Unconventional relaxaton dynamics in strongly correlated kagome systems

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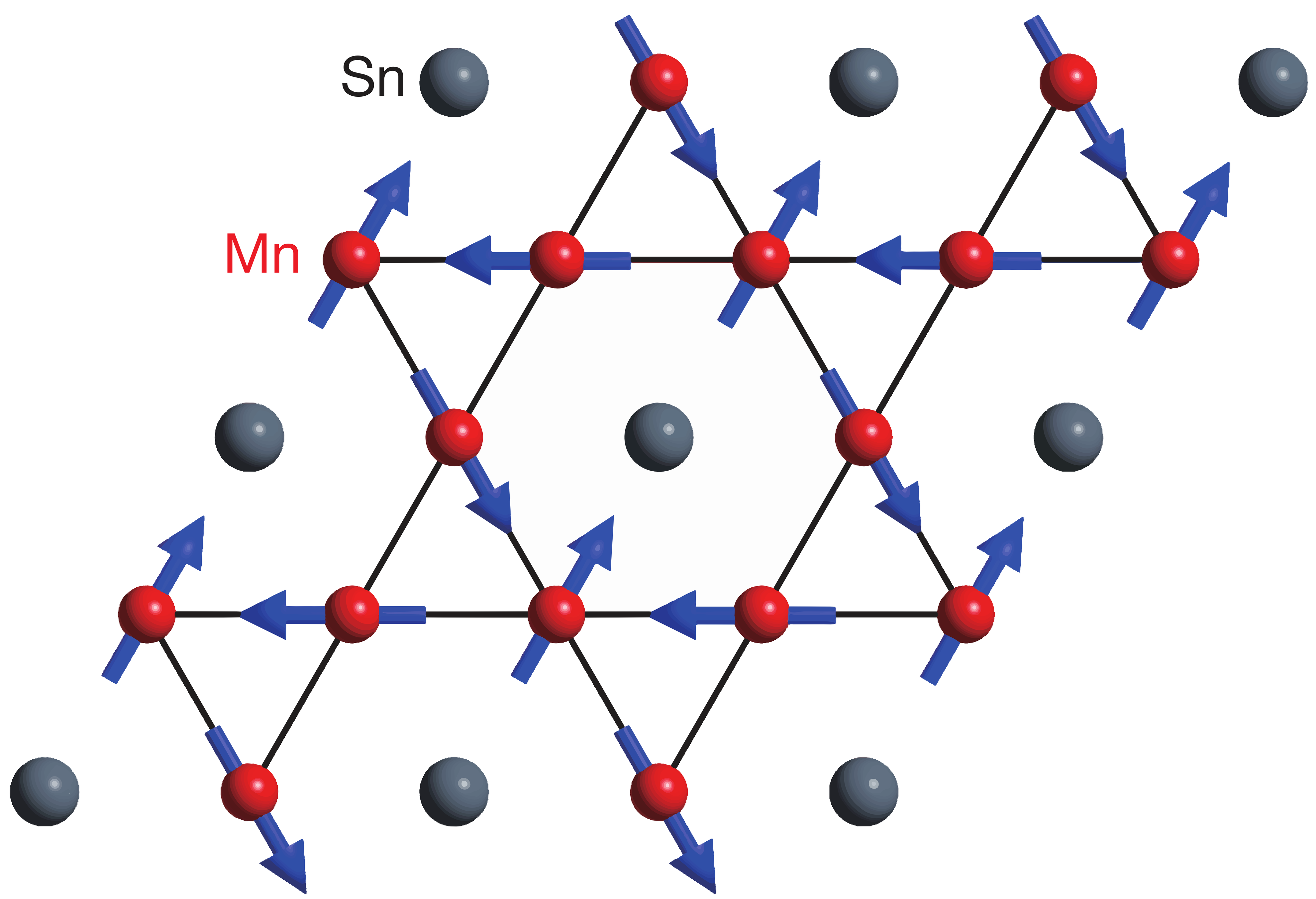
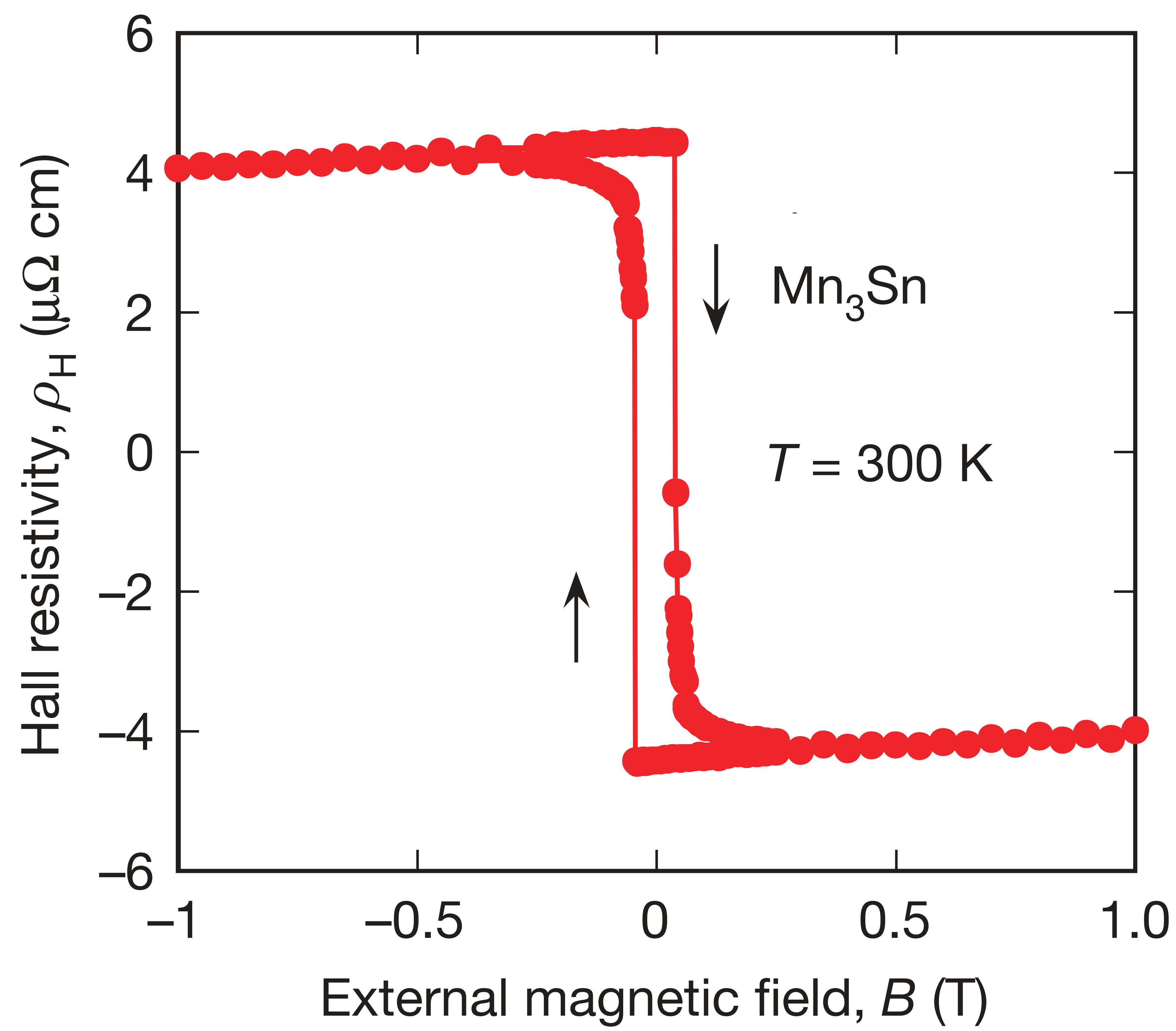
Michael Knap

