Accumulation of Beneficial Mutations in Low Dimensions

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Evolutionary dynamics

- Rate of adaptation influenced by
  - Fitness Landscape
  - Time dependence
  - Spatial Structure
  - Heterogeneity

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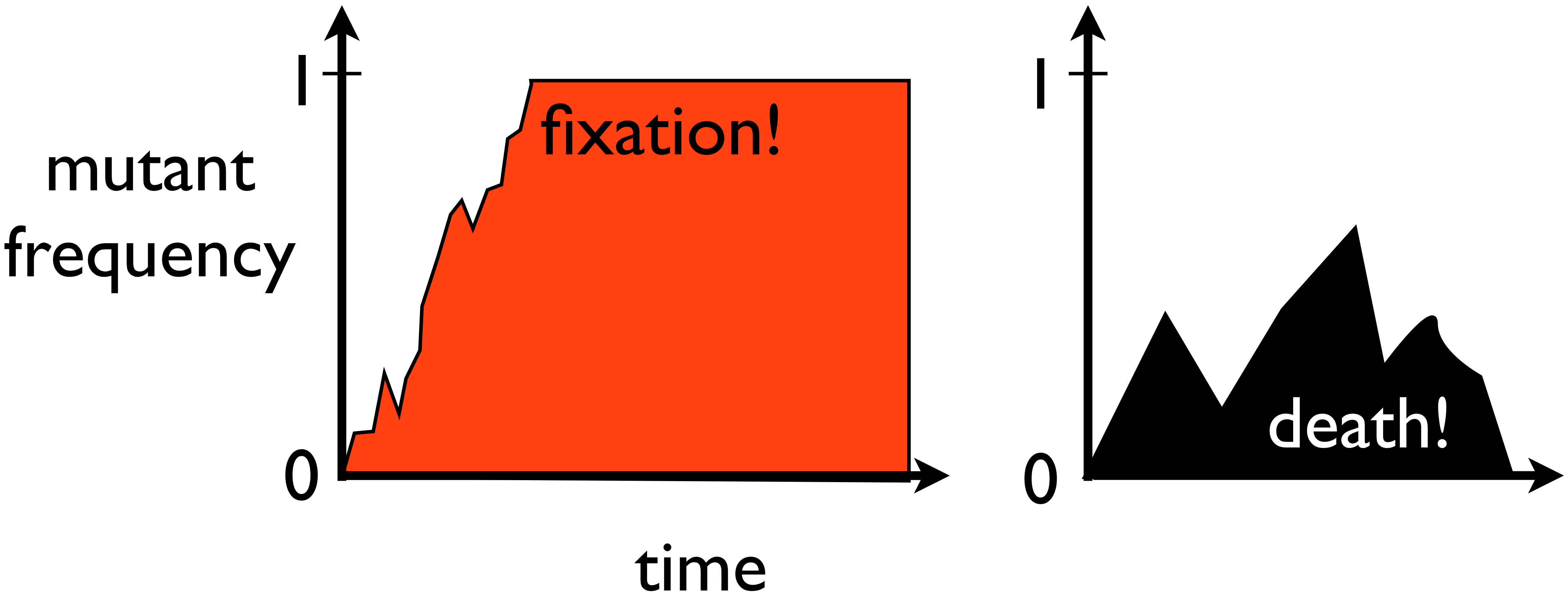
simple model

- *N* (asexual) organisms
- For each generation, random number of kids
- fitness = mean number kids
- keep total N fixed
- if p(n) ~ poisson, conditional on N being fixed ➔ multinomial

- kids inherit fitness

mutation

- single mutant fitness 1+s



Fixation

- If mutant has fitness = 1 + s
- Then probability of fixation = 2s (for small s, large Ns)
- example: s = 0.05, probability of mutation dying is 90%!

