Blue-Green Biological Sensing in the Marine Environment: Mechanisms, Regulation, and Evolution

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Thanks!
"Team CA4"

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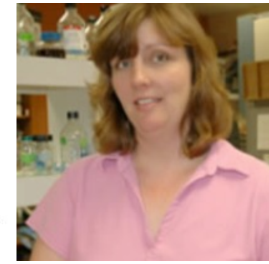
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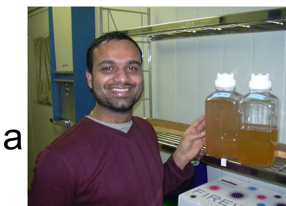
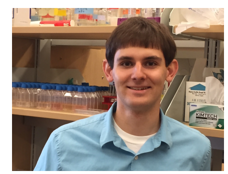
Jon Karty
Chemistry


Andrian Gutu

Animesh Shukla
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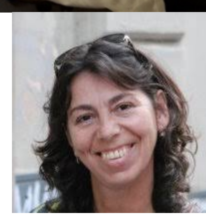

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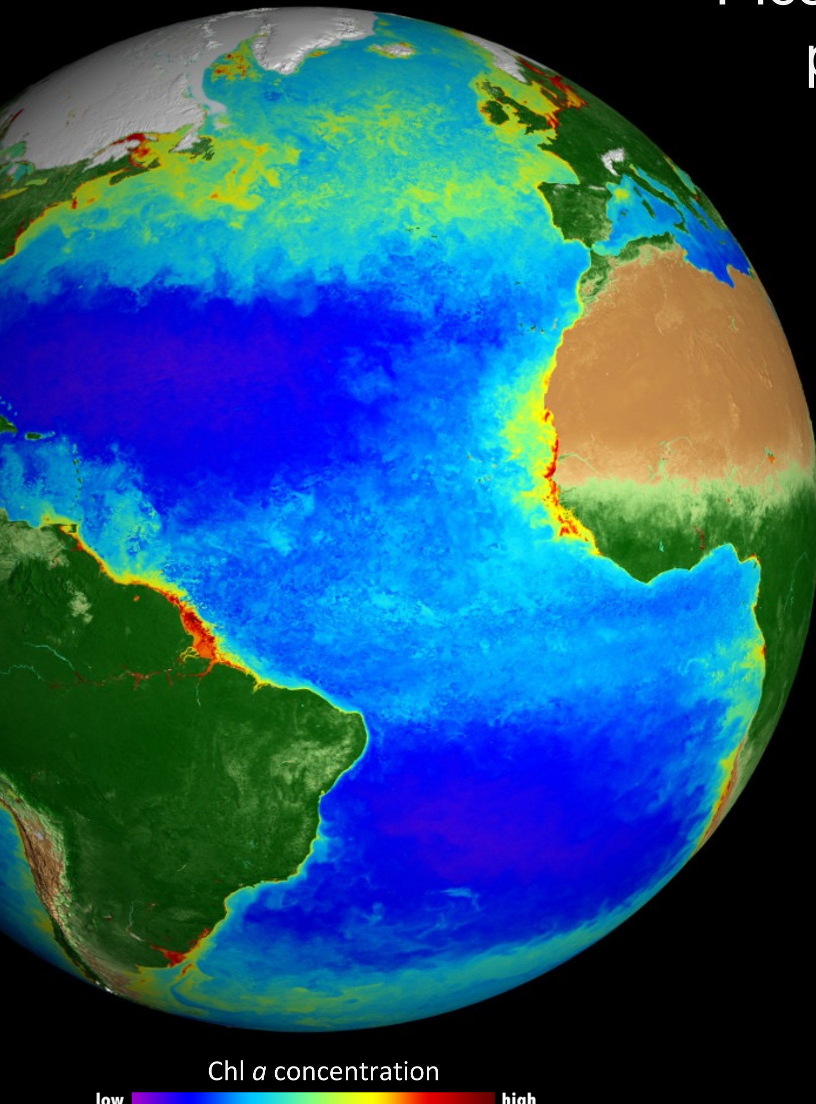
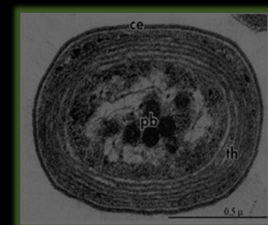
Picocyanobacteria are the most abundant photosynthetic organisms on Earth



