Quantum intertwined orders beyond Landau-Ginzburg

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Quantum matter: subtle intertwinement of classical orders.

Some Examples:

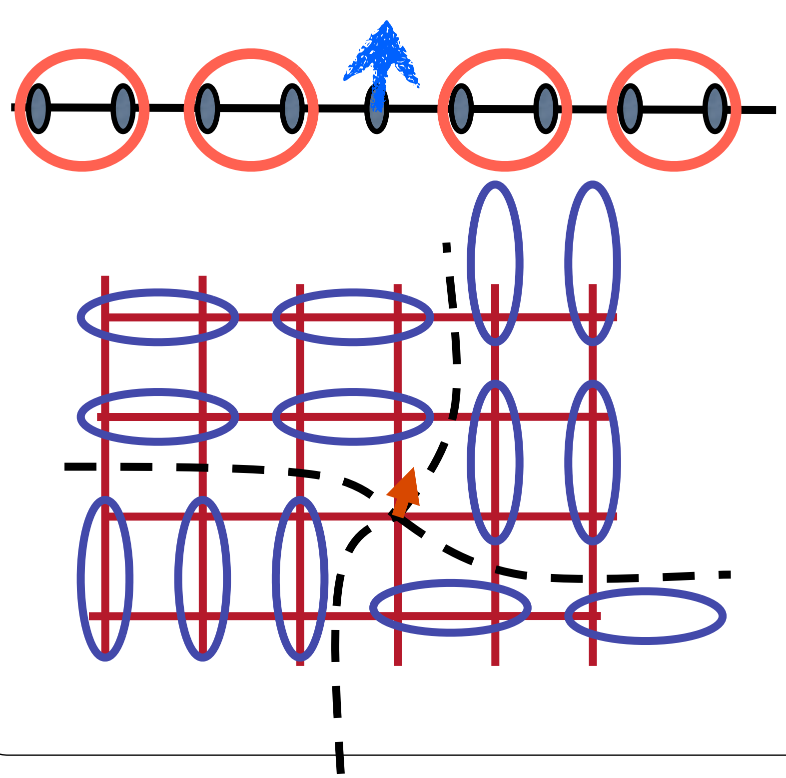
1. Superfluid - solid order of bosons in continuum

2. Neel - dimer order of spin-1/2 magnets in d = 1, 2, 3

3. SC- CDW of correlated electrons

A common theme: Topological defects of one order carry `fractional' quantum numbers (= ``non-trivial symmetry realization") of other order.

Examples:
Defects in dimer order in spin-1/2 magnets in d = 1,2 3



Many other examples:
dimer defects in 3d quantum magnets, vortices in SC order in diverse dimensions, ...

Many profound consequences - seriously affects phase diagram and (not just) nature of phase transitions.

Usual Landau-Ginzburg (LG) theory of competing/intertwined orders does not capture this defect structure
=> must modify

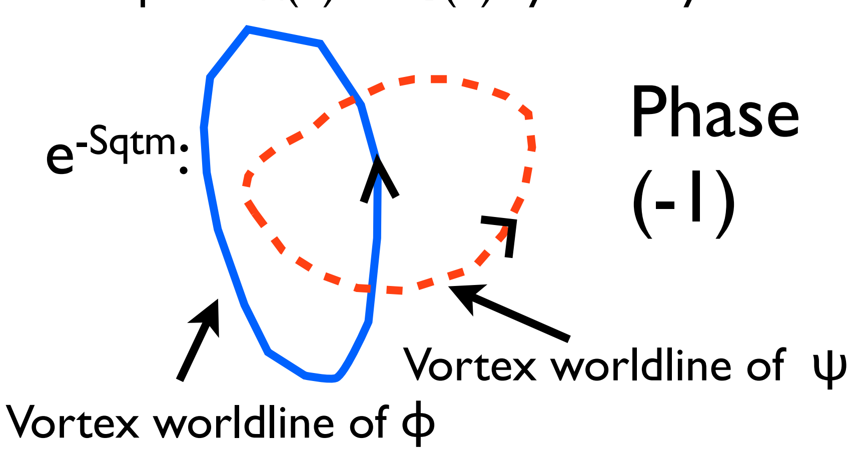
``Quantum" Landau-Ginzburg

$$S[\phi,\psi] = S_{usual}[\phi,\psi] + S_{qtm}[\phi,\psi]$$

ϕ, ψ: two intertwined order parameters

$e^{-S_{qtm}}$ captures non-trivial structure of defects.

Example: $U_A(1) \times U_B(1)$ symmetry



Application: SC vs CDW in quasi-1d doped Hubbard ladders

ϕ: SC order parameter
ψ: (Incommensurate) CDW order parameter

Symmetry $U_{charge}(1) \times U_{trans}(1)$

$$S_{usual} = \int d^3x K_\phi |\partial_\mu \phi|^2 + K_\psi |\partial_\mu \psi|^2 + V(\phi,\psi)$$

S_{qtm} as above (in a certain limit)
(Jaefari et al, 2010)

S_{qtm} is crucial !!
Vortices of one order carry 1/2-``charge" of other order!

Quantum LG not directly useful - but can reformulate as a U(1) gauge theory (Levin, TS 04)

Use SC vortices $z_\pm$ carrying $\pm 1/2$ charge of $U_{trans}(1)$

$$S_{vortex} = \sum_{s=\pm} |(\partial - ia) z_s|^2 + \tilde{V}(|z_+|, |z_-|)$$

Framework to usefully analyse phase diagram/ transitions

Other cases: no simple gauge theory (Eg: SU(2) invariant triangular magnets, 3d magnets,....)
Open challenge...!