Density Matrix Renormalization Group Study of Topological States

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Collaborators

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Outline

- Interaction driven topological phases

Chiral spin liquid

Spontaneous quantum Hall effect

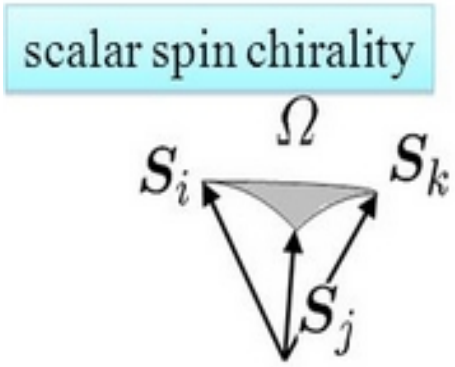
Identifying the non-Abelian 12/5 FQHE as Read-Rezayi state

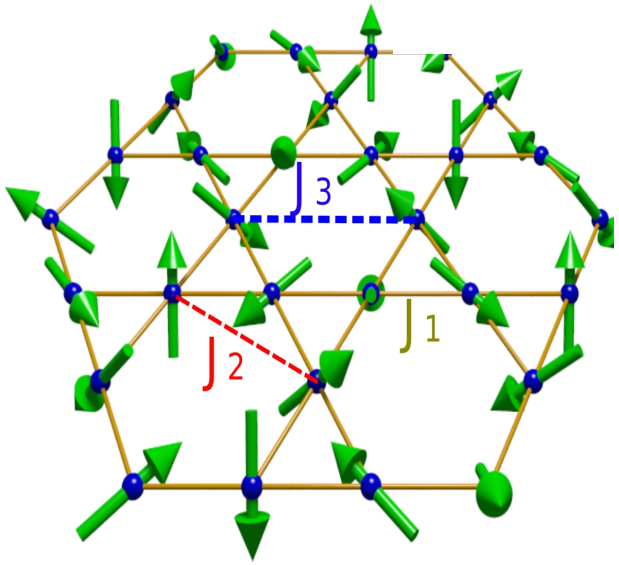
Bilayer Moore-Read 1/2 FQHE emerging from Tunneling (331 Halperin to Moore-Read)

Discovery of chiral spin liquid in Heisenberg spin systems—(a new state proposed 27 years ago)

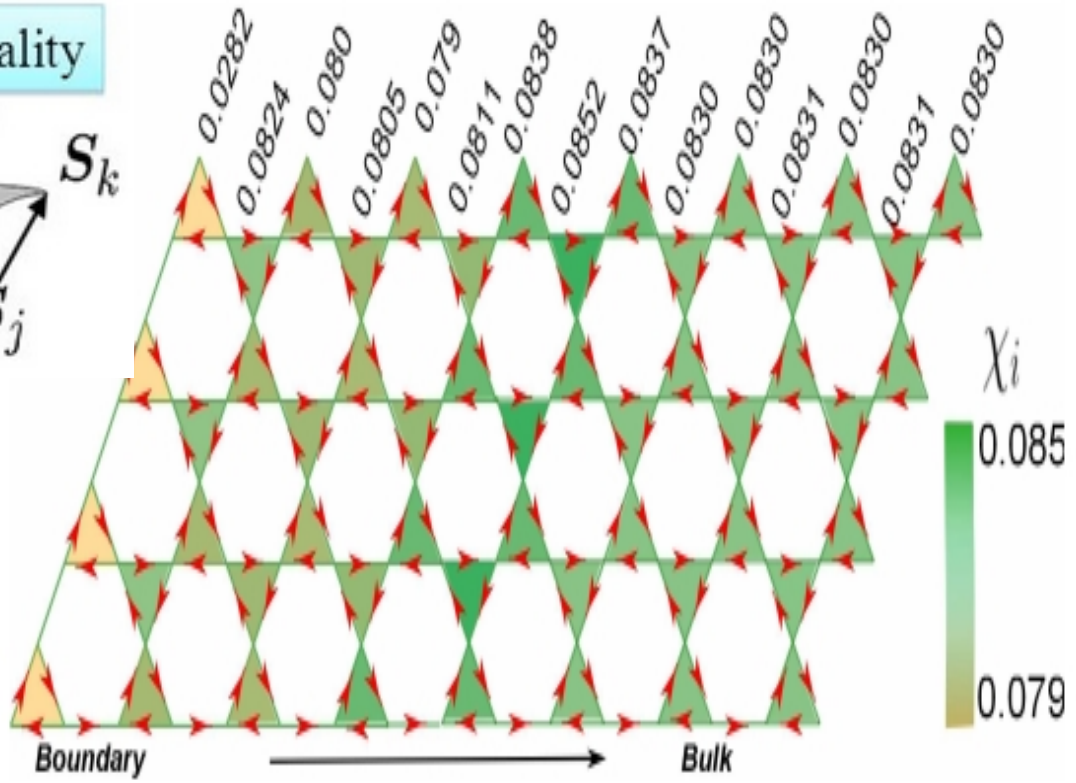
Shoushu Gong et al.

Herbertsmithite



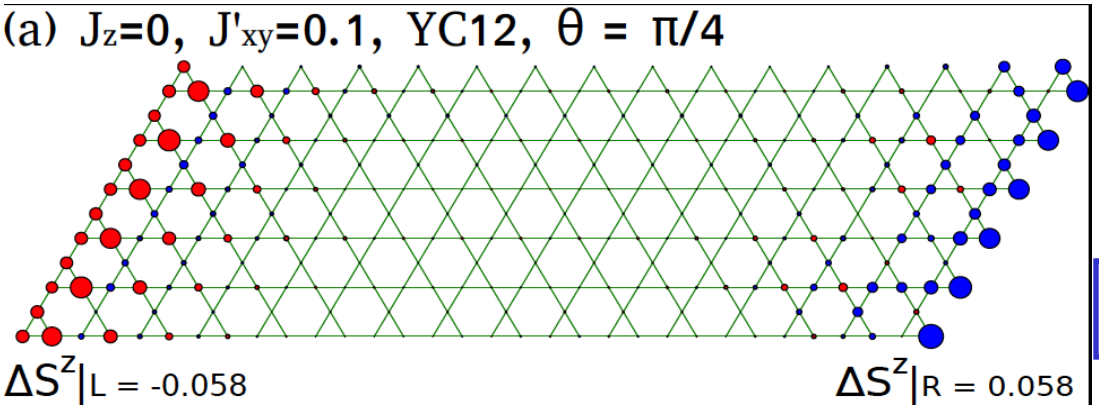


Spin dancing pattern



$$H = J_1 \sum_{\langle i,j \rangle} S_i \cdot S_j + J_2 \sum_{\langle\langle i,j \rangle\rangle} S_i \cdot S_j + J_3 \sum_{\langle\langle\langle i,j \rangle\rangle\rangle} S_i \cdot S_j$$

