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Driven Critical Dynamics in Gross-Neveu-Yukawa Universality Class

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Motivation

- **Driven dynamics:** changing the distance to the critical point linearly

--Scaling theory in usual Landau-Ginzburg-Wilson universality class:

(1) Kibble-Zurek mechanism (generation and scaling of topological defects after driving)[1,2]

(2) Finite-time scaling (full scaling form in the driving process)[3]

- **Dirac systems:** Graphene, Weyl/Dirac semimetal, surface of topological insulator

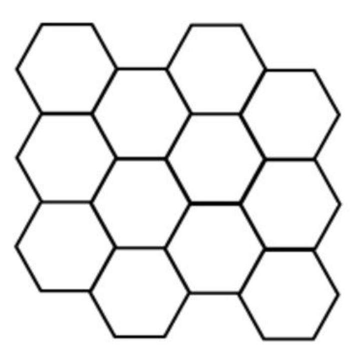
--Gross-Neveu-Yukawa universality class[4,5]

- **Question: How do Dirac fermions affect the dynamic scaling behavior?**

Model and Method

Hamiltonian:

- Half-filled 2D spin-1/2 Hubbard model on the honeycomb lattice



$$H = -t\sum_{\langle ij\rangle,\sigma} c_{i\sigma}^{\dagger}c_{j\sigma} + U\sum_i (n_{i\uparrow}-\frac{1}{2})(n_{i\downarrow}-\frac{1}{2})$$

t: hopping term coefficient

U: interacting term coefficient

$\langle ij\rangle$: nearest neighbor sites i and j

$c_{i\sigma}^{\dagger}(c_{j\sigma})$: the creation(annihilation) operator of electron at spin $\sigma(=\uparrow,\downarrow)$

$n_{i\sigma}$: the number operator of electron defined as $c_{i\sigma}^{\dagger}c_{i\sigma}$

Observables:

- Antiferromagnetic structure factor:

$$S(\boldsymbol{q}) = \frac{1}{L^4}\sum_{i,j} e^{i\boldsymbol{q}\cdot(r_i-r_j)}\langle m_i^{(z)}m_j^{(z)}\rangle$$

- Staggered magnetization:

$$m_i^{(z)} = \vec{c}_{i,A}^{\dagger}\sigma^z\vec{c}_{i,A} - \vec{c}_{i,B}^{\dagger}\sigma^z\vec{c}_{i,B}$$

i: the index of unit cell

A,B: different sublattices

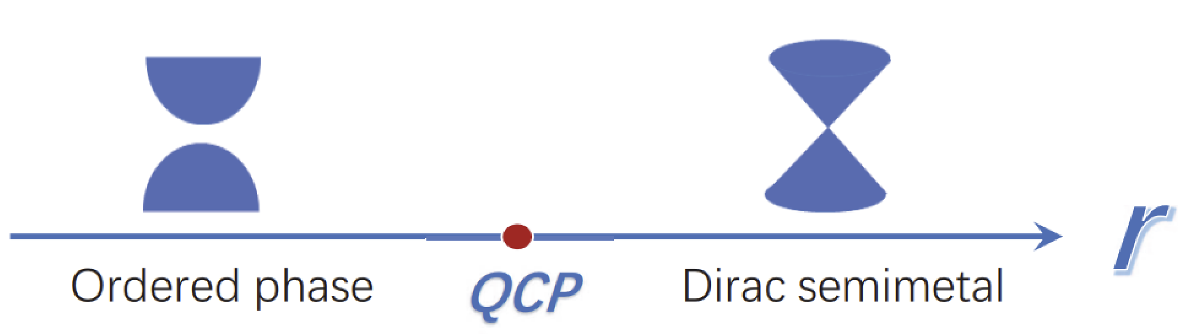
- The square of AFM order parameter:

$$m^2 = S(\boldsymbol{0})$$

- Correlation ratio:

$$R_s = 1 - \frac{S\left(0+\boldsymbol{a}\frac{2\pi}{L}\right)}{S(0)}, \boldsymbol{a} \equiv \boldsymbol{x}+\boldsymbol{y}/\sqrt{3}$$

Phase diagram:



Determinant quantum Monte Carlo

- We employ the determinant quantum Monte Carlo(DQMC) method.
- Trotter decomposition

$$e^{\tau H} = \left(e^{\Delta\tau H_t}e^{\Delta\tau H_U}\right)^M$$

$M = \tau/\Delta\tau$ (M is integer)

