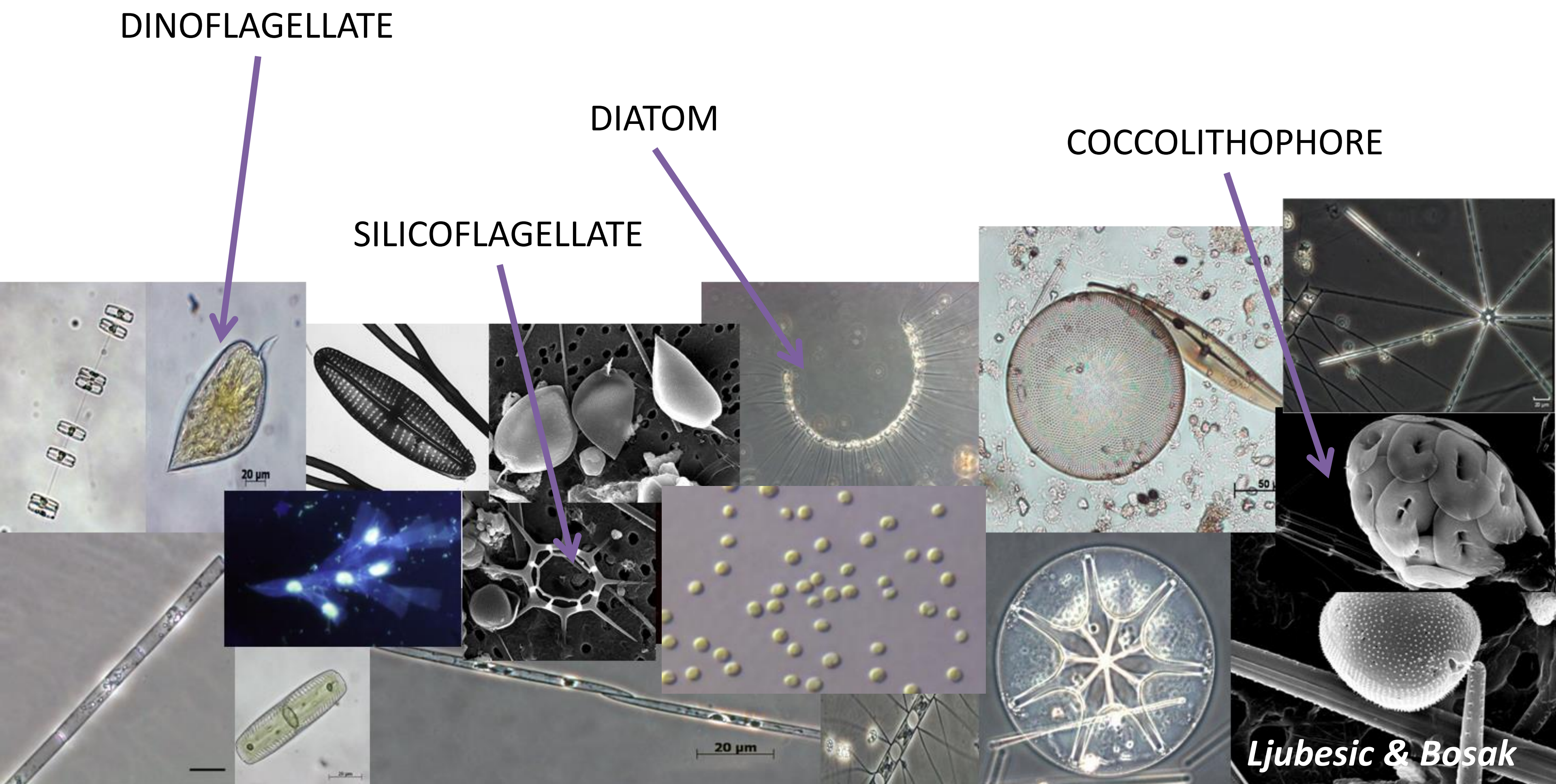
WHAT ARE PHYTOPLANKTON?

IVONA CETINIĆ

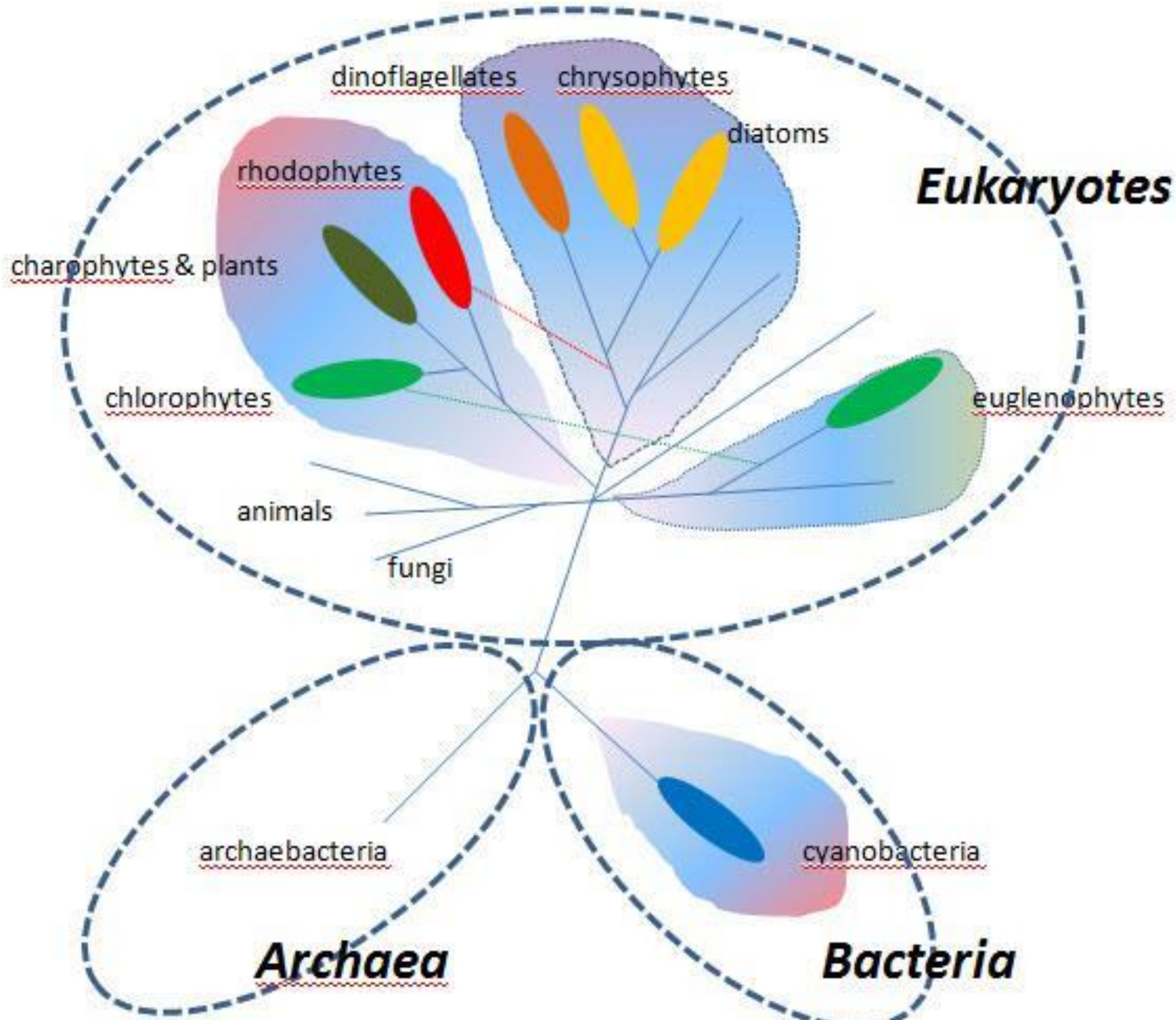
NASA GSFC / USRA

@teuta

PHYTOPLANKTON
"drifting plants", 1887

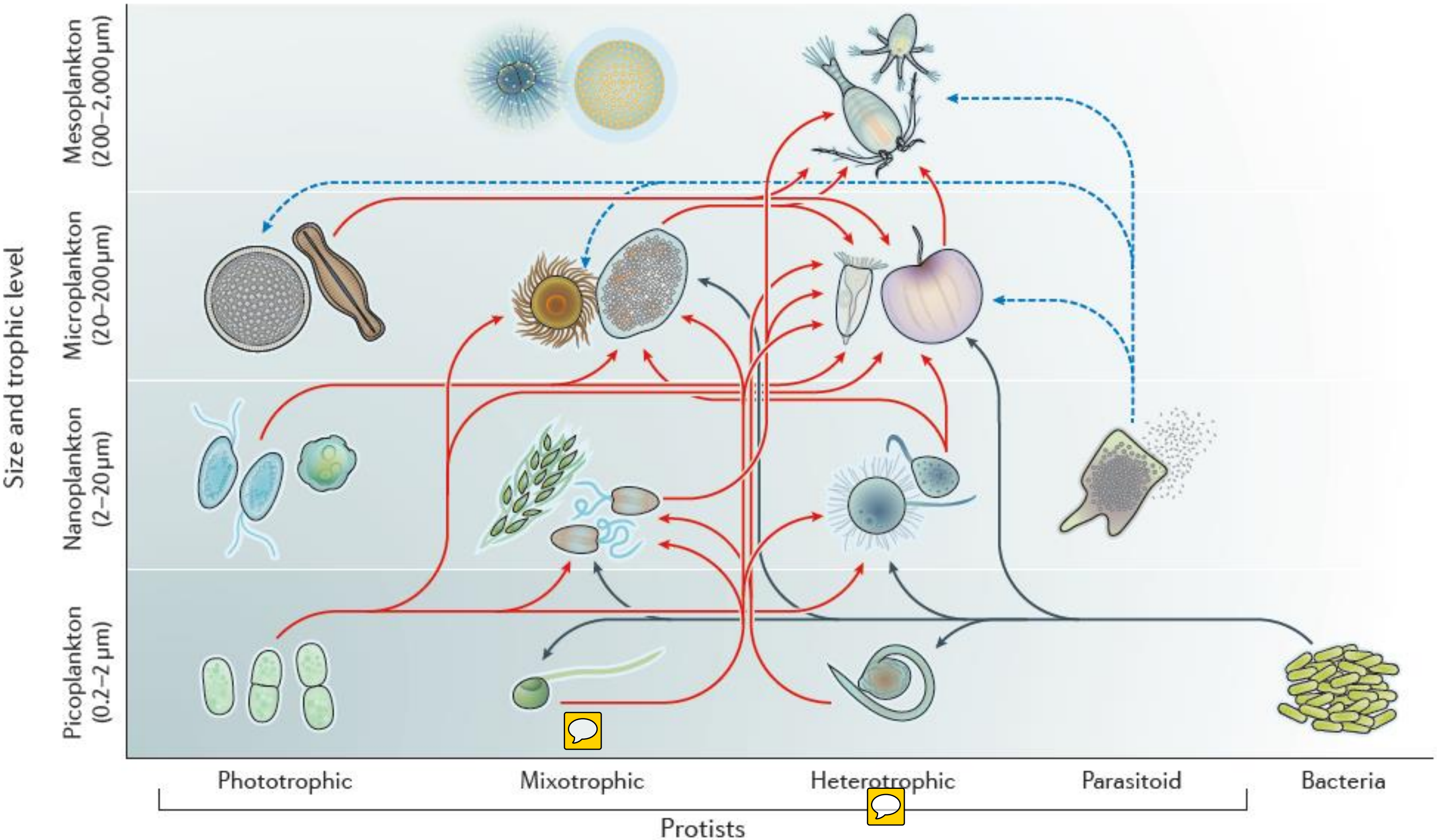


GREAT GENETIC DIVERSITY OF ORGANISMS THAT INTERACT WITH LIGHT IN THE OCEAN



Keeling et al. 2004
http://www.diatom.org

PLANKTON



Caron et al, 2017

PHYTO

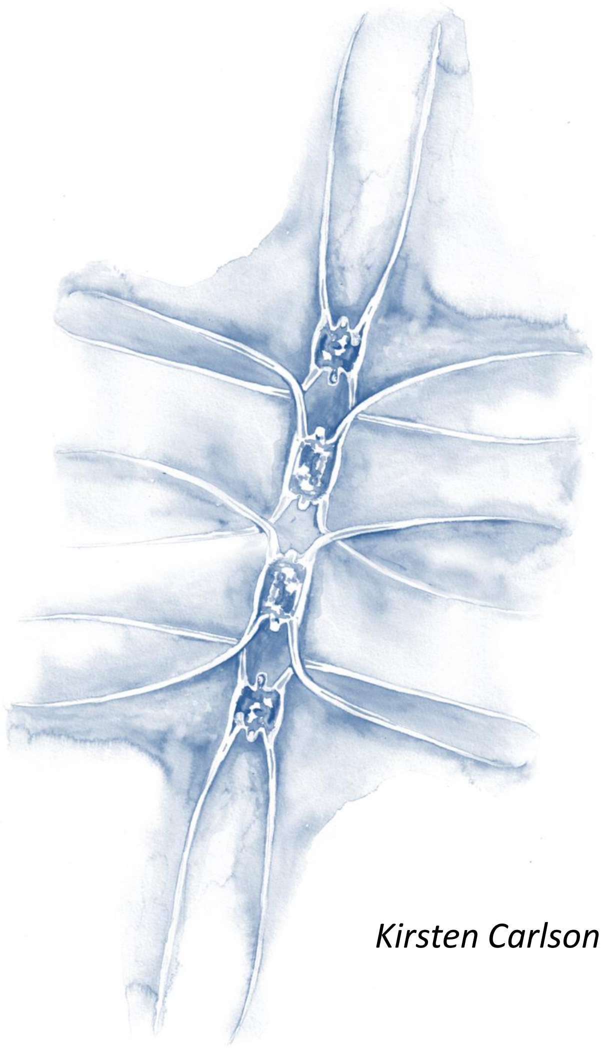
This is why they are so important and why we study them

process of photosynthesis:

DRAW DOWN CARBON DIOXIDE

MAKE CARBOHYDRATES (BASE OF MARINE FOOD WEB)

PRODUCE OXYGEN

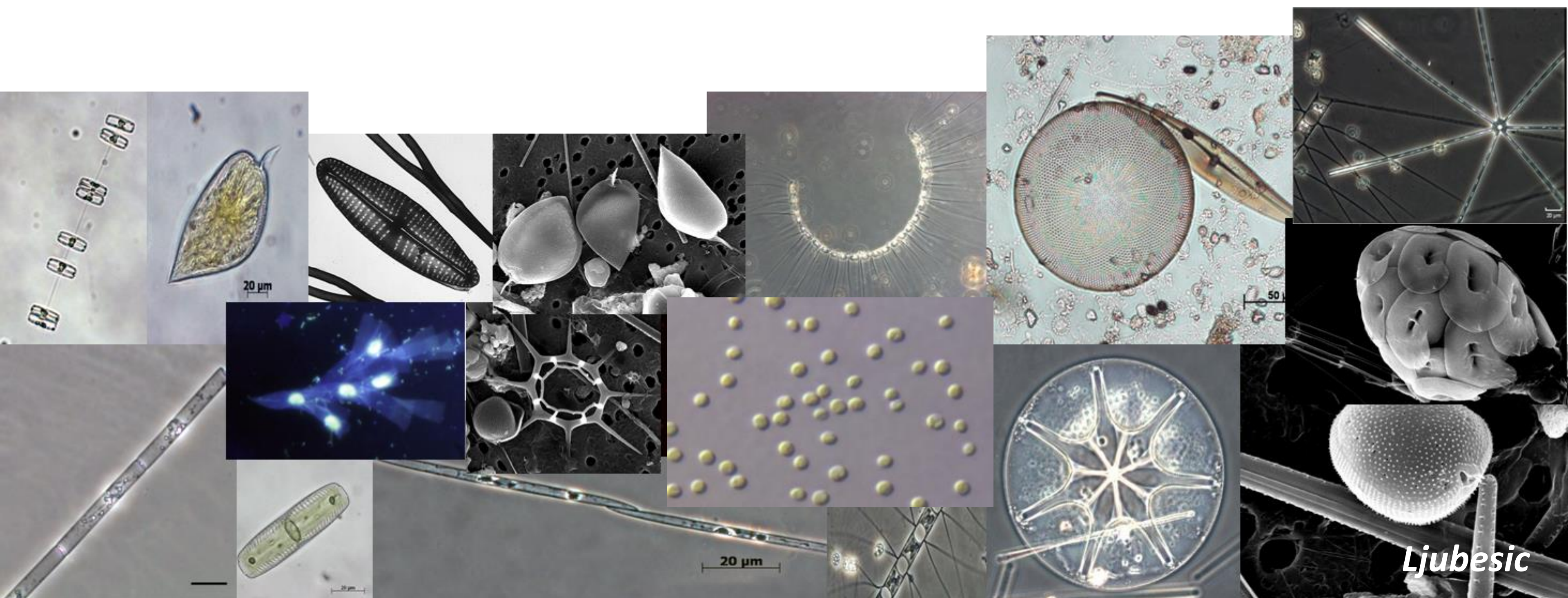


Kirsten Carlson SOI

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

PHYTOPLANKTON

Many shapes, colors and sizes..
…that define their role in marine ecosystem and oceanic carbon cycle



