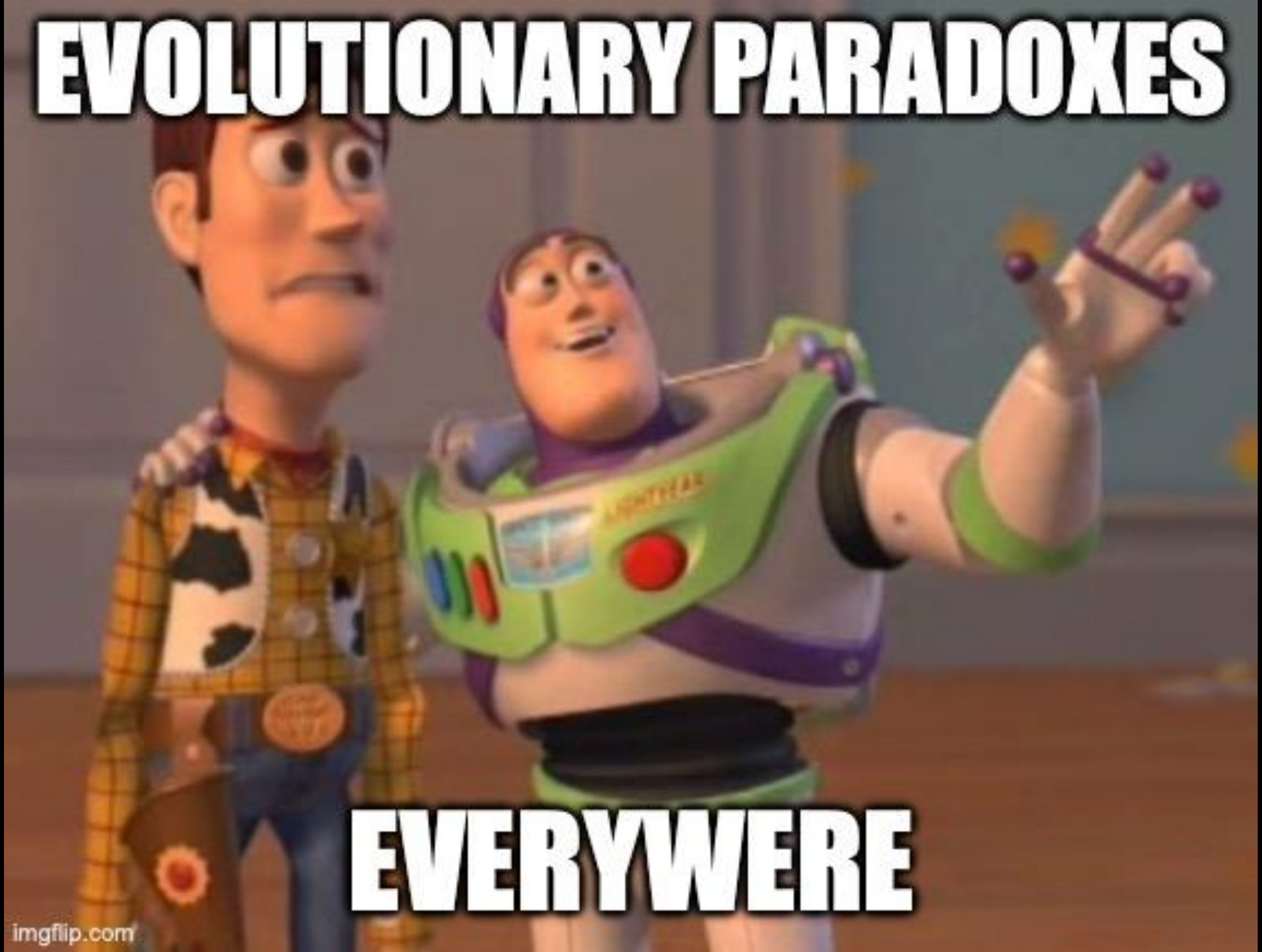
PARADOX OF PREDICTABILITY

EQGW 2025


EVOLUTIONARY PARADOXES
EVERYWERE
imgflip.com

IS MACROEVOLUTION JUST MICROEVOLUTION+TIME?

MICROEVOLUTION

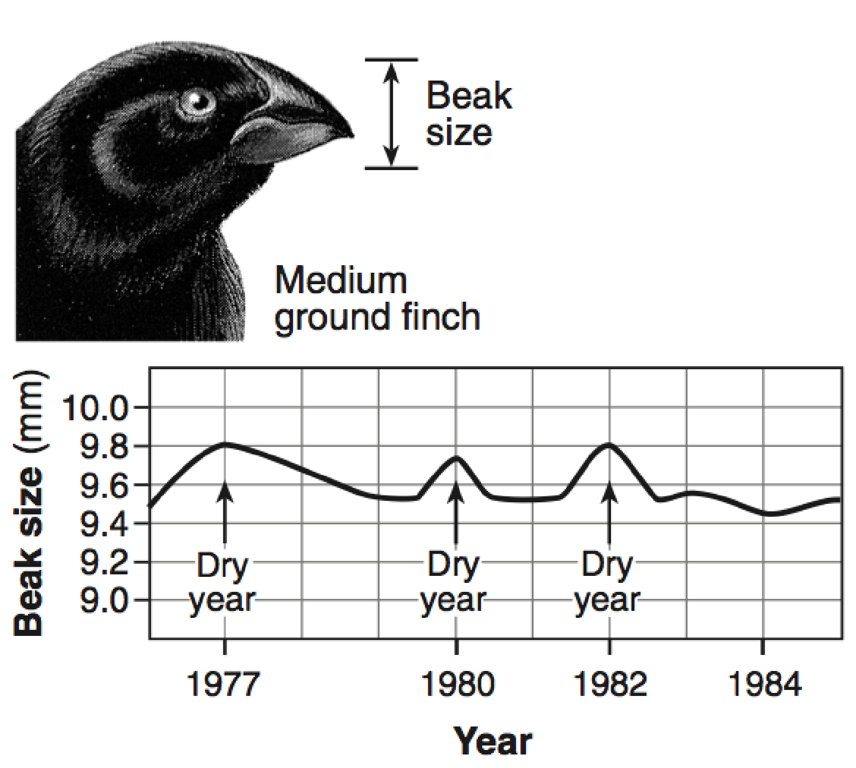
MACROEVOLUTION

MICROEVOLUTION

Within species

Small time scale (ys, gens)

Reduced magnitude

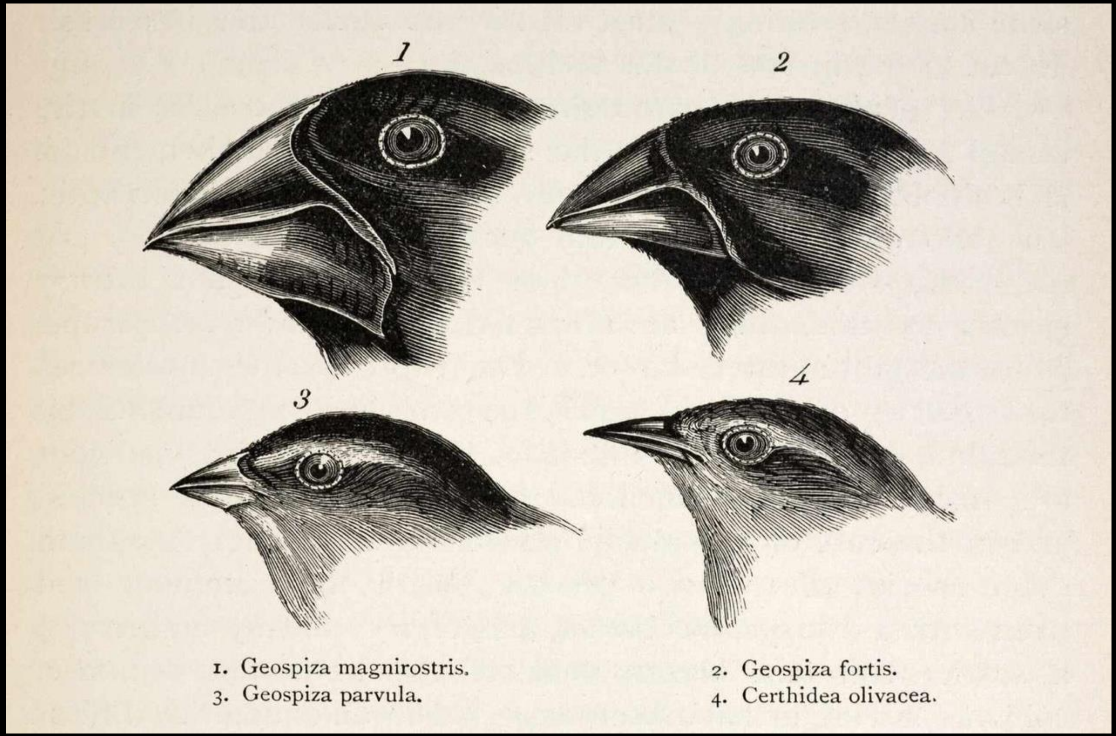


MACROEVOLUTION

Multiple species

Large time scale (mys, geological time)

Larger magnitude



MICROEVOLUTION

Within species

Small time scale (ys, gens)

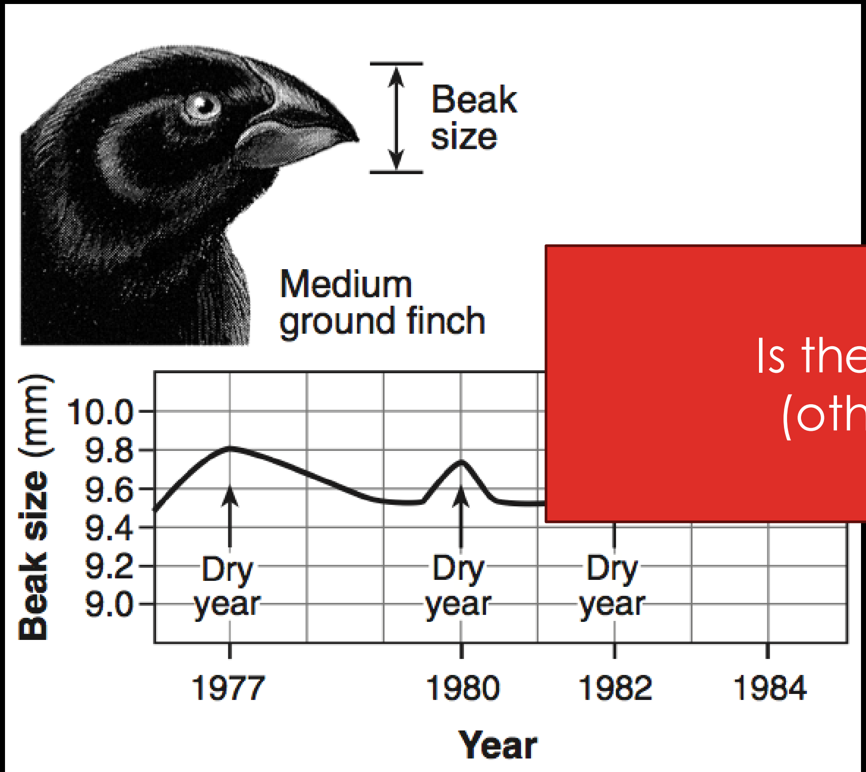
Reduced magnitude

MACROEVOLUTION

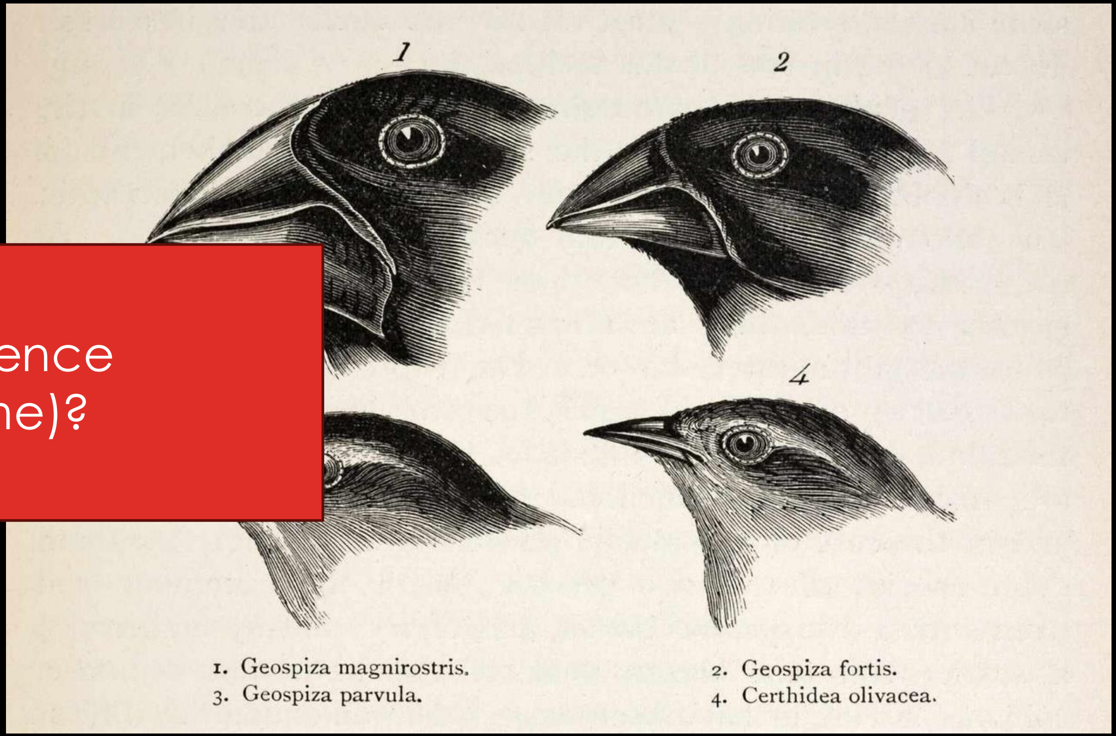
Multiple species

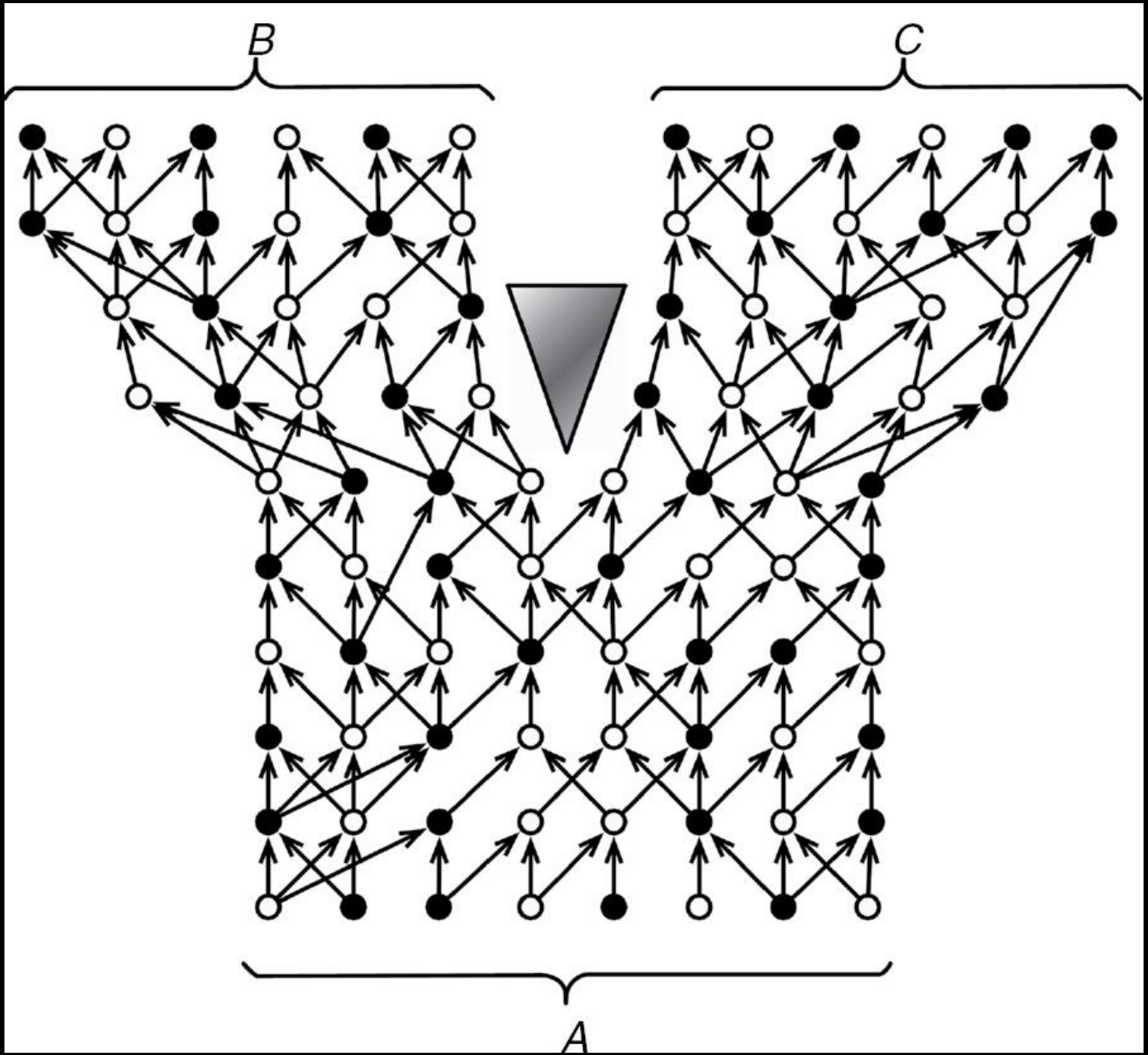
Large time scale (mys, geological time)

Larger magnitude

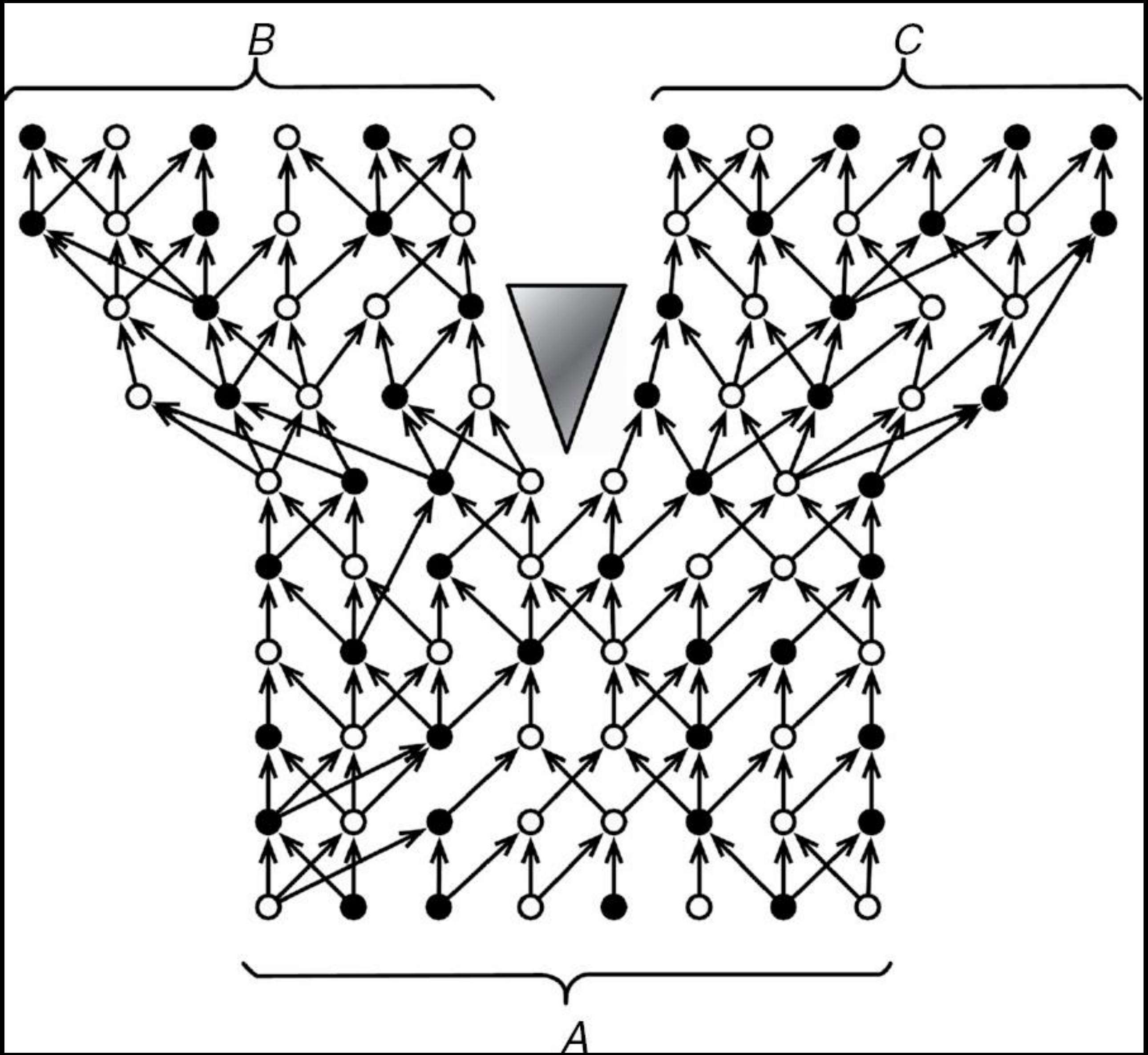


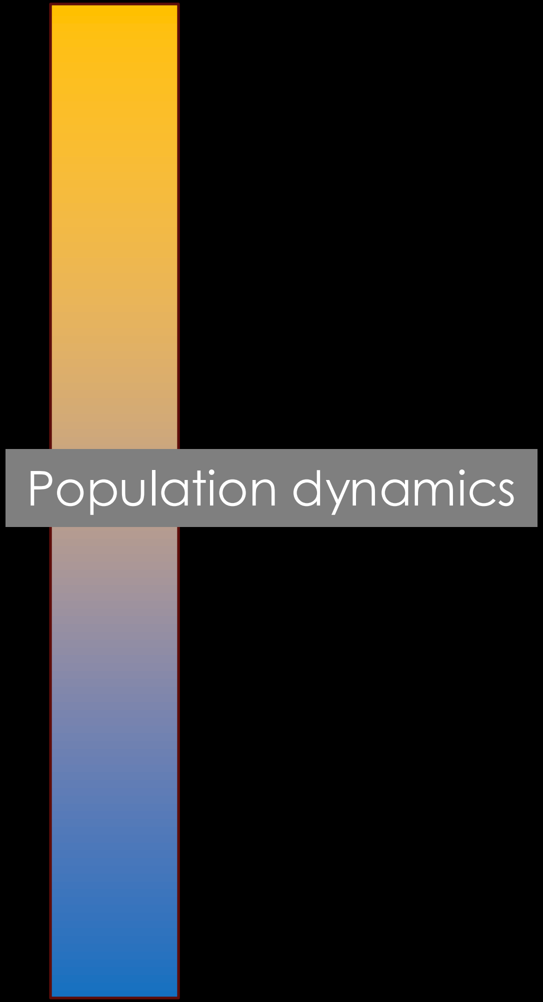
Is there a difference (other than time)?





