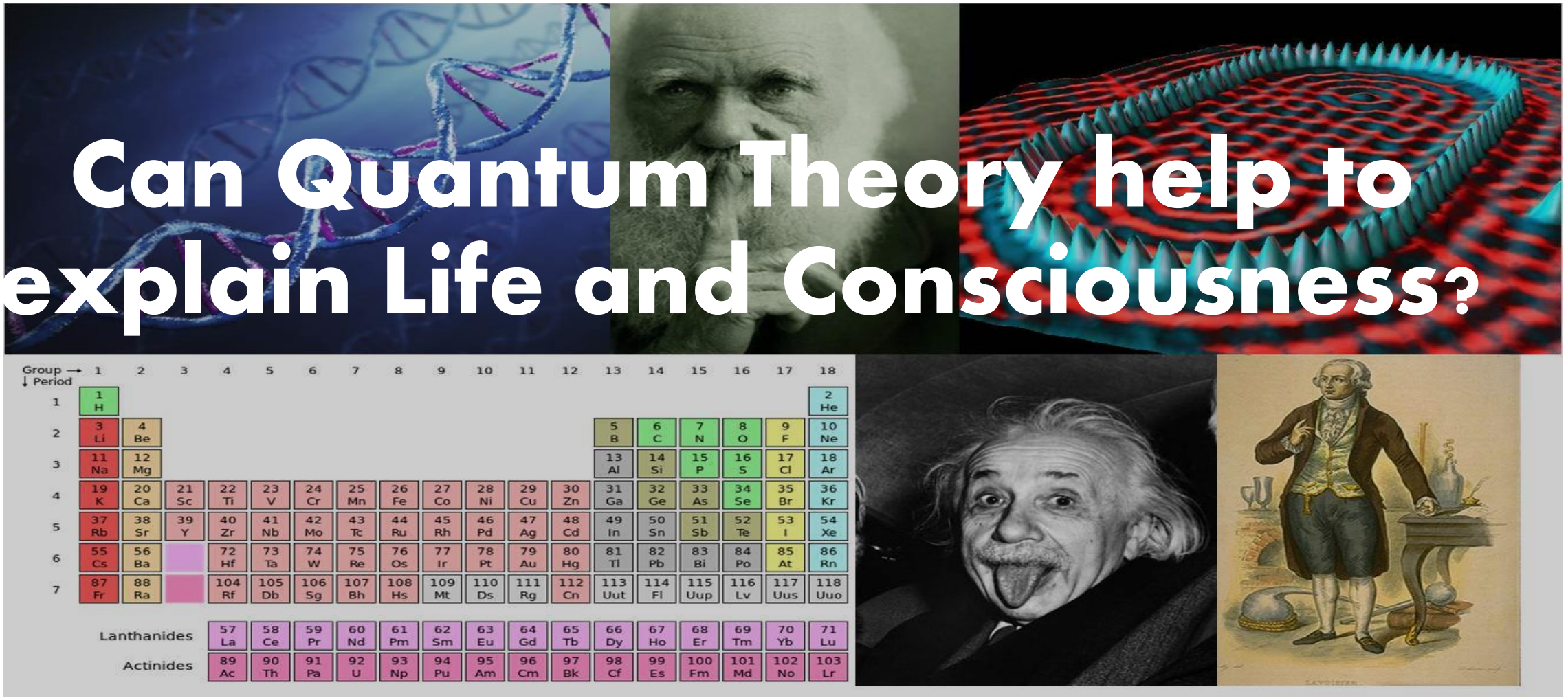
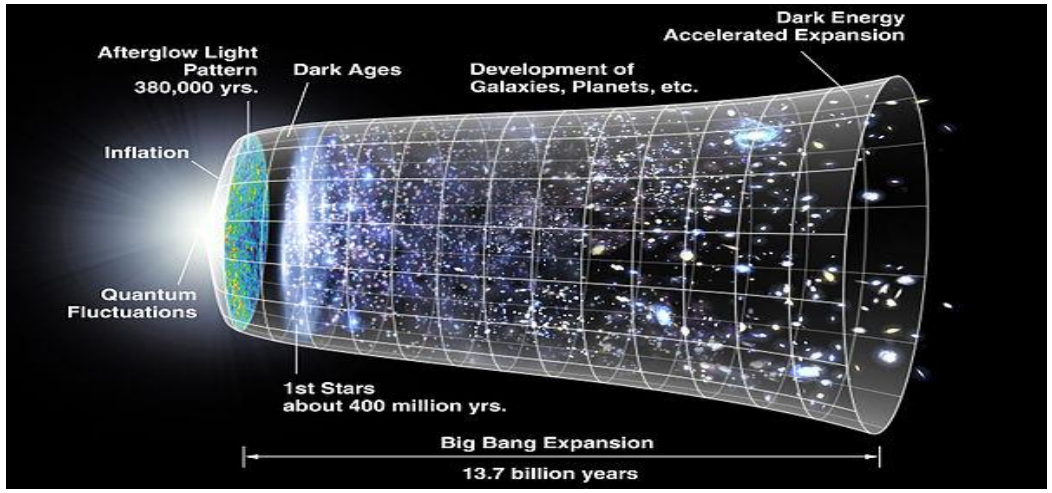


Vahid Salari

Isfahan University of Technology

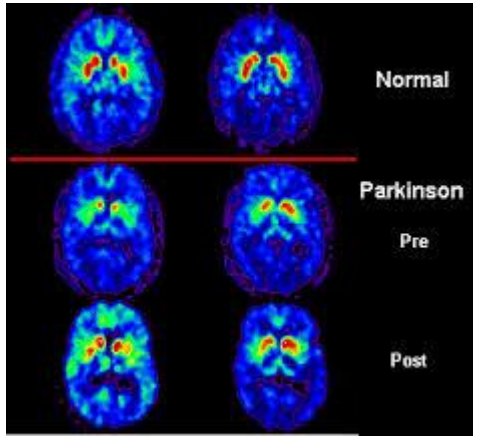
December 2015

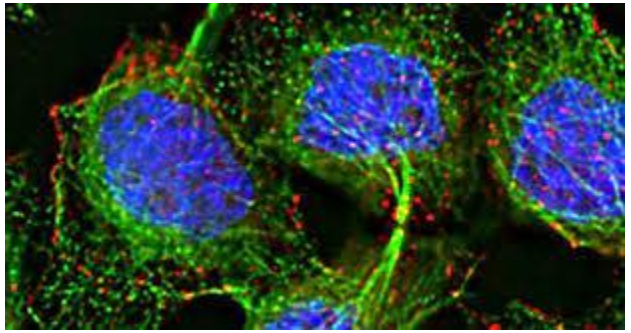


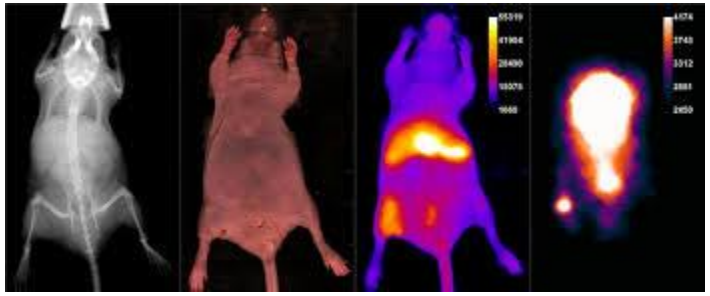
Our Universe

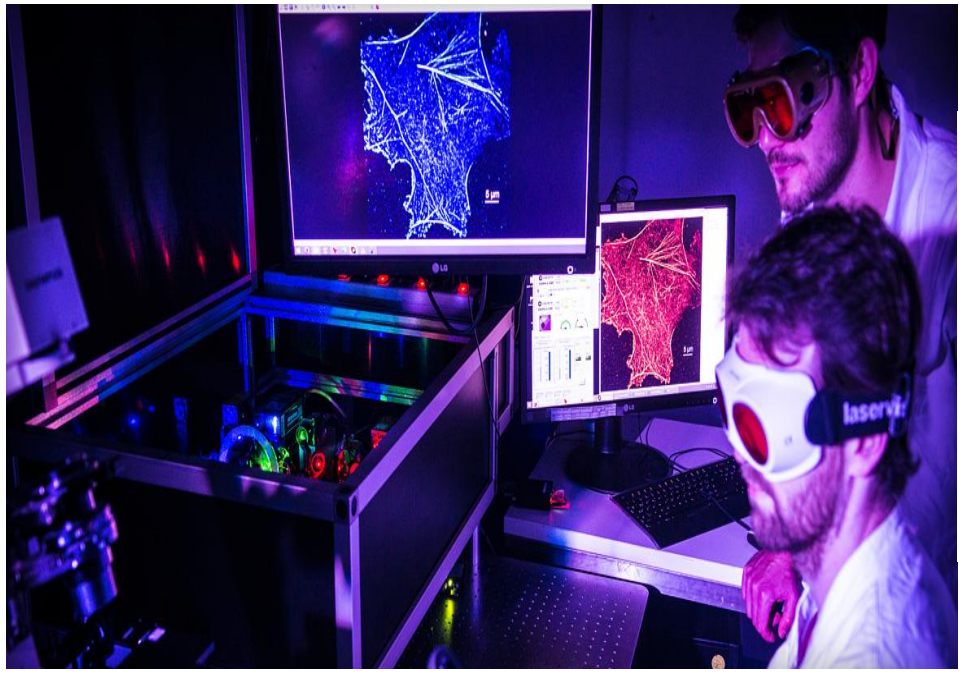
Our Planet, Earth

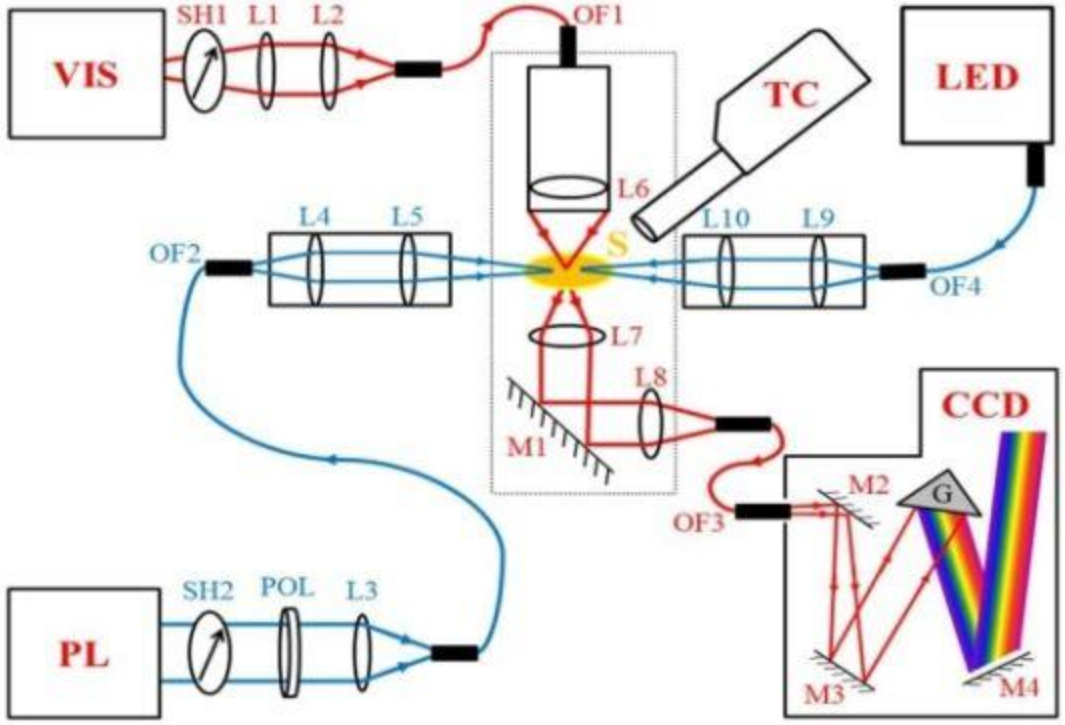
Physics and Biology



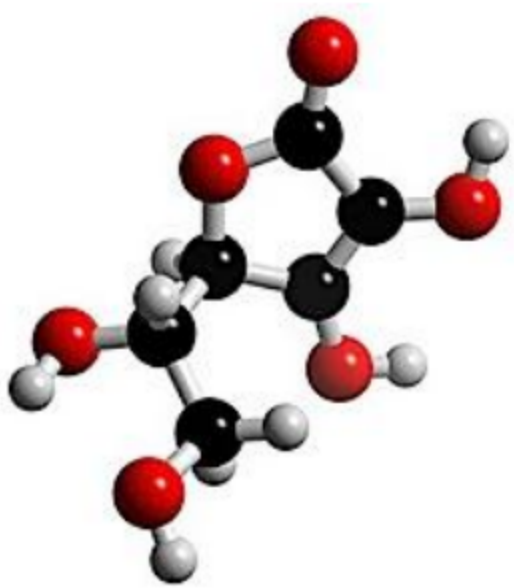


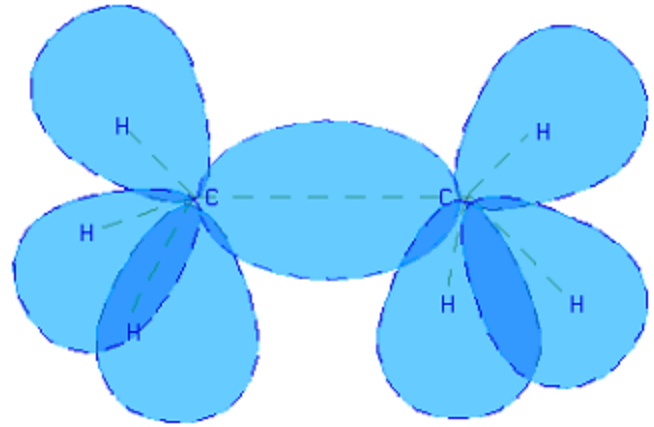






Chemical Bonds





Quantum coherence certainly exist in the level of chemical bonds

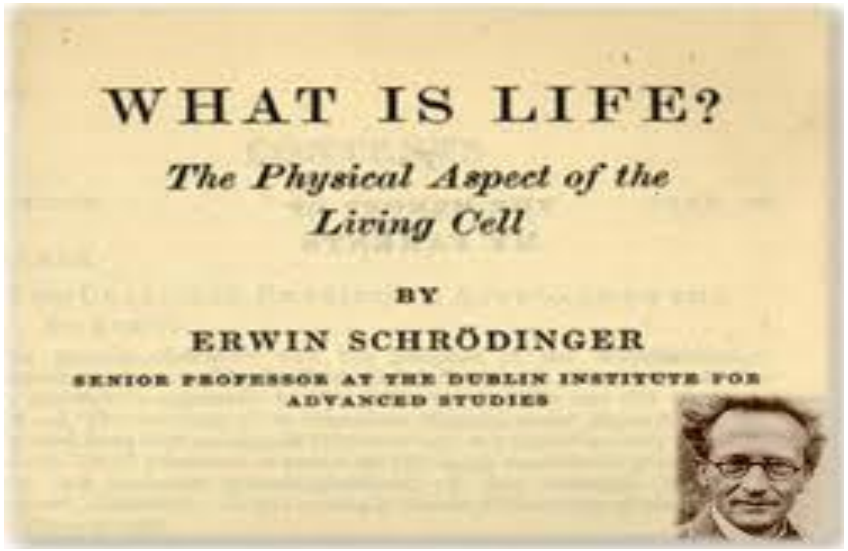
Delocalized electrons can be found at that level

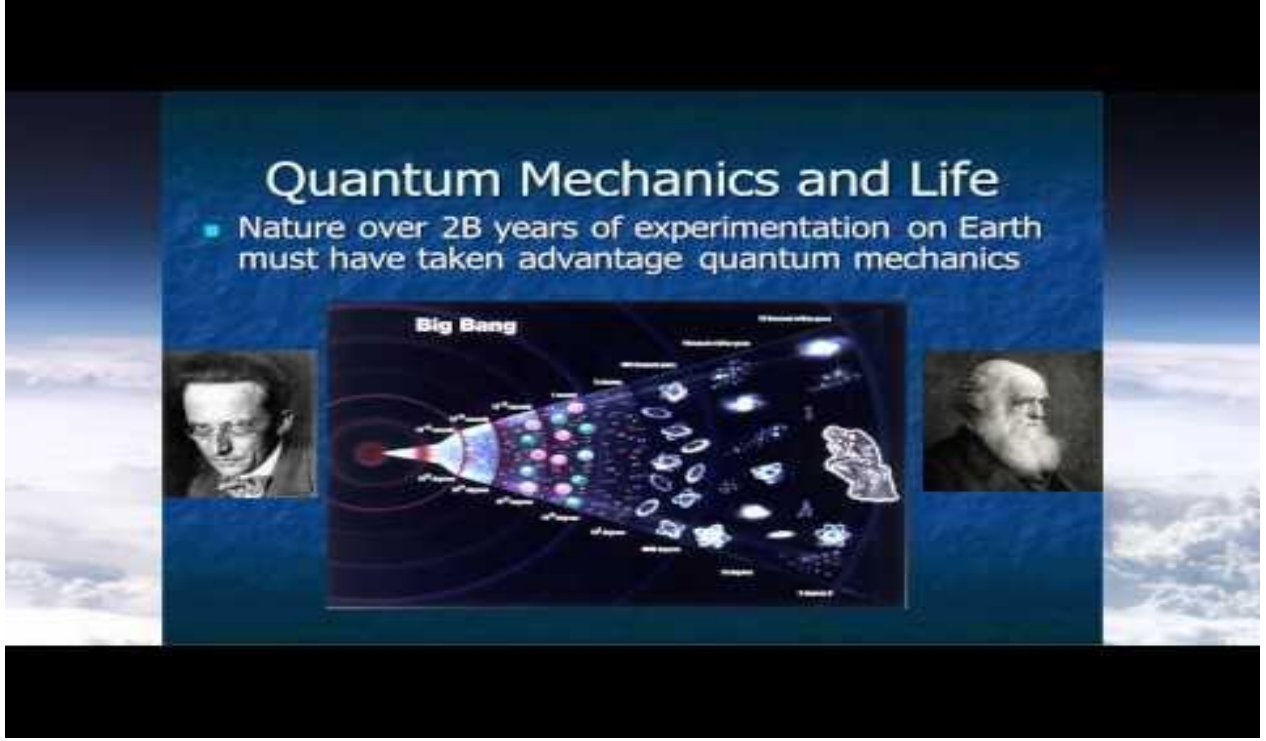
These kind of coherences are some how trivial and less interesting

