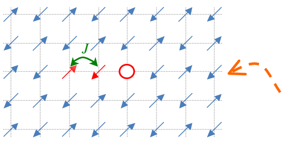
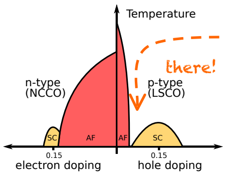
Exciton condensation in strongly correlated electron bilayers

Louk Rademaker[1], Kai Wu[1], Jan Zaanen[1] and Hans Hilgenkamp[1,2]

1: Institute-Lorentz for Theoretical Physics, Leiden University; 2: MESA+ Institute for Nanotechnology, University of Twente

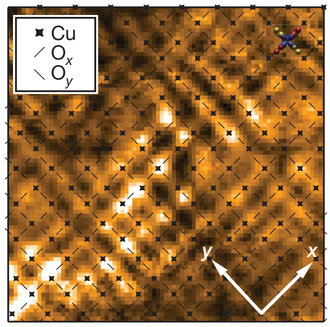


Mott insulator with a single hole

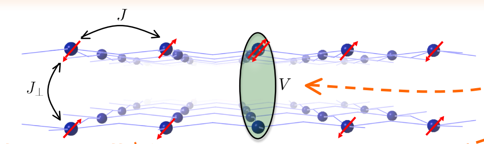


Why strongly correlated materials?

- The parent-compounds of the high-temperature superconducting cuprates are layered Mott insulators: one localized electron spin on each lattice site.
- Upon doping, a whole zoo of complex ordered phases appear in between the antiferromagnetic phase and the superconducting phase.
- There exists no good theory due to strong electron interactions. The fermionic nature of electrons makes it impossible to solve Hamiltonians or to use Monte-Carlo.



Eun-Ah Kim and co-workers showed this complex electronic patterns in BSCCO [1]

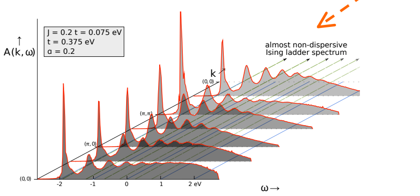


New: bilayer excitons

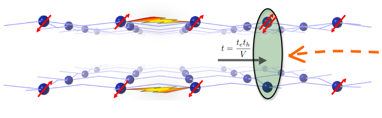
A *bilayer exciton* is the bound state of a doubly occupied and a vacant site.

We have shown that the dynamics of a single (bosonic) exciton shows frustration effects similar to the (fermionic) hole in a single layer. [2]

Hence now we can try to understand complex ordered phases in a purely bosonic theory!



The spectral function of a bilayer exciton



Basic theoretical parameters

Magnetic exchange coupling, both in-plane J and inter-plane $J_\perp$

Hopping of exciton t scrambles up AF order

Model Hamiltonian

$$\mathcal{H} = J \sum_{<ij>l} \mathbf{S}_{il} \cdot \mathbf{S}_{jl} + J_\perp \sum_i \mathbf{S}_{i1} \cdot \mathbf{S}_{i2} - t \sum_{<ij>} |E_j\rangle \left(|0\,0\rangle_i \langle 0\,0|_j + \sum_m |1\,m\rangle_i \langle 1\,m|_j \right) \langle E_i|$$

Heisenberg terms

Hopping term = exchange of exciton |E> with magnetic states | s m >

Mean field phase diagram

EC = Exciton condensate

Superposition on each site of singlet ground state with exciton:

$$\prod_i (u_i + v_i \hat{E}_i^\dagger)|0\,0\rangle$$

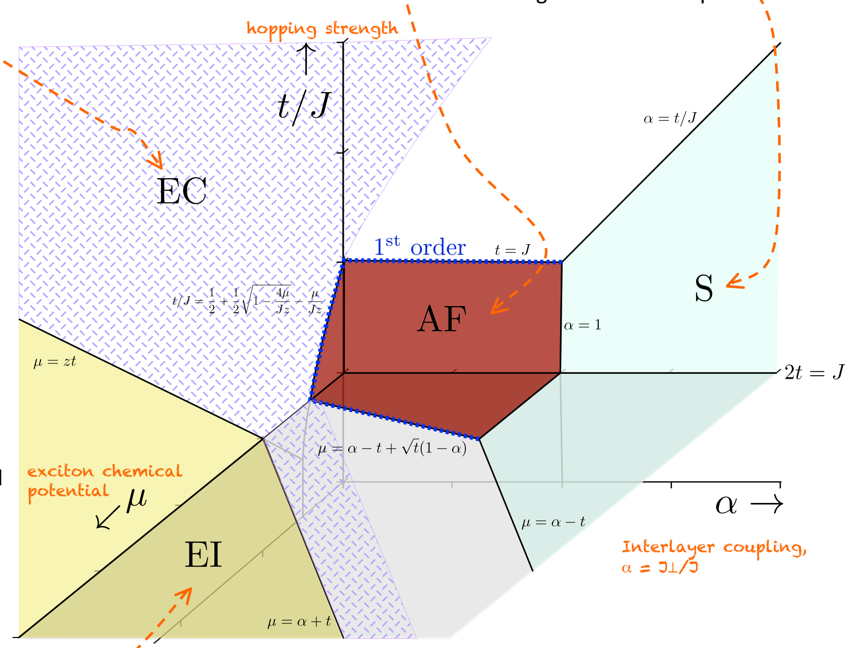
Usually, an exciton condensate is detectable via its enhanced interlayer tunneling. [3]
However, because of the singlet ground state the tunneling of opposite spin species cancels eachother. Consequently, the 'singlet exciton condensate' has no tunneling matrix element and is therefore a 'dark' exciton condensate.

AF = Antiferromagnetism

Just the normal Néel state, without excitons.

S = Rung singlets

Boring phase without excitons, on each interlayer rung there is a singlet of electron spins.



EI = Excitonic insulator

Boring phase with only excitons.

Inhomogeneous phases

In the *shaded region*, the mean field solution is instable towards inhomogeneities.
Amongst the possibilities:

- *Stripe* phases can appear: one-dimensional ordering of exciton density.
- *Phase separation* of excitonic regions and magnetically ordered regions.
- *Domain walls* or other topological structures in the magnetic order can couple to exciton condensate vortices.

The role of electric dipole exciton-exciton interaction in phase formation is still a subtle question.

Universiteit Leiden

References

[1] Mesaros, et al. Science **333**, 426 (2011)
[2] Rademaker, Wu, Hilgenkamp and Zaanen, *EPL* **97** 27004 (2012)
[3] Eisenstein and MacDonald, Nature **432**, 691 (2004)

Contact & more info

Email: rademaker@lorentz.leidenuniv.nl
Website: loukrademaker.wordpress.com