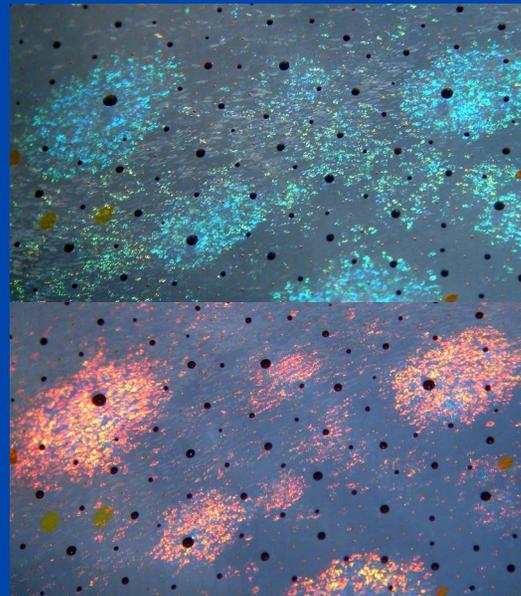
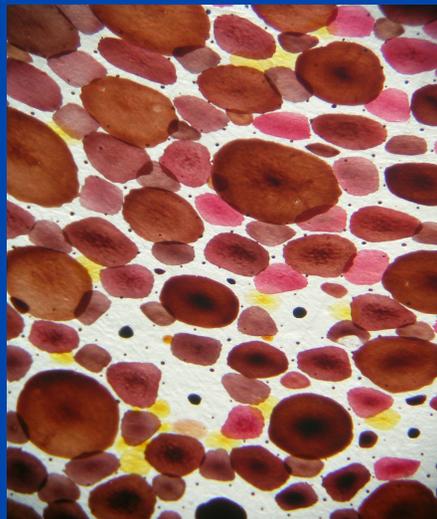


Rapid adaptive camouflage and signaling by cephalopods

Part 3: Changeable skin
Controlling pigments and reflectors
& implications for biotechnology



Roger Hanlon

Marine Biological Laboratory, Woods Hole, MA
Brown University, Providence, RI

Transition to camouflage

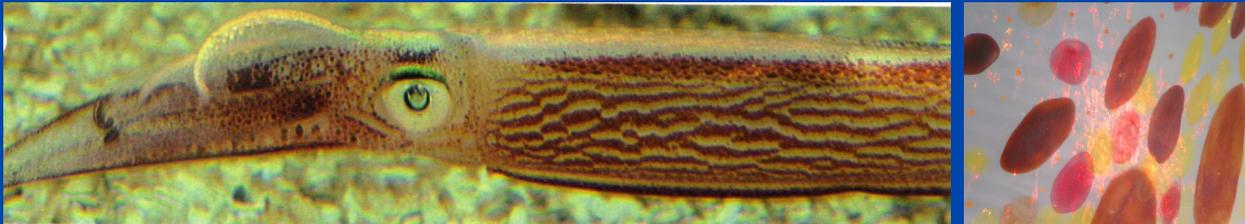


Millions of pigment organs
are controlled with precision

Two complementary systems

- **Pigmentary Color** (long λ)

Chromatophores - active control



- **Structural Color** (short λ + white)

Reflecting cells - passive/active

Hierarchy of control of the skin

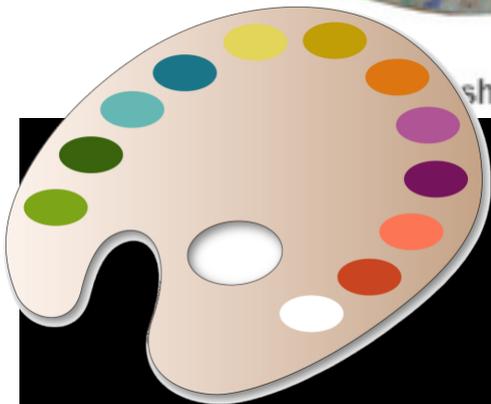
“Electric skin”



NOVA 2007: Kings of Camouflage

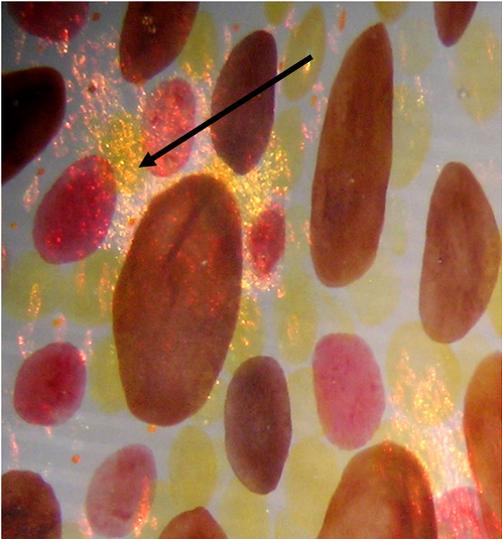
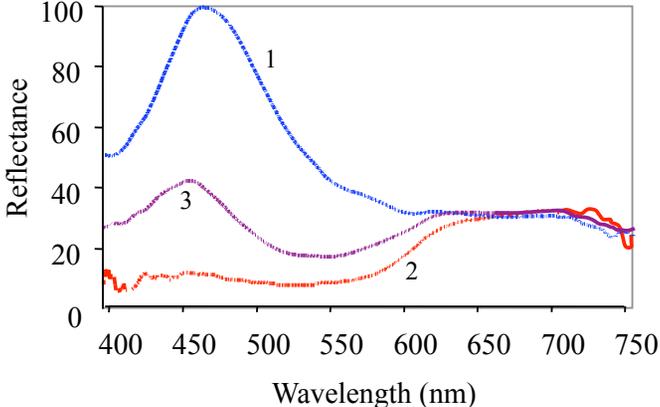
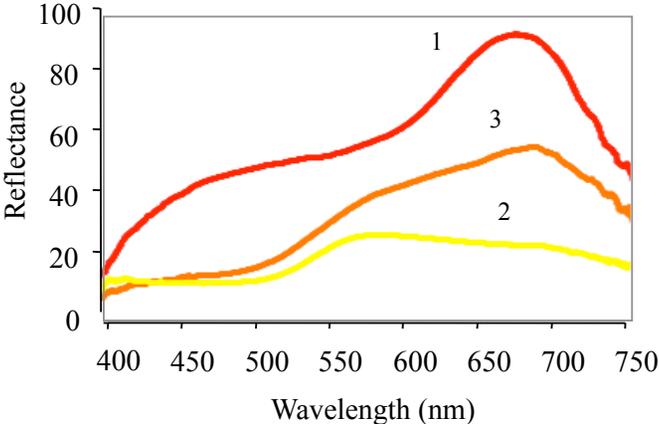


