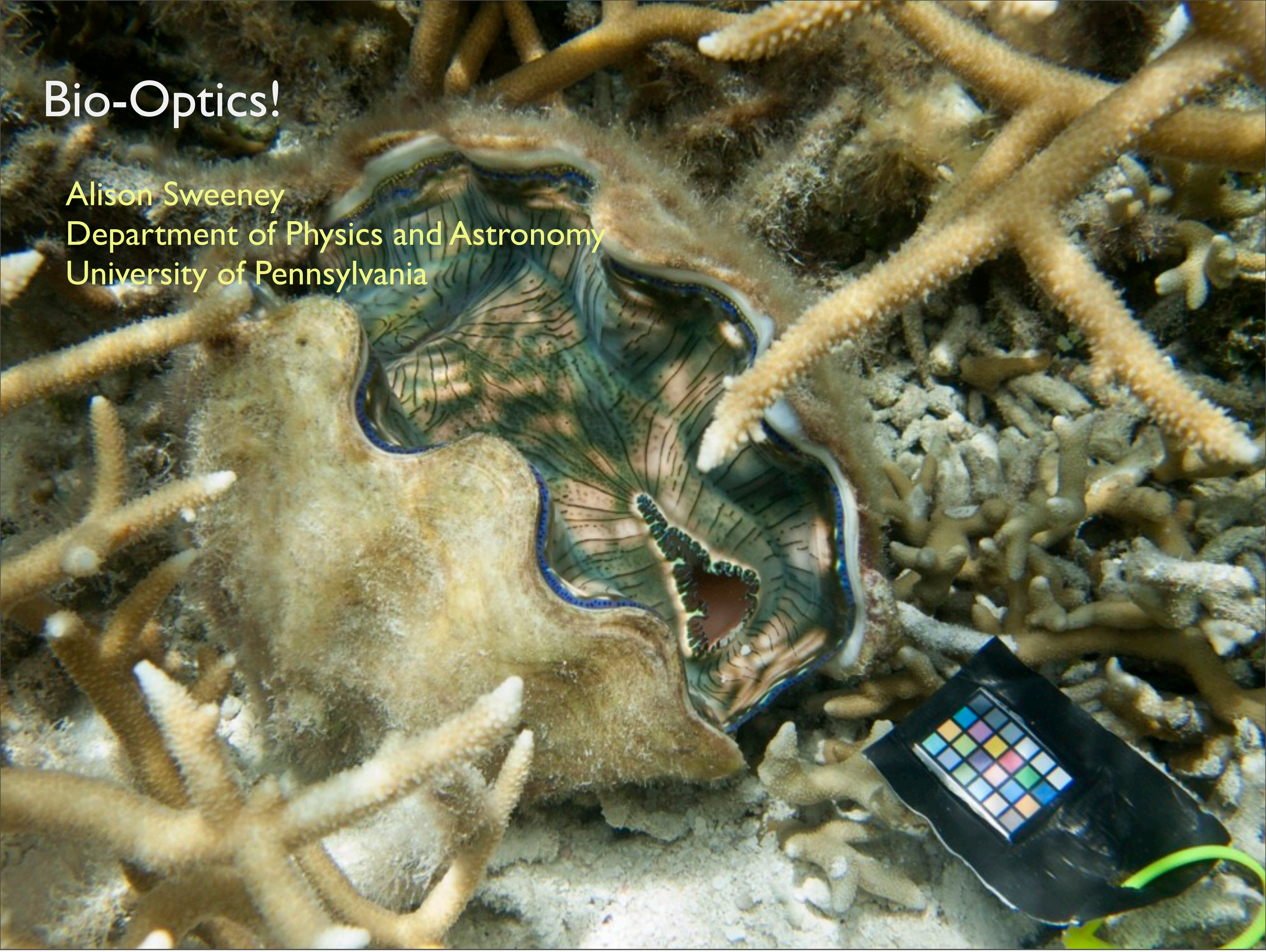
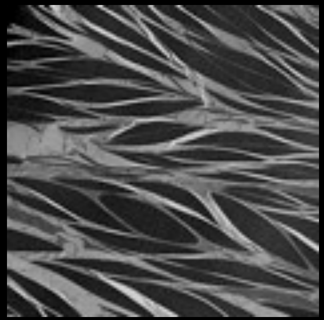
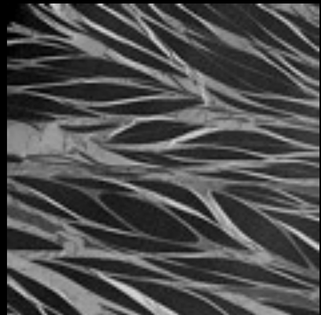
Bio-Optics!

Alison Sweeney
Department of Physics and Astronomy
University of Pennsylvania





This is only one example of dozens of novel structures in the ocean, each adapted for a different optical niche



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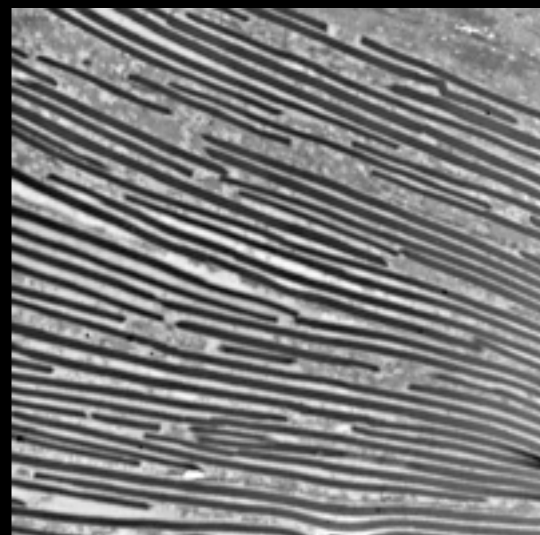

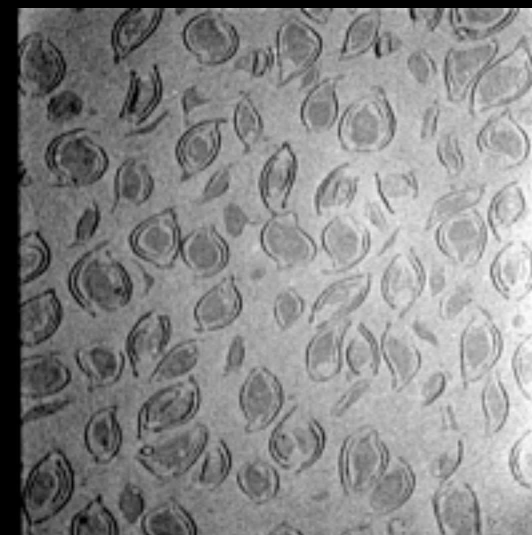

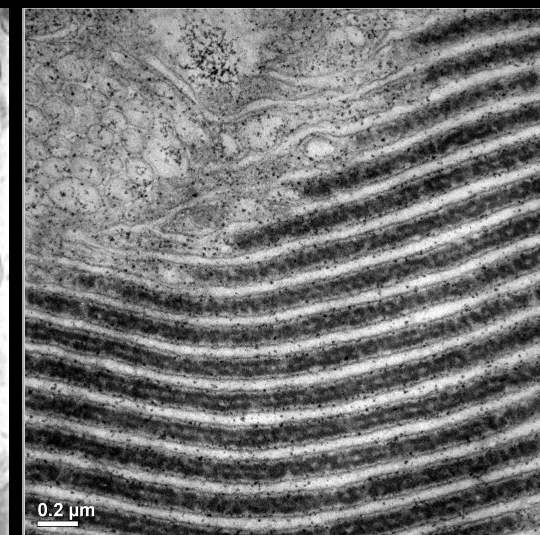

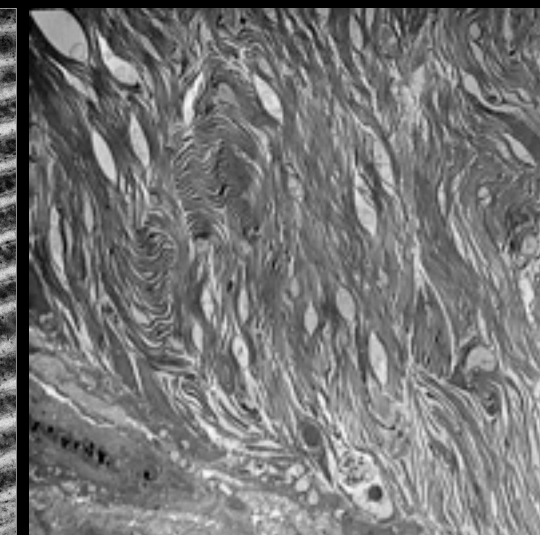

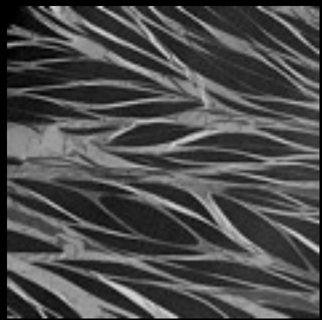

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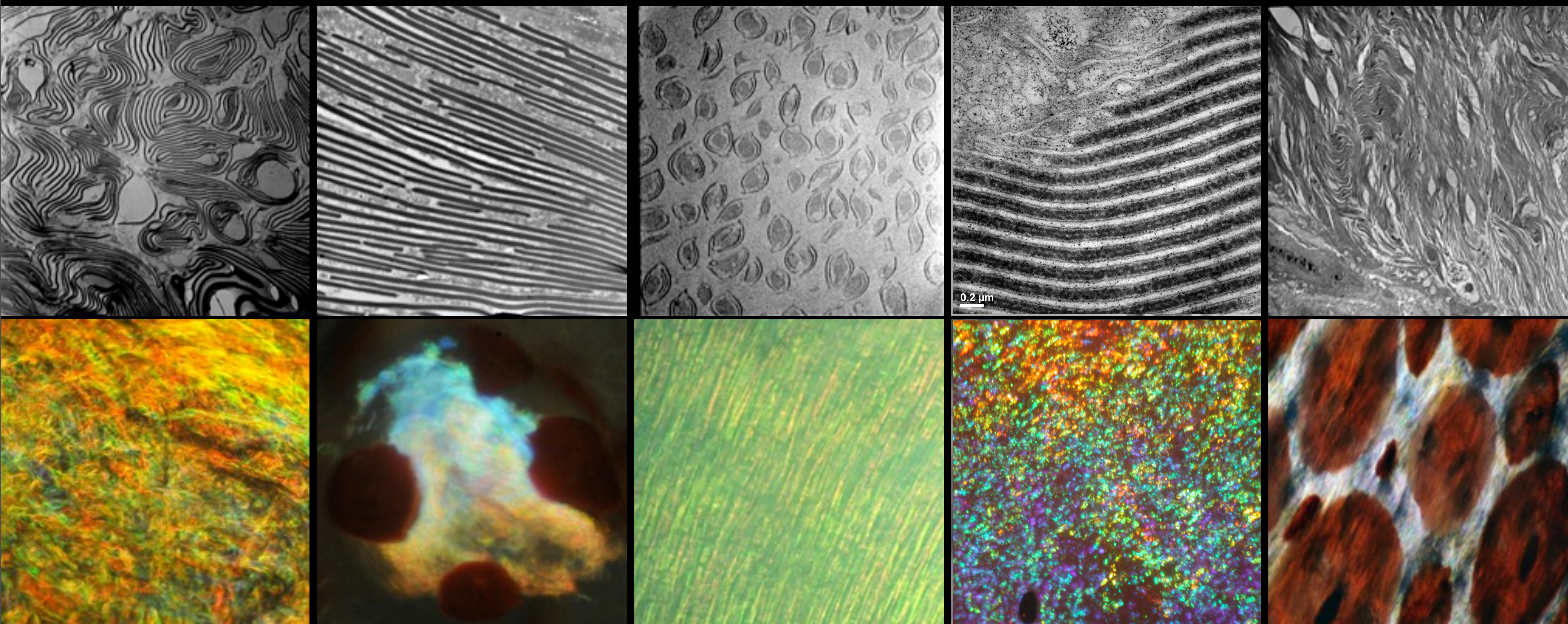
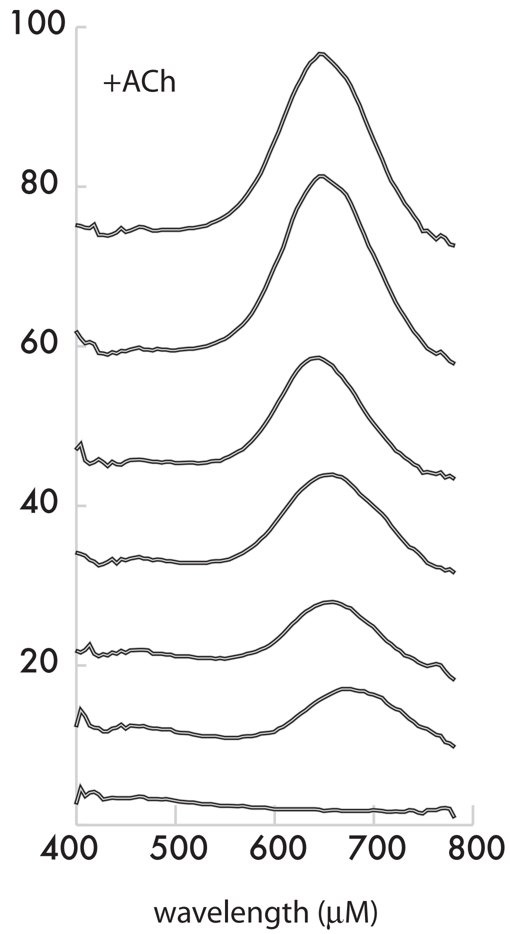
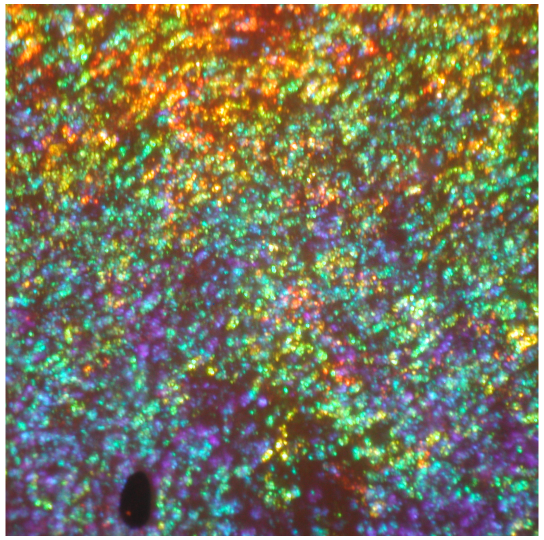
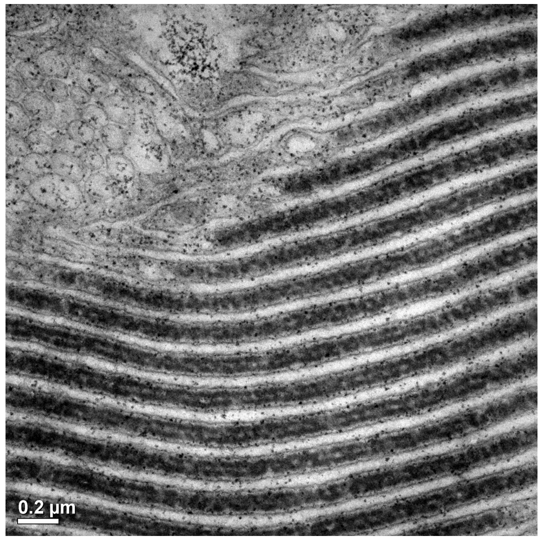


Dynamic iridescence in *Loligo opalescens* - acetylcholine-mediated dynamic iridescence against Raman-scattered light in the ocean







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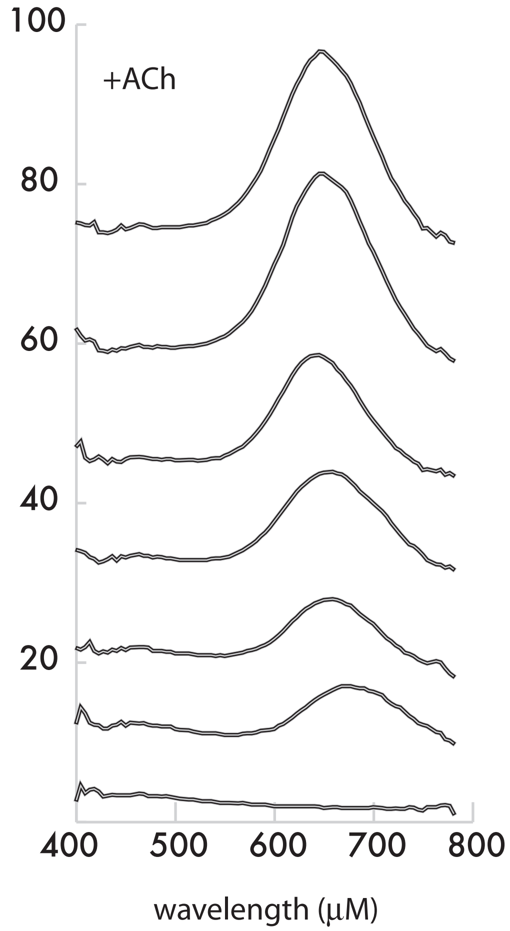
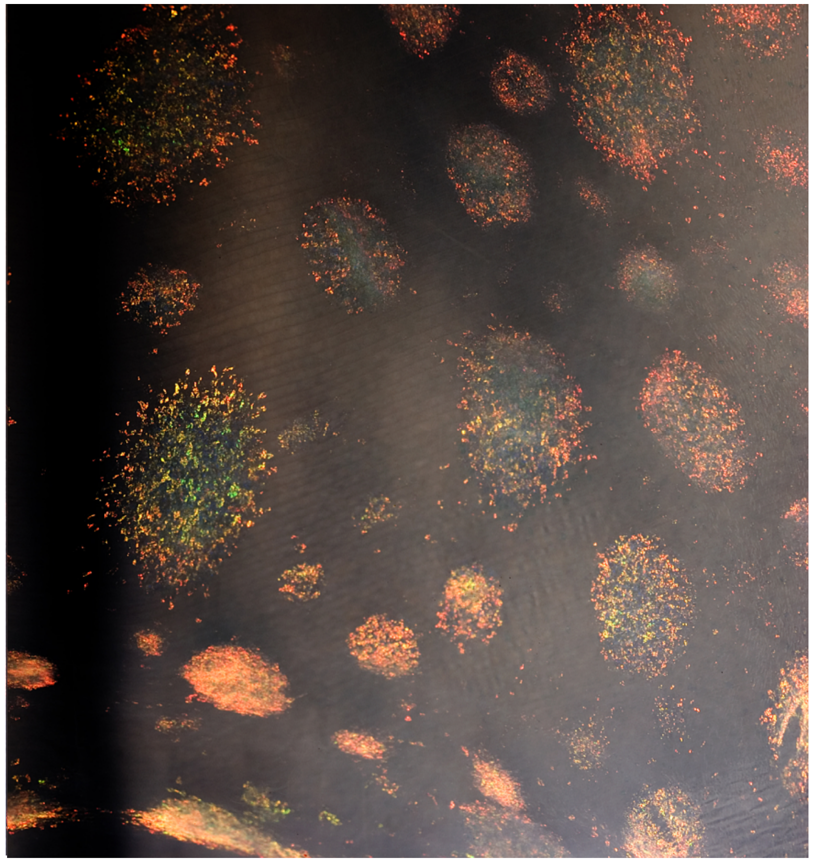
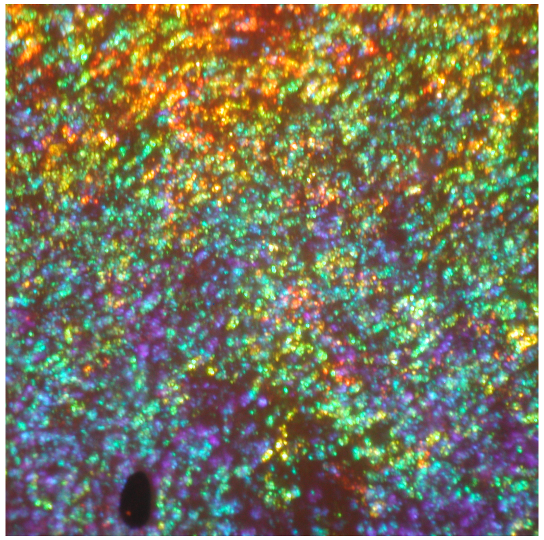
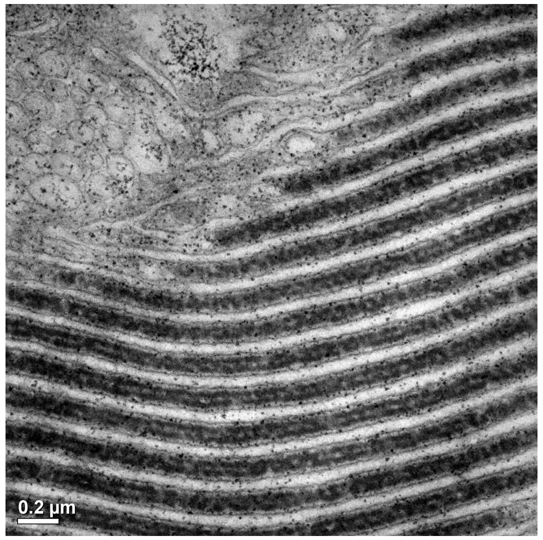
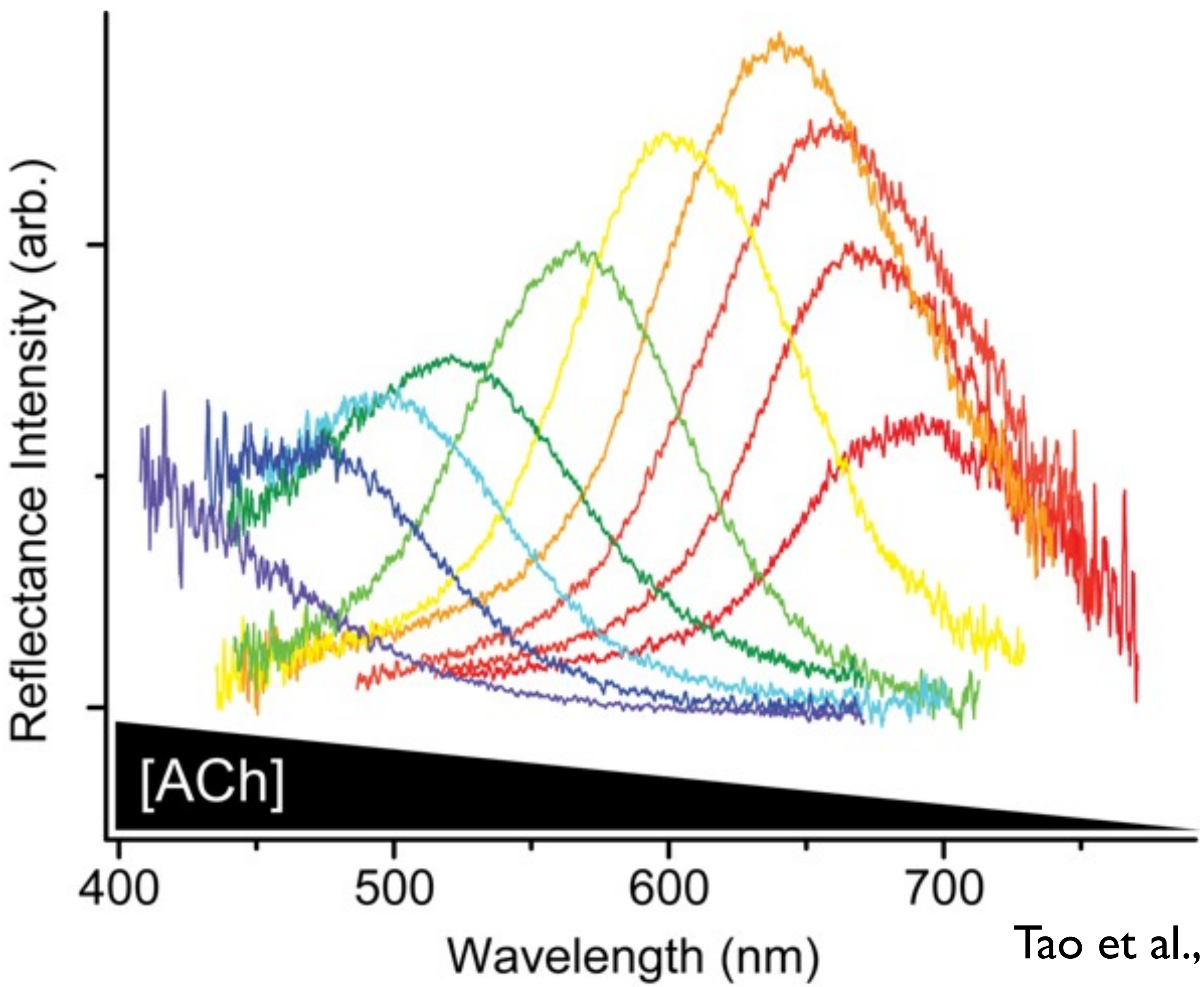






