# Orbitally Controlled Quantum Hall States in Decoupled Two-Bilayer Graphene Sheets

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We report on integer and fractional quantum Hall states in a stack of two twisted Bernal bilayer graphene sheets. By exploiting the momentum mismatch in reciprocal space, the single-particle tunneling between both bilayers is suppressed[1]. Since the bilayers are spatially separated by only 0.34 nm, the stack benefits from strong interlayer Coulombic interactions. These interactions can cause the formation of a Bose-Einstein condensate[2]. Indeed, such a condensate is observed for half-filling in each bilayer sheet. However, only when the partially filled levels have orbital index 1. This discrepancy is tentatively attributed to the role of skyrmion/anti-skyrmion pair excitations and the dependence of the energy of these excitations on the orbital index[3, 4]. The application of asymmetric top and bottom gate voltages enables to influence the orbital nature of the electronic states of the graphene bilayers at the chemical potential and to navigate in orbital mixed space. The latter hosts an even denominator fractional quantum Hall state at total filling of -3/2. These observations suggest a unique edge reconstruction involving both electrons and chiral p-wave composite fermions.

References

[1] Y. Kim, H. Yun, S. Nam, M. Son, D. S. Lee, D. C. Kim, S. Seo, H. C. Choi, H. Lee, S. W. Lee, and J. S. Kim, Phys. Rev. Let. **110**, 096602 (2013)

[2] J. I. A. Li, T. Taniguchi, K. Watanabe, J. Hone and C. R. Dean, Nature Physics **13**, 751 (2017)

[3] D. Kim, B. Kang, Y. Choi, K. Watanabe, T. Taniguchi, G. Lee, G. Y. Cho, and Y. Kim, Nano Lett. **23**, 163 (2023)

[4] Q. Shi, E. Shih, D. Rhodes, B. Kim, K. Barmak, K. Watanabe, T. Taniguchi, Z. Papic, D. A. Abanin, J. Hone and C. R. Dean, Nature Nanotechnology **17**, 577 (2022)