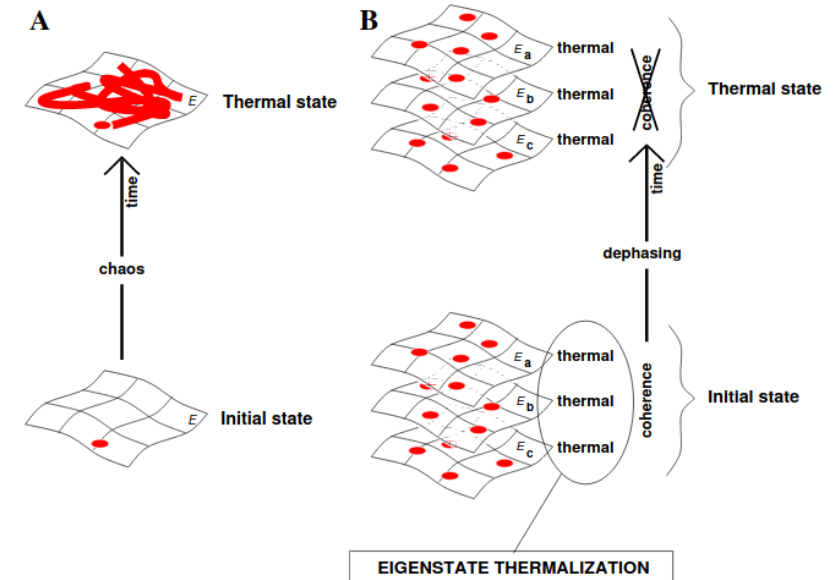
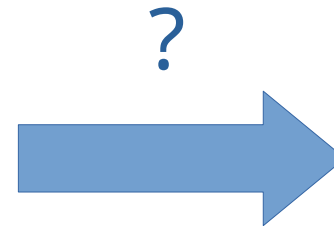
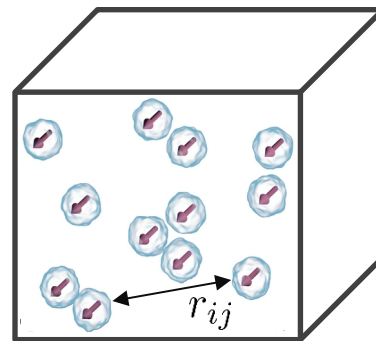


# Localization with Rydberg atoms



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# Motivation

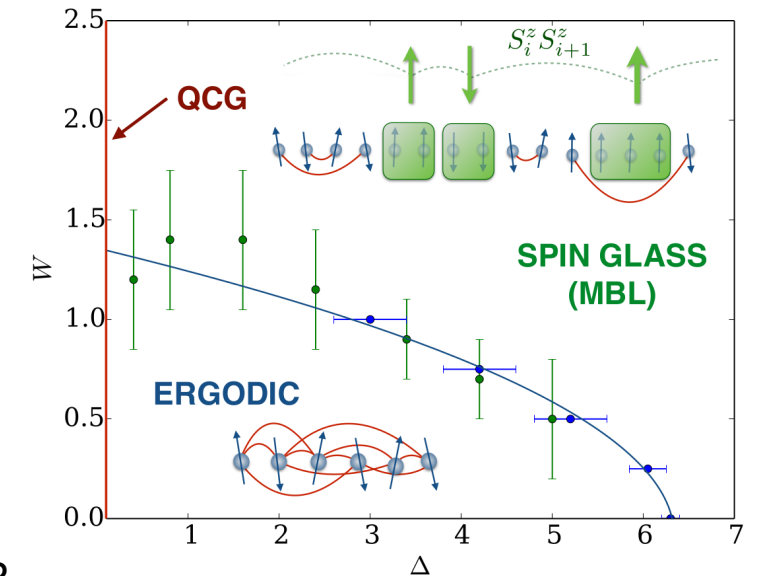
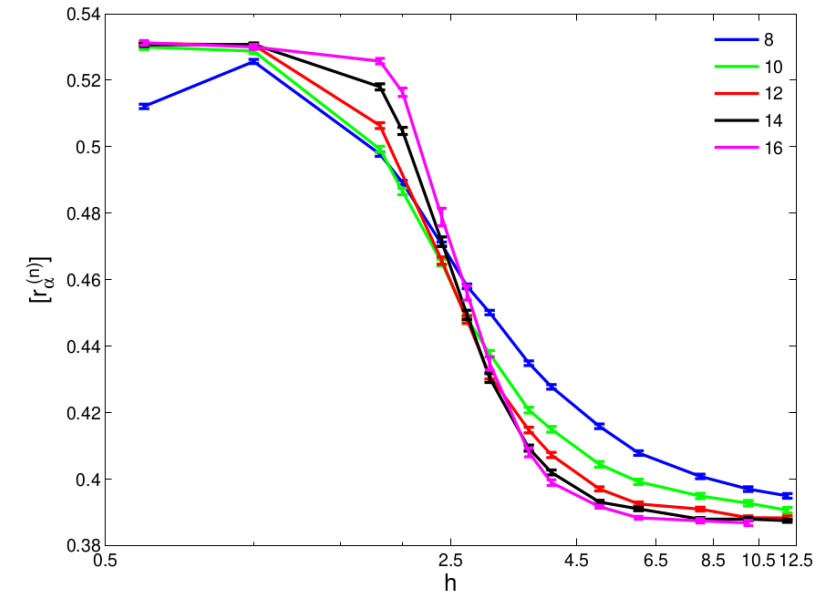
Common types of randomness in MBL systems:

