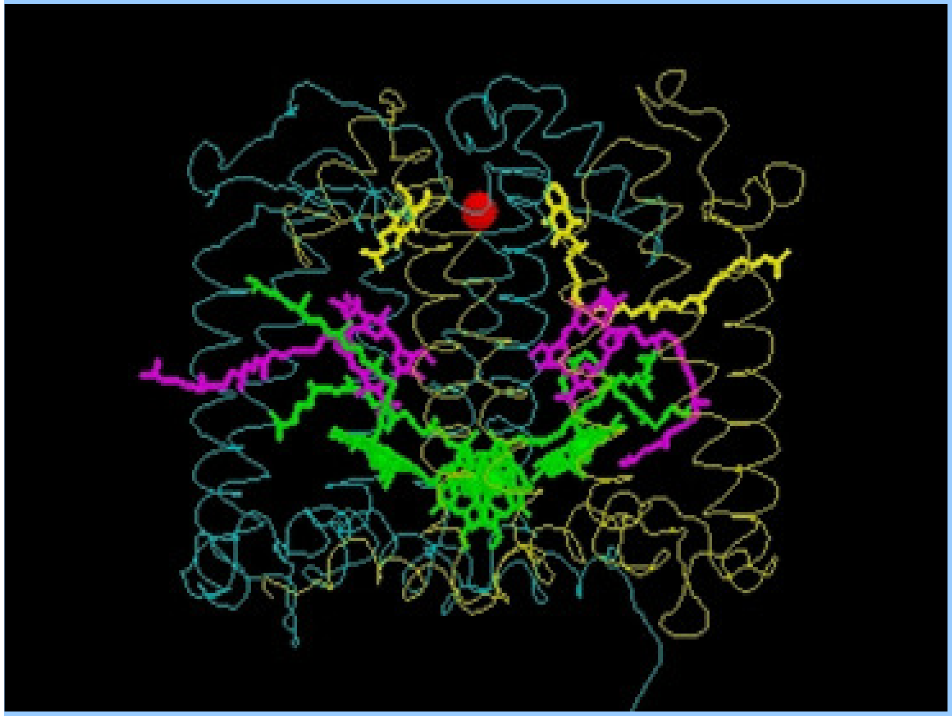
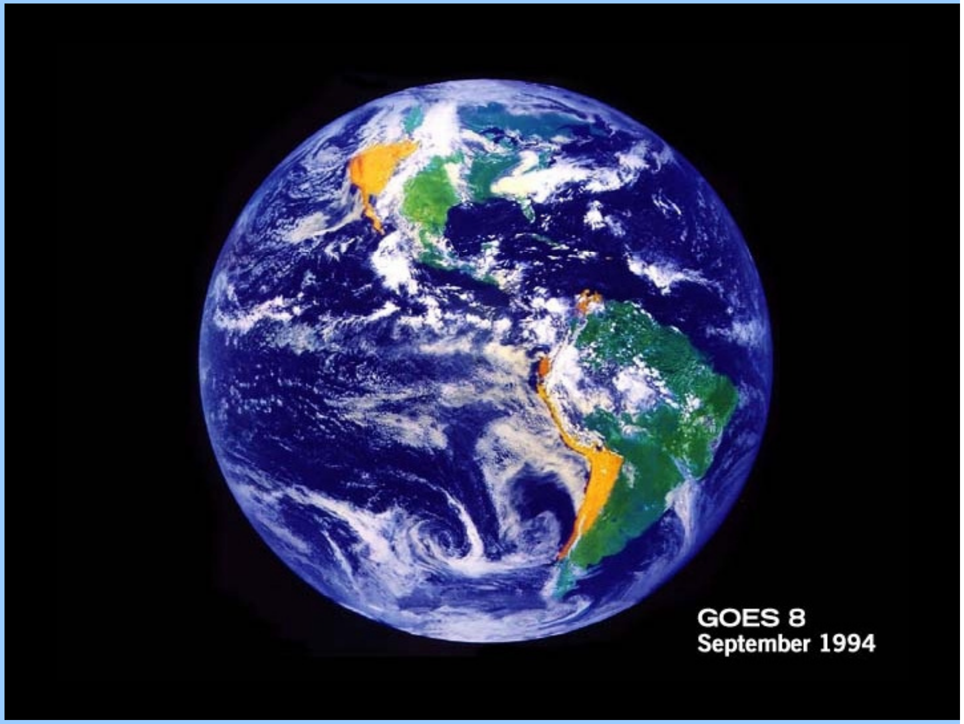

Albert Szent-Györgyi
Nobel prize for vitamin C

Photosynthesis:
Molecular Mechanisms– Global Effects





Győző Garab, Biological Research Center, Szeged, Hungary

SAIP - UNISA, 2011

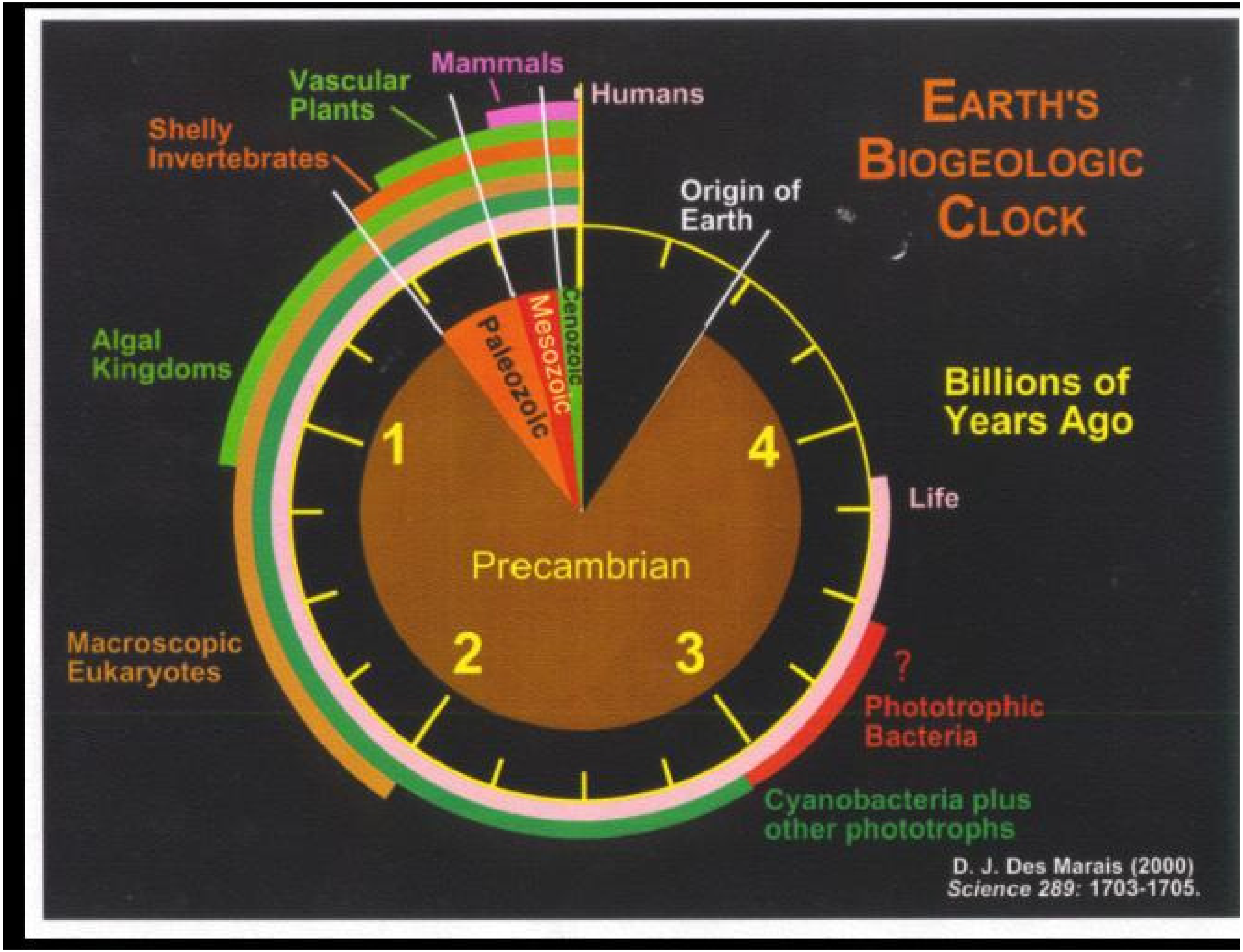
In this talk:

1. **Why photosynthesis?**
2. **What is photosynthesis?**
3. **Some of own research**

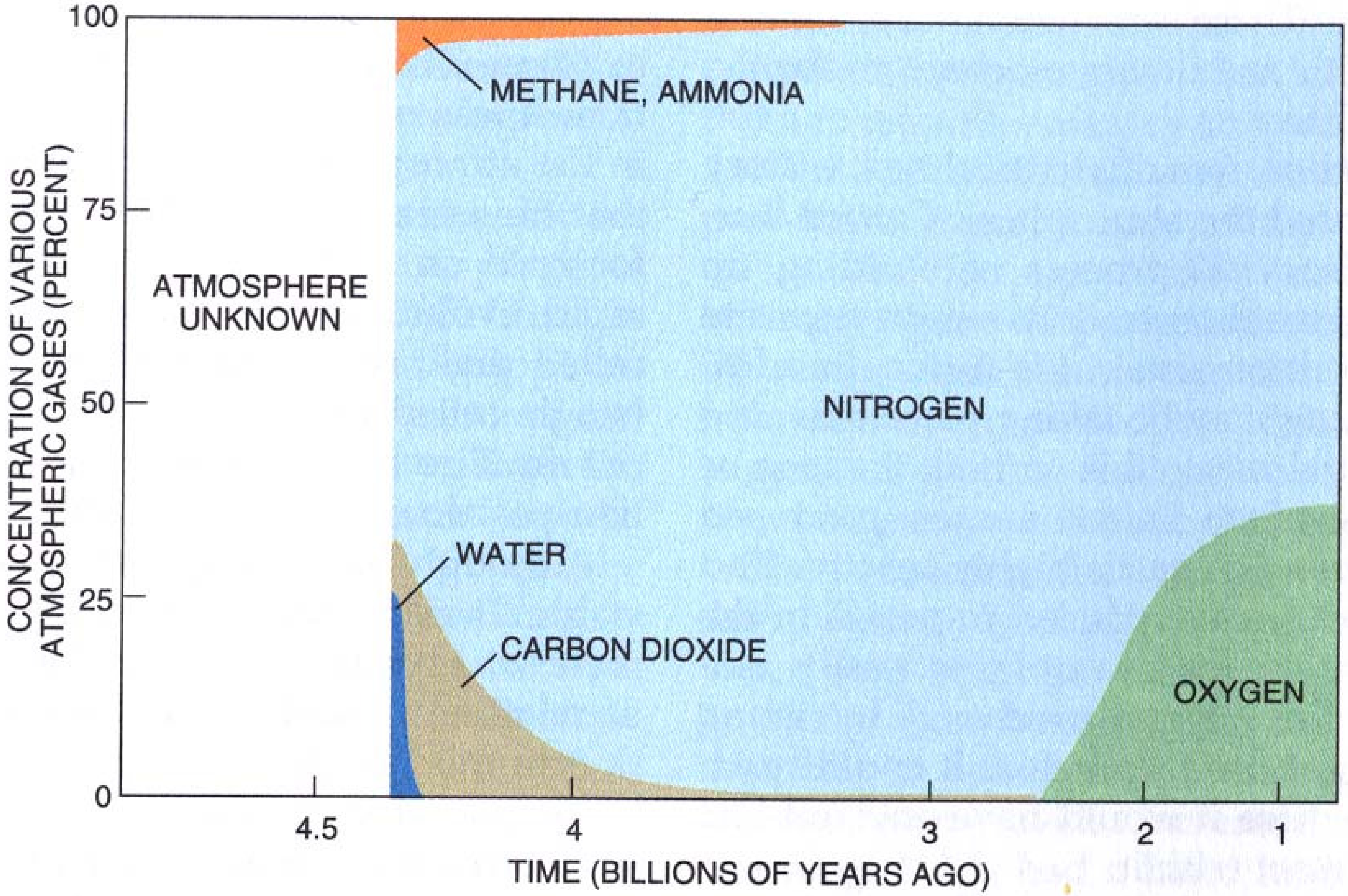
Why photosynthesis?

(i) global effects: evolution & bio-geo.chemical cycles

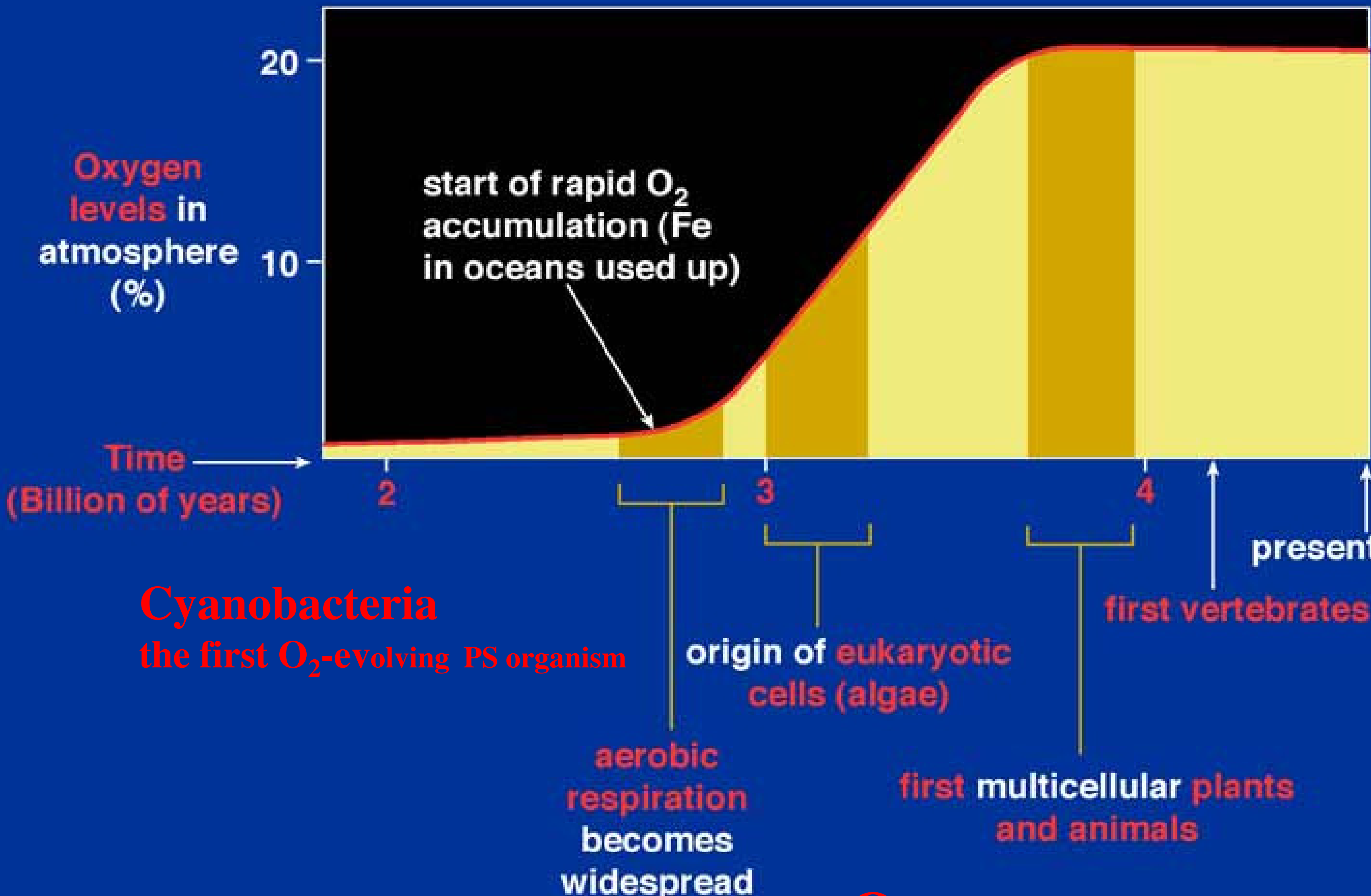
$$6H_20 + 6CO_2 \xrightarrow[\text{light}]{} C_6H_{12}O_6 + 6O_2$$



EARTH'S BIOGEOLOGIC CLOCK
Mammals
Humans
Vascular Plants
Shelly Invertebrates
Origin of Earth
Algal Kingdoms
Paleozoic
Mesozoic
Cenozoic
Billions of Years Ago
1
4
Life
Precambrian
2
3
Macroscopic Eukaryotes
?
Phototrophic Bacteria
Cyanobacteria plus other phototrophs
D. J. Des Marais (2000)
Science 289: 1703-1705.


100
75
50
25
0
CONCENTRATION OF VARIOUS ATMOSPHERIC GASES (PERCENT)
ATMOSPHERE UNKNOWN
METHANE, AMMONIA
NITROGEN
WATER
CARBON DIOXIDE
OXYGEN
4.5
4
3
2
1
TIME (BILLIONS OF YEARS AGO)