Defining Life

These are some generally agreed-upon characteristics that any lifeform should have:

- ability to react to environment
- ability to grow by taking in nourishment and processing it into energy
- ability to reproduce, with offspring having some characteristics of parent
- ability to evolve/capacity for genetic change


WHAT IS LIFE?
The Physical Aspect of the Living Cell
BY
ERWIN SCHRÖDINGER
SENIOR PROFESSOR AT THE DUBLIN INSTITUTE FOR ADVANCED STUDIES


Quantum Mechanics and Life
Nature over 2B years of experimentation on Earth must have taken advantage quantum mechanics
Big Bang

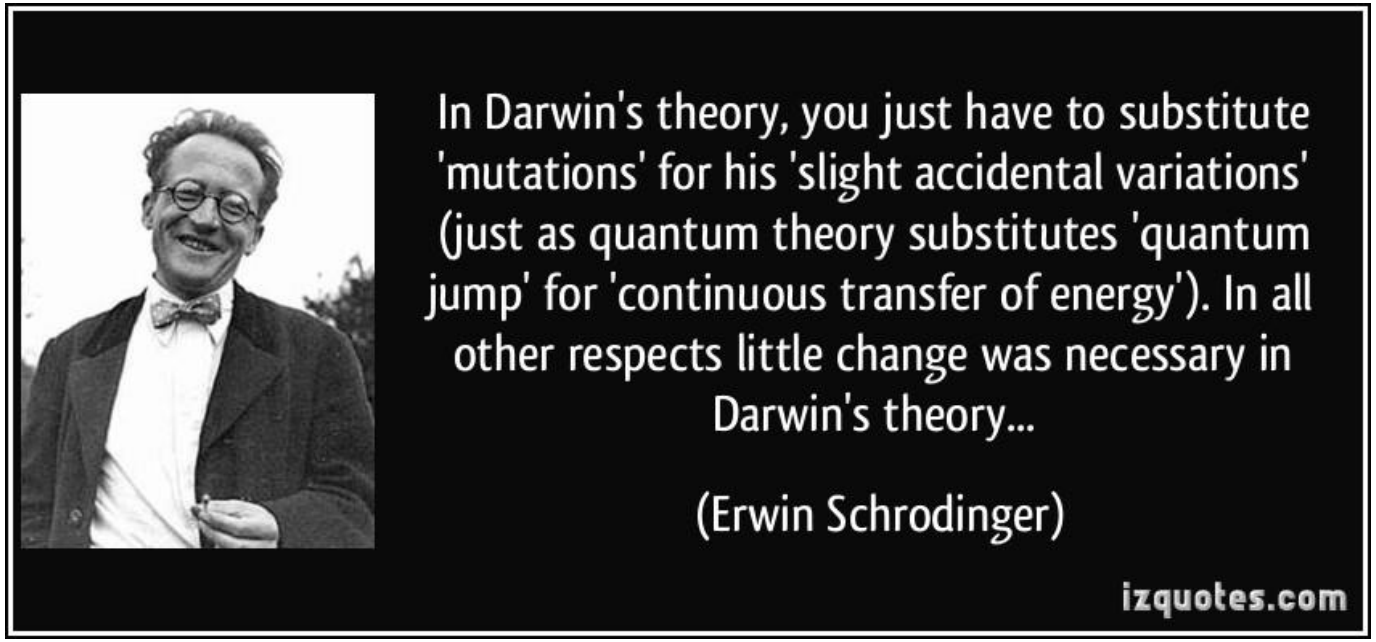
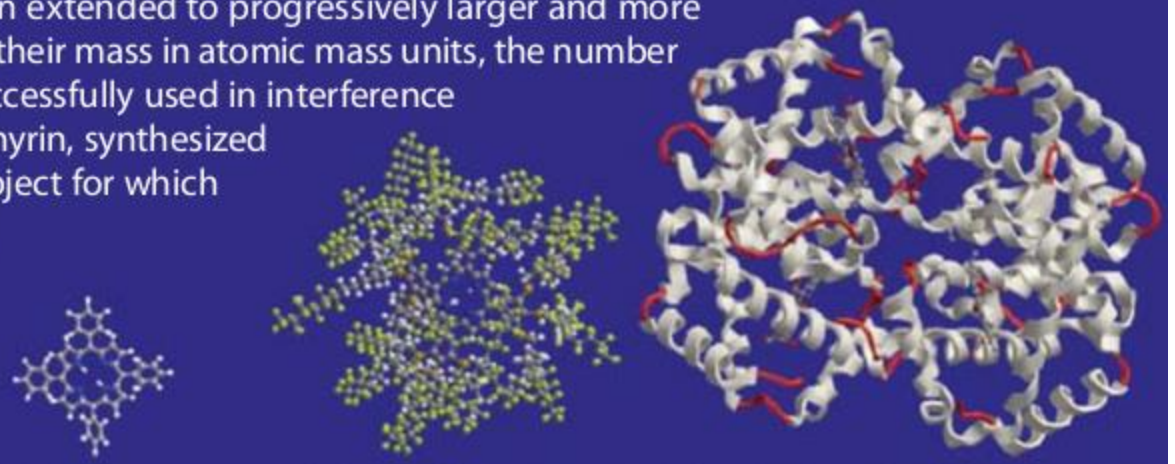

In Darwin's theory, you just have to substitute 'mutations' for his 'slight accidental variations' (just as quantum theory substitutes 'quantum jump' for 'continuous transfer of energy'). In all other respects little change was necessary in Darwin's theory...
(Erwin Schrodinger)
izquotes.com

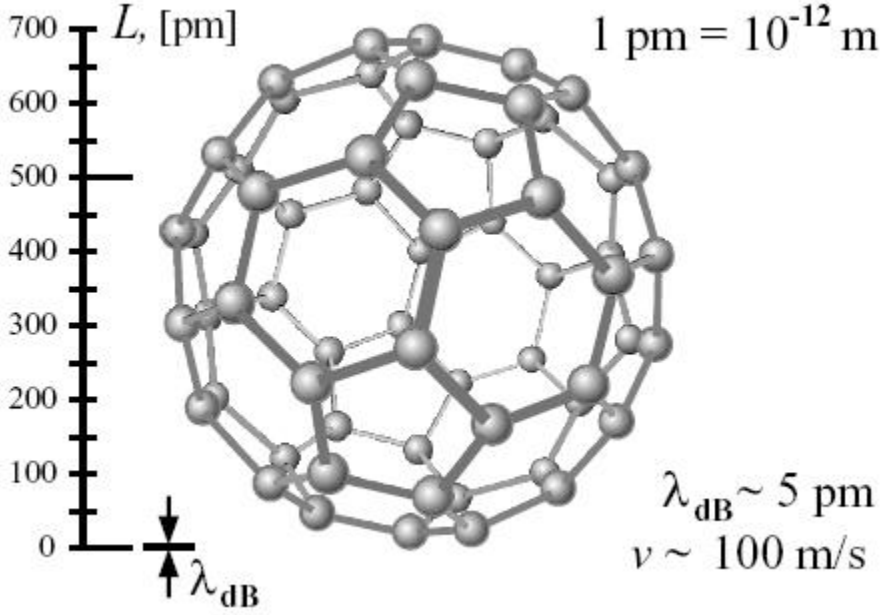
Figure 5. Matter-wave diffraction started in 1930 with diatomic particles, but it didn't gain momentum until the early 1990s. Since then the technique has been extended to progressively larger and more complex molecules; some are depicted here along with their mass in atomic mass units, the number of atoms they comprise, and the year they were first successfully used in interference experiments. To date, a functionalized tetraphenylporphyrin, synthesized by Marcel Mayor and colleagues, is the most massive object for which matter-wave interference has been seen. In the future, bionanomatter such as hemoglobin proteins will likely be studied using matter-wave-enhanced measurements.



H_2	He_2, Na_2, I_2	Buckminsterfullerene	Tetraphenylporphyrin	Functionalized Tetraphenylporphyrin	Hemoglobin
2 amu, 2 atoms (1930)	8–254 amu, 2 atoms (1994–95)	720 amu, 60 atoms (1999)	614 amu, 78 atoms (2003)	10 123 amu, 810 atoms (2013)	>60 000 amu, ~10 000 atoms (?)

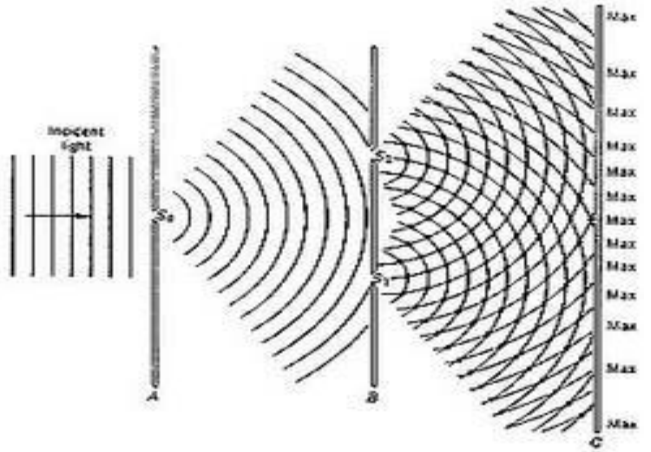
de Broglie

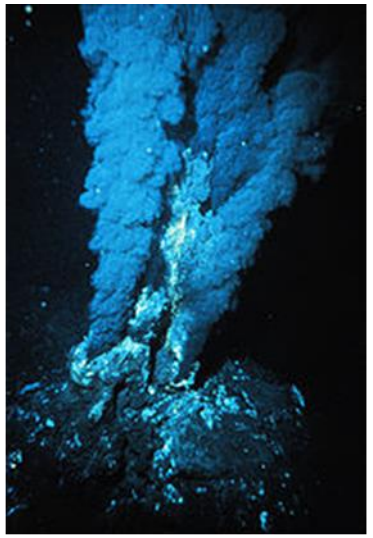
$$\lambda = \frac{h}{mv}$$



Markus Arndt

Anton Zeilinger





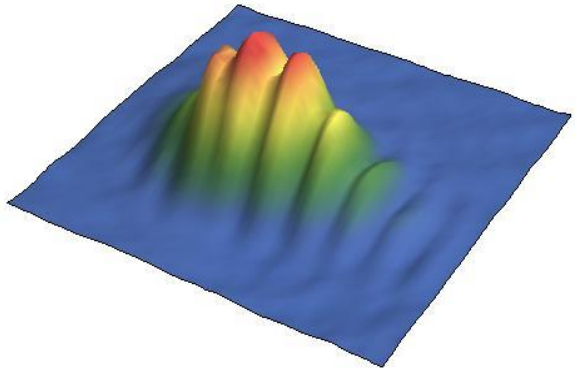
A black smoker in the Atlantic Ocean ~ 2000m deep

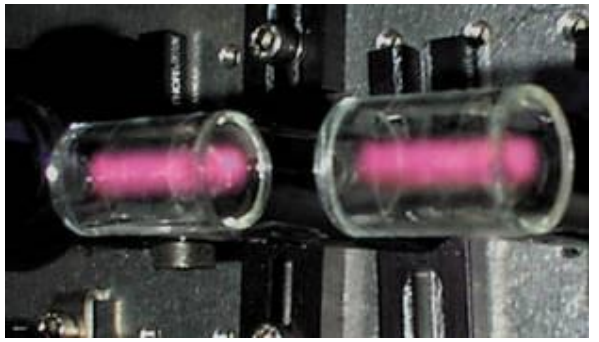
Quantum Coherence and Very High Efficiency of Energy Transfer

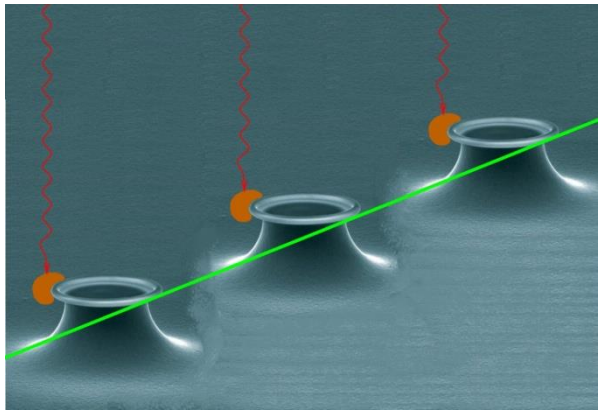
In Black sea (~100 m) this bacteria receives ~10 photons per day.

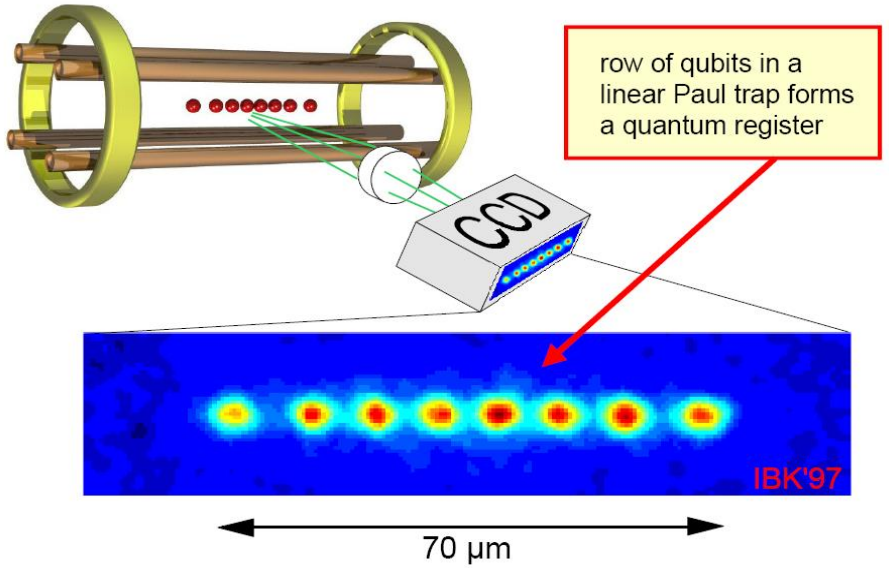
It is extremely efficient and does not miss any photon

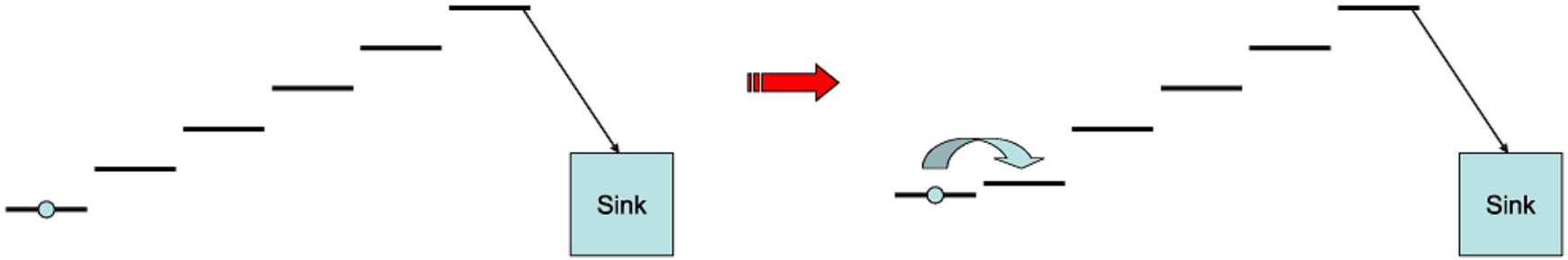
Noise seems a problem here as it destroys quantum coherence



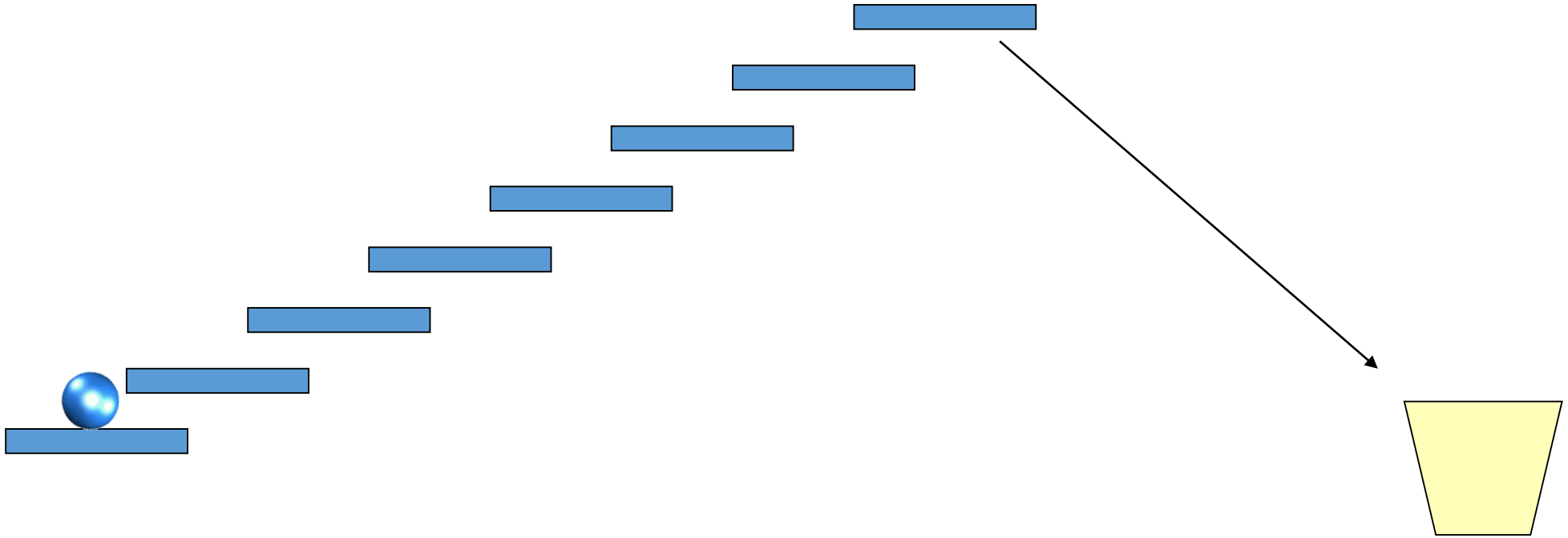








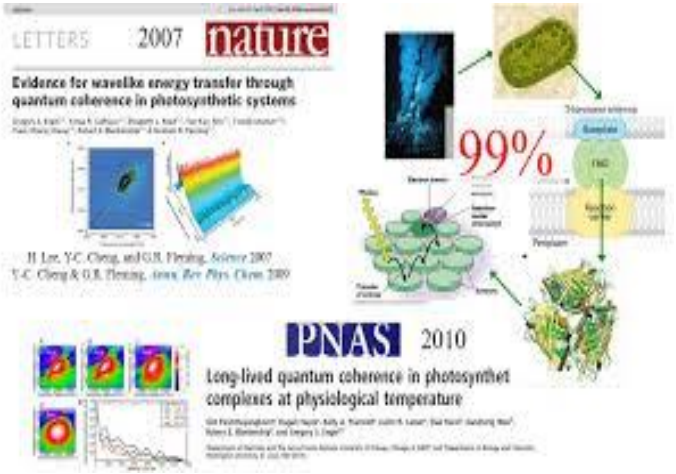
Fluctuation of energy levels ⟶ increase overlap ⟶ excitation may hop



