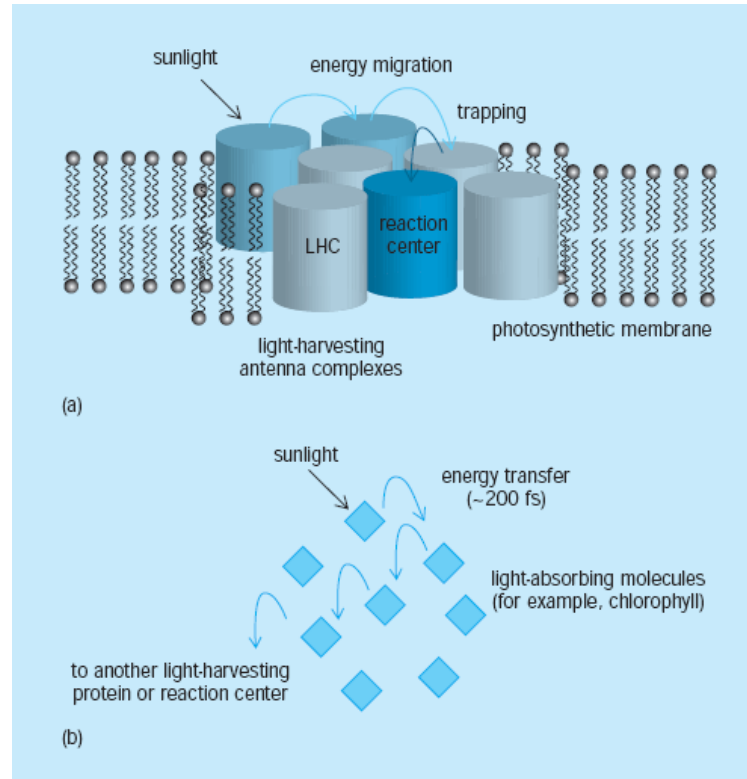




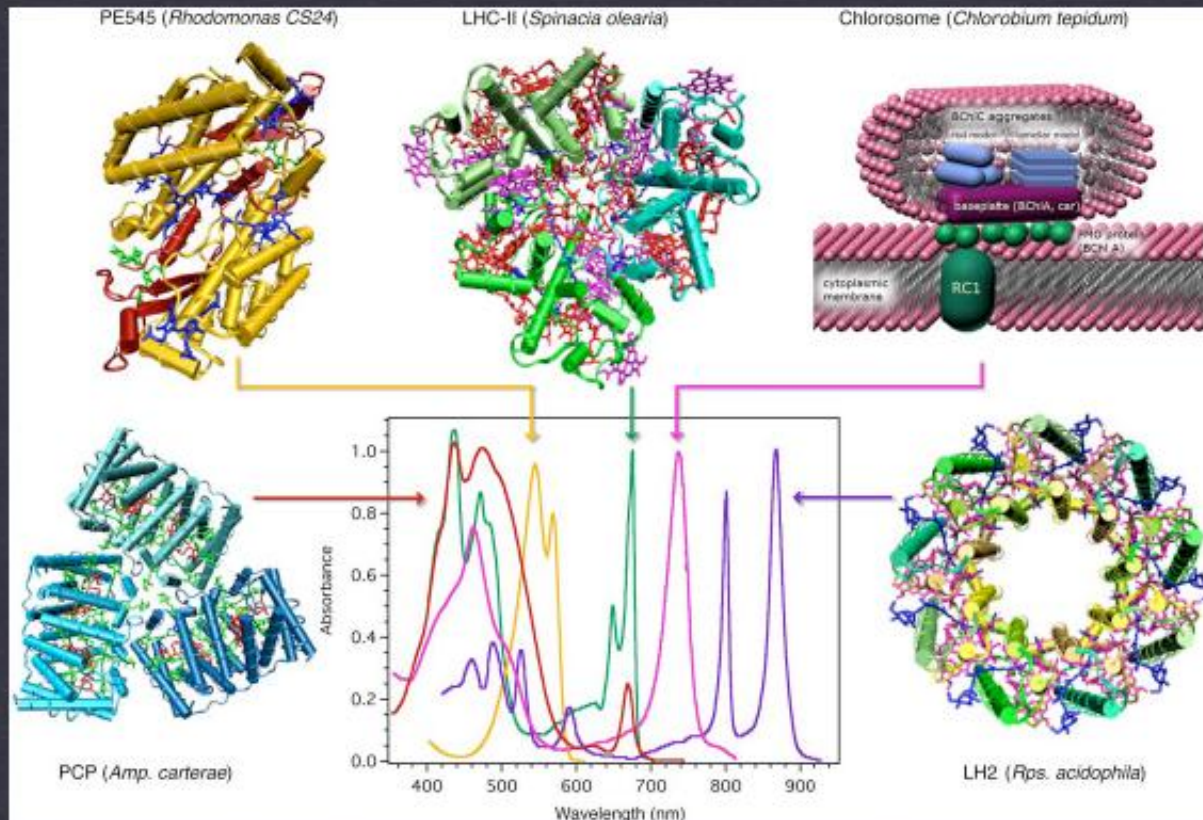
**Quantum-mechanical optimization
of light-harvesting in photosynthesis**
Greg Scholes, University of Toronto

