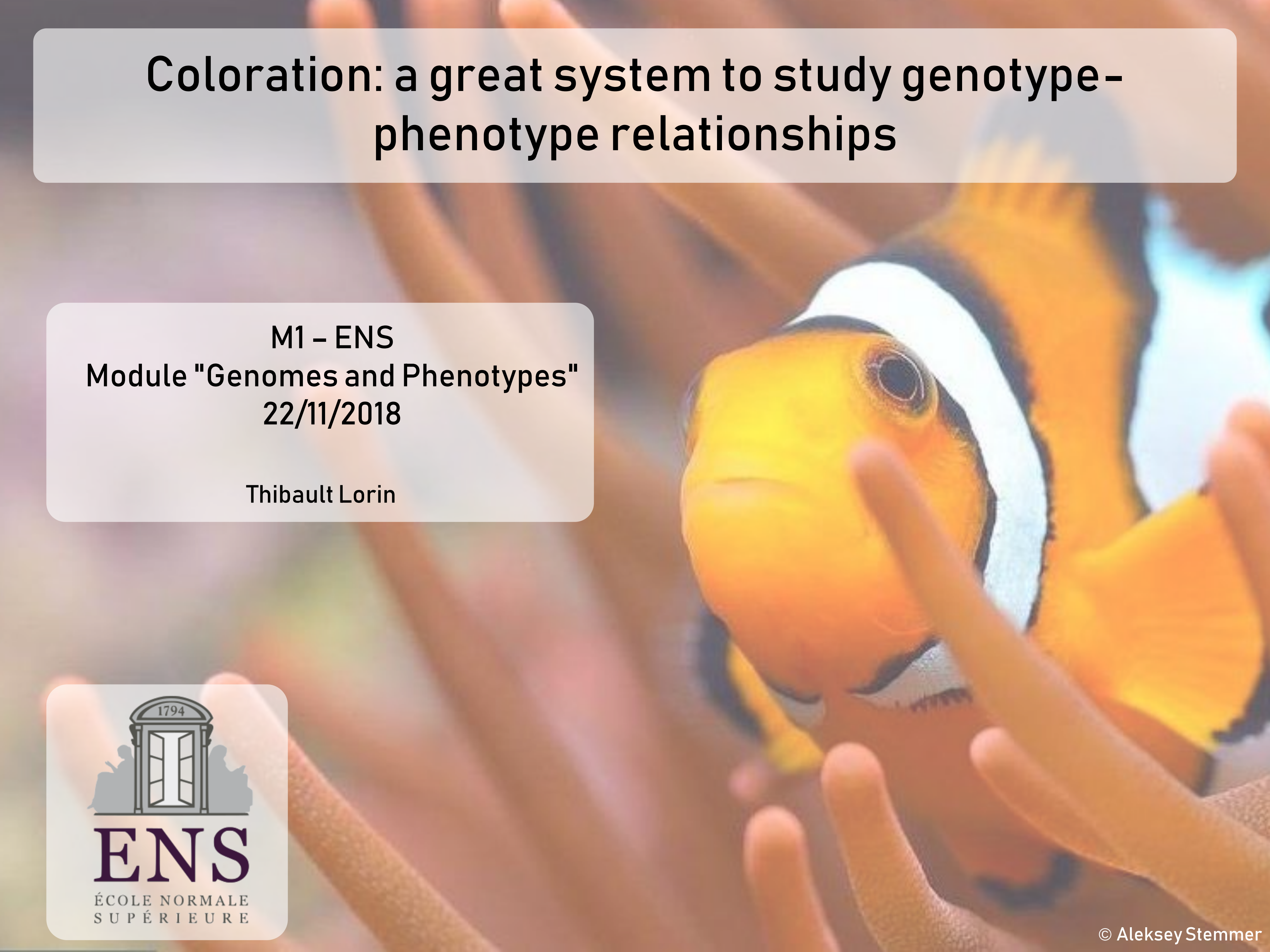
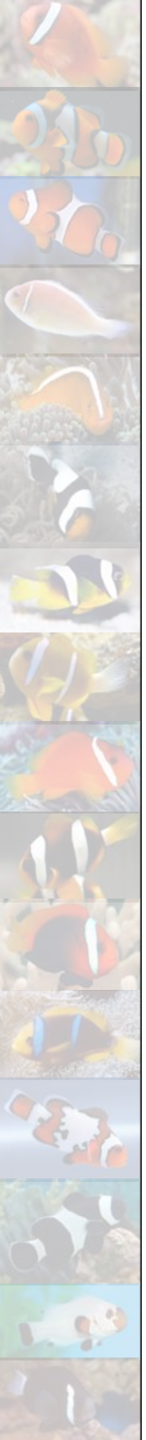


Coloration: a great system to study genotype-phenotype relationships

M1 – ENS
Module "Genomes and Phenotypes"
22/11/2018

Thibault Lorin

ÉCOLE NORMALE SUPÉRIEURE



UNIVERSITÉ DE LYON

ENS DE LYON

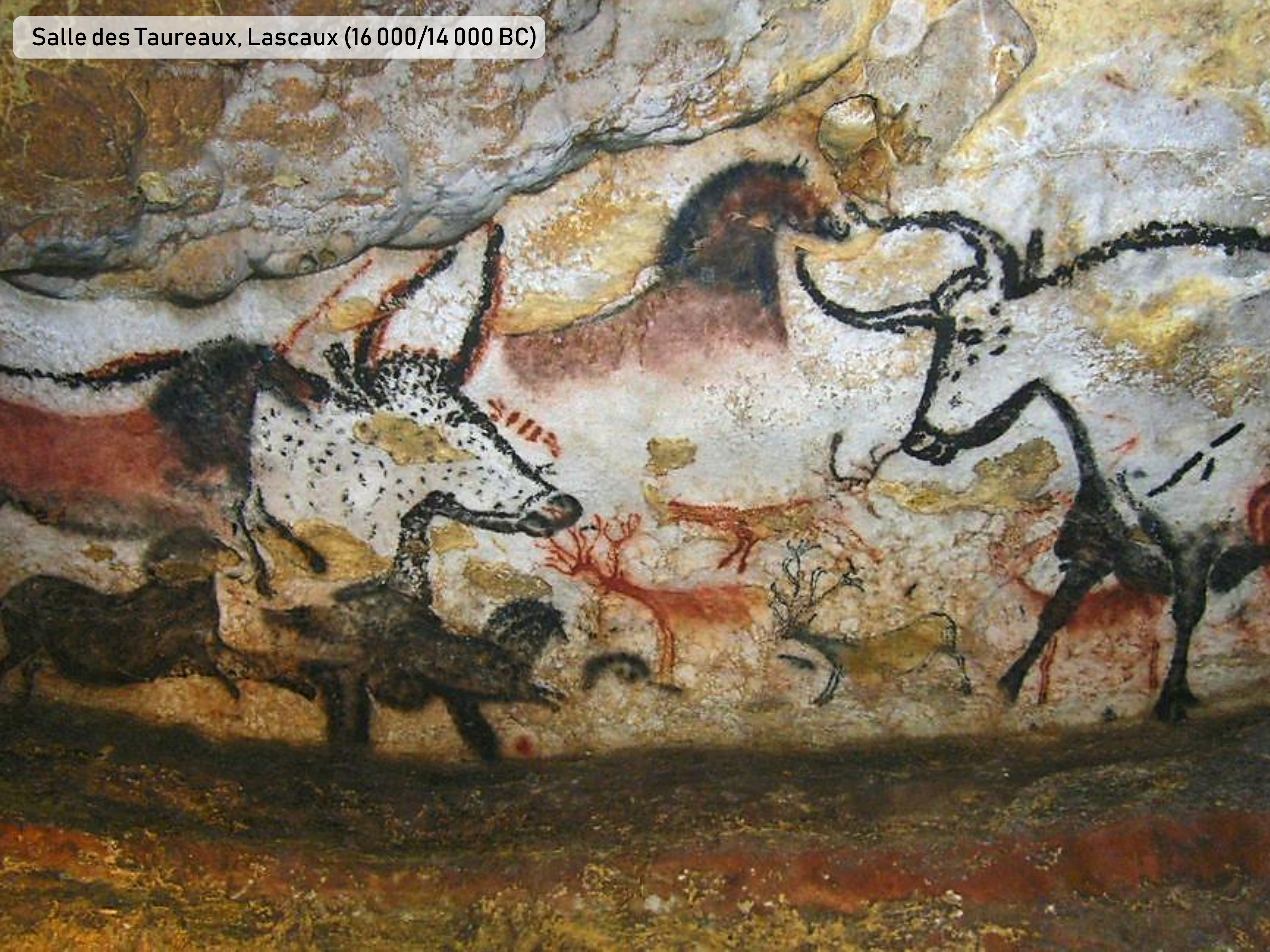
Institut de Génomique Fonctionnelle de Lyon

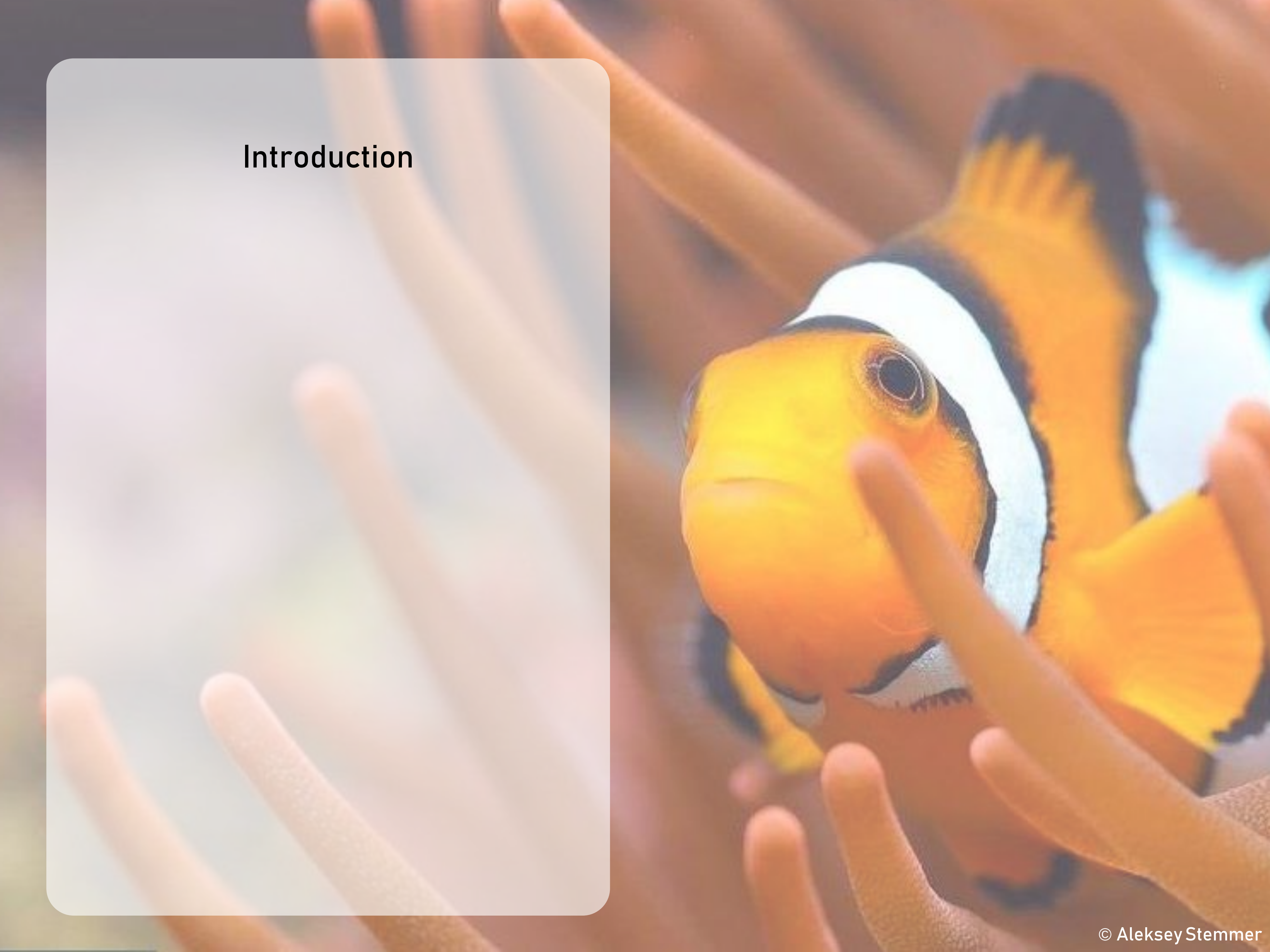
Volff's lab

OBSERVATOIRE OCÉANOLOGIQUE de Banyuls/Mer 1882

Laudet's lab

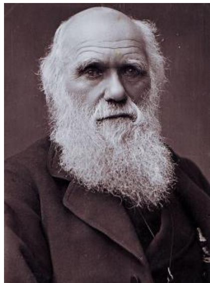
Salle des Taureaux, Lascaux (16 000/14 000 BC)

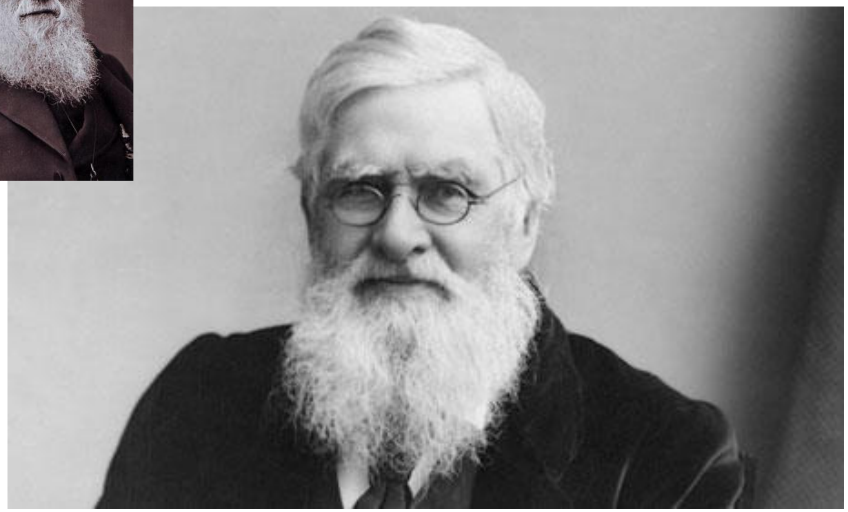




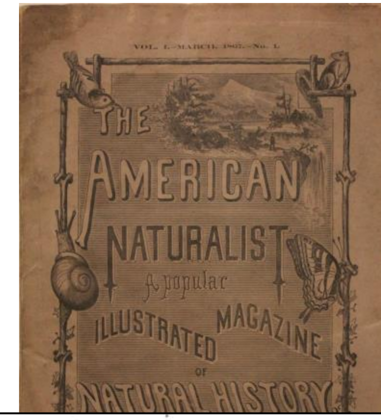
Introduction

Wallace and "coloration"





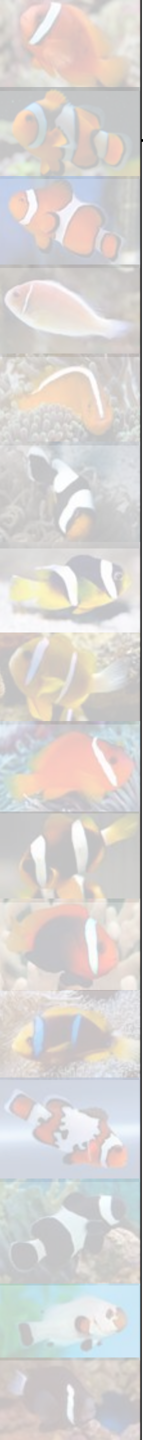
Alfred R. Wallace (1823-1913)



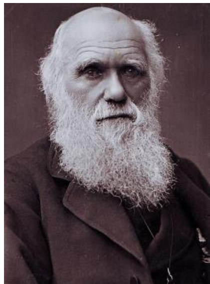
Vol. xi. — *NOVEMBER*, *1877.* — *No. 11.*

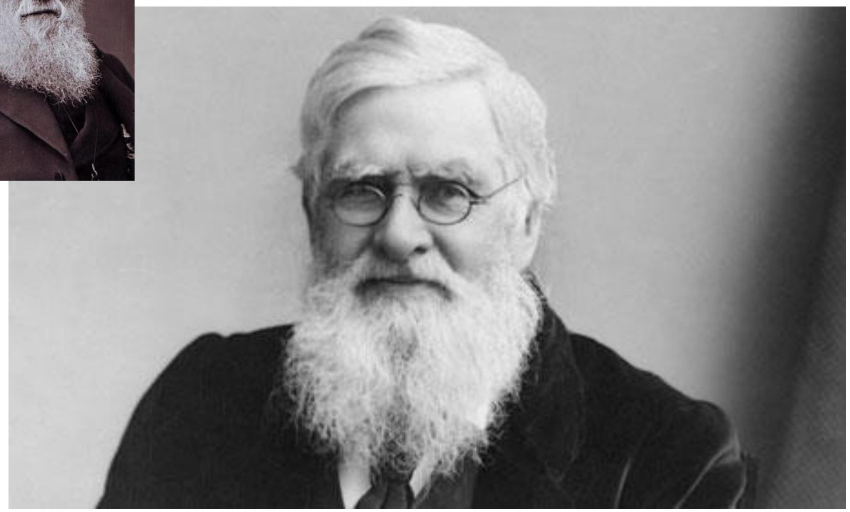
THE COLORS OF ANIMALS AND PLANTS.[1]

BY ALFRED RUSSEL WALLACE.



Wallace and "coloration"





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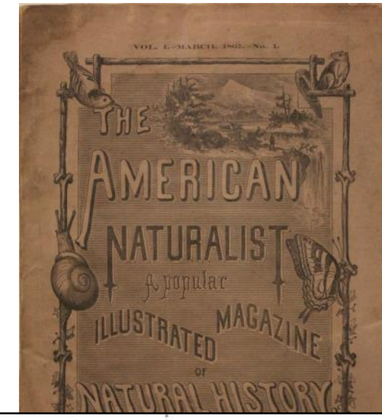


VOL. XI. — NOVEMBER, 1877. — No. 11.

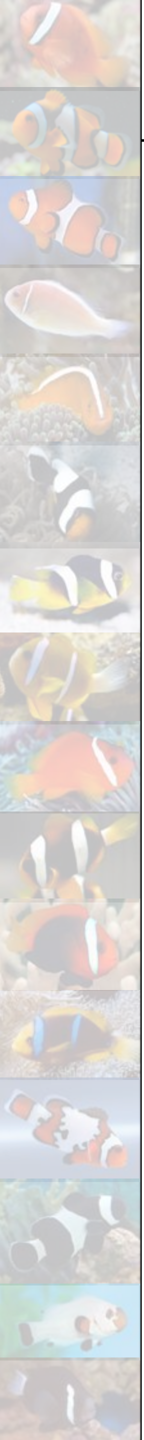
THE COLORS OF ANIMALS AND PLANTS.[1]

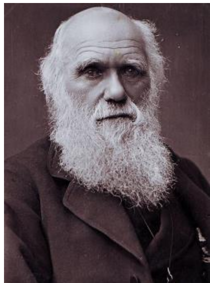
BY ALFRED RUSSEL WALLACE.

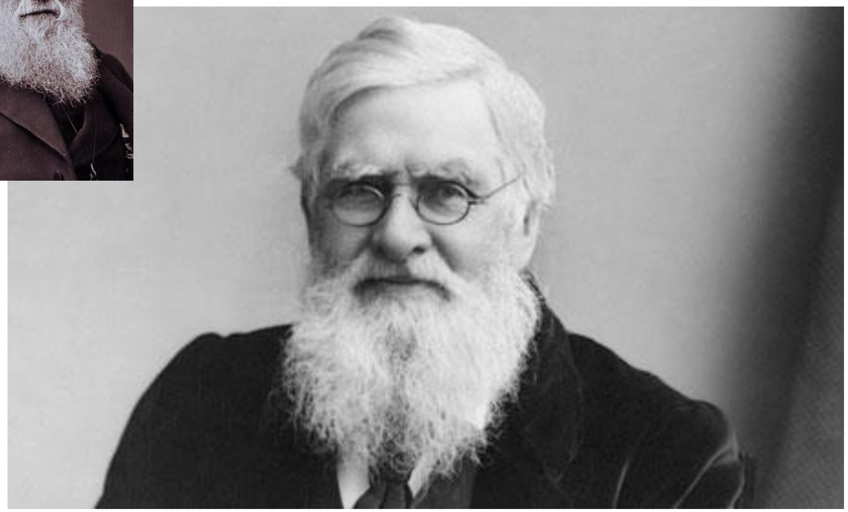
Animals.
1. Protective colors.
2. Warning colors.
3. Sexual colors.
4. Typical colors.

Plants.
5. Attractive colors

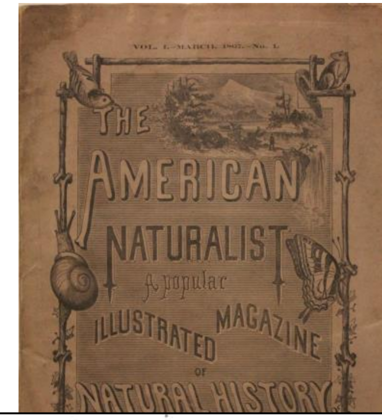
Wallace and "coloration"







Alfred R. Wallace (1823-1913)



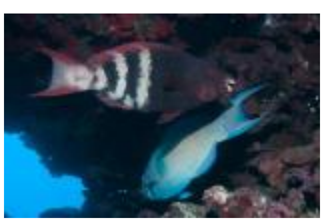
Vol. xi. — *NOVEMBER*, *1877.* — *No. 11.*

THE COLORS OF ANIMALS AND PLANTS.[1]

BY ALFRED RUSSEL WALLACE.

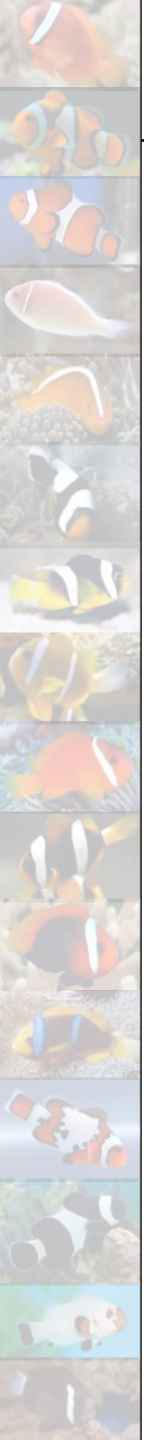
Camouflage

Animals.
1. Protective colors.
2. Warning colors.
3. Sexual colors.
4. Typical colors.



Intra- or Interspecific communication colors

"Coloration" or "pigmentation"?



"Structural colors"

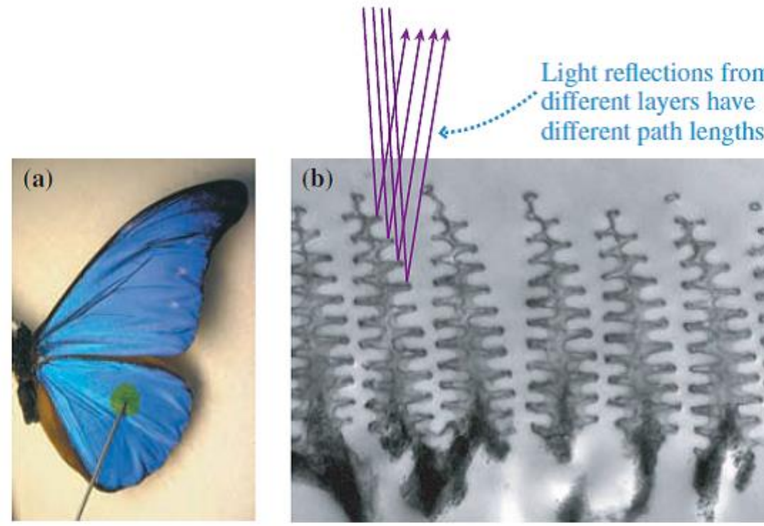
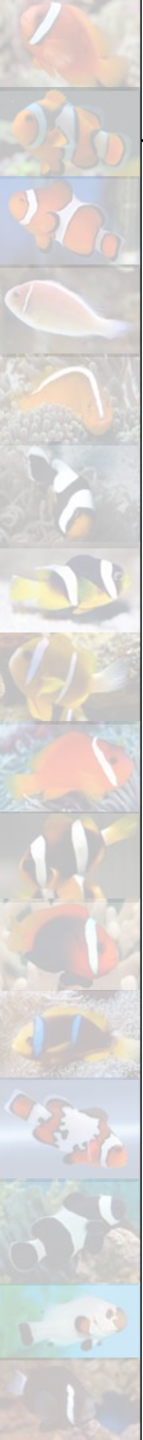
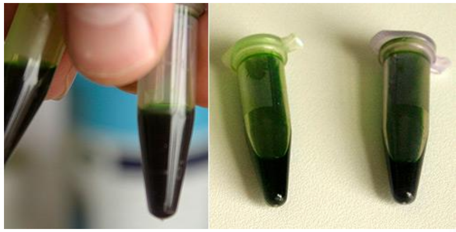
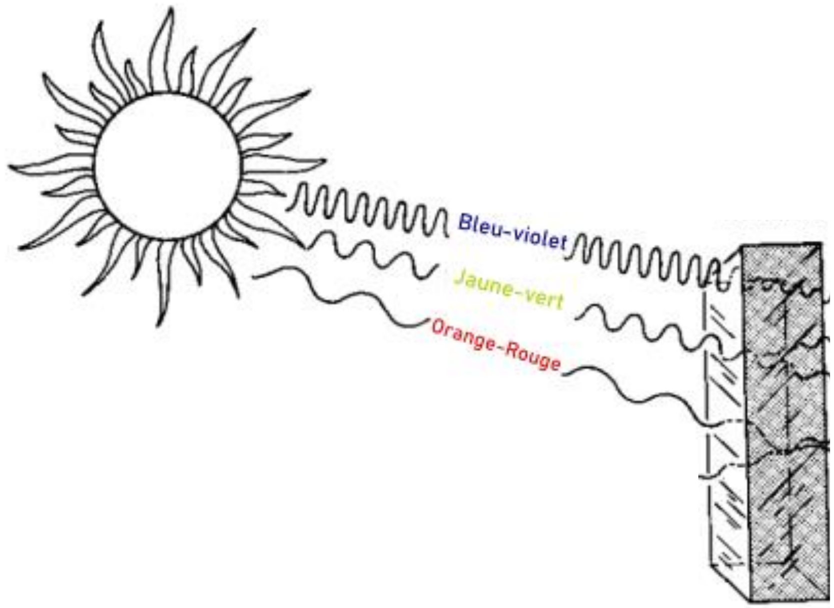


FIGURE P17.73

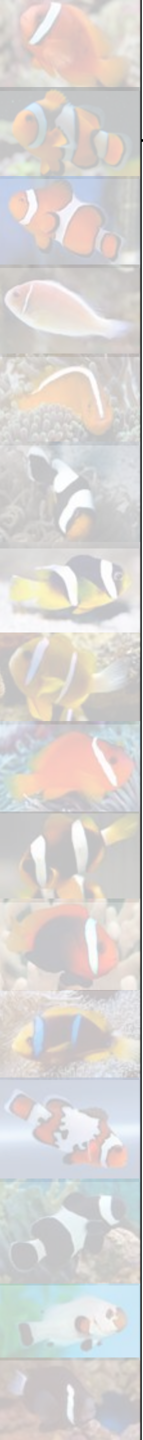


"Chemical" colors...

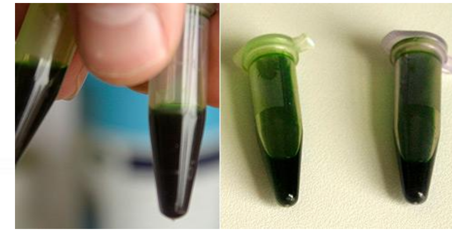


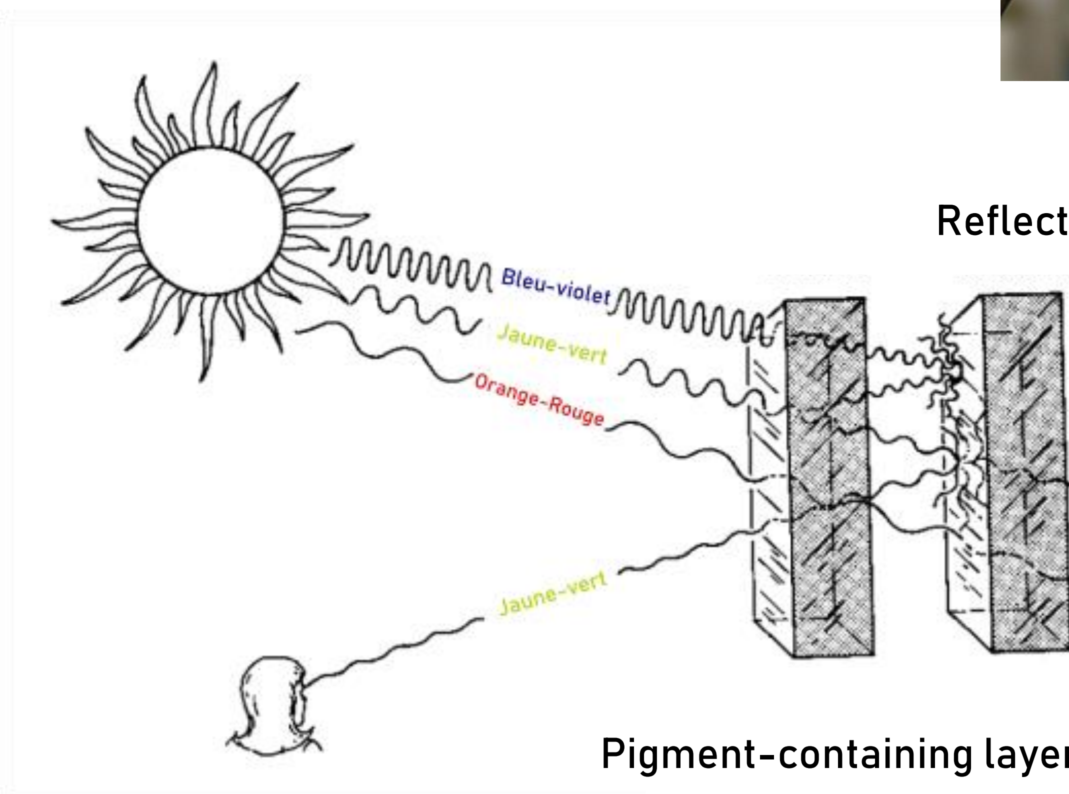


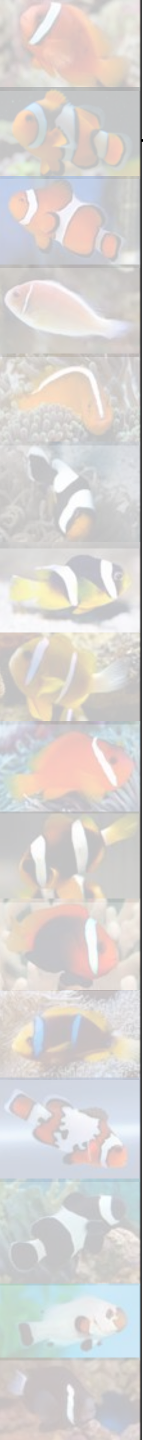
Pigment-containing layer



"Chemical" colors.... Need structural layers!

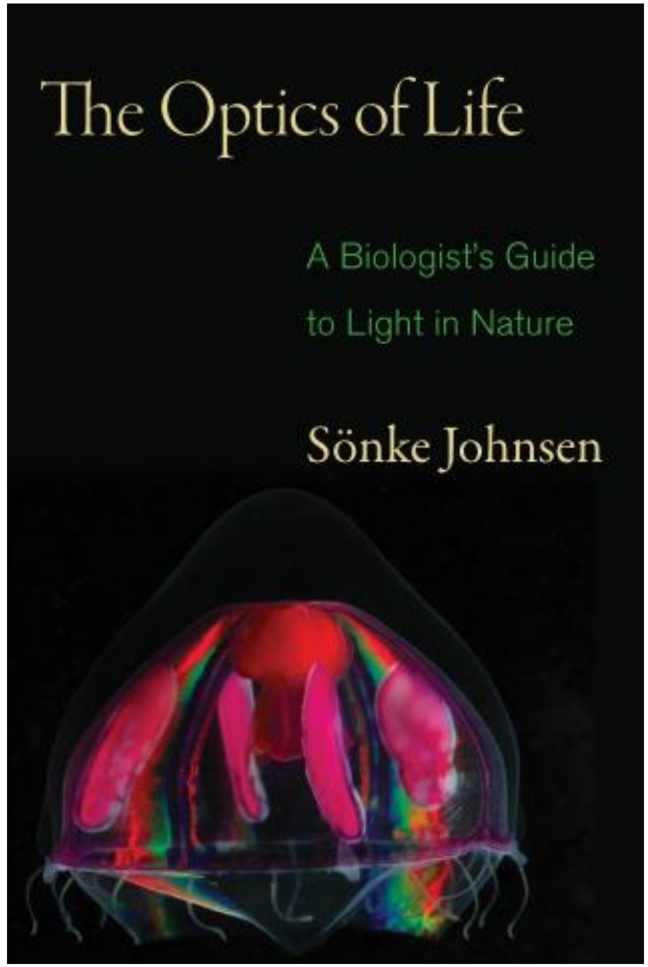




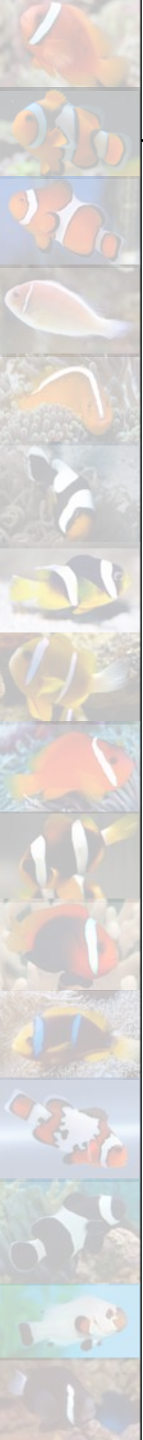


"Coloration" ≠ "pigmentation"

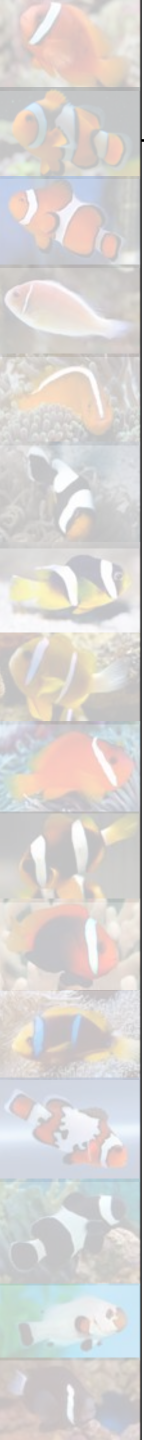
"Coloration" ≠ "pigmentation"

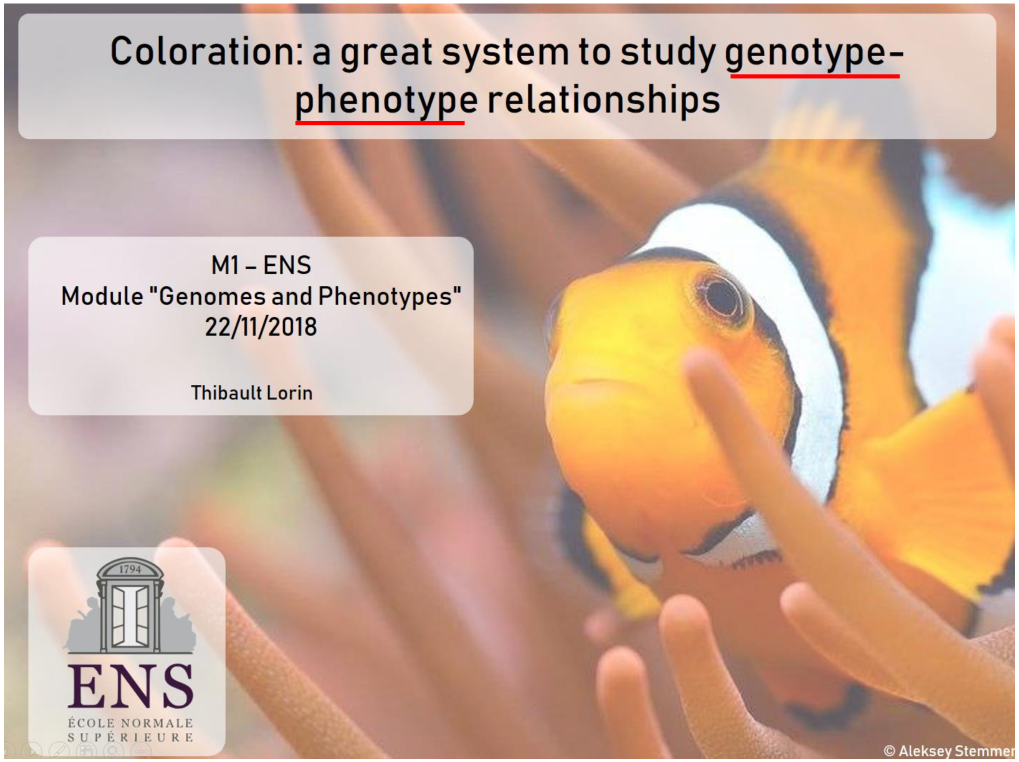


2011

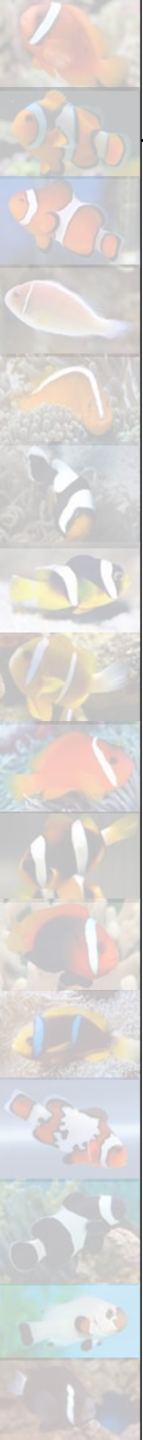


Genotype-phenotype relationships





Relationships between genes and the phenotype, and their modulation by the environment



Genotype-phenotype relationships

(more detail and info here)

frontiers in Genetics

HYPOTHESIS AND THEORY
published: 19 May 2015
doi: 10.3389/fgene.2015.00179

The differential view of genotype–phenotype relationships

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

[1] CNRS, UMR 7592, Institut Jacques Monod, Université Paris Diderot, Paris, France, [2] Aix Marseille Université, CNRS, CEPERC UMR 7304, Aix en Provence, France, [3] Department of Molecular Cell Biology, University of California, Berkeley, CA, USA

