The role of CO_2 concentrating mechanisms (CCMs) in microalgal photosynthesis

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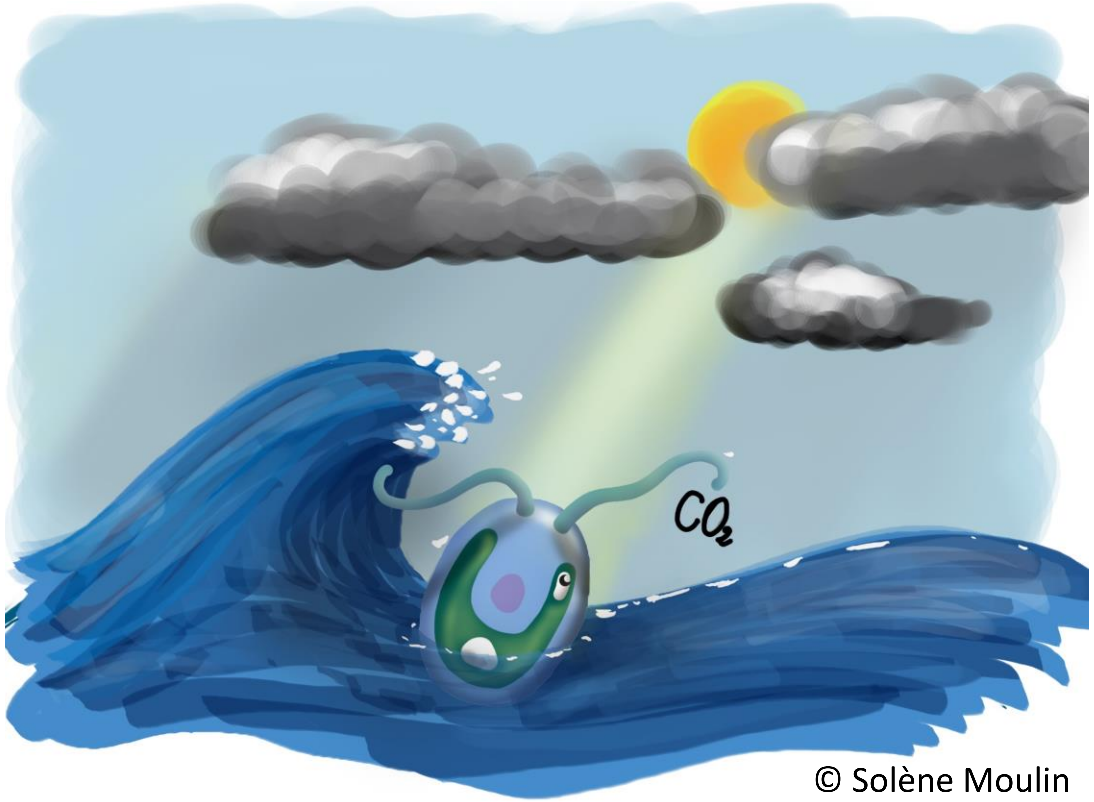
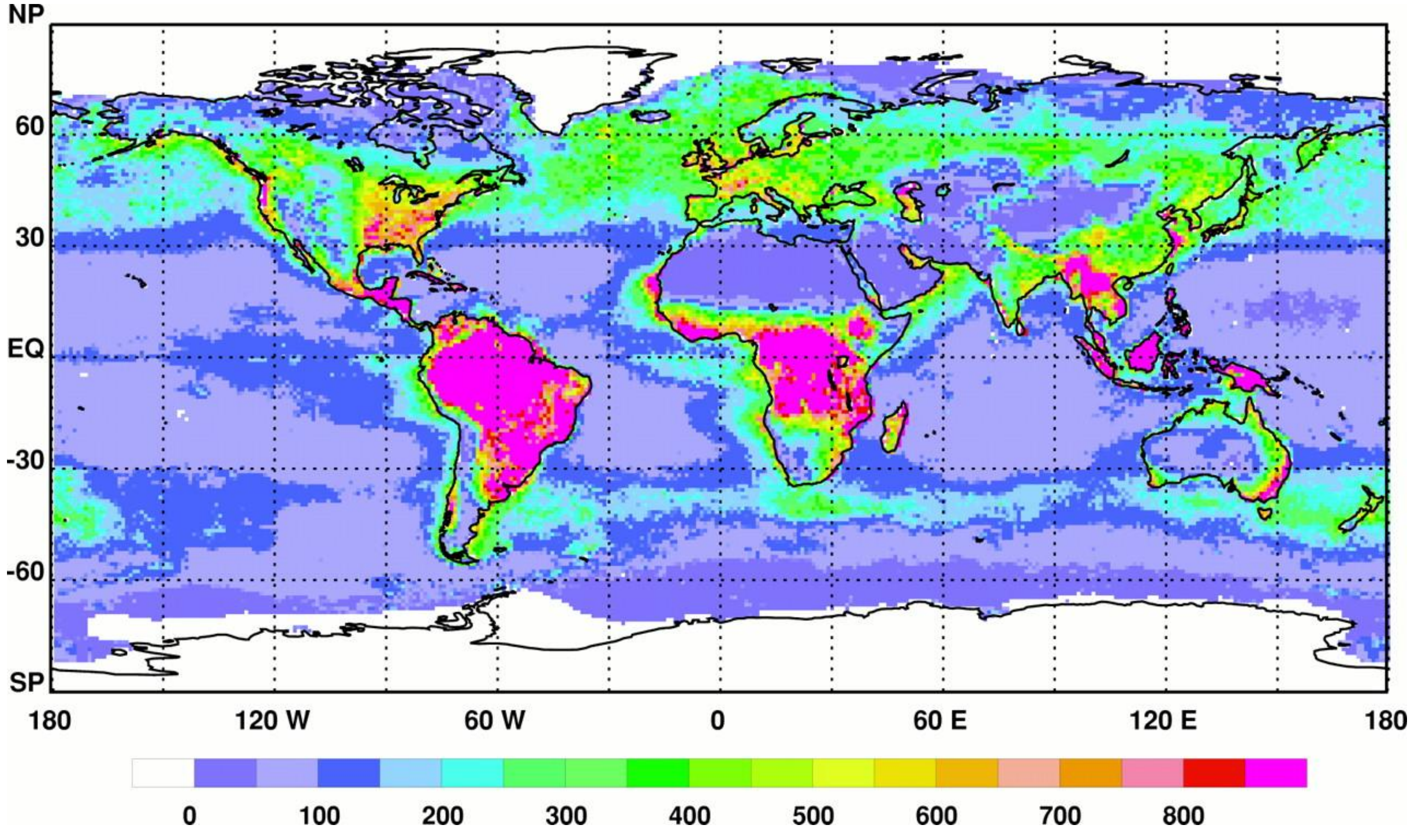


CO_2 capture on Earth by photosynthesis

50% of CO_2 fixation is due to photosynthetic microorganisms

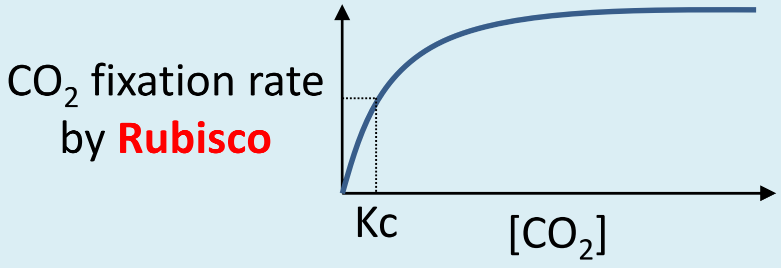
Eukaryotic microalgae and cyanobacteria

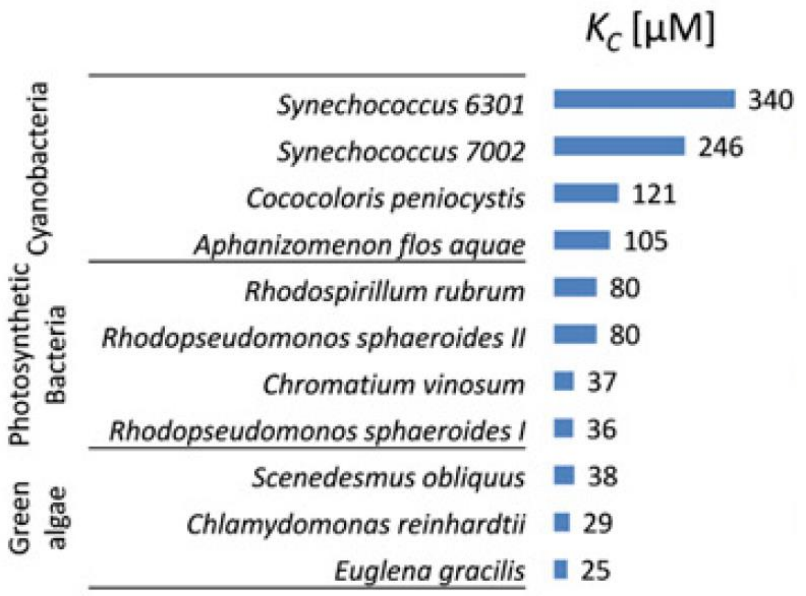


Net primary production
(g of C m^{-2} $year^{-1}$)

