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Quenching to field-stabilized magnetization plateaus in the unfrustrated Ising antiferromagnet

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Better title: *Stable frozen states without disorder*

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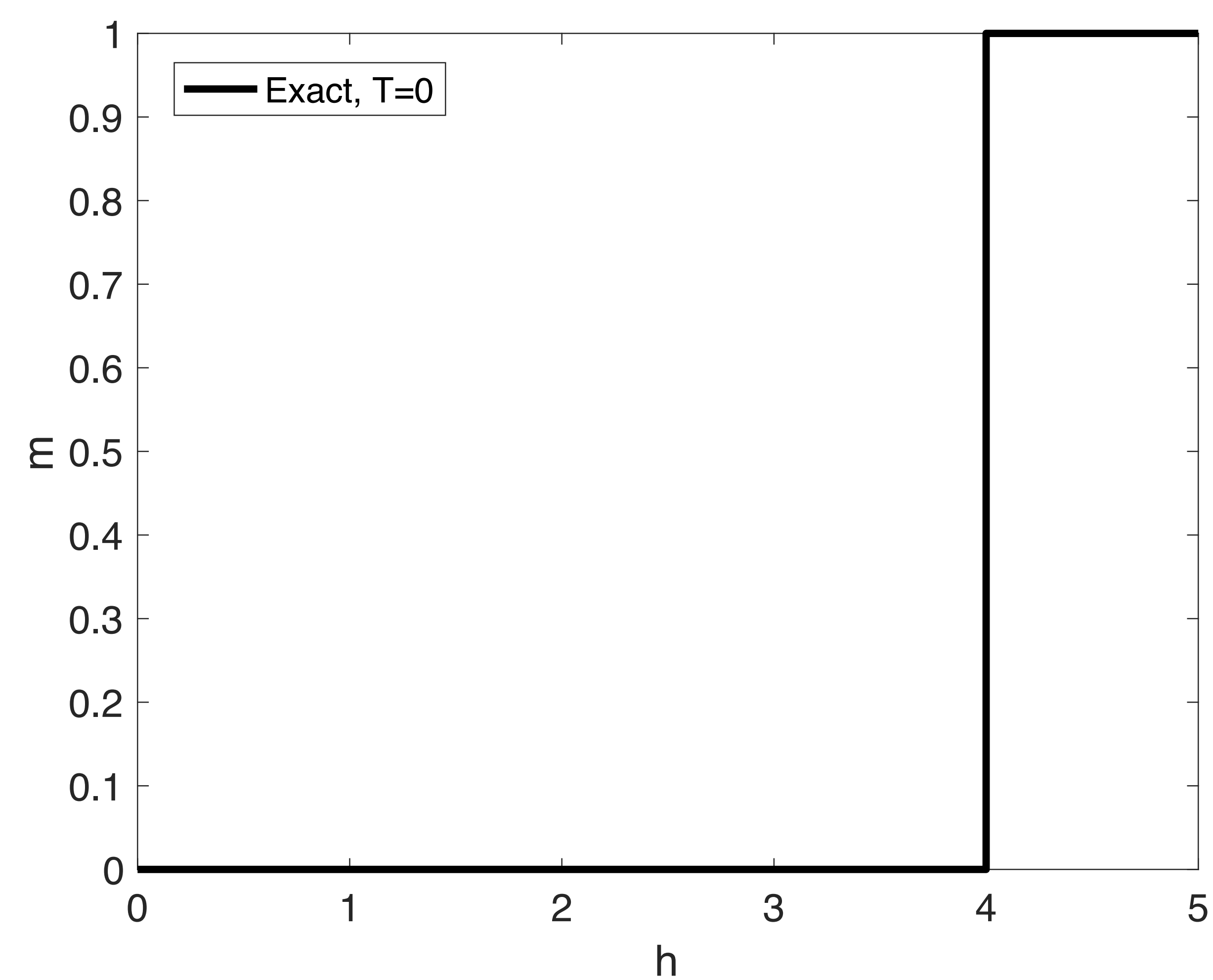
2D Ising AFM

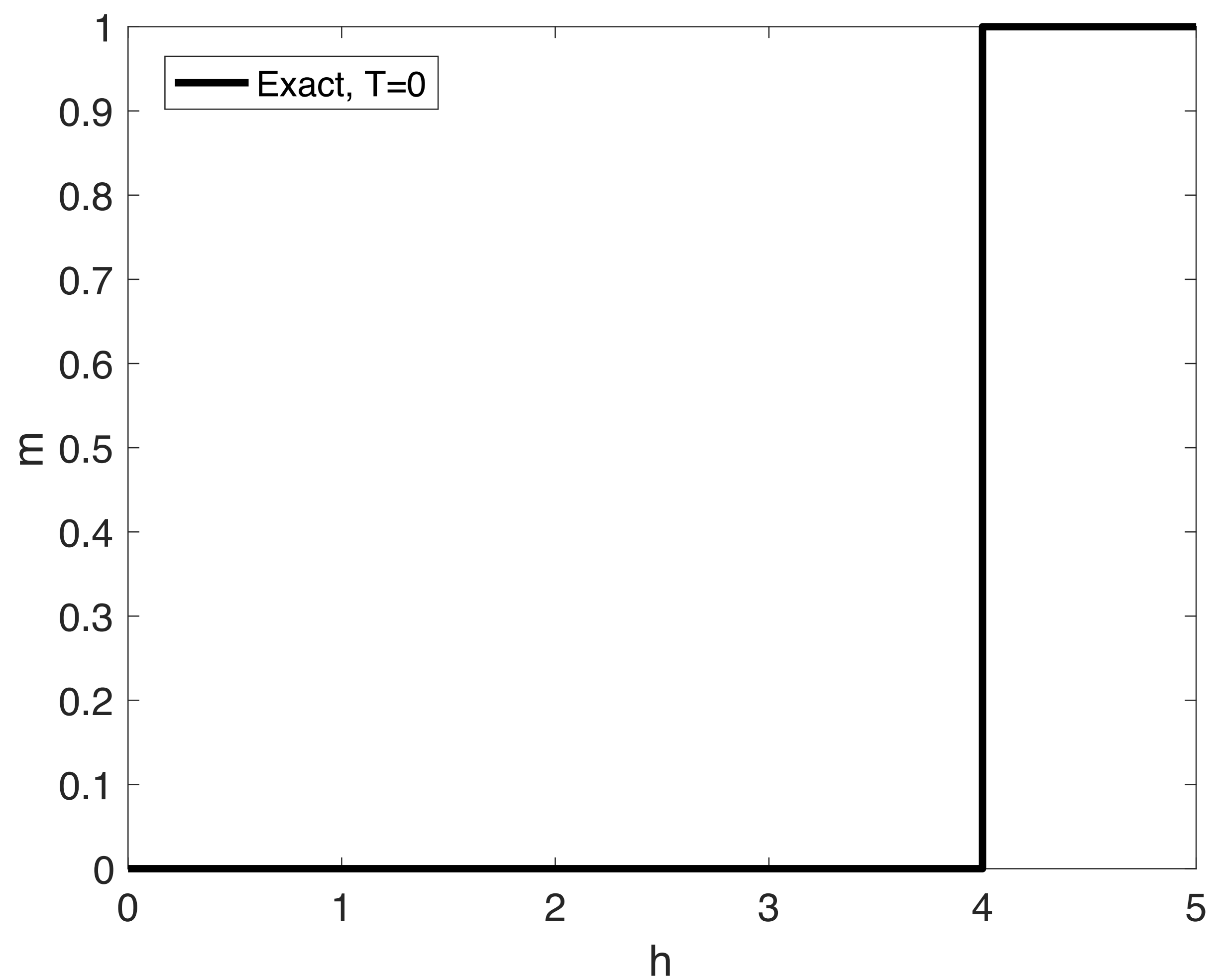
- $$H = J\sum_{\langle i,j\rangle}\sigma_i\sigma_j - h\sum_i \sigma_i$$
- Square lattice
- Antiferromagnet
  - 2-fold degenerate GS
  - $T_c = 2.26\ldots$
  - Simplest model with PT
- With field: poorly studied