Introduction

I. Coloration: a great system to study genotype-phenotype relationships

II. A case study: clownfish coloration

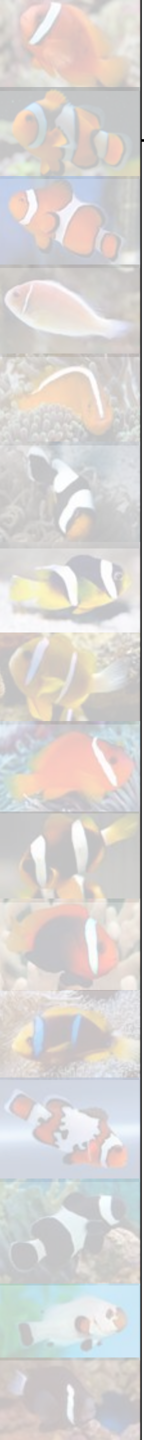
Introduction

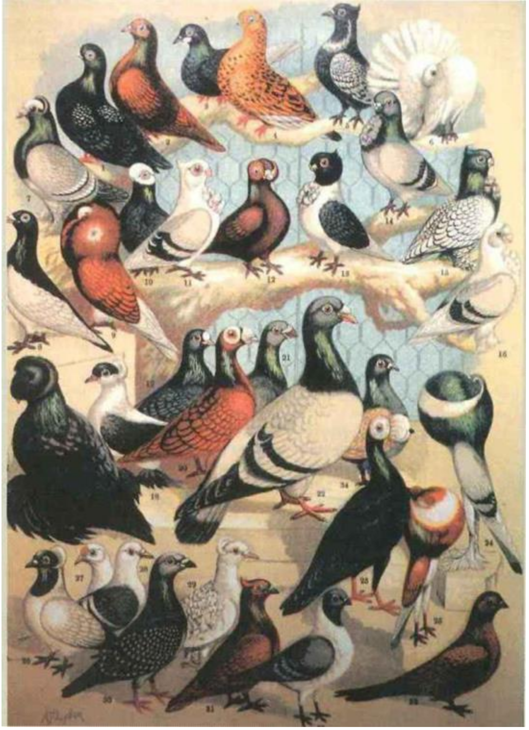
I. Coloration: a great system to study genotype-phenotype relationships

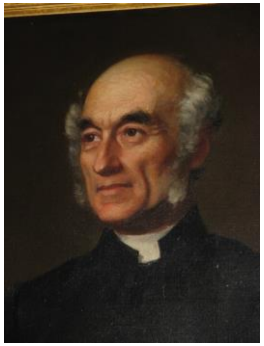
a. Coloration in the History of Science

b. Coloration in Vertebrates

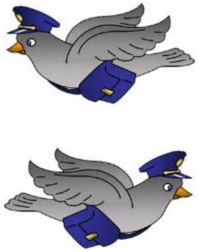
Coloration and naturalists' interest

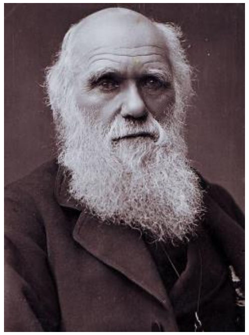






Whitwell Elwin

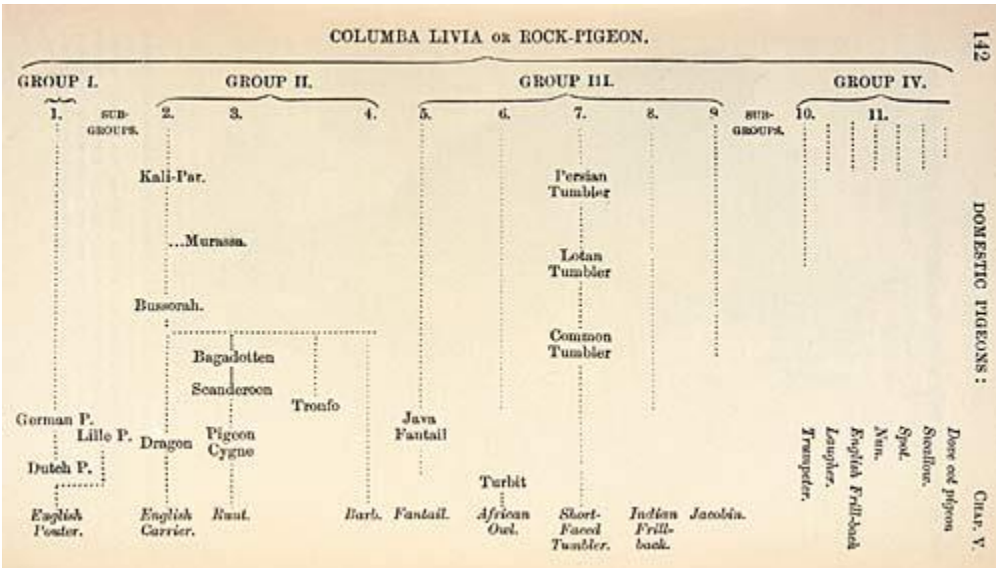




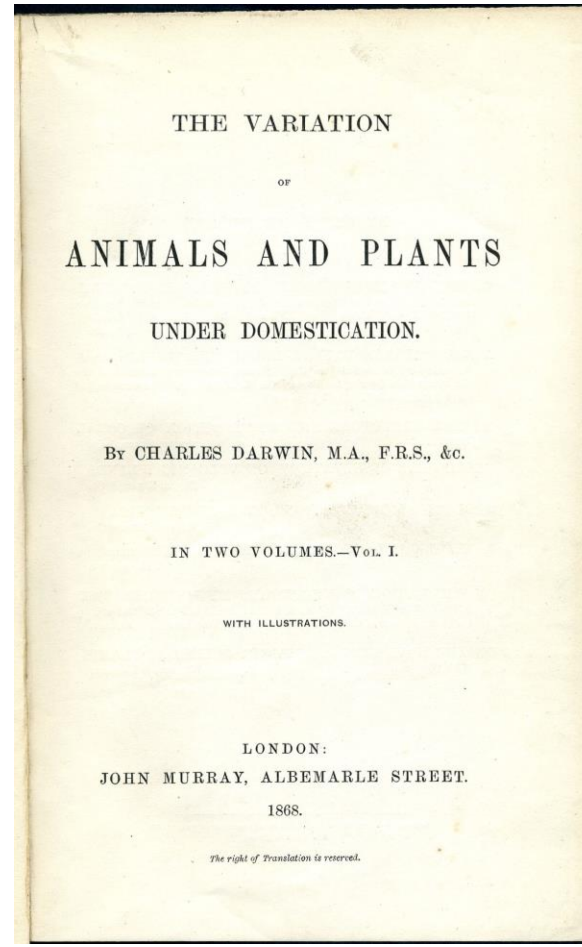
Charles Darwin

"Everybody is interested in pigeons". [A book like this would] "be reviewed in every journal in the kingdom and soon be on every table."

Coloration and naturalists' interest



"I do not hesitate to affirm that some domestic races of the rock-pigeon differ fully as much from each other in external characters as do the most distinct natural genera."



THE VARIATION

OF

ANIMALS AND PLANTS

UNDER DOMESTICATION.

BY CHARLES DARWIN, M.A., F.R.S., &c.

IN TWO VOLUMES.—VOL. I.

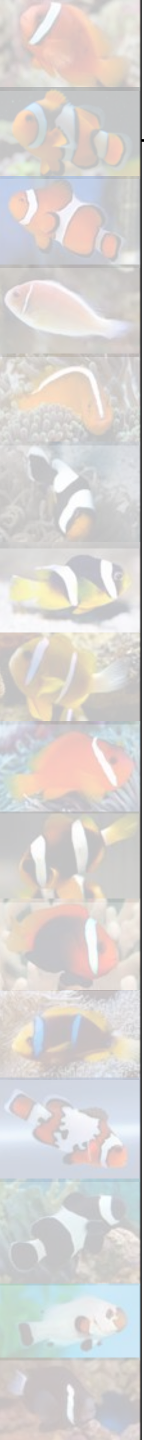
WITH ILLUSTRATIONS.

LONDON:

JOHN MURRAY, ALBEMARLE STREET.

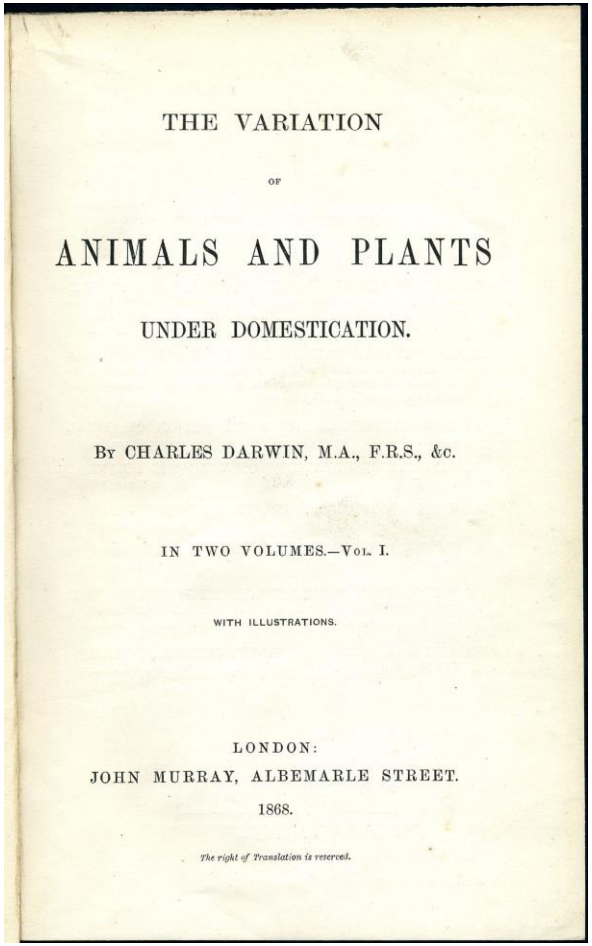
1868.

The right of Translation is reserved.



Coloration and naturalists' interest… also in plants!

Maize has varied in an extraordinary and conspicuous manner … The whole ear is variable in shape … The seeds are arranged in the ear in from 6 to even 20 rows, or are placed irregularly. The seeds are coloured – white, pale-yellow, orange, red, violet …



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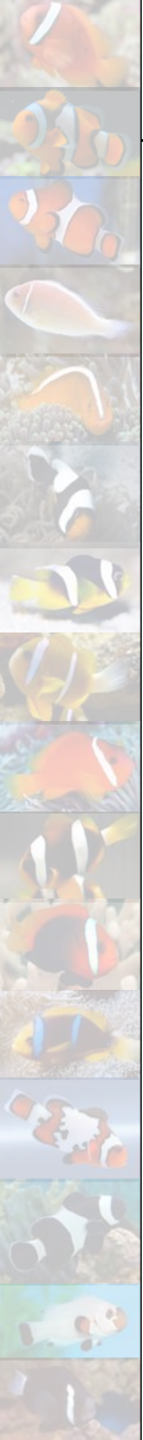
Why study coloration?



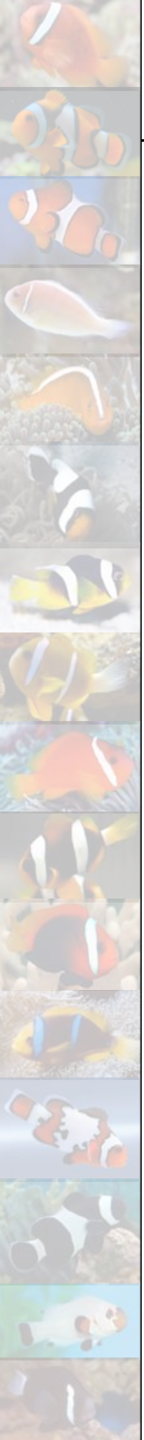
Why study coloration?

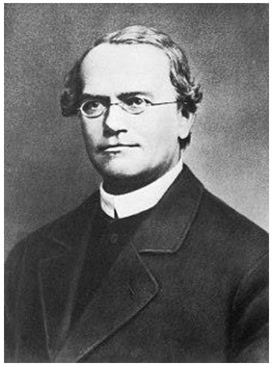
→ Aesthetic

→ Profitable

→ Convenient

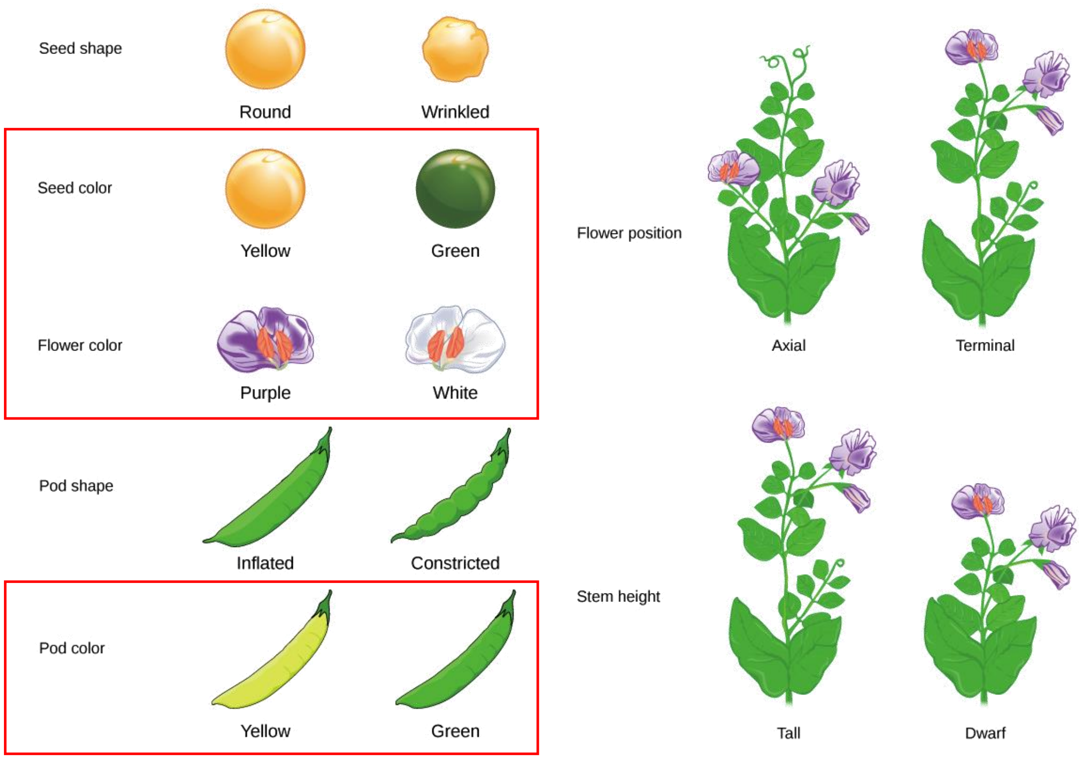
Coloration and the History of the comprehension of GP relationship: Mendel

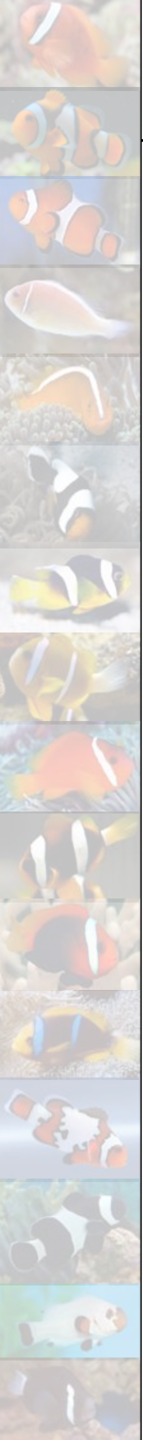




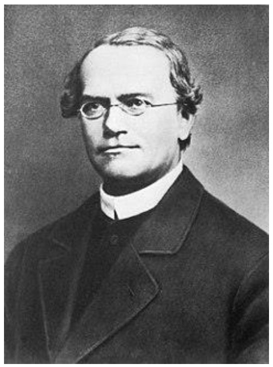
Gregor Mendel
(1822-1884)

"Father of modern genetics"





Coloration and the History of the comprehension of GP relationship: Mendel



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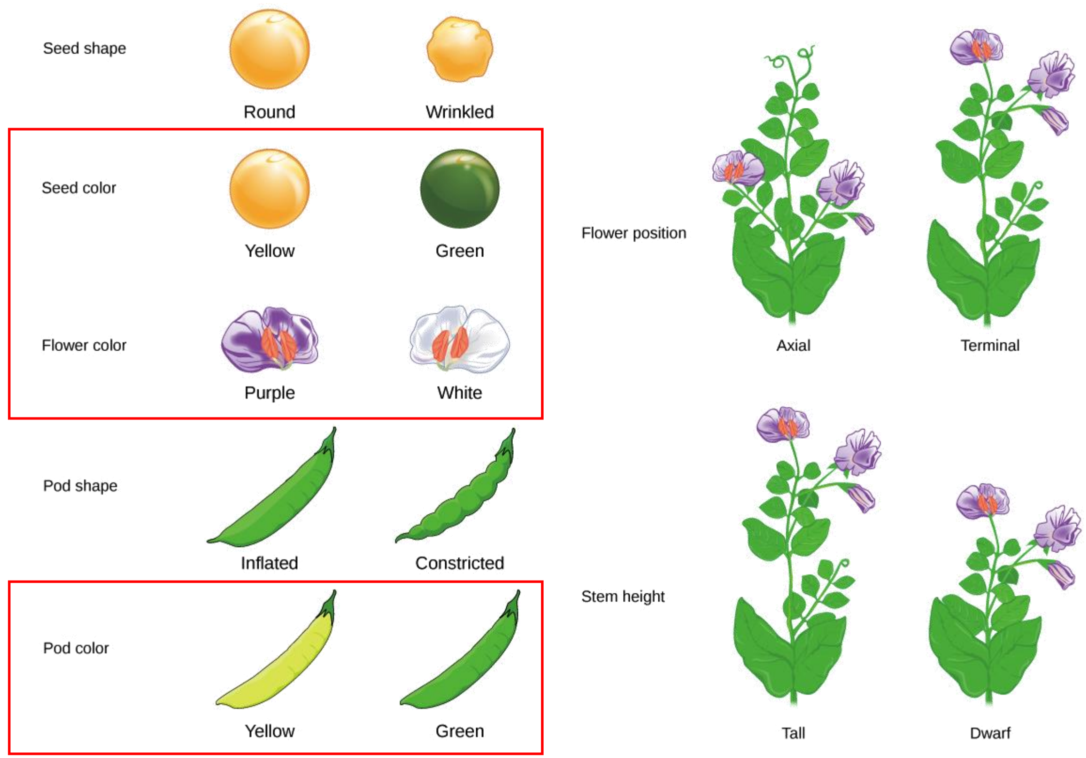
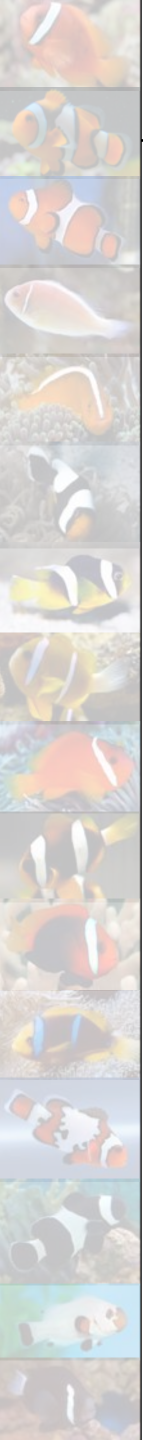


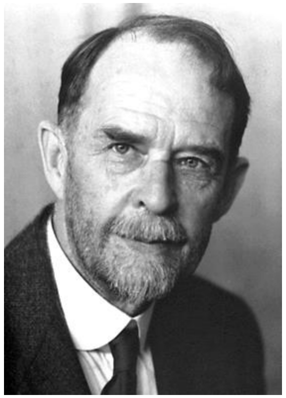
→ Coloration at the basis of the Mendel's Laws of Inheritance:

Law of Segregation, Law of Independent Assortment, Law of Dominance

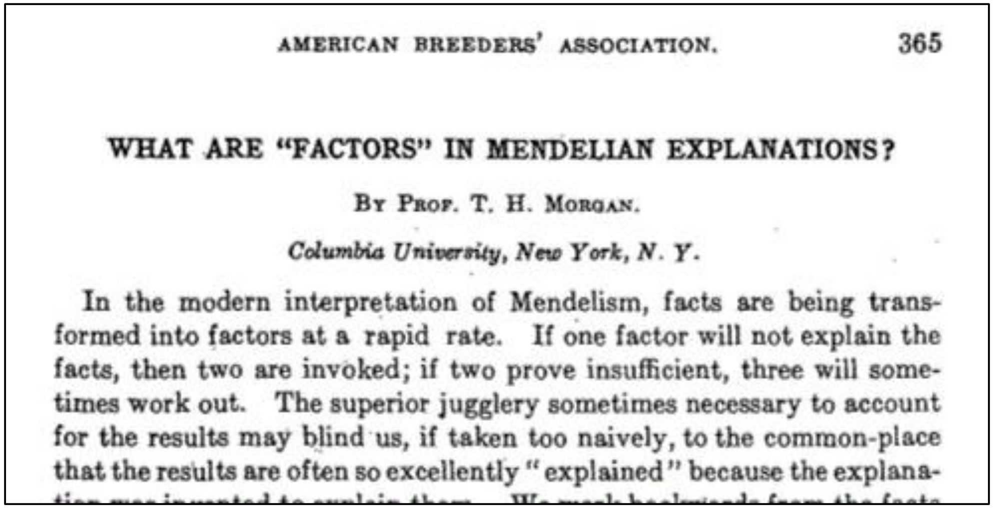


Coloration and the History of the comprehension of GP relationship: Morgan

1909



Thomas Hunt MORGAN (1866-1945)



AMERICAN BREEDERS' ASSOCIATION. 365

WHAT ARE "FACTORS" IN MENDELIAN EXPLANATIONS?

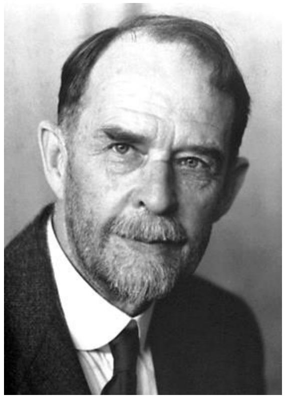
BY PROF. T. H. MORGAN.

Columbia University, New York, N. Y.

In the modern interpretation of Mendelism, facts are being transformed into factors at a rapid rate. If one factor will not explain the facts, then two are invoked; if two prove insufficient, three will sometimes work out. The superior jugglery sometimes necessary to account for the results may blind us, if taken too naively, to the common-place that the results are often so excellently "explained" because the explana-

white gene

Coloration and the History of the comprehension of GP relationship: Morgan



1910

→ Coloration at the basis of the discovery of heredity: chromosomes carrying "genes" that allow inheritance

+ genetic linkage

becoming manifest when conditions favoring transpiration are marked." The disease is therefore not due to the presence of parasitic organisms, but is what has been rather loosely called a physiological disorder.

In a short paper in the *Annales du Jardin Botanique de Buitenzorg* (2d Ser., Supp. III.) Professor Ramaley enumerates and discusses the European plants growing without cultivation in Colorado. In addition to an annotated list of species the author discusses the region included, and the mode of introduction and occurrence of the species. Botanists who have not given attention to these immigrants will be much surprised at the extent of the list.

Professor Sargent continues his studies of the species of hawthorns in Pennsylvania in a paper entitled "Crataegus in Pennsylvania, II.," published in the *Proceedings of the Academy of Natural Sciences of Philadelphia* (March, 1910). His first paper on the Pennsylvania hawthorns appeared about five years ago, since when much additional material has become available for study, resulting in a thick pamphlet of about one hundred pages. In this space the author enumerates and describes 110 species, of which 80 are described as new! Think of what the new editions of the botanical manuals will have to contain when these new species are added! We may have to grant the necessity of distinguishing these forms from one another in descriptive botany, but what an amount of work will have to be done by the taxonomists of the future in reducing these multitudinous forms to such categories as will be distinguishable by botanists, other than specialists in the hawthorns!

Charles E. Bessey
The University of Nebraska

SPECIAL ARTICLES

SEX LIMITED INHERITANCE IN DROSOPHILA

In a pedigree culture of *Drosophila* which had been running for nearly a year through a considerable number of generations, a male appeared with white eyes. The normal flies have brilliant red eyes.

The white-eyed male, bred to his red-eyed sisters, produced 1,237 red-eyed offspring, (F_1), and 3 white-eyed males. The occurrence of these three white-eyed males (F_1) (due evidently to further sporting) will, in the present communication, be ignored.

The F_1 hybrids, inbred, produced:

2,459 red-eyed females,
1,011 red-eyed males,
782 white-eyed males.

No white-eyed females appeared. The new character showed itself therefore to be sex limited in the sense that it was transmitted only to the grandsons. But that the character is not incompatible with femaleness is shown by the following experiment.

The white-eyed male (mutant) was later crossed with some of his daughters (F_1), and produced:

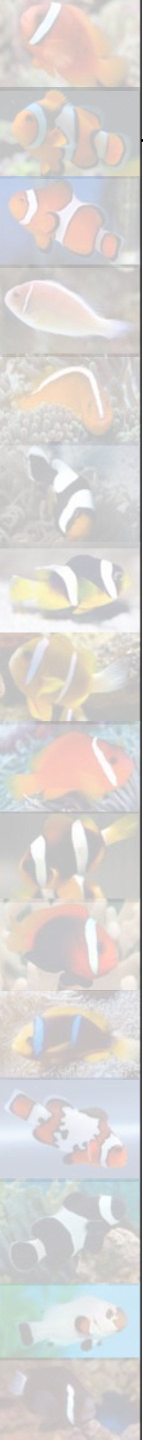
129 red-eyed females,
132 red-eyed males,
88 white-eyed females,
86 white-eyed males.

The results show that the new character, white eyes, can be carried over to the females by a suitable cross, and is in consequence in this sense not limited to one sex. It will be noted that the four classes of individuals occur in approximately equal numbers (25 per cent.).

An Hypothesis to Account for the Results.—The results just described can be accounted for by the following hypothesis. Assume that all of the spermatozoa of the white-eyed male carry the "factor" for white eyes "W"; that half of the spermatozoa carry a sex factor "X" the other half lack it, *i. e.*, the male is heterozygous for sex. Thus the symbol for the male is "WWX," and for his two kinds of spermatozoa WX—W.

Assume that all of the eggs of the red-eyed female carry the red-eyed "factor" R; and that all of the eggs (after reduction) carry one X, each, the symbol for the red-eyed female will be therefore RRXX and that for her eggs will be RX—RX.

When the white-eyed male (sport) is crossed with his red-eyed sisters, the following combinations result:



Coloration and the History of the comprehension of GP relationship

1917

EVIDENCE OF MULTIPLE FACTORS IN MICE AND RATS

C. C. LITTLE

HARVARD MEDICAL SCHOOL

THE object of this paper is to record certain data on the inheritance of two complex characters and analyze these data together with those obtained in certain analogous experiments by other investigators. This is done with a

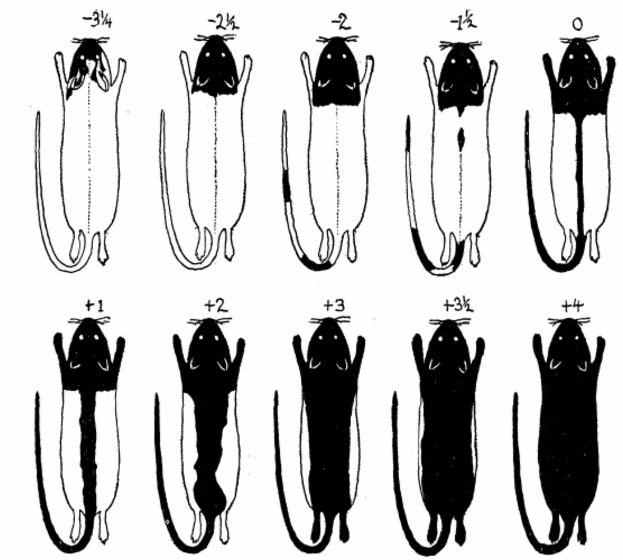
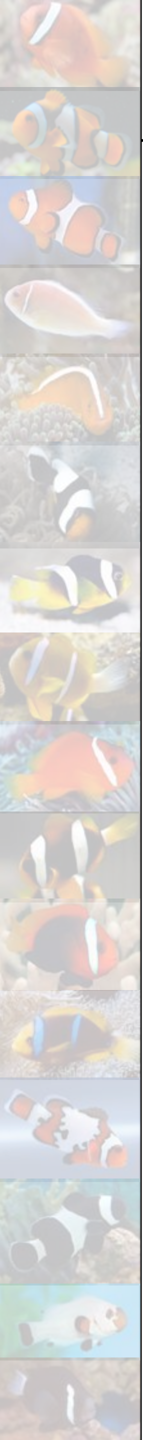


FIG. 2

"All indicate that in mammals the <u>multiple factor hypothesis</u> is steadily being strengthened as a scientific theory (…) of great interest and importance."

→ Coloration at the basis of the discovery of epistasis

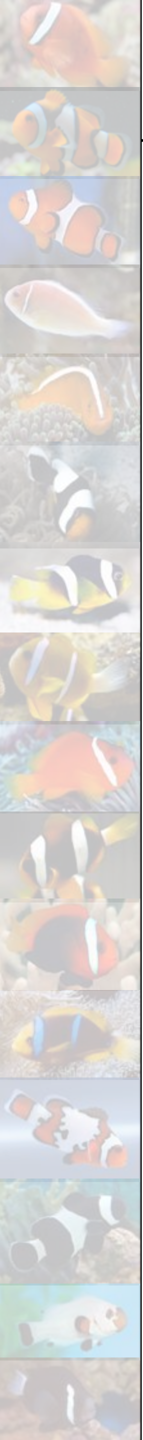


Coloration and the History of genetics: a summary (in Vertebrates only)

Table 1 Timeline of some milestones and fundamental discoveries using pigmentation phenotypes

Date	*Milestone*	*Representative reference*
1700s	Establishment of laboratory mouse strains with 'fancy' coat color patterns	Morse (1978)
1902–1904	Demonstration of Mendelian inheritance in vertebrates using the albino locus	Castle and Allen (1903), Cuenot (1904)
1915	Establishment of genetic linkage in mammals using two pigmentation loci	Haldane *et al* (1915)
1917	Seminal papers on coat color genetics in laboratory animals	Wright (1917a, b, c, d)
1920s	Natural history studies linking vertebrate pigmentation to environmental variation	Sumner (1921, 1929a, b), Benson (1933), Dice and Blossom (1937)
1948	First mathematical treatment of clinal variation based on adaptive pigmentation traits	Haldane (1948)
1950s	First estimate of radiation-induced mammalian mutation rates at six coat color loci	Russell (1951), Russell and Major (1957)
1960s	Estimates of spontaneous mammalian mutation rates using coat color phenotypes	Schlager and Dickie (1966, 1969)
1986	Cloning of the first pigmentation gene	Shibahara *et al* (1986)
2000s	Linking mutations in pigmentation genes to adaptive phenotypic variation in the wild	

Hoekstra (2006) *Genetics, development and evolution of adaptive pigmentation in vertebrates*



Coloration and the History of the comprehension of GP relationship: McClintock

Barbara McClintock
(1902-1992)

Maize variegation

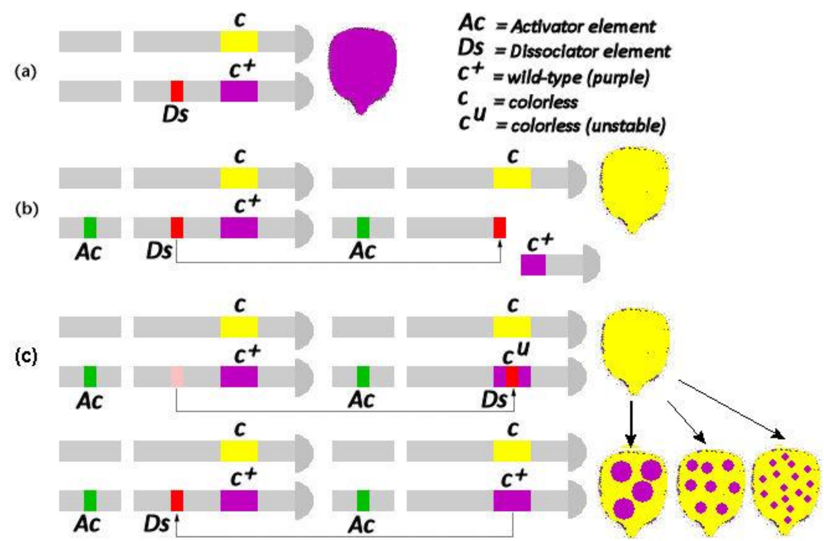
THE ORIGIN AND BEHAVIOR OF MUTABLE LOCI IN MAIZE

BY BARBARA McCLINTOCK

DEPARTMENT OF GENETICS, CARNEGIE INSTITUTION, COLD SPRING HARBOR, NEW YORK

Communicated April 8, 1950

In the course of an experiment designed to reveal the genic composition of the short arm of chromosome 9, a phenomenon of rare occurrence (or recognition) in maize began to appear with remarkably high frequencies in the cultures. The terms mutable genes, unstable genes, variegation,

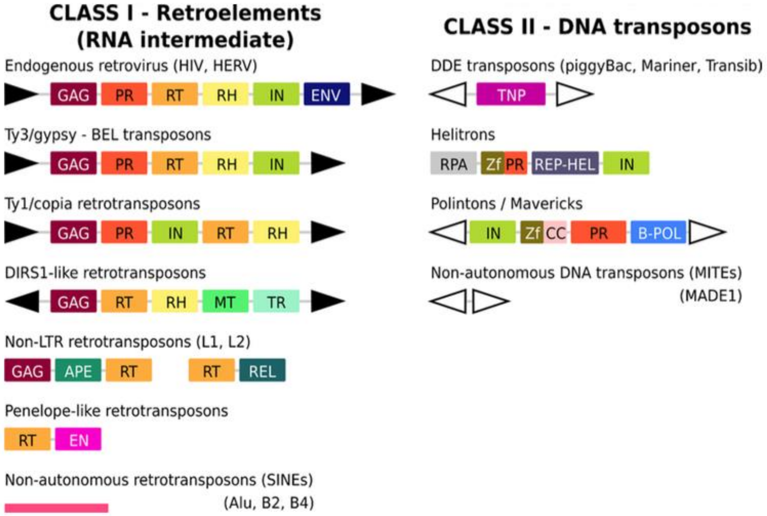


Coloration and the History of the comprehension of GP relationship: McClintock

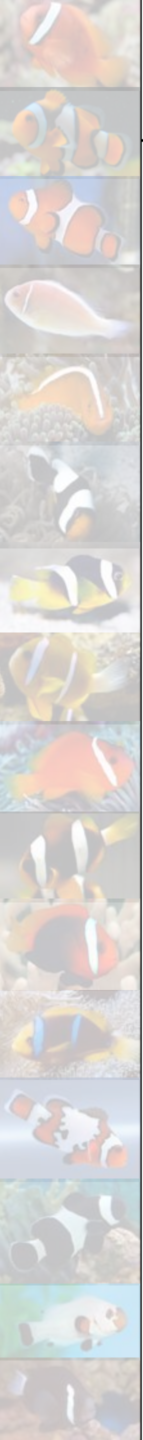
Barbara McClintock
(1902-1992)

Maize variegation

→ Coloration at the basis of the discovery of major genome sequences, transposable elements ("controlling elements")



Warren, Naville, Chalopin et al. (2015)

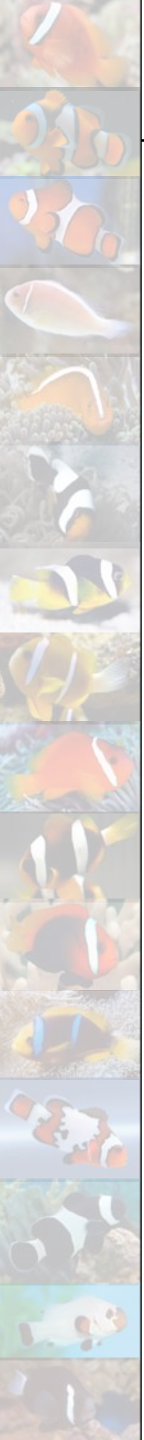


More recently… "Color" is still a first-considered trait

Nature cover (1981)

Among all possible mutants used to describe the emergence of a new model system, guess which one was used?

Golden… a pigmentary mutant!



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Potential biases in the choice of model systems?

