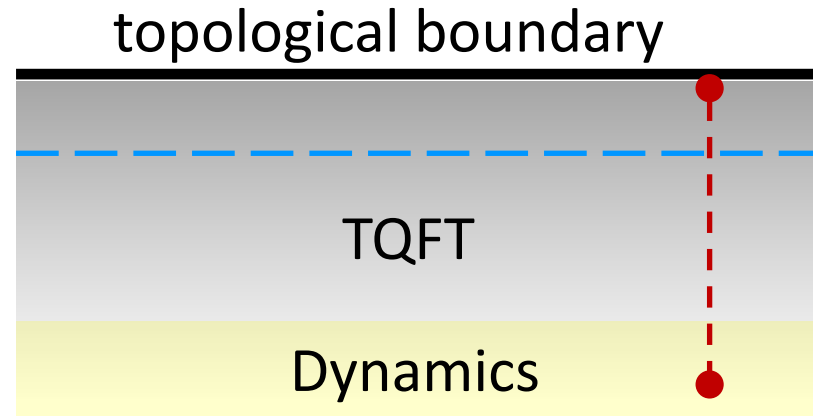
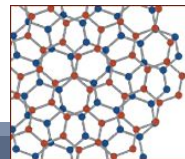




Generalized symmetries and beyond Landau phase transitions

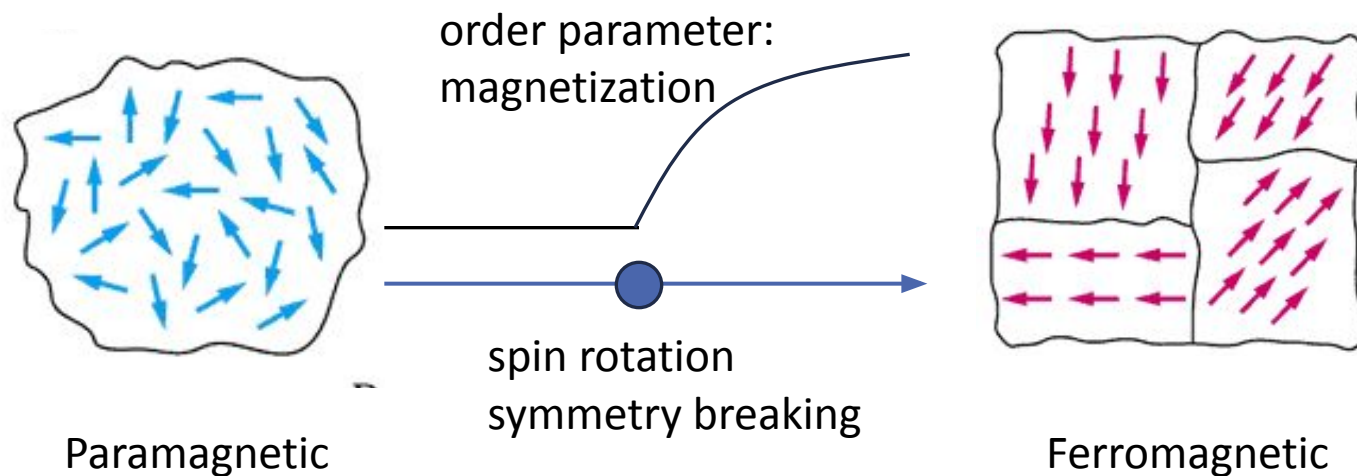