Rene Nome, Instituto de Química, Unicamp

Basics of Photosynthetic Light Harvesting



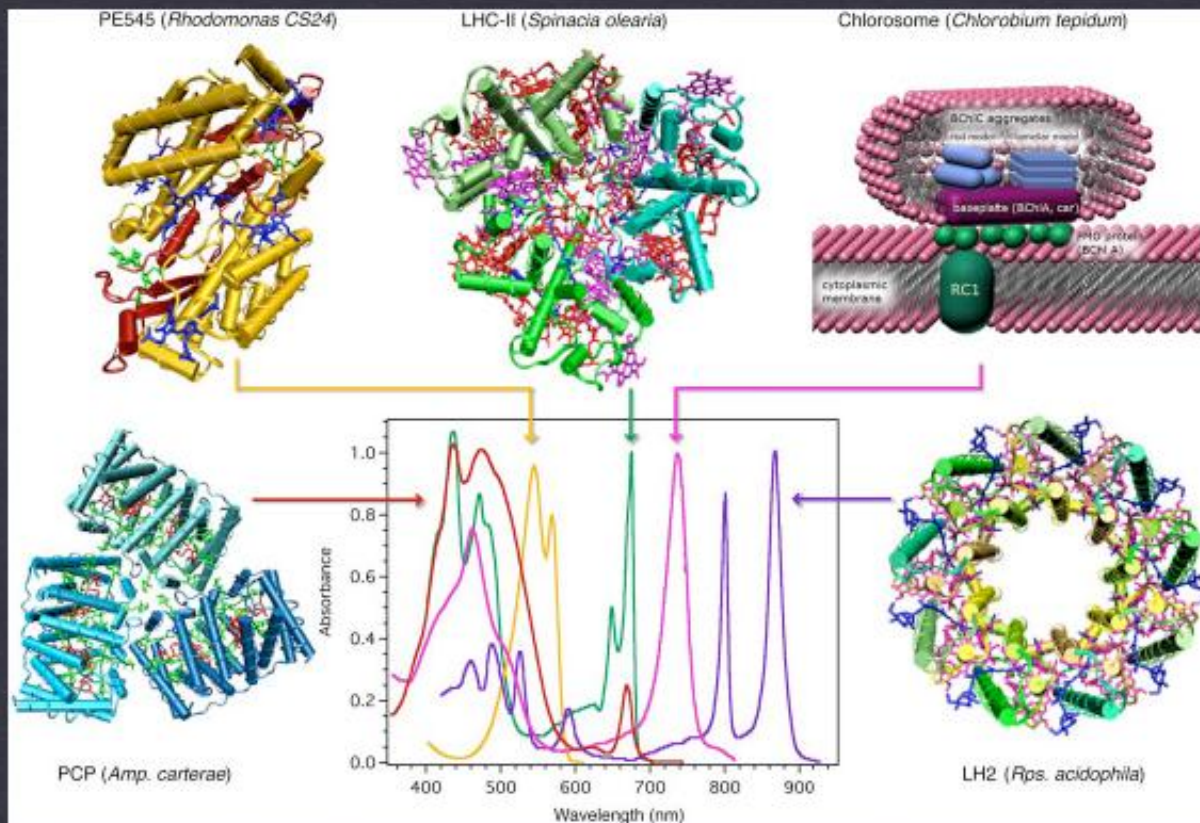
Energy migration: From Sunlight to antennas to reaction centers...



Light-harvesting proteins

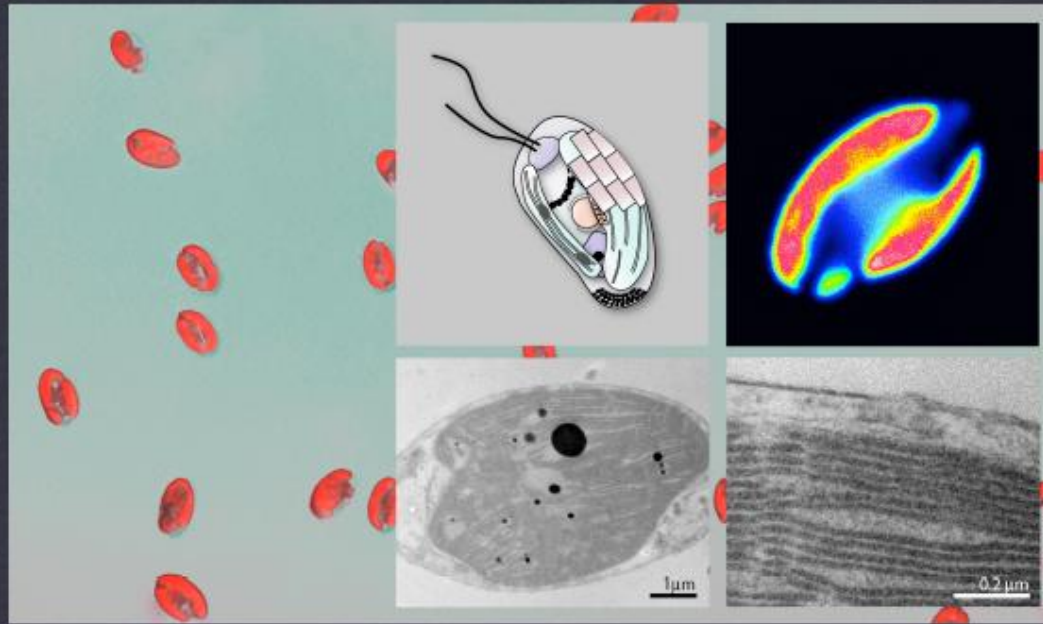
Molecular engineering to optimize light capture

movie



Light-harvesting proteins

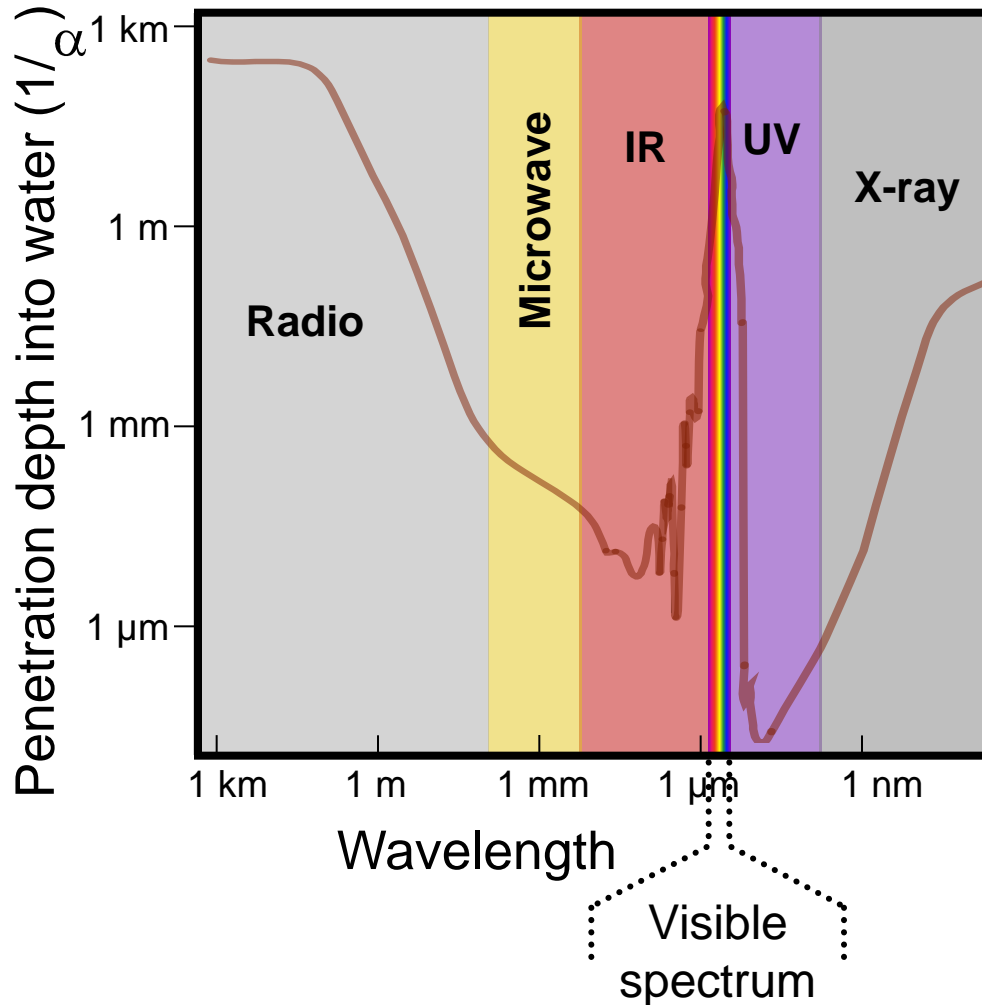
Molecular engineering to optimize light capture



