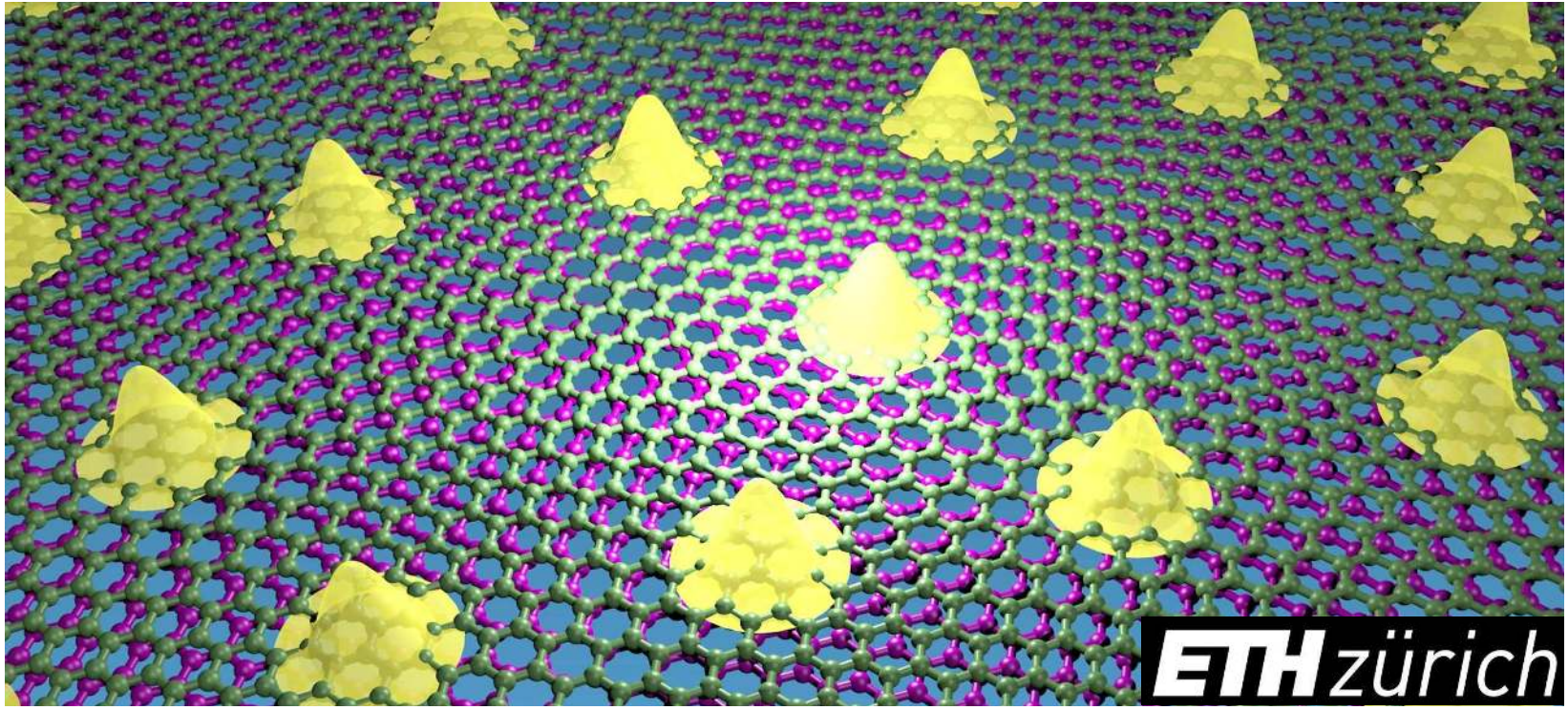
Electrically controllable Kagome lattices in tiny-angle twisted bilayer graphene

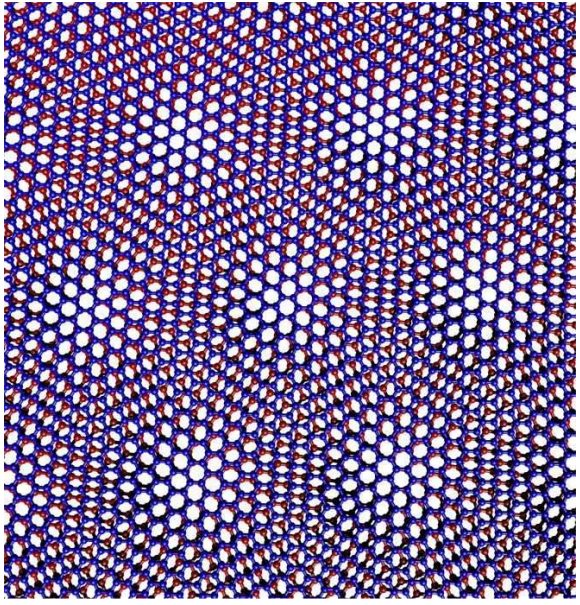
Jose Lado, ETH Zurich



Moire in Paris, June 4th 2019

A story of success, with a twist

Twisted graphene multilayers



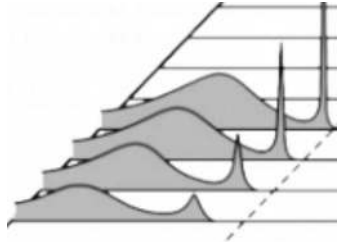
Superconductivity

Nature 556, 43–50 (2018)

Topological networks

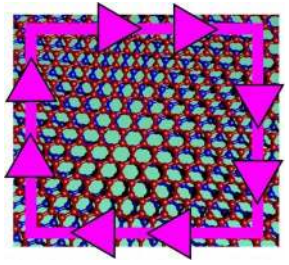
Nano Lett. 18, 11, 6725-6730 (2018)

Strange metals



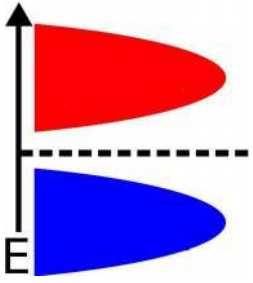
arXiv:1901.03710 (2019)

Anomalous Hall



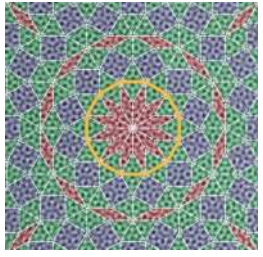
arXiv:1901.03520 (2019)

Correlated insulators



Nature 556, 80–84 (2018)

Quasicrystalline physics



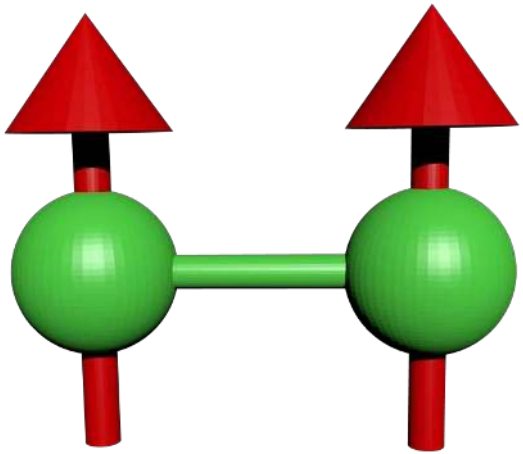
Science 361.6404 782-786 (2018)

Twisted graphene multilayers provide a powerful platform for emergent phenomena

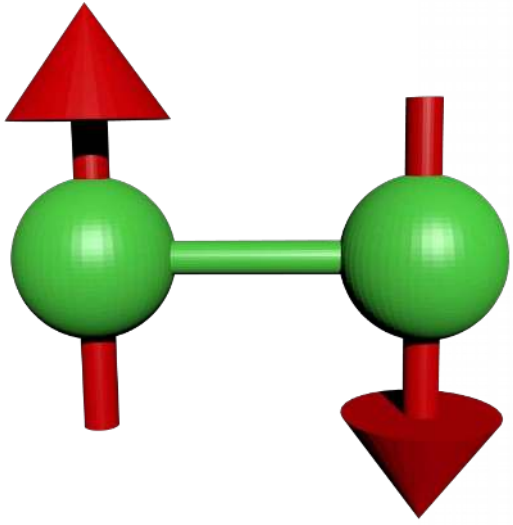
Frustration

A bird’s eye view on magnetism

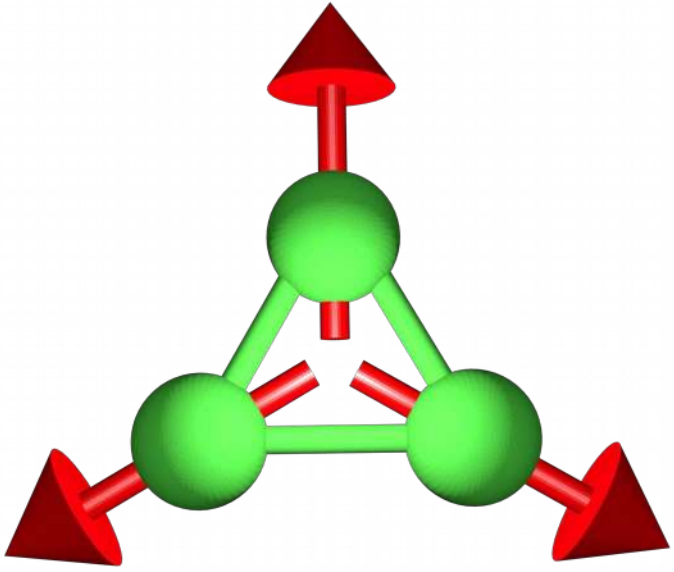
Ferromagnetism



Antiferromagnetism



Frustrated magnetism



Can we control the microscopic properties of a magnet?

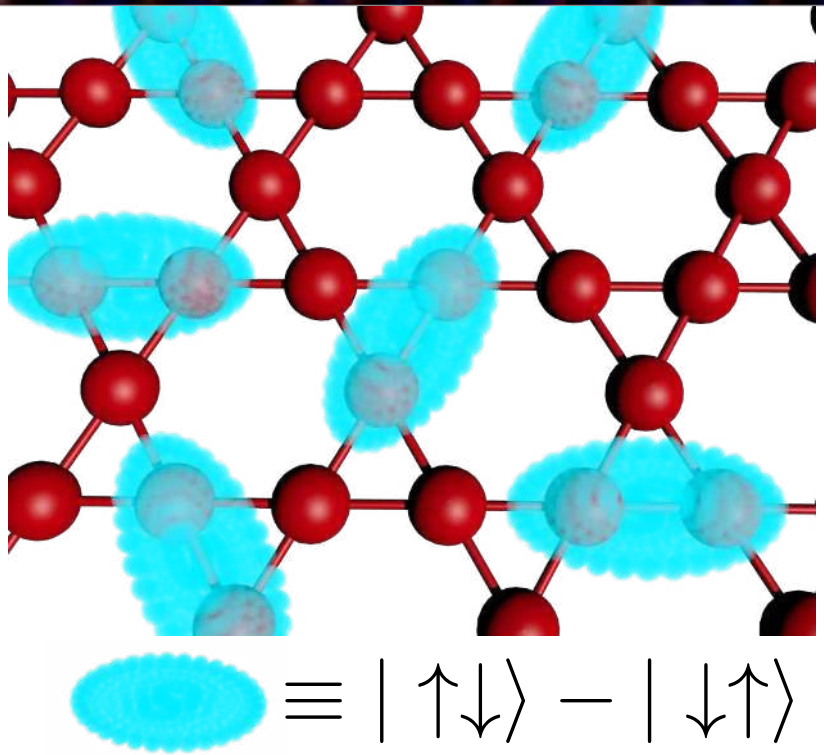
What is the best that can happen?

