Quarter- and Half-Filled Quantum Hall States and their Competing Interactions in Bilayer Graphene

Ravi Kumar[1*], André Haug[1*], Jehyun Kim[1], Misha Yutushui[1], Konstantin Khudiakov[1], Vishal Bhardwaj[1], Alexey Ilin[1], Kenji Watanabe[2], Takashi Taniguchi[3], David F. Mross[1], Yuval Ronen[1†]

[1]*Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel*
[2]*Research Center for Functional Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan*
[3]*International Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan*

[†]Corresponding author: yuval.ronen@weizmann.ac.il
[*]These authors contributed equally to this work.

Bilayer graphene has emerged as a key platform for studying non-Abelian fractional quantum Hall (FQH) states [1, 2, 3]. Its multiple half-filled plateaus with large energy gaps combined with its tunability offer an opportunity to distill the principles that determine their topological order. Here, I will present the observation of four additional plateaus at $\nu = \frac{1}{2}$ for different spin and valley, revealing a systematic pattern of non-Abelian states according to their Levin–Halperin daughter states. Whenever a pair of $N = 1$ Landau levels cross, anti-Pfaffian and Pfaffian develop at half filling of the lower and higher levels, respectively. In the $N = 0$ levels, where half-filled plateaus are absent, we instead observe four unexpected incompressible quarter-filled states along with daughters. The mutual exclusion of half- and quarter-filled states indicates a robust competition between the interactions favoring either paired states of two-flux or four-flux composite fermions.

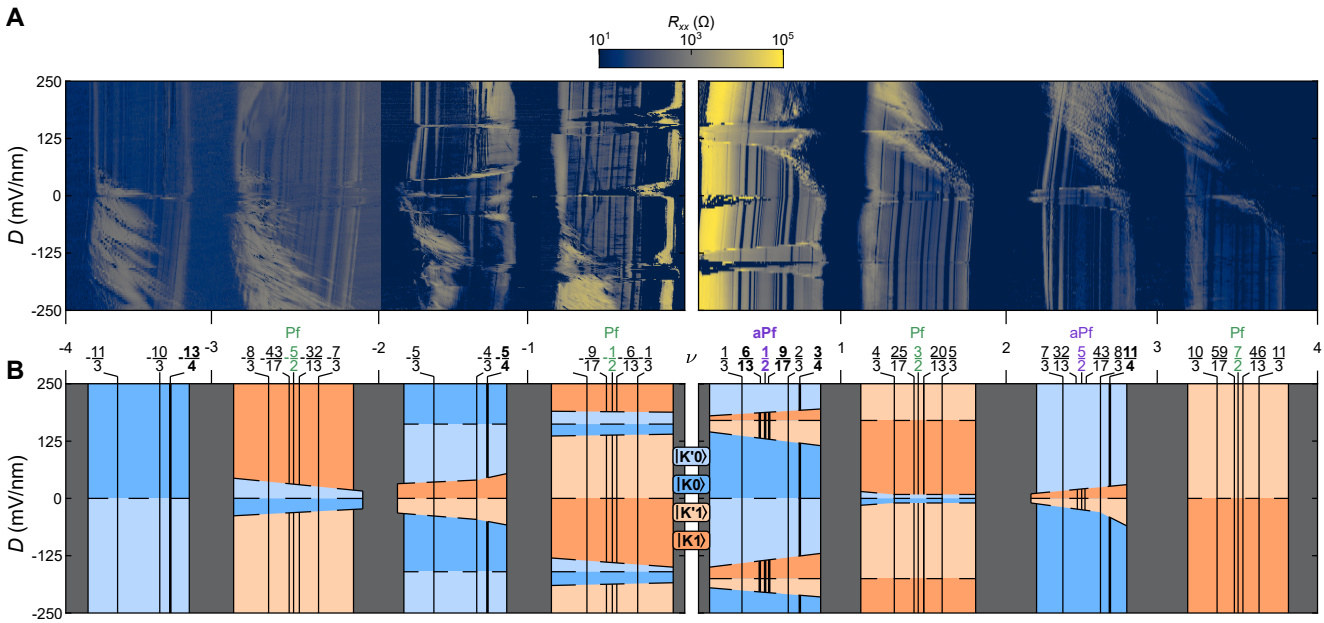

Fig. 1. (**A**) R_{xx} as a function of ν and D. Dark-blue areas mark incompressible states where $R_{xx} < 10\,\Omega$. (**B**) Schematic of all even- and selected odd-denominator FQH states observed in (A). Bold vetical lines mark newly observed states. Dashed lines mark valley and orbital crossings along the ν–D phase space. Green and purple labels indicate Pfaffian (Pf) and anti-Pfaffian (aPf) states, respectively, according to their Levin–Halperin daughter states.

References

[1] Ki *et al.*, Nano Lett. **14**, 2134–2139 (2014).
[2] Li *et al.*, Science **358**, 648–652 (2017).
[3] Huang *et al.*, Phys. Rev. X **12**, 031019 (2022).