## Random field

- Anderson (1958): XX + single excitation
- Pal & Huse (2010): XXZ + random z field

## Random coupling

- Pekker et al. (2014): real-space renormalization group
- Vasseur et al. (2016): nearest neighbour XXZ
- Mohdeb et al. (2022): fractionally filled lattice + power-law

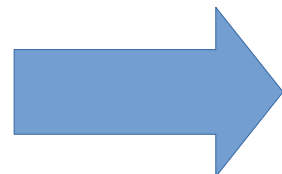
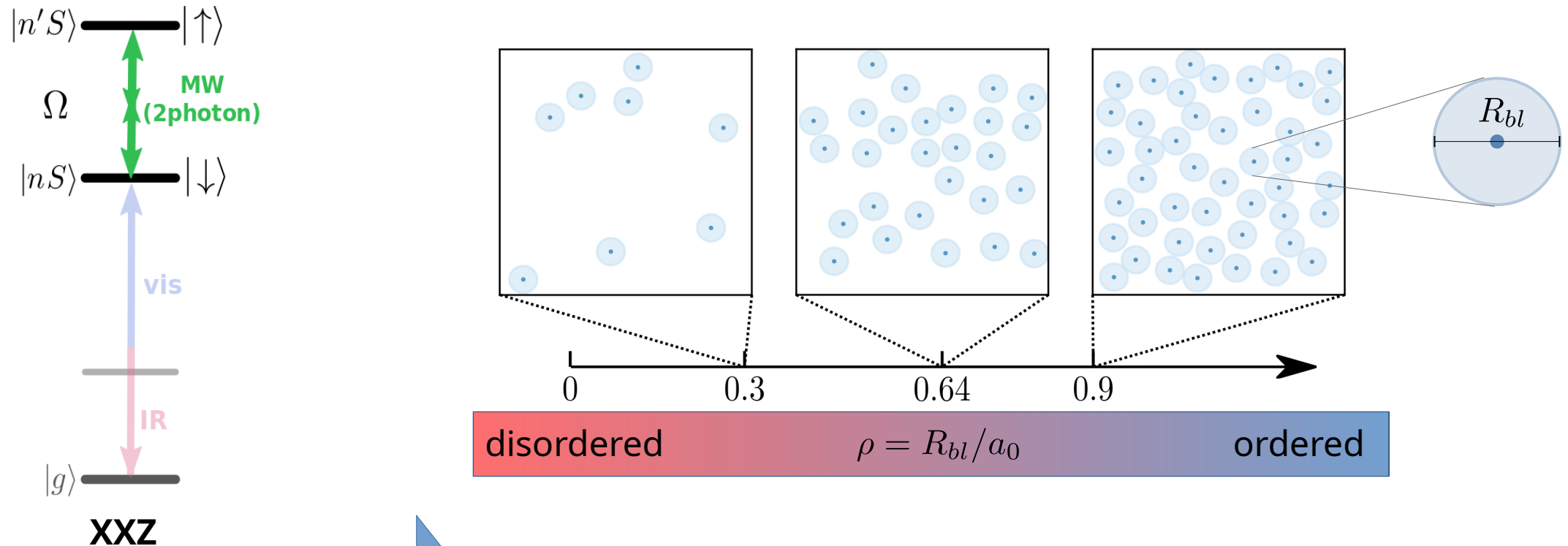


