http://power.itp.ac.cn/~suncp/quantum.htm

What is Life ?, Cambridge, 1946.

"

"

Erwin Schrödinger
1887-1961

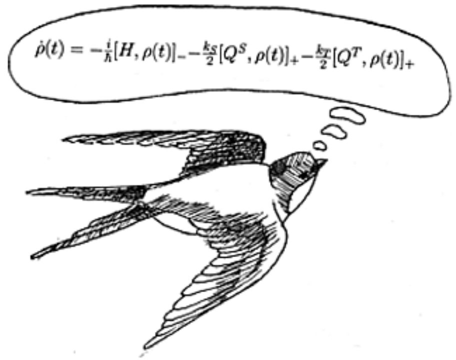
DNA

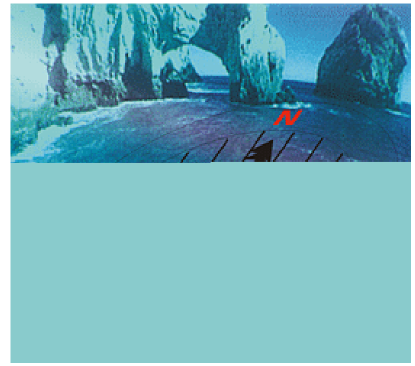
free radical pair

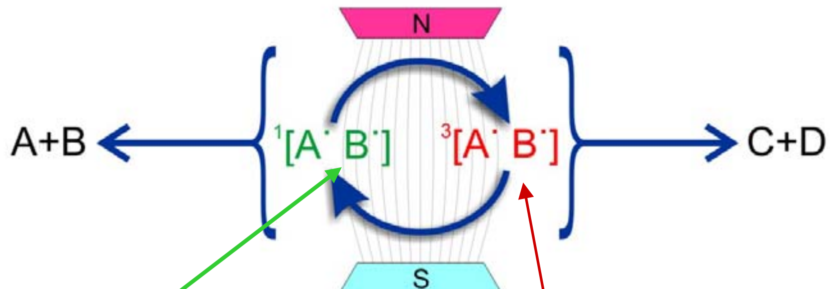
Biophysical Journal Volume 78 February 2000 707–718

A Model for Photoreceptor-Based Magnetoreception in Birds

Thorsten Ritz, Salih Adem, and Klaus Schulten







$$|0,0\rangle = (\uparrow\downarrow - \downarrow\uparrow)/\sqrt{2} \;\} \quad s = 0 \quad \text{(singlet)}$$

$|1,1\rangle = \uparrow\uparrow$

$\downarrow + \downarrow\uparrow)/\sqrt{2}$ } $s = 1$ (triplet) $|1,0\rangle = (\uparrow\downarrow$

$|1,-1\rangle = \downarrow\downarrow$

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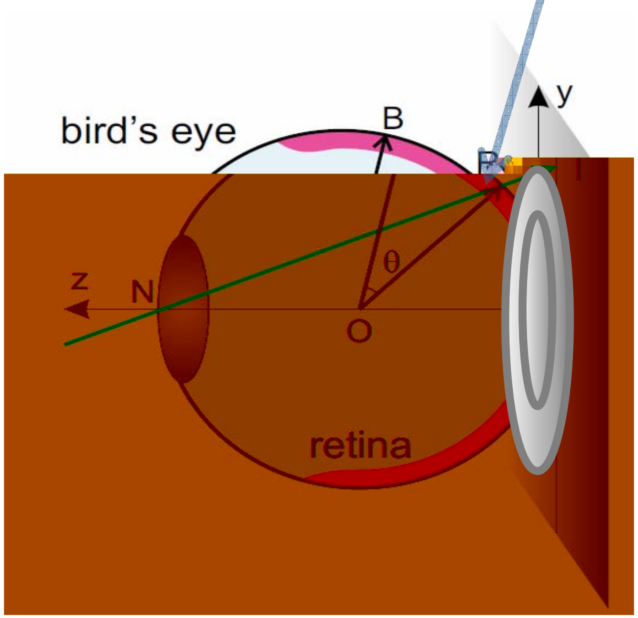
$$[A^{+}B^{-}]^{S} \longrightarrow CD$$

$$[A^{+}B^{-}]^{T} \longrightarrow EF$$



Chemical compass model of avian magneto

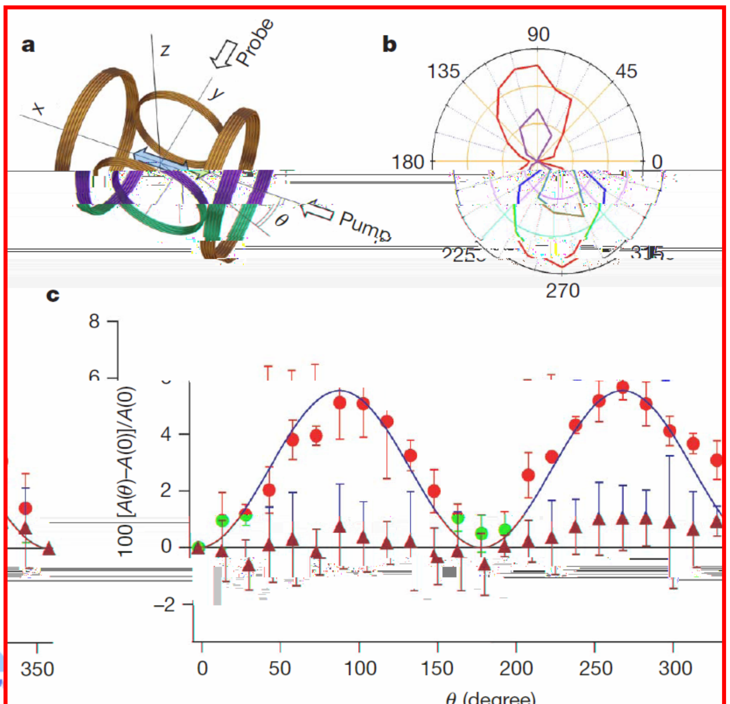
topher T. Rodgers[2], Paul Liddell[3], Devens Gust[3], Christiane R. Timmel[1] & P. J. Hore[2]

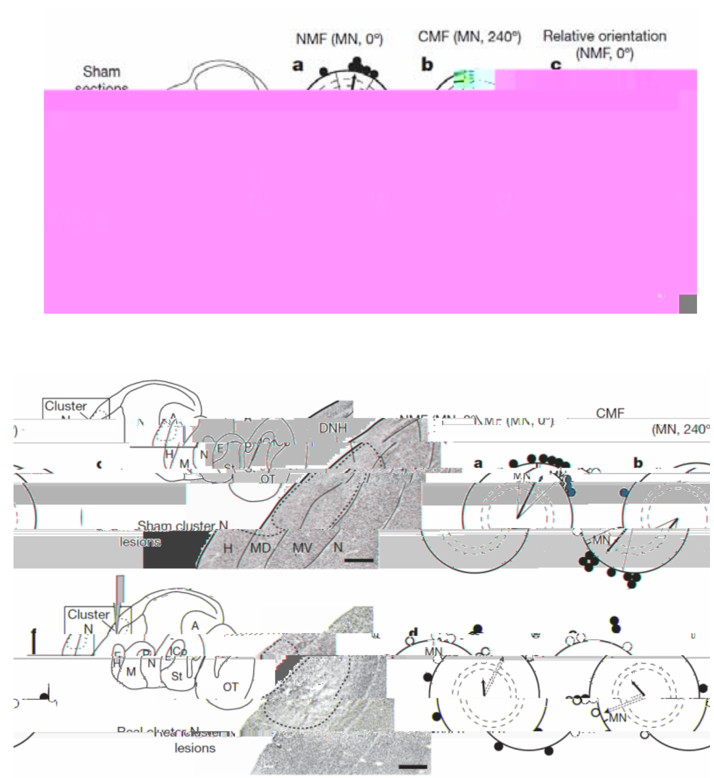
Nature, Vol 453| 15 May 2008

Visual but not trigeminal mediation of magnetic compass information in a migratory bird

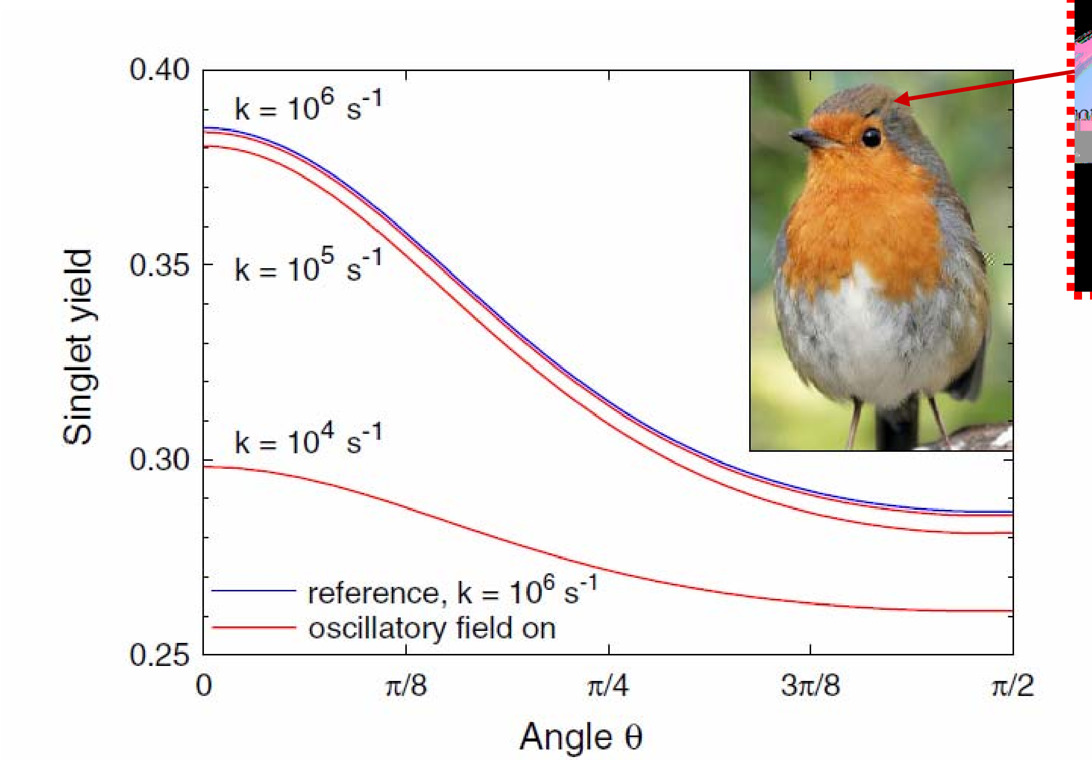
Manuela Zapka[1], Dominik Heyers[1], Christine M. Hein[1], Svenia Engels[1], Nils-Lasse Schneider[1], Jörg Hans[1], Simon Weiler[1], David Dreyer[1], Dmitriy Kishkinev[1], J. Martin Wild[2] & Henrik Mouritsen[1]