XIE CHEN, CALTECH
STRINGS 2025



Simons Collaboration on
Ultra-Quantum Matter

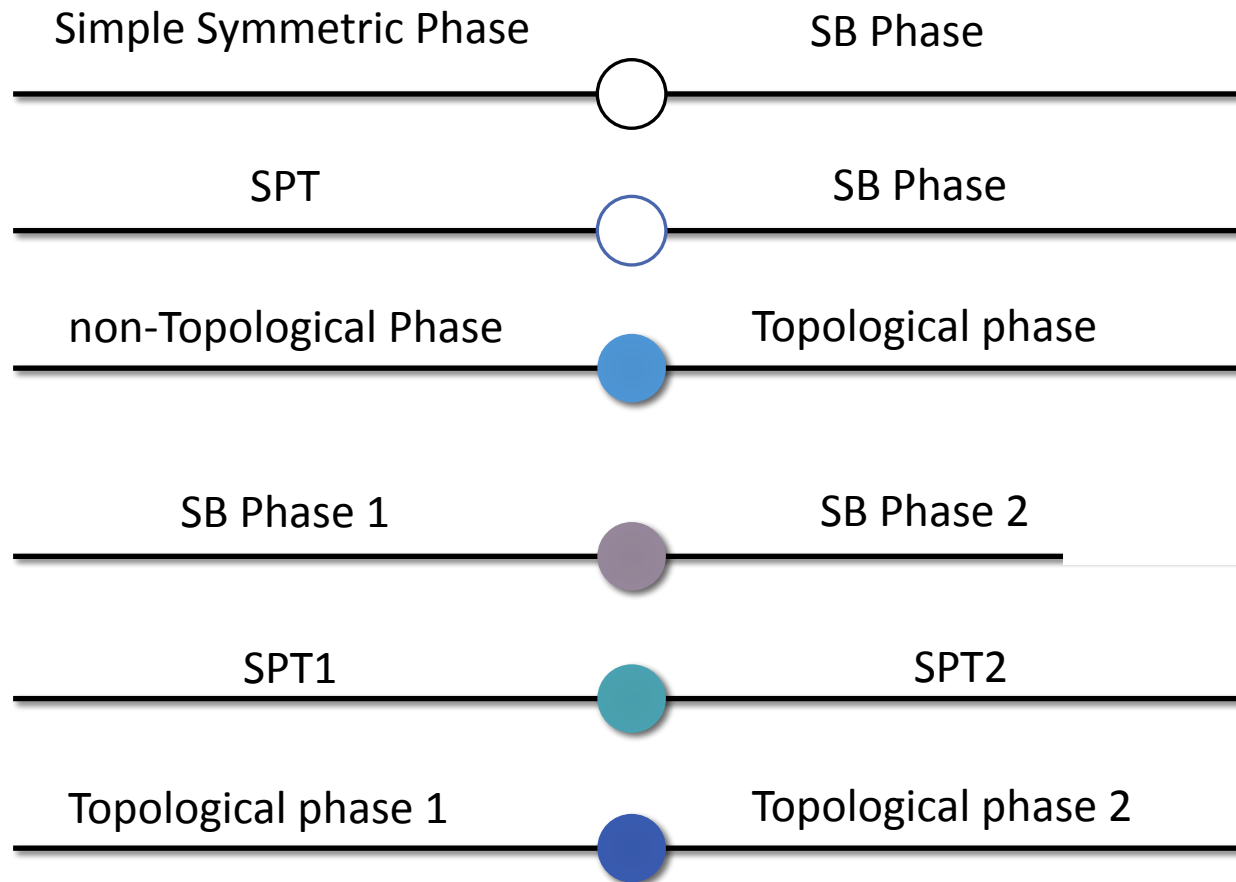


Landau vs. non-Landau: phase transitions

