Does KPZ describe pushed interfaces with quenched disorder?

CompPhys18

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Outline:

- **Kardar-Parisi-Zhang:**
  Recent successes for $d = 2$ (i.e., $1 + 1$)
  versus stagnation for $d > 2$

- **Frozen disorder: rough interfaces & percolation:**
  Generalized percolation, $T = 0$ RFIM, "mimimal model"

- $d = 2$

- **Morphological phase transitions for supercritical percolation:**
  Sponge phases

  – Bond percolation, $3 \leq d \leq 6$

  – GEP

- **KPZ for non-spongy transition in $d = 3$?**

KPZ:
Driven interfaces with **annealed** noise
Critical exponent known exactly in $d = 2$ ($1 - d$ interfaces)
Scaling functions also known exactly in $d = 2$
$d > 2$: exponents known approximately; upper critical dimension = ?

Experimental verification:

- Old experiments (< 2000): uncontrolled mix of annealed & quenched noise:
  burning cigarette paper, coffee filter wetting, wetting in sponges, magnetic domain propagation, ...
  $\longrightarrow$ no clear conclusions

- Takeuchi et al., 2010:
  very well controlled;
  $d = 2$
  $\longrightarrow$ everything ok.

Frozen disorder:

Interfaces can get **pinned** !

Critically pinned interfaces:

- Fractal: percolation
- non-fractal but rough: self-affine

Transitions between both observed since 1980's:
Robbins, Cieplak, Ji, Martys, Koiller, ...

- Small surface tension in fluid imbibition, large disorder in RFIM: $\rightarrow$ fractal
- High surfae tension, small disorder: $\rightarrow$ rough surfaces

But little deeper understanding

Generalized Epidemic Process (GEP)
H.-K. Janssen et al., 2004

$p_k = \text{prob}\{$ site gets infected (wetted) during k-th attack$\}$
$q_k = q_{k-1} + (1 - q_{k-1})p_k = \text{prob}\{$ site is infected after k-th attack$\}$

Critical interface is non-fractal, if p_k increases sufficiently with k
Transition fractal $\leftrightarrow$ non-fractal is **tricritical point**

Special GEP's:

- T=0 RFIM without spontaneous nucleation:

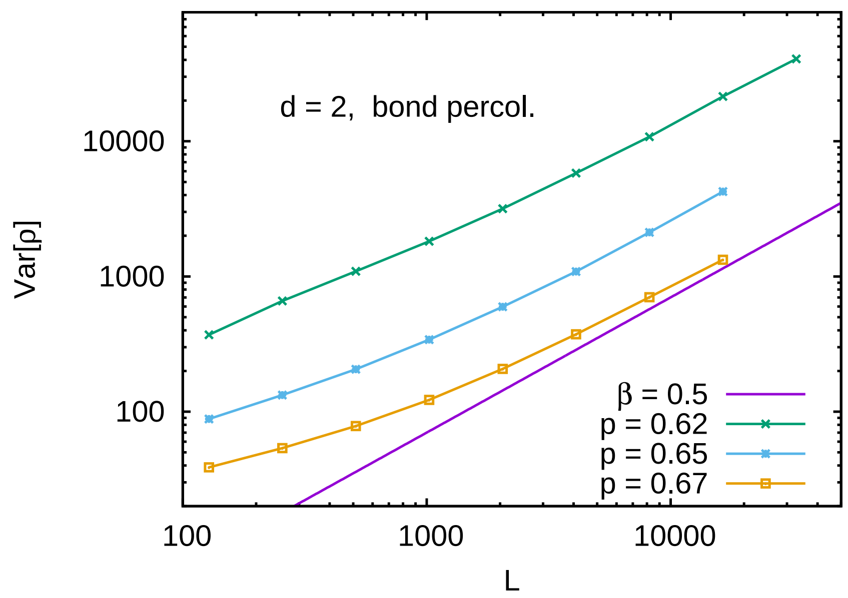
  Spins flip, when neighboring spins have flipped $p_k = \text{prob}\{\text{neighbor flipping pushes local magnetic field above/below zero}\}$

- "Minimal model": $p_2 \neq p_1$, but $p_k = p_2$ for $k > 2$

All following results are for minimal model, but all tests with other versions show universal behavior

d = 2:

- Critically pinned interfaces are **always** in percolation universality class (P. Grassberger, arXiv:1711.02904; PRL 2017)
- Supercritical GEP $\sim$ KPZ



Morphological phase transitions for supercritical percolation:

Site percol., $d \geq 3$**:**

$p_c < 1/2$
$\rightarrow$ for $p_c < p < 1 - p_c$, there exist co-existing ∞ clusters
(wetted & non-wetted sites both percolate)

Is this also true for
– bond percolation?
– for GEP?

