Internship/PhD topic: Unconventional Superconductivity in Twisted Bilayer Graphene

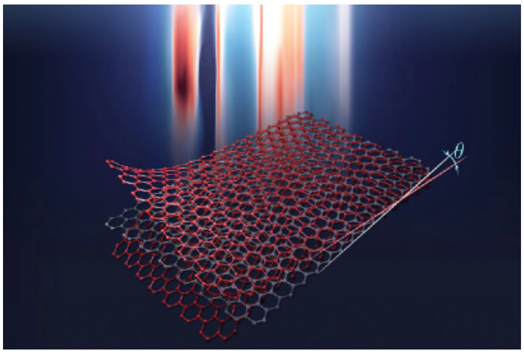
Lab: Structures, Properties and Modelling of Solids (SPMS)

Supervision: The thesis will be co-supervised by Dganit MEIDAN from SPMS/CS and Cosimo GORINI from SPEC/CEA.

Keywords: Topological quantum matter, Quantum anomalous Hall effect, Superconductivity, Twisted bi-layer graphene.

Quick summary of the internship/thesis project:

Context: Van der Waals heterostructures are emerging as a platform for next-generation quantum technologies and for uncovering extraordinary states of matter. One of the most celebrated examples is bilayer graphene twisted at the so-called magic angle. At this special angle electronic bands become flat, which slows down the motion of electrons and greatly amplifies their interactions. Twisted "magic-angle graphene" hosts a wealth of remarkable behaviors, including exotic band topology, strong correlation effects, and unconventional superconductivity. Many experiments have revealed these striking quantum effects, but exactly what's happening at the microscopic level is still a mystery.



Twisted trilayer graphene. Credit: Polina Shmatkova and Margarita Davydova

Our experimental collaborators have recently discovered a unique twisted superconductor that is strengthened by an external magnetic field. This is unusual since a magnetic field typically suppresses superconductivity by breaking the time-reversal symmetry that protects Cooper pairs.

A different context in which magnetic field can enhance conductivity is found in Chern insulators, which exhibit the anomalous quantum Hall effect. Individually, both the intrinsic breaking of time-reversal symmetry—responsible for the anomalous Hall effect—and an applied external magnetic field tend to suppress conductivity. Yet, when these two effects compete, their interplay can instead enhance conductivity, giving rise to a metallic state. Twisted heterostructures are a promising candidates for Chern insulators and quantized anomalous Hall states have been observed in bilayer and trilayer graphene aligned with hBN [1–4].

Research question: Can the interplay between band topology and magnetic field account for this distinctive superconducting behavior? What are the properties of this emergent and unconventional superconducting state?

Project: We will address these questions using a combination of analytical and numerical tools. Starting from a lattice mean-field model for the twisted bi-layer Graphene that exhibits the quantum anomalous Hall effect, incorporating both a magnetic field and superconducting pairing. We will first analyze superconducting pairing within the mean-field approximation. Then, we will test the validity of our assumptions using a self-consistent mean-field approach. We will study the electrical response of the system extending advanced schemes developed for the quantum transport simulation Kwant [5].

Methods:

Analytical tools: BSC mean field theory, tight binding, linear response, proficiency in Python.
Numerical simulations: using Kwant

Contact: Interested candidates can send a CV, and motivation letter to:
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Bibliography:

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[4] Grover, S., Bocarsly, M., Uri, A. et al. Chern mosaic and Berry-curvature magnetism in magic-angle graphene. Nat. Phys. 18, 885–892 (2022).
[5] Raphael Kozlovsky , Ansgar Graf, Denis Kochan, Klaus Richter, and Cosimo Gorini Phys. Rev. Lett. 124, 126804 (2023)