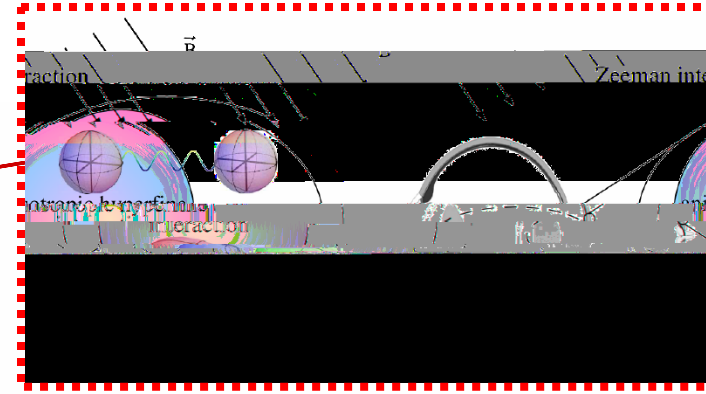
Nature ,Vol 461|29 October 2009

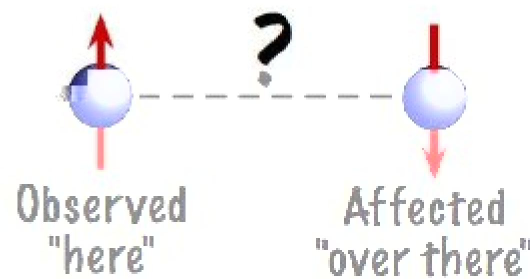




Guager et al , Phys. Rev. Lett. 106, 040503 (2011)







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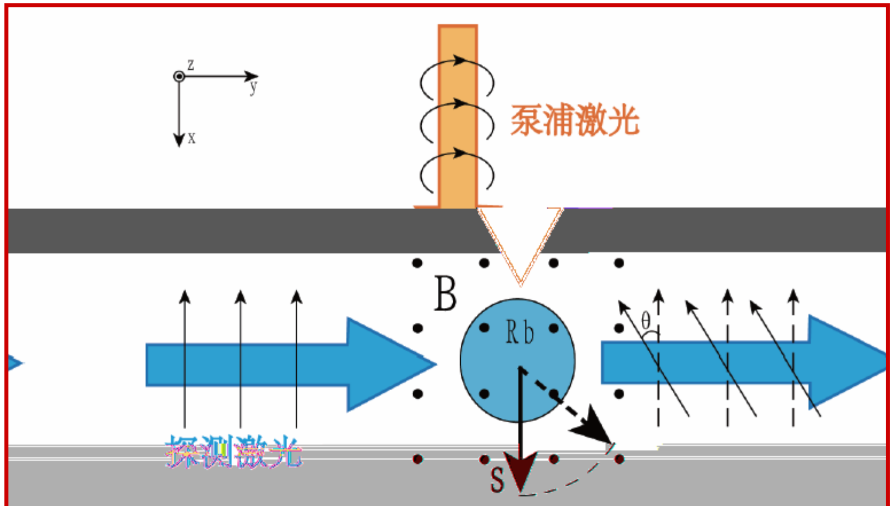
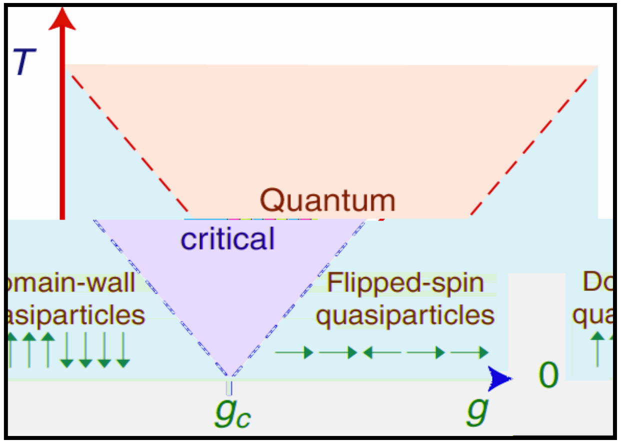


图1 原子磁强计原理示意图。

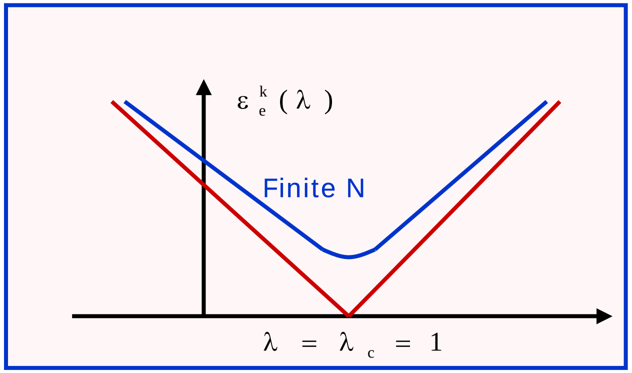
Romalis　　2002

10 fT / √Hz　　　　2aT / √Hz

SQUID



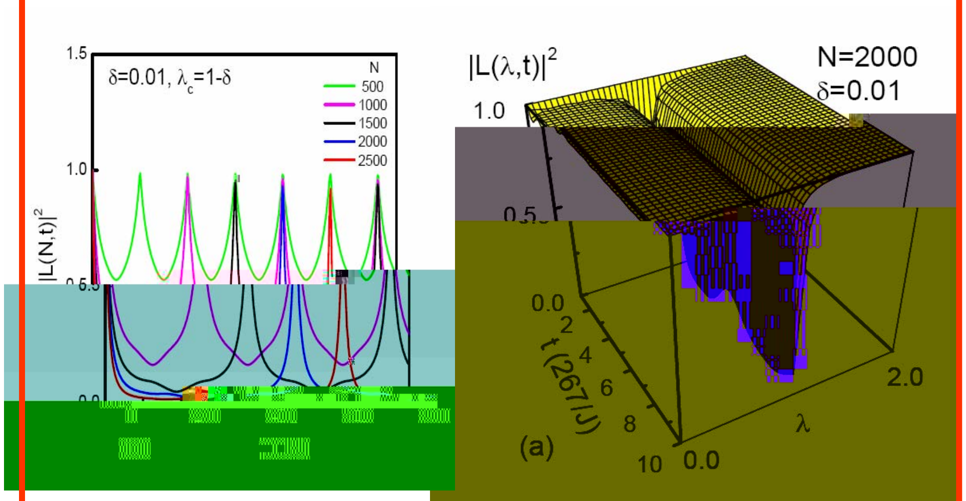
S Sachdev, (2000)
Quantum Phase Transitions.
Cambridge University Press



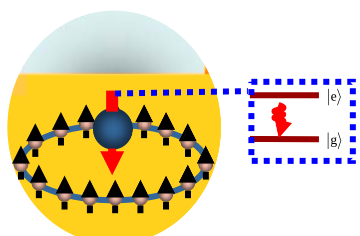
$$\varepsilon_e^k(\lambda) = 2J\sqrt{1+\lambda^2 - 2\lambda\cos(ka)}$$

Quan, Song, Liu, Zanardi, Sun Phys. Rev. Lett. 96, 140604 (2006)

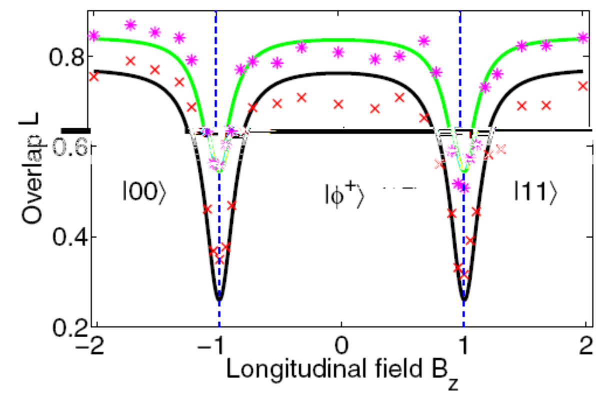
Suter

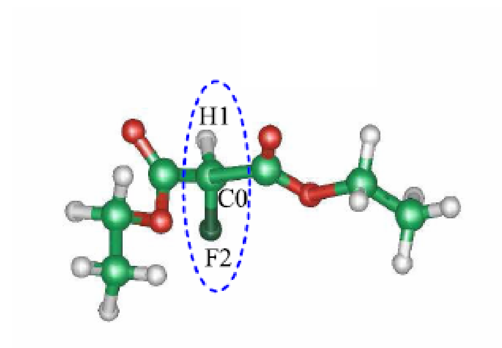


Critical Point
Loschmidt Echo



PRL 100, 100501 (2008)





Quan et al , Phys. Rev. Lett. 96, 140604 (2006)-[6]