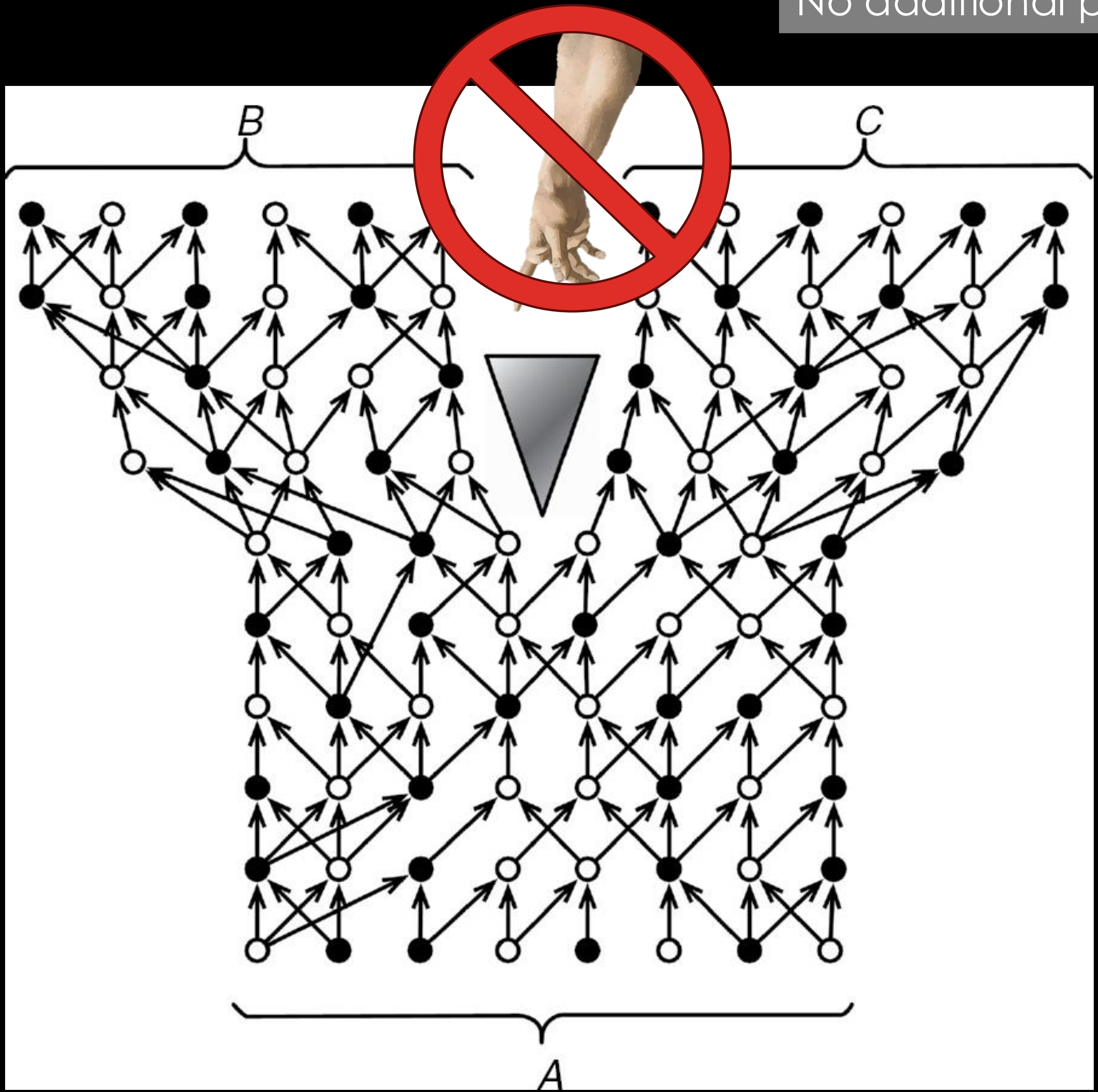
Hennig, 1966





Hennig, 1966

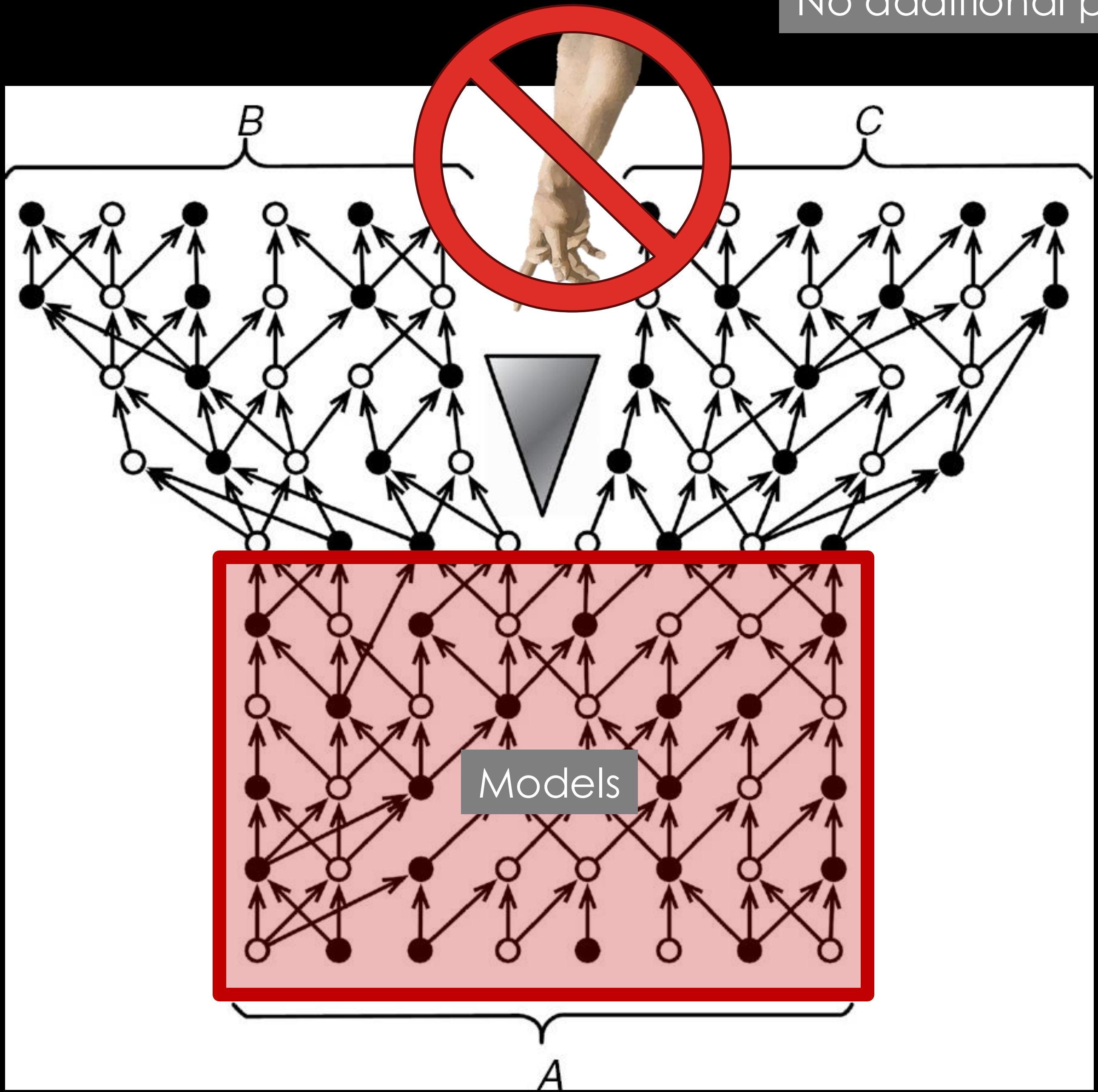
No additional processes required

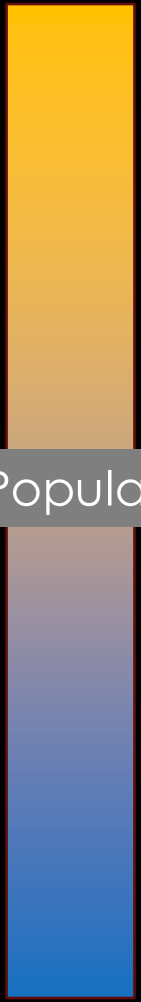


Population dynamics

Hennig, 1966

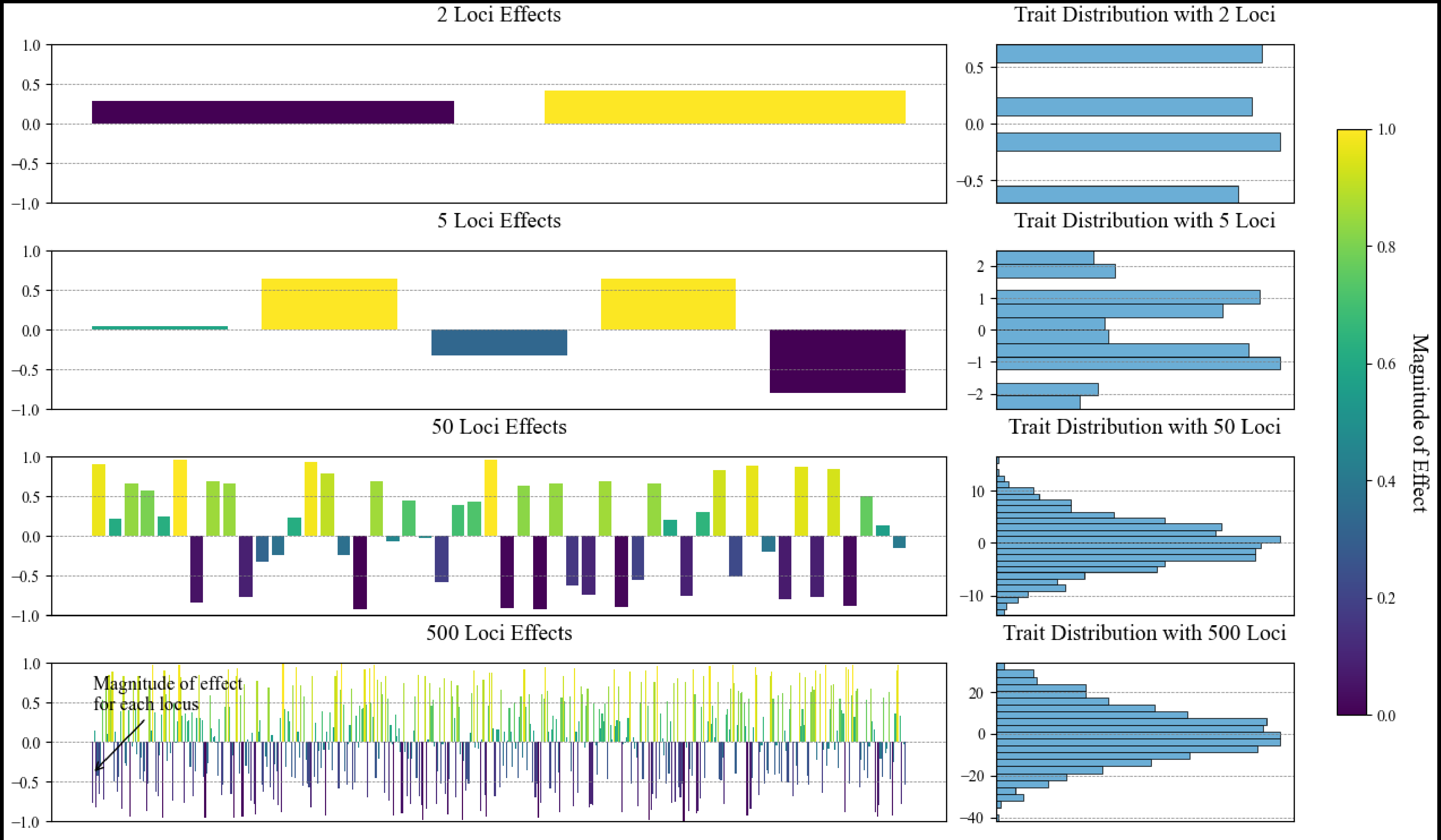
No additional processes required


B
C
A
Models


Population dynamics

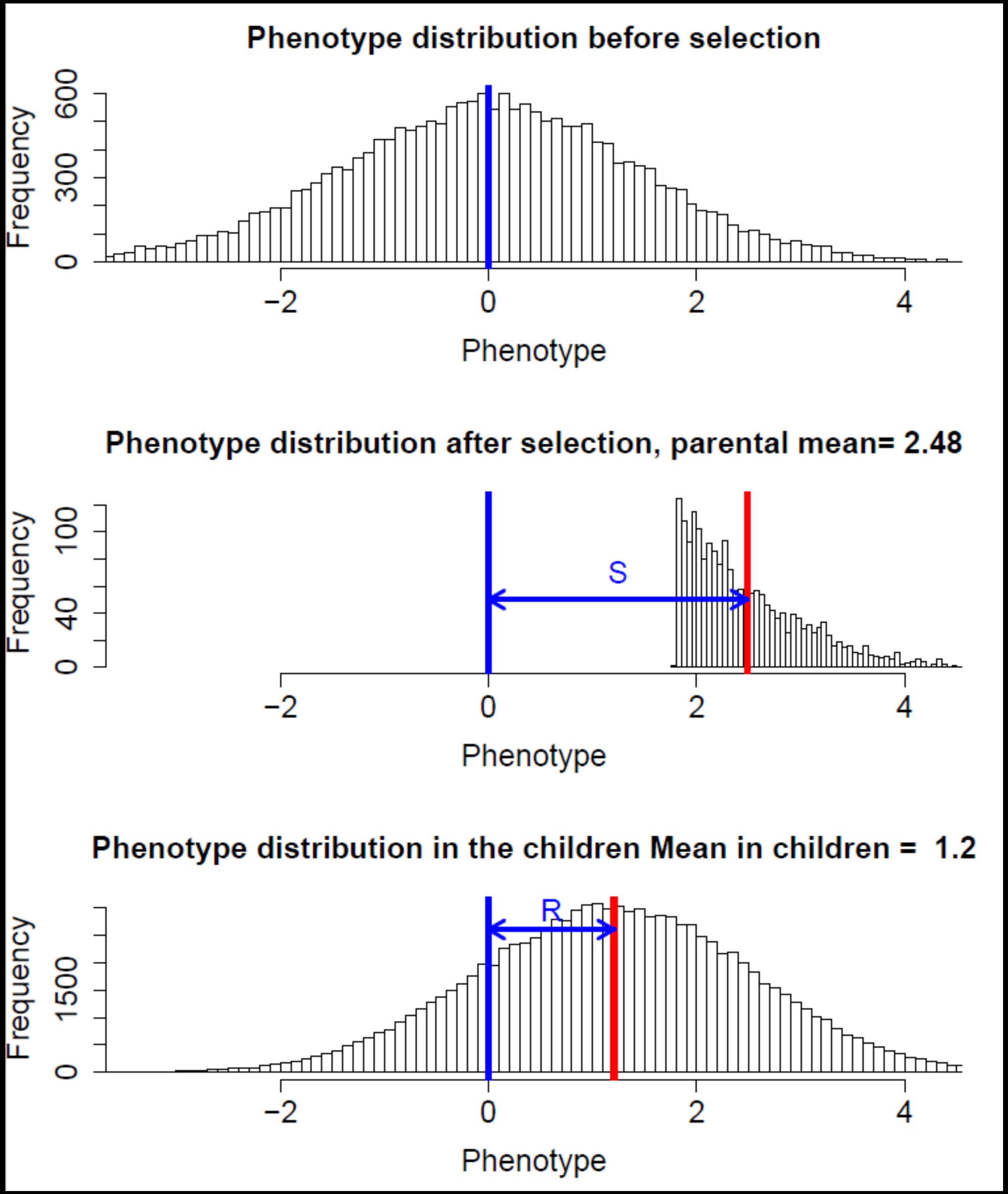
Hennig, 1966

Infinitesimal model of trait variation



Allows for the statistical treatment of the evolution of continuous traits

Models of trait evolution based on evolutionary processes

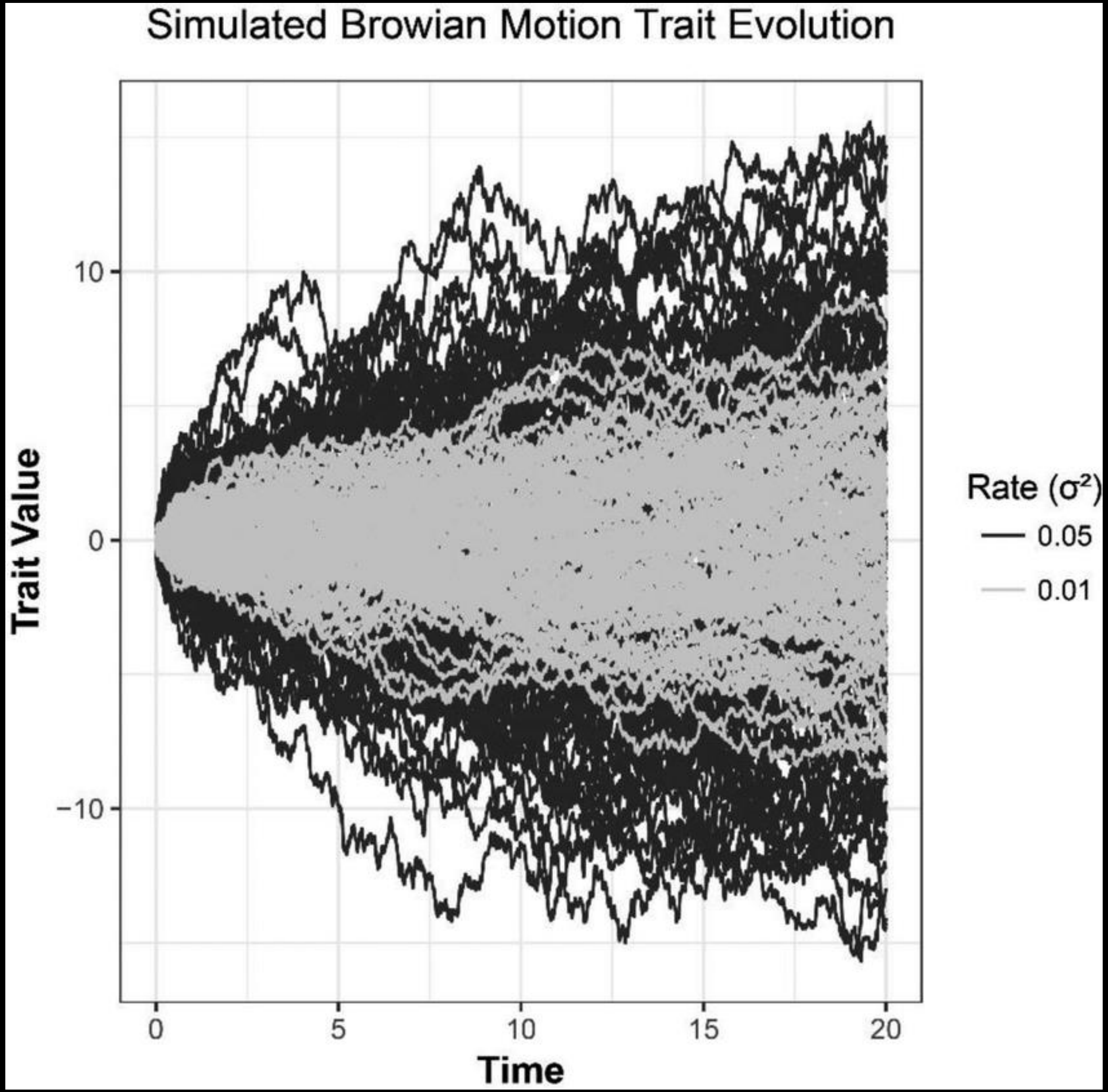


Directional selection

$$R = Sh^2$$

$$\Delta\bar{z}(t) = [\bar{z}_w(t) - \bar{z}(t)]\,\frac{\sigma_a^2}{\sigma_p^2}$$