Field *et al.* (1998) *Science*

In aquatic environments photosynthesis is limited by CO_2 diffusion





Savir *et al*. (2010) *PNAS*

Diffusion coefficient of CO_2

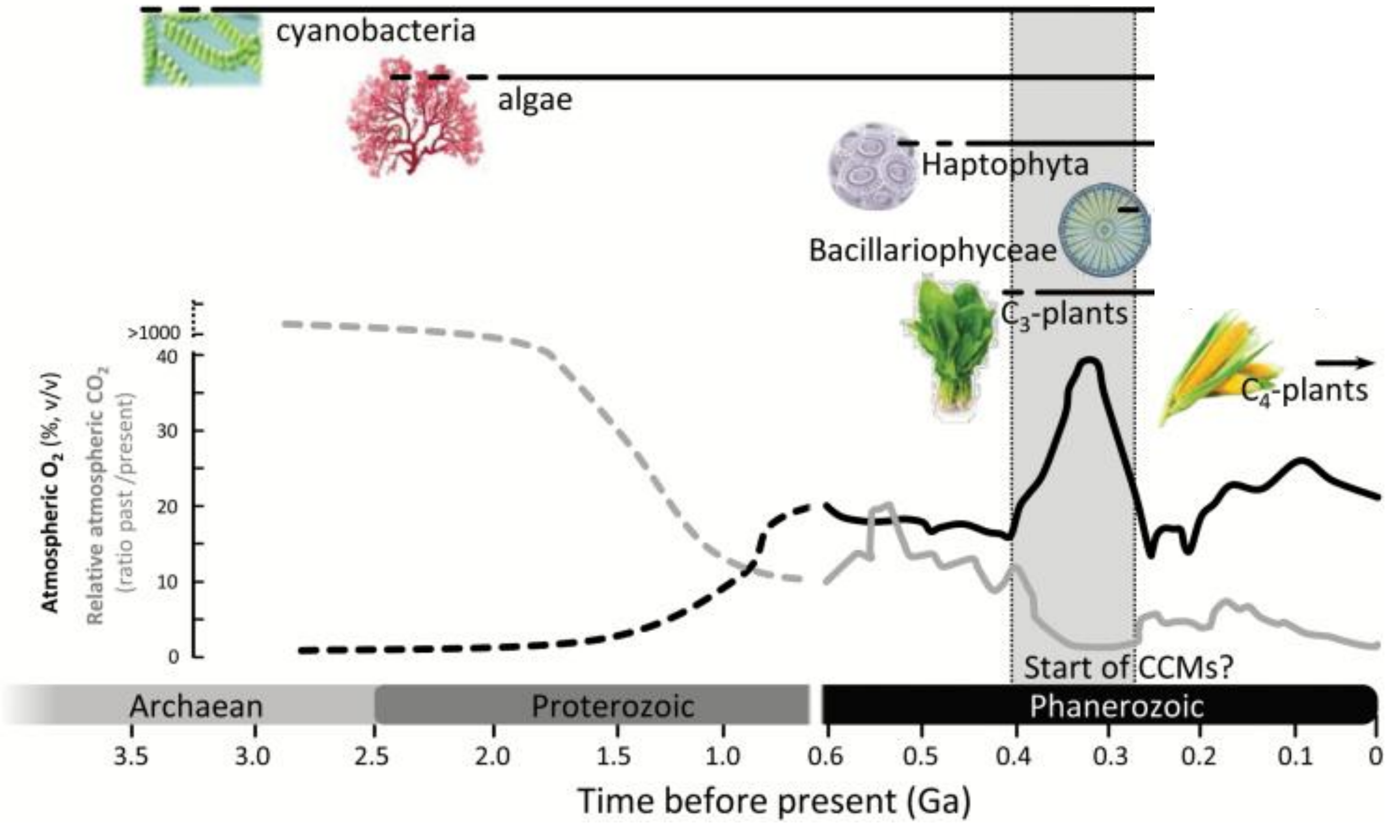
Air
0.19 cm^2 s^{-1}

Water
0.00021 cm^2 s^{-1}

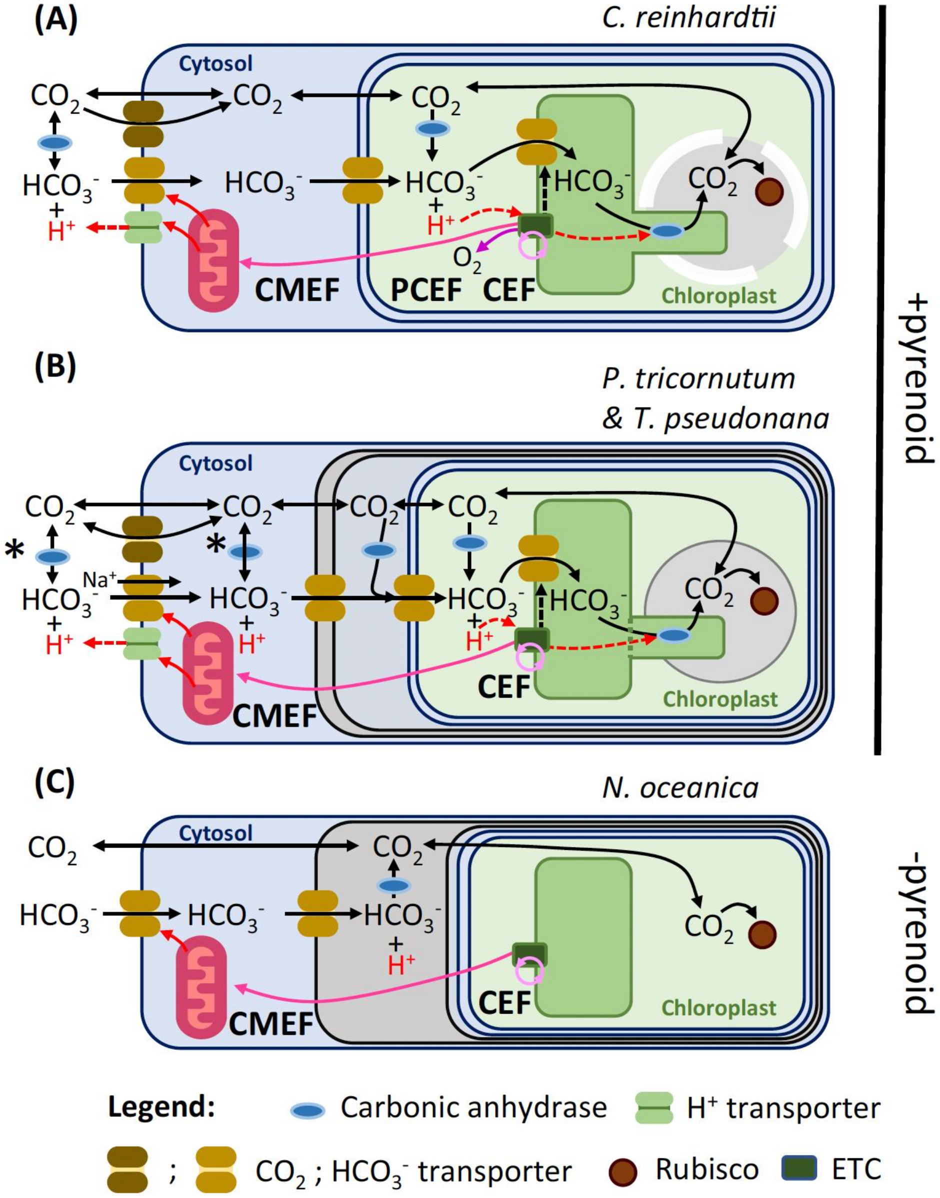
CO_2 diffusion is slow in water…

At 400 ppm CO_2 in the atmosphere, dissolved CO_2 (15µM at 20°C) is low for photosynthesis…

