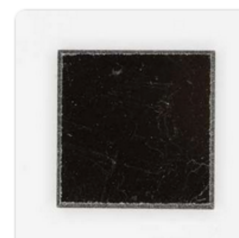

WTe2


Bi2S3


GaS


GaSe


AuSe (Alpha phase)


Graphite HOPG


Graphite Natural


GeS


GeSe


HfS2

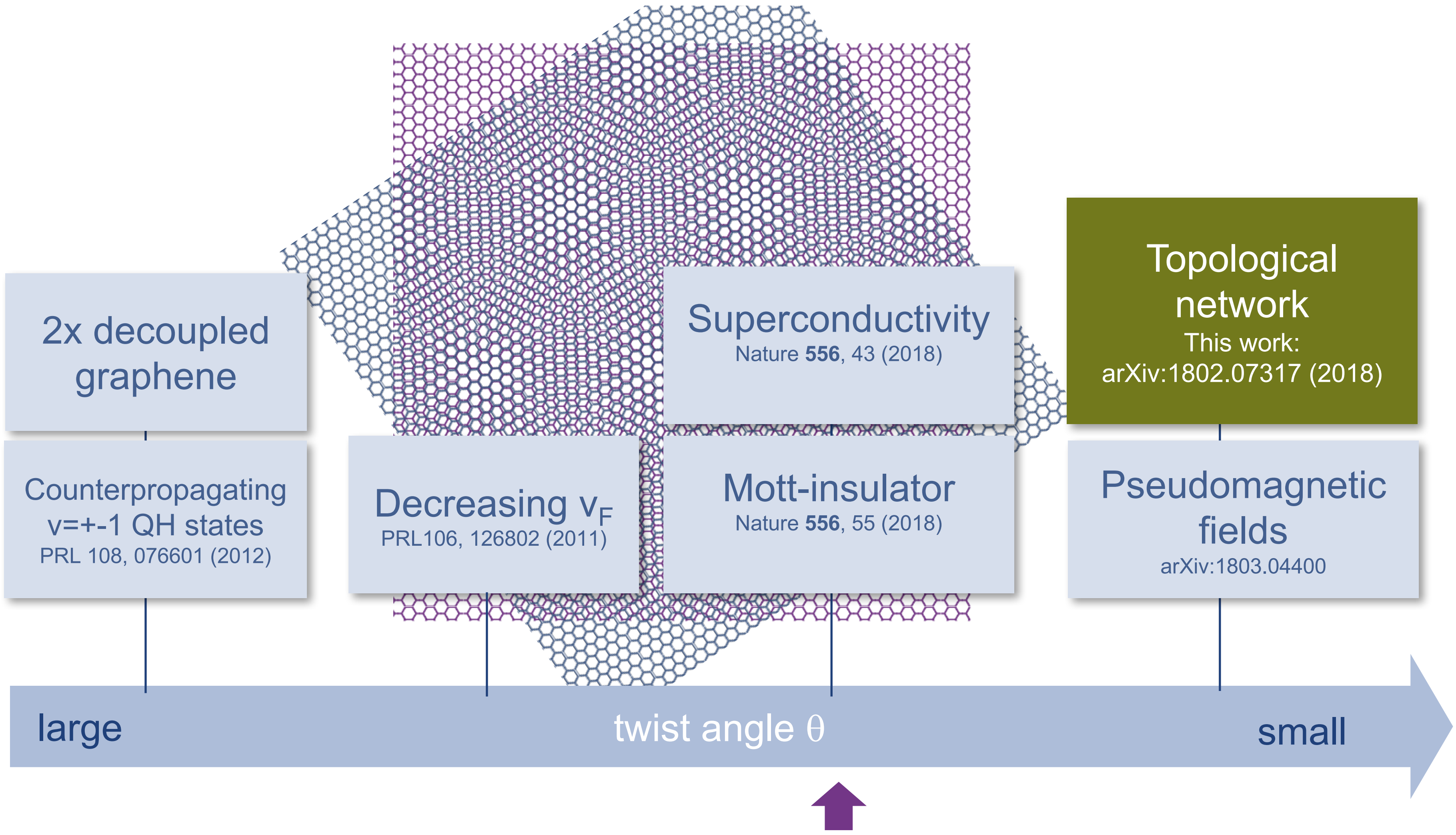

MoTe2 (1T phase)


NbSe2 (2H phase)

