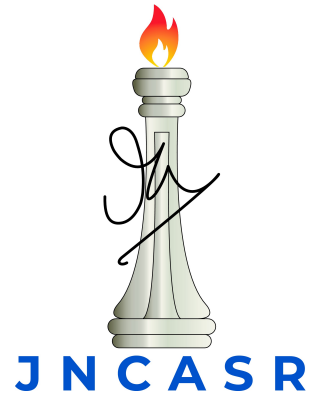
Mpemba Effect in Ising Model



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Outline

(1) Introduction: What is Mpemba Effect?

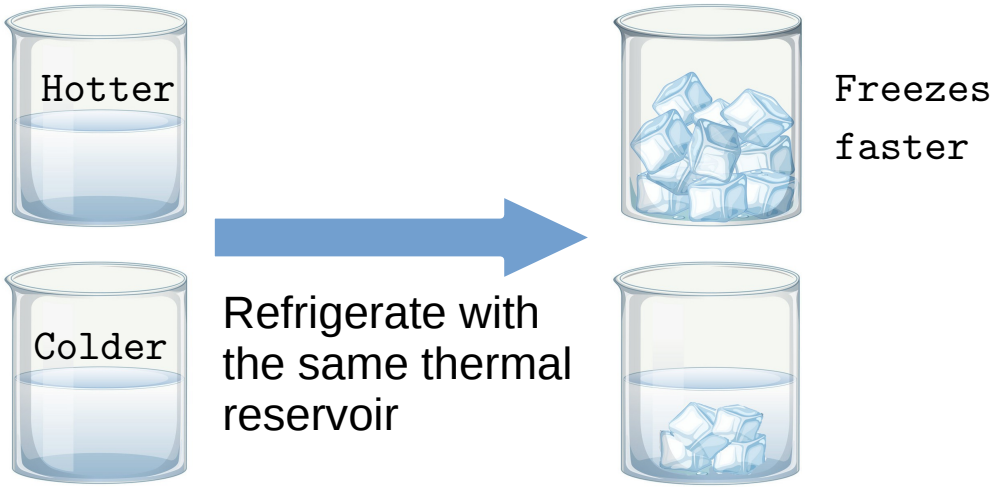
(2) Our system of interest; Model and Methods

(3) Observations

(4) Conclusions

Introduction to Mpemba Effect

"A hotter system of water freezes faster than a colder one."



https://www.vectorstock.com/royalty-free-vector/two-glass-beakers-filled-with-ice-and-water-vector-29650949

- Aristotle (384–322 BC) in Meteorologica, Roger Bacon, Rene Descartes, Francis Bacon, and others.
- Re-introduced to the scientific community by a then school boy (1963) Erasto B. Mpemba.

  E.B. Mpemba and D.G. Osborne, Physics Education (1969).
- The effect is not specific to the ice-water system.
- Observed in spin glass[1], granular gas[2], antiferromagnets[3], colloidal systems[4], etc.
- Typically, the effect is thought to be associated with the slowly evolving systems with complex energy landscape.

1) M. Baity-Jesi et al., PNAS (2019).
2) A. Lasanta et. al., PRL (2017).
3) A. Gal and O. Raz, PRL (2020).
4) A. Kumar and J. Bechhoefer, Nature (2020).

Our Study

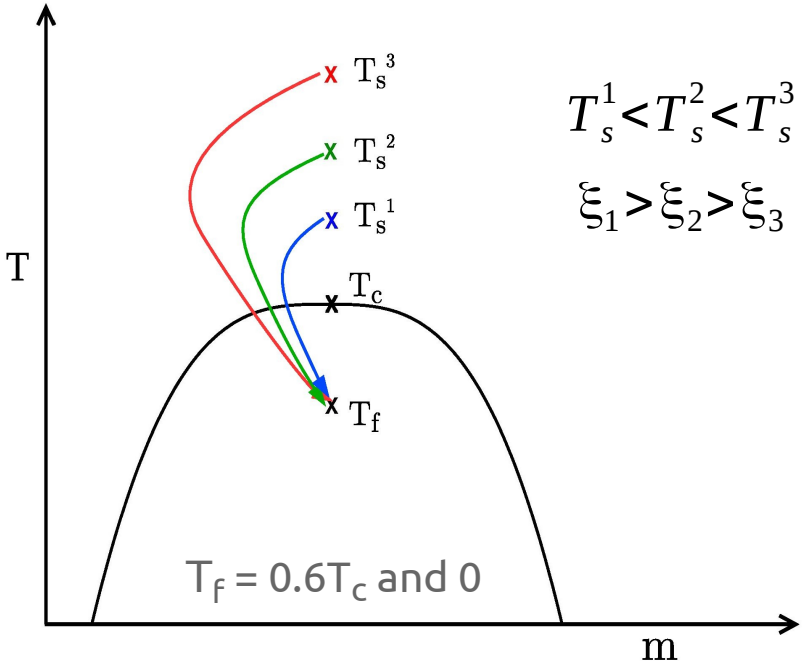
We investigate the presence of Mpemba effect in a ferromagnetic system.

