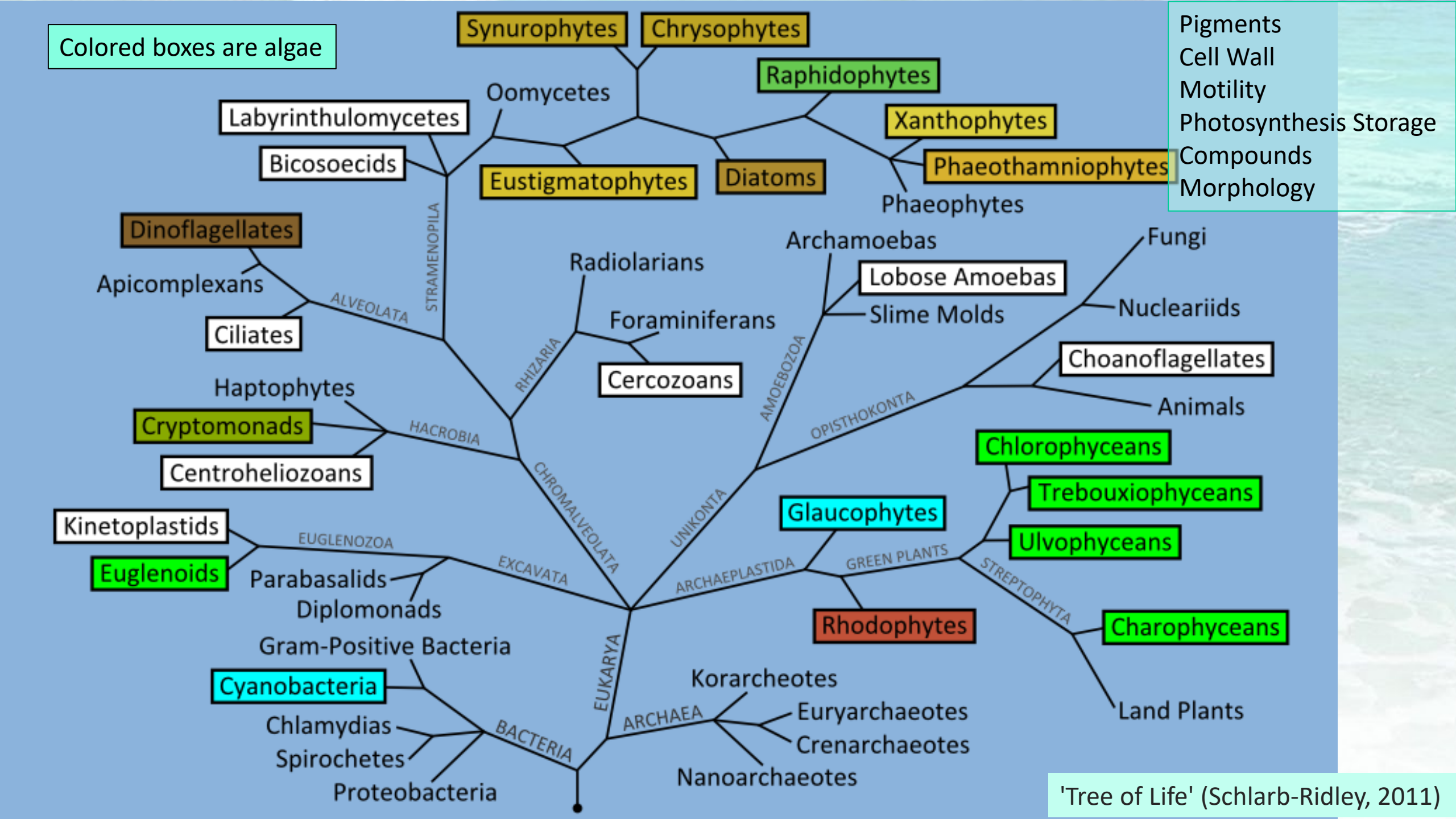
Cyanobacteria Introduction-Biology, Ecology and Taxonomy

Barry H. Rosen, Ph. D.
Florida Gulf Coast University
World-Class Scholar and Professor

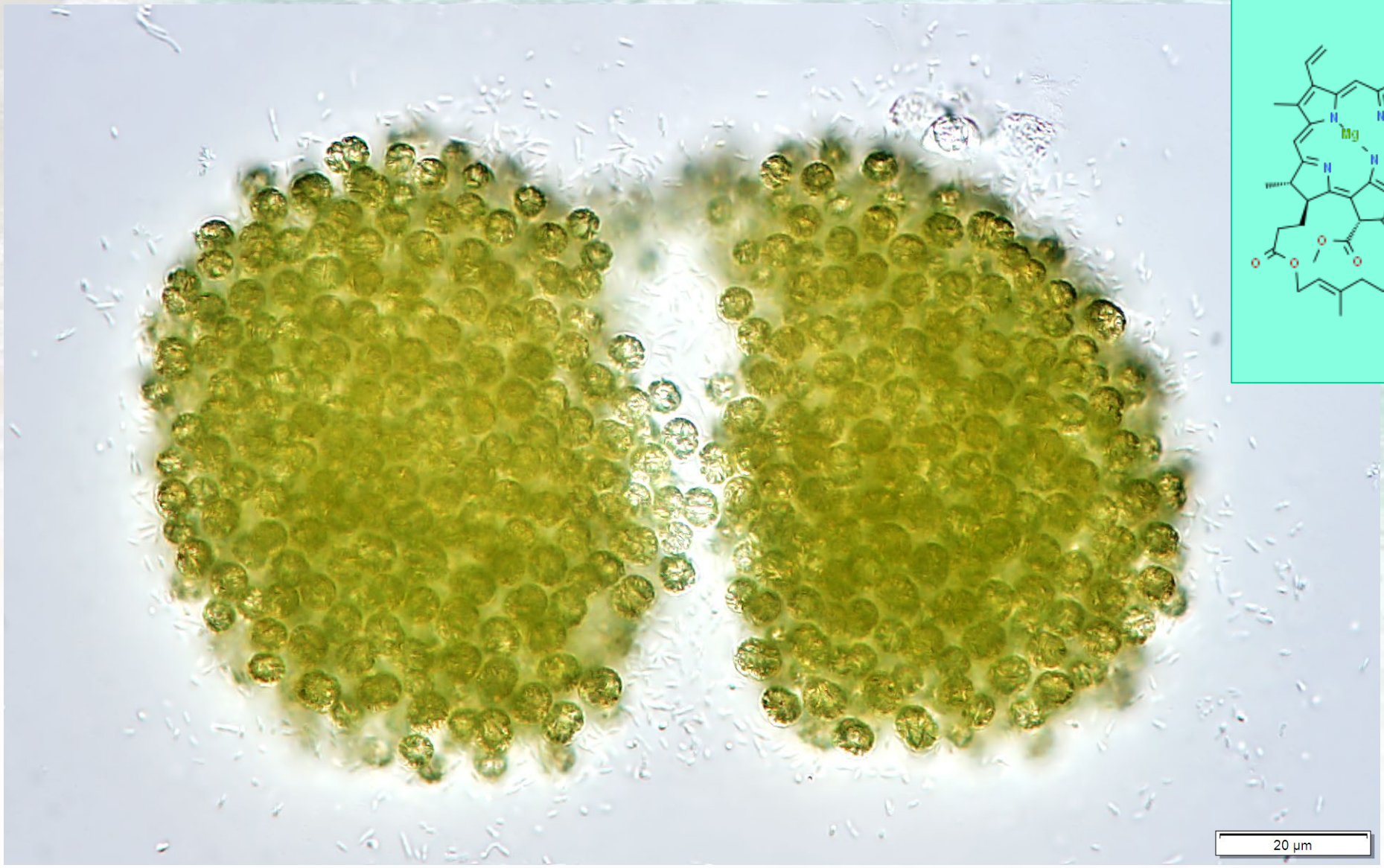
brosen@fgcu.edu

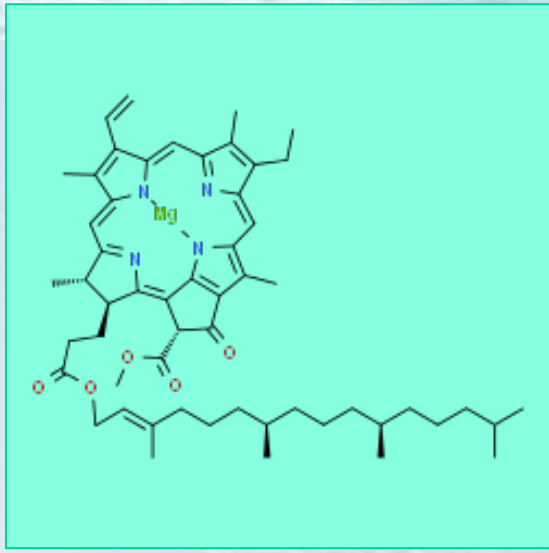
239-745-4589

THE WATER SCHOOL AT FGCU


Colored boxes are algae
Pigments
Cell Wall
Motility
Photosynthesis Storage Compounds
Morphology
Synurophytes
Chrysophytes
Raphidophytes
Xanthophytes
Phaeothamniophytes
Phaeophytes
Diatoms
Eustigmatophytes
Oomycetes
Labyrinthulomycetes
Bicosoecids
STRAMENOPILA
Dinoflagellates
Apicomplexans
Ciliates
ALVEOLATA
Radiolarians
Foraminiferans
Cercozoans
RHIZARIA
Archamoebas
Lobose Amoebas
Slime Molds
AMOEBOZOA
Fungi
Nucleariids
Choanoflagellates
Animals
OPISTHOKONTA
Haptophytes
Cryptomonads
Centroheliozoans
HACROBIA
CHROMALVEOLATA
UNIKONTA
Chlorophyceans
Trebouxiophyceans
Ulvophyceans
GREEN PLANTS
Glaucophytes
ARCHAEPLASTIDA
STREPTOPHYTA
Charophyceans
Land Plants
Rhodophytes
Kinetoplastids
Euglenoids
EUGLENOZOA
Parabasalids
Diplomonads
EXCAVATA
Gram-Positive Bacteria
Cyanobacteria
Chlamydias
Spirochetes
Proteobacteria
BACTERIA
EUKARYA
Korarcheotes
Euryarchaeotes
Crenarchaeotes
Nanoarchaeotes
ARCHAEA
'Tree of Life' (Schlarb-Ridley, 2011)

Unifying Feature of all Algae/Cyanobacteria: chlorophyll *a*

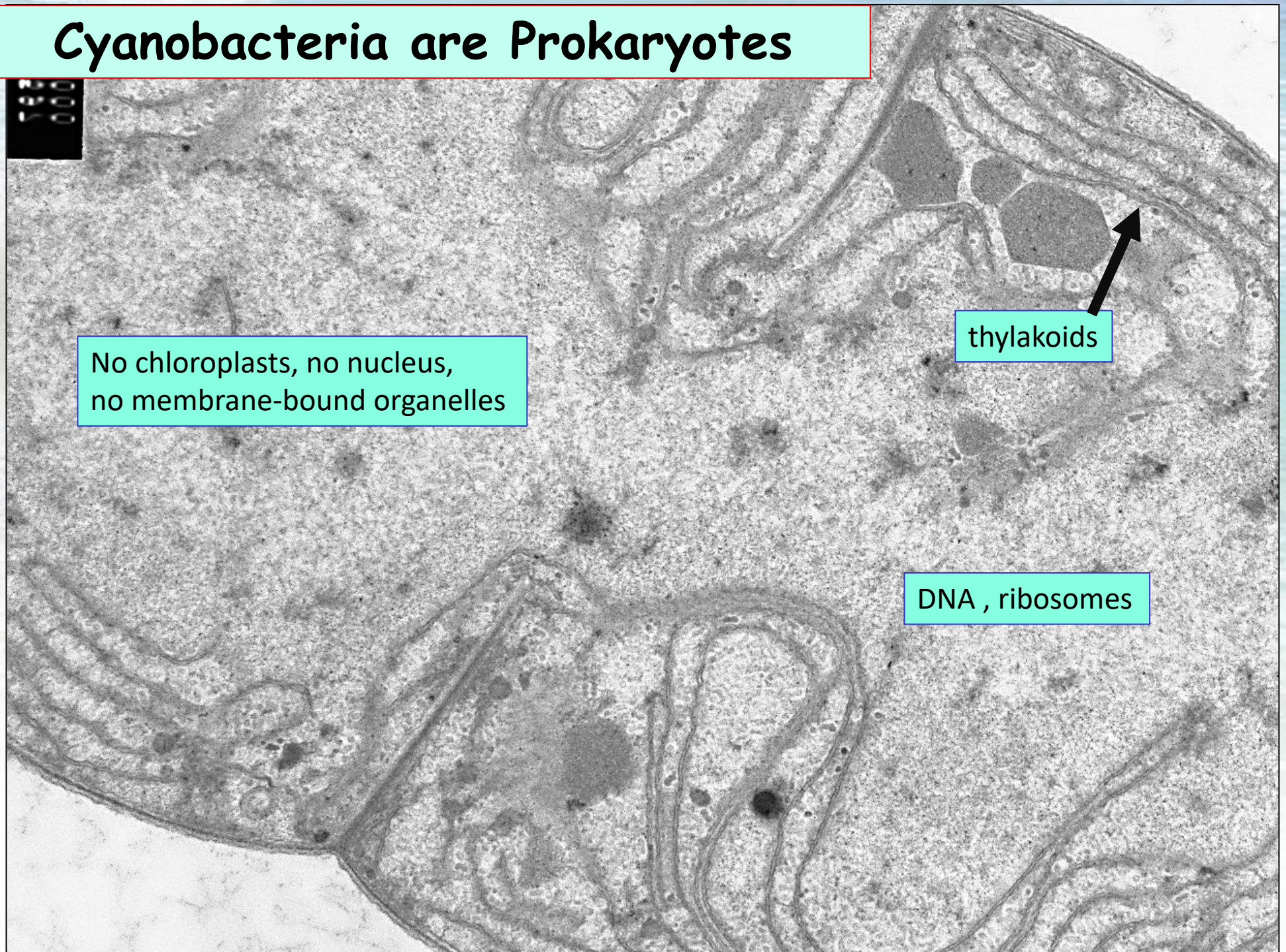




Cyanobacteria are Prokaryotes

pigments in thylakoids

have chlorophyll *a* like "regular algae" i.e. , the eukaryotic algae



Transmission electron microscope images: Rosen, unpublished

Cyanobacteria

- *AKA:* blue-green algae; cyanoHABs
- gram negative bacteria

Mucilage

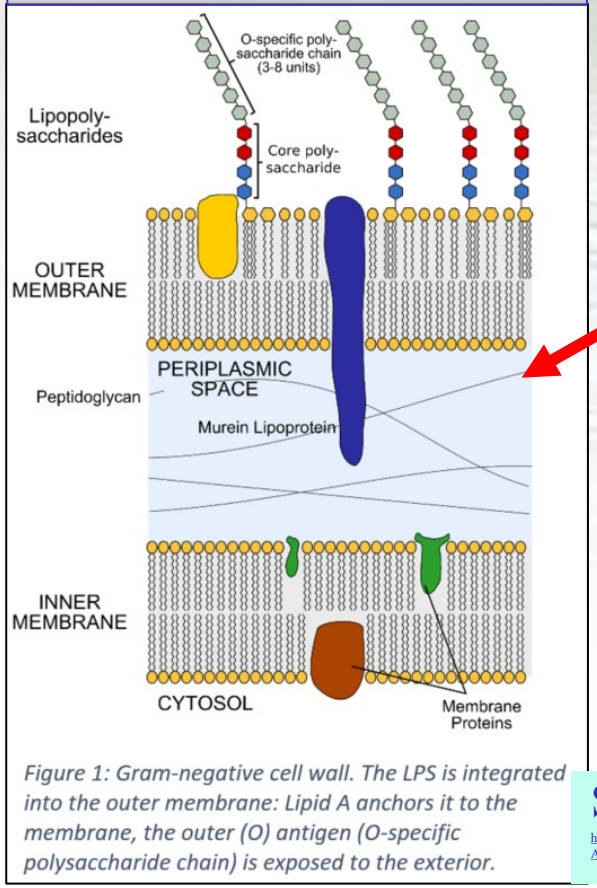


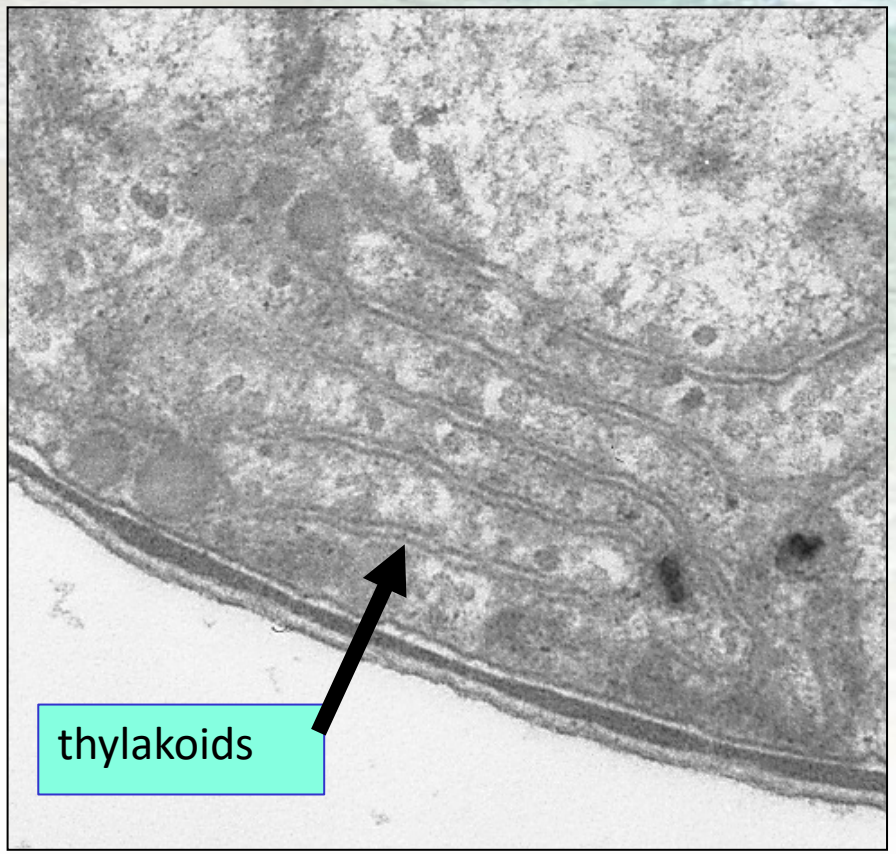
Figure 1: Gram-negative cell wall. The LPS is integrated into the outer membrane: Lipid A anchors it to the membrane, the outer (O) antigen (O-specific polysaccharide chain) is exposed to the exterior.

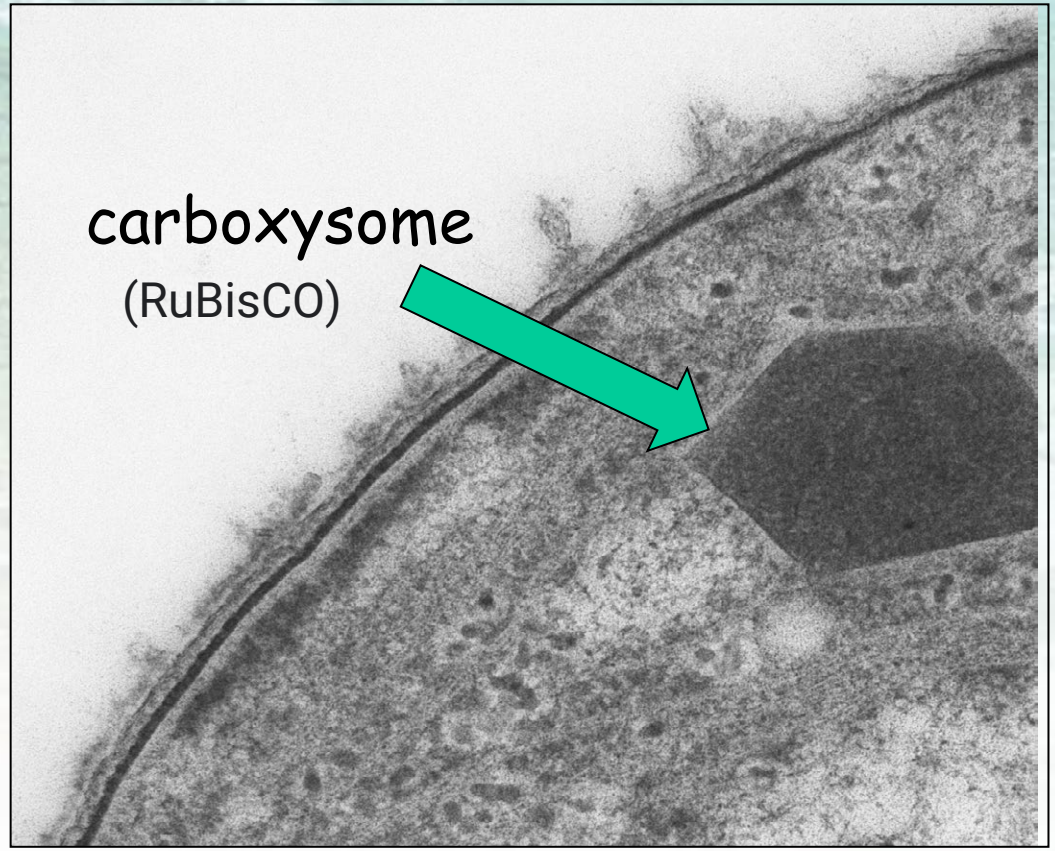
Source

https://bio.libretexts.org/Bookshelves/Microbiology/Microbiology_%28Boundless%29/04%3A_Cell_Structure_of_Bacteria_Archaea_and_Eukaryotes/4.04%3A_Cell_Walls_of_Prokaryotes/4.4B%3A_Gram-Negative_Outer_Membrane

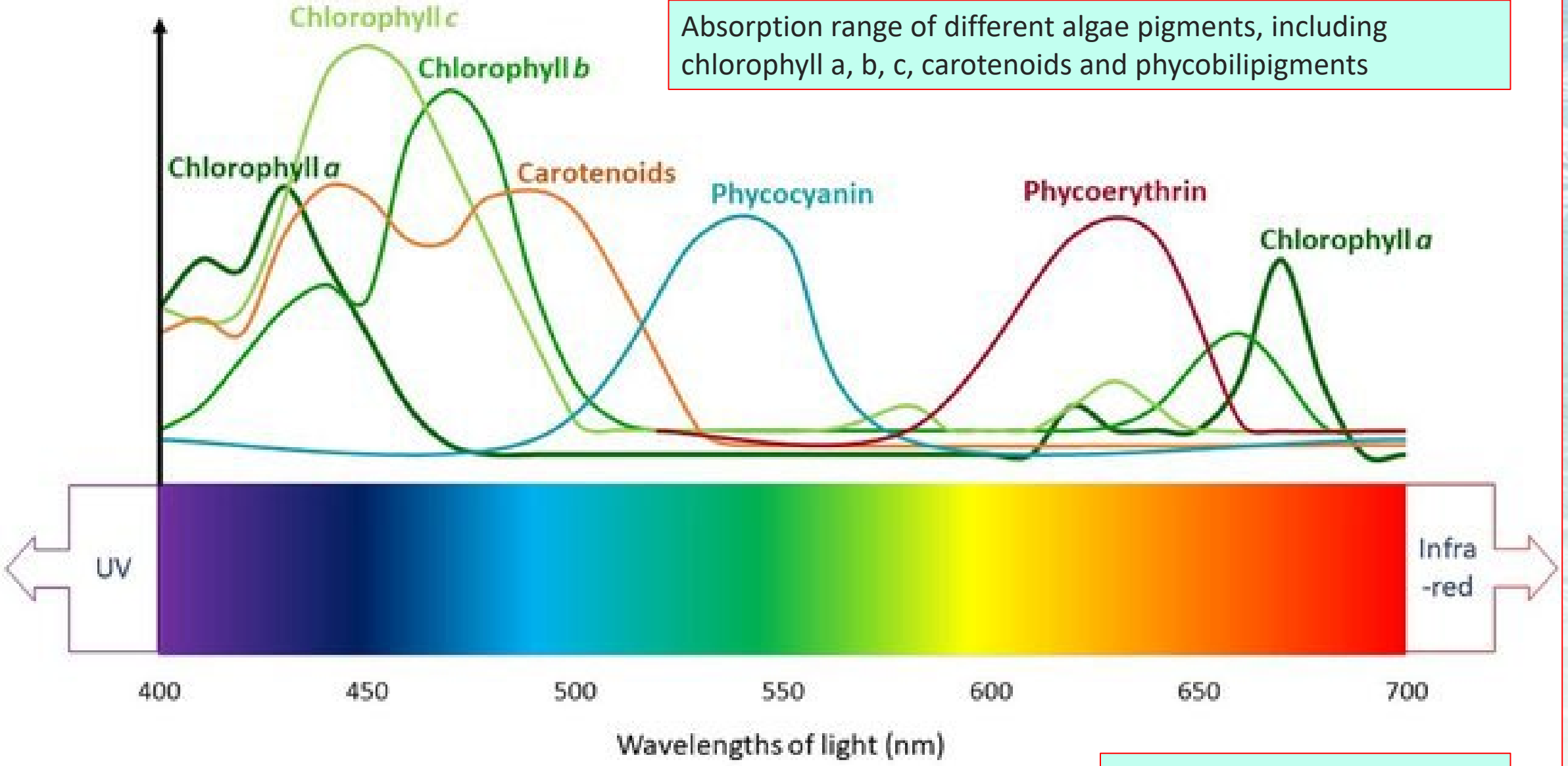
Top Priority: Photosynthesis

1) Energy captured in biochemical form (ATP, NADPH)
2) H_2O is split (**oxygen waste product to the cyano's**)
3) eventually, CO_2 fixed into "sugars" needed for metabolism





Absorption range of different algae pigments, including chlorophyll a, b, c, carotenoids and phycobilipigments

