O RICERCHE
CO FERMI

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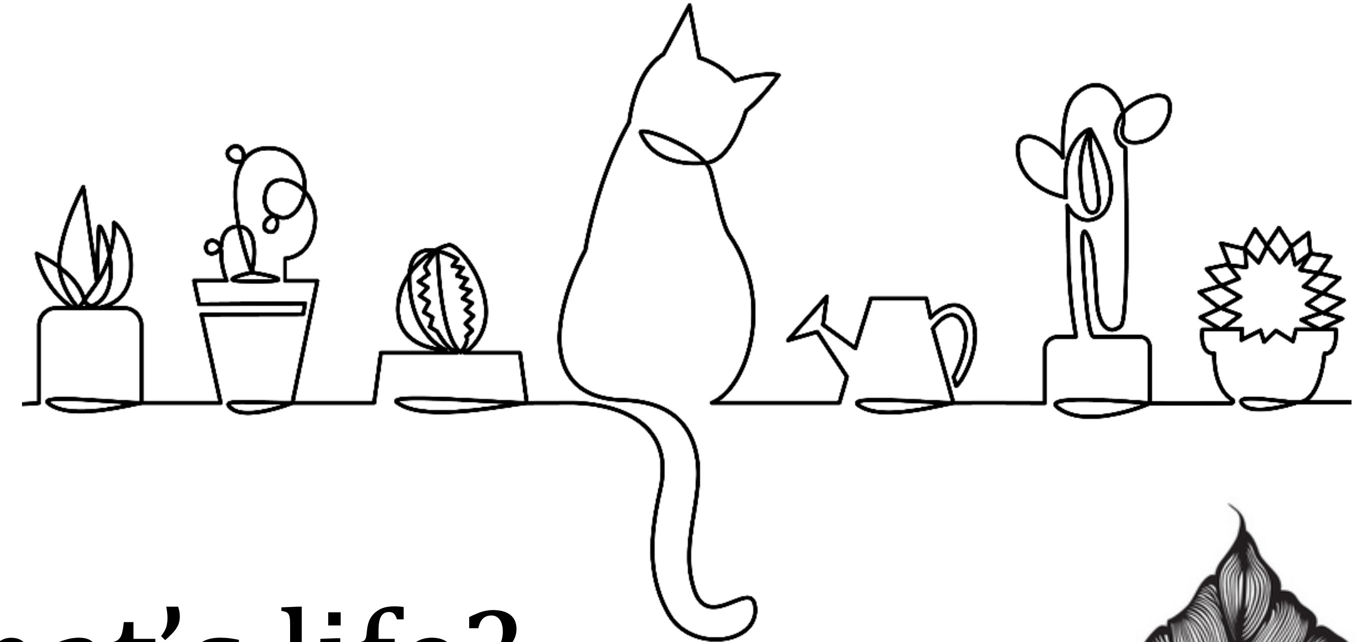
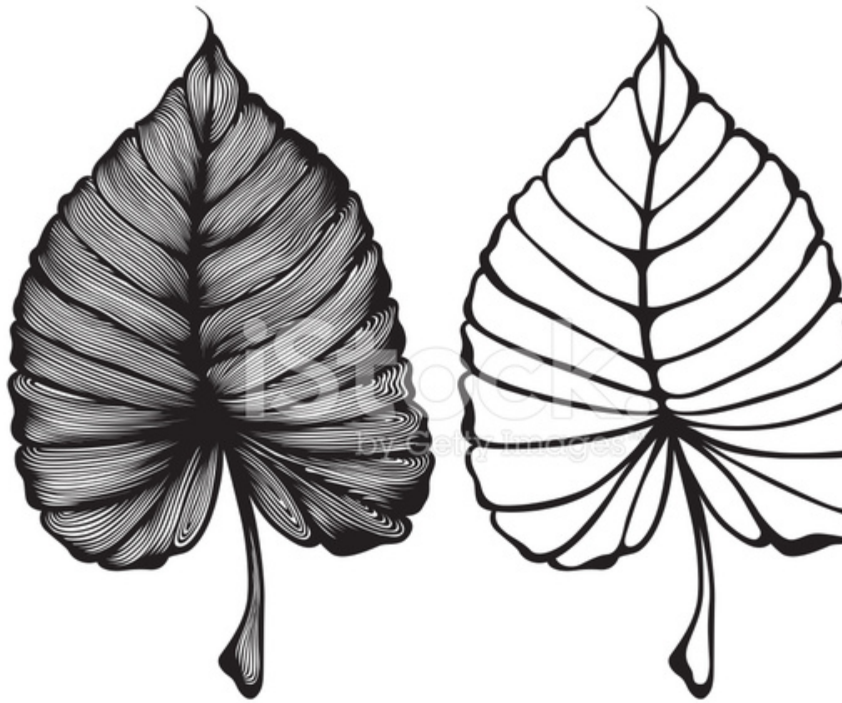


What’s life?