shutterstock.com · 1942157

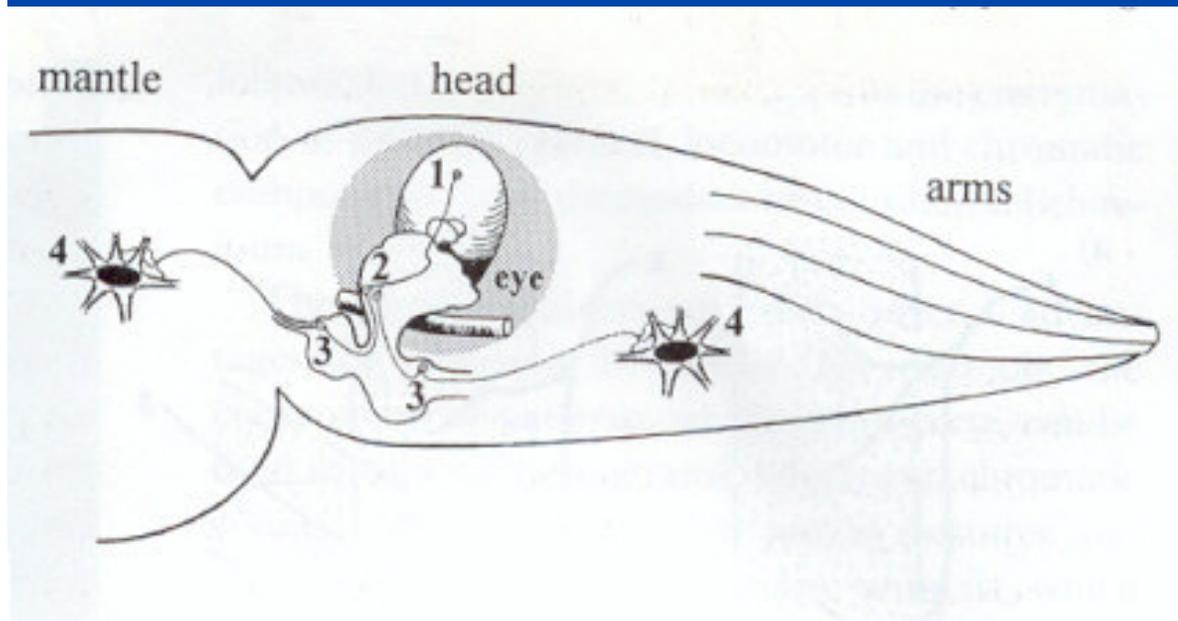


Chromatophores and iridophores

FULL SPECTRUM COLOR

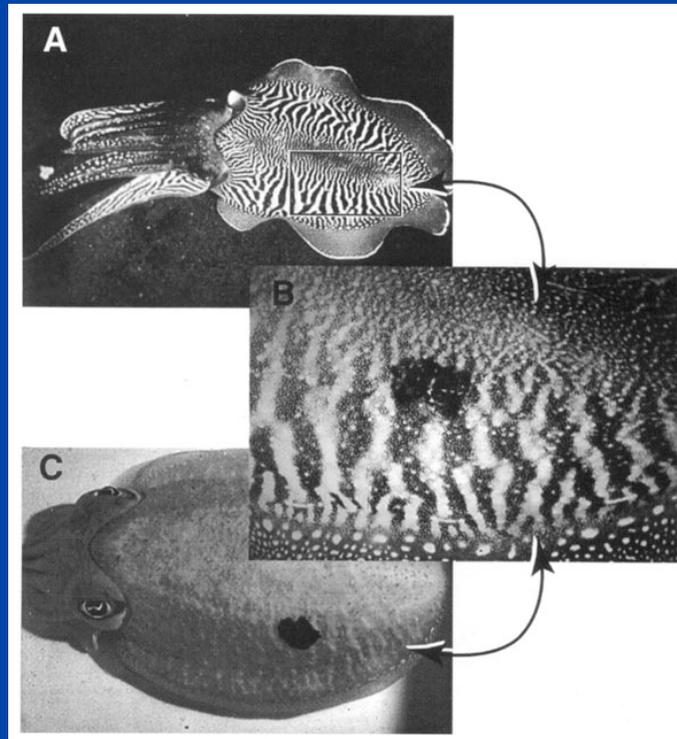
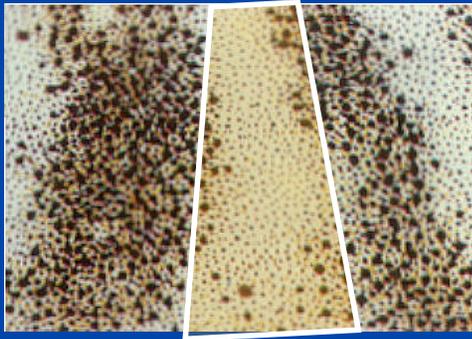
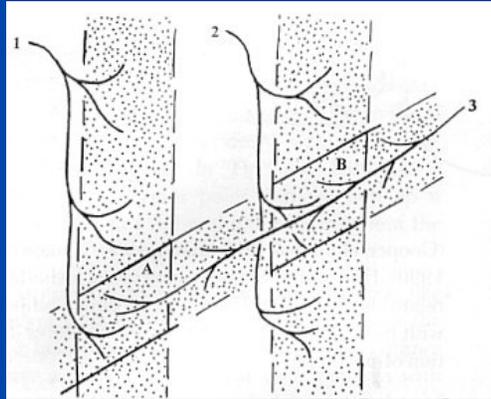


Chromatophore control: visual pathway Eye - Brain - Skin

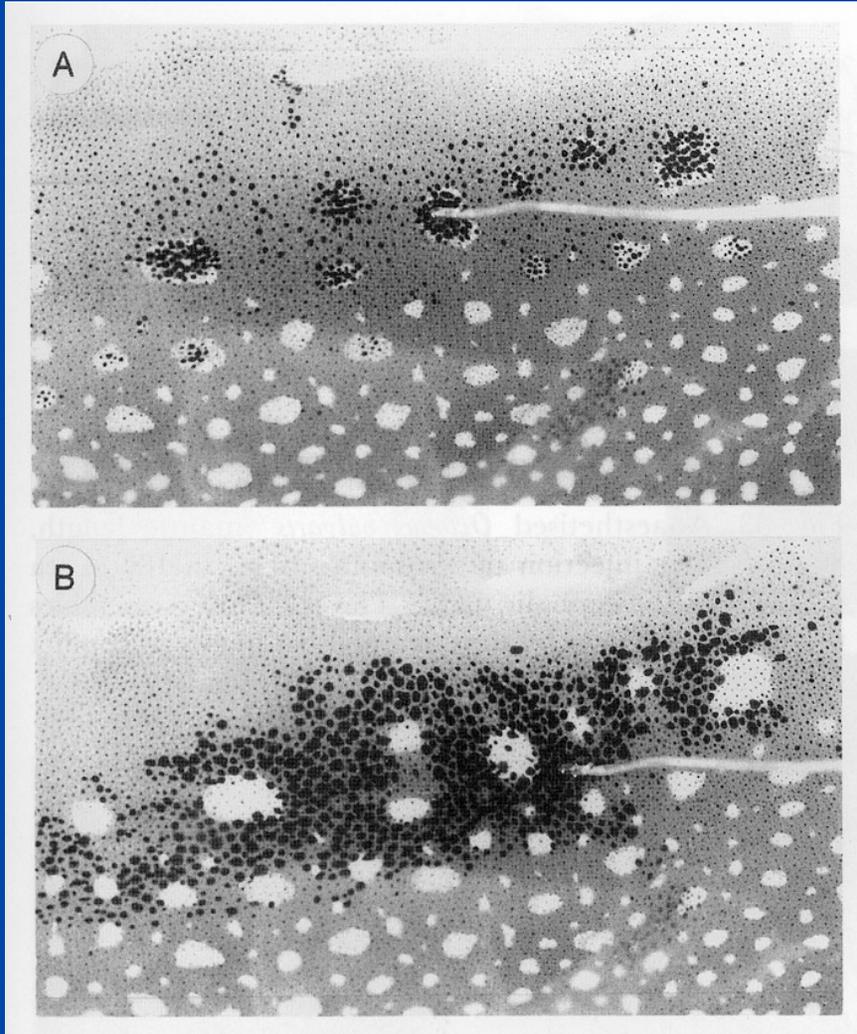


Speed of patterning change: < 1 sec

Chromatophore patterning via neural control



Multiple innervation of
chromatophore radial muscles



Complementary motoneurons
to **enhance/ mask** chromatic skin
components

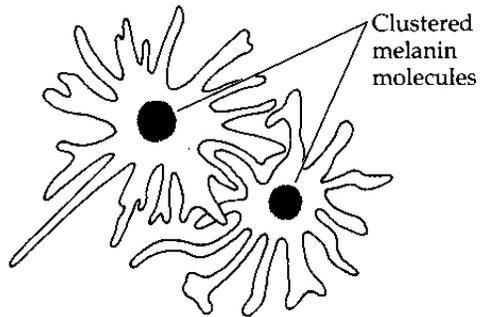
Chromatophores mask or enhance underlying white leucophores



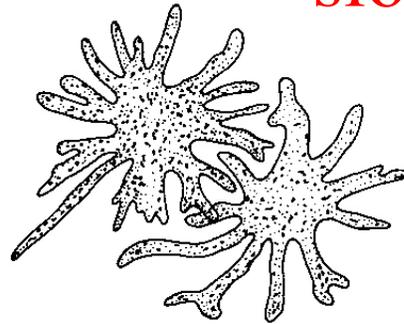
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Chromatophore types

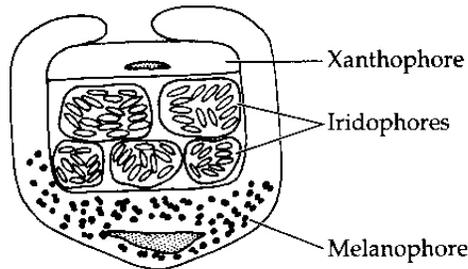
Fish (melanophore)



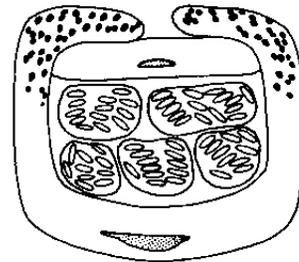
slow



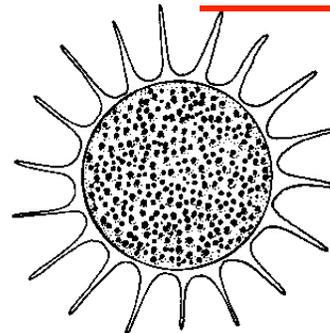
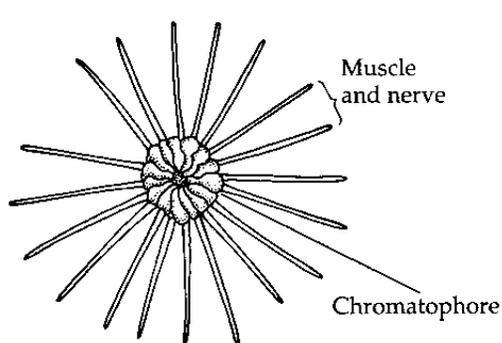
Frog and Lizard (dermal chromatophore unit)



