Some implications of neutral evolution for ecology

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Work with

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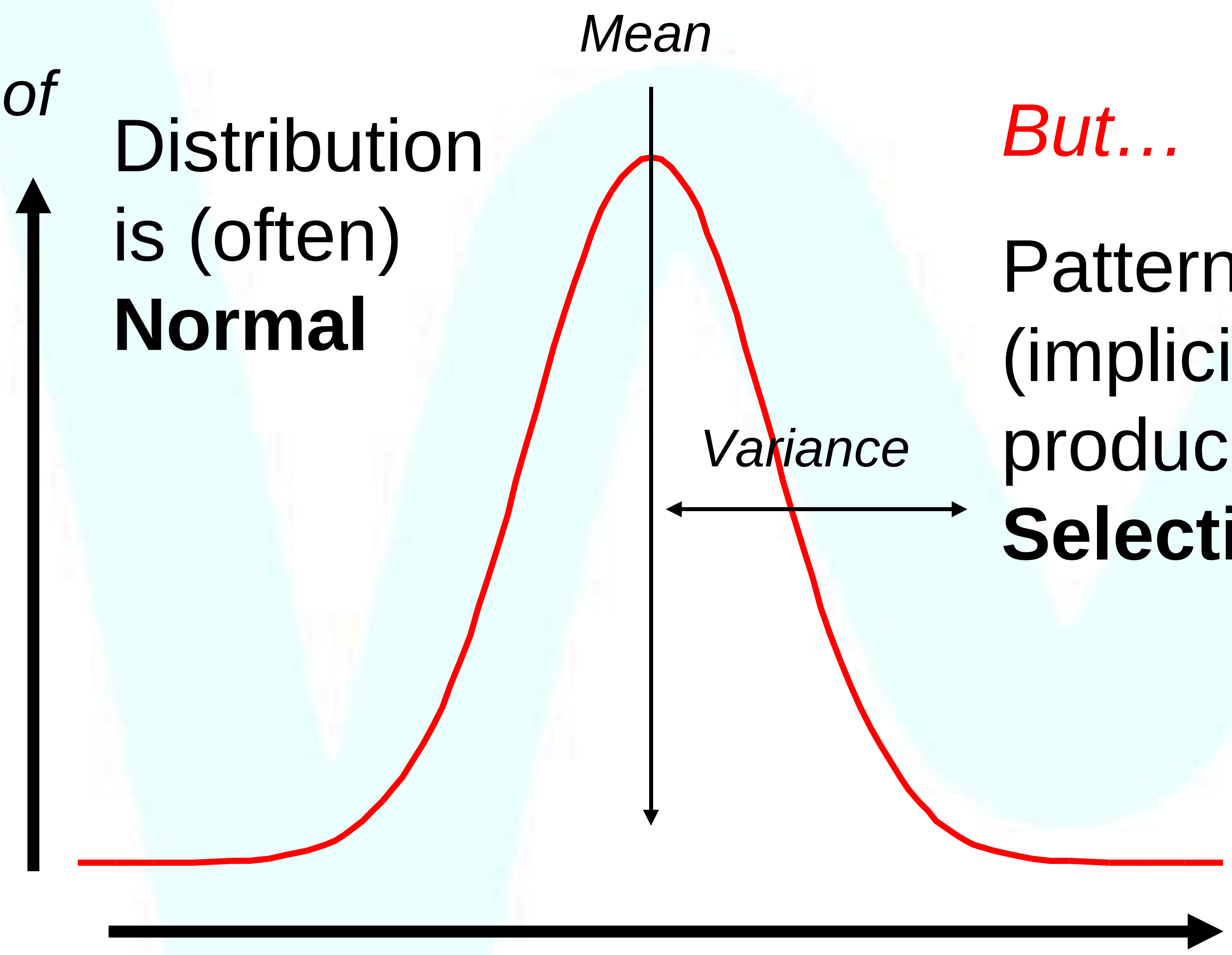
Phenotype Distribution