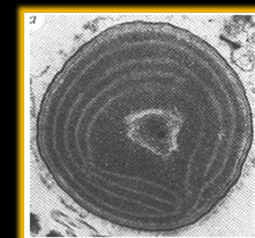


Prochlorococcus

0.5-0.8 µm

Warm/temperate

Oligotrophic waters



Synechococcus

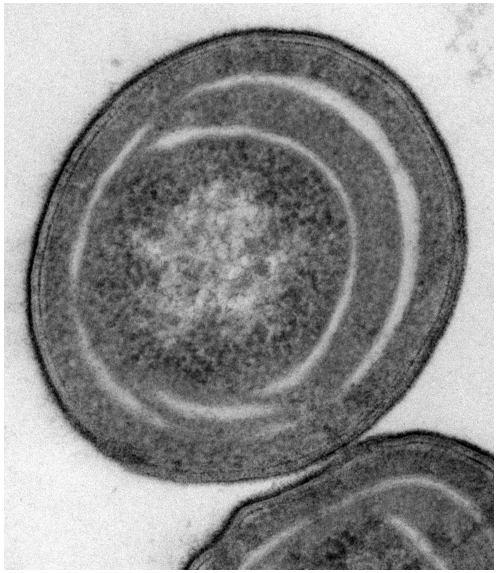
0.8-1.2 µm

Equator/polar circles

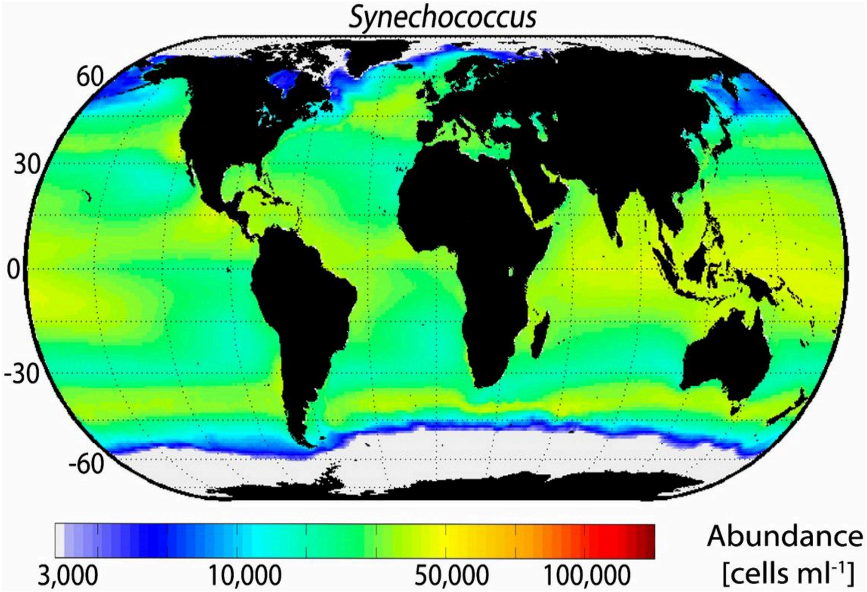
Mesotrophic waters

16% of global primary production

Synechococcus are photosynthetic microbes that are widely distributed in oceans and strongly impact global ecology



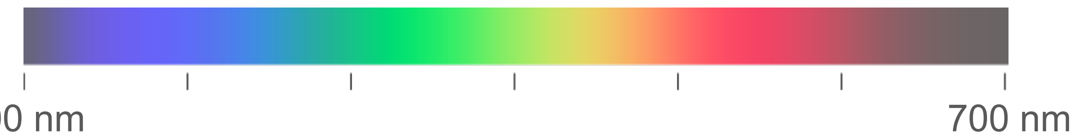
Electron micrograph of *Synechococcus*



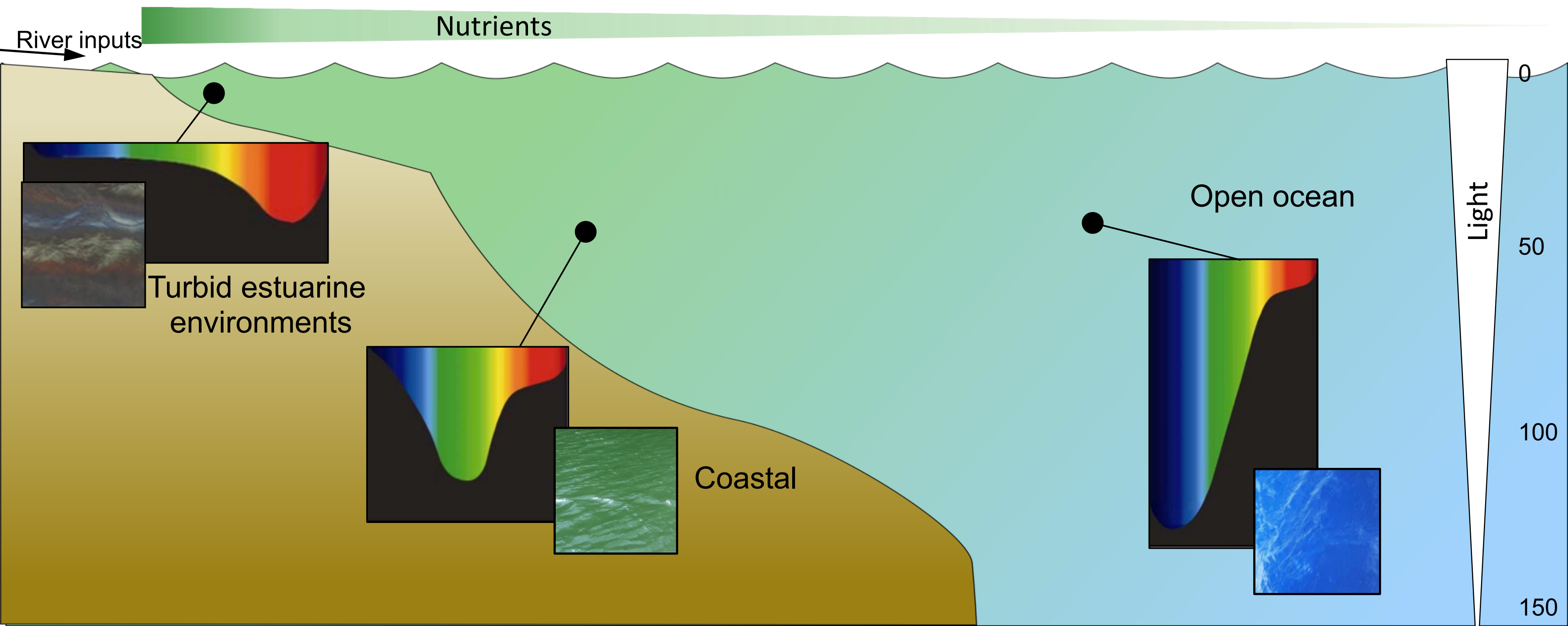
- estimated global population of 7 x 10^{26} cells
- some *Synechococcus* phenotypes are spread by "horizontal gene transfer"
- variation in ***photosynthetic light harvesting ability*** is one of these phenotypes

Synechococcus pigmentation varies with spectral distribution in the marine environment

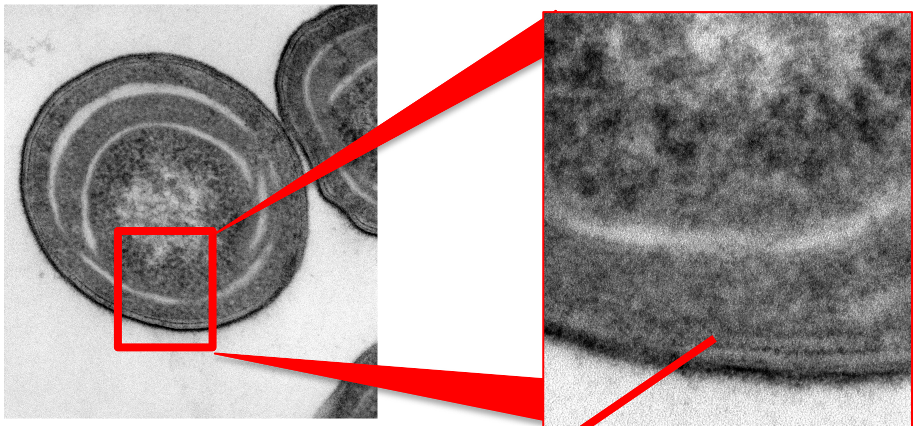
Spectral distribution of sunlight:

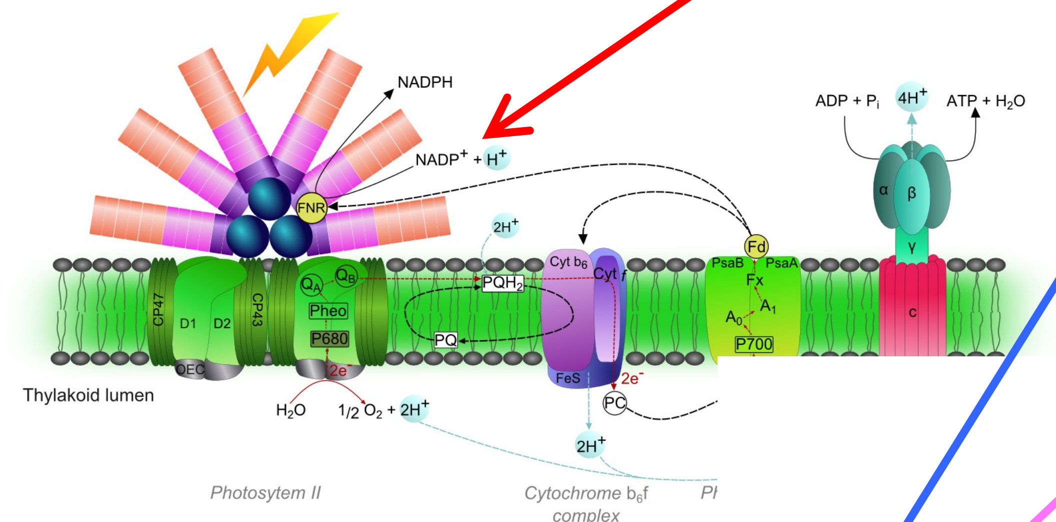


Marine *Synechococcus* strains

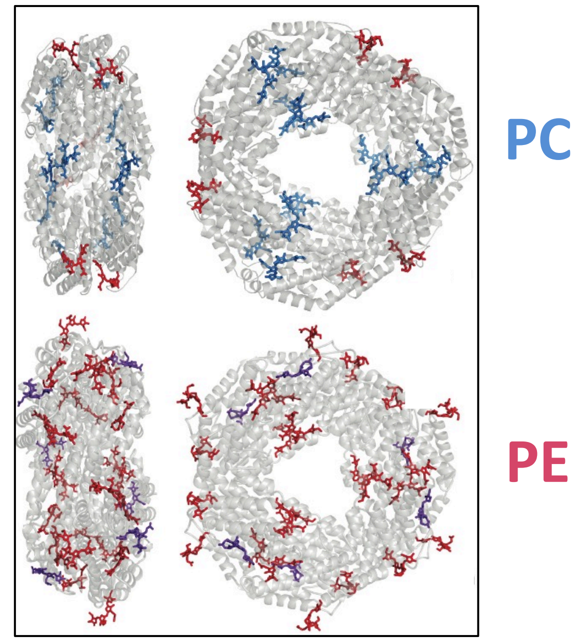


Light harvesting structures in *Synechococcus* are “phycobilisomes”





chromophores (blue and red) are added to proteins (gray) by enzymes called “ lyases ”



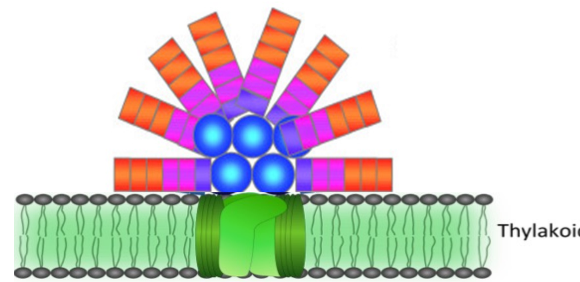
“ Rod ”

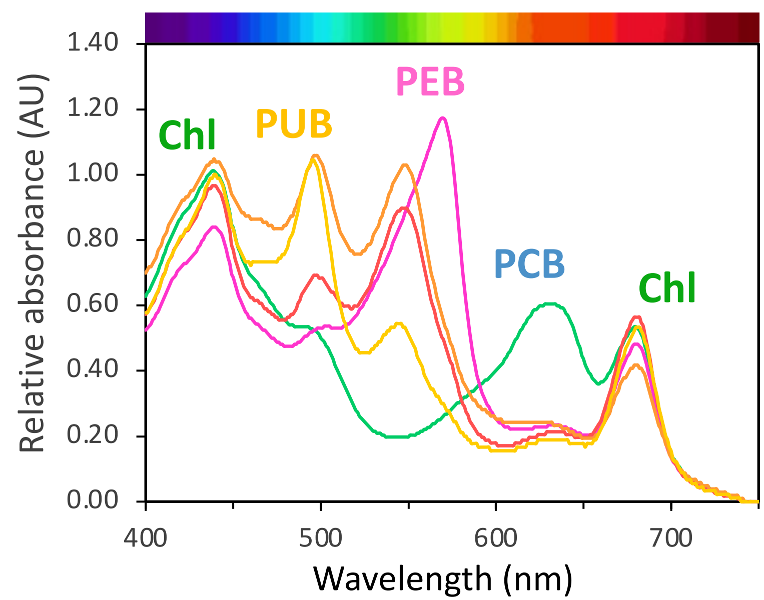
Rod phycobiliproteins:

PC	Phycocyanin
PEI	Phycoerythrin I
PEII	Phycoerythrin II

Synechococcus strains can vary significantly in their chromophore content to exploit different light environments

