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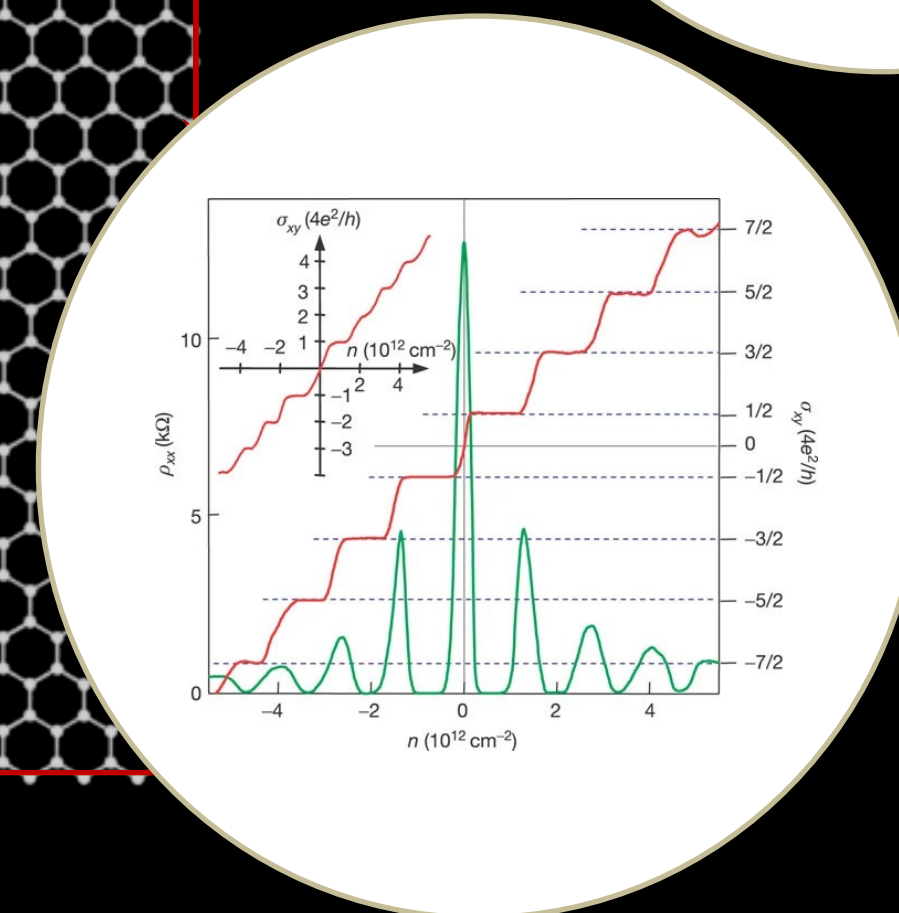
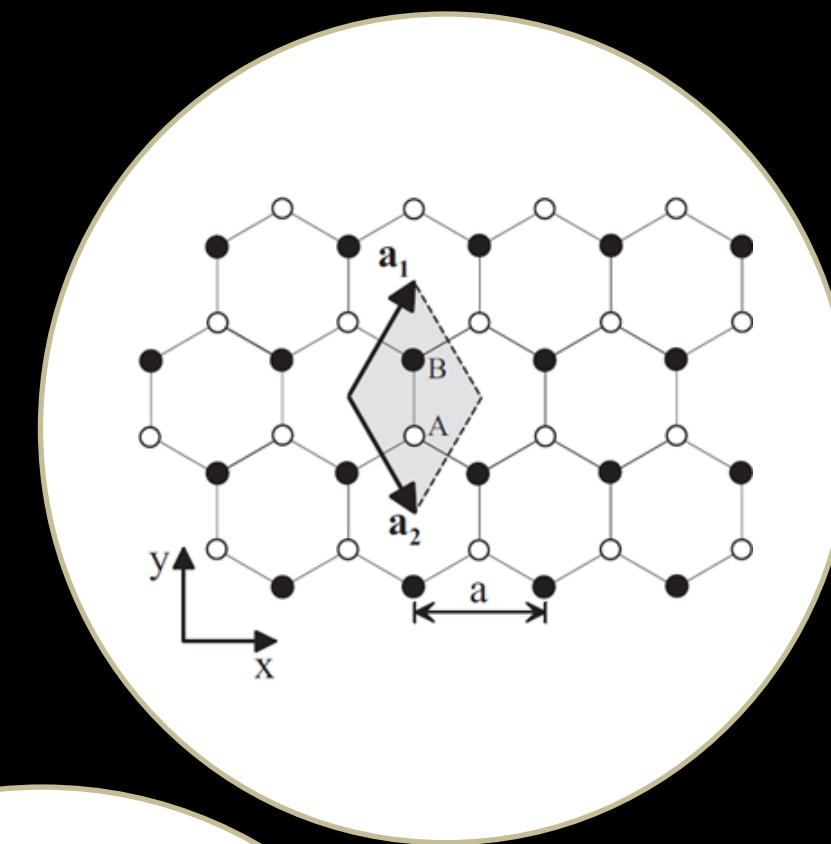
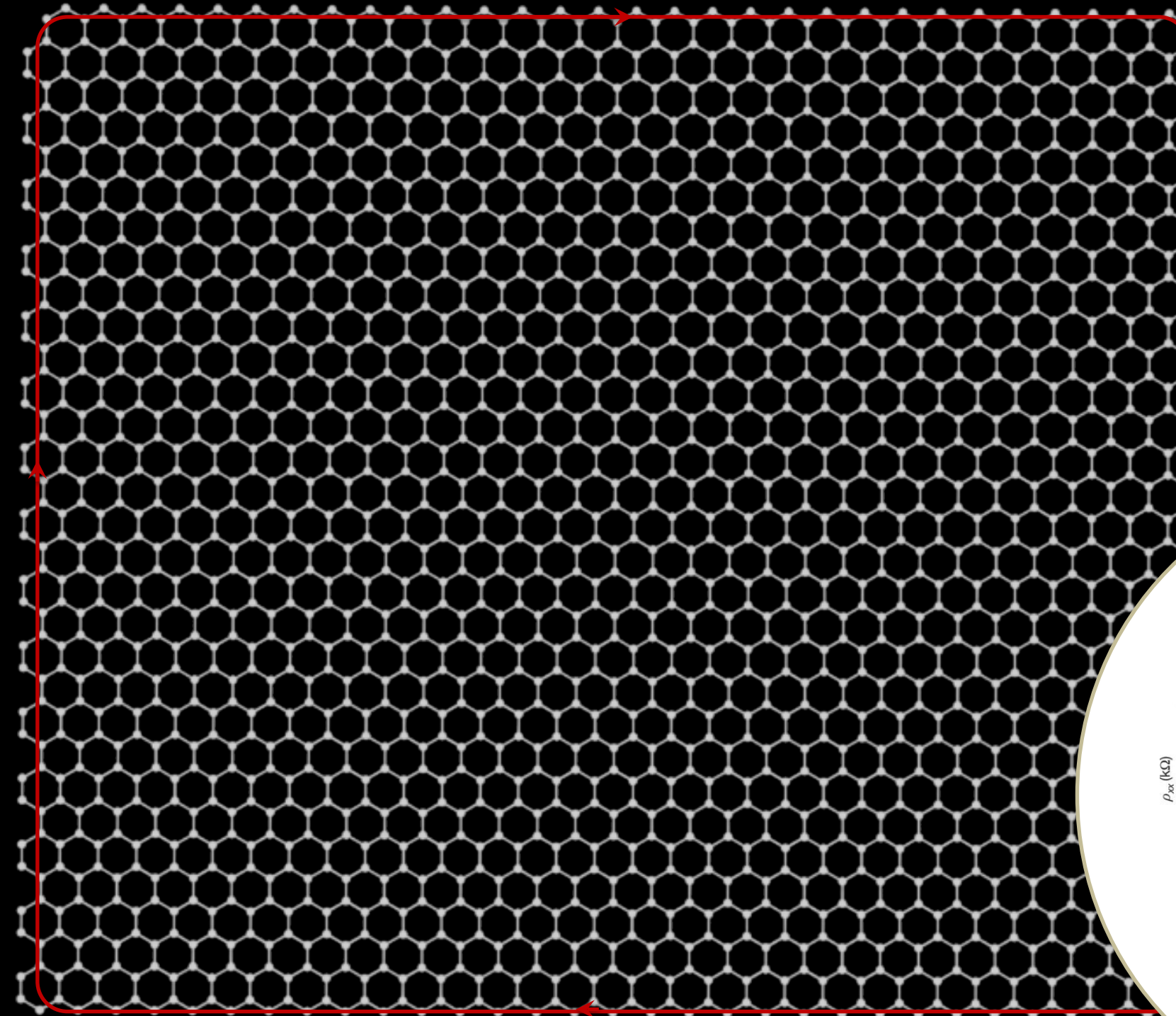
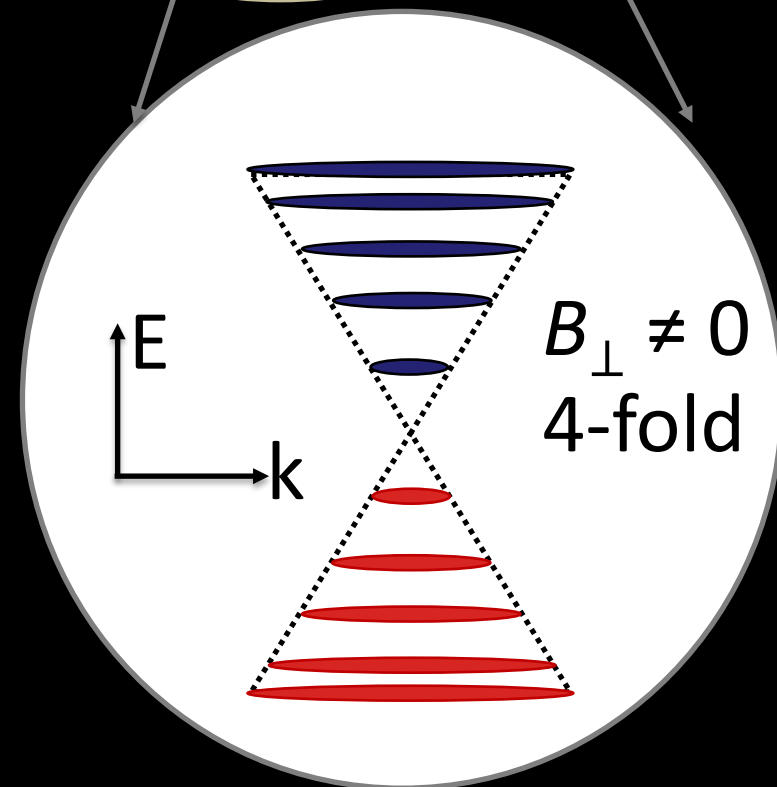
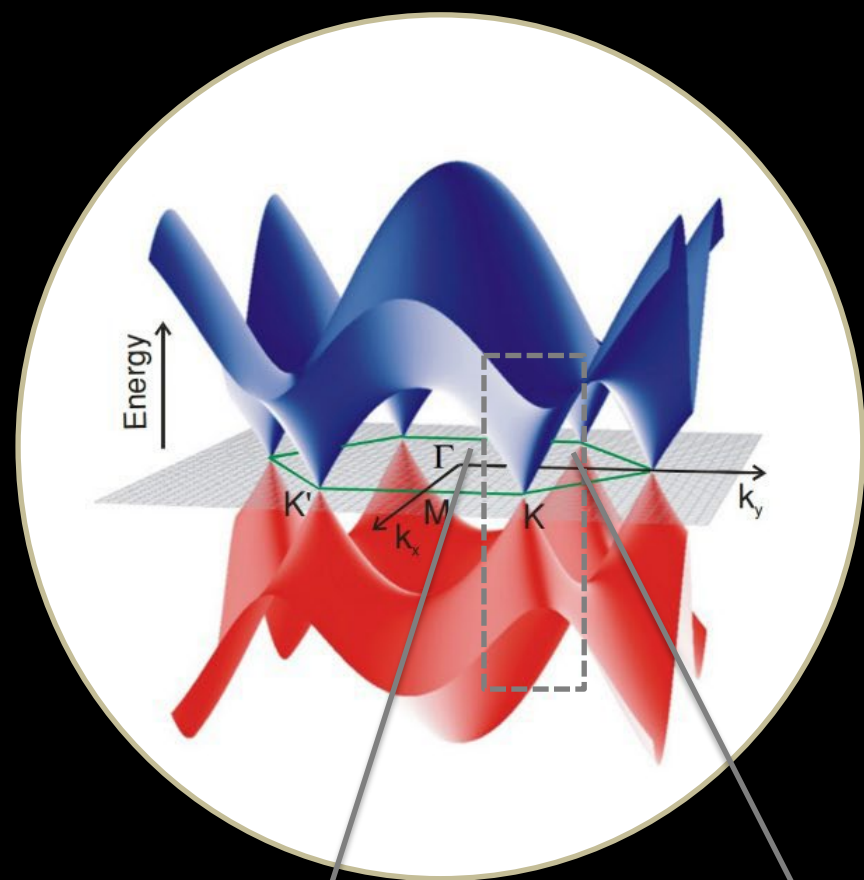
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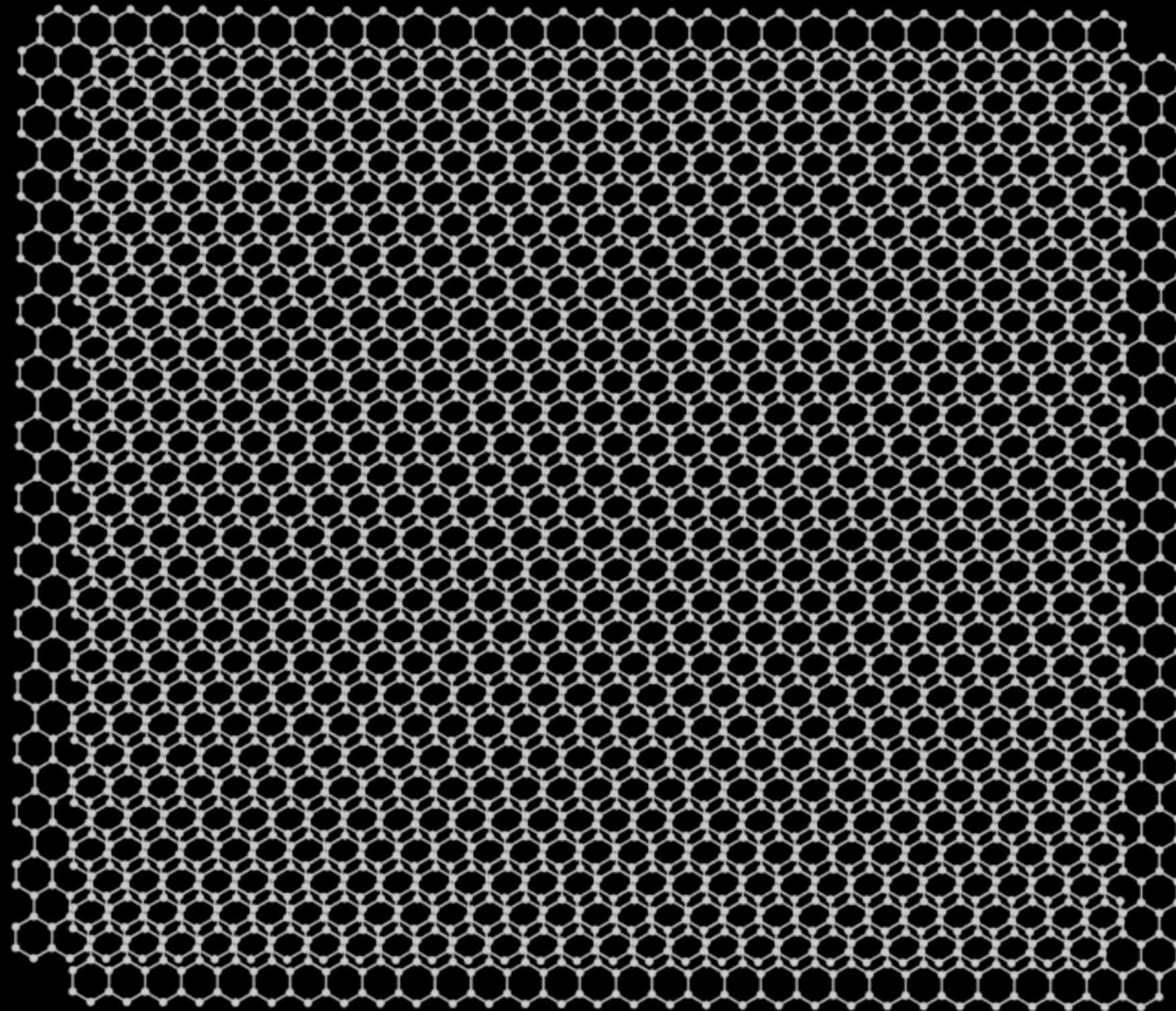
Recoverable symmetry-broken quantum Hall states through reconstructive supermoiré in TBG/*h*-BN heterostructure

