Localization with Rydberg atoms

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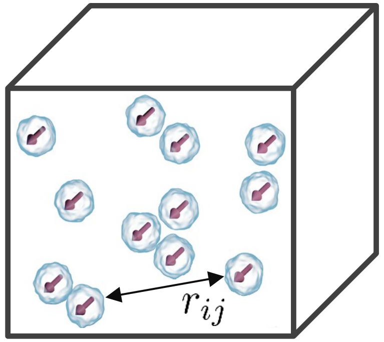

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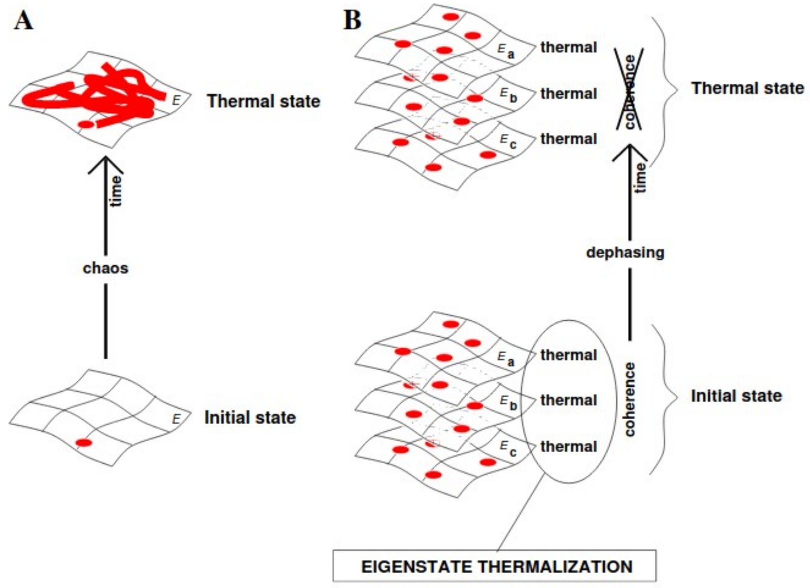


Rigol et al. Nature 452, p. 854–858 (2008)

Motivation

Common types of randomness in MBL systems:

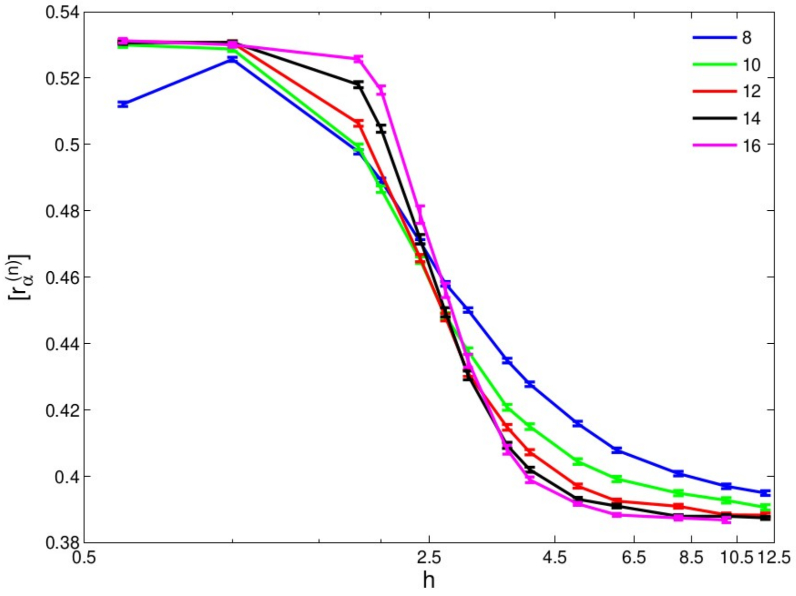
Random field

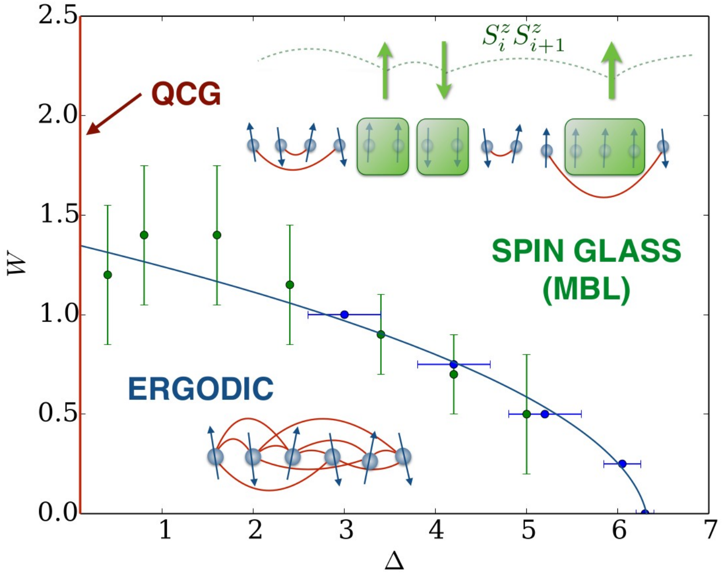
- Anderson (1958): XX + single excitation
- Pal & Huse (2010): XXZ + random z field

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

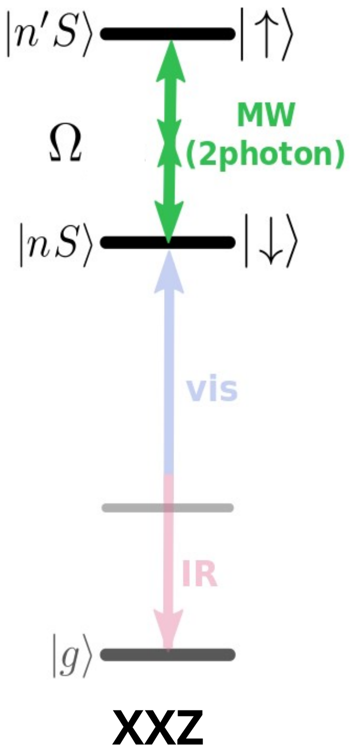
Hard to engineer! Can't we use what's readily available?

