Micro-evo-devo: Genotype-phenotype relationships, convergences, environmental factors

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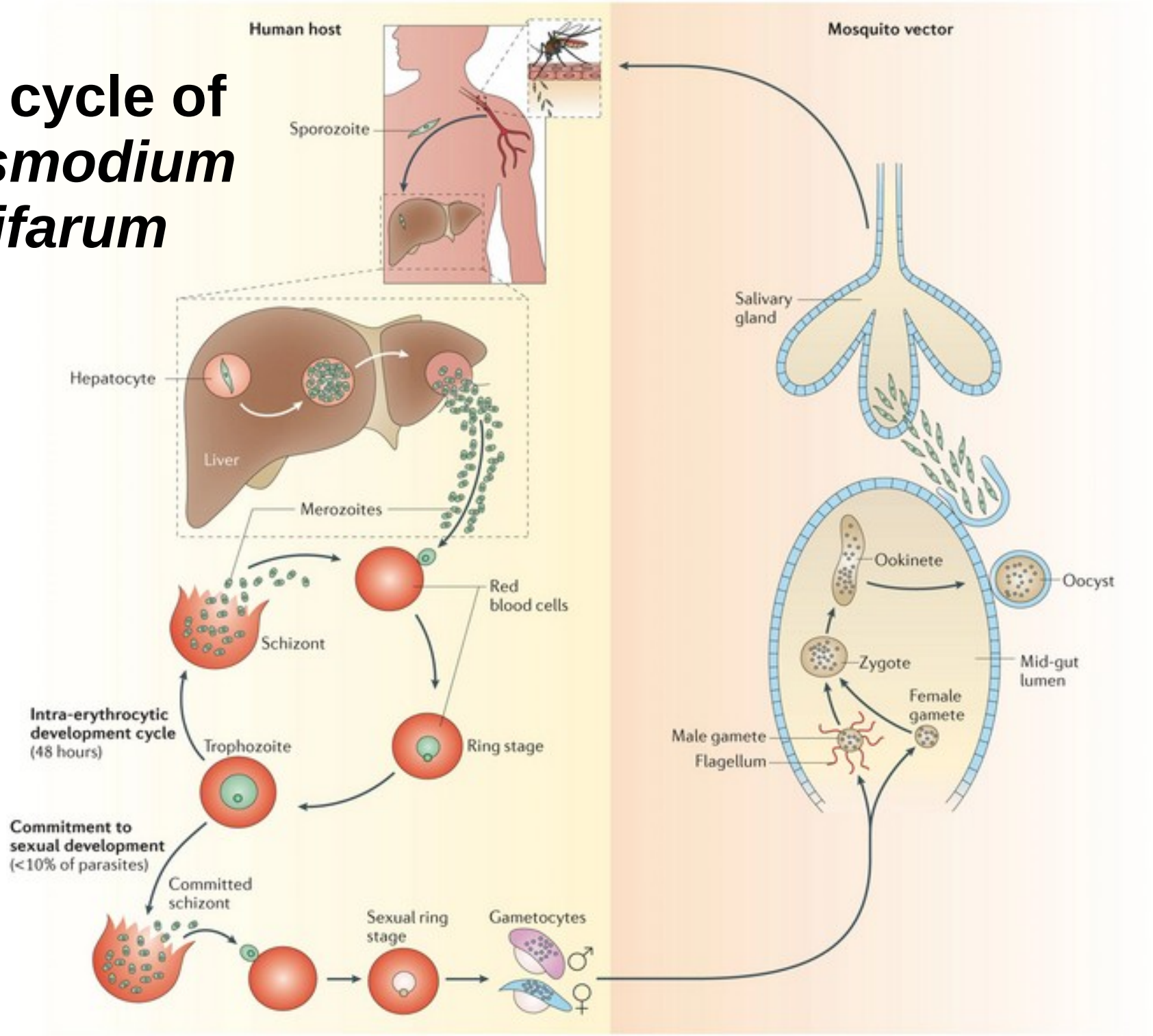
Institut Jacques Monod, Paris

What is evo-devo?

- Development
- Evolution
- Evo-devo

Life cycle of *Plasmodium falcifarum*



https://www.nature.com/articles/nrmicro3519/figures/1

Life cycle of *Sacculina carcini*

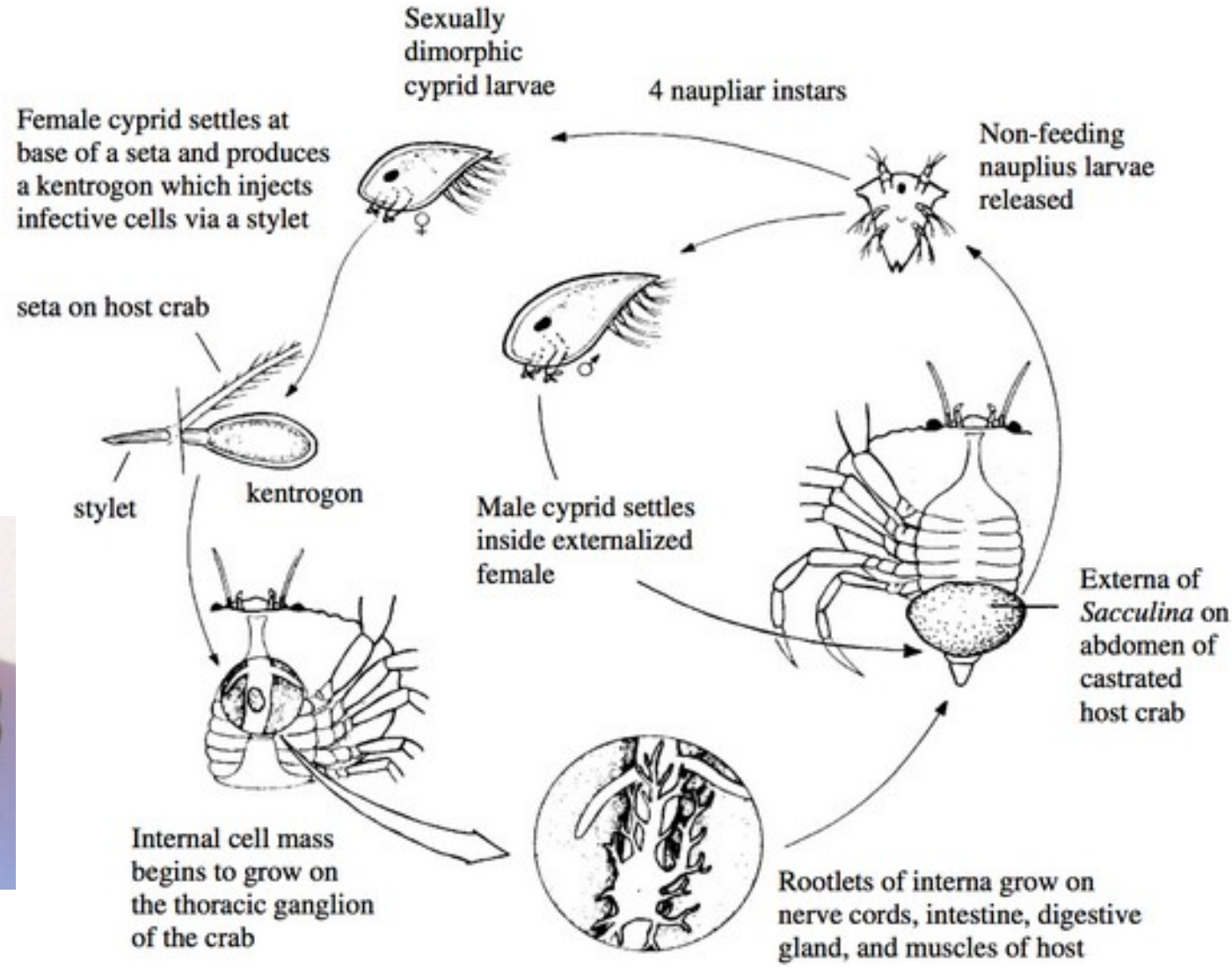


Figure 1. Life cycle of *Sacculina carcini* modified from Hickman et al. (1988).

https://wsg.washington.edu/crabteam/about/newsletter/late-summer-2016/

Development

process through which a single cell (often a fertilized egg) gives rise to a complex multicellular organism

Frontiers:
Regeneration
Unicellular organisms
Asexual reproduction
Aging
Cell death

Examples of subfields:
Morphogenesis
Organogenesis
Cell differentiation

Pradeu, T., Laplane, L., Prévot, K., Hoquet, T., Reynaud, V., Fusco, G., ... & Vervoort, M. (2016). Defining “development”. In Current topics in developmental biology (Vol. 117, pp. 171-183). Academic Press.

What is Evolution?

The peppered moth

In Manchester, in the early 1800s, nearly all were light coloured:

By 1895, nearly all were dark:

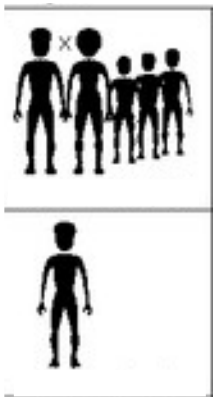
Classical Darwinian Evolution

Variation

Mutations in DNA

Transmission

Differential reproduction

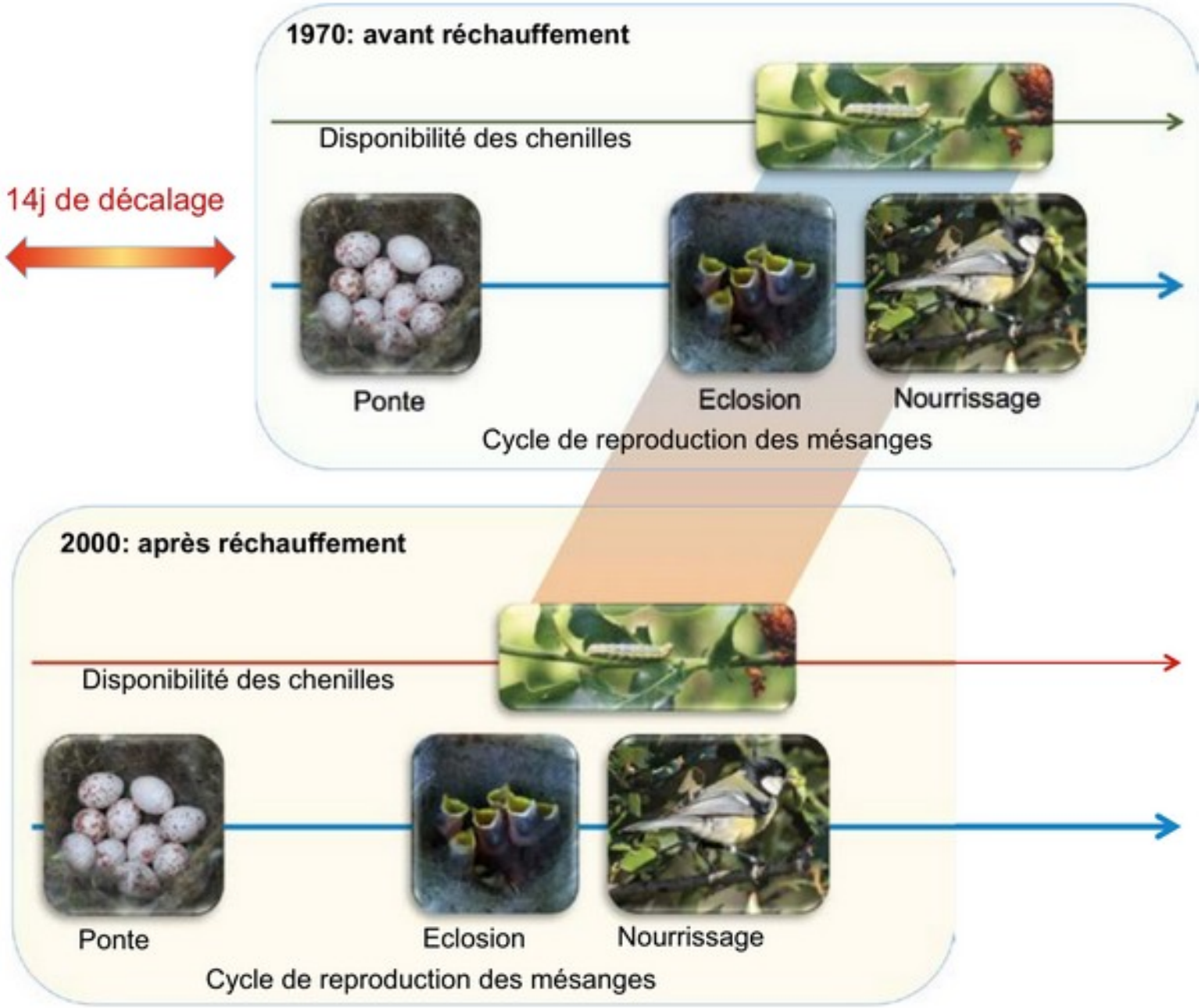


Selection

Genetic Drift

http://evolution.berkeley.edu

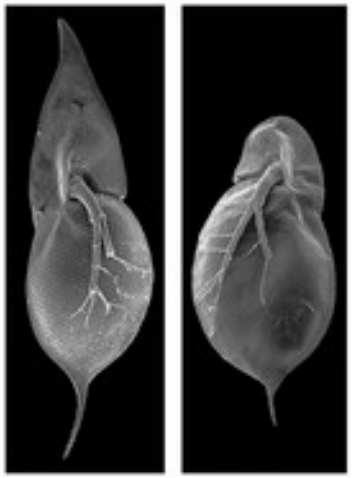
Rapid evolution of great tits



Etonnant vivant : découvertes et promesses du XXIe siècle (2017)

Plasticity: one genotype → several phenotypes

Daphnia



with helmet | without helmet

Nemoria arizonaria caterillars

spring: caterpillars feed on catkins

summer: caterpillars feed on leaves

Water crowfoot plant

leaves growing above water | leaves growing below water

Desert locusts

solitary

gregarious

Commodore butterfly

winter

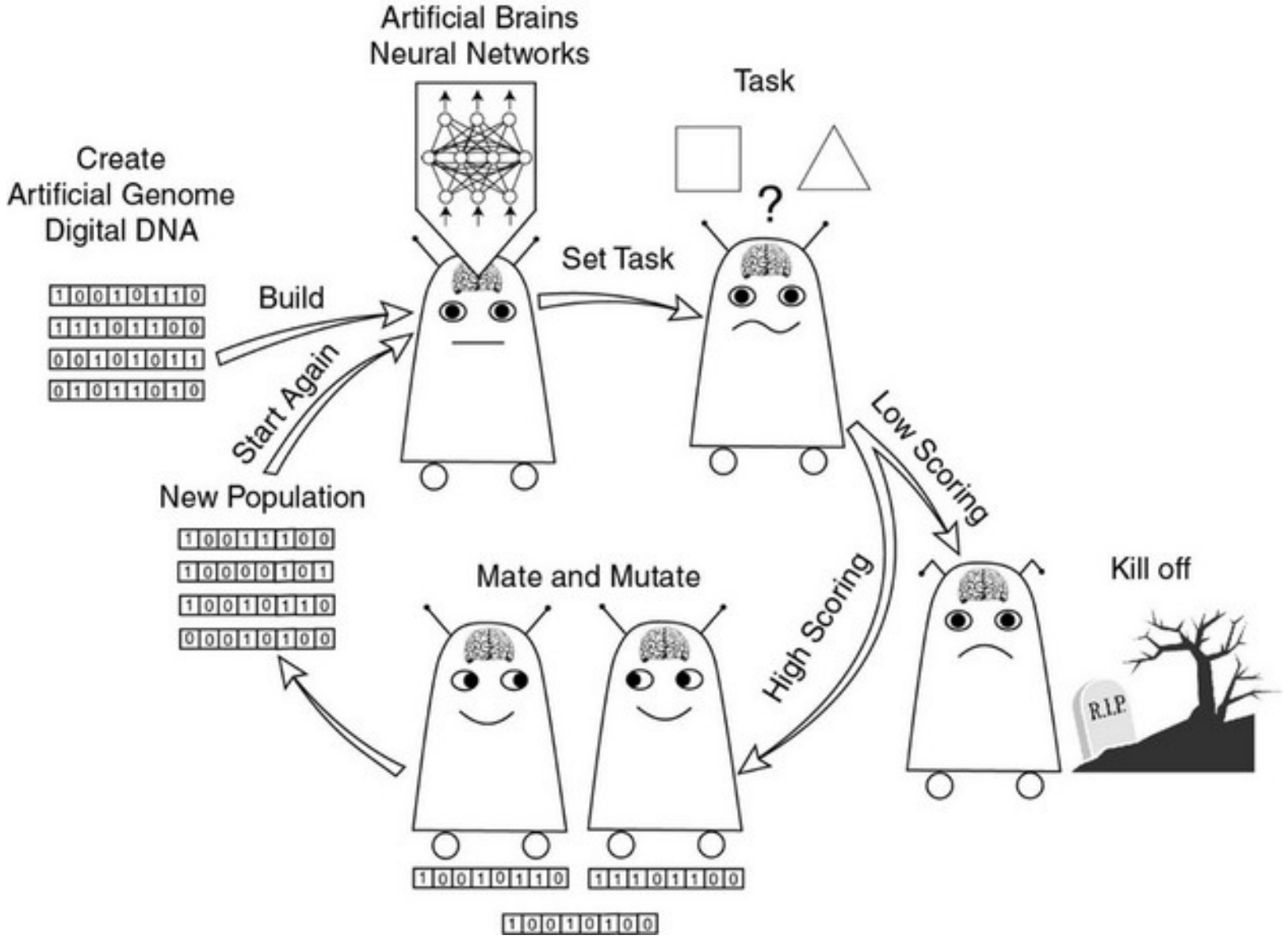
summer

Commodore butterly: Michael Wild, CC-BY-SA-3.0 (winter), Svdmolen, CC-BY-SA-3.0 (summer)

Daphnia: Agrawal *et al* (1999)

Nemoria arizonaria caterillars: Sadava *et al* (2014)

Water crowfoot plant: J R Crellin, CC BY-NC-ND 3.0


Artificial Brains
Neural Networks
Task
Create
Artificial Genome
Digital DNA
Build
Set Task
Start Again
Low Scoring
New Population
Mate and Mutate
High Scoring
Kill off
R.I.P.

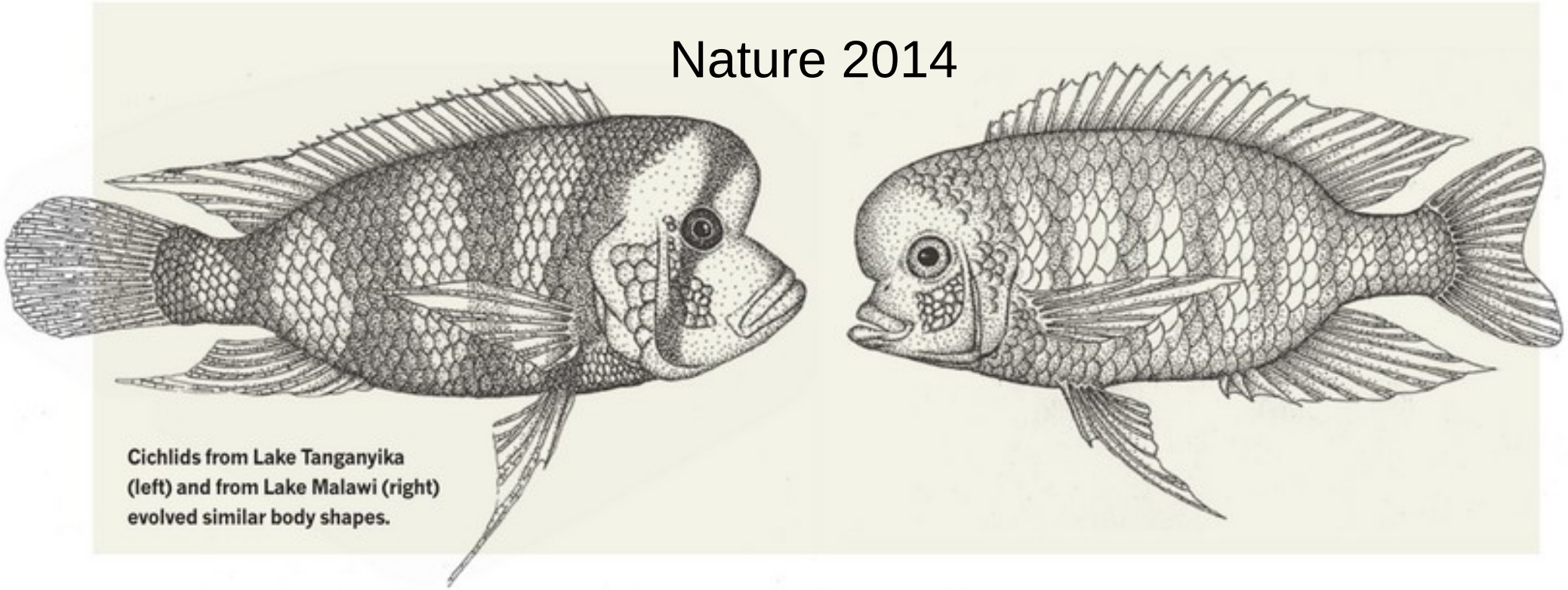
Evolution

process through which the characteristics of populations or species change over successive generations

Frontiers:
Origin of Life
Evolutionary robotics
Plasticity

Examples of subfields:
Paleontology
Experimental evolution
Modelling of Evolution

Nature 2014



Cichlids from Lake Tanganyika (left) and from Lake Malawi (right) evolved similar body shapes.

Does evolutionary theory need a rethink?

Researchers are divided over what processes should be considered fundamental.

POINT

Yes, urgently

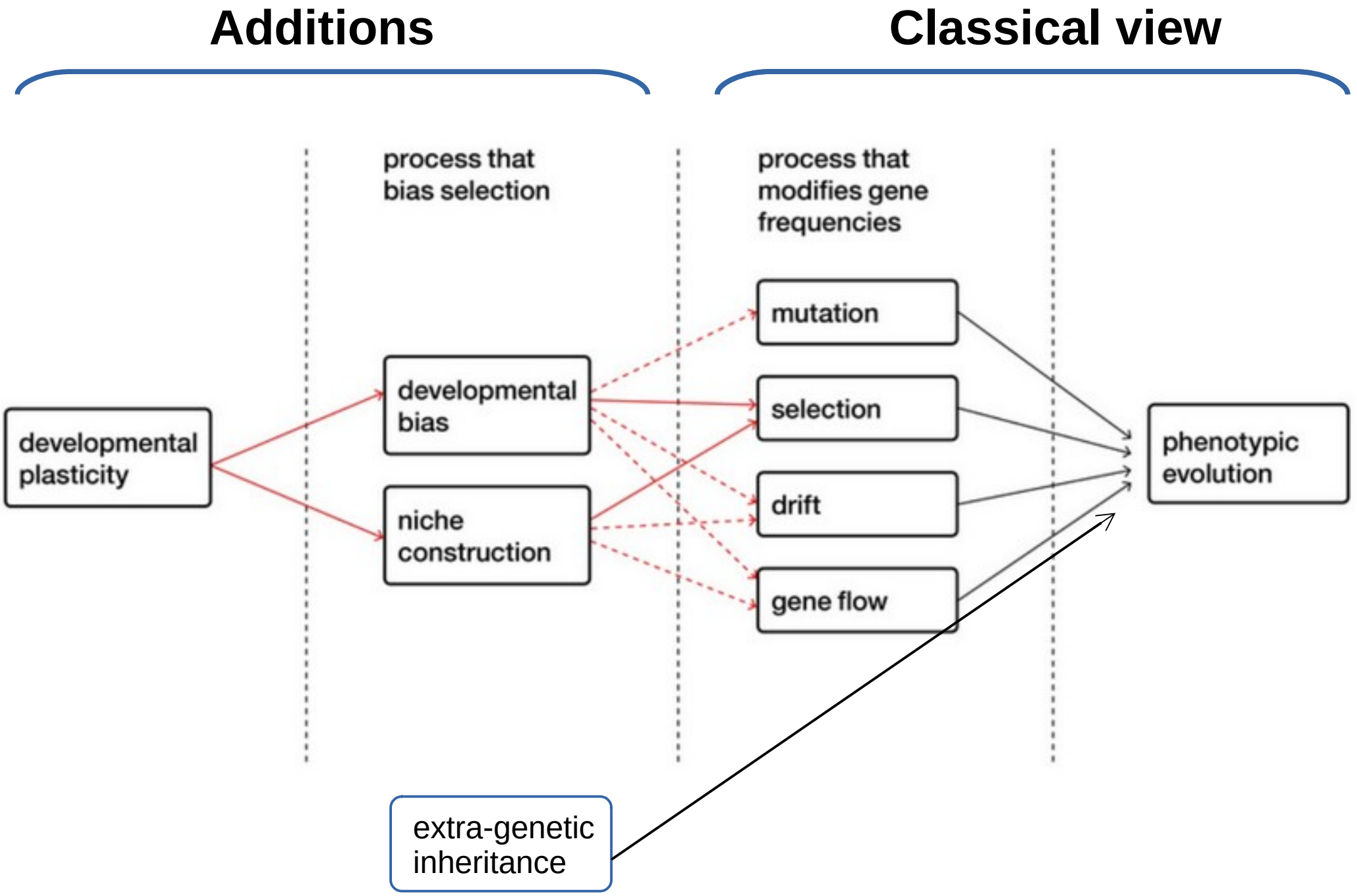
Without an extended evolutionary framework, the theory neglects key processes, say Kevin Laland *and colleagues.*

COUNTERPOINT

No, all is well

Theory accommodates evidence through relentless synthesis, say Gregory A. Wray, Hopi E. Hoekstra *and colleagues.*