Diverse forms of CCMs appeared after emergence of the different plant lineages



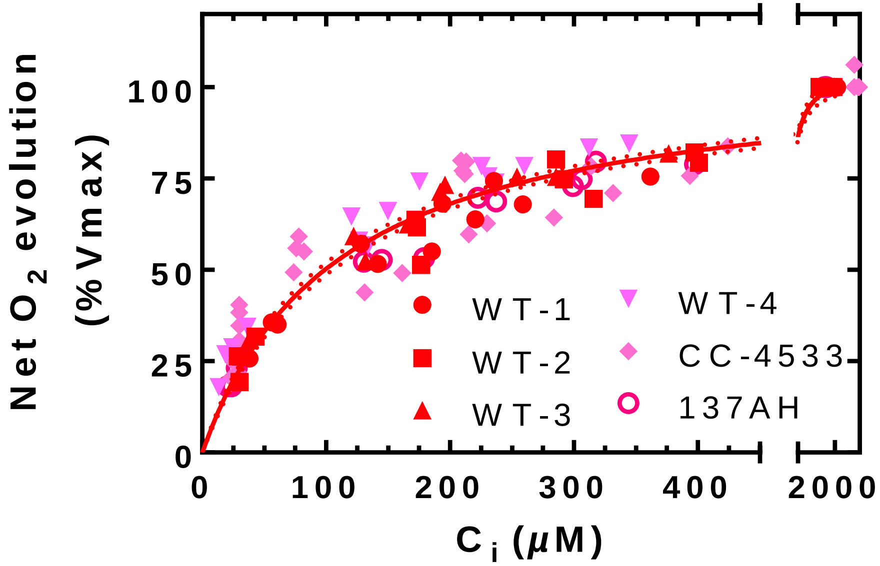
Heureux *et al*. (2017) *J. Exp. Bot.*



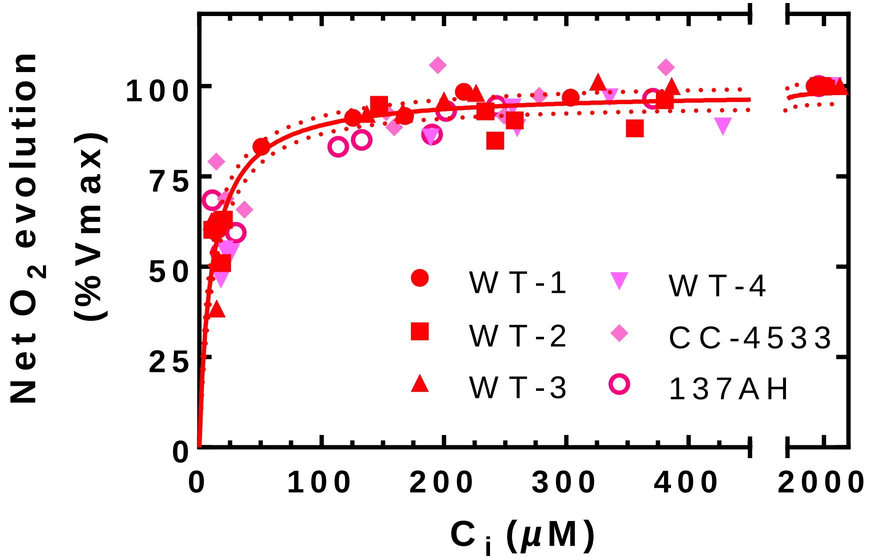
Burlacot *et al*. (2023) *Trends in Plant Science*

At low CO_2 algae induce a CO_2 Concentrating Mechanisms (CCM)

High CO_2-grown (no CCM)



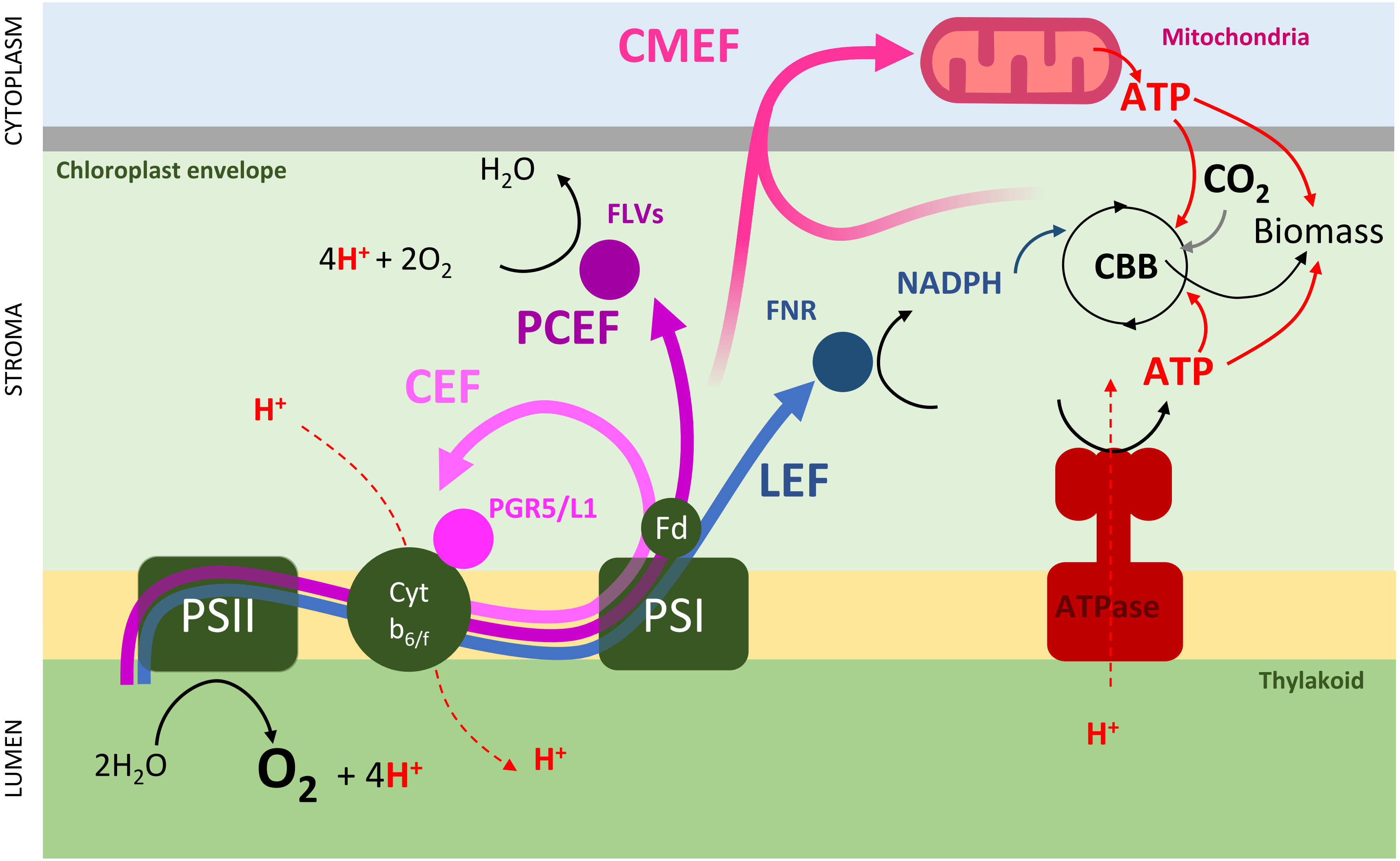
Low CO_2-grown (CCM induced)

