Glassy features of crystal plasticity

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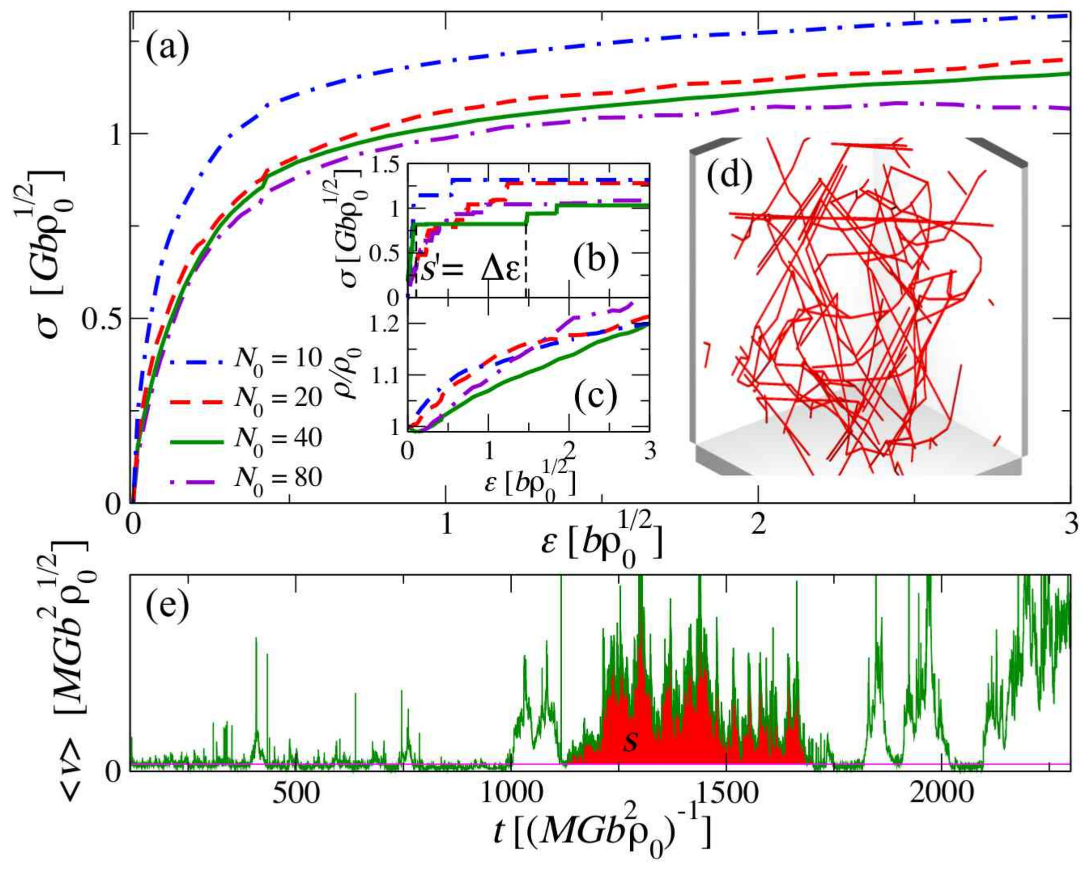
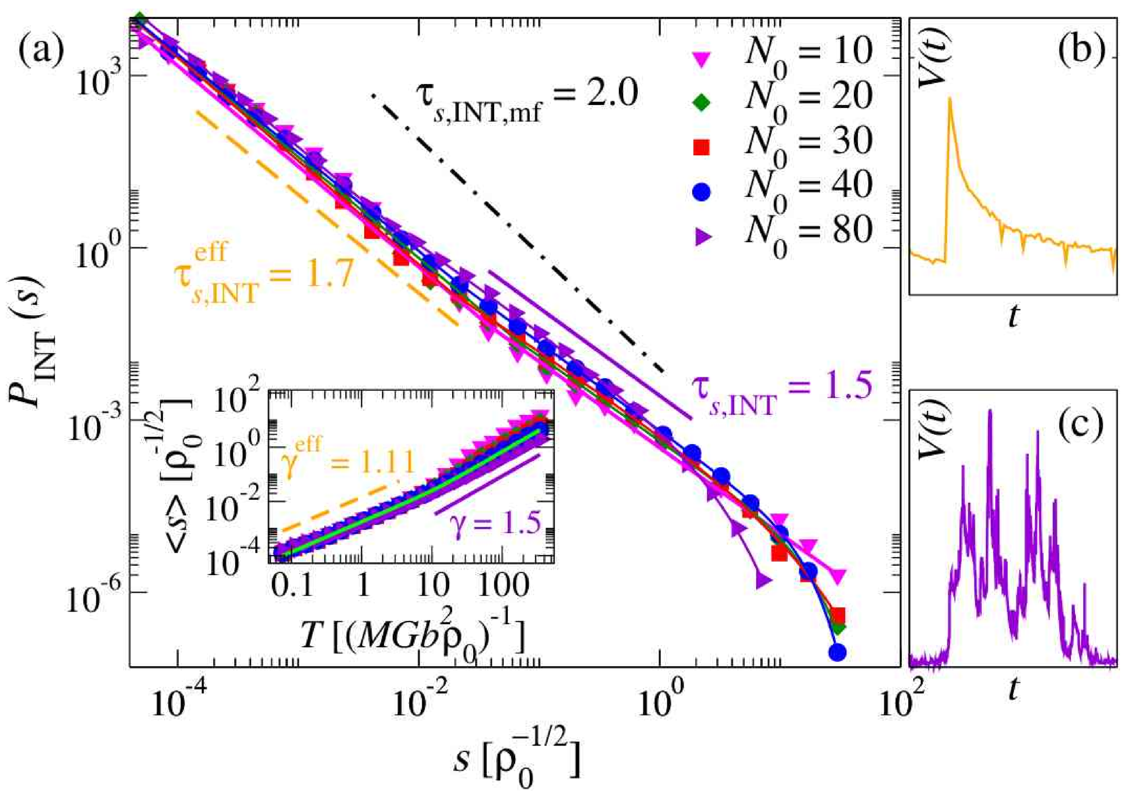
Abstract