Quantum spin liquids

No magnetic ordering at T=0
Non-trivial topological properties
Fractional excitations
Macroscopic quantum state
“Ultra-quantum” matter

$$\mathcal{H} = \sum_{ij} \vec{S}_i \hat{J}_{ij} \vec{S}_j$$

Rep. Prog. Phys. 80, 016502 (2017)



$$\equiv |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

Kitaev’s honeycomb

Annals of Physics 321.1 (2006)

Kagome Heisenberg

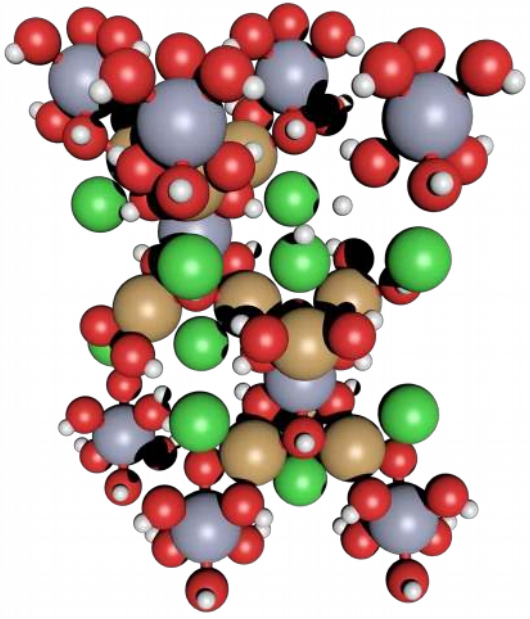
Science 332, 1173-1176 (2011)

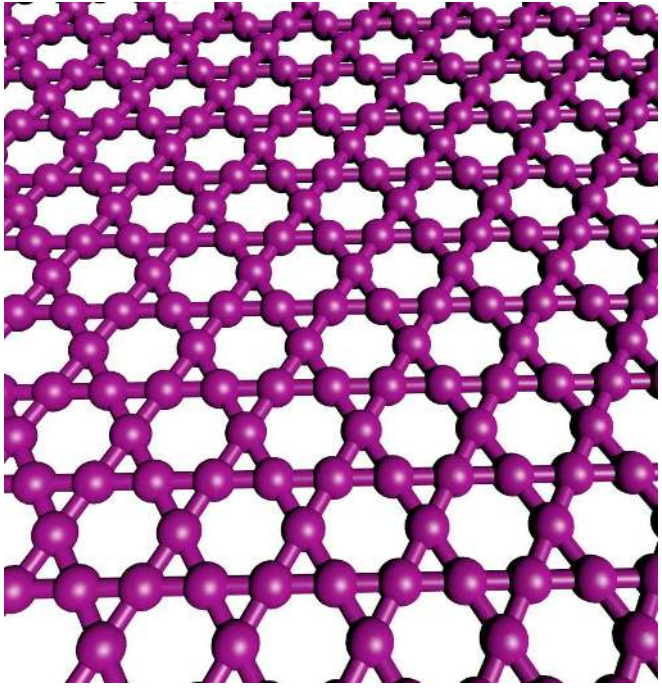
Extended triangular Heisenberg

J. Phys. Soc. Jpn 83, 093707 (2014)

A quest for frustrated quantum magnets

Herbertsmithite (Kagome)





Phys. Rev. Lett. 98, 107204 (2007)
Phys. Rev. Lett. 103, 237201 (2009)
Rev. Mod. Phys. 88, 041002 (2016)

A recipe for frustrated magnets

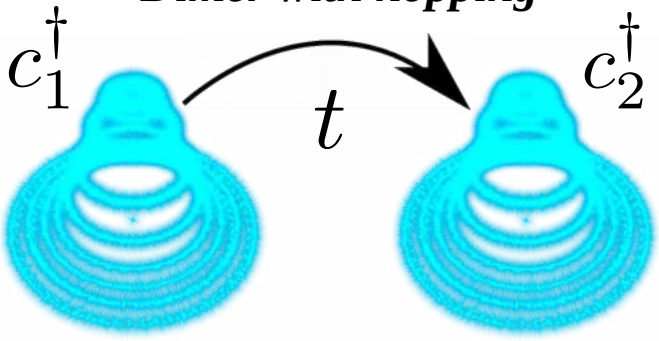
How to create a frustrated magnet

→ Localize electrons in a frustrated lattice

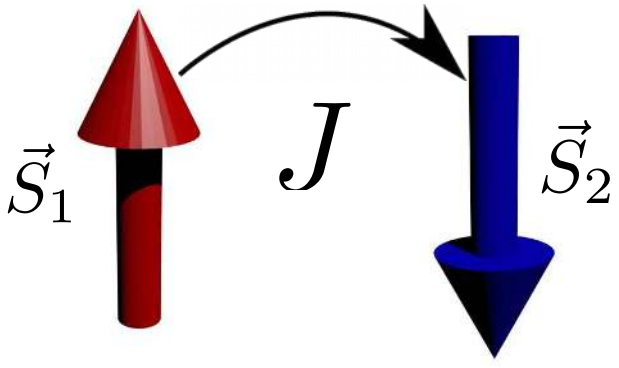
→ Add strong interactions

Building a magnet from scratch

Dimer with hopping



Heisenberg dimer



Interaction — Kinetic energy

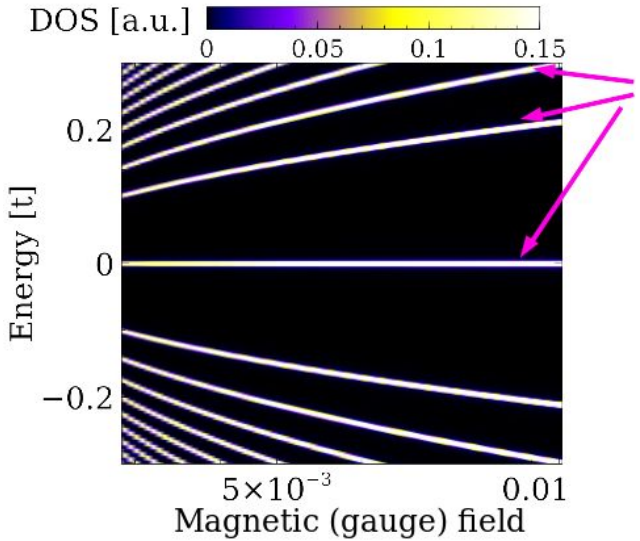
$$H = U \sum_i n_{i,\uparrow} n_{i,\downarrow} + t \sum_s c^\dagger_{1,s} c_{2,s} + h.c.$$

$$U \gg t \quad J \propto t^2/U$$

Spin Hamiltonian $\mathcal{H} = J \vec{S}_1 \cdot \vec{S}_2$

Ground state $|GS\rangle = \frac{1}{\sqrt{2}}(|\uparrow_1\downarrow_2\rangle - |\downarrow_1\uparrow_2\rangle)$

Building localized levels with artificial gauge fields



Localized states (Landau levels)

Localized pseudo Landau levels can be created with artificial gauge fields

Non-uniform strain in graphene

Physics Reports 496.4-5 (2010)

Non-abelian gauge field in TBG

Phys. Rev. Lett. 108, 216802 (2012)

Electric gauge field in biased TBG

Phys. Rev. Lett. 121, 146801 (2018)

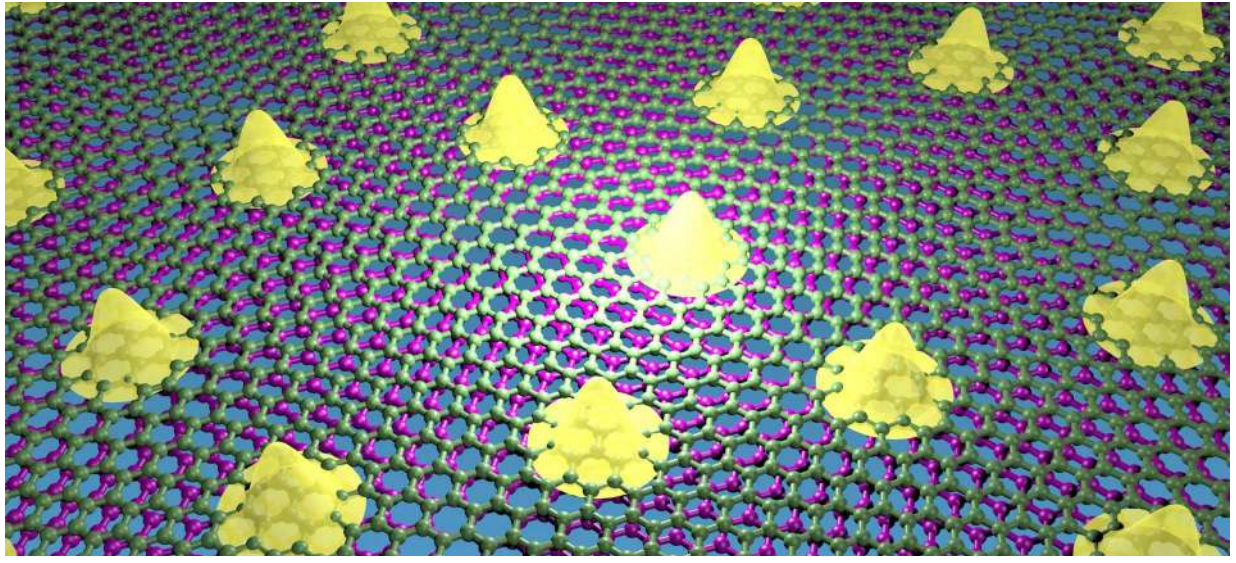
Moire patterns are a natural source of artificial gauge fields

Towards a Kagome lattice

Twisted 2D materials as a platform for controllable Kagome lattices

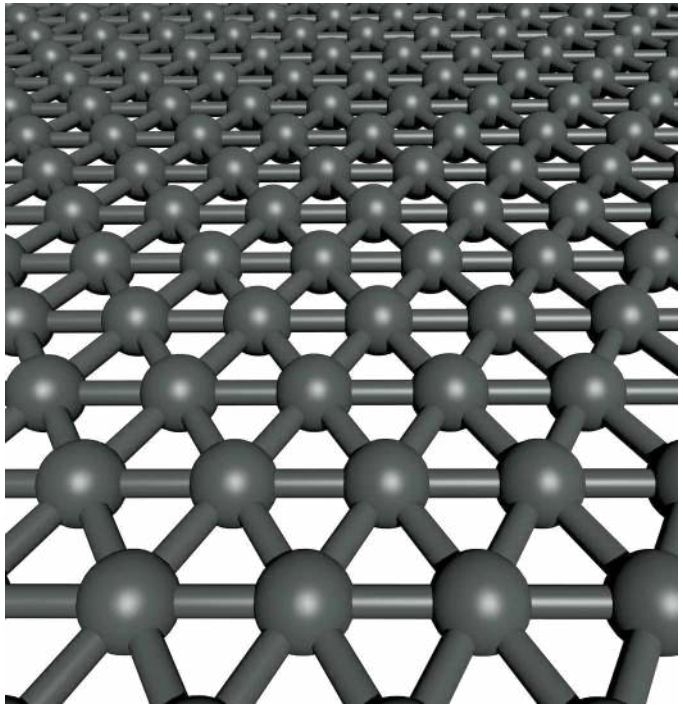
Electrically tunable Kagome lattices and gauge field in twisted bilayer grpahene

Aline Ramires



Aline Ramires and Jose lado, Phys. Rev. Lett. 121, 146801 (2018)