Ying Wang
NEM 2026

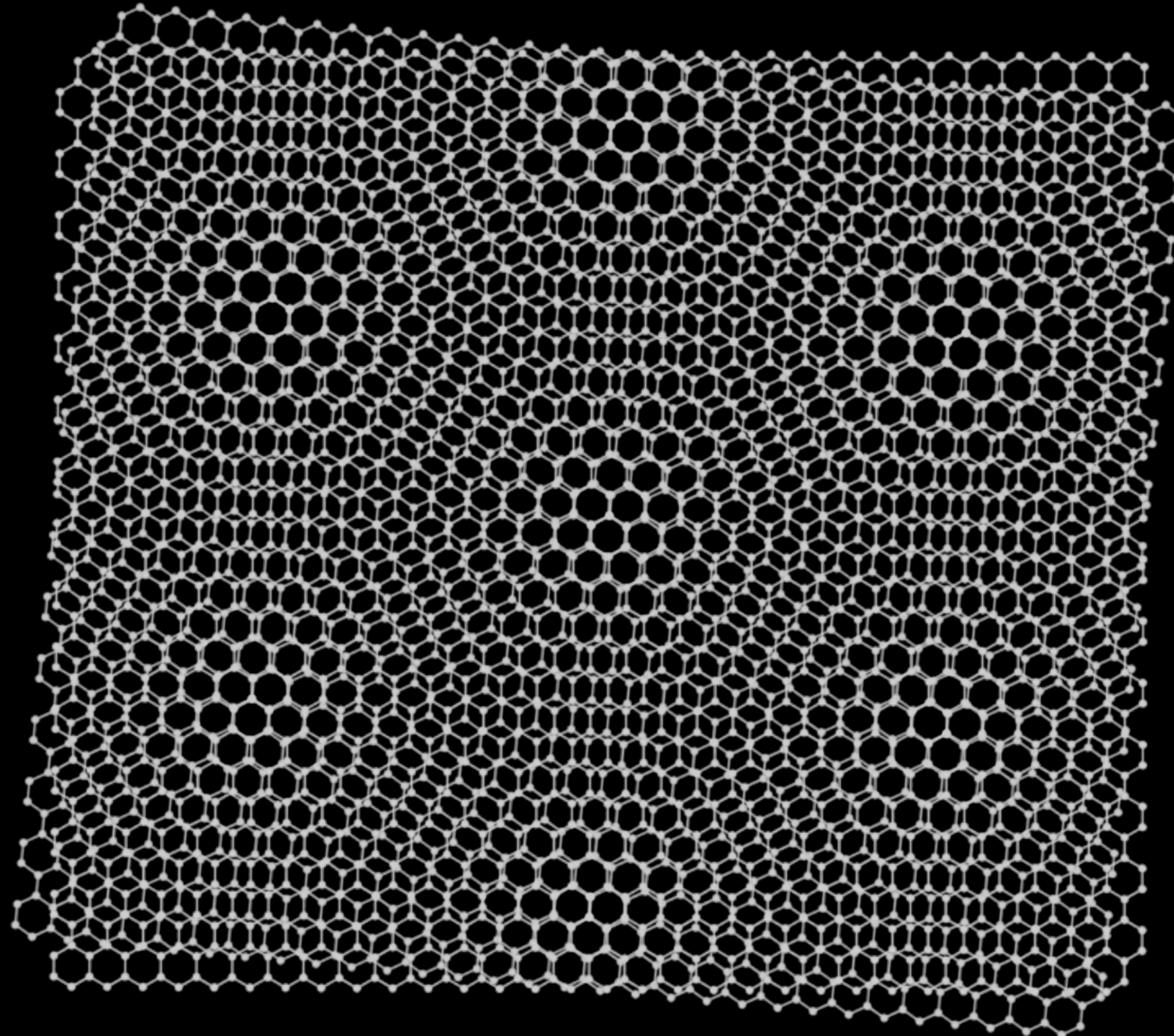
Monolayer graphene



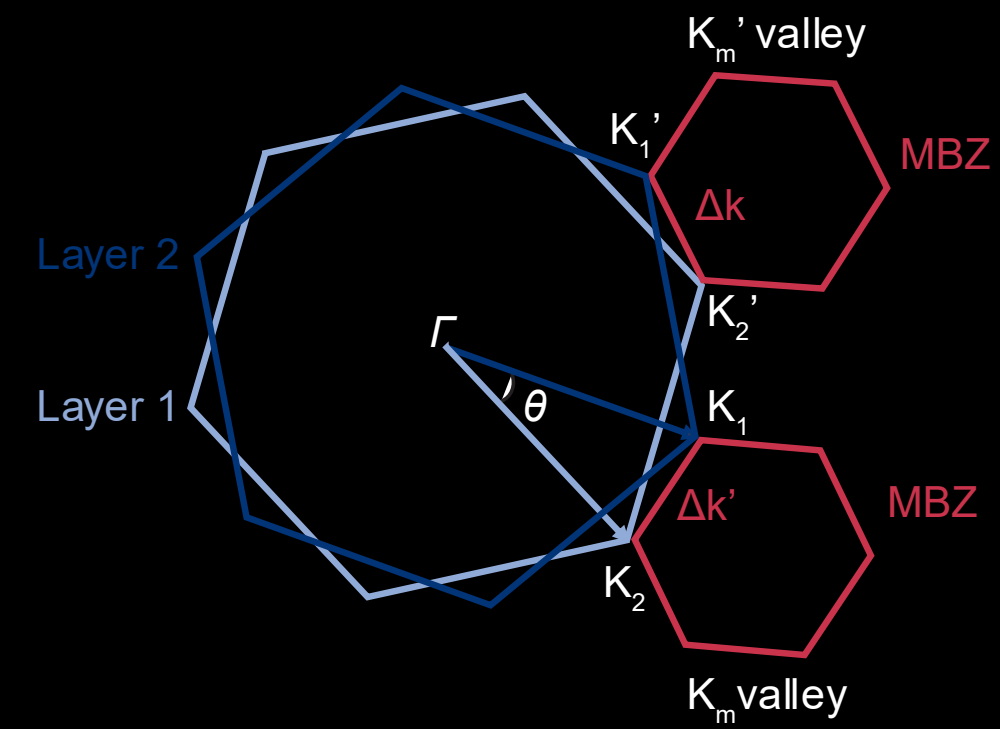
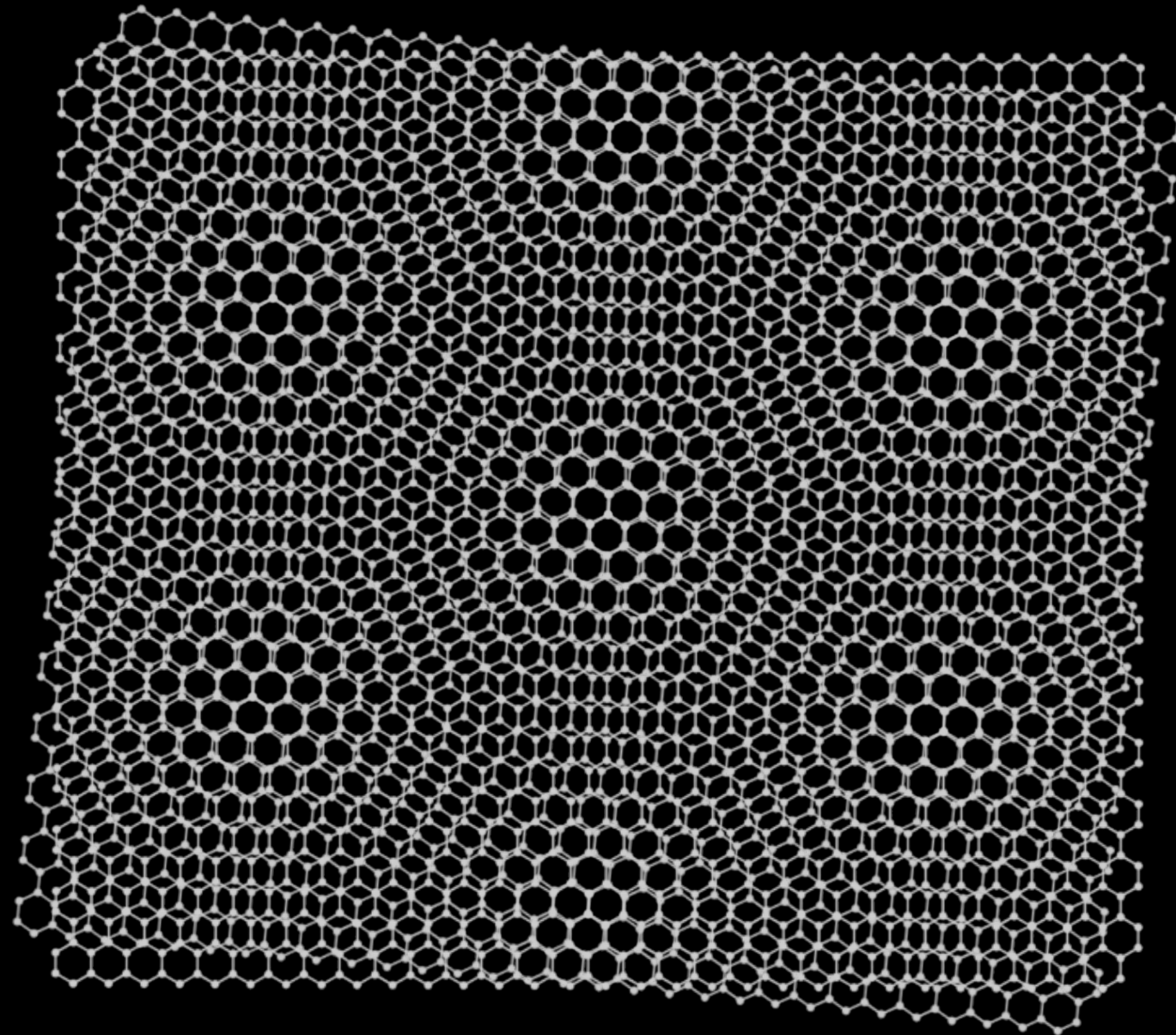
Twisted bilayer graphene



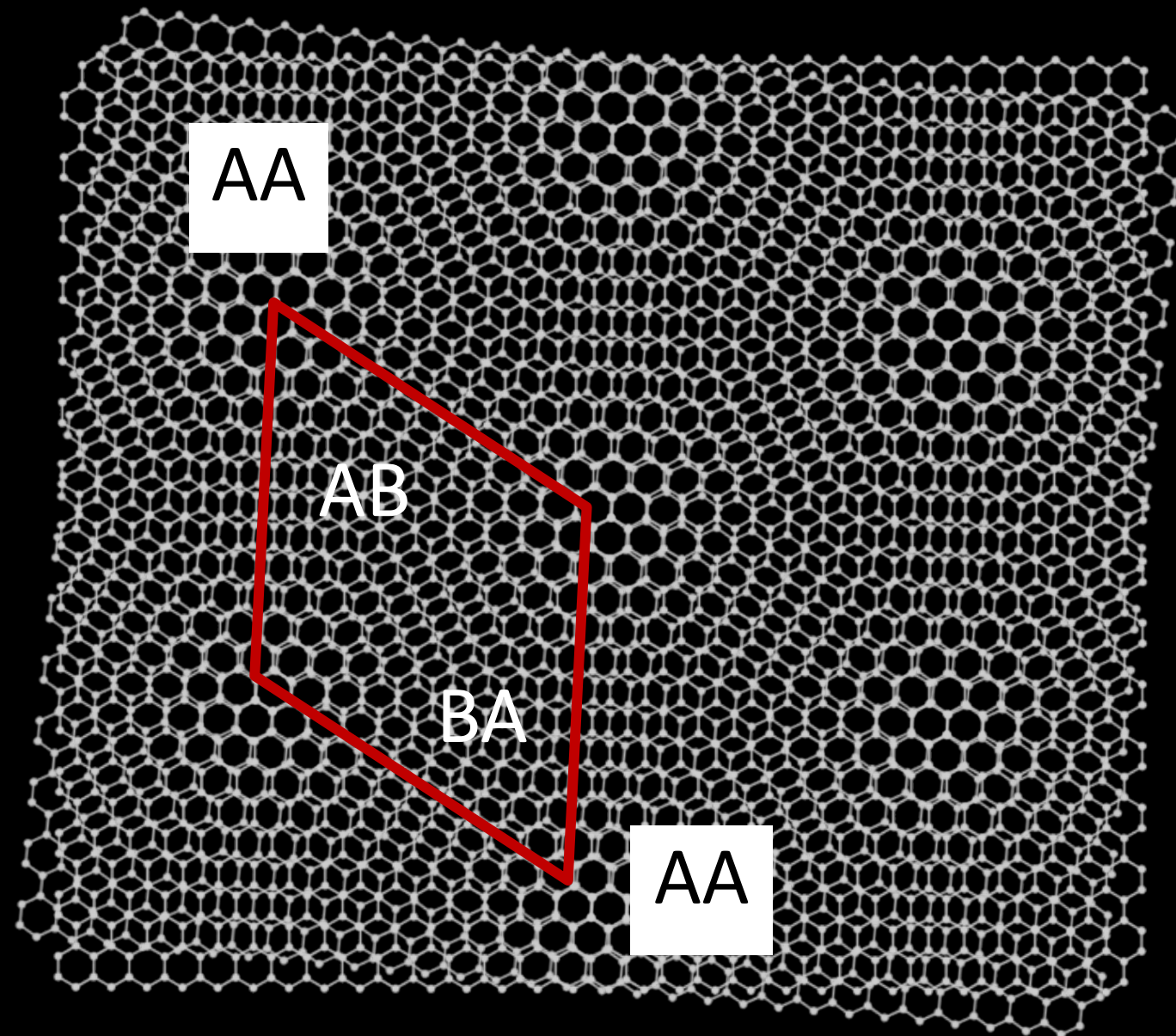
Twisted bilayer graphene



Twisted bilayer graphene

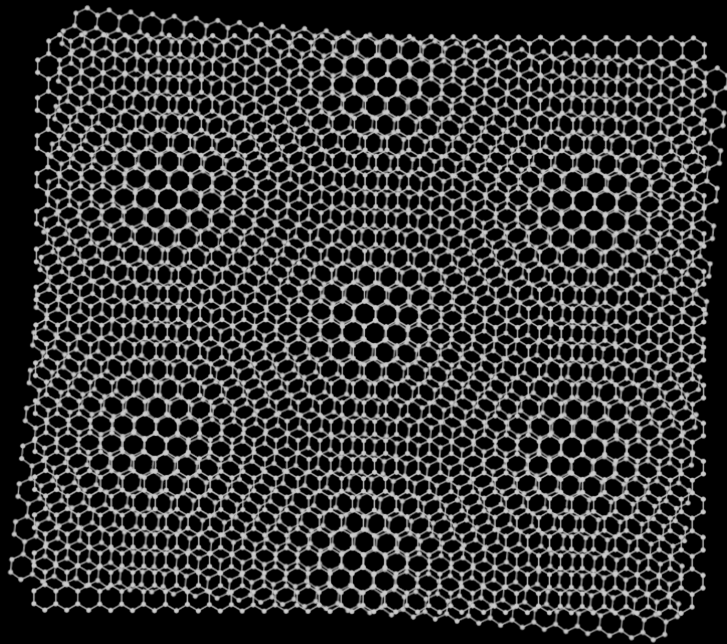


Twisted bilayer graphene

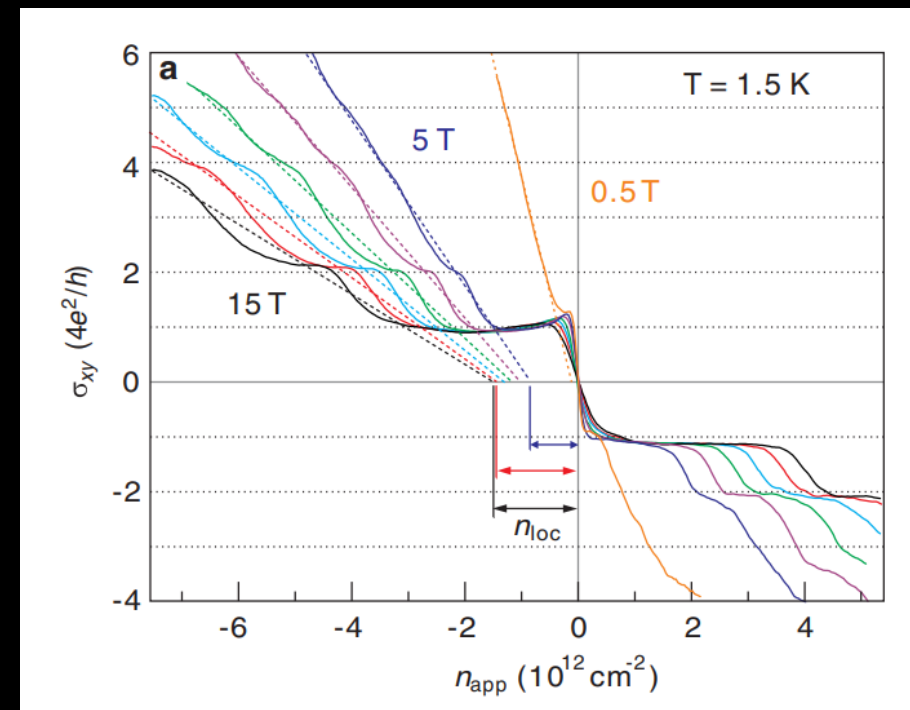
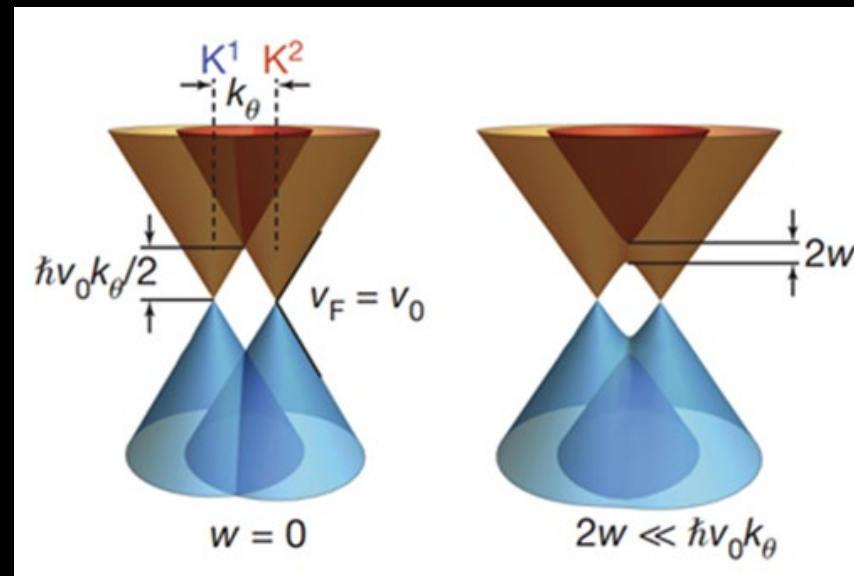


$$\lambda = a / [\sin(\theta/2)]$$

Twisted bilayer graphene



$$\theta > 2^\circ$$

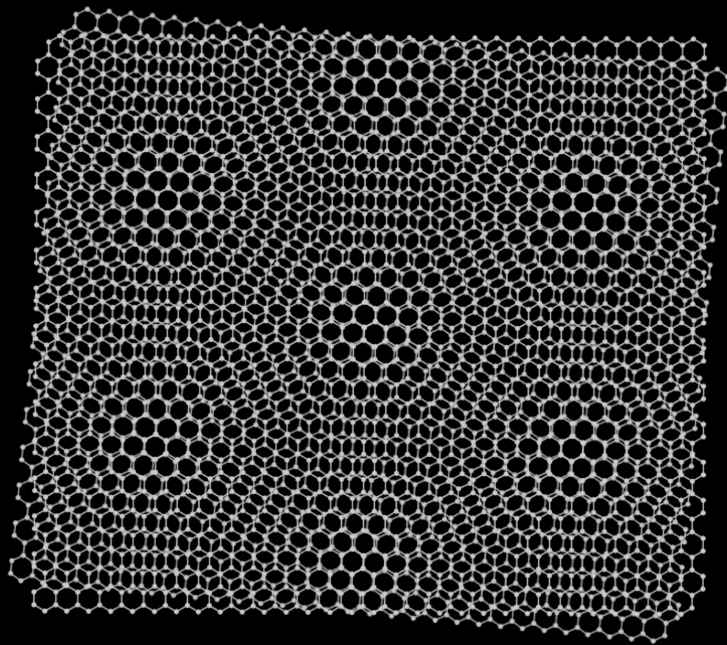


C_{2z} symmetry preserved

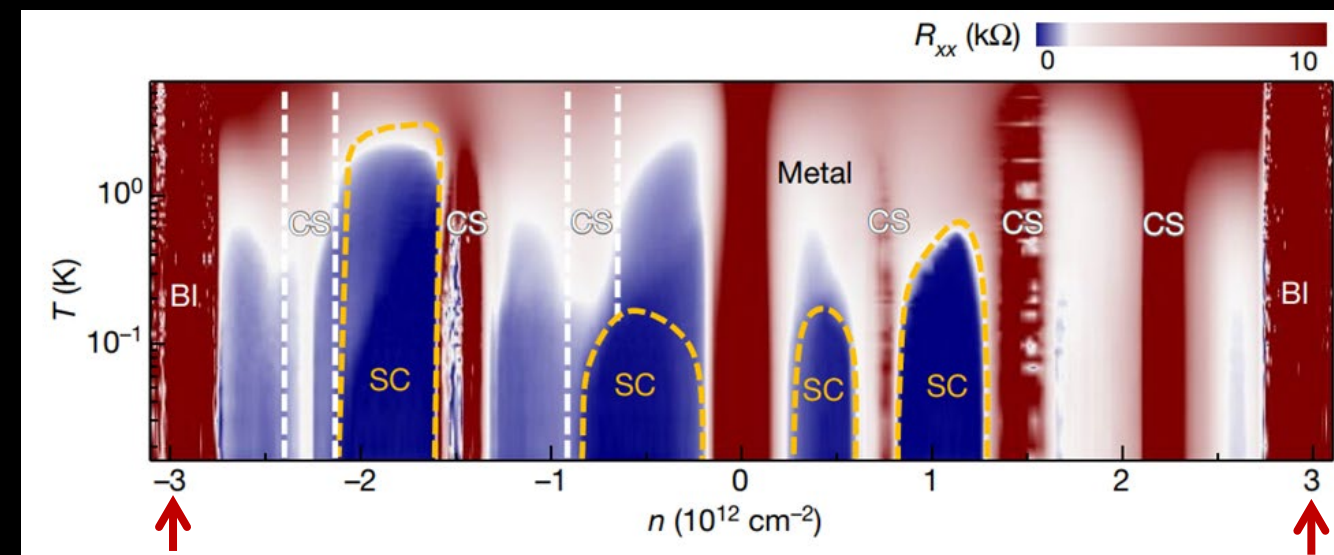
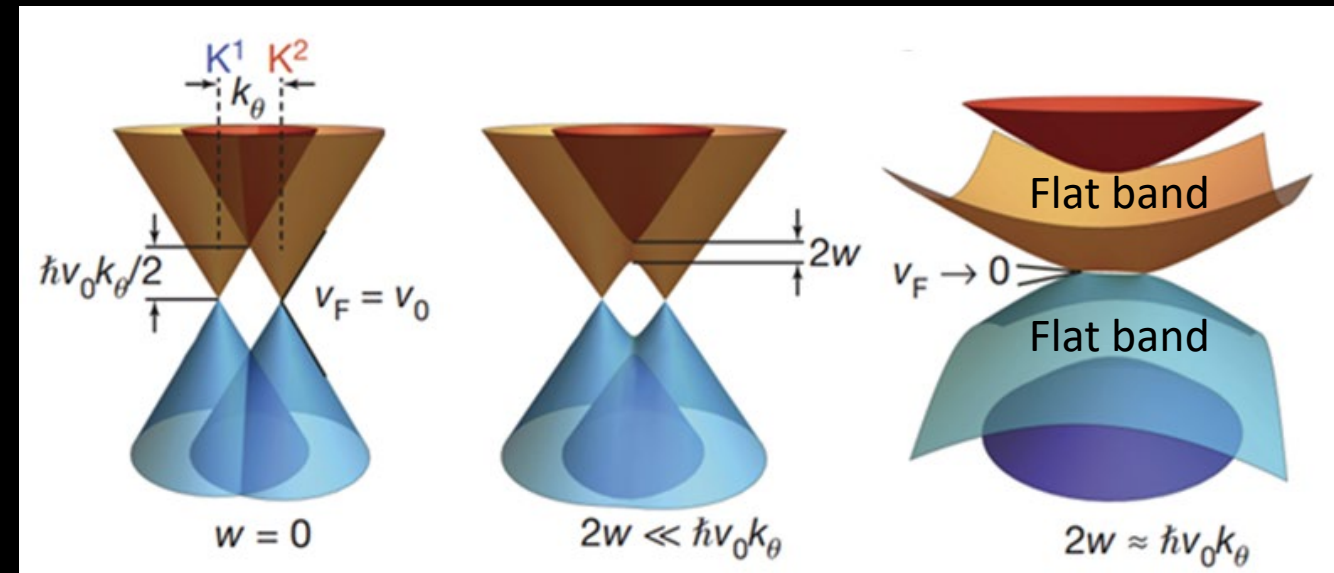
8-fold degeneracy at $n=0$
spin, sublattice, layer