Model:

2D Nearest-neighbor Ising model.

Hamiltonian: $H=-J\sum_{\langle ij\rangle} S_i S_j \;;\; S_i=\pm 1,\; J>0\;.$

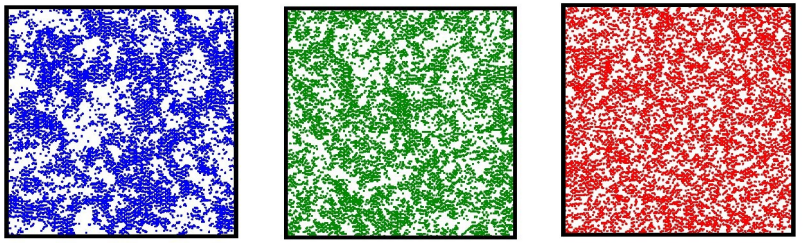
Protocol used:



$T_s^1 < T_s^2 < T_s^3$

$\xi_1 > \xi_2 > \xi_3$

$T_s =$ 2.4 2.6 2.8

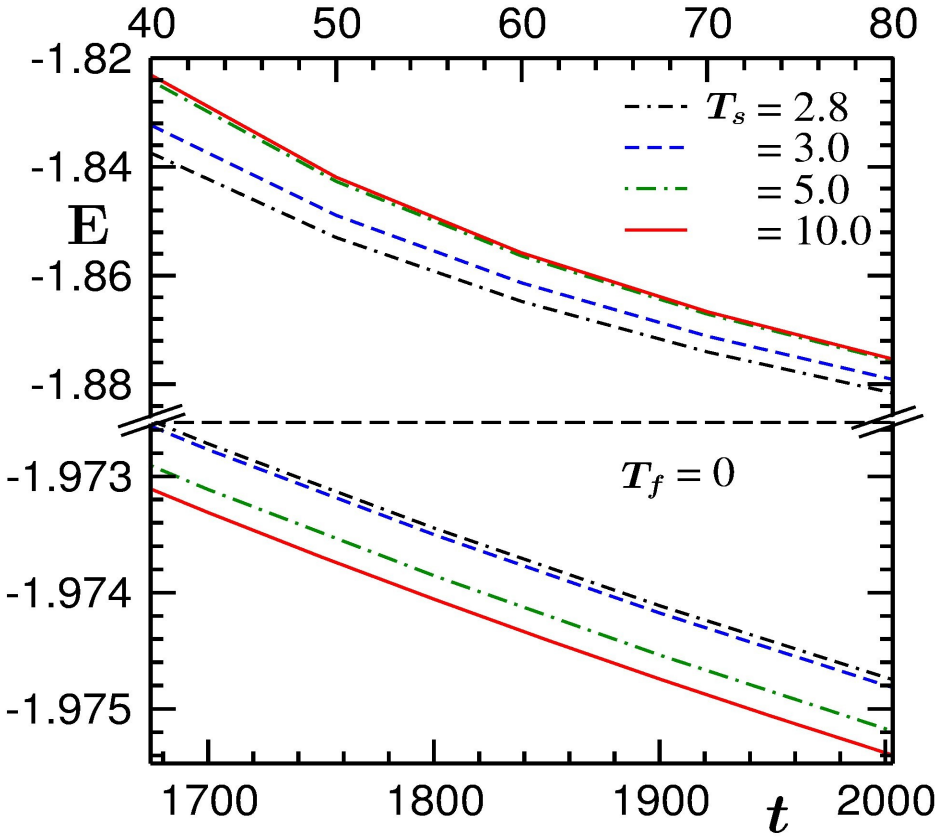


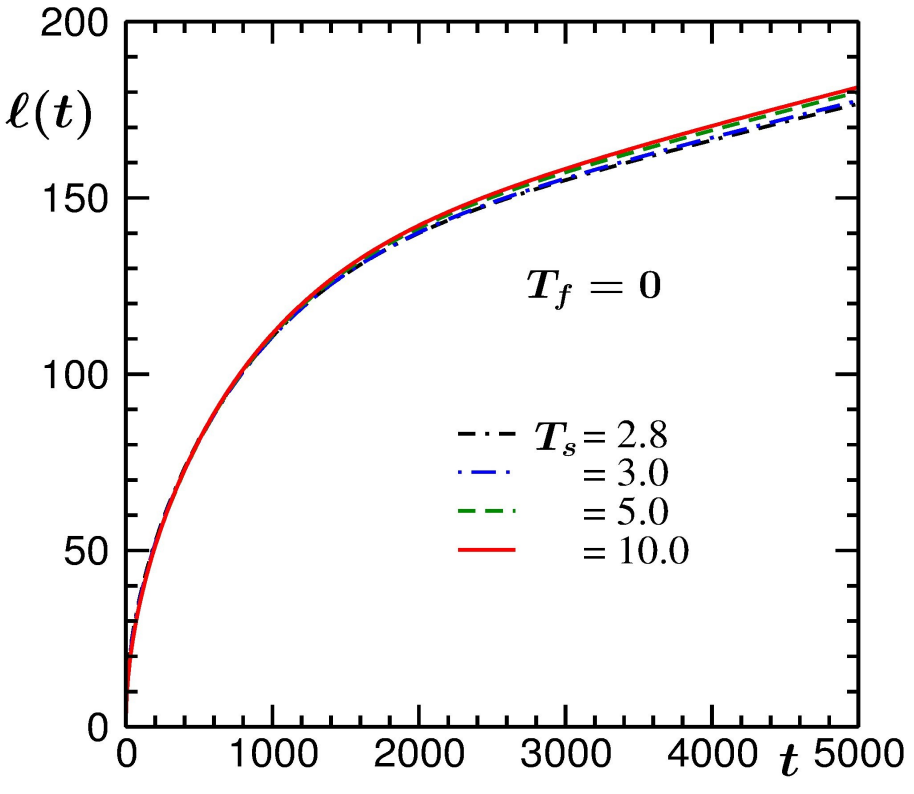
$\xi \sim |\epsilon|^{-\nu};\quad \epsilon = (T_s - T_c)/T_c$