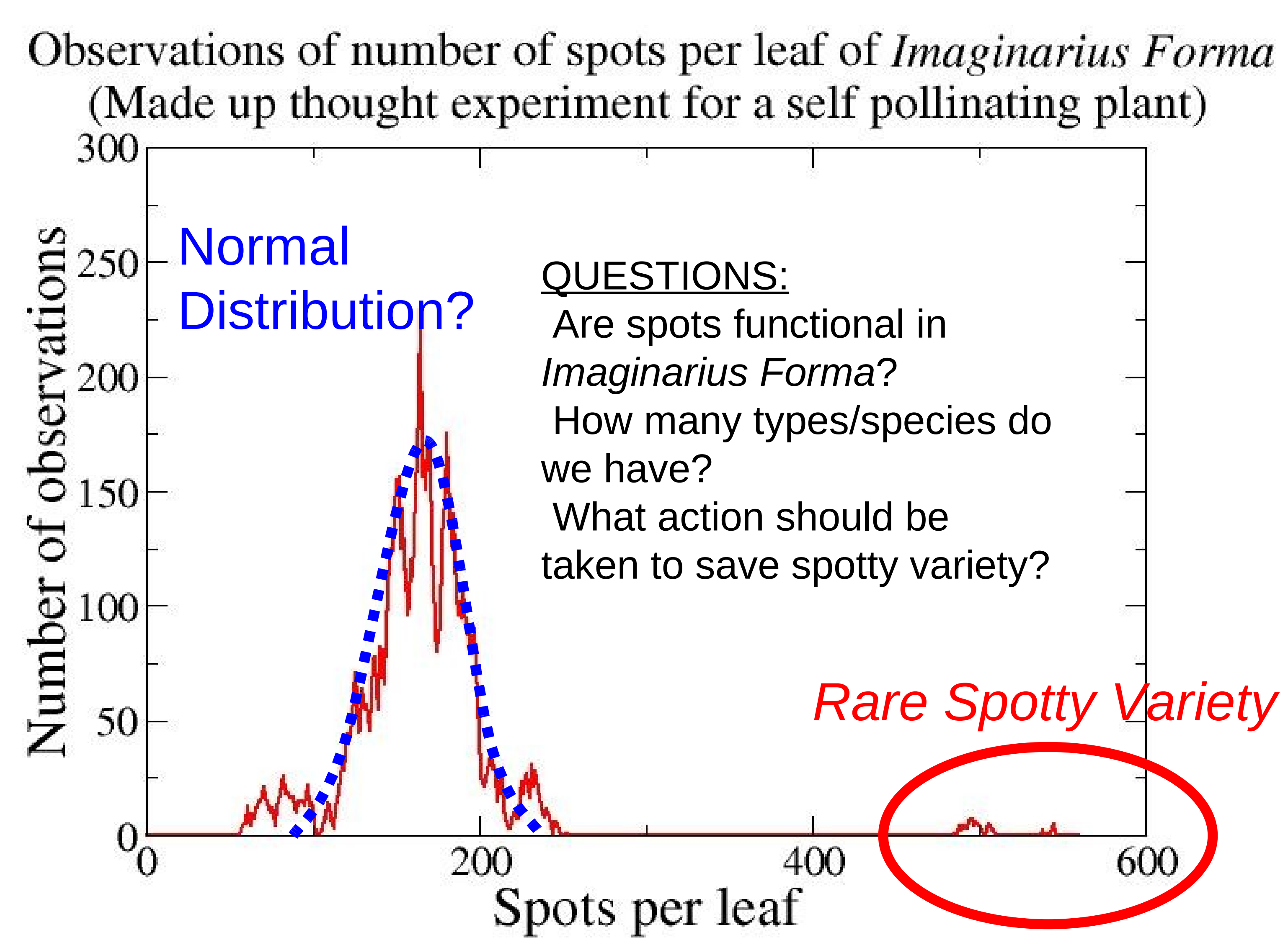
Distribution is (often) **Normal**



But…

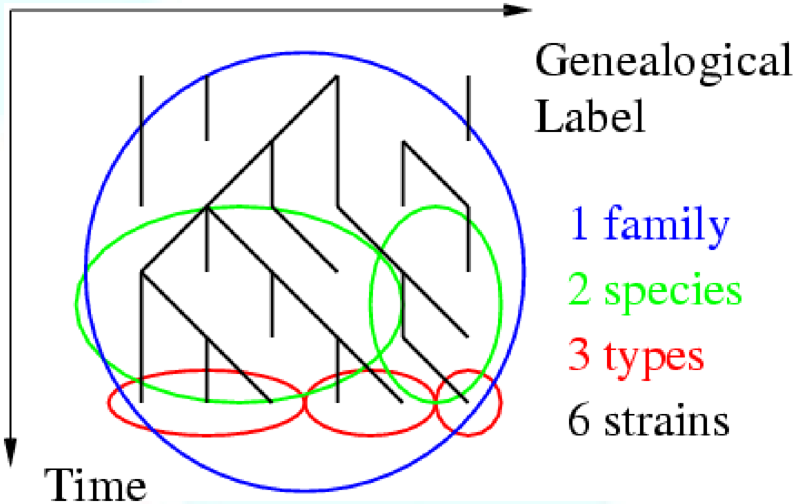
Pattern is (implicitly) produced by **Selection.**

Test Problem



Defining Diversity

- Ecological Sense: “number” of different species or types
- Requires definition of species:
  - *Biological Species concept?*
  - *Phenotypically distinct?*
  - *Genotypic species concept?*



- “Species” don't exist, but individuals form clusters
- Evolution definition of diversity: number of different clusters on a chosen threshold

The Neutral Model

- Assume that all individuals are 'equal'
    - Valid for Phenotypes that do not have function
    - Genotypes, considering the part of the genome that does not code for protein synthesis (12% of Human DNA is variable! *Redon et al. Nature. doi:10.1038/nature05329*)
  - Each individual has the same probability to die (p_k), or give birth (p_b), in a time step
    - For simplicity, assume the total population (N) has reached equilibrium ($p_k = p_b$)
- Mutations (and/or colonisation) can occur, reproduction is asexual