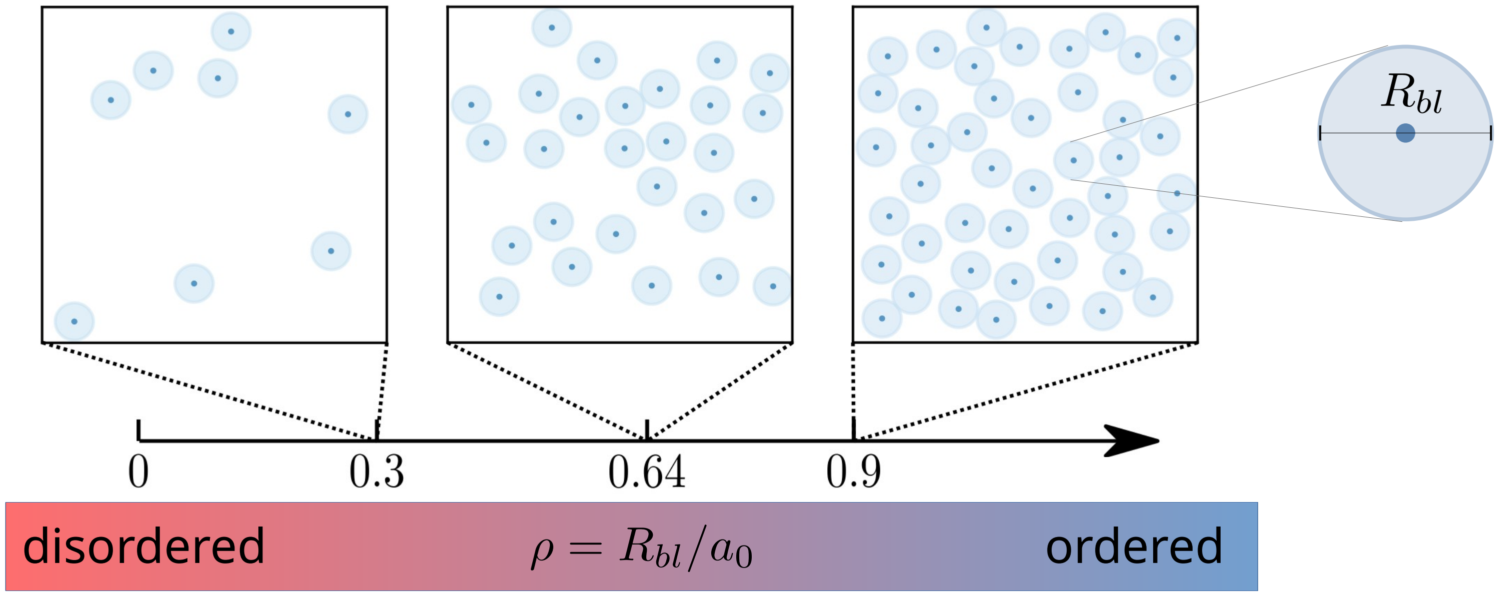




Blockaded disorder

$$\hat{H}_{XXZ} = \sum_{i,j} J_{ij} \left(\hat{S}_+^{(i)} \hat{S}_-^{(j)} + \hat{S}_-^{(i)} \hat{S}_+^{(j)} + 2\Delta \hat{S}_z^{(i)} \hat{S}_z^{(j)} \right) \qquad J_{ij} \propto \frac{1}{|r_i - r_j|^6}$$



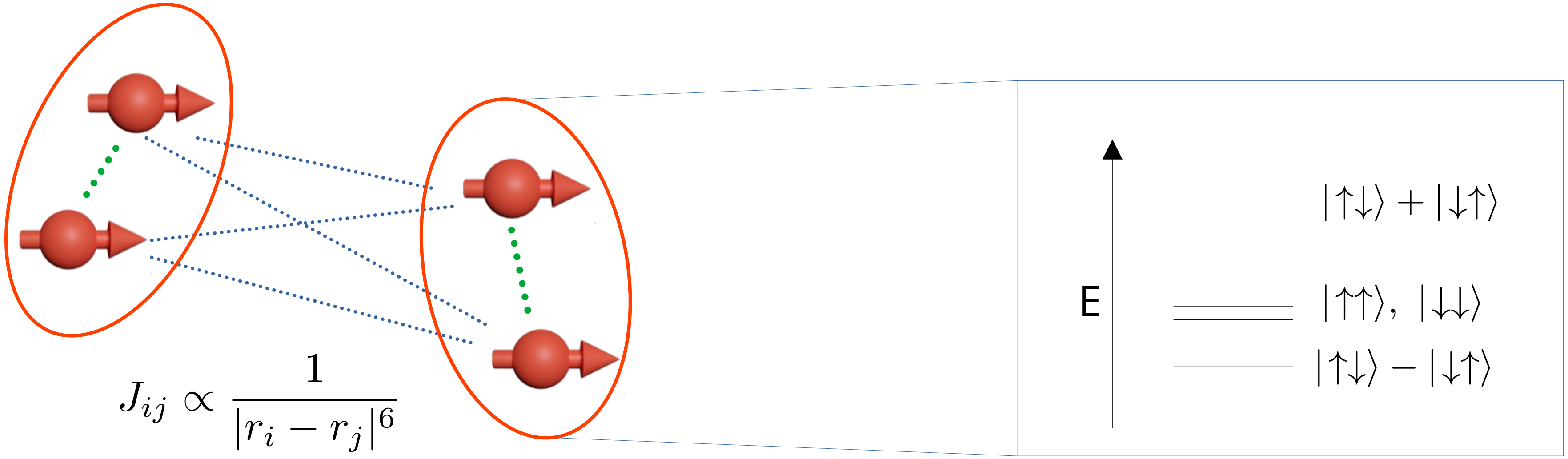


Rydberg blockade enables tunable disorder strength!

Signoles et al. 10.1103/PhysRevX.11.011011 (2021)

Why should it localize?

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



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

Pairs constitute local integrals of motion!

Vasseur et al. Phys. Rev. B 93, 134207 (2016)

