Critical role of oxygen photoreduction downstream of photosystem I : *photoprotection, energetic adjustment and ROS production in Symbiodinium*

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EPC6, London, august 25th 2015, *Symbiodinium session*

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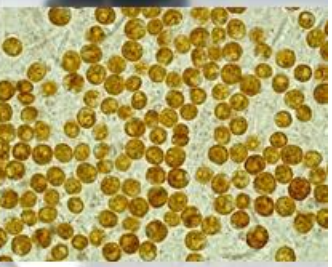
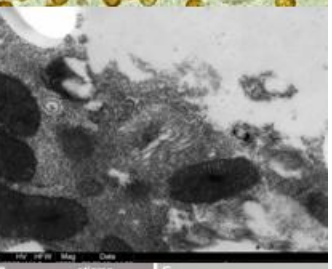
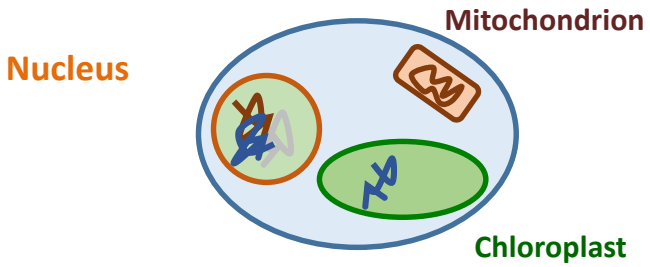




Bioenergetics in microalgae



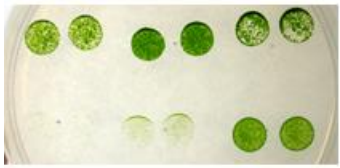
Mitochondrial respiration

$CH_2O + O_2 \rightarrow CO_2 + H_2O$ (+ATP)

Versus

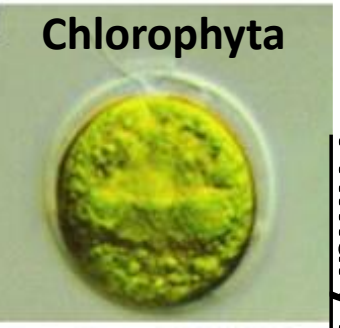
Chloroplastic photosynthesis

$CO_2 + H_2O + light \rightarrow CH_2O + O_2$ (+ATP)