he extraordinary revelation that Quantum Mechanics really matters



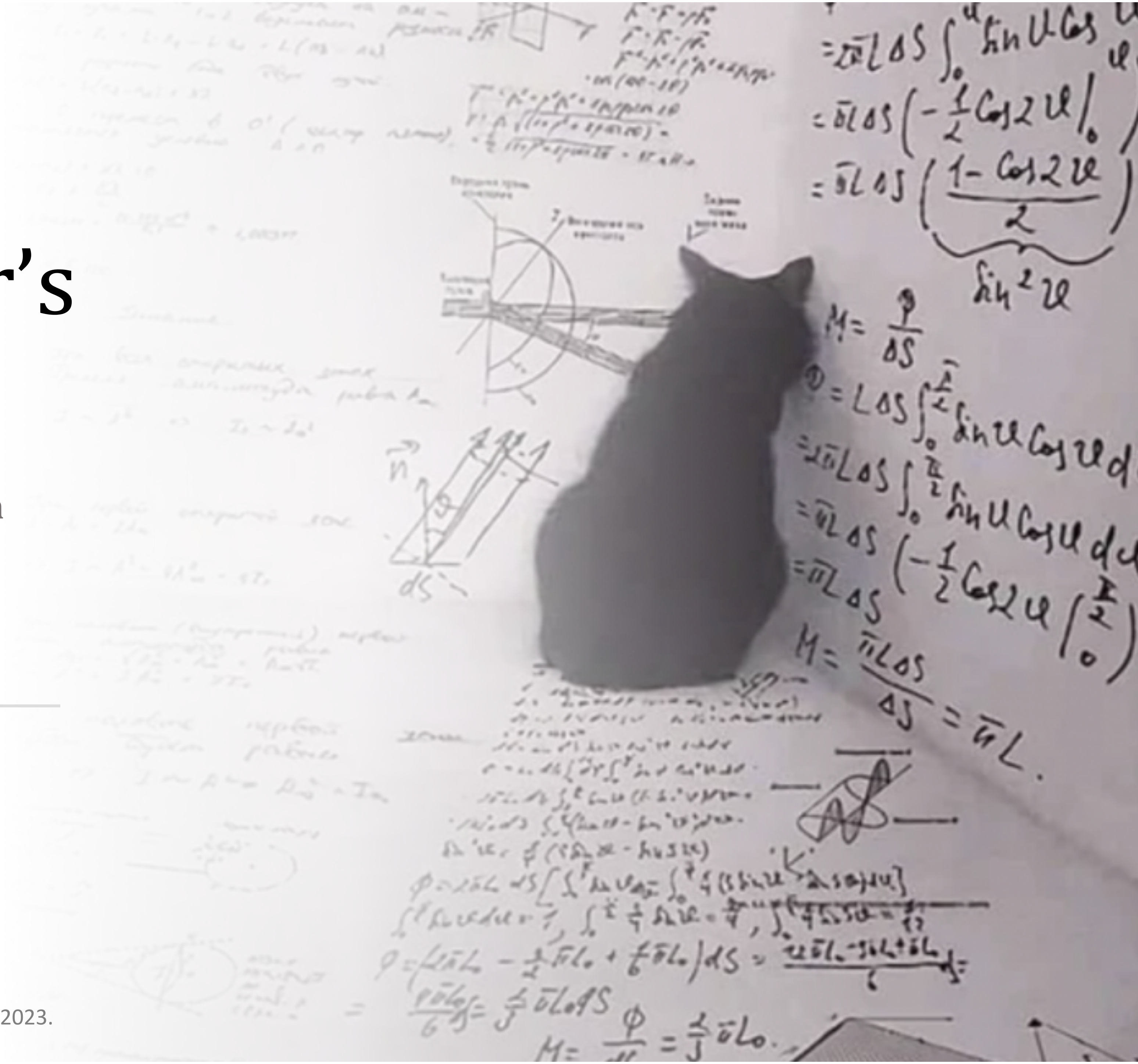
Silvia Pisano

useo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi

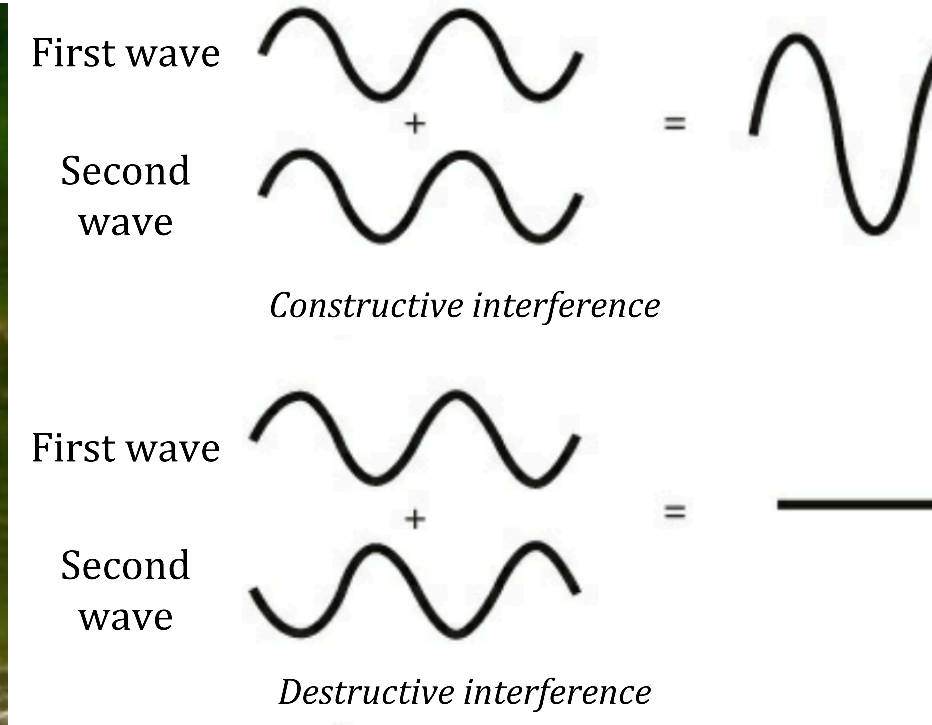
Laboratori Nazionali di Frascati - INFN

Schröedinger's cat

...or about the transition from quantum to classic world

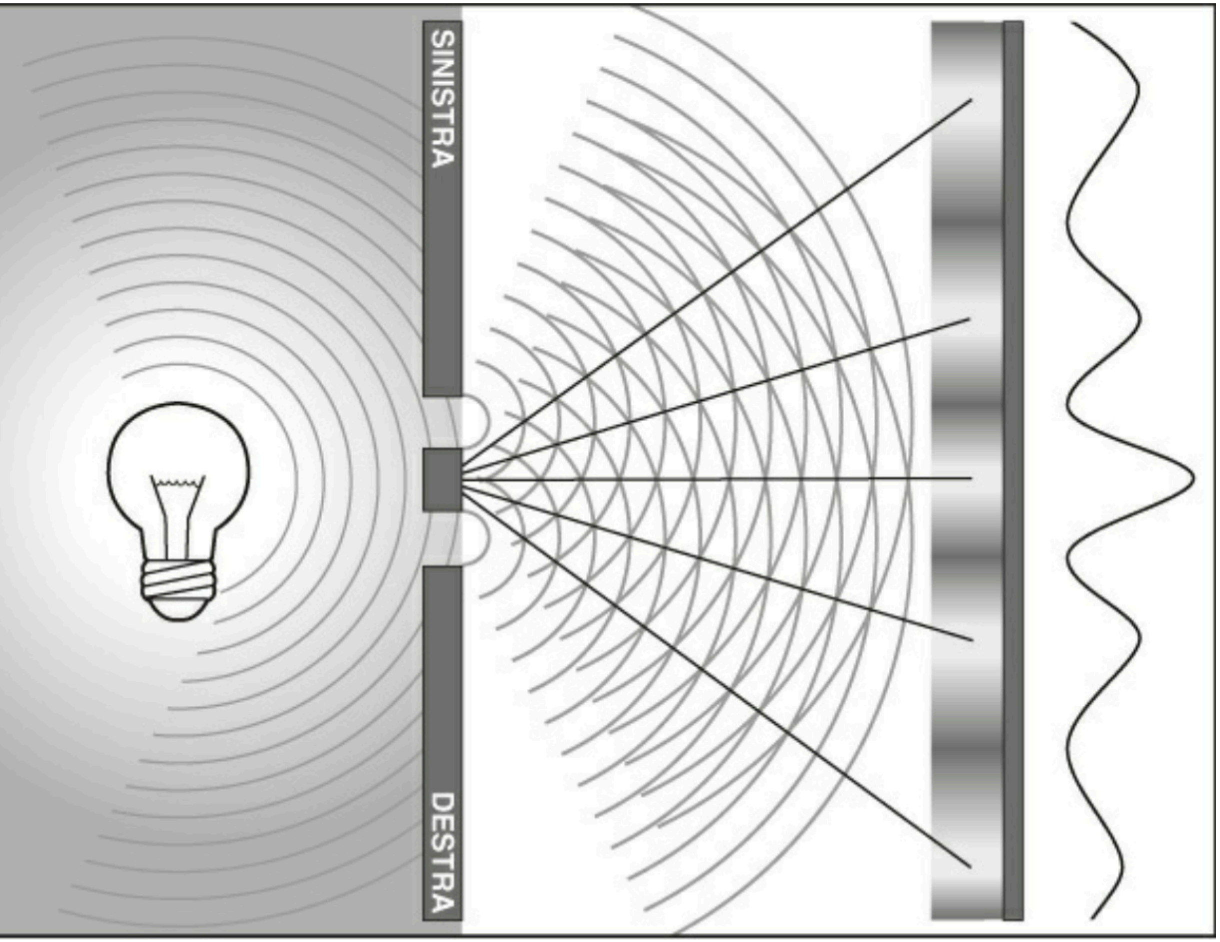


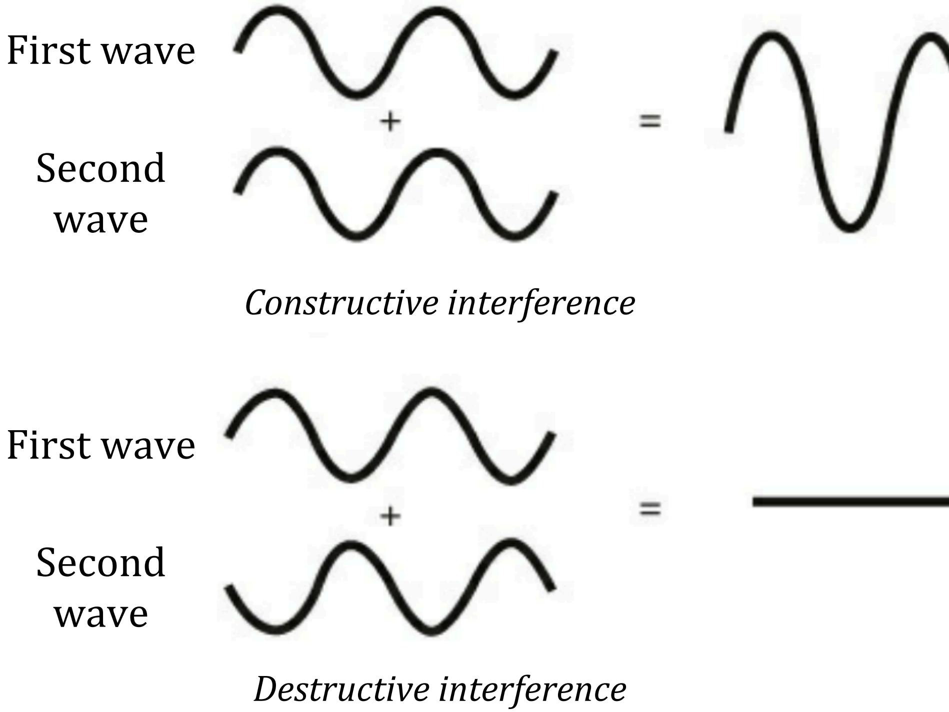
Stones in the pond



Stones in the pond

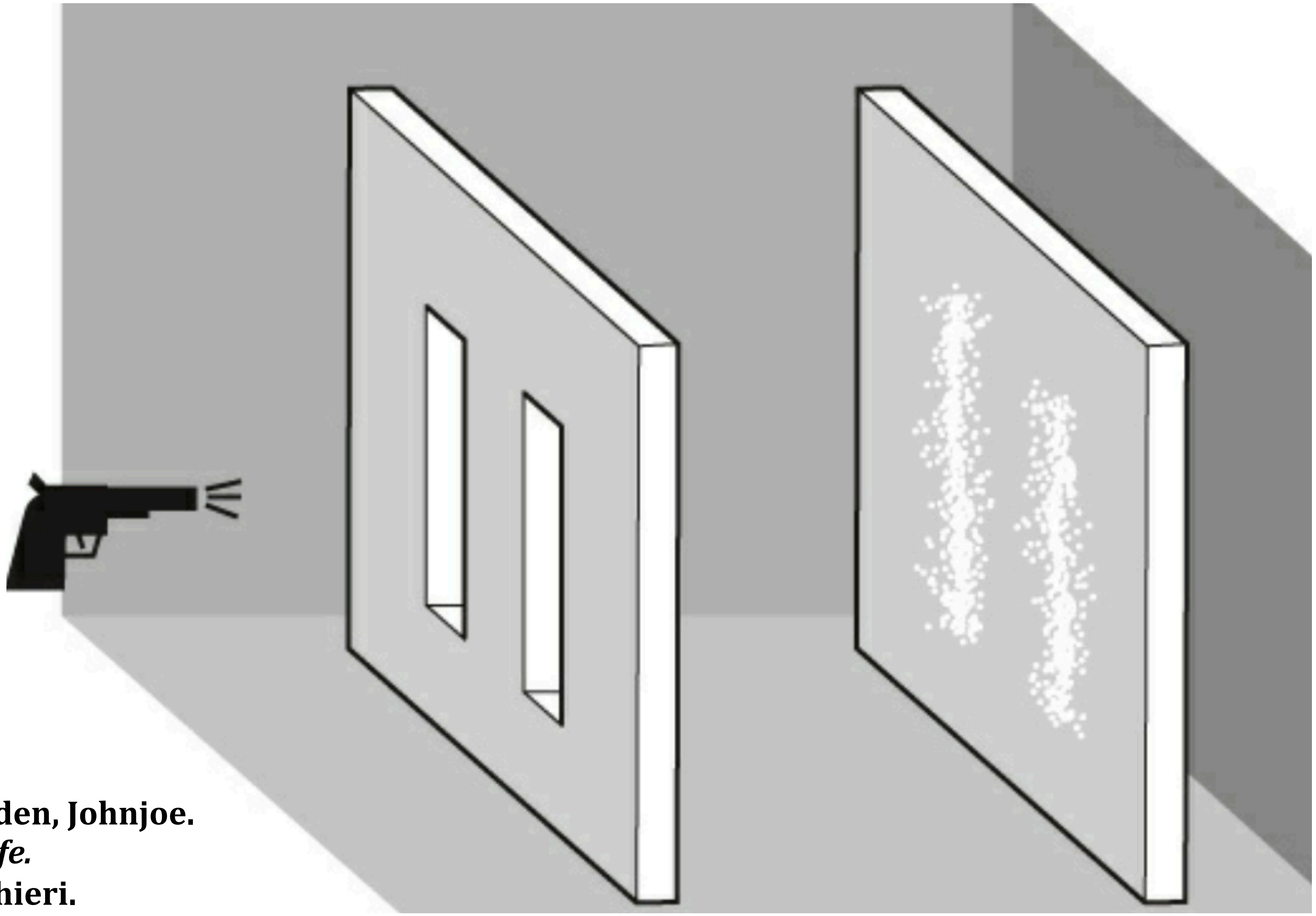
The double slit experiment





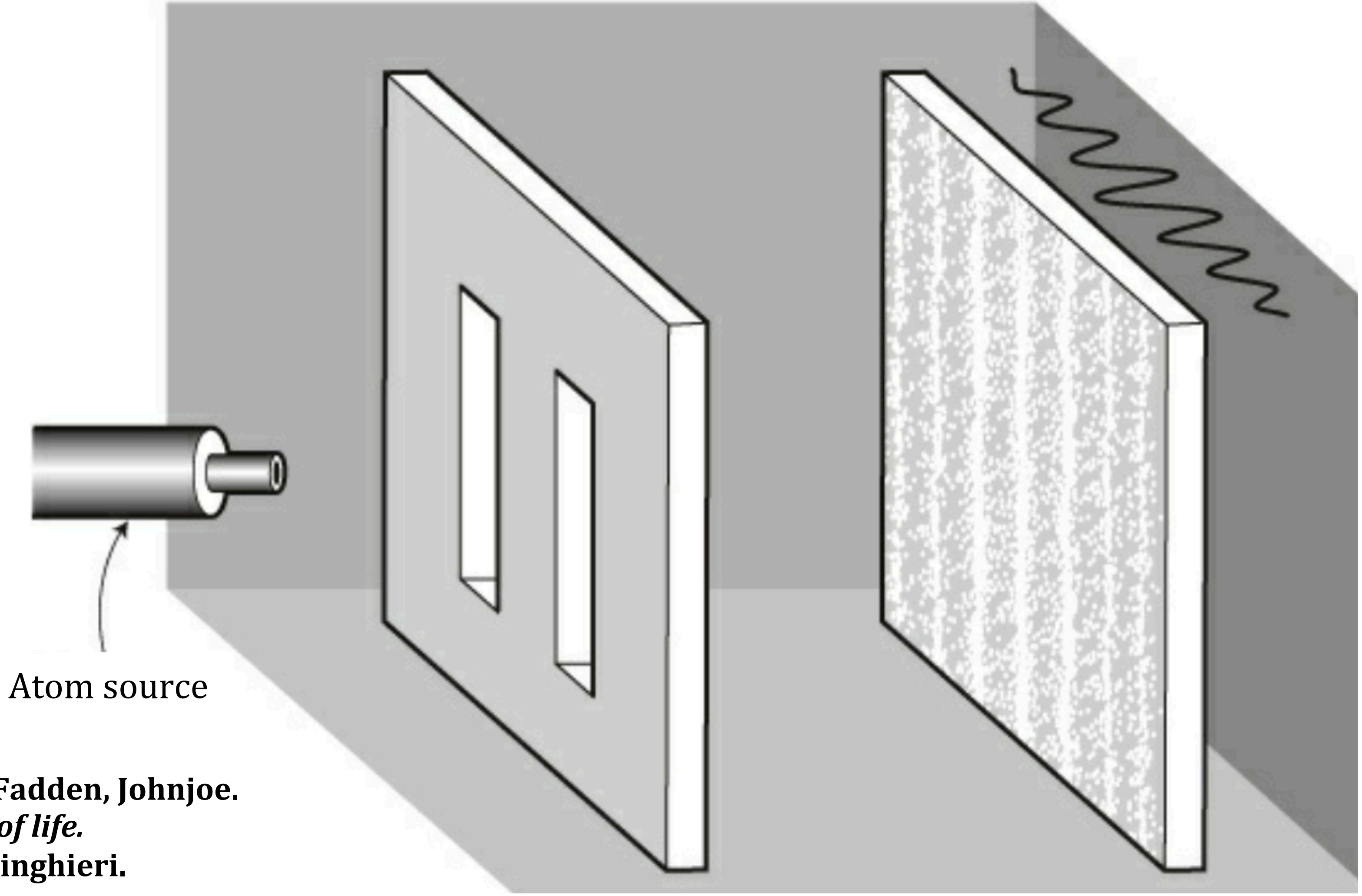
Al-Khalili, Jim; McFadden, Johnjoe. Physics of Li
Bollati Boringhieri.

The double slit experiment



Khalili, Jim; McFadden, Johnjoe.
Physics of life.
Bollati Boringhieri.

The double slit experiment



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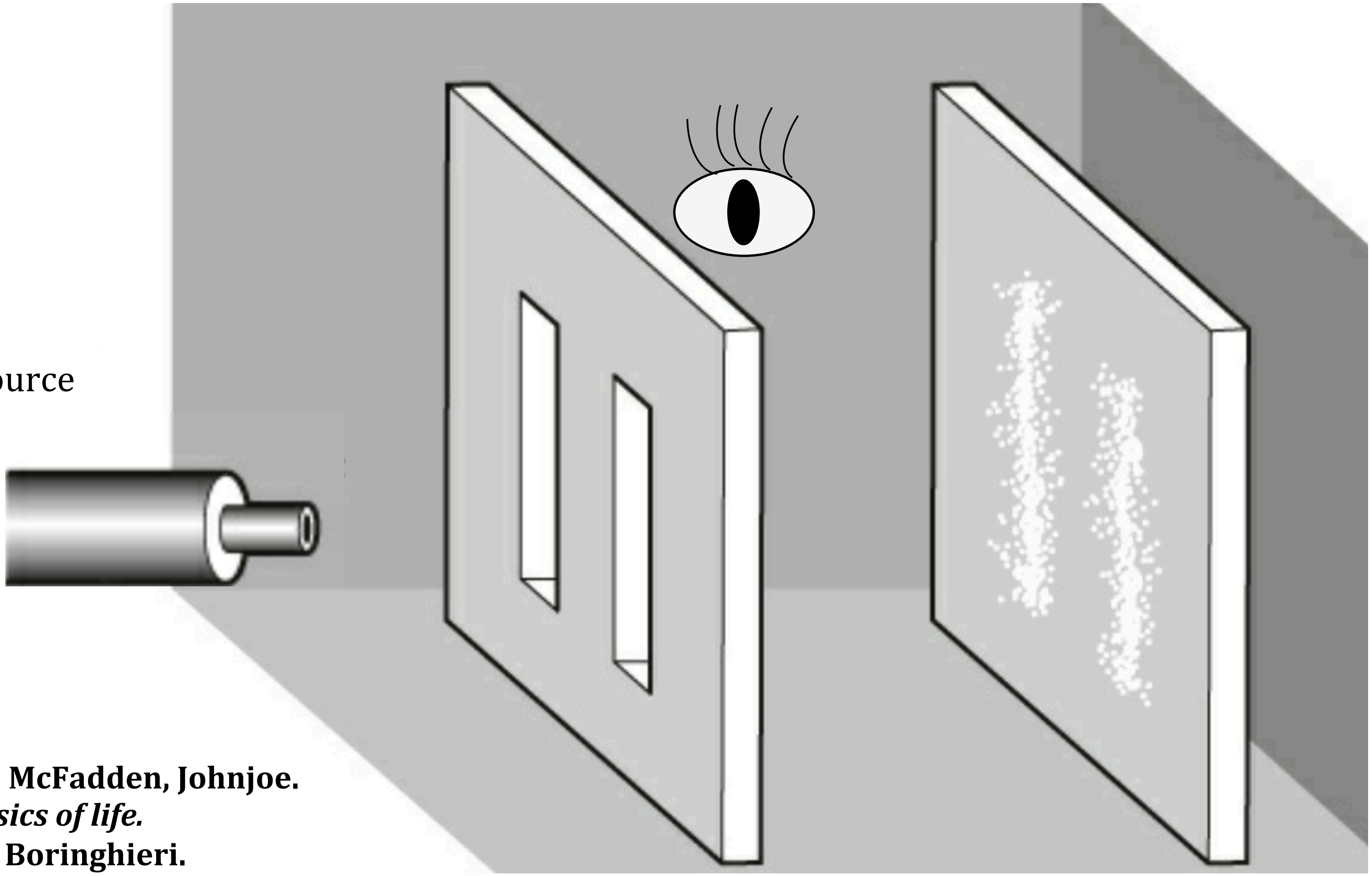
The double slit experiment

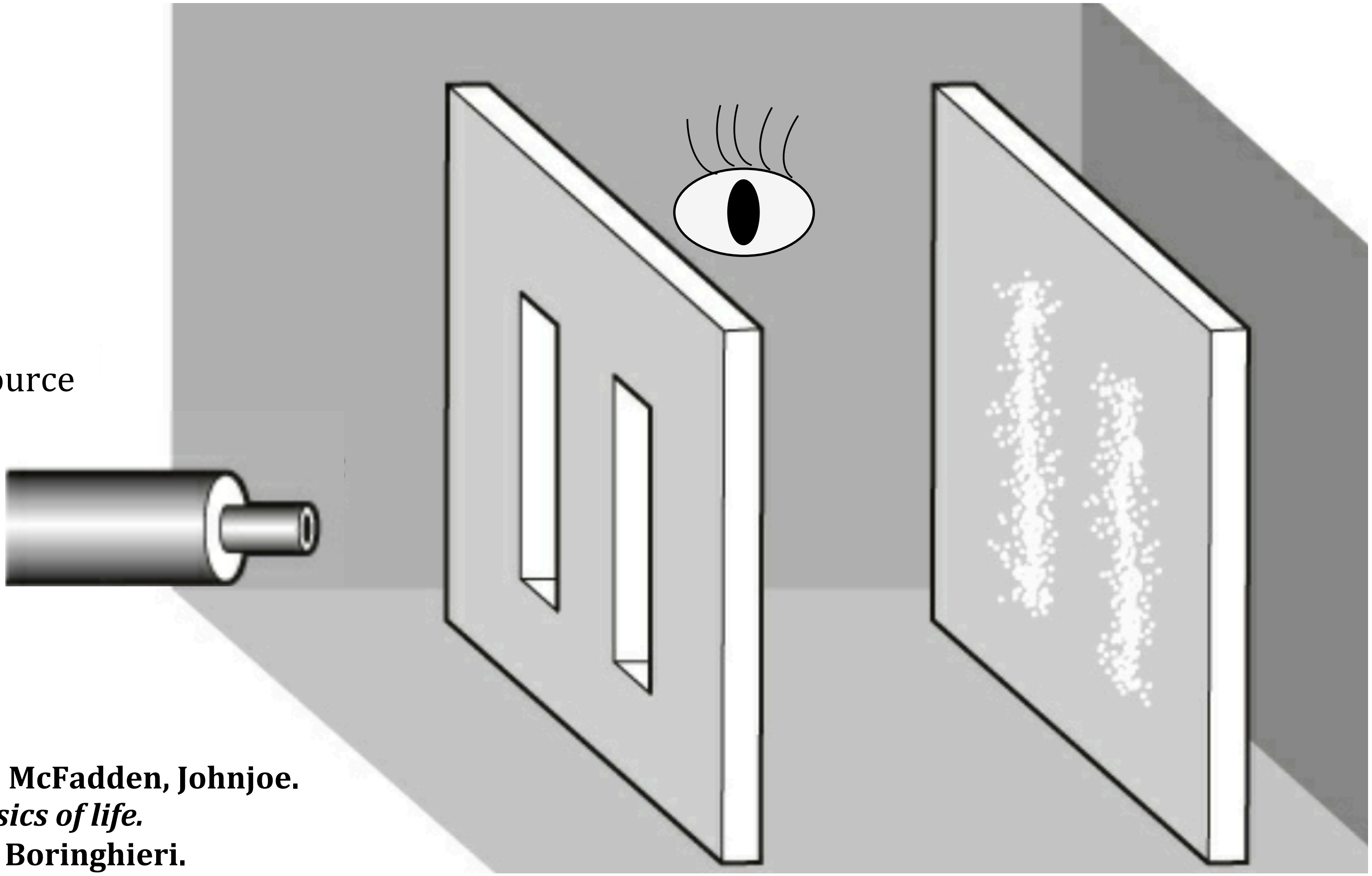
Atom source



Khalili, Jim; McFadden, Johnjoe.
Physics of life.
Bollati Boringhieri.

«Particles know.»

Atom source



Khalili, Jim; McFadden, Johnjoe.
Physics of life.
Bollati Boringhieri.

Yes, that's it.

Collapse in the classical world.

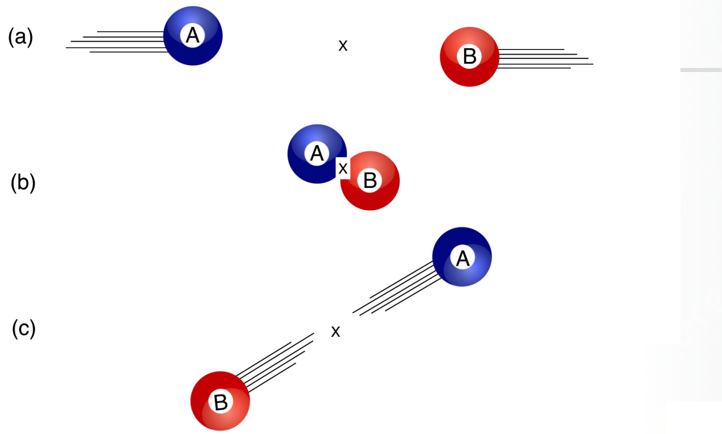
"Was the world wave function waiting to jump for thousand of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer for some highly qualified measurer, – with a Ph.D.?"

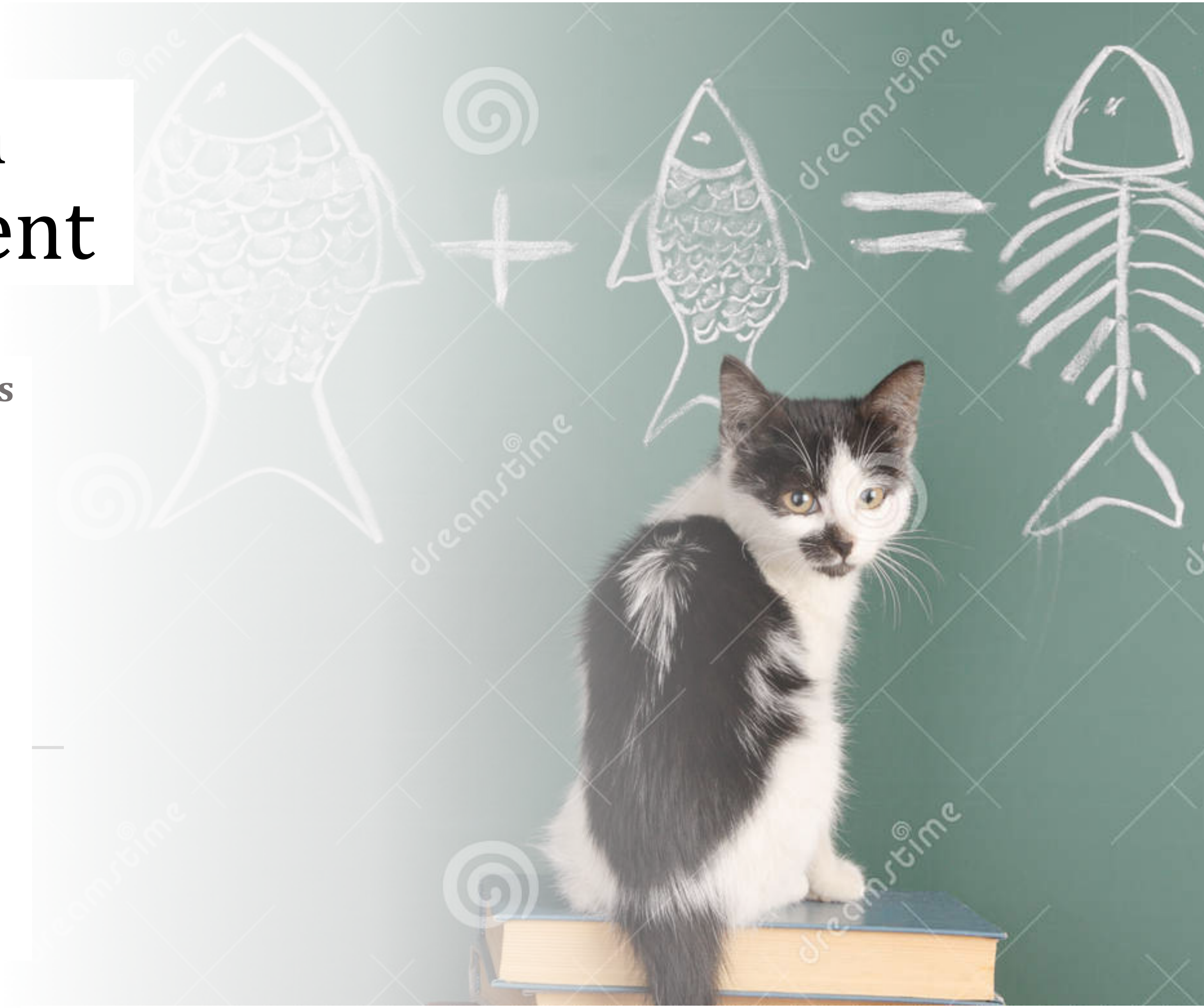
John Stewart Bell

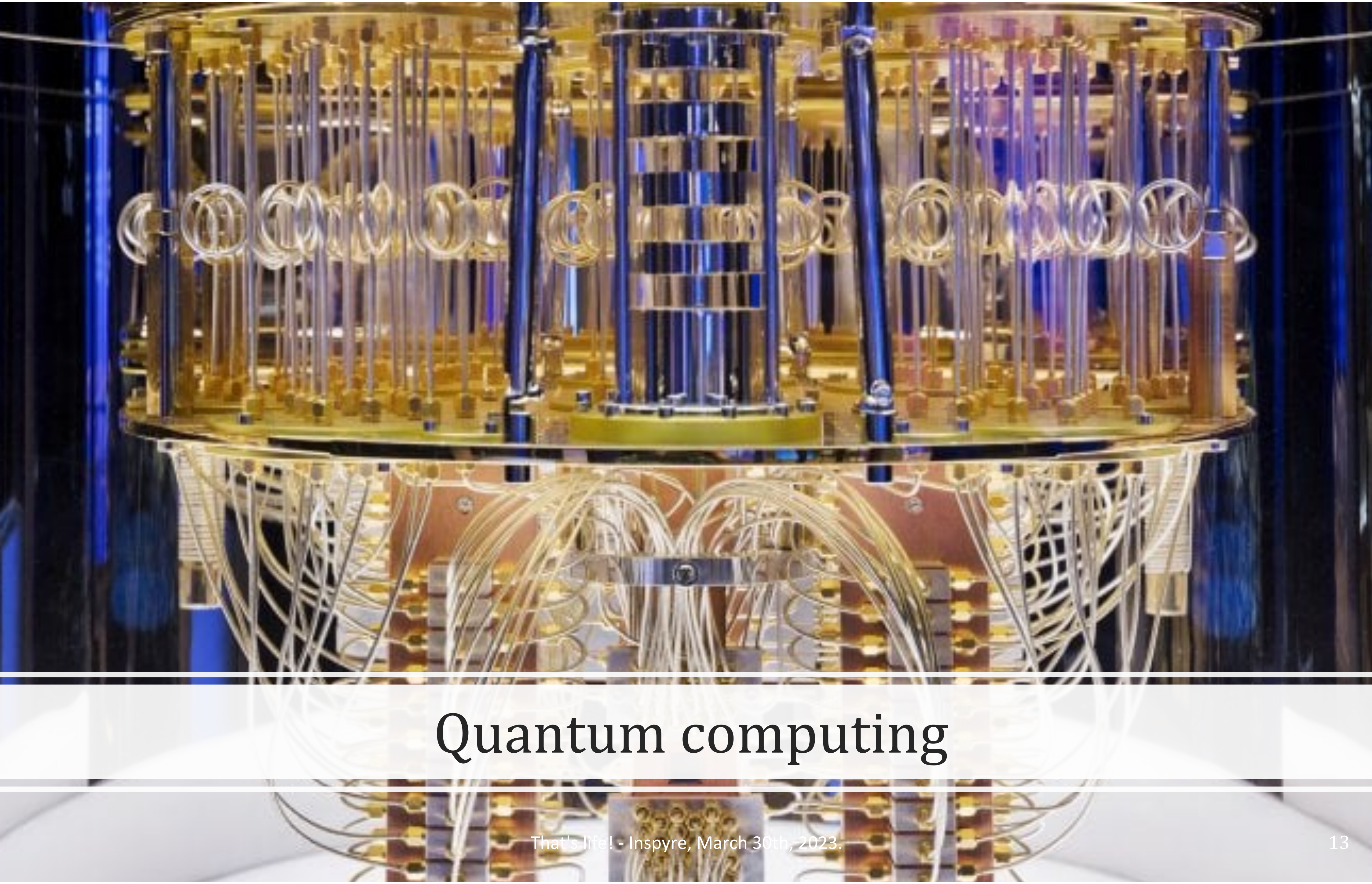
Quantum measurement

Any time we measure the status of a system, its quantum-mechanical behaviour is lost.