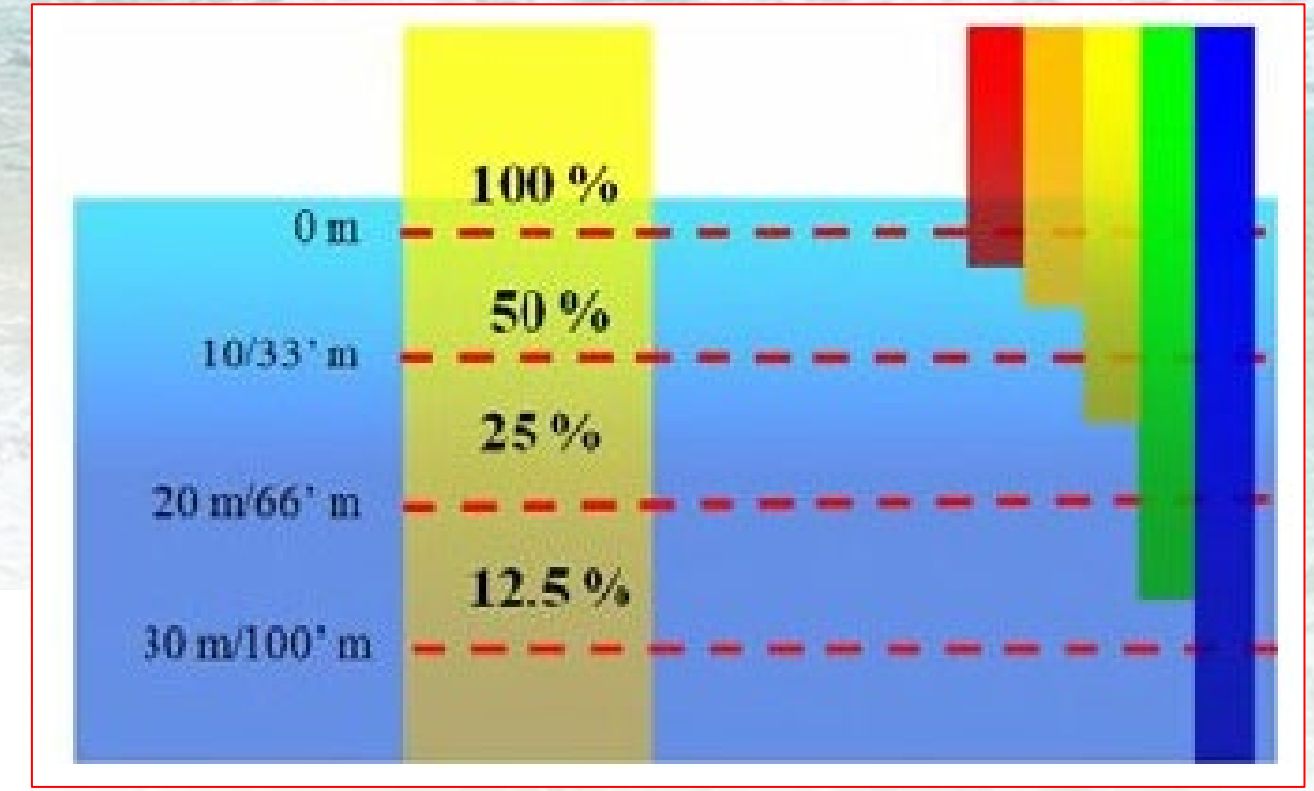


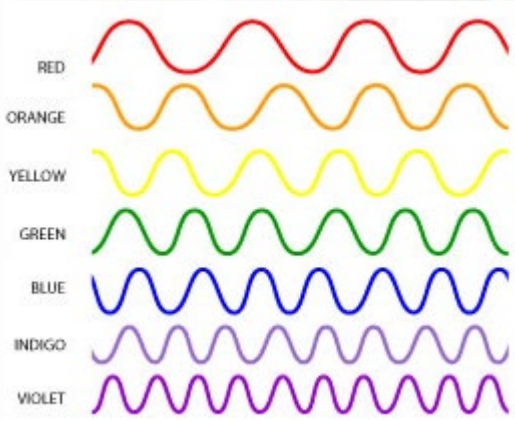
(Roy et al. 2011)

Cyanobacteria
chlorophyll *a* & *d* infrared light
phycocyanin, phycoerythrin

Buoyancy to optimize light capture

Penetration of light of various wavelengths through water; blue light is the strongest and red light is the weakest





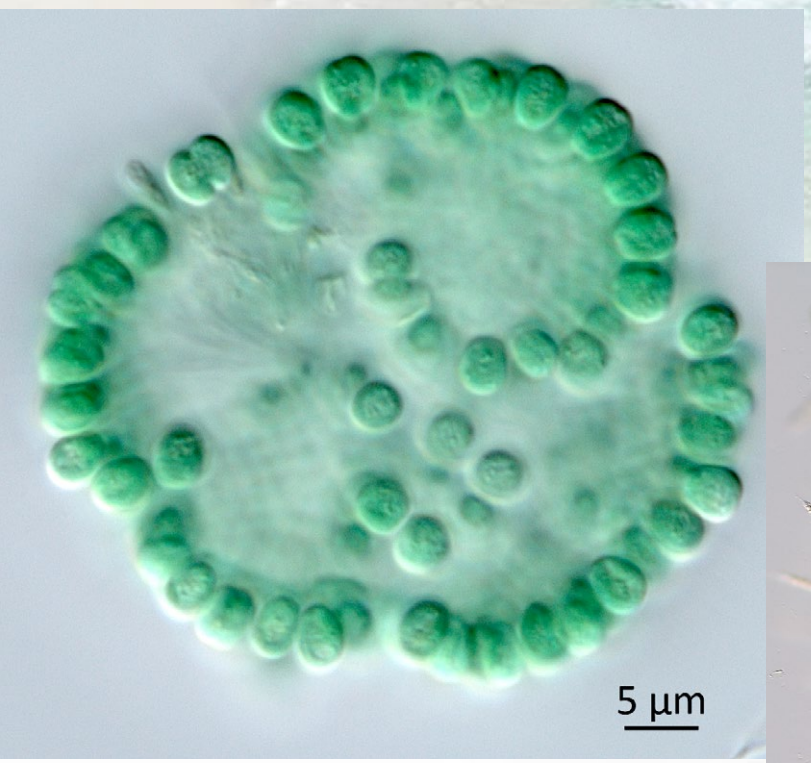
Various pigments

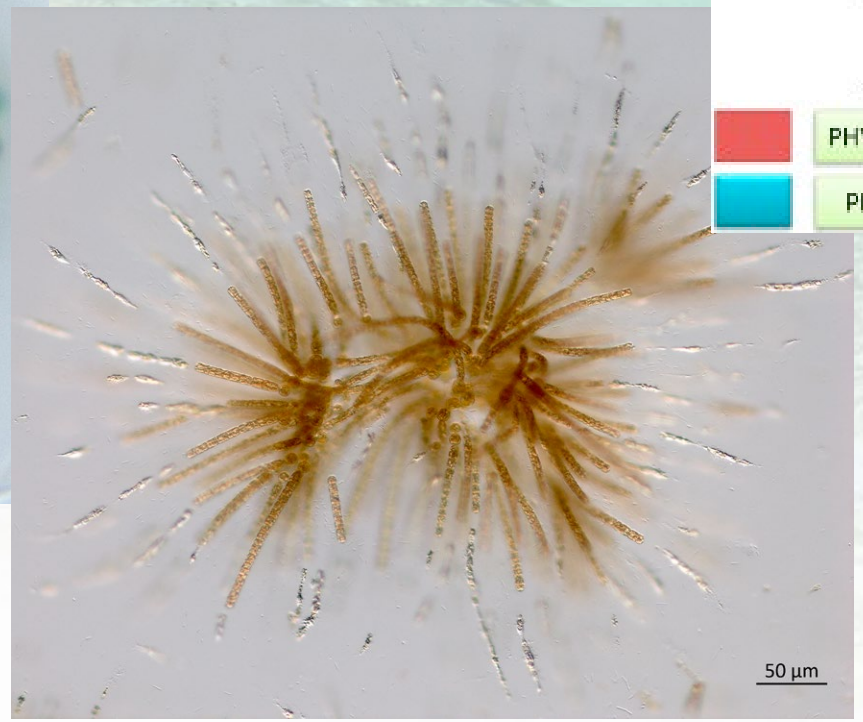
https://www.sciencedirect.com/science/article/pii/S1674205214606432

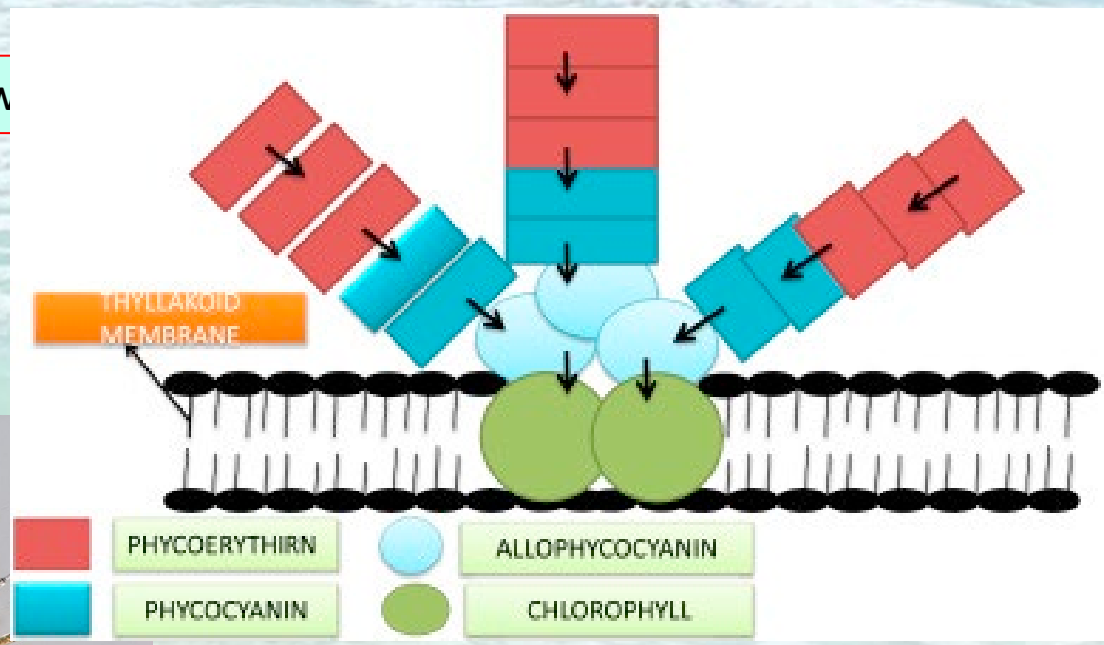
Light Capture and pigments

Chlorophyll *a*, phycocyanin, phycoerythrin, β-carotene and zeaxanthin, etc,

Pigments causes a variety of colors: green, black, pink, brow







https://doi.org/10.1016/j.fct.2018.08.002

Coupled with Light Capture: Buoyancy Regulation

Ecological Strategy: Staying in the light (photic zone), but much more; Gas Vesicles: Buoyancy regulation/vertical migration

Low light ↑

Competitive advantage: may shade out others

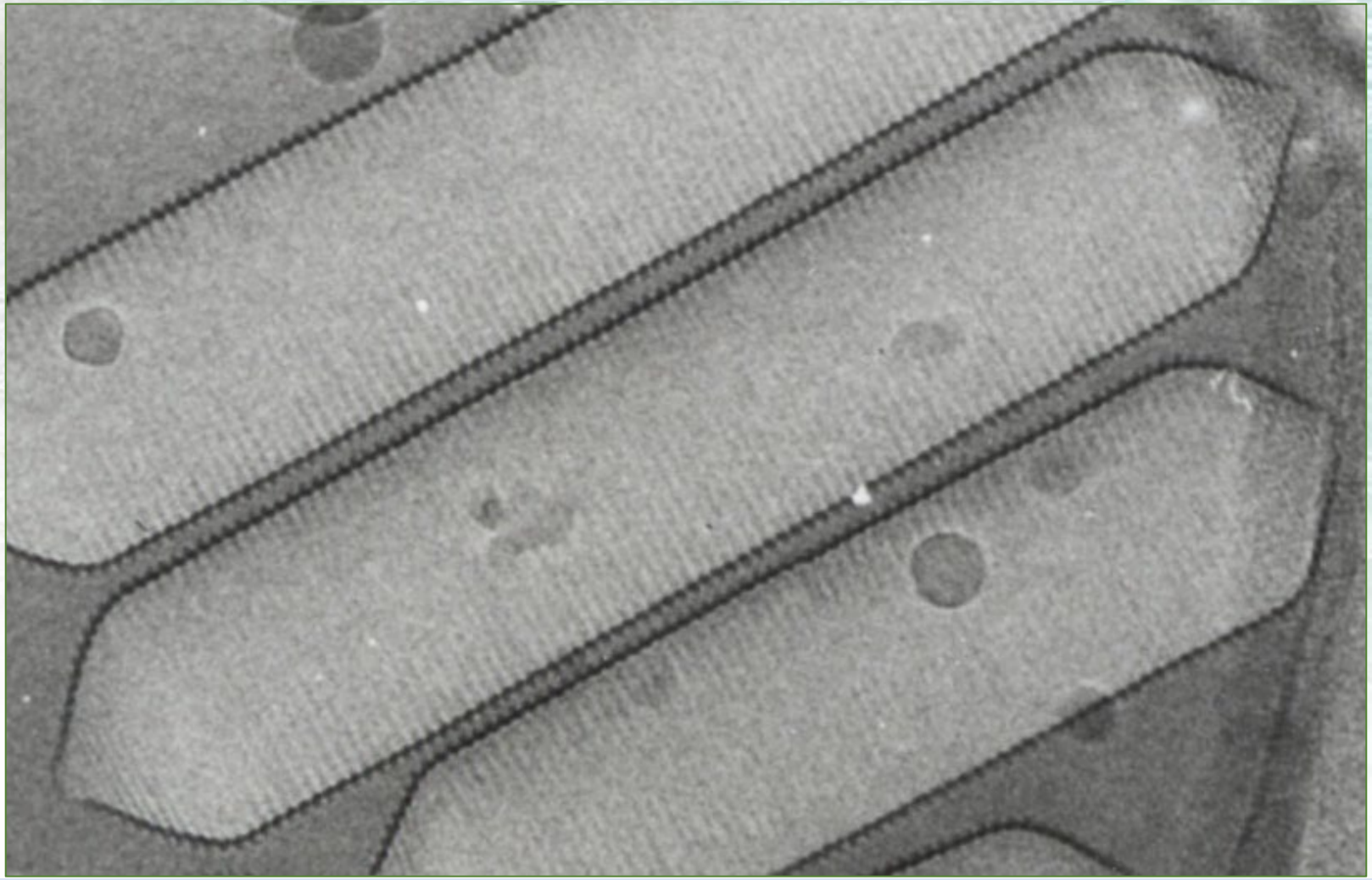
$(C_6H_{12}O_6)n$ (ballast) ↓

Nutrients scavenged whilst near bottom sediments or thermocline

Select genera

Anatomy of a Gas Vesicle

- hollow protein shells
- almost exclusively of gas vesicle protein A (GvpA)
- assembled and disassembled to change their density



Herzfeld J. Chapter 10 in *The Cell Biology of Cyanobacteria*, Caister Academic Press (Norfolk, UK, 2014).

Gas Vesicle under the microscope

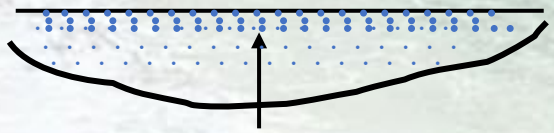
Drinking water & recreational impact

Beware of this phenomenon when sampling

initial distribution

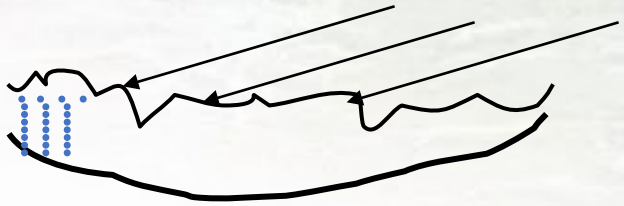
100,000 cells/L;
20 μg/L toxin

buoyancy



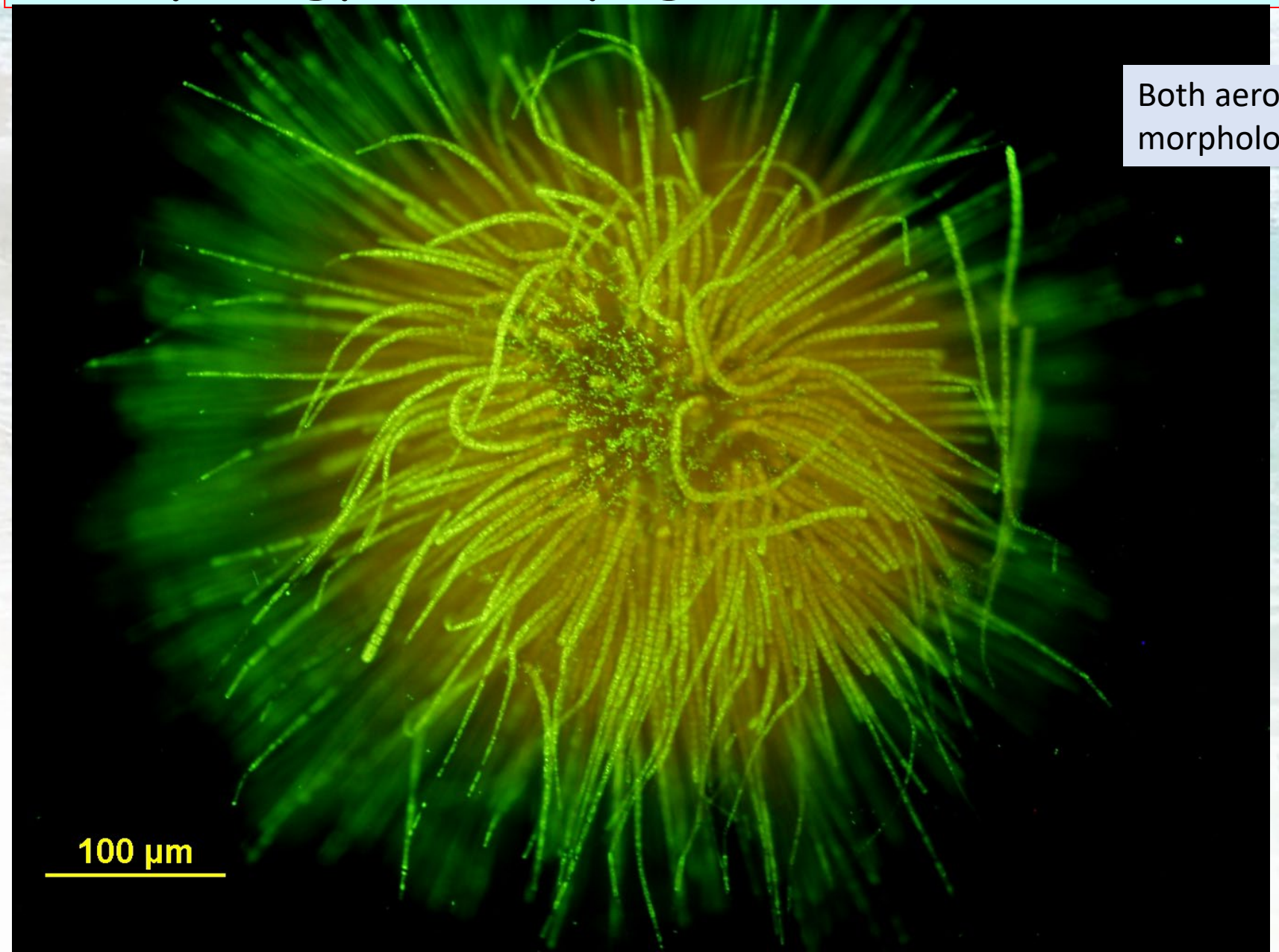
10,000,000 cells/L;
2000 μg/L toxin

wind



100,000,000 cells/L;
20,000 μg/L toxin

Morphology for staying in the water column



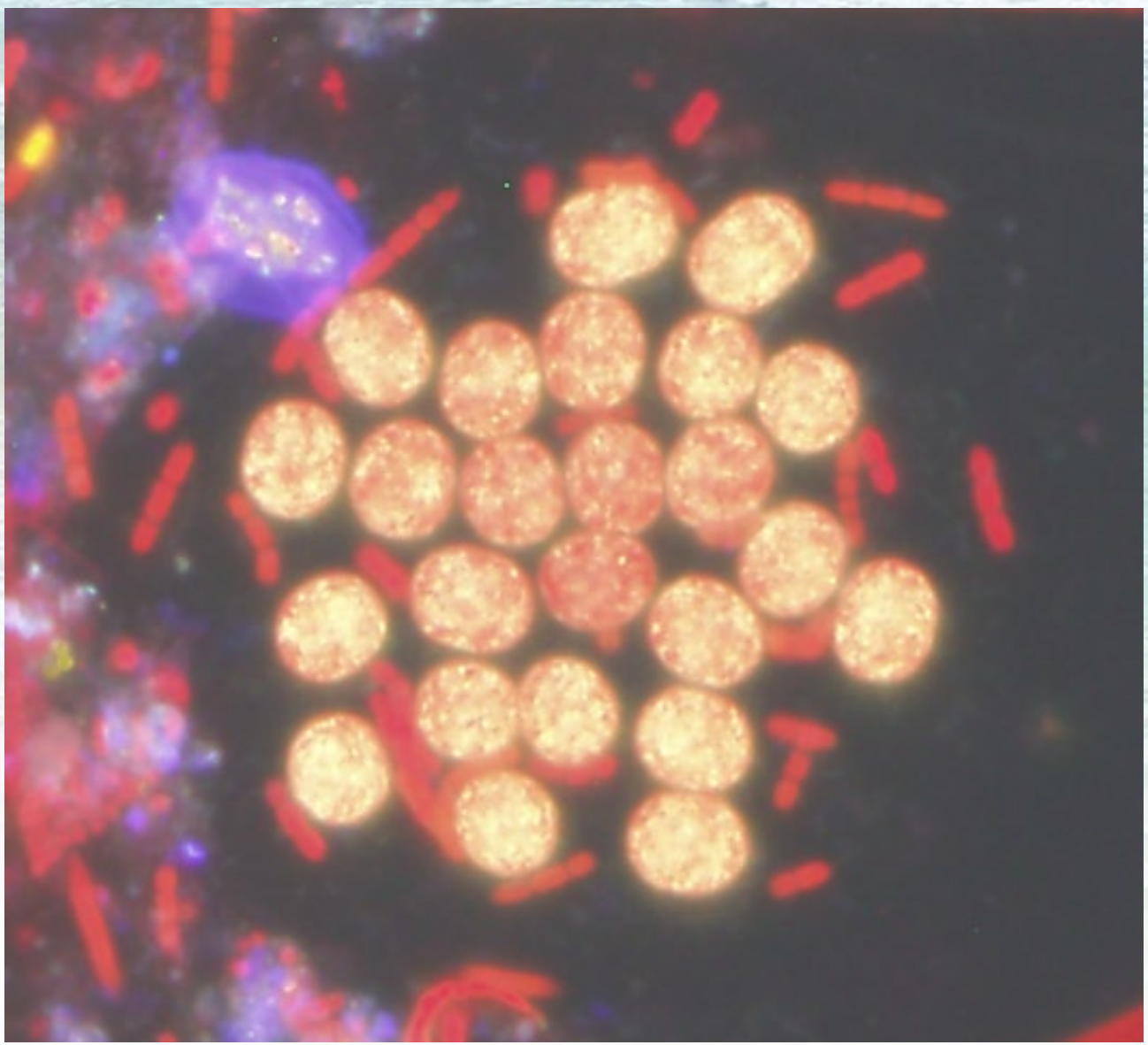
Both aerotopes and morphology

Morphology for staying in the water column

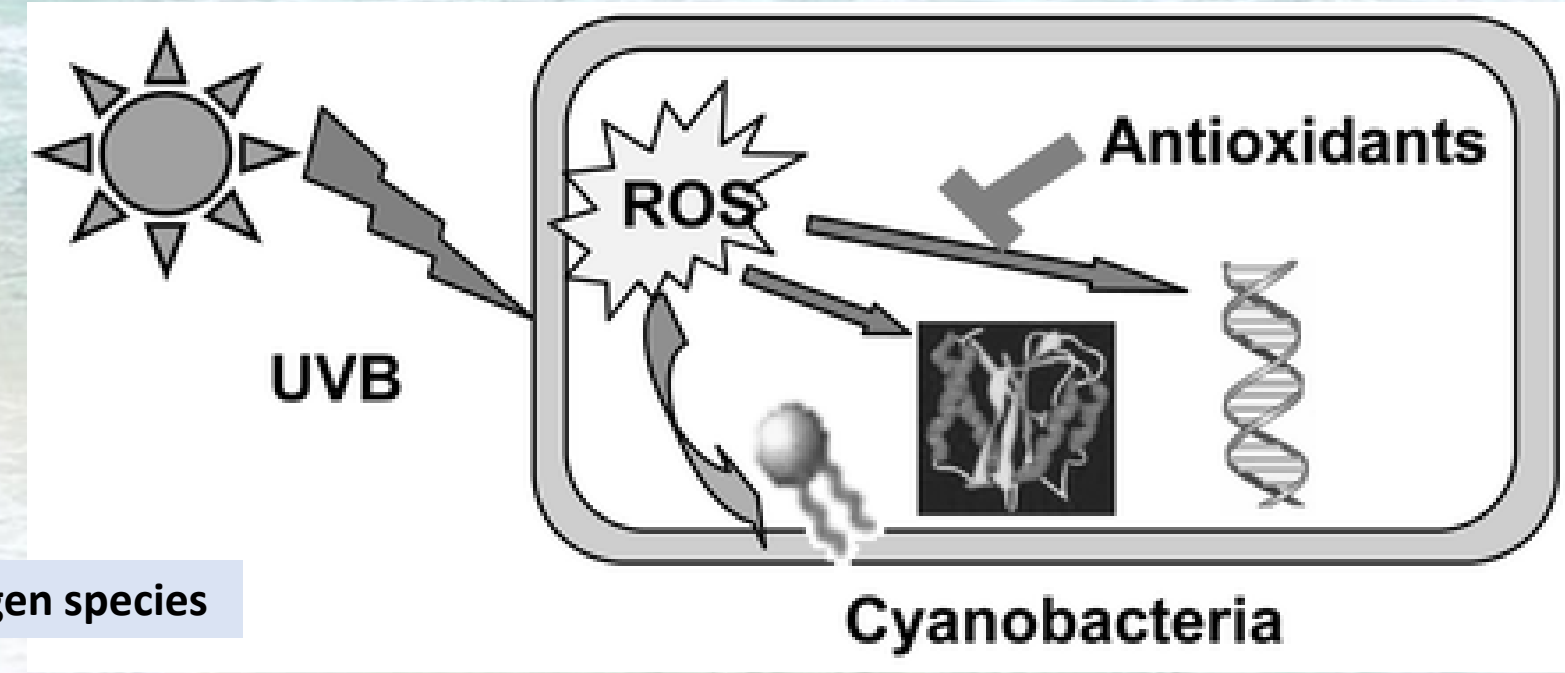
Morphology for staying in the water column

Morphology for staying in the water column

Commensalism?: organisms staying in the water column



Optimize light capture without photooxidation



Reactive oxygen species

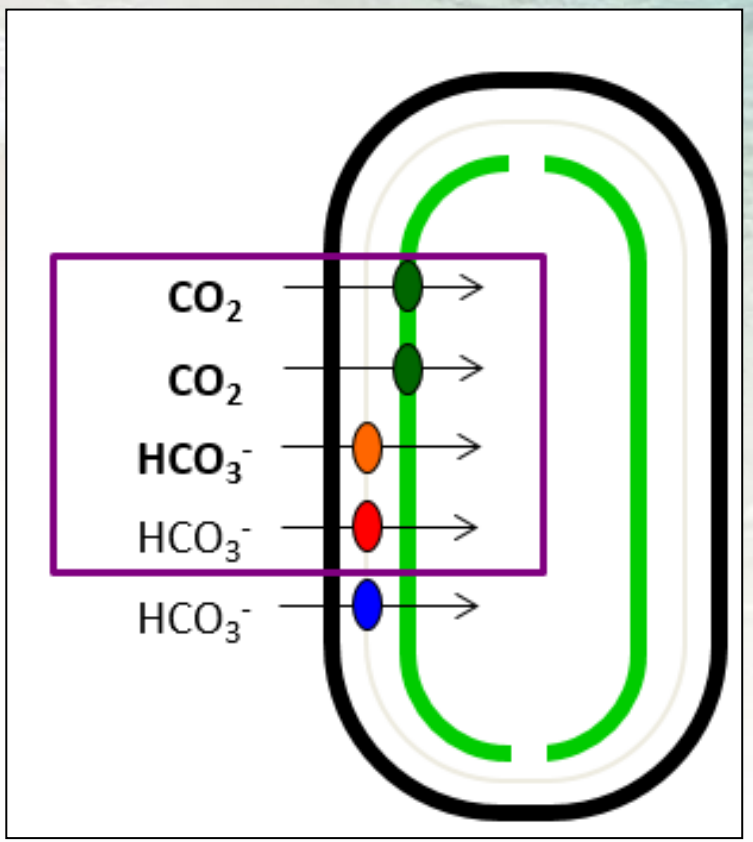
The damage to photosynthetic apparatus induces the inhibition of photosynthesis that is mediated partially by ROS. UV-B-induced oxidative stress and oxidative damage increases with irradiation time and can be reversed after long-term irradiation.

