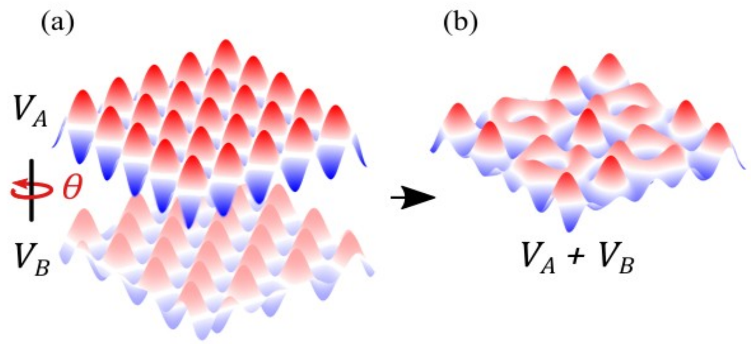
Quantum Simulation of Twisted Bilayer Systems using Ultracold Quantum Gases

It was recently discovered that twisted bilayer lattice systems show remarkable quantum properties, such as exotic superconductivity and non-standard insulating states. They appear notably in graphene and other so-called van der Waals materials. These materials are made up of parallel layers at an angle θ to each other, see figure (a). Interestingly, **such fascinating materials can be emulated with almost no defect in ultracold-atom quantum simulators** using atom-light interaction in dedicated laser configurations [Meng *et al.*, Nature **615**, 231 (2023)].



The aim of the internship and PhD thesis will be to investigate the behavior of ultracold quantum gases in twisted bilayer optical lattices. The main challenge will be to determine the phase diagrams of these systems and to understand the mechanisms that stabilize exotic quantum phases. Particular attention will be paid to the search for superfluid states and states induced by non-commensurate layers. We will also search for signatures accessible to on-going experiments in the field.

These questions will be addressed using a combination of analytical work and advanced numerical approaches. **Our group has extensive experience in this field [1-6]**, where we have carried out pioneering work in the case of strong coupling where layers merge, see figure (b). Our aim here is to extend this work to the case where the layers are well separated.

[1] L. Sanchez-Palencia and L. Santos, Phys. Rev. A **72**, 053607 (2005).
[2] H. Yao, H. Khouldi, L. Bresque, and L. Sanchez-Palencia, Phys. Rev. Lett. **123**, 070405 (2019).
[3] H. Yao, T. Giamarchi, and L. Sanchez-Palencia, Phys. Rev. Lett. **125**, 060401 (2020).
[4] R. Gautier, H. Yao, and L. Sanchez-Palencia, Phys. Rev. Lett. **126**, 110401 (2021).
[5] Z. Zhu, H. Yao, and L. Sanchez-Palencia, Phys. Rev. Lett. **130**, 220402 (2023).
[6] Z. Zhu, S. Yu, D. Johnstone, and L. Sanchez-Palencia, submitted (2023).