Hard to engineer! Can't we use what's readily available?

# Blockaded disorder

$$\hat{H}_{XXZ} = \sum_{i,j} J_{ij} \left( \hat{S}_+^{(i)} \hat{S}_-^{(j)} + \hat{S}_-^{(i)} \hat{S}_+^{(j)} + 2\Delta \hat{S}_z^{(i)} \hat{S}_z^{(j)} \right)$$

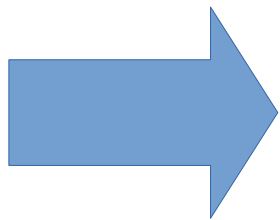
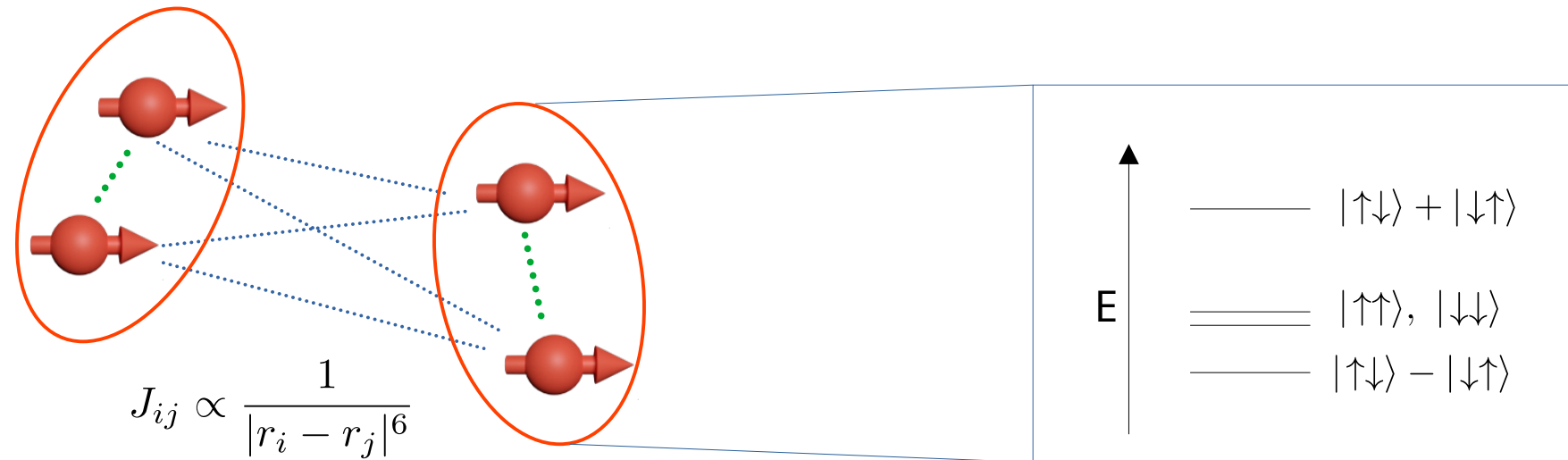
$$J_{ij} \propto \frac{1}{|r_i - r_j|^6}$$



Rydberg blockade enables tunable disorder strength!