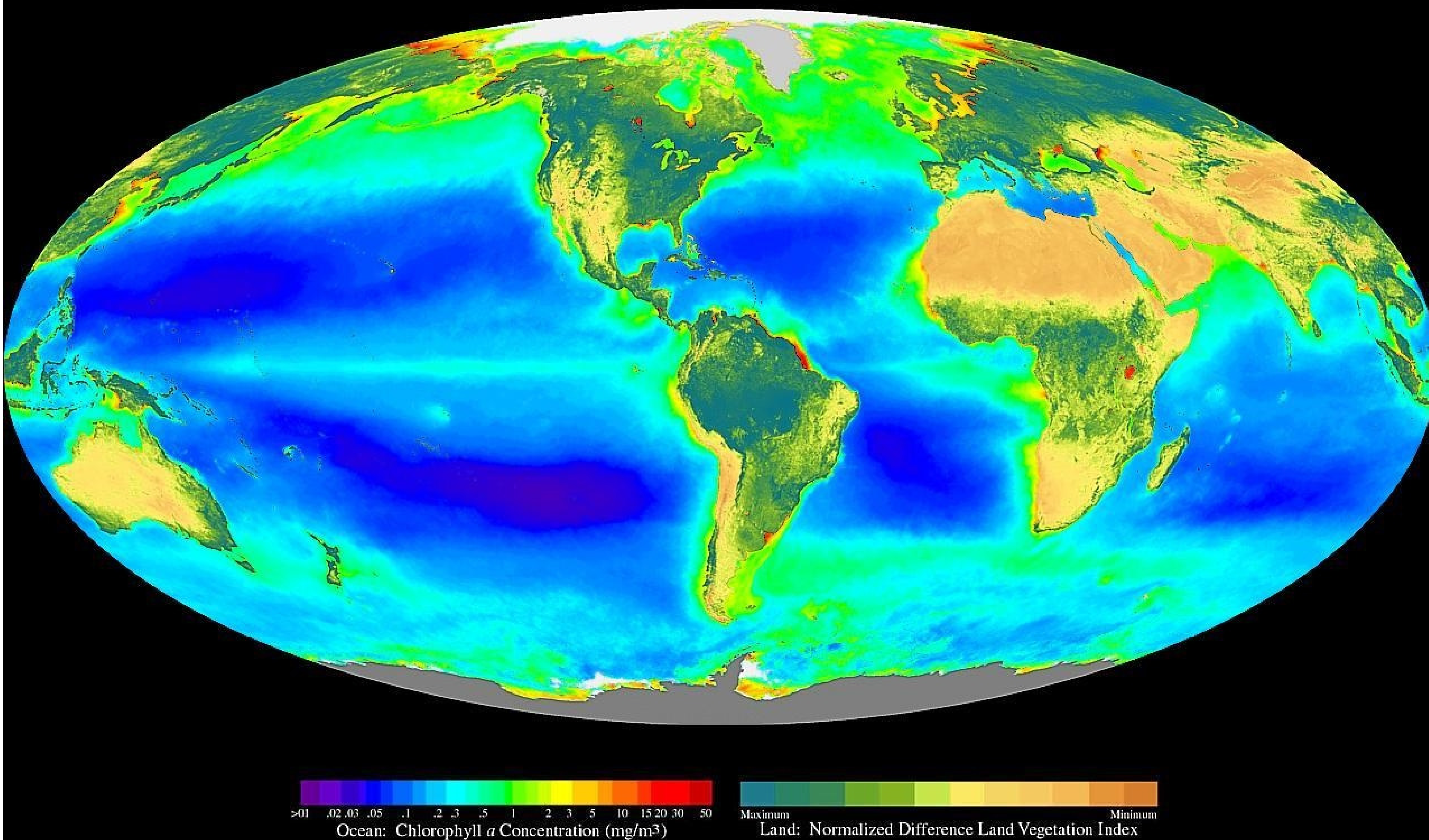
EVOLUTION AND OXYGEN LEVELS



Cyanobacteria
the first O_2-evolving PS organism

Ozone –

SeaWiFS Global Biosphere September 1997 – August 2000
Three Year Anniversary



Generalized scheme of bio-geo-chemical cycle

- Oxygen
- Carbon

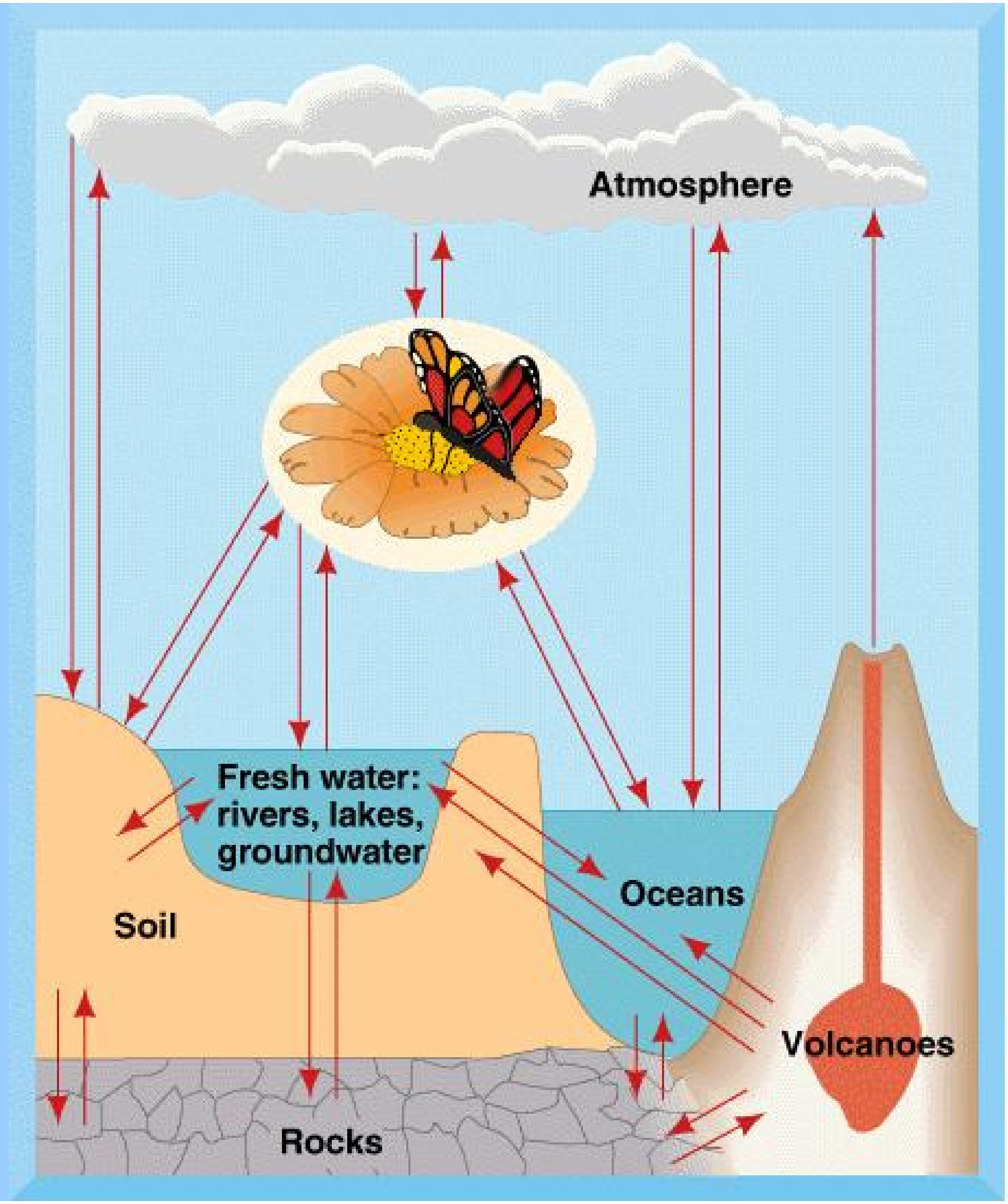


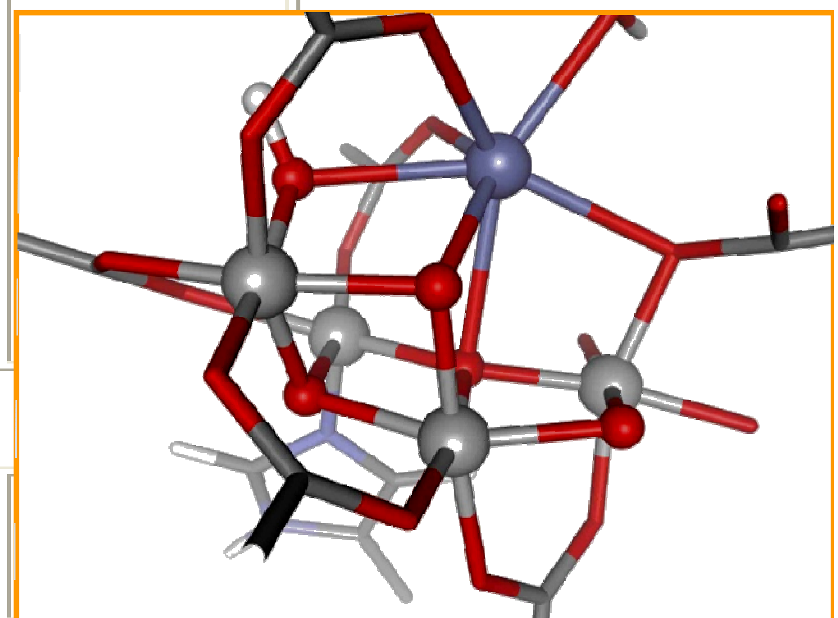
Table 2: Annual gain and loss of atmospheric oxygen (Units of 10^{10} kg O_2 per year

Gains	
Photosynthesis (land)	16,500
Photosynthesis (ocean)	13,500
Photolysis of N2O	1.3
Photolysis of H2O	0.03
Total Gains	~ 30,000
Losses - Respiration and Decay	
Aerobic Respiration	
Microbial Oxidation	
Combustion of Fossil Fuel (anthropologic)	
Photochemical Oxidation	
Fixation of N2 by Lightning	
Fixation of N2 by Industry (anthropologic)	
Oxidation of Volcanic Gases	
Losses - Weathering	
Chemical Weathering	
Surface Reaction of O3	
Total Losses	~ 30,000

300 Gt O_2 per annum

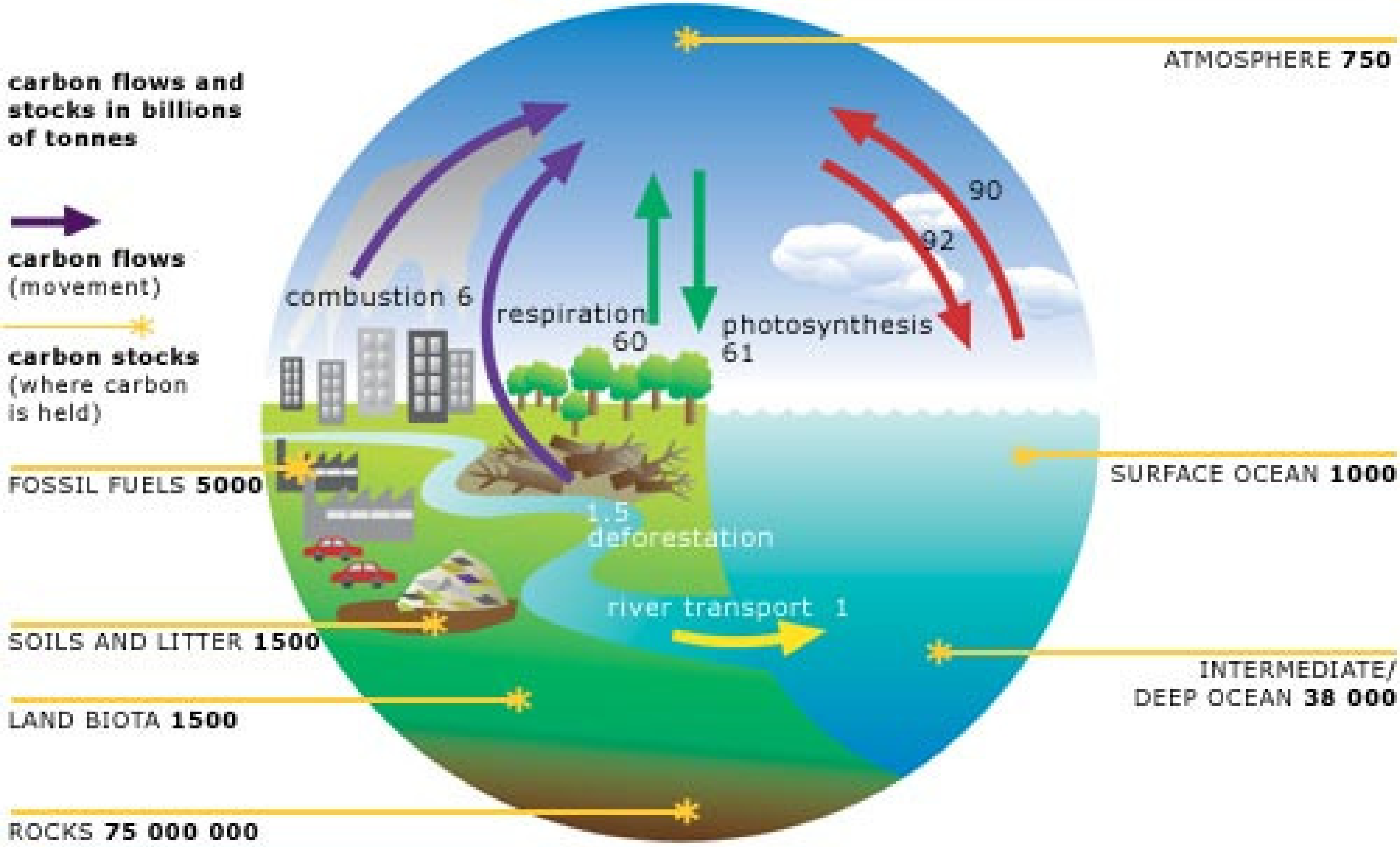
Residence time in the atmosphere: 4 500 years

$$2\,H_2O + 4\,h\nu \longrightarrow 4\,e^- + 4\,H^+ + O_2$$



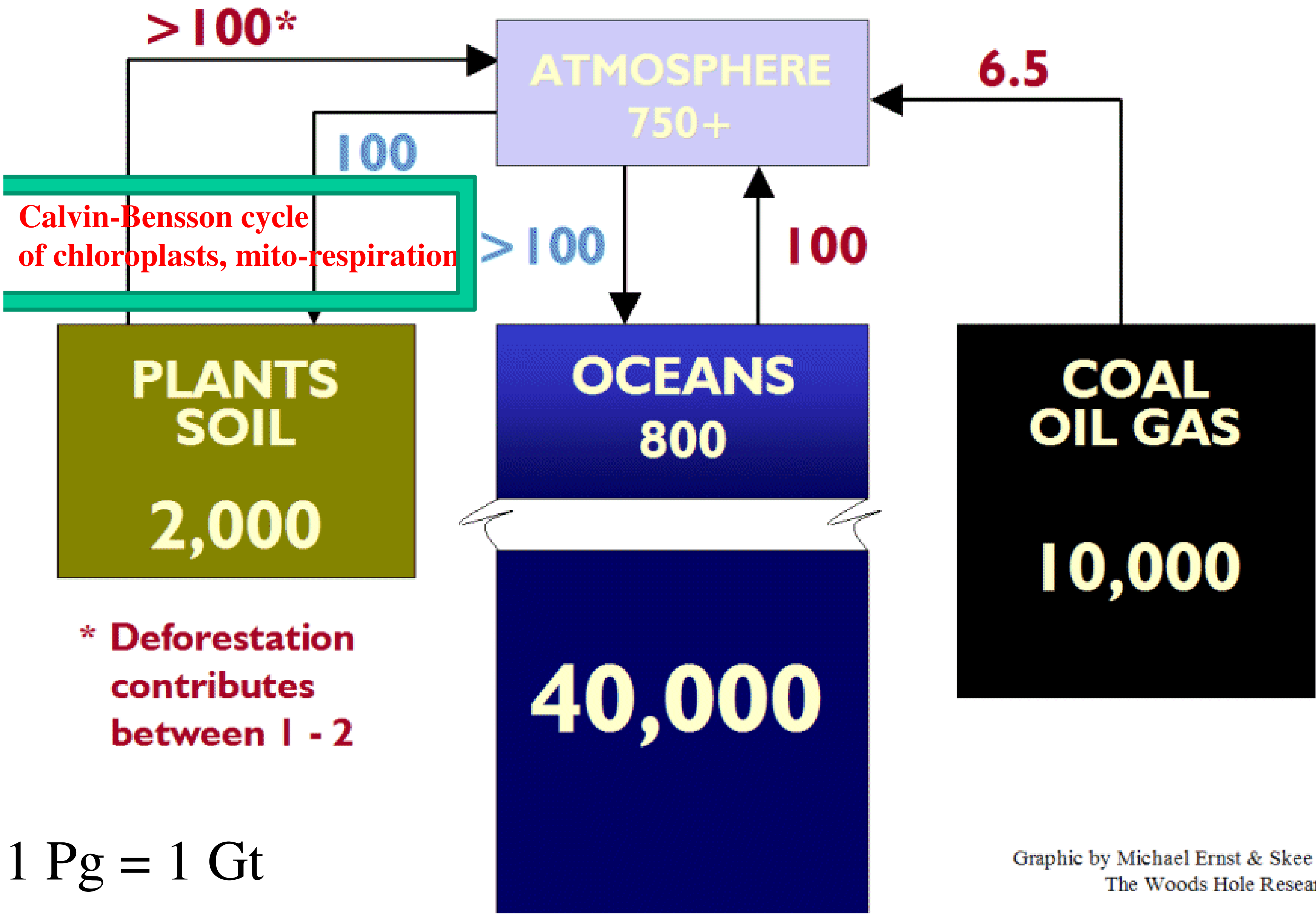
Mn_4 Ca

Global carbon cycle and fixed C (Gt)



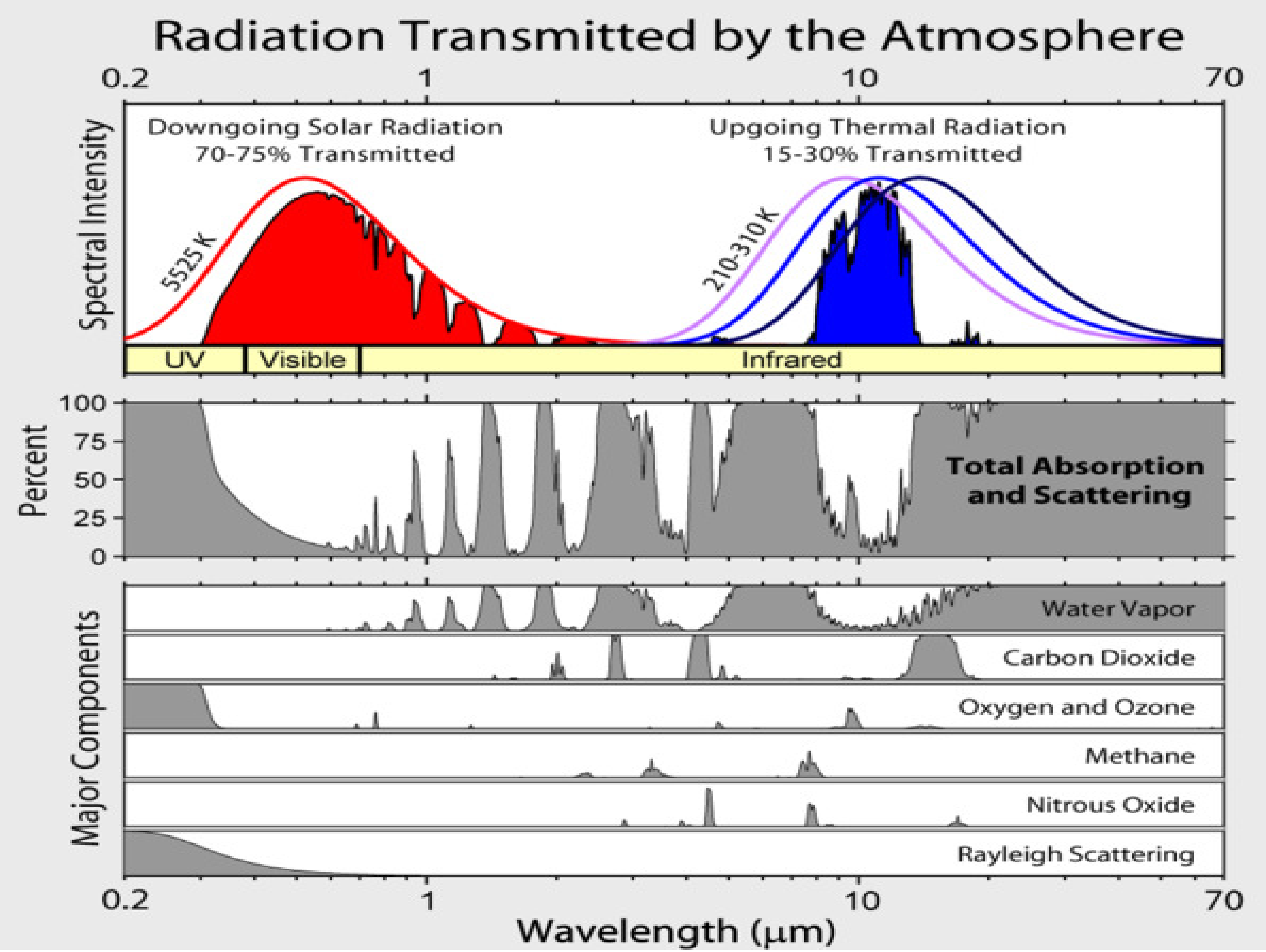
Global Flows of Carbon

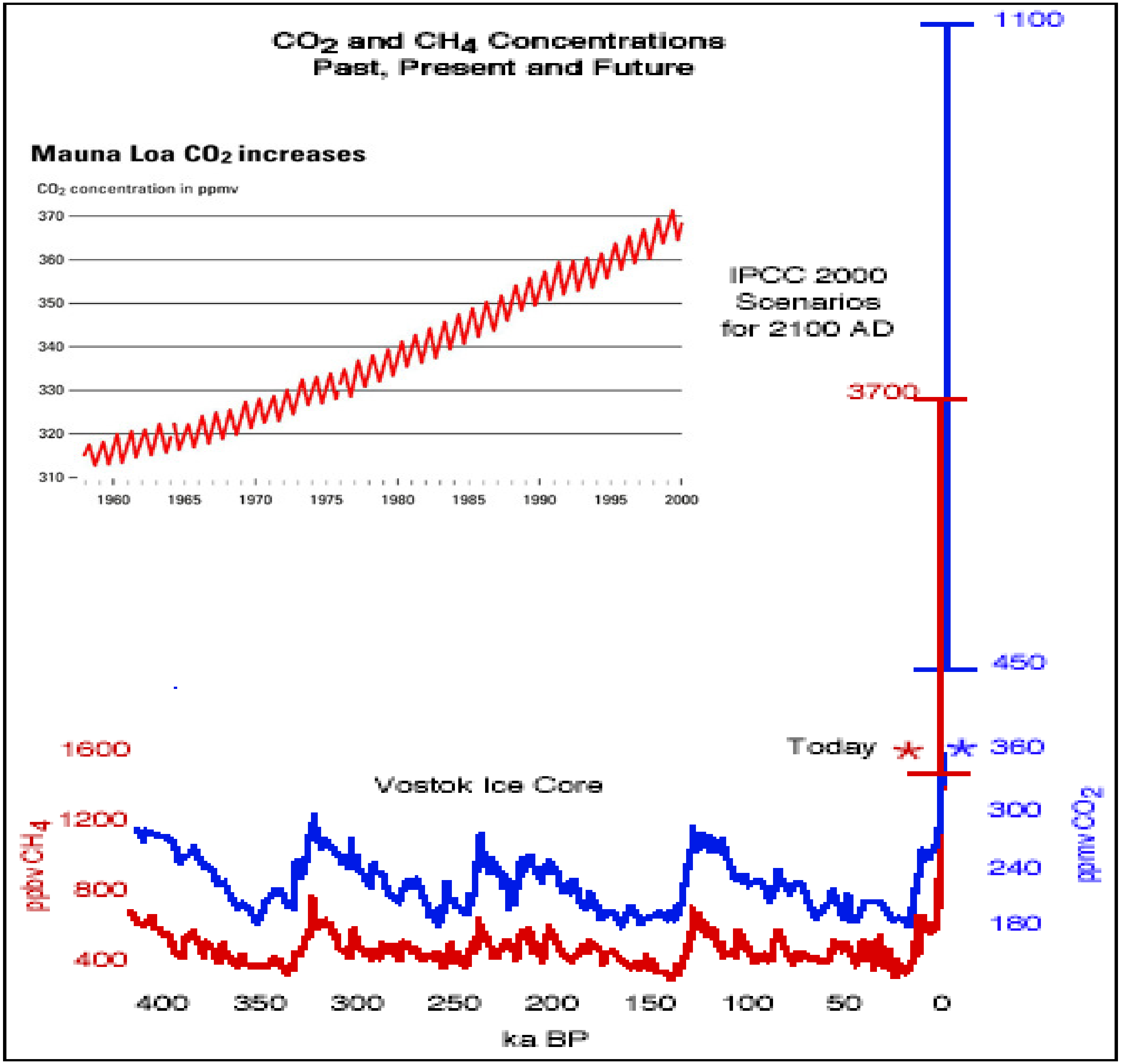
(Petagrams of Carbon/Year)