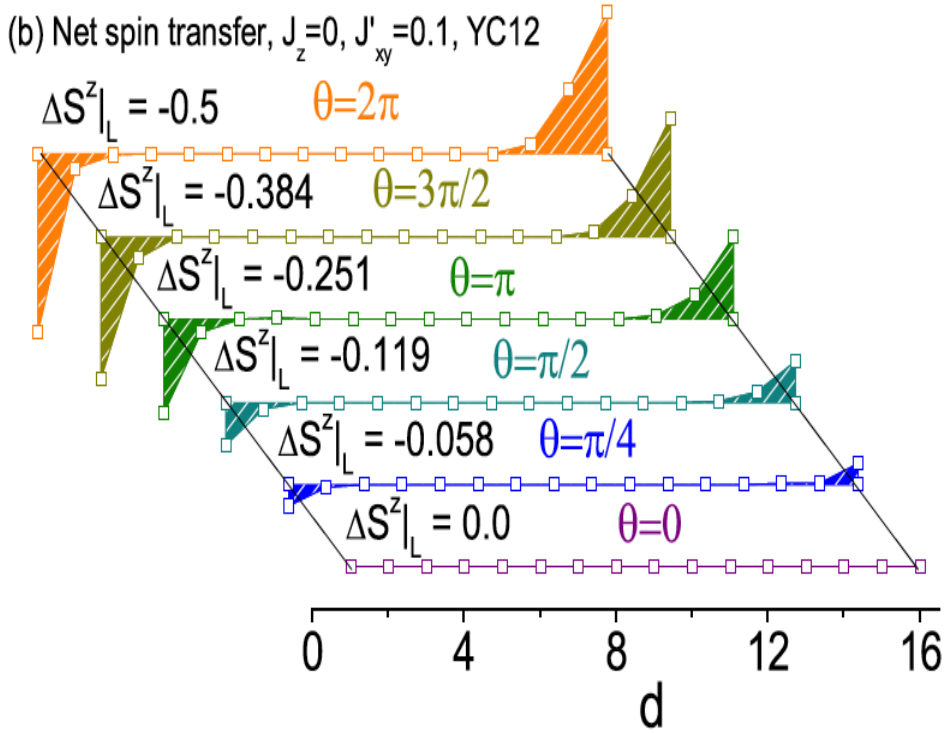
Inserting flux adiabatically, spin pump, and C=1/2 quantization
Signature of nu=1/2 Laughlin state and CSL