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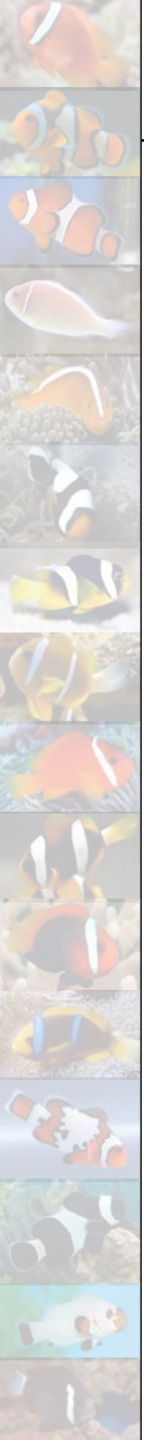
a. Coloration in the History of Science

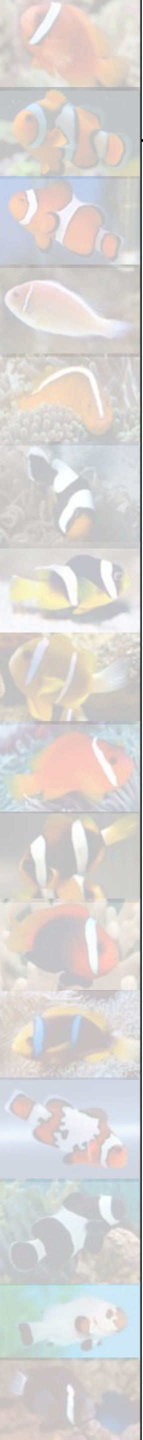
b. Coloration in Vertebrates

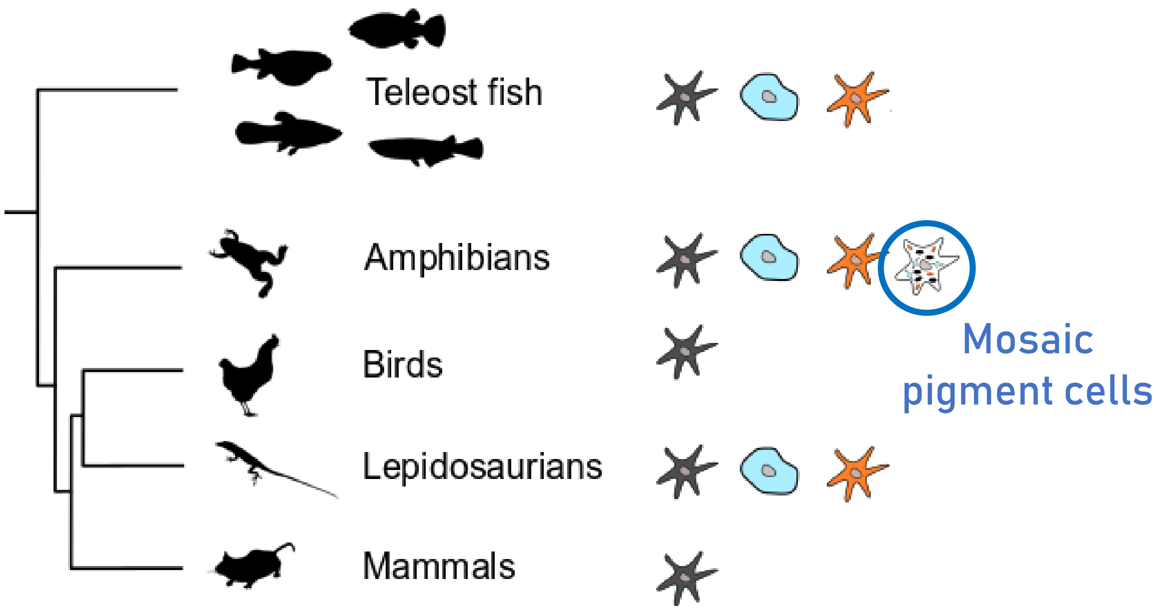


Developmental, cellular and molecular basis of pigmentation in Vertebrates

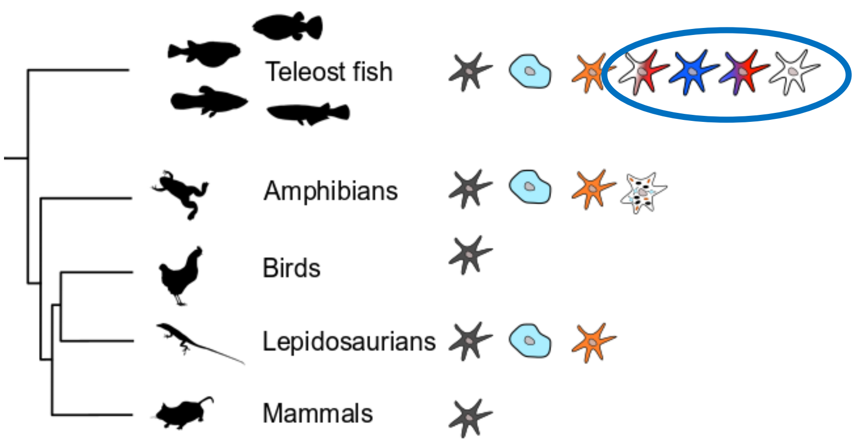
Lorin *et al.* (2018) *G3: Genes|Genomes|Genetics*

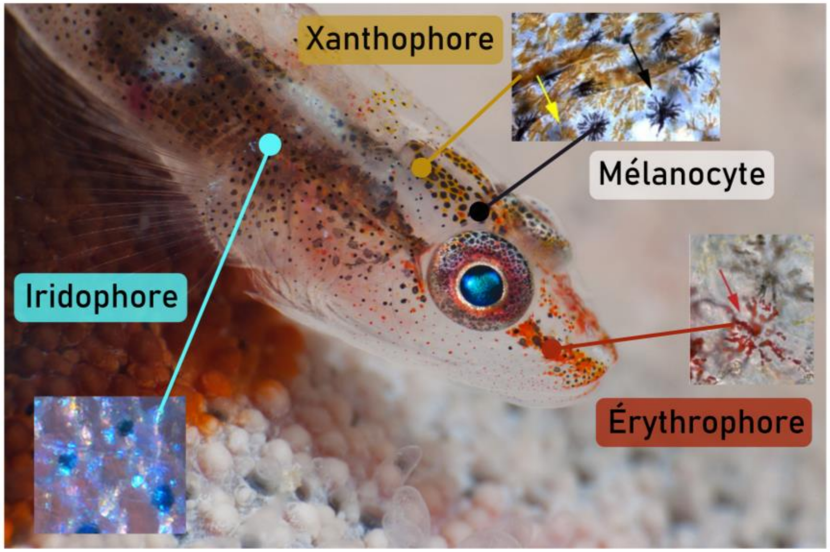
Developmental, cellular and molecular basis of pigmentation in Vertebrates





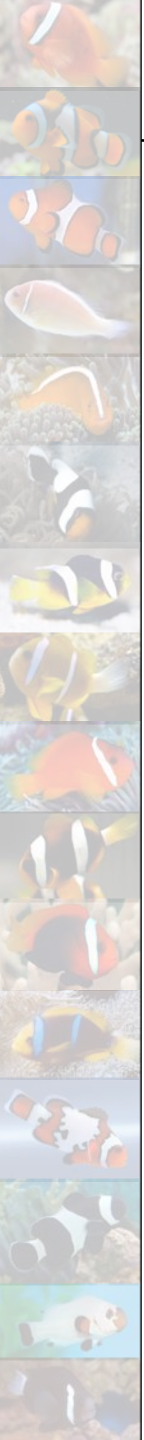
Developmental, cellular and molecular basis of pigmentation in Vertebrates

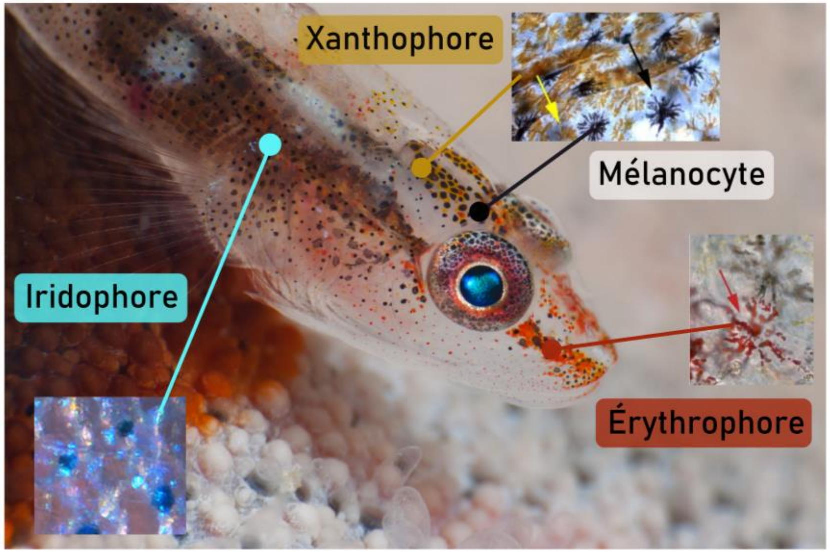


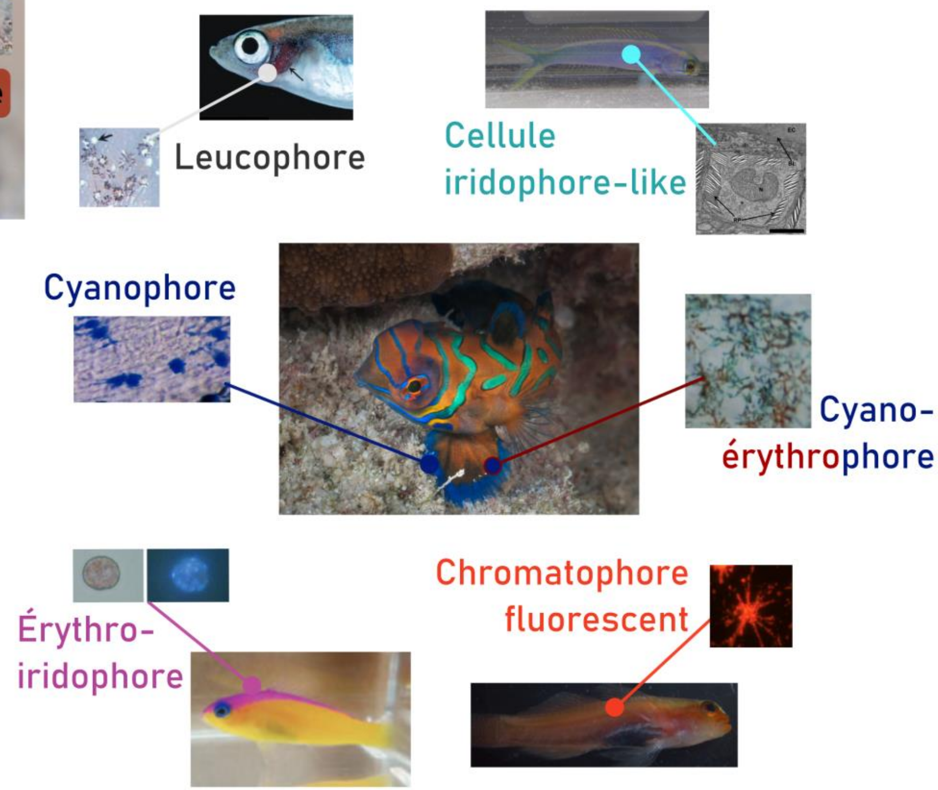


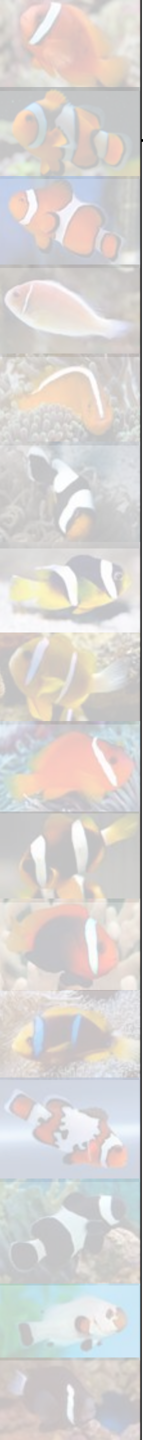
Picture: Germain Boussarie

Developmental, cellular and molecular basis of pigmentation in Vertebrates

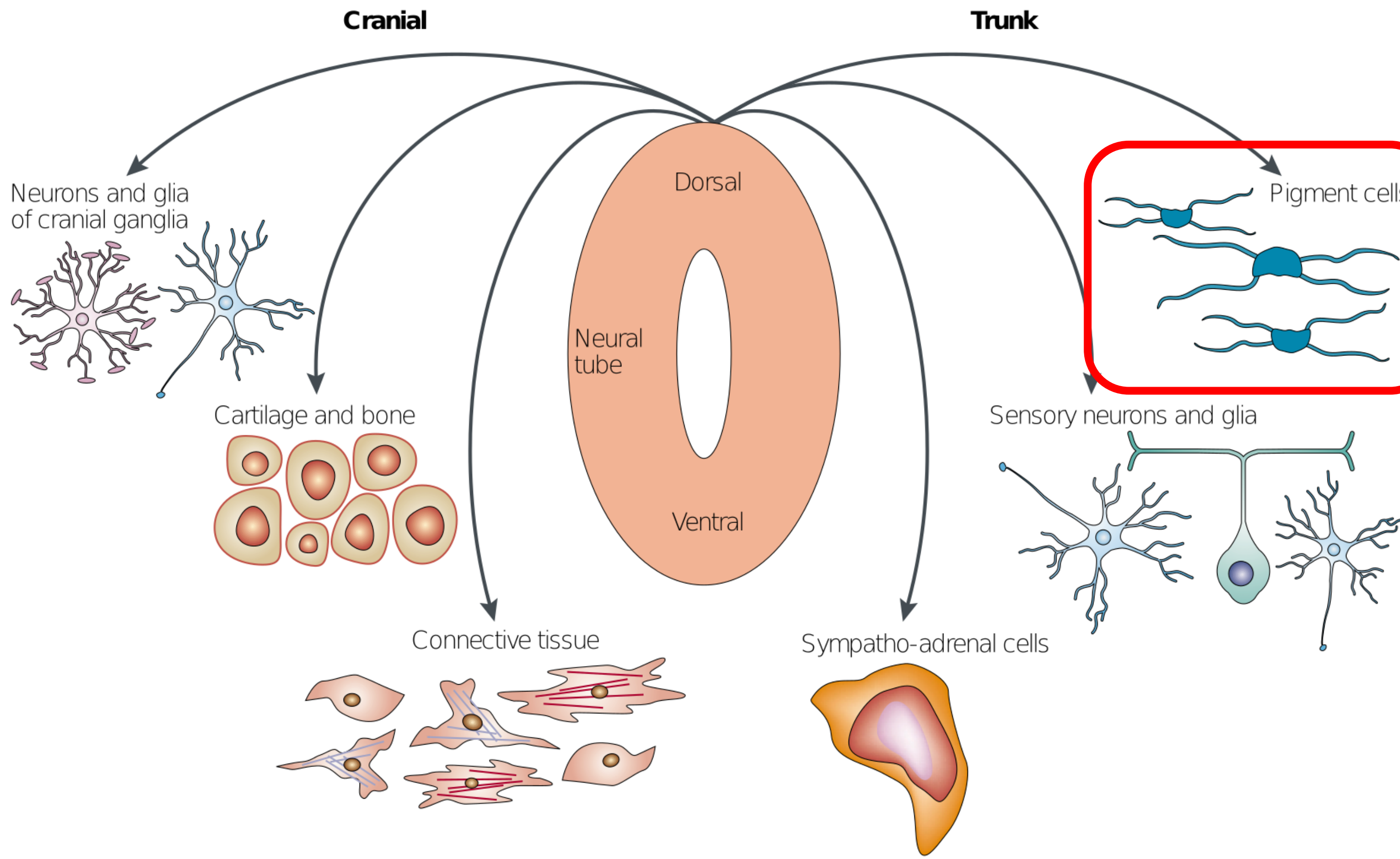






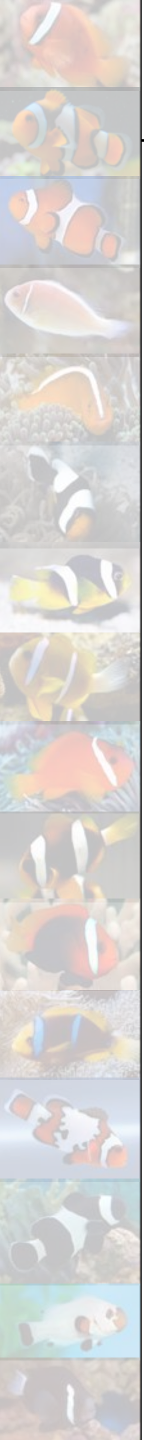


Pigment cells in vertebrates originate from the neural crest

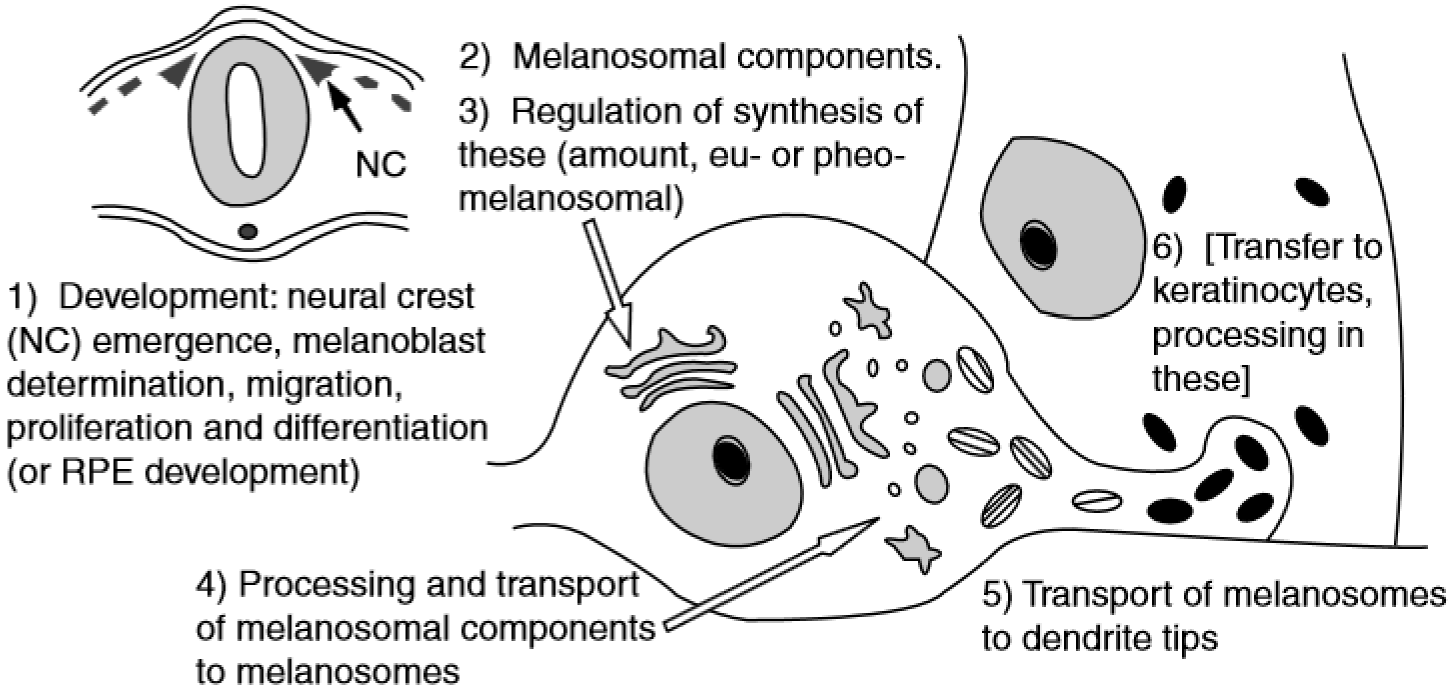


Les cellules des crêtes neurales : « la seule chose intéressante » chez les Vertébrés ?

Knecht *et al.* (2002) *Nat. Rev. Gen.*



Coloration is a very diverse trait



Bennett and Lamoreux (2003) *Pigment Cell Res.*

Coloration is a very diverse trait… endoded by a plethora of genes

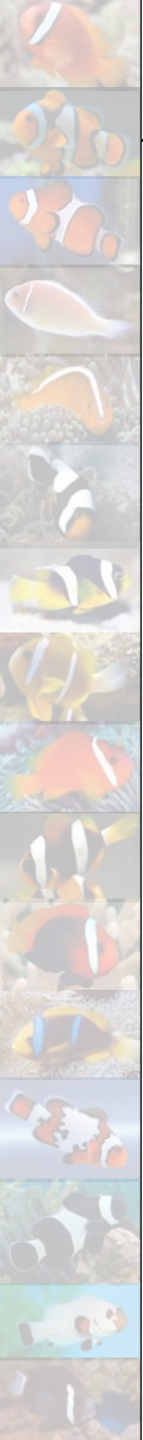
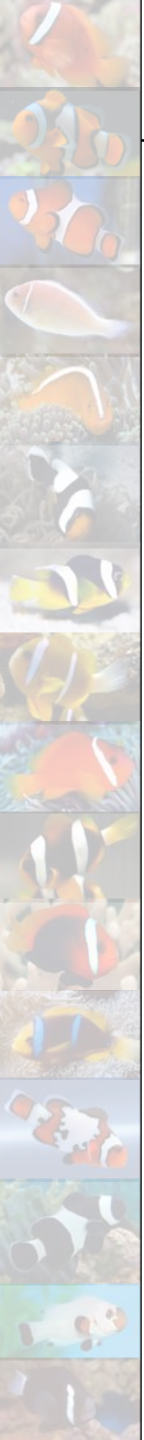


Table 1. Summary of the cloned mouse color genes

Symbol (old symbol)	Name (old name)	Chromosome	Function	Human symbol	Human chr'some	Syndrome
(a) Melanocyte development						
Adam17	A disintegrin and metalloprotease domain 17	12	Protease, processing various bioactive proteins	*ADAM17*	2p25	N
Adamts20 (bt)	A disintegrin and metalloprotease domain (reprolysin type) with thrombospondin type 1 motif, 20 (belted)	15	Metalloprotease. Melanoblast migration?	*ADAMTS20*	12q12	N
Brca1	Breast cancer 1	11	Development of various organs; tumor suppressor	*BRCA1*	17q21	BC
Eda (Ta)	Ectodysplasin-A (tabby)	X	Sweat gland, tooth and hair morphogenesis	*ED1*	Xq12-q13	EDA/HED
Edn3 (ls)	Endothelin 3 (lethal spotting)	2	Growth and differentiation factor	*EDN3*	20q13	HD, WSS
Ednrb (s)	Endothelin receptor type B (piebald spotting)	14	Growth factor receptor	*EDNRB*	13q22	HD, WSS
Egfr (Dsk5)	Epidermal growth factor receptor (dark skin 5)	11	Growth factor receptor	*EGFR*	7p12.3	N
Fgfr2	Fibroblast growth factor receptor 2	7	Growth factor receptor	*FGFR2*	10q26	CrS, PfS
Ikbkg	Inhibitor of κB kinase, γ subunit (NEMO)	X	IκB kinase. Required for NFκB signaling	*IKBKG*	Xq28	IP, HED-ID, EDA-ID
Kit (W)	Kit oncogene (white spotting)	5	Growth factor receptor	*KIT*	4q11-q12	PS
Kitl (Sl)	Kit ligand (steel)	10	Growth and differentiation factor	*KITLG*	12q22	N
Krt2-17 (Dsk2)	Keratin 2–17 (dark skin 2)	15	Cytoskeleton	*KRT2A*	12q11-q13	IBS
Lmx1a (dr)	LIM homeobox transcription factor 1α (dreher)	1	Transcription factor	*LMX1A*	1q22–23	N
Mcoln3 (Va)	Mucolipin 3 (varitint-waddler)	3	Cation channel	*MCOLN3*	1p22.3	N
Mitf (mi)	Microphthalmia-associated transcription factor (microphthalmia)	6	Transcription factor	*MITF*	3p12–14	WS2
Pax3 (Sp)	Paired box gene 3 (splotch)	1	Transcription factor	*PAX3*	2q35	WS1, WS3
Sfxn1 (f)	Sideroflexin 1 (flexed tail)	13	Tricarboxylate carrier	*SFXN1*	5q35.3	N
Snai2	Snail homolog 2/Slug	16	Transcription factor	*SNAI2*	8q11	WS2
Sox10 (Dom)	SRY-box containing gene 10 (dominant megacolon)	15	Transcription factor	*SOX10*	22q13.1	WSS
Sox18 (rg, Dcc1)	SRY-box containing gene 18 (ragged, dark coat color 1)	2	Transcription factor	*SOX18*	20q13.33	N
Wnt1	Wingless-related MMTV integration site 1	15	Growth factor/morphogen	*WNT1*	12q13	N
Wnt3a	Wingless-related MMTV integration site 3A	11	Growth factor/morphogen	*WNT3A*	1q42	N
(b) Components of melanosomes and their precursors						
Dct (slt)	Dopachrome tautomerase (slt)	14	Melanosomal enzyme	*DCT*	13q31-q32	N
Gpnmb	Glycoprotein (transmembrane) NMB	6	Apparent melanosomal component	*GPNMB*	7p15	N
Matp (uw)	Membrane-associated transporter protein (underwhite)	15	Apparent transporter	*MATP*	5p	OCA4
Rab38 (cht)	RAB38, member RAS oncogene family (chocolate).	7	Targeting of Tyrp1	*RAB38*	11q14	N
Si (si)	Silver (silver)	10	Melanosome matrix	*SILV*	12q13-q14	N
Tyr (c)	Tyrosinase (color, albino)	7	Melanosomal enzyme	*TYR*	11q21	OCA1
Tyrp1 (b)	Tyrosinase-related protein 1 (brown)	4	Melanosomal protein	*TYRP1*	9p23	OCA3
(c) Melanosome construction/protein routing (HPS-related)						
Ap3b1 (pe)	Adaptor-related protein complex AP-3, β 1 subunit (pearl)	13	Organellar protein routing	*AP3B1* [HPS2]	15q15	HPS
Ap3d (mh)	Adaptor-related protein complex AP-3, δ subunit (mocha)	10	Organellar protein routing	*AP3D1*	19p13.3	N
Vps33a (bf)	Vacuolar protein sorting 33a (buff)	5	Organellar protein routing	*VPS33A*	12q24.31	N
cno (cno)	Cappuccino	5	Organelle biogenesis	*CNO*	4p16-p15	N
Hps1 (ep)	Hermansky-Pudlak syndrome 1 homolog (pale ear)	19	Organelle biogenesis and size	*HPS1*	10q24	HPS
Hps3 (coa)	Hermansky-Pudlak syndrome 3 homolog (cocoa)	3	Organelle biogenesis	*HPS3*	3q24	HPS
Hps4 (le)	Hermansky–Pudlak syndrome 4 homolog (light ear)	5	Organelle biogenesis and size	*HPS4*	22q11-q12	HPS
Hps5 (ru2)	Hermansky–Pudlak syndrome 5 homolog (ruby-eye 2)	7	Organelle biogenesis	*HPS5*	11p14	HPS
Hps6 (ru)	Hermansky–Pudlak syndrome 6 homolog (ruby-eye)	19	Organelle biogenesis	*HPS6*	10q24.31	HPS
Lyst (bg)	Lysosomal trafficking regulator (beige)	13	Organelle biogenesis and size	*LYST*	1q42	CHS

Bennett and Lamoreux (2003) *Pigment Cell Res.*



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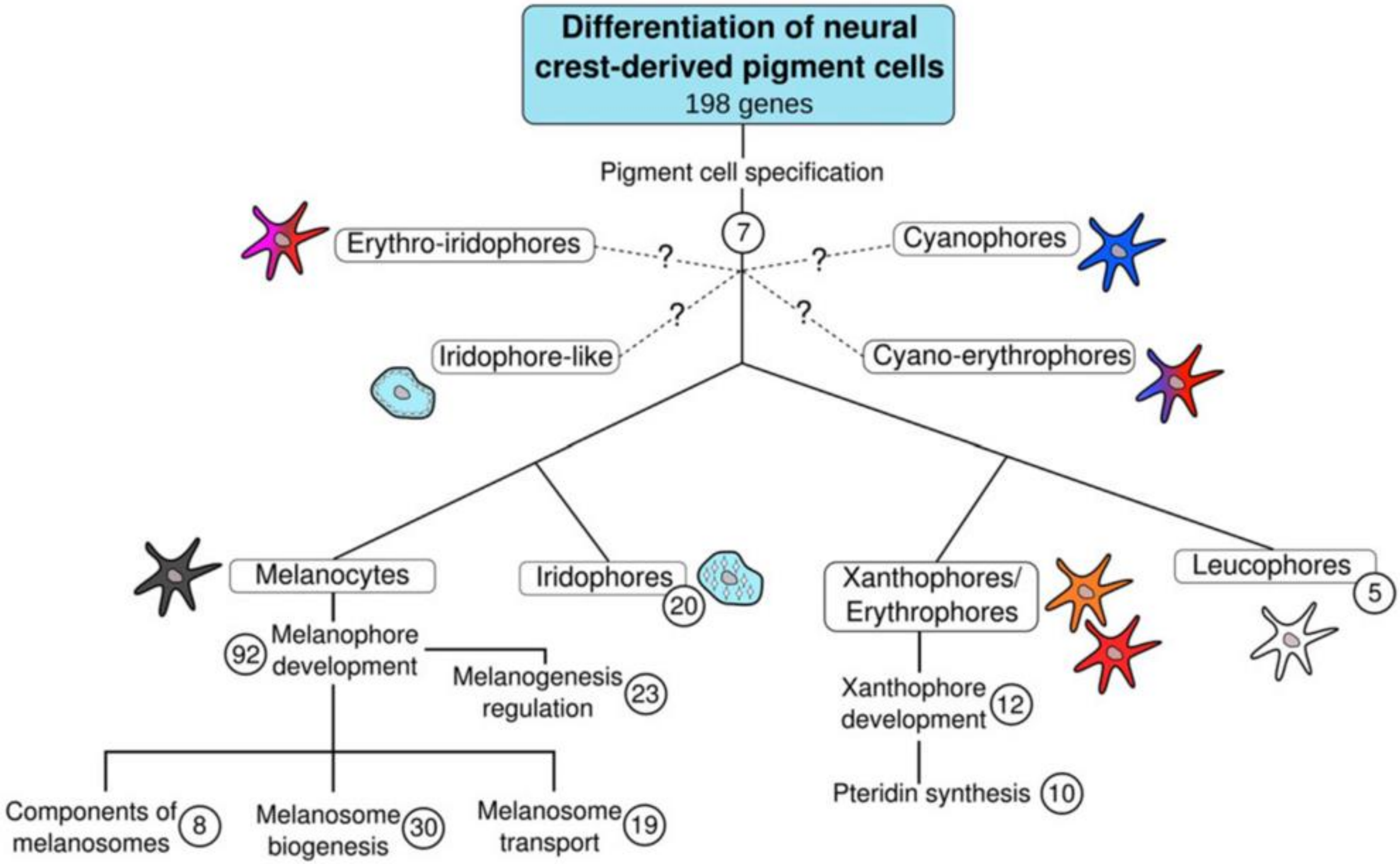
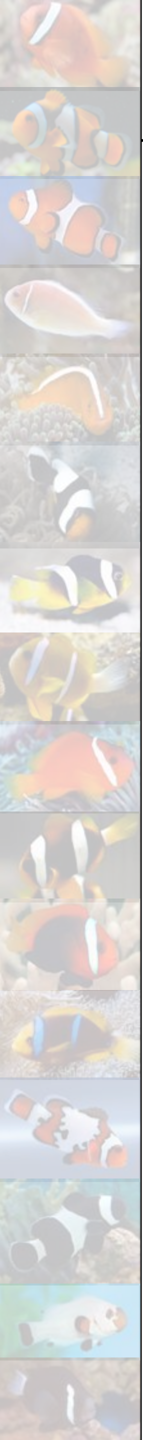
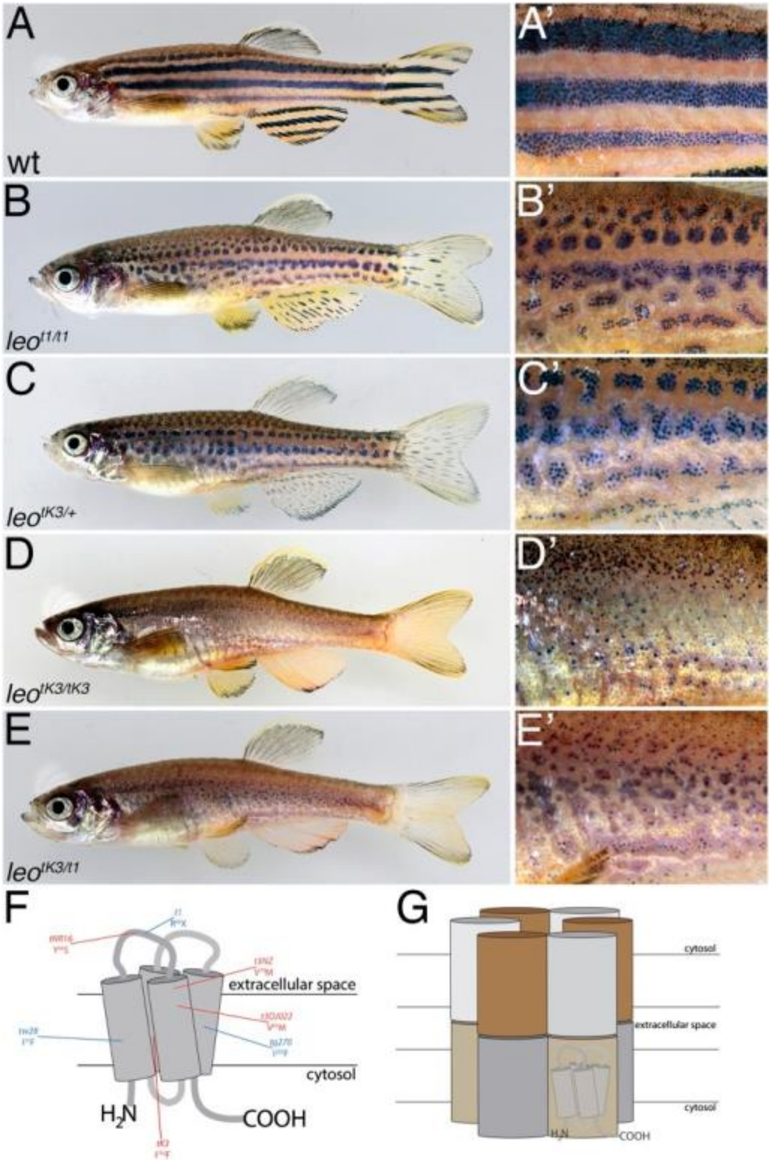


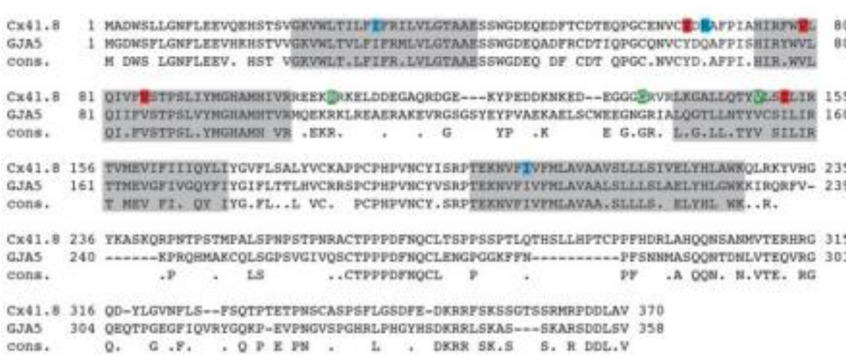
Lorin et al. (2018) *G3*



Changes in "coding sequences" → changes in coloration: "direct GP relationship"

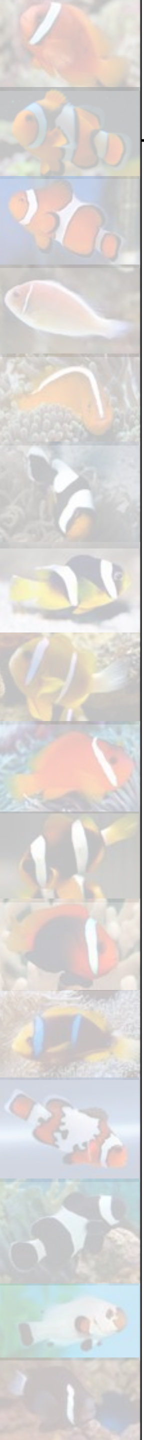


Example: gene cx41.8 in zebrafish

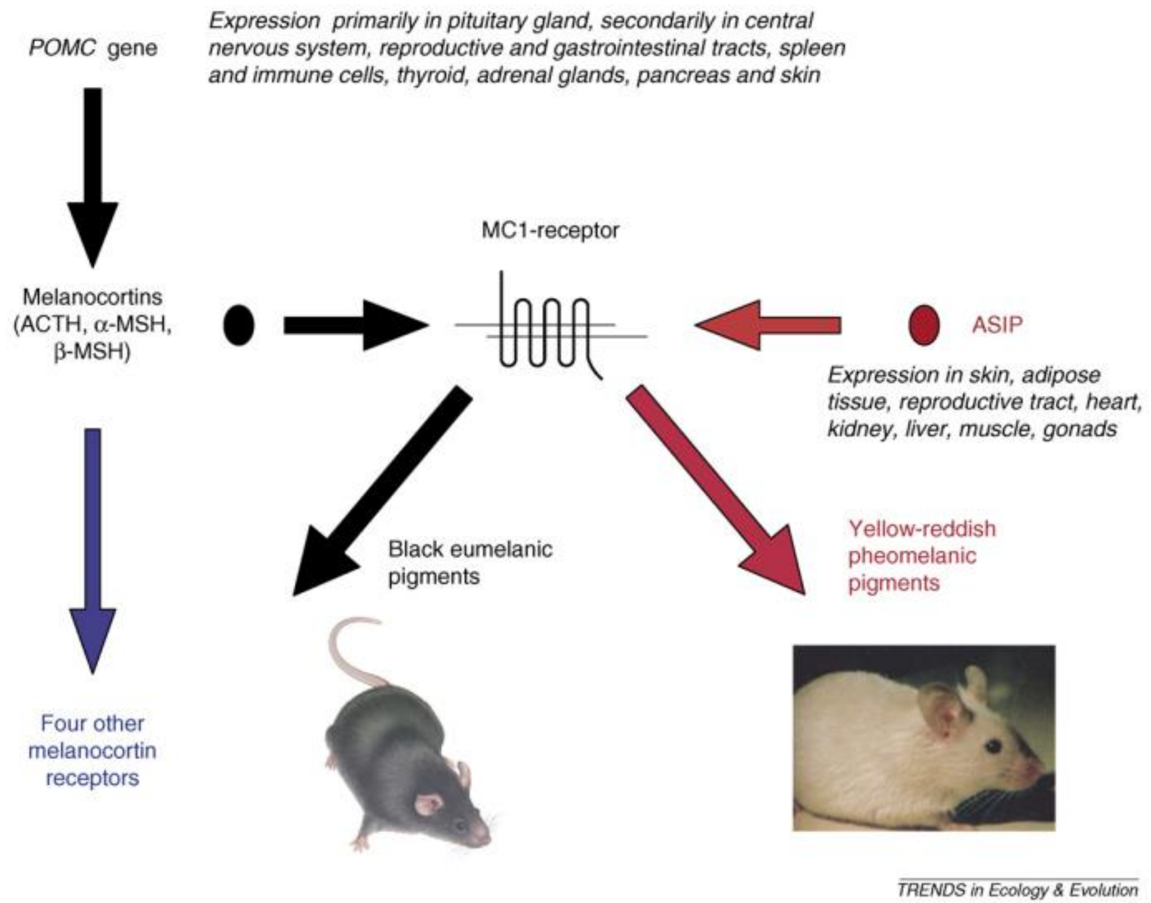


Irion et al. (2014) *eLife*

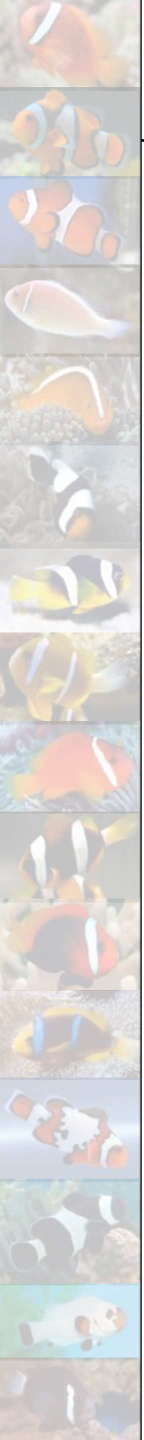
But… The GP relationship is more complex than "one gene / one trait"



→ One gene / MULTIPLE traits: Pleiotropy of "color genes"