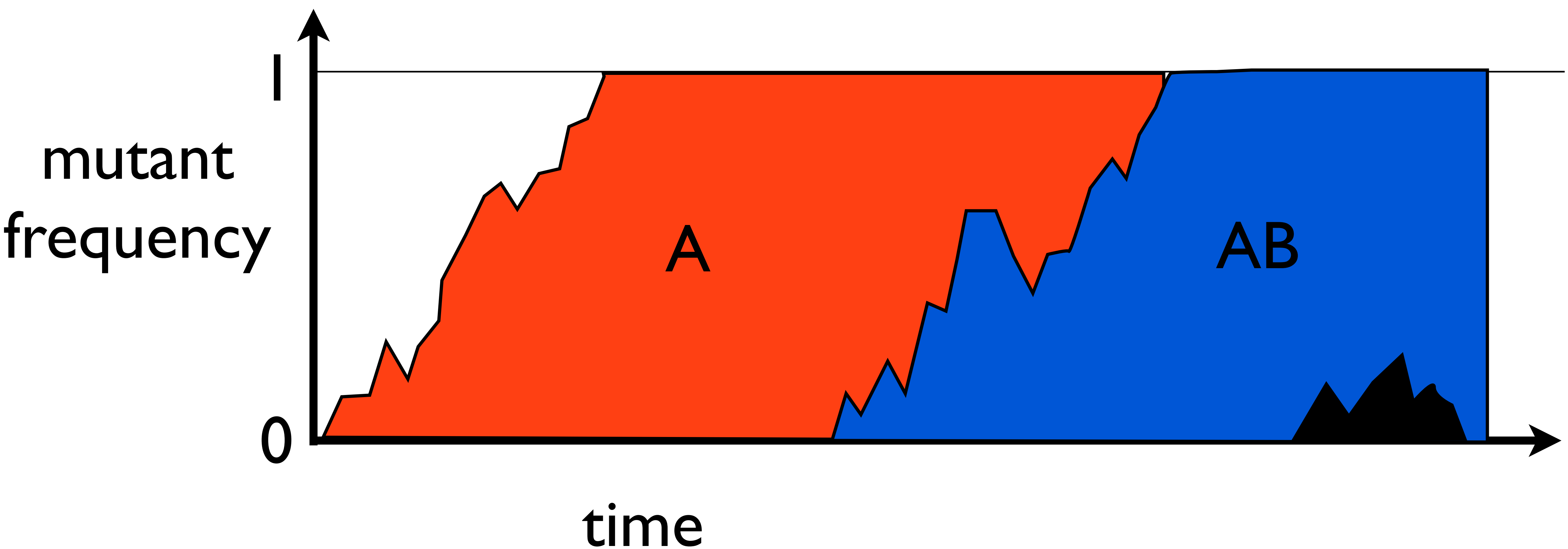
Multiple mutations

- beneficial mutations arrive with some rate U, per individual
- $\log f' = \log f + s$
- $s \sim 0.01$

Mutation limited evolution

- fixation time << mutation time

$$\frac{2}{s}\ln N \ll \frac{1}{2sUN} \qquad R = \frac{1}{t_{mut}} = 2sUN$$



competing mutations

- fixation time ~ mutation time

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Clonal Interference

- mutation A established
- before A fixates, B established
- who wins? A or B?
- one mutation is "wasted"
- probability of fixation reduced

Multiple Mutation Effect

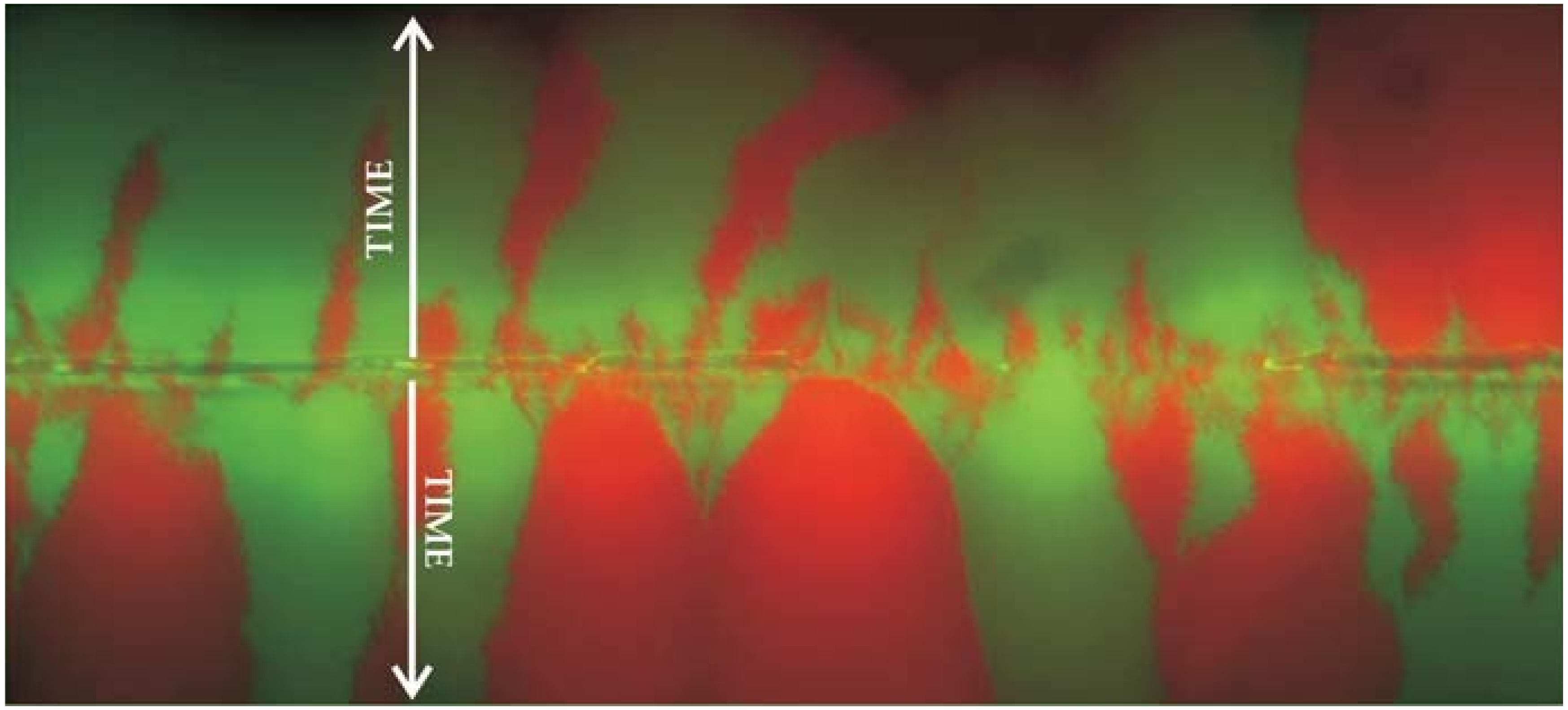
- A and B compete
- A -> AC, AC has a better chance of winning
- mutation C is not wasted

