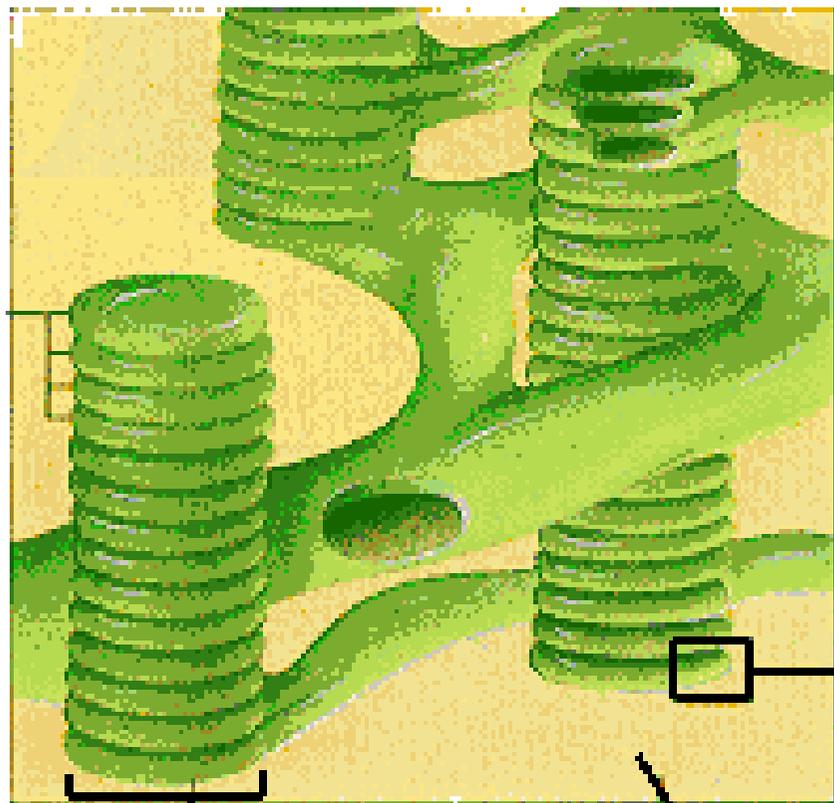
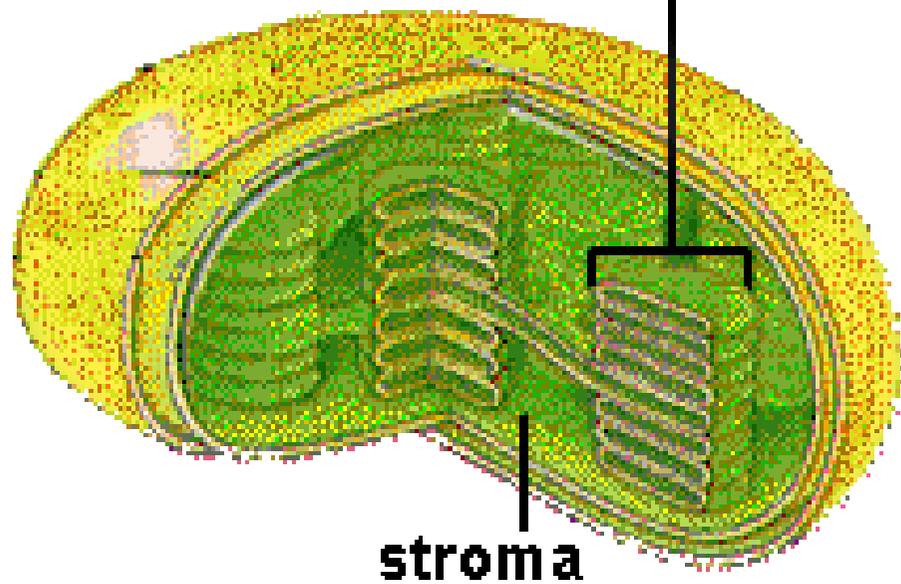
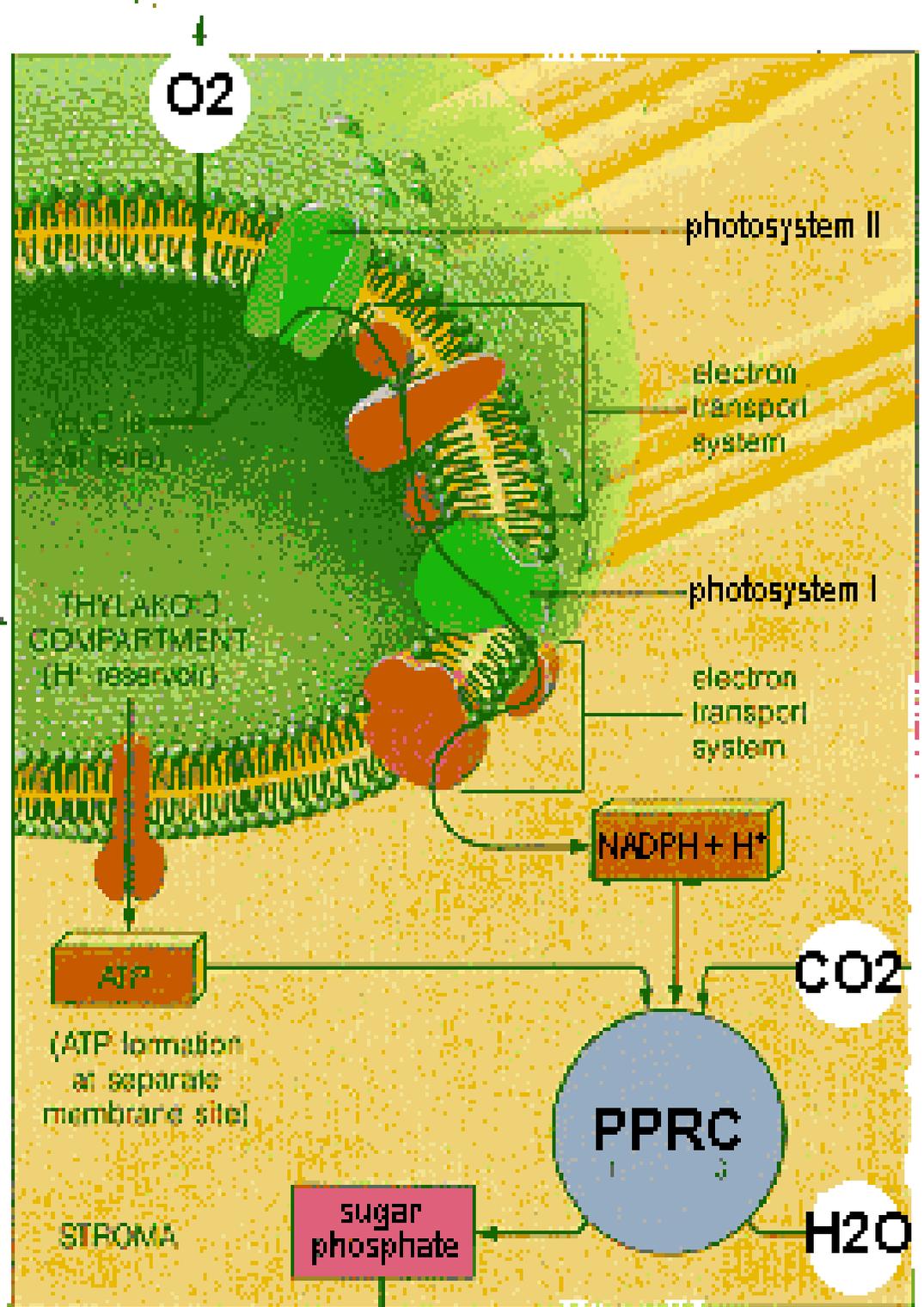


Introduction to Biophysics of Photosynthesis

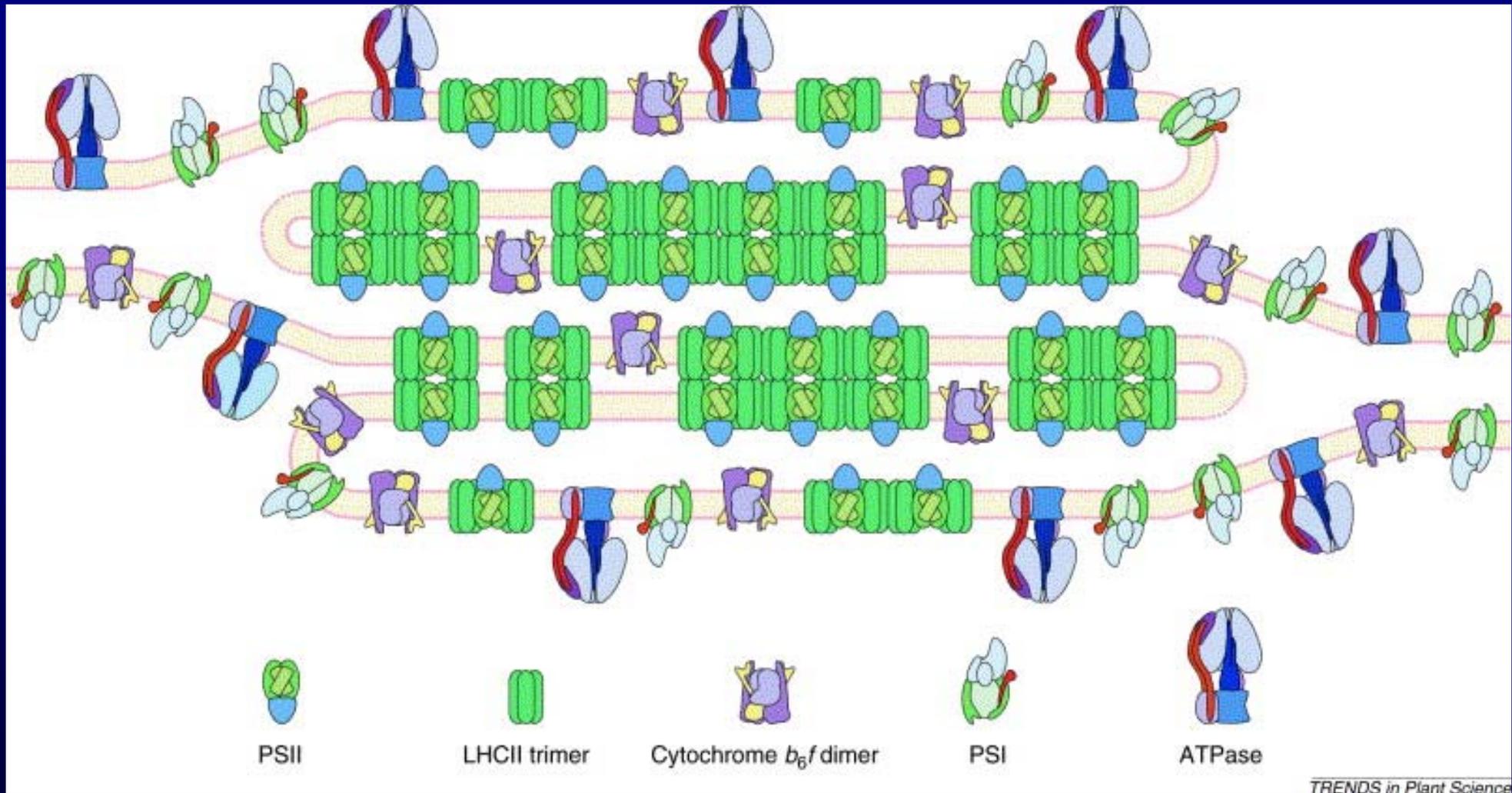


granum stroma



stroma

Influence of steric hindrance on grana stacking

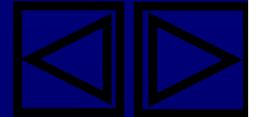
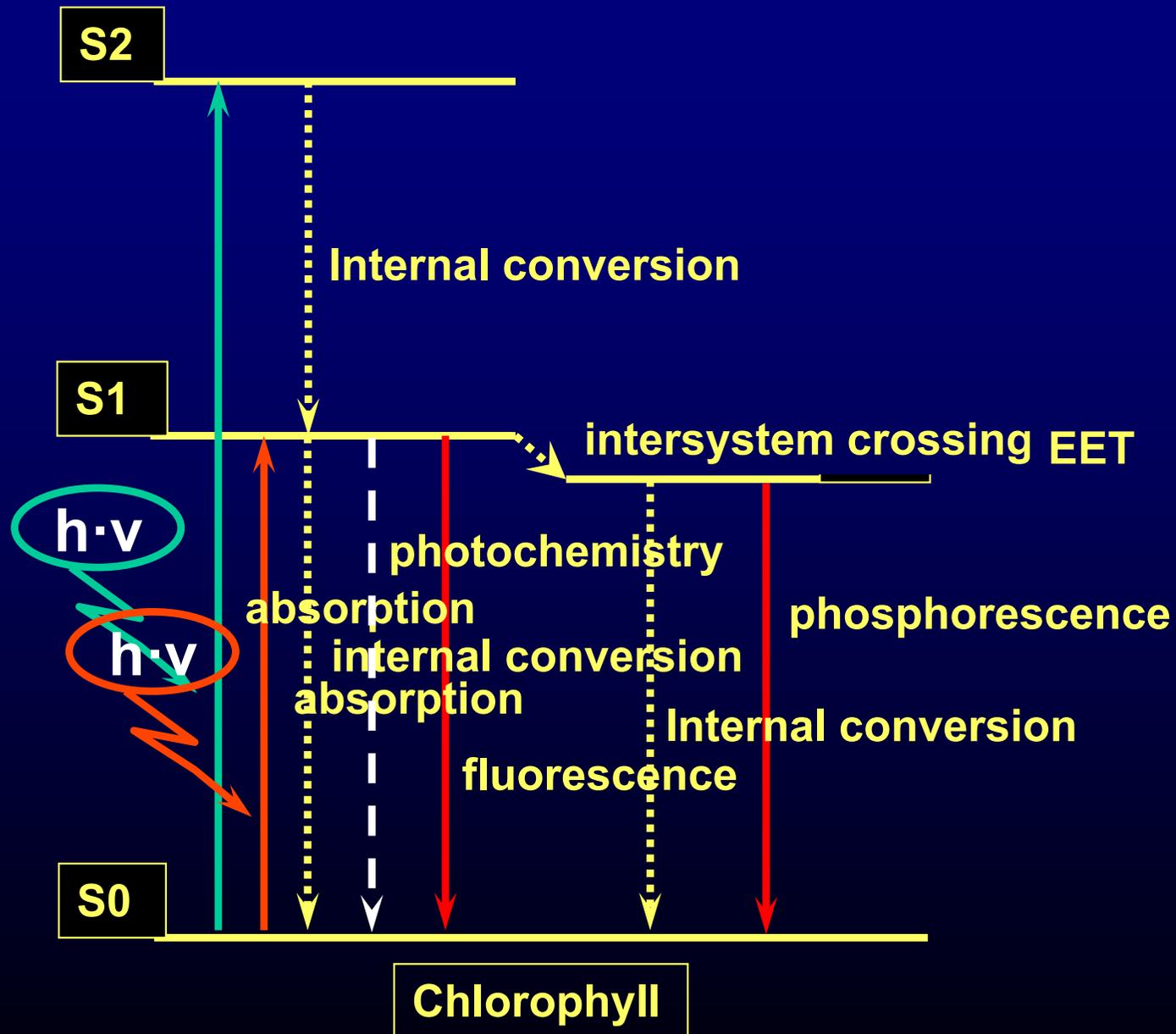