4-fold degeneracy at $n>0$

Twisted bilayer graphene



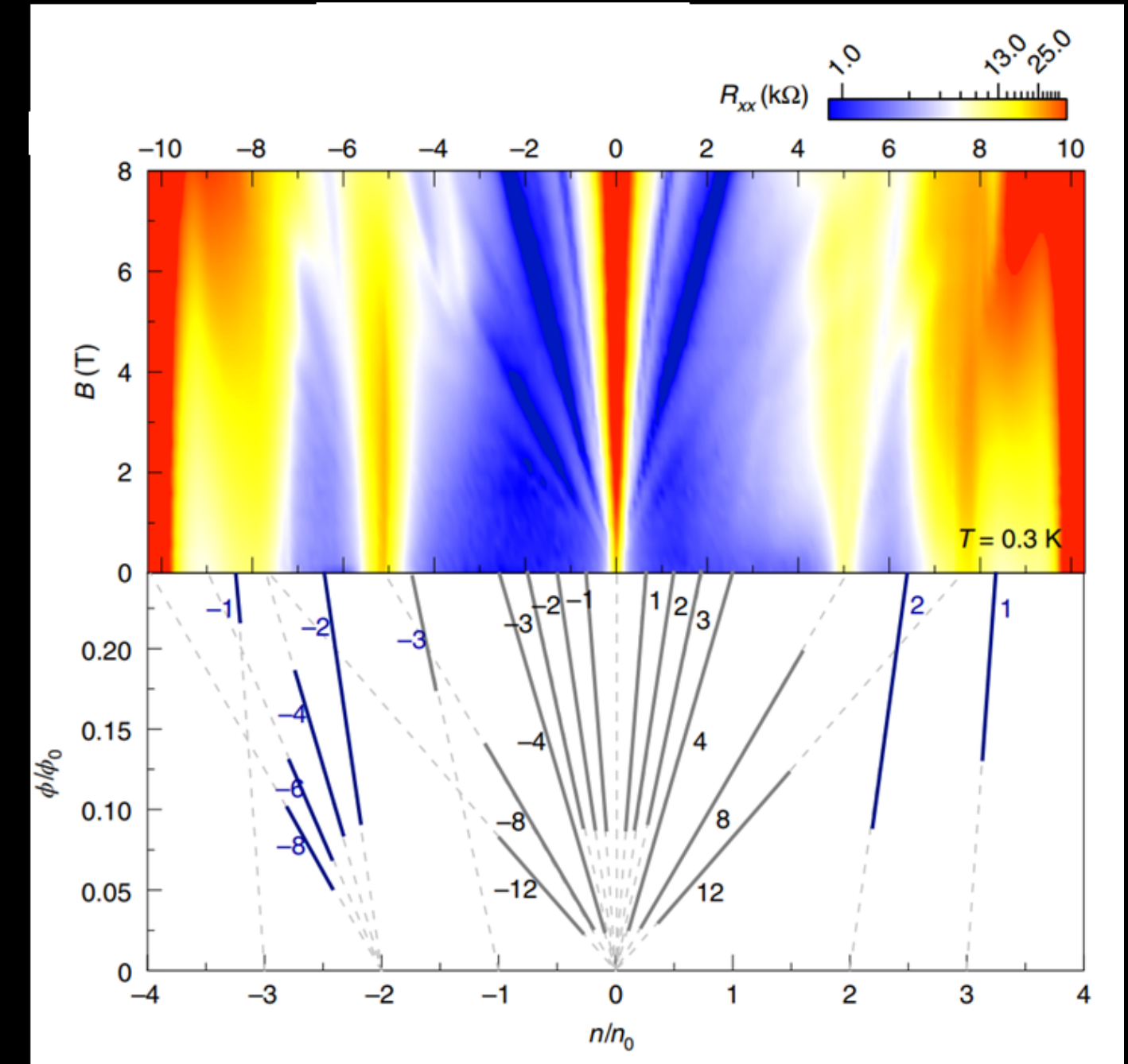
$\theta \approx 1^\circ$
“Magic angle”



Band insulator

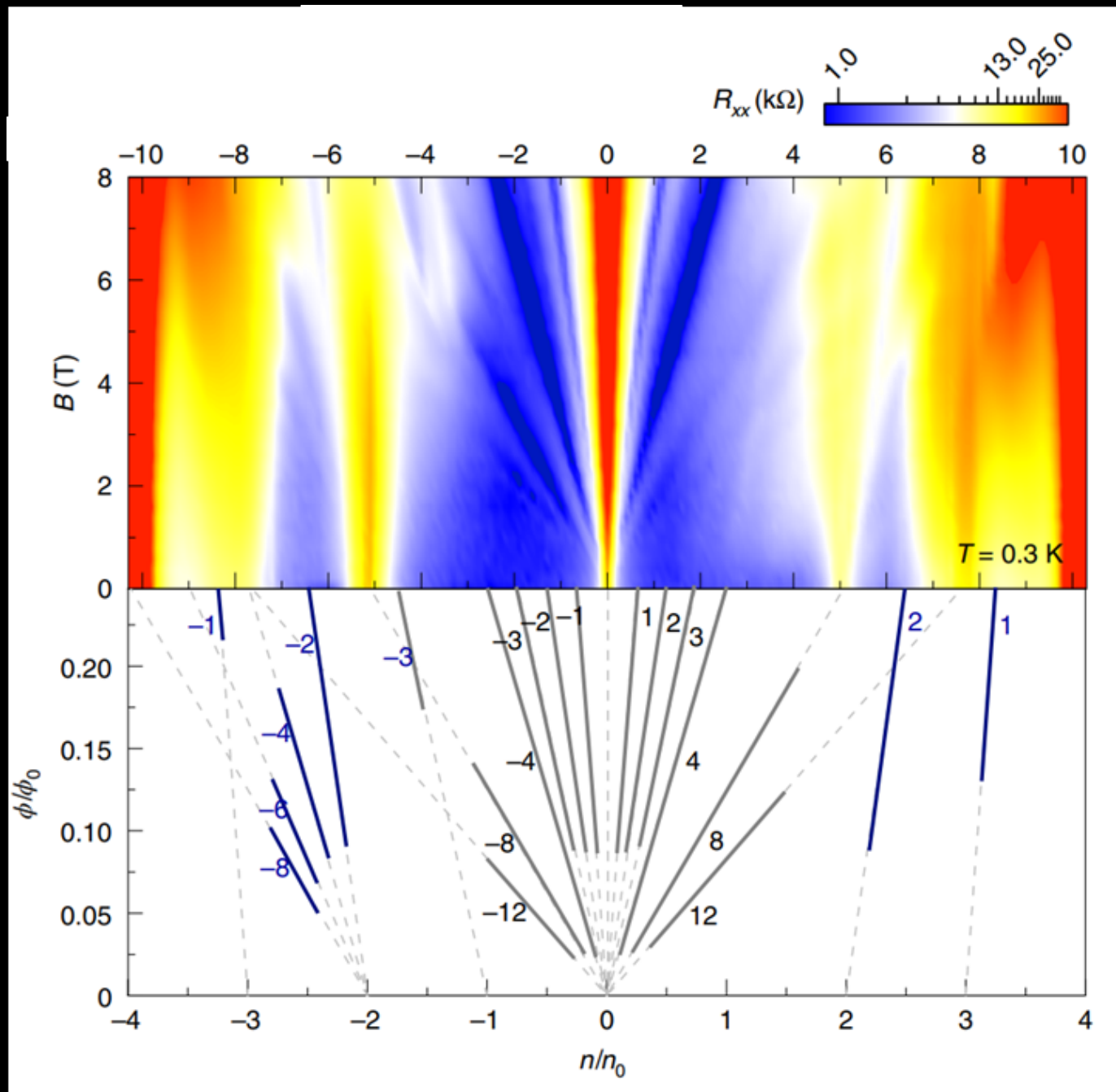
CNP

Band insulator

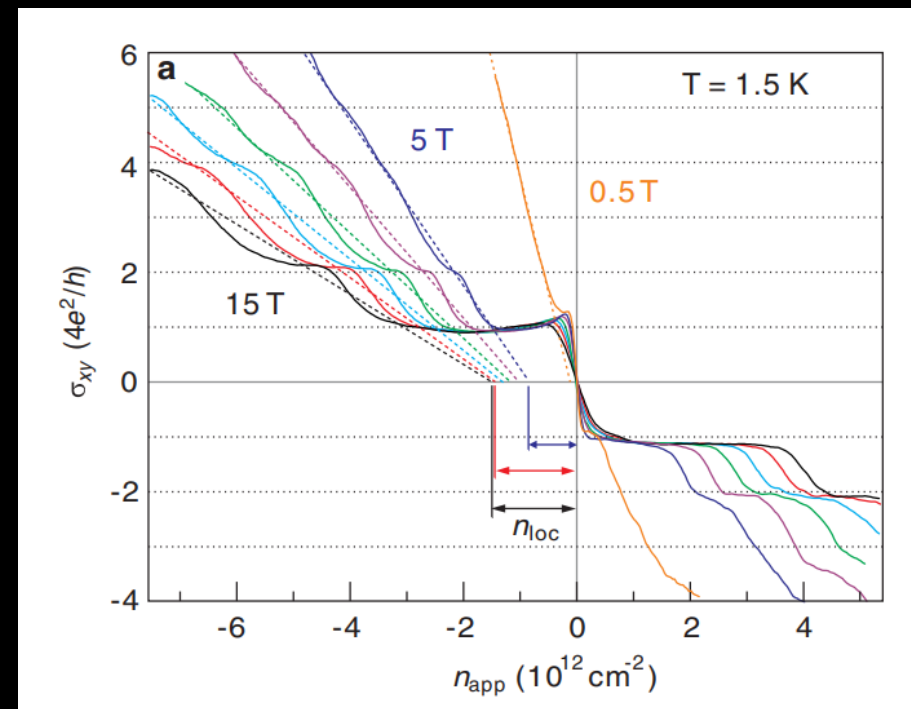


$B \neq 0$

Twisted bilayer graphene



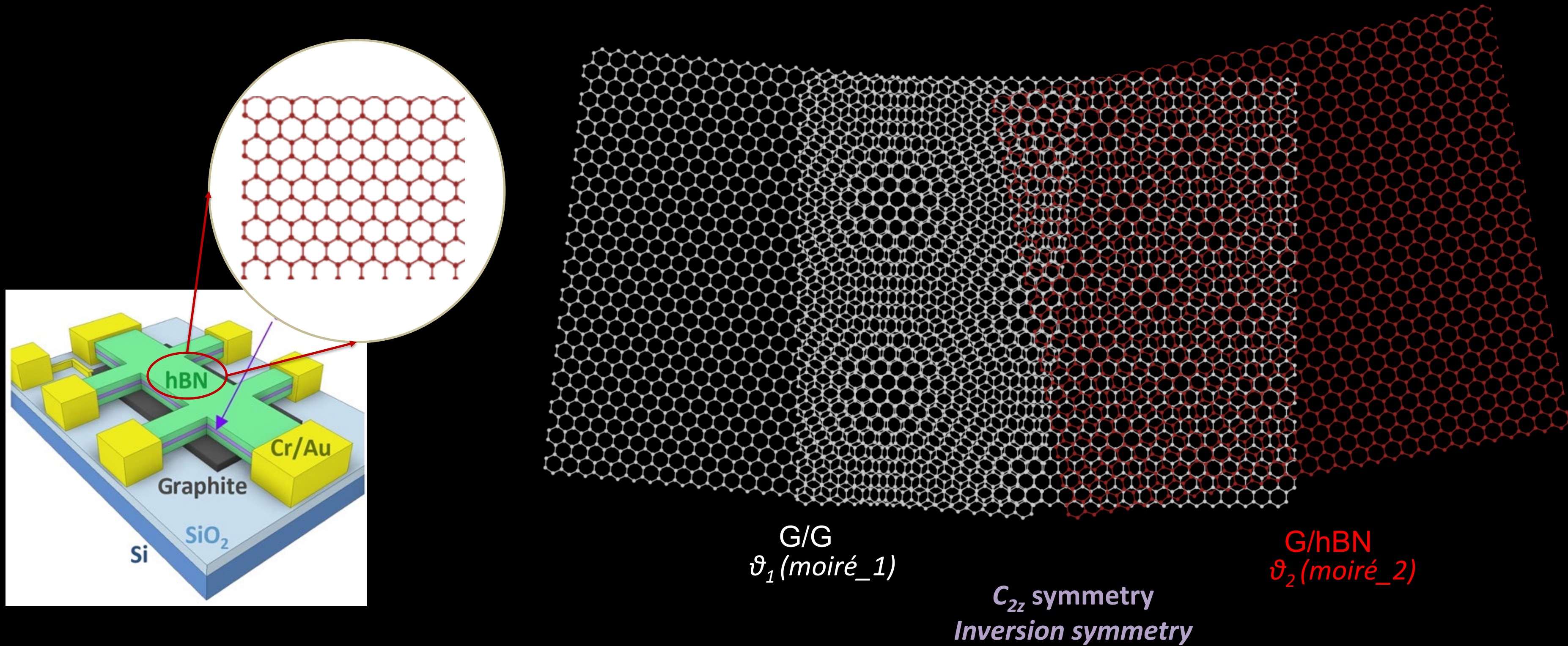
$$\theta \approx 1^\circ$$



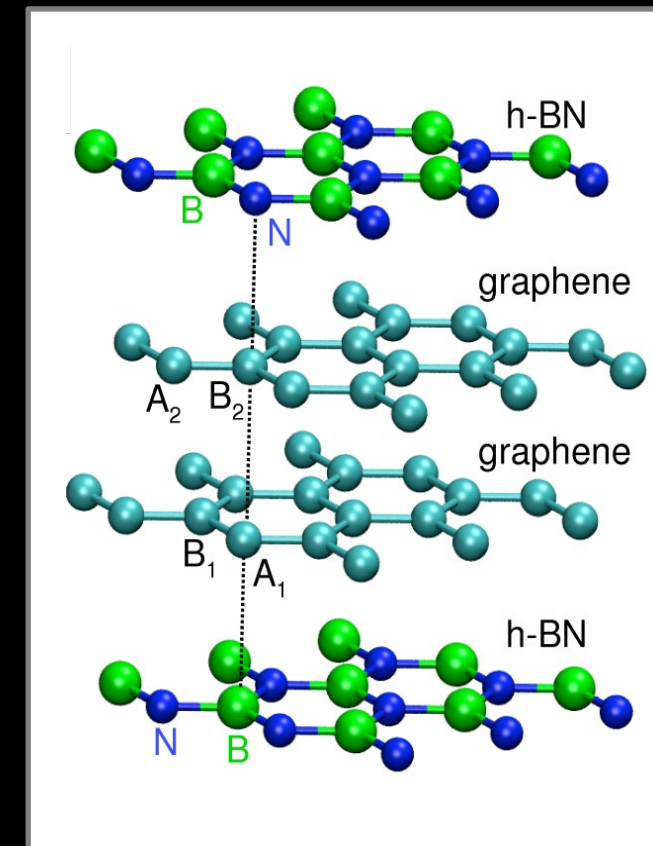
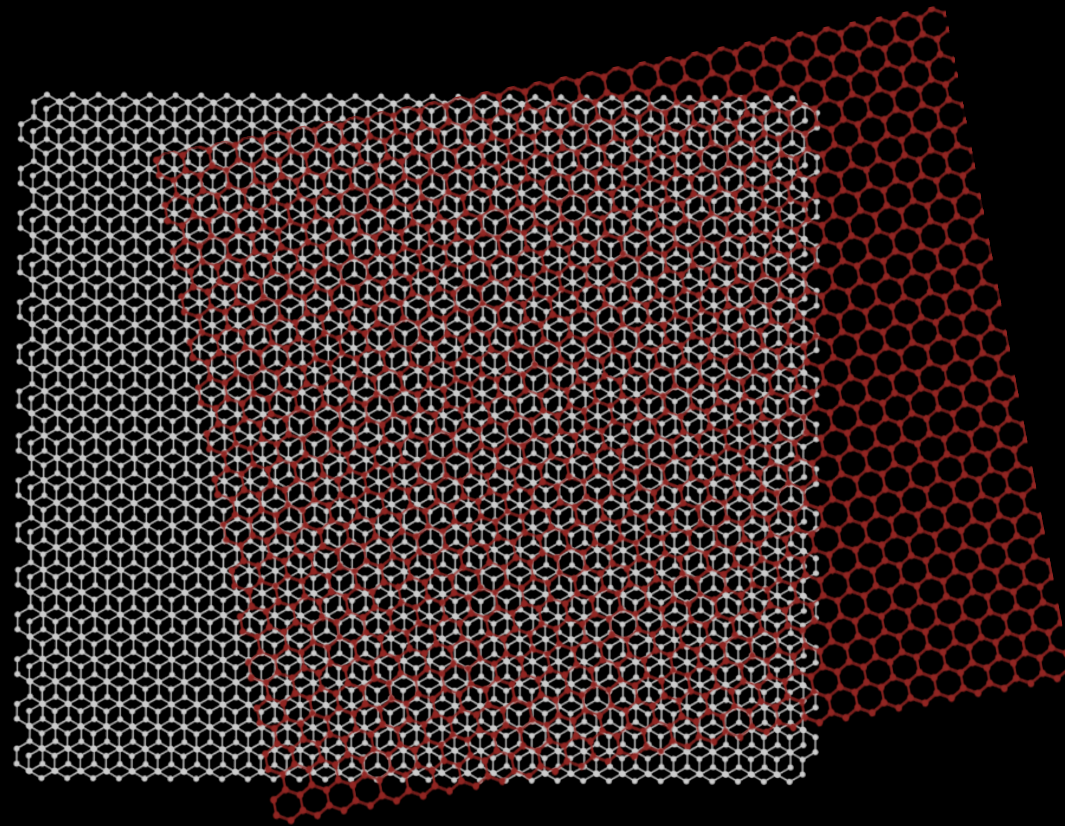
$$\theta > 2^\circ$$