Unconventional transports in kagome

Anomalous Hall effect in low-T order on kagome



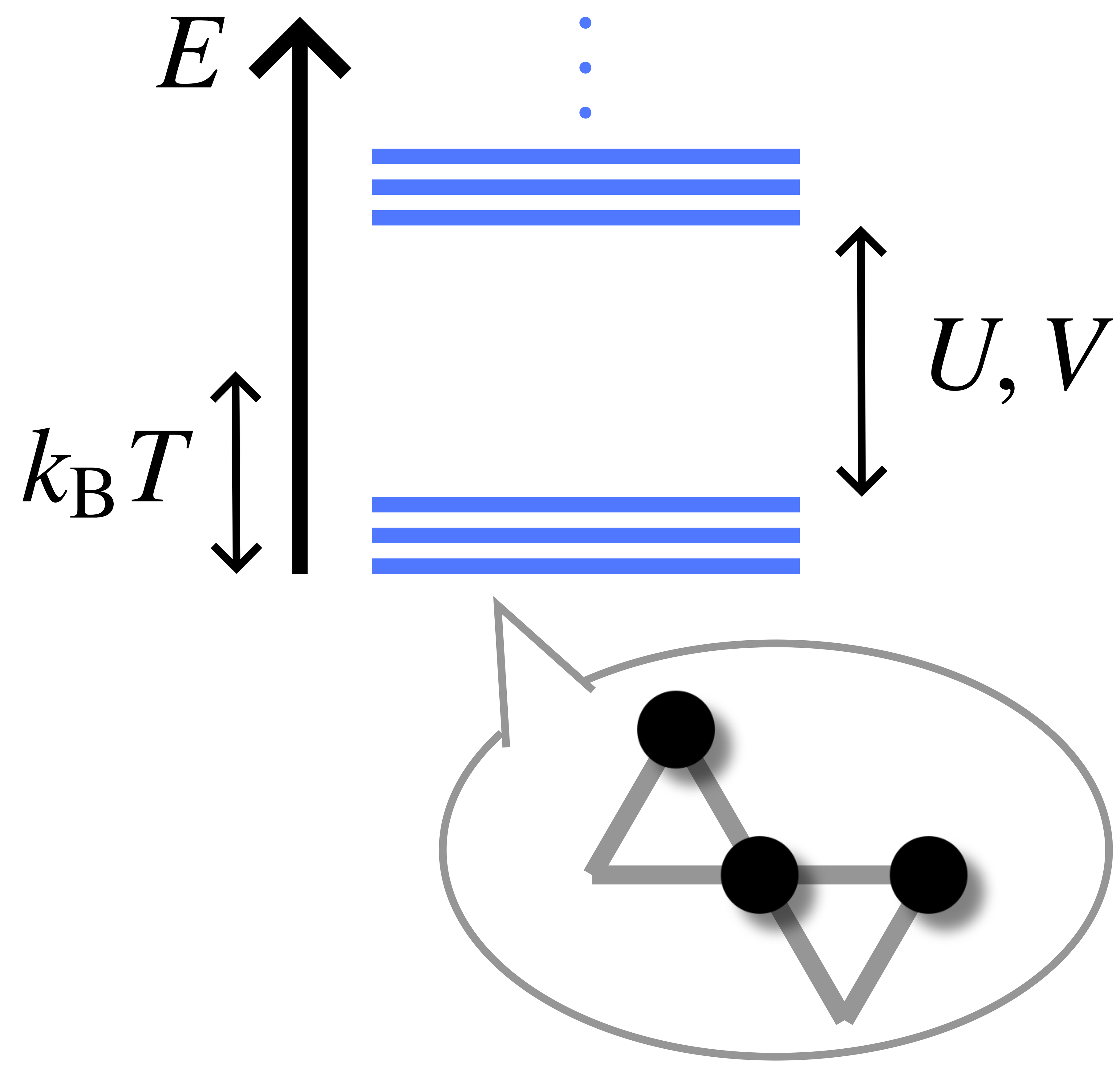


[Nakatsuji *et al.*, Nature 2016]

This work: Unconventional relaxation even in high-T disordered kagome with strong correlations

Model (2/3 filling)

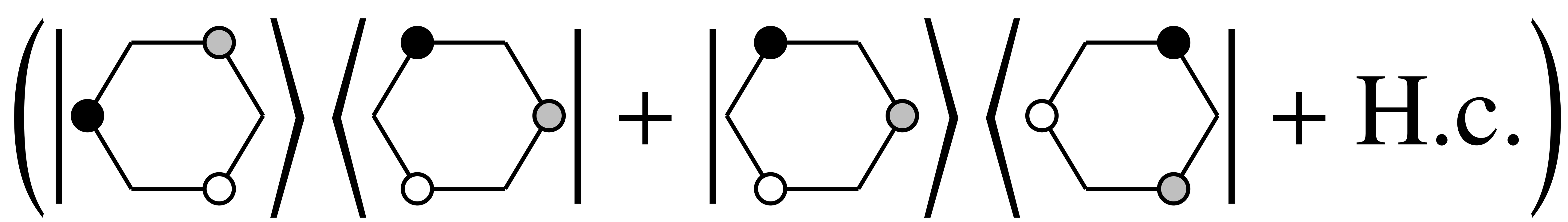
$$\hat{\mathcal{H}} = -\mathrm{t} \sum_{\langle \boldsymbol{r}, \boldsymbol{r}' \rangle} \sum_{\sigma} \left(\hat{c}^{\dagger}_{\boldsymbol{r},\sigma} \hat{c}_{\boldsymbol{r}',\sigma} + \mathrm{H.c.} \right) + U \sum_{\boldsymbol{r}} \hat{n}_{\boldsymbol{r},\uparrow} \hat{n}_{\boldsymbol{r},\downarrow} + V \sum_{\langle \boldsymbol{r}, \boldsymbol{r}' \rangle} \hat{n}_{\boldsymbol{r}} \hat{n}_{\boldsymbol{r}'}$$



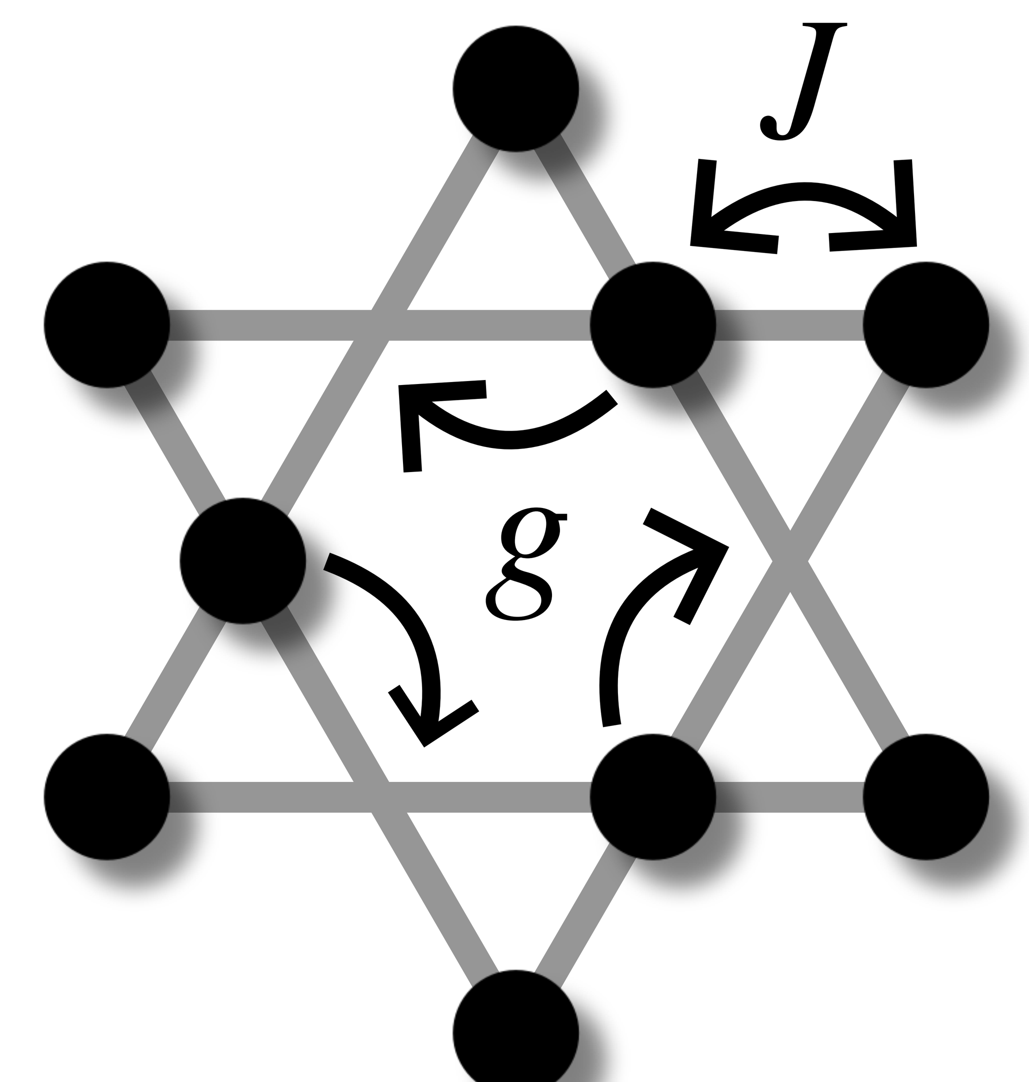
Strong-coupling limit

[Pollmann et al., PRB 2014]

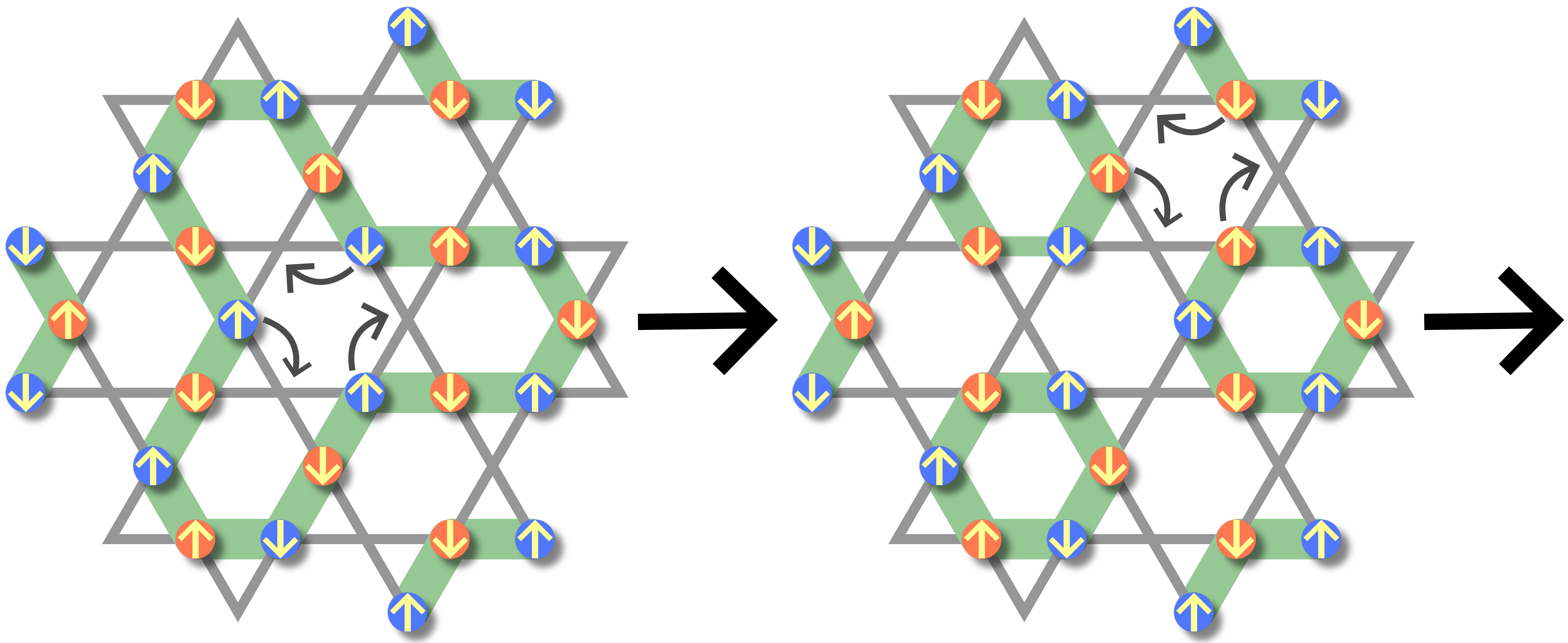
$$\hat{\mathcal{H}}_{\mathrm{eff}} = -g \sum_{\hexagon}$$