From: Allen JF, Forsberg J (2001) TIBS 6, 317–326

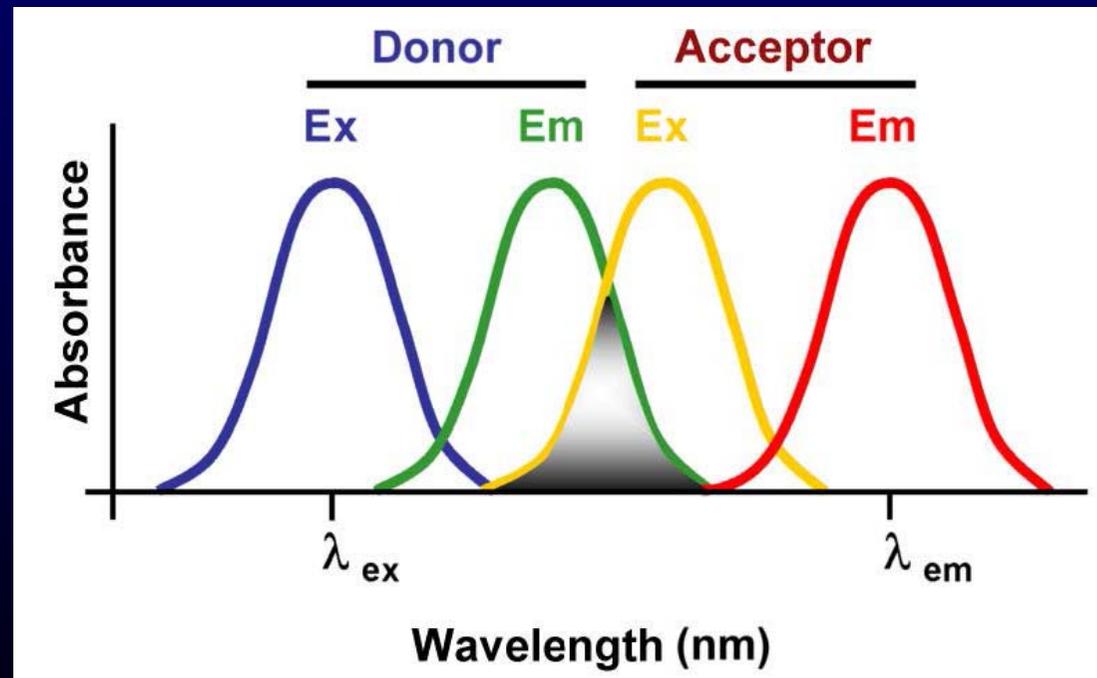
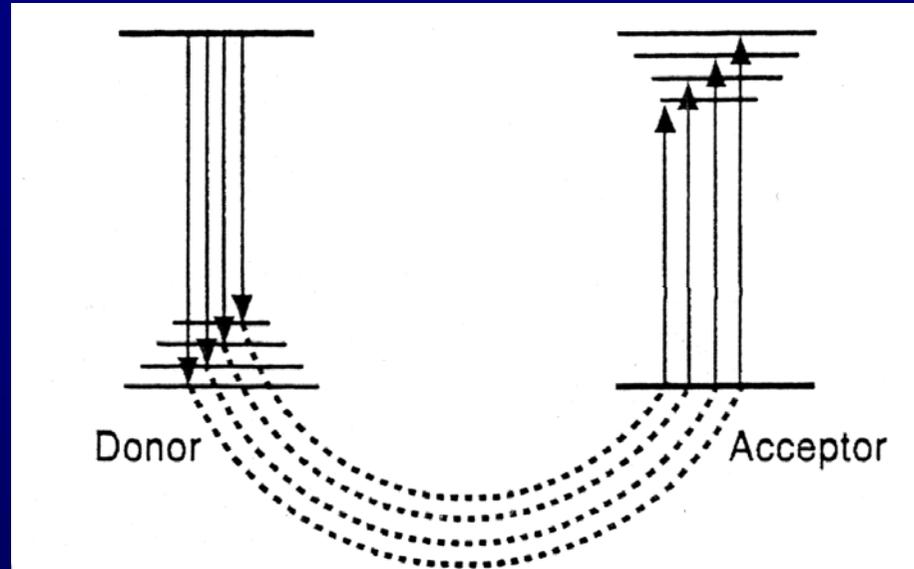
Mechanism of grana stacking

- 1. LHCII tends to aggregate
- 2. thylakoids containing a lot of LHCII will stick together, forming grana. PSIIIRC nicely fits in because it does not protrude much out of the membrane
- 3. The more bulky PSIRC 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

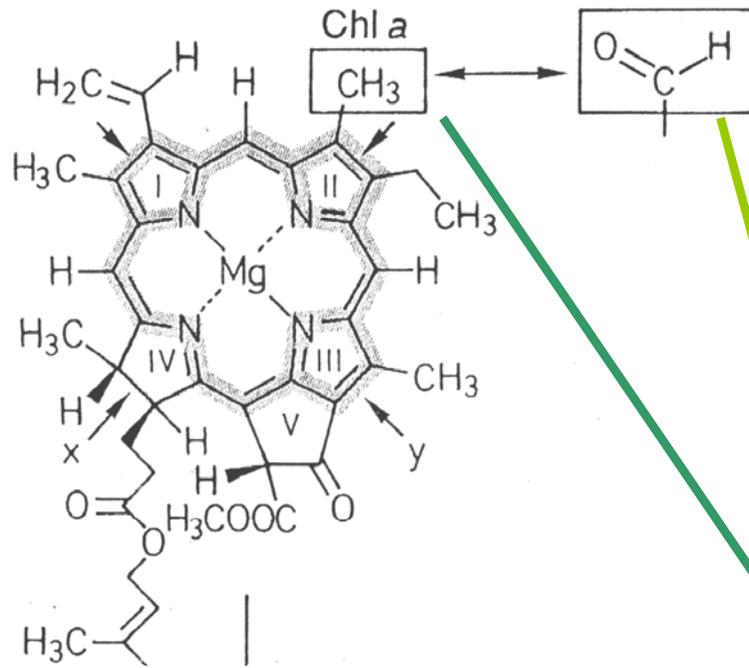


Adjustment of absorption bands by chemical modification

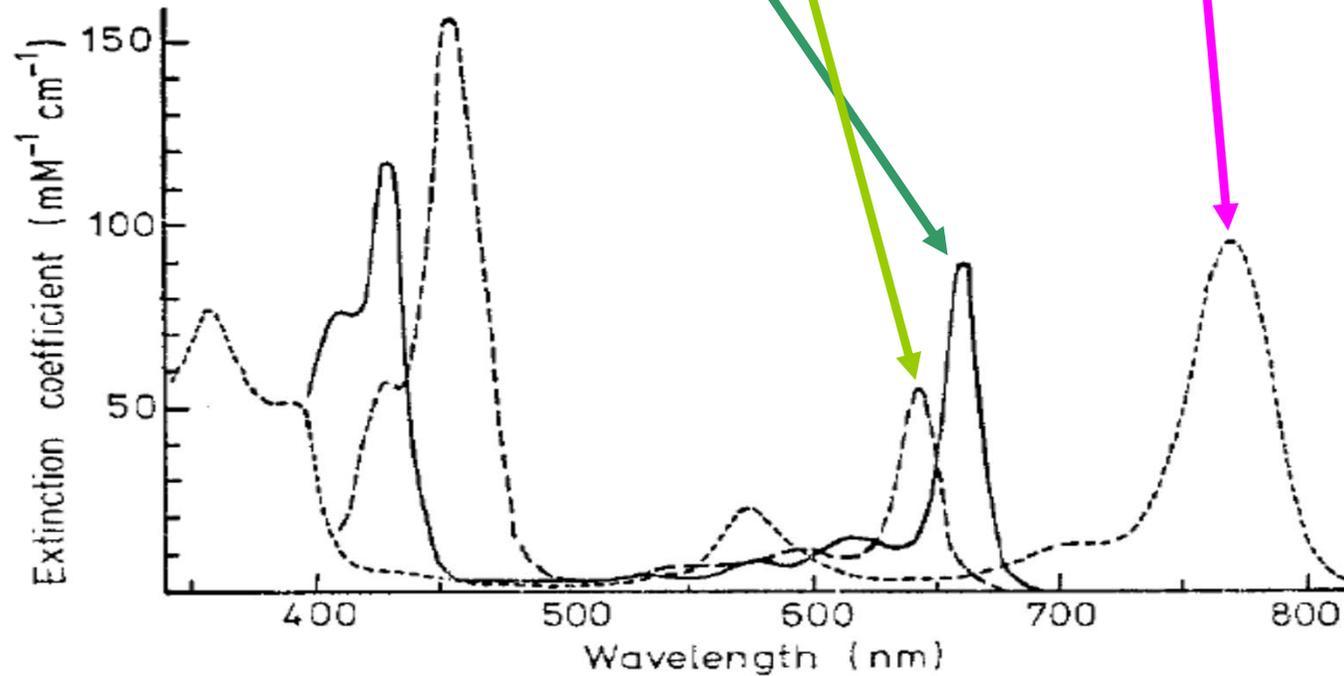
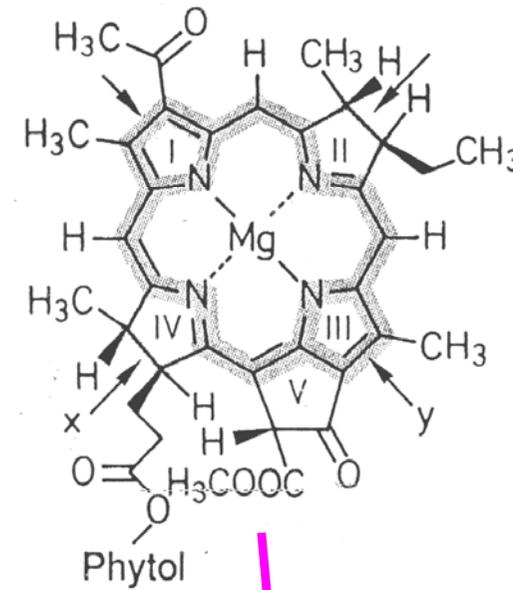
From: Lawlor DW (1990) Thieme, Stuttgart, 377S

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

Chlorophyll a und b

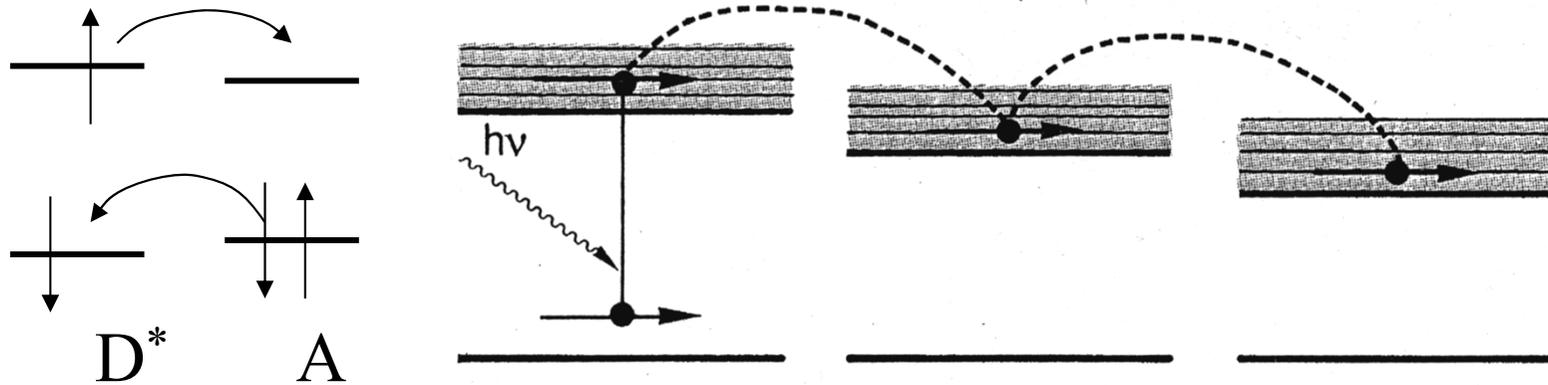


Bacteriochlorophyll

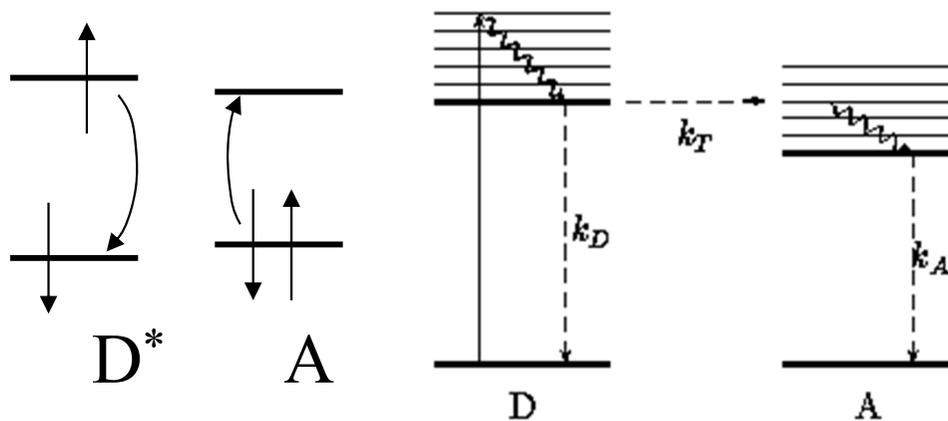


Mechanisms of energy transfer between chlorophylls

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 inductive Resonance („Förster-Mechanism“)

