Adaptive Dynamics and Evolving Biodiversity

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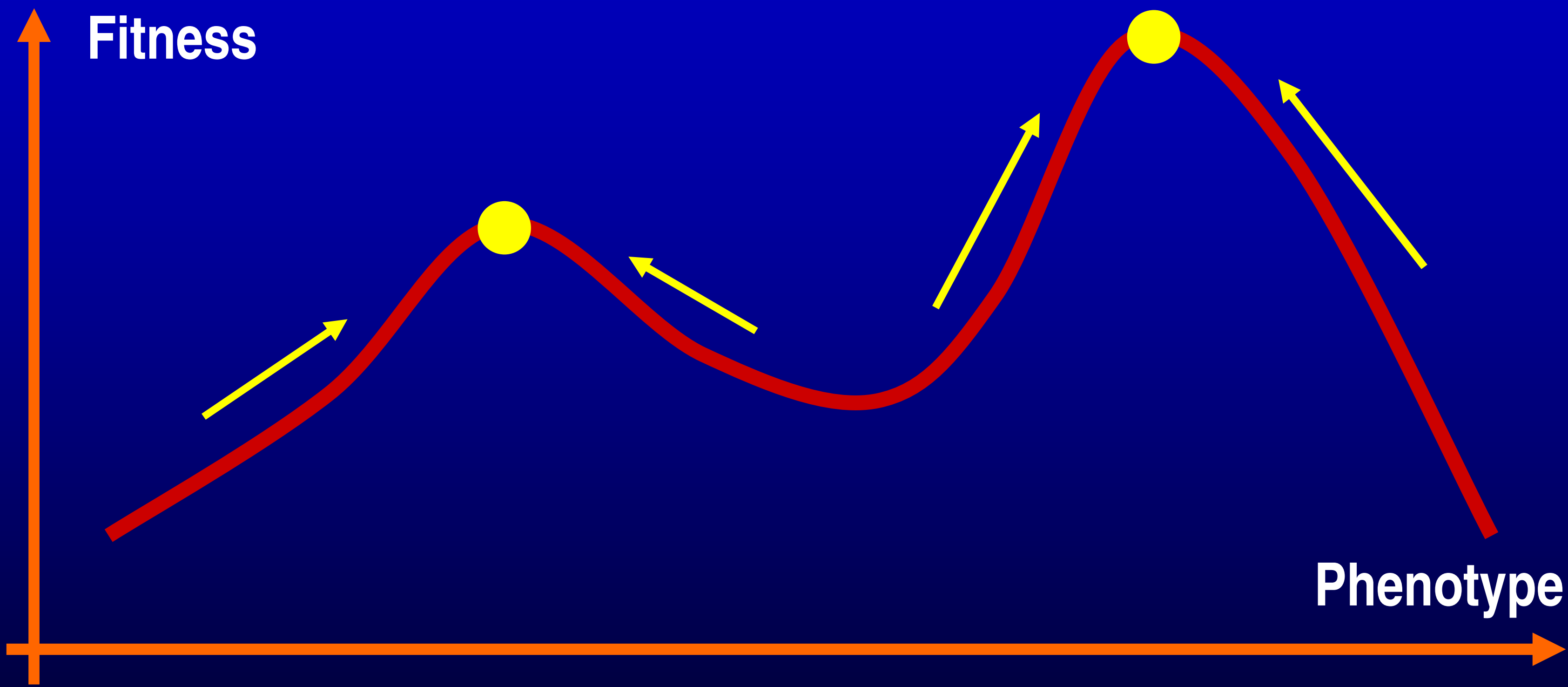
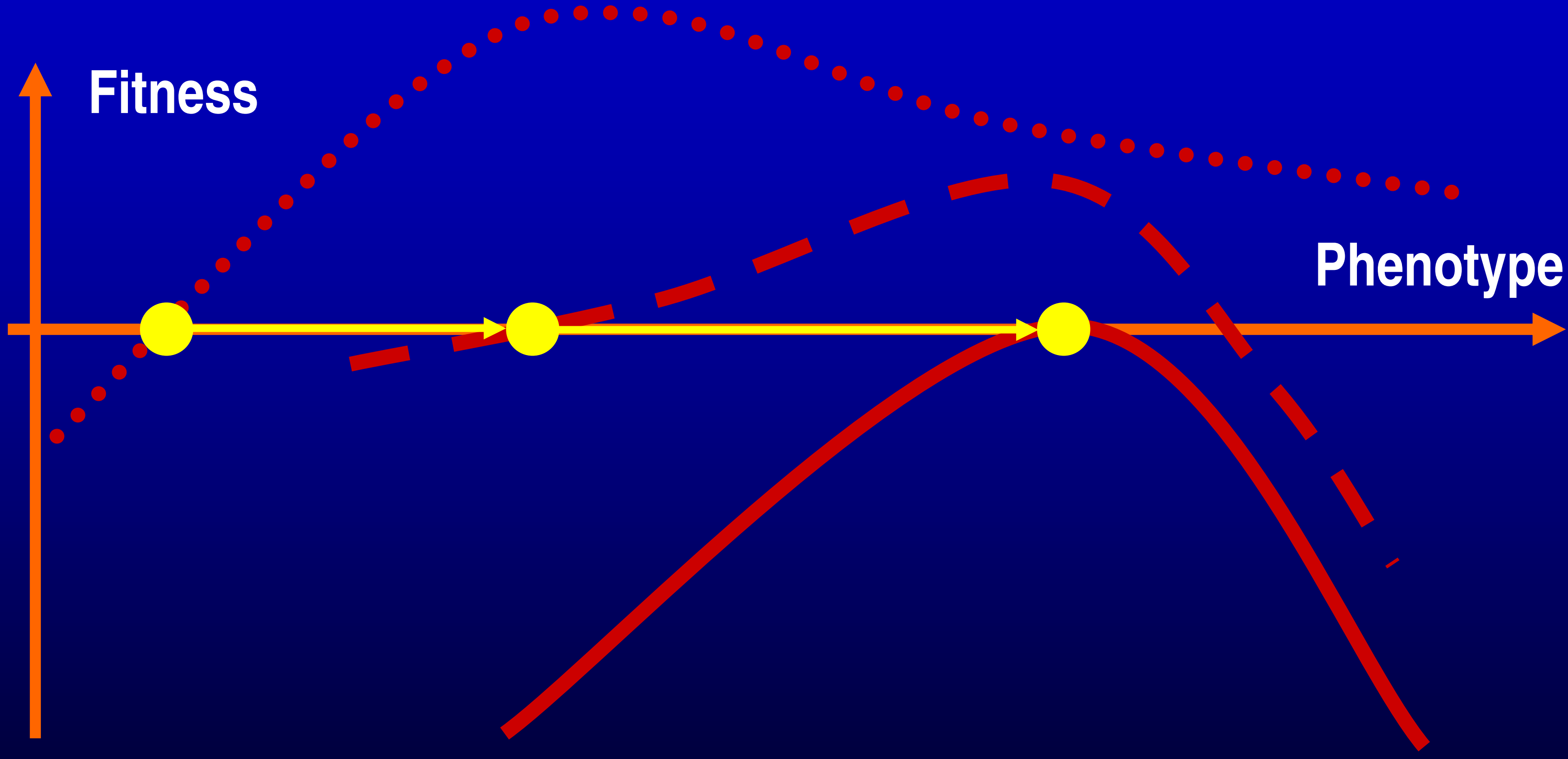
Evolutionary Optimization



Envisaging evolution as a hill-climbing process on a static fitness landscape is attractively simple, but essentially wrong for most systems.