Different chromophores can be present in the rods of the antennae





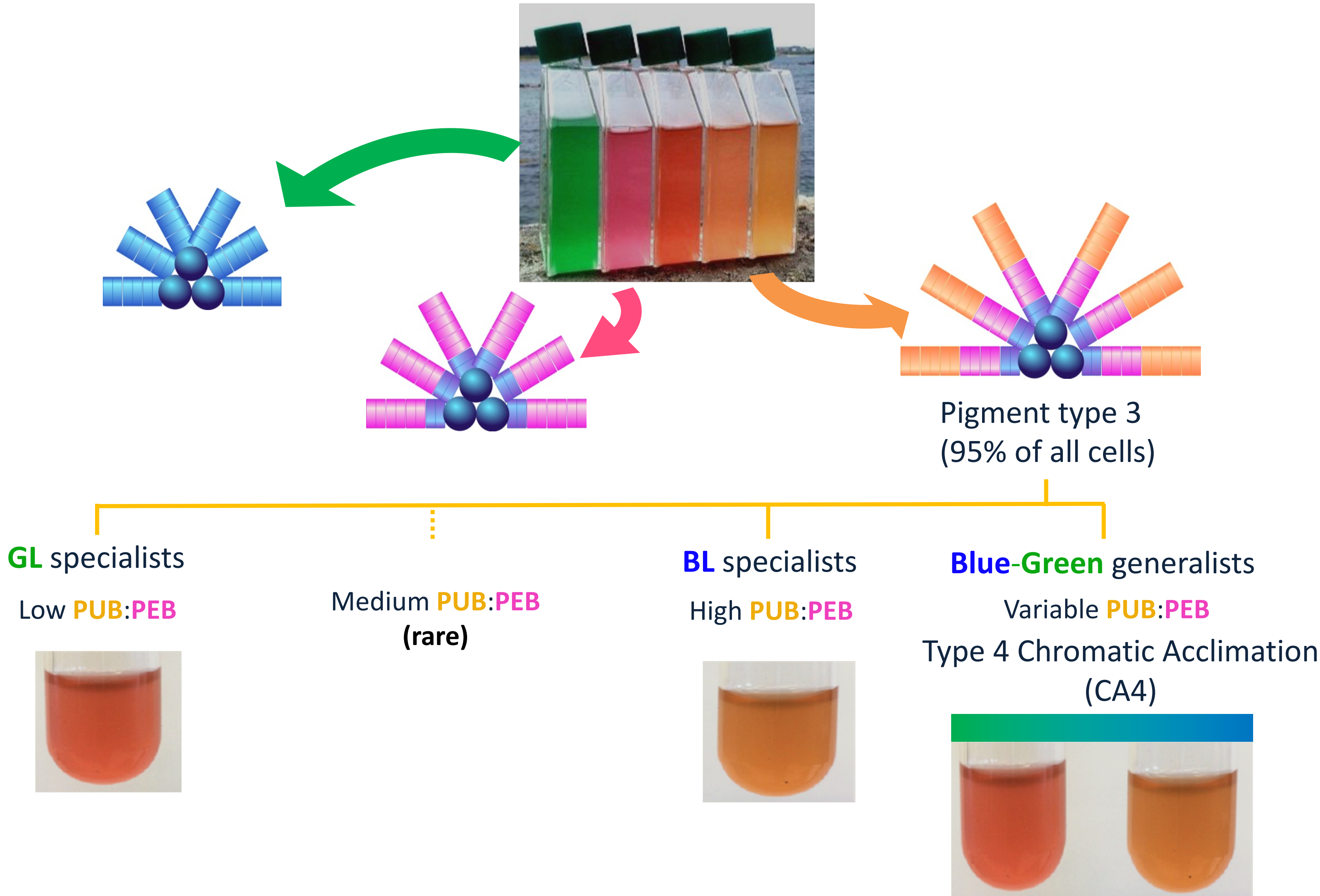
<u>*Synechococcus* light harvesting pigments:</u>

Phycourobilin=**PUB** A_{max}= 495 nm

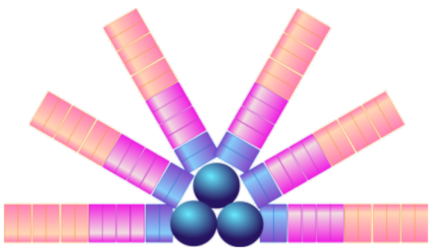
Phycoerythrobilin=**PEB** A_{max} = 550 nm

Phycocyanobilin=**PCB** A_{max} = 620 nm

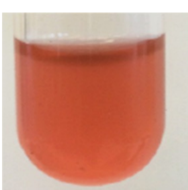
The major *Synechococcus* pigmentation types are: green light specialists, blue light specialists, and blue-green generalists



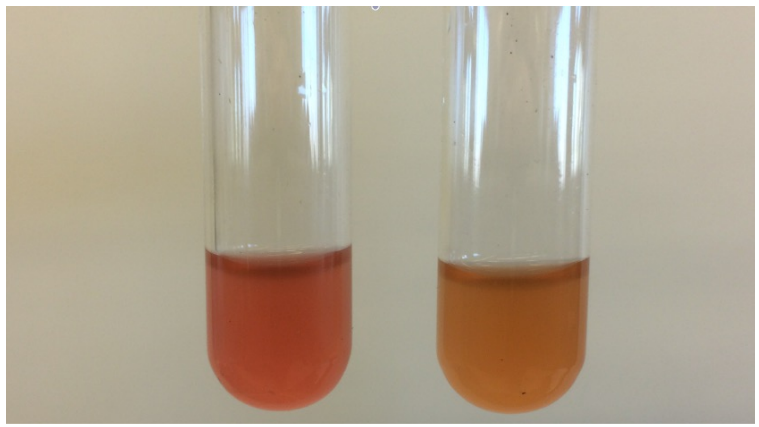
Type 4 Chromatic Acclimation (CA4) provides *Synechococcus* with the ability to efficiently absorb both blue and green light

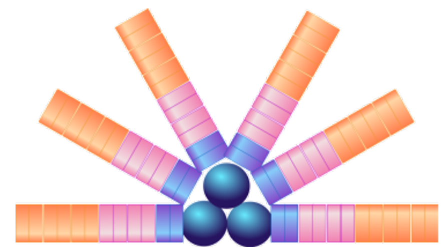


Low PUB: PEB ratio
GL specialist
phenocopy



Green Light **Blue Light**





High PUB: PEB ratio
BL specialist
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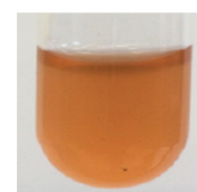


CA4 shift occurs in 3-5 days

<u>Today's questions:</u>

What confers CA4 to some *Synechococcus*?

How does CA4 work?

How do these cells perceive blue and green light?

