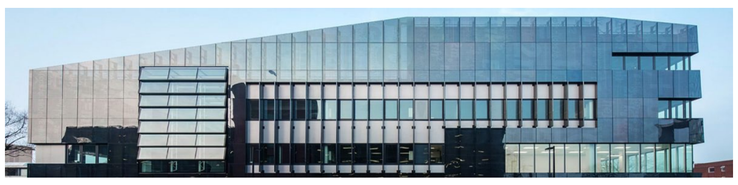
Quantum Hall Ferromagnetism in Two-Dimensional Atomic Lattices



Angelika Knothe[1], John Wallbank[1], Thierry Jolicœur[2], Vladimir Fal'ko[1]

[1]National Graphene Institute, University of Manchester, UK

[2]Université Paris Sud/ Paris Saclay, France

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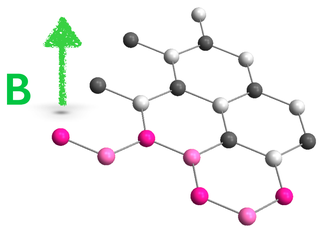
Abstract

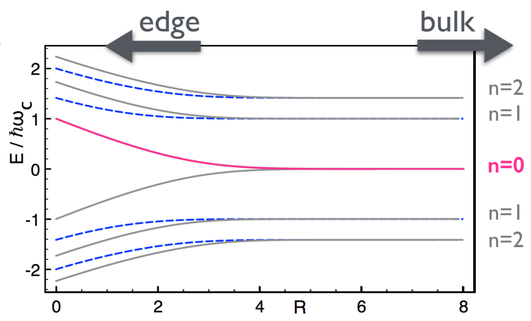
Two-dimensional (2D) atomic crystals have proven to be an exciting playground for investigating novel quantum Hall (QH) phenomena. We theoretically investigate several of these novel QH systems within the framework of QH ferromagnetism, i.e, treating the electronic degrees of freedom as spins and isospins. Hartree Fock (HF) theory is employed to study the influence of electronic interactions in these multicomponent spin and isospin systems on the mean field level.

1. Neutral Monolayer Graphene with an Edge

Setup:



Neutral monolayer graphene,
Filling factor ν=0,
Spin **S**, Valley isospin **T**,
Magnetic field **B**



nth Landau Level in the presence of an edge as a function of the distance r to the edge: $R=\sqrt{2}r/\ell_B$

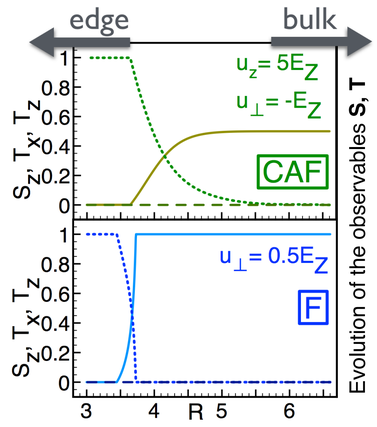
Leading Question:

- Different phases are characterised by different spin and isospin configurations
- Tilting of the magnetic field entails different phases in the bulk

➡ How do the bulk phases change in the presence of an edge ?

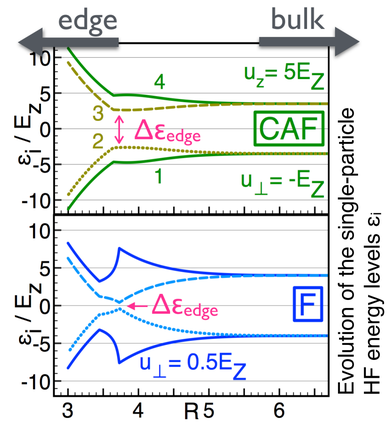
➡ Consequences for the edge states ?

