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Tunneling spectroscopy of the graphene quantum Hall topological insulator

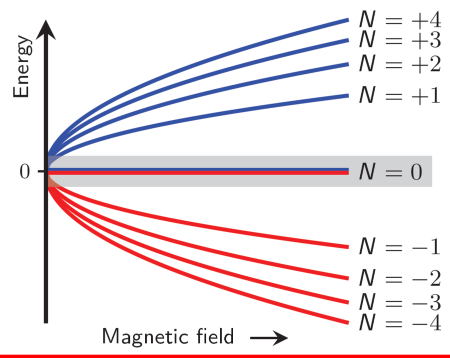
Alexis COISSARD[1], Louis VEYRAT[1], Hadrien VIGNAUD[1], Kenji WATANABE[2], Takashi TANIGUCHI[2], Hervé COURTOIS[1], Hermann SELLIER[1], Benjamin SACÉPÉ[1,†]

[1] Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble, France

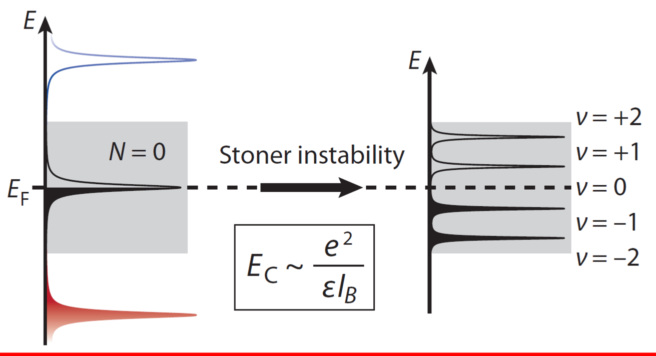
[2] National Institute for Materials Science, Tsukuba, Japan

Context

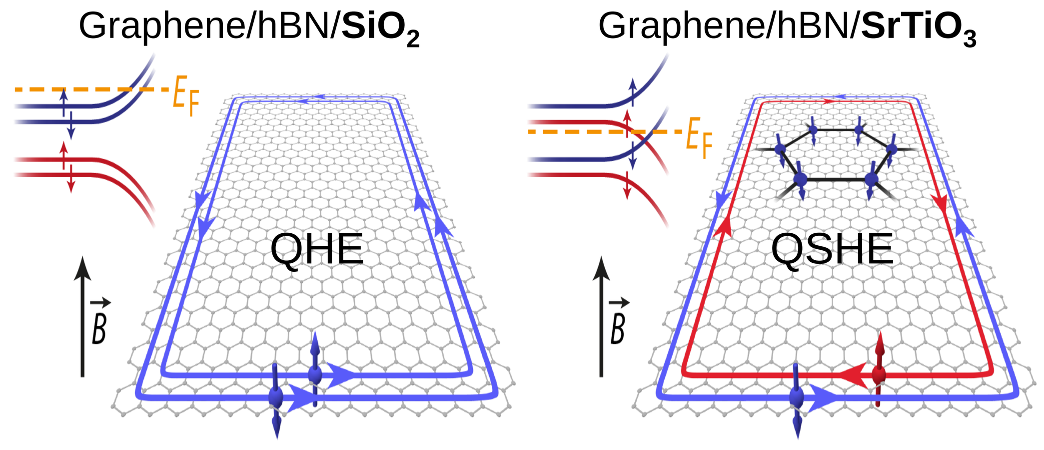
Charge neutral graphene develops a **quantum Hall topological insulator** phase when the **Coulomb potential is screened** by a high-k dielectric environment. The expected ferromagnetic phase features **spin-filtered helical edge channels** and exhibits the **quantum spin Hall effect** [1], which are of high interest for spintronics and topological superconductivity.