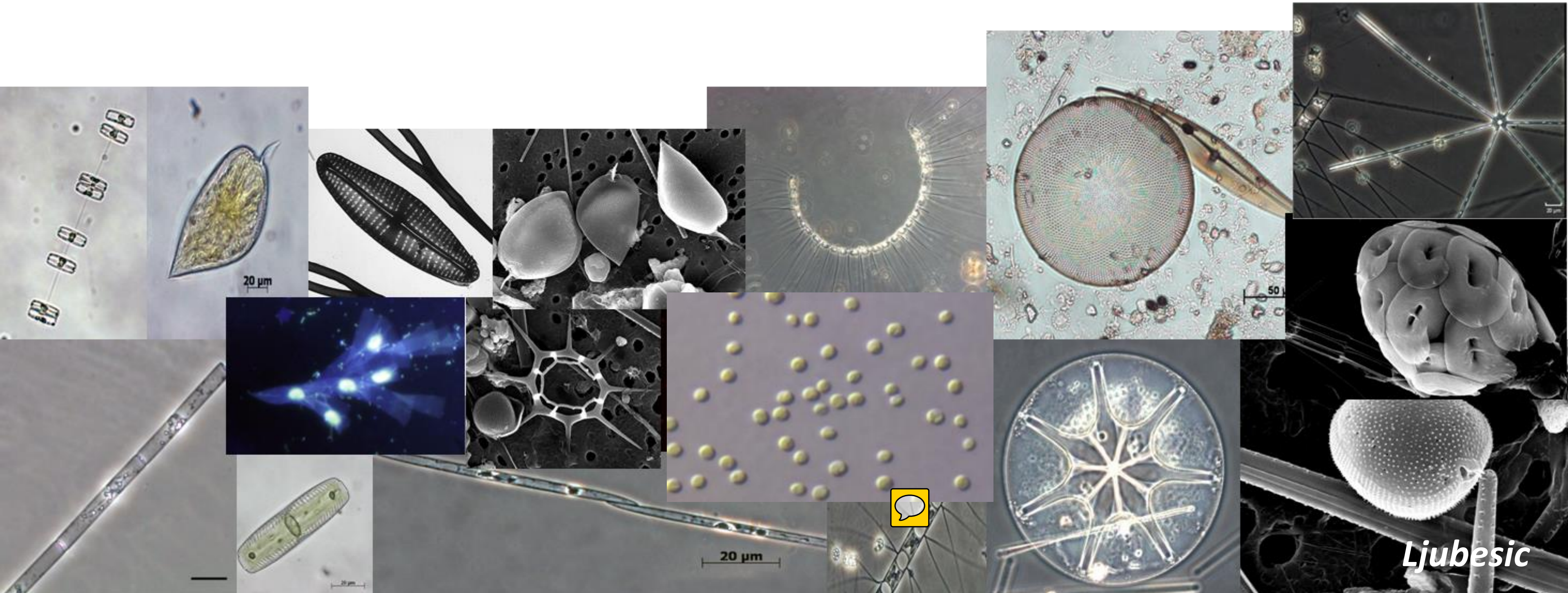
Connect optics to carbon cycle and ecosystem

shapes, colors and size drive both characteristics

PHYTOPLANKTON

Many shapes, colors and sizes..

...that define their optical signal



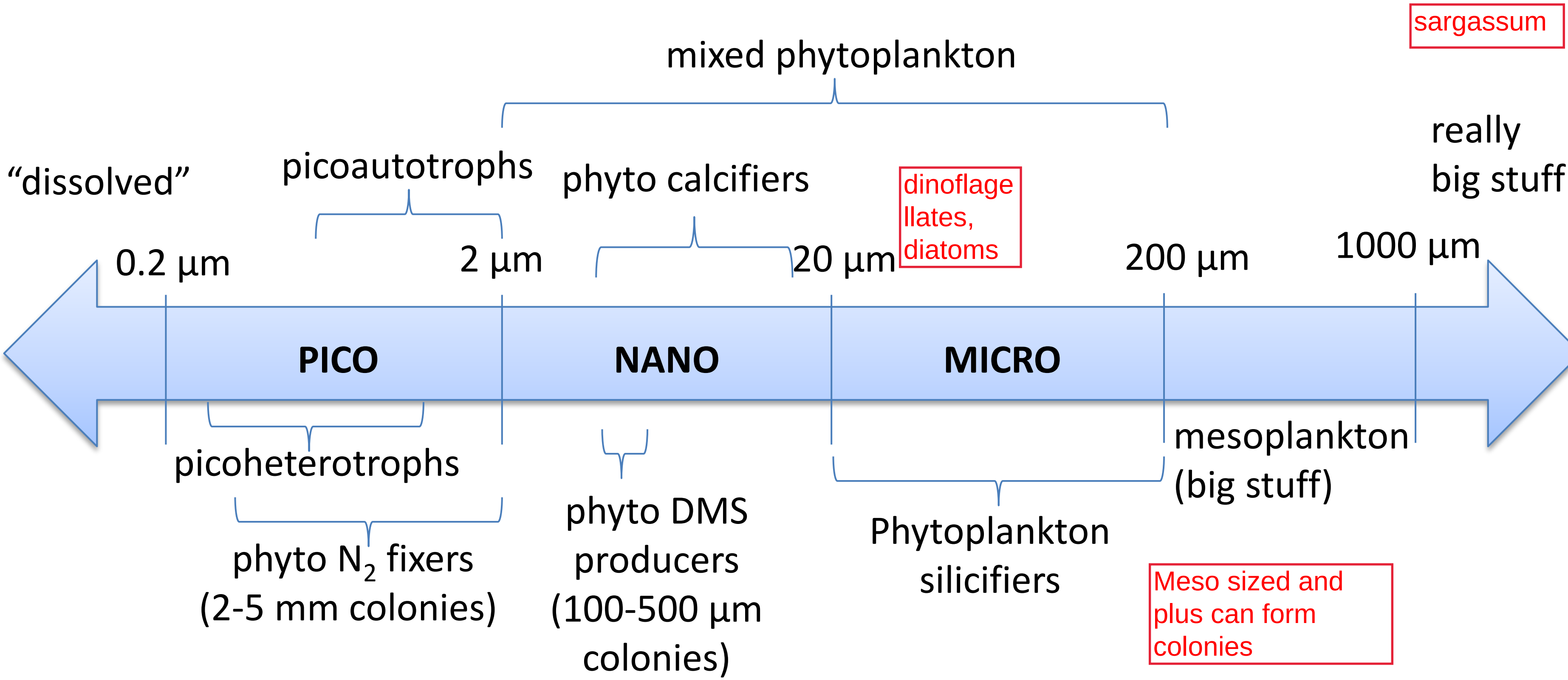
PHYTOPLANKTON

- Particle (size, shape, morphology)
- Taxa (Taxonomic approach)
- Chemistry (pigments, minerals, metabolites..)
- Function (role)

silicates

toxins are metabolites, influence cloud formation

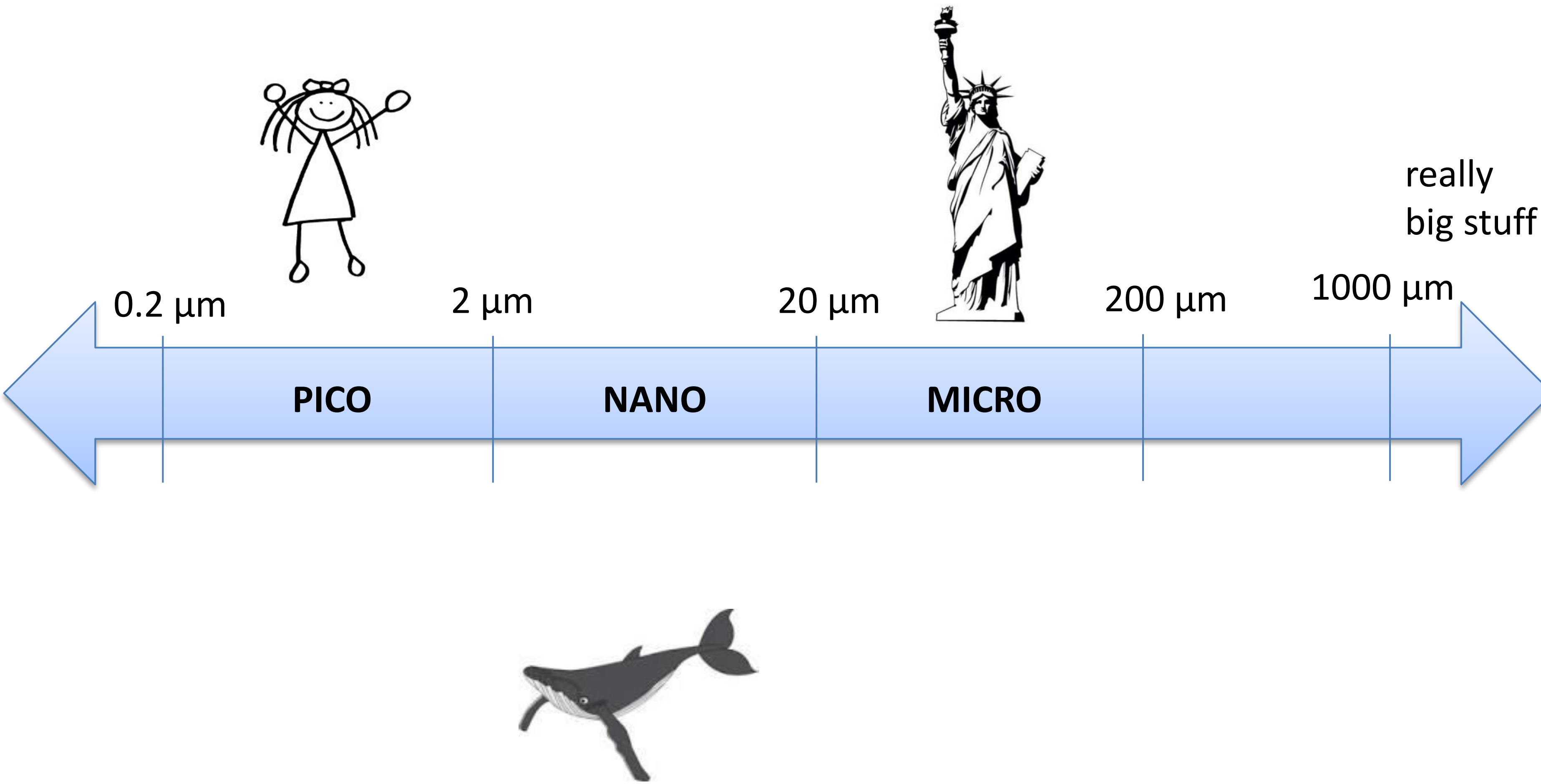
PHYTOPLANKTON AS PARTICLES



ultra < 2µm (smallest; mostly prokaryotes)
pico < 5µm

Le Quéré et al. (2005)

PHYTOPLANKTON AS A PARTICLE…



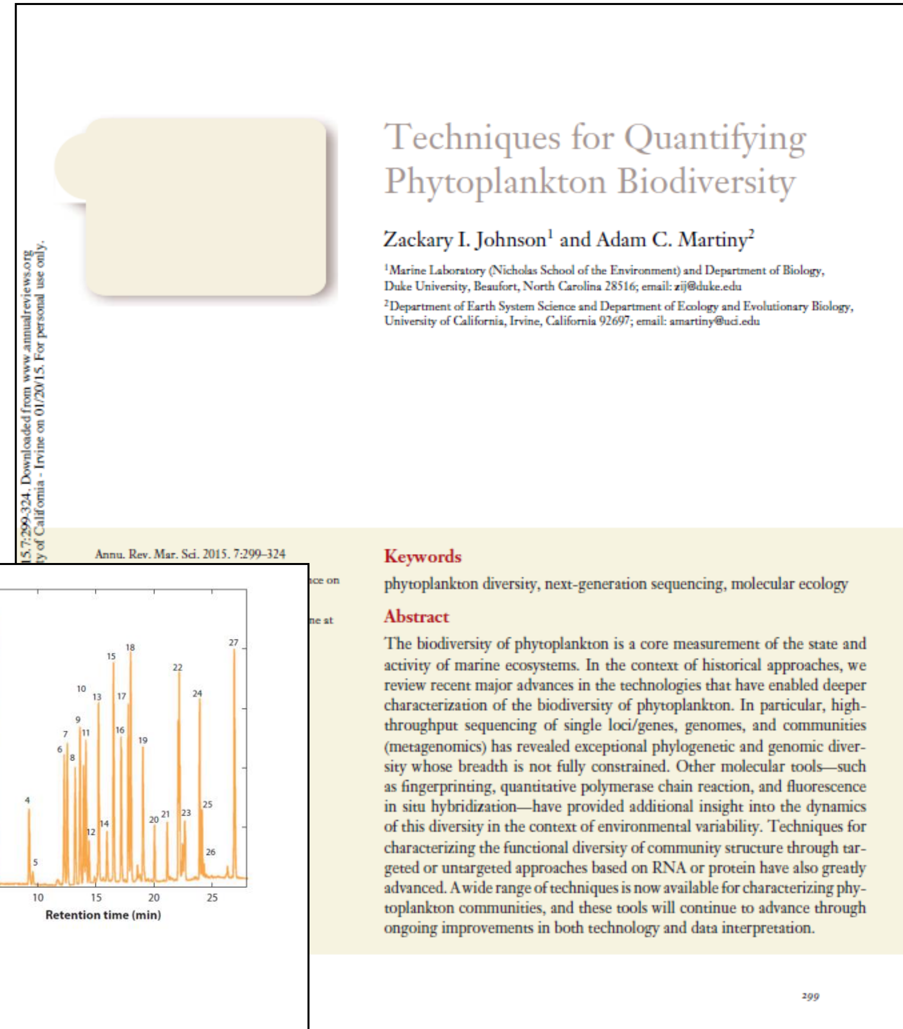
More about particle properties on Friday

PHYTOPLANKTON

- Particle (size, shape, morphology)
- Taxa (Taxonomic approach)
- Chemistry (pigments, minerals, metabolites..)
- Function (role)

PHYTOPLANKTON AS TAXA

- Evolution of concept of taxa
- Driven by the development of the methods



Techniques for Quantifying Phytoplankton Biodiversity

Zackary I. Johnson[1] and Adam C. Martiny[2]

[1]Marine Laboratory (Nicholas School of the Environment) and Department of Biology, Duke University, Beaufort, North Carolina 28516; email: zij@duke.edu

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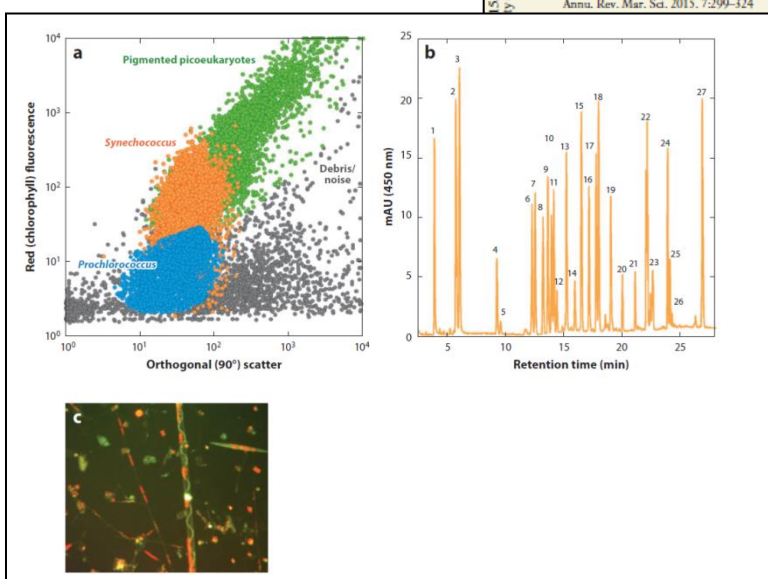
Annu. Rev. Mar. Sci. 2015. 7:299–324

Keywords

phytoplankton diversity, next-generation sequencing, molecular ecology

Abstract

The biodiversity of phytoplankton is a core measurement of the state and activity of marine ecosystems. In the context of historical approaches, we review recent major advances in the technologies that have enabled deeper characterization of the biodiversity of phytoplankton. In particular, high-throughput sequencing of single loci/genes, genomes, and communities (metagenomics) has revealed exceptional phylogenetic and genomic diversity whose breadth is not fully constrained. Other molecular tools—such as fingerprinting, quantitative polymerase chain reaction, and fluorescence in situ hybridization—have provided additional insight into the dynamics of this diversity in the context of environmental variability. Techniques for characterizing the functional diversity of community structure through targeted or untargeted approaches based on RNA or protein have also greatly advanced. A wide range of techniques is now available for characterizing phytoplankton communities, and these tools will continue to advance through ongoing improvements in both technology and data interpretation.