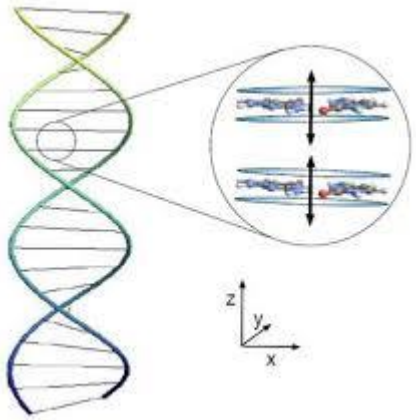
Single Photon Detectors
in the Eye

Olfaction

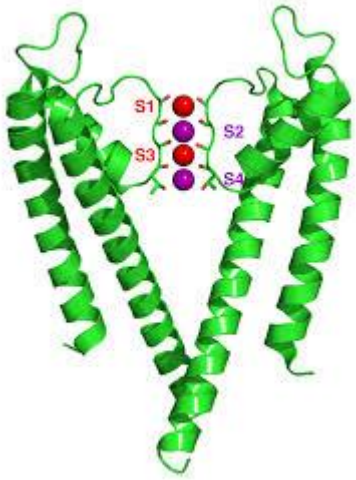
Migratory Birds



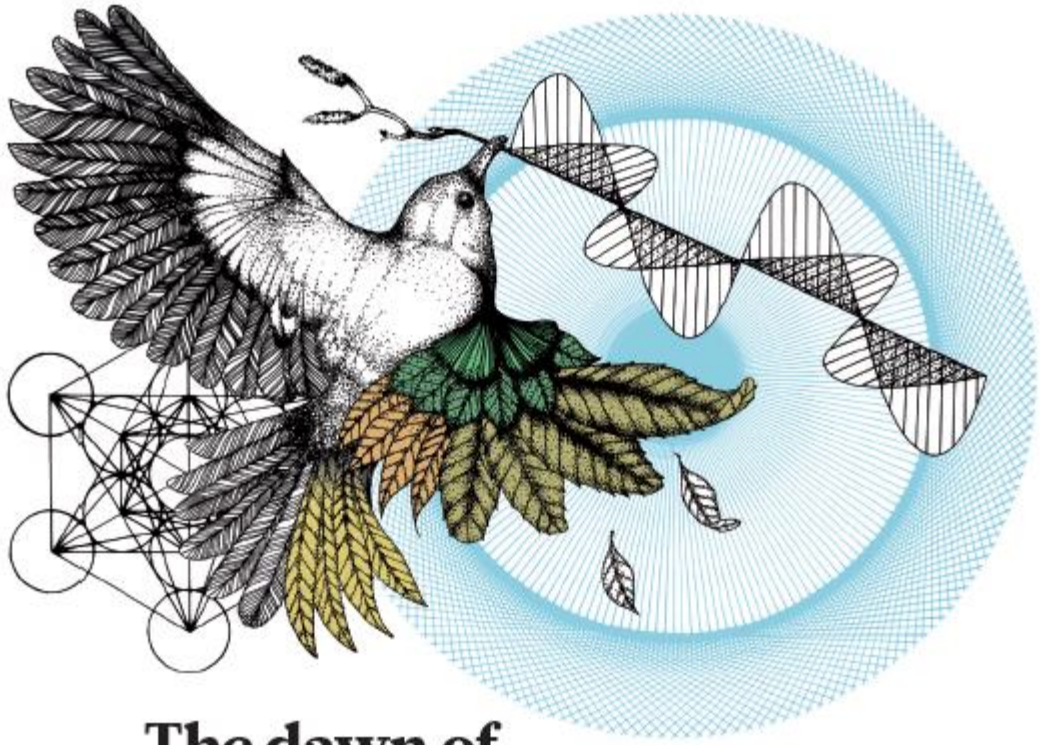
Photosynthesis



Quantum Effects in DNA



Ion Channels



The dawn of quantum biology

The key to practical quantum computing and high-efficiency solar cells may lie in the messy green world outside the physics lab.

BY PHILIP BALL

On the face of it, quantum effects and living organisms seem to occupy utterly different realms. The former are usually observed only on the nanometre scale, surrounded by hard vacuum, ultra-low temperatures and a tightly controlled laboratory environment. The latter inhabit a macroscopic world that is warm, messy and anything but controlled. A quantum phenomenon such as 'coherence,' in which the wave patterns of every part of a system stay in step, wouldn't last a microsecond in the tumultuous realm of the cell.

Or so everyone thought. But discoveries in recent years suggest that nature knows a few tricks that physicists don't: coherent quantum processes may well be ubiquitous in the natural world. Known or suspected examples range from the ability of birds to navigate using Earth's magnetic field to the inner workings of photosynthesis — the process by

Nature knows a few tricks that physicists don't.

"This might just give us a few clues in the quest to create quantum technology."

QuEBS 2009, Lisbon University

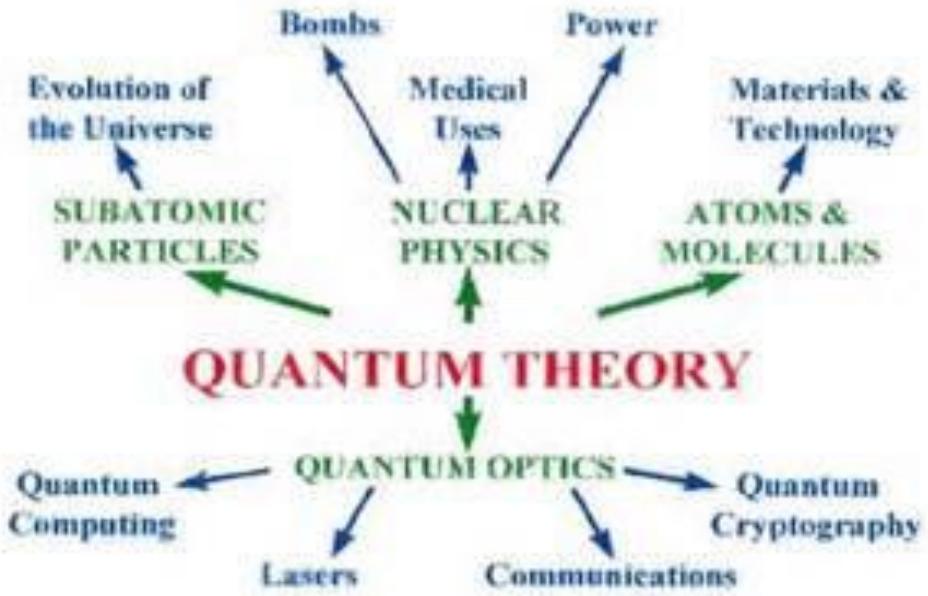
QuEBS 2010, Harvard University

QuEBS 2011, Ulm University

QuEBS 2012, UC Berkeley

QuEBS 2013, Vienna University

QuEBS 2014, NUS, Singapore


Bombs
Power
Evolution of the Universe
Medical Uses
Materials & Technology
SUBATOMIC PARTICLES
NUCLEAR PHYSICS
ATOMS & MOLECULES
QUANTUM THEORY
QUANTUM OPTICS
Quantum Computing
Quantum Cryptography
Lasers
Communications


QUANTUM
THEORY
www.quantumtheorygame.com

Measurement Problem

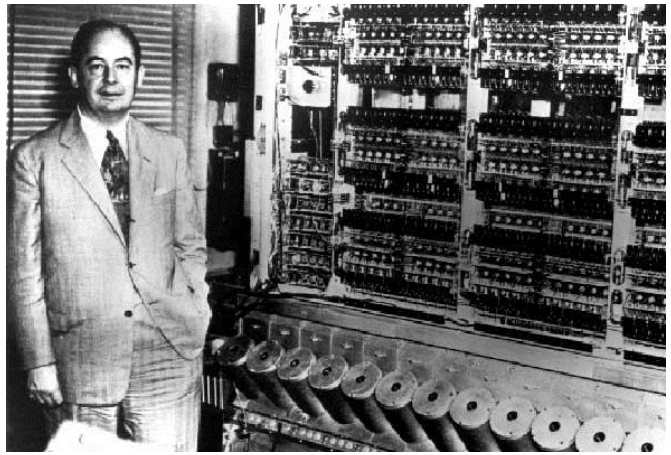
So what constitutes a measurement is really important

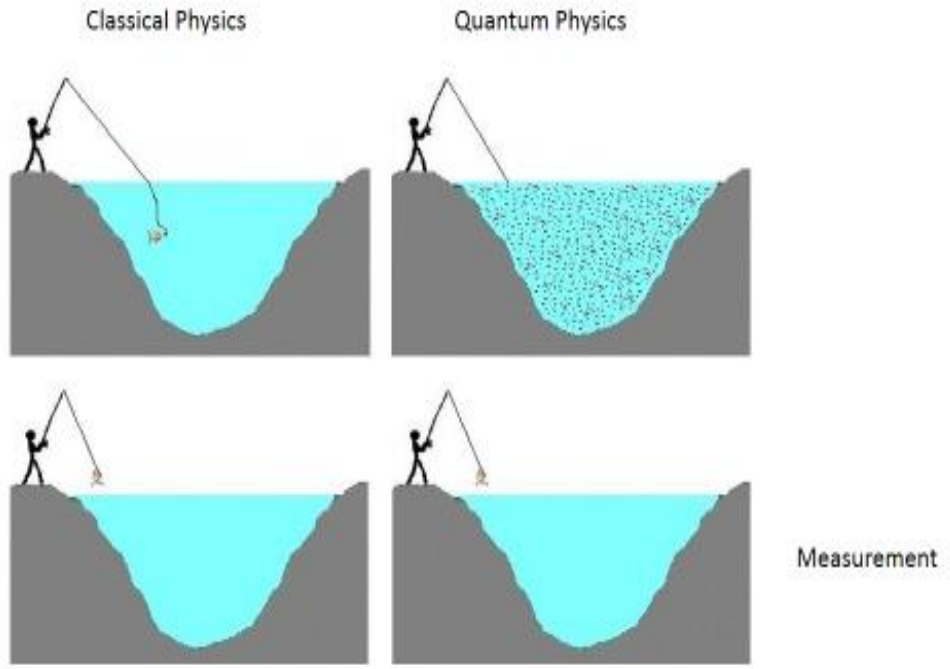
Def1: A measurement is something what you do with a measurement device….

Usable in the daily practice of physics

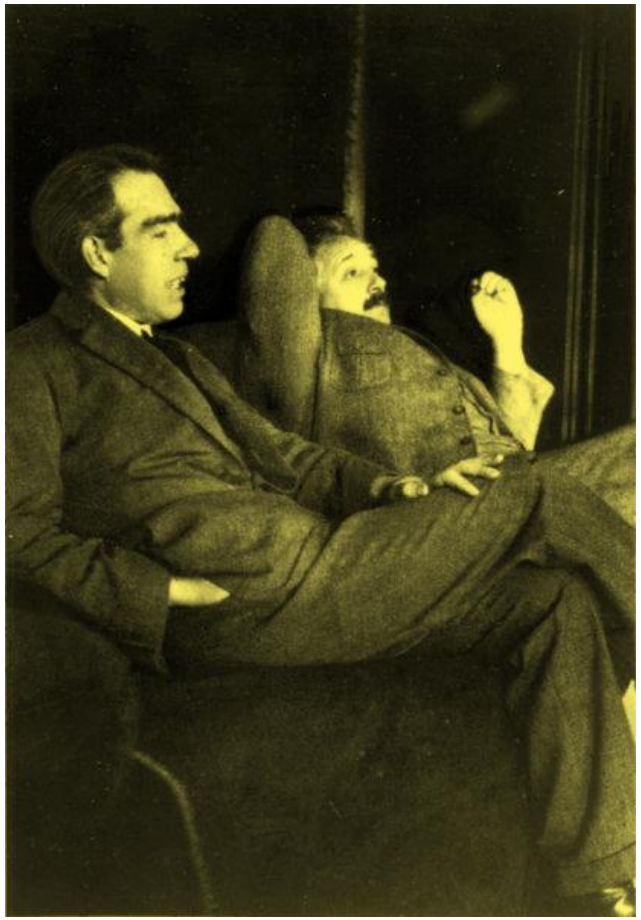
But incorrect

(von Neumann)





The Bohr-Einstein Debate on Quantum Mechanics, 1925-1935 (and beyond)



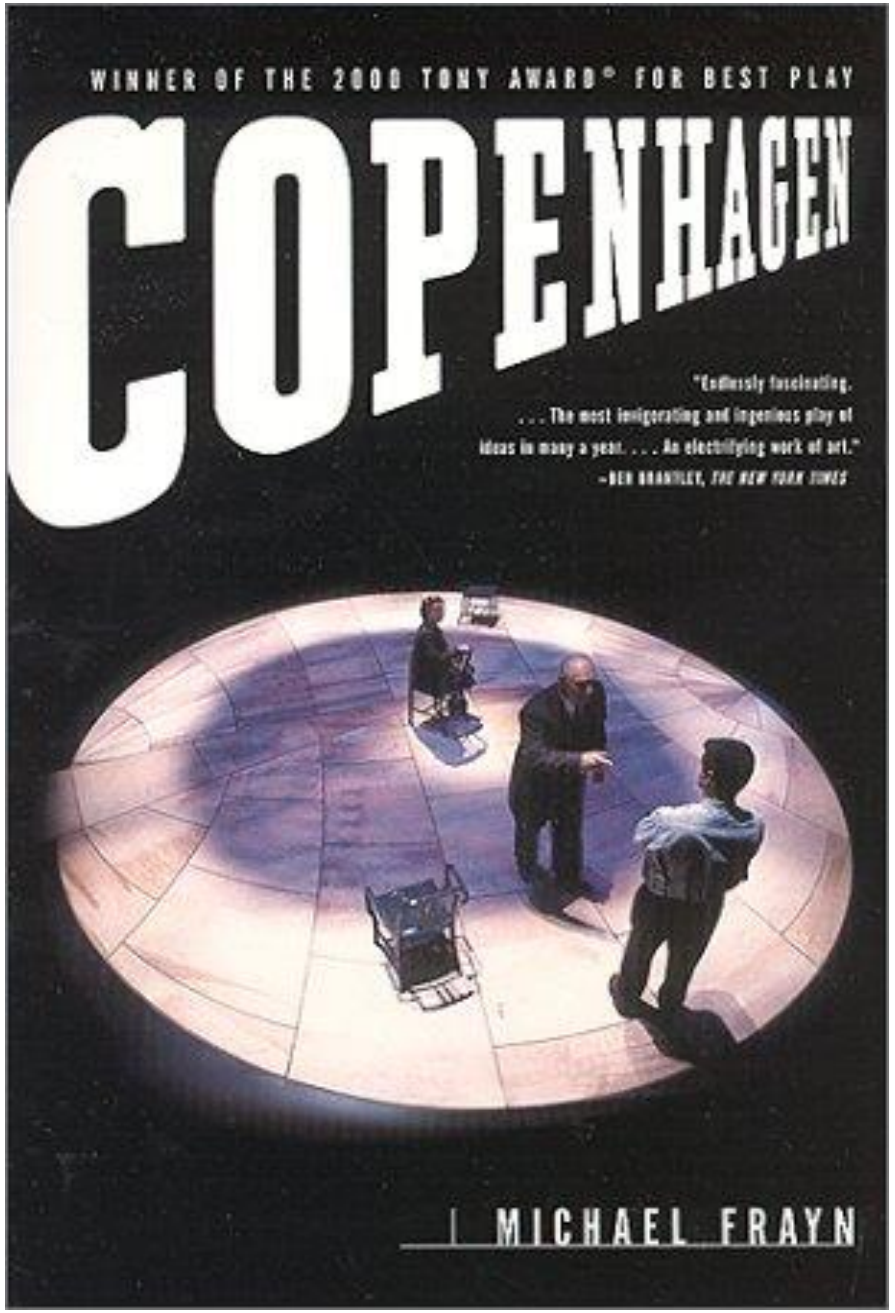
Copenhagen school

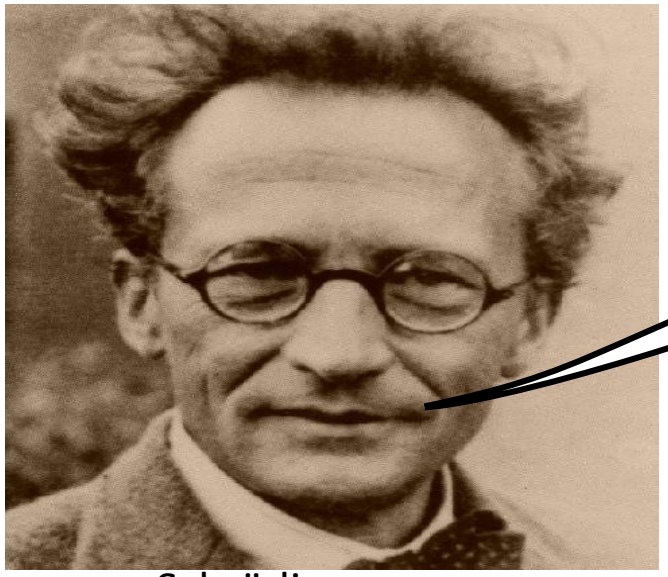
Since my talks with Bohr often continued till long after midnight and did not produce a satisfactory conclusion, ...both of us became utterly exhausted and rather tense…

I had no faith in a theory that ran completely counter to our Copenhagen conception.

--Heisenberg, recollection

Bohr, Heisenberg, Pauli





Schrödinger

I don’t like it and I’m sorry I ever had anything to do with it.