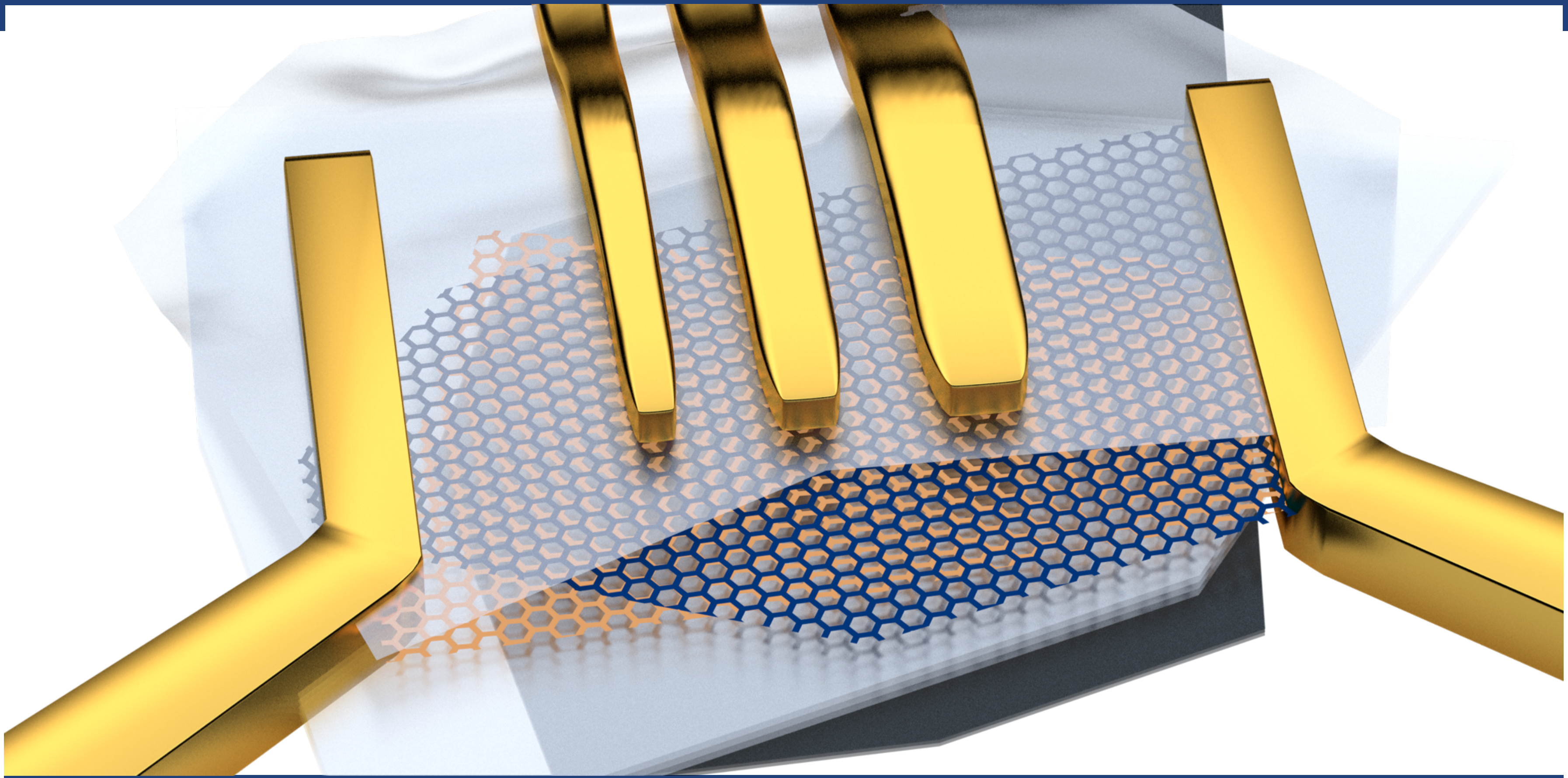

NbS2 (2H phase)

ETH zürich

Graphene on graphene - a trivial combination?



ETH zürich



Transport through a network of topological states in twisted bilayer graphene

Peter Rickhaus, Graphene 2018, Dresden

Acknowledgements

Experiments

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Marius Eich
Riccardo Pisoni
Yongjin Lee