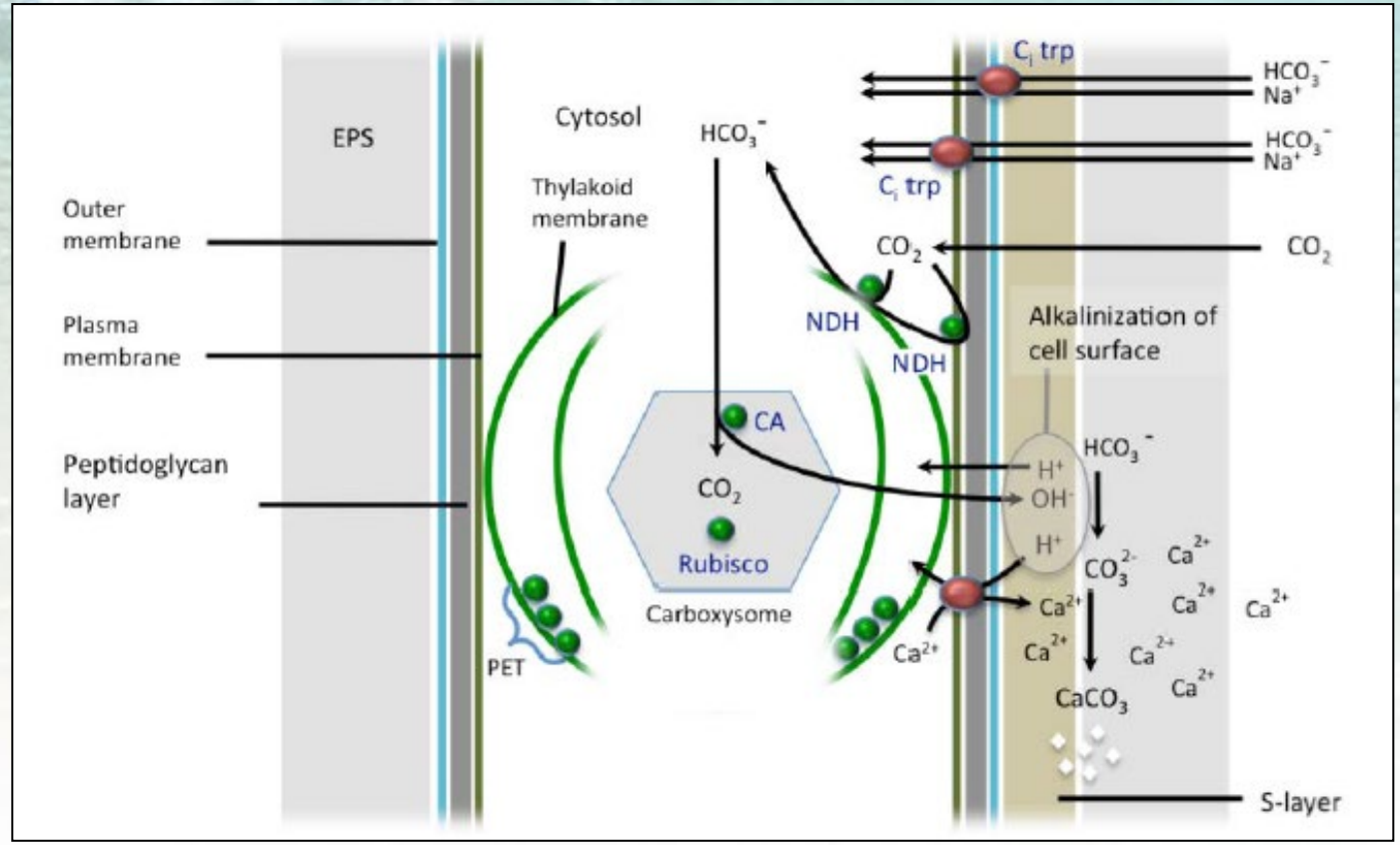
https://pubs.rsc.org/en/content/articlelanding/2002/pp/b110365m

Ecological Strategies: carbon dioxide concentrating mechanism

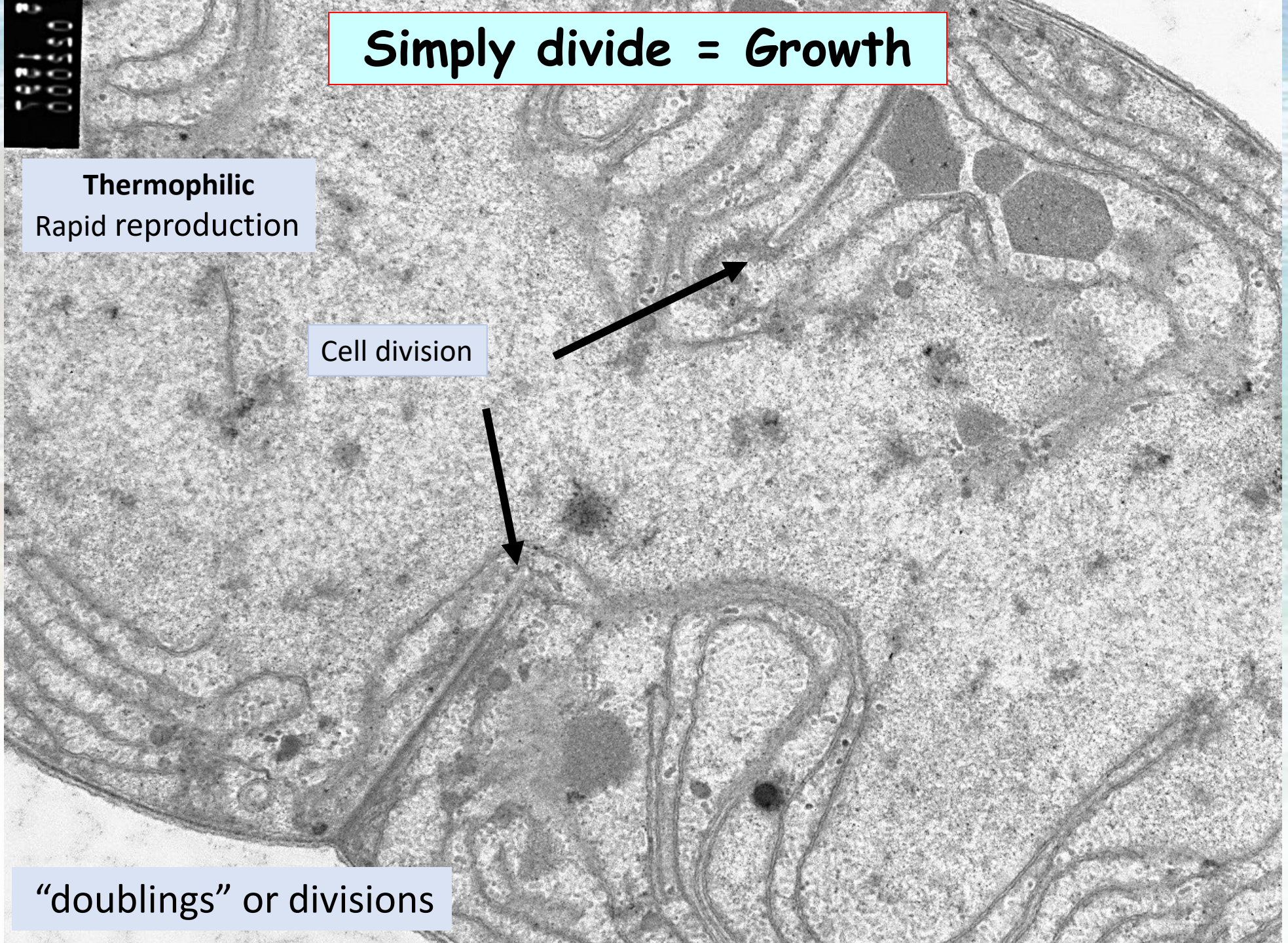
Take in CO_2 and bicarbonate, up to **1000-fold** over that in the surrounding water.

- 5 separate transport systems; some require ATP





Simply divide = Growth

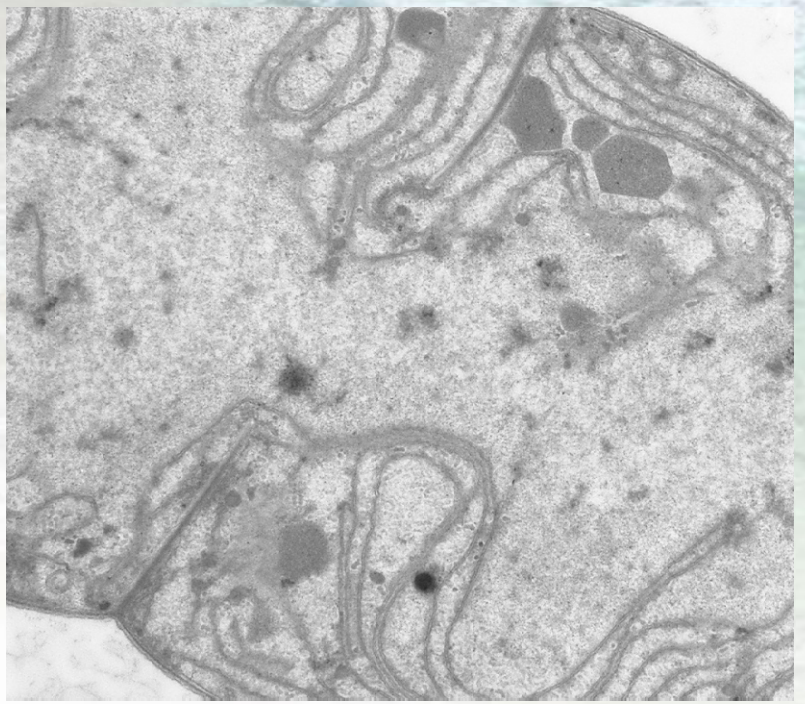


Thermophilic
Rapid reproduction

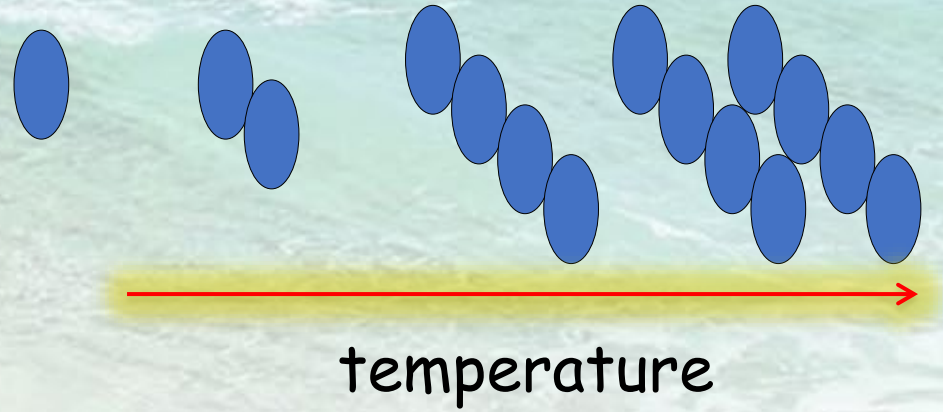
Cell division

“doublings” or divisions

Ecological Strategies: bacteria in a eukaryotic world-thermophiles grow faster



Rapid Growth



3 “doublings” or divisions per day!

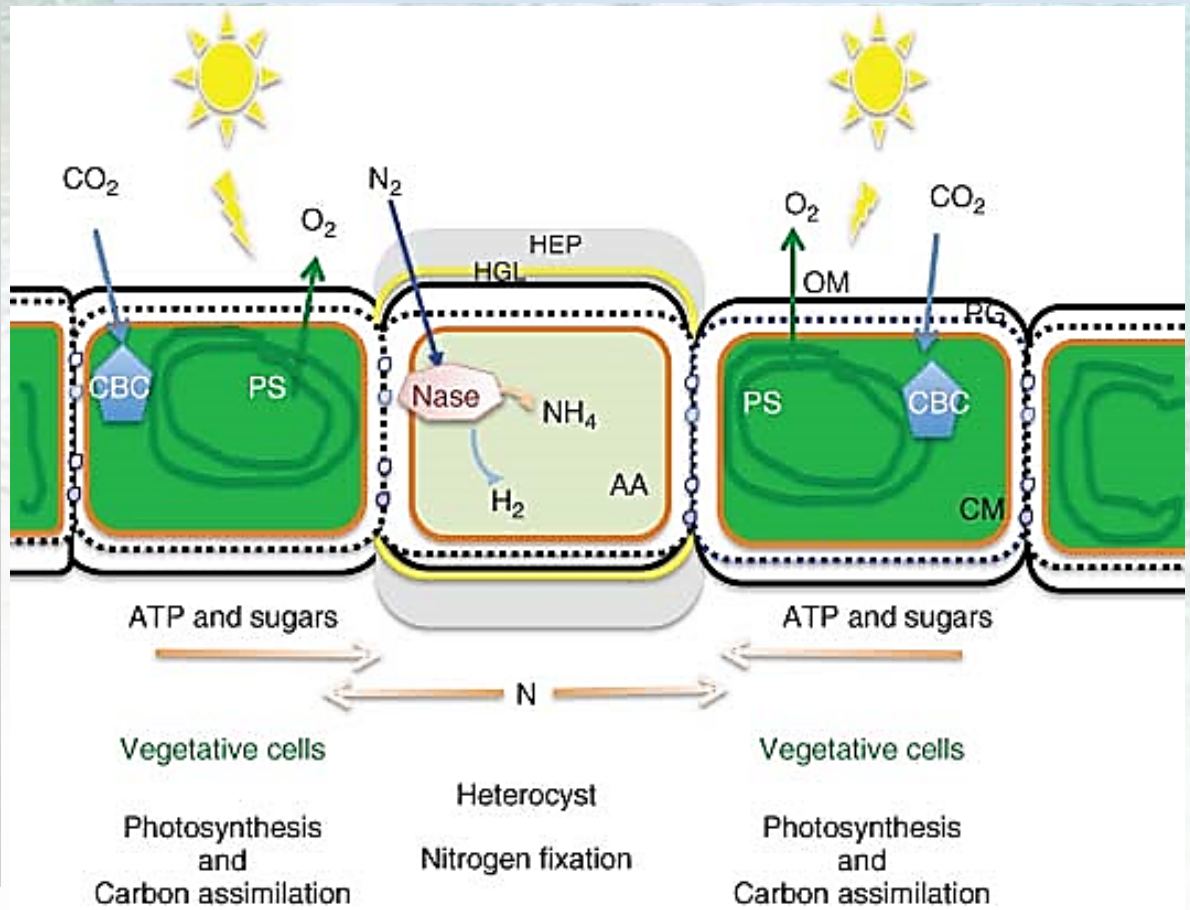
Caveats: light, temperature, nutrients must not be limiting

Some genera (Nostocales) can overcome a limiting factor, like nitrogen limitation

Heterocytes

A differentiated cell that has the specific function of

atmospheric nitrogen (N_2) fixation



- **Nitrogenase: a complex of 60 enzymes**
- **Only known way of fixing N_2 in all bacteria**
- **Inhibited in the presence of oxygen**
- **Nitrogenase acts as a <u>catalyst</u>**

Heterocytes

Oxygen reduction strategies-1

Courtesy of Hans Paerl

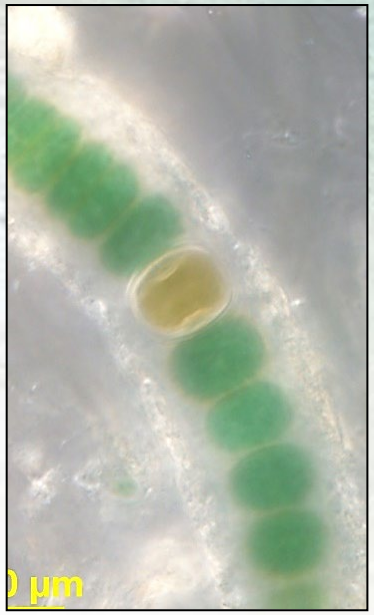
Lipid layer around cell wall

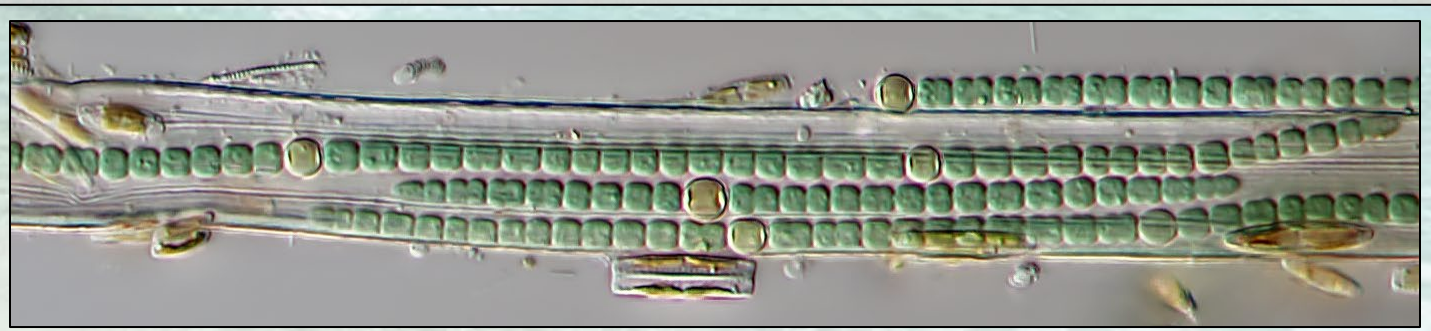
Heterocytes

Oxygen reduction strategies-2

Loss of oxygenic-photosystem II

- **Visible pigment difference**



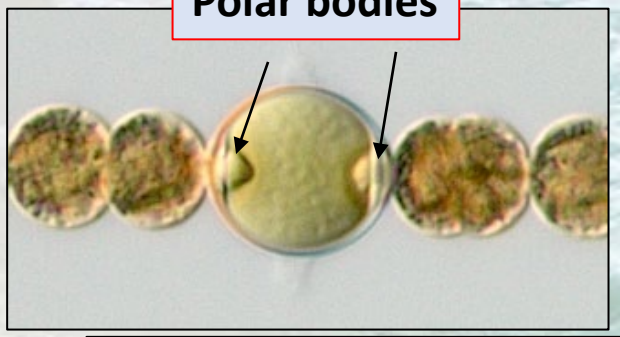


16 ATP molecules to fix one molecule of dinitrogen N_2

Heterocytes

Oxygen reduction strategies/transport

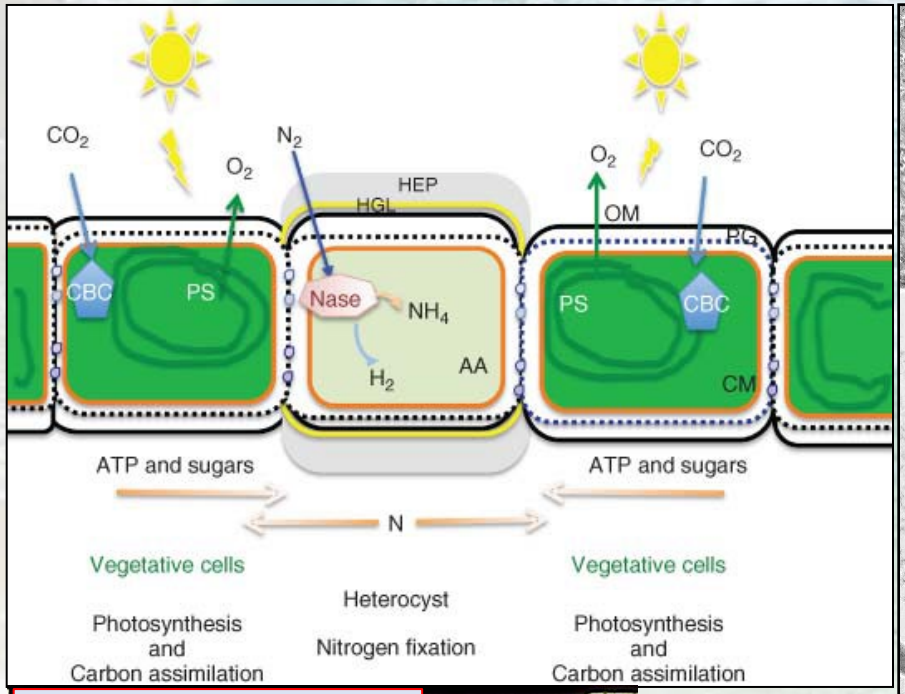
Polar bodies



Microplamadesmata

Transport of fixed nitrogen (glutamate) through the lipid layer

Some genera can overcome a limiting factor, like nitrogen limitation: heterocytes, etc.