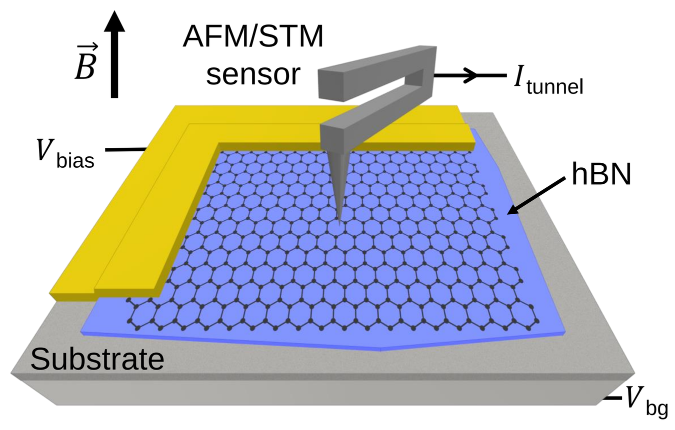


Landau levels in graphene : $E_N = \pm v_F\sqrt{2\hbar e|N|B}$



Lifting of spin and valley degeneracies when E_F is pinned in the zeroth Landau level.

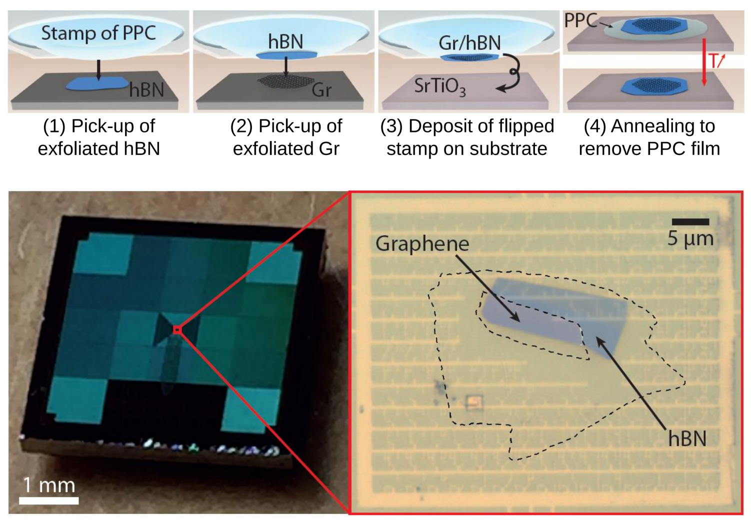




We measure the $\nu = 0$ gap that opens in bulk graphene via tunneling spectroscopy for the both phases with gapped and gapless edge excitations at charge neutrality. Such phases are engineered in graphene via suitable substrate-screening [1].

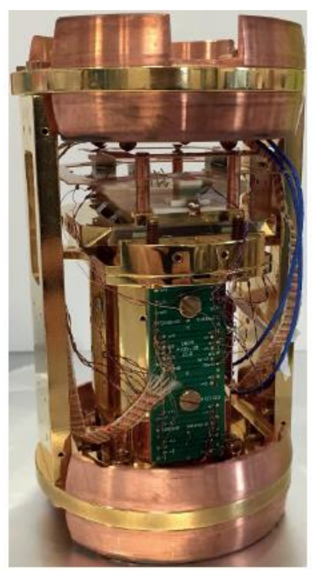
Sample fabrication

- **Surface-free graphene** stacked on hexagonal boron nitrite flake (hBN).
- Two substrates : SiO_2/Si (conventional) and $SrTiO_3$ ($\varepsilon_r \sim 10^4$ at 4 K).
- **$SrTiO_3$ screens electron-electron interactions** depending on the thickness of the hBN spacer.
- **Guiding markerfield** for the tip patterned by e-beam on the whole substrate.