From triangular to Kagome



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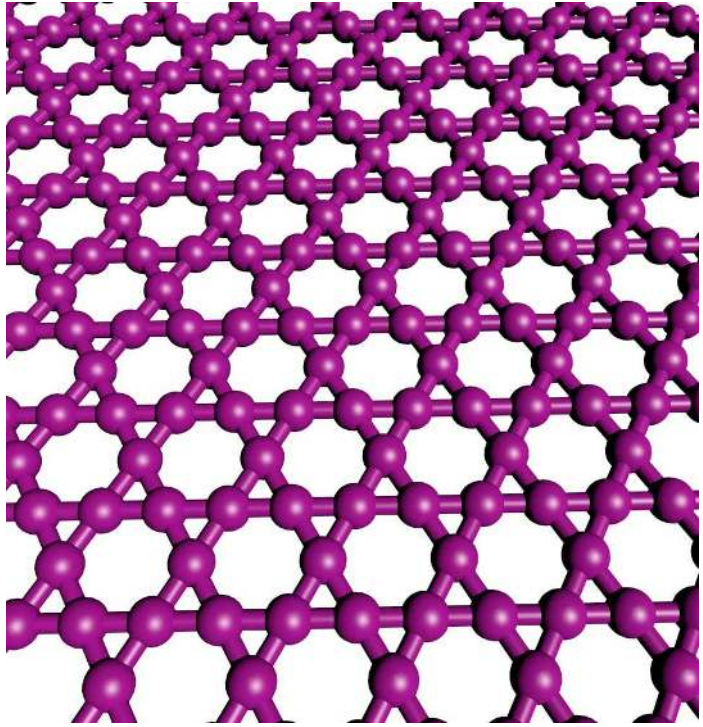
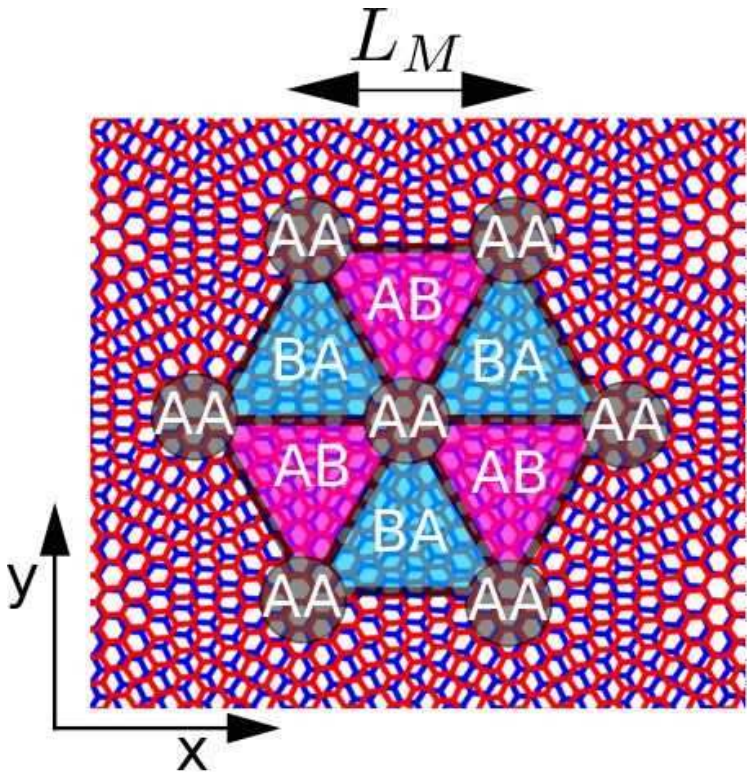
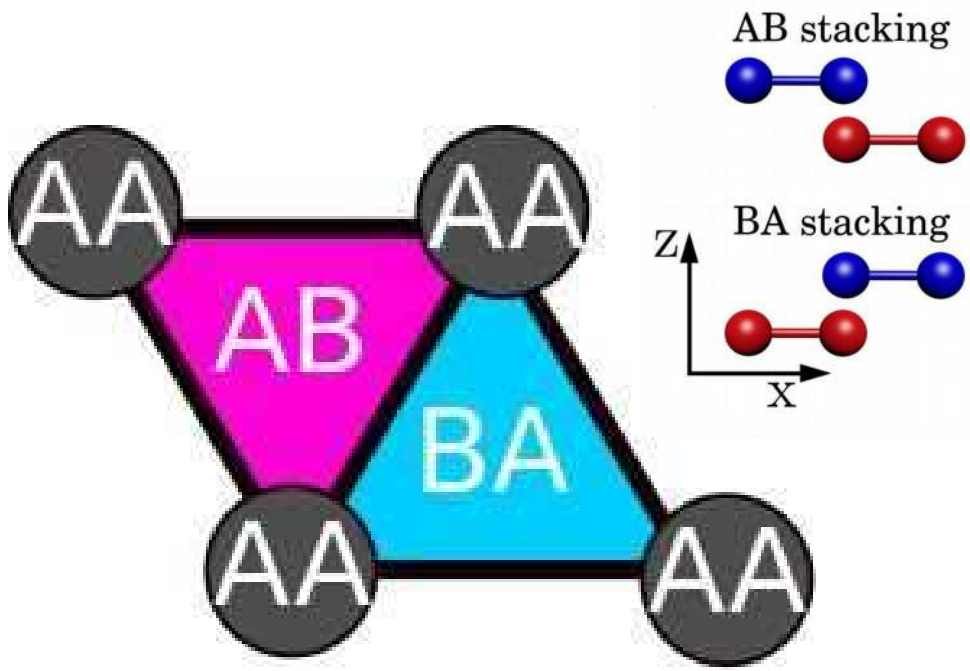


Can we generate additional gauge fields in twisted bilayers?