$$m(T=0,h) = \begin{cases} 0 & h < 4 \\ 1 & h > 4 \end{cases}$$

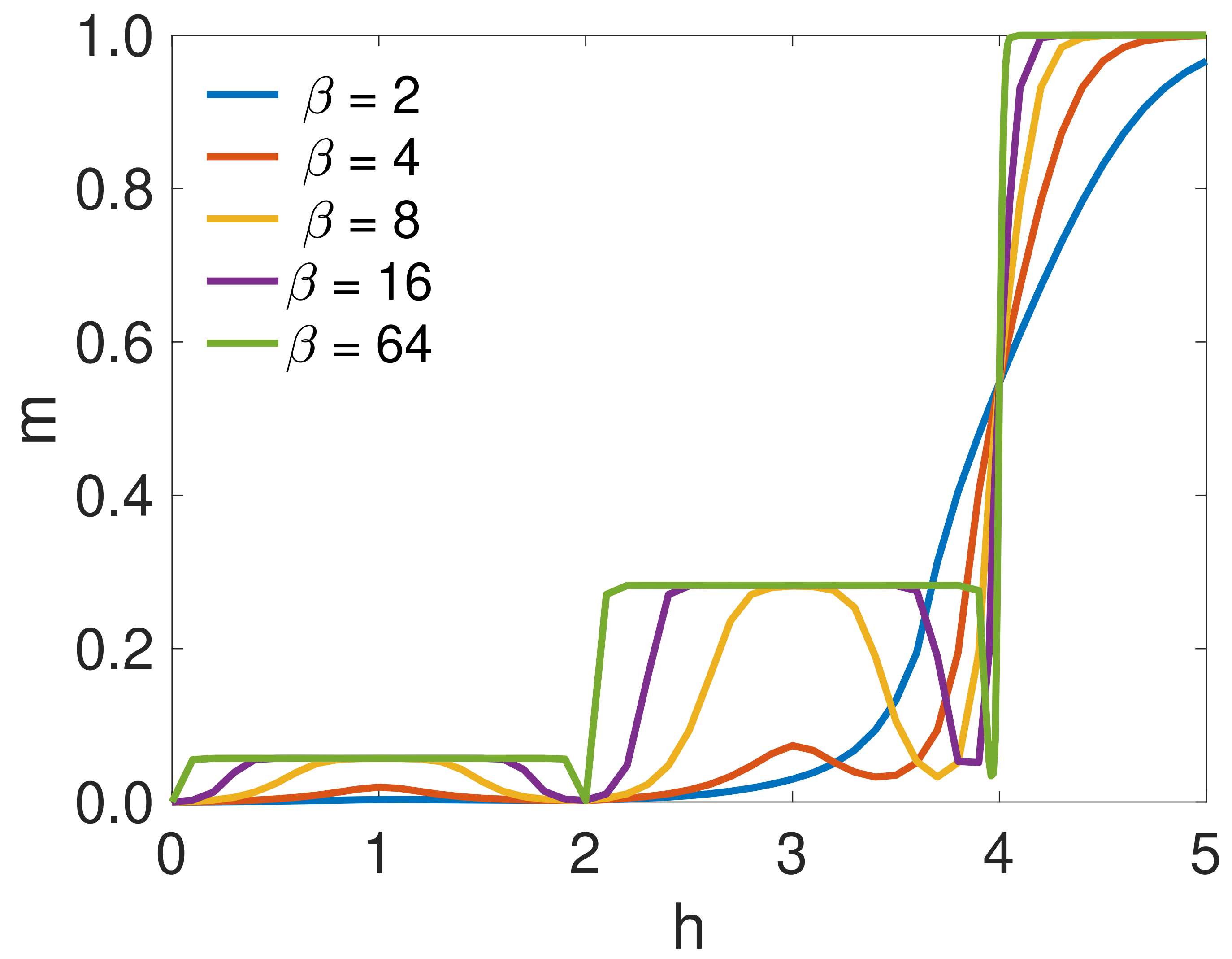
Dynamics

- Metropolis Monte Carlo
- Single-spin-flip updates
  - Choose spin at random
  - Flip with probability $P = \min\left[1, e^{-\Delta E/T}\right]$
- Quench:
  - Start from $T = \infty$ (totally random) state
  - Instant quench to T
- What happens?