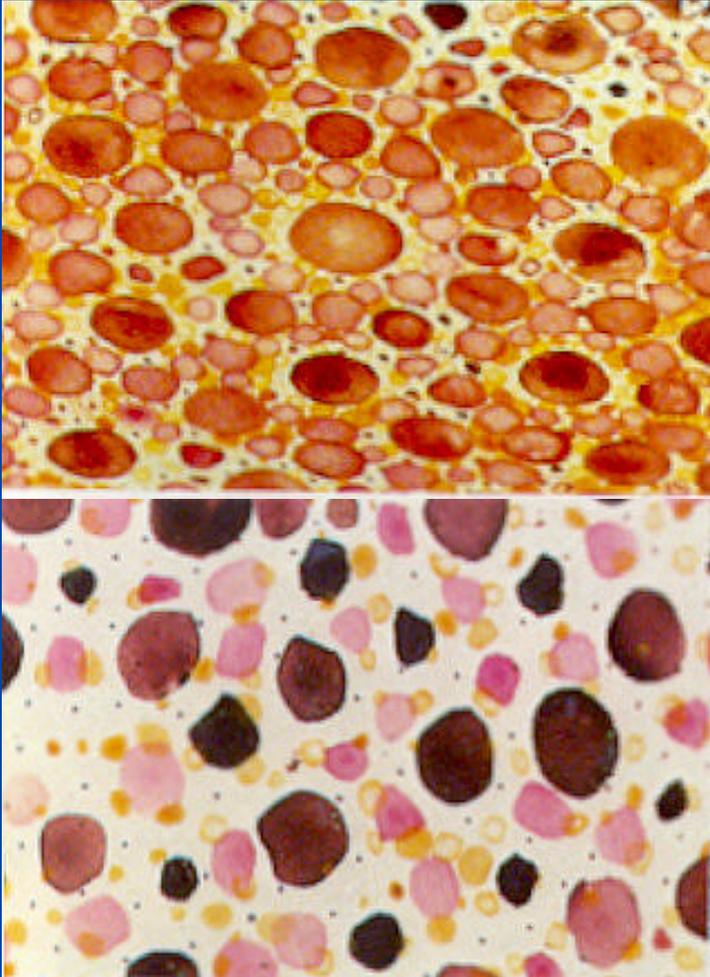
slow



Cephalopod (chromatophore organ) FAST



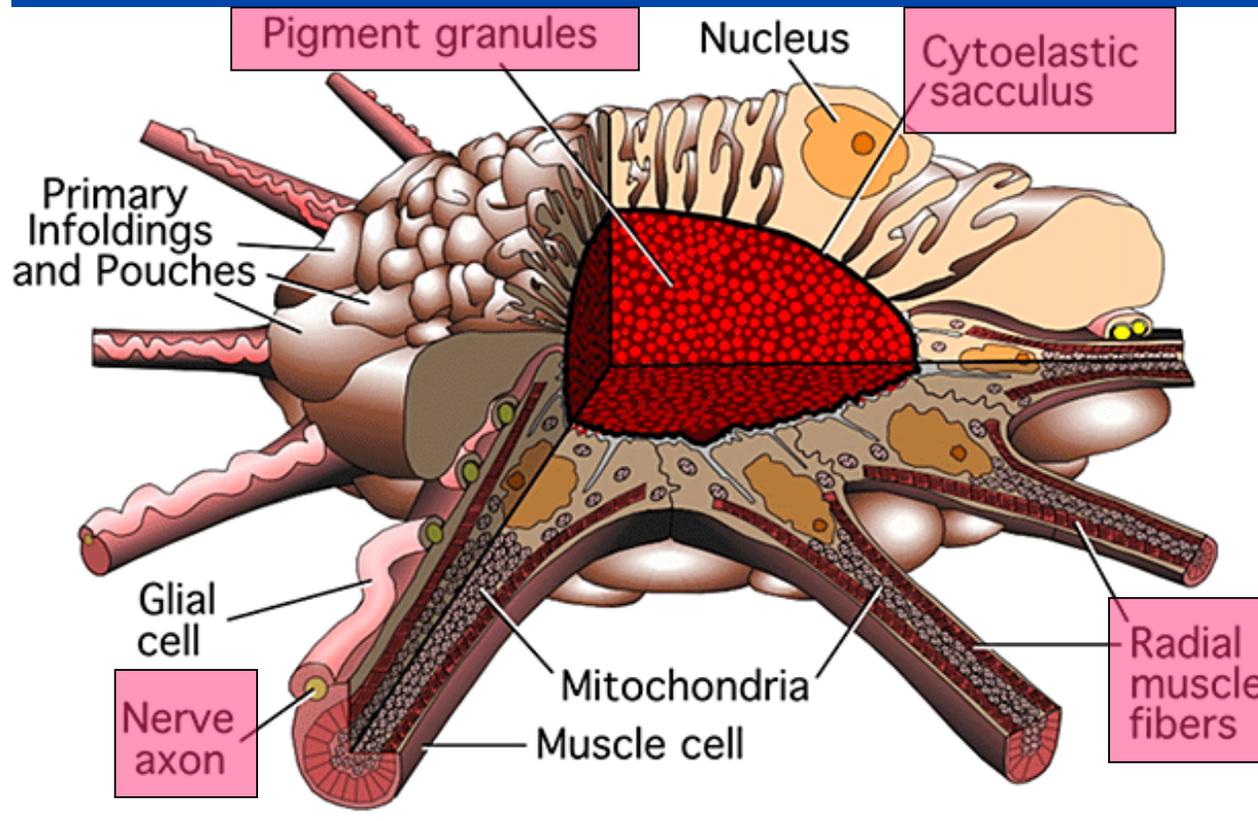
Chromatophores (pigmented)



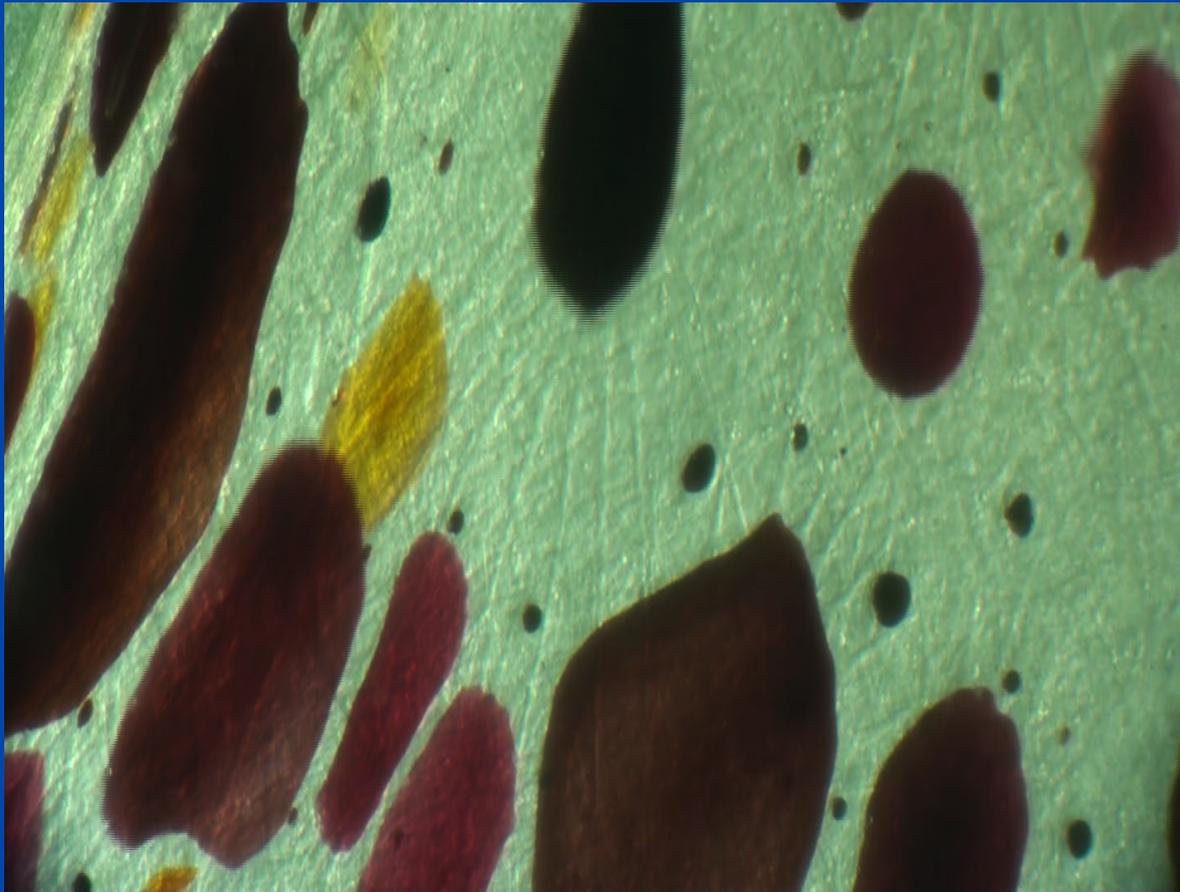
Brown, Red, Yellow

-each chromatophore is one color only

The cephalopod chromatophore organ



Radial muscles pull the pigment sac out into a disc of color

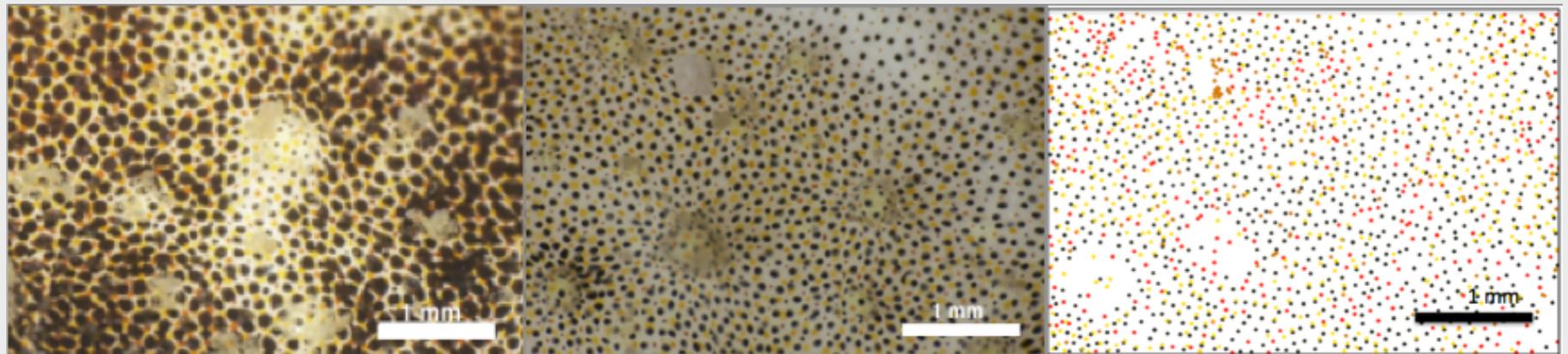
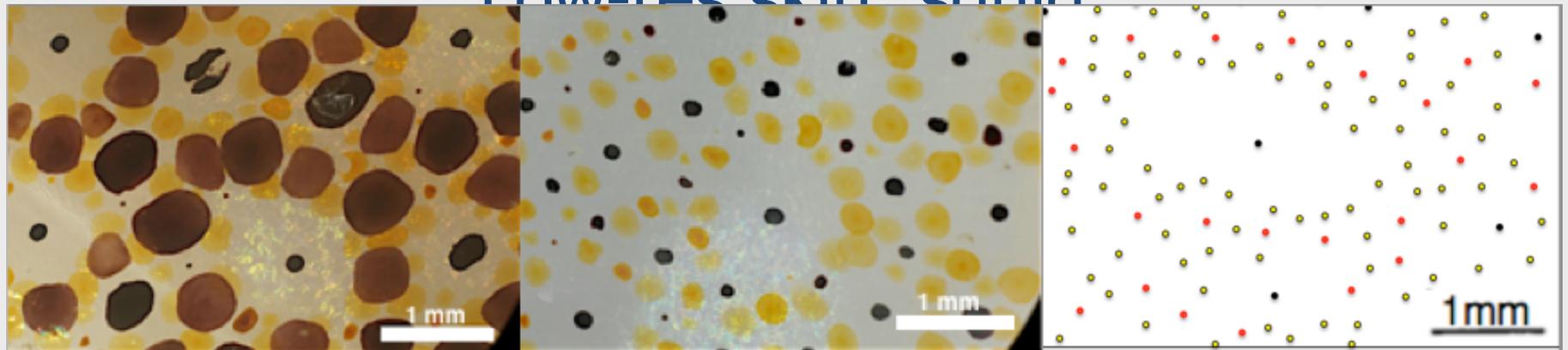