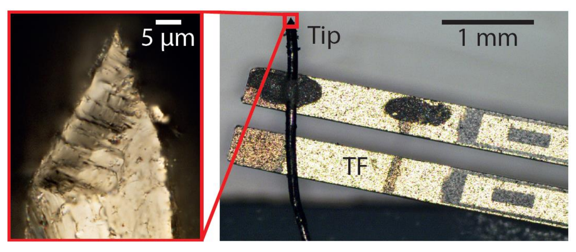


hBN thickness d_{BN} : 14 nm (SiO_2) / 8 nm ($SrTiO_3$)

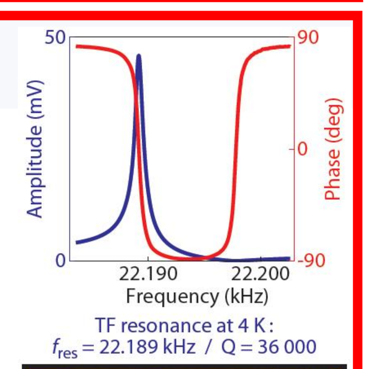
4 K - 14 T AFM/STM

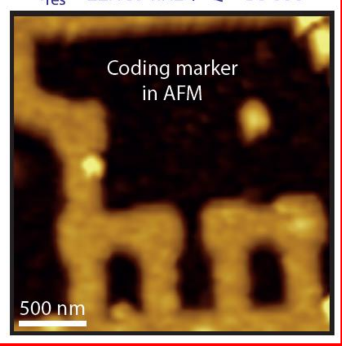


- **Combined AFM/STM sensor :** PtIr tip (⌀ 50 µm) glued on one prong of a tuning fork (TF).

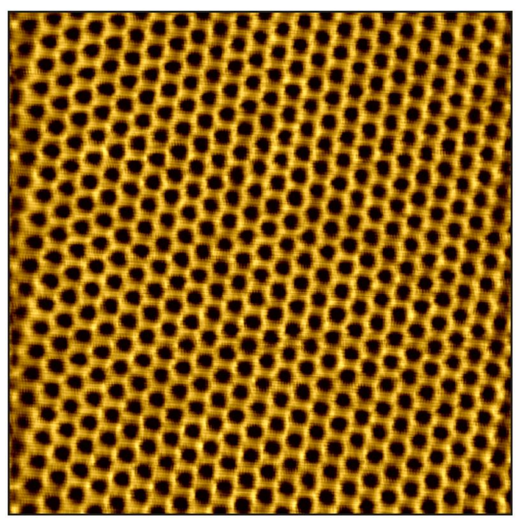


- **AFM to guide the tip** towards graphene at 4 K.
- Guiding done in about 15 steps (~ 10 hours).



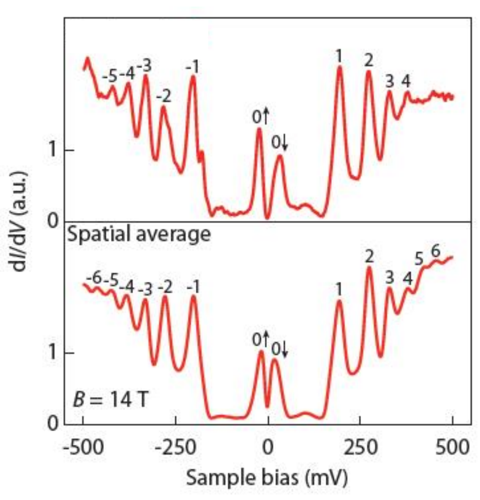


Atomic resolution

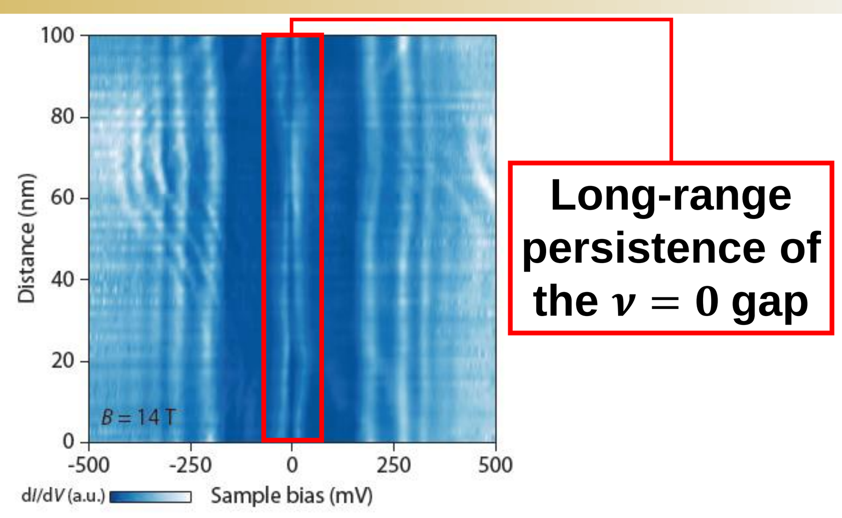


Honeycomb lattice of graphene
in STM at 4 K (5 nm × 5 nm).