Actual behavior

- Instantaneous quench to finite $T<T_c$
- High T: EQ
- Low T: Non-ergodic
  - Plateaus
  - Stable frozen states
  - No intrinsic disorder
- Valleys of ergodicity



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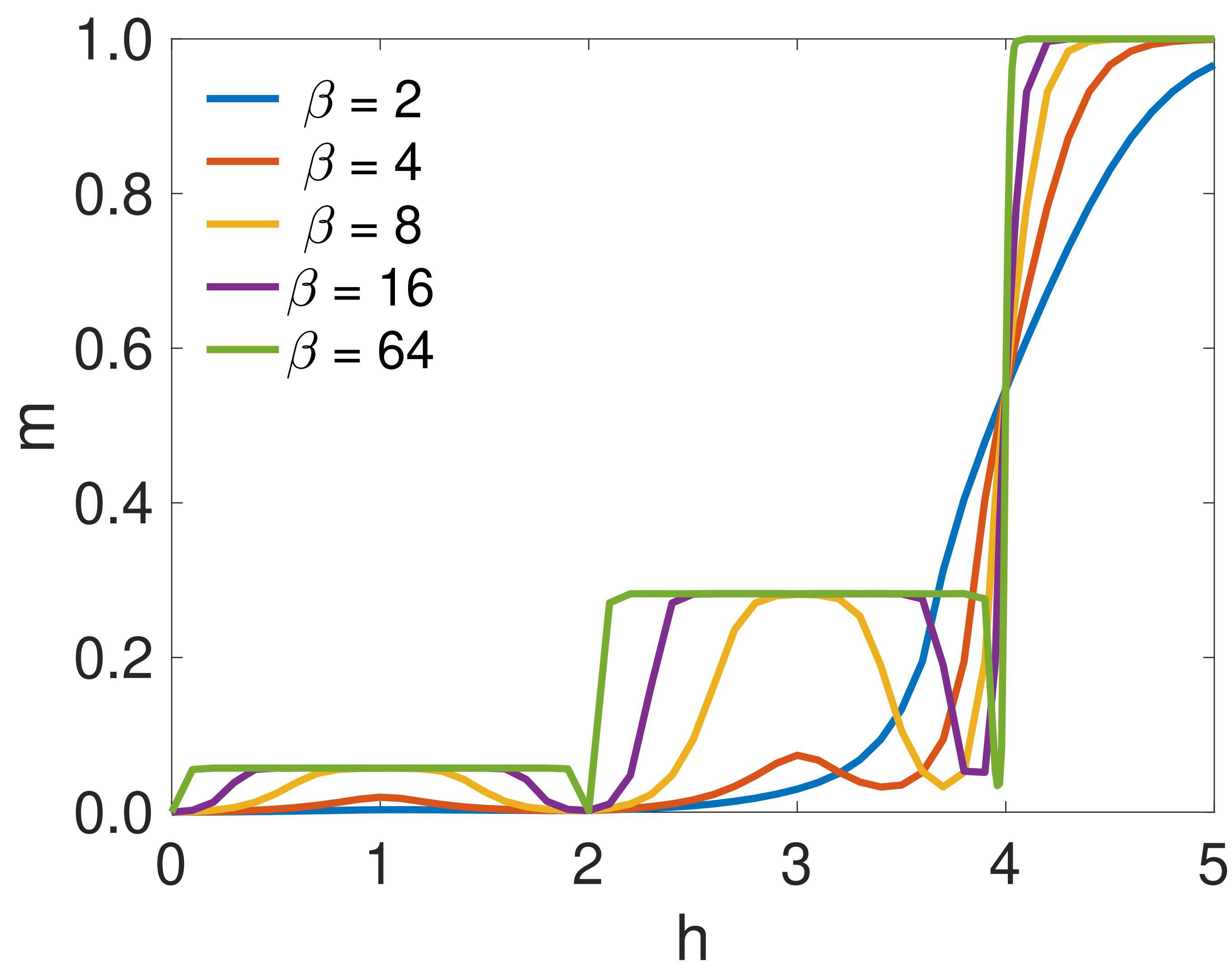
Zero temperature magnetization

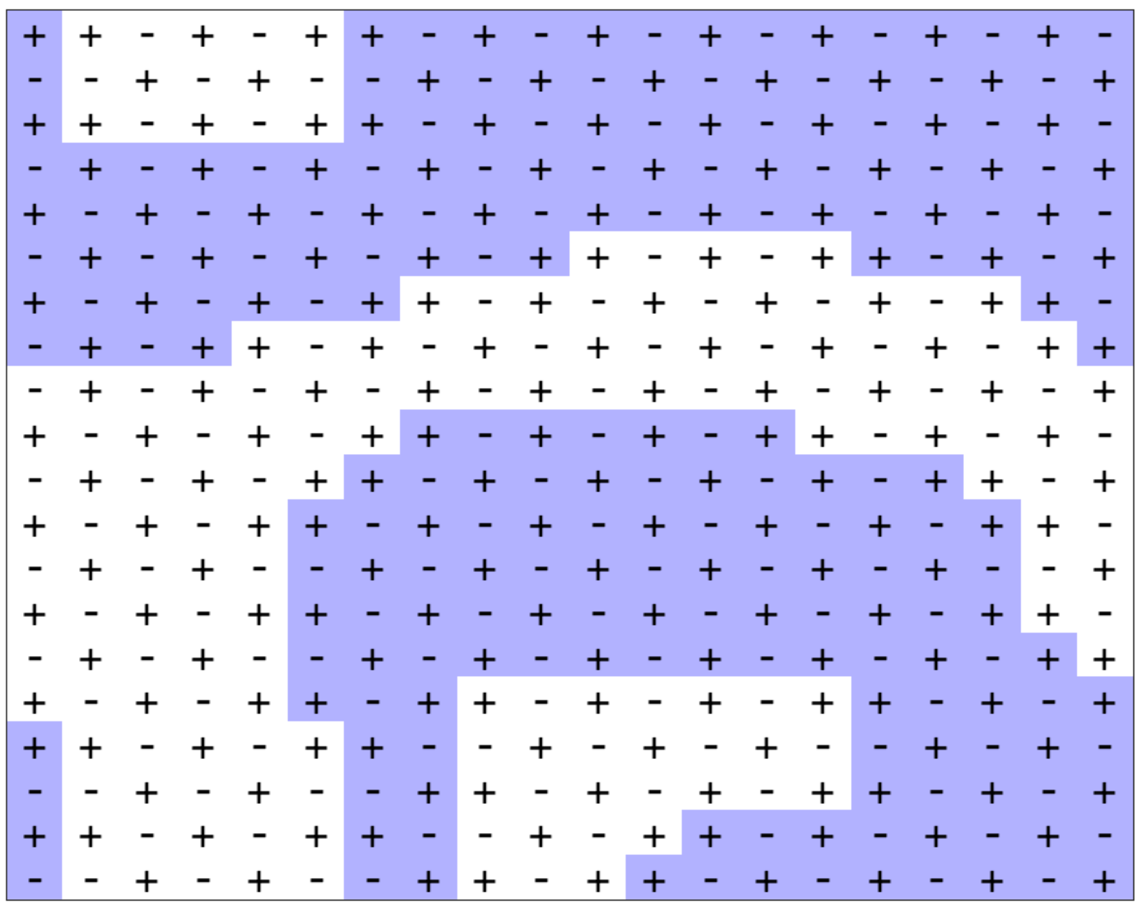
$$m(T=0,h) = \begin{cases} 0 & h = 0, \\ 0.057 & 0 < h < 2J, \\ 0 & h = 2J, \\ 0.282 & 2J < h < 4J, \\ 0.55 & h = h_s = 4J, \\ 1 & h > h_s. \end{cases}$$