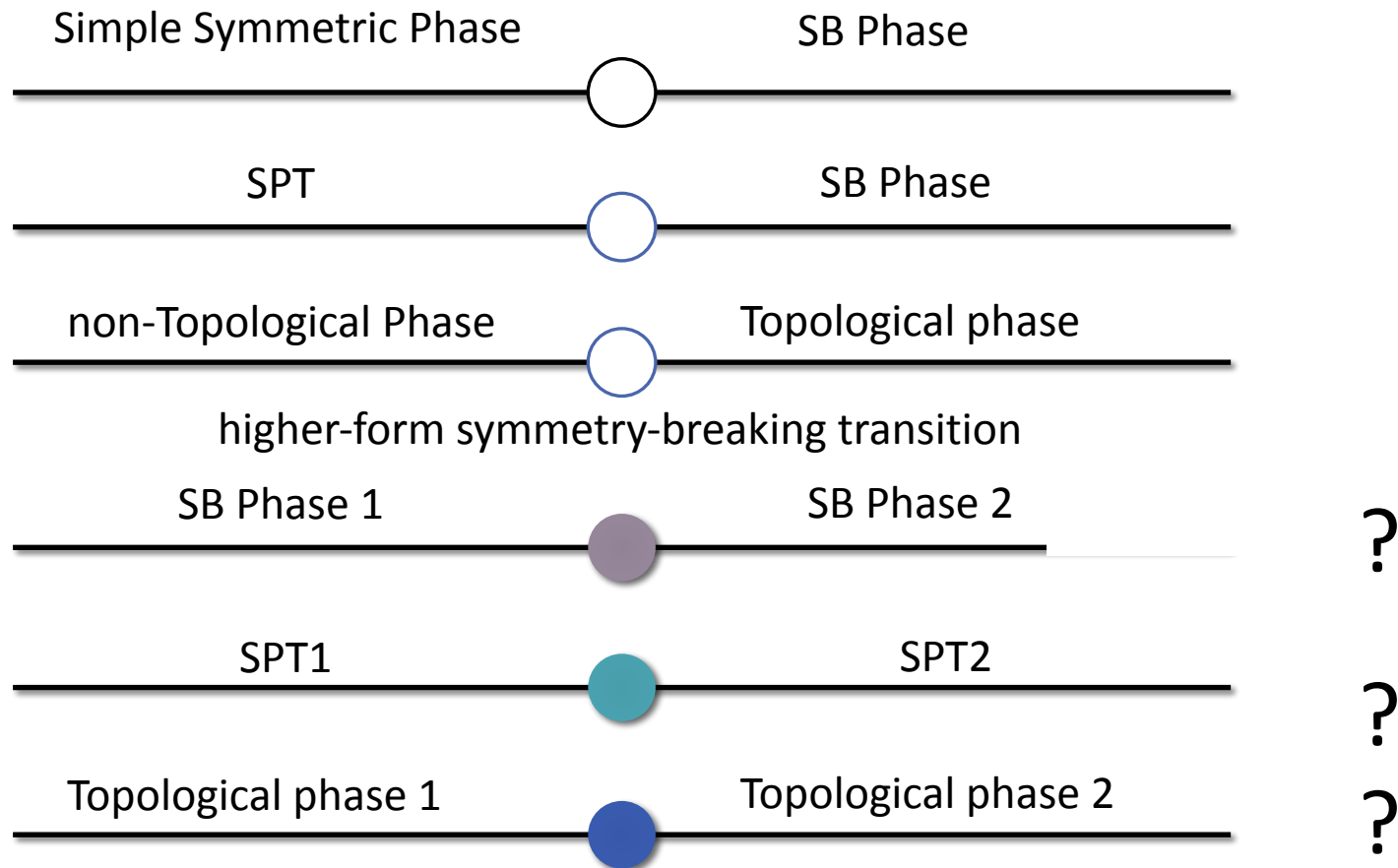


$$F(T, \eta) - F_0 = a(T)\eta^2 + \frac{b(T)}{2}\eta^4 + \dots$$

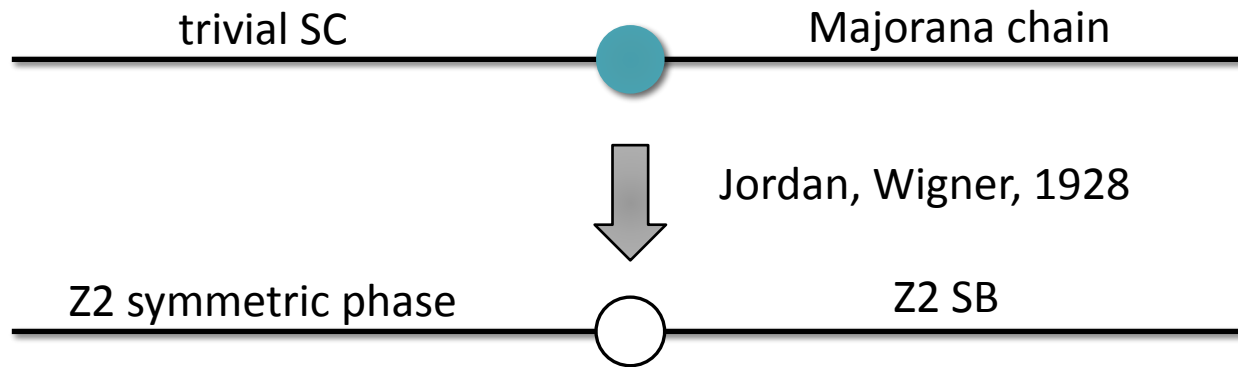
Landau vs. non-Landau: phase transitions