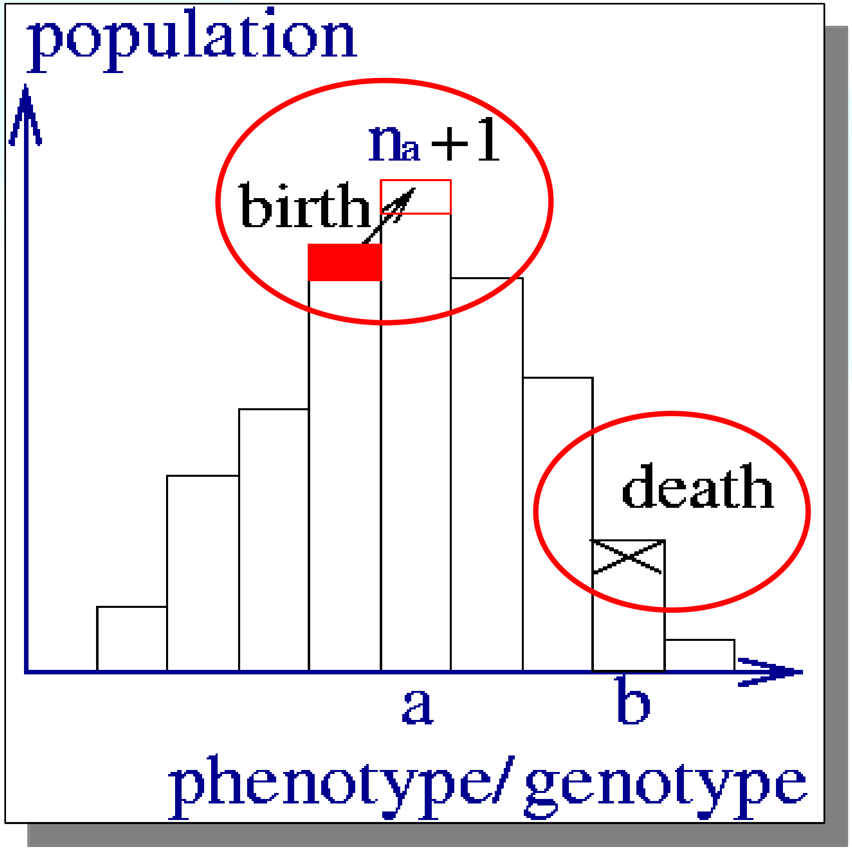
A neutral evolution model

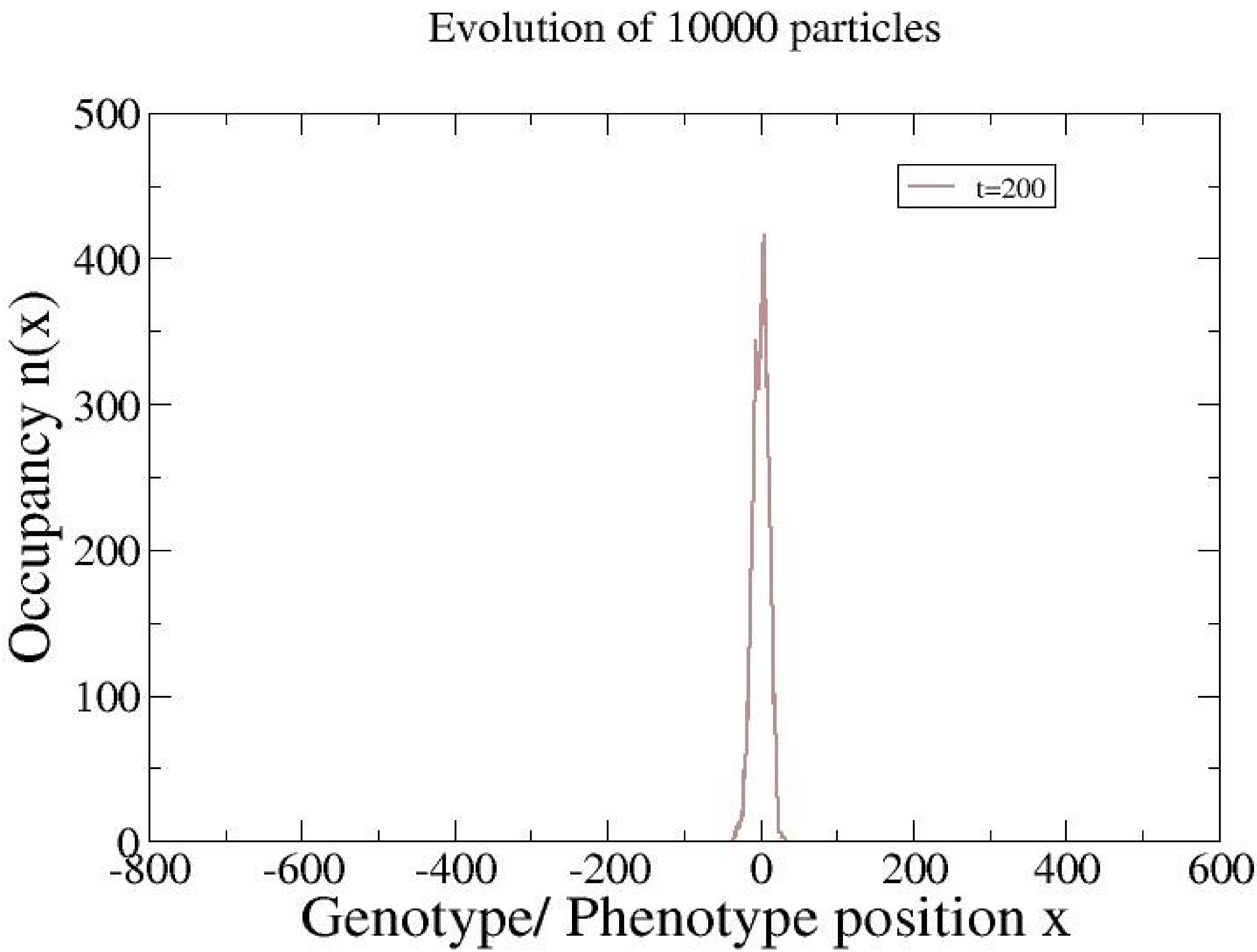
- Consider N individuals each labeled by phenotype position:

TIMESTEP:

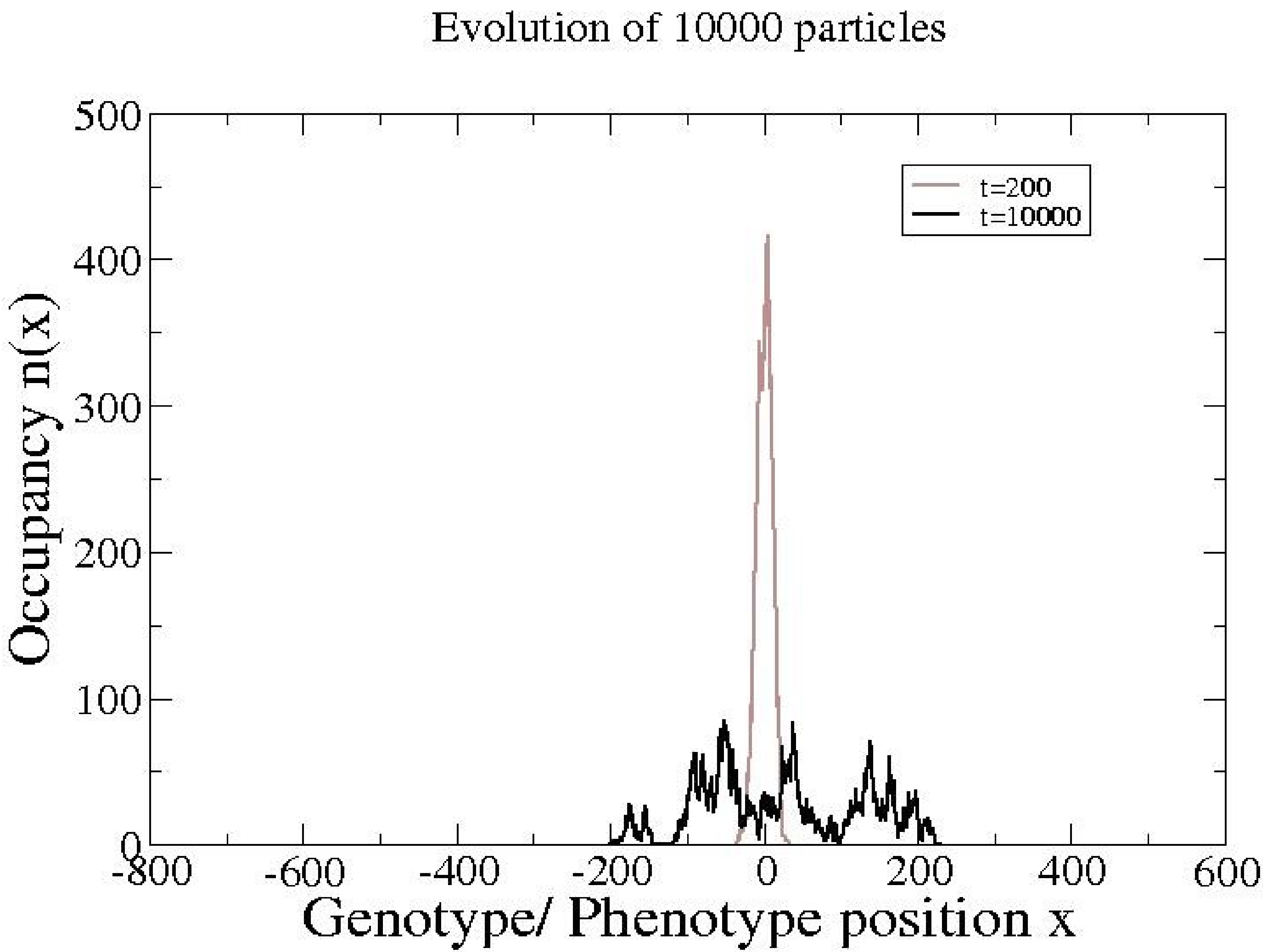
- Pick an individual (from N) and mark it to die.
- Pick an individual (from N) and copy it. With probability p_m Mutate to a similar type.
- Kill the marked individual.