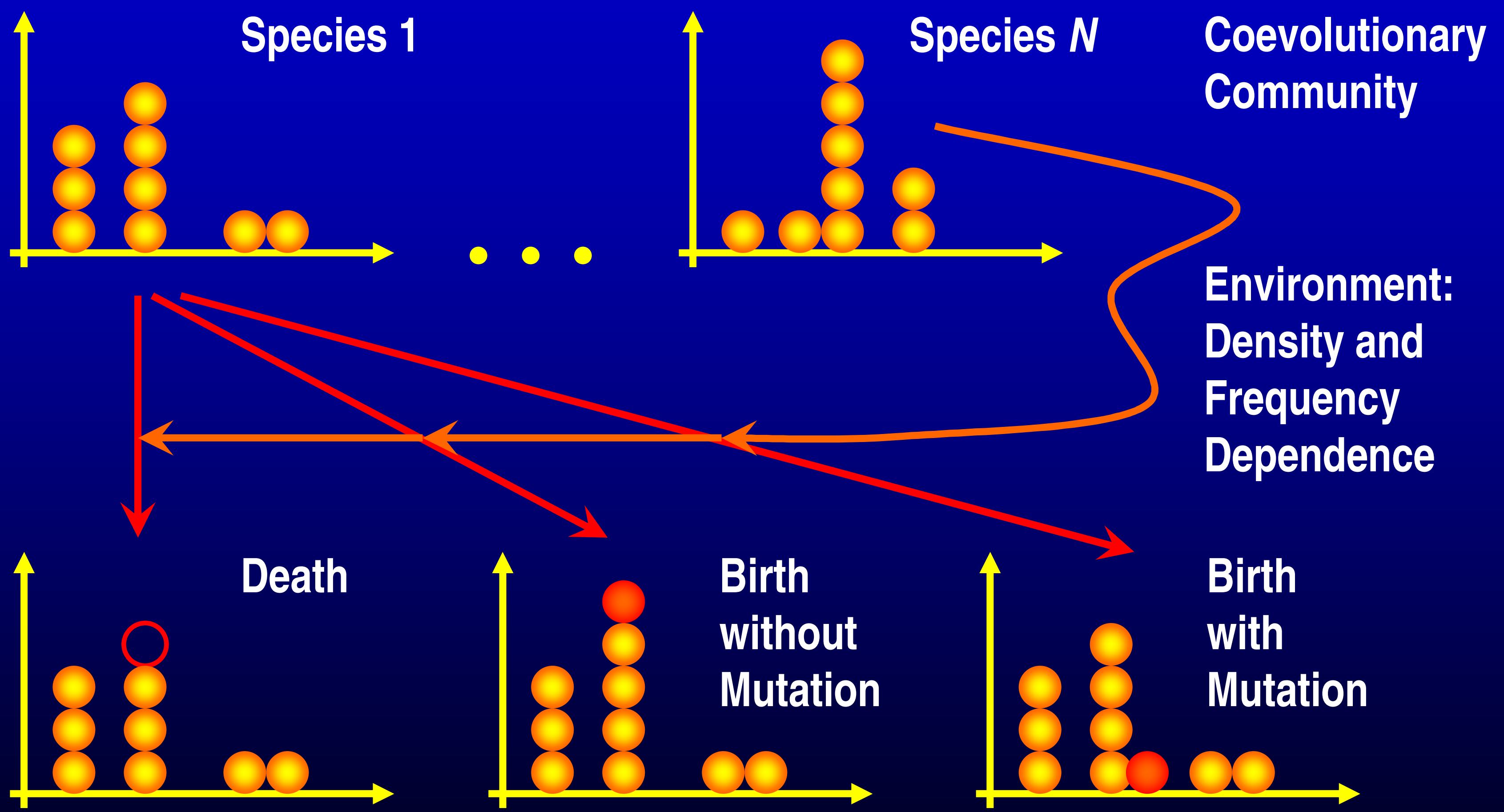
Frequency-Dependent Selection



Fitness landscapes change in dependence on a population's current composition.

1 Models of Adaptive Dynamics

Birth-Death-Mutation Processes



Individual-based Evolutionary Dynamics

Polymorphic and Stochastic

Dieckmann (1994)

- **Generalized Replicator Equation**

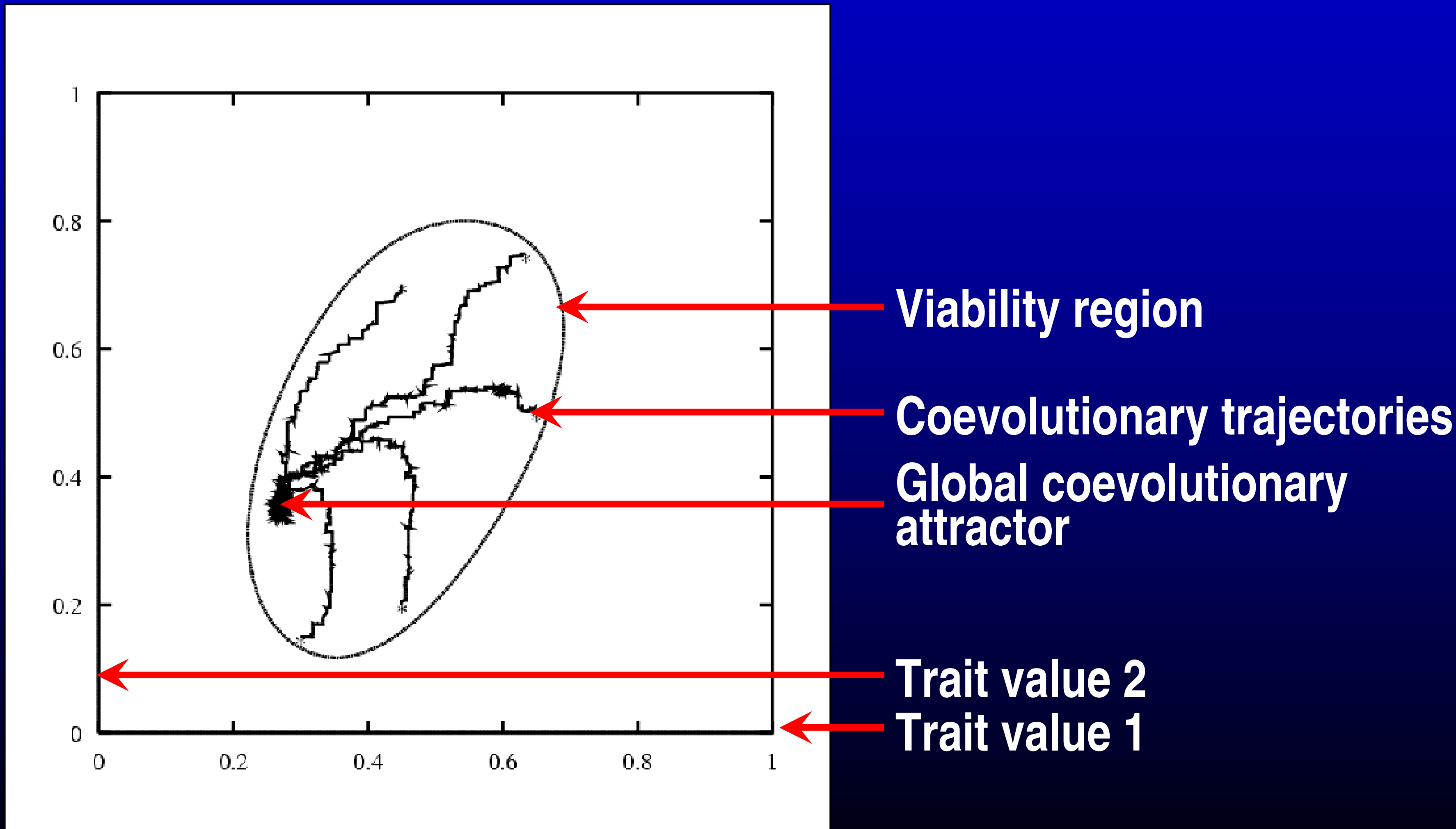
$$\frac{d}{dt} P(p) = \int \left[w(p \mid p') P(p') - w(p' \mid p) P(p) \right] dp'$$

$$w(p' \mid p) = \sum_{i=1}^{N} \int \left[d_i(s_i', p) p_i(s_i') \Delta(p_i - \delta_{s_i'} - p_i') \prod_{j \neq i} \Delta(p_j' - p_j) \right.$$

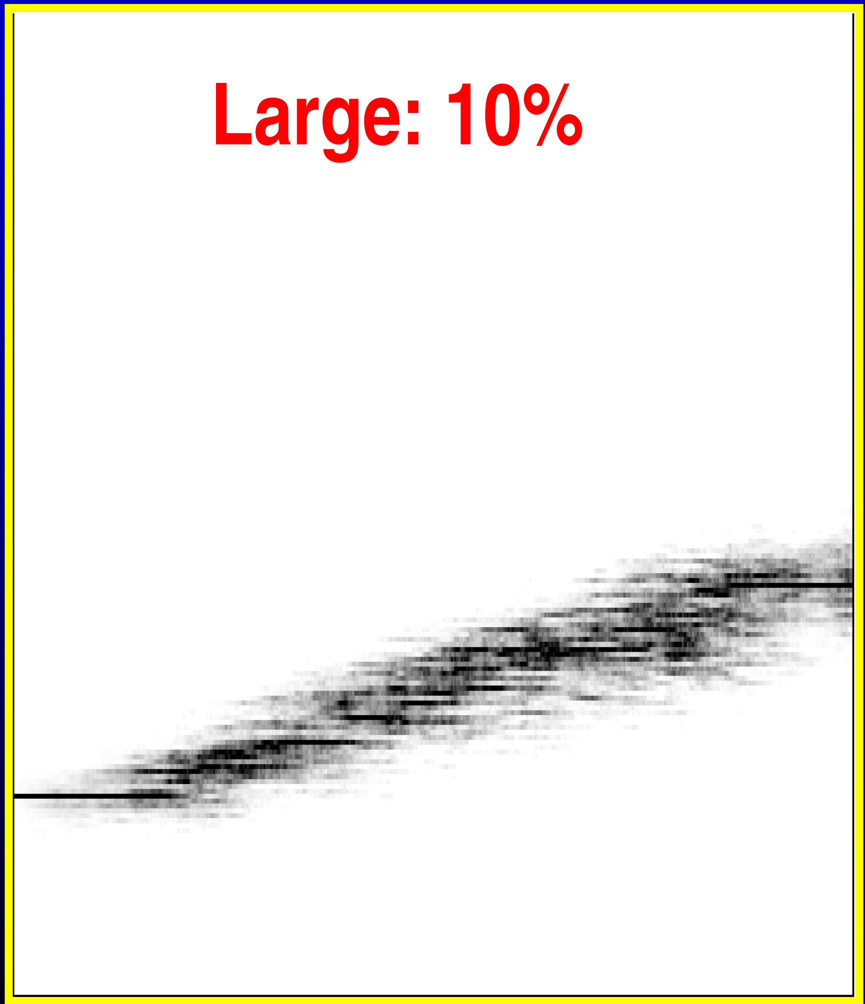
$$\left. + \int b_i(s_i, p) p_i(s_i) B_i(s_i', s_i) \, ds_i \, \Delta(p_i + \delta_{s_i'} - p_i') \prod_{j \neq i} \Delta(p_j' - p_j) \right] ds_i'$$