2006

160

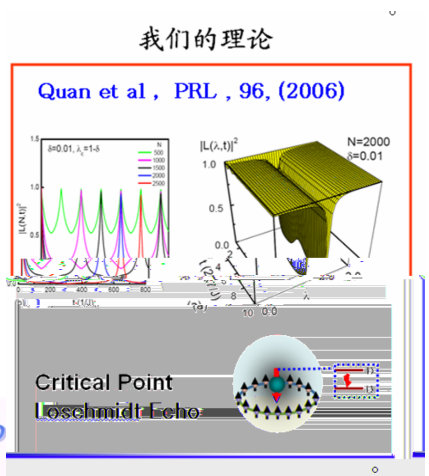
4

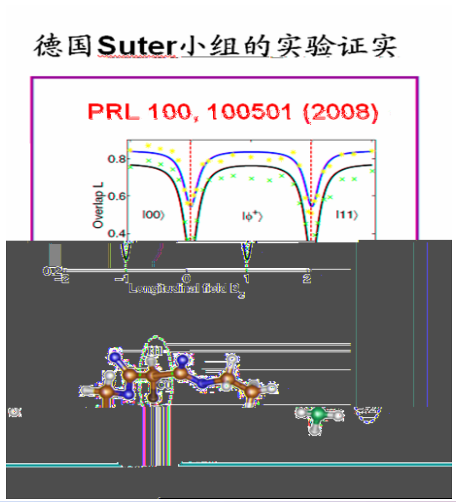
2

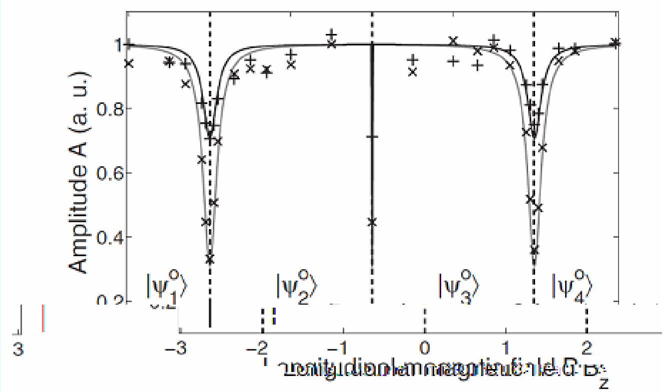
Laflamme

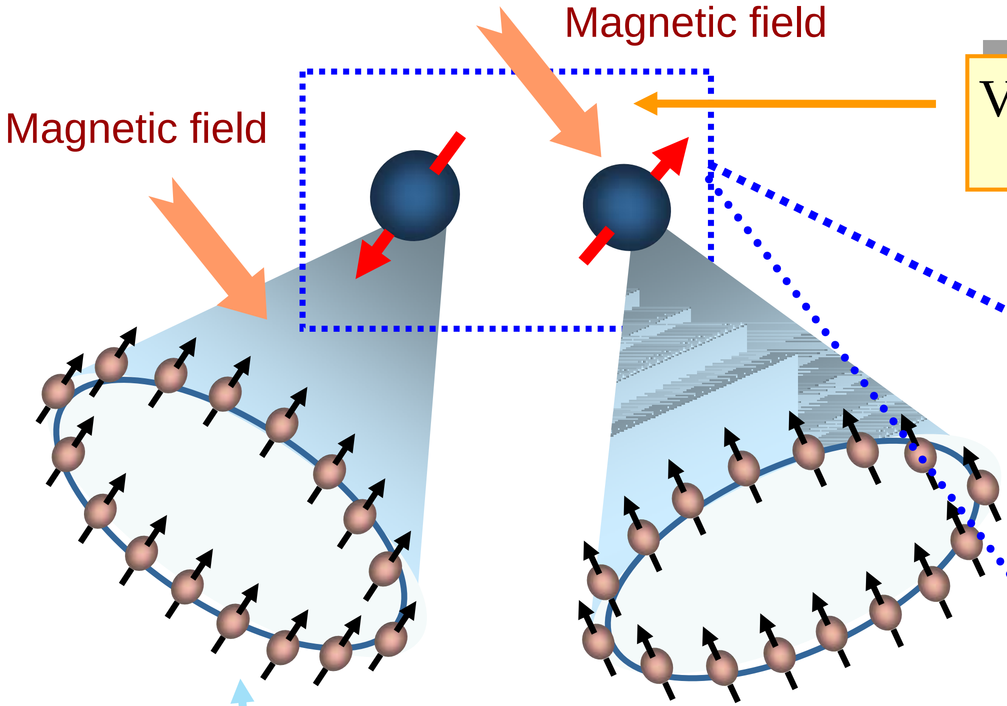
Phys.Rev. A 79,012305 (2009)

There has been a recent flurry of activity following the bservation [6] that the proximity to a quantum critical point nhances the sensitivity of a system to external perturbations, s measured by quantum-information-theoretical quantities [redacted]









$$V_n = \varepsilon\sigma_n^z + \Delta\sigma_n^x + Jg\sigma_n^x \sum_j I_{n,j}^x,$$

$$|S\rangle_e = \frac{1}{\sqrt{2}}(|\uparrow\downarrow\rangle_e - |\downarrow\uparrow\rangle_e)$$

$$|T_+\rangle_e = |\uparrow\uparrow\rangle_e, \quad |T_-\rangle_e = |\downarrow\downarrow\rangle_e,$$

$$|T_0\rangle_e = \frac{1}{\sqrt{2}}(|\uparrow\downarrow\rangle_e + |\downarrow\uparrow\rangle_e)$$

$$H_n = J\sum_{j=1}^{N}(I_{n,j}^z I_{n,j+1}^z + \lambda I_{n,j}^x)$$

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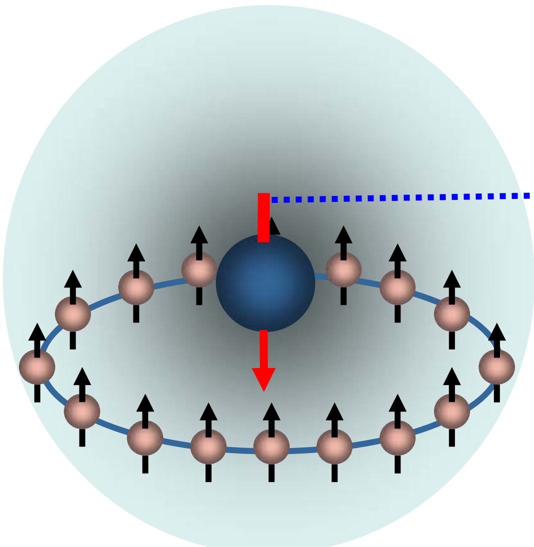
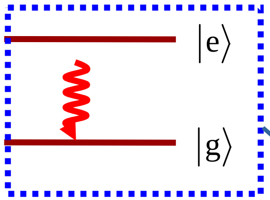
Hepp-Coleman

$$H = H_0 + H_1 = -J\sum_j (\sigma_j^z \sigma_{j+1}^z + g\sigma_j^x + \delta|e\rangle\langle e|\sigma_j^x)$$





$$\mathrm{H_e} = \mathrm{H_e}(\lambda) = \mathrm{H_g} + \mathrm{V_e}$$

$$V_e = -J\delta\sum_j \sigma_j^x$$

$$H_g = H_0 = -J\sum_j (\sigma_j^z \sigma_{j+1}^z + g\sigma_j^x)$$

$$|\psi(0)\rangle = (c_g|g\rangle + c_e|e\rangle)\otimes|G\rangle_g \quad \longrightarrow \quad |\psi(t)\rangle = c_g|g\rangle\otimes|\varphi_g(t)\rangle + c_e|e\rangle\otimes|\varphi_e(t)\rangle$$

$$\rho_S(t) = c_g c_g^*|g\rangle\langle g| + c_e c_e^*|e\rangle\langle e| + \langle\phi_e|\phi_g\rangle c_g c_e^*|g\rangle\langle e| + \langle\phi_g|\phi_e\rangle c_e c_g^*|e\rangle\langle g|$$

Loschmidt echo

$$[\rho_s(t)]_{eg} = c_g c_e^* D(t)$$

$$D(t) = \langle \varphi_g(t) | \varphi_e(t) \rangle \qquad |\varphi_\alpha(t)\rangle = \exp(-iH_\alpha t)|G\rangle_g$$

(Loschmidt echo)

$$L(\lambda,t) = \left| \langle \phi_g(t) | \phi_e(t) \rangle \right|^2 = \left| \langle G|_g \exp(iH_g t)\exp(-iH_e t)|G\rangle_g \right|^2$$

$$L(\lambda,t) = \prod_{k>0} [1 - \sin^2(2\alpha_k)\sin^2(\varepsilon_e^k t)].$$

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$$H_e = -J\sum_j [\sigma_j^z \sigma_{j+1}^z + (g+\delta)\sigma_j^x] = \sum_k \varepsilon_e^k (A_k^\dagger A_k - 1/2)$$

$$H_g = -J\sum_j (\sigma_j^z \sigma_{j+1}^z + g\sigma_j^x) = \sum_k \varepsilon_g^k (B_k^\dagger B_k - 1/2)$$

$$\mathrm{A_k} |\mathrm{G}\rangle_e = 0 \qquad \mathrm{B_k} |\mathrm{G}\rangle_g = 0$$

$$\mathrm{B}_{\pm k} = \cos(\alpha_k)\mathrm{A}_{\pm k} - i\sin(\alpha_k)(\mathrm{A}_{\mp k})^\dagger,$$

BCS-like ground state:

$$|\mathrm{G}\rangle_g = \prod_{k>0}\left[i\cos(\alpha_k) + \sin(\alpha_k)\mathrm{A}_k^\dagger \mathrm{A}_{-k}^\dagger\right]|\mathrm{G}\rangle_e$$

H. T. Quan, Z. Song, X. F. Liu, and C. P. Sun, PRL 96, 140604 (2006)

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Born-Oppenheimer

$$|\psi_+\rangle = \cos\frac{\theta}{2}|\uparrow\rangle + \sin\frac{\theta}{2}|\downarrow\rangle,$$

$$|\psi_-\rangle = -\sin\frac{\theta}{2}|\uparrow\rangle + \cos\frac{\theta}{2}|\downarrow\rangle,$$

$$\theta = \frac{\Upsilon}{2} - \tan^{-1}\left(\frac{\text{[illegible]}}{\text{[illegible]}}\right).$$

$| \ \rangle$

Loschmidt Echo (I)

$$\psi(0) = |S\rangle \otimes \psi_1 \otimes \psi_2$$

$$\rho_S(t) = \frac{1}{2}\Big[|+-\rangle\langle+-| + |-+\rangle\langle-+| - D(t)|+-\rangle\langle-+| - D^*(t)|-+\rangle\langle+-|\Big]$$

Loschmidt Echo

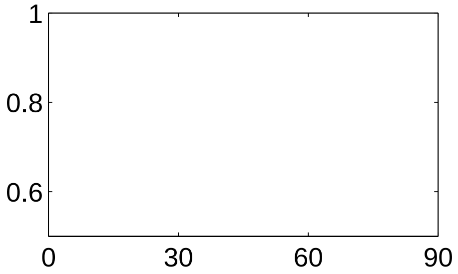
$$L(t) = D(t) = \mathrm{tr}\left|U_+^{\dagger}\,\psi\,U_-(t)\right|^2$$

