Coercivity Panorama of Dynamic Hysteresis

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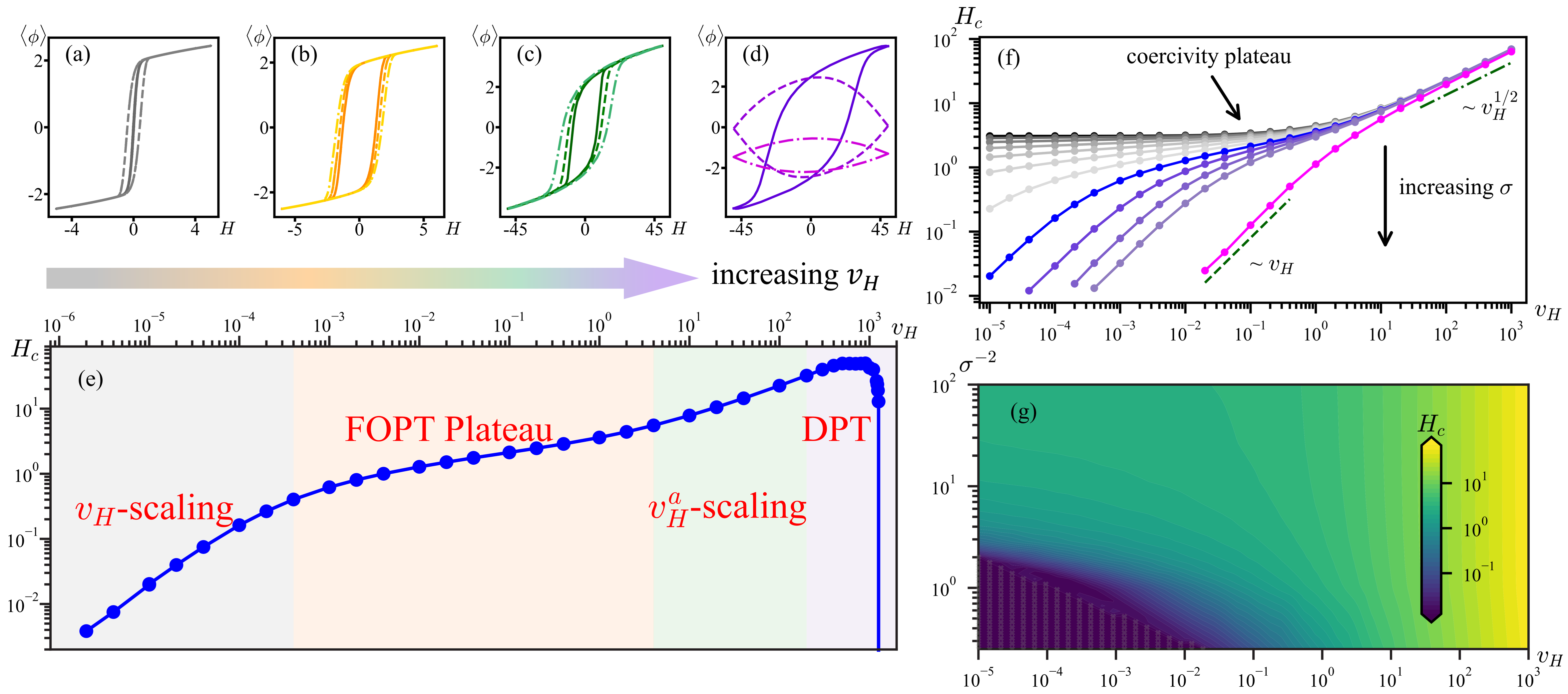
1. Introduction

Hysteresis, a phenomenon where a system's current state depends not only on its present conditions but also on its past, is widespread in magnetism, mechanics, electronics, optics, thermodynamics, biology, chemistry, and even economies. Research focuses on the evolution of hysteresis with driving parameters, including scaling laws of loop area and dynamic phase transitions(DPT), while systems undergoing first-order phase transitions**(FOPT)** display distinct behaviors. However, current studies face challenges: **unexplored scaling relations** in microscopic theories, **poor grasp of phenomenological models and dynamic hysteresis**, and **ambiguous theory-experiment comparisons**. To address these, we introduce the concept of **"coercivity panorama"**—a comprehensive view of how coercivity, **the point where the external field response is zero,** changes with driving speed, aiming to unify scaling across **time scales and system sizes.**

2. Coercivity Panorama: stochastic ϕ^4 Model



Hysteresis loops (a-d) and **coercivity panorama** (e) of the stochastic ϕ^4 model. (f) Coercivity landscape $H(v_H, \sigma)$ for different noise strengths. (g): A contour illustration of (f) after interpolation.