Models of trait evolution based on evolutionary processes



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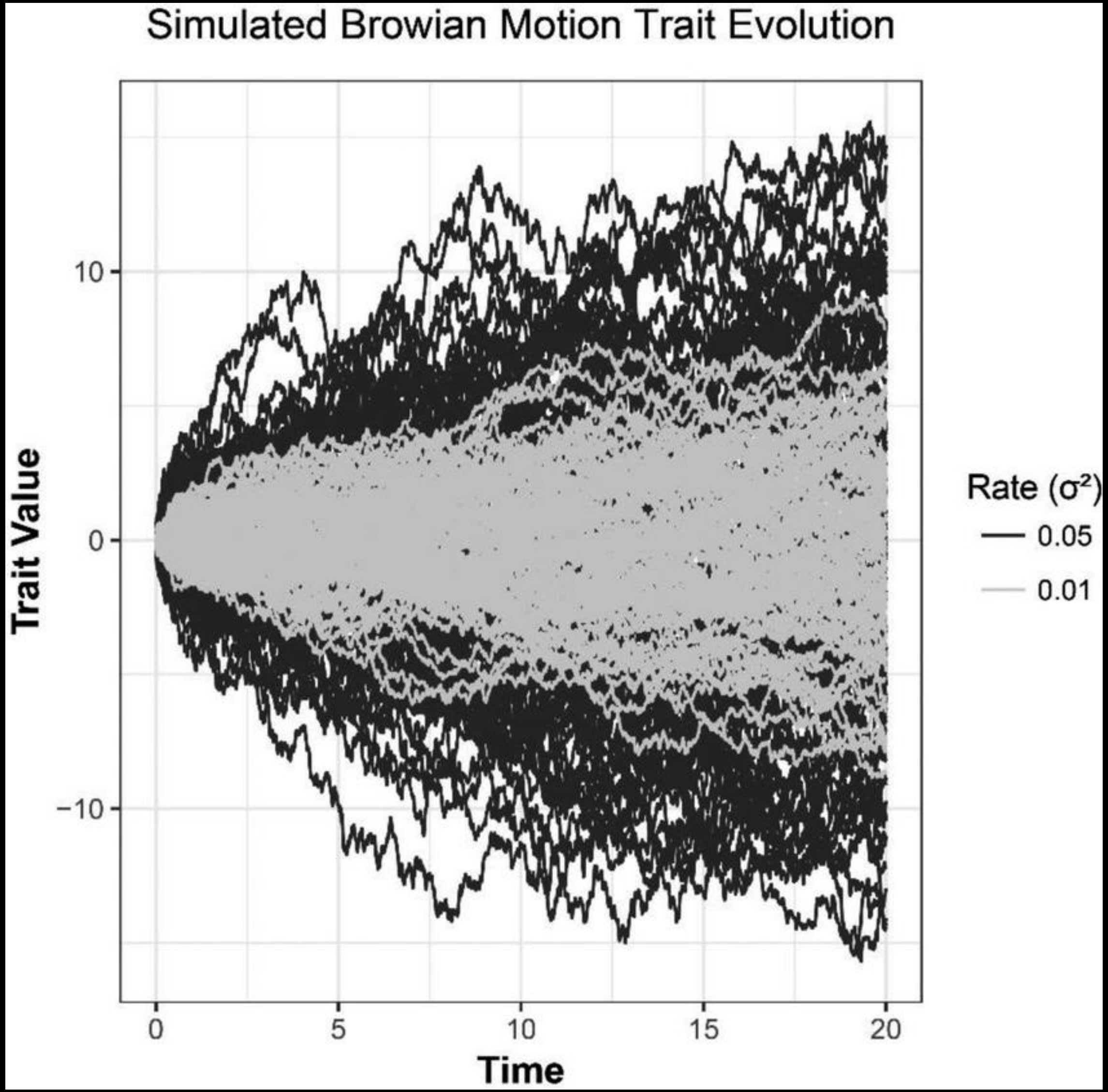
Genetic Drift

$$\sigma_b^2(t) = \sigma_a^2\,\frac{t}{N}$$

Models of trait evolution based on evolutionary processes



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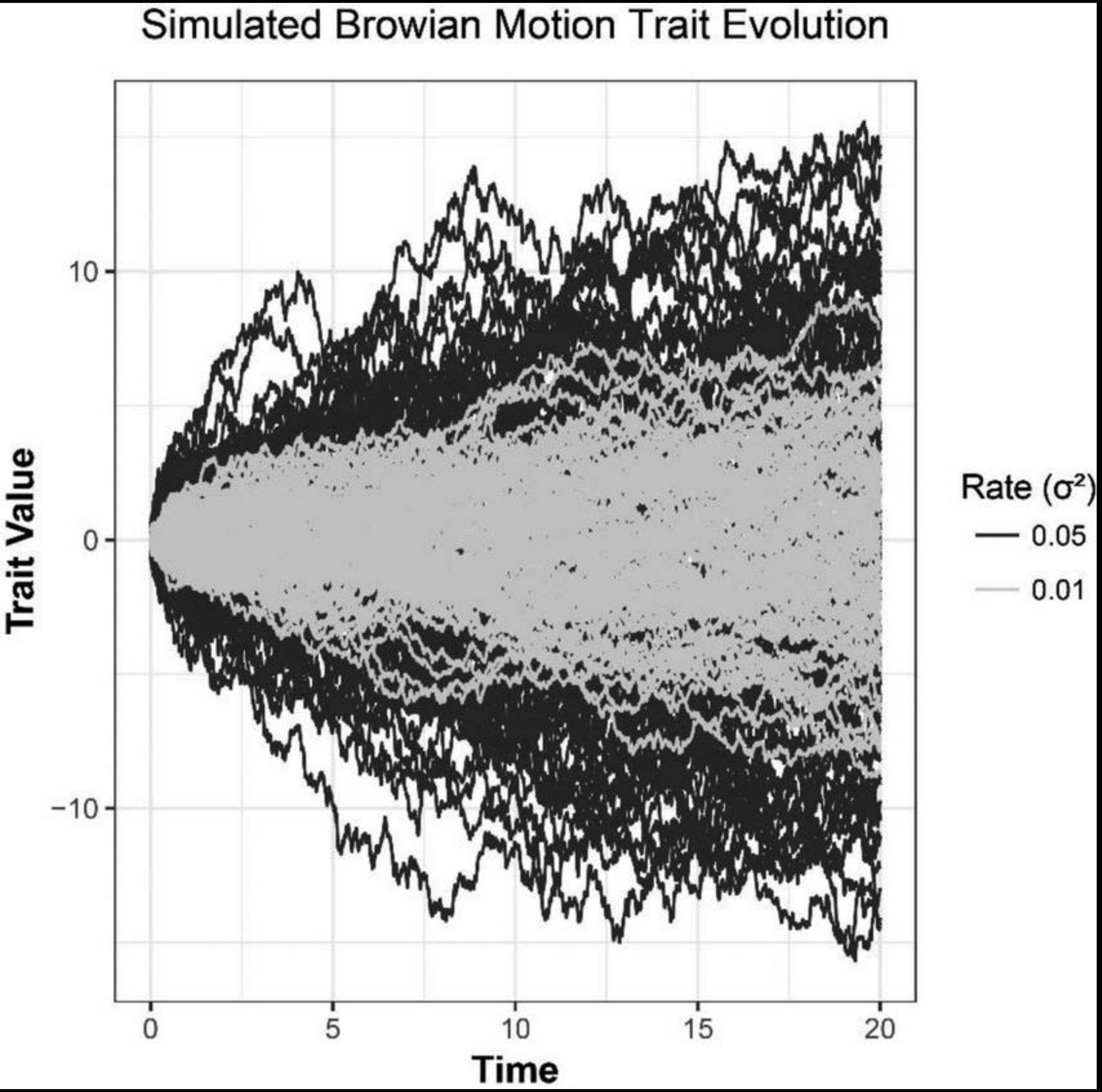
Can we use any of these models in macroevolution?

Models of trait evolution based on evolutionary processes



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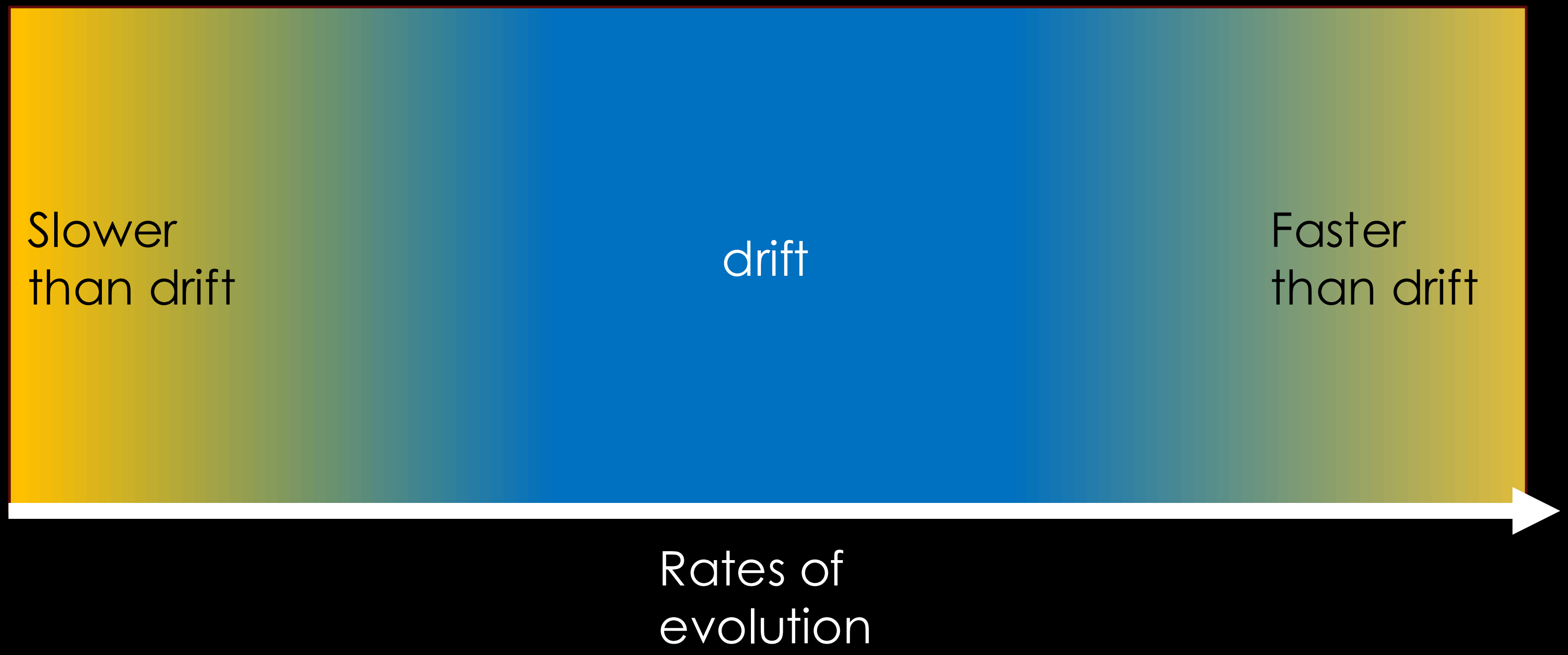
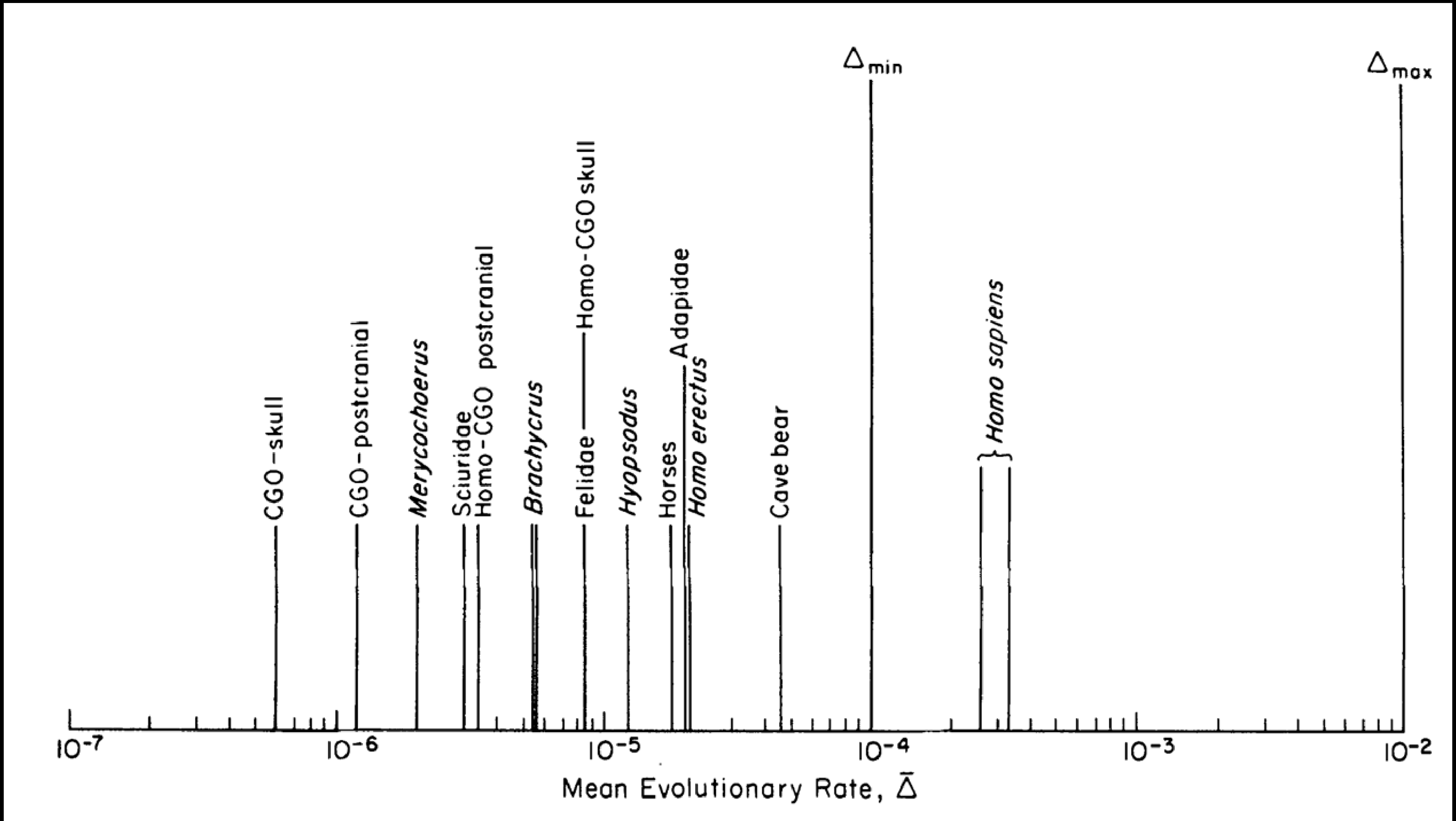
Null model

USING GENETIC DRIFT AS A NULL MODEL OF MACROEVOLUTION

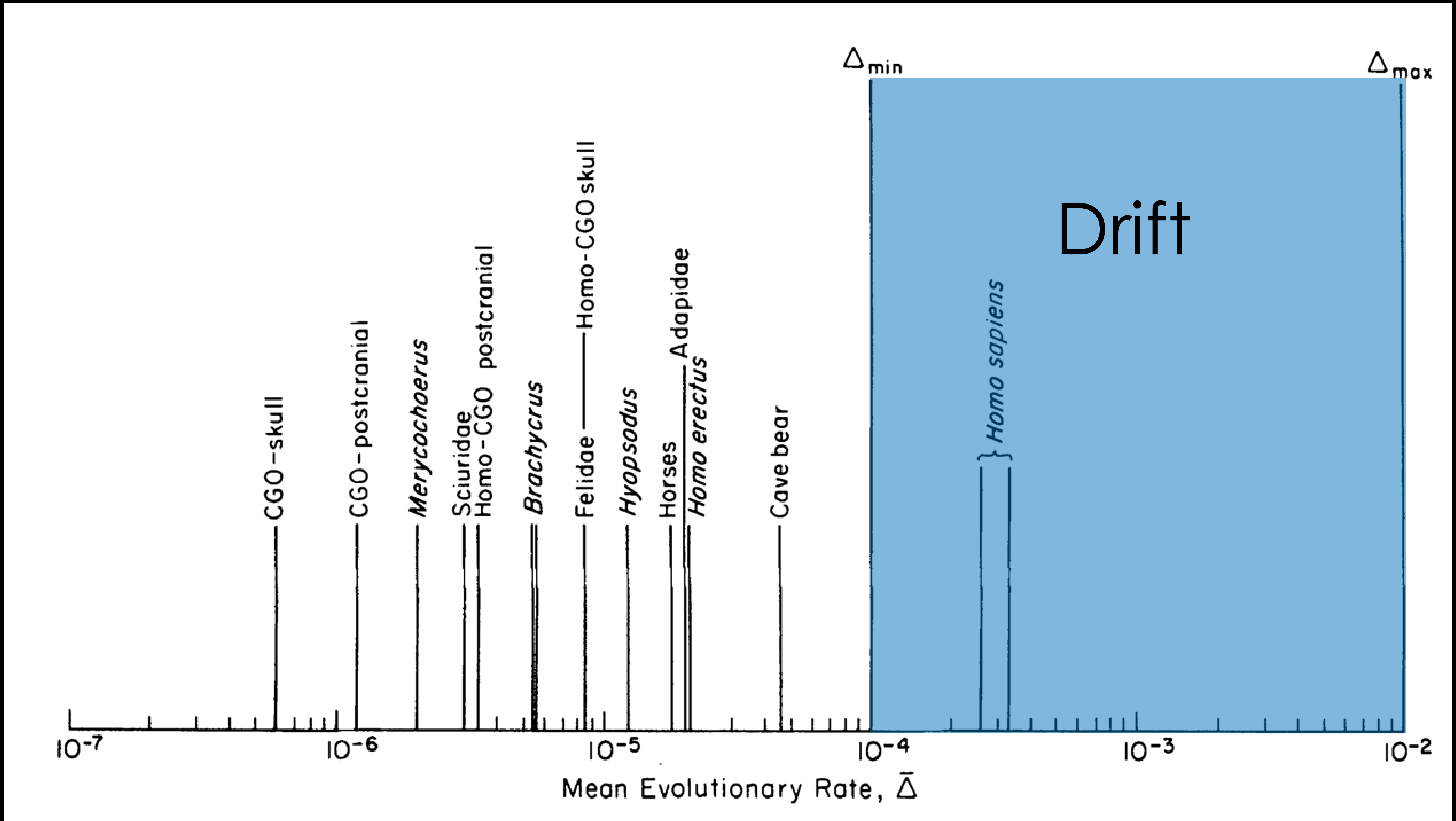
Make assumptions of quantitative genetic traits
Generate null expectation under drift
Calculate empirical rates of evolution
Confront them

$$\sigma_b^2(t) = \sigma_a^2 \frac{t}{N}$$




Δ_{min}
Δ_{max}
CGO-skull
CGO-postcranial
Merycochoerus
Sciuridae
Homo-CGO postcranial
Brachycrus
Felidae
Homo-CGO skull
Hyopsodus
Horses
Adapidae
Homo erectus
Cave bear
Homo sapiens
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Mean Evolutionary Rate, $\bar{\Delta}$