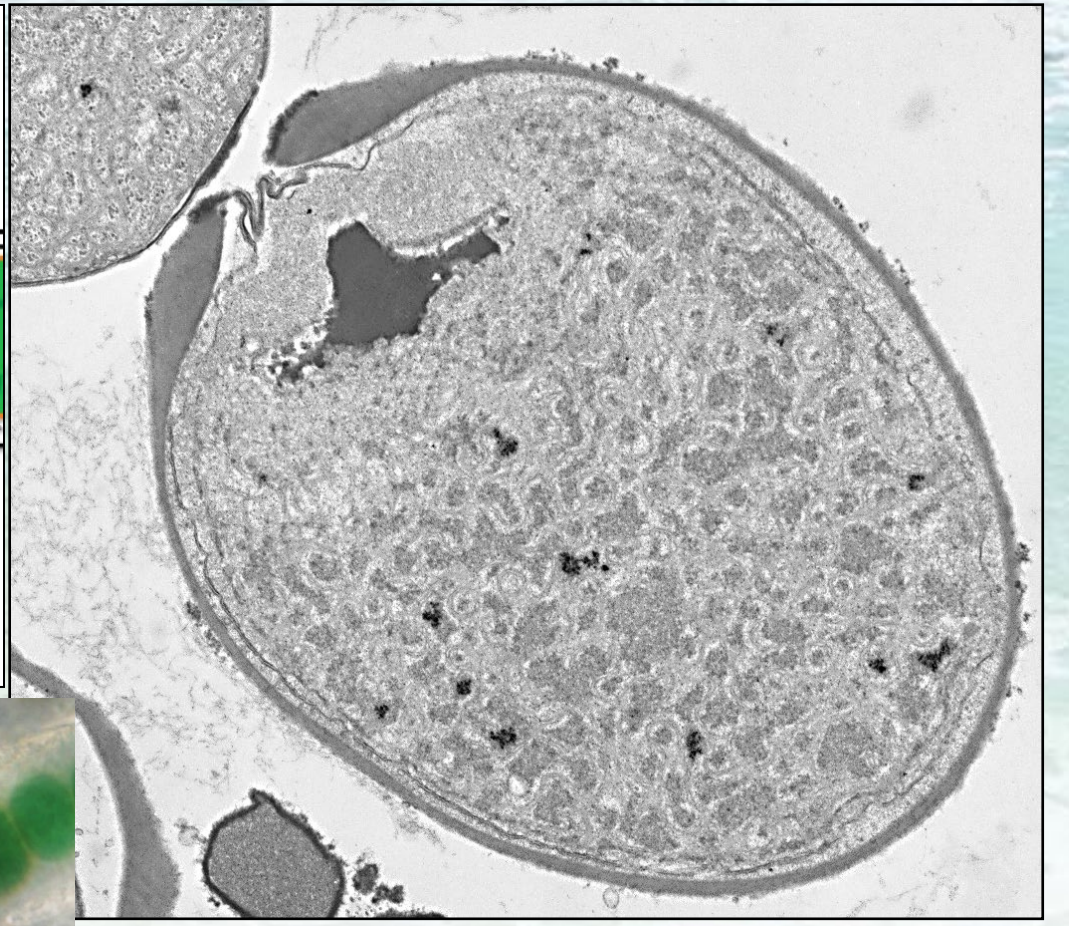
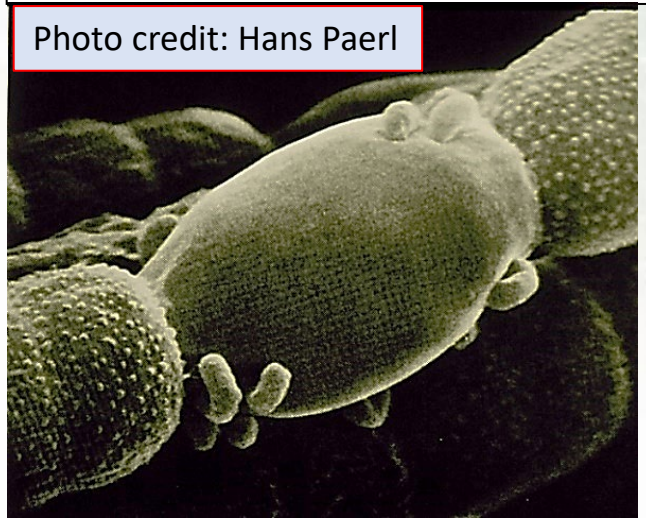
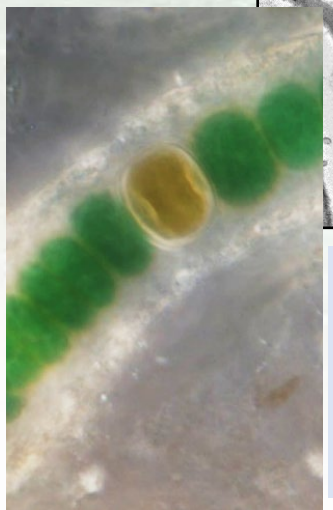


Photo credit: Hans Paerl

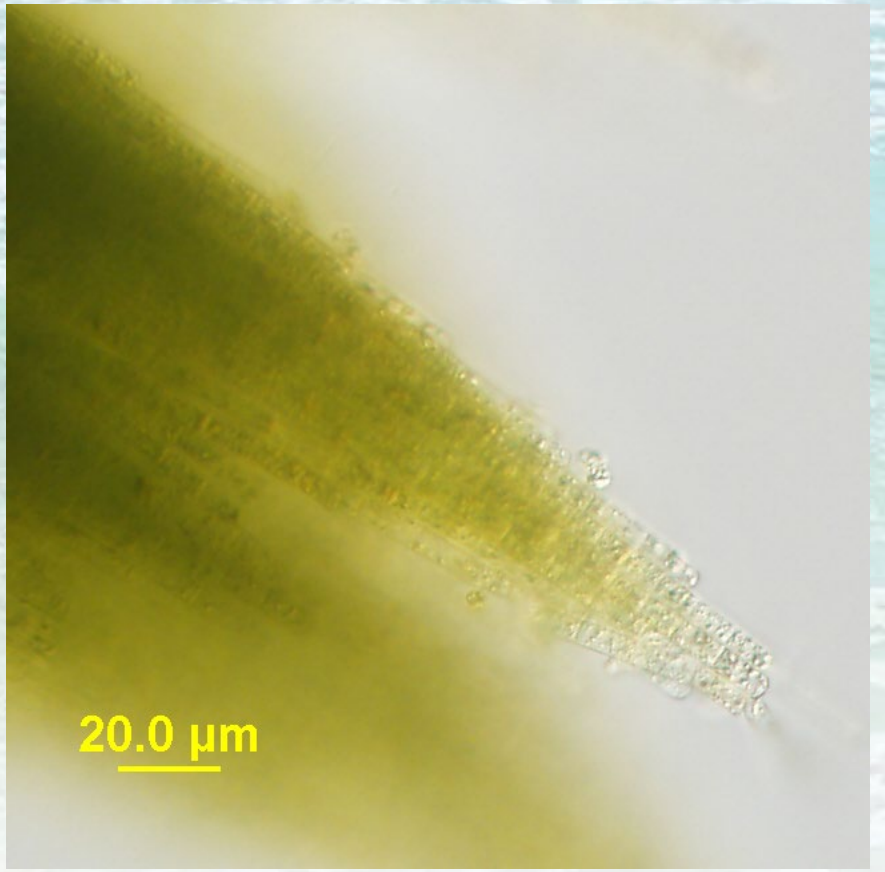


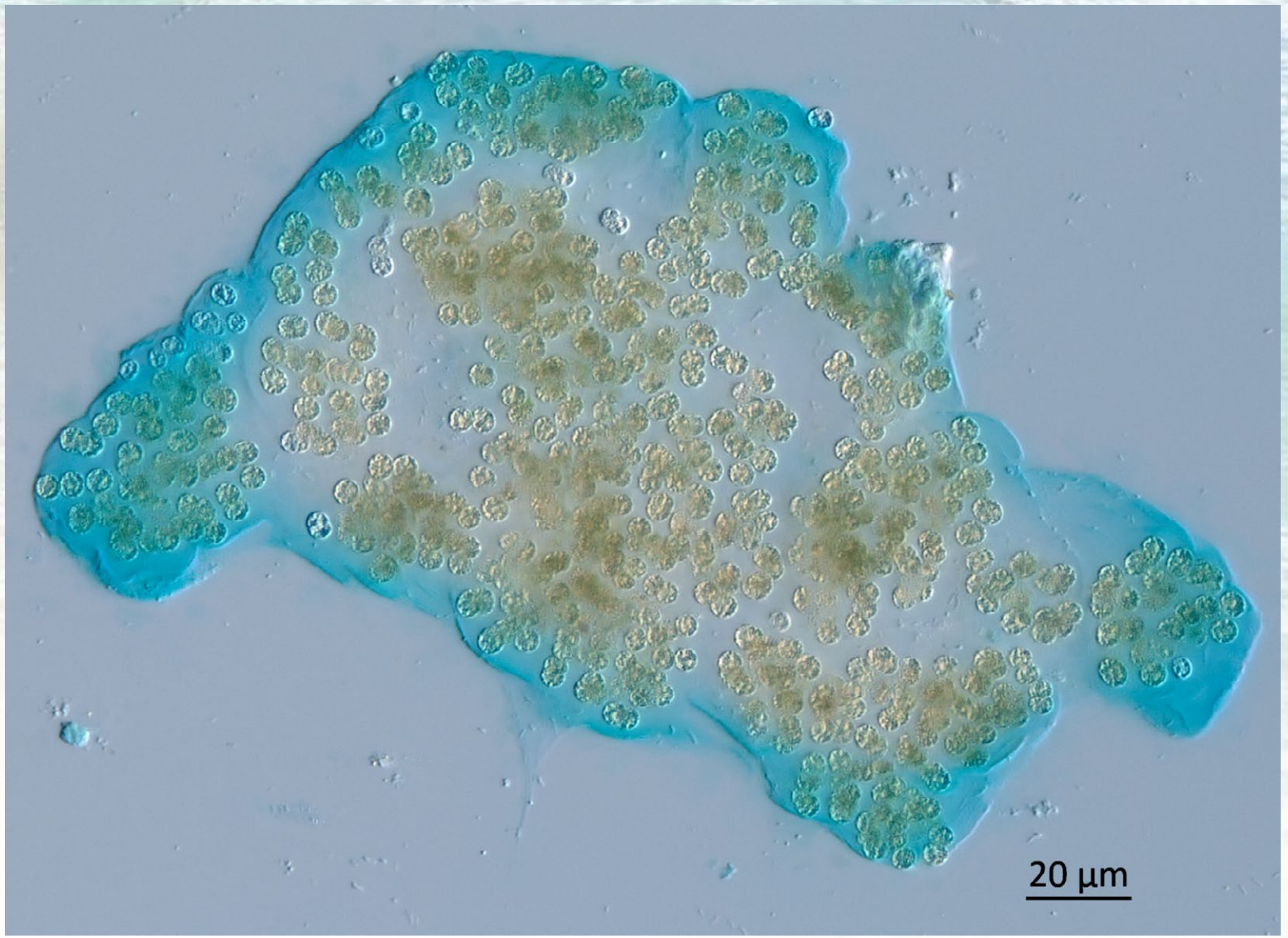


- Lipid layer around cell wall
- Loss of oxygenic-photosystem II
- Visible pigment difference

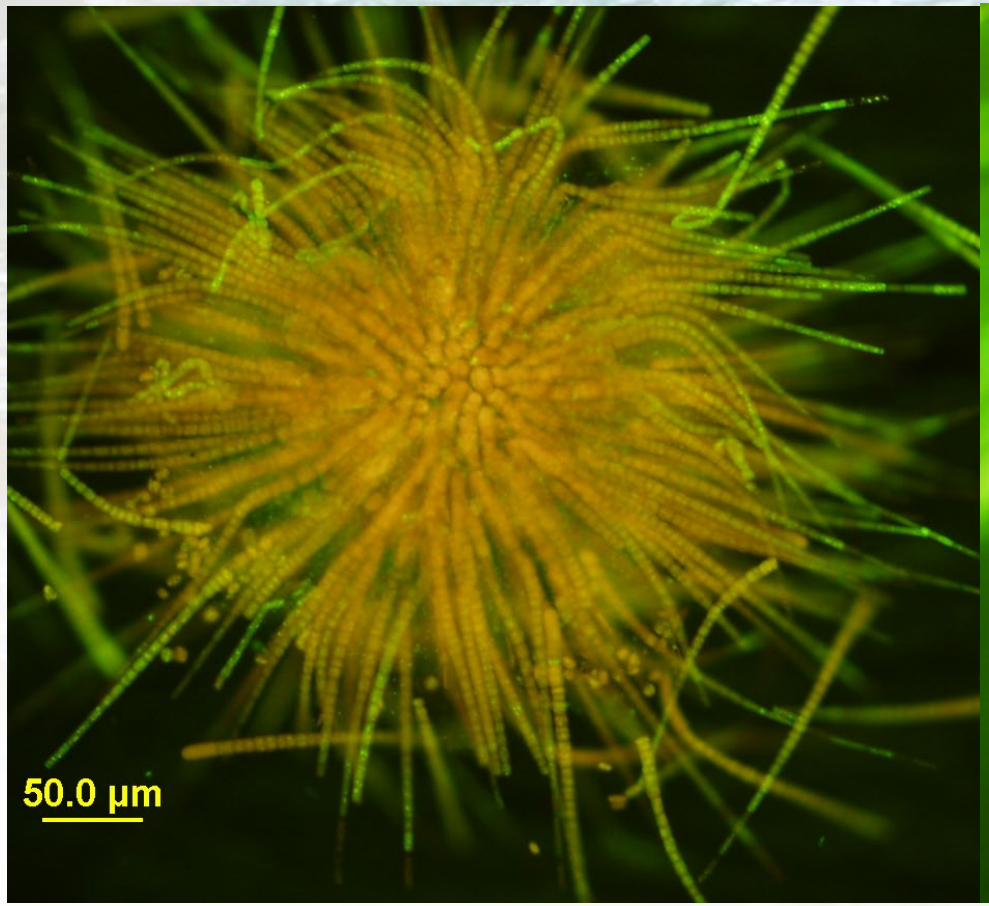
EXCEPTIONS

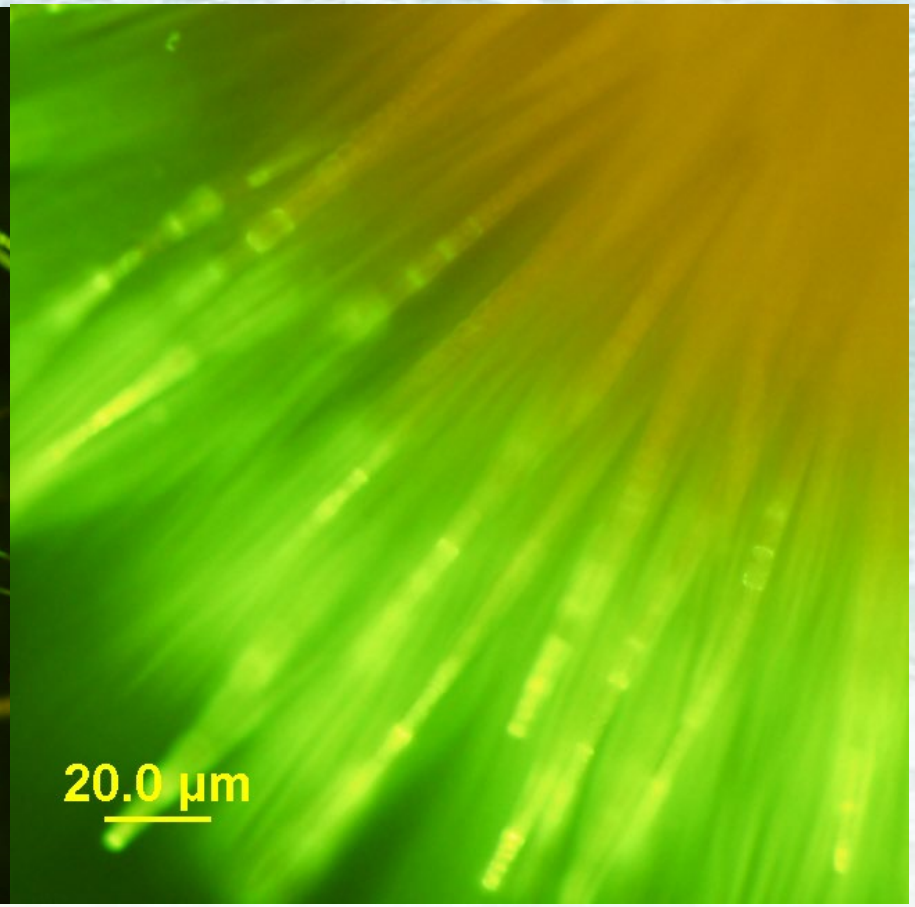
Ecological Strategies: morphology to prevent grazing



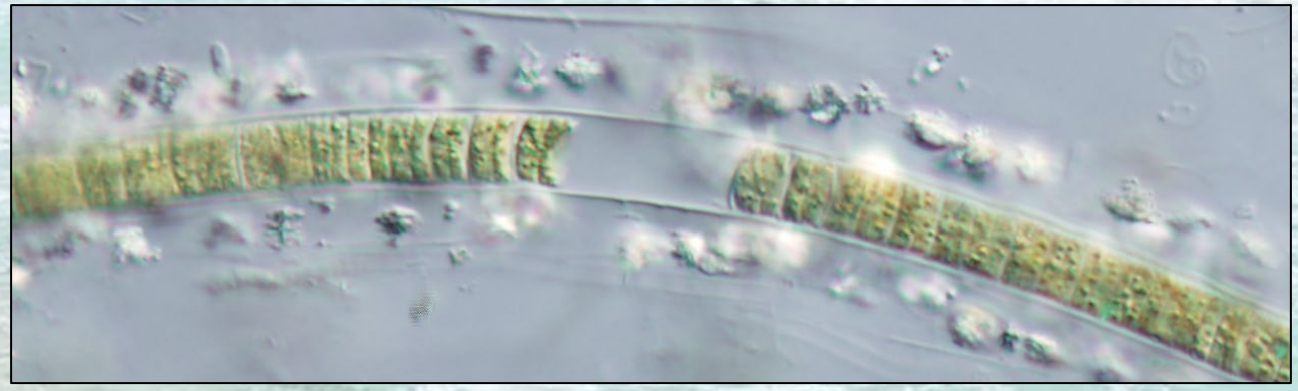

20 µm

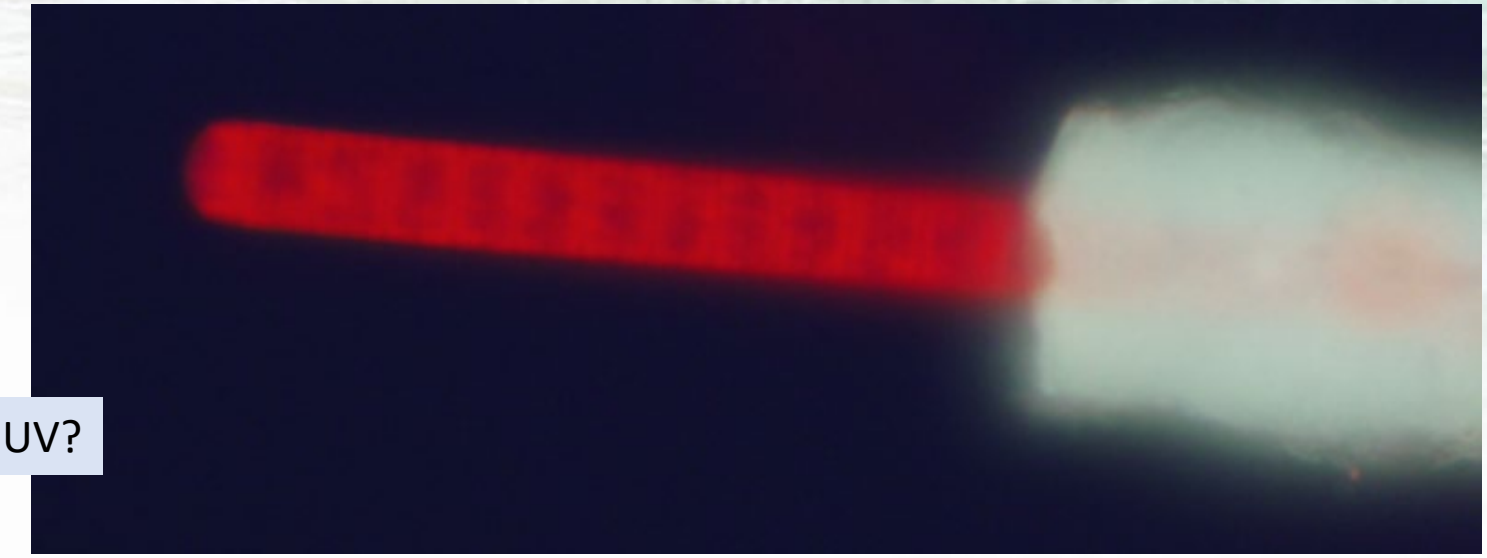
Ecological Strategies: morphology to prevent grazing





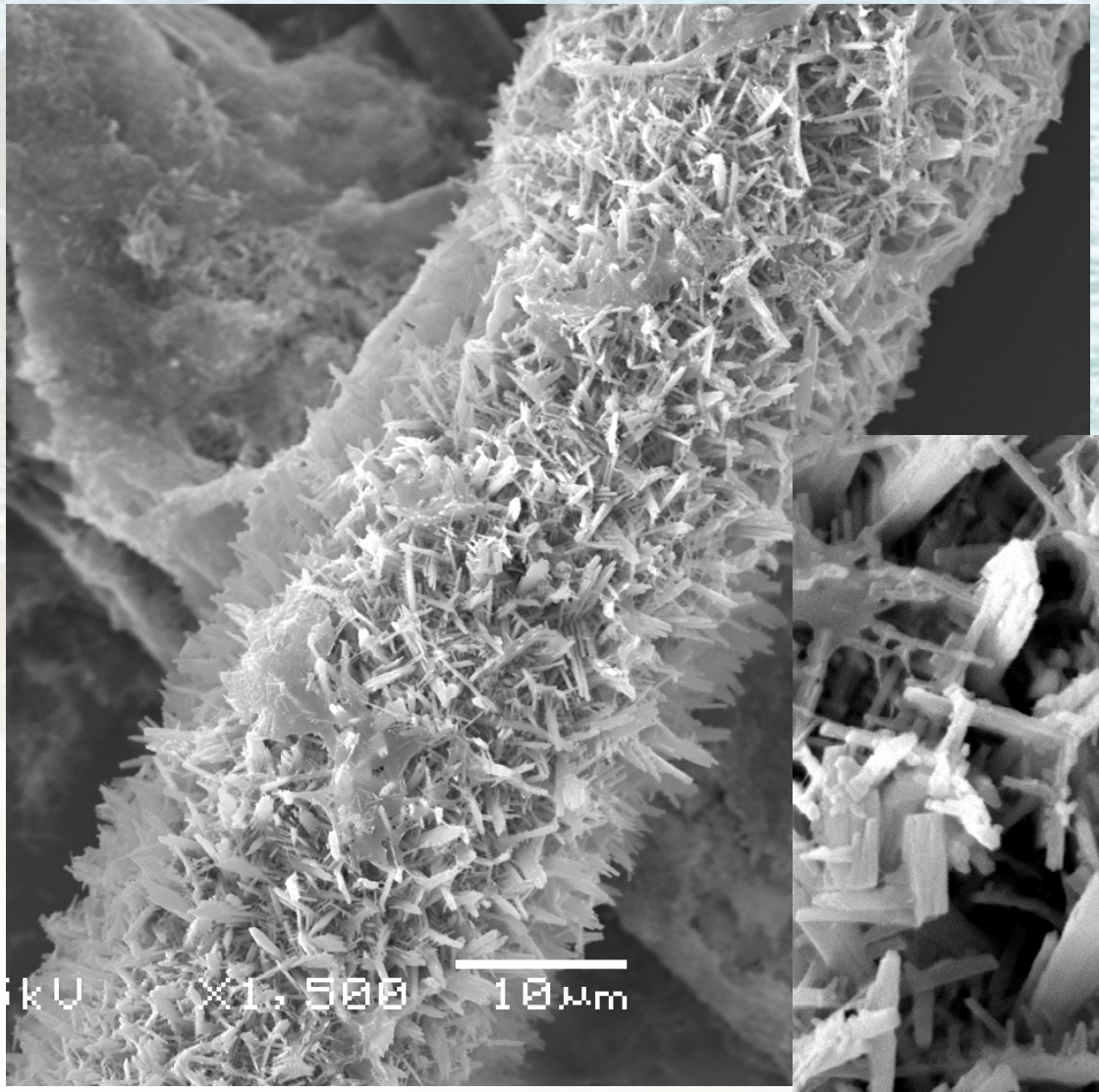
Ecological Strategies: prevent grazing benthic cyanobacteria

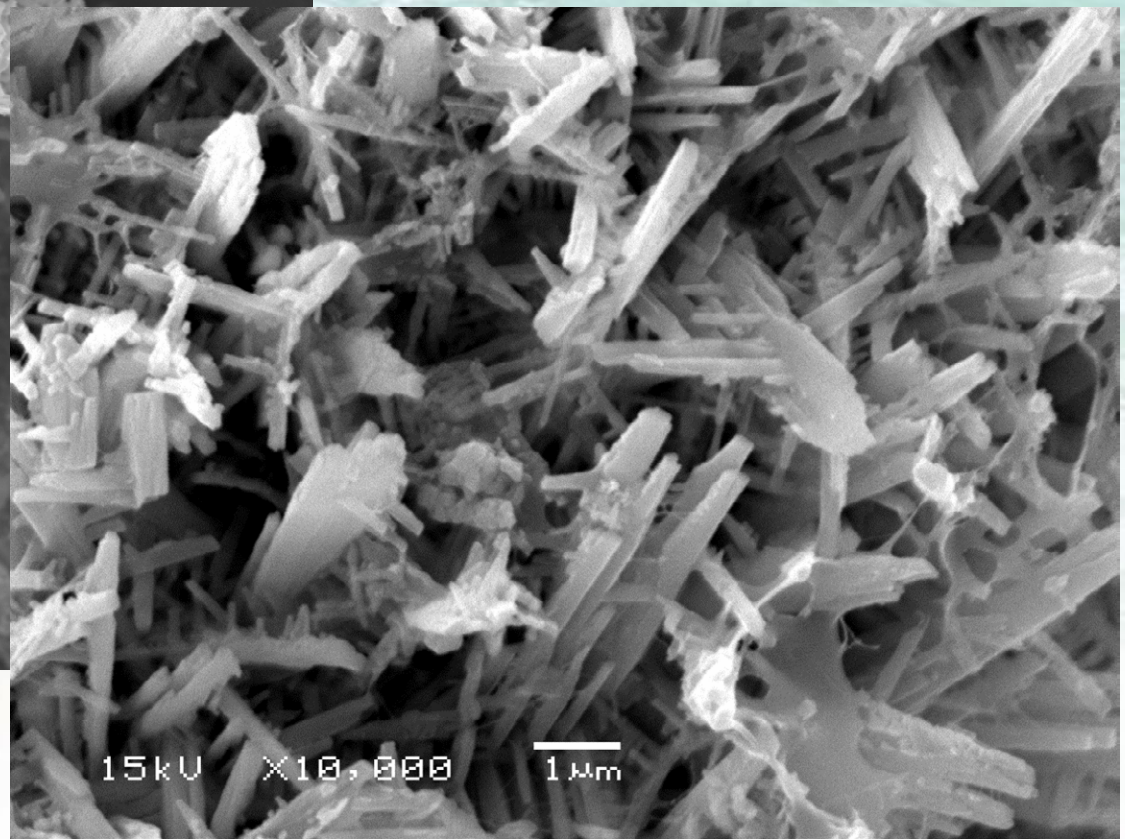




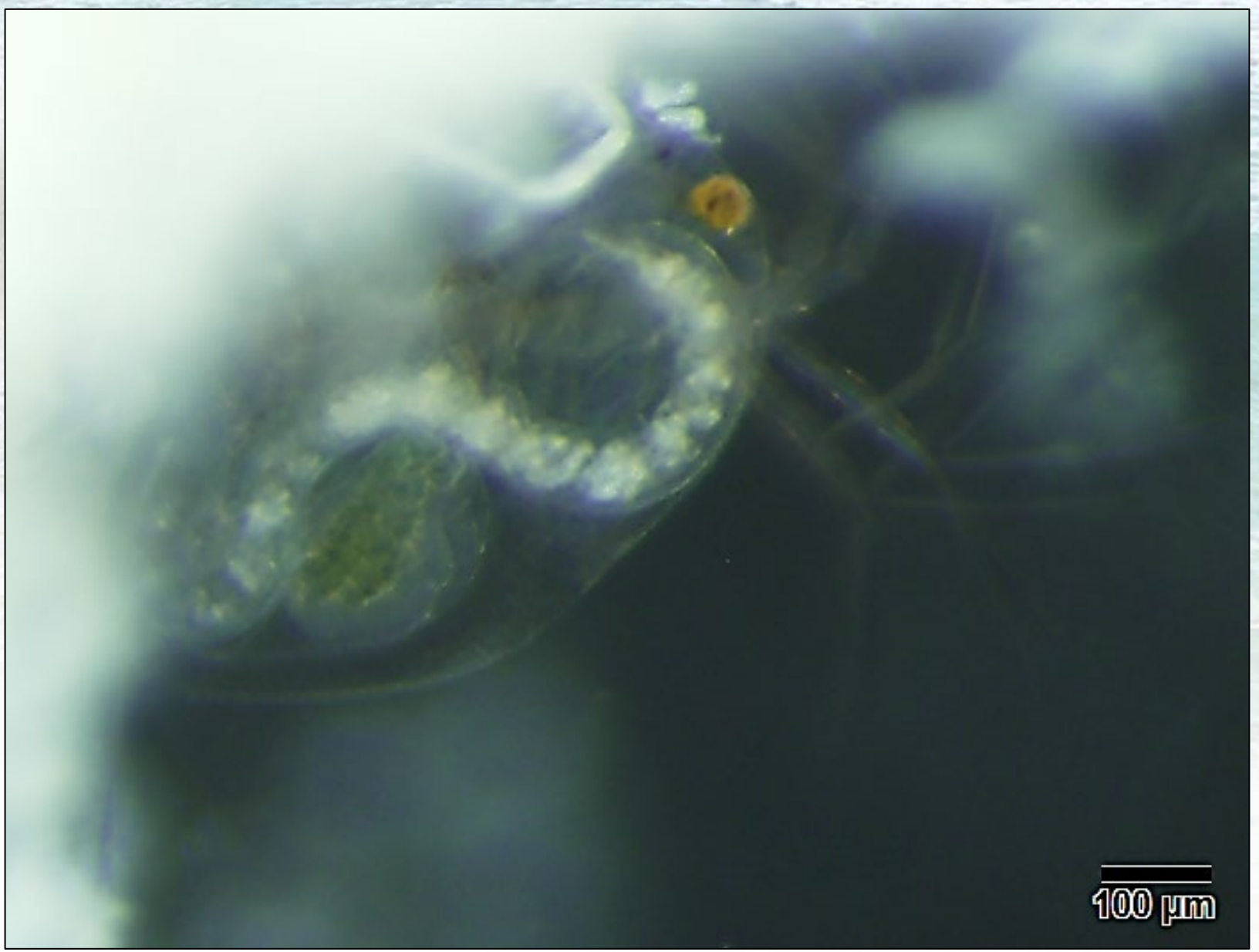
UV?