- Systems with different T_s are prepared and quenched to a final lower temperature, T_f.
- Monte Carlo simulations with Glauber spin flip mechanism have been performed.

Observations

Relaxation of the system:



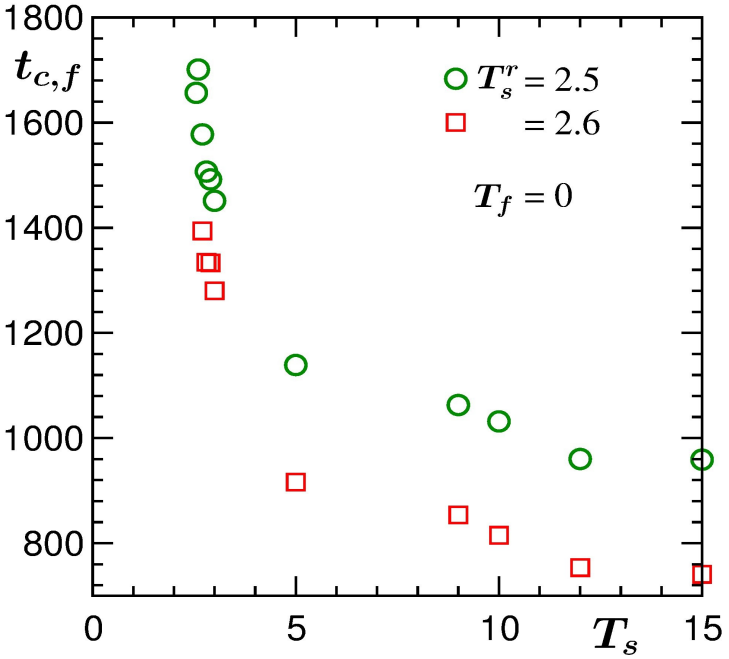


Energy for the higher T_s values are smaller than the smaller T_s values at late time.