$$+ J \sum_{\langle \boldsymbol{r}, \boldsymbol{r}' \rangle} \hat{\boldsymbol{S}}_{\boldsymbol{r}} \cdot \hat{\boldsymbol{S}}_{\boldsymbol{r}'}$$



Hidden spin conservation law (J=0)

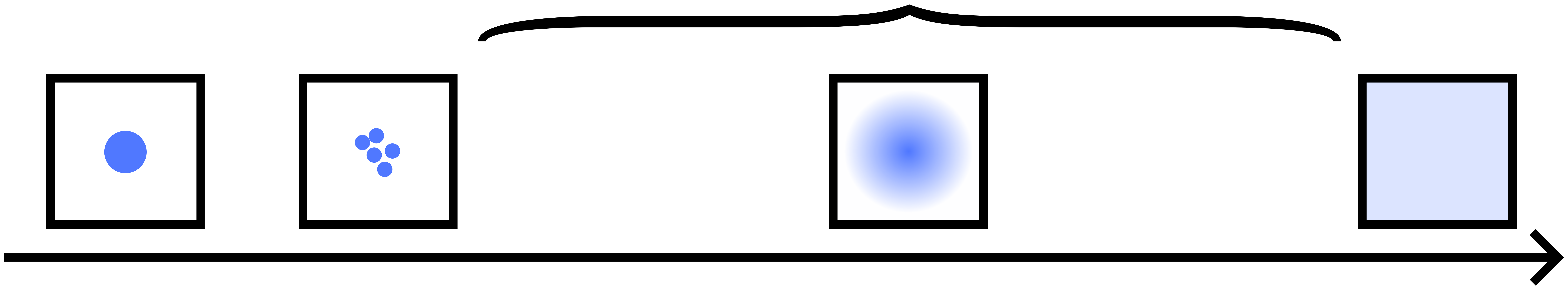


Total Sz on each dynamic sublattice is conserved

[Pollmann et al., PRB 2014]

Late-time relaxation dynamics

Only determined by **conservation laws** [Doyon, Scipost 2020]

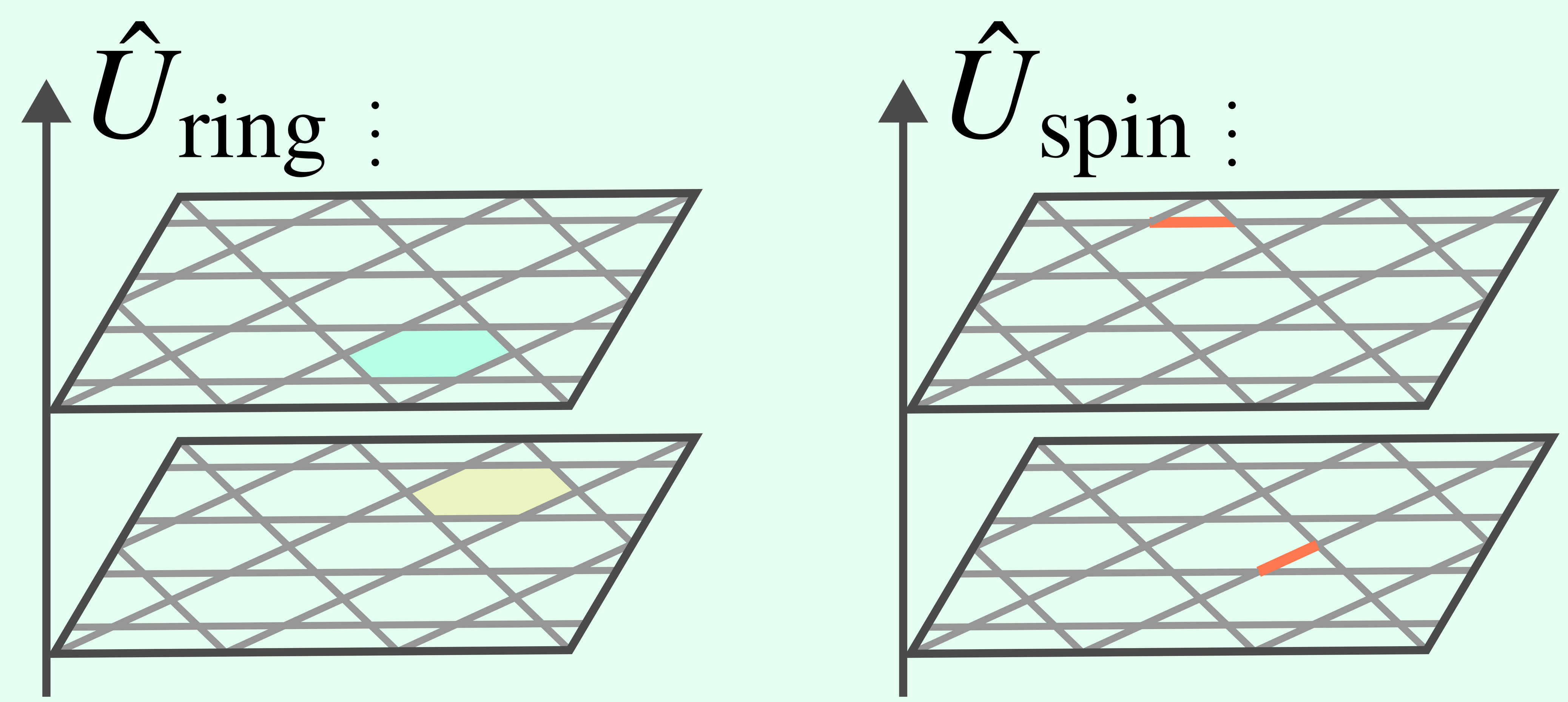


Cellular automaton circuit $\hat{U}(t) = \cdots \hat{U}_{\text{ring}} \hat{U}_{\text{ring}} \hat{U}_{\text{spin}} \hat{U}_{\text{ring}} \cdots$