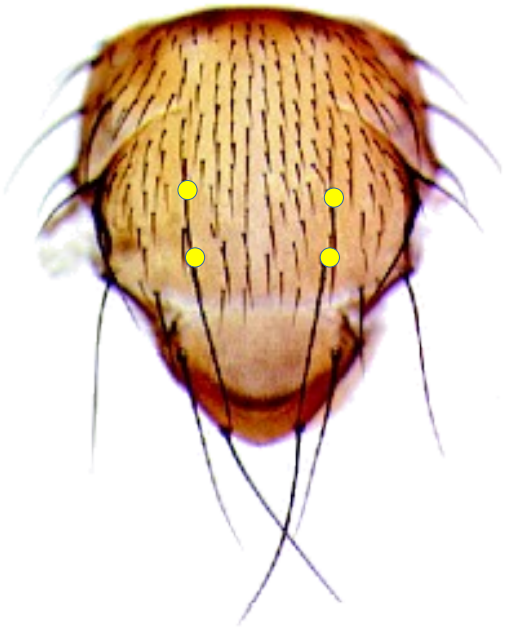
Extended evolutionary synthesis

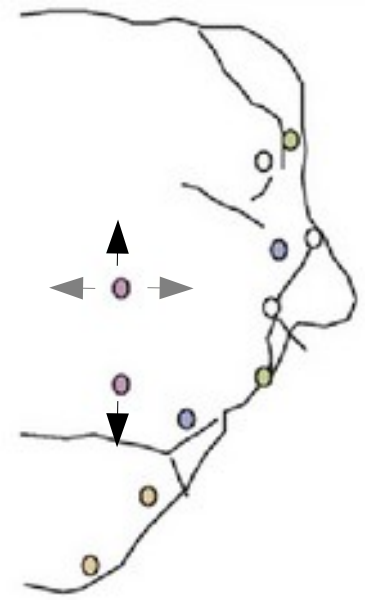


Developmental Bias

Standing variation

D. melanogaster

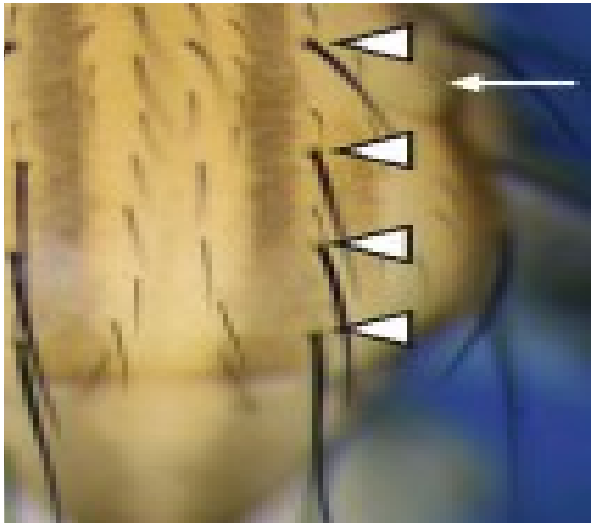




variation
no variation

Natural evolution

D. quadrilineata

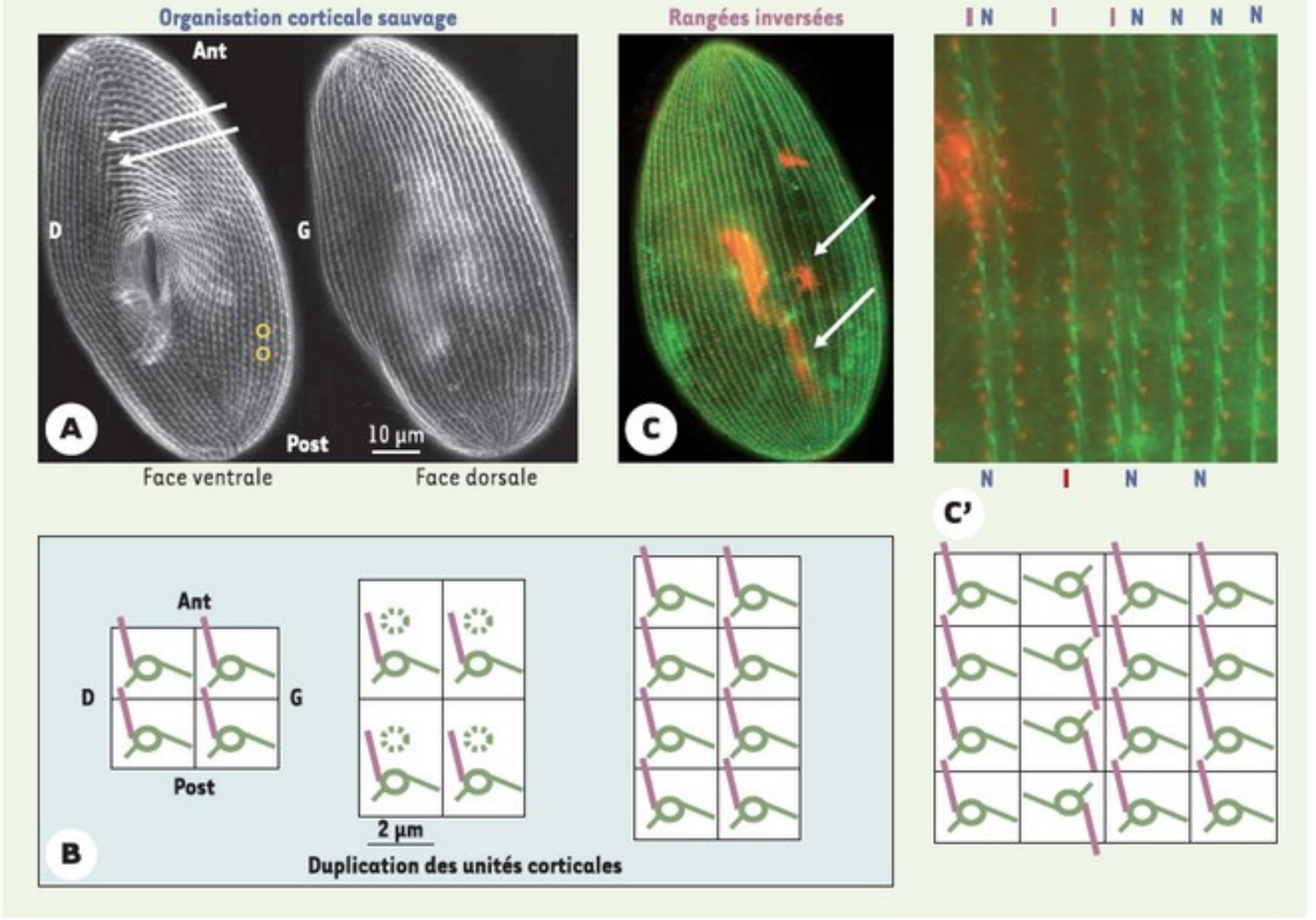


Marcellini et al 2006 PloS Biol

Garcia-Vázquez 1988 J. Heredity

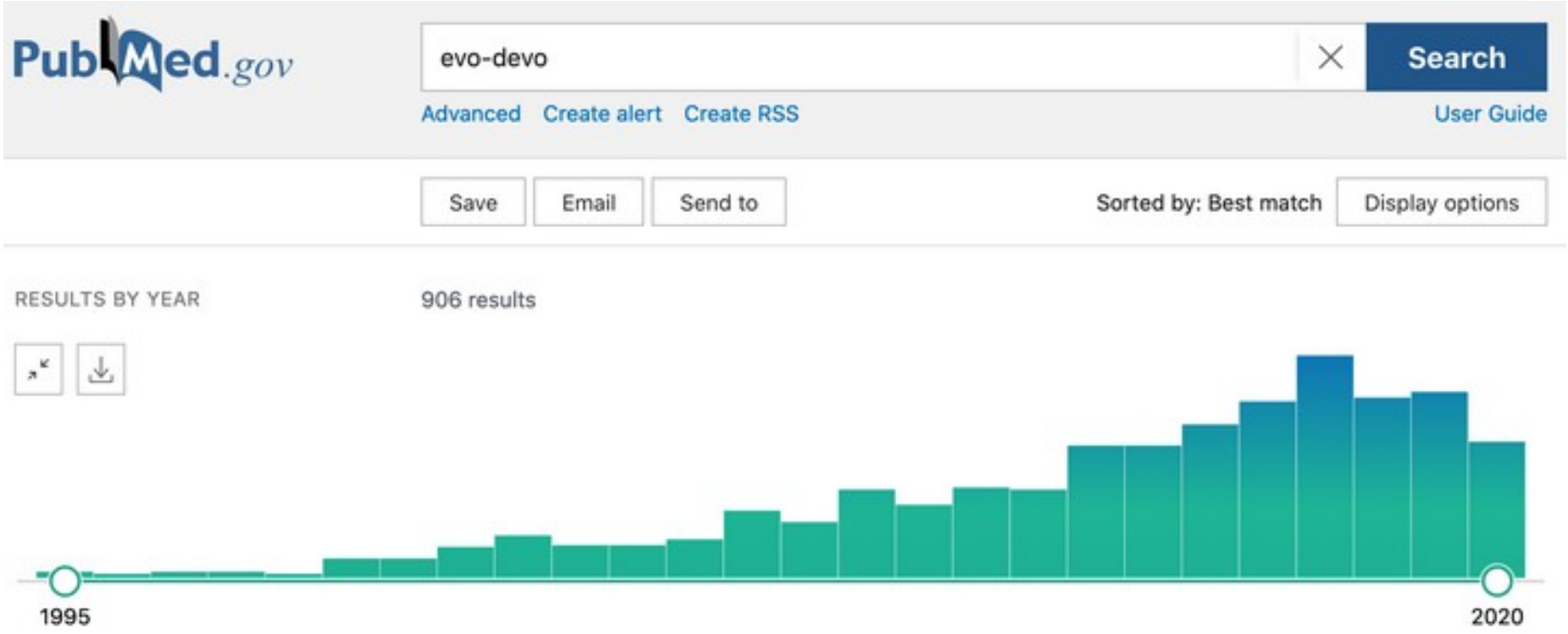
Niche construction

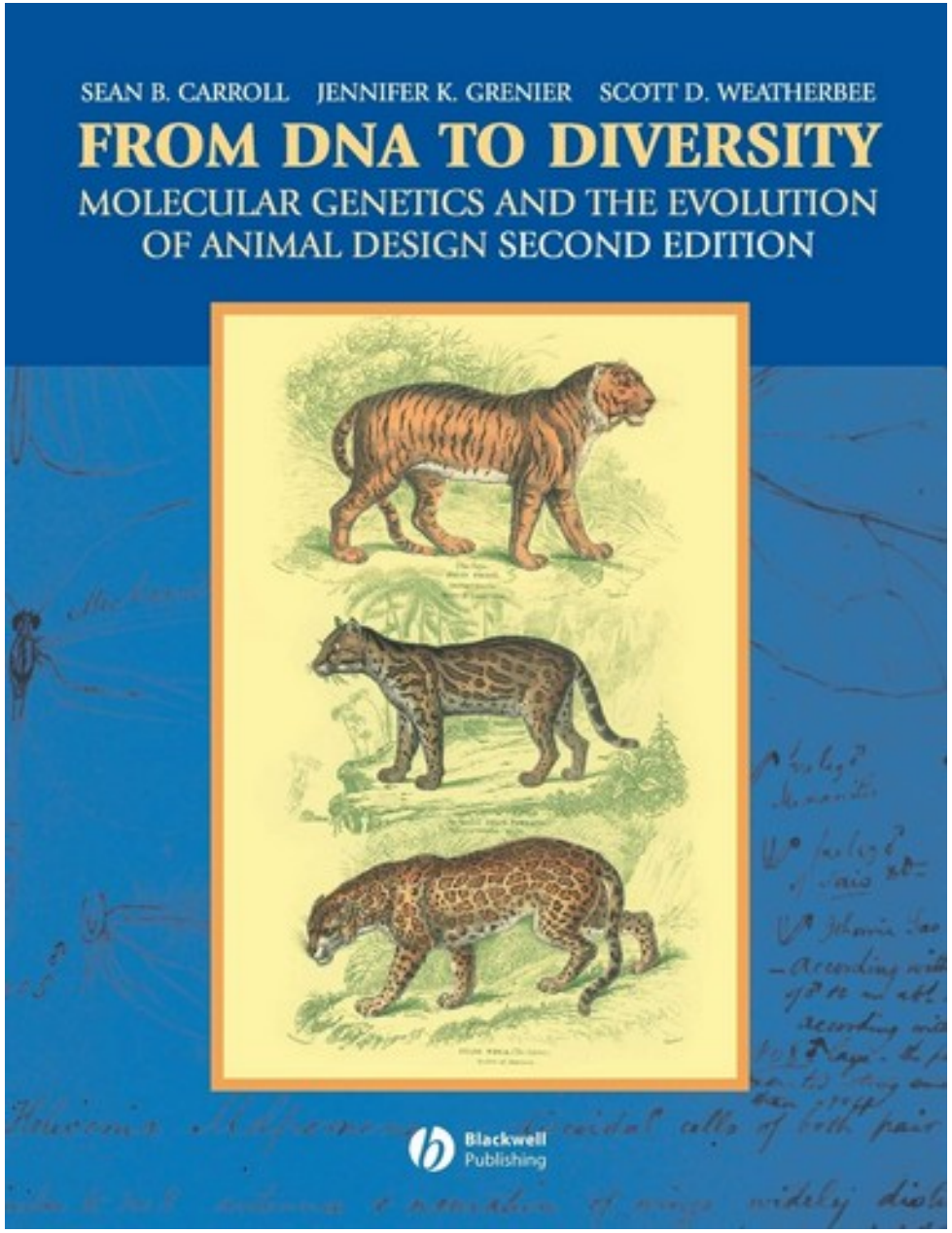
Cortical heredity in *Paramecium*

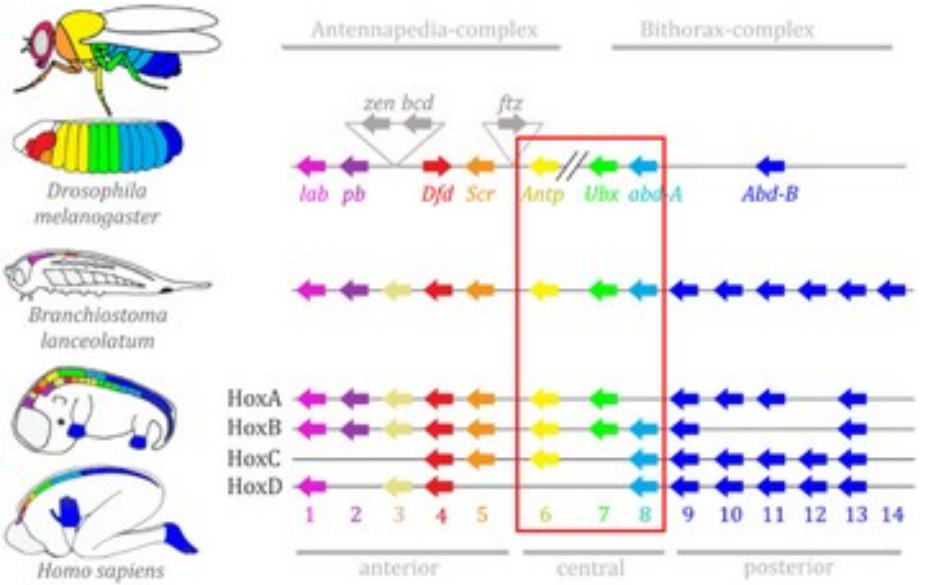


Meyer & Beisson M/S 2005

What is Evo-Devo?




SEAN B. CARROLL JENNIFER K. GRENIER SCOTT D. WEATHERBEE
FROM DNA TO DIVERSITY
MOLECULAR GENETICS AND THE EVOLUTION OF ANIMAL DESIGN SECOND EDITION
Blackwell Publishing

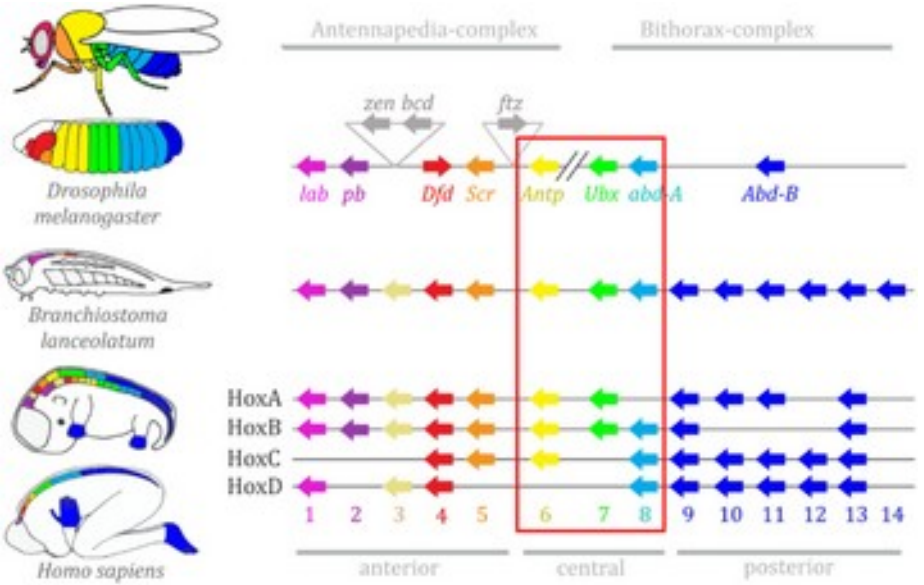

Antennapedia-complex
Bithorax-complex
zen bcd
ftz
lab pb Dfd Scr Antp Ubx abd-A Abd-B
Drosophila melanogaster
Branchiostoma lanceolatum
Homo sapiens
HoxA
HoxB
HoxC
HoxD
1 2 3 4 5 6 7 8 9 10 11 12 13 14
anterior
central
posterior

2001

Evo-devo

field of biological research that compares development between species to understand how they evolved

Frontiers:
Same as development and evolution
Ecology
Physiology, Behavior



subfields:
Macro-evo-devo (distantly related species)
Micro-evo-devo (closely related species or populations)

UNDERSTANDING EVO-DEVO

WALLACE ARTHUR

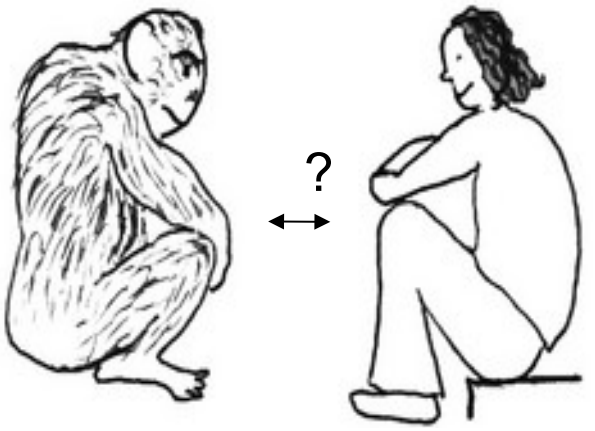
April 2021

Micro-evo-devo in Drosophila

What makes us different?

between individuals

between species



Where do we come from?

What are the mutations responsible for phenotypic differences?

Genomic approach

identifies rapidly-evolving genomic regions, new genes, deleted genes

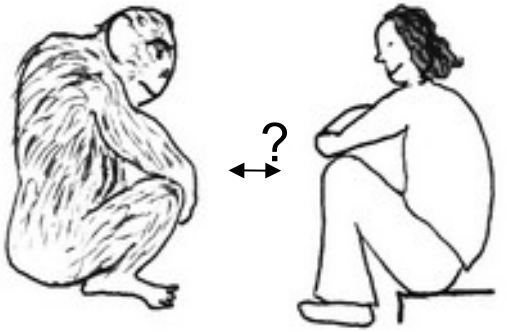
?

Genomes

```
CCTCCTCCATACCCAAATGGATGGTACGGCATTCTTGAATCATCAAAGCT
TAGAGCGGGGGAATCGAAGCATATATCATGTCTAGGCGAGCAACTTATAG
TGTTCCGTTCCCAAGCTGGTGAAGTTTATATCTTGGATGCGTATTGCCCG
CACTTGGGCGCTAATTTGAGTAAGGGAGGTCGAGTTATAGGAGATAATAT
TGAATGTCCCTTTCACCACTGGAGCTTTAGAGGCAGTGATGGCATGTGTA
CCAATATTCCCTACAGCAGCAATATACACTCATCTACAAAAACTAAAAAA
TGGACCTCCACCGAAGTGAATGGATTCATATTTCTTTGGTACAATGTCGA
AGAATCTGAAGTTCCGTGGAATATACCAAAATCAGTTGGTGTTGCAAAAA

CCTCCTCCATACCCAAATGGATGGTACGGCATTCTCGAATCATCAAAGCT
TAGAGCGGGGGAATCGAAGCATATATCATGTCTAGGCGAGCAACTTATAG
TGTTCCGTTCCCAAGCTCGTGAAGTTTATATCTTGGATTCGTATTGCCCG
CACTTGGGCGCTAATTNGAGTAAGGGAGGTCGAGTTATAGGAGATAATAT
TGAATGTCCCTTTCACCACTGGAGCTTTAGAGGCAGTGATGGCATGTGTA
CCAATATTCCCTACAGCAGCAATATACACTCATCTACAAAAACTAAAAAA
TGGACTTCCACCTAAGTGAATGGATTCATATTTCTCTGGTACAATGTCGA
AGAATCTGAAGTTCCGTGGAATATACCAAAATCAGTTGGTGTTGCAAAAA
```

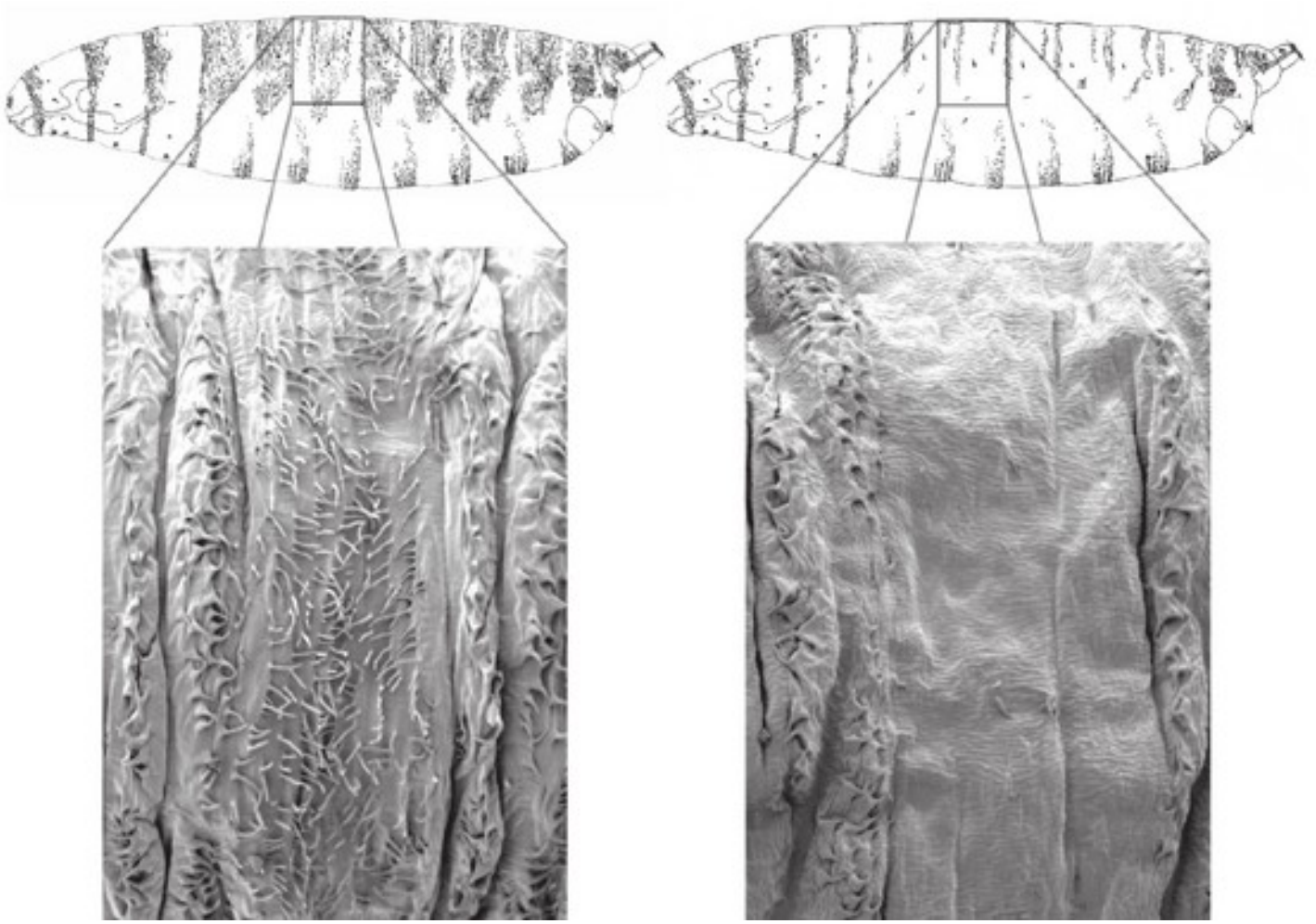
Phenotypic differences



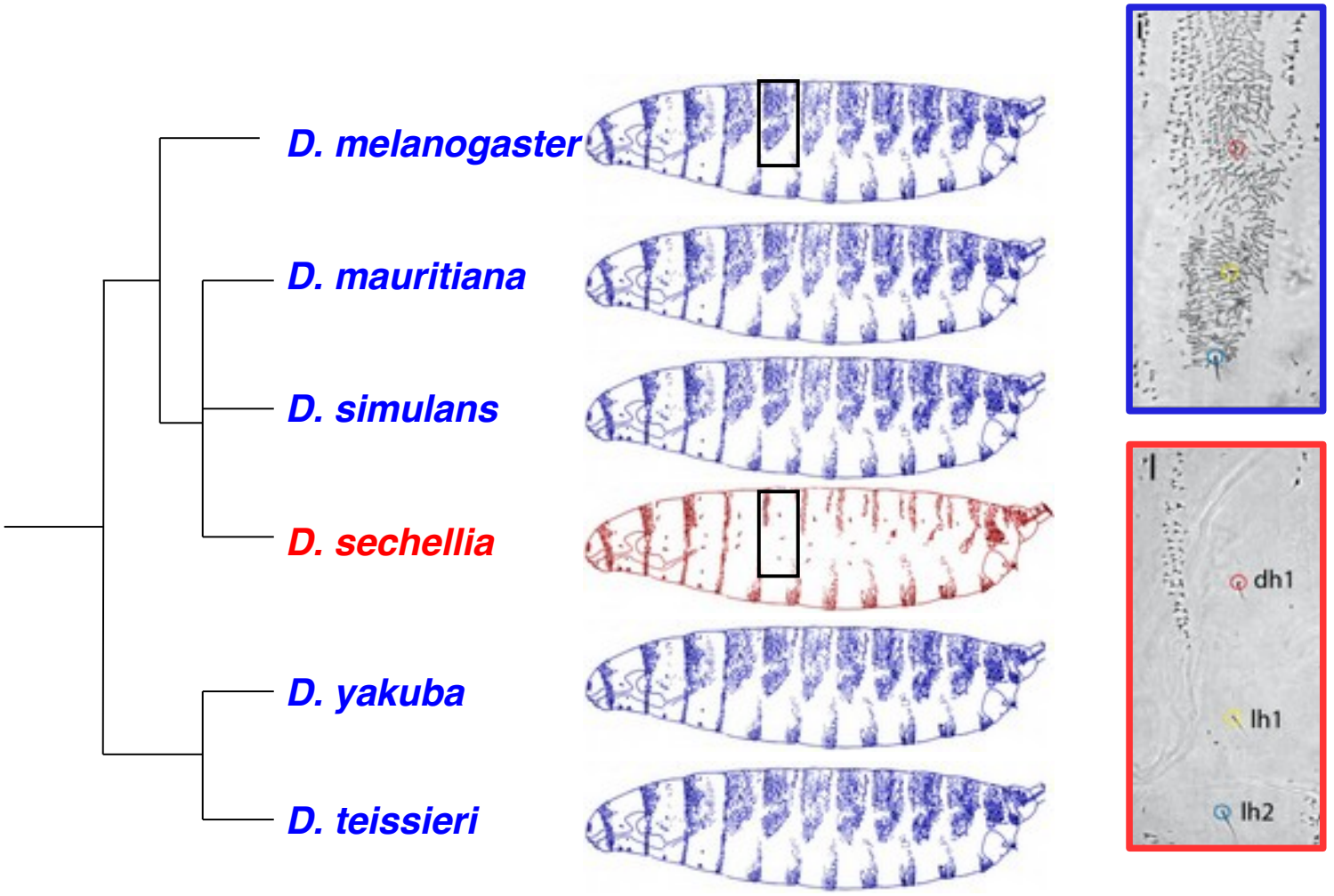
Phenotypic approach

identifies the gene(s) and the mutation(s) responsible for a phenotypic change

Hair pattern in flies



Succena and Stern 2000 PNAS
McGregor, Orgogozo et al. 2007 Nature
Frankel, Wangl and Stern 2012 PNAS


D. melanogaster
D. mauritiana
D. simulans
D. sechellia
D. yakuba
D. teissieri
dh1
lh1
lh2

The causing mutation is on the X chromosome

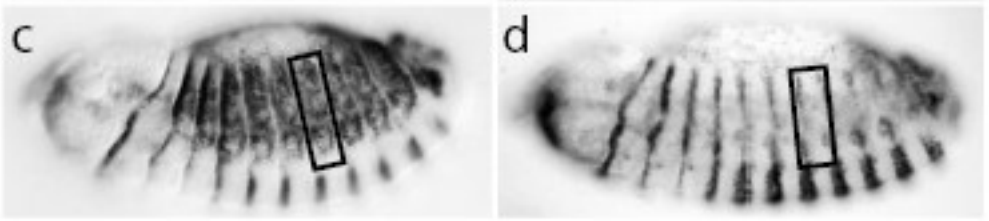
Sucena and Stern, 2000

The causing mutation is on the X chromosome

Evolution caused by a change in the *svb* gene

1. Transcription factor that promotes trichome formation

2. Correlation between expression pattern and phenotype



D. melanogaster *D. sechellia*

D. melanogaster *D. sechellia*

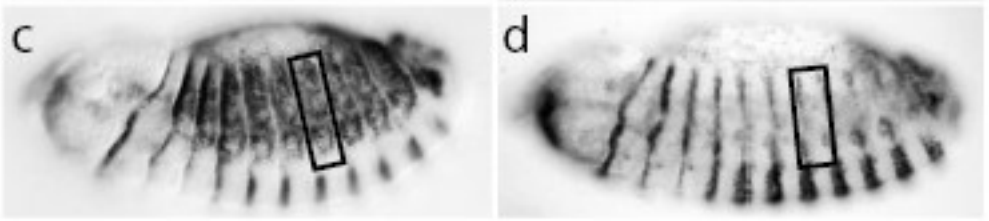
Sucena and Stern, 2000

The causing mutation is on the X chromosome

Evolution caused by a change in the *svb* gene

1 **Transcription factor that promotes trichome formation**

2 **Correlation between expression pattern and phenotype**

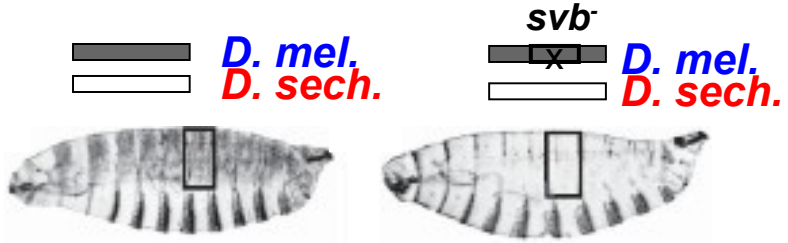


D. melanogaster ***D. sechellia***

D. melanogaster ***D. sechellia***

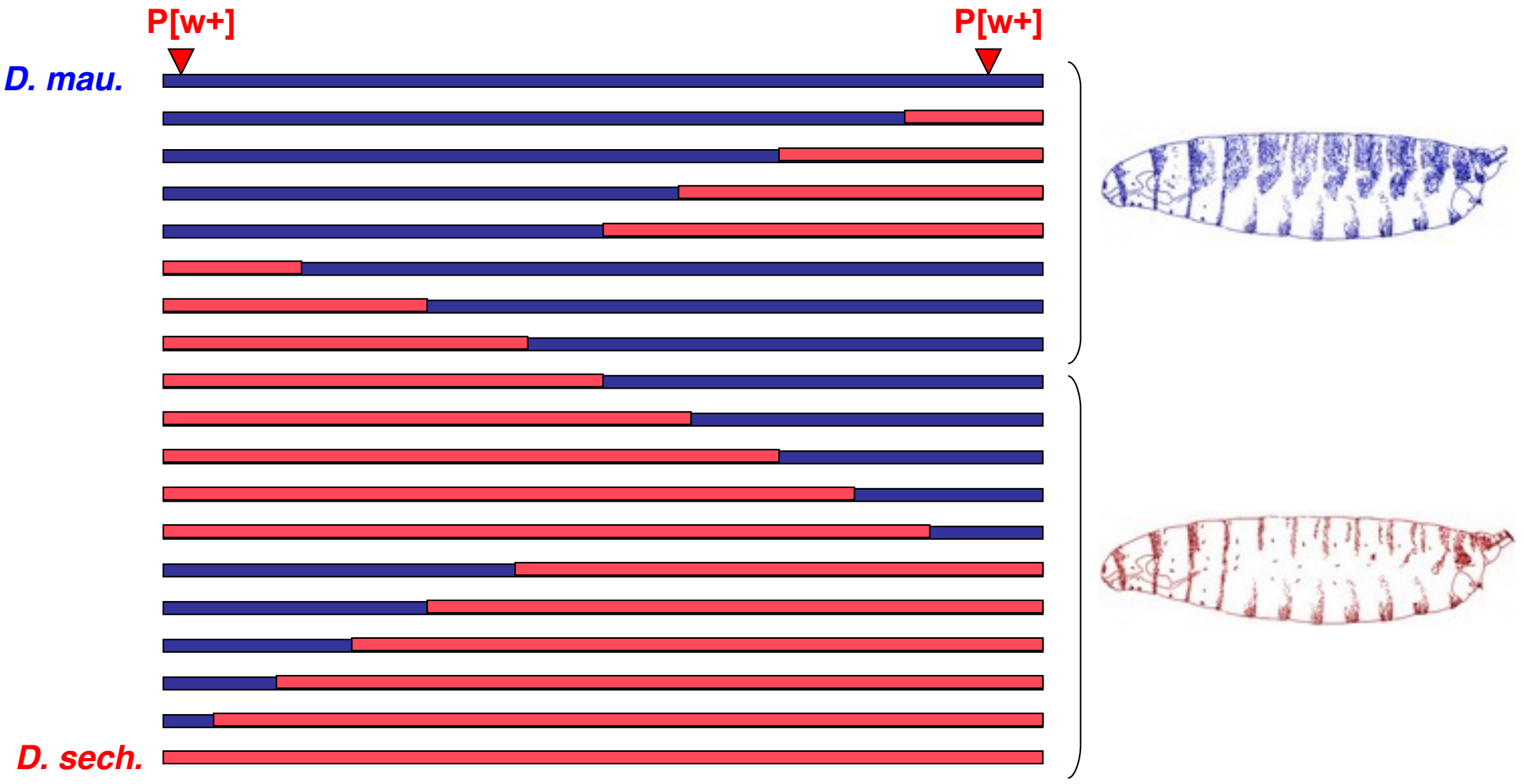
3 **Complementation assay with *D. melanogaster svb^{WT}* or *svb^{-}***

hybrids *D. mel./D.sech.*

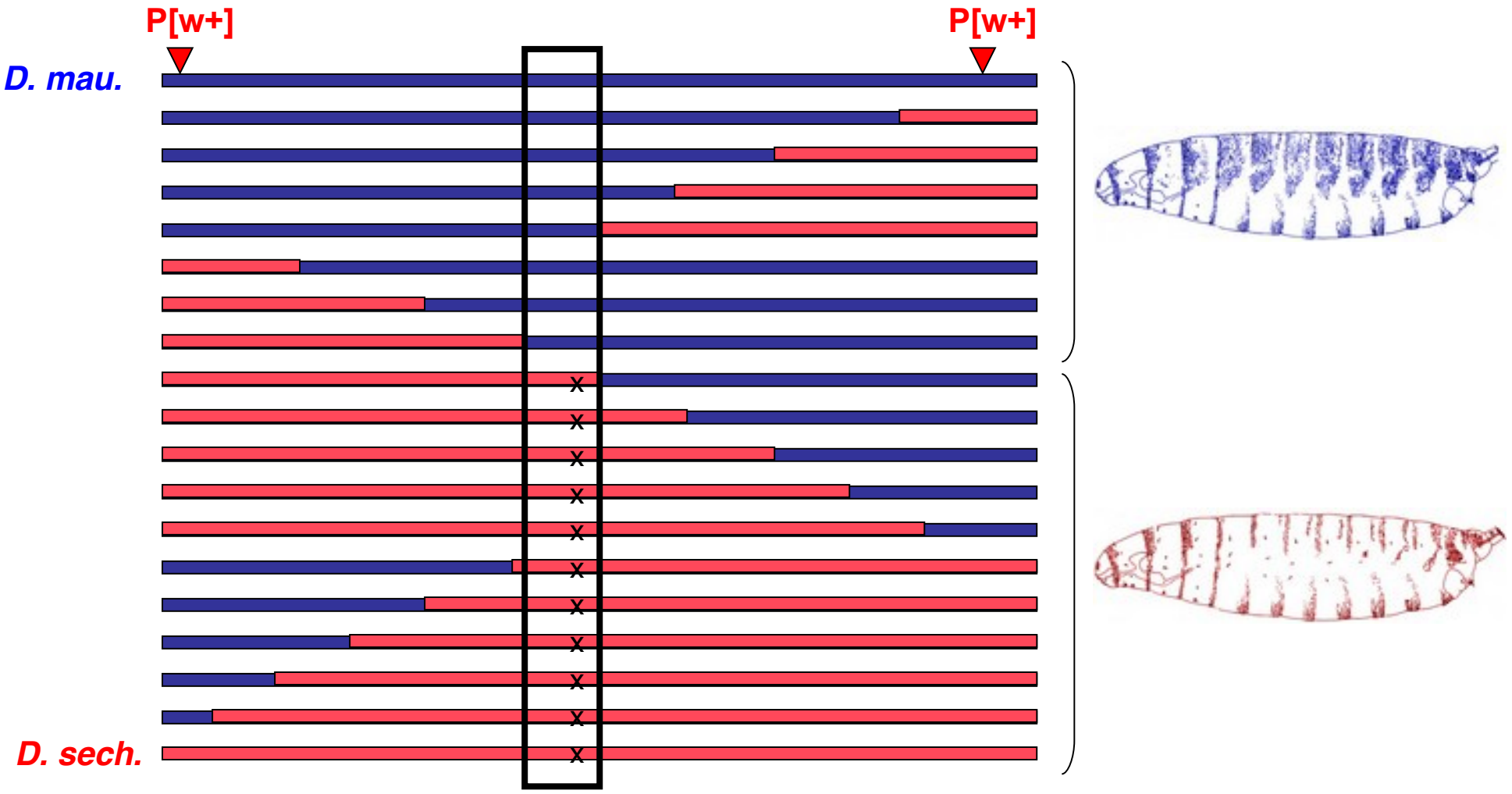


Sucena and Stern, 2000

Where is the mutation ?