Diversity of photosynthetic microalgae

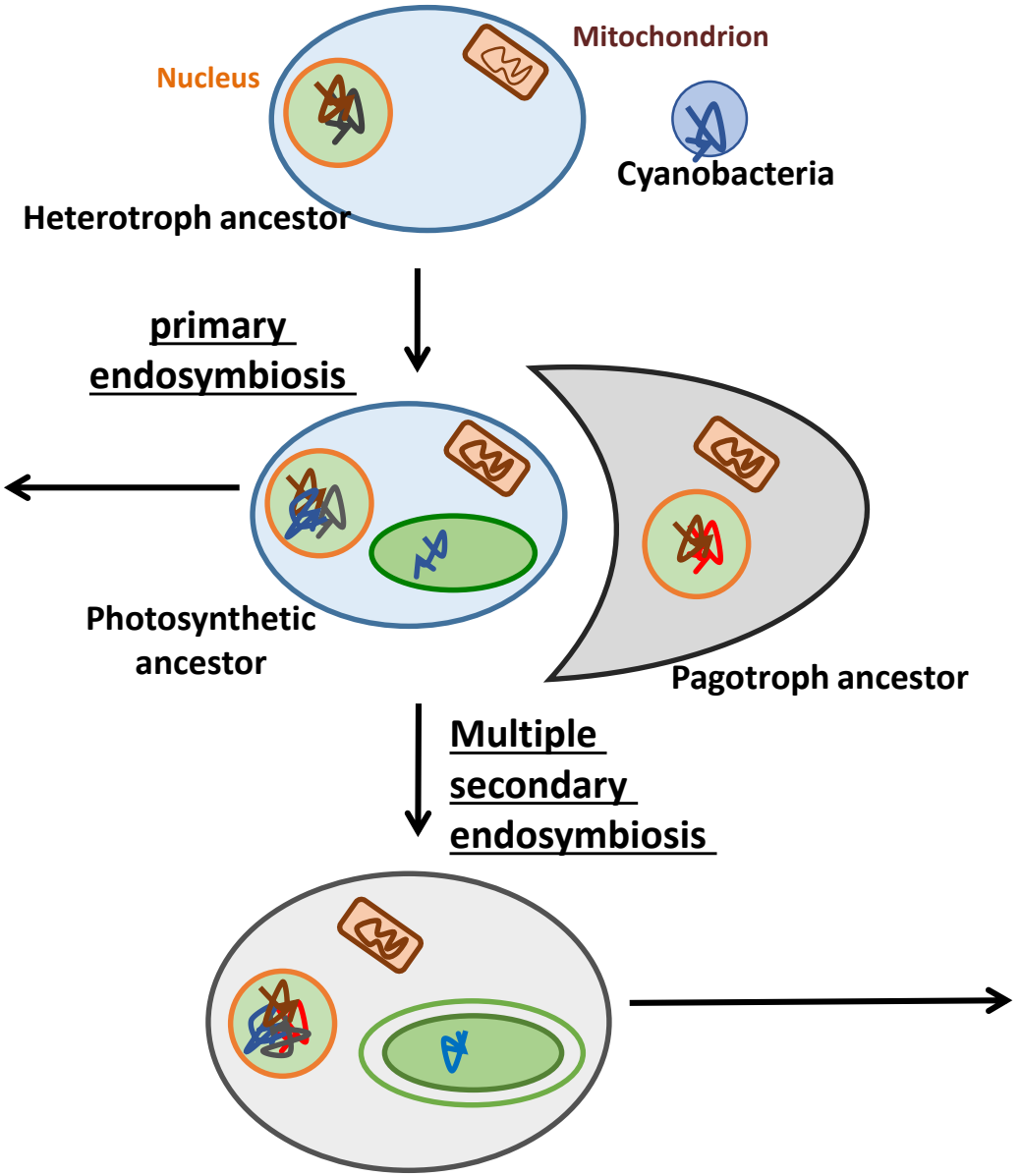
Chlorophyta

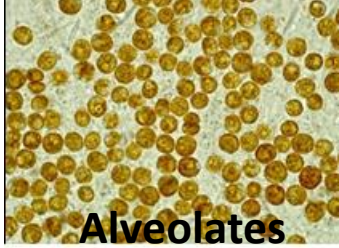


Rhodophyta

Streptophyta

Primary Photosynthetic eukaryotes





Alveolates

Euglenozoa

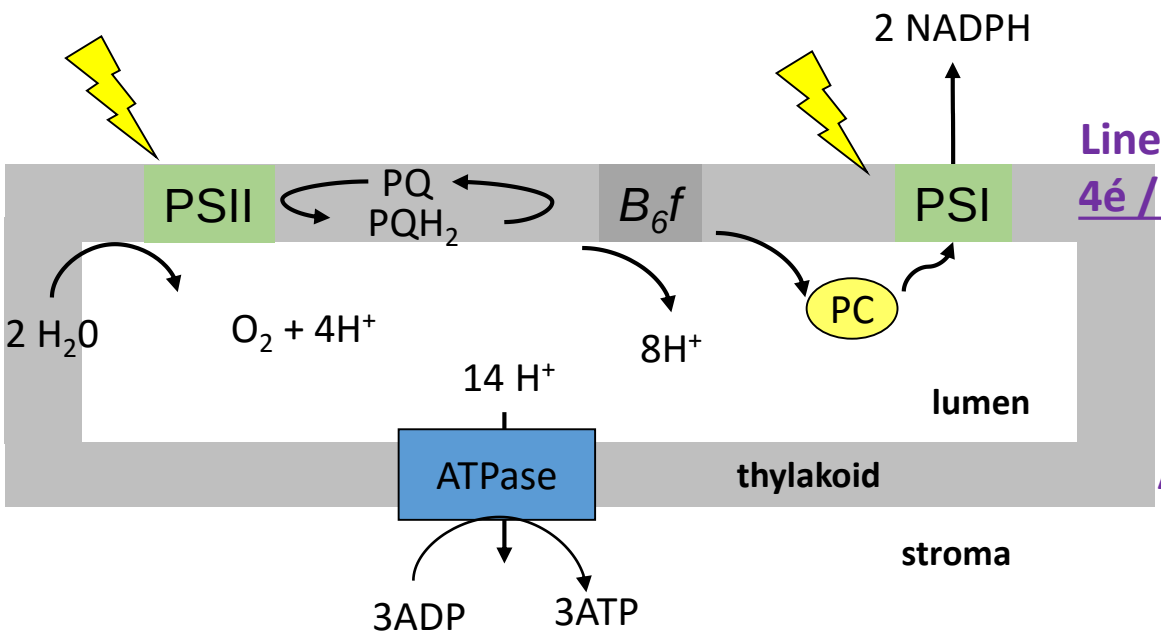
Diatoms

Rhizaria

Haptophyta

Secondary Photosynthetic eukaryotes

Adjustment of photoproduced NADPH/ATP



Linear electron flow :
4é / 2 NADPH / 12 H^+

ATP synthase :
14H^+ /3 ATP

Electron transport chain : 2 NADPH / 2.6 ATP

CO_2 fixation (CBB cycle) : 2 NADPH / 3 ATP

→ Regulatory mechanisms
-to consume NADPH in excess
-to produce extra ATP

Alternative electron flows

PSI-cyclic electron flow $1H^+/e^-$

NDA

PGR

H_2O — PSII → PQ — B_6f → PC — PSI → Fdx — FNR → $NADP^+$ — CBB → -CHO

O_2 O_2 O_2 O_2

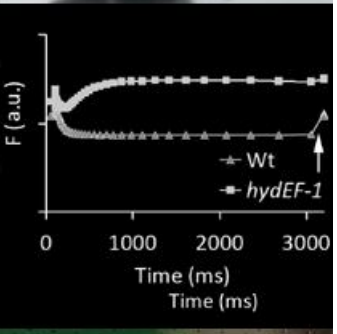
Chlororespiration -PTOX $1H^+/e^-$

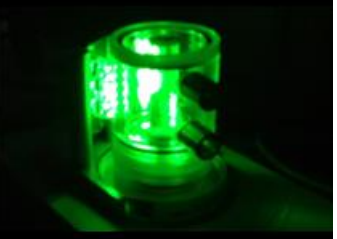
Mehler reaction $3H^+/e^-$

Mitochondrial respiration $\geq 3H^+/e^-$

Light-dependent oxygen uptake

Alternative electron flows : Biophysical tools





PSI-cyclic electron flow :
<u>comparison of PSI and PSII rates</u>

$$ETR_{PS} = \Psi_{PS} \cdot I \cdot \sigma_{PS} \cdot n_{PS}$$

NDA

PGR

H_2O — PSII → PQ — B_6f → PC — PSI → Fdx — FNR → $NADP^+$ — CBB → -CHO

O_2 — Chlororespiration -PTOX

O_2 — Mehler reaction

O_2 — Mitochondrial respiration

Light-dependent oxygen uptake (O_{UL}) :
<u>comparison of PSII and O_2 exchange rate</u>

$$ETR_{PSII} = O_{2\ (gross)}$$

$$VO_2 = O_{2\ (gross)} - O_{UL}$$

Diversity of photosynthetic regulations

PSI-cyclic electron flow

Chlamydomonas reinhardtii
(Chlorophyte, Archaeplastida)
(Cardol et al., 2003, Plant Physiol.
Cardol et al., 2009, PNAS
Dang et al., 2014, Plant Cell)