Theory

Sergey Slizovski
John Wallbank

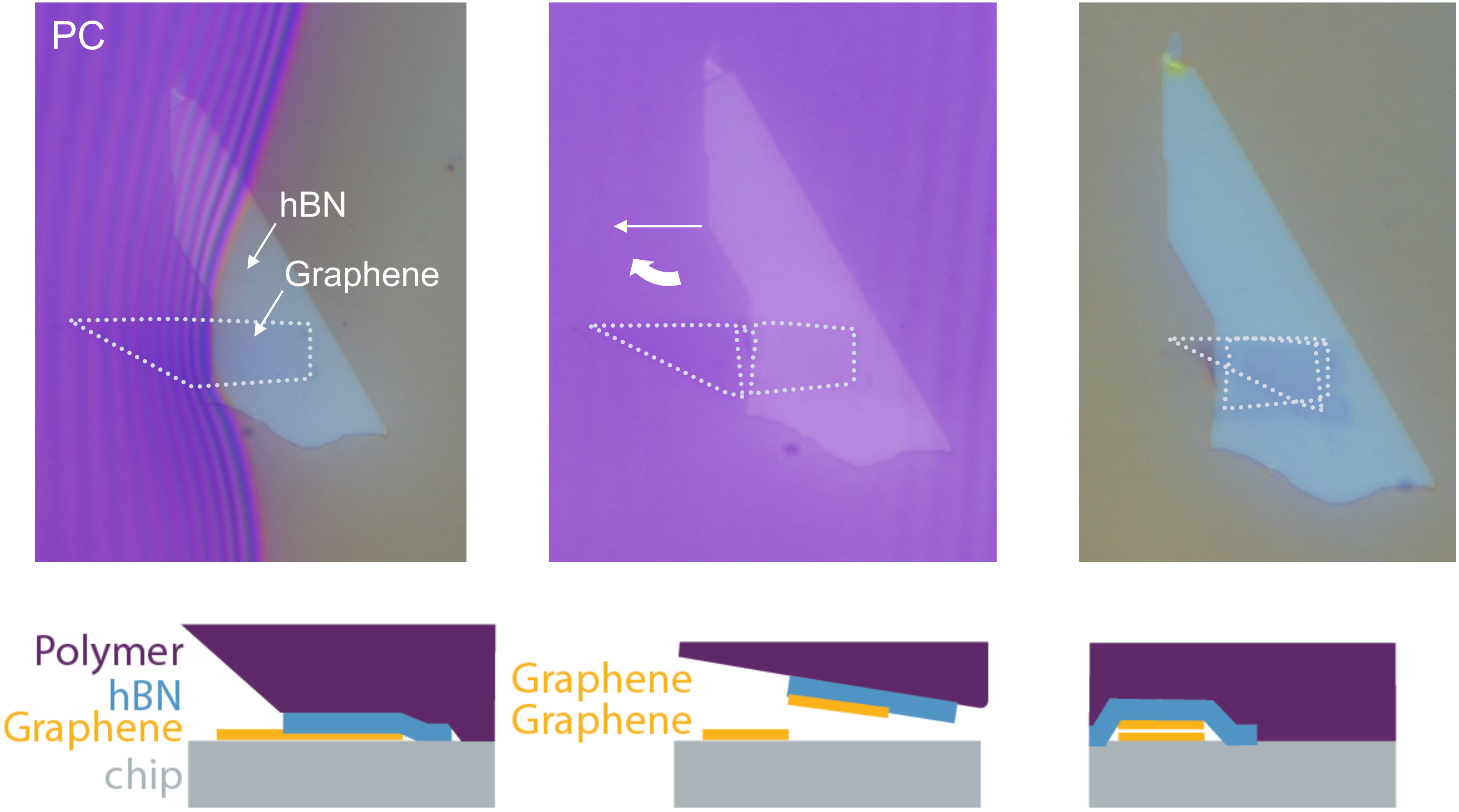
Ming-Hao Liu

QSIT Quantum Science and Technology
National Centre of Competence in Research

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

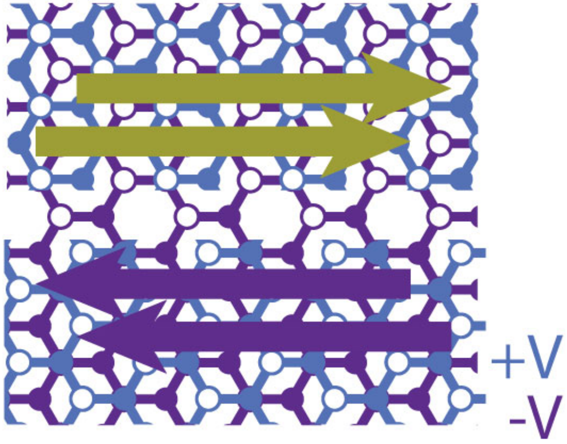
GRAPHENE FLAGSHIP

Fabrication



Quantum Valley-Hall effect in Graphene

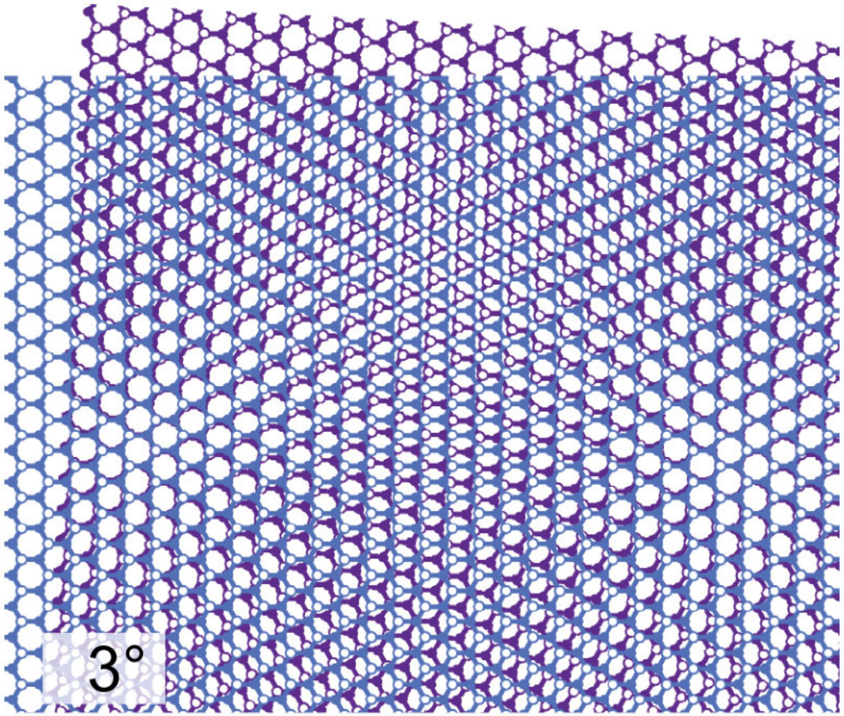
Single-layer Graphene
Bilayer Graphene
+ Interlayer bias +V/-V
+ Stacking fault

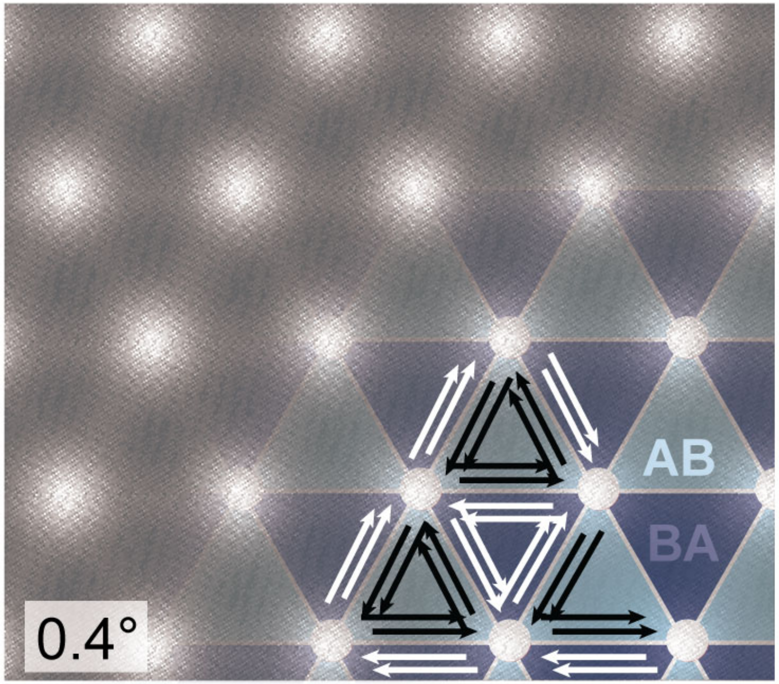


→ **Quantum Valley-Hall effect**

Small angle twisted bilayer graphene

… has „a bulk full of boundaries“



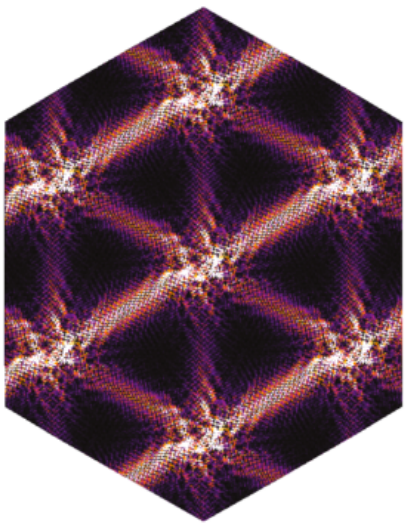


In our device: λ=33nm, θ=0.4°

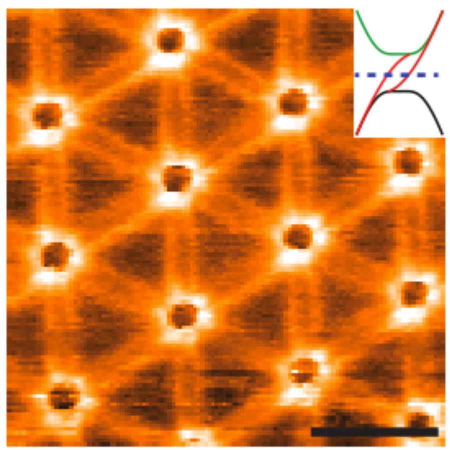
Small angle twisted bilayer graphene

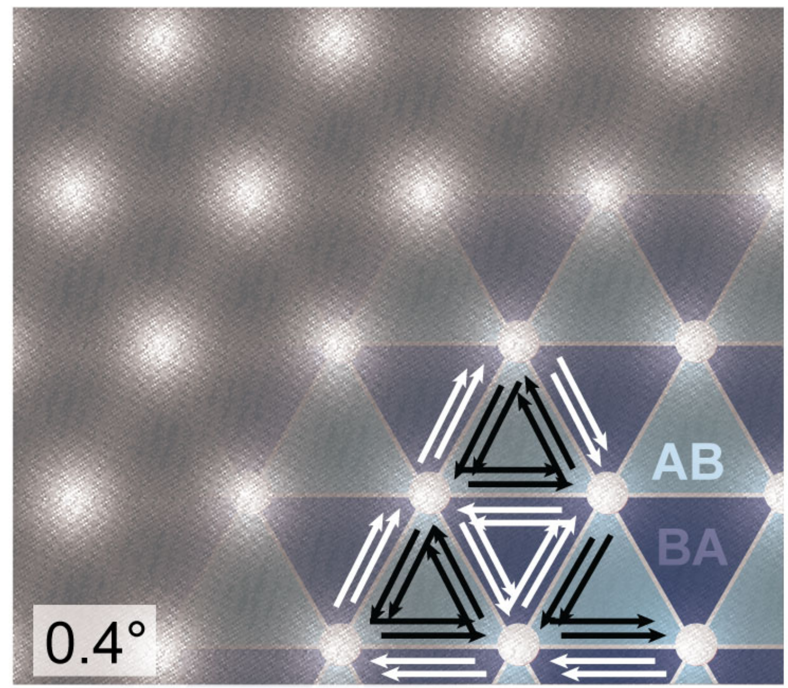
… has „a bulk full of boundaries“

TB theory:



STM:



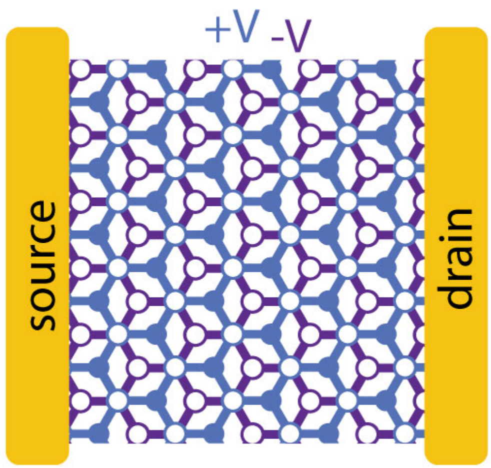


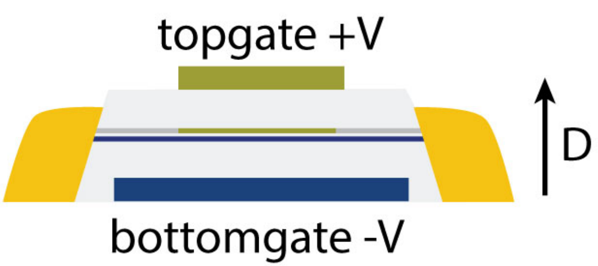
Theory: *P. San-Jose and E. Prada, Phys. Rev. B* ***88****, (2013).*
STM: *S. Huang, … B. J. Leroy, arXiv:1802.02999v1 (2018).*

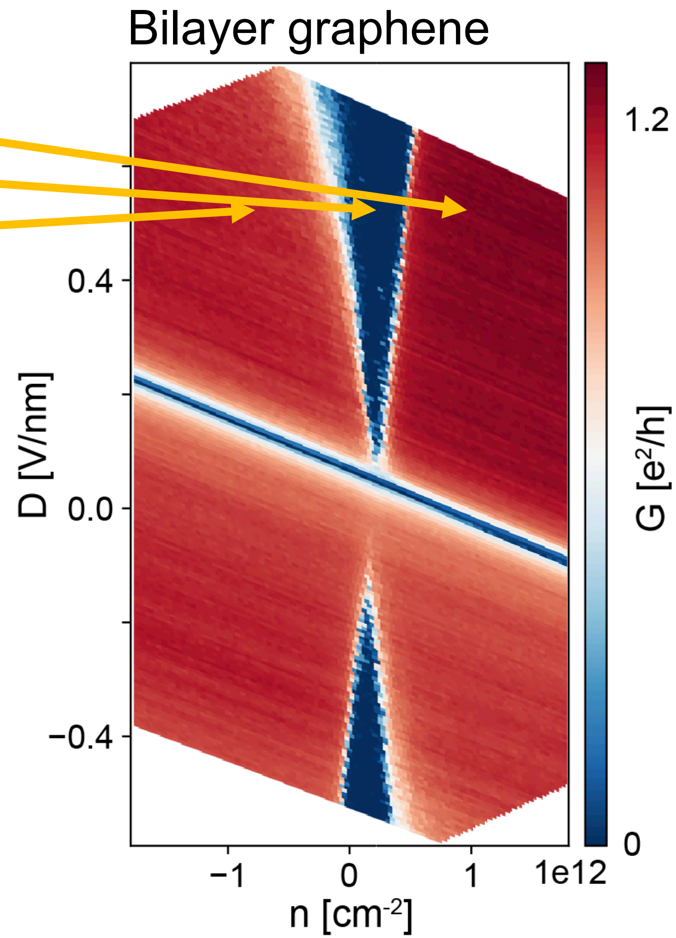
How to measure the topological network in a transport experiment?

2-terminal measurement with global top- and bottomgate?