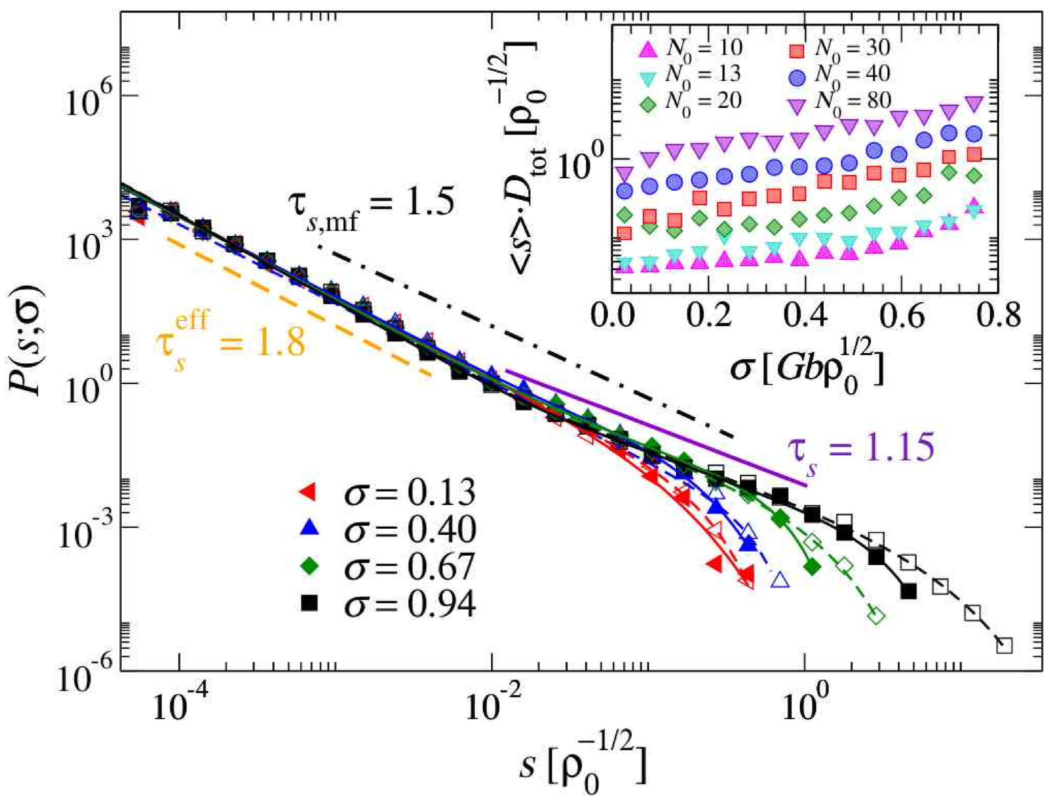
Crystal plasticity occurs by deformation bursts due to the avalanche like motion of dislocations. Here we perform extensive numerical simulations of a three-dimensional dislocation dynamics model under quasistatic stress-controlled loading. Our results show that avalanches are power-law distributed and display peculiar stress and sample size dependence: The average avalanche size grows exponentially with the applied stress, and the amount of slip increases with the system size. These results suggest that intermittent deformation processes in crystalline materials exhibit an extended critical-like phase in analogy to glassy systems instead of originating from a nonequilibrium phase transition critical point.