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

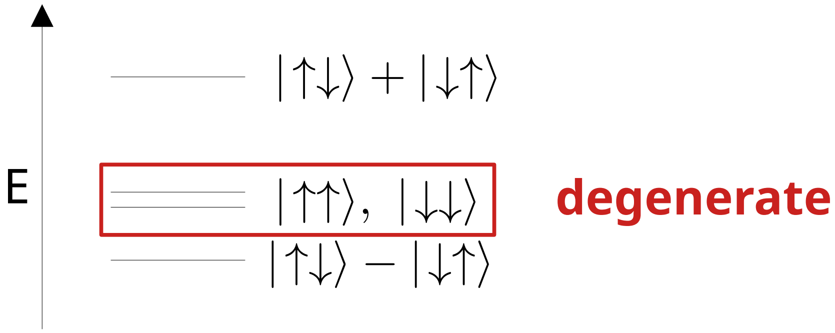
  $$\langle r \rangle \approx 0.52$$

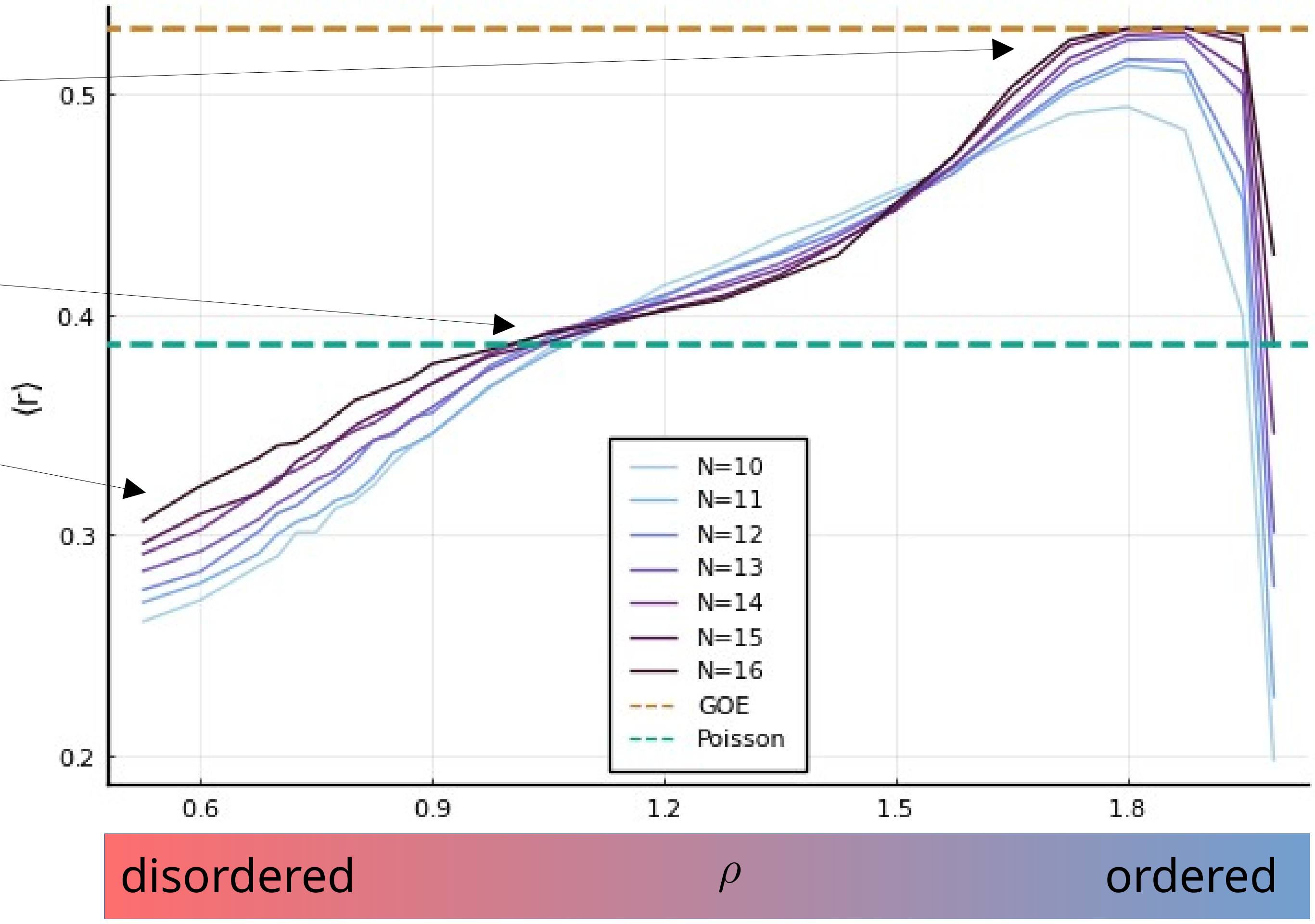
- MBL – Poisson

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

- Pairs – Level attraction

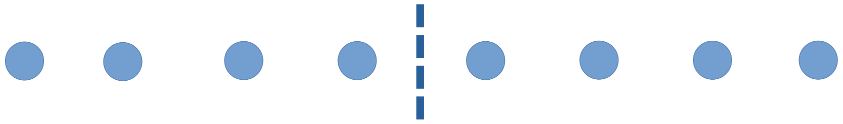
  $$\langle r \rangle < 0.39$$





Pal&Huse Phys. Rev. B 82, 174411 (2010)

