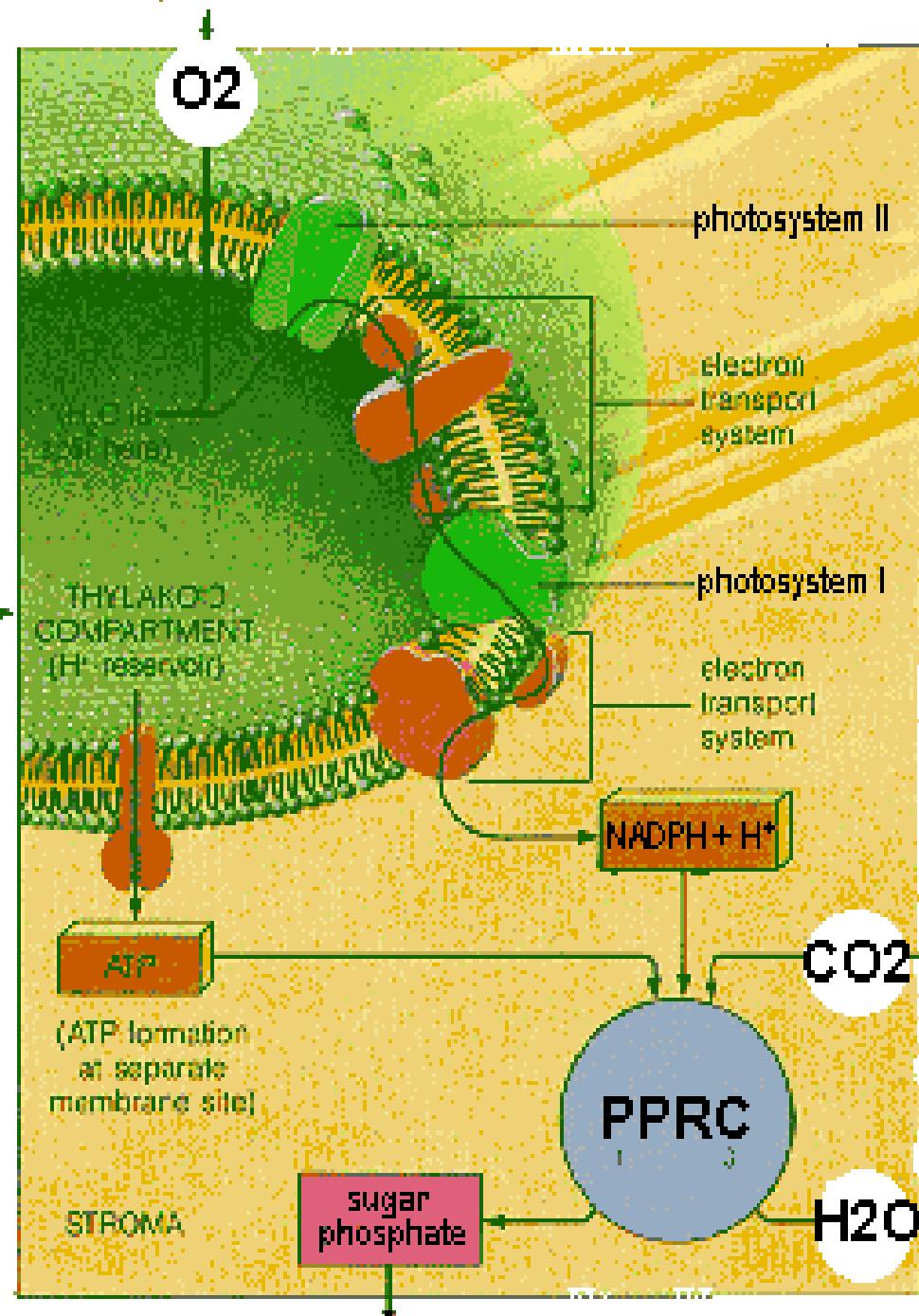
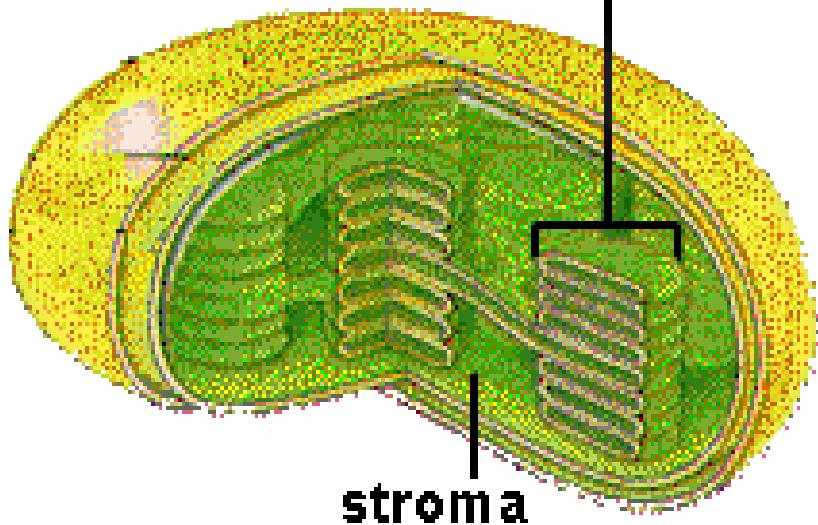
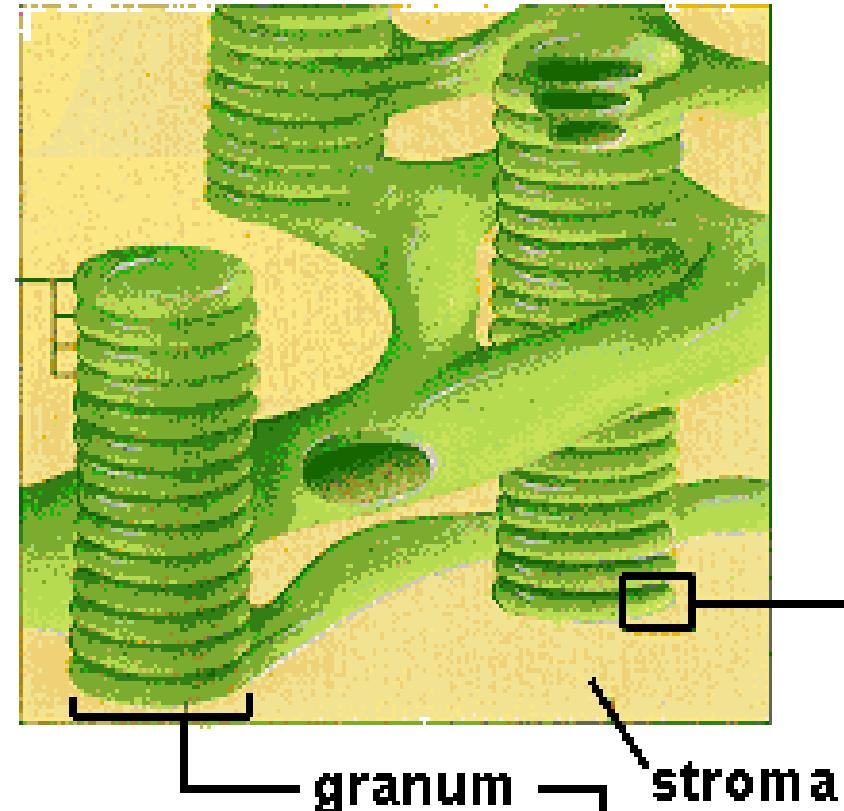
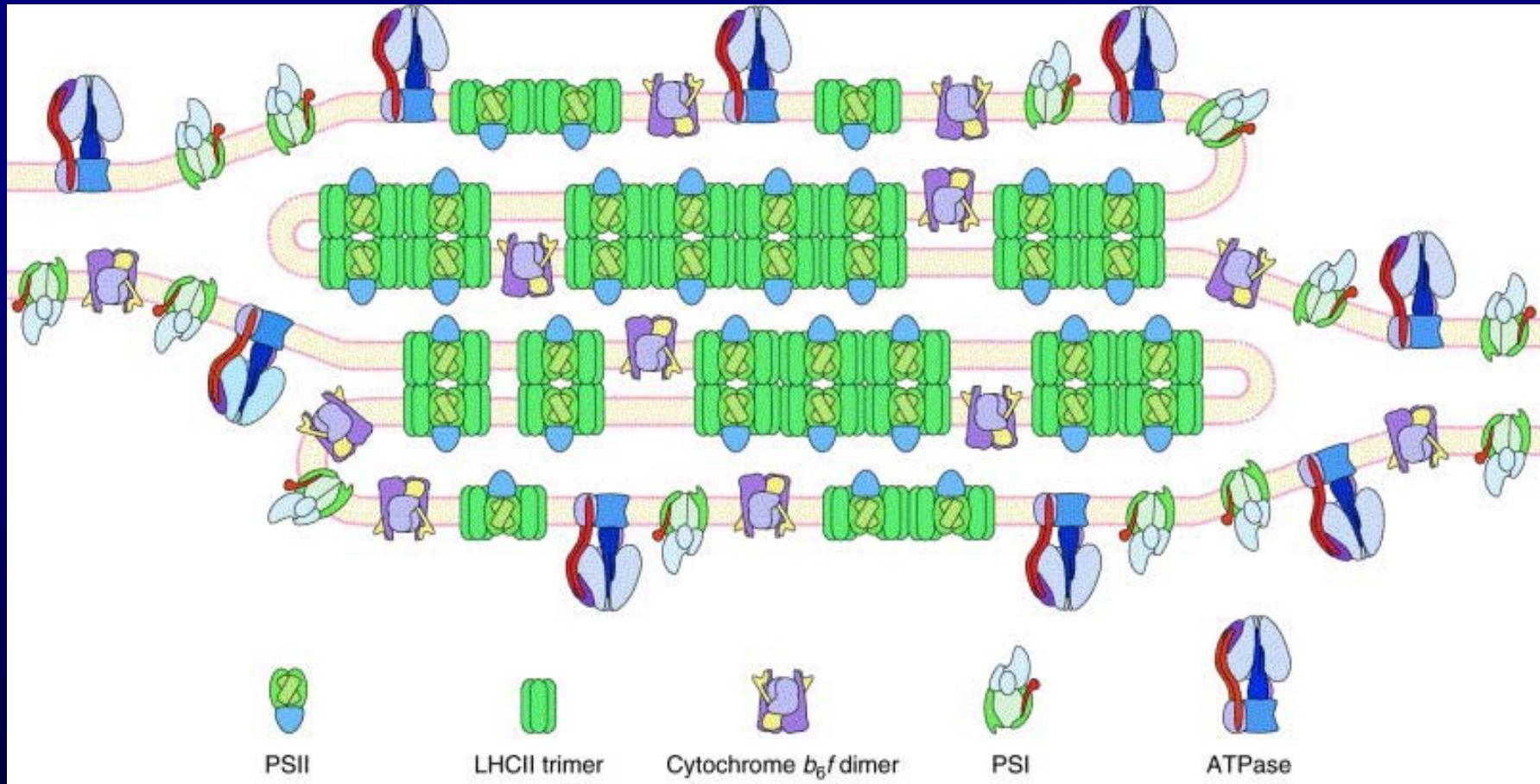


Introduction to Biophysics of Photosynthesis



Influence of steric hindrance on grana stacking



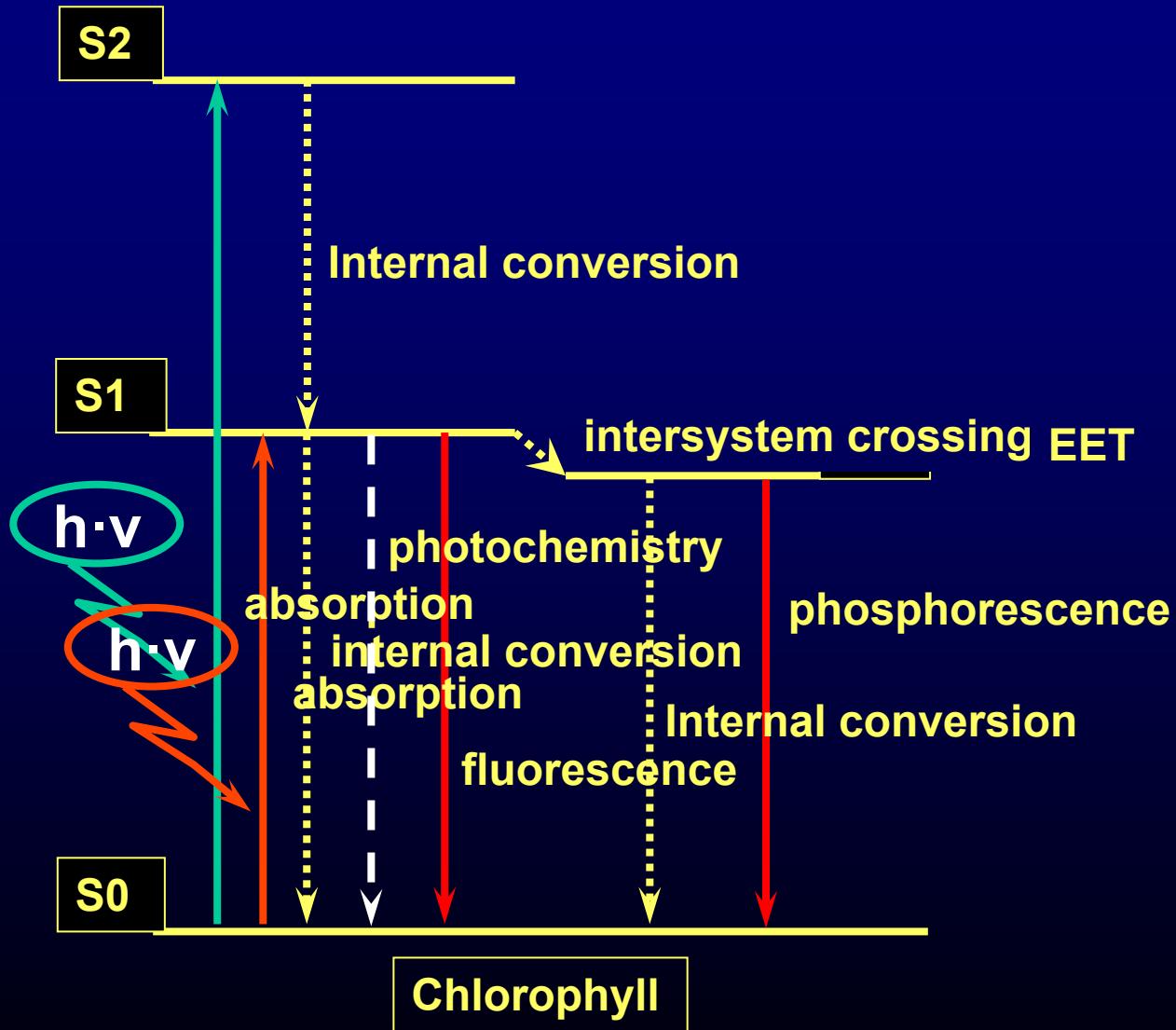
From: Allen JF, Forsberg J (2001) TIBS 6, 317–326

TRENDS in Plant Science

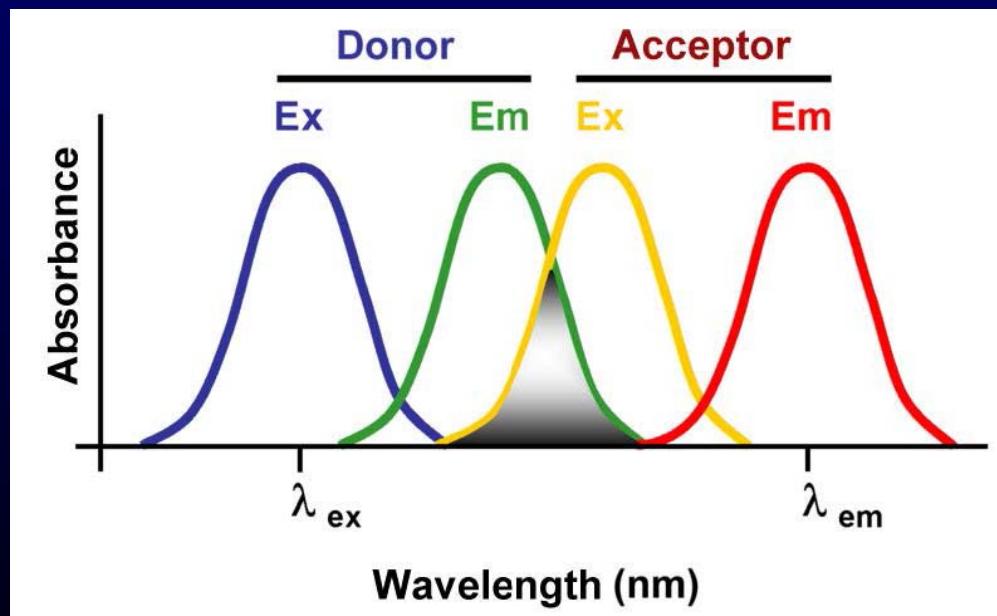
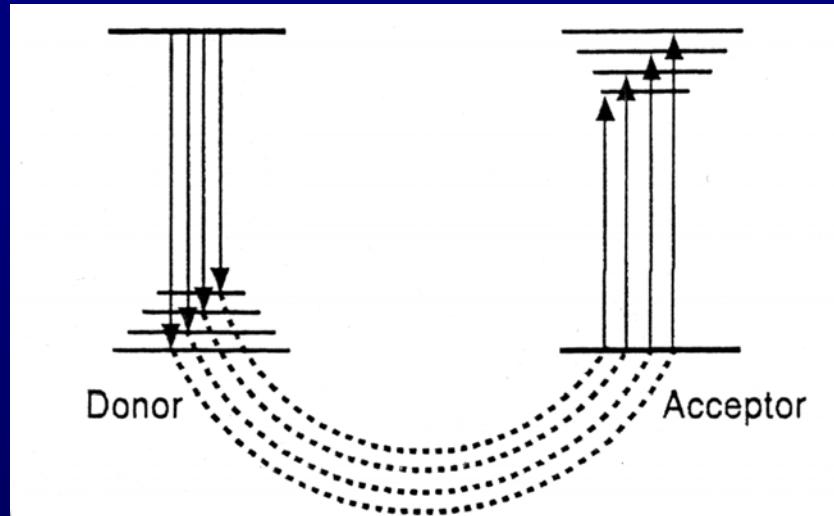
Mechanism of grana stacking