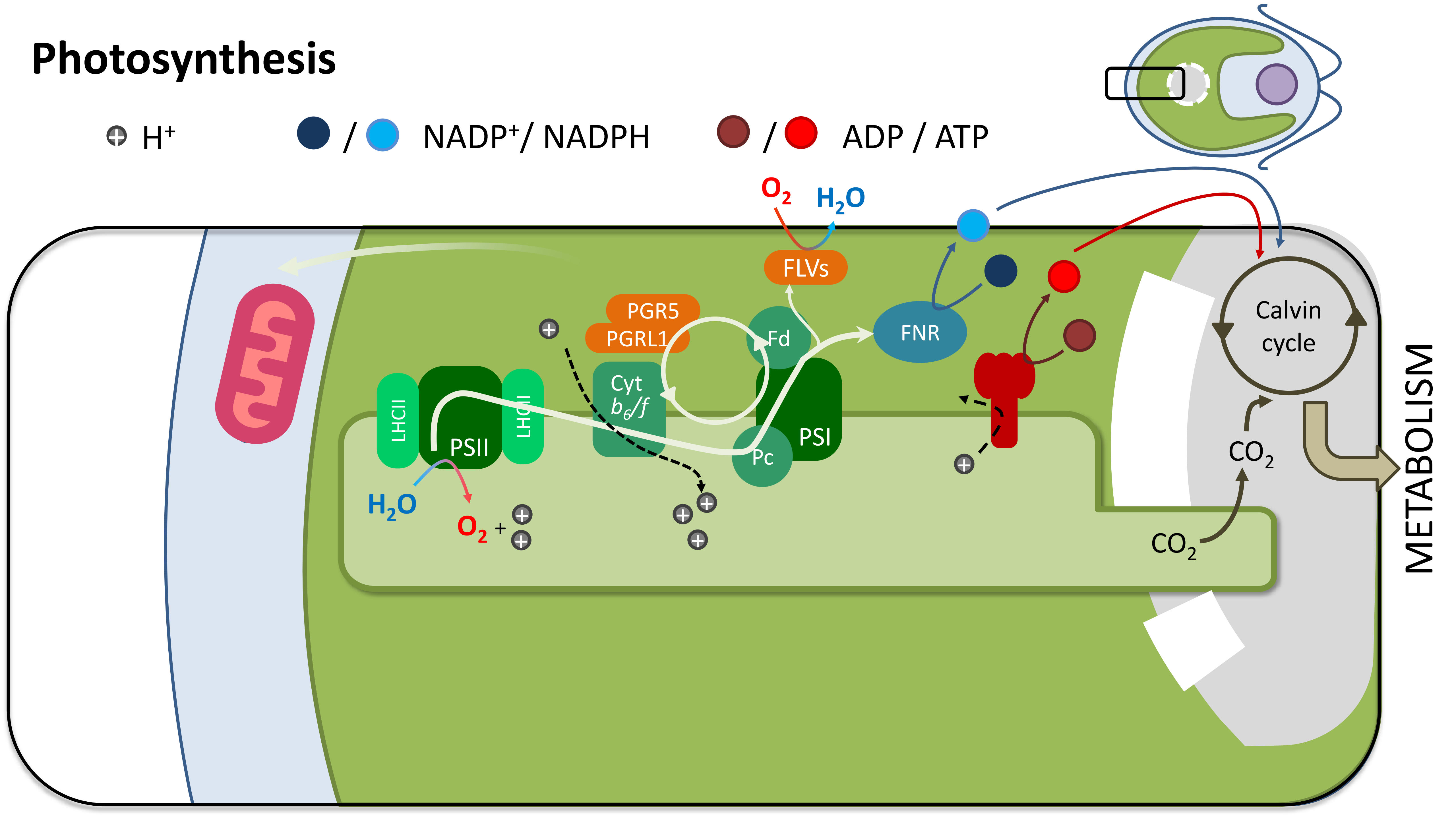


The CCM requires the energy of photosynthesis

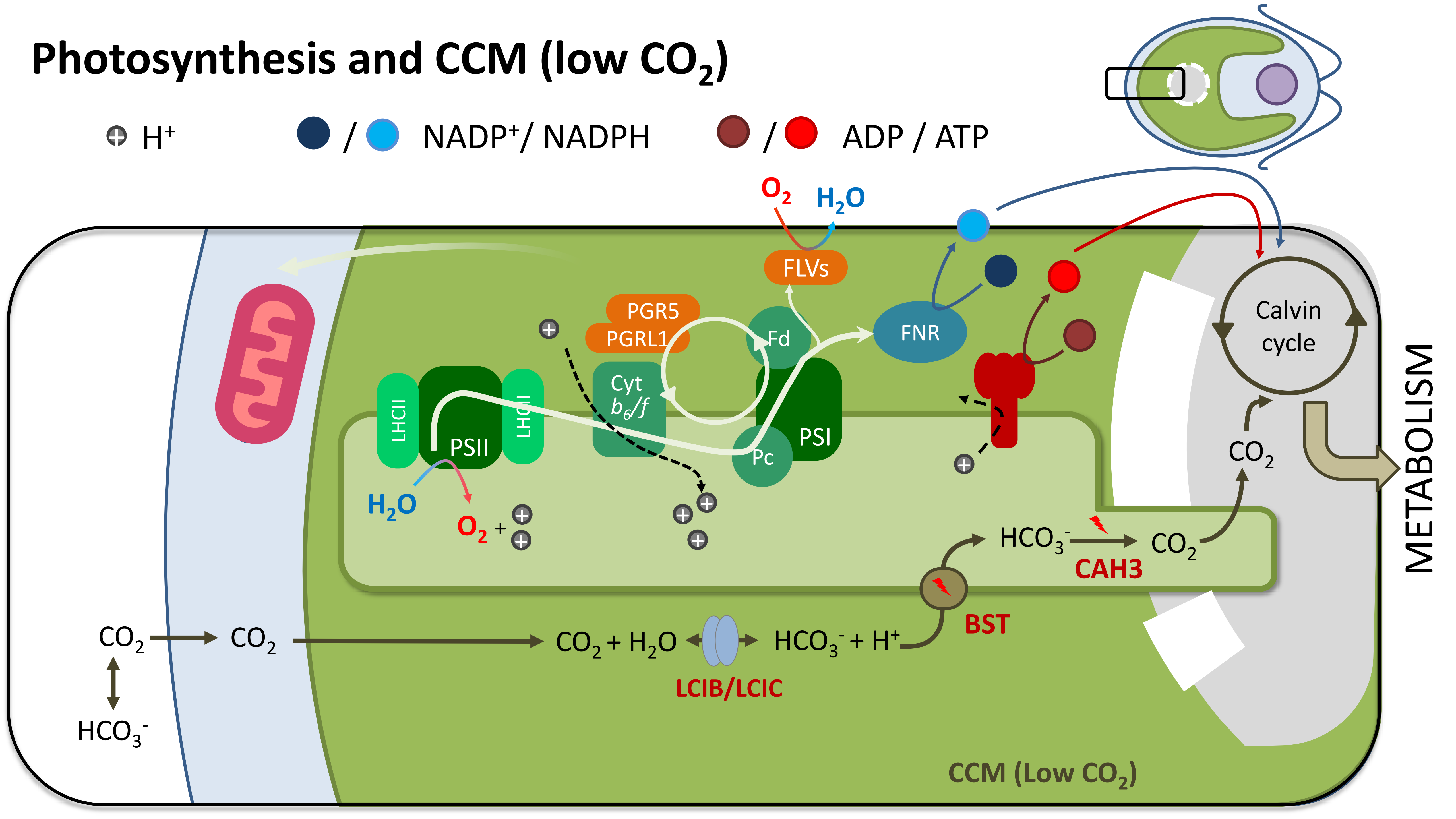
Badger *et al*. (1980) *Plant Physiol.*

Different alternative electron pathways may contribute to the ATP supply

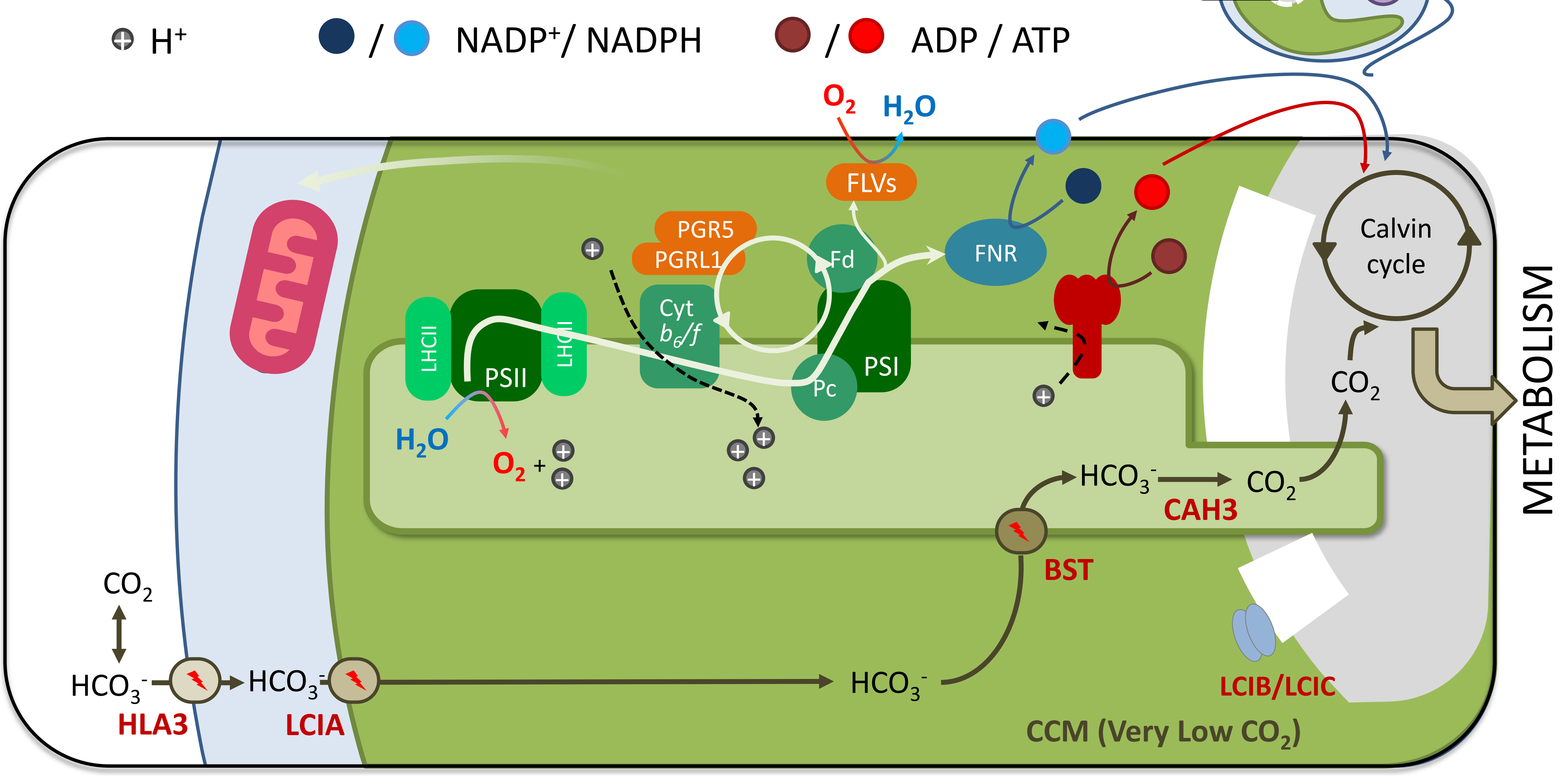



Photosynthesis