Ducrest et al. (2008) *TREE*



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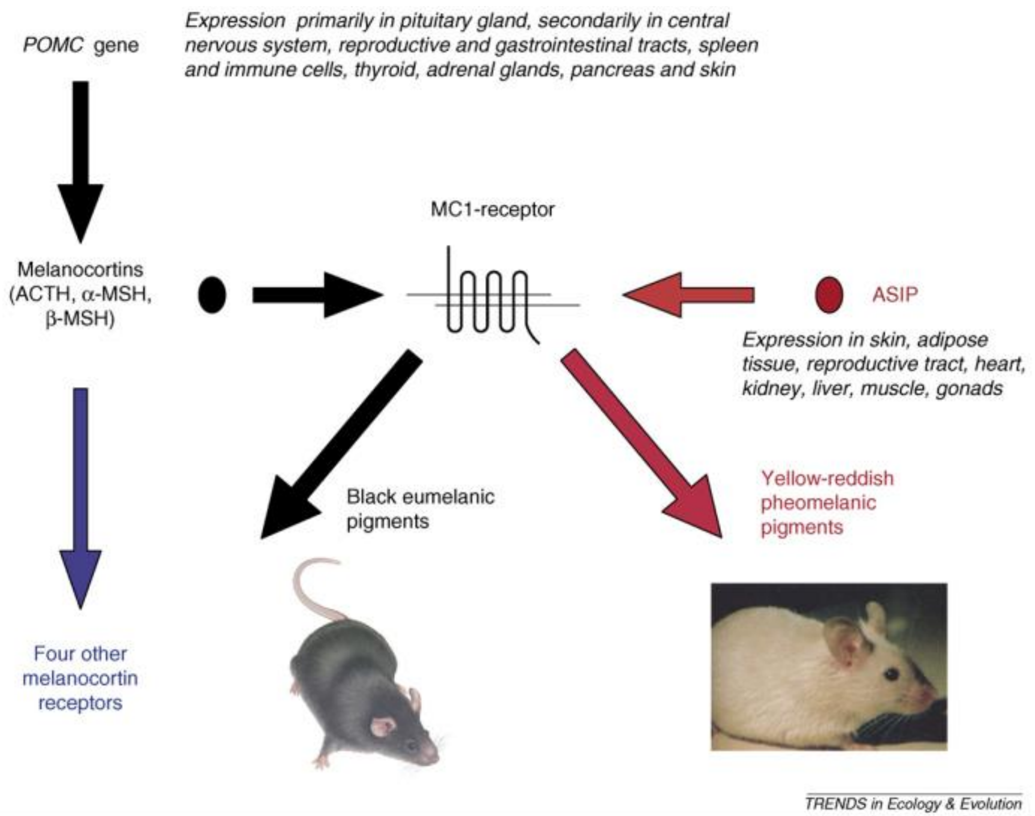
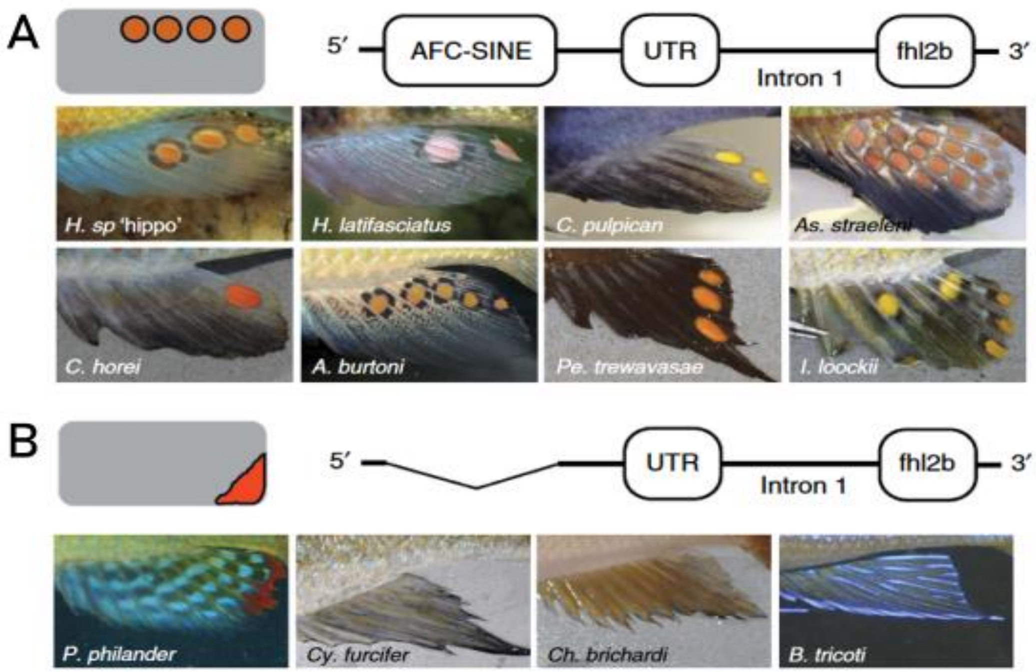
→ MULTIPLE genes / one trait



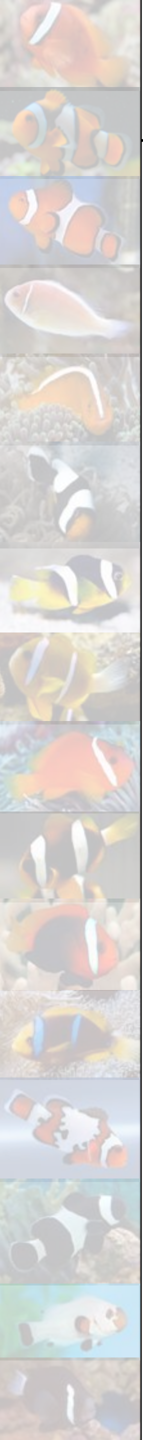
Ducrest et al. (2008) *TREE*

Coloration is sometimes due to regulatory sequences rather than "genes"

1. *Cis*-regulatory sequences

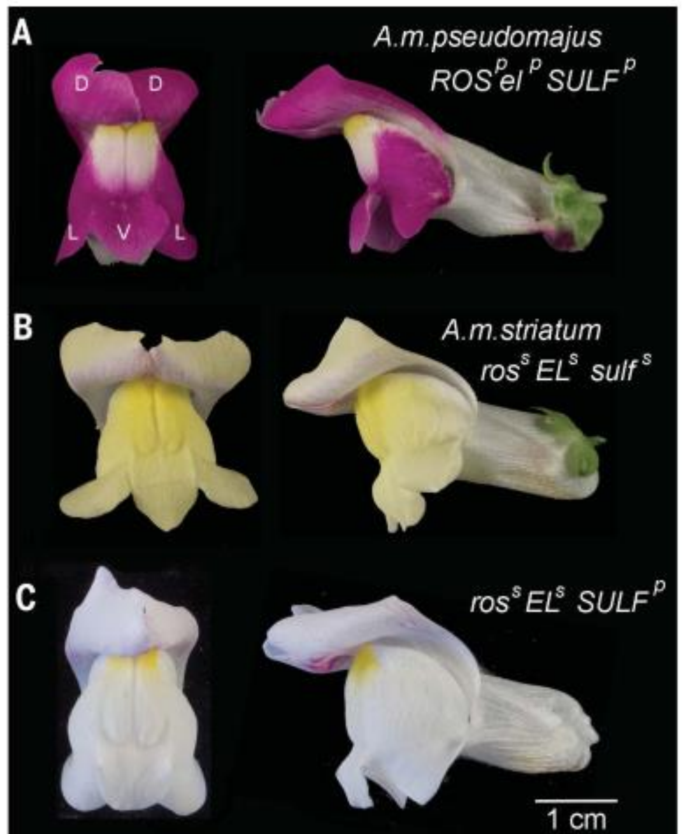


Santos et al. (2014) *Nature Comm.*

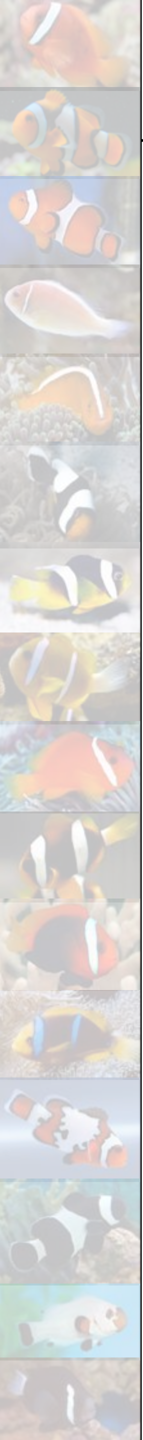


Coloration is sometimes due to regulatory sequences rather than "genes"

1. *Cis*-regulatory sequences
2. Non-coding RNAs / Epigenetics



Bradley et al. (2017) *Science*

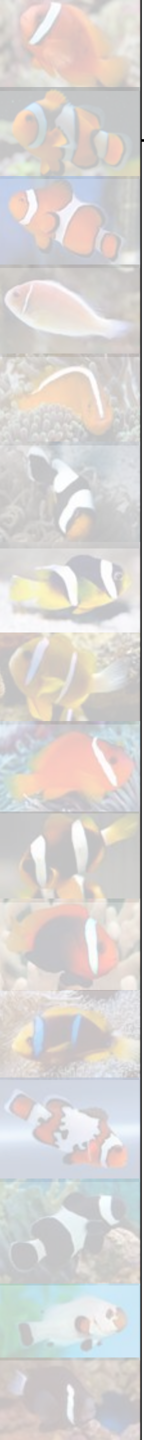


Why study coloration?

→ Profitable

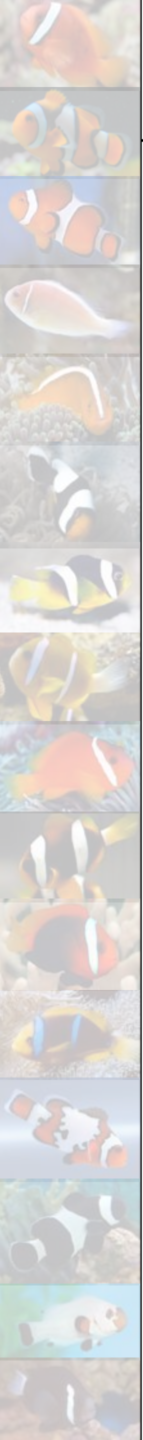
→ Aesthetic

→ Convenient



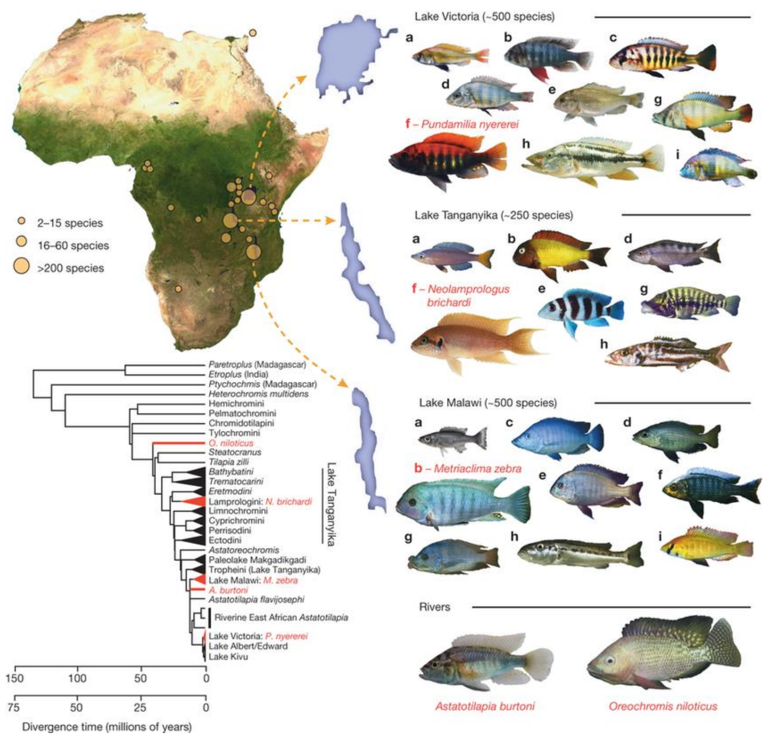
Why study coloration?

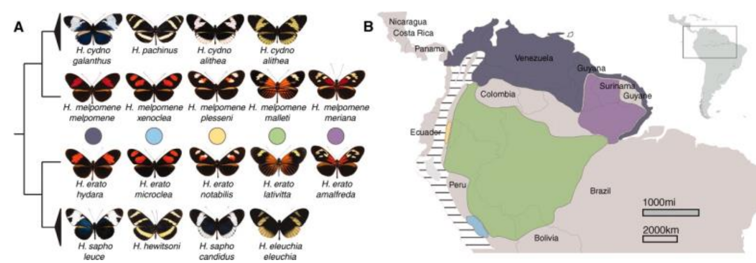
Coloration is a fast-evolving trait

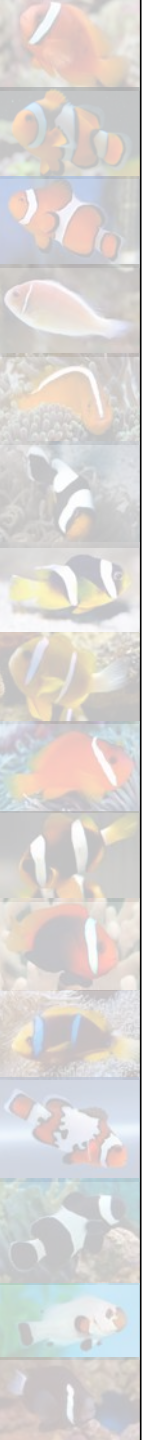


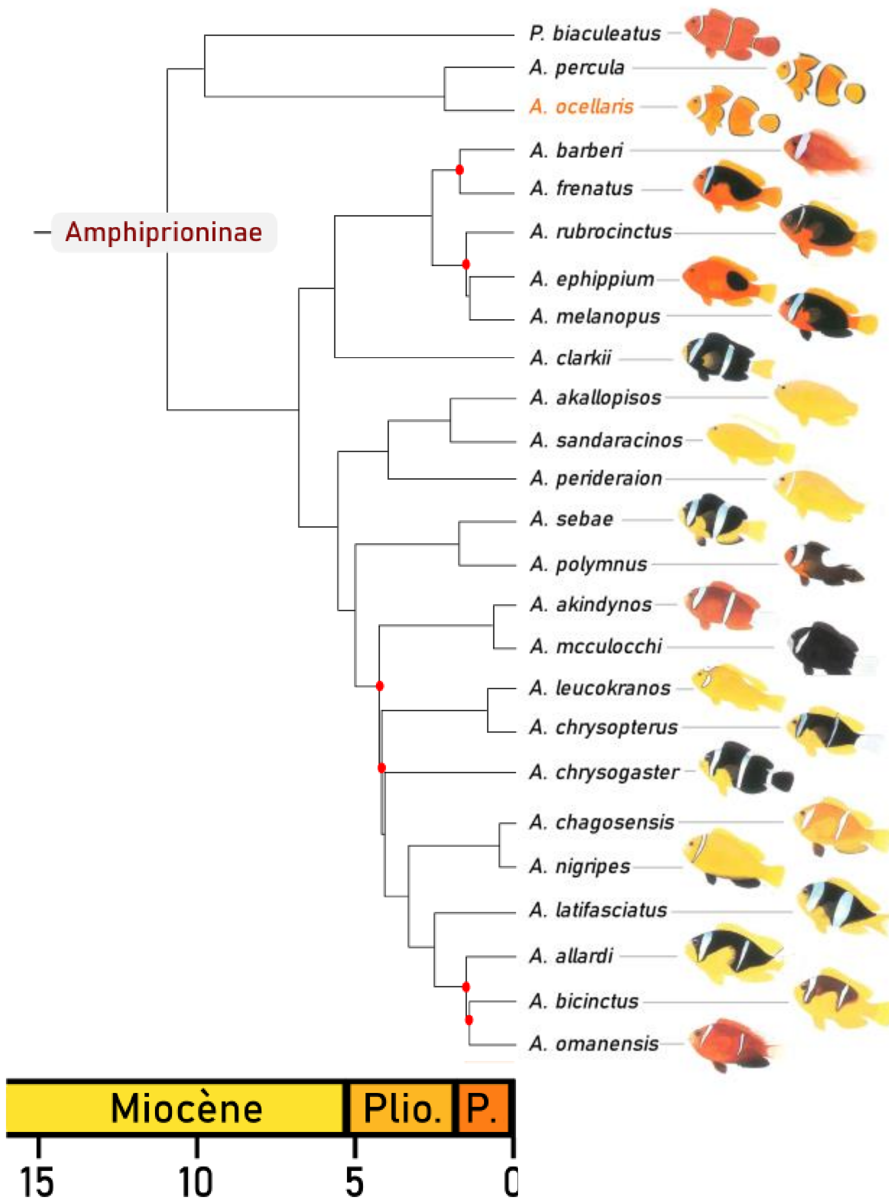
Coloration is a fast-evolving trait

Gautier et al. (2018) *Current Biol.*









Adapted from Litsios *et al.* (2012), Litsios, Pearman *et al.* (2014) and Litsios and Salamin (2014)

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→ Many cell types and genes
→ Not only genes
→ Fast evolution

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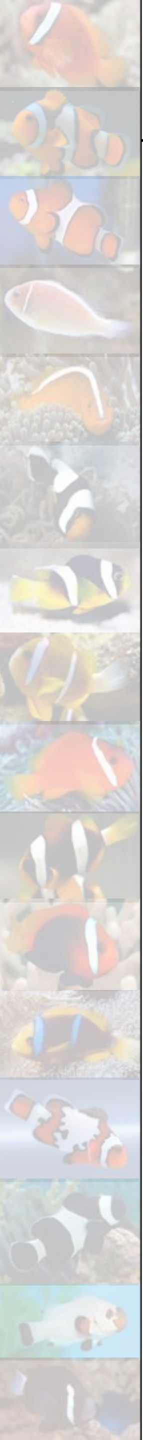
II. A case study: clownfish coloration

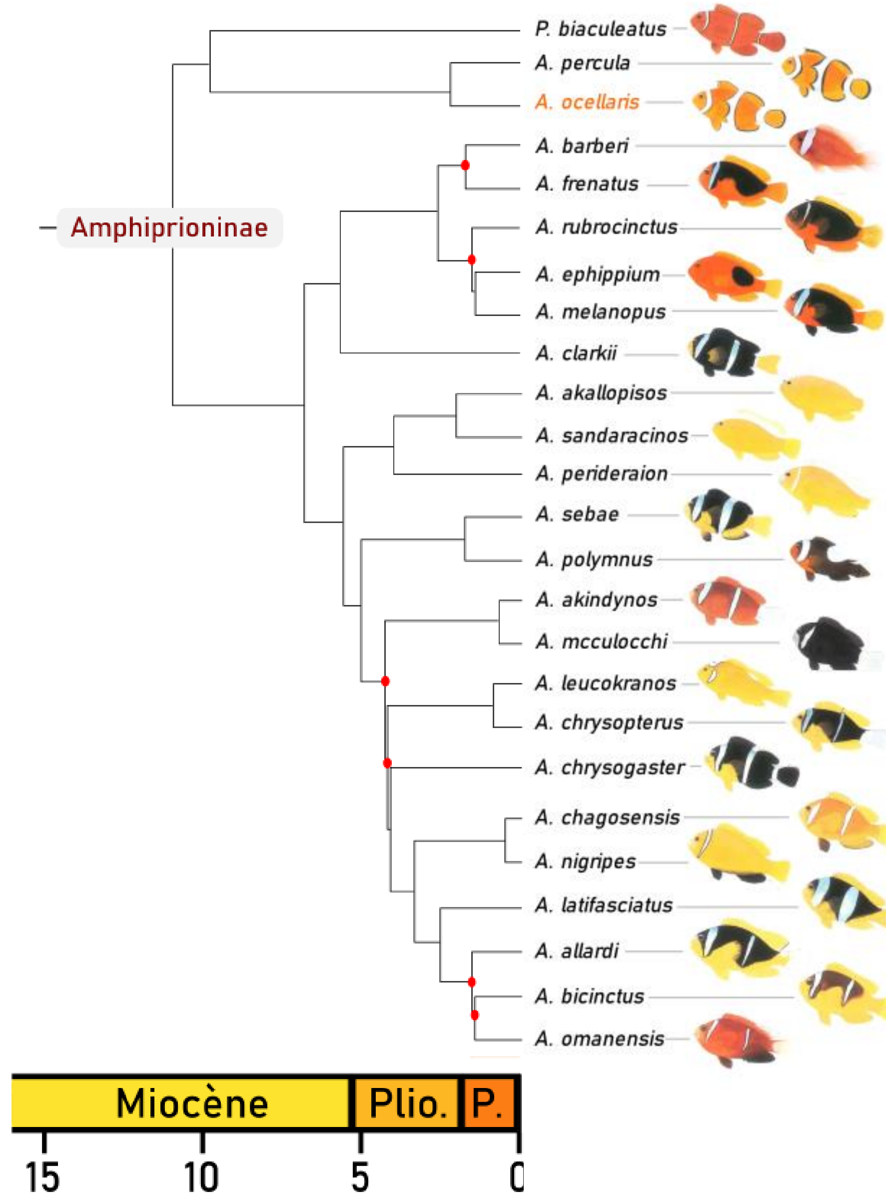
a. Clownfish: a new model system

b. Determinism of clownfish coloration

Why a new model system ?

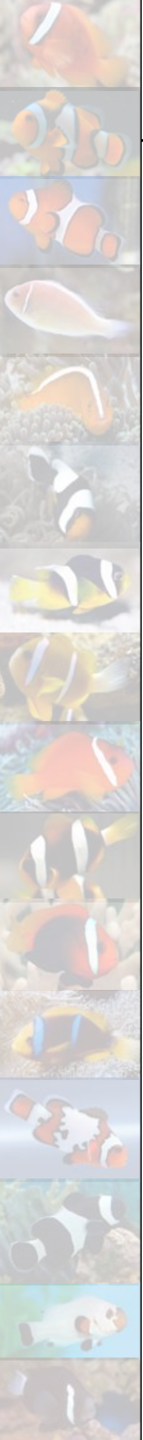
Ecology and evolution of clownfish *Amphiprion ocellaris*

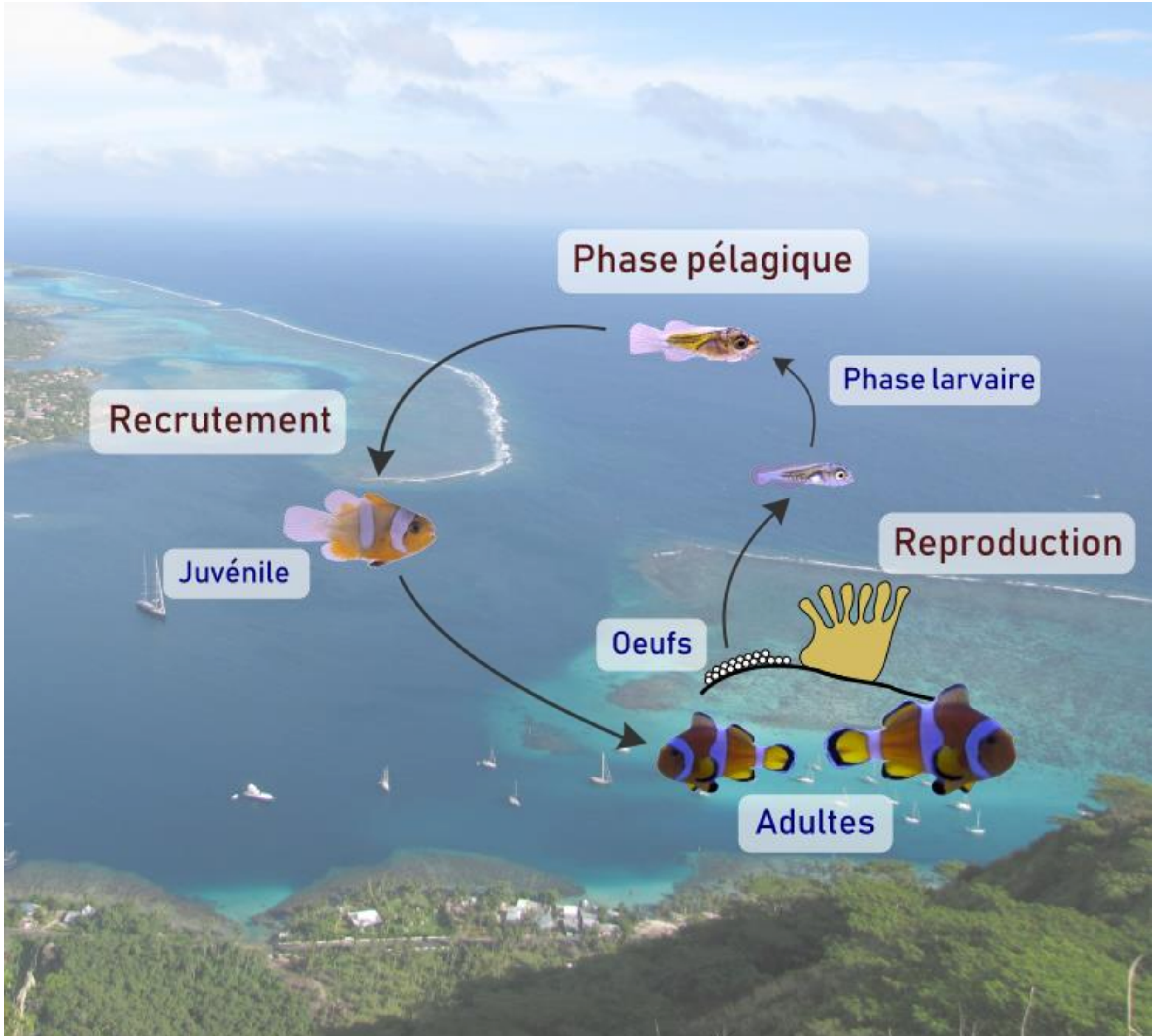


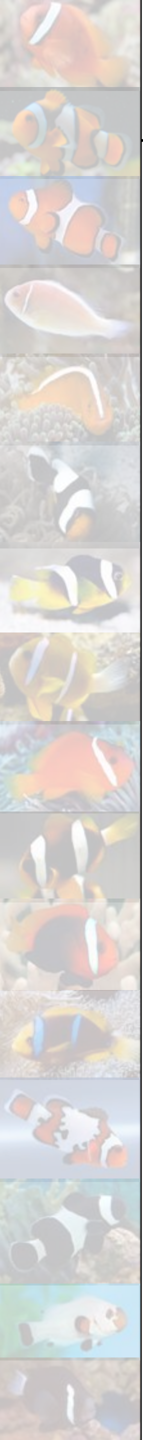


Topology adapted from Litsios *et al.* (2012), Litsios, Pearman *et al.* (2014) and Litsios and Salamin (2014)

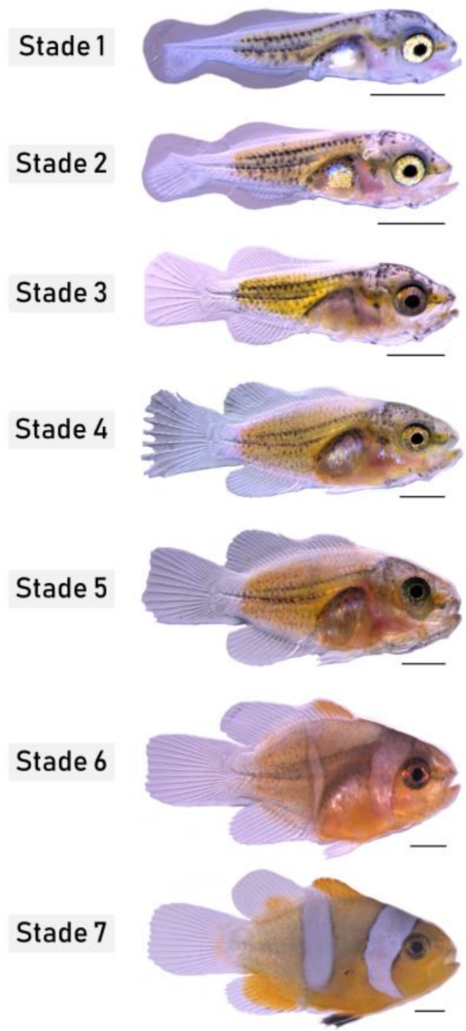
Lifecycle of clownfish *A. ocellaris*

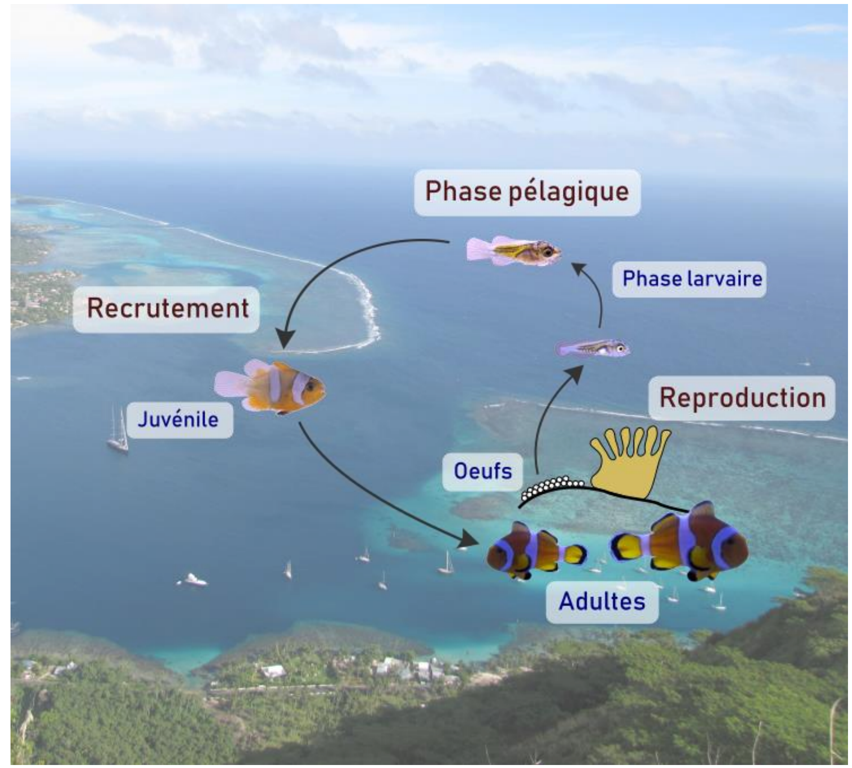






Pigmentary changes during *A. ocellaris* post-embryonic development





OBSERVATOIRE OCÉANOLOGIQUE de Banyuls/Mer 1882

Roux *et al.* (in prep.)

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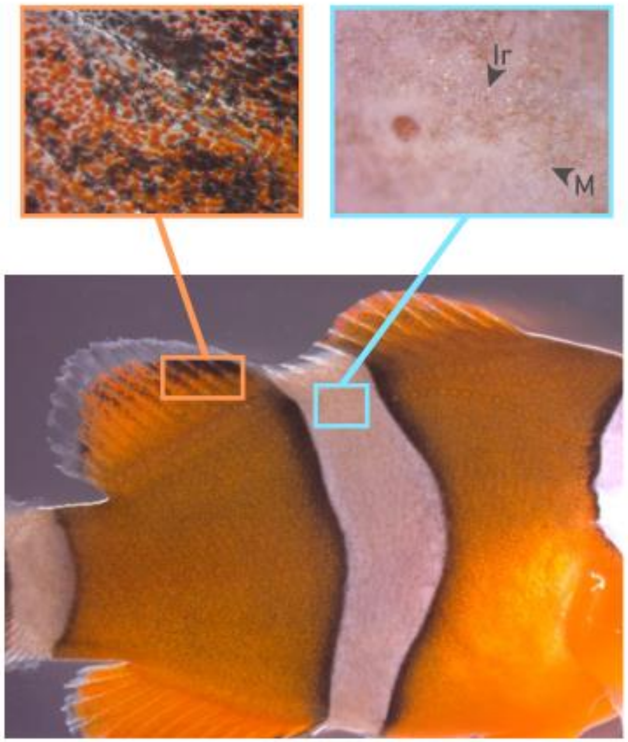
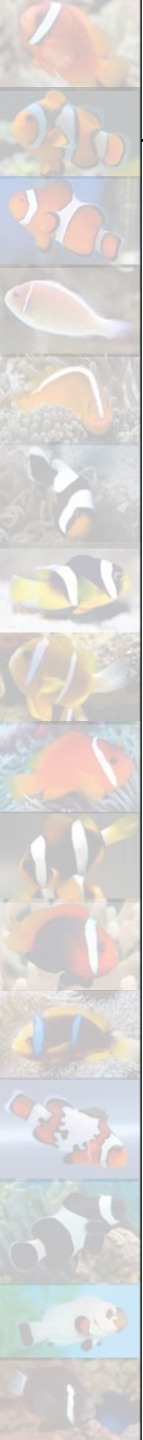
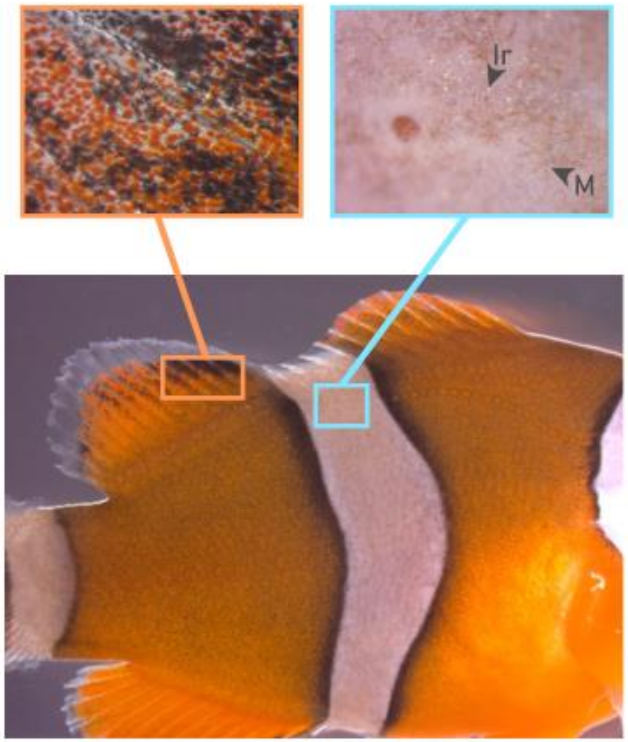
Cells present in each band in *A. ocellaris*



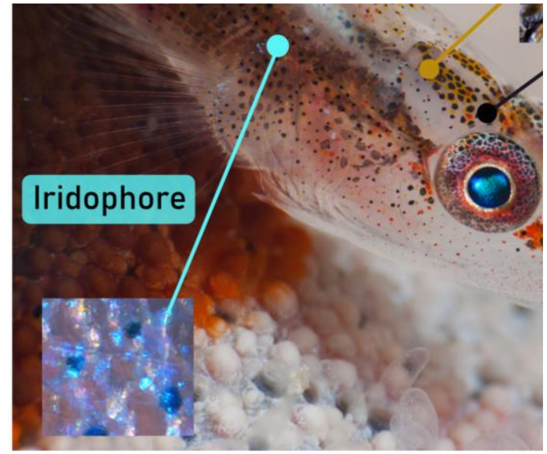
Pictures: N. Roux



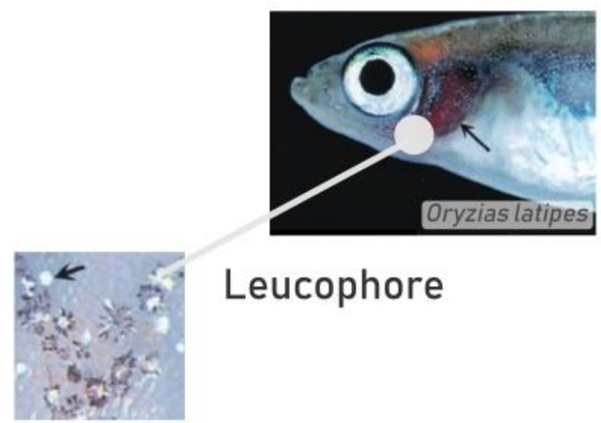
Cells present in each band in *A. ocellaris*



Pictures: N. Roux



?



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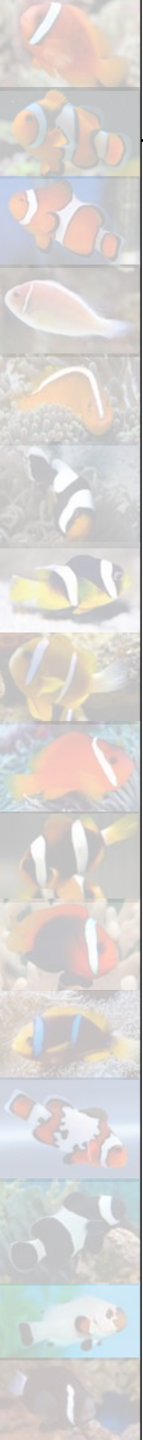

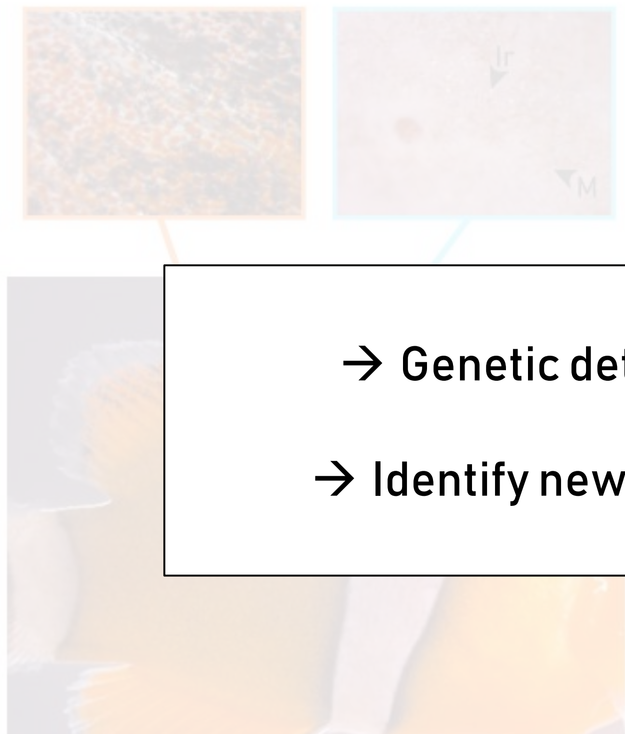

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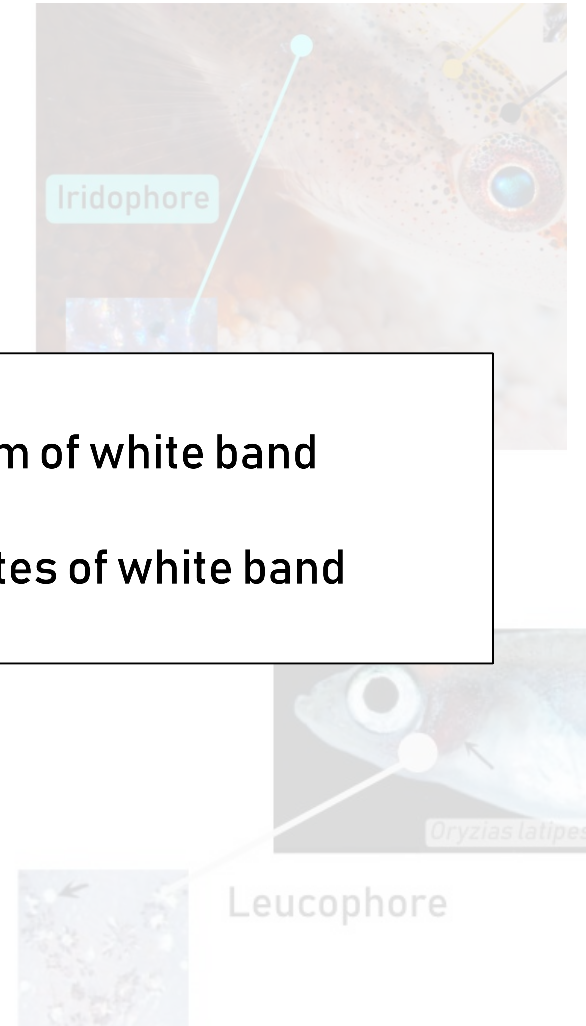
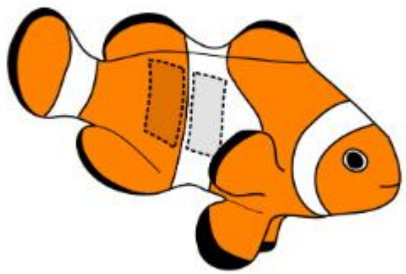


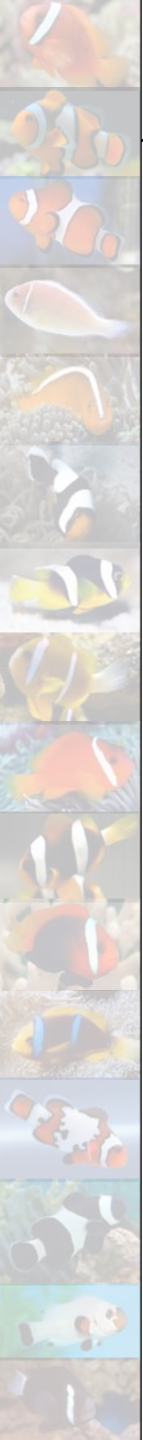
?