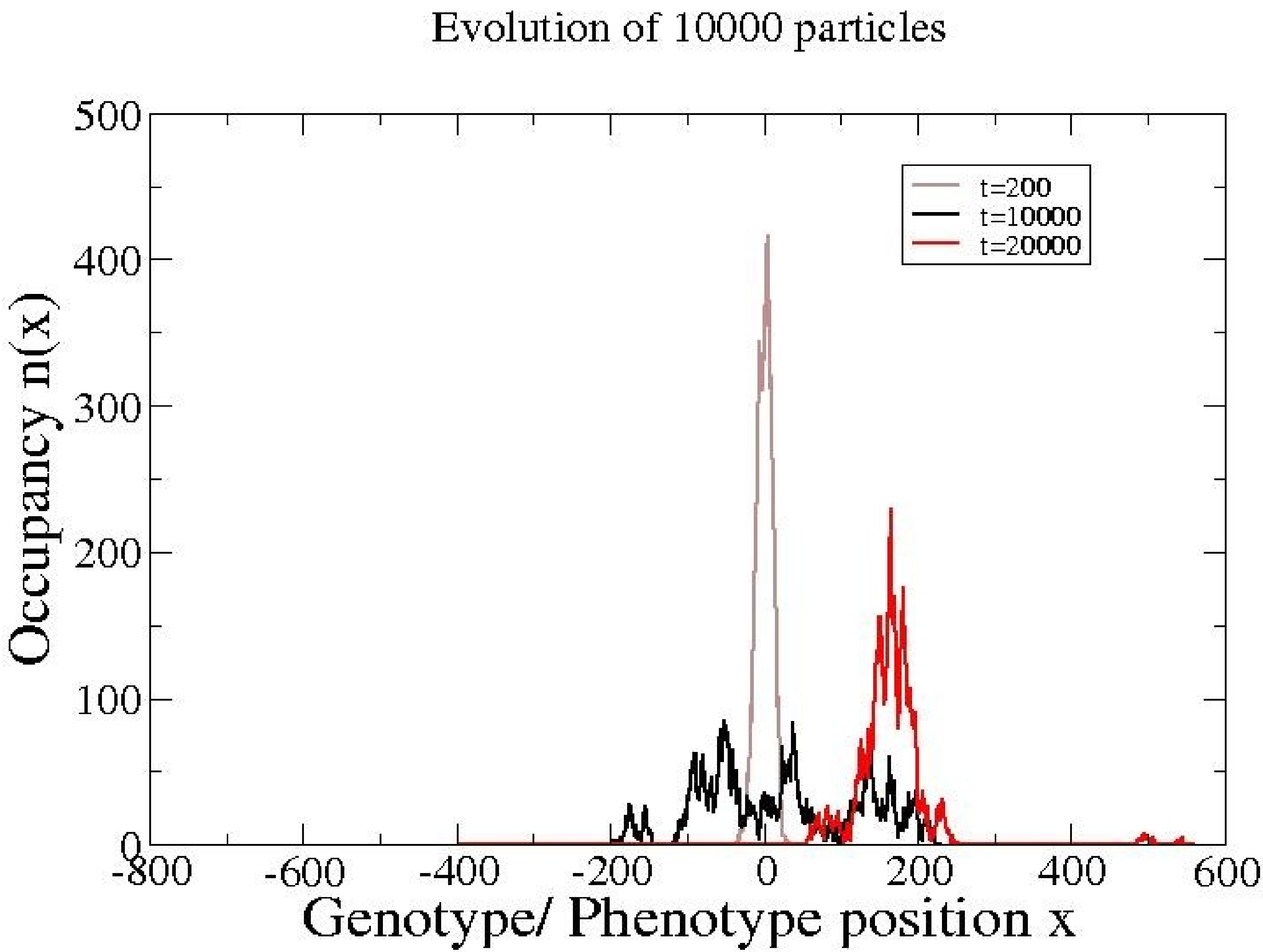
We follow a single neutrally evolving phenotype





