EMERGENT QUANTUM MATERIALS

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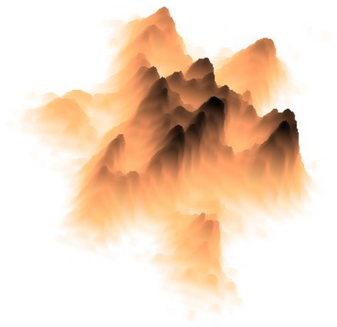

Fermi surface, measured using ARPES, of a 2D electron system at the (111) surface of SrTiO3. This is a transparent insulator promising applications ranging from oxide-based electronics to artificial photosynthesis. Adapted from T. C. Rödel et al, Phys. Rev. Applied 1, 051002 (2014).

In recent years, new materials have emerged to the forefront of condensed matter physics: topological materials and multifunctional electronic states in the two-dimensional (2D) limit, novel superconductors. The interplay of Coulomb interactions, disorder and crystal structure leads to the formation of novel quantum collective states, promising new developments in forthcoming quantum technologies.

Our course proposes to explore this physics introducing select theoretical tools and experimental techniques allowing one to study electronic states in the presence of strong correlations (Mott), disorder and topology.

There will be eight lectures enriched with a one hands-on computer session devoted to the DMFT study of a correlated quantum phase transition (the Mott transition .

Highlights:

- Hidden order and quantum phase transitions
- Electronic correlations and Mott transition
- Oxides and oxide interfaces
- Angle-resolved photoemission spectroscopy
- Experimental electronic structure of correlated-electron systems
- Effects of many-body interactions
- Effects of 2D and 1D confinement

Lectures:

1) General introduction to emergent quantum materials.
- Why quantum functionalities in materials do matter?
- Quantum Phase Transitions, the Lego bricks of emergent functional materials.
- "More is different": the role of correlations.

2) Introduction to strongly correlated electronic systems.
- Green's function formalism.
- Microscopic basis of Fermi liquid Theory.
- The mother example: the Kondo interaction.
- Experimental example of Kondo effect.

3) Correlation driven Mott transition
- Many-body correlated physics: the Hubbard model.
- Connection between Kondo and Mott: Dynamical Mean Field Theory.
- Correlation-driven Mott-Hubbard transition in transition metal oxides
- Experimental example of Mott transition.

4) *Tutorial –Correlation driven Mott transition using DMFT (dynamical mean field theory) Computer Lab session based on python.*

5) Measuring the electronic structure of materials (I): Introduction to ARPES.
- Photoemission and Angle-Resolved PhotoEmission Spectroscopy (ARPES)
- Experimental aspects: instrumentation and implementation
- The photoemission process: independent electrons
- Band mapping with light

6) Measuring the electronic structure of materials (II): Many-body effects.
- The photoemission process: Many-body effects
- Matrix elements: unveiling the symmetries of the electronic state in the solid
- Spectral function and self-energy: quantifying many-body interactions from ARPES
- Experimental examples: Fermi liquid, electron-phonon interactions.
- Advanced techniques: laser-ARPES, spin-resolved ARPES, time-resolved ARPES, nano-ARPES.

7) Experimental electronic structure of strongly correlated materials
- Transition-metal oxides as correlated functional materials
- Vanadates
- High-Tc superconducting cuprates
- 1D cuprates – spin/charge separation

8) Some systems of current interest (I)
- 2D electron gases at the surface of transition-metal oxides
- Spin-polarized states and topological materials
- Disordered systems: renormalization and pseudogap by resonance scattering

9) Some systems of current interest (II)
- Hidden-order transition(s)
- Ferromagnetic quantum criticality
- Vanadates reloaded: Metal-to-insulator transition

Evaluation: 1 oral exam (30 minutes) based on the reading of 2-3 papers provided two weeks before the exam.