INTERNSHIP PROPOSAL

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Internship location: Campus Pierre et Marie Curie, 4 place Jussieu, 75005 Paris
Thesis possibility after internship: YES
Funding: NO but applied for it through a proposal

Investigating electronic correlation effects in epitaxial single atomic layers

Surface systems prepared under ultrahigh vacuum (UHV) became highly suitable materials to study two-dimensional physics in a well-controlled manner. The reason is that two-dimensional (2D) materials are fragile systems whose structural and electronic properties usually react strongly in ambient conditions. In this internship we propose to use an original family of 2D materials to study the effect of mutual Coulomb repulsion between electrons on the electronic and structural properties of a 2D metal. When the electronic Coulomb repulsion is present in a 2D metal, this can completely change the nature of the metallic groundstate: it can drive the material into an electronic insulator called Mott insulator. This insulating state is usually accompanied by magnetic and/or charge ordering at low temperature.
The family of materials we propose to study consists in a single atomic layer of Sn or Pb atoms grown on semiconducting substrate Si(111) or Ge(111). They are characterized by a half-filled single electronic band located in the middle of the band gap of the substrate. As the distance between Sn or Pb atoms is large, the electronic hopping term is small and the on-site Coulomb repulsion between electrons is strong. For this reason, this family of surface materials is believed to realize the conditions to become Mott insulators. This makes them very attractive because they can be used to study complicated phenomena appearing in other quasi-2D materials presenting Mott physics, like the iconic cuprates where high-temperature superconductivity was discovered at the end of the 1980's. Morever as our materials have a much simpler chemical structure it will enable simplifying and having a better control over various theoretical models attempting to describe their structural and electronic properties.
In recent studies we have investigated by low temperature scanning tunneling microscopy and spectroscopy (STM/STS) the Pb/Si(111) compound [1,2]. While this compound was theoretically predicted to be at the verge between Mott insulator and correlated metal [3], we have shown that its ground state is that of a correlated metal with local charge ordering and charge-density wave [1,2]. A very important aspect of our work was to combine state-of-the-art experiment with advanced theoretical DFT calculations. This enabled us to show that in our 2D materials the coupling between the metallic electrons and the substrate lattice degree of freedom is crucial. Here we propose to confirm our approach by investigating the Pb/Ge(111) phase. For this material advanced DFT calculations were already performed by our colleagues [4]. A correlated metallic phase with a local charge ordering is predicted and is to be experimentally investigated by STM/STS at low temperature during this internship. Based on a current PhD thesis project in our group [5], we alternatively propose to investigate the Mott state of the 1T-$TaSe_2$ monolayer phase. This topic could be the main subject of a future PhD project following the internship, having in plan to study the doped Sn/Si(111) phase to investigate a chiral superconducting phase reported recently [6].

[1] C. Tresca et al. PRL, 120, 196402 (2018) [2] C. Tresca et al. PRB 107, 035125 (2023) [3] P. Hansmann et al. Phys. Rev. Lett., 110, 166401 (2013) [4] C. Tresca et al. PRB 104, 045126 (2021) [5] PhD thesis of Robin Salvatore [6] F. Ming et al. Nature Physics 19, 500 (2023)

Environmental impacts: Efforts will be put forward in order to reduce the various direct environmental impacts of this project by paying attention in particular to energy and consumables consumption. The applicant will have the possibility to be trained on these issues during her,his internship. In this spirit, the preliminary results obtained by our team on this scientific topic will be studied in details by the applicant before planning new experiments. The applicant will have the possibility to present an estimate of the carbon footprint of the internship.

Condensed Matter Physics:	YES	Soft Matter and Biological Physics:	NO
Quantum Physics:	YES	Theoretical Physics:	NO