July 26-28 2023, Yunnan, China

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

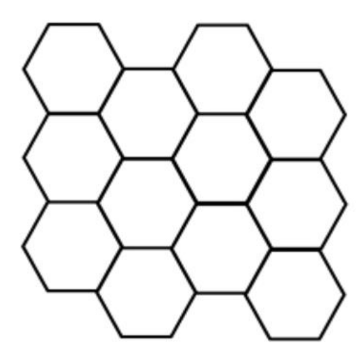
--Gross-Neveu-Yukawa universality class[4,5]

- **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:

$$S(\boldsymbol{q}) = \frac{1}{L^2}\sum_{i,j} e^{i\boldsymbol{q}\cdot(r_i-r_j)}\langle m_i^{(z)} m_j^{(z)}\rangle$$

- 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

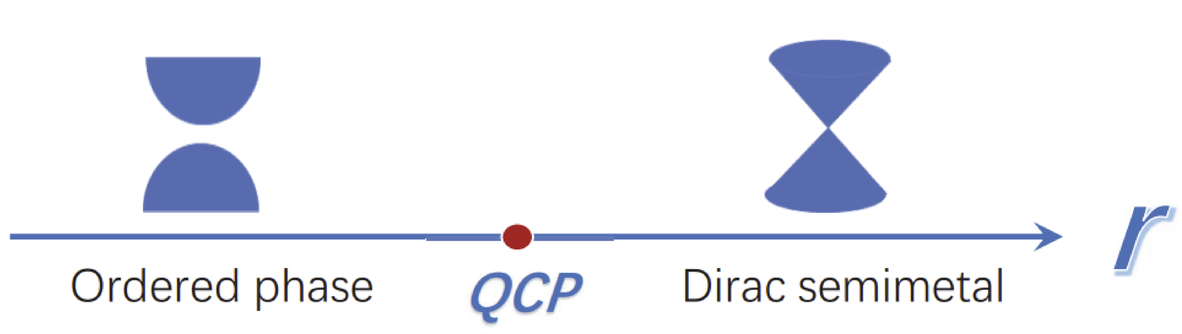
- The square of AFM order parameter:

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

- 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

$\Delta\tau/t = 0.05$

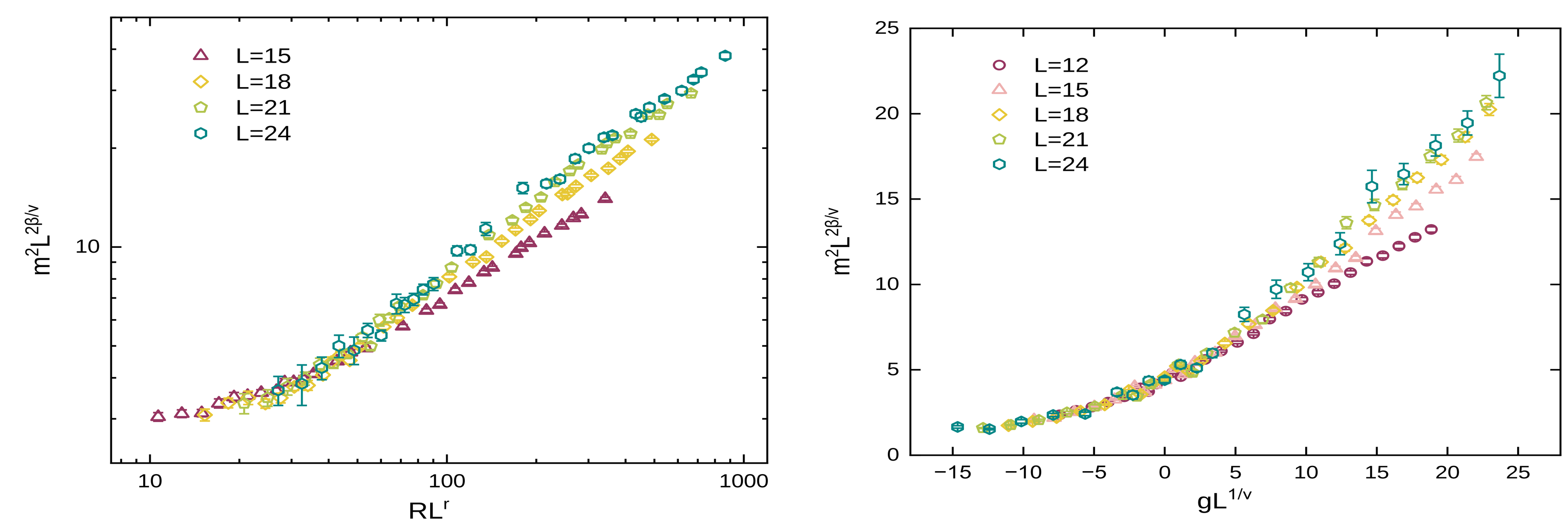
- Discrete Hubbard-Stratonovich transformation

