

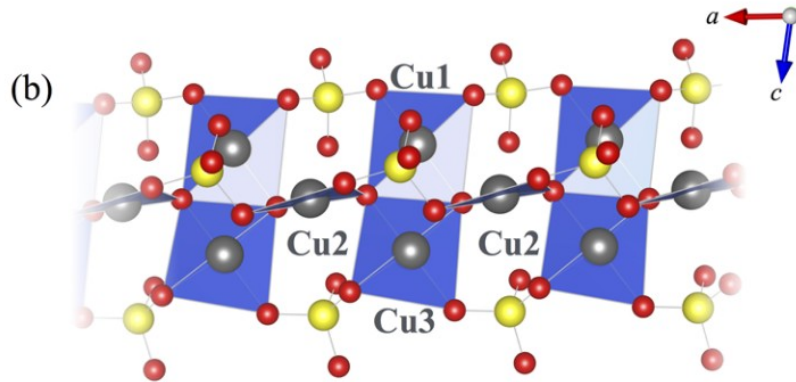


Magnetismo quântico em 1D

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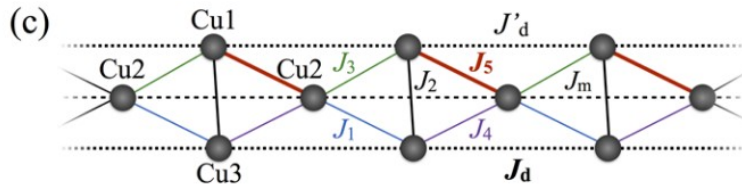


Modelos de rede



$$H = J \sum_{\langle i,j \rangle} \mathbf{S}_i \cdot \mathbf{S}_j$$

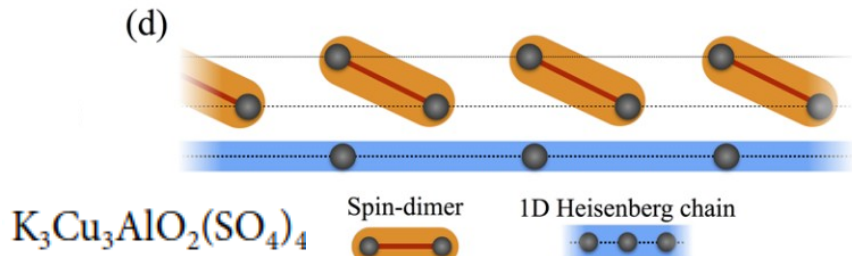
$$H = J \sum_{\langle i,j \rangle} S_i^z S_j^z + \frac{1}{2} (S_i^+ S_j^- + S_i^- S_j^+)$$



Sistema de 2 spins

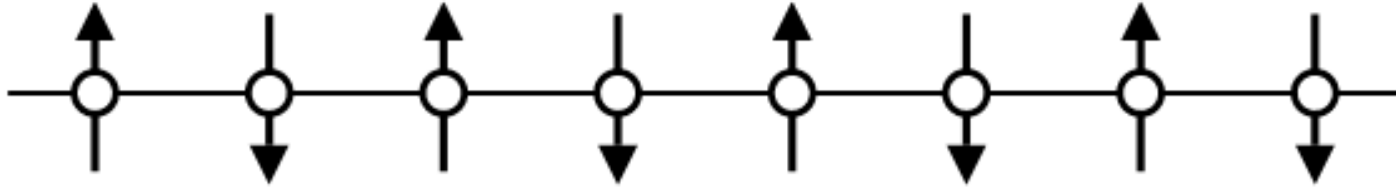
$$|\uparrow\rangle |\downarrow\rangle \text{ or } |\downarrow\rangle |\uparrow\rangle \Rightarrow -J/4$$

$$\frac{1}{\sqrt{2}} (|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle) \Rightarrow -3J/4$$



Fujihala, Scientific Reports (2017)

Cadeia de spin-1/2

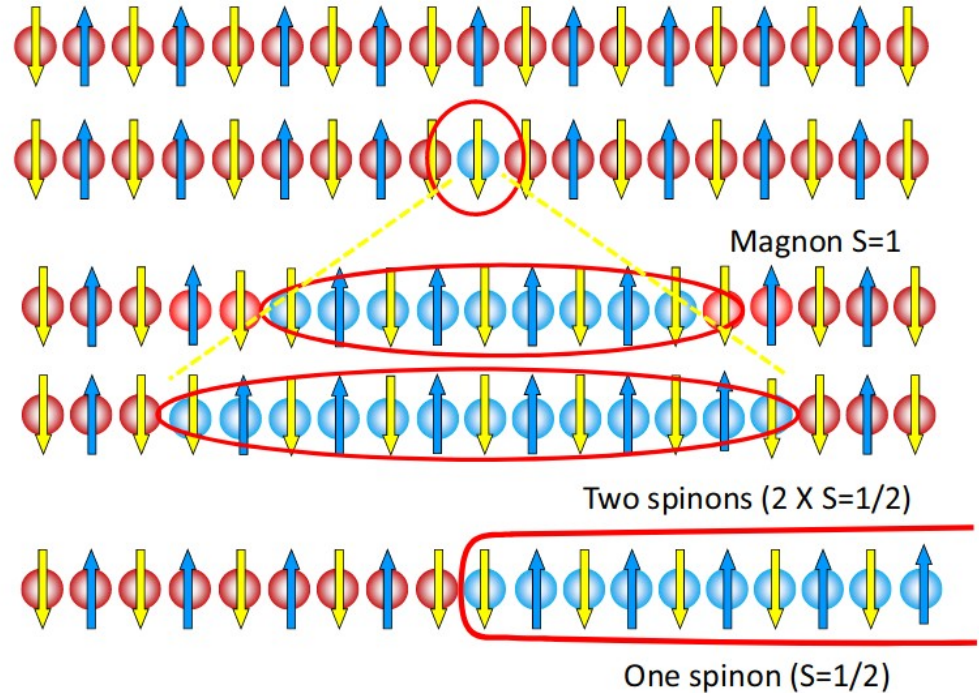


- Solução exata de Bethe (1931)
- Sem gap
- Sem ordem magnética de longo alcance
- Líquido de Luttinger
 - correlações tipo lei de potência

$$\langle \mathbf{S}_i \cdot \mathbf{S}_{i+r} \rangle \sim (-1)^r \frac{1}{r} \quad (\text{crítico})$$

$$\langle S^z(x) S^z(0) \rangle = \frac{1}{x^2} + (-1)^x A_z \left(\frac{1}{x} \right)^{2K}$$