Where is the mutation ?

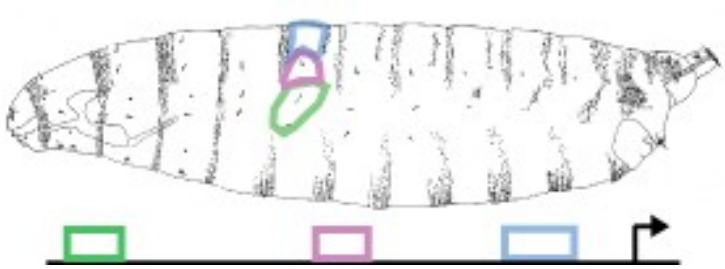


Several mutations in a single gene

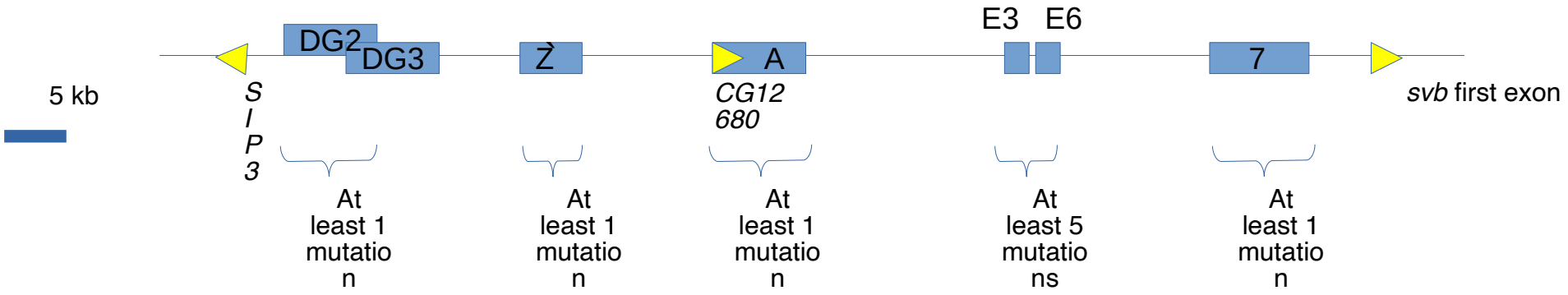
D. mauritiana

svb

D. sechellia

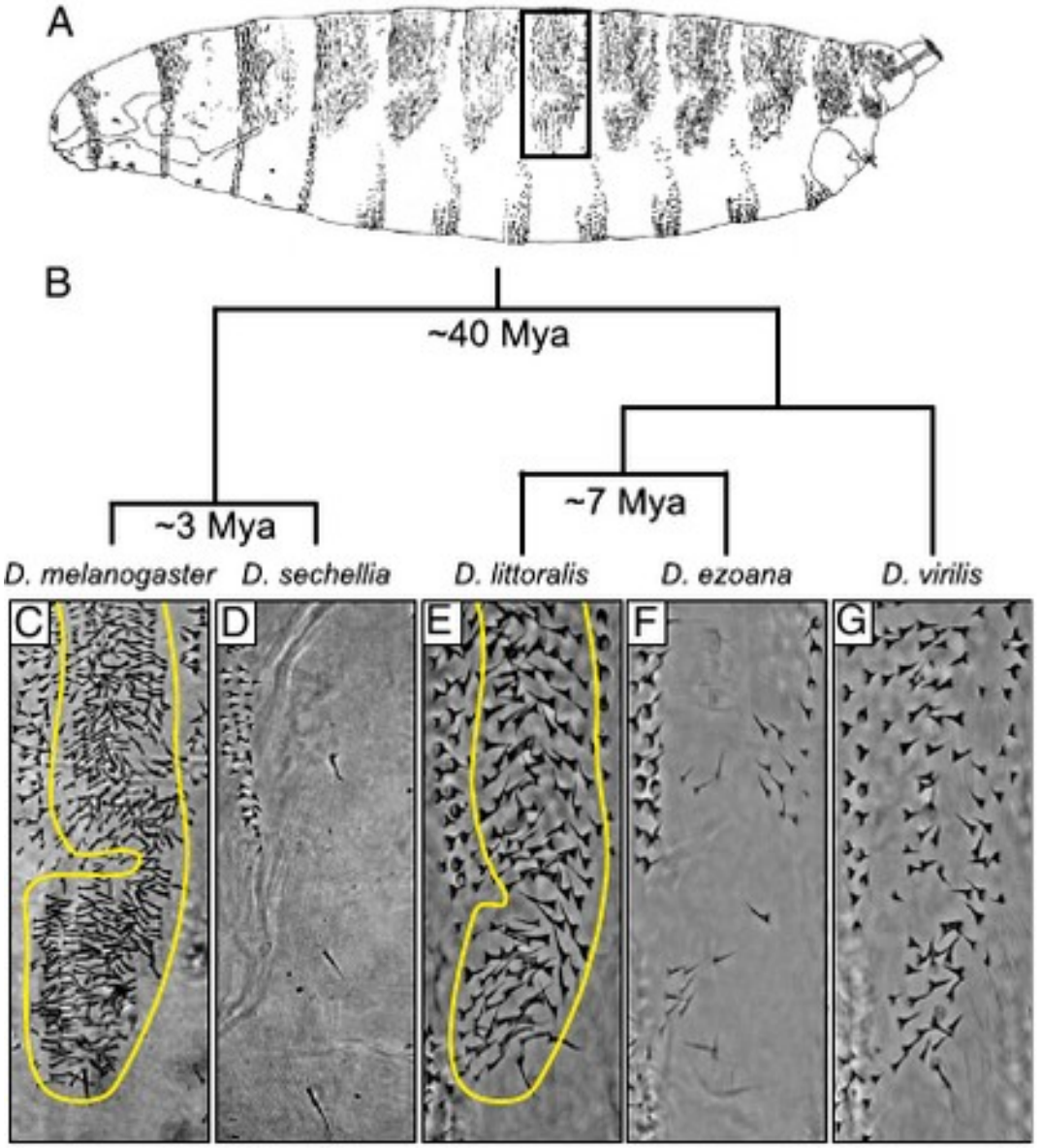


svb



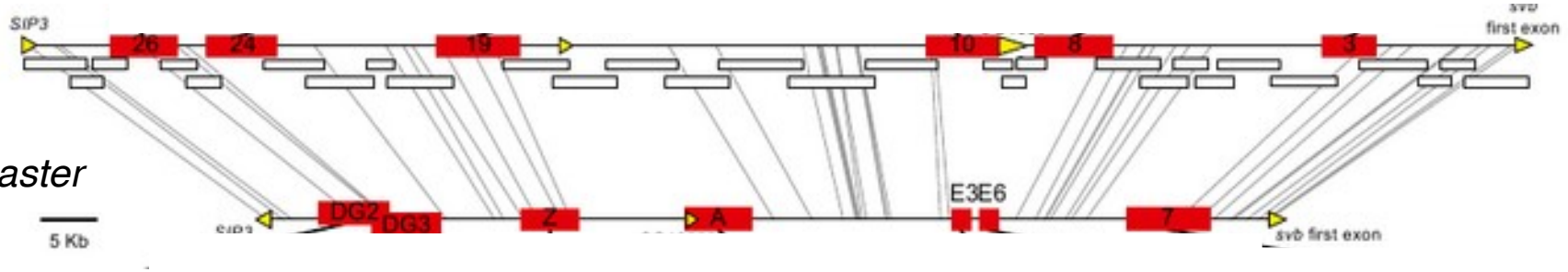
- McGregor, Orgogozo et al. 2007 Nature
- Frankel et al 2010 Nature
- Frankel et al 2011 Nature

Convergent evolution in *D. ezoana*



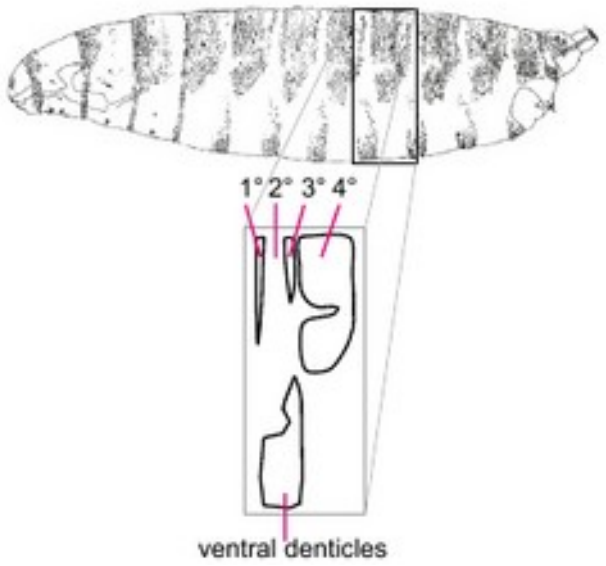
- Frankel, Wangl and Stern 2012 PNAS

- *D. virilis*

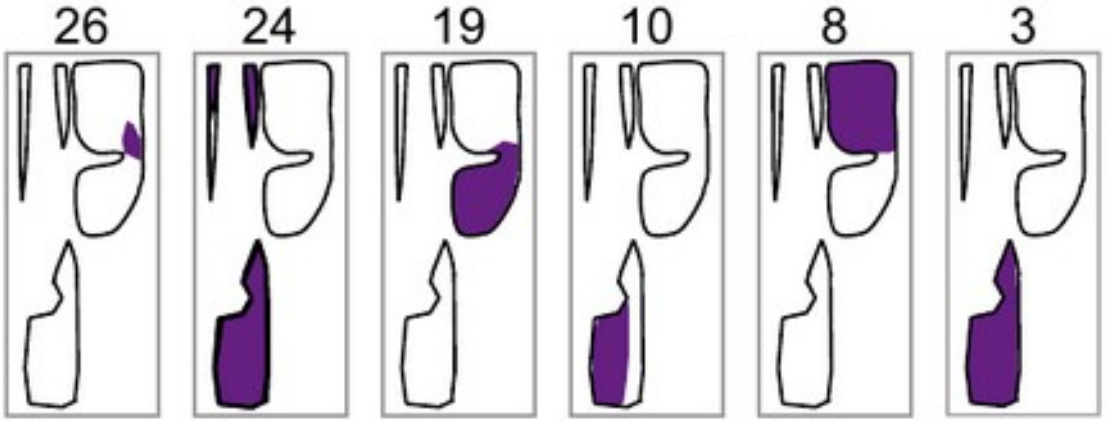


- *D. melanogaster*

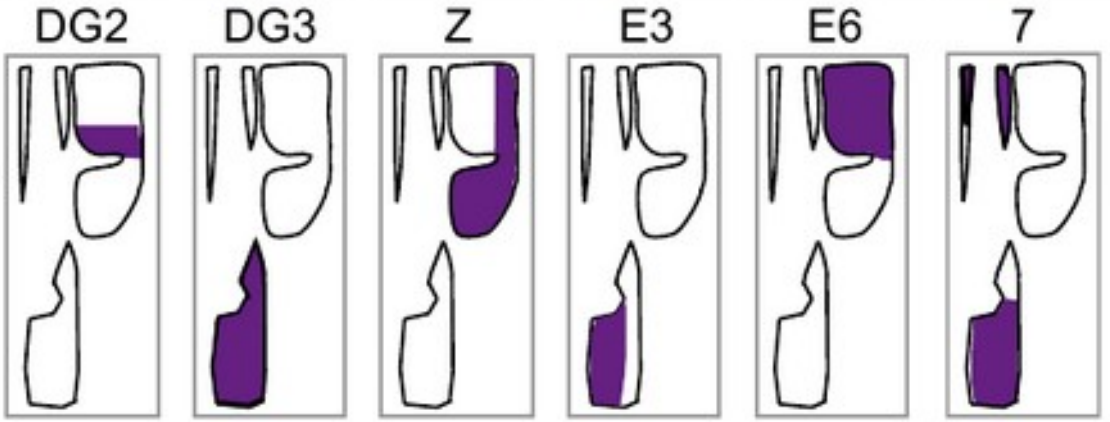
Links = 30-bp-conserved sequences



D. virilis enhancer constructs

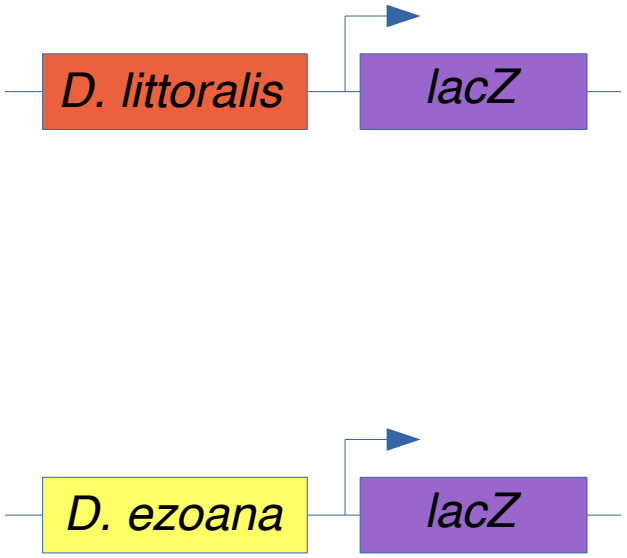


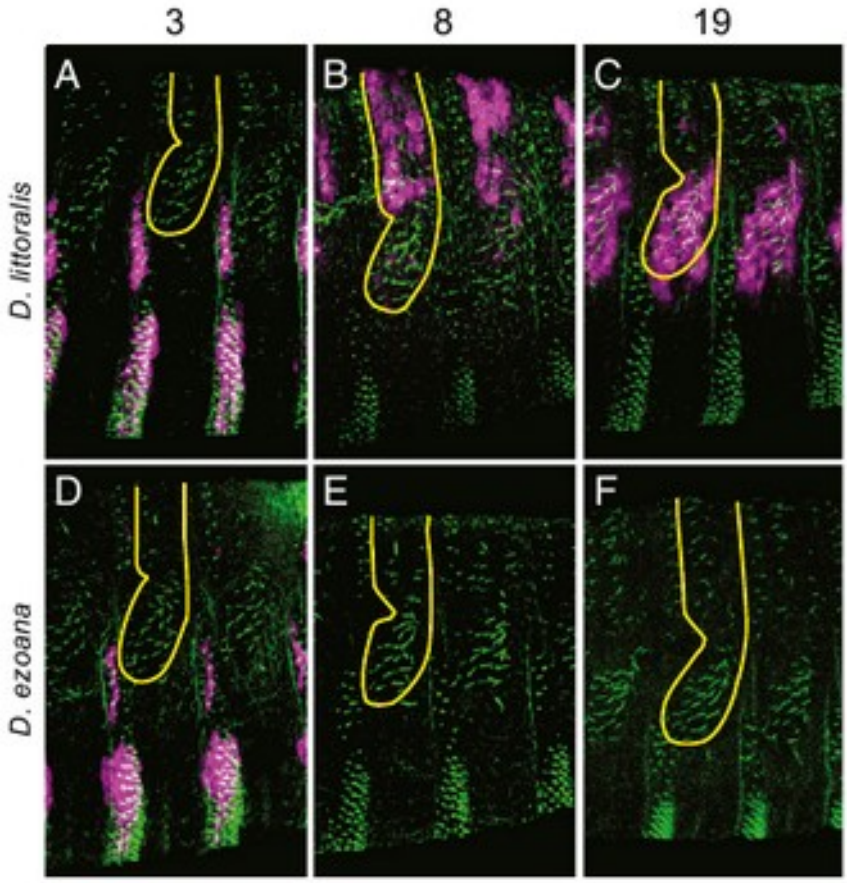
D. melanogaster enhancer constructs



At least two cis-regulatory mutations

Reporter genes tested in *D. virilis*



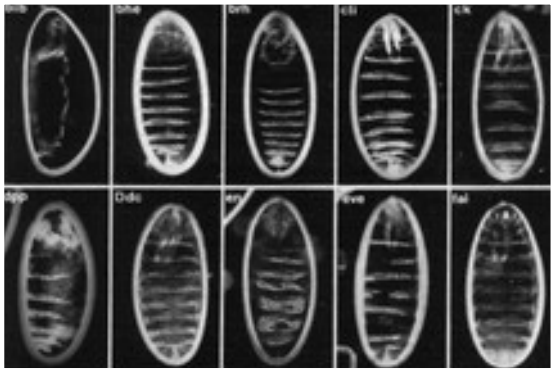


svb is a hotspot gene for evolution

EVOLUTION

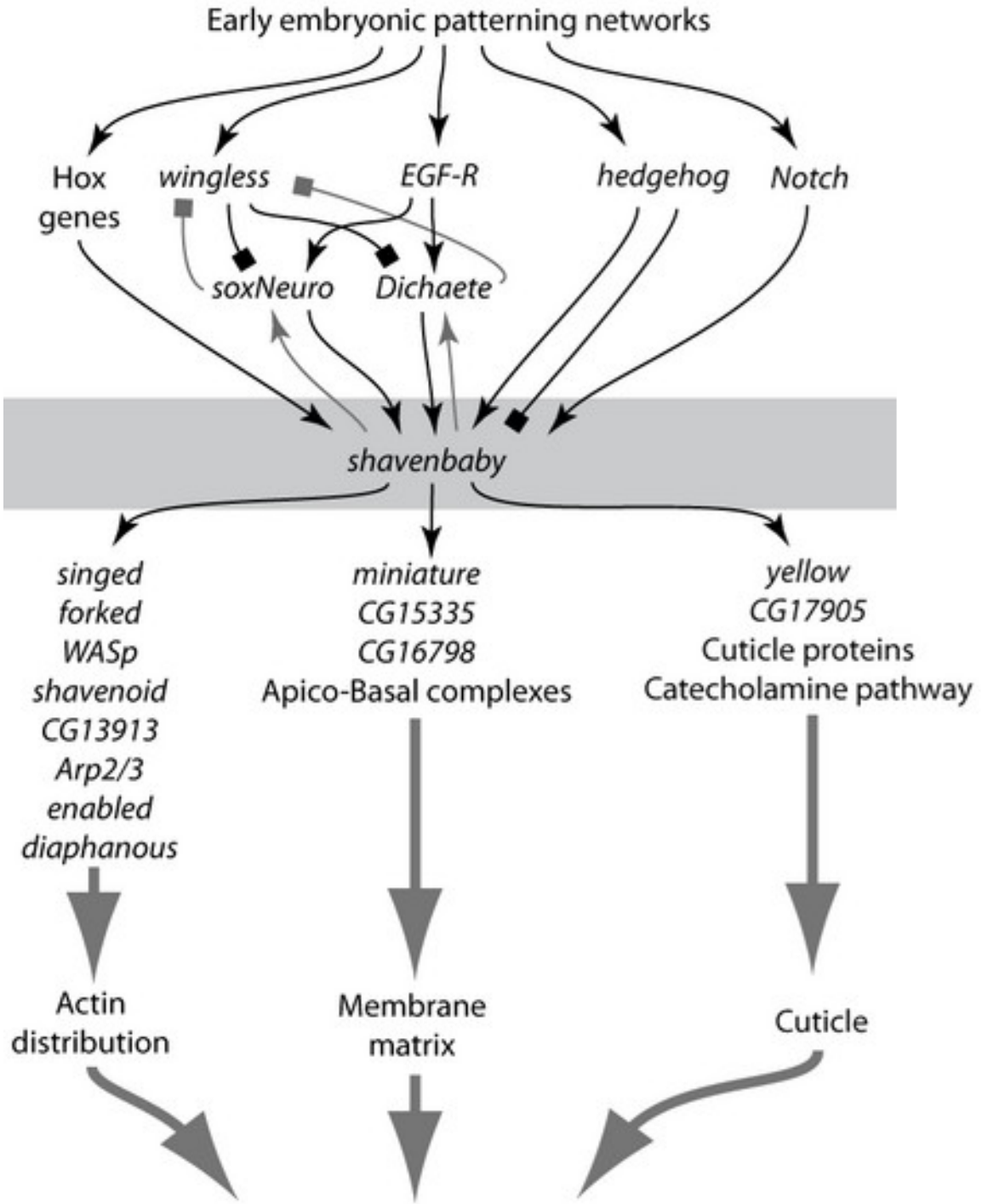
A single gene

MUTAGENESIS



(Nüsslein-Volhard et Weischaus)

~100 genes



(Stern et Orgogozo, 2008 Evolution – Stern et Orgogozo, 2009 Science)

