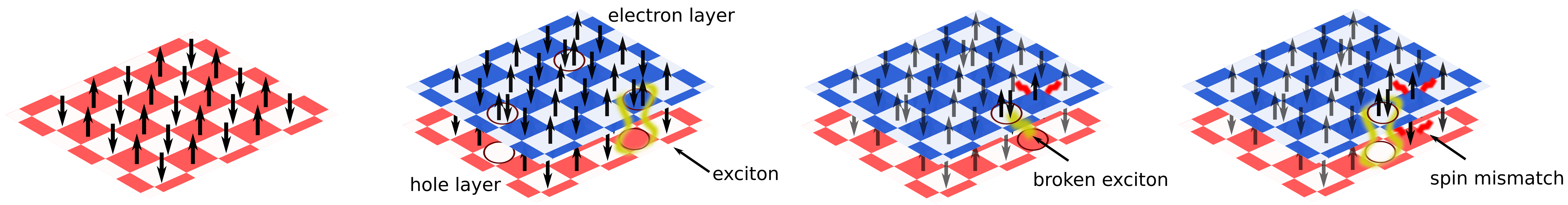
Exciton motion in strongly correlated heterostructures

Louk Rademaker[1], Marcel Hoek[2], Francesco Coneri[2], Kai Wu[1,3], Jan Zaanen[1], Hans Hilgenkamp[1,2]

[1]Instituut Lorentz for Theoretical Physics, Leiden University
[2]MESA+ Institute for Nanotechnology, University of Twente
[3]Center for Advanced Study, Tsinghua University, Beijing, China

Layered heterostructures of strongly correlated electron systems present a new territory of physics with unexpected phenomena. The coming year we will perform Hall and drag measurements on NCCO/LSCO multilayers. Theoretically, we predict that the motion of an exciton causes an unrepairable spin mismatch which implies exciton localization.



Undoped Mott insulator

Coupled p,n-doped Mott insulators with excitons

Exciton must break up in order to move

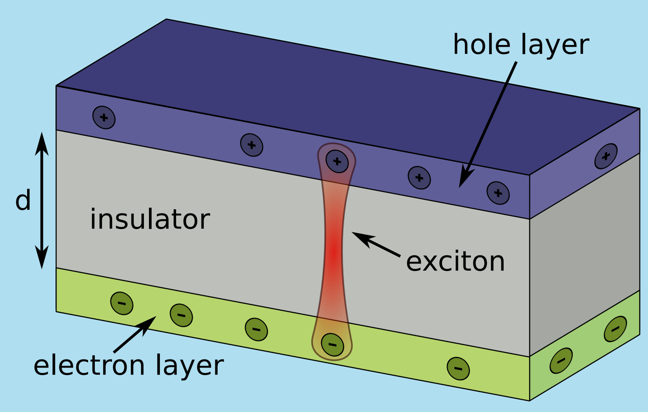
Moved exciton causes a spin mismatch in the AF background

