# Atomic simulation of lattice gauge-Higgs model: Phase diagram and timeevolution of atomic simulator

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## Cold Atom in an Optical lattice





Quantum Simulator for Lattice gauge theories?

There are many proposal...

Abelian Compact U(1)LGT Non-Abelian SU(2), SU(N)

We want to experimentally simulate gauge theories in cold atomic systems!



Cold atom Condensed matter physics



Gauge theories QED, QCD and Standard model Our proposal: U(1) gauge-Higgs model can be experimentally constructed from Bose Hubbard model in BEC state



Bose Hubbard Hamiltonian with long range interaction.

$$H = -\sum_{r,a\neq b} J_{a,b} \hat{\psi}_{r,a}^{\dagger} \hat{\psi}_{r,b} + \frac{V_0}{4} \sum_{r,a} \hat{\rho}_{r,a}^2 + \sum_{r,a\neq b} \frac{V_{ra,rb}}{2} \hat{\rho}_{r,a} \hat{\rho}_{r,b},$$

$$\hat{\psi}_{r,a} = \sqrt{\rho_0 + (-)^r \hat{\eta}_{r,1} \exp((-)^r i\hat{\theta}_{r,a})}$$

BEC density fluctuation BEC phase Effective model... Let's propose! Gauss's low term + Electric term + Higgs coupling term = U(1) gauge-Higgs

$$H_{a} = \frac{1}{2\gamma^{2}} \sum_{r} \left( \sum_{i} \nabla_{i} \hat{\eta}_{r,i} \right)^{2} + \frac{V_{0}'}{2} \sum_{r,i} \hat{\eta}_{r,i}^{2} + H_{L}$$
$$H_{L} = -2J\rho_{0} \sum_{r} \left[ \cos(\hat{\theta}_{r,1} - \hat{\theta}_{r,2}) + \cos(\hat{\theta}_{r,1} + \hat{\theta}_{r,4}) \right]$$
$$+ \cos(\hat{\theta}_{r,2} + \hat{\theta}_{r,3}) + \cos(\hat{\theta}_{r,3} - \hat{\theta}_{r,4}) \right]$$

$$\hat{E}_{r,i} = -\hat{\eta}_{r,i} \quad \hat{A}_{r,i} = \hat{\theta}_{r,i}$$

Electric field

Vector potential

#### Numerical simulation

Real observation of the electric flux in cold atomic system

The dynamics of the electric flux in cold atomic system





### $10^{-4}$ Confinement phase





t=10

Higgs phase

0







**t**=50



t=70

#### Phase diagram

