Intertwining topological order and broken symmetries in insulators and metals

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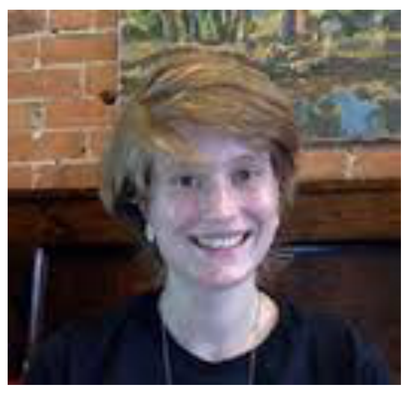


Harvard University and Perimeter Institute

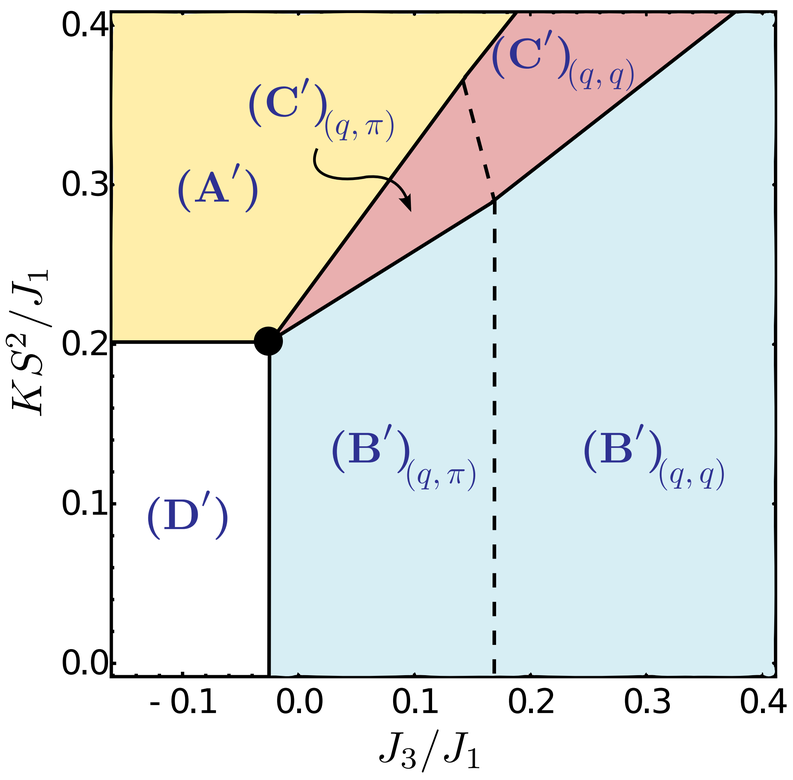
arXiv:1703.00014

arXiv:1705.06289

Insulators

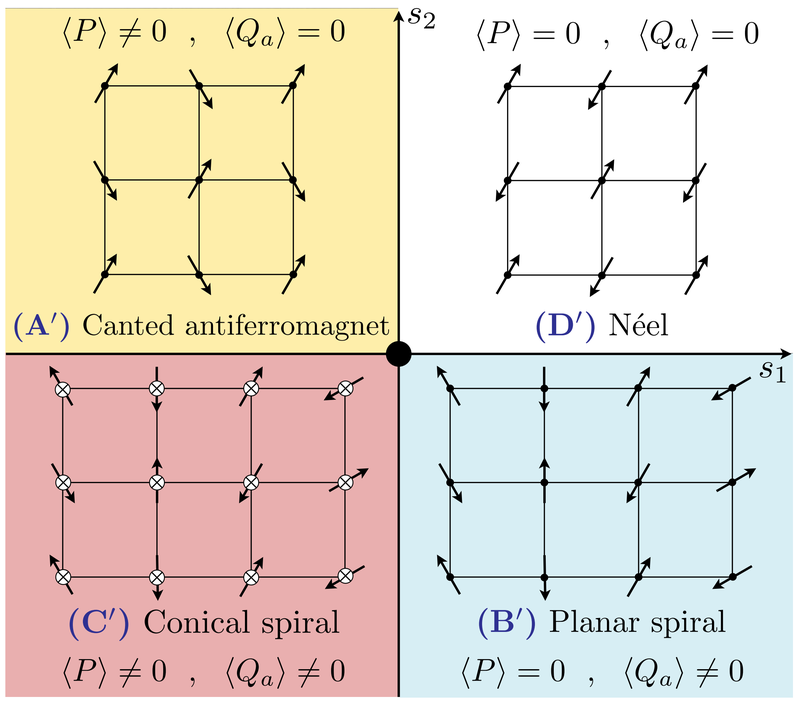
Classical phase diagram of square lattice antiferromagnet with near-neighbor exchanges J_1, J_2, J_3, J_4 and ring-exchange K