A collision itself is a measurement!







Quantum computing

That’s life!

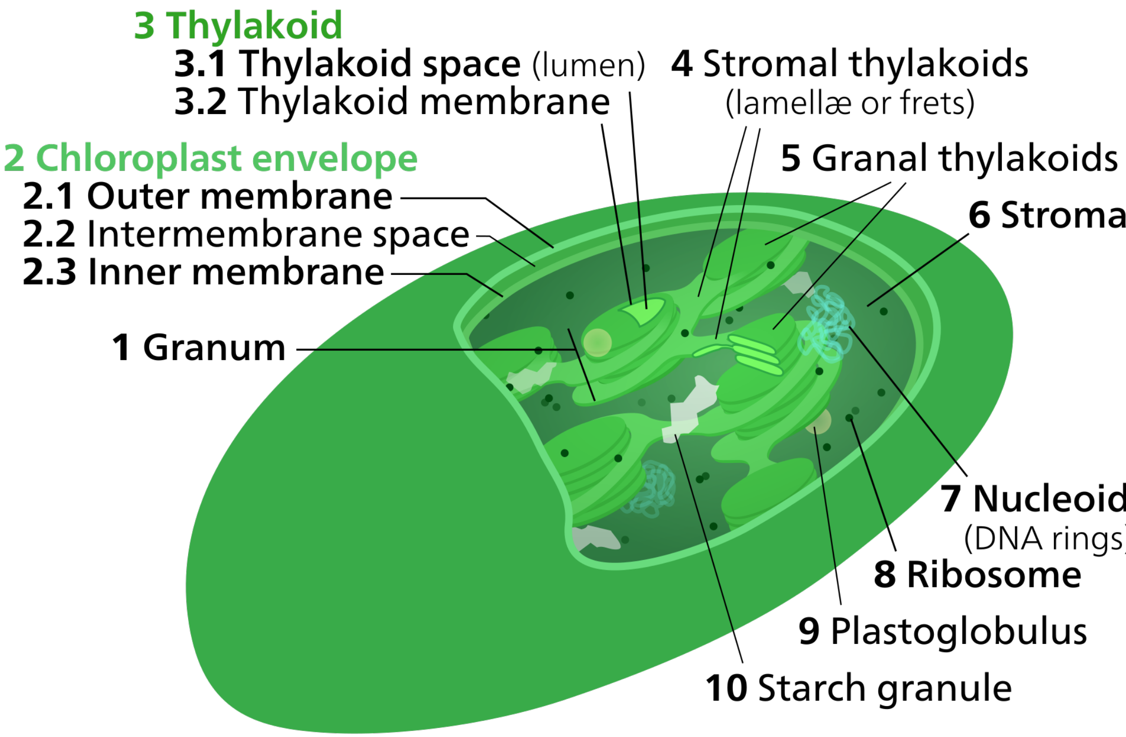
That's life! - Inspyre, March 30th, 2023.

That's life! - Inspyre, March 30th, 2023.

Light, air, water.

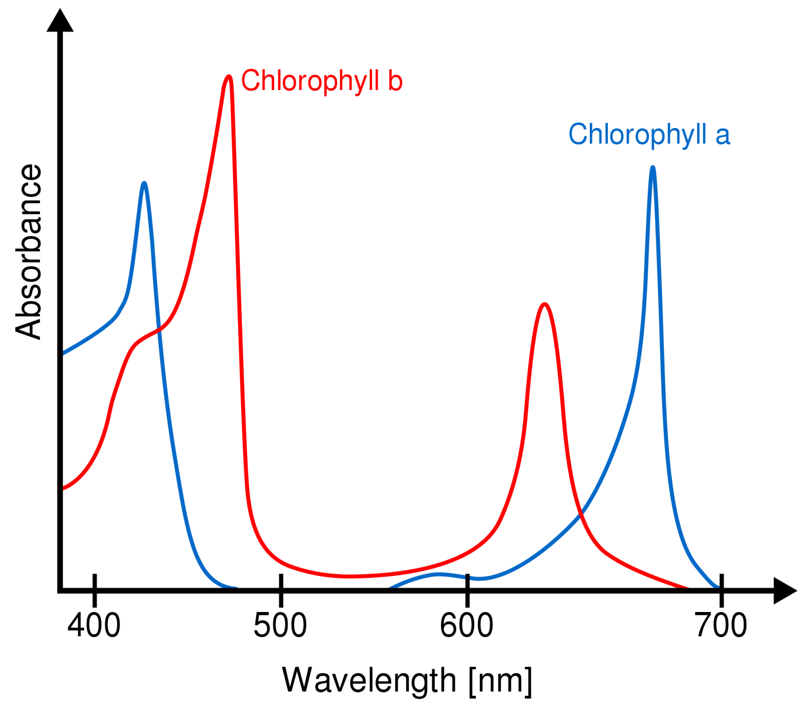
Photosynthesis

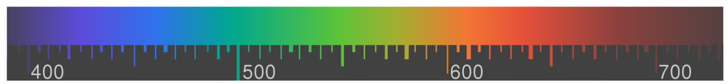
Photosynthesis



I tilacoidi contengono molecole di clorofilla.

Photosynthesis

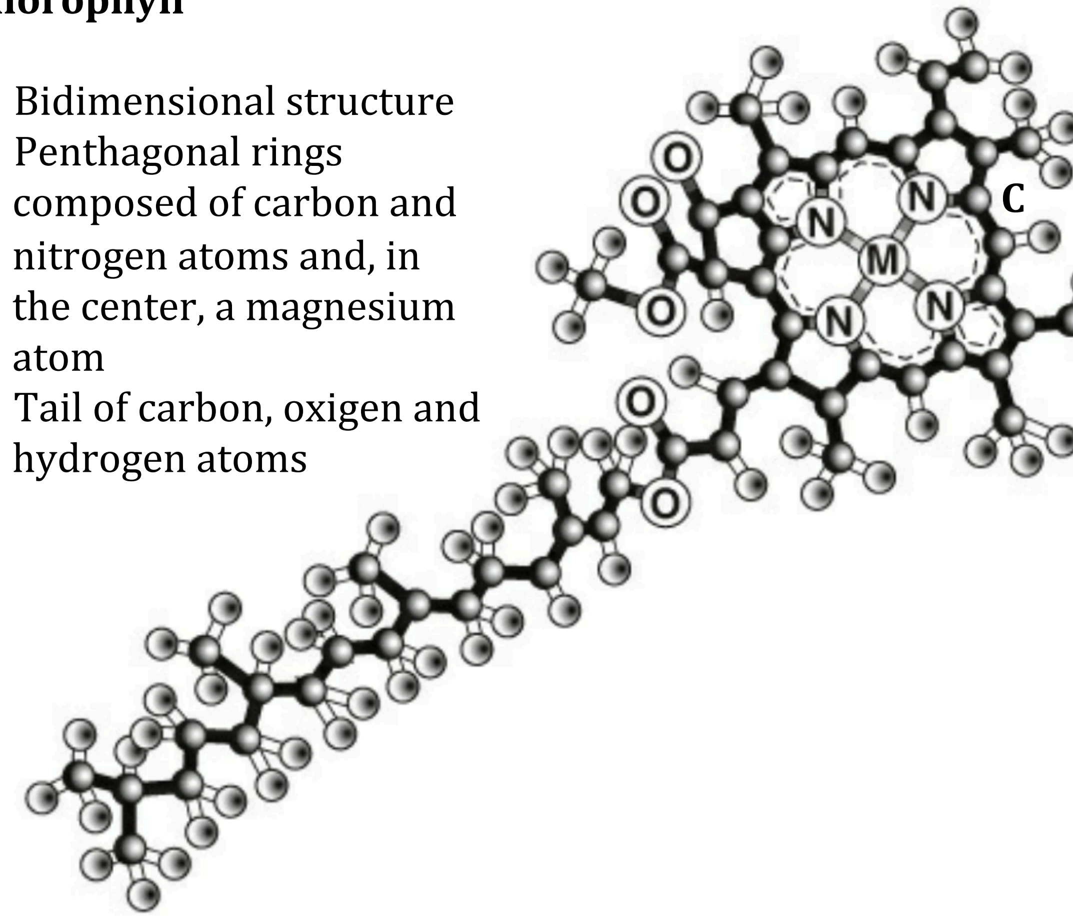




Photosynthesis

Chlorophyll

- Bidimensional structure
- Penthagonal rings composed of carbon and nitrogen atoms and, in the center, a magnesium atom
- Tail of carbon, oxigen and hydrogen atoms



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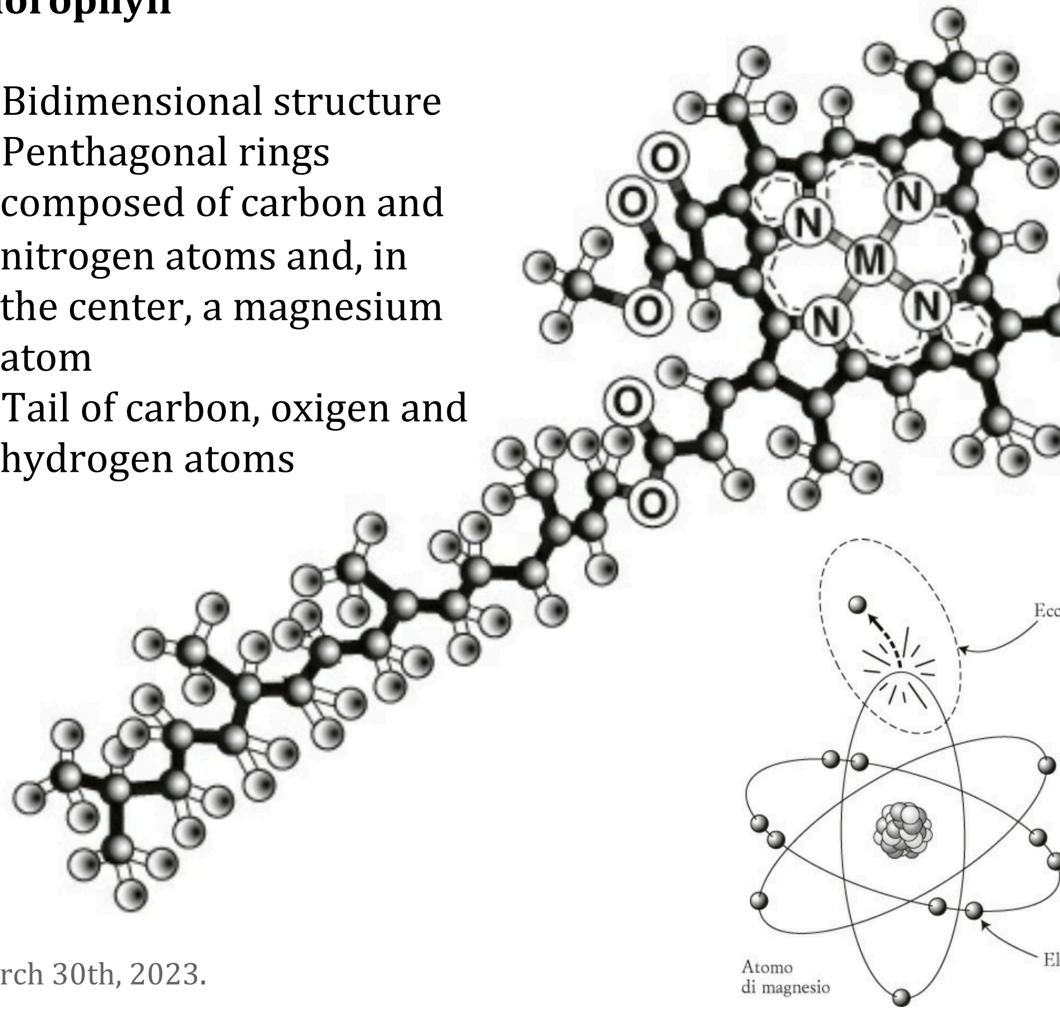
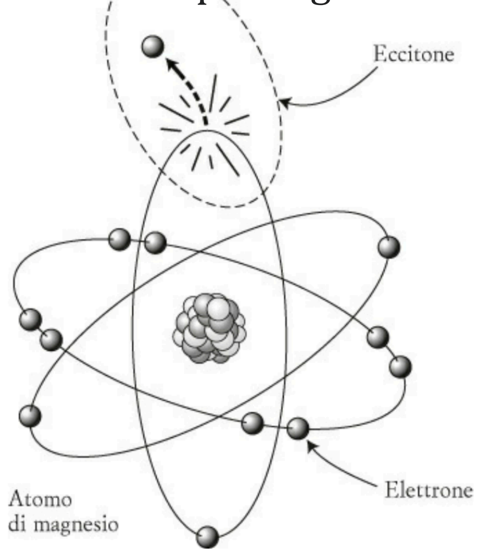


Photosynthesis

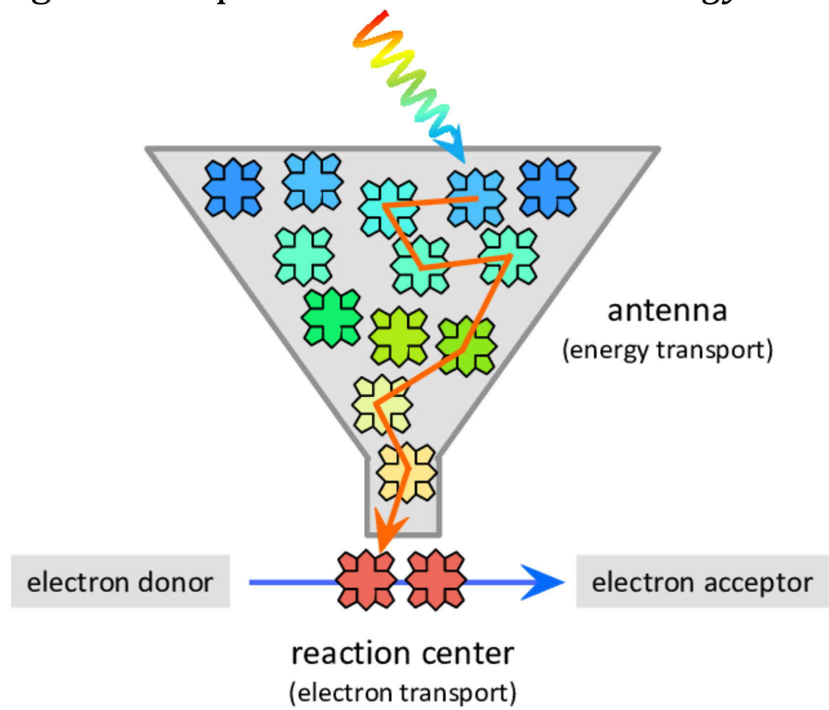
- The outmost $e\uparrow-$ is sligthly bound and can be extracted by the cage
- A «**exciton**» is left: $e\uparrow-$ and positively charged atom
- It is a bound state of an electron and an electron hole which are attracted to each other by the electrostatic Coulomb force → electrically neutral quasiparticle, that can transport energy without transporting net electric charge.



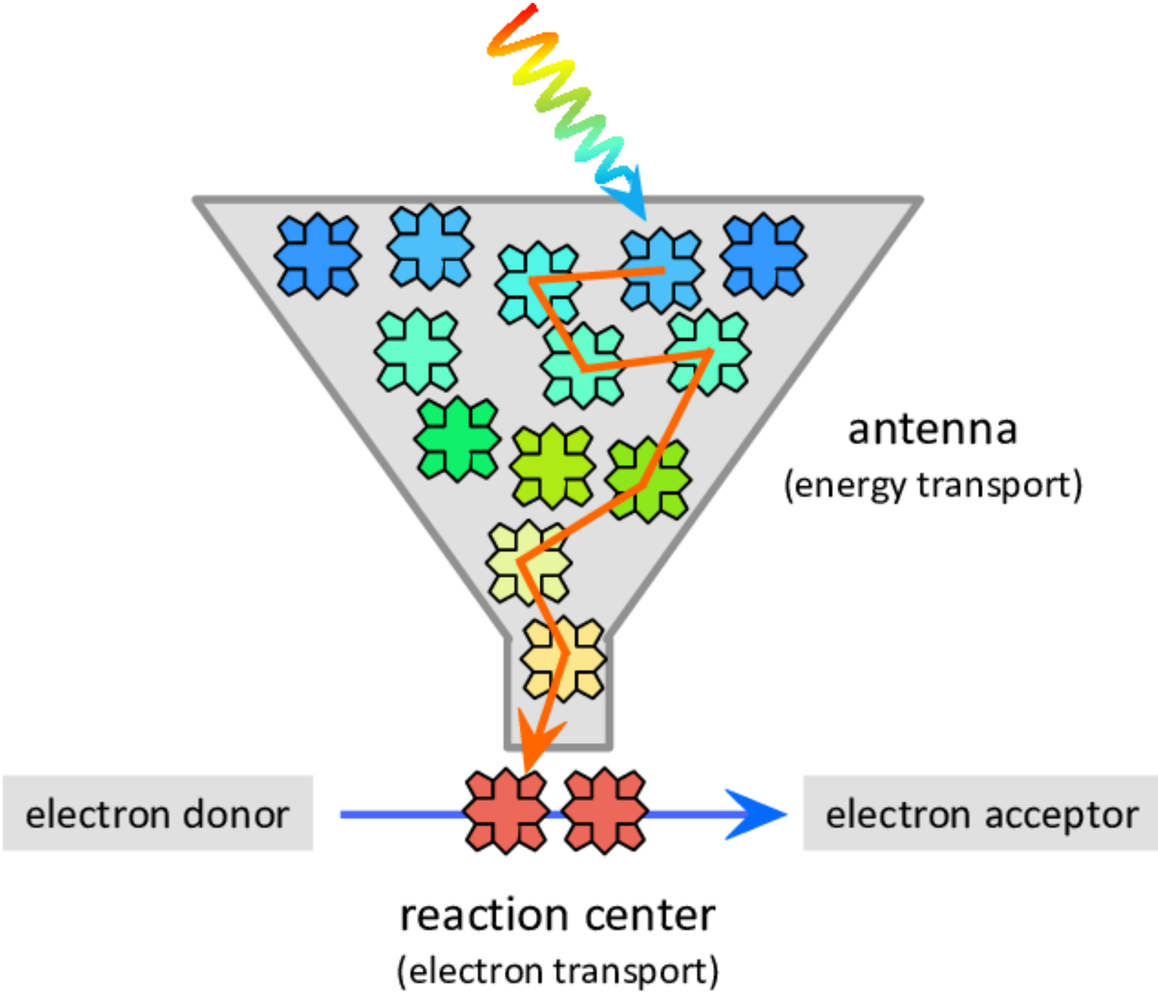
Tend to recombination → needs to be transported to a reaction center where the actual «charge separation» takes place. **The transfer proceeds through the different chlorophyll molecules.**

Photosynthesis

Chlorofyll is highly concentrated → the exciton is transferred by th
different molecules up to the reaction center.
Final step: **charge separation** ⇒ it will be operated in a dedicated
structure that eventually will convert the energy absorbed by a
pigment through a solar photon to *biochemical energy.*



Google, what is the fastest way?



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Google, what is the fastest way?