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

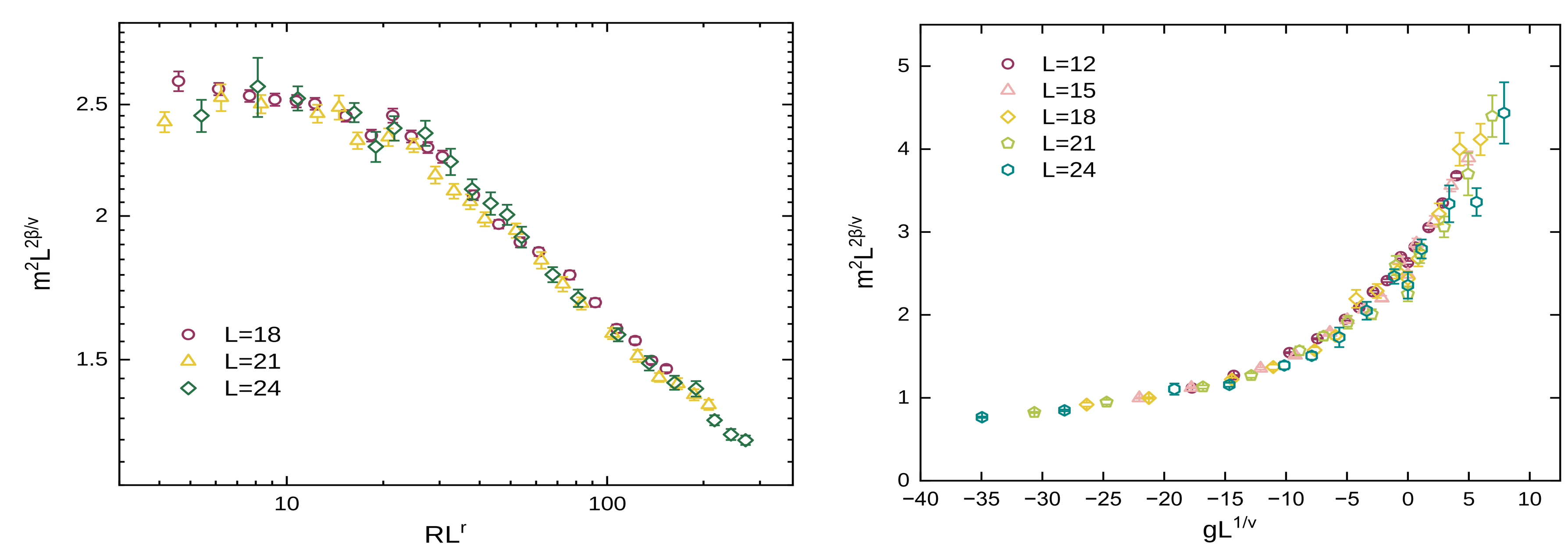
Here, we introduce a four-component space-time local auxiliary fields $\gamma(\pm1) = 1+\sqrt{6}/3$, $\gamma(\pm2) = 1-\sqrt{6}/3$, $\eta(\pm1) = \pm\sqrt{2(3-\sqrt{6})}$, $\eta(\pm2) = \pm\sqrt{2(3+\sqrt{6})}$, and use DQMC for importance sampling over these space-time configurations.

Results: Chiral Heisenberg[5]