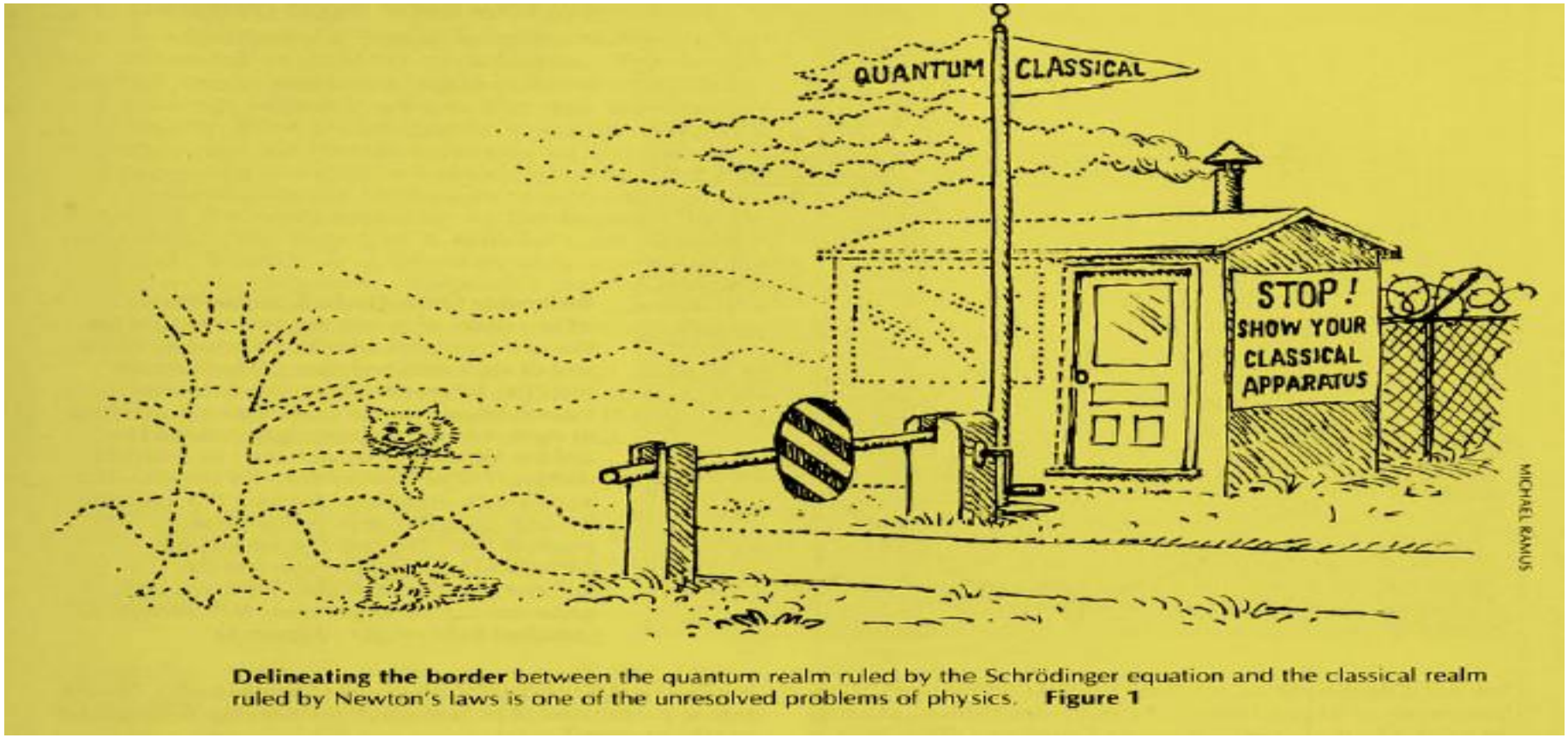
Schrödinger’s cat

Radiation from a radioactive material initiates a buttet that kills the cat.

Before the observation, the cat is acc. to Copenhagen interpret. in a **superposition of dead and alive**.

collapse is **<u>not</u> described** by any ***dynamical*** process

(with forces, potentials etc.)



Delineating the border between the quantum realm ruled by the Schrödinger equation and the classical realm ruled by Newton's laws is one of the unresolved problems of physics. **Figure 1**

The Measurement Problem ‘solutions’

- **Many World solution (Everett)**

- **Deterministic solution (Bohm)**

- **Non linear Schrodinger equation (GRW)**

- **Objective Reduction (Penrose)**

- **Radical subjective solution (Wigner, Stapp)**

Quantum-mechanical decoherence has been verified experimentally

Haroche et al, PRL **77**, 4887 (1996)

Zeilinger et al., Nature **401**, 680 (1999)

Haroche

Zeilinger

Observing the Progressive Decoherence of the "Meter" in a Quantum Measurement

M. Brune, E. Hagley, J. Dreyer, X. Maître, A. Maali, C. Wunderlich, J. M. Raimond, and S. Haroche
Laboratoire Kastler Brossel, Département de Physique de l'Ecole Normale Supérieure, 24 Rue Lhomond, F-75231 Paris Cedex 05, France*
(Received 10 September 1996)

A mesoscopic superposition of quantum states involving radiation fields with classically distinct phases was created and its progressive decoherence observed. The experiment involved Rydberg atoms interacting one at a time with a few photon coherent field trapped in a high Q microwave cavity. The mesoscopic superposition was the equivalent of an "atom + measuring apparatus" system in which the "meter" was pointing simultaneously towards two different directions—a "Schrödinger cat." The decoherence phenomenon transforming this superposition into a statistical mixture was observed while it unfolded, providing a direct insight into a process at the heart of quantum measurement. [S0031-9007(96)01848-0]

Radical Solution

- *…. The reduction of the state vector is a physical event which occurs only when there is an interaction between the physical measuring apparatus and the psyche of some observer…..*

John Von Neumann Fritz London Eugene Wigner Edmond Bauer

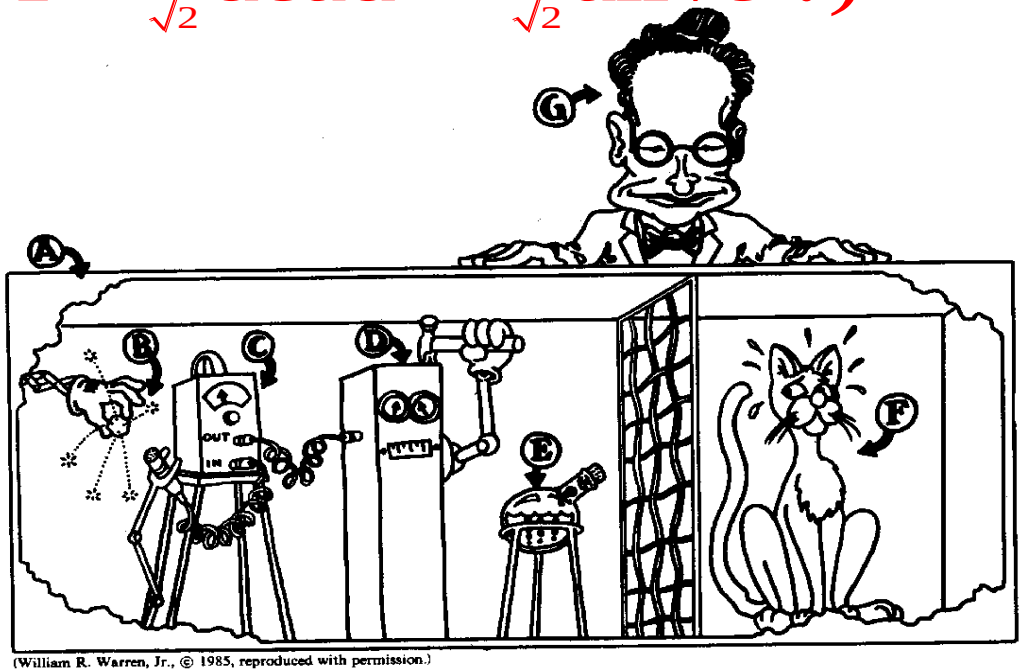
Quantum States Collapse
in the Brain (Mind)

Schrödinger's Cat

Experiment: A cat is placed in a sealed box containing a device that has a 50% chance of killing the cat.

$(\Psi = \frac{1}{\sqrt{2}}\text{dead} + \frac{1}{\sqrt{2}}\text{alive}\ ?)$

Question 1: What is the wave function of the cat just before the box is opened?



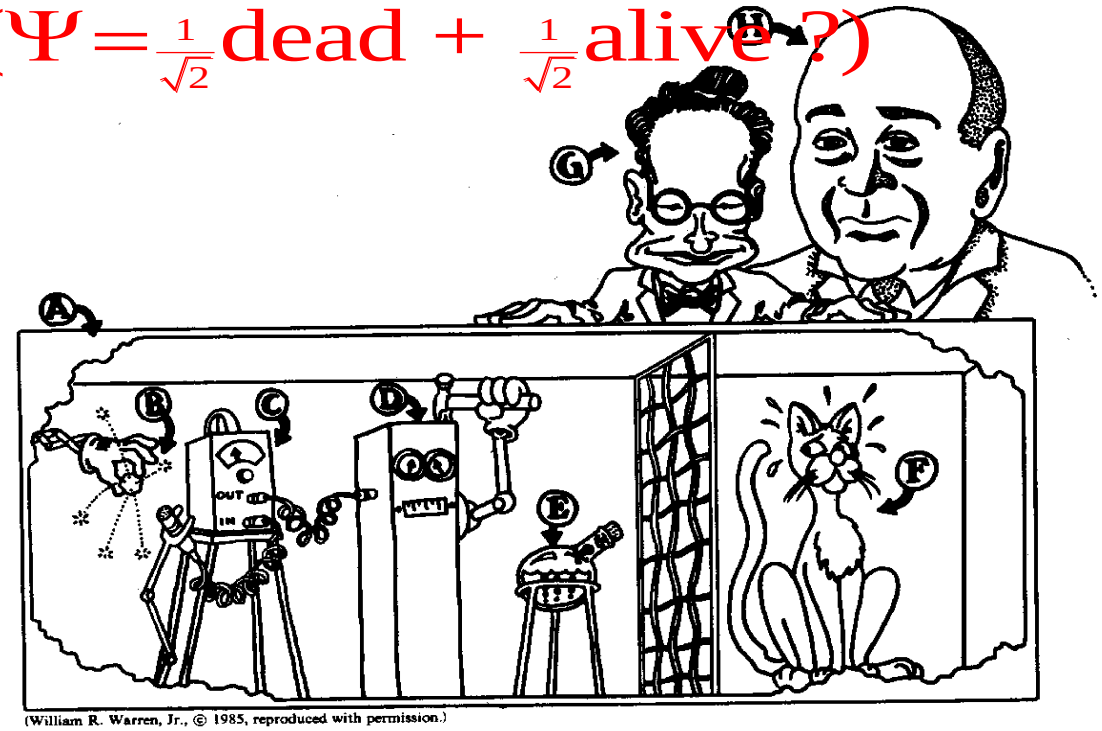
(William R. Warren, Jr., © 1985, reproduced with permission.)

When does the wave function collapse?

Schrödinger's Cat

Experiment: A cat is placed in a sealed box containing a device that has a 50% chance of killing the cat.

$(\Psi = \frac{1}{\sqrt{2}}\text{dead} + \frac{1}{\sqrt{2}}\text{alive}$??$)$

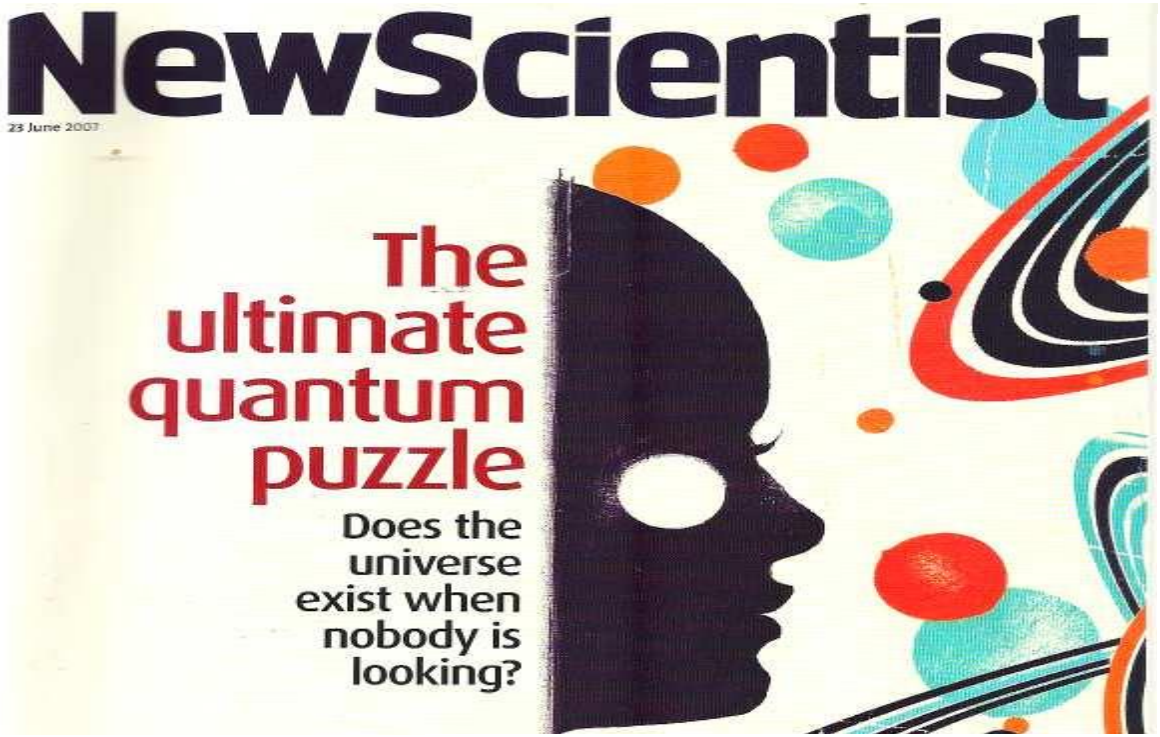


(William R. Warren, Jr., © 1985, reproduced with permission.)

Question 1: What is the wave function of the cat just before the box is opened?
When does the wave function collapse?

Question 2: If we observe Schrödinger, what is his wave function during the experiment? When does it collapse?

IS THE MOON THERE IF NOBODY LOOKS?



- In the Copenhagen interpretation, observers have a special role as the collapsers of wave functions. This leads to problems, e.g., in quantum cosmology where no observers are present.
- Thus, the observer-centric aspects of the Copenhagen interpretation are controversial

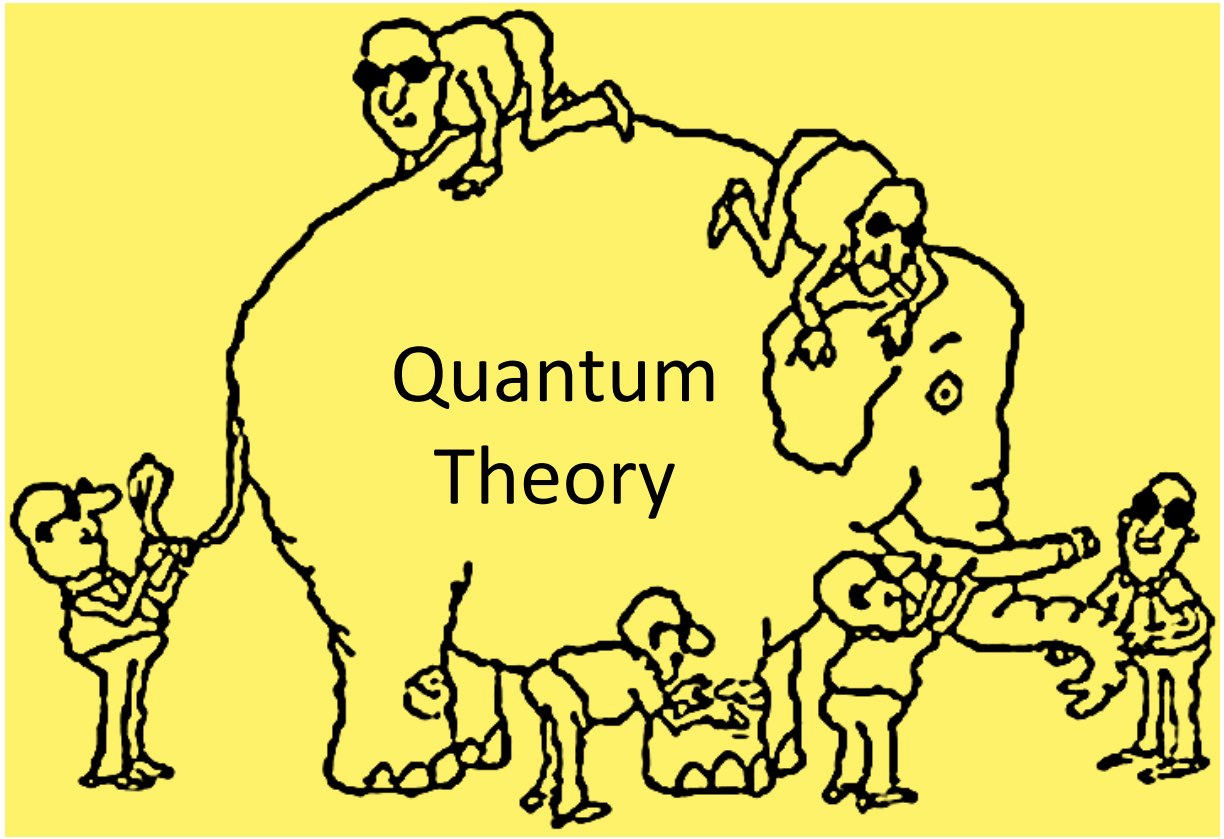
Problems with the Copenhagen interpretation

- The measurement process requires an **external observer**. Cannot be applied to the universe as a whole.

- The **collapse of the wave function** does not follow any known laws of physics.

- Born's **statistical interpretation** is an additional assumption that does not follow from the model.

- **Artificial border** between micro and macro systems. Unclear how classicality emerges from the quantum world.

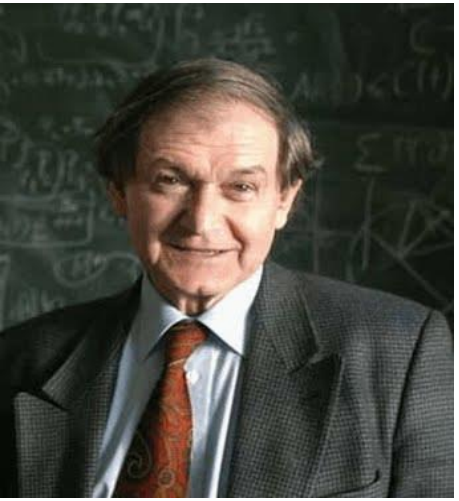

Quantum
Theory

Can Quantum Theory help to understand Consciousness?