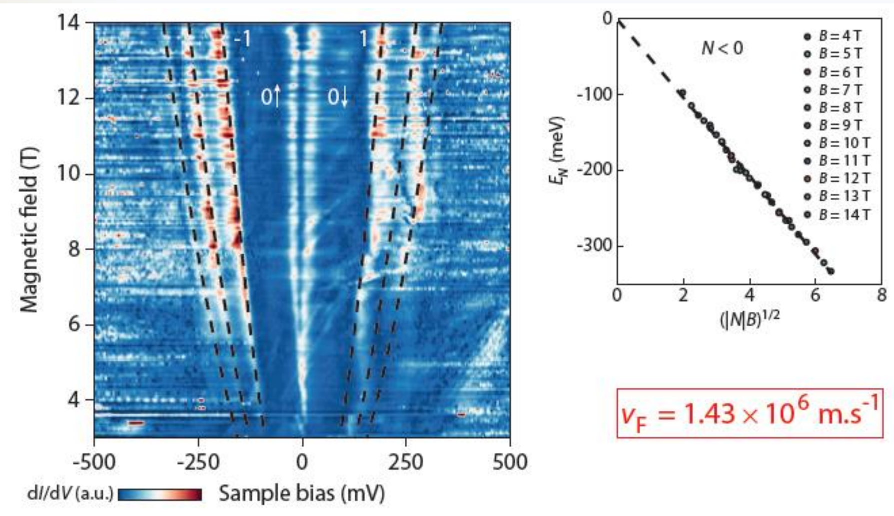
Landau levels of Dirac fermions



Landau levels in graphene at 14 T.



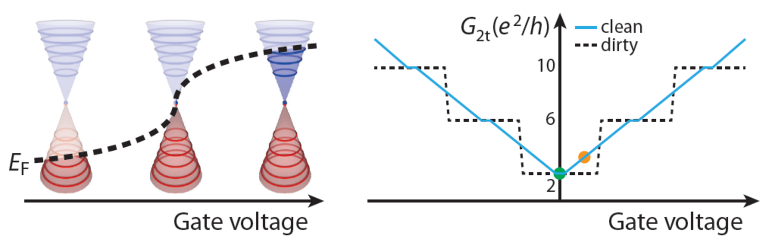
Very weak spatial dispersion of the Landau levels.