The stochastic ϕ^4 model, governed by **the free energy**

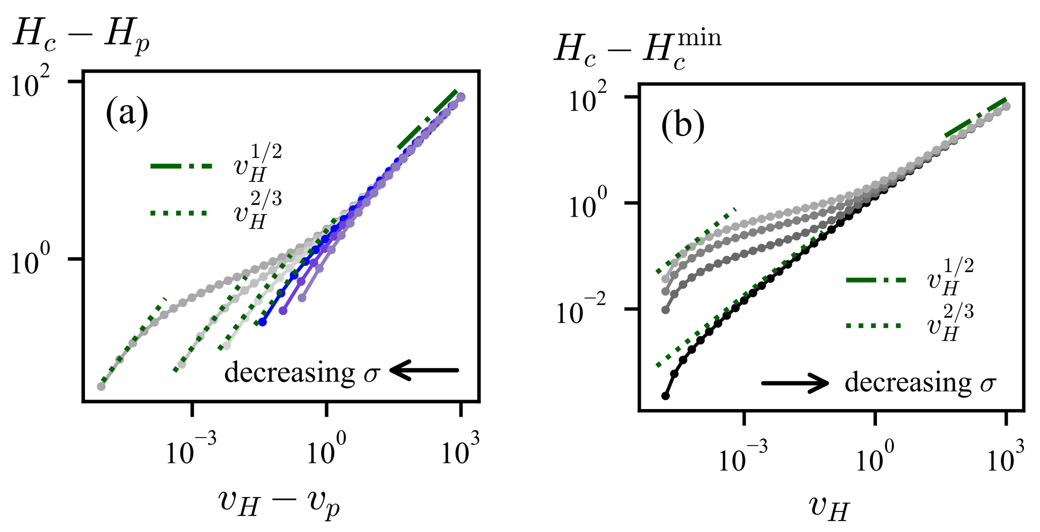
$$f_4(\phi, H) = \frac{1}{2}a_2\phi^2 + \frac{1}{4}a_4\phi^4 - H\phi,$$

with the **dynamics** of $\phi(t)$ under a time-dependent field $H(t)$

$$\frac{\partial \phi}{\partial t} = -\lambda \frac{\partial f_4(\phi, H)}{\partial \phi} + \zeta(t),$$

Intriguingly, **a non-commutativity of limits** emerges at the far left side of the FOPT plateau

$$\begin{cases} \lim_{\sigma\to 0} \lim_{v_H\to 0} H_c = 0, \\ \lim_{v_H\to 0} \lim_{\sigma \to 0} H_c = H^*. \end{cases}$$



Reduced coercivity after the FOPT plateau normalized by

(a) the reference plateau coercivity value;

(b) the minimum observed coercivity value.