Ecological Strategies: prevent grazing benthic cyanobacteria

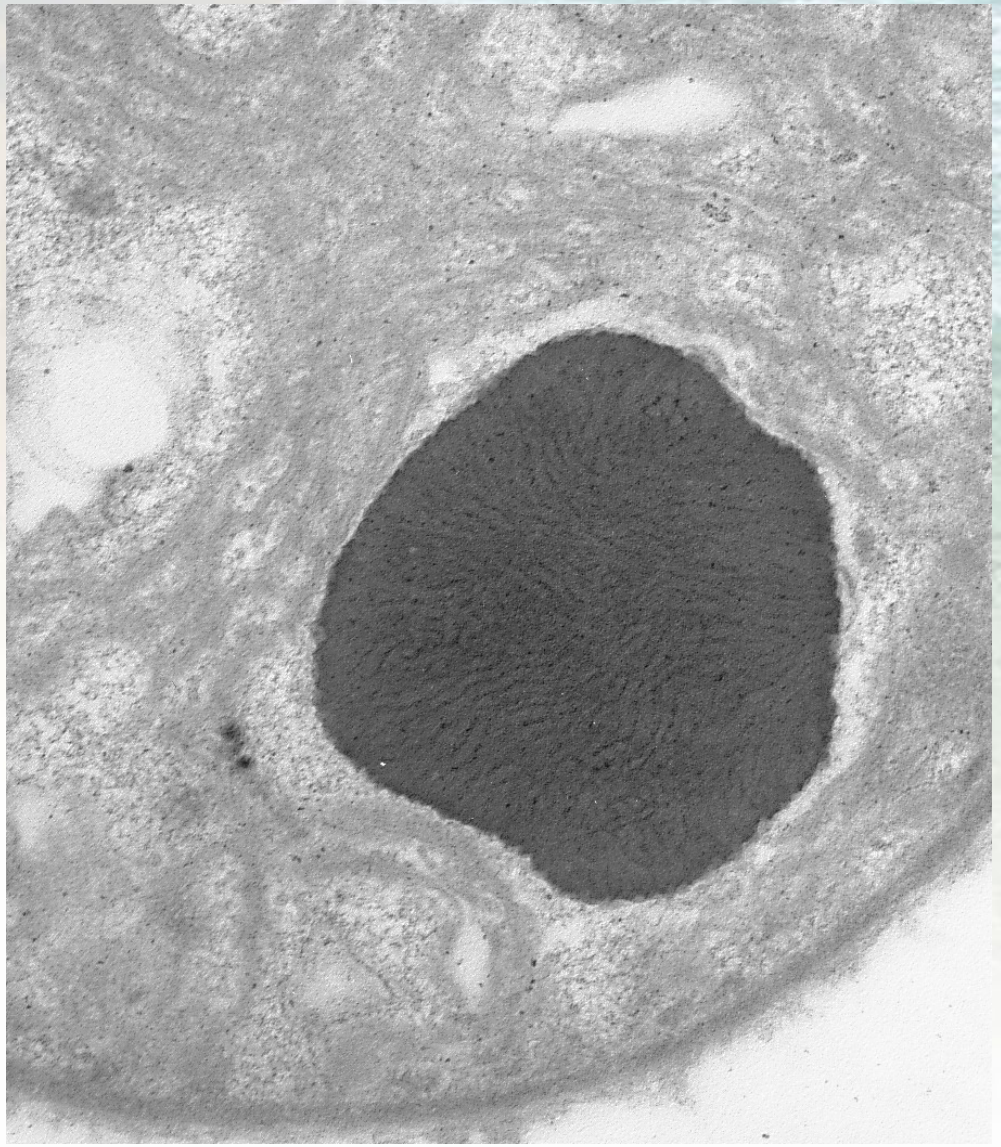




Ecological Strategies: prevent grazing benthic cyanobacteria, or not

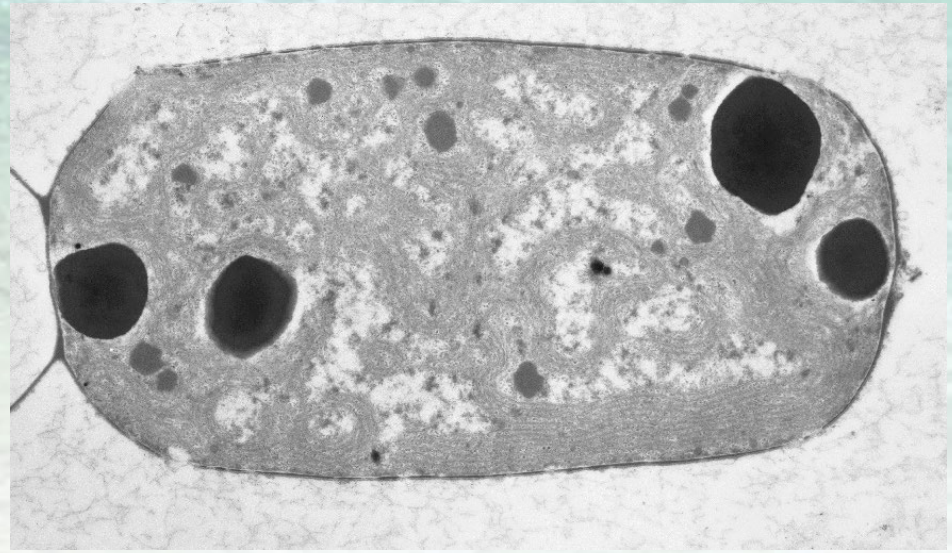


Ecological Strategies: luxuriant nutrient uptake and storage & metal sequestration



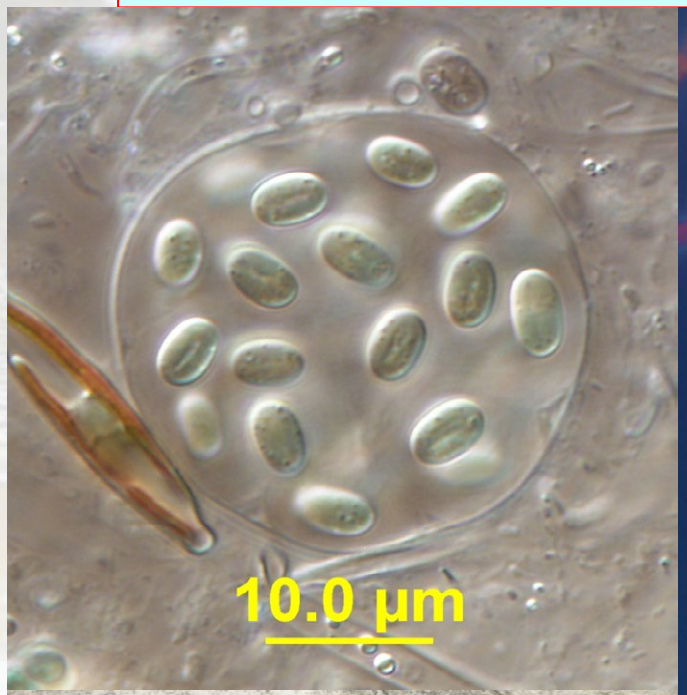
Fluctuating phosphorus availability

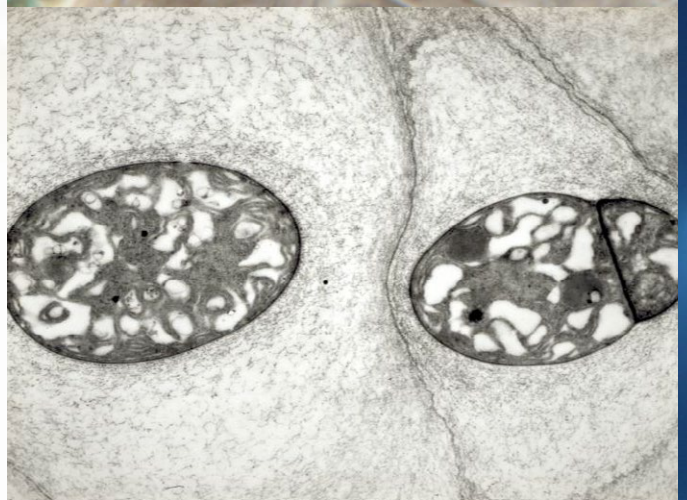
- Contain protein, lipids, polyP
- Na, Mg, Ca, K, Mn, Fe, Cu

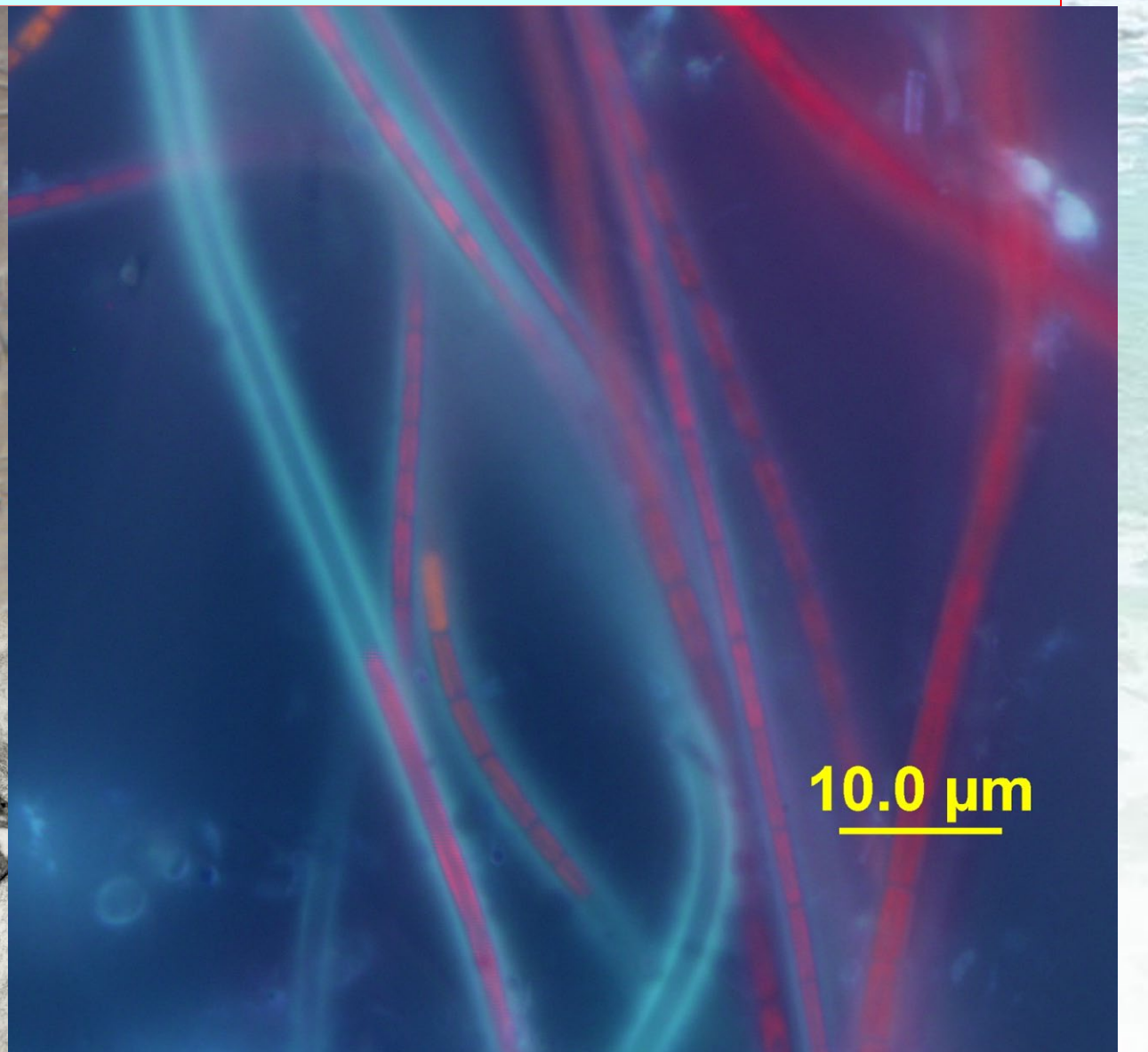


Phosphorus Feast and Famine in Cyanobacteria: Is Luxury Uptake of the Nutrient Just a Consequence of Acclimation to Its Shortage? *Cells* 2020, 9, 1933; doi:10.3390/cells9091933

Ecological Strategies: desiccation tolerant (polysaccharide sheath-often pigmented)







Ecological Strategy: cyanotoxins

- **Hepatotoxins**
  - Disrupt proteins that keep the liver functioning, may act slowly (days to weeks)
- **Neurotoxins**
  - Cause rapid paralysis of skeletal and respiratory muscles (minutes)
- **Dermatotoxins**
  - Produce rashes and other skin reactions, usually within a day (hours)
- **b-*N*-methylamino-L-alanine**
  - Neurological: potentially linked to ALS

microcystins (300+ variants)
nodularin
cylindrospermopsin

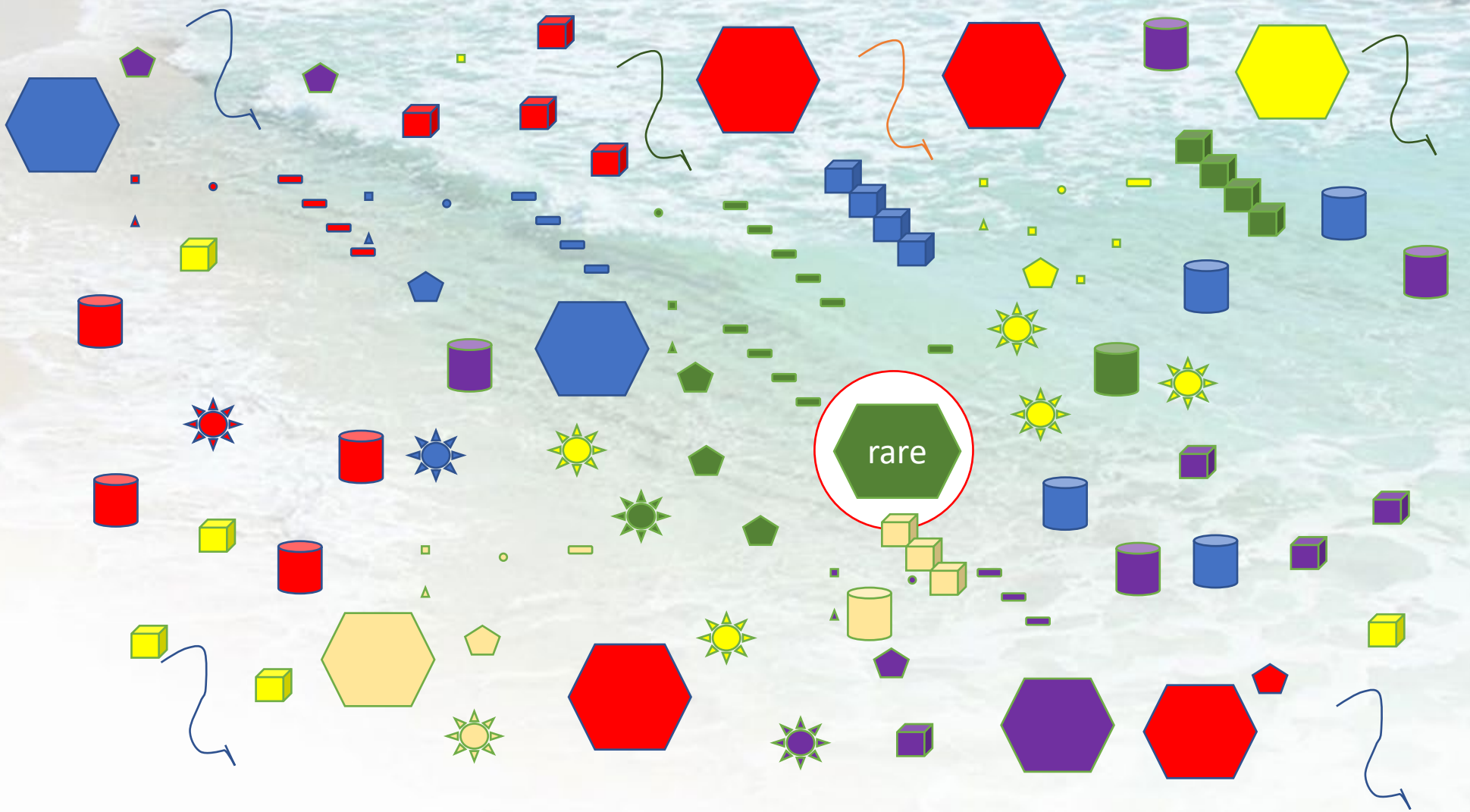
anatoxin -a
guanitoxin [anatoxin -a (s)]
saxitoxin
neosaxitoxin

lyngbyatoxin

BMAA

Paradox of the plankton

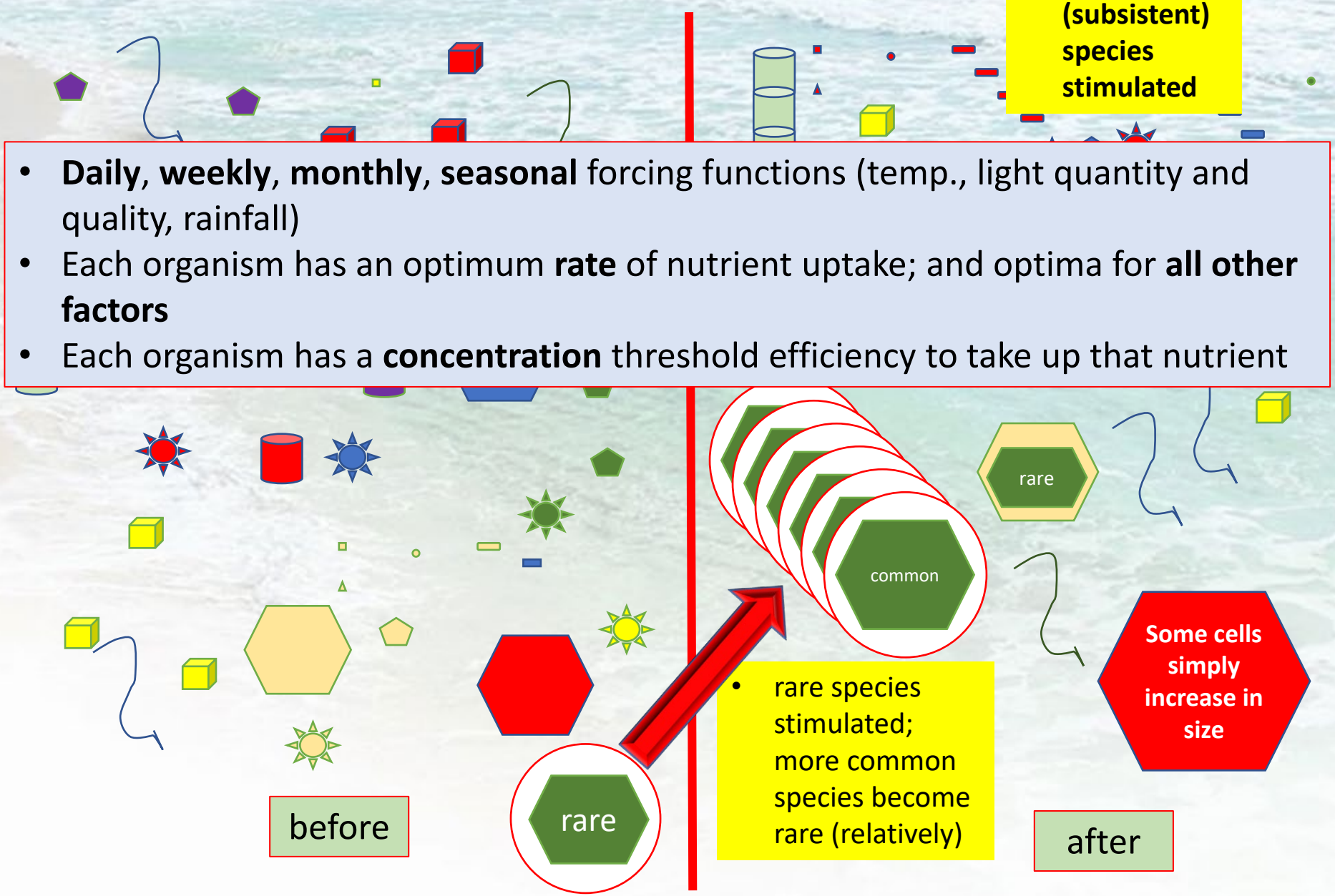
Depiction of the primary producers (algae and cyanobacteria)



Add a limiting factor

- **quiescent (subsistent) species stimulated**

- **Daily**, **weekly**, **monthly**, **seasonal** forcing functions (temp., light quantity and quality, rainfall)
- Each organism has an optimum **rate** of nutrient uptake; and optima for **all other factors**
- Each organism has a **concentration** threshold efficiency to take up that nutrient



- rare species stimulated; more common species become rare (relatively)

How do you find Cyanobacteria?

Lakes	Phytoplankton
Reservoirs	Benthic
Wetlands	
Rivers	Periphyton
Streams	Epiphytes
Moist soil	Epilithic

In the air!