TAXONOMY - ALL ROLLS BACK TO THE EVOLUTION OF THE TAXA CONCEPT

Modern system of algal classification (20-ish yrs old)

- DNA, RNA, protein based (genetics, genomics, transcriptomics… proteonomics) + ultrastructure electron microscopy

Cool & easy read - Caron (2013), *Journal of Eukaryotic Microbiology*

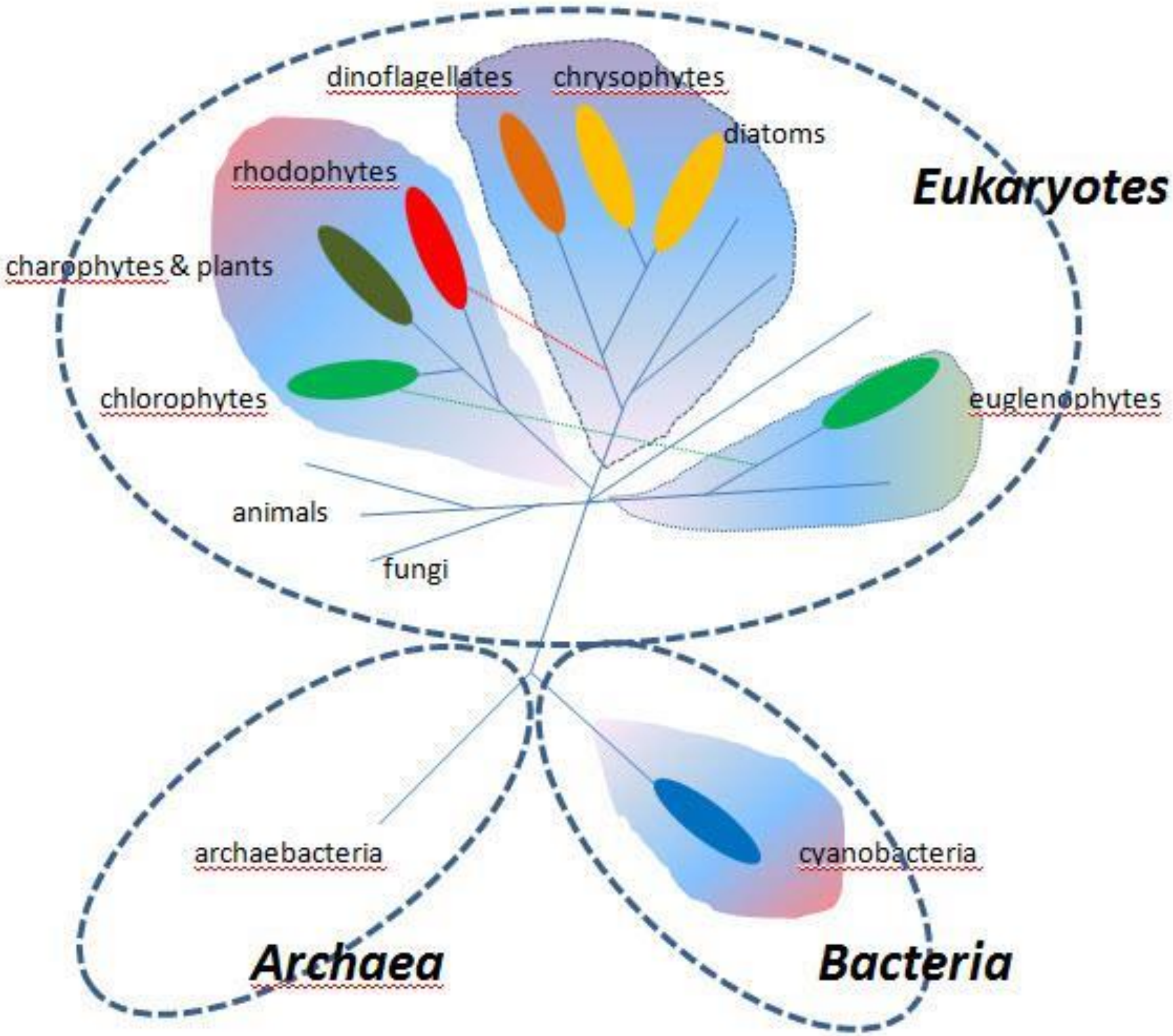
Classical system (~ 350 yrs old)

- Classification based on morphological characteristics based purely on light microscopy
- Electron microscopy (ultrastructure)
- Pigmentation

Dinoflagellates, diatoms, and flagellates are terms from this classical system

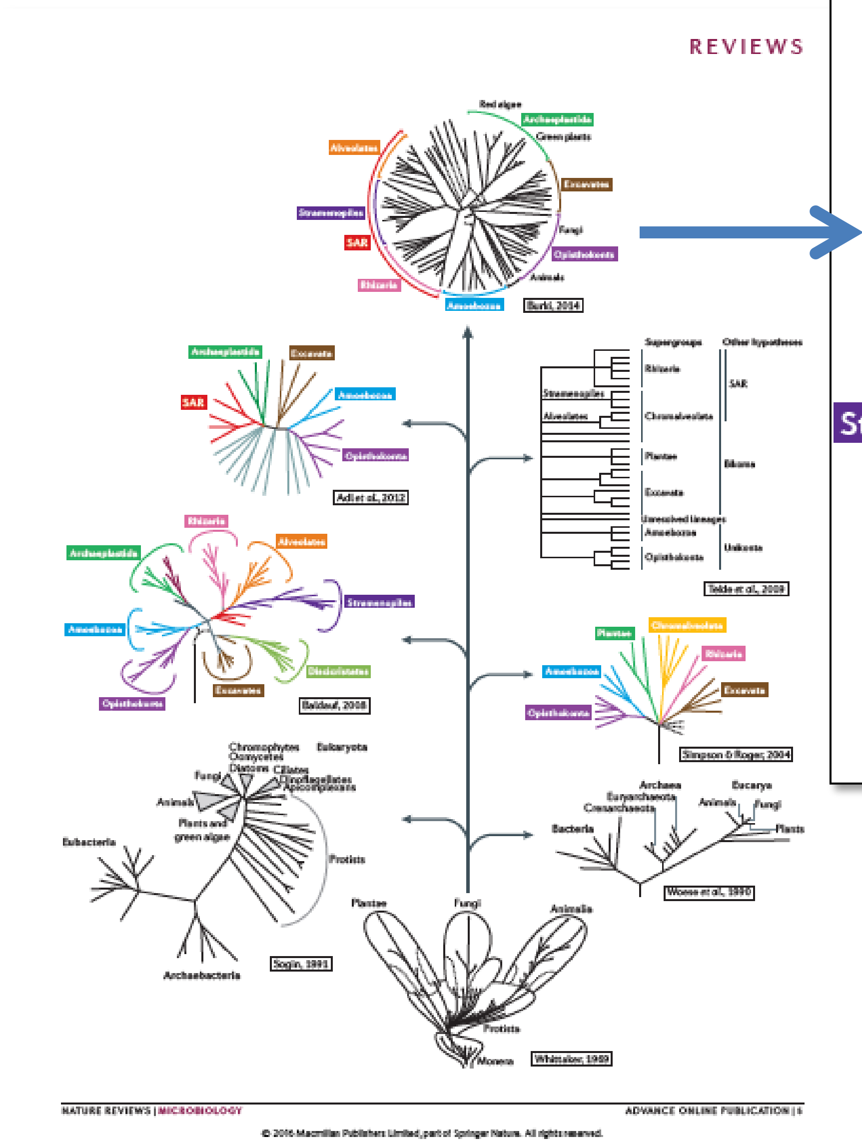
VERY SIMPLE TREE OF LIFE (EMPHASIS ON PHYTOPLANKTON)

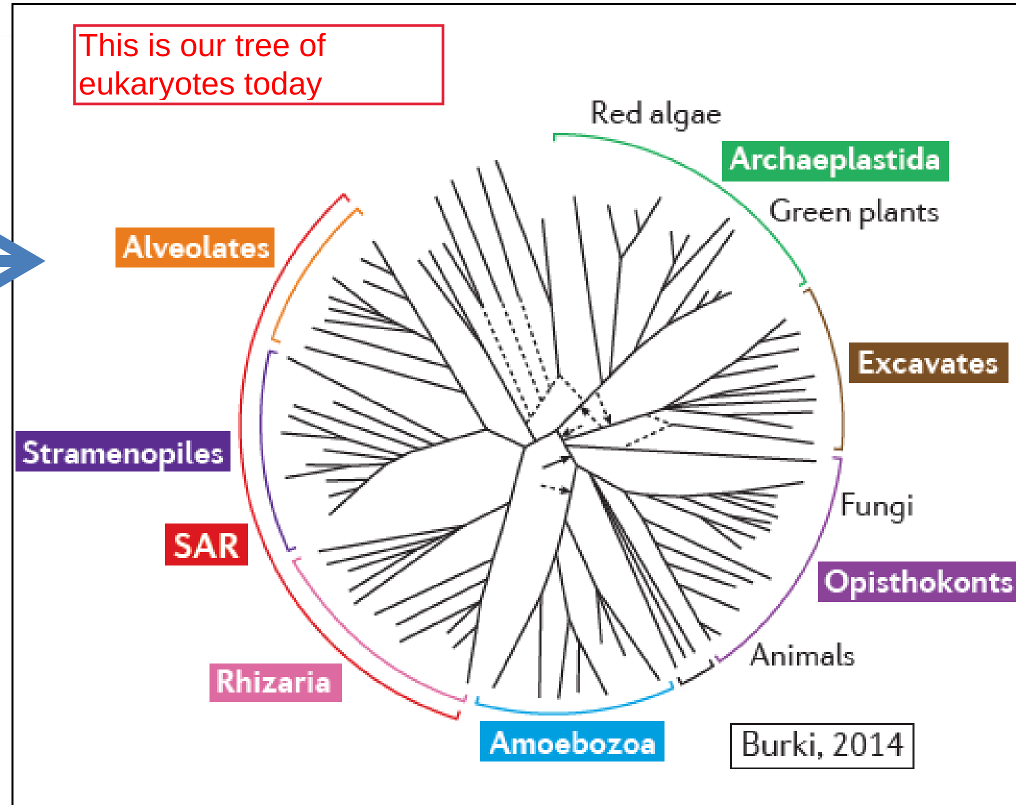
Ph



http://www.diatom.org

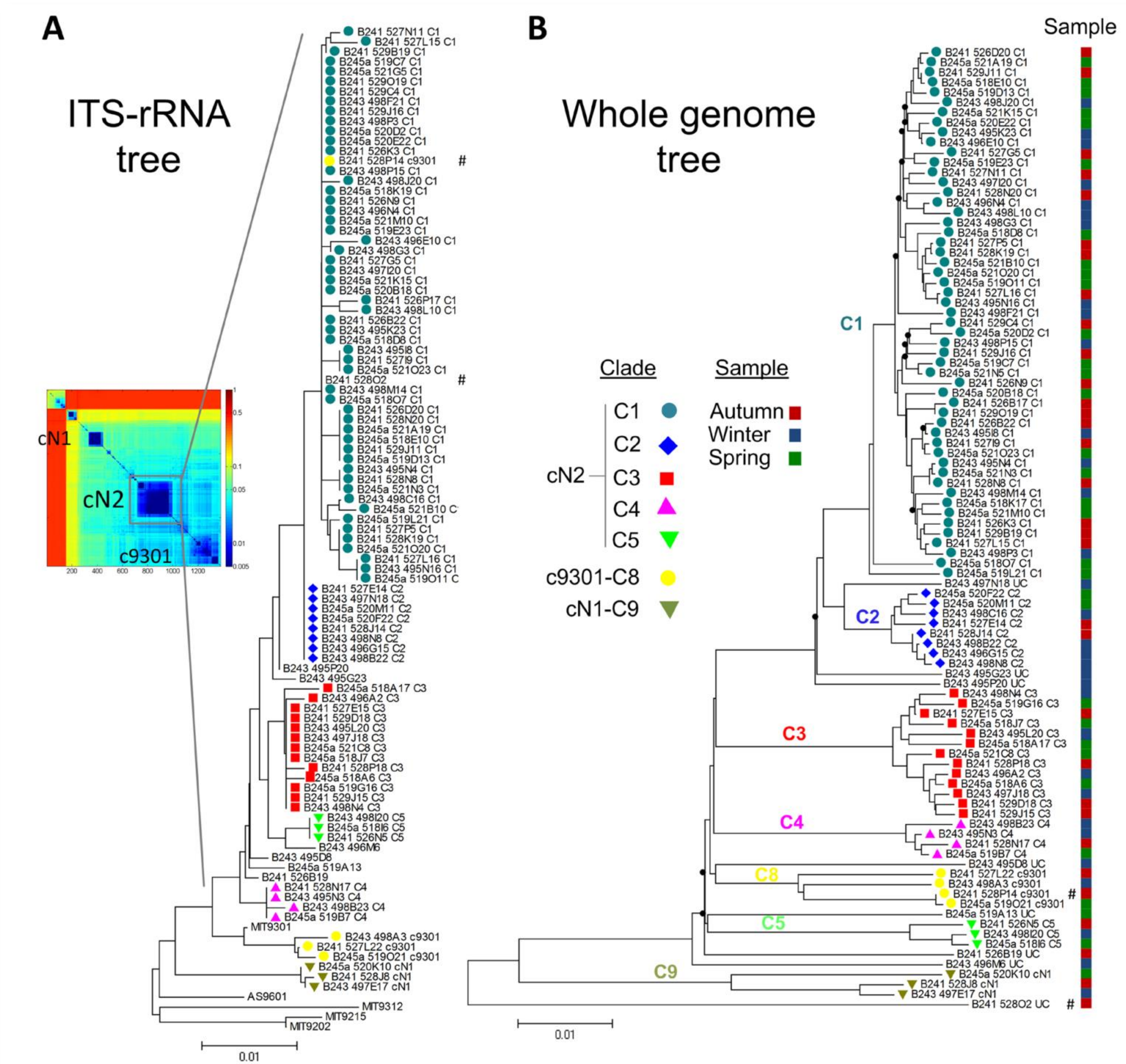
EUKARYOTE PHYLOGENETIC TREE





Caron et al, 2017

PROCHLOROCOCCUS PHYLOGENETIC TREES



prokaryoatic bacterial autotrophs found everyone in the ocean

Kashtan, Nadav, et al. (2014)