Evolution of Drosophila glue

ENBA
European Network of BioAdhesion Expertise

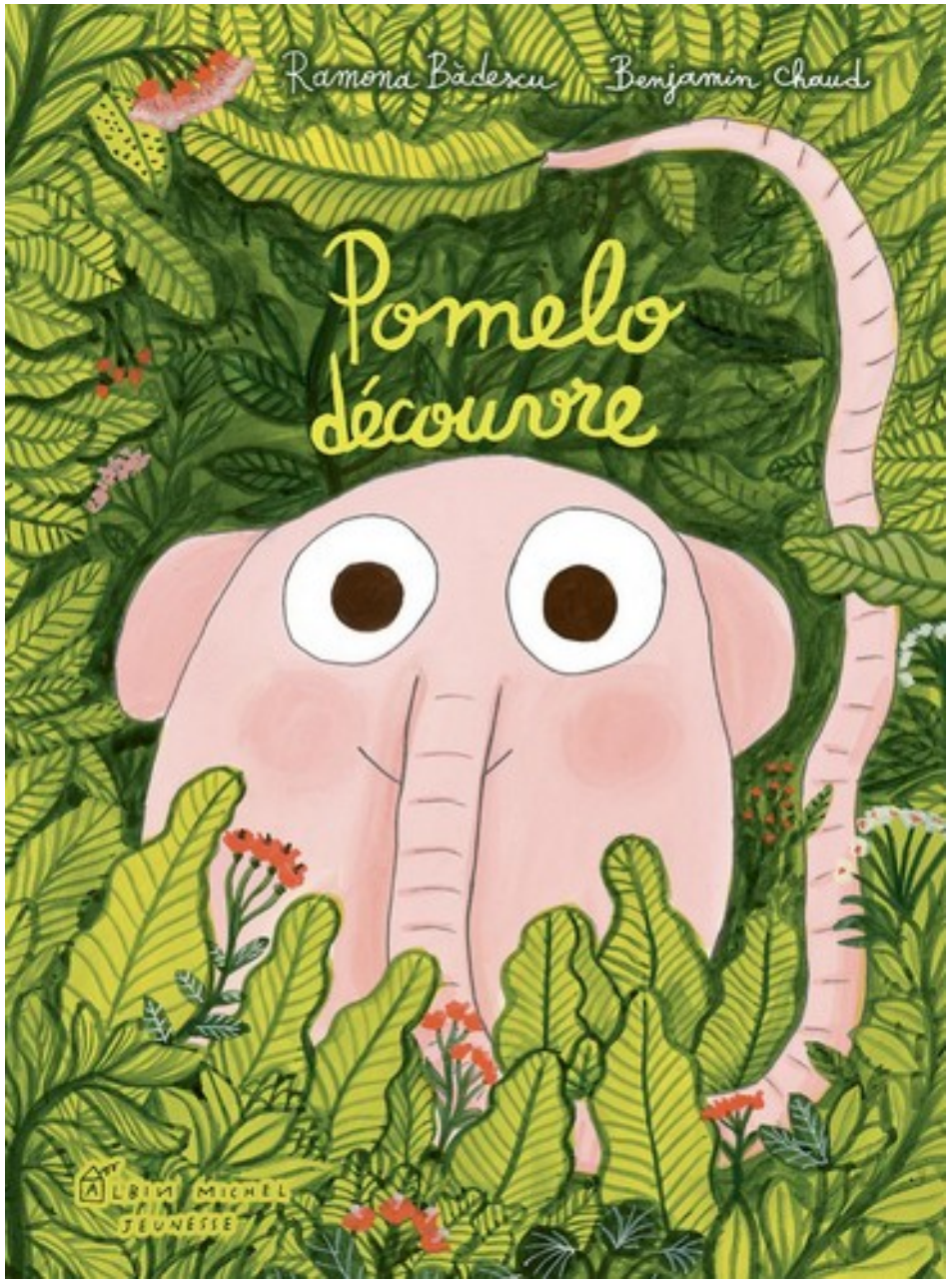
cnrs

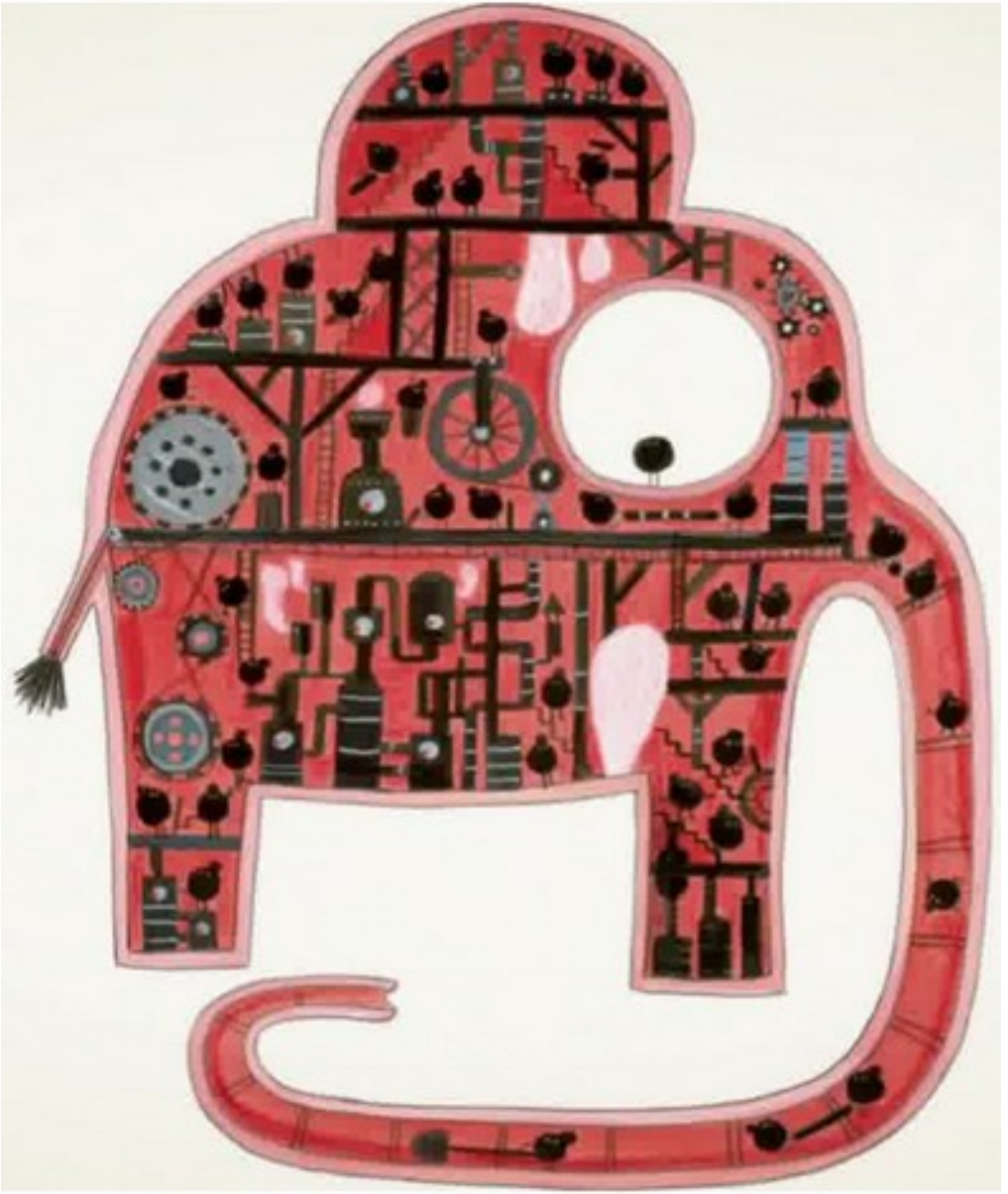
Université de Paris

Institut JACQUES MONOD

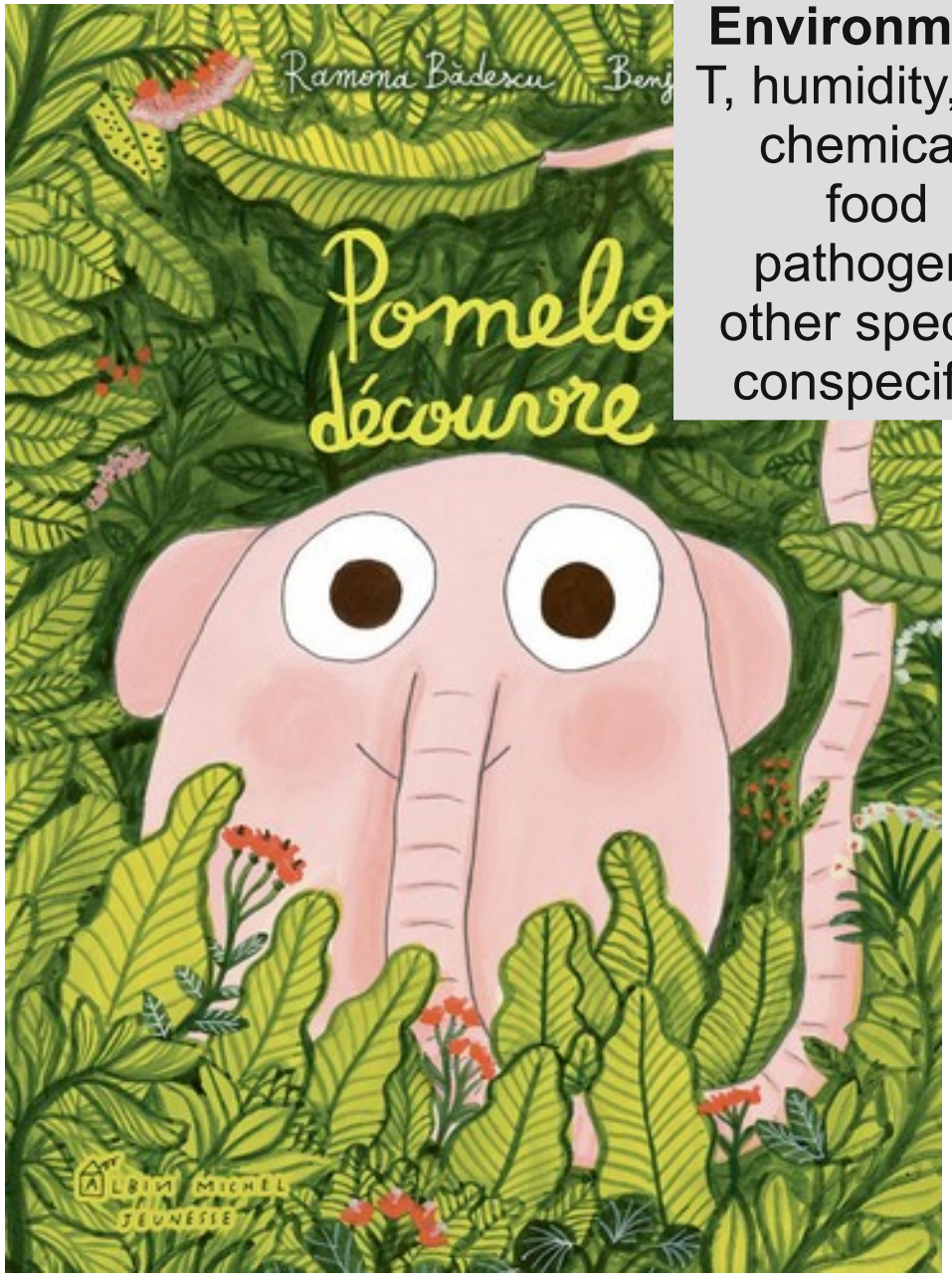
université PARIS DIDEROT PARIS 7

The Organism and its Environment

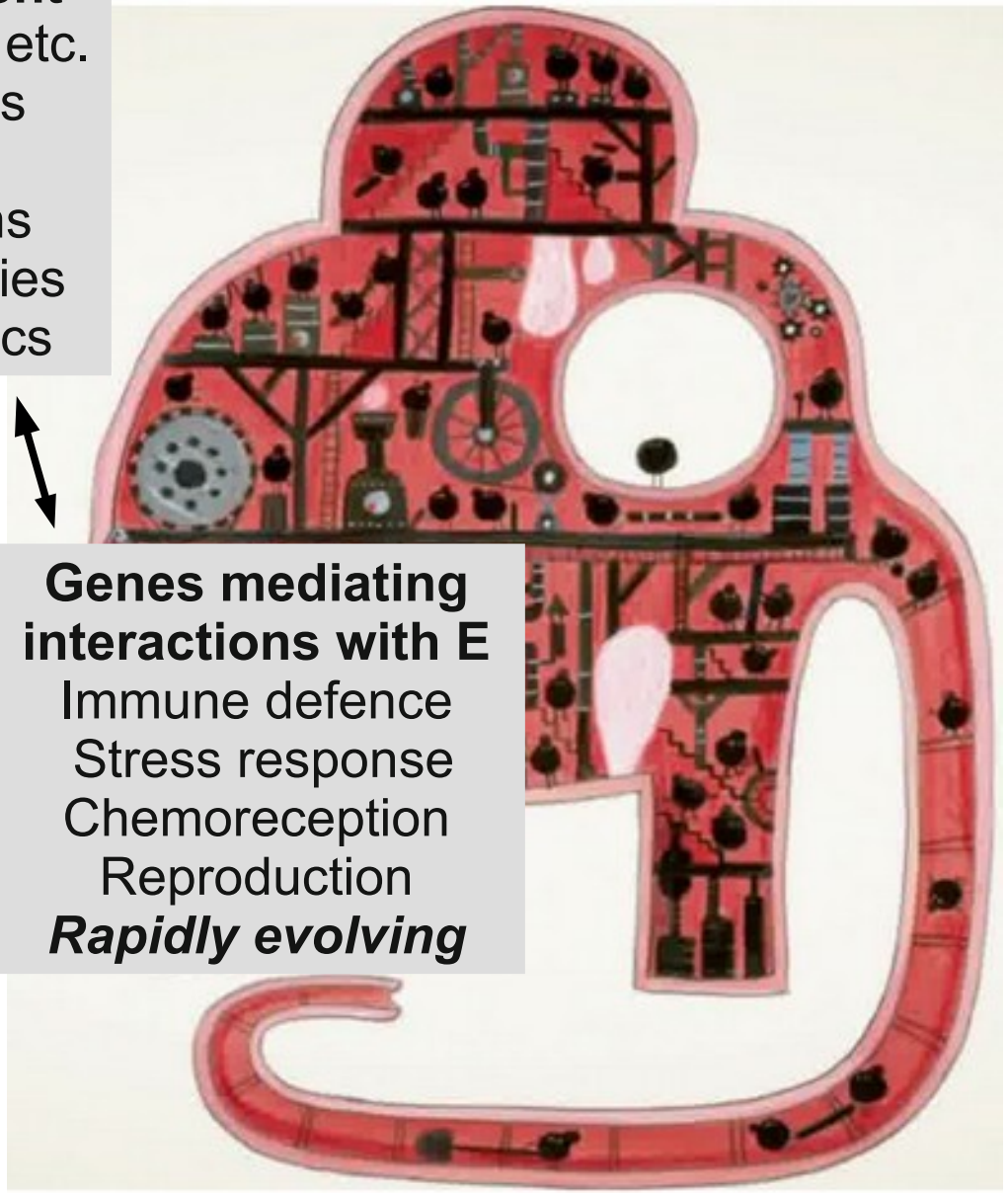




The Organism and its Environment

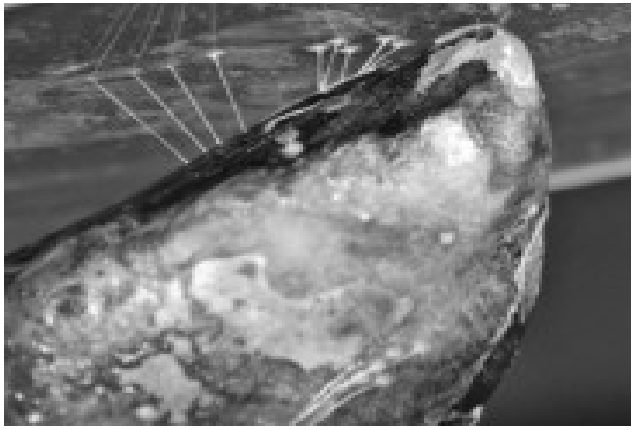


Environment
T, humidity, etc.
chemicals
food
pathogens
other species
conspecifics



Genes mediating interactions with E
Immune defence
Stress response
Chemoreception
Reproduction
Rapidly evolving

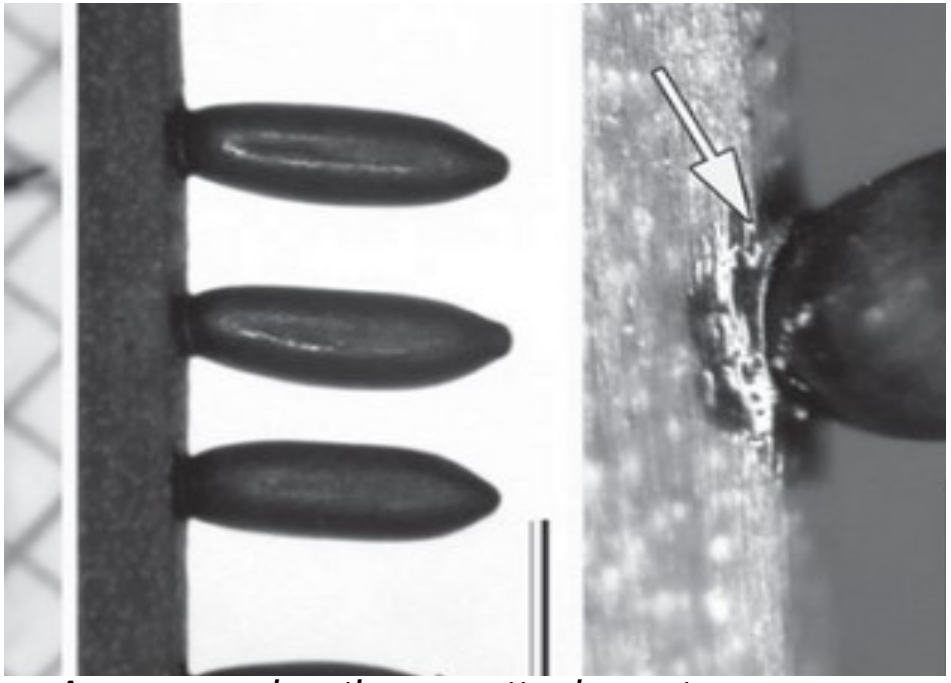
Bioadhesives



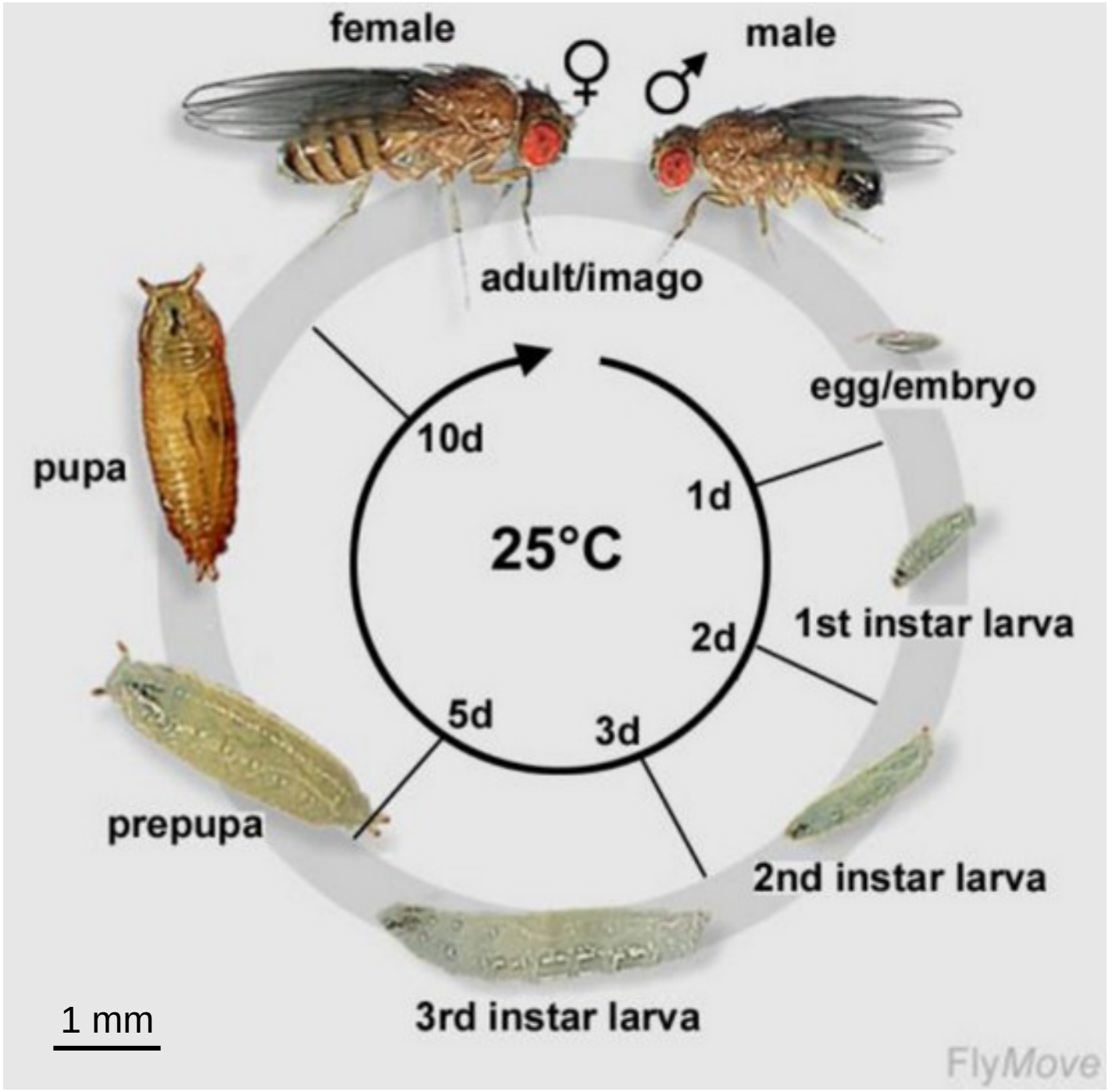
Mussle adhesion
Burkett et al. 2009

In insects

- Locomotion
- Egg attachment
- Cocoon formation (silk)
- Pupa attachment



Asparagus beetle egg attachment
Voigt and Gorb 2006


female
male
♀
♂
adult/imago
egg/embryo
1d
1st instar larva
2d
2nd instar larva
3d
3rd instar larva
5d
prepupa
10d
pupa
25°C
1 mm
FlyMove


1 cm

Drosophila glue

- A wide variety of environments
- Stick to a wide variety of substrates
- Difficult to observe pupae in nature

soil

D. grimshawi

rotten strawberry

D. suzukii

grape

D. melanogaster

potato

D. repleta

crab

D. carcinophila

Glue genes ↔ Chemistry Molecular biology Development ↔ Adhesion ↔ Ecology

Fly Glue Evolution

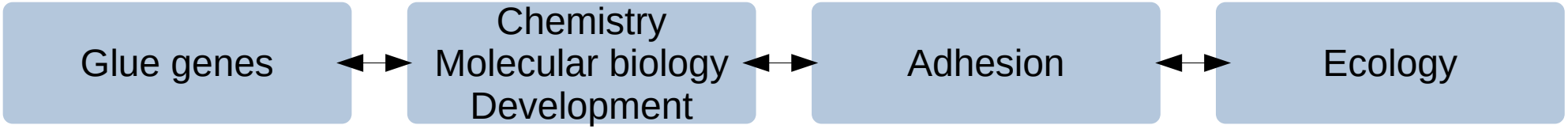
A Lalouette (genitalia)
JN Lorenzi (SARS-CoV-2)
R Vijendravarma (organ size)

Flora Borne
PhD (3 years)

Manon Monier
M2+PhD (3 years)

Isabelle Nuez
Technician

Co-supervision: F. Graner & I



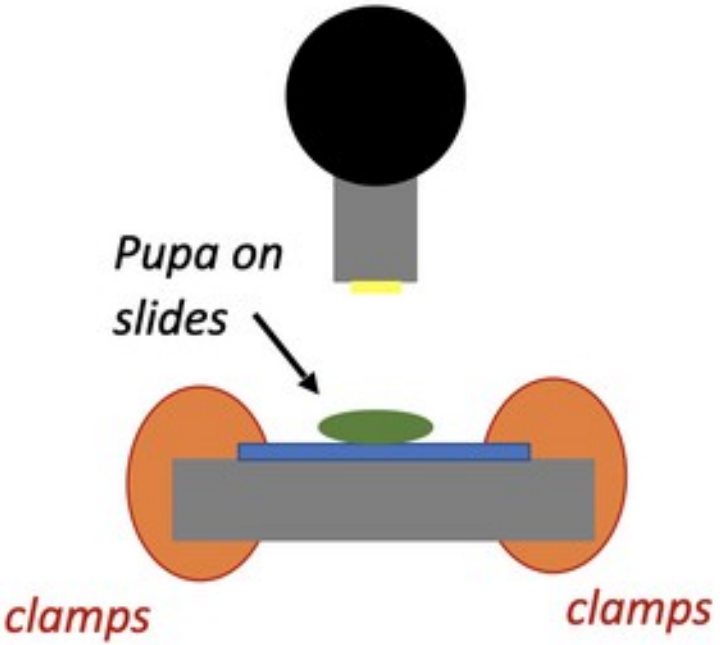
JL Da Lage
R Kulathinal (Philadelphia)

JM Camadro
Y Guerardel
K Hagen (USA)

S Gorb (Kiel)
A Kovalev (Kiel)
L Corté
F Graner

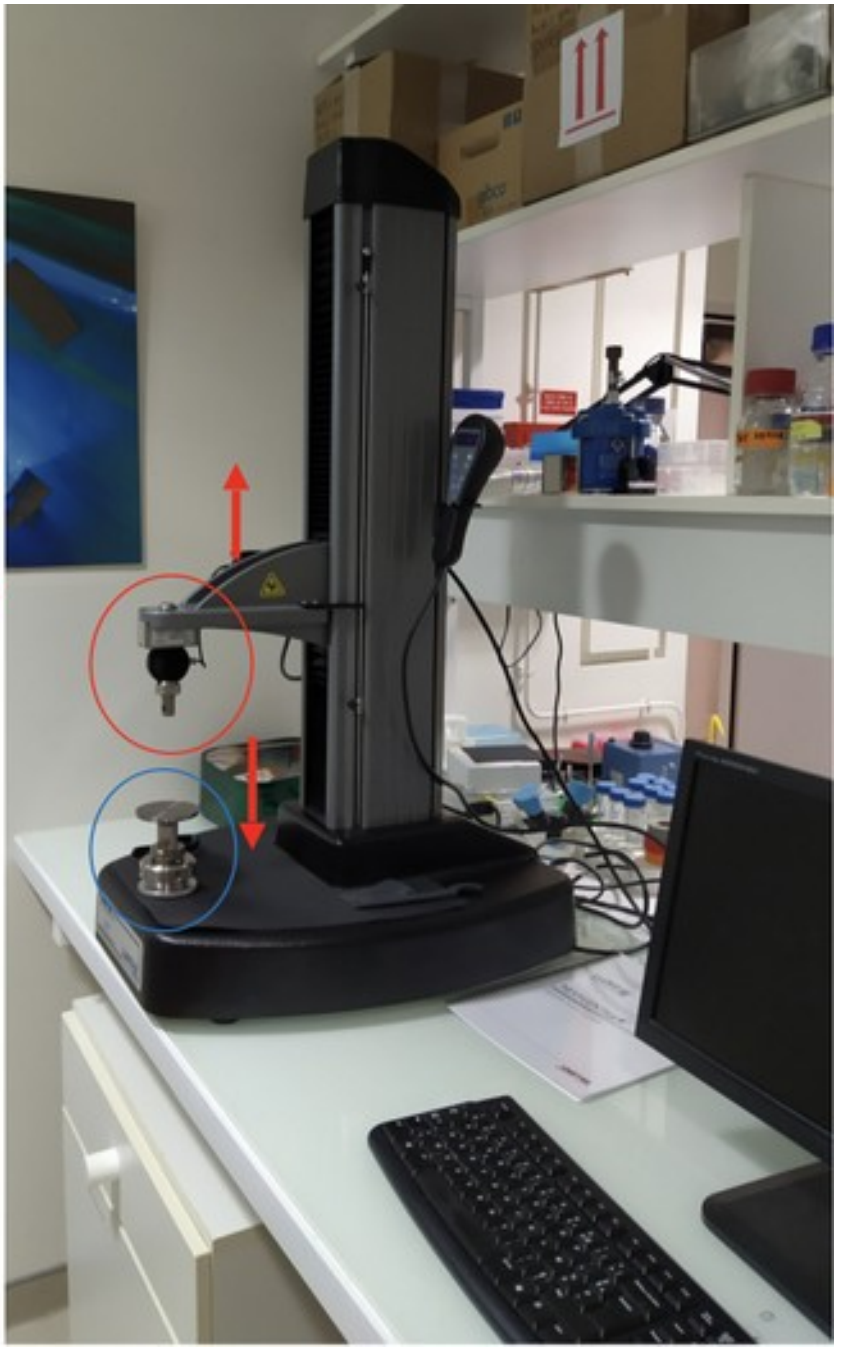
M Molet

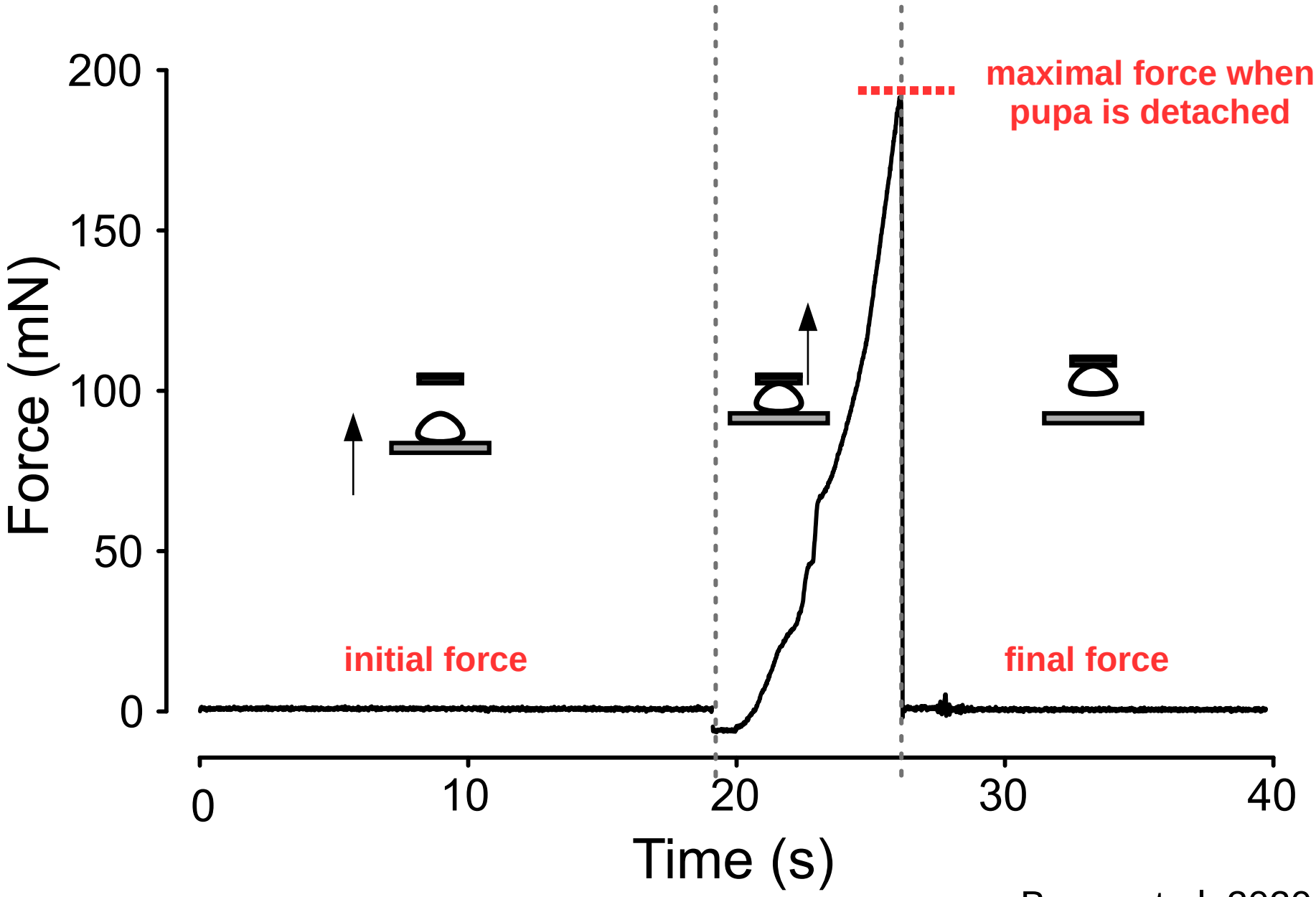
Experimental set up



Force sensor attached to the mobile part

Sample holder which is fixed





Borne et al. 2020 JEB

Drosophila glue is a universal glue

Same force on all tested substrates except Teflon

Force around 200 mN (like very adhesive tape)
Strength around 200 kPa
(~15 000 times the pupa weight)

moth eggs < Drosophila glue < mussel, barnacle < superglue
10-100 kPa 100-300 kPa 300-1000 kPa 10 MPa

Borne et al. 2020 JEB

Function of fly glue
Multiple hypotheses

Adhesion

Avoid predation (pupa hidden, cannot be removed)
Resist to rain, wind, etc.
Help adult emerge from the pupal case

Repellent

Avoid predation (pupa are not eaten)

Preservative

Avoid fungi or bacteria infections on the pupal case

Beňová-Liszeková et al. 2019

Function of fly glue
Multiple hypotheses

Adhesion

Avoid predation (pupa hidden, cannot be removed)
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Preservative

Avoid fungi or bacteria infections on the pupal case

Beňová-Liszeková et al. 2019

Test in Bois de Vincennes

detached attached

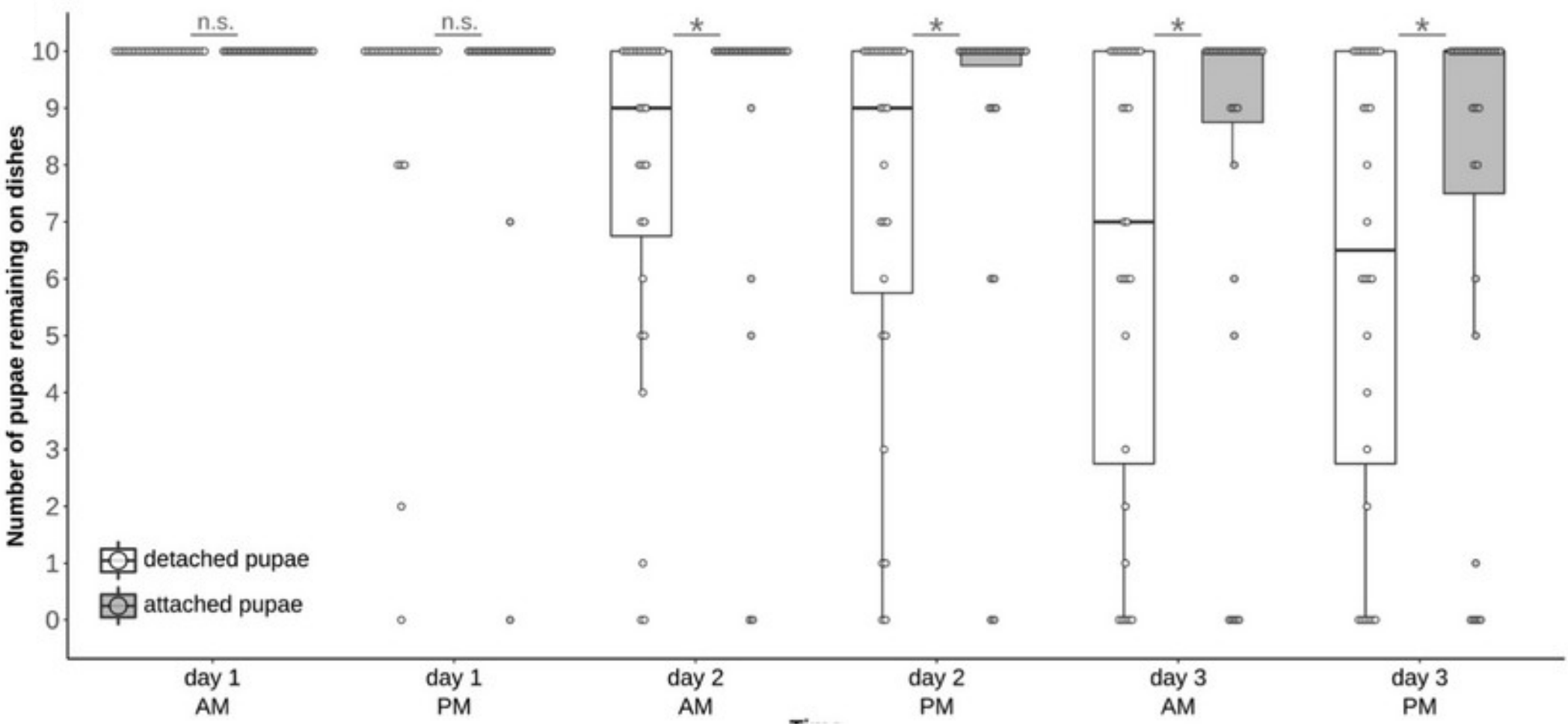
In each bucket (n=28):

one Petri dish w/ 10 detached pupae

one Petri dish w/ 10 attached pupae

Checked twice a day

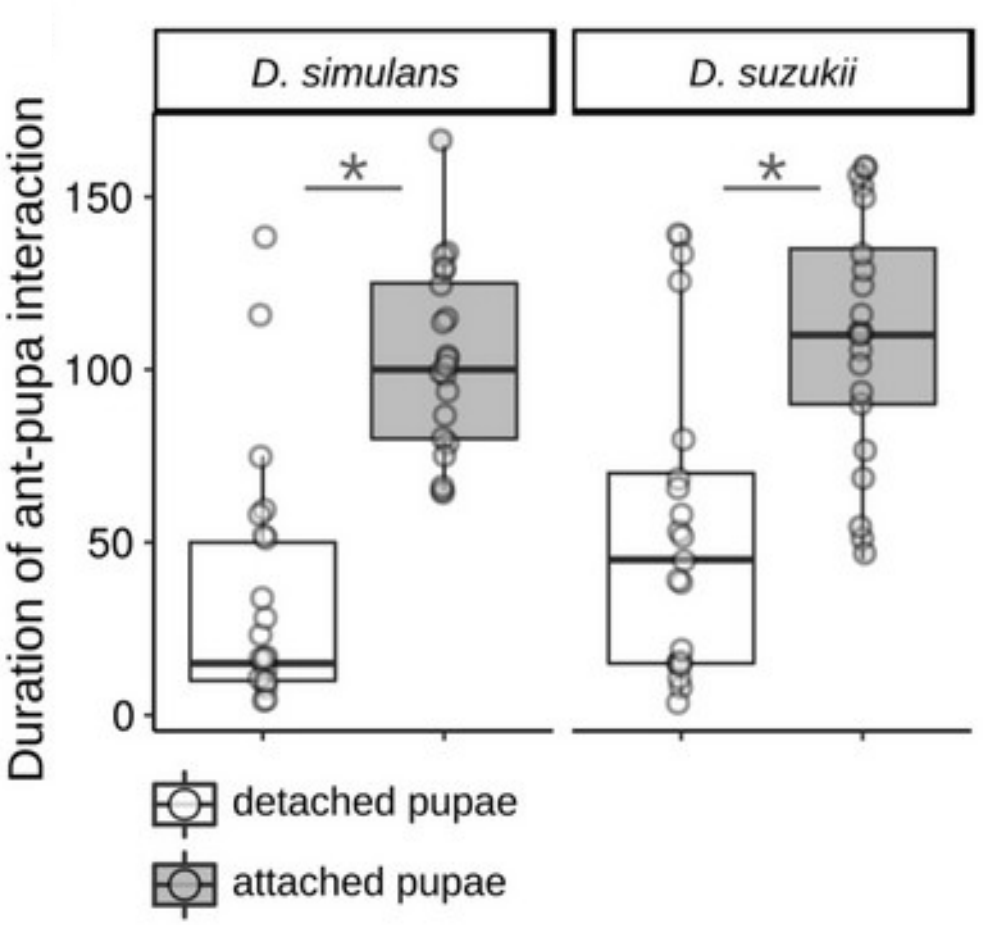
Attached pupae are taken away less frequently than detached pupae