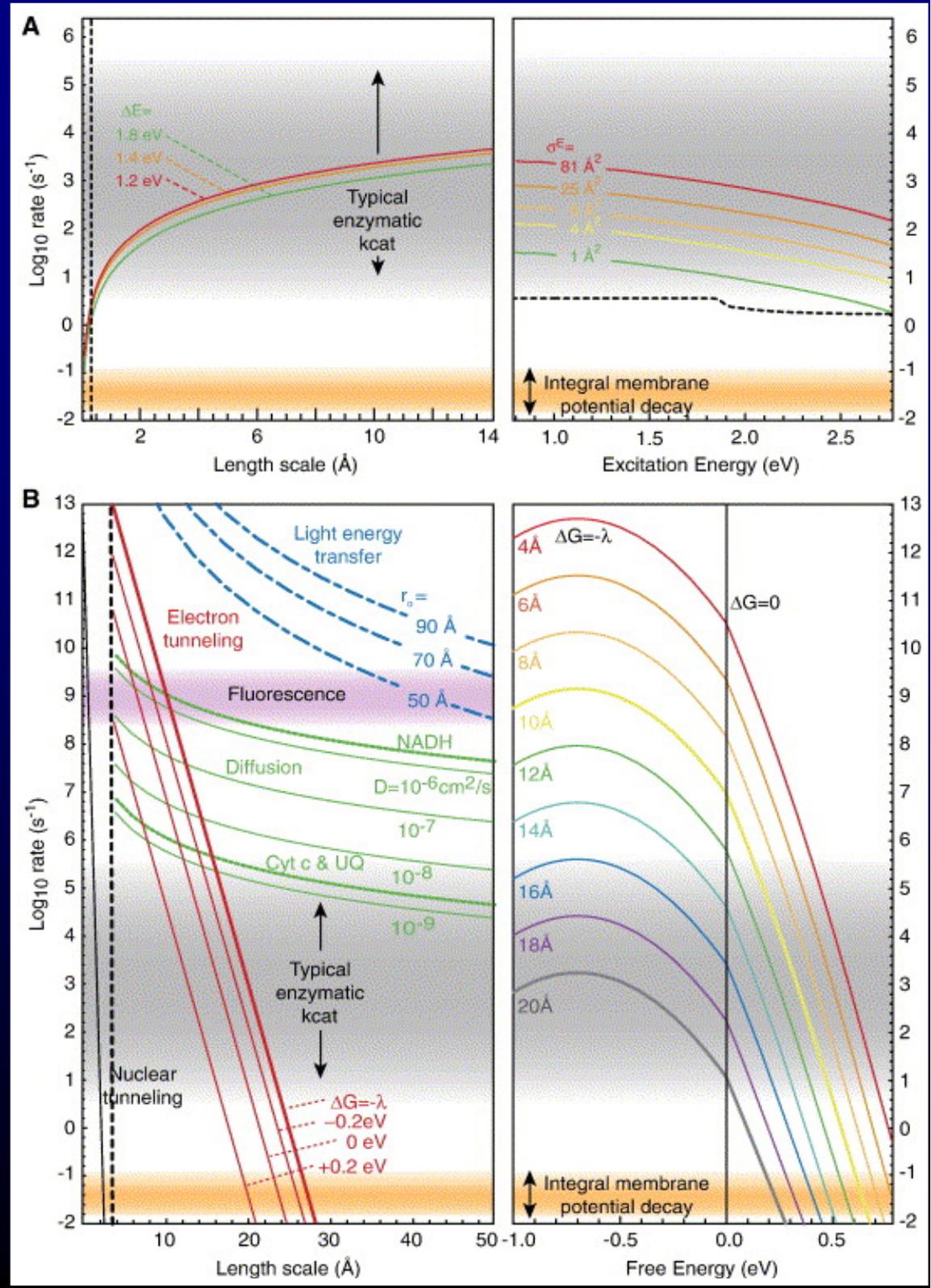


$$\Gamma_{DA} = k_D \left(\frac{R_0}{R} \right)^6$$

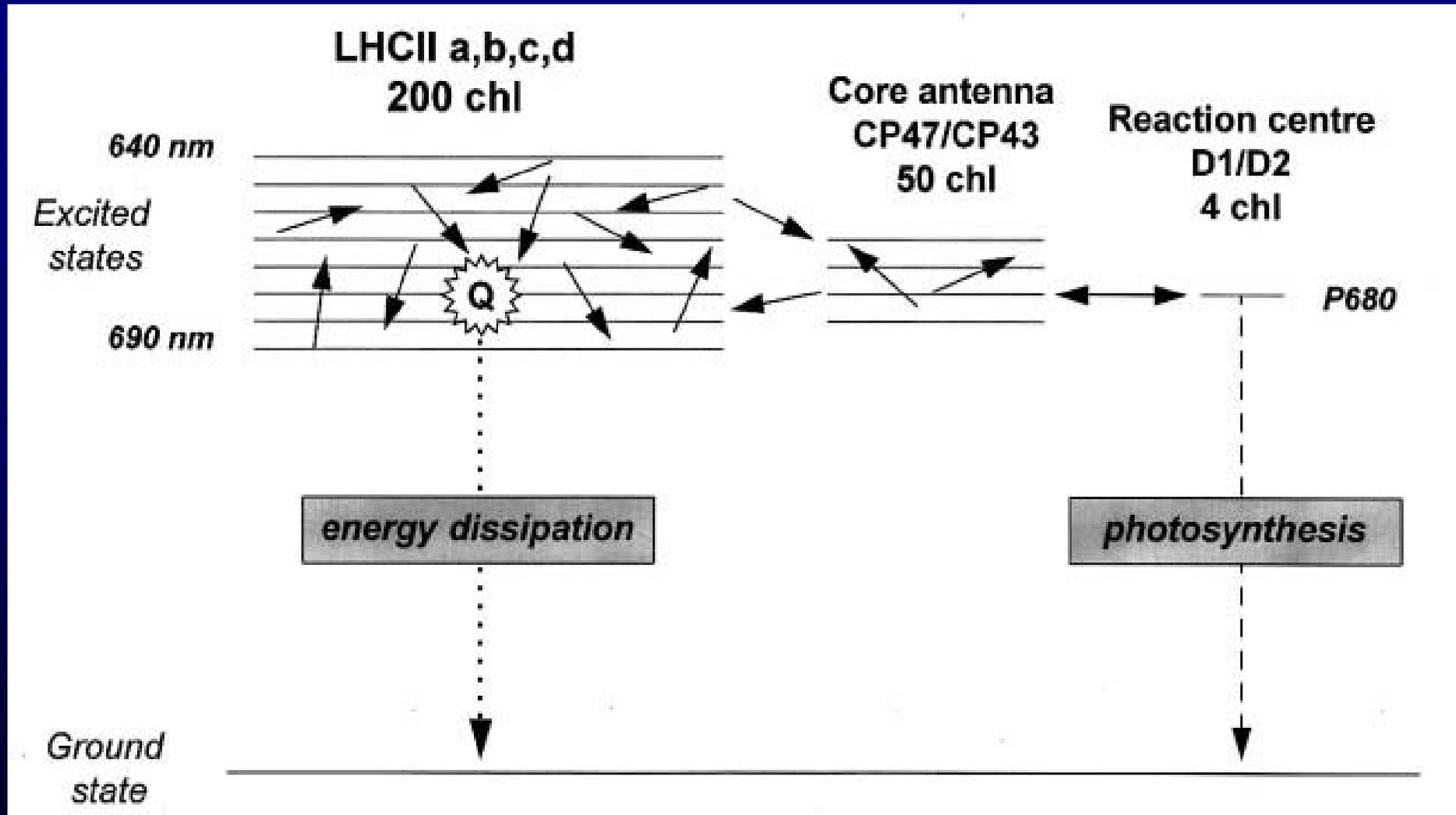
$$R_0^6 = 8.8 \times 10^{17} \frac{\kappa^2}{n^4} J$$

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 <math><10\text{\AA}</math>.
- Diffusion speed decreases less with increasing distances, therefore it becomes faster than tunnelling at more than 10-20\AA.

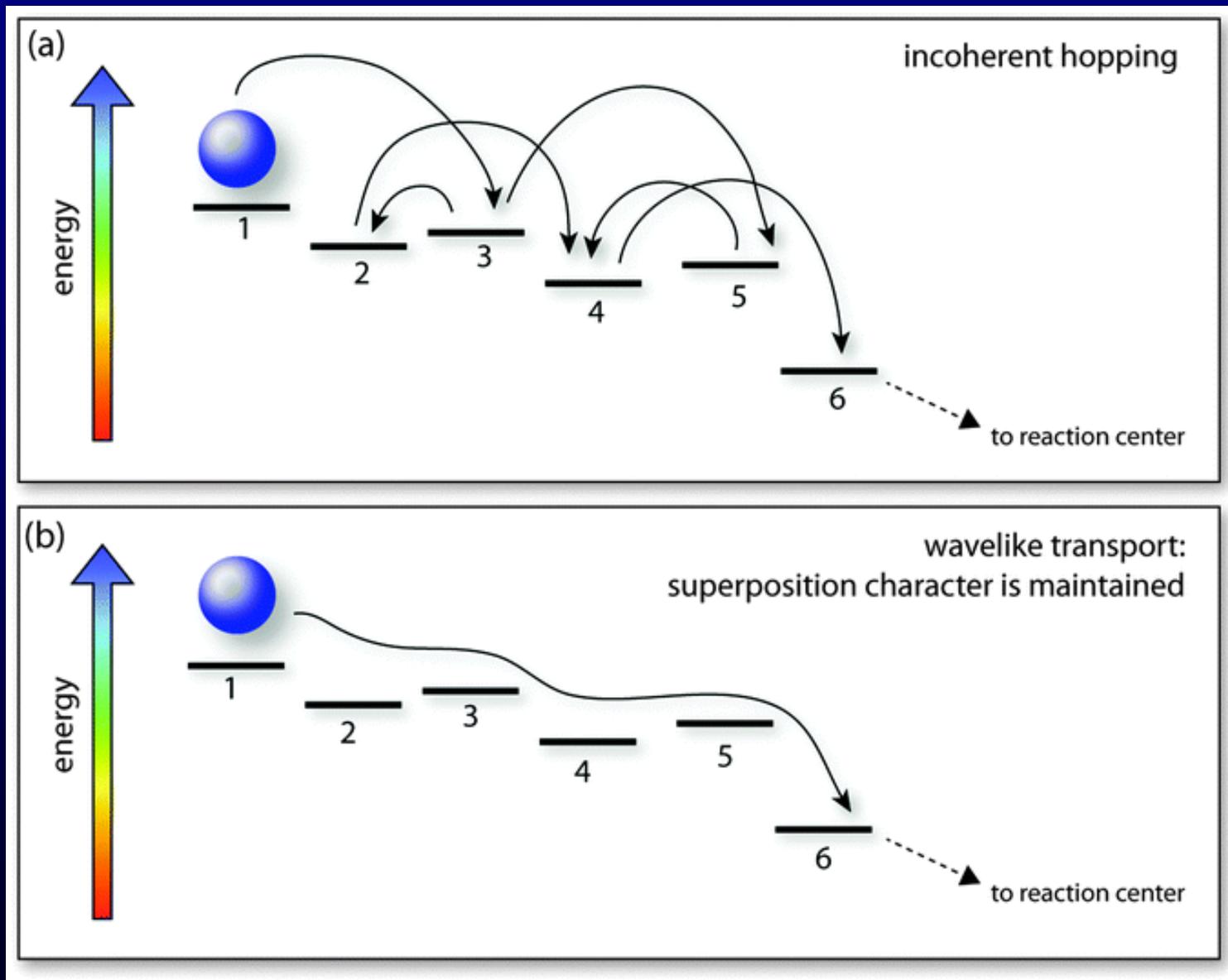


Energy transfer – funnel principle (II): Scheme in higher plants



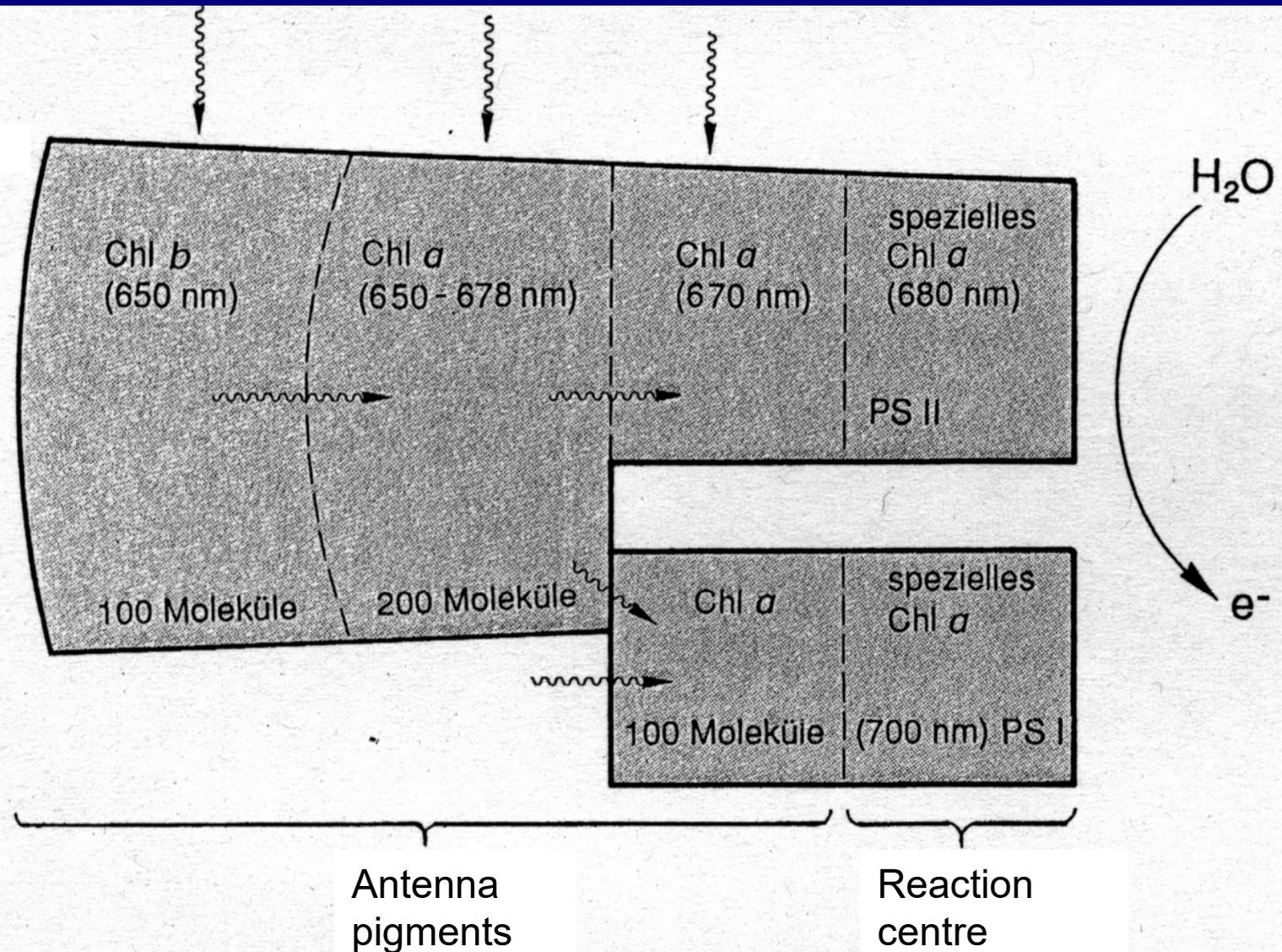
From: Horton P, Ruban AV, Walters RG (1996) *Annu Rev Plant Physiol Plant Mol Biol* 47: 655-84