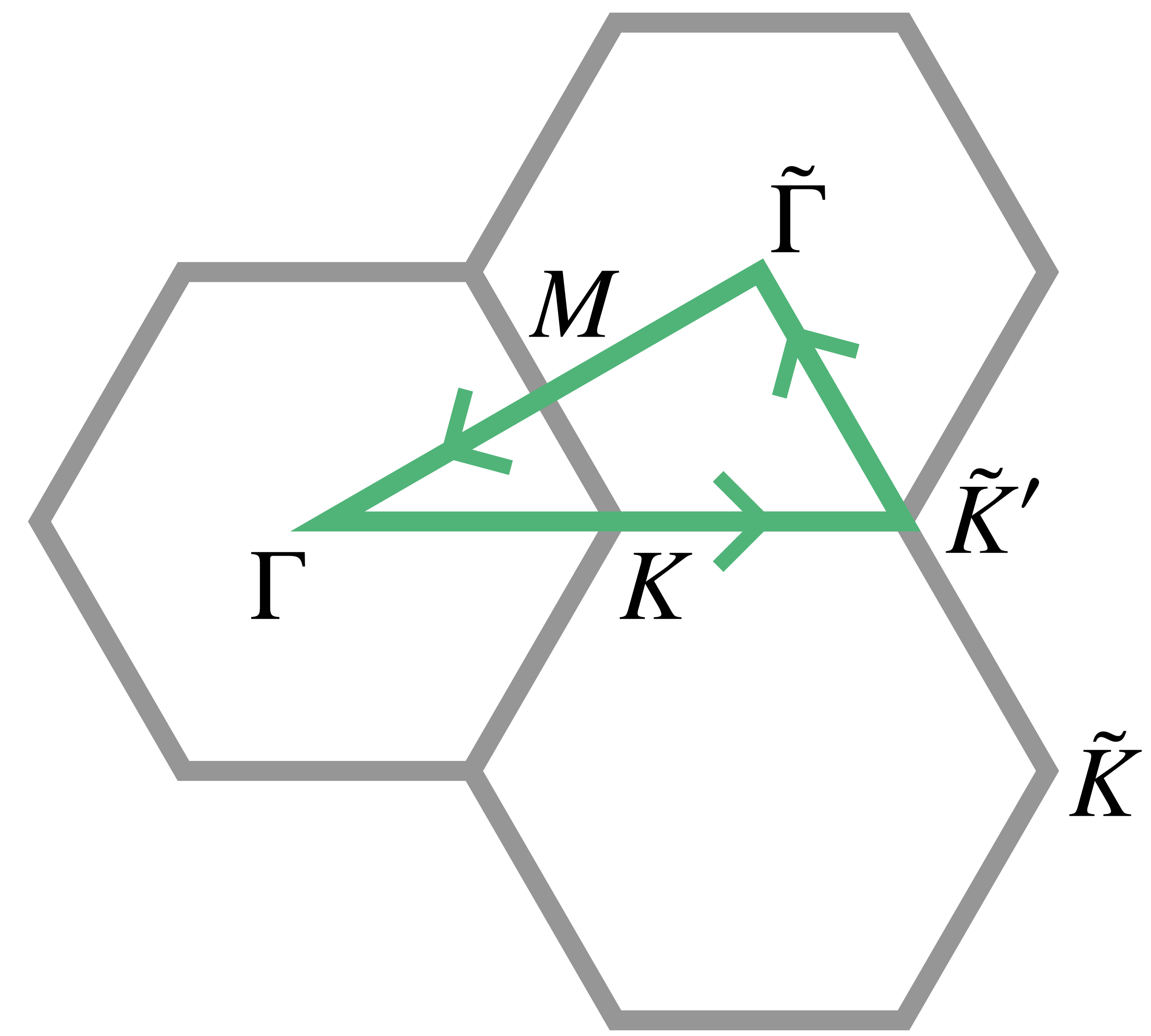
✓ Classically simulable

✓ Same conservation laws

[Medenjak et al., PRL 2017],
[Gopalakrishnan&Zakirov QST 2018], ...

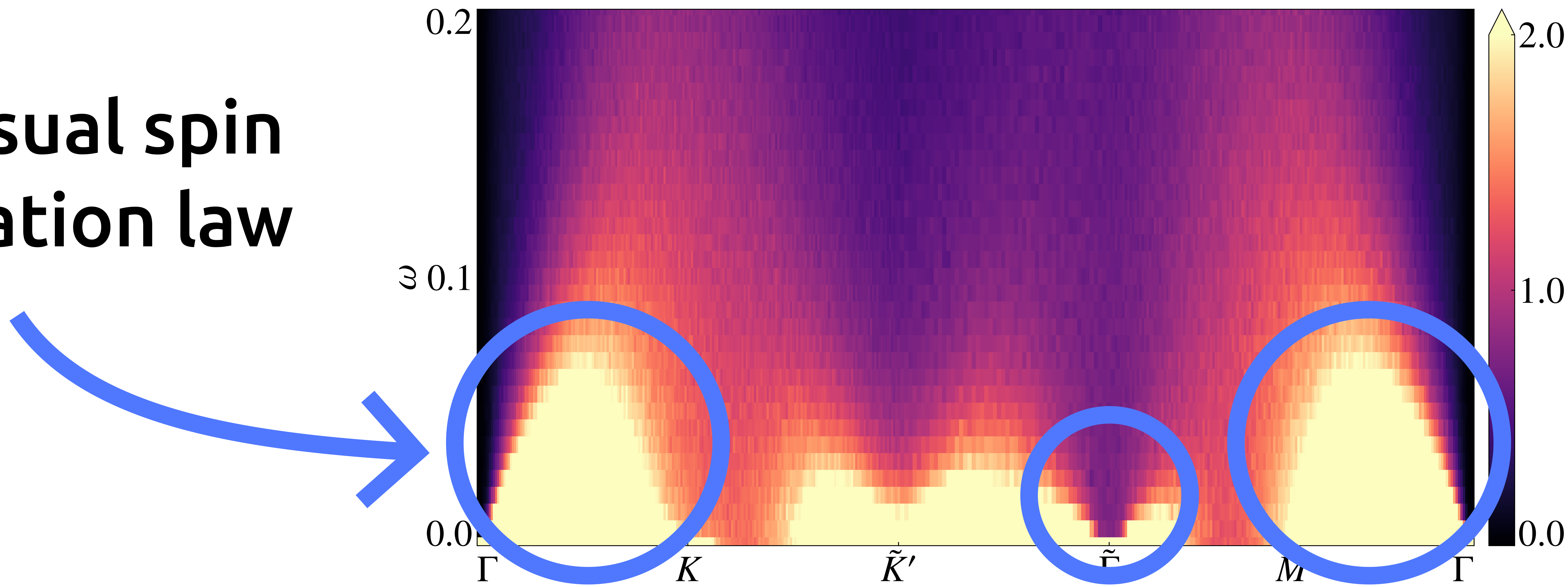


Dynamic spin structure factor (J=0)

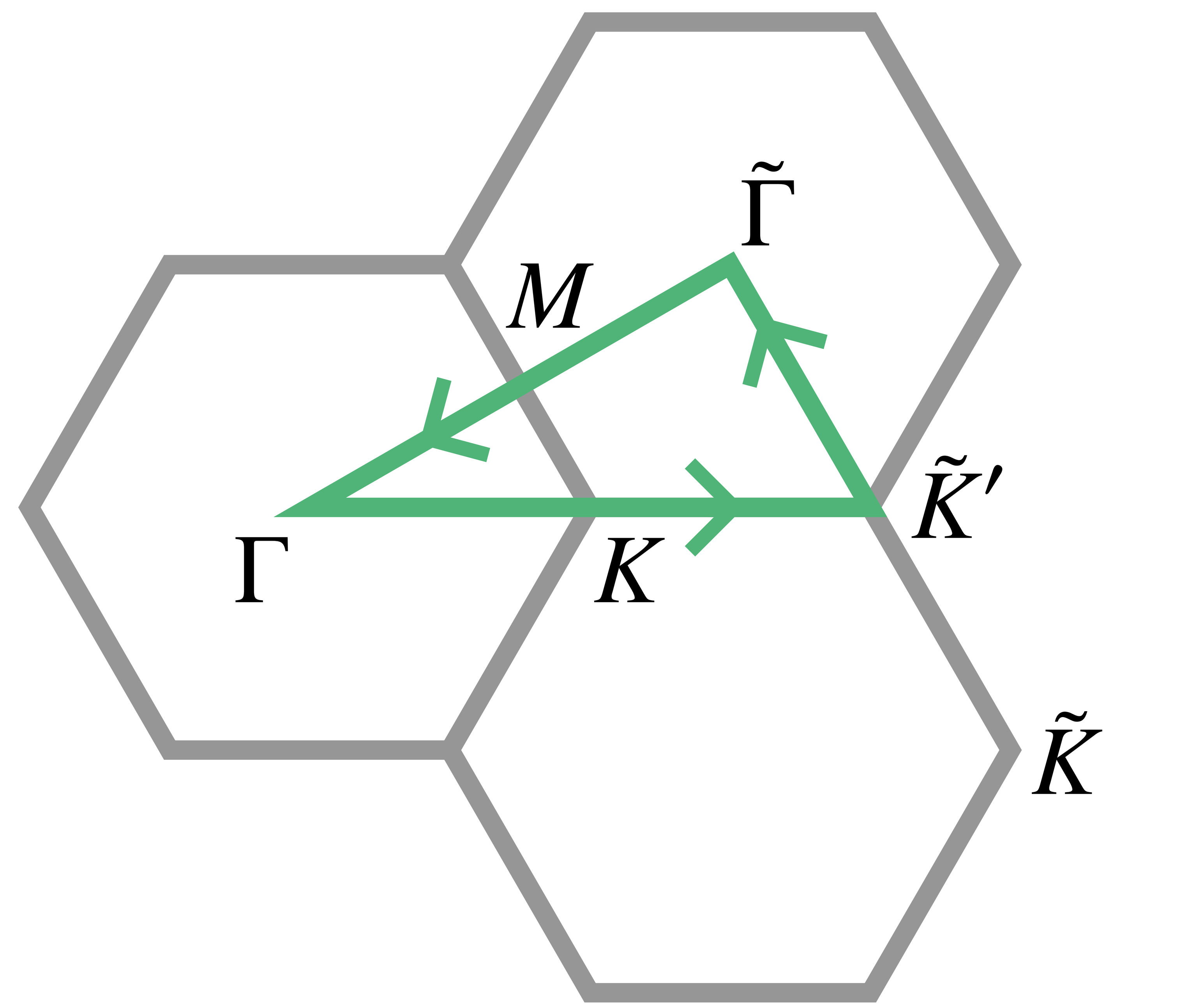


$$S(\boldsymbol{k},\omega) = \frac{1}{N}\sum_{\boldsymbol{r},\boldsymbol{r}'}\int_{-\infty}^{\infty} dt\ \langle \hat{S}^z_{\boldsymbol{r}}(t)\hat{S}^z_{\boldsymbol{r}'}(0)\rangle\, \mathrm{e}^{-i\boldsymbol{k}\cdot(\boldsymbol{r}-\boldsymbol{r}')+i\omega t}$$