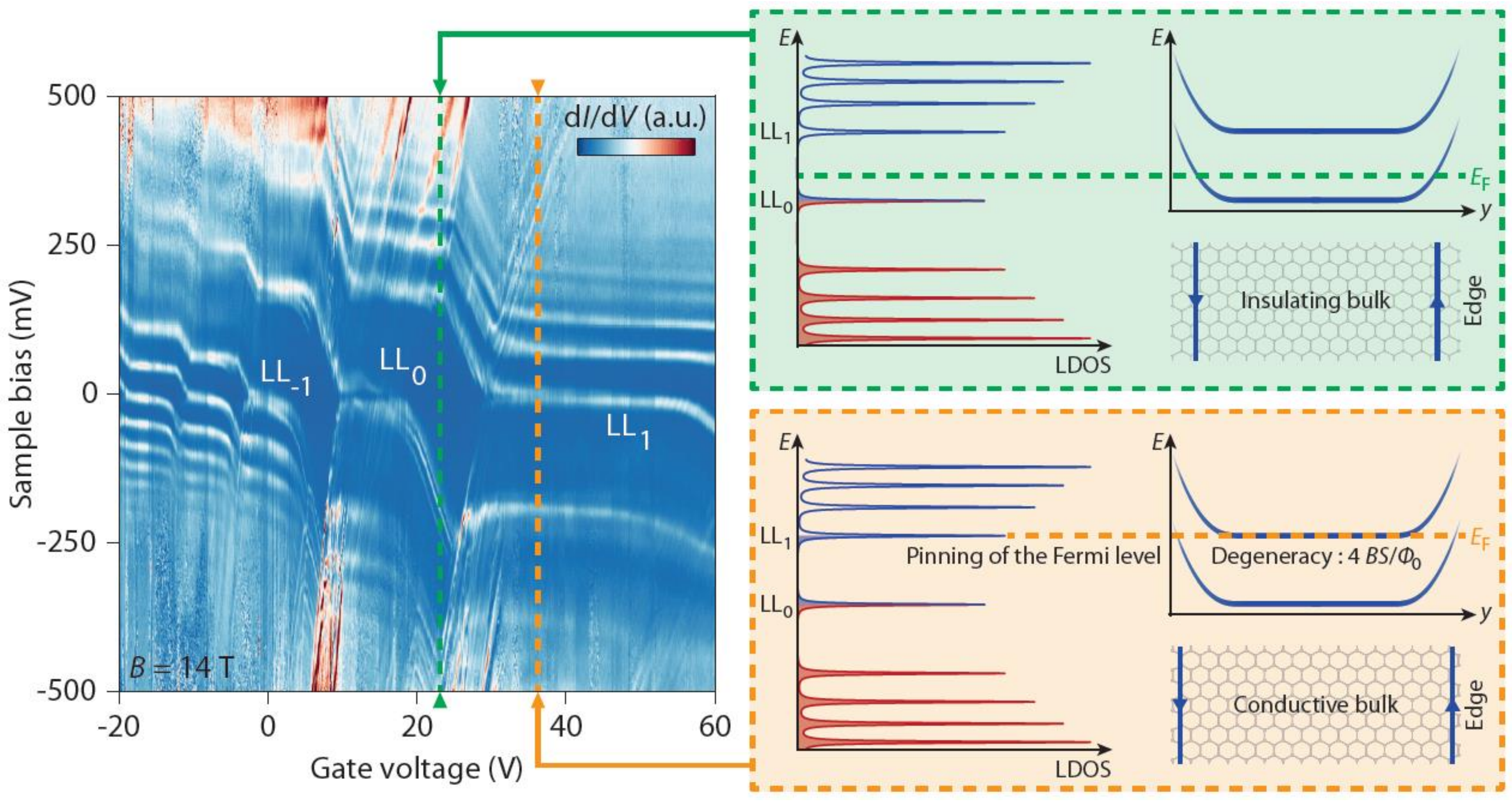


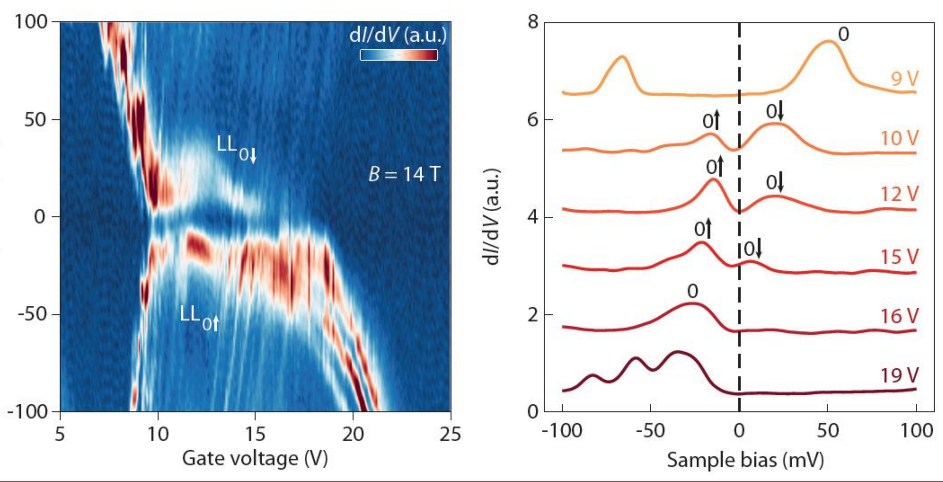
Magnetic-field dispersion of the Landau levels and fit with respect to theory ($SrTiO_3$).