Introduction

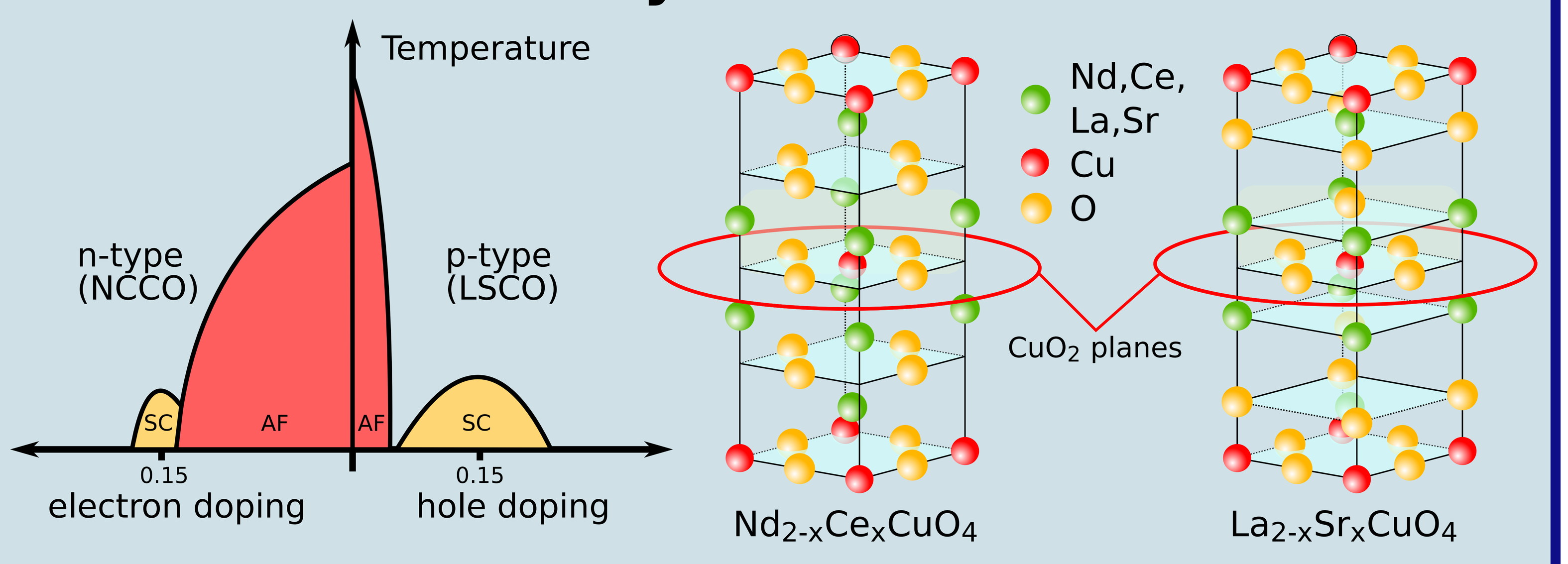
Mott materials are characterized by strong interactions between the electrons. At half-filling (one electron per unit cell) the system becomes insulating and antiferromagnetic. Small amounts of holes or electrons can be introduced by doping the materials.

A proper theory is lacking for the Mott materials which makes it an exciting new playfield for physics. In our combined theoretical and experimental research we will **couple *n*- and *p*-type Mott insulators** into one heterostructure.

We are especially interested in the formation of **bilayer excitons**, their transport properties and the possibility of Bose-Einstein condensation of excitons in these hetero-structures.



NCCO/LSCO multilayers



The layered cuprate materials $Nd_{2-x}Ce_xCuO_4$ (NCCO, *n*-type) and $La_{2-x}Sr_xCuO_4$ (LSCO, *p*-type) are considered to be ideal candidates for our bilayer systems.

Theory: the exciton t-J model

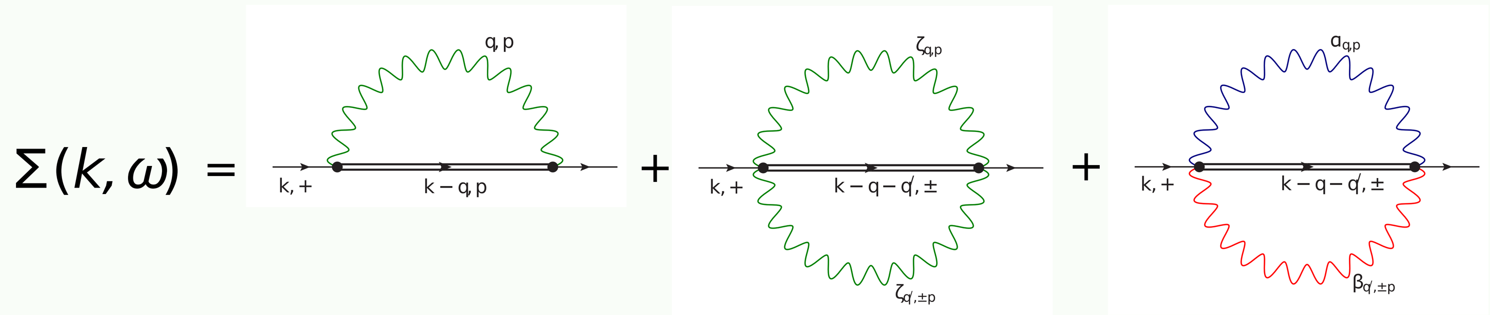
The standard theory for doped Mott insulators is **the t-J model**. We extended this model to a bilayer system with excitons.