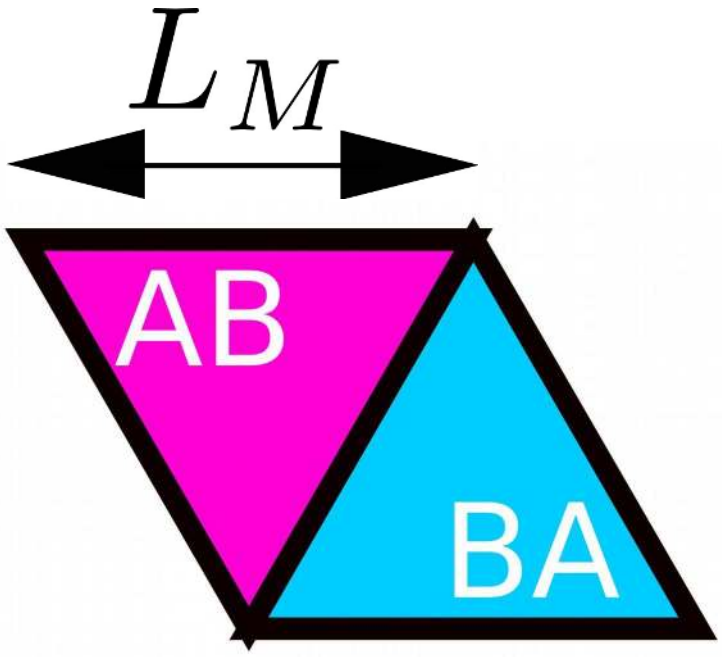
Towards a possible Kagome lattice

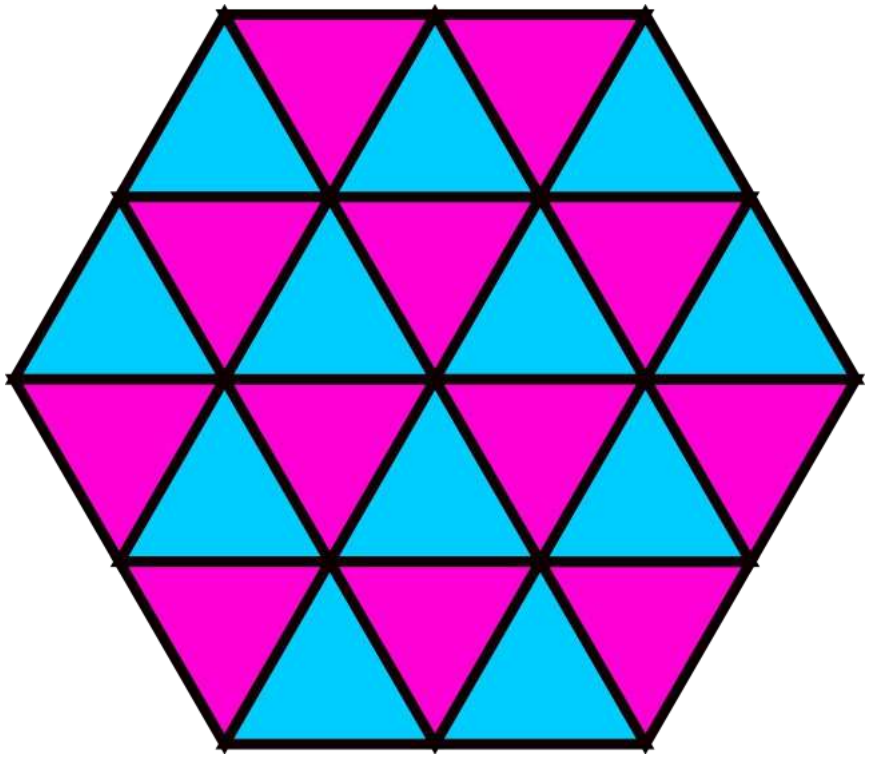




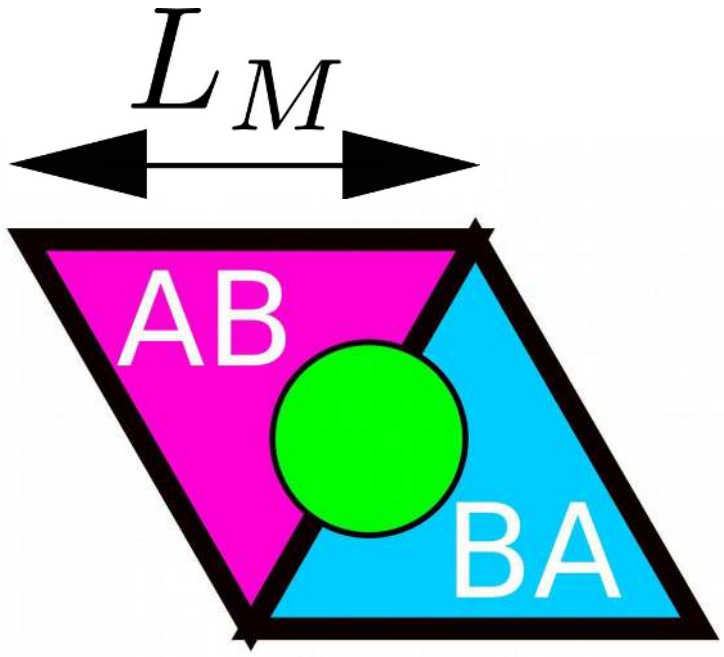
Let us look at the AB/BA structure

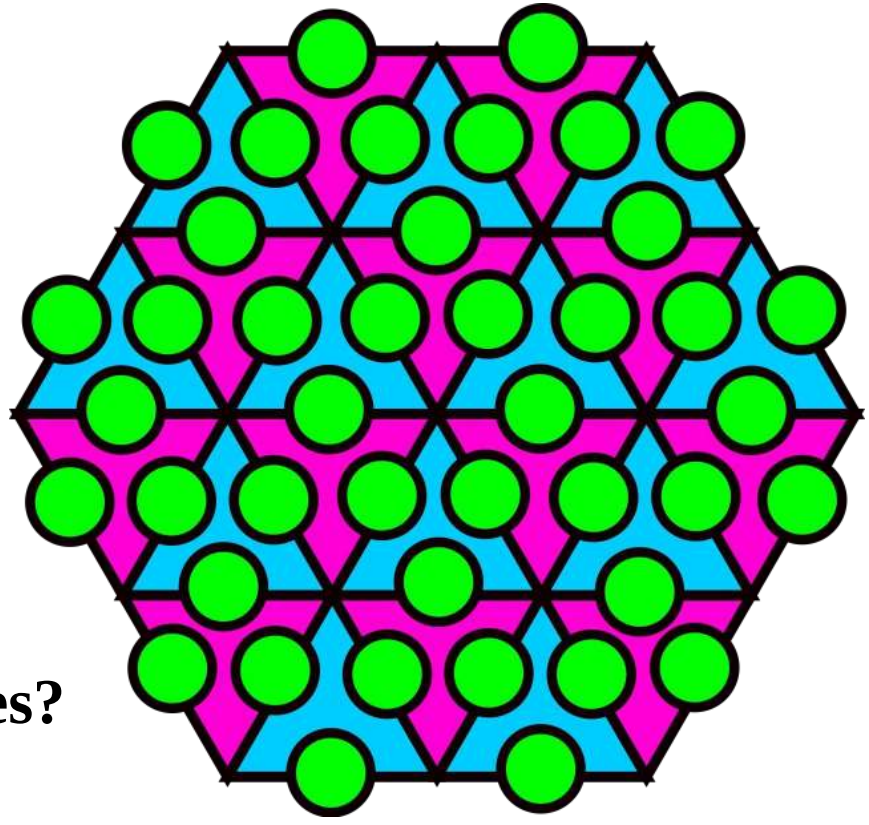
The possible Kagome lattice in TBG





The possible Kagome lattice in TBG

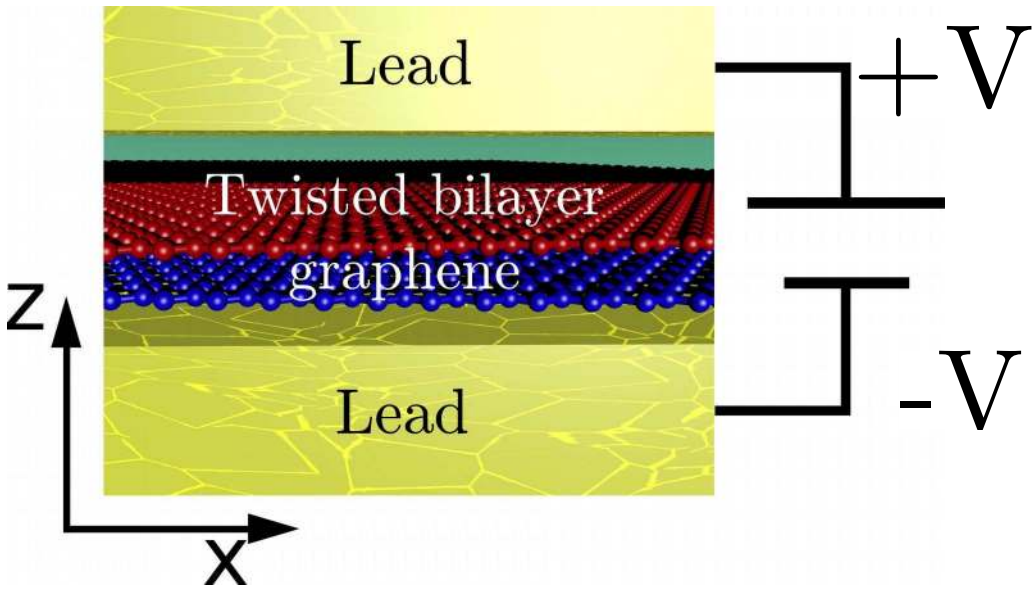


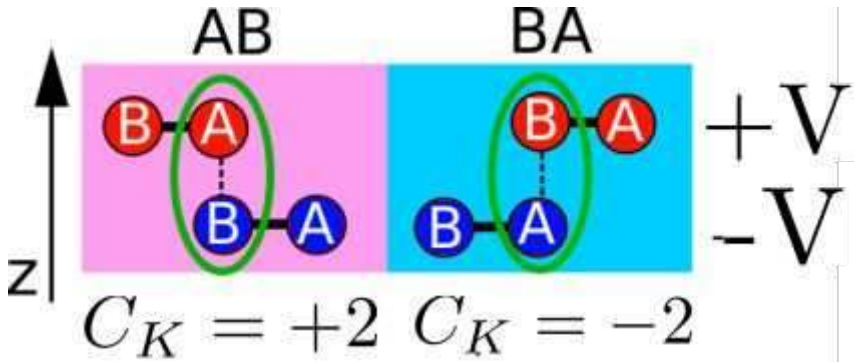


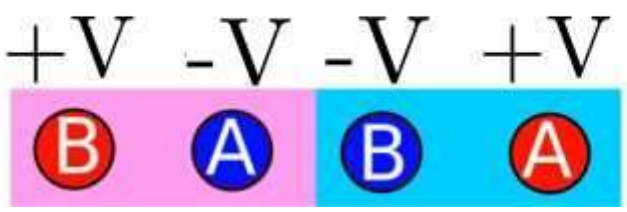
How do we generate such localized modes?

Electric gauge fields in TBG

$$\alpha \approx 0.3^\circ$$





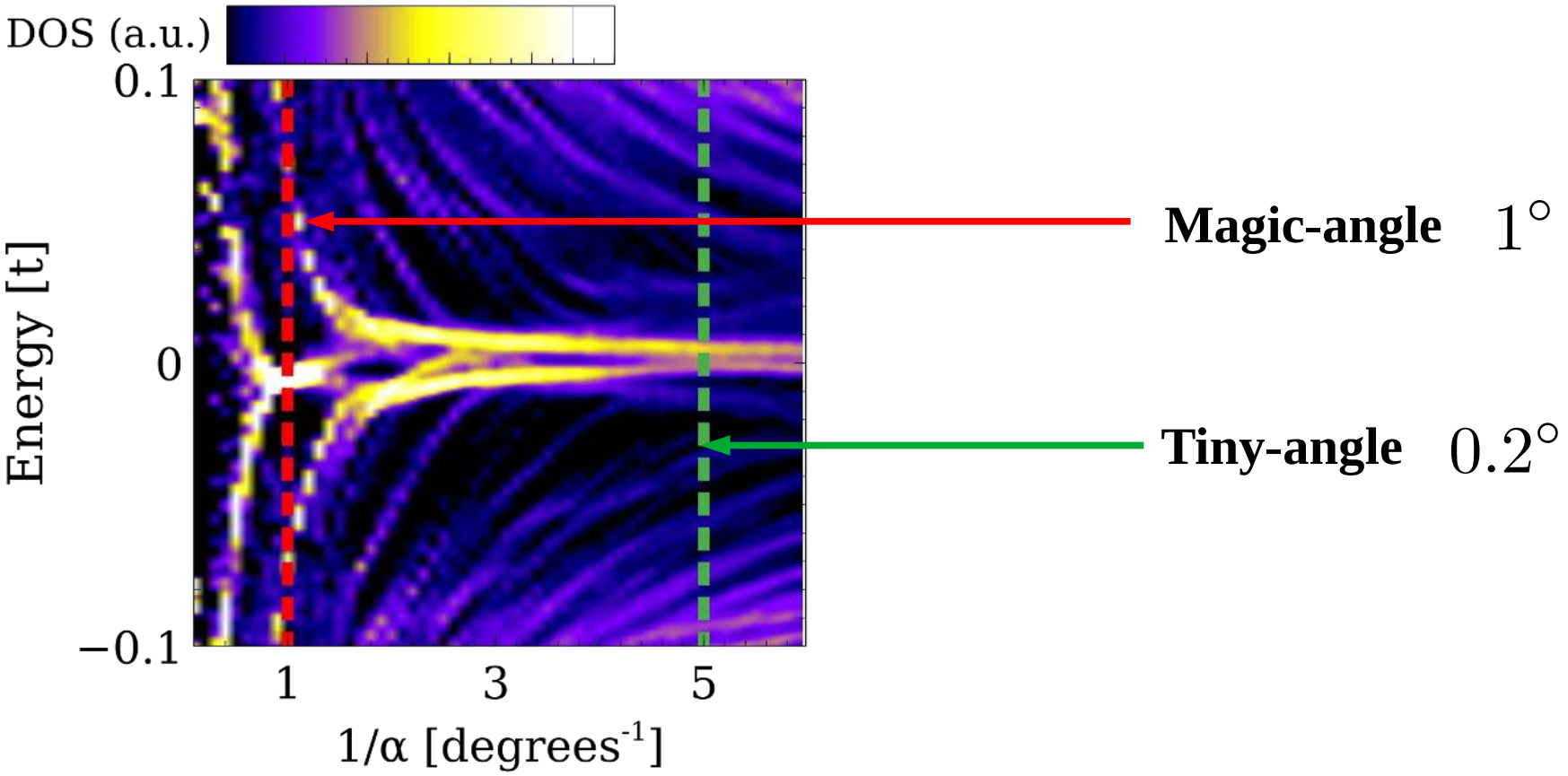


Electrically generated gauge field

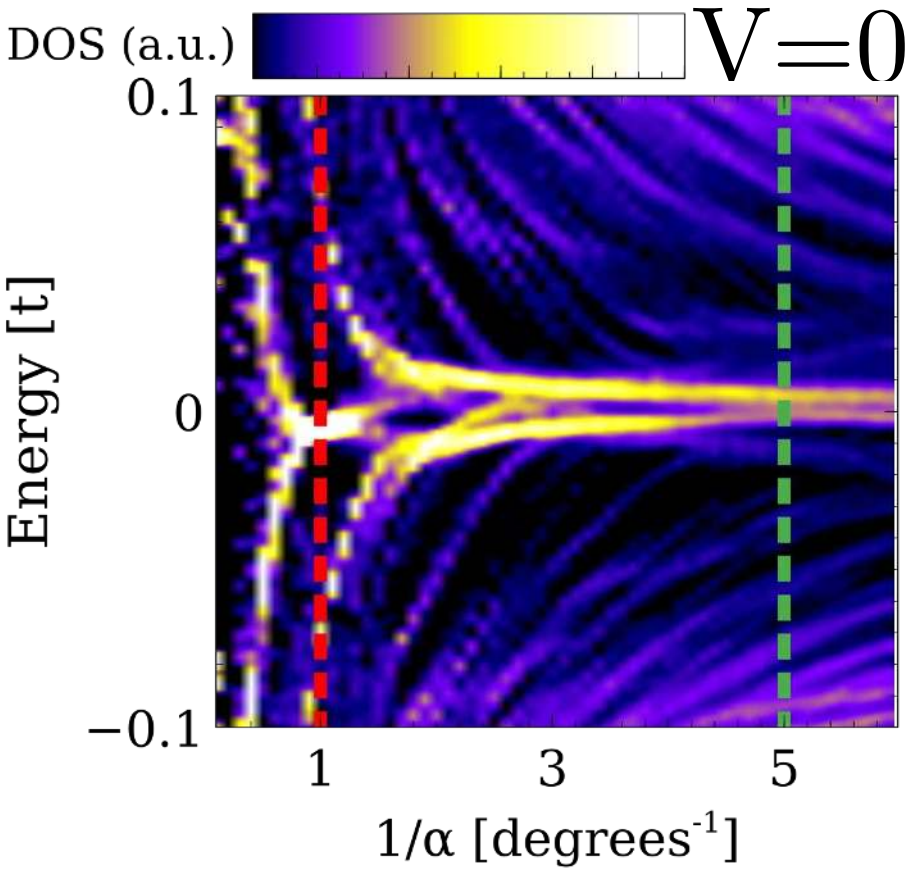
$$H(\vec{p}, \vec{R}) \rightarrow H(\vec{p} + \vec{A})$$