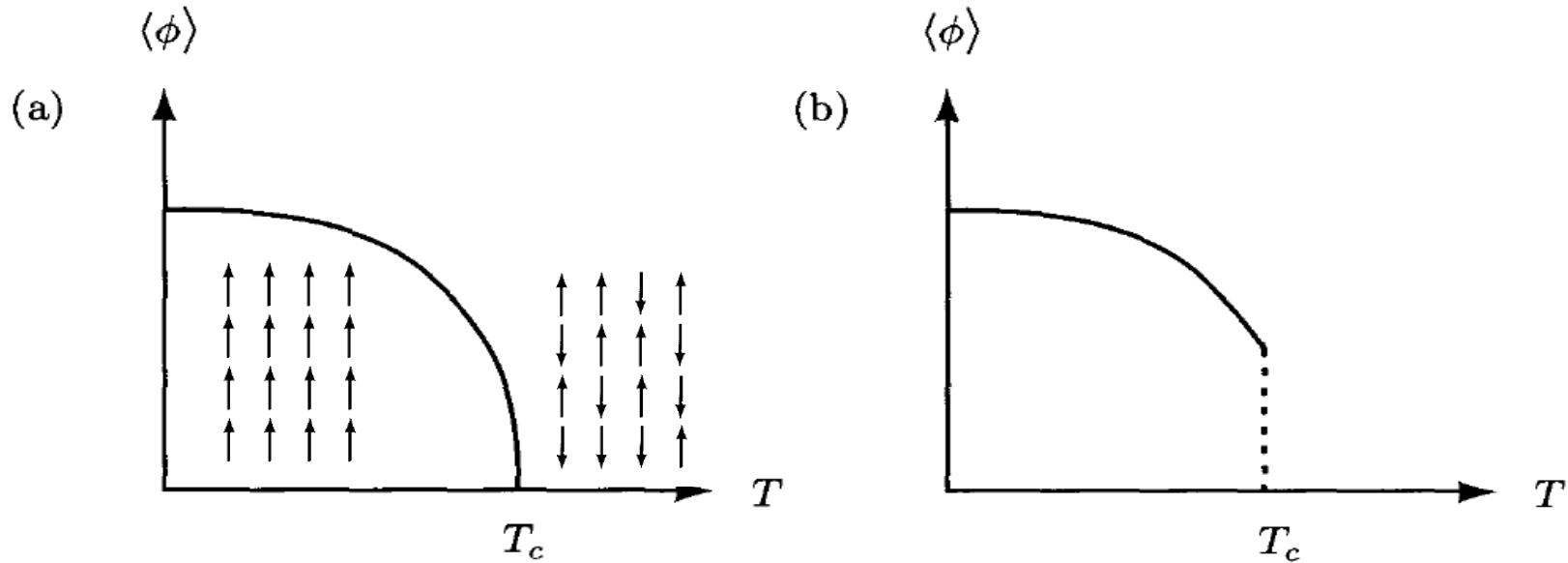
$$\langle S^-(x) S^+(0) \rangle = (-1)^x A_x \left(\frac{1}{x} \right)^{\frac{1}{2K}} + B_x \left(\frac{1}{x} \right)^{\frac{1}{2K} + 2K}$$



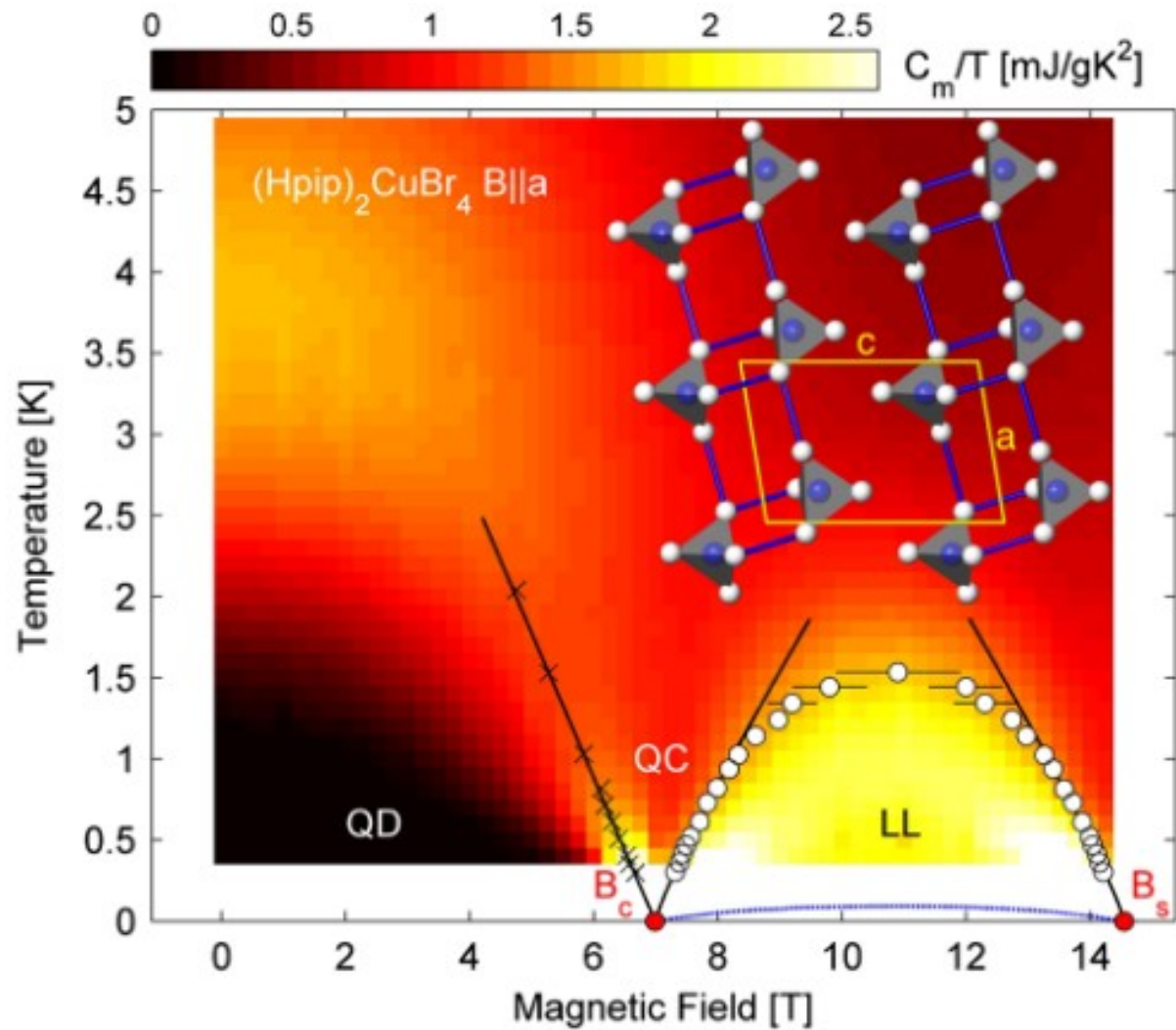
Giamarchi, IJMPB (2012)