- 1. LHCII tends to aggregate
- 2. thylakoids containing a lot of LHCII will stick together, forming grana. PSII/RC nicely fits in because it does not protrude much out of the membrane
- 3. The more bulky PSII/RC and the most bulky ATPase go into stroma regions

Necessary for energy transfer:
stable S₁-state



Necessary for energy transfer:
Overlap of emission/absorption bands

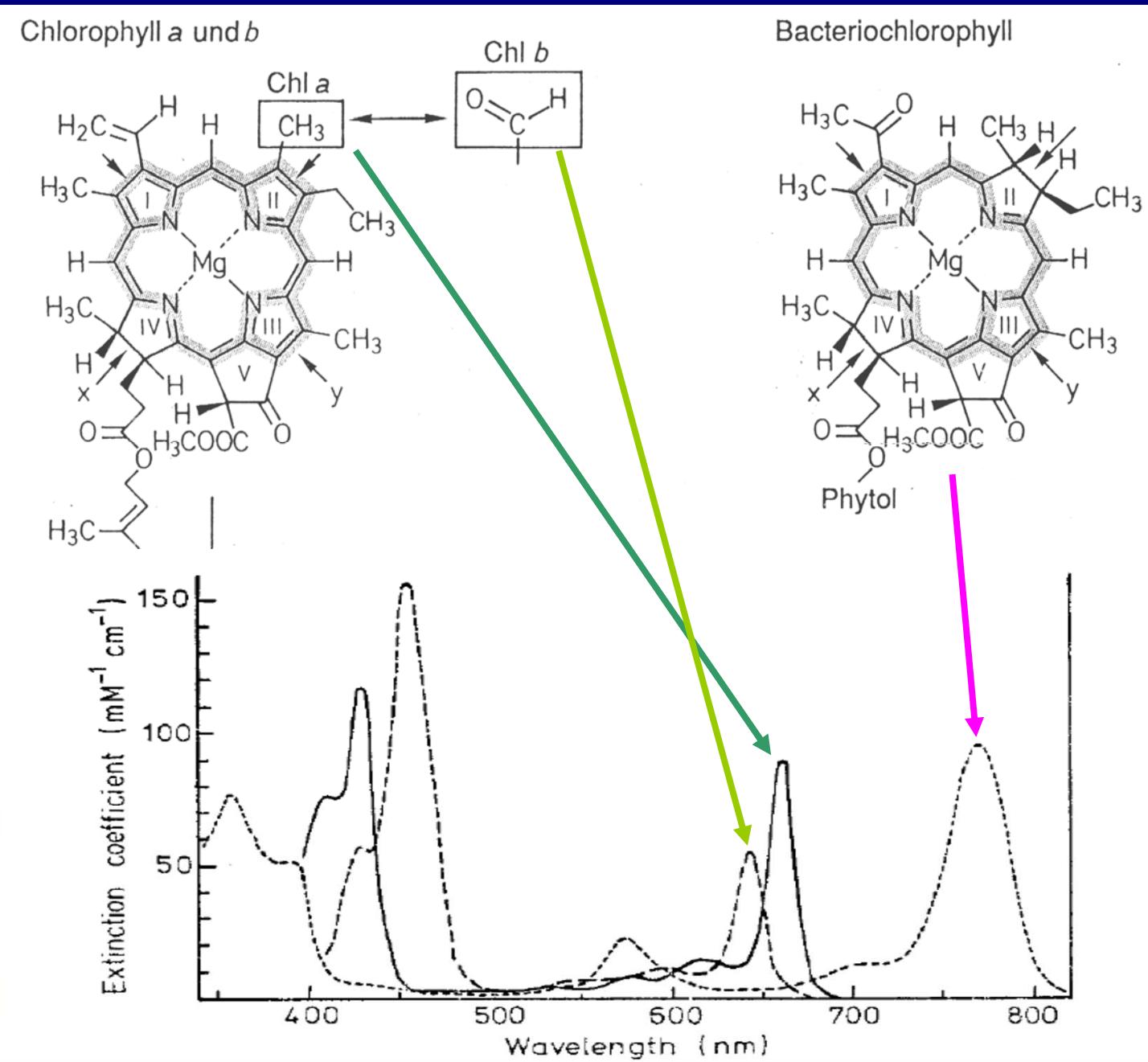


From: bio.libretexts.org

Adjustment of absorption bands by chemical modification

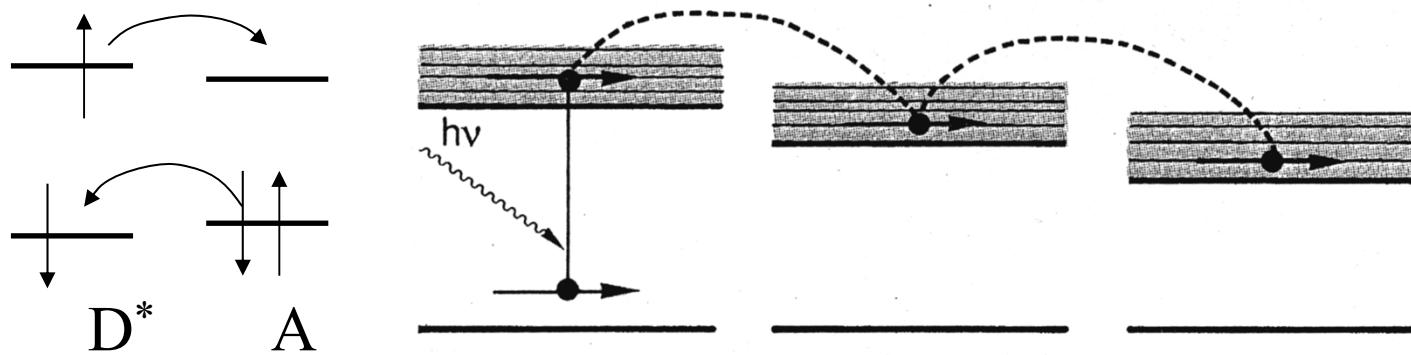
From: Lawlor
DW (1990)
Thieme,
Stuttgart,
377S

From: Barber J
(1978) Rep
Prog Phys 41,
1158-99

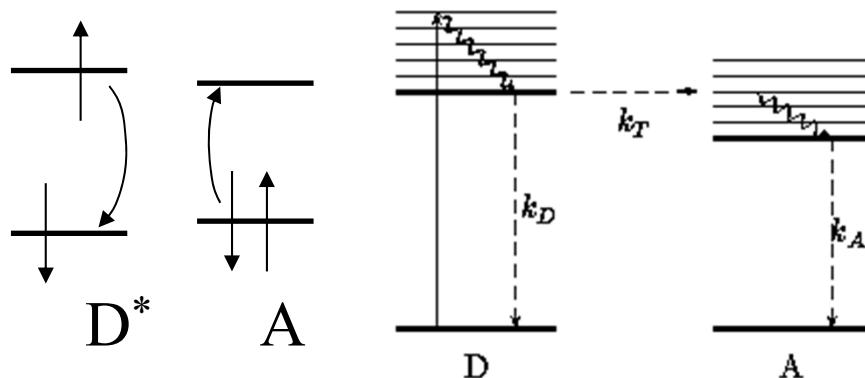


Mechanisms of energy transfer between chlorophylls

Short distance, requires overlap of molecular orbitals (\rightarrow only Chls in extremely short distance to each other, e.g. special pair) : direct transfer of S₁ excited state (Dexter-Mechanism)



Larger distance, requires overlap of absorption/emission spectra: Transfer by induktive Resonance („Förster-Mechanism“)



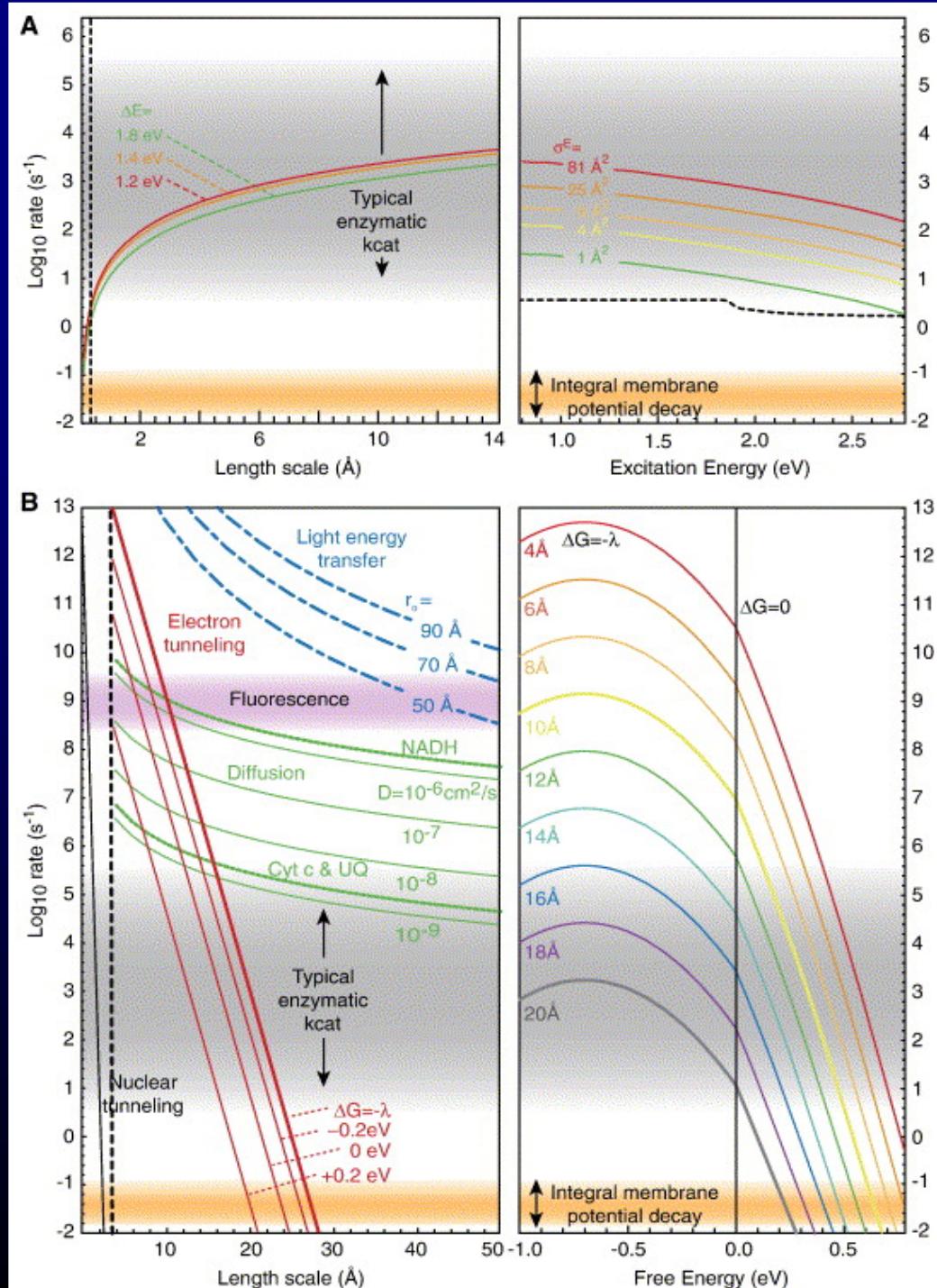
$$\Gamma_{DA} = k_D \left(\frac{R_0}{R} \right)^6$$

$$R_0^6 = 8.8 \times 10^{17} \frac{\kappa^2}{n^4} J$$

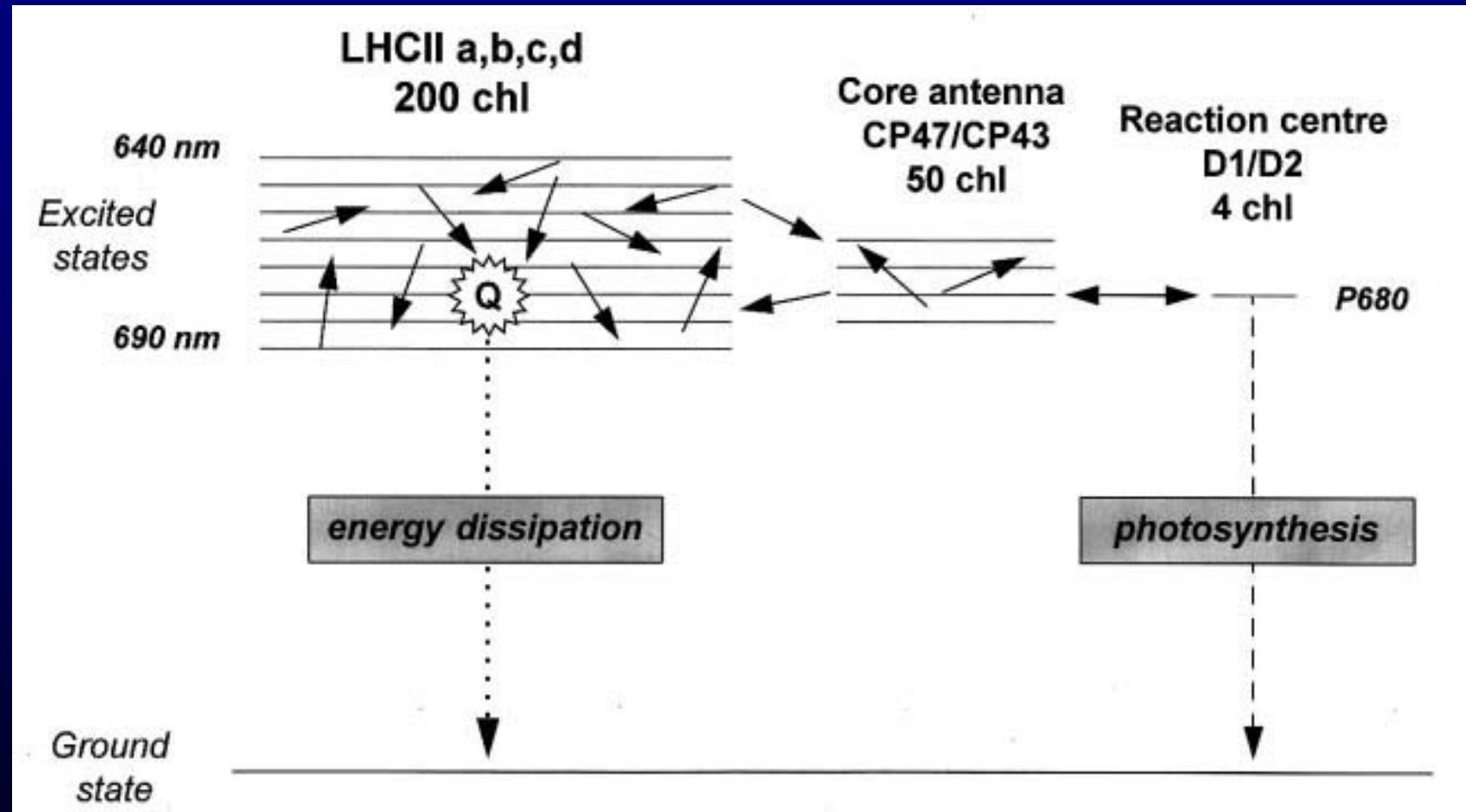
Comparison of other Energy transfer mechanisms

- For all processes, speed of energy transfer decreases with increasing distance.
- This limits the rate and efficiency of enzymatic and non-enzymatic processes. The longer the transfer time, the higher the risk of energy loss by unwanted processes
- Light energy transfer is fast and covers large distances, but required re-absorption and thus is not very efficient
- Electron tunnelling is fast for very short distances, but very slow for longer distances → most relevant <10Å.
- Diffusion speed decreases less with increasing distances, therefore it becomes faster than tunnelling at more than 10-20Å.