Cryptophyte algae

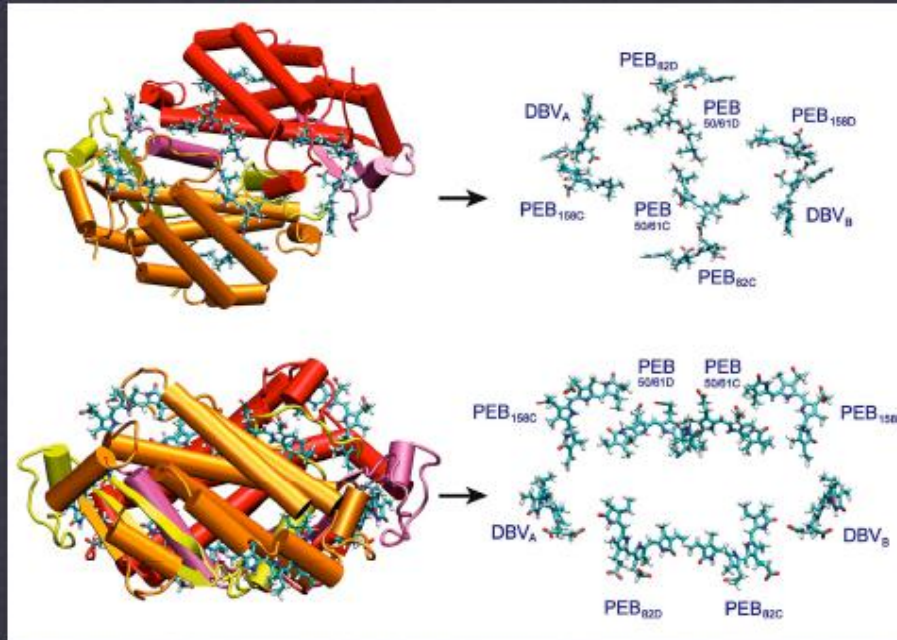
Rhodomonas salina CS24

Why use the biliproteins?



...because they are better matched to the solar spectrum transmitted through water.

An odd photosynthetic apparatus

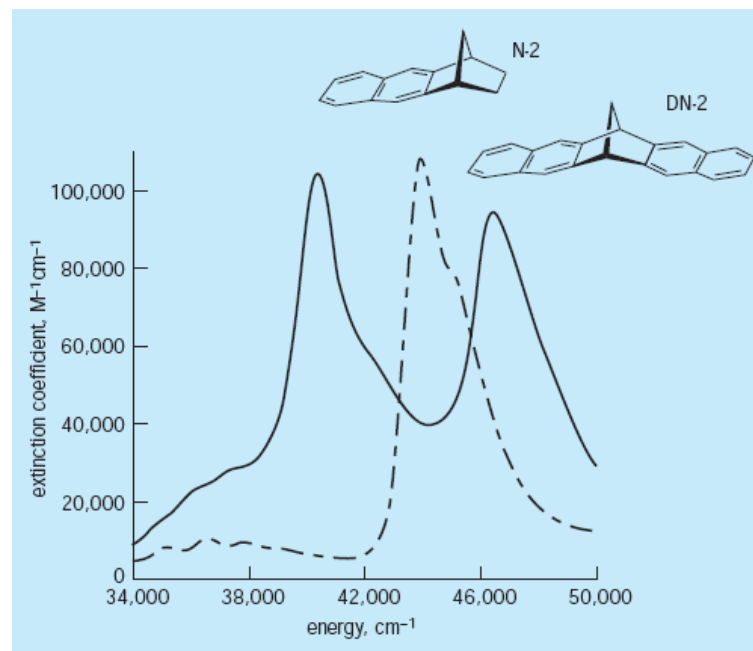
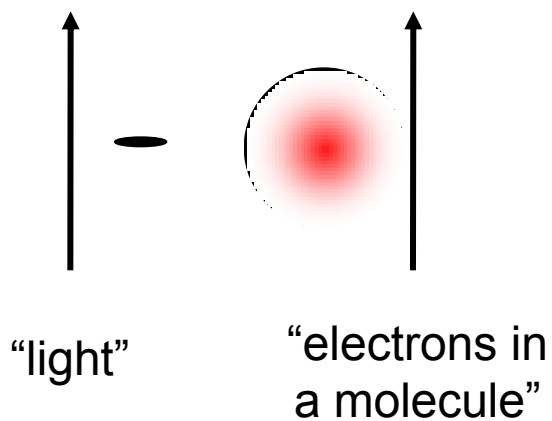


PE545: half the concentration
of chromophores compared to antenna
systems like LHCII

Very high light-to-charge conversion (>95%)!

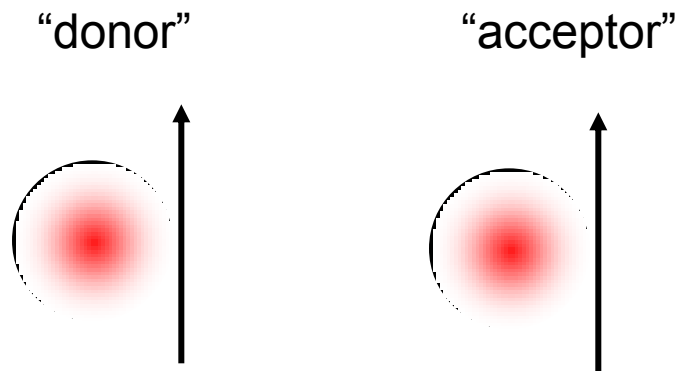
Energy transfer: from light to molecule

Concept of resonance:



Spectrum of N₂

Energy transfer: from molecule to molecule



Factors important for efficient energy transfer:

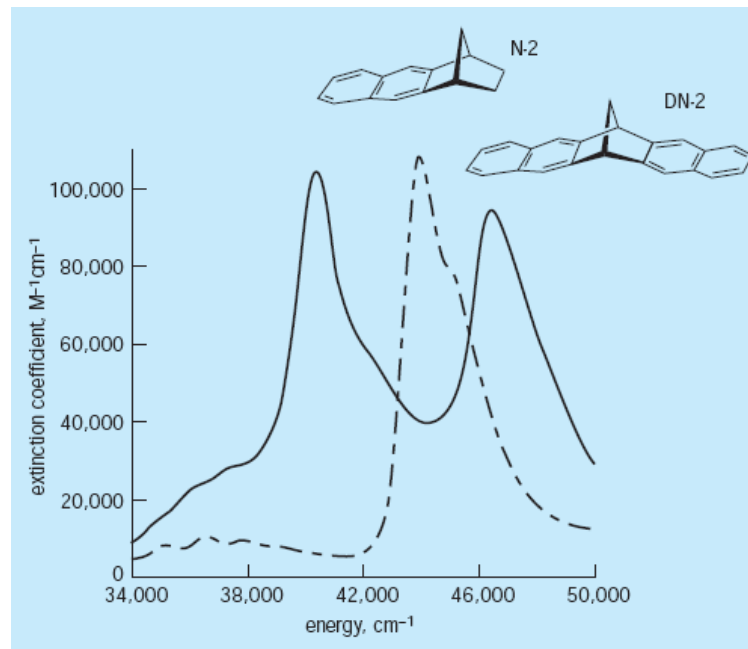
- Donor-acceptor spectral overlap
- Donor-acceptor separation and relative orientation



Theodor Förster

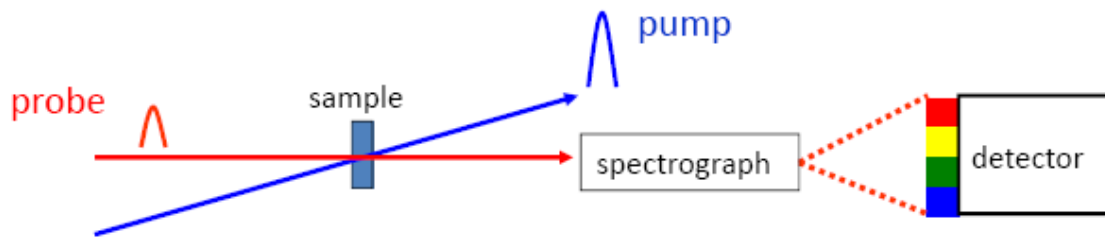
Movie...

Quantum mechanics makes molecules share excitation

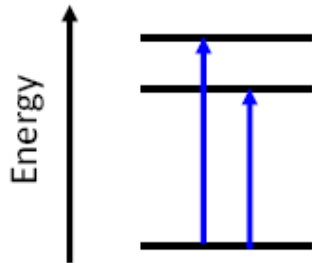


Spectrum of DN-2 is explained by the quantum-mechanical superposition principle

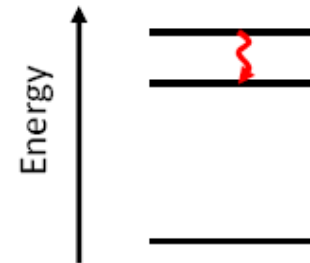
Measuring ultrafast energy transfer



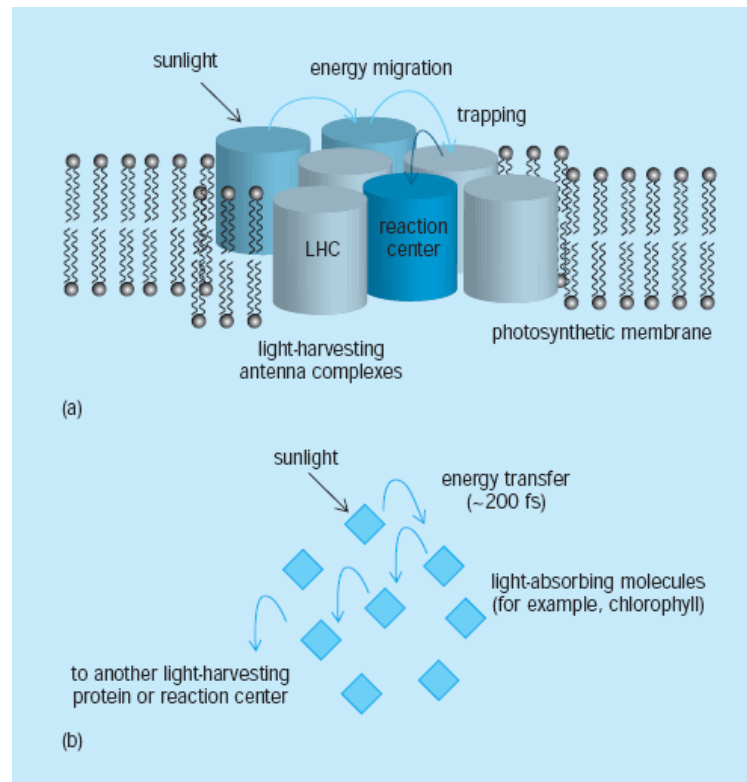
Pump pulse populates
excited electronic states