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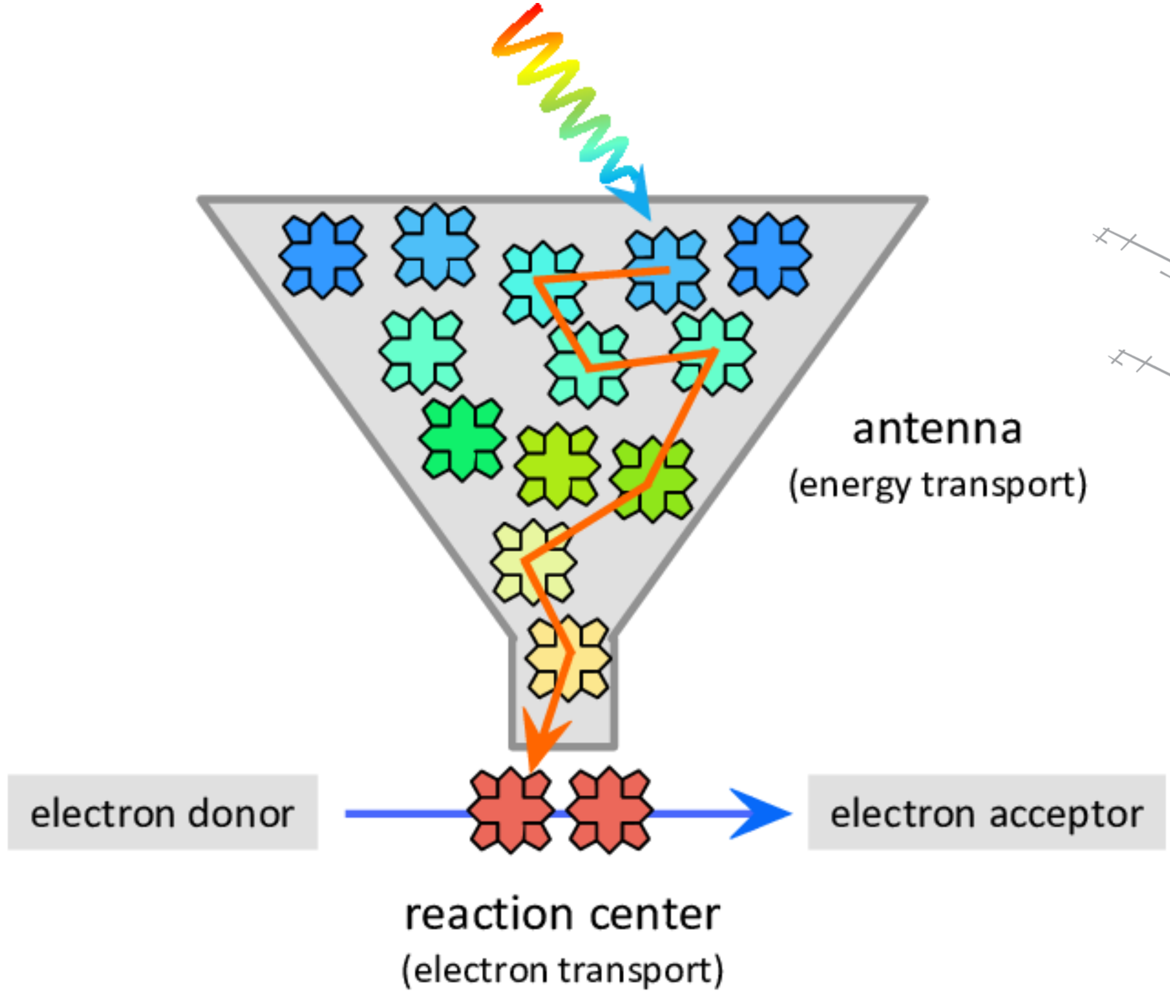

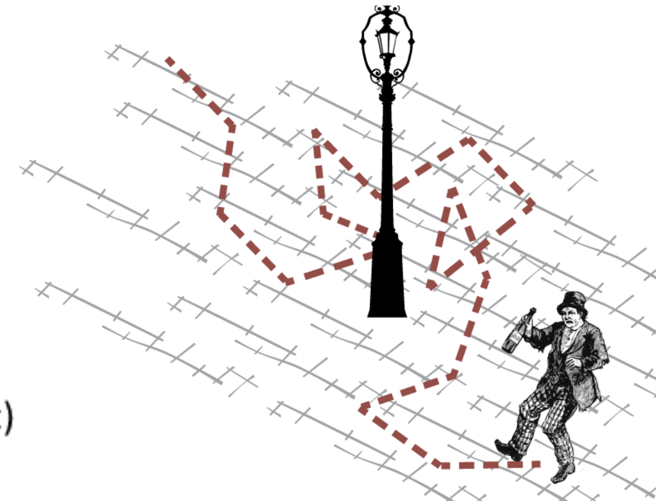

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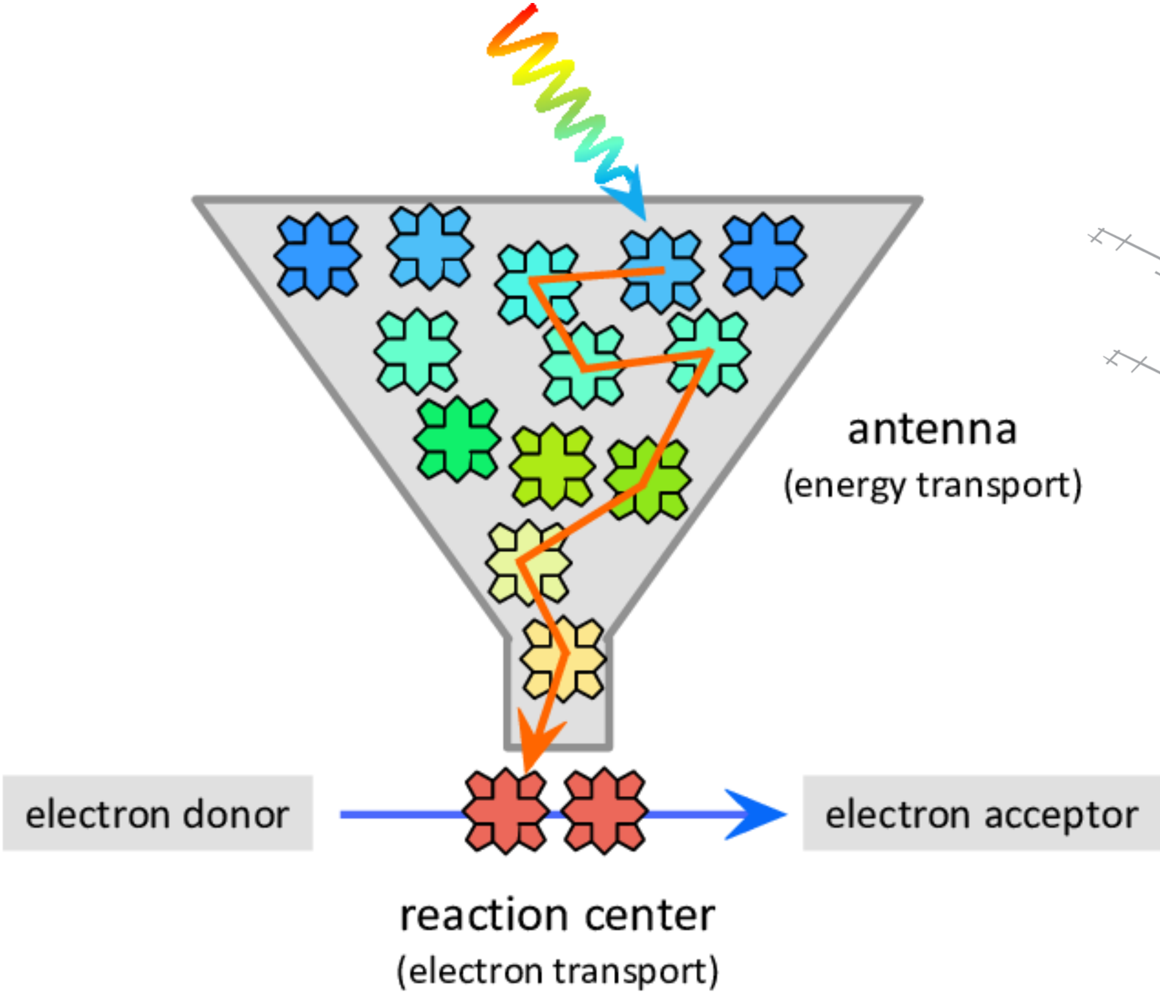
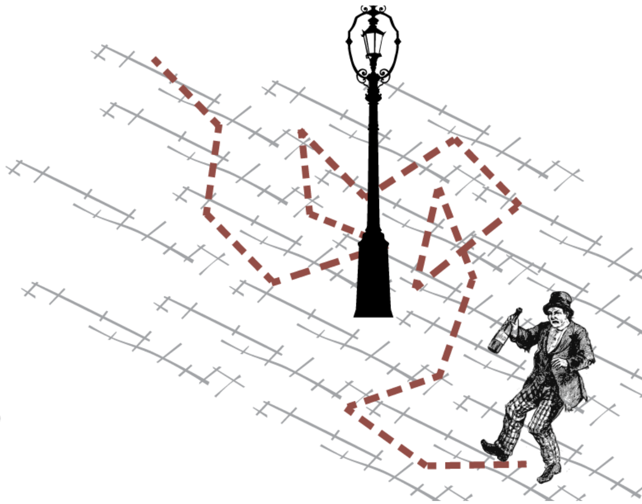
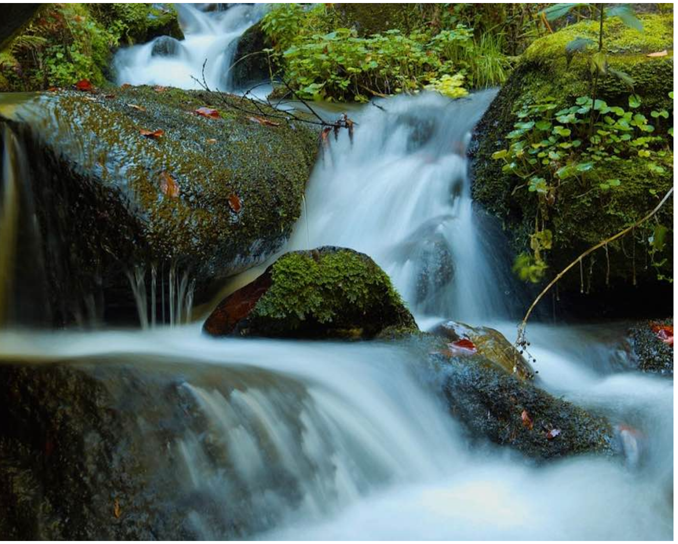
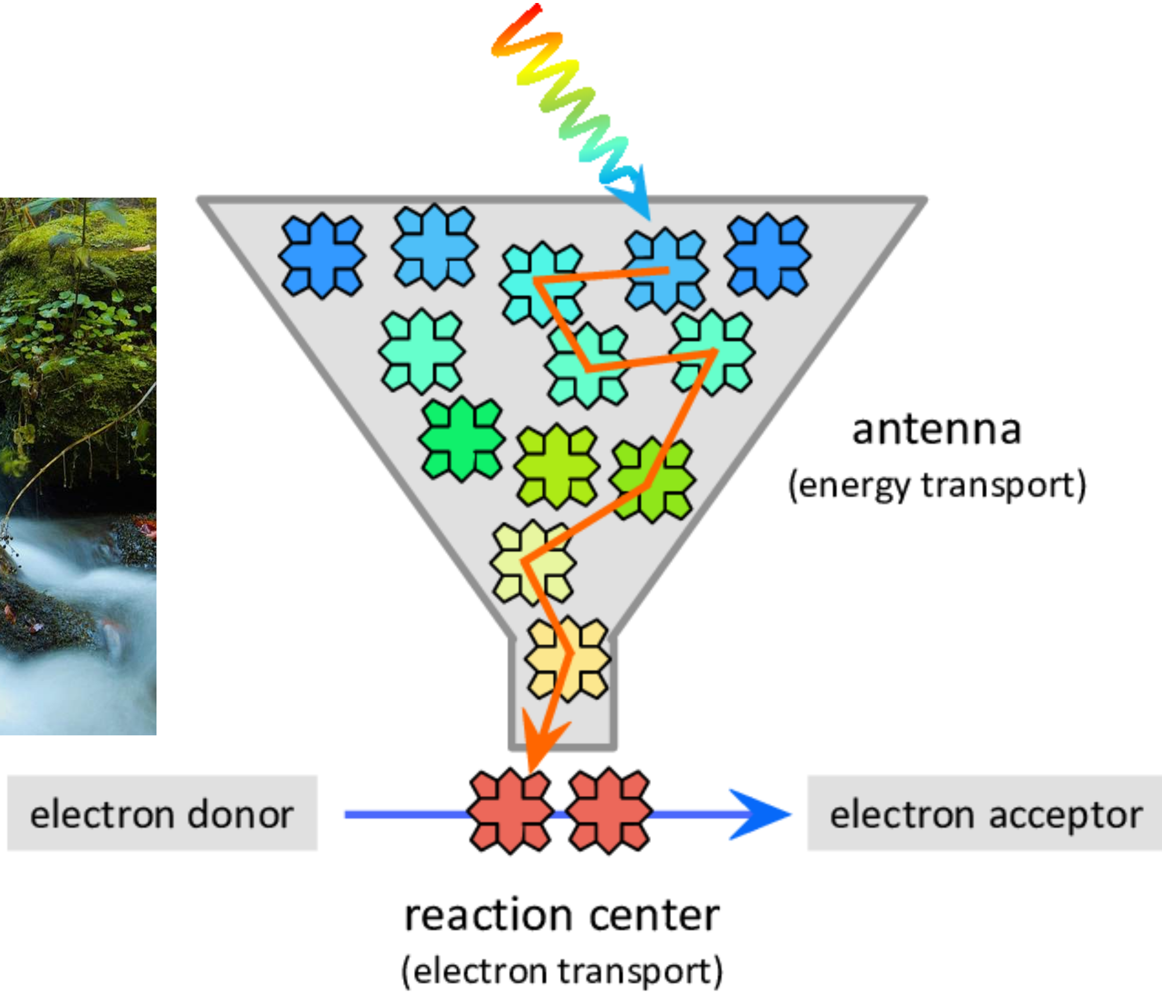




If so, how can the efficiency of the process so close to 100%?

Google, what is the fastest way?





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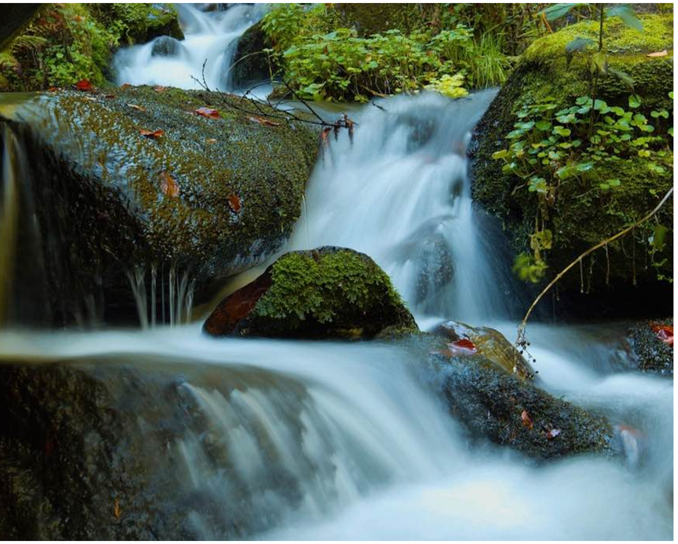