Key toxin-producing organisms: a phylogenetical diverse group

Unicellular forms

Microcystis, Woronichinia

Filamentous (non-N fixers)

Lyngbya, Phormidium,
Microcoleus, Oscillatoria
Planktothrix, Microseira

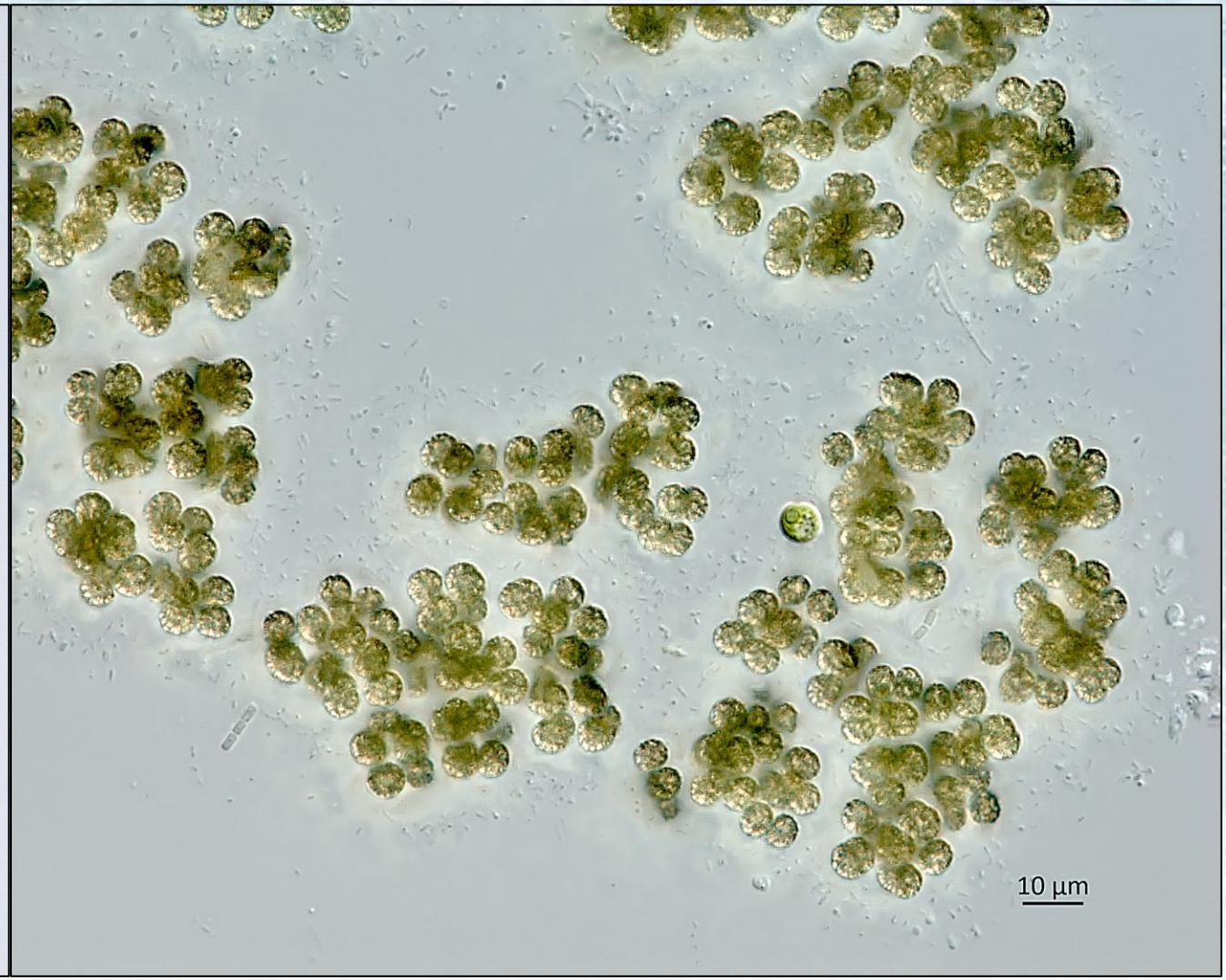
Filamentous (heterocystous)

Dolichospermum
Aphanizomenon
Raphidiopsis
Nodularia
Anabaenopsis
Cylindrospermum
Cuspidothrix, Chrysosporum

How? No sextual reproduction, how about lateral gene transfer?

Unicellular forms

Microcystis aeruginosa



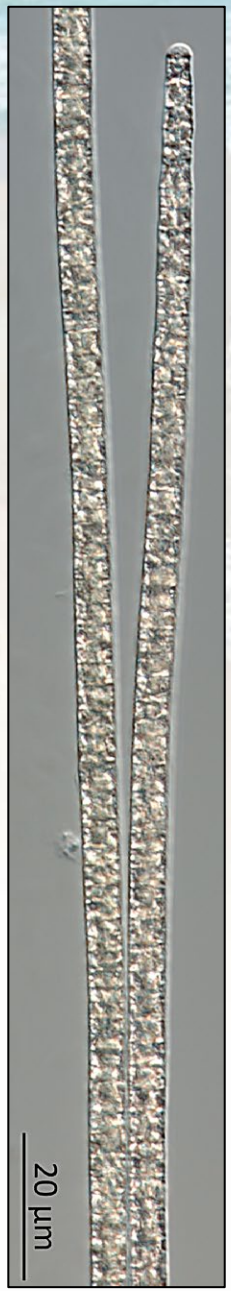
Microcystis viridis

Unicellular forms

Microcystis wesenbergii

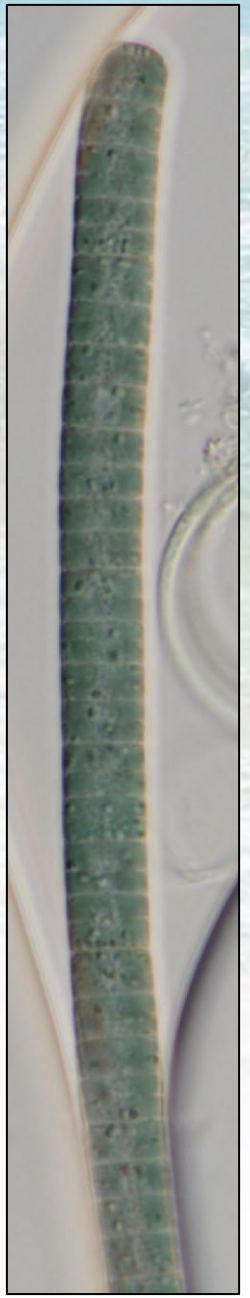
Woronichinia naegeliana

Non-Nitrogen fixing filaments

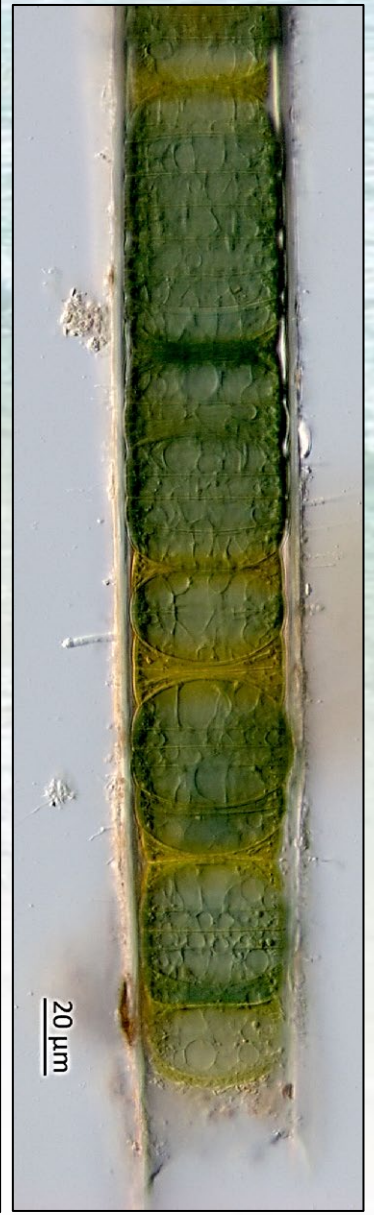


Planktothrix

Oscillatoria

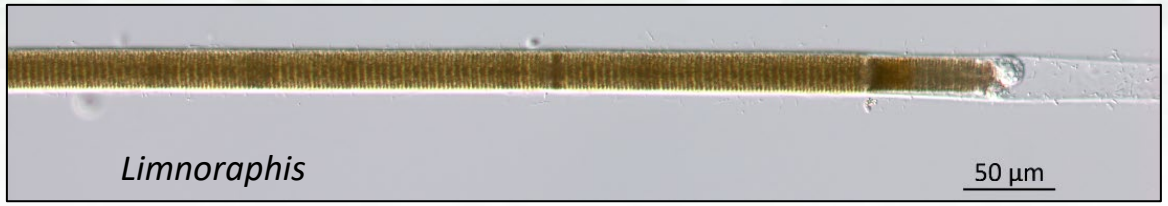


Phormidium



Microseira

Lyngbya



Morphology 3: Nostocales (have heterocytes)

Heterocytes

- A differentiated cell that has the specific function of atmospheric nitrogen (N_2) fixation
- **Identification of a genus or species:**
  - **Size relative to the filament**
  - **Intercalary vs. terminal**
  - **Site of false branching**
  - **Position relative to the akinetes**
- **They can also be a resting stage and germinate**

Morphology 3: Nostocales

Akinetes

An akinete is an enveloped, thick-walled, non-motile, dormant cell formed by filamentous, heterocyst-forming cyanobacteria. **Akinetes are resistant to cold and desiccation**.

Triggered by season, bloom stage and nitrogen availability

Morphology 3: Nostocales

Akinetes

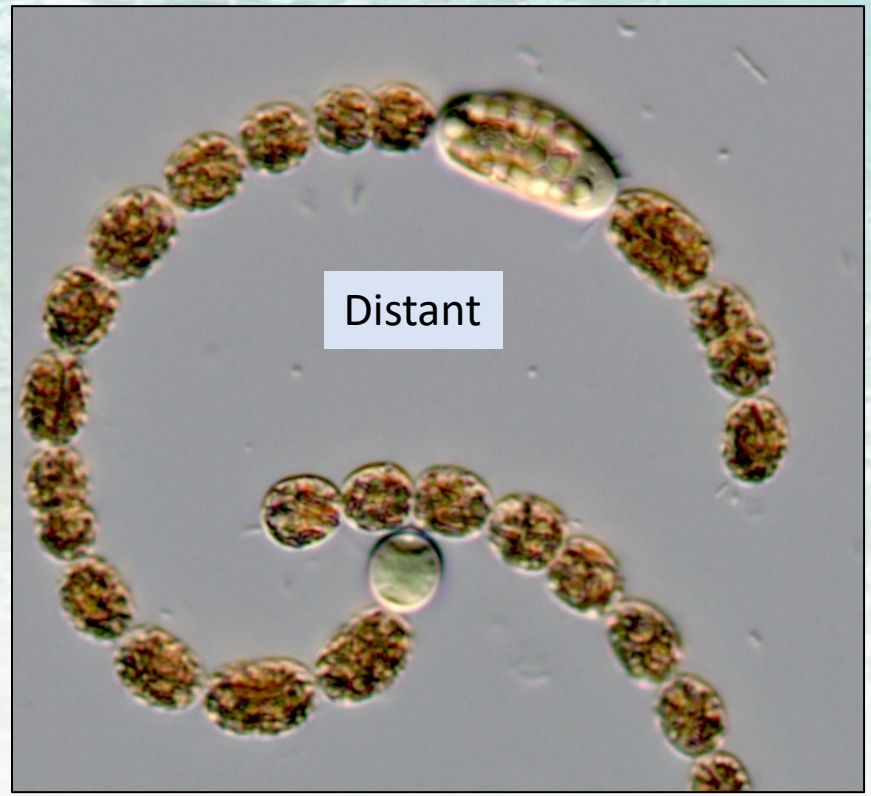
- **Identification of a genus or species:**
  Shape

Morphology 3: Nostocales

Akinetes

- **Identification of a genus or species:**
  Relative position from the heterocyte

Adjacent



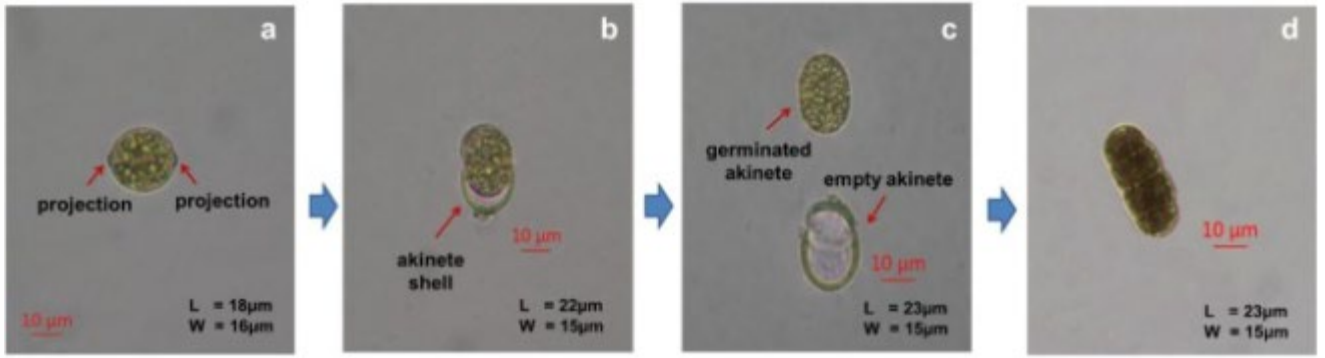
Morphology 3: Nostocales

Akinetes

- **Identification of a genus or species:**
  Relative position from the heterocyte

Morphology/Ecology: Nostocales

Akinetes: Germination



Morphology 3a: Filaments

Nostocales (have heterocytes)

unbranched

branched

tapered trichome?

true vs. false branching

heterocyte location

akinete shape and location

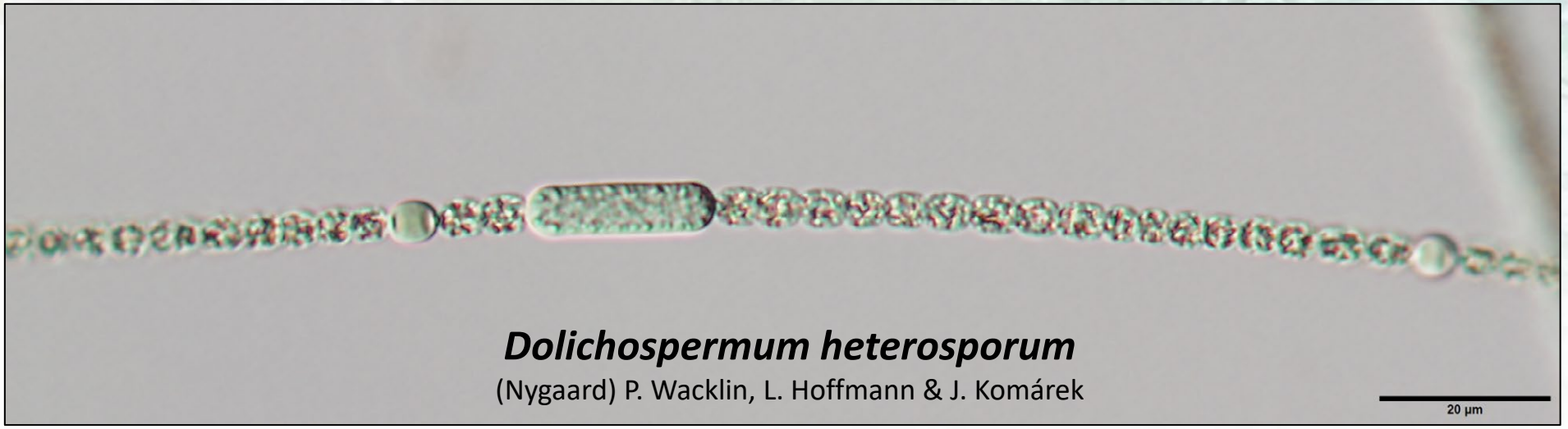
planktonic vs. benthic

Planktonic

(gas vesicles/aka aerotopes)

Dolichospermum

(in 2009 renamed-prior name was *Anabaena*)



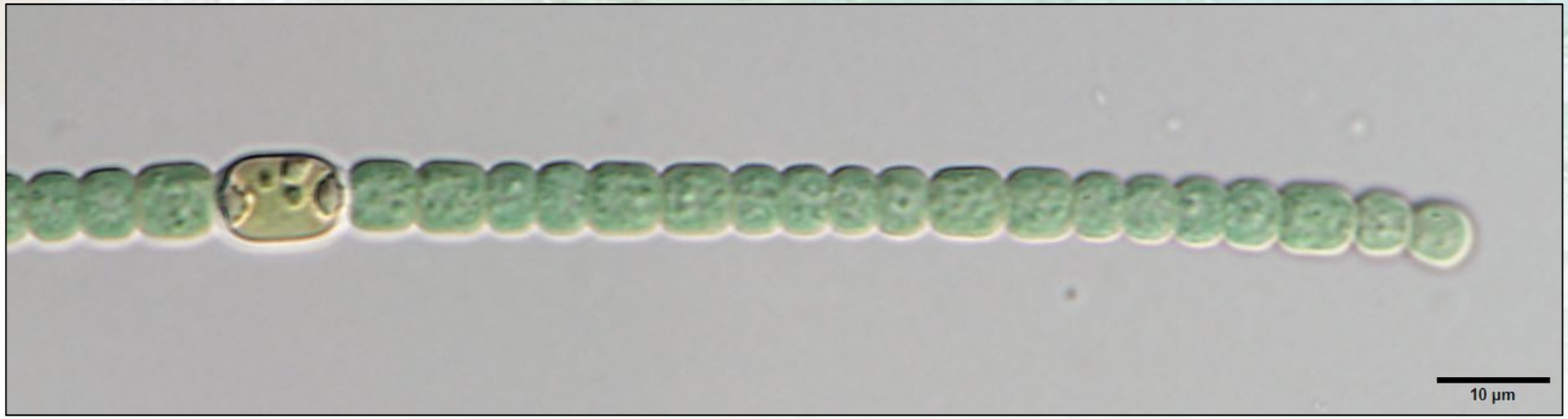
Dolichospermum heterosporum

(Nygaard) P. Wacklin, L. Hoffmann & J. Komárek

Benthic

(no gas vesicles)

Anabaena/Trichormus

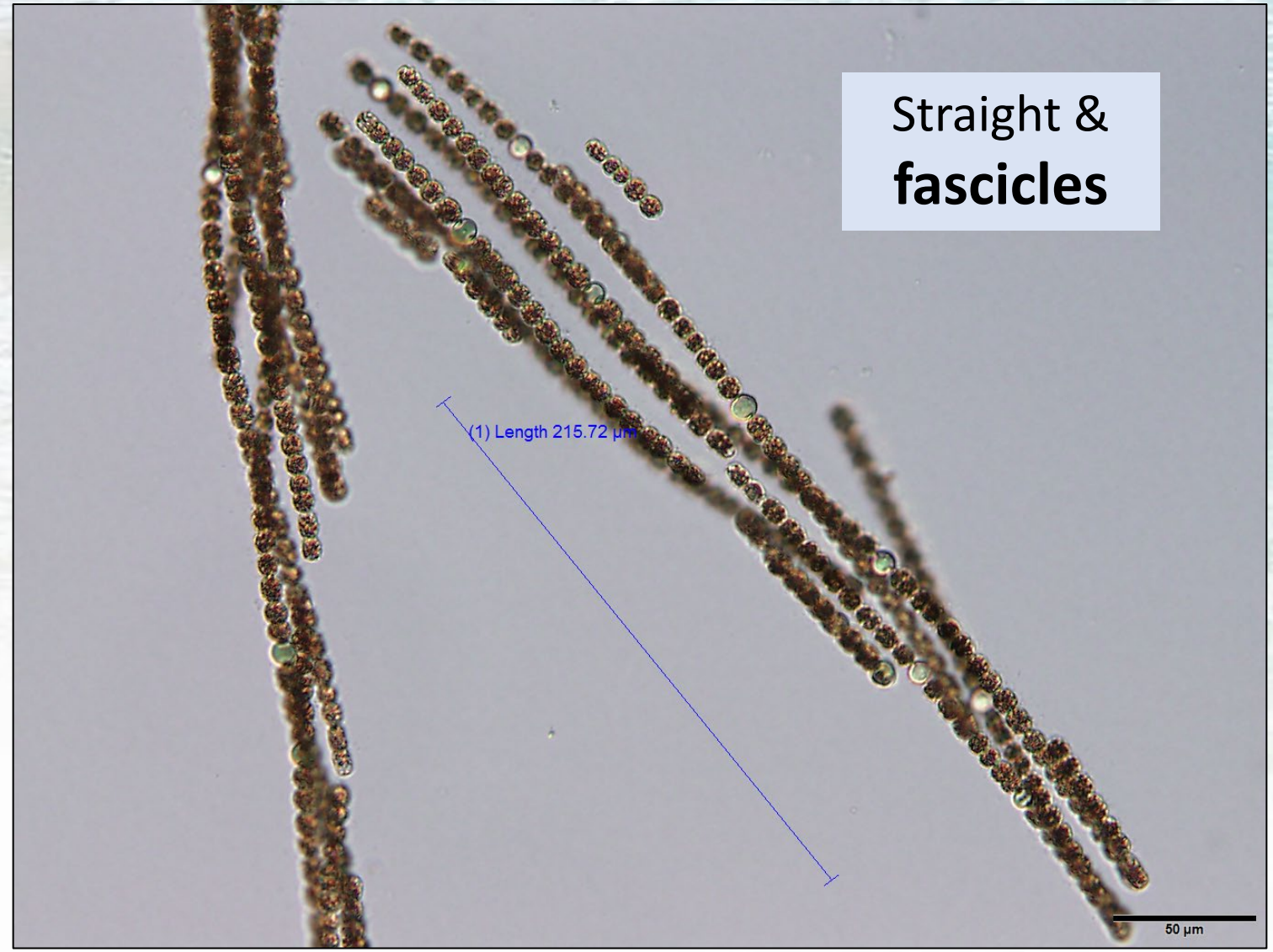


1a. Trichomes irregularly or screw-like coiled……..2
1b. Trichomes straight or slightly flexuous…. 17
2a. Vegetative cells spherical, akinetes spherical or elongated……3
2b. Vegetative cells slightly elongated, barrel-shaped up to cylindrical; akinetes always elongated……..12
3a. Trichomes densely and regularly screw-like coiled (almost touching one another, usually long and with width of spirals 11-16 mm; akinetes widely oval to almost spherical, 8-12 x 7-11 mm. ***D. compactum***
3b. Trichomes not very densely and regularly screw-like coiled (if regularly coiled, then coils do no touch densely one to another and
occur in part of the population usually forming irregular cluster ……4
4a. Akinetes elongated……..5
4b. Akinetes spherical; trichomes enveloped by colorless mucilaginous envelop ***D. mucosum***
5a. Akinetes widely cylindrical with widened exospore, 18-30 x 8-13 mm; trichomes 5-10 mm wide…… ***D. berezowskii***
5b. Akinetes without widened exospore……..6
6a. Akinetes (mature) widely ellipsoid or oval, sometimes slightly arcuated (kidney-shaped), maximally 2 x longer than wide……..7
6b. Akinetes (mature) cylindrical with rounded ends, always 2 x or more longer than wide……..11
7a. Filament mostly irregularly coiled; the width of the coils mostly 68-120 mm ……8
7b. Filaments often regularly, screw-like coiled, only with facultative irregularities; coils mostly not wider than 70 mm. ……..9
8a. Trichomes (2.5) 4-7 (8.3) mm wide; akinetes kidney-shaped, 12-35 x 5-14 mm…… ***D. flosaquae***
8b. Trichomes (7) 8-11 mm wide; akinetes ellipsoidal up to cylindrical, 12.5-42 x 9-21 mm …***D. circinale***
9a. Trichomes mostly less than 10 mm wide (5.8-10 mm);in screw-like coiled trichomes numerous irregularities…. 10
9b. Trichomes mostly more that 10 mm wide (8-15 mm); coiling regular screw-like, only exceptionally with irregularities ……..***D. crassum***