Transição de fase quântica

Transição de fase térmica



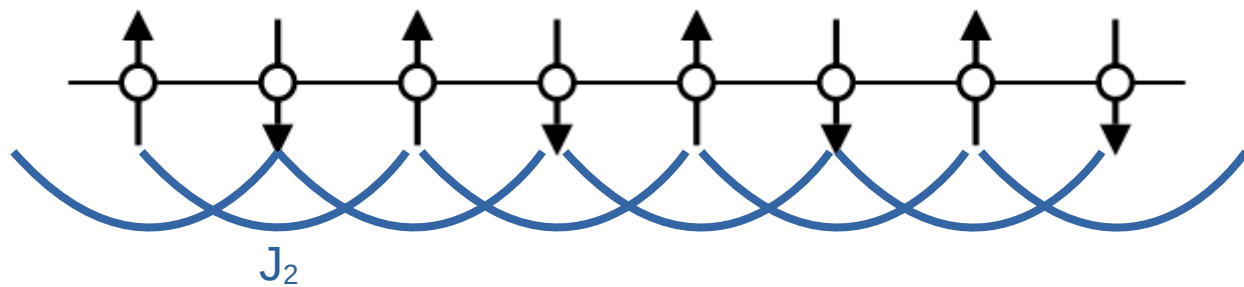
Transição de fase quântica: variação nos acoplamentos do hamiltoniano do modelo



Ruegg et al, PRL (2008)

Cadeia de spin-1/2 frustrada

Variando \mathbf{J}_2
Induz uma fase com gap



$$\langle \mathbf{S}_i \cdot \mathbf{S}_{i+r} \rangle \sim e^{-r/\xi}$$



$$\bullet\text{---}\bullet = \frac{1}{\sqrt{2}} (|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$$

Conjectura de Haldane & Cadeia de spin-1

- Conjectura de Haldane, PRL (1983): spin-1/2,3/2,5/2, ... (sem gap) e spin-1,2,3,... (gap)
- Spin-1:
- Gap finito
- Decaimento exponencial das correlações
- Estados de borda
- O emaranhamento exibe um padrão sem quebra espontânea da simetria de translação
- Fase topológica

spin-1



AKLT Model, PRL (1987)



$$\bullet\text{---}\bullet = \frac{1}{\sqrt{2}} (|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$$

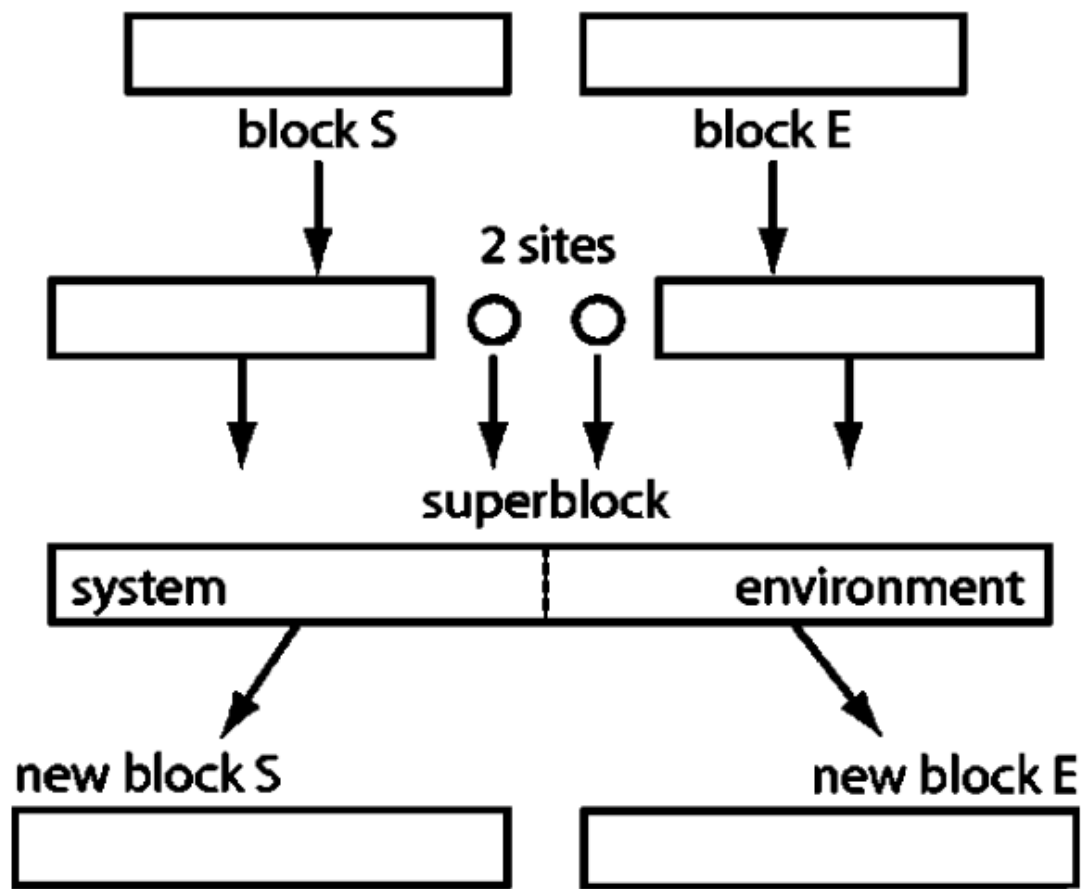
$$\bigcirc = |+\rangle\langle\uparrow\uparrow| + |0\rangle\frac{\langle\uparrow\downarrow| + \langle\downarrow\uparrow|}{\sqrt{2}} + |-\rangle\langle\downarrow\downarrow|$$