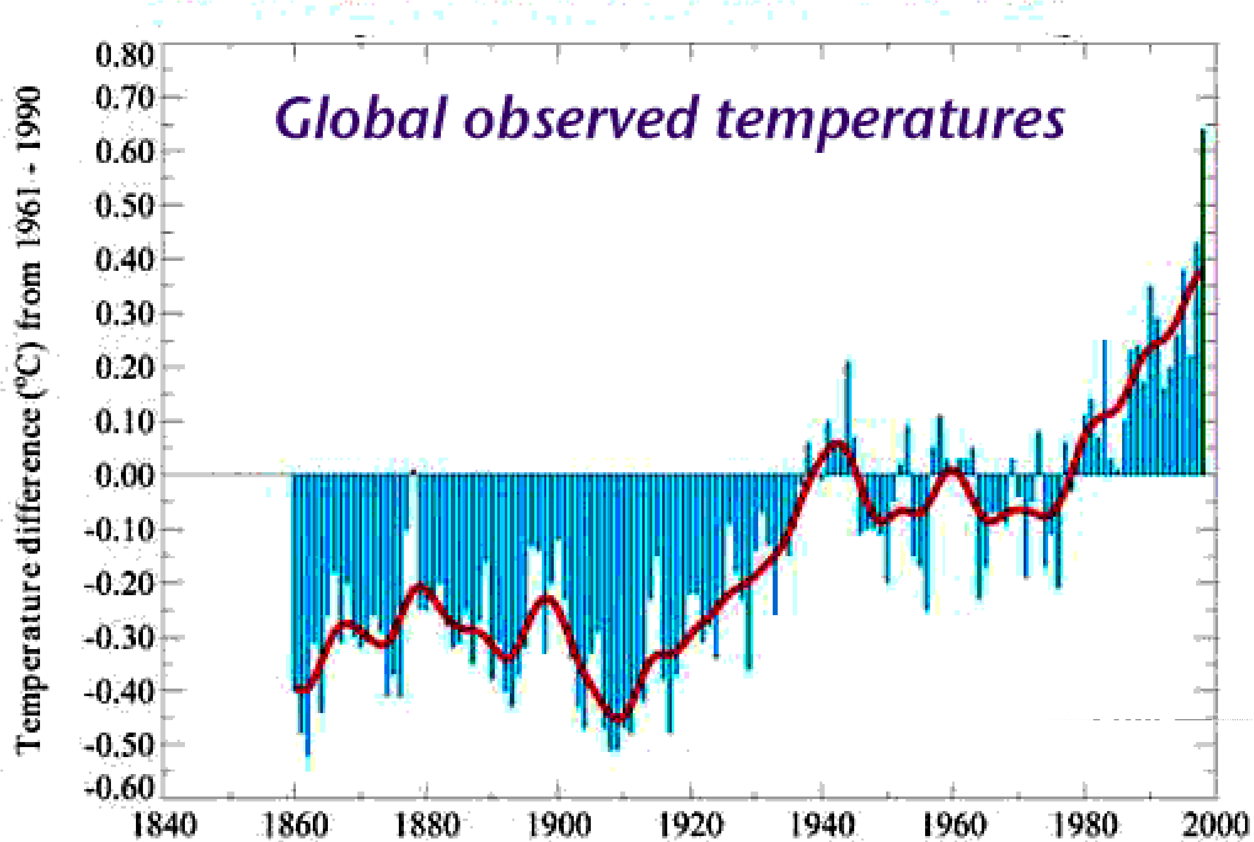
1 Pg = 1 Gt

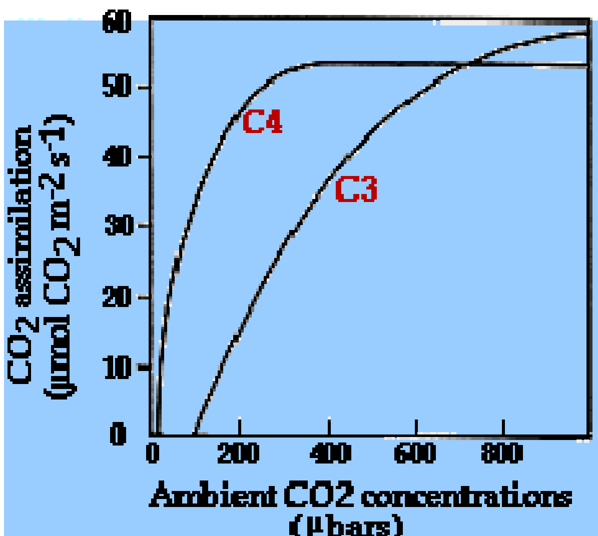
Graphic by Michael Ernst & Skee Houghton
The Woods Hole Research Center


Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption
and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)


CO2 and CH4 Concentrations
Past, Present and Future
Mauna Loa CO2 increases
CO2 concentration in ppmv
370
360
350
340
330
320
310
1960
1965
1970
1975
1980
1985
1990
1995
2000
IPCC 2000
Scenarios
for 2100 AD
1100
3700
450
Today
360
1600
Vostok Ice Core
1200
800
400
ppbv CH4
300
240
180
ppmv CO2
400
350
300
250
200
150
100
50
0
ka BP

WDCP/IPCC





For photosynthesis, the present levels of CO2 and T are suboptimal -chance for some -compensation

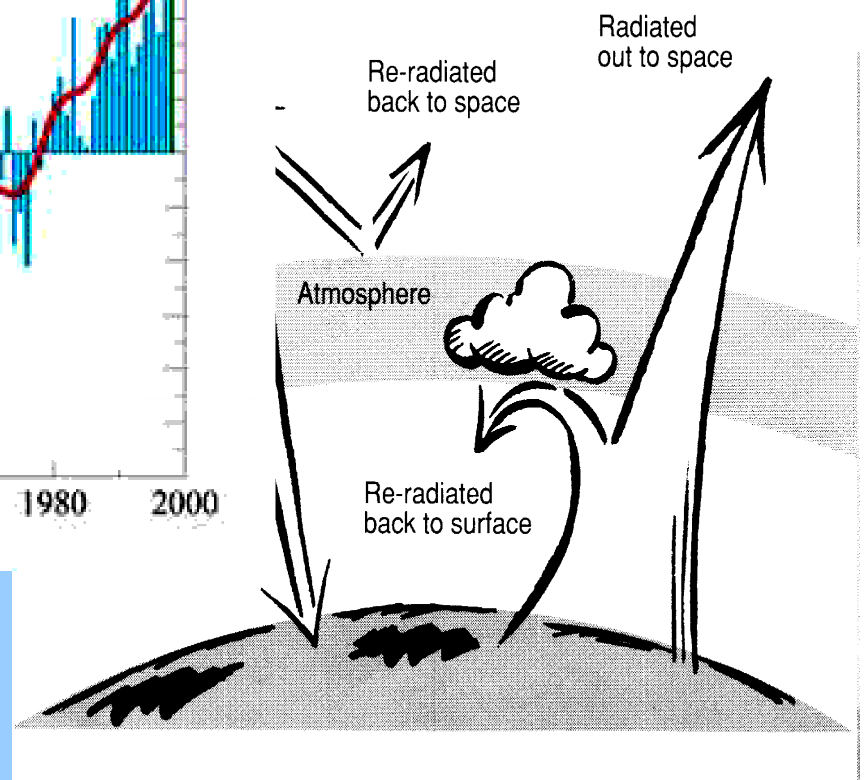


Fig. 7.3 The greenhouse effect. Simplified version of Figure 7.2. Some incoming solar radiation is reflected back into space by clouds, some is absorbed by the atmosphere, and some (mostly visible light) reaches the Earth's surface. In turn, the Earth radiates heat as infra-red. Some of this is again absorbed by the atmosphere which then radiates part of it back to Earth and part of it back into space. This raises the current global mean surface temperature from about -18°C (the estimated steady-state temperature at which heat input and heat lost would come into balance in the absence of an atmosphere) to 15°C.

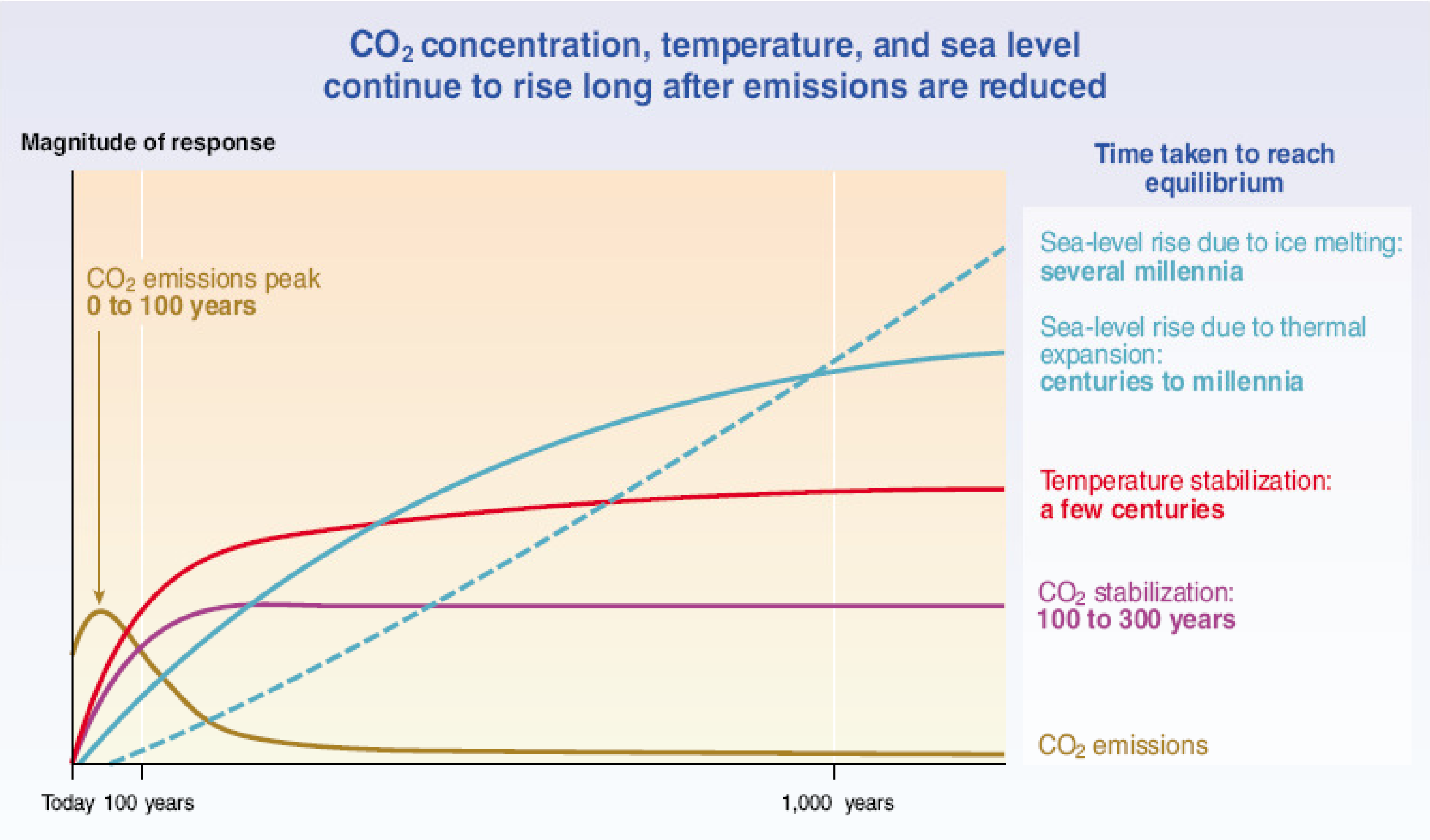


Figure SPM-5: After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more. Thermal expansion of the ocean continues long after CO_2 emissions have been reduced, and melting of ice sheets continues to contribute to sea-level rise for many centuries. This figure is a generic illustration for stabilization at any level between 450 and 1,000 ppm, and therefore has no units on the response axis. Responses to stabilization trajectories in this range show broadly similar time courses, but the impacts become progressively larger at higher concentrations of CO_2.

Q5 Figure 5-2

The annual oil – consumption of an average American family in 1970 (by now, it has increased by about 40%).

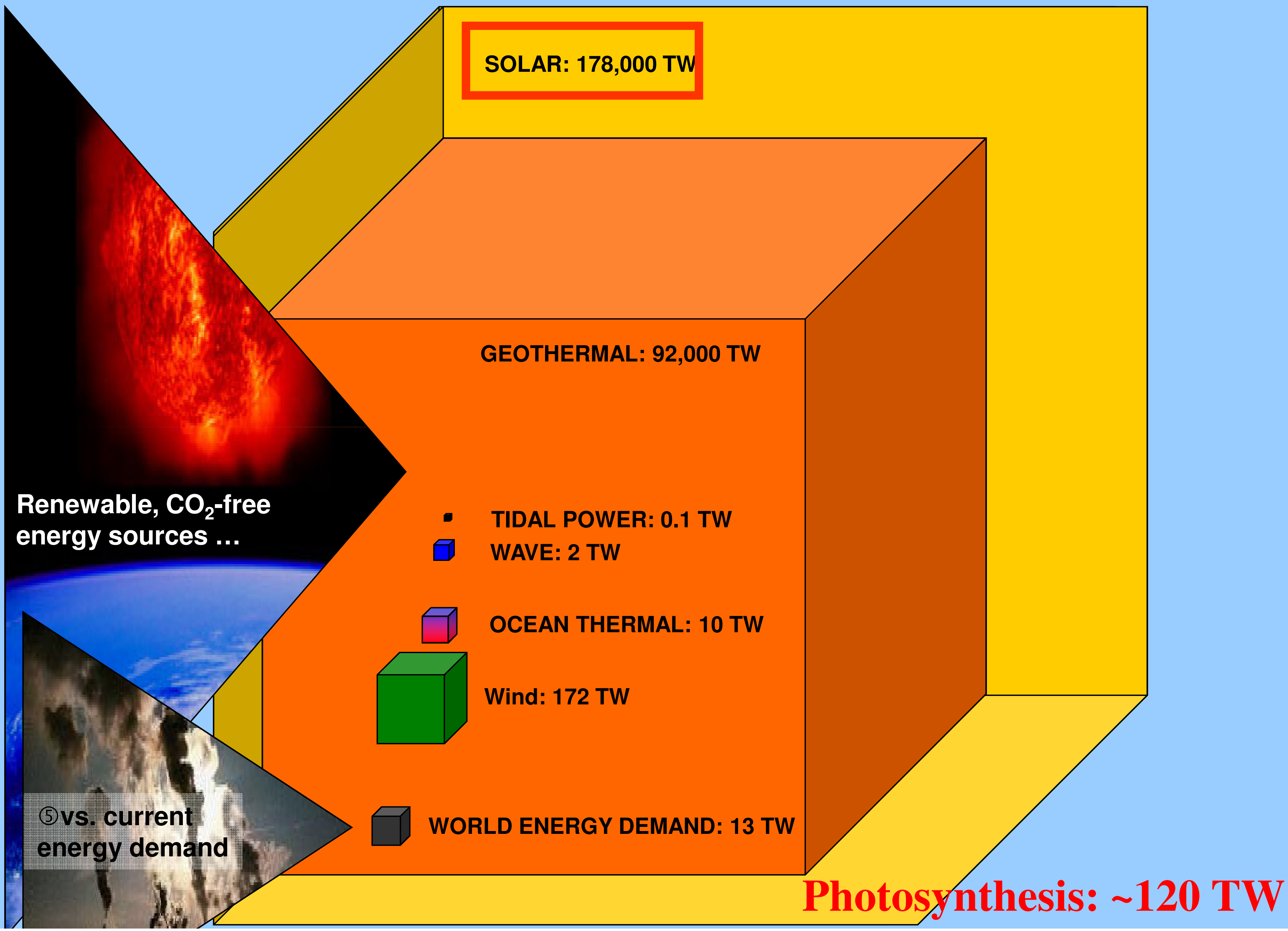
Man's footprint on the planet today.

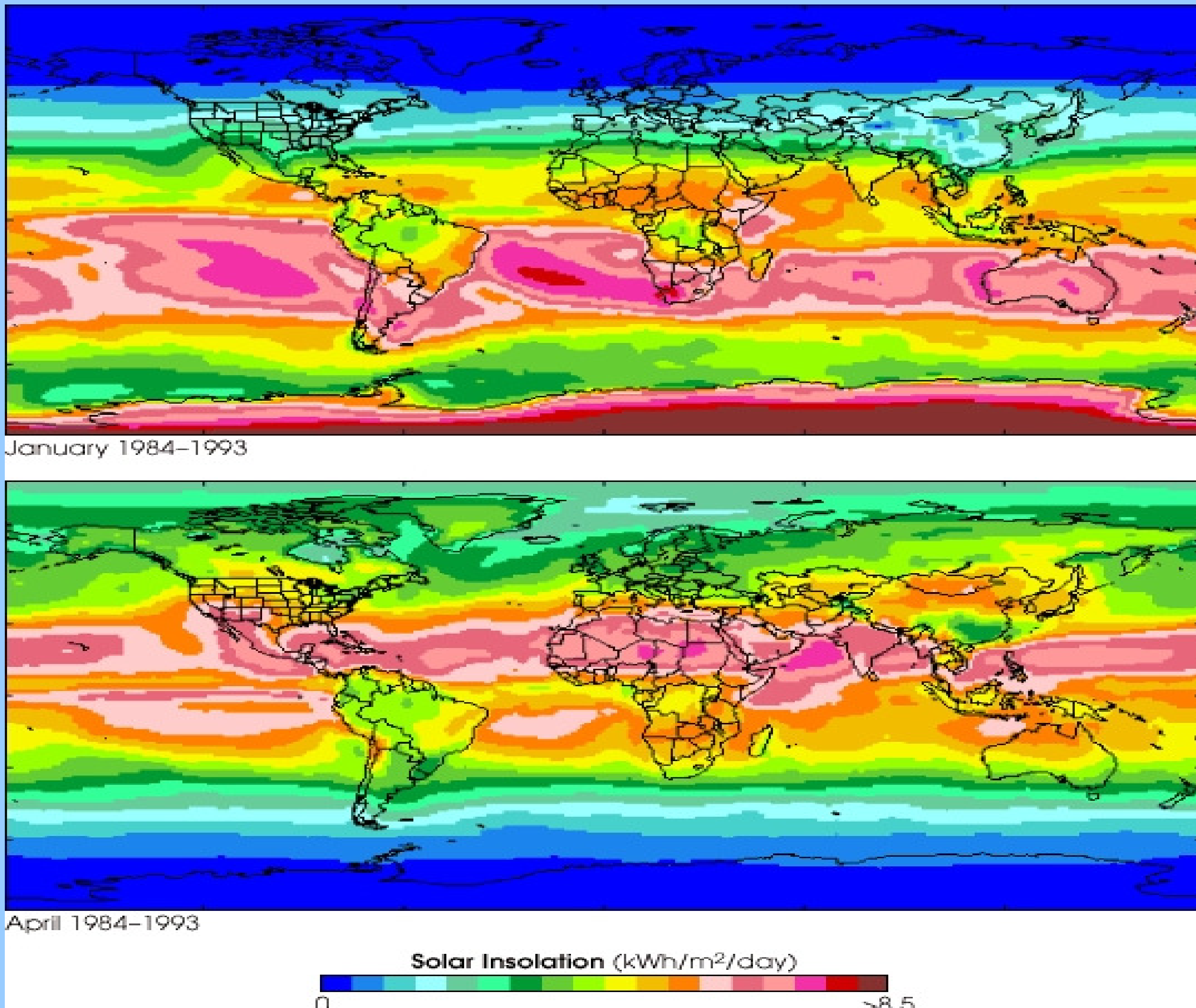
Why photosynthesis?