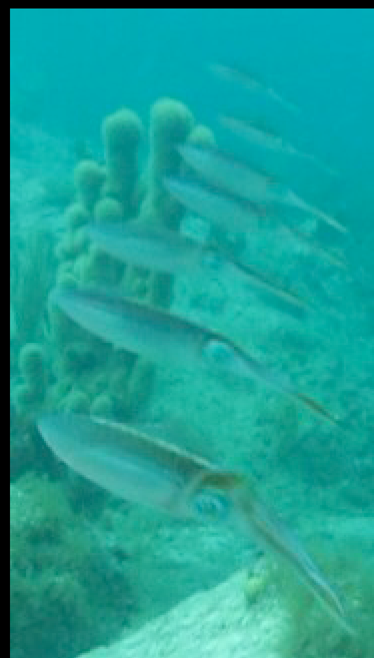


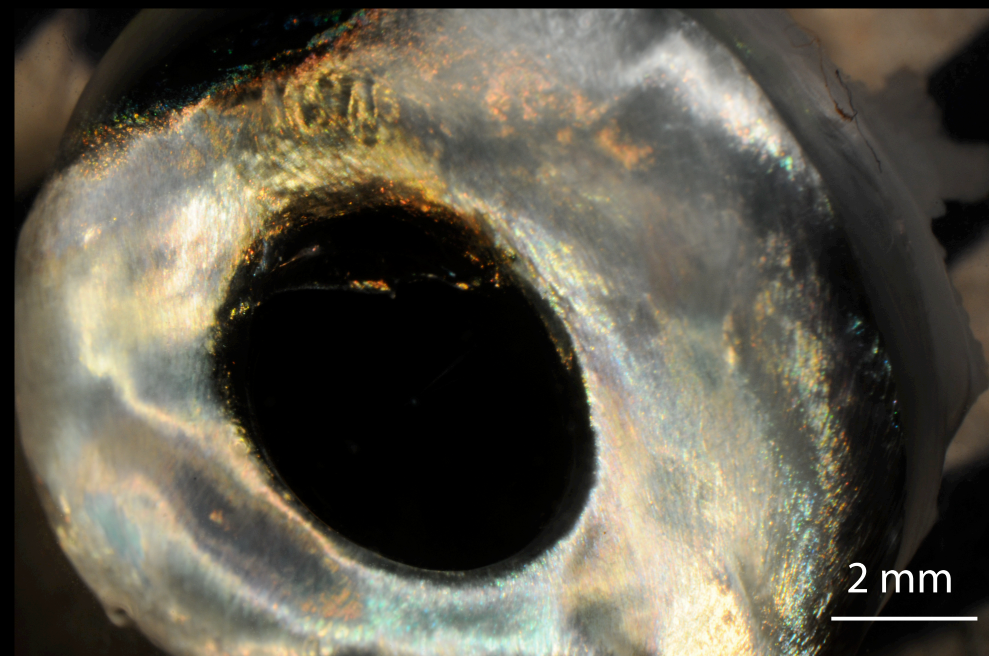


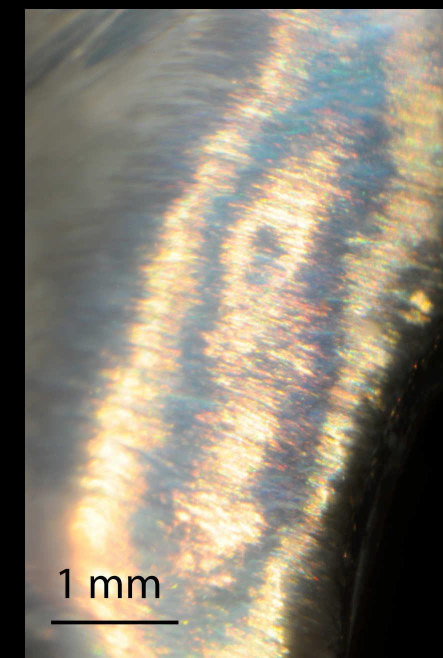
Tao et al., 2009

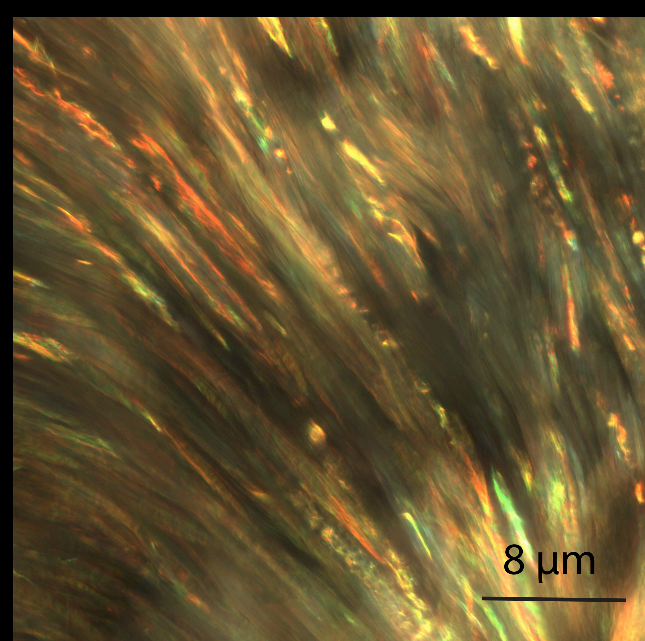
2. Self-assembly of squid camouflage

First study: Self-assembling broad-band camouflage in *Loligo* eyes









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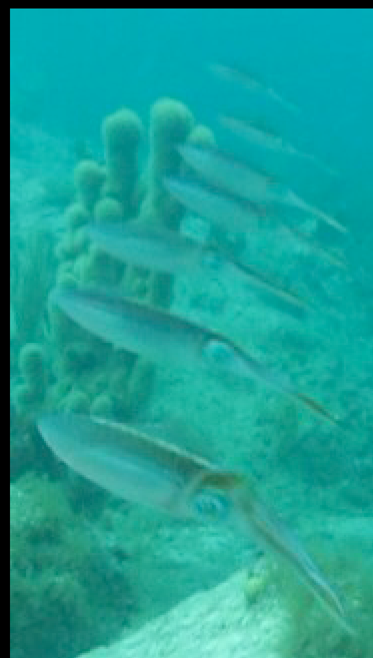
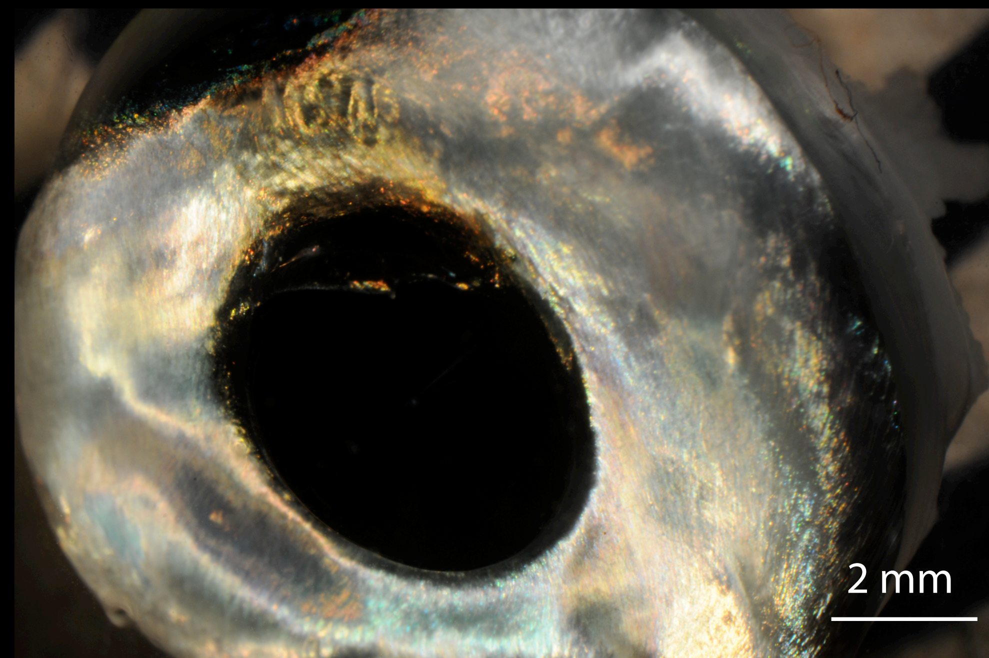
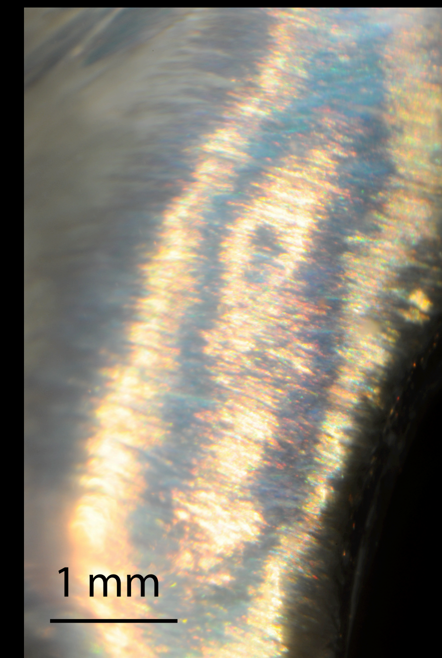
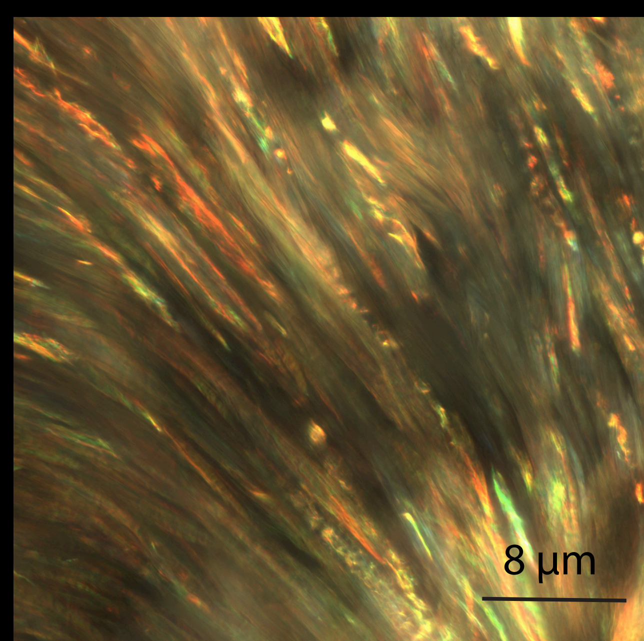
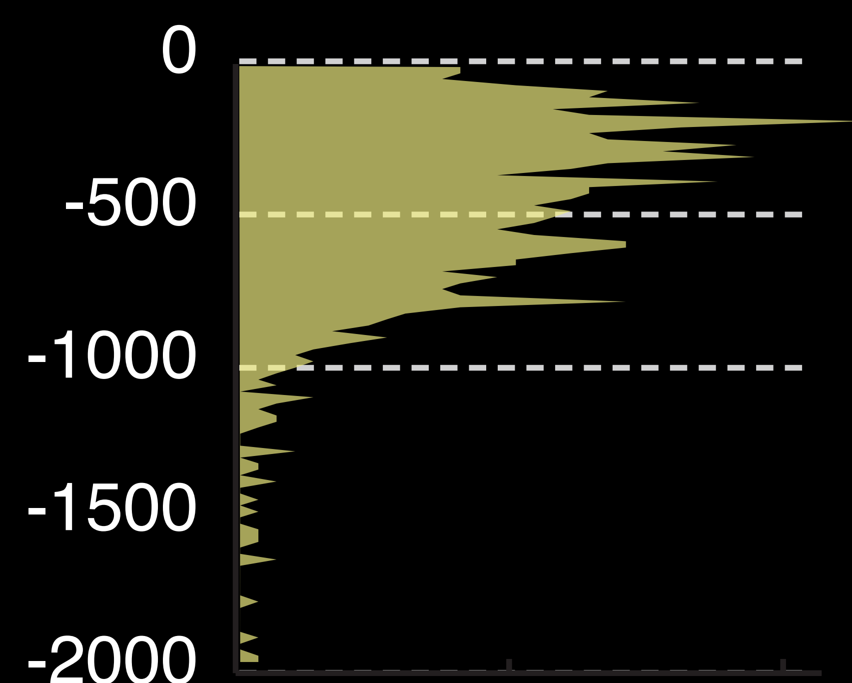


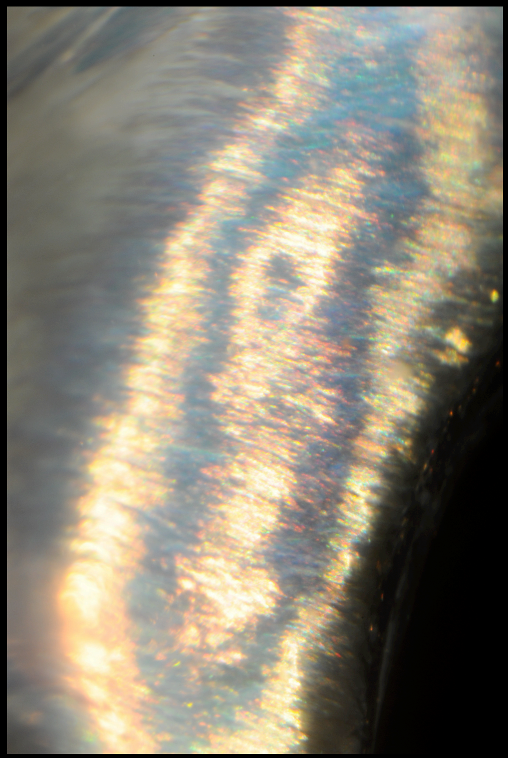


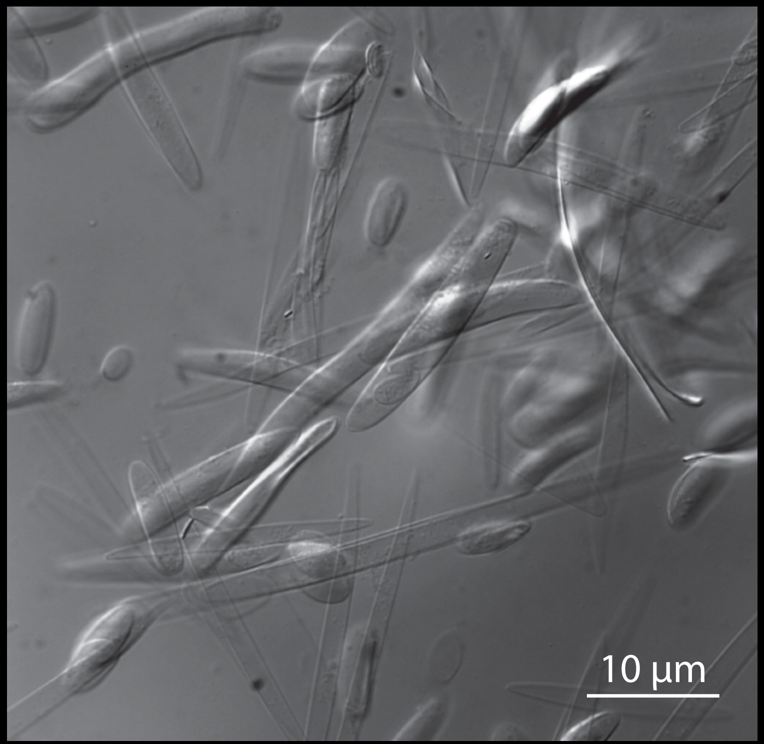


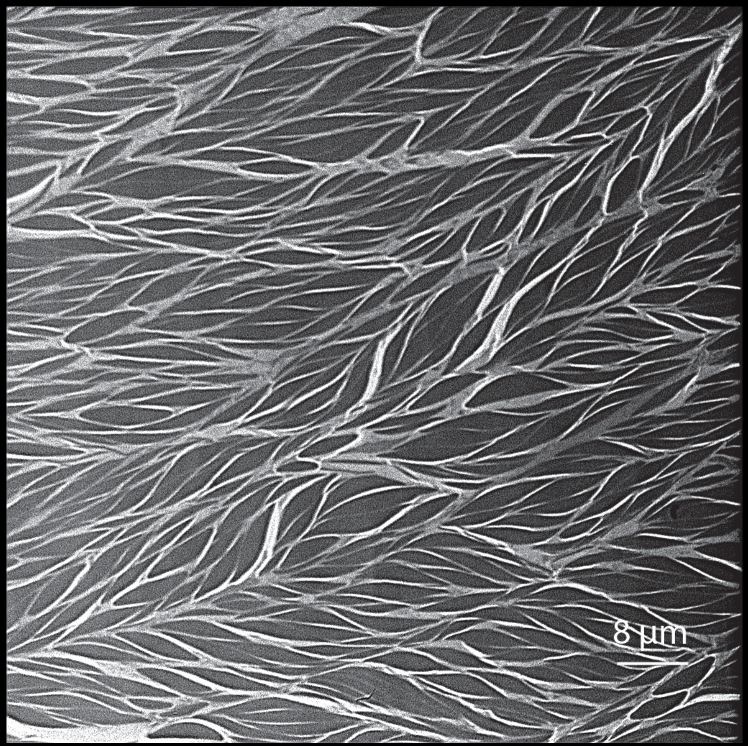




3D structure of laminated “silver” tissue

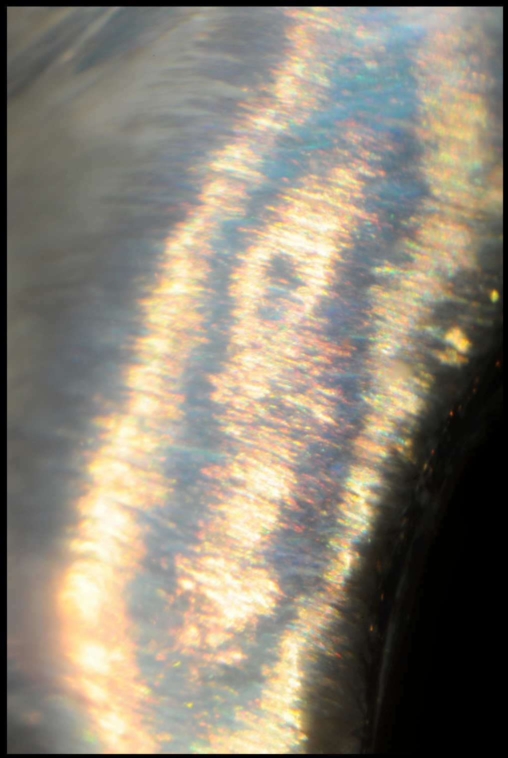


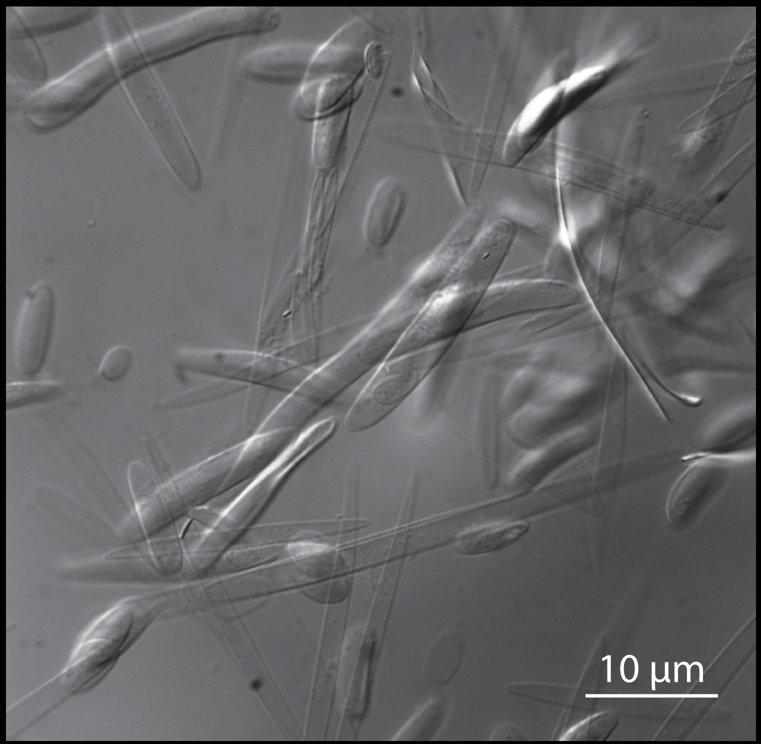


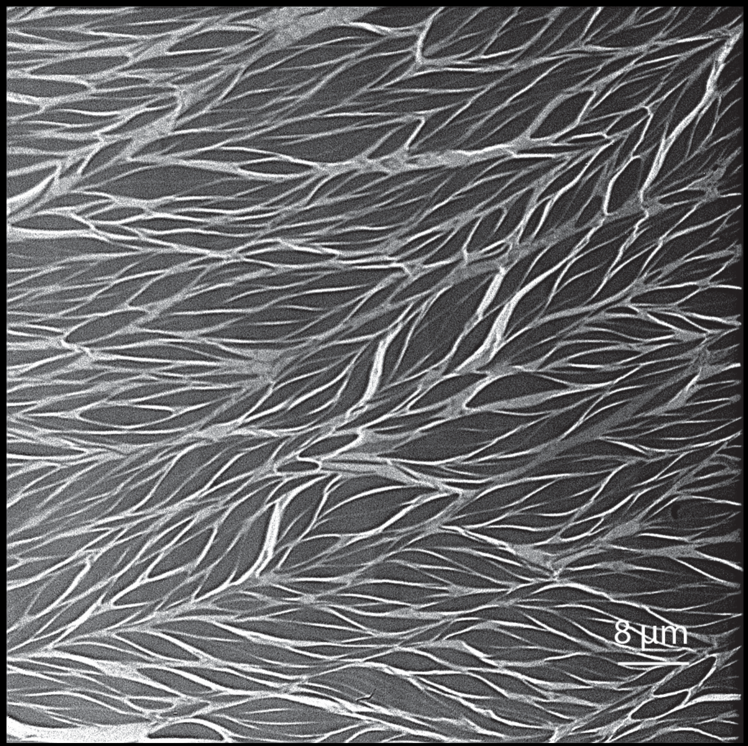


Nested-spindle structure
resulting in a self-assembling
highly distributed Bragg stack

3D structure of laminated “silver” tissue







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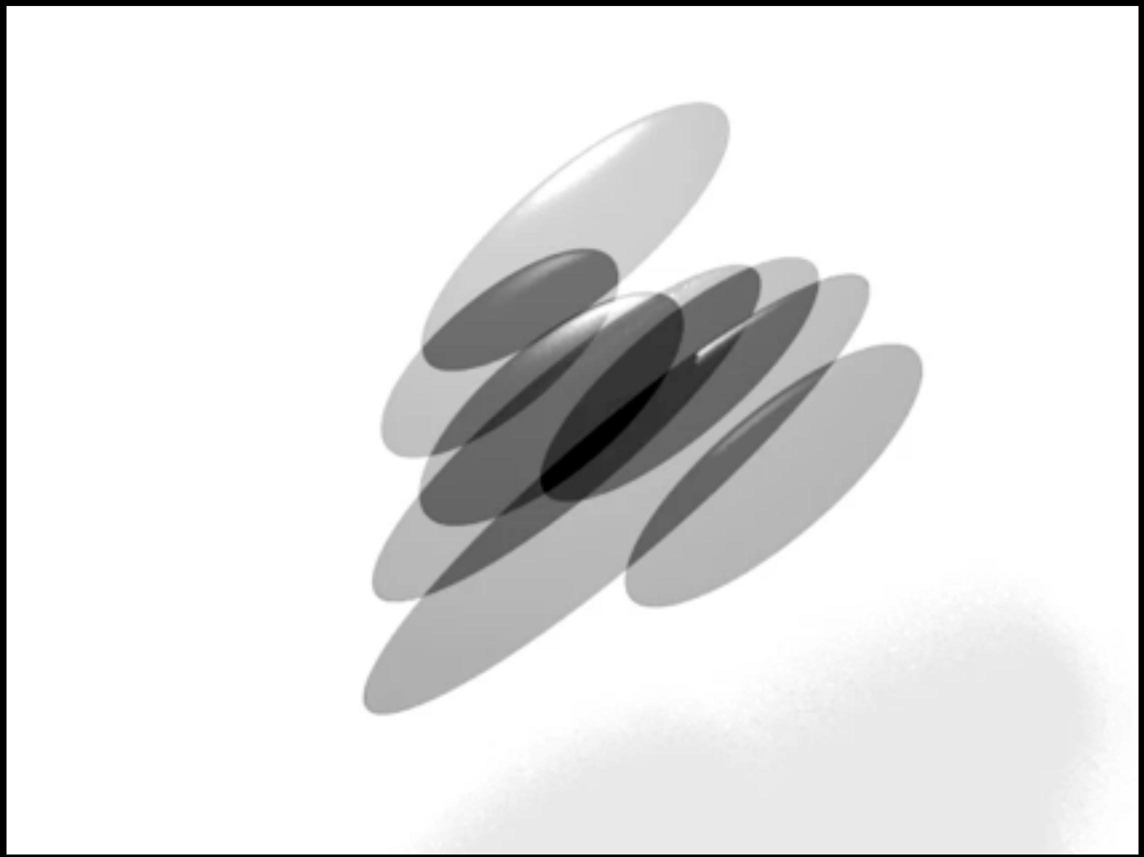

