A mechanism for spatial and temporal earthquake clustering

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[1] The Gutenberg-Richter law states that the size-frequency distribution of earthquakes follows a power law. This trend is usually justified using spring-block models, where slips with the appropriate statistics of sizes have been numerically observed. However, prominent spatial and temporal clustering features of earthquakes, as those implied by the Omori law of aftershocks, are not accounted for by this kind of model unless they are complemented with ad hoc assumptions, such as stress recovery laws after slip events, or the phenomenological rate-and-state equations to describe friction. We show that when a mechanism of structural relaxation is incorporated into a spring-block model, realistic earthquake patterns following the Gutenberg-Richter and Omori laws are obtained. Moreover, features well known from laboratory friction experiments, such as velocity weakening and increase of static friction with contact time, appear as a consequence of the relaxational mechanism as well, without making any a priori assumptions on the velocity dependence of the friction force in the model. In this way, our model shows that a single physical mechanism may be a unifying concept behind the Gutenberg-Richter and Omori laws and the rate-and-state equations of rock friction.

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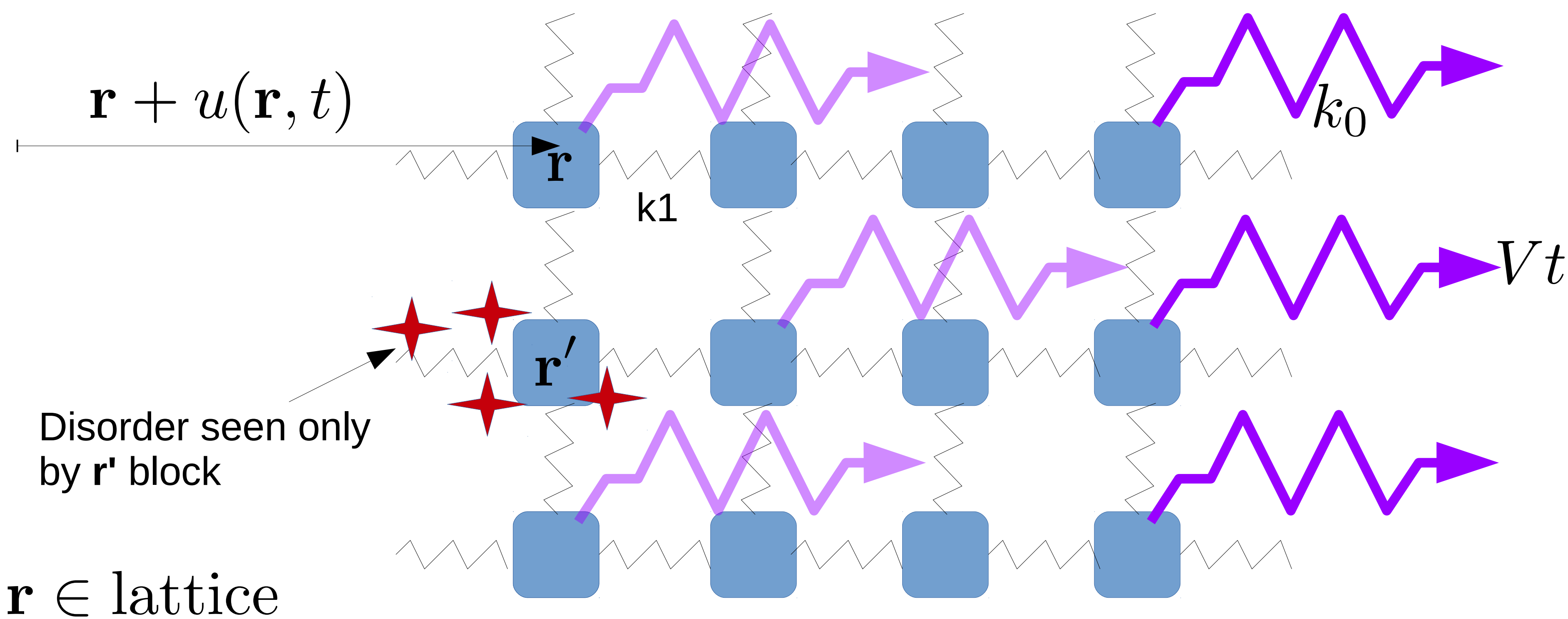
$$H = \int d^2r [V(u(\mathbf{r}) - u_0(\mathbf{r}), \mathbf{r}) + \frac{k_1}{2}(\partial_{\mathbf{r}} u)^2 + \frac{k_0}{2}(u(\mathbf{r}) - Vt)^2]$$