$$P_S(t) = \int_0^t r_c(t)\, f_S(t)\, dt,$$

$$f_S(t) = \langle S|\psi_e(t)|S\rangle$$

$$r_c(t) = k_S \exp(-k_S t)$$

$$\Lambda(\theta) = \frac{\partial \Phi_S}{\partial \theta}.$$



Loschmidt Echo （ ）

$$P_S = \frac{1}{2} - \frac{1}{2} k_S \int_0^{\infty} L(t) e^{-k_S t} dt$$

$$f_S(t) = \frac{1}{2}\left(1 - L(t)\right)$$

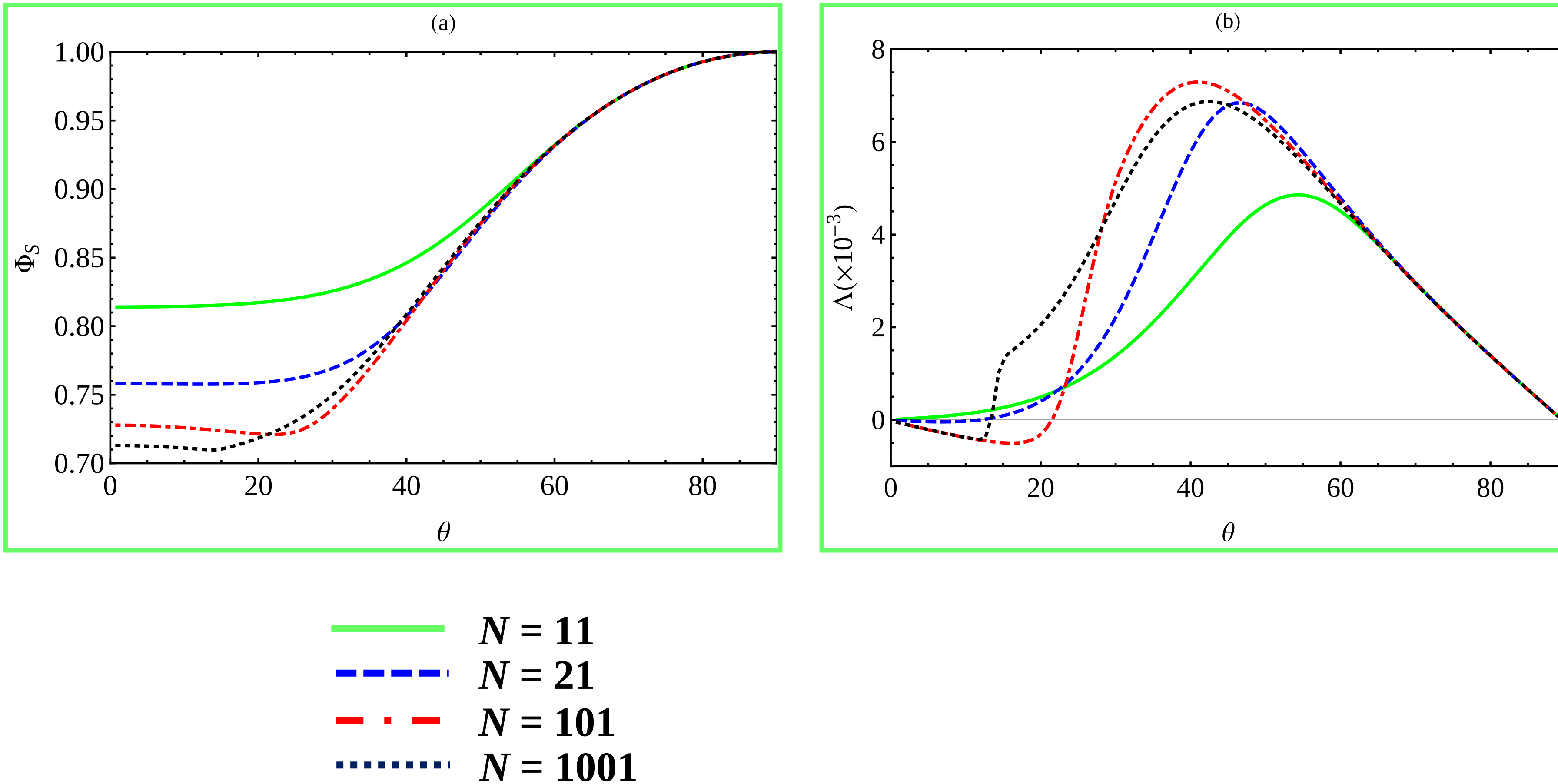
$$L(t) = \prod_{k>0} \frac{A_k^2 + B_k^2}{\left[1+\cosh\left(\beta\varepsilon_k^-\right)\right]^2},$$

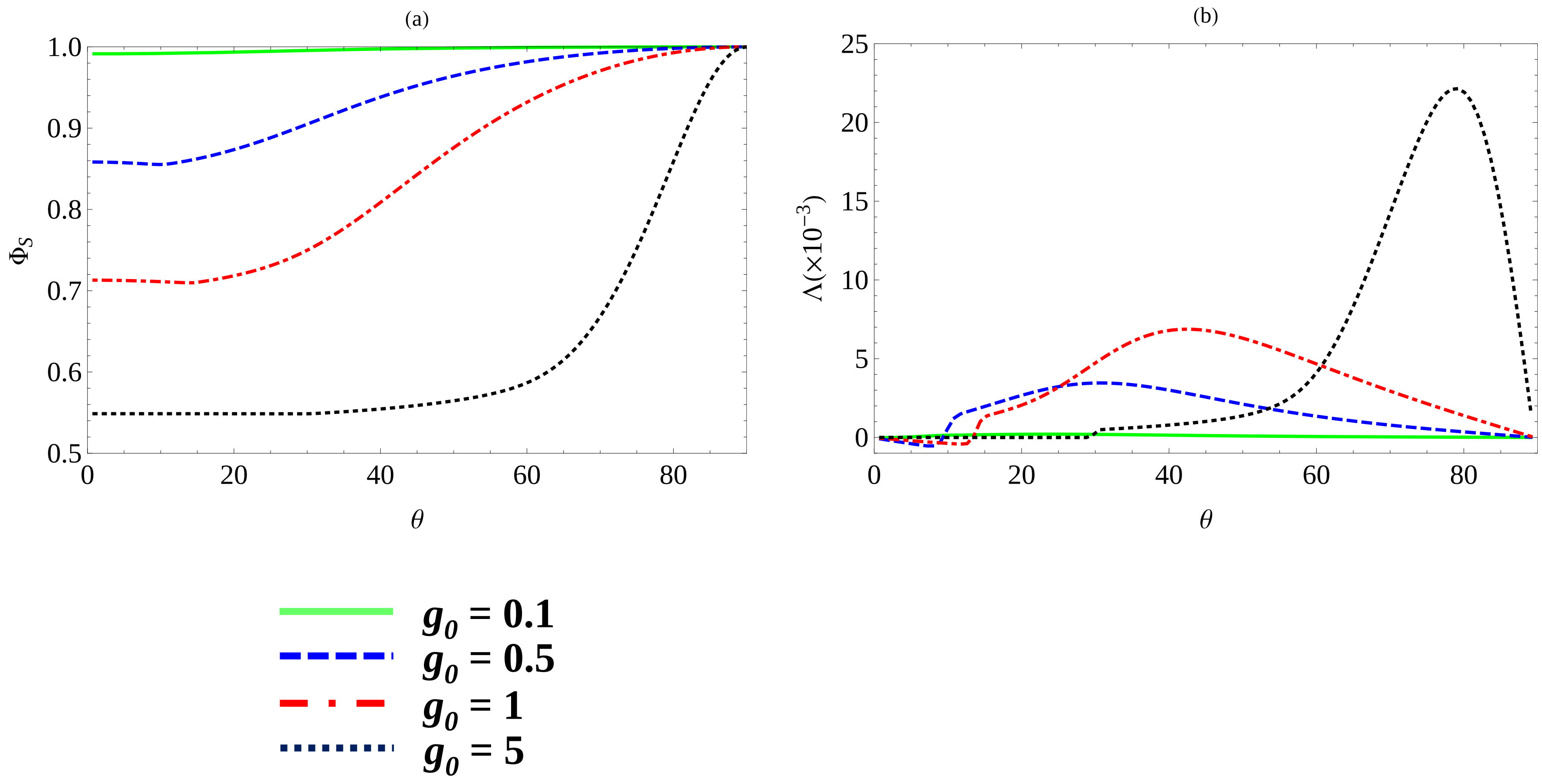
$$A_k = \left[\cos^2\alpha_k \cos(\varepsilon_k^+ - \varepsilon_k^-)t + \sin^2\alpha_k \cos(\varepsilon_k^+ + \varepsilon_k^-)t\right]\cosh\left(\beta\varepsilon_k^-\right) + 1,$$

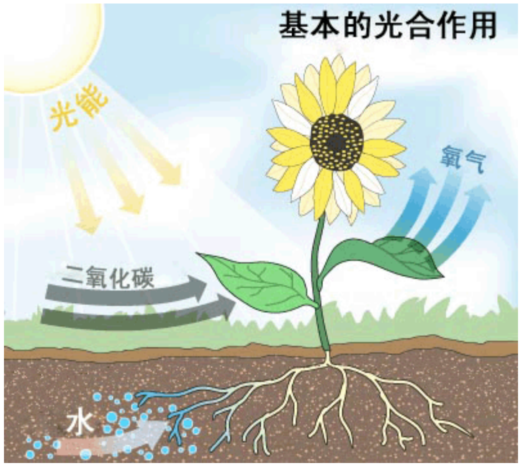
$$B_k = \left[\cos^2\alpha_k \sin(\varepsilon_k^+ - \varepsilon_k^-)t - \sin^2\alpha_k \sin(\varepsilon_k^+ + \varepsilon_k^-)t\right]\sinh\left(\beta\varepsilon_k^-\right),$$

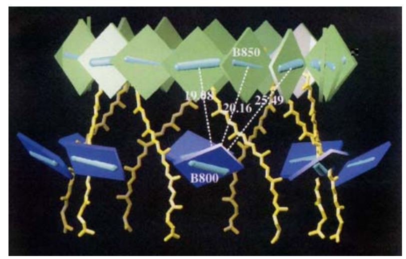
$$\alpha_k = \frac{1}{2}\left(\theta_k^- - \theta_k^+\right), \qquad \theta_k^{\pm} = \tan^{-1}\left(\Delta_k / \eta_k^{\pm}\right),$$

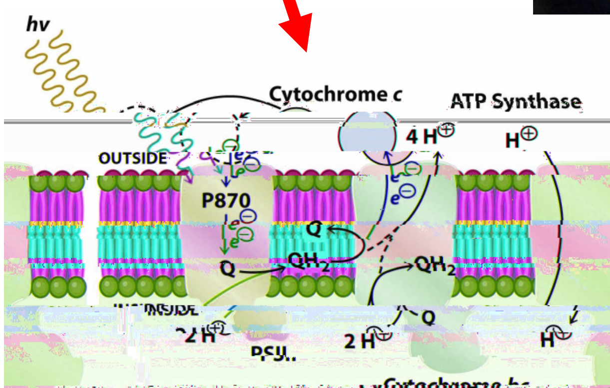
$$\varepsilon_k^{\pm} = \sqrt{\left(\eta_k^{\pm}\right)^2 + \Delta_k^2}, \qquad \eta_k^{\pm} = \eta_k\left(\lambda_{\pm}(\theta)\right).$$

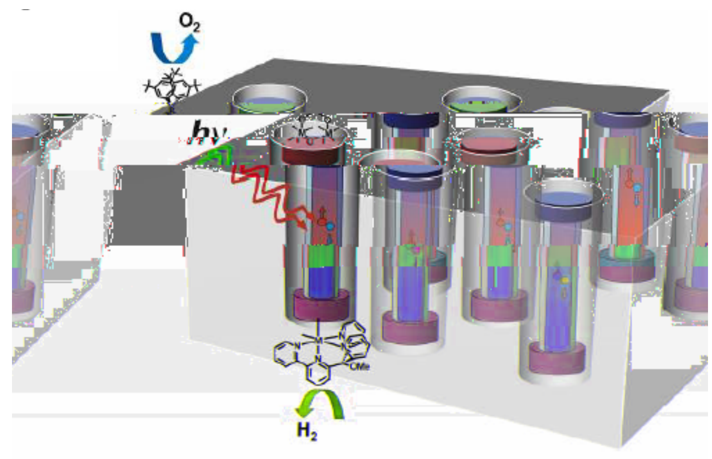

(a)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Φ_S
0
20
40
60
80
θ
(b)
8
6
4
2
0
$\Lambda(\times 10^{-3})$
0
20
40
60
80
θ
N = 11
N = 21
N = 101
N = 1001


(a)
(b)
1.0
0.9
0.8
0.7
0.6
0.5
0
20
40
60
80
Φ_S
θ
25
20
15
10
5
0
$\Lambda(\times 10^{-3})$
g_0 = 0.1
g_0 = 0.5
g_0 = 1
g_0 = 5