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

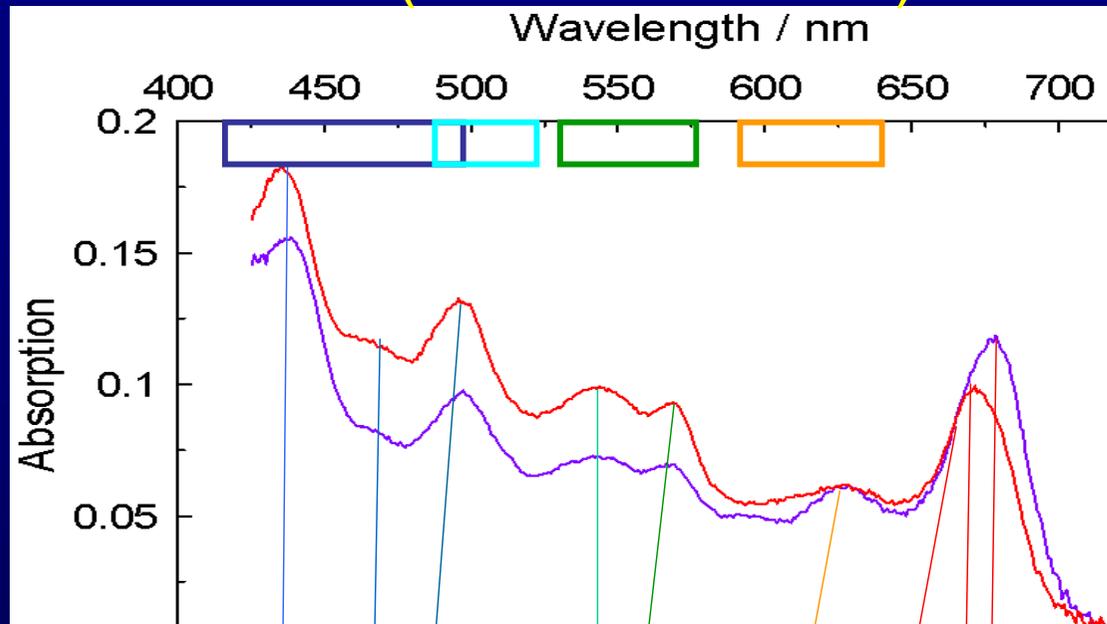


Absorb shortest wavelengths

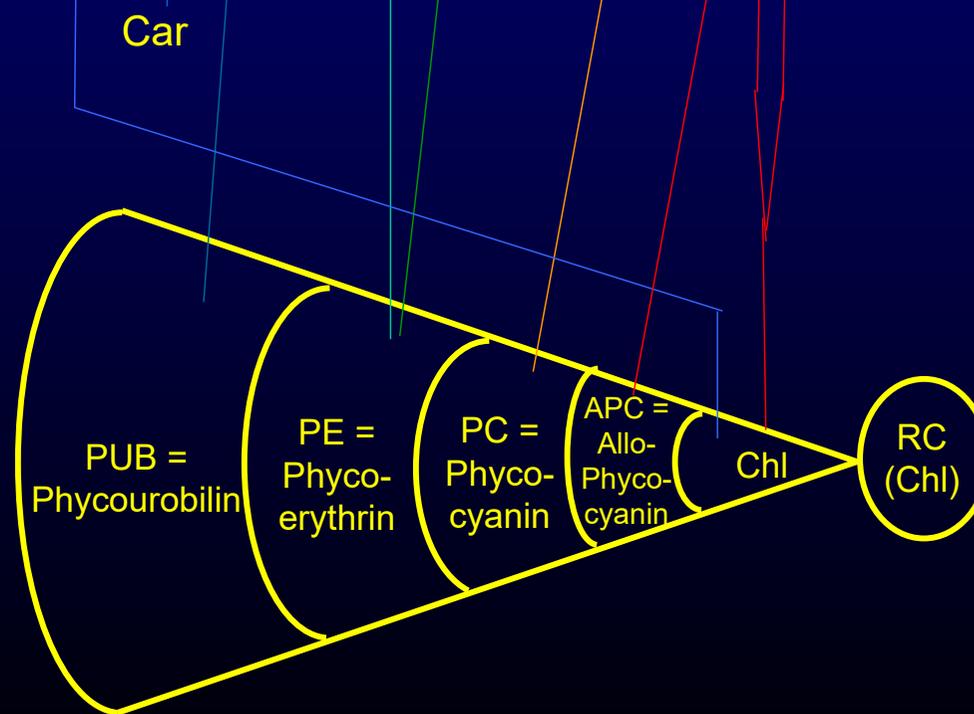
→ absorb longer wavelengths

→ absorb longest wavelengths

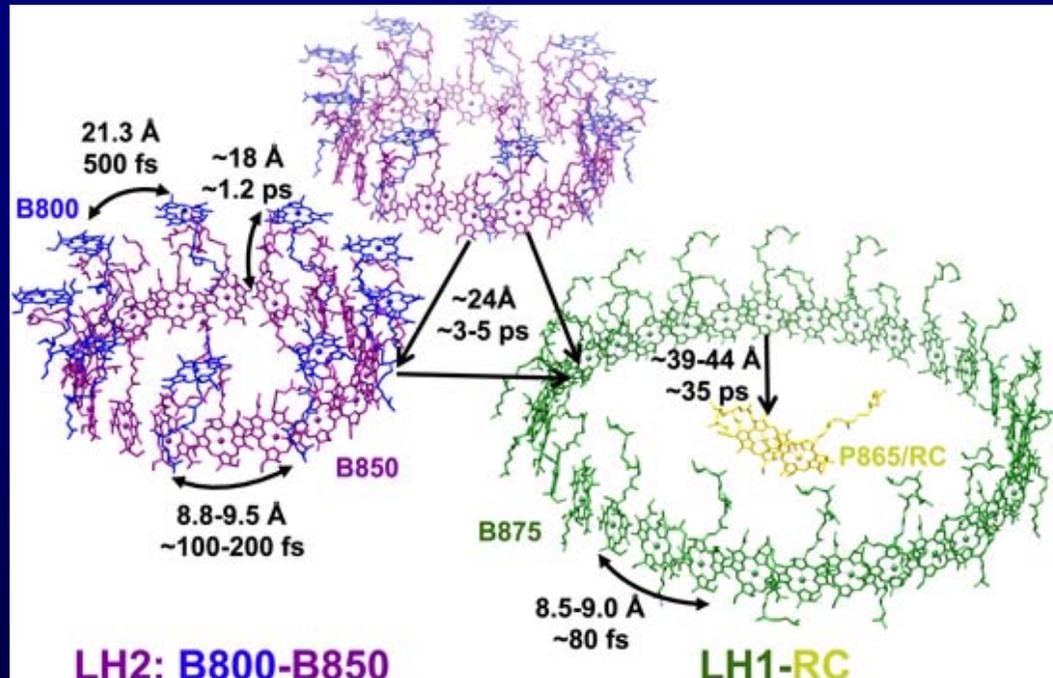
Energy transfer – funnel principle (II): Scheme in cyanobacteria (*Trichodesmium*)



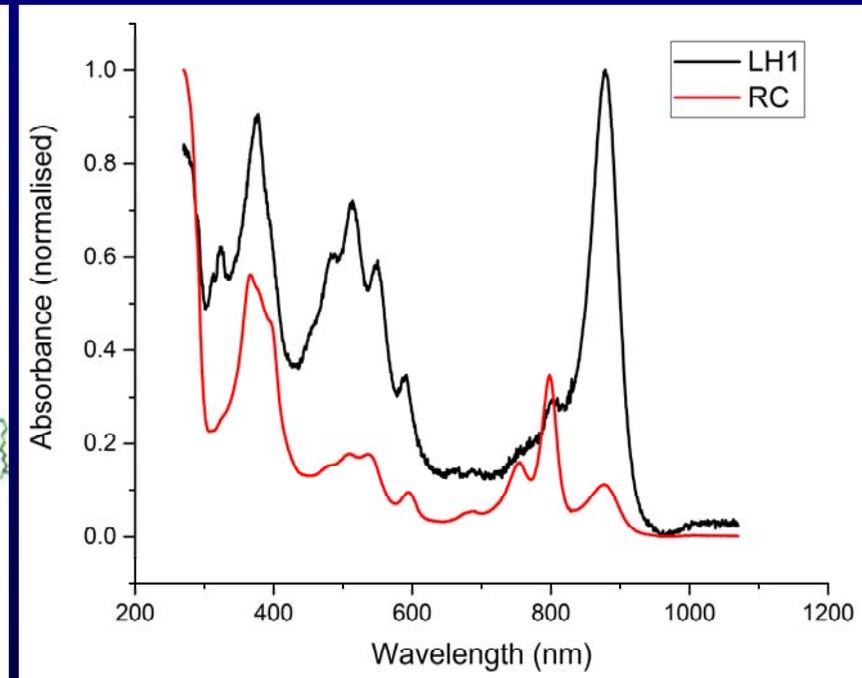
Transmission of filters for selective excitation



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

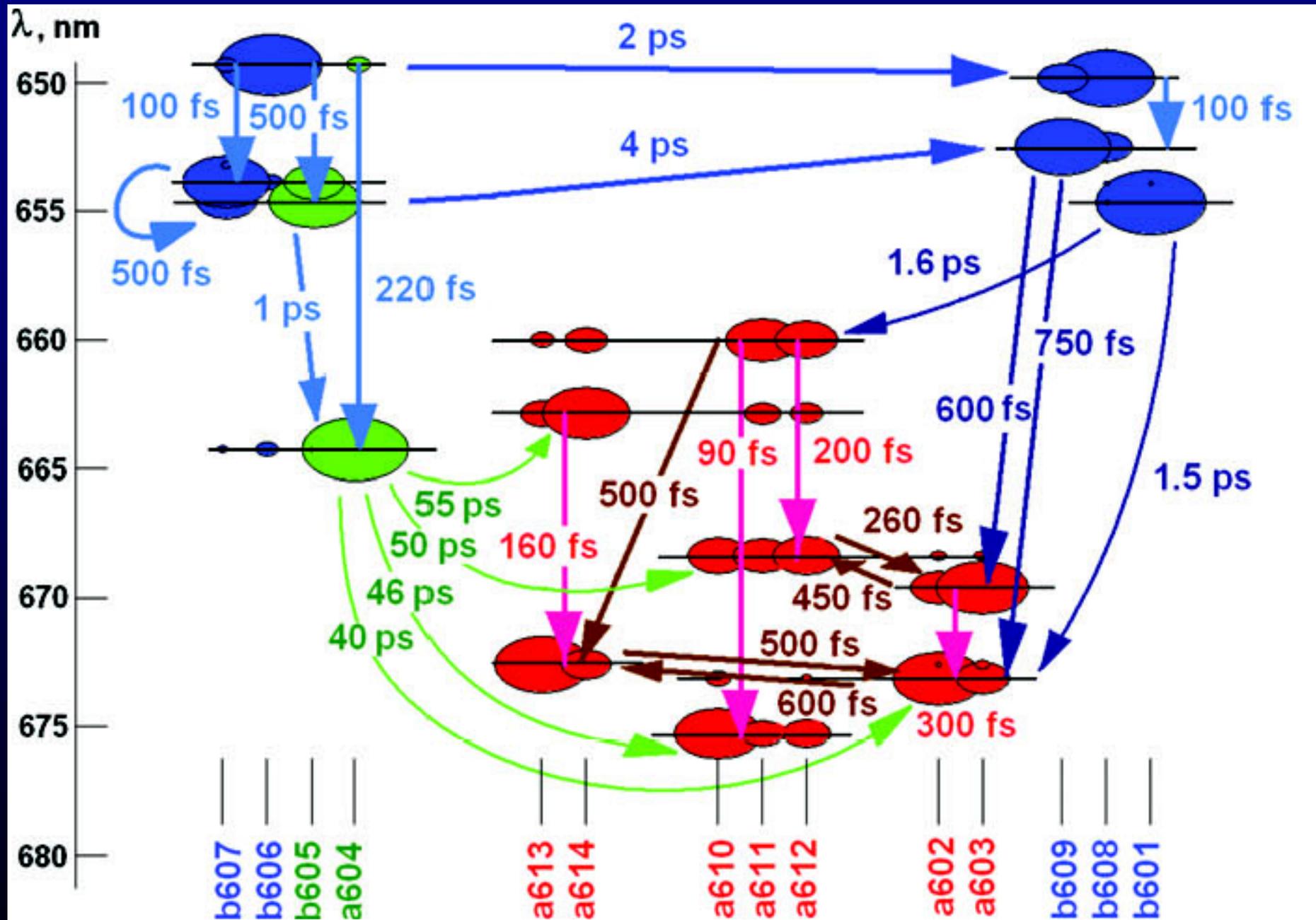


From: Bryant DA, Canniffe DP (2018) J Physics B: At. Mol. Opt. Phys. 51 033001.



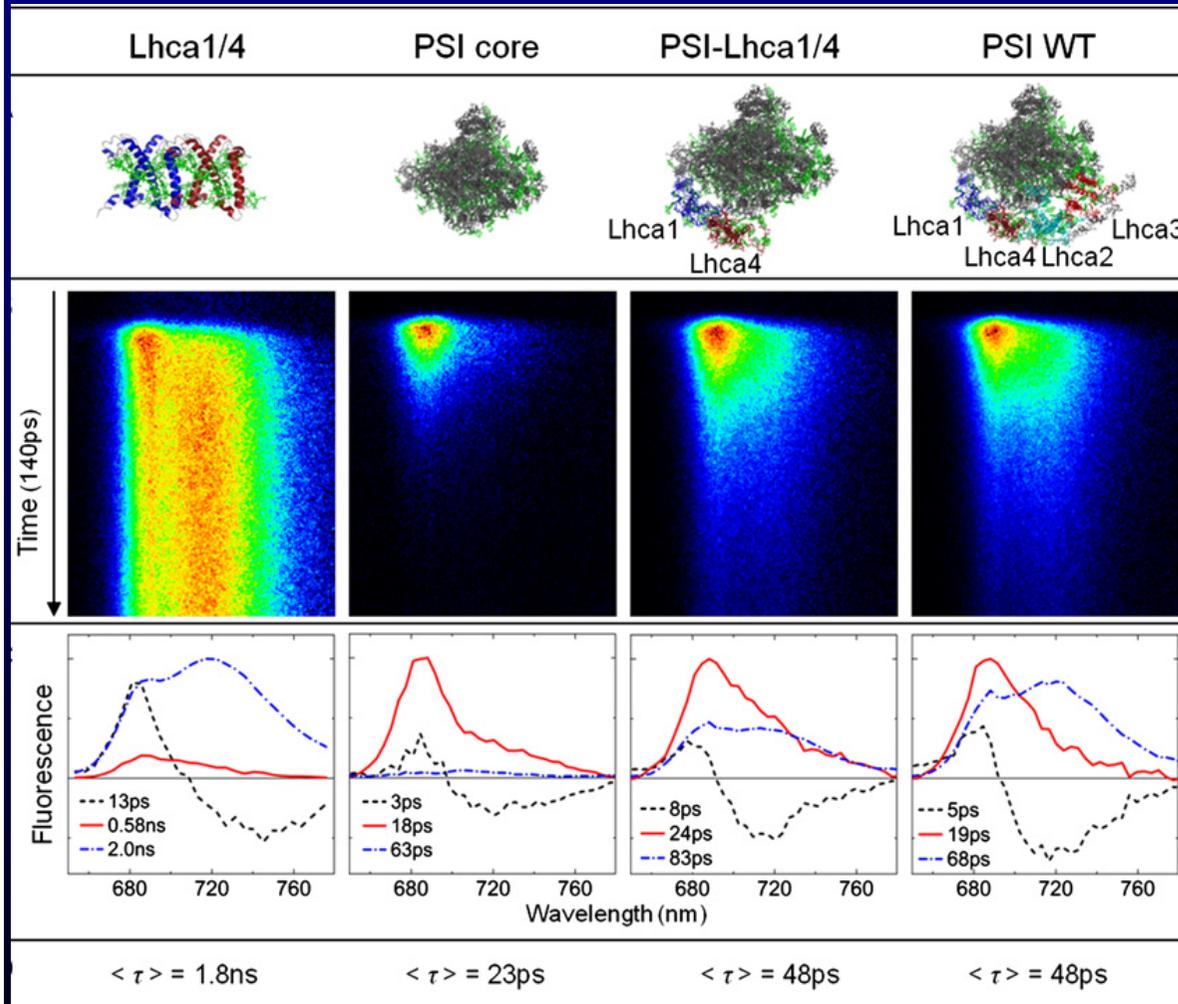
From: Jaime-Perez N et al. (2019) unpublished data H330