$J_2/J_1 = 0.05,\ J_4/J_1 = -0.1$



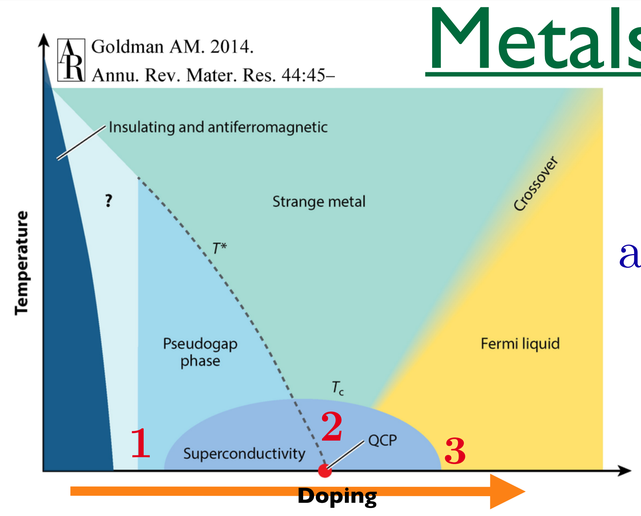
$\mathbb{CP}^1$ model of bosonic spinons z_α coupled to a U(1) gauge field a_μ, and charge 2 Higgs fields $P \sim \varepsilon_{\alpha\beta} z_\alpha \partial_t z_\beta$ and $Q_a \sim \varepsilon_{\alpha\beta} z_\alpha \partial_a z_\beta$ $(a = x, y)$.

$$\mathcal{L} = \frac{1}{g}|(\partial_\mu - i a_\mu) z_\alpha|^2 + s_1 |P|^2 + s_2 |Q_a|^2$$