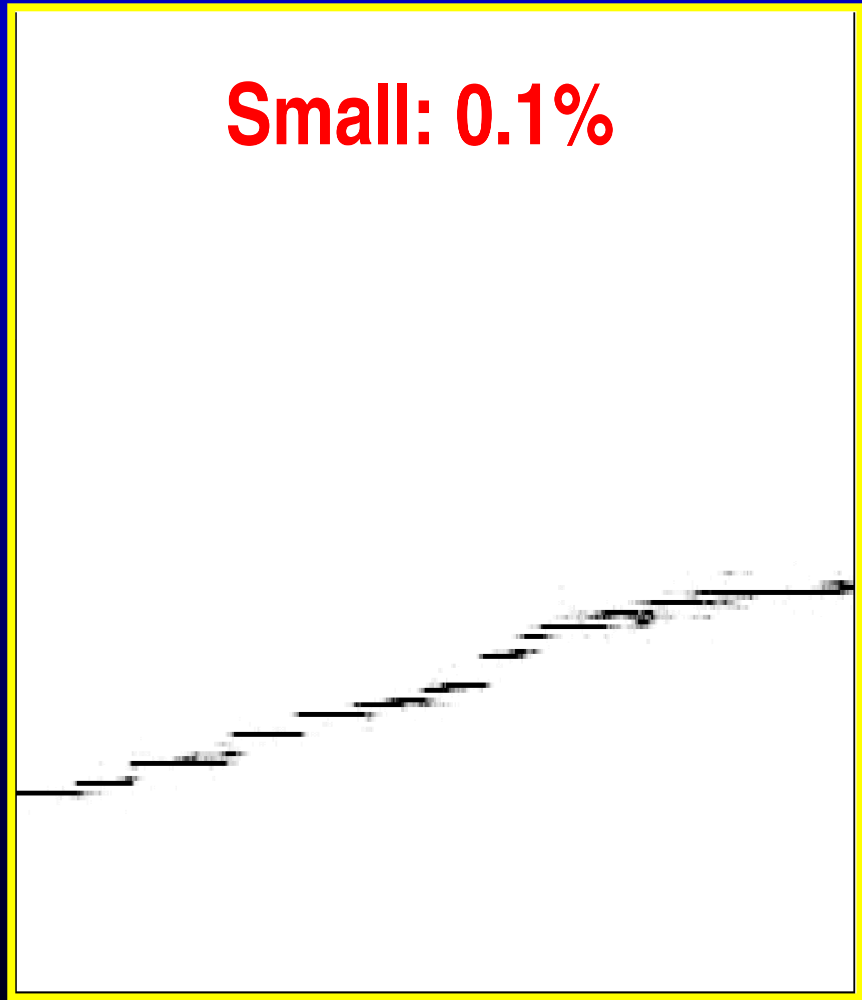
Measure-valued stochastic process in a space of atomic distributions.

Individual-based Coevolution



Effect of Mutation Rates



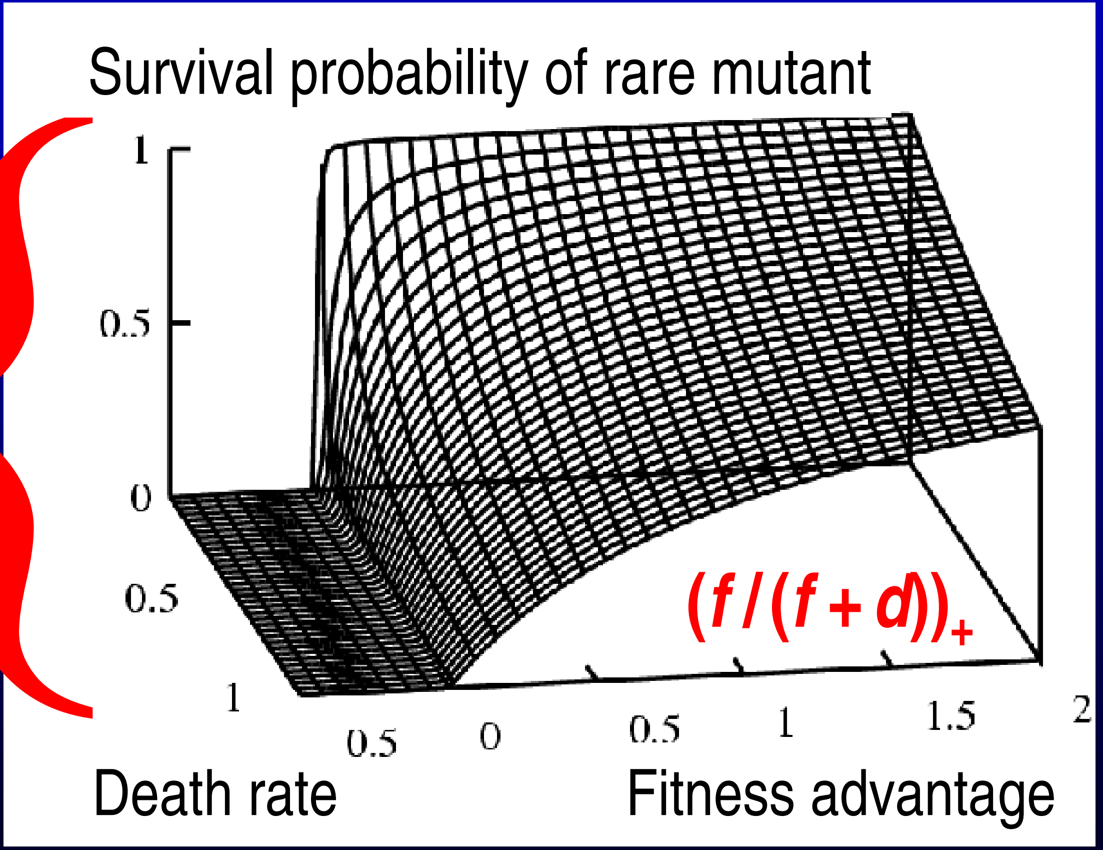


Probability for a Trait Substitution

❶ **Mutation**
population dynamics

❷ **Invasion**
branching process theory

❸ **Fixation**
invasion implies fixation



Random Walk Models

Monomorphic and Stochastic

Dieckmann & Law (1996)

- **Master Equation**

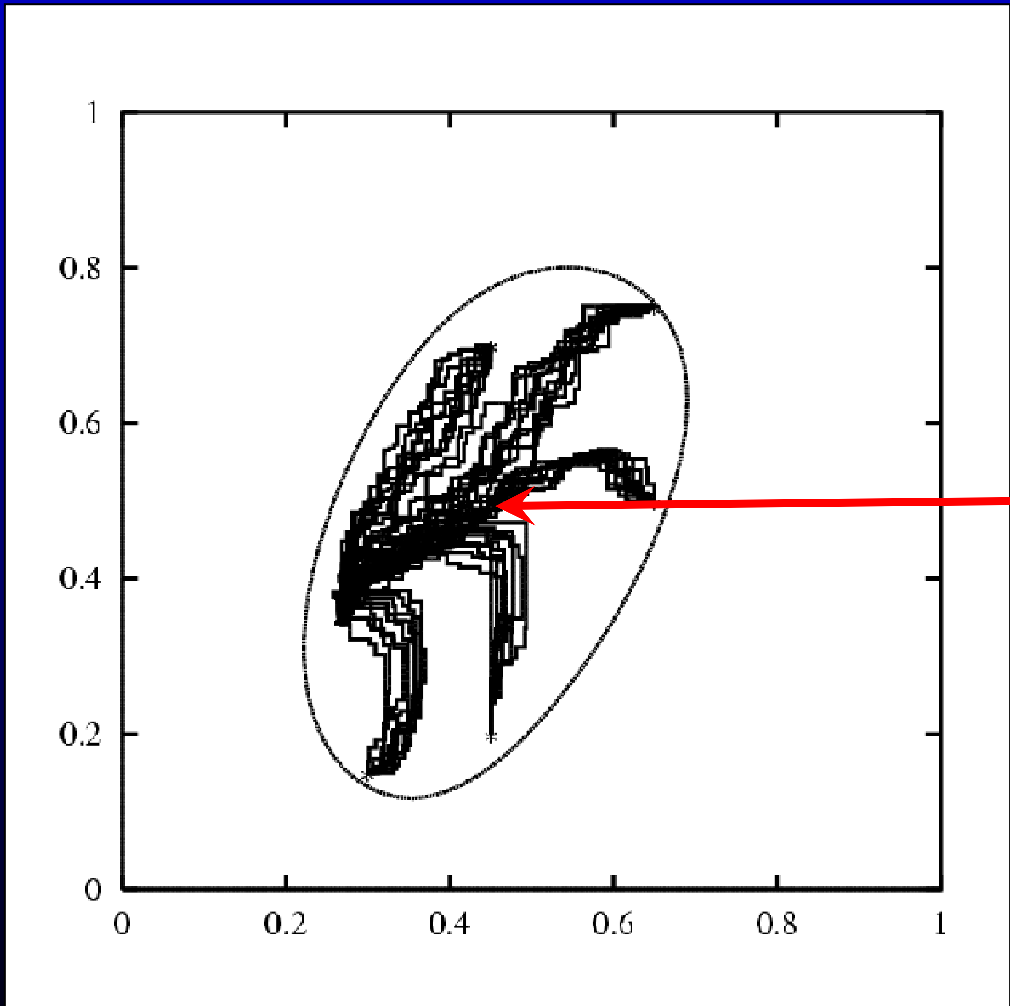
$$\frac{d}{dt}P(s) = \int \left[w(s \mid s')P(s') - w(s' \mid s)P(s) \right] ds'$$

$$w(s' \mid s) = \sum_{i=1}^{N} w_i(s_i', s) \prod_{j \neq i} \delta(s_j' - s_j)$$

$$w_i(s_i', s) = \mu_i b_i(s_i, s) n(s) M(s_i - s_i') \cdot f_i(s_i', s) / b_i(s_i', s)$$

Real-valued stochastic process in trait space.