(ii) energy conversion:

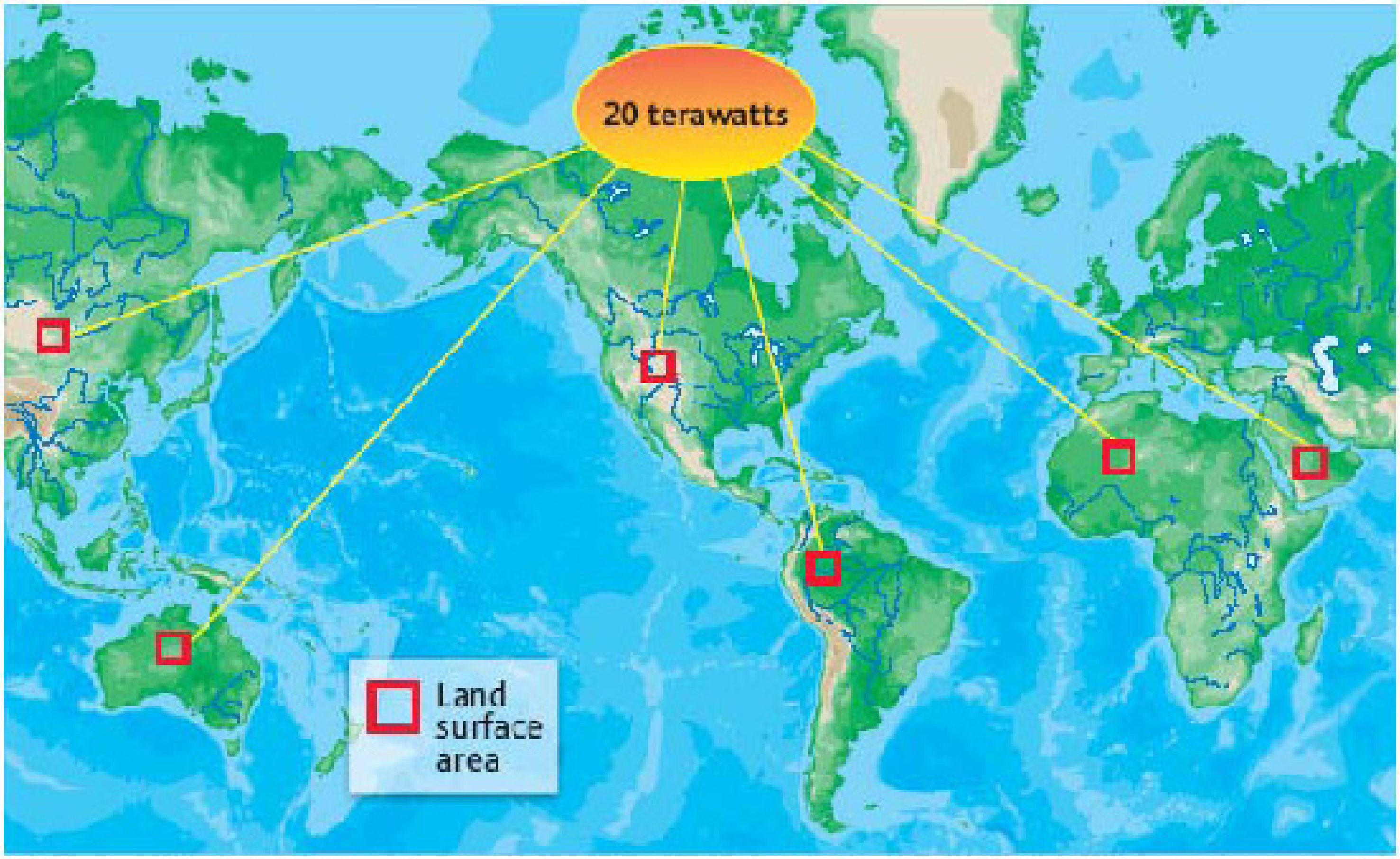
The energetic basis of (virtually) all life on Earth, also source of fossil fuels

Alternatives



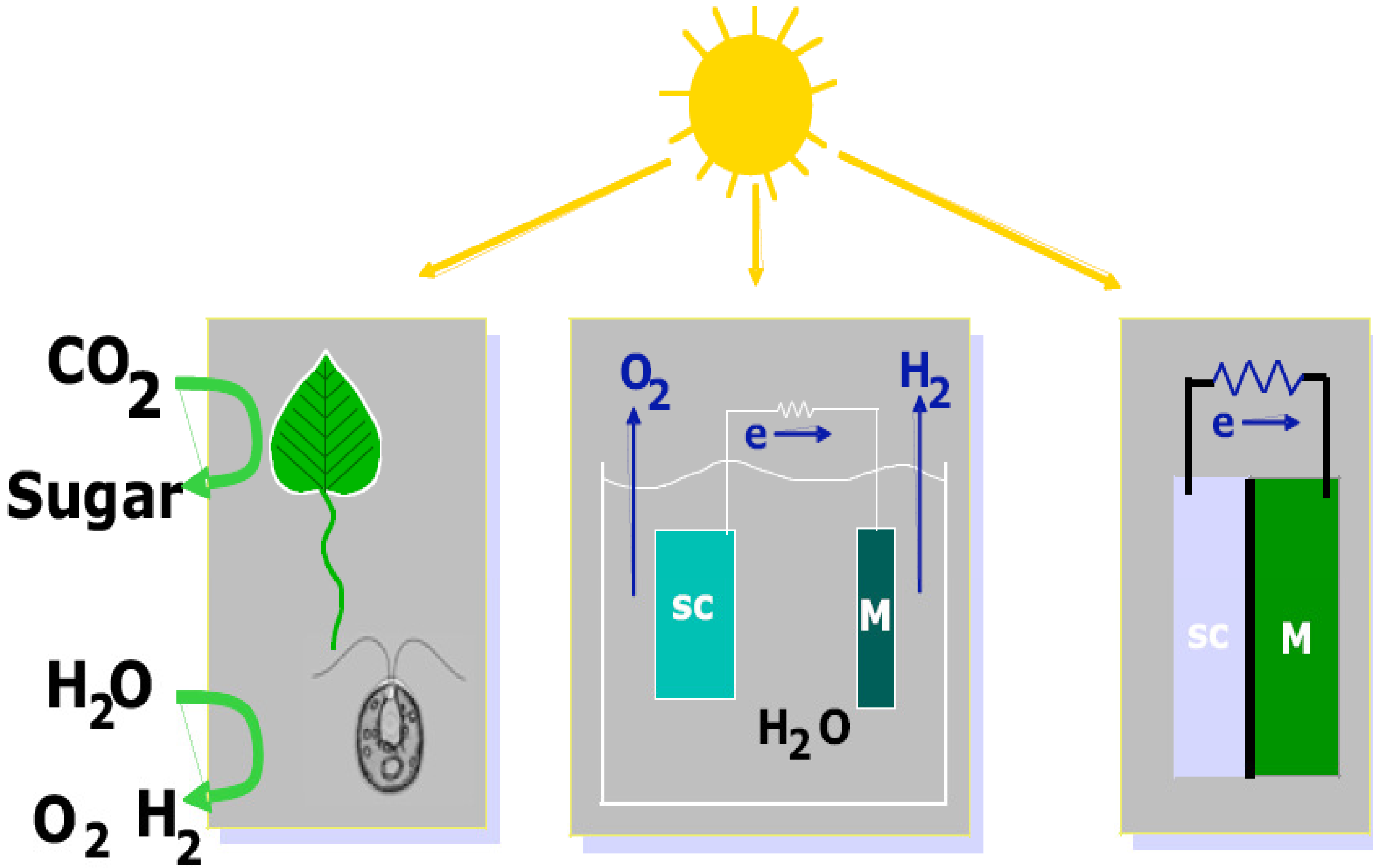

January 1984–1993
April 1984–1993
Solar Insolation (kWh/m2/day)
0
>8.5

To get 20 TW, 0.16 % of land covered with PV panels with 10% efficiency (Current 13 TW, 150.000 Km²)



Global need. This map shows the amount of land needed to generate 20 TW with 10% efficient solar cells.

Science, 2005, **309**, 548



Photosynthesis
Biomass
Biofuels

Semiconductor/
liquid junctions
Hybrid systems

Photovoltaic
⇒ electricity
⇒ chemical

'Whie Book' - E

EBSA Biophysics Course on Solar Energy - Biological and Biomimetic Solutions
August 27 – 31, 2011
BRC, Szeged

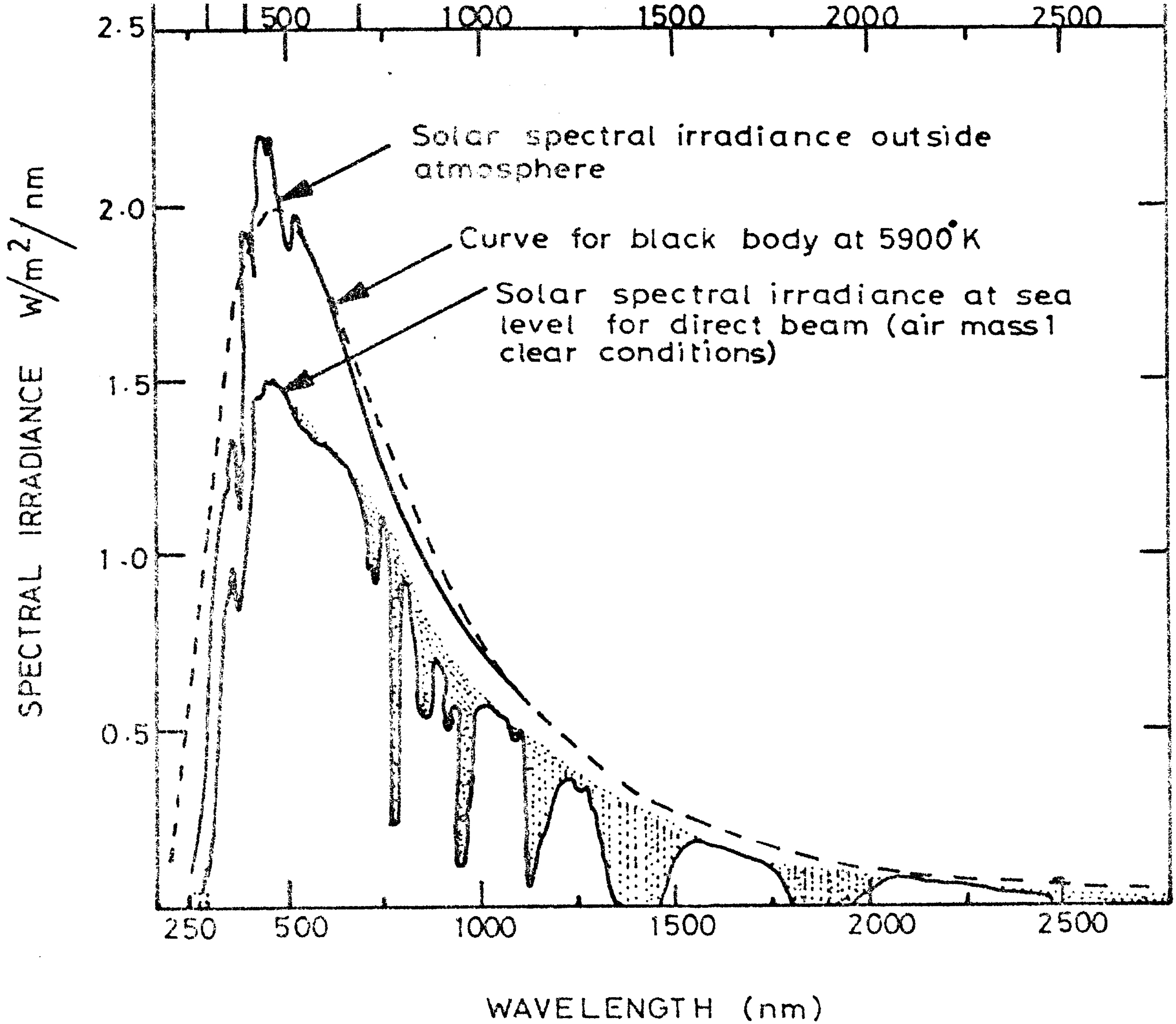
http://www.artificialphotosynthesis.eu/solarschool/

gyozo@brc.hu

What is photosynthesis?

Light energy converted into chemical energy

$$6H_20 + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$$



2.5
2.0
1.5
1.0
0.5
500
1000
1500
2000
2500
250
Solar spectral irradiance outside atmosphere
Curve for black body at 5900°K
Solar spectral irradiance at sea level for direct beam (air mass 1 clear conditions)
SPECTRAL IRRADIANCE W/m²/nm
WAVELENGTH (nm)

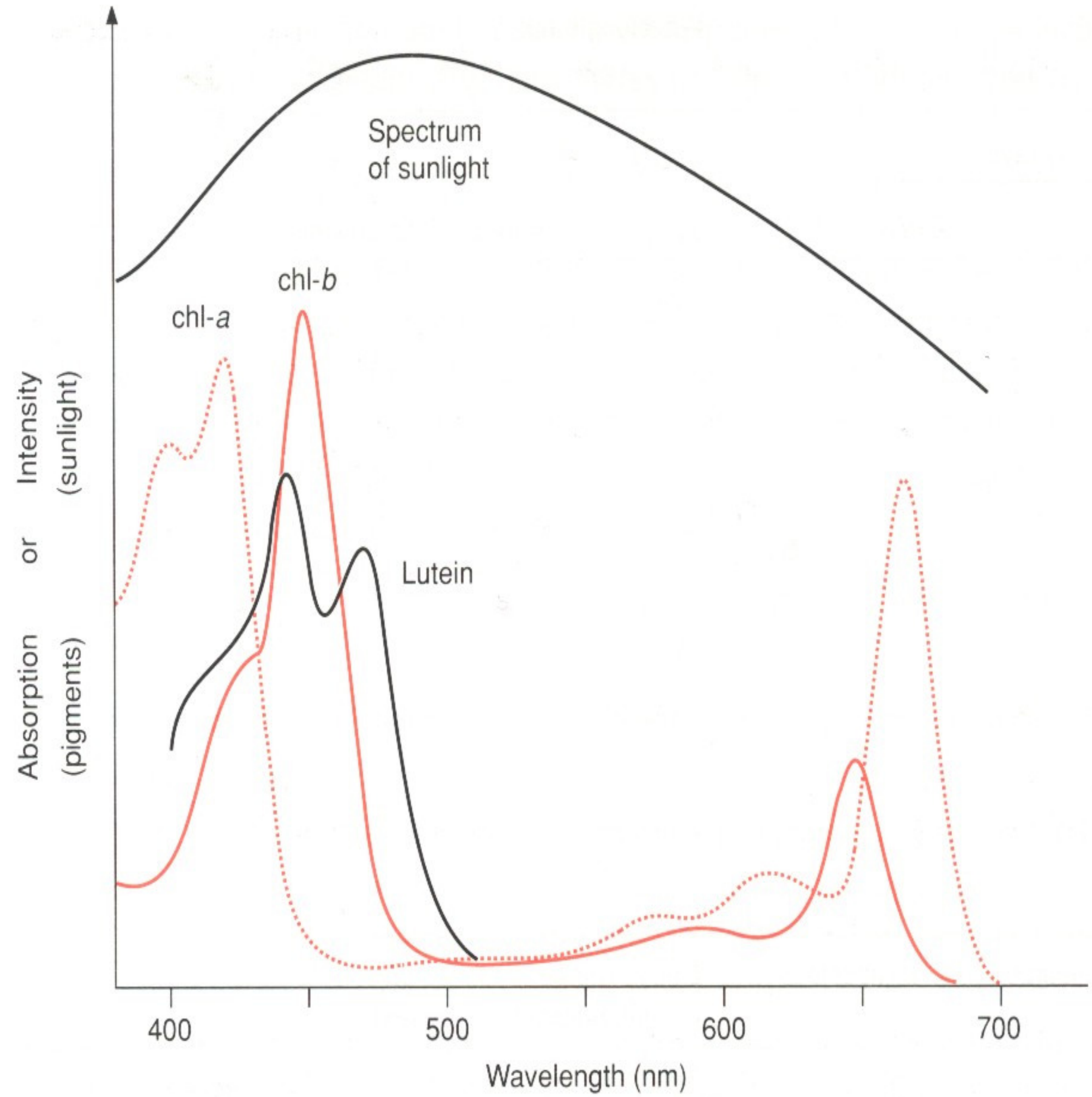
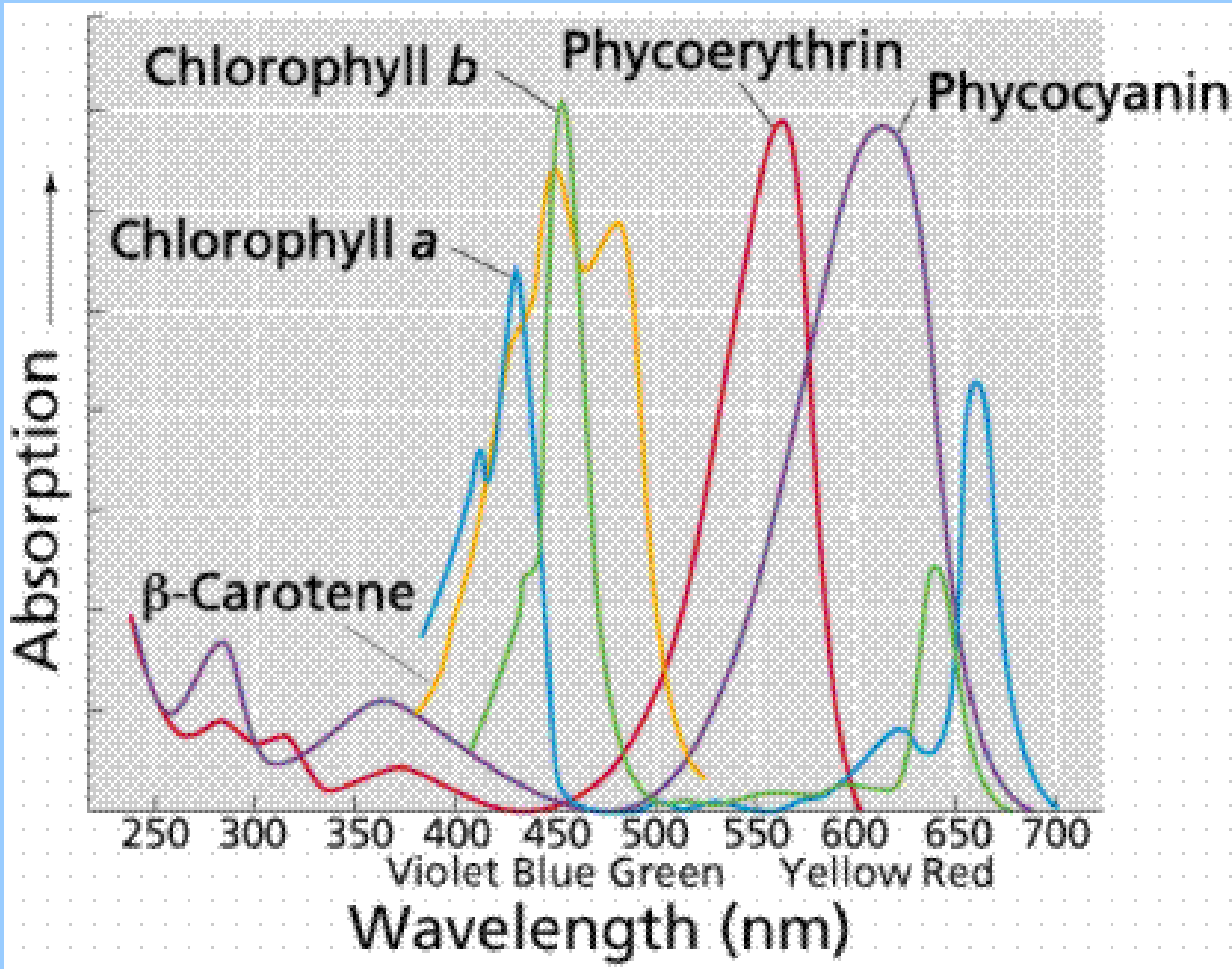


Figure 2.3 Absorption spectrum of chorophyll-*a* (chl-*a*) and chlorophyll-*b* (chl-*b*) and of the xanthophyll lutein dissolved in acetone. The intensity of the sun's radiation at different wavelengths is given as a comparison.