From: Noy D, Moser CC, Dutton PL (2006) BBA Bioen. 1757, 90-105

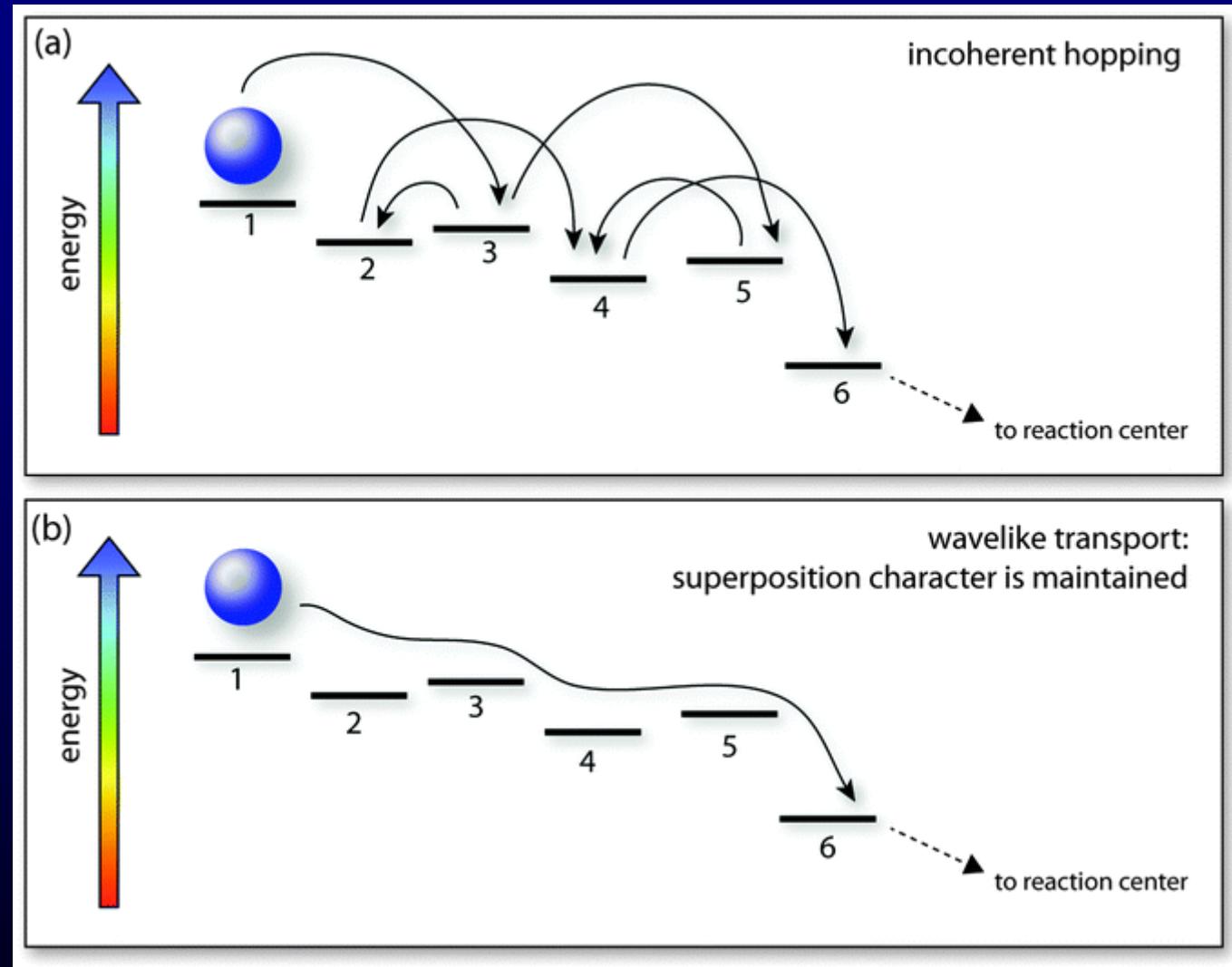


Energy transfer – funnel principle (II): Scheme in higher plants



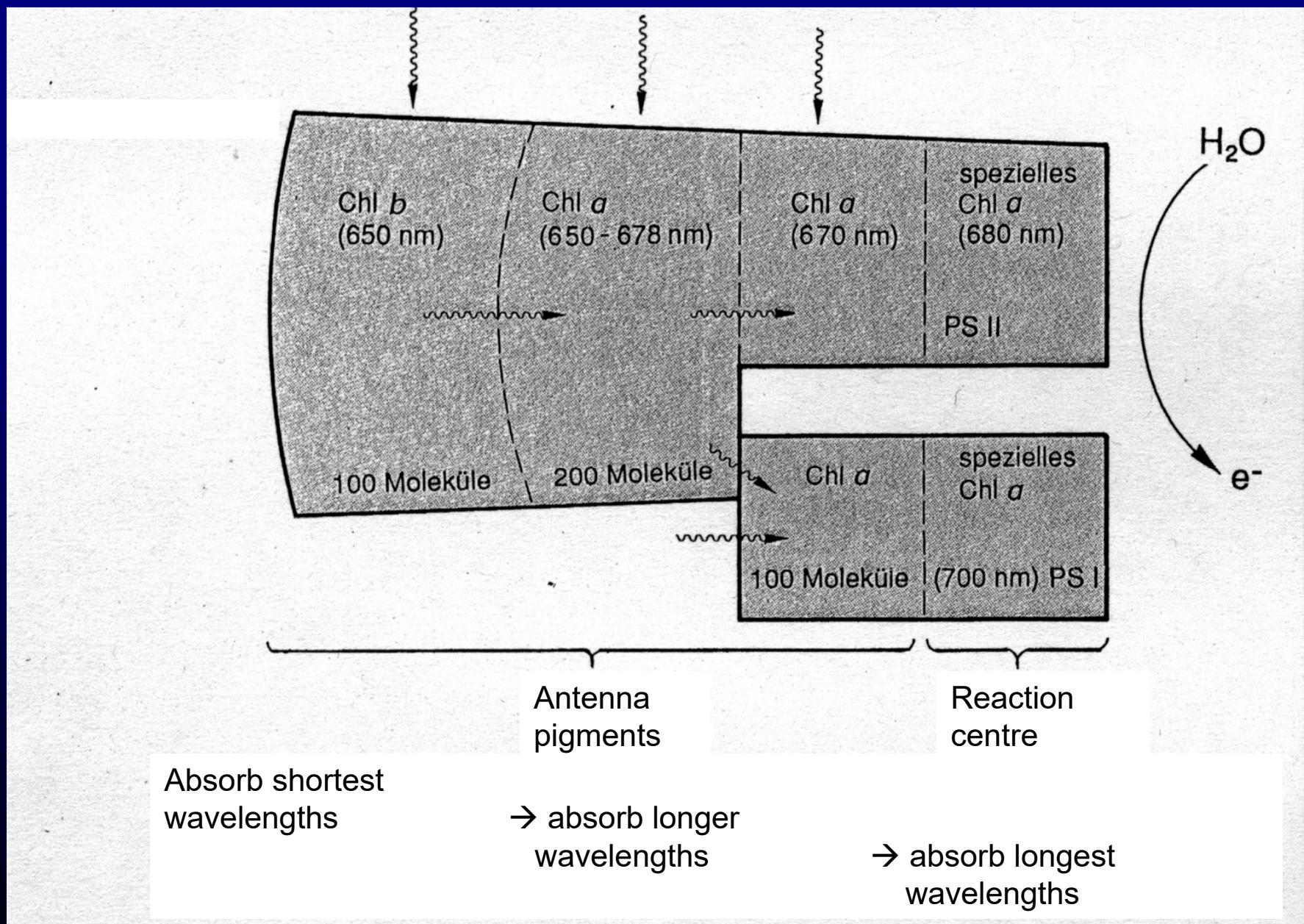
From: Horton P, Ruban AV, Walters RG (1996) Annu Rev Plant Physiol Plant Mol Biol 47: 655-84

Energy transfer – funnel principle (II): debated modern view



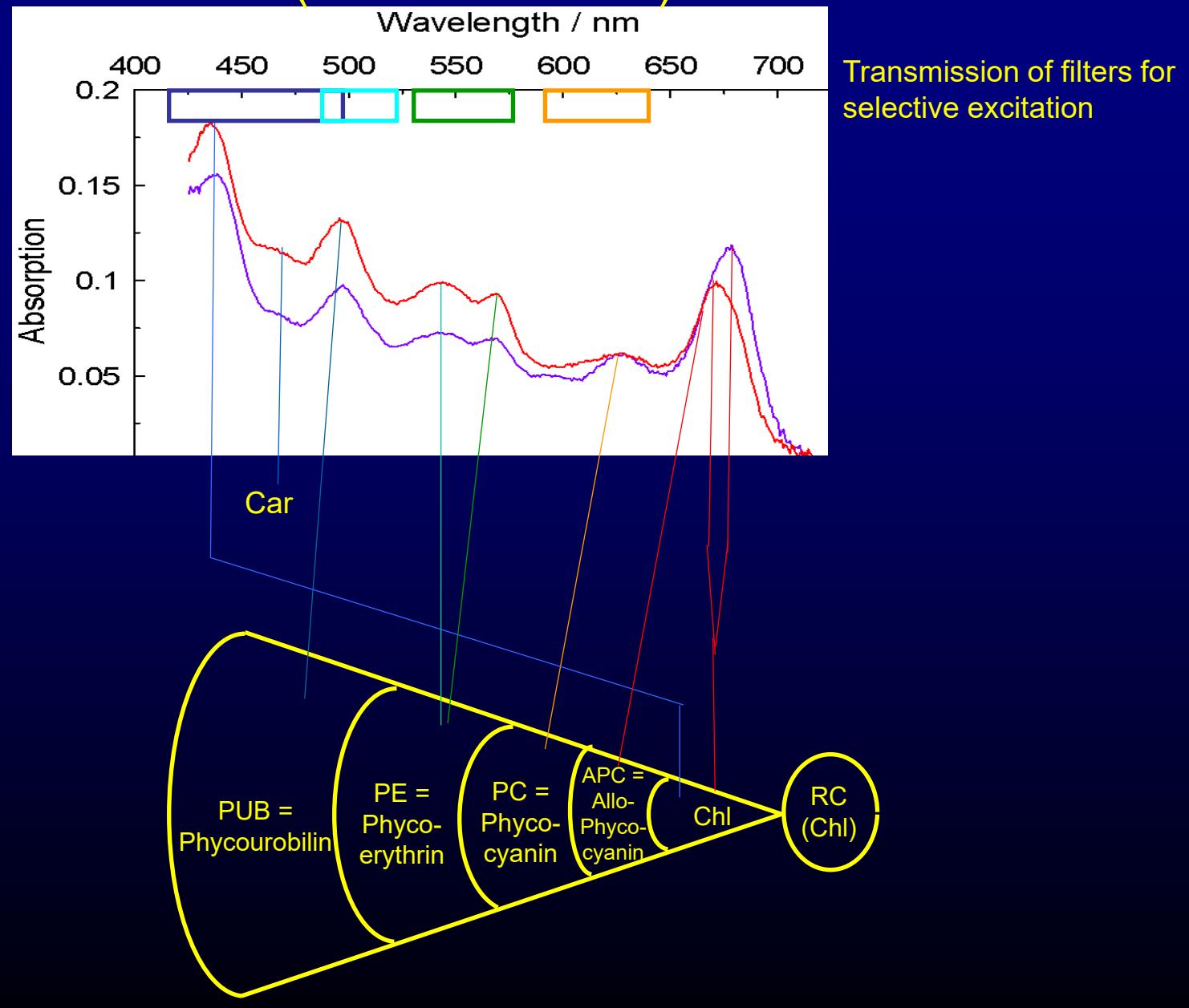
From: Collini E (2013) Spectroscopic signatures of quantum-coherent energy transfer. Chemical Society Reviews 42, 4932-4947

Energy transfer – funnel principle (II): Scheme in higher plants

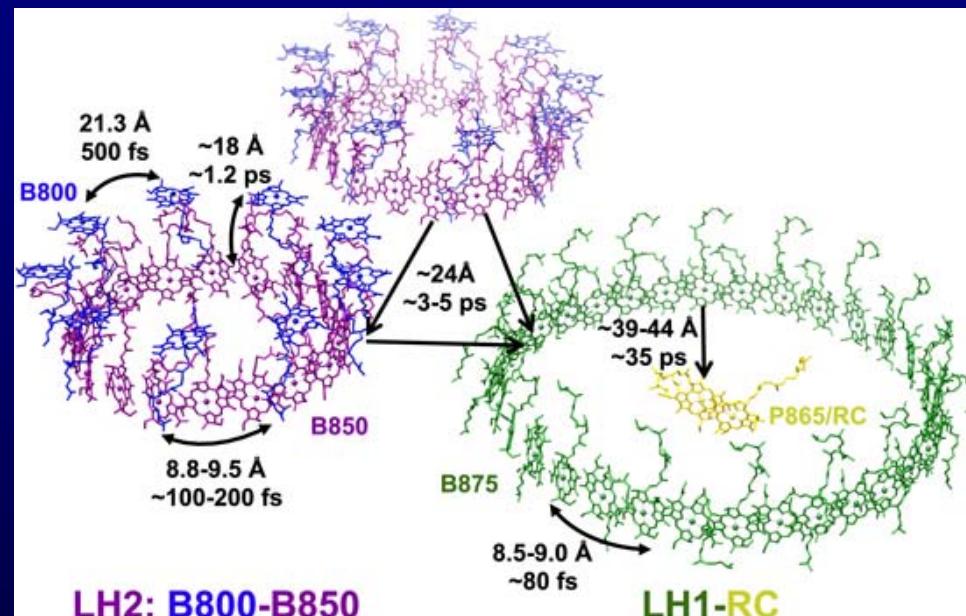


From: Lawlor DW (1990) Thieme, Stuttgart, 377S

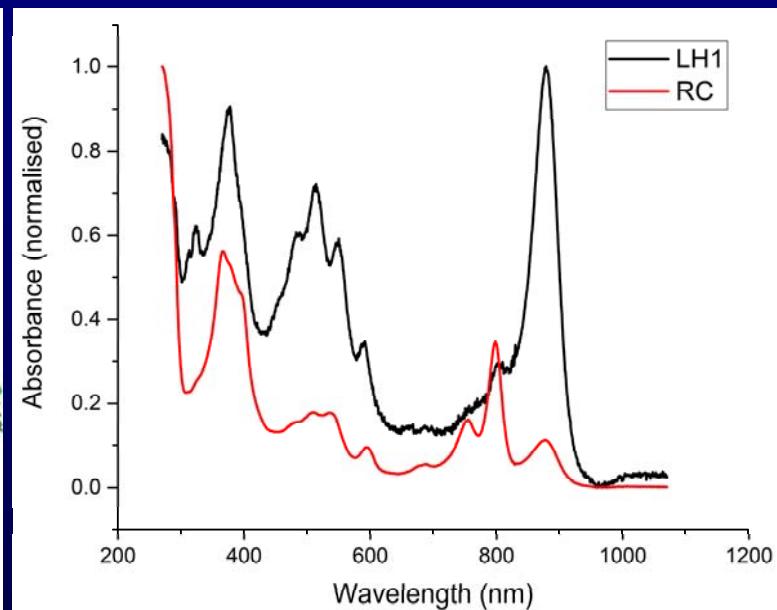
Energy transfer – funnel principle (II): Scheme in cyanobacteria (*Trichodesmium*)



Energy transfer – funnel principle (II): Scheme in purple bacteria

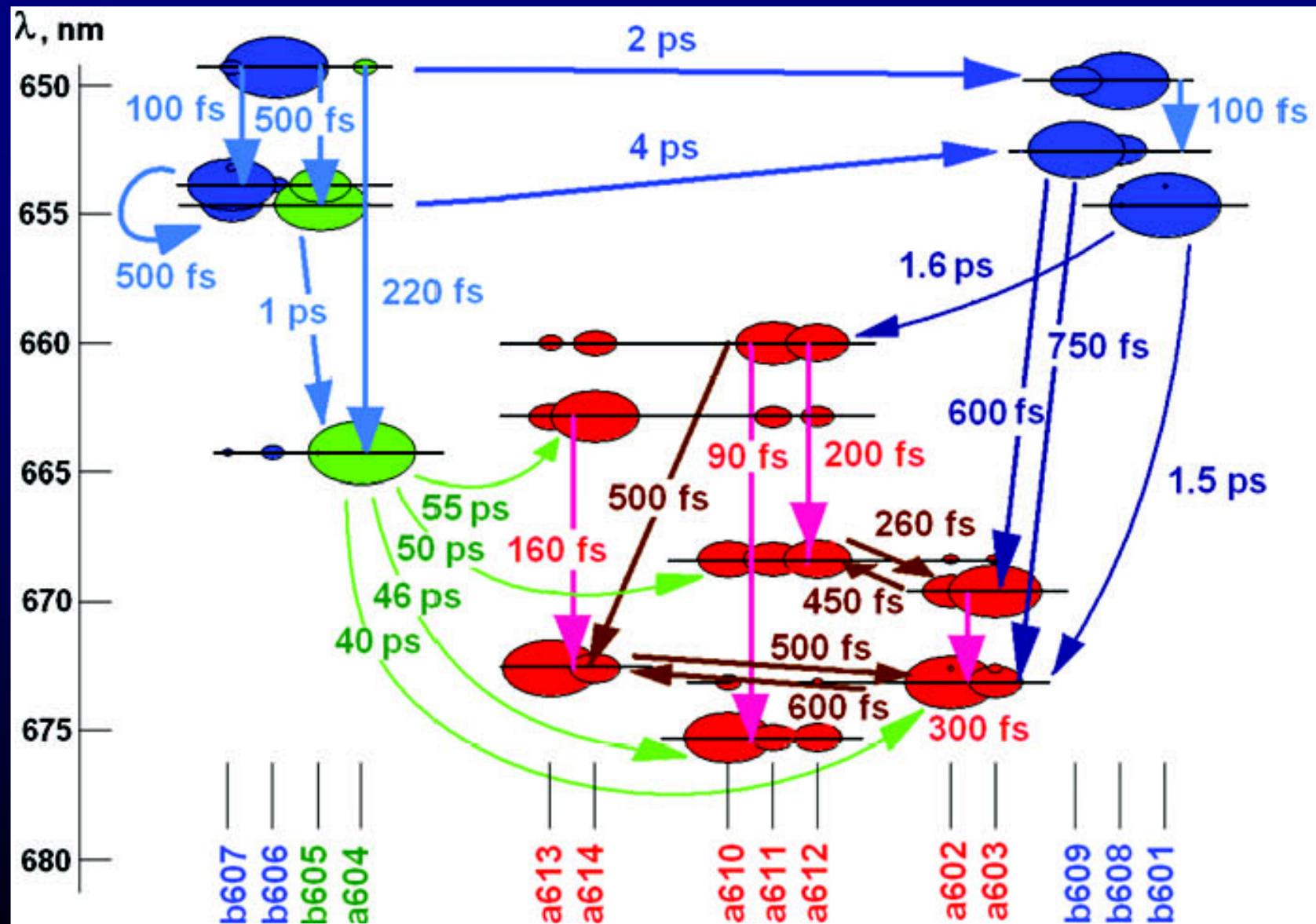


From: Bryant DA, Canniffe DP (2018) J Physics B: At. Mol. Opt. Phys. 51 033001.