# Why should it localize?

$$\hat{H}_{XXZ} = \sum_{i,j} J_{ij} \left( \hat{S}_+^{(i)} \hat{S}_-^{(j)} + \hat{S}_-^{(i)} \hat{S}_+^{(j)} + 2\Delta \hat{S}_z^{(i)} \hat{S}_z^{(j)} \right) \xrightarrow{\text{Strong disorder}} \hat{H}_{XXZ} \approx \sum_{\text{Pairs } i,j} J_{ij} \hat{H}_{pair}^{(i)(j)}$$



Pairs constitute local integrals of motion!

# Level-spacing ratio

$$r_i = \frac{\min(E_{i+1} - E_i, E_i - E_{i-1})}{\max(E_{i+1} - E_i, E_i - E_{i-1})}$$

- Thermal – Level repulsion

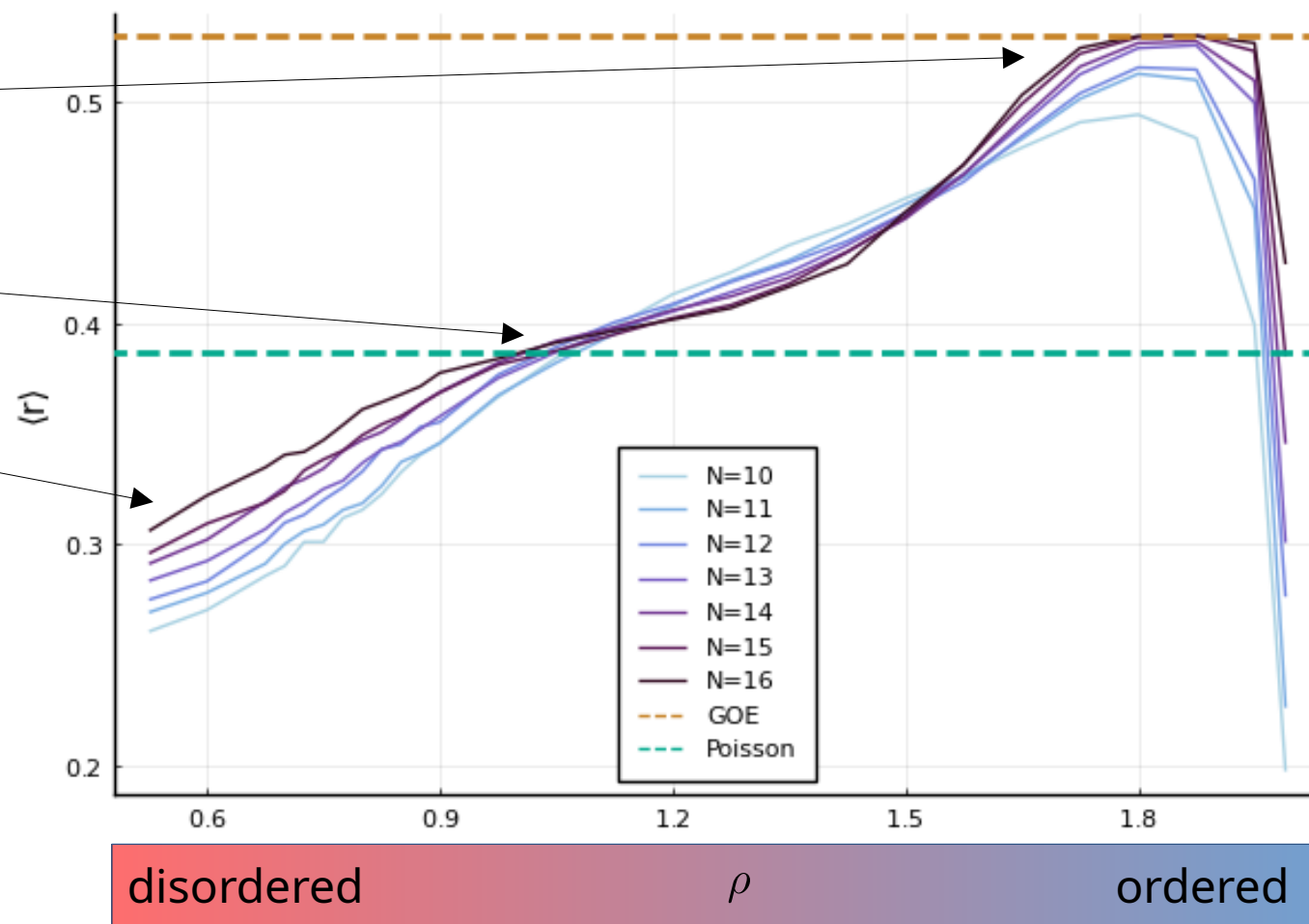
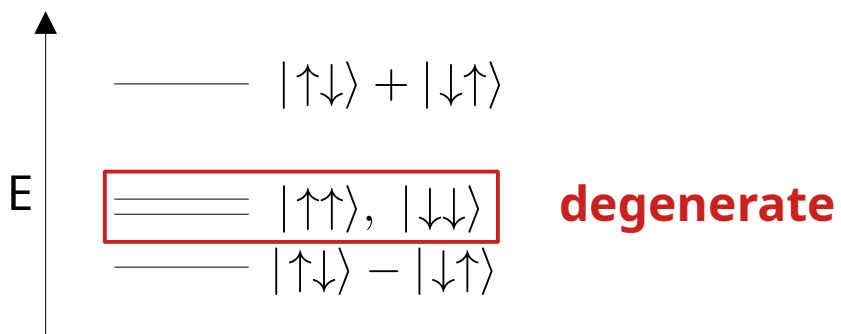
$$\langle r \rangle \approx 0.52$$

