Transport signatures of van Hove singularities in mesoscopic twisted bilayer graphene

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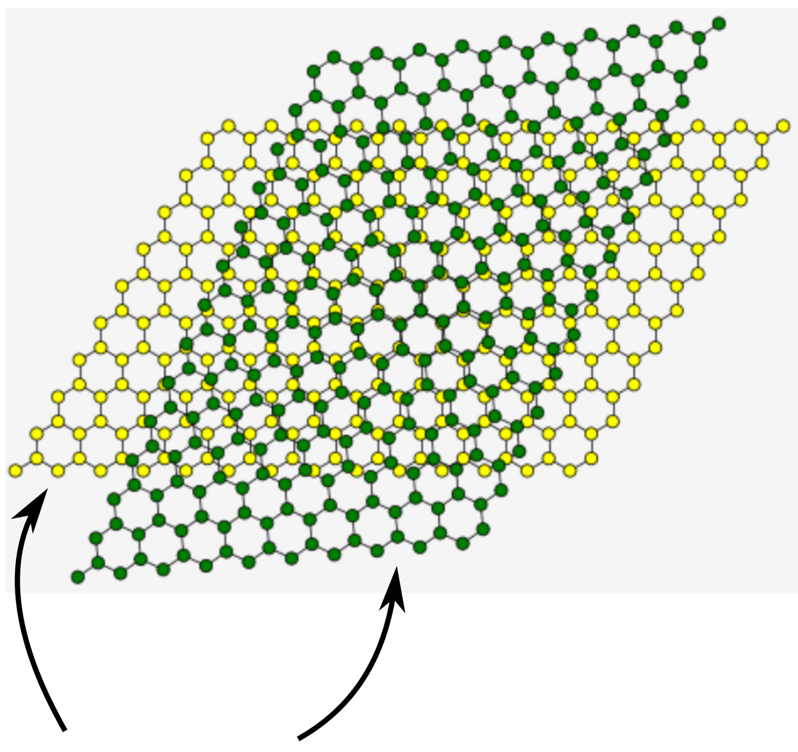
Introduction and motivation



Graphene layers

Twisted bilayer graphene is a fascinating material made of two graphene layers stacked with a relative angle between them. At certain "magic" twist angles it has extraordinary properties [1-3]:

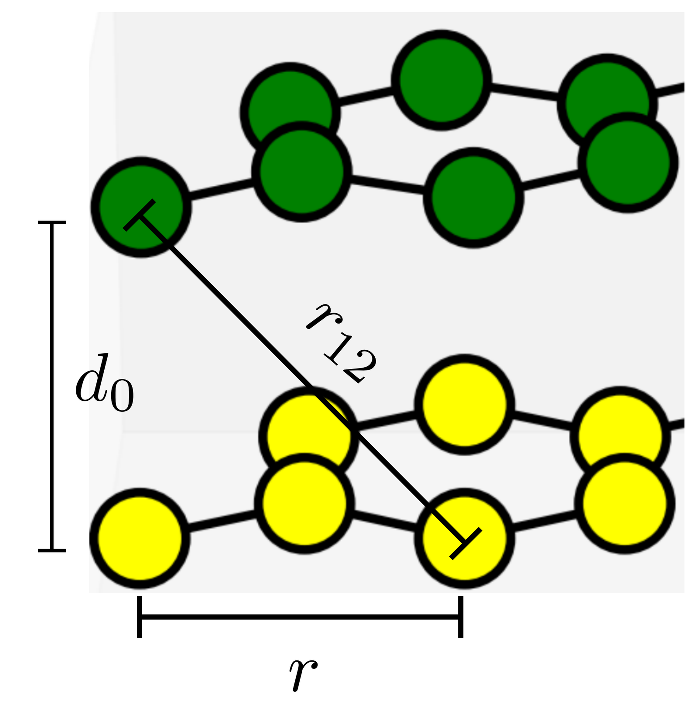
- contains low-energy, remarkably flat bands in the spectrum
- is a low-temperature superconductor
- exhibits strongly correlated phases
- its quasi-flat bands contain special singularities (van Hove singularities) which are tunable to the Fermi level.