NDA

PGR

H_2O — PSII → PQ — B_6f → PC — PSI → Fdx — FNR → $NADP^+$ — CBB → -CHO

Chlororespiration
-PTOX

O_2

Mehler
reaction

O_2

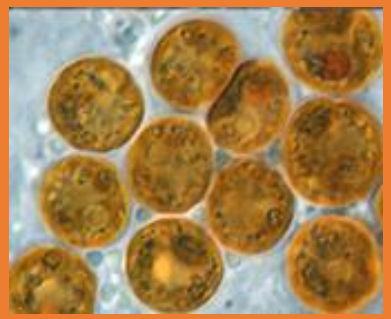
O_2

Mitochondrial
respiration

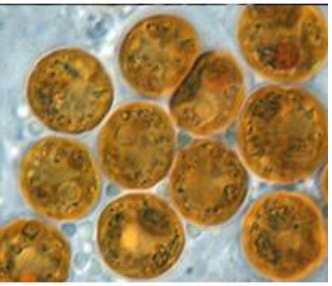
Ostreococcus sp.
(Prasinophyte, Archaeplastida)
(Cardol et al., 2008, PNAS)

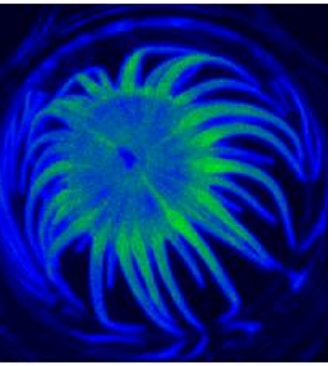
Symbiodinium (Alveolata)
Light-dependent O2 uptake (U_{OL})
capacity up to 45% of ETR_{PSII}

(Jones et al., 1998;
Leggat et al., 1999;
Badger et al., 2000).



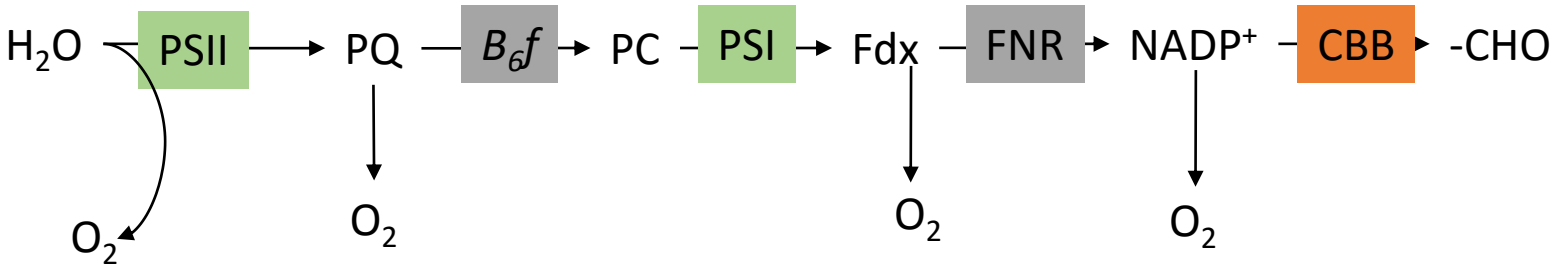
Phaeodactylum tricornutum
(diatom, stramenopile)
(Bailleul et al, 2015, Nature)