Rate of Fixation

- With competing mutations:
  - R is sublinear with N
- Bacterial experiments show multiple competing mutations are present
  - distributed s? changing U? landscape?

Spatial Structure

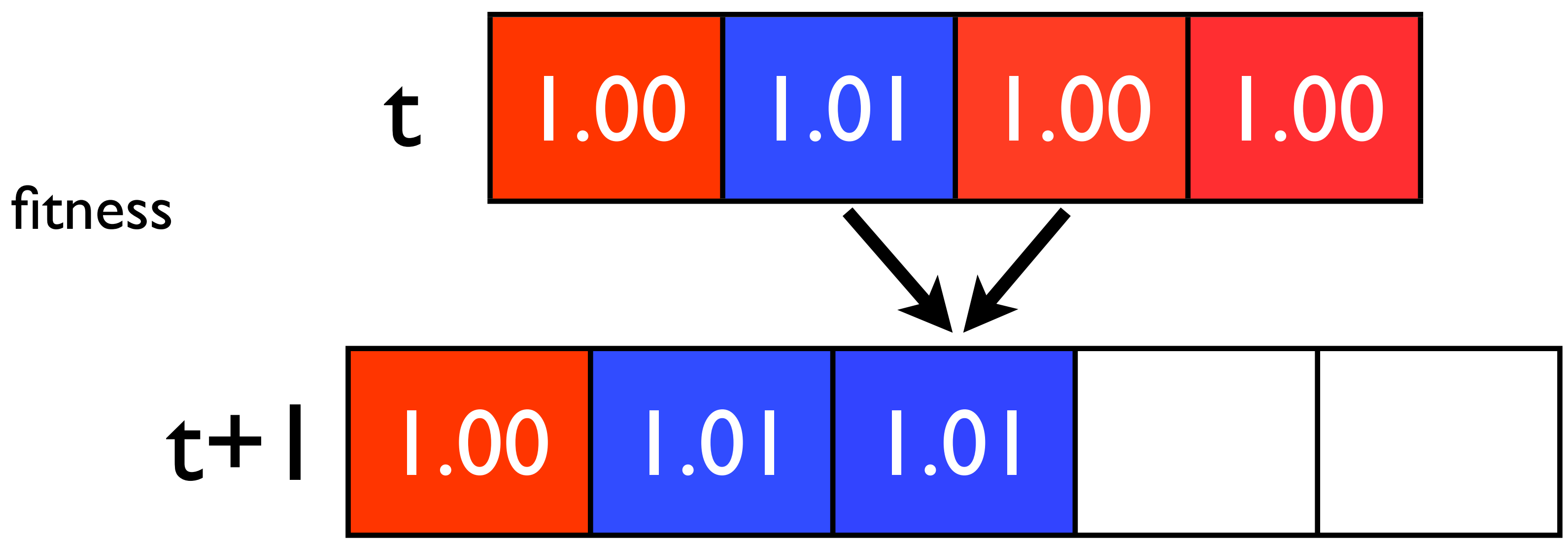
- competition only between neighbors
- desegregation of 2 types