H^+
NADP+/ NADPH
ADP / ATP
O_2
H_2O
FLVs
PGR5
PGRL1
Fd
FNR
Cyt
b_6/f
LHCII
PSII
LHCII
PSI
Pc
H_2O
O_2 +
Calvin cycle
CO_2
CO_2
METABOLISM

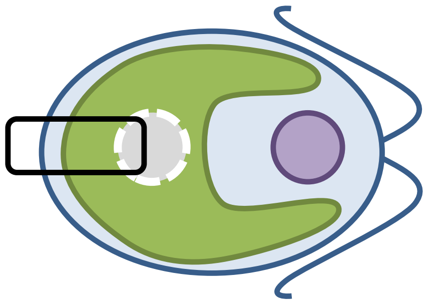
Photosynthesis and CCM (low CO_2)



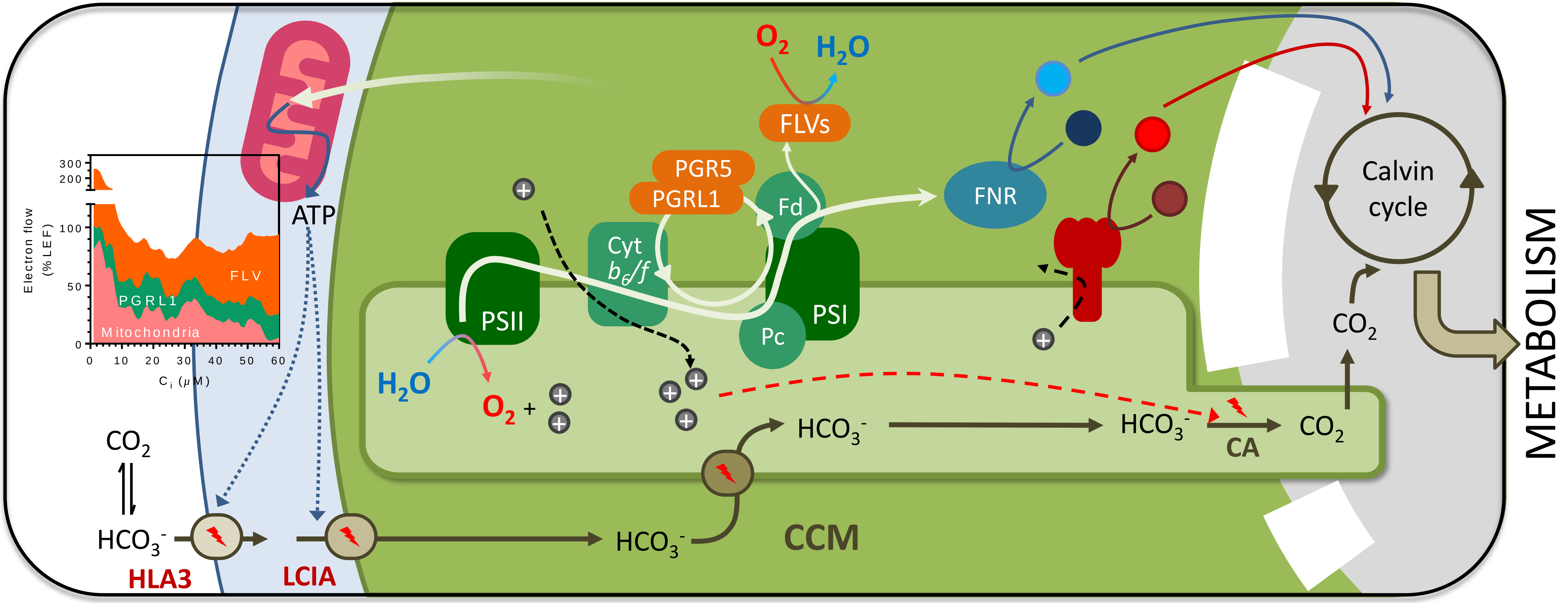
Photosynthesis and CCM (Very Low CO_2)