by the usual spin conservation law

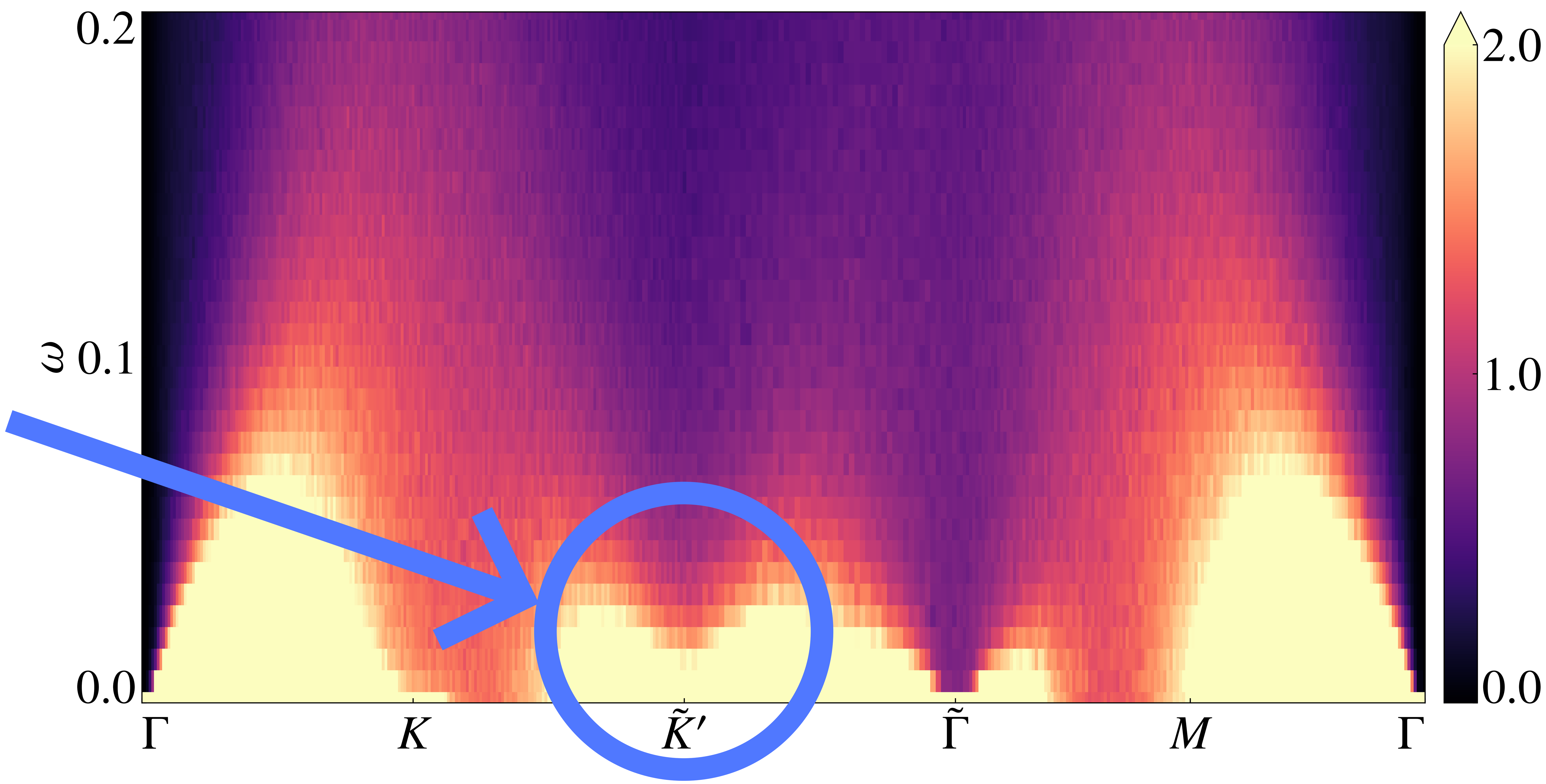


Dynamic spin structure factor (J=0)



$$S(\boldsymbol{k},\omega) = \frac{1}{N}\sum_{\boldsymbol{r},\boldsymbol{r}'}\int_{-\infty}^{\infty} dt\ \langle \hat{S}^z_{\boldsymbol{r}}(t)\hat{S}^z_{\boldsymbol{r}'}(0)\rangle\, \mathrm{e}^{-i\boldsymbol{k}\cdot(\boldsymbol{r}-\boldsymbol{r}')+i\omega t}$$

Strong response by the hidden spin conservation law



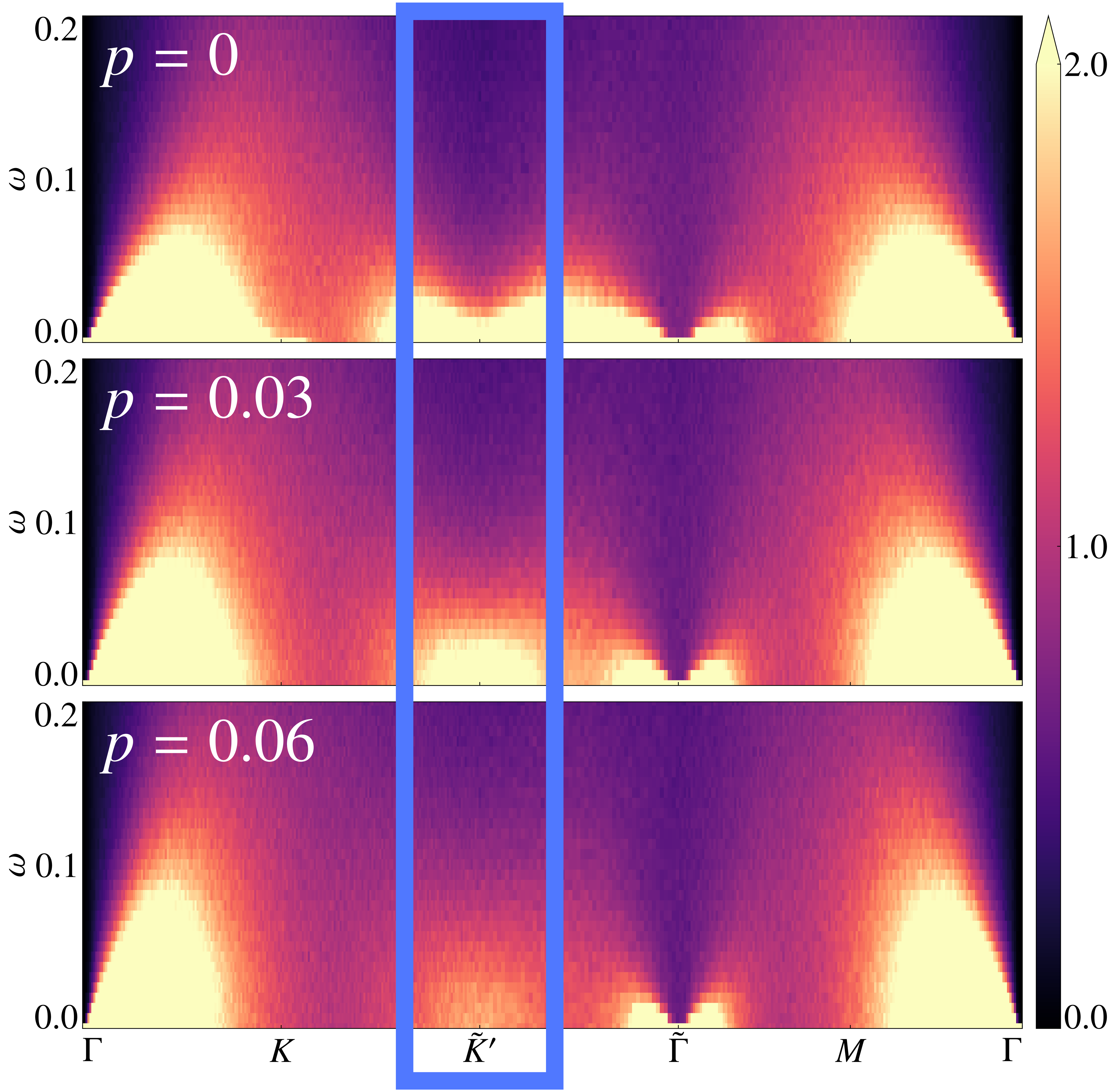
Dynamic spin structure factor (J≠0)