Hallatschek and Nelson, Physics Today 2009

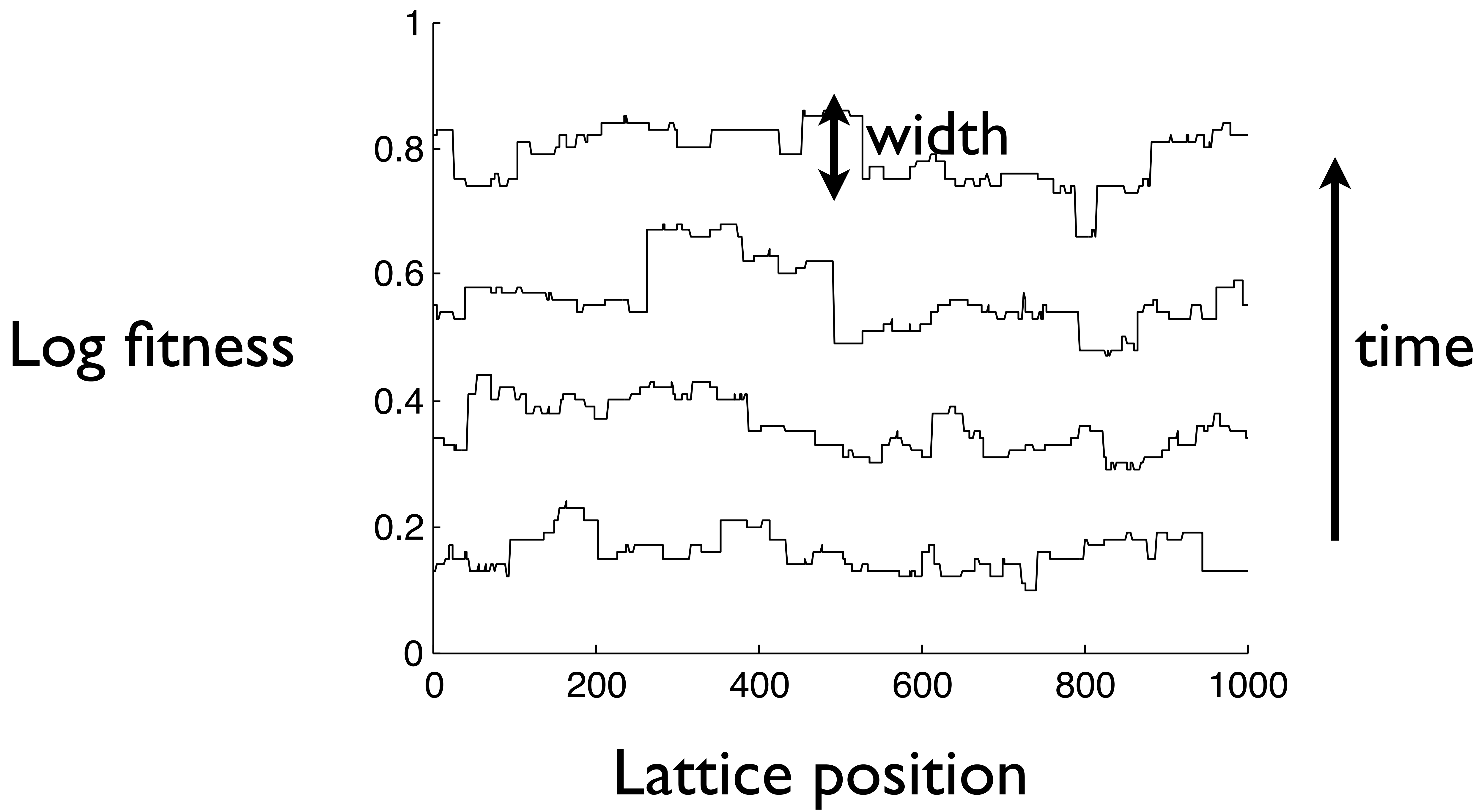
Our model

- one dimension: one organism per site
- kids can only choose one of two parents:



- p = 1.01/2.01
- boundaries spread with speed s/2

Surface growth

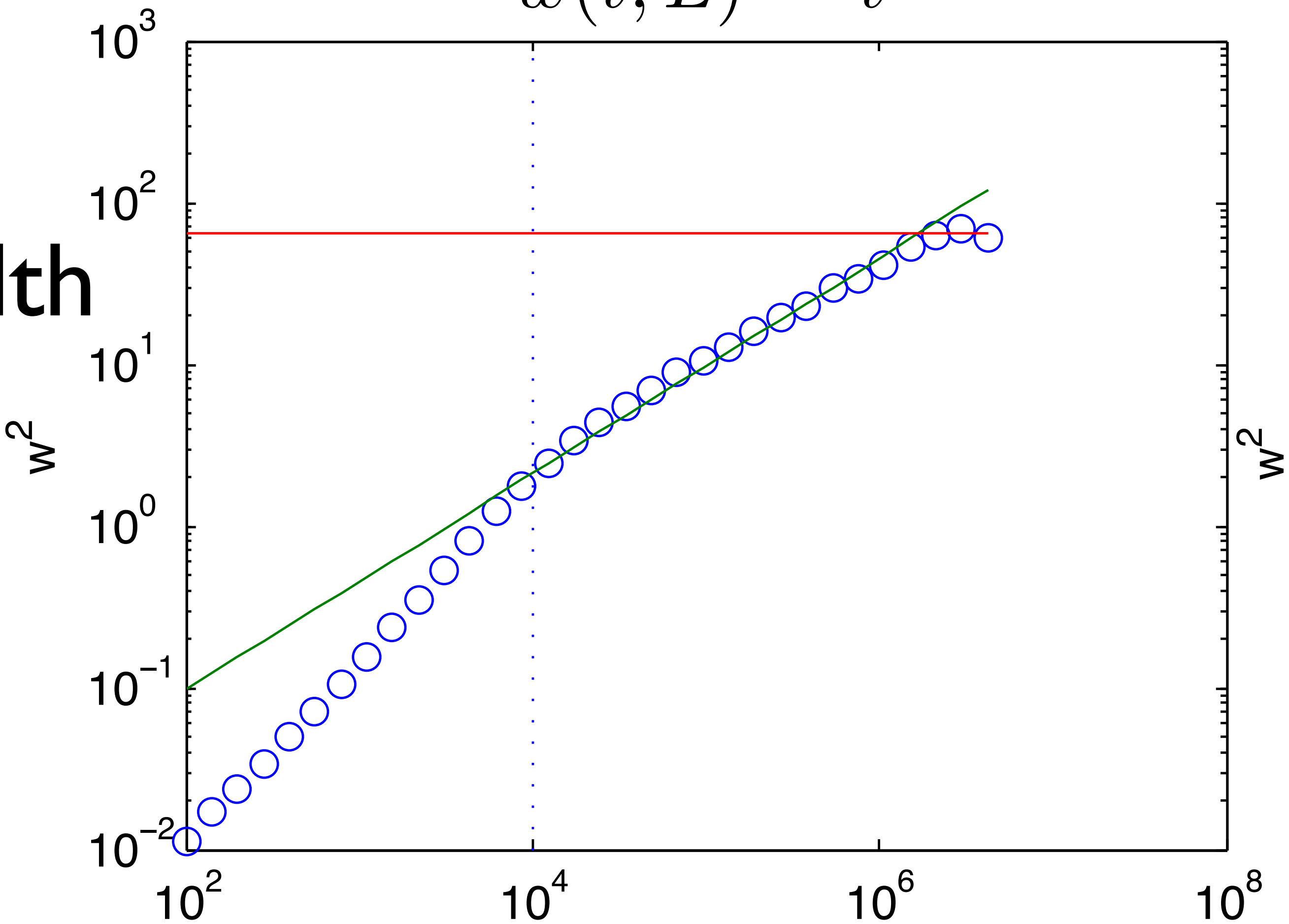


Surface growth

- width = std deviation of log f
- KPZ exponents: $\beta = \frac{1}{3} \qquad \alpha = \frac{1}{2}$