Two Mysteries:

1- The mind is mysterious,

2- quantum mechanics is also mysterious

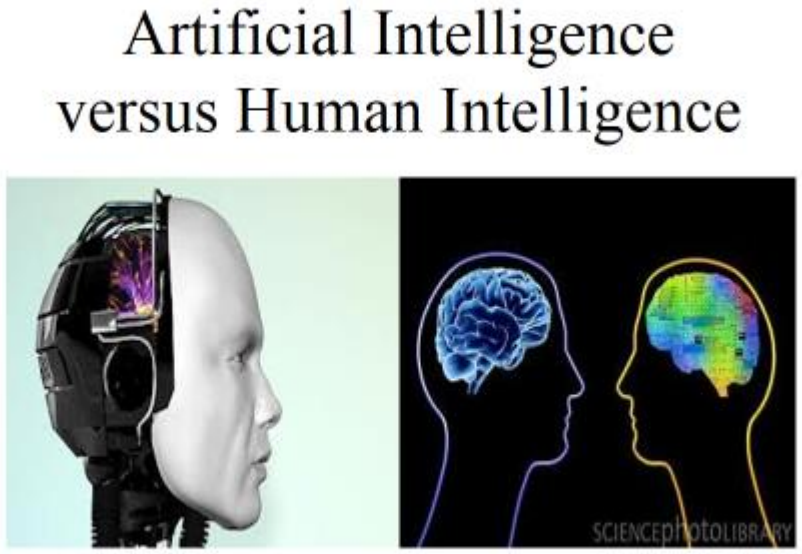


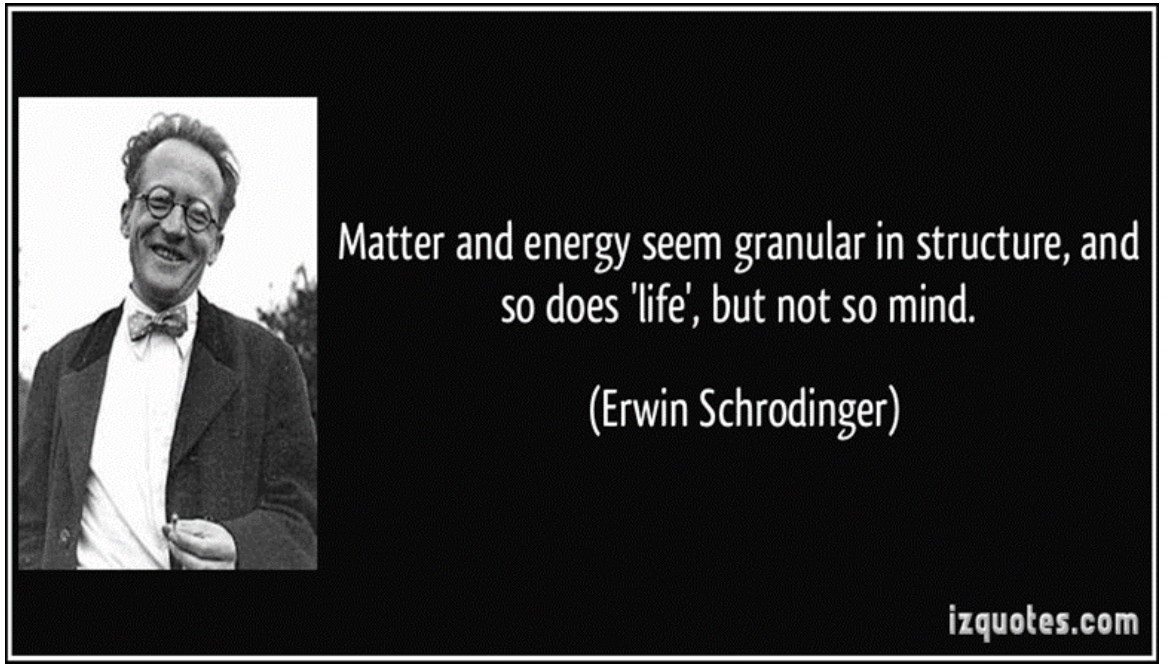
Current status of a "Theory of everything".

*Nature (**433**, 257 – 259, January 2005)*

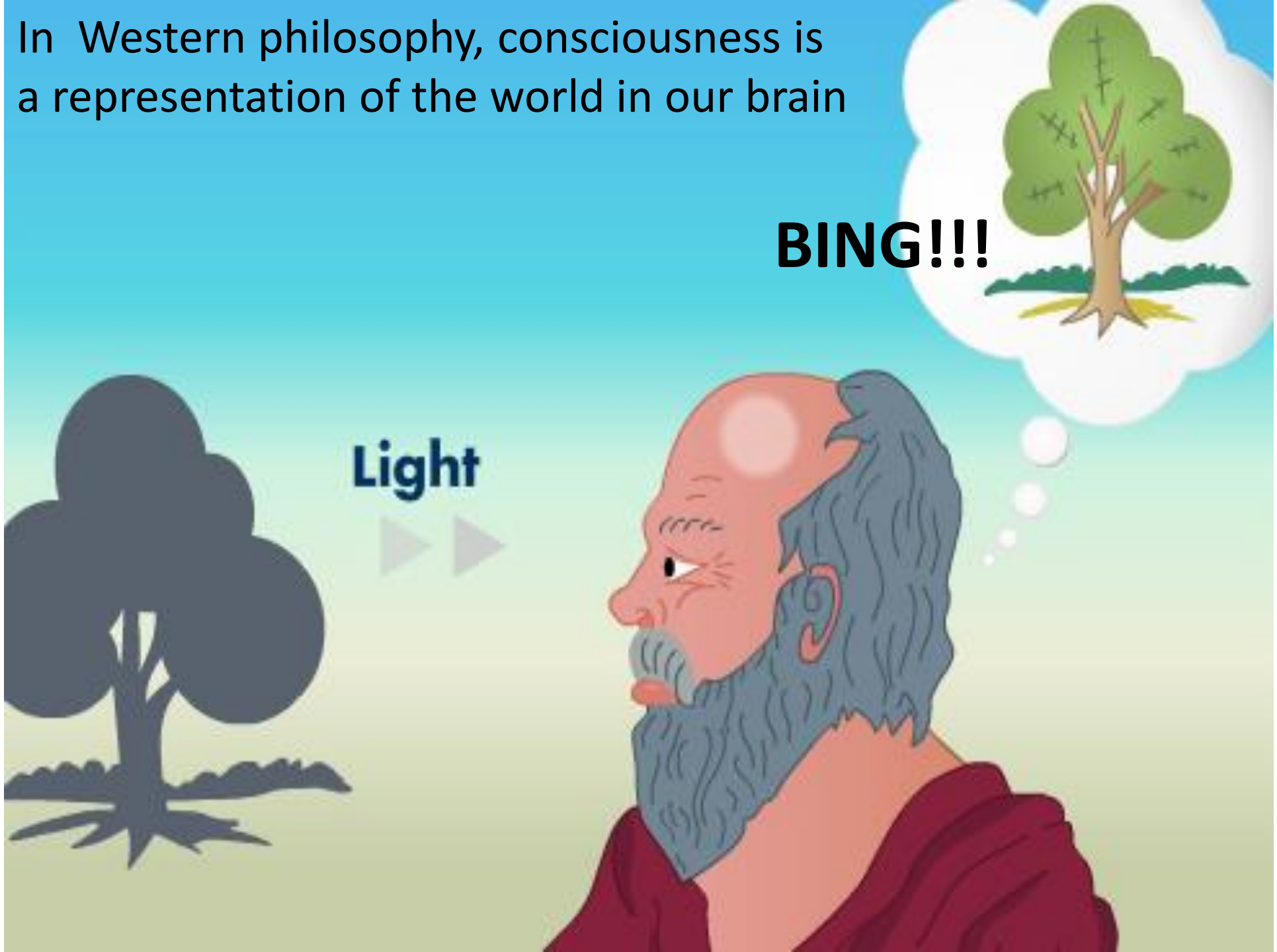
Roger Penrose

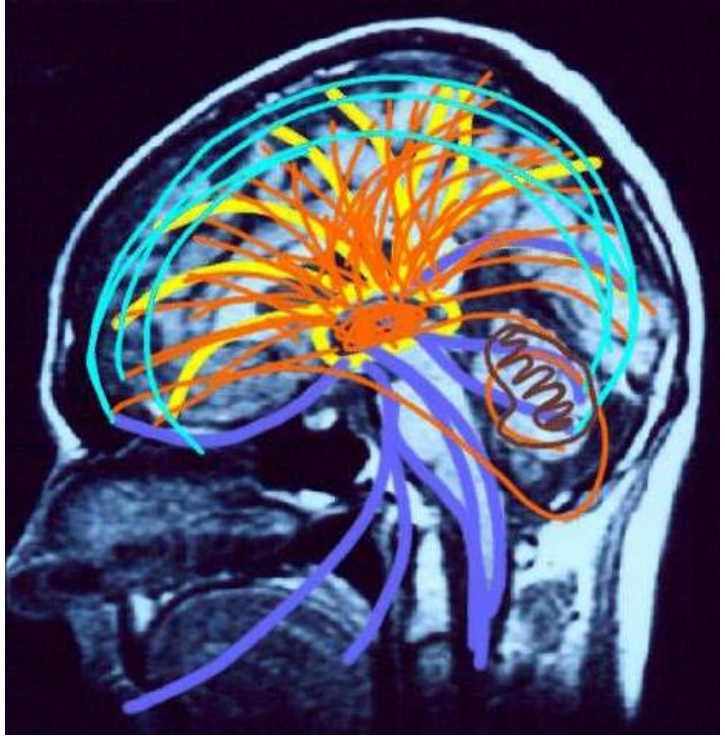
The terminology 'theory of everything' has always worried me. There is a certain physicist's arrogance about it that suggests that knowing all the physical laws would tell us everything about the world, at least in principle. Does a physical theory of 'everything' include a theory of consciousness?





In Western philosophy, consciousness is a representation of the world in our brain





Neuroscientists Baars, Edelman/Tononi, Changeux/Dehaene, Crick/Koch cast thalamo-cortical oscillations as Global workspace for consciousness

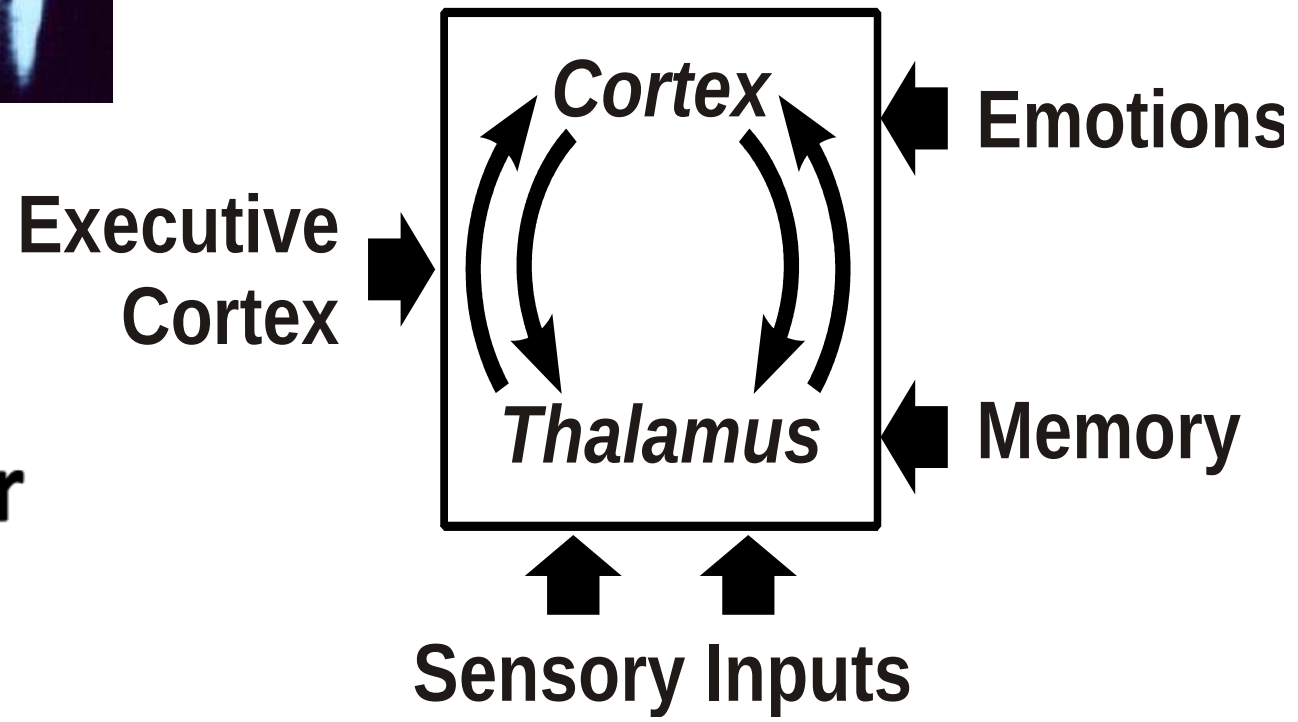
BING!!

Consciousness

Materialism

Brain=Mind=Computer

Mind ⬅ Matter

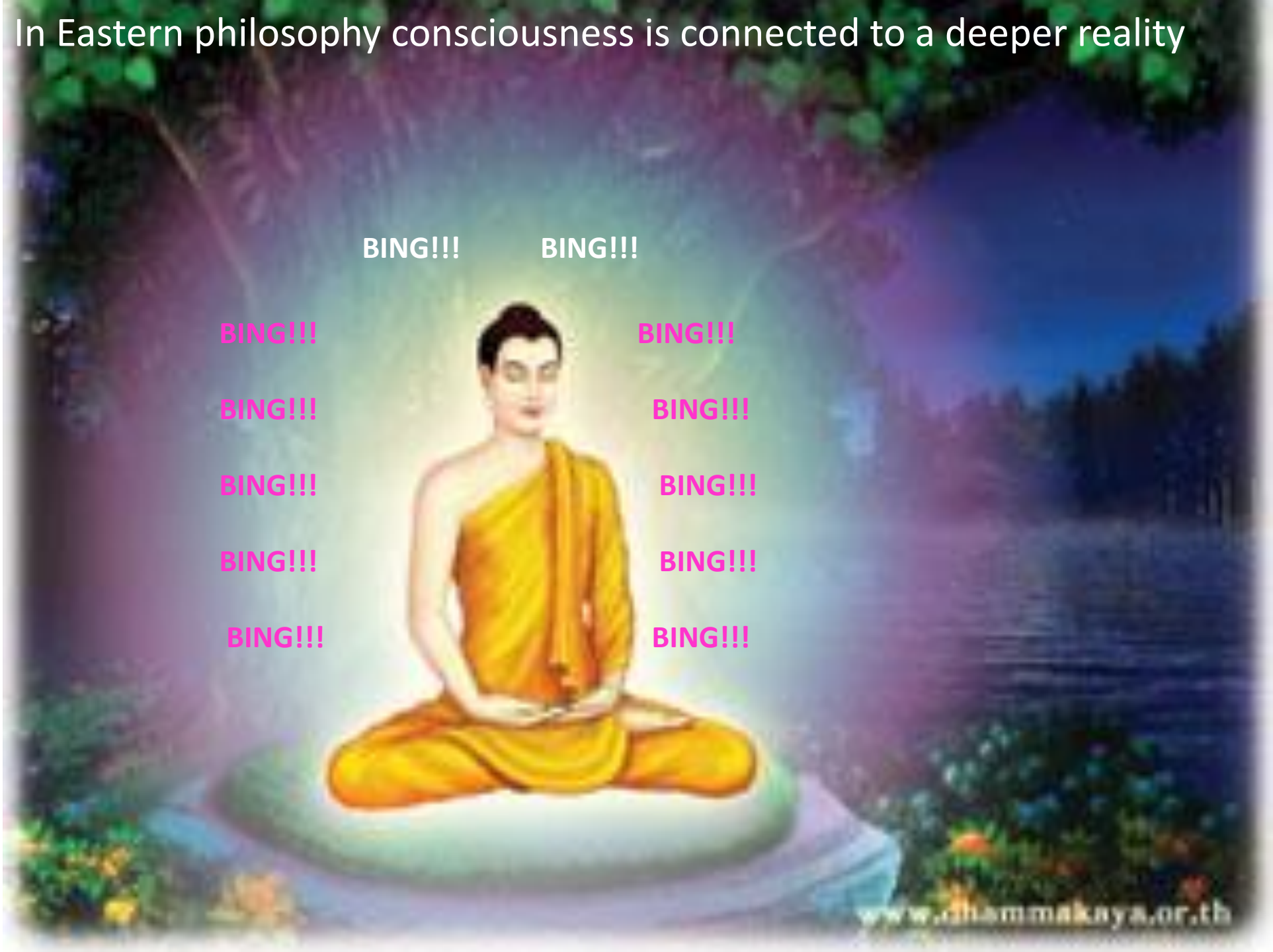


Materialism

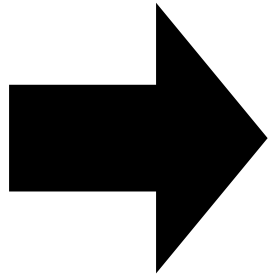
Brain=Mind=Computer

Mind ⬅ Matter

In Eastern philosophy consciousness is connected to a deeper reality



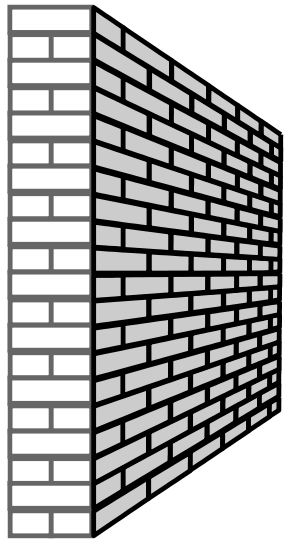
Idealism

Mind  **Matter**

BING!!