degeneracy $\leftrightarrow$ symmetry

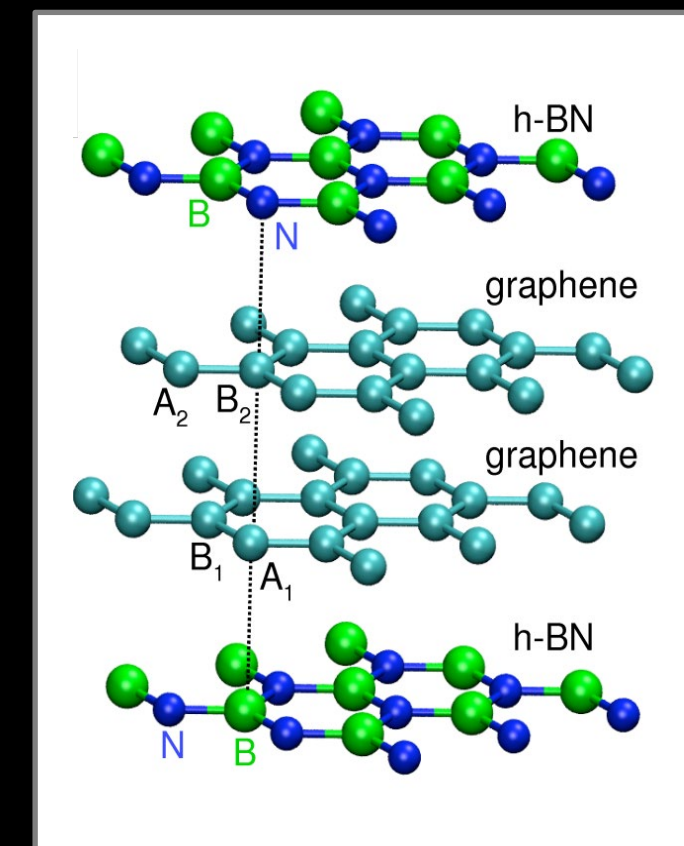
Twisted bilayer graphene/ hBN



Bernal stacking bilayer graphene

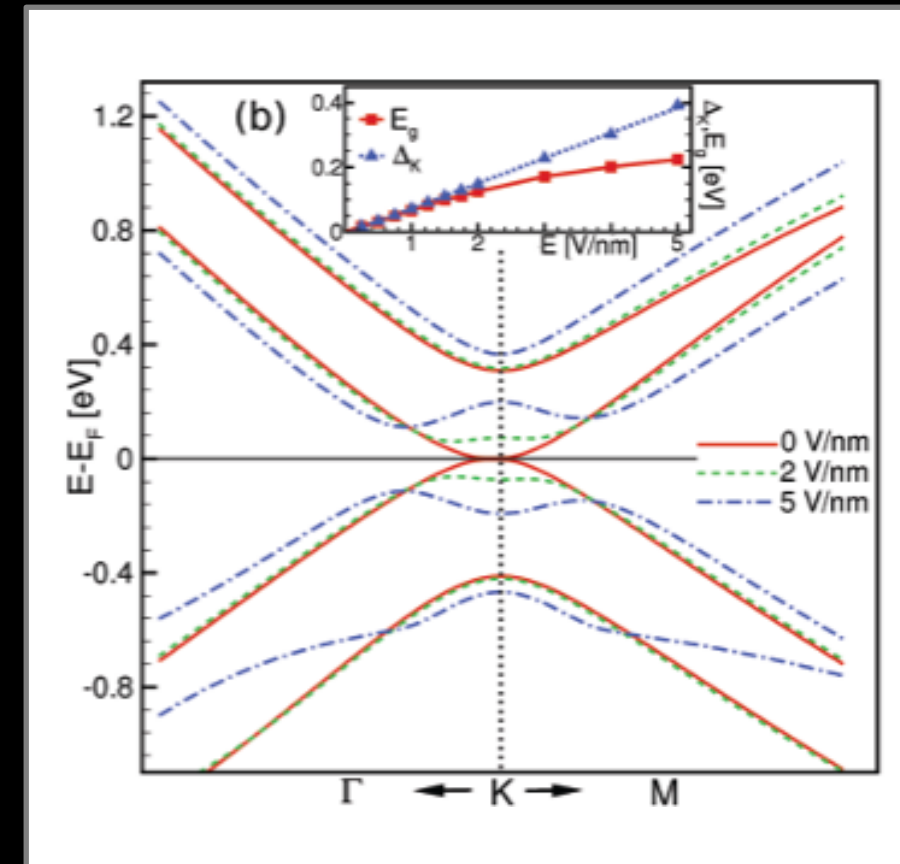
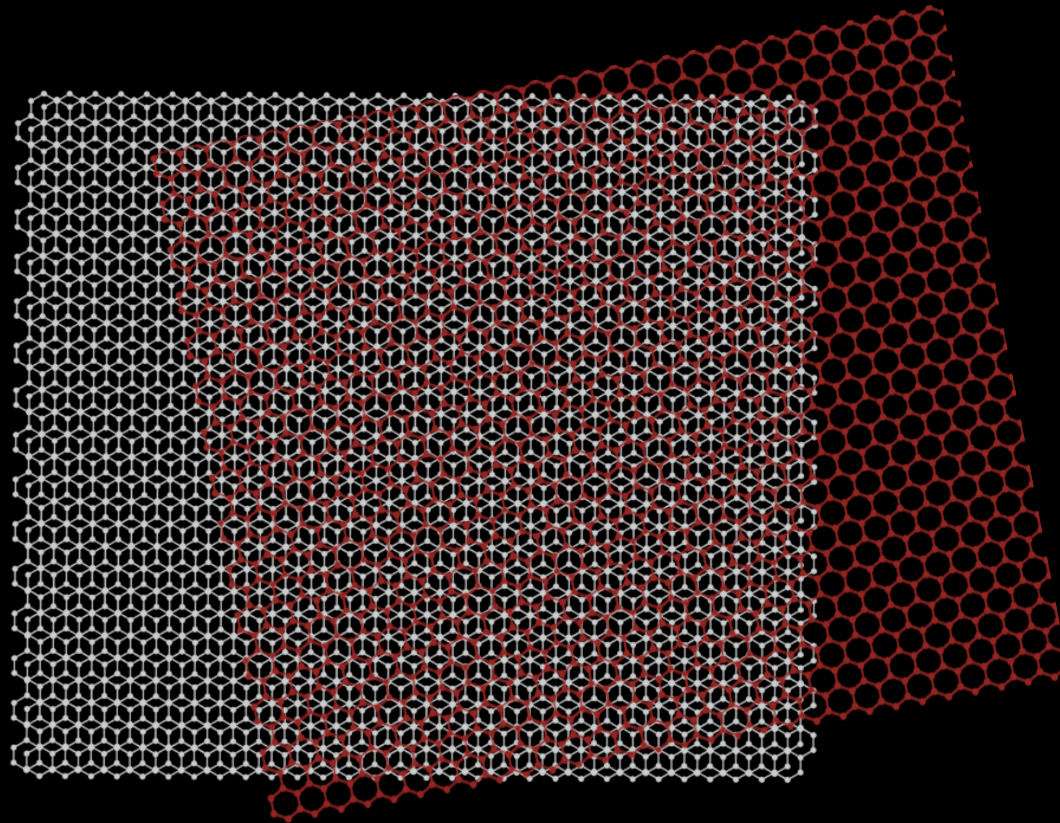


B-C-C-B
N-C-C-N

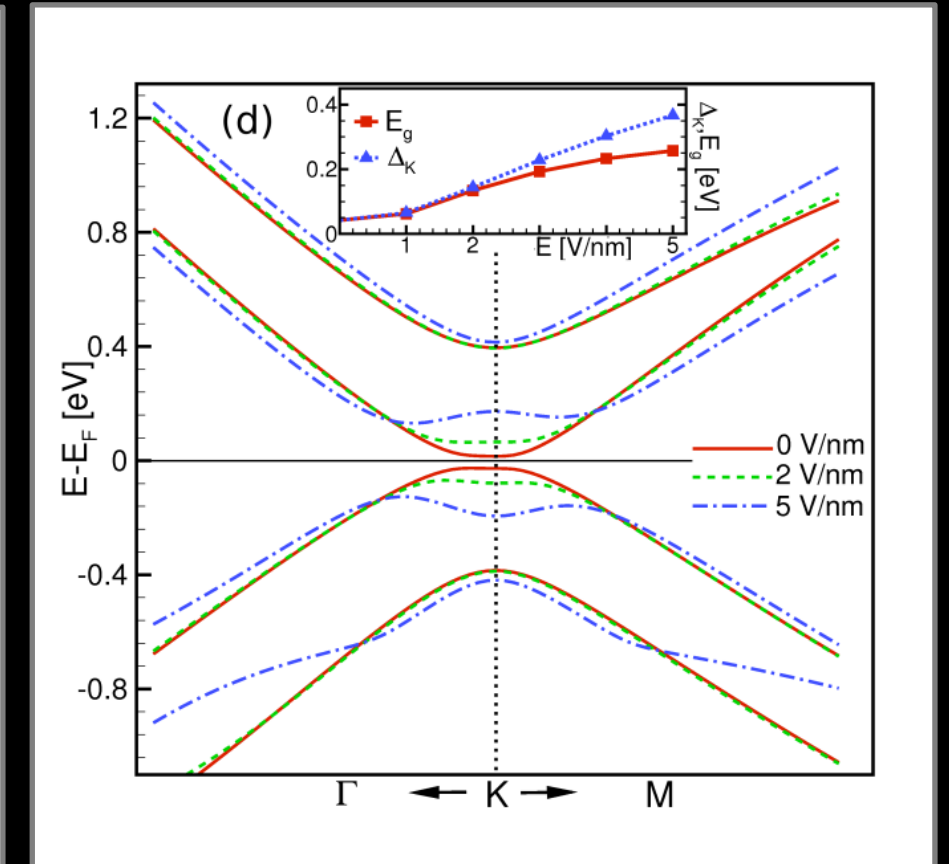


N-C-C-B
Breaking inversion symmetry

Bernal stacking bilayer graphene



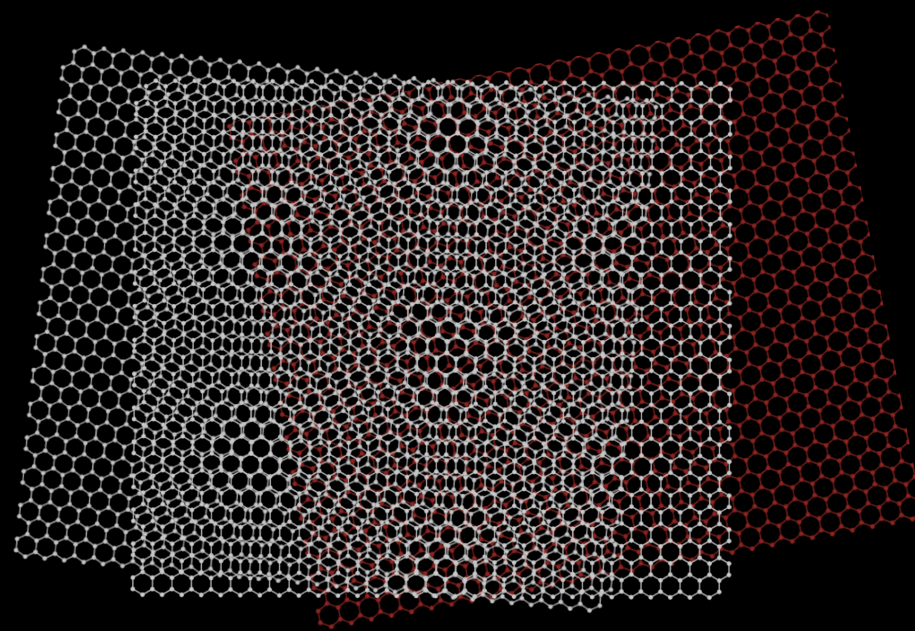
B-C-C-B
N-C-C-N



N-C-C-B
Breaking inversion symmetry

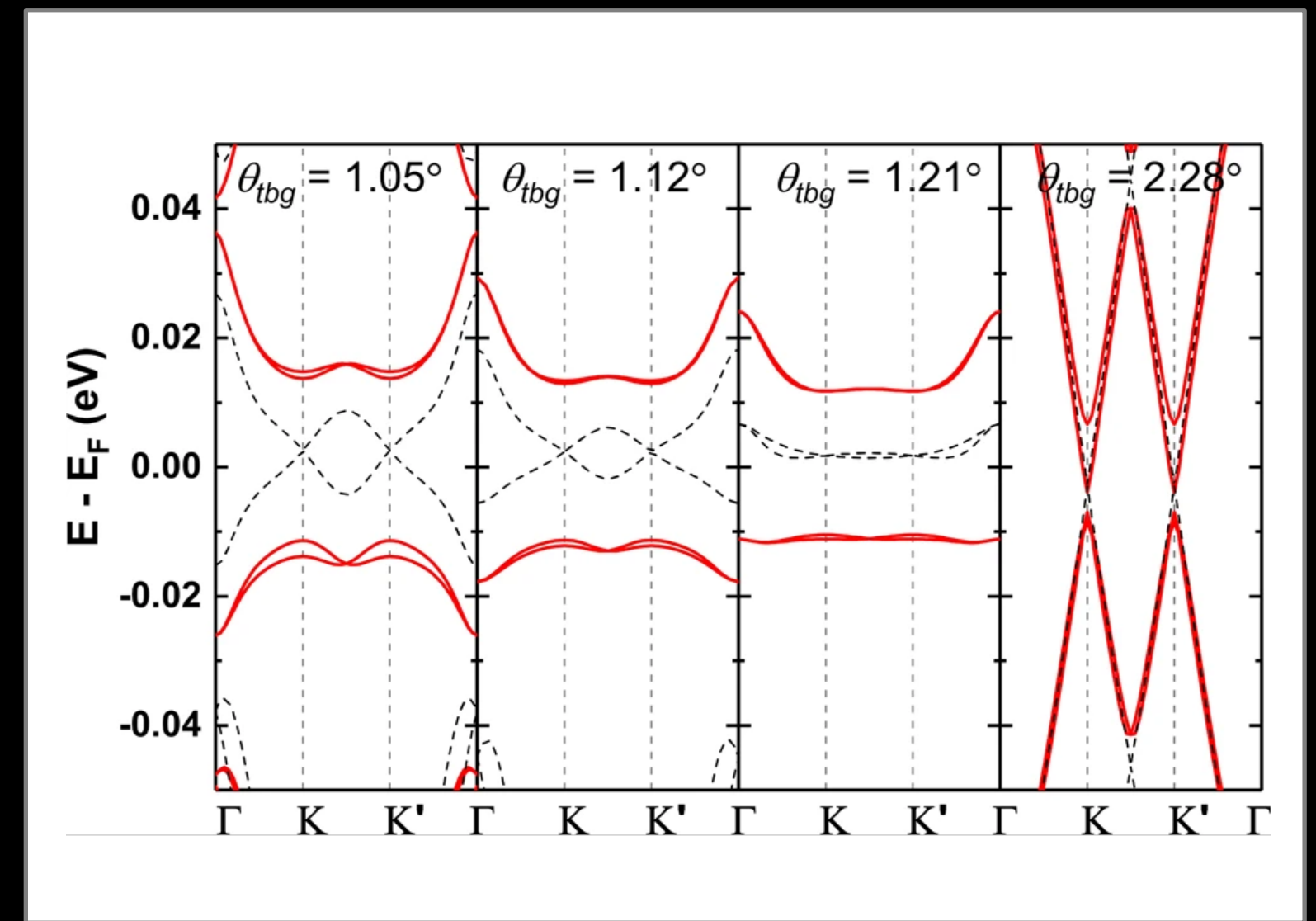
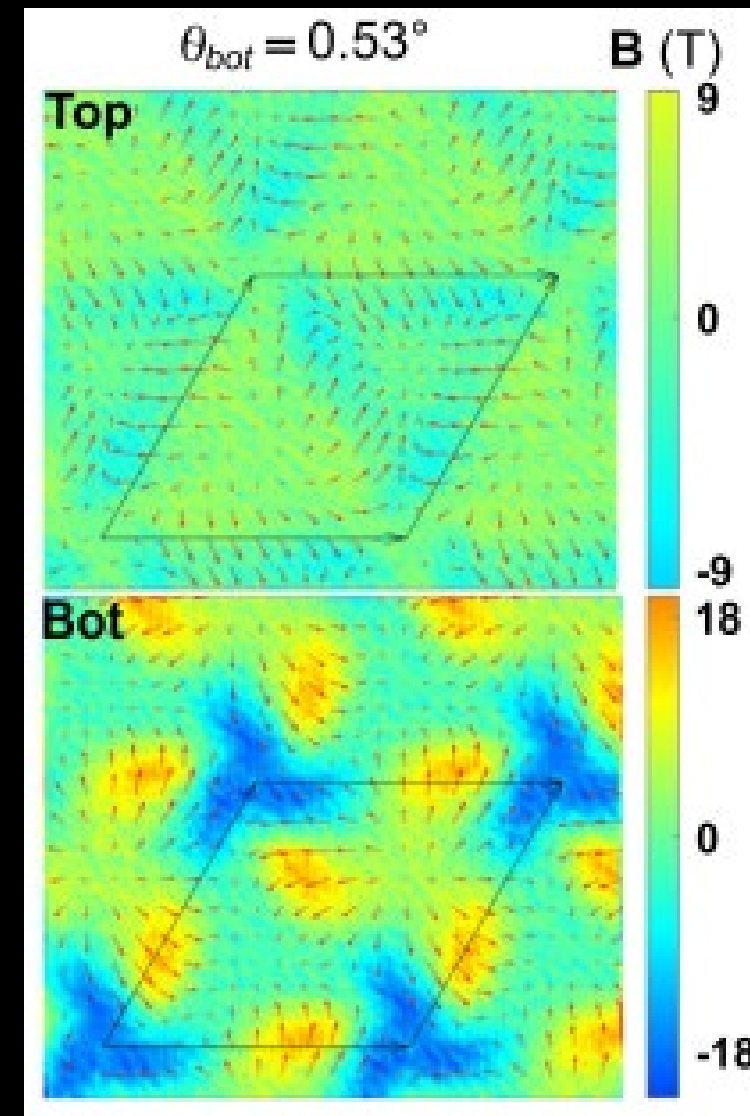
Twisted bilayer graphene/ hBN

TBG/ hBN

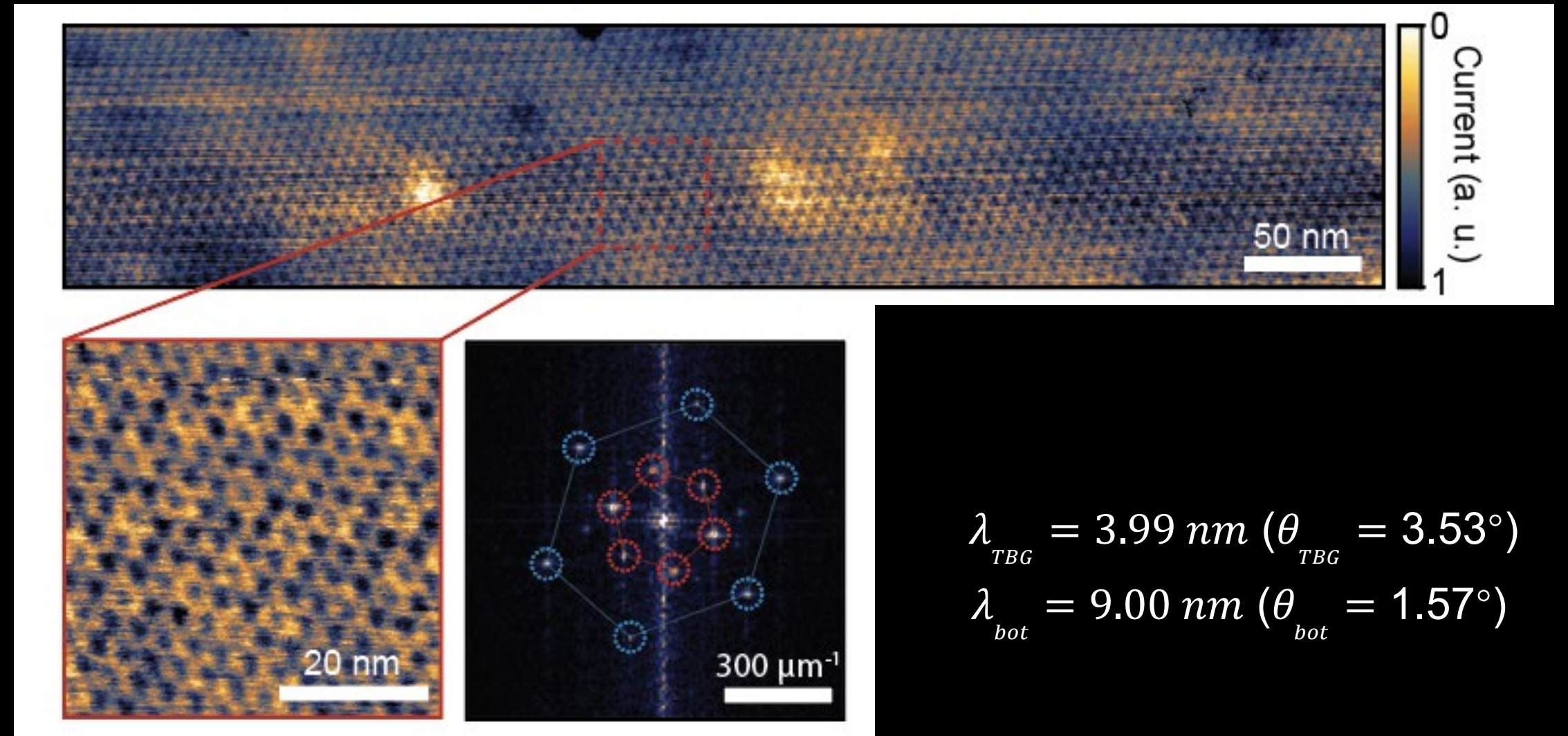
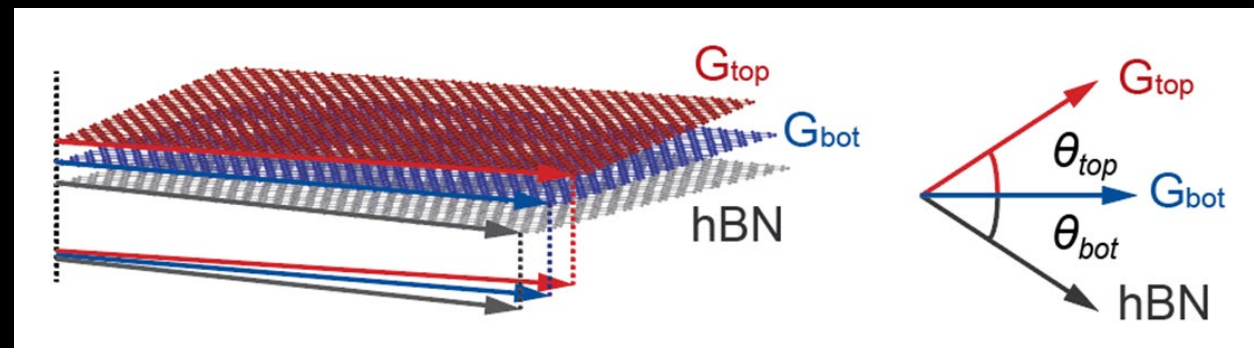
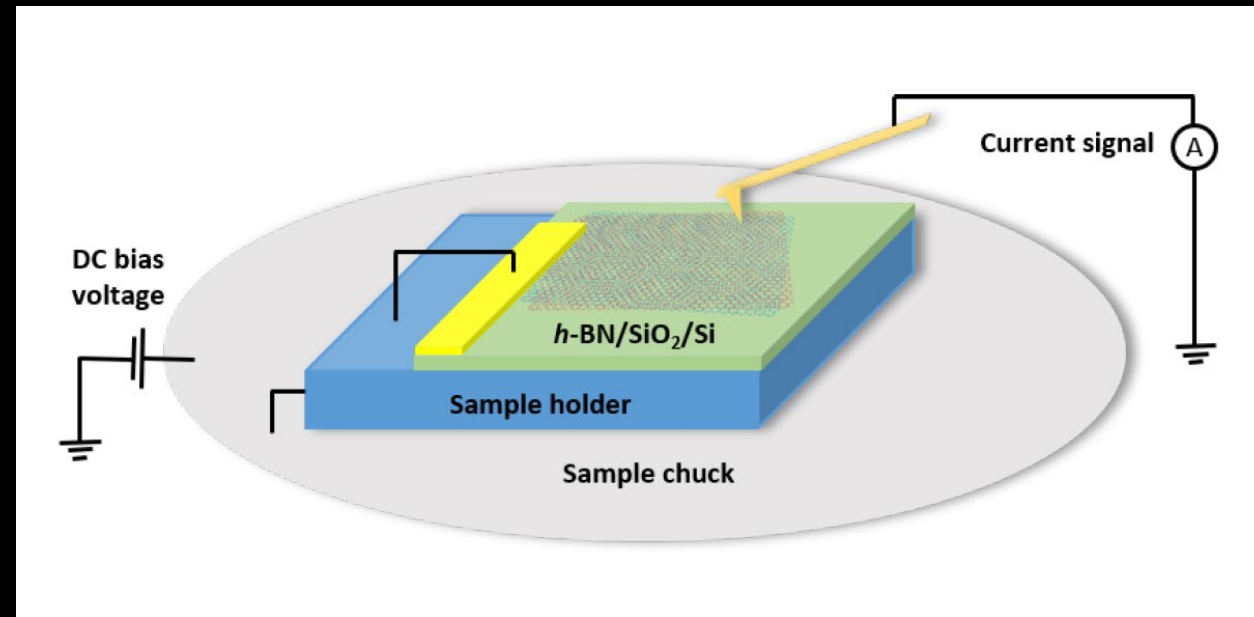