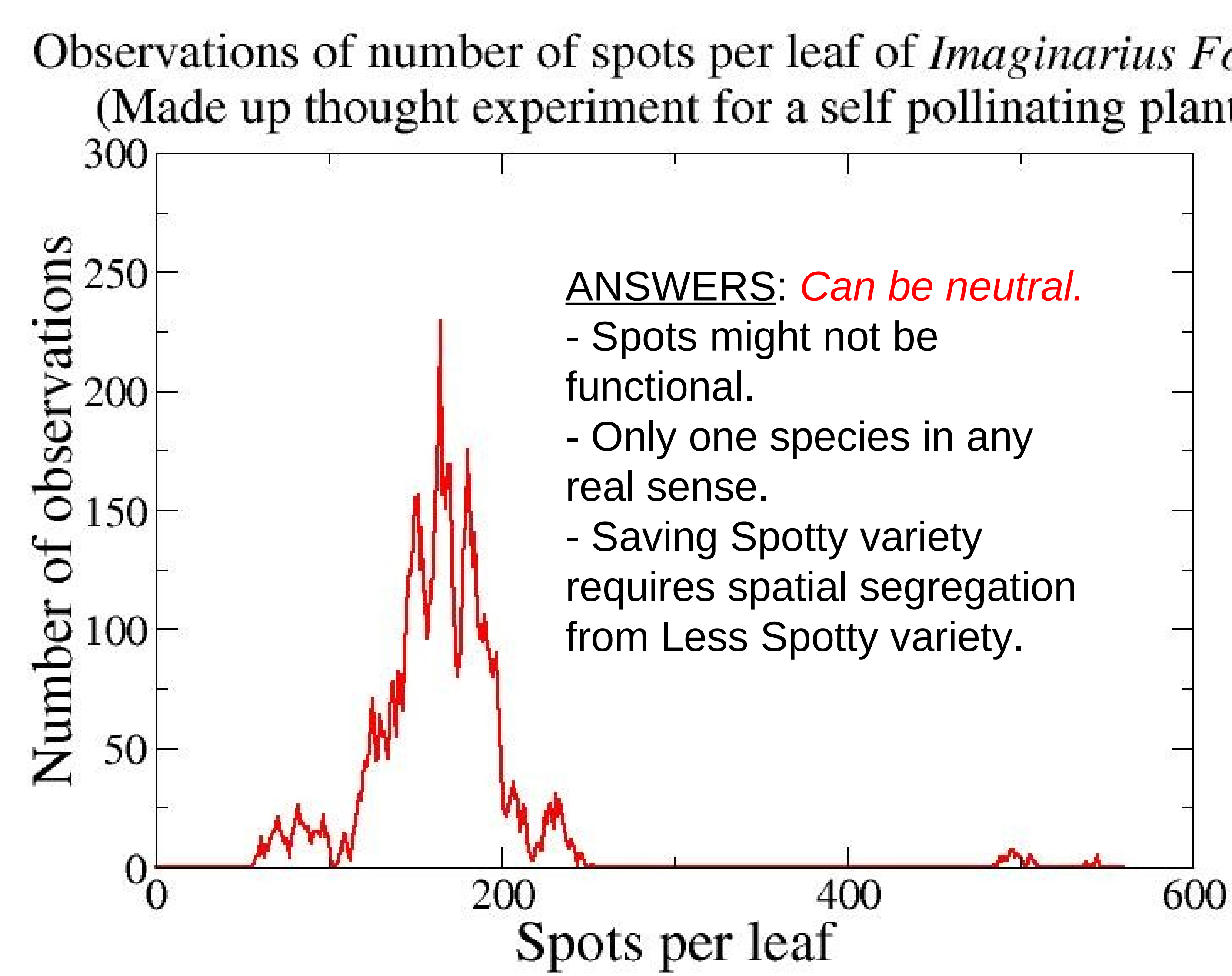
Evolution of 10000 particles
t=200
Occupancy n(x)
Genotype/ Phenotype position x
500
400
300
200
100
0
-800
-600
-400
-200
0
200
400
600


Evolution of 10000 particles
Occupancy n(x)
500
400
300
200
100
0
-800
-600
-400
-200
0
200
400
600
Genotype/ Phenotype position x
t=200
t=10000



Evolution of 10000 particles
Occupancy n(x)
Genotype/ Phenotype position x
t=200
t=10000
t=20000
500
400
300
200
100
0
-800
-600
-400
-200
0
200
400
600

Test Problem



ANSWERS: *Can be neutral.*
- Spots might not be functional.
- Only one species in any real sense.
- Saving Spotty variety requires spatial segregation from Less Spotty variety.