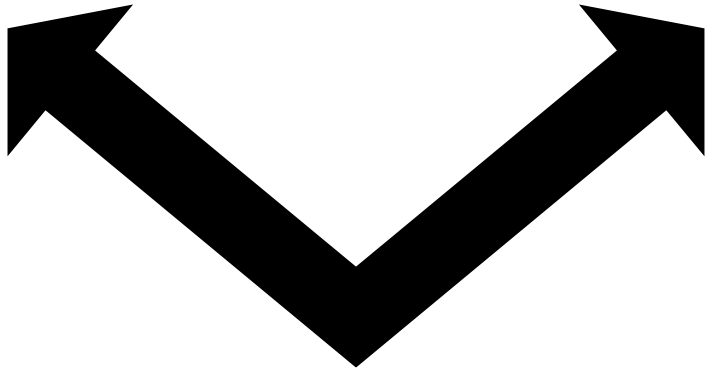
Descartes believed an immaterial soul perceived the world in our head

Cartesian Dualism

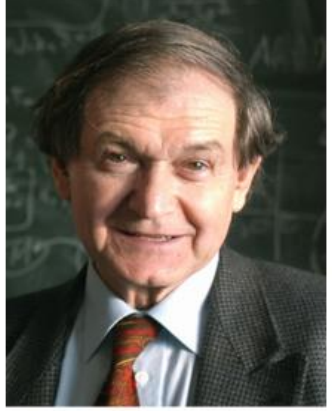
Mind  **Matter**

Neutral Monism

Mind **Matter**



Deeper reality



Sir Roger Penrose

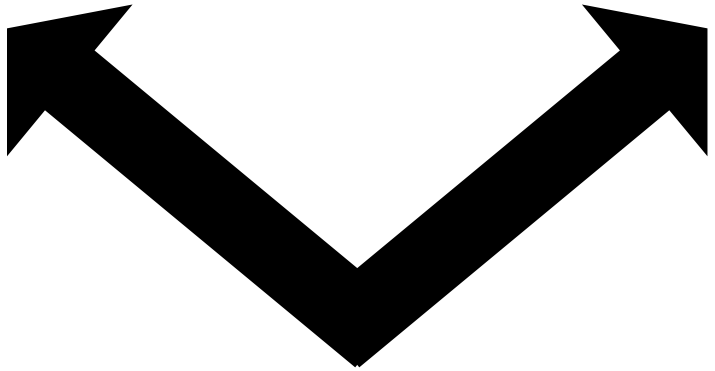
Consciousness is an actual physical process, a sequence of quantum state reductions connected by E=h/t to an objective threshold inherent in spacetime geometry (objective reduction, OR)

Bing!!!

Nonduality

Neutral Monism

Mind Matter



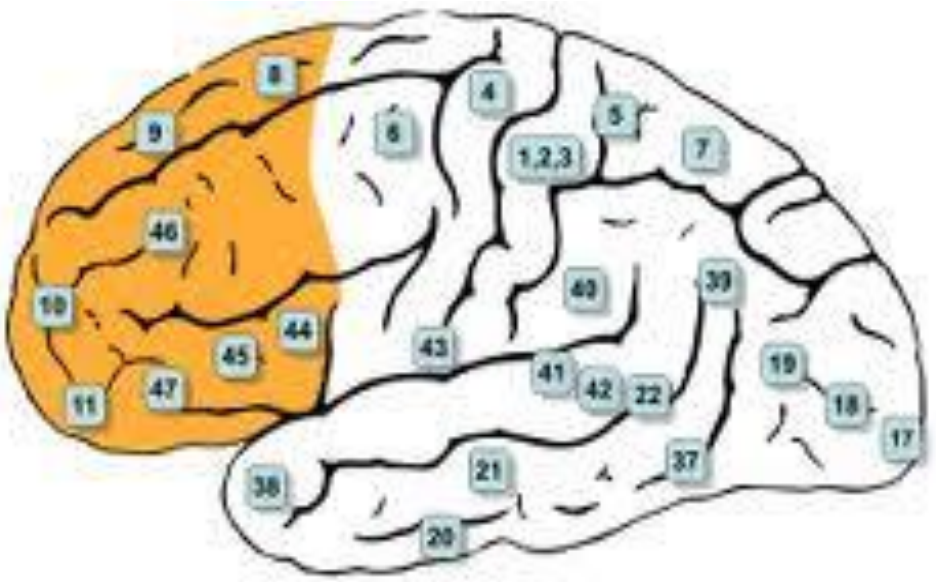
Quantum spacetime geometry

Ground of being

Localization of Intelligence

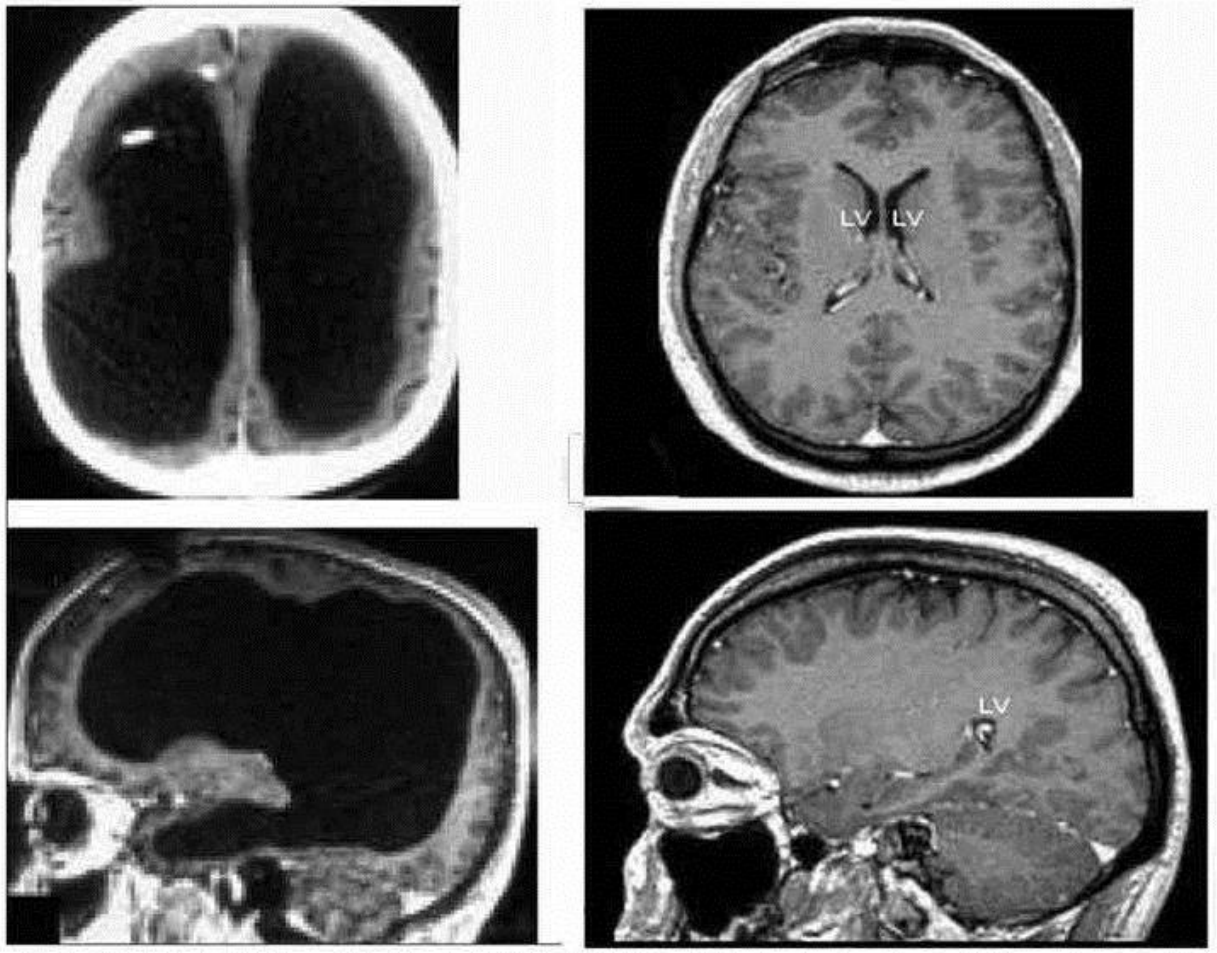
The general intelligence is localized to regions of the lateral prefrontal cortex.

M. Atherton et al. *Cognitive Brain Research*, 16 (2003) 26-31, pg. 27

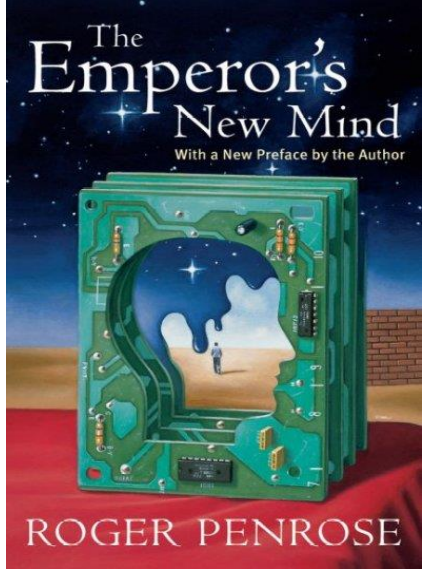


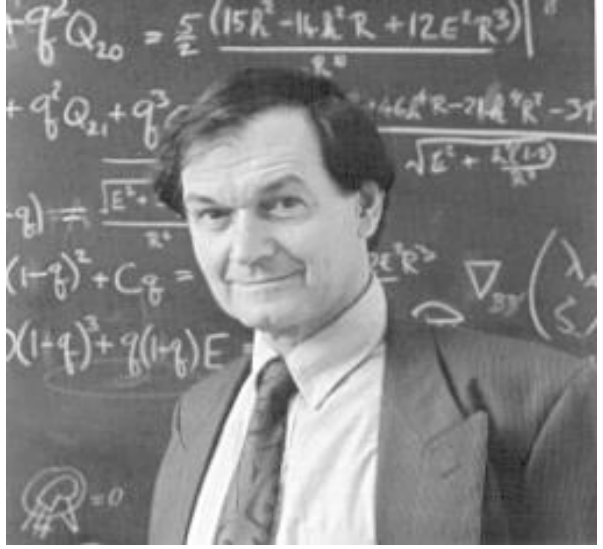
Man with tiny brain shocks doctors

July 2007 by New Scientist and Reuters

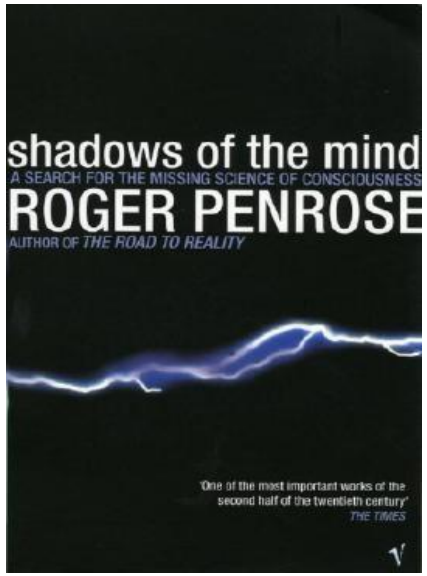


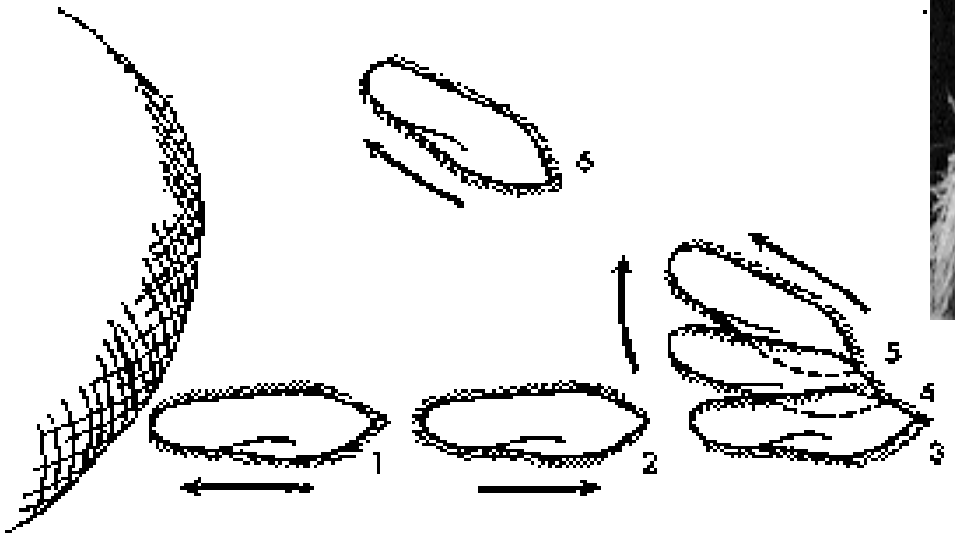
The Lancet , 2007, vol 370, p 262

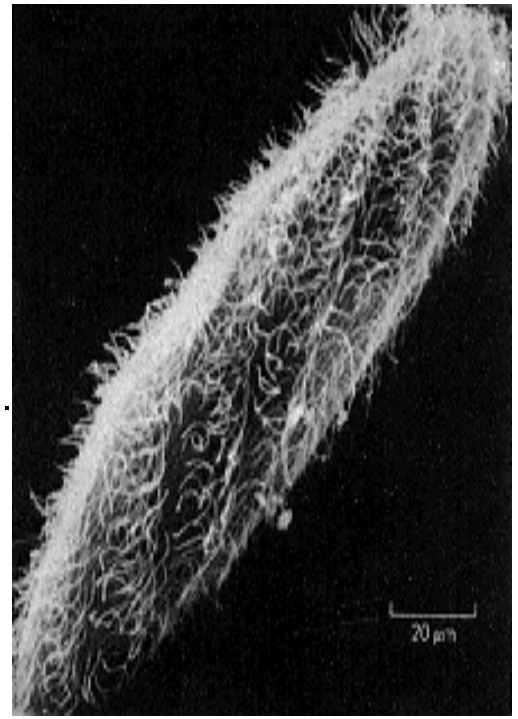




Roger Penrose







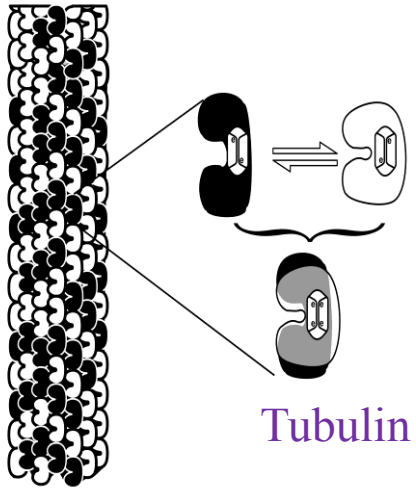
Paramecium

What is Consciousness?

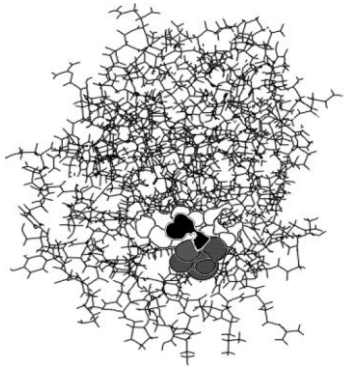
Anesthesia - the "other side" of consciousness

Stuart Hameroff, MD

Microtubule

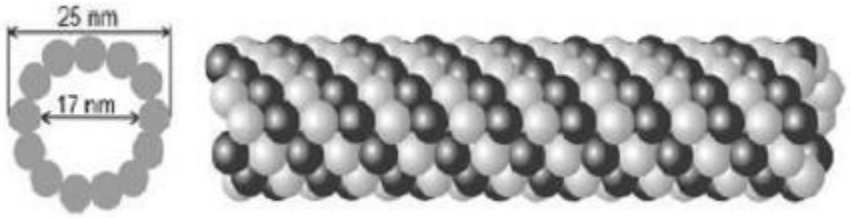


Tubulin

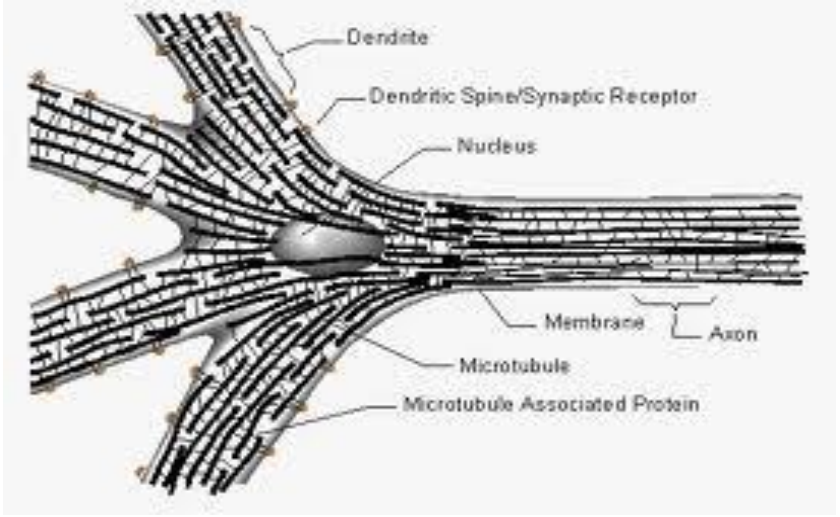


The anesthetic-sensitive enzyme papain with halothane (black) “docked” by energy minimization into its major hydrophobic pocket