Entanglement Entropy



- Thermal – volume law

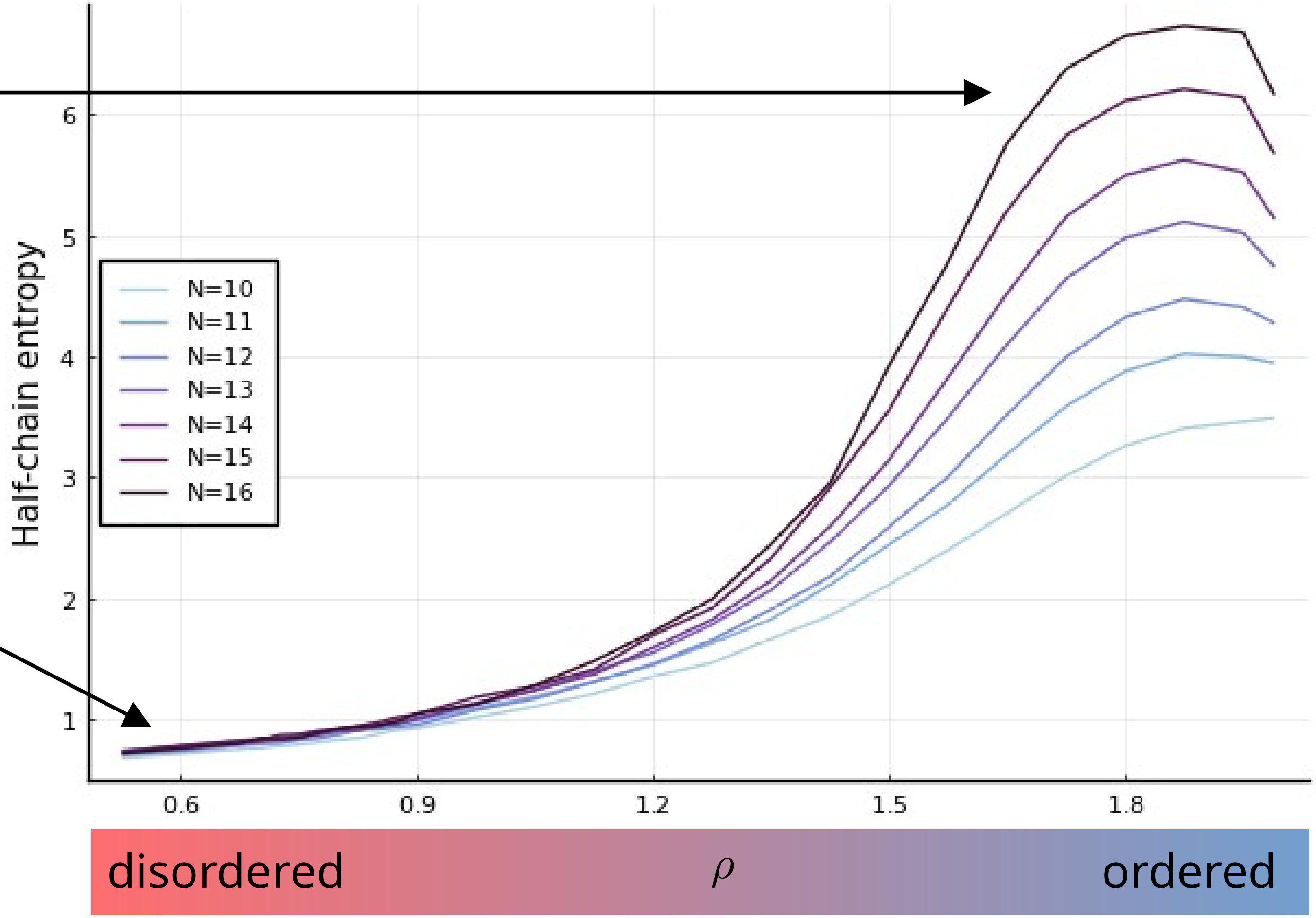
$$\langle S \rangle \propto N$$

- MBL – area law

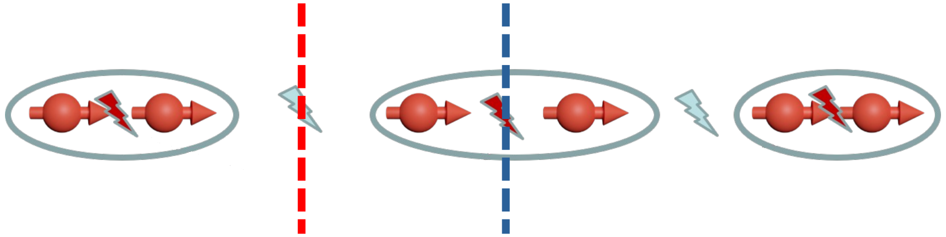
$$\langle S \rangle \propto const$$

- Pairs

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