Chlorophyll b
Phycoerythrin
Phycocyanin
Chlorophyll a
β-Carotene
Absorption
250 300 350 400 450 500 550 600 650 700
Violet Blue Green Yellow Red
Wavelength (nm)

The fate of excitation in molecular assemblies

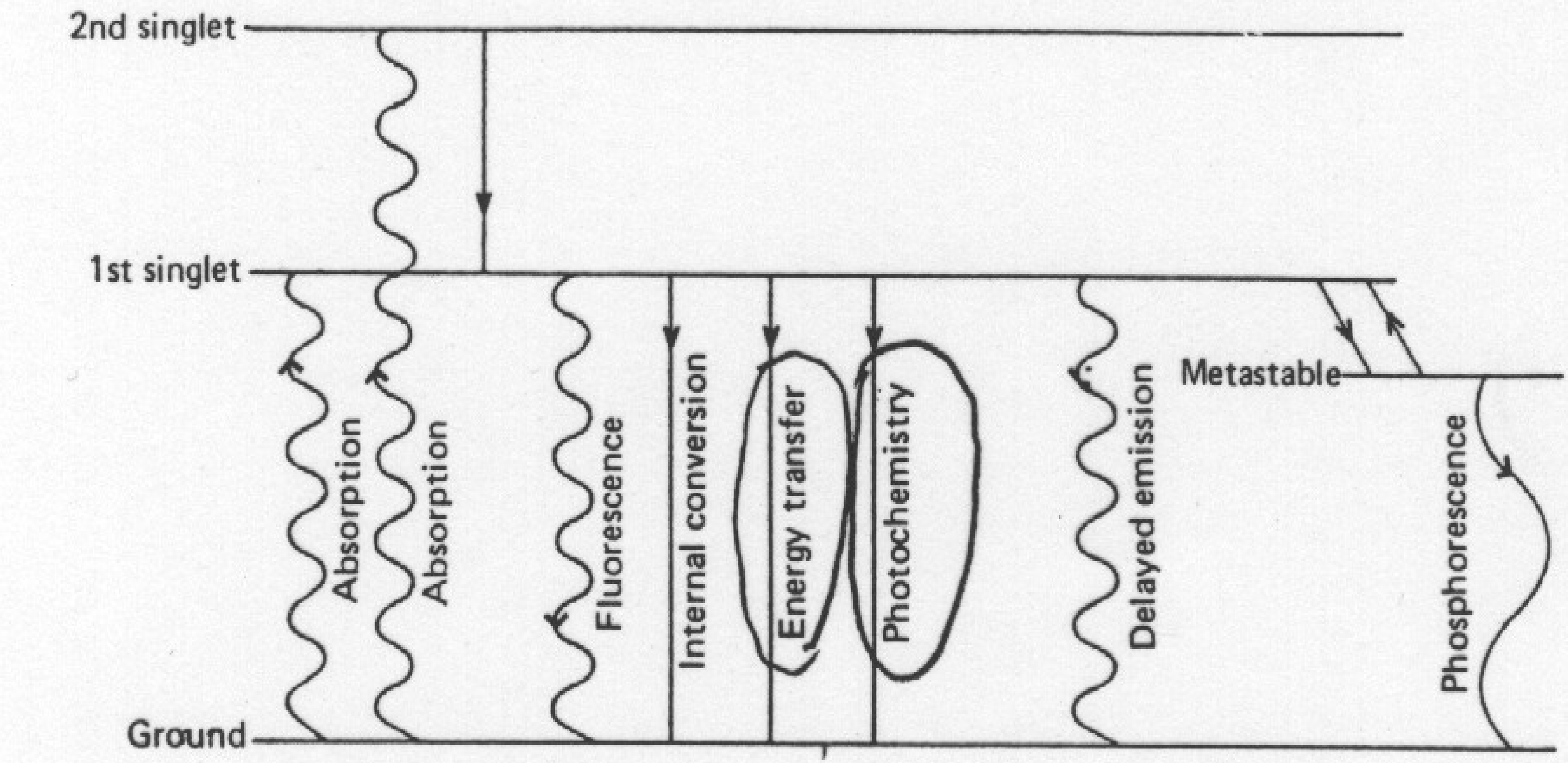


Fig. 3.22. Diagram showing the different modes of deexcitation.

Energy transfer: D* + A → D + A*
(usually) depends on the distance (R^{-6}) and the mutual orientation of the pigment dipoles (ordered arrays!)

Funnel concept of the 'energy flow' in the light harvesting antenna and the reaction center

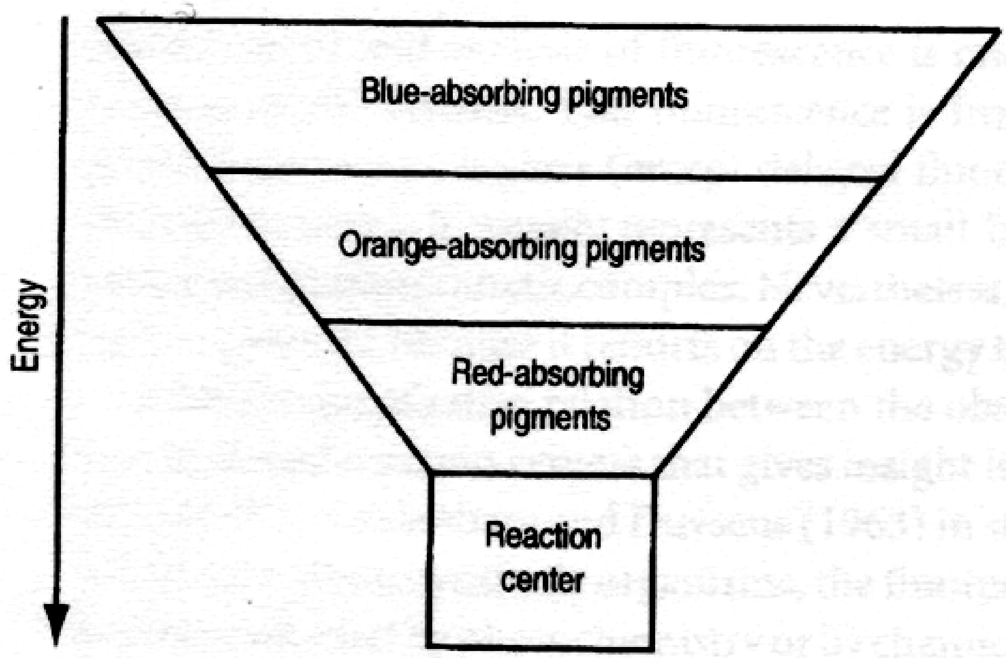


Figure 5.3 The funnel concept in photosynthetic antennas. Sequential excitation transfers from higher-energy pigments (blue-absorbing) to lower-energy pigments (red-absorbing) deliver excitations to the proximity of the reaction center.

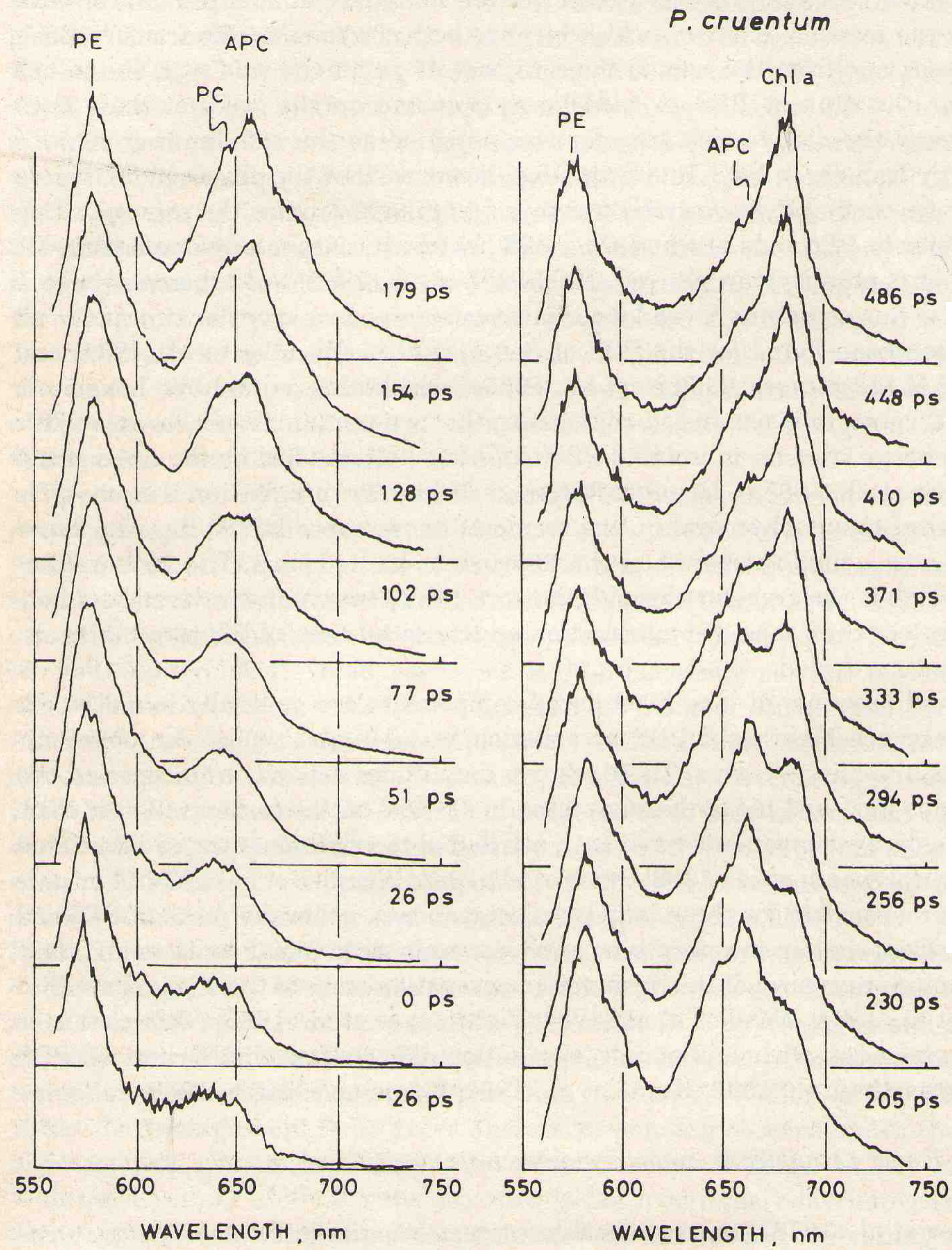
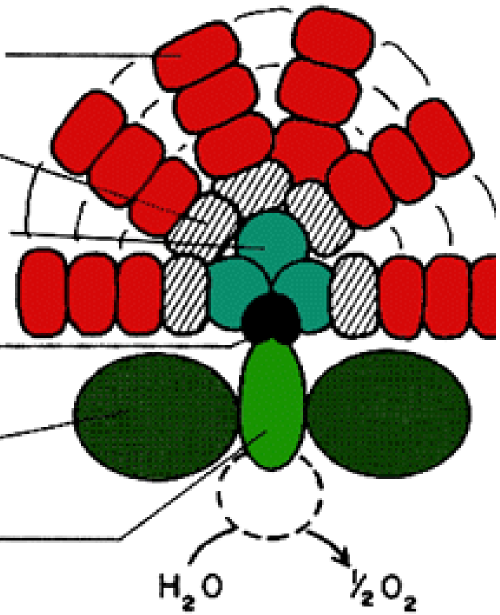


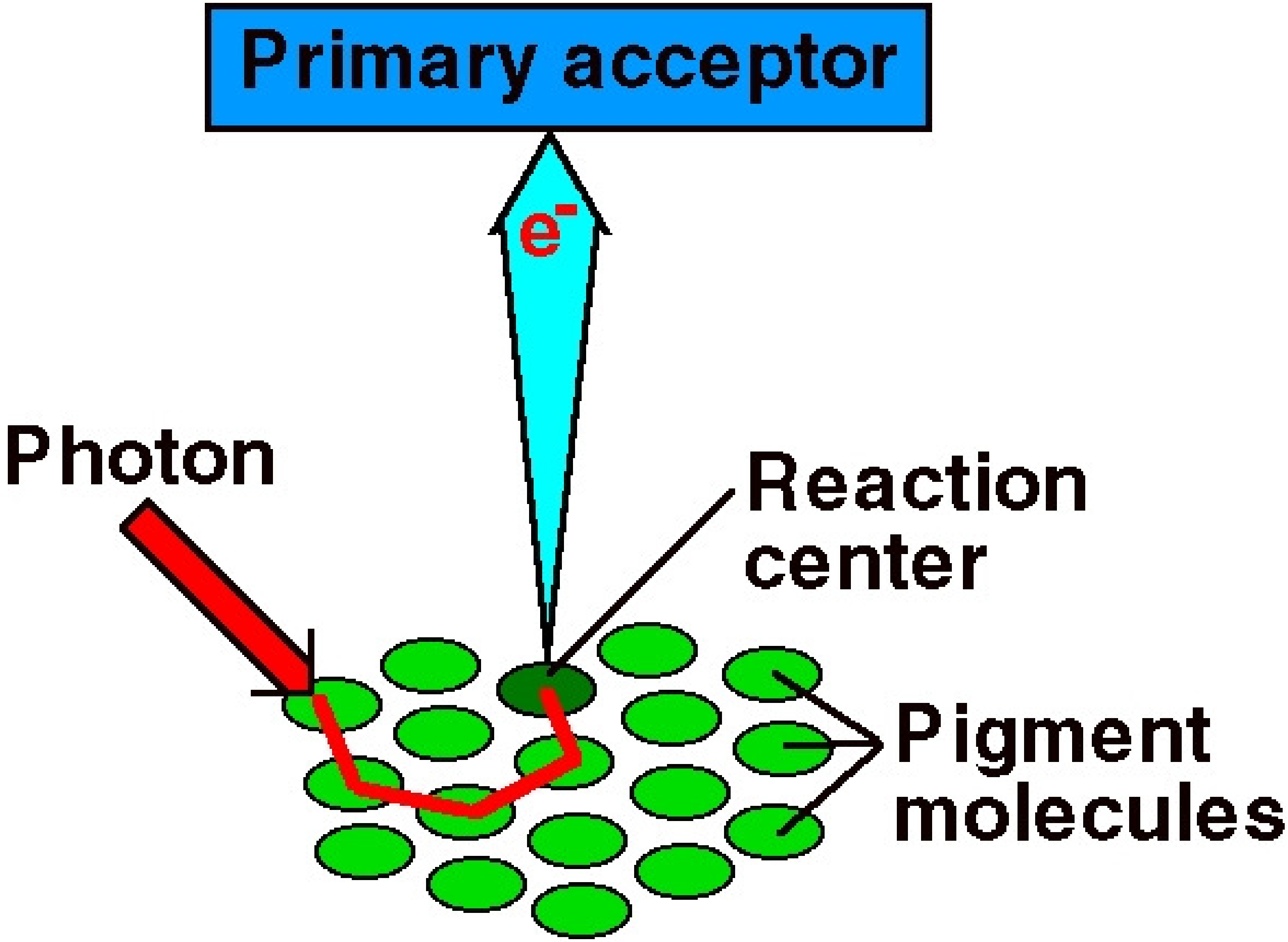
Fig. 3.7. Fluorescence spectra of *Porphyridum cruentum* taken at different delay times after the exciting light pulse. B-phycoerythrin was selectively excited at 540 nm (taken from Yamazaki et al., 1984).



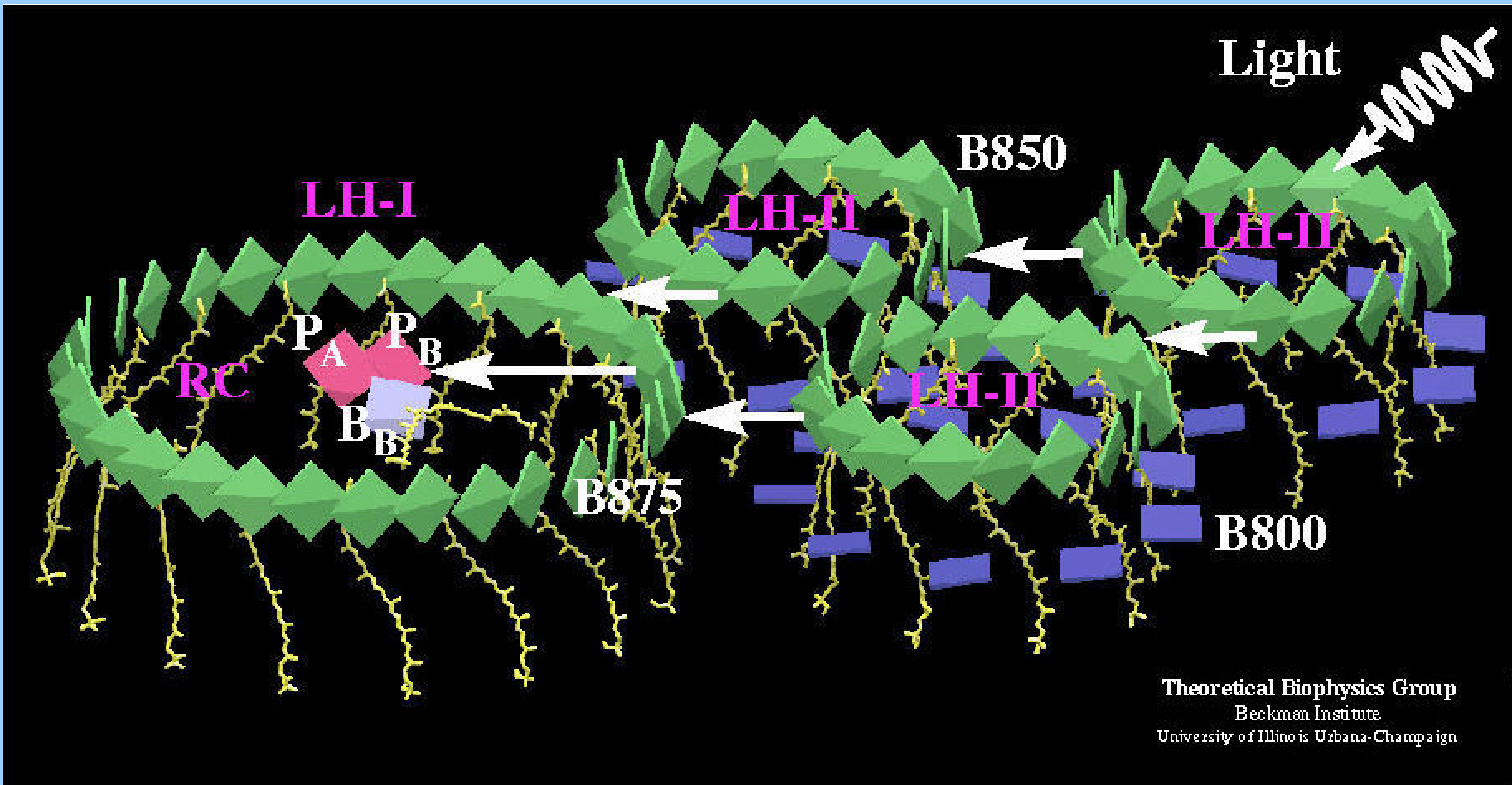
Phycobilisome

Vectorial energy-migration

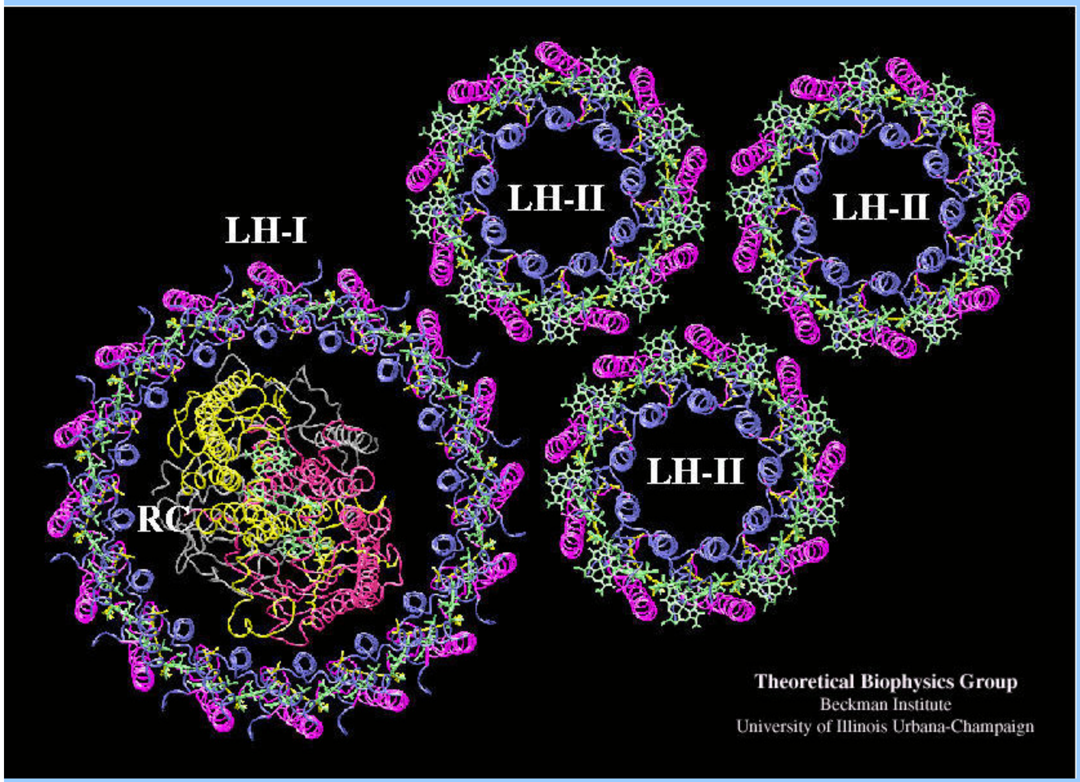
Scheme of the light harvesting antenna and the photochemical reaction center



