Bistability in the 1D dissipative Far-East model

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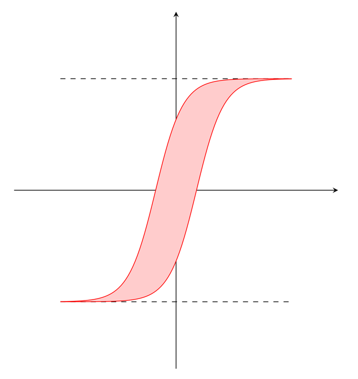
Why Kinetically Constrained Models (KCMs)?

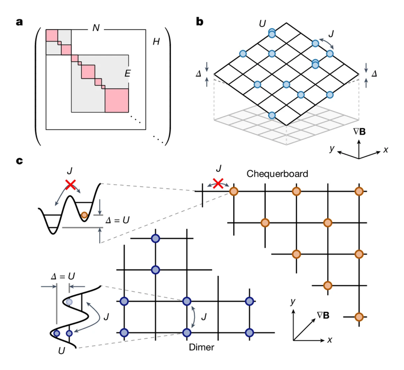
In a KCM dynamics must satisfy a specific set of local rules

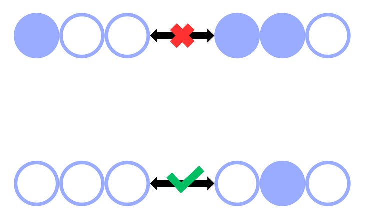
KCMs landscape is vast. We can find:

- **Classical KCMs:** originally developed as toy models for structural glasses; they exhibit trivial thermodynamics but anomalous, slow relaxation dynamics.
- **Quantum KCMs:** generalization to Hamiltonian dynamics; known for hosting exotic phenomena like weak ergodicity breaking and acting as effective low-energy theories for strongly interacting systems (e.g., PXP models).
- **Dissipative KCMs:** the interplay of kinetic constraints and open system dynamics provides a robust platform for novel non-equilibrium phases.

They feature **very rich and non trivial dynamics**, such as **Hilbert space fragmentation, quantum many-body scars, anomalous transport and bistability**[1],[2],[3]:







Classical Far-East

Unbiased thermal fluctuations T compete with the chiral out-of-equilibrium steady-state induced by the majority vote with **transition probabilities** γ_μ, γ_ν.

Given a plaquette configuration, the first site will **flip with probability** $p \in \{\gamma_\mu, \gamma_{\bar{\mu}}, \gamma_\nu, \gamma_{\bar{\nu}}\}$

Absence of bistability to be expected $\forall T \neq 0$

Quantum Far-East

Coherent Dynamics (Quantum Fluctuations):

$$\hat{H} = \Omega \sum_j \hat{S}_j^x \tag{1}$$

Incoherent Dynamics (Majority Vote):

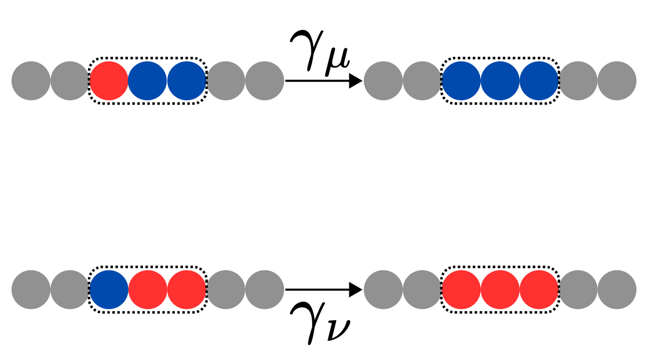
Dissipation on a 3-site unit cell $j_{...} = \{j, j+1, j+2\}$ flips spin j through the jump operators:

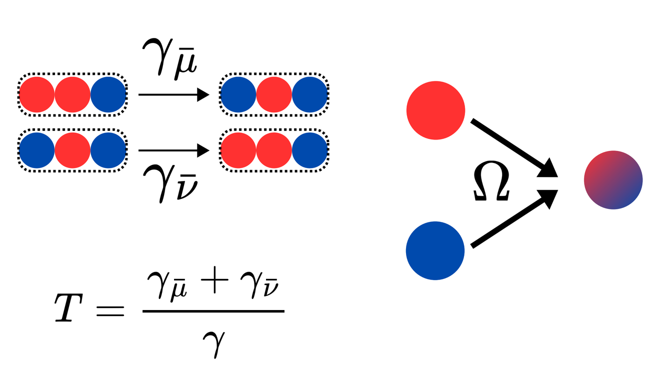
$$\hat{L}_{j,\nu} = \sqrt{\gamma_\nu}\hat{\sigma}_j^- \hat{\mathbb{P}}_{j+1}^{\uparrow}\hat{\mathbb{P}}_{j+2}^{\uparrow} \quad \text{and} \quad \hat{L}_{j,\mu} = \sqrt{\gamma_\mu}\hat{\sigma}_j^+ \hat{\mathbb{P}}_{j+1}^{\downarrow}\hat{\mathbb{P}}_{j+2}^{\downarrow} \tag{2}$$

Classical fluctuations destroy bistability in 1D systems:
are quantum fluctuations equally destructive?

References

[1] P. Brighi *et al.*, *Dissipative quantum north-east-center model: steady-state phase diagram, universality and nonergodic dynamics*, SciPost Phys. 20, 019 (2026).
[2] D. Adler *et al.*, *Nonergodic multidimensional system of automata*, Nat. 636 (2024).
[3] A. Hudomal*et al.*, *Driving quantum many-body scars in the PXP model*, Phys. Rev. B 106.