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

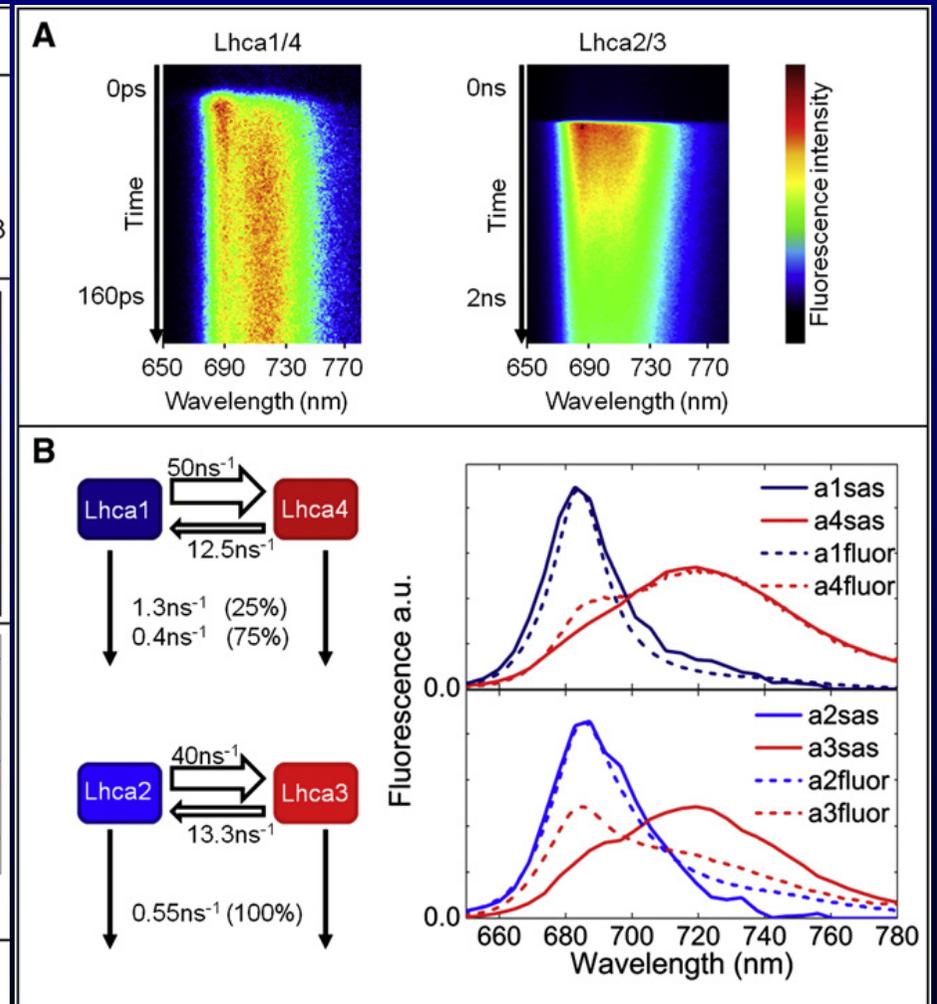


Photosynthesis related Proteins with metal centres

1. Excitation transfer times between light harvesting complexes



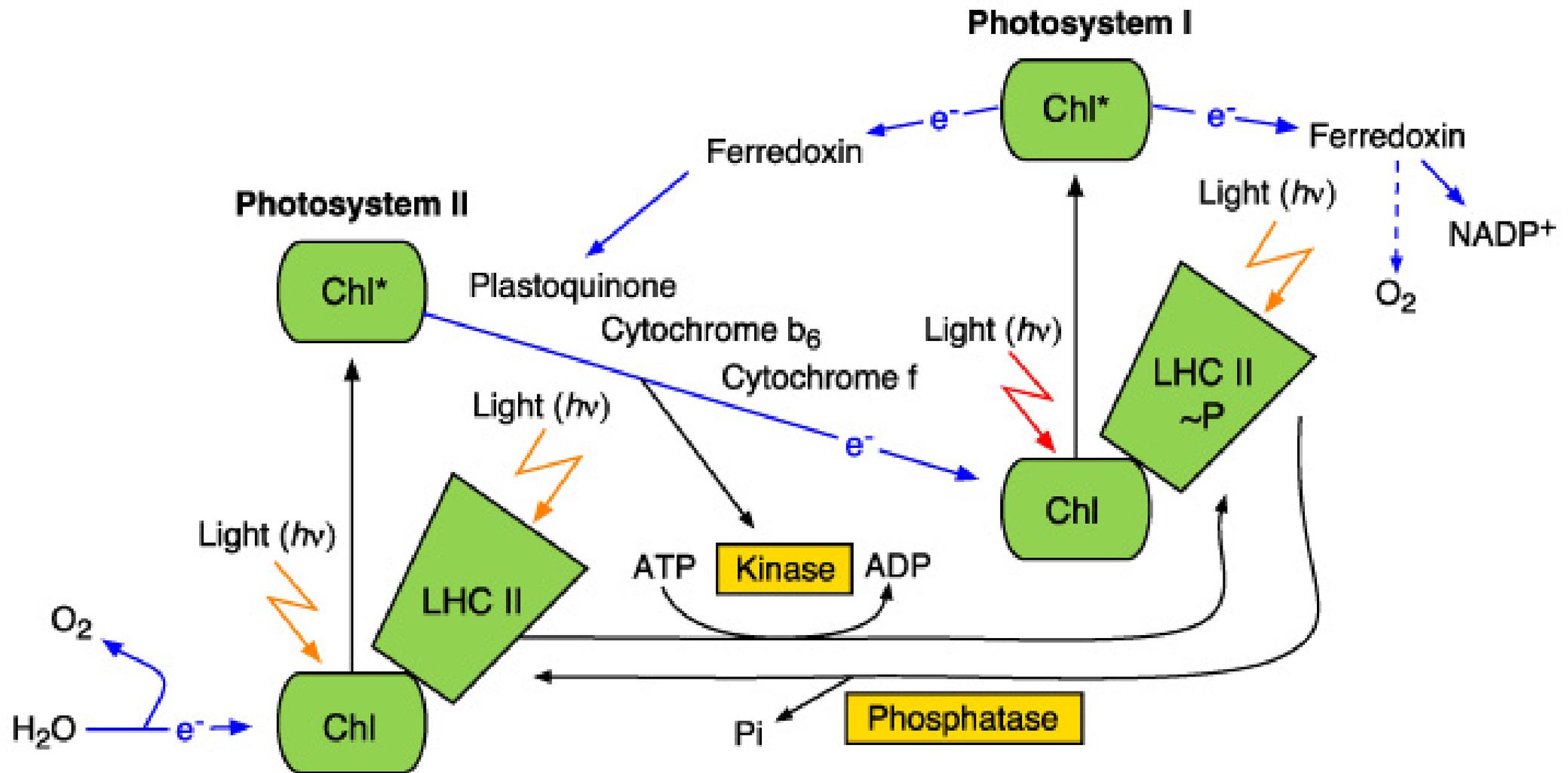
From: Wientjes E_et al (2011) BiophysJ101, 745-54



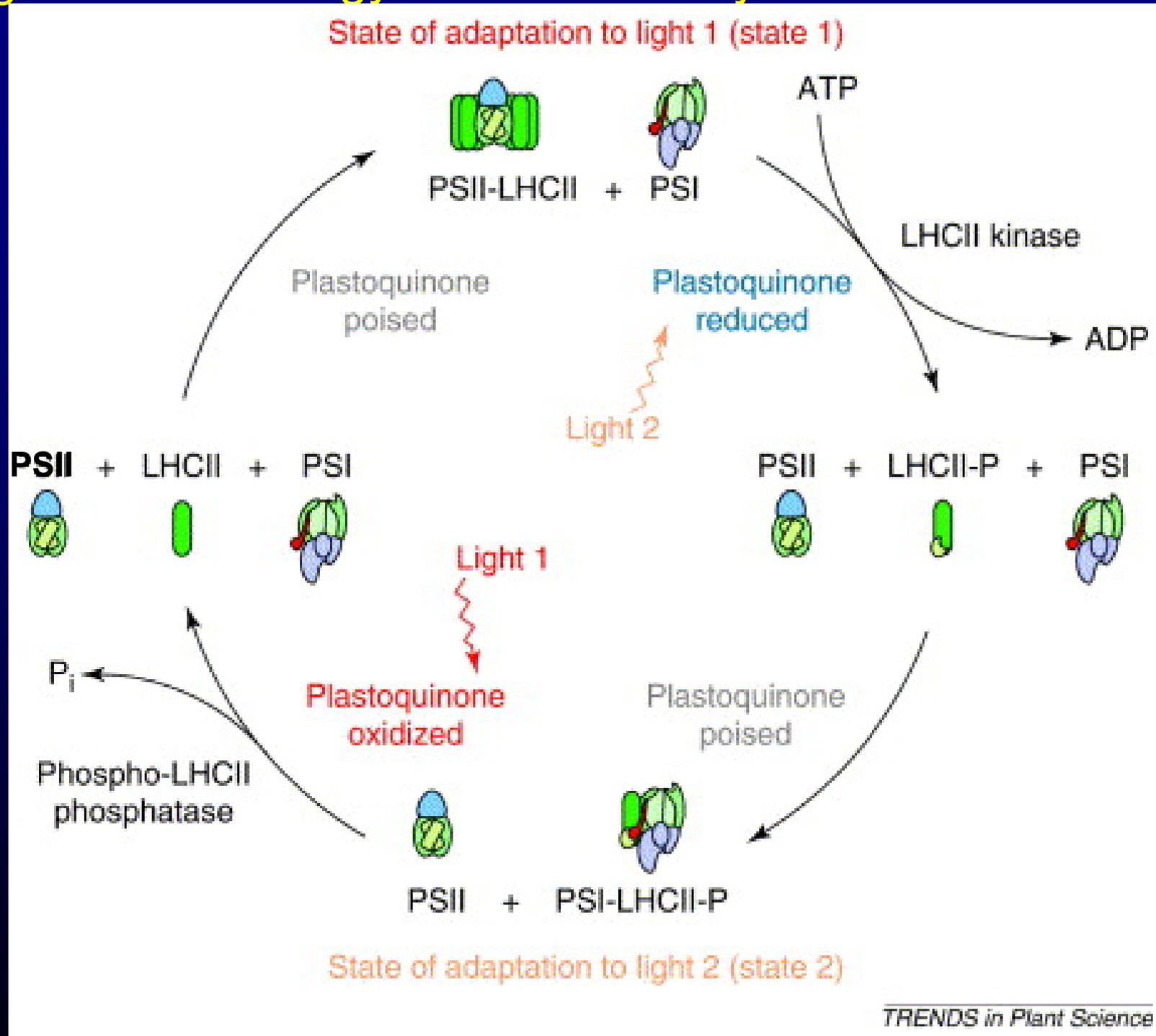
From: Wientjes E_et al (2011) BiophysJ 100, 1372-80

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

Higher plants, many algae

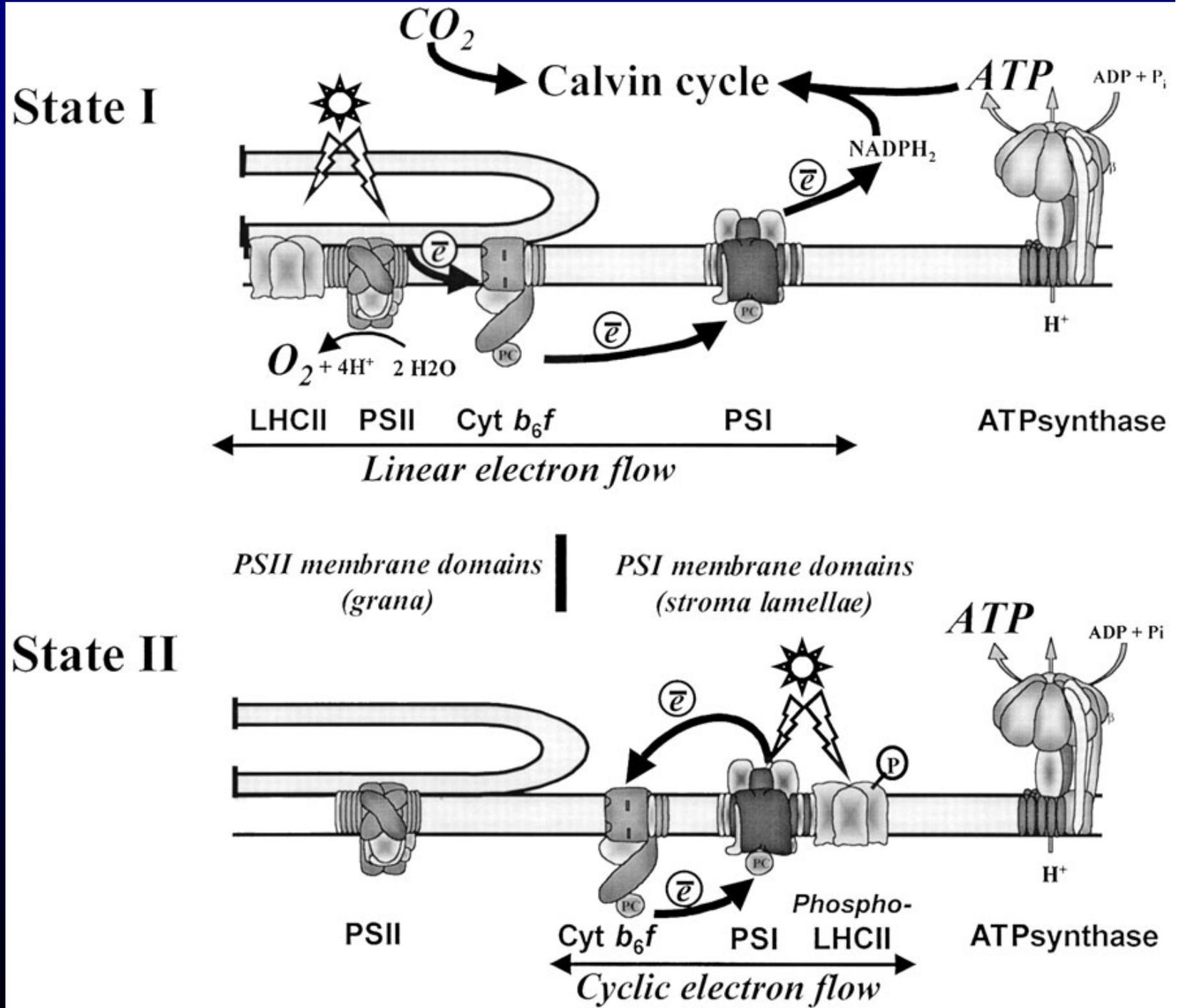


Regulation of energy transfer: The cycle of state transitions

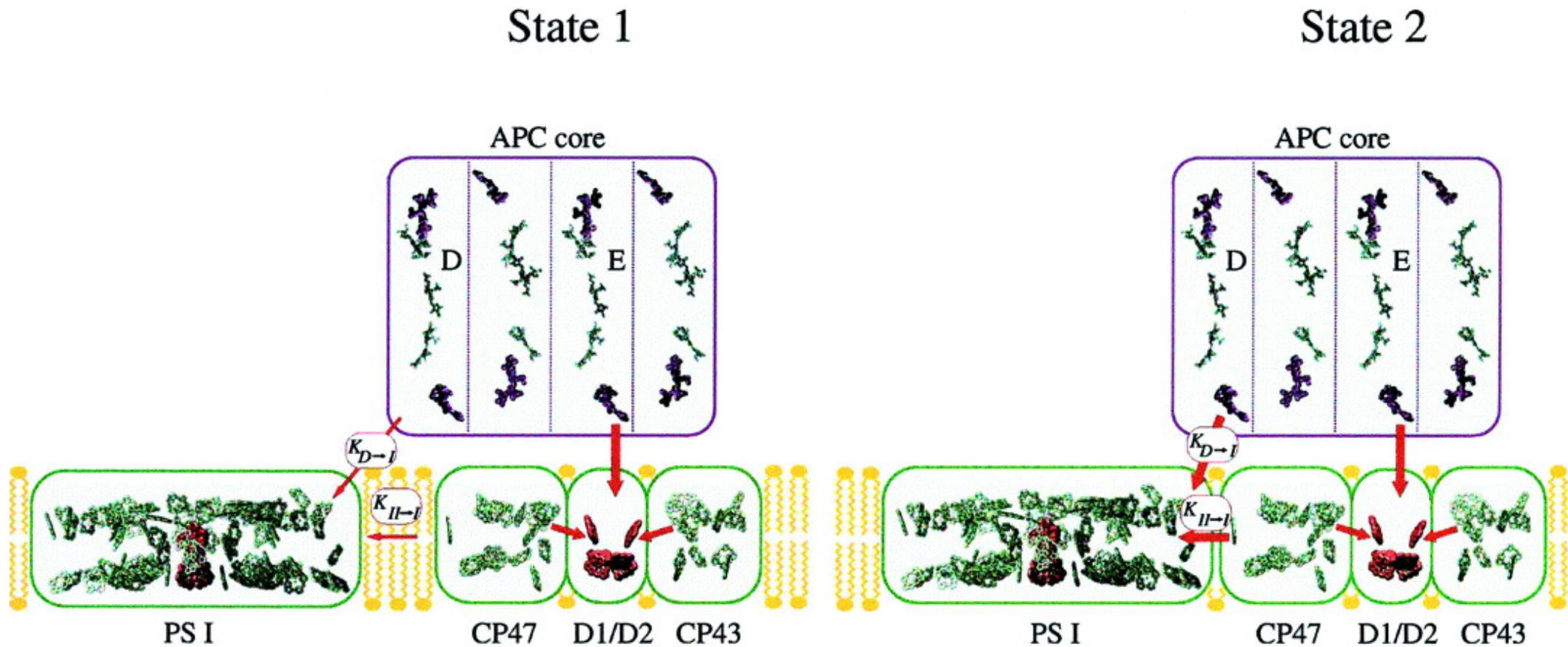


Regulation of energy transfer: another view of „state transitions“

Alternative view of the function of state transitions

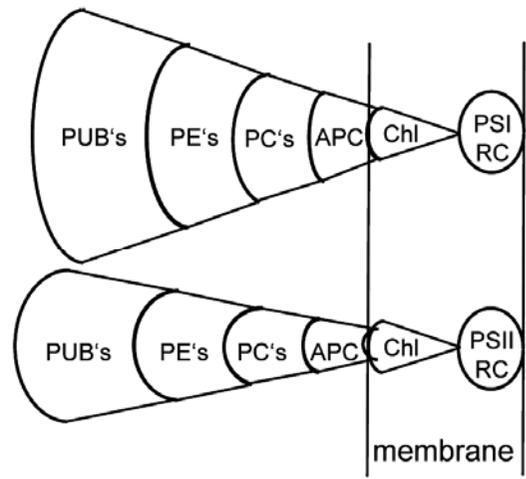


Regulation of energy transfer (I): „state transitions“ in cyanobacteria and red algae

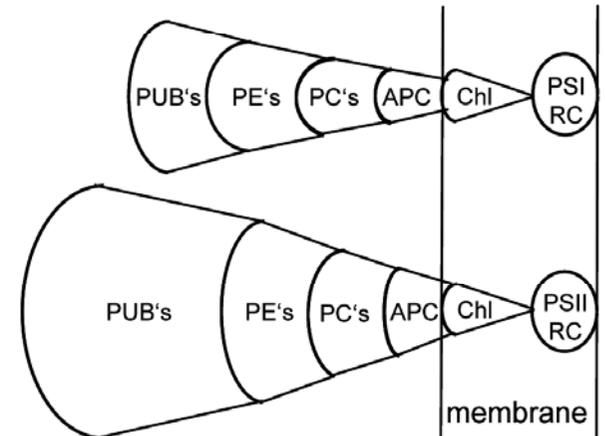


Reversible coupling of individual phycobiliproteins...