van Hove singularities are saddle points in the energy dispersion → $\vec{\nabla}E(\mathbf{k}) = 0$ → the Density of States diverges → enhanced electron correlation

Motivation: it remains an outstanding challenge to understand the effects of quasi-flat bands, VHSs and the rich variety of possible Fermi surface topologies on the quantum transport in mesoscopic TBLG samples. Most research to date has focused on observables in the thermodynamic limit and on transport in macroscopic samples in the semiclassical regime

Our contribution: we study the correspondence of four-terminal conductance and the Fermi surface topology as a function of the twist angle, pressure, and energy in mesoscopic samples

Model and four-terminal transport setup



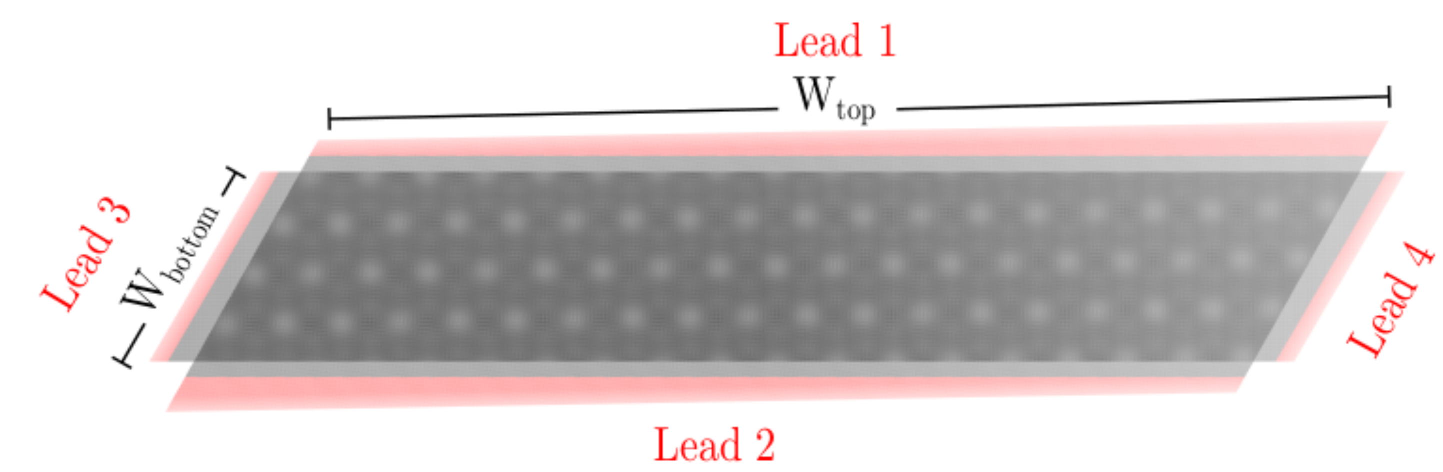
Tight-binding model

- Intralayer: Only nearest-neighbour hoppings
- Interlayer: Minimal model with exponential decay [4]:

$$H_{12} = -\sum_{\langle i,j\rangle\sigma} t'(r_{ij}) c^{\dagger}_{i,2,\sigma} c_{j,1,\sigma} + \text{h.c.}$$

$$t'(r) = V^0_{pp\sigma} e^{-\left(\sqrt{r^2+d_0^2}-d_0\right)/\lambda} \frac{d_0^2}{r^2+d_0^2}$$