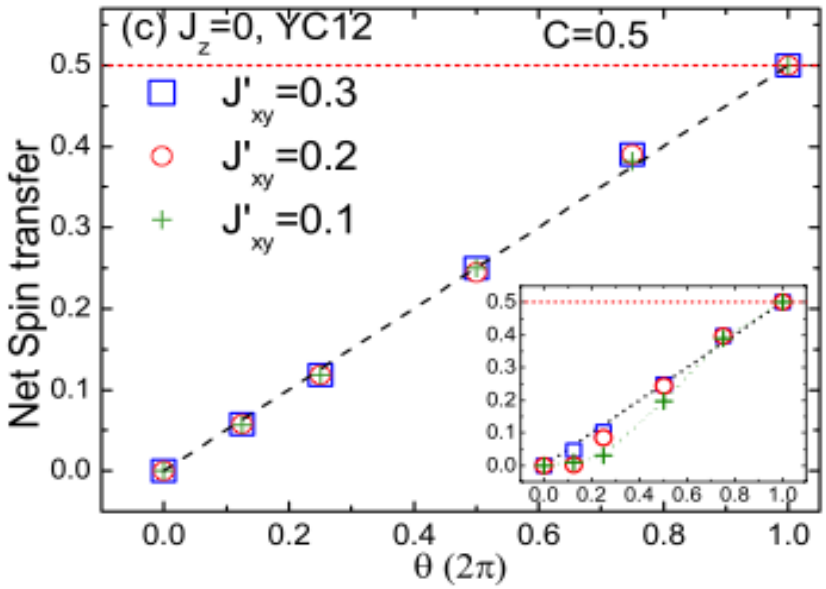


- Flux=twist boundary Phase

- Haldane and Arovas 1995

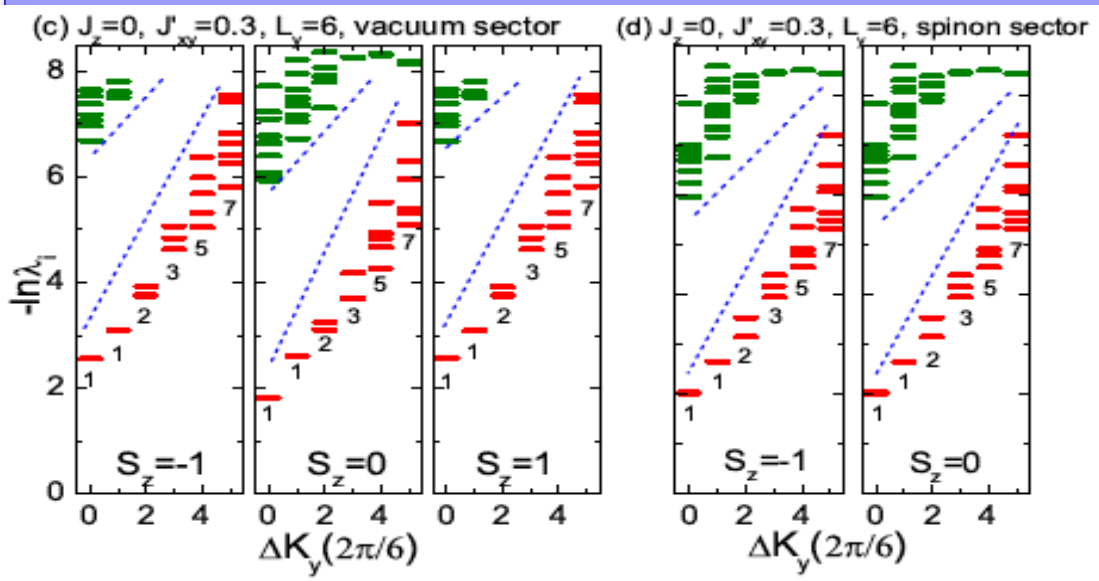
- Ly=12

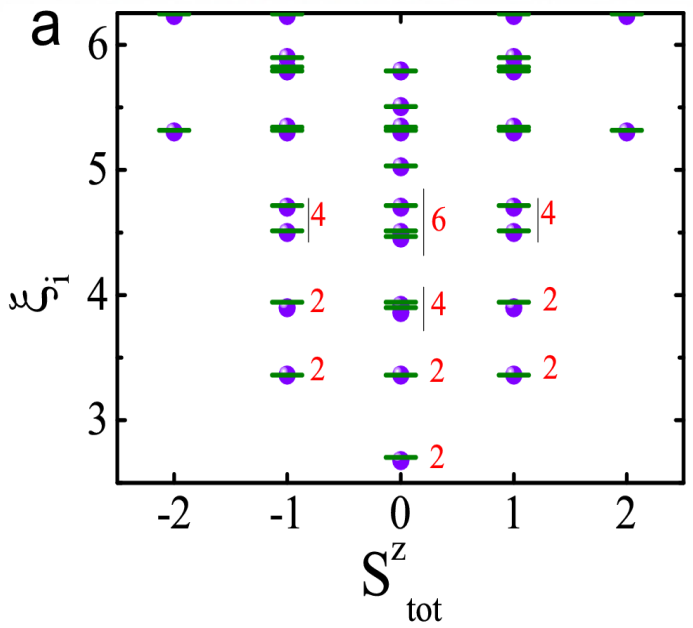


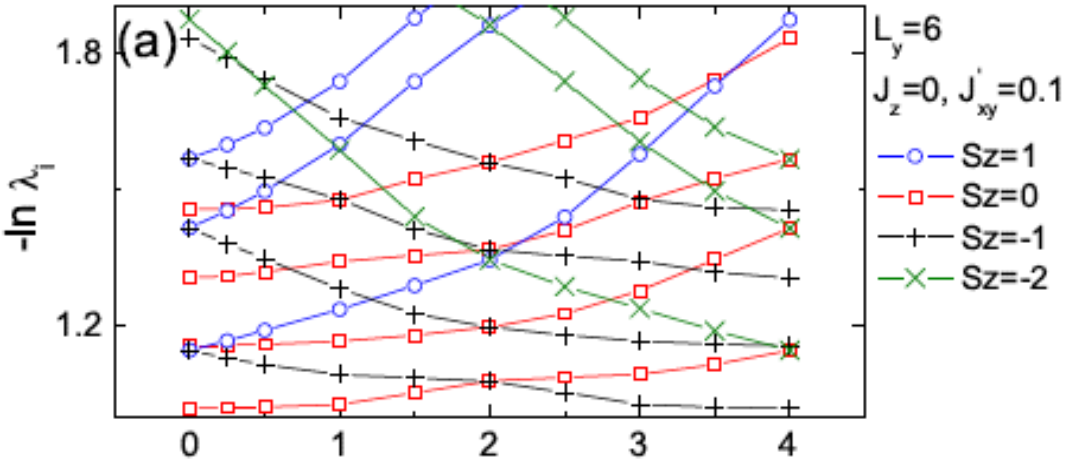


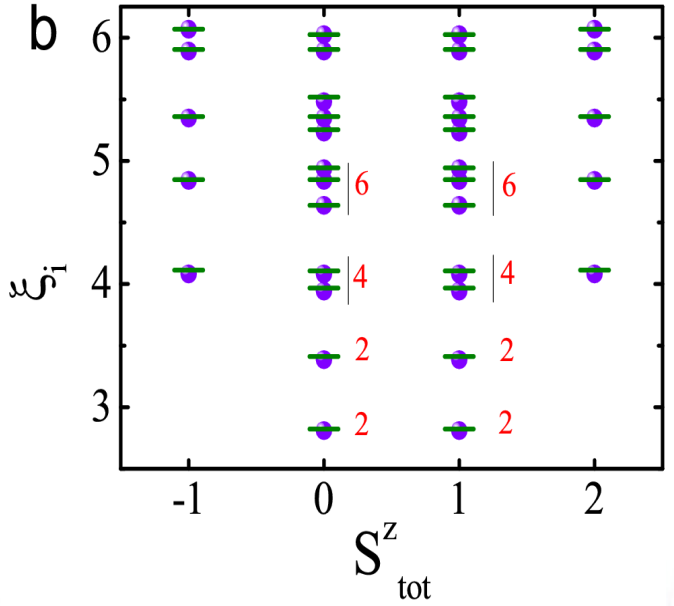
Entanglement spectra of CSL: emerging Laughlin v=1/2 FQHE

Wei Zhu et al.