Probe pulse monitors
electronic relaxation

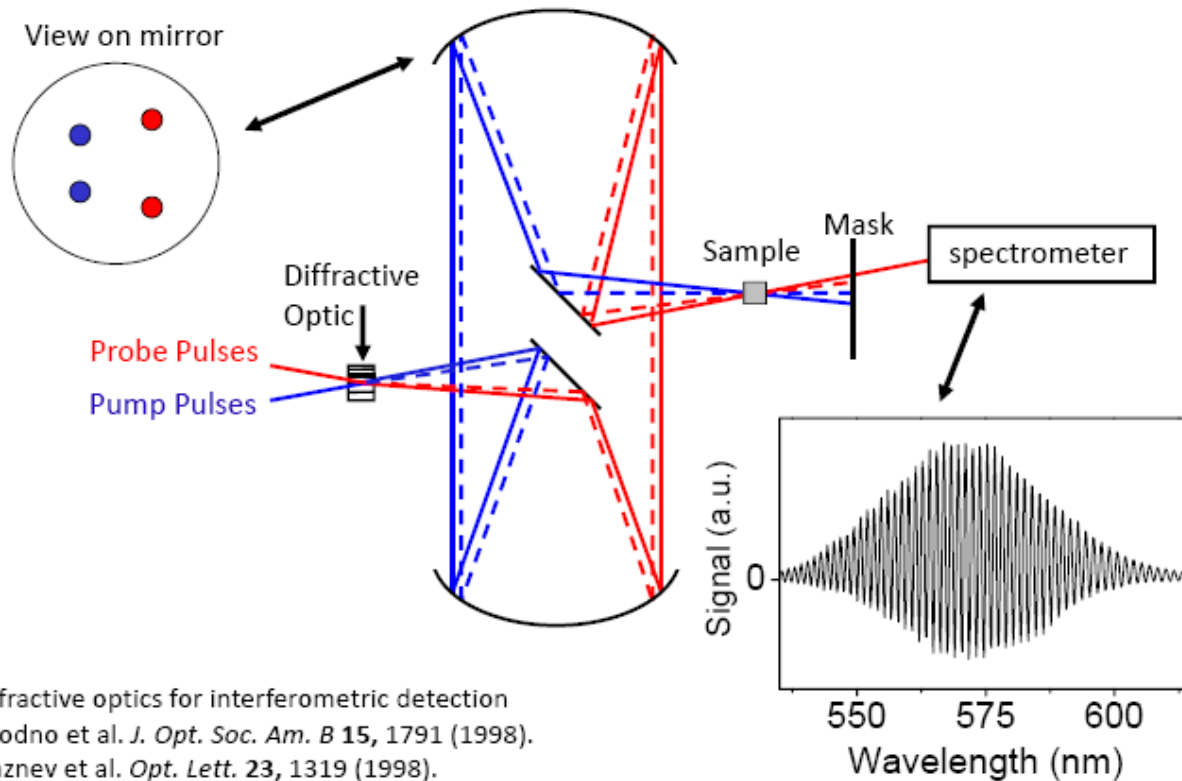


“Imaging” of quantum-coherent energy sharing



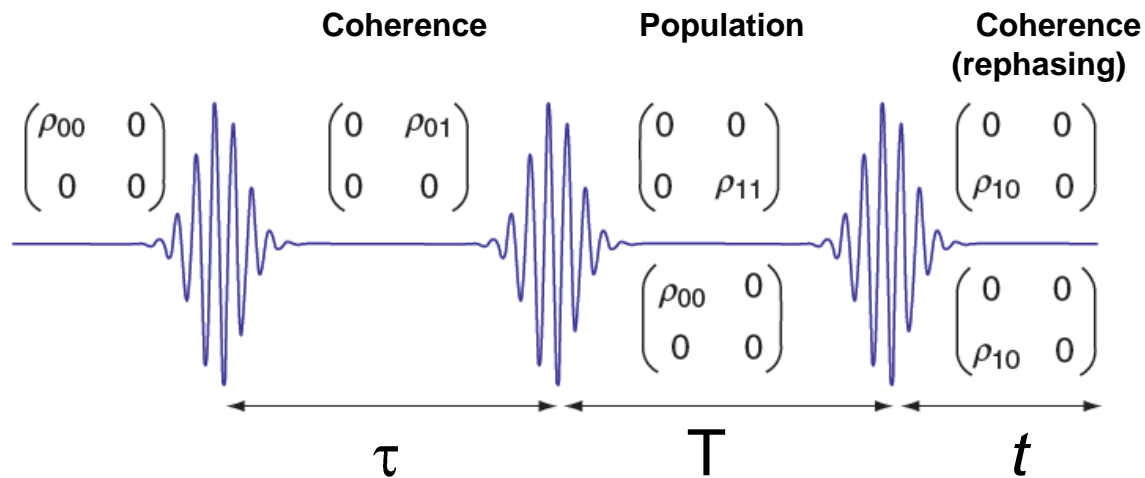
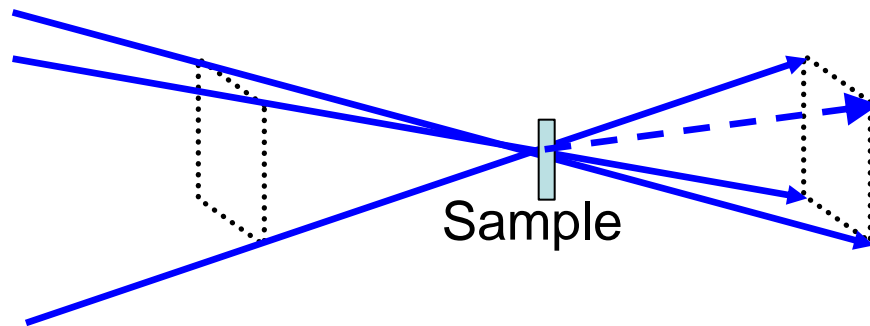
With two-dimensional photon echo spectroscopy, one can detect energy transfer pathways

Probing relaxation mechanisms with nonlinear spectroscopies



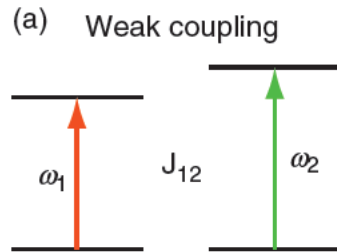
Diffractive optics for interferometric detection
Goodno et al. *J. Opt. Soc. Am. B* **15**, 1791 (1998).
Maznev et al. *Opt. Lett.* **23**, 1319 (1998).

Two-dimensional photon-echo spectroscopy (2DPE)

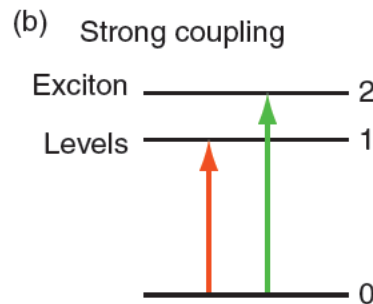


2DPE – Optical Analog of 2D NMR

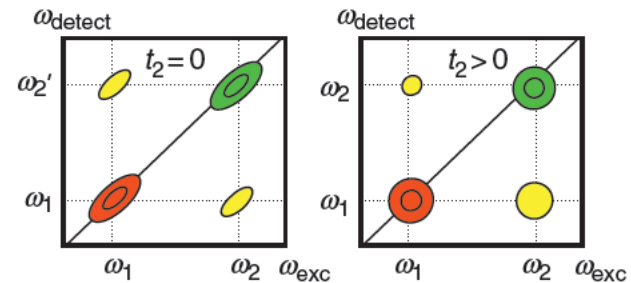
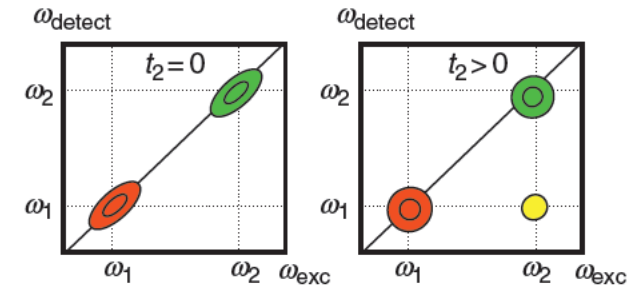
“Förster”