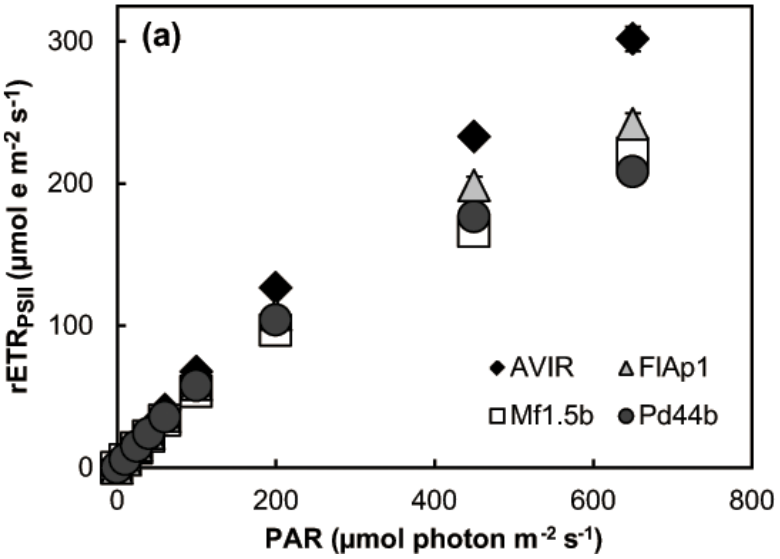


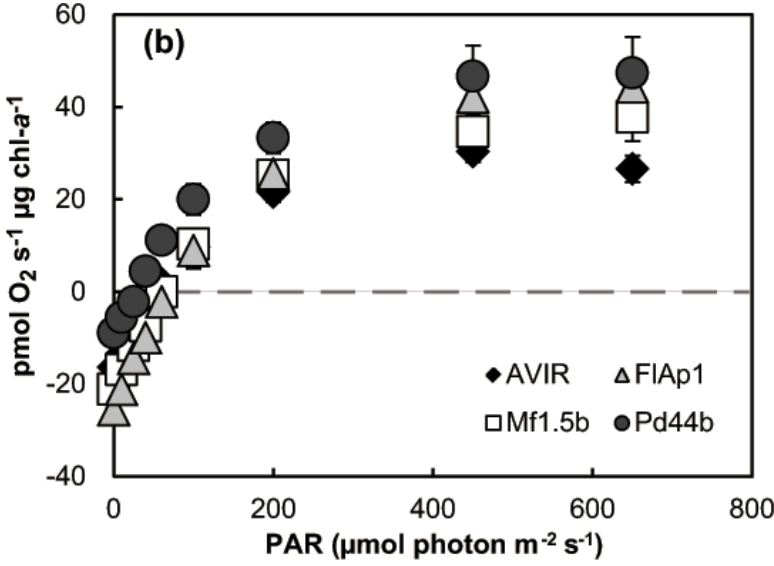


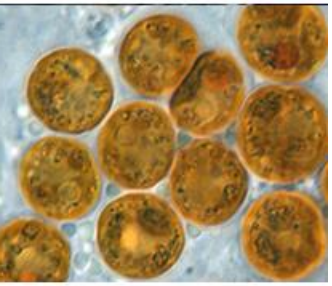
Light-oxygen uptake in Symbiodinium (*Roberty et al., 2014, New Phytol.*)

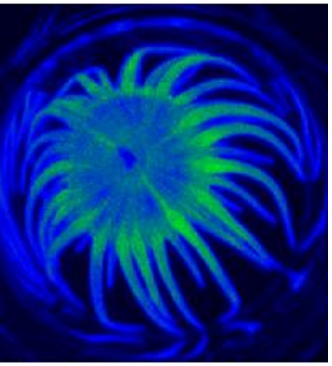
Strain ID	Host	Location	Country	Ocean	cp23S type[a]	ITS type[b]
Avir	*Anemonia viridis*	Villefranche-sur-Mer	France	Mediterranean Sea	N.D.	A1
FlAp1	*Aiptasia pallida*	Florida Keys	USA	Caribbean Sea	B184	B1
Mf1.5b	*Montastrea faveolata*	Florida Keys	USA	Caribbean Sea	B184	B1
Pd44b	*Porites divaricata*	Florida Keys	USA	Caribbean Sea	F178	F1











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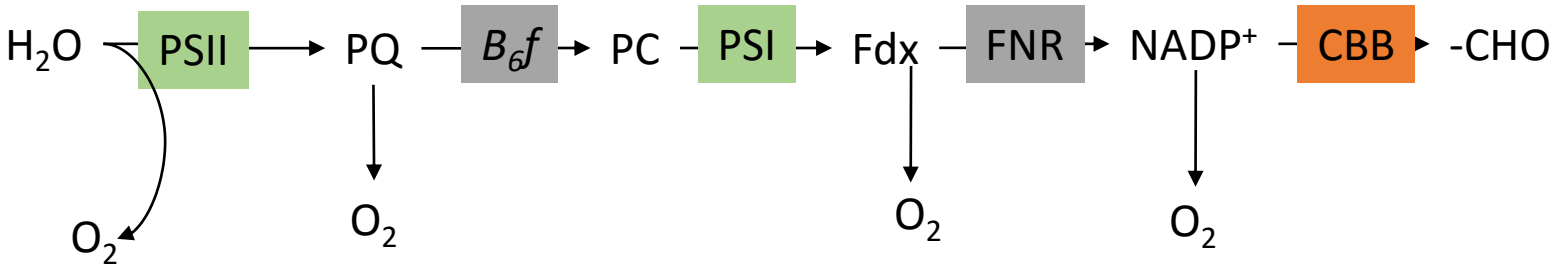
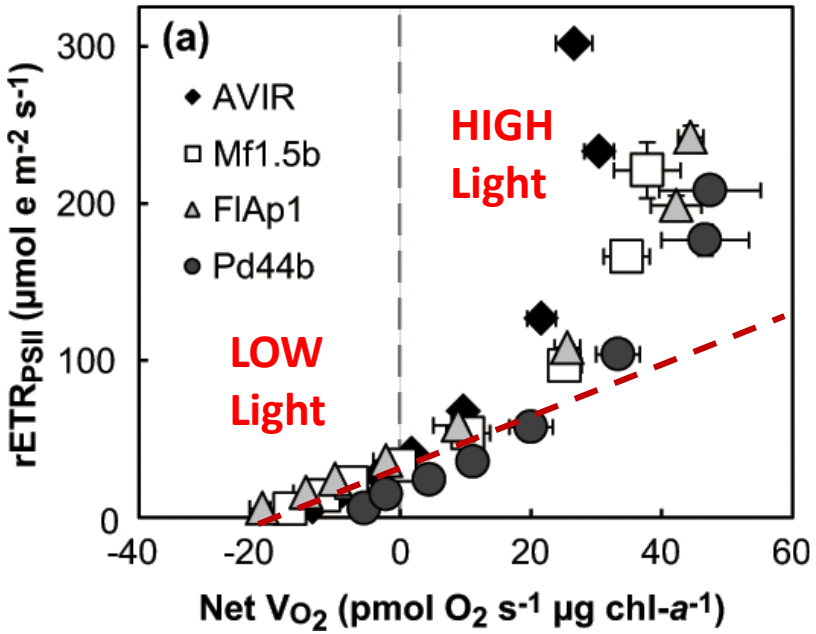
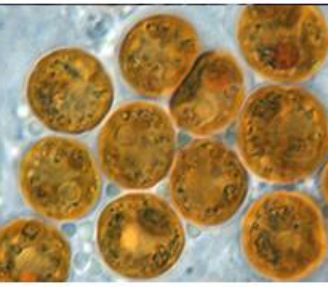
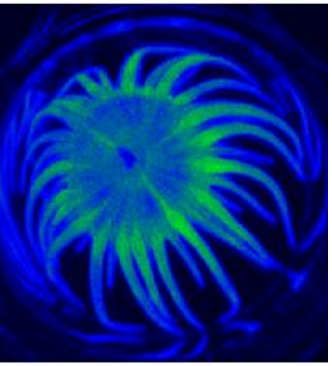


