Thermally Locked Chaotic Spin Textures in Moiré CrI_3 Bilayers

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Moiré engineering in two-dimensional van der Waals magnets enables the emergence of nonlinear magnetic states beyond conventional static order [1,2]. In bilayer CrI_3 moiré systems, we demonstrate through micromagnetic simulations that the competition between a ferromagnetic background and moiré-modulated interlayer antiferromagnetic exchange generates chaotic spin textures composed of skyrmion- and bubble-like patterns.

These textures exhibit strong sensitivity to initial spin configurations, a hallmark of chaos, while remaining thermally locked at low temperatures: the global topology and spatial texture persist despite thermal fluctuations. Despite their thermal stability, the chaotic spin textures exhibit exceptionally high sensitivity to ultra-small external magnetic fields, enabling large-scale reconfiguration in response to minute field perturbations. This combination highlights their potential for ultra-sensitive magnetic detection and control.

The chaotic spin textures are quantitatively characterized using damage spreading analysis, from which positive Lyapunov exponents are extracted in real space. Complementary measures, including Shannon entropy and correlation entropy, consistently confirm strong chaos with pronounced initial-condition dependence.

These results introduce a new class of chaotic magnetic textures in moiré van der Waals magnets and establish a quantitative framework for characterizing chaos in nanoscale spin systems. The combination of thermal locking and ultra-low-field tunability suggests new opportunities for exploiting nonlinear magnetism in ultra-sensitive magnetic functionalities and unconventional information processing based on two-dimensional materials.

References:

[1] K. -M. Kim et al., Nano Lett. 23 (2023) 6088
[2] K. -M. Kim et al., Nano Lett. 24 (2024) 74