ϑ_1 (moiré_1)

ϑ_2 (moiré_2)



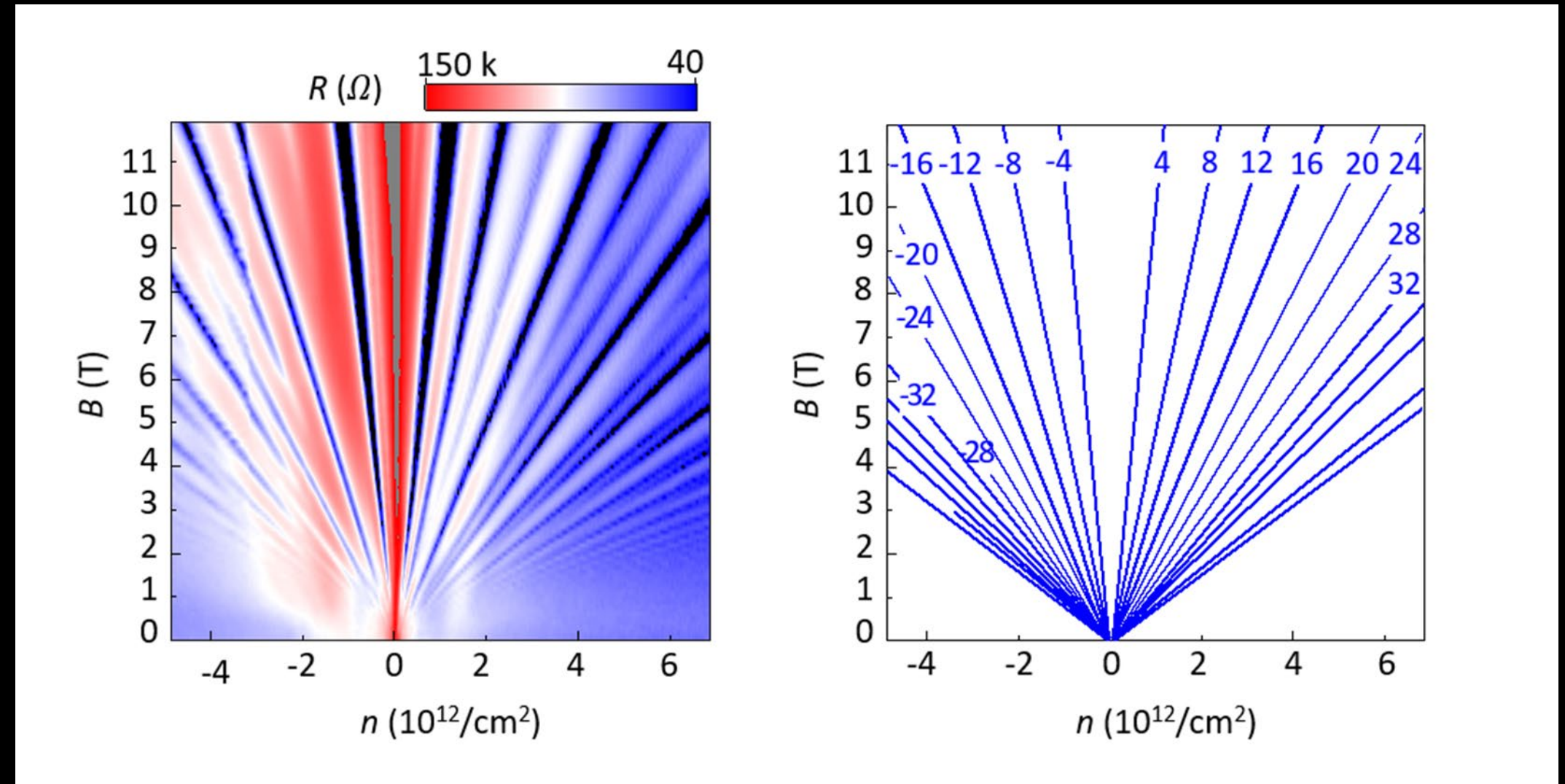
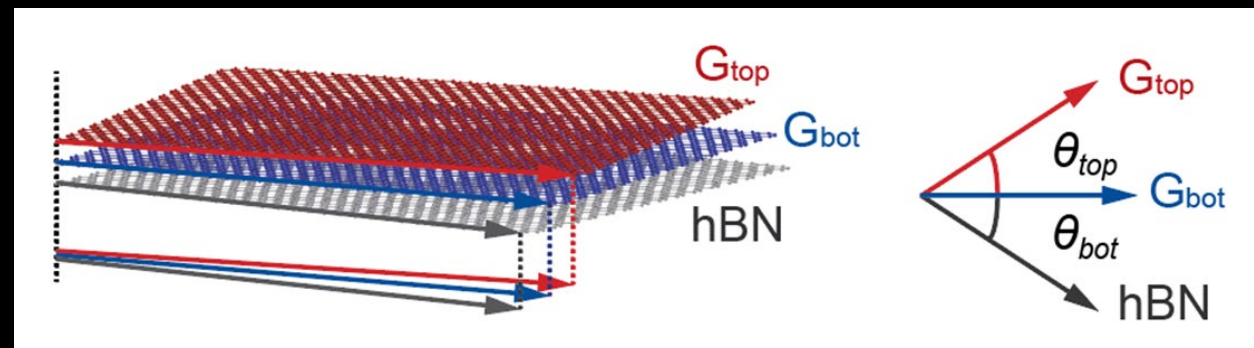
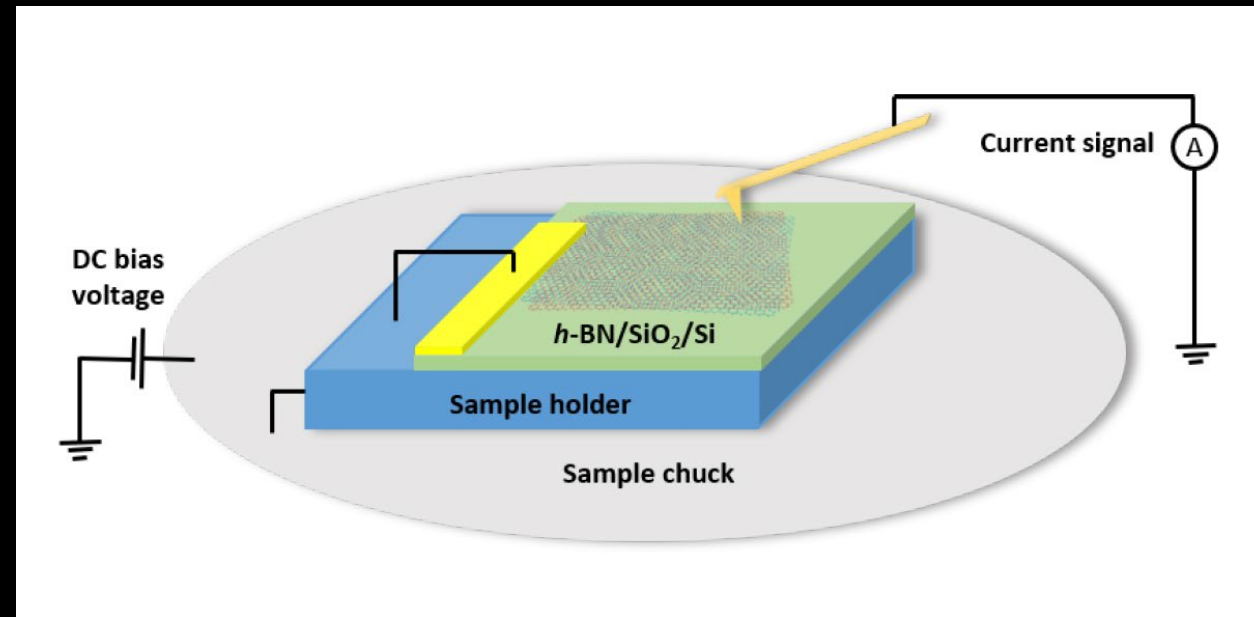
Twisted bilayer graphene/ hBN



$$\lambda_{TBG} = 3.99 \text{ nm} (\theta_{TBG} = 3.53^\circ)$$

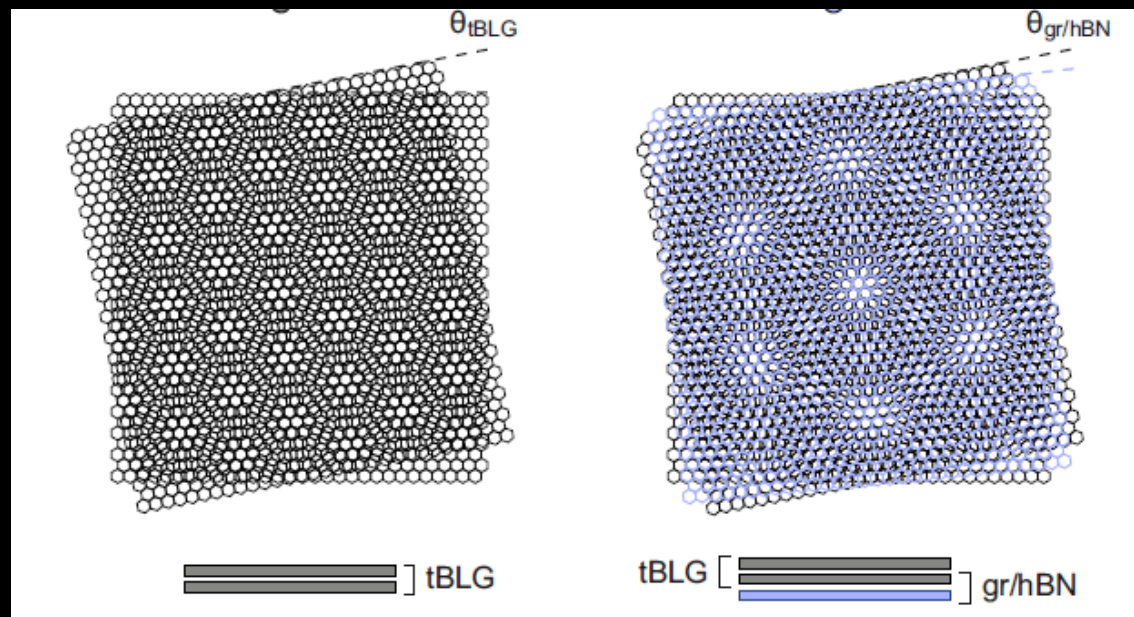
$$\lambda_{bot} = 9.00 \text{ nm} (\theta_{bot} = 1.57^\circ)$$

Twisted bilayer graphene/ hBN

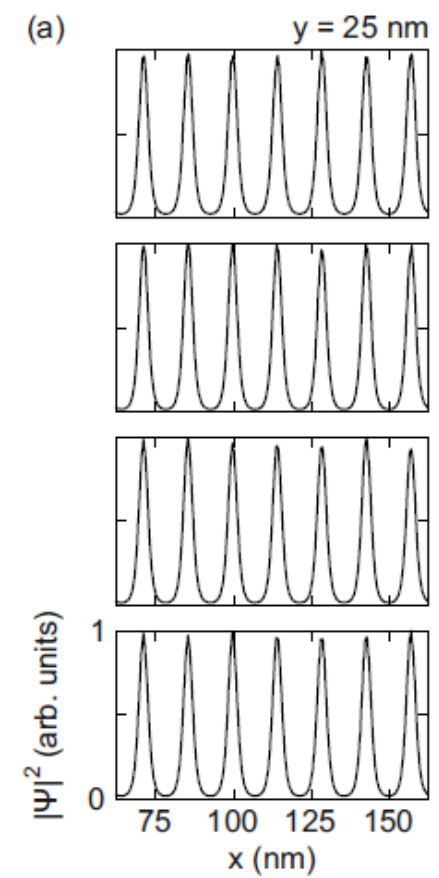


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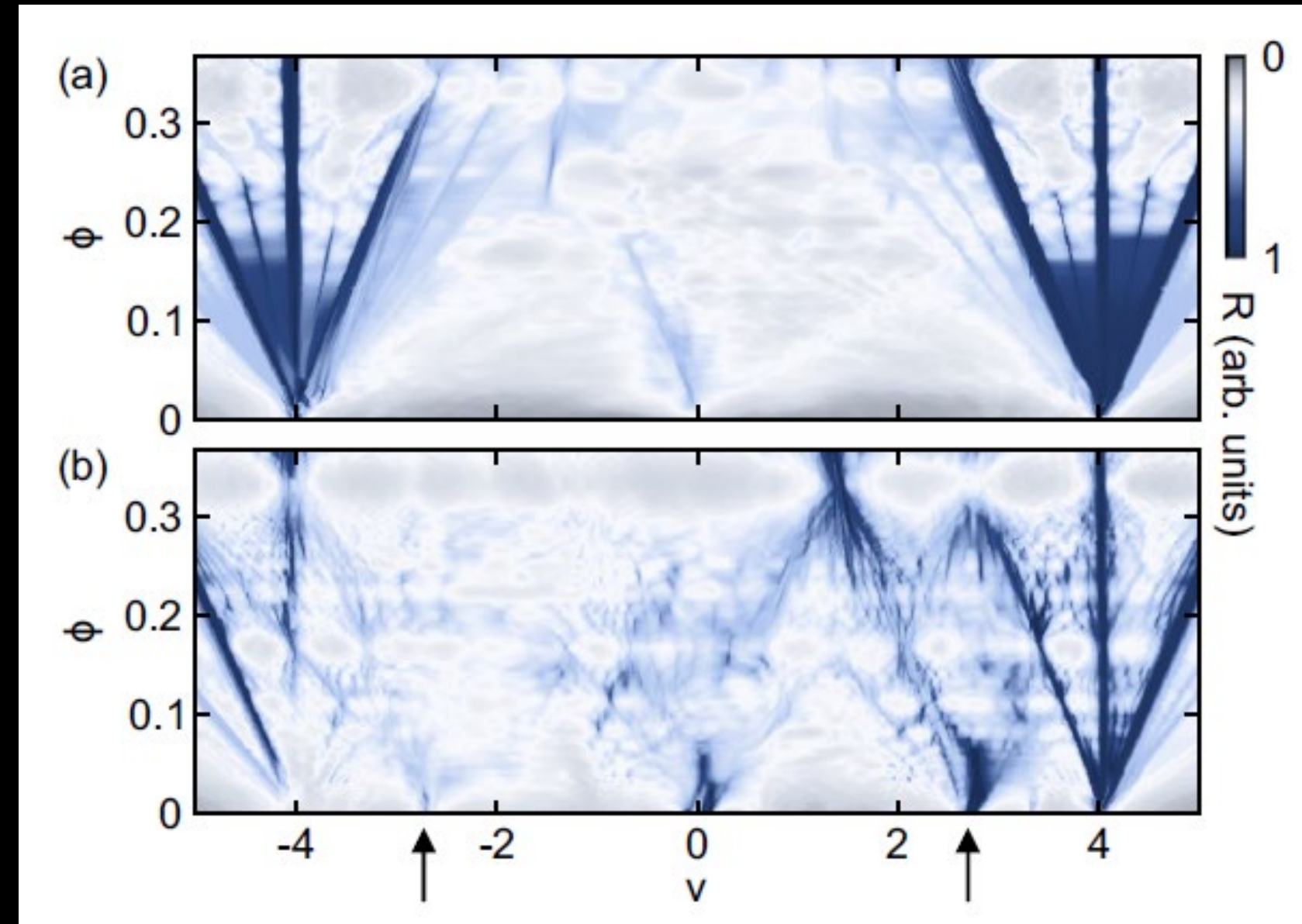
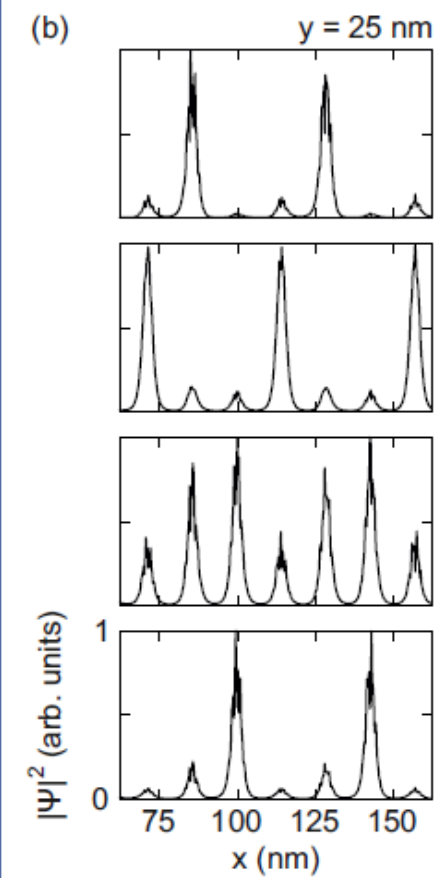
Twisted bilayer graphene/ hBN