Maximally entangled



Not entangled

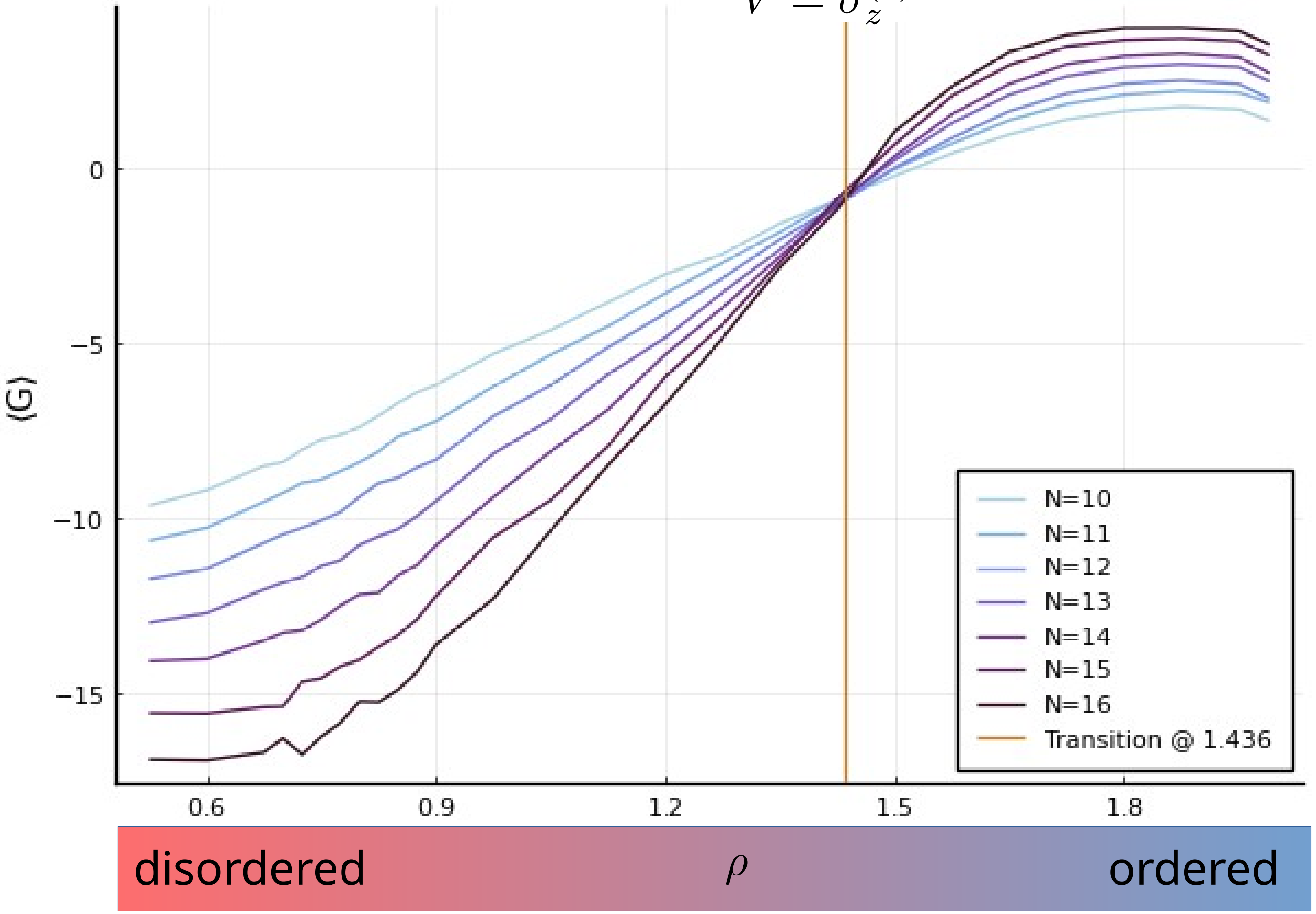
Thouless parameter

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

Local operator

- 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:
$$\langle \mathcal{G} \rangle = \text{const}$$