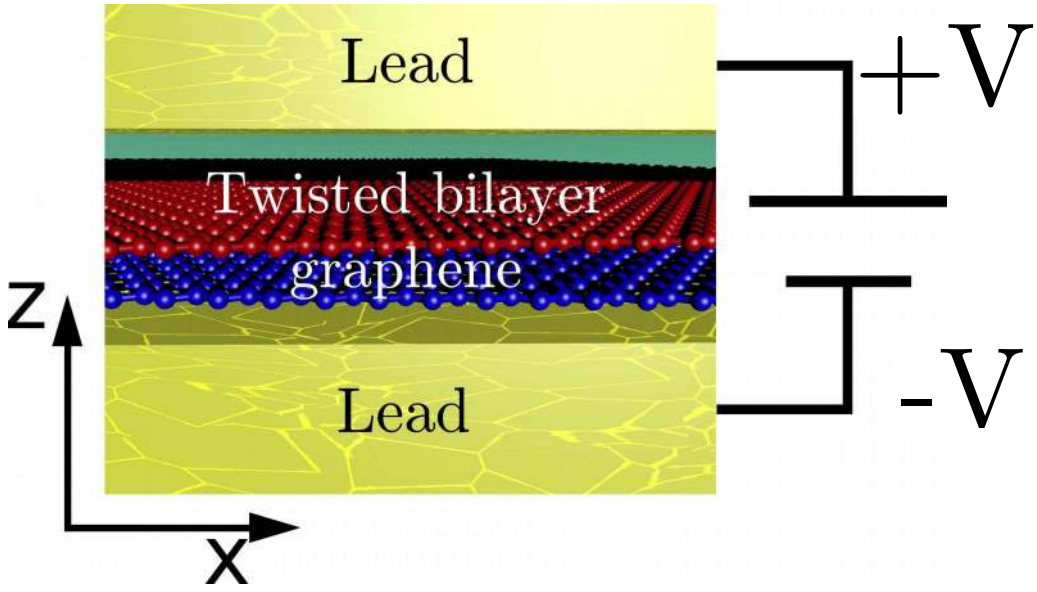
Phys. Rev. Lett. 121, 146801 (2018)

Diving into the tiny-angle regime

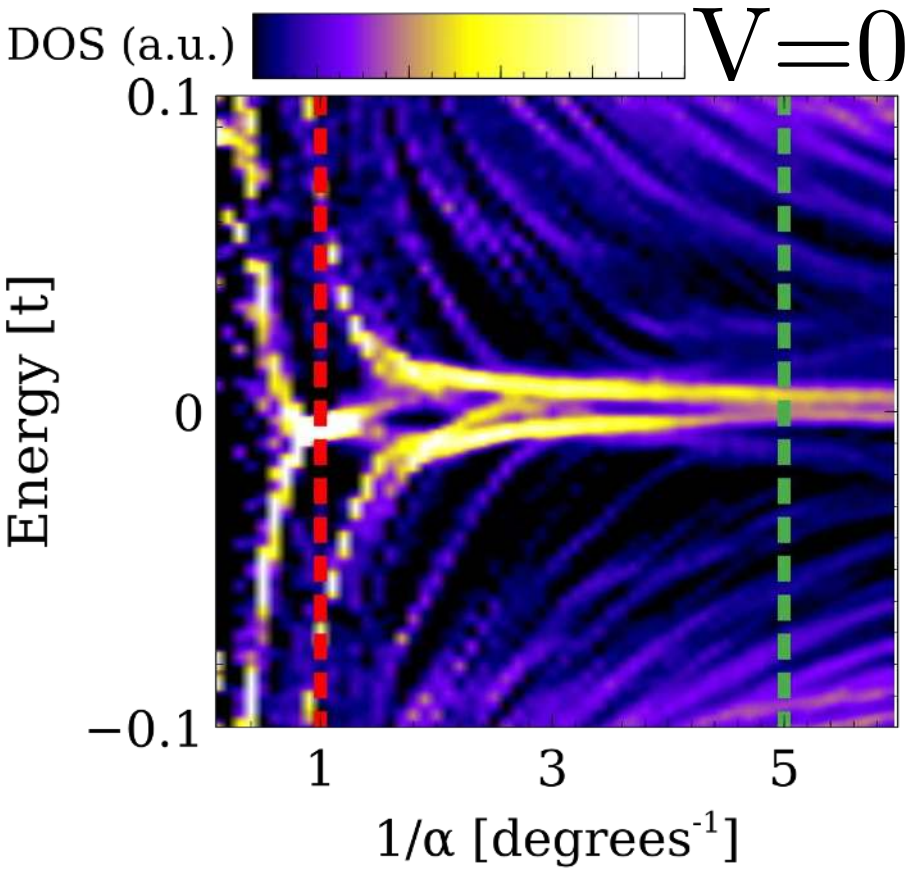


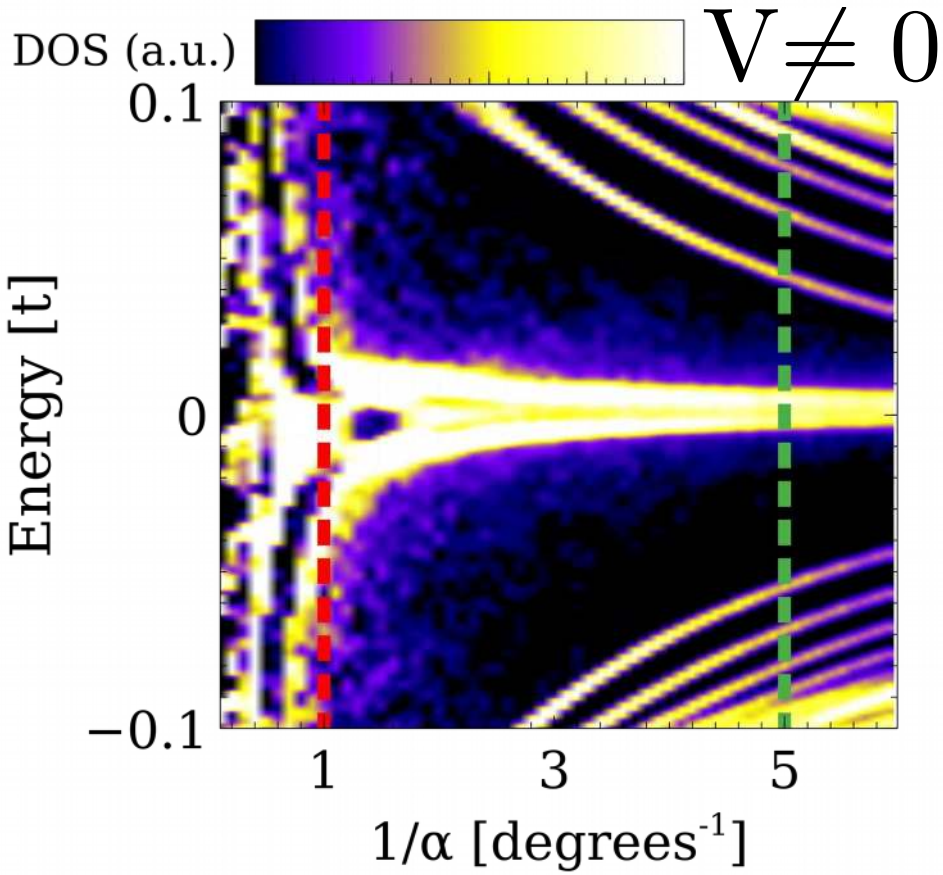
Diving into the biased tiny-angle regime



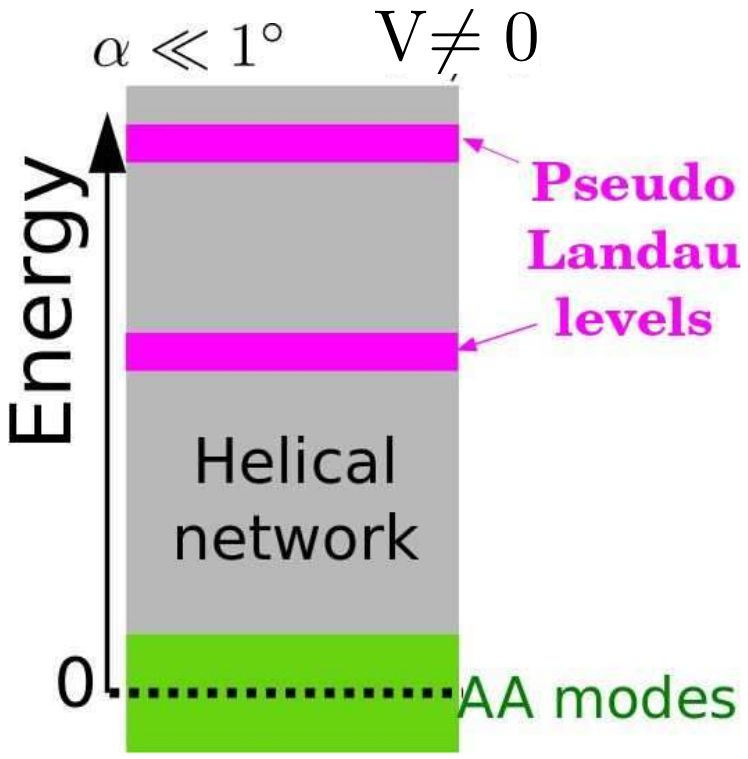


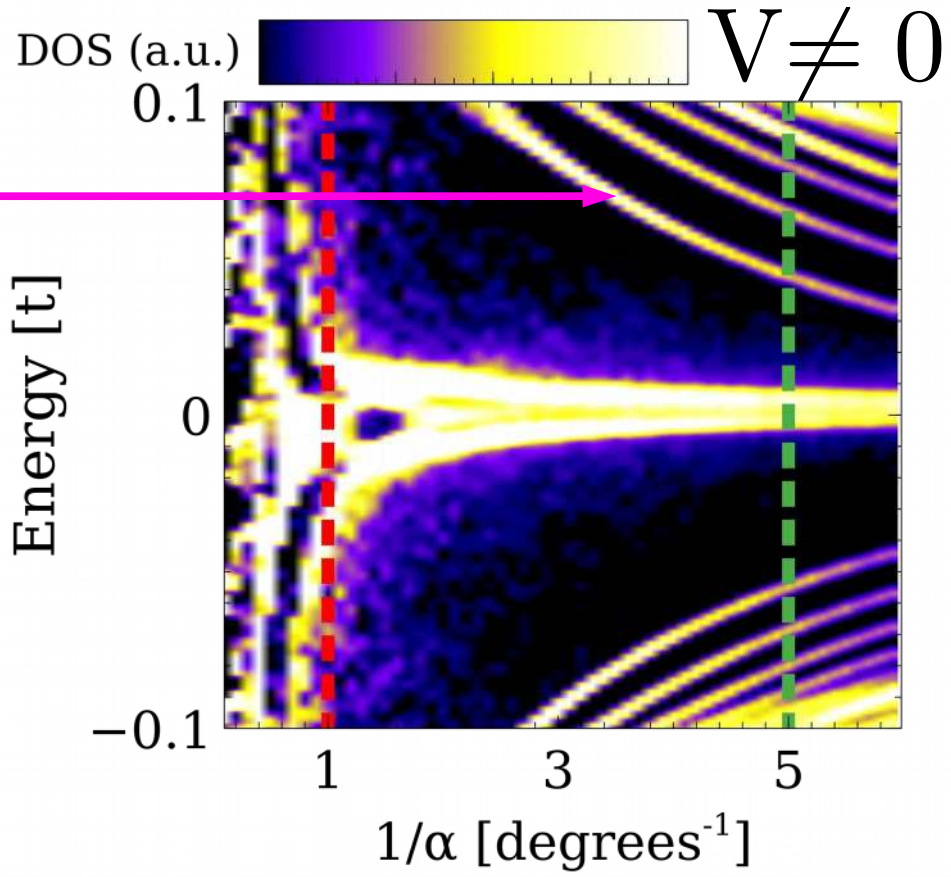
Diving into the biased tiny-angle regime