Grupo de Renormalização da Matriz Densidade

$$H = J \sum_{\langle i,j \rangle} \mathbf{S}_i \cdot \mathbf{S}_j$$

$\{|\sigma_1 \sigma_2 \dots \sigma_N\rangle\}$ 2^N estados

→ Matriz e diagonaliza





$$\hat{\rho} = \text{Tr}_E |\psi\rangle\langle\psi|,$$

Cadeia escada de Spin-1/2 com Interações competitivas

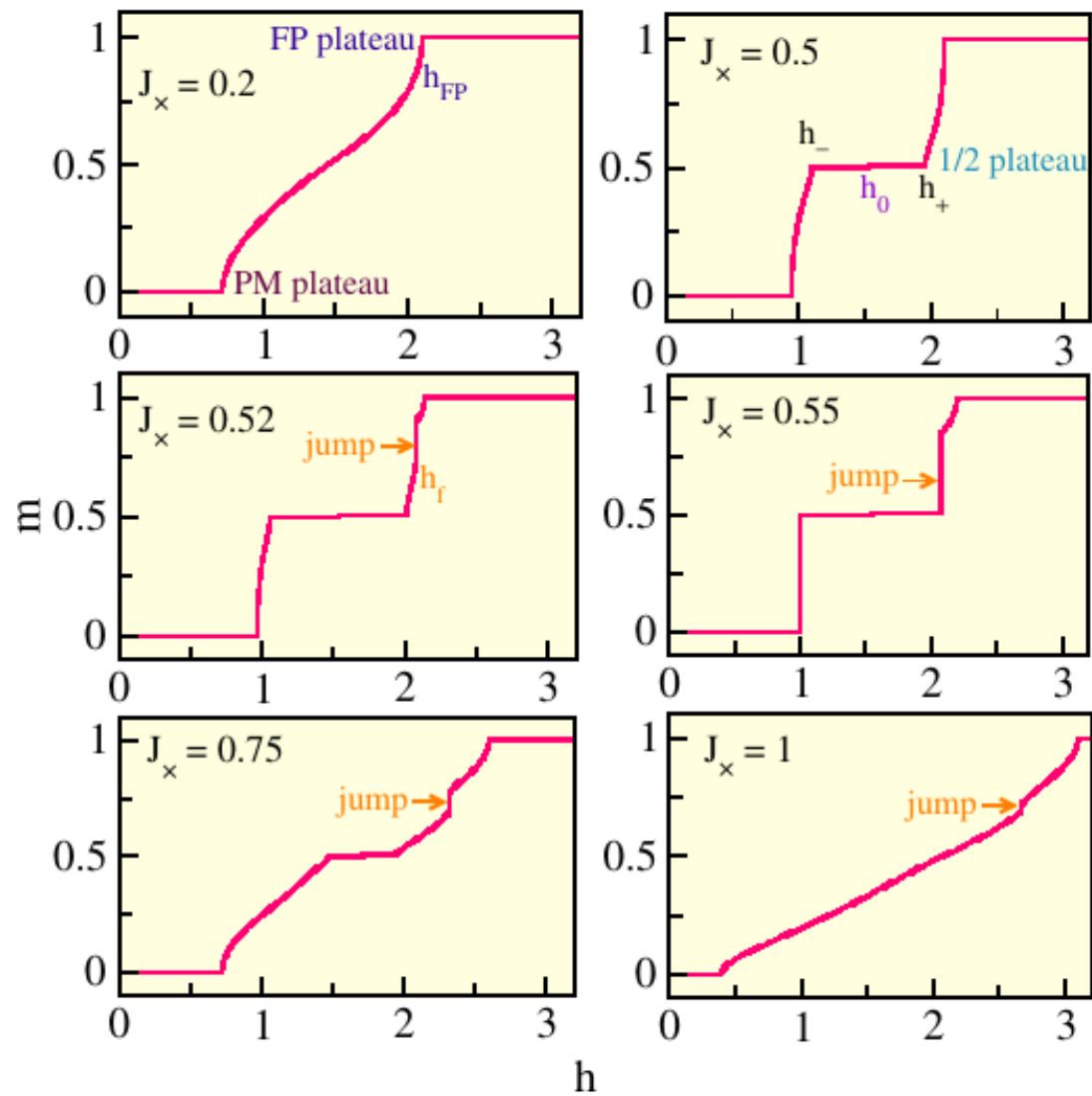
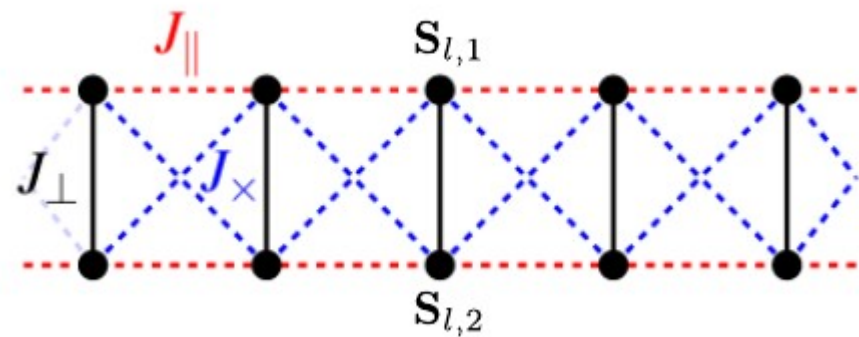