$$H_t = t \sum_{<ij>} E_j^\dagger E_i \left(\cos 2\chi (1 - e_i^\dagger e_j) + \sin 2\chi (e_i^\dagger + e_j) - \sum_\sigma b_{i\sigma}^\dagger b_{j\sigma} \right)$$

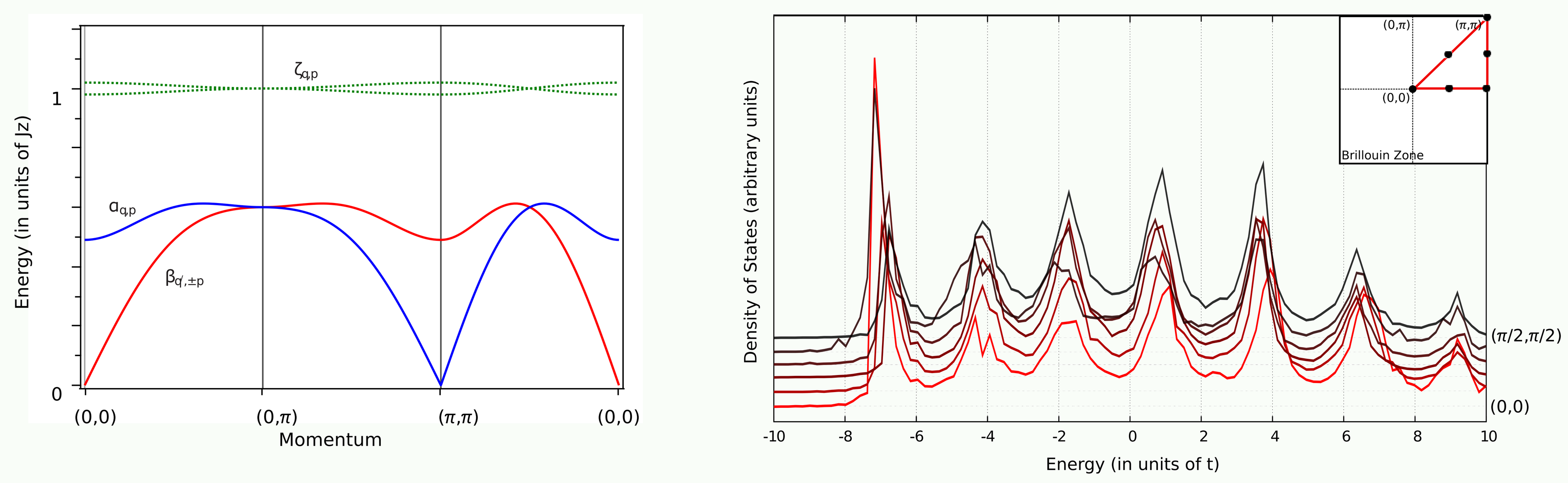
$$H_J = J \sum_{<ij>\alpha} S_{i\alpha} \cdot S_{j\alpha} + J_\perp \sum_i S_{i1} \cdot S_{i2}$$

Hamiltonian for the exciton t-J model. Capital Es are the exciton operators, small e and b represent spinon excitations.

We needed to formulate a **new linear-spin-wave method** to capture the complicated magnetic structure of a Mott bilayer. Subsequently we used the **self-consistent Born approximation** to compute the exciton spectral function.



Diagrammatic representation of the self-consistent Born approximation.