基本的光合作用
光能
氧气
二氧化碳
水

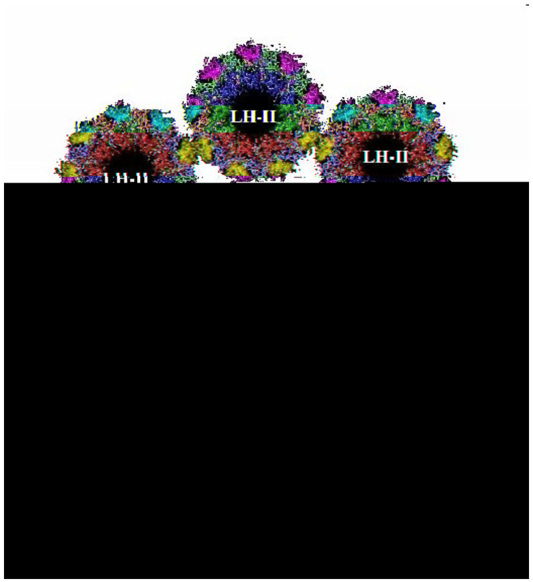

B850
19.68
20.16
25.49
B800

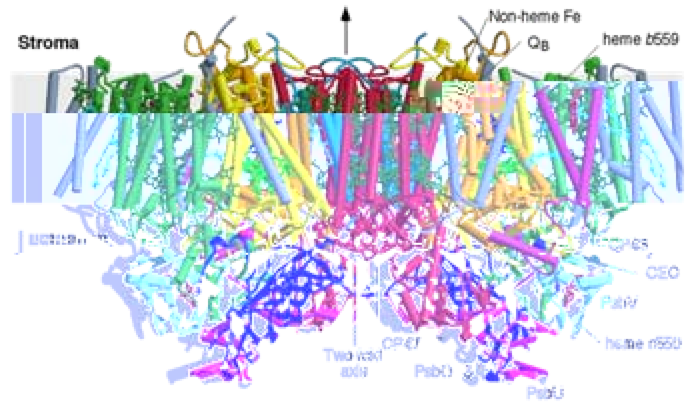

hv
Cytochrome c
ATP Synthase
OUTSIDE
P870
4 H⊕
H⊕
Q
QH2
2 H⊕


O2
hv
OMe
H2

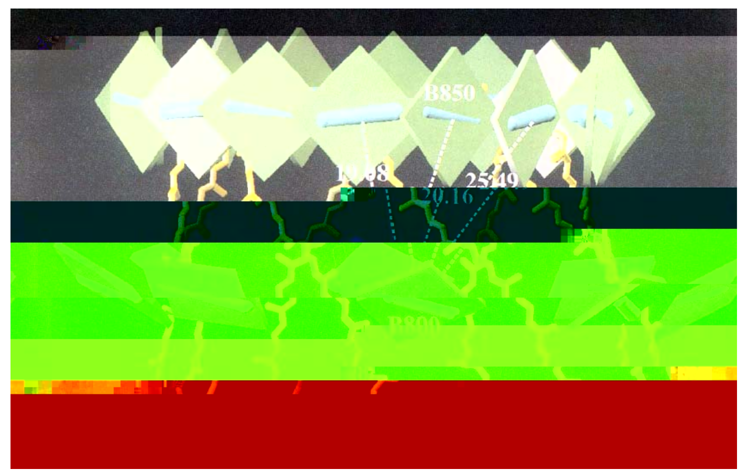
2009

LH II LH I

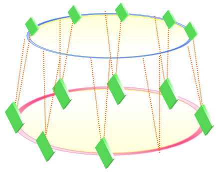




LH II

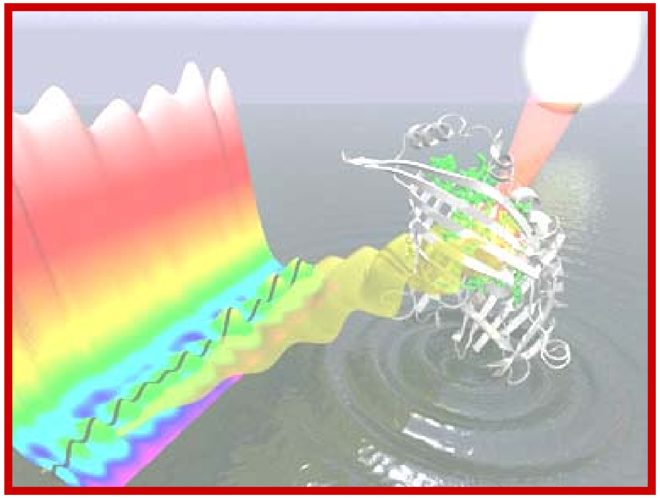


purple bacteria
(photosystem II)



Coherence Dynamics in Photosynthesis: Protein Protection of Excitonic Coherence

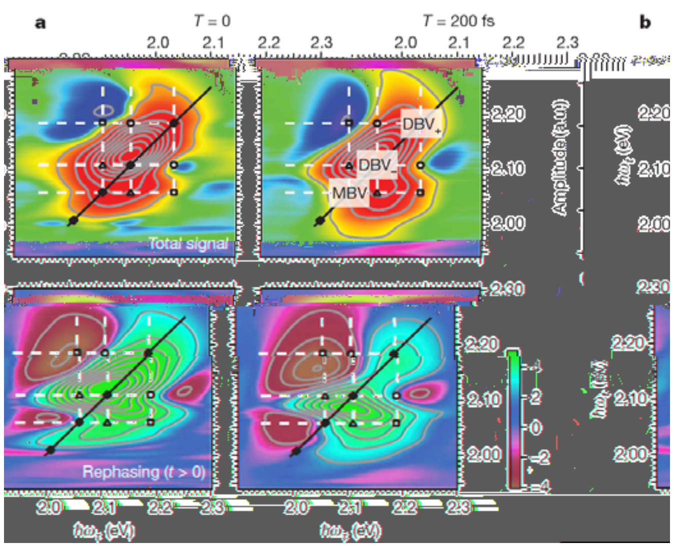
Science 8 June 2007:Vol. 316. no. 5830, pp. 1462



Fleming 2007
77K ,
(Fenna-
Matthew-Olson(FMO)
bacteri-ochlorophyll
complex) 660fs

Coherently wired light-harvesting in photosynthetic marine algae at ambient temperature

NATURE| Vol 463|644 |2010



(marinecryptophytealgae)

(

(two Dimensional photon echo spectroscopy),

300fs .

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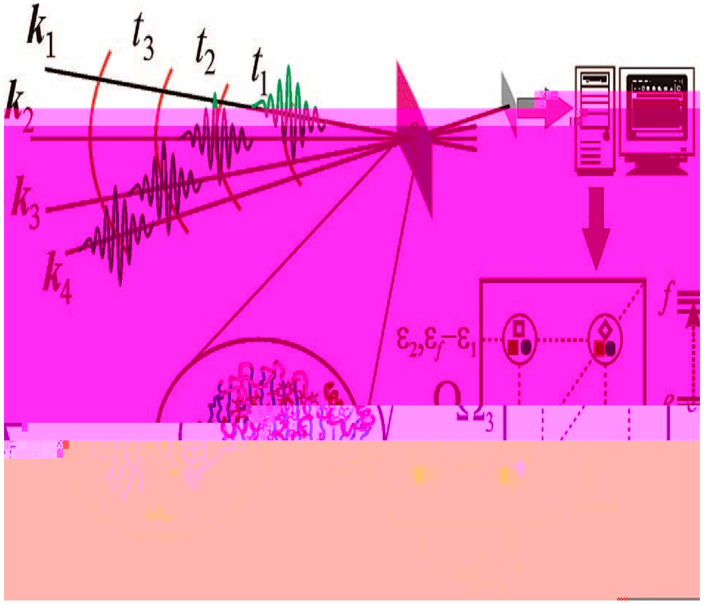
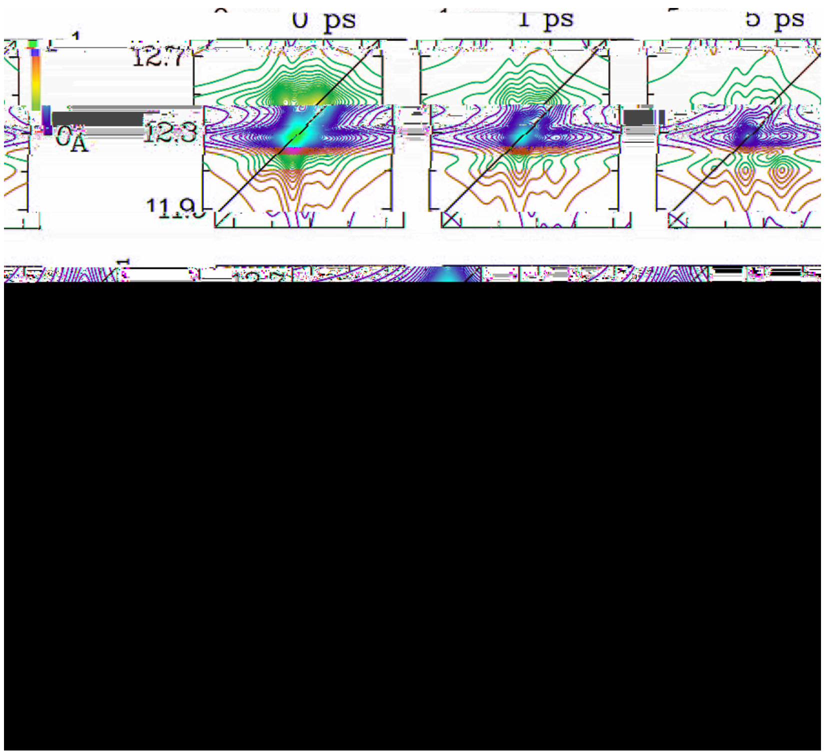
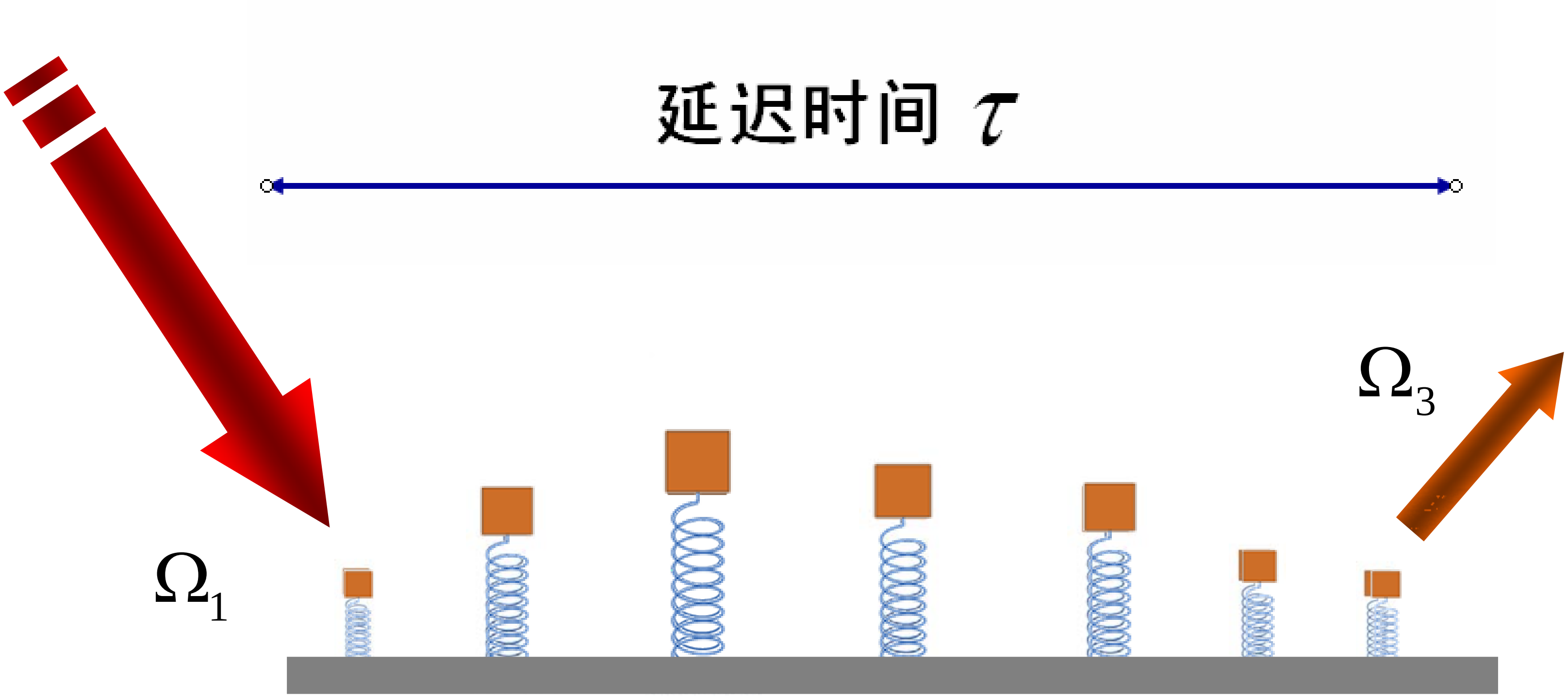
, 25 .