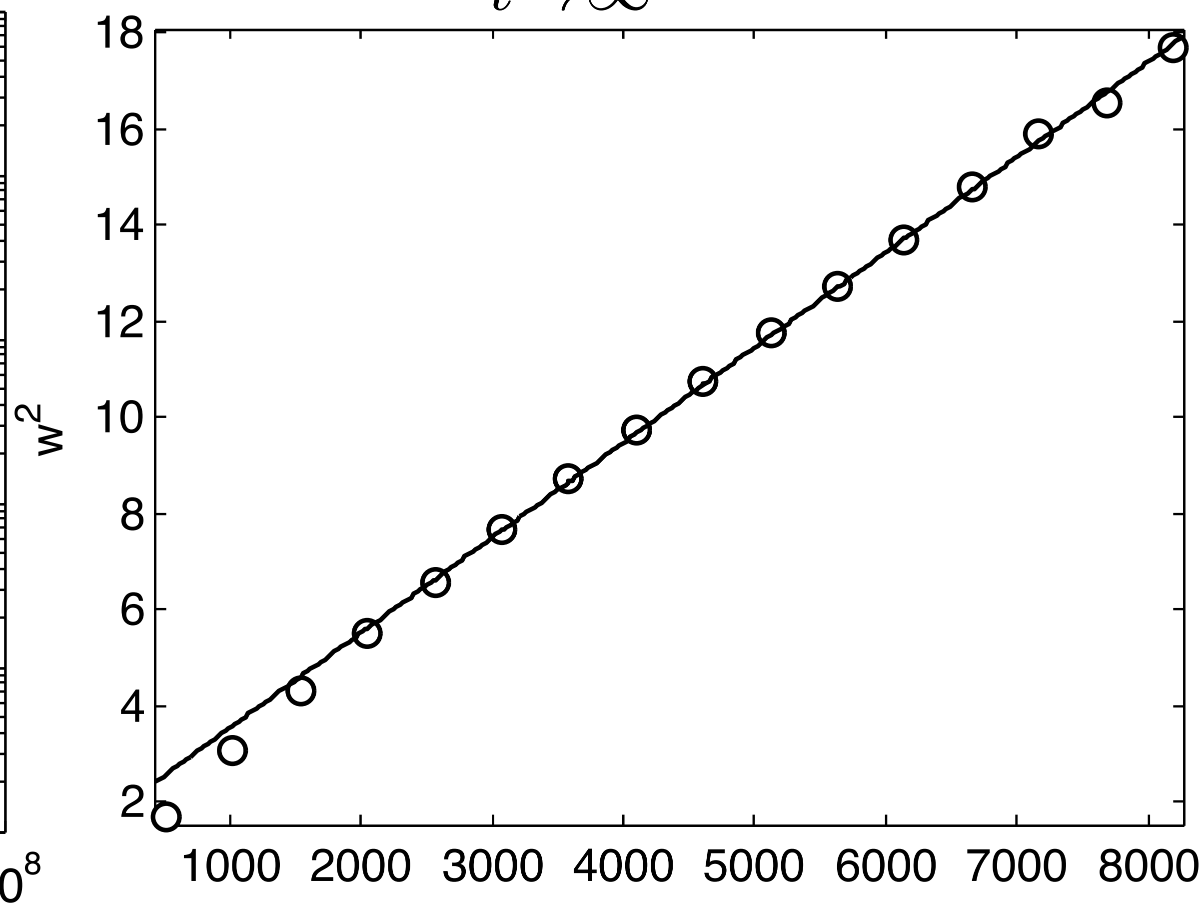
$w(t, L) \sim t^{\beta}$

width



time

$w_{t\to\infty} \sim L^{\alpha}$



system size

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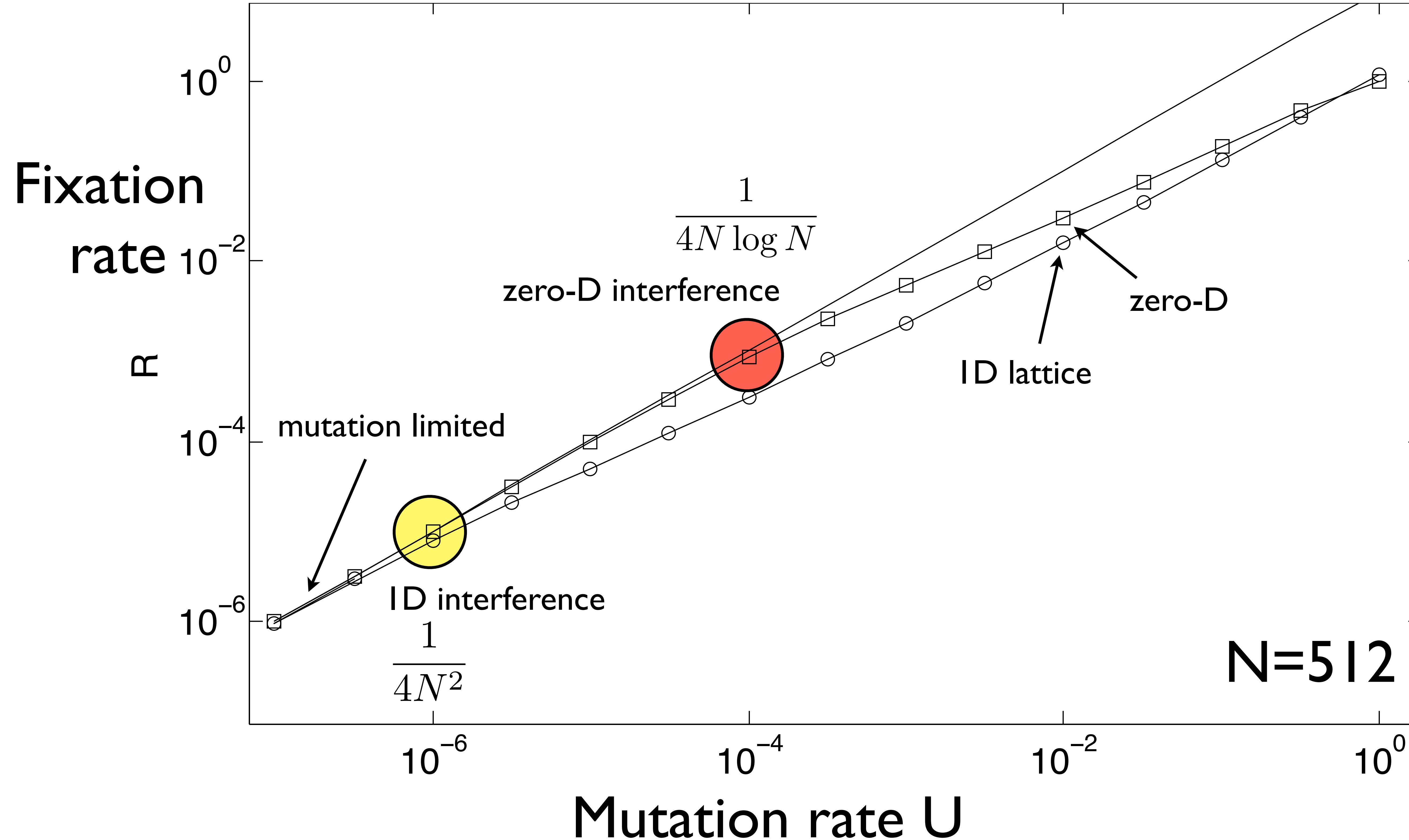
Our model