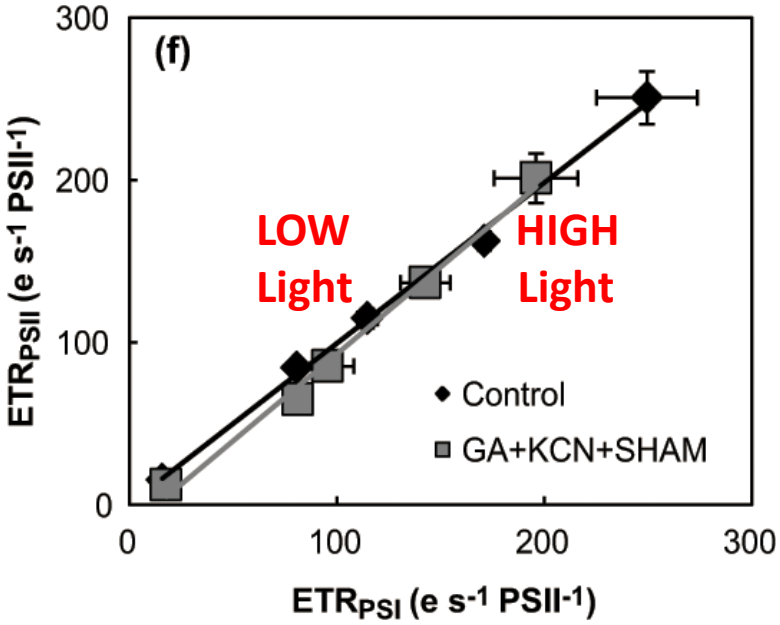


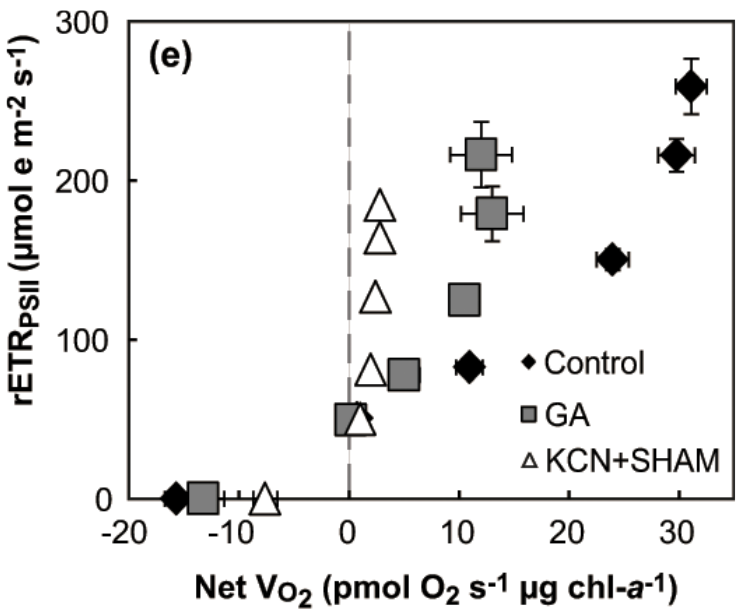


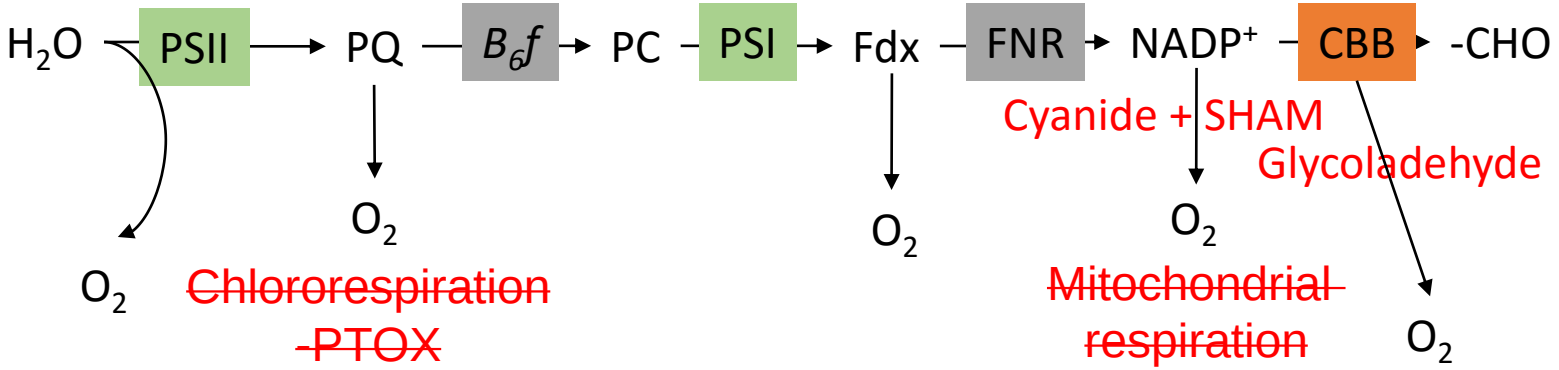


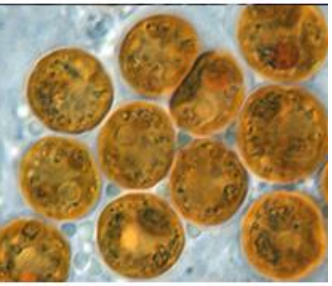
Relationship between PSII and PSI

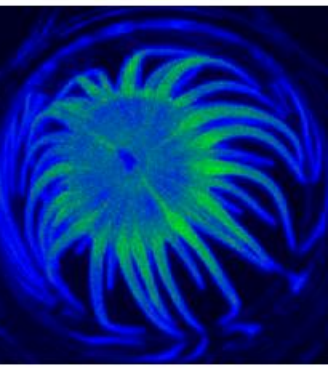
(*Roberty et al., 2014, New Phytol.*)









Roles of Mehler reaction in Symbiodinium

Acts a valve for excess electrons in high light

$2\ e^- + 2\ O_2 \rightarrow 2\ O_2^-$ (PSI-Fdx)

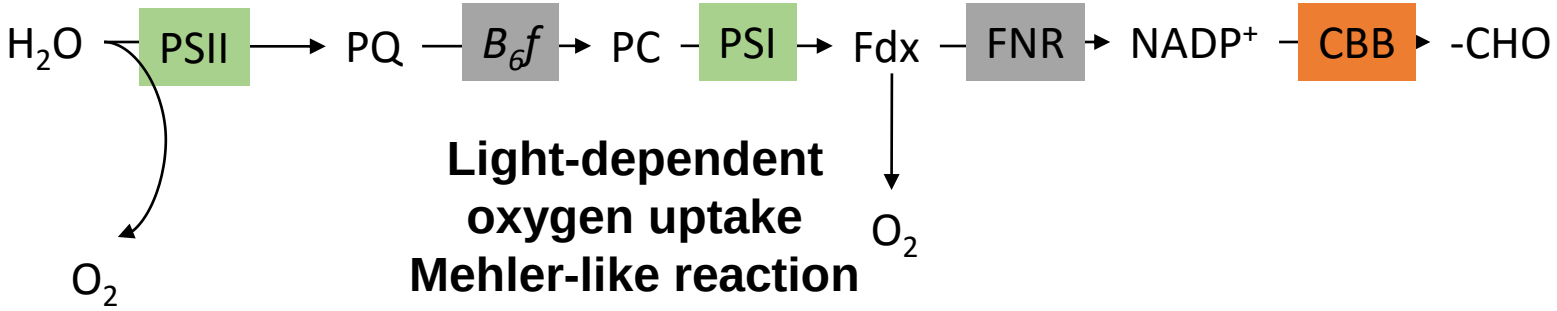