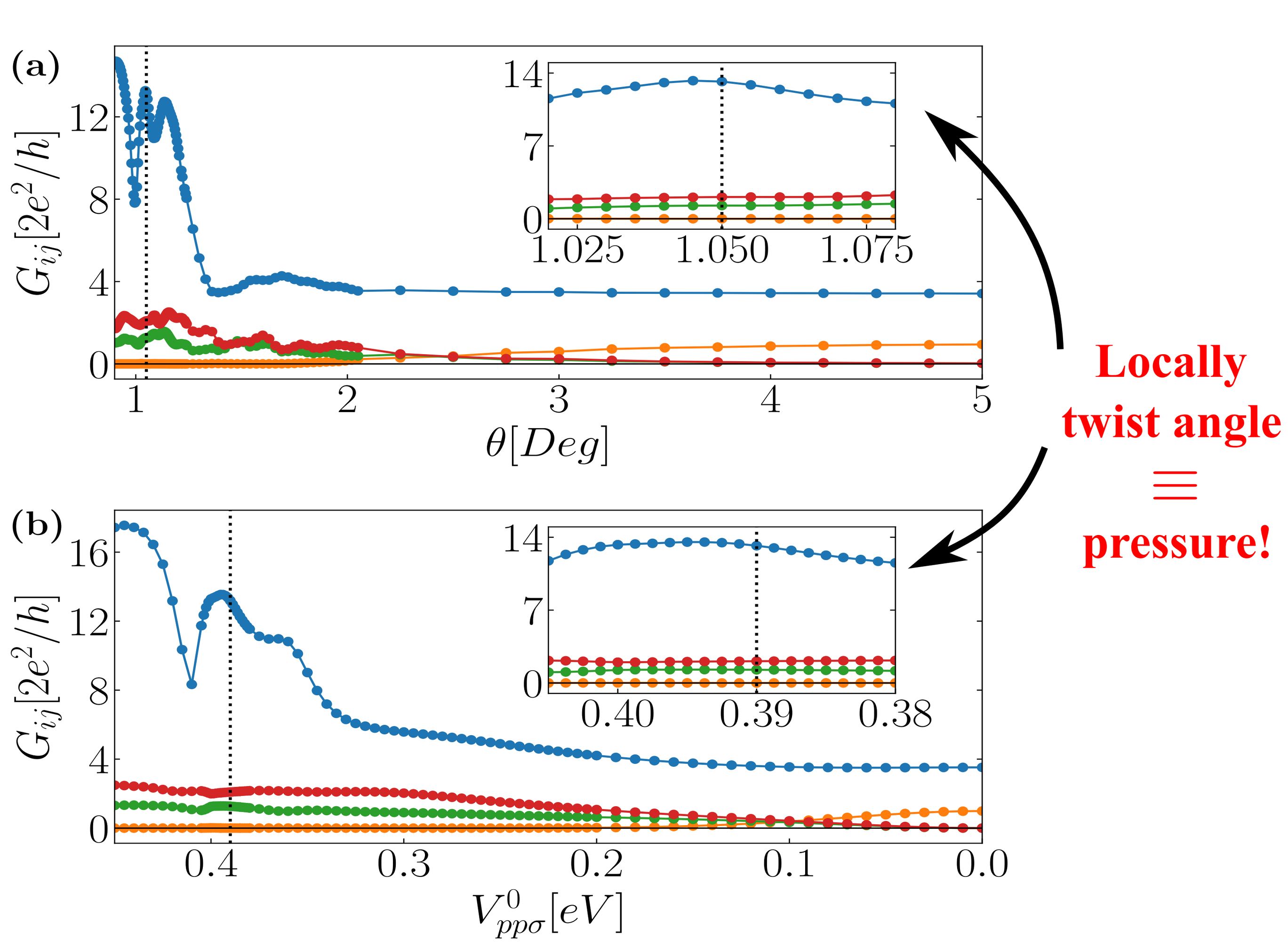
Four-terminal setup for conductance calculations



- Channel 1 => 2: Wide-junction, through the same graphene layer (top)
- Channel 3 => 4: Narrow-junction, through the same graphene layer (bottom)
- Channels 1 => 4 & 3=> 2: Interlayer junctions, terminals in different layers