CCM energization network

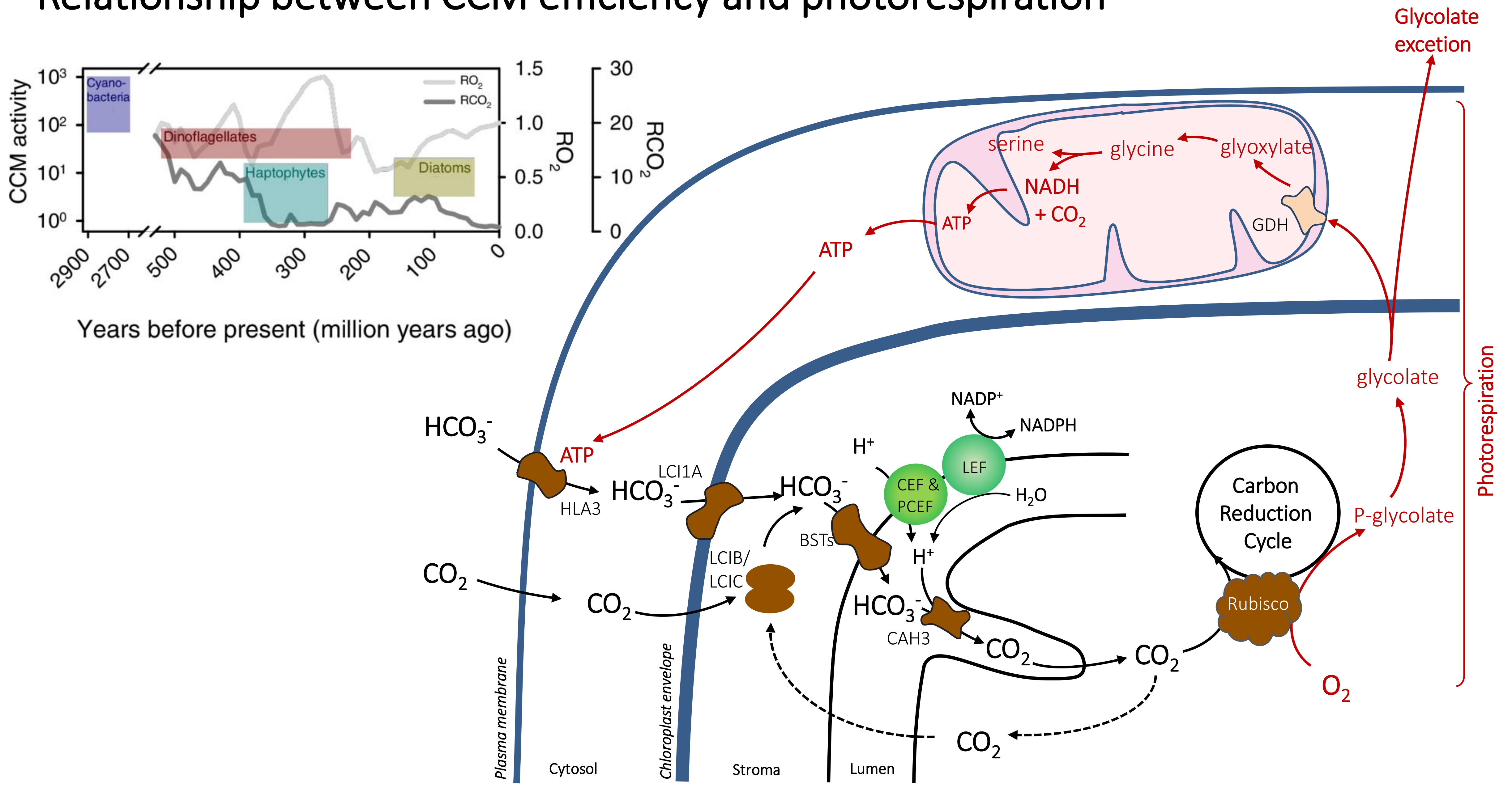


H^+ — $NADP^+$/ NADPH — ADP / ATP



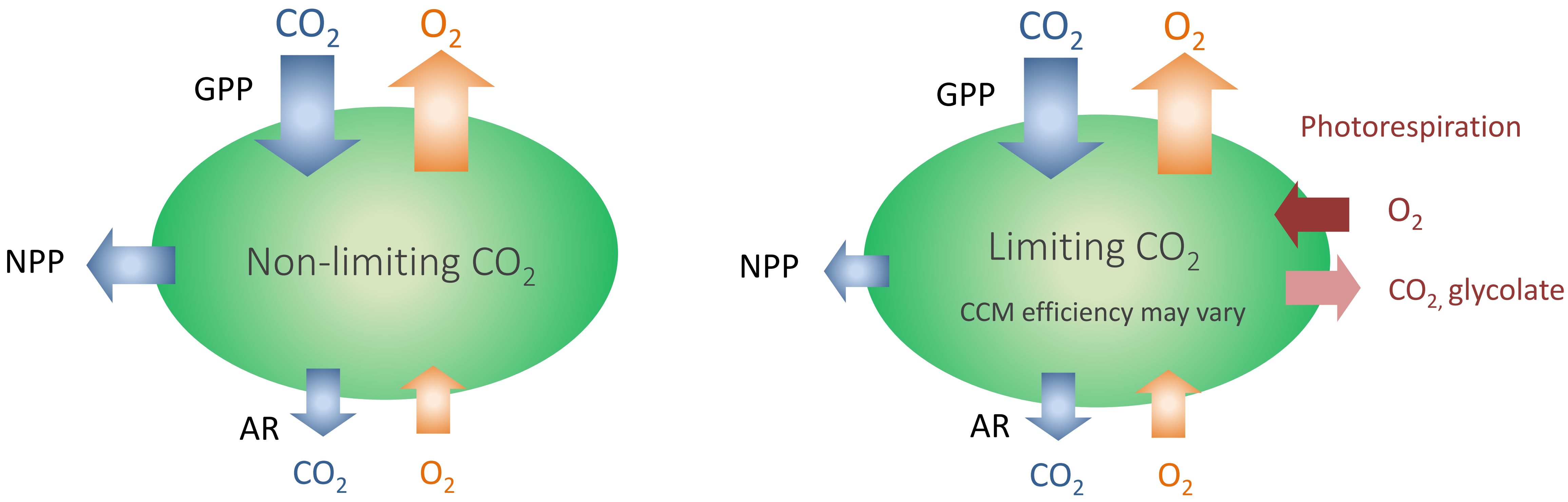
Burlacot *et al.* (2022) *Nature*

Relationship between CCM efficiency and photorespiration



Working hypothesis:

Depending on conditions and/or species CCM activity may vary, thus triggering photorespiration

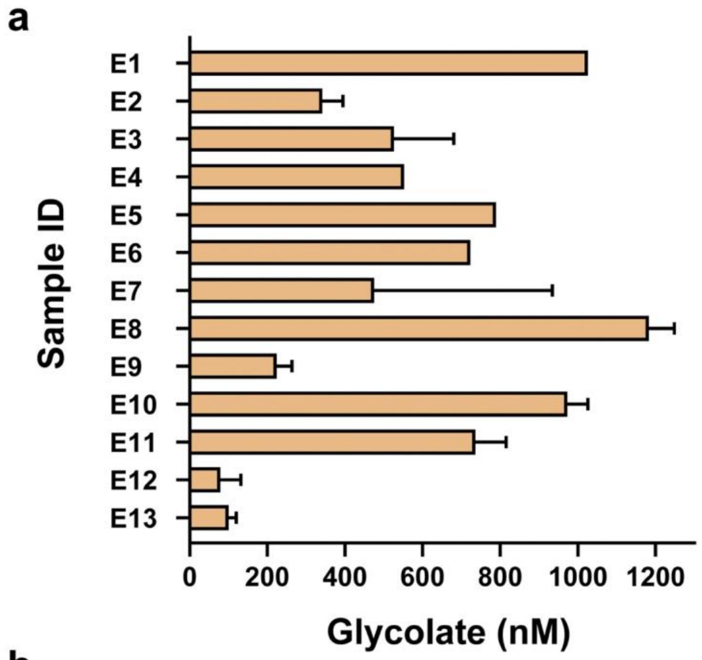


GPP: Gross Primary Production

NPP: Net Primary Production

AR: Autotrophic Respiration (measured in the dark, extrapolated in the light)

Glycolate concentration in the ocean can reach high levels despite the presence of marine bacteria