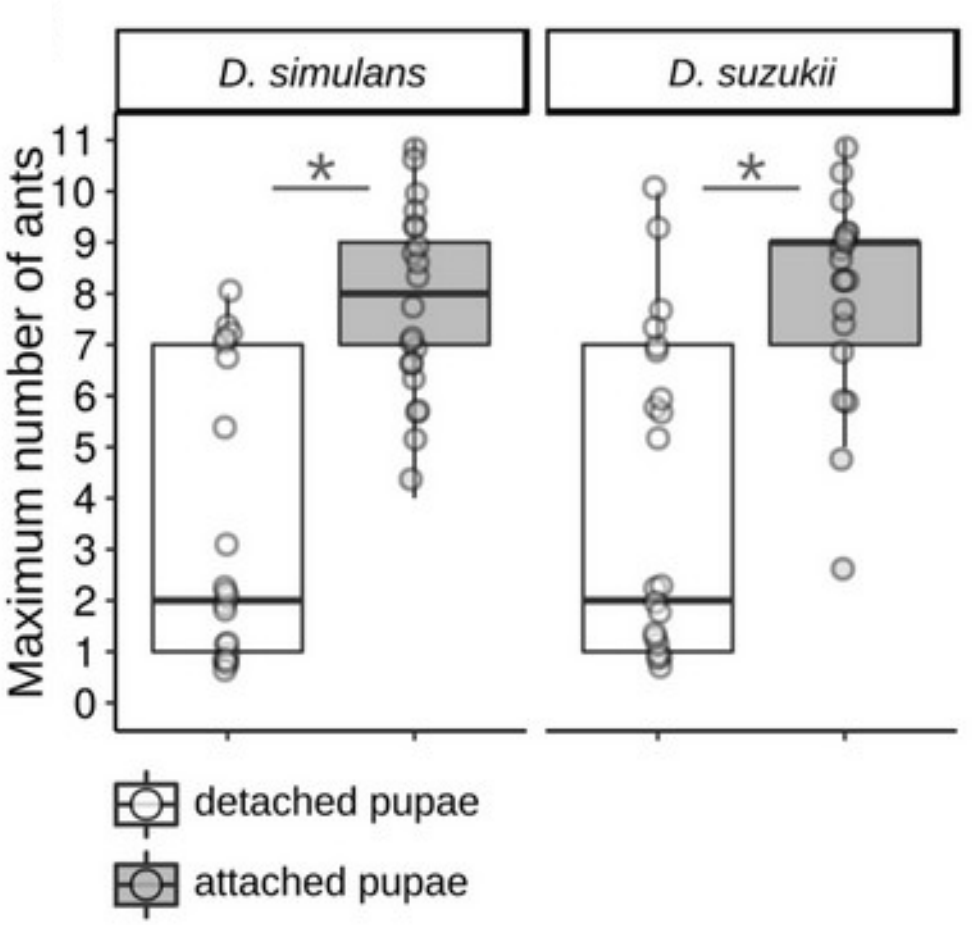


Test in the lab with *Temnothorax* ants

7 ant colonies, one test per day, 6 days
either *D. simulans* or *D. suzukii*

Attached pupae require more time and more ants to go away



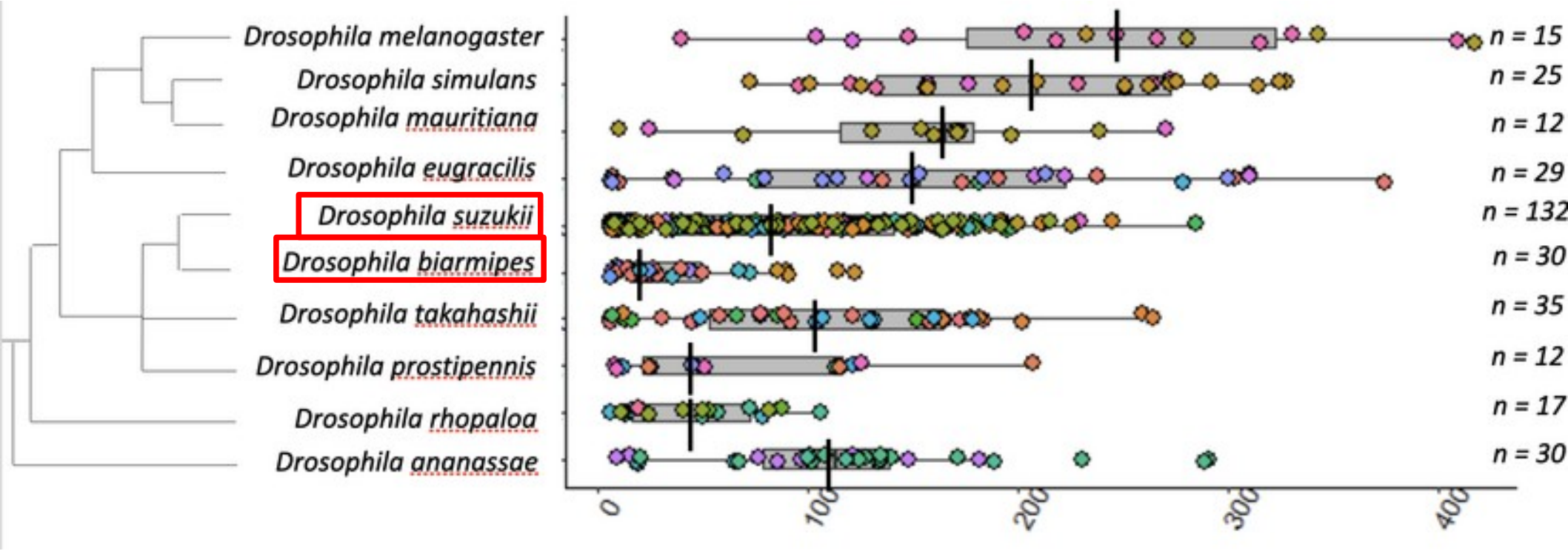


Ecology of fly glue: what is the function of the glue?

- **Glue protects from predation**
- **Detached pupae are brought to the nest while attached pupae are eaten on site and require more ants and more time**

Borne, Prigent, Molet and Courtier, Proc B, 2021

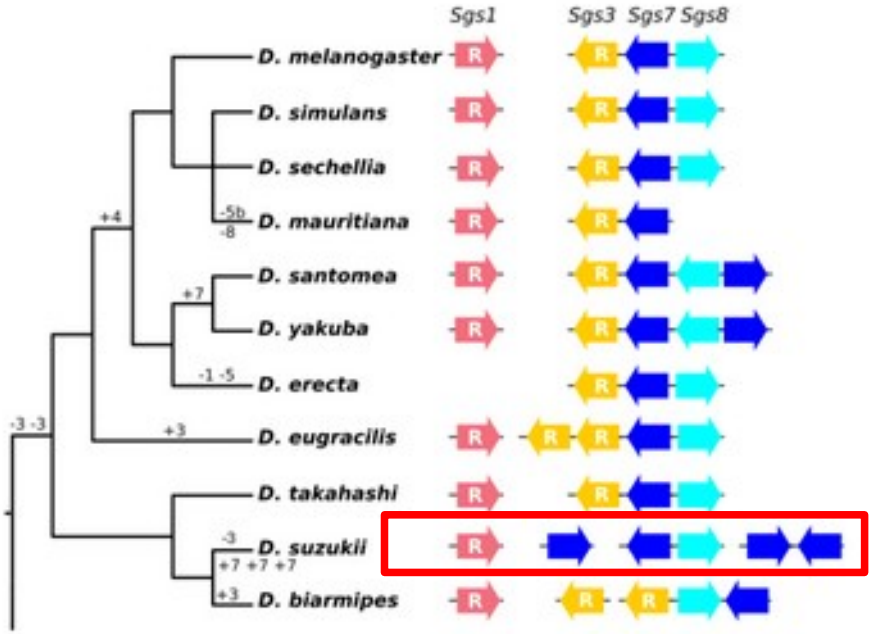
Weaker adhesion in *D. suzukii* and *D. biarmipes*

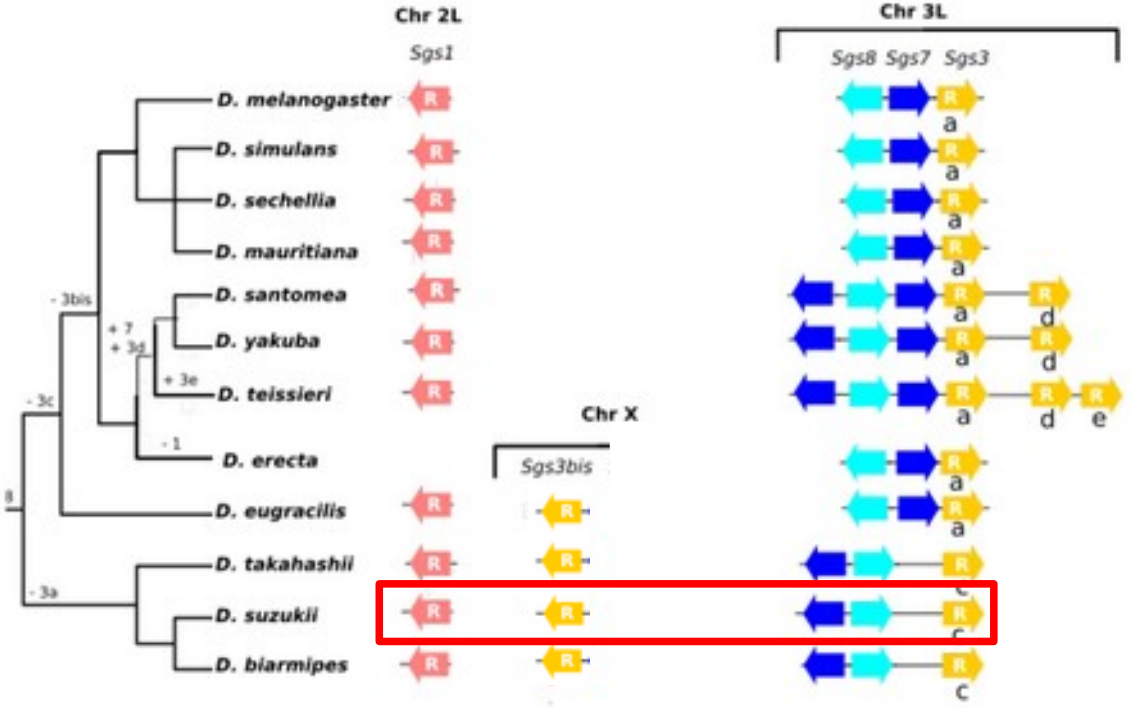


Weaker adhesion in *D. suzukii* and *D. biarmipes*

Due to loss of *Sgs3* in *D. suzukii* ?

No.



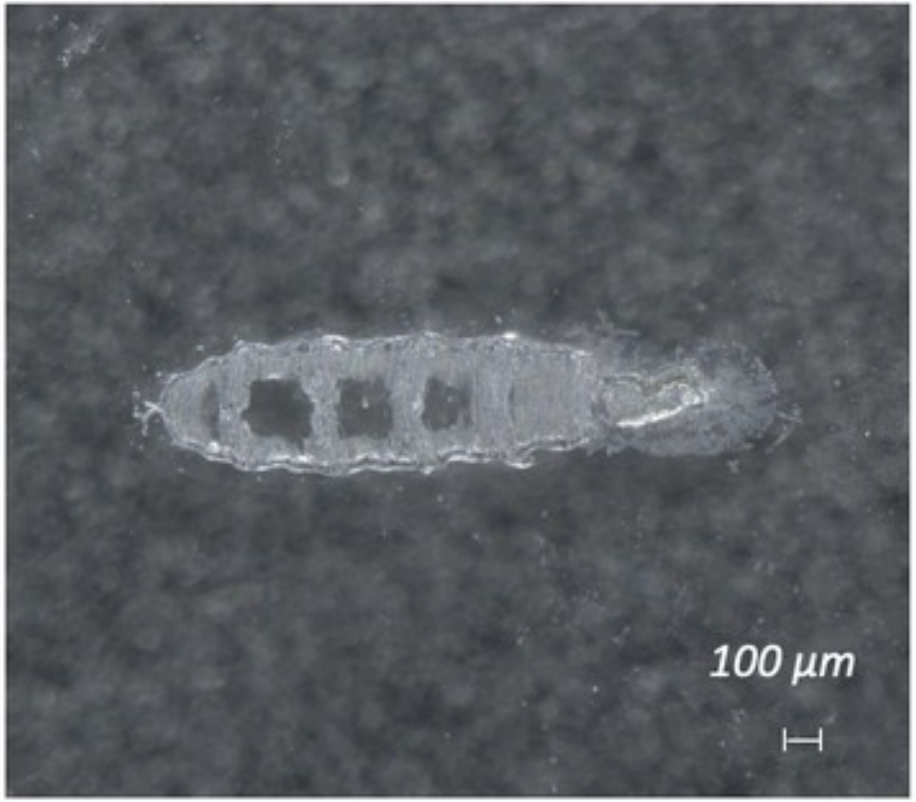


Da Lage 2019 BMC Evol Biol

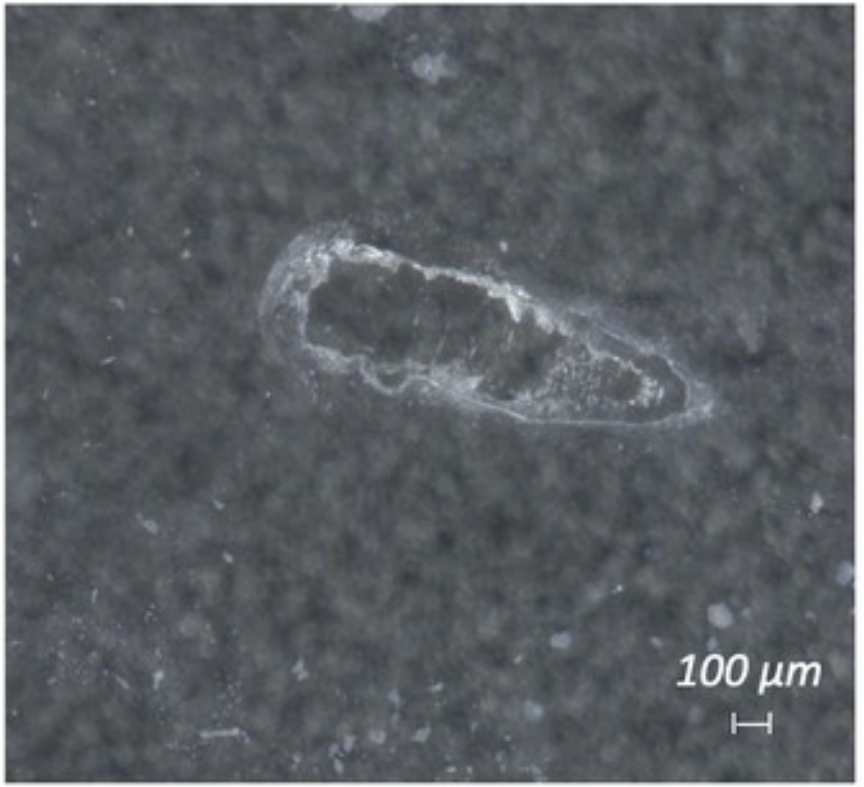
Our new study, unpublished

Little glue produced?

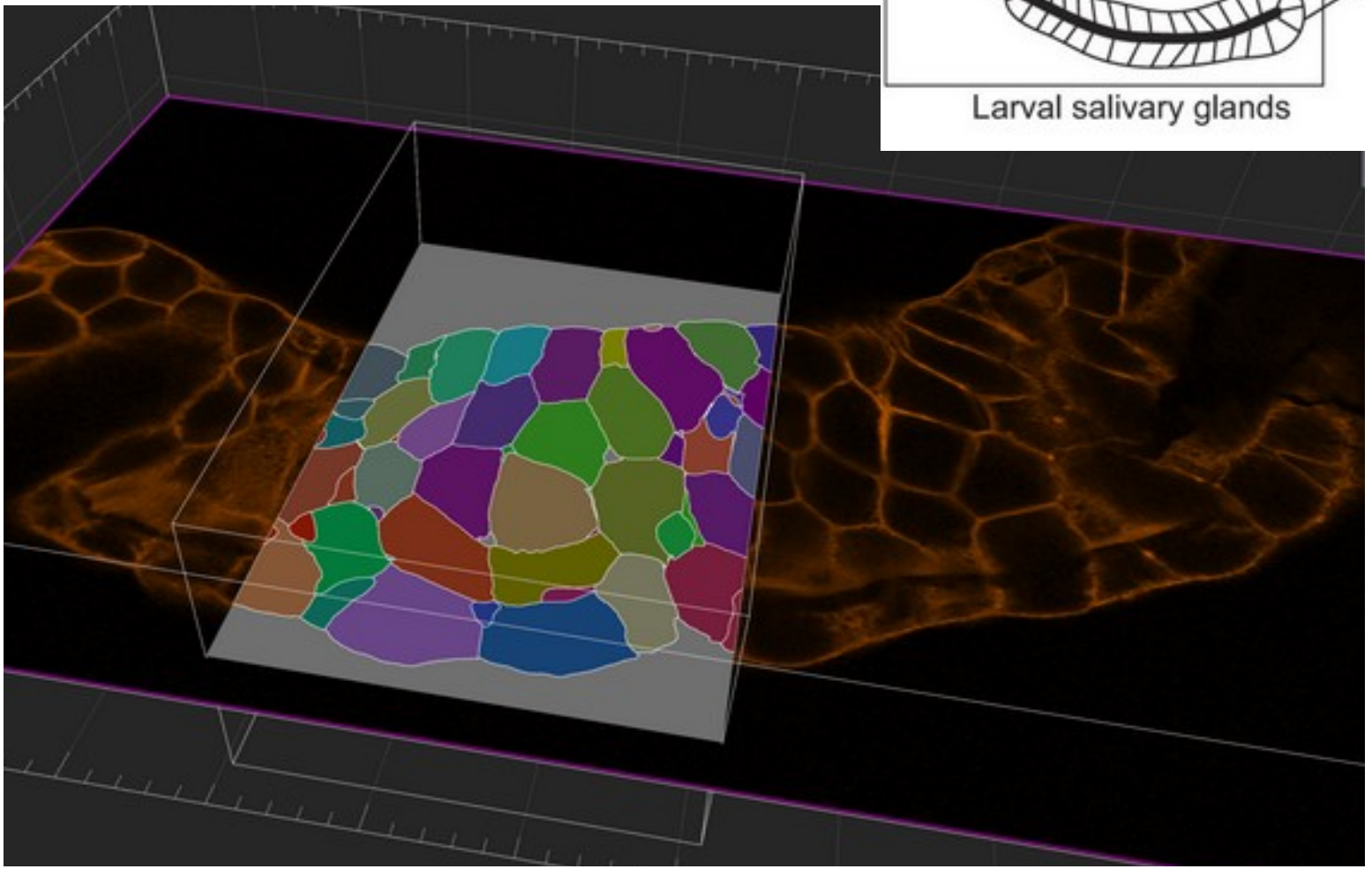
Drosophila simulans

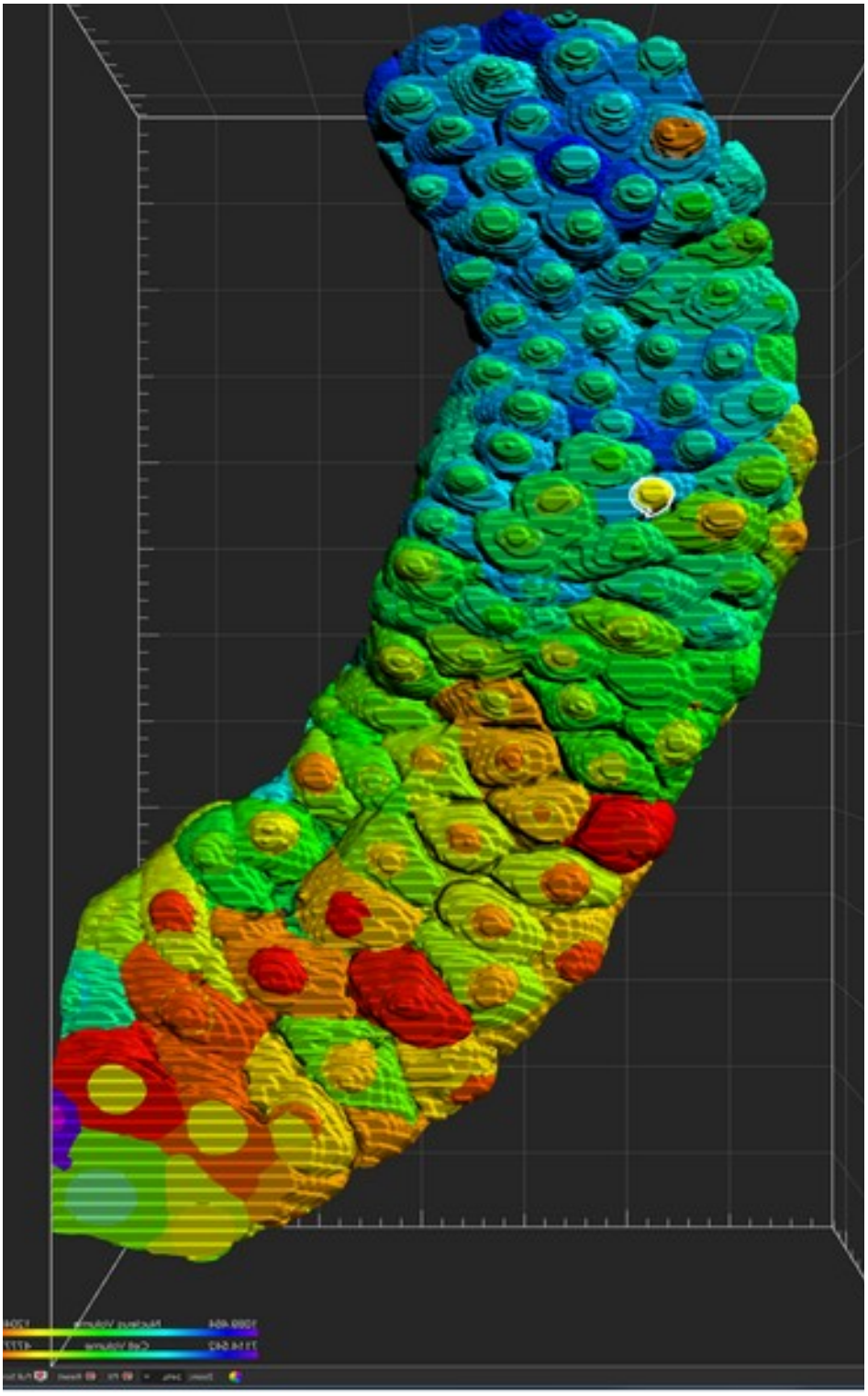


Drosophila suzukii



Ongoing: measure of glue prints and salivary gland size


Drosophila
larva
Secretory cells
Larval salivary glands



The genotype-phenotype relationship

The distinction between genotype and phenotype is the basis of genetics

“The view of natural inheritance as realized by an act of transmission, viz., the transmission of the parent's (or ancestor's) personal qualities to the progeny, is the most naive and oldest conception of heredity.”

“All "types" of organisms, distinguishable by direct inspection or only by finer methods of measuring or description, may be characterized as "**phenotypes**.”

“ A "**genotype**" is the sum of all the "genes" in a gamete or in a zygote.”

Johansen 1911

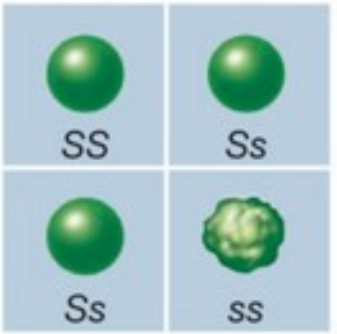
Phenotype = observable attributes of an individual

Genotype = inheritable genetic material
= DNA or RNA

How do genotypes map onto phenotypes ?

A very brief history of genetics

Transmission + *Phenotypic expression*



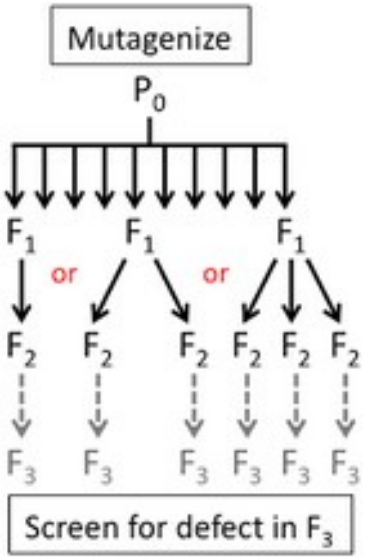
- **Mendel 1860s**
Controlled breeding, use of probabilities
Dominant/recessive/intermediate expression of traits
Random transmission of "factors"

- **Cytology from 1880-90s** Flemming, Boveri, Sutton
chromosomes as support of heredity, meiosis

- **Classical genetics 1900-1950**
distinction genotype-phenotype
segregation of characters & genes
genetic map, sex chromosomes
penetrance - expressivity
"Rediscovery" of Mendel's law
Extension to animals

- **Foundation of molecular biology 1940-1970**
  in part using bacteria and phage genetics
  DNA as the material support of heredity

- Deciphering the role of the genes: 1970-
Cellular, developmental, behavioral genetics: Screens
"High-throughput" versions 2000- (e.g. deletion libraries)
Reverse genetics



- Association mapping on natural populations: 2000-

Divergences and syntheses

Mendelian genetics
"Mendelians"

Statistical genetics
"Biometricians"

1900

agriculture

"Neodarwinian synthesis"

1930

Laboratory genetics

Population genetics
evolution
genotype

Quantitative genetics
phenotype

1950 Molecular biology

Molecular genetics
cell biology, development physiology, etc.

1975

Molecular evolution

Molecular markers

1990

Functional genomics

Evo-Devo

Evolutionary genomics

Quantitative genetics
molecular basis

How do genotypes map onto phenotypes ?

DEVELOPMENTAL BIOLOGY

EVO-DEVO

Both are direct descendants of Morgan's school. Emphasis on genes.

How does an organism form from a single cell?

What makes one organism different from another one?

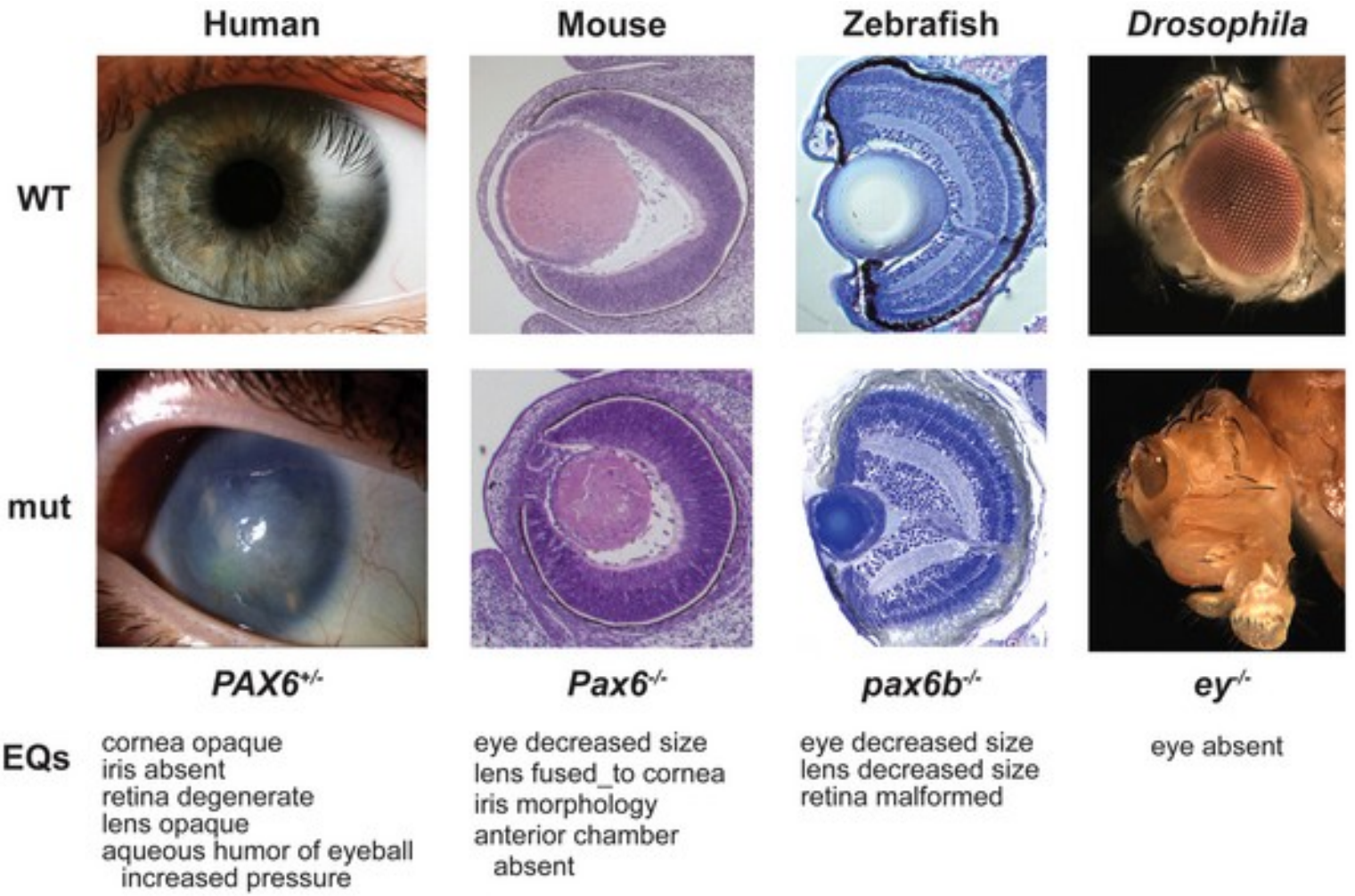
One of the central problems of biology is that of differentiation - how does an egg develop into a complex many-celled organism? That is, of course, the traditional major problem of embryology; but it also appears in genetics in the form of the question,
"How do genes produce their effects?

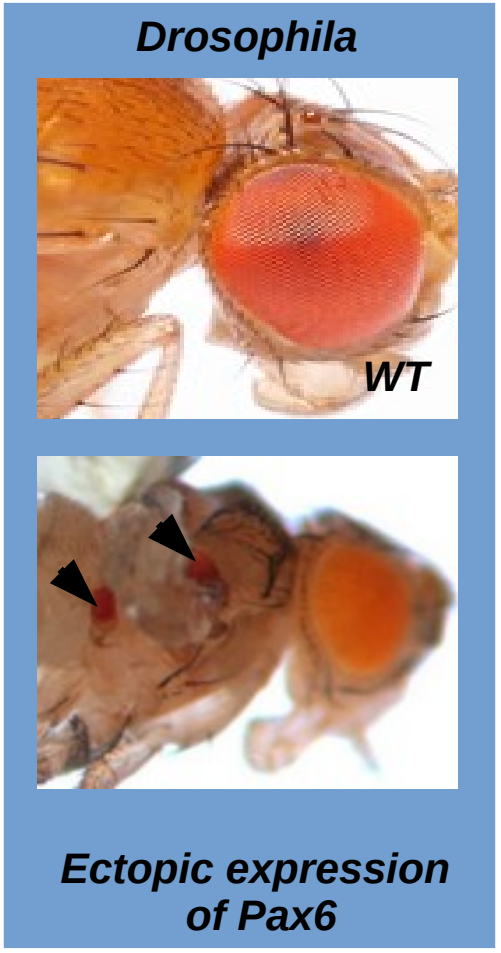
Sturtevant, 1932

How do genes produce observable traits?