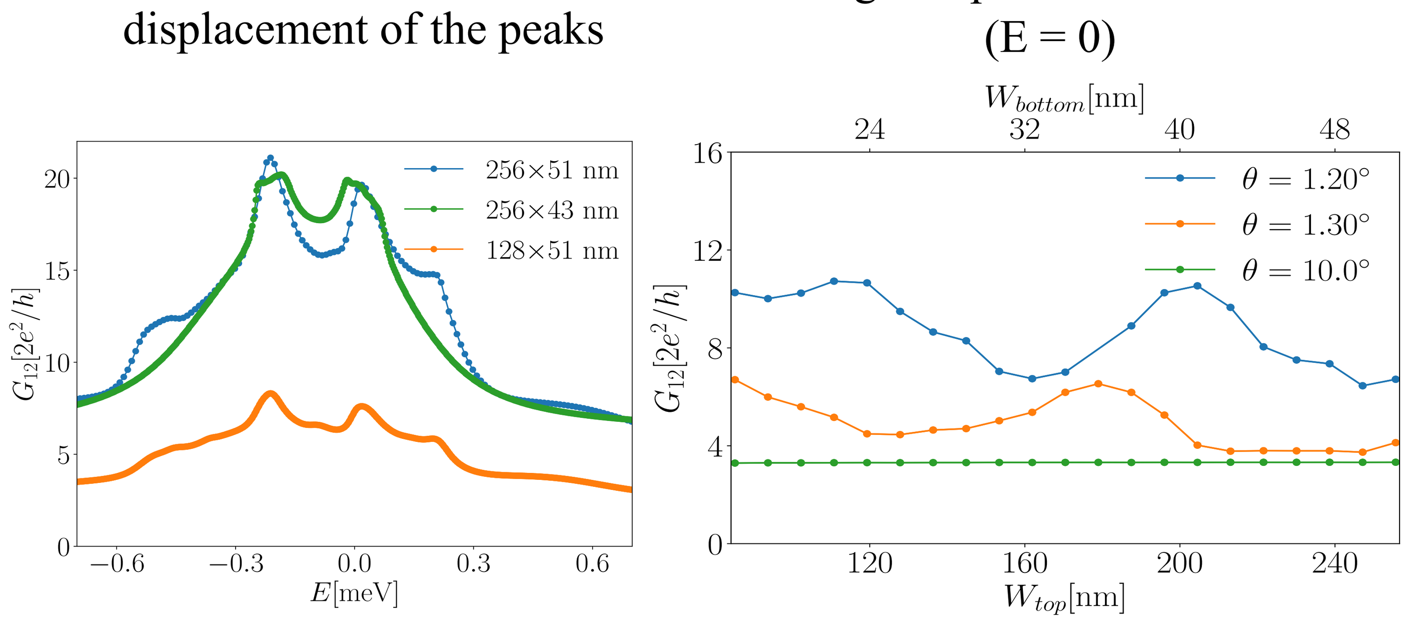
General conductance results

Two regimes: Coupled and uncoupled layers (E = 0)