Ordered initial state

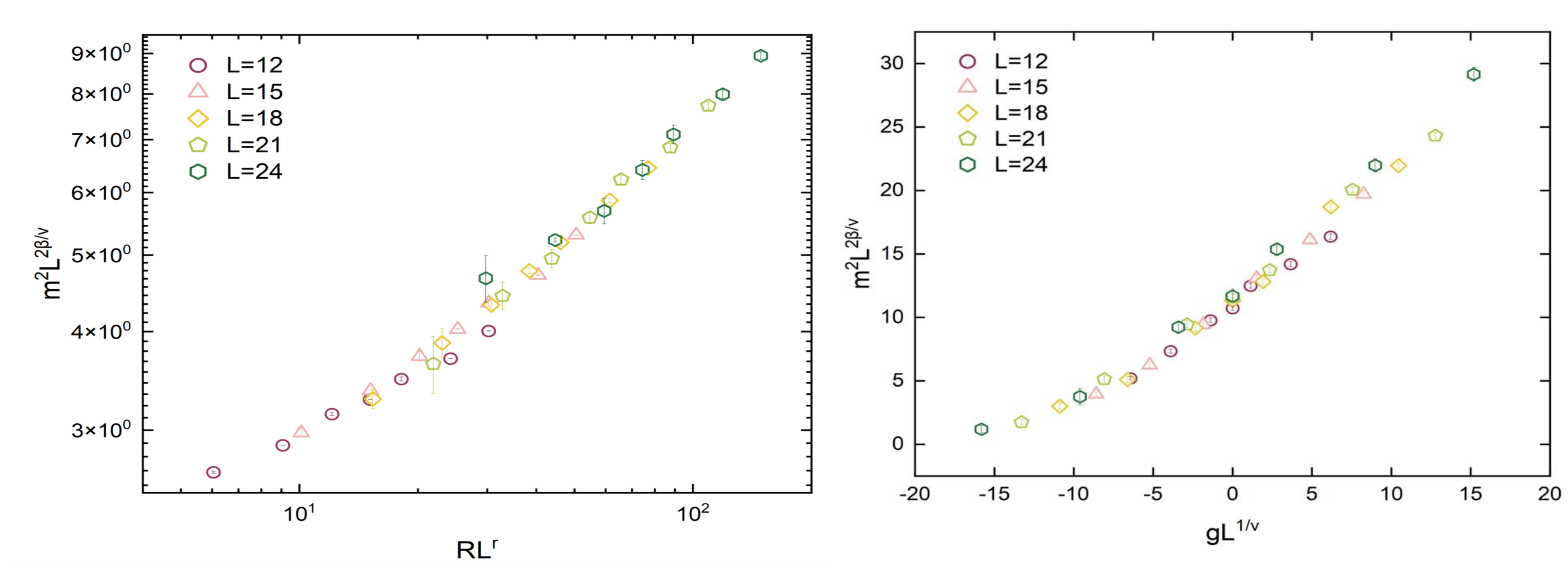


Semimetal initial state

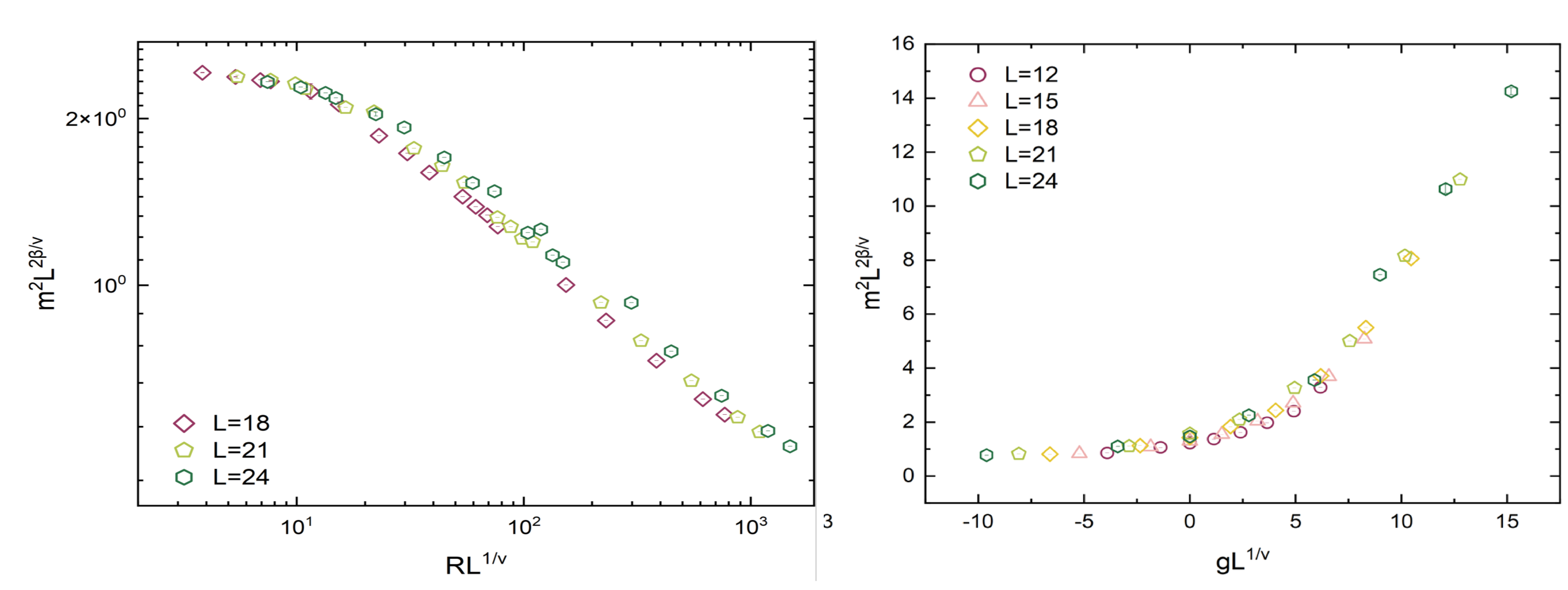


Results: Chiral Ising[6]

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.

The work is supported by is supported by the National Natural Science Foundation of China, Grants No. 12075324 and No. 12222515. Z.Z. and Y.K.Y are partly supported by College Students' Innovative Entrepreneurial Training Plan Program, Sun Yat-Sen University.

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