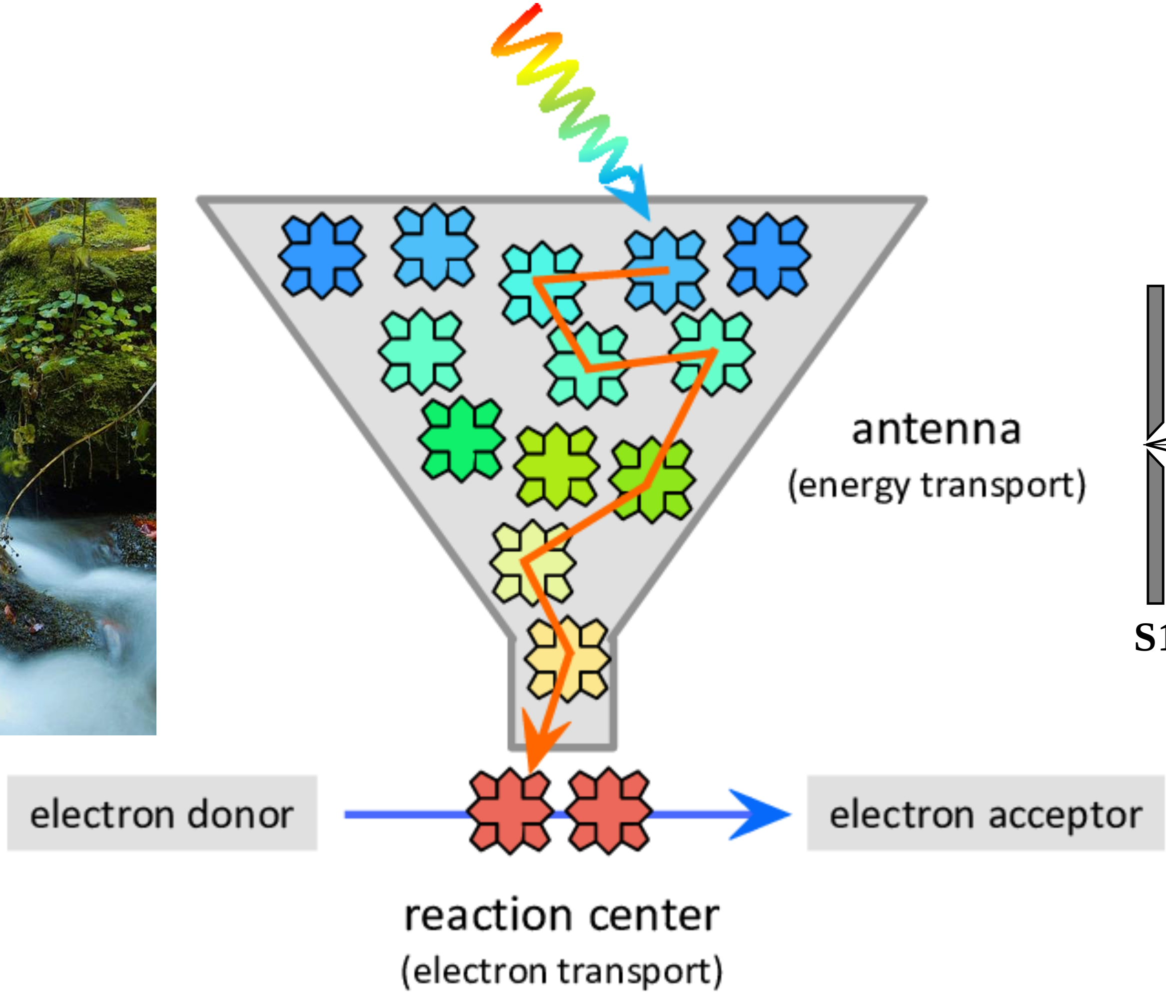

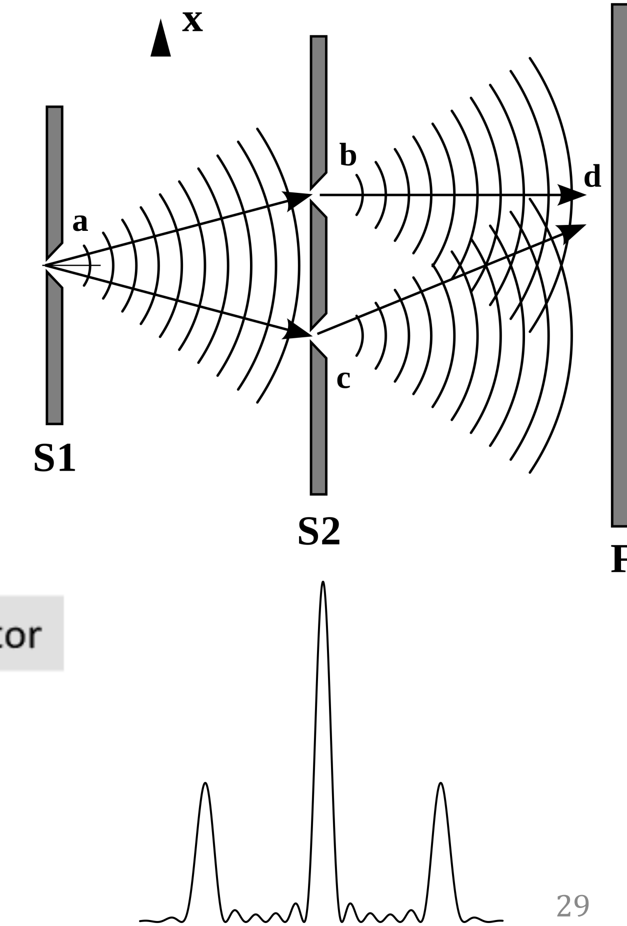

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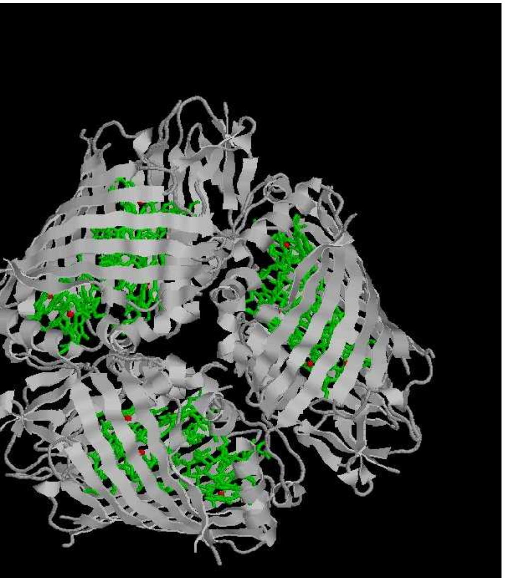
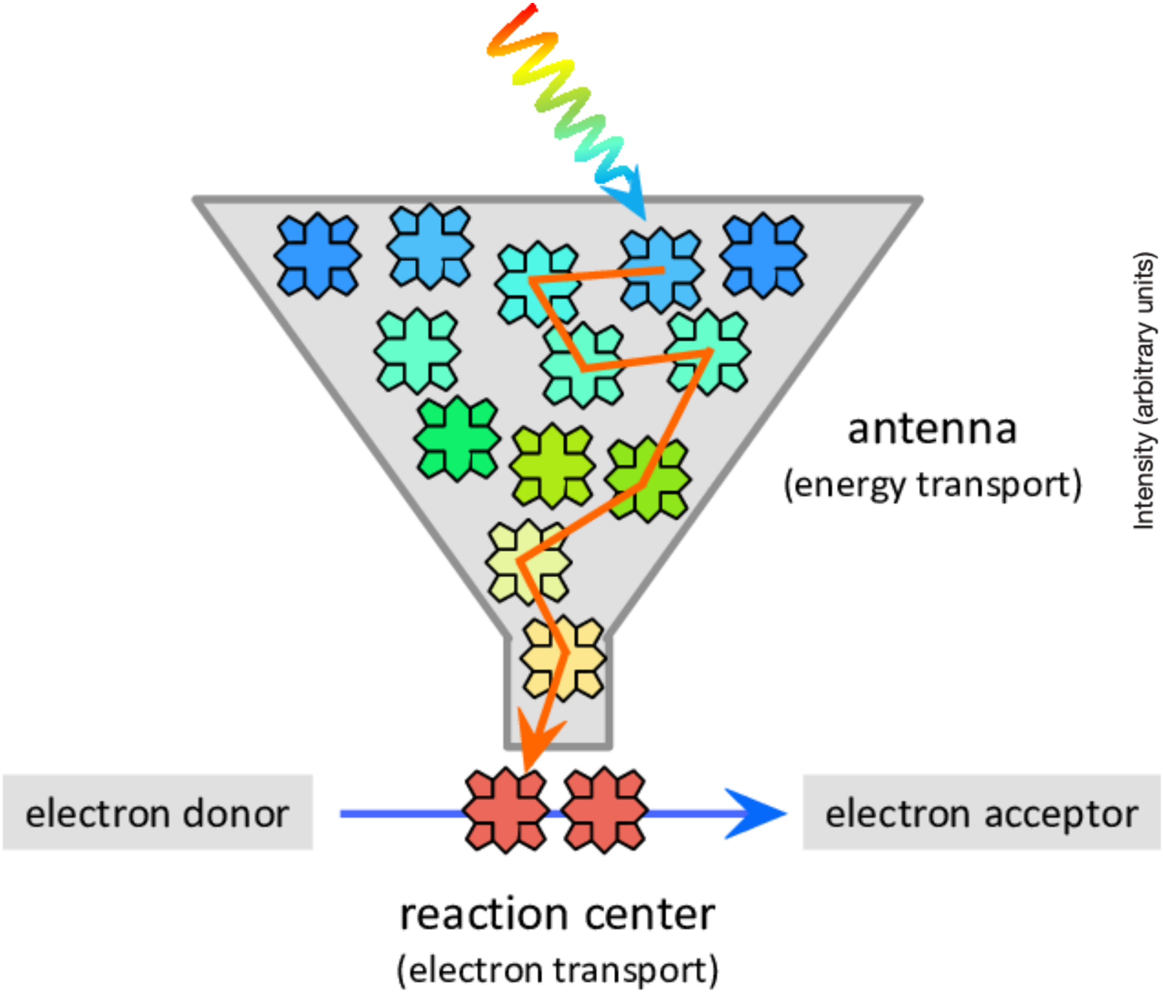
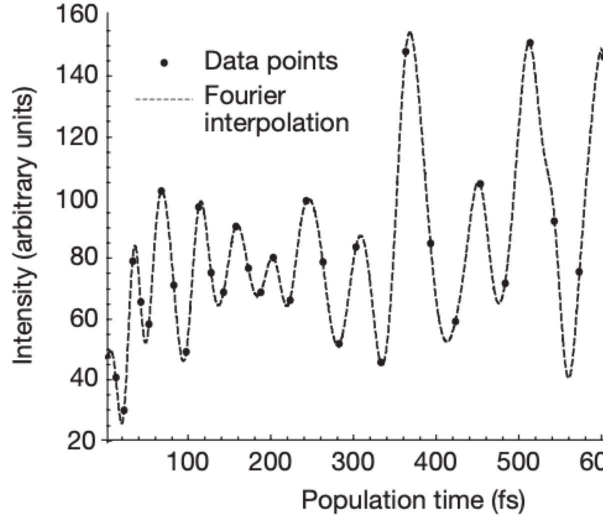


https://en.wikipedia.org/wiki/Fenna
80%93Matthews%E2%80%93Olson_complex

nplesso di Fenna-Matthew-Olson:
va nei chlorobi (batteri in grado di
effettuare la fotosintesi)





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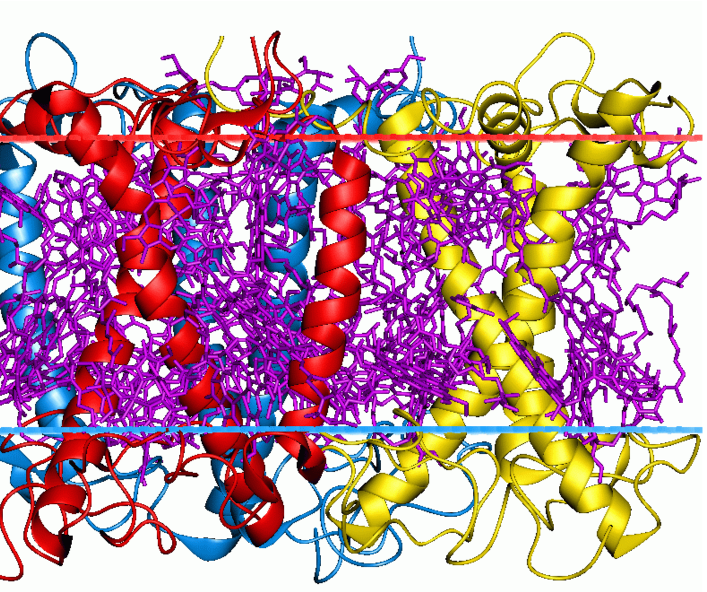
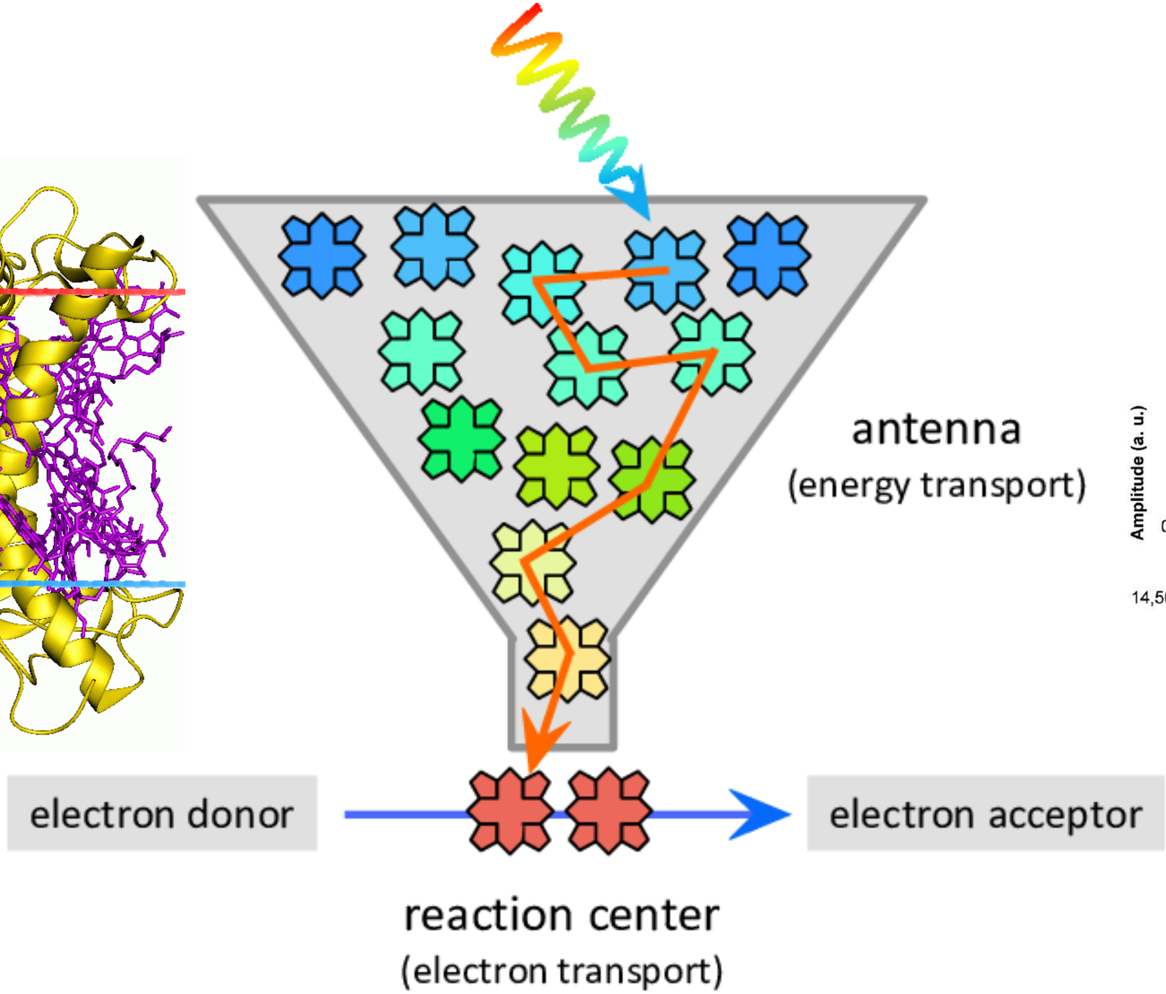
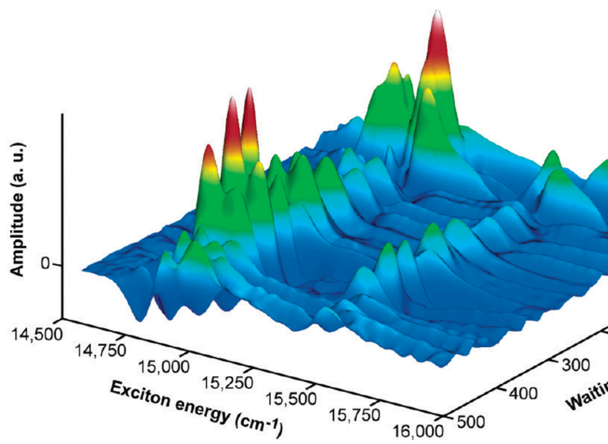




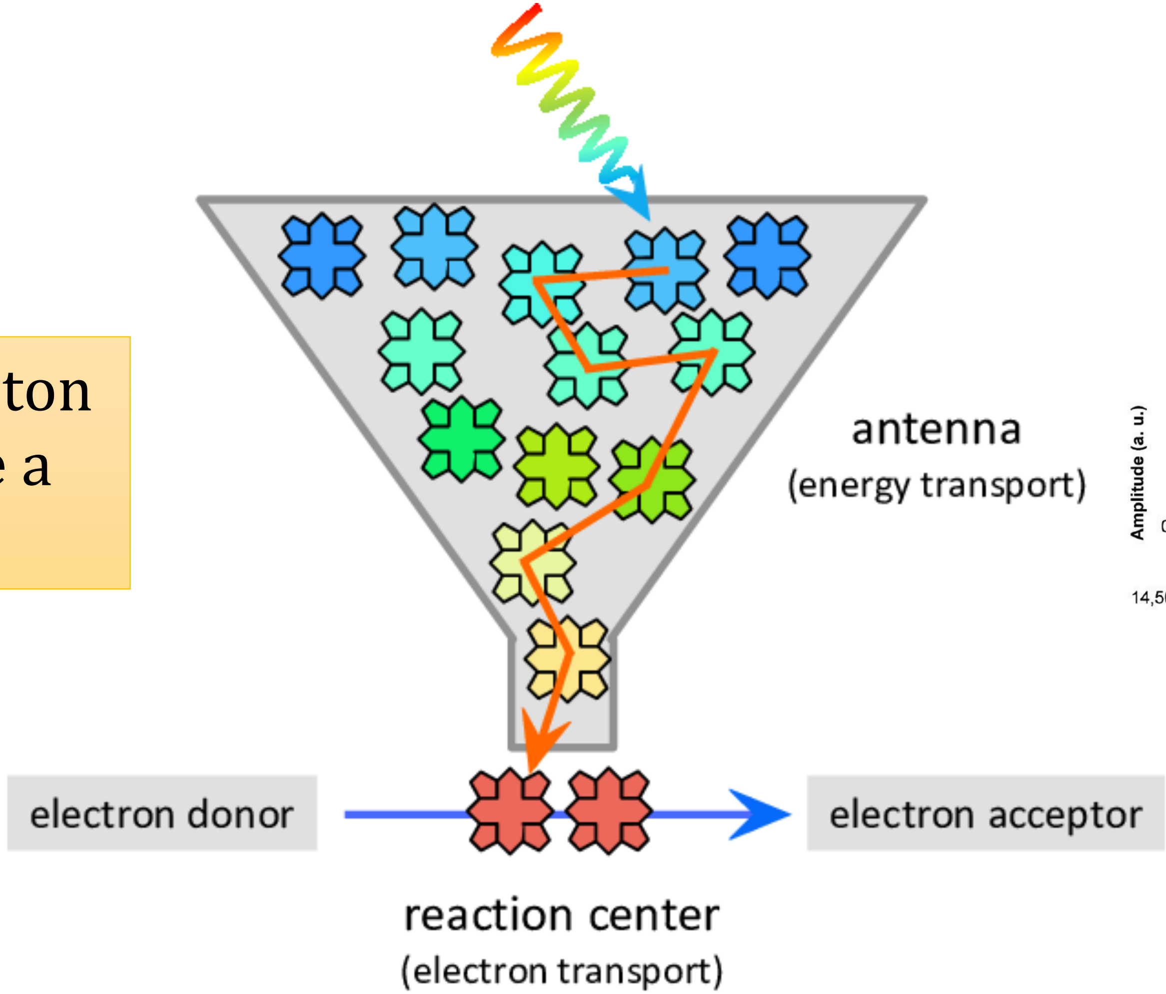
Light-Harvesting Comple



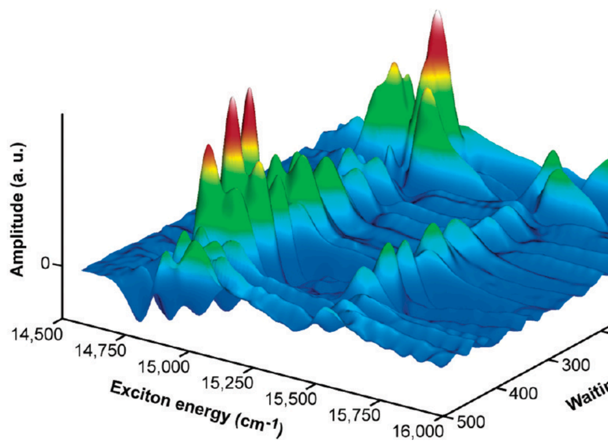
Quantum Coherence Enabled Determinat the Energy Landscape in Light-Harvest Complex II
J. Phys. Chem. B 2009, 113, 51, 16291–1

Google, what is the fastest way?

How can the exciton still behave like a wave?



Light-Harvesting Comple



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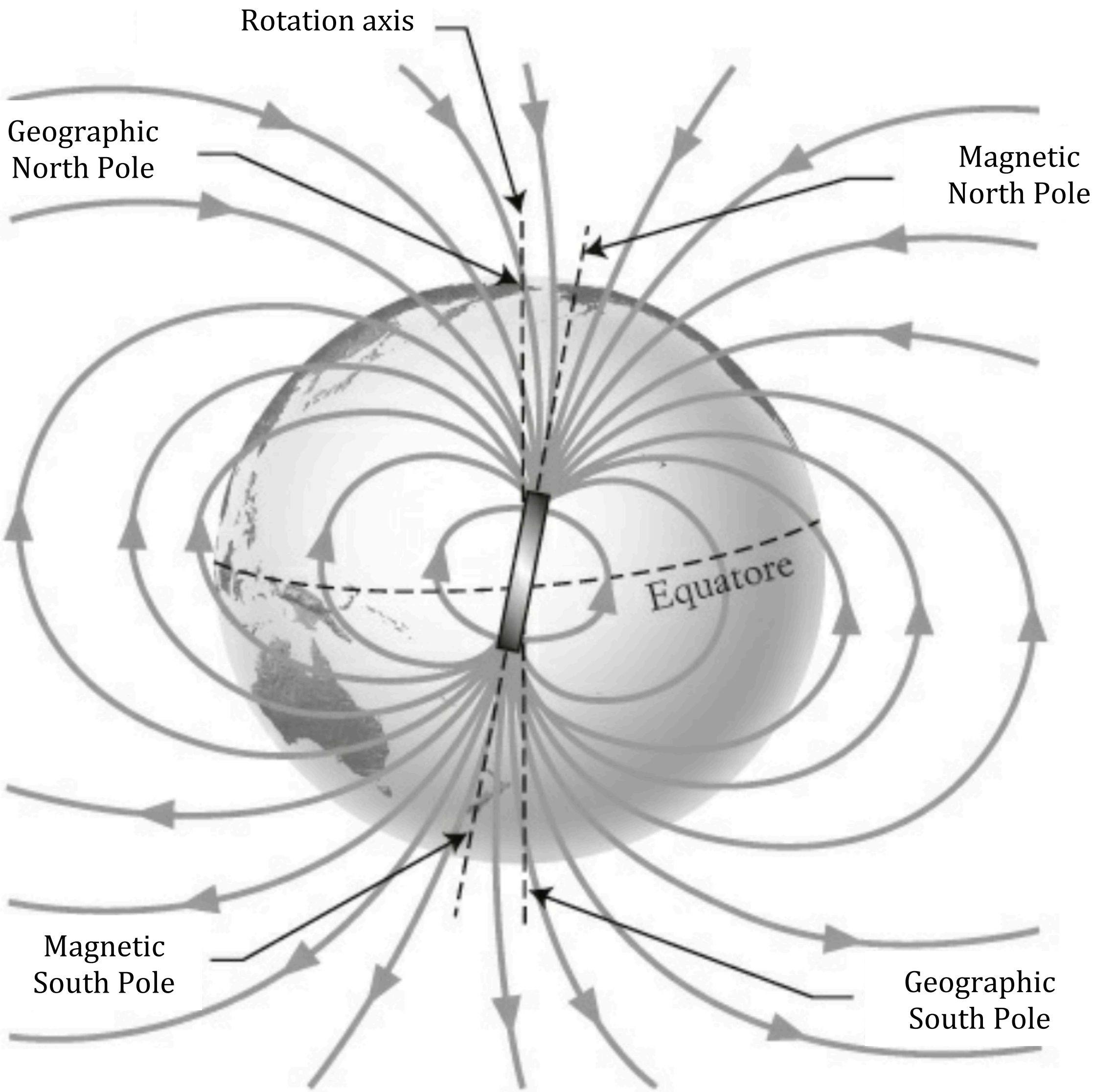
The quantum robin