Lynch, 1990



Δ_{min}
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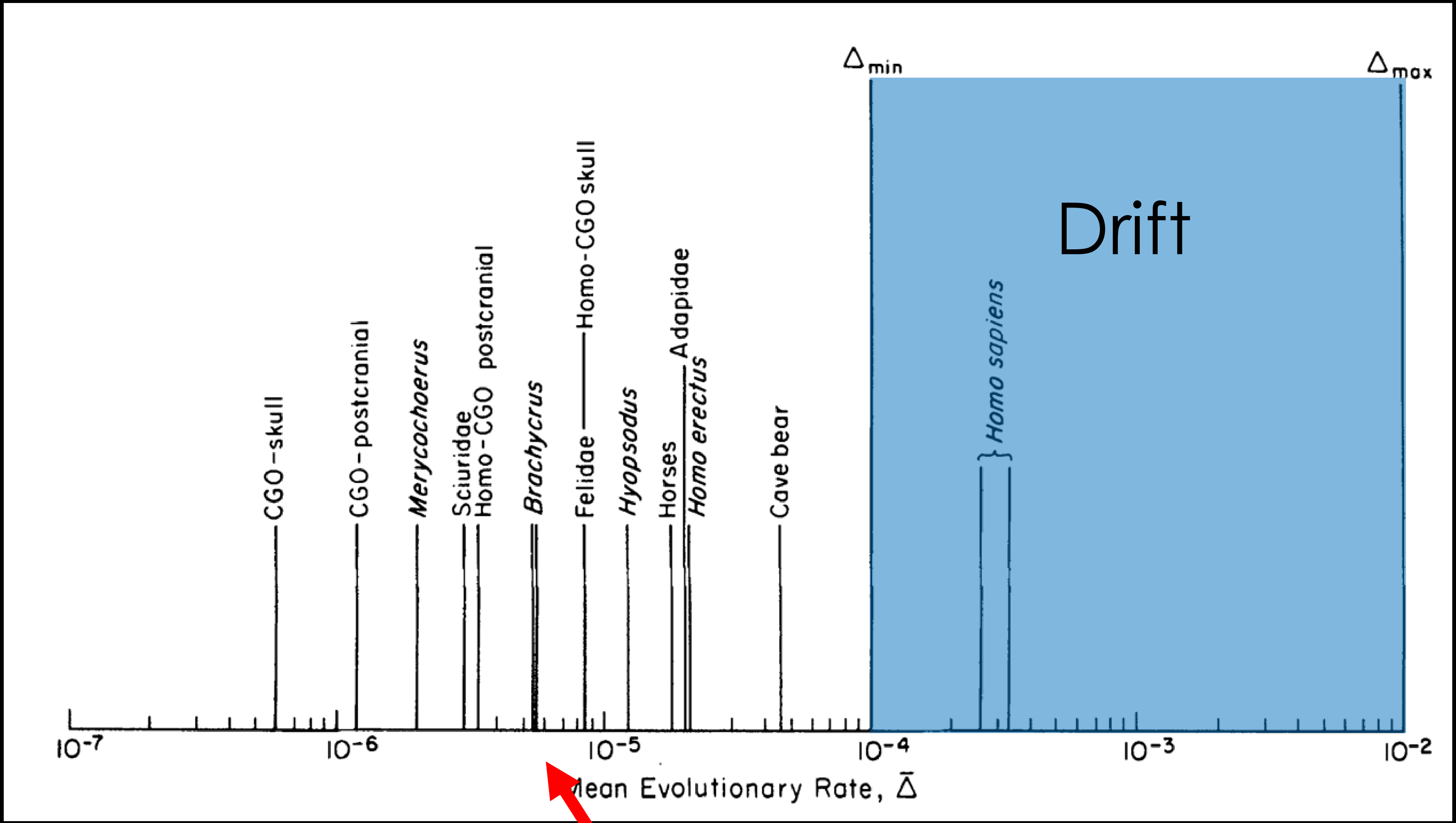
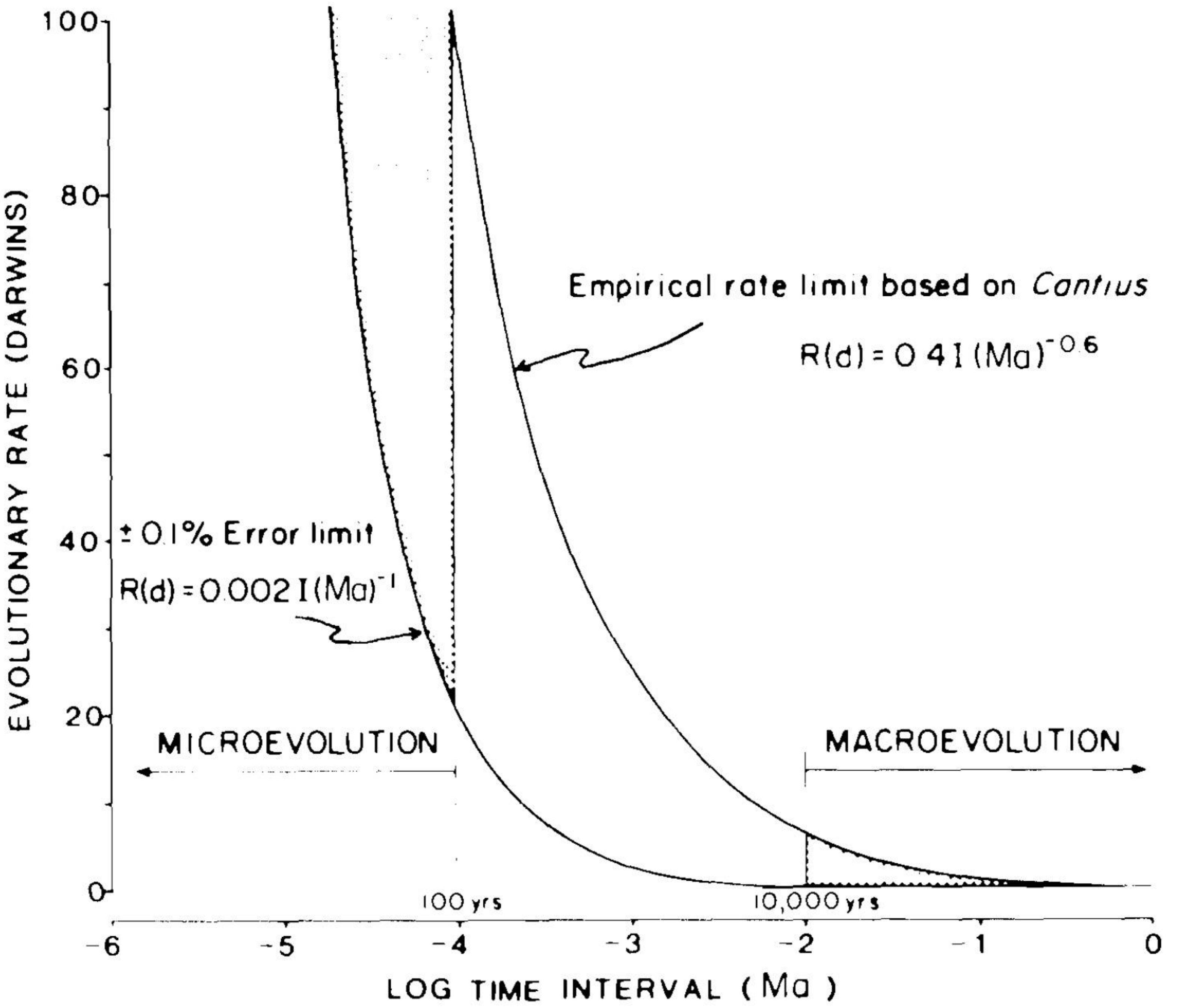
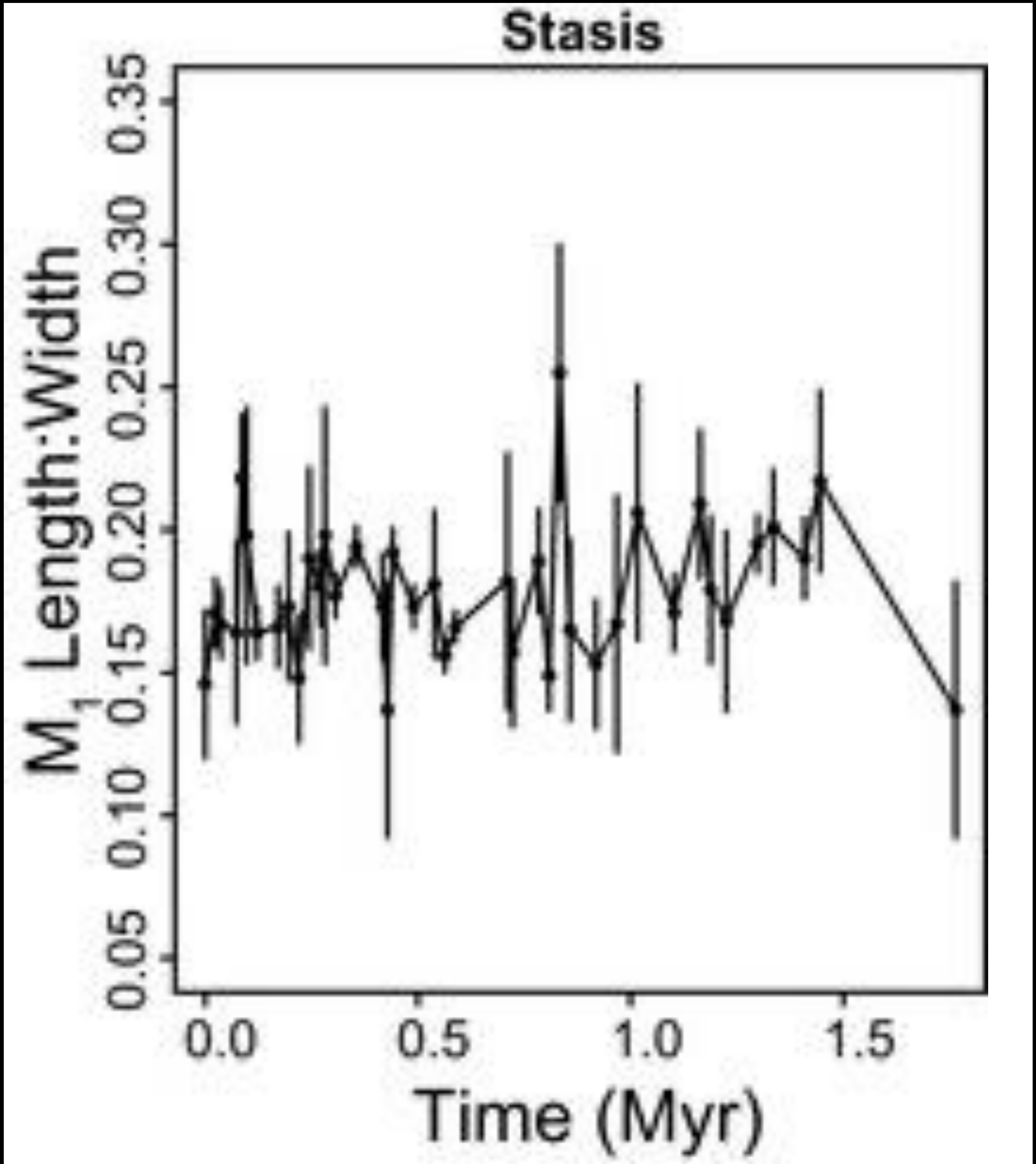


Consistent with …?

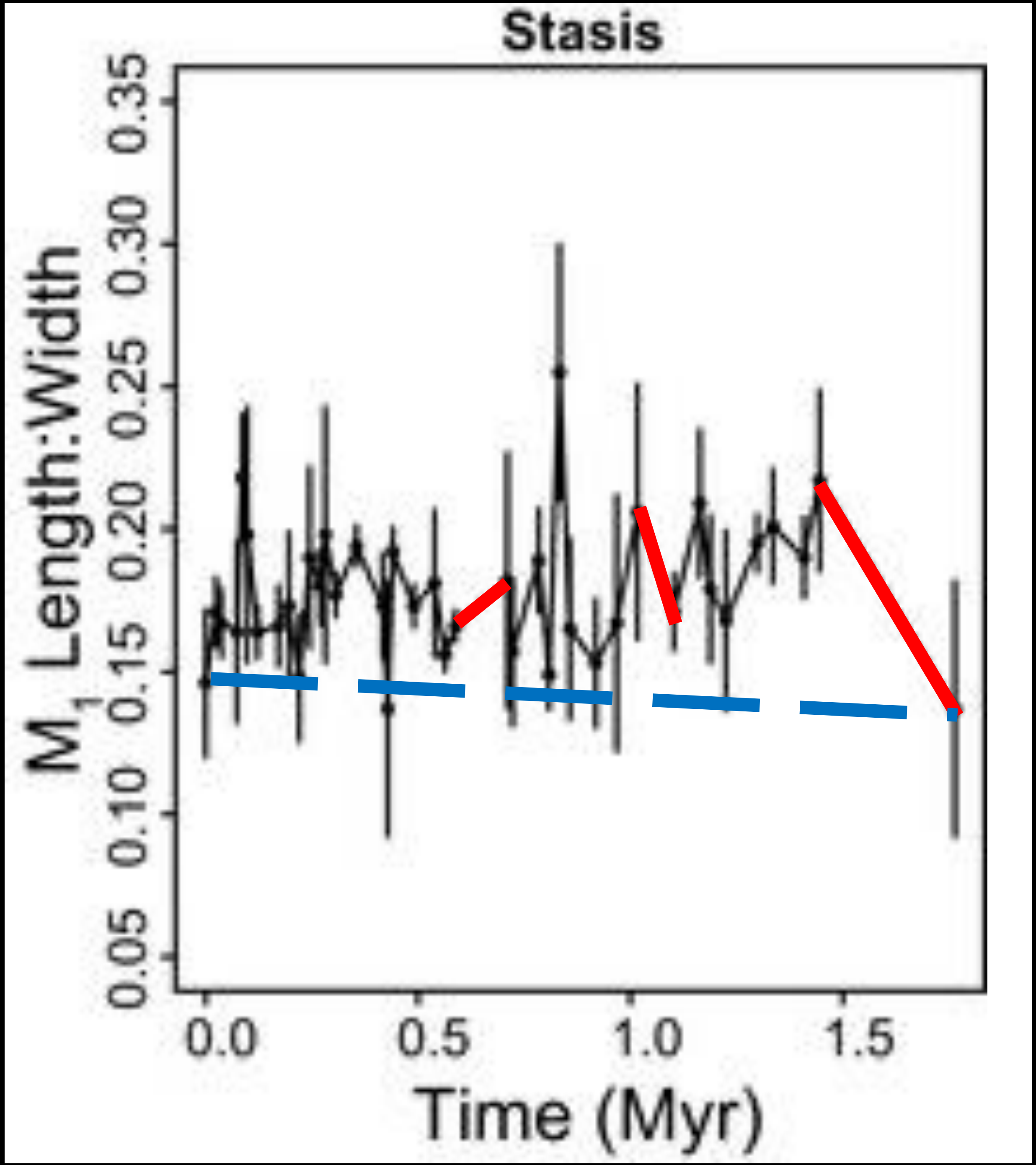
Lynch, 1990



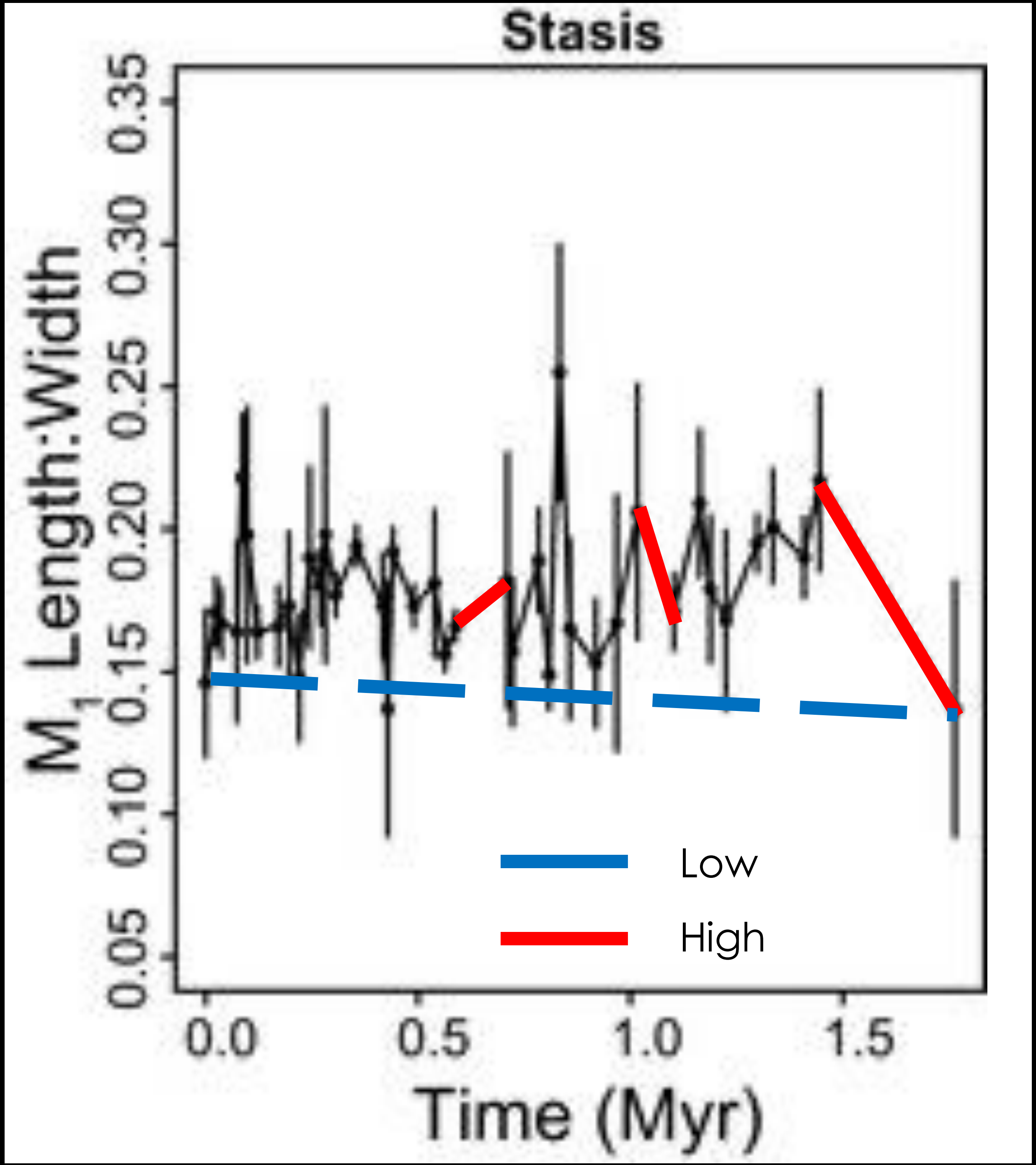
Gingerich, 1987



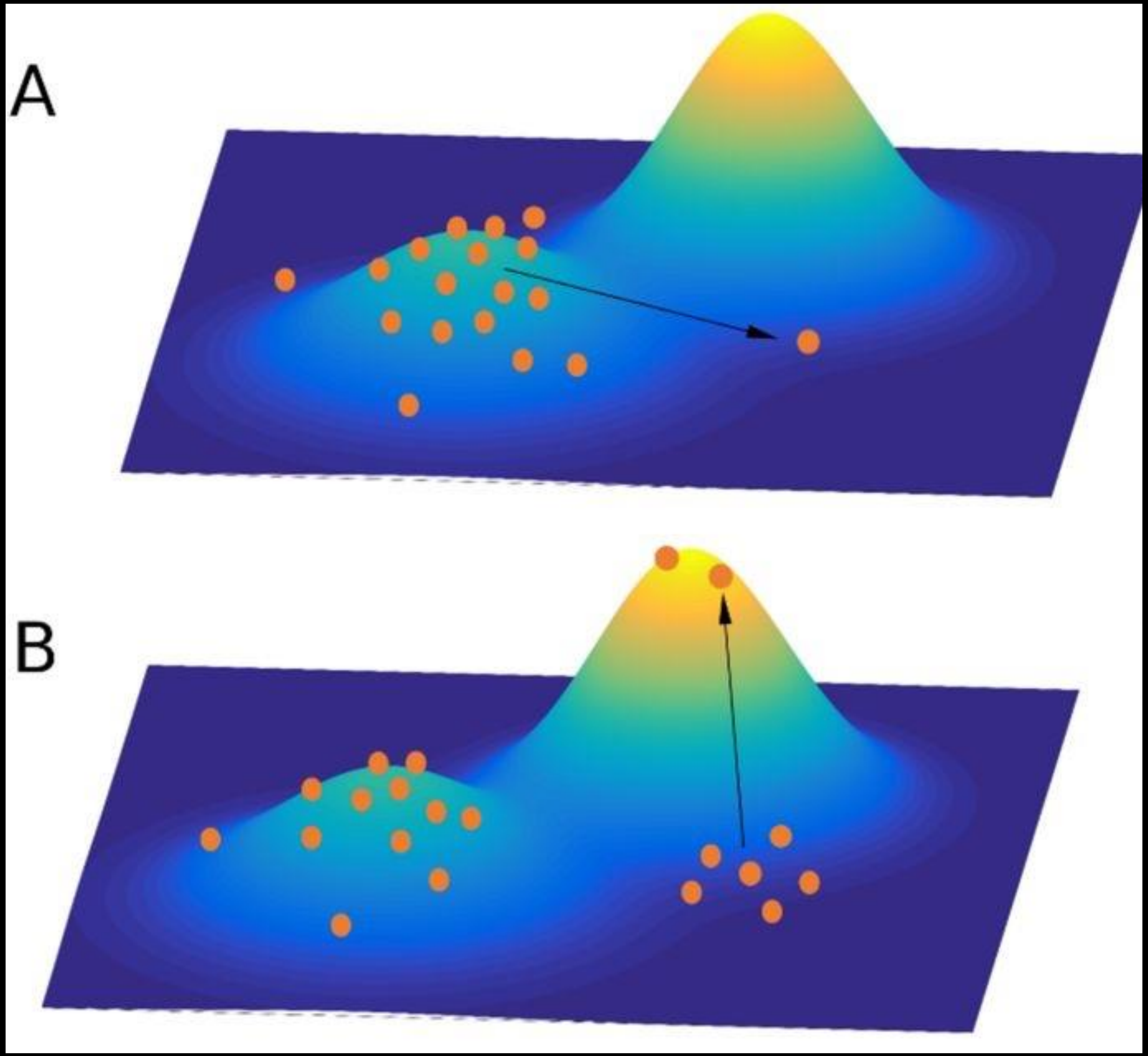
Clyde and Gingerich 1994



Clyde and Gingerich 1994



Clyde and Gingerich 1994



Climbing new peaks is very fast (given the availability of additive genetic variance), **so large scale macroevolutionary dynamics are the result of peak dynamics**

IS MACROEVOLUTION JUST MICROEVOLUTION+TIME?

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YES.

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YES. Well, sort of.