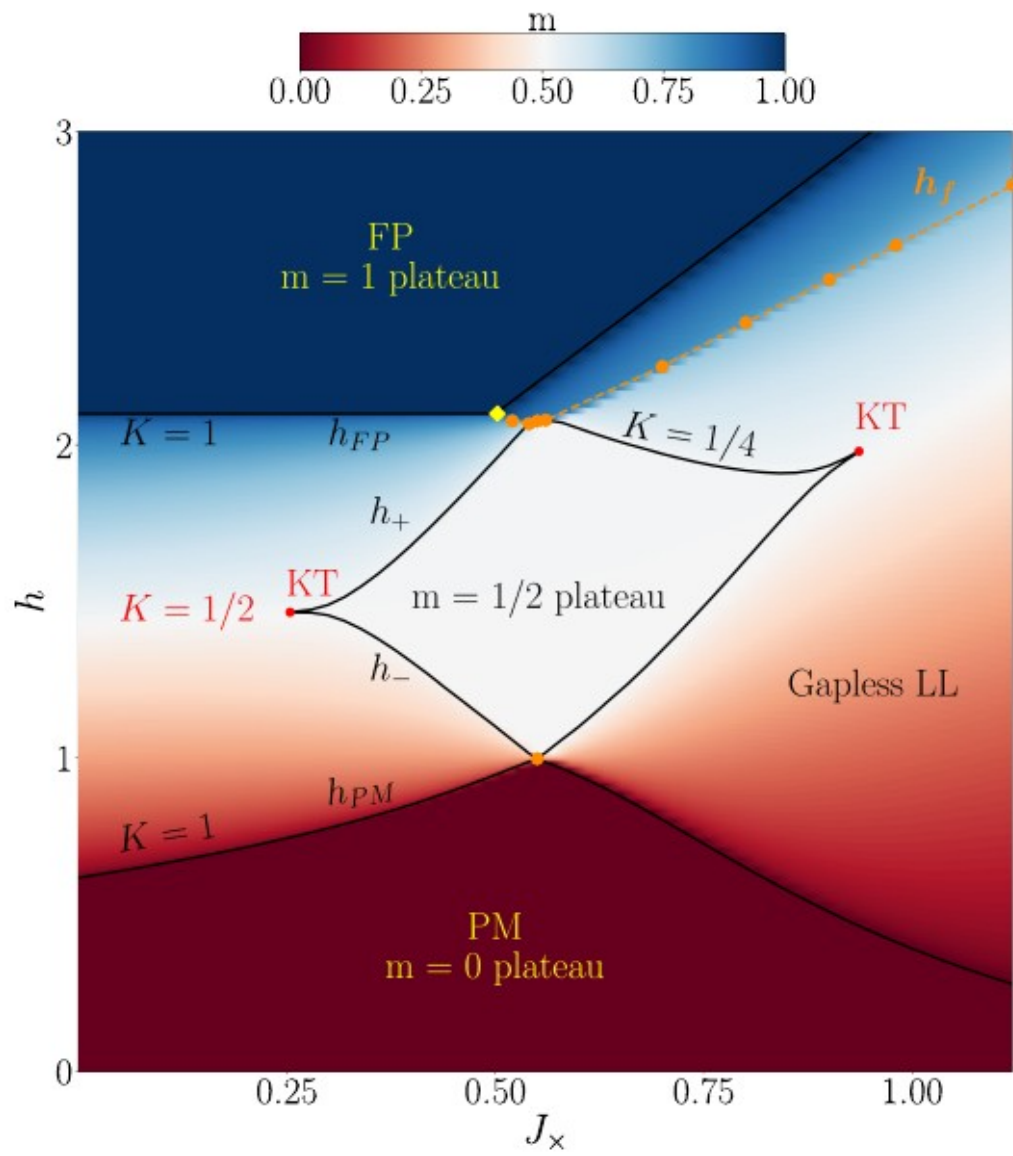
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Quantum bicritical point and phase separation in a frustrated Heisenberg ladder

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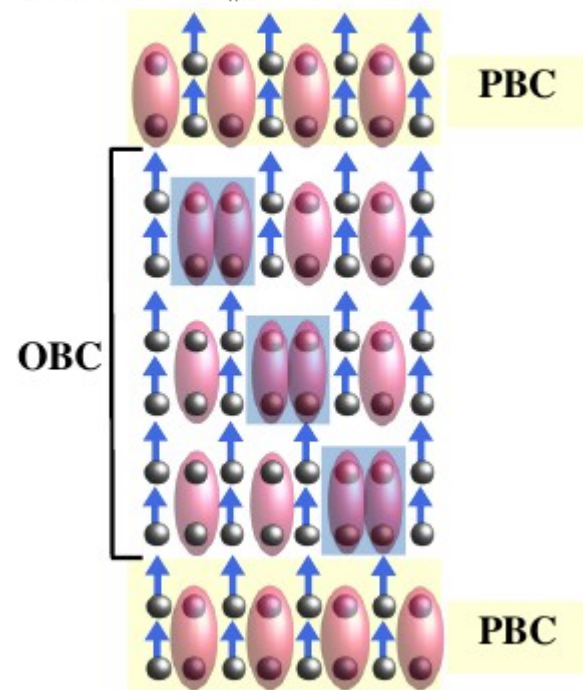