Landau vs. non-Landau: phase transitions

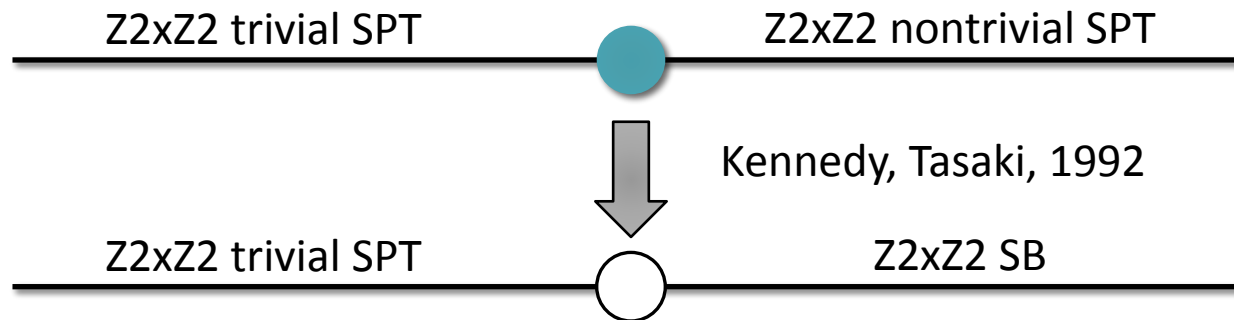


1+1D p-wave superconductor

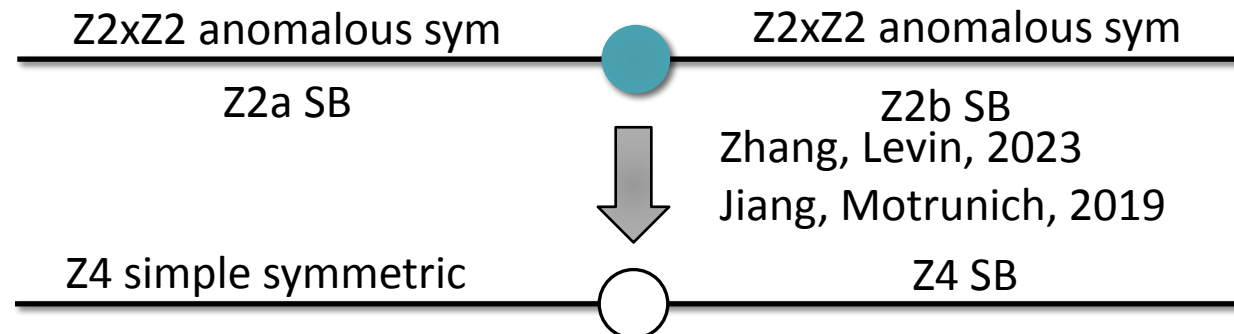


Other examples

1+1D SPT transition

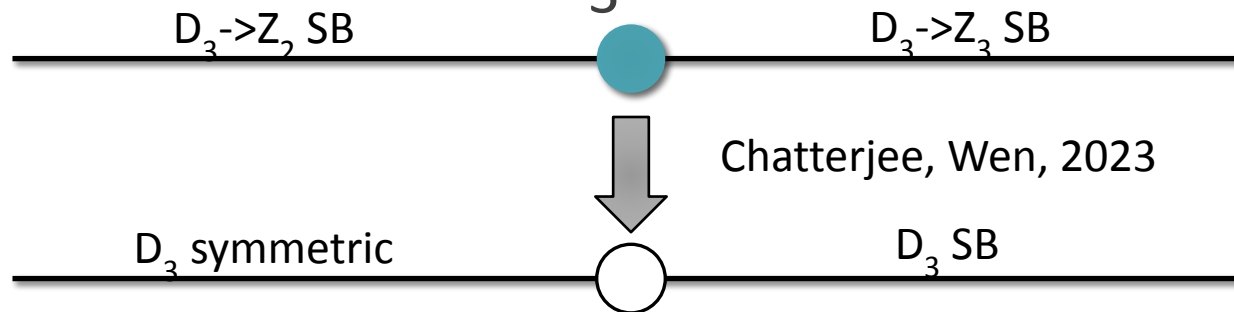


1+1D DQCP transition (incompatible symmetry breaking)

