

Nonlocality in kinetic roughening

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We propose a phenomenological equation to describe kinetic roughening of a growing surface in presence of long range interactions. The roughness of the evolving surface depends on the long range feature, and several distinct scenarios of phase transitions are possible. Experimental implications are discussed.

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"Suppose that we take a bin and gently and uniformly pour in granular material. As the material in the bin builds up we can identify a surface and ask the question, 'What is the magnitude of the fluctuation in the height of surface (measured from the base of the bin)?' Also of interest is the length scale of the surface fluctuations and how they behave dynamically as more material is added." [1] And thus was born the Edwards-Wilkinson (EW) model for surface growth - a solvable linear model at the heart of our current understanding of numerous growth processes. A relevant nonlinear term, added to this by Kardar-Parisi-Zhang (KPZ) [2-4], brought to light the nuances of growth phenomena to the extent that the KPZ equation very soon became a paradigm, in particular for dynamic phase transitions. The applicability of the KPZ equation seems to encompass length scales from atomic level to macroscopic phenomena of every day life, but still a specter is haunting the field : why is the KPZ behavior not observed [3]?

Many of the experimental situations however involve complex processes which beg to go beyond the idealization as pouring of noninteracting particles. This is especially true if medium or fluctuations induced interactions interfere with the process as for example in the several recently studied systems involving proteins, colloids or latex particles [5-8], or in sedimentation. The major interaction one has to reckon with, as detailed numerical computations suggest [9,10], is the *long ranged* hydrodynamic interaction. Are such long range interactions relevant for the roughness of the surface? This question, the absence of a formalism to handle such interactions in the growth process, and the elusiveness of the KPZ behavior, led us to propose a simple phenomenological model by focusing on the long range nature of the extra force.

We like to develop a Langevin equation type description where long range aspects can be simulated by a force at each point of the growing surface exerted by the particles away from it - a hint to go beyond a strict local description. In the linear EW model, the growth is along

the global normal to the surface without any overhang. The height $h(\mathbf{r}, t)$ at point \mathbf{r} and time t satisfies the diffusion equation with an additional noise term. If, instead of the global, the local normal is favored, the KPZ $(\nabla h)^2$ term is needed [2]. This nonlinear term describes the lateral growth at a point as can be seen from the height profile [3,4]. We now extend this physical interpretation and take the gradient (or its magnitude) as a measure of the local density of deposited particles. The long range effect is now incorporated by coupling these gradients at two different points. Based on this intuitive picture, the equation we propose is the following:

$$\frac{\partial h(\mathbf{r}, t)}{\partial t} = \kappa \nabla^2 h(\mathbf{r}, t) + \eta(\mathbf{r}, t) + \frac{1}{2} \int d\mathbf{r}' \partial(\mathbf{r}') \nabla h(\mathbf{r} + \mathbf{r}', t) \cdot \nabla h(\mathbf{r} - \mathbf{r}', t), \quad (1)$$

where κ is the diffusion constant for the particles on the surface, and η is a random space time dependent white noise of zero mean and $\langle \eta(\mathbf{r}, t) \eta(\mathbf{r}', t') \rangle = 2\Delta \delta(\mathbf{r} - \mathbf{r}') \delta(t - t')$. The kernel $\partial(\mathbf{r})$ is of long range and, in principle, connected to the underlying interactions [11]. So, we take $\partial(\mathbf{r})$ to have a short range part $\lambda_0 \delta(\mathbf{r})$ and a long range part $\sim r^{d-\chi}$, or more precisely, in Fourier space, $\partial(\mathbf{k}) = \lambda_0 + \lambda_\phi k^{-\chi}$. Eq. 1 then smoothly [12] goes over to the KPZ equation for $\lambda_\phi = 0$. We show that this leading term introduced is sufficient to yield a new fixed point with continuously varying exponents, and different phase transitions not found in the KPZ problem. The connection with experiments is discussed near the end of this paper.

A central quantity of interest in growth problems is the scaling behavior of fluctuation of the height, $\langle |h(\mathbf{r}, t) - h(\mathbf{0}, 0)|^2 \rangle$ which on a large length and time scale has a scaling form $|\mathbf{r}|^{2\chi} \mathcal{F}(|t|/|\mathbf{r}|^\alpha)$. Here χ is the roughness exponent of the growing surface and α is the dynamic exponent. These two exponents define the universality classes of roughening.

At $d = 1$, for the local growth (i.e. KPZ) equation a disorder dominated rough phase is found for all λ_0 by several exact treatments [13,14] providing $\chi = 1/2$ and

Nonlocality And Modality

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