From: Jaime-Perez N et al. (2019) unpublished data H330

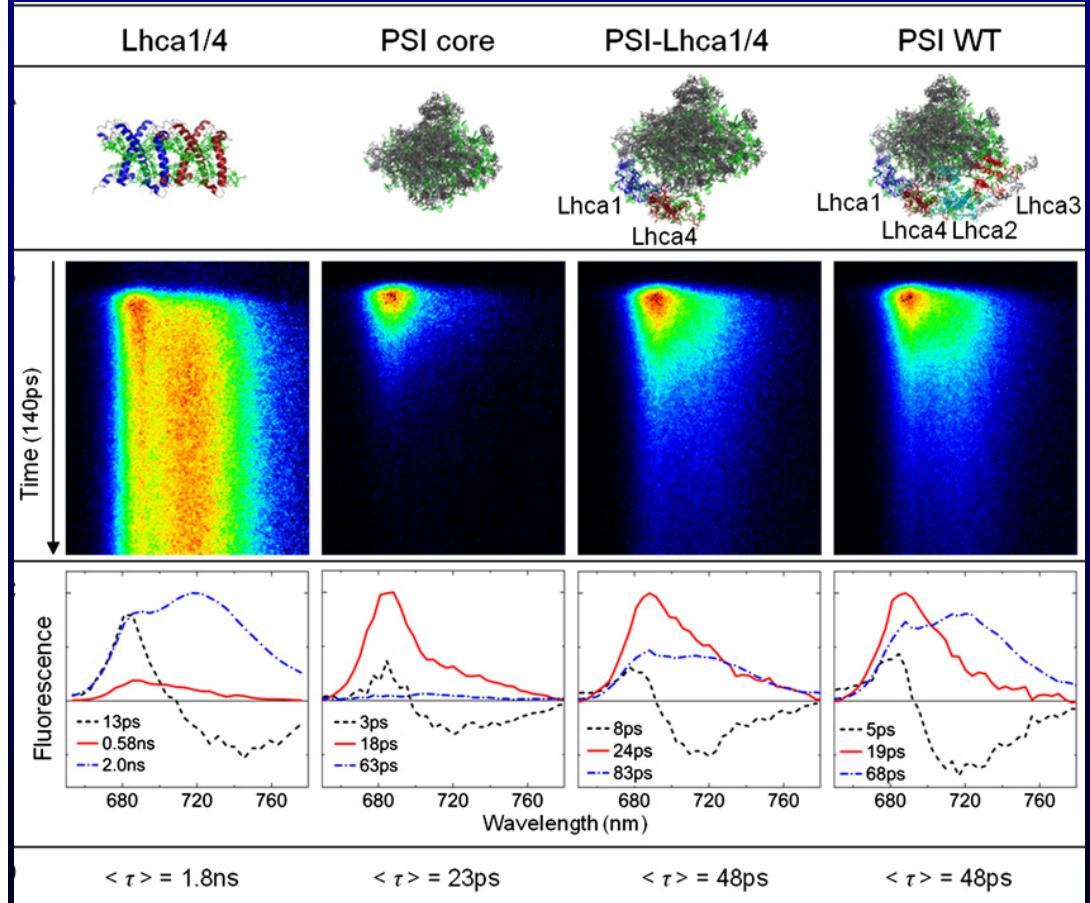
Energy transfer – funnel principle (III): Transfer times between Chls towards & in PSIIRC



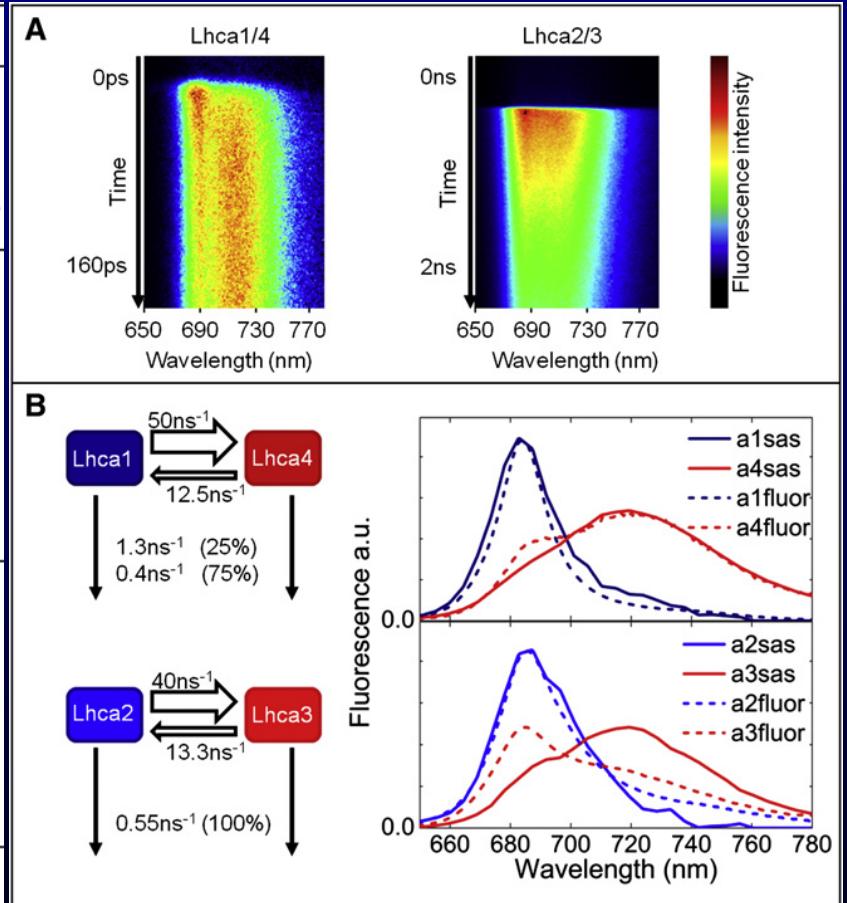
From: vanGrondelle R, Novoderezhkin VI, 2006, PCCP8, 793-807

Photosynthesis related Proteins with metal centres

1. Excitation transfer times between light harvesting complexes



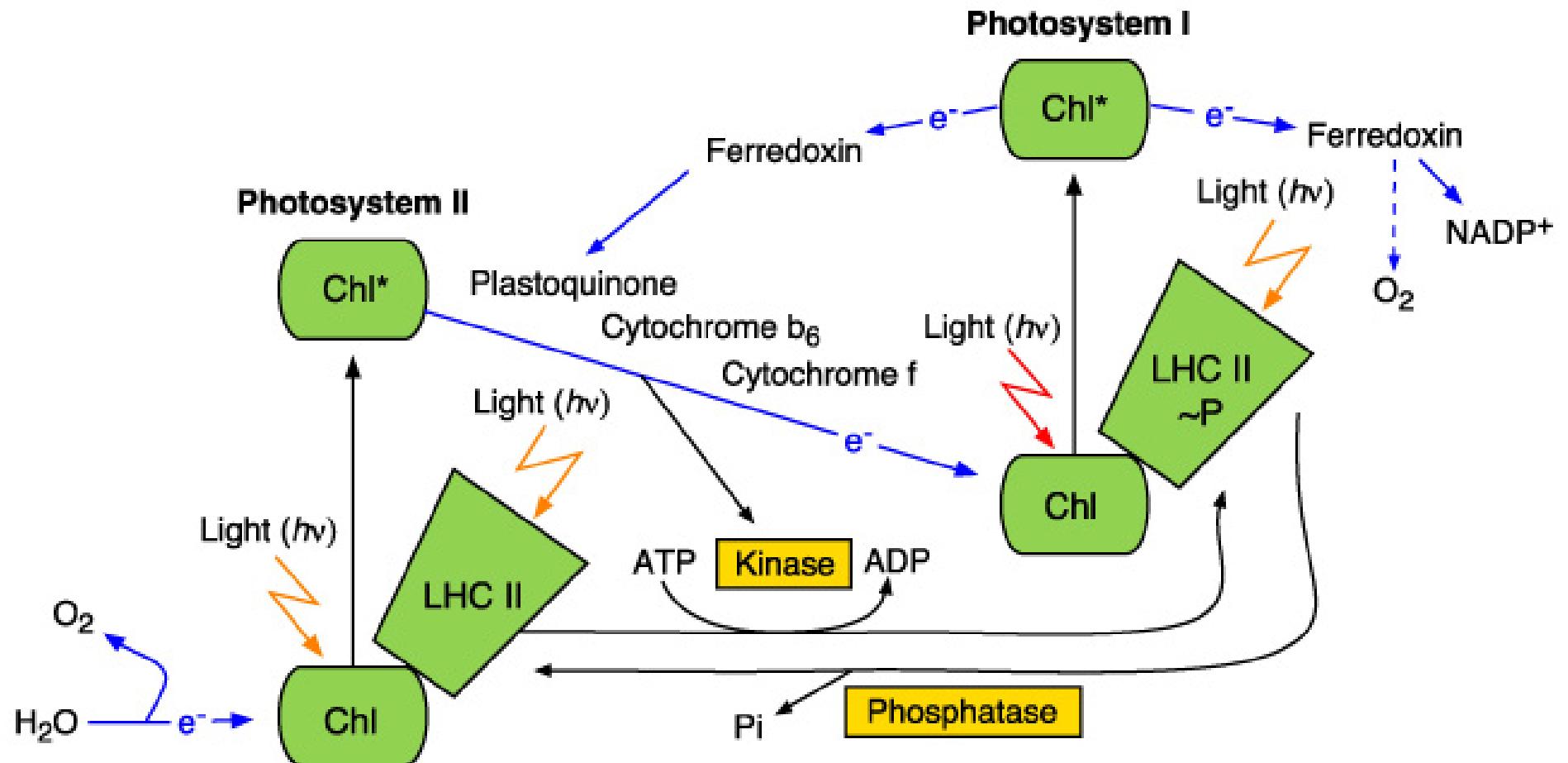
From: Wientjes E et al (2011) BiophysJ 101, 745-54



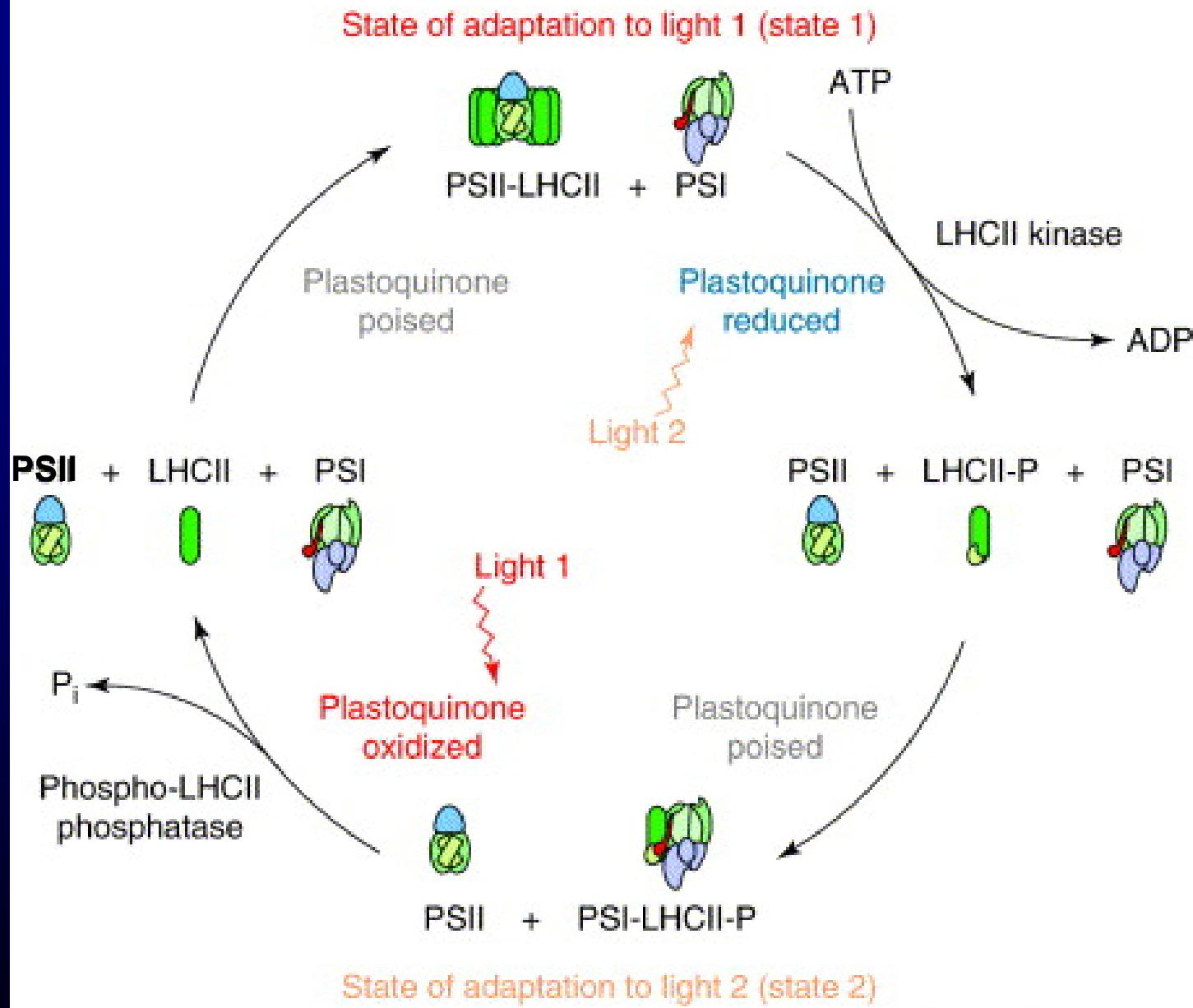
From: Wientjes E et al (2011) BiophysJ 100, 1372-80