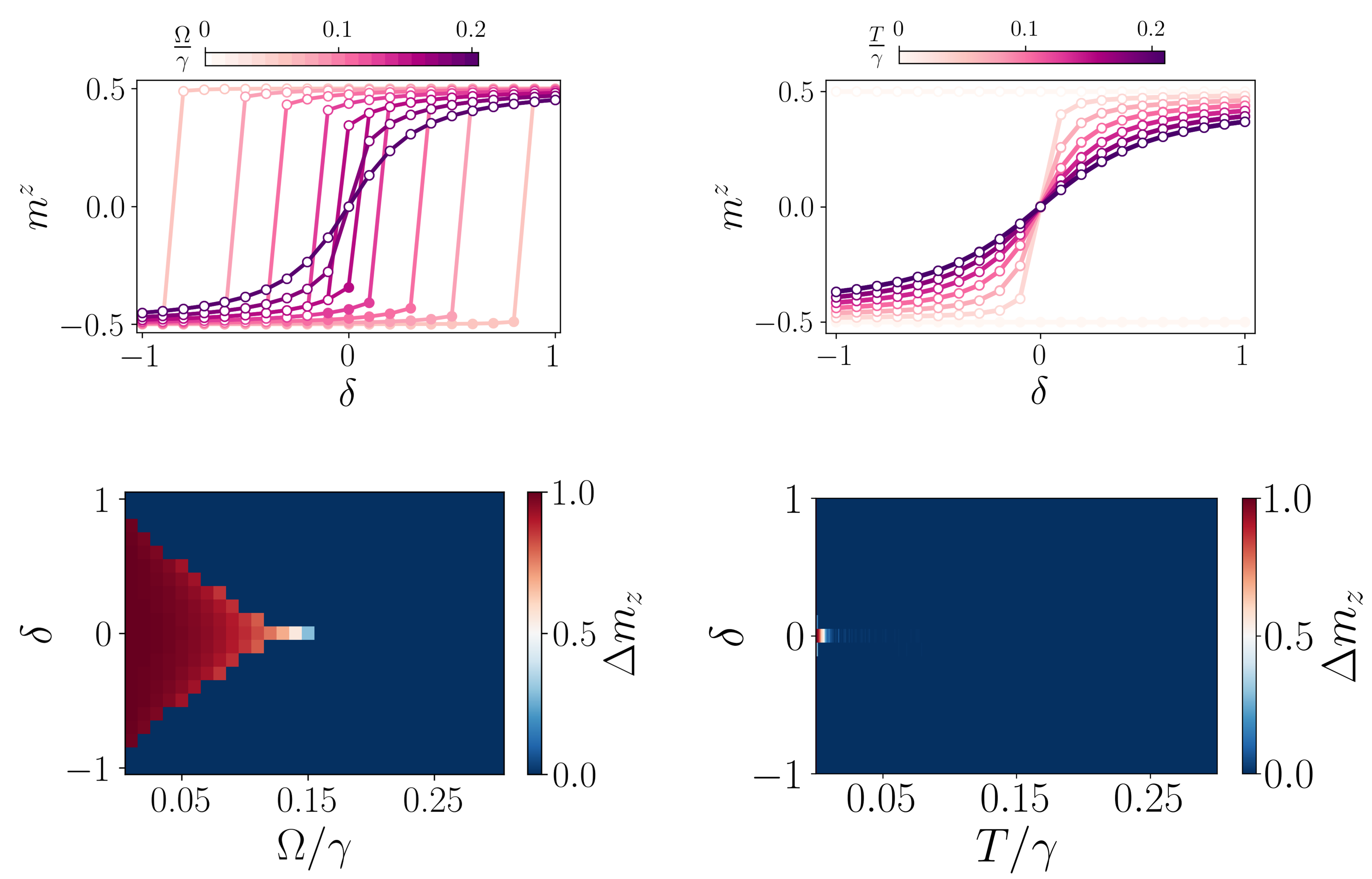




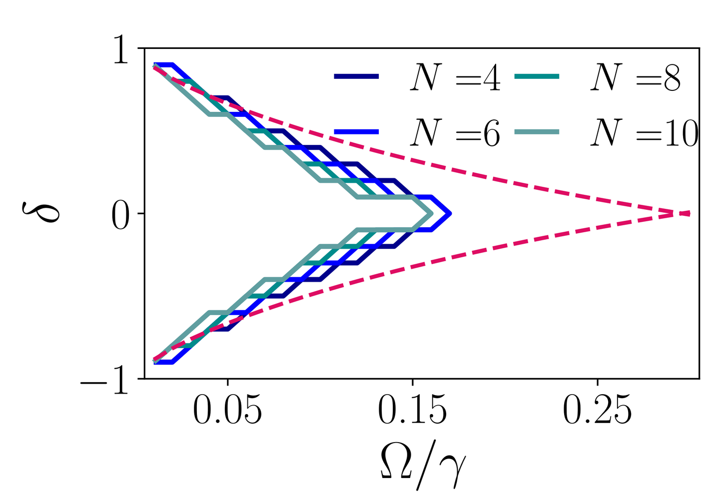
Steady-State Phase Diagram

Bias between transition rates $\delta = \frac{\gamma_\nu - \gamma_\mu}{\gamma}$
Quantum FE: **Cluster Mean-Field (CMF)** approach, clusters of size N
Classical FE: **Monte Carlo** approach

Hysteresis cycles in δ let us build the phase diagrams:



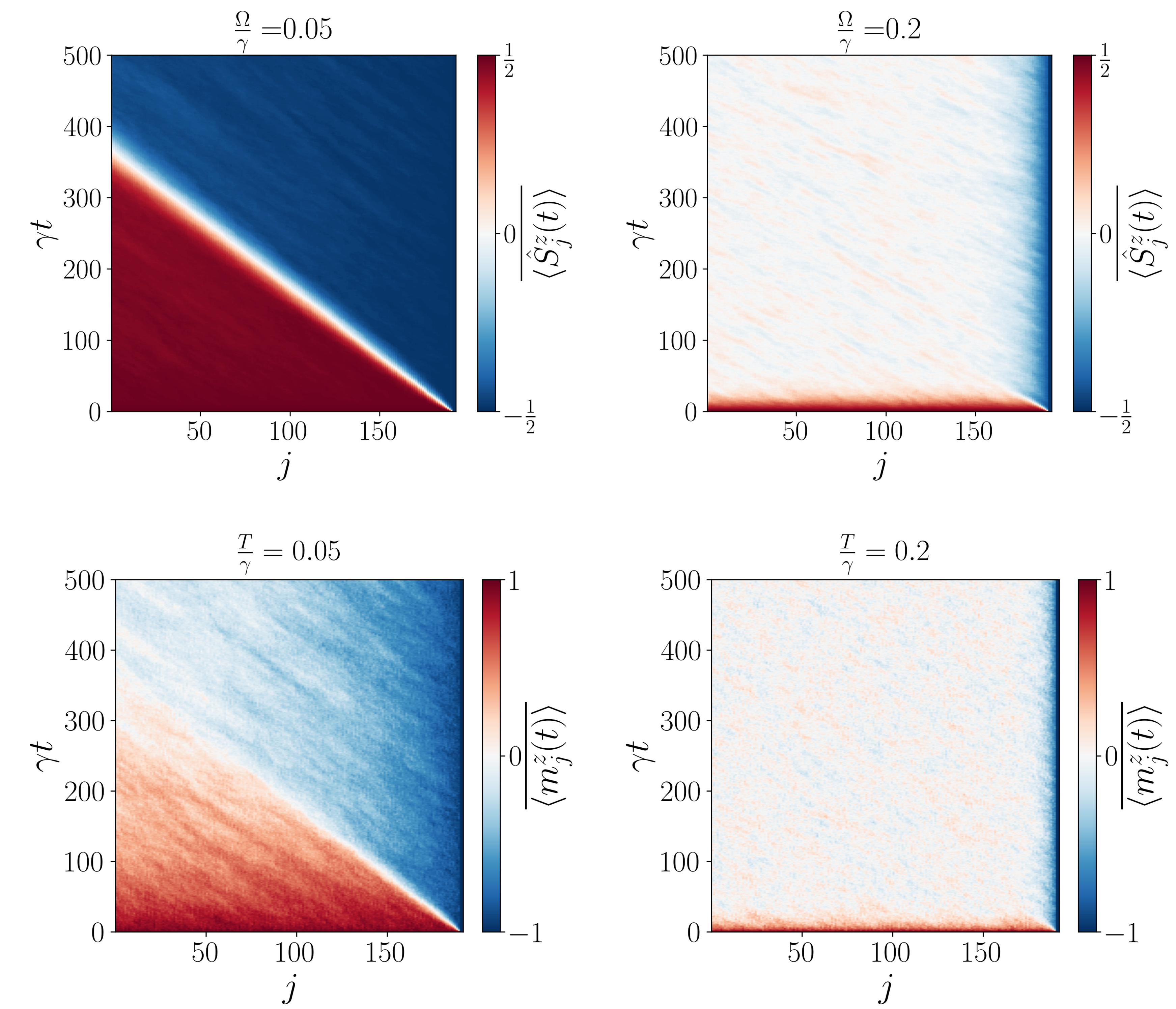
Increasing the cluster size N shrinks the bistable region.



Nonergodic Dynamics & Bubble Reabsorption

Beyond CMF, we analyze the real-time dynamics using **Tensor Network methods (TEBD)** and **exact quantum trajectories** to contrast the classical and quantum regimes.

- **Bubble Reabsorption:** a minority island of up-spins surrounded by down-spins initialized in the center of the system consistently drifts leftwards and is entirely reabsorbed by the bulk. This is a clear signature of robust bistability.
- **Macroscopic Bubble Dynamics:** coupling an initially fully polarized (all-up) system to a spin-down bath predictably induces distinct, phase-dependent boundary dynamics in the bistable region.



Outlook & Open Questions

- **Generality:** does the Far-East dynamics showcases features of a broader, generic class of kinetically constrained dissipators?
- **Multistability:** could artificially extending the length of the jump operator strings to length n induce generalized $(n-1)$-stability?
- **Engineering dynamics:** can we induce by extending to non-trivial projections in the Kraus Operators (e.g., local superpositions) new, exotic non-equilibrium steady states?
- **Characterization:** the generic non-equilibrium dynamics of dissipative KCMs is still a vast, unexplored frontier.