Chromatophore patterning in squid



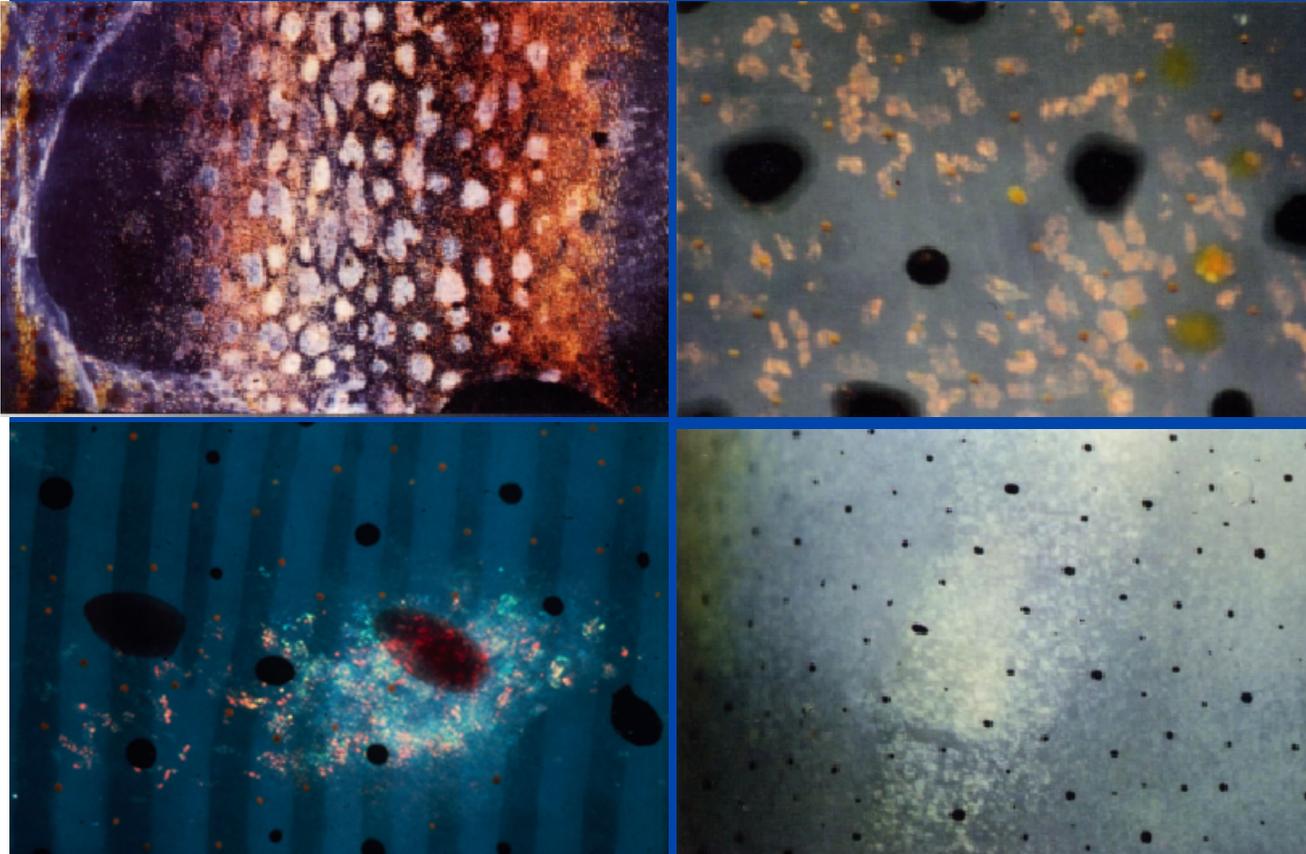
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Low-res skin: squid



High-res skin: cuttlefish

Structural color: reflecting cells



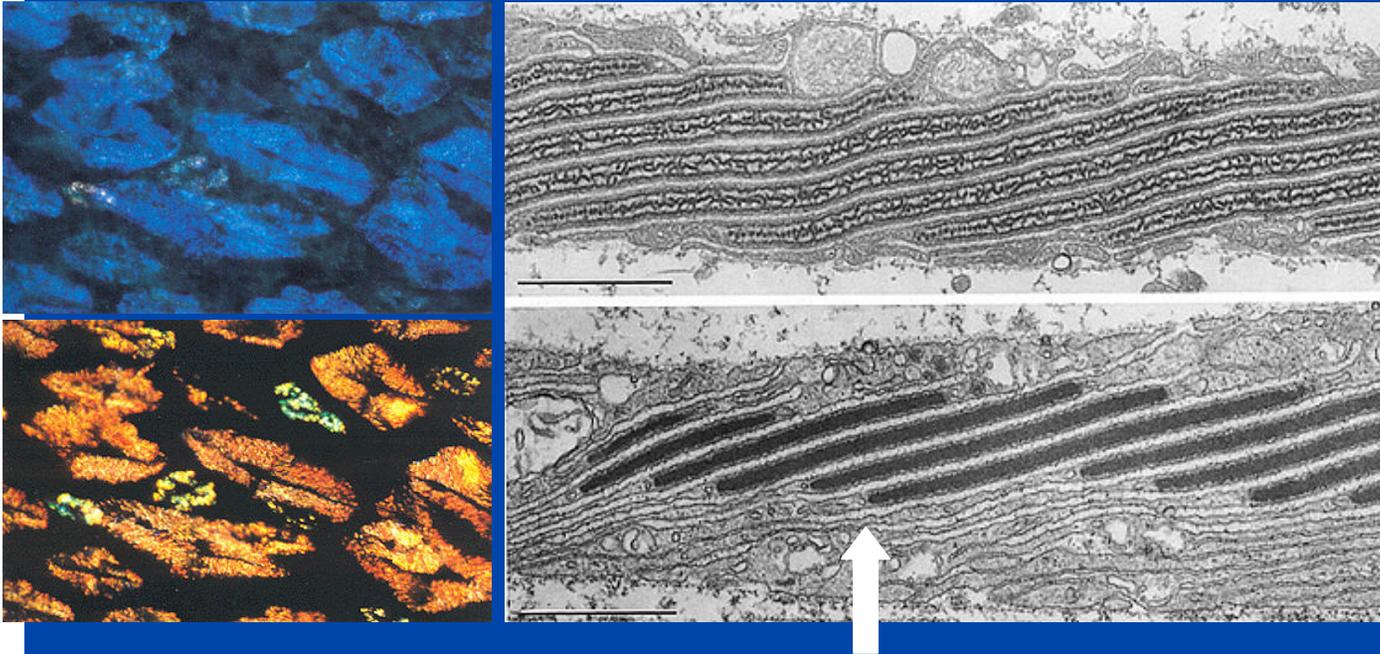
Some are passive cells,
some are actively controlled

Dynamic iridescence in reef squid



06:00:41;23

Iridophores: how do they work?



1. Turn reflectance ON
2. Change COLOR of reflectance

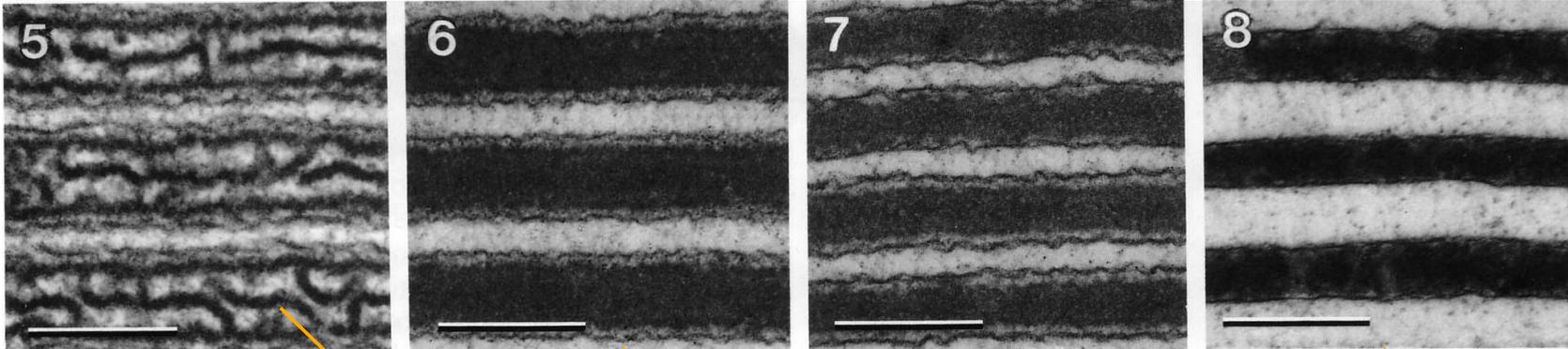
Non-iridescent

Iridescent >

Pink and gold

Mix of colors

Green and blue



**MESSAGE:
chemically
tuned
color**

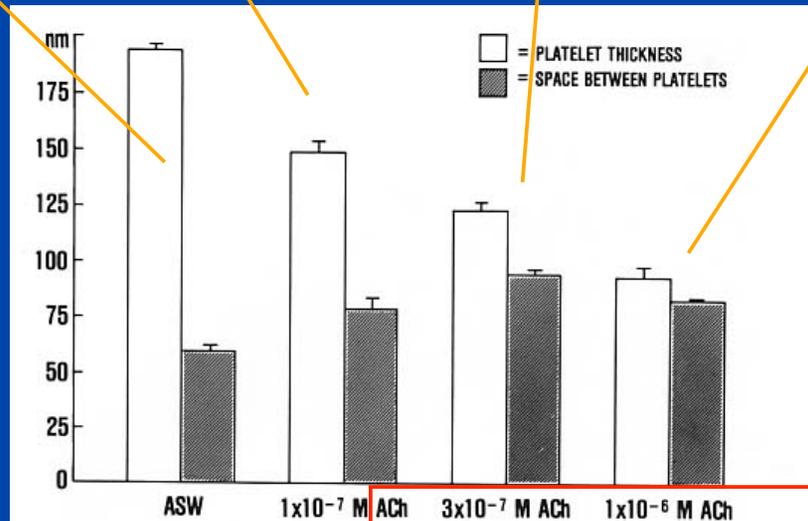


Fig. 17. Graphic representation of the mean thicknesses of platelets and interplatelet spaces of active iridophores (Group 2, Table 1). Those iridophores in ASW were non-iridescent; those treated with 1×10^{-7} M ACh were mostly red to gold; those in 3×10^{-7} M ACh were a mixture of colors; and those treated with 1×10^{-6} M ACh were mostly green and blue. Bars: standard errors of the means

These iridophores comprise thin plates of protein

- The recently discovered “reflectin proteins” are unique among animal reflectors.
- Crookes, et al. 2004.
Reflectins: the unusual proteins of squid reflective tissues. *Science* 303: 235-238.