Straight *Dolichospermum*

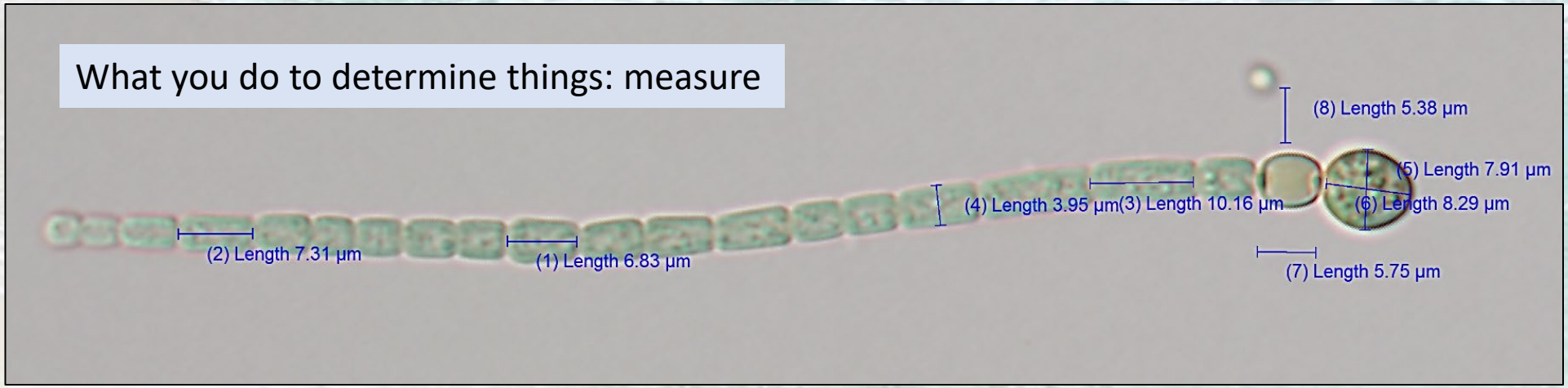
Akinete shape, size

Straight *Dolichospermum*



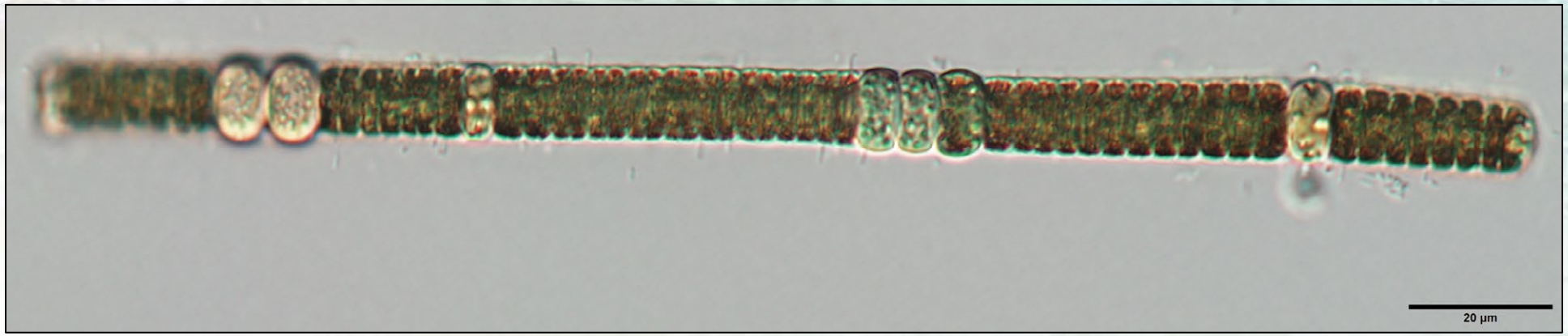
Macrospermum

What you do to determine things: measure

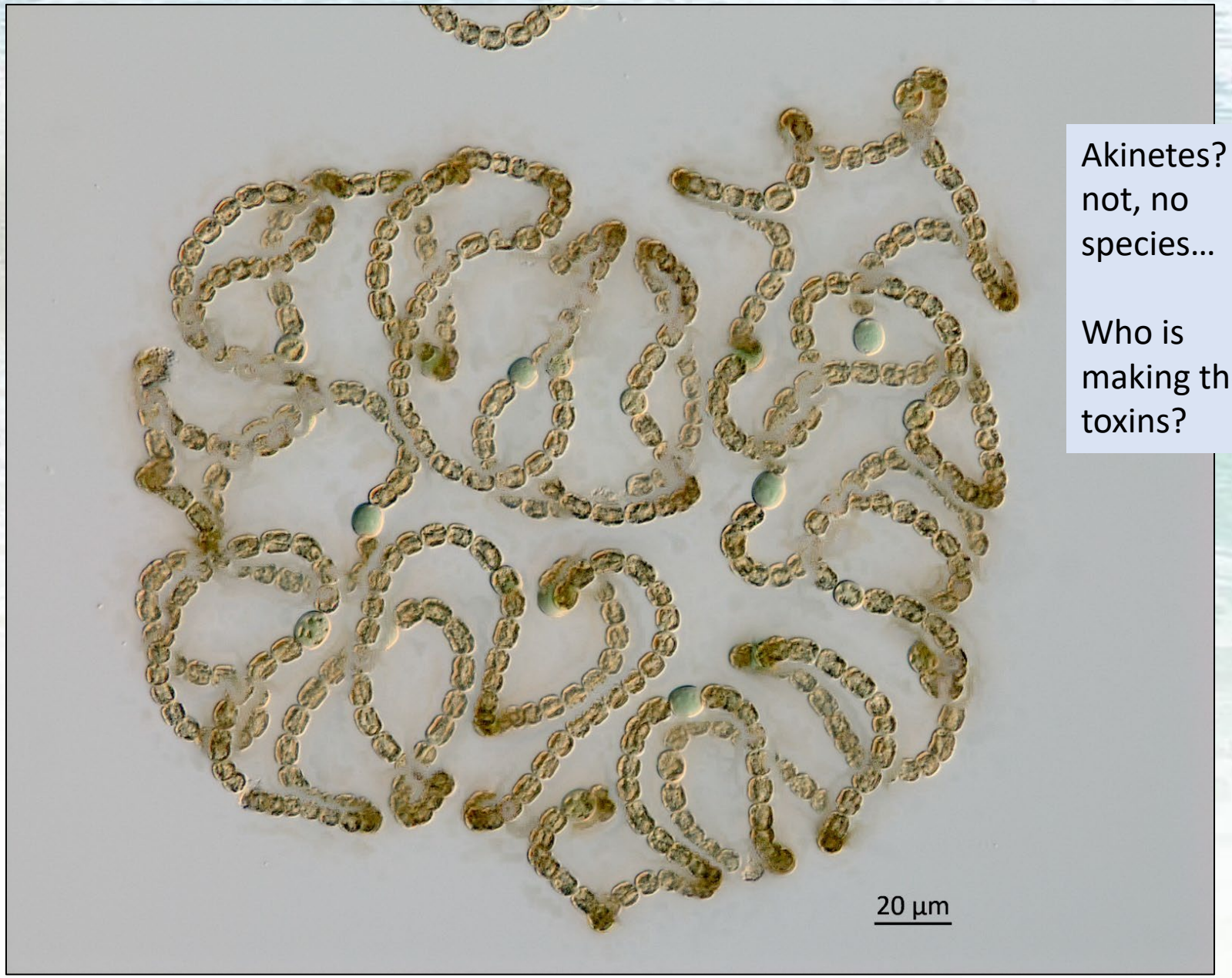


Nodularia

Nodularia spumigena



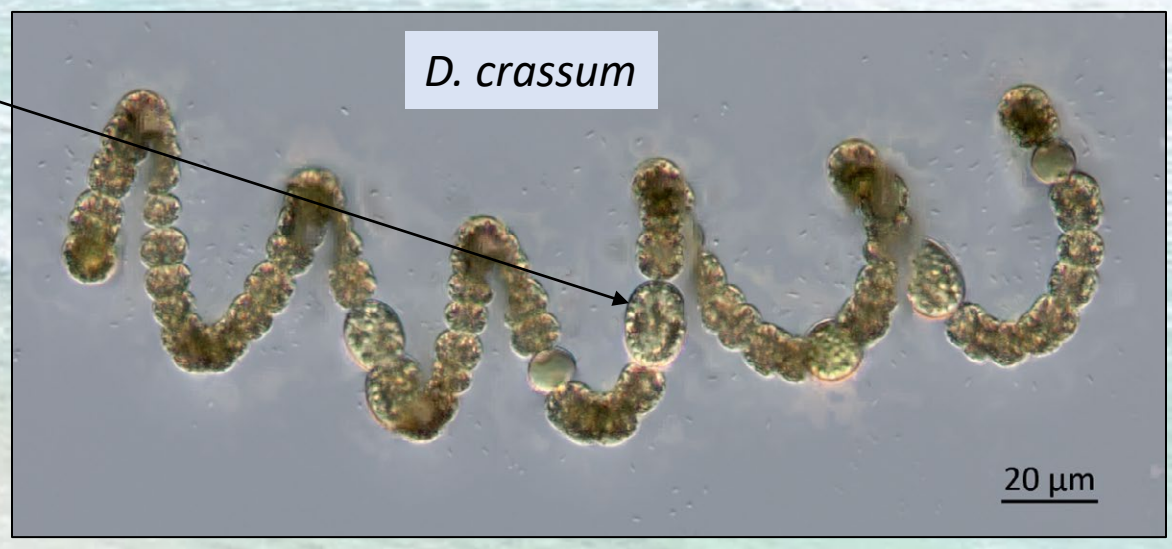
Coiled *Dolichospermum*



Akinetes? If not, no species…

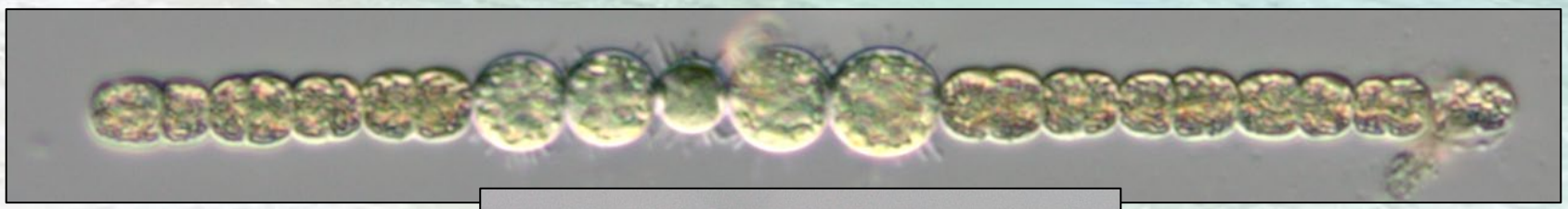
Who is making the toxins?

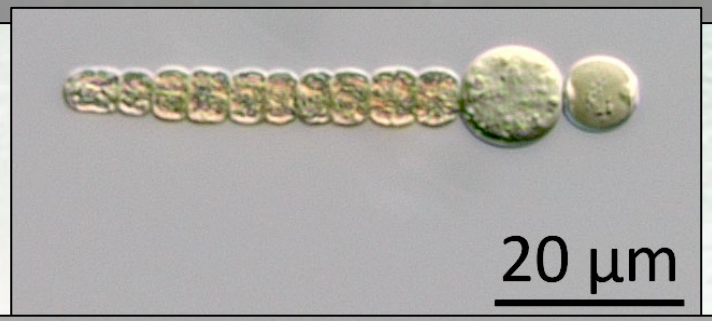
Coiled *Dolichospermum*



Sphaerospermopsis

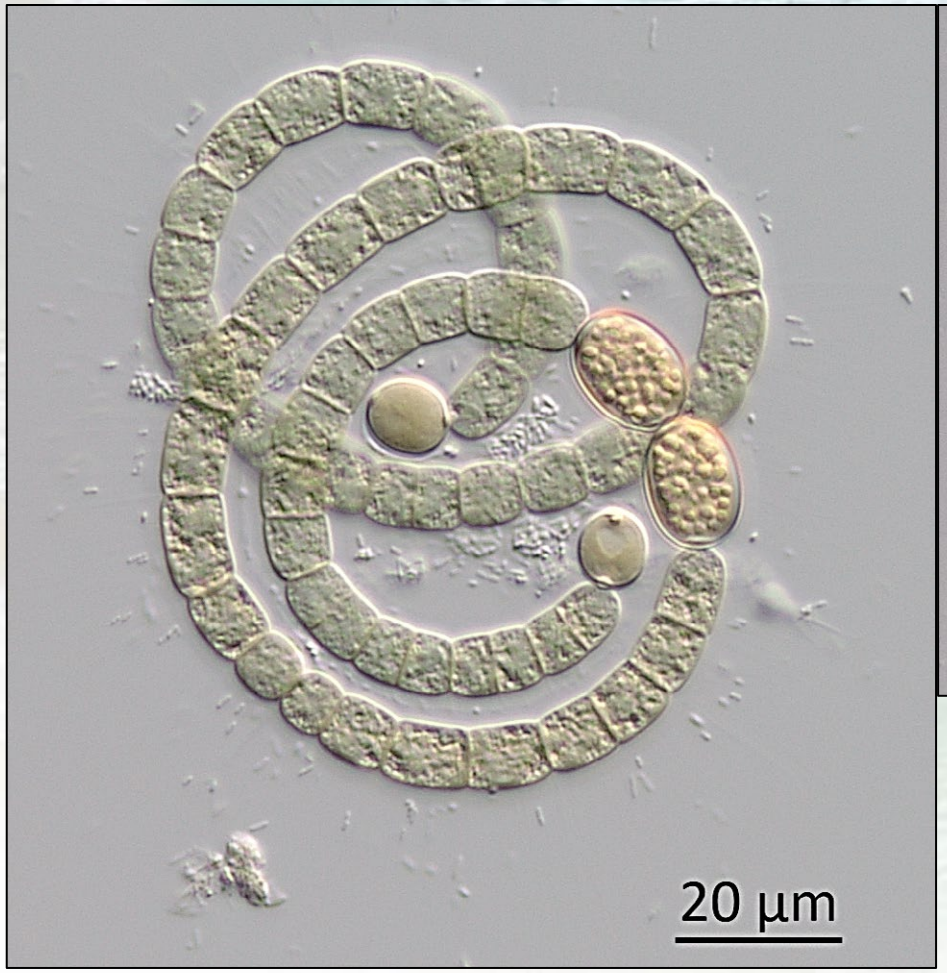
- Coiled or straight
- Akinete position relative to heterocyte (adjacent)
- Round akinetes
- Population to ID
- salinity

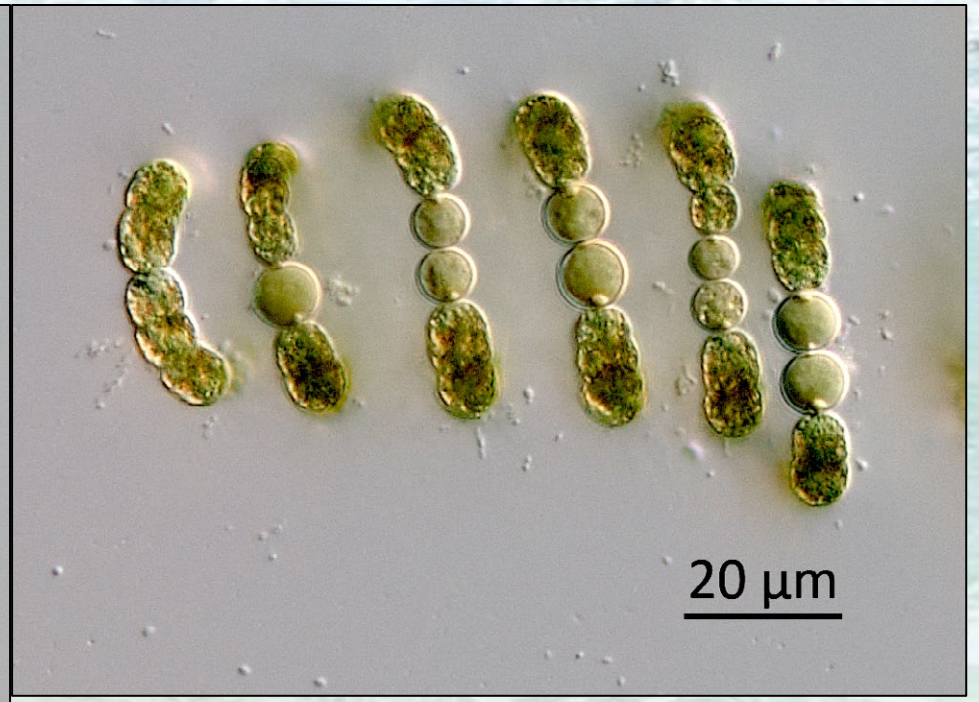




- population

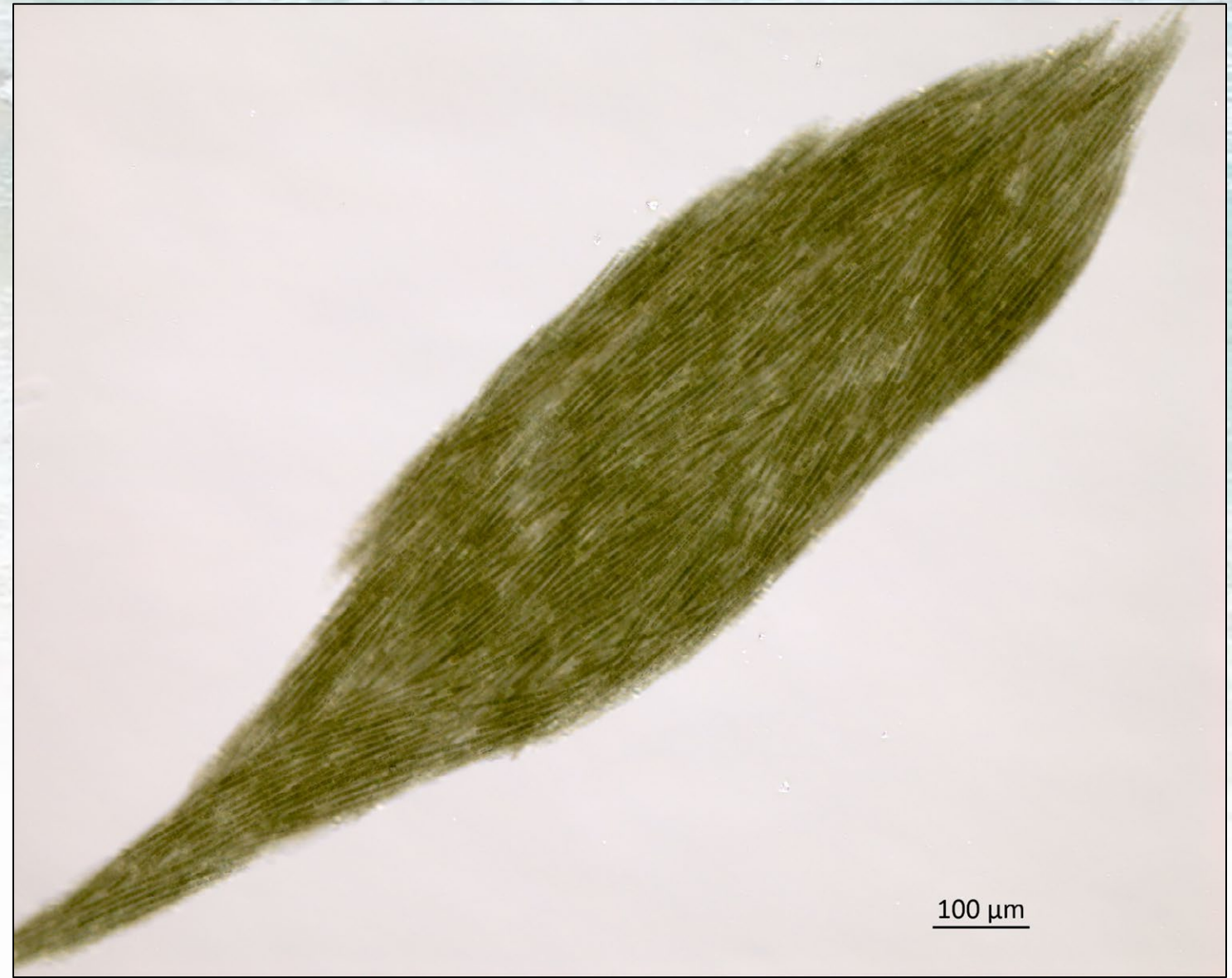
Anabaenopsis



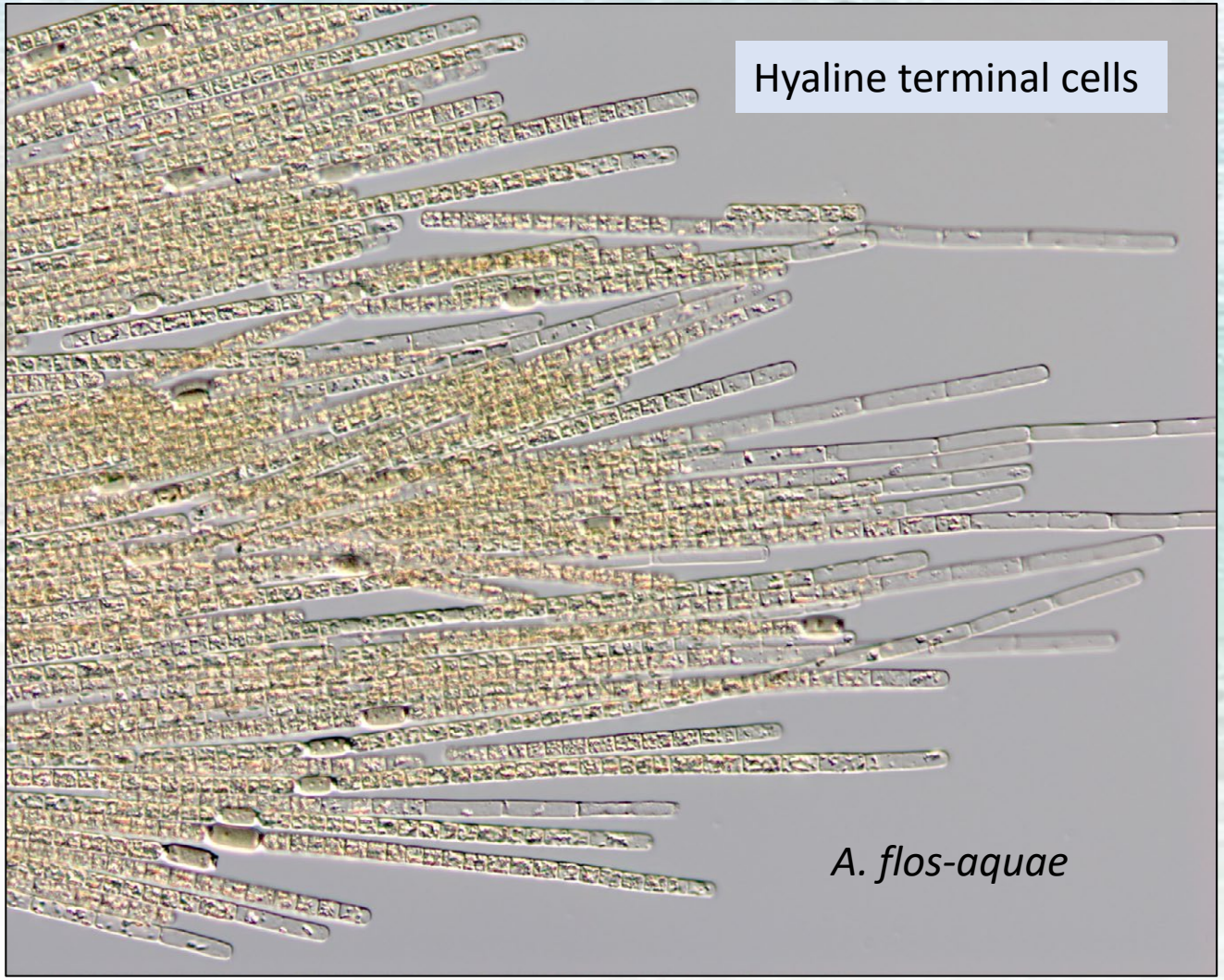


- Heterocytes terminal on both ends
- As filaments grow, two heterocytes may look adjacent
- salinity

