IS2M-CNRS-UHA. Mulhouse - Team: Physics of low-dimensional systems. The team is currently seeking candidates for a PhD position funded by ED182, starting in October 2025. Application dead line May 05, 2025. Contact: laurent.simon@uha.fr.

Title: Epitaxial Graphene, Flat Bands, and Heavy Fermions: What Fermiology?

This thesis topic is part of the current race to explore the properties of graphene at critical points of its band structure, specifically in the region of very high electron doping, where the van Hove singularity and then the Lifshitz transition occur. In this region, the Fermi surface may exhibit a non-dispersive region where the bands are "flat," and significant electron-electron correlation effects are expected, potentially leading to the emergence of new physical properties (e.g., unconventional superconductivity). Graphene doping can be achieved in various ways, one of which involves inserting atoms between two graphene layers or between graphene and its substrate: this is known as functionalization by intercalation, as is the case for epitaxial graphene on SiC (0001). Intercalation is simply carried out by ultra-high-vacuum evaporation of the element of interest, followed by annealing at different temperatures. Most elements can be intercalated, and by analogy with graphite intercalation compounds (GICs), the prospect of creating batteries, as well as the observation of a superconducting transition, has led to extensive studies on alkali atoms such as Li, Na, K, Rb, and Cs. More recently, lanthanides have been explored, enabling the achievement of record doping levels. With erbium intercalation, we have highlighted a new ordered structure, a "supergraphene," obtained by the ordered intercalation of Er atoms beneath the surface of graphene. This non-Bravais (honeycomb) lattice, 1.4 nm thick, exhibits a Fermi surface topology with a flat band where the Lifshitz transition is surpassed, for the first time, without any additional dopant atoms on the graphene. XMCD measurements reveal the presence of diluted atoms with a significant out-of-plane magnetic moment.

In this thesis, by combining physicochemical characterizations using X-ray photoelectron spectroscopy (XPS), dispersion and Fermi surface measurements via Angle-Resolved Photoemission Spectroscopy (ARPES) and Low-Energy Electron Diffraction (LEED), along with low-temperature Scanning Tunneling Microscopy (STM) and Scanning Tunneling Spectroscopy (STS) measurements, as well as synchrotron radiation experiments, we will investigate the magnetic interactions between these moments and how electrons become delocalized in the graphene π-band with this Fermi surface topology, and how to modify these interactions. The doctoral candidate will contribute to the development of a five-axis analyzer operating at 8K to study the temperature dependence of the band structures.

This work will be carried out in a close collaboration with theoretical support (recruitment of a PhD student at the Laboratoire de Physique théorique-CEA-Saclay) and ANR COM2D (Lab. Lumière Matière-Lyon and IPCMS-Strasbourg).

Keywords: Graphene, Flat-band, Heavy Fermion, Kondo Physics, Correlation-driven Topological Phase

References:

"Flat band and Lifshitz transition in long-range-ordered supergraphene obtained by Erbium intercalation" A. Zaarour, V. Malesys, J. Teyssandier, M. Cranney, E. Denys, J.-L. Bubendorff, A. Florentin, L. Josien, F. Vonau, D. Aubel, A. Ouerghi, C. Bena, and L. Simon, *Physical Review Research*, 5(1), 013099 (2023), DOI: 10.1103/PhysRevResearch.5.013099