

Excitons and spins in strongly correlated systems

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Leiden University. The university to discover.

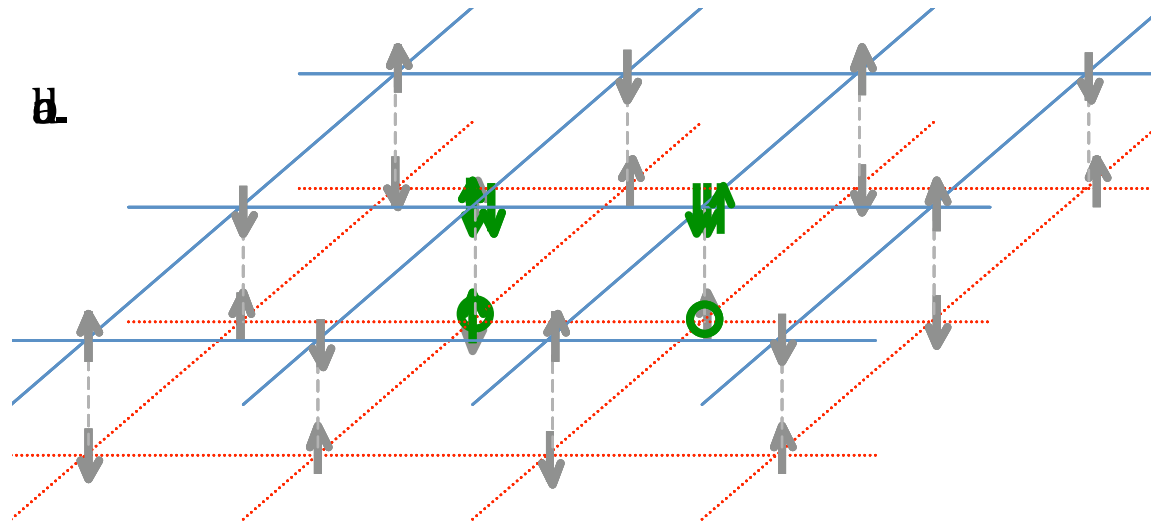
Overview

- Excitons in Mott insulators
- Bilayer Heisenberg Spin Wave theory
- Results



Excitons in Mott insulators

- What are Mott insulators?
- Interlayer excitons



Interlayer excitons

- Spin (magnetic) background

$$H = J \sum_{\langle ij \rangle} (S_{1,i} \cdot S_{1,j} + S_{2,i} \cdot S_{2,j}) + J_{\perp} \sum_i S_{1,i} \cdot S_{2,i}$$

- Exciton motion term

$$H_{t,e} = -\frac{t^2}{V} \sum_{\langle ij \rangle \sigma \sigma'} e_j^{\dagger} \left[c_{in\sigma'}^{\dagger} c_{ip\sigma}^{\dagger} c_{jp\sigma} c_{jn\sigma'} \right] e_i$$

- Pretty awful...



Linear Spin Wave theory

- Mean field ground state



$$H = J \sum_{\langle ij \rangle} S_i \cdot S_j$$

- Local spin excitations



$$\begin{aligned} S_i^+ &= a_i \\ S_i^- &= a_i^\dagger \\ S_i^z &= \frac{1}{2} - a_i^\dagger a_i \end{aligned}$$

- Only consider 'linear' terms (no interactions)

$$H = -\frac{1}{8}NJz + \frac{1}{2}Jz \sum_i \hat{n}_i + \frac{1}{2}J \sum_{\langle ij \rangle} (a_i b_j + a_i^\dagger b_j^\dagger)$$

- Diagonalize using Fourier & Bogoliubov

$$\begin{aligned} \alpha_k &= \cosh \theta_k a_k + \sinh \theta_k b_k^\dagger \\ \beta_k &= \sinh \theta_k a_k^\dagger + \cosh \theta_k b_k \\ \tanh 2\theta_k &= \gamma_k \end{aligned}$$

$$H = E_0 + \frac{1}{2}Jz \sum_k \sqrt{1 - \gamma_k^2} (n_k^\alpha + n_k^\beta)$$