H_t: the hopping term in the Hamiltonian

H_U:the Hubbard interaction in the Hamiltonian

$\Delta\tau/t = 0.05$

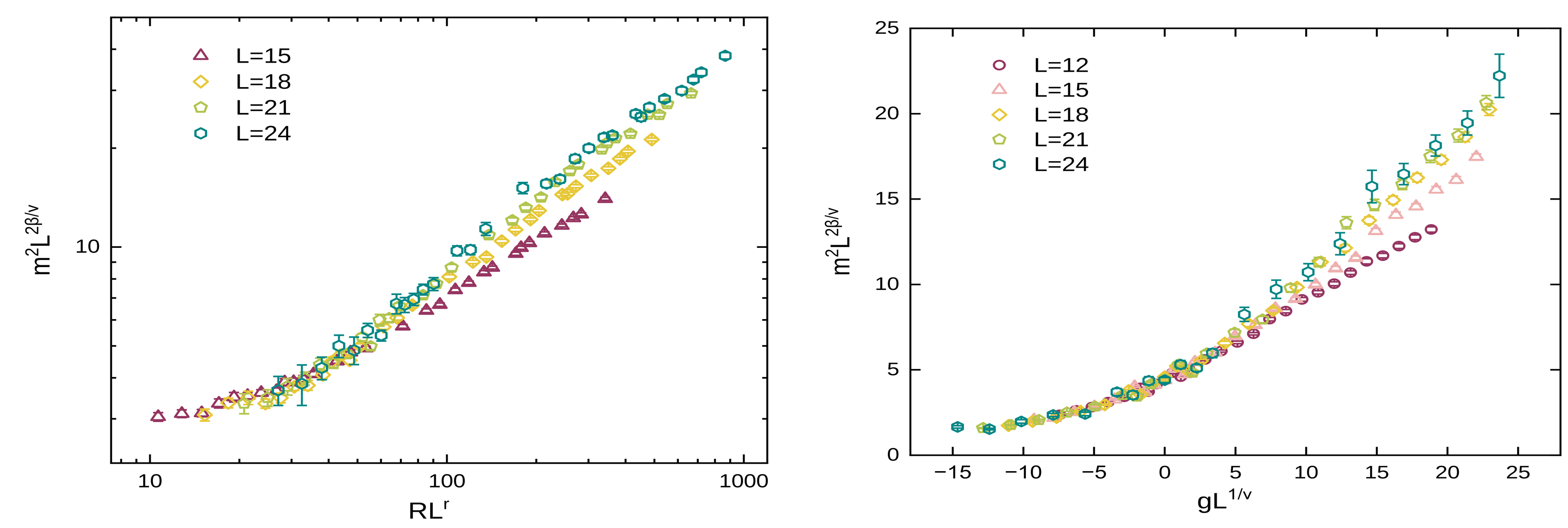
- Discrete Hubbard-Stratonovich transformation

$$e^{-\frac{\Delta\tau U}{2}(n_{i\uparrow}+n_{i\downarrow})^2} = \sum_{l=\pm1,\pm2}\gamma(l)e^{i\sqrt{\frac{\Delta\tau U}{2}}\eta(l)(n_{i\uparrow}+n_{i\downarrow})}$$