Modeling the nested-spindle structure

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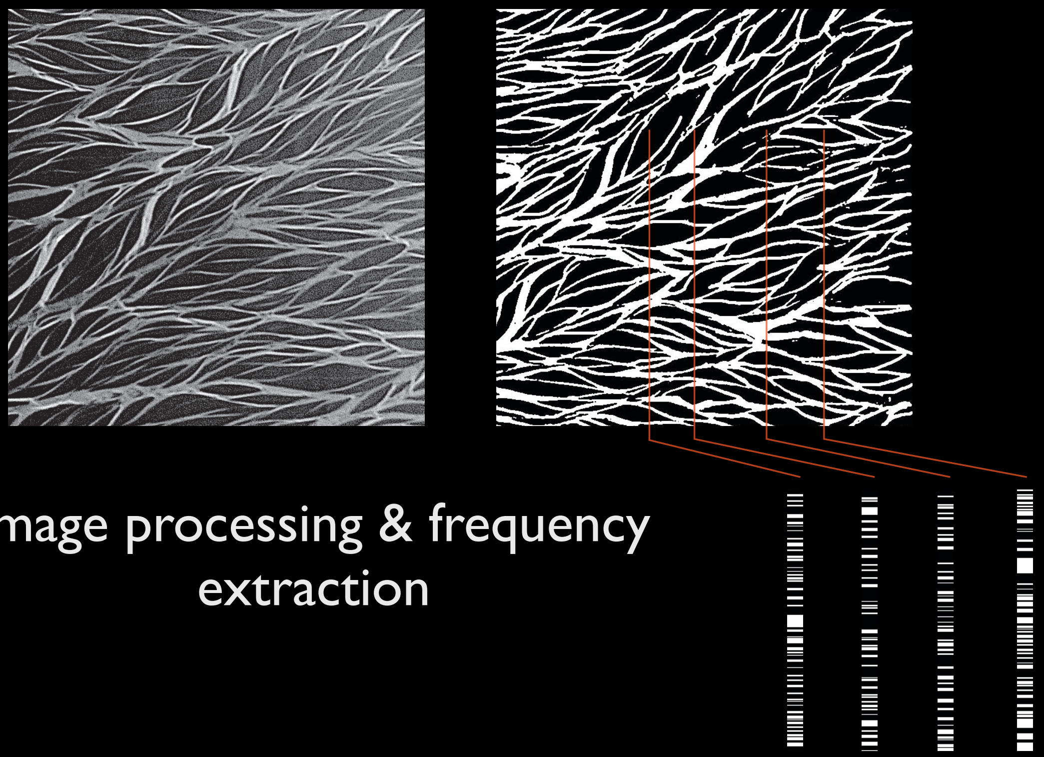
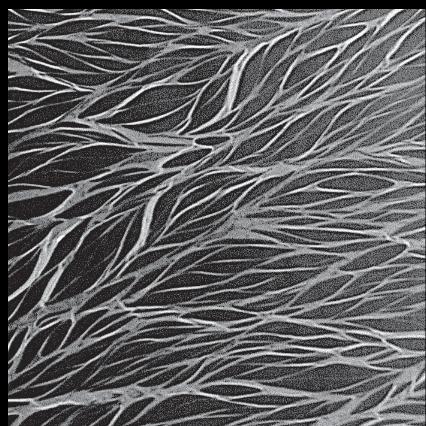


Image processing & frequency extraction

Modeling the nested-spindle structure



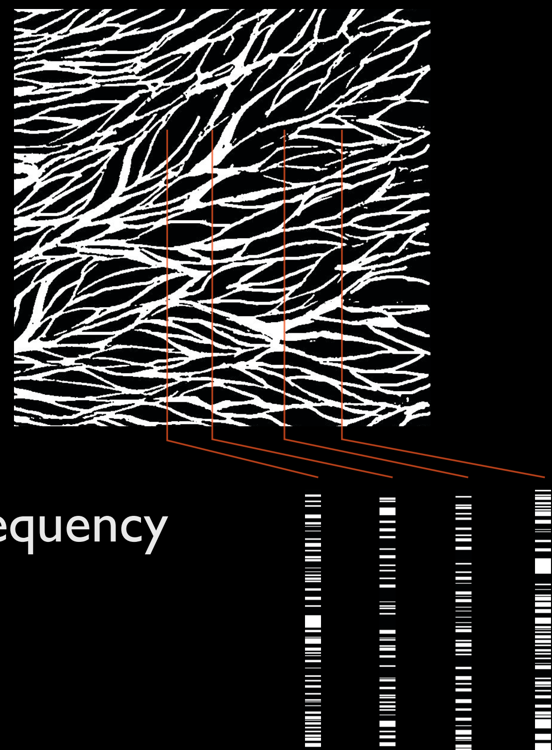
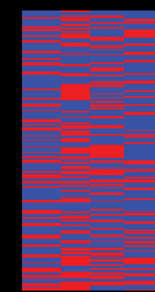
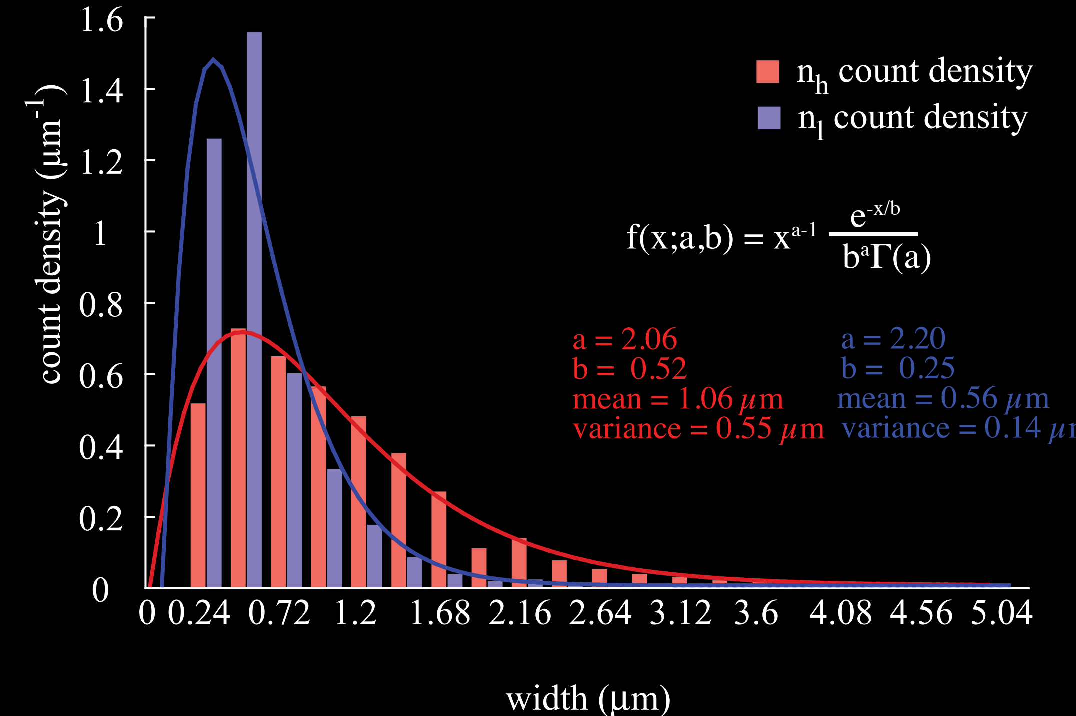


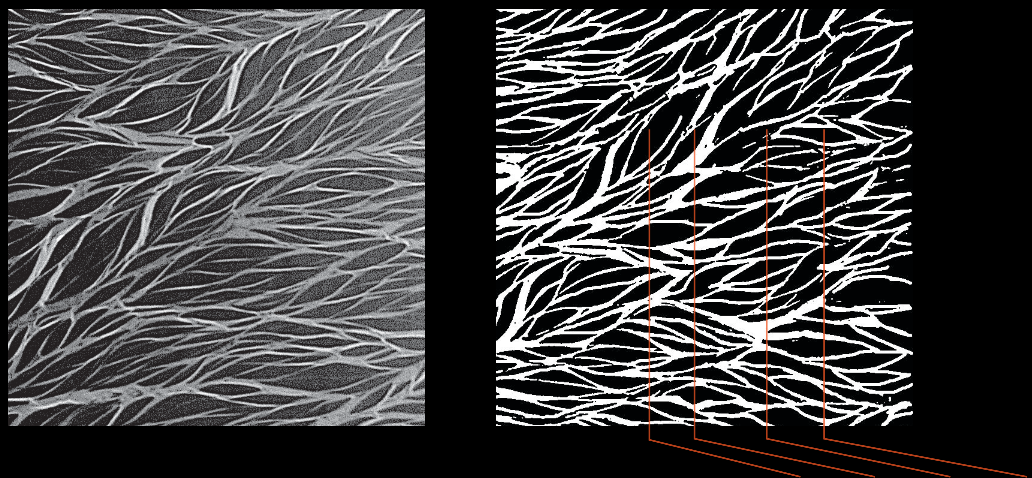
Image processing & frequency extraction





Statistical fitting of image frequencies

Modeling the nested-spindle structure



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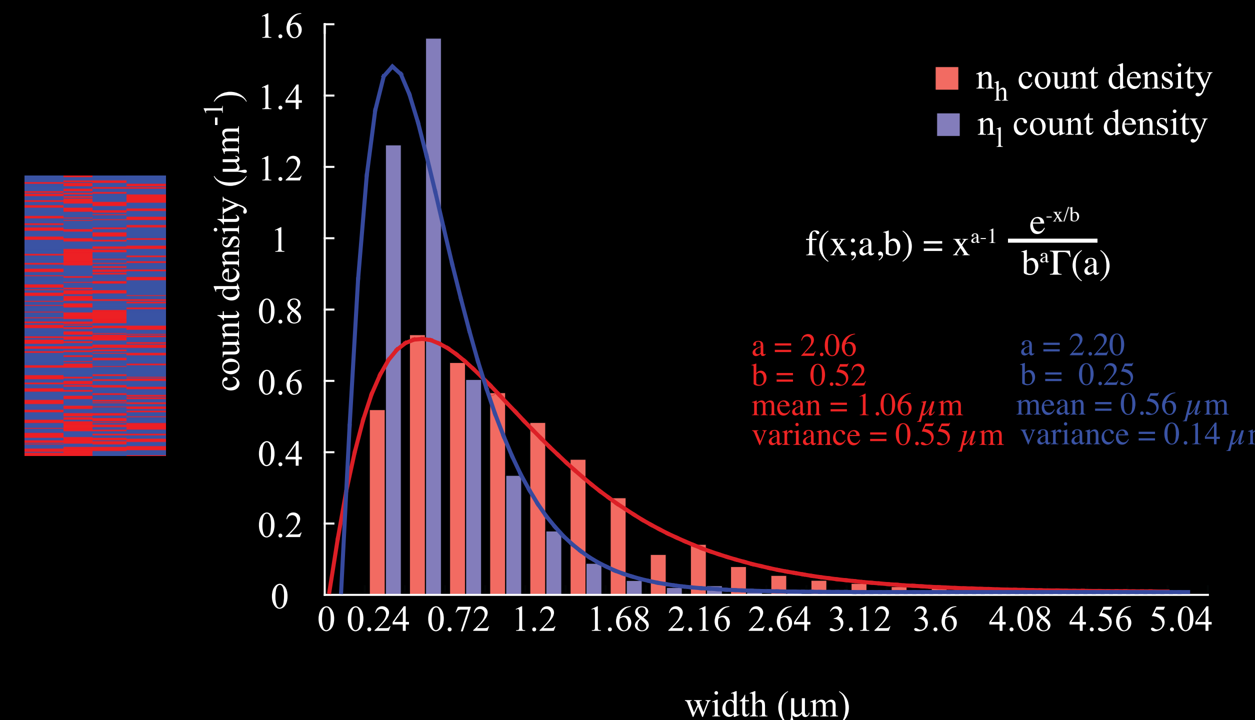

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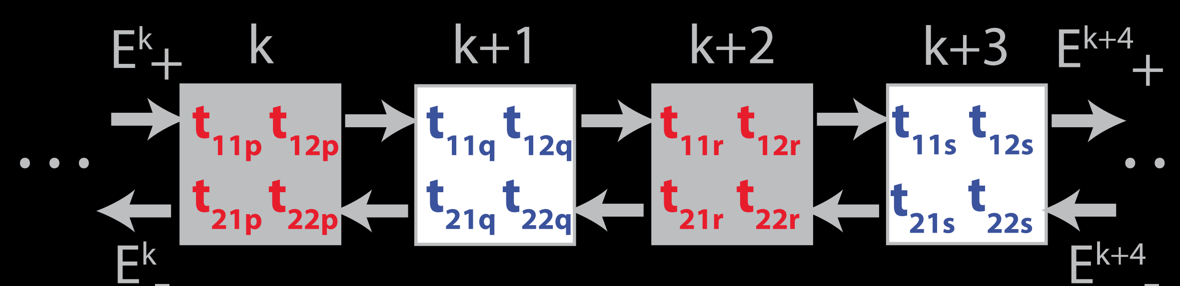
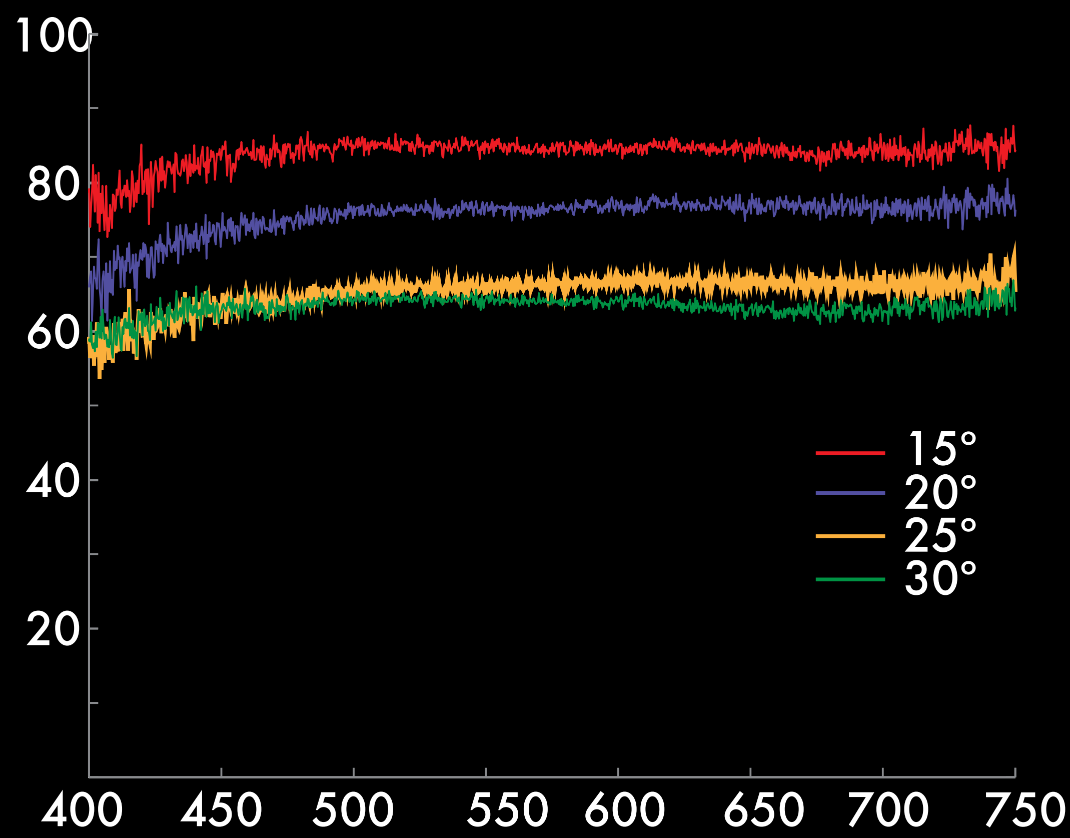


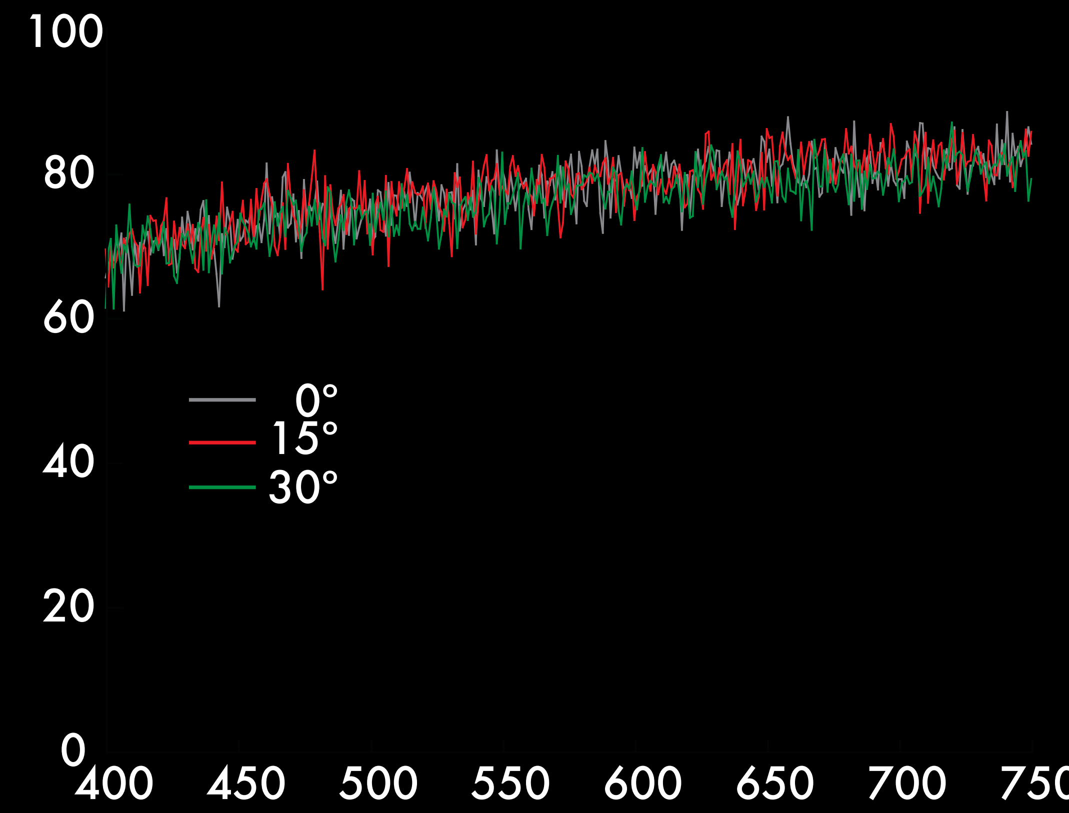
$$\begin{pmatrix} 1 \\ re \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \bullet \begin{pmatrix} tr \\ 0 \end{pmatrix} \Rightarrow re = \frac{T_{21}}{T_{11}},\ tr = \frac{1}{T_{11}}$$

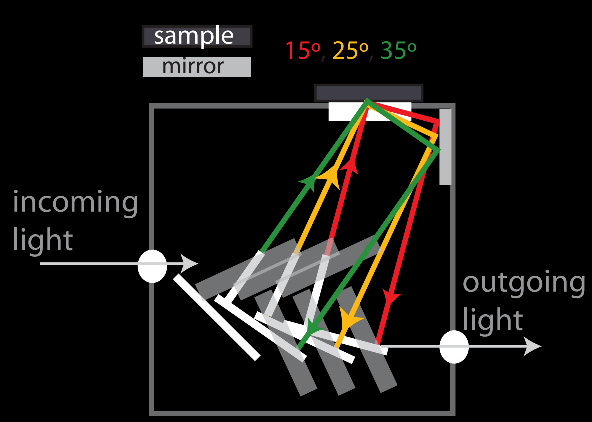
Transfer matrix model of stack reflectance using statistical fits of the structure's frequencies