Random Walks in Trait Space



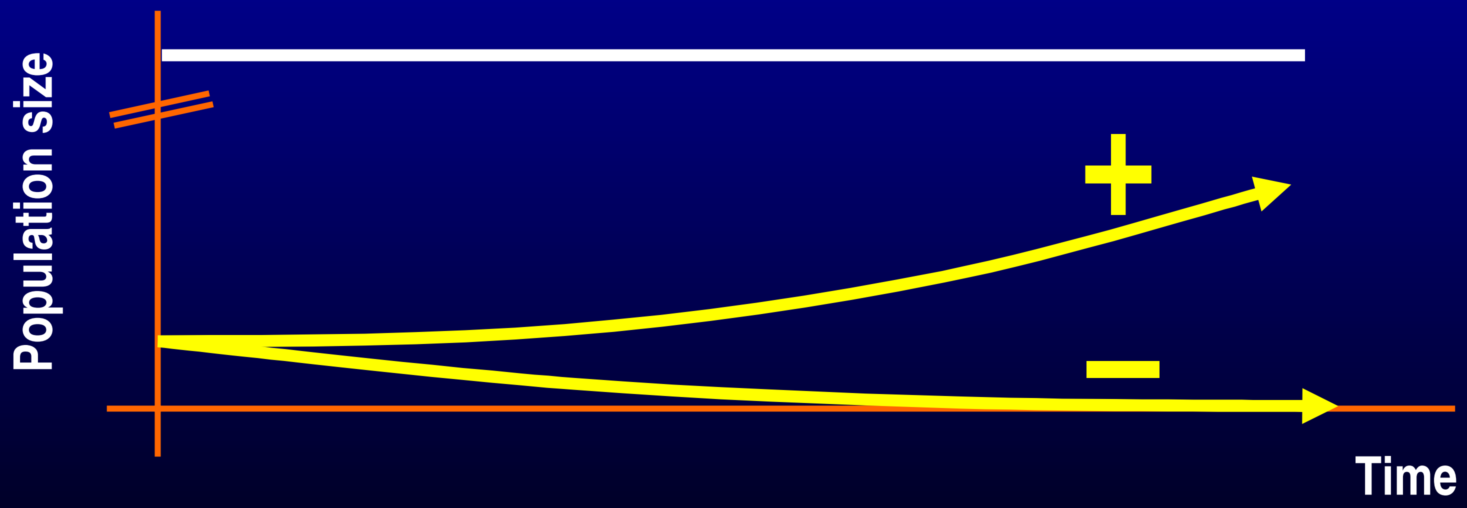
Bundles of coevolutionary trajectories

Invasion Fitness

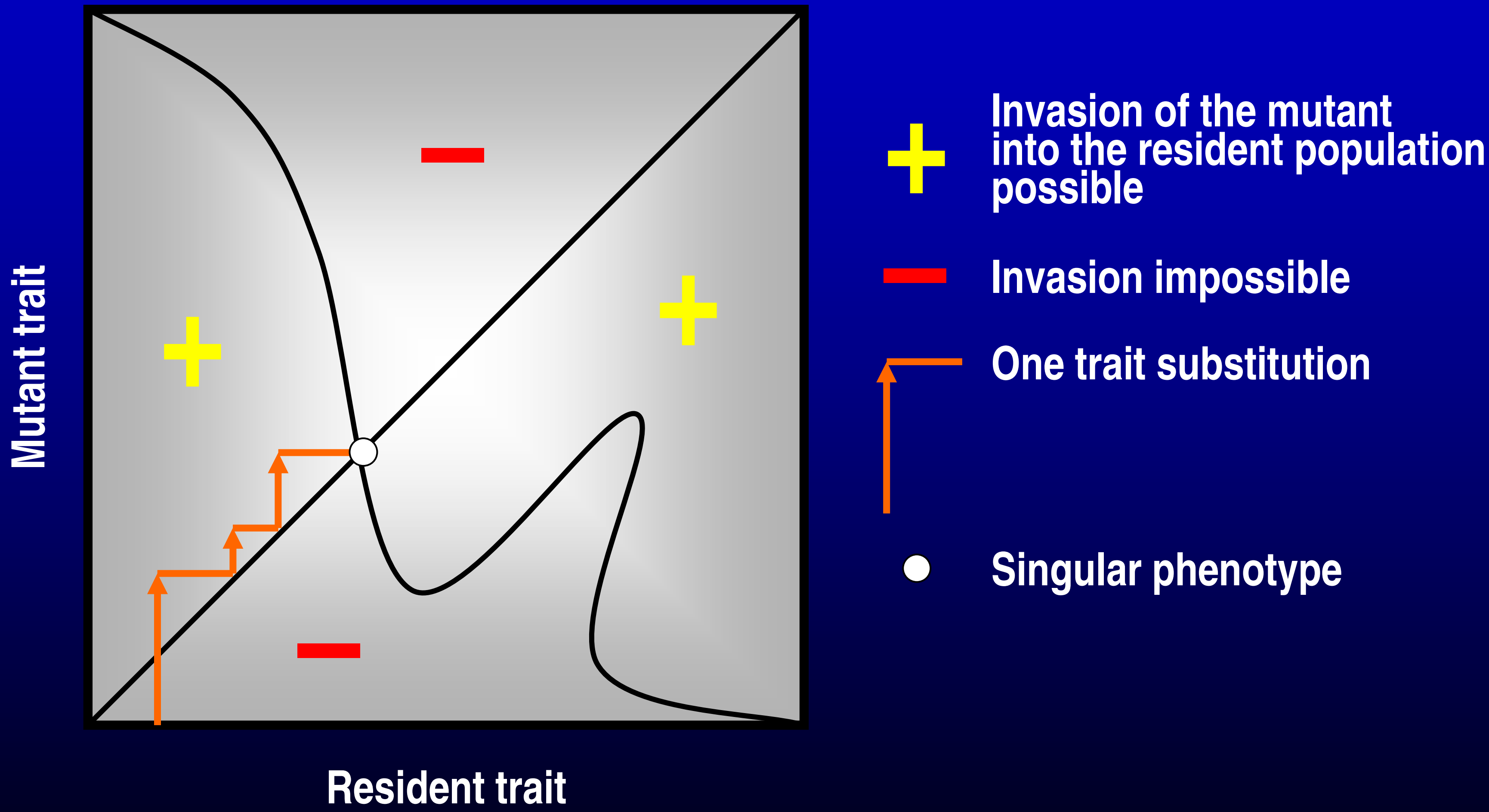
Metz *et al.* (1992)

Definition

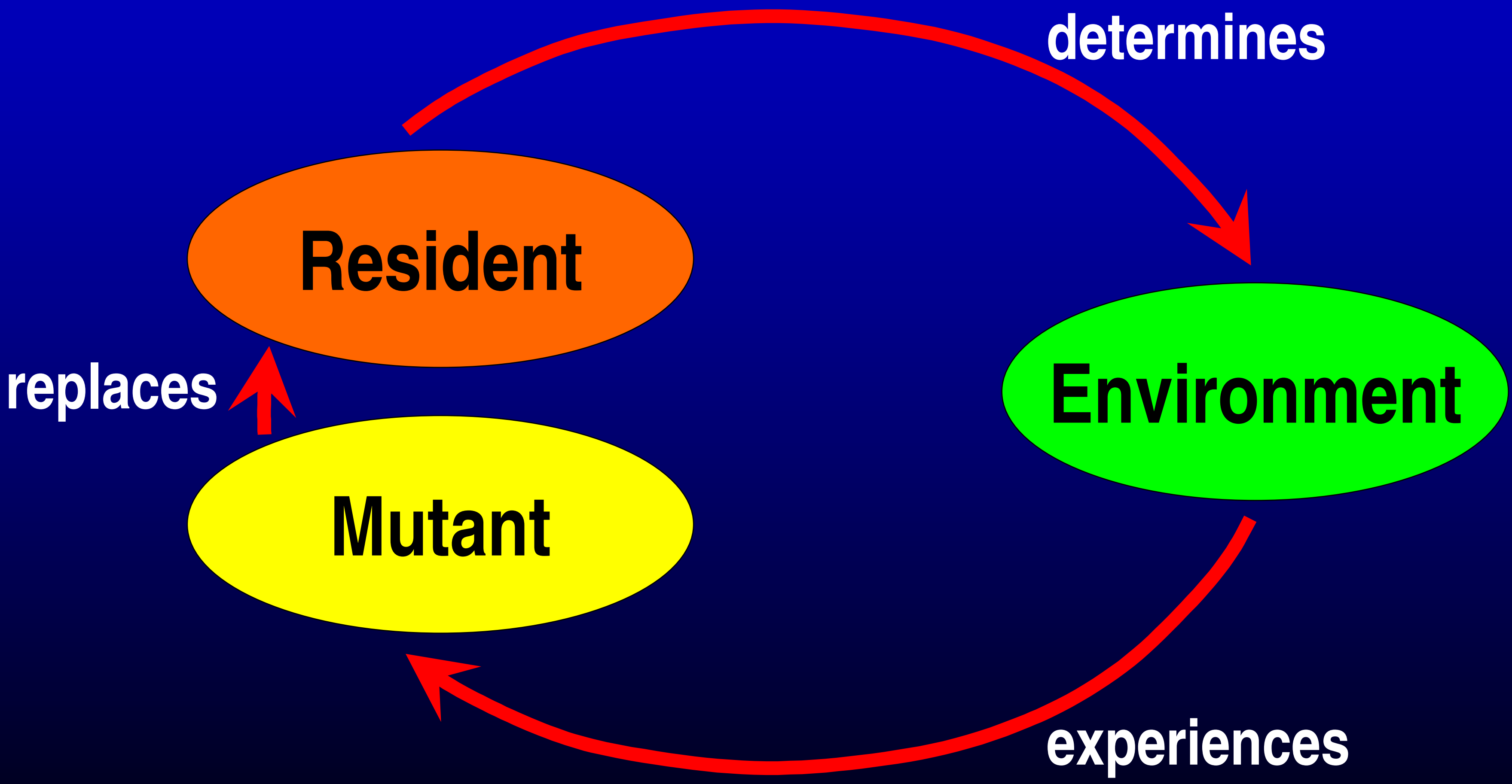
Initial per capita growth rate of a small mutant population within a resident population at ecological equilibrium.