Measure the gap in bilayer graphene

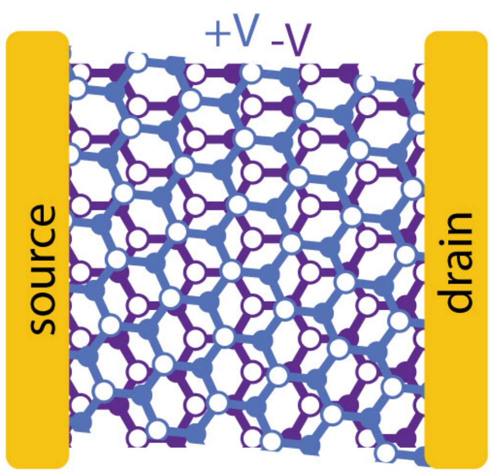


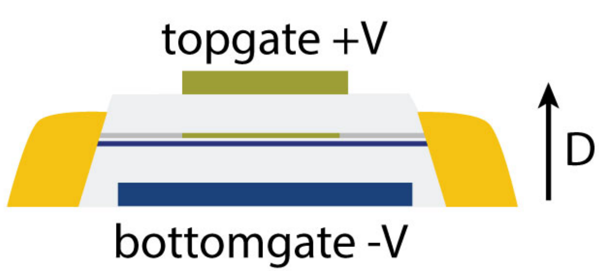


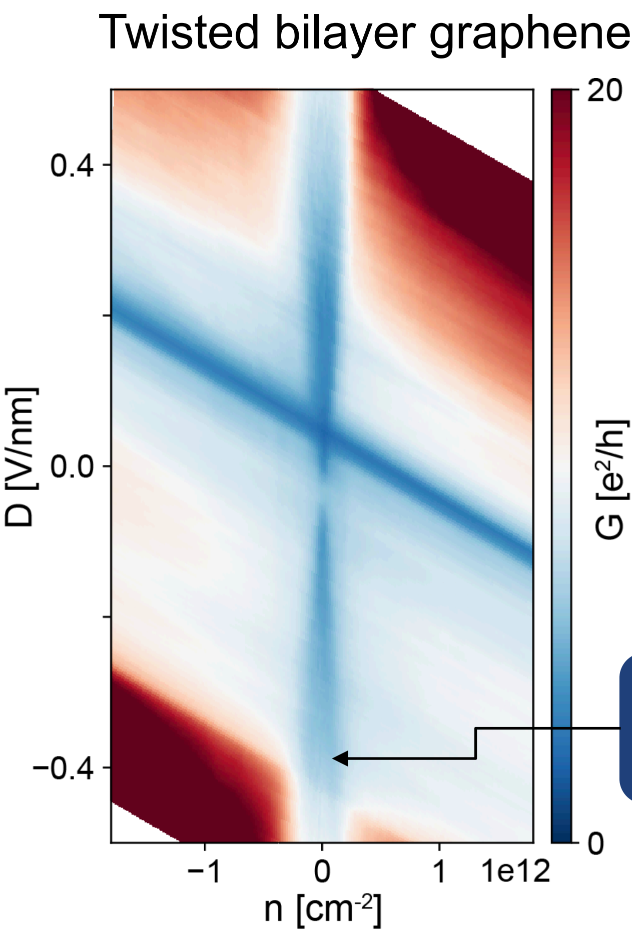


Displacement field: $D \sim V_{tg} - V_{bg}$
Density: $n \sim V_{tg} + V_{bg}$

Measure the gap in twisted bilayer graphene







G is nonzero

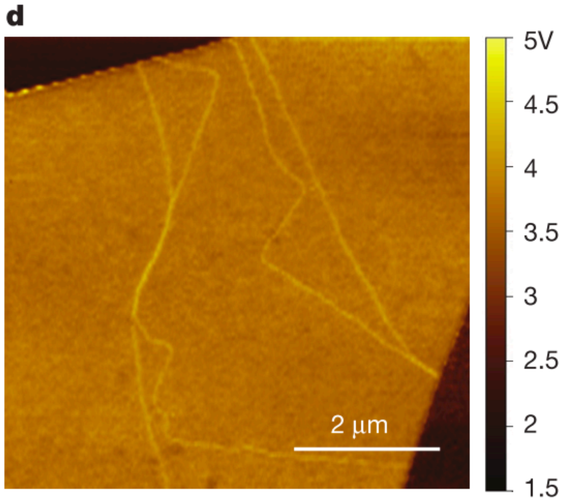
Displacement field: D~V_{tg}-V_{bg}
Density: n~V_{tg}+V_{bg}

How to measure the topological network in a transport experiment?

2-terminal measurement with global top- and bottomgate?
→ not enough information

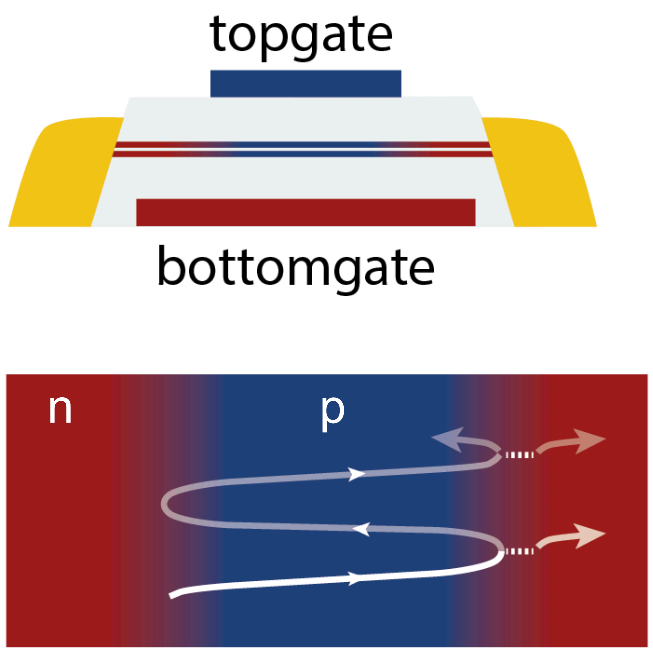
Hallbar?
→ probes the boundaries

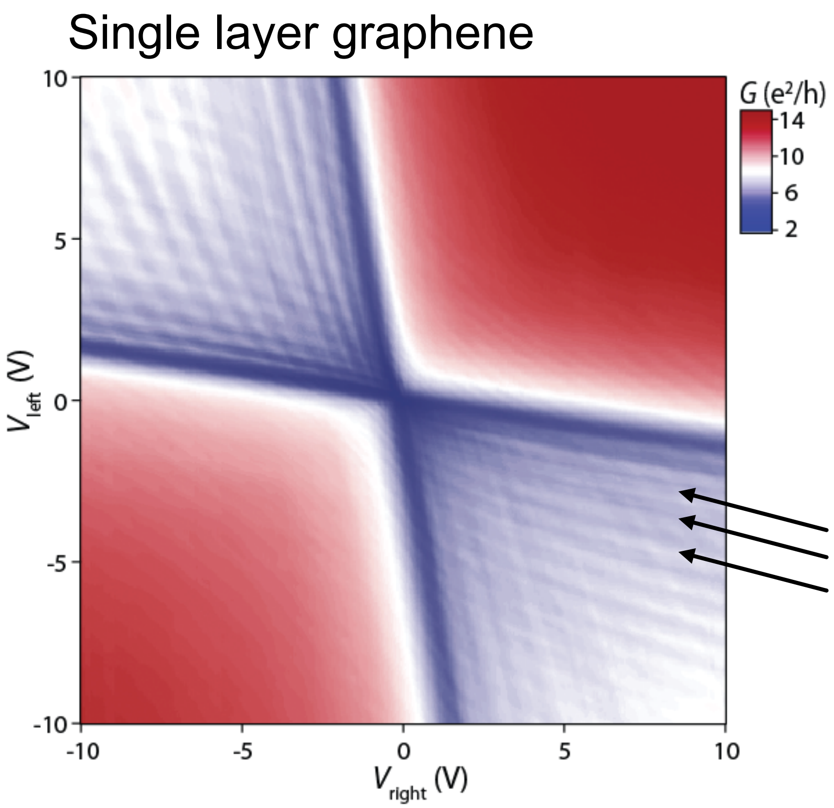
Conductance of a single boundary?
→ We are interested in the network



*L. Ju, ... F. Wang, Nature **520**, 650 (2015).*

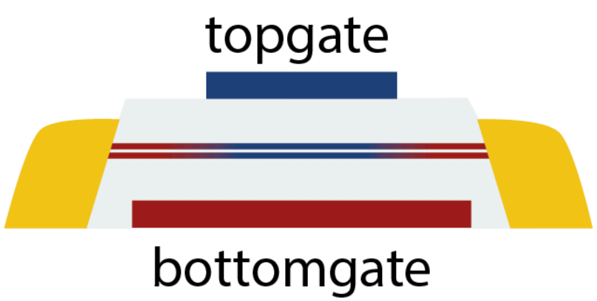
Using an electronic Fabry-Pérot interferometer!

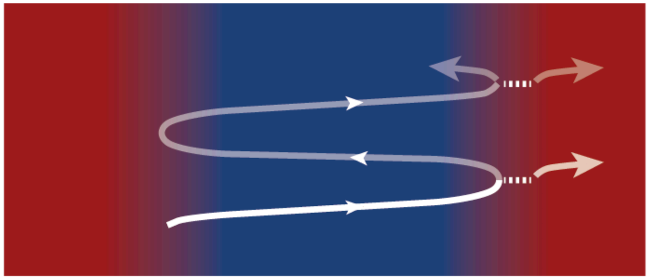




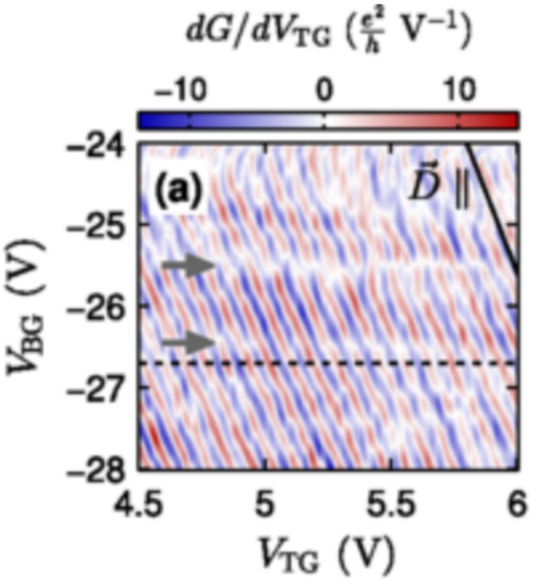
P. Rickhaus, R. Maurand, M.H. Liu et al. Nature Comm. 4, 2342 (2013)
P. Rickhaus, M.-H. Liu, P. Makk, et.al. Nano Lett. 15, 5819 (2015)

Using an electronic Fabry-Pérot interferometer!