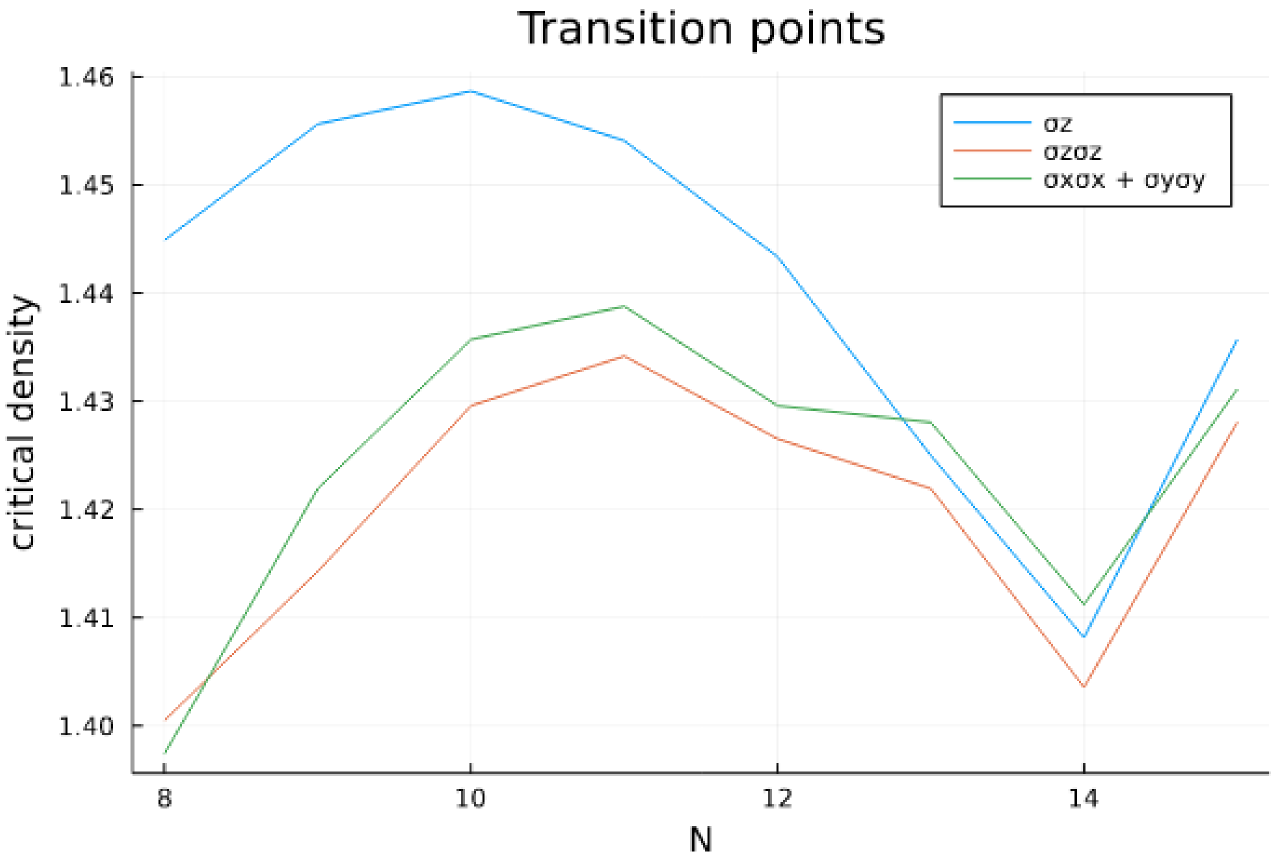
$$V = \sigma_z^{(1)}$$



Serbyn et al. PRX 5, 041047 (2015)

Conclusion & Outlook

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



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