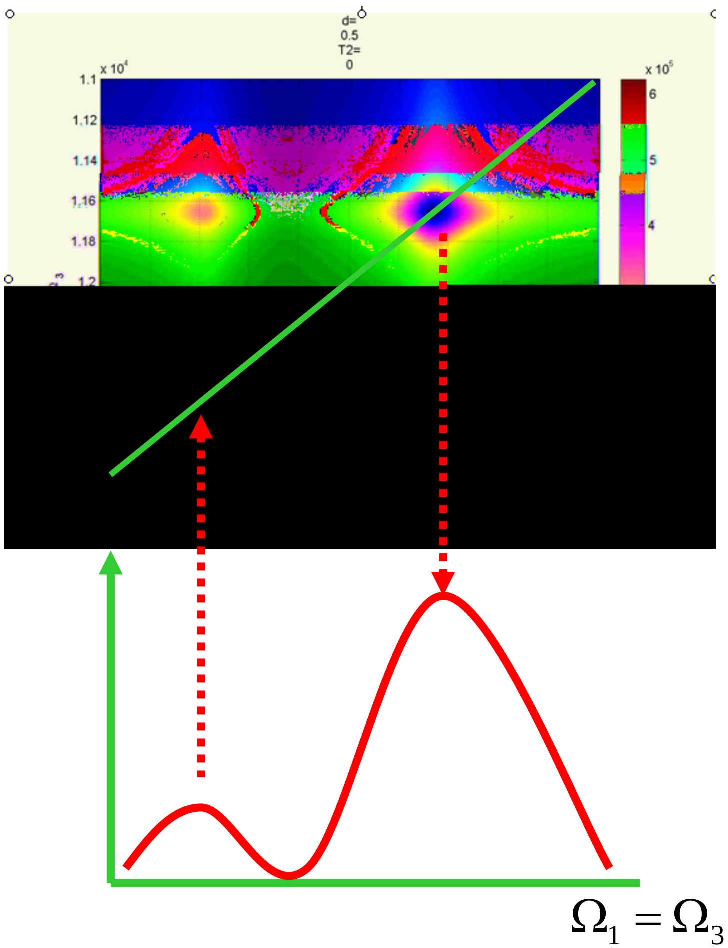




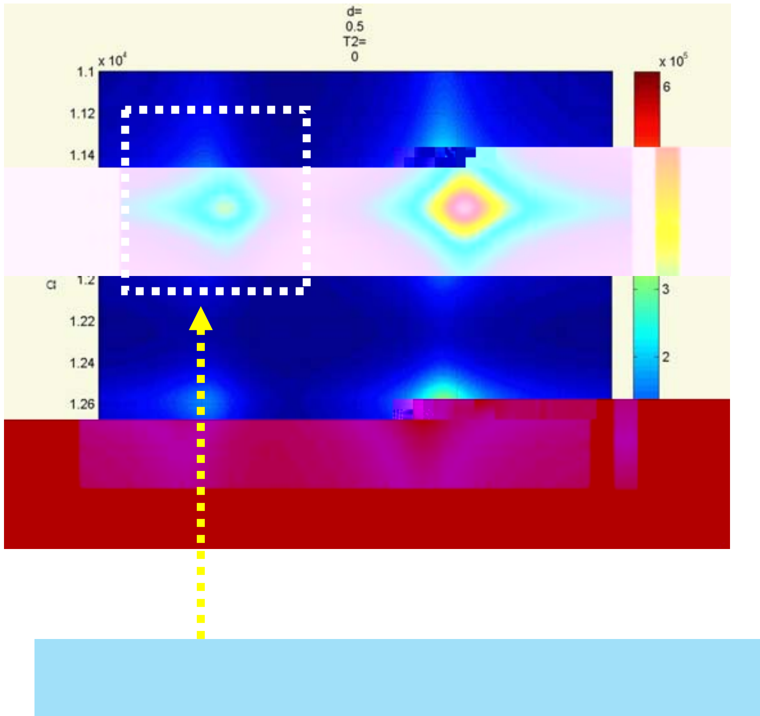
Fleming et. al, 2007



$$I_{k_s}(\Omega_3, \tau, \Omega_1)$$



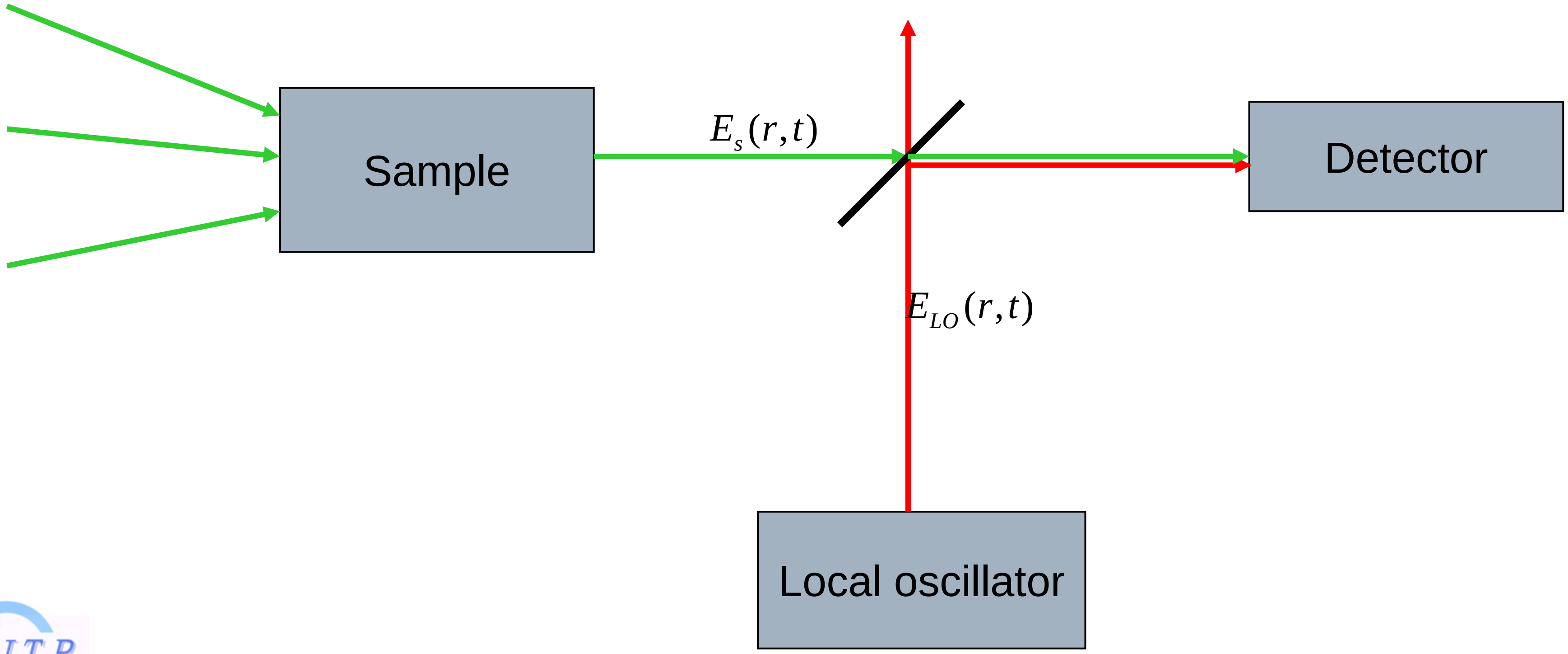
d=
0.5
T2=
0
x 10^4
1.1
1.12
1.14
1.16
1.18
1.2
x 10^5
6
5
4
$\Omega_1 = \Omega_3$



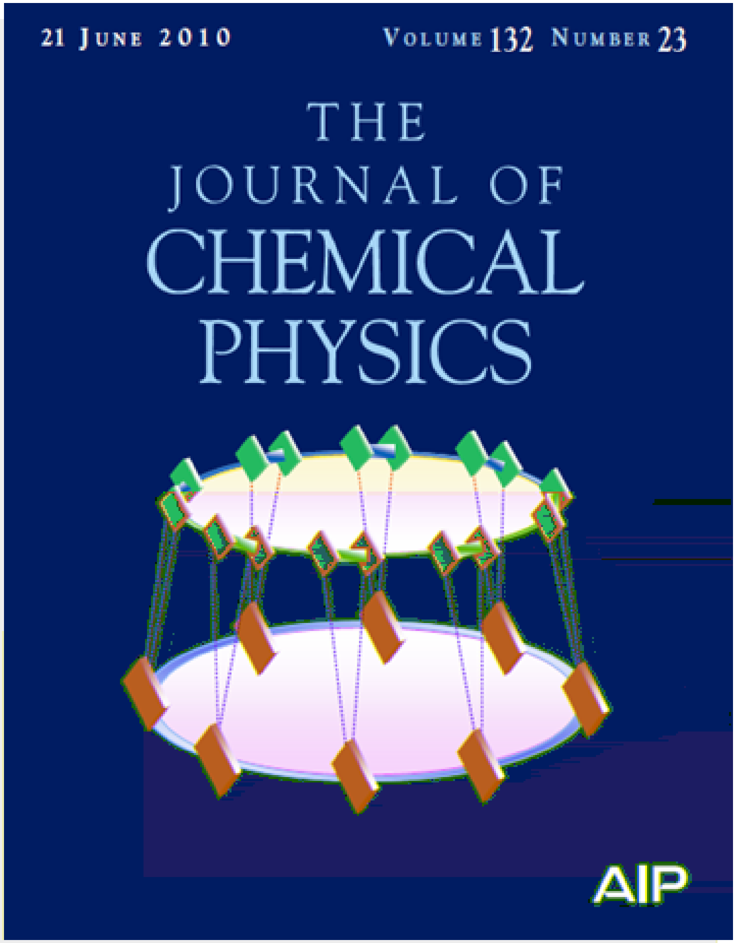
d=
0.5
T2=
0
x 10^4
1.1
1.12
1.14
1.2
1.22
1.24
1.26
x 10^5
6
3
2