$$\hat{U}(t) = \cdots \hat{U}_{\text{ring}} \hat{U}_{\text{spin}} \cdots$$

probability p

J/g

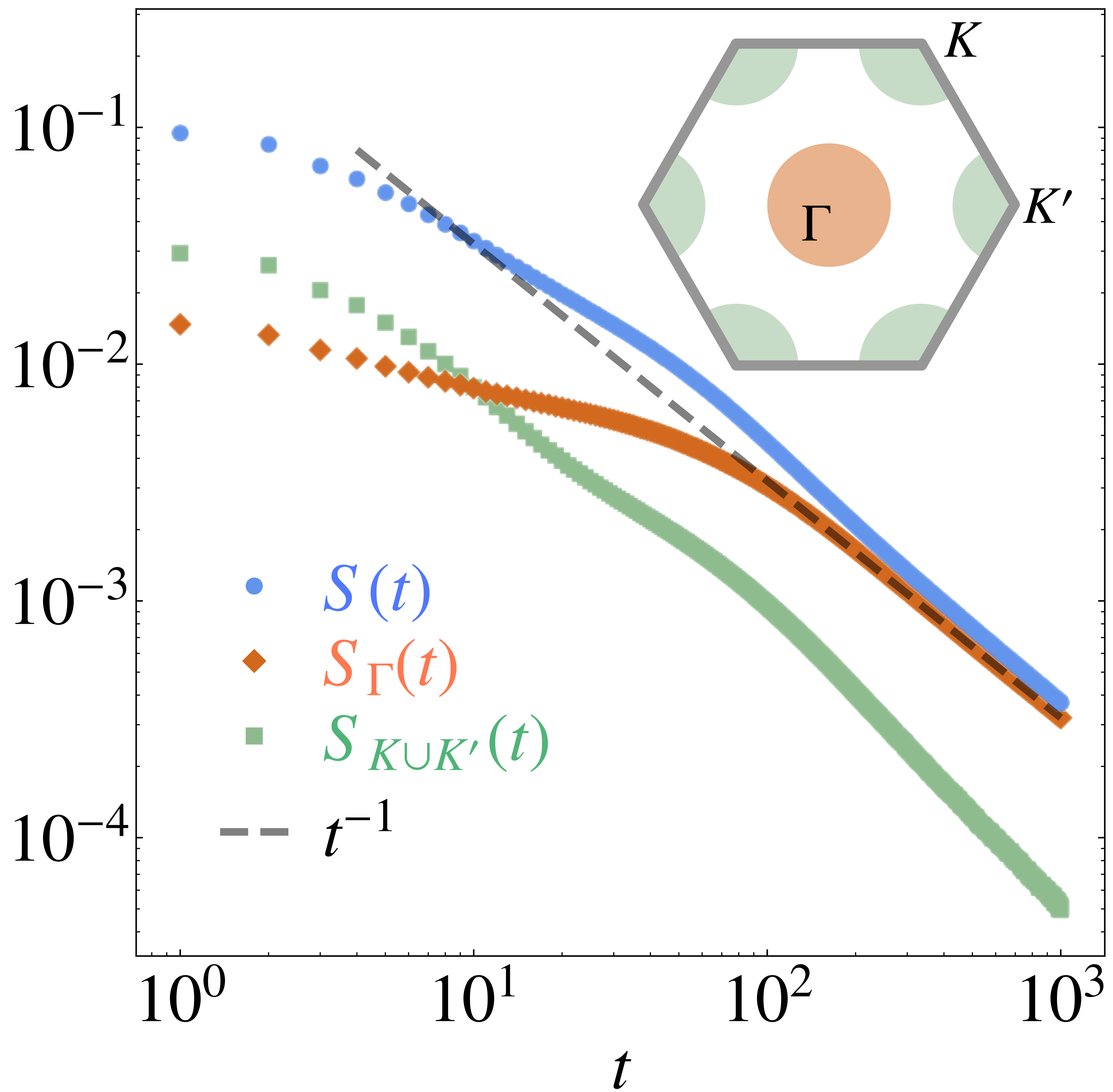
Robust against small J/g



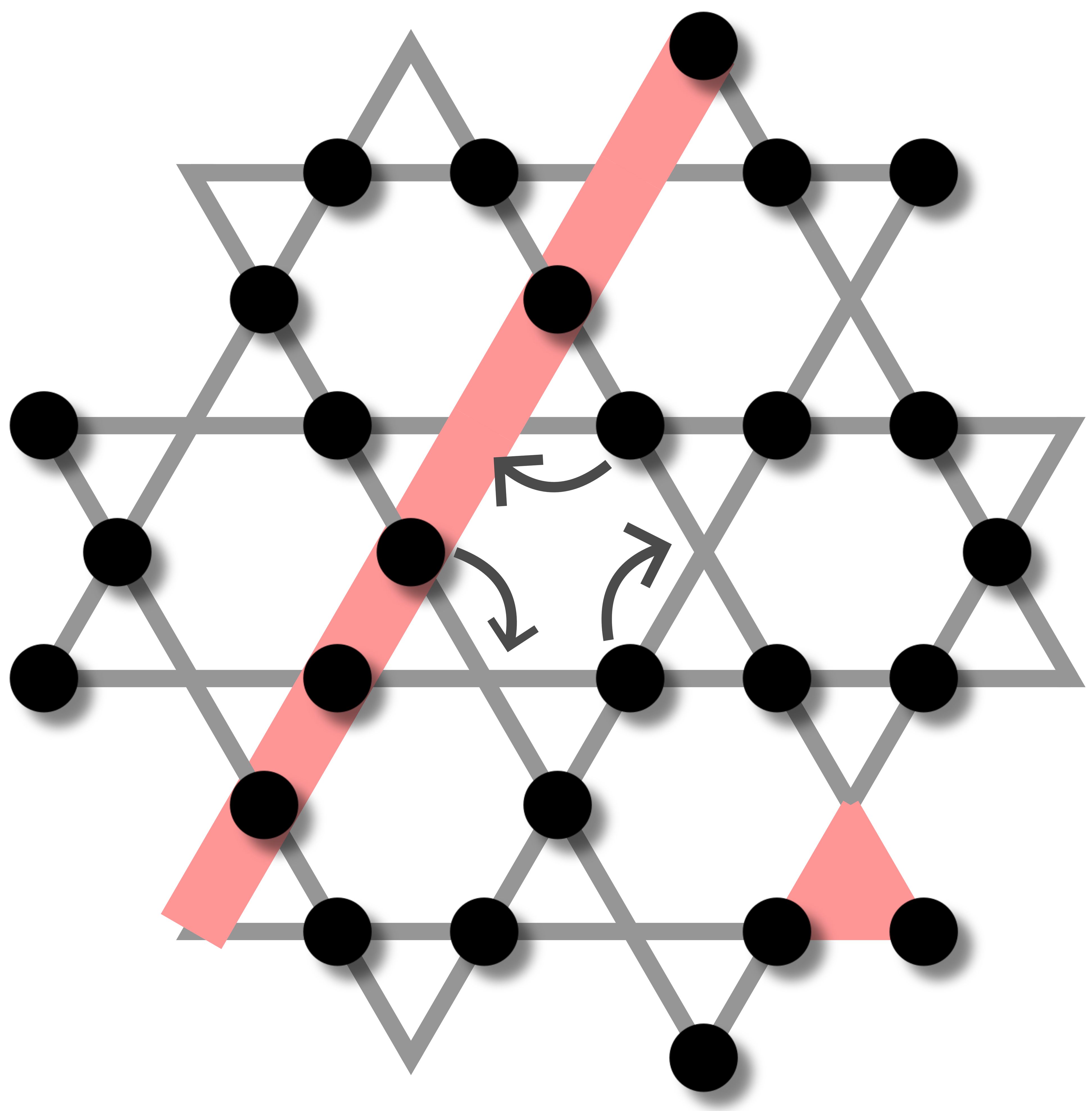
Spin autocorrelation function (J=0)

$$S(t) = \frac{1}{N}\sum_{\boldsymbol{r}} \langle \hat{S}^z_{\boldsymbol{r}}(t)\hat{S}^z_{\boldsymbol{r}}(0)\rangle$$
$$= \frac{1}{N}\sum_{\boldsymbol{k}} \mathrm{tr}[S(\boldsymbol{k}, t)]$$
$$\simeq S_\Gamma(t) + S_{K\cup K'}(t)$$