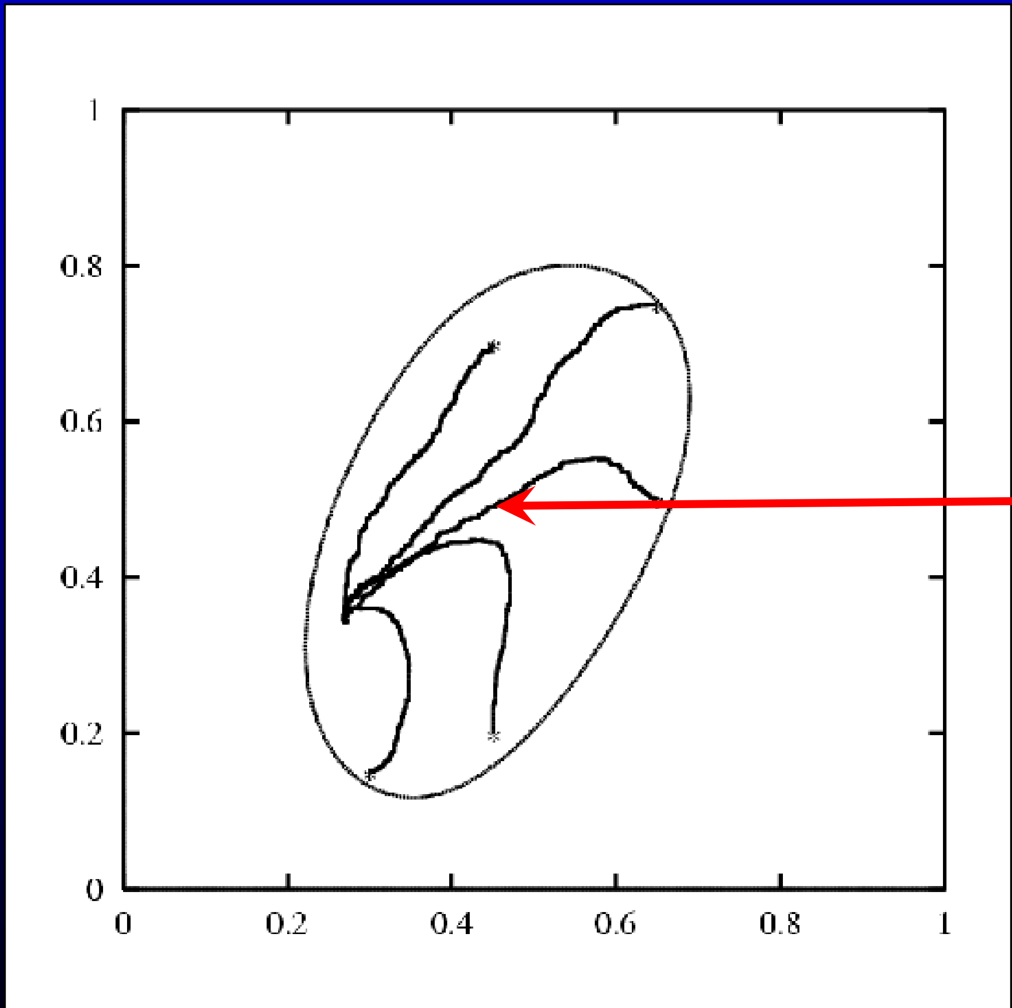
Pairwise Invasibility Plots (PIPs)



Environmental Feedback



Average of Random Walks



Mean
coevolutionary trajectories

Hill-climbing on Adaptive Landscapes

Monomorphic and Deterministic

Dieckmann & Law (1996)

- Canonical equation of adaptive dynamics

$$\frac{d}{dt} s_i = \frac{1}{2} \mu_i \sigma_i^2 n_i \frac{\partial}{\partial s_i'} f(s_i', s_i)\Big|_{s_i' = s_i}$$

evolutionary rates

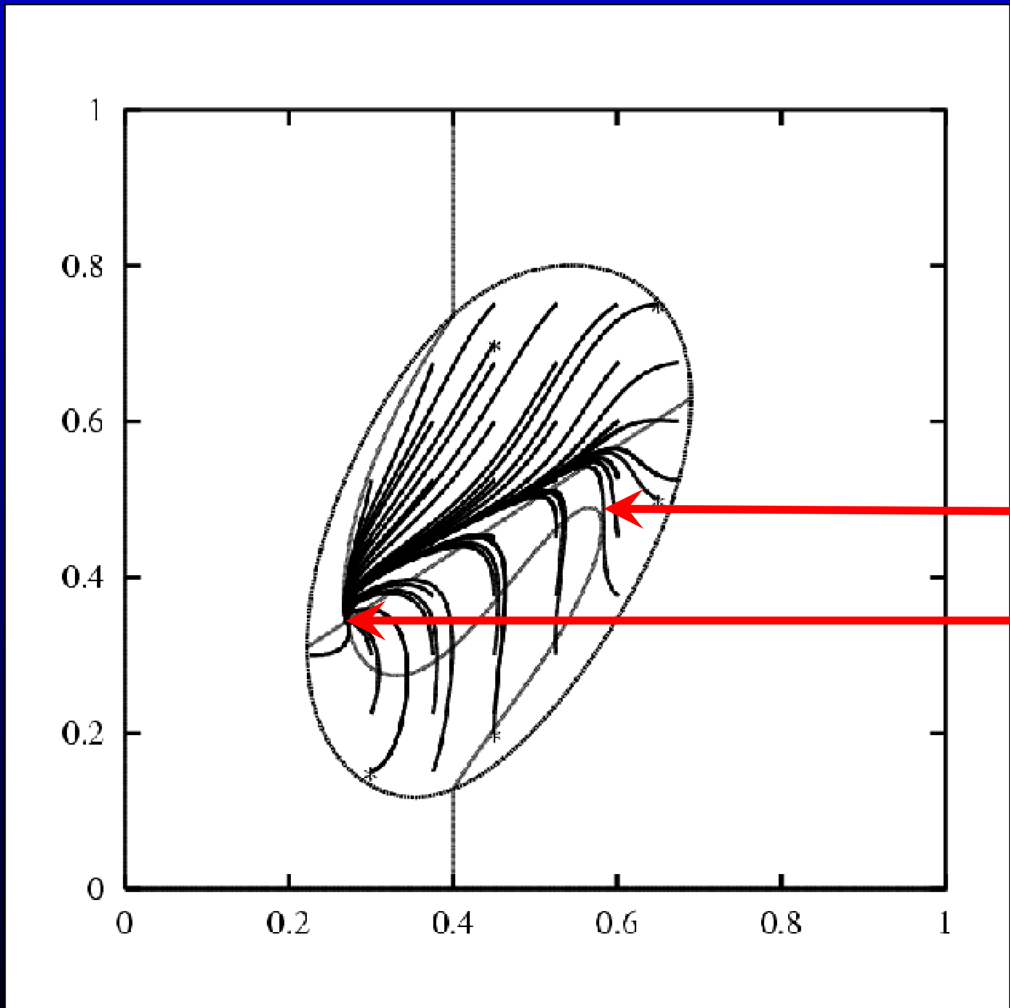
mutation probability

mutation variance

population size

invasion fitness

ODE Approximation



Coevolutionary isoclines

Global coevolutionary attractor

Reaction-Diffusion Models

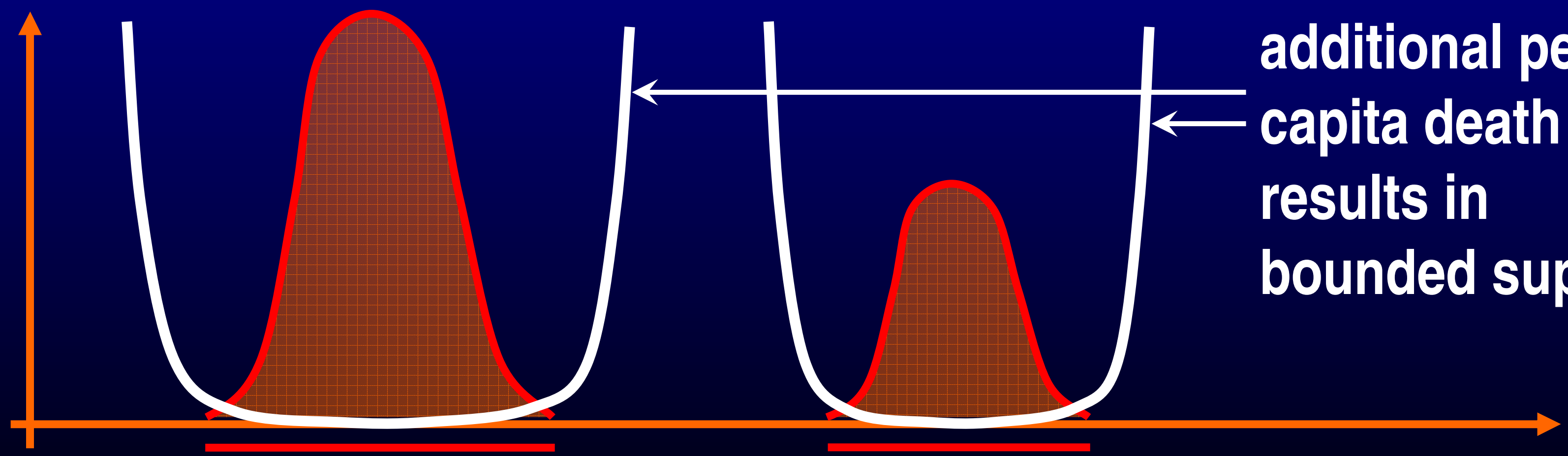
Polymorphic and Deterministic

Dieckmann (in preparation)