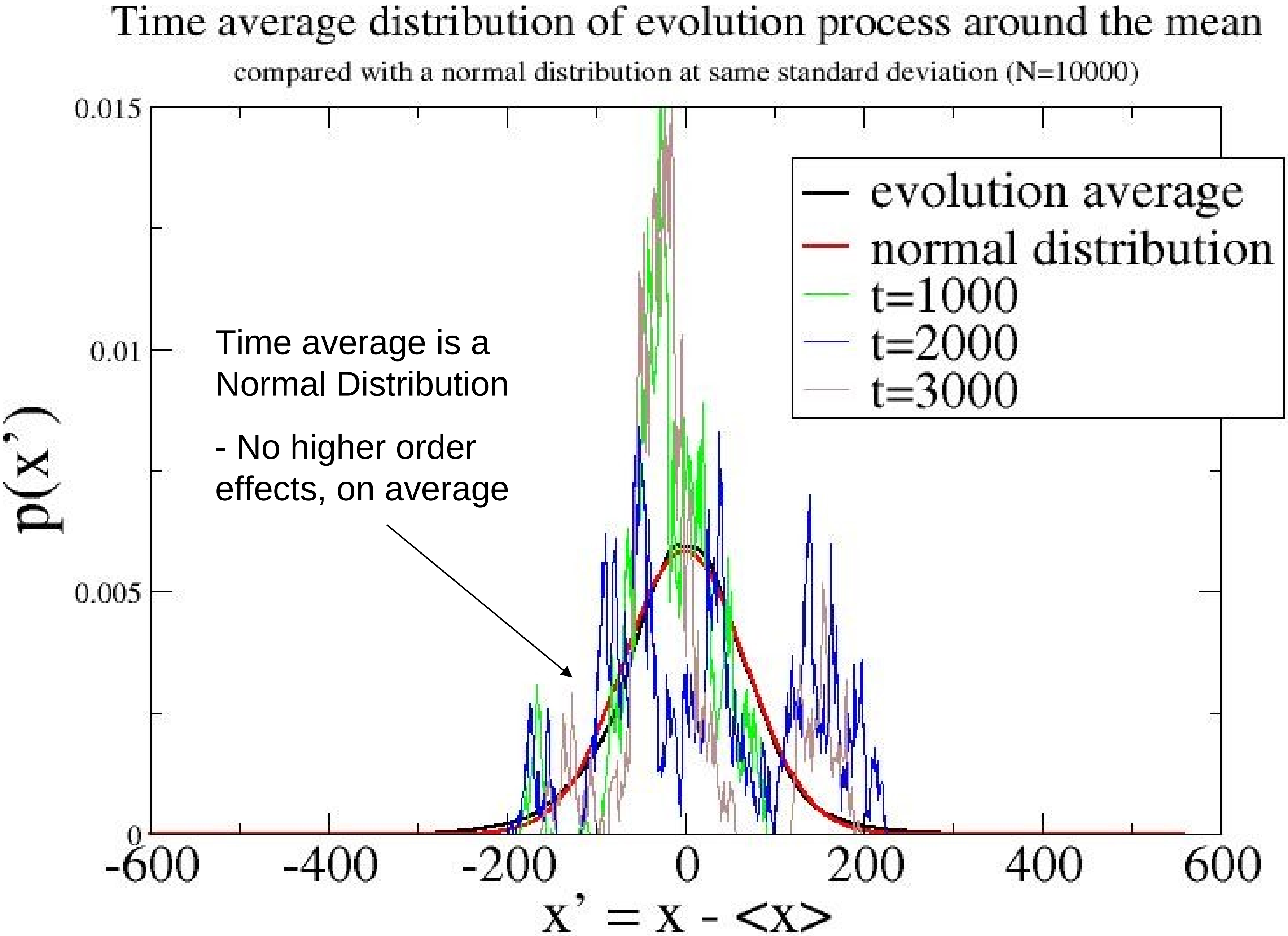
Solution

- Simplify the model – consider only first two moments of the distribution
- Peak is a Gaussian distribution of area *1* with dynamic mean μ and width w.

- Select death location x
- Select birth location y, mutated by 1 with probability P_m
- Remove $1/N$ from death location and place at birth location
- Update μ and w

Solution method

- Write down equations for the change in the mean and the variance of the peak position *μ* and the width *w*
- Take continuous limit to obtain Stochastic Differential Equations
- Solve!
- This works because the distribution is normal only when *averaged over time*, measured *relative* to the *current mean position*



Time average is a Normal Distribution

- No higher order effects, on average

Neutral Clustering results

- Mean width:

$$\langle w \rangle = \sqrt{\frac{N p_m \pi}{8}}$$

Fluctuations in w also ~ $N^{0.5}$

- Position:

$$\langle x \rangle_{\mathrm{RMS}} = \sqrt{T(p_m + w^2)} \quad \sqrt{\frac{p_m T}{2}}$$

With time in generations… $\langle x \rangle_{RMS}$ is independent of N !

Neutral evolution results

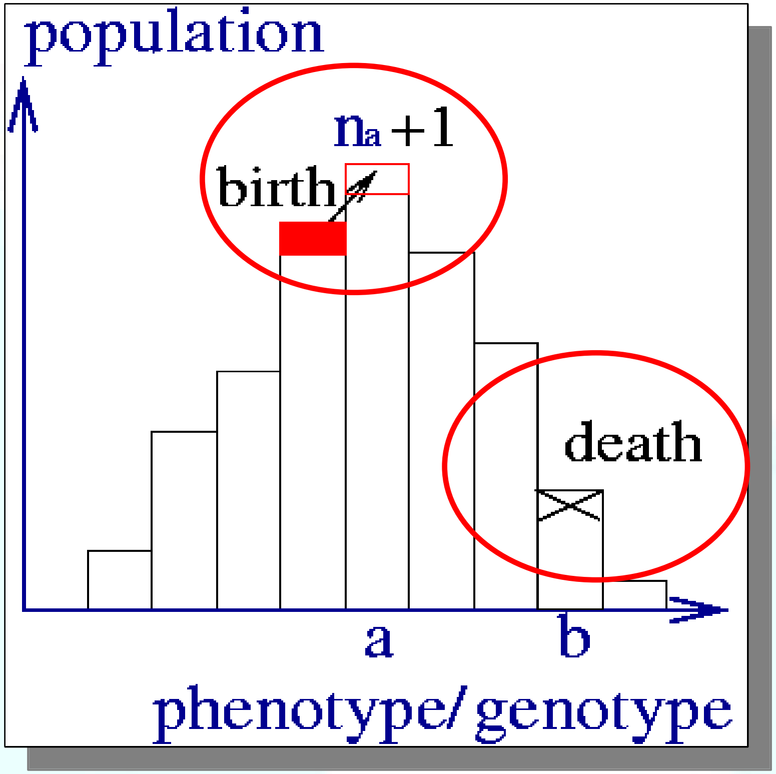
- Selection produces a stable peak, neutrality produces an *unstable* peak.
- Characteristic peak width, but large fluctuations *(multiple clusters).*
- Evolution speed *independent* of population size!
- (evolution) provides null model for expected (ecological) phenotype distributions: *non-trivial* distributions are probable.
- Genotype Distribution evolves similarly….
- As do sexual populations

Reference

Lawson and Jensen:
"Neutral Evolution as Diffusion in phenotype space: reproduction with mutation but without selection"
*Physics Review Letters, March 07 (**98**, 098102)*
www.arxiv.org/abs/q-bio/0609009

Thank you for your attention!