Simulations:

- Hyperplane seed:
  start with entire L^{d-1} "bottom hyperplane" of $d-$dimensional lattice infected

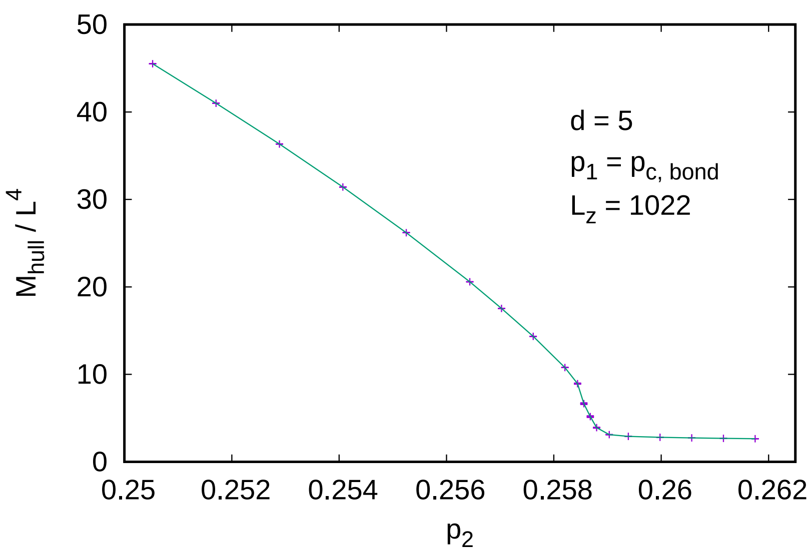
- Spread the epidemic into region $z > 0$, with periodic lateral b.c.

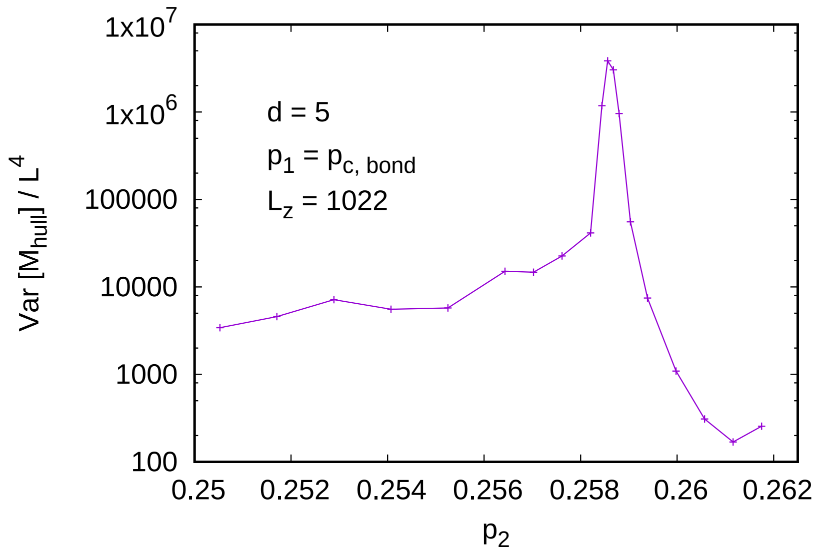
- Stop epidemic just before top hyperplane $z = L_z$ is reached

- Starting from top hyperplane, find the hull of th infected cluster by means of (depth-first) recursive hull-walking algorithm