- **Kimura limit**

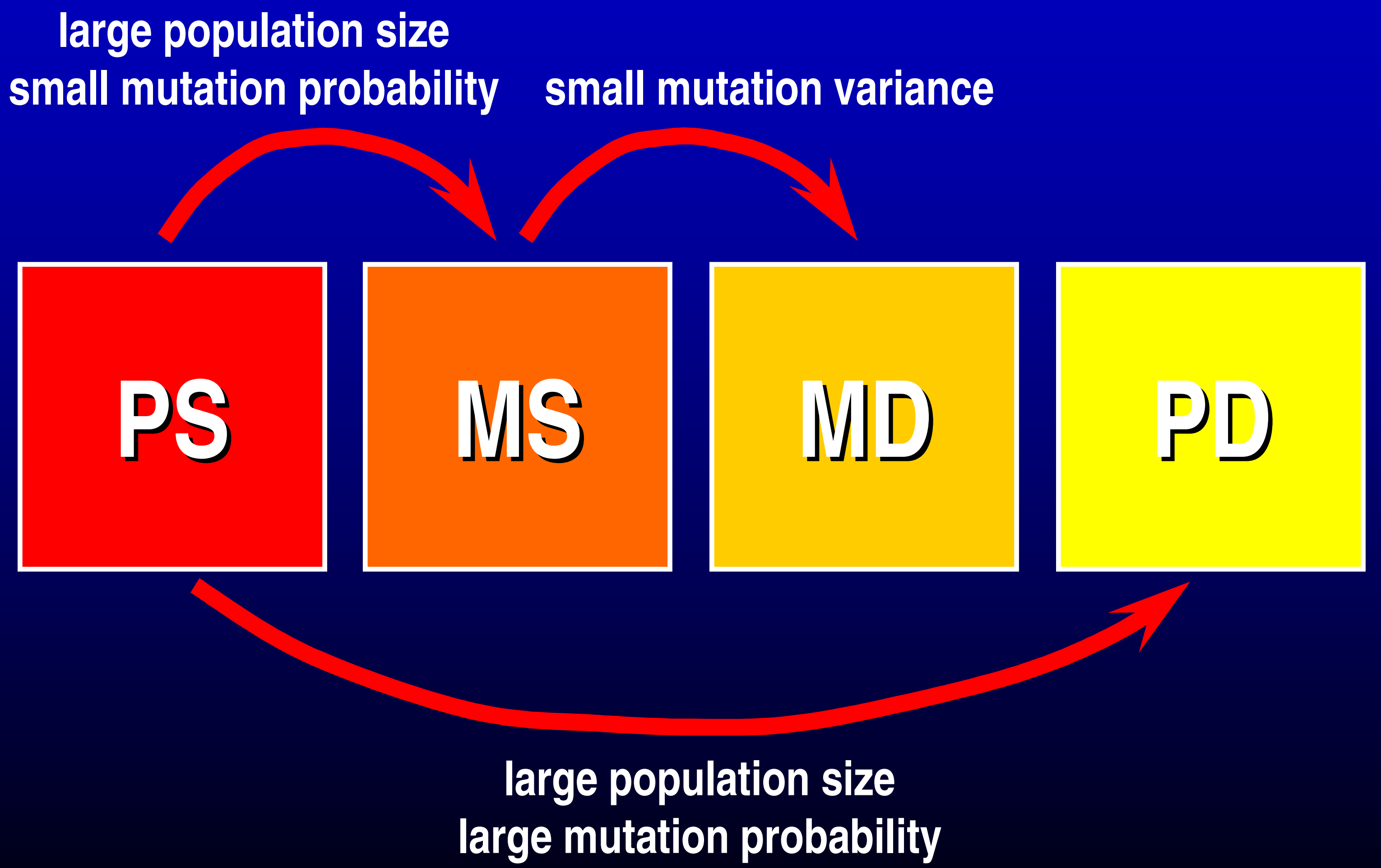
$$\frac{d}{dt}p_i(s_i) = [b_i(s_i,p) - d_i(s_i,p)]p_i(s_i) + \frac{1}{2}\mu_i\sigma_i^2\frac{\partial^2}{\partial s_i^2}b_i(s_i,p)p_i(s_i)$$

- **Finite-size correction**



additional per capita death rate results in bounded support

Summary of Derivations



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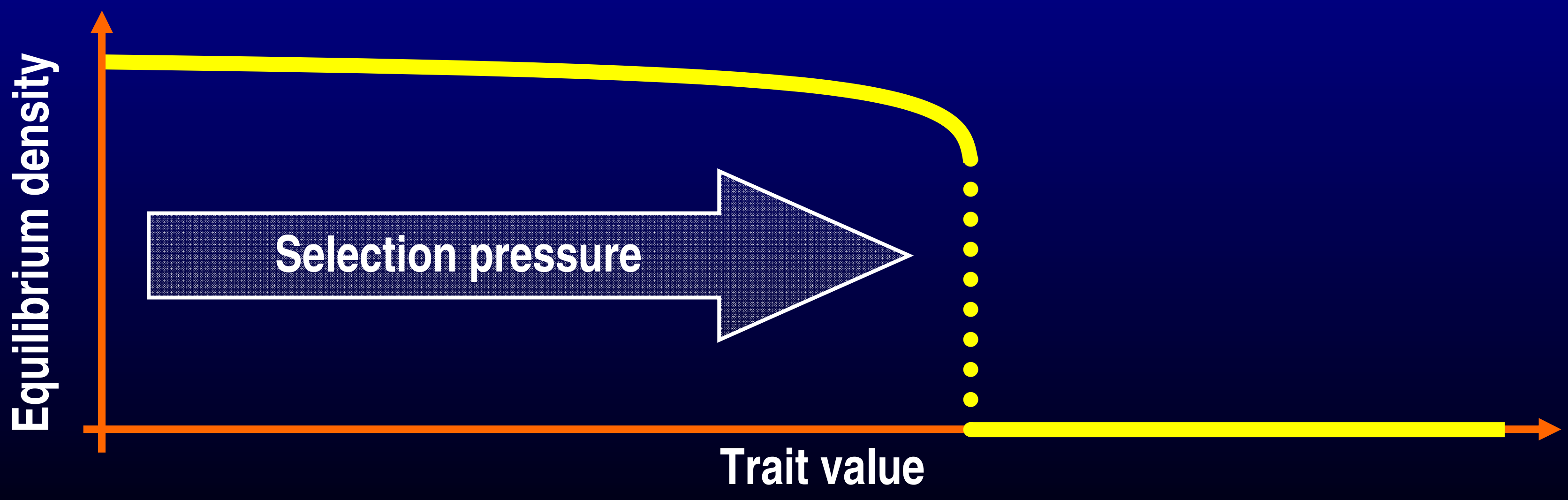
Evolutionary Suicide

Evolutionary Suicide

Ferrière (2000)

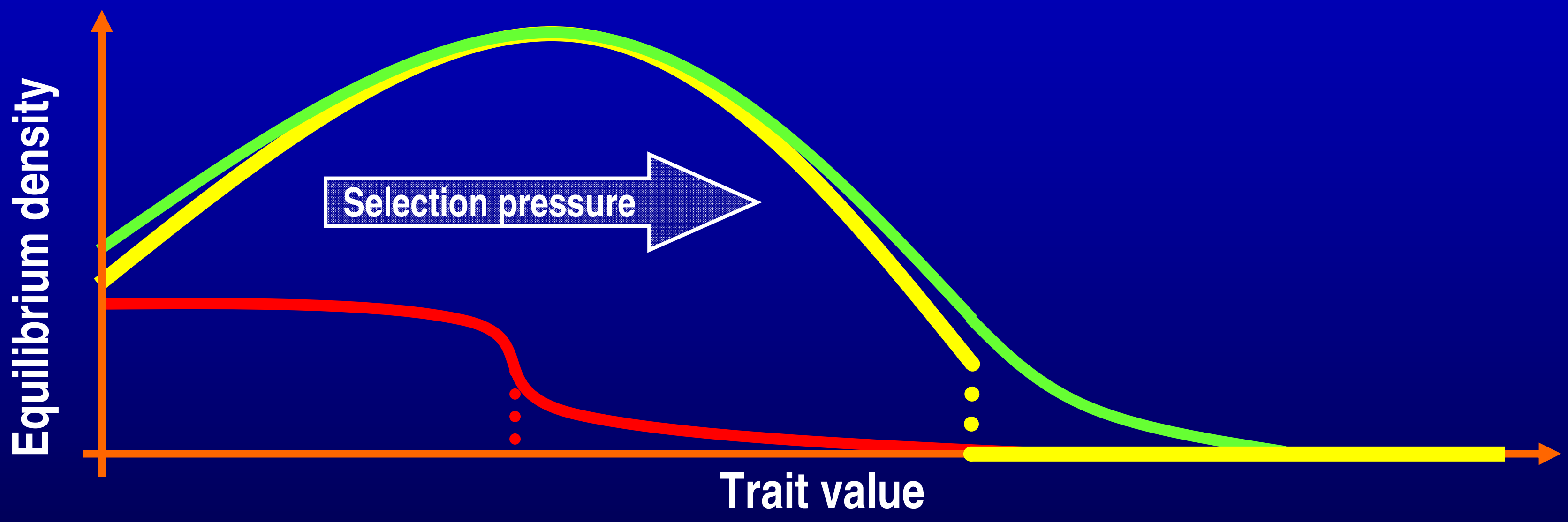
- Evolutionary suicide = selection-driven extinction
- Evolutionary suicide occurs when the evolution of an adaptive trait induces a bifurcation in the underlying population dynamics that involves a discontinuous transition to extinction:



Simplest Setting

Matsuda & Abrams (1994)

- Unimodal carrying capacity with asymmetric competition:

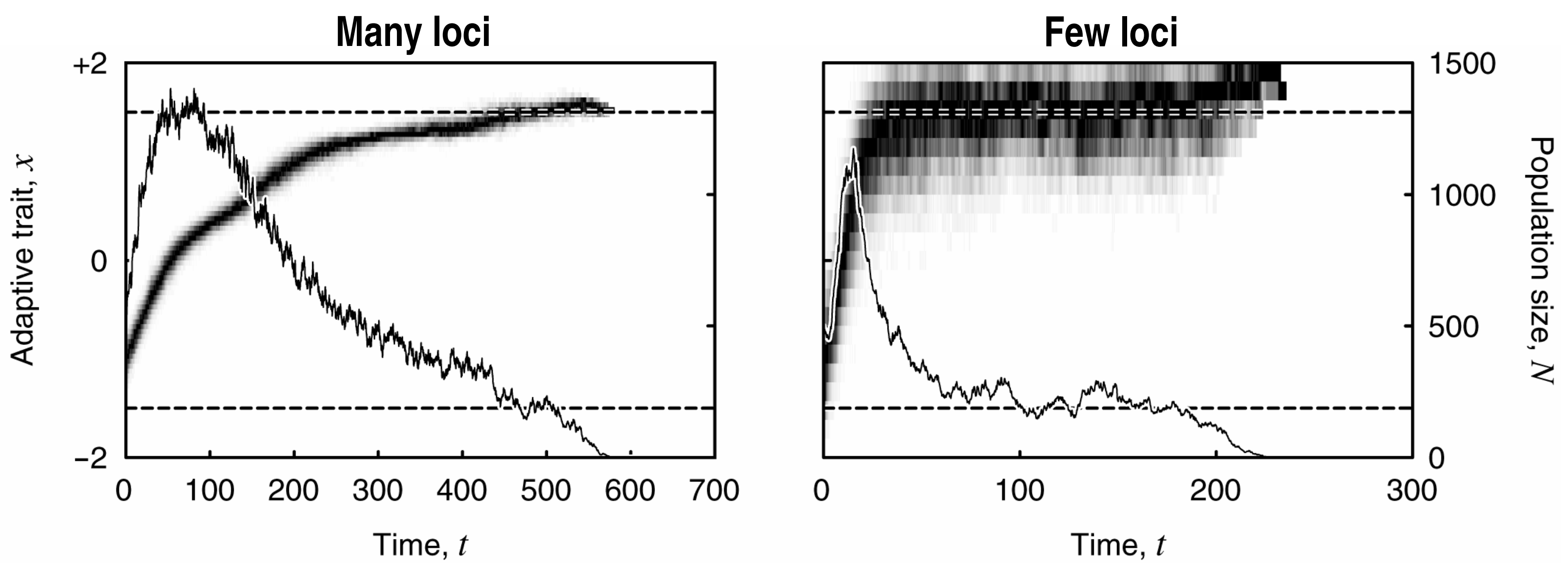


- Allee effects imply discontinuous transitions to extinction.
- Many other ecological settings also give rise to evolutionary suicide: a well-studied example is dispersal evolution in metapopulations.

Sexual Evolution

Dieckmann & Ferrière (2004)

- Evolutionary suicide is not an artifact of phenotypic evolutionary models; it can also occur in sexual populations:



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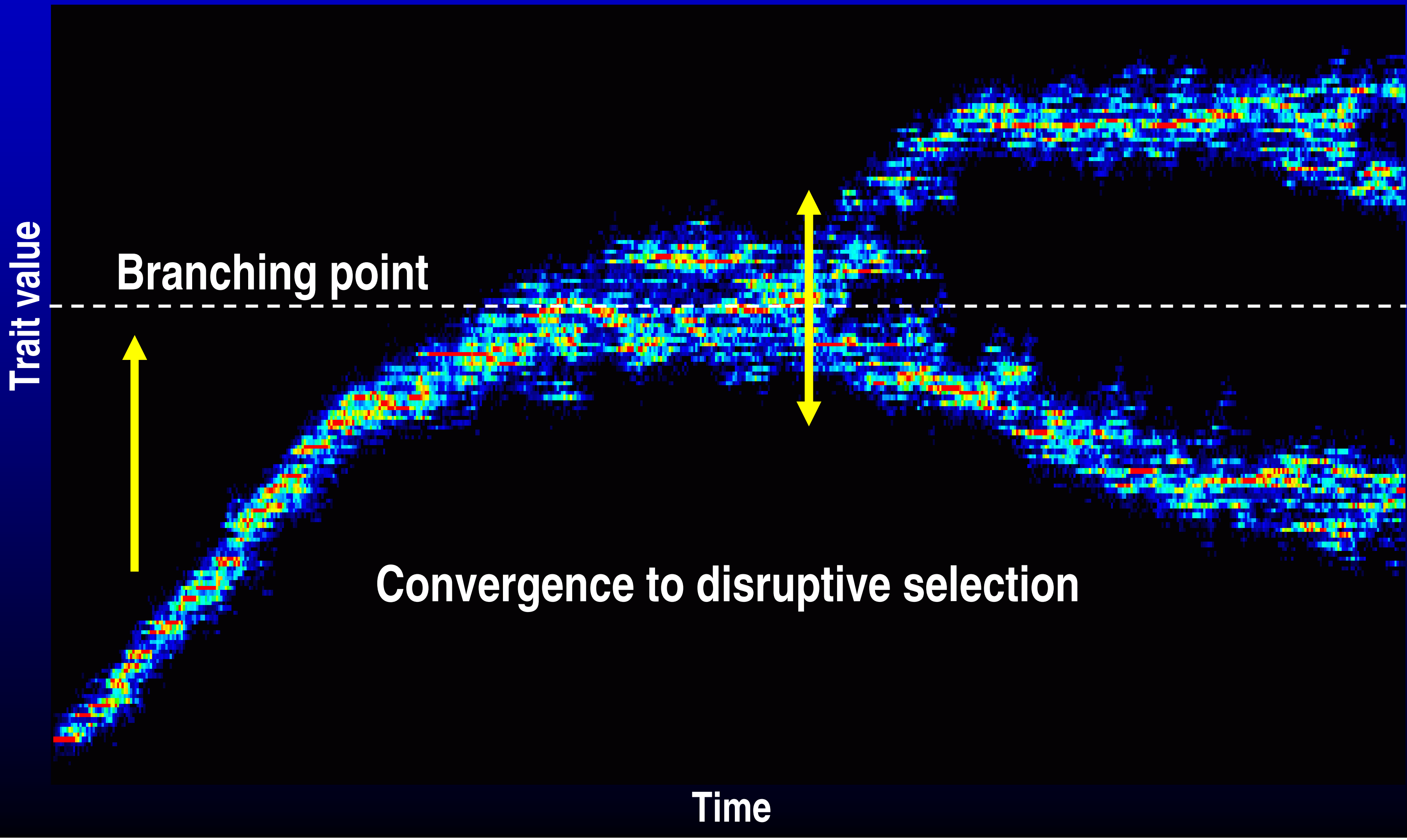
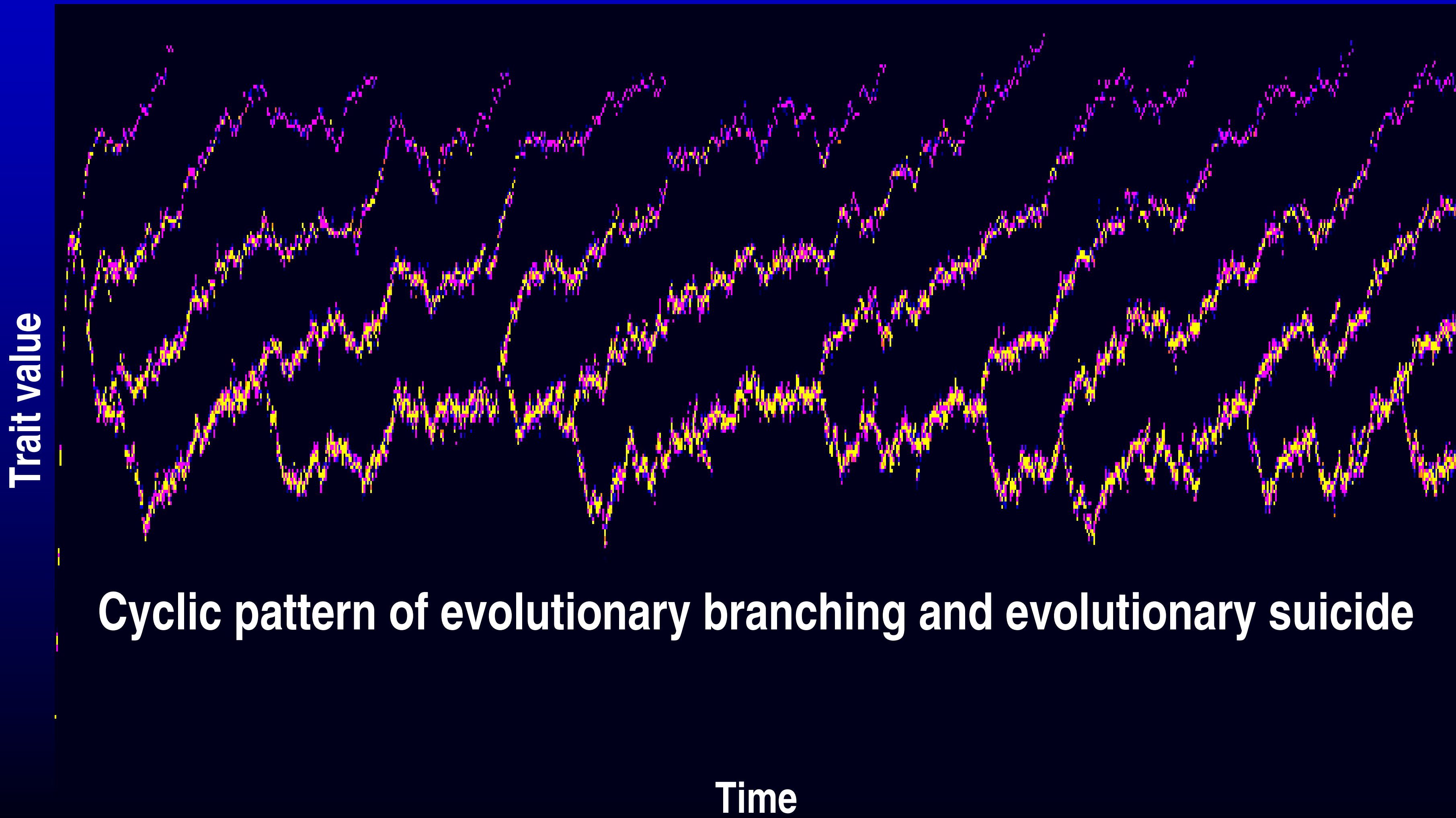
Adaptive Speciation