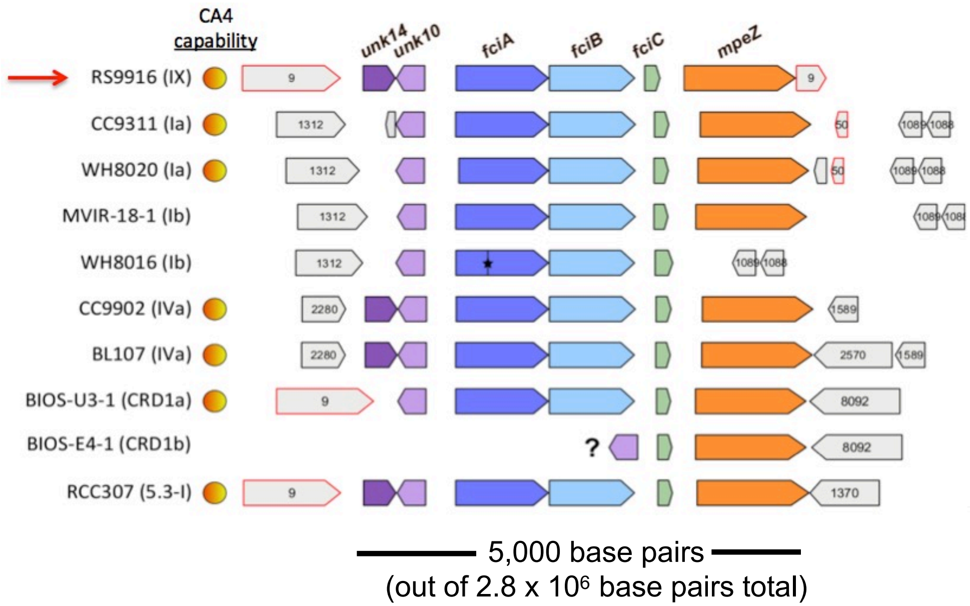
How did C4 evolve?

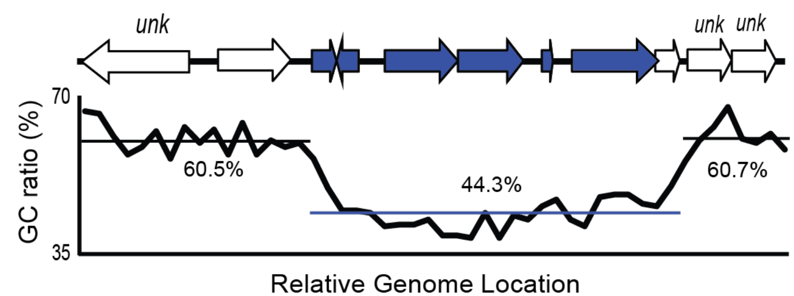
How common is CA4 and where is it found globally?

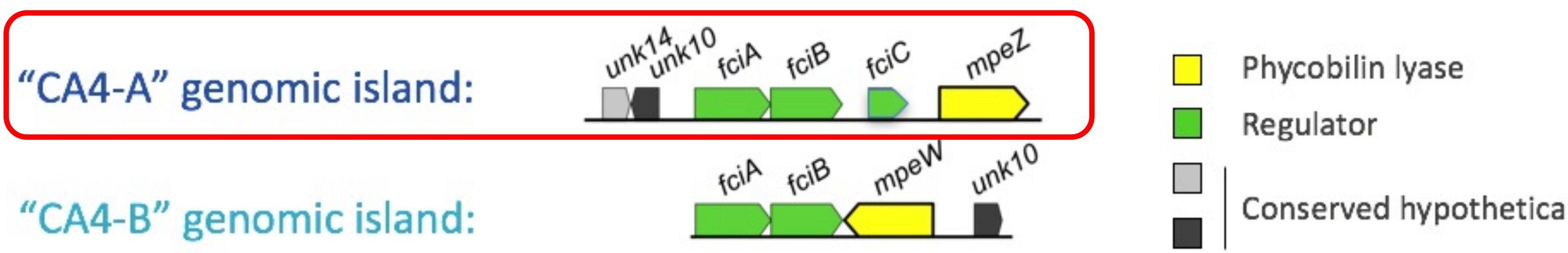
Can CA4 be detected by remote sensing?

What confers CA4?

Analysis of over 70 *Synechococcus* genomes revealed two types of "genomic islands"



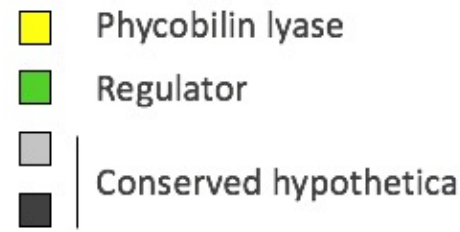




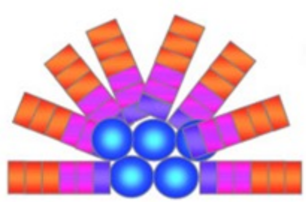
How does CA4 work?

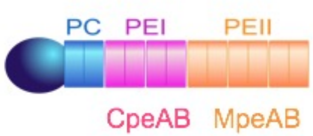
Gene expression and chromophore location data gave initial hints

“CA4-A” genomic island:



RNA abundance increase in BL: 40x 10x 35x





PE II = (MpeA, MpeB)

PE I = (CpeA, CpeB)

Protein	Cysteine position	Bilin in GL	Bilin In BL
MpeA	75 83 140	PUB PEB PEB	PUB PUB PUB
MpeB	50, 61 82 165	PUB PEB PEB	PUB PEB PEB
CpeA	82 139	PEB PEB	PEB PUB
CpeB	50, 61 82 159	PUB PEB PEB	PUB PEB PEB

Genetic tools developed:

- -transformation
- -CRISPR/cpf1
- -Tn5 mutagenesis
- -insertional mutagenesis
- -selectable markers
- -autonomously replicating plasmids
- -reporter constructs

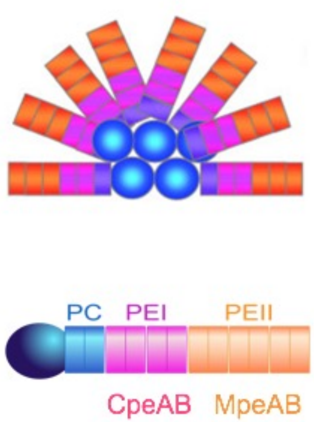
How does CA4 work?