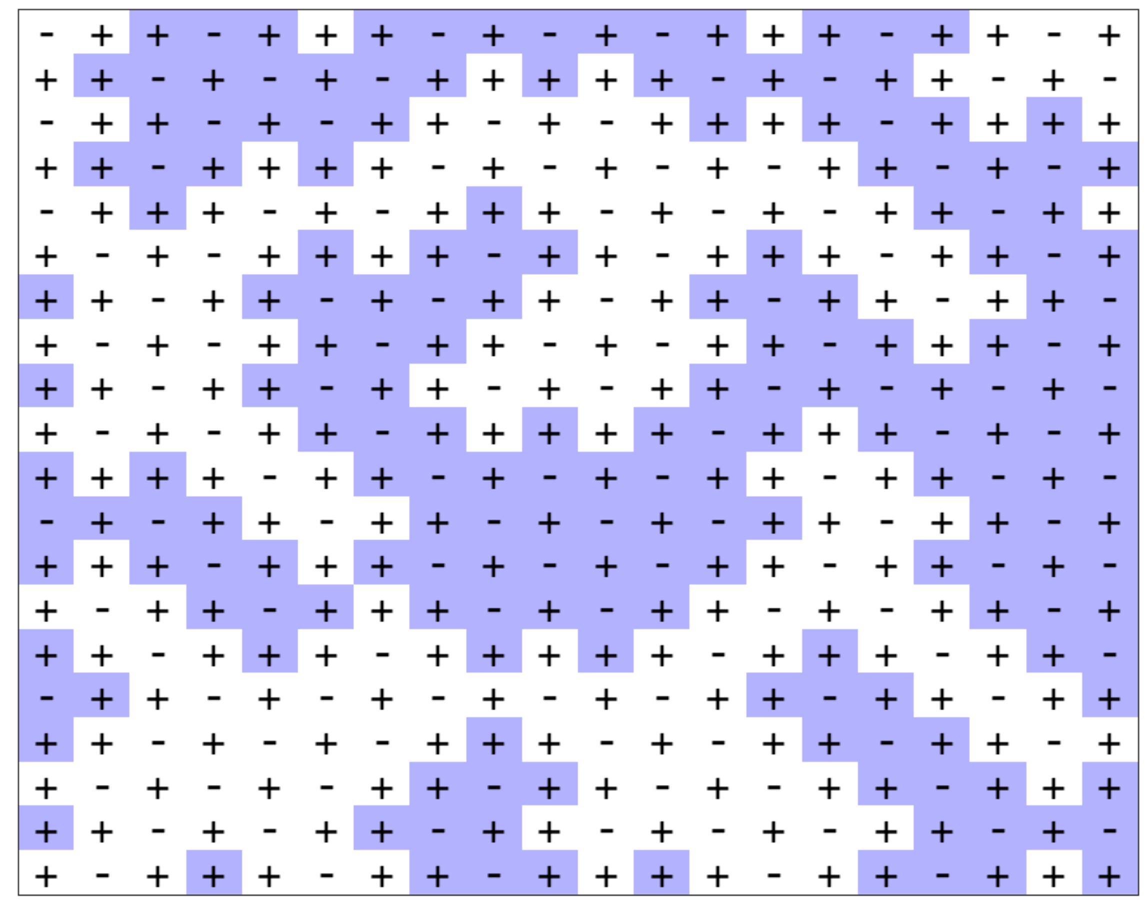
- Ergodic for $h = 0, \pm 2, \pm 4$
- From now on: $T = 0$

What is happening?