Heterodyne detected signal

- Experimental setup for heterodyne detection



Dimerization-assisted energy transport in light-harvesting complexes



THE JOURNAL OF CHEMICAL PHYSICS 132, 234501 (2010)

Dimerization-assisted energy transport in light-harvesting complexes

S. Yang,[1] D. Z. Xu,[1] Z. Song,[2] and C. P. Sun[1,a)]
[1]*Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*
[2]*School of Physics, Nankai University, Tianjin 300071, China*

(Received 20 February 2010; accepted 5 May 2010; published online 15 June 2010)

We study the role of the dimer structure of light-harvesting complex II (LH2) in excitation transfer from the LH2 [without a reaction center (RC)] to the LH1 (surrounding the RC) or from the LH2 to another LH2. The excited and unexcited states of a bacteriochlorophyll (BChl) are modeled by a quasispin. In the framework of quantum open system theory, we represent the excitation transfer as the total leakage of the LH2 system and then calculate the transfer efficiency and average transfer time. ... states with various quantum superposition properties. We study how the dimerization of the B850 BChl ring can enhance the transfer efficiency and shorten the average transfer time. © 2010 *American Institute of Physics*. [doi:10.1063/1.3435213]

I. INTRODUCTION

To face the present and forthcoming global energy crisis, ... should search for clean and effective energy sources. ... the investigations on the basic energy science for ... purpose has received great attention and experienced impressive progress based on the fundamental physics.[1,2] In ... photosynthetic process, the structural elegance and chemical efficiency of the natural system based on pigment molecules in transferring the energy of sunlight have stimulated those driven investigation,[3–13] finding artificial analogs of porphyrin-based chromophores. These artificial systems replicate the natural process of photosynthesis[2] so that the much higher efficiencies could be gained than that obtained in the conventional solid systems.[2] It is because one of the most attractive features of photosynthesis is that the light energy can be captured and transported to the reaction center

[illegible]

... energy. Most recent experiments have been able to determine the time scales of various transfer processes by the ultrafast laser technology.[16–18] These great progresses obviously offer us a chance to quantitatively ...

its induced decoherence could affect on the efficiency of the primary photosynthetic event. The present paper will similarly study the influences of spatial structure on the primary processes of photosynthesis for the light-harvesting complexes (LH2).

In the past, by making use of the x-ray crystallographic techniques, the structure of light-harvesting system has been elucidated.[3,19] In the purple photosynthetic bacteria, there exist roughly two types of light-harvesting complexes, referred to as light-harvesting complex I (LH1) and LH2. In LH1, the RC is surrounded by a B875 bacteriochlorophyll (BChl) ring with maximum absorption peak at 875 nm. The LH2 complex, however, does not contain the RC but can transfer energy excitation to the RC indirectly through LH1. In the purple bacteria, LH2 is a ring-shaped aggregate built up by eight (or nine) minimal units, where each unit consists of an $\alpha\beta$-heterodimer, three BChls, and one carotenoid. The

[illegible]

the neighbor one through the Föster mechanism,[4] while the electron is spatially transferred via the Marcus mechanism.[20] Generally, it is independent of the global geometry configuration of the system.

S. Yang, D. Z. Xu, Z. Song, CPS, JCP,132,234501(2010)

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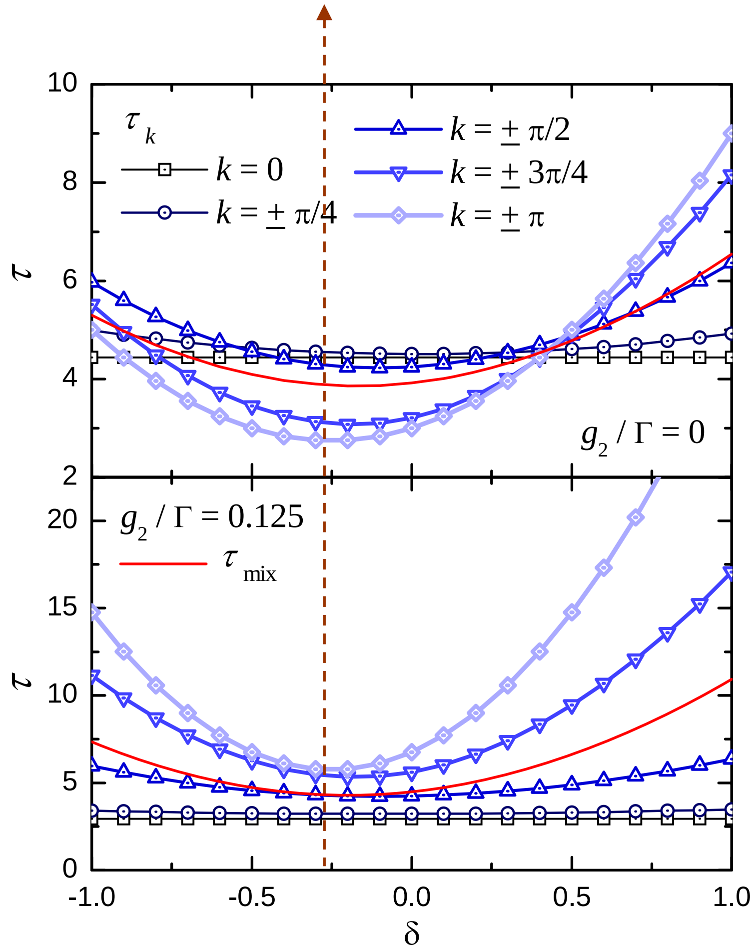
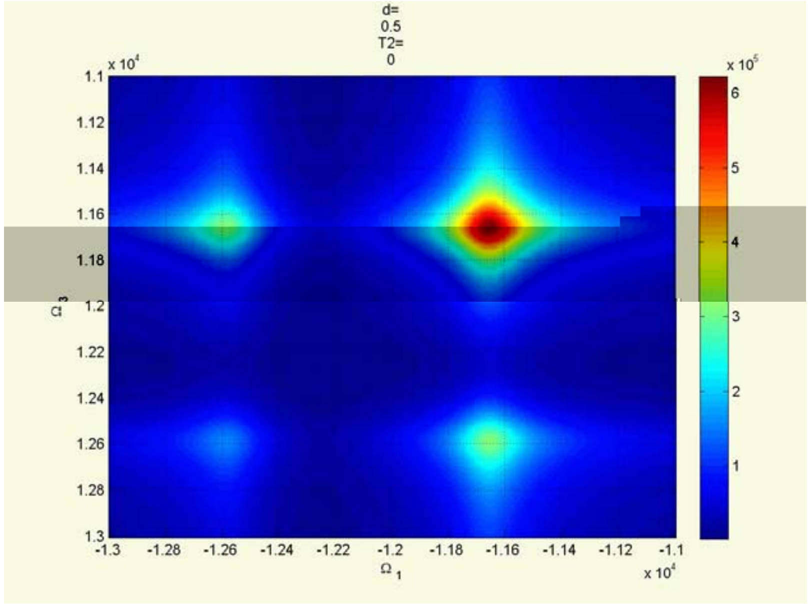
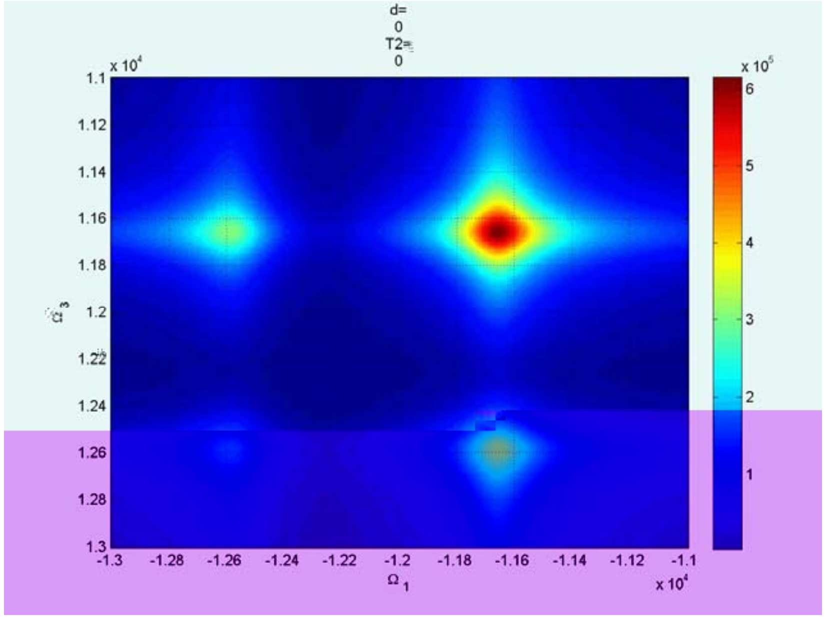


τ_k
k = 0
k = ± π/4
k = ± π/2
k = ± 3π/4
k = ± π
g_2 / Γ = 0
g_2 / Γ = 0.125
τ_mix
τ
δ





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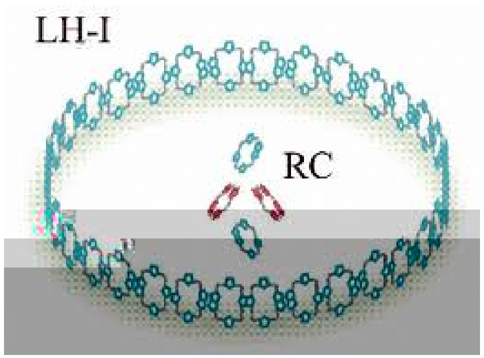
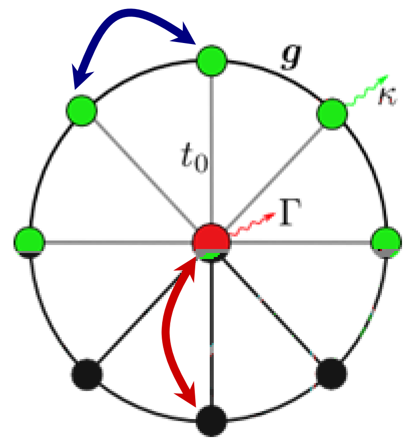
LH-I Model (I)





$$H_{DA} = \sum_{i=1}^{N} \left[\epsilon_i e_i^\dagger e_i + g\left(e_i^\dagger e_{i+1} + h.c.\right) \right] + \epsilon_A A^\dagger A + \sum_{i=1}^{N} t_i \left(e_i A^\dagger + e_i^\dagger A\right)$$