nature
materials

VOL. 6 NO. 7 JULY 2007
www.nature.com/naturematerials

From squid to optical devices

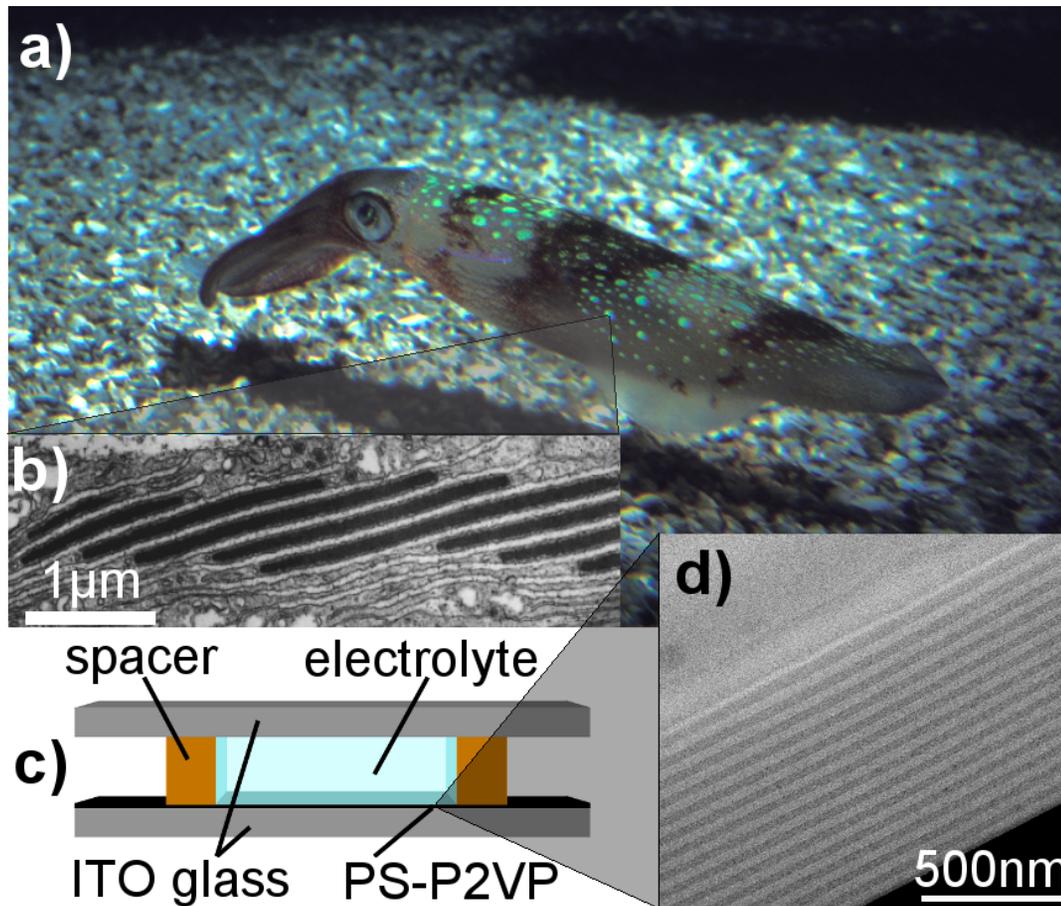
NANOSCALE ENGINEERING
Playing with carbon and silicon

MAGNETIC SEMICONDUCTORS
Close up on strain effects

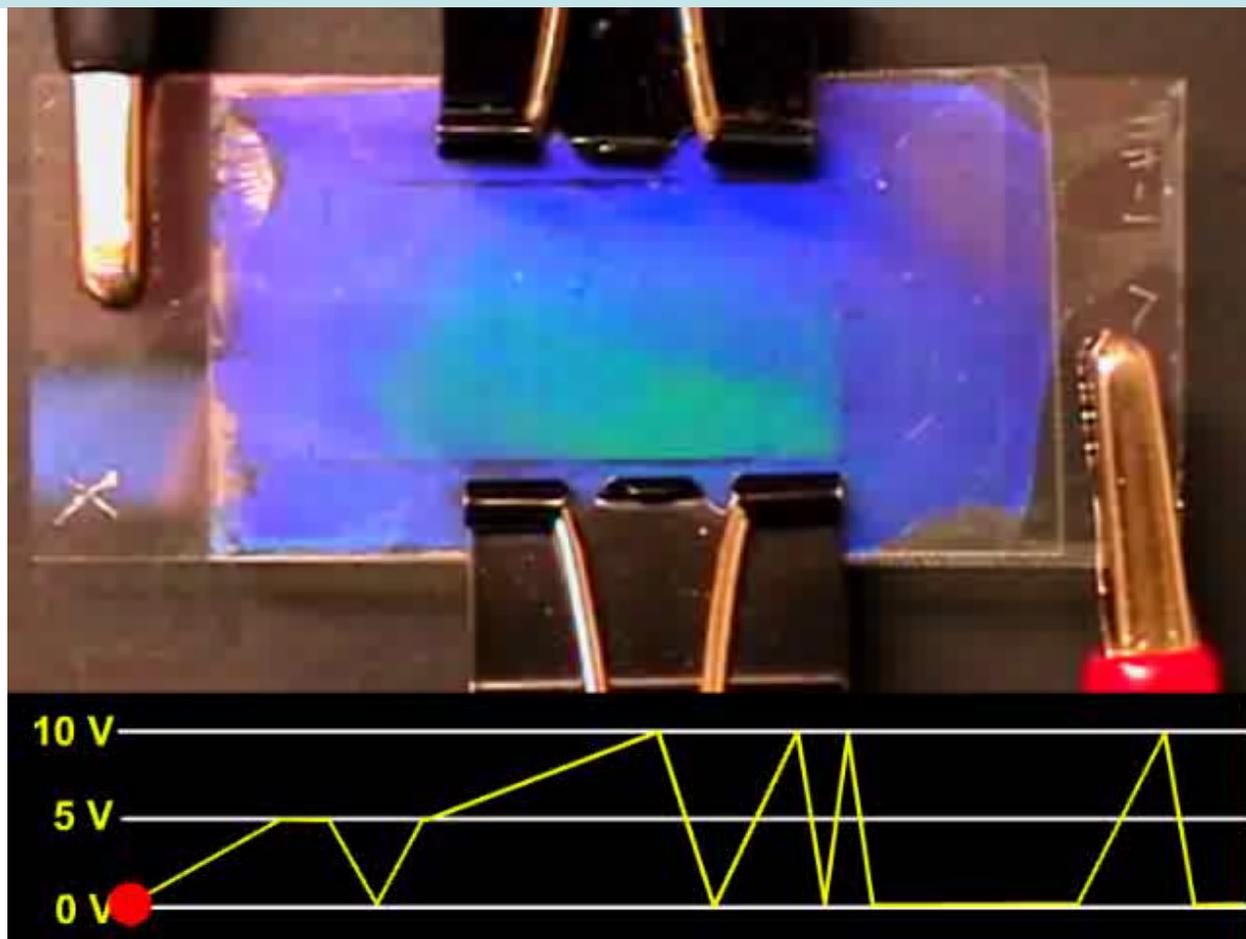
MODERN UNIVERSITIES
Academic freedom versus private funding

Biologically Inspired Photonic Gels

Professor Ned Thomas, MIT



Electrochemical Color Tuning

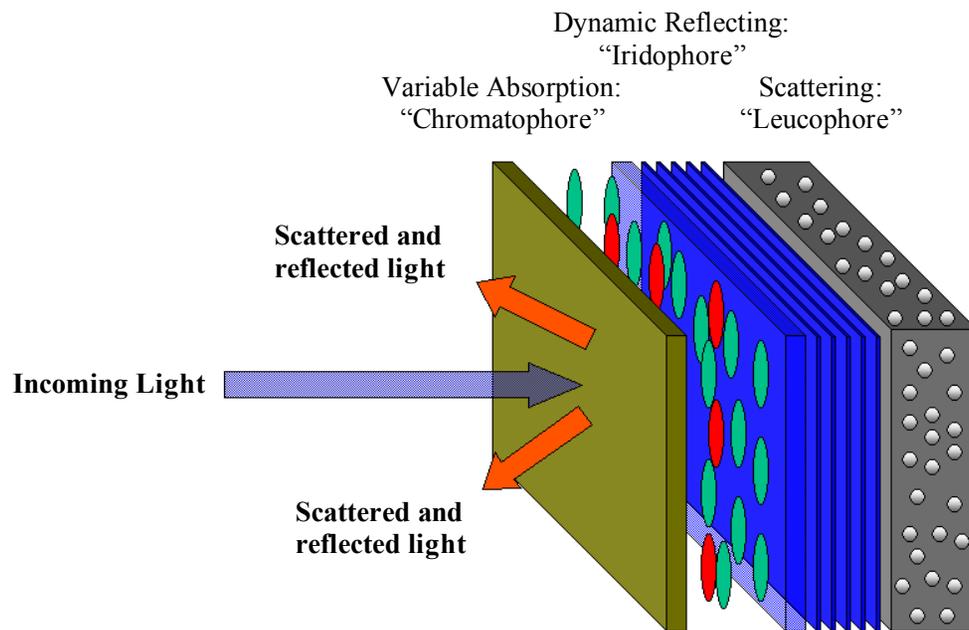


Walish, J.J., Kang, Y., Mickiewicz, R., Thomas, E.L.,
"Bio-Inspired Electrochemically Tunable Block Copolymer
Full Color Pixels," *Advanced Materials*, (2009)

Brief summary of iridophore story

- Active and passive cells complement appearance
- 2 mechanisms: become iridescent; change color
- Muscles or neurons do not directly affect either mechanism; cholinergic, non-synaptic control?
- ACh induces ultrastructural change in “reflectin” protein
- Molecular switch being worked out (=dynamics)
- Thin-film interference / diffraction grating mechanisms