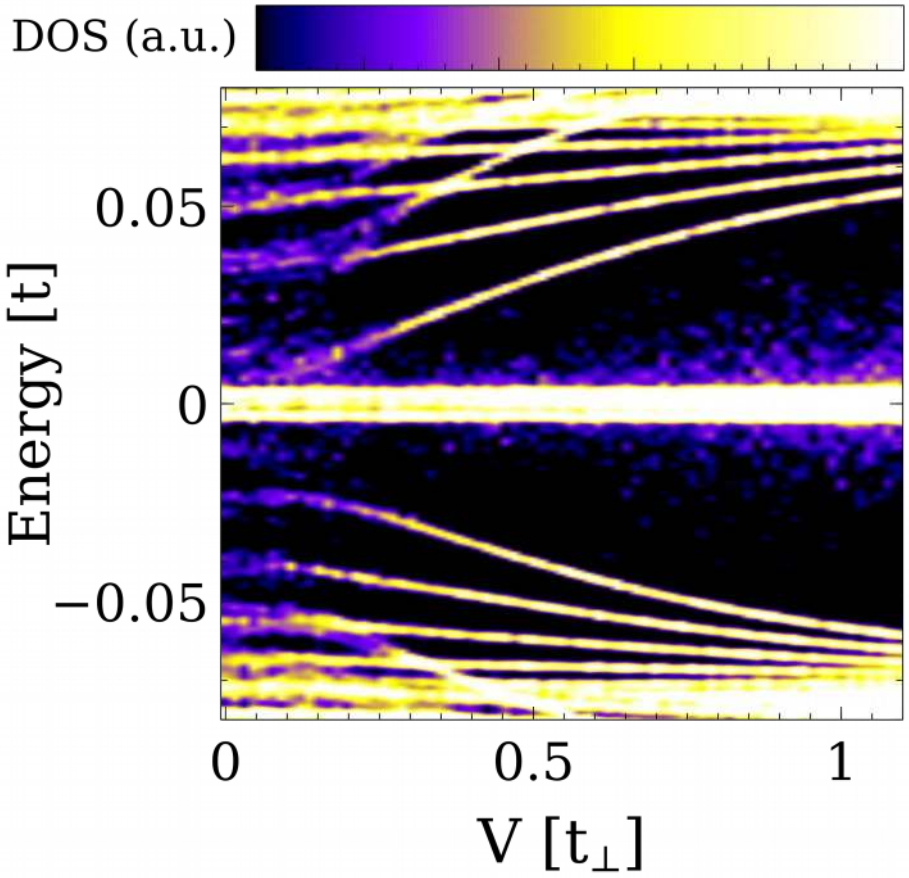
Diving into the biased tiny-angle regime

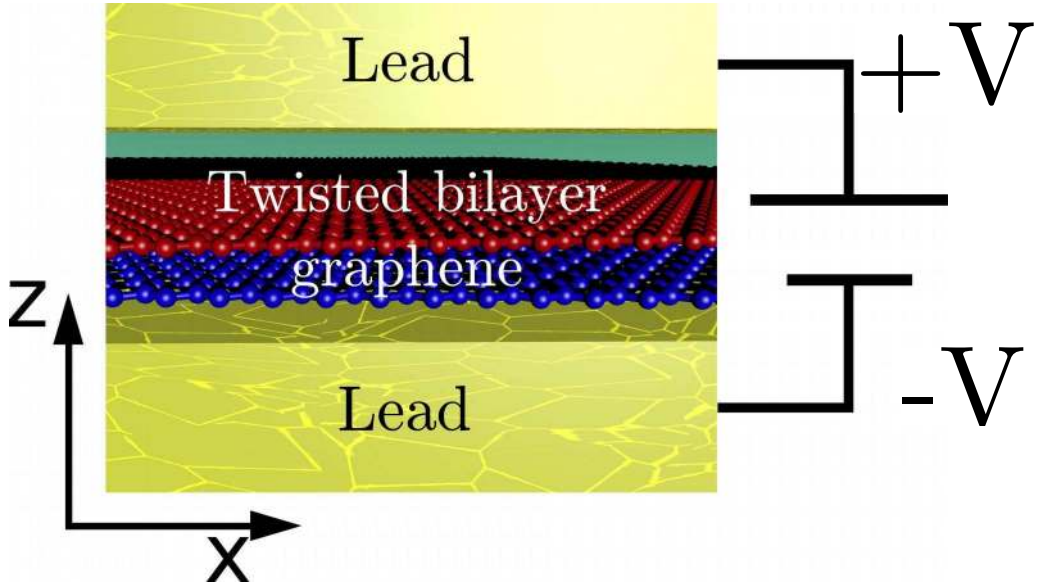




Phys. Rev. B 88, 121408 (2013)
Phys. Rev. Lett. 121, 146801 (2018)

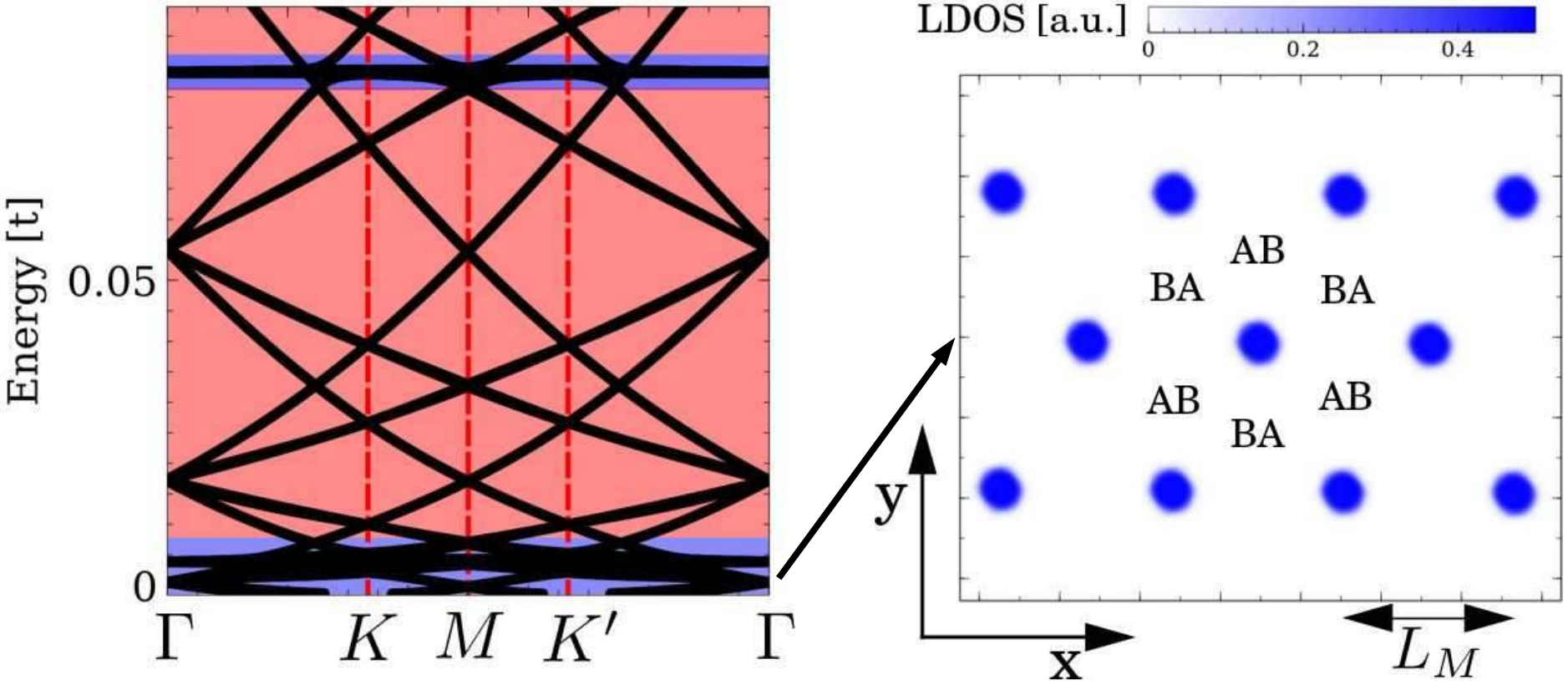
Controlling pseudo Landau levels electrically