The avian compass mistery

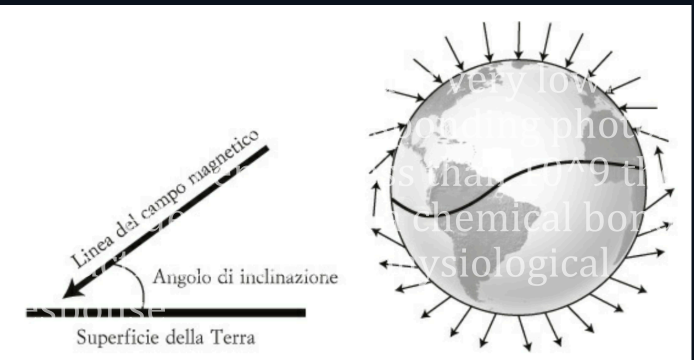
The quantum robin

Earth’s magnetic field is very low: 20÷70 μT. The corresponding photon vehicles an energy less than 10^9 the one needed to break a chemical bond and activate, then, a physiological response

Avian compass ⇒ tilt compass: it measures the angle between the field lines and the Earth surface, distinguishing poles from the Equator (but not the two poles)



The quantum robin



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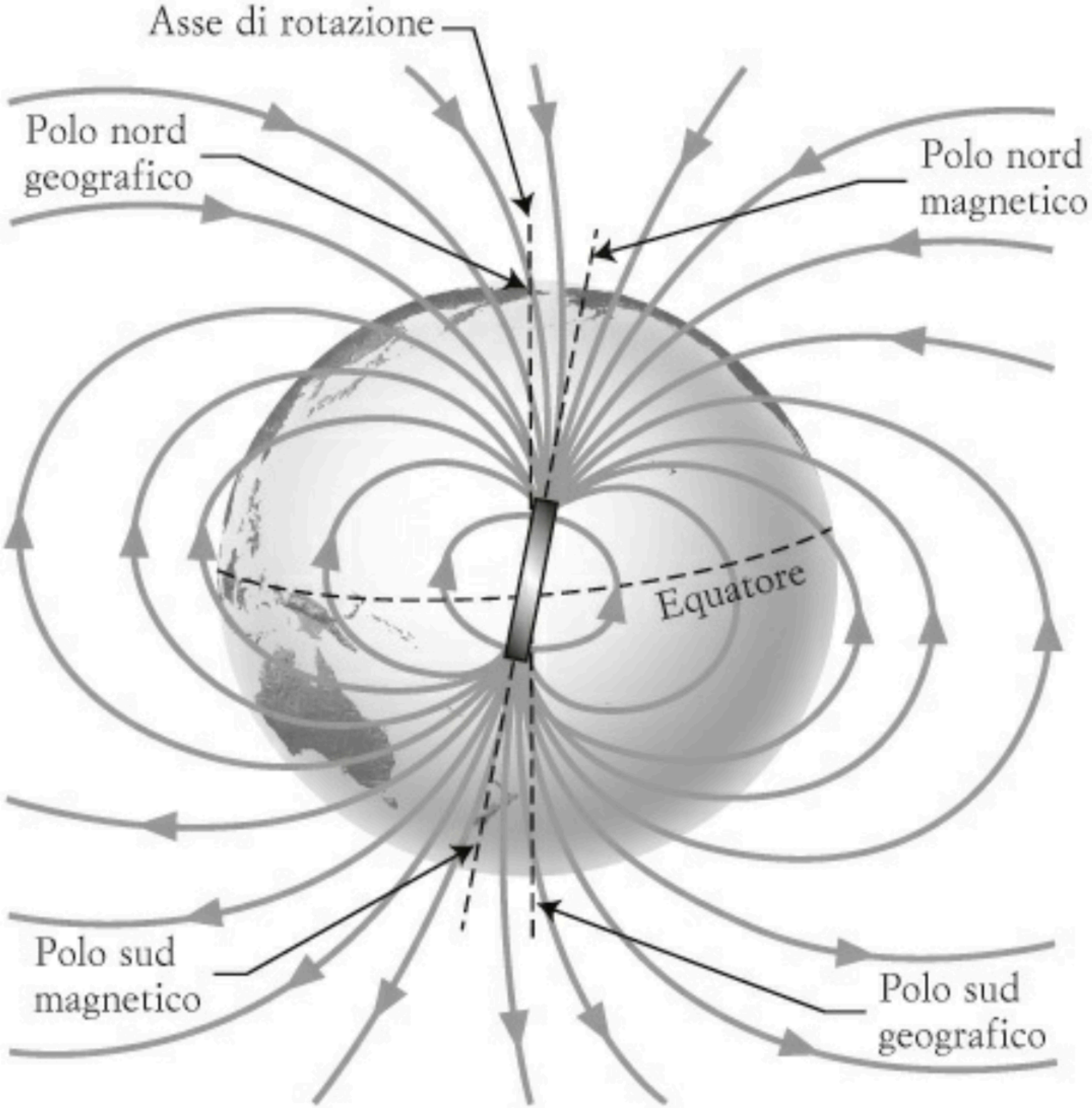
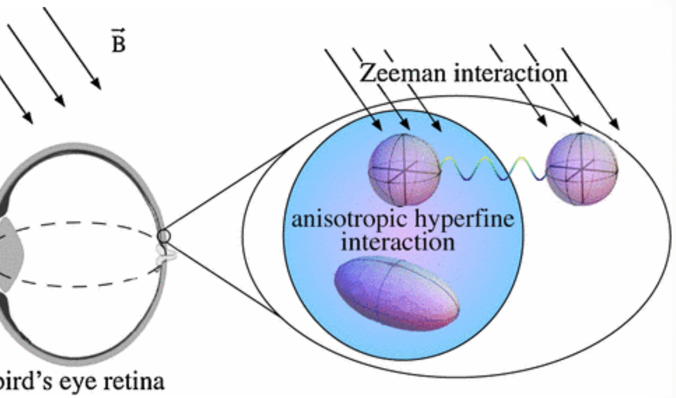


he quantum robin



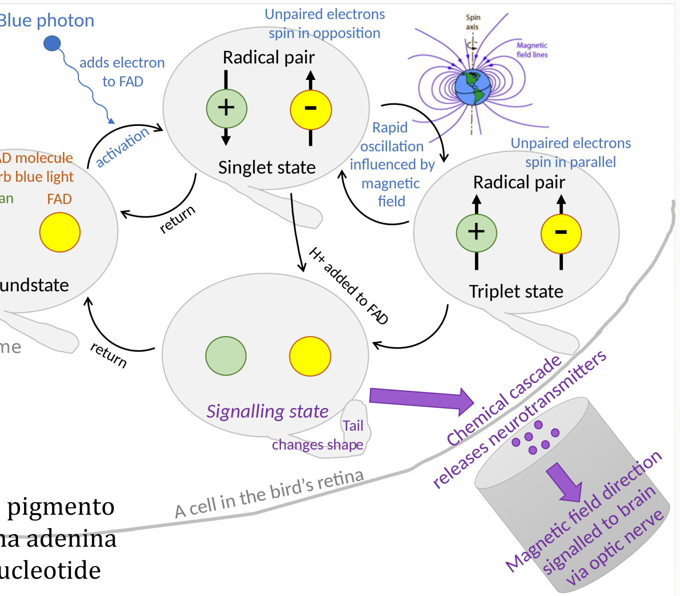
mlen S., Wiltschko W., Demong N. e Wiltschko R., *Magnetic direction finding: evidence for its se in migratory indigo buntings*, «Science», vol. 193 (1976), pp. 505-08.

he quantum robin

- Atoms are bound by sharing $e{\uparrow}-$
- If the molecules breaks, two free radicals are produced
- *Free radicals*: molecule with an unpaired $e{\uparrow}-$ in the external orbitals → the non-zero spin gets sensitive to the magnetic field
- The two external $e{\uparrow}-$ are normally in a *singlet* state
- However, the coupling with the Earth's magnetic field may produce a *triplet* component
- The different percentage of singlet and triplet states affect the final chemical products of the physiological reaction

e initial break of the original molecule may be oduced by a visible photon (in the blue-light gion).

he quantum robin



pigmento
na adenina
ucleotide

del for Photoreceptor-Based Magnetoreception in Birds

me 78, Issue 2, February 2000, Pages 707-718

he quantum robin

e candidate structure, observed in bird's eyes, is a **yptochrome**, a flavoprotein excited by blue-green ht (also involved in cicardian rhythms)

rds could see a «magnetic color» mapping the world!

he quantum robin

ne candidate structure, observed in bird's eyes, is a **yptochrome**, a flavoprotein excited by blue-green ght (also involved in cicardian rhythms)

rds could see a «magnetic color» mapping the world!

How can coherence be mantainec the time the singlet-triplet oscilla affects the biochemical reaction the bird's eyes?

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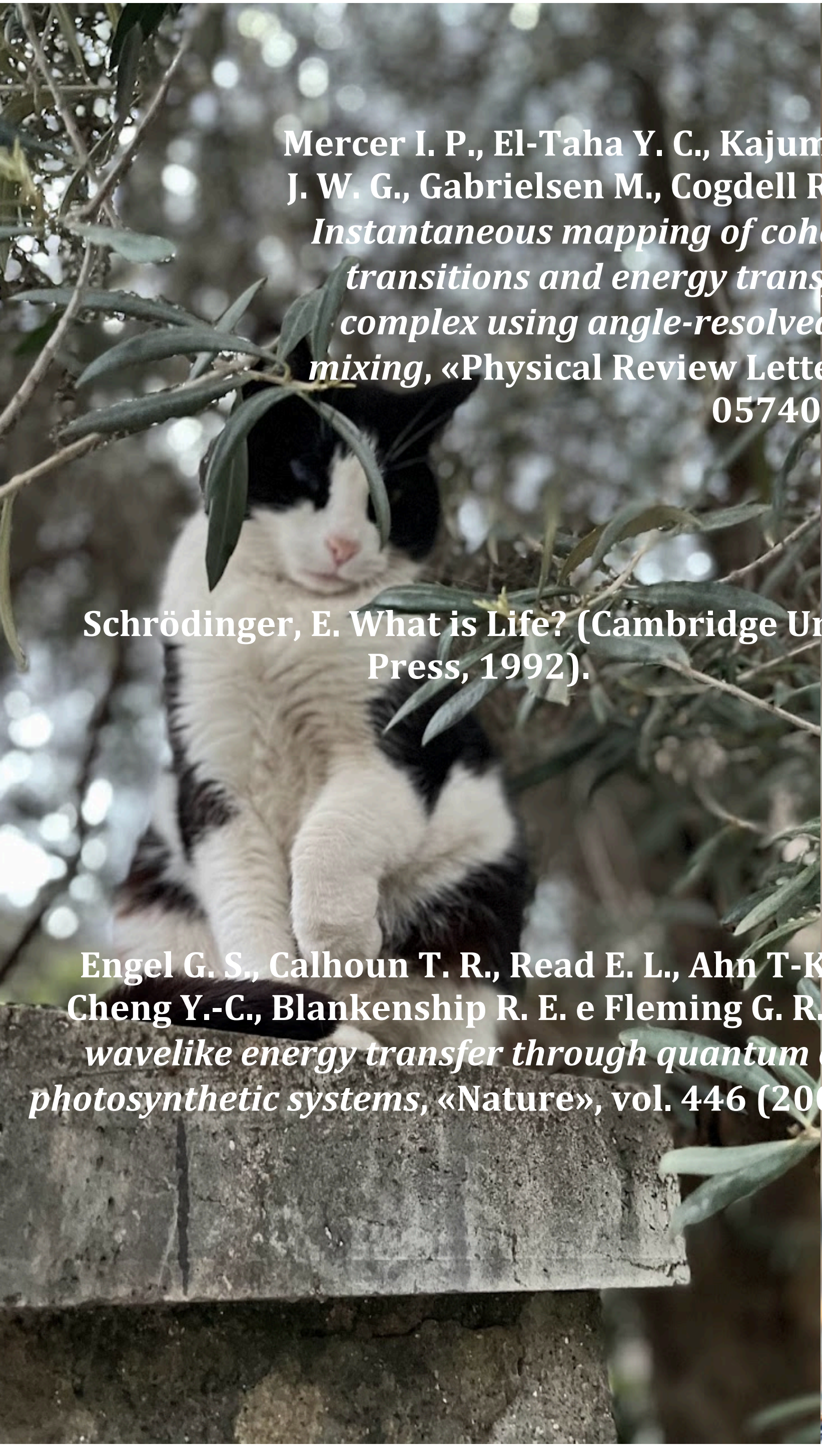
The European Robin *is the new* Schröedinger’s cat




Mercer I. P., El-Taha Y. C., Kajumba N., Marangos J. P., Tisch J. W. G., Gabrielsen M., Cogdell R. J., Springate E. e Turcu E., *Instantaneous mapping of coherently coupled electronic transitions and energy transfers in a photosynthetic complex using angle-resolved coherent optical wave-mixing*, «Physical Review Letters», vol. 102: 5 (2009), p. 057402.

21 Cha Y., Murray C. J. e Klinman J., *Hydrogen tunnellin in enzyme reactions*, «Science», vol. 243: 3896 (1989), pp. 1325-330.

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That's life!

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backup

Mercer I. P., El-Taha Y. C., Kajumba N., Marangos J. P., Tisch J. W. G., Gabrielsen M., Cogdell R. J., Springate E. e Turcu E., *Instantaneous mapping of coherently coupled electronic transitions and energy transfers in a photosynthetic complex using angle-resolved coherent optical wave-mixing*, «Physical Review Letters», vol. 102: 5 (2009), p. 057402.

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Il *passero europeo* is the new *gatto di Schröedinger*

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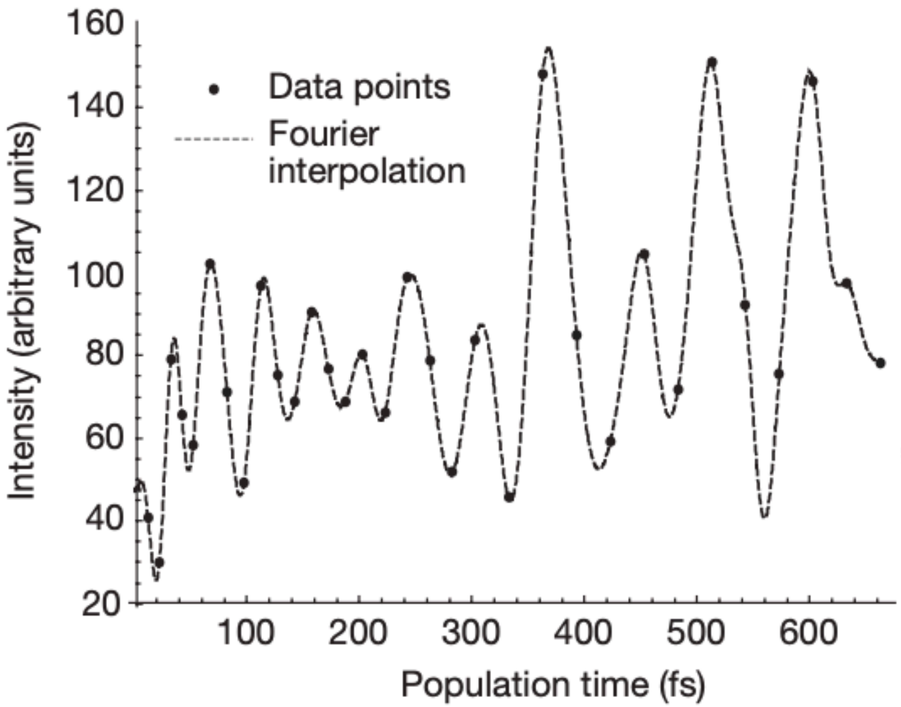
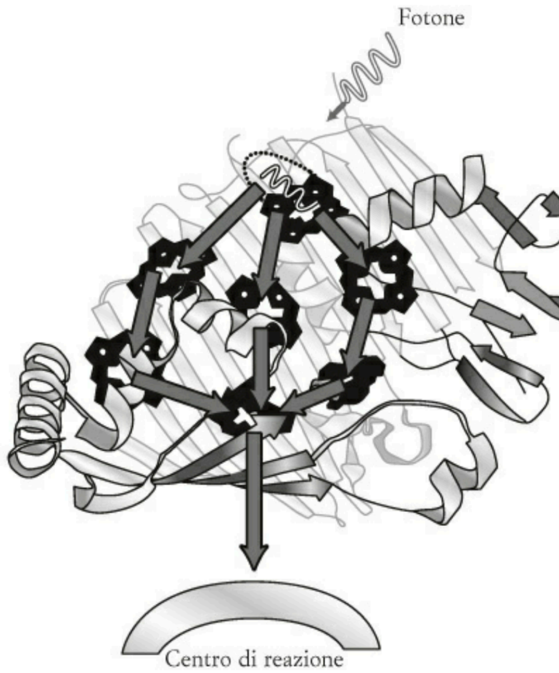
Al-Khalili, Jim; McFadden, Johnjoe. *La fisica della vita: La nuova scienza della biologia quantistica*. Bollati Boringhieri.

Battimenti quantistici

Complesso fotosintetico «Fenna-Matthews-Olson» (FMO) → microbi fotosintetici chiamati chlorobi, che si trovano nelle profondità di bacini ricchi di zolfo, come il Mar Nero.