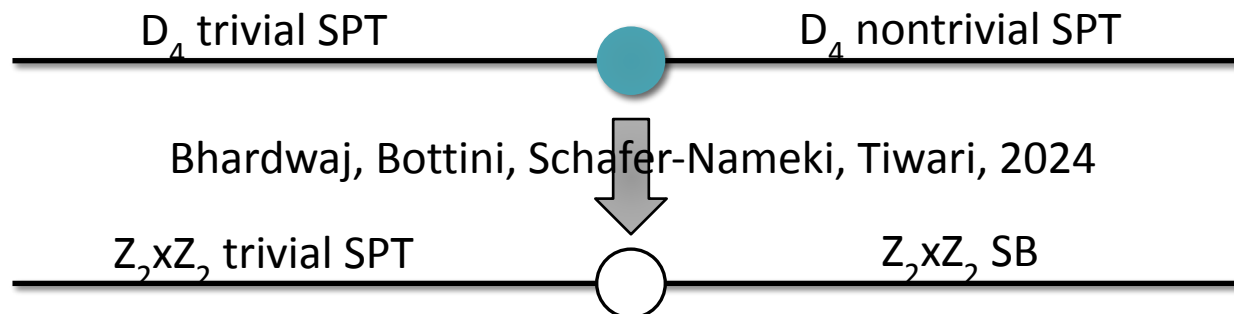


Other examples

1+1D DQCP with D_3 symmetry

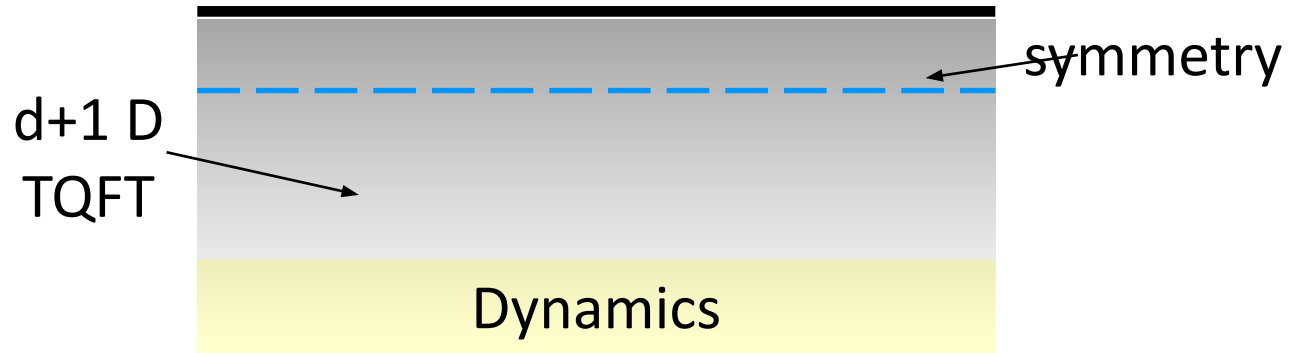


1+1D D_4 SPT transition



The sandwich (Sym TFT)

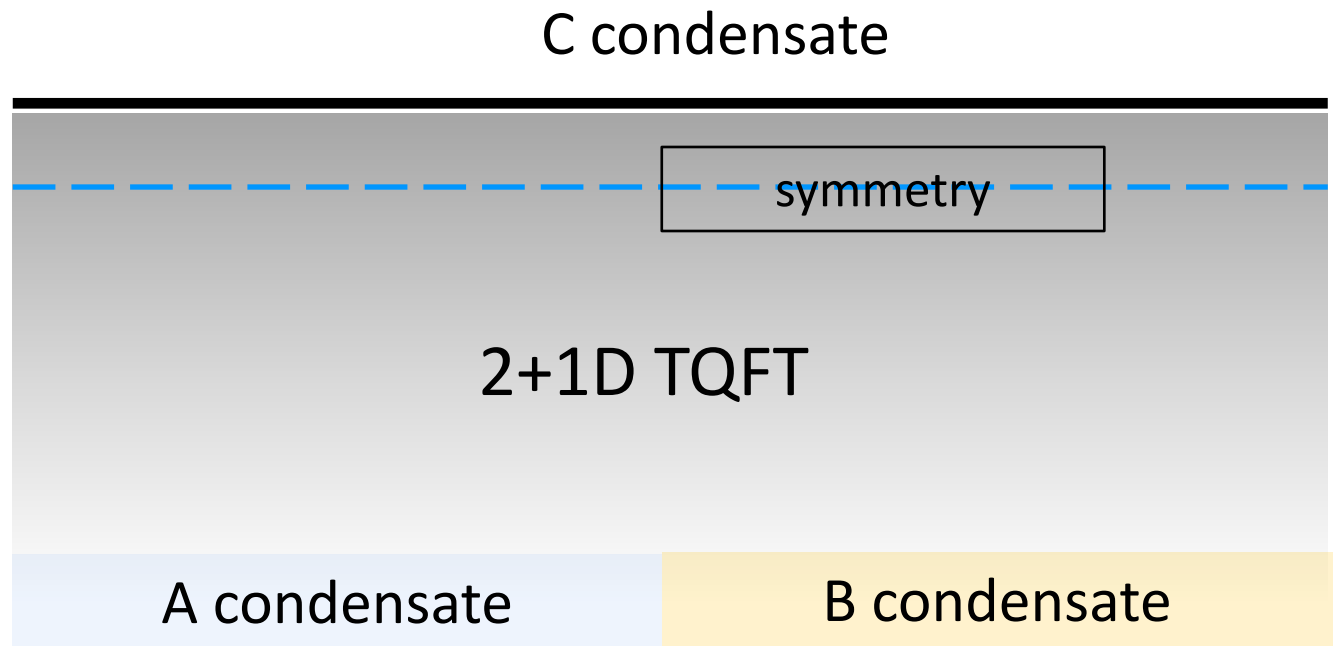
topological boundary (condensation)