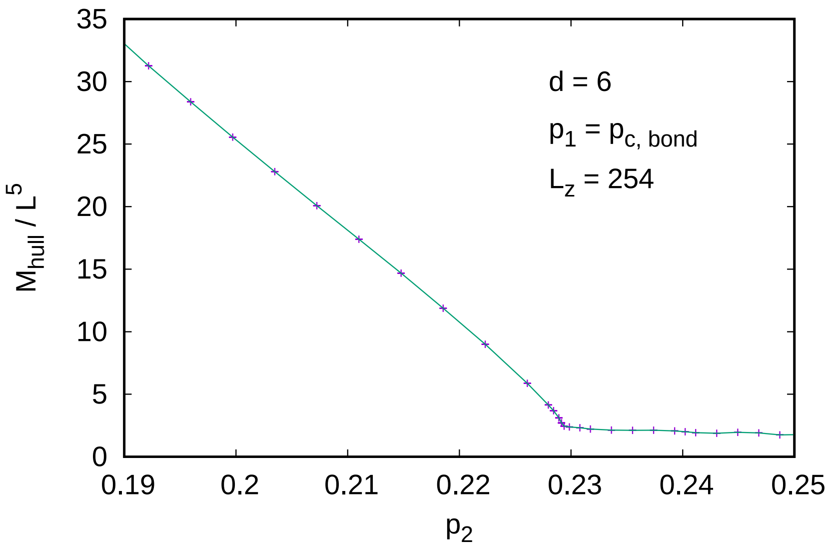
- How far does hull reach down?
  Are there "fjords" or "channels" in where hull reaches down to bottom?
  Average hull mass =?

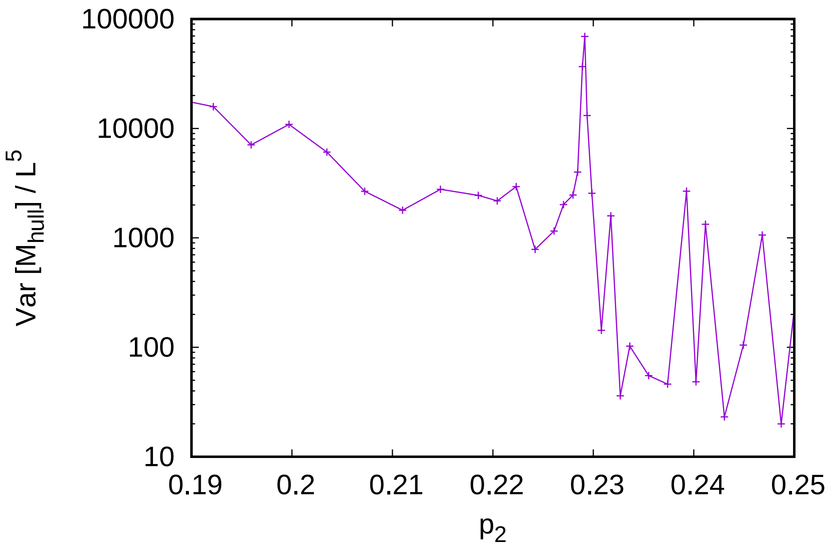
$d = 5$, bond percolation:





$d = 6$, bond percolation:





Thresholds for spongy clusters at bond percolation:

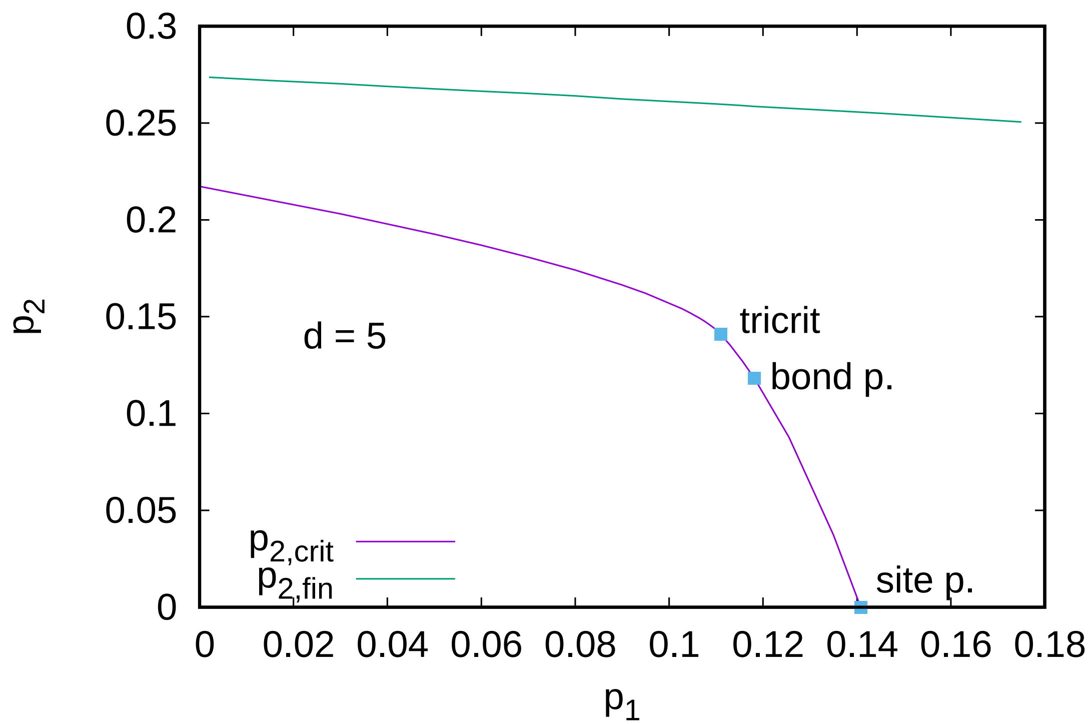
```
d      p_{inf}       p{fin} / p_c

3      0.3605(10)      1.449
4      0.2987(10)      1.865
5      0.2586(5)       2.188
6      0.2291(5)       2.432
```

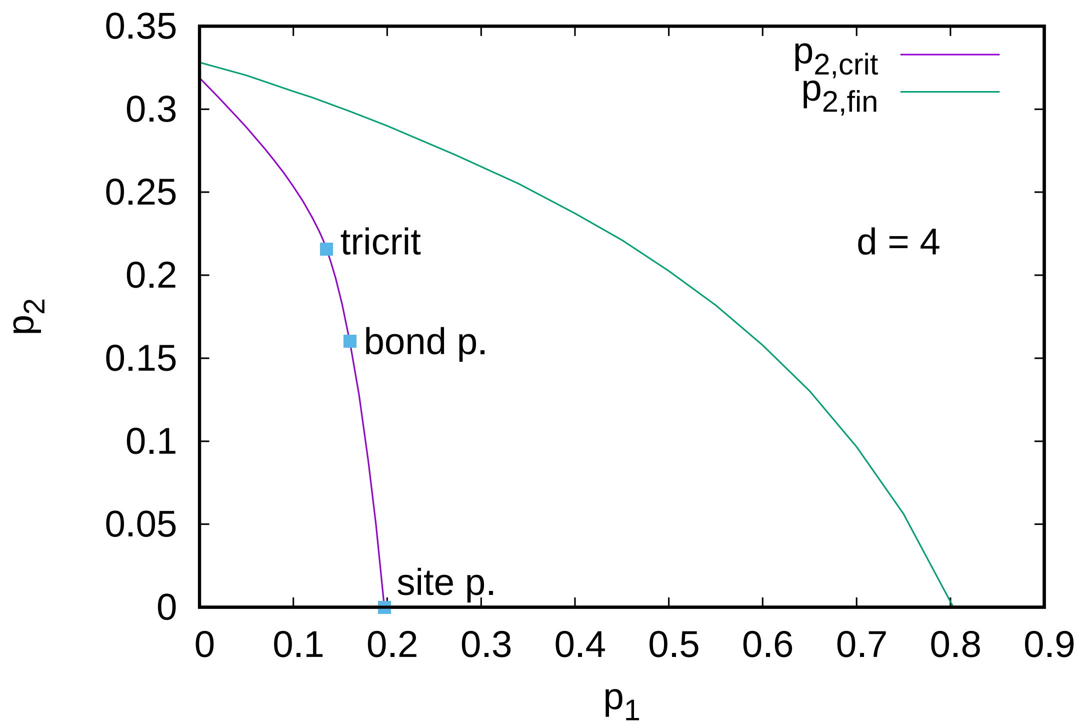
B. Bock et al., aXiv:1811.01678 (2018):