TAXONOMY

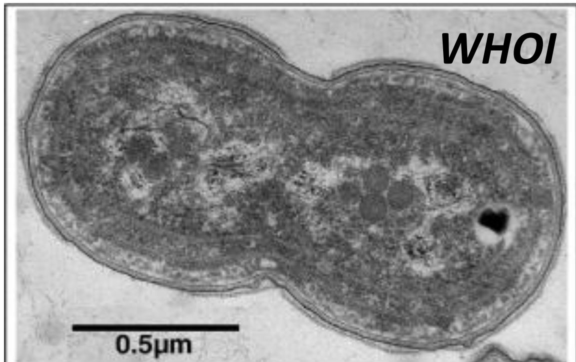
1) Old, classical system (~ 350 yrs old)

- Classification based on morphological characteristics based purely on light microscopy
- Electron microscopy (ultrastructure)
- Pigmentation

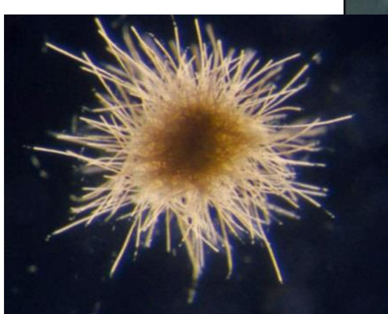
Dinoflagellate & diatom

CYANOBACTERIA

Prokaryote, teeny tiny, DNA piled up inside, Penny Chisholm found them by accident like 20 years ago

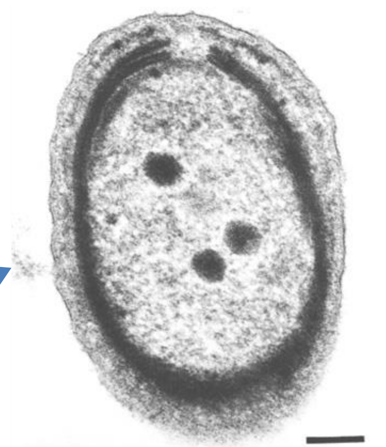


Synechococcus



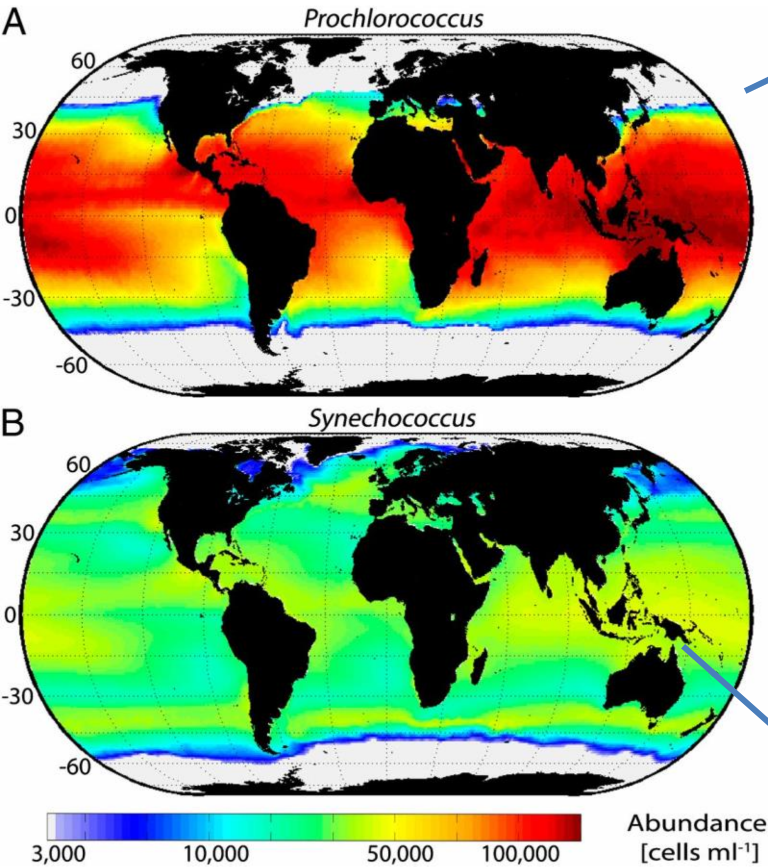
Trichodesmium (puff)

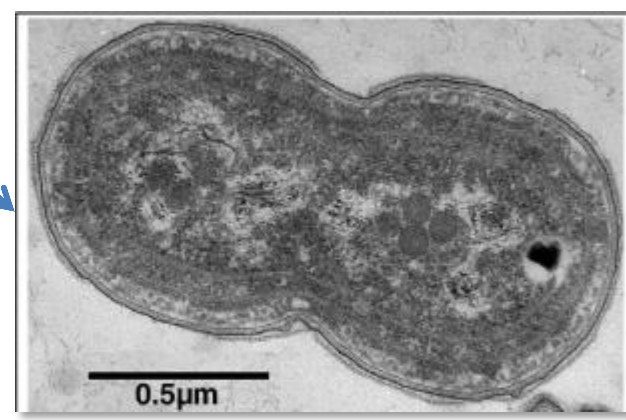
- Includes many of the picoplankton
- Many do Nitrogen Fixation
- Smallest and most abundant phytoplankton in the ocean
- Tropical to cosmopolitan



Electron micrograph of a longitudinal section of Prochlorococcus (isolate MIT 9313). Tightly appressed intracytoplasmic lamellae are present near the cell periphery, and carboxysomes are visible within the cell interior. Scale bar, 0.1mm.
(C. Ting, J. King, S.W. Chisholm, 1999)

Prochlococcus
Smallest and most abundant.
(~ 0.7 µm)
Diagnostic: very small size,
lack of orange fluorescence,
divinyl chlorophyll a & b.



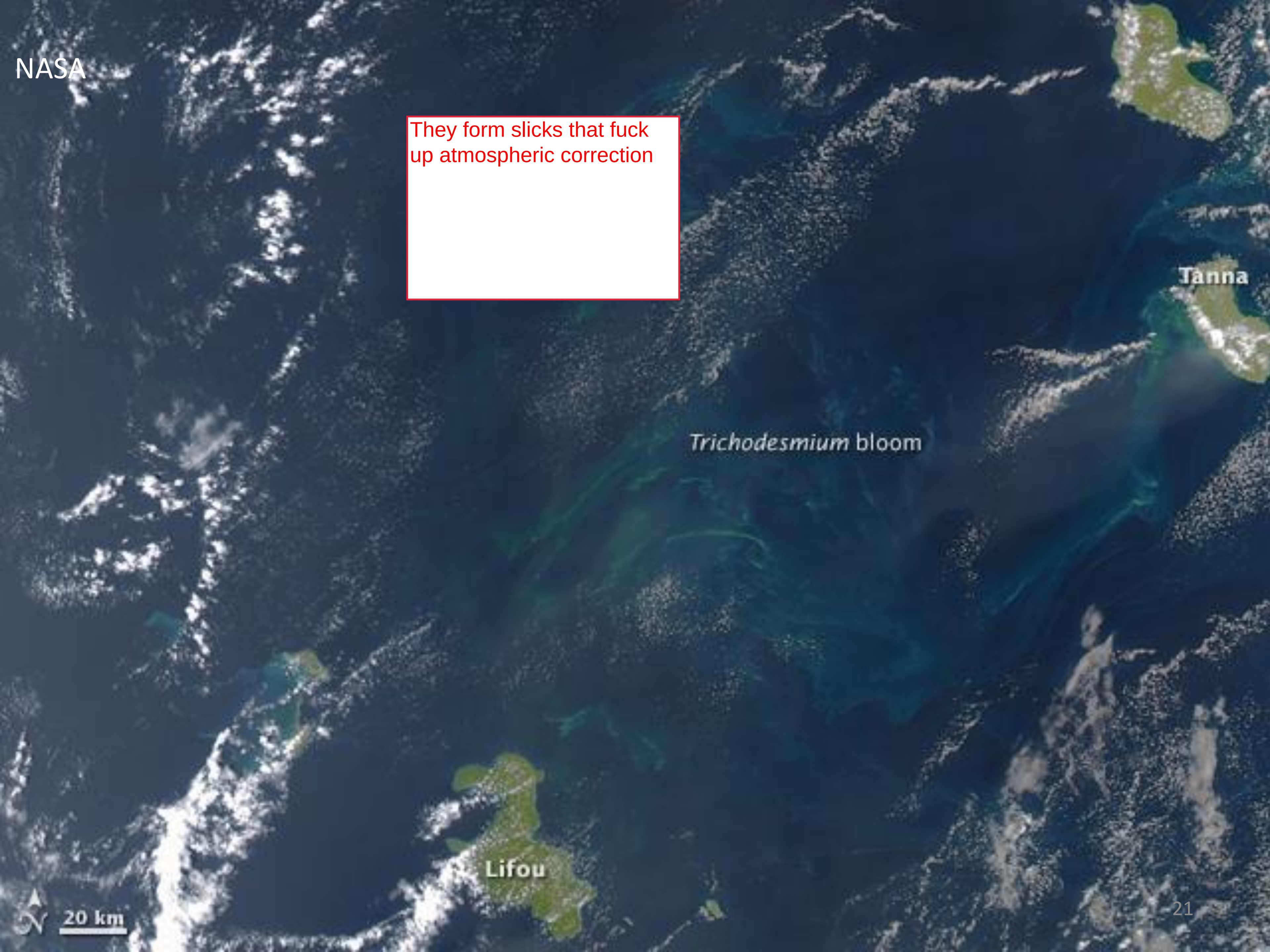


Synechococcus
(~ 1 µm)
Diagnostic: phycoerthyrin pigment fluoresces orange (in contrast to chlorophyll, which fluoresces red.

Pedro Flombaum et al. (2013)

Trichodesmium

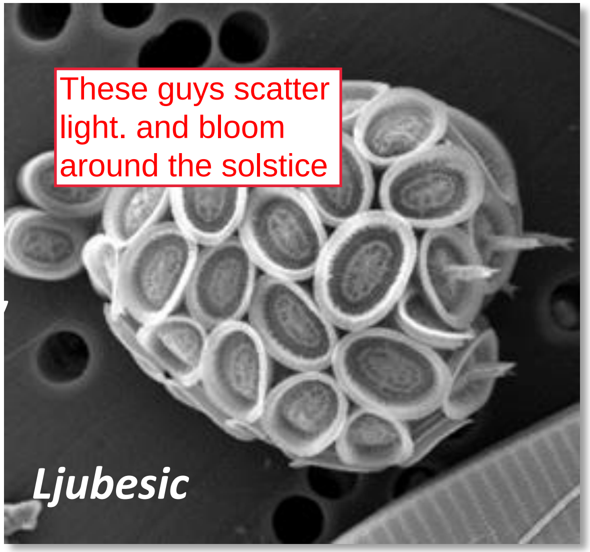
cyanobacteria, nitrogen fixer, warm waters, puffs and tuffs, phycoerthyrin, Fe may regulate abundance



NASA

They form slicks that fuck up atmospheric correction

PRYMNESIOPHYTES



These guys scatter light. and bloom around the solstice

7-10 nm

Phaeocystis, makes floating with hundreds of cells embedded in a polysaccharide gel matrix

DMSP producers

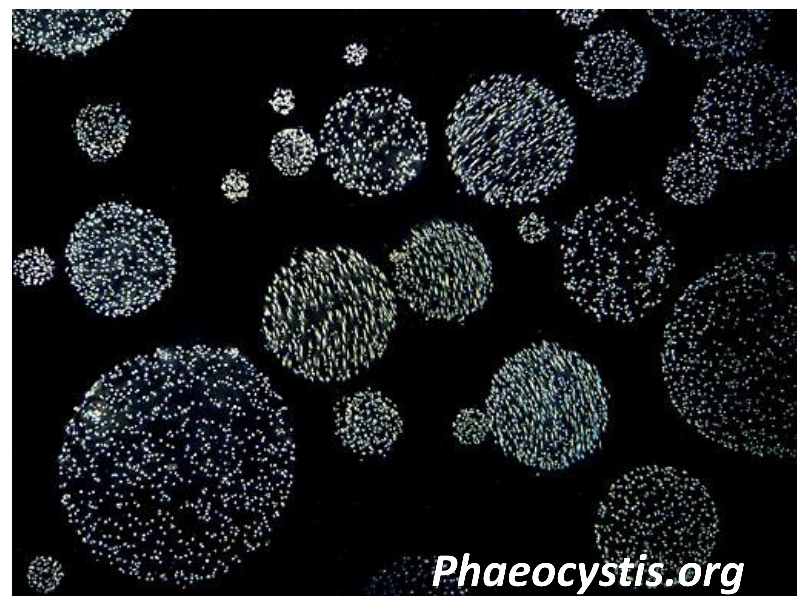
Form ugly foam on beaches in UK (smell of the seaside?)

Coccolithophores, calcareous phytoplankton – calcium carbonate “shells”, nano-micro

Sensitive to sea surface temperature - important tool in paleontology

Sensitivity to pH

Important for Carbon Export, climate studies



17 August 2011
NASA
We can see coccolithophores from space; makes them milky
Barents Sea
Norway
N
50 km

DINOFLAGELLATES

These are the blooms of the spring

- Flagellate containing algae
- Plant-like, but sometimes animal like (heterotroph), even predators
- Mostly coastal, warm waters
- Are also often symbionts of benthic and pelagic “heterotrophs”
- Red tide organisms, some toxic

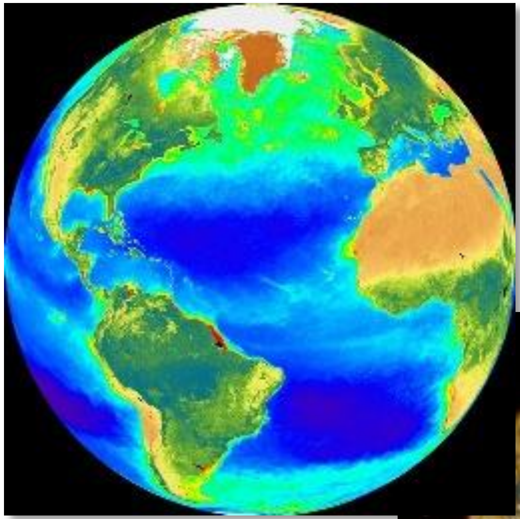
Alexandrium

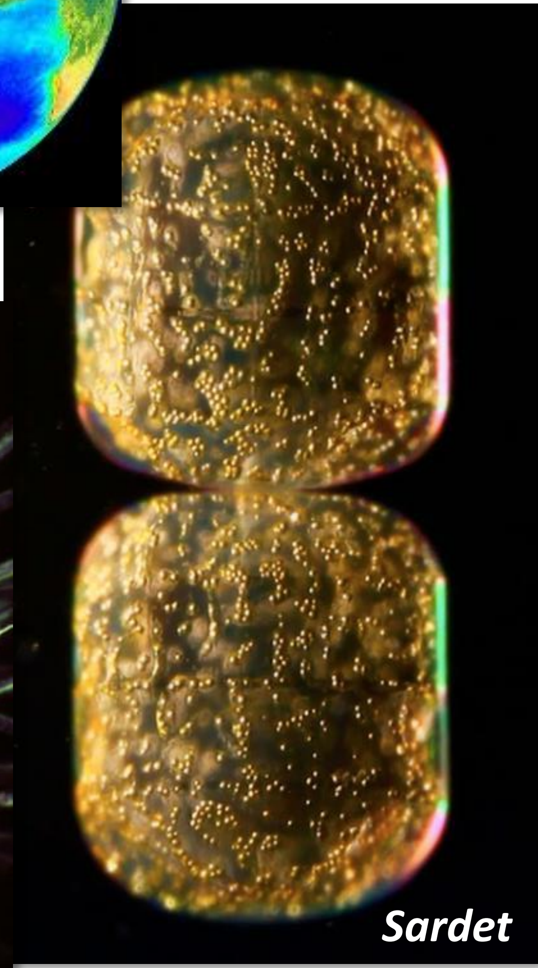

Not toxic, but
causes hypoxia

DIATOMS

Usually in nano and microsize

- Most common type of phytoplankton
- Have silica shells
- Single cells occasionally form chains
- Two forms: pennate, centric
- Some toxic (domoic acid)
- Spring bloomers, effective carbon exporters