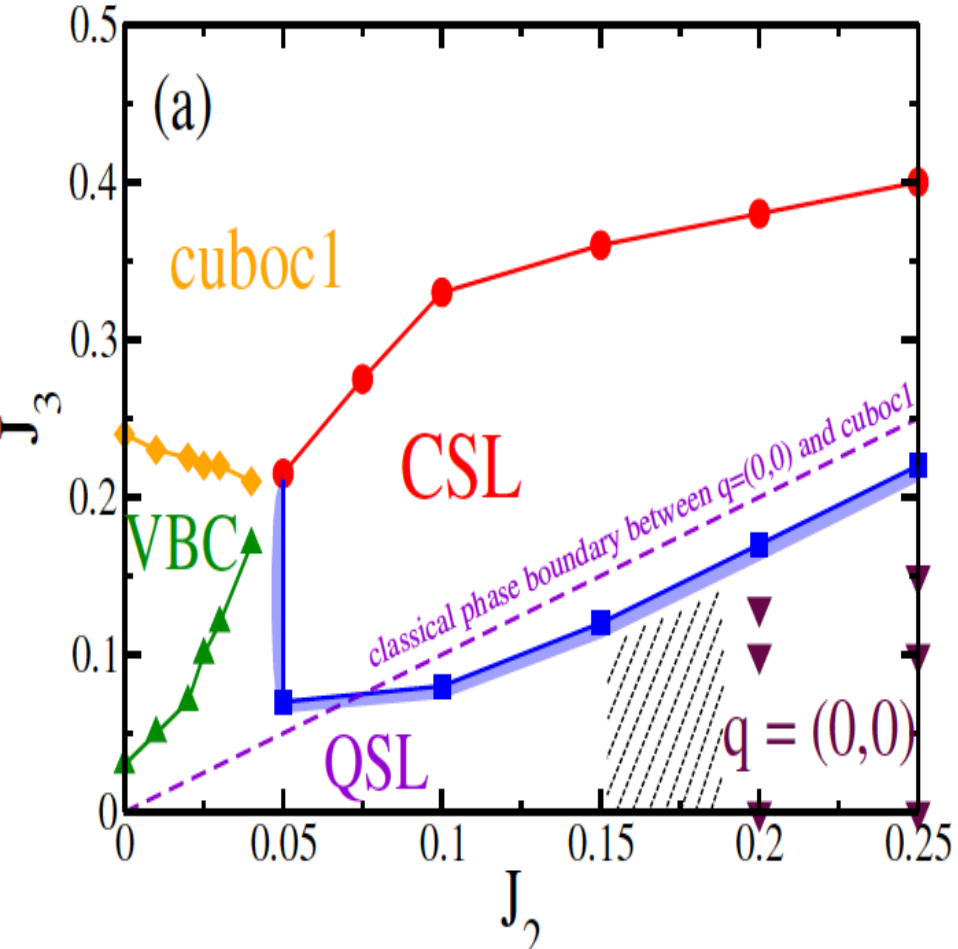


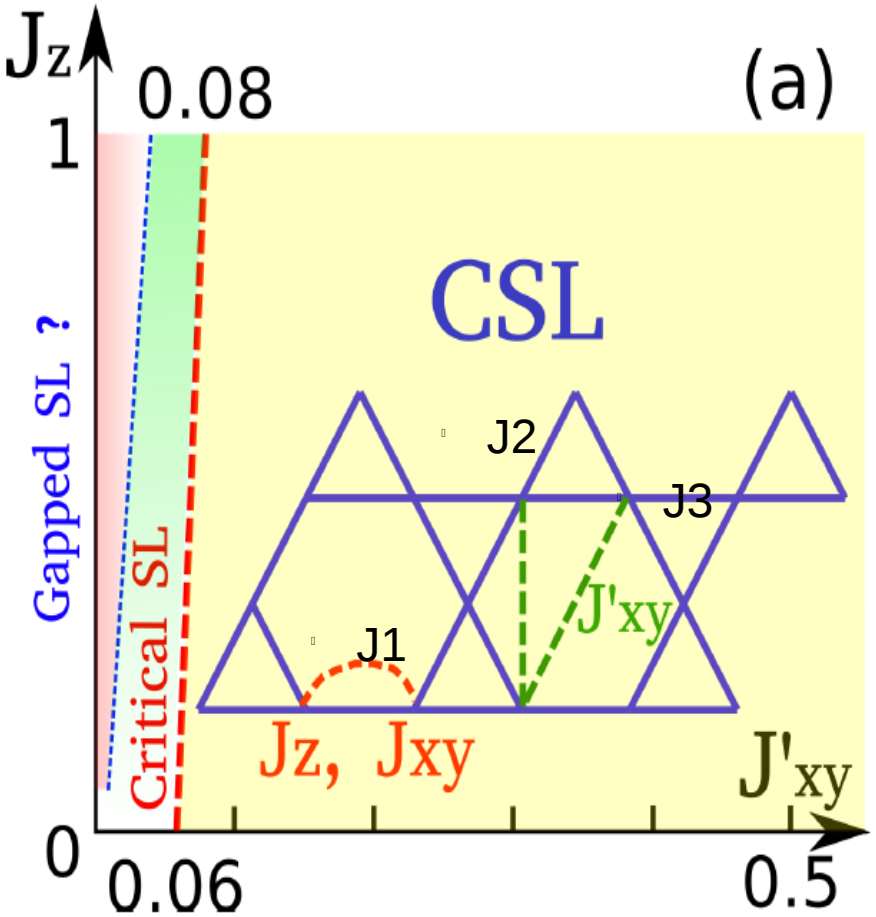


- Inserting flux turns the ground state
- from vacuum to spinon sector

Robust examples of discovering chiral spin liquid in kagome spin ½ models Shoushu Gong et al

$$H = J_1 \sum_{\langle i,j \rangle} S_i \cdot S_j + J_2 \sum_{\langle\langle i,j \rangle\rangle} S_i \cdot S_j + J_3 \sum_{\langle\langle\langle i,j \rangle\rangle\rangle} S_i \cdot S_j$$