First plateau: $h = 1$



Second plateau: $h = 3$



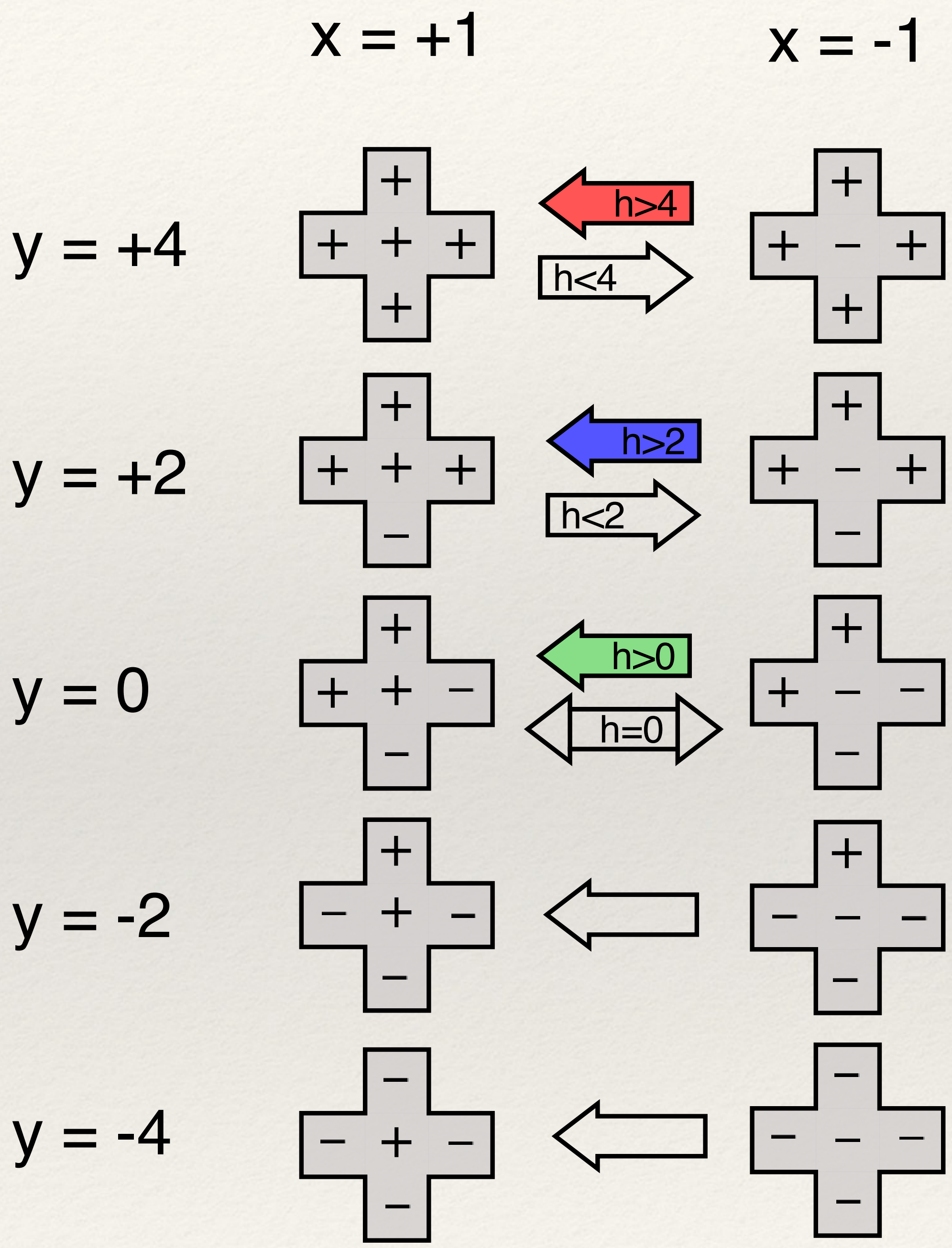
Freezing Mechanism

$$x = \sigma_i = \pm 1$$

$$y = \sum_j \sigma_j = 0, \pm 2, \pm 4$$

$$P = \min\left[1, e^{-(y-h)\Delta x/T}\right]$$

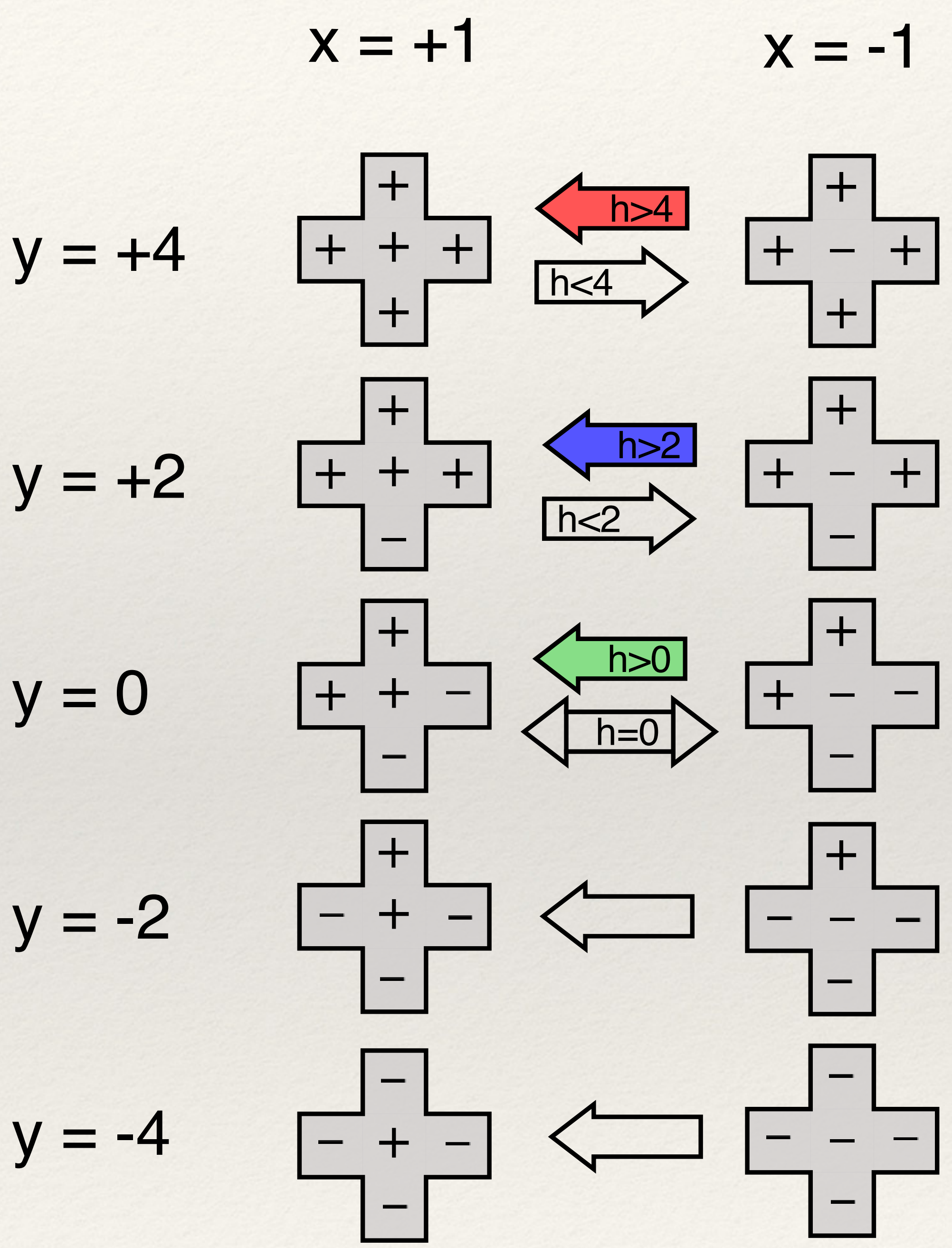
- 10 local spin configurations
- 5 pairs