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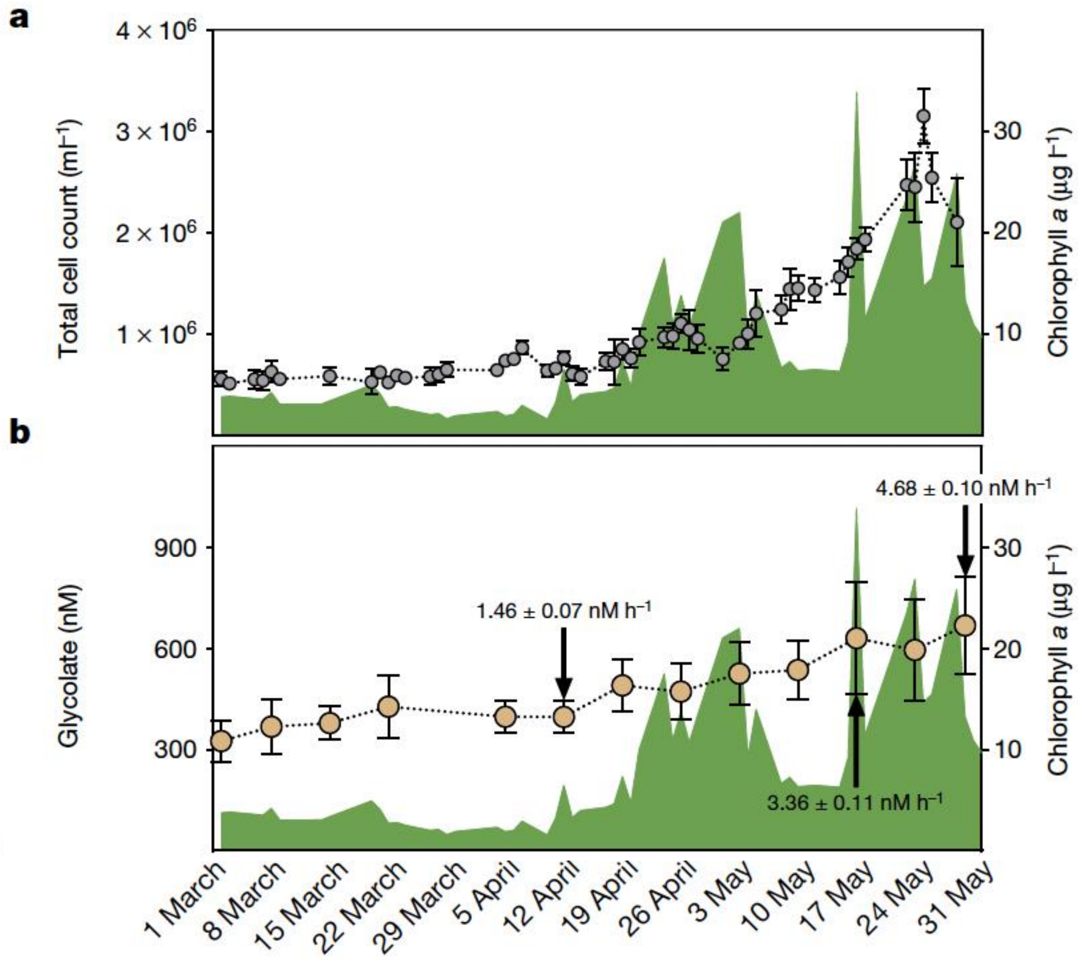
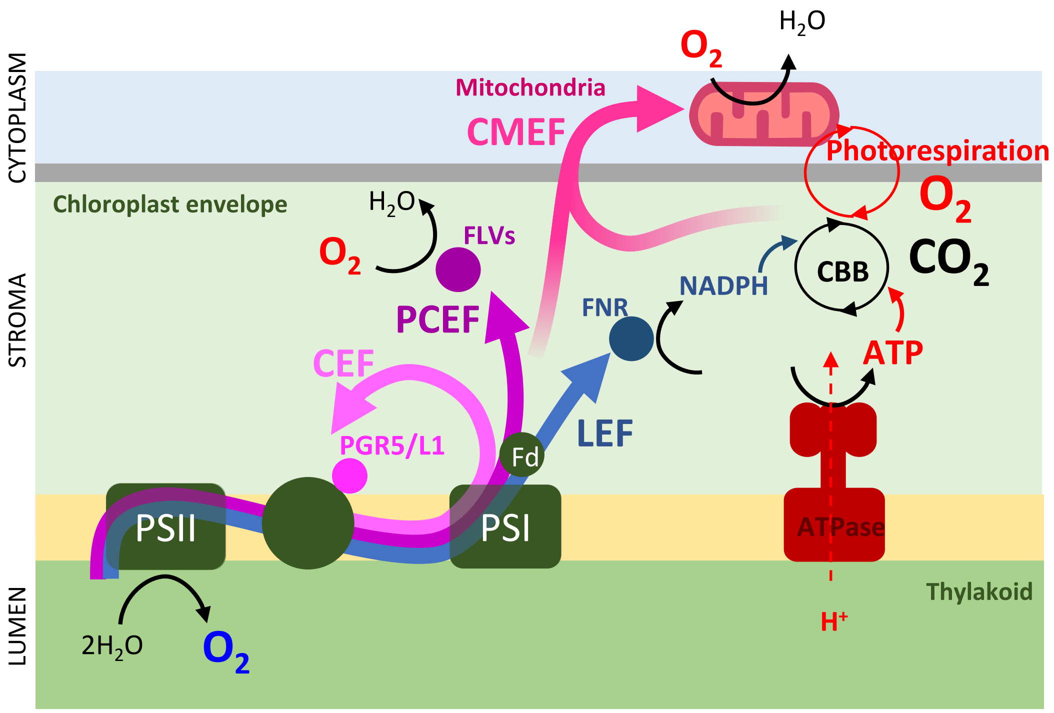
Sample ID	Sample	Maximum glycolate concentration [nM]	Analytical method
E1	Coastal seawater (Ipswich Bay, MA, USA)	1,026	Colorimetry
E2	Atlantic Ocean (51°40' S, 57°48' W)	342 ± 53	Colorimetry
E3	Antarctic lake (60°42' S, 45°37' W)	526 ± 154	
E4	Coastal seawater (Ipswich Bay, MA, USA)	552	Colorimetry
E5	Coastal seawater (Menai Straits, Anglesey, UK)	789	Colorimetry
E6	Coastal seawater (Ipswich Bay, MA, USA)	723	Colorimetry
E7	Coastal seawater (New York Bight, NY, USA)	475 ± 459	Colorimetry
E8	Mediterranean Sea (42°28' N, 30°16' E)	1,183 ± 66	HPLC
E9	Atlantic Ocean (oligotrophic waters, 21°01'54" N, 31°09'62" W)	224 ± 39	HPLC
E10	Atlantic Ocean (mesotrophic waters, 18°27'22" N, 21°10'18" W)	973 ± 53	
E11	Atlantic Ocean (eutrophic waters, 20°31'49" N, 18°34'39" W)	736 ± 79	
E12	Mediterranean Sea (43°25' N, 7°52' E)	79 ± 53	GC
E13	Coastal seawater (Dabob Bay, WA, USA)	100 ± 20	HPLC

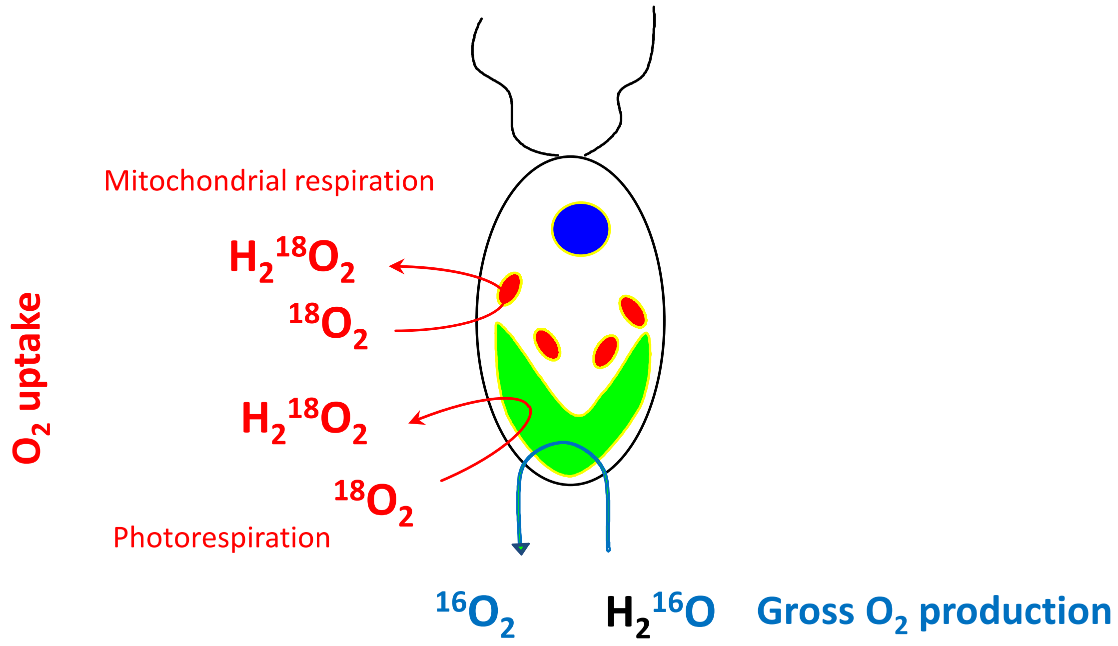
von Borzyskowski *et al.* (2019) *Nature*