Results:



- Bulk phases change upon approaching the edge

➡ Formation of domain walls and edge phases

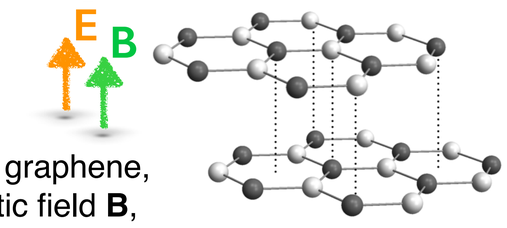


- Edge states gapped / gapless depending on the *edge phase*

➡ For comparison with experiments: No direct correspondence between *conductance* and *bulk phase*

2. Bilayer Graphene with Electric and Magnetic Fields

Setup:



Bilayer graphene,
Magnetic field **B**,
Electric field **E**,
Zero-energy states degenerate in Spin **S**, Valley isospin **T**, Landau Levels n = 0,1 (translates into an orbital isospin **L**)

Leading Question:

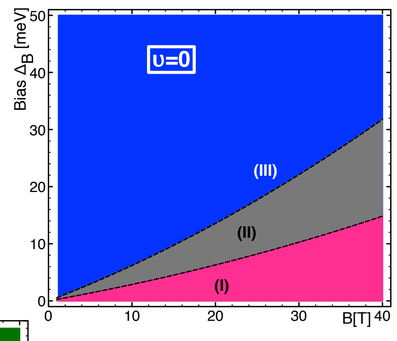
At different filling factors, ν, of the zero-energy states:

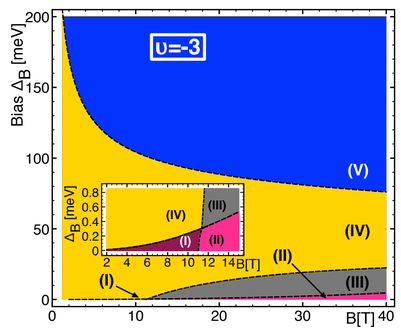
➡ For different B = |**B**| and bias $\Delta_B \propto$ |**E**| which spin and isospin configurations yield the ground state phase ?

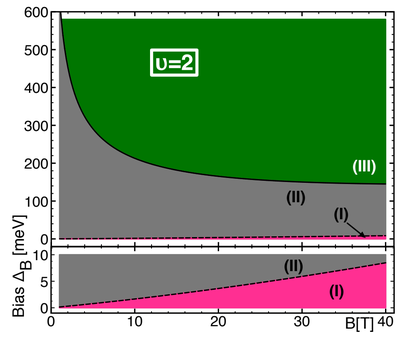
Results:

Phase diagrams for filling factors ν=-3,..,3

(three examples shown)







➡ Predicting a plethora of different ground state properties for different B and Δ_B:

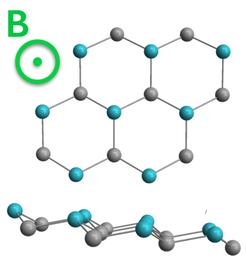
Magenta: **S** ∝ $\mathbf{e}_z$, **T** canted → valley coherence

Yellow: **S** ∝ $\mathbf{e}_z$, **L** canted → orbital coherence

Gray/Blue/Green: **S**,**T** ∝ $\mathbf{e}_z$ for **L** = 0 or **L** ∝ $\mathbf{e}_z$ → partial polarization

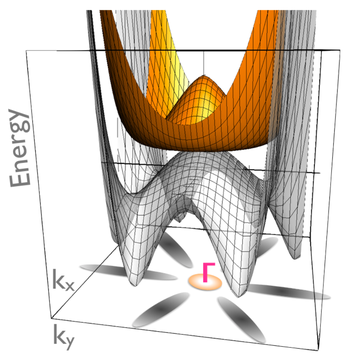
3. 2D Surface States of Crystals

Setup:



2D surfaces of crystals can support surface states with dispersions with an involved shape

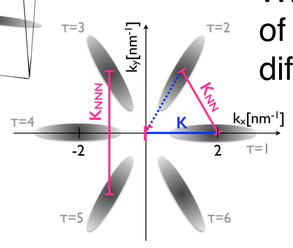
Example: (111) surface of Bi, 6 anisotropic valleys around the Γ-point