→ Genetic determinism of white band

→ Identify new candidates of white band

Comparison white vs. orange skin using RNA-Seq





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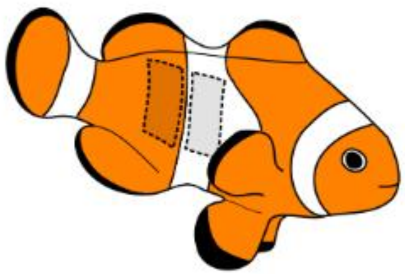


Pauline Salis

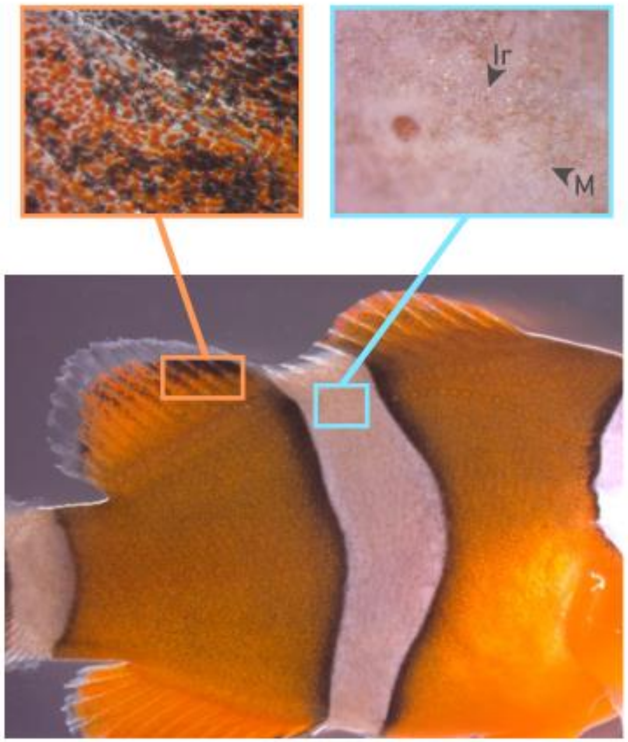
Anna Marcionnetti

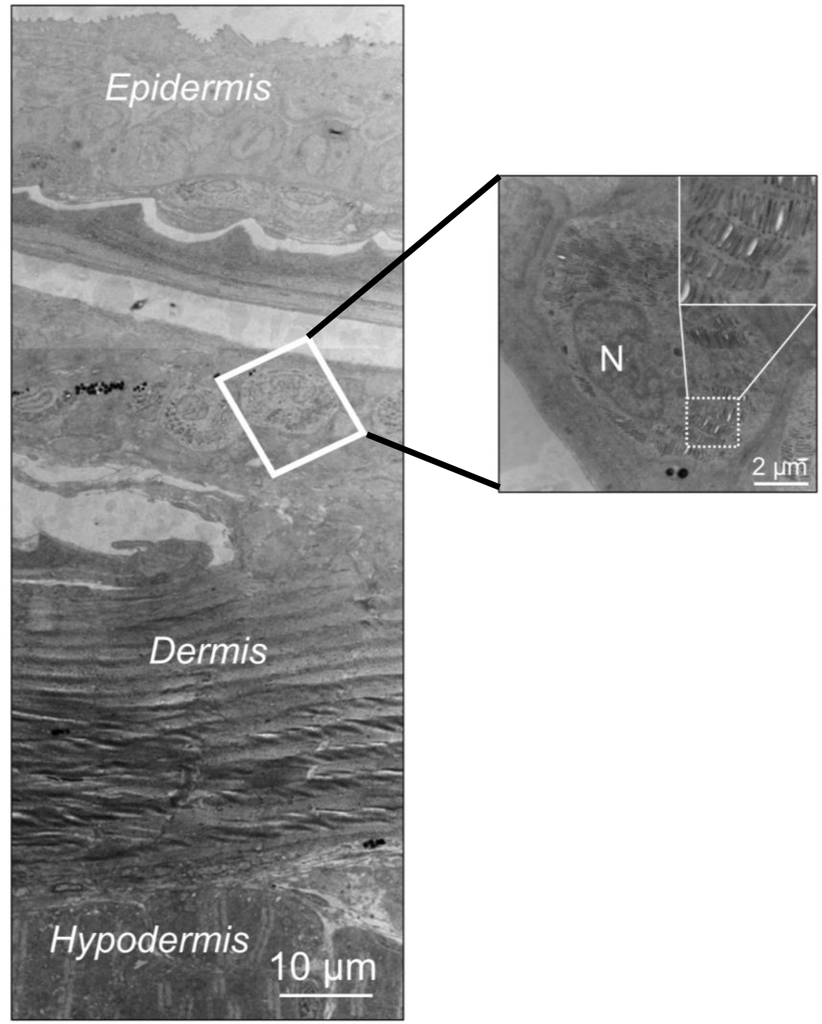
Nicolas Salamin

Carine Rey

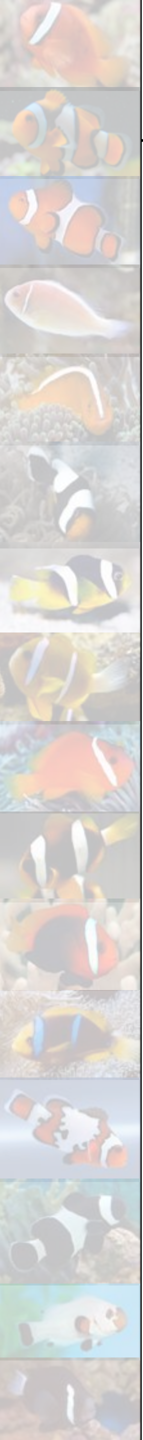
Marie Sémon

White skin of *A. ocellaris* harbors iridophores, not leucophores

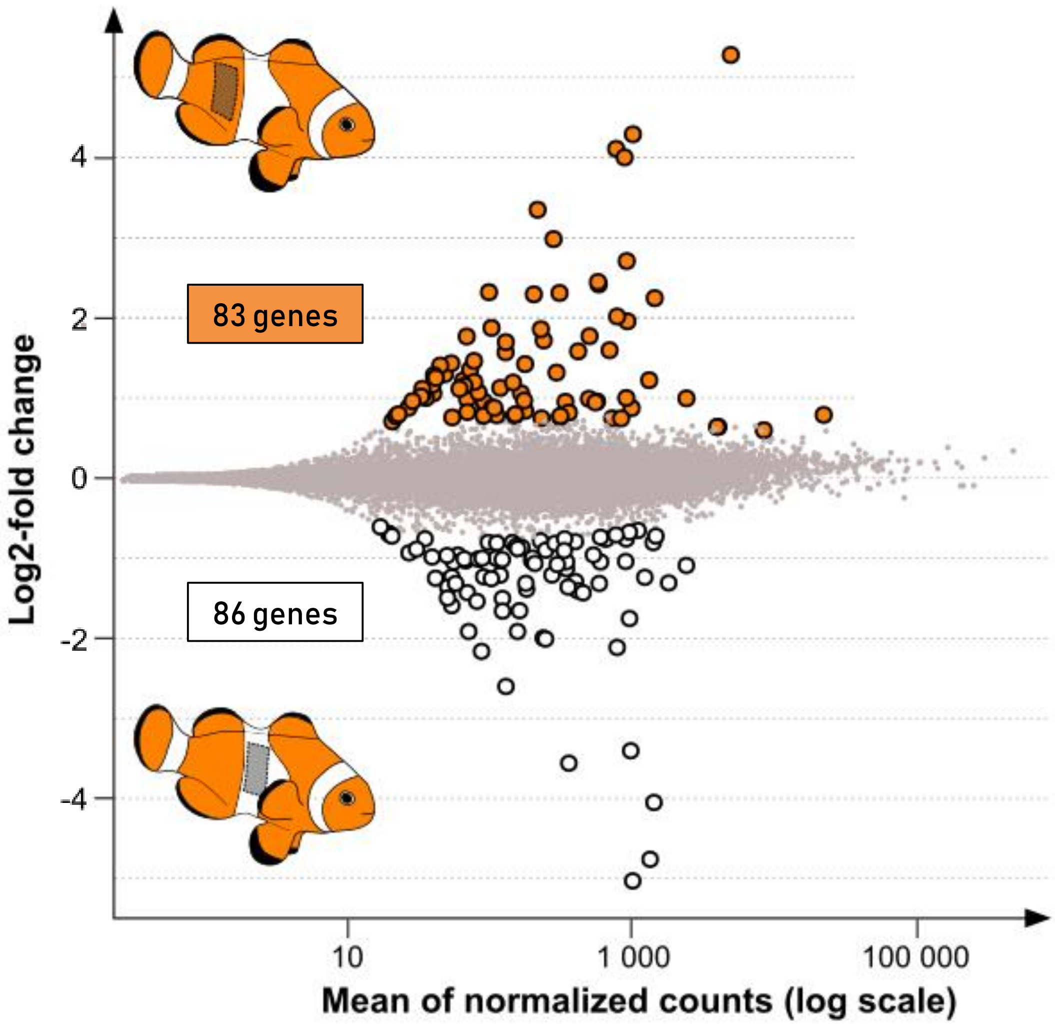




Salis*, Lorin* *et al.* (in prep.)



RNA-Seq comparison of white vs. orange skin



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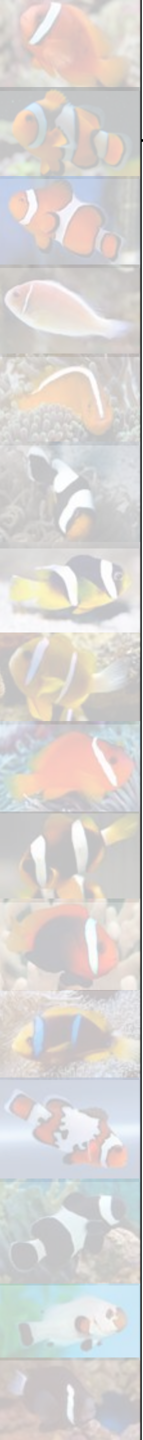

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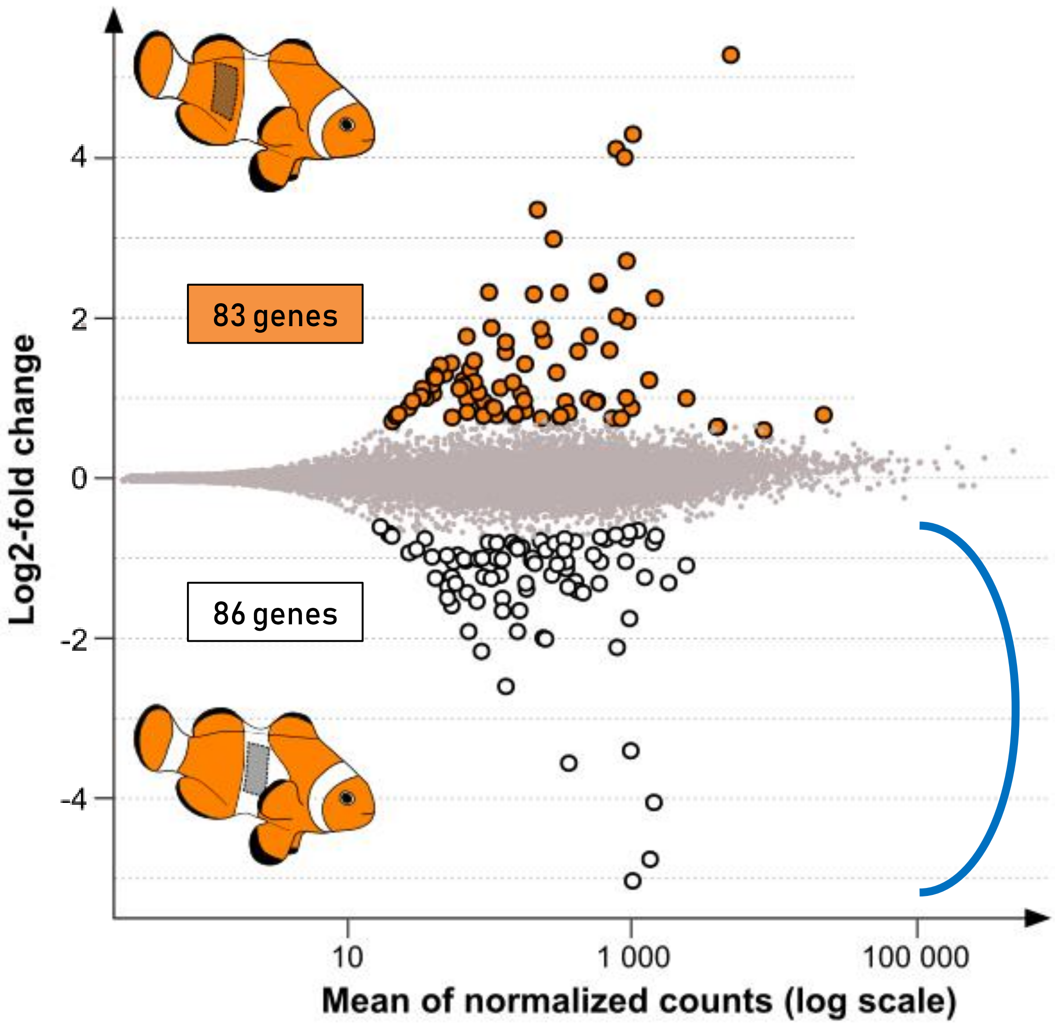
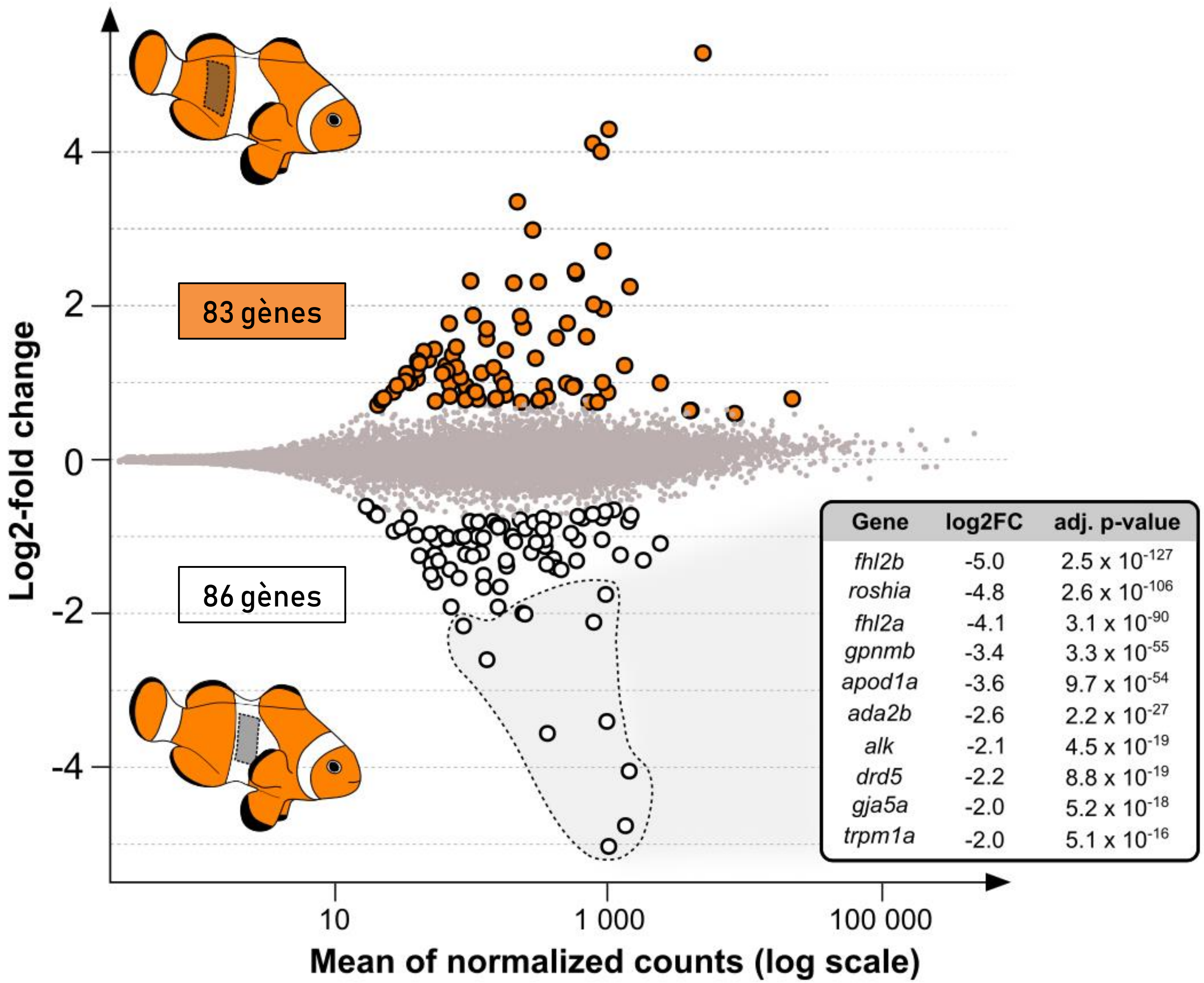


Comparable with
zebrafish iridophores

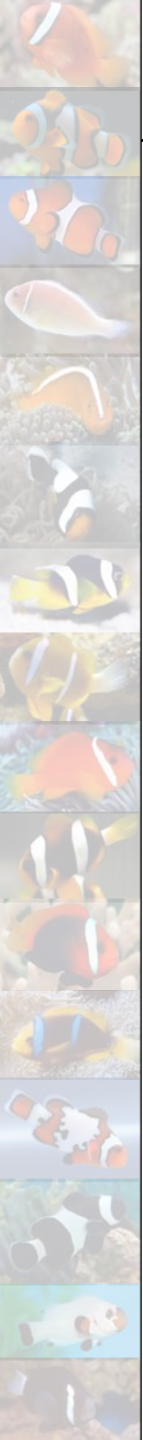
Salis*, Lorin* *et al.* (in prep.)

10 most DEGs in white skin



Gene	log2FC	adj. p-value
fhl2b	-5.0	2.5×10^{-127}
roshia	-4.8	2.6×10^{-106}
fhl2a	-4.1	3.1×10^{-90}
gpnmb	-3.4	3.3×10^{-55}
apod1a	-3.6	9.7×10^{-54}
ada2b	-2.6	2.2×10^{-27}
alk	-2.1	4.5×10^{-19}
drd5	-2.2	8.8×10^{-19}
gja5a	-2.0	5.2×10^{-18}
trpm1a	-2.0	5.1×10^{-16}

Salis*, Lorin* *et al.* (in prep.)



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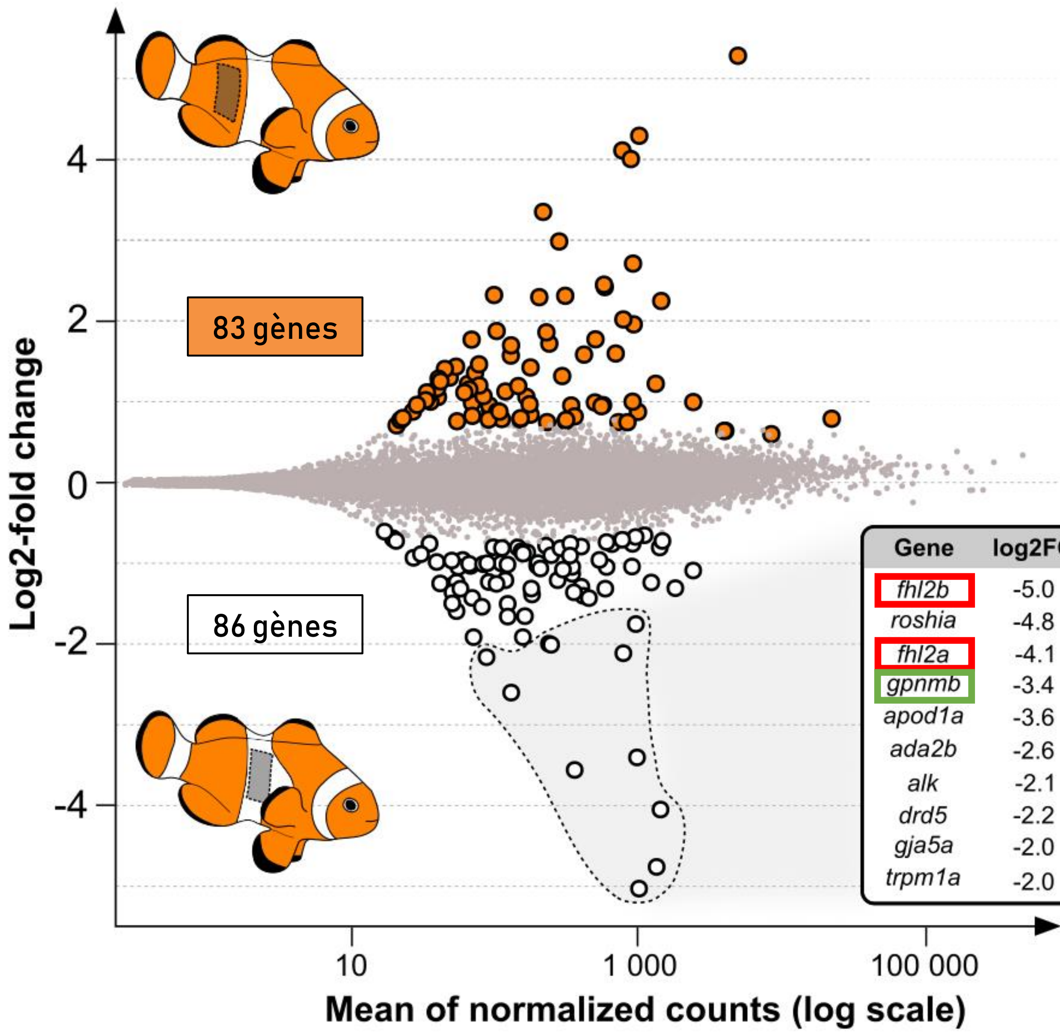

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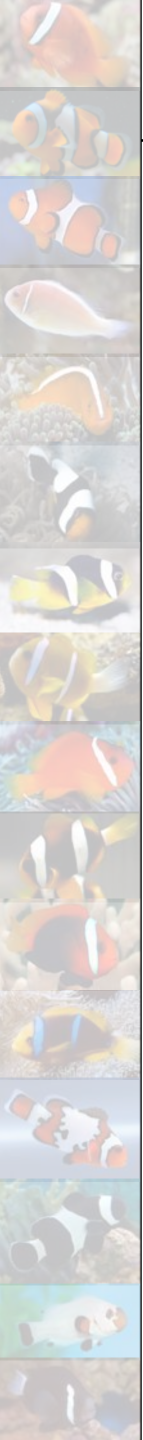
Salis*, Lorin* *et al.* (in prep.) / Santos *et al.* (2014) *Nature Comm.*



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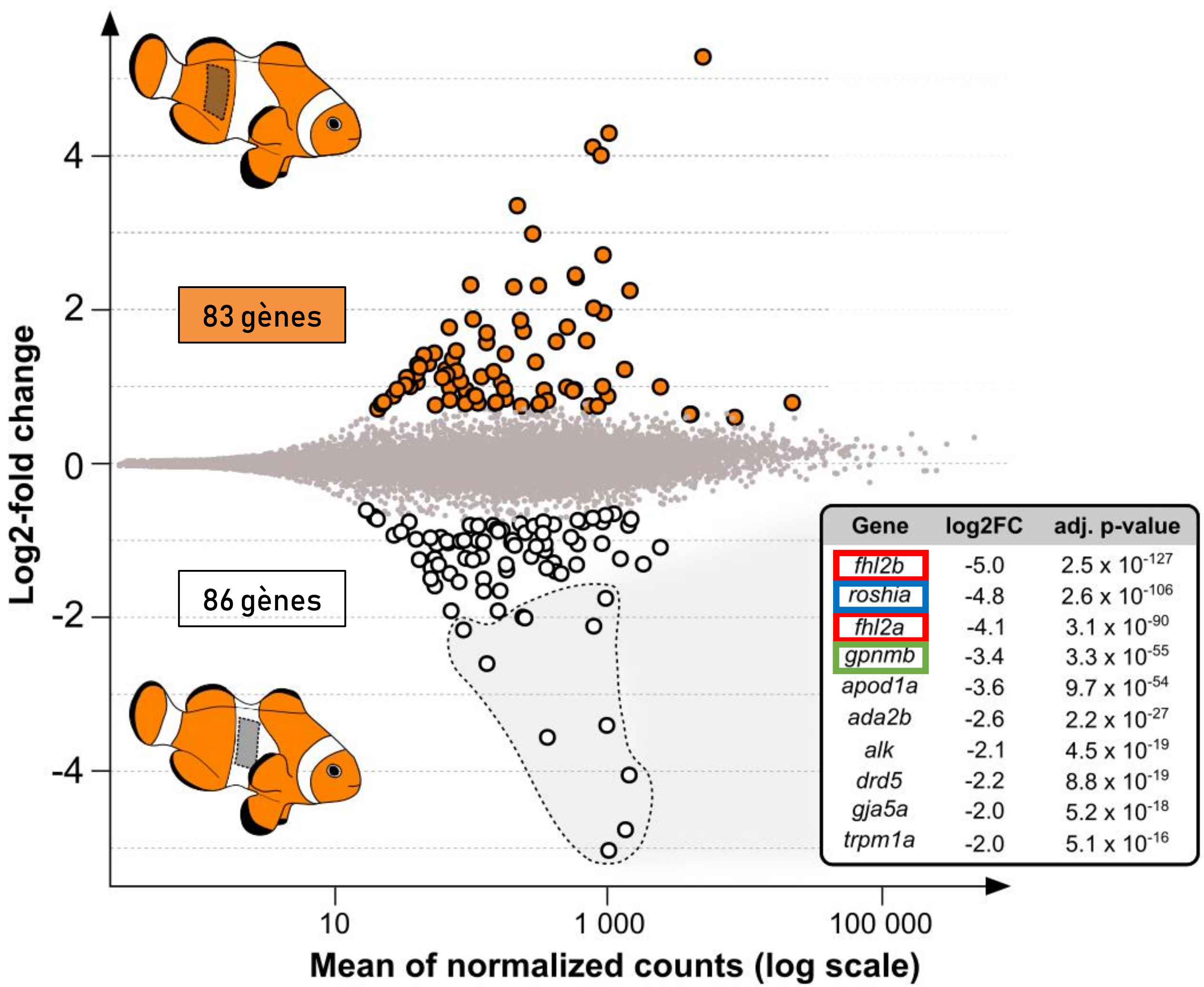

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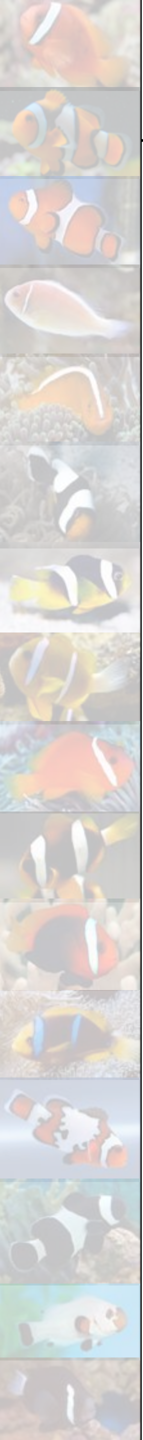
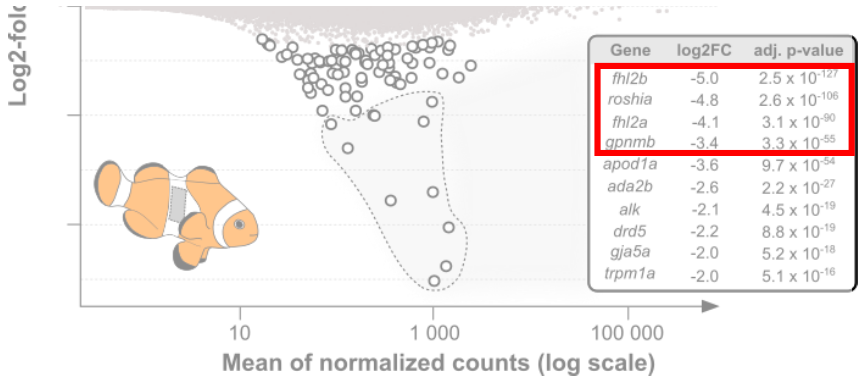
non-annotated
→ *roshi-a*

Salis*, Lorin* *et al.* (in prep.)

Functional validation of new candidate genes using CRISPR-Cas9 in *D. rerio*





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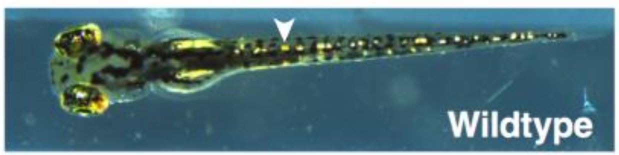

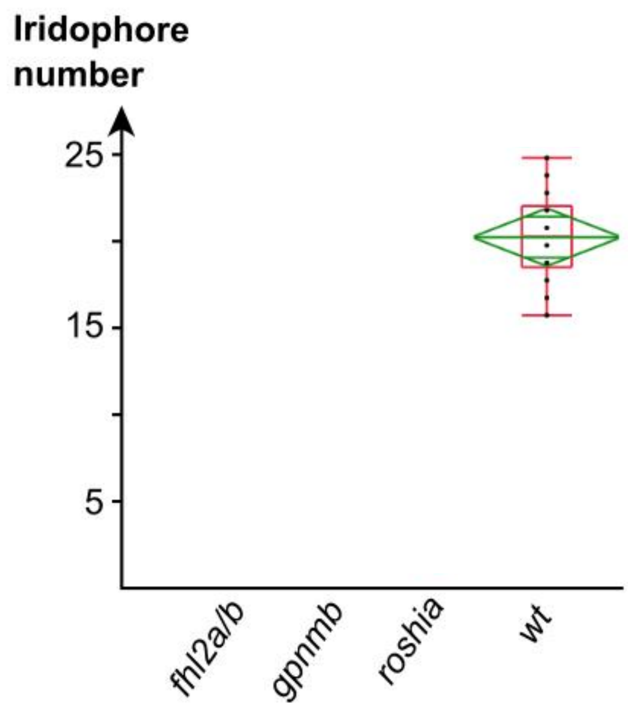

David Parichy

Victor Lewis

Salis*, Lorin* *et al.* (in prep.)

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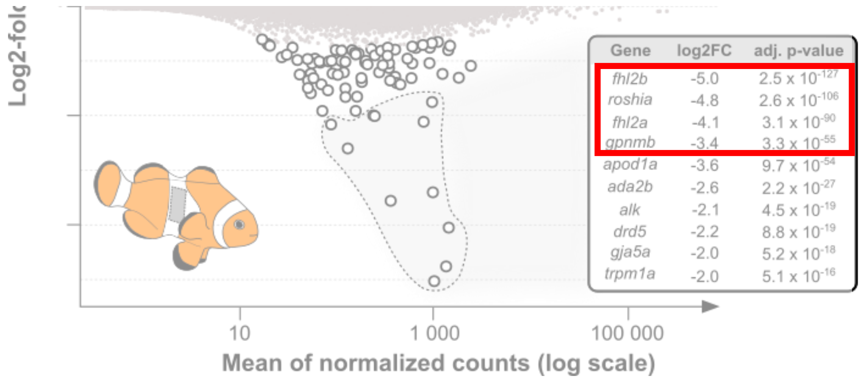

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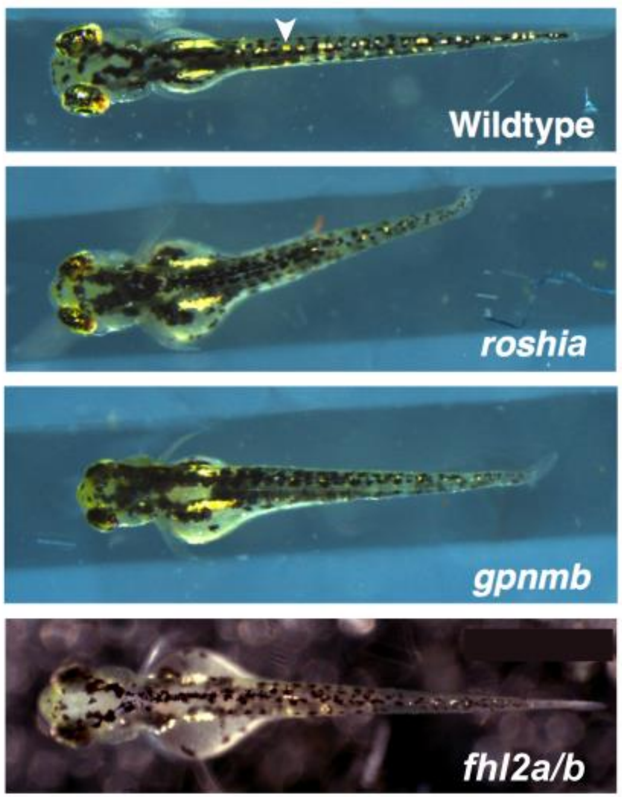

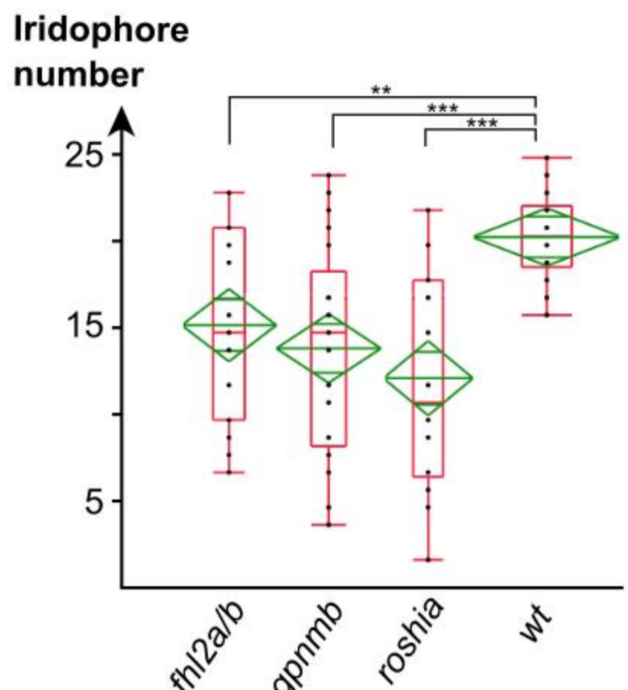

University of Virginia

David Parichy

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Salis*, Lorin* *et al.* (in prep.)

Introduction

I. Coloration: a great system to study genotype-phenotype relationships

a. Coloration in the History of Science

b. Coloration in Vertebrates

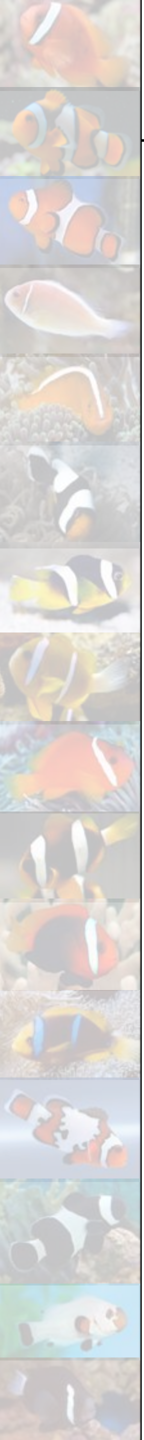
II. A case study: clownfish coloration

a. Clownfish: a new model system

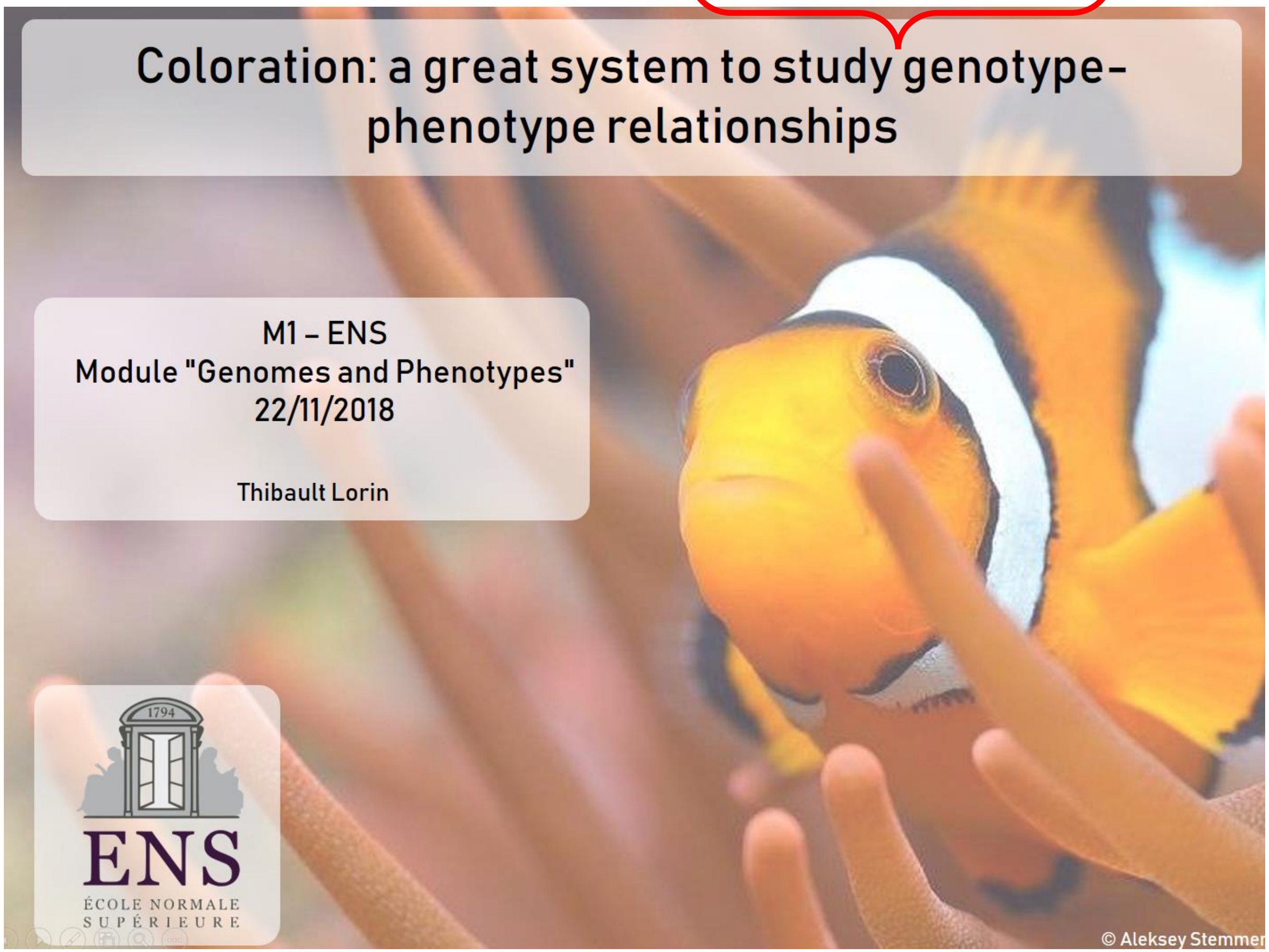
b. Determinism of clownfish coloration

Conclusion

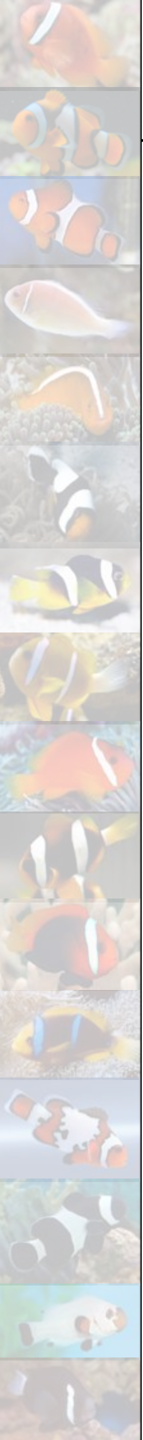
Evolution of GP relationships

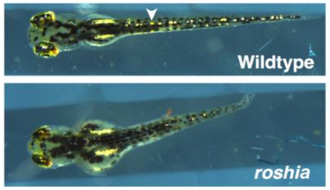


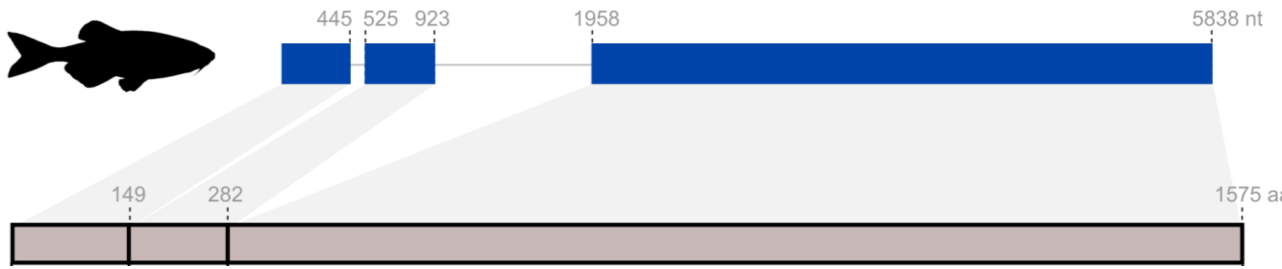
The EVOLUTION of

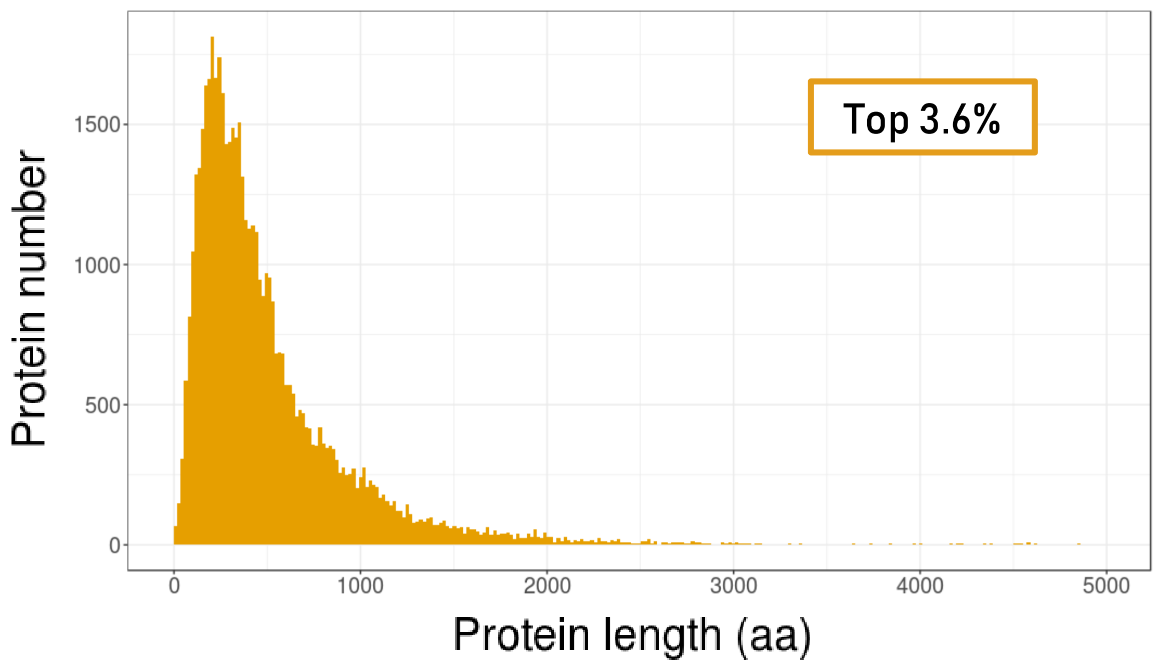


Structure and putative function of Roshi-a

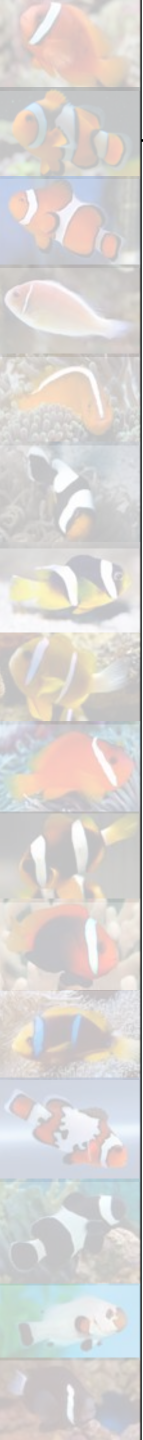








Lorin *et al.* (in prep.)