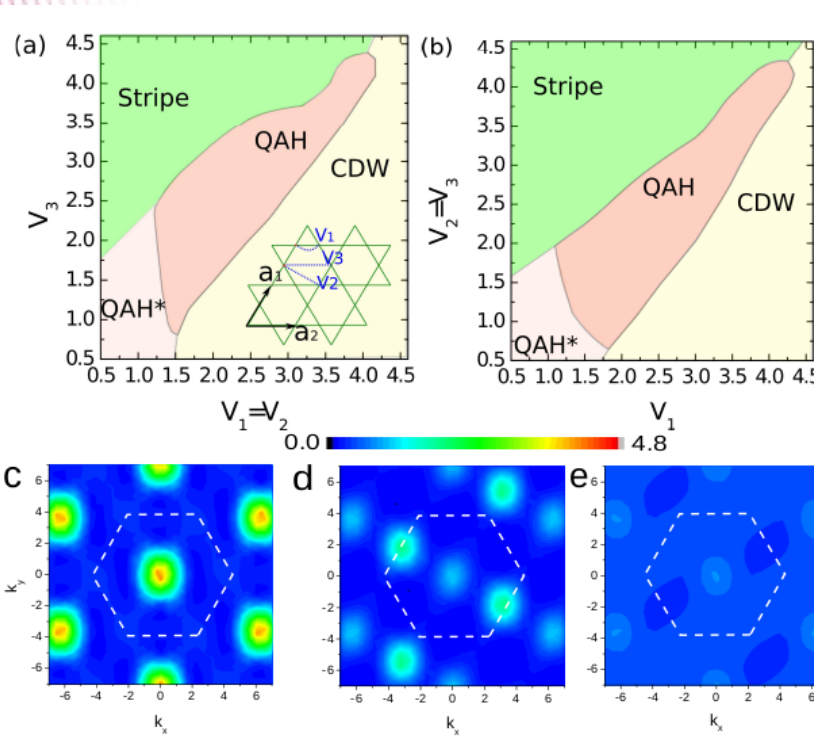


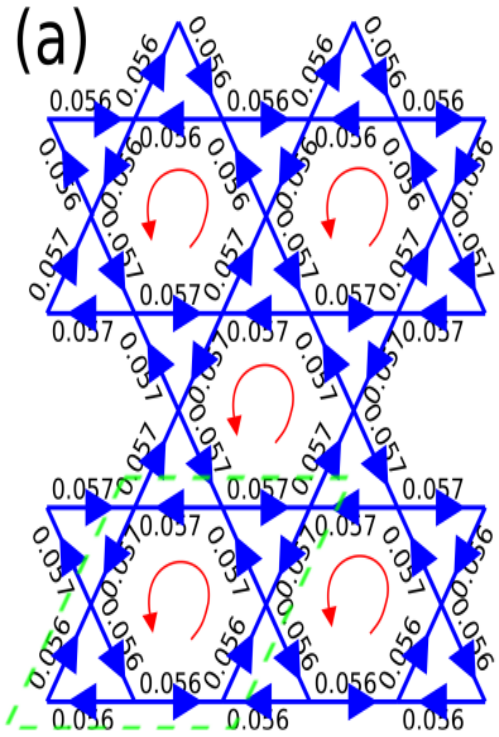
Interaction-Driven Spontaneous Quantum Hall Effect on Kagome Lattice

Wei Zhu et al.

$$H = t \sum_{\langle \mathbf{r}\mathbf{r}' \rangle} \left[c^{\dagger}_{\mathbf{r}'} c_{\mathbf{r}} + \text{H.c.} \right] + V_1 \sum_{\langle \mathbf{r}\mathbf{r}' \rangle} n_{\mathbf{r}} n_{\mathbf{r}'} + V_2 \sum_{\langle\langle \mathbf{r}\mathbf{r}' \rangle\rangle} n_{\mathbf{r}} n_{\mathbf{r}'} + V_3 \sum_{\langle\langle\langle \mathbf{r}\mathbf{r}' \rangle\rangle\rangle} n_{\mathbf{r}} n_{\mathbf{r}'},$$

In agreement with mean-field & low energy renormalization group





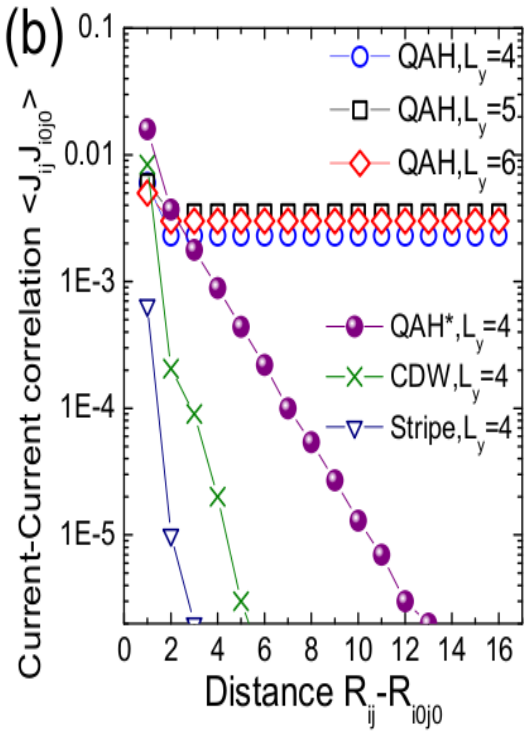


FIG. 1: Phase diagram of an extended fermion Hubbard model (Eq.

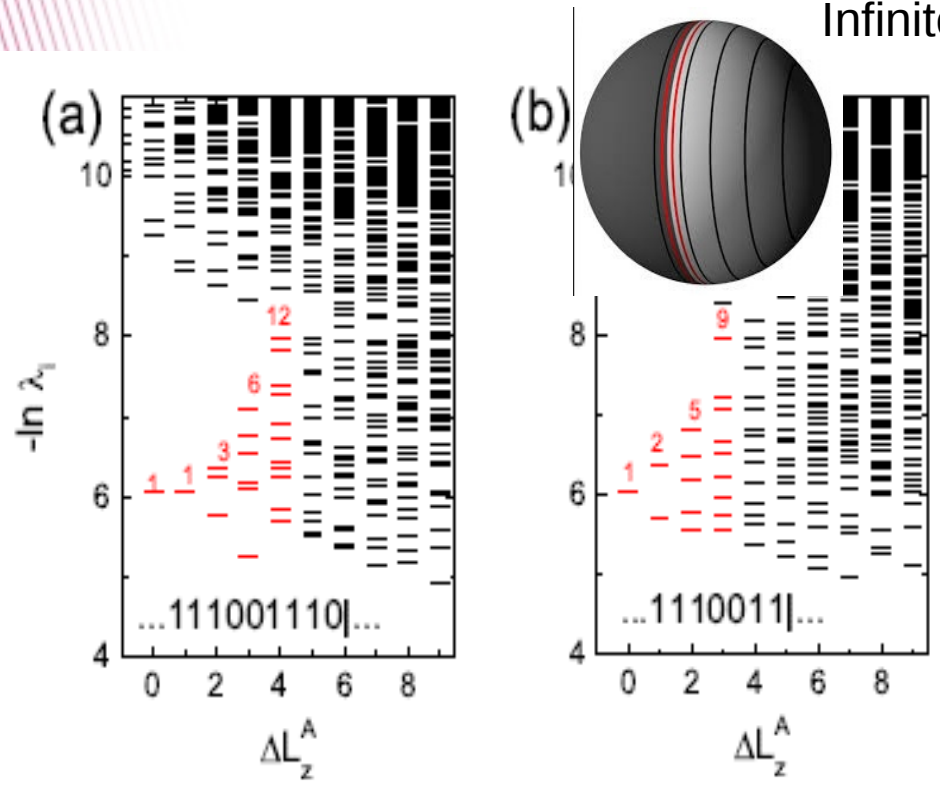
Entanglement Spectrum: 12/5 FQHE as Read-Rezayi state Wei Zhu et al