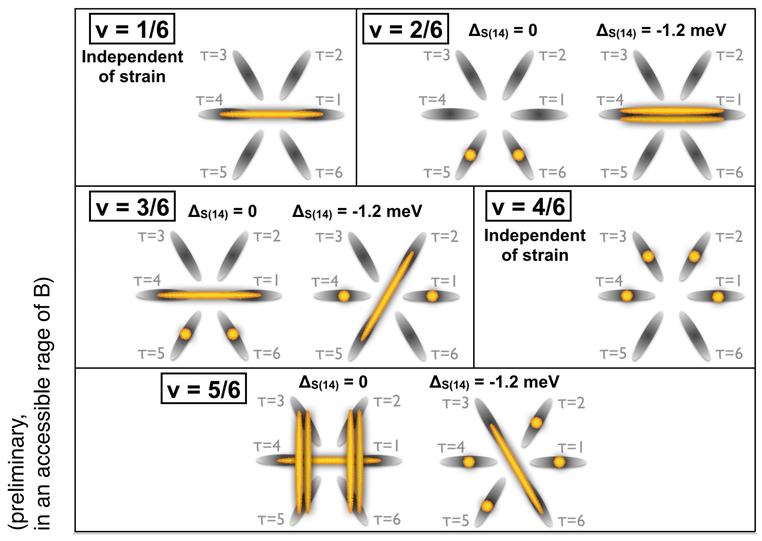
Leading Question:

For different filling factors, ν, and under the influence of local strain Δ_S:

➡ What is the valley ordering of the ground state within different valleys τ ?

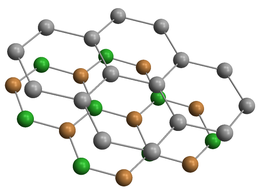


Results:



4. 2D Heterostructures

Setup:



Graphene on hBN, incommensurate lattices yield Moiré superlattice (SL) patterns

Periodicity of SL ~ magnetic length, allows for large values of flux per unit cell $\phi \sim \phi_0$ for reasonable B

Bands and LLs in the presence of the SL:

Fractal structure with reappearing Dirac mini bands

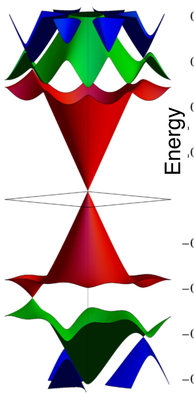
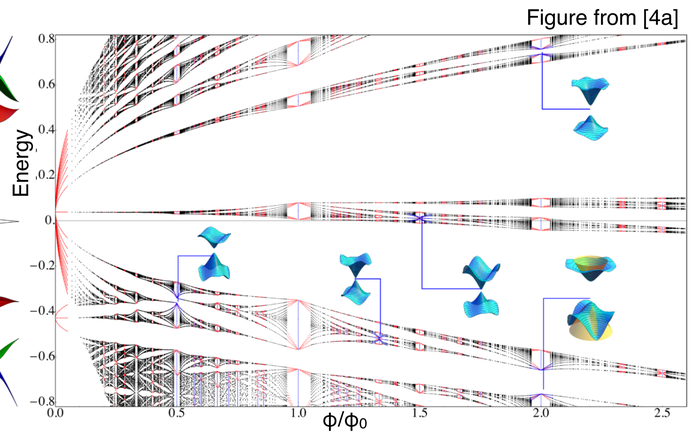
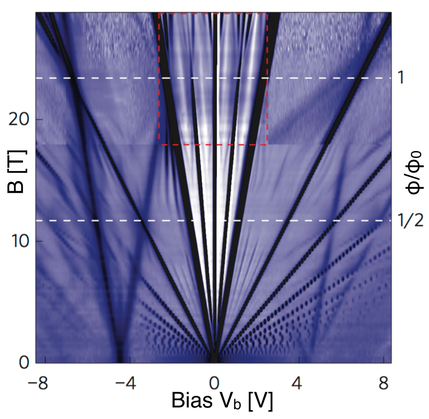


Figure from [4a]



Leading Question, Outlook:



Experimental evidence for interaction effects in the spectra of graphene on hBN (figure from [4b]):

➡ Influence of electron-electron interactions ?

Further Reading

[1] A. Knothe and T. Jolicœur, PRB 92, 165110 (2015)
[2] A. Knothe and T. Jolicœur, PRB 94, 235149 (2016)
[3] B. E. Feldman, A. H. MacDonald, Ali Yazdani, et al., Science 354, 316-321 (2016)
[4a] Xi Chen, J. R. Wallbank, E. McCann, V. I. Fal'ko, et al., PRB 89, 075401 (2014)
[4b] G. L. Yu, K. S. Novoselov, V. I. Fal'ko, A. K. Geim, et al., Nat. Phys. 10, 525–529 (2014)
[5] A. Knothe, Ph.D. Thesis, University of Freiburg (2017)

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