- Existence of multiple supercritical bond percolation clusters proven for $d \geq 8$
- $p_{inf} > \log(d)/2d \quad$ for large d

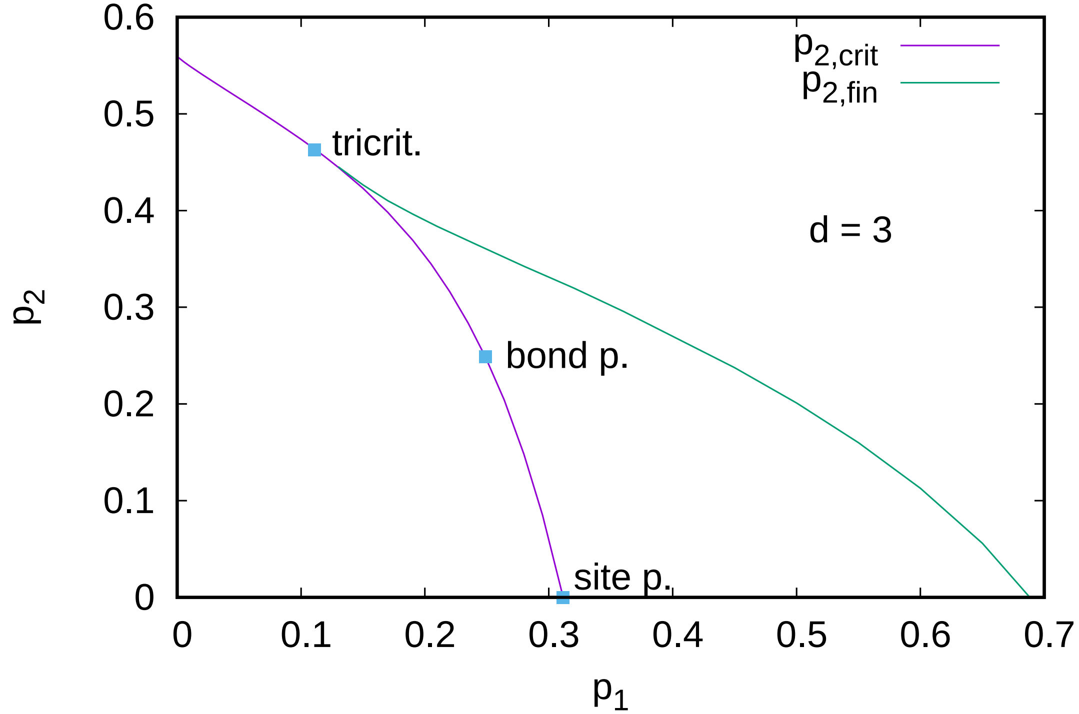
$d = 5$, minimal model GEP:



$d = 4$, minimal model GEP:

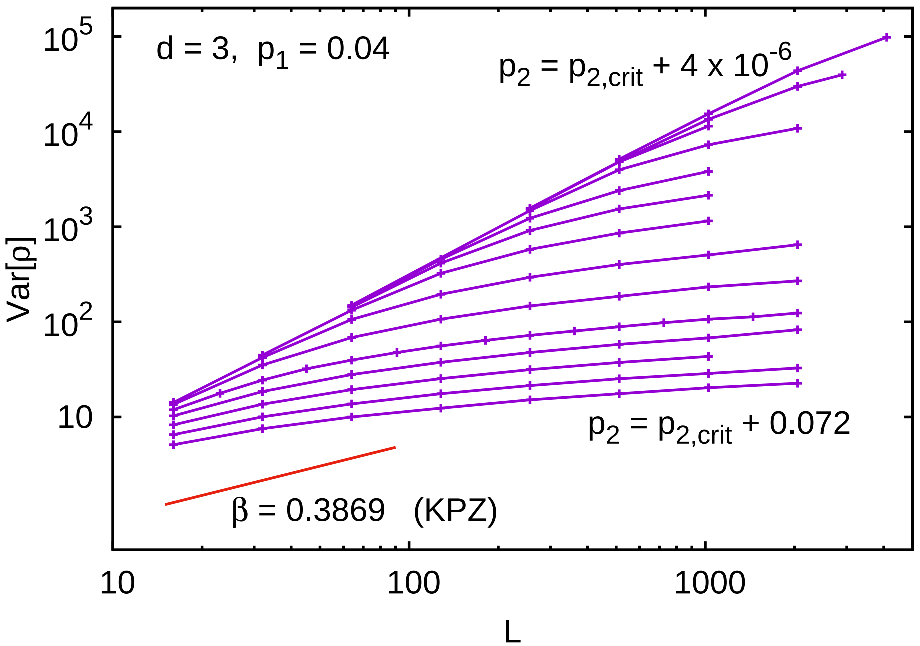


$d = 3$, minimal model GEP:

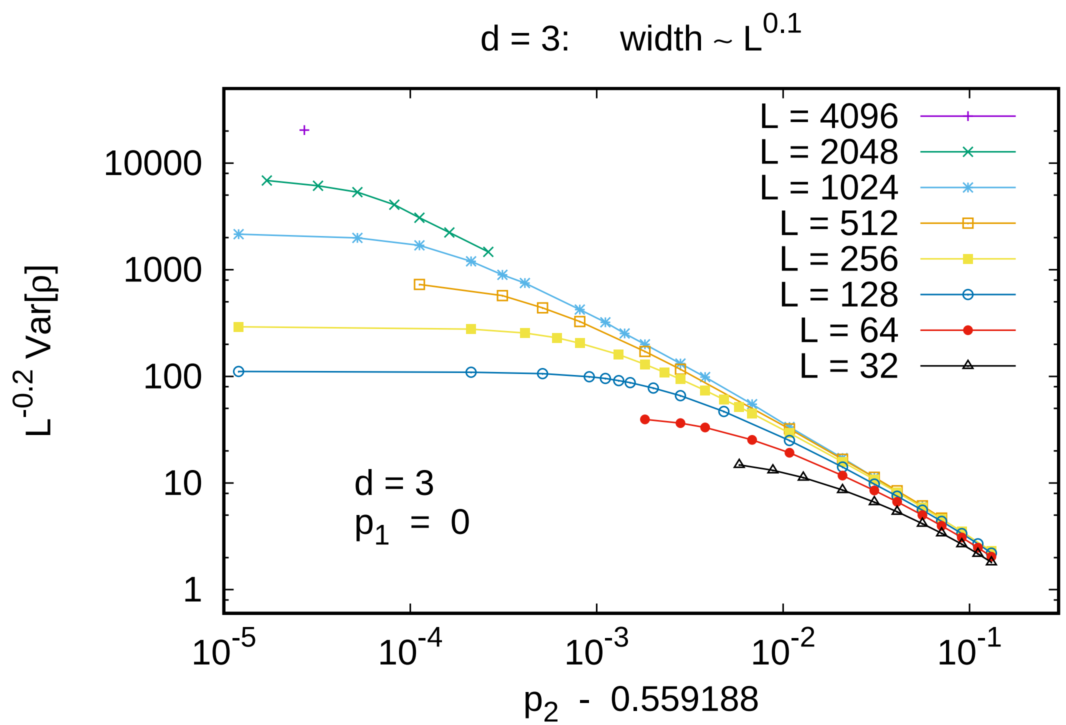


- In spongy phase, obviously no KPZ scaling
- KPZ in compact (non-spongy) phase?

$d = 3$, minimal model GEP with $p_1 = 0.04$:



Similar for $p_1 = 0$:



Conclusions:

- Existence of multiple coexisting supercritical clusters:
  $\rightarrow$ "spongy" phases, where clusters penetrate each other
- Transition spongy $\leftrightarrow$ compact is a true (2nd order?) phase transition, at least for $3 \leq d < 6$
- For $d = 6$ is transition more complex?
- Even in compact (non-spongy) phase, interfaces in $d = 3$ are NOT in KPZ universality class
- $d = 2$:
  – No fractal $\leftrightarrow$ nonfractal transition for critical surfaces
  – supercritical surfaces are KPZ