Gene → Observable character

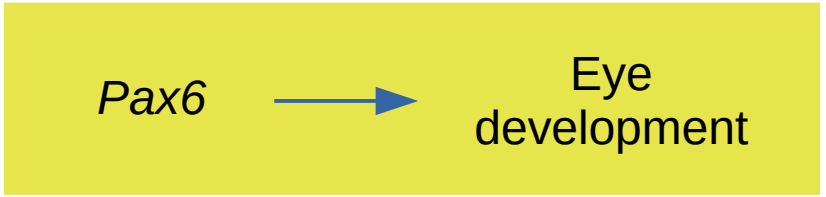
Pax6 : an eye gene ?



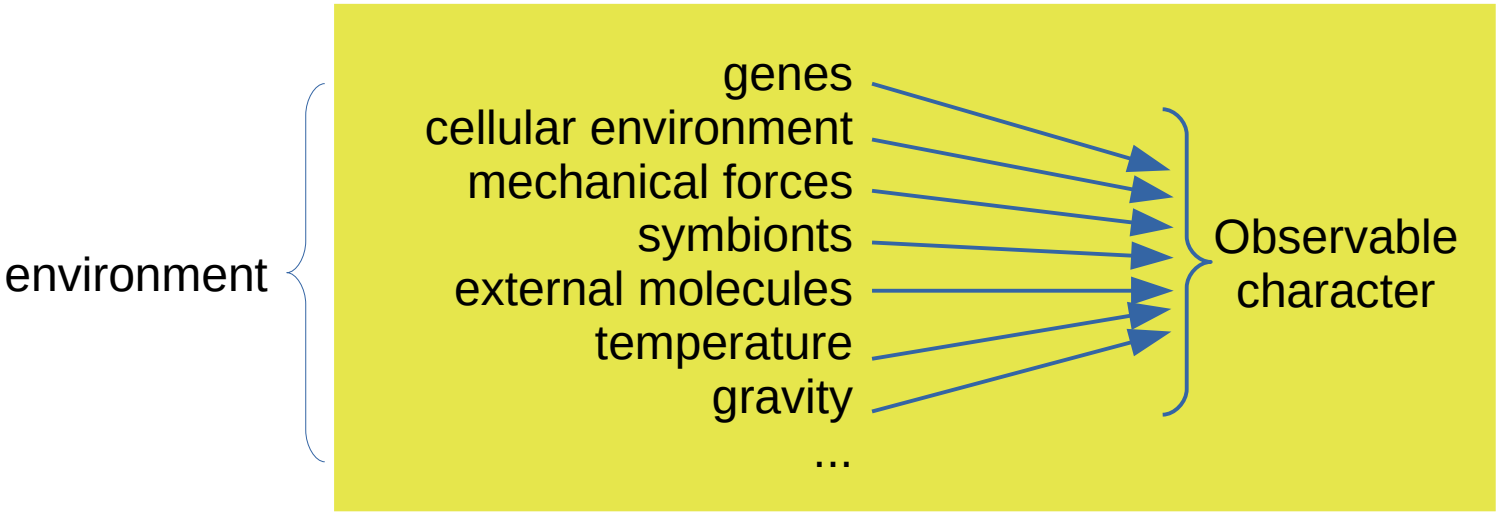


Gene → Observable character

Pax6 → Eye development

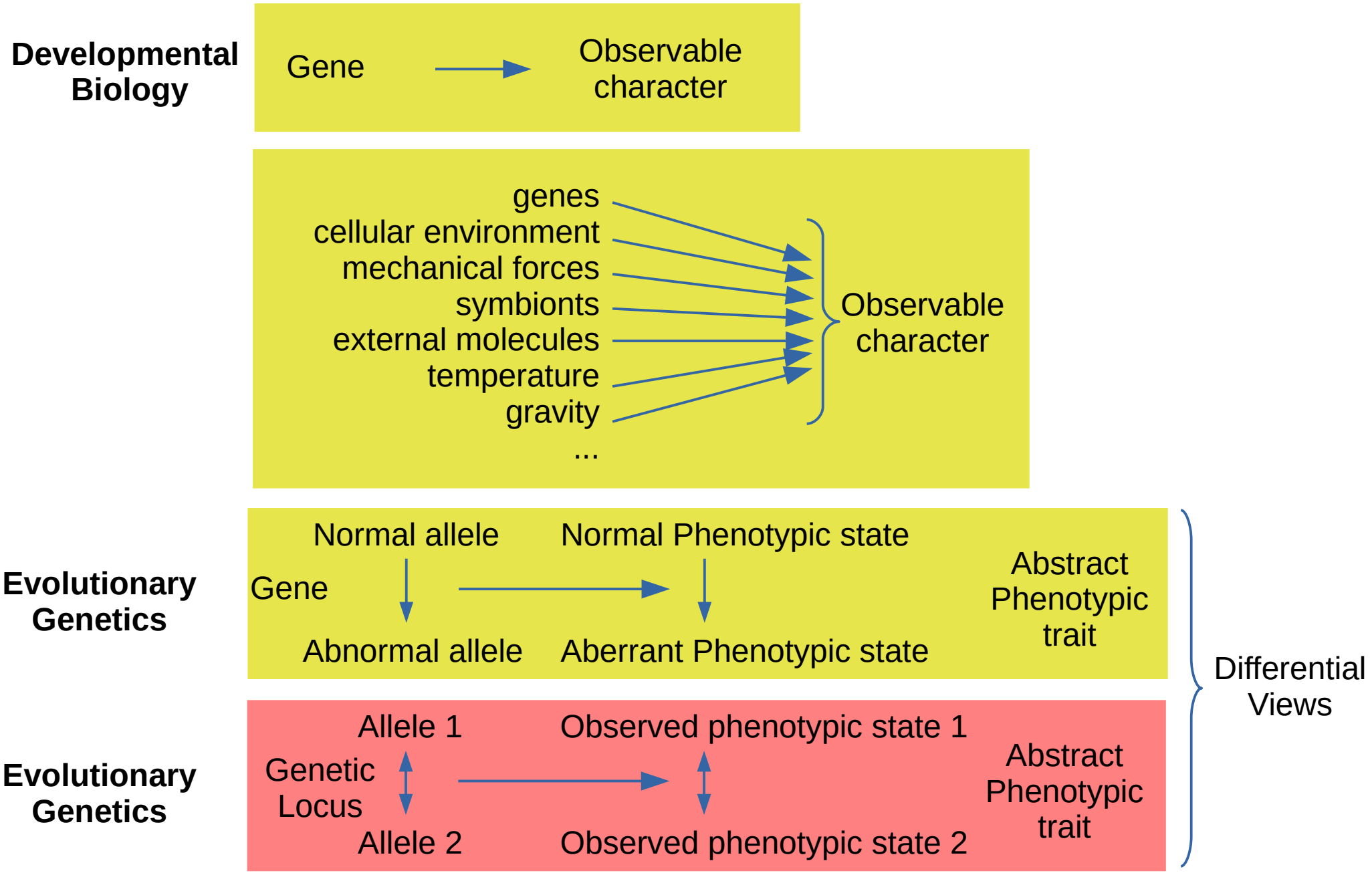


Too simplistic



Better, but difficult to disentangle the effects

A Cause/Mechanism relates to a Difference



Different kinds of phenotypes

Morphology

- **Color**
- **Size and shape**
- **Presence/ absence**
- **Position**

Aristote, Historia animalium, book I, 2, 300BC

Physiology

Behavior

Genotype & Phenotype

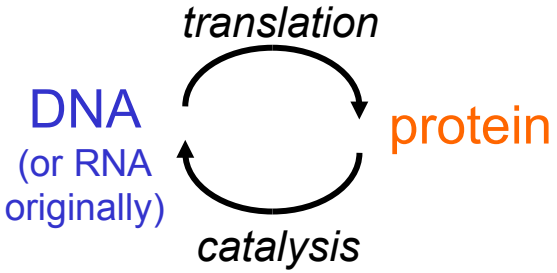
= what engenders = what is apparent

DNA/RNA

- **Regulation of gene expression**
- **Biochemical reactions**
- **Subcellular architecture**
- **Assembly of cells**
- **Organism morphology and behavior**

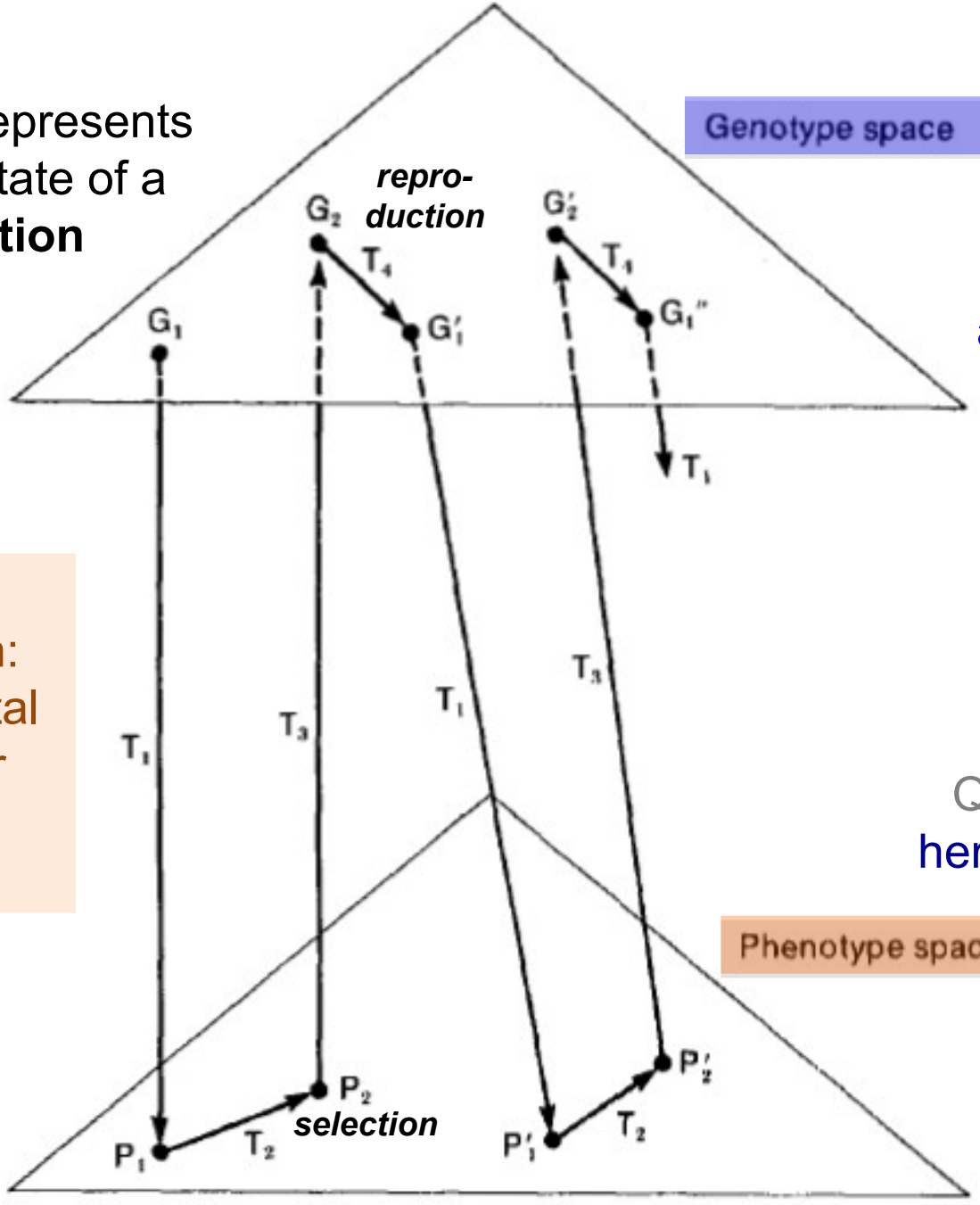
etc.

distinction appeared at the origin of life:



The first genotype-phenotype map

Here a dot represents the mean state of a **population**



Phenotype construction: developmental and cellular biology physiology

Population genetics: stochastic processes and selection coefficient

Quantitative genetics: heritability of phenotypes

Evolutionary biology of phenotypes, evolutionary ecology

Lewontin 1974

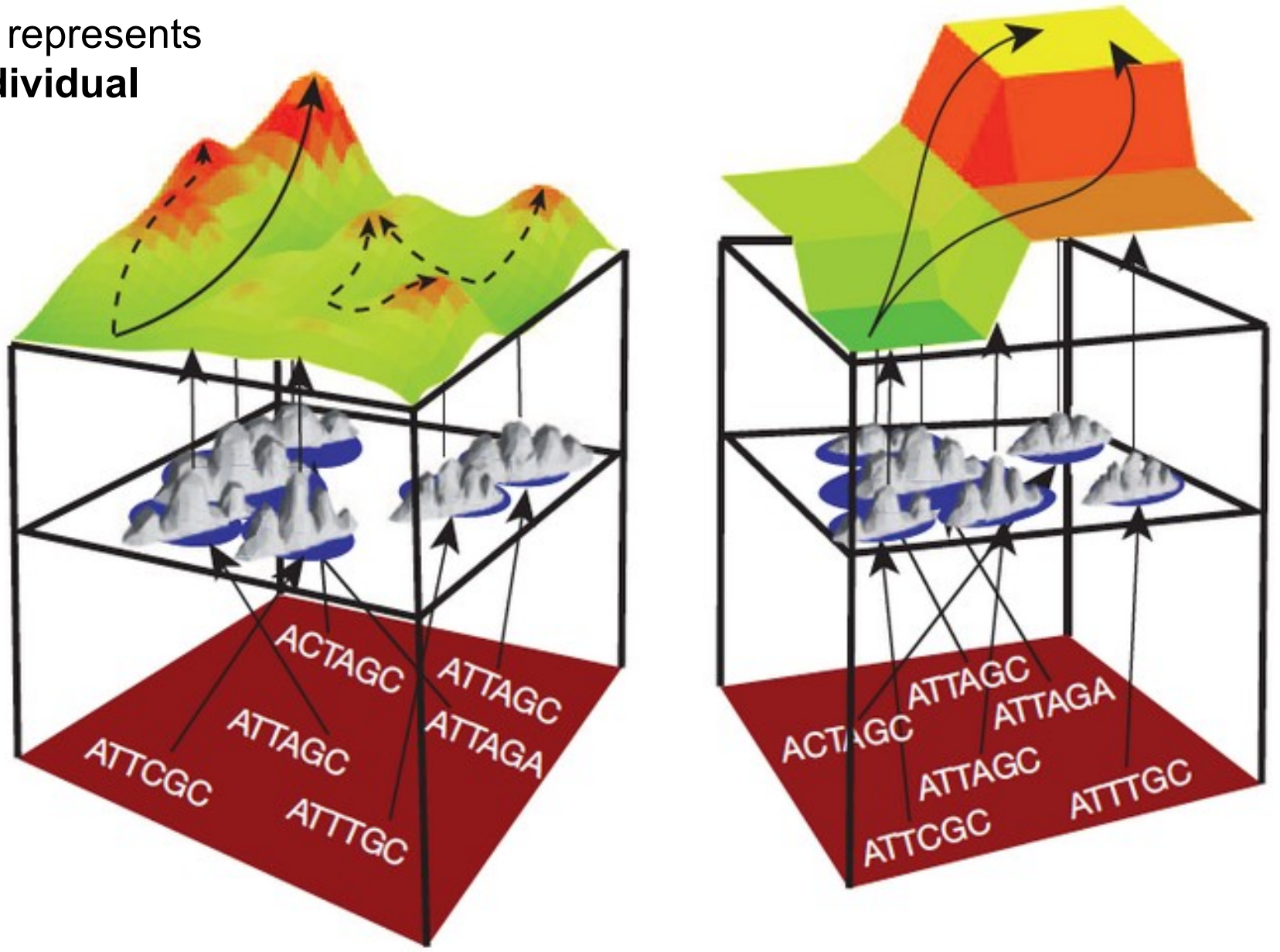
The genotype-phenotype-fitness map

Here a dot represents one **individual**

Fitness

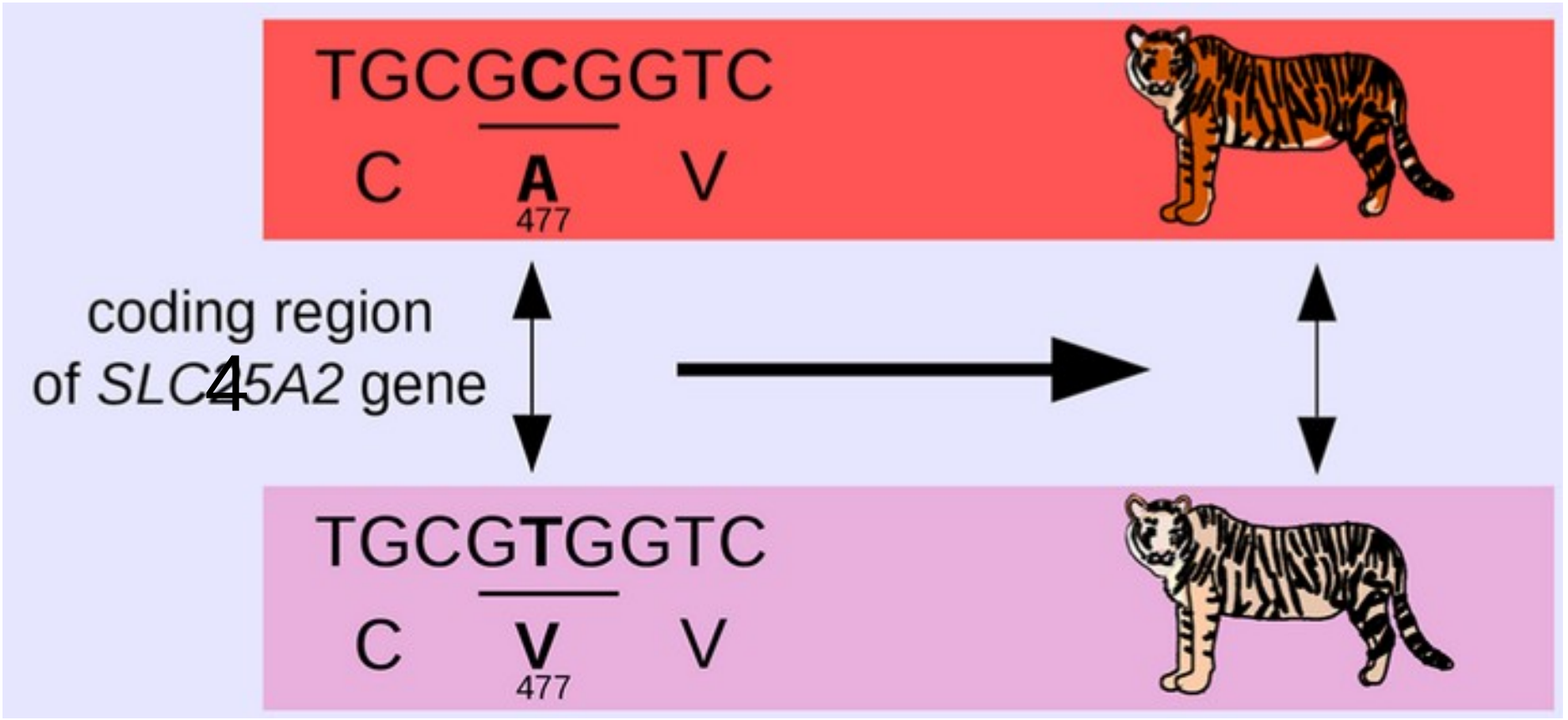
Phenotype
Tooth morphology

Genotype



Salazar-Cuidad & Martin-Riera 2013

The genotype-phenotype connection



Xu et al 2013 Current Biology

Orgogozo et al 2015 Frontiers Genetics

Genotype = “the genetic makeup of an organism that determines a specific phenotype (trait), from one generation to the next, and potentially throughout the population”.

Report of the National Academy of Sciences on gene drive, 2016

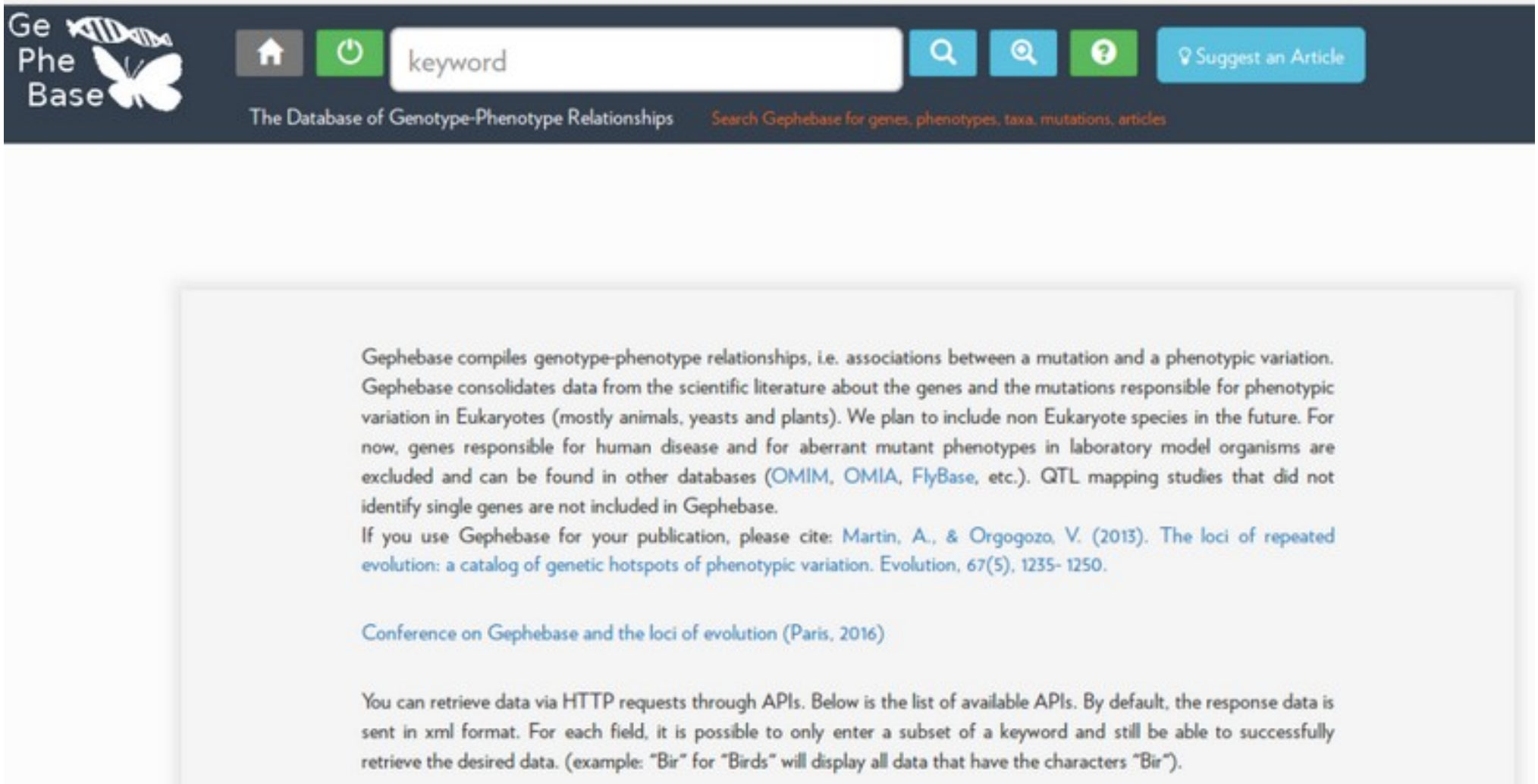
NO!

The genotype-phenotype connection is about differences

The genes contributing to evolution

www.Gephebase.org
>2000 entries

@gephebase



Orgogozo et al Nucleic Acid Research 2019

oca2 in cavefish

Ge Phe Base

keyword

Suggest an Article

The Database of Genotype-Phenotype Relationships Search Gephebase for genes, phenotypes, taxa, mutations, articles

GEPHE SUMMARY

Gephebase Gene	Oca2	GephelD	GP00000745
Entry Status	Published	Main curator	Courtier

PHENOTYPIC CHANGE

Show All Details

Trait Category	Morphology
Trait	Coloration (albinism)
Trait State in Taxon A	Astyanax mexicanus surface
Trait State in Taxon B	Astyanax mexicanus Molino
Ancestral State	Taxon A
Taxonomic Status	Intraspecific

Taxon A

Latin Name	*Astyanax mexicanus*
Common Name	Mexican tetra
Synonyms	Mexican tetra; blind cave fish; Astyanax mexicanus (De Filippi, 1853)
Rank	species
Lineage	Show more ... eopterygii; Teleostei; Osteoglossocephalai; Clupeocephala; Otomorpha; Ostariophysi; Otophysi; Characiphysae; Characiformes; Characoidei; Characidae; Characidae incertae sedis; Astyanax clade; Astyanax
Parent	Astyanax () - (Rank: genus)
NCBI Taxonomy ID	7994
is Taxon A an Infraspecies?	No

Taxon B

Latin Name	*Astyanax mexicanus*
Common Name	Mexican tetra
Synonyms	Mexican tetra; blind cave fish; Astyanax mexicanus (De Filippi, 1853)
Rank	species
Lineage	Show more ... eopterygii; Teleostei; Osteoglossocephalai; Clupeocephala; Otomorpha; Ostariophysi; Otophysi; Characiphysae; Characiformes; Characoidei; Characidae; Characidae incertae sedis; Astyanax clade; Astyanax
Parent	Astyanax () - (Rank: genus)
NCBI Taxonomy ID	7994
is Taxon B an Infraspecies?	Yes
Taxon B Description	Astyanax mexicanus Molino

Trait Category	Morphology
Trait	Coloration (albinism)
Trait State in Taxon A	Astyanax mexicanus surface
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Taxon A

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Taxon B

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Common Name	Mexican tetra
Synonyms	Mexican tetra; blind cave fish; Astyanax mexicanus (De Filippi, 1853)
Rank	species
Lineage	Show more ... eopterygii; Teleostei; Osteoglossocephalai; Clupeocephala; Otomorpha; Ostariophysi; Otophysi; Characiphysae; Characiformes; Characoidei; Characidae; Characidae incertae sedis; Astyanax clade; Astyanax
Parent	Astyanax () - (Rank: genus)
NCBI Taxonomy ID	7994
is Taxon B an Infraspecies?	Yes
Taxon B Description	Astyanax mexicanus Molino

GENOTYPIC CHANGE

Show All Details

Generic Gene Name	**Oca2**
Synonyms	p; D7Nic1; p<cas>; D7H15S12; D7Icr28RN; P
String	10090.ENSMUSP00000032633
Sequence Similarities	Belongs to the CitM (TC 2.A.11) transporter family.
GO - Molecular Function	-
GO - Biological Process	GO:0055085 : transmembrane transport ... show more
GO - Cellular Component	GO:0016021 : integral component of membrane ... show more

UniProtKB	**Q62052**
Mus musculus	
GenebankID or UniProtKB	**ABB29299**

Presumptive Null	**Yes**
Molecular Type	**Coding**
Aberration Type	**Deletion**
Deletion Size	-
Molecular Details of the Mutation	**Deletion of exon 21**
Experimental Evidence	**Linkage Mapping**
Main Reference	Genetic analysis of cavefish reveals molecular convergence in the evolution of albinism. (2006)
Authors	Protas ME; Hersey C; Kochanek D; Zhou Y; Wilkens H; Jeffery WR; Zon LI; Borowsky R; et al. ... show more
Abstract	The genetic basis of vertebrate morphological evolution has traditionally been very difficult to examine in naturally occurring populations. Here we describe the generation of a genome-wide linkage map to allow quantitative trait analysis of evolutionarily derived morphologies in the Mexican cave tetra, a species that has, in a series of independent caves, repeatedly evolved specialized characteristics adapted to a unique and well-studied ecological environment. We focused on the trait of albinism and discovered

Additional References

RELATED GEPHE

Related Genes 1 (MC1R)

Related Haplotypes 1

COMMENTS

YOUR FEEDBACK is welcome!