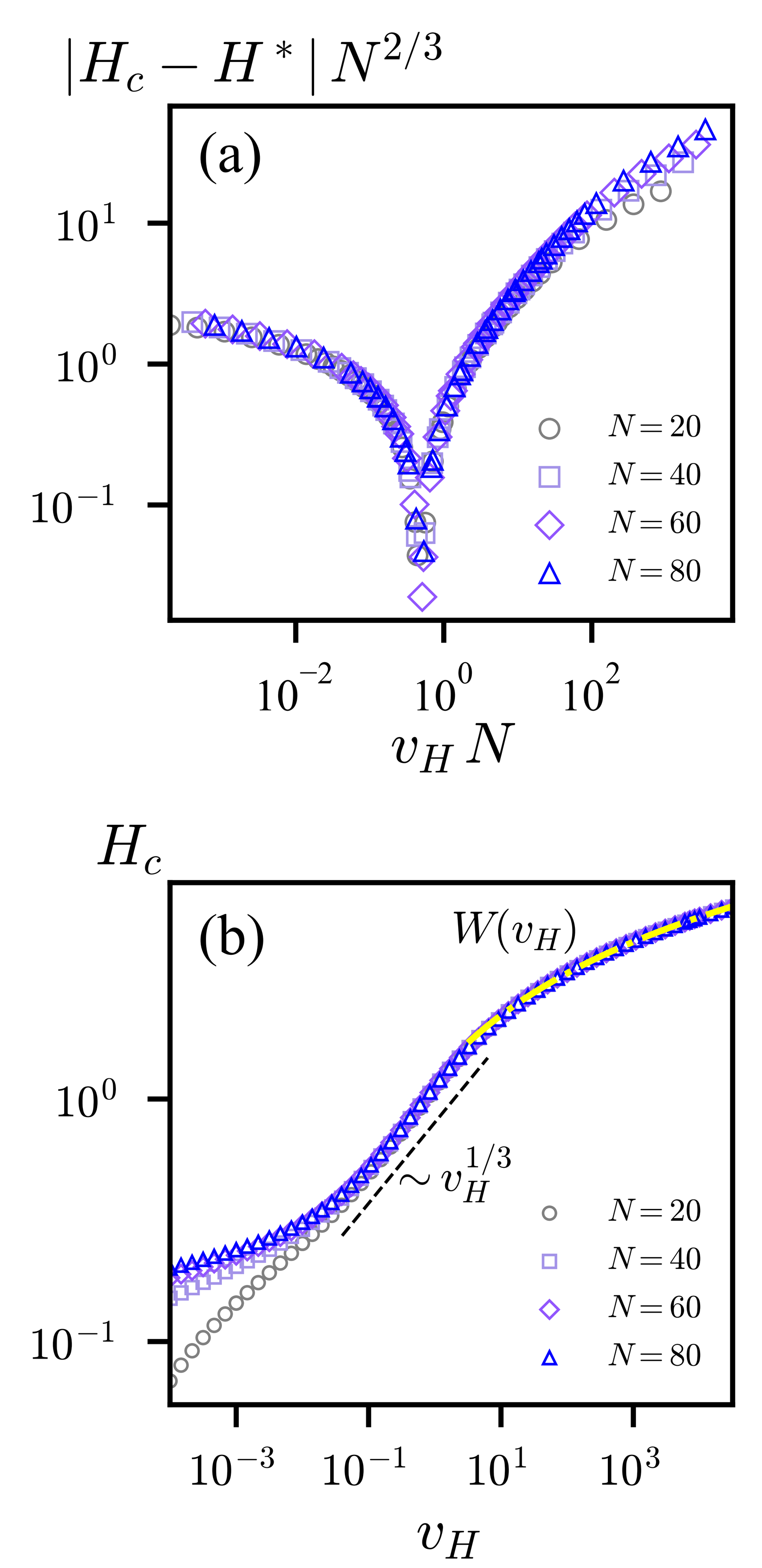
3. Magnetic Hysteresis

The Curie-Weiss model, with the free energy

$$\mathcal{F}_H(M) = -\frac{JM^2}{2N} - HM - \beta^{-1}\ln\Omega(M)$$

exhibits the link between stochastic fluctuations and finite-size effects $\sigma \sim N^{-1/2}$

Finite-size scaling collapse of FOPT plateau



4. Main Findings

	Stochastic ϕ^4 model		Curie-Weiss model	
	Finite σ	$\sigma \to 0$	Finite N	$N \to \infty$
Near-equilibrium	$H_c \sim v_H$	Unreachable	$H_c \sim v_H$	Unreachable
FOPT Plateau	$H^* - H_P \sim \sigma^{4/3}$ $v_P \sim \sigma^2$	$H_P \to H^*$ $v_P \to 0$	$H^* - H_P \sim N^{-2/3}$ $v_P \sim N^{-1}$	$H_P \to H^*$ $v_P \to 0$
Post-plateau	$H_c - H_P \sim (v_H - v_P)^{2/3}$	$H_c - H^* \sim v_H^{2/3}$	$H_c - H_P \sim (v_H - v_P)^{2/3}$	$H_c - H^* \sim v_H^{2/3}$
Fast-driving	$H_c \sim v_H^{1/2}$		$H_c \sim v_H^{1/3}$ and Lambert W function	

5. Conclusions

- ✓ **Coercivity panorama** characterizes hysteresis irreversibility across **time scales**, reflecting competition between thermodynamic and quasi-static limits.
- ✓ Scalings **near the FOPT plateau**are **universal**, confirmed in the Curie-Weiss model.
- ✓ Only in **fast-driving regime**, the stochastic ϕ_4 and Curie-Weiss models show **model-specific** scaling behaviors.

6. References

[1] Miao Chen, Xiu-Hua Zhao, and Yu-Han Ma, *Coercivity Panorama of Dynamic Hysteresis*, arXiv:2506.24035

[2] Miao Chen, Xiu-Hua Zhao, and Yu-Han Ma, *Finite-time and Finite-size scalings of coercivity in dynamic hysteresis*, arXiv:2507.07933