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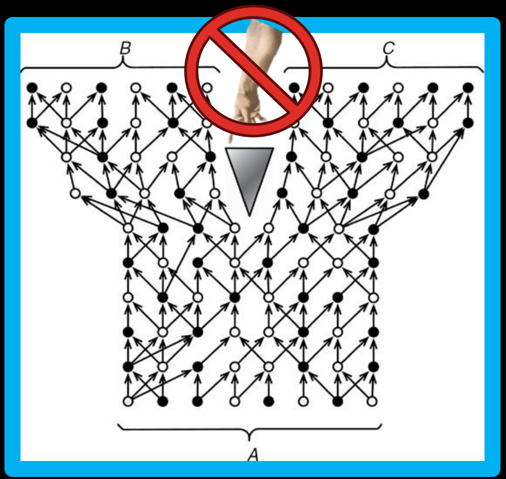
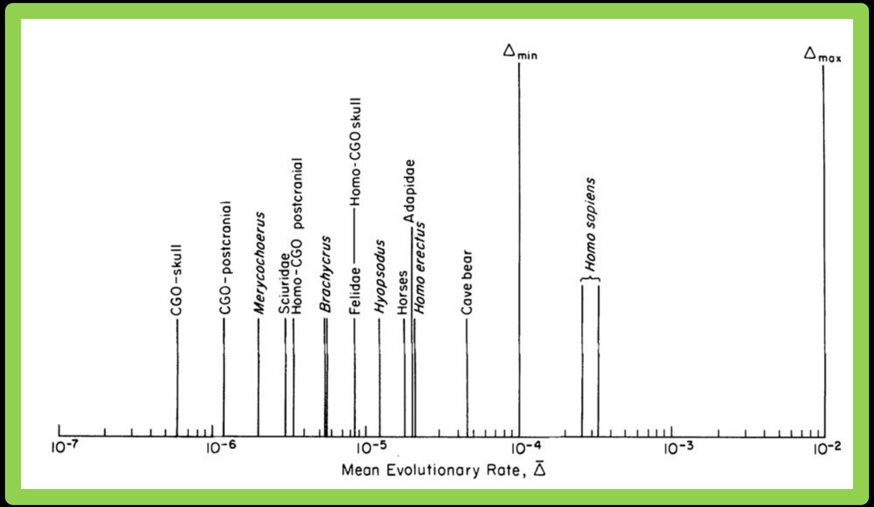





MICRO-TO-MACRO
RESEARCHER
VOID
imgflip.com

GENETIC DRIFT

Univariate case - rate of evolution is a function of additive genetic variance and a constant

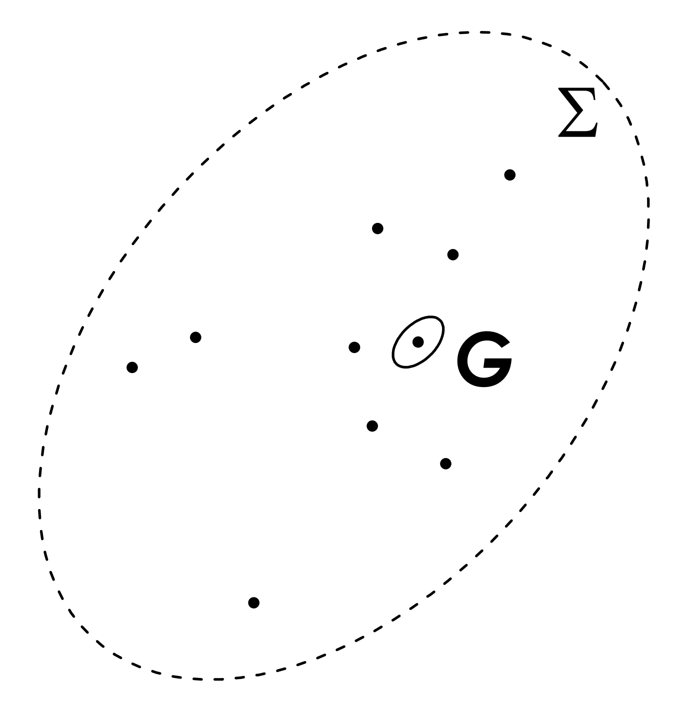
$$\sigma_b^2(t) = \sigma_a^2 \frac{t}{N}$$

Univariate

Multivariate case- rates of evolution are a function of additive genetic variance for each trait and a constant (t/Ne)

$$\Sigma(t) = \mathrm{G} \frac{t}{N}$$

Multivariate



Divergence should be proportional to the amount of intraspecific variation

Kluge & Kerfoot (1976)

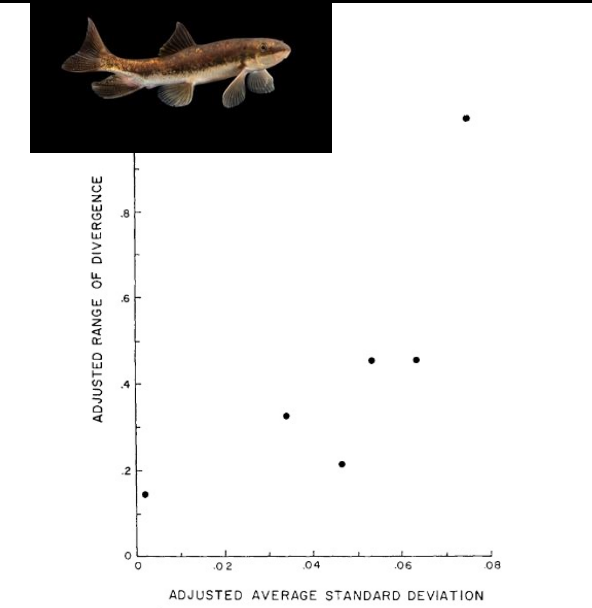


FIG. 3.—Bivariate plot of RD_A against $\bar{s}_A$ in *Catostomus*

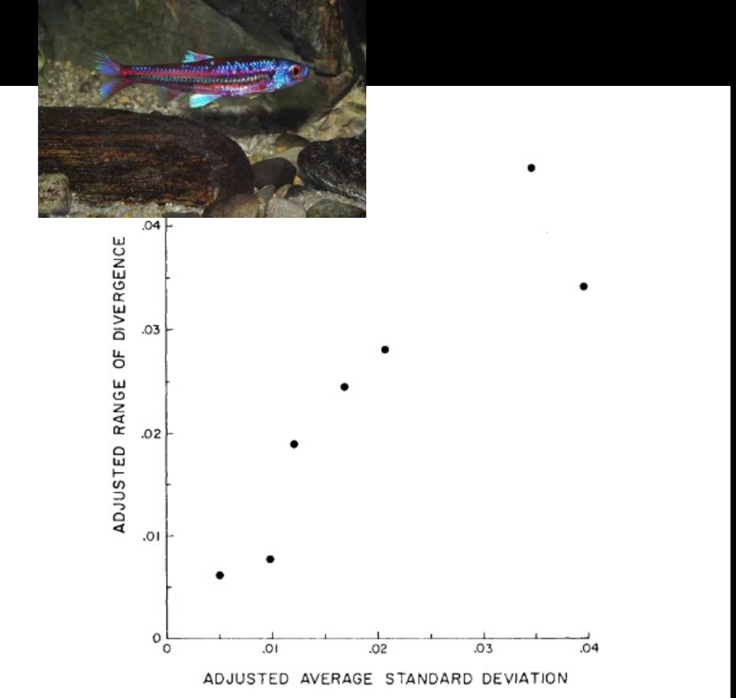


FIG. 4.—Bivariate plot of RD_A against $\bar{s}_A$ in *Notropis*

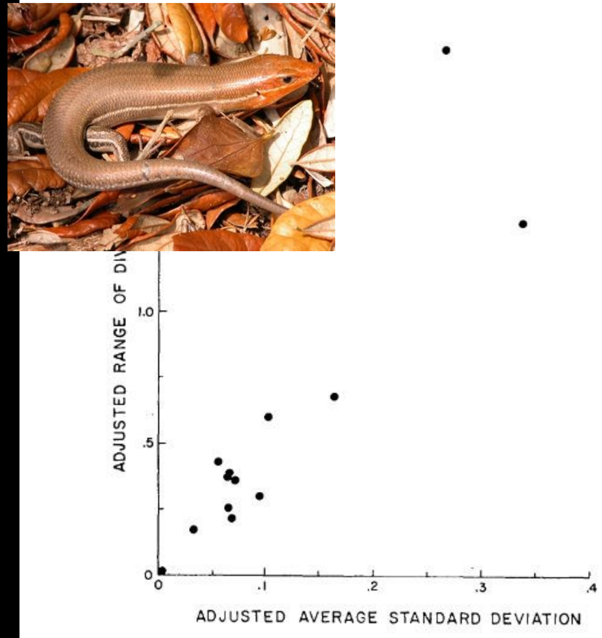


FIG. 5.—Bivariate plot of RD_A against $\bar{s}_A$ in *Eumeces*

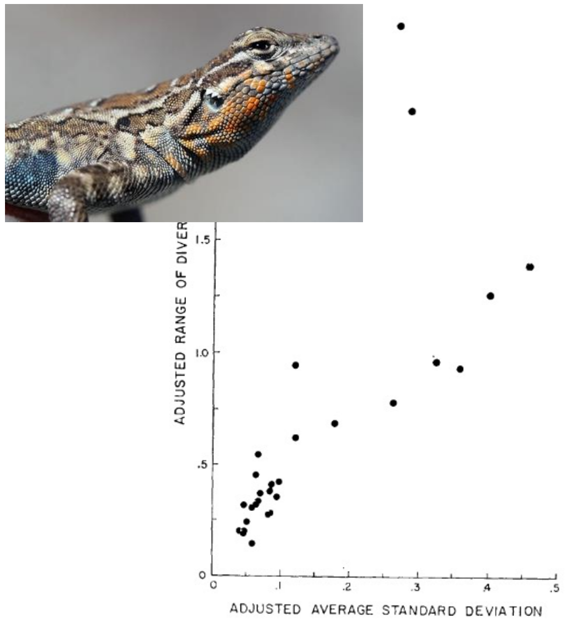


FIG. 6.—Bivariate plot of RD_A against $\bar{s}_A$ in Uta_2

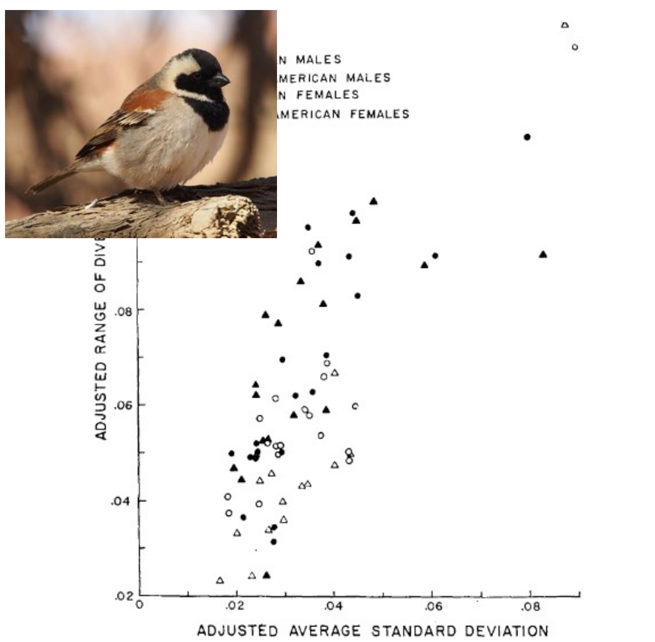
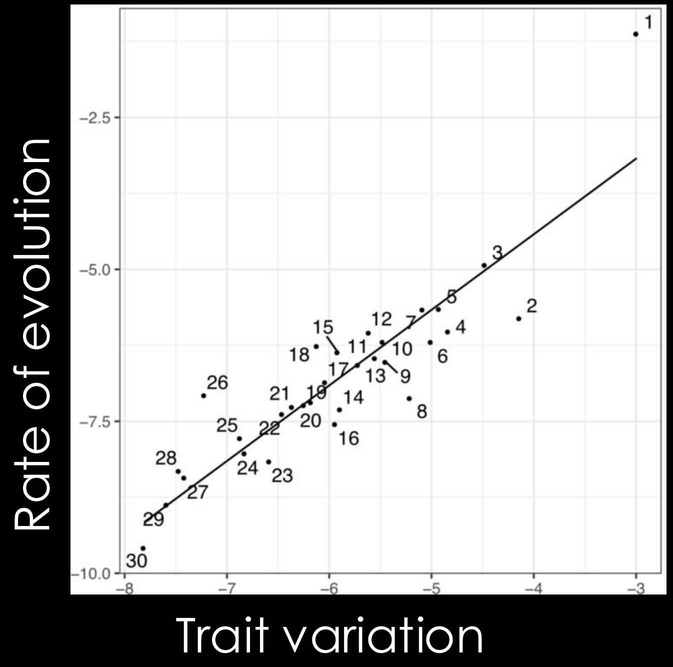
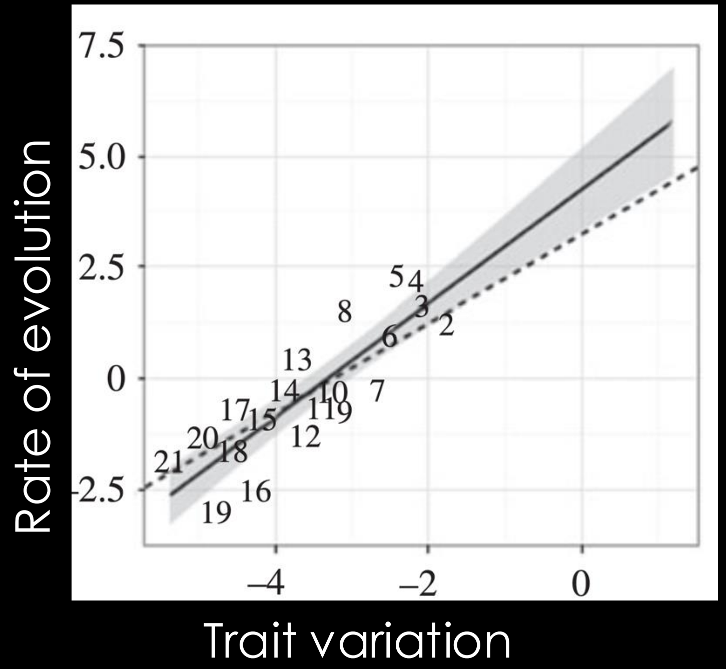


FIG. 9.—Bivariate plot of RD_A against $\bar{s}_A$ in *Passer*



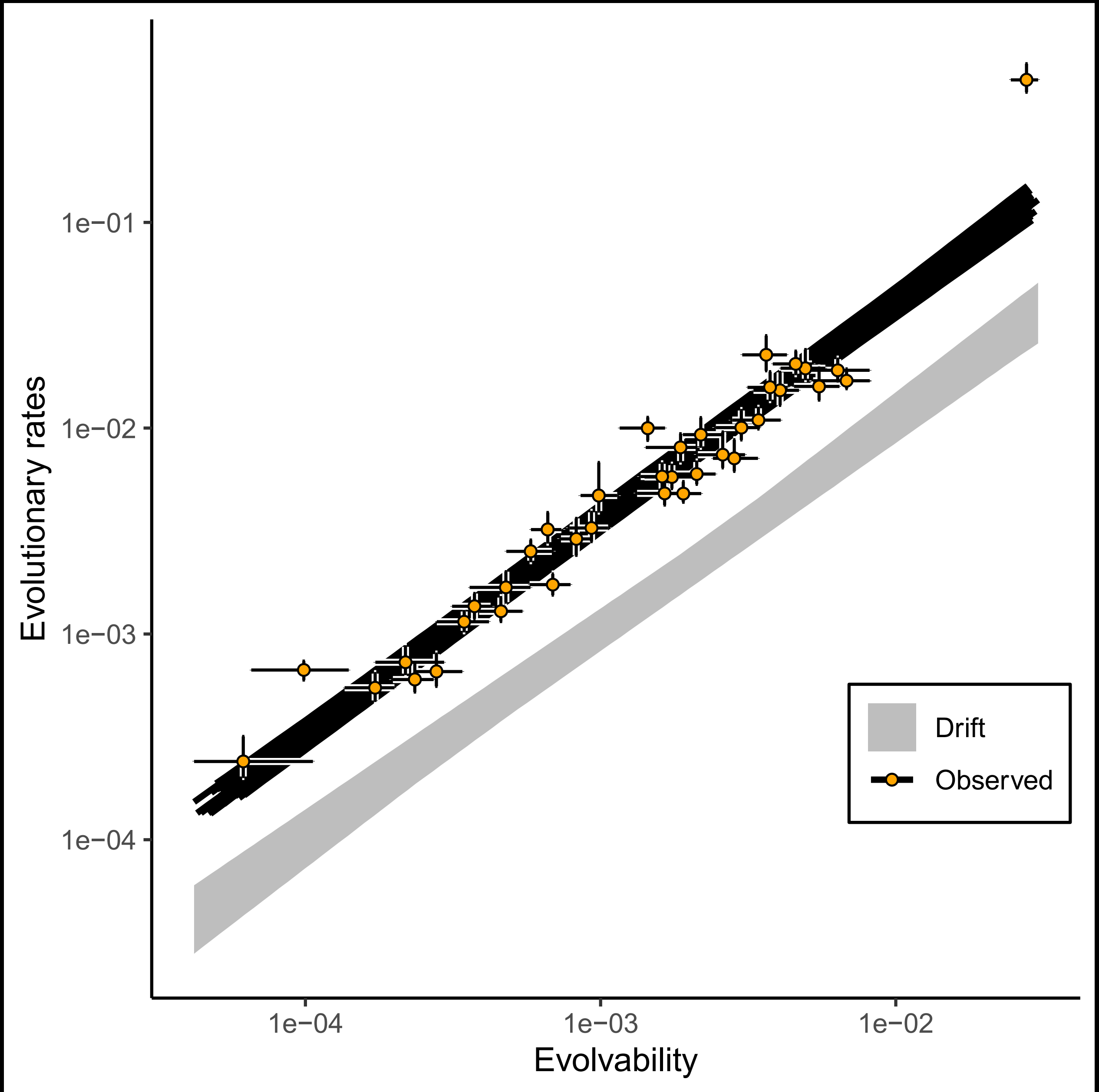


Machado. 2020

13 mya

Simon, Machado, Marroig, 2016

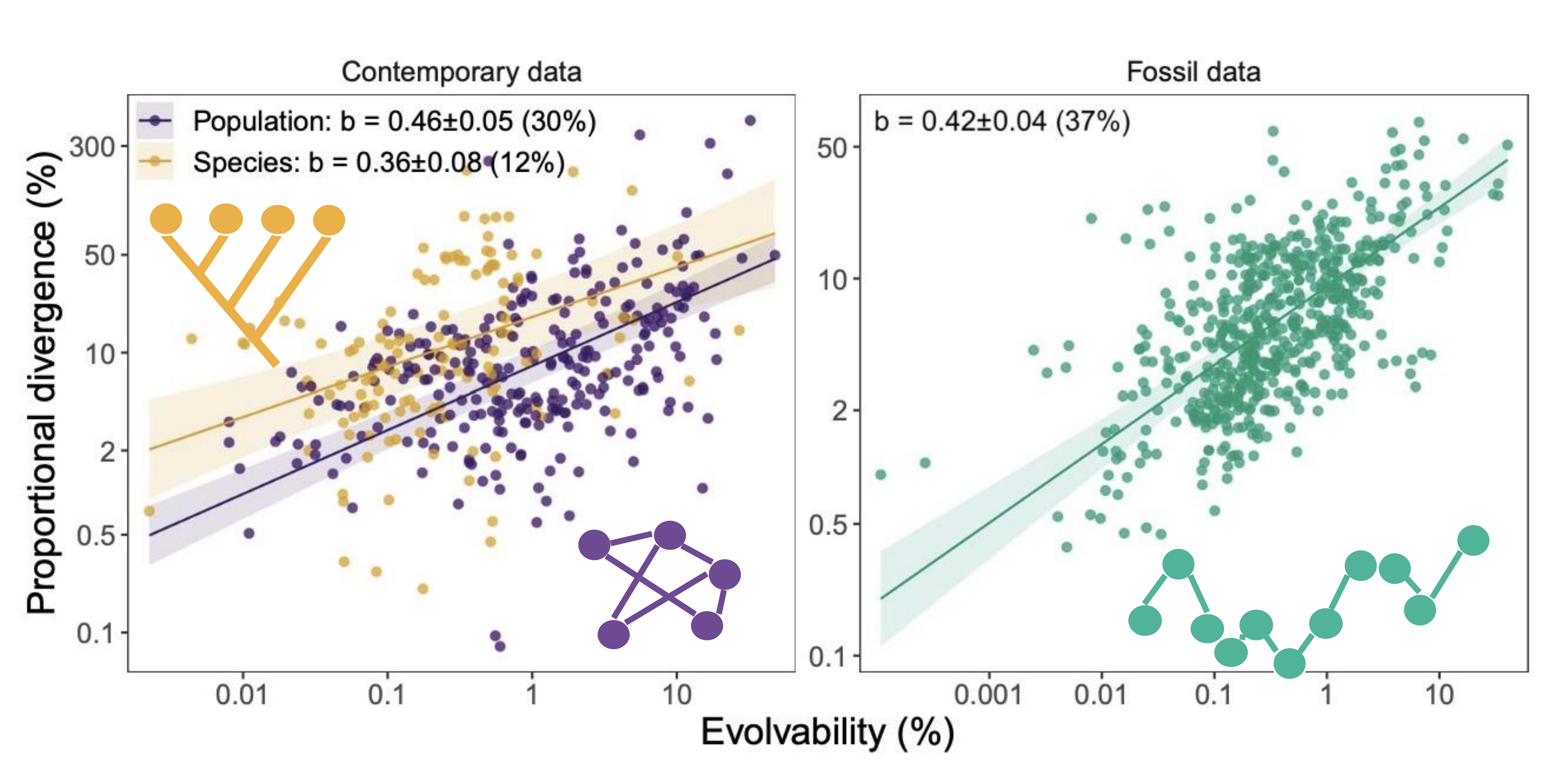
9 mya



65 mya

Penna et al., Machado *in prep*

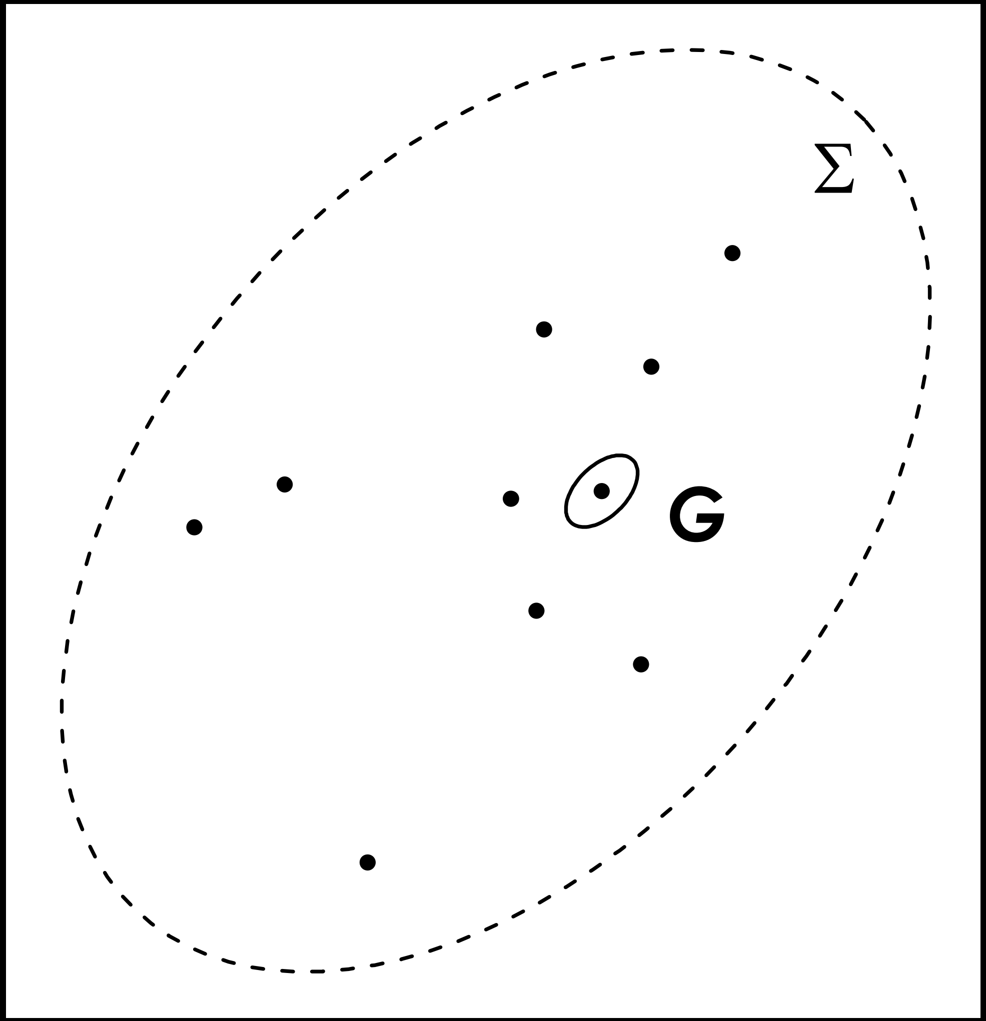

ME
THE REST
OF THE
BIOSPHERE
DOGS
FROGS
MONKEYS
imgflip.com



But why?