Sutherland, Mathger, Hanlon, Urbas,
Stone. 2008. J Opt Soc Amer 25



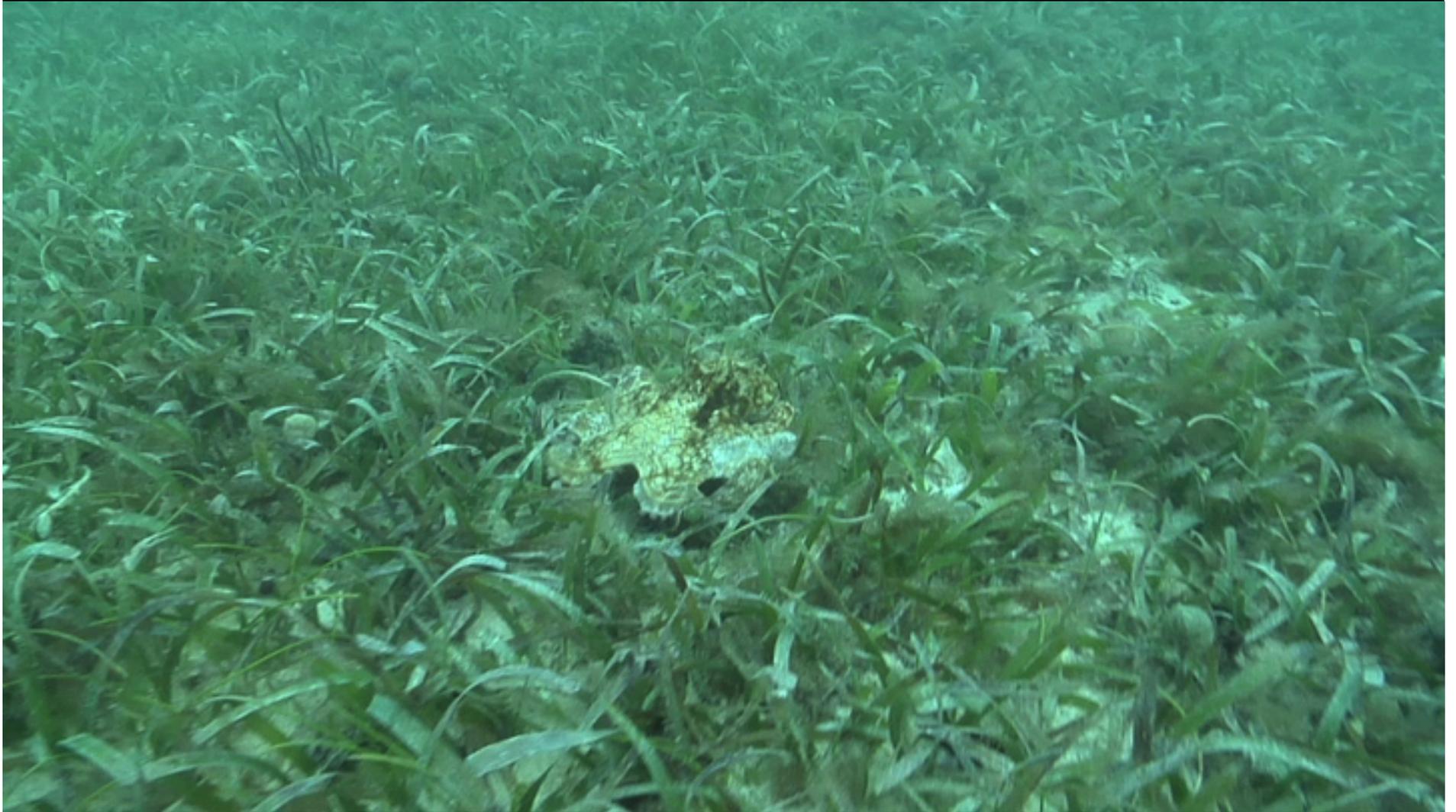
LEUCOPHORES

- leucophores: “white cell”
assemblage of spheres mixed
with iridophores (flat platelets)
- passive cells that manipulate
light (ie no muscles or nerves
to power the cells)
- leucosomes: spherical light
diffusers composed of protein

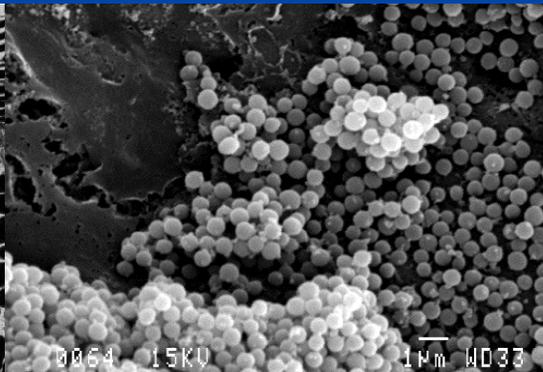
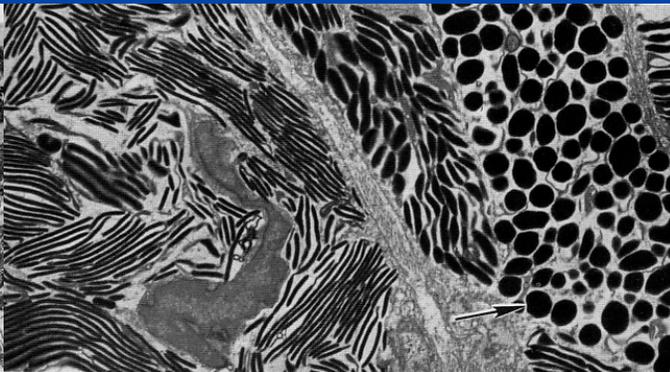
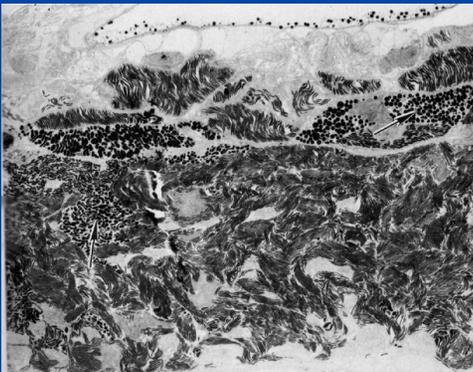
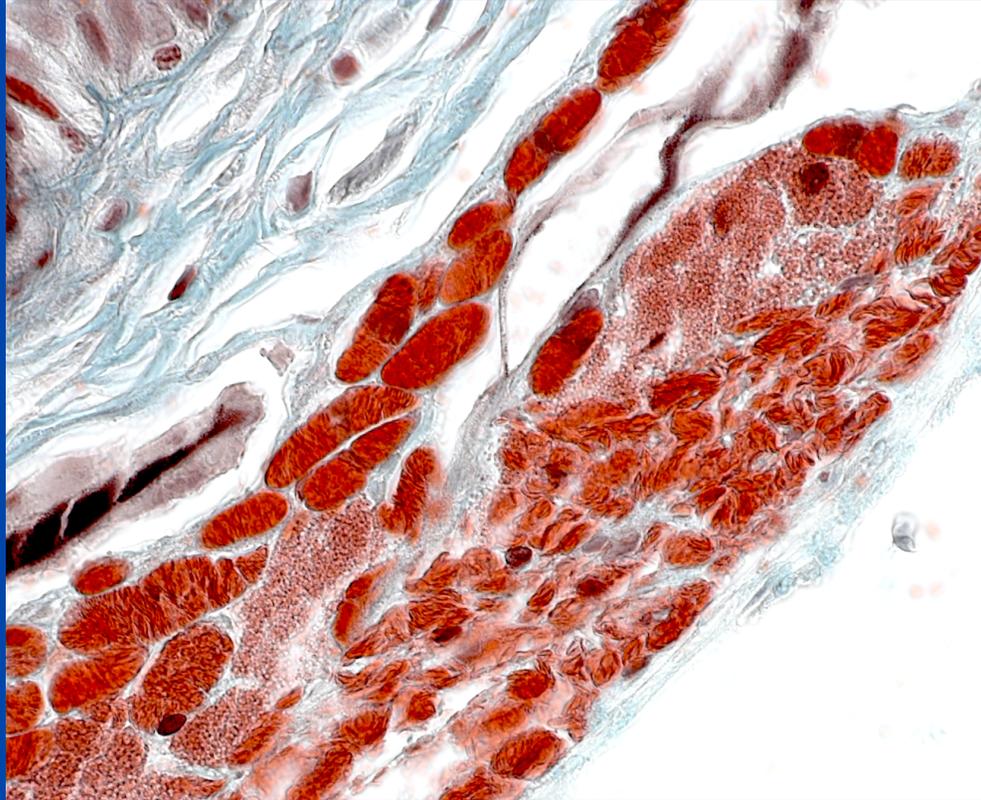
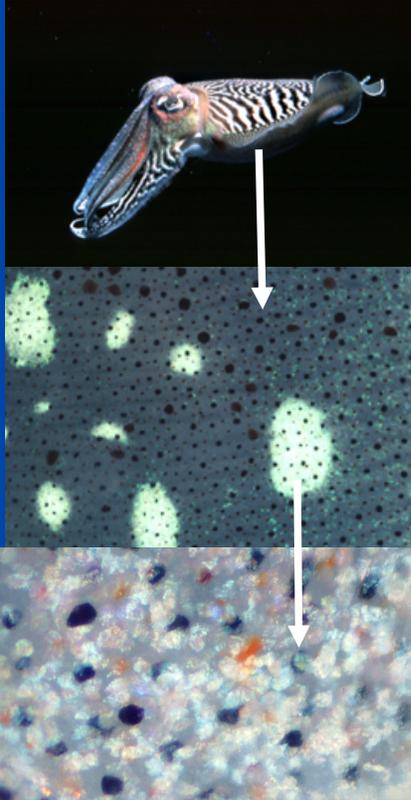


- shadow mitigation
- maximum tonal contrast for disruptive coloration & pictorial relief
- act as a light base layer upon which patterning is applied in artificial architectures

The importance of white for signaling



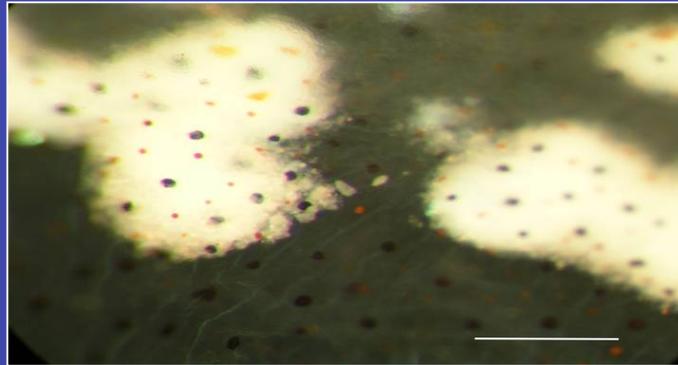
White leucophore spots: macro to nano scale