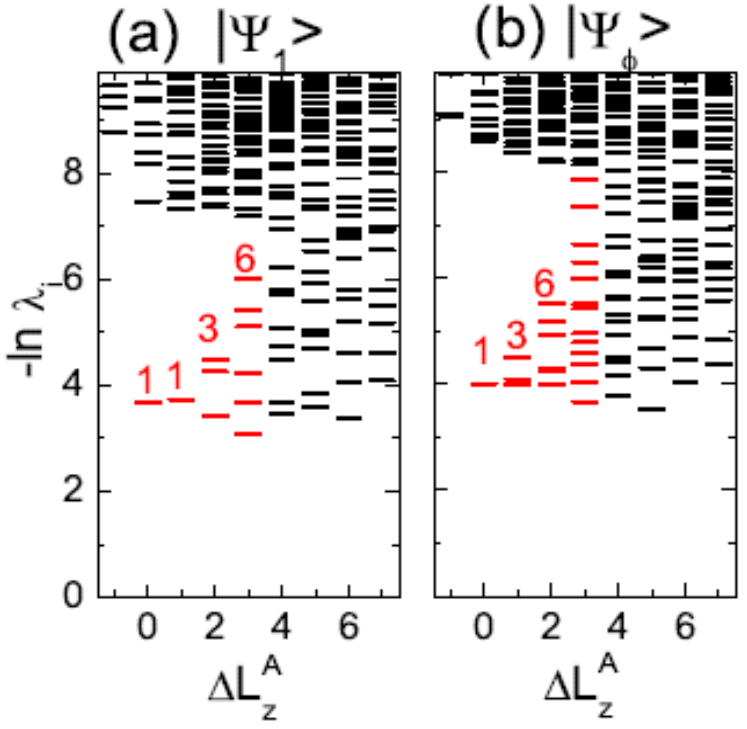
Detected by Entanglement Spectrum:
111001110011100…..
1: 1,1,3,6,12…
111001110011…..
: 1,2,5,9,….

On cylinder, we also find another ground state: 10101 10101 10101

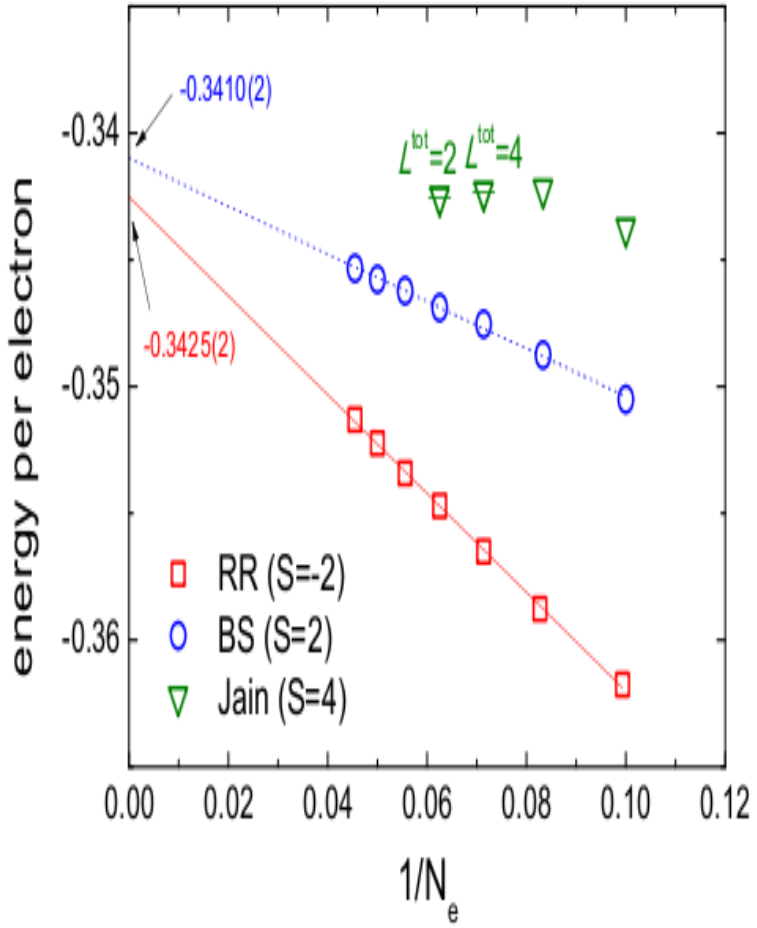
Entanglement spectrum:
1,1,3,6 ... and 1,3,6, (13)