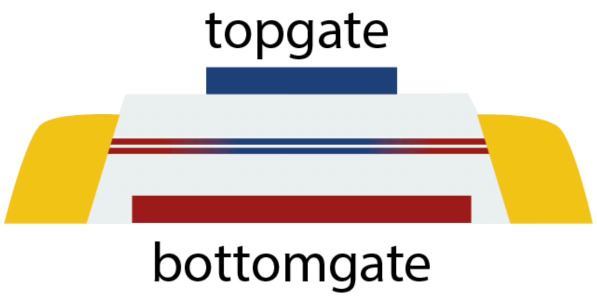


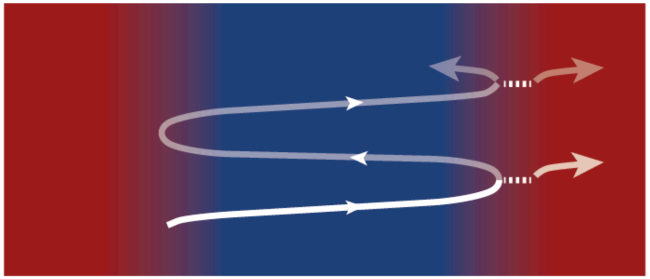
Bilayer graphene



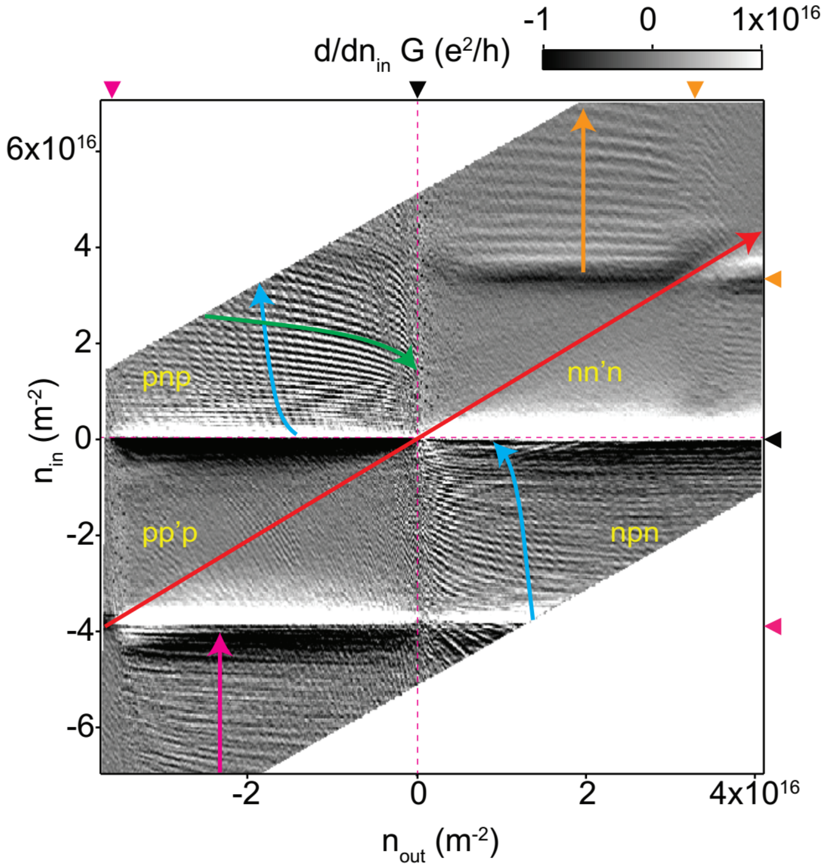
A. Varlet, M.-H. Liu, .. K. Ensslin, and T. Ihn, Phys. Rev. Lett. **113**, 116601 (2014).

Using an electronic Fabry-Pérot interferometer!



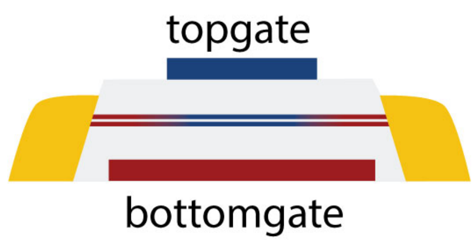


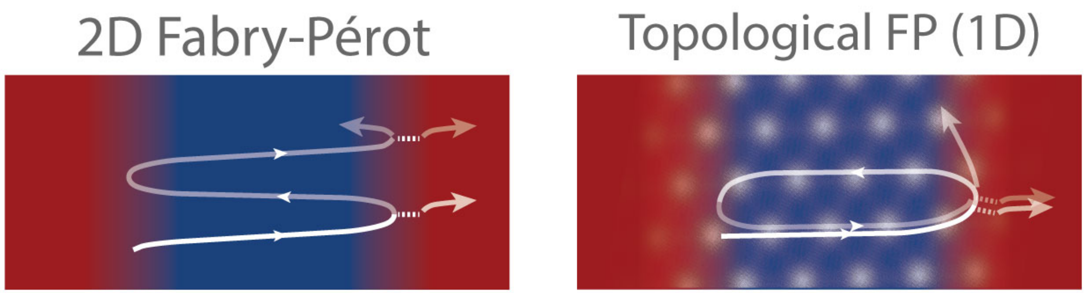
Graphene + hBN moiré superlattice



C. Handschin, P. Makk, .. P.Rickhaus, ... Nano Lett., 17, 328 (2017)

Using an electronic Fabry-Pérot interferometer!