Sardet's book Plankton Chronicles

PHYTOPLANKTON

- Particle (size, shape, morphology)
- Taxa (Taxonomic approach)
- Chemistry (pigments, minerals, metabolites..)
- Function (role)

PHOTOSYNTHETIC PIGMENTS

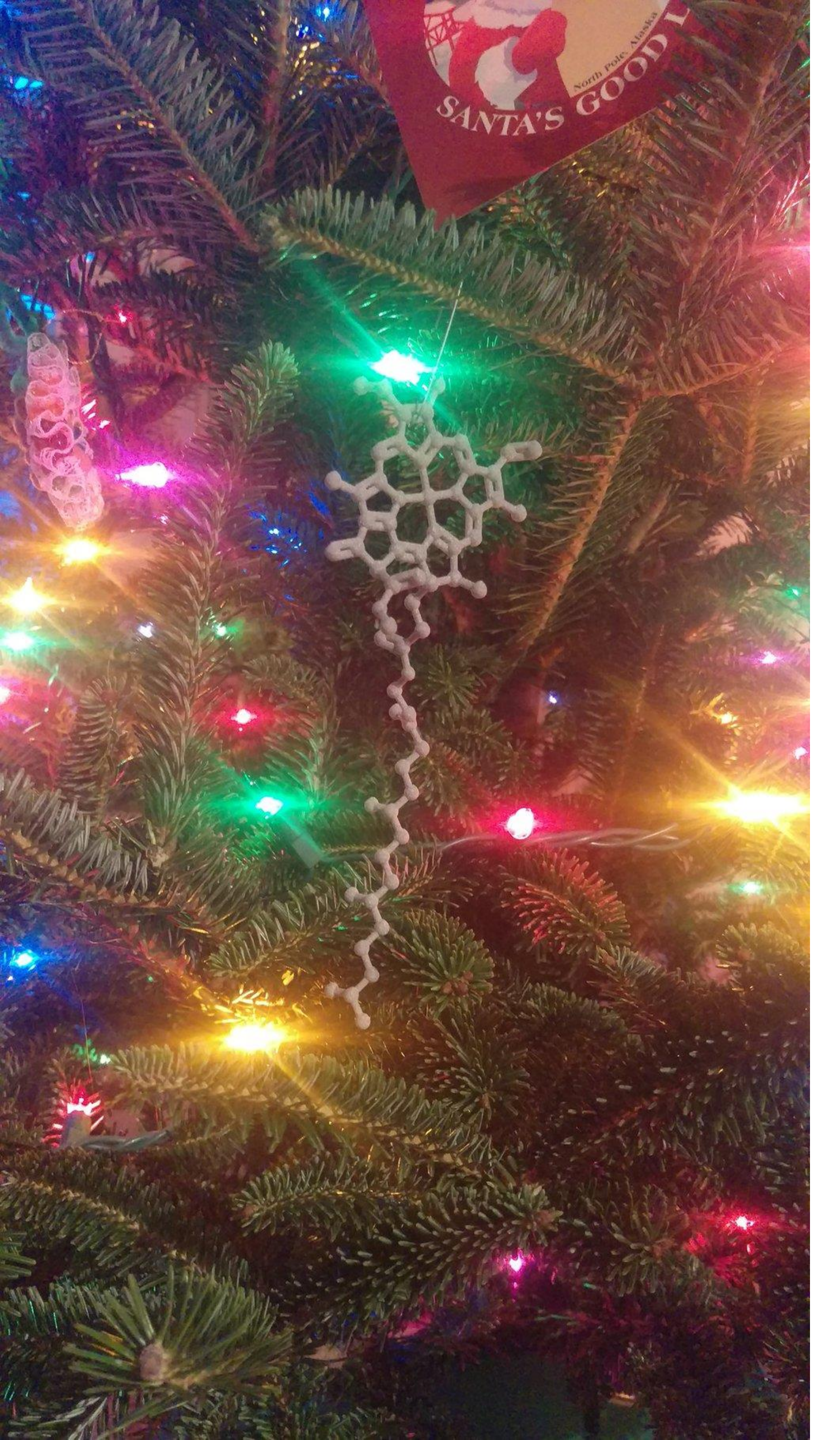
(Ps-Light harvesting, PP – photoprotective)

- **Chlorophylls (green)**
  - Chlorophylls a, b, c, d
  - Divinyl chlorophyll
- Carotenoids(brownish/orangish)
  - Carotenes
    - Beta-carotenes
  - Xanthophylls
    - Peridinin
    - Alloxanthin
    - Zeaxanthin…..
- Phycobilins (blue-green/redish)
  - Phycocyanin
  - Phycoerithrin

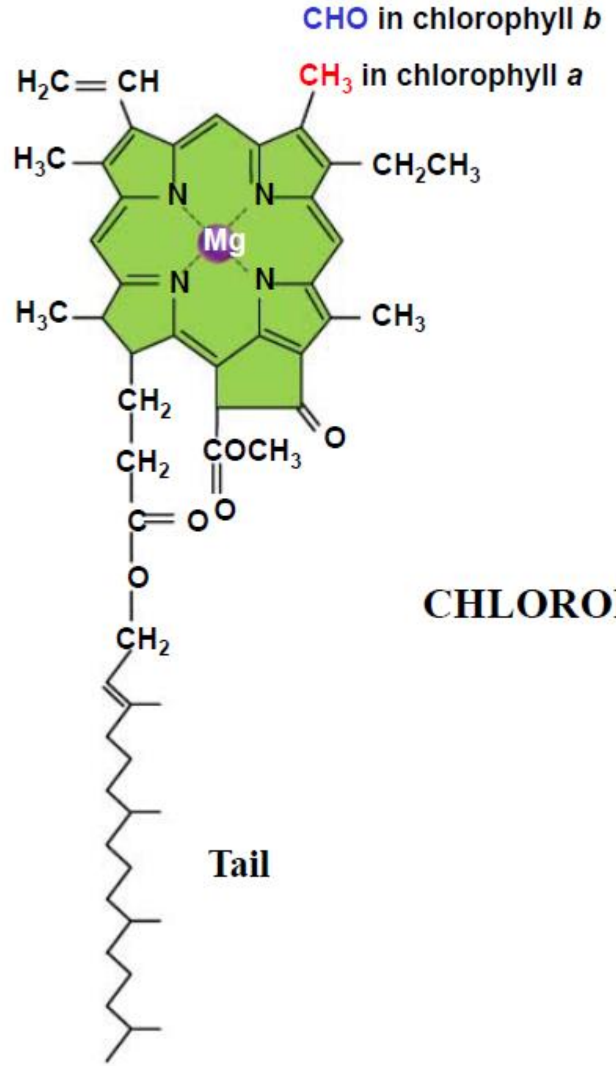
help with photosynthe sis and a little with blocking

These are the photoprotective

Intense light damages the system of the cell, can drive your ability to do photochemistry to zero That is where photoprotective pigments come in



HRH CHLOROPHYLL



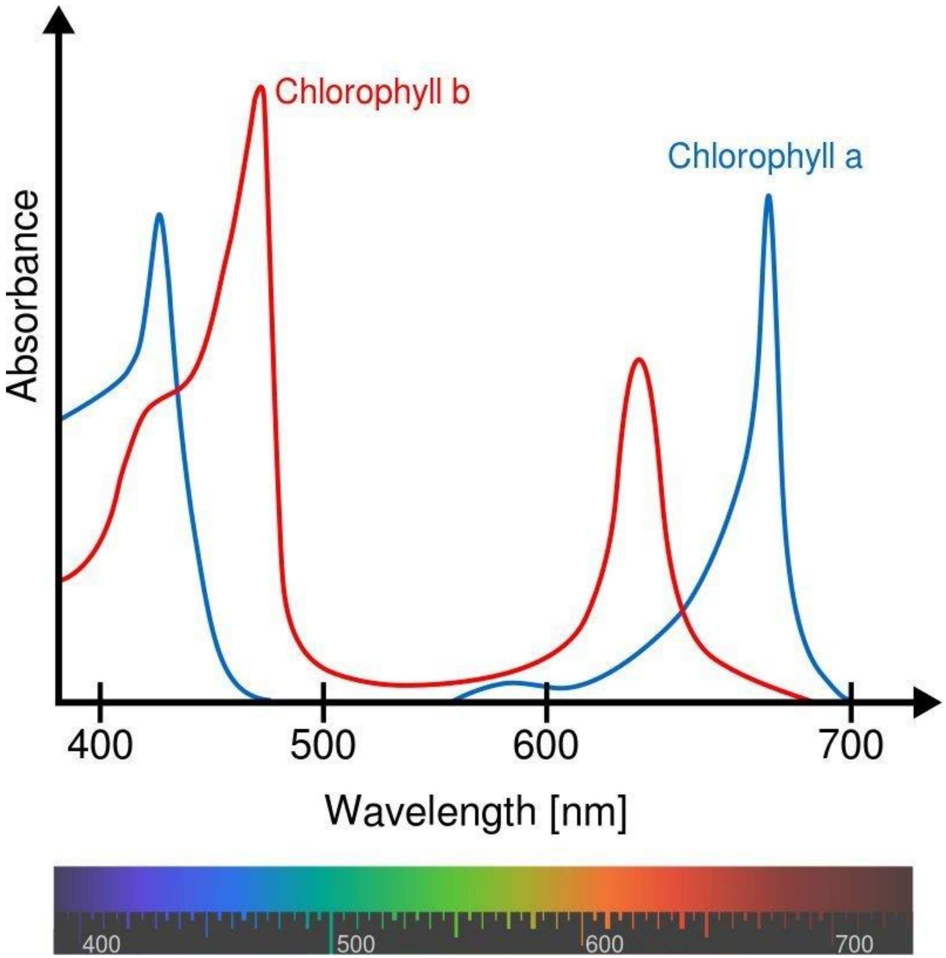
Center is Magnesium

Attachments are different depending on which organism

Porphyrin ring

CHLOROPHYLL a & b

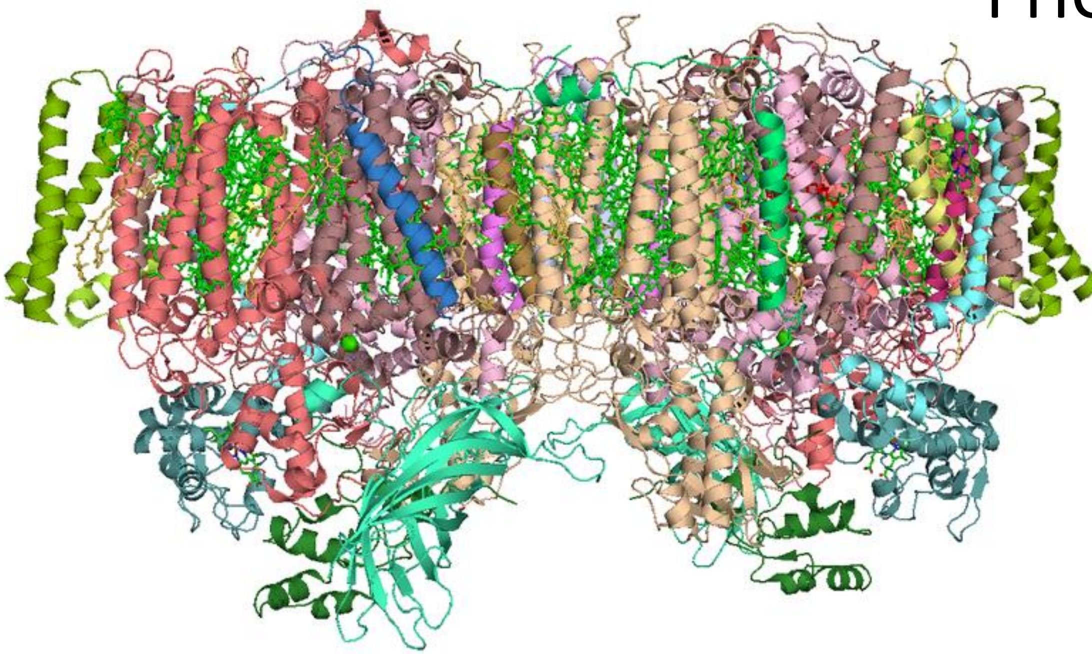
Chlorophyll absorption spectra (in vitro)



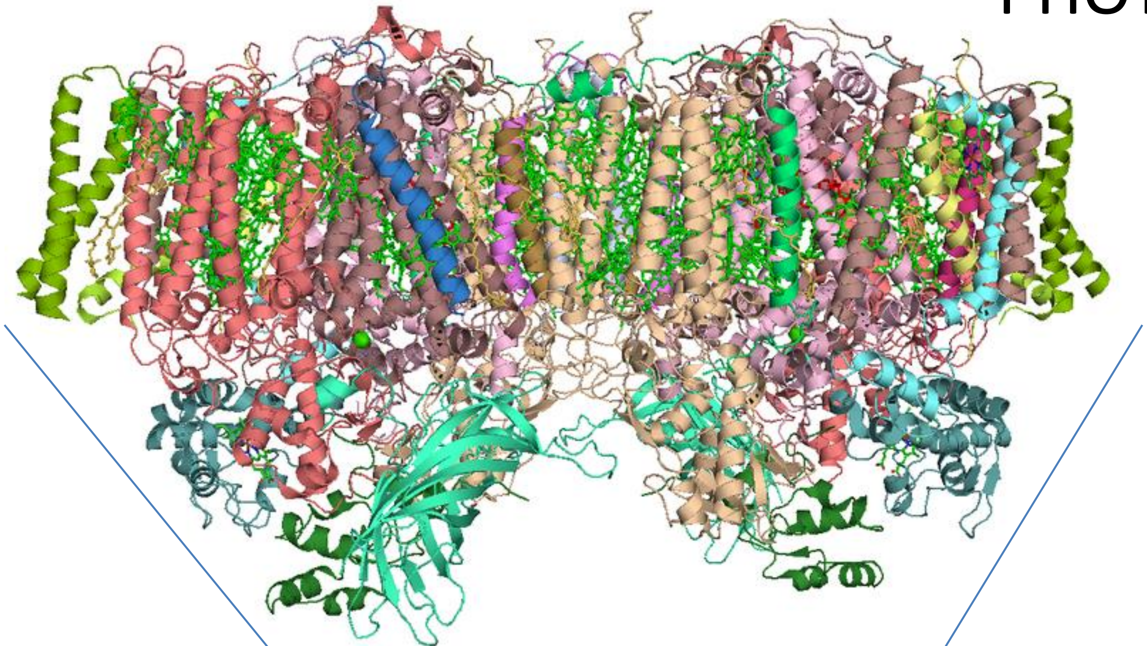
Pigment	Solvent	λmax (nm)
Chl a	Acetone	430, 662
	Diethyl ether	428, 660
	95% Ethanol	432, 664
	Methanol	432, 665
Chl b	Acetone	457, 646
	Diethyl ether	453, 642
	95% Ethanol	464, 649
	Methanol	469, 652