Fascicles (bundles)
***Aphanizomenon flosaquae* (AFA)**

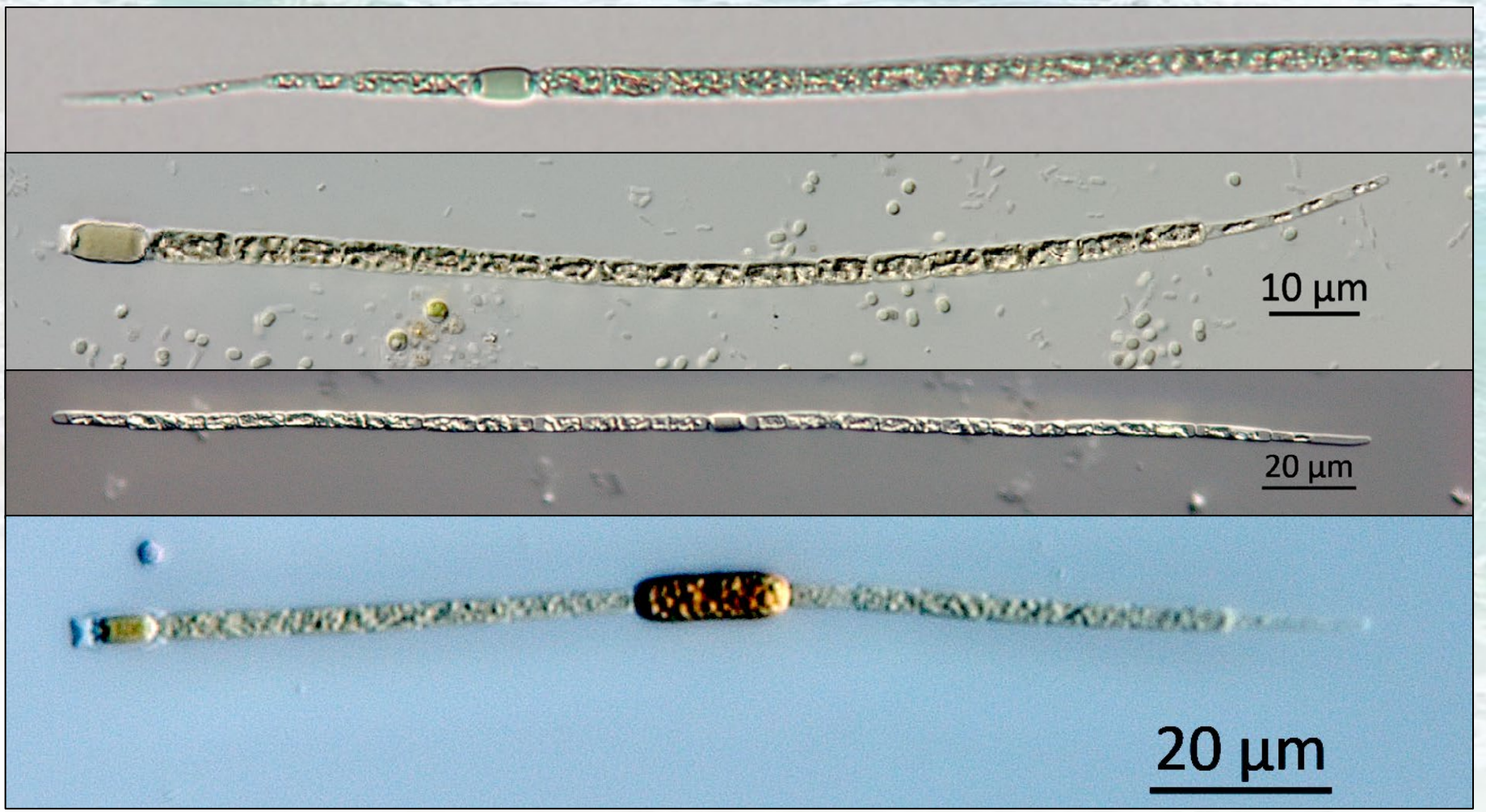


Aphanizomenon

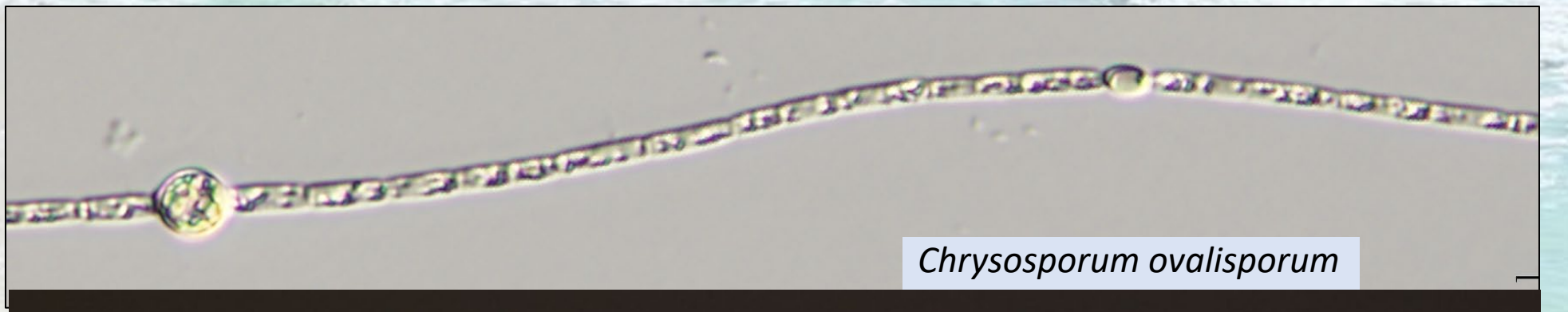


A. gracile

Cuspidothrix



Chrysosporum

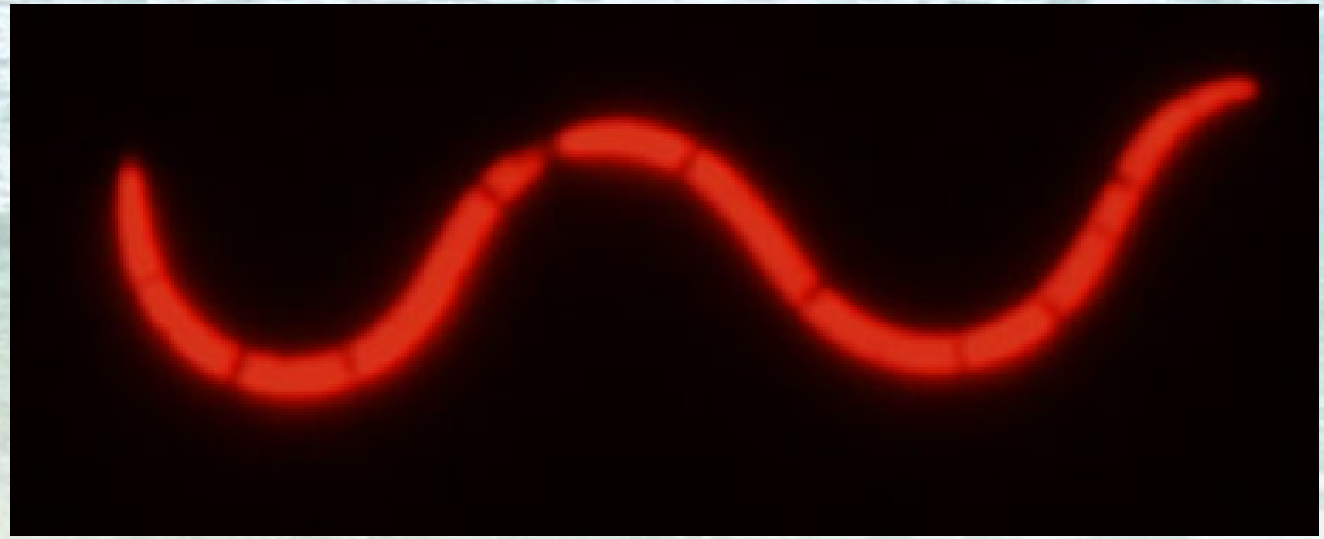


Chrysosporum ovalisporum

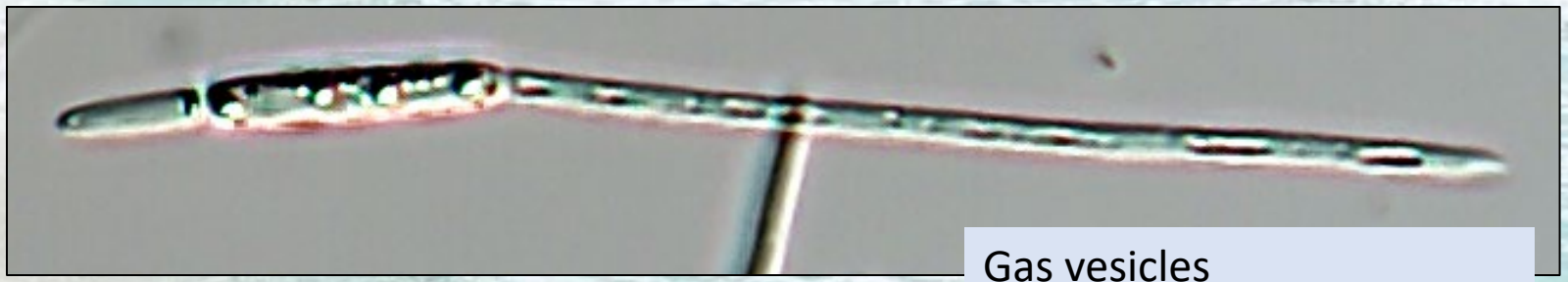
cylindrospermopsin

Raphidopsis (formerly *Cylindrospermopsis*

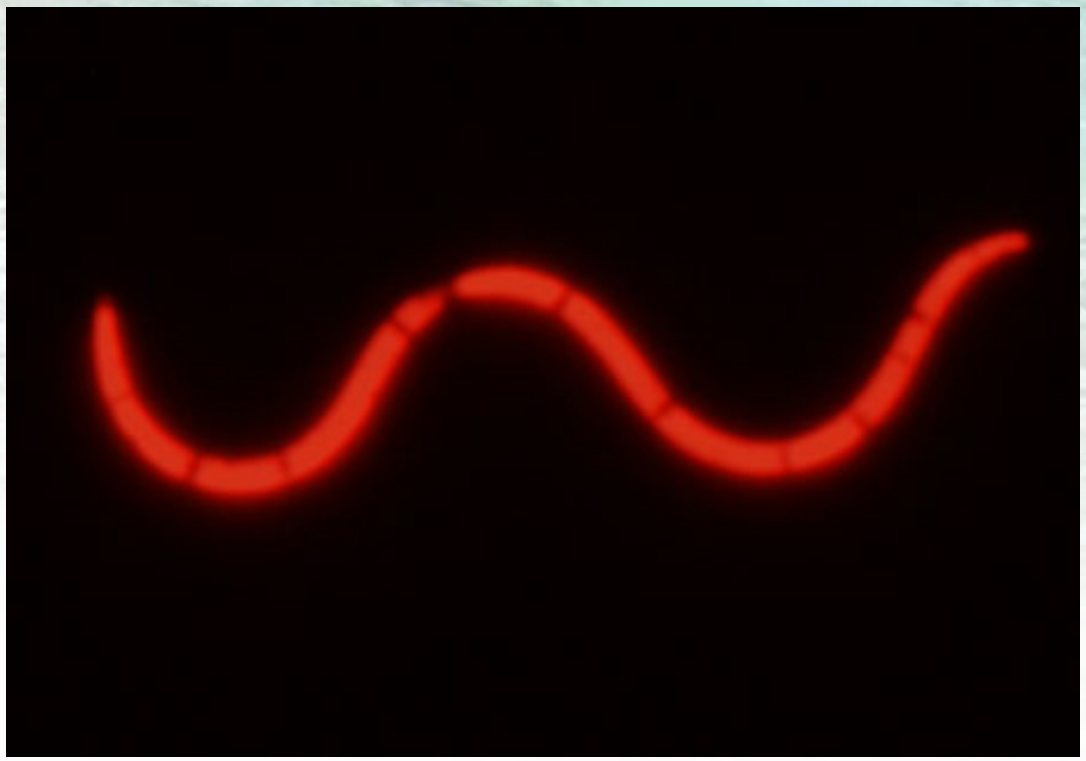
Gas vesicles
Mid-water column bloomer



Raphidopsis



Gas vesicles
Mid-water column bloomer



Morphology 3a: Filaments

Nostocales (have heterocytes)

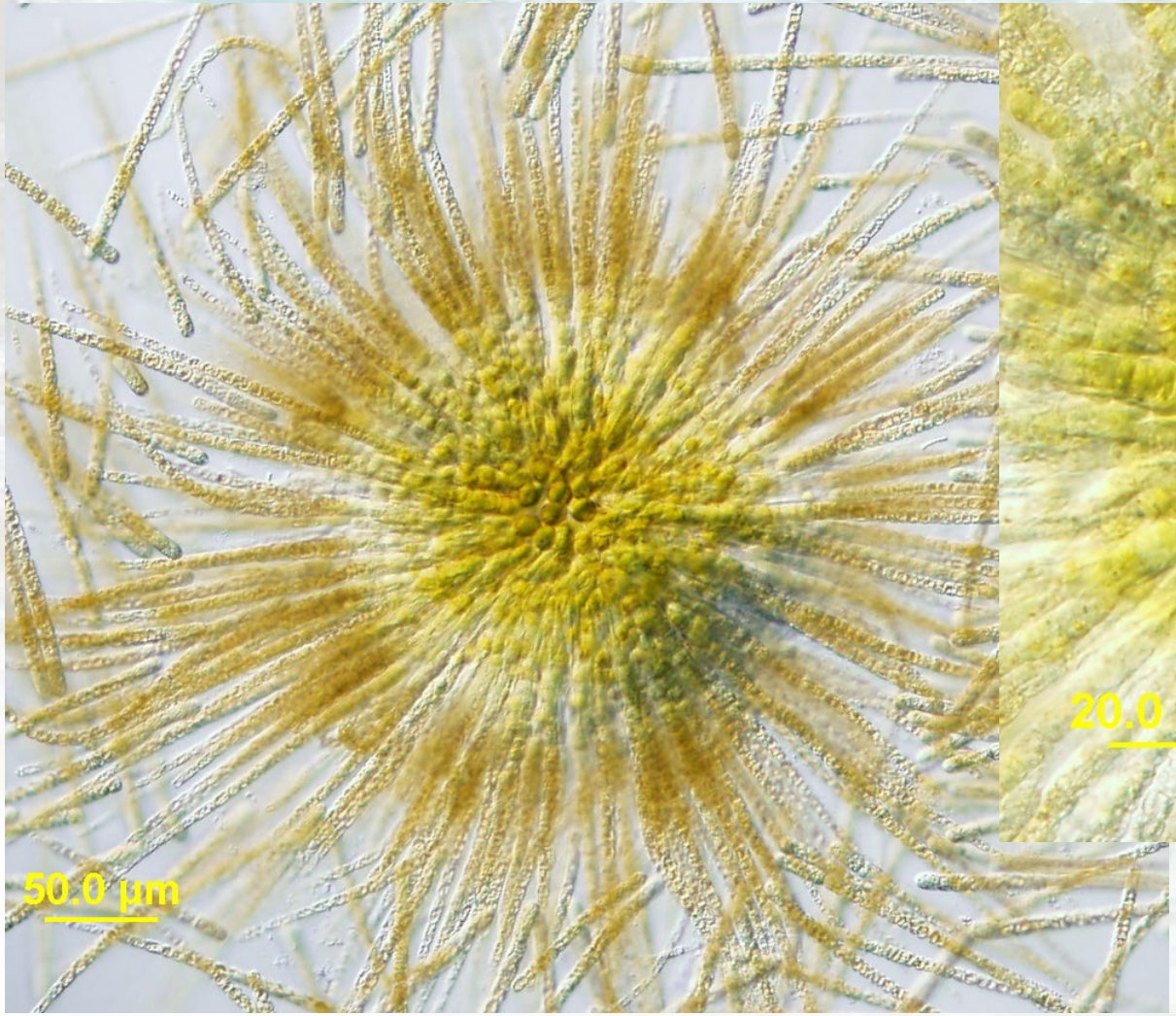
unbranched

tapered trichome?

branched

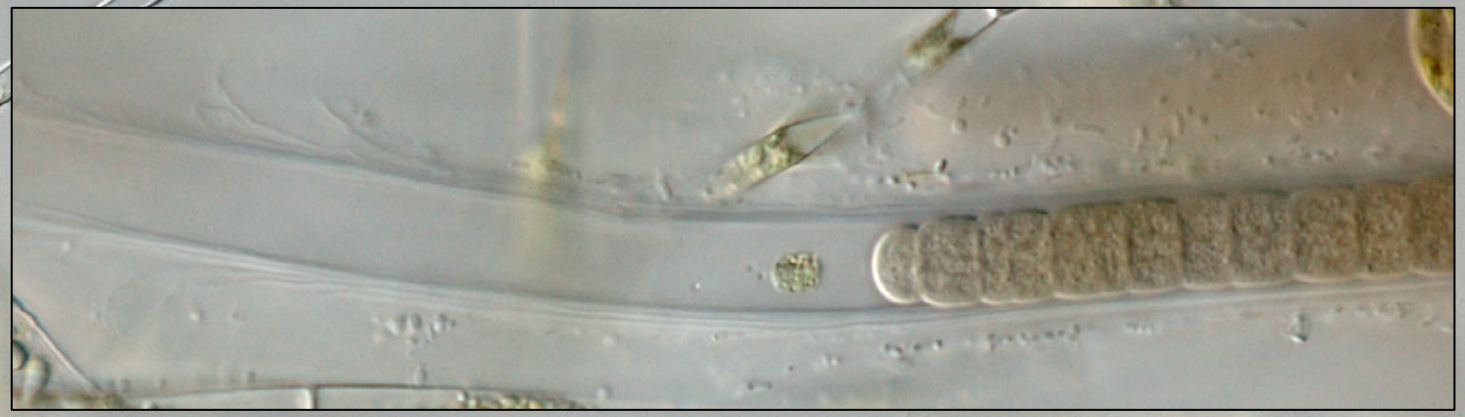
true vs. false branching

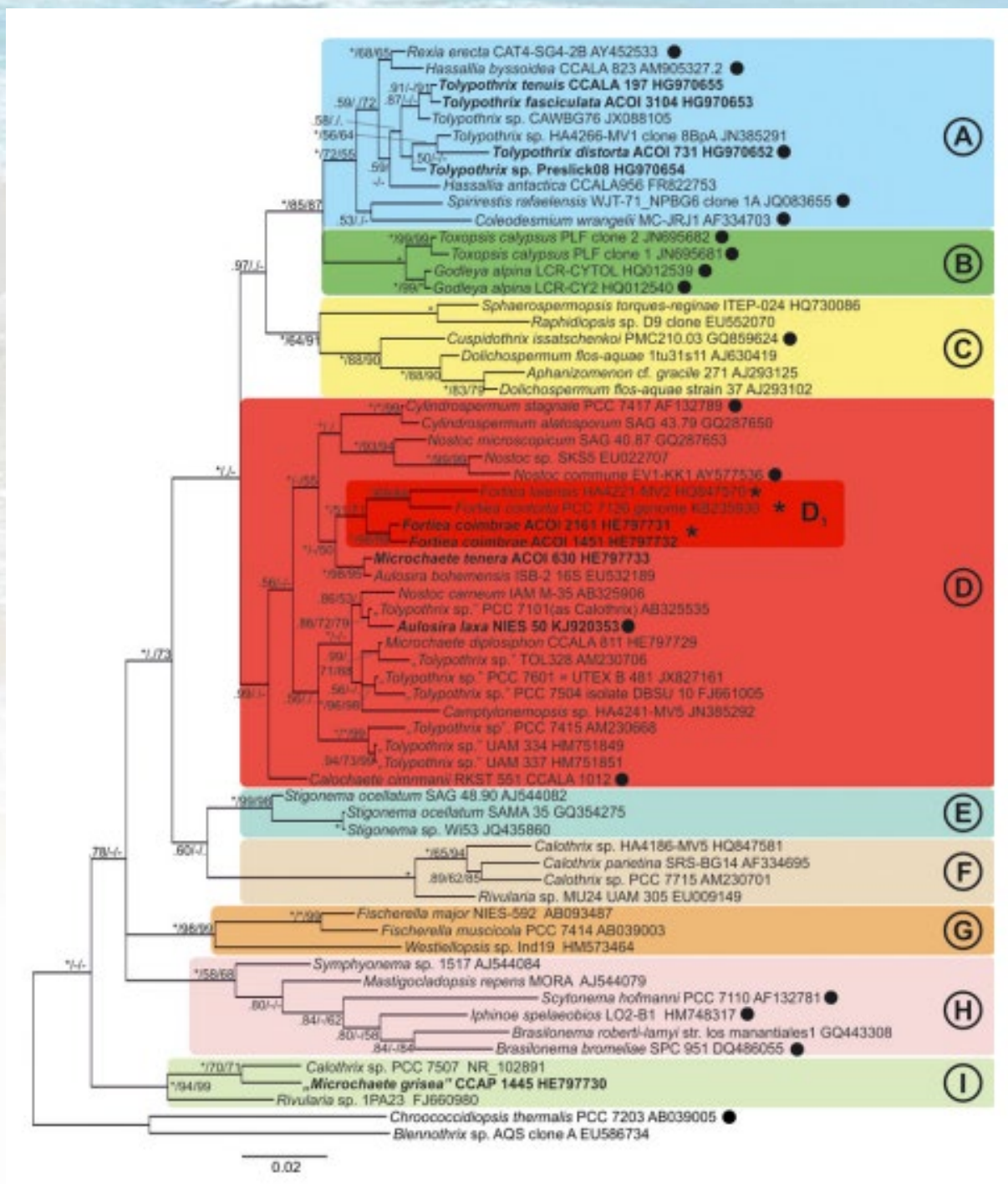
Gloeotrichia



Microchaete

Microchaete epiphytica





REASSESSMENT OF THE CYANOBACTERIAL FAMILY MICROCHAETACEAE AND ESTABLISHMENT OF NEW FAMILIES TOLYPOTHRICHACEAE AND GODLEYACEAE

DOI: 10.1111/jpy.12241

The p-distance of their 16S rRNA gene sequences is, etc….

>Our results clearly show that the family Microchaetaceae as currently defined in Komarek (2013) does not exist. Its members occur in several distant clusters and differ also in morphology."

Microchaete

Morphology 3b: Filaments

Nostocales (have heterocytes)

branched

true vs. false branching

Morphology 2: Filaments

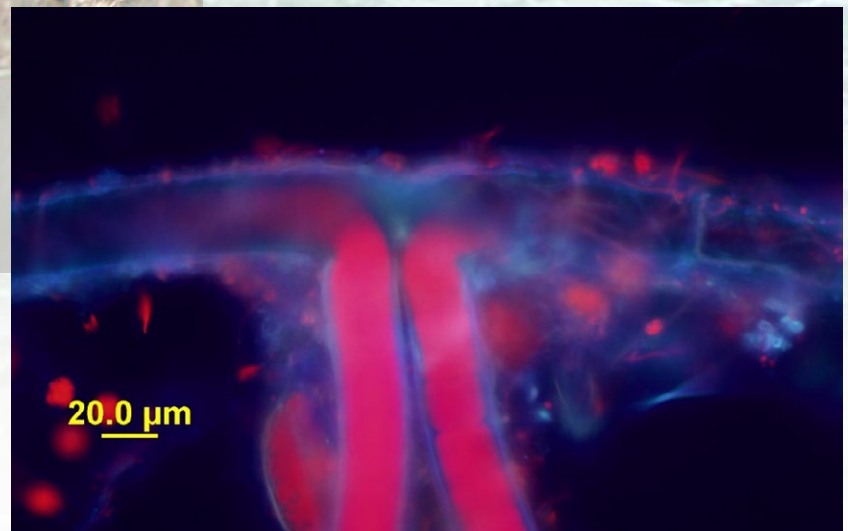
Nostocales (have heterocytes)

false branching
Tolypothrix

Morphology 2: Filaments

Nostocales (have heterocytes)

false branching
Scytonema



Morphology 2: Filaments

Nostocales (have heterocytes)

true branching

Iphinoe (Hapalosiphon-like)

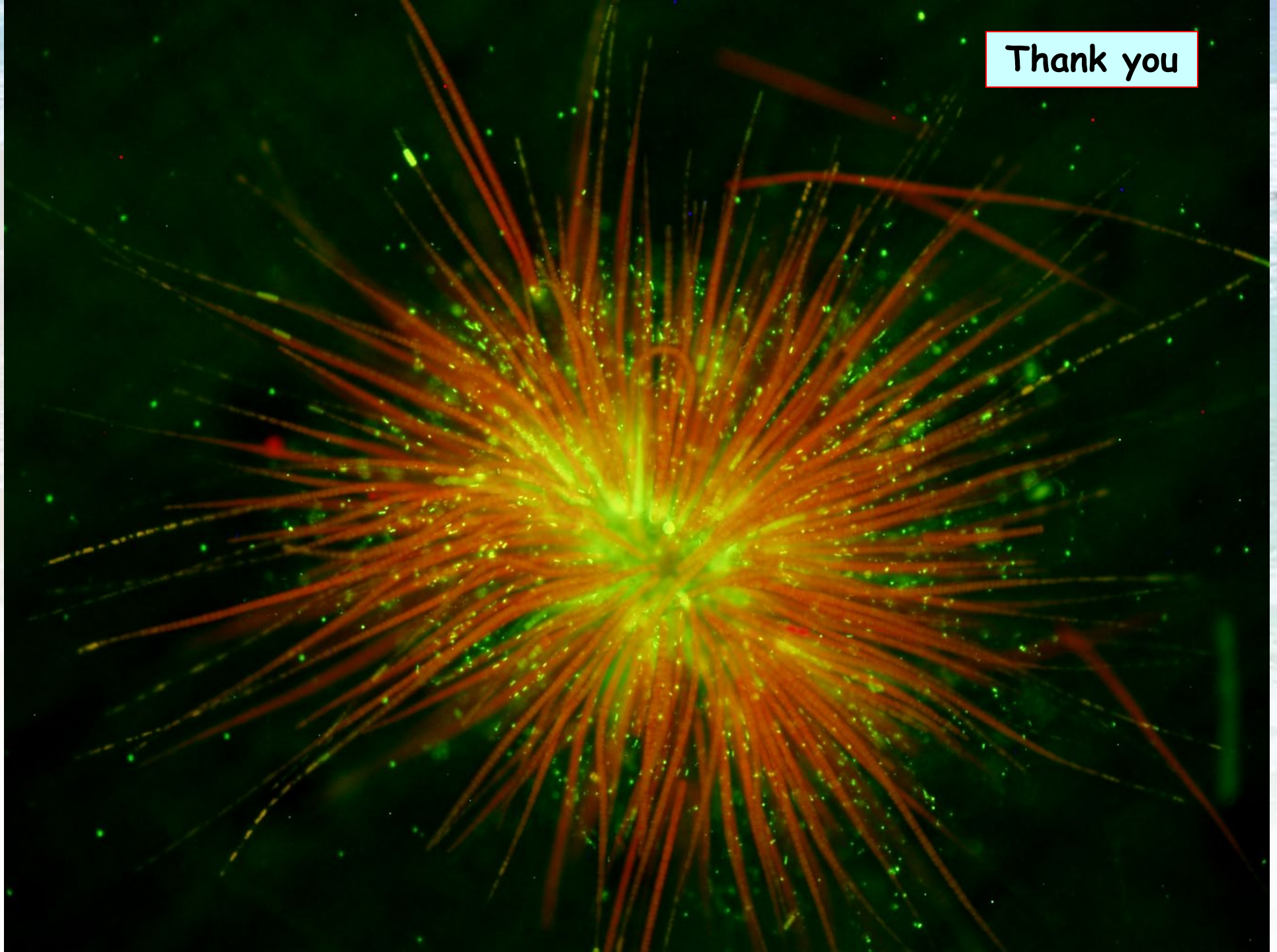
Morphology 2: Filaments

Nostocales (have heterocytes)

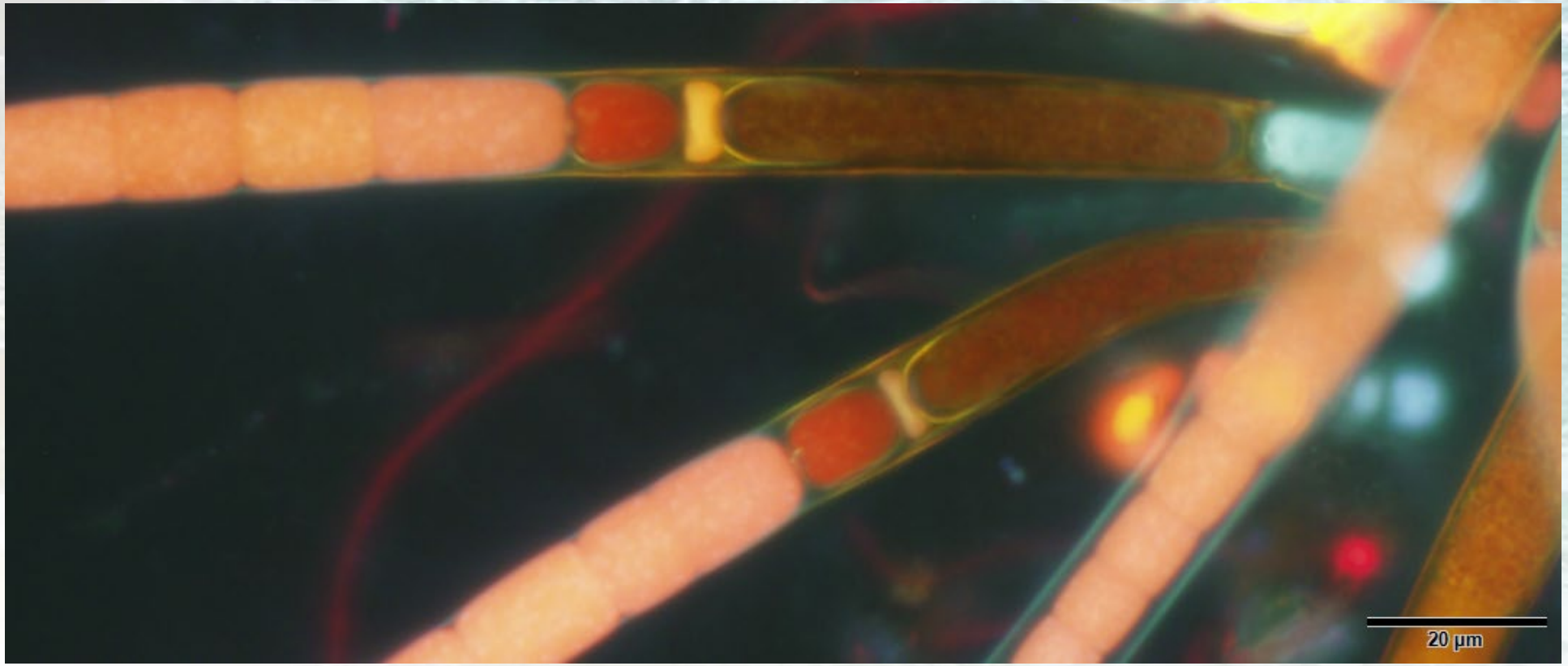
true branching and multiseriate

Stigonema


WARNING
LIFEGUARD,
BACTERIOLOGIST,
MICROBIOLOGIST
PHYCOLOGIST
NOT ON DUTY
SWIM AT YOUR
OWN RISK


Thank you

Thank You!



Live Sample Hunt!

Barry H. Rosen, Ph. D.
Florida Gulf Coast University
USGS Emeritus

brosen@fgcu.edu

239-745-4589

THE WATER SCHOOL AT **FGCU**