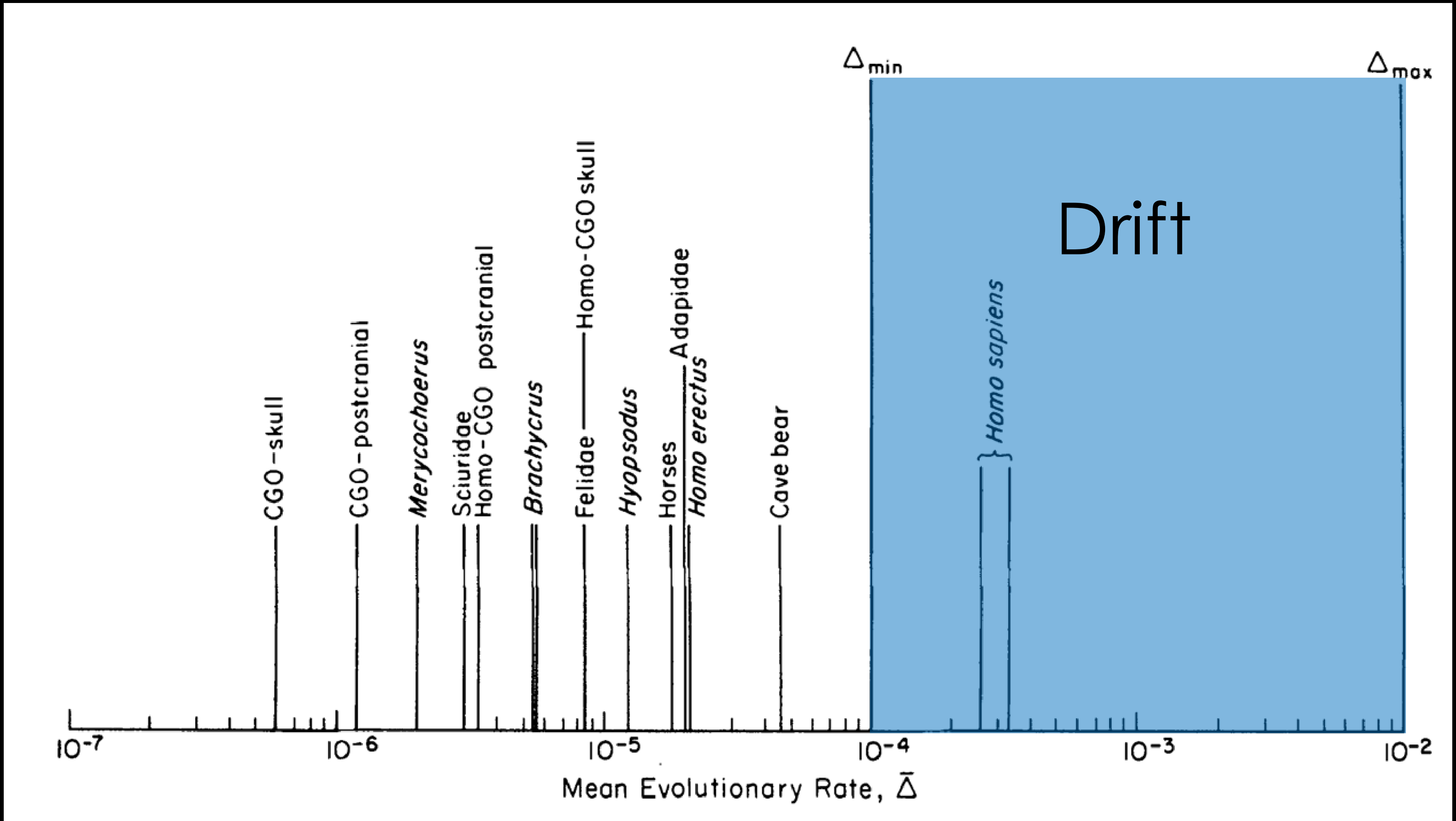
Holstad et al. 2024

GENETIC DRIFT



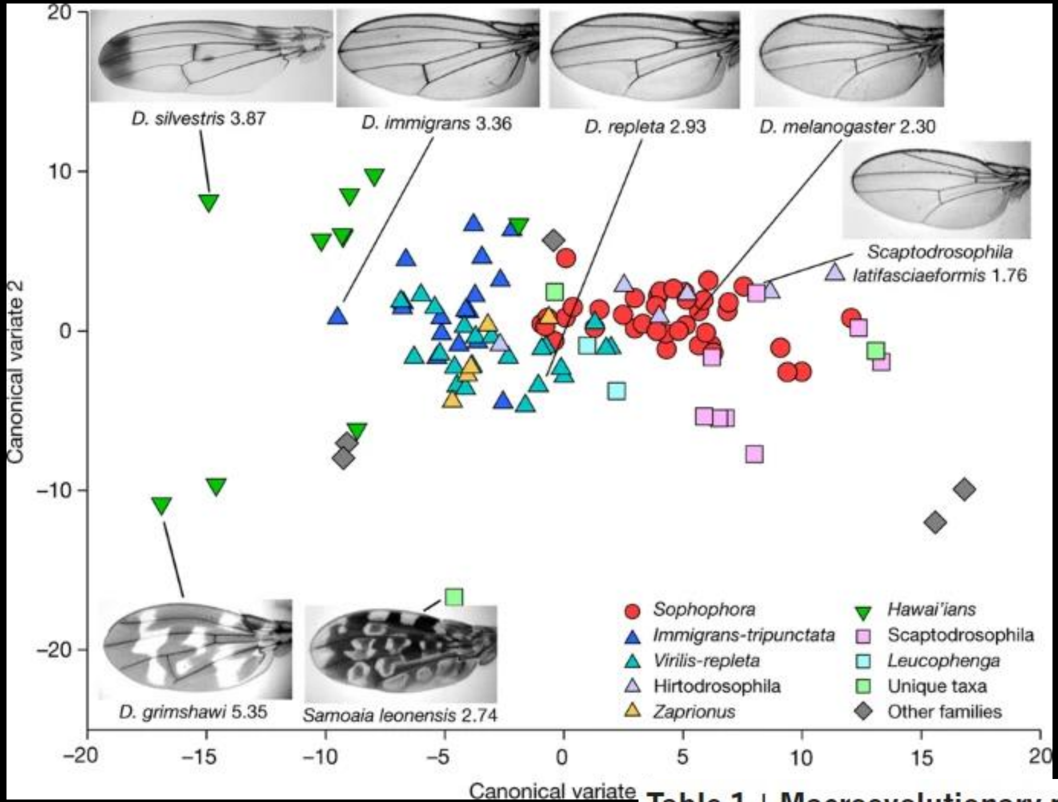
$$\Sigma(t) = \mathrm{G}\frac{t}{N}$$

- Under genetic drift divergence should be proportional to the amount of intraspecific variation
- Variation and divergence are proportional
- It's possible that traits are evolving neutrally



Drift seams unlikely

Lynch, 1990



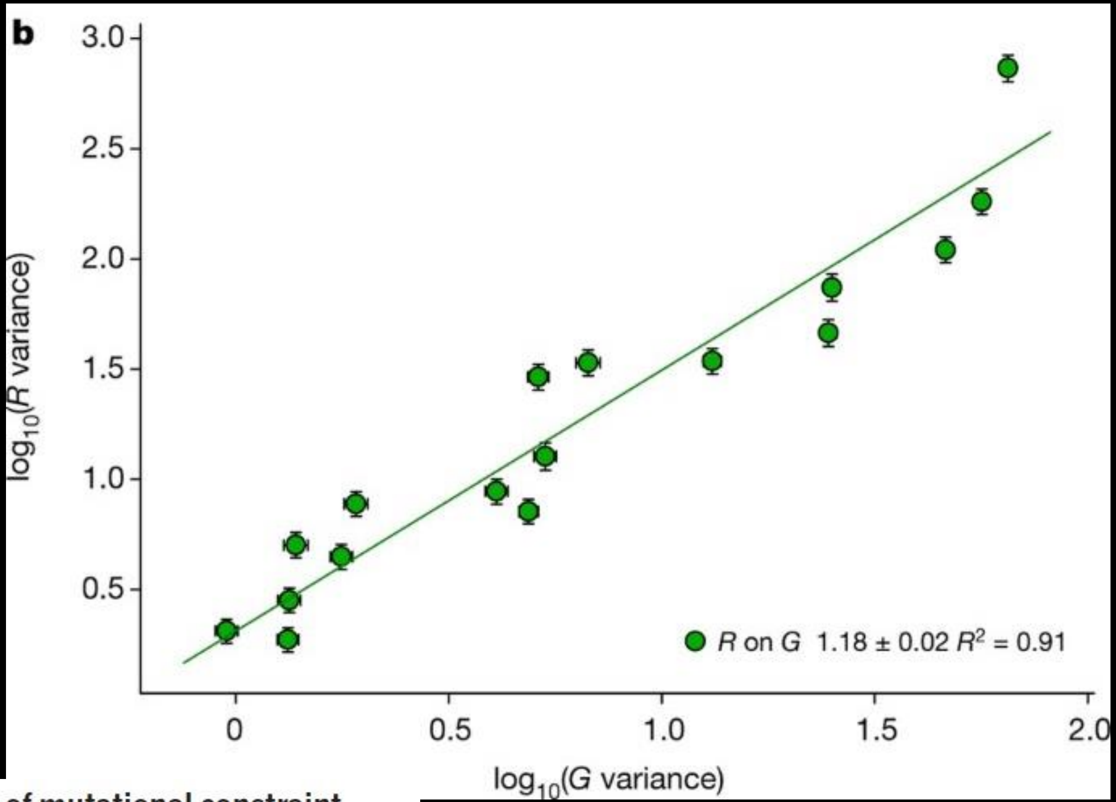


Table 1 | Macroevolutionary predictions of mutational constraint models

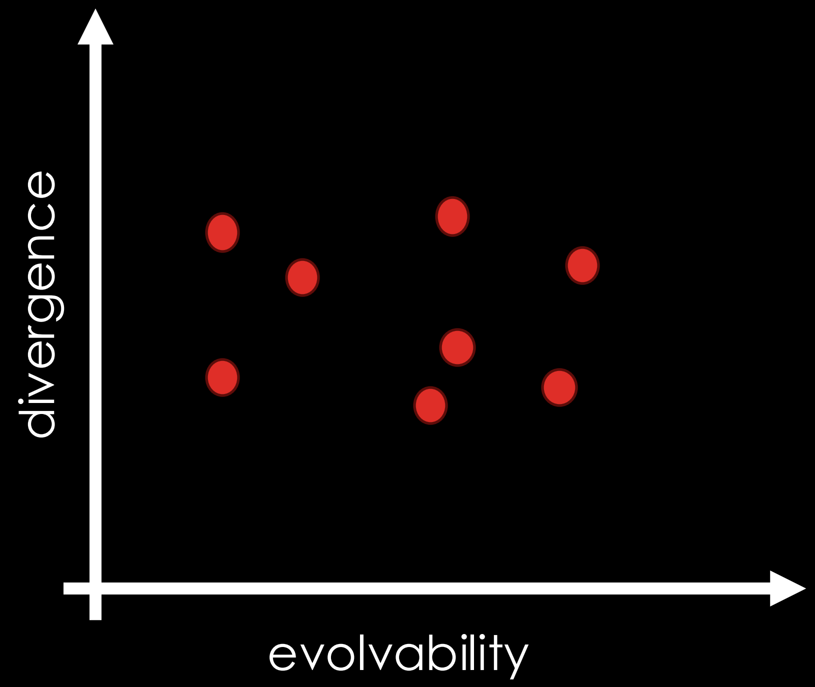
Evolutionary model[7]	Fitness function	Divergence rate[*]	Scaling exponent	Phylogenetic heritability
Neutral evolution	Flat	High ($2V_M$[†])	**1**	**High**
Fluctuating directional selection	Linear	High	2	**High**
Divergent selection[‡]	Linear	Very high $>2V_M$	2	Intermediate
BM[§] slow[‖]	Moving optimum[¶]	**Low**	∼0	**High**
BM[§] fast[‖]	Moving optimum	Very high	∼0	**High**
White noise[**]	Moving optimum	**Low**	0	0
OU[††] slow[‖]	Moving optimum	**Low**	∼0	Intermediate
OU[††] intermediate[‖]	Moving optimum	**Low**	**0–1**	Low
OU[††] fast[‖]	Moving optimum	**Low**	∼0	∼0
Observed		**Low**	**∼1**	**High**

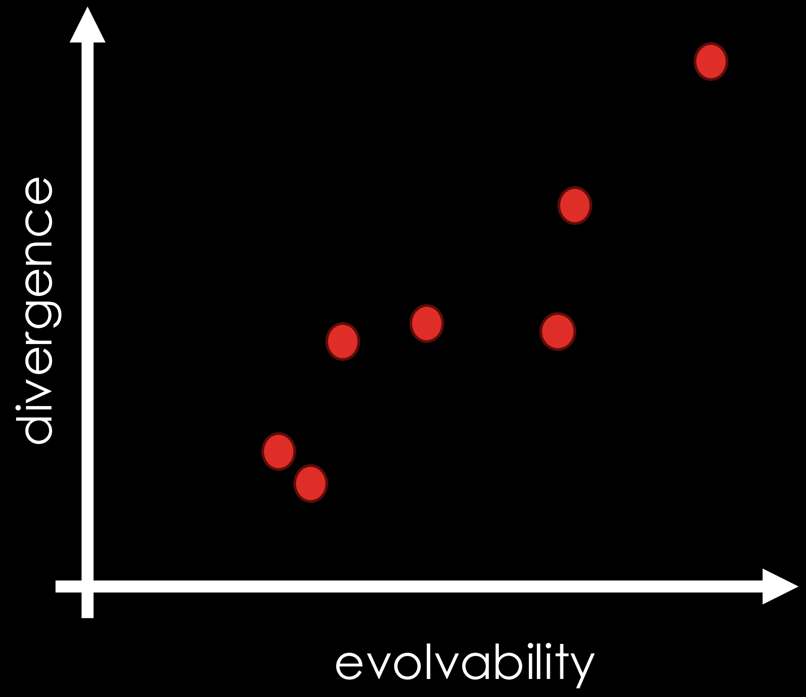
Houle et al. 2017

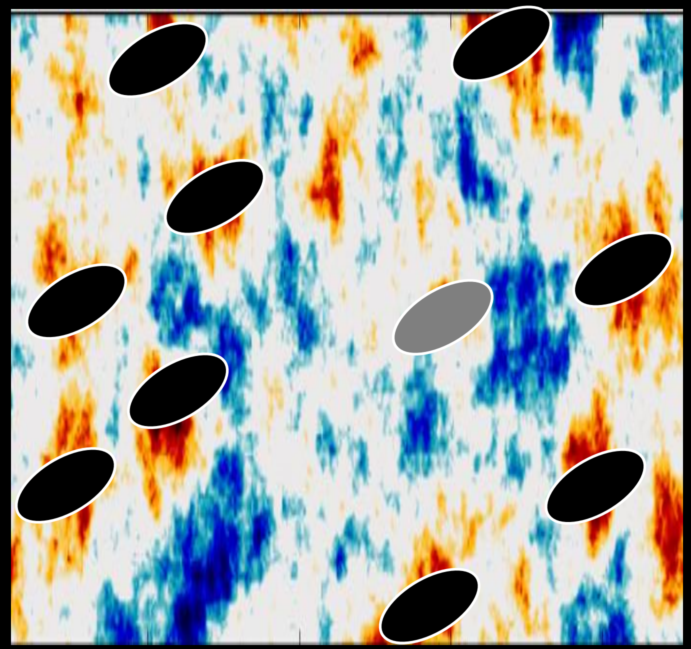
“PARADOX OF PREDICTABILITY”

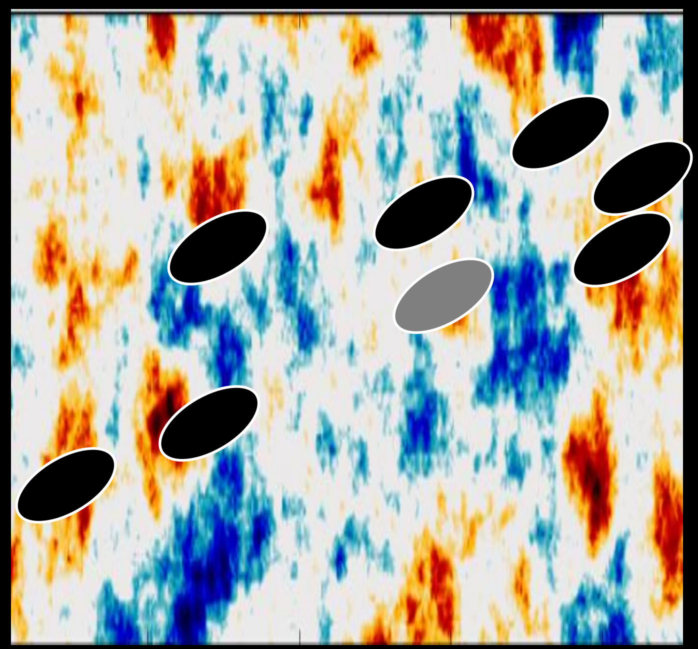
Tsuboi et al. 2024

- Species can reach peaks rapidly (unlikely to be maladapted)
- Rates of evolution are too slow, implying strong influence of stabilizing selection
- Evolution is likely dominated by peak distribution and stabilizing selection
- Peak distribution should have no relation to phenotypic variation
- Still, the amount of trait variation predicts how traits will evolve on large time scales.







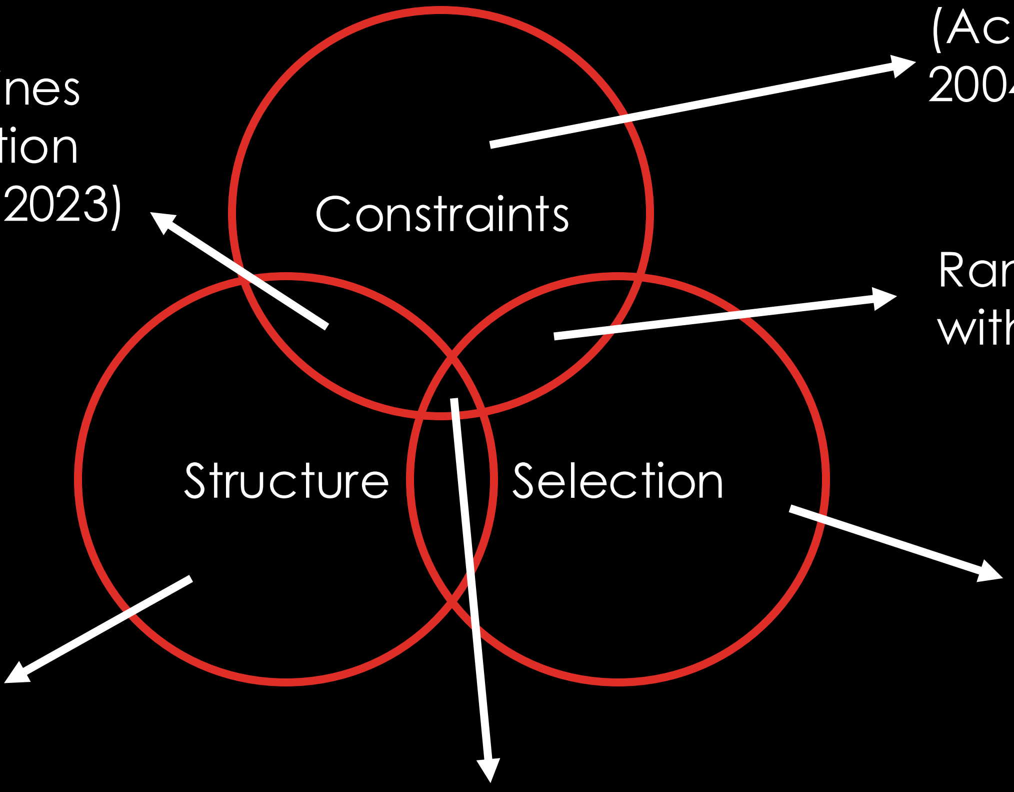


Why?