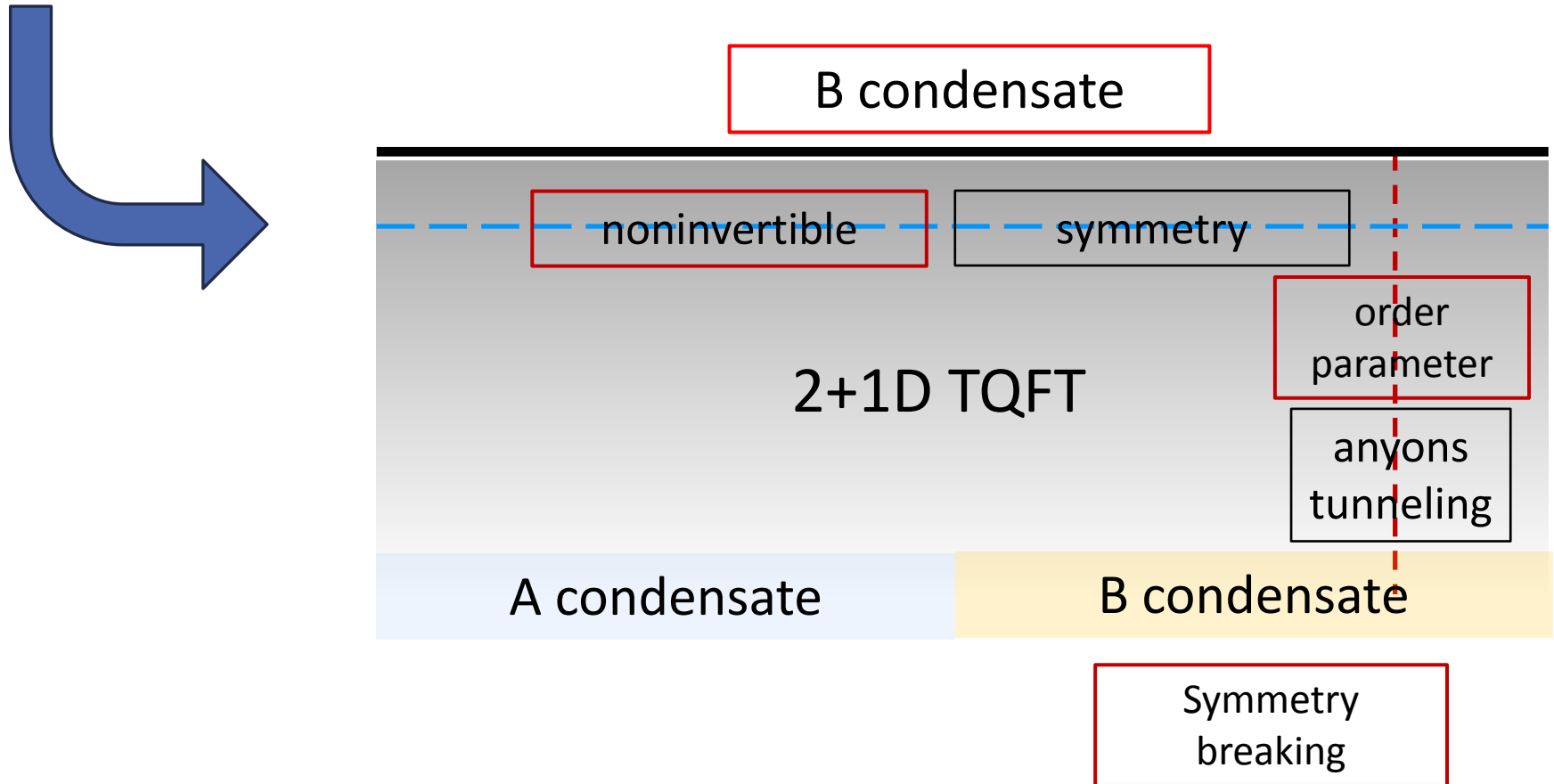
Kong, Lan, Wen, Zhang, Zheng, 2020; Ji, Wen, 2020; Gaiotto, Kulp, 2021; Lichtman, Thorngren, Lindner, Stern, Berg, 2021; Apruzzi, Bonetti, Etxebarria, Hoseeini, Schäfer-Nameki, 2022; Kong, Zheng, 2021; Freed, Moore, Teleman, 2022; Chatterjee, Wen, 2022; Moradi, Moosavaian, Tiwari, 2022 ...