Reflectance measurements

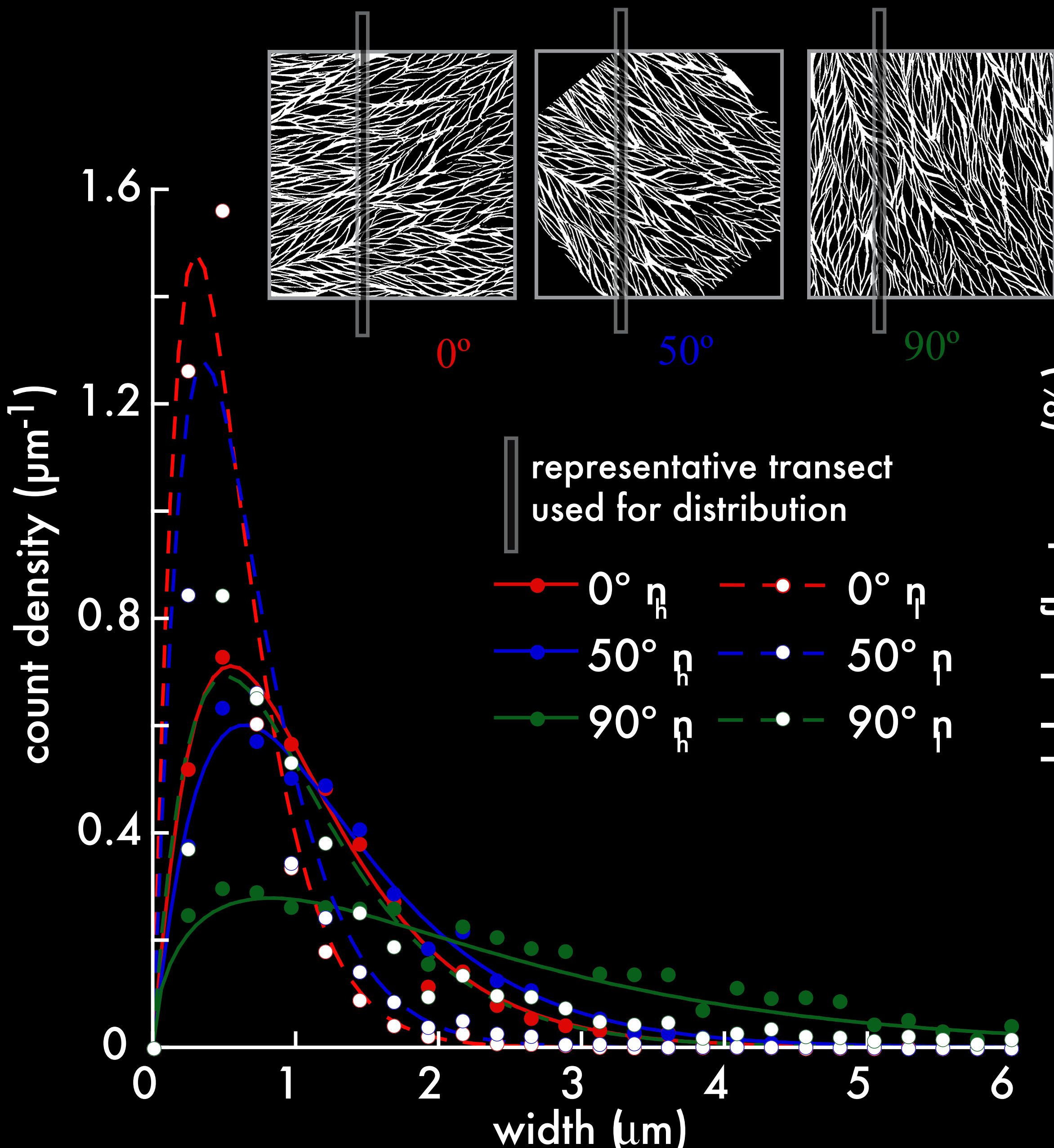


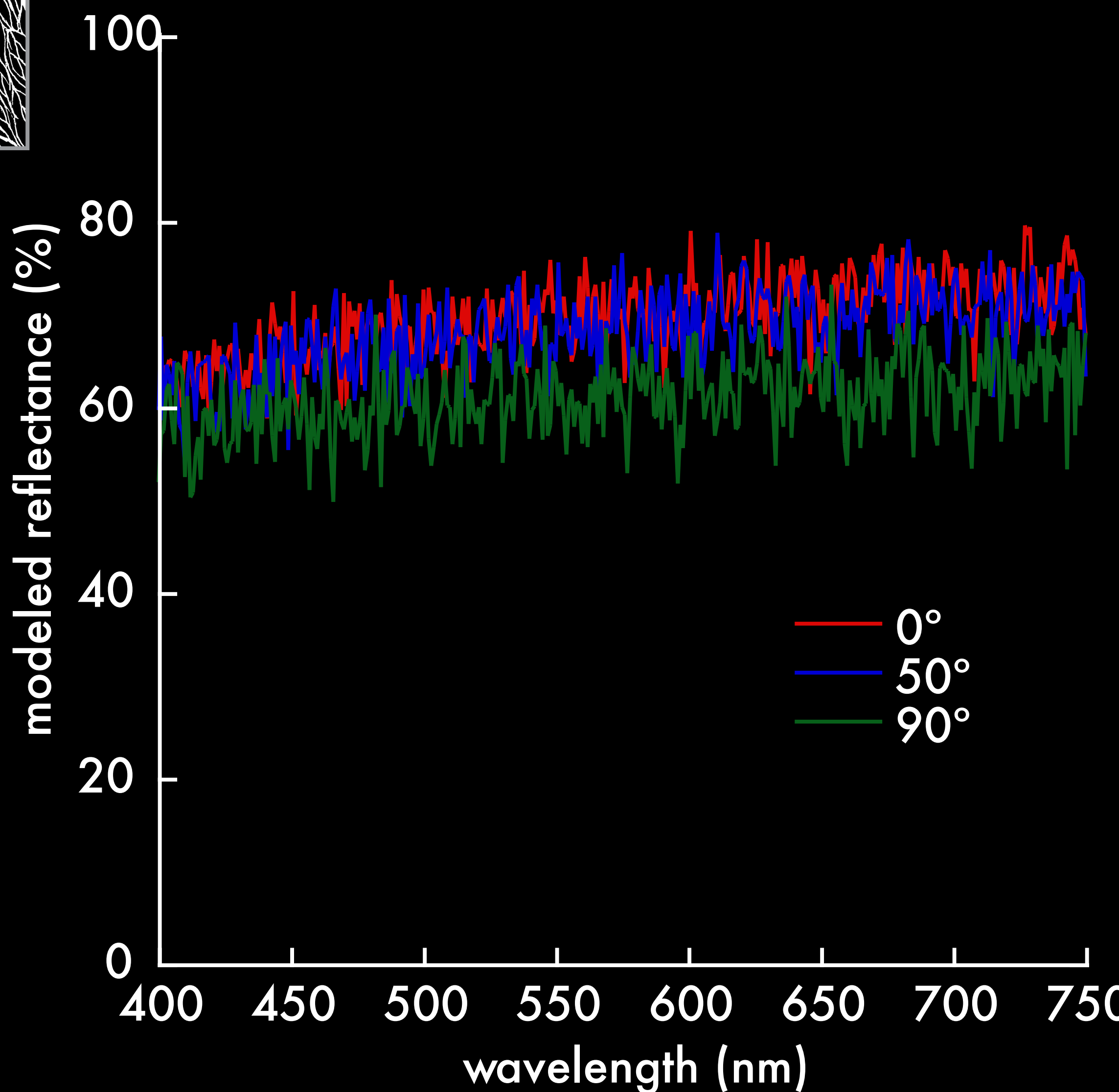
Model data



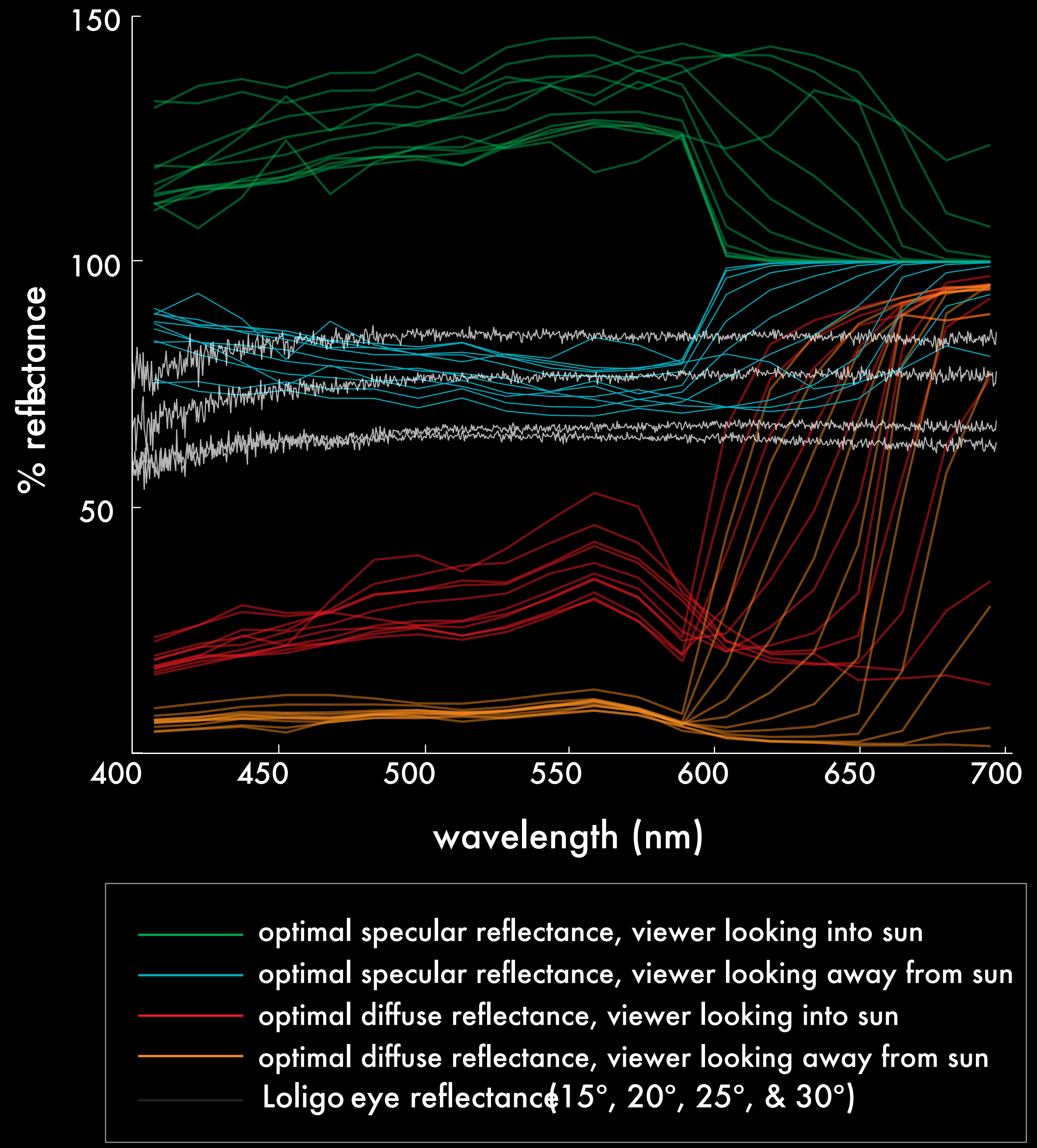


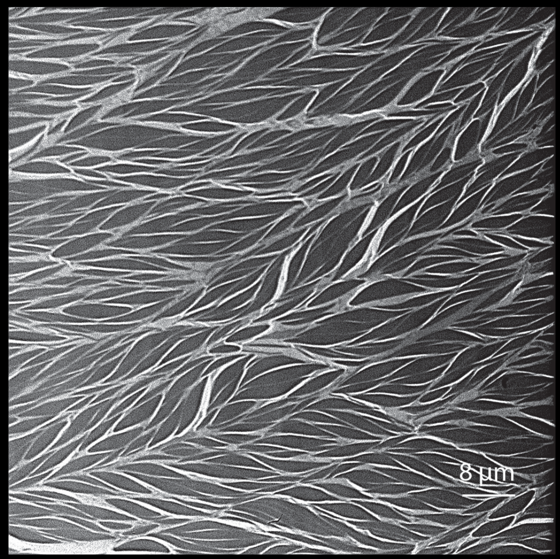
Structure provides a constant reflectance for any given viewing angle



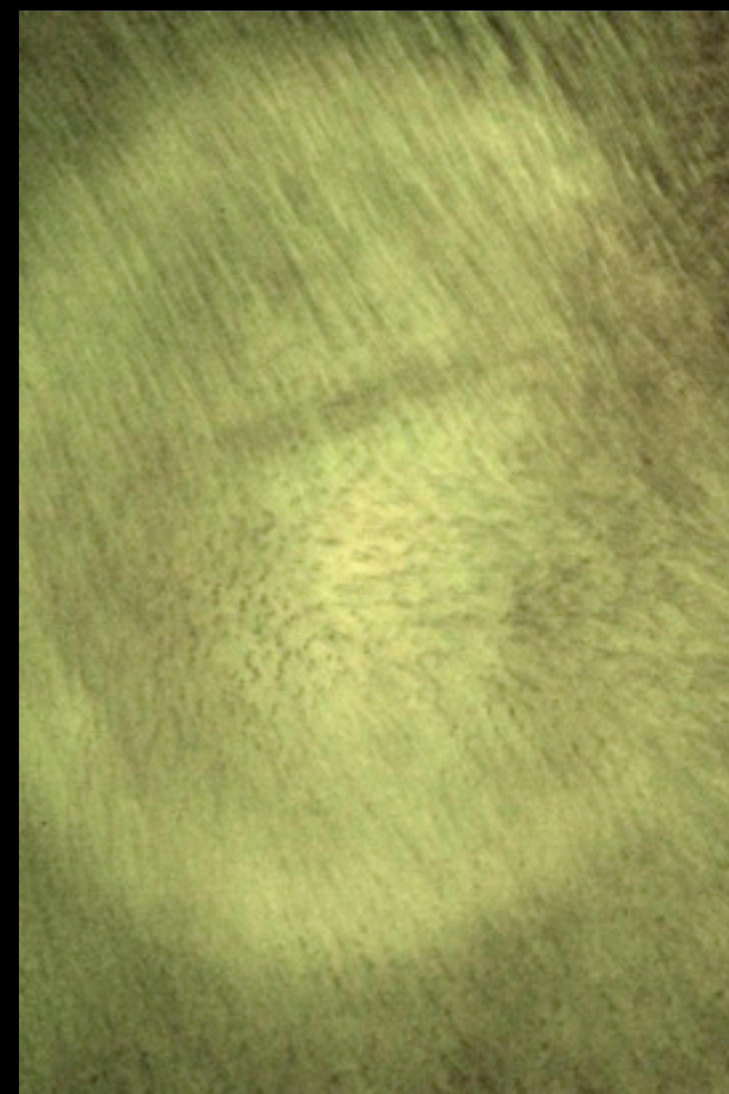


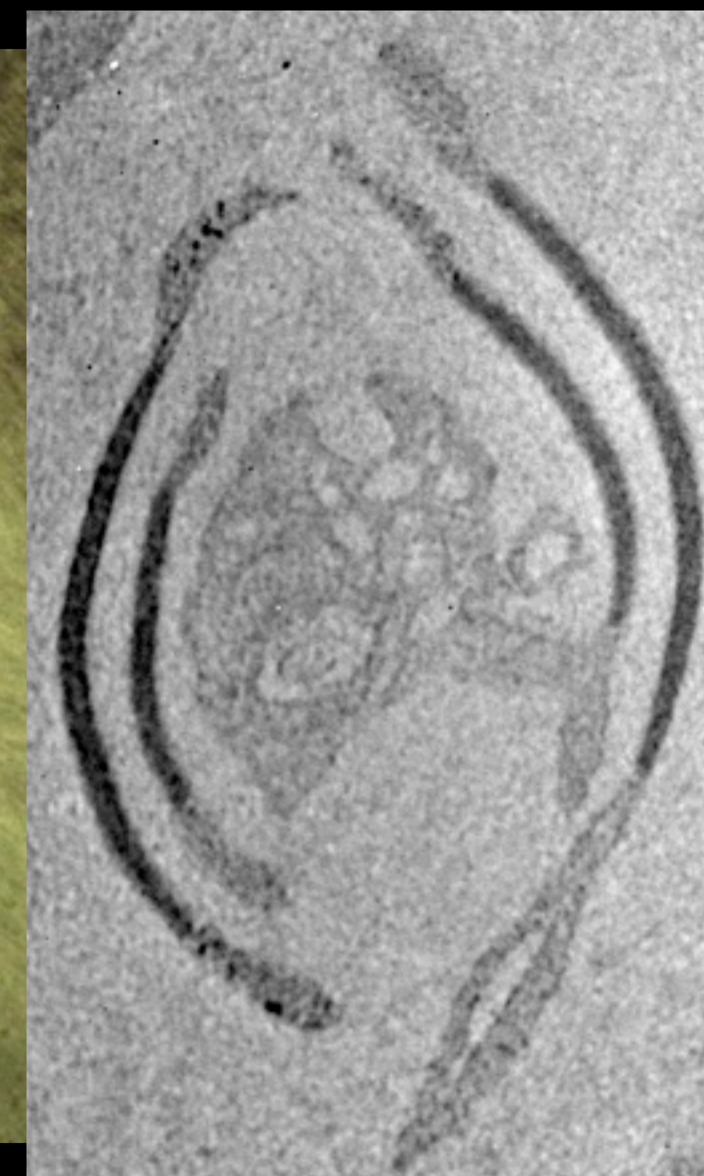
Reflectance of this structure appears to be a reasonable average match to theoretical perfect for a lateral surface in the ocean



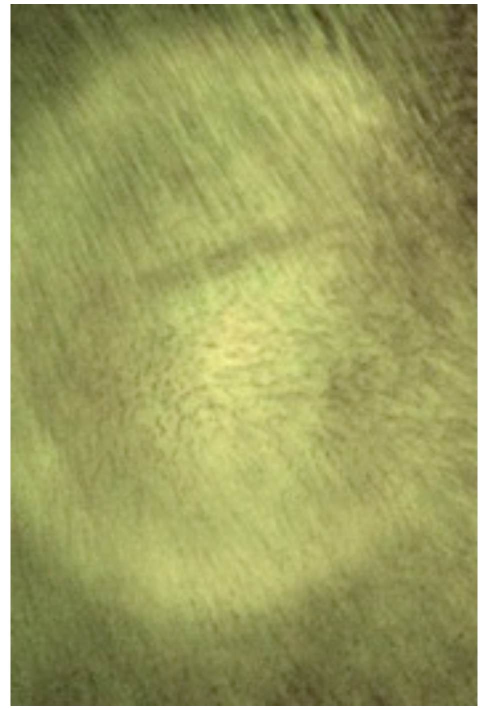


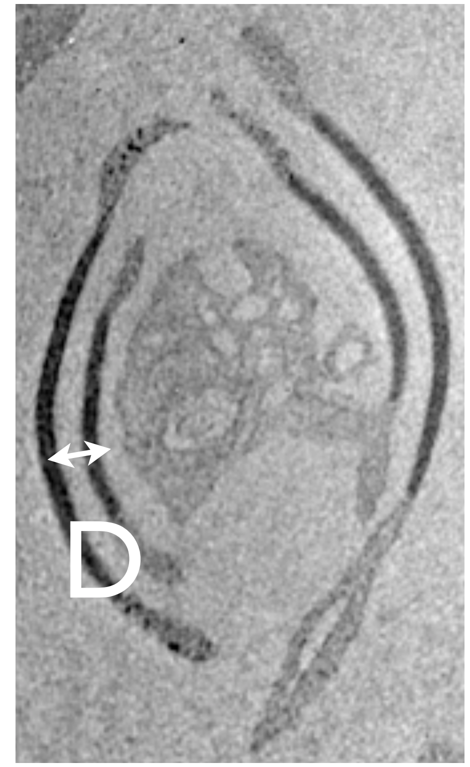
Mechanism #2: Wavelength-modulated Bragg fibers in *Galiteuthis*





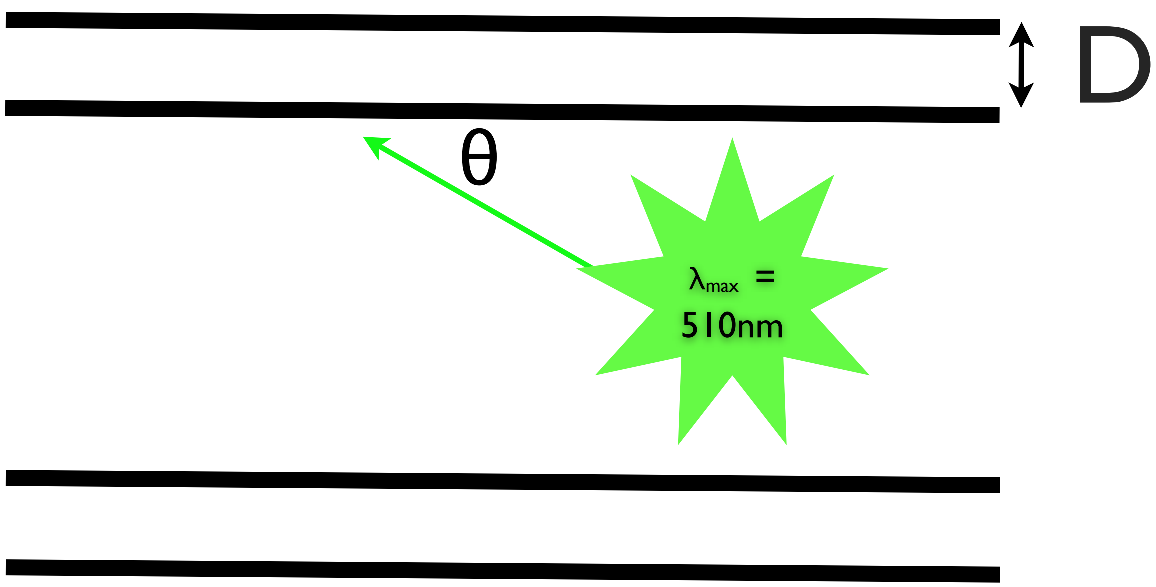
A.M.S. et al., unpublished

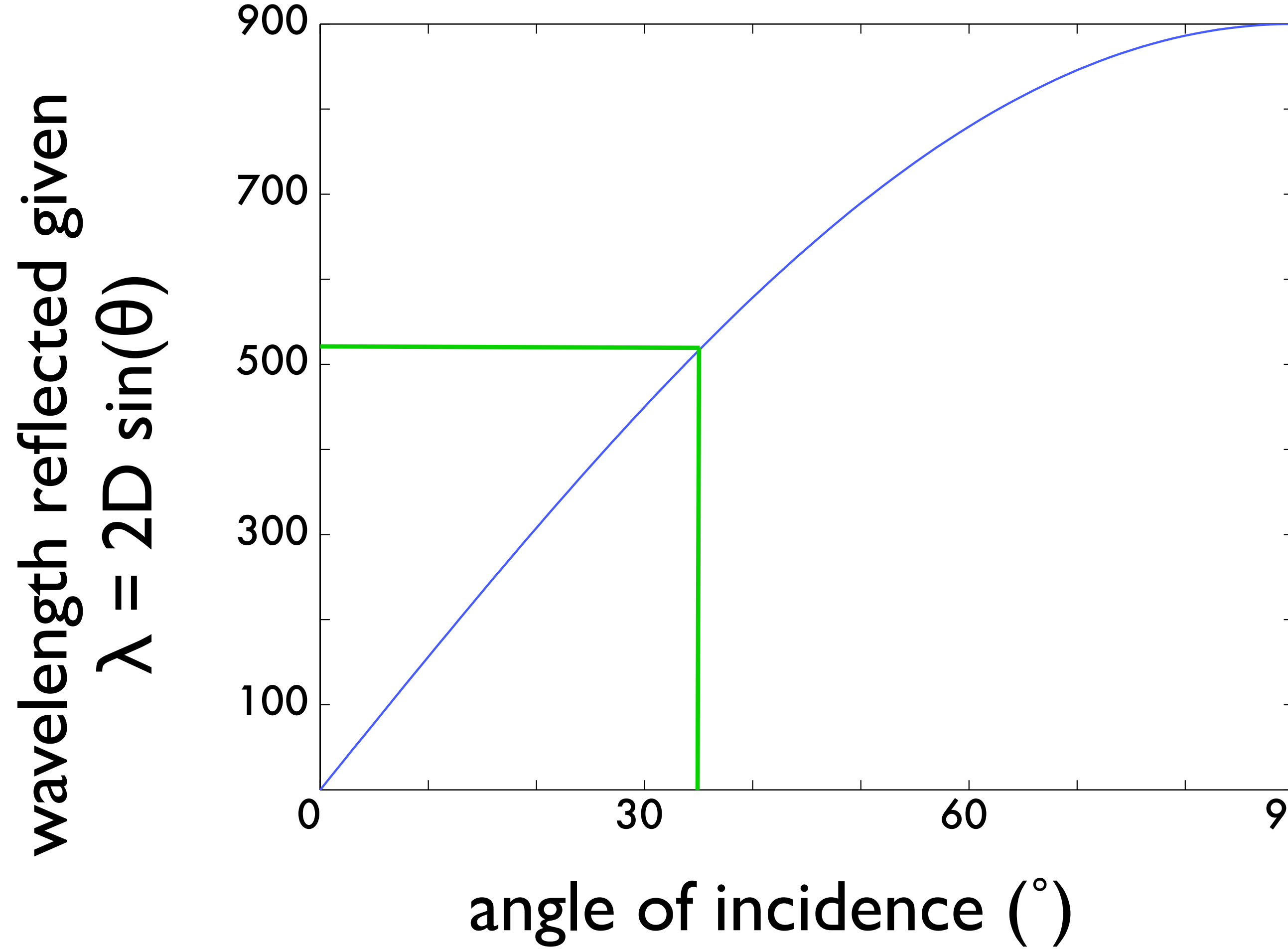




Galiteuthis

$D \approx 450$ nm



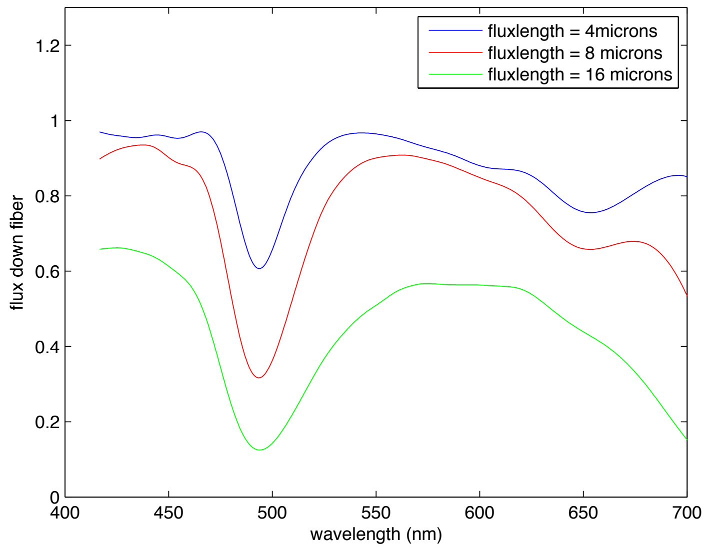


A.M.S. et al., unpublished

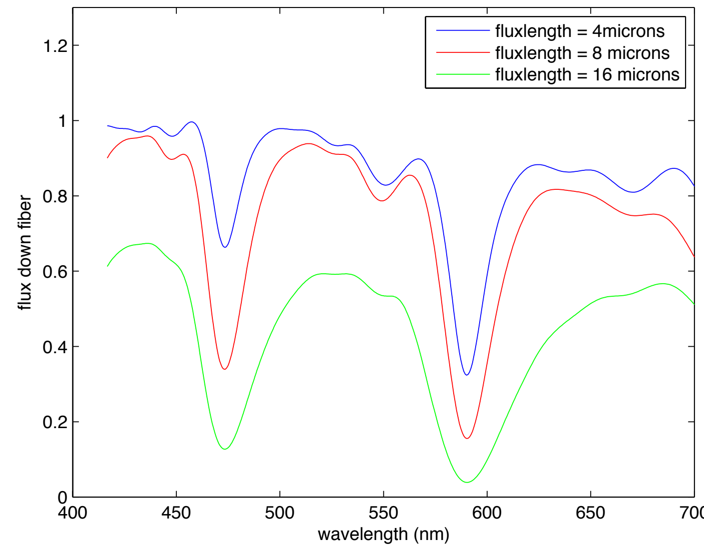
FDTD model of *Galiteuthis* fiber transmission

flux (%)