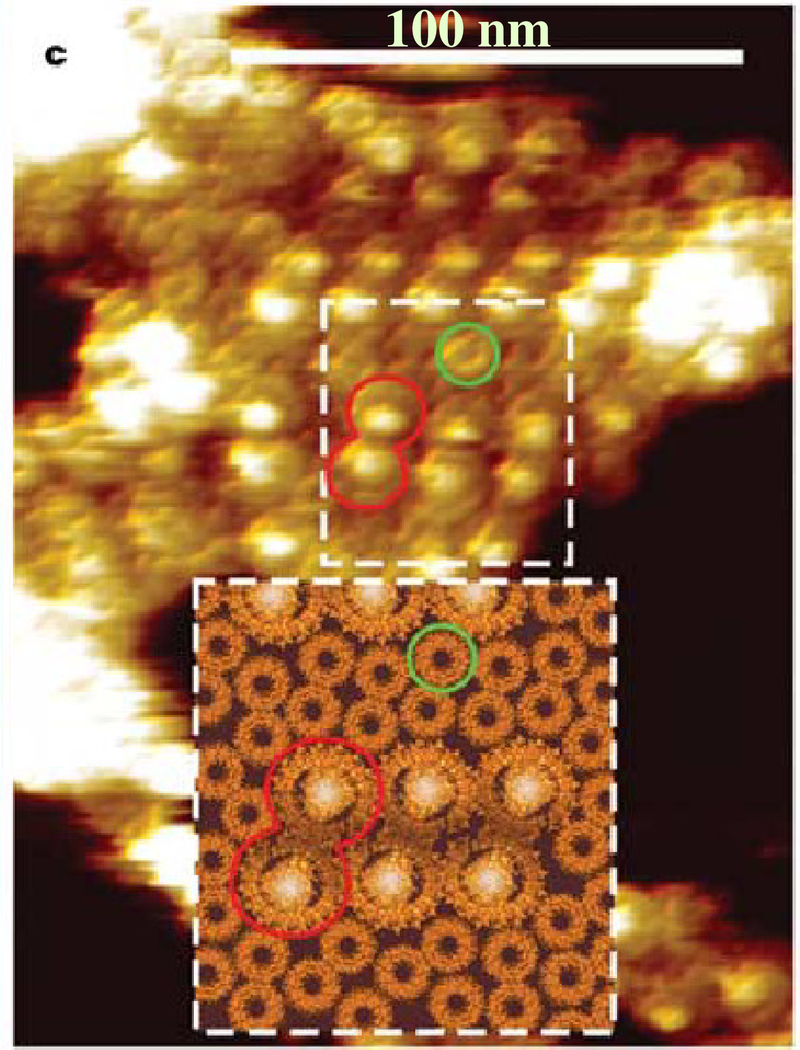
olecular order in the antenna


Light
B850
LH-I
LH-II
LH-II
P
A
P
B
RC
B
B
LH-II
B875
B800
Theoretical Biophysics Group
Beckman Institute
University of Illinois Urbana-Champaign

Light harvesting complexes and reaction center in purple bacterial membranes



Model
Cogdell's structure

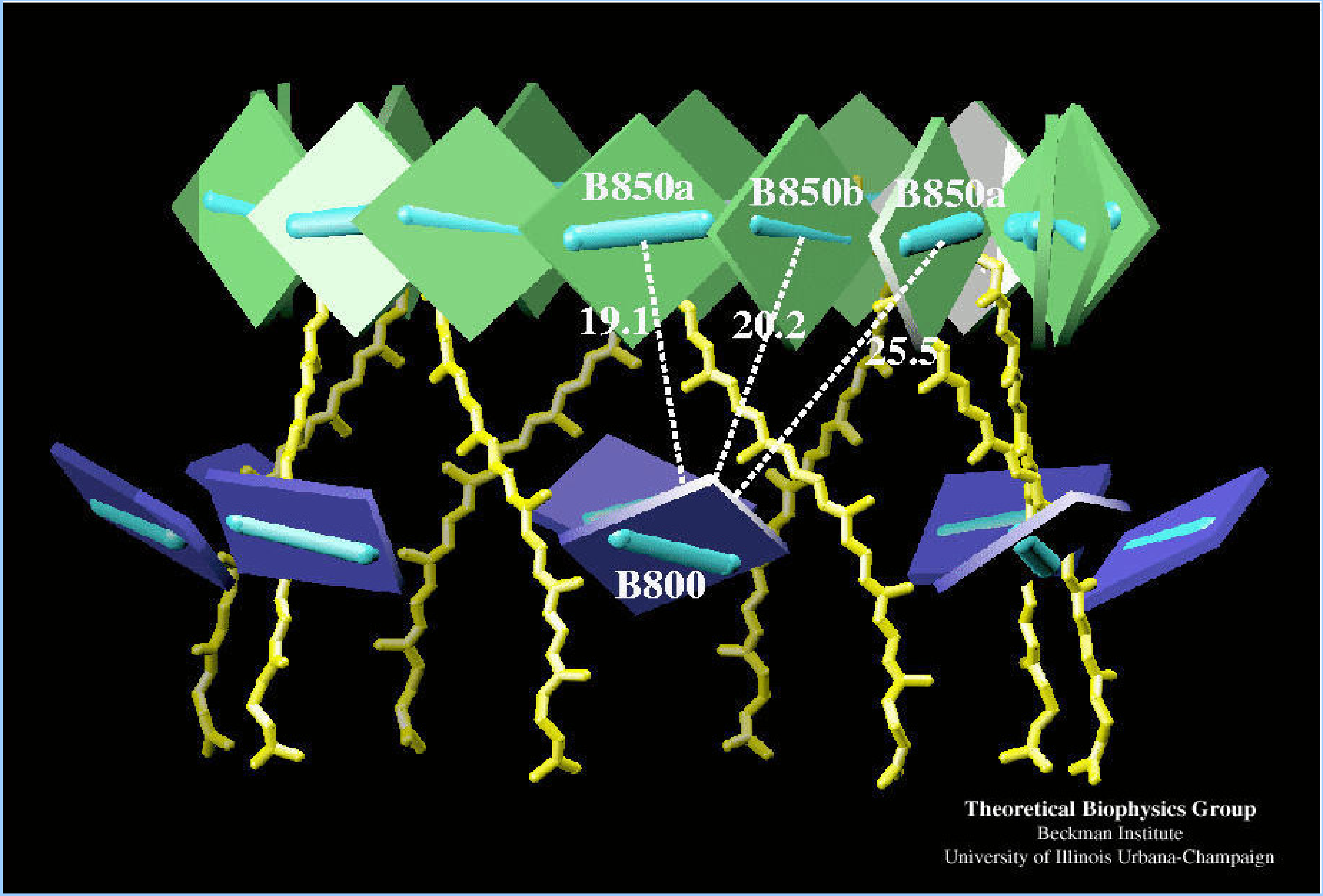


AFM image of the native membrane

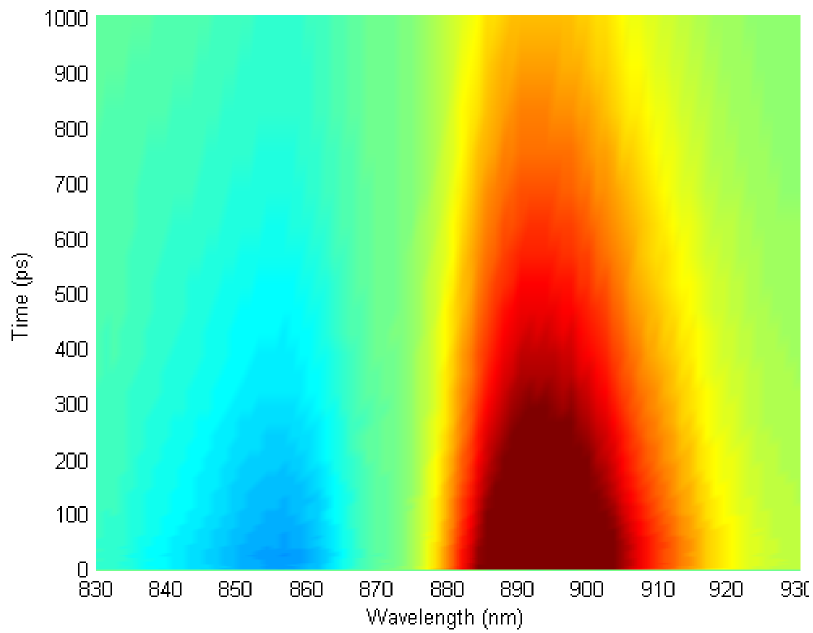
Hunter and coworkers, Nature, 2004

Ordered array of transition dipoles in LH2

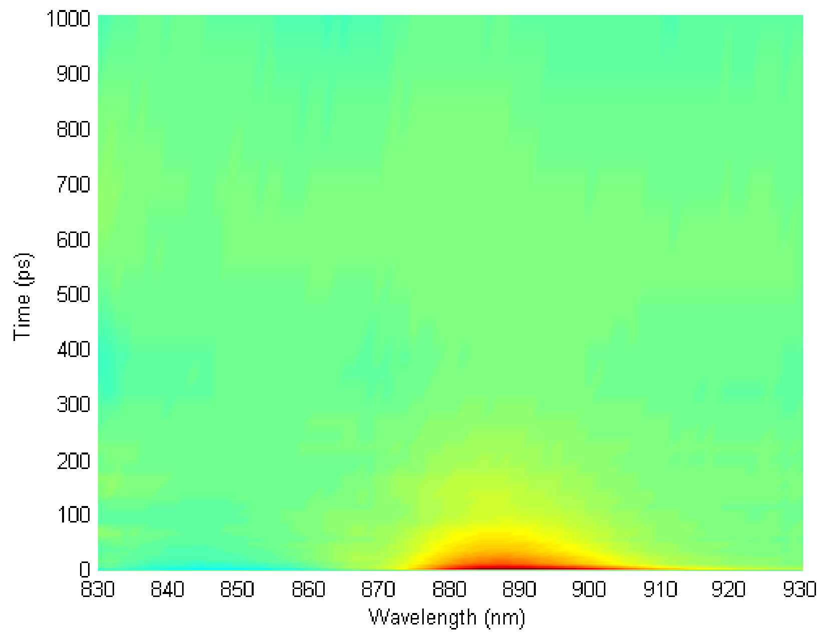
emerging quantum mechanical descriptions



Energy migration / heat dissipation dynamics in reconstituted bacterial LH1 antenna



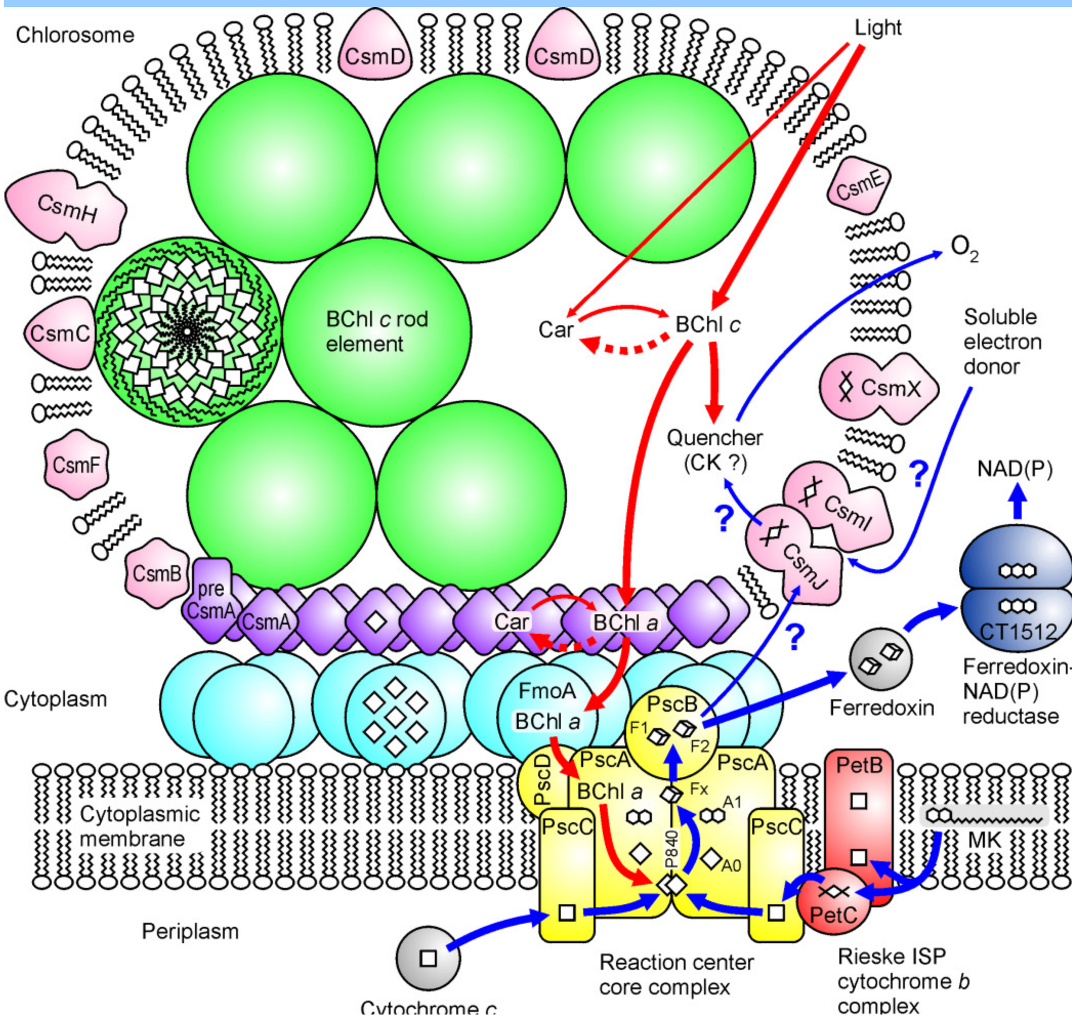
Control LH1

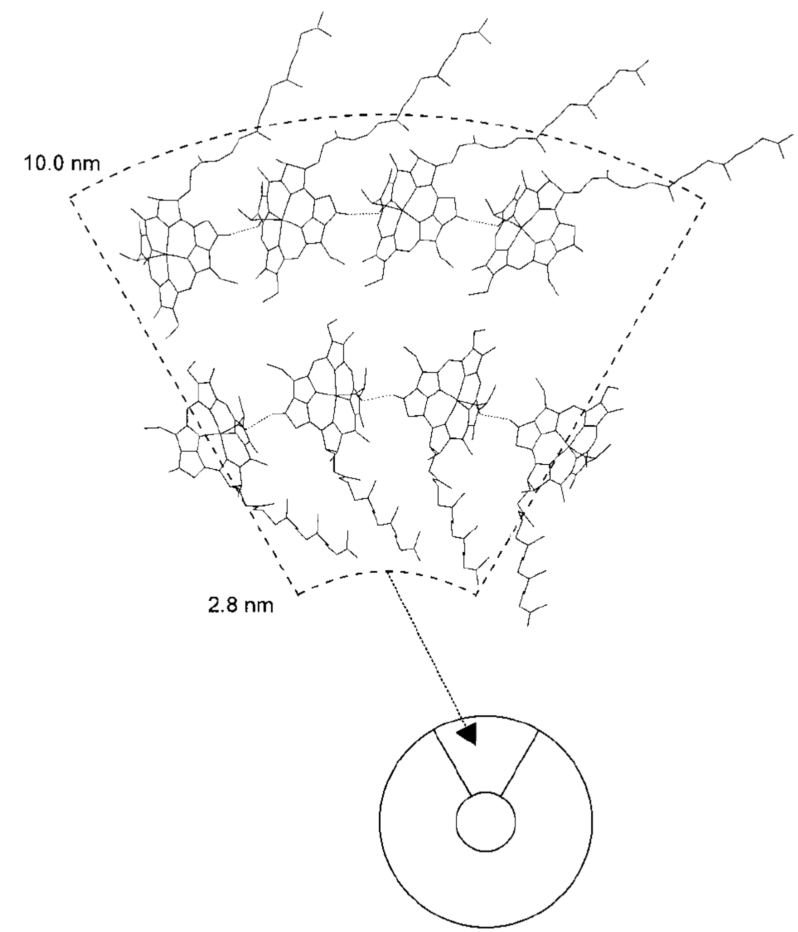


LH1 with Ni-Bchl

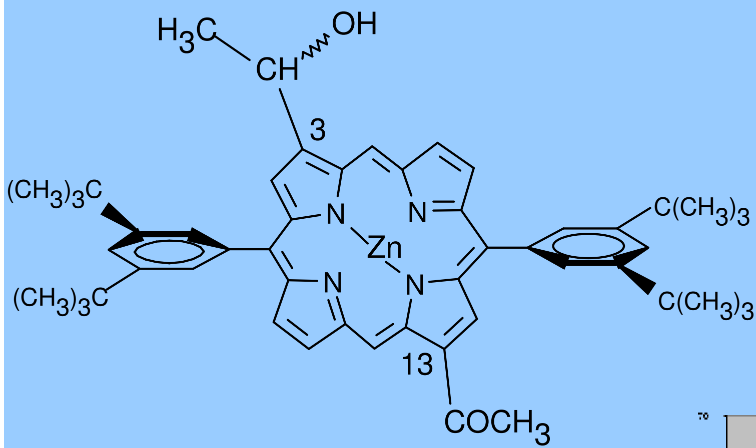
P. Lambrev, Y. Miloslavina, L. Fedor, G. Garab, M-L. de Groot, R. van Grondelle - unpublished