$2\ O_2^- + 2\ H^+ \rightarrow H_2O_2 + O_2$ (SOD)

$H_2O_2 + 2ASC \rightarrow 2\ H_2O + 2\ MDA$ (APX)

$2\ MDA + 2e^- + 2H^+ \rightarrow 2\ ASC$ (MDAR)

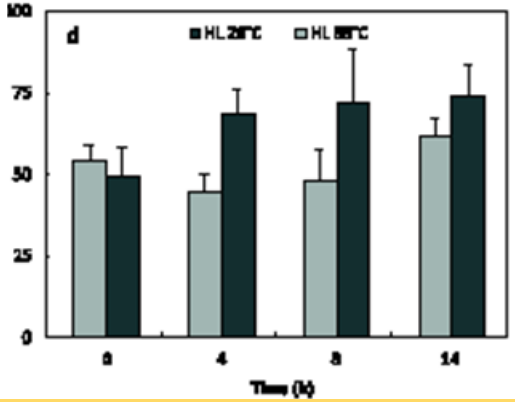
(Mehler, 1951; Asada et al., 1999)

Photoprotective role as long as ROS detoxification occurs



Mehler and ROS detoxification capacity

(26°C vs 33°C in High Light)

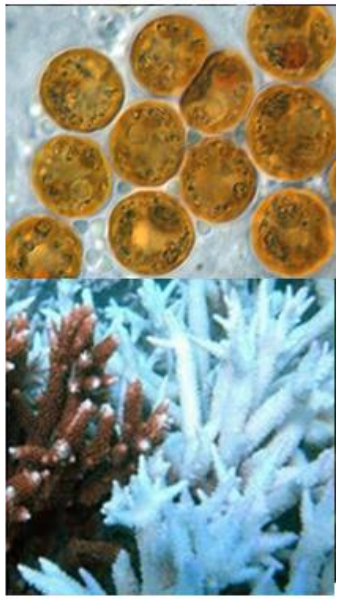


$2\ H_2O \rightarrow O_2 + 4\ H^+ + 4e^-$ (PSII)