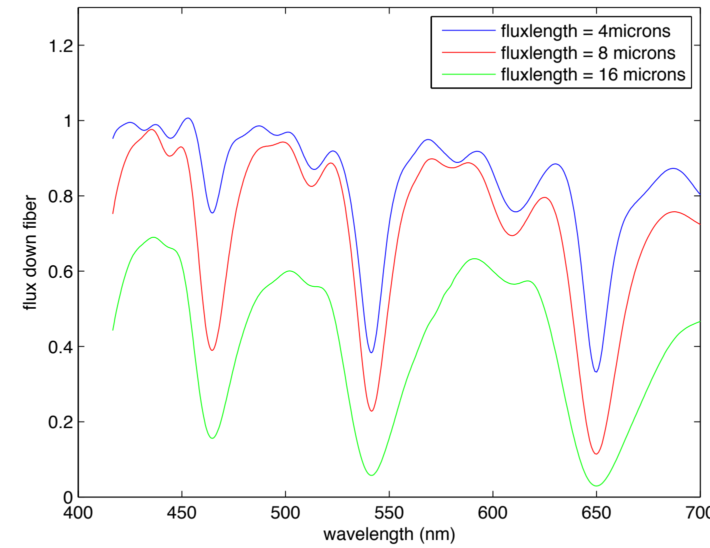
3 layers



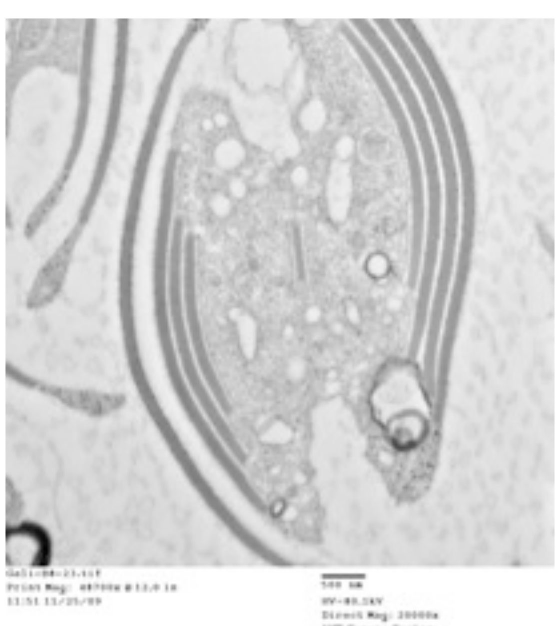
5 layers



7 layers

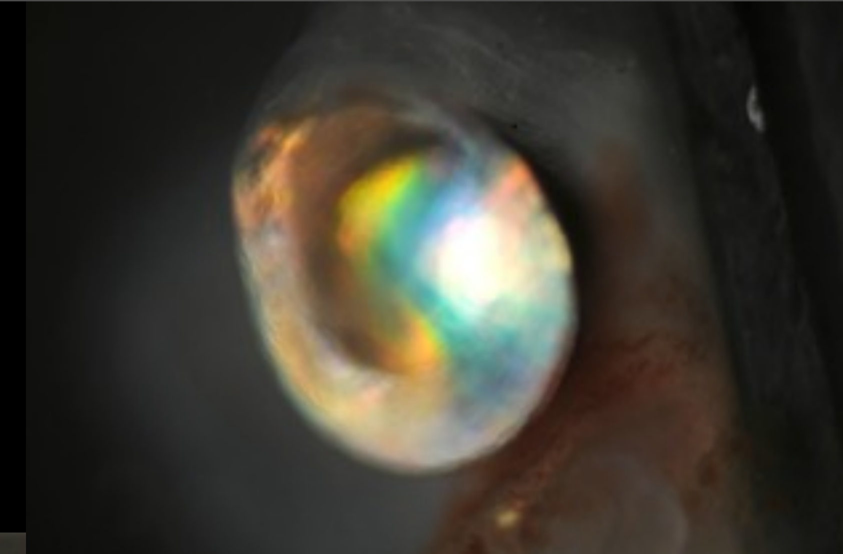


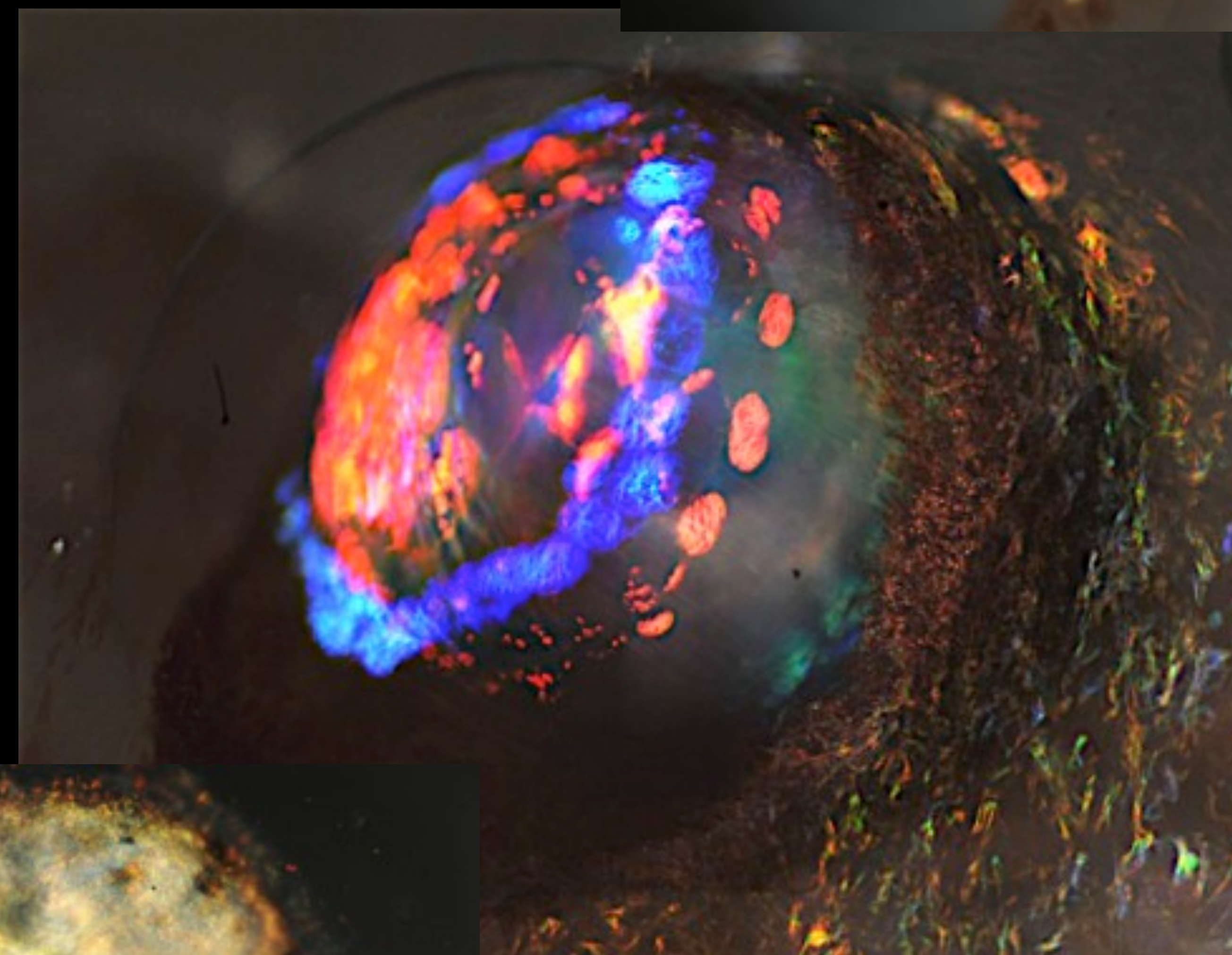
wavelength (400 - 700 nm)

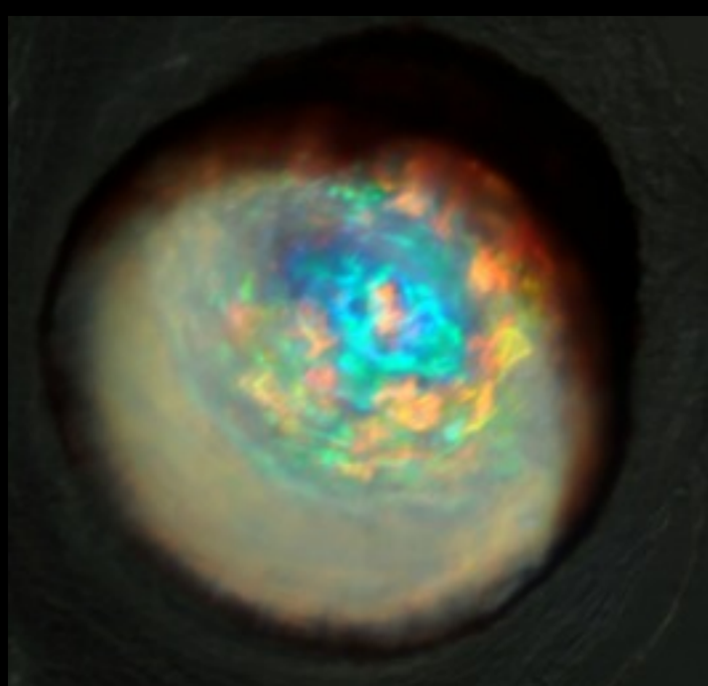


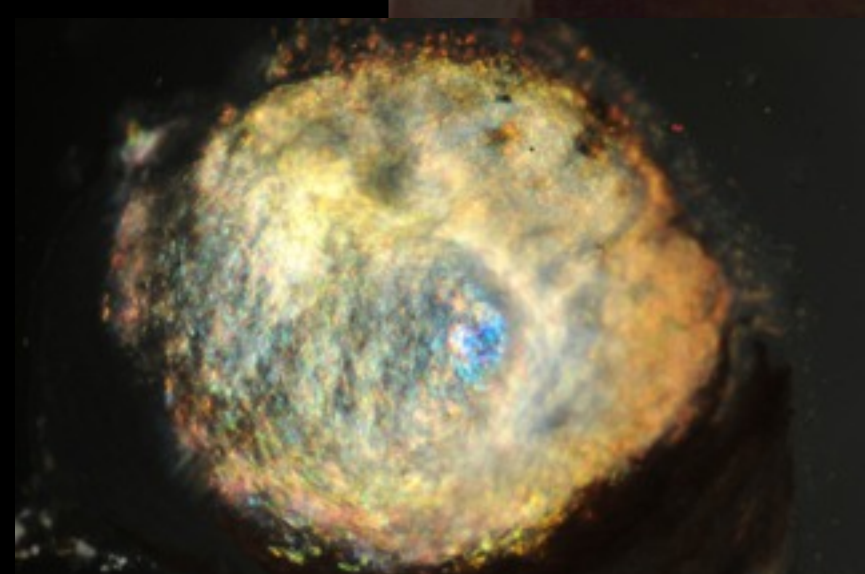
7 layers
nh=1.55
nl=1.33
dh=140 nm
dl=60 nm
r=2 microns

Pterygioteuthis photophores

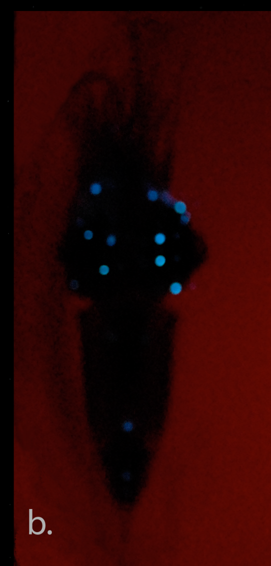


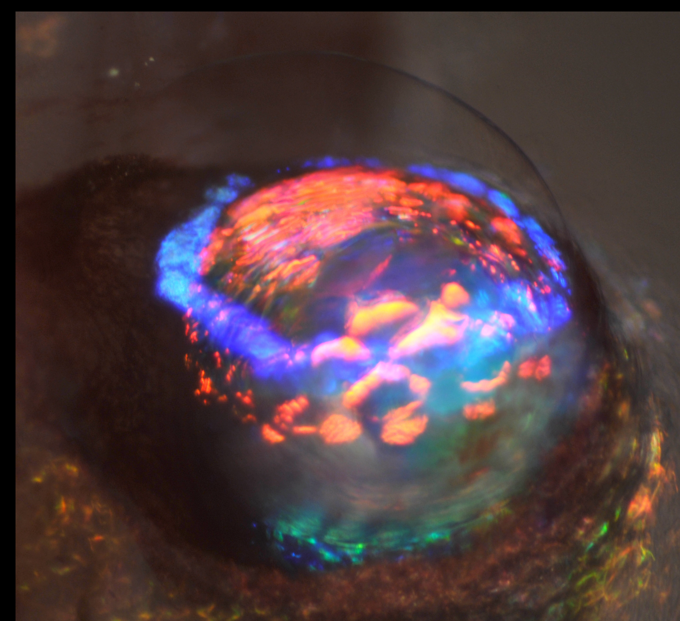


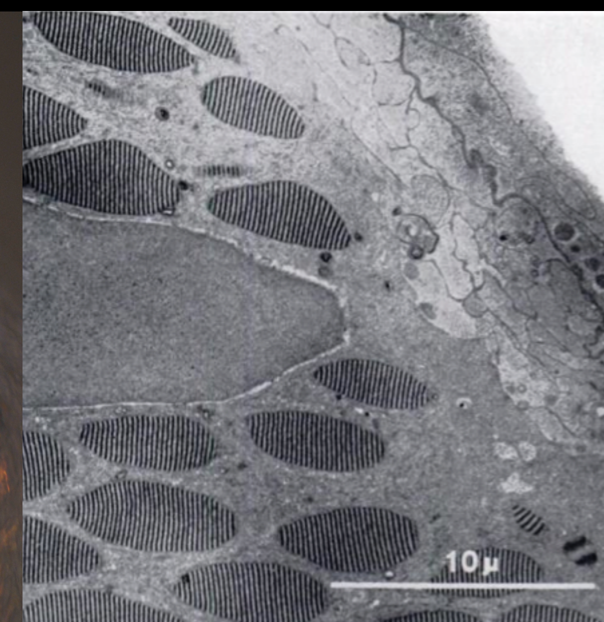




Super-complex self-assembly in *Pterygioteuthis* light organs - precise radiance-shaper?

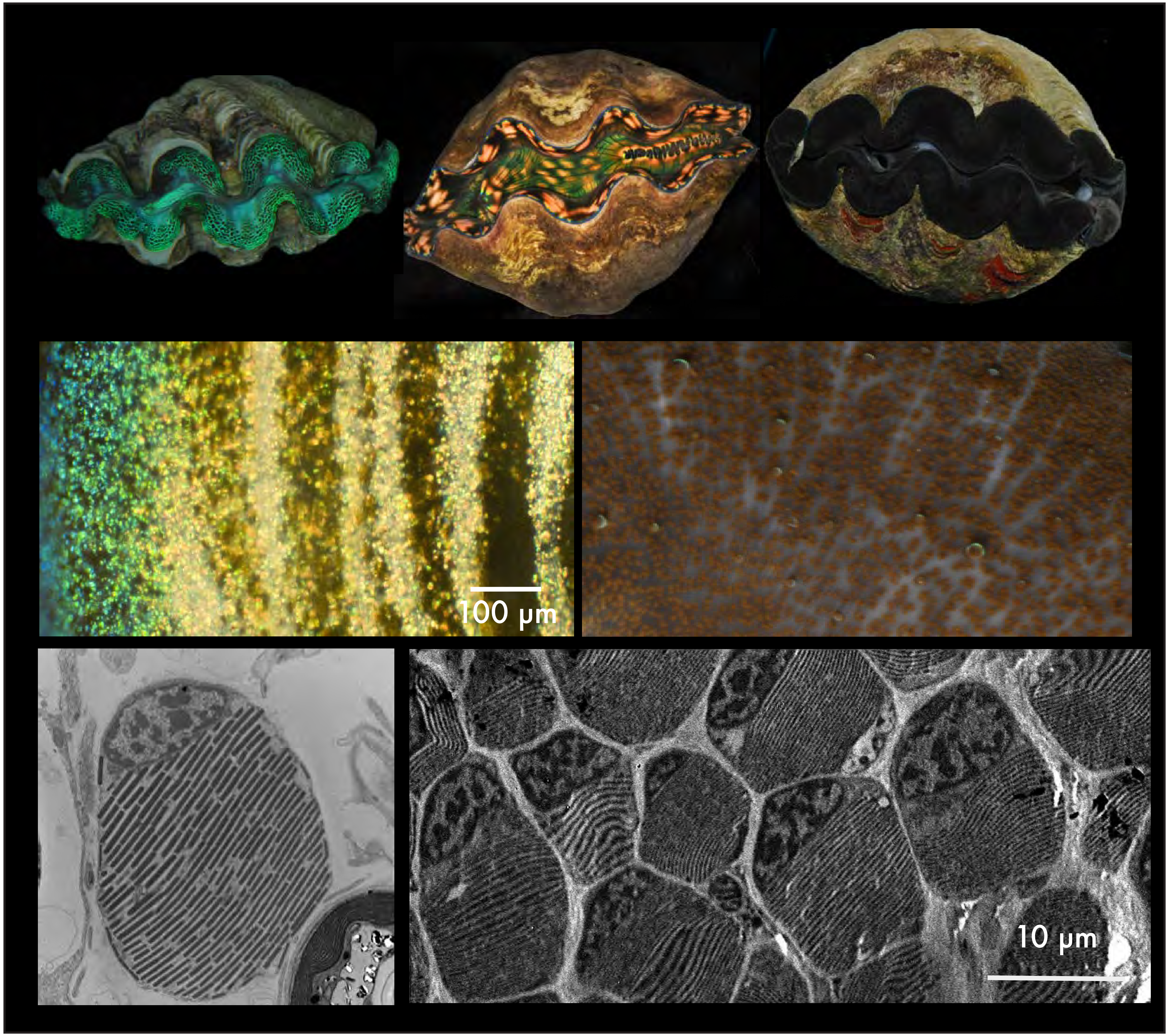




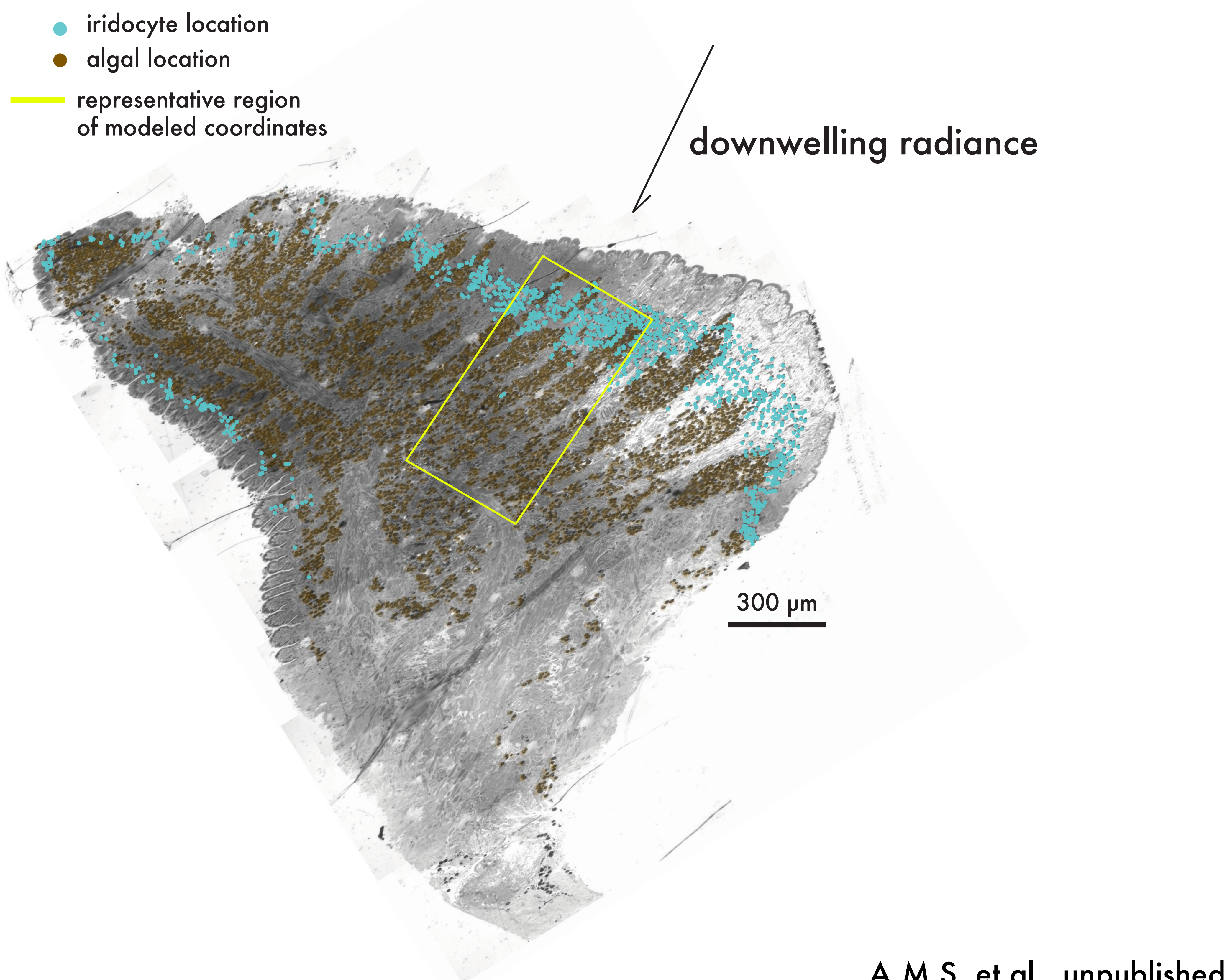


Arnold et al., 1974

Mechanism #1: Photosynthesis in Giant Clams

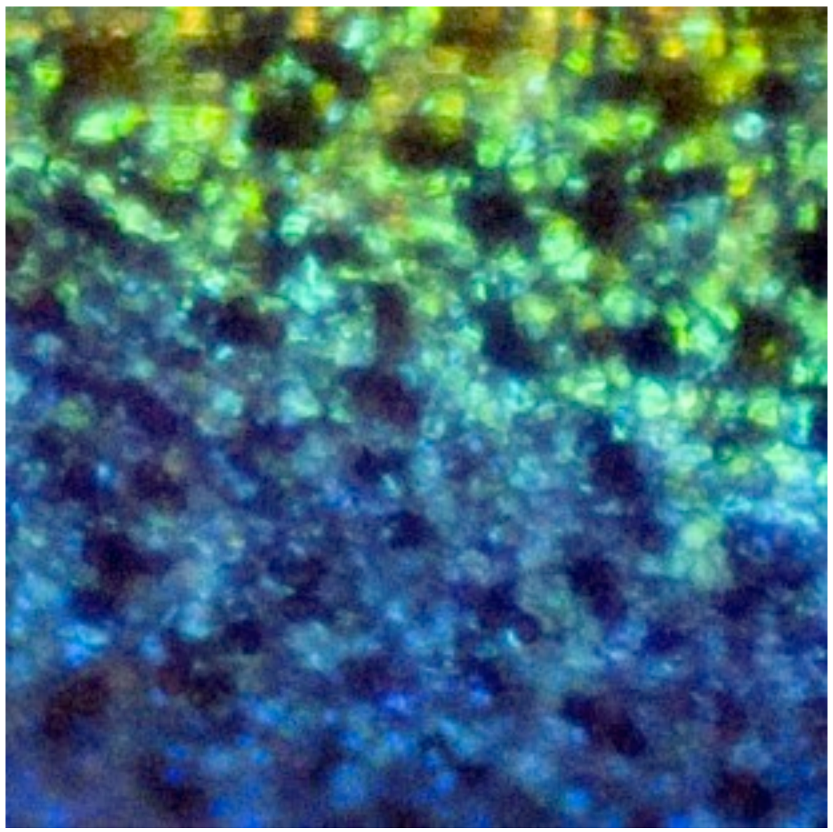


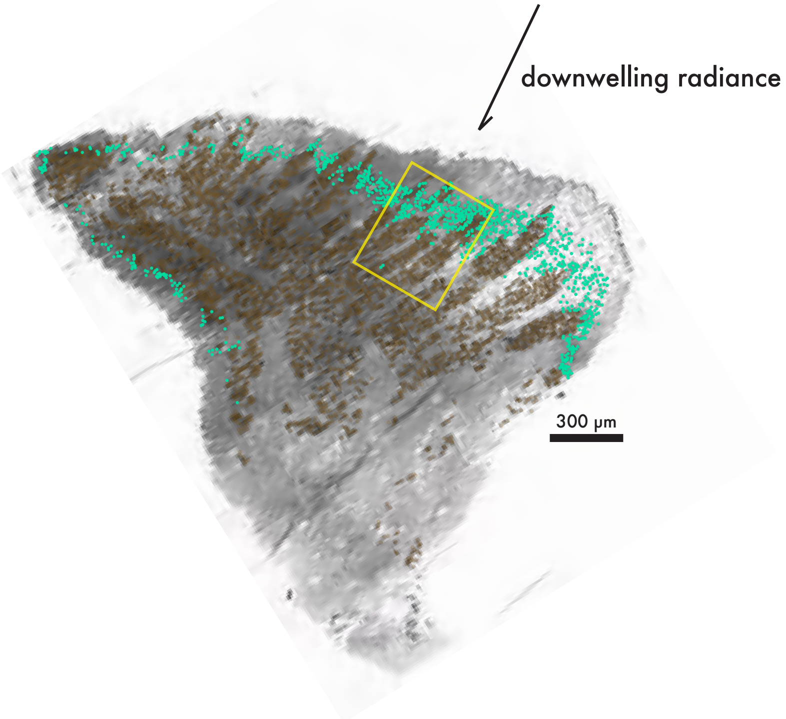
A.M.S. et al., unpublished


iridocyte location
algal location
representative region
of modeled coordinates
downwelling radiance
300 μm
A.M.S. et al., unpublished