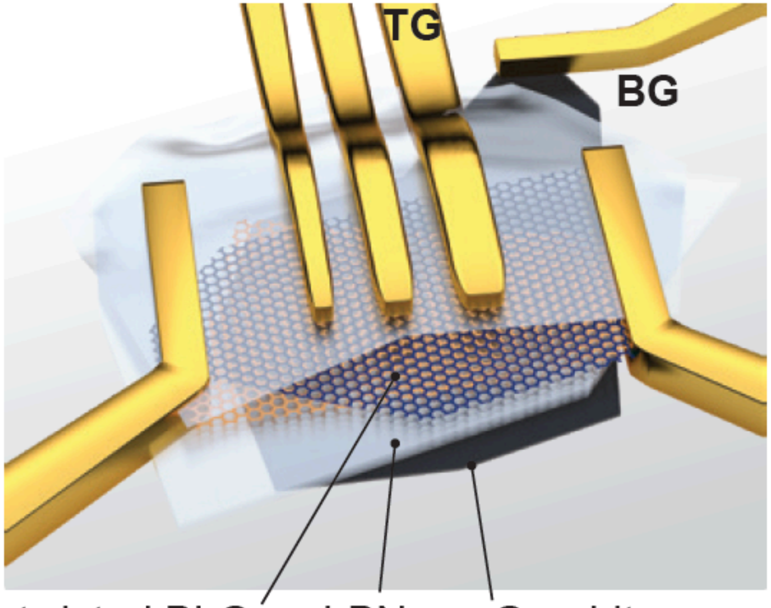




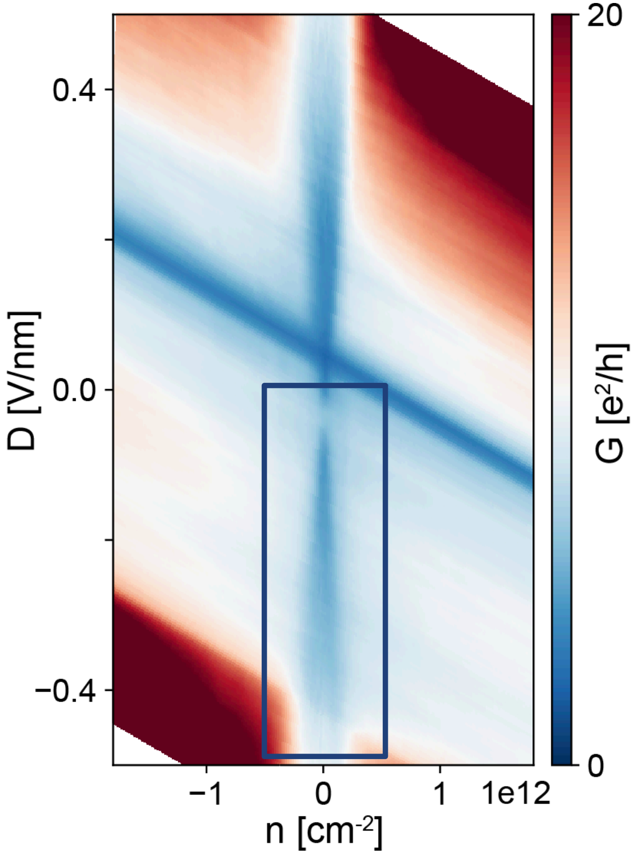
2D Fabry-Pérot	Topological FP (1D)
$N\lambda = 2L$	$N\lambda = 2L$
$\lambda = 2\pi/k$	$\lambda = 2\pi/k$
$k \sim \sqrt{n}$	$k \sim n$

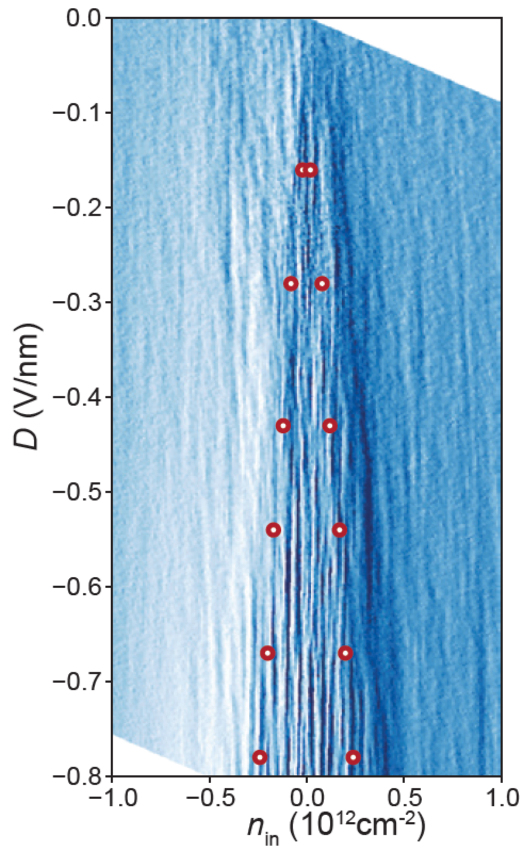
Bending of Fab
P. Rickhaus... C. Schönenberger, Nat. Commun. **6**, 6470 (2015).