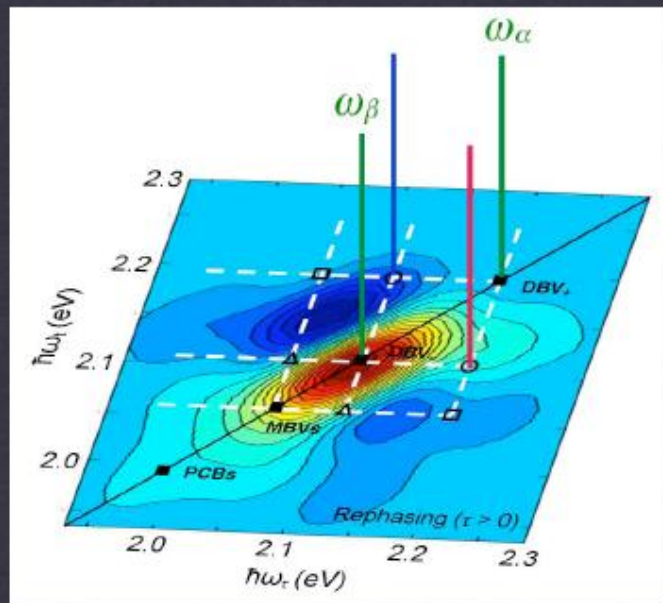
“Exciton”



Detection Frequency

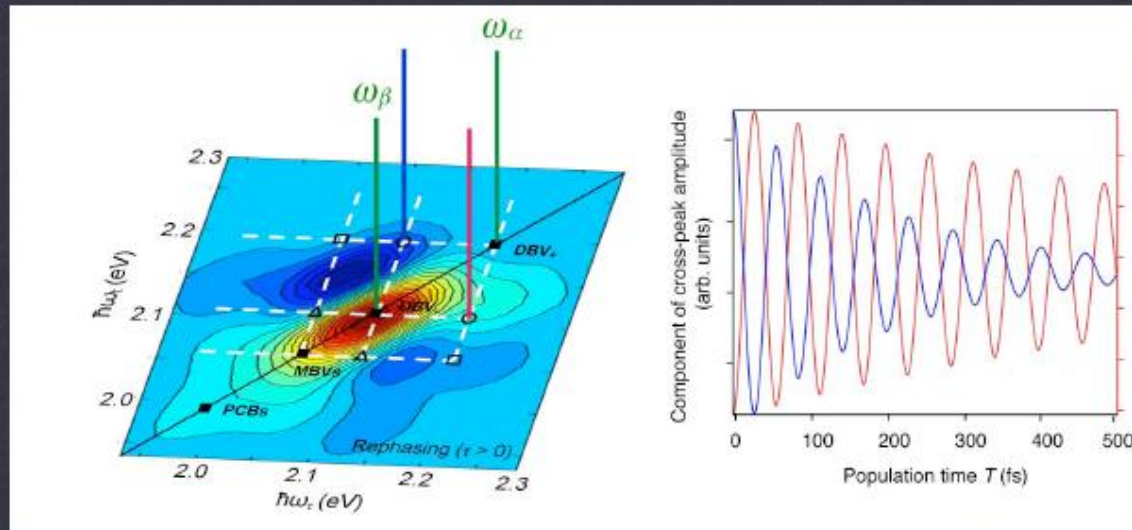


Excitation Frequency



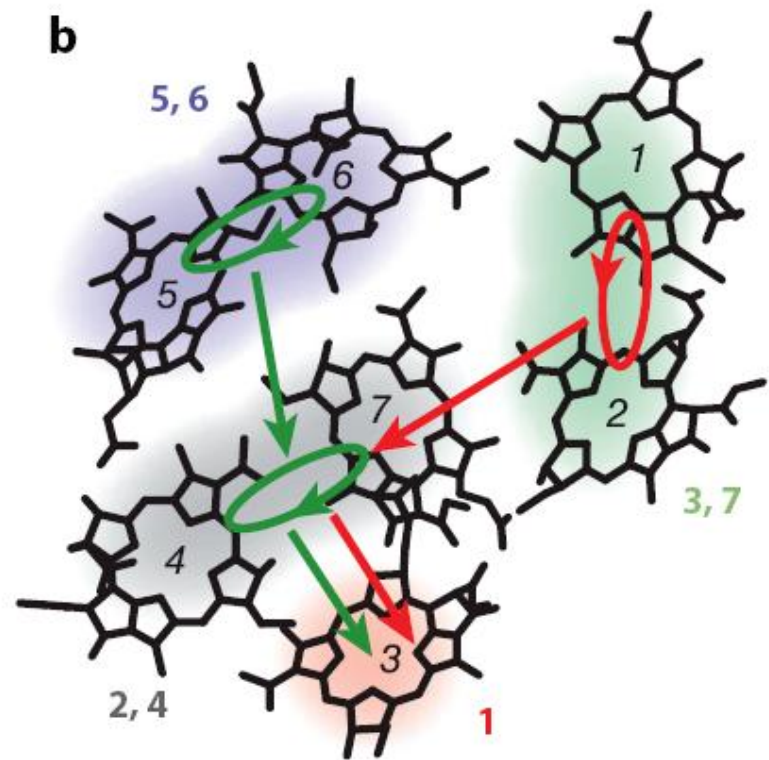
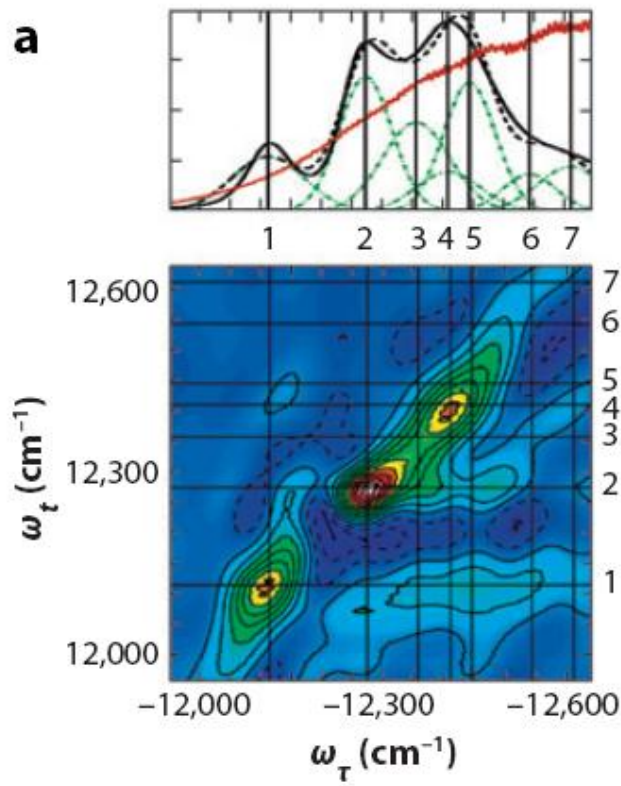
2D Photon echo experiments