$2\ e^- + 2\ O_2 \rightarrow 2\ O_2^-$ (PSI-Fdx)

<u>Increase of ETR towards O_2</u>

Imbalance might participate to coral bleaching under high light and high temperature

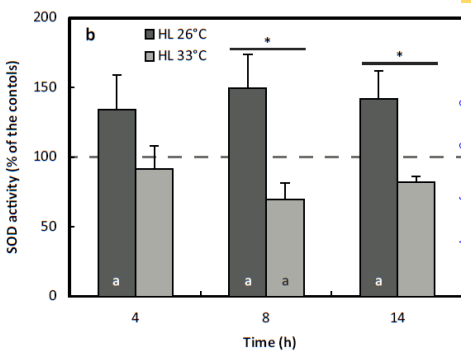


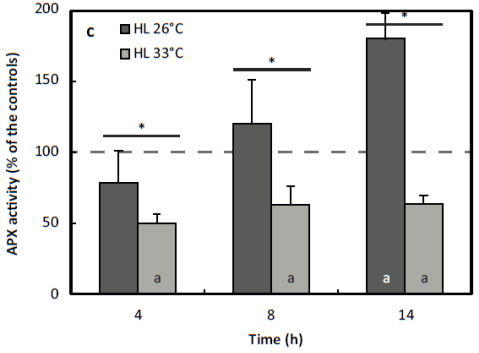
<u>Decrease of ROS scavenging capacity</u>

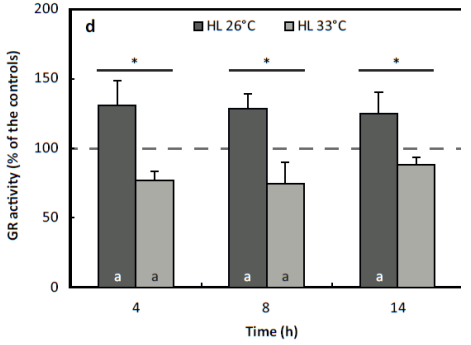
$2\ O_2^- + 2\ H^+ \rightarrow H_2O_2 + O_2$ (SOD)

$H_2O_2 + 2ASC \rightarrow 2\ H_2O + 2\ MDA$ (APX)

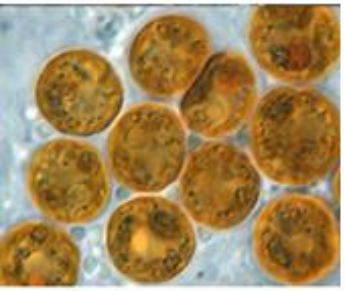
$2\ MDA + 2e^- + 2H^+ \rightarrow 2\ ASC$ (MDAR)