Adapted from Roy et al, 2012

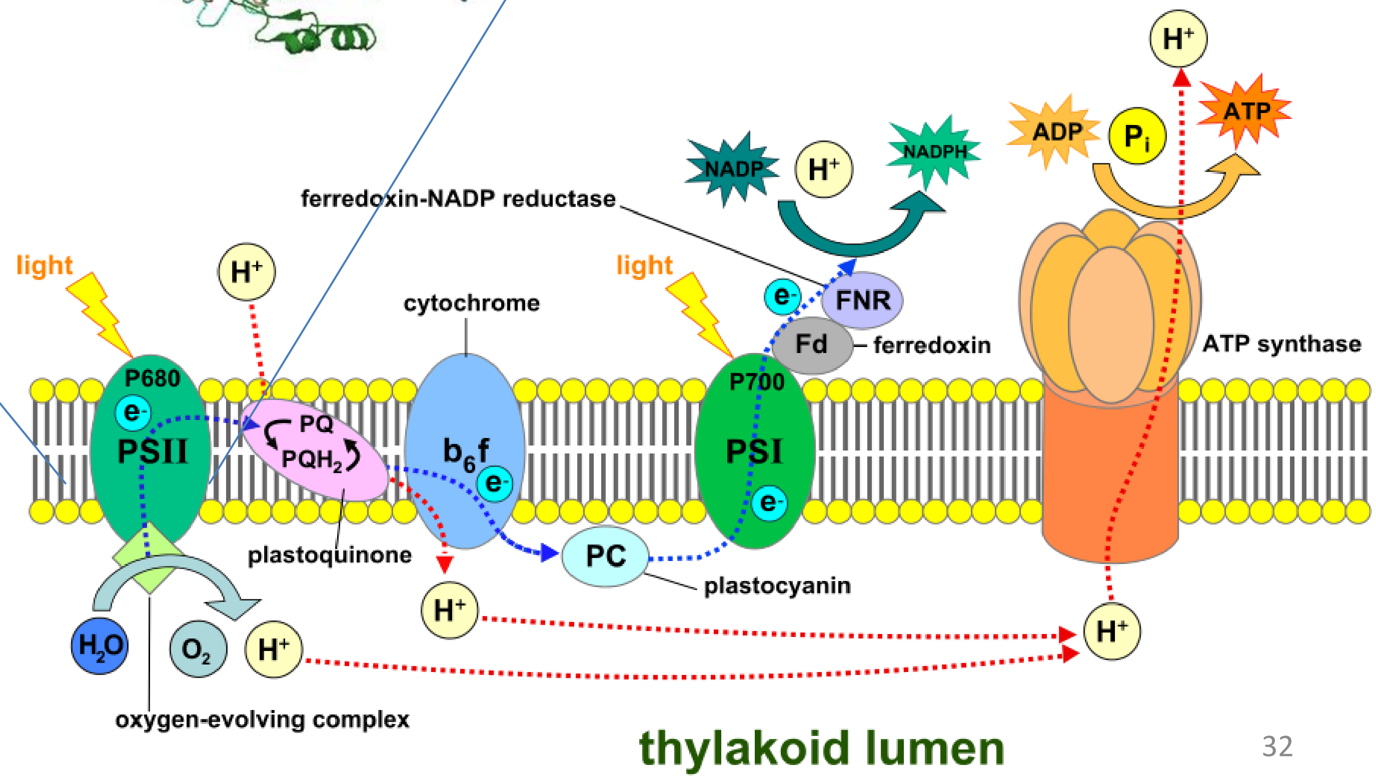
PHOTOSYSTEM II



PHOTOSYSTEM II



chlorophyll is not floating int he cell. It is embedded in a protein complex that is in a membrane that is inside a photosystem is inside a plastid in eukaryotes.
In prokaryotes, the photosystems are in thylakoids not in an organelle



The majority of energy absorbed goes to heat - not every cell but on a global level. If the cell is stressed those ratios change

Fluorescence is a tiny part

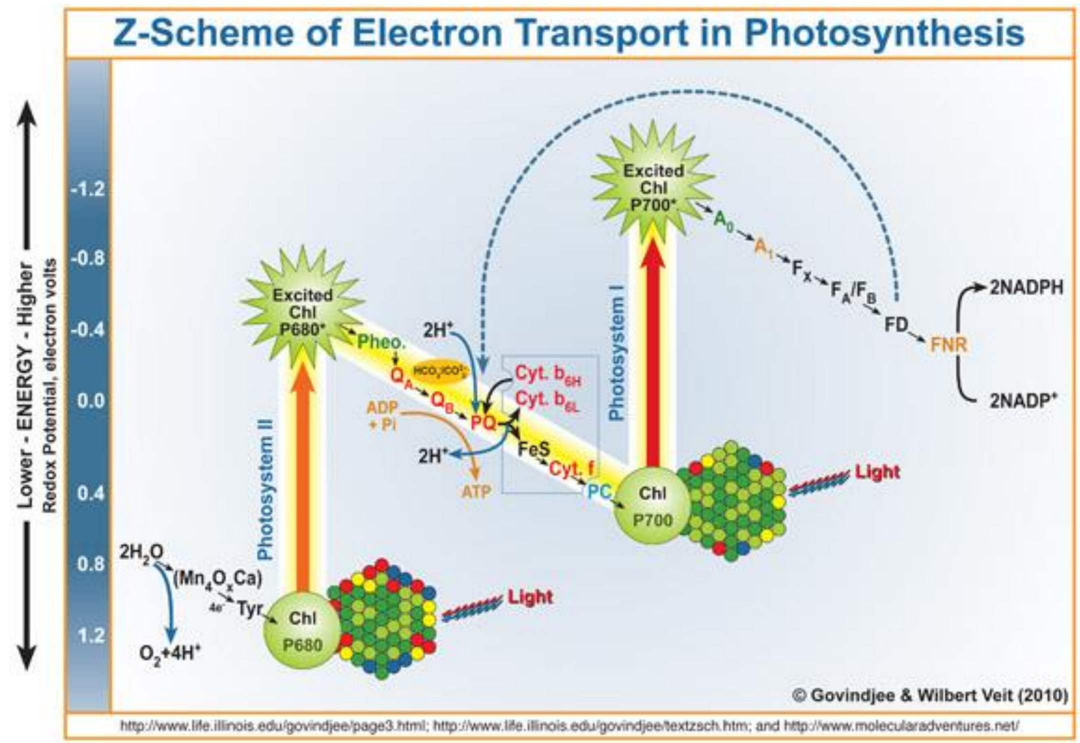
Different colors of dots are different pigments

MAGIC OF CHLOROPHYLL

NOT ALL ENERGY ABSORBED GOES TO PHOTOSYNTHESIS !!!

1) Heat (~60%)
2) Fluorescence (~7%)
3) Photosynthesis (~33 %)

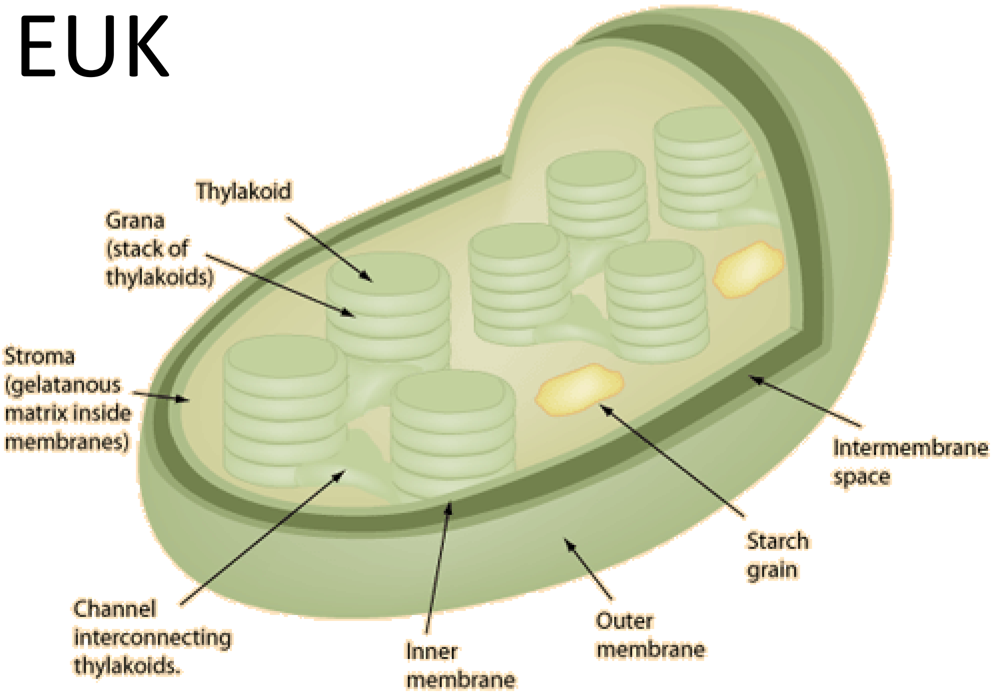
(Lin et al, 2016)



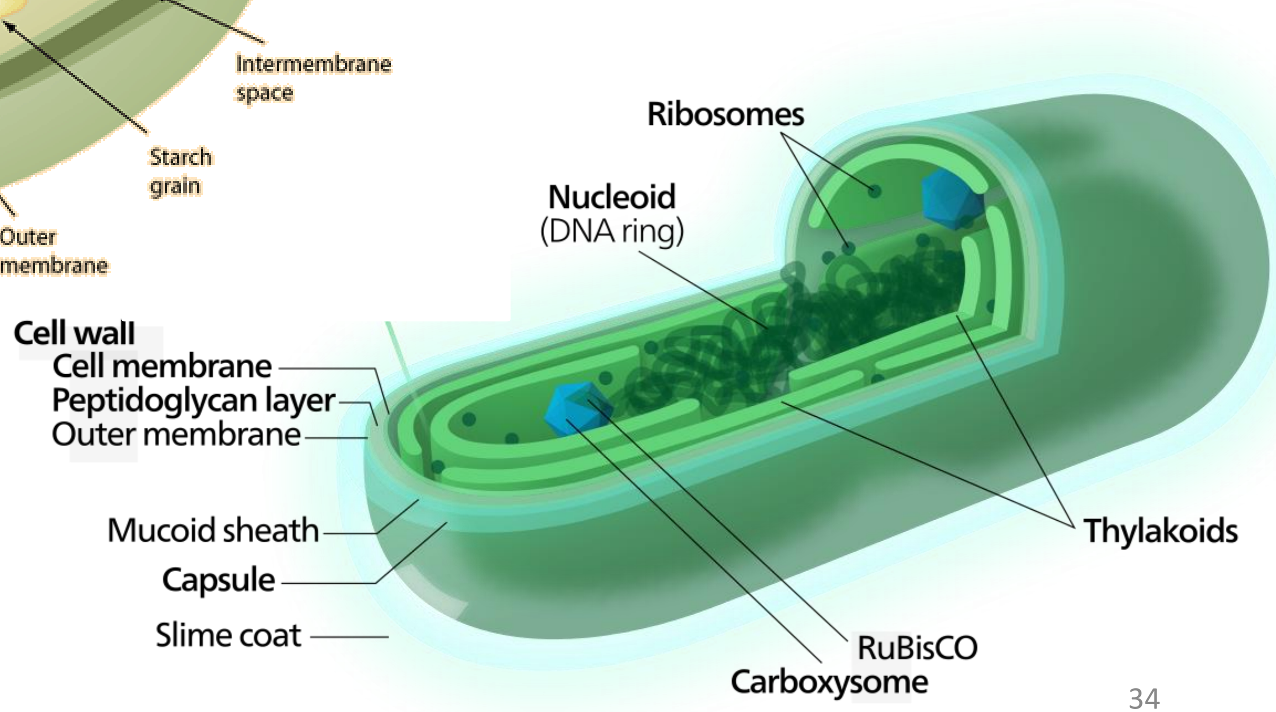
(Collin's lecture!!!)

CHLOROPHYLL (IN VIVO)

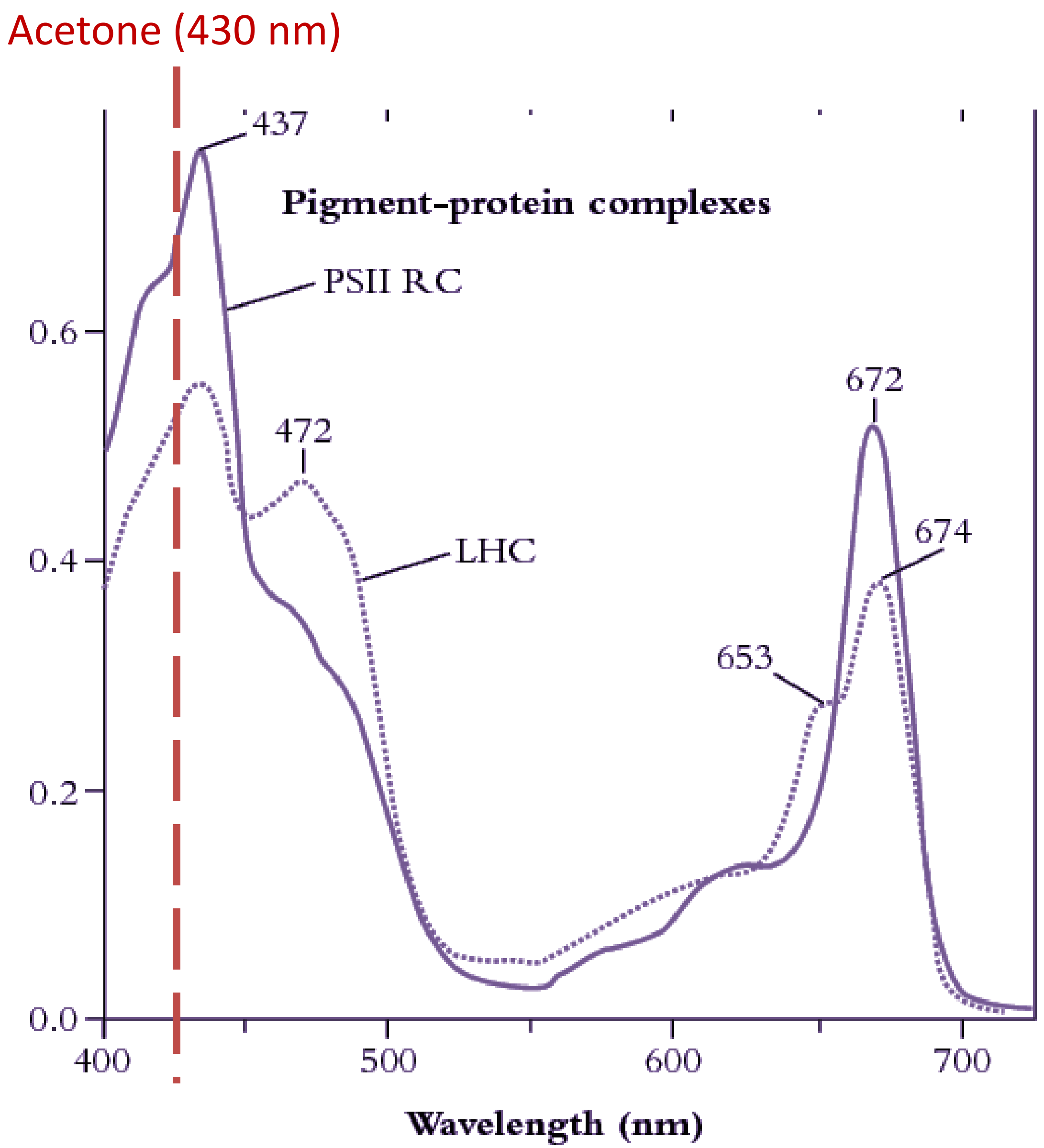
EUK



PRO



Chlorophyll *absorption* spectra (in vivo)