iridocyte coordinate

algal coordinate

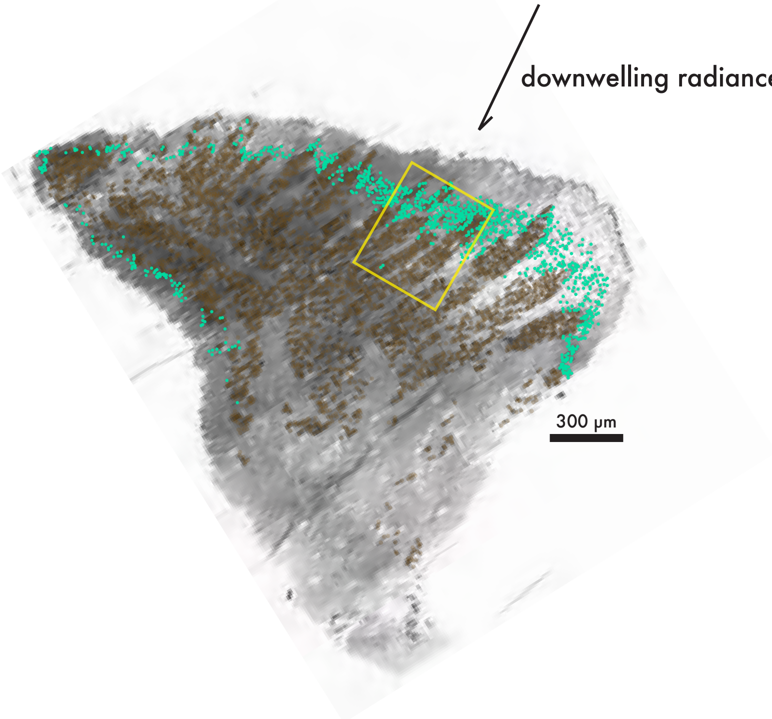


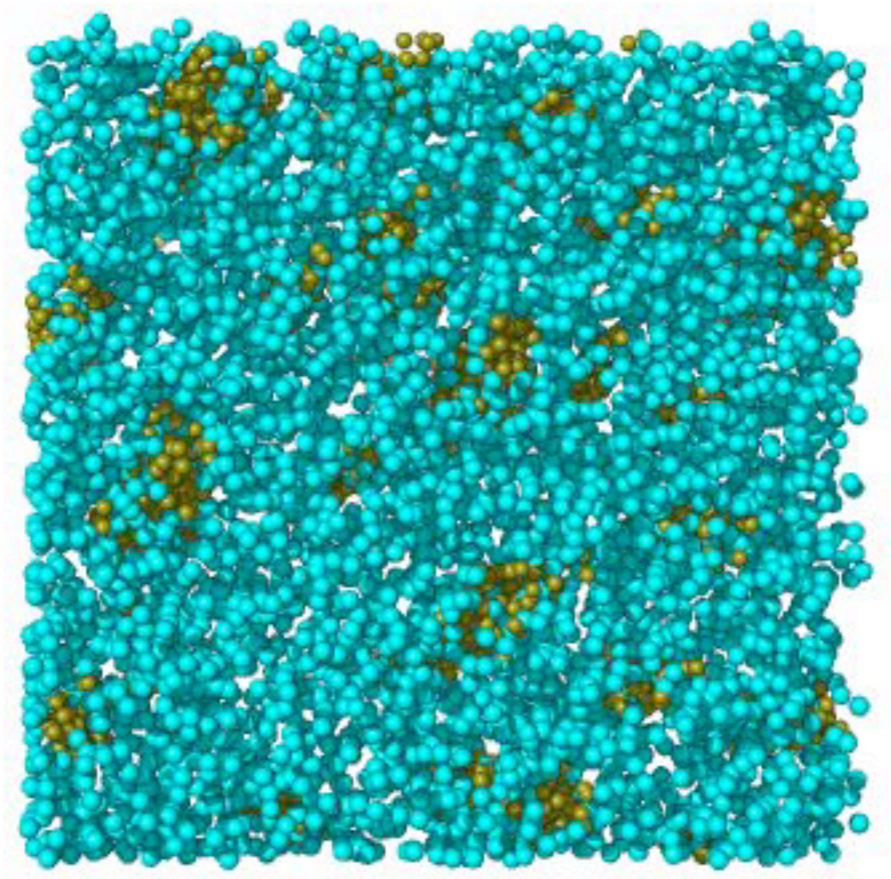


A.M.S. et al., unpublished

iridocyte coordinate

algal coordinate

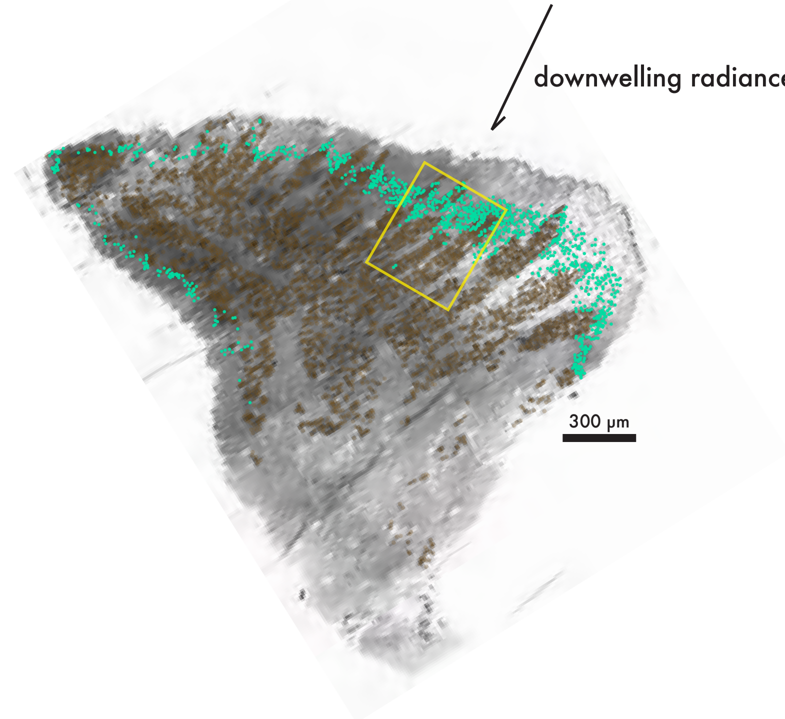


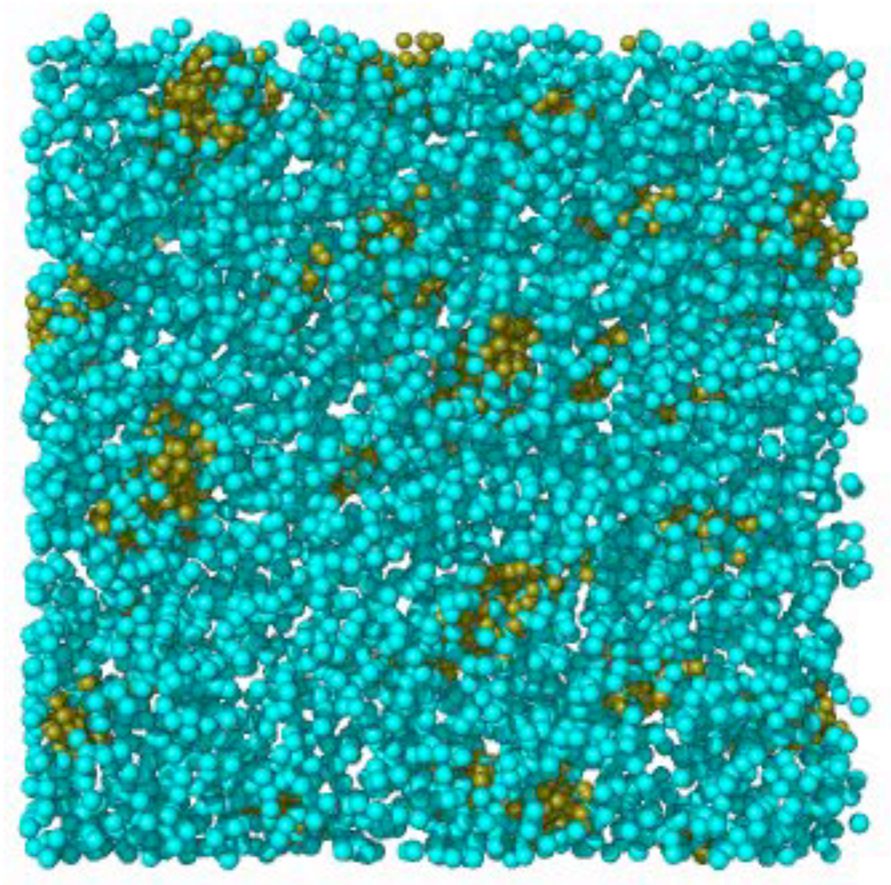


A.M.S. et al., unpublished

iridocyte coordinate

algal coordinate





A.M.S. et al., unpublished

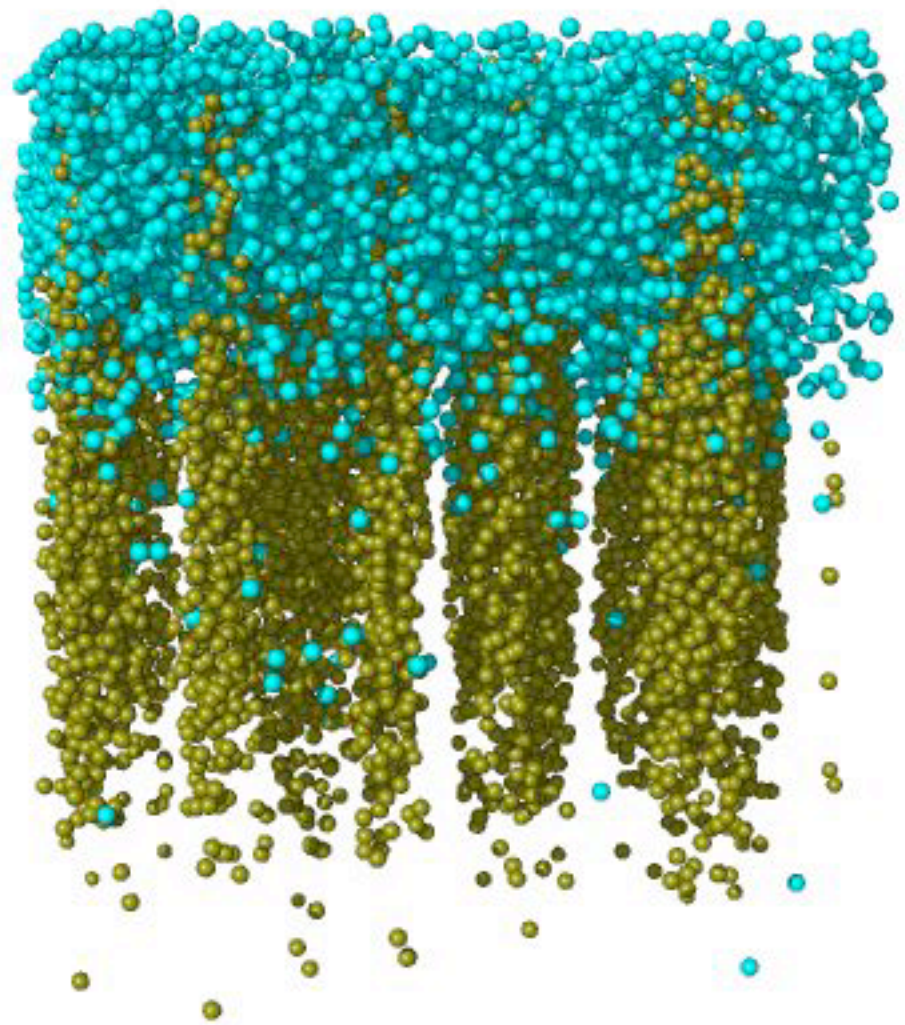
iridocyte coordinate

algal coordinate

A.M.S. et al., unpublished

iridocyte coordinate

algal coordinate



A.M.S. et al., unpublished

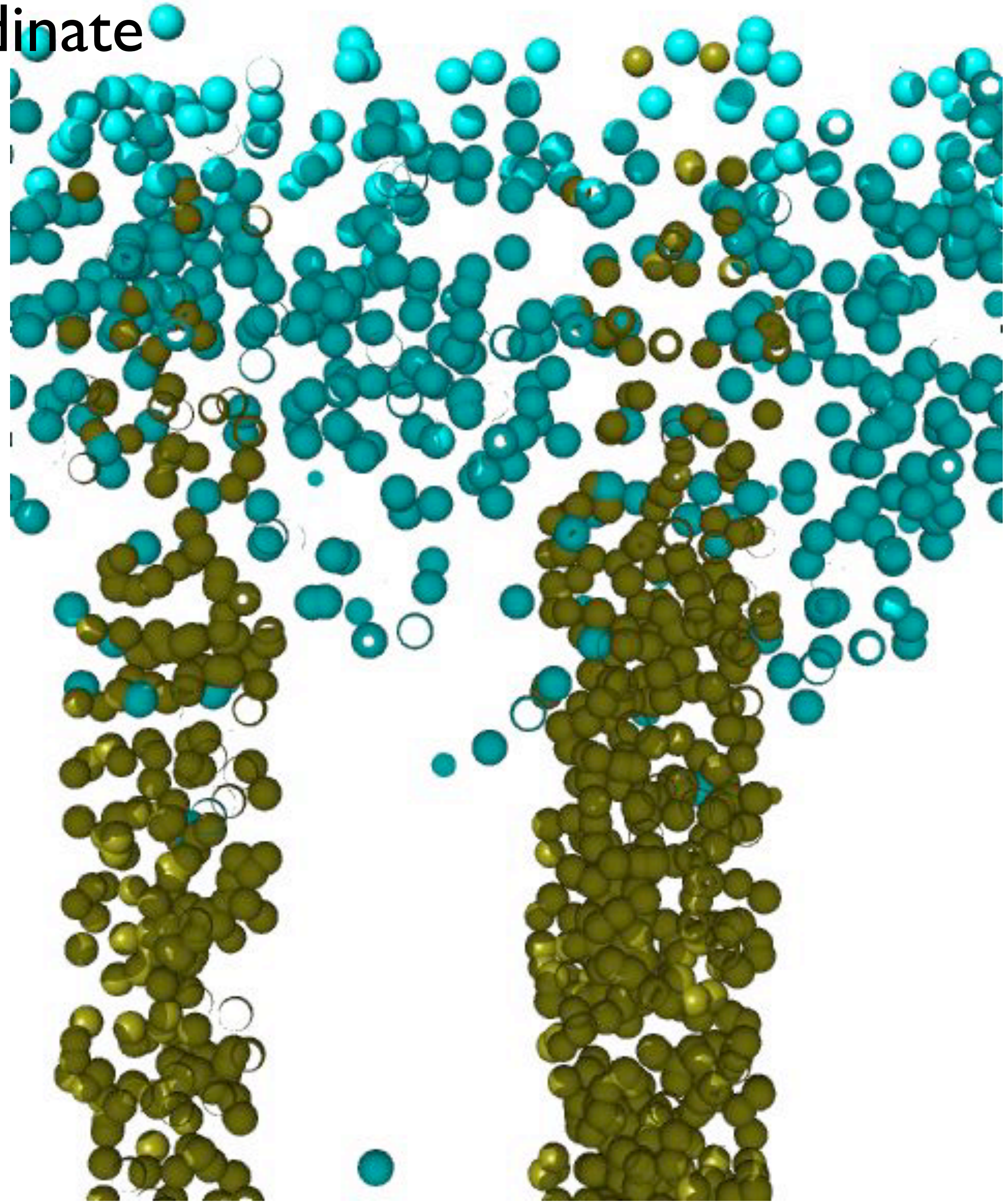
iridocyte coordinate

algal coordinate

A.M.S. et al., unpublished

iridocyte coordinate

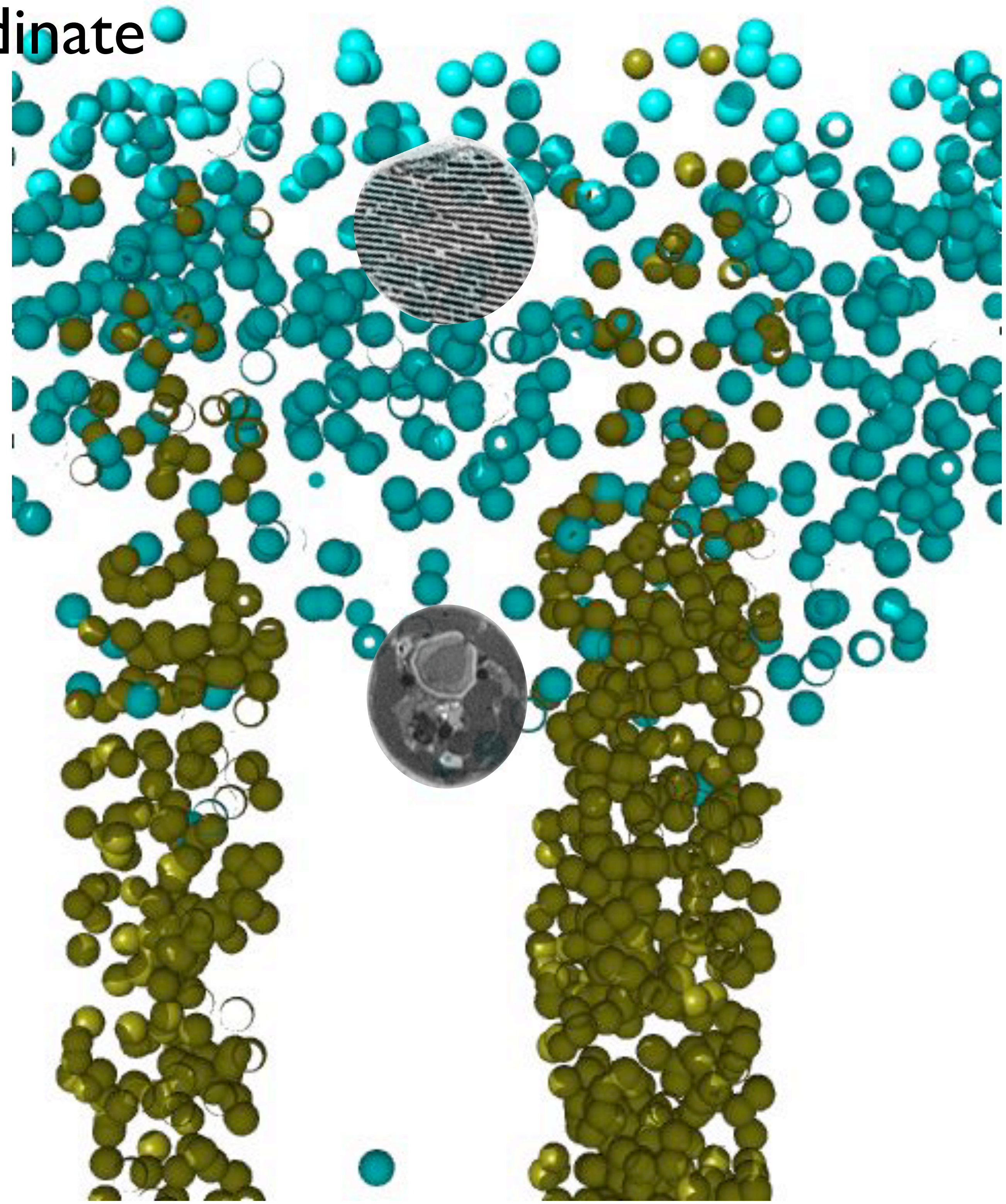
algal coordinate



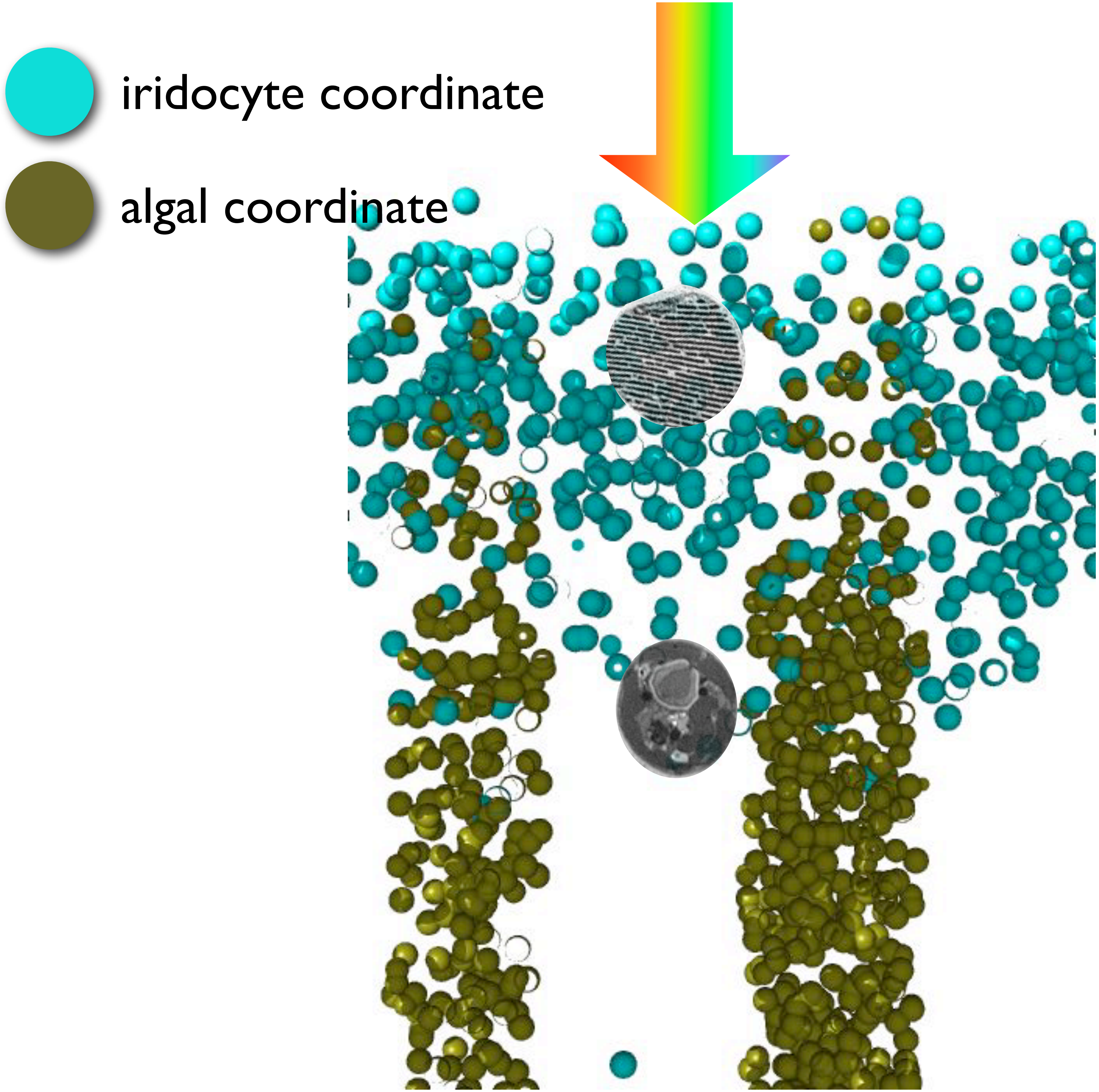
A.M.S. et al., unpublished

iridocyte coordinate

algal coordinate

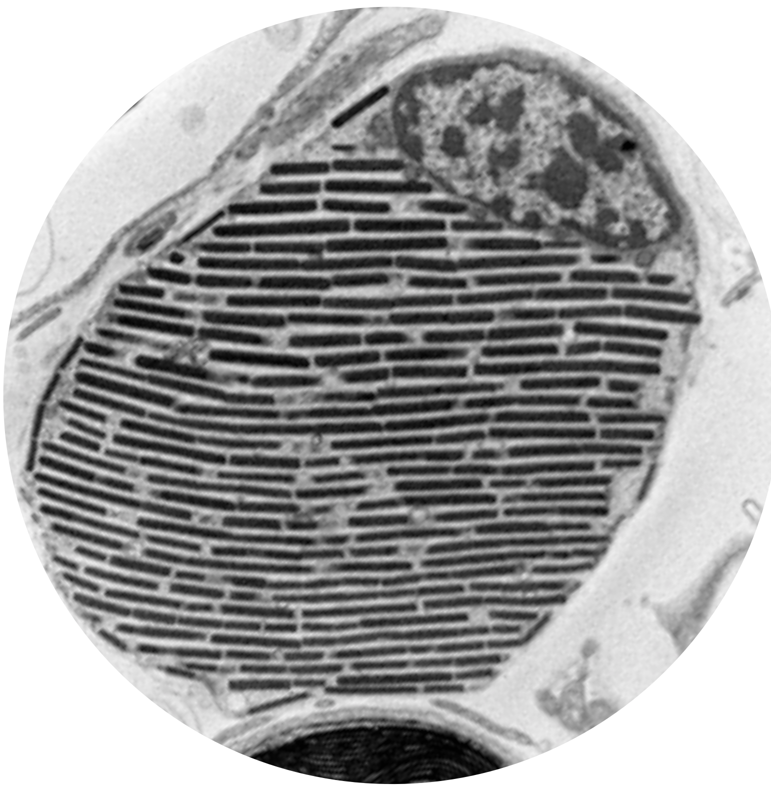


A.M.S. et al., unpublished



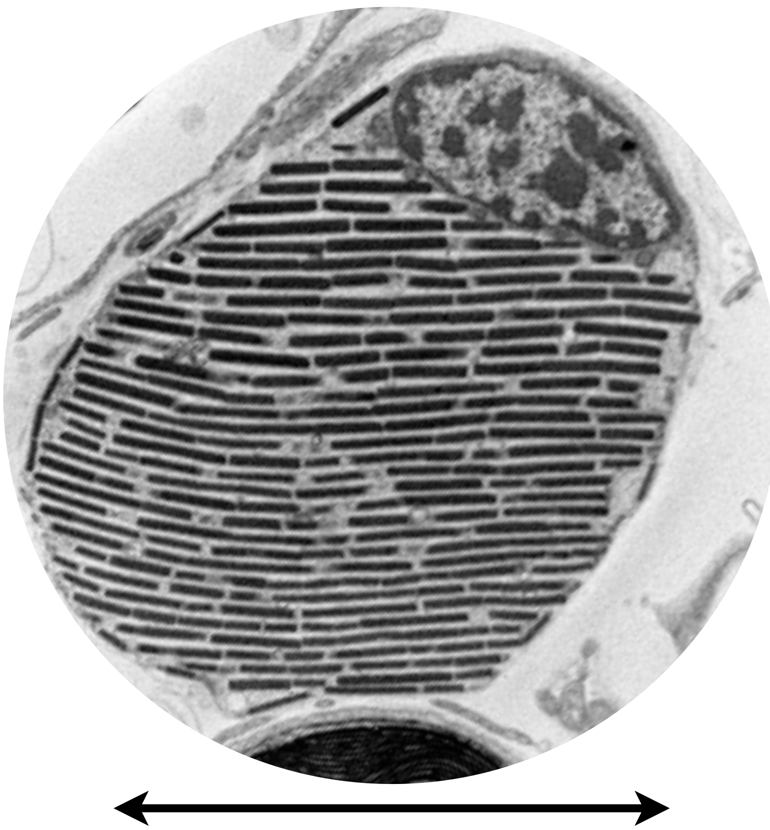
A.M.S. et al., unpublished

Clam iridocytes are a funny superposition of a Mie sphere



A.M.S. et al., unpublished

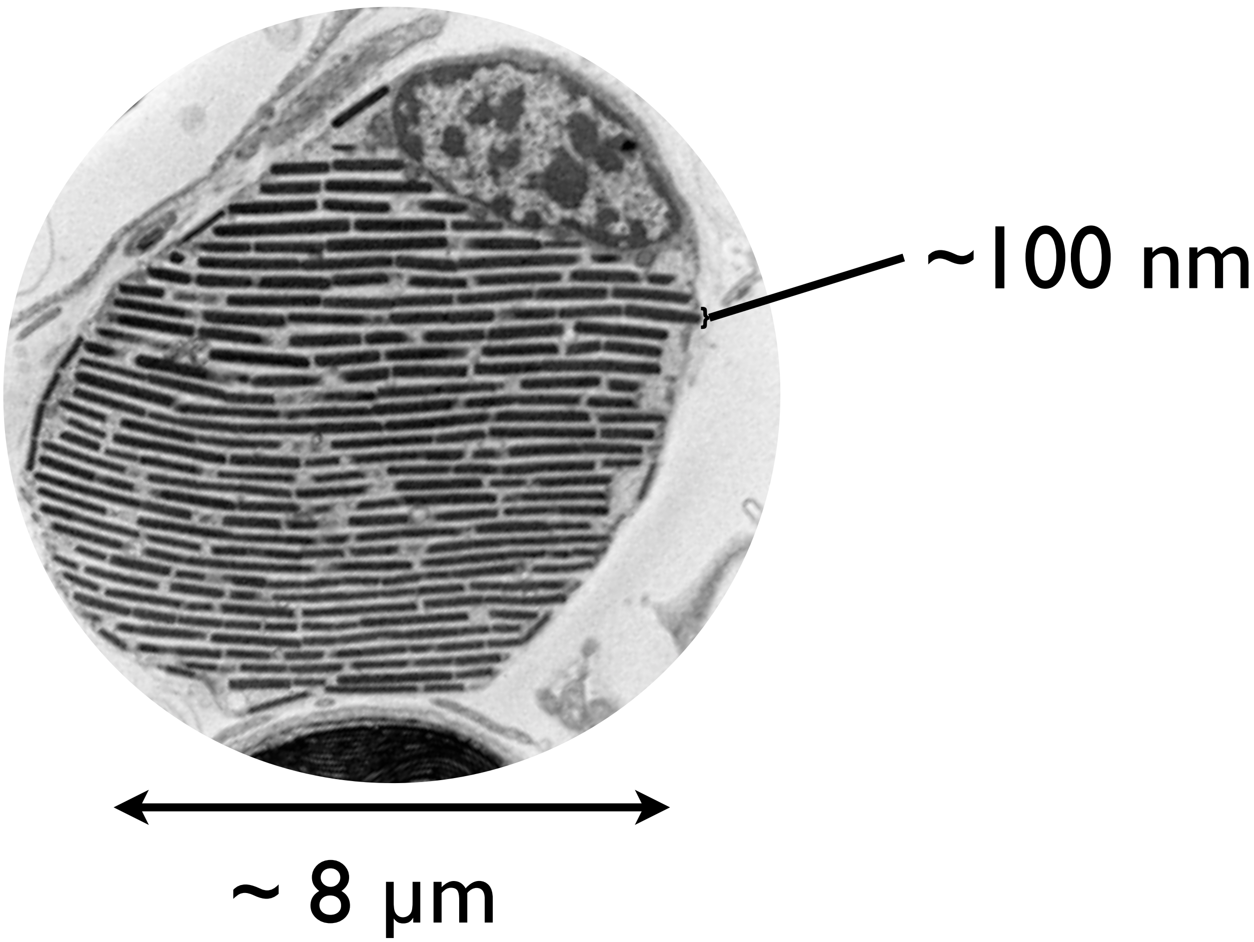
Clam iridocytes are a funny superposition of a Mie sphere



~ 8 μm

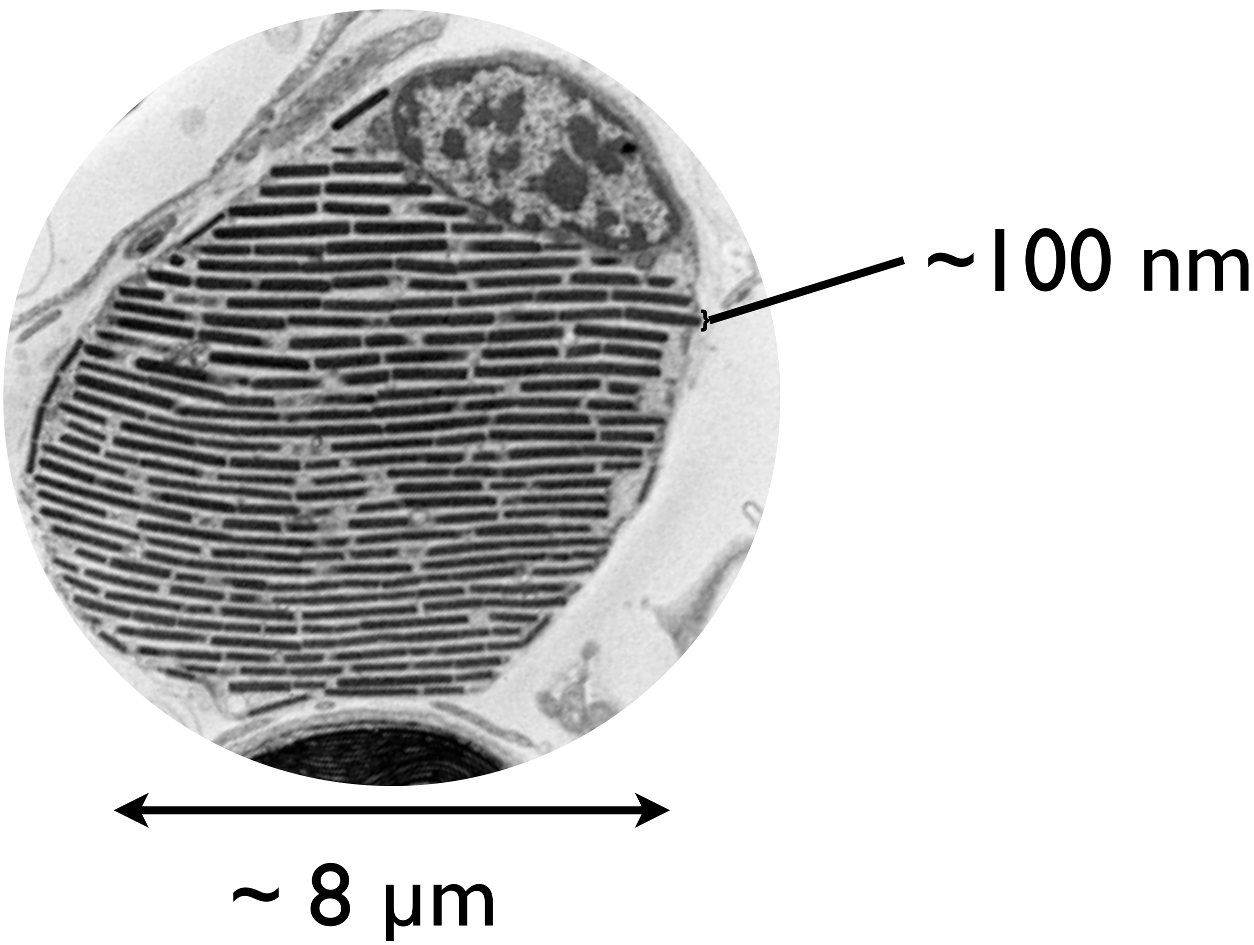