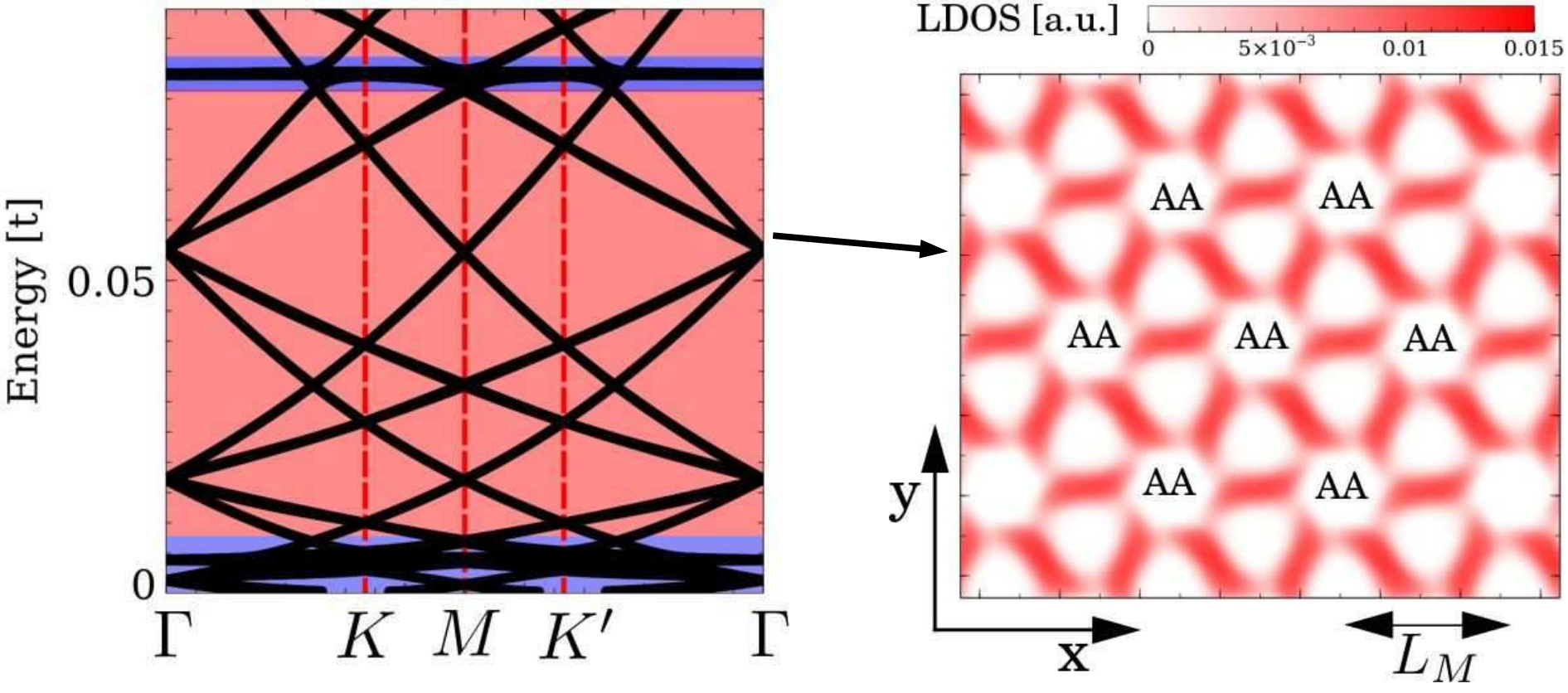


$$B_{eff} \propto V$$

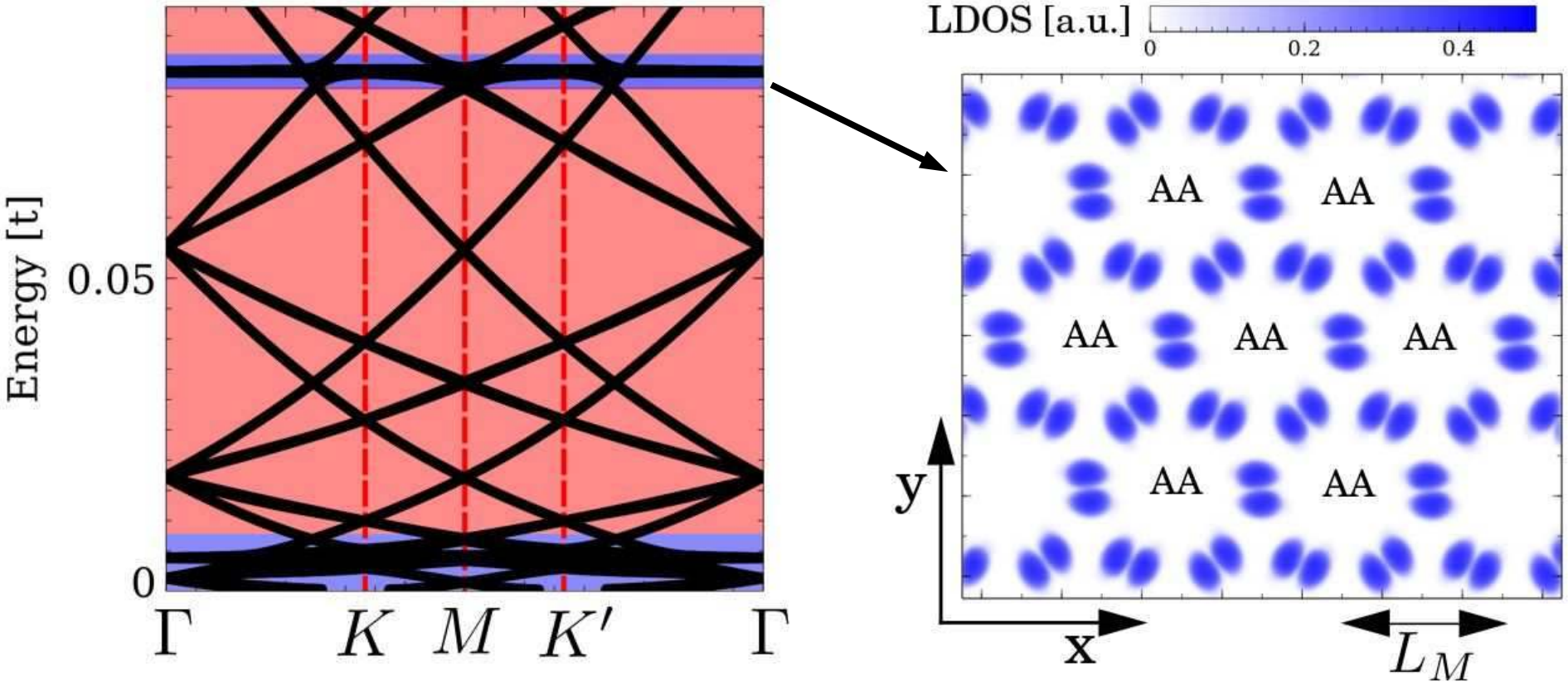
AA modes tiny angle TBG



Helical network in tiny angle TBG

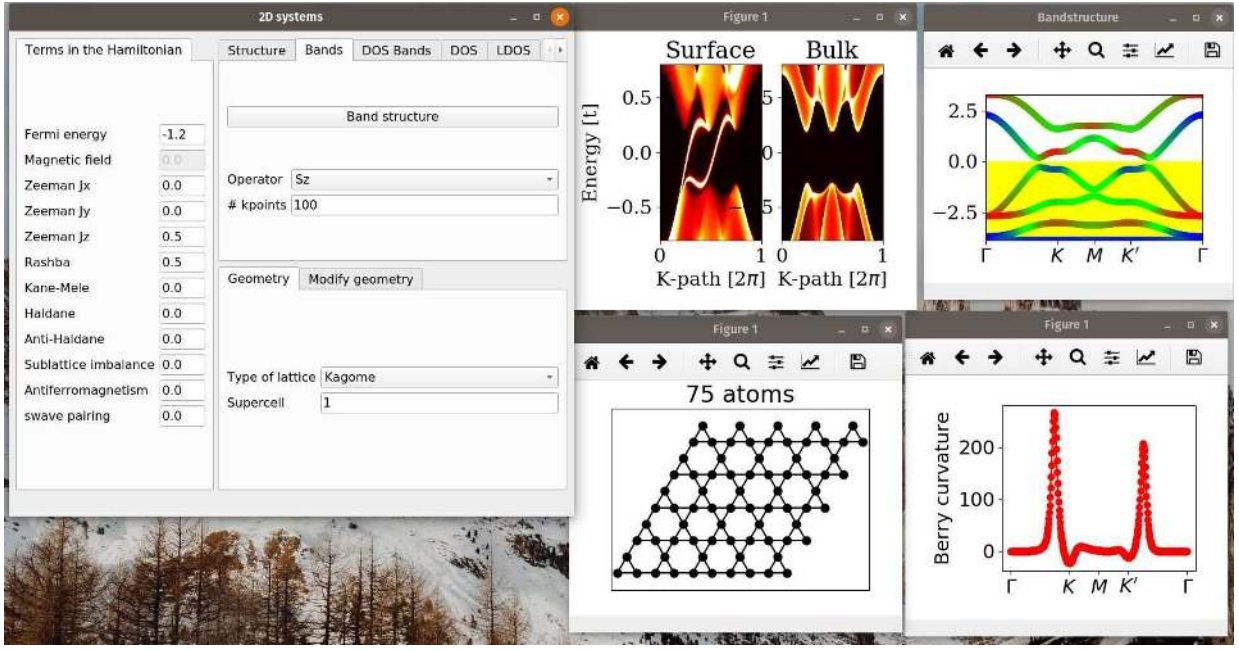


Pseudo Landau level in tiny angle TBG



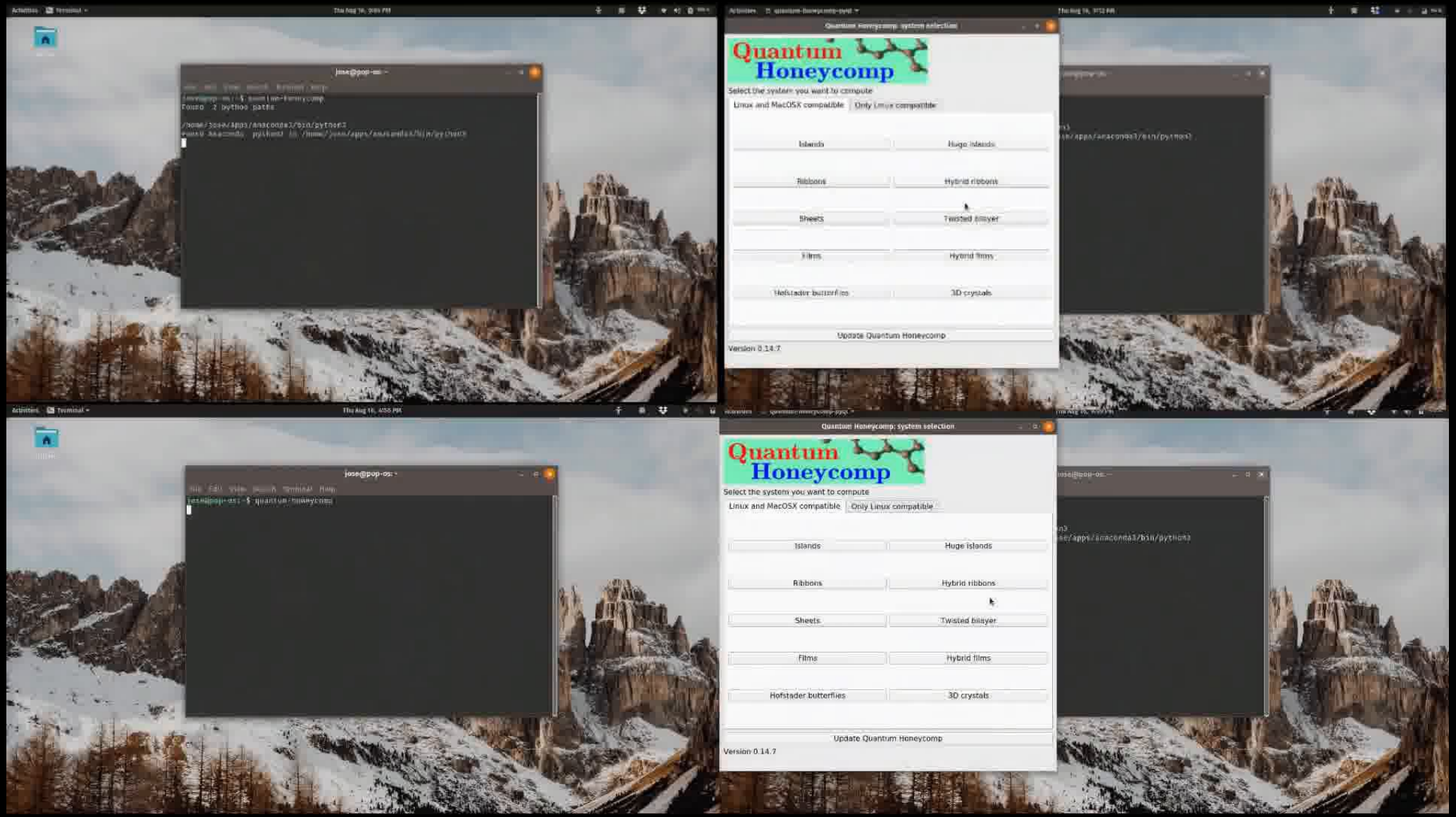
Computing electronic properties

A user interface to compute electronic properties

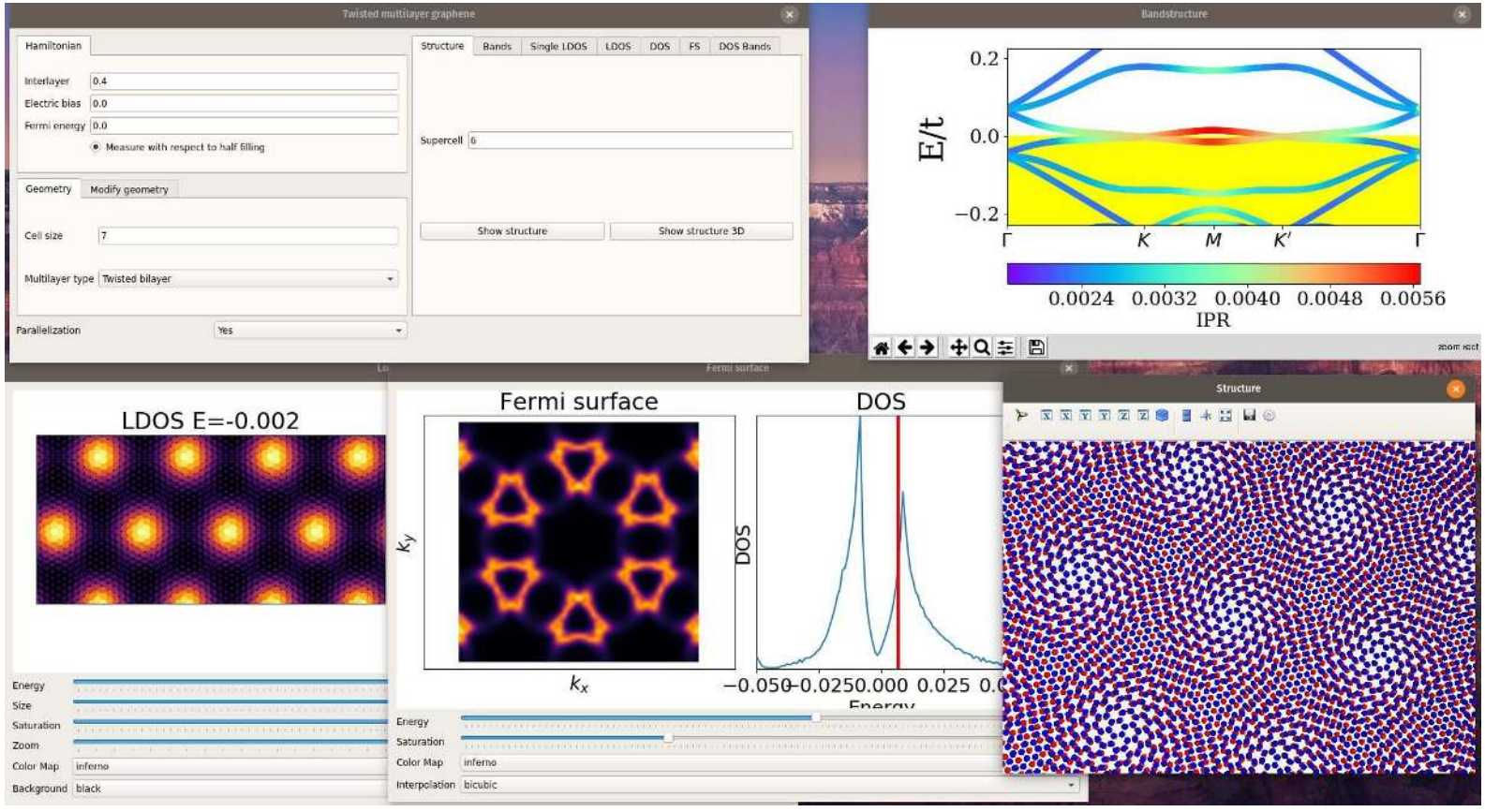


Quantum Honeycomp: open source interactive interface for tight binding modeling

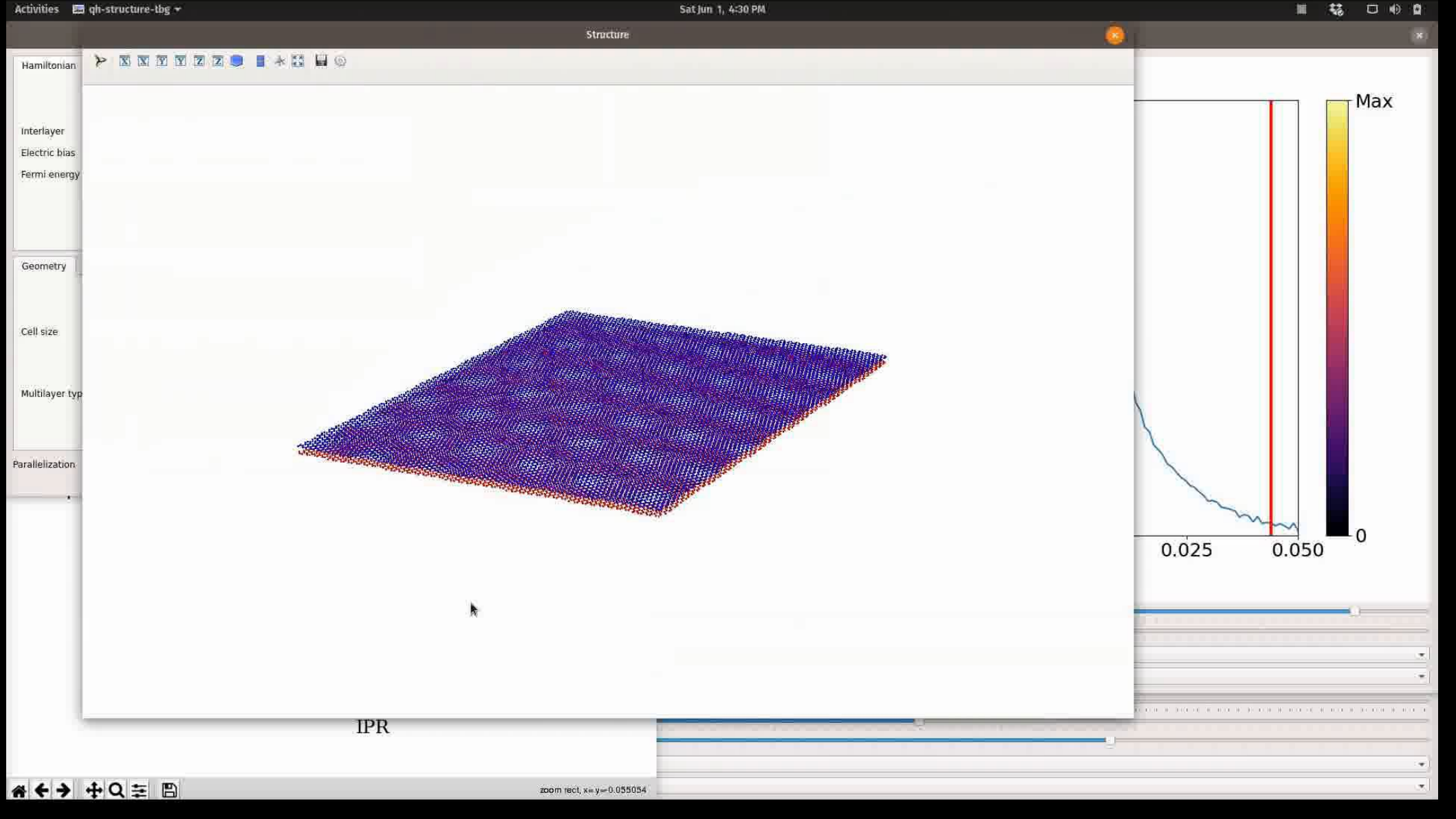
https://github.com/joselado/quantum-honeycomp


Quantum Honeycomp: system selection
Quantum Honeycomp
Select the system you want to compute
Linux and MacOSX compatible
Only Linux compatible
Islands
Huge islands
Ribbons
Hybrid ribbons
Sheets
Twisted bilayer
Films
Hybrid films
Hofstader butterflies