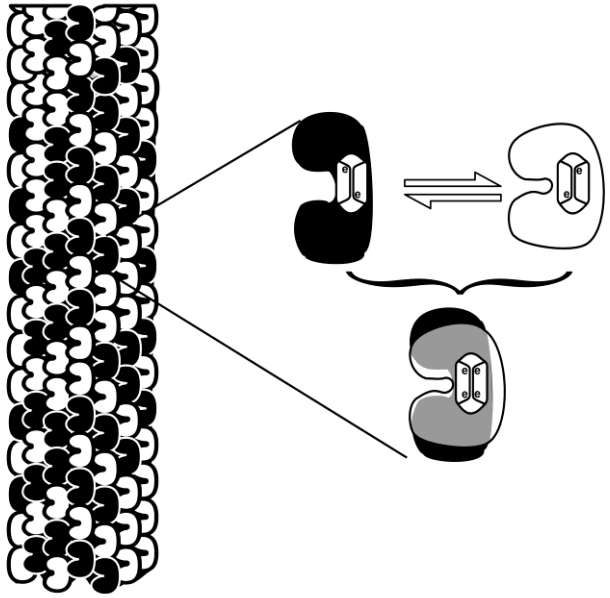
Grand Canyon, Arizona, Tucson, 1994



Microtubule

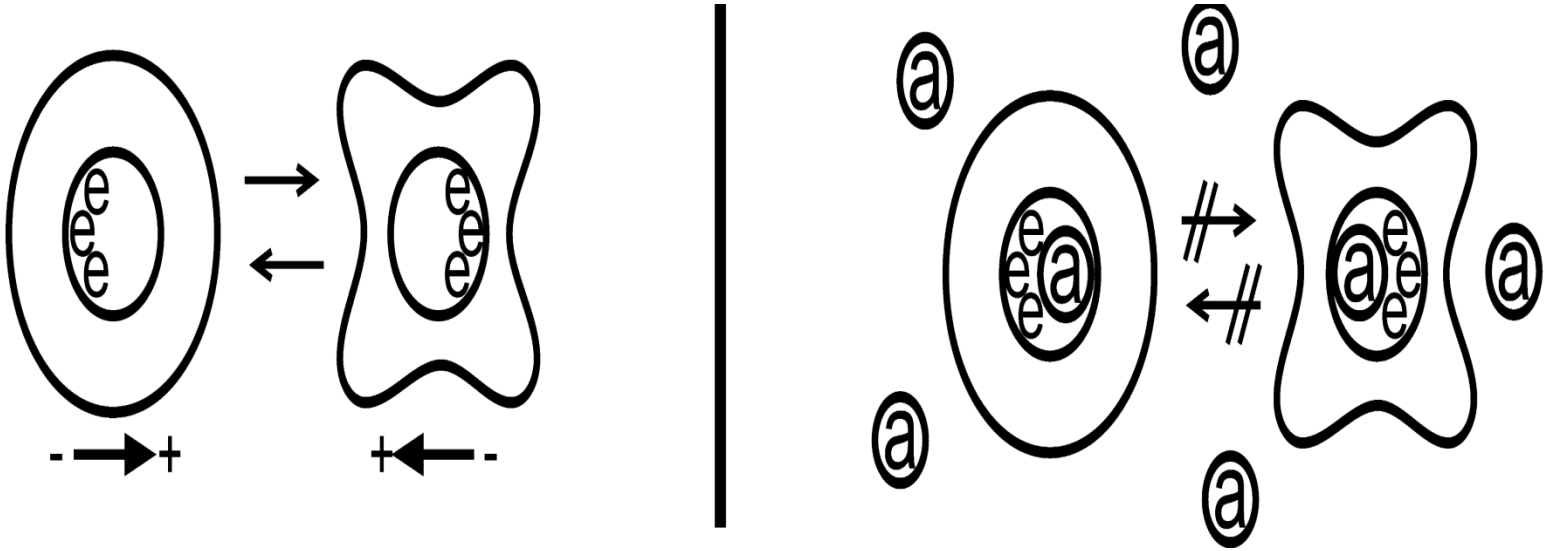


Microtubules in a Neuron



Tubulin

Conscious **Anesthetized**



…in which anesthetic gases act via quantum London forces to selectively erase consciousness

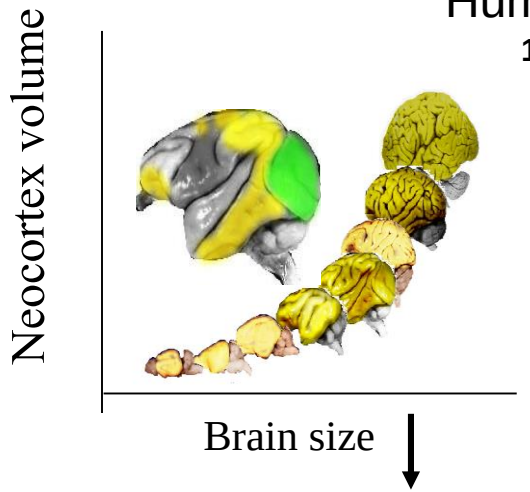
Hameroff S (2006) *Anesthesiology* 105:400-412

Scaling the organization of membrane signals in the brain_

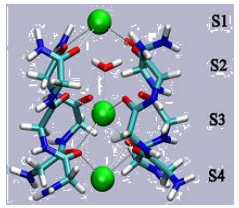
from brains to atoms

Human brain

1500 cm^3

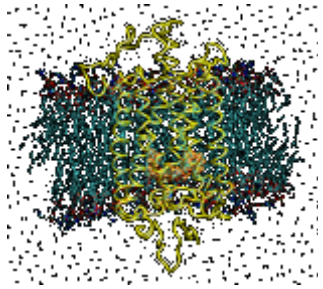


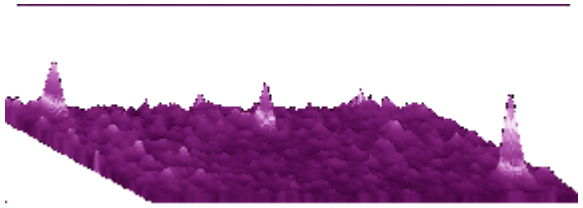
Filter region



nano-scale

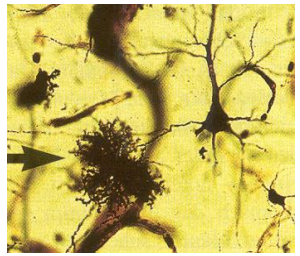
Ion channels





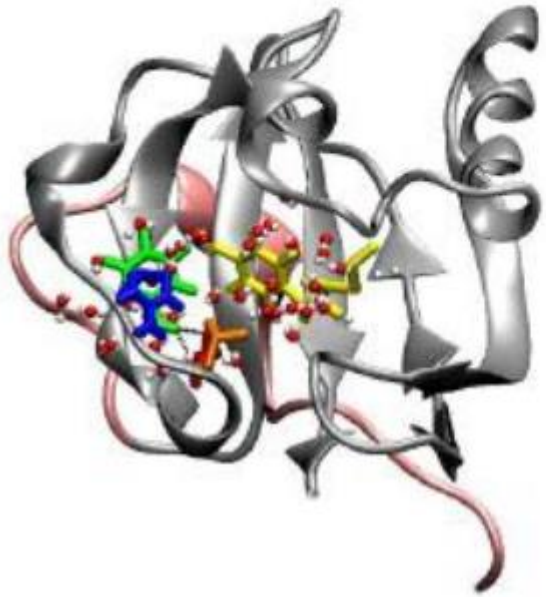
60 μm

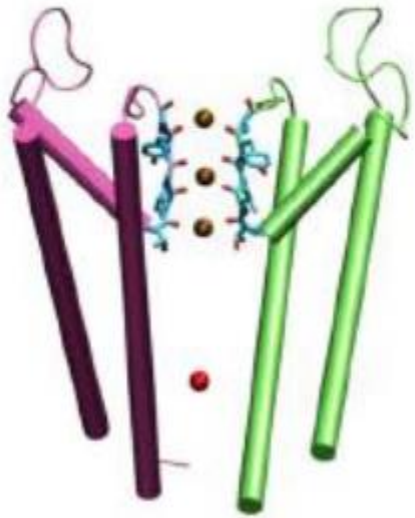
TRIFM image of Ca channels

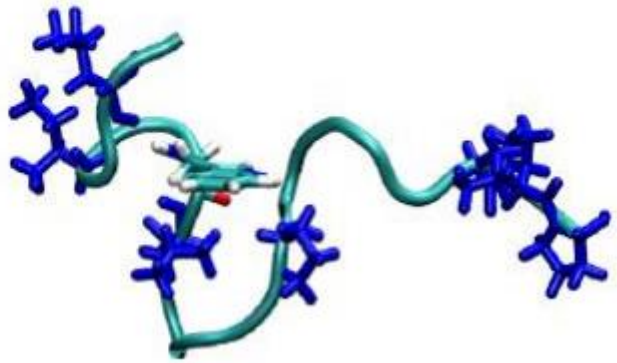


cells

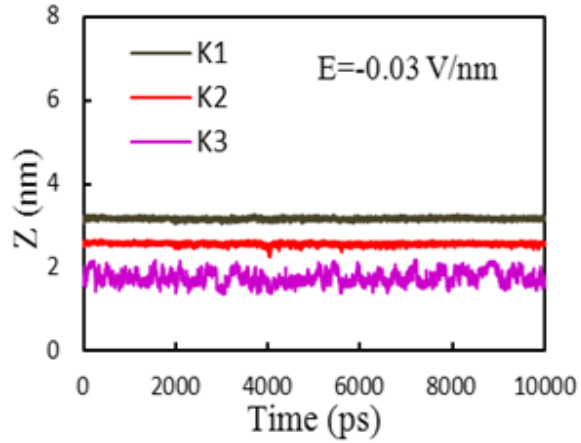
What Quantum Biology is Looking For?

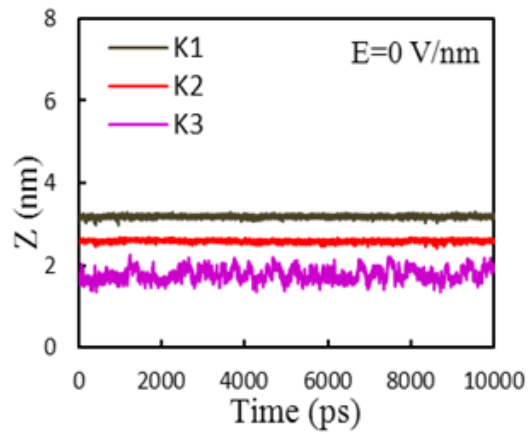


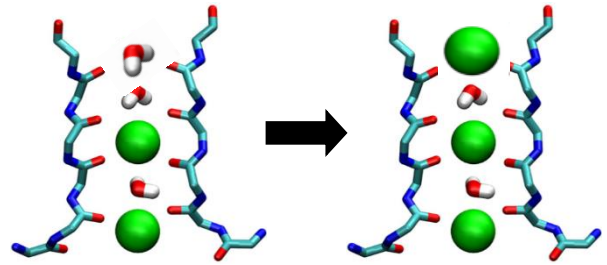


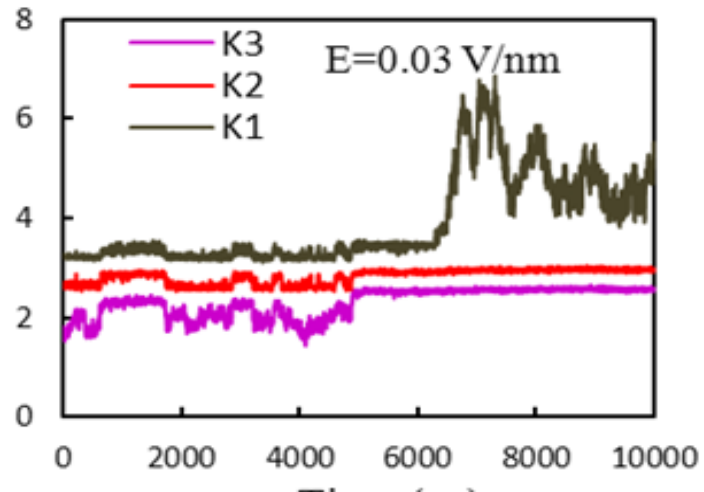


1. The length and time scales of quantum coherences
2. Role of Coherence
3. Role of environment (organic systems are wet and hot)
4. Developing theories for system-environment interactions
5. Experimental verifications

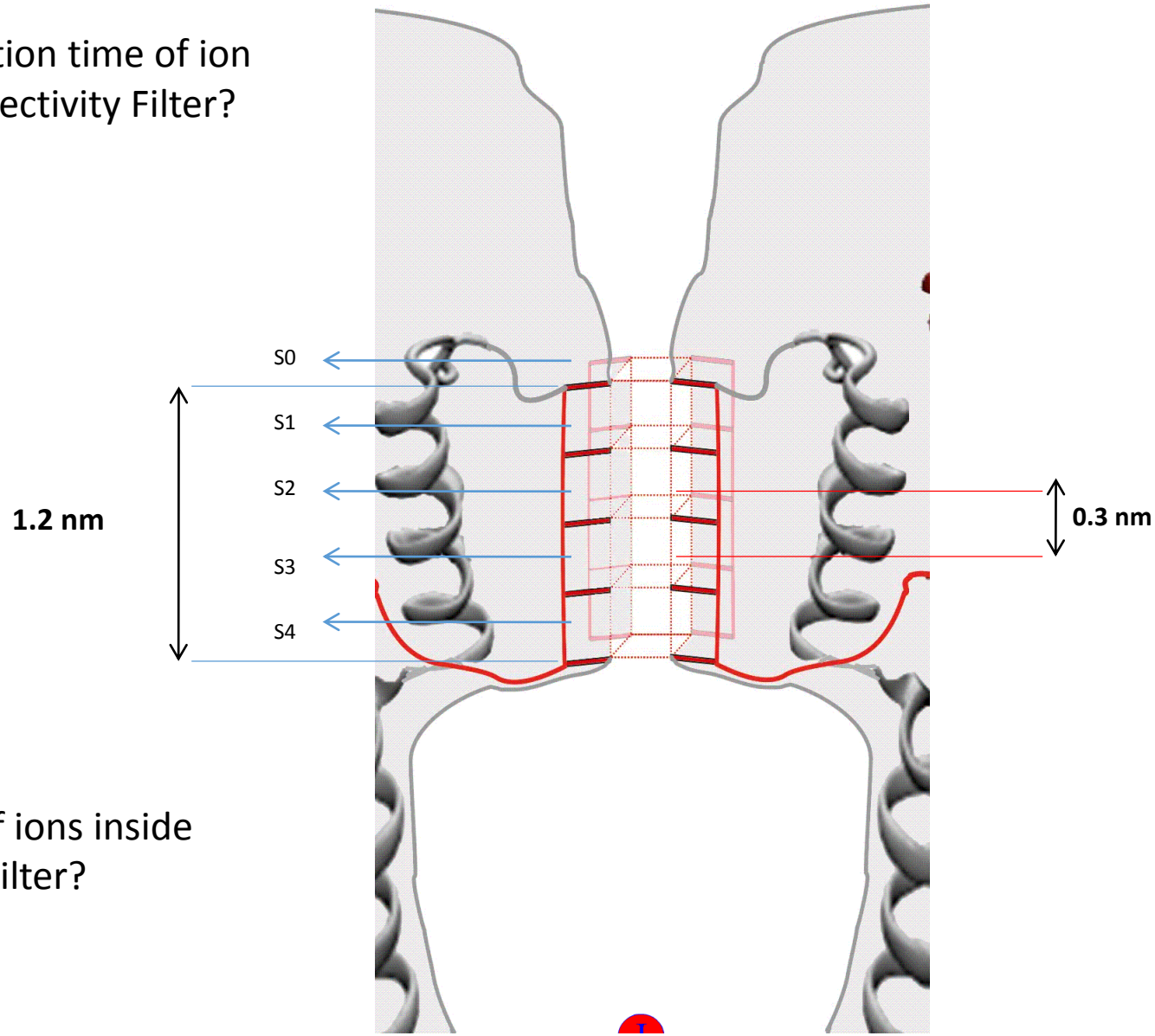

K1
K2
K3
E=-0.03 V/nm
Z (nm)
Time (ps)
0
2
4
6
8
0
2000
4000
6000
8000
10000


K1
K2
K3
E=0 V/nm
Z (nm)
Time (ps)
0
2
4
6
8
0
2000
4000
6000
8000
10000

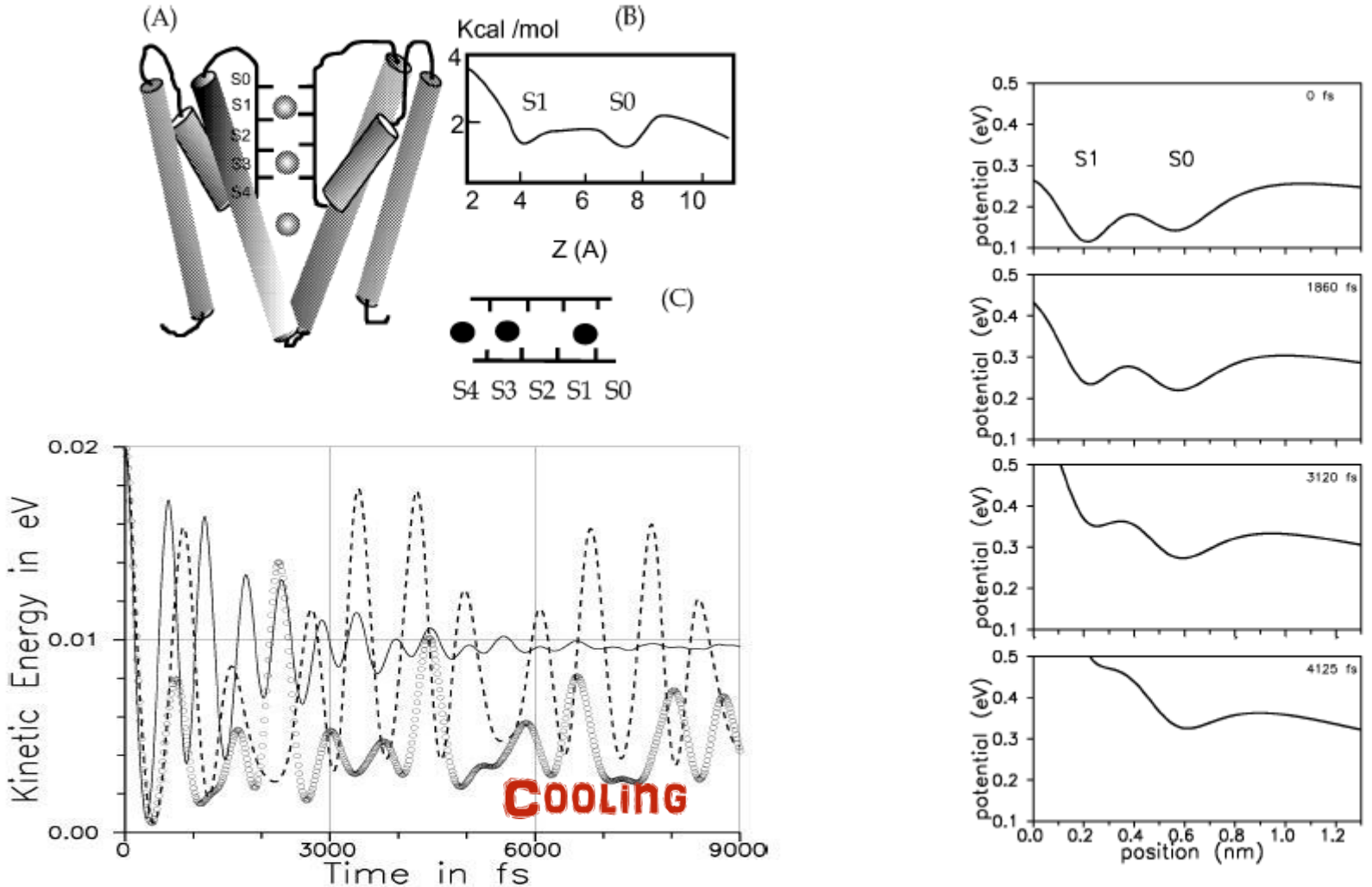



K3
K2
K1
E=0.03 V/nm
0
2
4
6
8
0
2000
4000
6000
8000
10000

What is the translocation time of ion movement in the Selectivity Filter?