A.M.S. et al., unpublished

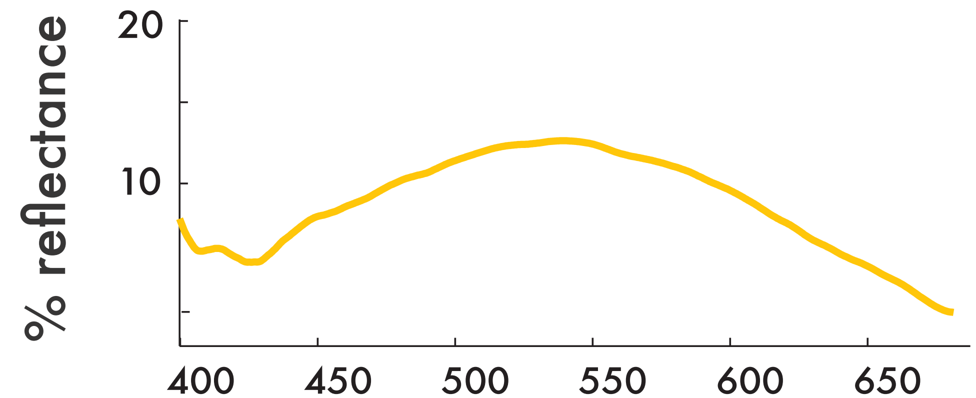
Clam iridocytes are a funny superposition of a Mie sphere
and a classical Bragg reflector

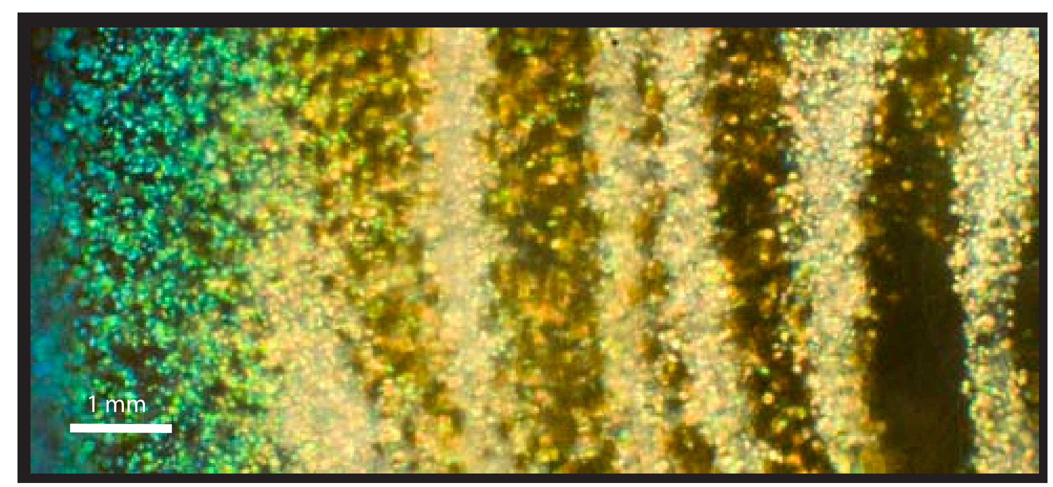


A.M.S. et al., unpublished

Clam iridocytes are a funny superposition of a Mie sphere and a classical Bragg reflector







A.M.S. et al., unpublished

Discrete dipole approximation of scattering from large, "fluffy" particles

Contents lists available at ScienceDirect

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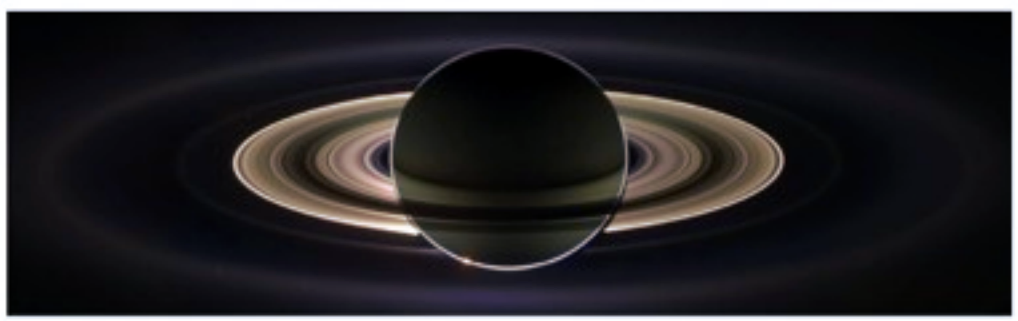
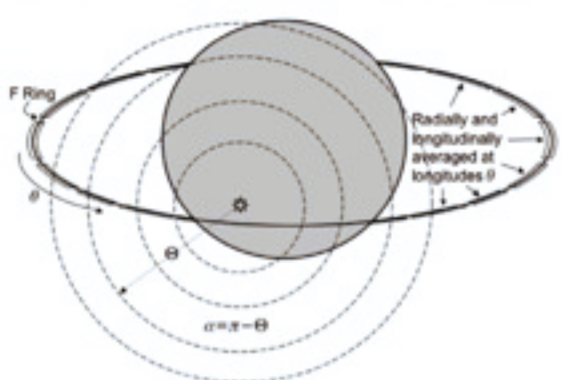
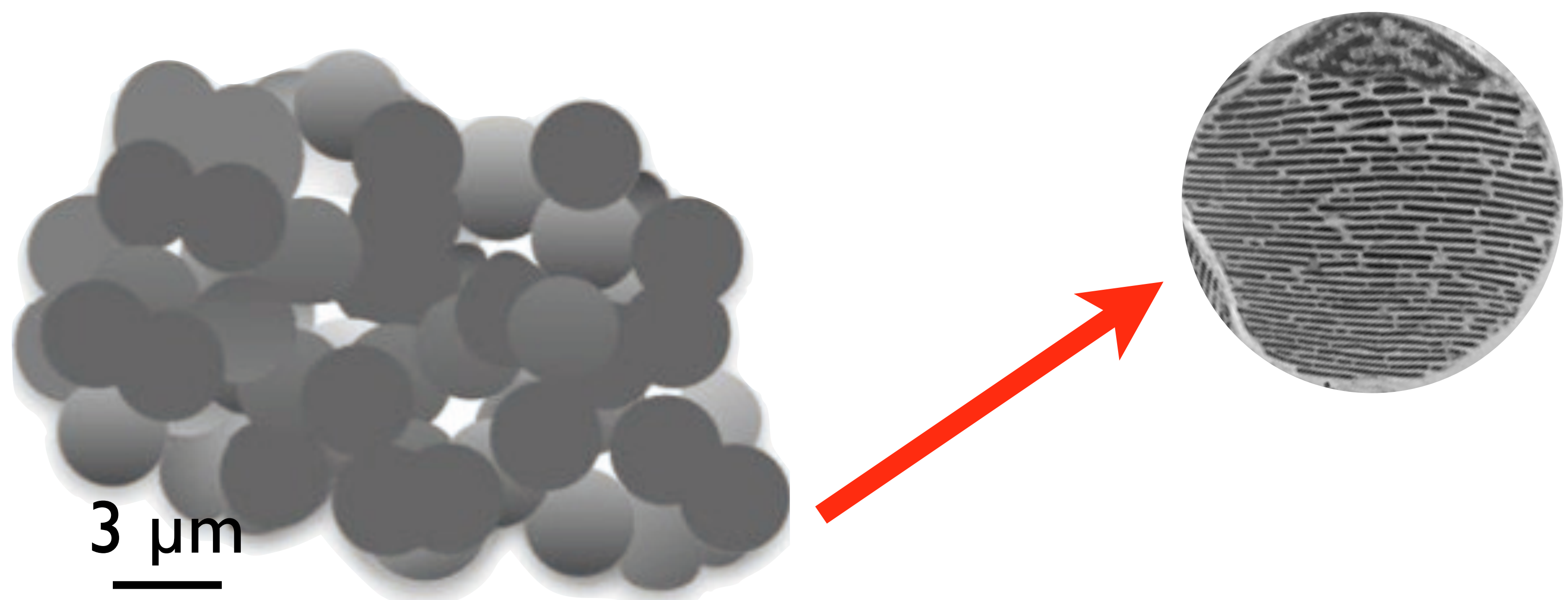
Sanaz Vahidinia *, Jeffrey N. Cuzzi, Matt Hedman, Bruce Draine, Roger N. Clark, Ted Roush, Gianrico Filacchione, Philip D. Nicholson, Robert H. Brown, Bonnie Buratti, Christophe Sotin

NASA Post Doctoral Program, Space Science Division, Ames Research Center, Mail Stop 245-3, NASA Moffett Field, CA 94035, USA







Saturn dust particle

Discrete dipole approximation of scattering from large, “fluffy” particles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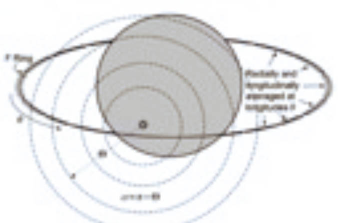
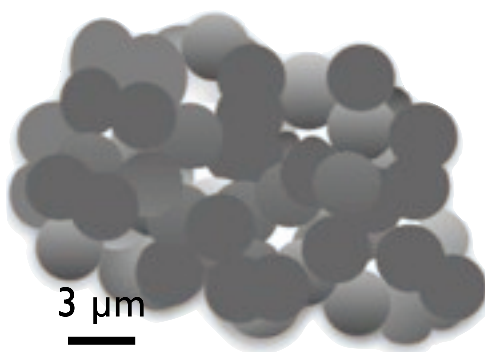
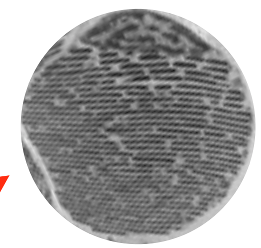