- MBL – Poisson

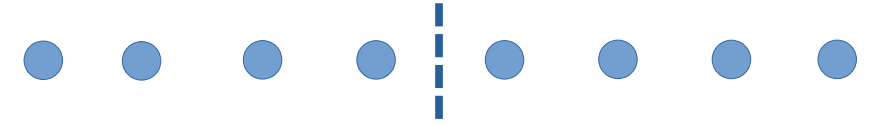
$$\langle r \rangle \approx 0.39$$

- Pairs – Level attraction

$$\langle r \rangle < 0.39$$



# Entanglement Entropy



- Thermal – volume law

$$\langle S \rangle \propto N$$

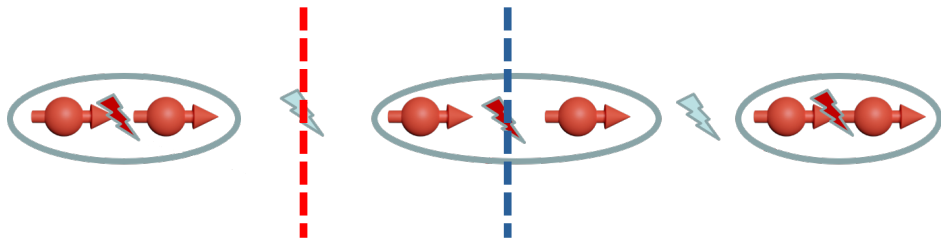
- MBL – area law

$$\langle S \rangle \propto \text{const}$$

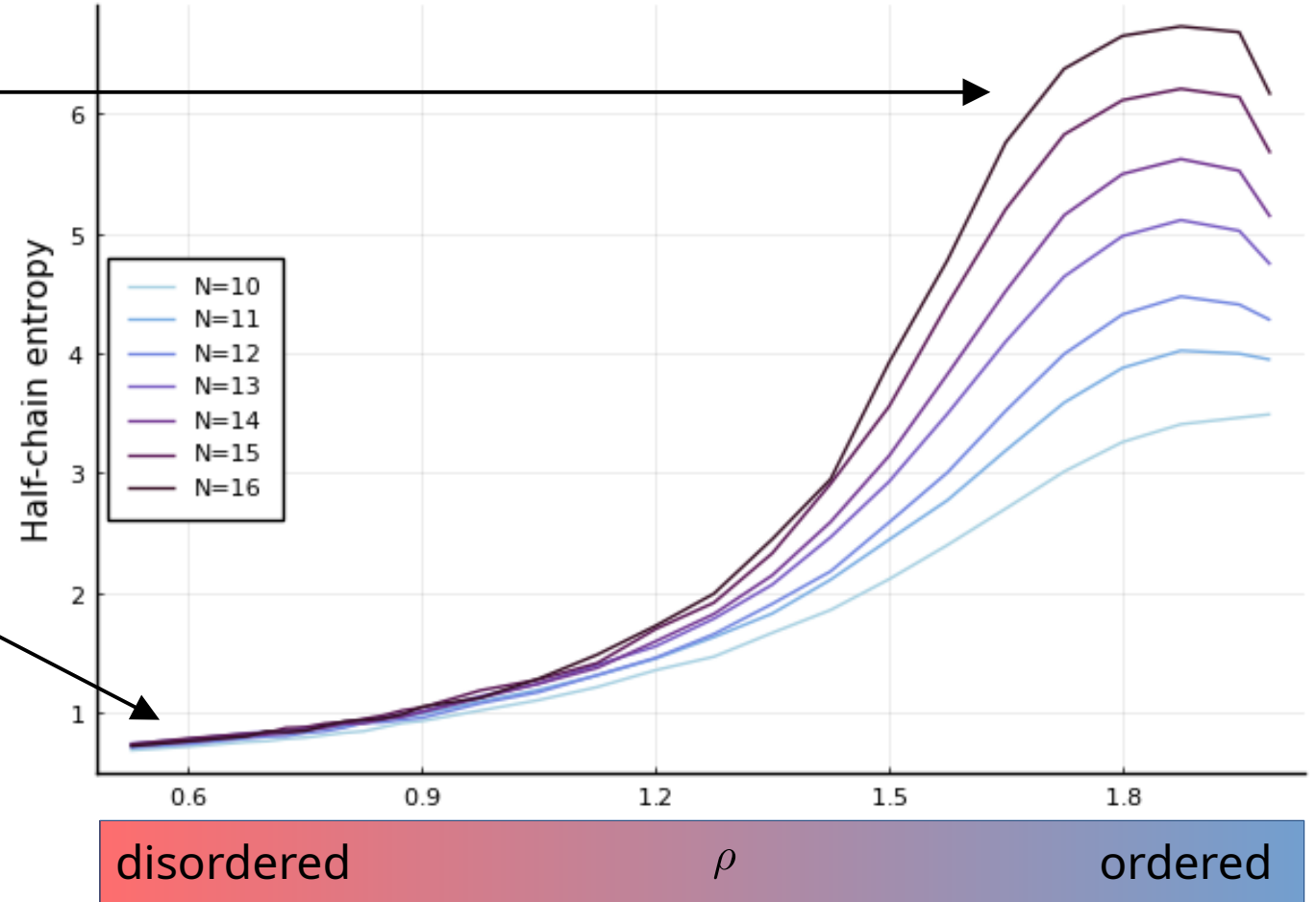