Observations

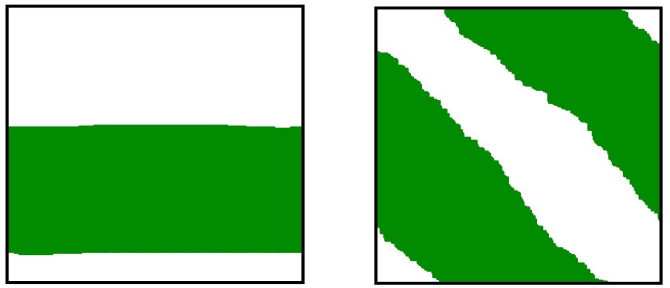
$t_{c,f}$ → the crossing time for energy curve for different values of T_s.

A systematic decrease in $t_{c,f}$ with the increase in T_s.



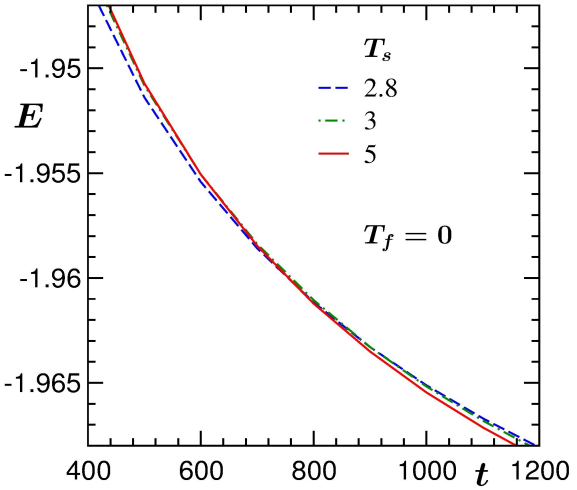
Presence of Mpemba effect.

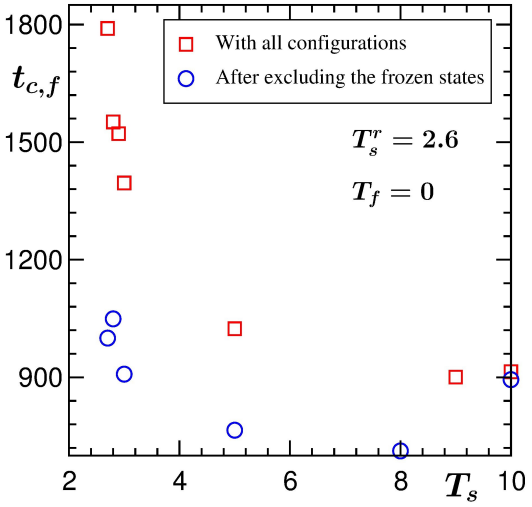
Frozen states in the 2D Ising model:



Probability ≃ 0.339

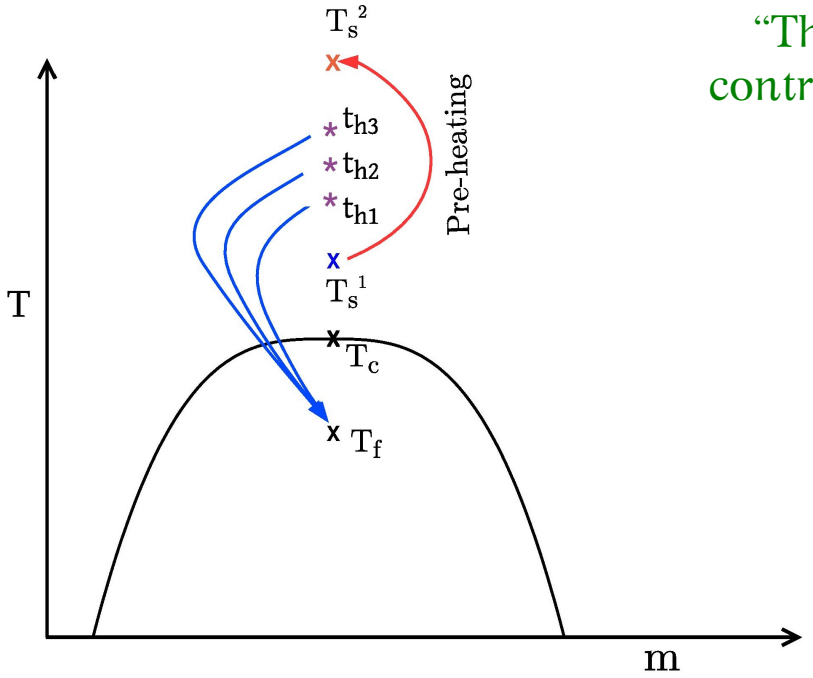
J. Olejarz, P. L. Krapivsky, and S. Redner, Phys. Rev. Lett. (2012).