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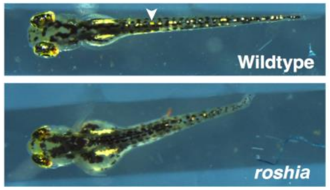
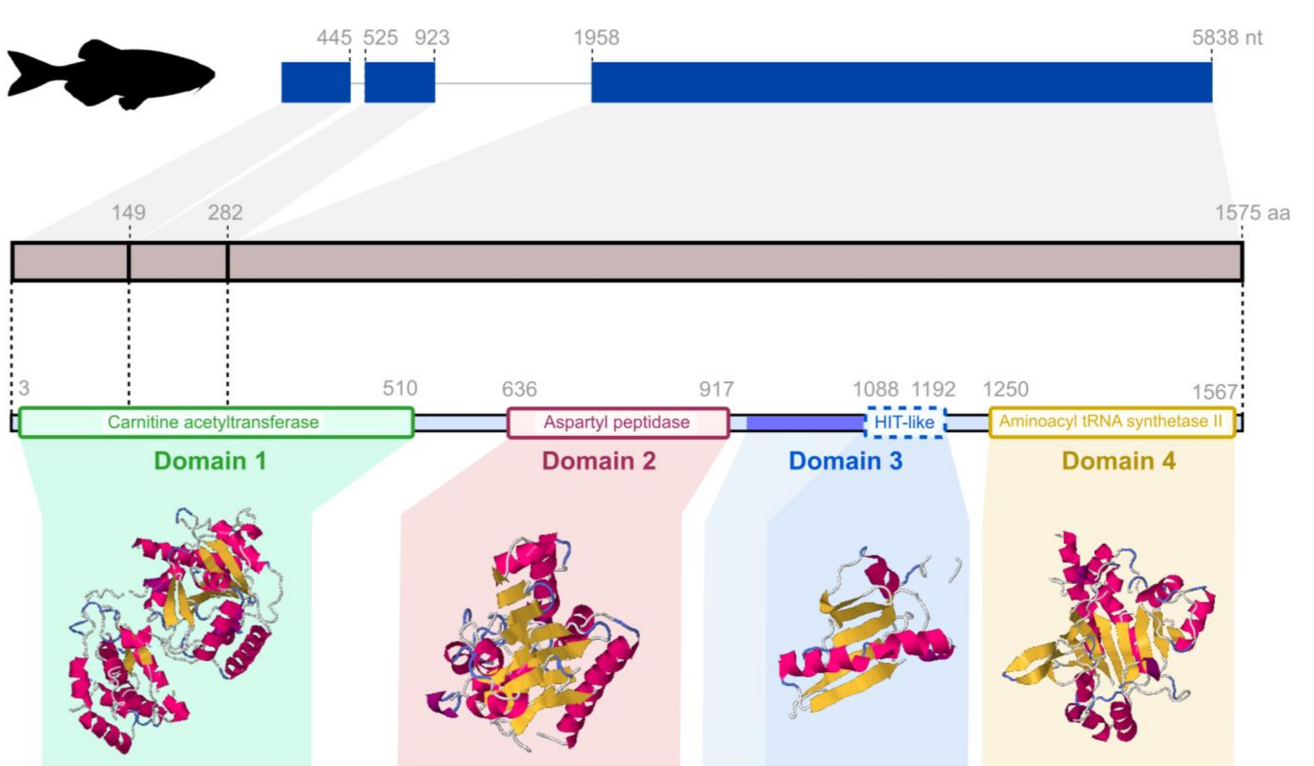


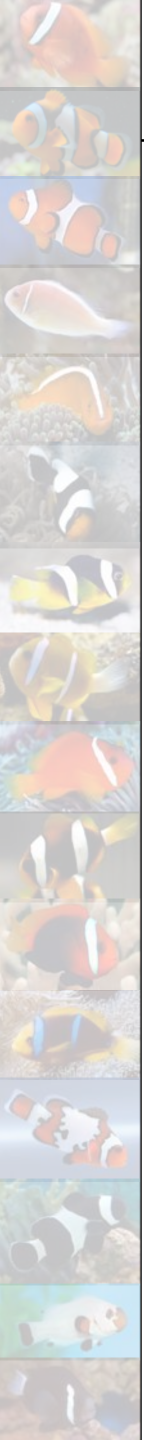
Roshi-a is "Long Putative Multifunctional Cytosolic Enzyme"

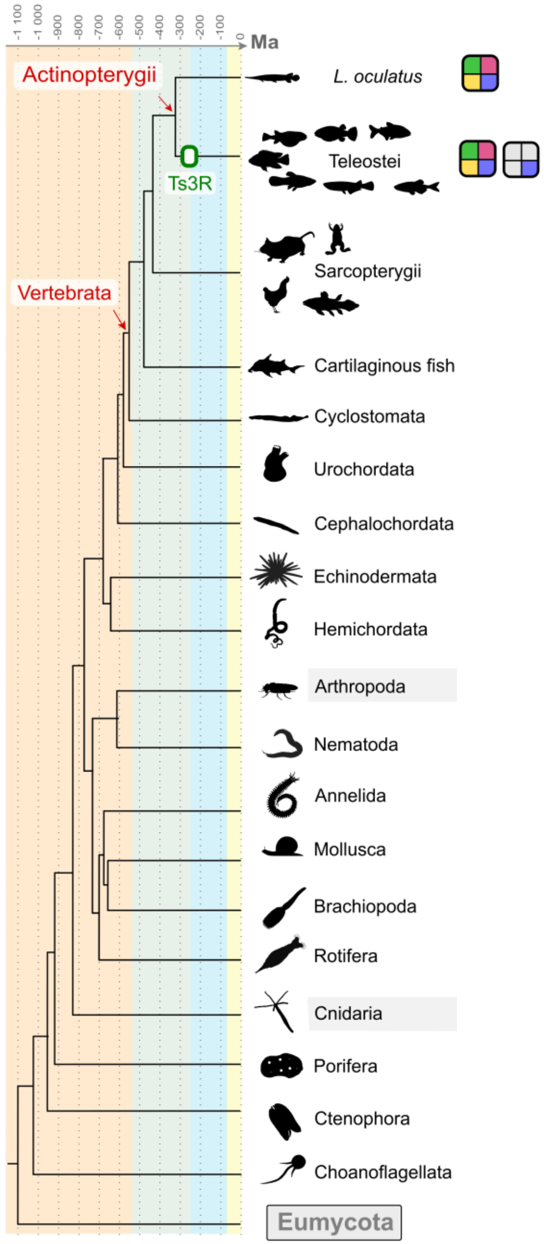


Carnitine acetyltransferase | Aspartyl peptidase | HIT-like | Aminoacyl-tRNA synthetase

Lorin *et al.* (in prep.)

Roshi has a patchy distribution within animals





Lorin *et al.* (in prep.)

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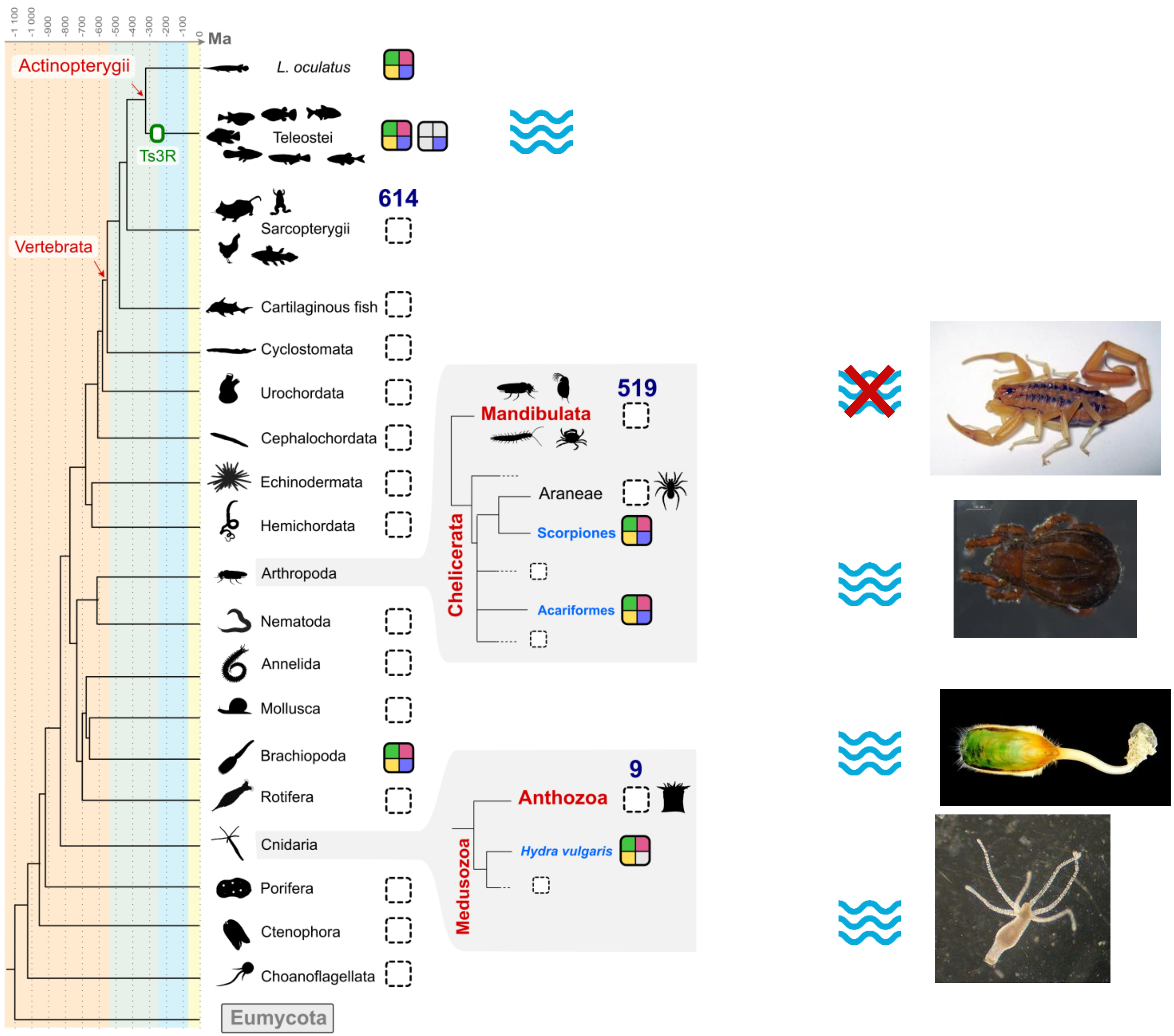

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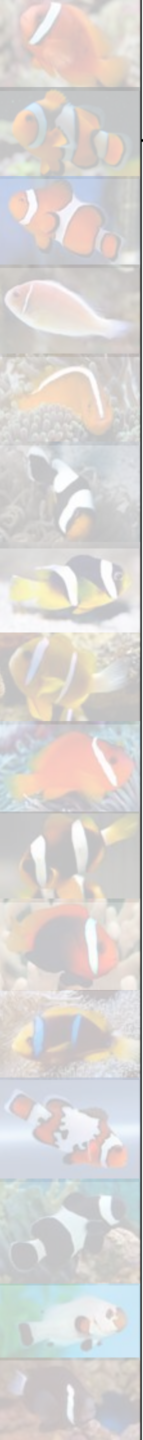
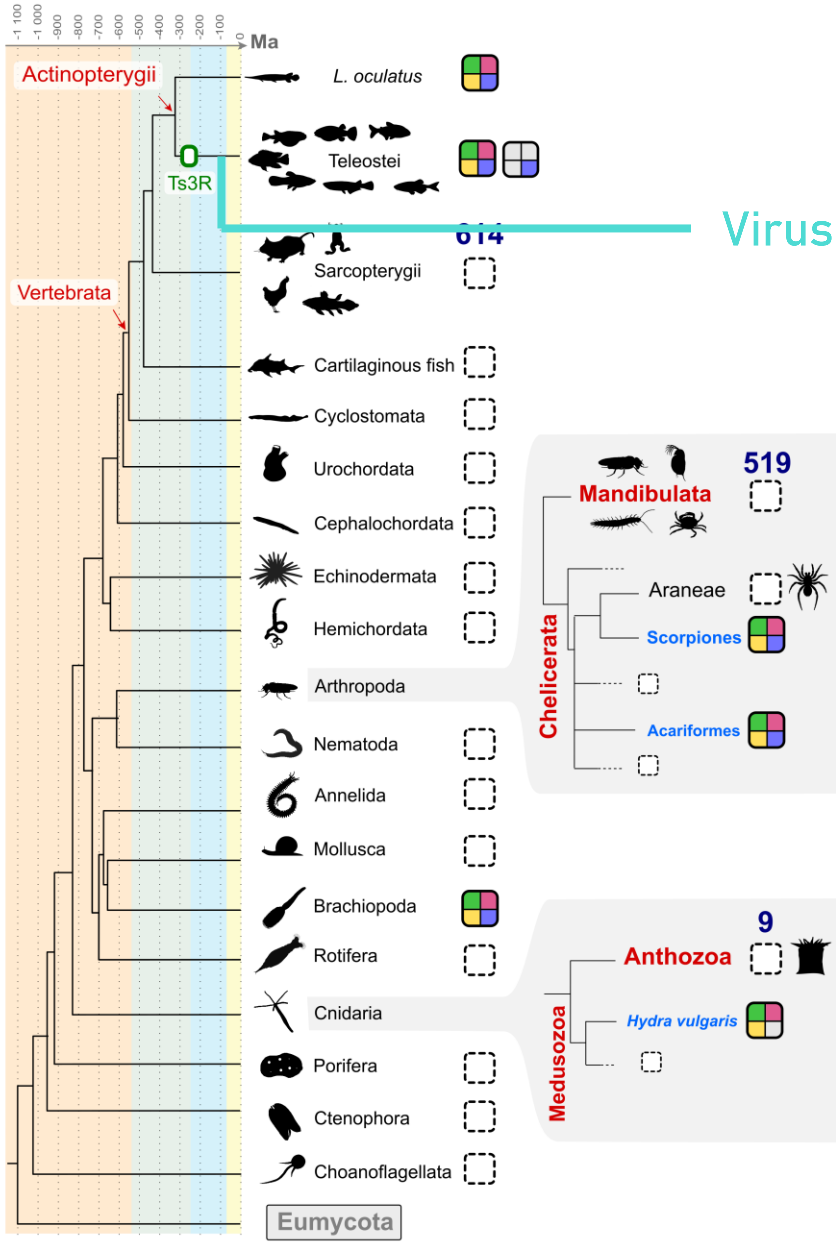
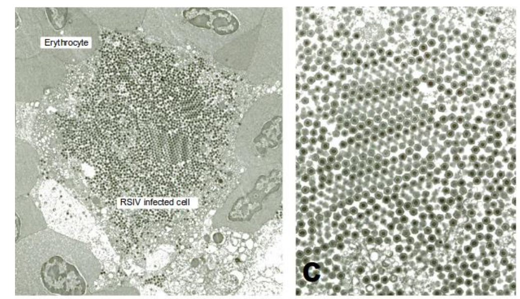
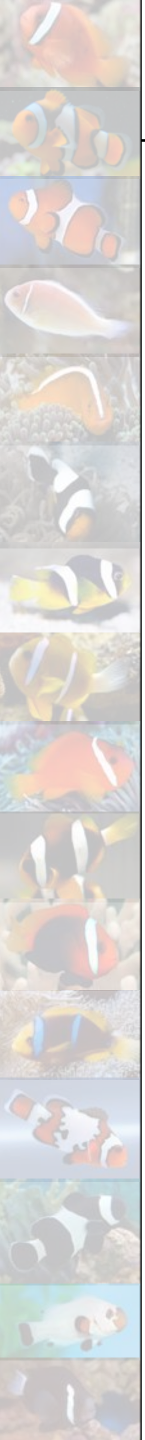




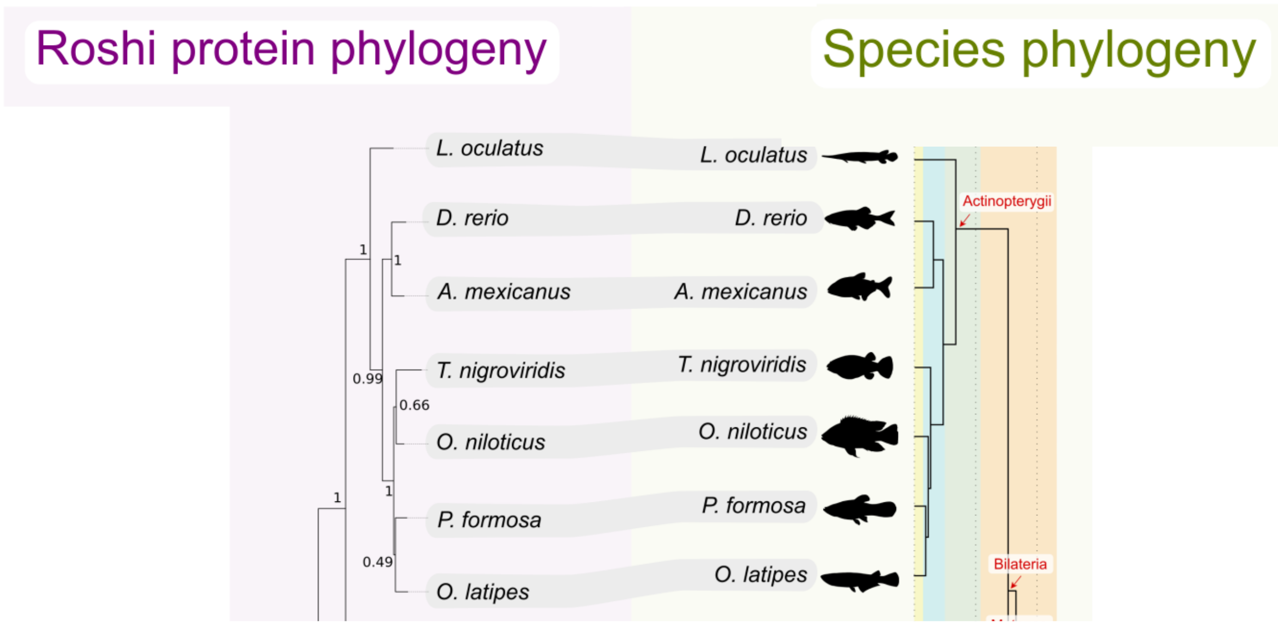
Viruses.... Iridoviruses!



Lorin *et al.* (in prep.)



roshi gene tree does not correspond to species tree



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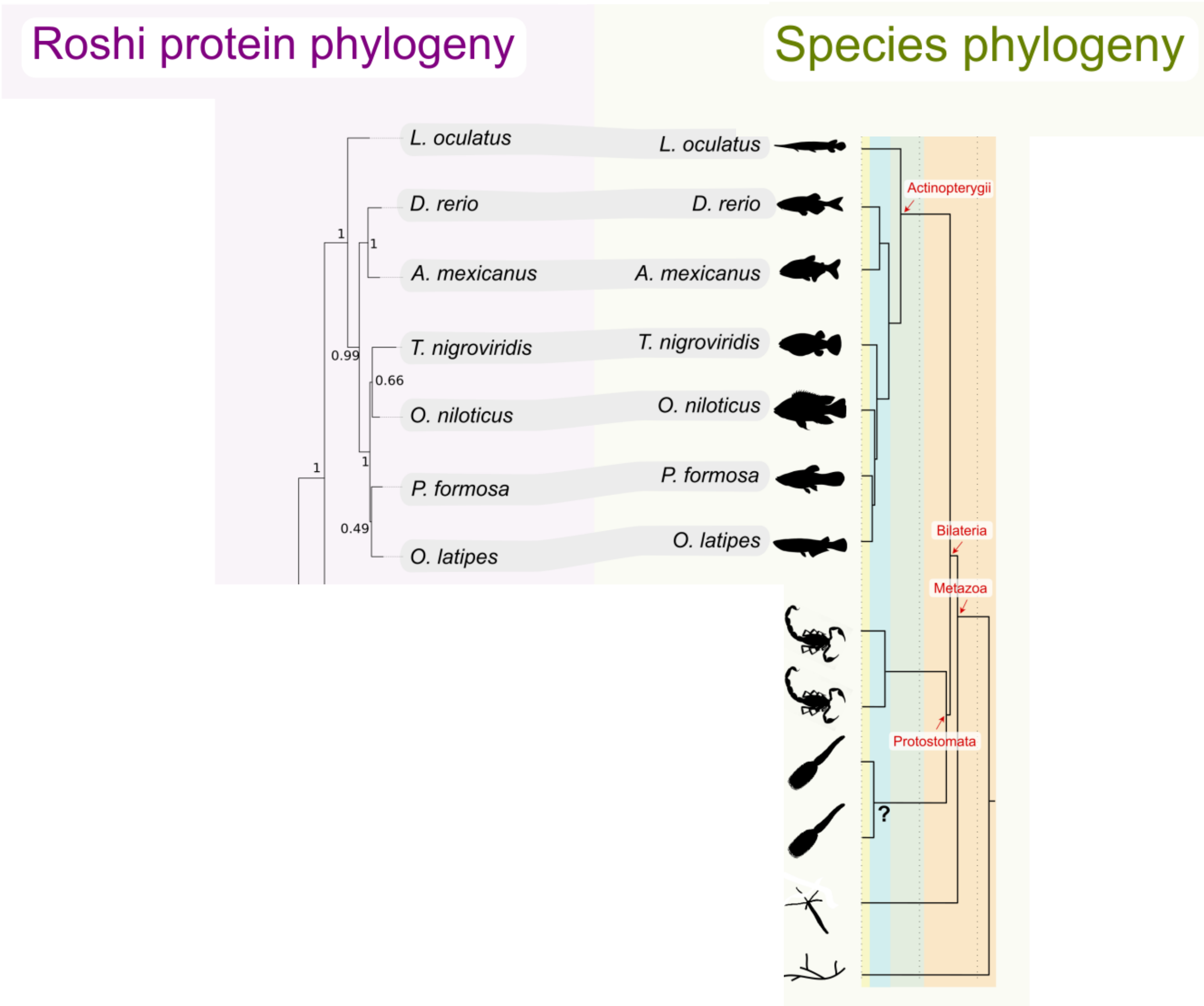
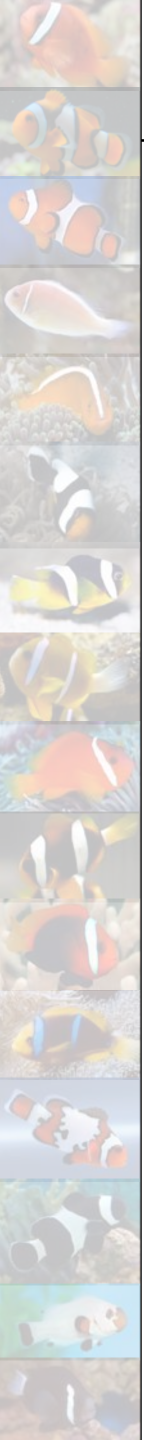


Lorin *et al.* (in prep.)



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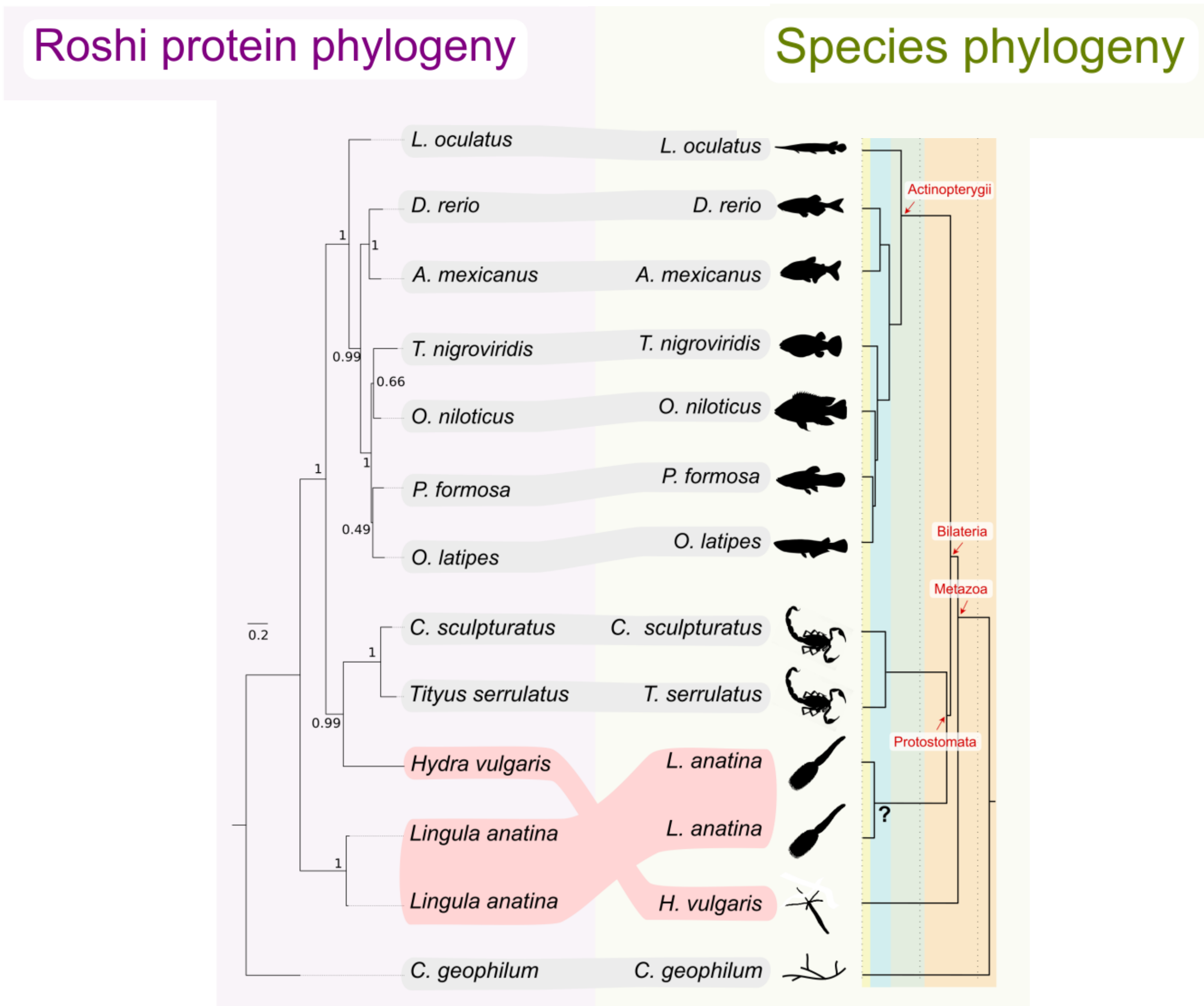
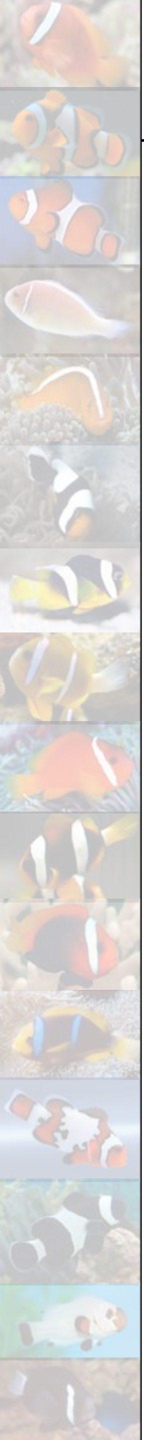
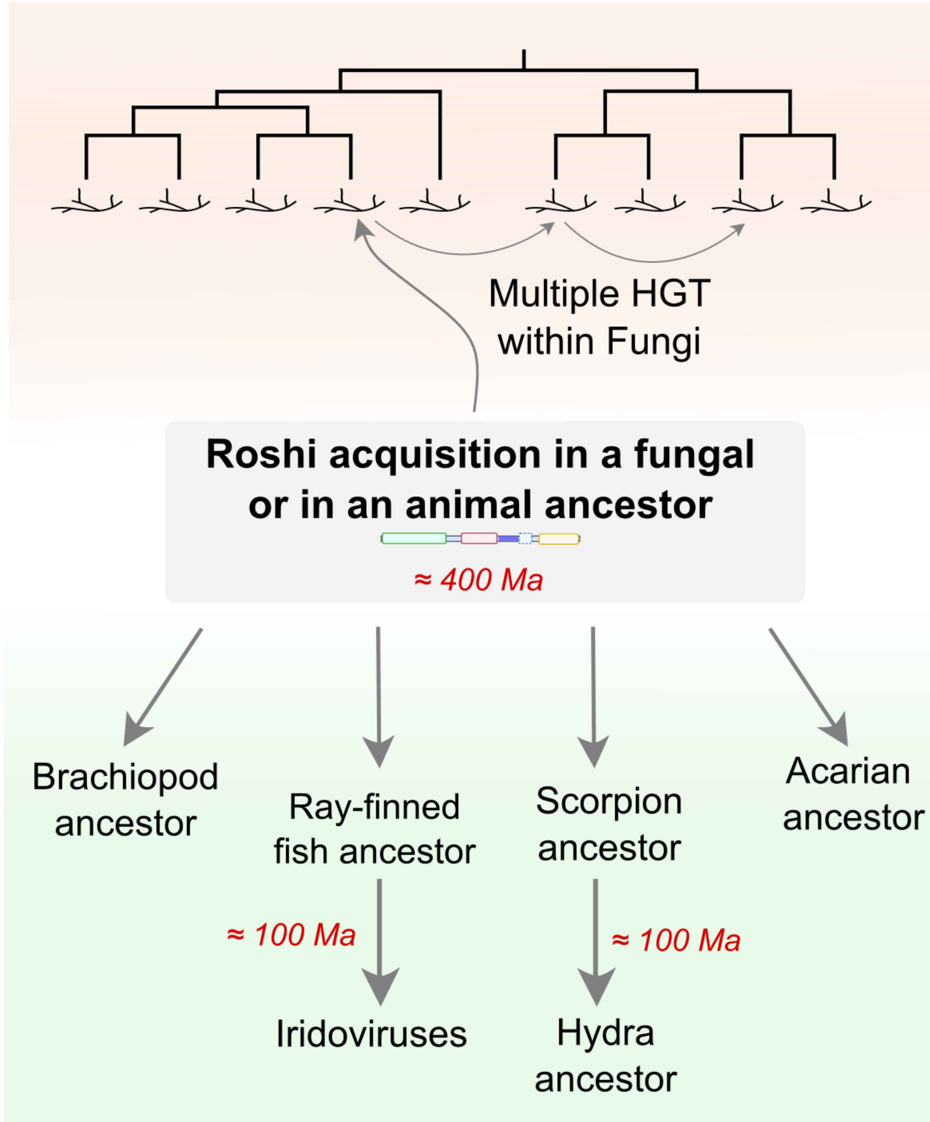


Lorin *et al.* (in prep.)