Femtosecond lasers probe what happens after light is absorbed by molecules

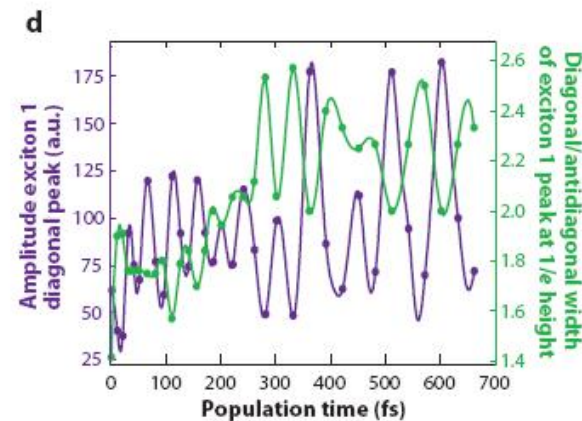
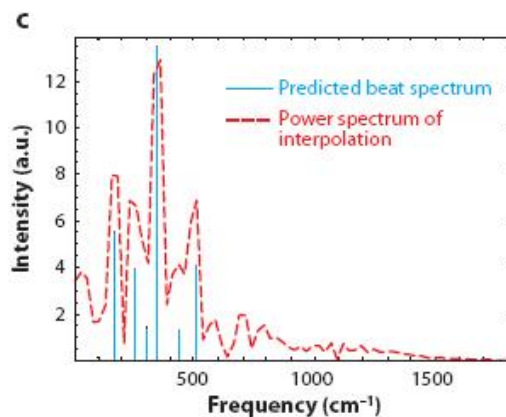
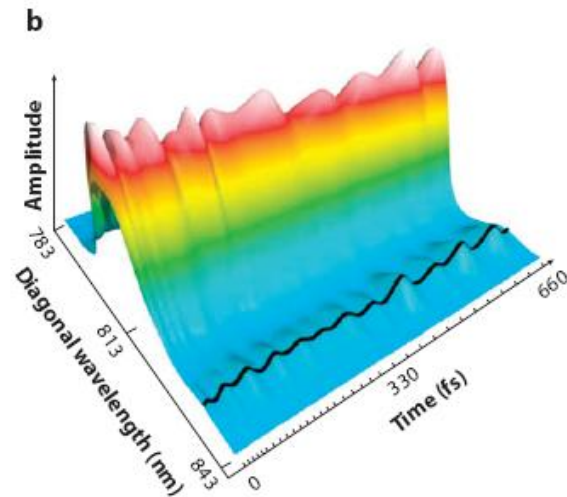
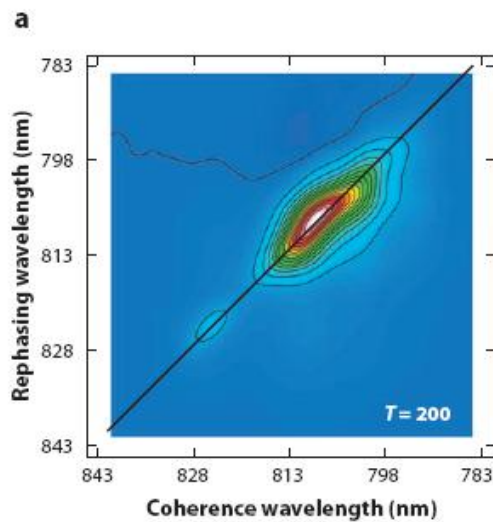


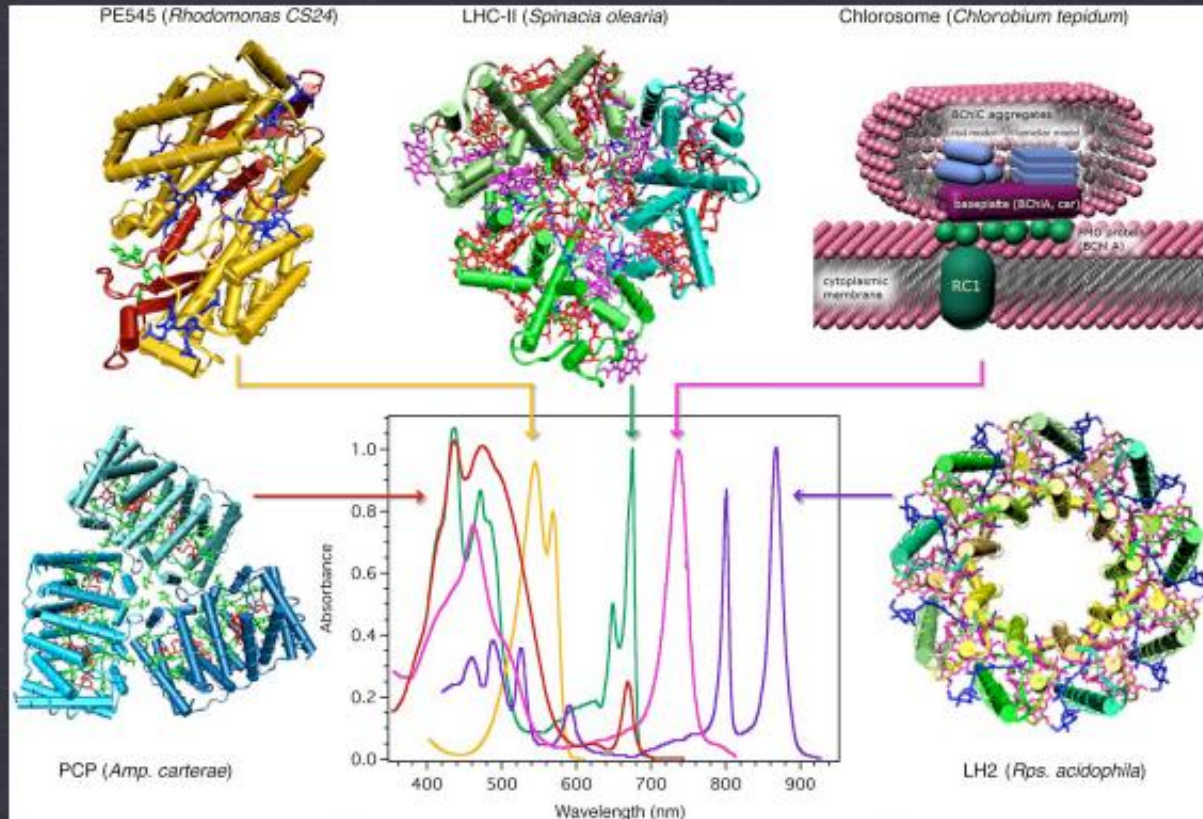
2D Photon echo experiments
can detect the existence of quantum
coherences