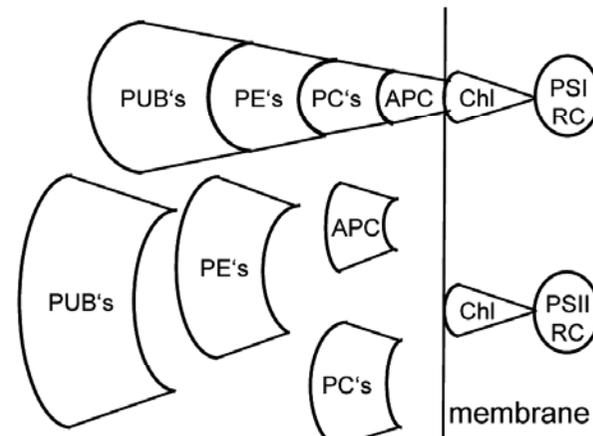
...as a basis for diazotrophic photosynthesis



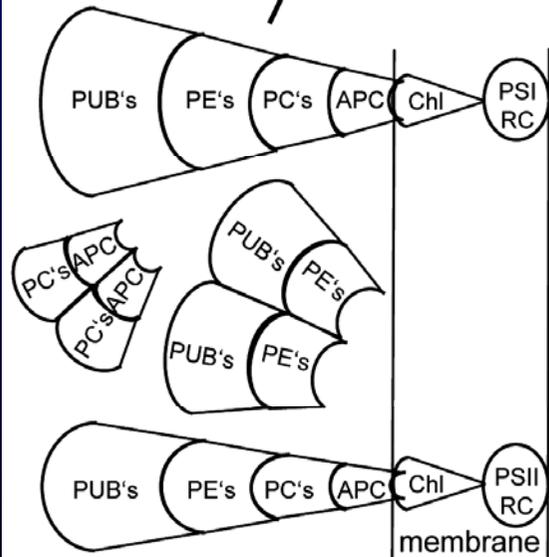
normal non-diazotrophic
(large phycobiliprotein antenna coupled to PSI)



bright I → diazotrophic
(large PUB antenna coupled to PSII)



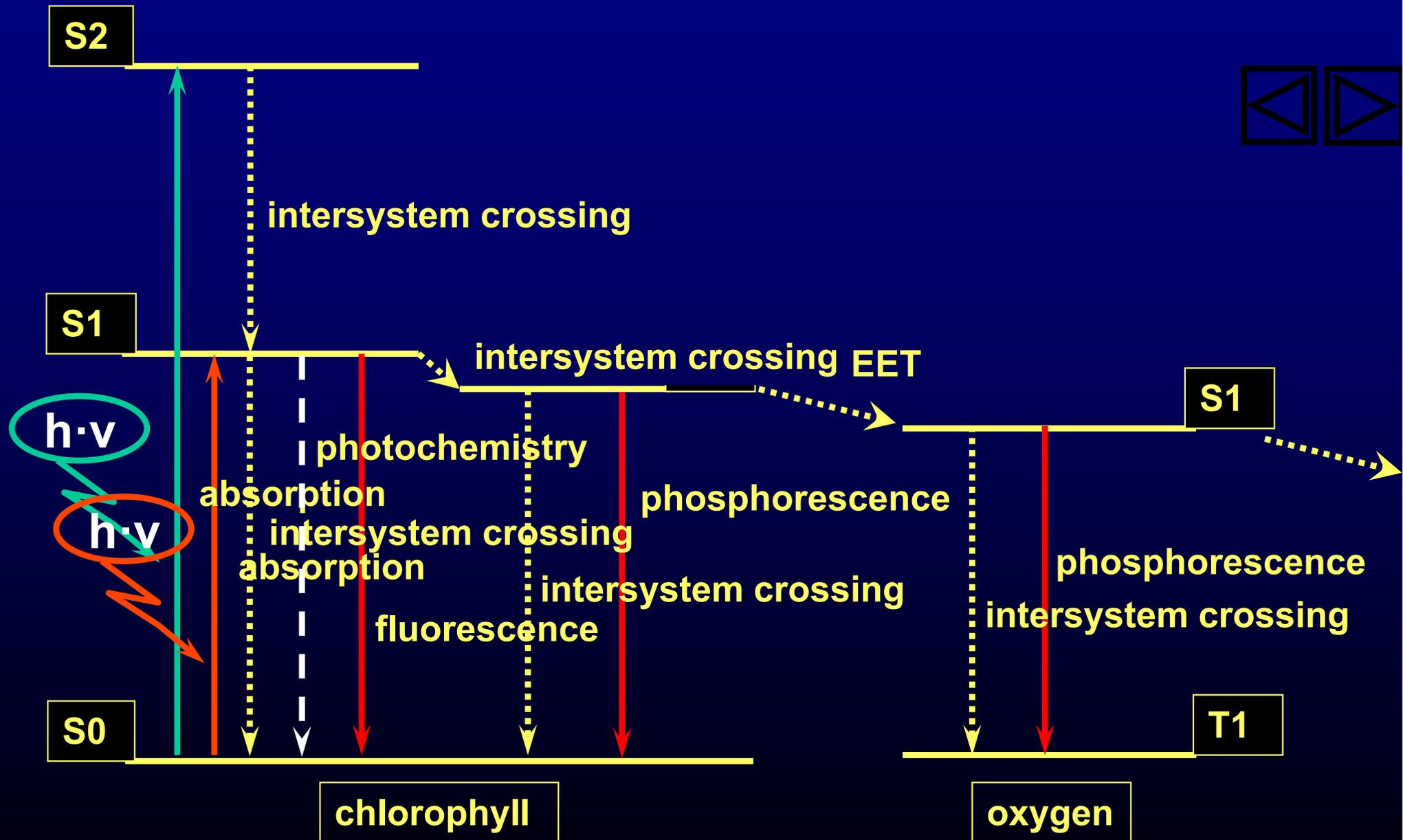
bright II („very bright“)
(uncoupled phycobiliproteins)



low fluorescence (quenching)
(unknown quenching arrangement, probably phycobiliprotein aggregation)

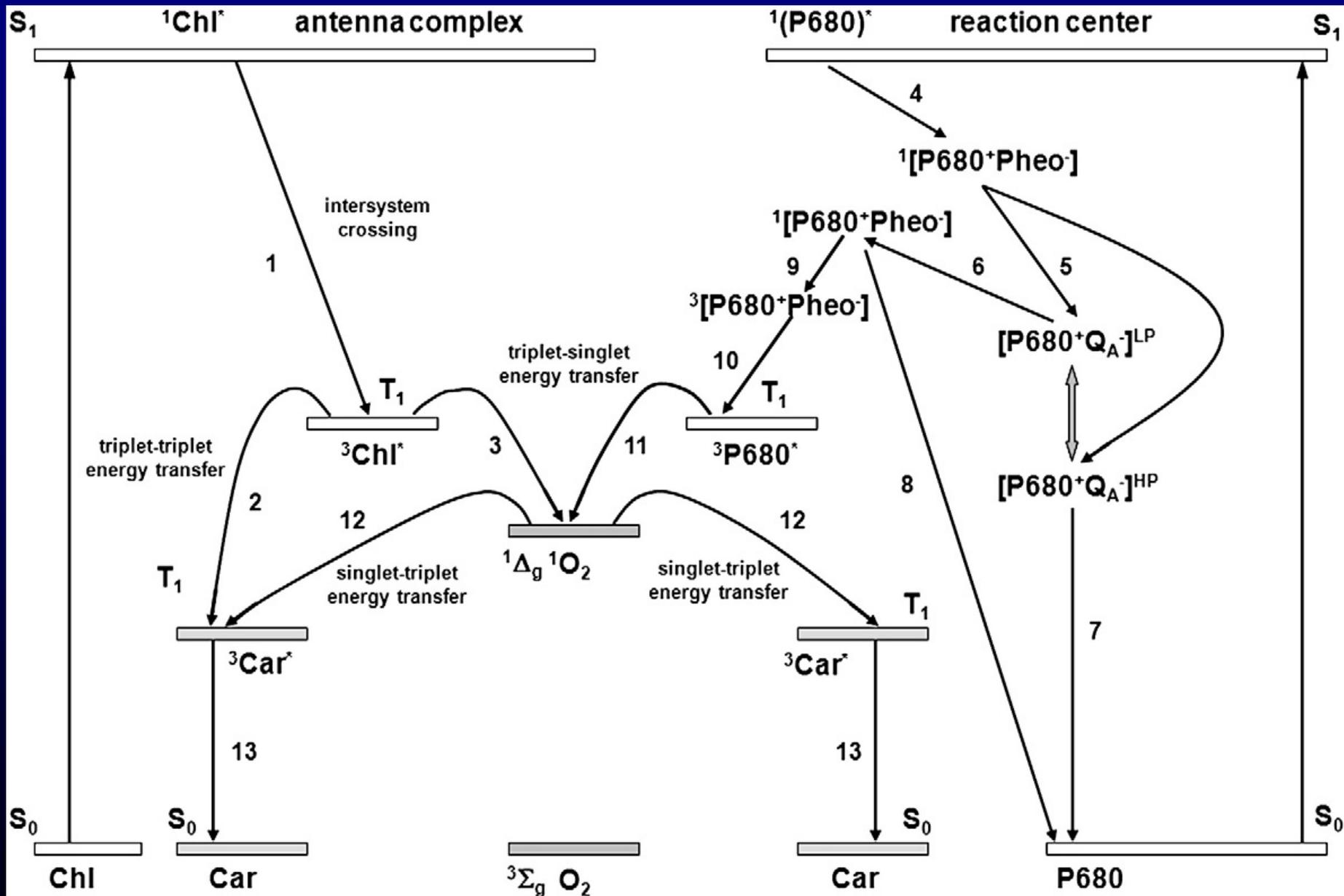
Küpper H, Andresen E, Wiegert S, Šimek M, Leitenmaier B, Šetlík I (2009) Biochim. Biophys. Acta (Bioenergetics) 1787, 155-167

Excitation energy transfer between chlorophyll derivatives and singlet oxygen

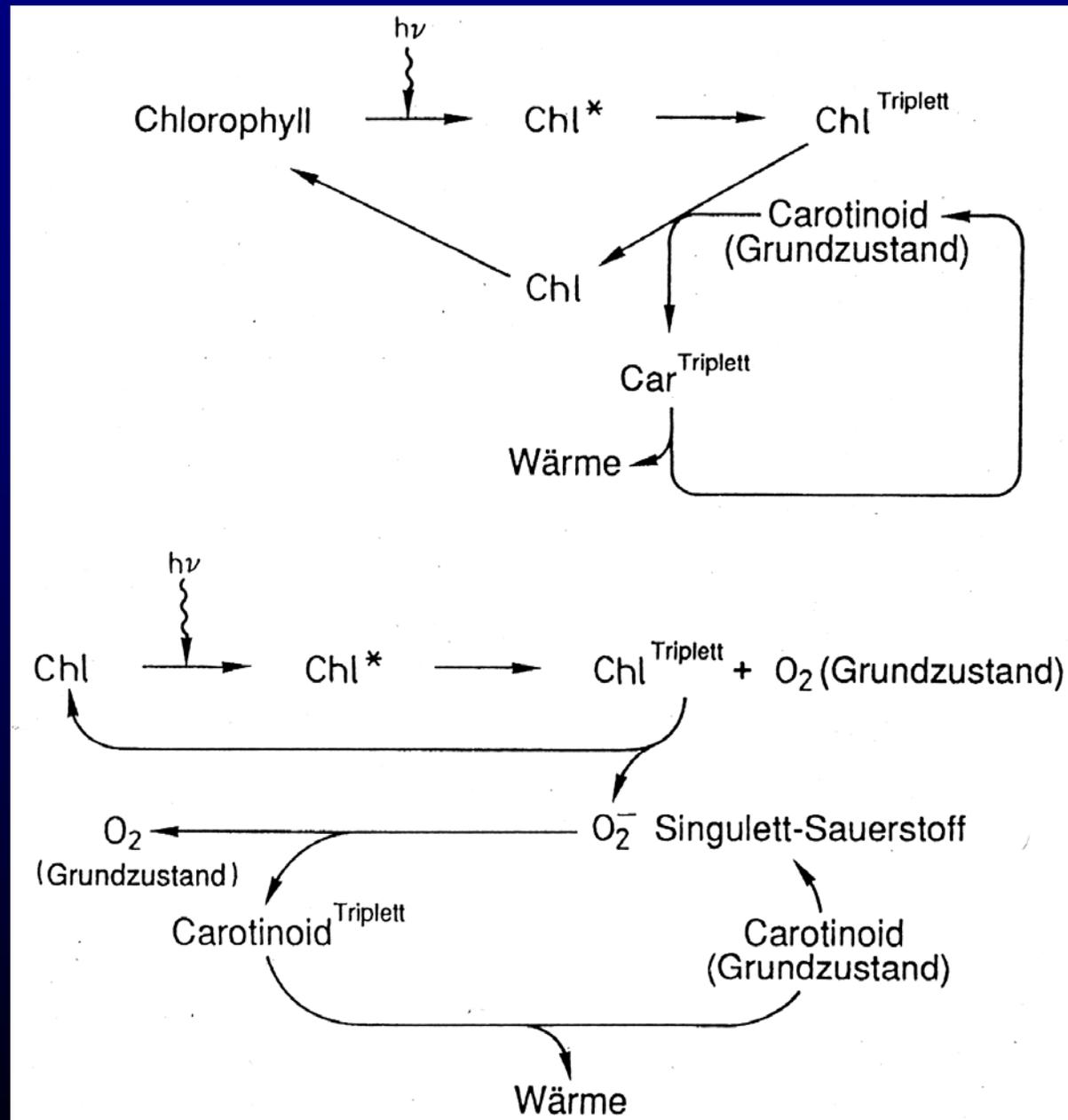


Photosynthesis related Proteins with metal centres

1. LHCII & PSIIRC: generation & quenching of 1O_2



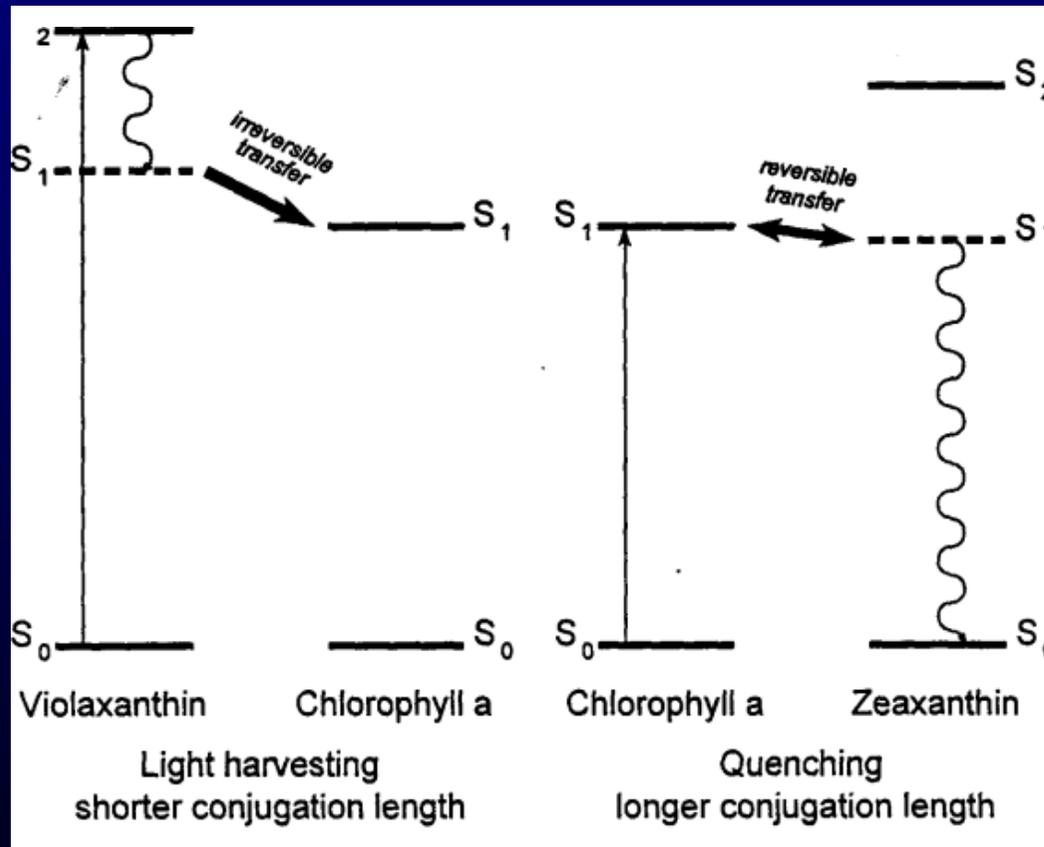
Regulation of energy transfer (II): Mechanisms of protection by carotenoids against singlet oxygen