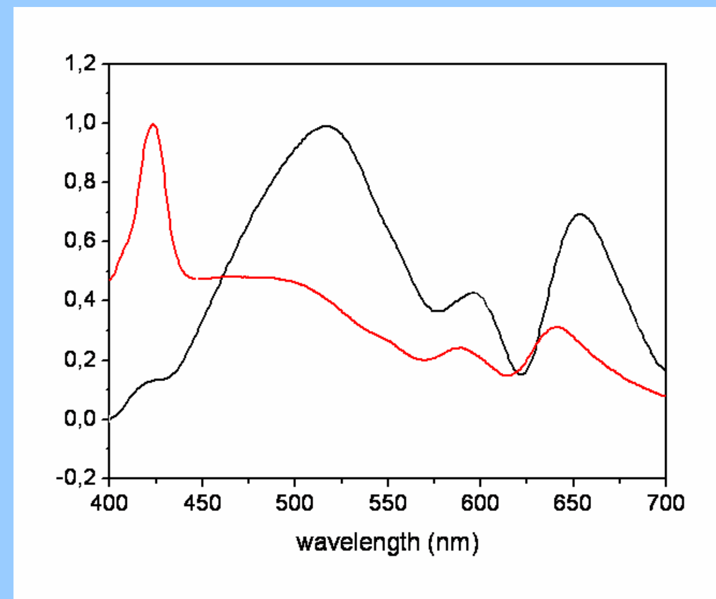
Chlorosome – ordered arrays of Bchls

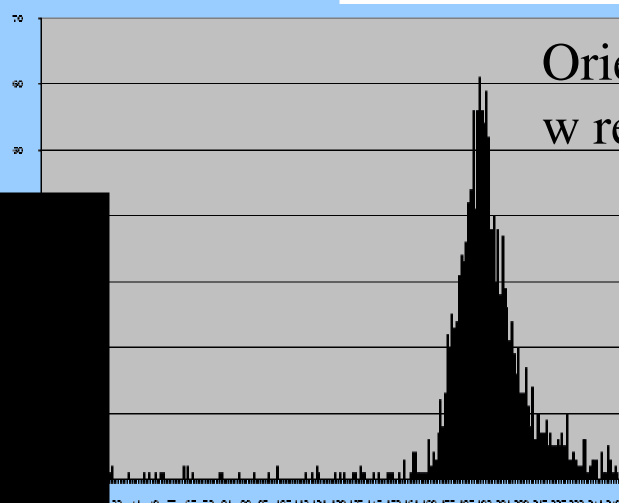


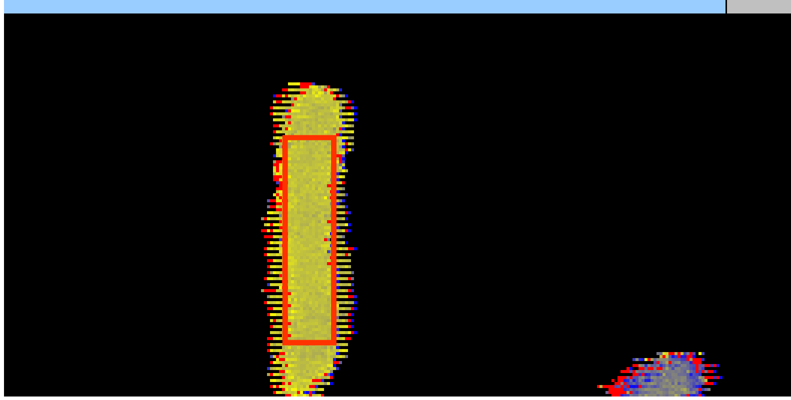


Anisotropy (FDLD) of ‘artificial chlorosomes’ (synthetic porphyrin nanorods)







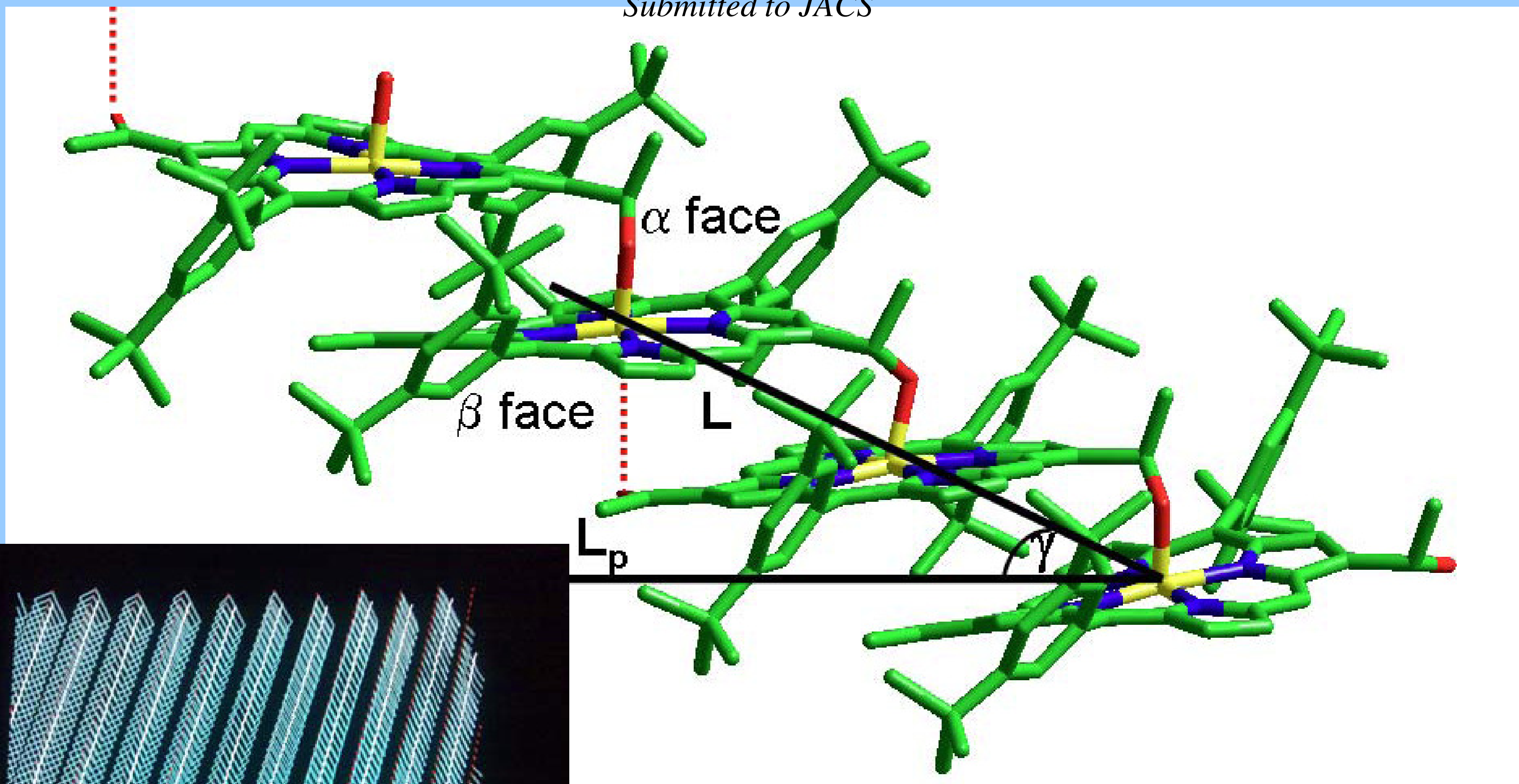


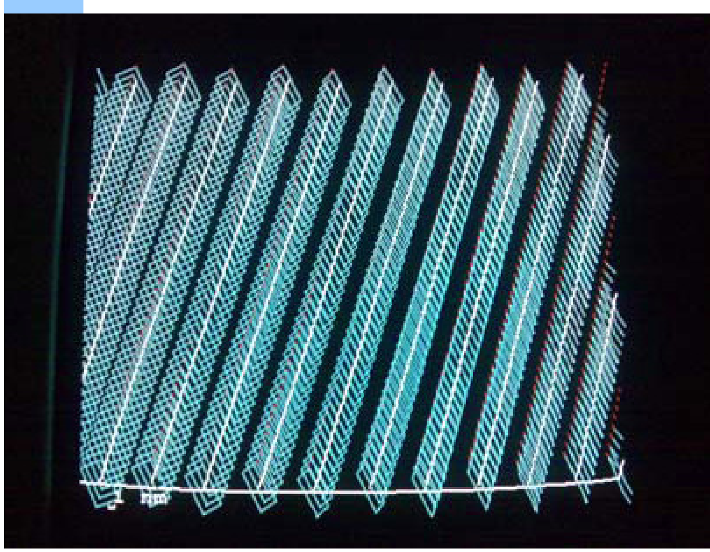
Orientation of transition dipoles w respect to the rod axis:

Qx 43°±8
Qy 37°±7
Bx 39°±4

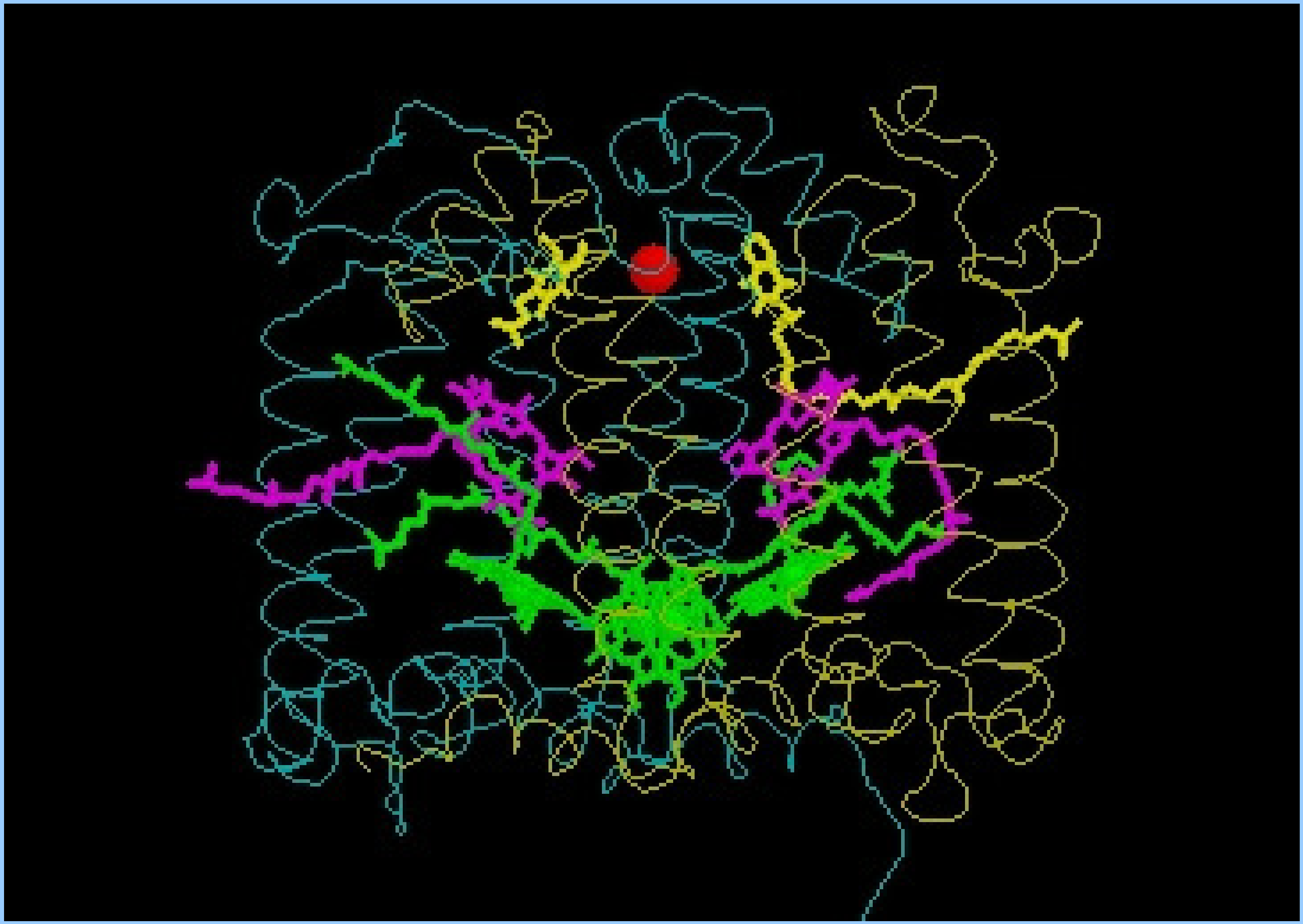
Model of rod

Gillot, Marek, Blaive, Canard, Bürck, Garab, Hahn, Jávorfi, Kelemen, Krupke, Mössinger, Ormos, Reddy, Roussel, Steinbach, Szabó, Ulrich, Vanthuyne, Vijayaraghavan, Zupcanova, Balaban:
Anisotropic organization and microscopic manipulation of self-assembling synthetic porphyrin micro-rods that mimic chlorosomes, bacterial light-harvesting organelles
Submitted to JACS