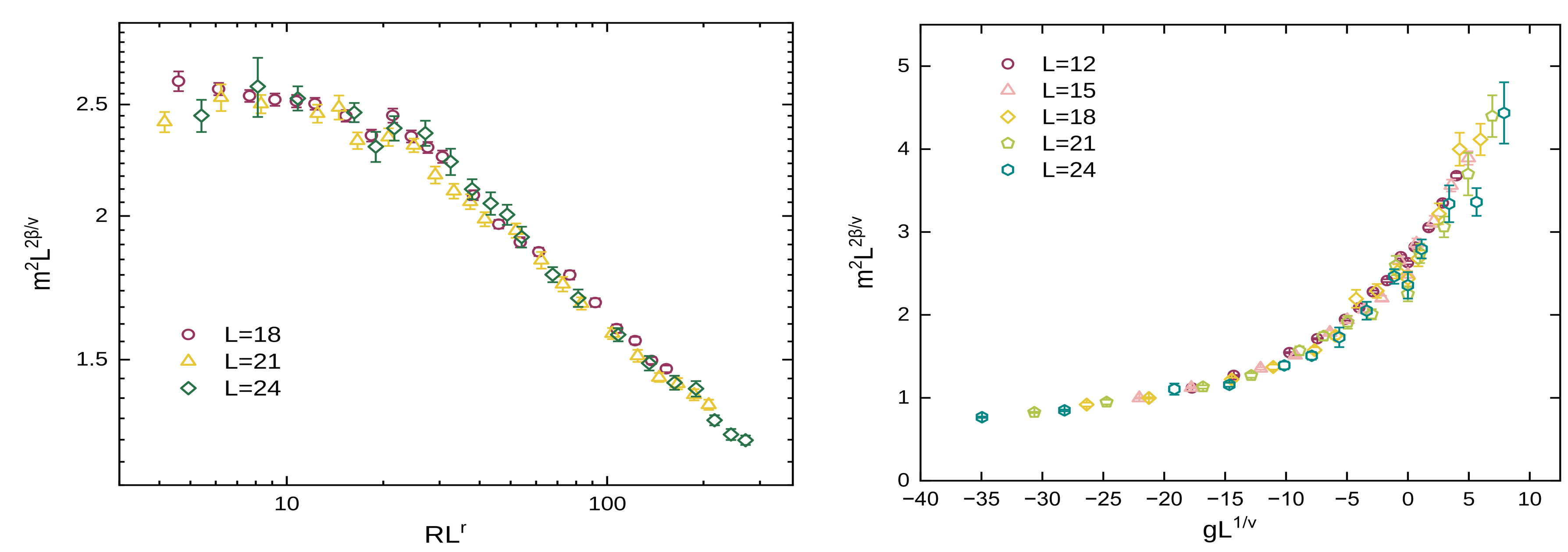
Here, we introduce a four-component space-time local auxiliary fields $\gamma(\pm1) = 1+\sqrt{6}/3$, $\gamma(\pm2) = 1-\sqrt{6}/3$, $\eta(\pm1) = \pm\sqrt{2(3-\sqrt{6})}$, $\eta(\pm2) = \pm\sqrt{2(3+\sqrt{6})}$, and use DQMC for importance sampling over these space-time configurations.

Results: Chiral Heisenberg[5]