3D crystals
Update Quantum Honeycomp
Version 0.14.7

Twisted bilayer with the user interface

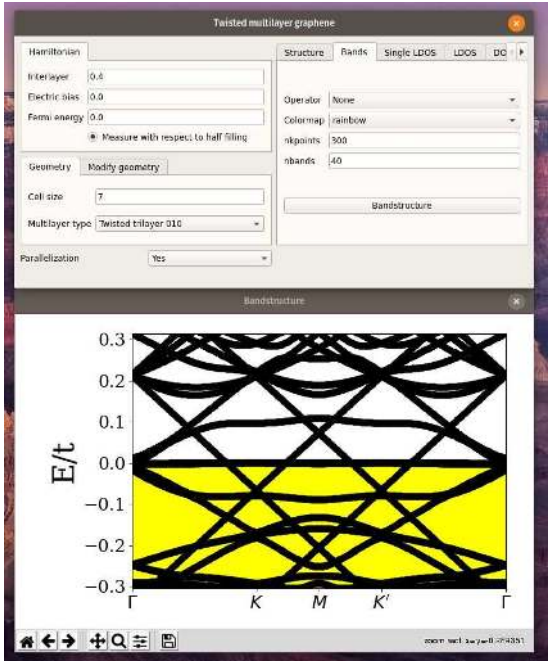


https://github.com/joselado/quantum-honeycomp

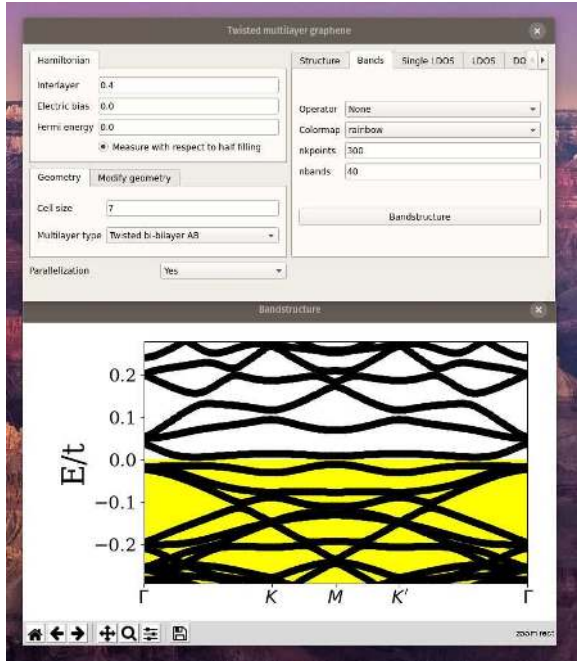

Activities
qh-structure-tbg
Sat Jun 1, 4:30 PM
Structure
Hamiltonian
Interlayer
Electric bias
Fermi energy
Geometry
Cell size
Multilayer typ
Parallelization
Max
0
0.025
0.050
IPR
zoom rect, x=y=0.055054

Twisted multilayers

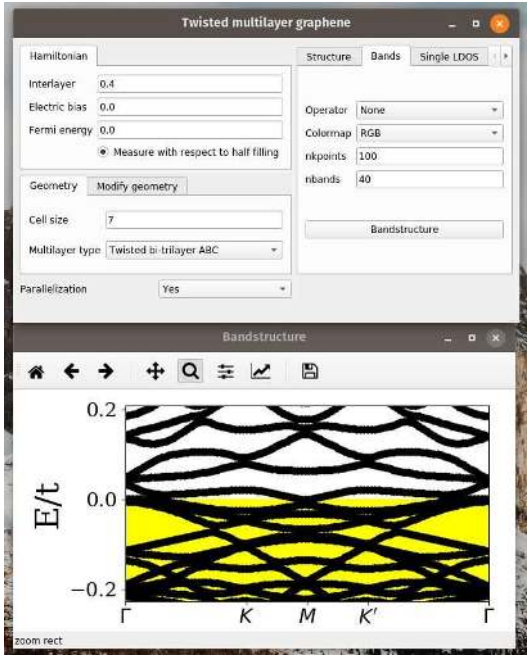
Twisted trilayer graphene



Twisted bi-bilayer graphene



Twisted bi-trilayer graphene



https://github.com/joselado/quantum-honeycomp

Take home

Twisted bilayer graphene opens up a route to create electrically controllable Kagome lattices

Financial support from the ETH Fellowship program

Phys. Rev. Lett. 121, 146801 (2018)