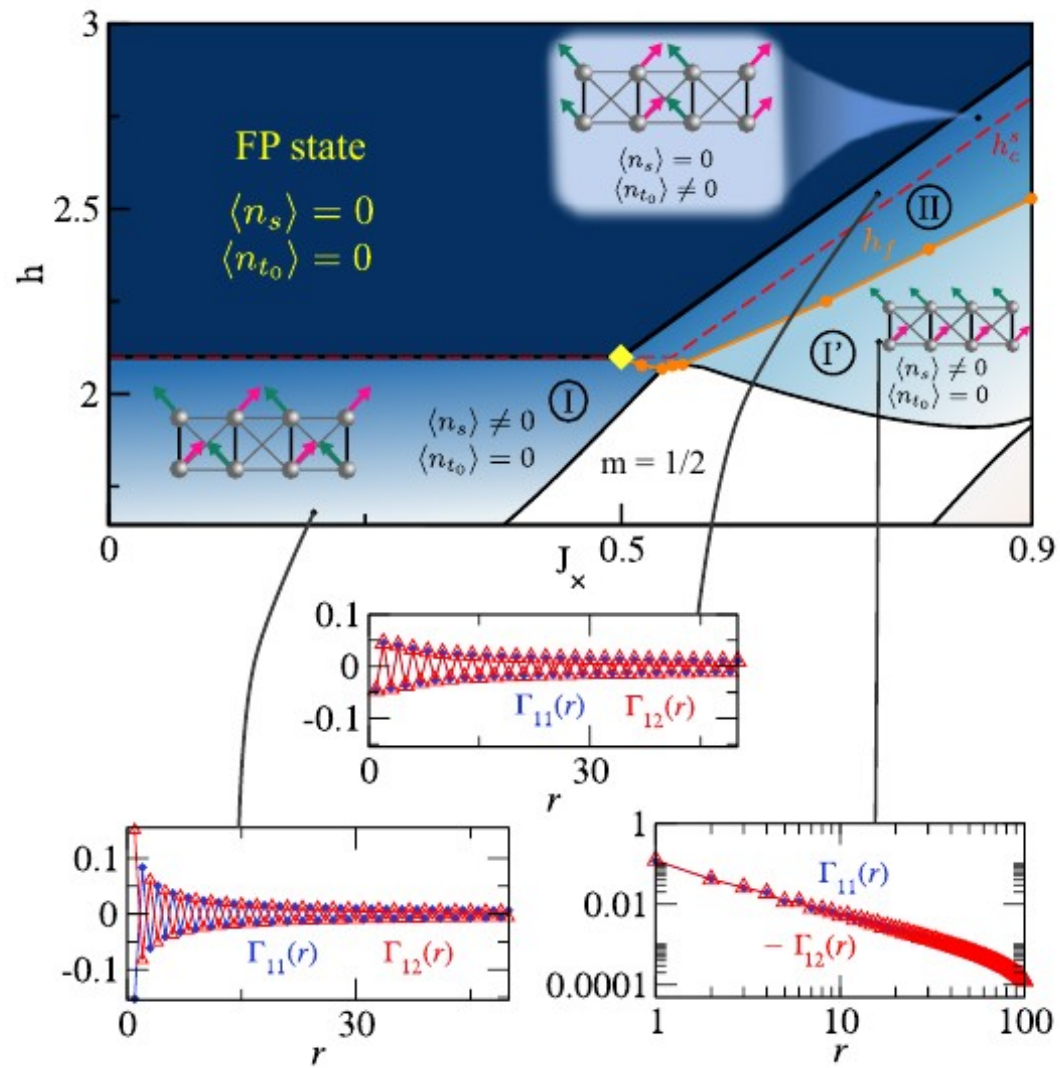
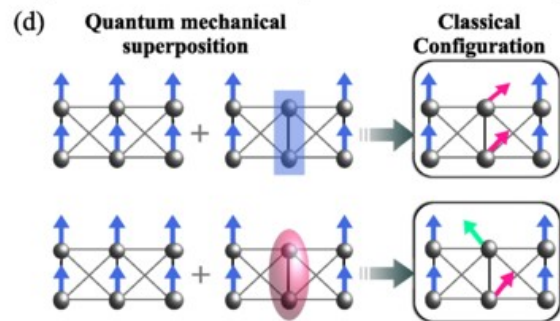
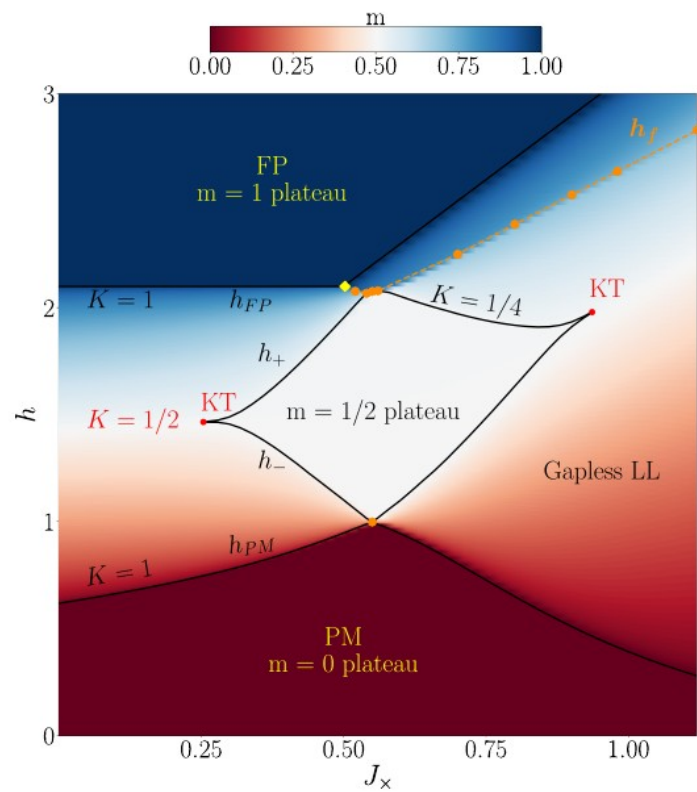