Regulation of energy transfer: xanthophyll cycle

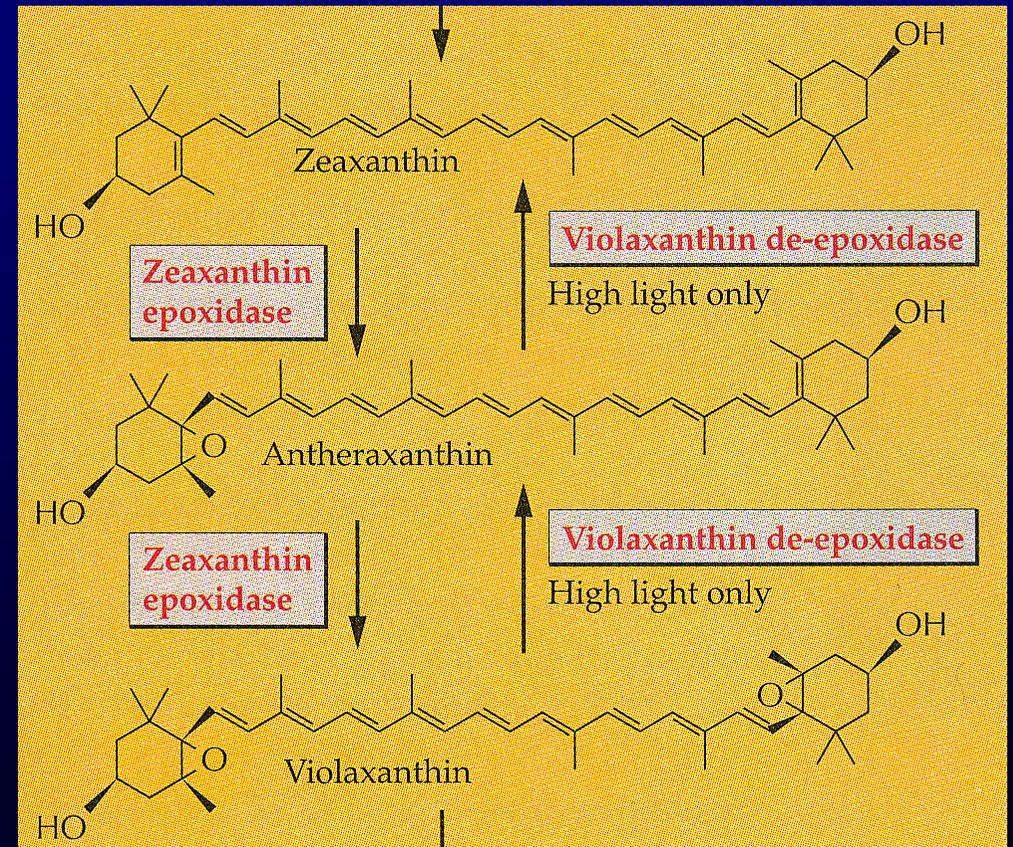
little light

much light

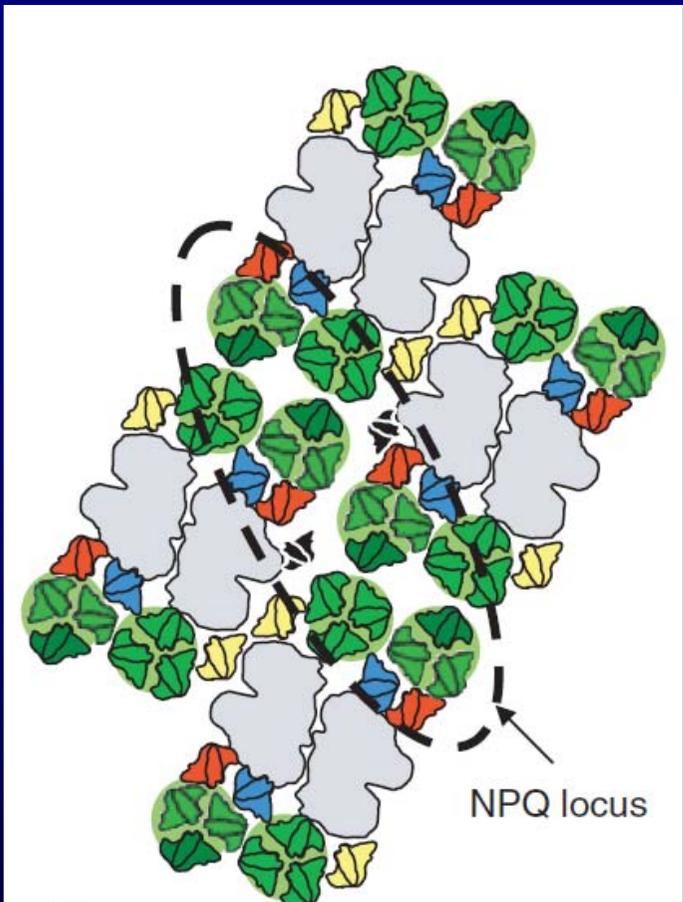


little light

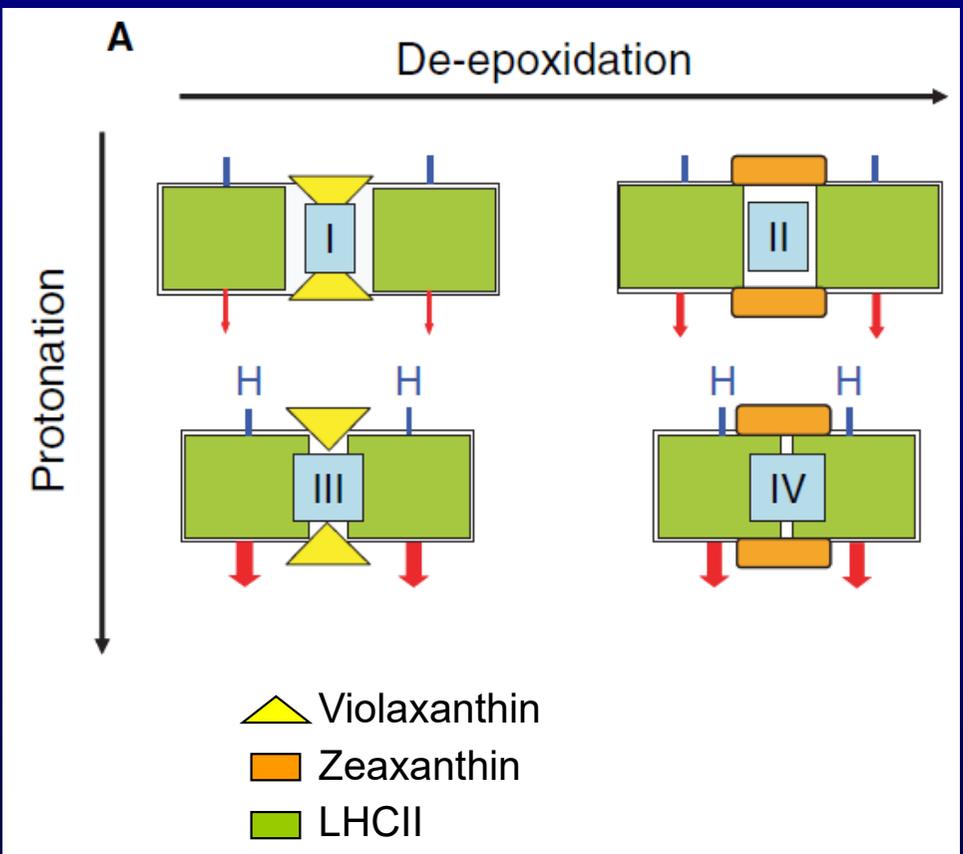
much light



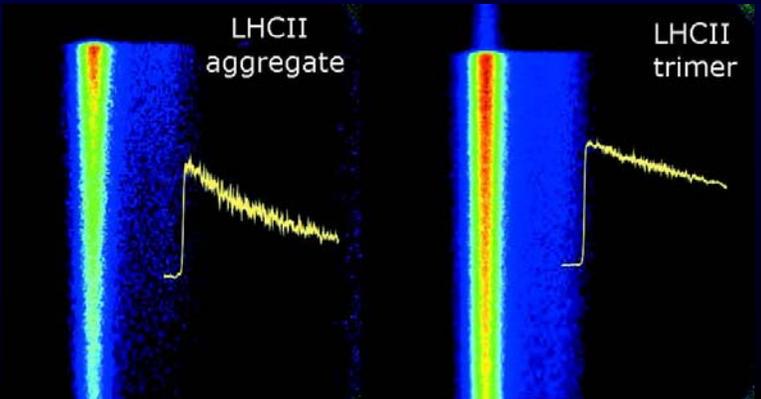
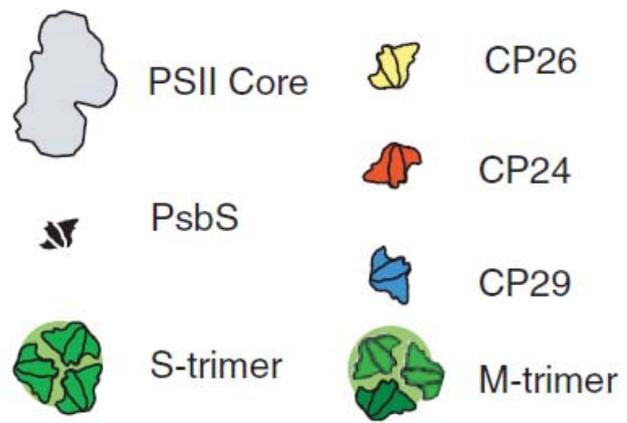
Fast adaptation to irradiance changes: combination of LHCII-aggregation with xanthophyll cycle



NPQ = non-photochemical quenching

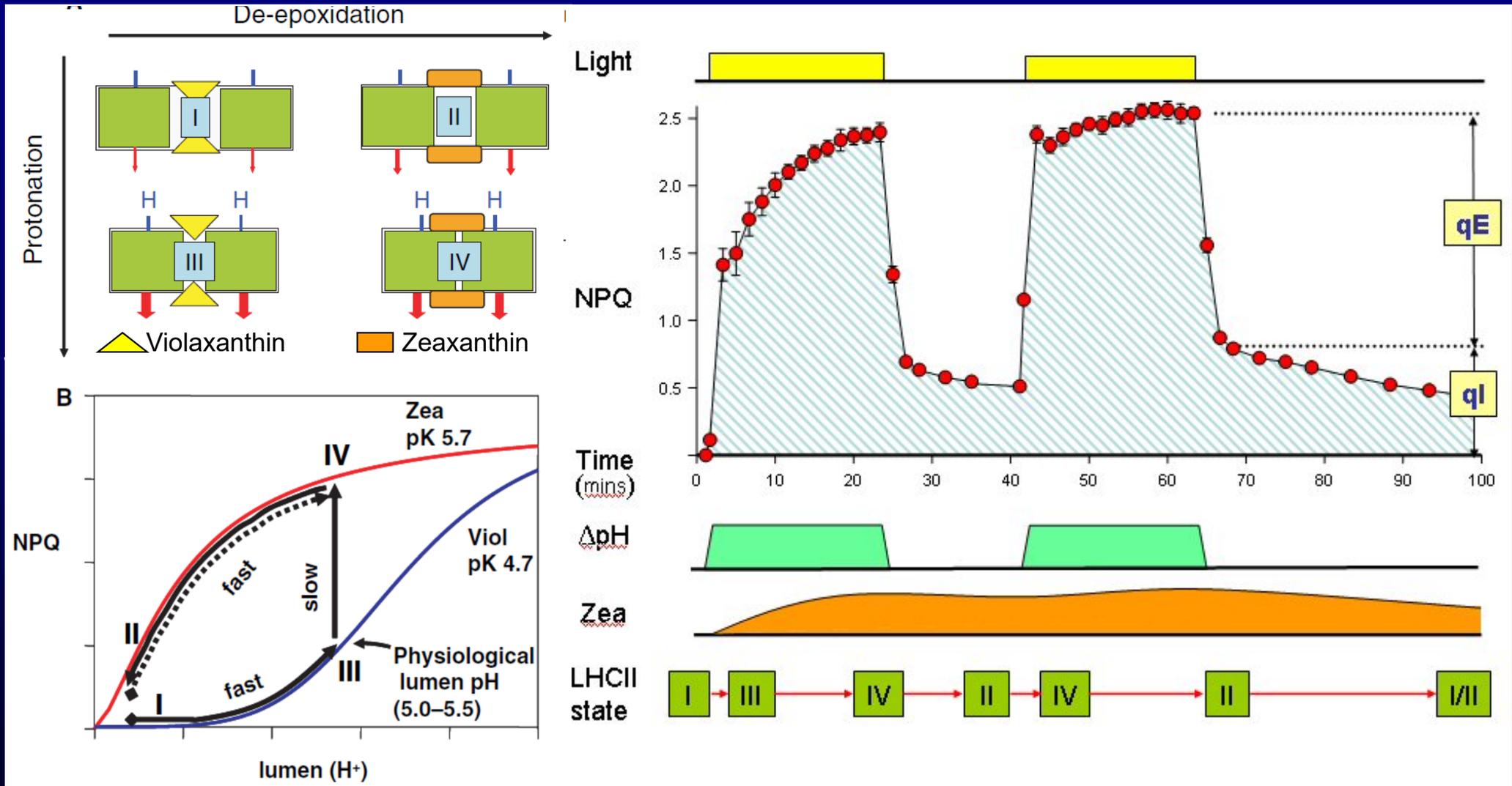


From: <http://photosynthesis.peterhorton.eu/research/ligtharvesting.aspx>
 Horton P, Johnson MP, Perez-Bueno ML, Kiss AZ, Ruban AV (2008) FEBS Journal 275, 1069-79