- Pairs

$$\langle S \rangle \approx 0.5$$

Maximally entangled



Not entangled



disordered

$\rho$

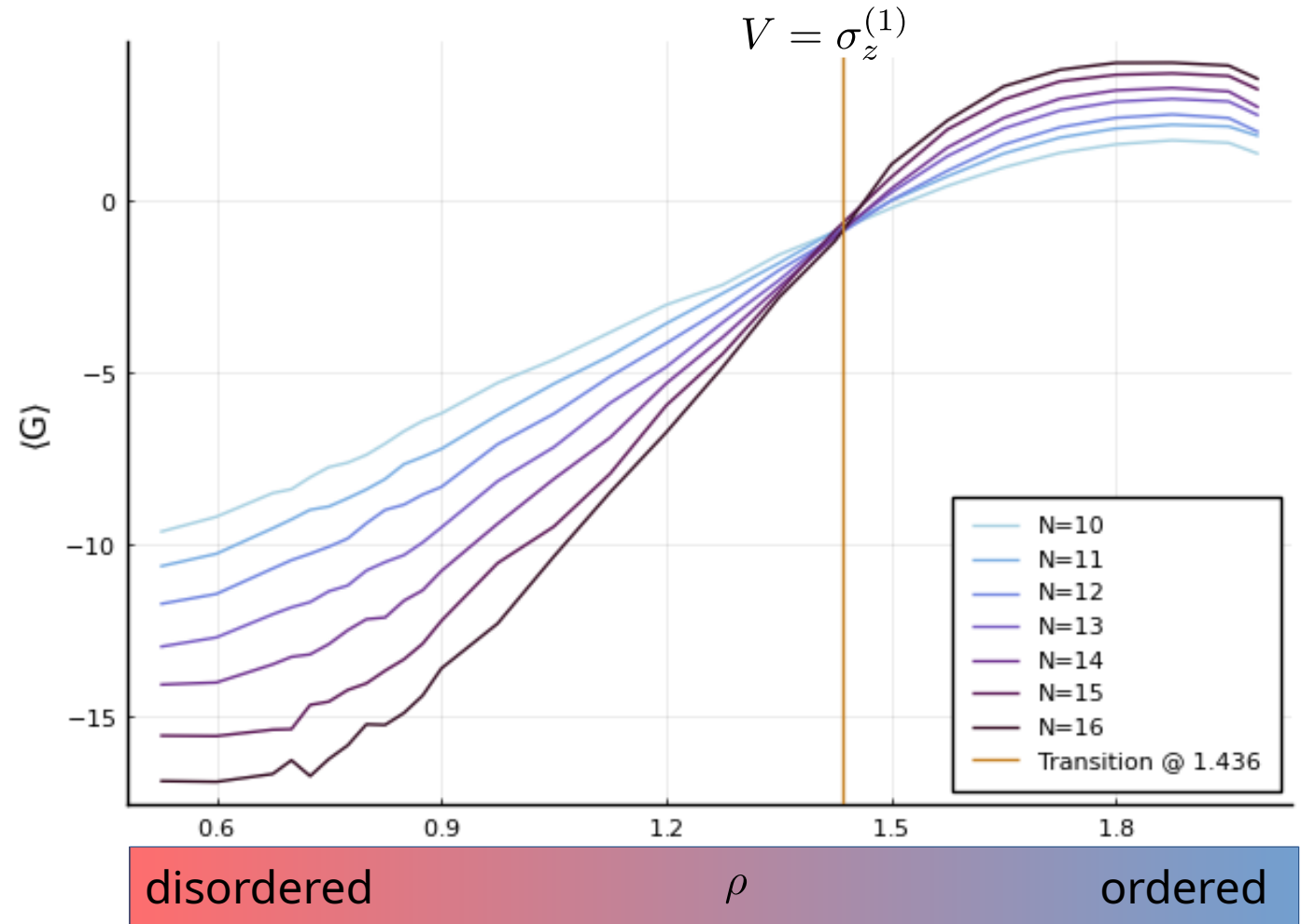
ordered

# Thouless parameter

- Like an order parameter for MBL
- Thermal: Eigenstates close in energy have similar structure  
 $\langle \mathcal{G} \rangle \propto N$
- MBL: Eigenstates close in energy have totally different structure  
 $\langle \mathcal{G} \rangle \propto -N$
- Critical:  
 $\langle \mathcal{G} \rangle = \text{const}$

$$\mathcal{G}_n = \ln \frac{|V_{n,n+1}|}{E'_{n+1} - E'_n}$$

Local operator



# Conclusion & Outlook

- Found a clear transition
- Transition does not depend strongly on system size
- Next: Propose an experiment!

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