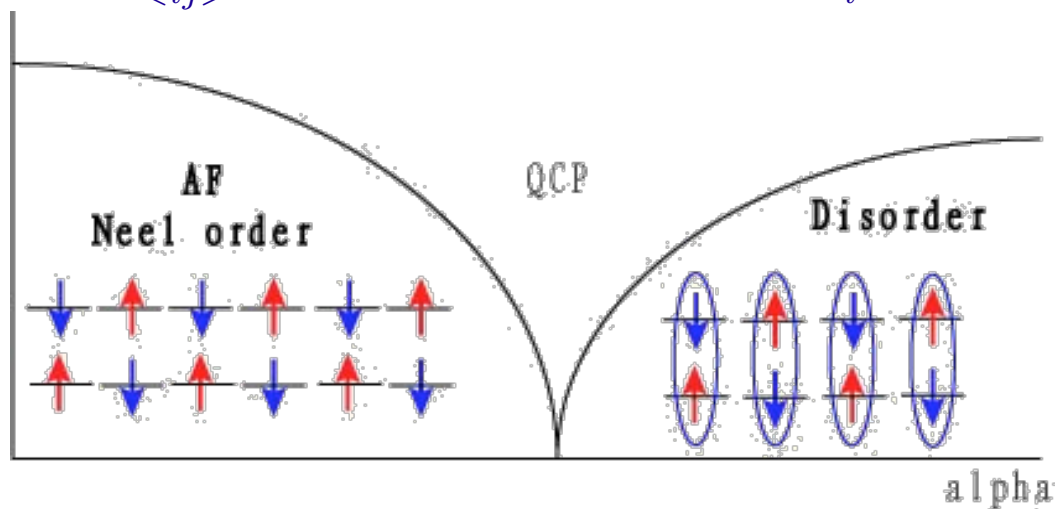


Bilayer Heisenberg model

- Naïve way doesn't work:

1. Order-disorder phase transition

$$H = J \sum_{\langle ij \rangle} (S_{1,i} \cdot S_{1,j} + S_{2,i} \cdot S_{2,j}) + J_{\perp} \sum_i S_{1,i} \cdot S_{2,i}$$



2. Number of spin modes

Bilayer Heisenberg

- Ground state: Singlet+Triplet competition

$$|G\rangle_i = \begin{cases} \cos \chi |0\ 0\rangle - \sin \chi |1\ 0\rangle, & i \in A \\ -\cos \chi |0\ 0\rangle - \sin \chi |1\ 0\rangle, & i \in B \end{cases}$$

- 3 different spin waves

$$e_{iA}^\dagger = \sin \chi |0\ 0\rangle_i \langle G|_i + \cos \chi |1\ 0\rangle_i \langle G|_i$$

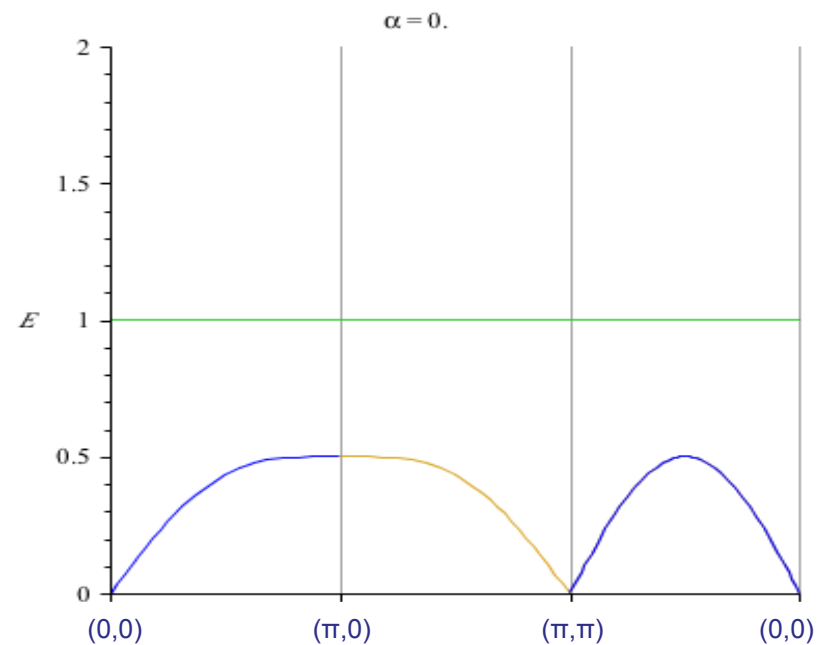
$$b_{+iA}^\dagger = |1\ 1\rangle_i \langle G|_i$$