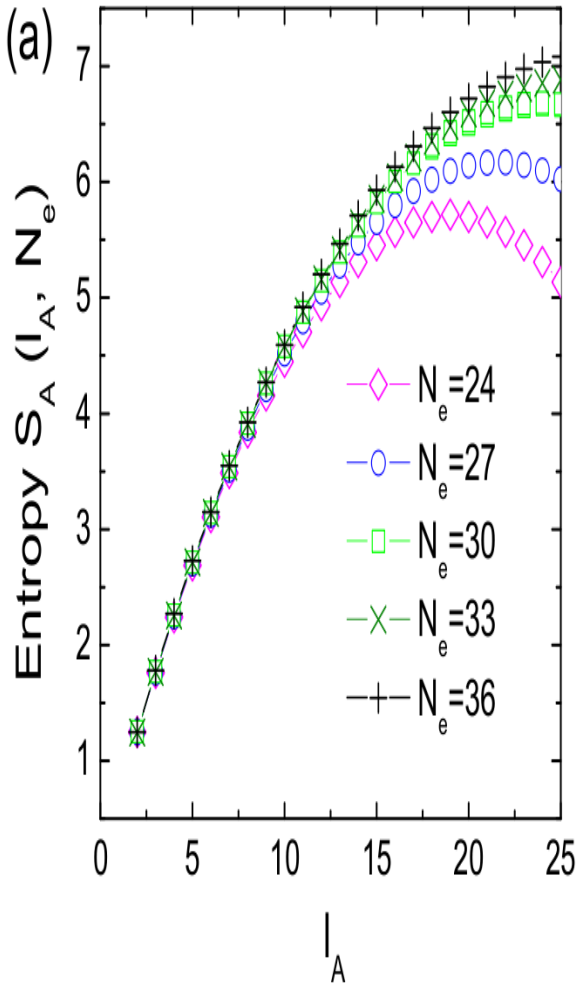
Infinite Cylinder Ly=24

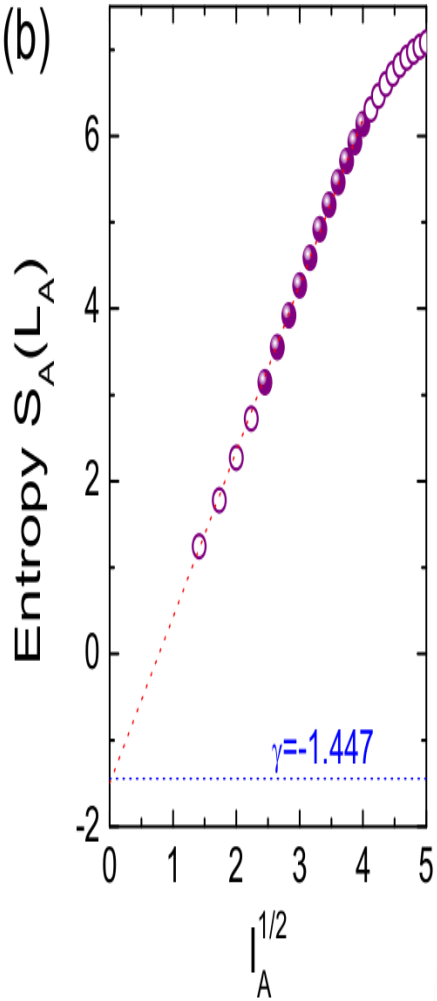




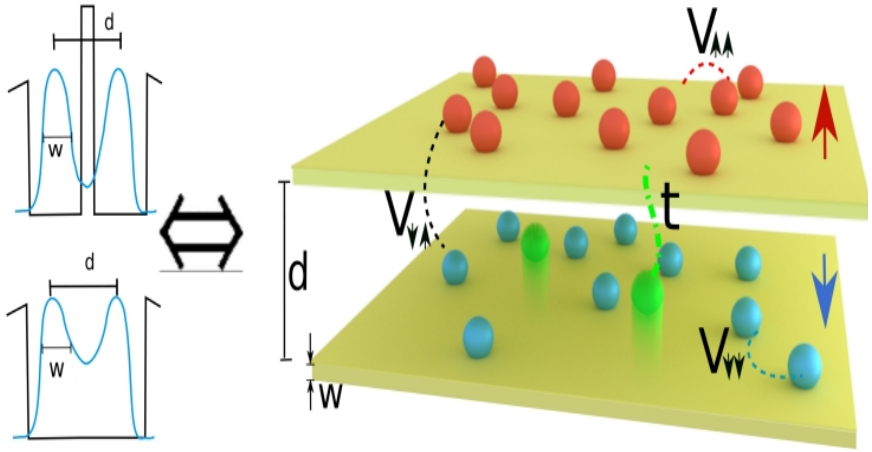
Energy and Topological entanglement entropy: 12/5 FQHE as Read-Rezayi state