Deleting *mpeZ* and *unk10* showed that they are needed for adding the three PUB chromophores in blue light

"CA4-A" genomic island:

RNA abundance increase in BL:	40x	-	-	10x	35x

Phycobilin lyase
Regulator
Conserved hypothetical



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CpeA	82 139	PEB PEB	PEB PUB
CpeB	50, 61 82 159	PUB PEB PEB	PUB PEB PEB

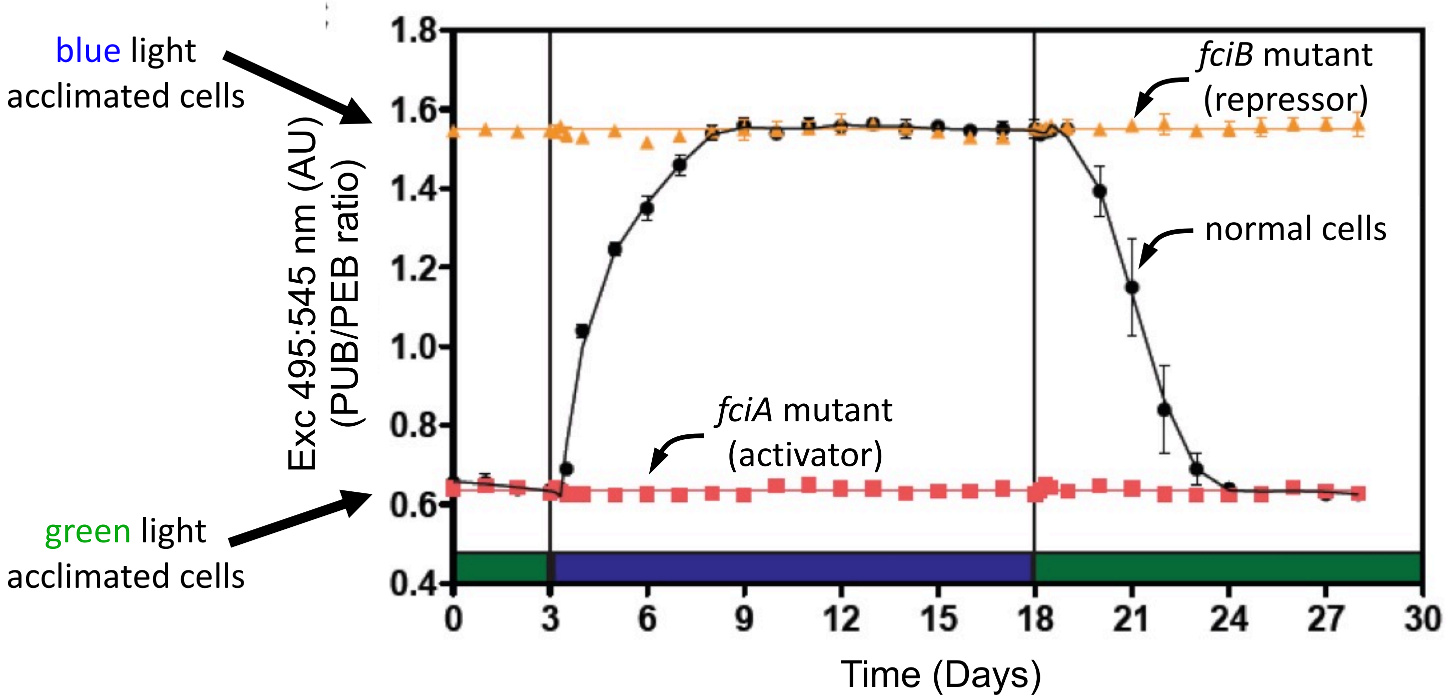
controlled by MpeZ (lyase)

controlled by Unk10 (????)

How do these cells "see" blue and green light?

Deleting *fciA* and *fciB* showed that they encode CA4 master regulators that appear to be a new class of photoreceptors

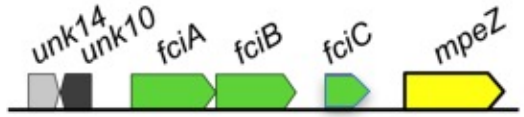
"CA4-A" genomic island:



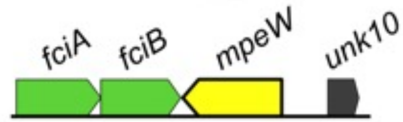
How did CA4 evolve?

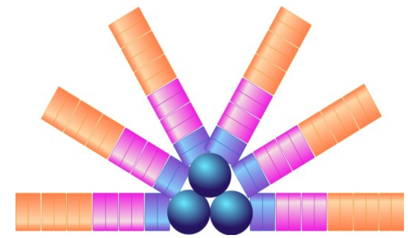
Two types of CA4 genomic islands and two types of specialists....

"CA4-A" genomic island:



"CA4-B" genomic island:



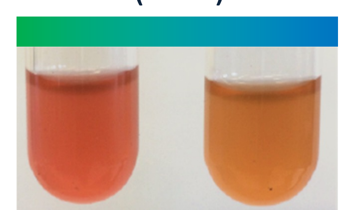


Pigment type 3

Green Light specialists

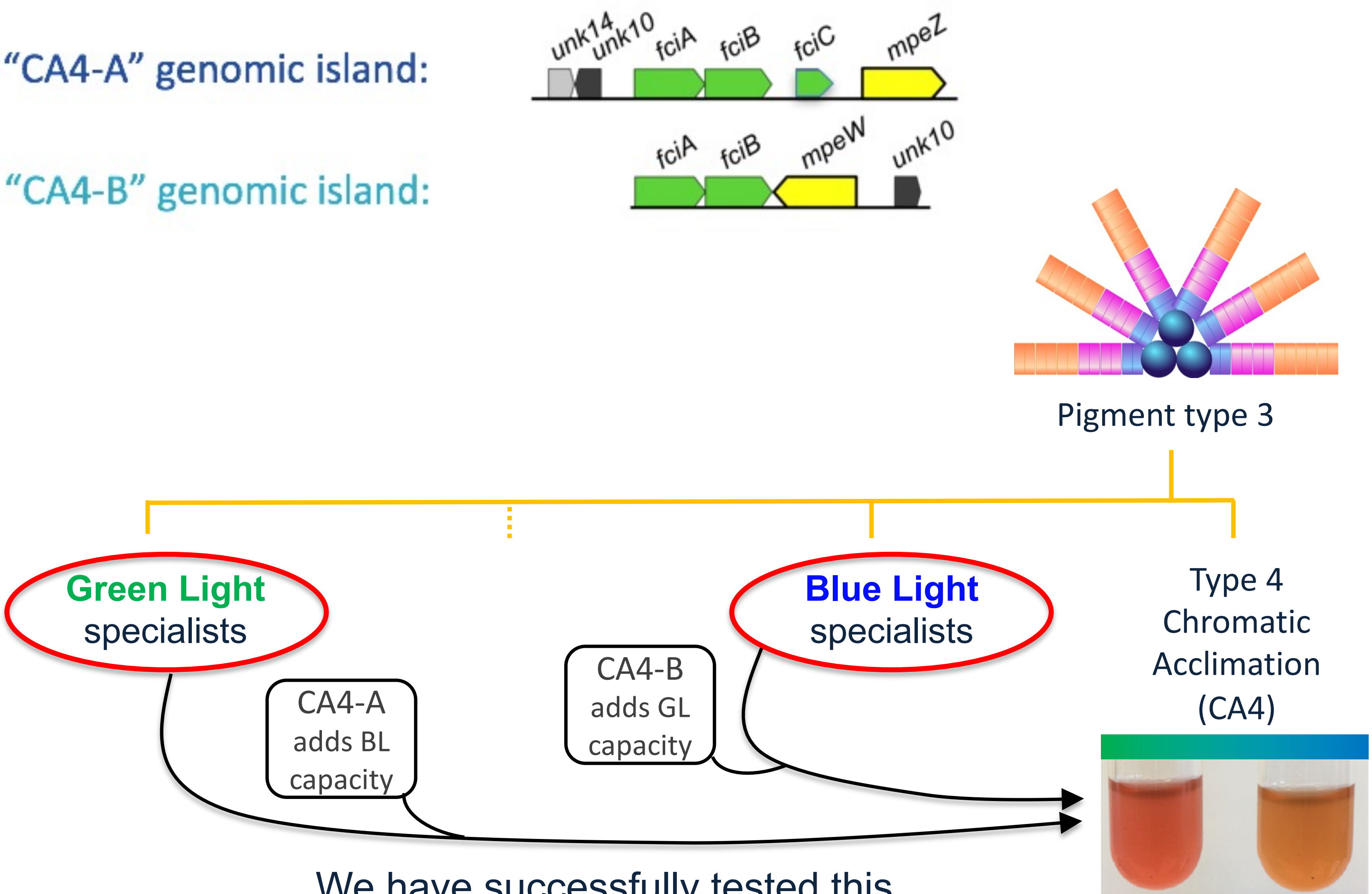
Blue Light specialists

Type 4 Chromatic Acclimation (CA4)



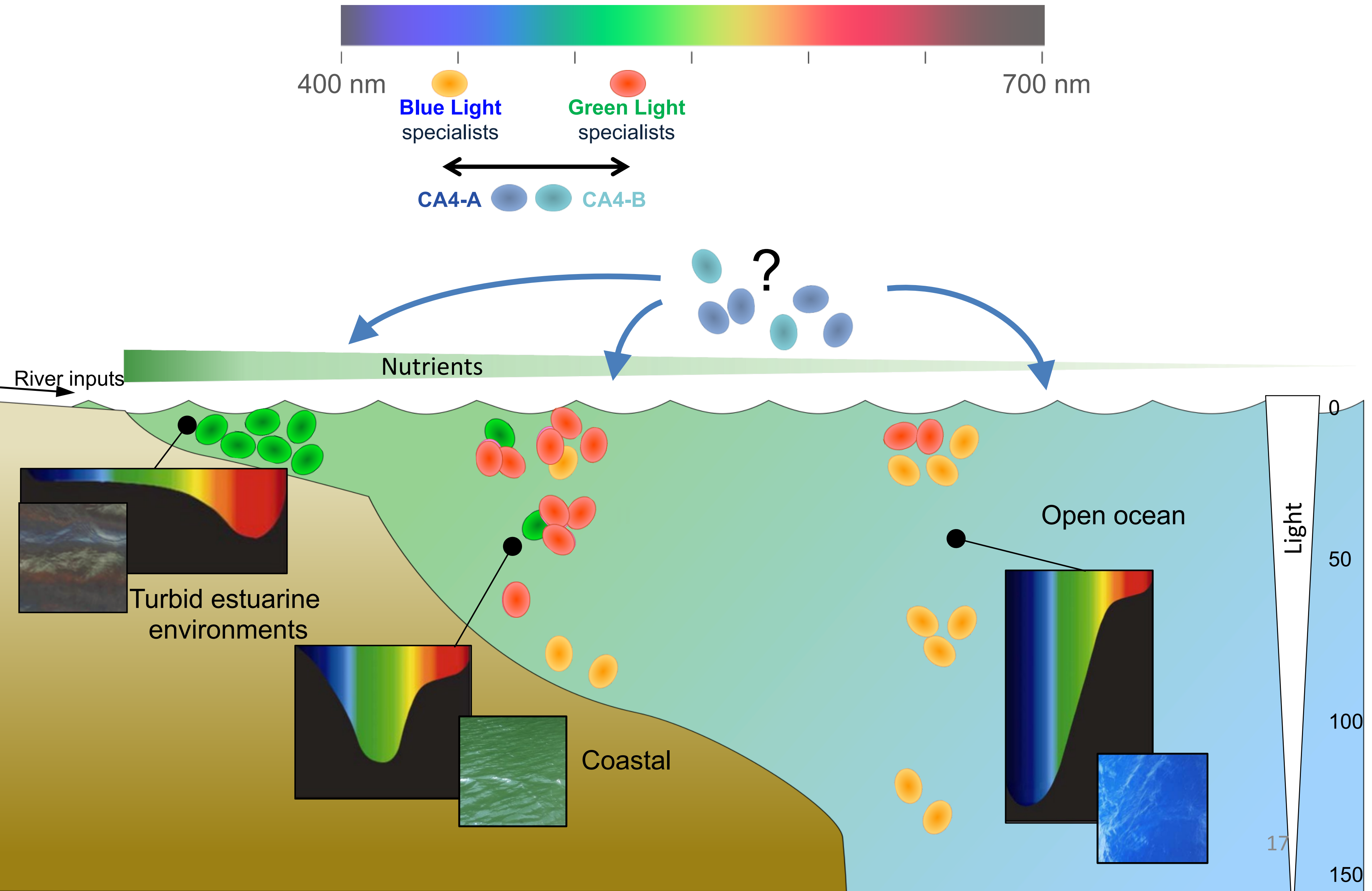
How did CA4 evolve?

Two types of CA4 genomic islands and two types of specialists....