Bar 10 microns

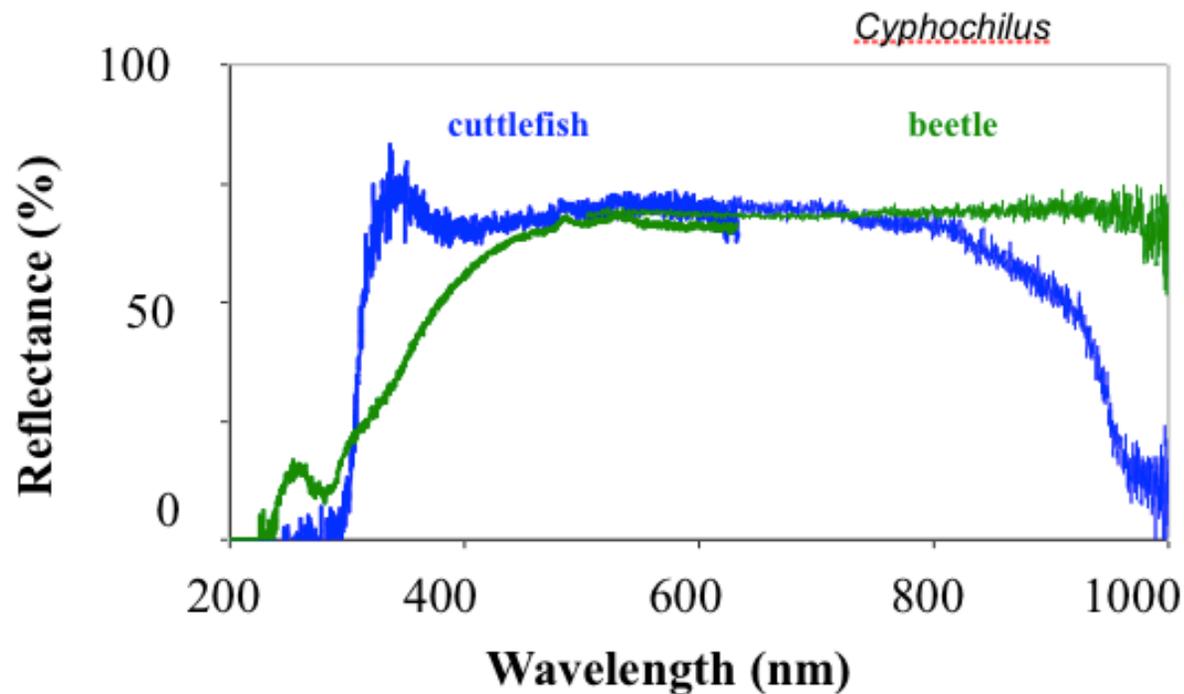
Bar 1 micron

Spectrometry of cuttlefish leucophores



LEUCOPHORES

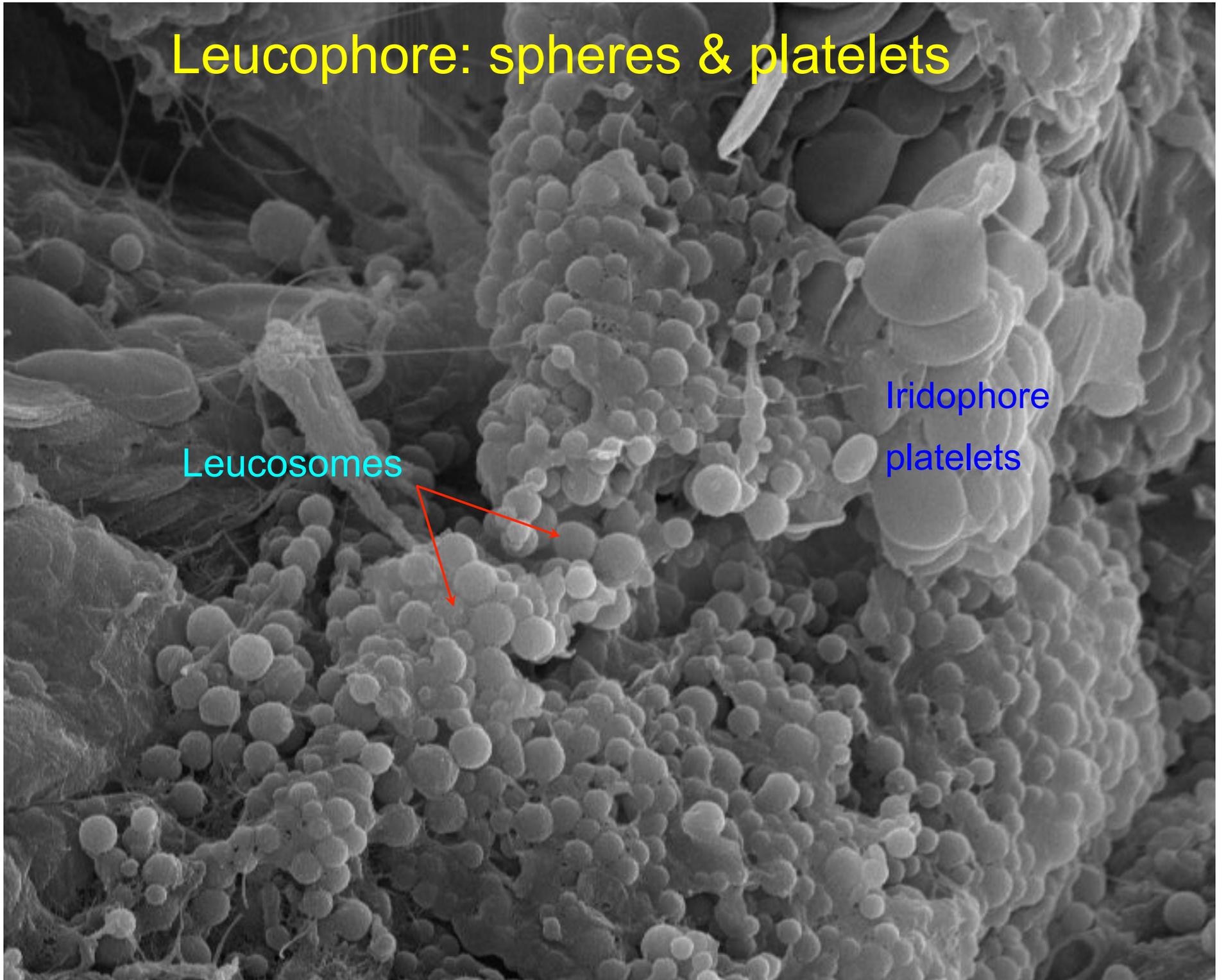
exceptional whiteness



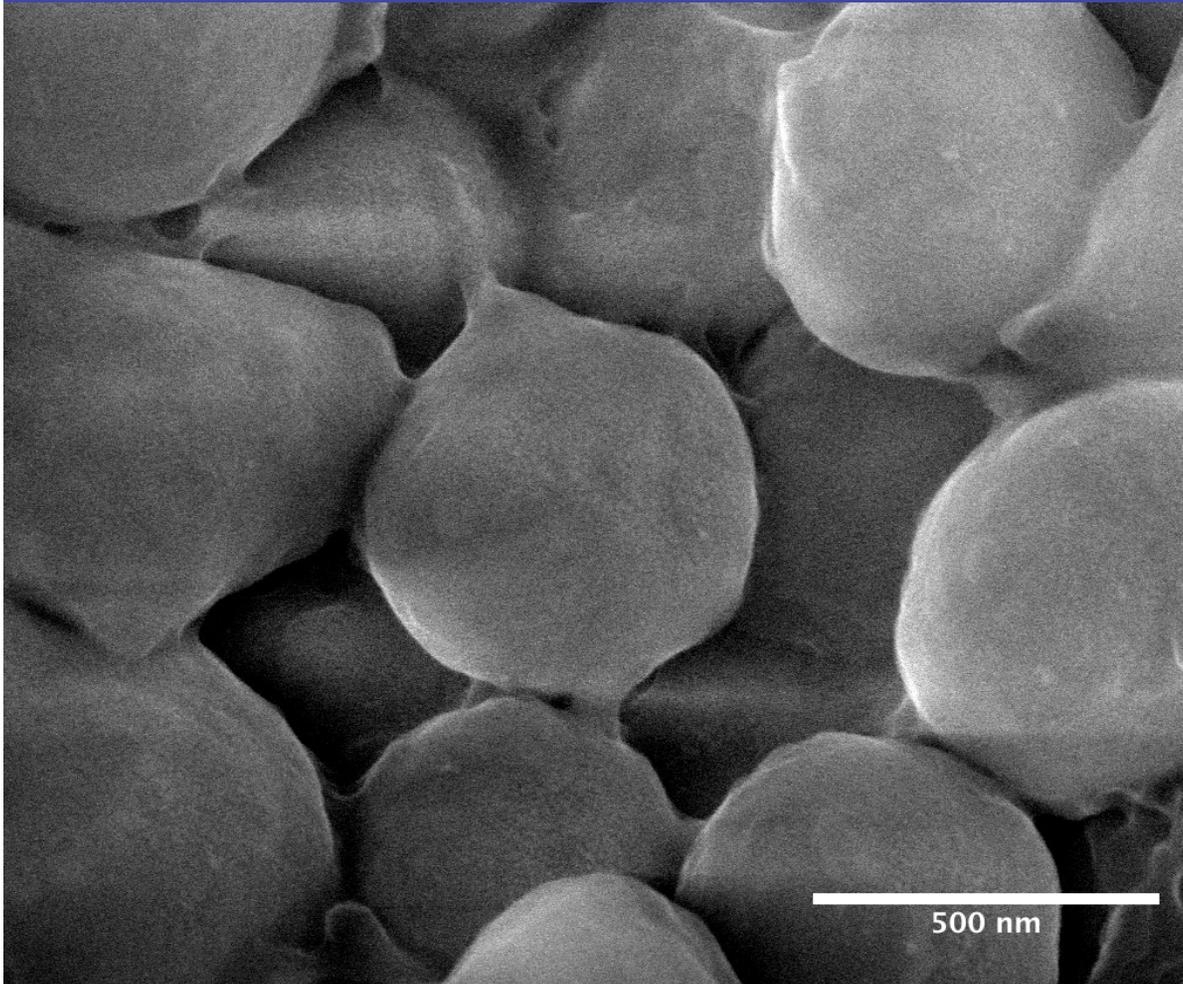
Leucophore: spheres & platelets

Leucosomes

Iridophore
platelets

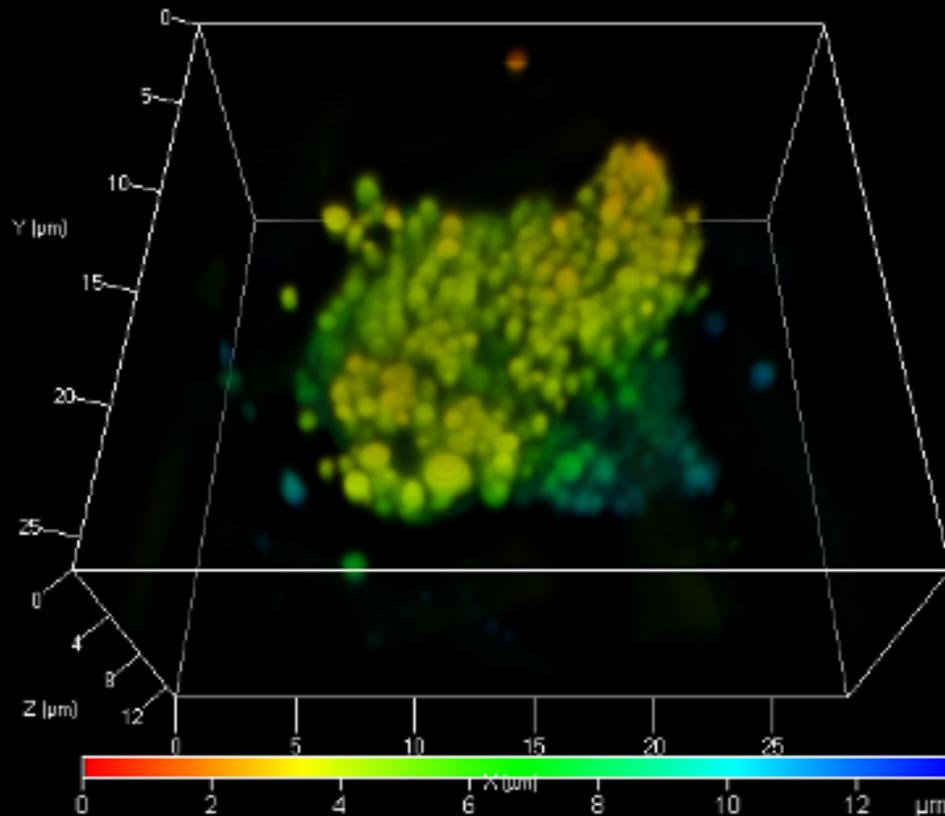


Sepia leucophore



3D Sepia leucophore

spheres range ca. 200-1200nm



SKIN PAPILLAE



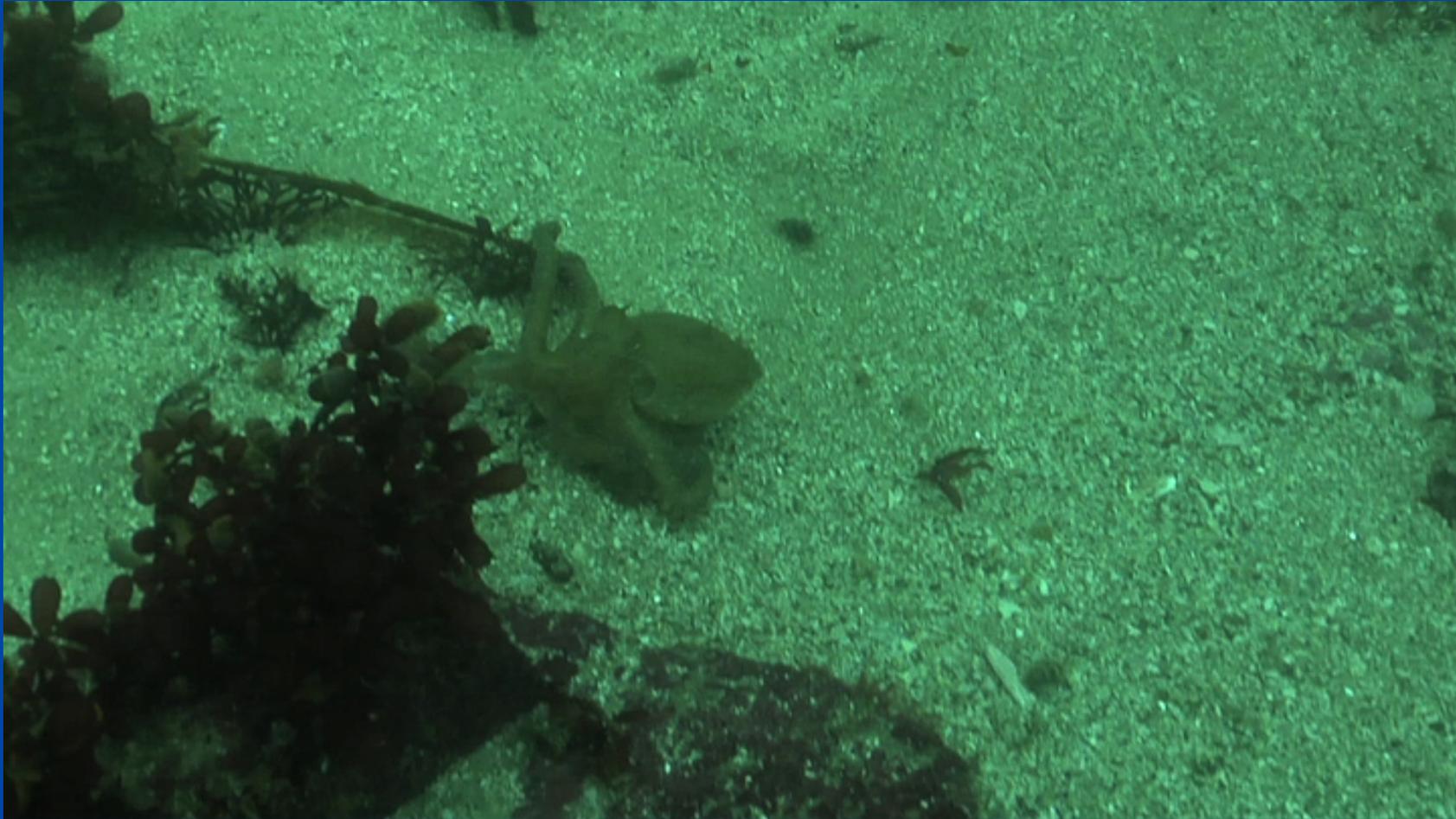
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The animal's capabilities

First: conspicuous appearance





Papillae: muscular hydrostats?

mimic octopus



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Summary