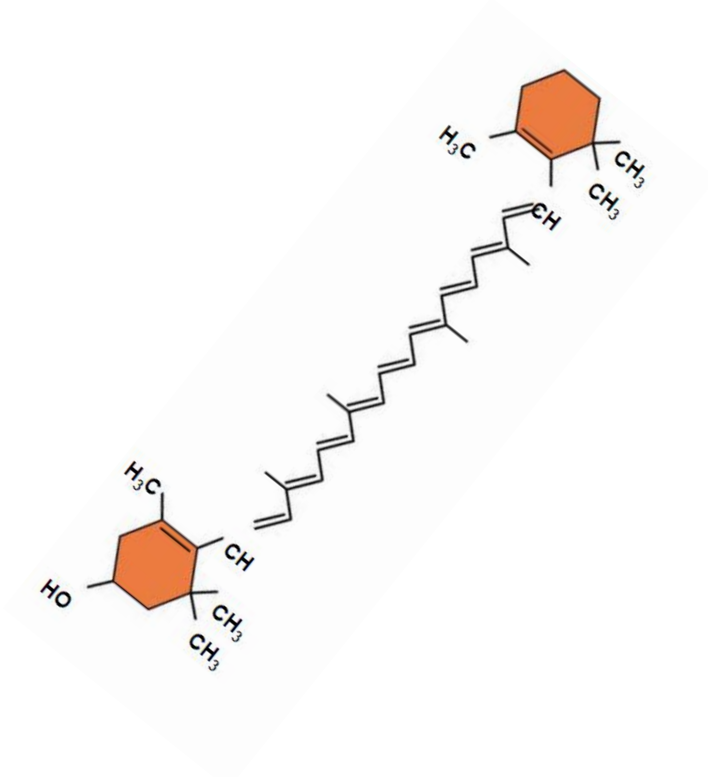


PS 2 is at 437

Acetone reflects in 430

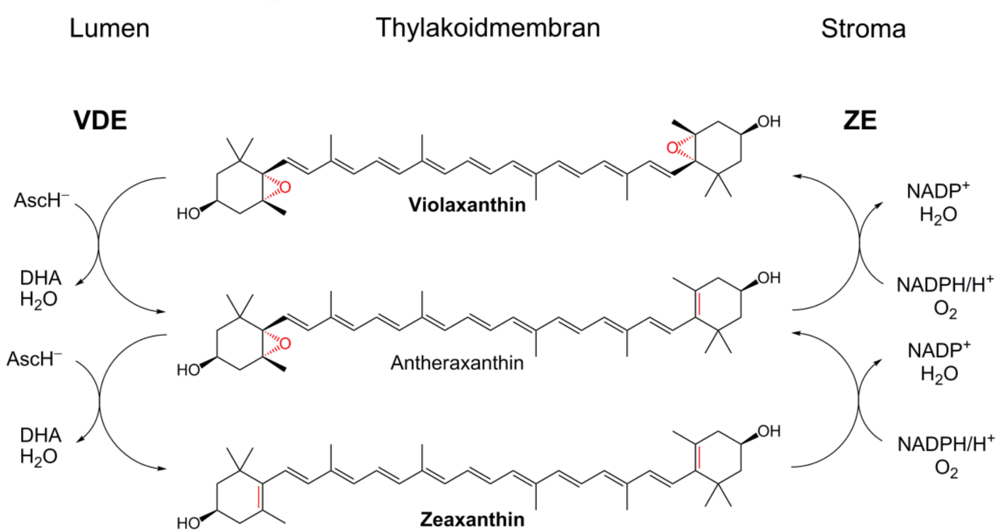
Evans, 1987

CAROTENOIDS



β – carotene (**Carotenes**)

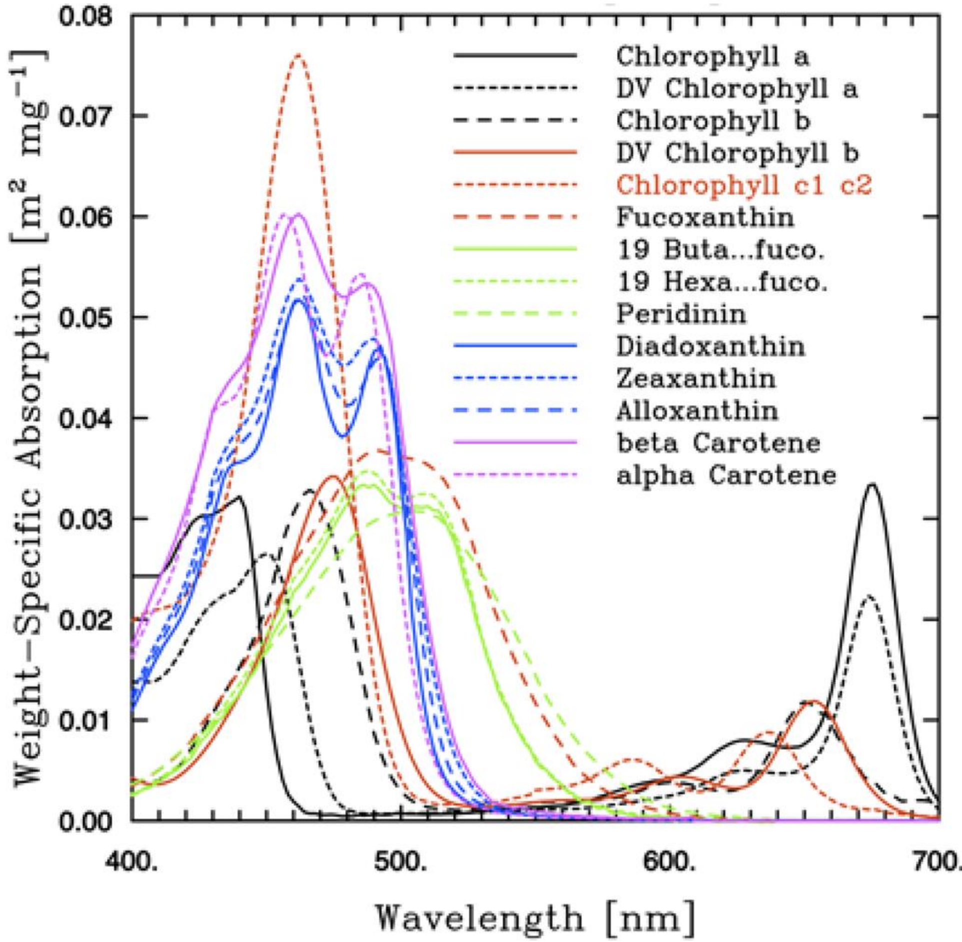
- Photosynthetic/photoprotective pigment
- Both in Photosystem I and II



Xanthophylls

- Photoprotective pigments
- Xanthophyll cycle – protective mechanism against photoinhibition…

Many other pigments



Devred et al, 2013

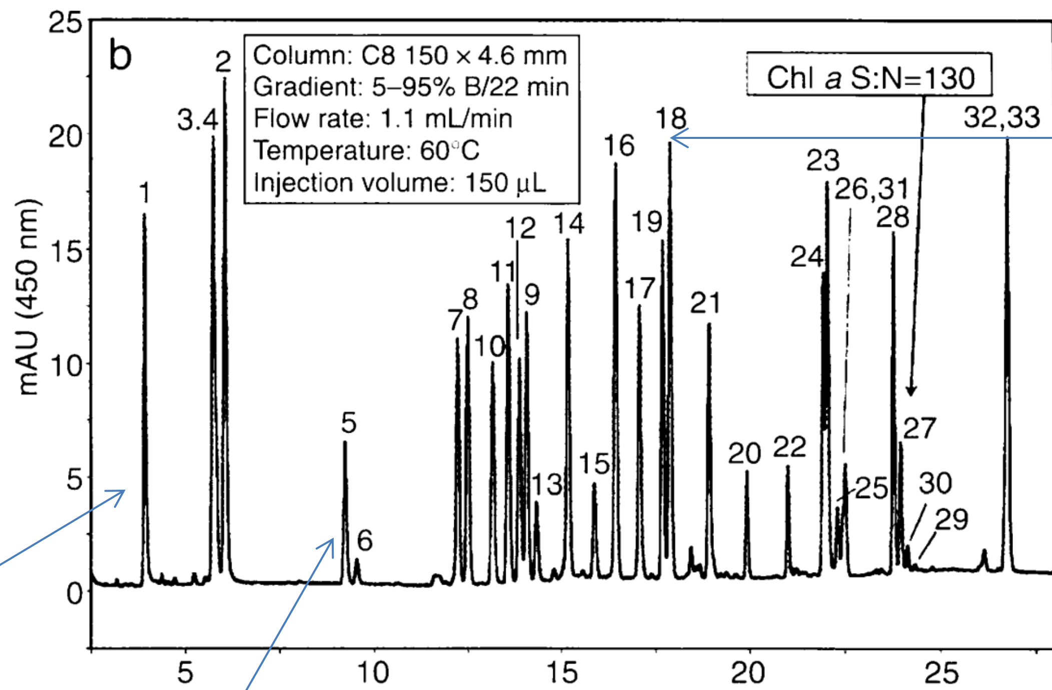
Pigments…

How we take the pigments out of the cell and analyze them.

High Preformance Liquid Chromatography (HPLC)

These are absorption heights

Each peak is a different pigment

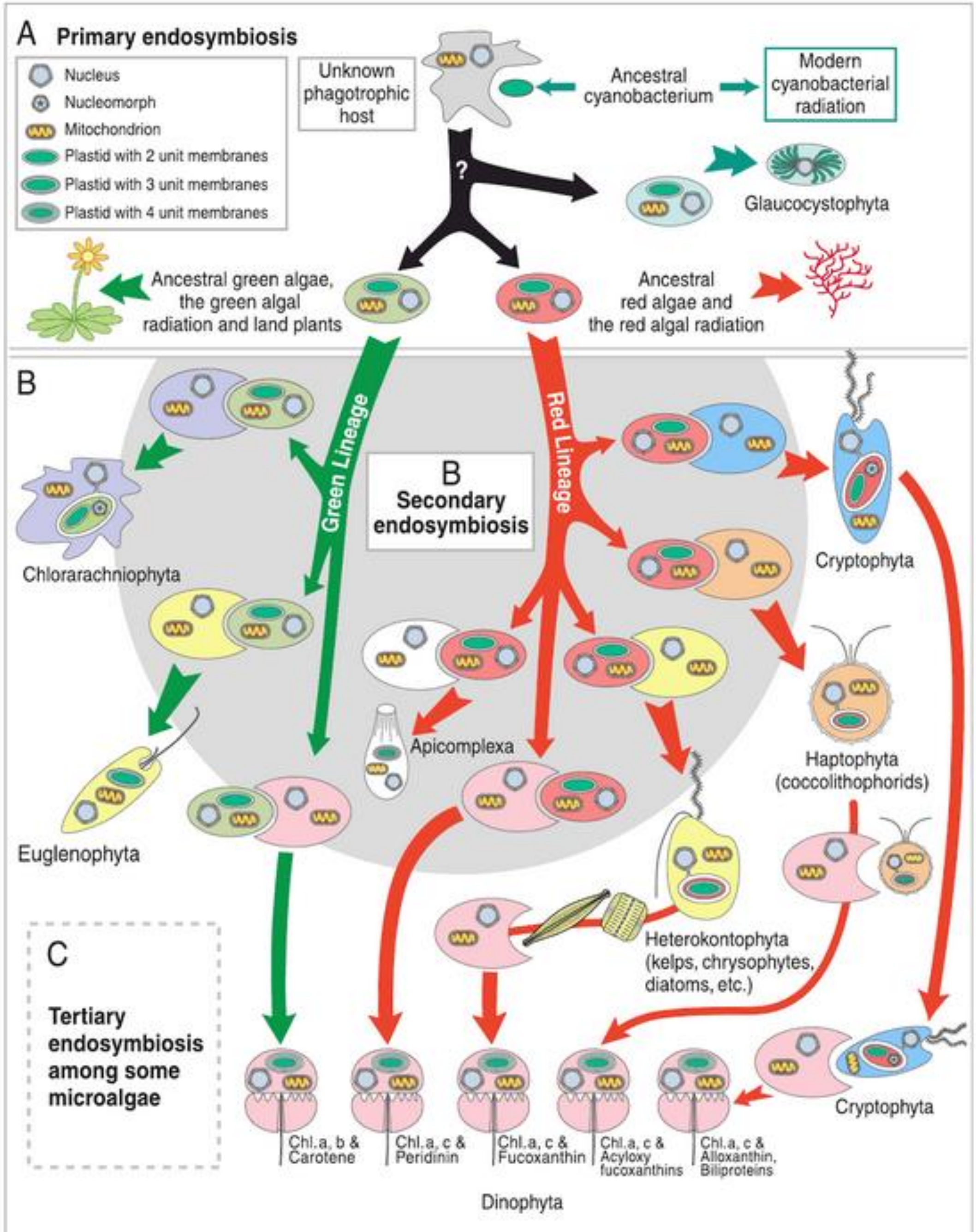


Lutein

Chl C

Peridinin

Bidigare, R. R., Van Heukelem, L., & Trees, C. C. (2005)

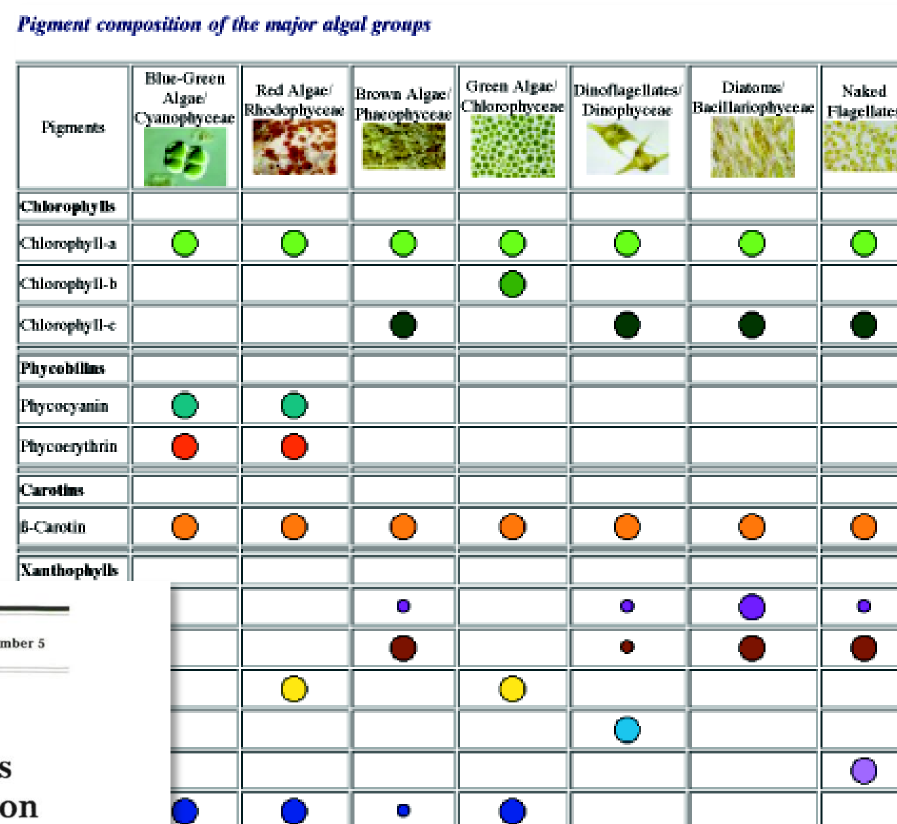


Different cells have different pigments, so we can use HPLC to identify different types

Origin of the species and the plastids in the cell will define their pigment structure..