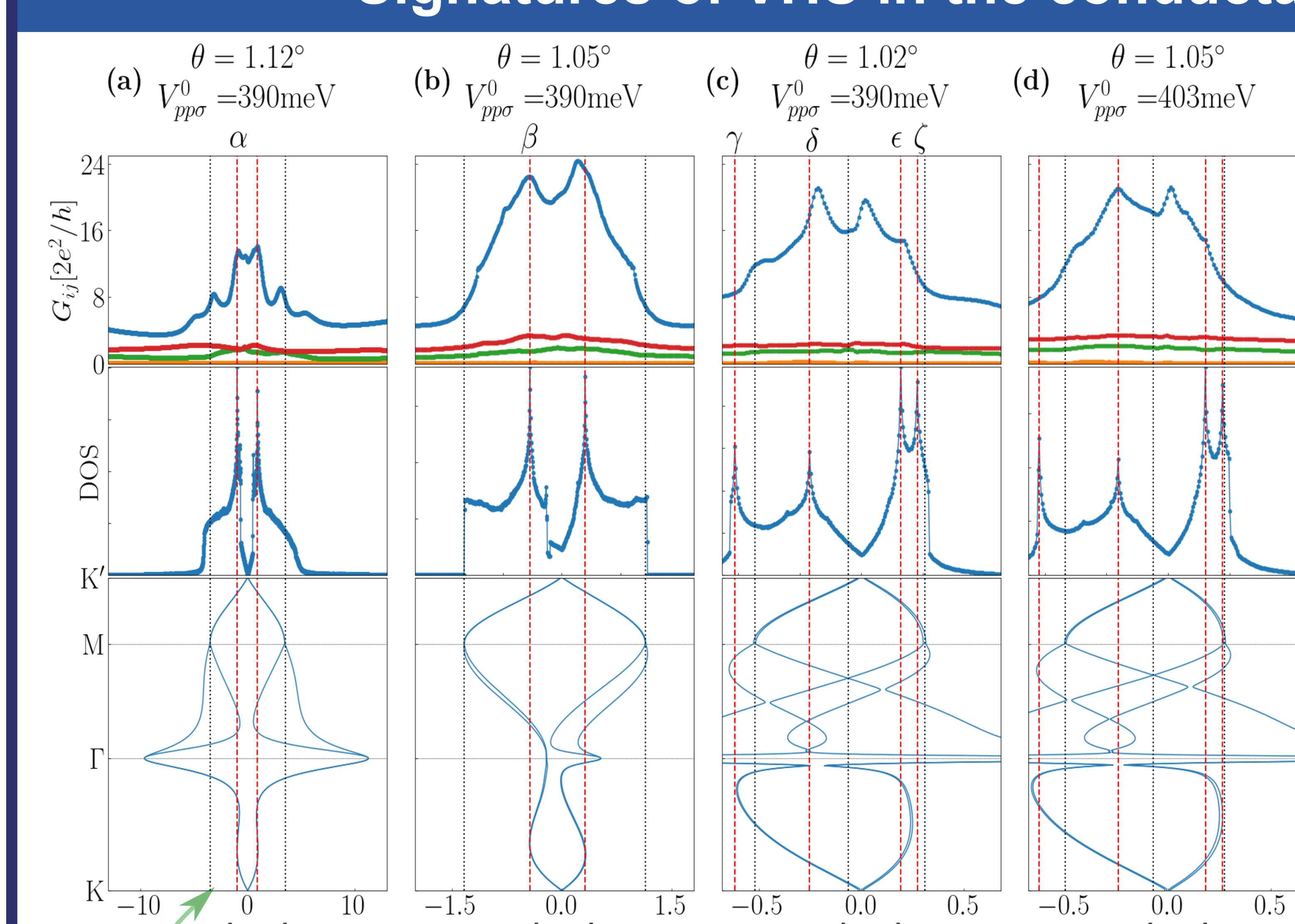


Non-trivial finite-size effects

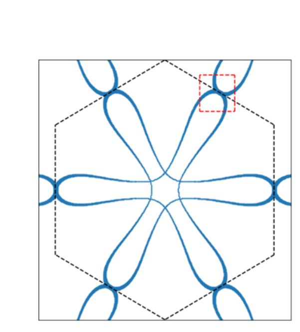
- Broadening and displacement of the peaks
- Large-amplitude oscillations (E = 0)