Regulation of energy transfer (I): the principle of „state transitions“

Higher plants, many algae



Regulation of energy transfer: The cycle of state transitions

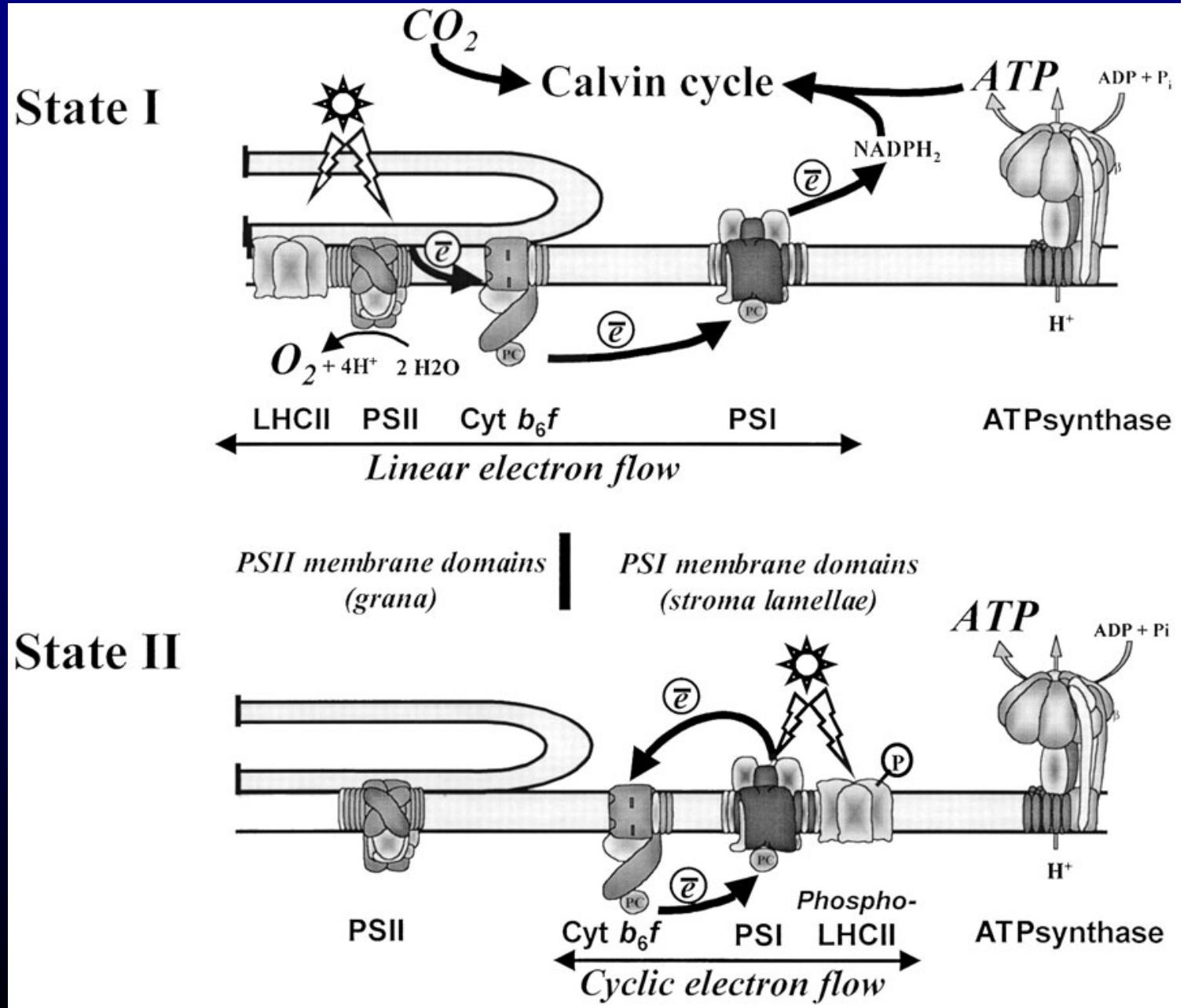


TRENDS in Plant Science

From: Allen JF, Forsberg J (2001) TIBS 6, 317–326

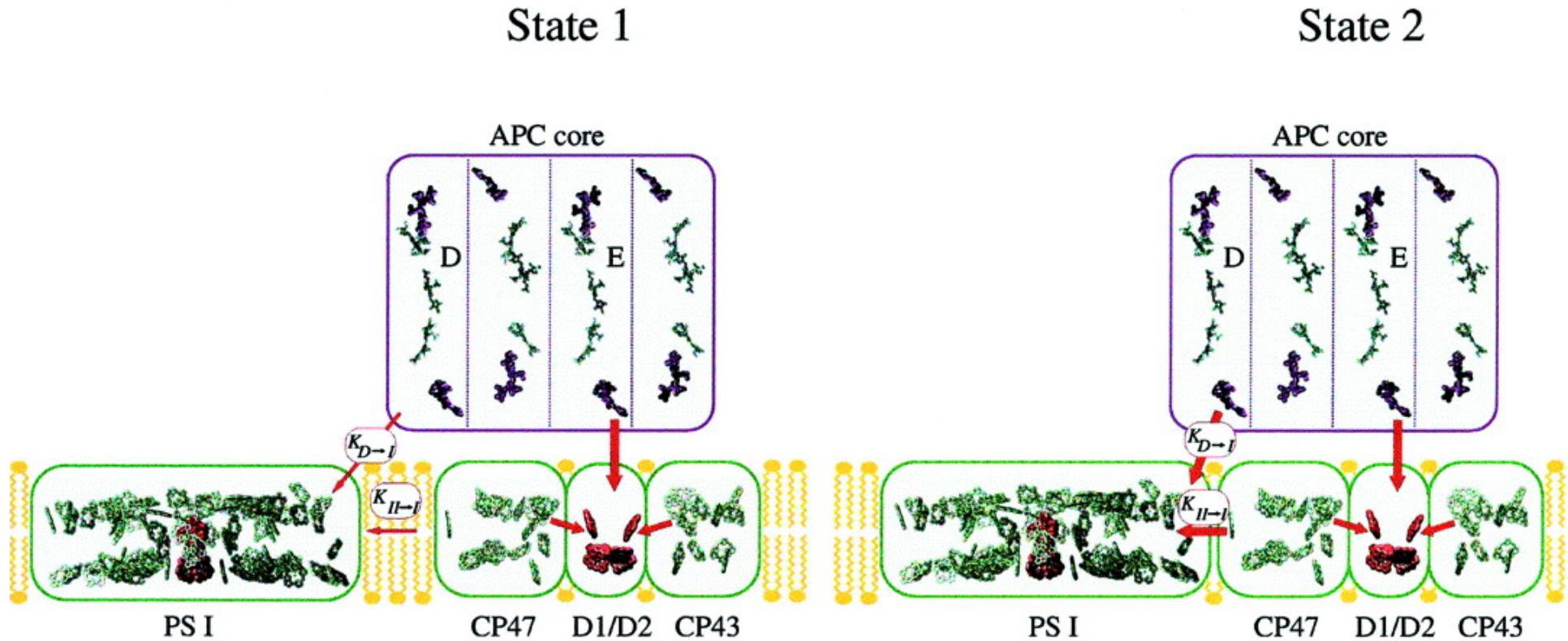
Regulation of energy transfer: another view of „state transitions“

Alternative view of
the function of
state transitions



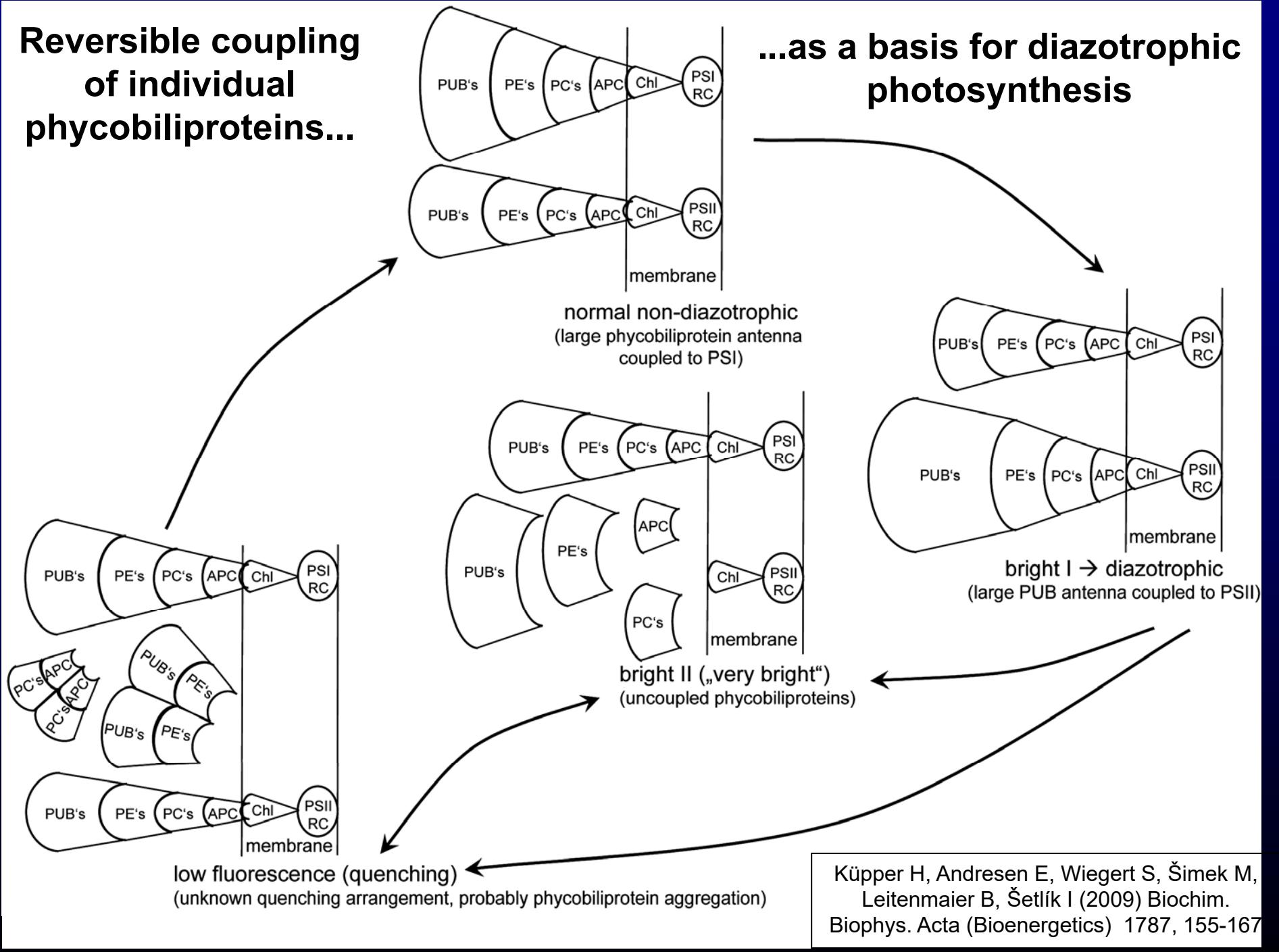
From: Wollman FA (2001) The
EMBO Journal (2001) 20, 3623 -
3630

Regulation of energy transfer (I): „state transitions“ in cyanobacteria and red algae



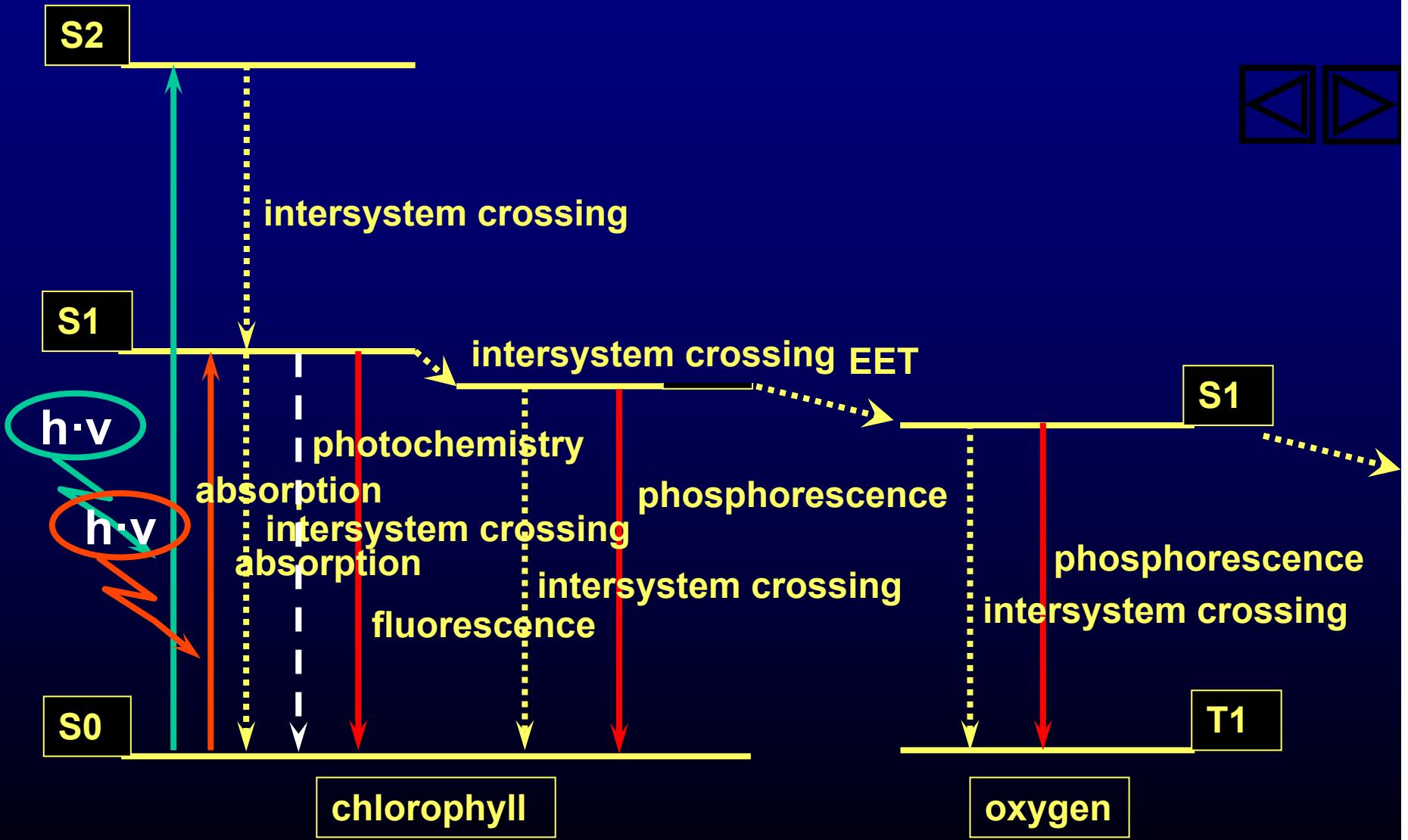
Reversible coupling of individual phycobiliproteins...

...as a basis for diazotrophic
photosynthesis



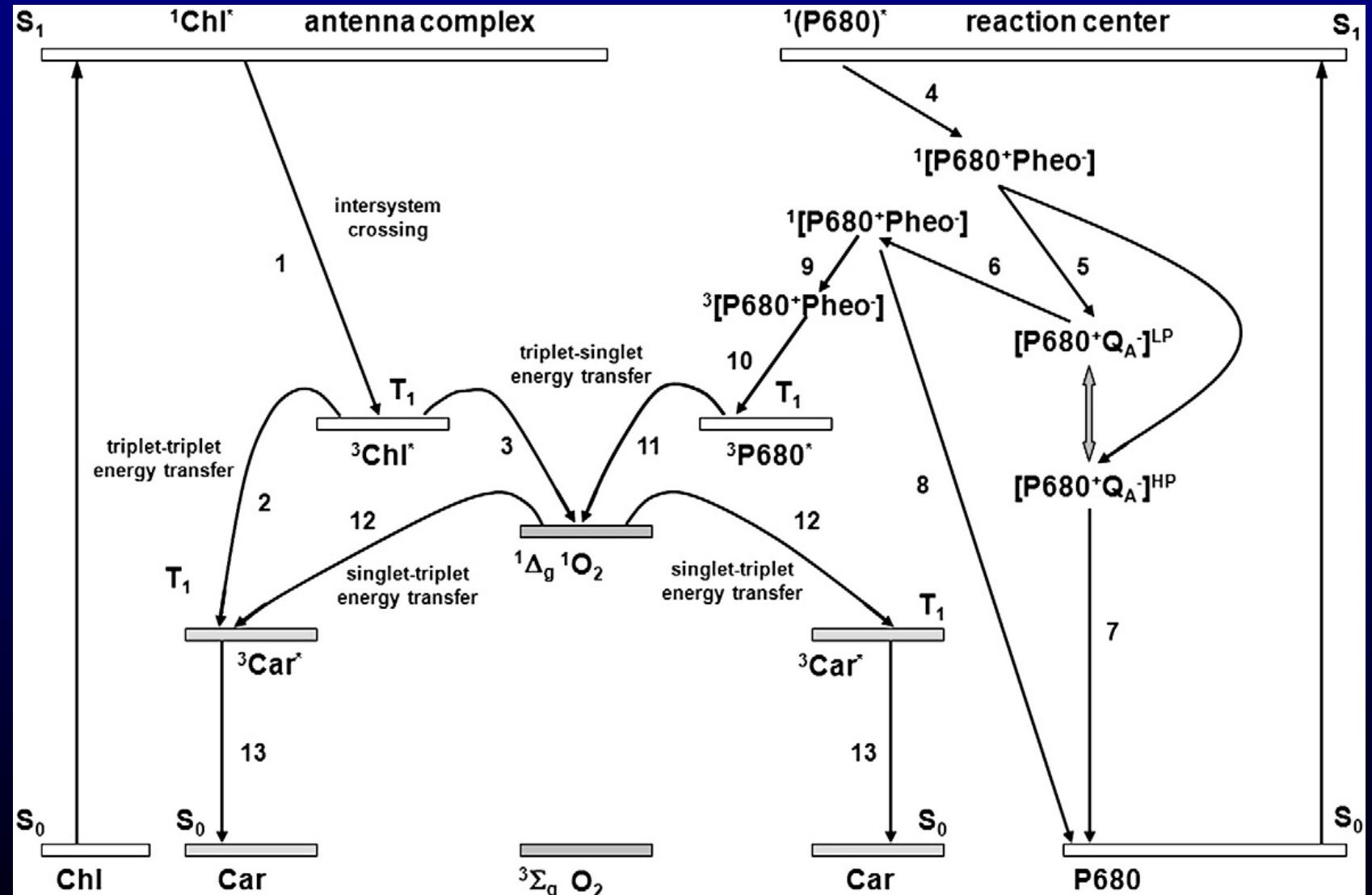
Küpper H, Andresen E, Wiegert S, Šimek M,
Leitenmaier B, Šetlík I (2009) Biochim.
Biophys. Acta (Bioenergetics) 1787, 155-167