- on a lattice, fixation probability is the same as in zero-D:
  - $p = 2s$
- $R = 2sUN$ in mutation limited regime
- fixation time:
  - zero-D: $2/s \ln N$
  - one-D: $2/s\, N$

competition slows evolution



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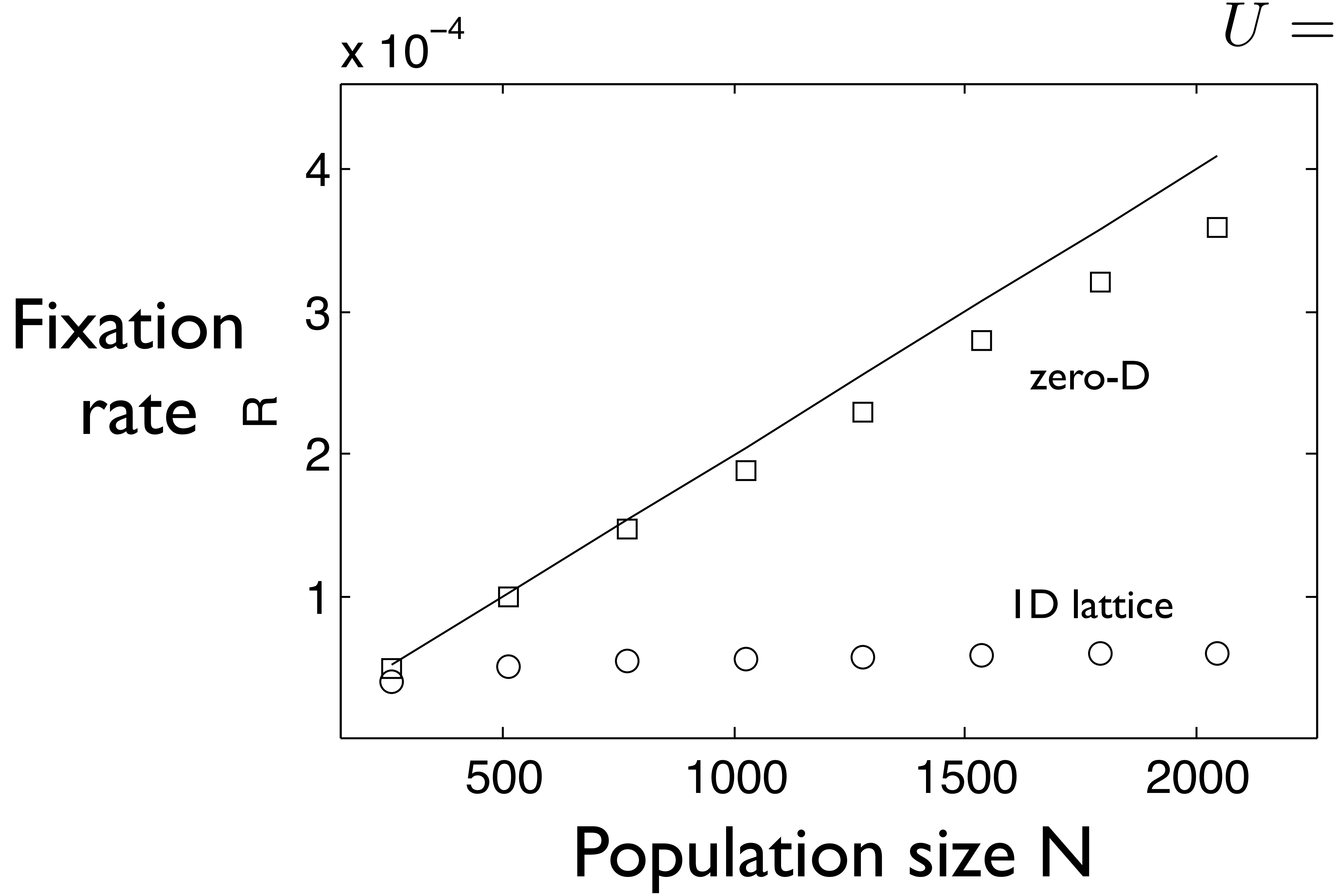
speed versus N