Zero temperature dynamics

$$\Delta E = (y - h)\Delta x$$

- $T = 0$ dynamics:
  - Accept if $\Delta E \leq 0$
  - Reject if $\Delta E > 0$
- $\Delta E = 0$: *reversible* update
- Reversible updates when $h = y = 0, \pm 2, \pm 4$
  - Valleys of ergodicity



$h = 0$

- Maps onto ferromagnet
- Bulk domains and straight domain walls stable
- $T = 0$ quench, stuck in stripe state w/$P = 0.3390...$
    - Connection to critical percolation theory
- Otherwise reach G.S.

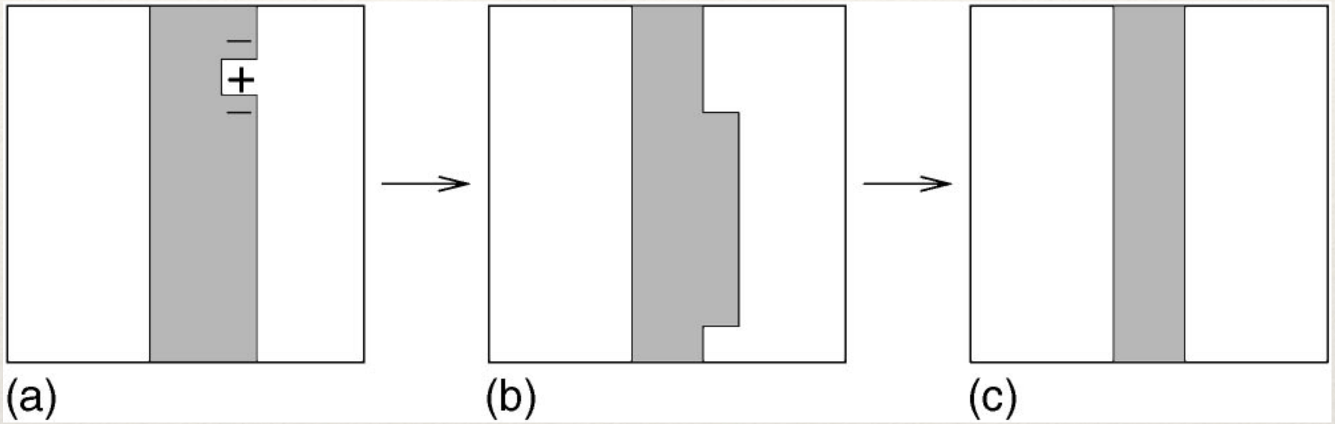


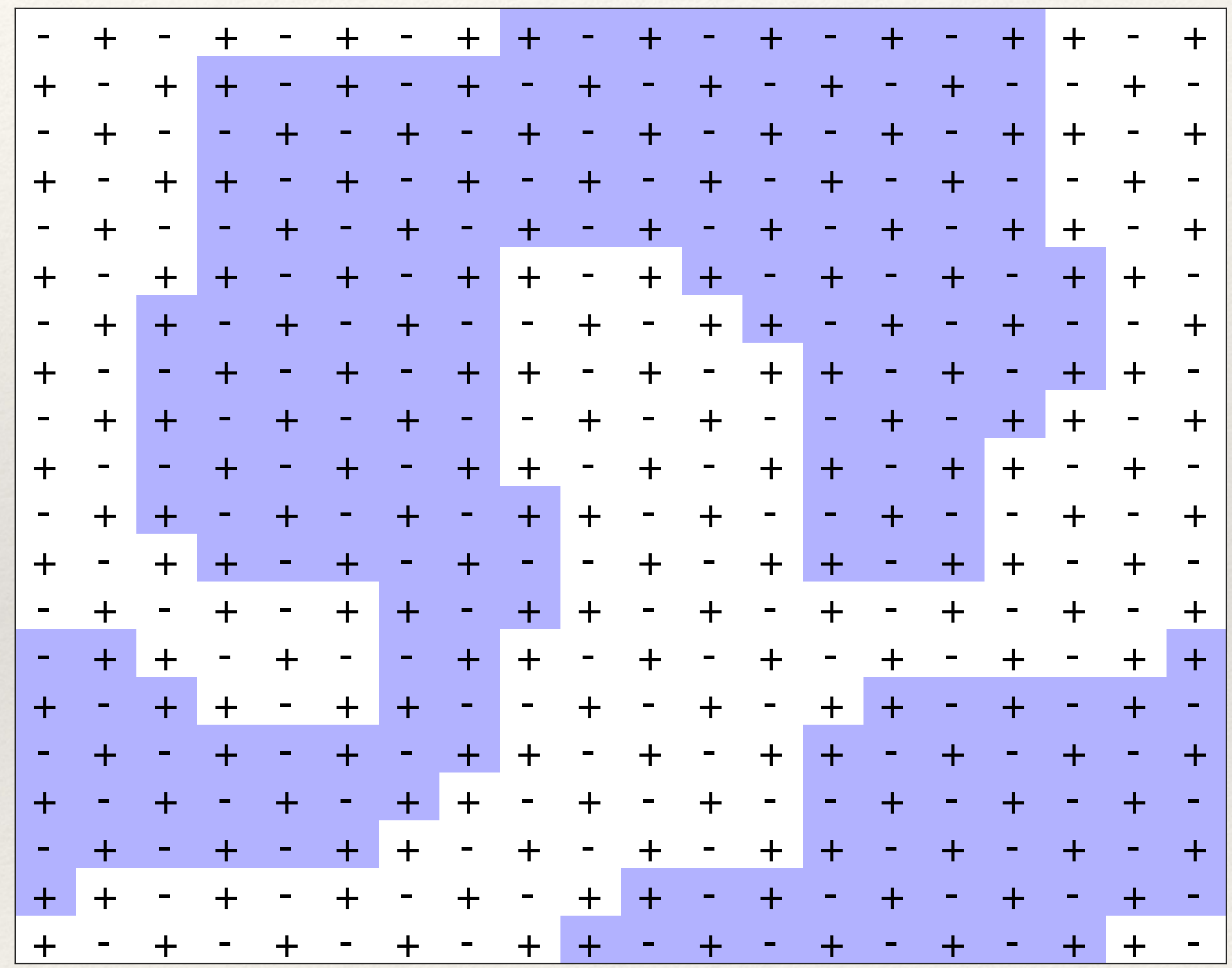
FIG. 13. Relaxation of a stripe state in two dimensions at small nonzero temperature: (a) nucleation of a dent (freely flippable spins are indicated); (b) diffusive growth of the dent; (c) dent reaches the system size and hence the domain wall steps to the left. This overall process ultimately leads to the disappearance of the stripe.