Small g with $\langle z_\alpha \rangle \neq 0$

Metals

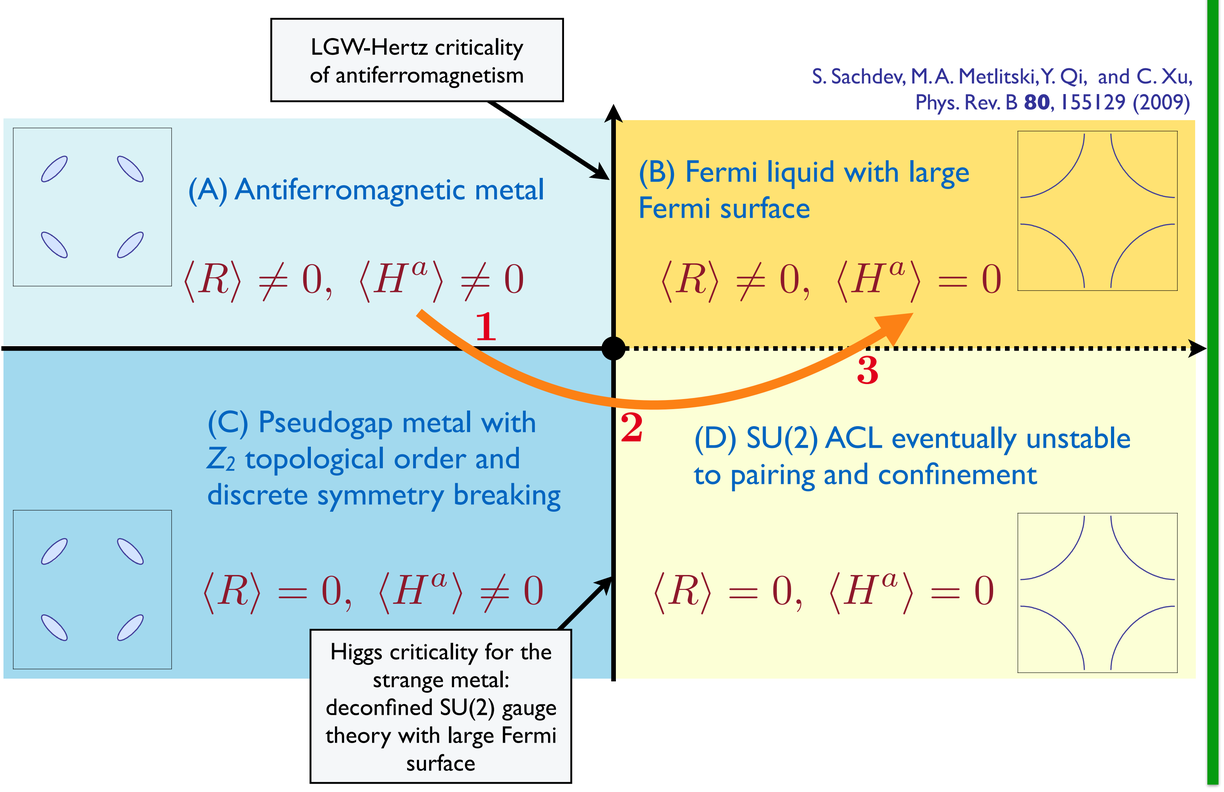


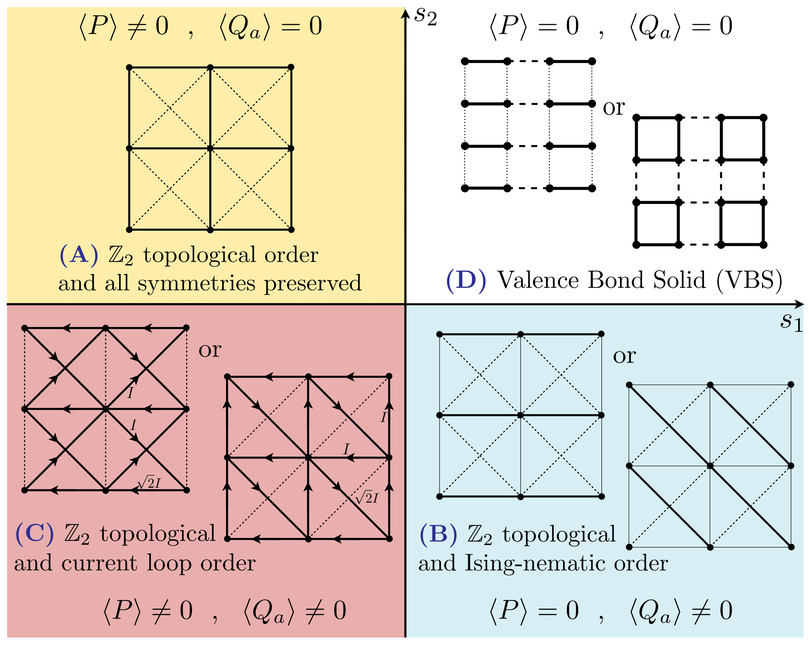
SU(2) gauge theory with bosonic spinons R, adjoint Higgs field H^a, and fermionic chargons ψ.

$$c = R\,\psi$$
$$\sigma^a \Phi^a = R\,\sigma^b H^b\,R^\dagger$$

R is a 2×2 unitary matrix which transforms the spin components of the electron into a rotating reference frame. The Higgs field, H^a, measures the local magnetic order in the rotating reference frame.

Field	Symbol	Statistics	$SU(2)_{gauge}$	$SU(2)_{spin}$	$U(1)_{e.m.charge}$
Electron	c	fermion	**1**	**2**	-1
Magnetic moment	Φ^a	boson	**1**	**3**	0
Chargon	ψ	fermion	**2**	**1**	-1
Spinon	R	boson	$\bar{\mathbf{2}}$	**2**	0
Higgs	H^a	boson	**3**	**1**	0





Large g with $\langle z_\alpha \rangle = 0$

SU(2) gauge theory coupled to $N_f = 2$ fundamental Dirac fermion spinons X, and adjoint Higgs fields Φ, Φ_1, and Φ_2

$$\mathcal{L}_{\mathrm{QCD}_3} = i\mathrm{tr}\left(\bar{X}\gamma^\mu(\partial_\mu X + iXa_\mu)\right) + (D_\mu \Phi^a)^2 + s\,(\Phi^a)^2 + \lambda_2\,\Phi^a\,\mathrm{tr}\left(\sigma^a \bar{X}\mu^y X\right) + (D_\mu \Phi_1^a)^2 + \bar{s}_1\,(\Phi_1^a)^2 + \lambda_3\,\Phi_1^a\,\mathrm{tr}\left(\sigma^a \bar{X}\mu^y\gamma^\tau\partial_\tau X\right) + (D_\mu \Phi_{2i}^a)^2 + \bar{s}_2\,(\Phi_{2i}^a)^2 + \lambda_5\,\Phi_{2i}^a\,\mathrm{tr}\left(\sigma^a \bar{X}\mu^y\gamma^\tau\partial_i X\right)$$