$U = 10^{-5}$



Speed limit

- rate saturates with system size
- holds for:
  - distributed s
  - different wave speed
  - planar habitats

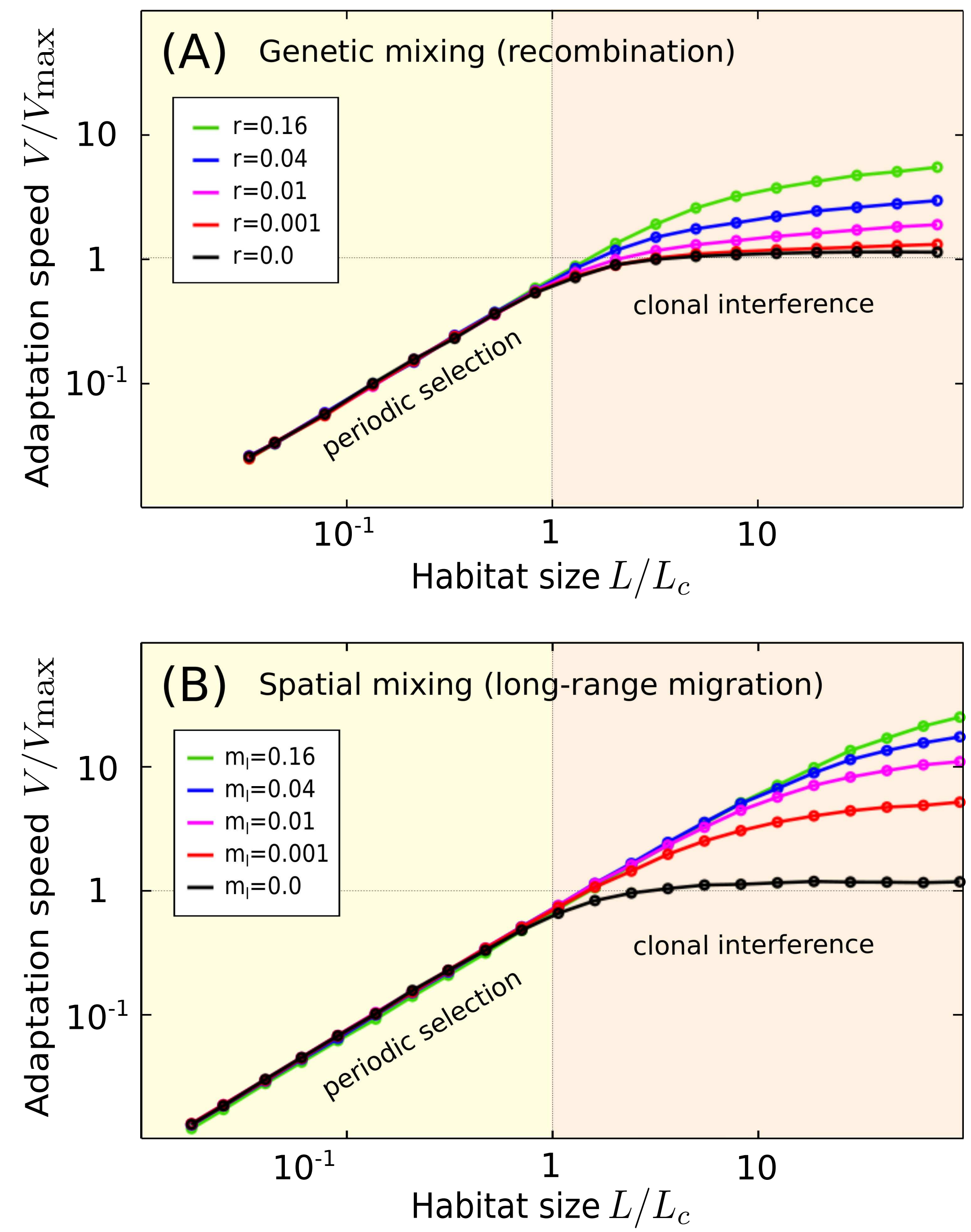
Martens, Hallatschek, Genetics, 2011

Summary

- Spatial structure increases fixation times. Threshold for interference lowered. Rate of fixation saturates
- rate of fixation reduced in bacterial exp.
- Assumptions: homogenous spatial structure, no rough fitness landscape (epistasis), constant selection pressure
- Harmful mutations?
- Acknowledgements: Stefan Boettcher, Joachim Krug, Fereydoon Family, George Hentschel, David Cutler, Ilya Nemenman

Mixing

- competition/ interference alleviated by:
  - spatial mixing
  - recombination



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