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Dislocation dynamics, plasticity and avalanche statistics using the phase-field crystal model[1]

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The plastic deformation of stressed crystalline materials is characterized by intermittency and scaling behavior. The sudden strain bursts arise from collective interactions between depinned crystal defects such as dislocations. Recent experiments on sheared nanocrystals provide insights into the connection between the crystal plasticity and the mean field theory of the depinning transition, based on the similar power-law statistics of avalanche events. However, a complete theoretical formulation of this connection is still lacking, as are high quality numerical data. Phase field crystal modelling provides an efficient numerical approach to simulating the dynamics of dislocations in plastic flows at finite temperature. Dislocations are naturally created as defects in a periodic ground state that is being sheared, without any ad hoc creation and annihilation rules. These crystal defects interact and annihilate with one another, generating a collective effect of avalanches in the global plastic strain rate. We examine the statistics of plastic avalanches both at finite and zero temperatures, and find good agreement with the predictions of the mean field interface depinning theory. Moreover, we predict universal scaling forms for the extreme statistics of avalanches and universal relations between the power-law exponents of avalanche duration, size and extreme value. These results account for the observed power-law distribution of the maximum amplitudes in acoustic emission experiments of crystal plasticity, but are also broadly applicable to other systems in the mean-field interface depinning universality class, ranging from magnets to earthquakes. The work reported here was performed in collaboration with: Georgios Tsekenis, Michael LeBlanc, Patrick Y Chan, Jon Dantzig, Karin Dahmen, and Nigel Goldenfeld.

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