$$b_{-iA}^\dagger = |1\ -1\rangle_i \langle G|_i$$

$$e_{k,p}^\dagger = \cosh \varphi_{k,p} \zeta_{k,p}^\dagger + \sinh \varphi_{k,p} \zeta_{-k,p}$$

$$b_{k,p,+}^\dagger = \cosh \theta_{k,p} \alpha_{k,p}^\dagger + \sinh \theta_{k,p} \beta_{-k,p}$$

$$b_{k,p,-}^\dagger = \cosh \theta_{k,p} \beta_{k,p}^\dagger + \sinh \theta_{k,p} \alpha_{-k,p}$$



Results

- Compute self-energy
- And spectral function

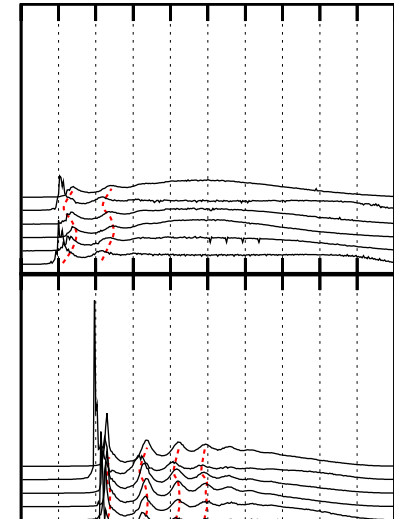
$$\Sigma(k, \omega) = \text{Diagram 1} + \text{Diagram 2} + \text{Diagram 3}$$

Diagram 1: A horizontal line with an incoming arrow from the left labeled $k, +$ and an outgoing arrow to the right labeled $k - q, p$. A green wavy loop is attached to the line, labeled q, p at its top.

Diagram 2: A horizontal line with an incoming arrow from the left labeled $k, +$ and an outgoing arrow to the right labeled $k - q - q', \pm$. A green wavy loop is attached to the line, labeled $\zeta_{q,p}$ at its top and $\zeta_{q',\pm p}$ at its bottom.

Diagram 3: A horizontal line with an incoming arrow from the left labeled $k, +$ and an outgoing arrow to the right labeled $k - q - q', \pm$. A blue wavy loop is attached to the line, labeled $a_{q,p}$ at its top and $\beta_{q',\pm p}$ at its bottom.

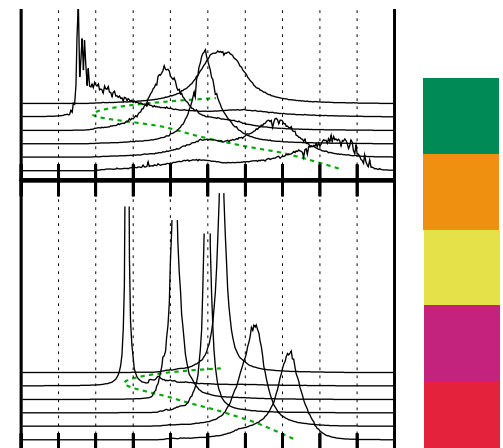
$\alpha = 0.0$



$\alpha = 0.2$

$\alpha = 1.0$

$\alpha = 1.4$



Conclusion

- Interlayer excitons in Mott insulators
- A new linear spin wave theory for the Bilayer Heisenberg model
- Used to compute spectral function of interlayer exciton



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... and you for your attention!



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