tBLG moiré



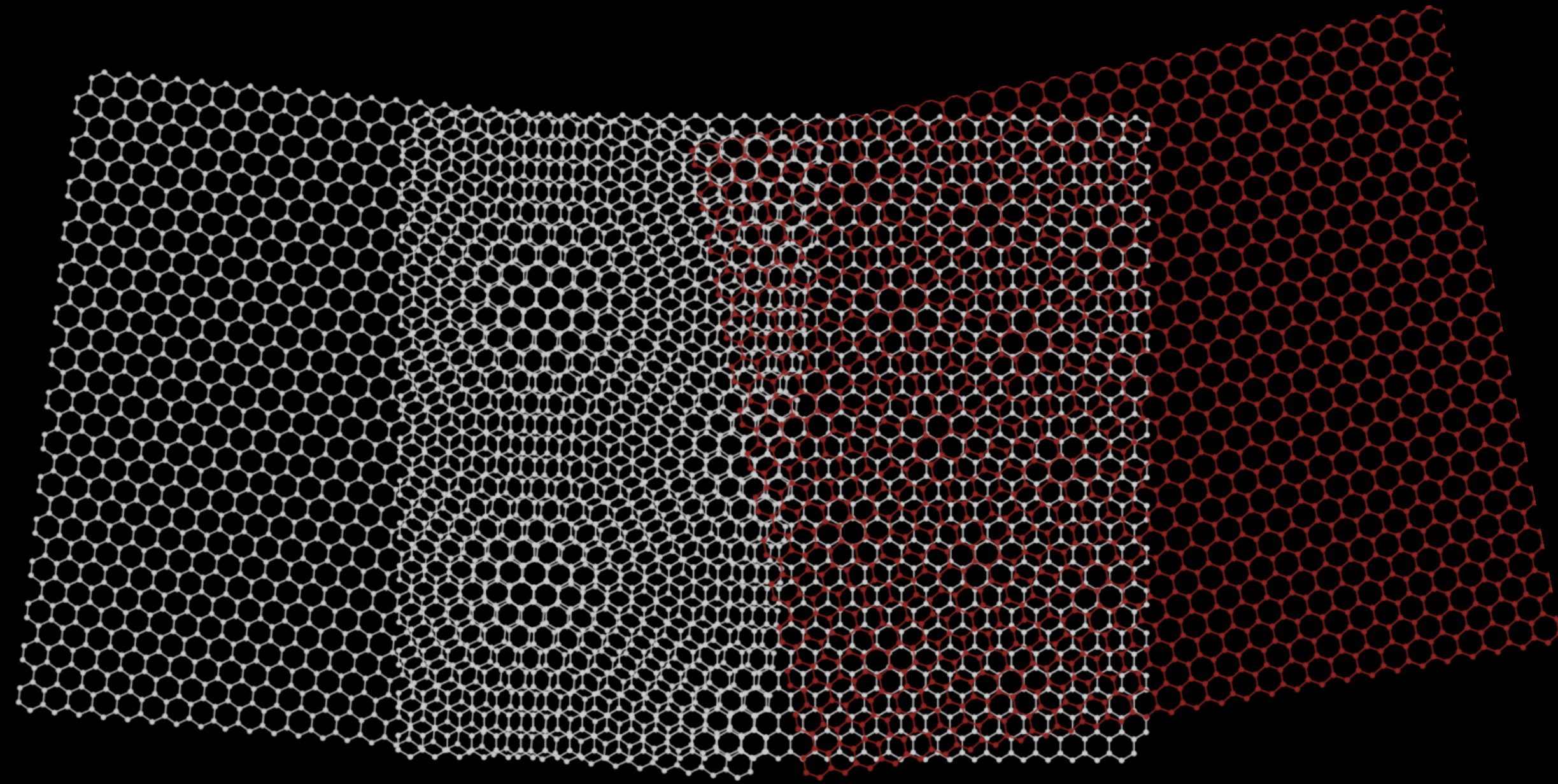
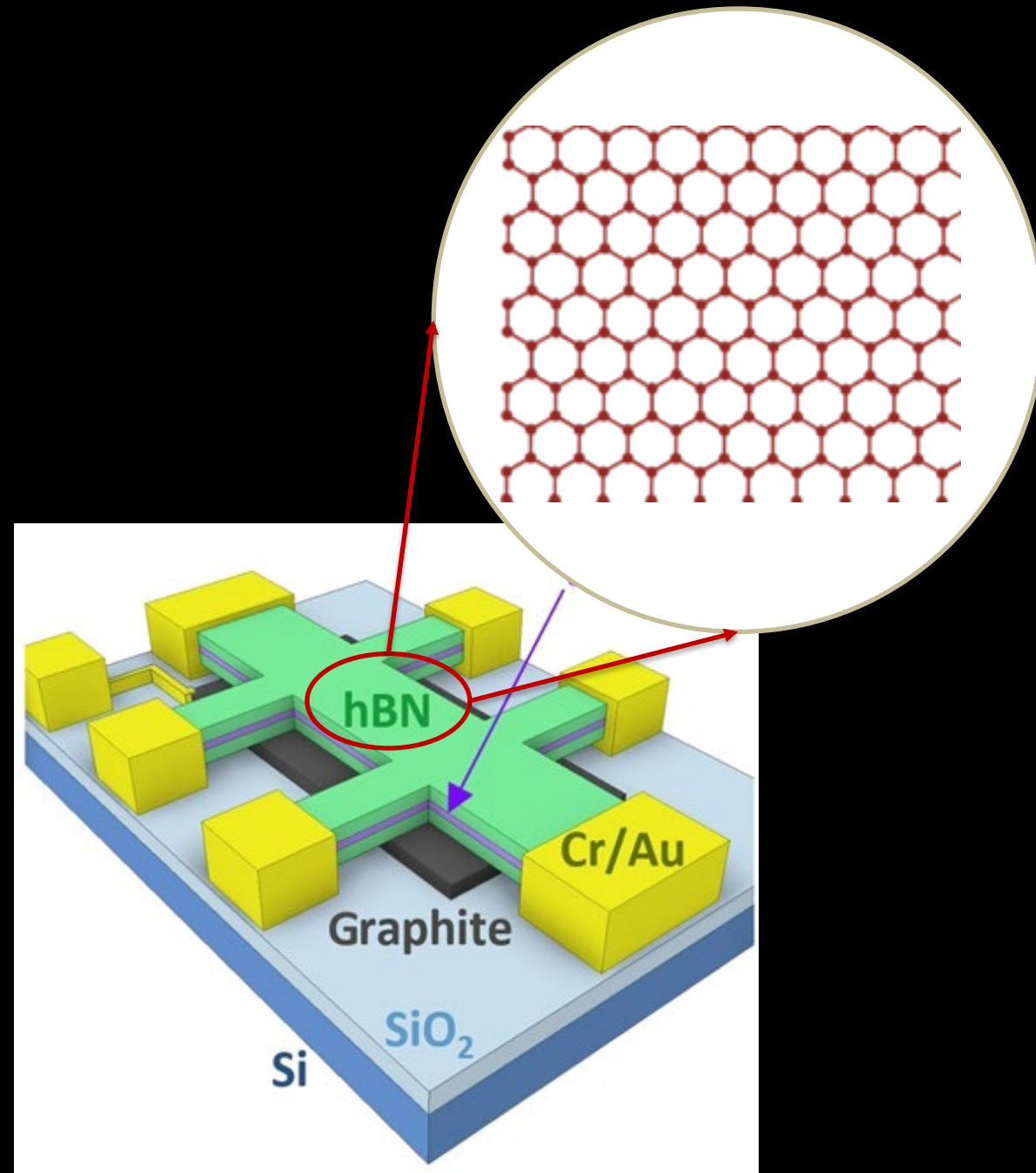
tBLG/hBN composite moiré



Commensurate morie_1 & morie_2

$$v_{\text{sat}}(l, p) = 4 \frac{p}{l} = 4 \frac{p A_{\text{tBLG}}}{m A_{\text{gr/hBN}}}, \quad p < l$$

Twisted bilayer graphene/ hBN

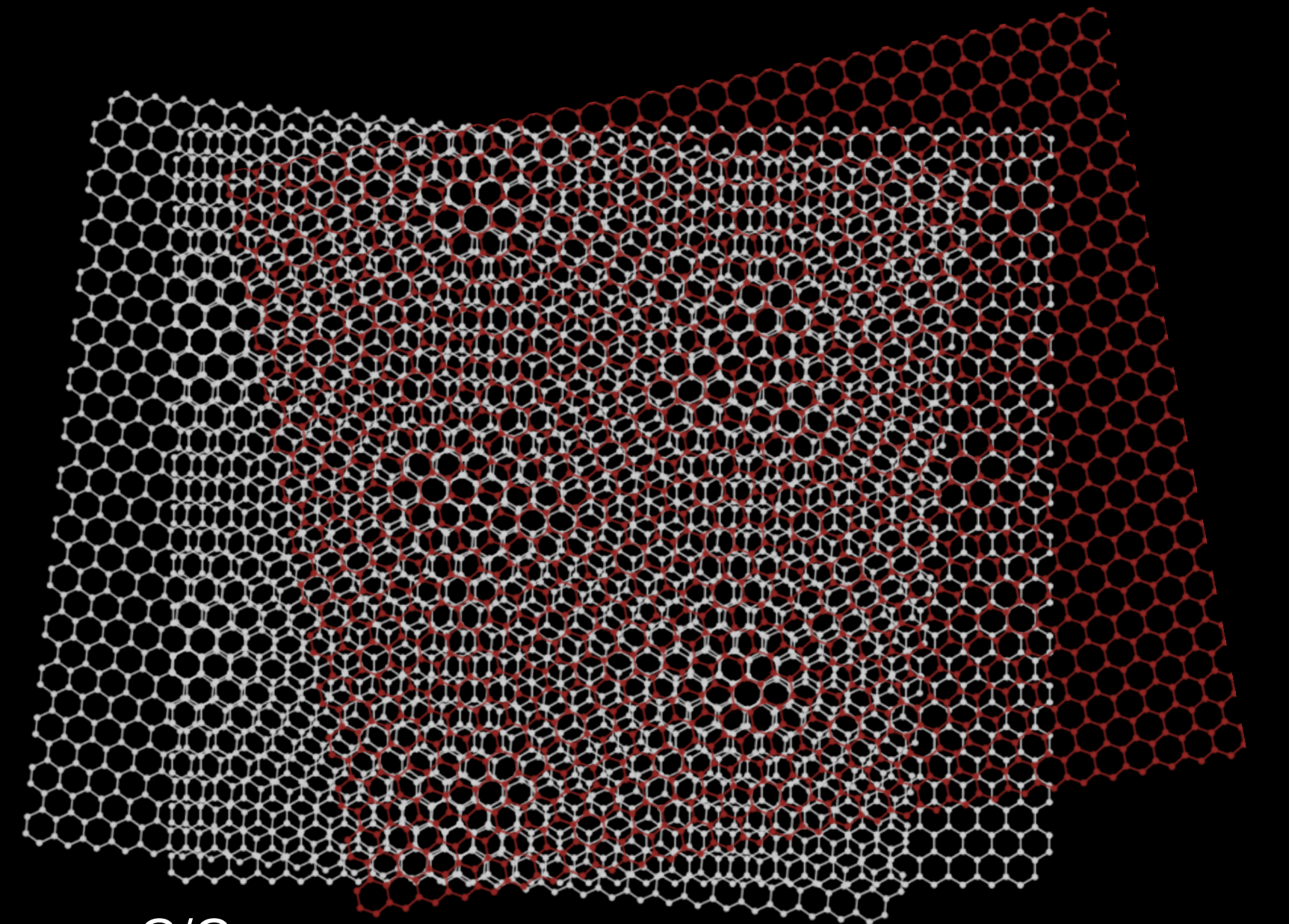
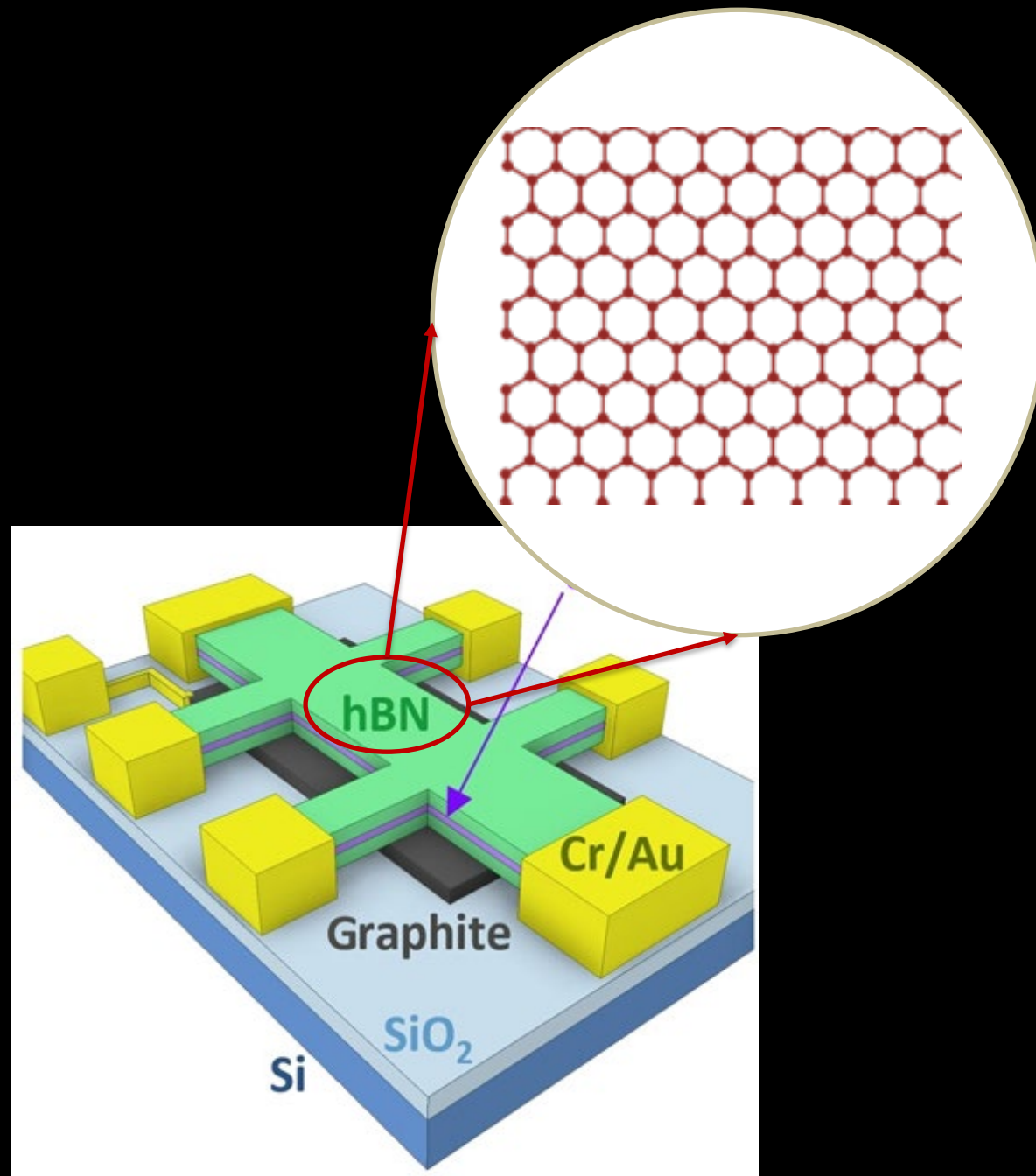


G/G
 ϑ_1 (moiré_1)

G/hBN
 ϑ_2 (moiré_2)

C_{2z} symmetry
Inversion symmetry

Twisted bilayer graphene/ hBN



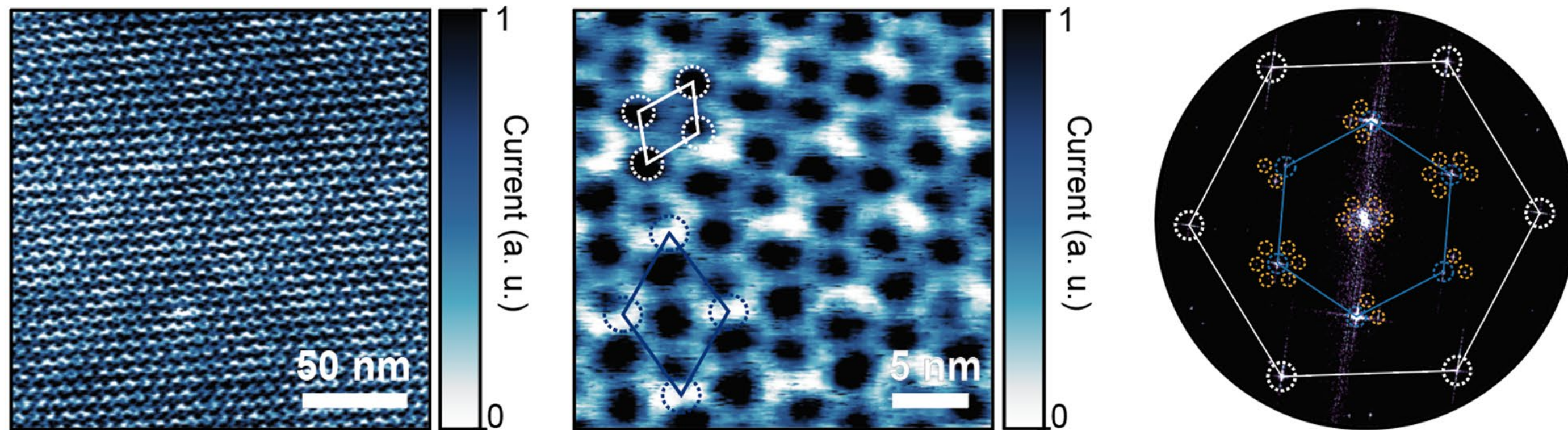
G/G
 ϑ_1 (moiré_1)

G/hBN
 ϑ_2 (moiré_2)

Interference maximum:

θ_3 (moiré_3): *reconstructive supermoiré*

Supermoiré in TBG/h-BN heterostructures

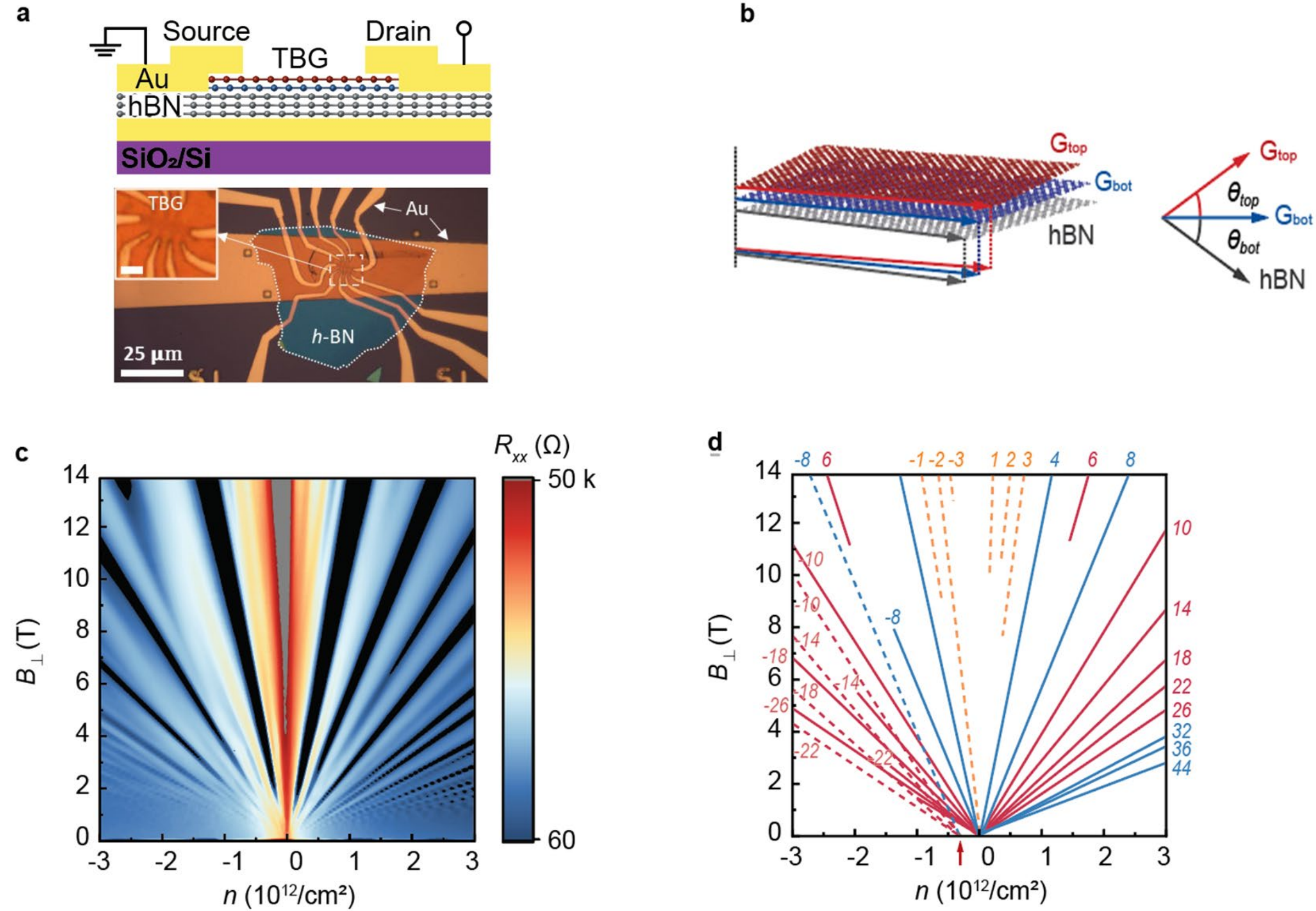


$$\lambda_{TBG} = 3.61 \text{ nm } (\theta_{TBG} = 3.26^\circ);$$

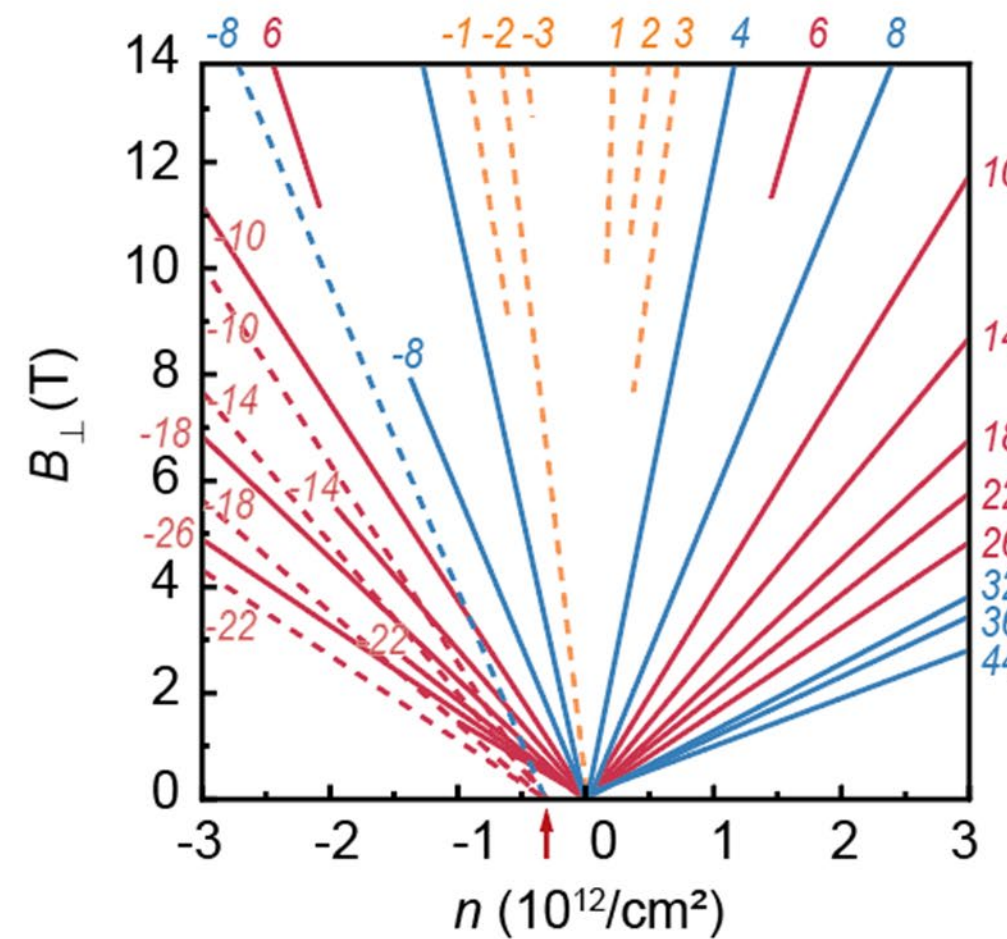
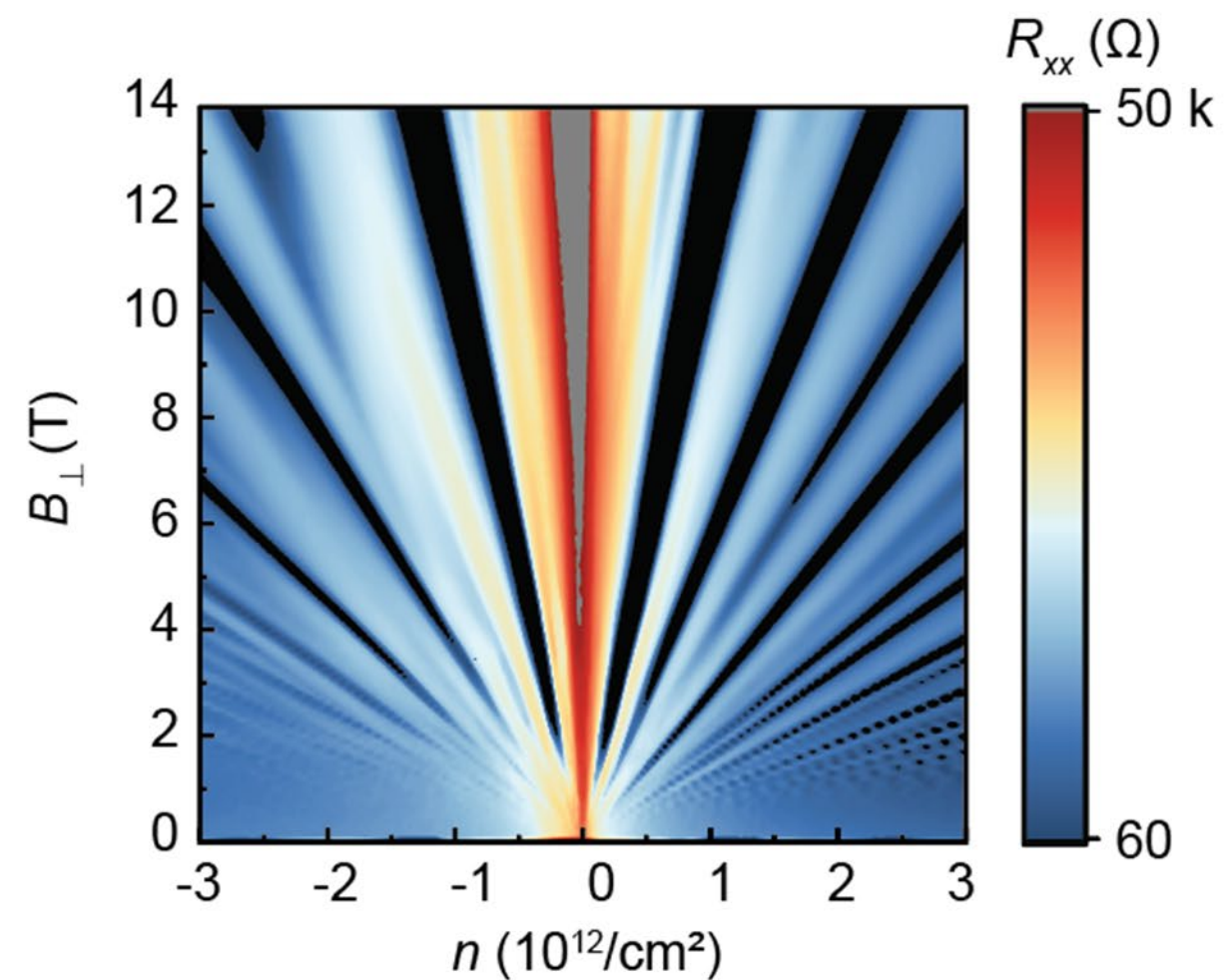
$$\lambda_{bot} = 7.57 \text{ nm } (\theta_{bot} = 1.86^\circ);$$

$$\lambda_{inter} = \mathbf{33.83 \text{ nm}}$$

Symmetry-broken quantum Hall states



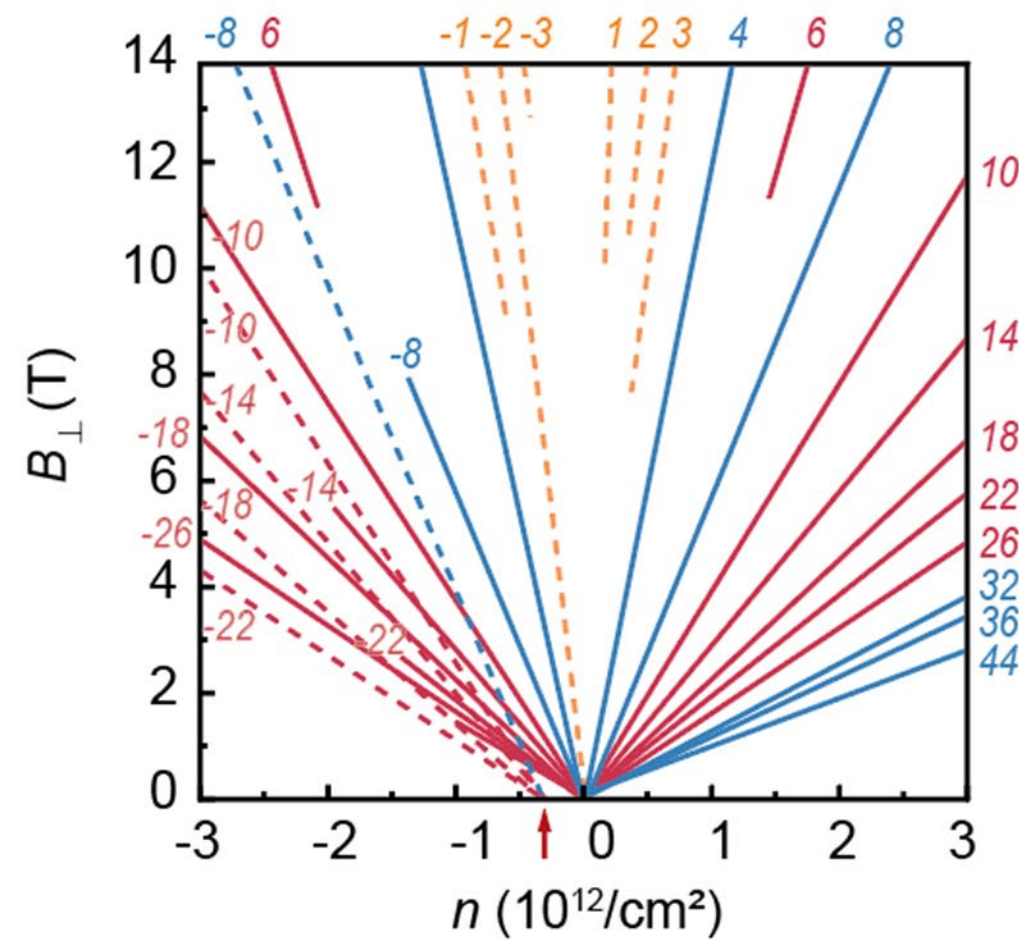
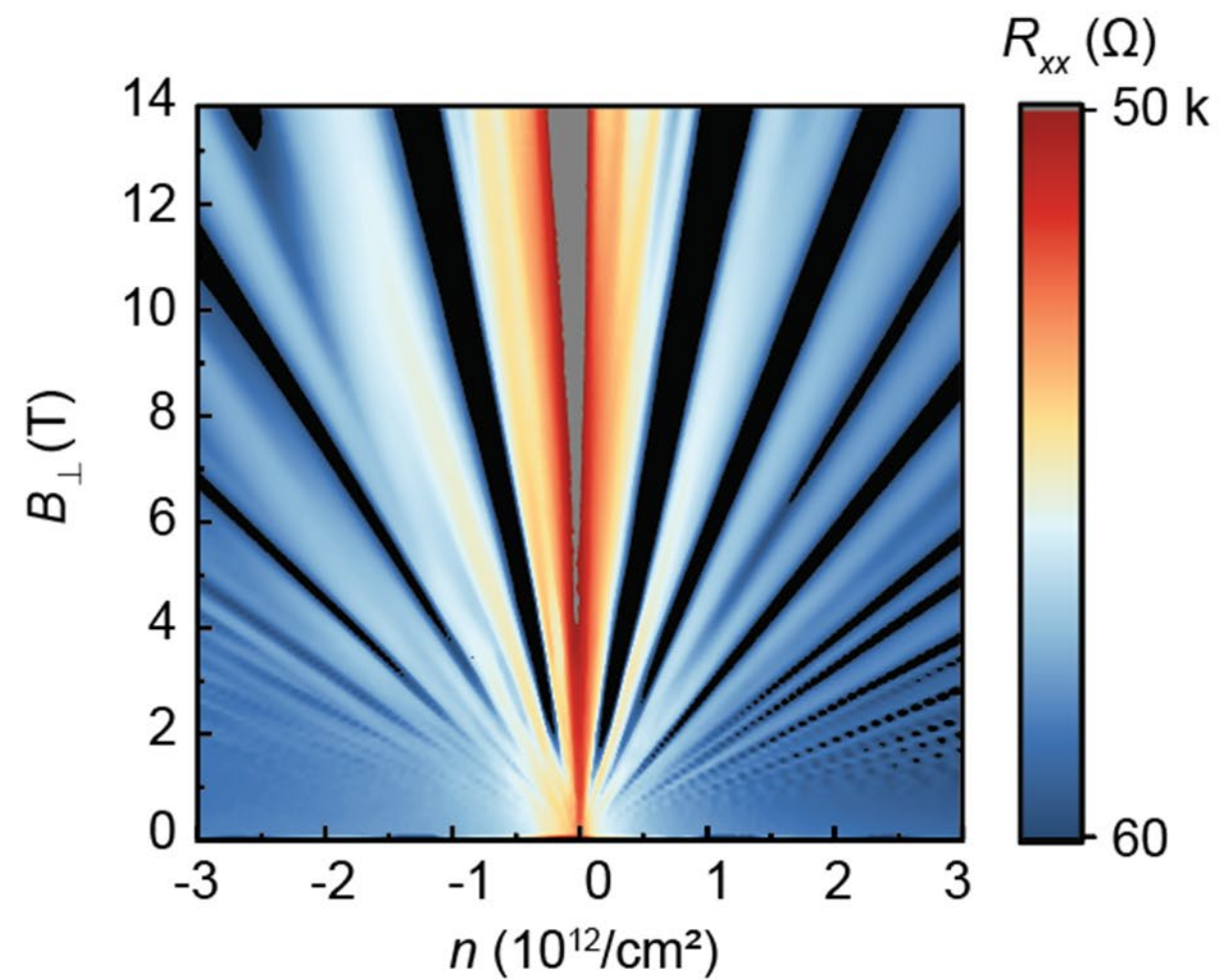
Symmetry-broken quantum Hall states



$$\Delta n = -0.238 \times 10^{12}/\text{cm}^2$$
$$\lambda = 31.18 \text{ nm}$$

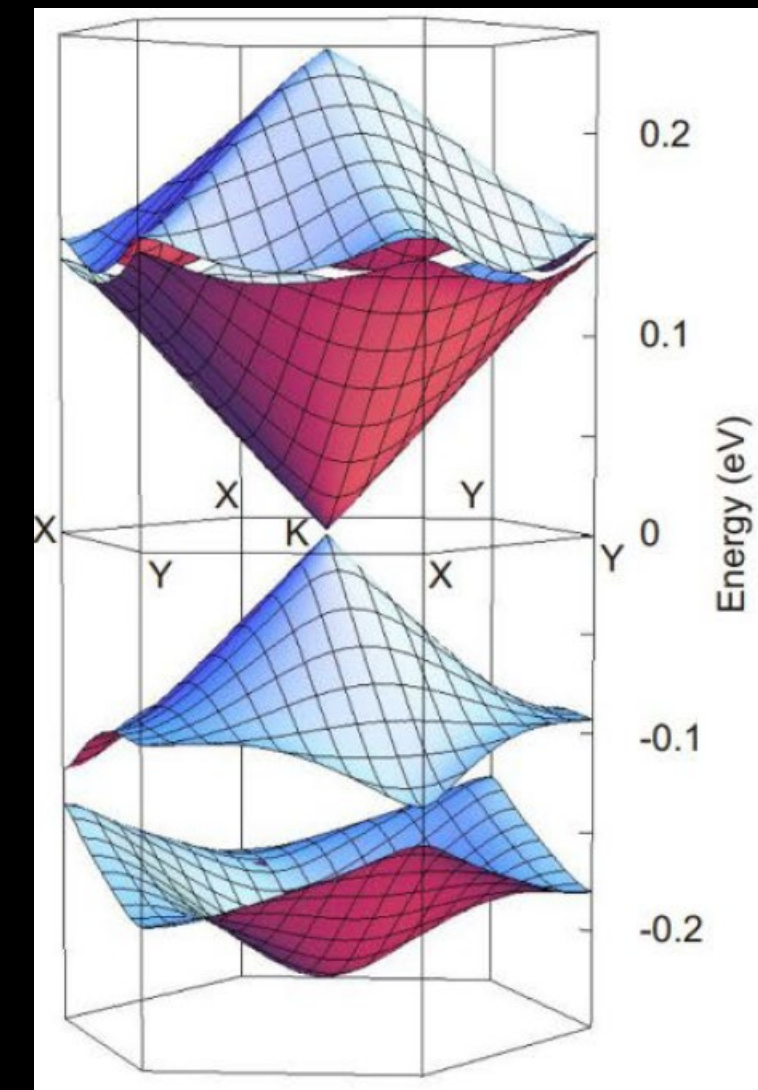
- Satellite Dirac point
- Electron-hole asymmetry
- 2-fold degeneracy, $n > 0$
1-fold degeneracy, $n = 0$

Symmetry-broken quantum Hall states

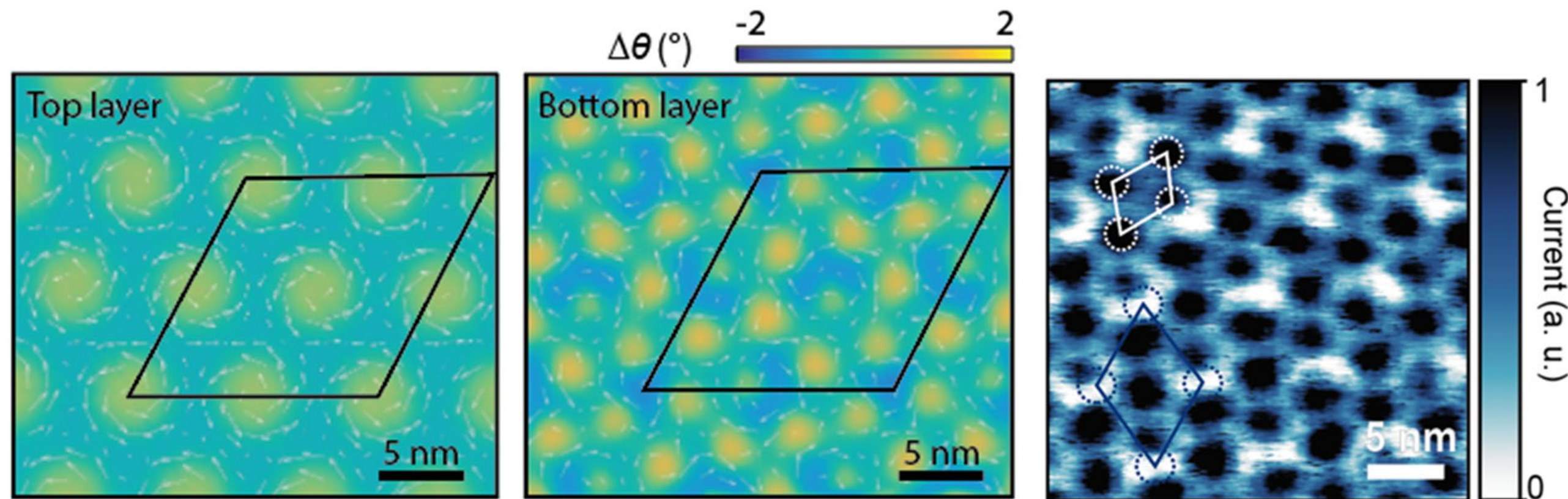


$$\Delta n = -0.238 \times 10^{12}/\text{cm}^2$$
$$\lambda = 31.18 \text{ nm}$$

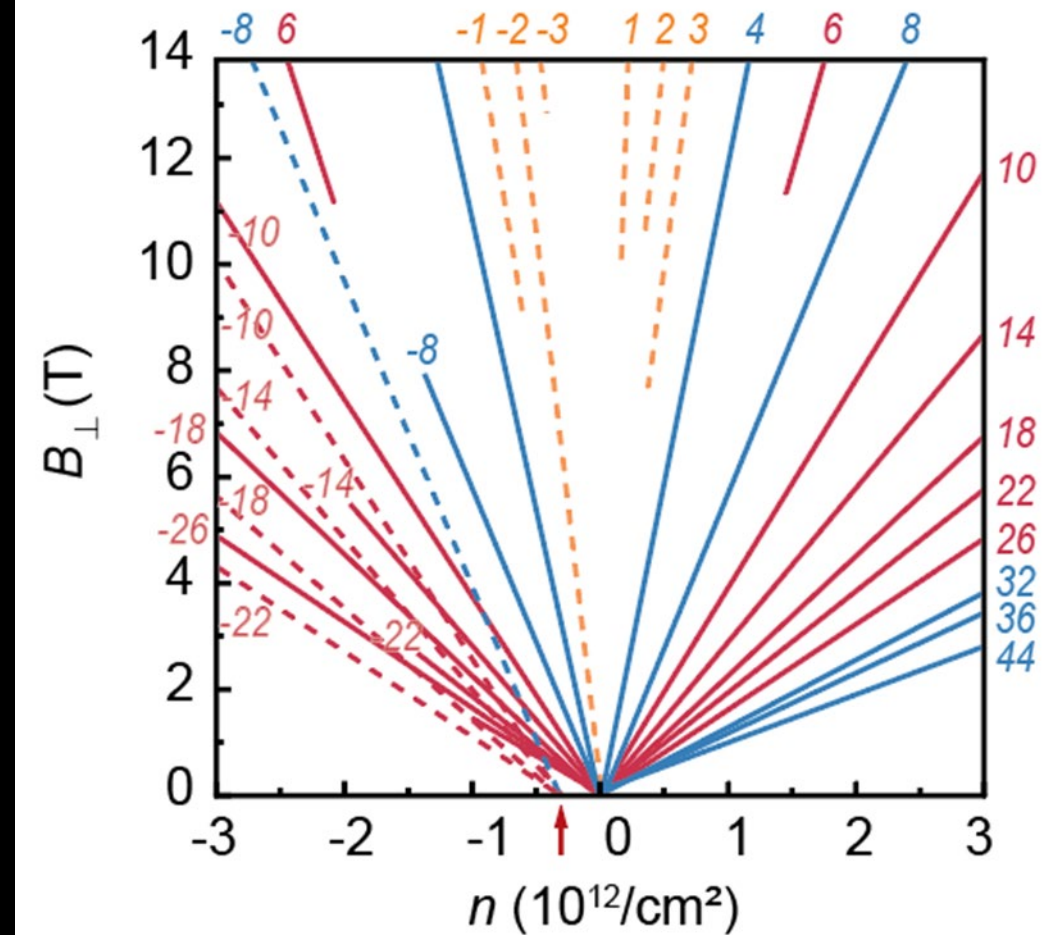
Satellite Dirac point
(supermoiré)