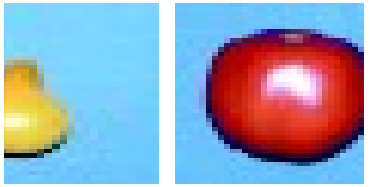
Feedback

Your E-mail

Optional and remains confidential (not displayed online). Only used to contact you if

Wrinkled seed: TE insertion
(Bhattacharyya 1990)

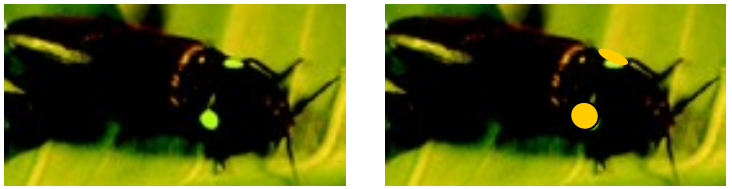
OVATE coding region
(Liu 2002)



FRI coding region
(Johanson 2000)

myostatin coding region
(Grobet 1997)

luciferase coding region
(Stolz 2003)



Mc1r coding region
(Eizirik 2003)

anthocyanin-2 coding region
(Quattrocchio 1999)

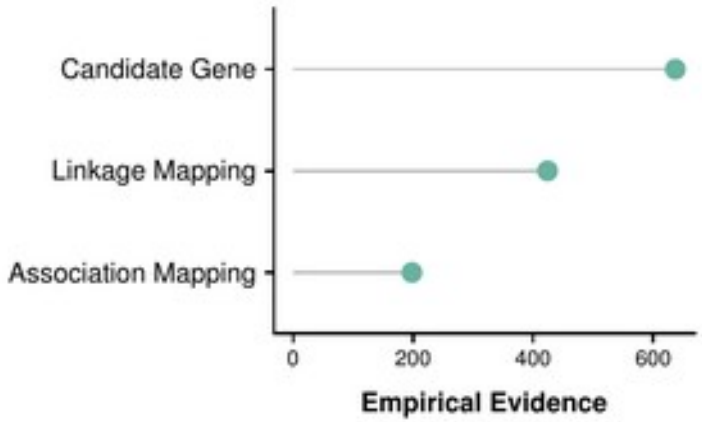
REVERSE GENETICS

From genes to traits

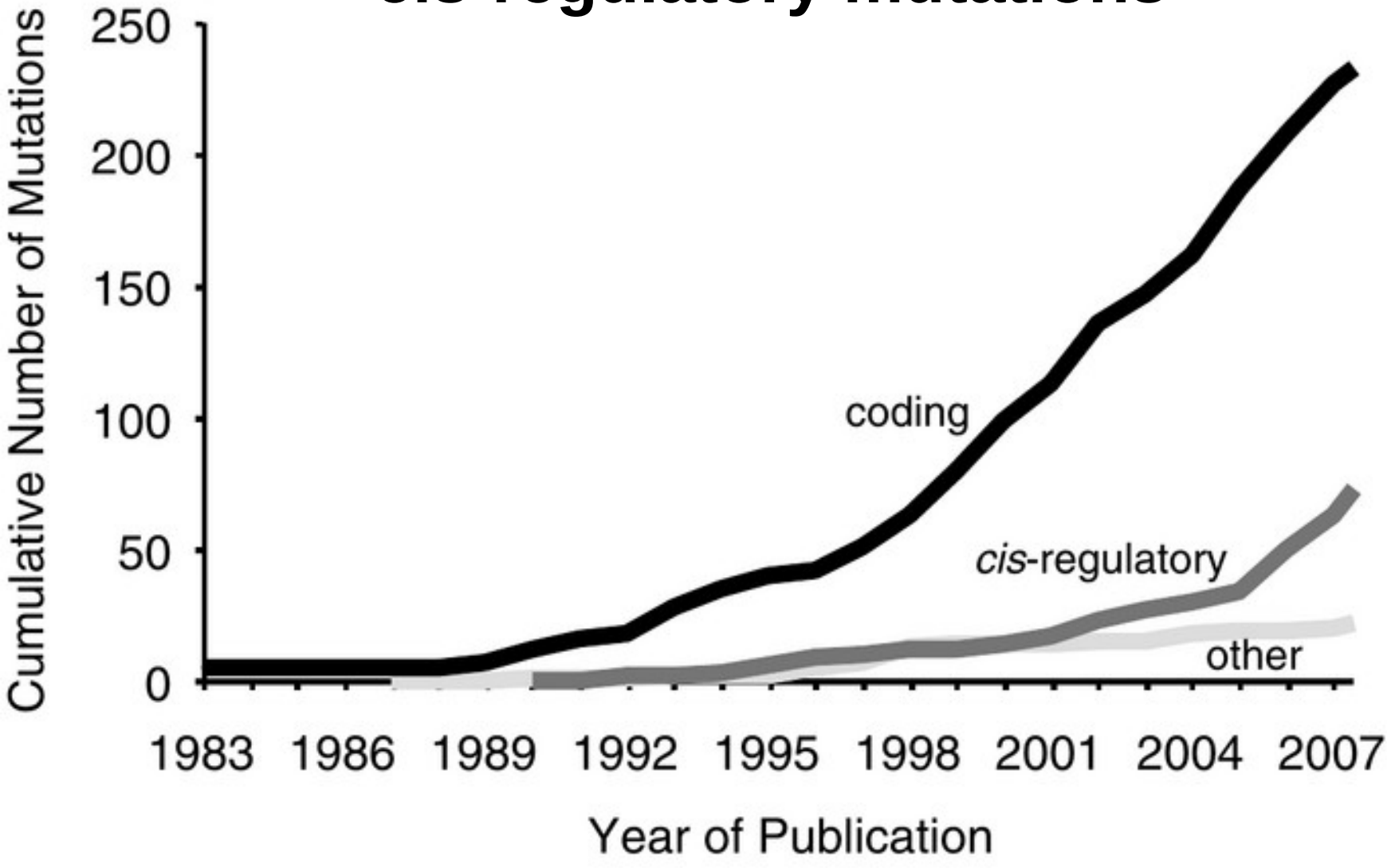
FORWARD GENETICS

From traits to genes

Little Ascertainment Bias, but Micro-Evolution only

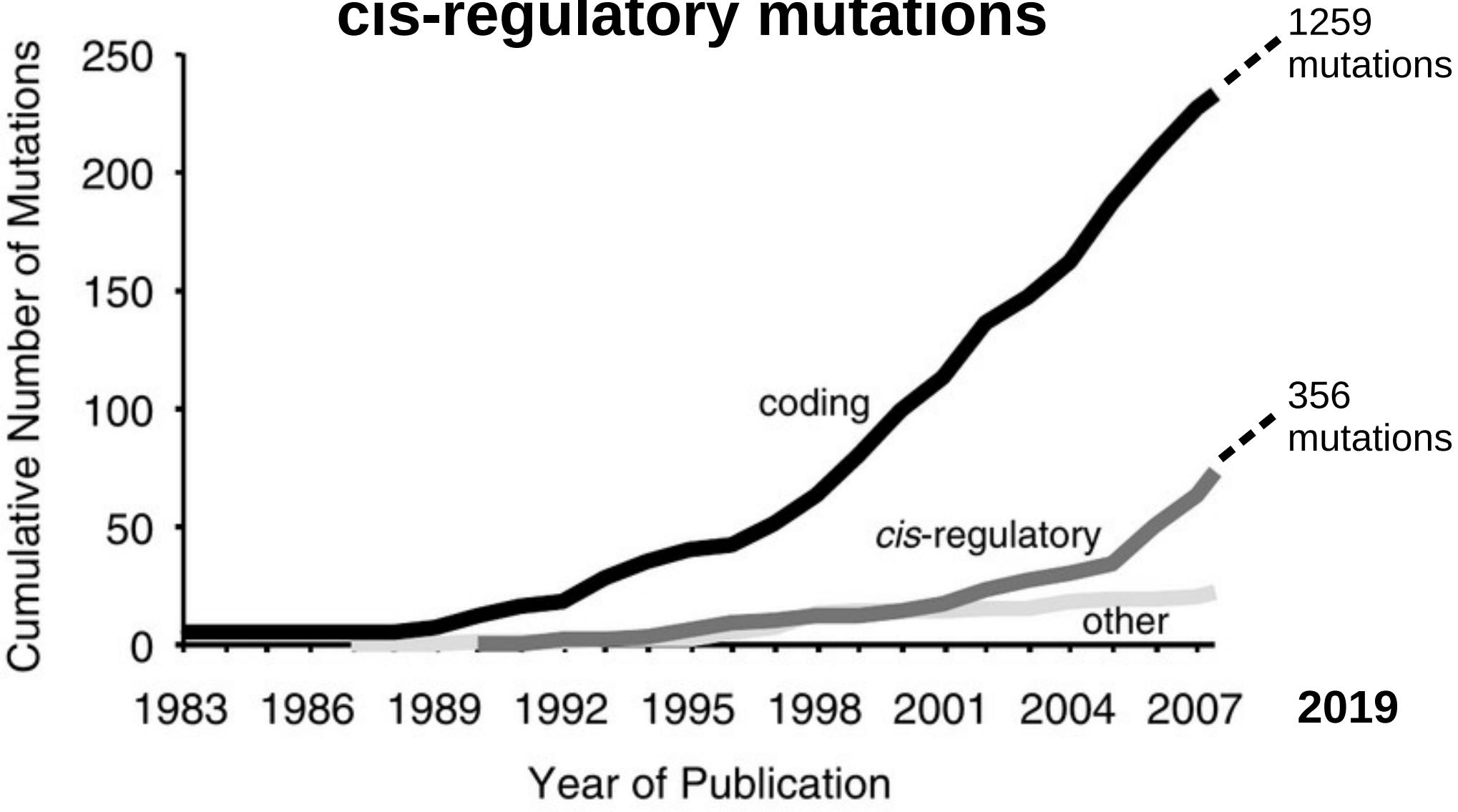


More cases of coding than cis-regulatory mutations



survey of ~300 articles
Stern and Orgogozo 2008 Evolution

More cases of coding than cis-regulatory mutations



Evolution repeats itself

Repeated evolution via the same amino acid change

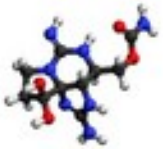
clam

garter snake

Nav1.4
X E945D

Nav1.4 sodium channel
X E945D

Saxitoxin



Tetrodotoxin

Nav1.4
E945D
X

toxic plancton

toxic newt

pufferfish (fugu)

Bricelj 2005
Geffeney 2005
Venkatesh 2005

Repeats in..

.. the genes responsible for natural evolution

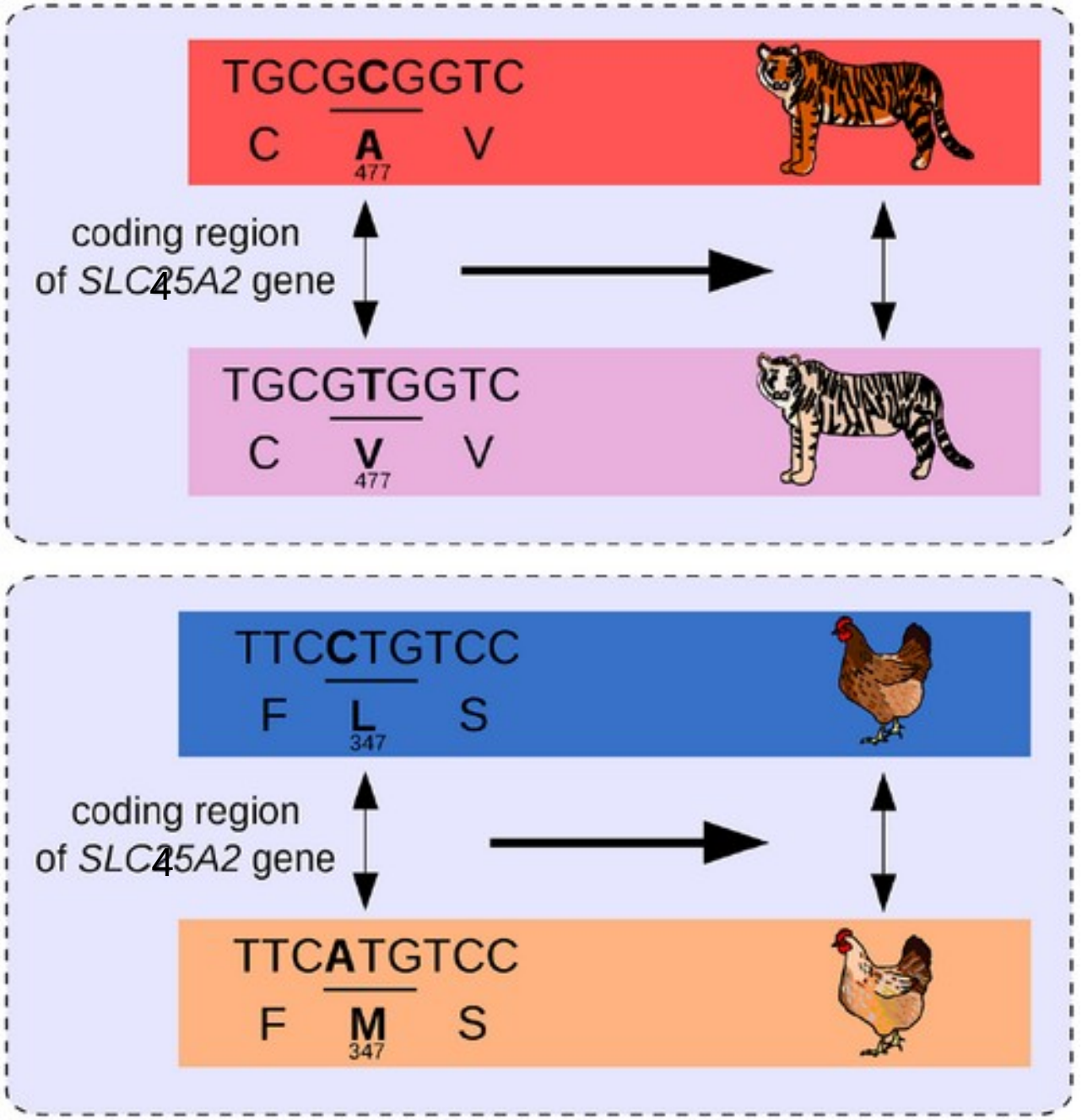
Ex : *hemoglobin* in dogs and humans in Tibet
(Wang et al 2014 GBE)

.. the genes responsible for experimental evolution

Ex : *sulfate transporter SUL1* in yeasts in low sulfate
(Gresham et al 2008 PloS Genetics)

Orgogozo 2014 Interface Focus

Repeated evolution



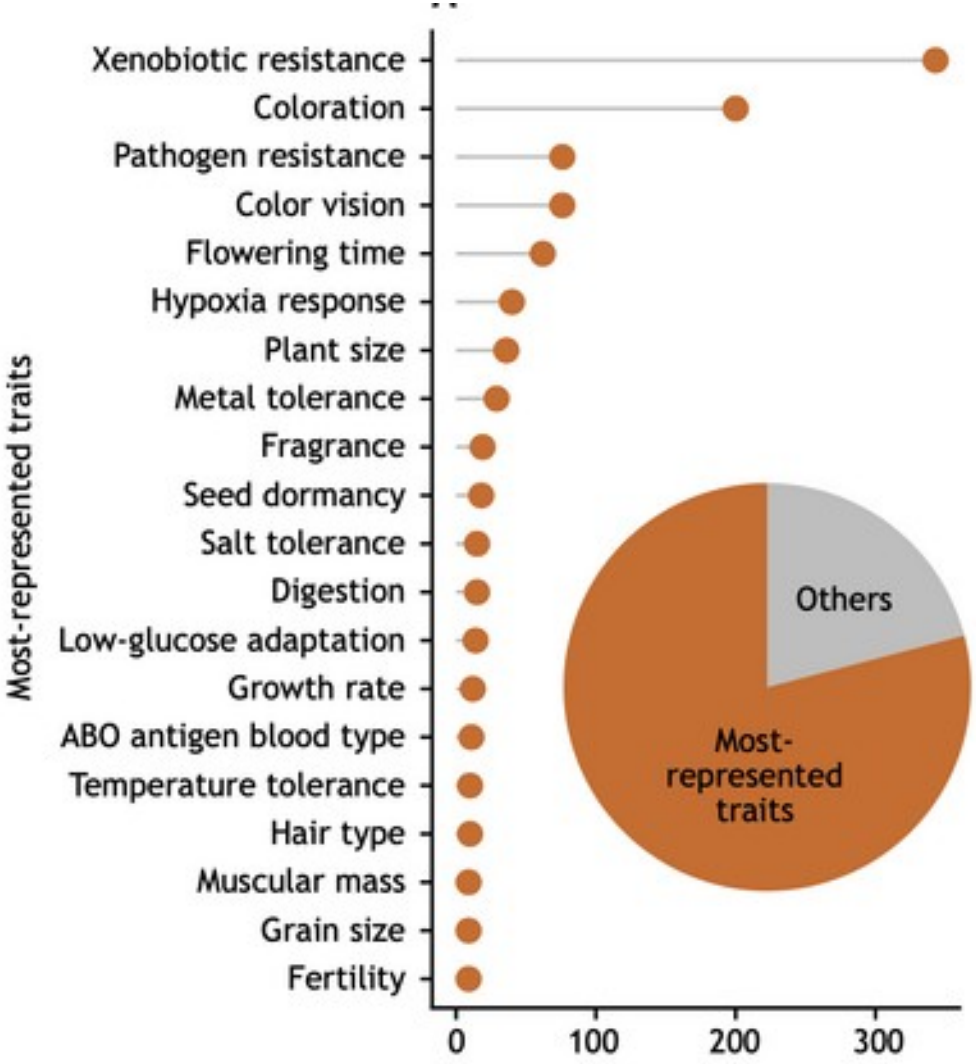
Also in:
Humans
Horses
Quails
Chickens
Mice
Pigeons

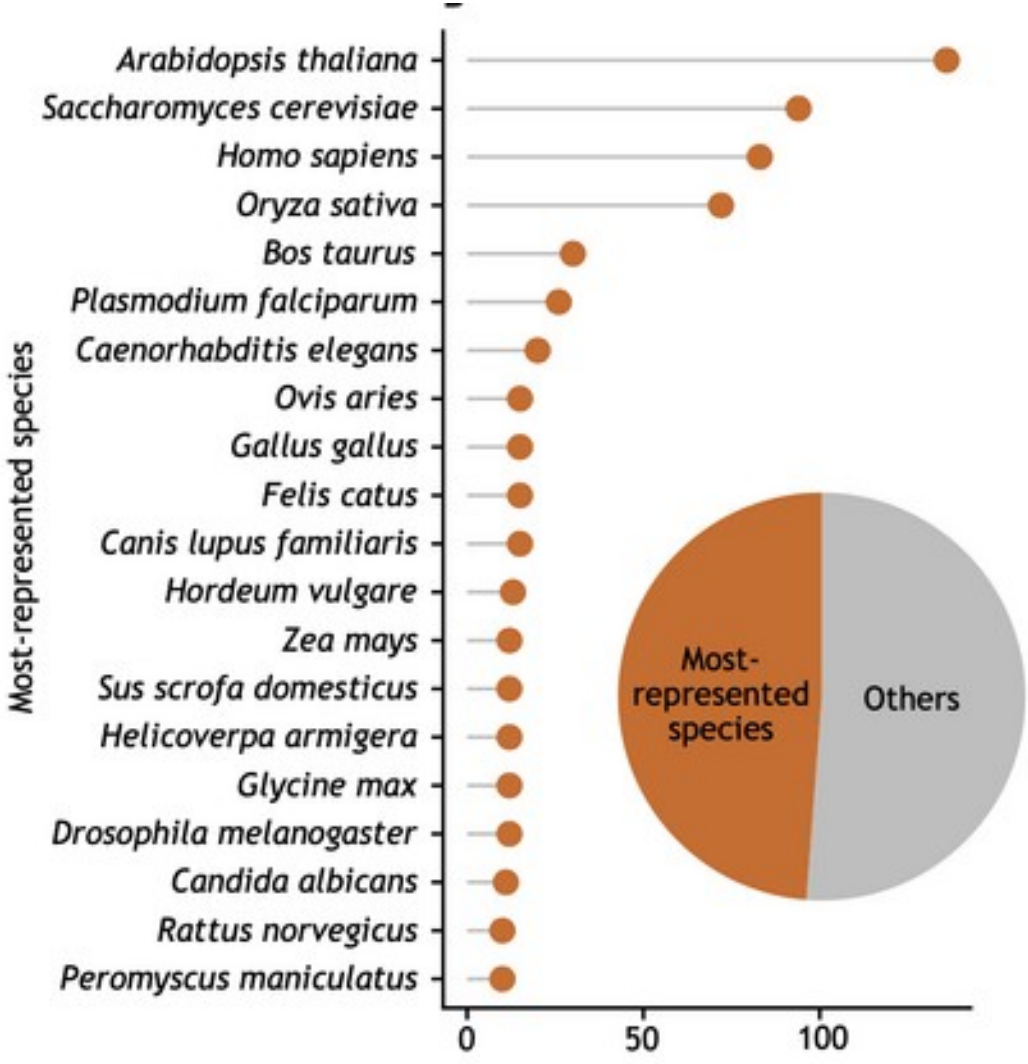
Orgogozo et al 2015 Frontiers Genetics

TOP HOTSPOT GENES 2022

MC1R (93)
para (kdr) (54)
Kit (type III receptor protein-tyrosine kinase) (46)
Na/K-ATPase alpha-subunit (45)
beta-tubulin (33)
beta-tubulin (ben-1) (27)
SCN4A (Nav1.4) (26)
Agouti (ASIP) (24)
tyrosinase (TYR) (24)
tyrosinase-related protein 1 (TYRP1) (24)
AtGA20ox1 (=GA5=Sd1) (24)
Agouti (24)
alcohol dehydrogenase (Adh) (23)
opsin - (SWS1) (20)

Bias towards certain traits and species





Specialized loci in the genome

Proteins that interact with external molecules

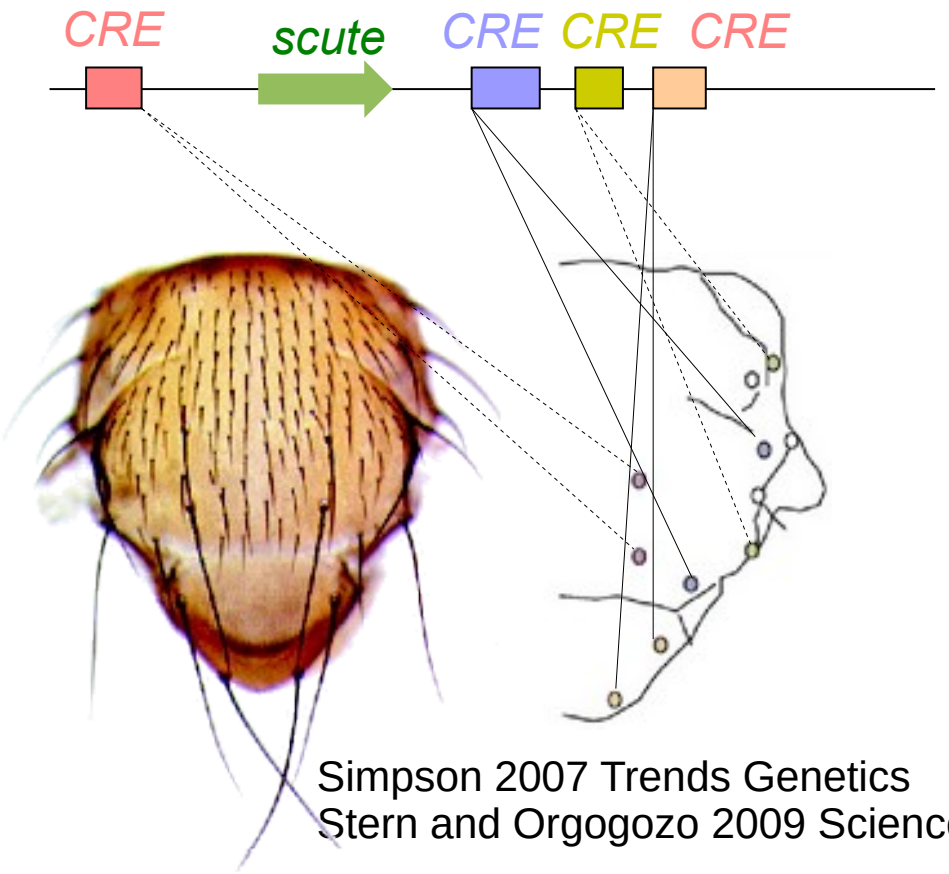
oxygen, photons, insecticide, cholesterol...

Specialized loci in the genome

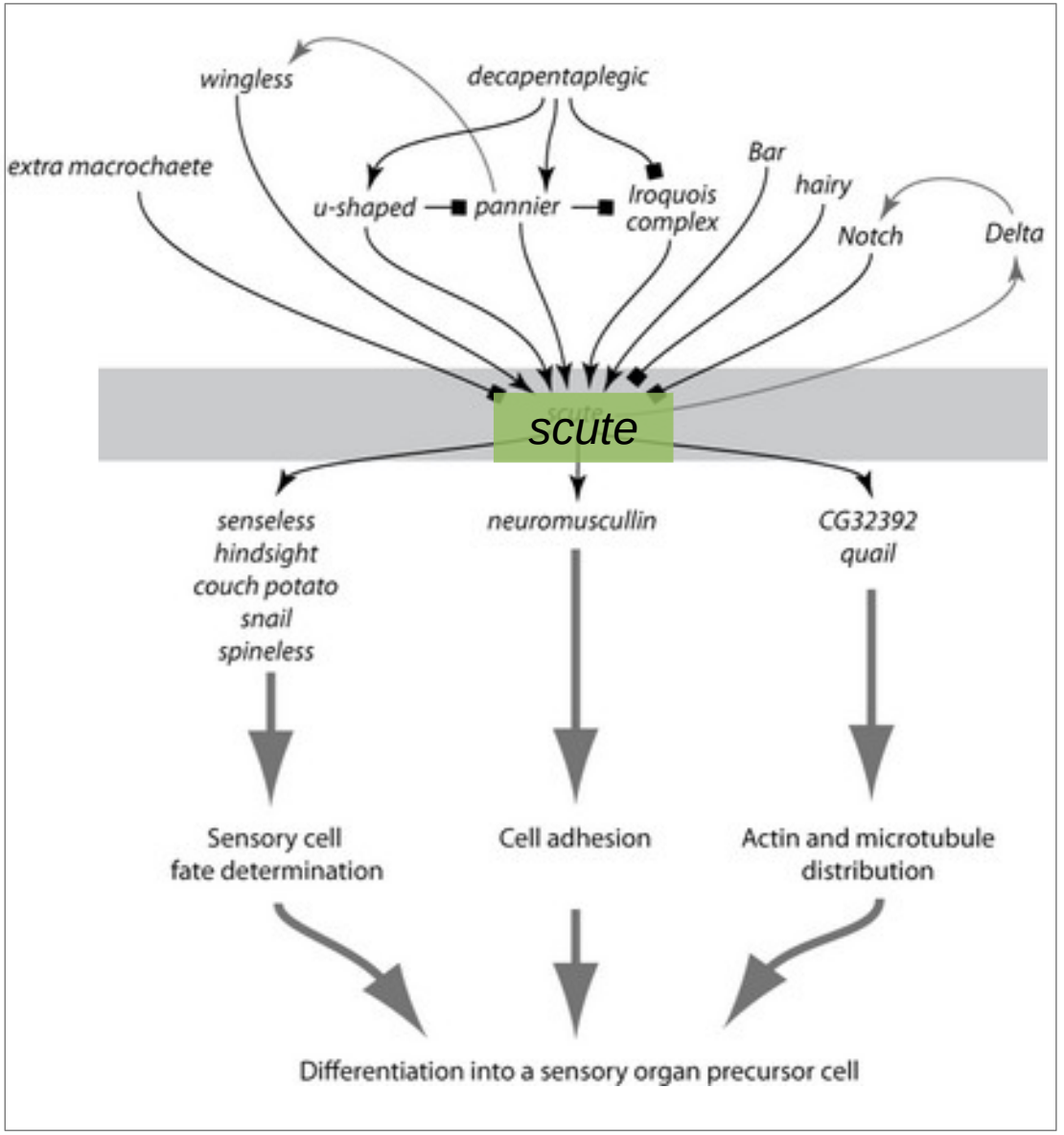
Proteins that interact with external molecules

oxygen, photons, insecticide, cholesterol...

Cis-regulatory elements of “developmental switch genes”



Simpson 2007 Trends Genetics
Stern and Orgogozo 2009 Science



From random processes can emerge predictability

Many unpredictable processes at a low level

Mutations in DNA
Chromosome segregation during meiosis
Assortative mating
Gamete competition during fecondation
Life history traits
Genetic linkage
Environmental changes (meteorite, etc.)
...

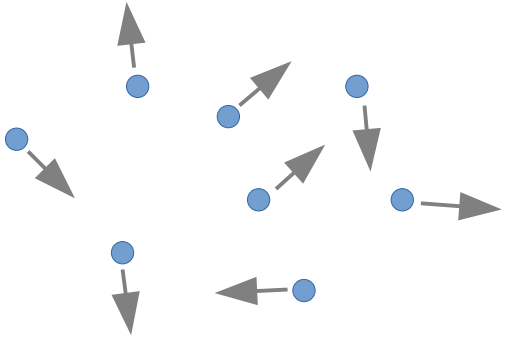
Predictable Evolution at the genetic level

coding mutation in *VKORC1* gene

Orgogozo 2014 Interface Focus

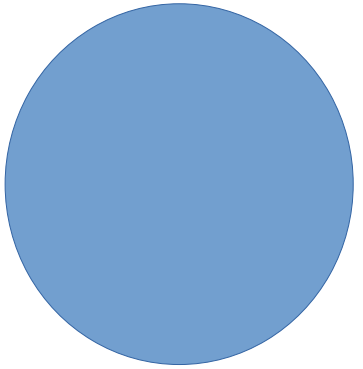
From random processes can emerge predictability

Microscopic world

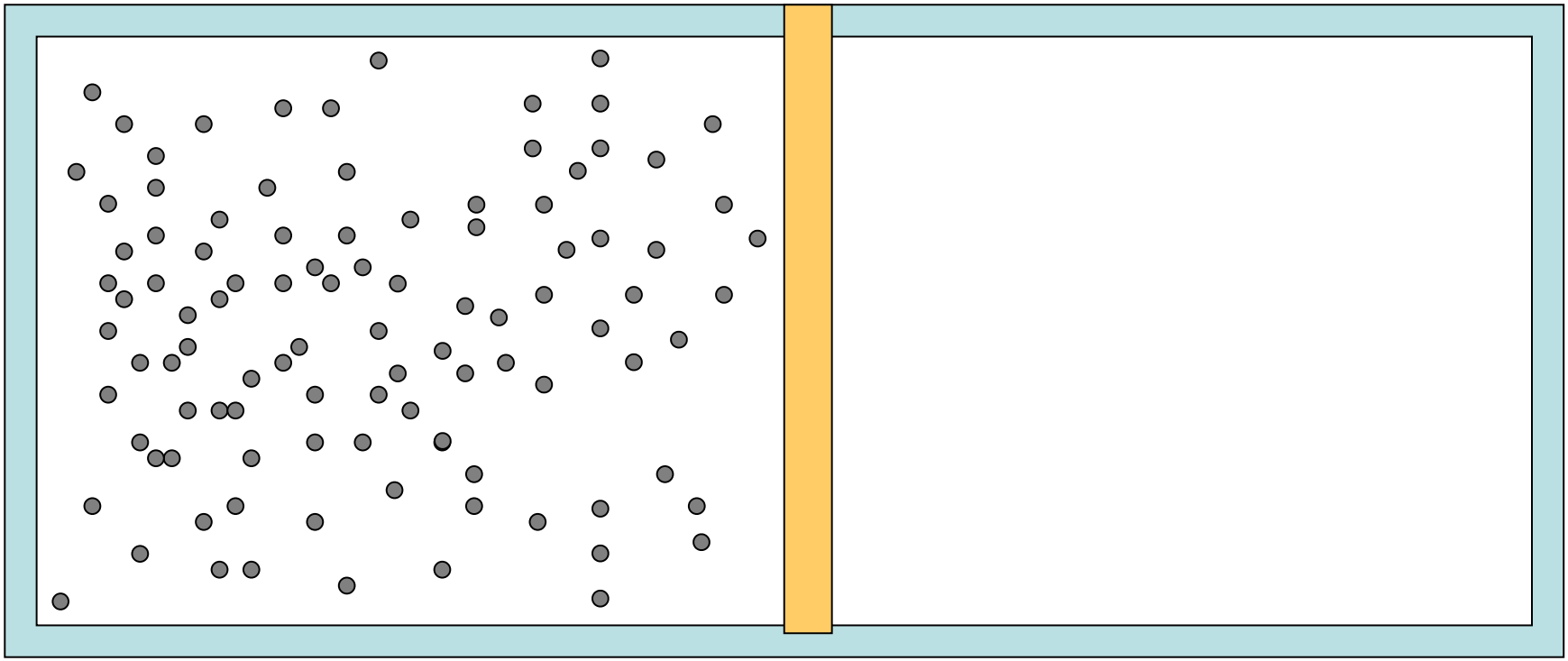


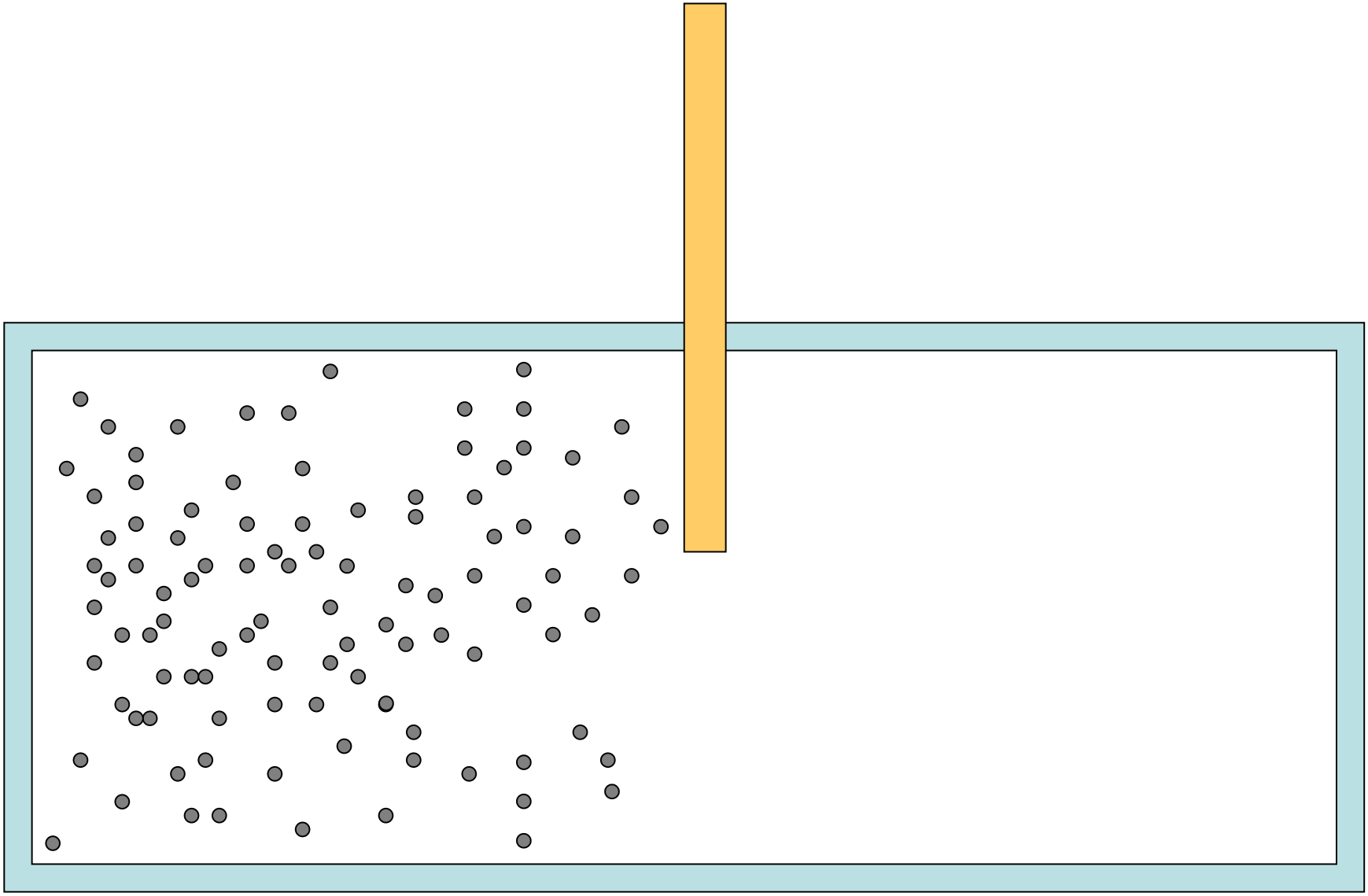
Position, mass, velocity of each particle