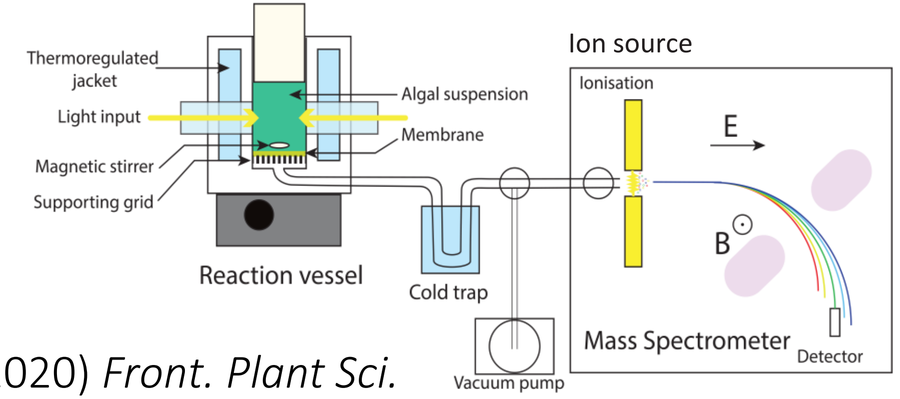
Glycolate concentration in seawater during a spring phytoplankton bloom at Helgoland (2018)

Oxygen uptake rates measurements in the light using Membrane inlet mass spectrometry and $^{18}O_2$



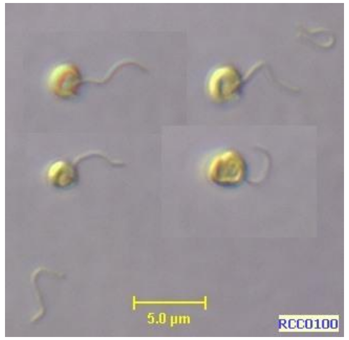


$$\text{Net } O_2 \text{ production} = \text{Gross } O_2 \text{ production} - O_2 \text{ Uptake}$$

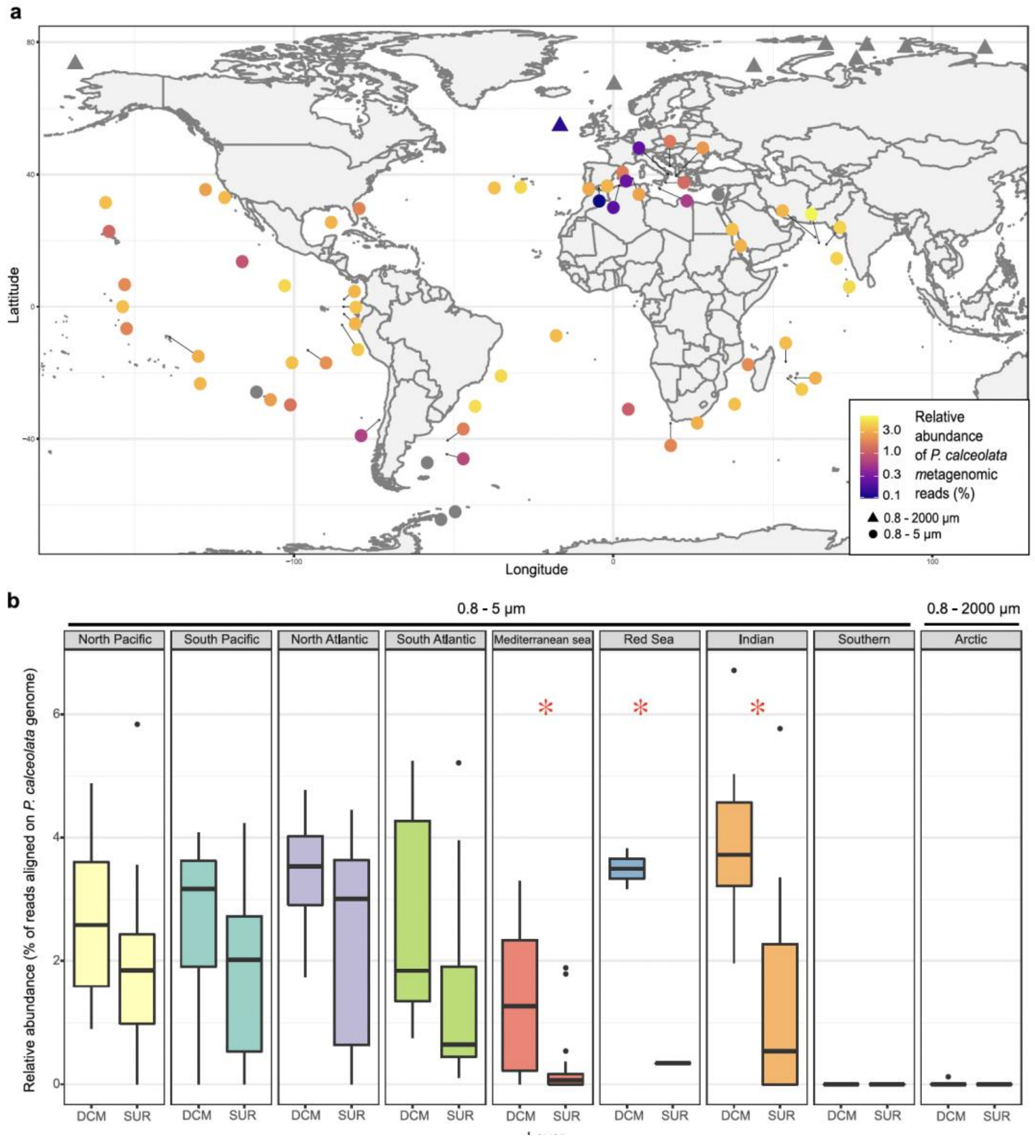


Burlacot *et al.* (2020) *Front. Plant Sci.*

Pelagomonas calceolata a model organism to study the effect of the environment on gene expression



P. calceolata is an abundant and cosmopolite photosynthetic pico-eukaryote



Aligning metatranscriptomic reads from Tara Oceans expeditions on the reference genome, allows to retrieve genes expressed by *P. calceolata* and study gene expression in different environmental contexts

Coll. Quentin Carradec Genoscope

UMR GENOSCOPE   OCEANOMICS   TARA OCEANS

Guérin *et al*. (2022) *Com. Biol.*

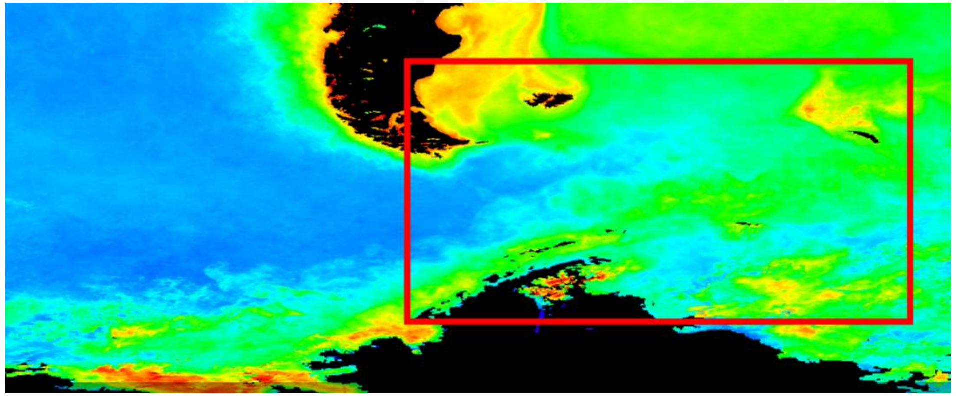
Linking geosciences and biology… a case study

Research objectives

- Explore the crosstalk between photorespiration and CCM in laboratory conditions in a few model species (O_2 exchange by MIMS and $^{18}O_2$, glycolate release, gene expression…)
- Evaluate CCM functioning and photorespiratory carbon release by photorespiration in oceanic ecosystems (seasonal blooms)

Research tools

- *Chlamydomonas reinhardtii, Pelagomonas calceolata, Fragilarius cylindricus,* blooms…
- Light O_2 consumption using $^{18}O_2$ and MIMS
- Glycolate measurements in seawater by LC-MS
- Gene expression data (Tara-Ocean)



Thanks to collaborators

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