Symmetry-broken quantum Hall states



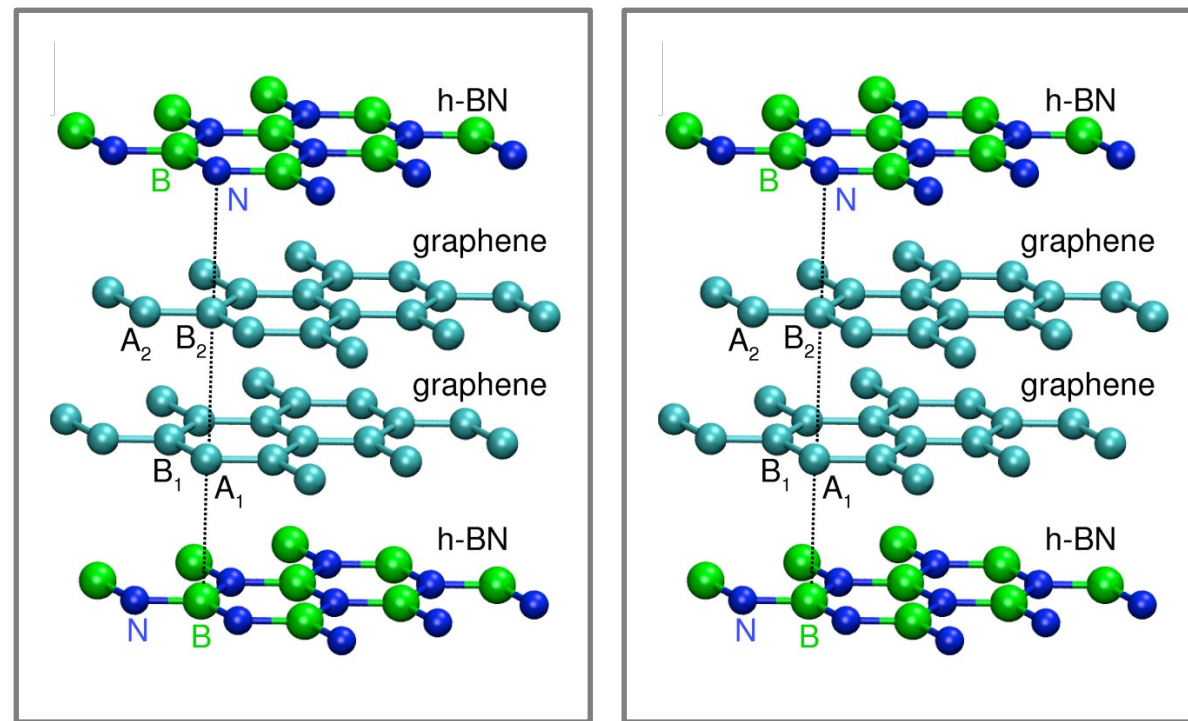
$$\lambda_{TBG} = 3.61 \text{ nm } (\theta_{TBG} = 3.26^{\circ}); \lambda_{bot} = 7.57 \text{ nm } (\theta_{bot} = 1.86^{\circ}); \lambda_{inter} = 33.83 \text{ nm}$$



$A \neq B$

Valley degeneracy lifting

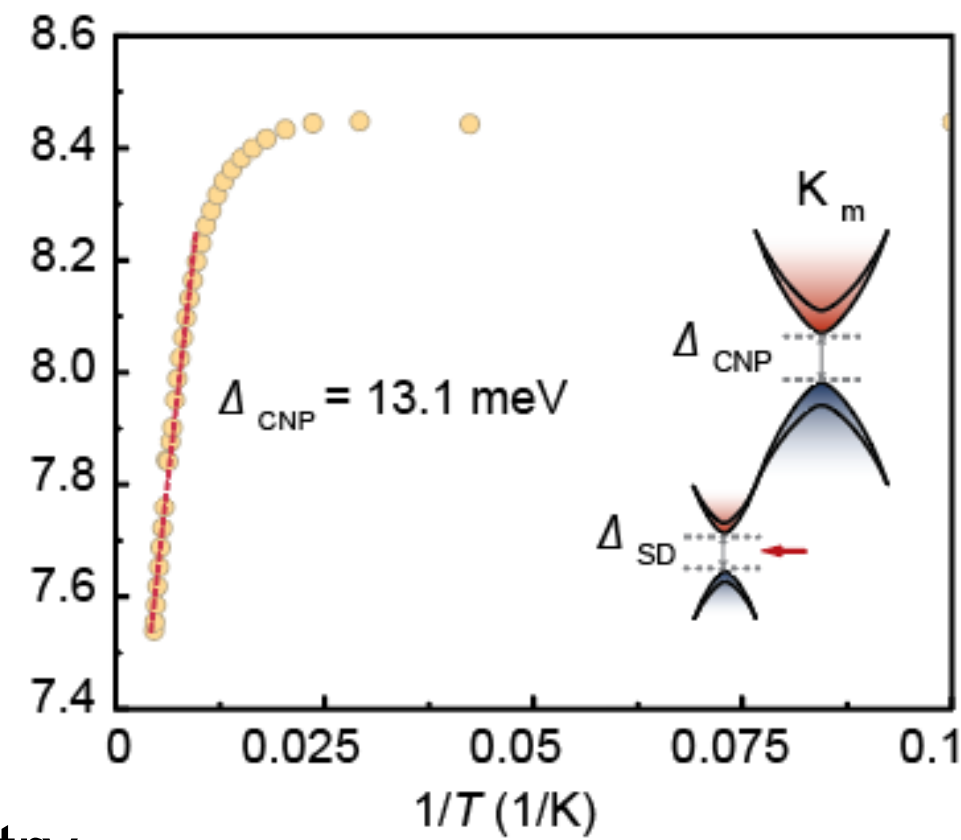
Symmetry-broken quantum Hall states



B-C-C-B
N-C-C-N

N-C-C-B

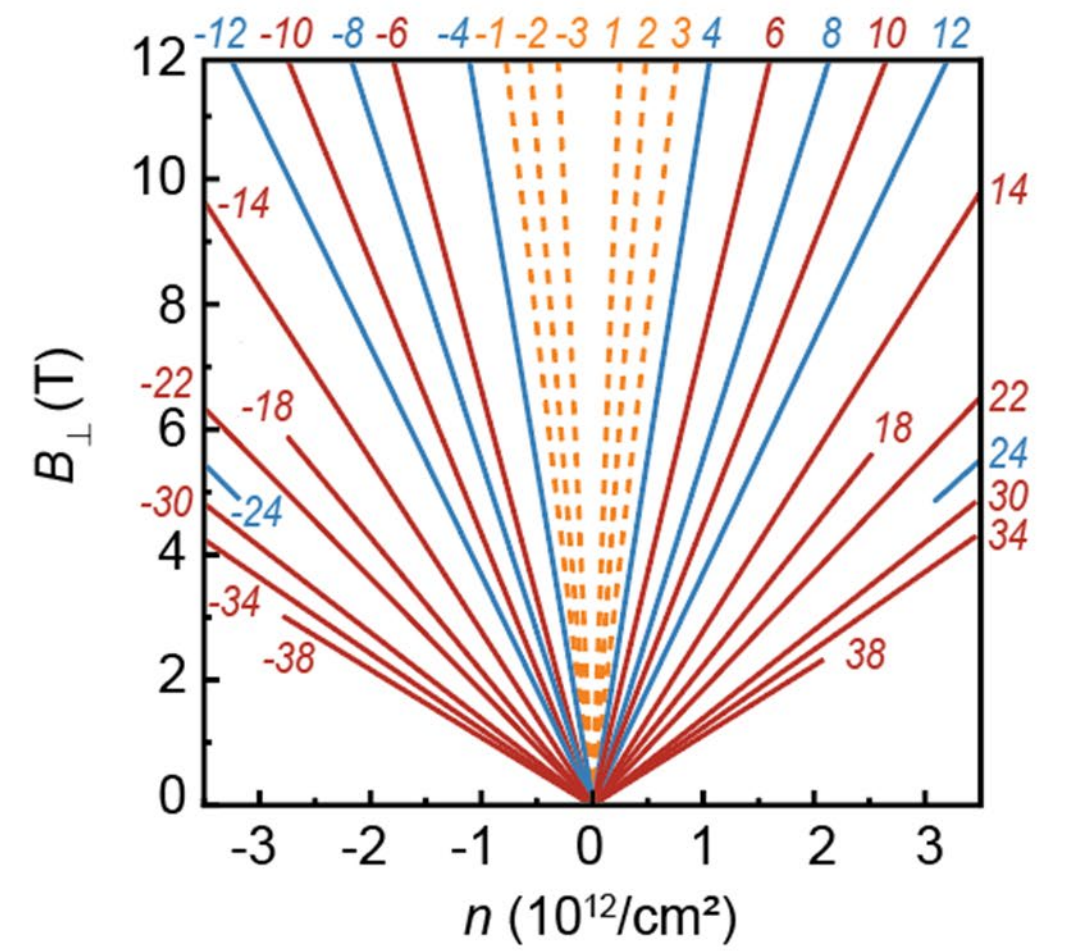
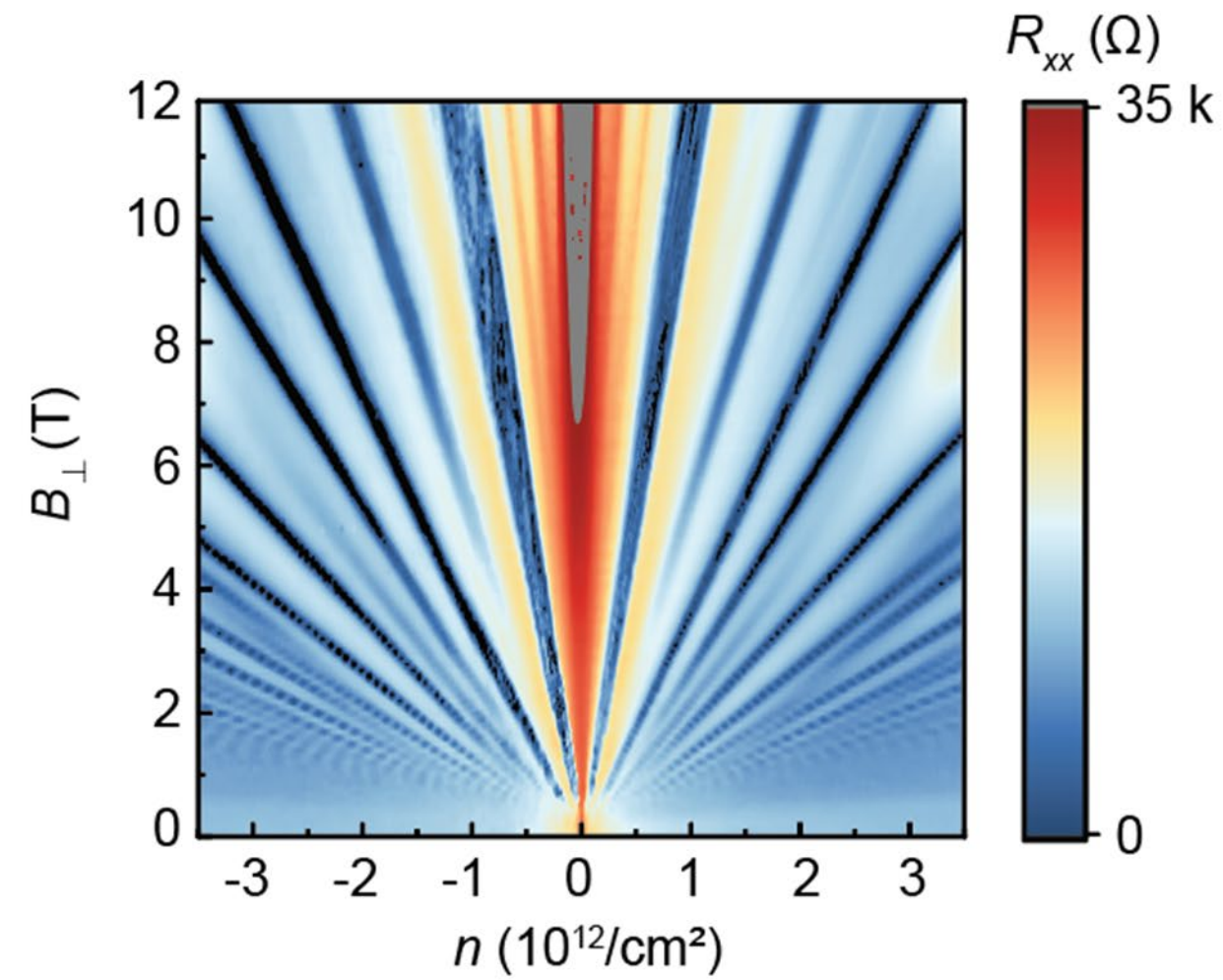
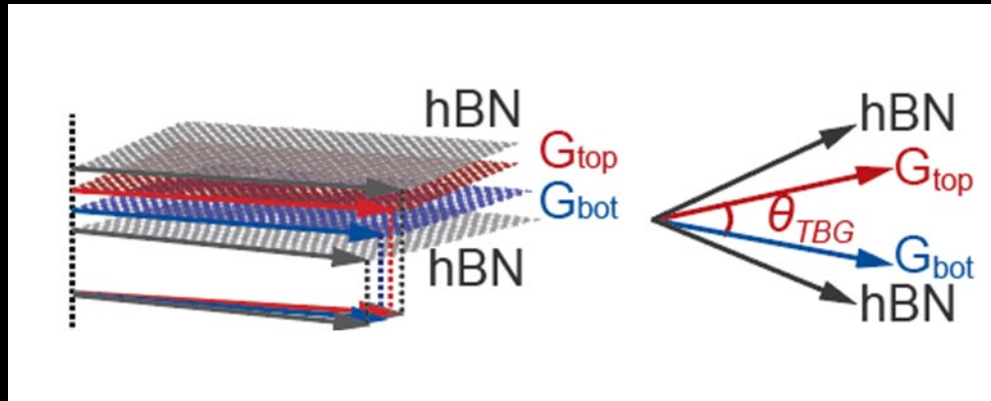
Breaking inversion symmetry



Gaped Dirac point

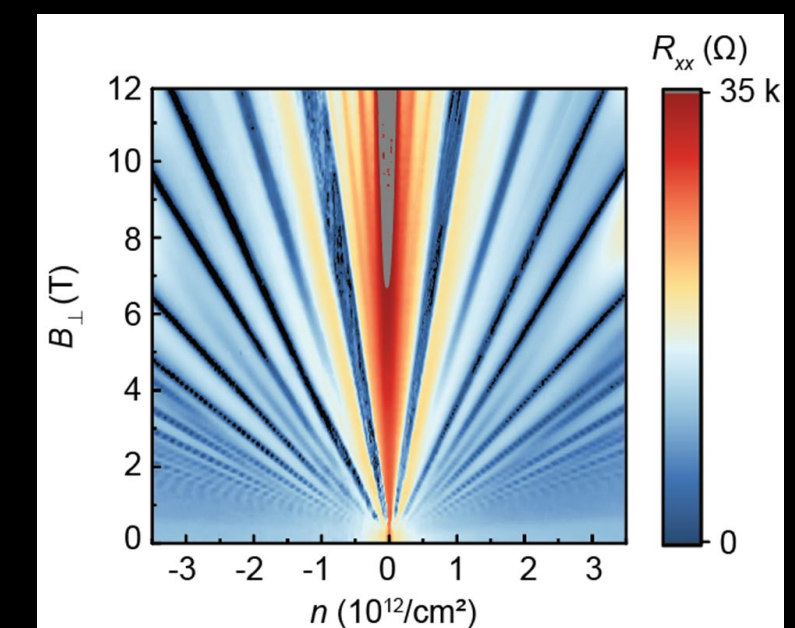
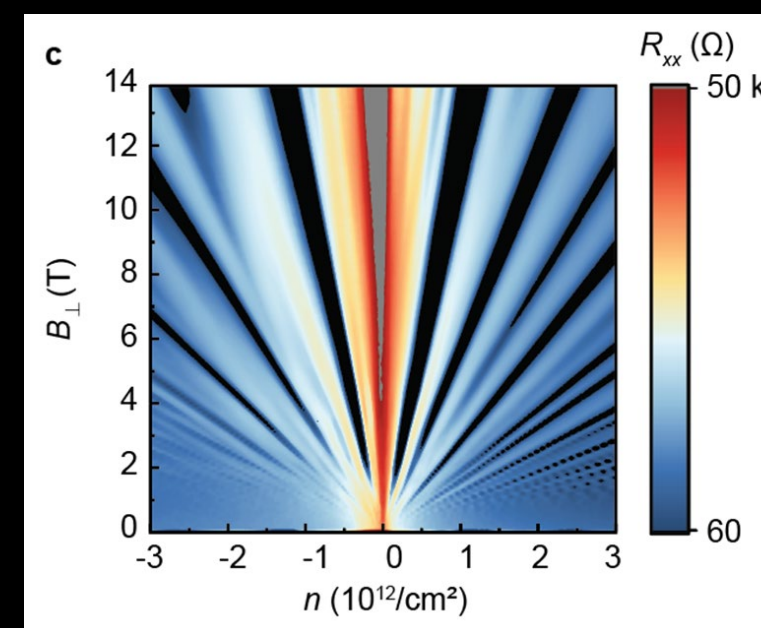
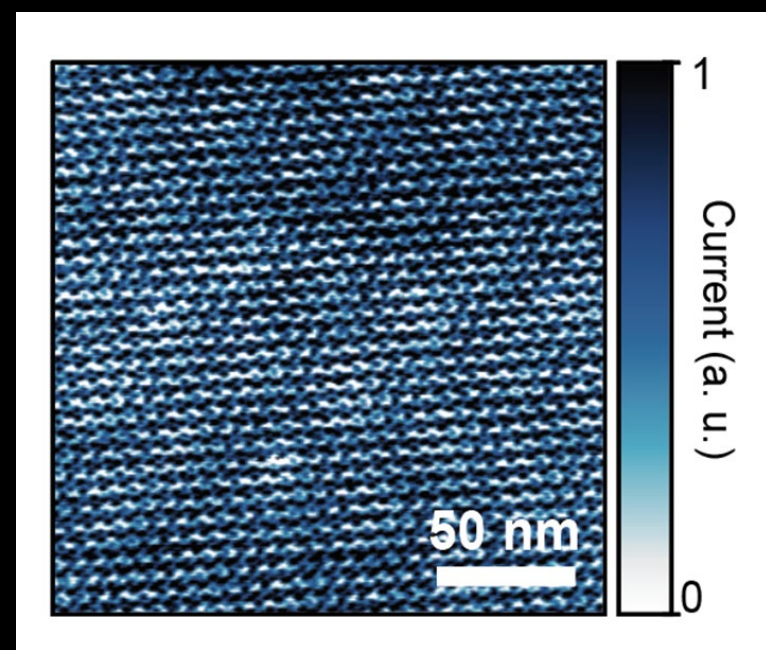
Interlayer coupling: G/hBN

Recovery of electron-hole asymmetry





- Graphene-based moiré systems provide a powerful platform to study symmetry effects in low dimensions.
- The electronic structure is strongly governed by lattice symmetries, especially C_{2z} and inversion symmetry.
- Moiré engineering enables controlled breaking or restoration of symmetries, allowing tuning and lifting of degeneracies in quantum Hall states.





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