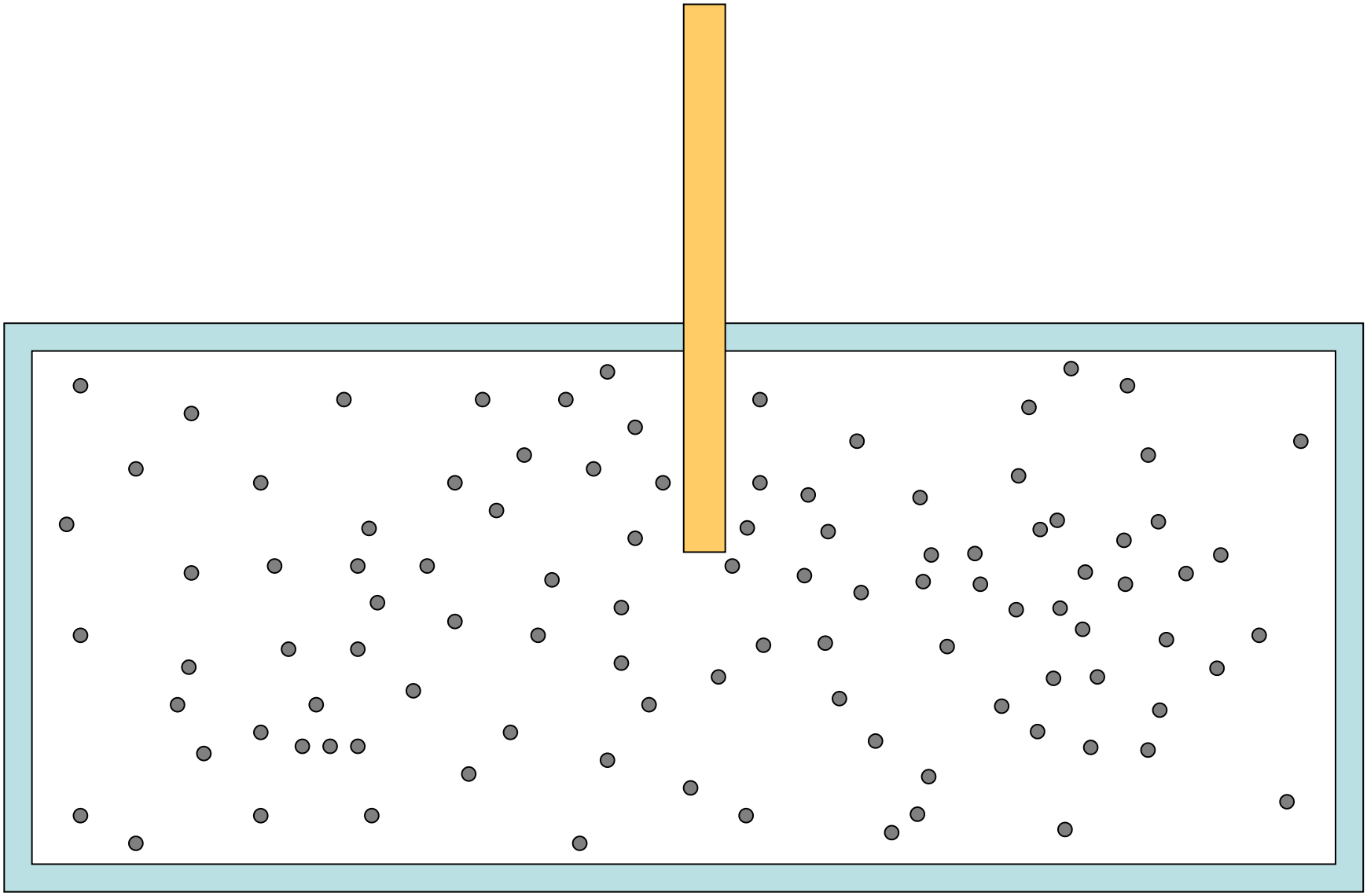
Macroscopic world



Pressure, Volume, Temperature,
Number of moles

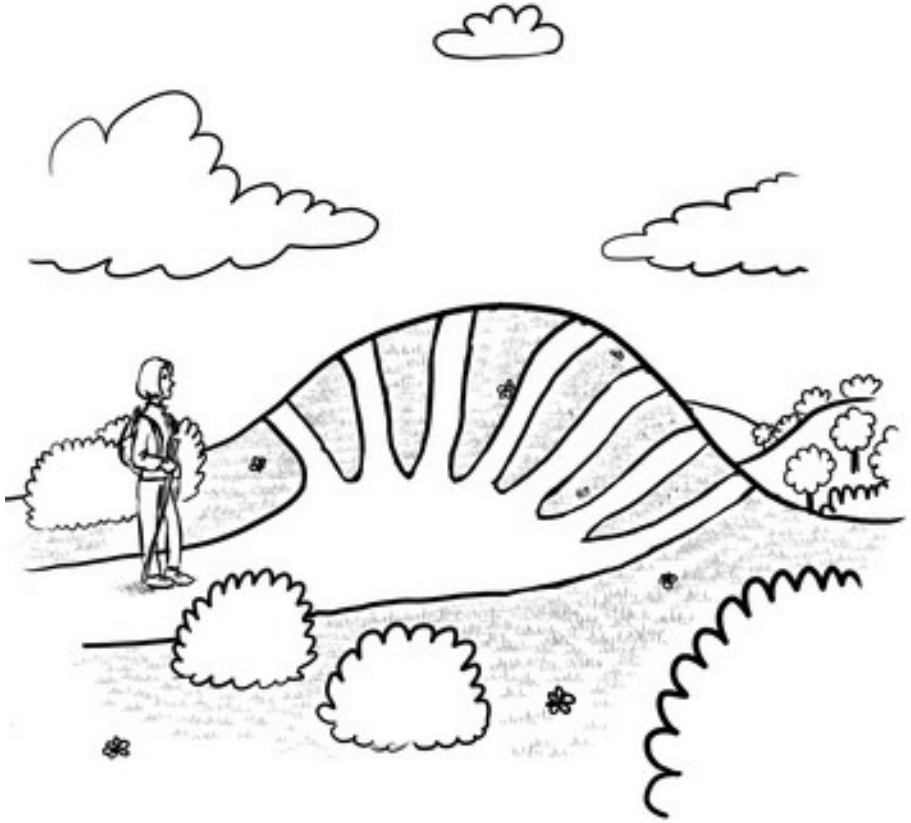


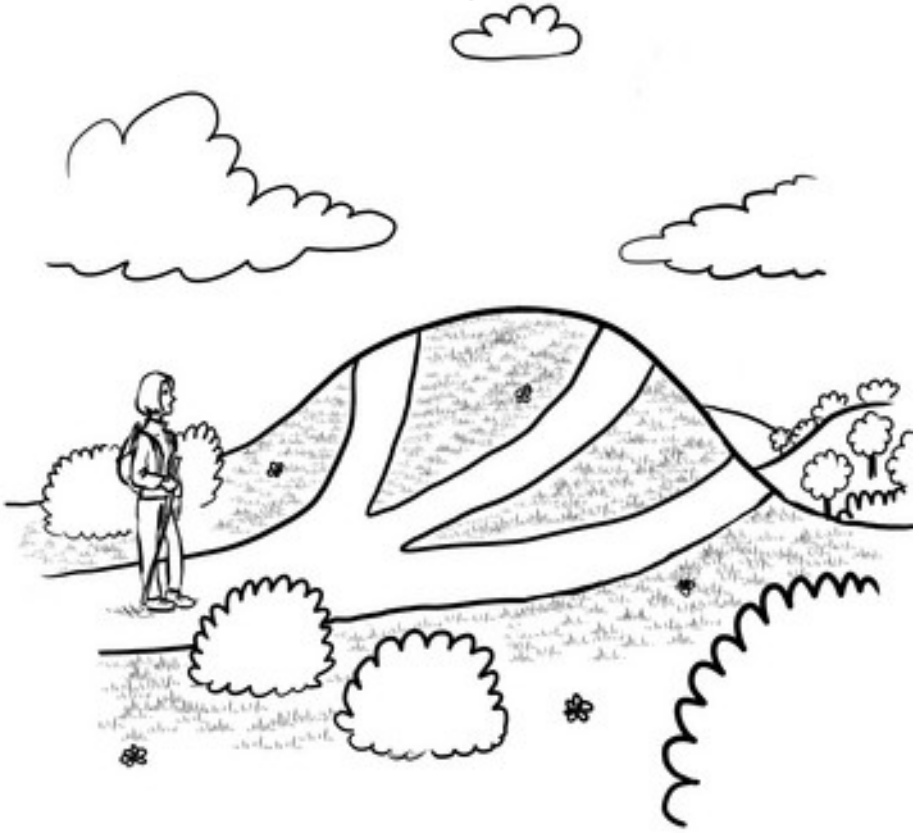




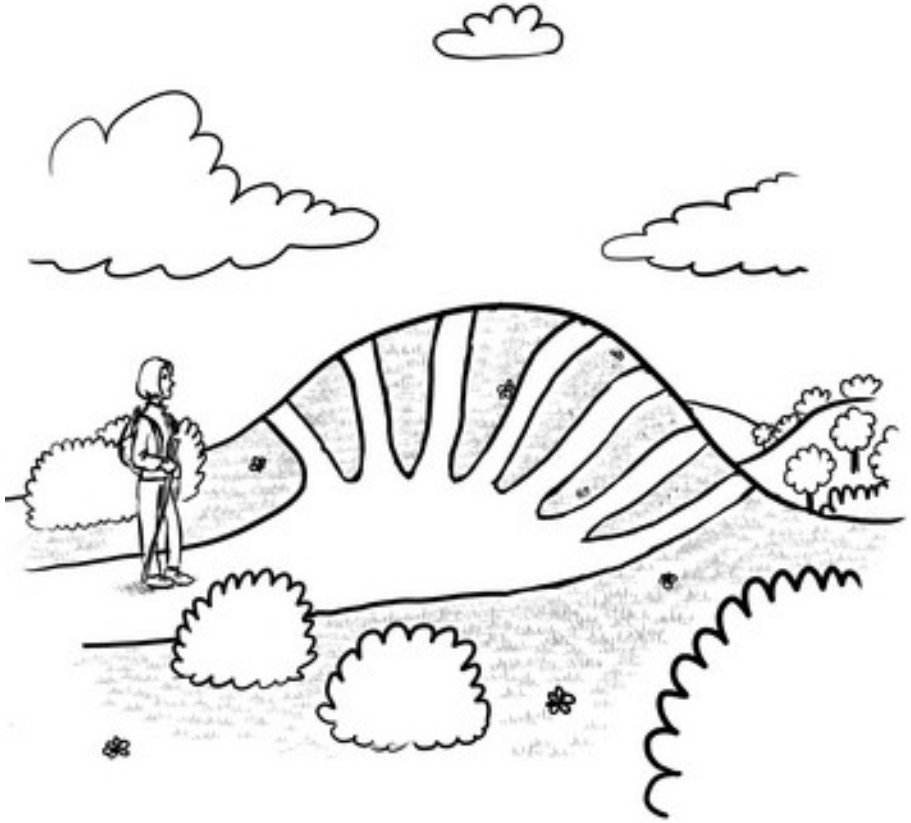
After a few seconds

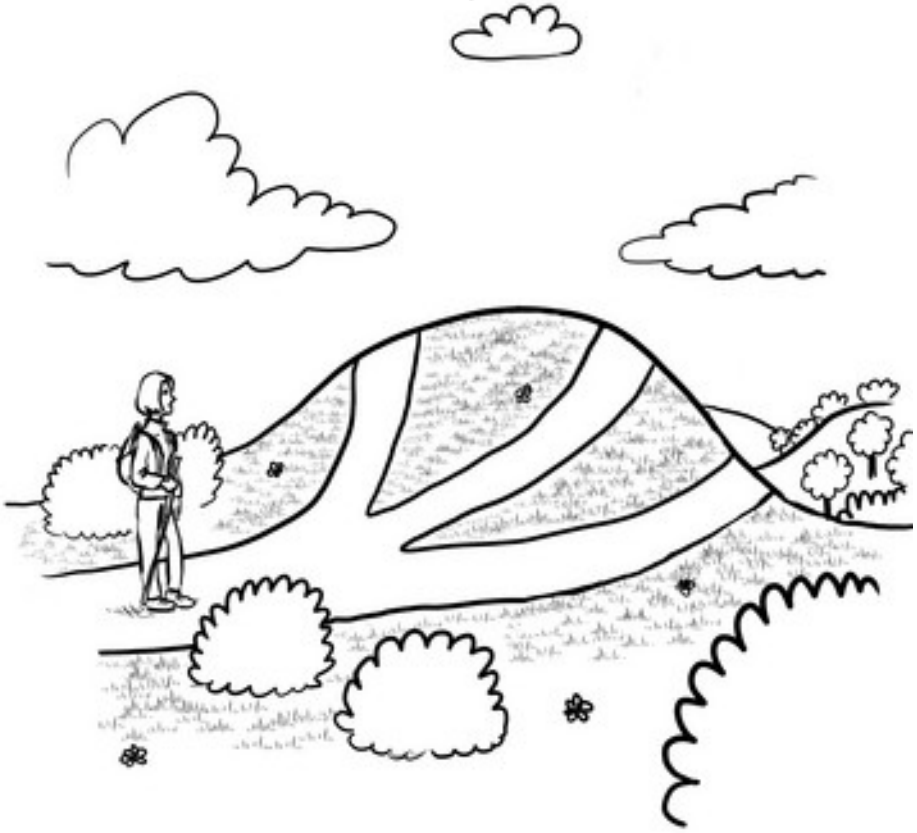
A small number of genetic solutions for a given phenotypic change





A small number of genetic solutions for a given phenotypic change



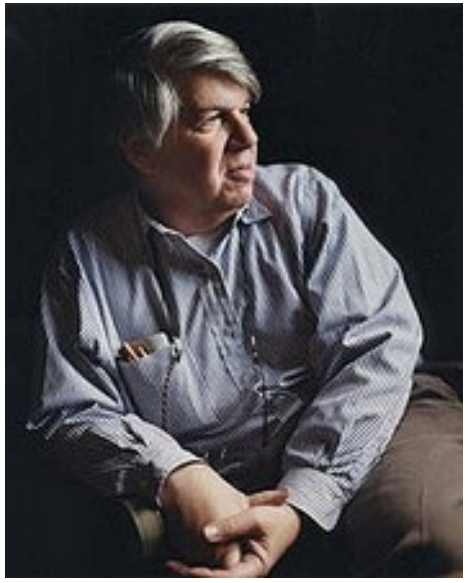


We sometimes seem to have forgotten that the original question in genetics was not what makes a protein but rather 'what makes a dog a dog, a man a man'.
(D. Noble – The Music of Life)

Evolution:
unconstrained and unpredictable?

[past and present organisms are]
a subset of workable, but basically fortuitous, survivals among a much larger set that could have functioned just as well, but either never arose, or lost their opportunities, by historical happenstance.

Stephen Jay Gould, 2002



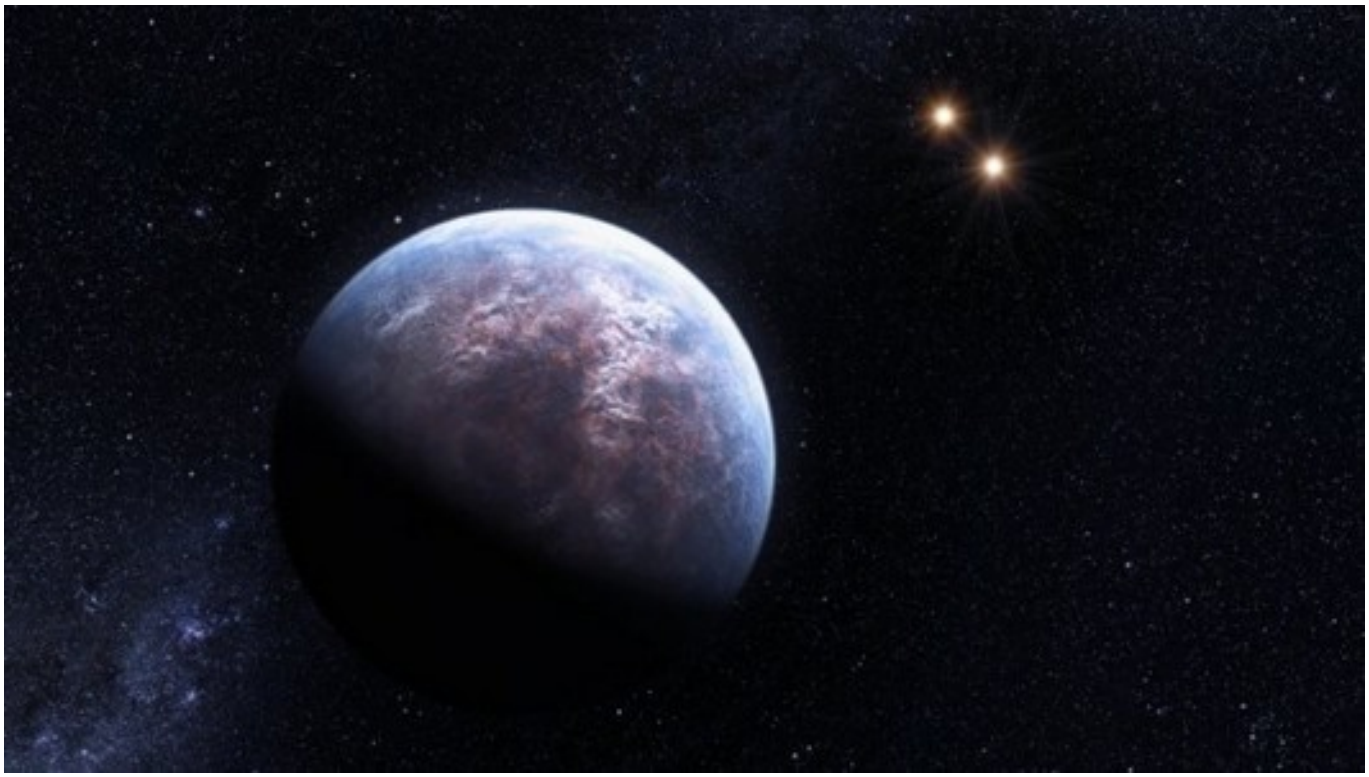
It is hard to realize that the living world as we know it is just one among many possibilities; that its actual structure results from the history of the earth.

1977

Evolution and Tinkering

François Jacob

Would life evolve again, would it produce similar living beings?



evolution

How?

Why? (1) rather than nothing

Why? (2) rather than another change

Lab

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Michael Lang (CR)
Alexis Lalouette (MCU)

Bénédicte Lefèvre (PhD)
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Morphometrics
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François Graner (Paris)

Genotyping
David L. Stern (Janelia Farm, USA)

Fly crosses
Daniel Matute (UNC, USA)

Gephebase
Arnaud Martin (Berkeley, USA)

The differential view of genotype–phenotype relationships

frontiers in Genetics

Virginie Orgogozo[1]*, Baptiste Morizot[2] and Arnaud Martin[3]

The "Mendelian Gene" and the "Molecular Gene": Two Relevant Concepts of Genetic Units

V. Orgogozo*,[1], A.E. Peluffo*, B. Morizot†
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[1]Corresponding author: e-mail address: virginie.orgogozo@normalesup.org

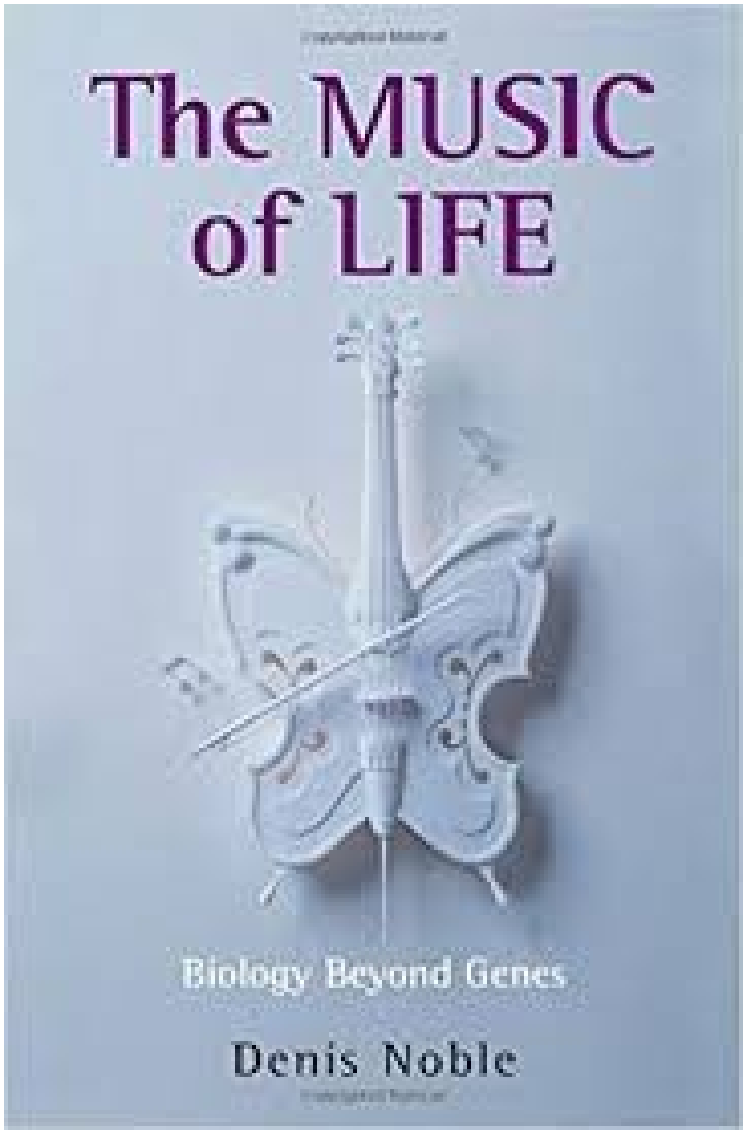
THE LOCI OF REPEATED EVOLUTION: A CATALOG OF GENETIC HOTSPOTS OF PHENOTYPIC VARIATION

Arnaud Martin[1,2] and Virginie Orgogozo[3]

Nucleic Acids Research, 2019 1
doi: 10.1093/nar/gkz796

Gephebase, a database of genotype–phenotype relationships for natural and domesticated variation in Eukaryotes

Virginie Courtier-Orgogozo[1,*], Laurent Arnoult[1], Stéphane R. Prigent[1], Séverine Wiltgen[2] and Arnaud Martin[3,*]



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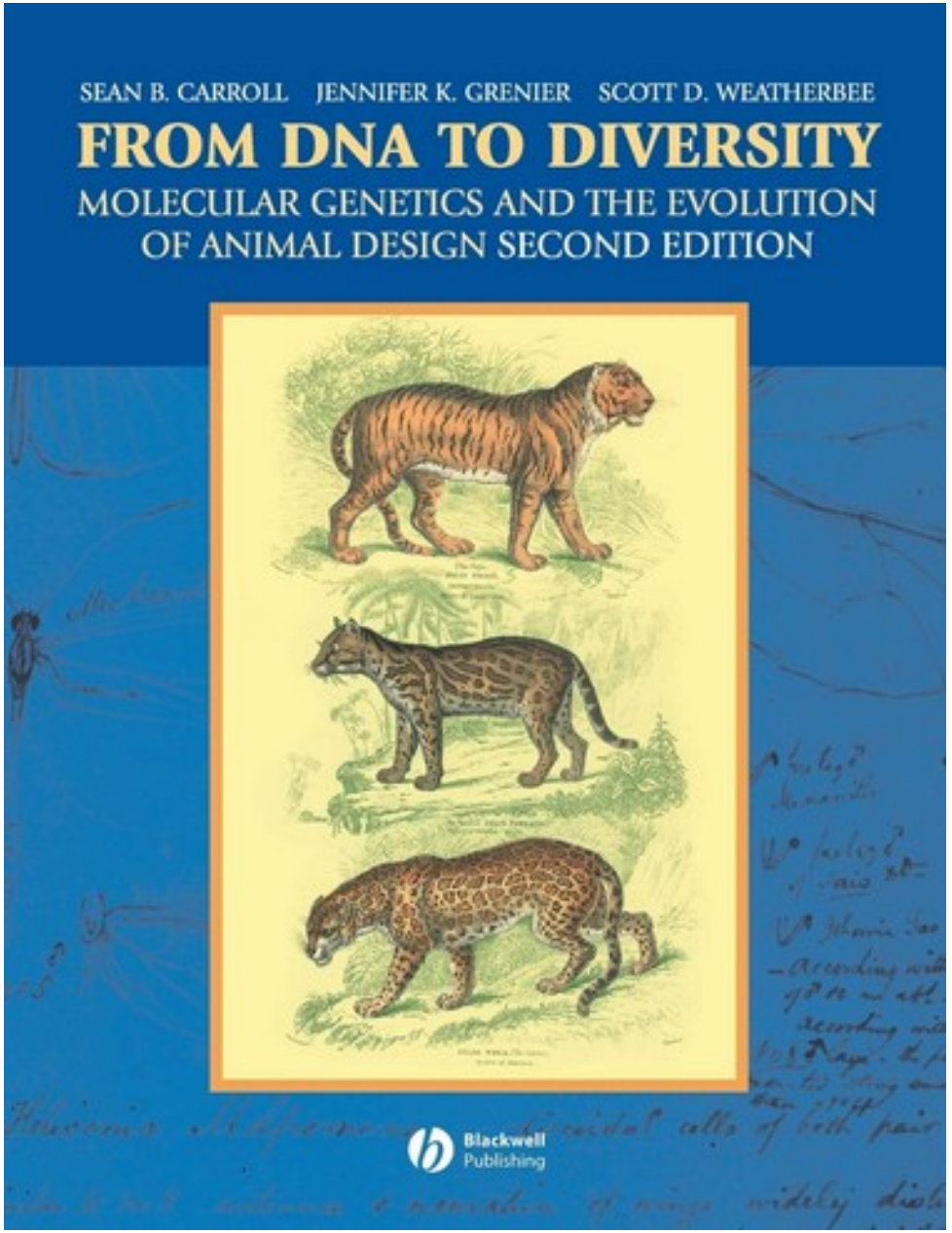
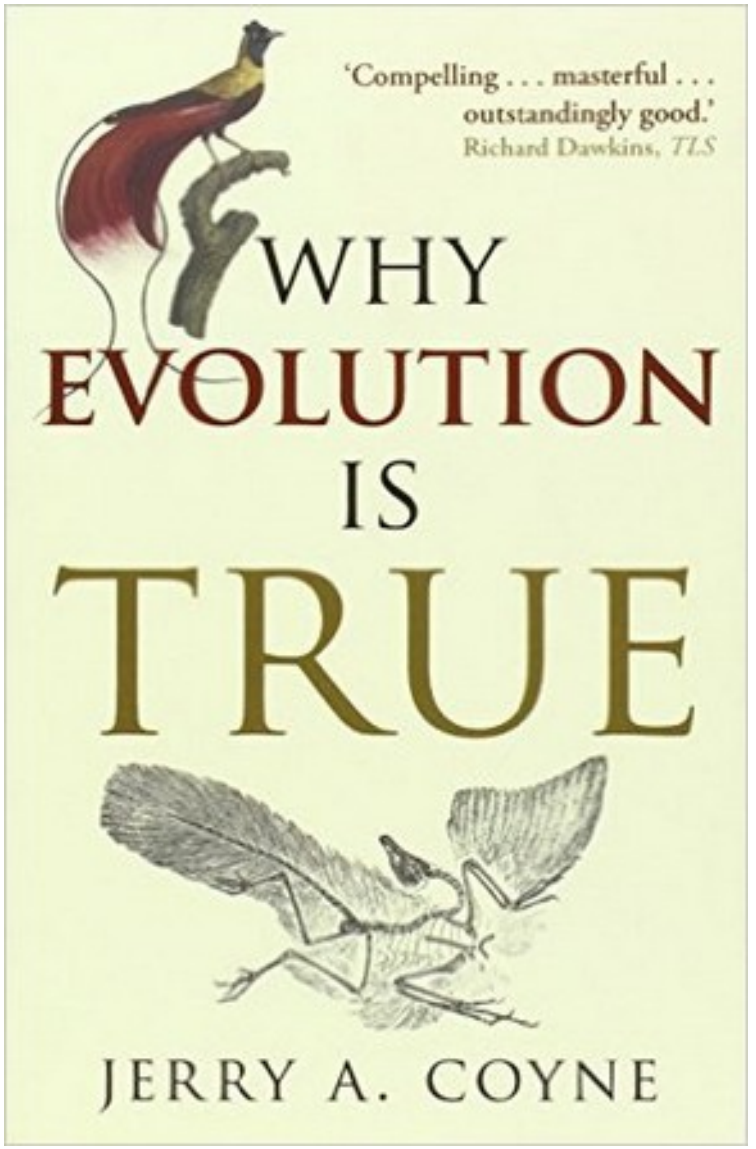
Replaying the tape of life in the twenty-first century

Virginie Orgogozo





https://www.youtube.com/watch?v=Ov30-7rXZCY
Une brève histoire de l'évo-dévo (Denis Duboule)