Solution: first try (1)



$$p_b(a) = \frac{n_a}{N}(1 - p_m) + \frac{p_m}{2}\frac{n_{a+1} + n_{a-1}}{N}$$

$$p_k(a) = \frac{n_a}{N}$$

Solution: first try (2)

- Consider average behaviour:

$$\langle n_a(t+1) - n_a(t) \rangle = p_b(a) - p_k(a)$$

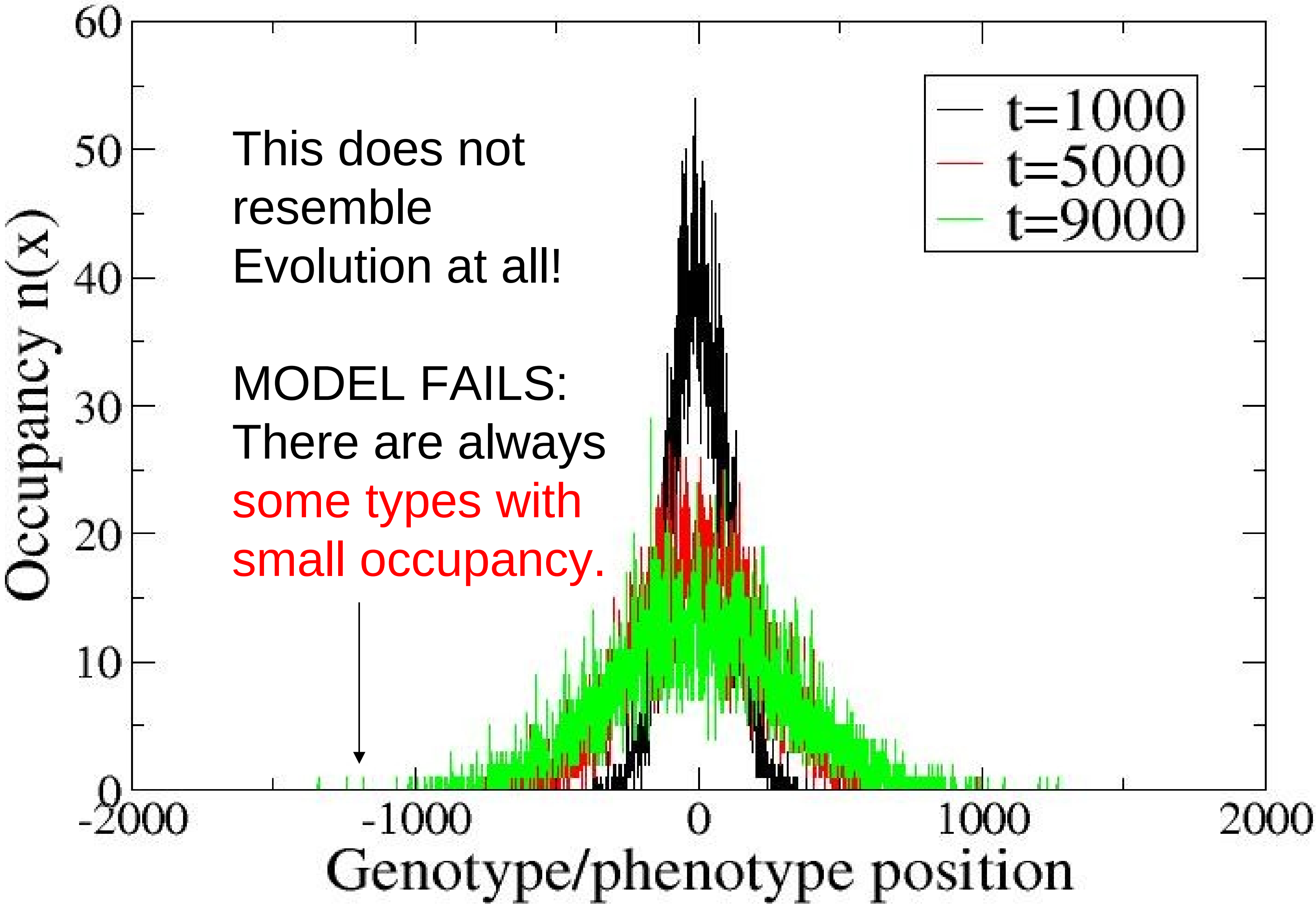
  – Expect this to be valid when N large?

- This becomes:

$$\langle n_a(t+1) - n_a(t) \rangle = \frac{p_m}{2N}\left[n_{a+1}(t) + n_{a-1}(t) - 2n_a(t) \right]$$

- This is just the diffusion of N particles!

Diffusion of 10000 particles



Solving for the width

Mutation distance → p^*; Generation time → dT

$$d(w^2) = \left(p^* - \frac{2w^2}{N}\right)dT \qquad + \frac{2w^2}{\sqrt{N}}\,dW$$

dW is Random, mean 0

Change in variance (in a timestep) = Deterministic part + Noise part

Solution at steady state:

$$p(w)dw = \frac{(Np_m)^2}{2w^5} e^{\frac{Np_m}{2w^2}} dw$$

Power-law decay at large w