Hypothetical scenario for *roshi* evolution

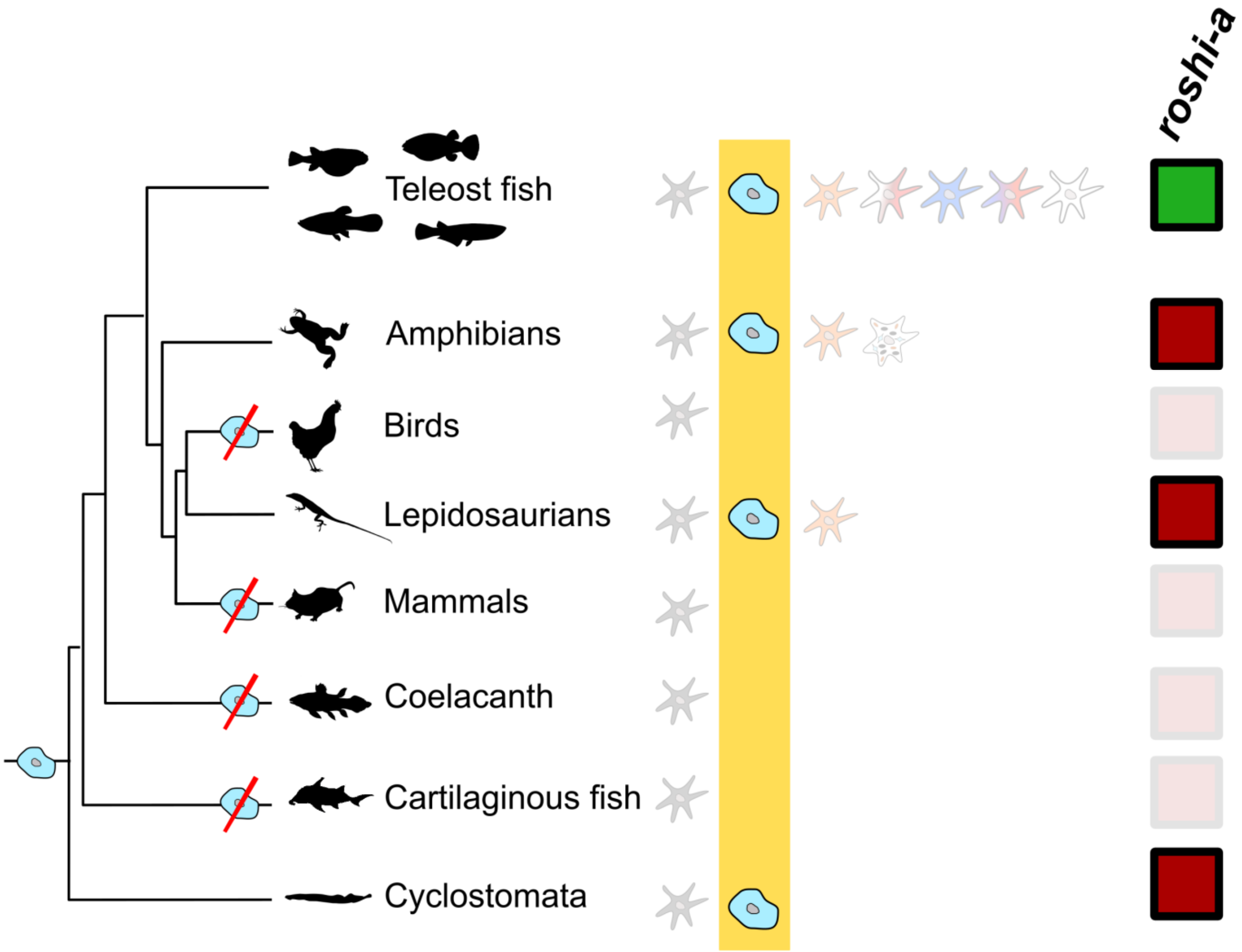


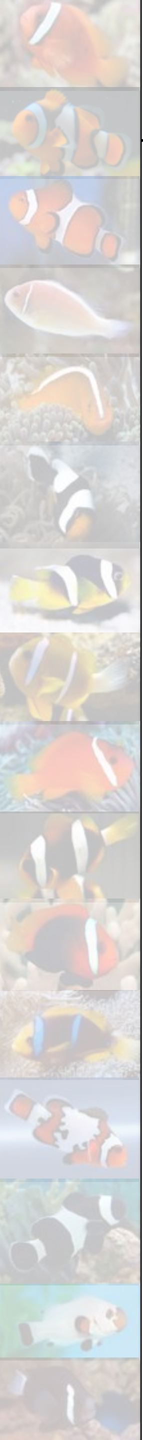


LBBE

Vincent Daubin

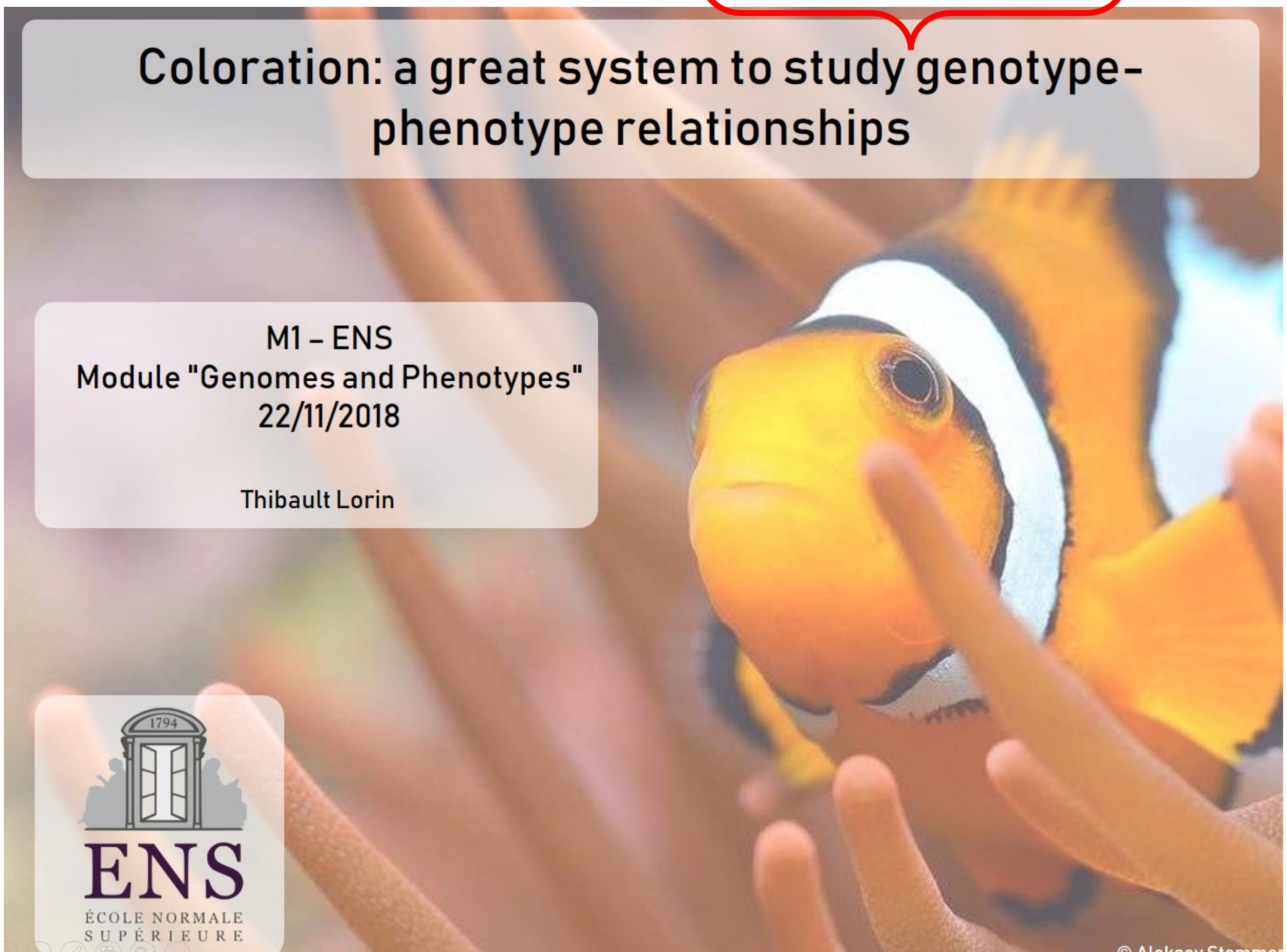
Roshi (among others) invite to reconsider the supposed monophyly of vertebrate iridophores

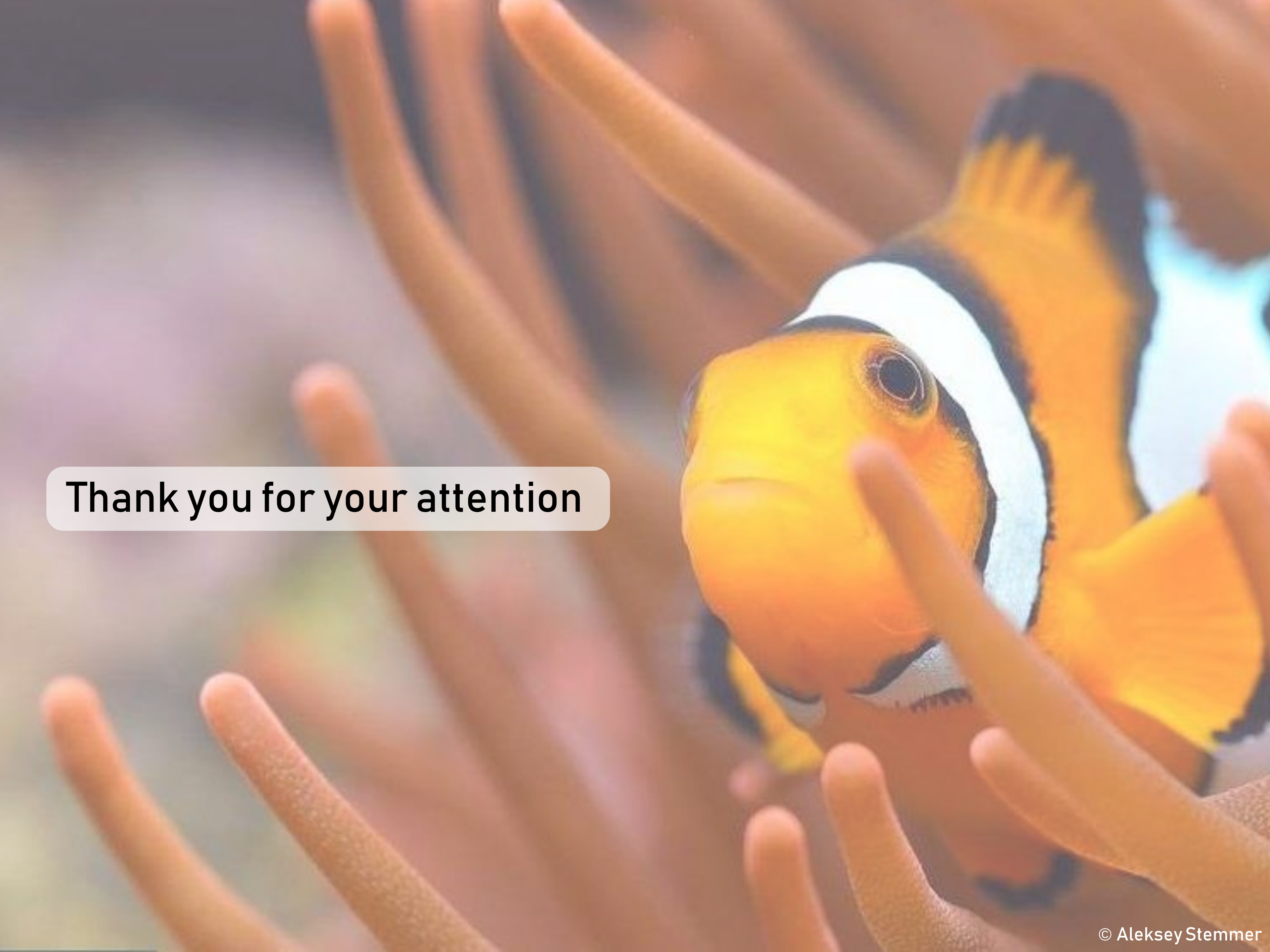




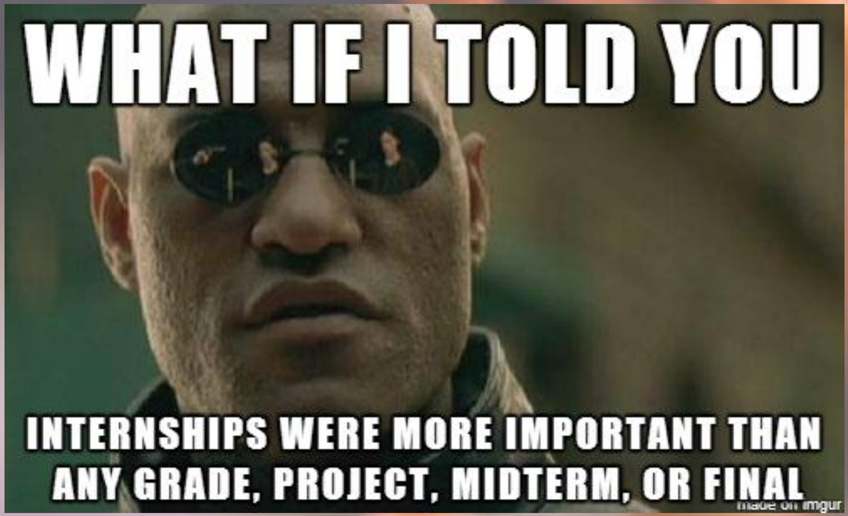
Evolution of GP relationships

The EVOLUTION of → Importance of HGT?





Thank you for your attention



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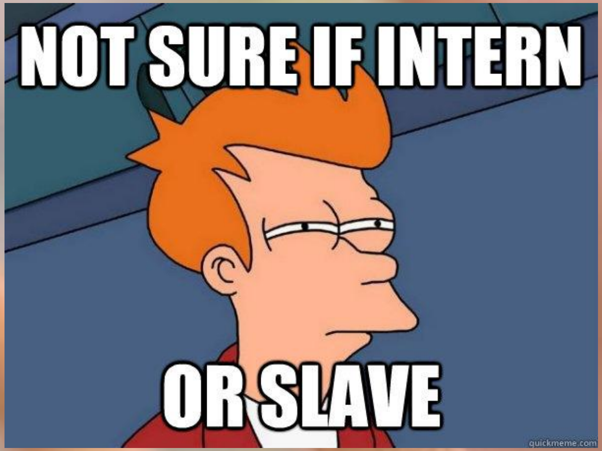

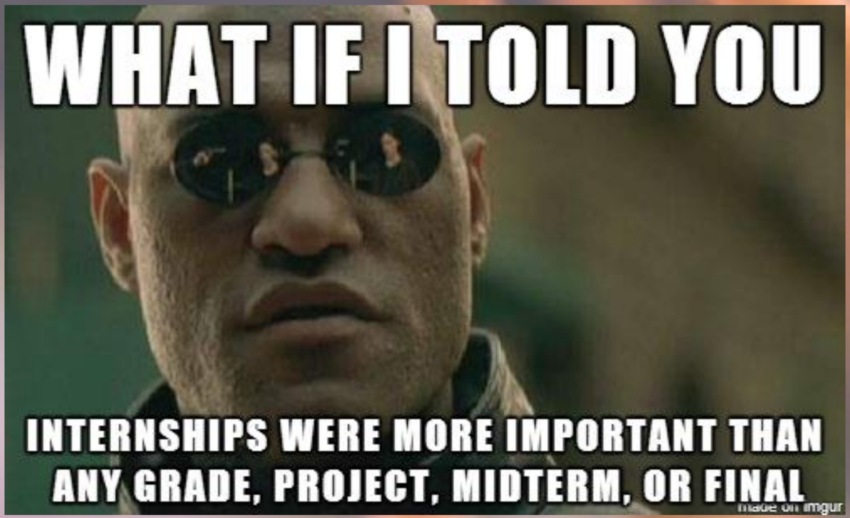

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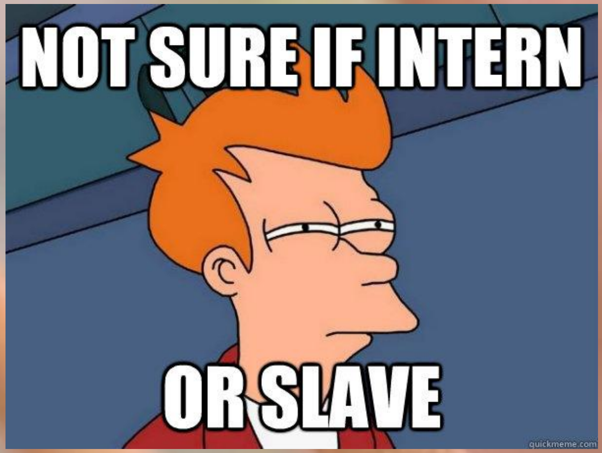
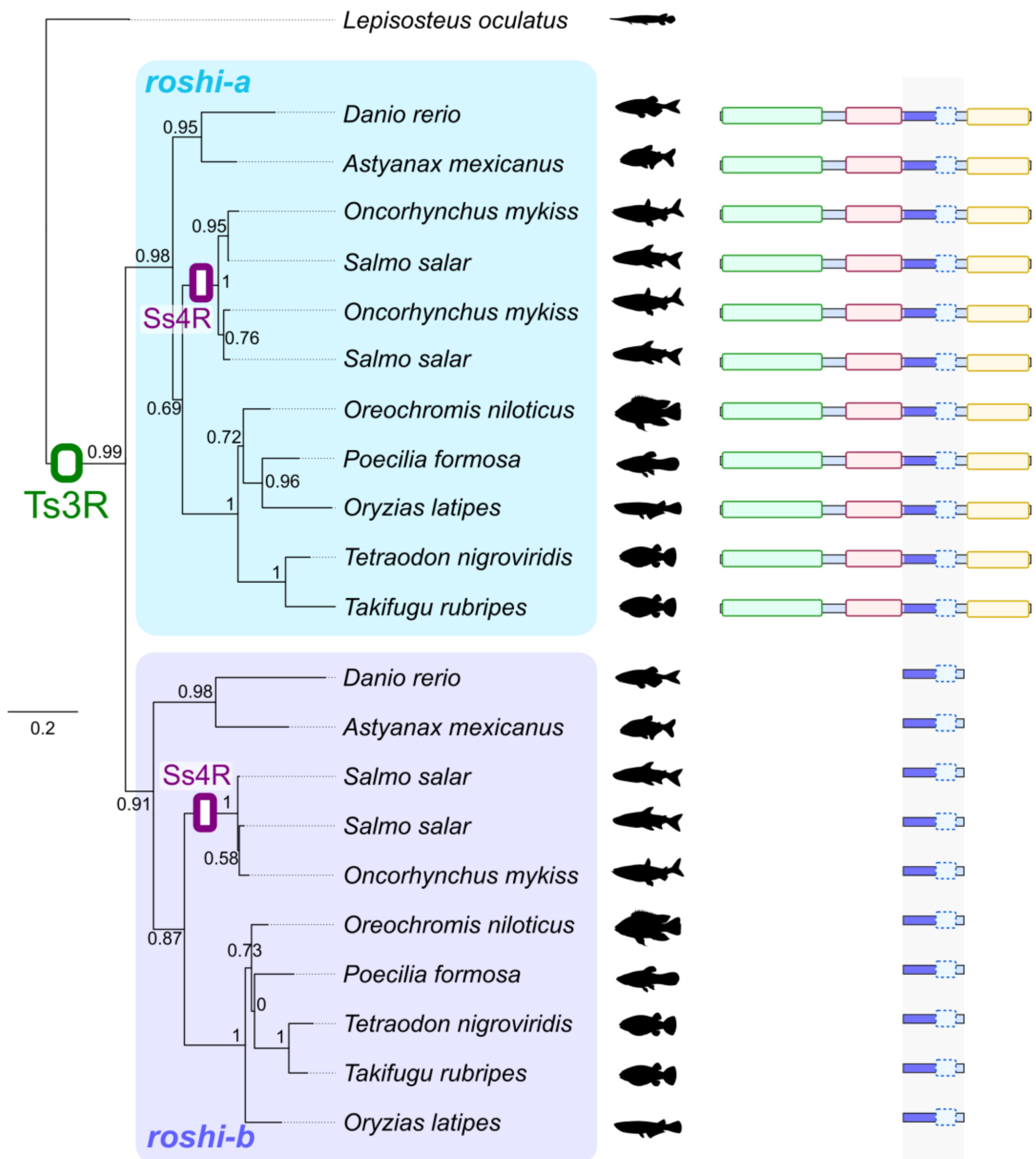
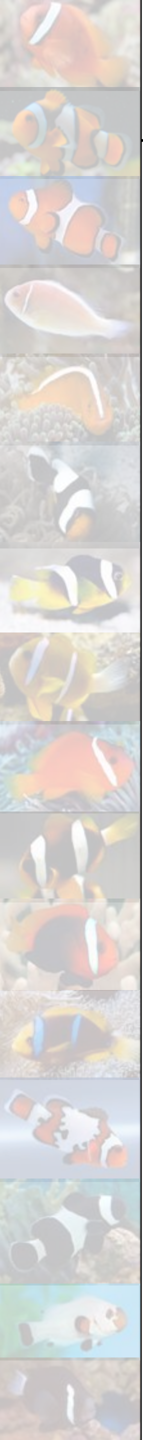


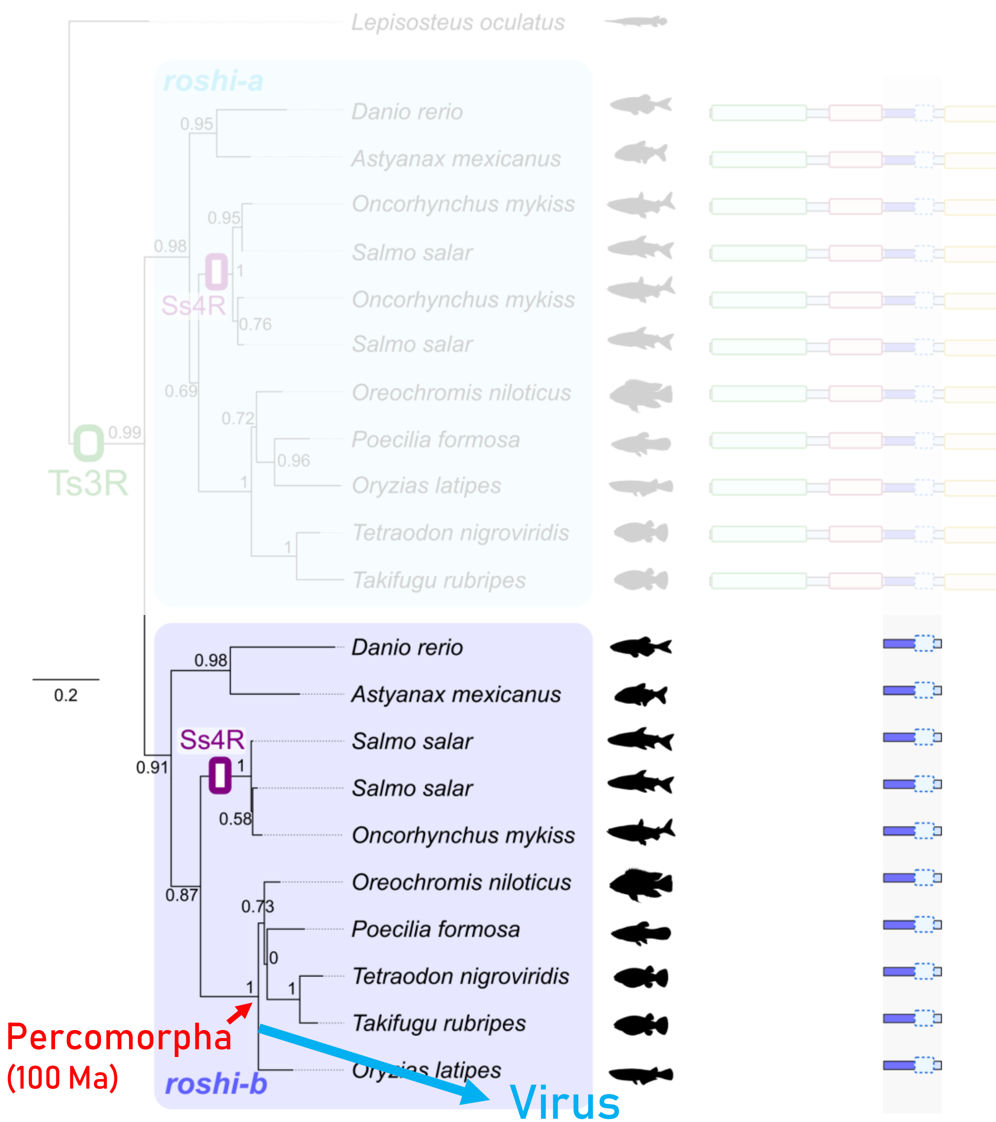
Roshi a été dupliqué et retenu après la Ts3R



Lorin *et al.* (in prep.)

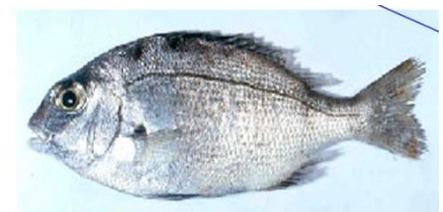


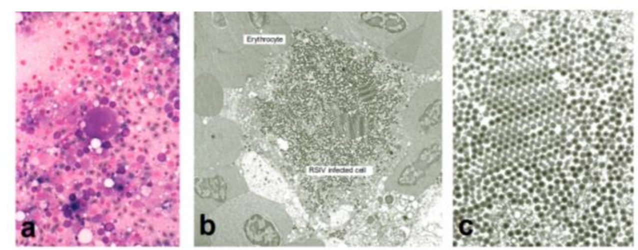
Roshi-b a été transféré à un virus de manière horizontale



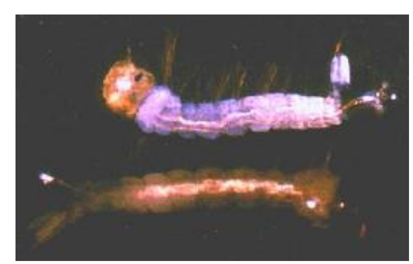
Séquences de Mégalocytivirus…

- Anémies
- Hémorragies
- Exophtalmie
- Gonflement de la rate

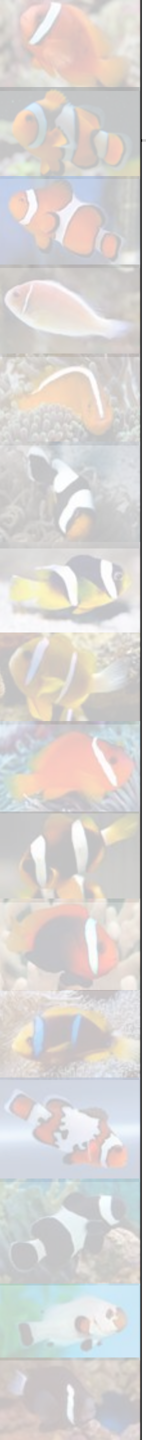




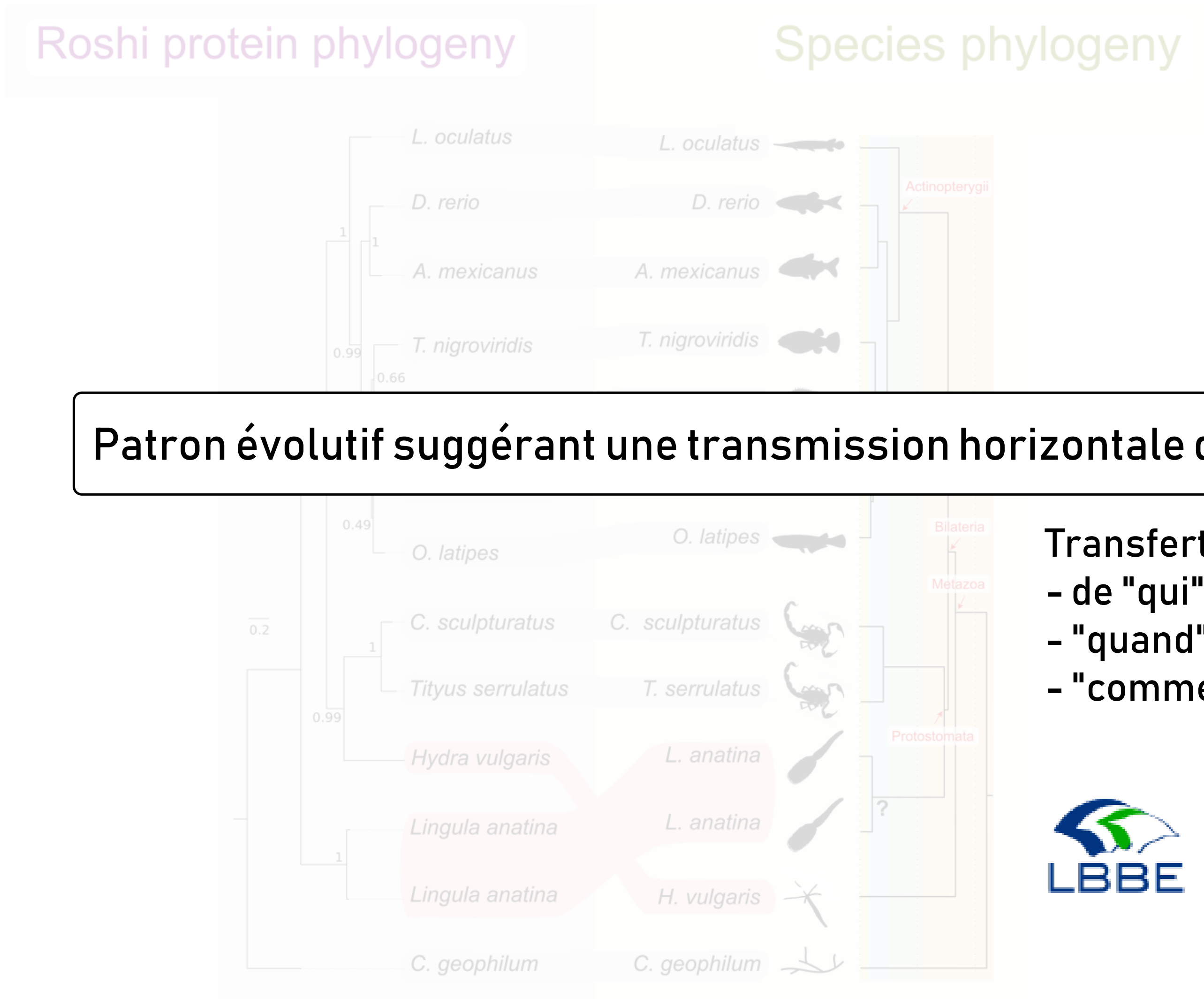
… qui sont des Iridovirus !



Kurita and Nakajima (2012) *Viruses*



La phylogénie de *roshi* ne correspond pas à la phylogénie des espèces



Patron évolutif suggérant une transmission horizontale du gène

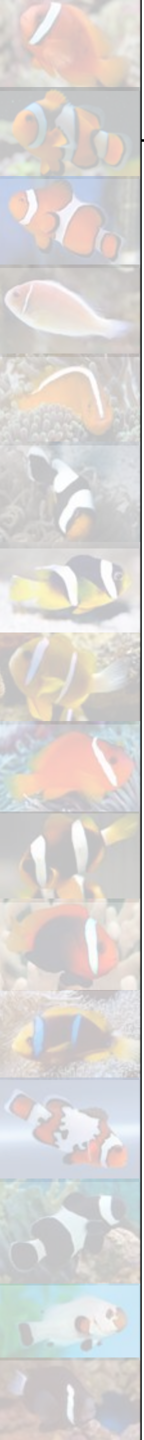
Transfert :
- de "qui" vers "qui" ?
- "quand" ?
- "comment" ?

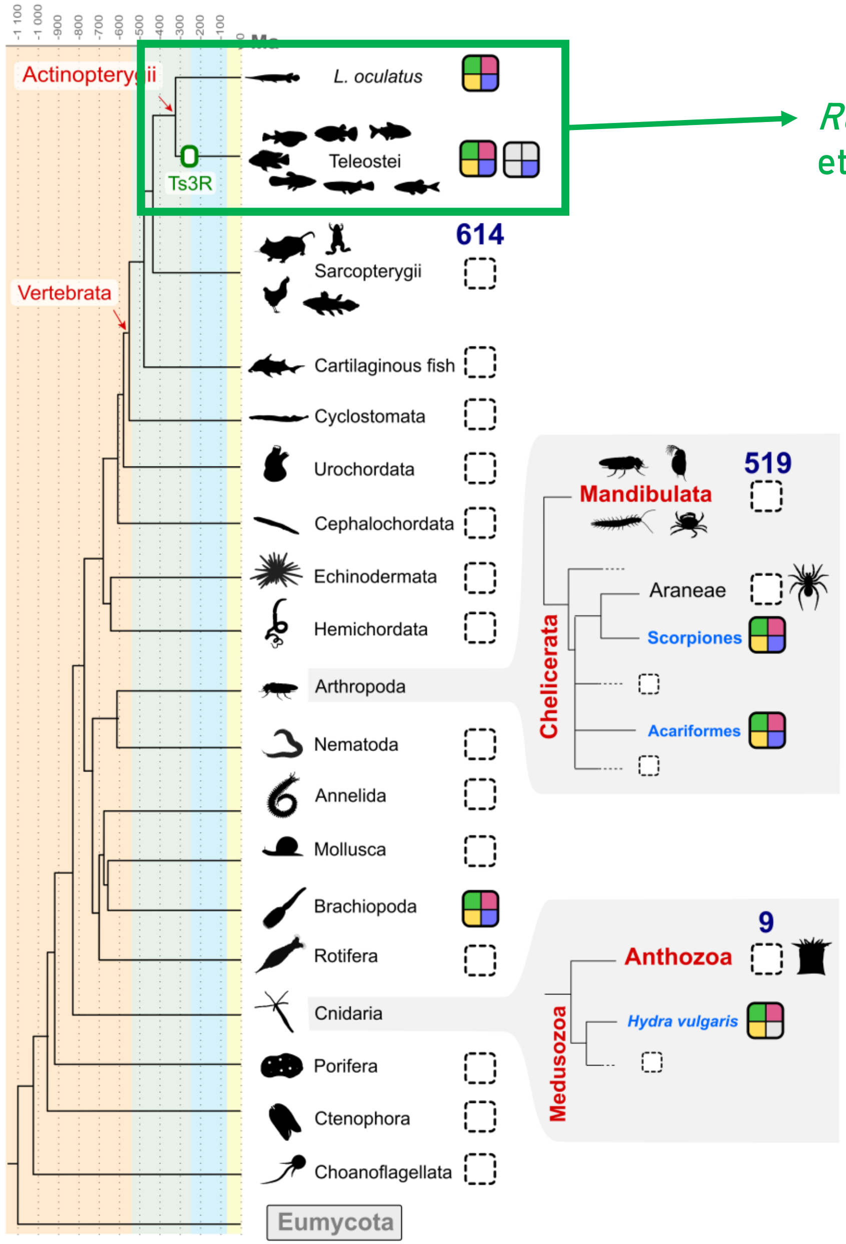
LBBE

Vincent Daubin

Lorin *et al.* (in prep.)

Estimation des âges de transfert de *roshi* chez les Animaux

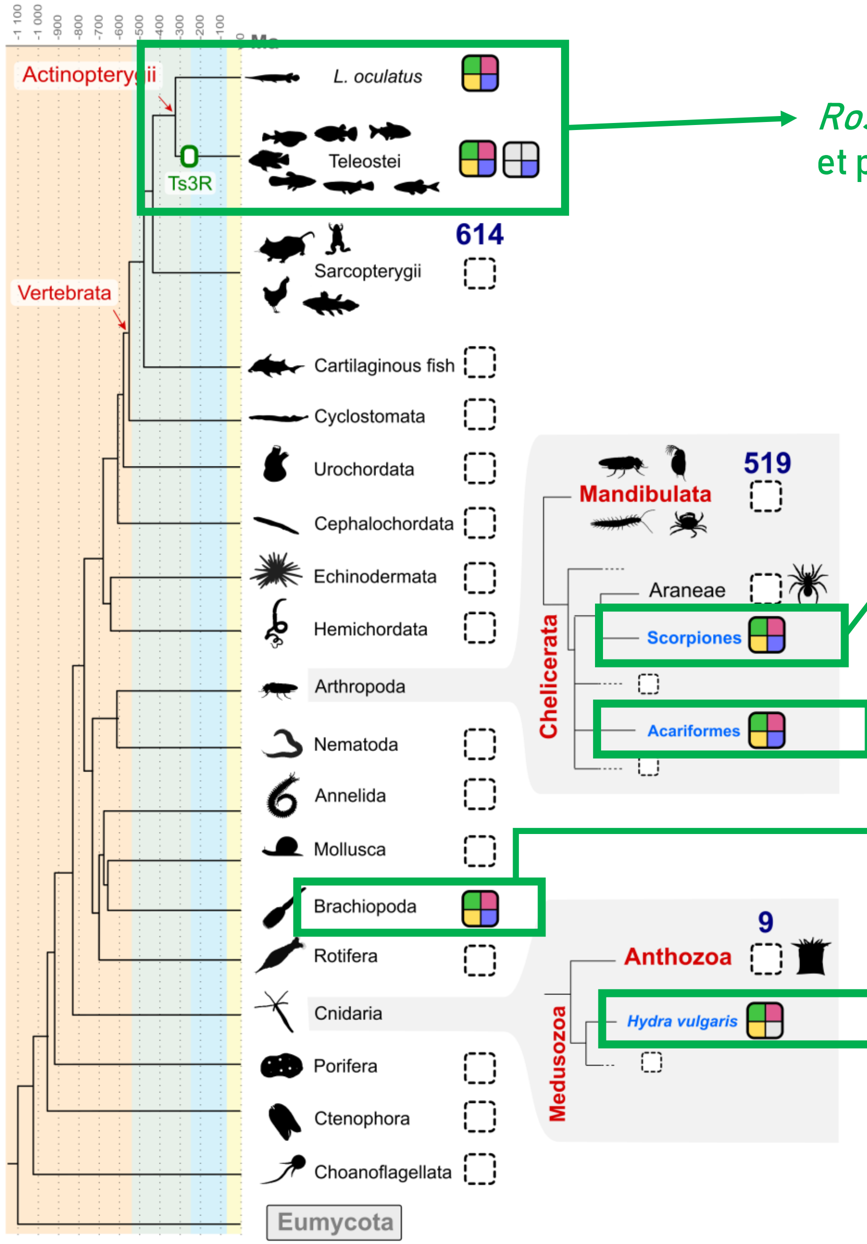




Roshi a moins de 450 Ma et plus de 350 Ma

Lorin *et al.* (in prep.)

Estimation des âges de transfert de *roshi* chez les Animaux



Roshi a moins de 450 Ma
et plus de 350 Ma

< 400 Ma

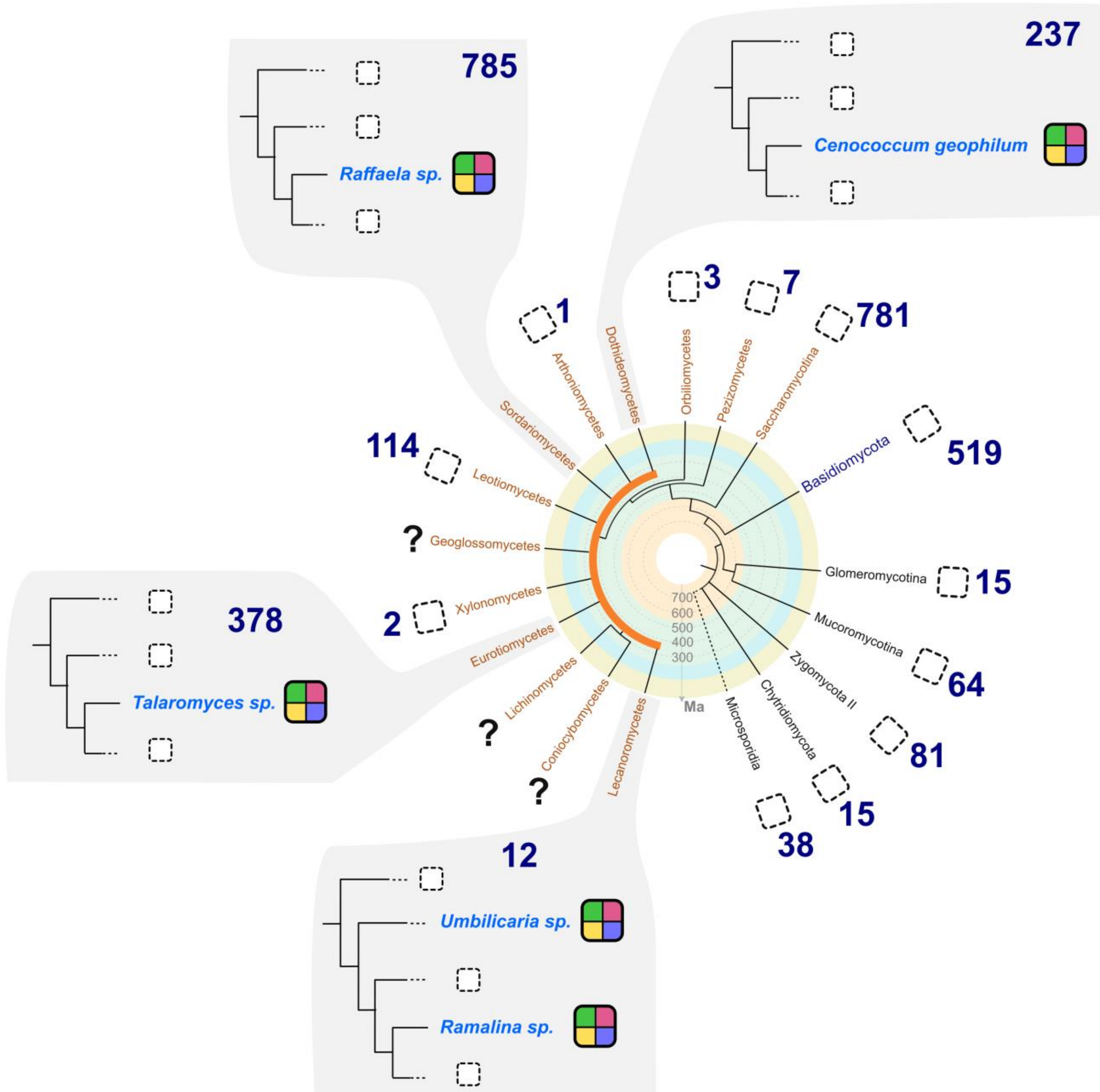
< 200 Ma

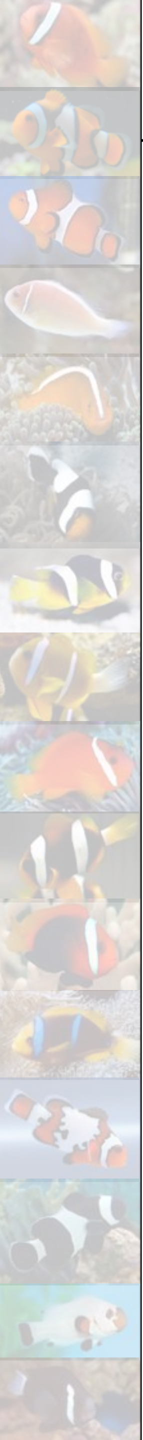
< 500 Ma

< 100 Ma

Lorin *et al.* (in prep.)

Distribution de *roshi* chez les Eumycètes





Quels sont les modes de transfert envisagés pour *roshi* ?