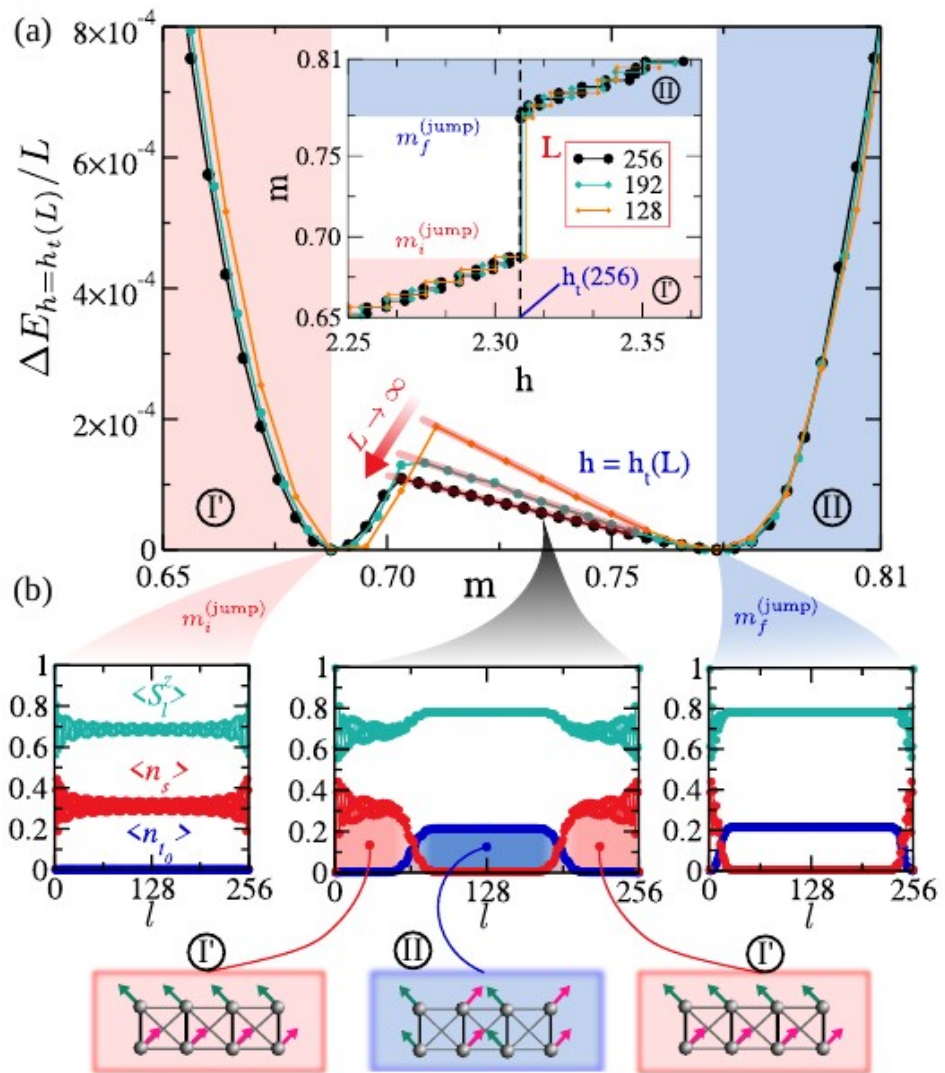
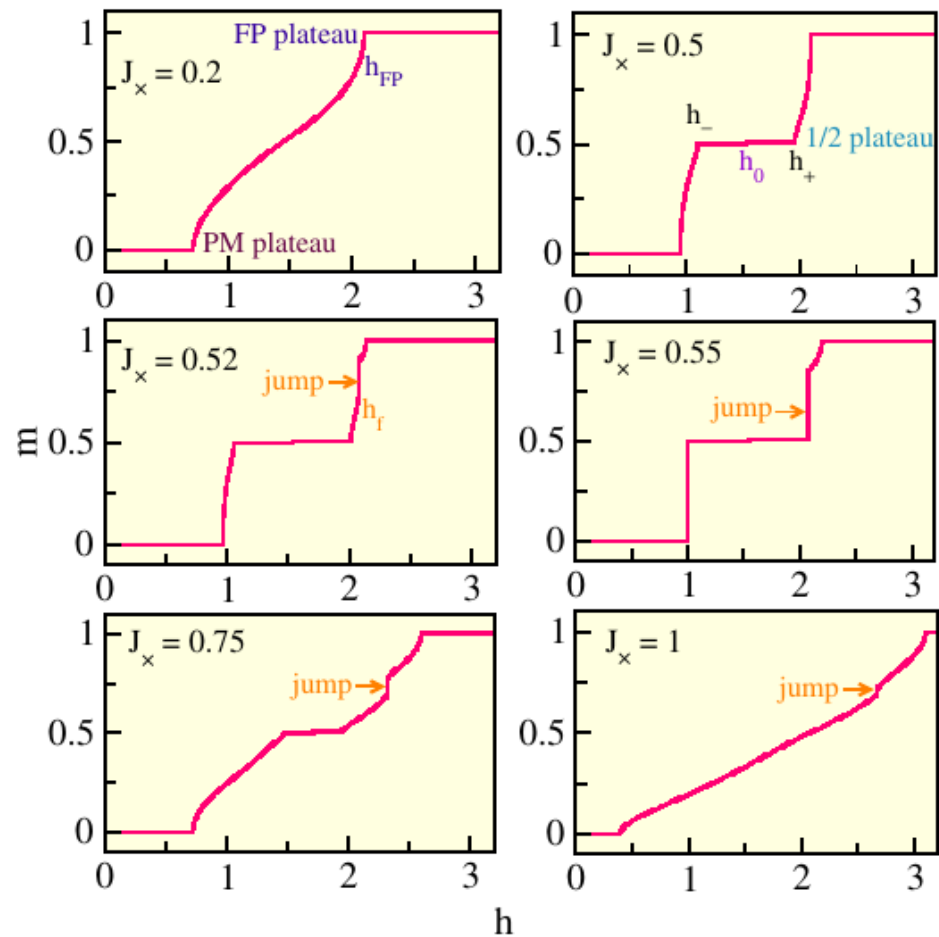
$$\Gamma(r) \sim \frac{1}{r^{1/2K}},$$