First 2DPE study of a photosynthetic system



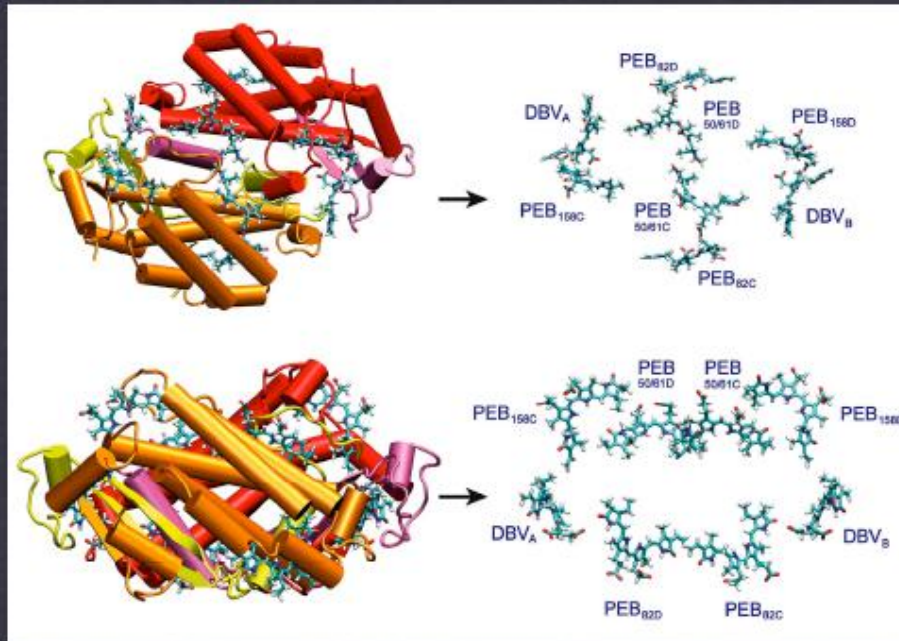
Evidence for wave-like energy transfer in photosynthesis





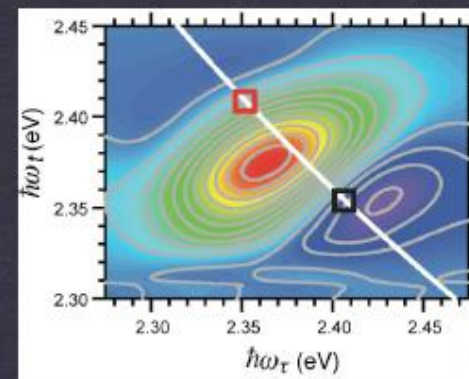
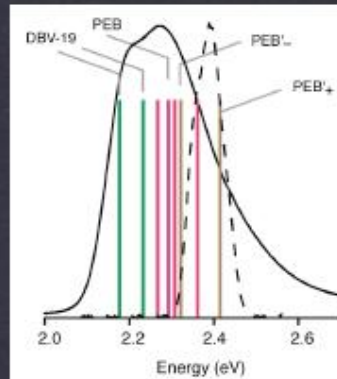
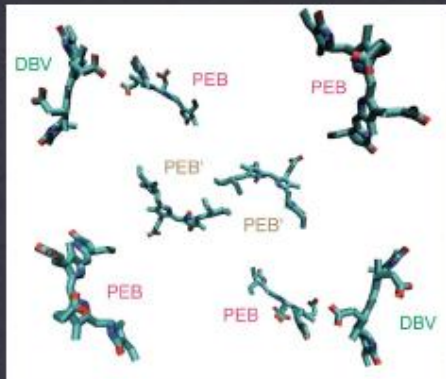
Light-harvesting proteins

Molecular engineering to optimize light capture



PE545: half the concentration
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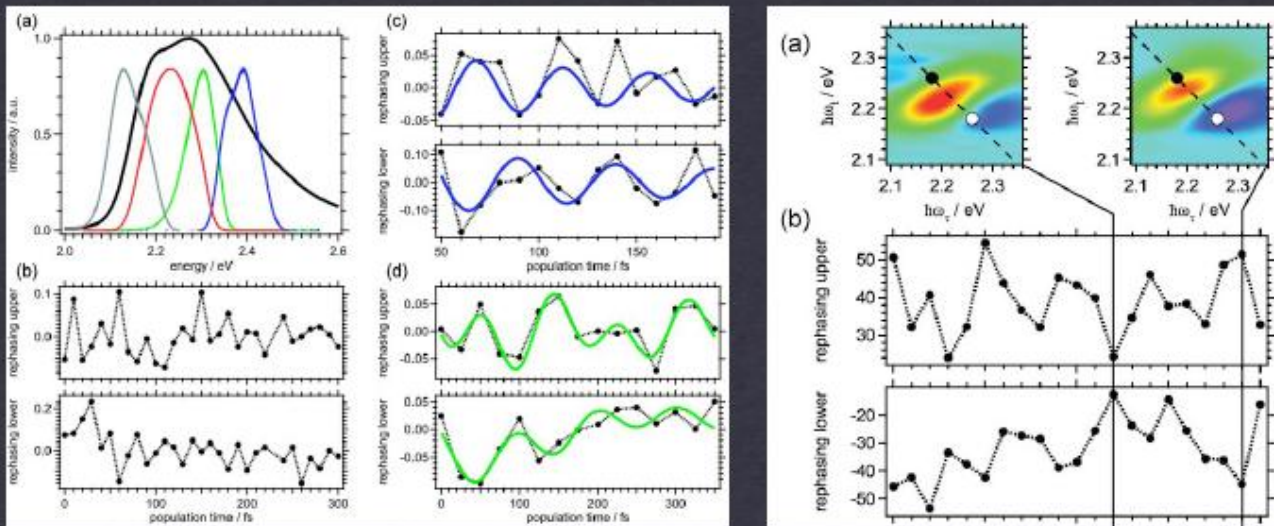
Elisabetta Collini, Cathy Wong, et al. *Nature* (2010), 463, 644–648.



Rhodomonas CS24 (PE545)

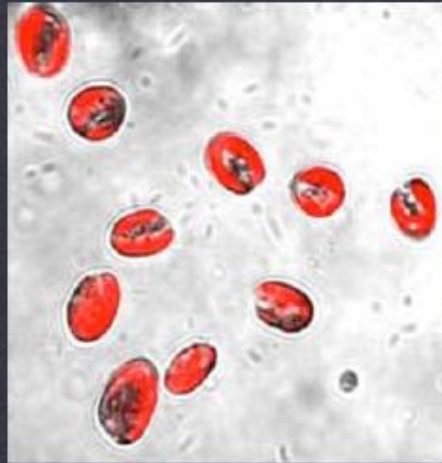
Quantum-coherence at 21°C

Elisabetta Collini, Cathy Wong, et al. *Nature* (2010), 463, 644–648
and unpublished results



2DPE beats depend on excitation
but no beats when exciting the far red side.

Nature Physics (2010) 6, 402–403.



Rhodomonas salina CS24



Quantum mechanical wires in biology?

Green quantum computers?



Quantum biology

But the question remains: Does quantum 'weirdness' matter for biological function?