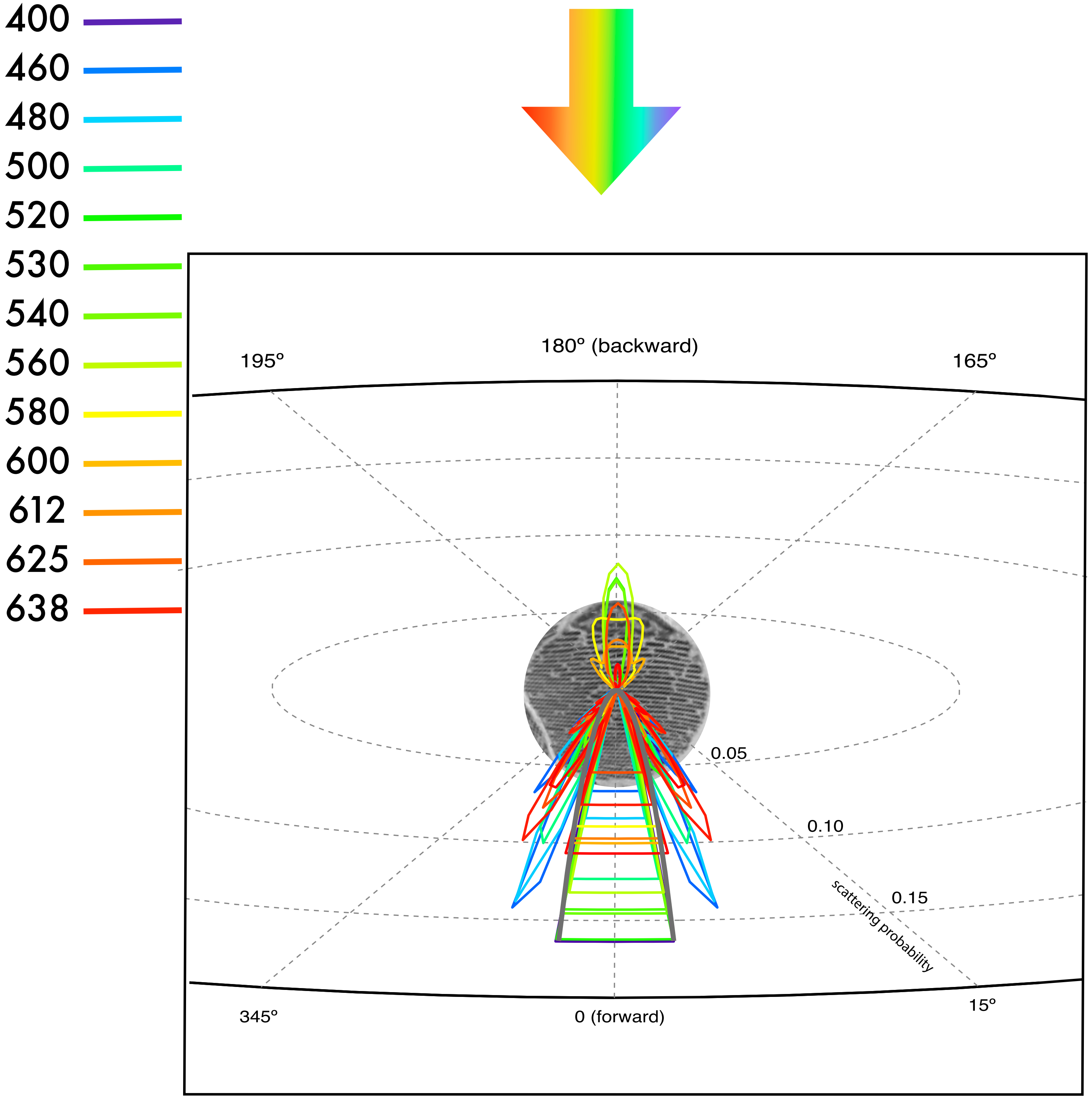


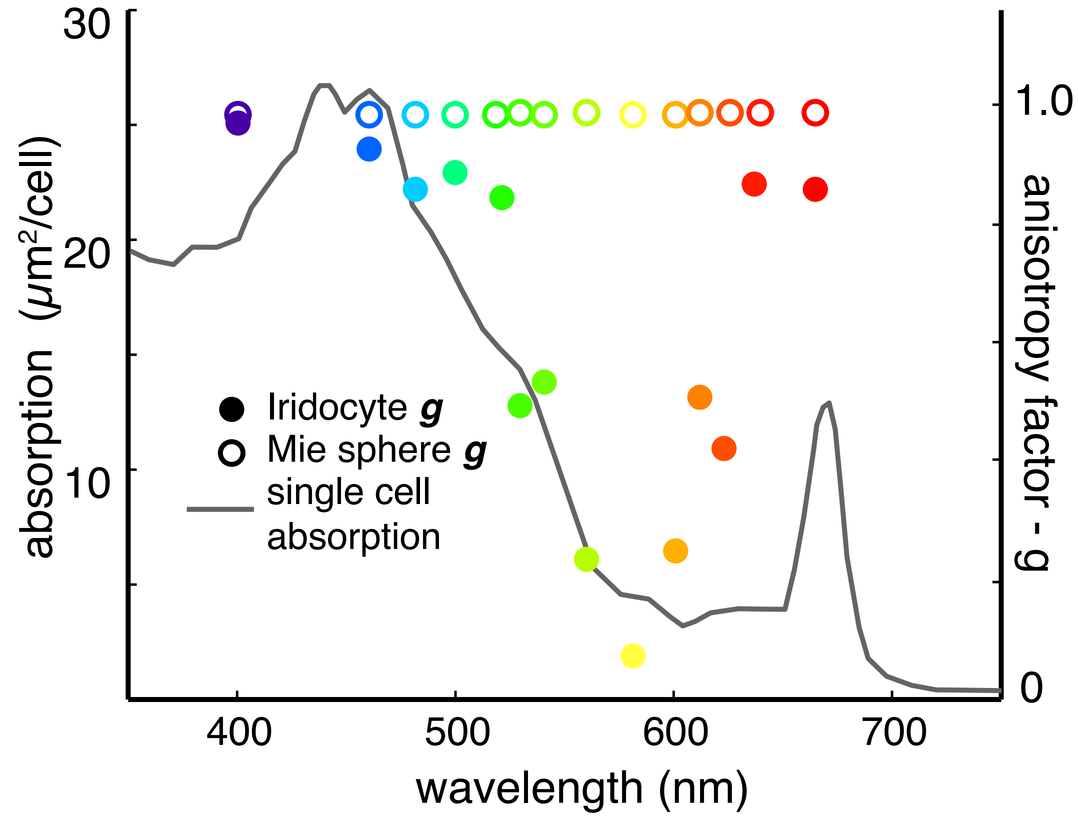
Saturn dust particle



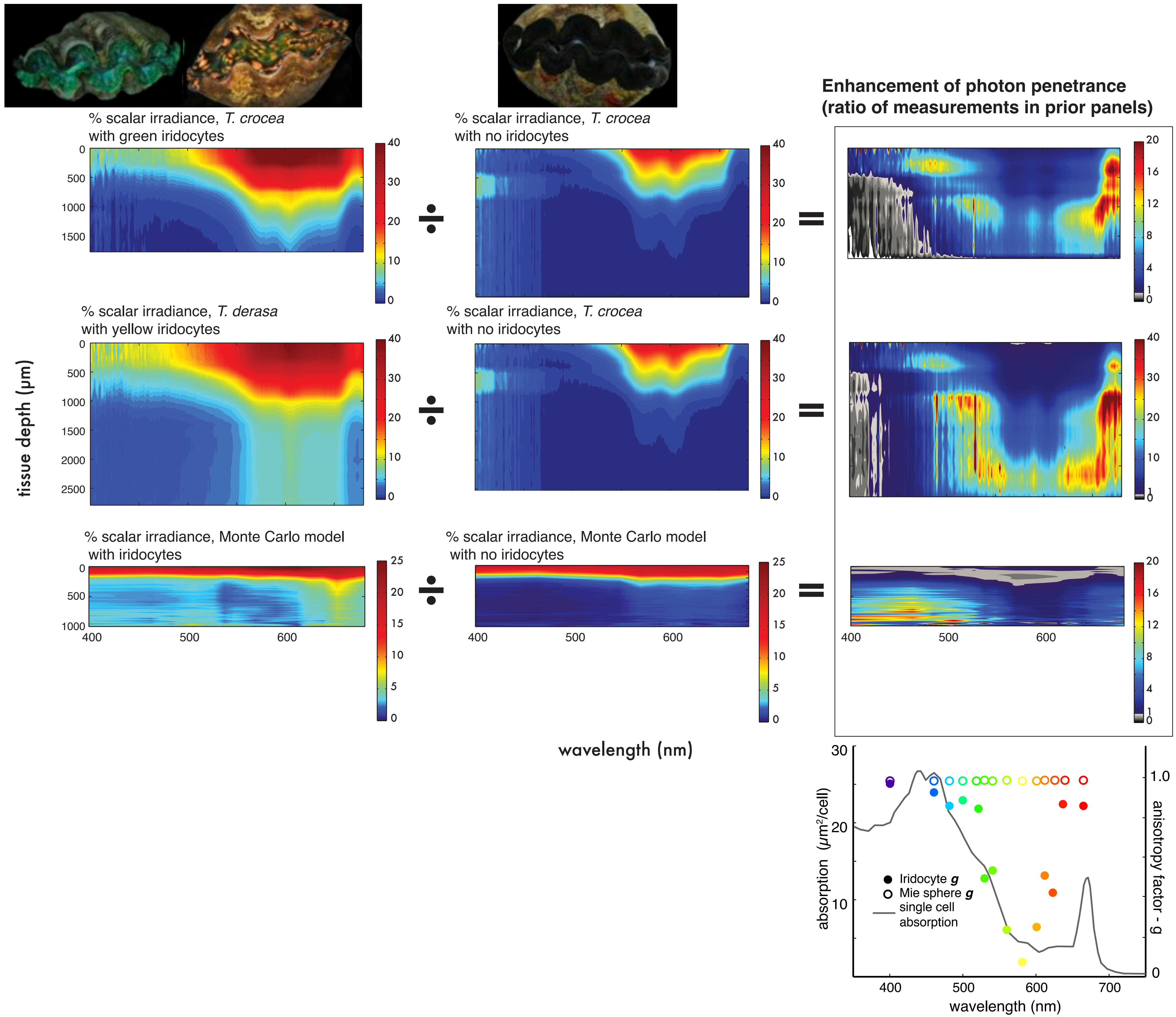
- 6 µm sphere
- 80 nm mean, 30 nm variance layers
- high index = 1.5
- low index =1.35
- external medium = 1.33

A.M.S. et al., unpublished



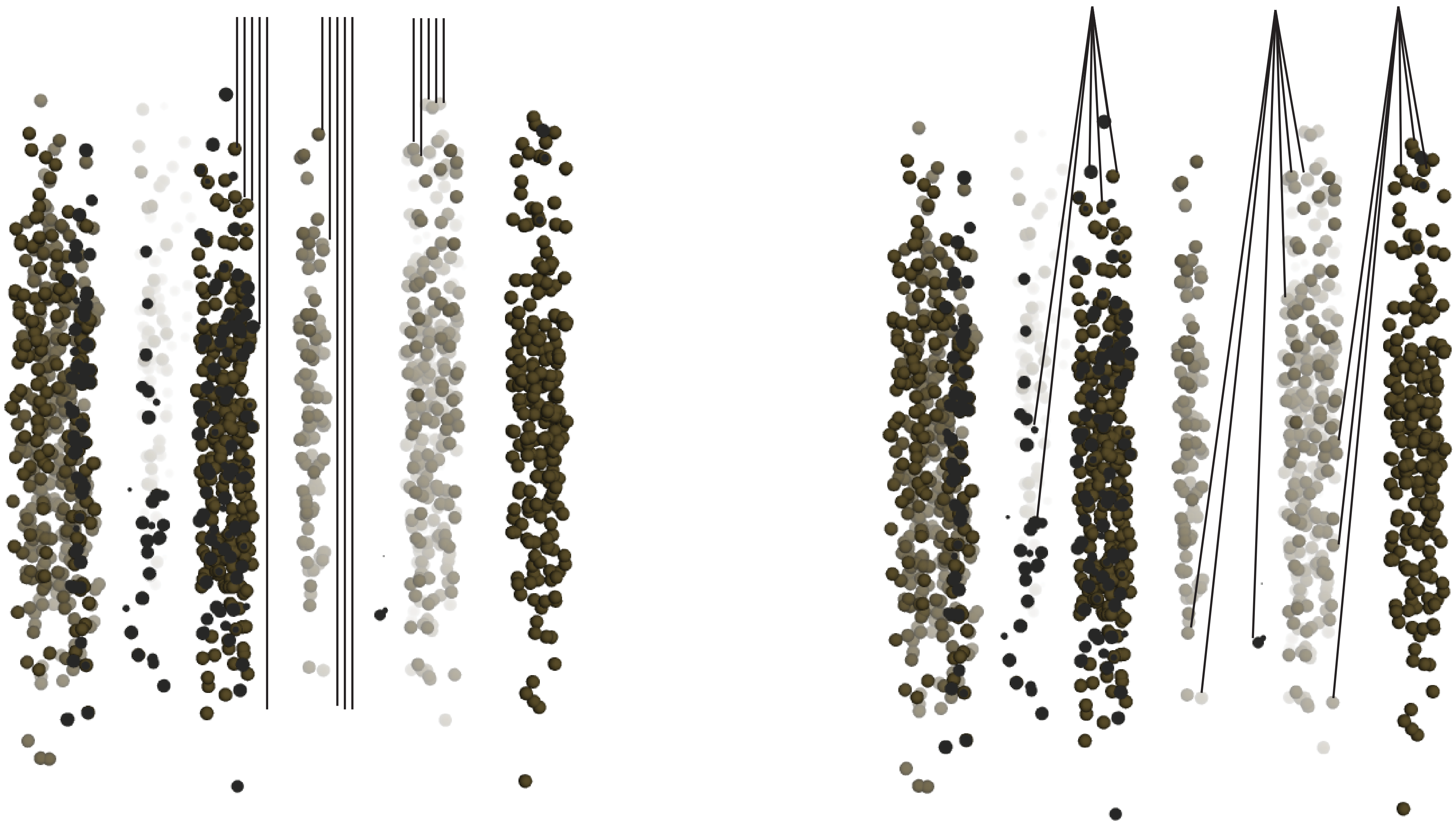


A.M.S. et al., unpublished

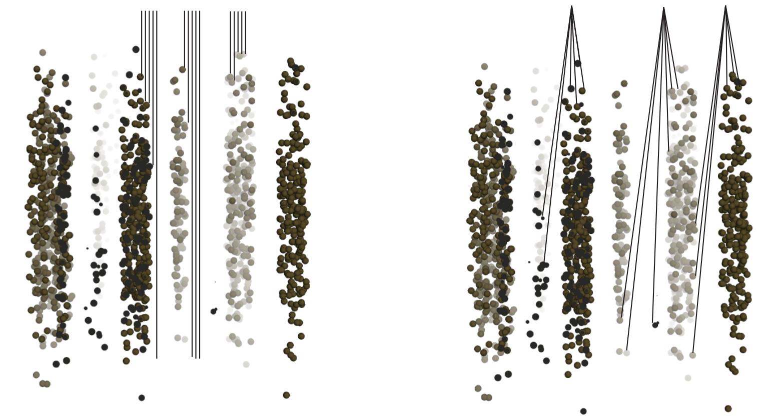


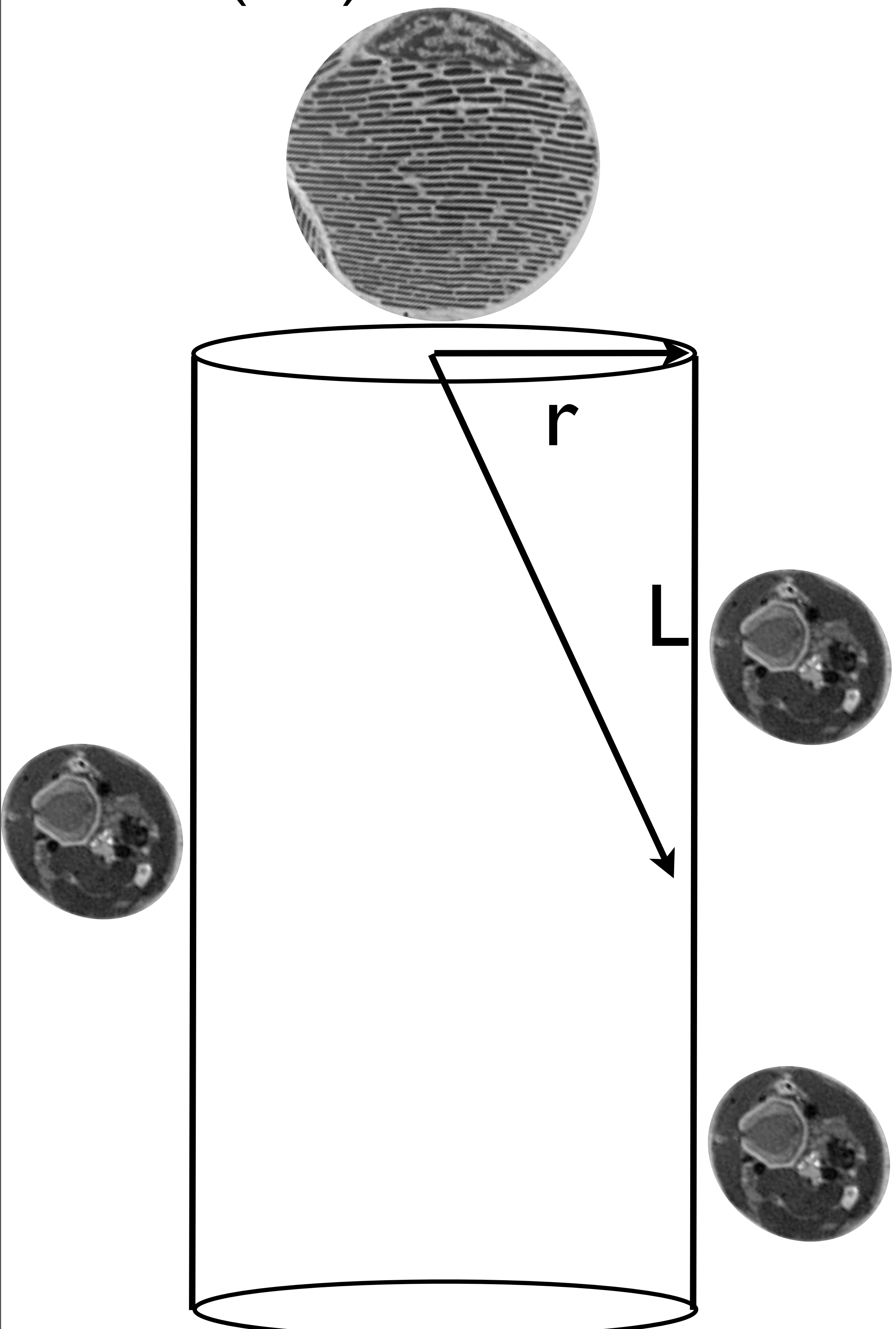
% scalar irradiance, T. crocea
with green iridocytes
% scalar irradiance, T. crocea
with no iridocytes
Enhancement of photon penetrance
(ratio of measurements in prior panels)
% scalar irradiance, T. derasa
with yellow iridocytes
% scalar irradiance, T. crocea
with no iridocytes
tissue depth (µm)
% scalar irradiance, Monte Carlo model
with iridocytes
% scalar irradiance, Monte Carlo model
with no iridocytes
wavelength (nm)
Iridocyte g
Mie sphere g
single cell
absorption
absorption (µm²/cell)
anisotropy factor - g
wavelength (nm)

What’s happening here?



An even illumination of the sides of this tube requires a phase function amounting to $\tan^{-1}(r/L)$.





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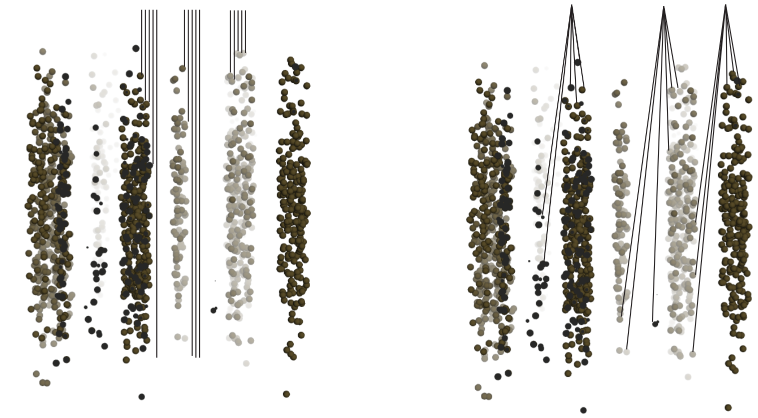
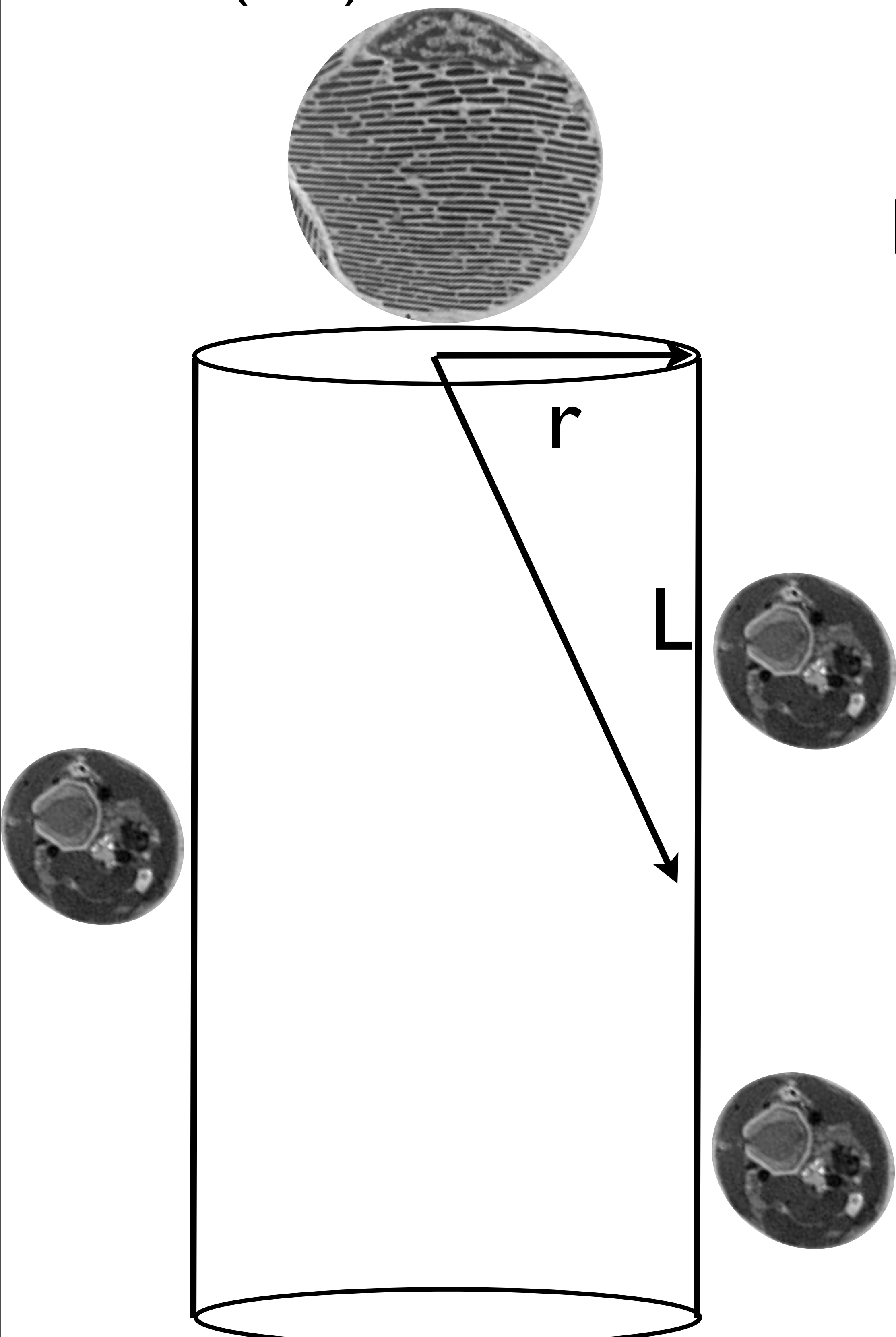
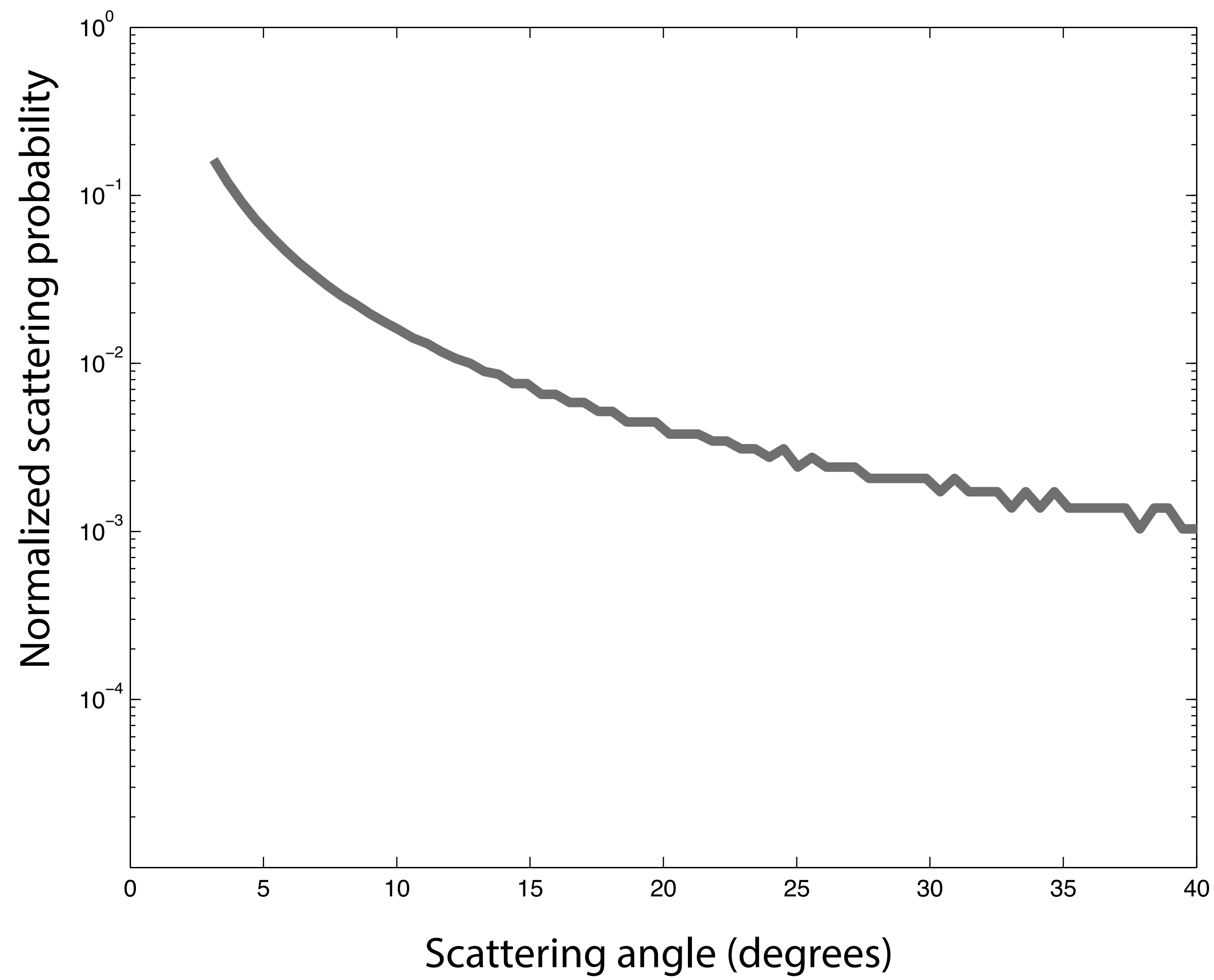
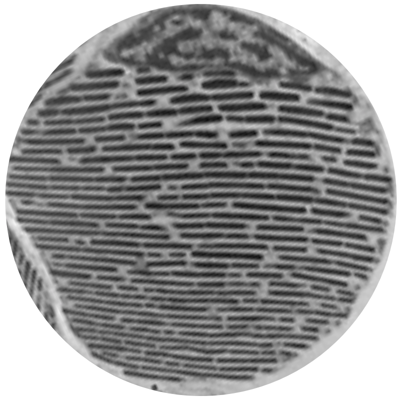




For estimates of r = 75 μm and L = 10 - 3000 μm, that looks like this:





The estimated iridocyte phase function may actually "aim" photons to specific spots deep in the clam tissue...