Excitation energy transfer between chlorophyll derivatives and singlet oxygen



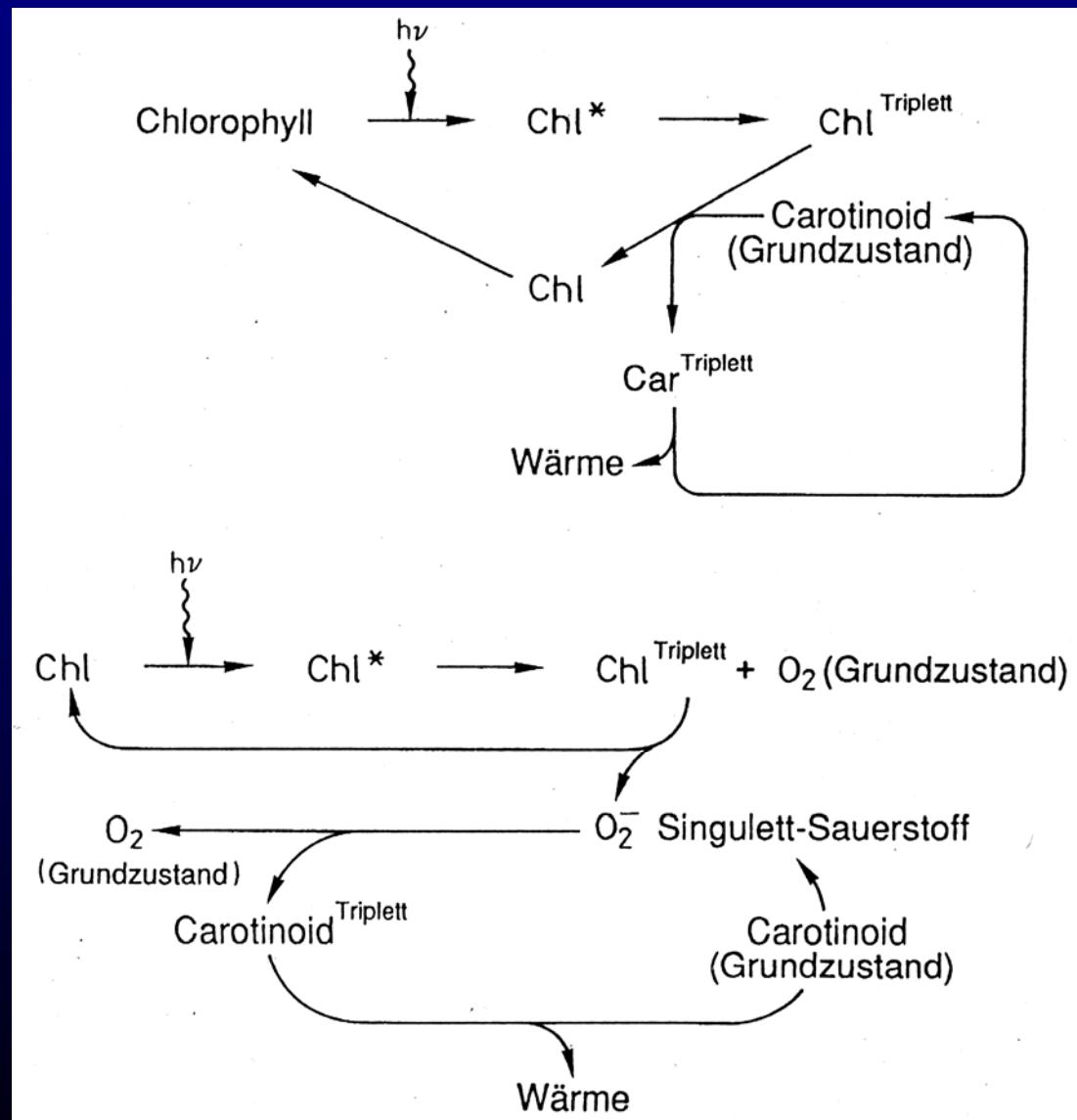
Photosynthesis related Proteins with metal centres

1. LHCII & PSII RC: generation&quenching of ${}^1\text{O}_2$



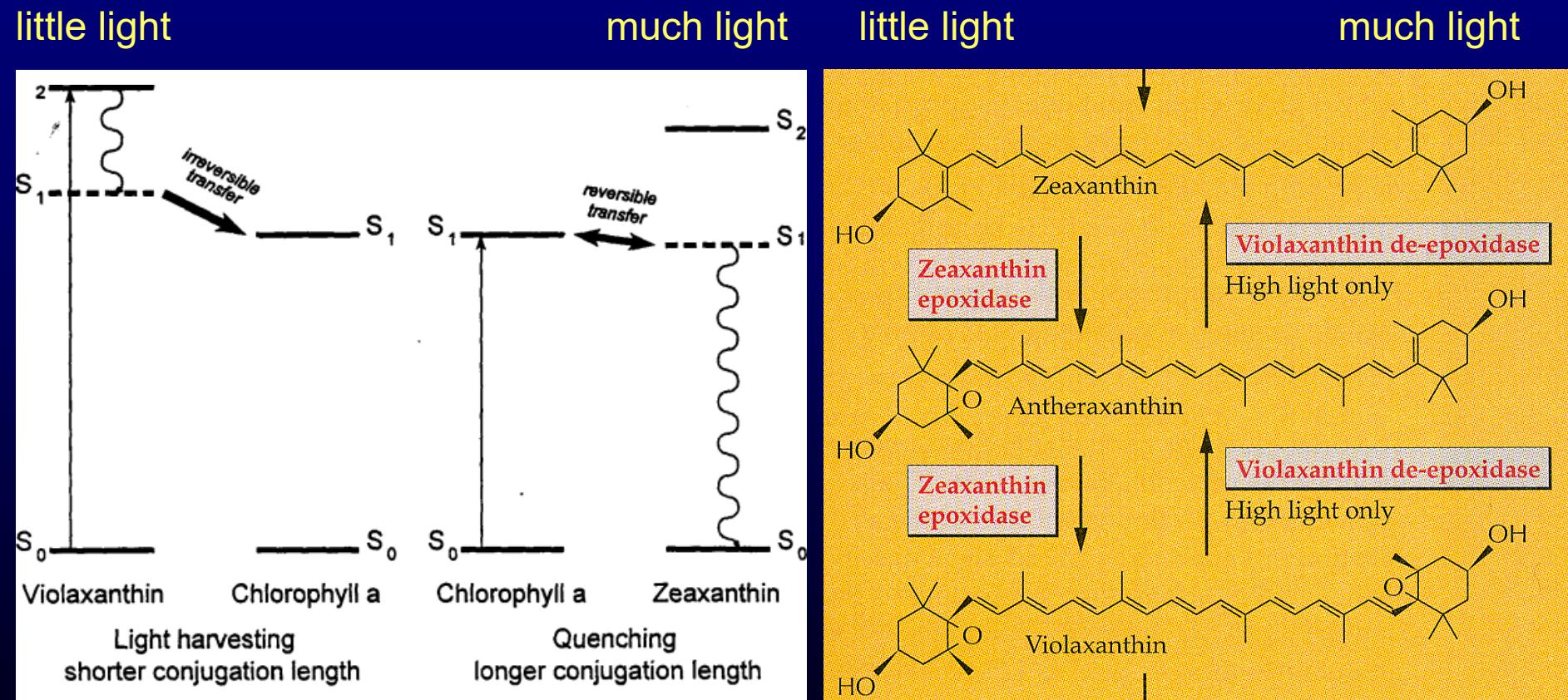
From: Pospisil P (2012) Biochimica et Biophysica Acta 1817, 218-31

Regulation of energy transfer (II): Mechanisms of protection by carotenoids against singlet oxygen

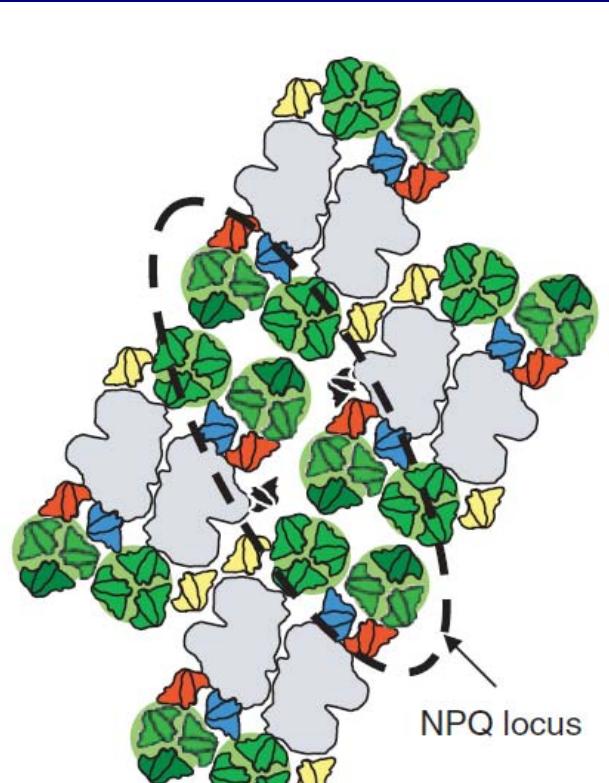


From: Lawlor DW (1990) Thieme, Stuttgart, 377S

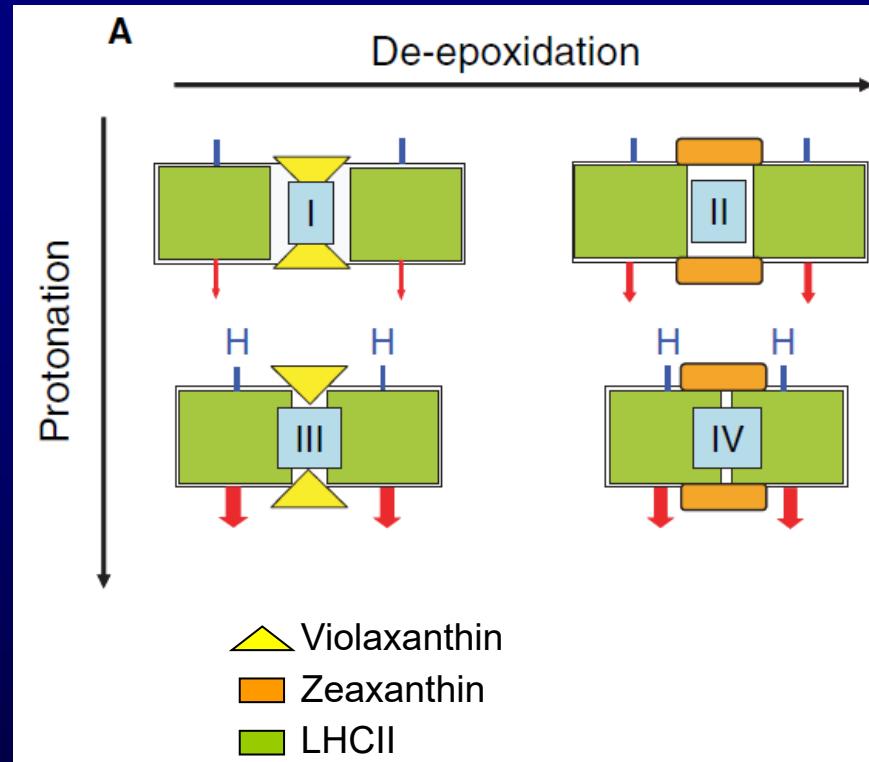
Regulation of energy transfer: xanthophyll cycle



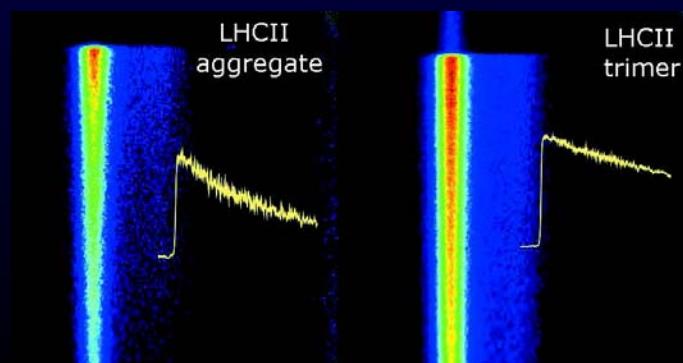
Fast adaptation to irradiance changes: combination of LHCII-aggregation with xanthophyll cycle



NPQ = non-photochemical quenching

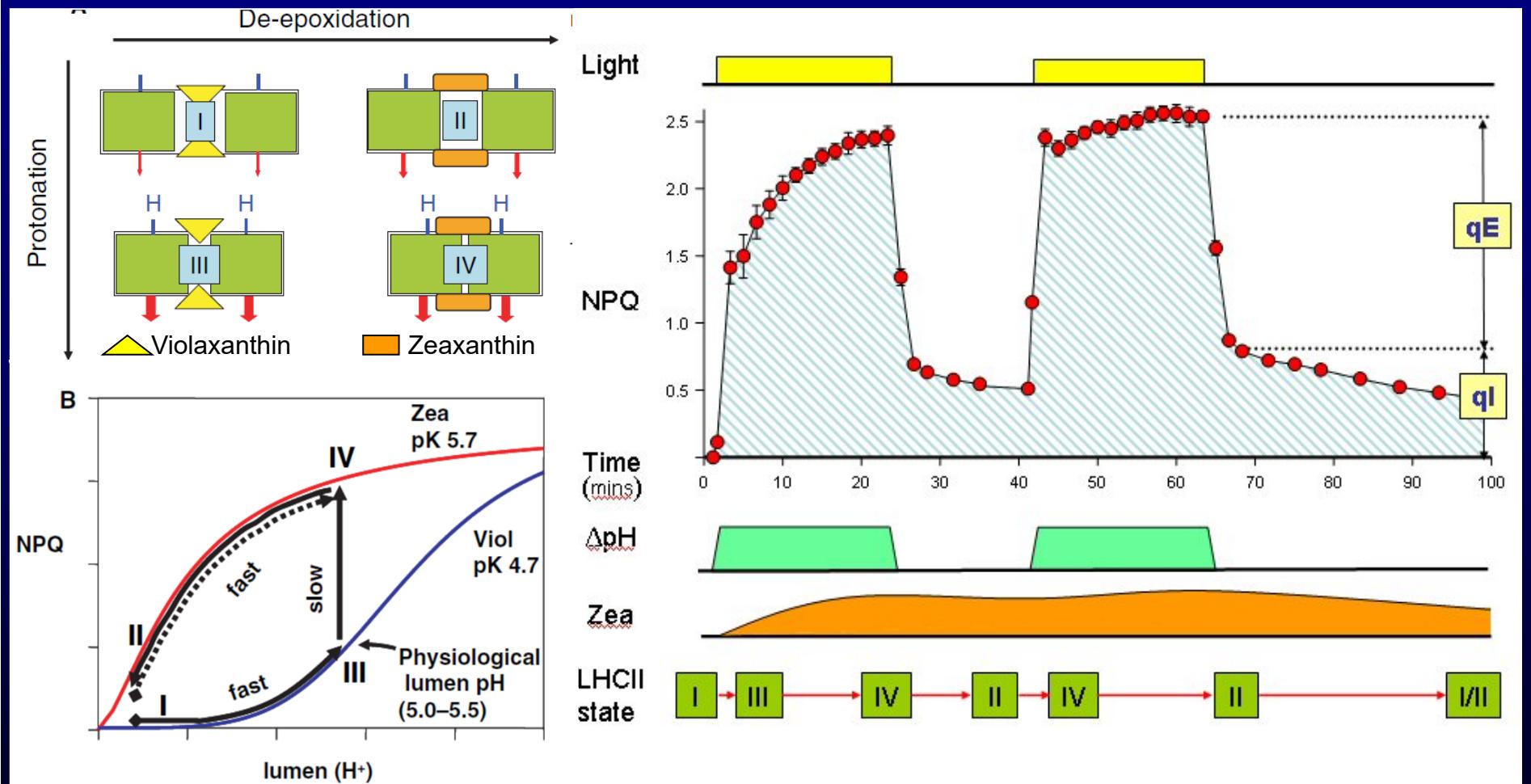


From: <http://photosynthesis.peterhorton.eu/research/lightharvesting.aspx>
Horton P, Johnson MP, Perez-Bueno ML, Kiss AZ, Ruban AV (2008) FEBS Journal 275, 1069-79