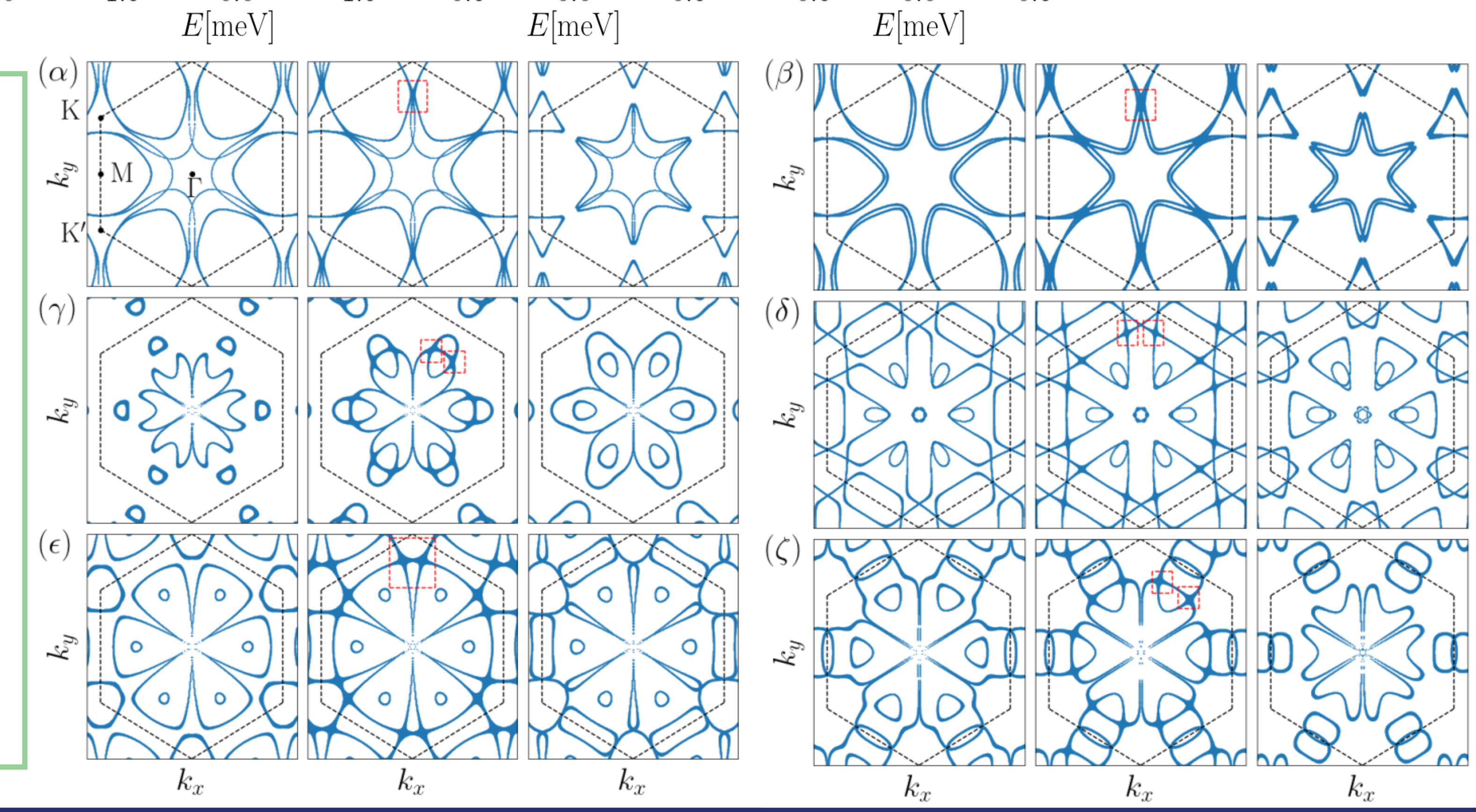
Signatures of VHS in the conductance



- Some peaks in the conductance align very well with VHSs, but not all!
- VHS in Fermi surface plots can be observed when two or more Fermi contours intersect at the saddle point



- Some features in the conductance seem to align with non-singular band crossings:



Conclusions

- the low-energy electron transport in twisted bilayer graphene is affected by several factors: the flattening of the bands, van Hove singularities, the size of the system and non-singular crossing points
- the system is highly sensitive to external parameters => possible applications in high-frequency devices and sensitive detectors
- the system shows oscillations with an unusually large amplitude in the conductance with system size
- van Hove singularities give rise to sharp, non-linear increases in the conductance

References

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[2] Yuan et al., Nat. Com. **10**, 5769 (2019)
[3] Bistritzer and MacDonald, PNAS **108**, 12233-12237 (2011)
[4] X. Lin, D. Tomanek, PRB 98, 081410 (2018)

Sanjuan, Tworzydło, Hyart, Lau, arXiv:2208.08366 (2022)

European Funds Smart Growth · Republic of Poland · FNP Foundation for Polish Science · European Union European Regional Development Fund · MARIE SKŁODOWSKA-CURIE ACTIONS Research Fellowship Programme · ACADEMY OF FINLAND · QUANTERA ERA-NET Cofund in Quantum Technologies