- Un laser deposita il segnale concentrato in picchi rapidi e perfettamente sincronizzati
- Si misura il segnale di luce prodotto dal campione
- *Questo permette di studiare come la luce si propaga nel sistema*





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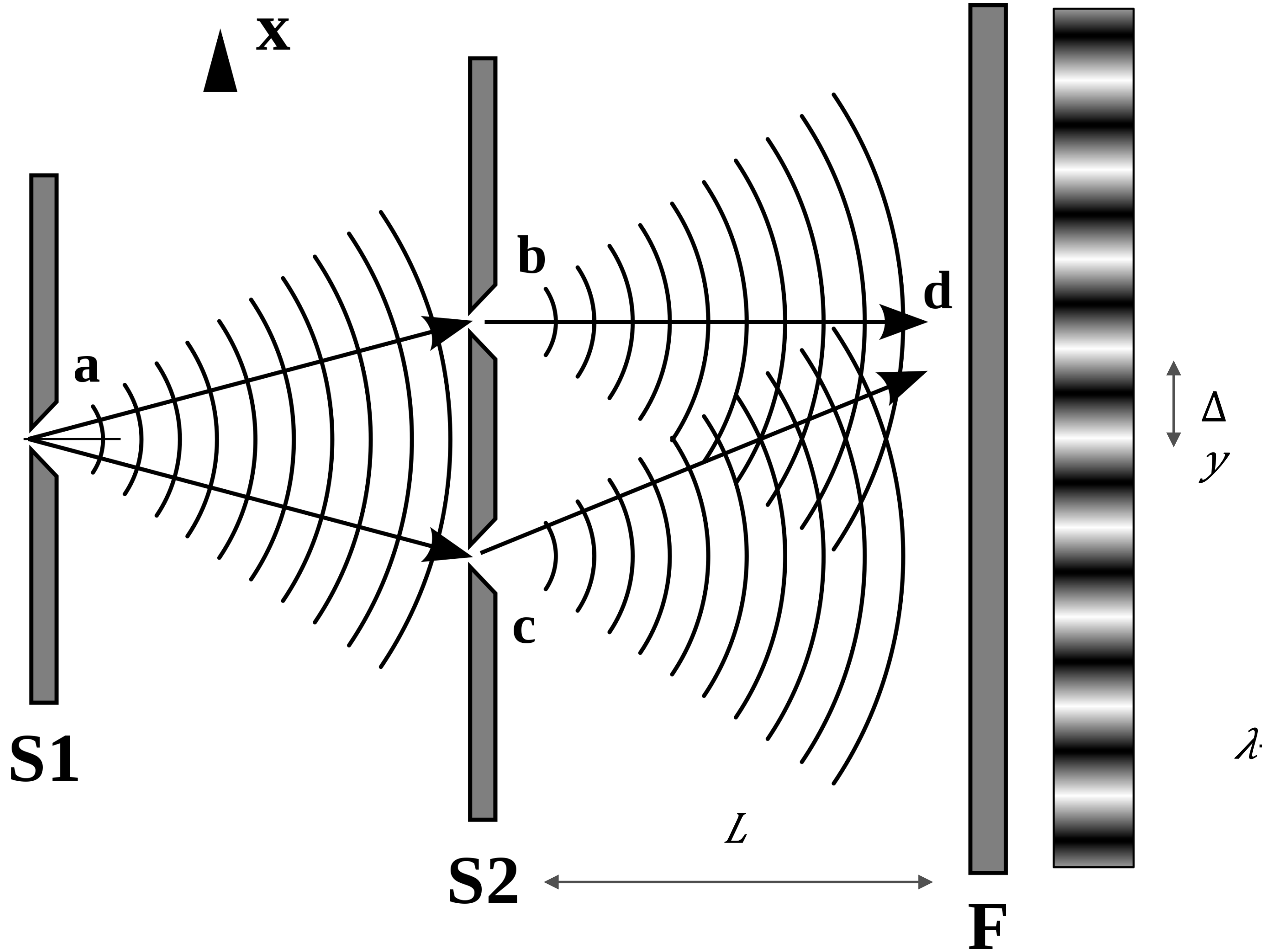
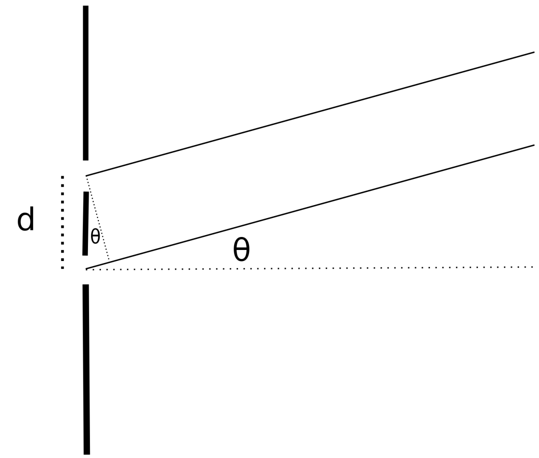
Esperimento di Young

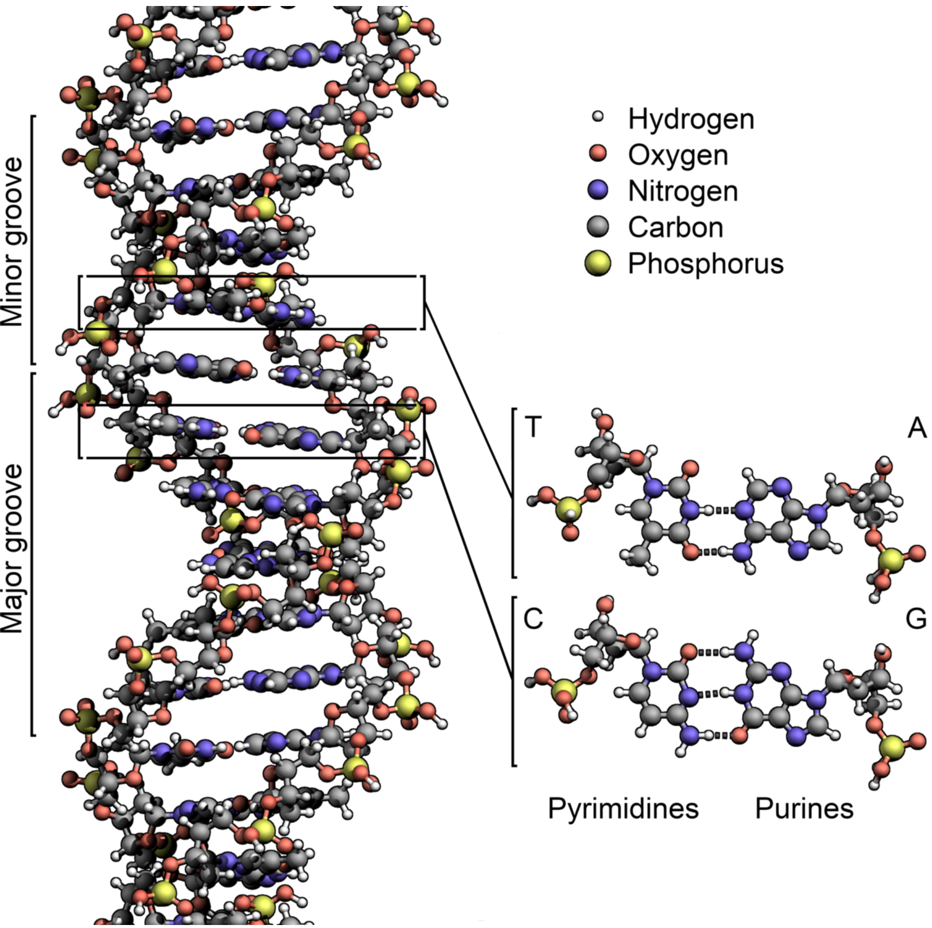


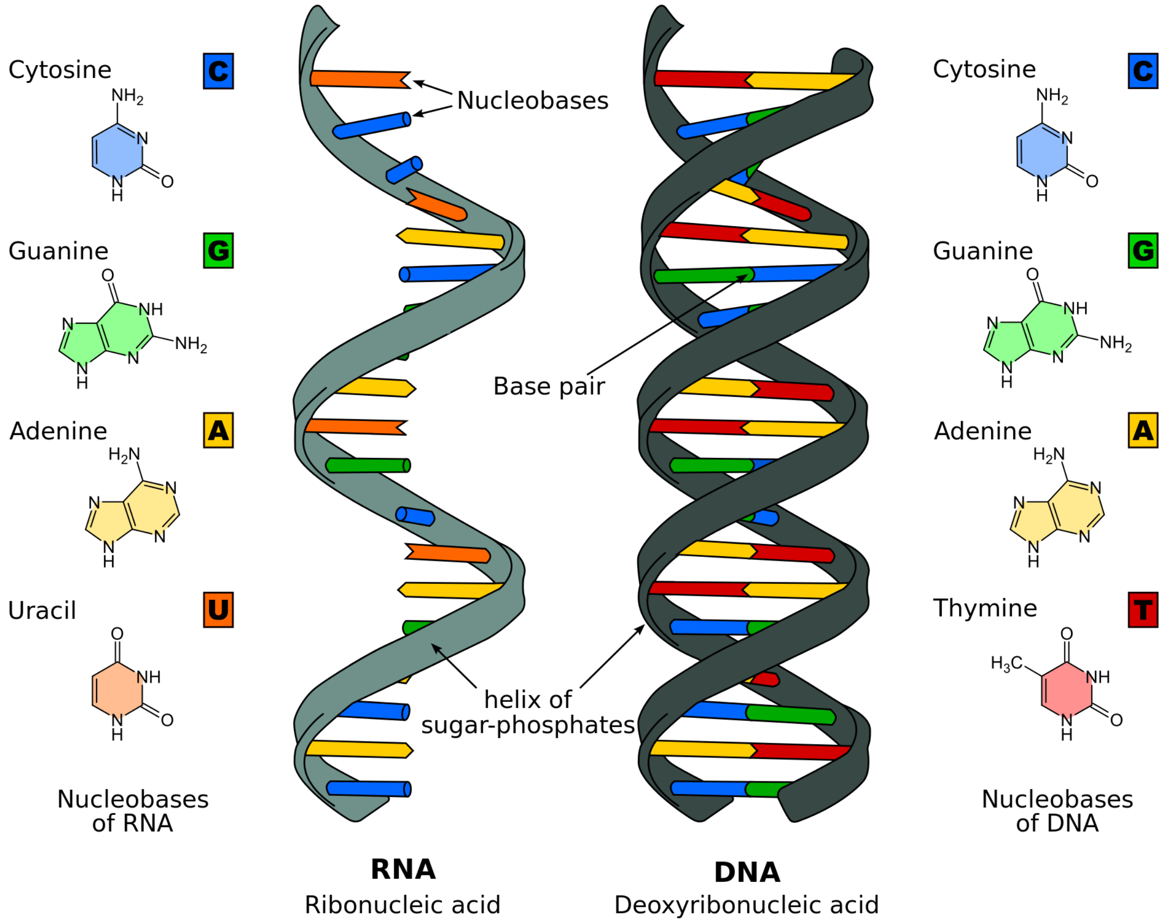


$\Delta y = L\lambda/d$

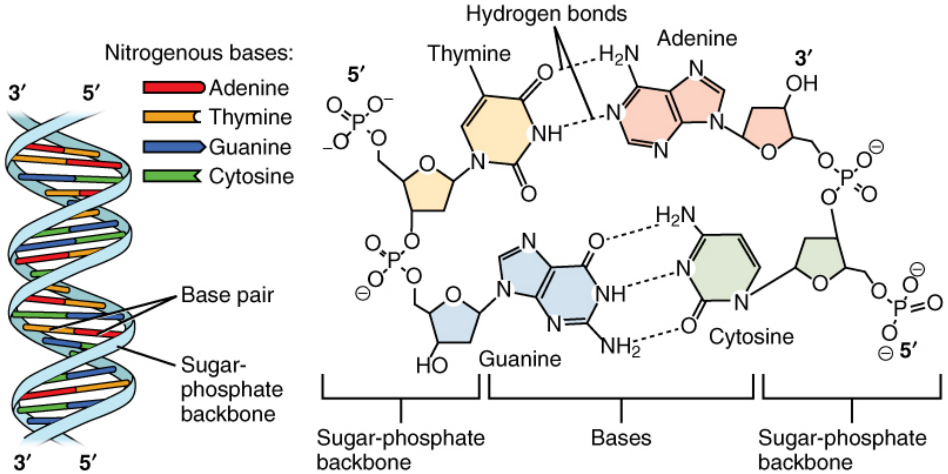
$\lambda \rightarrow$ lunghezza d'onda della luce

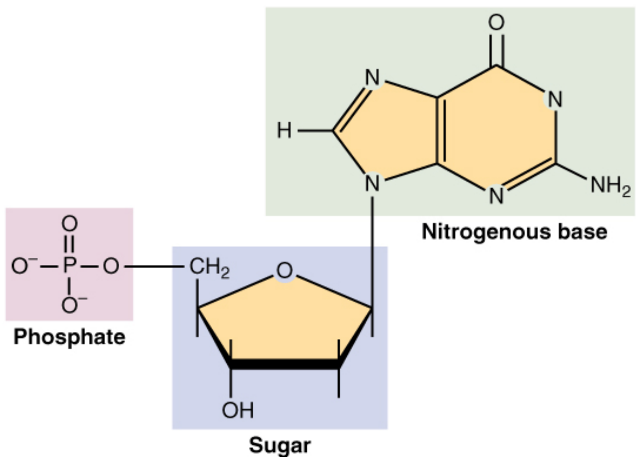
Deoxyribonucleic acid

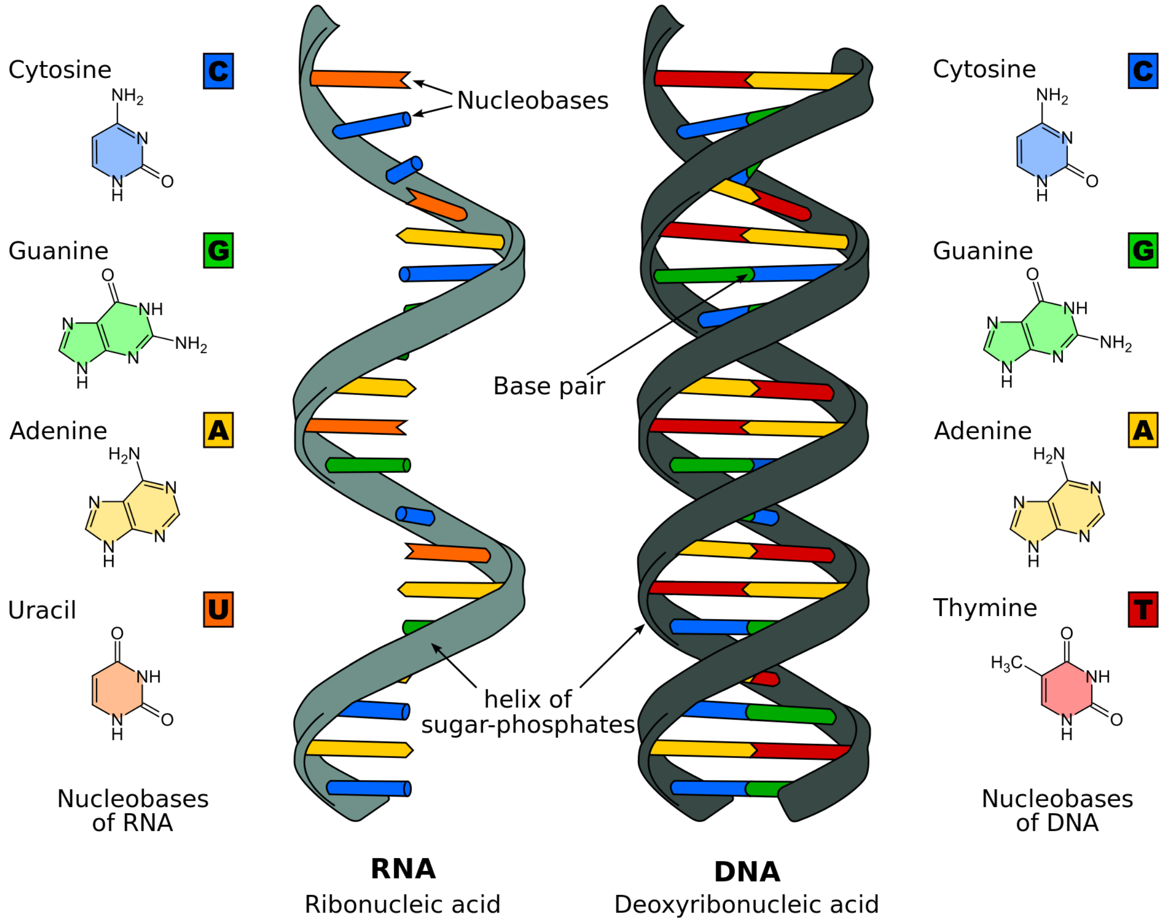




Deoxyribonucleic acid

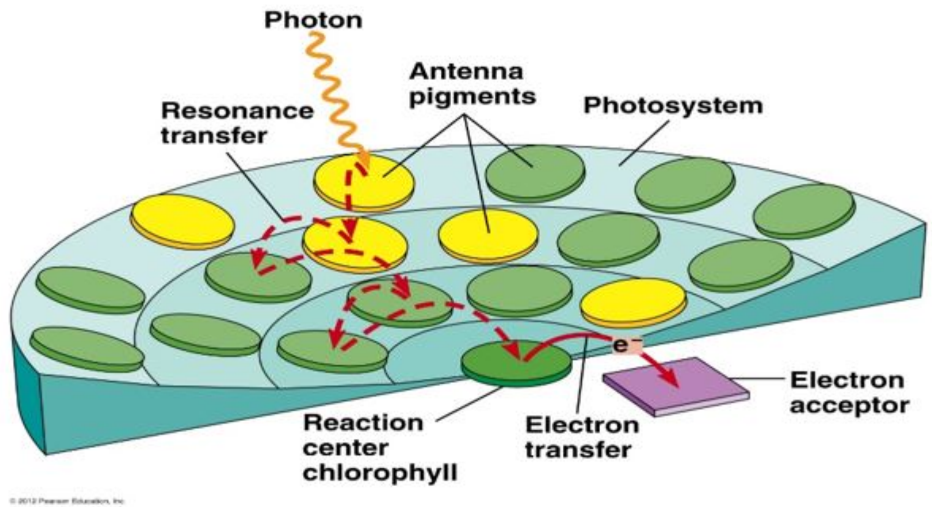






Nucleic acids are *naturally occurring chemical compounds* → primary information-carrying molecules in cells.

Fotosintesi

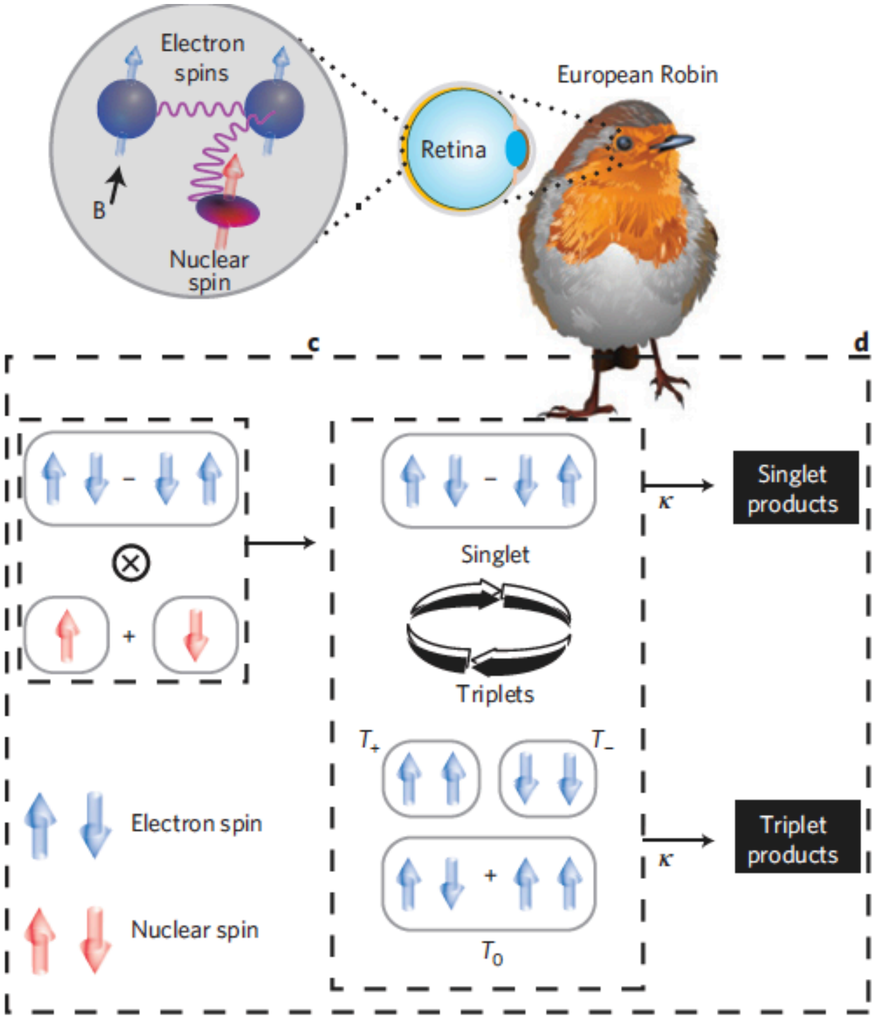


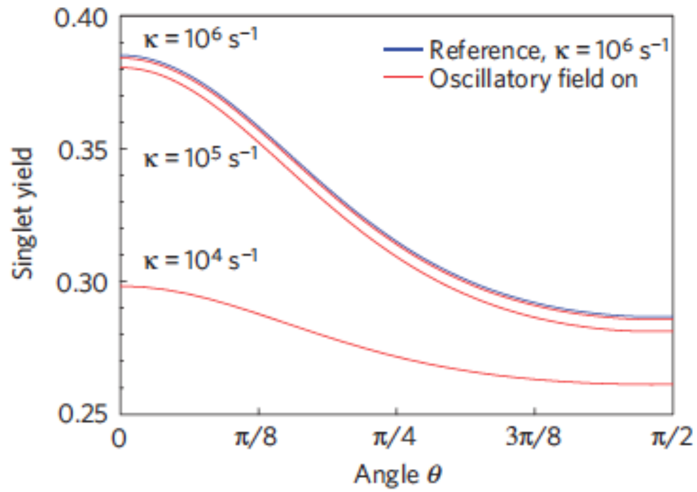
Engel G. S., Calhoun T. R., Read E. L., Ahn T-K., Manč al T., Cheng Y.-C., Blankenship R. E. e Fleming G. R., *Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems*, «**Nature**», vol. 44 (2007), pp. 782-86.