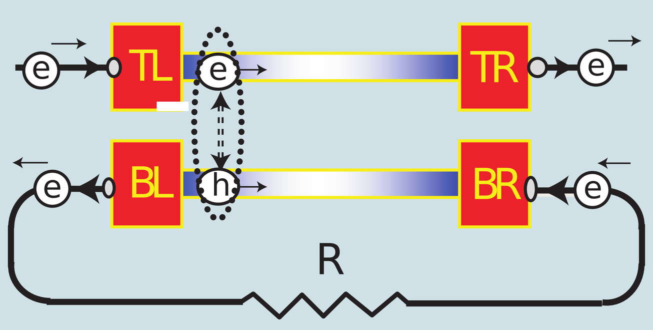
Magnon dispersions (left) and exciton spectral function (right) for J = 0.2t and a =0.2.

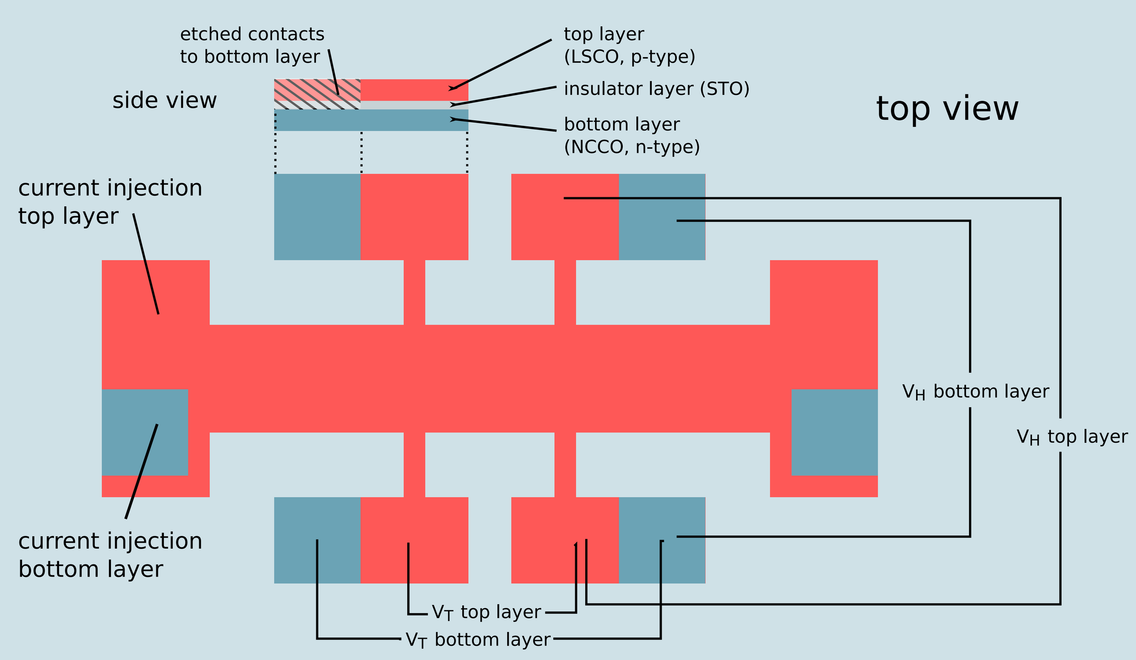
The resulting spectral function is surprising. A moving exciton causes a '**spin mismatch**' in the antiferromagnetic background. Unlike in the single layer, quantum fluctuations cannot restore this mismatch which causes exciton localization and a ladder-like spectrum.

Future Experiments

We will make NCCO/LSCO multilayers by Pulsed Laser Deposition (**PLD**). However, different growth conditions are required for the *n*- and *p*-type layers. Recently we succeeded in growing good quality *n*-type NCCO layers under oxygen pressures suitable for the growth of *p*-type LSCO.

In the near future we will perform Hall and drag measurements on NCCO/LSCO multilayers, with our without an insulator in between. Possible existence of excitons will be reflected in a **vanishing Hall resistance** and an **interlayer drag**.





Top: Drag measurements (Ref: Su & MacDonald, Nat. Phys. 2008). *Right*: Design for NCCO/ LSCO Hall bar.

NWO
UNIVERSITY OF TWENTE.
Universiteit Leiden