Crossings are present.

How does a pre-heating affect the dynamics?



"The fact that the water has previously been warmed contributes to its freezing quickly: for so it cools sooner."

-Aristotle (Meteorologica)

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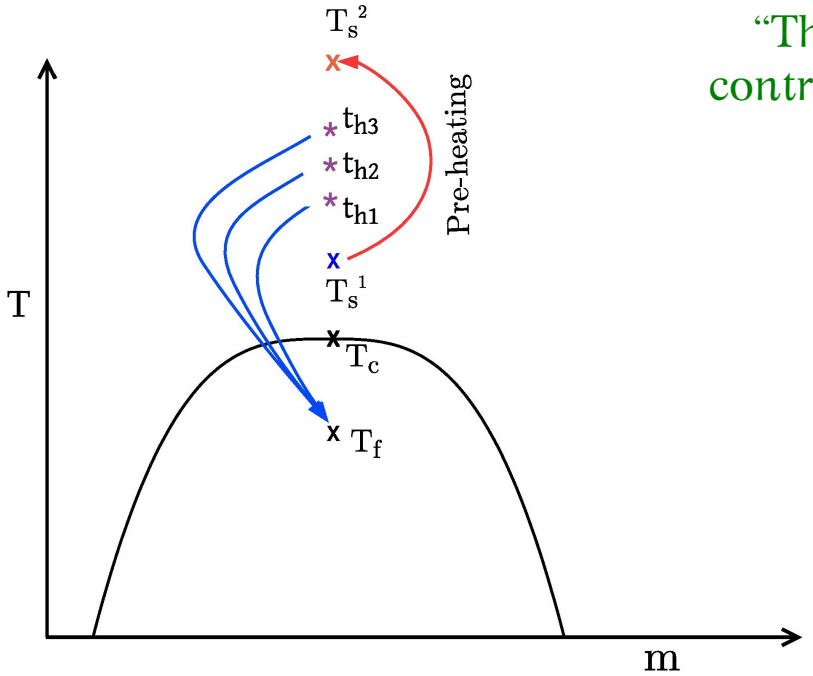

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- Pre-heating: Glauber dynamics and Kawasaki dynamics.
- Non-equilibrium configurations can be considered "effectively" as systems with different T_S.
- Quench to T_f via Glauber dynamics.

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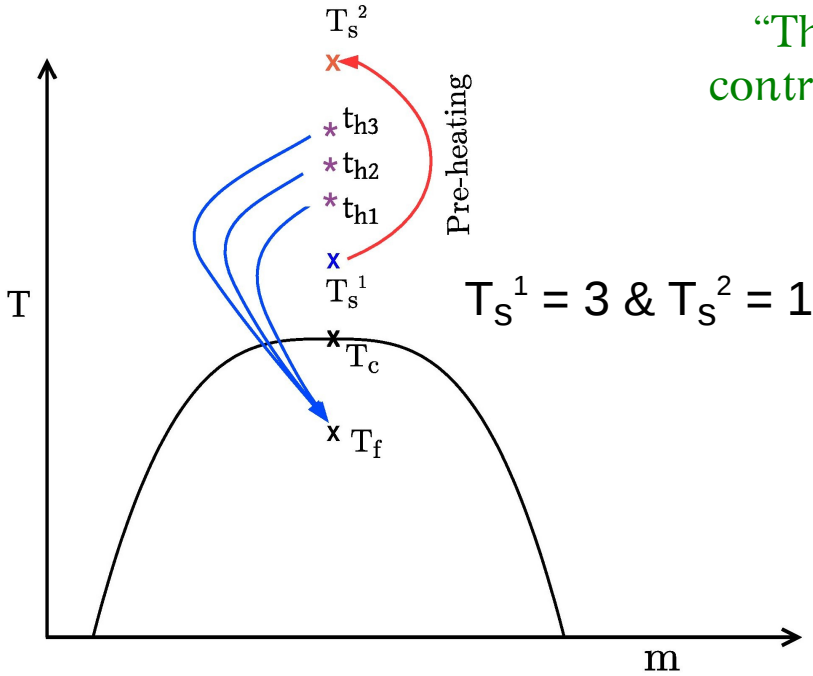