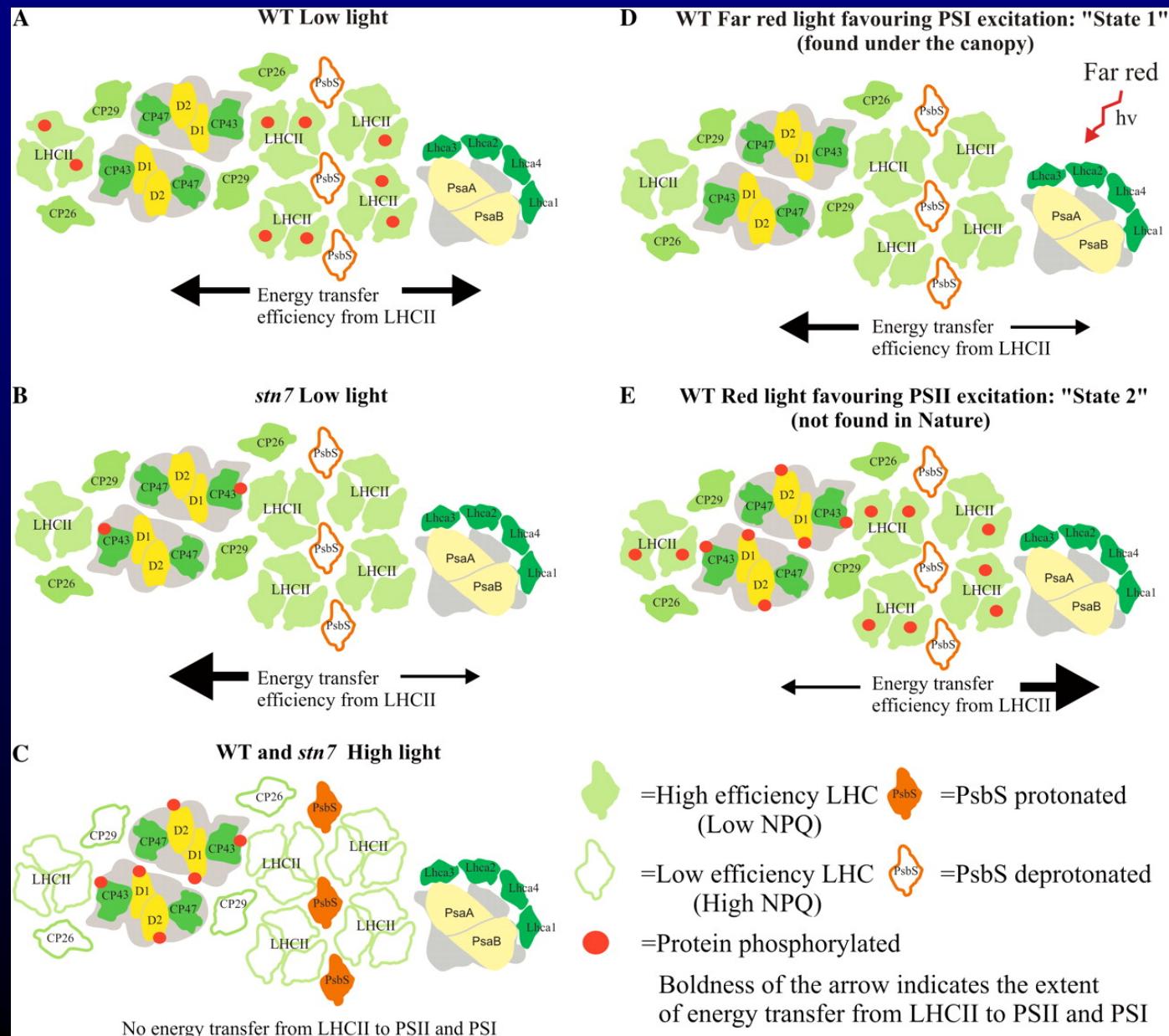
From:
http://www.laserlab.vu.nl/en/Research/research_projects/the_primary_processes_in_photosynthesis.asp

Fast adaptation to irradiance changes: combination of LHCII-aggregation with xanthophyll cycle



From: <http://photosynthesis.peterhorton.eu/research/lightharvesting.aspx> (Horton lab web page)
 Horton P, Johnson MP, Perez-Bueno ML, Kiss AZ, Ruban AV (2008) FEBS Journal 275, 1069-79

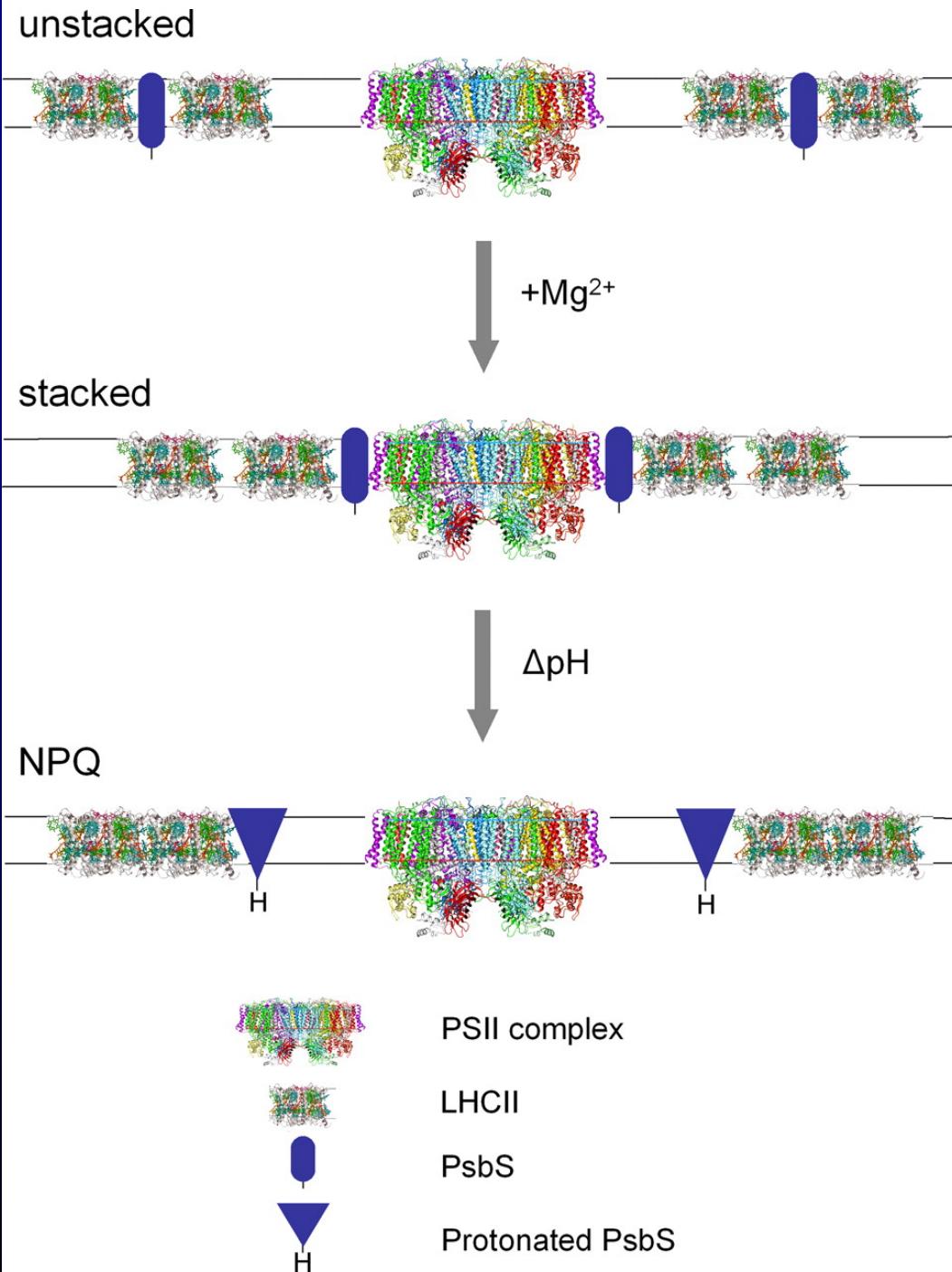
Model depicting the differential roles of PSII-LHCII protein phosphorylation in the regulation of excitation energy distribution between PSII and PSI. Such regulation mostly occurs in grana margins where PSII and PSI are in close proximity



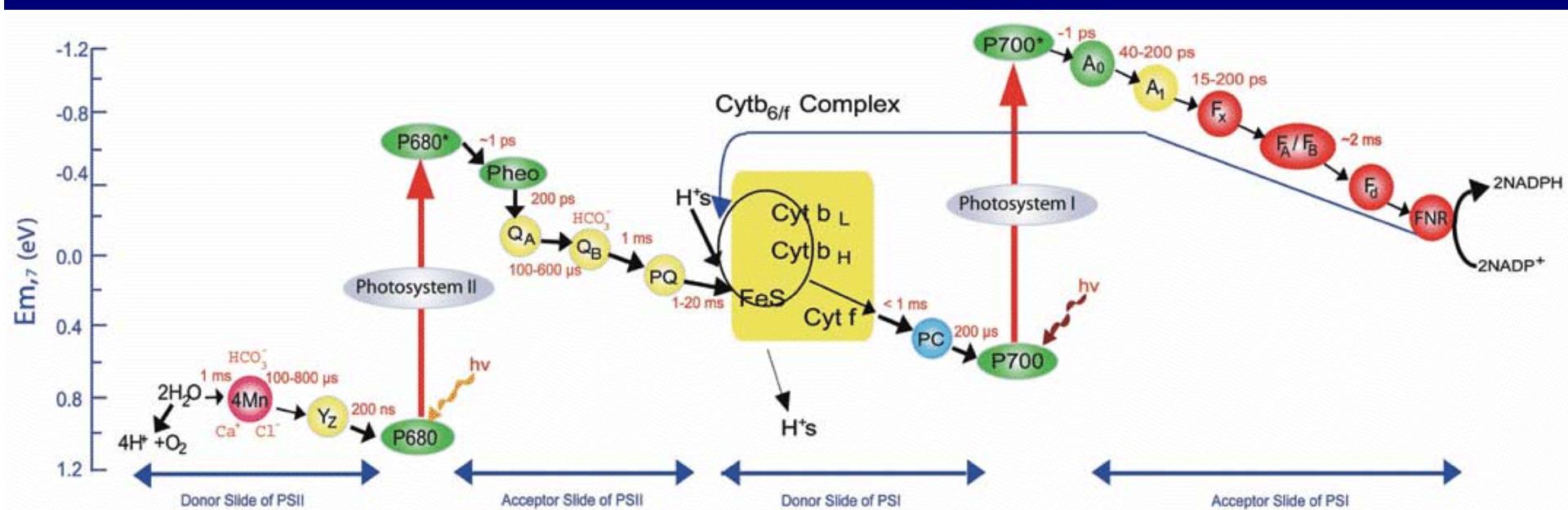
From: Tikkannen M et al.
Plant Physiol.
2010;152:723-735

PsbS modulation of the structure and function of the PSII antenna

- At relatively high but not inhibitory light, relatively many unstacked grana exist, where LHCII is not efficiently coupled to PSIIRC
- At low (limiting) light, enhanced grana stacking occurs, regulated via an increase of Mg²⁺.
- At inhibitory high light, grana unstack again, and in addition protonation of PsbS leads to strong non-photochemical quenching of excitons



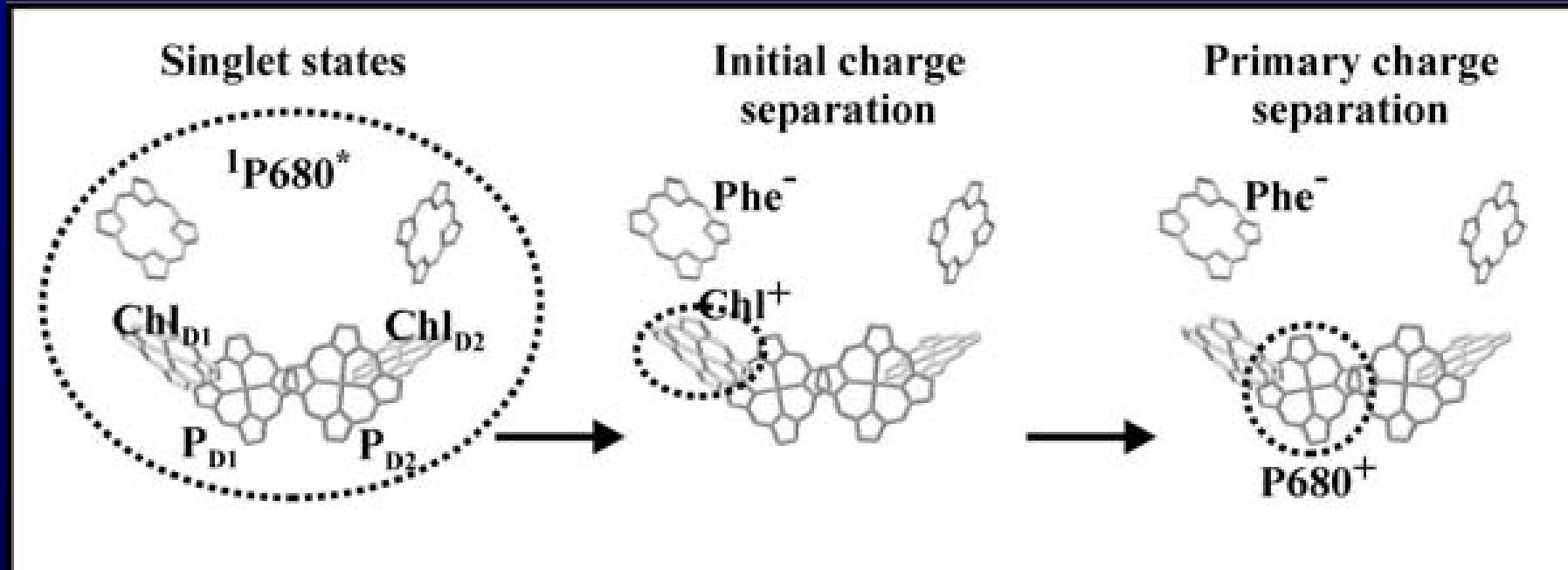
Overview of photosynthetic light reactions the „Z-scheme“



From: accessscience.com

Biophysical aspects of photosynthetic electron transport

A) Photosystem II reaction centre: special pair chlorophyll and pheophytins



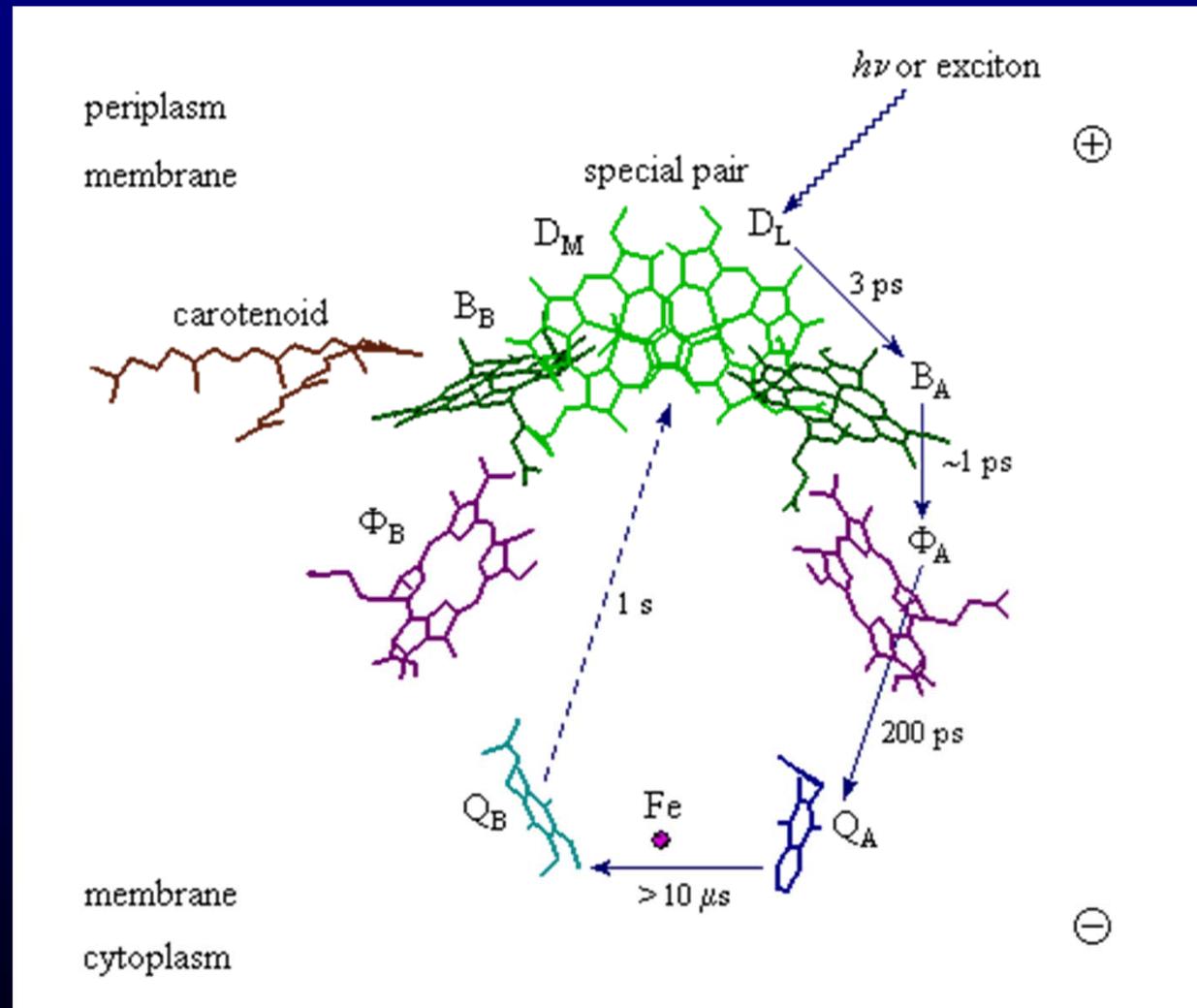
From: Barber J, 2003, QuartRevBiophys36, 71-89