Spirin, Krapivsky, Redner, PRE **65** 016119 (2001)

Barros, Krapivsky, Redner, PRE **80** 040101(R) (2009)

First plateau

- $0 < h < 2J$
- Corner domain walls now stable
- Corners host excess + spin
- Net magnetization 0.057



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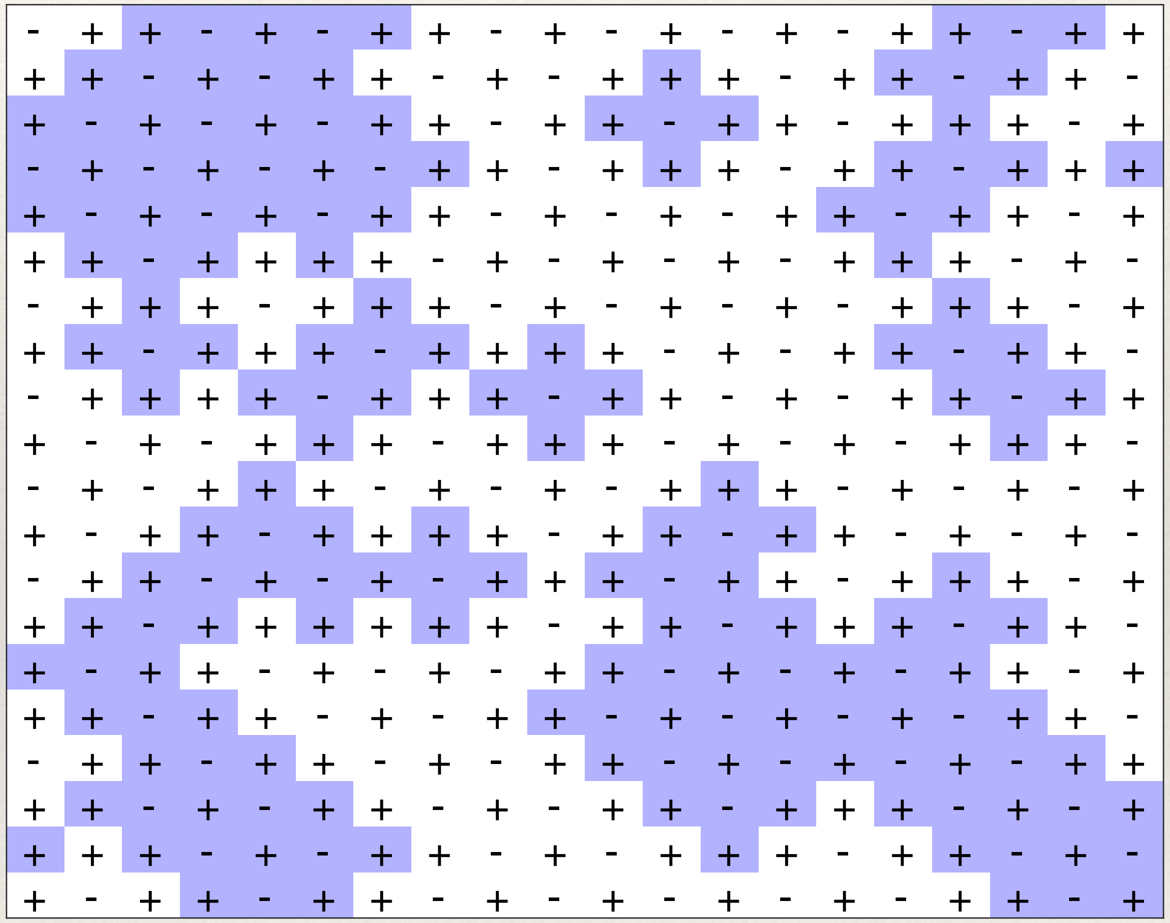
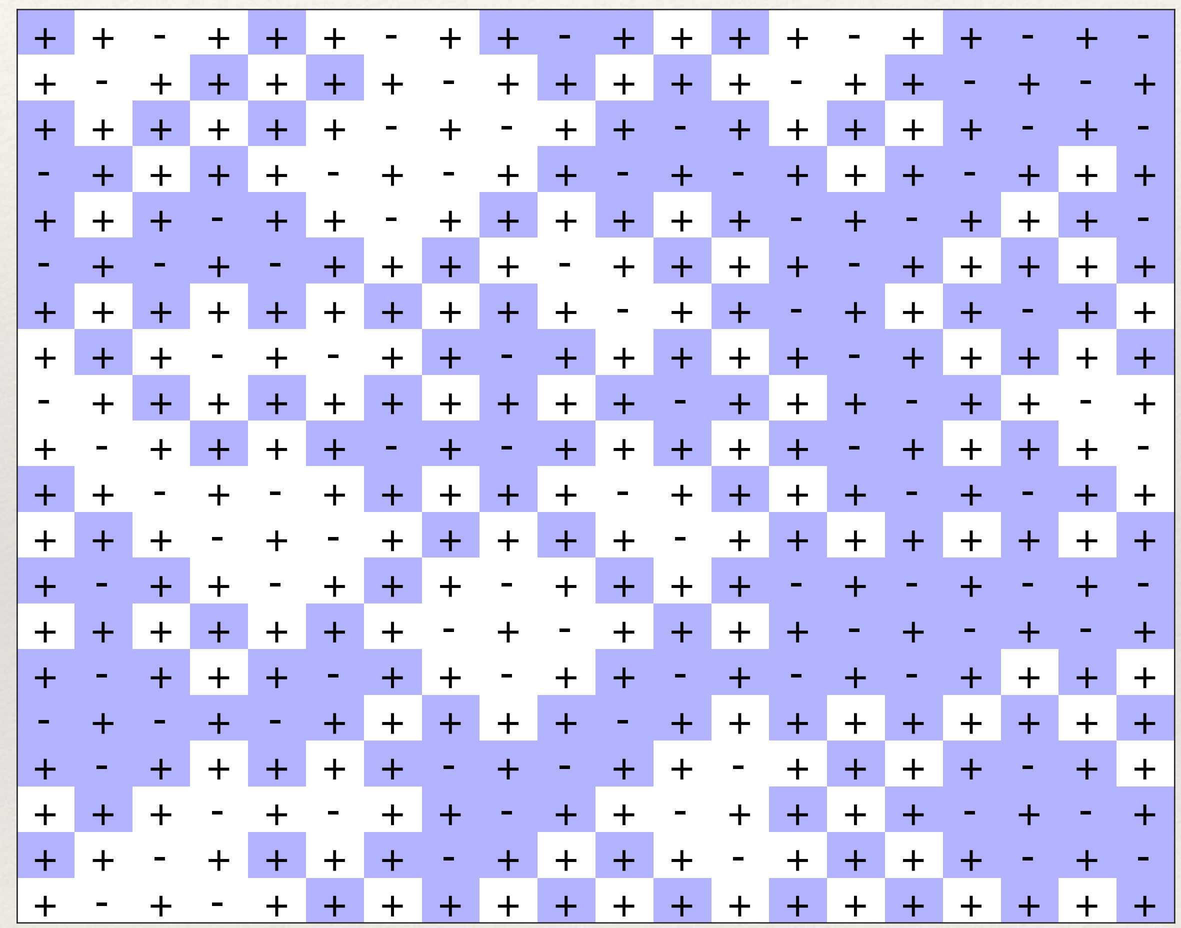
Second plateau