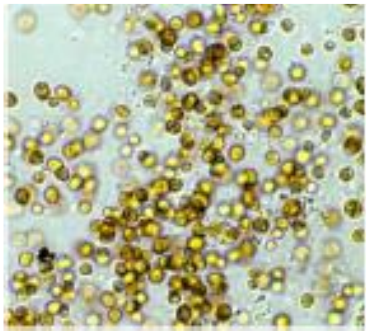




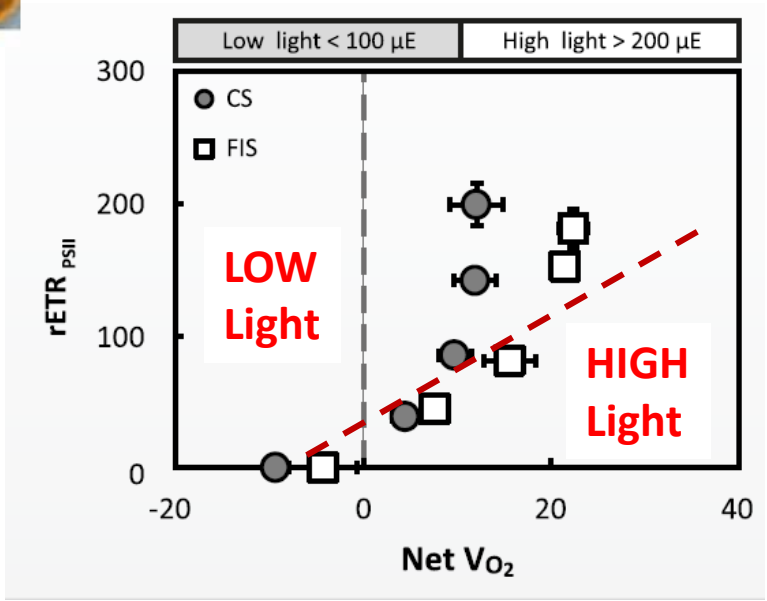
(Roberty et al., 2015, Coral Re

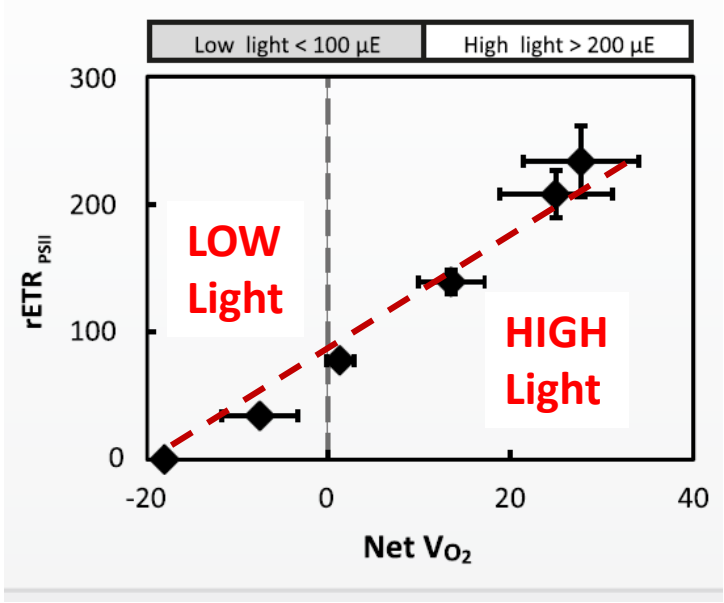


Does Mehler reaction occur *in hospite ?*



isolated *Symbiodinium / Stylophora pistillata*





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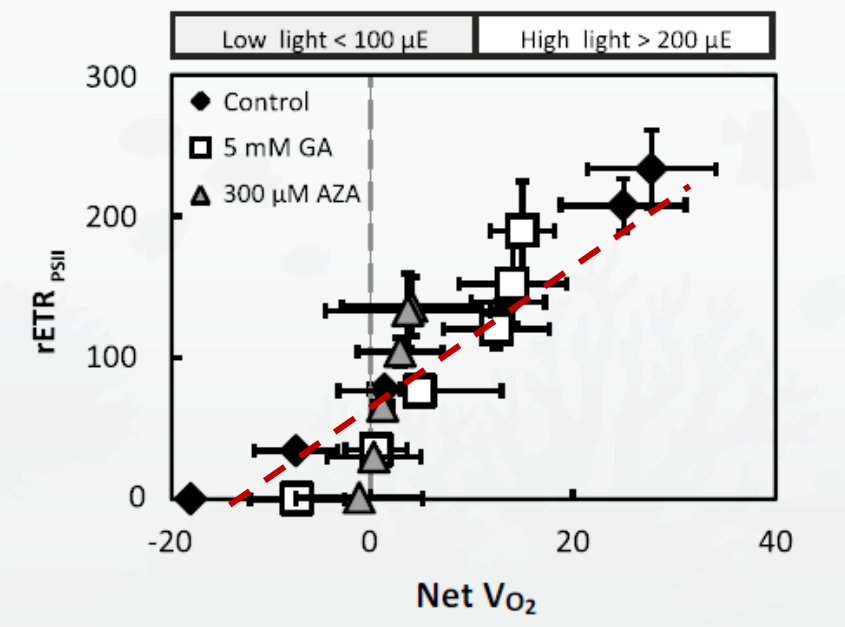
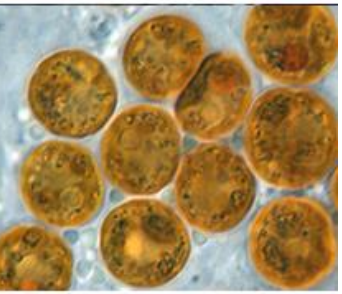
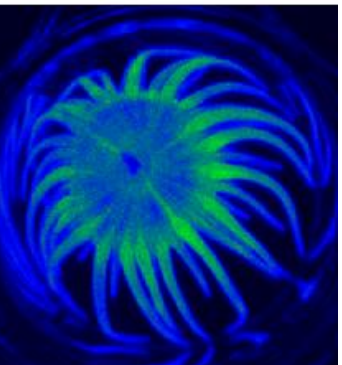


Glycoladehyde
Acetazolamide

PSII → PQ → B_6f → PC → PSI → Fdx → FNR → $NADP^+$ → ~~CBB~~ → -CHO

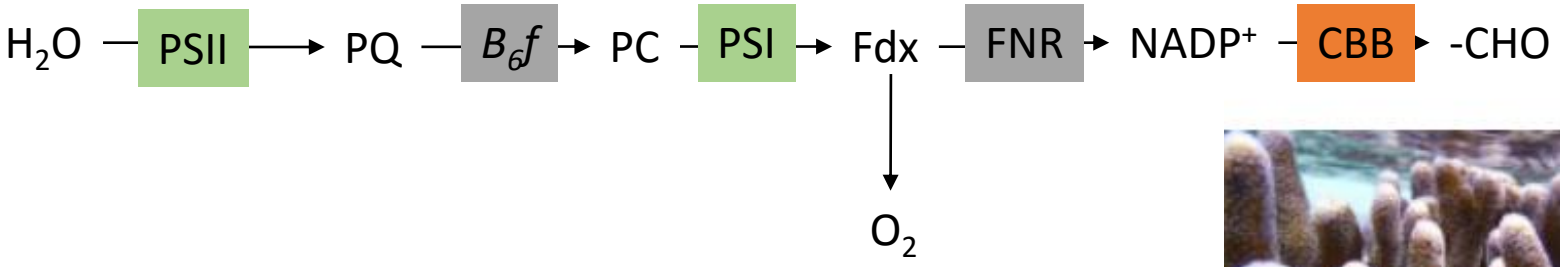
Fdx → O_2





Conclusions :

PSI-dependent Mehler reaction in Symbiodinium



The main light-dependent oxygen uptake in isolated Symbiodinium (up to 50% of ETR)

Provides extra ATP for cellular needs

Photoprotection mechanism as long as ROS detoxification occurs

Does not occurs under controlled laboratory conditions in *S. pistillata* unless carbon fixation capacity is compromised