Moore, Seiberg, 1989; Witten, 1989; Verlinde, 1988; Fuchs, Runkel, Schweigert, 2002-2005; Kapustin, Saulina, 2010...

General picture



General picture



Open questions

- Phase transition as transitions between condensates
- Categorical symmetry from the bulk
- Are all such transitions continuous?
- Are such transitions always dual to symmetry-breaking transitions?
- How to extract universal properties given the generalized symmetry being broken?

Paramagnet $\square$ GHZ

$$H = - \sum X_i \rightarrow H = - \sum Z_i Z_{i+1}$$

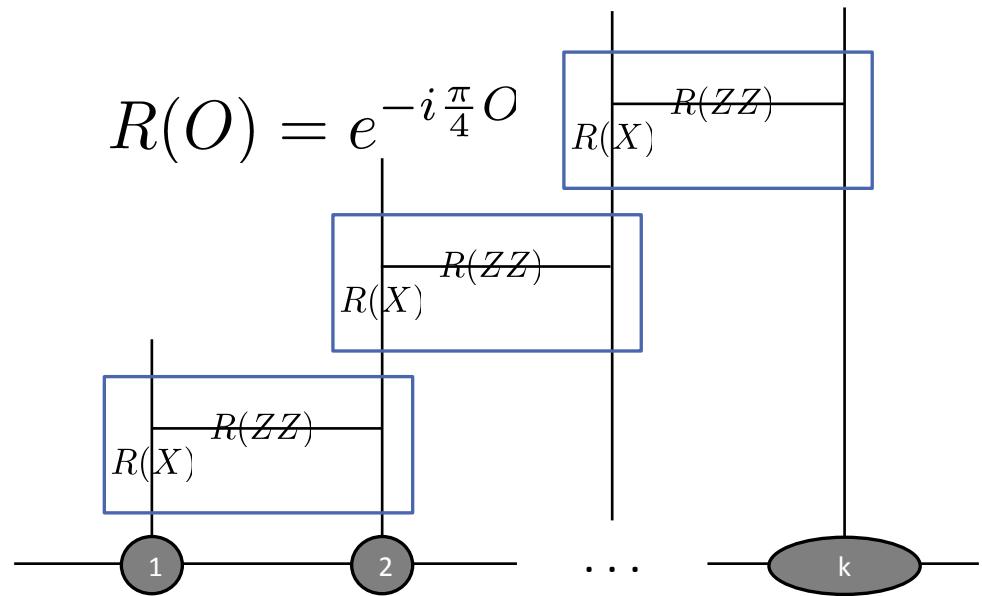
Global Z_2 symmetry

$$U = \prod X_i$$

$$|\psi\rangle = |++\dots+\rangle$$

$\downarrow$

$$|\psi\rangle = |00\dots 0\rangle + |11\dots 1\rangle$$



Paramagnet $\square$ GHZ

for Pauli operators P and Q ,

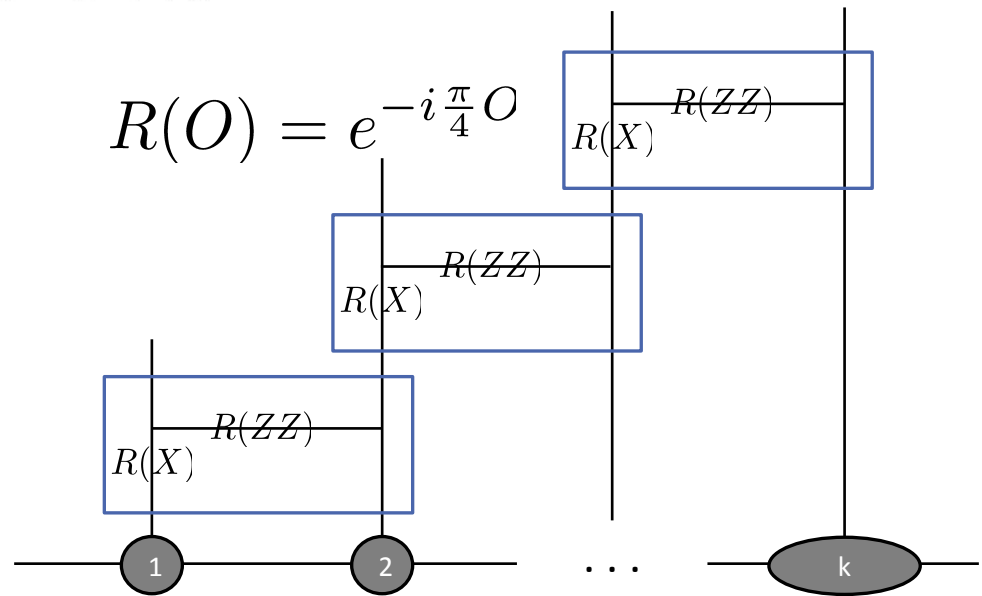
$$R(Q)PR(Q)^\dagger = \begin{cases} P; & [P, Q] = 0 \\ iPQ; & \{P, Q\} = 0 \end{cases}$$