Γ: Usage rate of excitation

κ: Decay rate of excitation

A. Olaya-Castro, et al, Phys. Rev. B 78, 085115(2008)

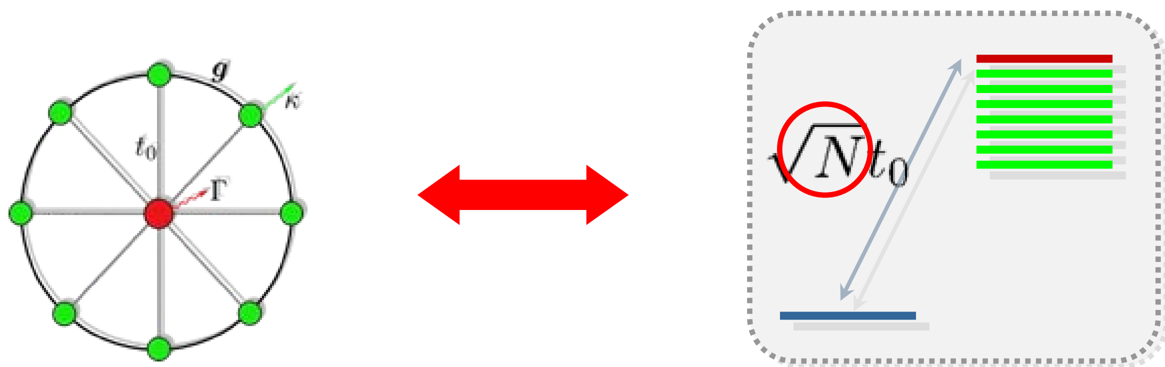
LH-I Model (II)

Fourier Transf: $\sum_k e^{ikj} e_k e_j = \frac{ikj}{\sqrt{N}}$

=0 mode: $|1_{k=0}\rangle = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} |1_i\rangle$

Effective Hamiltonian:

$$H^{DA} = (\omega_{\rm eff} + 2g)\,\tilde{a}^\dagger \tilde{a} + \omega_A A^\dagger A + \sqrt{N} t_0 \left(\tilde{c}_0 A^\dagger + \tilde{c}_0^\dagger A \right)$$



Transfer Properties

Transfer Efficiency:

$$\eta = \int_0^\infty 2\Gamma \left| v\left(t\right) \right|^2 dt$$

Population on Acceptor

Average transfer time:

$$\tau = \frac{1}{\eta} \int_0^\infty 2\Gamma t \left| v\left(t\right) \right|^2 dt$$

Average ouput power:

$$\mathcal{P} = \eta / \tau$$

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A. Olaya-Castro, et al, Phys. Rev. B 78, 085115(2008)

From Donor to Acceptor

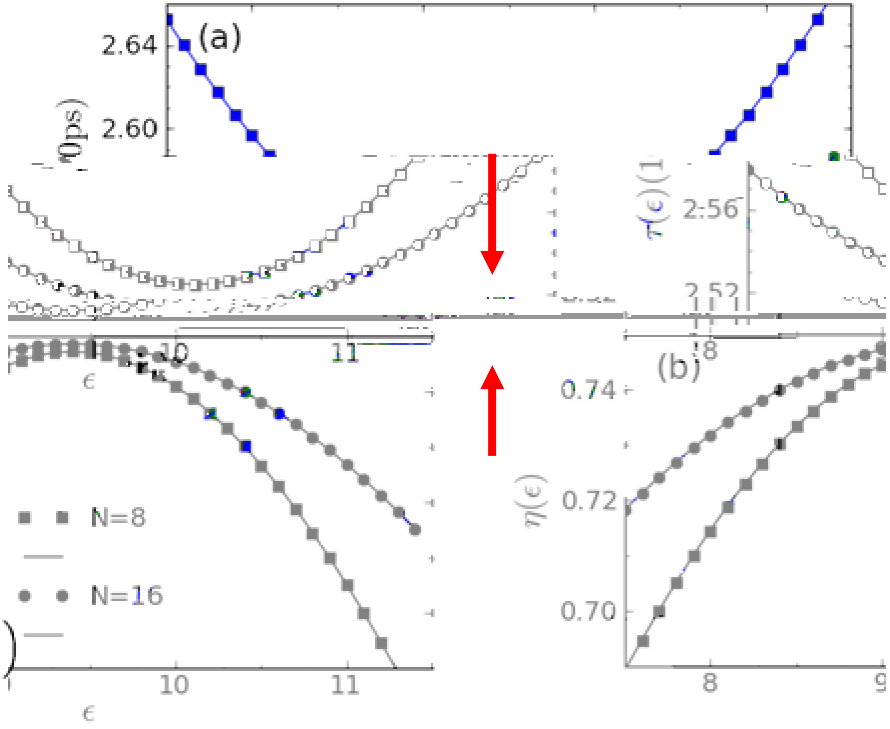
Initial Excitation on Donor ring

Optimal case:

$$\epsilon + 2g = \epsilon_A$$

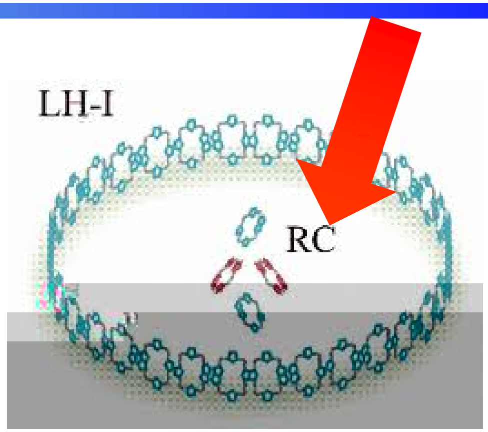
$\max \eta$ $\qquad$ $\min \tau$

$$\eta_{\max} \leq \Gamma/(\Gamma + \kappa)$$



There should be light...

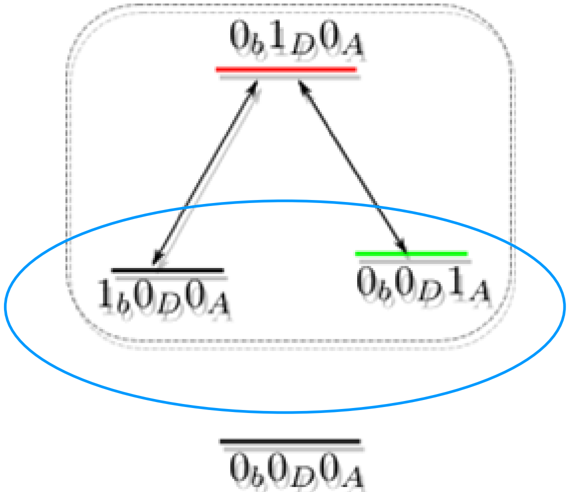
Visible light-wavelength ~ 500nm
LH-I radius ~ 4-6nm



Photon-Donor interaction:

$$H_{pD} = J \sum_{i=1}^{N} \left(e_i^{+} b + \mathrm{h.c} \right)$$

$$H_{\mathrm{eff}} = \omega_0 \tilde{e}_0^{\dagger} \tilde{e}_0 + \omega b^{\dagger} b + \omega_A A^{\dagger} A + \sqrt{N}[(t_0 \tilde{e}_0^{\dagger} A + J \tilde{e}_0^{\dagger} b) + \mathrm{h.c.}]$$



Oct.2010, ScientificAmerican.com

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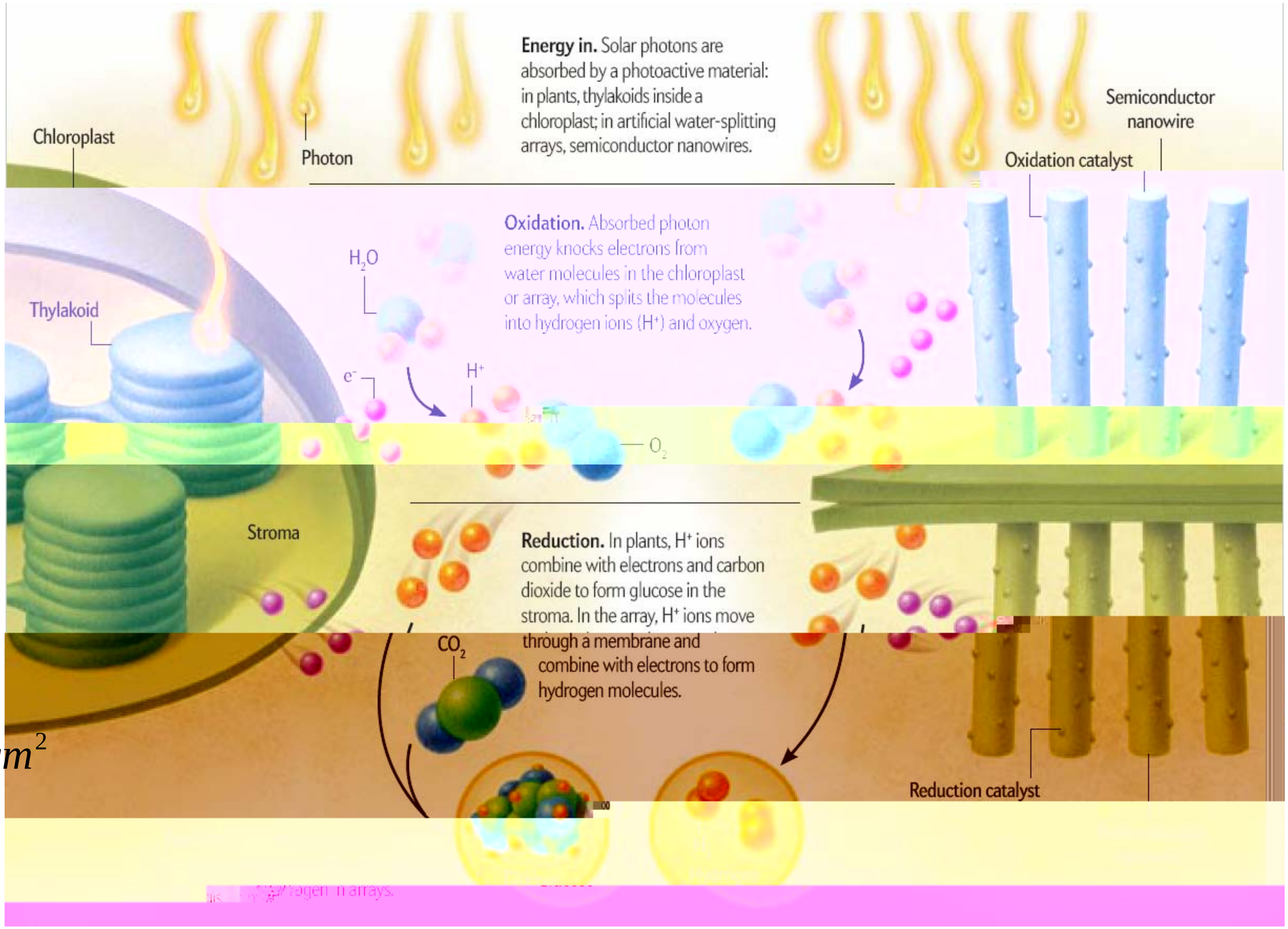
$10000 usd / cm^2$



Phys. Today **61, July 28 (2008)**

Grand challenges in basic energy sciences

Graham R. Fleming and Mark A. Ratner

Research focused in five related areas will allow unprecedented control over the microscopic world and could be the key to a sustainable future.

Thank You !

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