Mechanism of charge separation

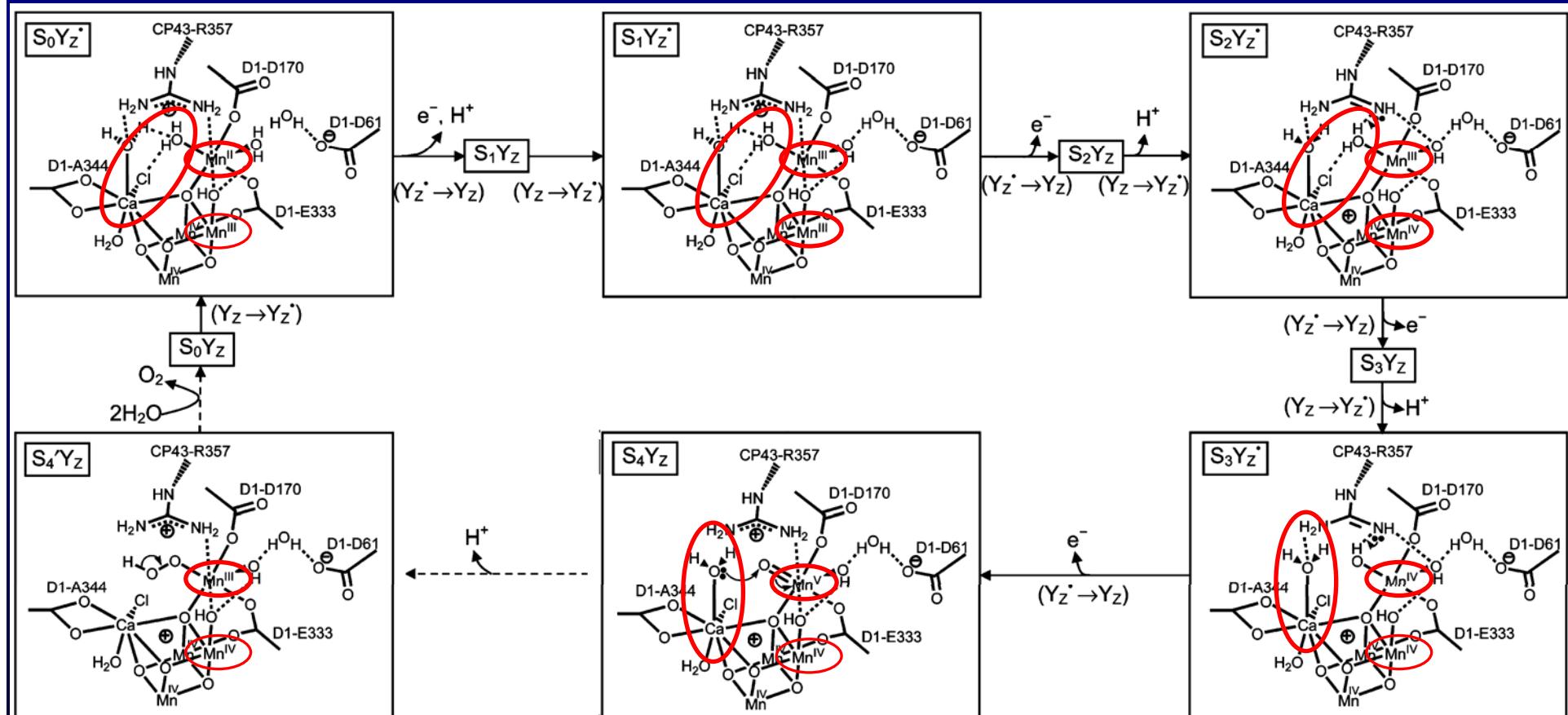
- 1. Special pair chlorophylls (=P680) accept excitons from antenna
- 2. $\text{Chl}_{\text{D}1}$ transfers an electron to Pheo ("initial charge separation")
- 3. Within a few ps, the electron hole in $\text{Chl}_{\text{D}1}$ is filled from P680 ($\rightarrow \text{P}680^+ / \text{Phe}^-$) "primary charge separation"
- (according to other authors, the initial charge separation is in P680, and ChlD1 transfers the electron to Pheo, see next scheme...)

Biophysical aspects of photosynthetic electron transport

A) Photosystem II reaction centre: speeds of electron transfer



Water splitting complex of the photosystem II reaction centre proposed mechanism



From: McEvoy JP, Brudvig GW, 2006, Chemical Reviews 106, 4455-83

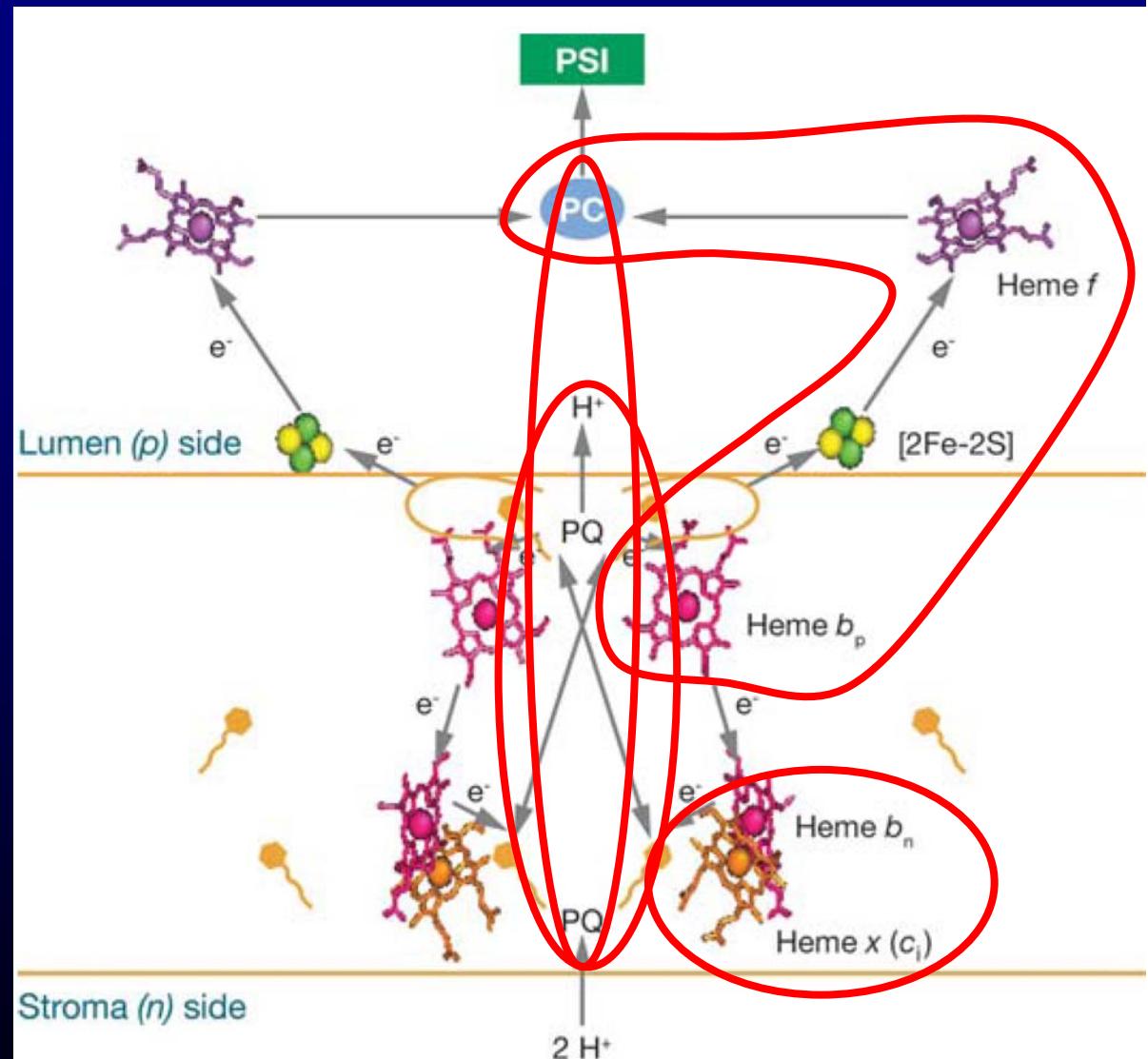
- 2 of the 4 Mn ions are redox-active ($^{3+}/^{4+}$), accepting electrons from water and transferring them to P680
- Ca^{2+} helps in binding the water

Biophysical aspects of photosynthetic electron transport

B) Cytochrome b₆f complex: mechanism

Functional characteristics

- transfers e- from PQ to plastocyanin (PC),
- It uses the difference in potential between Q_B and PC for translocating a proton via 2x2 heme *b* groups and 2x1 heme *x* group
- Electrons are transferred from the heme *b* groups to PC via a “Rieske” [2Fe2S]-cluster and a heme *f* group
- Cyclic electron transport occurs via coupling of ferredoxin to heme *x*



From: Cramer WA, Zhang H, Yan J, Kurisu G, Smith JL, 2006, AnnRevBiochem 75_769-90

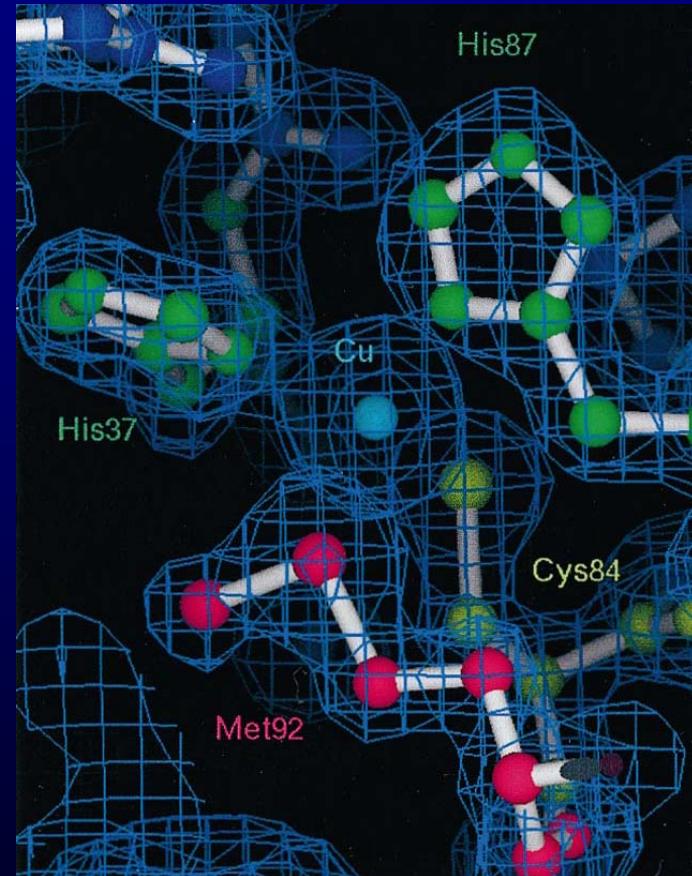
Biophysical aspects of photosynthetic electron transport

C) Plastocyanin

Functional characteristics

- Oxidised (Cu^{2+}) plastocyanin accepts electron from $\text{Cyt}_{\text{b}6\text{f}}$ complex,
- Reduced ($\rightarrow \text{Cu}^+$) plastocyanin diffuses to the PSIRC
- Plastocyanin releases the electron ($\text{Cu}^+ \rightarrow \text{Cu}^{2+}$)
- rigid protein structure facilitates fast red/ox-changes, but recent data show that copper binding still causes changes in structure (“induced rack” rather than “entatic state”)

From: Shibata N, Inoue T, Nagano C, Nishio N, Kohzuma T, Onodera K, Yoshizaki F, Sugimura Y, Kai Y, 1999, J Biol Chem. 274: 4225-30

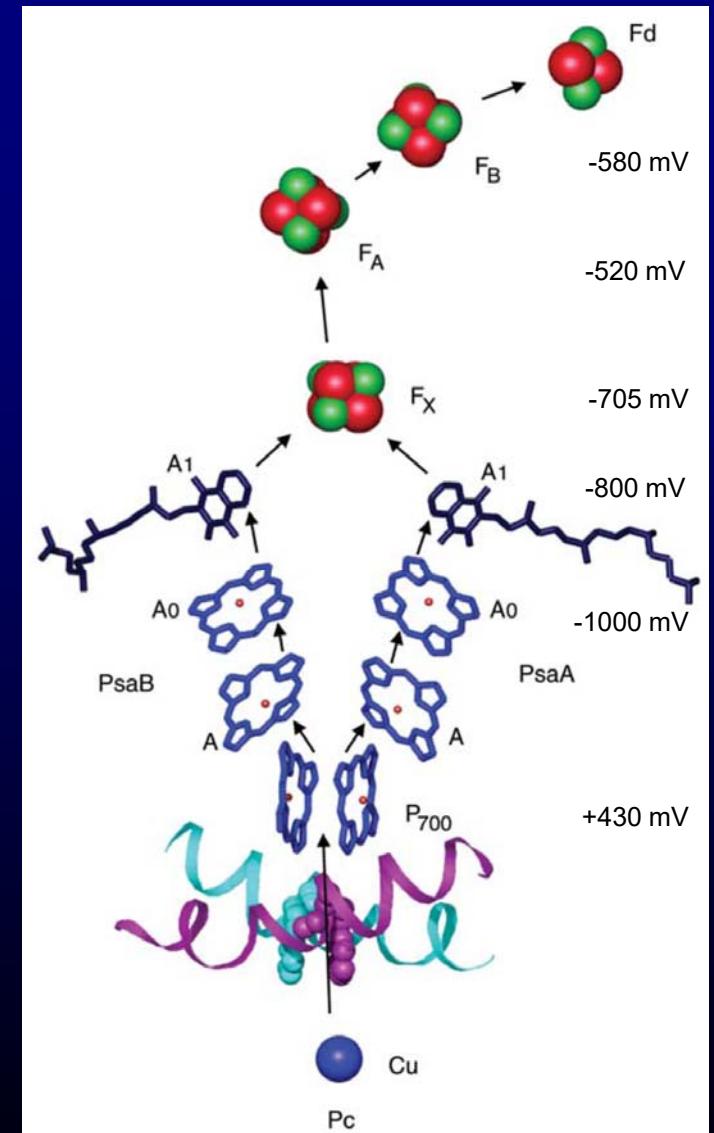


Biophysical aspects of photosynthetic electron transport

D) Photosystem I reaction centre

Functional characteristics:

- primary charge separation:
special pair (=P700, Chl a / Chl a' heterodimer),
releases e^- to A_0 via A (both Chl a)
- e^- transport via A_1 (phylloquinone) and the
[4Fe4S]-clusters F_x , F_A and F_B to the [4Fe4S]-
cluster of ferredoxin
- P700 is re-reduced by plastocyanin



From: Nelson N, Yocum CF, 2006, AnnRevPlantBiol 57, 521-65

**All slides of my lectures can be downloaded
from my workgroup homepage**

Biology Centre CAS → Institute of Plant Molecular Biology → Departments
→ Department of Plant Biophysics and Biochemistry,
or directly

http://webserver.umbr.cas.cz/~kupper/AG_Kuepper_Homepage.html