Methods

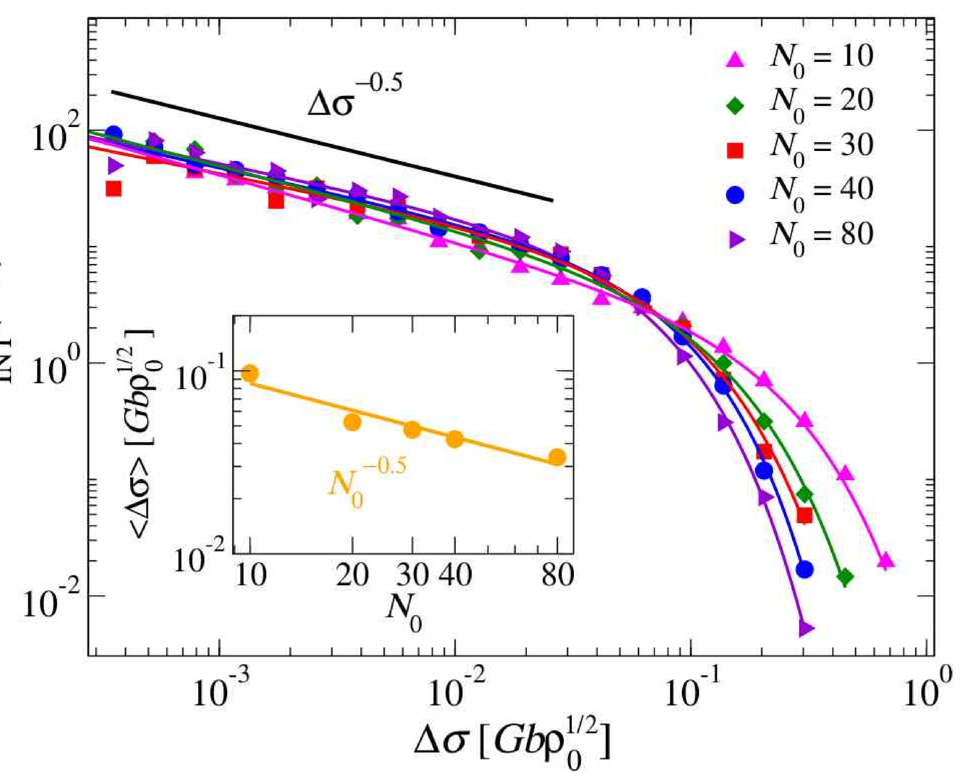
In order to simulate the dislocations dynamics we use a modified version of the discrete dislocation dynamics (DDD) code ParaDis. We consider the FCC crystal structure with parameters of Al and we employ periodic boundary conditions. To study the effect of the system size, we consider different linear sizes *L*=0.715, 1.001, 1.2298, 1.43 and 2.1473 *μm*, keeping the initial dislocation density roughly constant. To test the robustness of our results, we use two different driving protocols with a stress control.







