Electrically controllable Kagome lattices in tiny-angle twisted bilayer graphene

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A story of success, with a twist

Twisted graphene multilayers

Superconductivity

Topological networks

Strange metals

Anomalous Hall

Correlated insulators

Quasicrystalline physics

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

\[ \mathcal{H} = \sum_{i,j} \vec{S}_i \cdot \hat{J}_{ij} \cdot \vec{S}_j \]


Kitaev’s honeycomb

Kagome Heisenberg
Science 332, 1173-1176 (2011)

Extended triangular Heisenberg
A quest for frustrated quantum magnets

Herbertsmithite (Kagome)

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

Interaction

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

Kinetic energy

\[ U \gg t \quad J \propto t^2 / U \]

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


Non-abelian gauge field in TBG


Electric gauge field in biased TBG

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 graphene

Aline Ramires

From triangular to Kagome

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

$\alpha \approx 0.3^\circ$

Twisted bilayer graphene

Lead

$\begin{align*}
+V \\
- V \\
\end{align*}$

$C_K = +2 \quad C_K = -2$

$\begin{align*}
+V & \quad -V \\
- V & \quad +V \\
\end{align*}$

Electrically generated gauge field

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

Diving into the tiny-angle regime

Magic-angle 1°

Tiny-angle 0.2°
Diving into the biased tiny-angle regime

DOS (a.u.)

$V=0$

Energy [t]

$0$

$-0.1$

$1/\alpha$ [degrees$^{-1}$]

Lead

Twisted bilayer graphene

Lead

+$V$

$-V$
Diving into the biased tiny-angle regime

For $V = 0$:

For $V \neq 0$:
Diving into the biased tiny-angle regime

\[ \alpha \ll 1^\circ \quad V \neq 0 \]

Pseudo Landau levels

Helical network

AA modes

DOS (a.u.)

Energy [t]

\[ 1/\alpha \ [\text{degrees}^{-1}] \]

Controlling pseudo Landau levels electrically
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
Twisted bilayer with the user interface

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

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