Gate tunable Landau levels

Gate sweep at 14 T ($SrTiO_3$) :
Successive pinning of the Fermi level in the Landau levels [2].



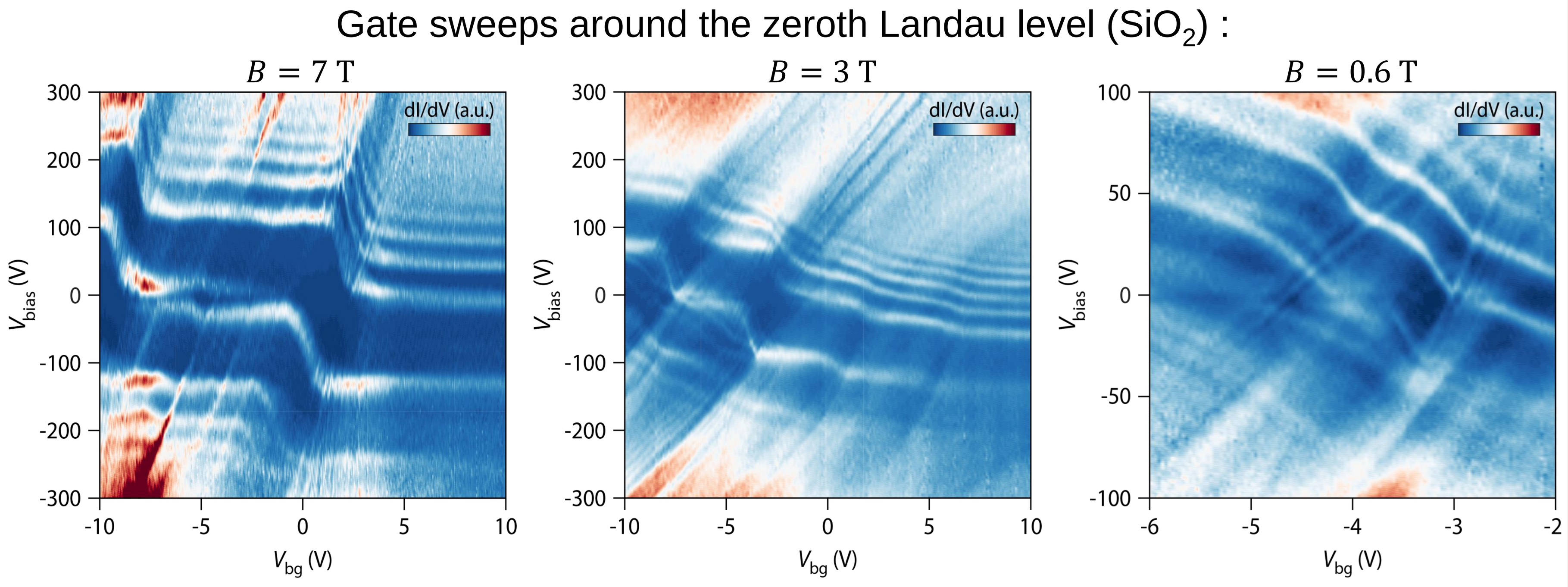




Opening of the ferromagnetic gap when the Fermi level lies inside the zeroth Landau level [3].