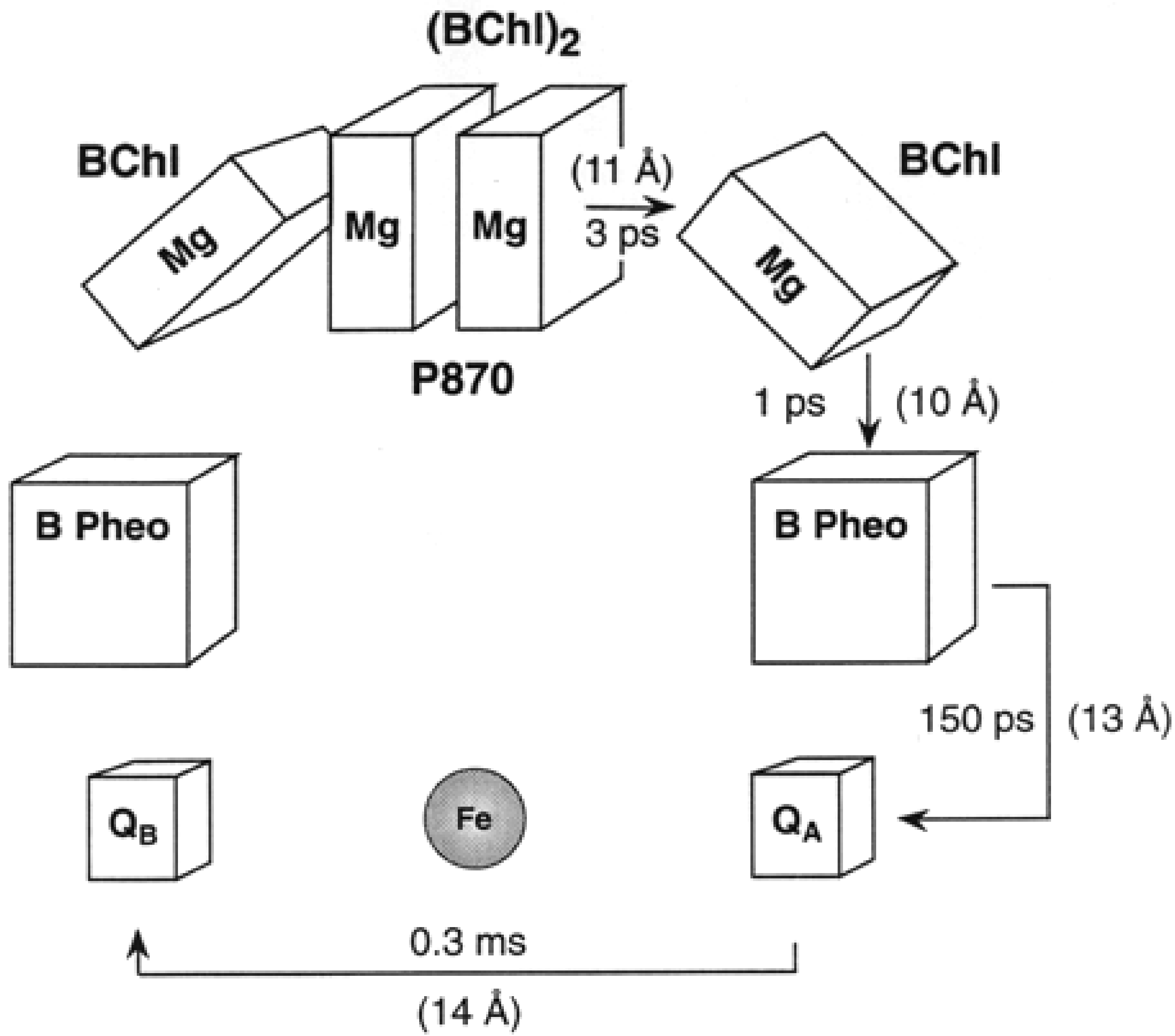


Reaction center complex of purple photosynthetic bacteria

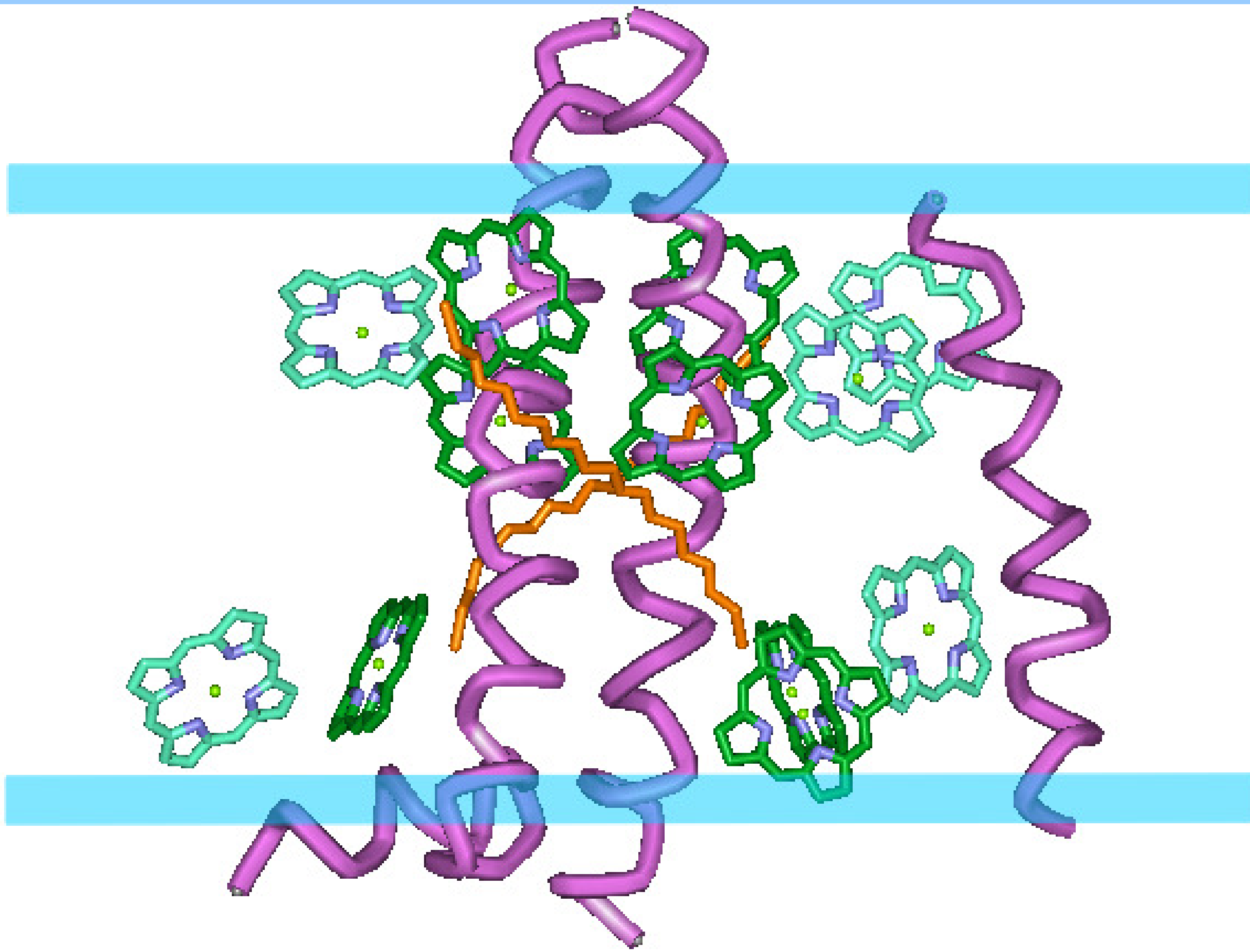


Michel, Deisenhofer, Huber – Nobel prize 1988

Bacterial Reaction Center

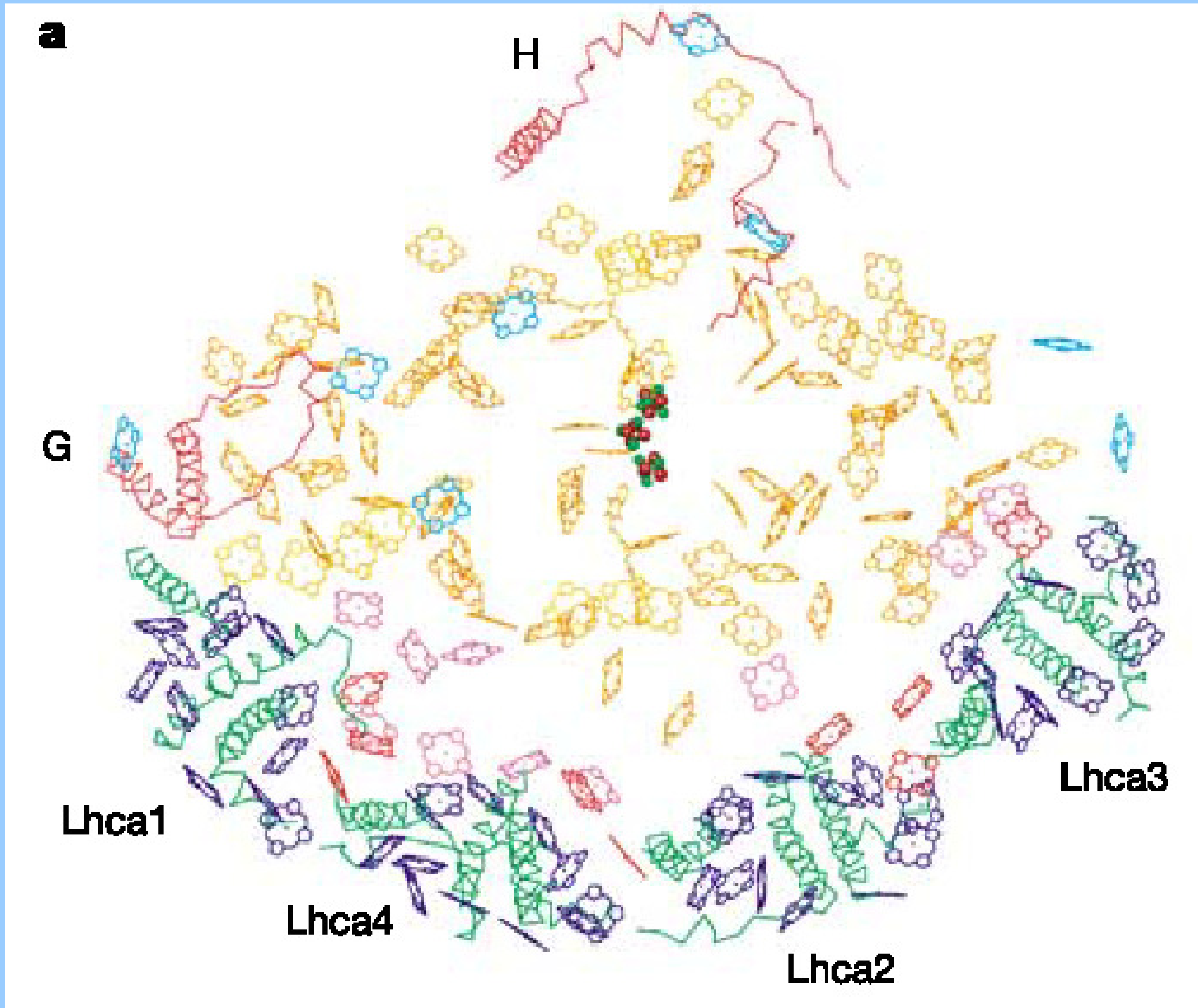


LHCII monomer



Kühlbrandt, Nature, 1994

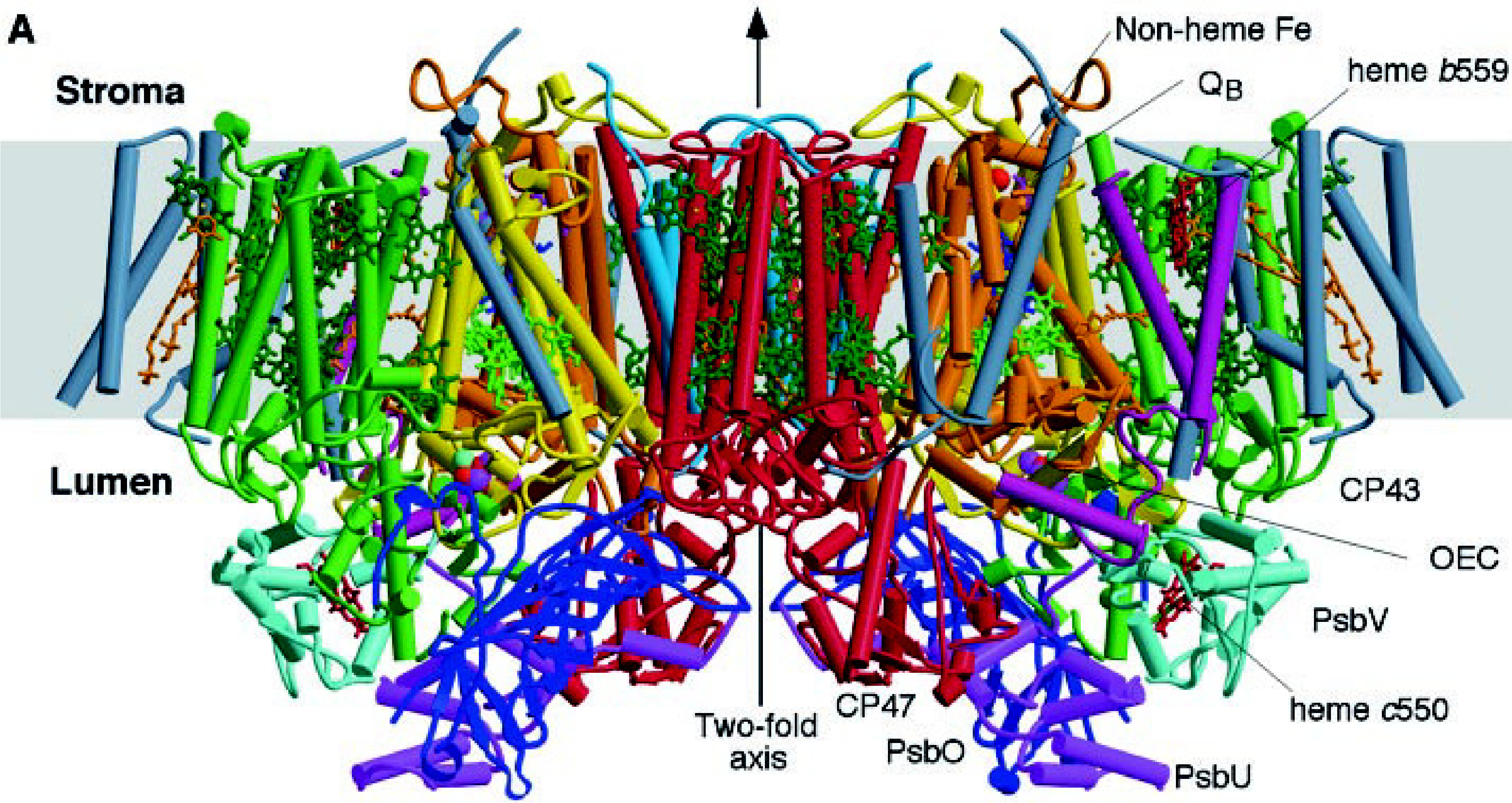
Photosystem I : ReCe& LH antennae



Nelson and coworkers, 2003, Nature

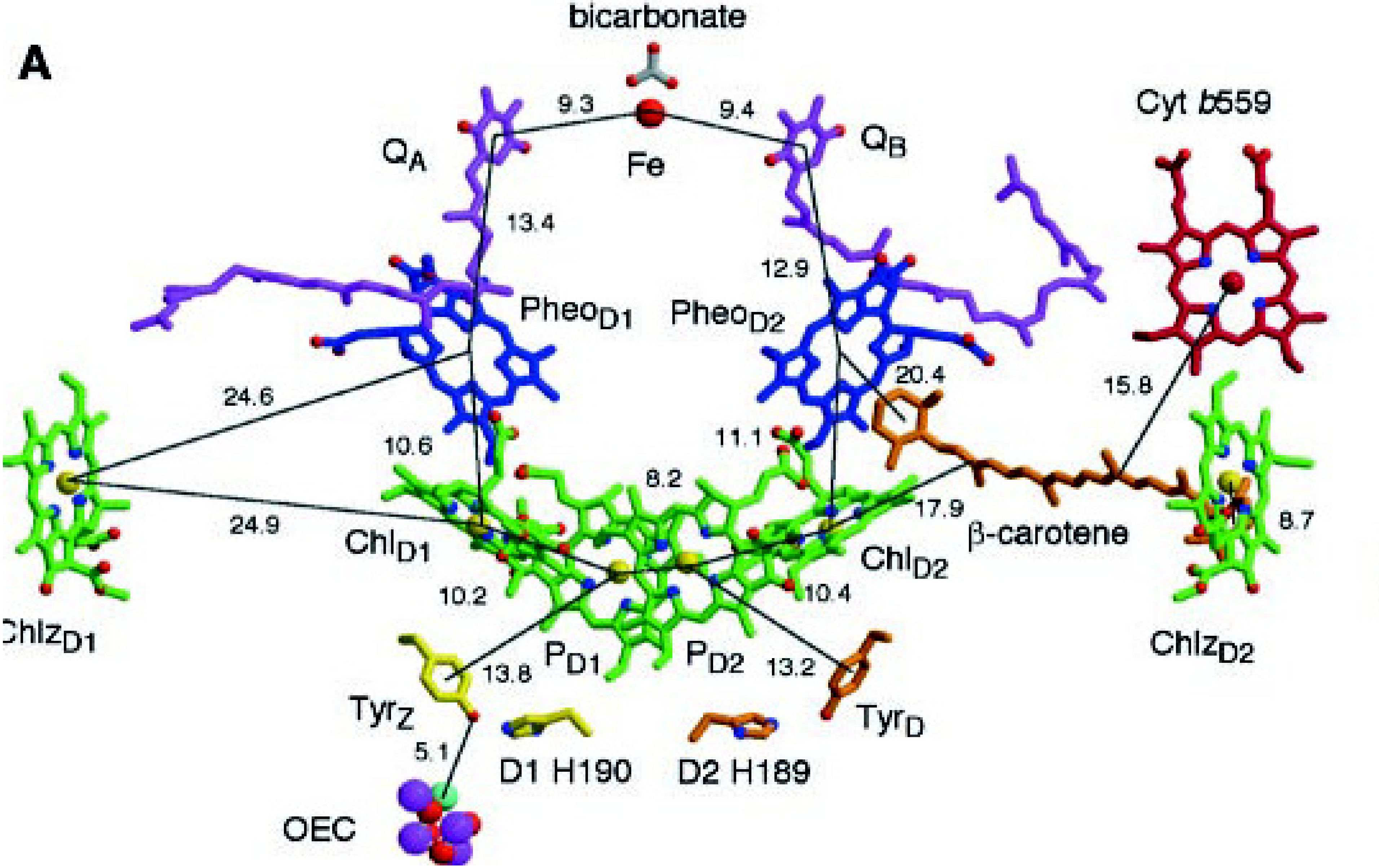
45 transmembrane helices

PSII reaction center and core complexes

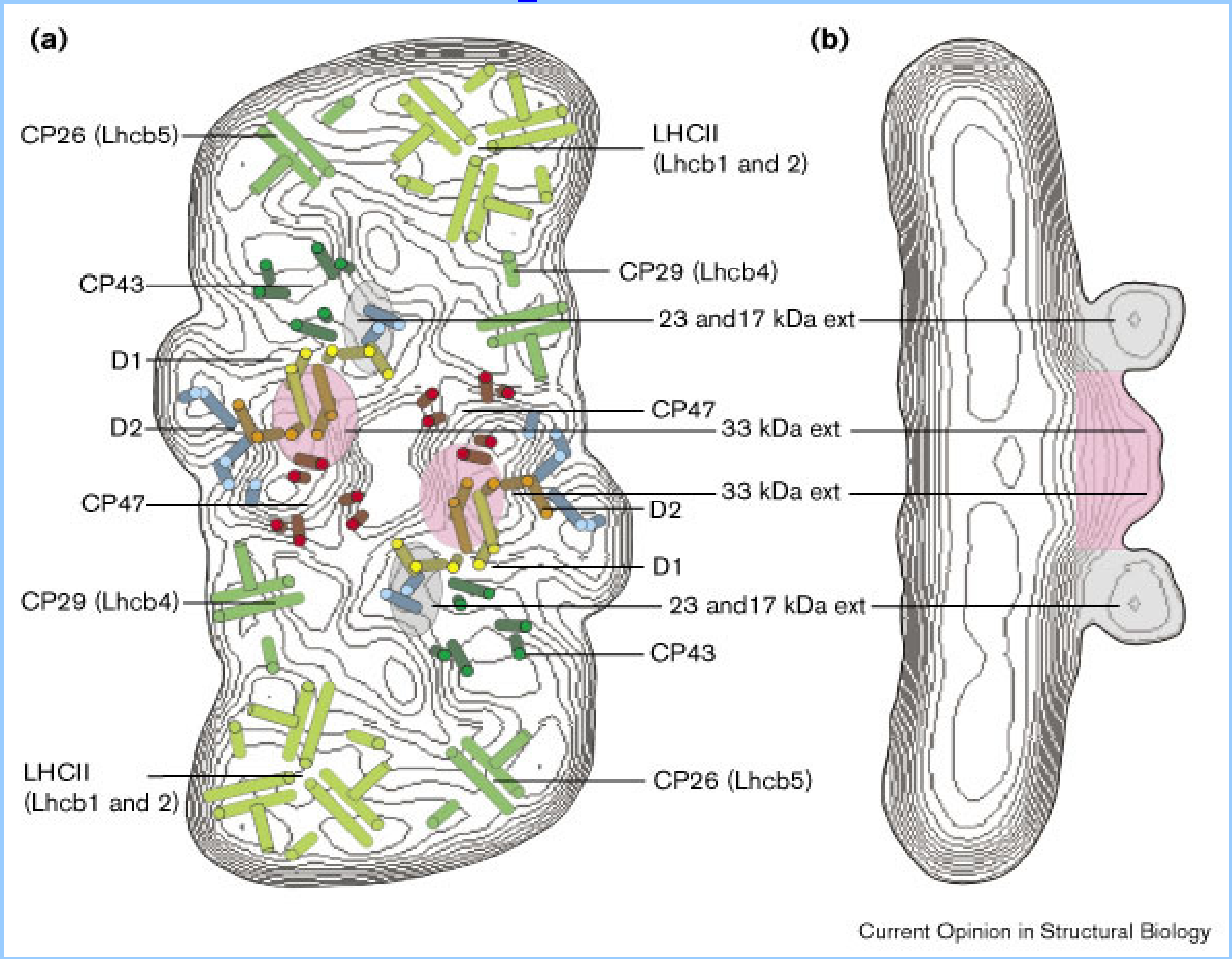


Barber and coworkers, Science, 2004; Umena et al. 2011 Nature: 1.9 A resolution

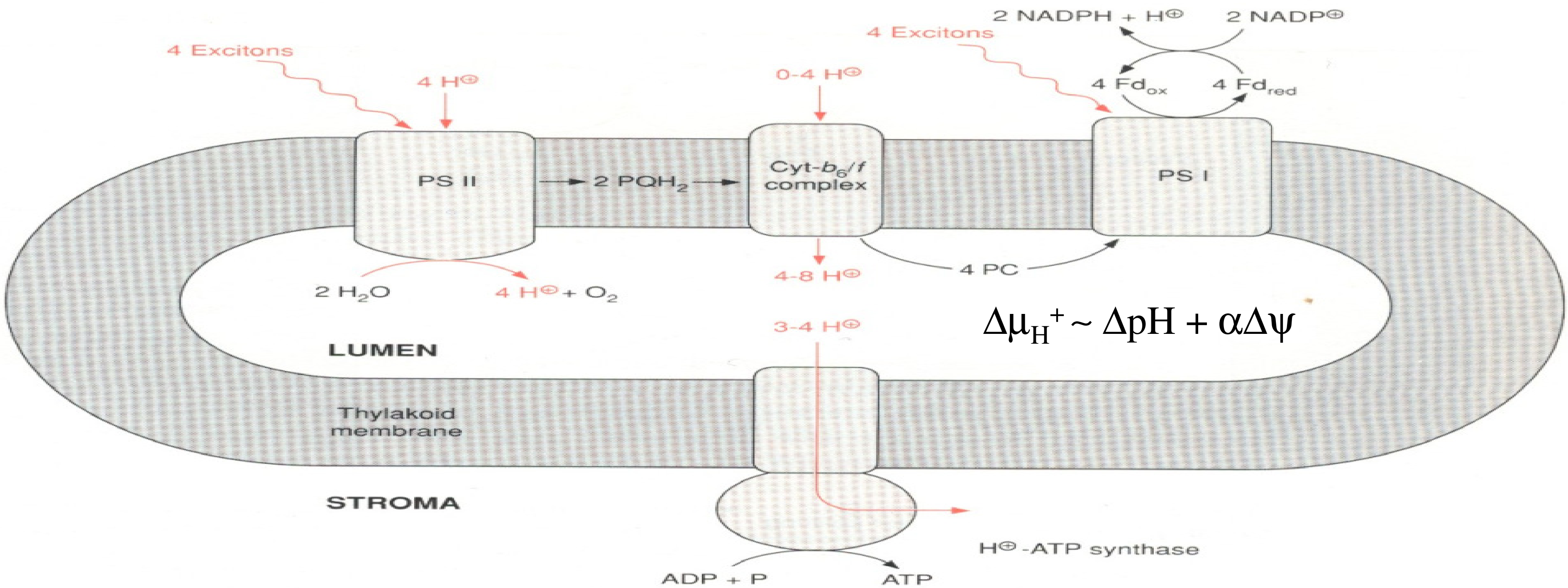
PSII reaction center complex



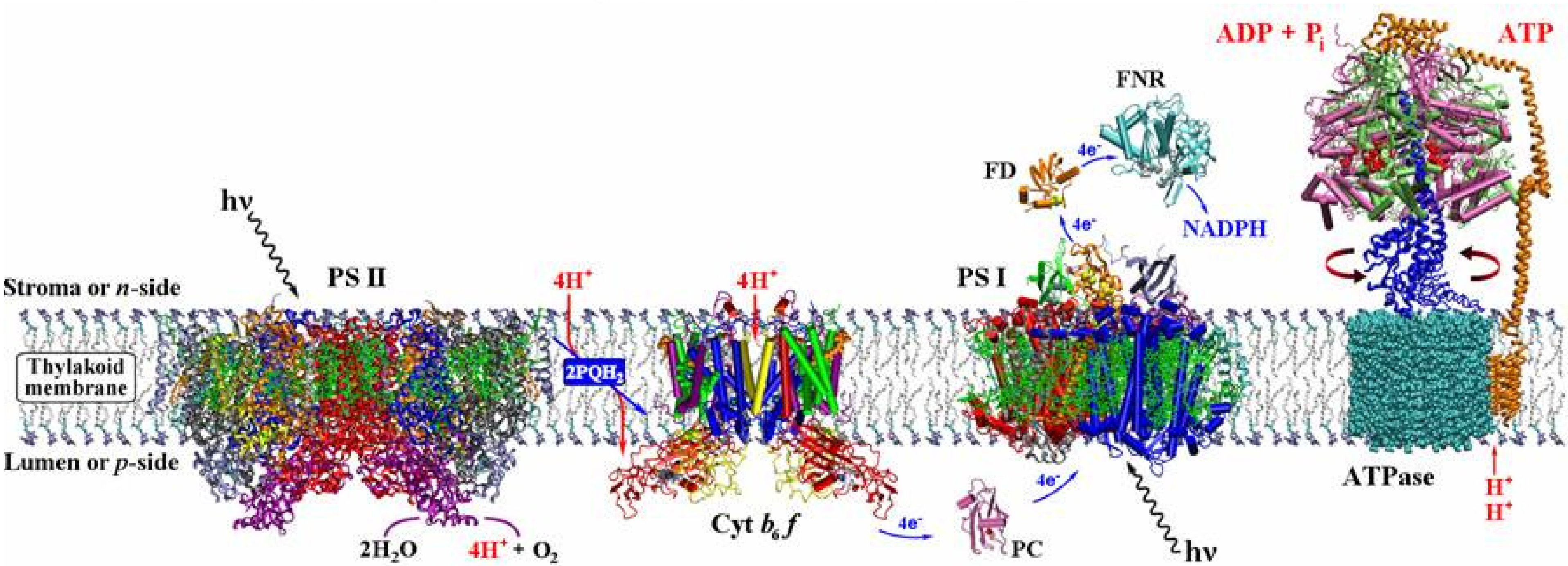
PSII particulum



Barber, 2000



$$\Delta\mu_{H^+} \sim \Delta pH + \alpha\Delta\psi$$



Block diagram (the hierarchy) of photosynthesis

Photophysics	Photochemistry	Biochemistry	Physiology	Ontogeny
Light absorption energy migration	charge separation redox chain NADPH, ATP, O_2	CO_2 ‘fixation’, Signal transduction Short-term regulation	synthesis, self-assembly repair transport Regulation	Ecology Evolution
~ 10^{-15} – 10^{-9} s	~ 10^{-12} – 10^{-2} s	~ 10^{-3} – 10^{3} s	~ 10^{2} – 10^{6} s	~ 10^{5} – 10^{17} s

Pigments, complexes | **Membrane vesicle** | **chloroplast** | **cell, plant, ecosystem, biosphere**