Evolutionary Branching

Metz *et al.* (1992)



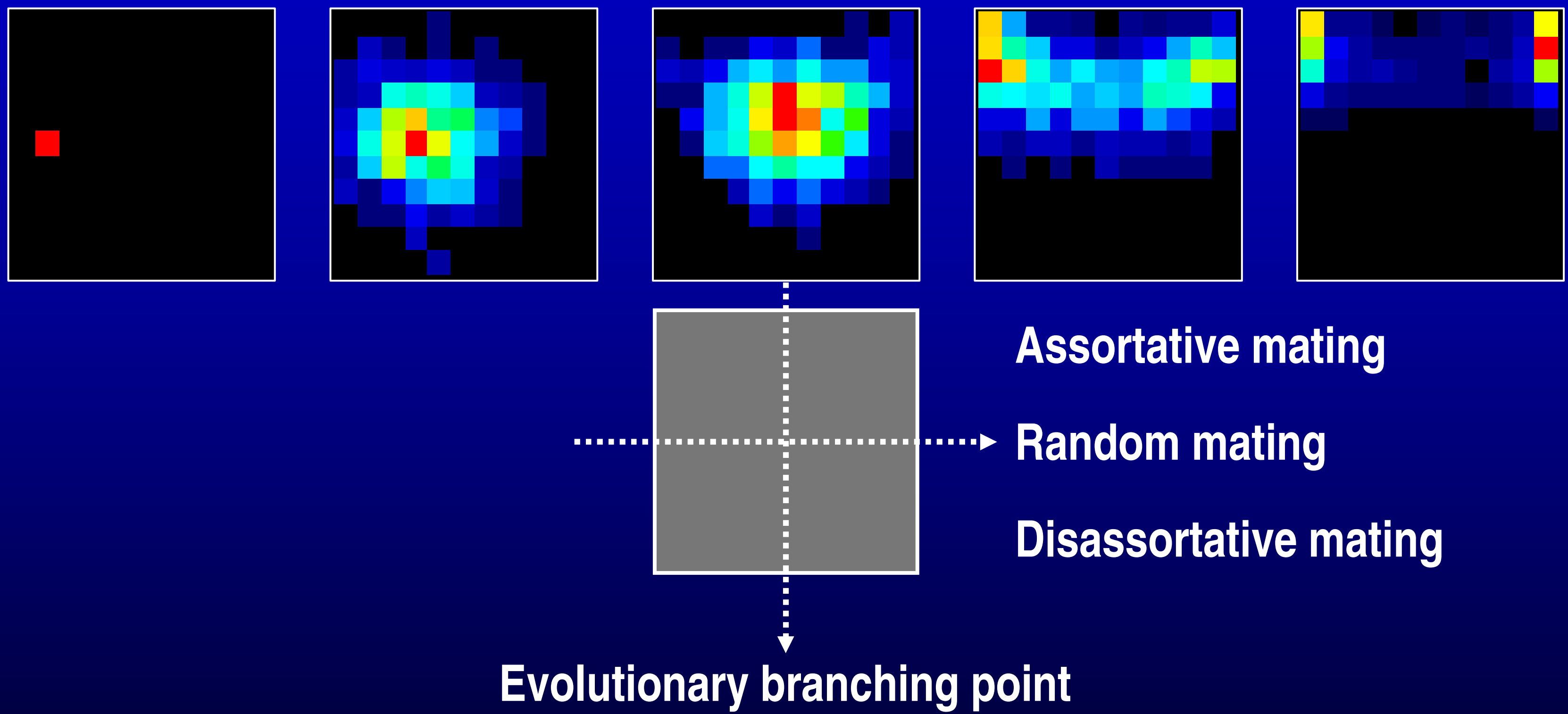
Multiple Evolutionary Branching



Cyclic pattern of evolutionary branching and evolutionary suicide

Sympatric Speciation

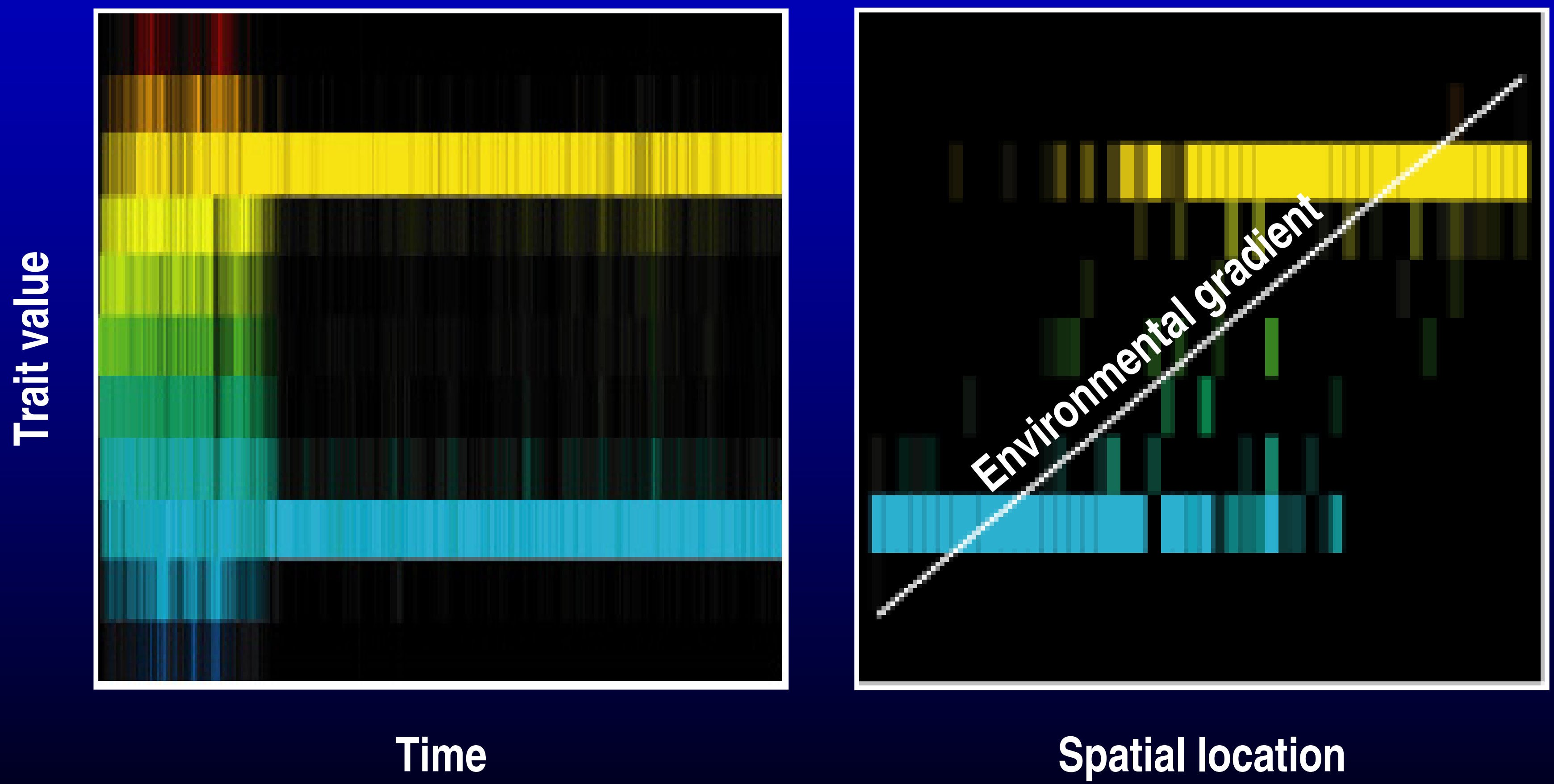
Dieckmann & Doebeli (1999)



Disruptive selection at branching point favors assortative mating and thus enables the emergence of genetic isolation.

Parapatric Speciation

Doebeli & Dieckmann (2003)



Summary

- The theory of adaptive dynamics offers a versatile toolbox for studying phenotypic evolution.
- Simplified models are deduced from a common individual-based underpinning.
- Adaptive dynamics are particularly helpful for investigating the evolutionary implications of complex ecological settings.
- Frequency-dependent selection, which lies at the heart of adaptive dynamics theory, is essential for understanding the evolutionary formation and loss of biological diversity.