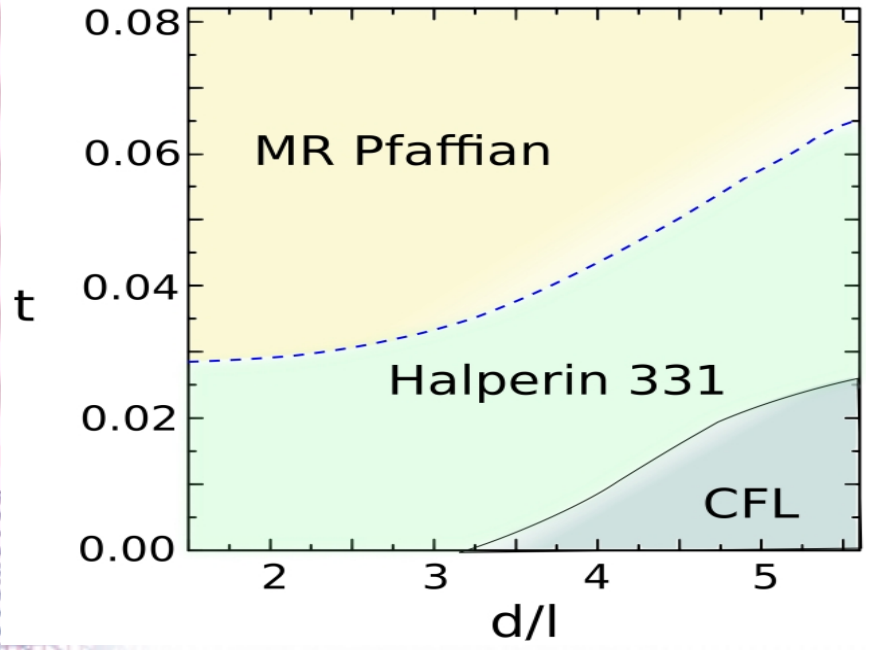


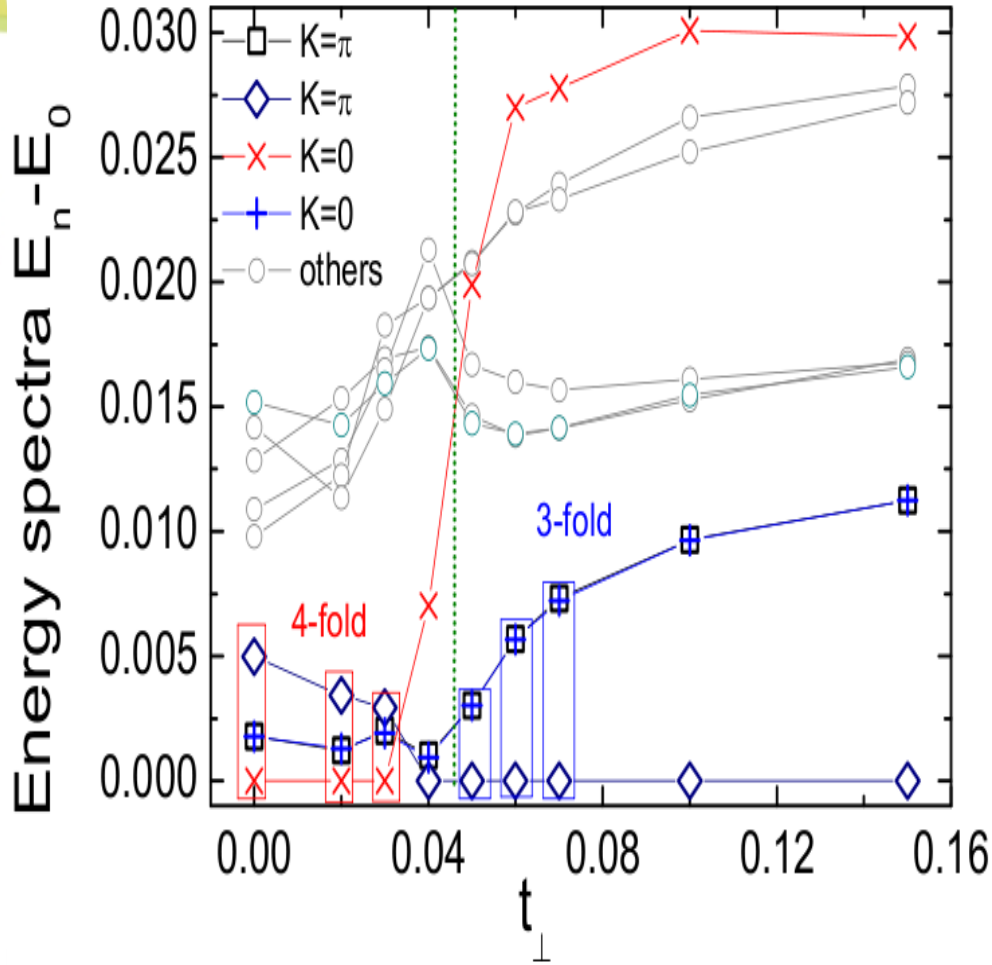


Fractional Quantum Hall Bilayers at Half-Filling: Tunneling-driven Non-Abelian Phase Wei Zhu et al.



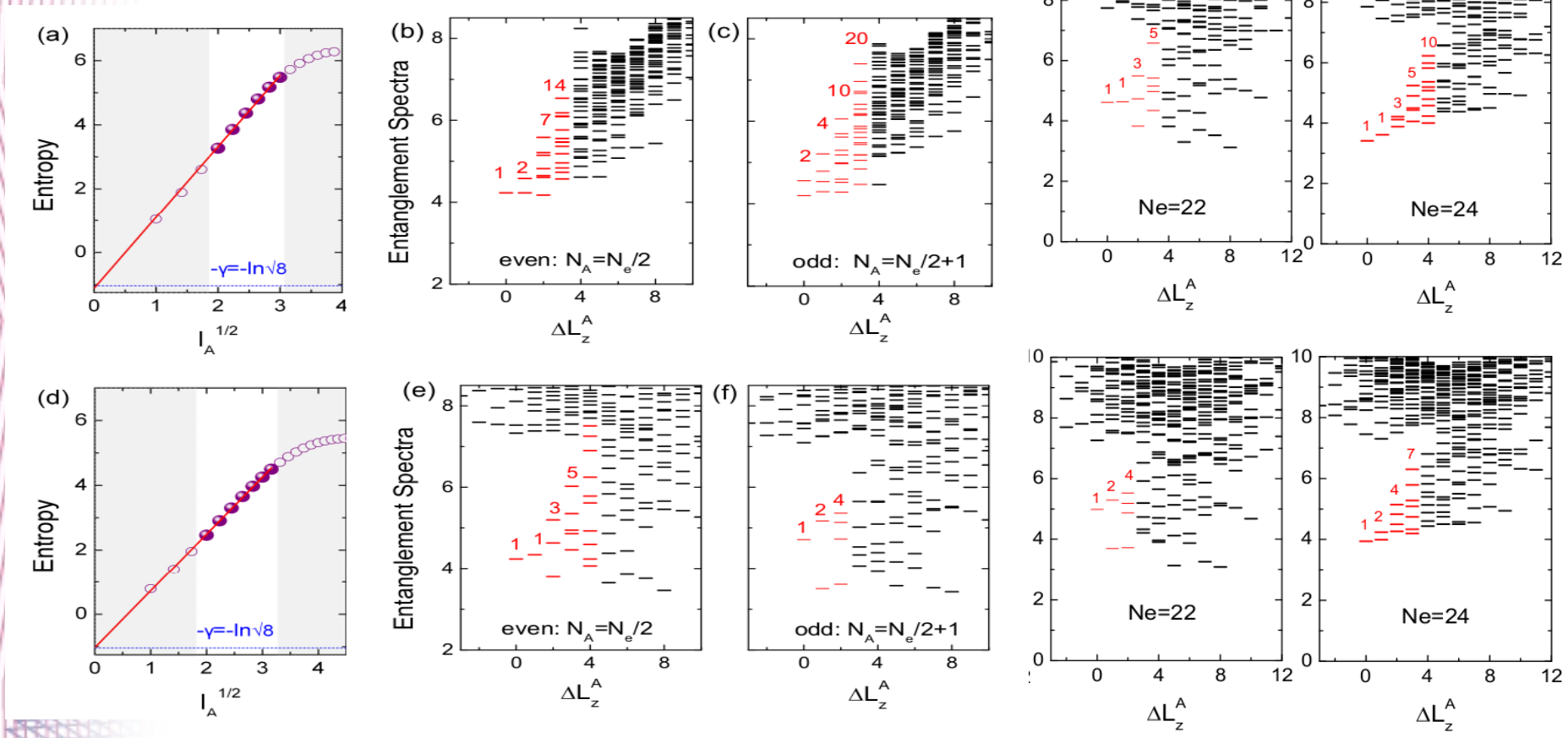
Predicted by Xiao-Gang Wen & other works





Entanglement spectrum and entropy, Moore-Read vs. Halperin 331

Halperin 331 state



Ne=22

Moore-Read state

Better spectrum for largest system (Ne=24)

Qantum phase transition through gapping out low energy state