1. Les HGT sont moins fréquents mais tout de même possibles chez les Eucaryotes

Moran *et al.* (2010) *Science*
Sun *et al.* (2015) *Sci Rep*

2. Les HGT "inter-Animaux" sont rares

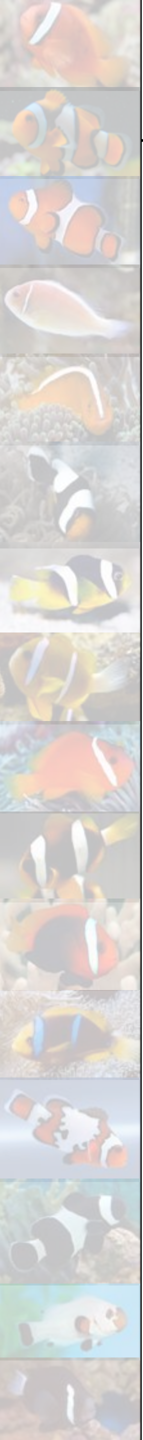
Gilbert *et al.* (2012) *Mol Biol Evol*
Graham *et al.* (2012) *BMC Evol Biol*
Peccoud *et al.* (2017) *PNAS*

3. Les mécanismes de transfert reposent probablement sur des vecteurs viraux

Gilbert *et al.* (2010) *Nature*
Gilbert and Cordaux (2017) *Curr Opin Virol*

Waddington *et al.* (2015)
Biol. Letters

- ✓ a. *Roshi-b* transféré horizontalement à des Iridovirus
- ✓ b. *Roshi* présent chez des Acariens
- ✓ c. Ecologie compatible (aquatique)



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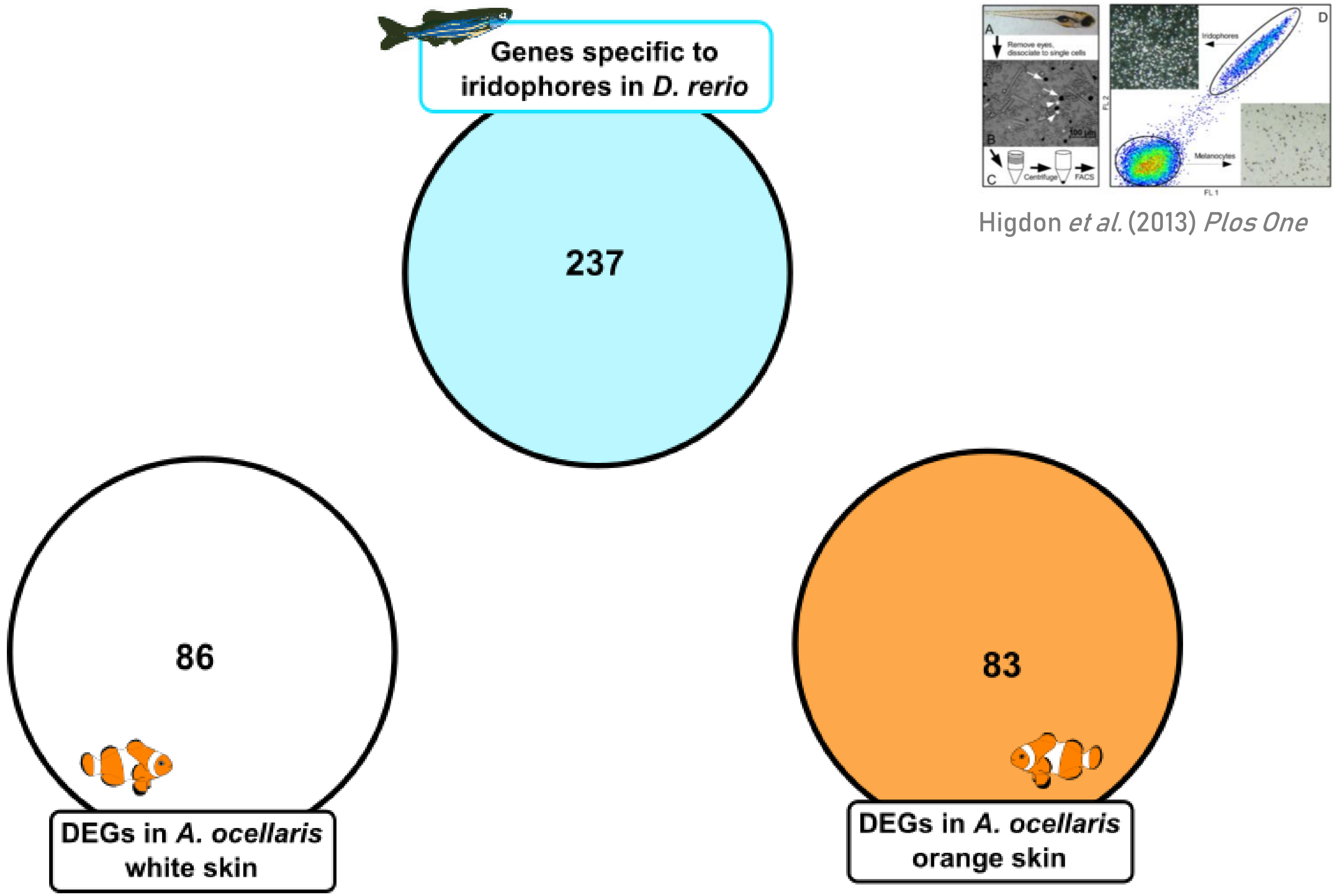
Gilbert *et al.* (2010) *Nature*
Gilbert and Cordaux (2017) *Curr Opin Virol*

4. Au sein des Champignons, les transferts horizontaux sont possibles

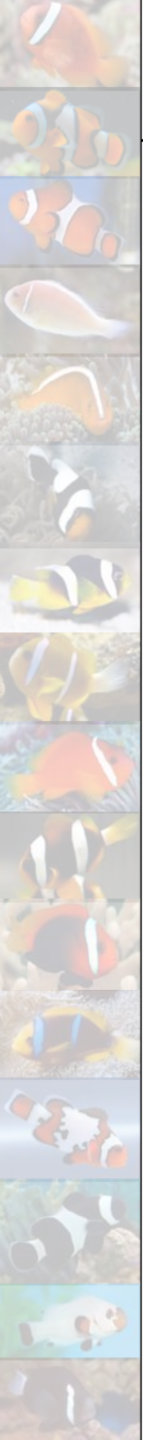
Fitzpatrick (2012) *FEMS Microbiol Lett*
Xie *et al.* (2008) *BMC Evol Biol*

La peau blanche a une "identité d'iridophores"



Higdon *et al.* (2013) *Plos One*

Salis*, Lorin* *et al.* (in prep.)



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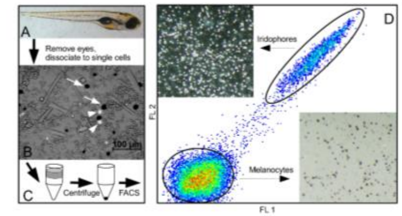

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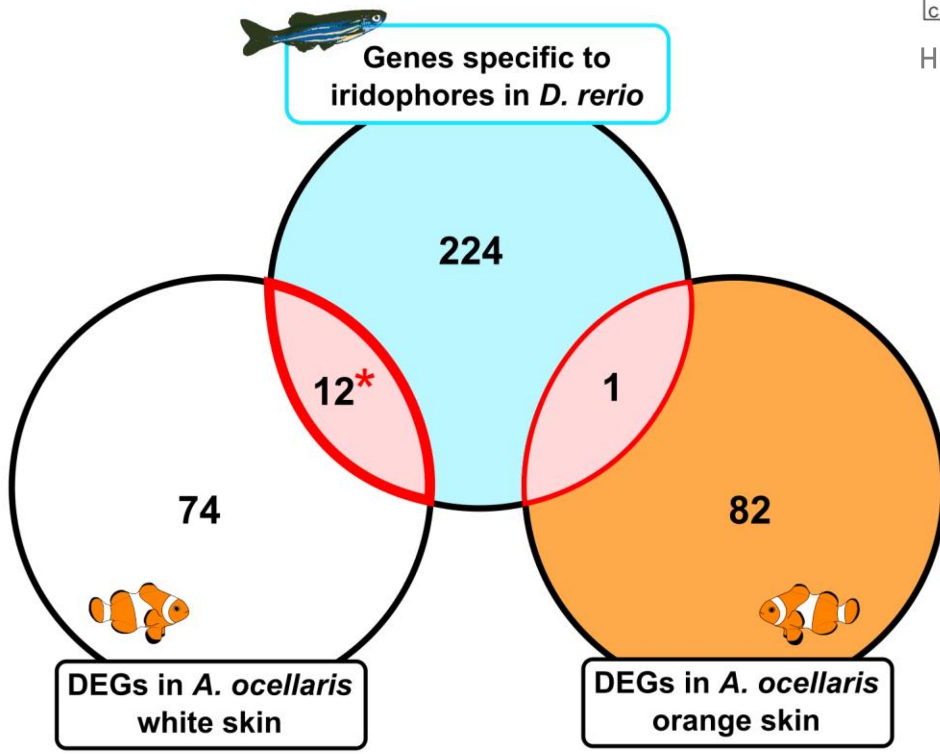

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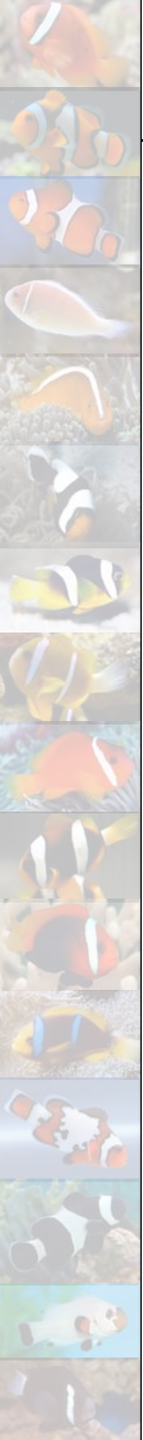
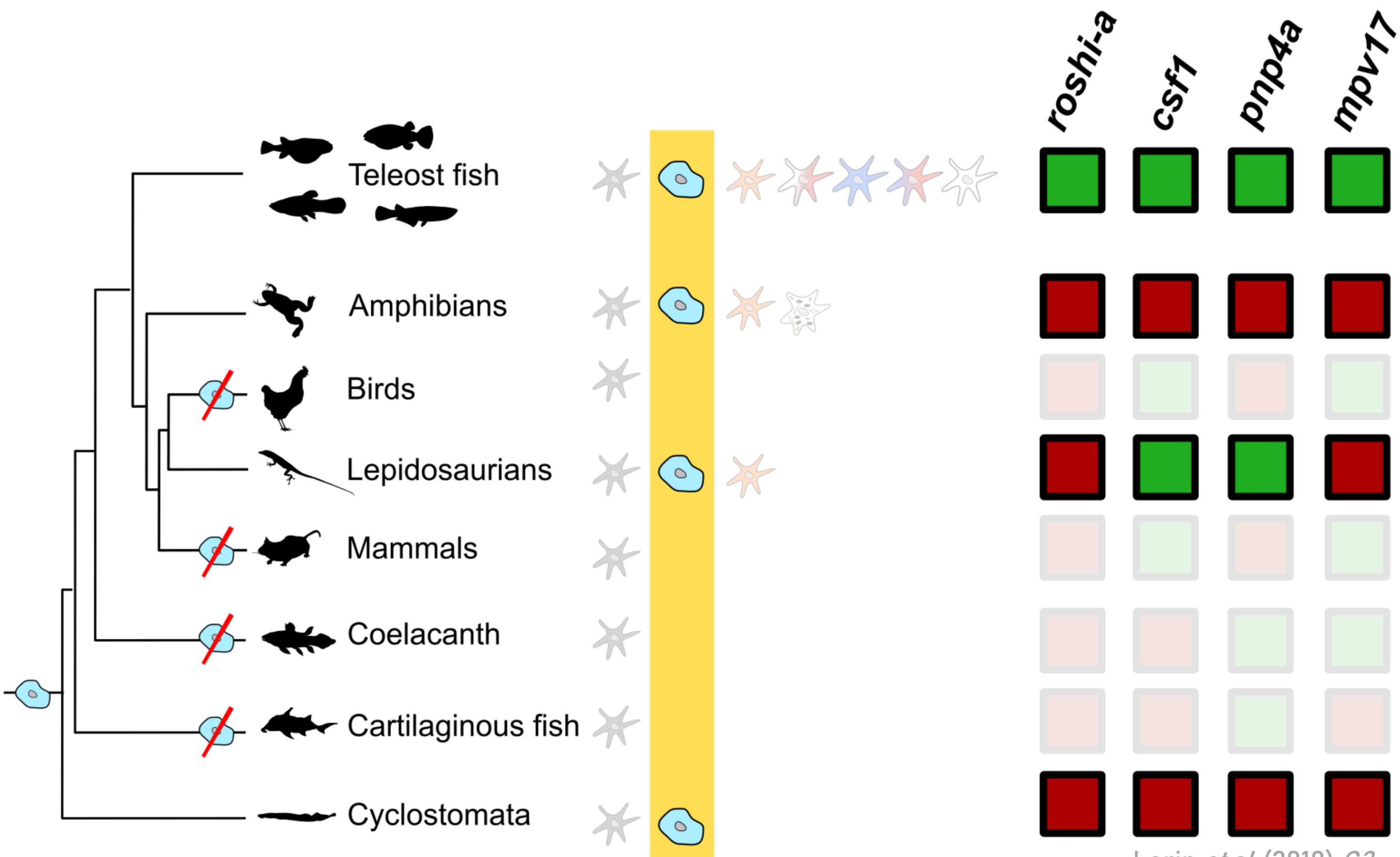
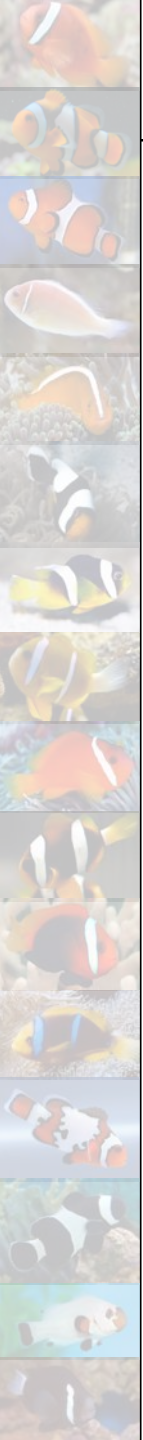


Roshi et d'autres gènes invitent à envisager l'évolution des iridophores chez les Vertébrés sous un nouvel angle



Lorin *et al.* (2018) *G3*

Wallace et la "coloration animale"
Une classification revisitée sur l'exemple des poissons coralliens



CAMOUFLAGE
("Protective colors")

Cryptisme

Assortiment à l'arrière-plan

Spécialisé

Hippocampus bargibenti
(Randall et al. 2005)

Généraliste

Antennarius commerson
(Randall et al. 2005)

Countershading

Chaetodon lunula
(Hamilton et al. 1971)

Coloration trompeuse

Dascyllus aruanus
(Phillips et al. 2017)

Transparence

Larve d'Acanthurus triostegus
(Holzer, Besson et al. 2017)

Mascarade

Juvénile de Platax orbicularis
(Randall et al. 2005)

COULEURS SEXUELLES
("Sexual colors")

Dimorphisme sexuel

Femelle (en haut) et mâle (en bas) de Poisson-perroquet

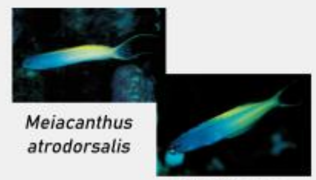
COULEURS D'AVERTISSEMENT
("Warning colors")

Organismes naturellement protégés

Aposématisme

Pterois volitans
(Nelsen et al. 2014)

Mimétisme müllérien



Meiacanthus atrodorsalis

Plagiotermus laudandus
(Randall et al. 2005)

Organismes non-protégés

Mimétisme batésien

Meiacanthus nigrolineatus (peu comestible, à gauche) et Ecsenius gravieri (inoffensif)
(Randall et al. 2005)

COULEURS DE COMMUNICATION INTRA- OU INTERSPÉCIFIQUE
("Typical colors")

Communication intraspécifique (hors sélection sexuelle)

Compétition intrasexuelle

Chaetodon lunula
(Hamilton et al. 1971)

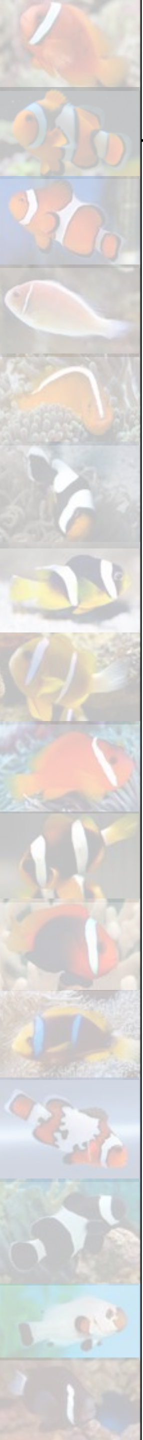
Signaux de regroupement

Myripristis murdjan
(McRobert et al. 1998)

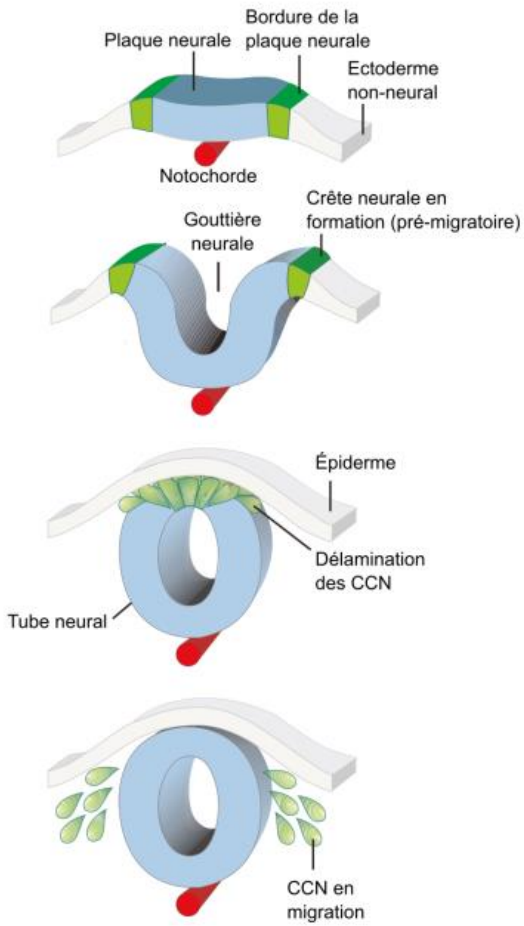
Communication interspécifique

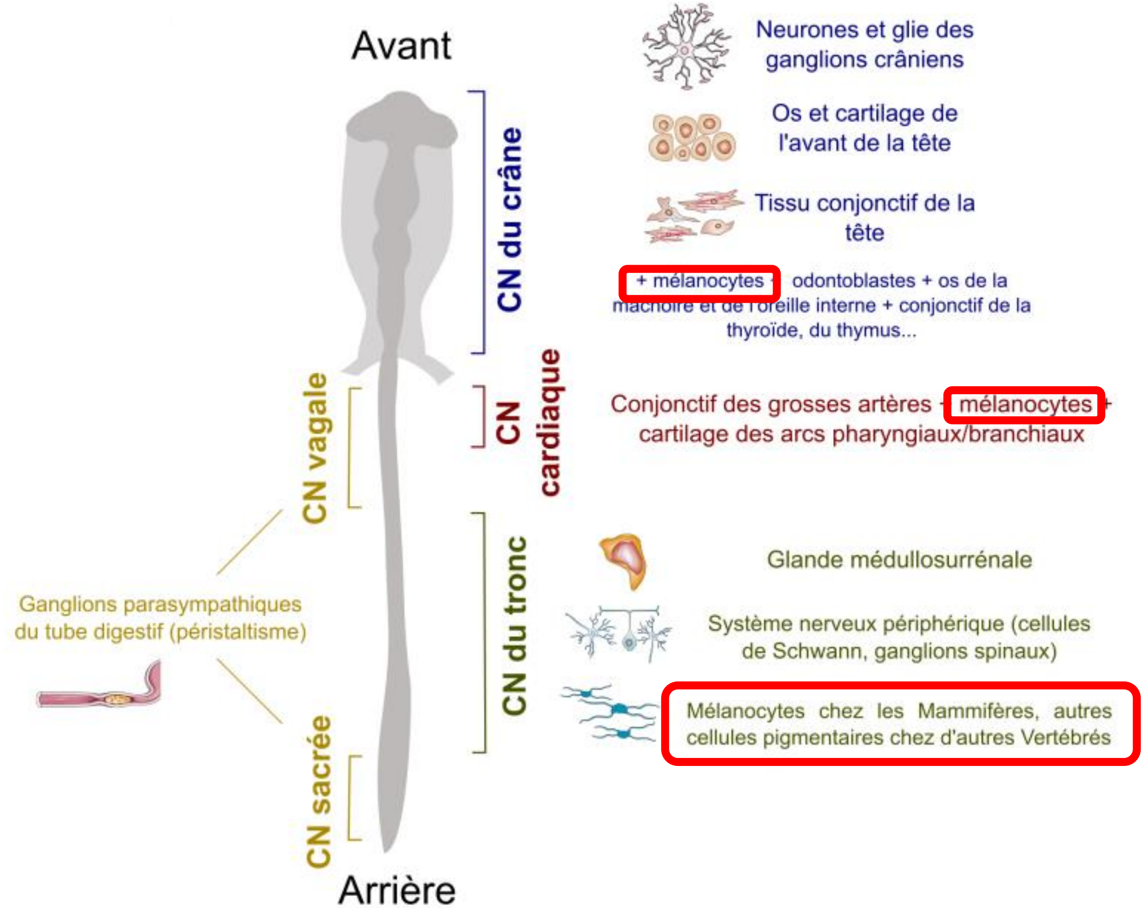
Confusion de prédateurs

Halichoeres brownfieldi
(Lönnstedt et al. 2013)

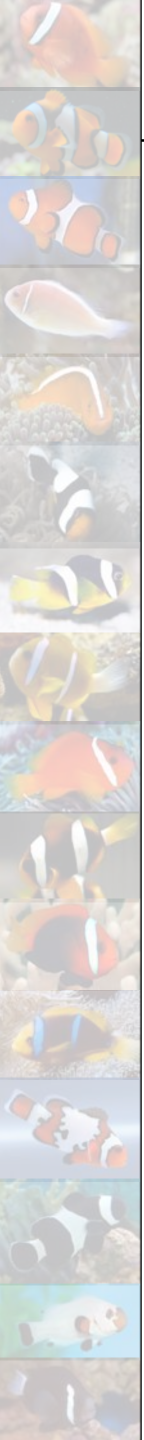


Les cellules pigmentaires proviennent de la crête neurale

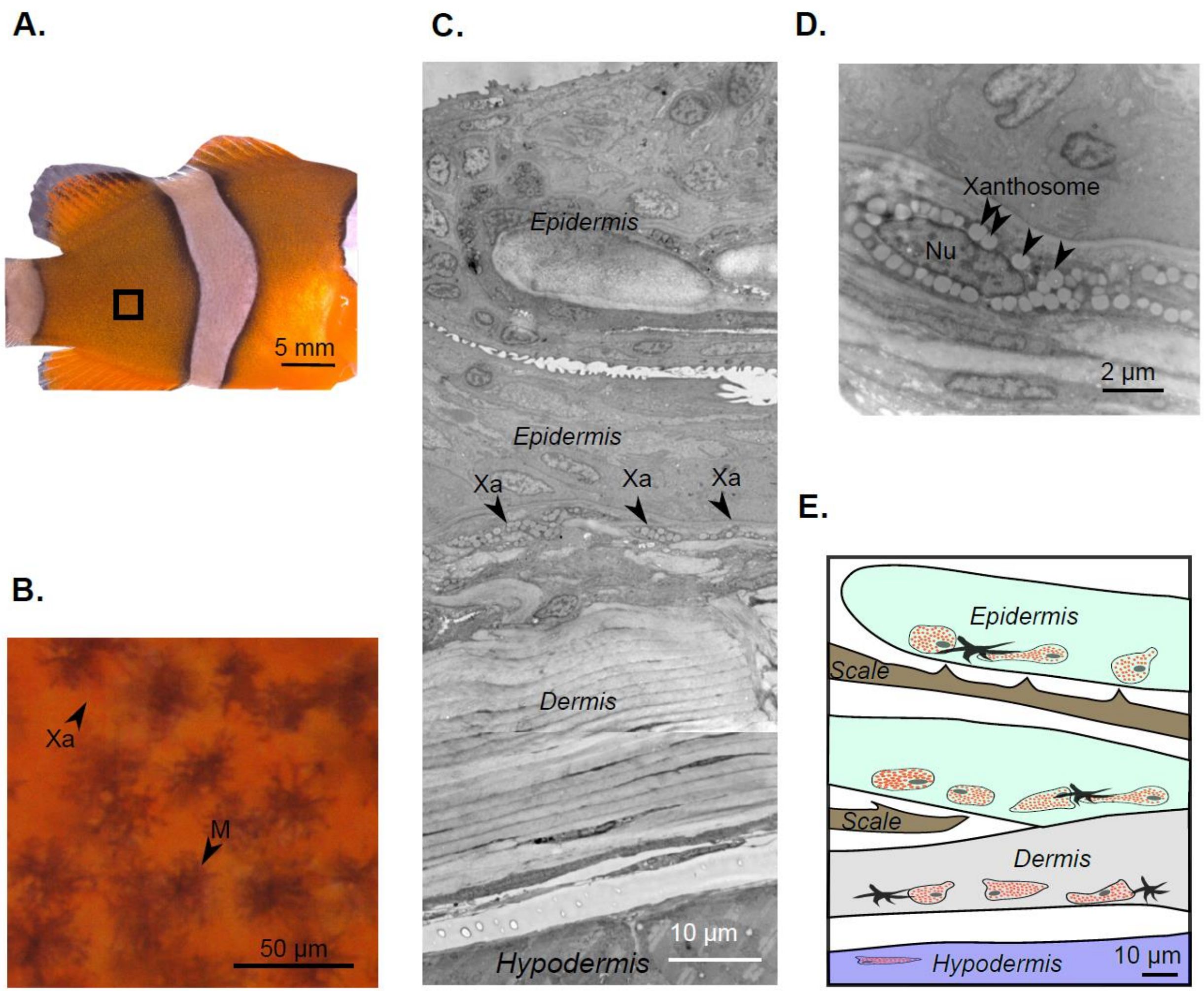




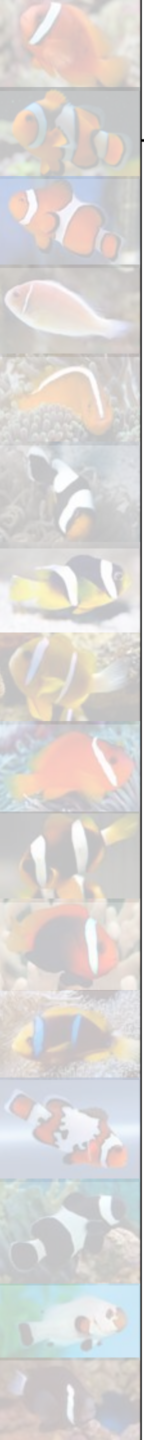
Adapté de Knecht *et al.* (2002) *Nat. Rev. Gen.* et de Simoes-Costa *et al.* (2015) *Development*



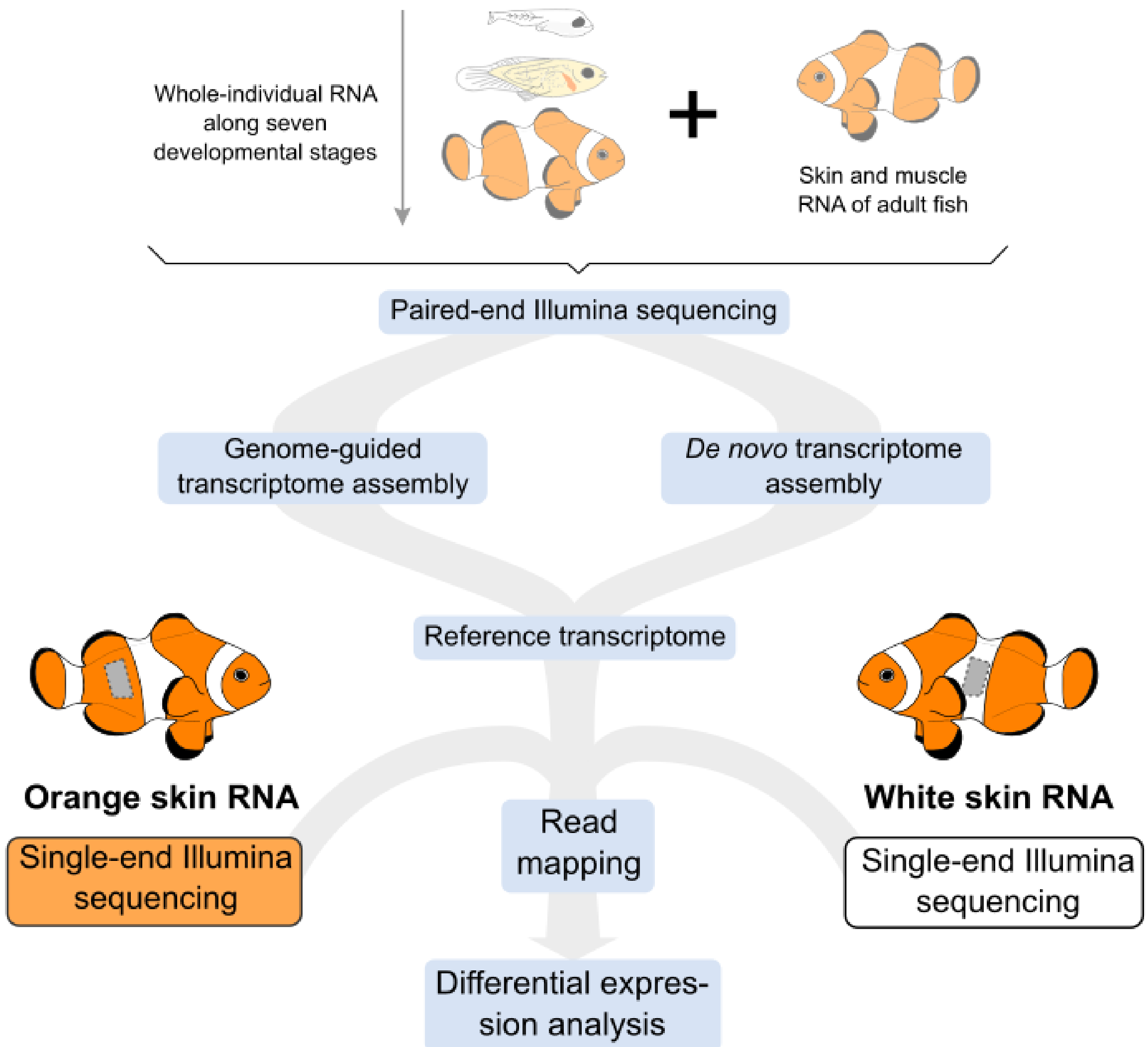
Peau orange en microscopie



Salis*, Lorin* *et al.* (in prep.)



Pipeline utilisé pour l'analyse des différences d'expression



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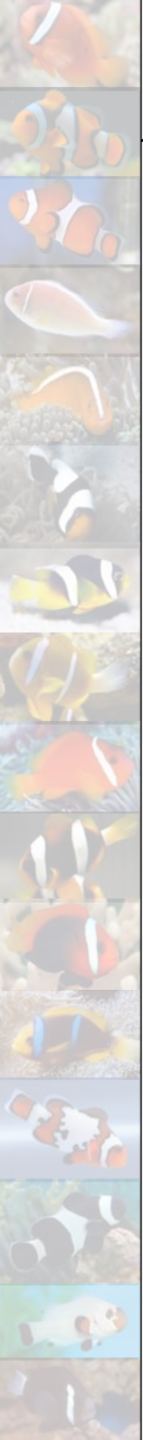

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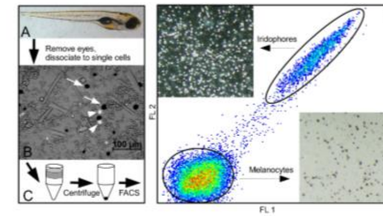
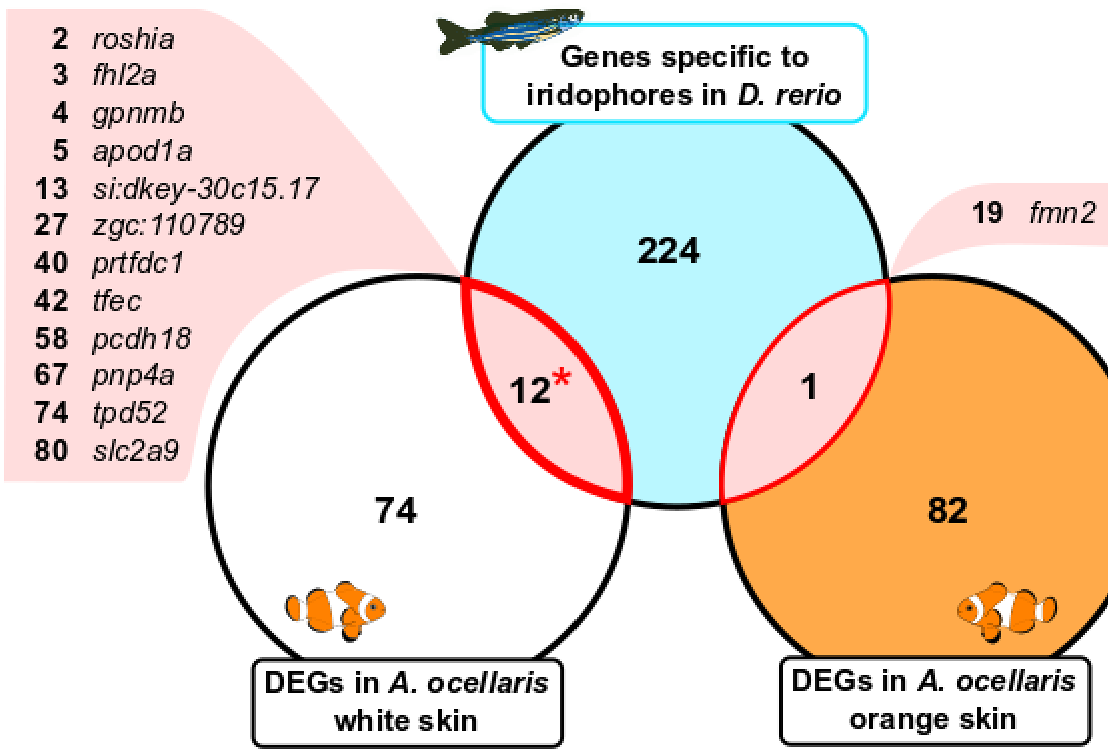


Higdon *et al.* (2013) *Plos One*



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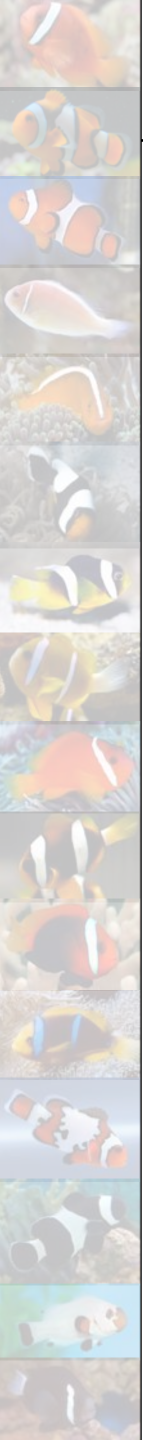

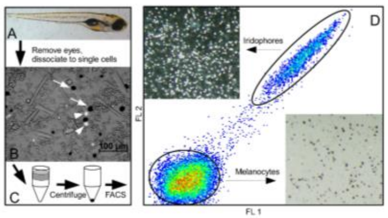

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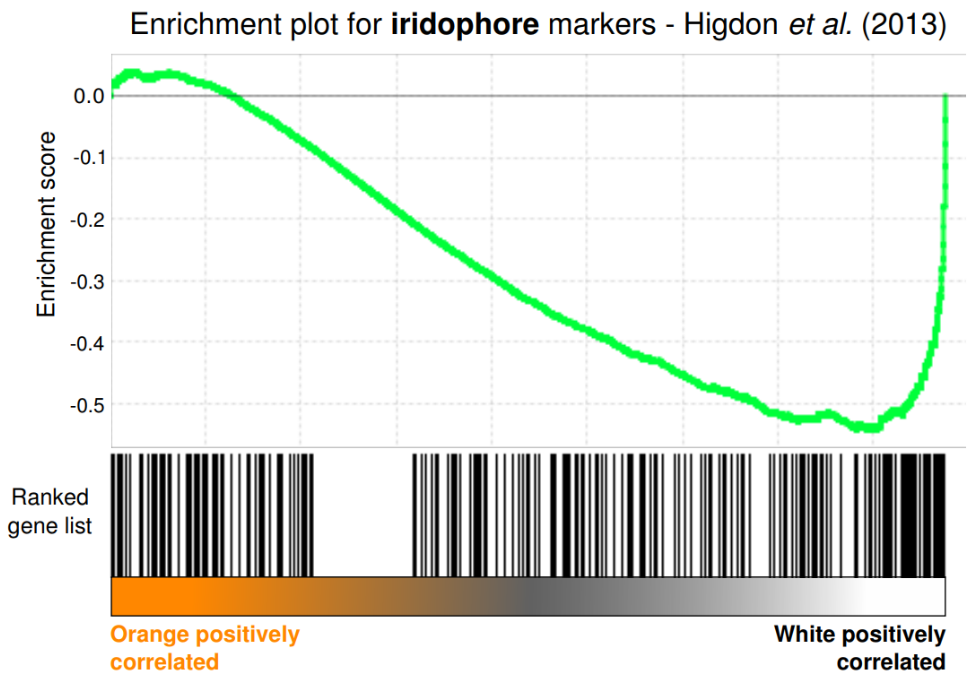

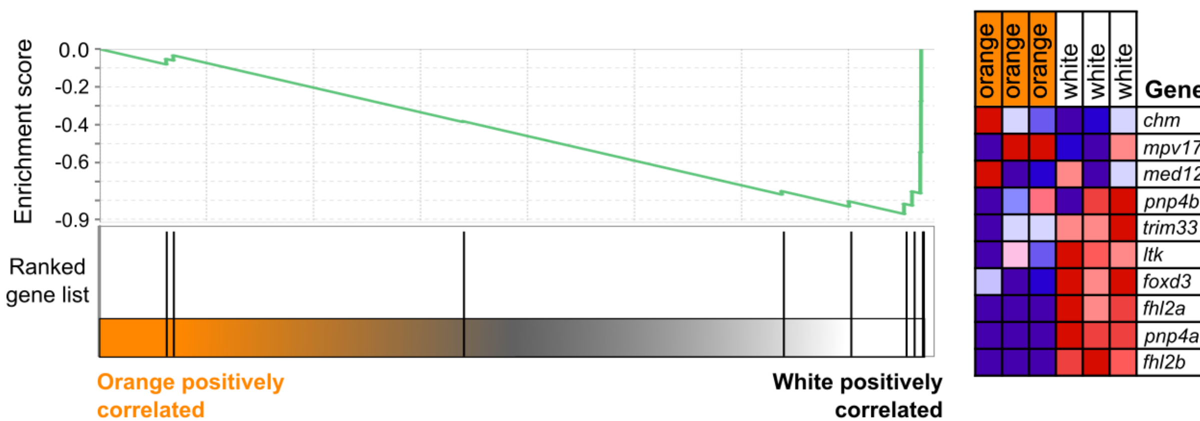

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Megalocytivirus (Iridoviridae)