POTENTIAL EXPLANATIONS

Development defines directions of variation (Rohner & Berger, 2023)

Drift in fact , governs (Ackerman & Cheverud 2004)



Random selection interacts with G (Holstad et al. 2024)

Selection aligns G and divergence (Schluter, 1996)

Development governs scaling of traits at both levels (Gould & Lewontin, 1979)

Selection shapes variation (imitative epigenotype, Riedl, 1978)

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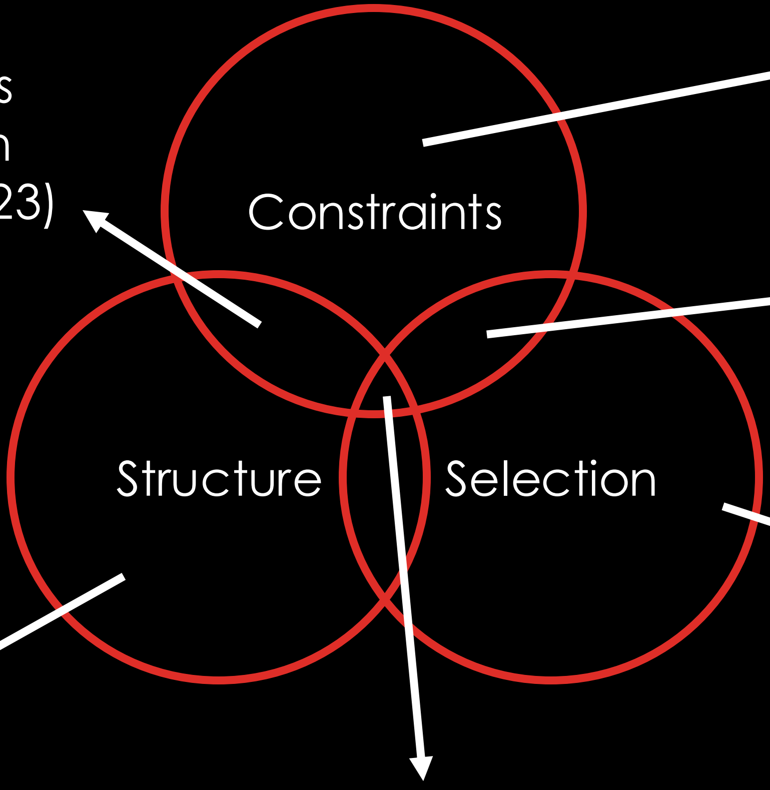

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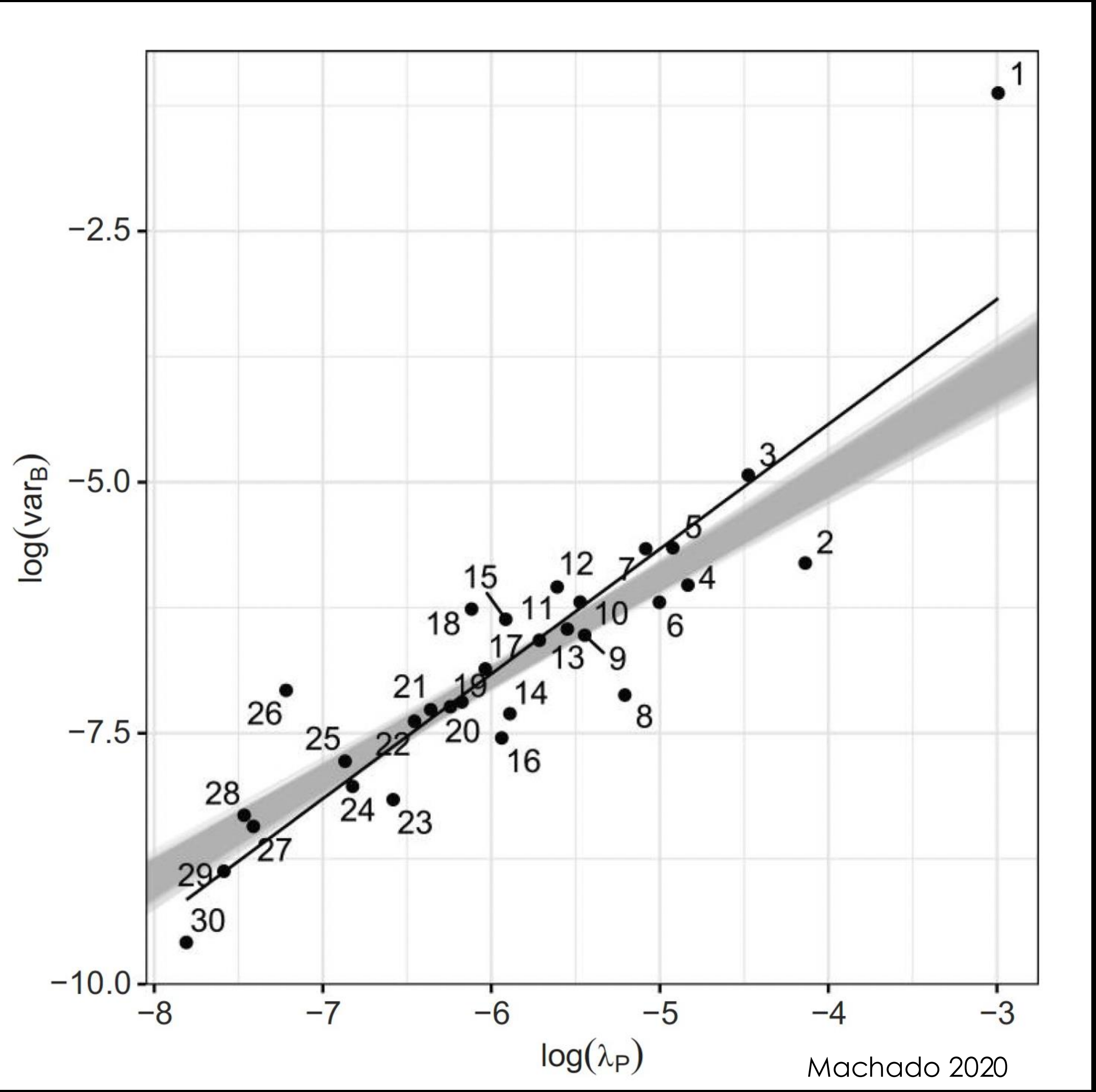
$$\mathbf{B} = \frac{t}{N_e}\mathbf{G},$$

$$\log(\mathrm{var_B}) = a + b[\log(\lambda)]$$

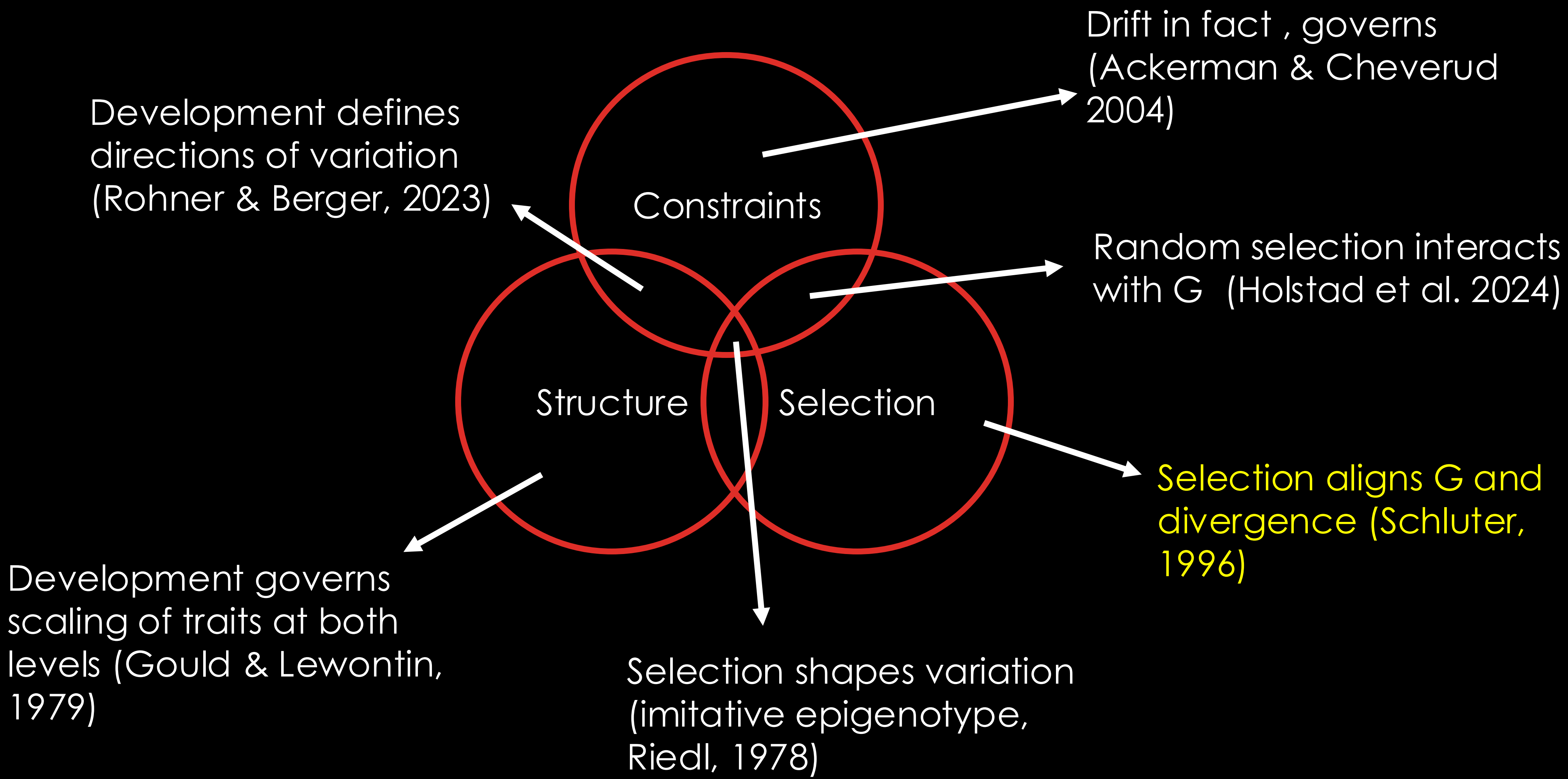
t/Ne -> Nuisance parameter



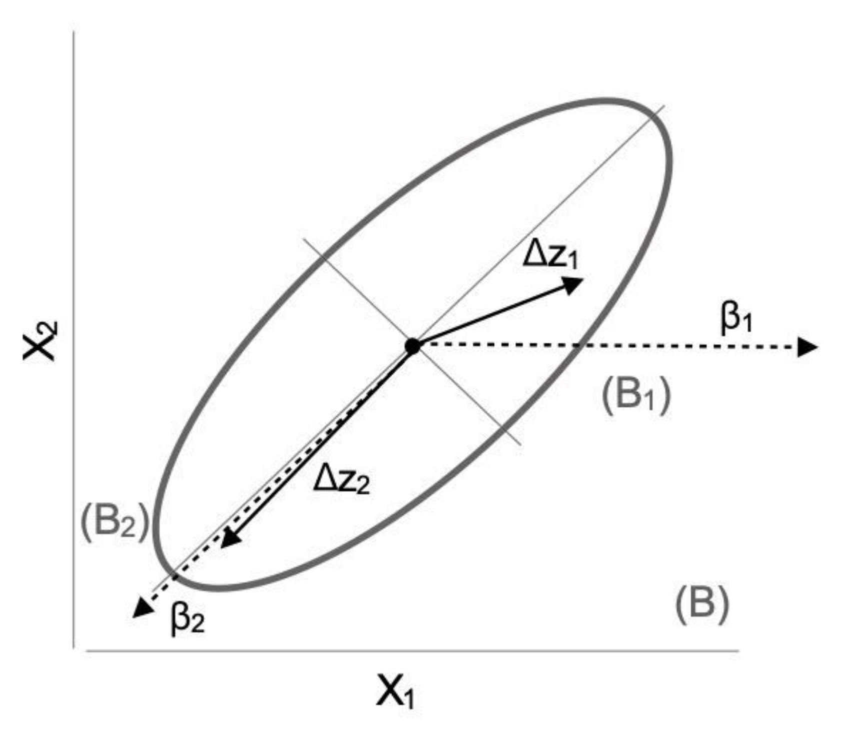
Problems?

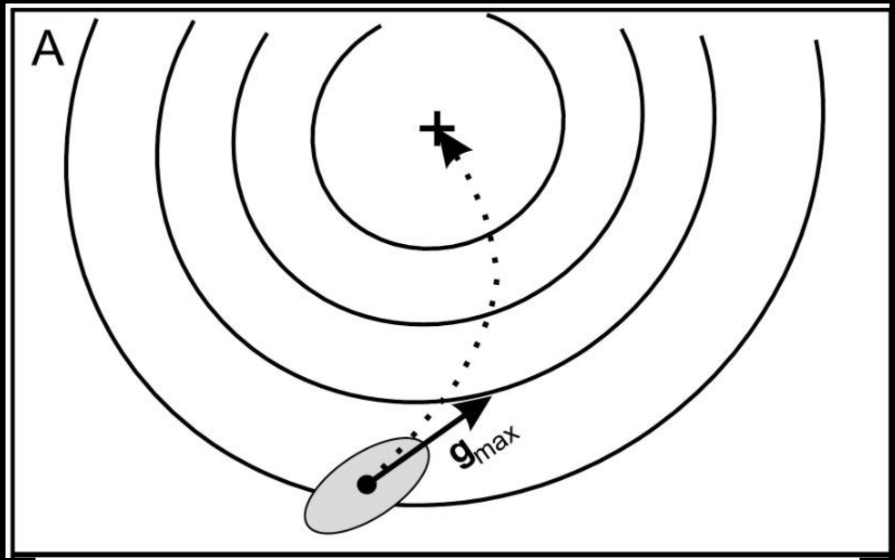
Ackerman & Cheverud 2004

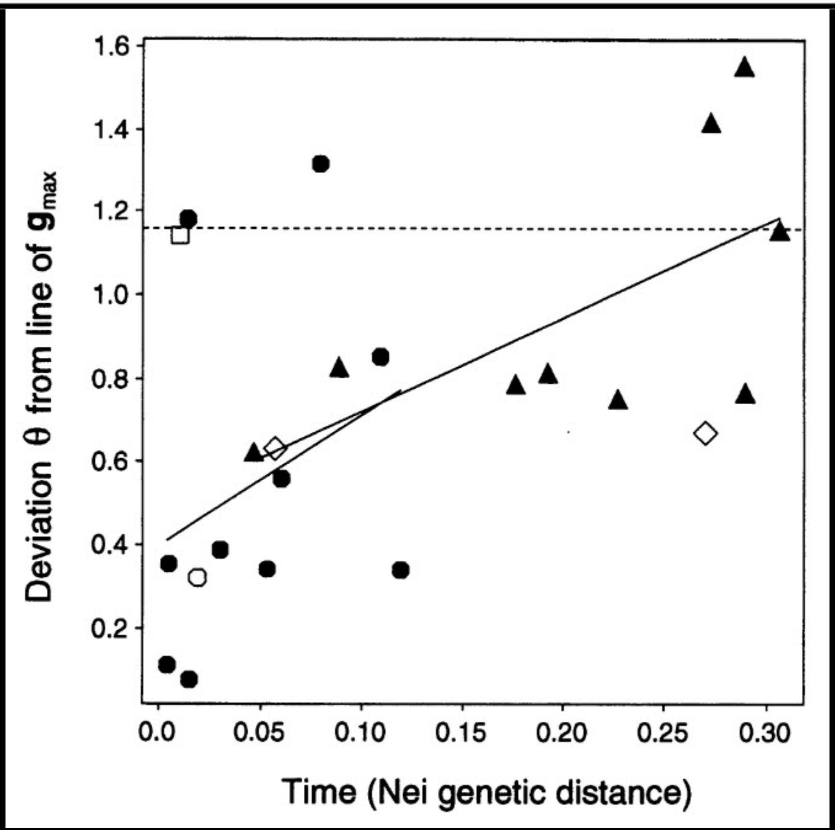
POTENTIAL EXPLANATIONS



$$\Delta \mathbf{z} = \mathbf{G}\beta$$







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Schluter 1996

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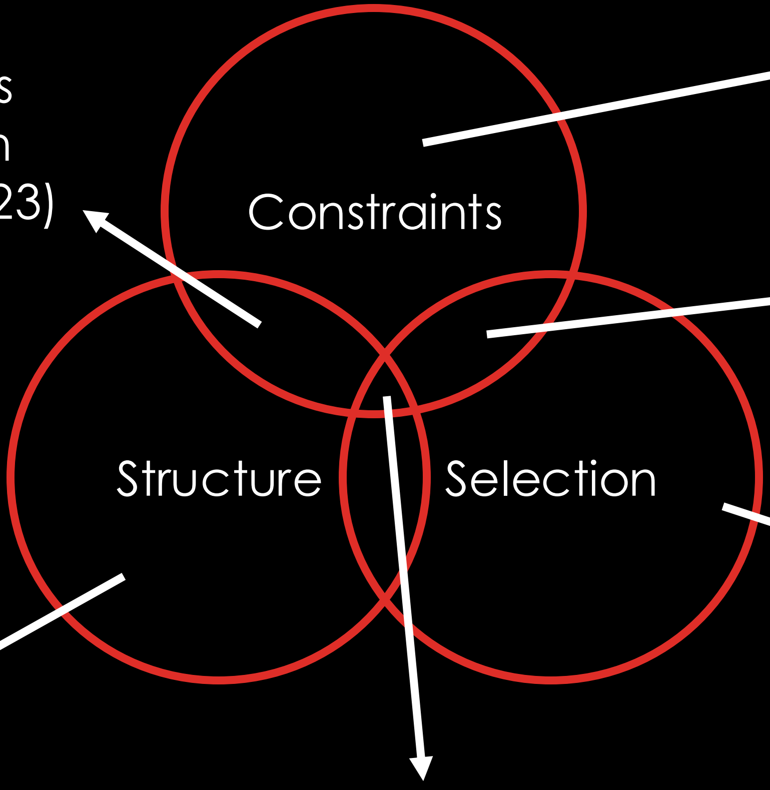

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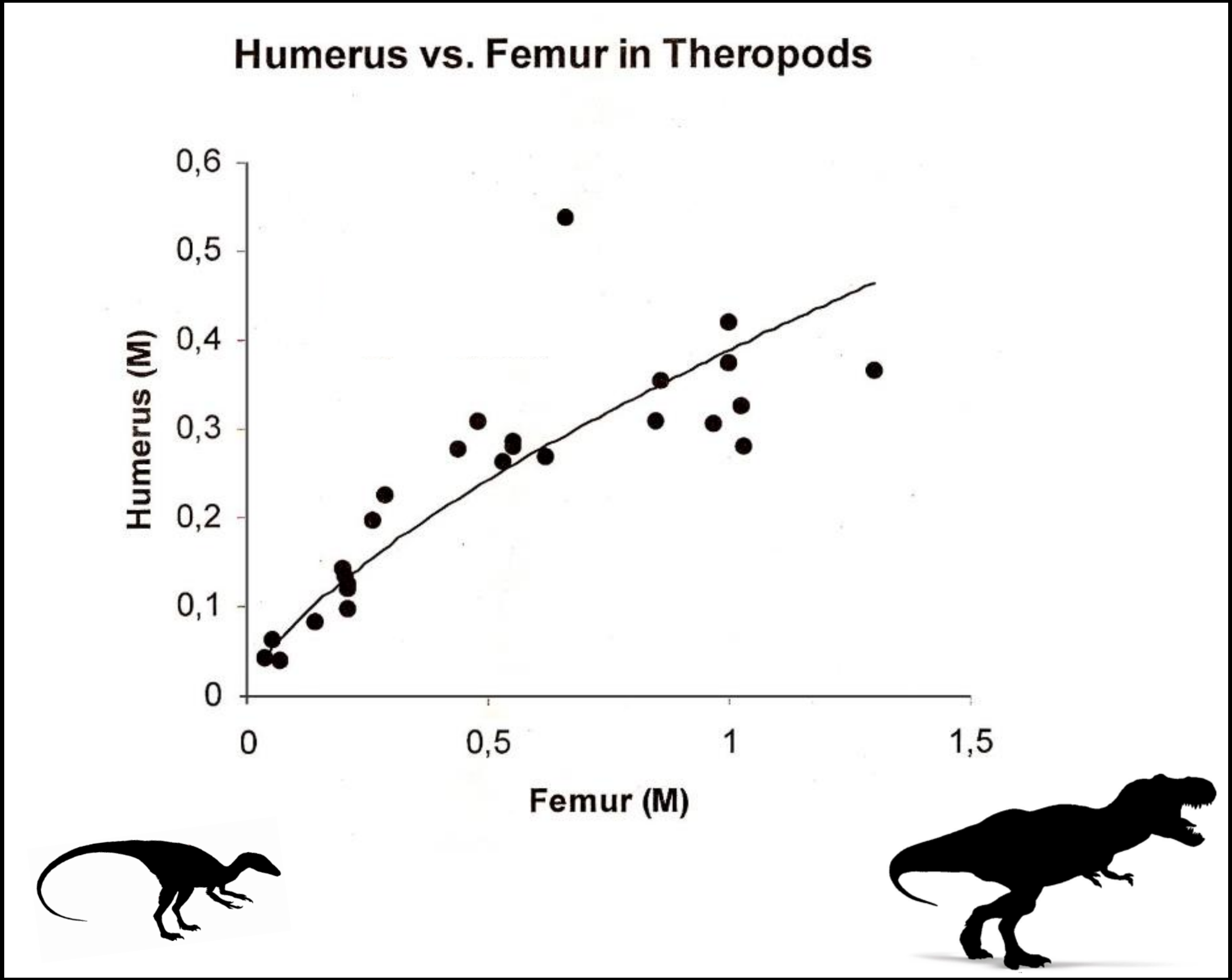