$$U = \prod X_i$$

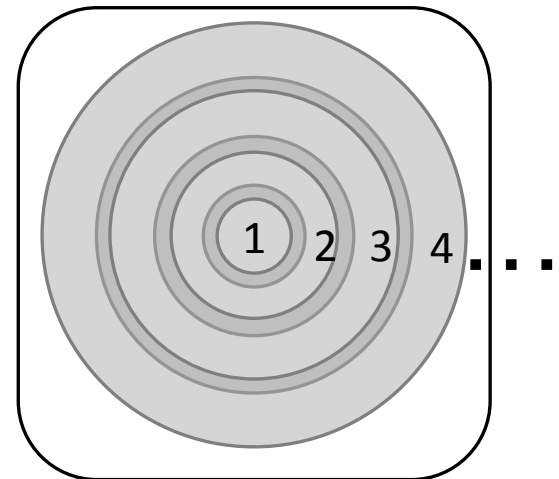
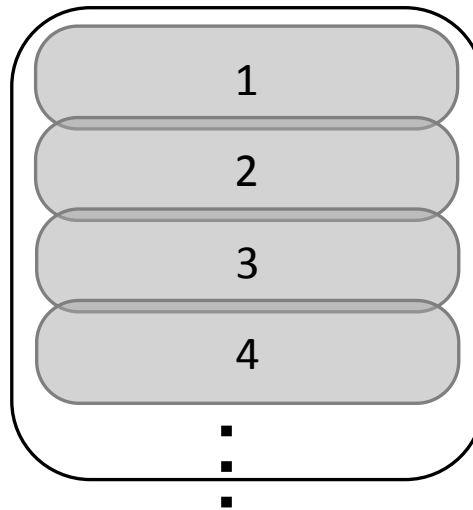
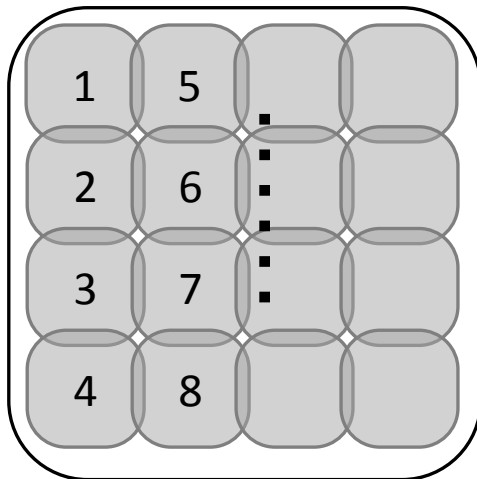
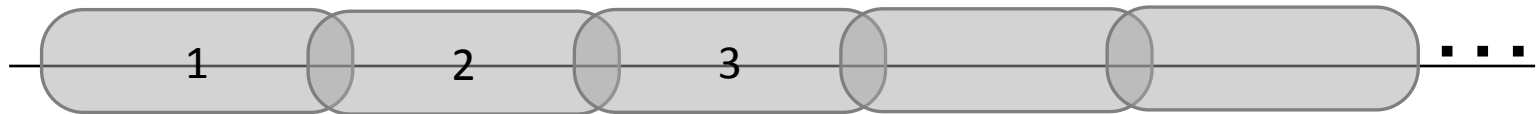
$$X_i \rightarrow Z_{i-1}Z_i$$

$$Z_iZ_{i+1} \rightarrow X_i$$

Sequential Linear
Depth Circuit



Sequential circuit



Schön, Solano, Verstraete, Cirac, 2005; Schön, Hammerer, Wolf, Cirac, 2007; Bañuls, Pérez-García, Wolf, Verstraete, Cirac, 2008; Wei, Malz, Cirac, 2022

Sequential circuit

- Each local DOF acted on by a finite number of gates
- Preserves entanglement area law
- Preserves gap