The transition from biology to inspired materials is well underway after a decade of “discussion.”

Some remarkable achievements have been made recently.

Very different disciplines (e.g. biology vs materials science/engineering) can inform each other, pose harder questions and stimulate new ways of thinking about old problems.

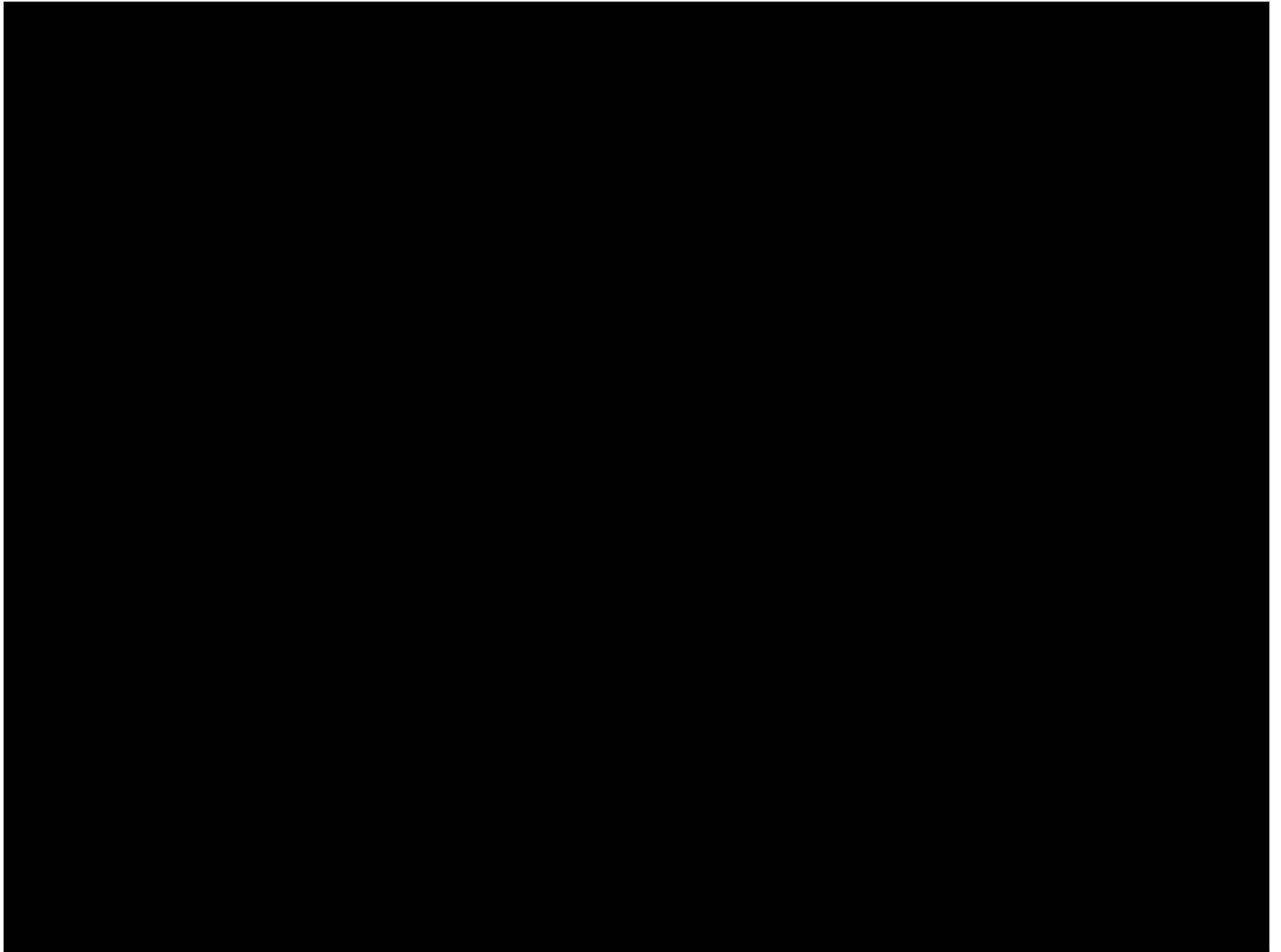
“Discover is to see what everyone has seen, and think what no one has thought” Albert St. Giorgi, MBL Nobel Laureate

Study nature, not books

L. Agassiz ca. 1890



Thank you



Video;
NOVA 40
Leuc 15
LMchro 22
Chro 1:50
SabaIri 18
OvDei 22
Pap2 17
Or):10
Or 0:42
defil 0:24

5min 20 sec

Skin structure