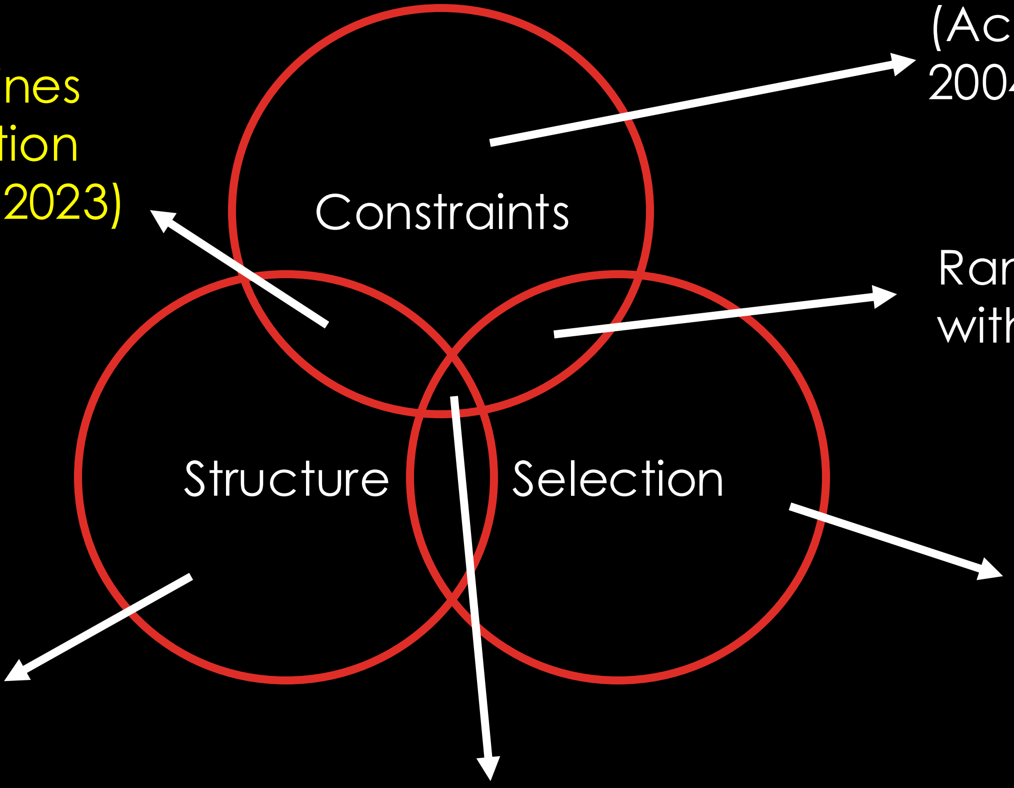
Vargas, 1999

Gould & Lewontin, 1979

POTENTIAL EXPLANATIONS

Development defines directions of variation (Rohner & Berger, 2023)

Drift in fact , governs (Ackerman & Cheverud 2004)

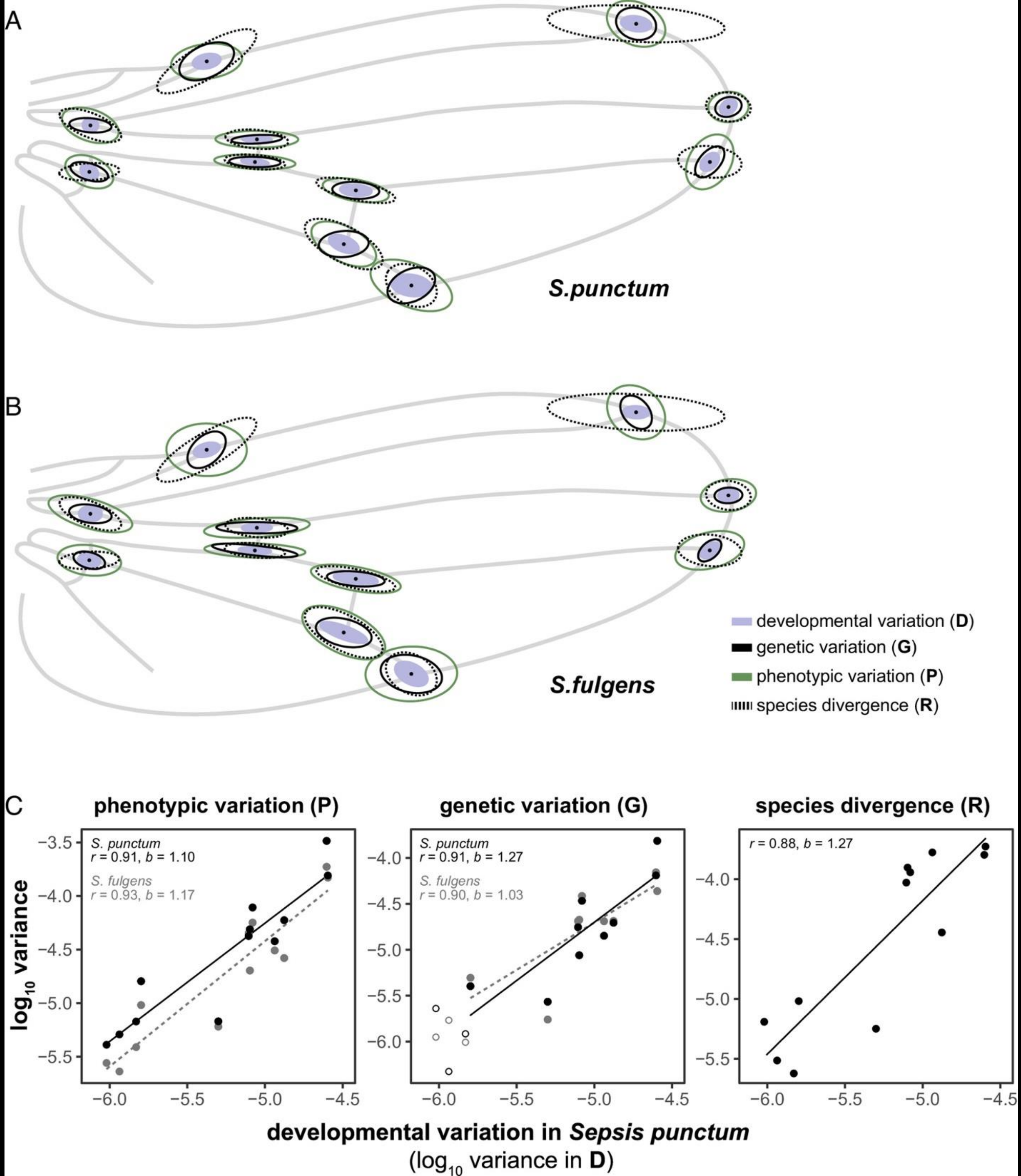


Random selection interacts with G (Holstad et al. 2024)

Selection aligns G and divergence (Schluter, 1996)

Development governs scaling of traits at both levels (Gould & Lewontin, 1979)

Selection shapes variation (imitative epigenotype, Riedl, 1978)



Rohner & Berger, 2023

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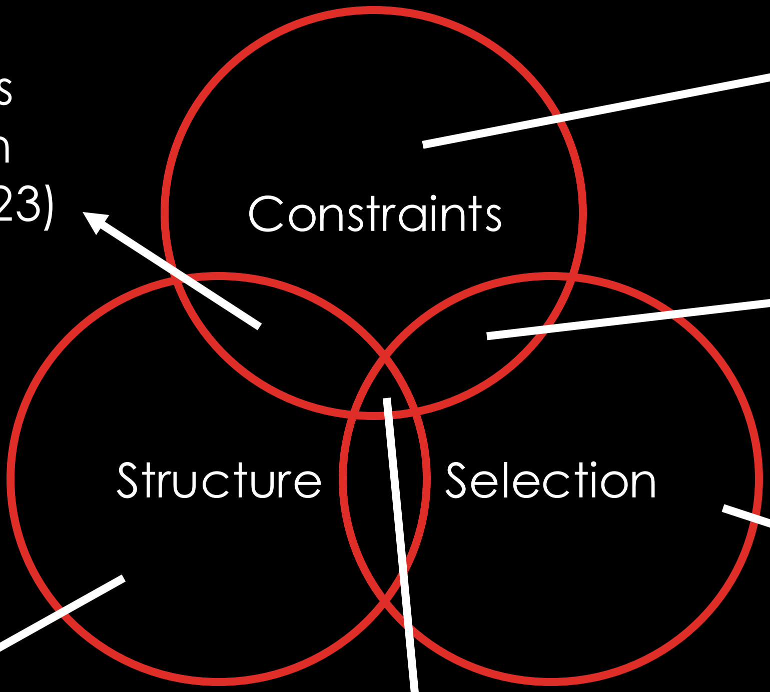

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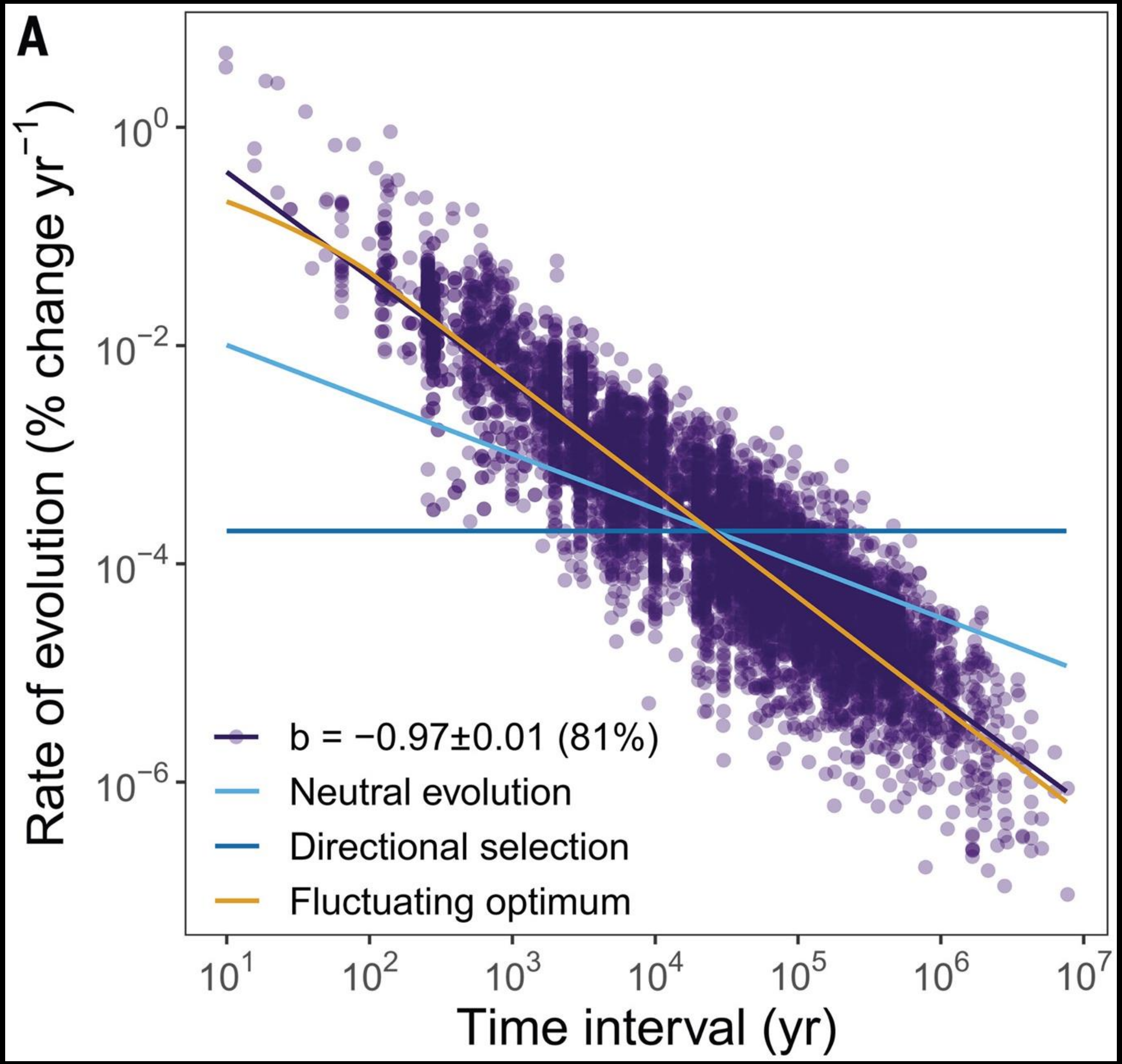
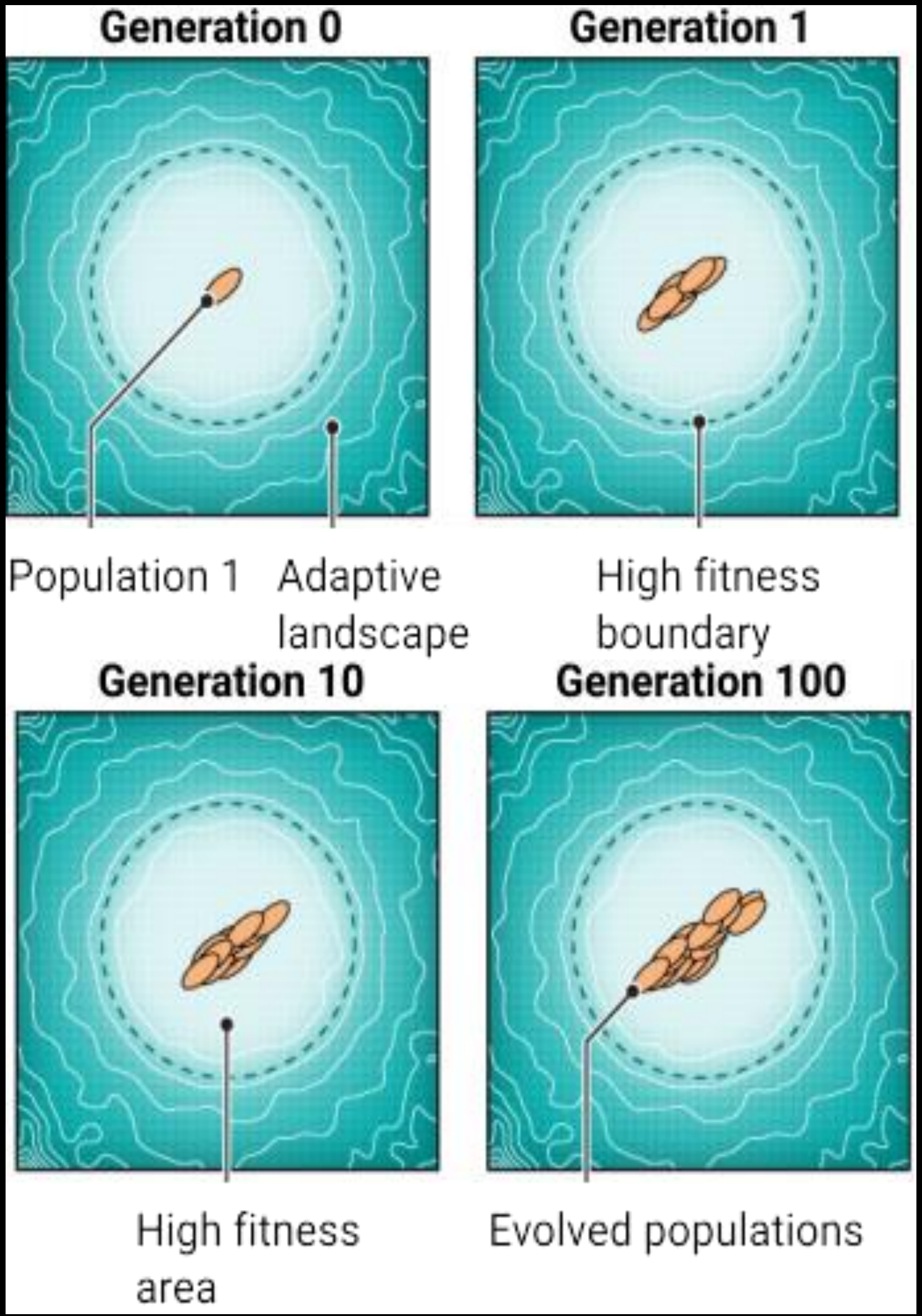


Holstad et al. 2024



Uyeda & McGlothin, 2024

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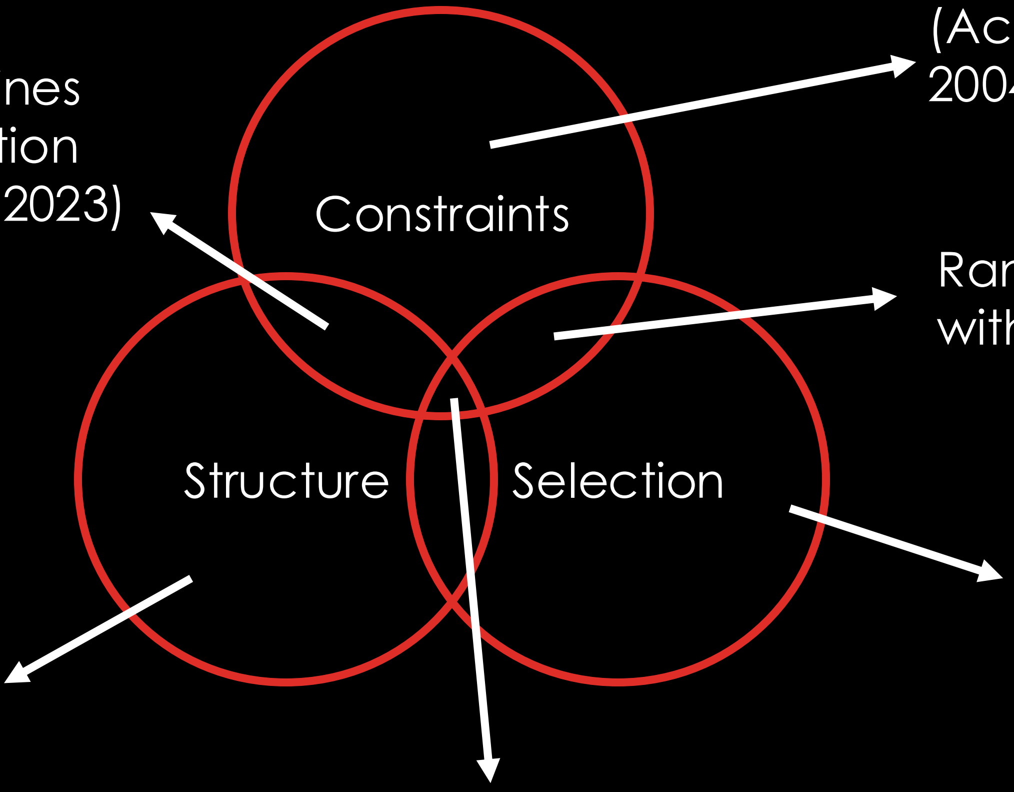

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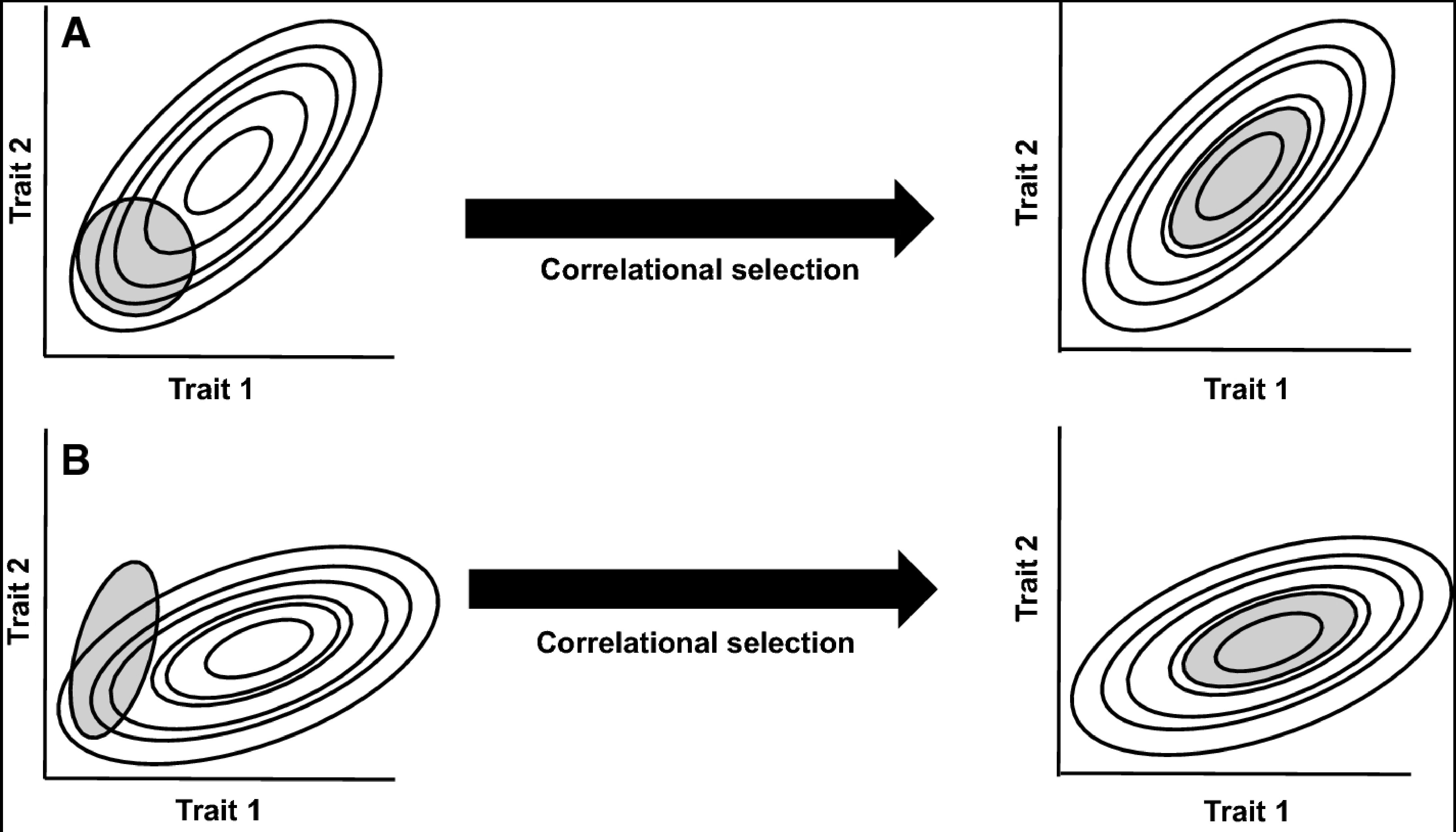

Svensoon 2022

Riedl, 1978