Evolution of the $\nu = 0$ gap with the magnetic field

Gate sweeps around the zeroth Landau level (SiO_2) :



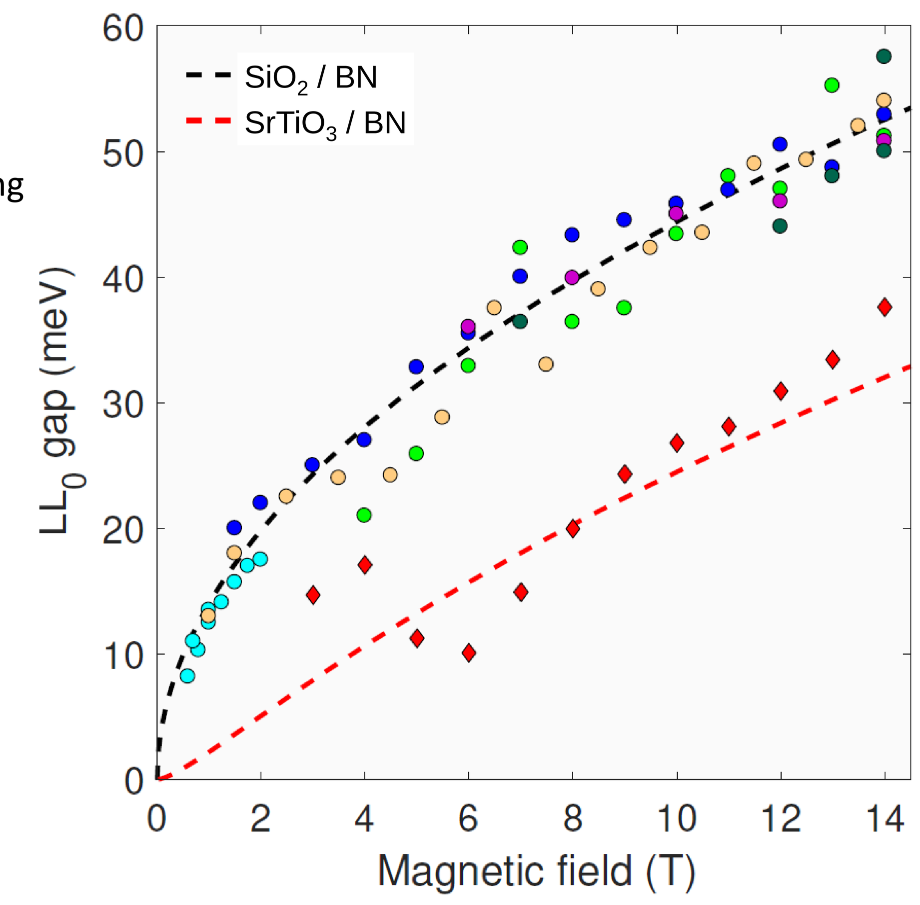
Bare Coulomb energy

$$\tilde{E}_C = \frac{e^2}{4\pi\varepsilon_0\varepsilon_{BN} l_B} \times S(B)$$

Screened Coulomb energy ($\tilde{E}_C$); E_C = Bare Coulomb energy; $S(B)$ = Substrate-screening

$$S(B) = 1 - \frac{\varepsilon_{SrTiO_3} - \varepsilon_{BN}}{\varepsilon_{SrTiO_3} + \varepsilon_{BN}} \frac{l_B}{\sqrt{l_B^2 + 4d_{BN}^2}}$$

- **The unscreened $\nu = 0$ gap scales as the Coulomb energy, proportional to $\sqrt{B}$.**
- **The screened $\nu = 0$ gap is in good agreement with the substrate-screened Coulomb energy scale.**
- **Confirmation of efficient substrate-screening with $SrTiO_3$.**



CONTACT PERSON

† benjamin.sacepe@grenoble.cnrs.fr

REFERENCES

[1] L. Veyrat, C. Déprez, A. Coissard, X. Li, F. Gay, K. Watanabe, T. Taniguchi, Z. Han, B. A. Piot, H. Sellier and B. Sacépé, *Helical quantum Hall phase in graphene on $SrTiO_3$*, Science (2020)

[2] A. Luican, G. Li and E. Y. Andrei, *Quantized Landau level spectrum and its density dependence in graphene*, PRB (2011)

[3] Y. J. Song, A. F. Otte, Y. Kuk, Y. Hu, D. B. Torrance, P. N. First, W. A. de Heer, H. Min, S. Adam, M. D. Stiles, A. H. MacDonald and J. A. Stroscio, *High-resolution tunnelling spectroscopy of a graphene quartet*, Nature (2010)

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