- Straight line DW not stable
- Corners / diagonal DW stable
- Excess + spin along DW
- Net magnetization 0.282



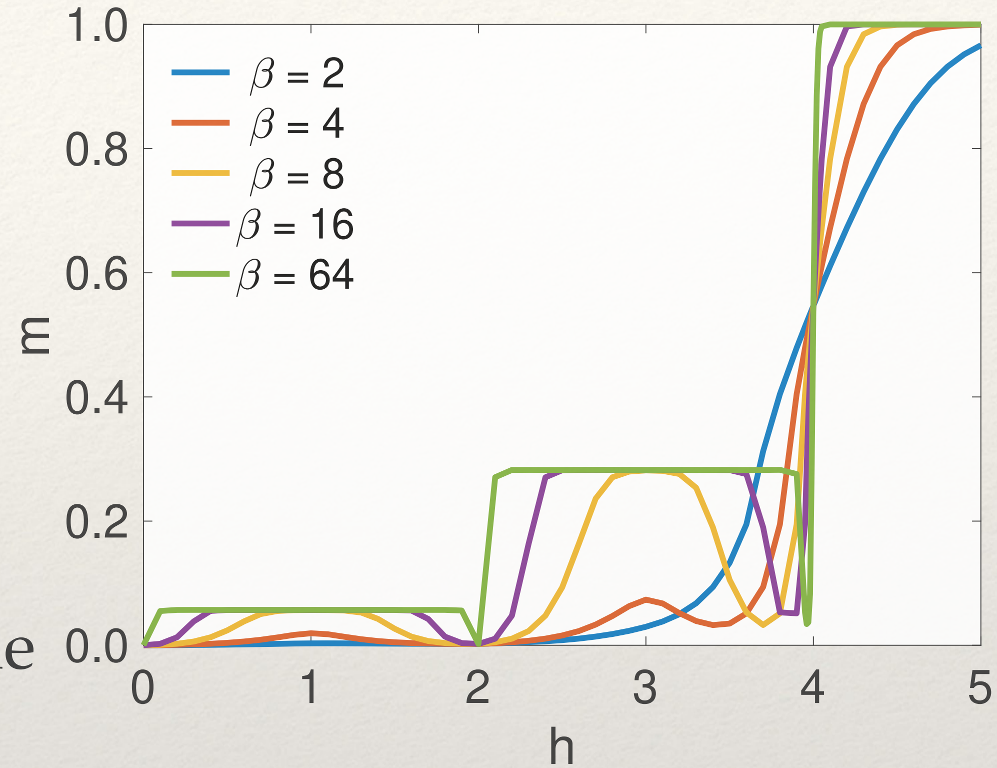
$h = h_s$

- Does not freeze
- Vanishing T dependence
- Coexistence of
  - 2x AFM G.S.
  - Fully-polarized state
- Equivalent to hard-squares problem



Conclusions

- Instantaneous quenches in Ising AFM + field
  - Stable plateaus without disorder
  - In plateau: all spins unflippable
  - Describe in terms of stable local configurations
- Ergodicity restored when $\Delta E = 0$ updates available
  - Useful for understanding when MC fails
- Monte Carlo dynamics $\neq$ physical dynamics
  - We choose the dynamics
  - Plateau states are local energy minima under these dynamics
  - Choosing dynamics rearranges energy surface



Open Questions

- Enumerate plateau states?
    - Connect to percolation theory?
    - Derive magnetization in plateaus
- What is the finite-T scaling of "valleys of ergodicity"?
- Other lattices?
- Other dynamics?

Thanks for your attention!

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