Ordered initial state

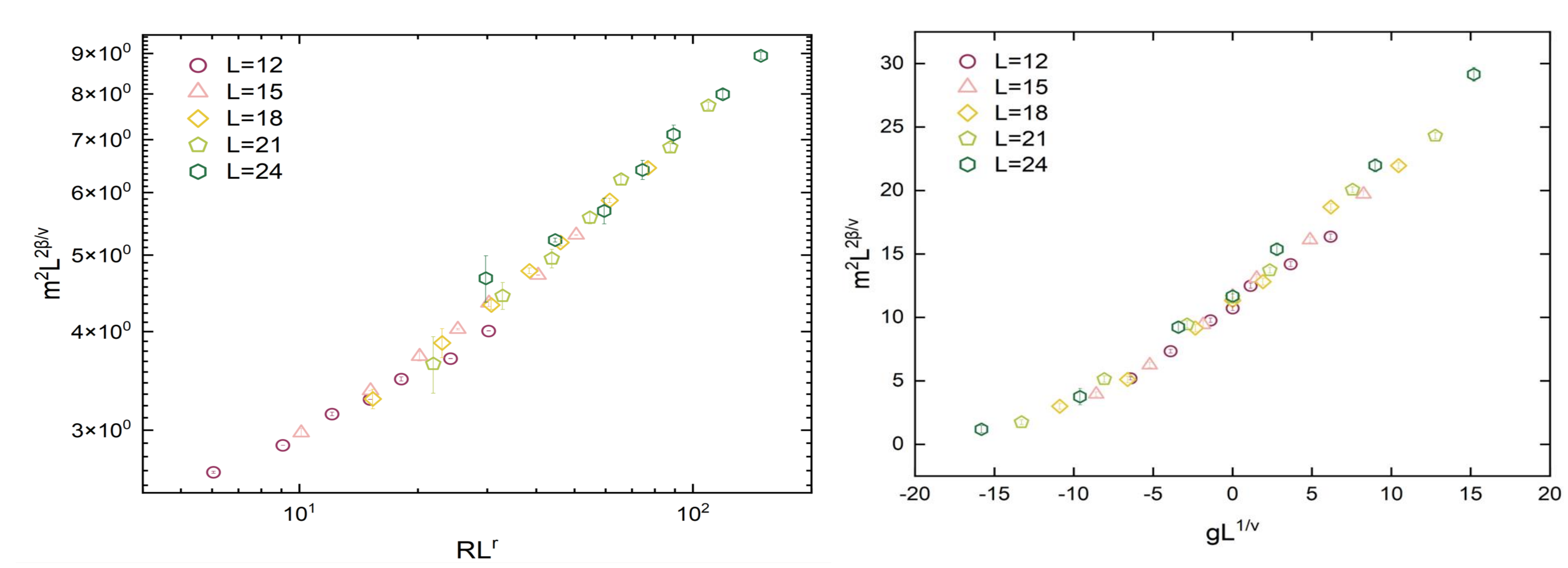


Semimetal initial state

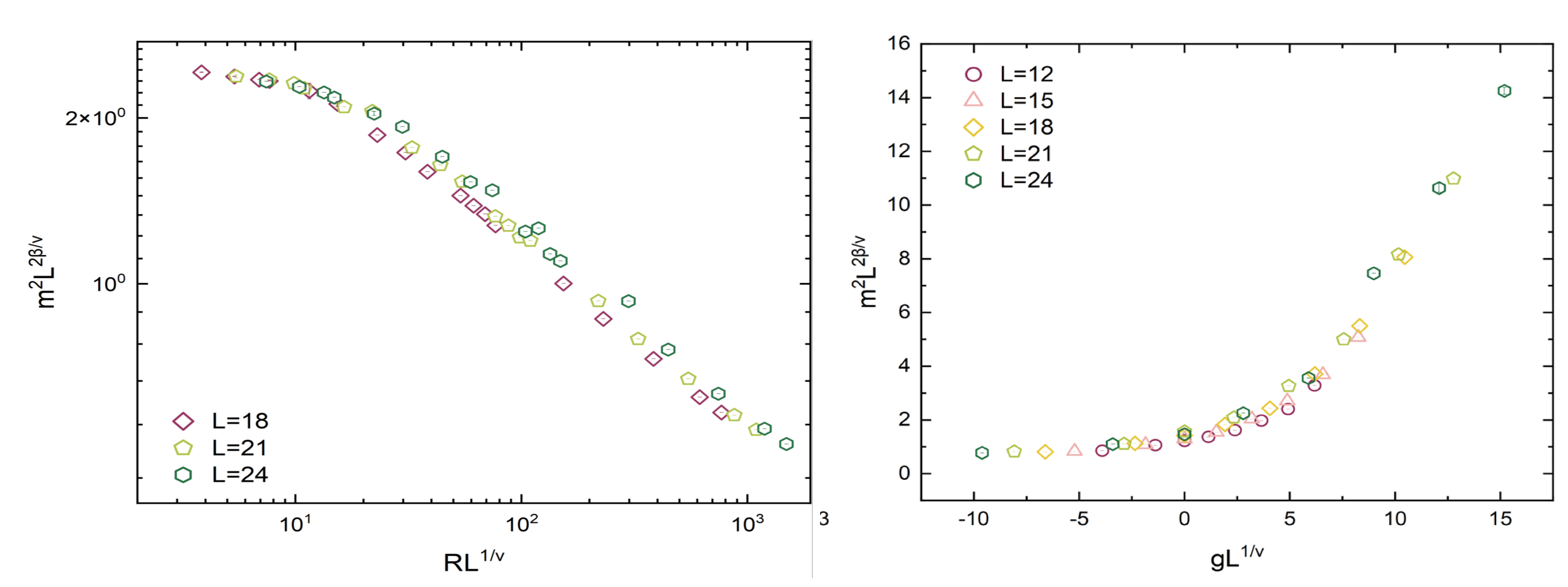


Results: Chiral Ising[6]

Ordered initial state



Semimetal initial state



Summary

- For the first time, we explored the driven dynamics in Gross-Neven-Yukawa universality class.
- We have verified that the driven dynamics satisfies the finite-time scaling.

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