PIGMENTS AS A TAXONOMICAL TOOL

- CHEMTAX – powerful tool if smart person uses it– careful of environmental condition and local flavors
- Other clustering methods



Pigment composition of the major algal groups

Pigments	Blue-Green Algae/ Cyanophyceae	Red Algae/ Rhodophyceae	Brown Algae/ Phaeophyceae	Green Algae/ Chlorophyceae	Dinoflagellates/ Dinophyceae	Diatoms/ Bacillariophyceae	Naked Flagellates
Chlorophylls							
Chlorophyll-a	●	●	●	●	●	●	●
Chlorophyll-b				●			
Chlorophyll-c			●		●	●	●
Phycobilins							
Phycocyanin	●	●					
Phycoerythrin	●	●					
Carotins							
ß-Carotin	●	●	●	●	●	●	●
Xanthophylls							
			●		●	●	●
			●		●	●	●
		●		●			
					●		
							●
	●	●	●	●			

Vol. 144: 265–283, 1996 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published December 5

CHEMTAX — a program for estimating class abundances from chemical markers: application to HPLC measurements of phytoplankton

M. D. Mackey[1,2], D. J. Mackey[2,*], H. W. Higgins[2], S. W. Wright[3]

[1]University Chemical Laboratory, Lensfield Rd, Cambridge CB2 1EW, United Kingdom
[2]CSIRO Division of Oceanography, PO Box 1538, Hobart, Tasmania 7001, Australia
[3]Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia

ABSTRACT: We describe a new program for calculating algal class abundances from measurements of

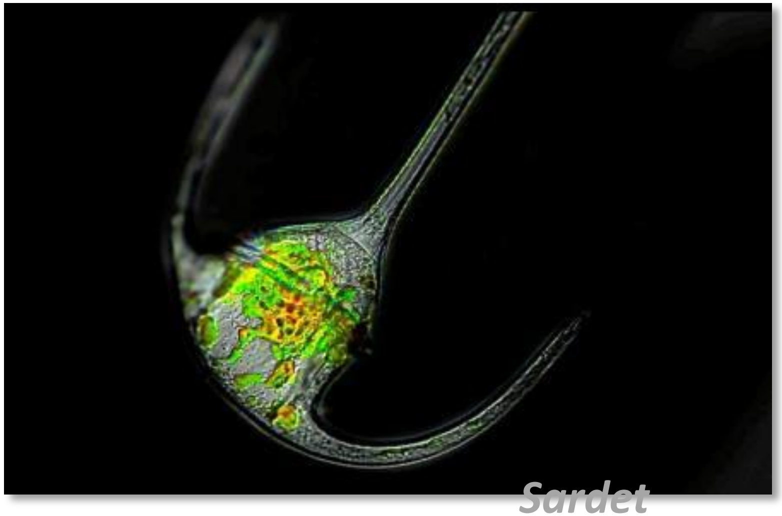
PHYTOPLANKTON

- Particle (size, shape, morphology)
- Taxa (Taxonomic approach)
- Chemistry (pigments, minerals, metabolites..)
- Function (role)

PHYTOPLANKTON FUNCTIONAL TYPES - physiological and ecological criteria

"…group of organisms (irrespective of taxonomic affiliation) that carry out a particular function, e.g. a chemical process such as calcification, silicification, nitrogen fixation, or dimethyl sulfide production; functional groups are also sometimes referred to as 'biogeochemical guilds'."

IOCCG Report 15, (2014)



Sardet

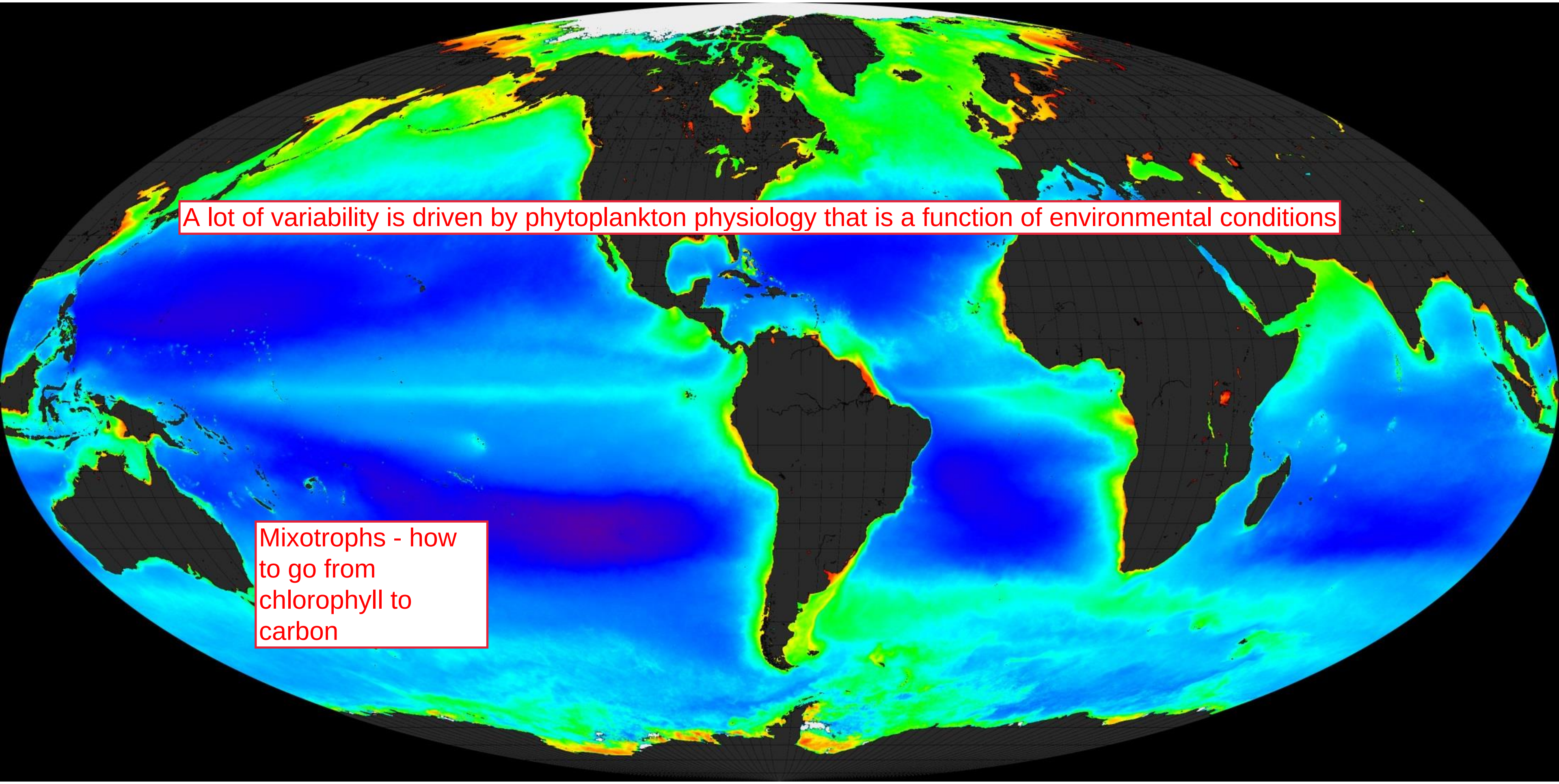
Another great read

PHYTOPLANKTON AS FUNCTIONAL TYPES

Functional type

- autotrophic, oxygenic, oxygen evolving
- size and shape
- transformer of specific nutrient (N2 fixer, CaCO3 precipitator, silica polymerizer, etc.); ballasting to enhance C flux; specialized nutrient-up take pathways, sequestering mechanisms; unique C:N:P:trace metal ratio
- nutritional value to higher trophic organisms, such as essential fatty acids, toxins or development disrupters, paleo markers
- ability to live in turbulent vs. stratified environment
- motility for enhancing nutrient acquisition, encounter gametes, avoiding predation
- what else ??

Is it straightforward?
Lets look at chlorophyll… (20yrs!)



Variability… 2-3 orders of a magnitude

Postulates:

- From chlorophyll we can get cell abundances

- From chlorophyll we can get cell carbon

- From change in chlorophyll we can get growth rates

Plant in your kitchen problem

Postulates:

- From chlorophyll we can get cell abundances
- From chlorophyll we can get cell carbon
- From change in chlorophyll we can get growth rates

Packaging - basil will get darker when you move it from the light.

Areas with less light, you can have one algae with a chlorophyll to cell ratio and a totally different ratio in an area with more light

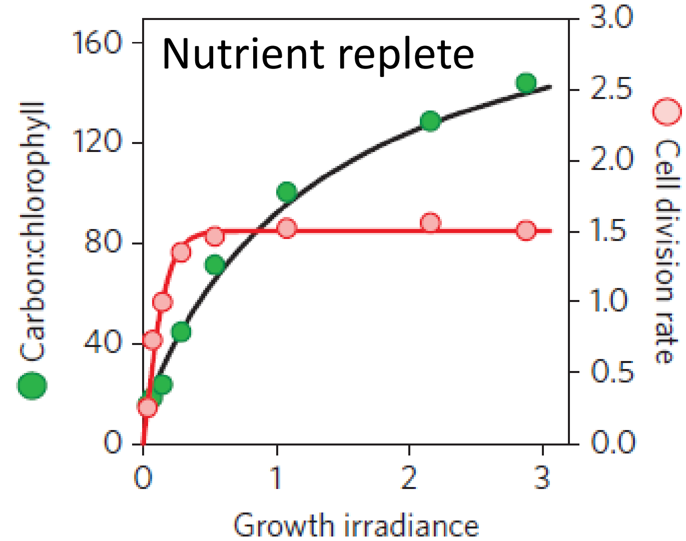
Plant in your kitchen problem

Postulates:

- From chlorophyll we can get cell abundances

- From chlorophyll we can get cell carbon

- From change in chlorophyll we can get growth rates



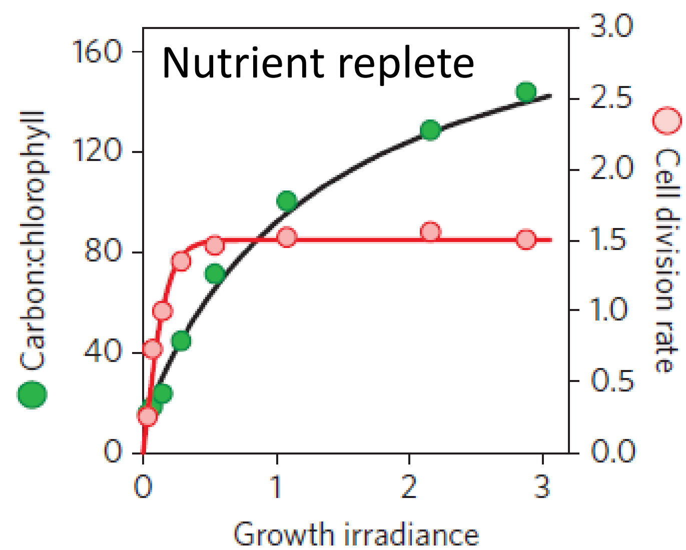
Plant in your kitchen problem

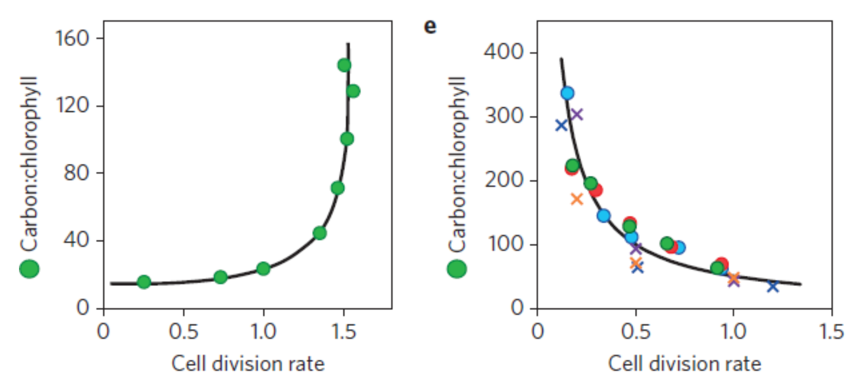
Postulates:

- From chlorophyll we can get cell abundances

- From chlorophyll we can get cell carbon

- From change in chlorophyll we can get growth rates



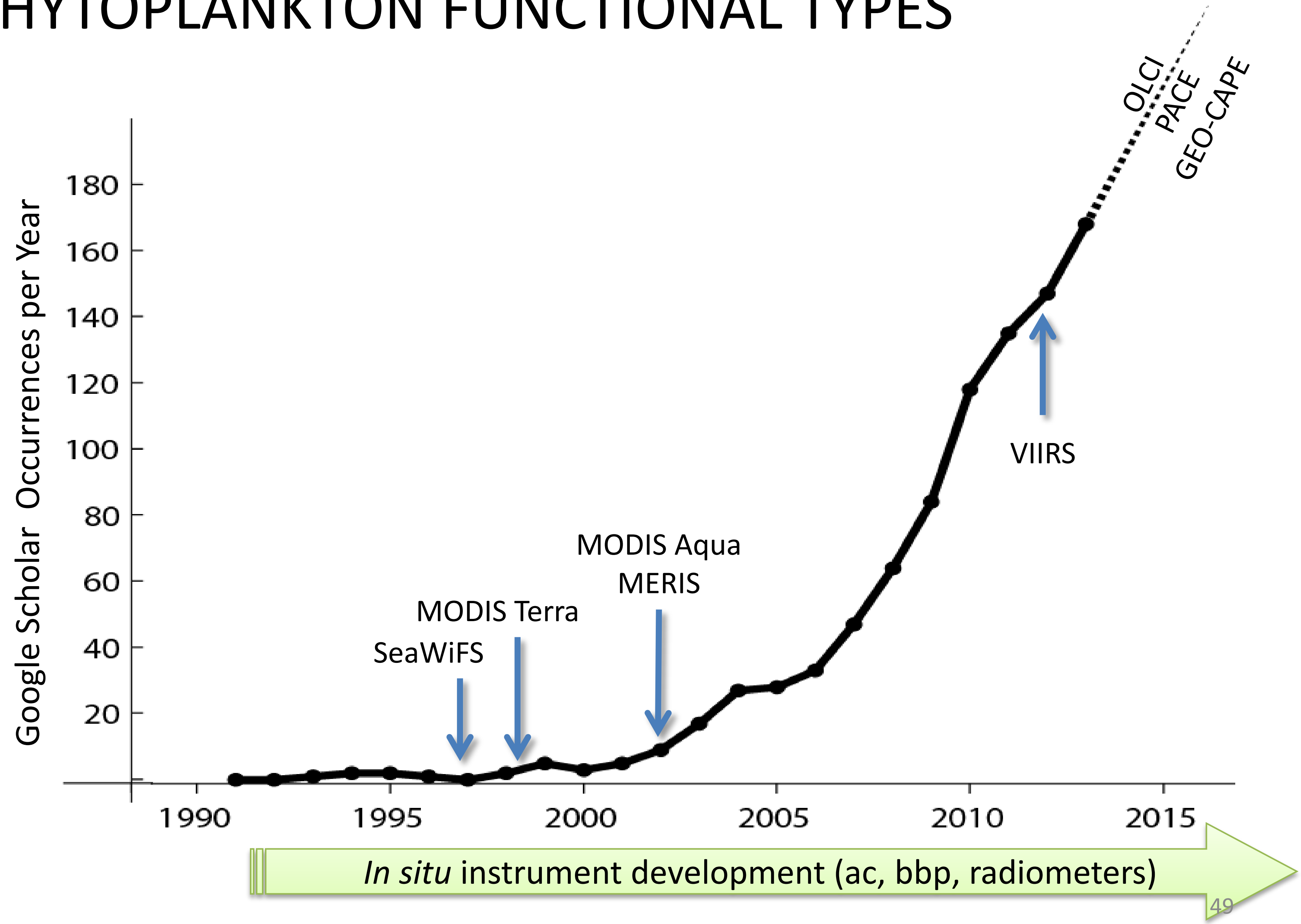


Nutrient replete

Nutrient limited

Behrenfeld, 2016

PHYTOPLANKTON FUNCTIONAL TYPES



HOW TO STUDY PHYTOPLANKTON FUNCTIONAL TYPES with OPTICS?

<u>Focus on specific morphological and structural features that impact light</u>

- Specific pigment structure leads to specific optical signal
- Specific size will lead to specific optical signal (then we talk about Particle Size Classes)
- Mind the ecology (and environment)

<u>Focus on taxa specific ecological traits and trophic states</u>

- E.g. Certain chlorophyll/ IOP concentration infers specific community composition

HOW (Feasible is) TO STUDY PHYTOPLANKTON FUNCTIONAL TYPES with OPTICS?

You will be able to answer that question in the end of this class

Remember!

- **Know your friends and your enemies**
- **Be realistic**
- **Validate**