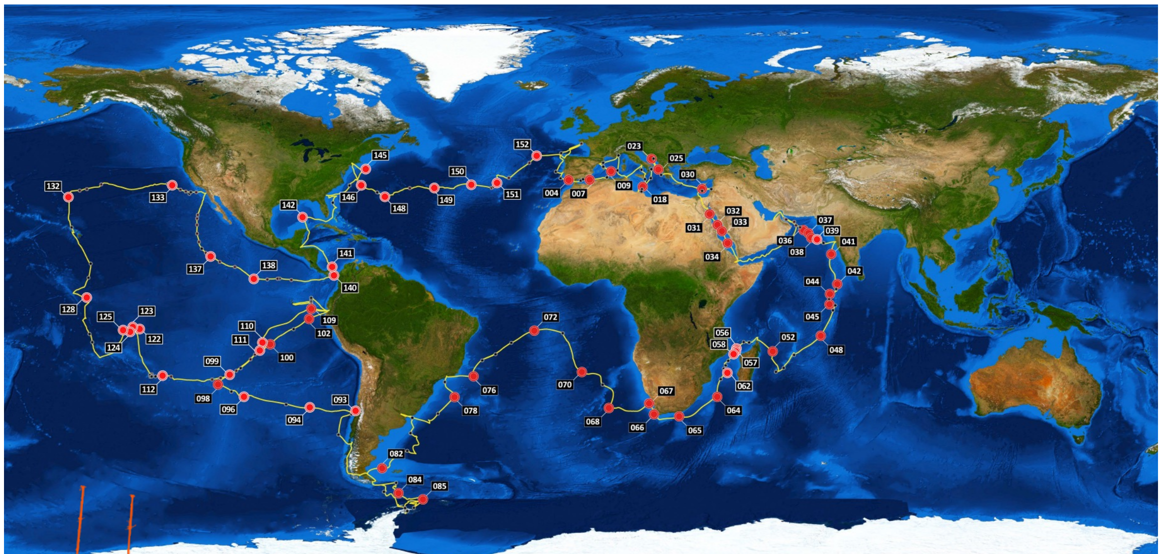
We have successfully tested this hypothesis by creating CA4 strains

How common is CA4 and where is it found globally?



How common is CA4 and where is it found globally?

Conclusions from Tara Oceans metagenomic data and marker genes



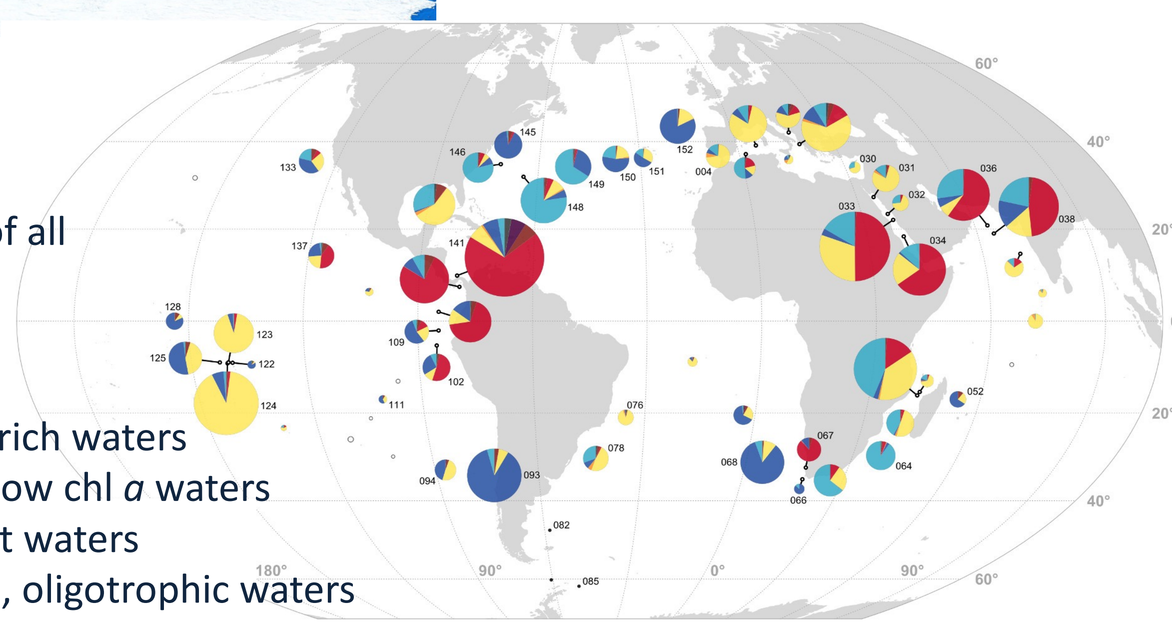
TARA OCEANS

GL specialist

BL specialist

CA4-A generalist

CA4-B generalist



- CA4-A and CA4-B make up almost 40% of all marine *Synechococcus* isolates
- CA4 strains are most prominant at depth and high latitudes
- GL specialist: high temps, green particle-rich waters
- BL specialist: high temps, low nutrients, low chl *a* waters
- CA4-A generalist: low temp, high nutrient waters
- CA4-B generalist: low nutrients, low light, oligotrophic waters

Can CA4 be detected by remote sensing?

Limnol. Oceanogr., 42(8), 1997, 1746–1754

Consequences of a *Synechococcus* bloom upon the optical properties of oceanic (case 1) waters

André Morel
Laboratoire de Physique et Chimie Marines, Université Pierre et Marie Curie and CNRS, BP 8, 06230 Villefranche-sur-Mer, France

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nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-019-08457-x OPEN

Ocean colour signature of climate change

Stephanie Dutkiewicz[1,2], Anna E. Hickman[3], Oliver Jahn[1], Stephanie Henson[4], Claudie Beaulieu[3,5] & Erwan Monier[2,6]

Today's ~~questions~~ answers:

What confers CA4 to some *Synechococcus*?

- two sets of genomic islands

How does CA4 work?

- changes in activity of chromophore attachment enzymes

How do these cells perceive blue and green light?

- FciA and FciB are likely novel photoreceptors

How did CA4 evolve?

- two genomic islands + two pigment types = two ways to make CA4

How common is CA4 and where is it found globally?

- 40% of all *Synechococcus*; found deep, cold, high latitudes

Can CA4 be detected by remote sensing?

- your thoughts?...

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Thanks!
"Team CA4"

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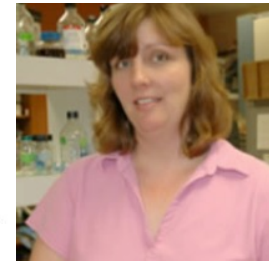

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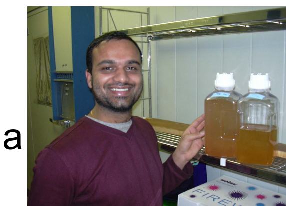

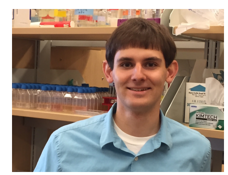

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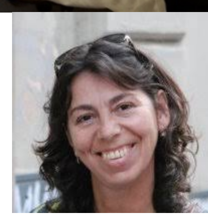

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