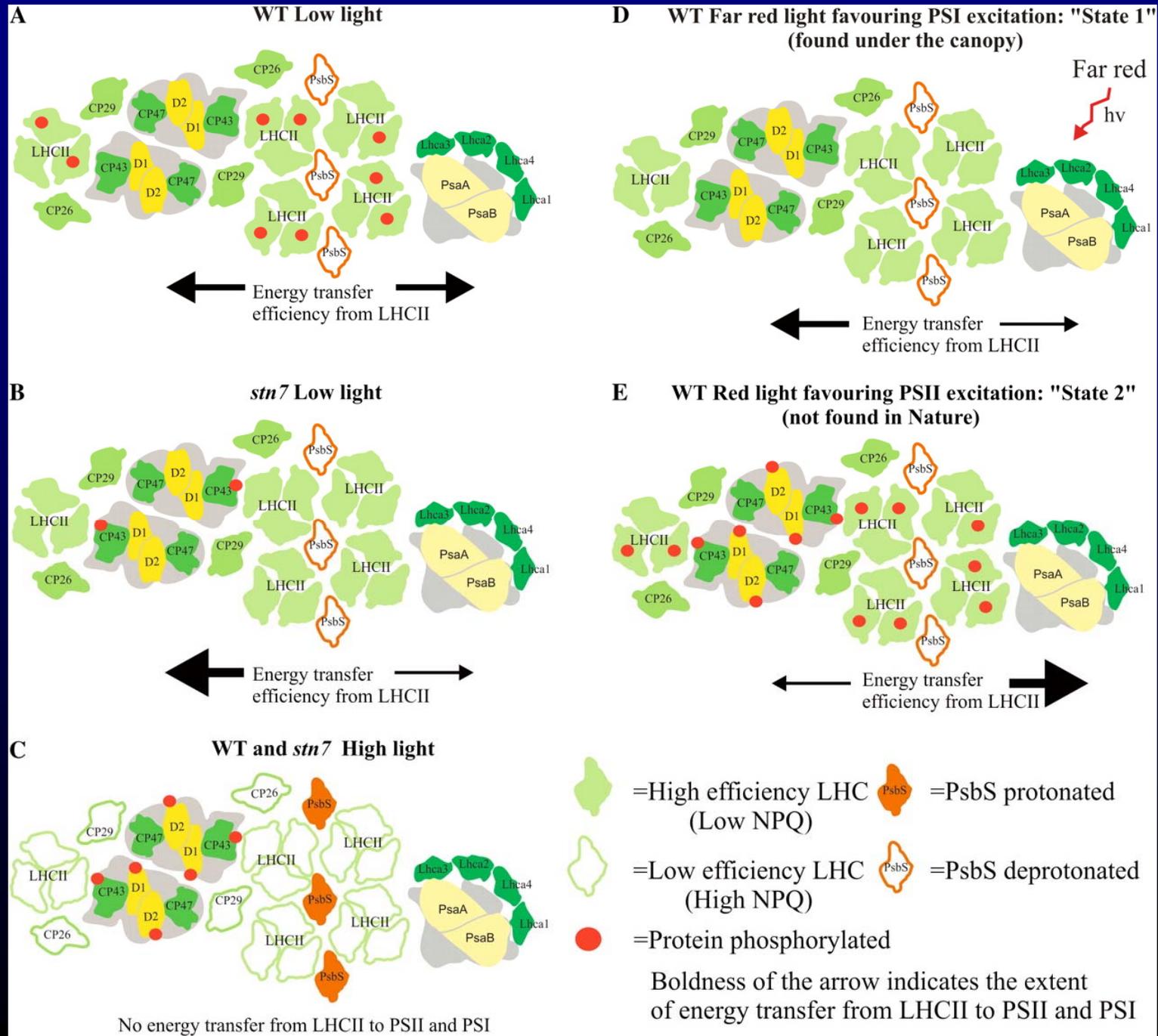
From: http://www.laserlab.vu.nl/en/Research/research_projects/the_primary_processes_in_photosynthesis.asp

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



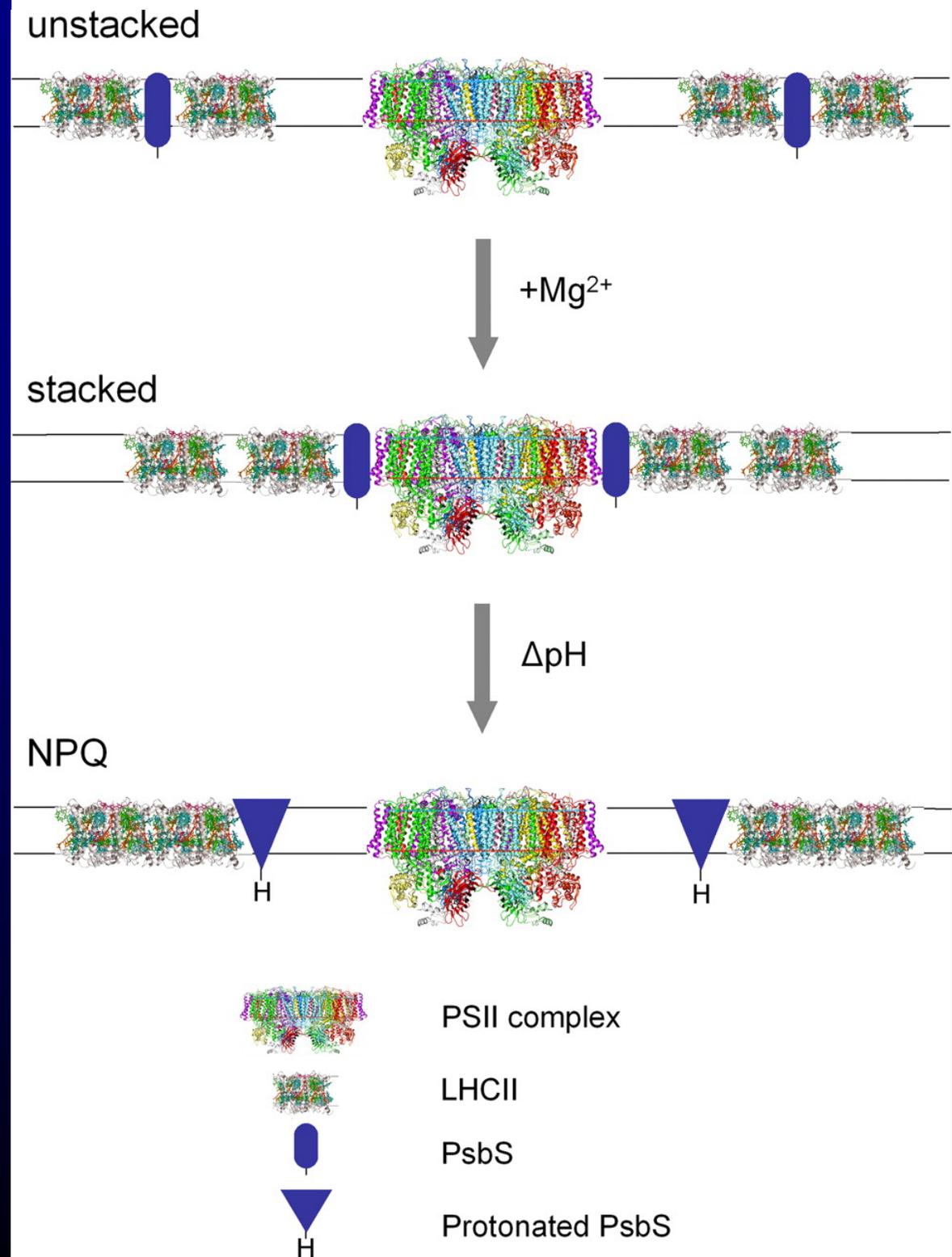
From: <http://photosynthesis.peterhorton.eu/research/ligtharvesting.aspx> (Horton lab web page)
 Horton P, Johnson MP, Perez-Bueno ML, Kiss AZ, Ruban AV (2008) FEBS Journal 275, 1069-79

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

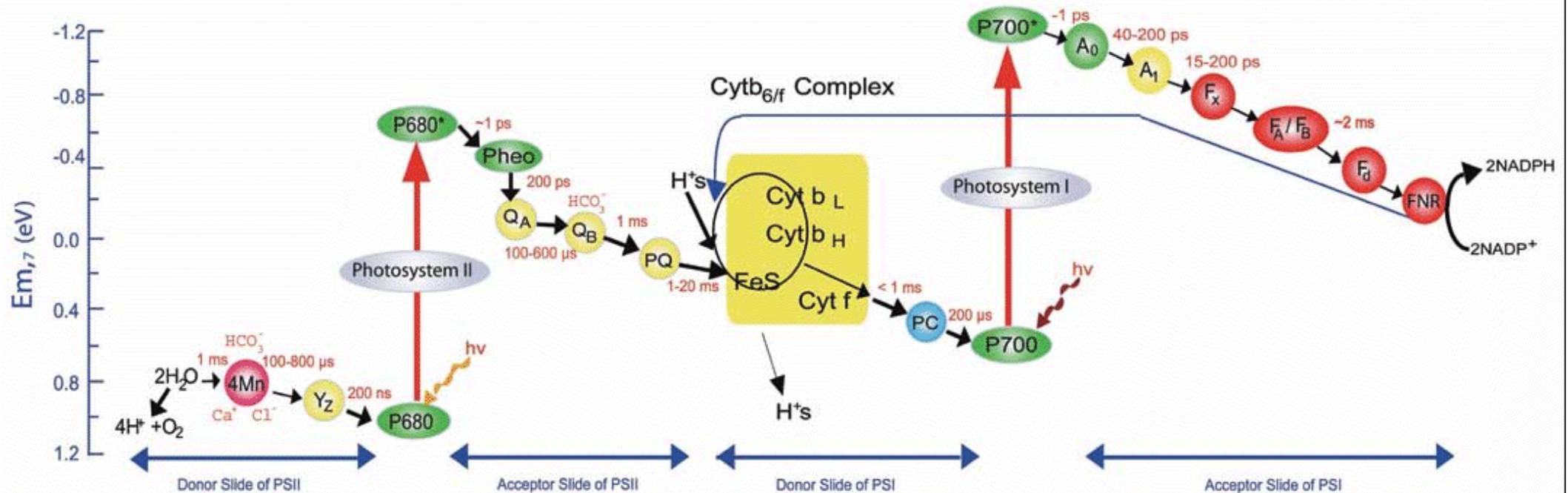


PsbS modulation of the structure and function of the PSII antenna

- At relatively high but not inhibitory light, relatively many unstacked grana exist, where LHCII is not efficiently coupled to PSII RC
- At low (limiting) light, enhanced grana stacking occurs, regulated via an increase of Mg^{2+} .
- At inhibitory high light, grana unstack again, and in addition protonation of PsbS leads to strong non-photochemical quenching of excitons



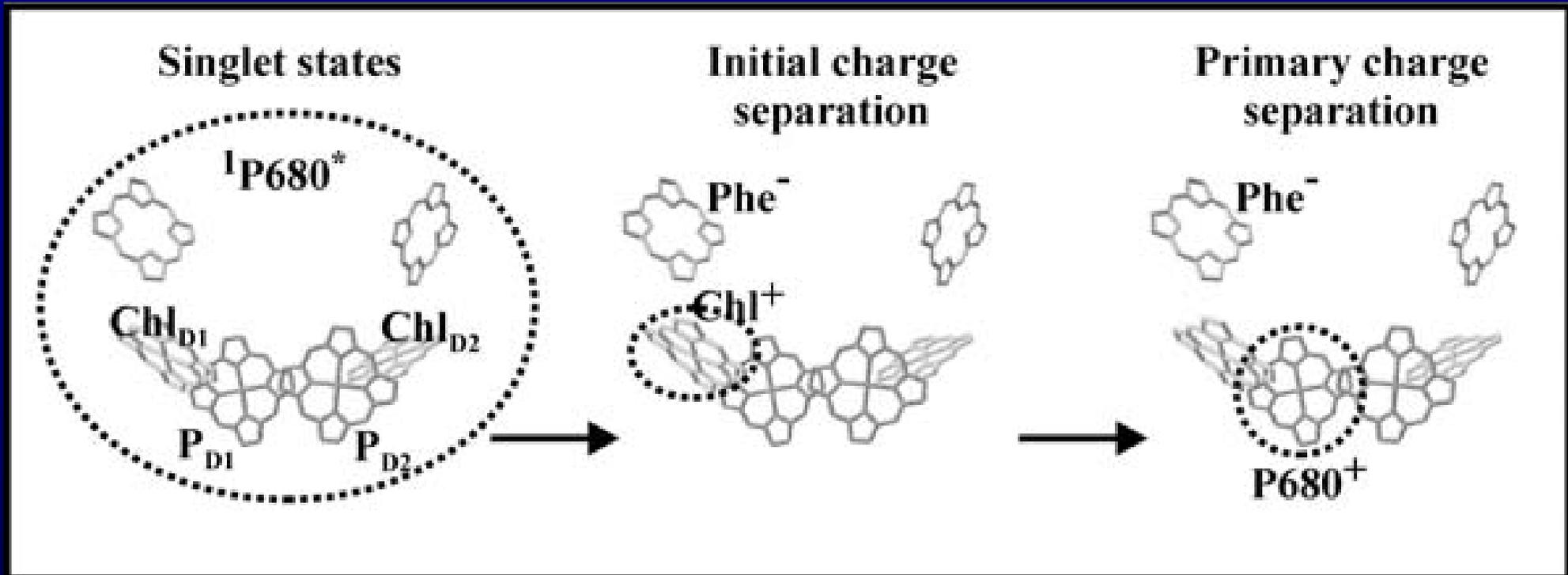
Overview of photosynthetic light reactions the „Z-scheme“



From: accessscience.com

Biophysical aspects of photosynthetic electron transport

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



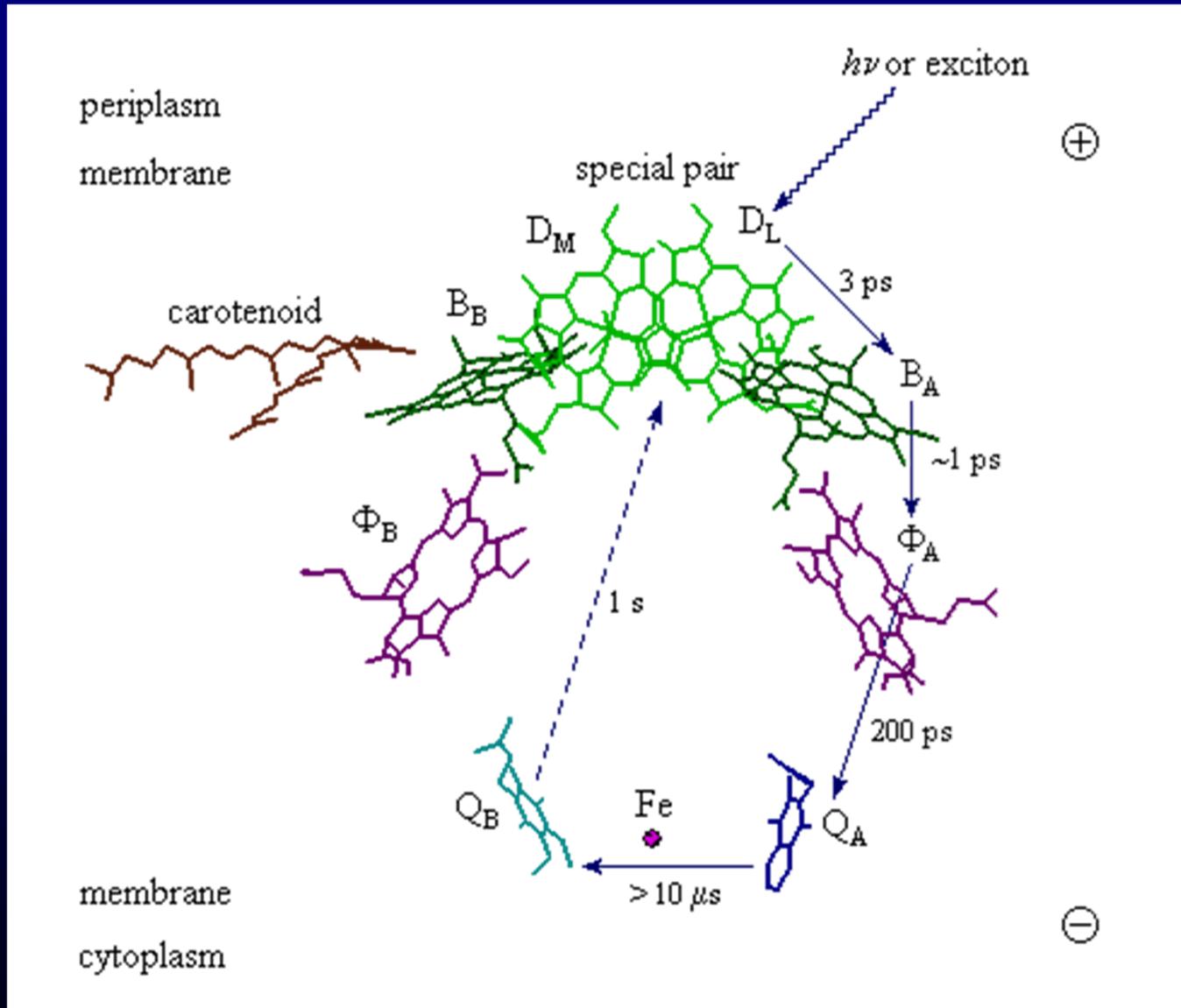
From: Barber J, 2003, QuartRevBiophys36, 71-89

Mechanism of charge separation

- 1. Special pair chlorophylls (=P680) accept excitons from antenna
- 2. Chl_{D1} transfers an electron to Pheo ("initial charge separation")
- 3. Within a few ps, the electron hole in Chl_{D1} is filled from P680 (→ P680⁺ / 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



**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