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TITLE: Avalanches through windows: multiscale visualization in magnetic thin films

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Digest Body: The motion of domain walls in soft magnetic materials, a basic example of complexity in materials science, has been the subject of a long and continuing series of studies.In bulk systems, most of the statistical properties are understood in terms of a depinning transition [1]. In thin films, the motion is presumably dominated by depinning as well, but our understanding of the dynamics is still preliminary. Also, experimental data available are poor, although very promising. Puppin [2] found the critical exponent τ of the avalanche size distribution $P(S)=S^{\tau} f(S/S_0)$ in a Fe film is about 1.1, less than for bulk systems. Recently, Ryu et al. [3] argued that in MnAs films (Tc~45°C) there is a cross-over between two universality classes, as τ changes from 1.32 to 1.04 with T increases from 20 to 35°C. These experiments rely upon measuring avalanches optically, in a small sub-window of the entire sample, and often comparing windows of varying sizes.
Here, we explore two issues associated with extracting avalanche statistics from images: good methods for extracting avalanche distributions, and a proper scaling approach to address the finite-size cutoff in the avalanche sizes induced by the observation window.
The determination of avalanche size from images is not as simple as in fluxometric measurements because it is far more challenging to separate signal from noise in the richer space-time information provided. This is particularly important for size distributions, where small avalanches are crucial for estimation of the exponents. To address this question, we acquired images of domain walls on Py films using an high-resolution MOKE, with a slow varying longitudinal in-plane field.
After background subtraction and contrast enhancement, we tried to determine a reliable procedure to identify the domains in the images. Edge detection routines, for instance, are not useful in determining the position of the walls; by analyzing single images, we lose the useful information provided by the time sequence. Indeed, an effective point is to ignore the spatial information and consider only the evolution in time for each pixel. A significant jump

in the measured intensity represents the switching time for the magnetization at that point. Spatial information must be then used to correct for the small number of pixels which appear to switch at a wrong time. While it is essential to make these corrections, these methods are pretty delicate. An example of avalanche visualization is shown in fig. In this case, we applied a procedure which significantly depleted small avalanches. We are exploring alternative methods which may perform better, to ensure a reliable estimation of the critical exponents.

We then consider the effect of the window size of images. Generally, the windows size both suppresses the largest avalanches and can add extra truncated avalanches at smaller sizes. Given that one can measure up to three decades of sizes for a given window, it is valuable to combine information from several window sizes; to do so we must understand the finite-size effects with windowed boundary conditions. We thus considered a realistic simulation of an elastic line moving in a random environment, and made distributions with/without avalanches that touch the borders of the window -- including/avoiding the extra truncated avalanches. The fig. shows the results where only the avalanches that did not touch the sides of a LxL window are incorporated.

The tricky part of analyzing this data is that the large avalanches near depinning transitions are increasingly anisotropic: an avalanche with width W will have typical height $H \sim W^{\zeta}$. If $\zeta<1$, as in our case ($\zeta=0.63$), large avalanches become short and fat. This means that the main effect of large windows is to cut off the widest avalanches, while at small window sizes a substantial number of tall avalanches may also be removed. Thus, unlike isotropic finite-size scaling, the effects of larger windows are not similar to the small windows: they are similar to smaller windows *of a different shape*.

We can analyze the data using the finite-size scaling form

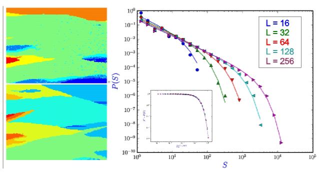
$P(S,L)=S^{\tau} P_W(S/L^{1/\sigma\nu})$, appropriate for systems with a strip geometry of width L and infinite height. Doing so, we find that the fitted exponents $\tau=1.14$, $1/\sigma\nu=1+\zeta=1.68$ are close to the theoretical expected values (1.13, and 1.63). In contrast, we found that the distribution including the avalanches touching the window borders has an exponent τ which continuously changes with window size, approaching the theoretical value only at the largest window sizes.This analysis enables us to conclude that the measurements at different window sizes must be take with care, but at the same time, when statistical distributions are properly rescaled, offer other critical exponents which can better characterize the dynamics domain wall in thin films.

References: [1]G.Durin and S.Zapperi, in "The Science of Hysteresis", Academic, II, 181 (2005)

[2] E.Puppin, Phys. Rev. Lett., 84, 5415 (2000)

[3] K.-S. Ryu, et al., Nat. Phys. 3,547 (2007)

(No Table Selected)



(left) Two avalanche sequences on a Py thin film. (Right) Distribution of avalanche sizes inside windows but not touching the borders. Inset shows the finite-size scaling collapse.