Unconventional scaling by the contribution from K and K' points



Hidden charge conservation laws



Conserved quantities

✓ Total charge along lines

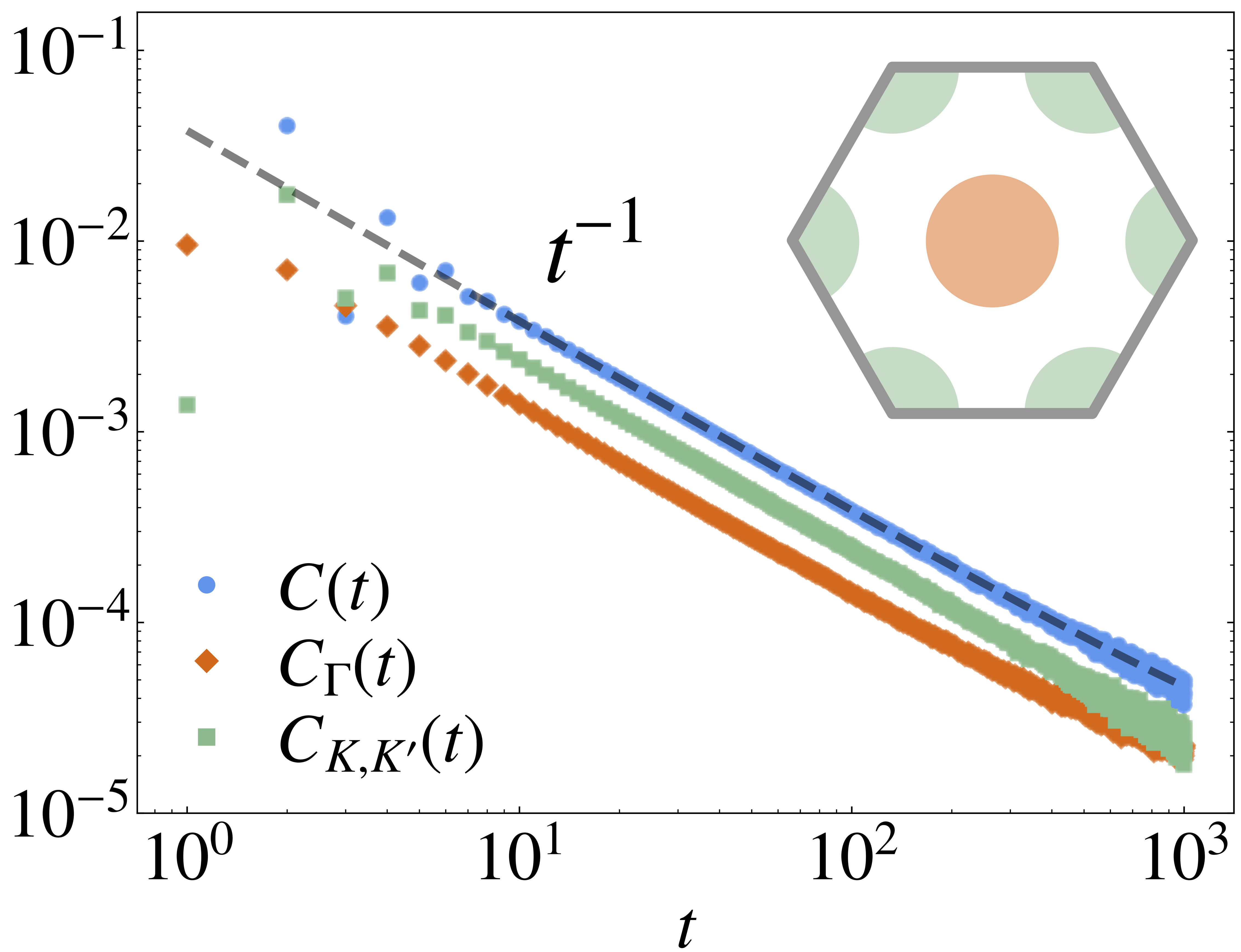
✓ Total charge on triangles

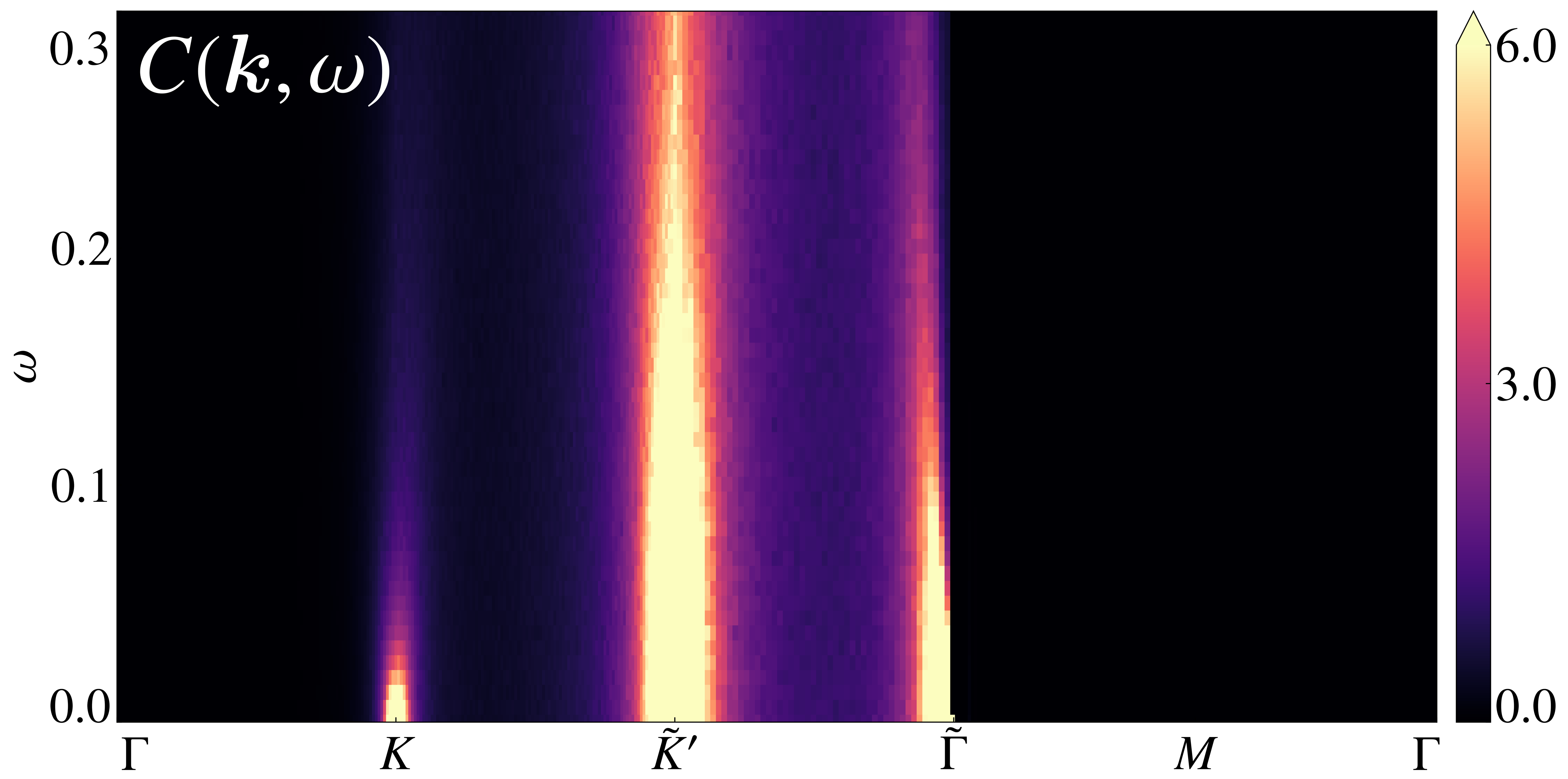
[Pollmann et al., PRB 2014]

Charge relaxation dynamics

✓ Finite contribution to C(t) from K and K' points

✓ Strong responses in C(k,ω) near K and K̃' point





Effective field theory

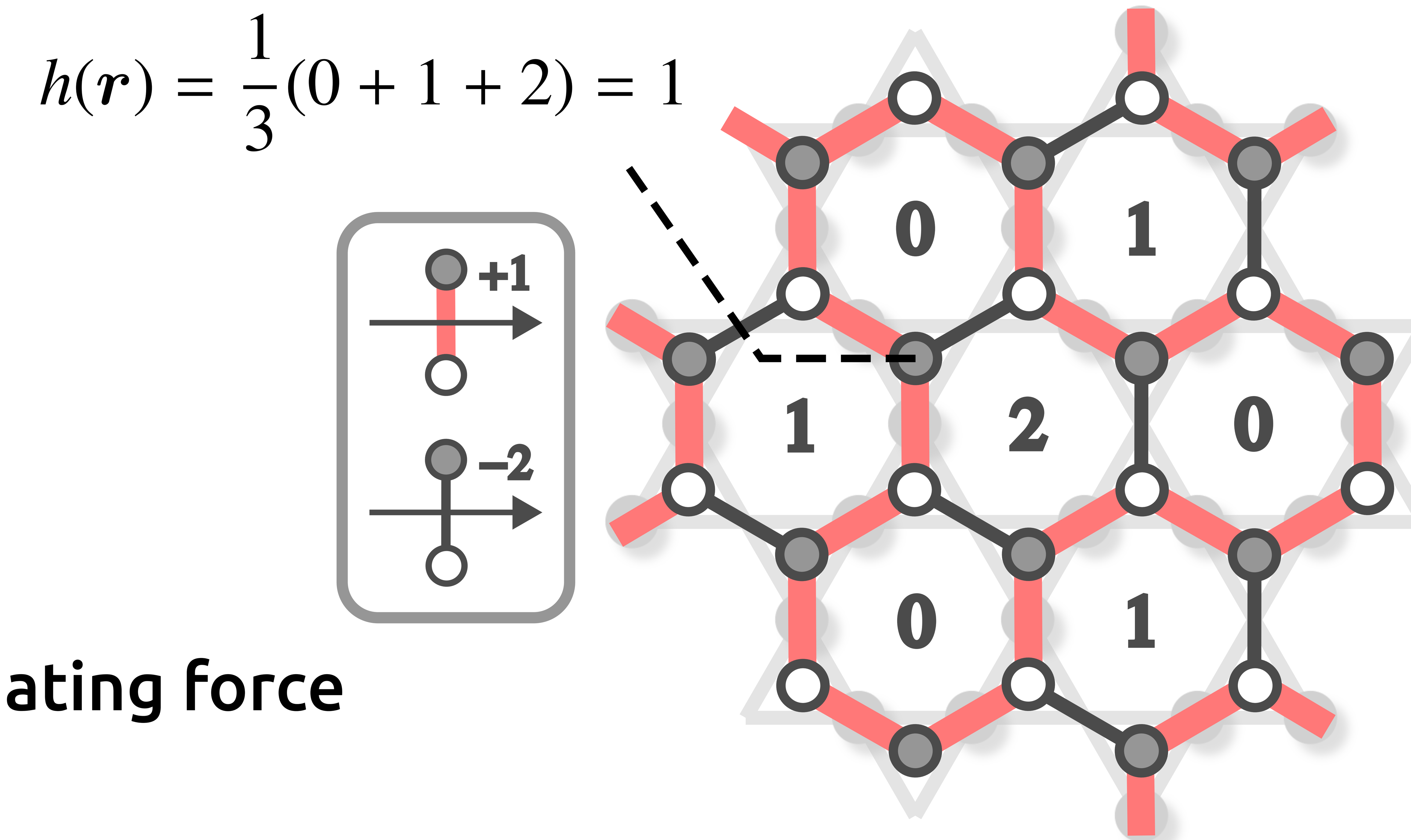
[Henley, JSP 1997]
[Moessner&Sondhi, PRB 2003]

Relaxation to uniform h(r) by an entropic effect

$$S\left[h(\boldsymbol{r})\right] = \frac{\pi}{18}\int d^2\boldsymbol{r}\,(\nabla h(\boldsymbol{r}))^2$$

$$\frac{\partial}{\partial t}h(\boldsymbol{r},t) = -\gamma\frac{\delta S\left[h(\boldsymbol{r},t)\right]}{\delta h(\boldsymbol{r},t)} + \zeta(\boldsymbol{r},t)$$