Interface (fast)

$$\partial_t u = -\lambda \, \delta H / \delta u$$

Relaxation or contact aging (slow)

$$\partial_t u_0 = R \, \nabla^2 \delta H / \delta u_0$$



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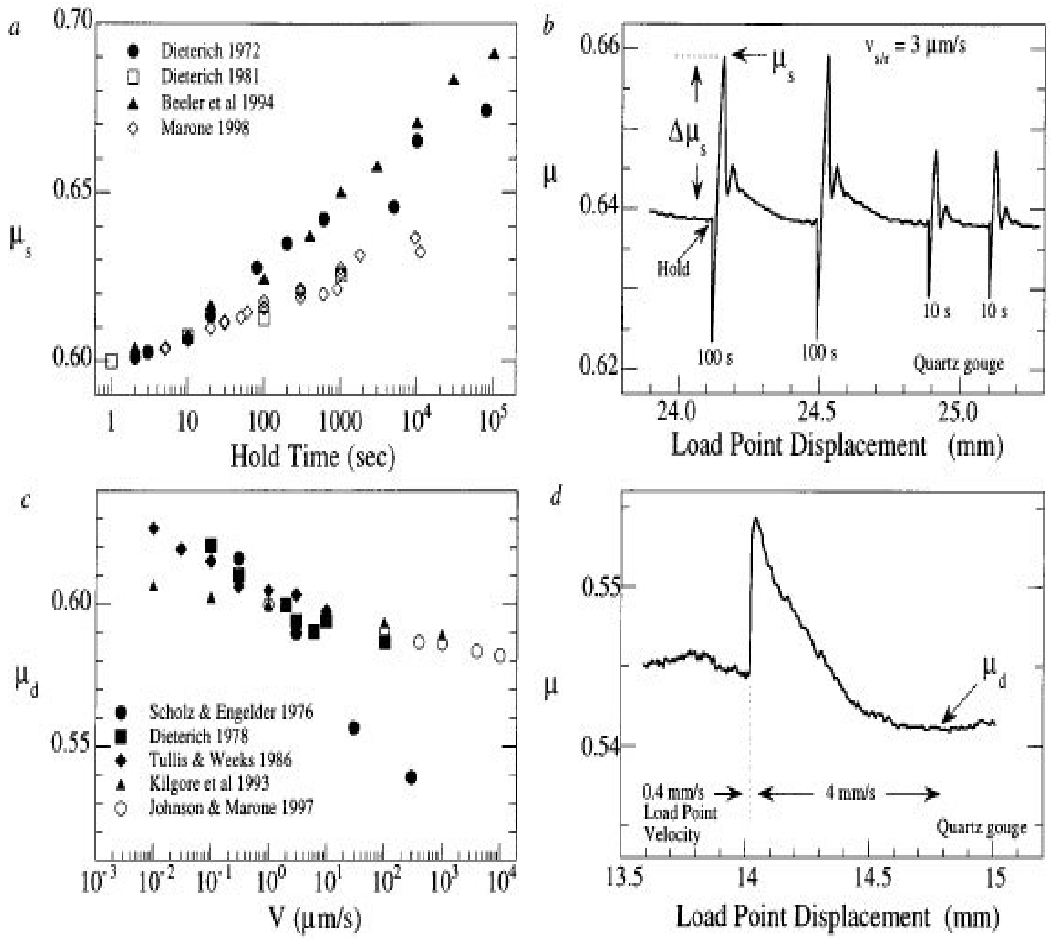
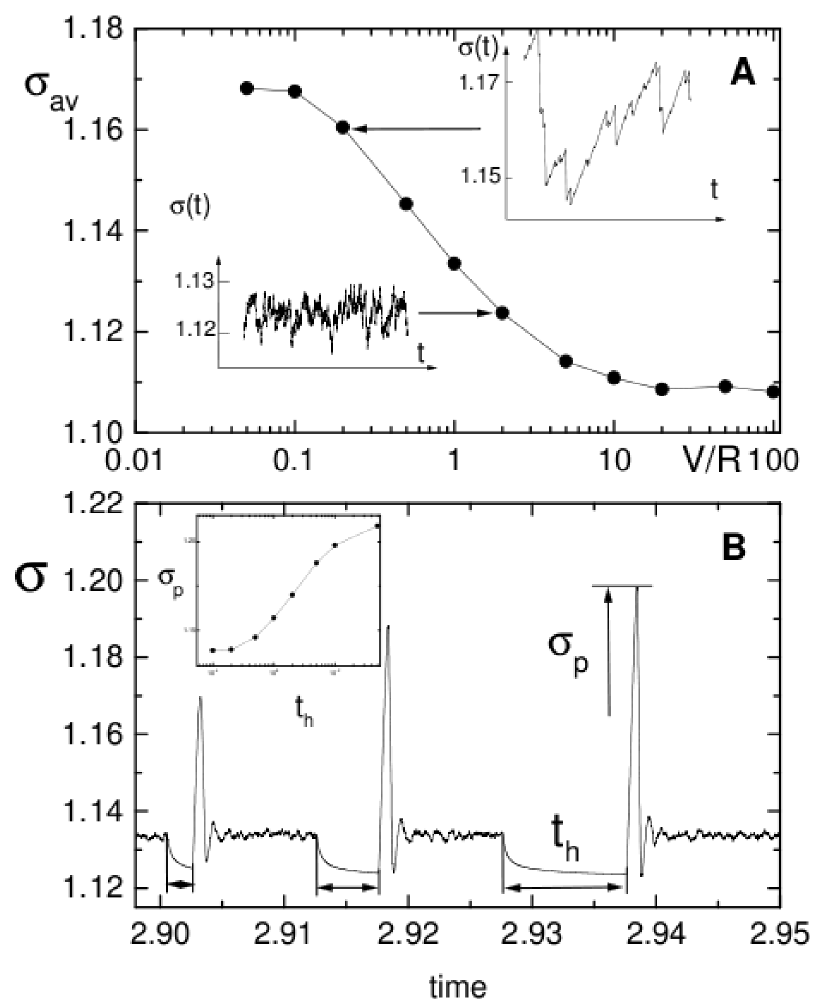
Original Motivation: *Frictional properties of the model*