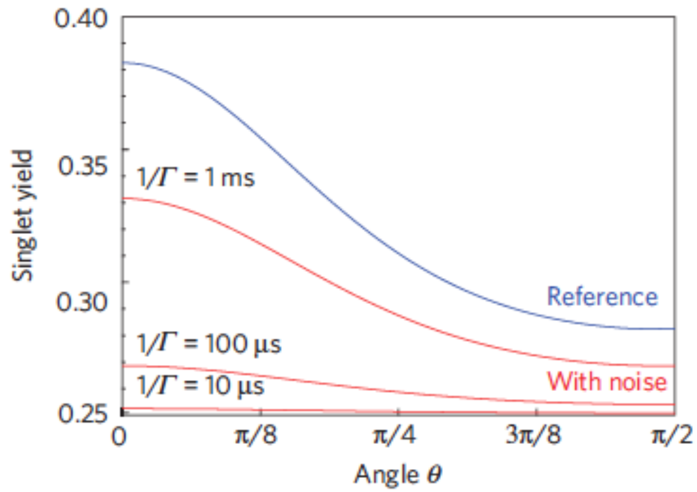
O RICERCHE
CO FERMI

The quantum robin

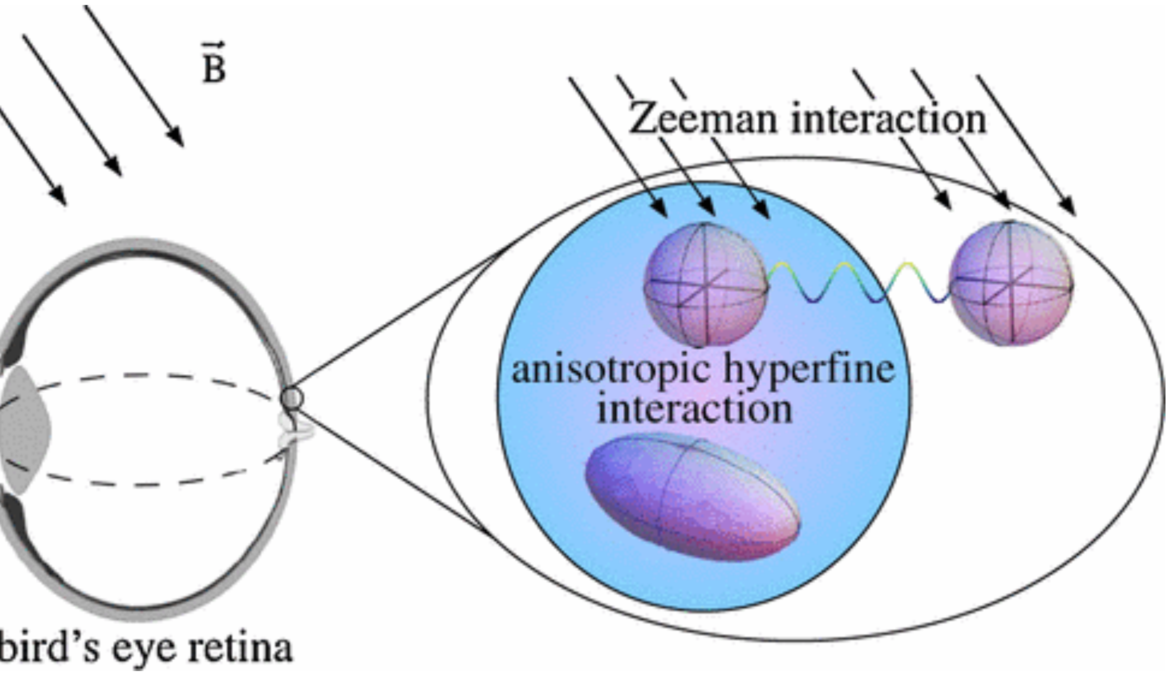
Istituto Nazionale di Fisica Nu
Laboratori Nazionali di Fras

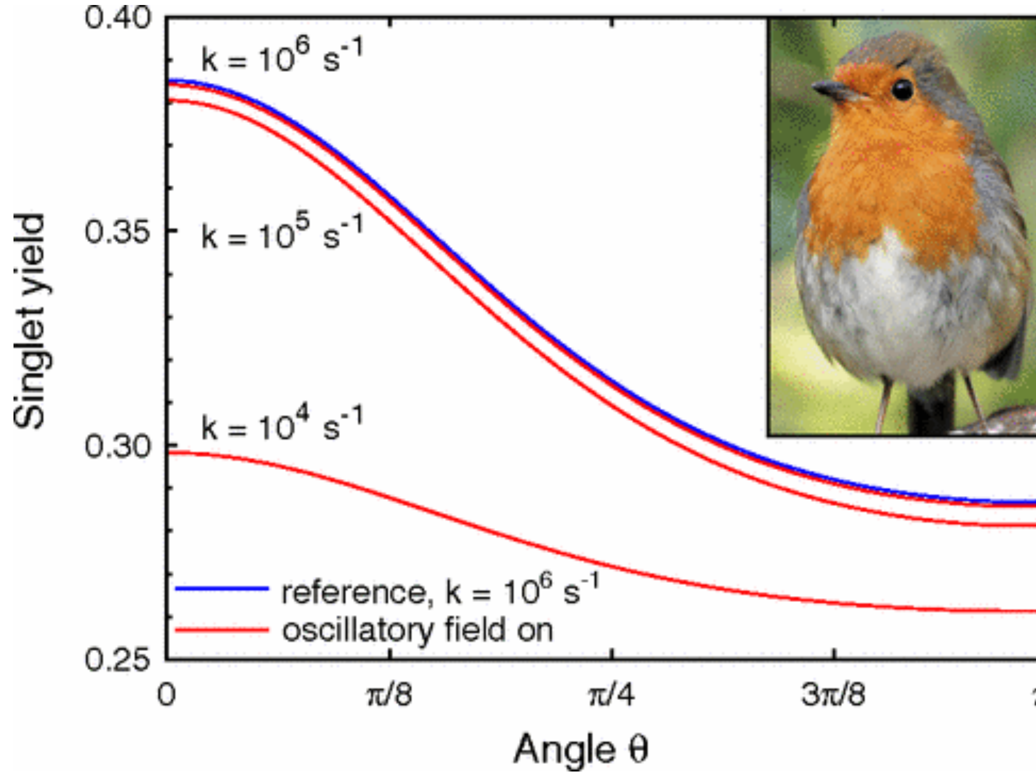




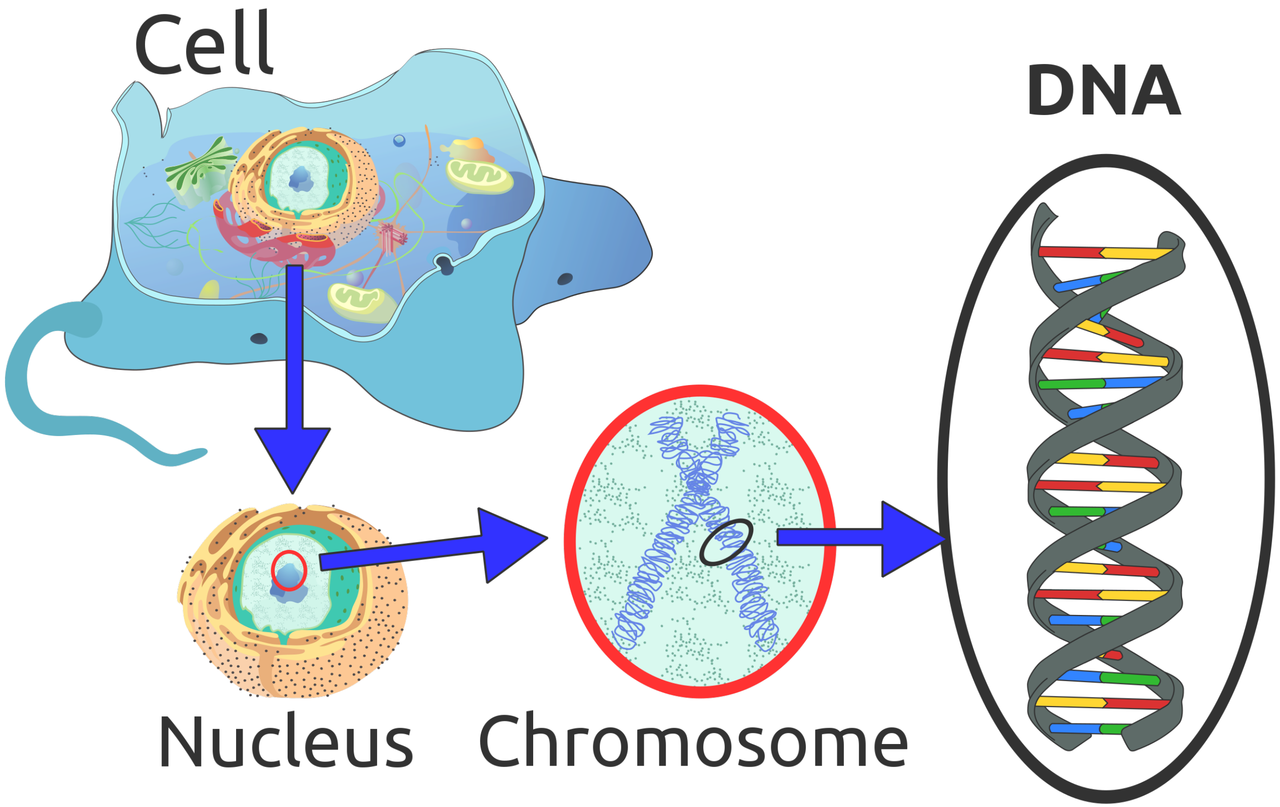


A great (quantum) scientist

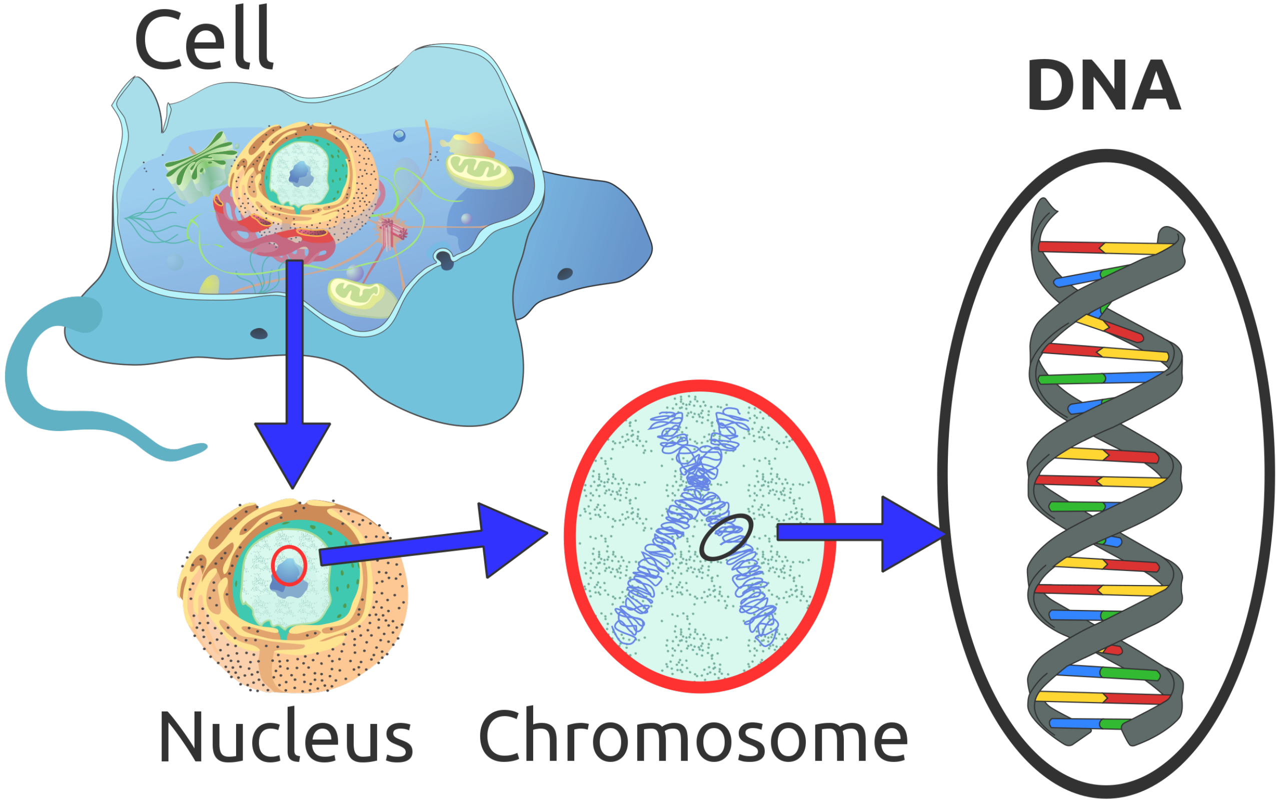




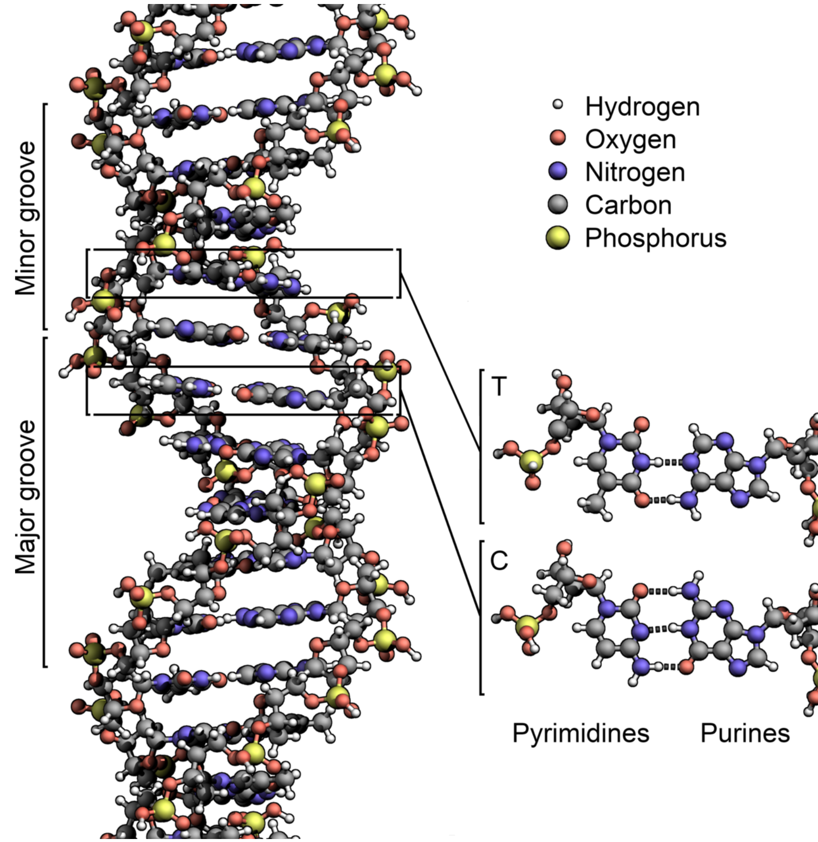
Coming back to life

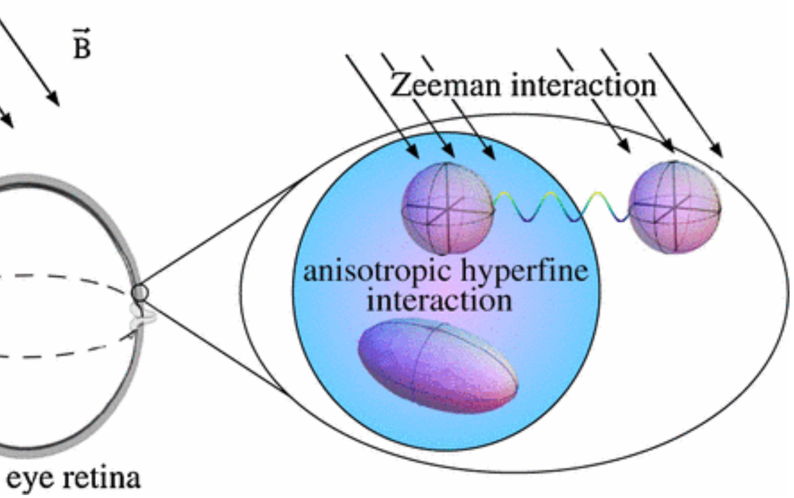


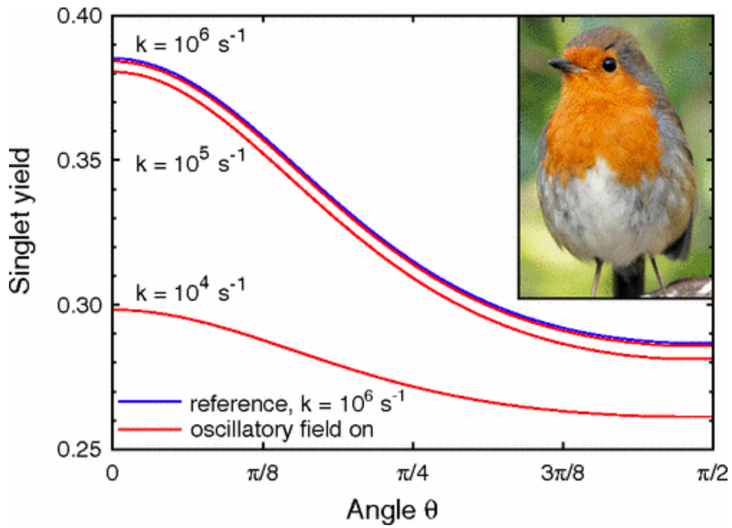
Coming back to life



Deoxyribonucleic acid

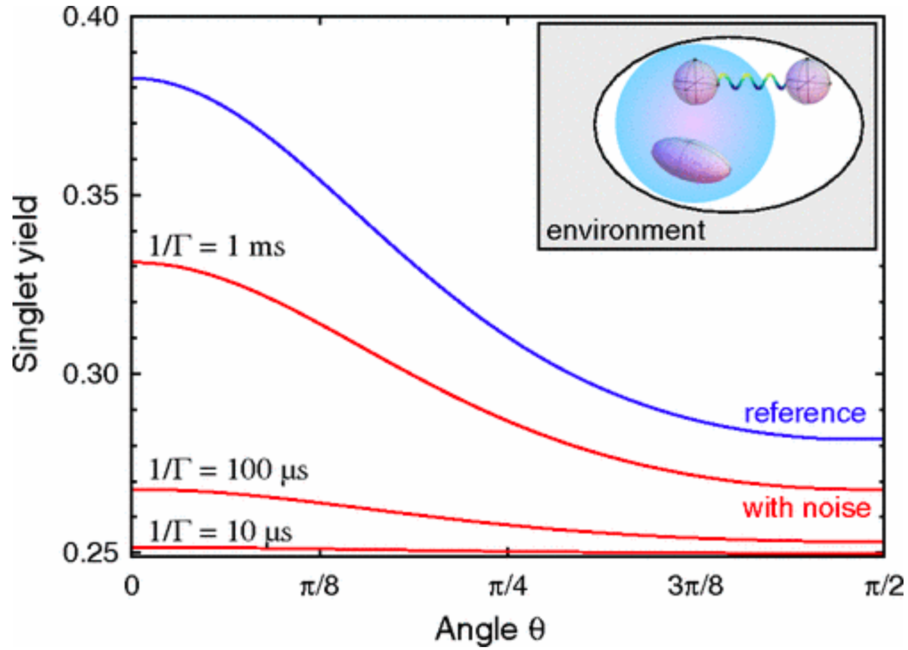






Angular dependence of the singlet yield in presence of an oscillatory field. The blue cu provides a reference of the singlet yield in Earth's magnetic field (B0=47 μT). The reference is independent of the decay rate for k≤107 s−1, but has been shifted upwar 0.001 for better visibility. The red curves s the singlet yield when a 150 nT field oscill at 1.316 MHz (i.e., resonant with the Zeem frequency of the uncoupled electron) is superimposed perpendicular to the directi the static field. This only has an appreciabl effect on the singlet yield once k is of order −1.

ding to the RP model, the back of the bird's eye ns numerous molecules for magnetoreception These molecules give rise to a pattern, nible to the bird, which indicates the orientation field. Note that this implies that the molecules ed are at least fixed in orientation, and possibly ed with respect to one another [8]. In the est variant, each such molecule involves three l components (see inset): there are two ons, initially photoexcited to a singlet state, and a ar spin that couples to one of the electrons. This ng is anisotropic, so that the molecule has a ionality to it.



Angular dependence of the singl yield in the presence of noise (for k=104). The blue curve provides a reference in the absence of noise, and the red curves show the singlet yield for different noise rates. As is apparent from the plot, a noise rate Γ>0.1k has a dramatic effec on the magnitude and contrast o the singlet yield. Inset: The partitioning between compass a environment.