Device with three topgates

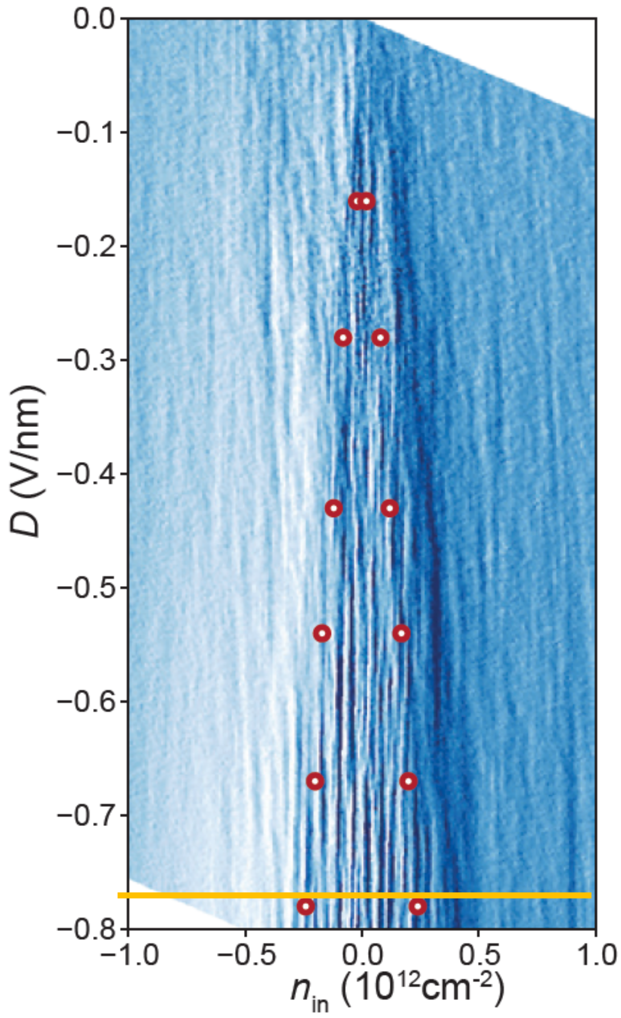


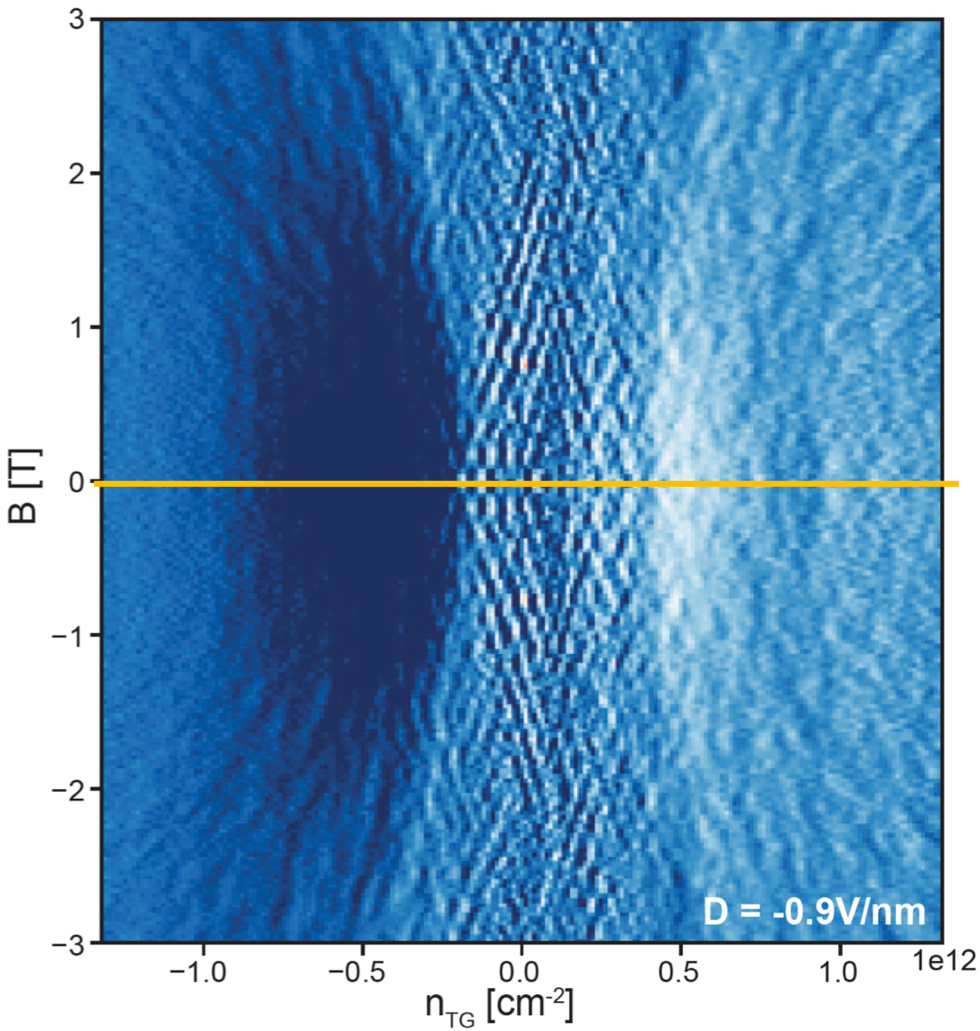
Fabry-Pérot resonances in twisted BLG





Fabry-Pérot resonances in twisted BLG



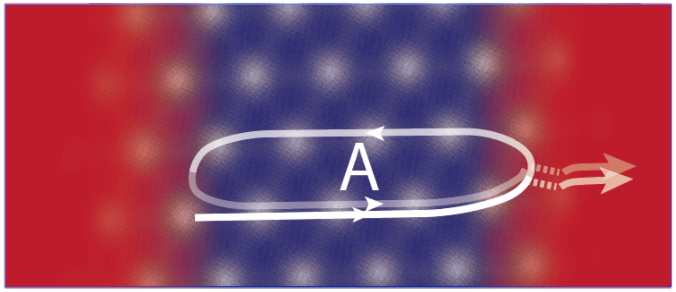


Magneto-conductance oscillations

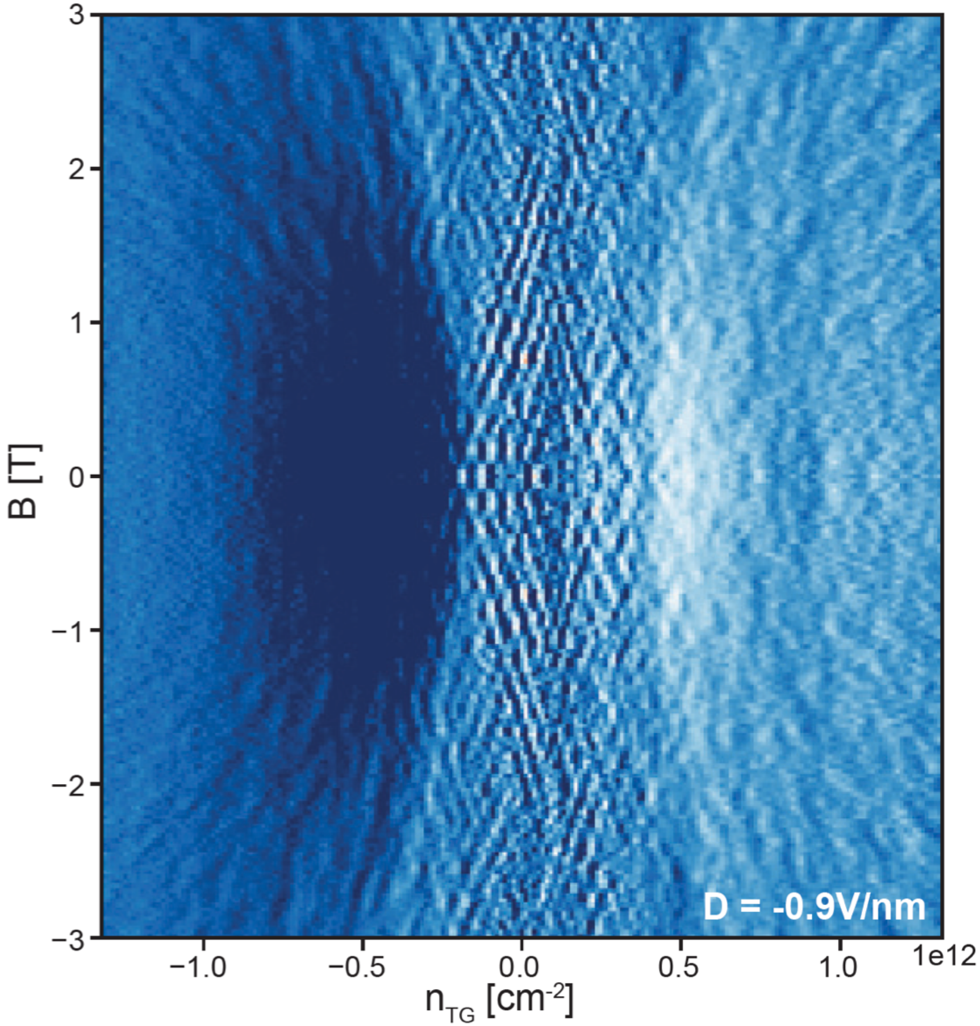
Resonances do not disappear!
They follow the condition:

$$j = L\frac{k_F}{\pi} \pm A\frac{B}{\phi_0}$$

Where A is the area of one row of AB/BA regions:



For different gates (9) lengths
On different samples (3)



Summary

- Topological **network**
- Current flows along ideal geometric boundaries **in the bulk**
- Probed with a Fabry-Pérot resonator
  - Resonances stable in B>>0
  - Resonances linear in n

Valleytronics:

- FP resonator as source of valley-polarized current