Rock Friction Experiments (Lab scale)



Modified Depinning Model



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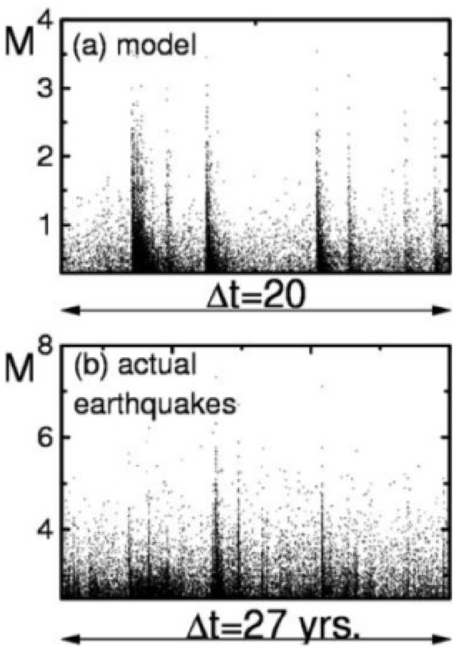
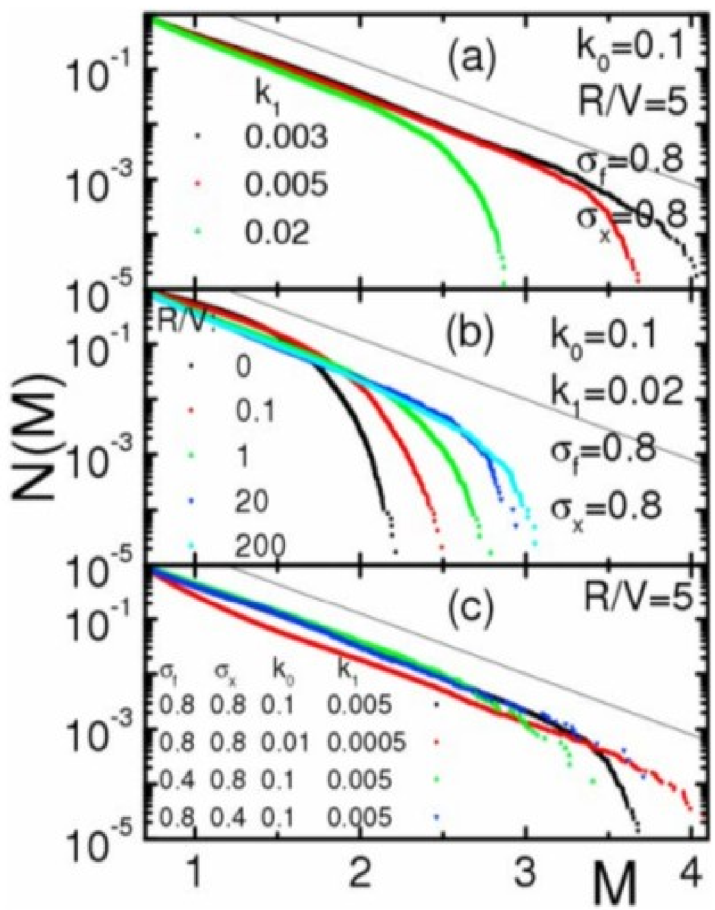
EVENTS

$$M = 2/3 \log_{10} S$$



Gutenberg-Richter

$$N(M) \sim 10^{-bM}$$



Omori

$$N(t) = A/(t + c)^p + N_0$$

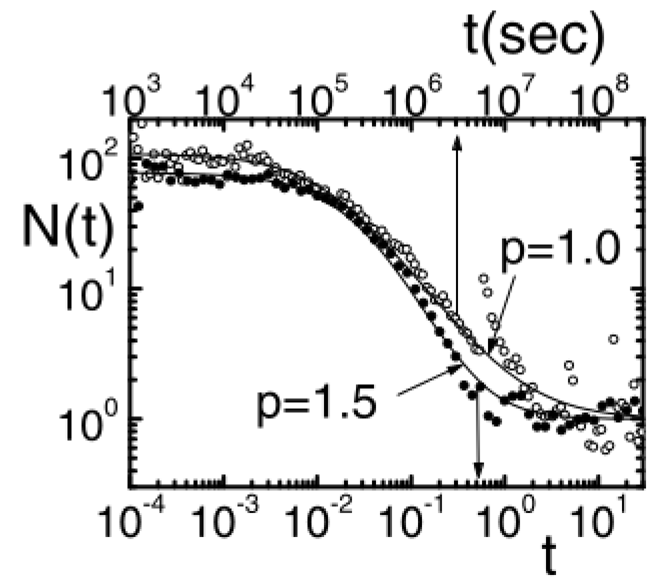


Figure 7. Number of events after main shocks in our model (solid symbols) for parameters and system size as in Figure 3a, normalized to the background seismicity (i.e., $N(t \to \infty) = 1$). We stacked the events after about 450 main shocks with $M > 3$, and the lower magnitude cutoff used to count aftershocks is $M_0 = 1.5$. For comparison, the same analysis for data in the California region is presented with open symbols. In this case we sum over 7 events of magnitude larger than 6.0. For this case $M_0 = 2.0$. For reference, the continuous lines correspond to decays following the Omori law, with exponents $p = 1.0$ and $p = 1.5$.