$T_s^1 = 3$ & $T_s^2 = 10$

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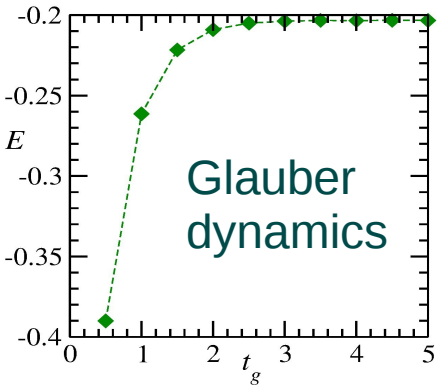

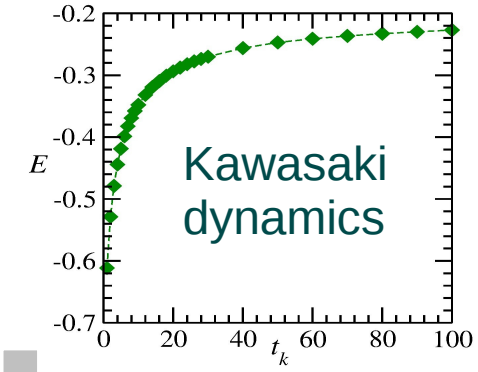

$T_f = 0.6T_c$

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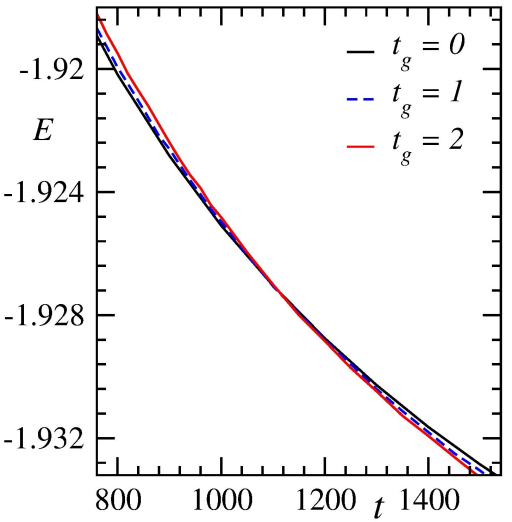
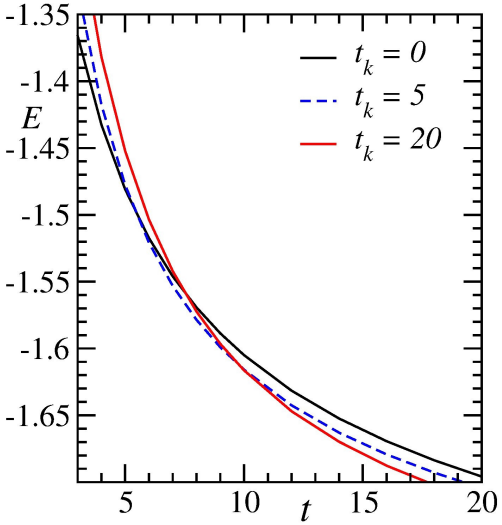
- Non-equilibrium configurations can be considered "effectively" as systems with different T_s.
- Quench to T_f via Glauber dynamics.





Presence of Mpemba effect.

A possible reason for the ME

Difference in the correlation length in initial structures.

An observation of the absence of ME in the same model with Kawasaki dynamics (mimics the phase separation in binary mixtures) is even more interesting.

Work done by T. Paul, K. Das and S.K. Das

Along with the correlation length, the associated dynamics is also playing an important role.

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Conclusions

- We investigated the presence of Mpemba effect in uniaxial ferromagnet using 2D nearest neighbor Ising model.
- The system which was quenched from higher initial temperatures (T_s) was approaching the new equilibrium faster than those started with lower T_s values.
- **This indicates the presence of the Mpemba effect (ME) in the system.**
- A pre-heating process also supports the above fact.
- The system we considered does not have any glass-like energy landscapes, which makes the observation even more surprizing.

Acknowledgement

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- Other labmates

THANK YOU

For Your Attention