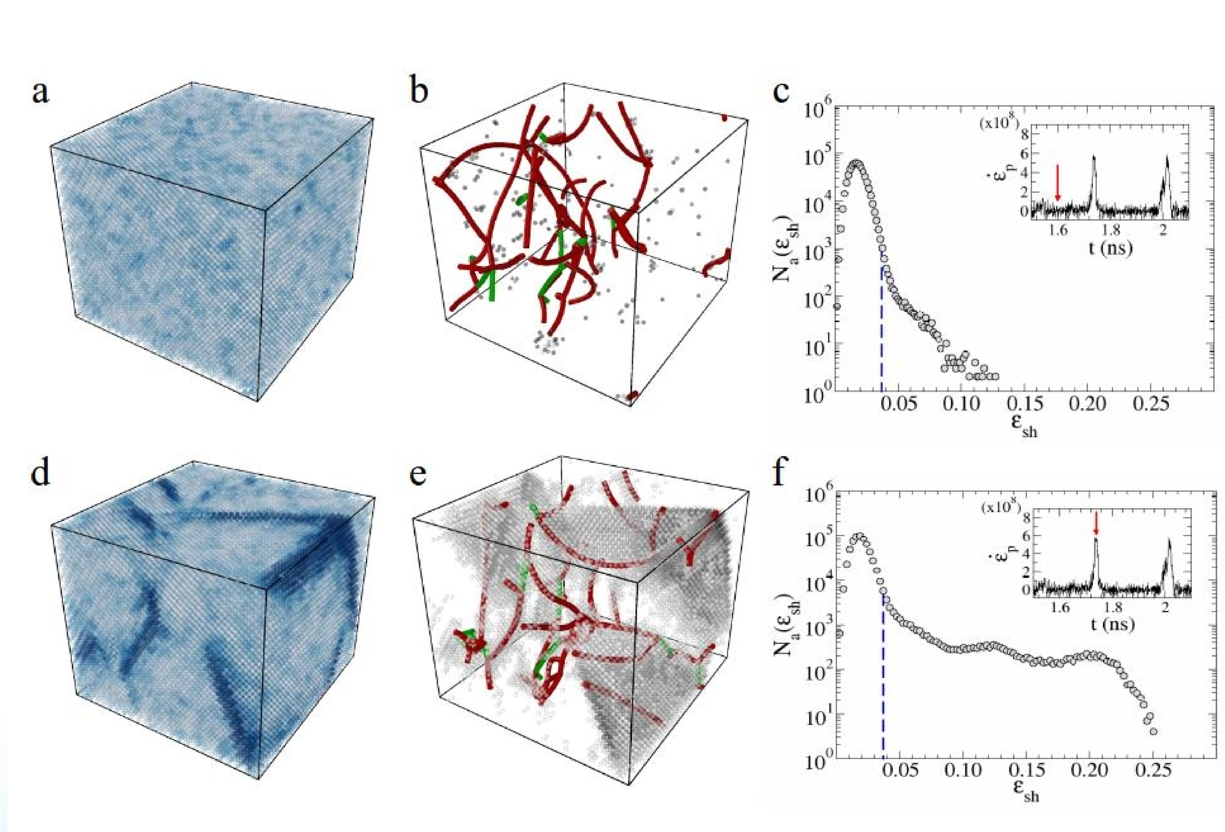
$$P_{\rm INT}(s)\,\frac{As^{-\tau_{s,INT}}}{e^{(s/s_0)^b}}\left[1+\left(\frac{s}{s^*}\right)^{\left(\tau_{s,\rm INT}-\tau^{eff}_{s,\rm INT}\right)k}\right]^{1/k}$$



Results

We measure the stress-integrated avalanche size distribution $P_{INT}(s)$ from 3D DDD simulations for different N_0. They exhibit two power law regimes with a crossover scale separating scaling regimes of "small" and "large" avalanches. Our data is well described by a crossover scaling form with a parameter *k* that controls the sharpness of the crossover.
Also the average size $\langle s(T)\rangle$ as a function of the avalanche duration *T* shows two scaling regimes. The stress-resolved avalanche size distribution provides strong evidence suggesting that our avalanches cannot be described by mean-field depinning.

MD Simulations



Conclusions

The bursty three-dimensional crystal plasticity cannot be envisaged in terms of a depinning transition but is rather a manifestation of an extended criticallike phase, reminiscent of glassy systems. Interesting extensions of our study could be performed by adding a significant population of pinning centers, representing the effect of various additional defects such as precipitates, acting as obstacles for dislocation motion. Recent 2D studies suggest that when in the competition between dislocation jamming and pinning due to obstacles the latter starts to dominate, a depinninglike scenario may be recovered. Our results point out the possibility that there are several universality classes in mesoscopic plasticity starting from the pure case studied here.

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