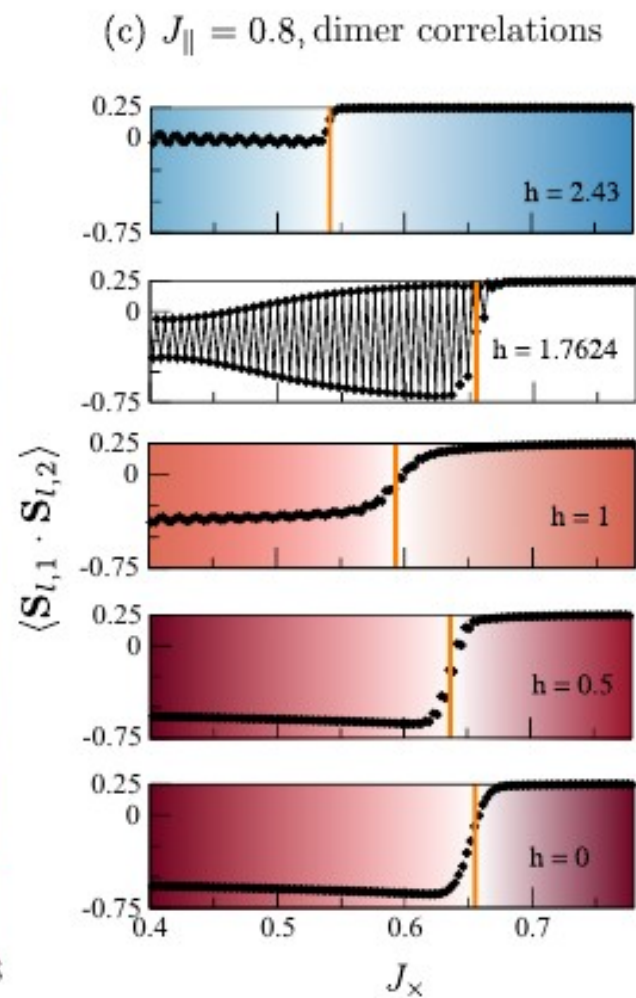
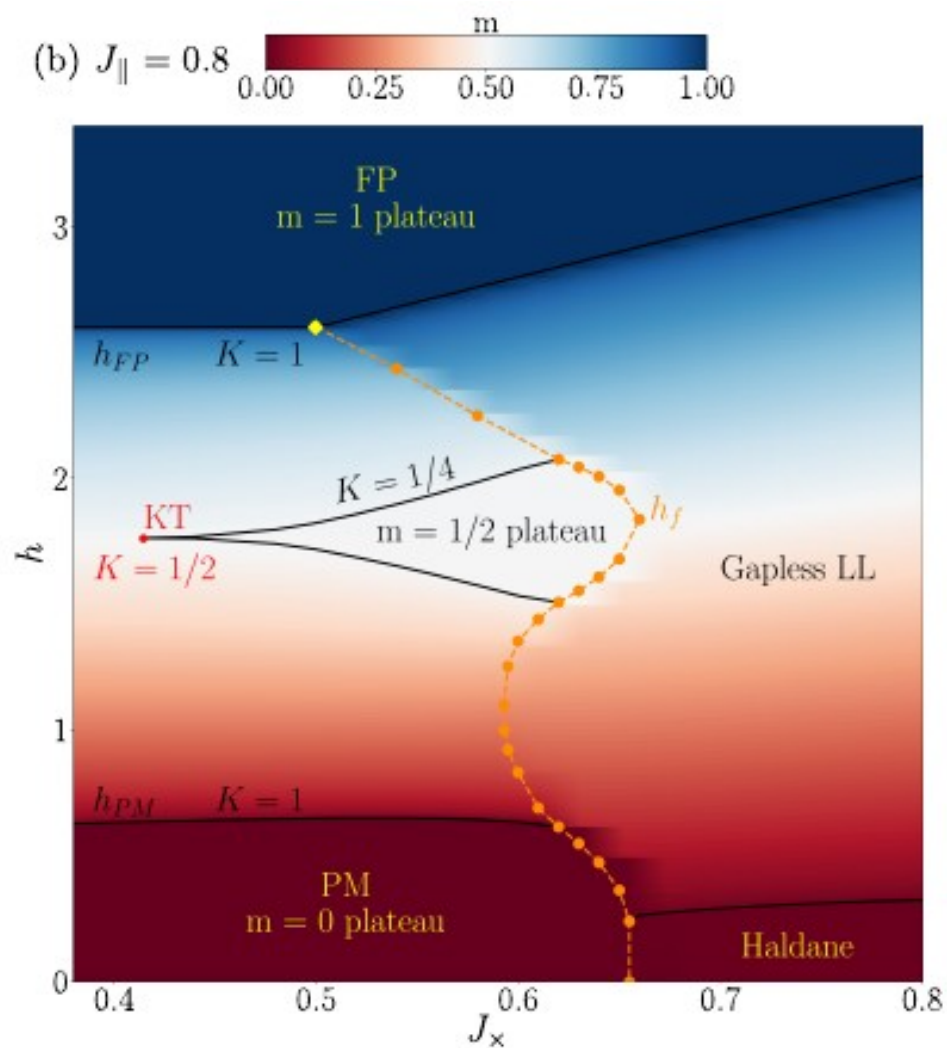
$$(S_u - m_u) = \text{integer},$$

(a) $J_x = J_{\parallel}$, $m = 1/2$









Obrigado