Damping force **Randomly fluctuating force**

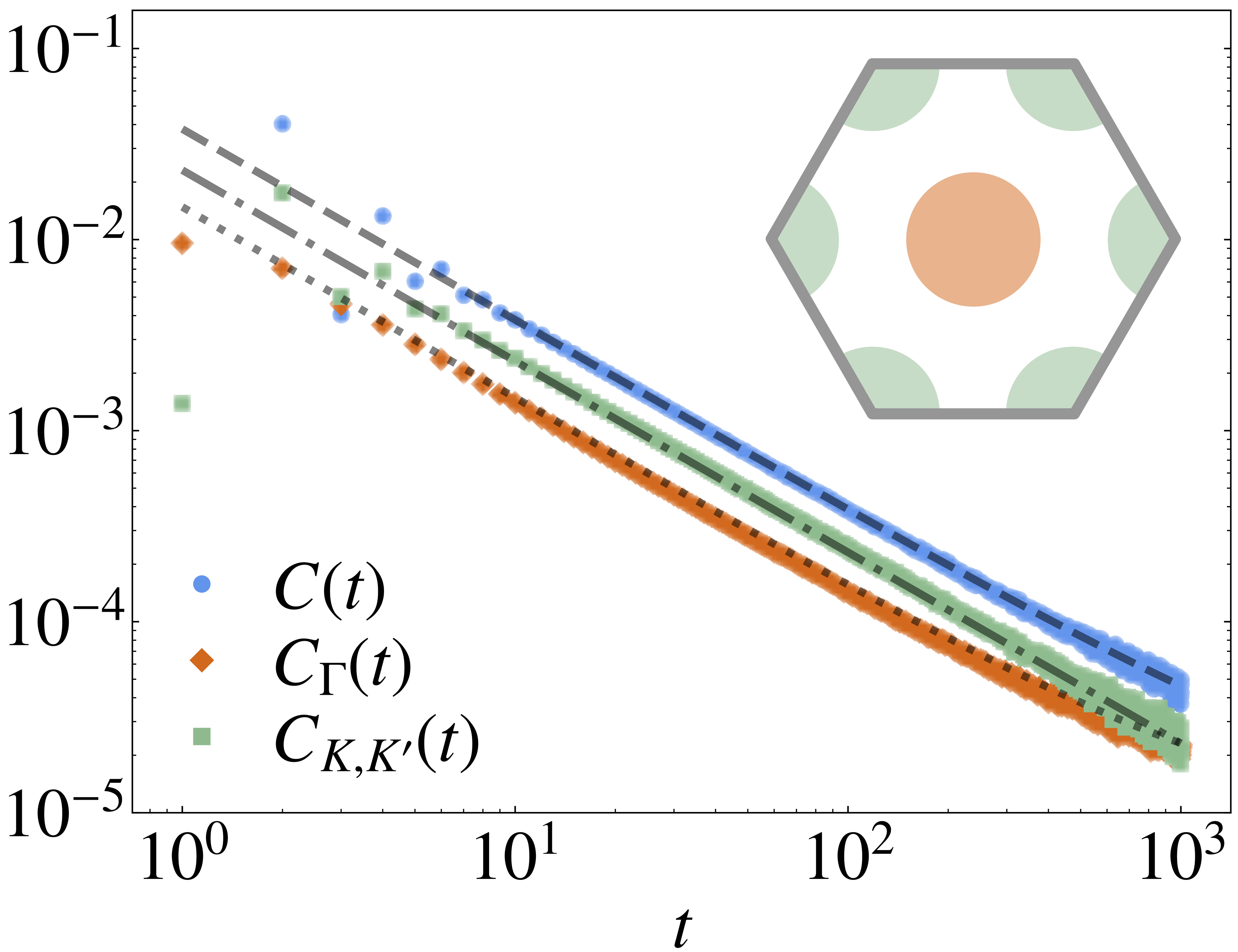


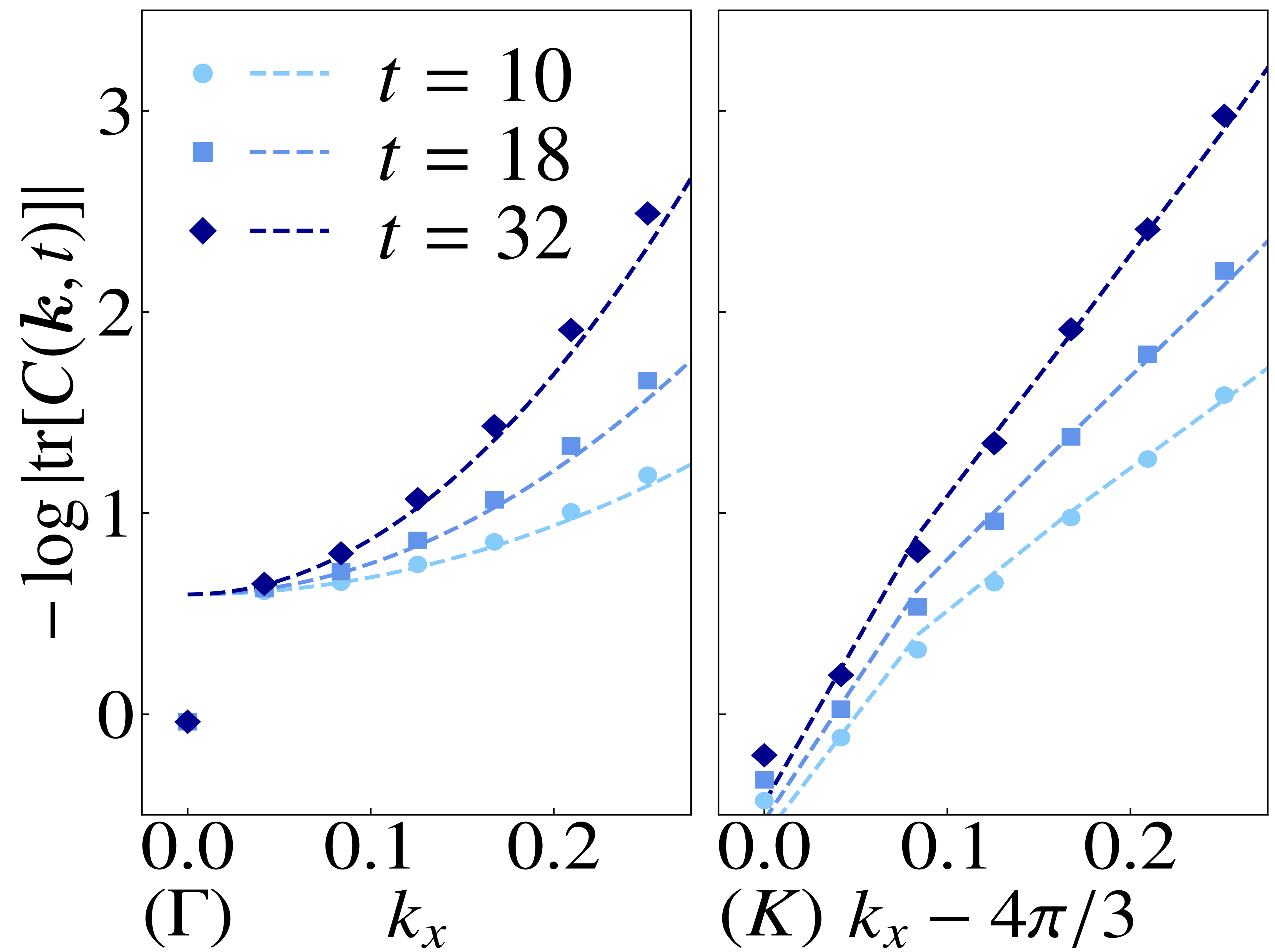
$$n_\ell(\boldsymbol{r}) - \frac{2}{3} = \frac{1}{3}\partial_\ell h(\boldsymbol{r}) + \frac{1}{2}\sum_{\boldsymbol{k}_0=\boldsymbol{K},-\boldsymbol{K}'}\cos\left(\boldsymbol{k}_0\cdot\boldsymbol{r} + \frac{2(\ell-1)\pi}{3} + \frac{2\pi}{3}h(\boldsymbol{r})\right)$$

Rapidly modulated in space even when h(r) takes a uniform value

Comparison with numerical results

$$\frac{1}{3}\sum_{\ell}\langle\delta n_\ell(\boldsymbol{r},t)\delta n_\ell(\boldsymbol{0},0)\rangle = \frac{1}{\pi V}+\frac{1}{2\pi V}\sum_{\boldsymbol{q}\neq\boldsymbol{0}}\mathrm{e}^{-(\pi/9)\boldsymbol{q}^2\gamma t}+\frac{1}{8}\sum_{\boldsymbol{k}_0=\pm\boldsymbol{K},\pm\boldsymbol{K}'}\exp\left[i\boldsymbol{k}_0\cdot\boldsymbol{r}-\sum_{\boldsymbol{q}}\frac{4\pi}{\boldsymbol{q}^2}\left(1-\mathrm{e}^{-(\pi/9)\boldsymbol{q}^2\gamma t}\cos\boldsymbol{q}\cdot\boldsymbol{r}\right)-\frac{4\pi^2\gamma t}{9V}\right]$$





Almost perfectly reproduces the numerical results

Summary

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Hidden conservation law and unconventional relaxation dynamics even in the high-temperature disordered kagome system by strong correlations