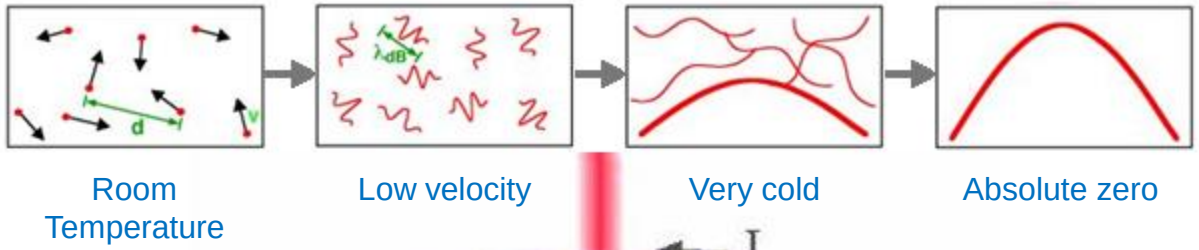
What is the velocity of ions inside the Selectivity Filter?



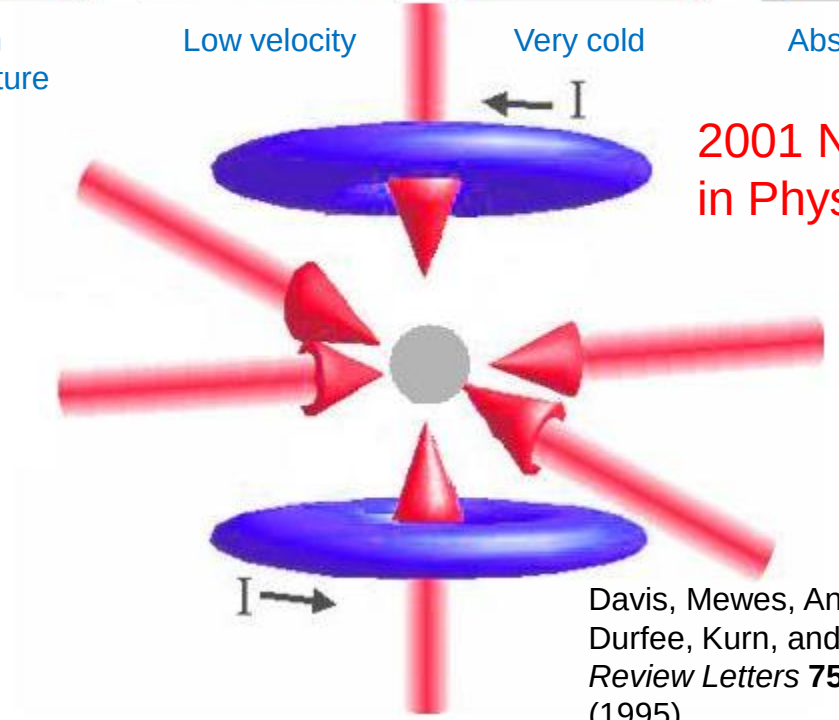
Summhammer, Salari, Bernroider,
J. Integrative Neuroscience, 11, No.2,123-135 (2012).

Laser cooling increases de Broglie wavelength of particles

$$\lambda_{dB} = \frac{h}{mv}$$



Particles become waves in laser cooling



2001 Nobel Prize in Physics

T=0

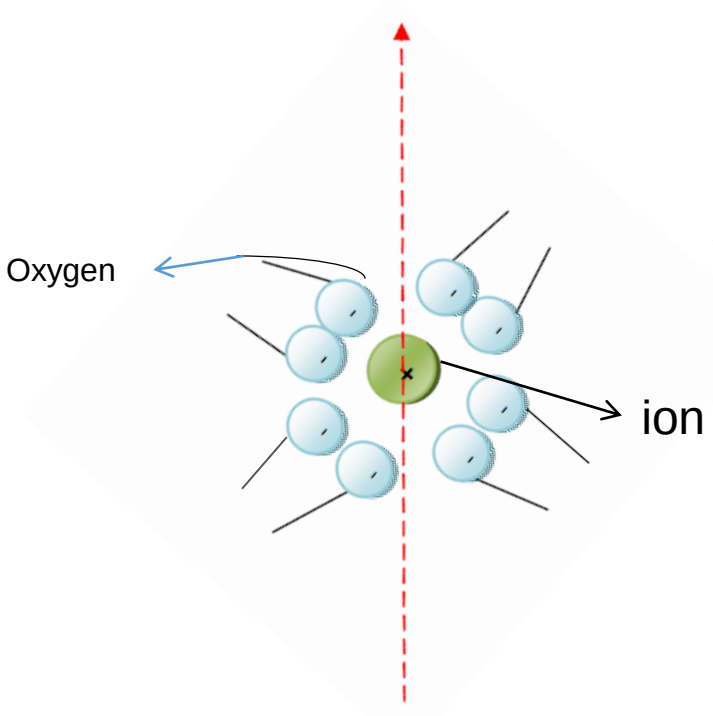
1- Bosons (Bose-Einstein Condensation)

2- Fermions (Fermi Gas)

Davis, Mewes, Andrews, van Druten, Durfee, Kurn, and Ketterle. *Physical Review Letters* **75** (22): 3969–3973 (1995).

Ions are trapped in the selectivity filter

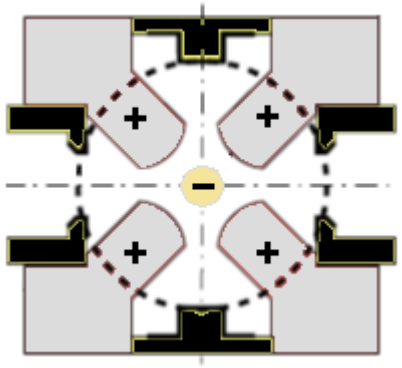
Selectivity Filter



Ions become slower in SF via trapping by eight C=O bonds

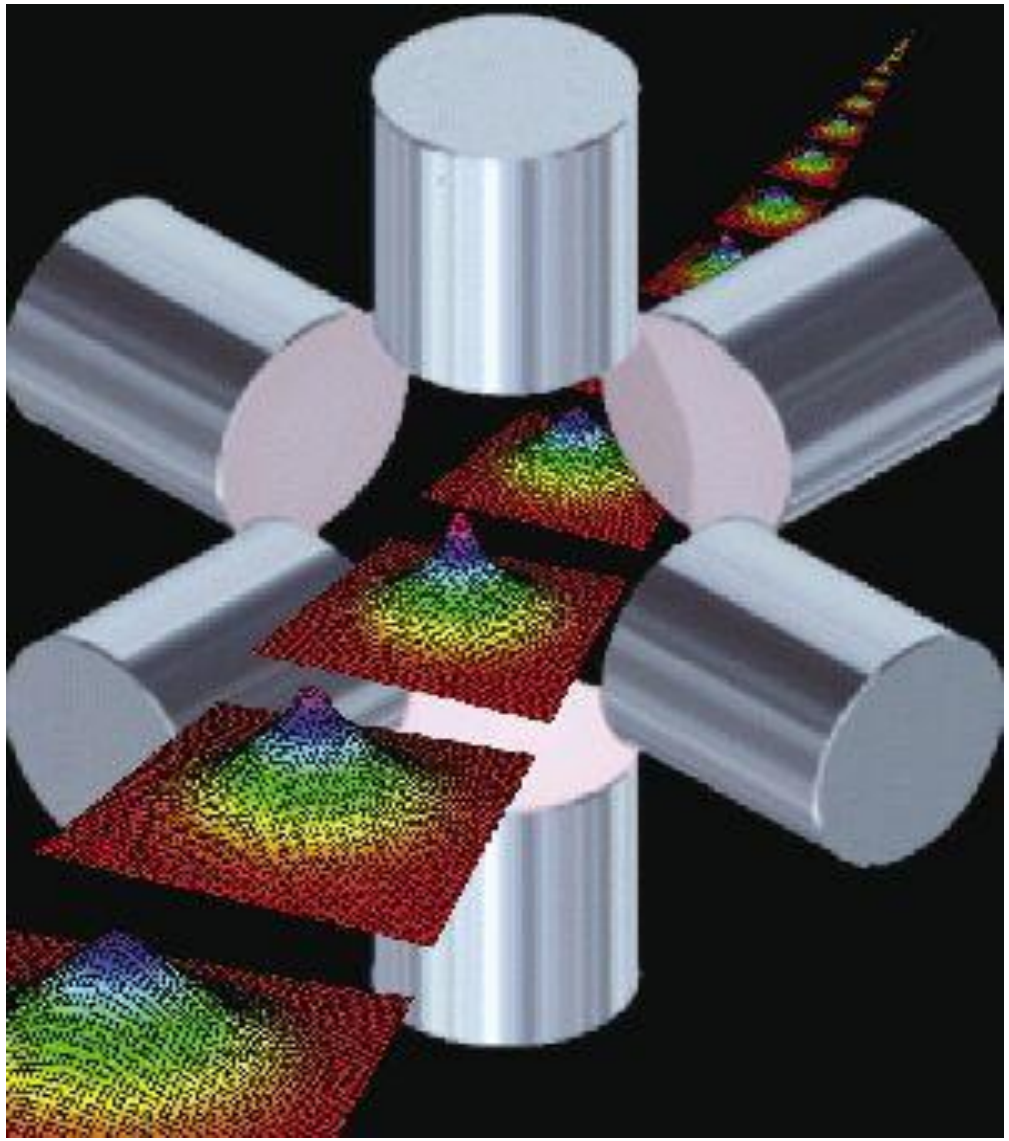
Trapping is similar

Quadrupole Ion Trap

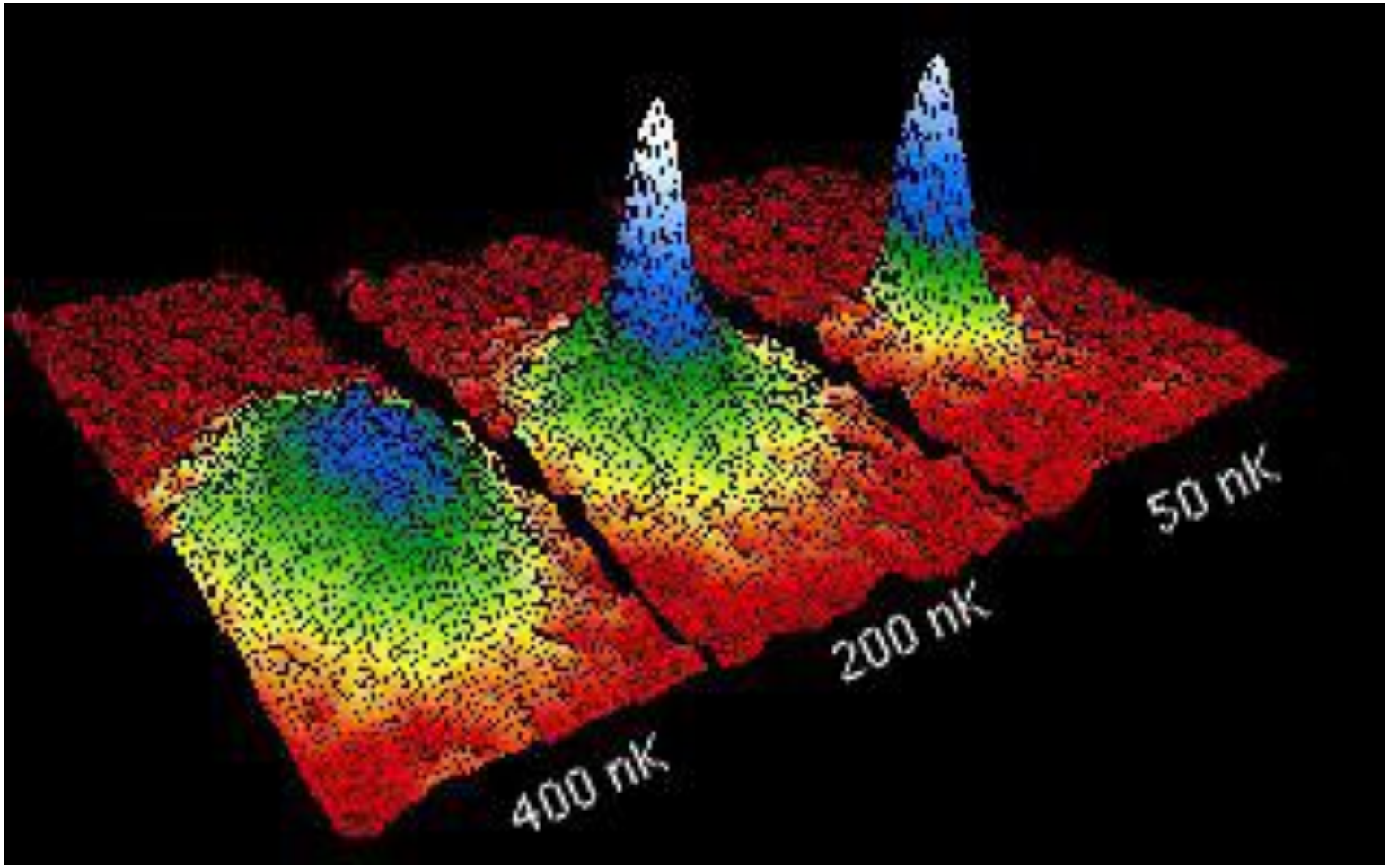


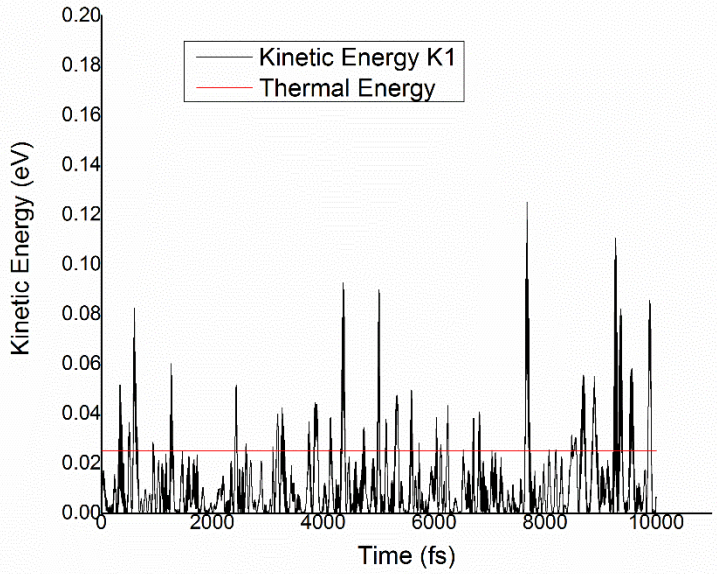
Quadrupole Ring in Ion Trap Device

March, Raymond (1997). "An Introduction to Quadrupole Ion Trap Mass Spectrometry". *Journal of Mass Spectrometry* 32 (4): 351–369.

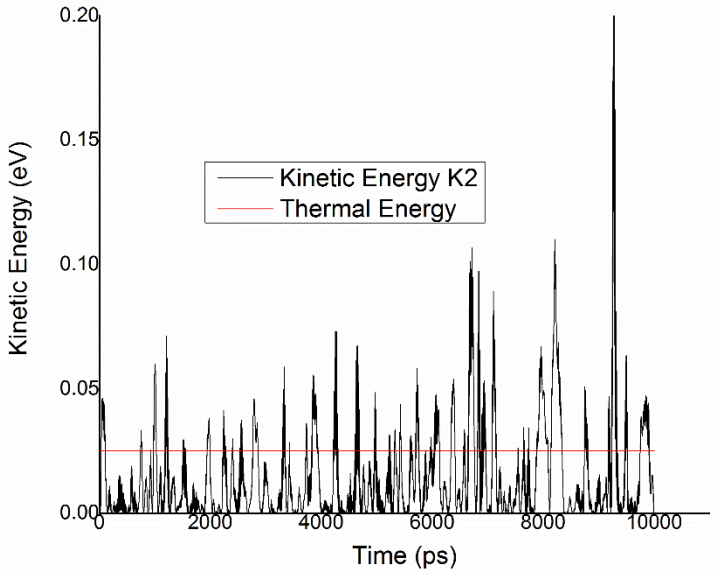


More Wave Nature at Colder Temperatures

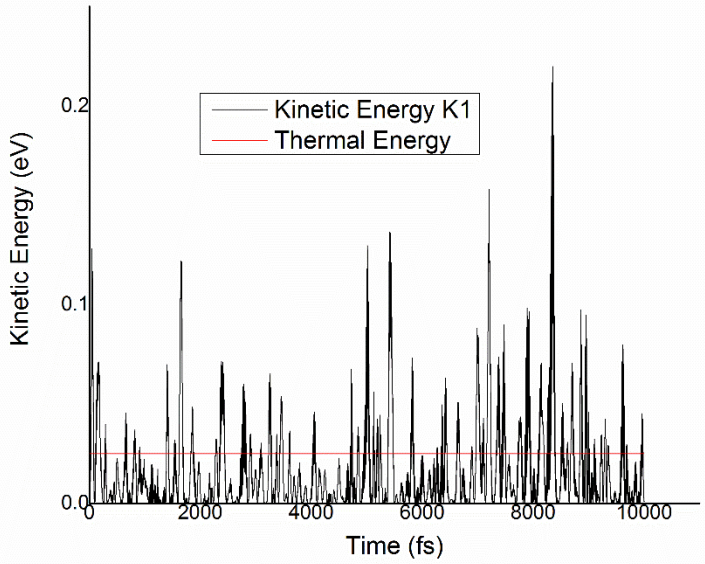




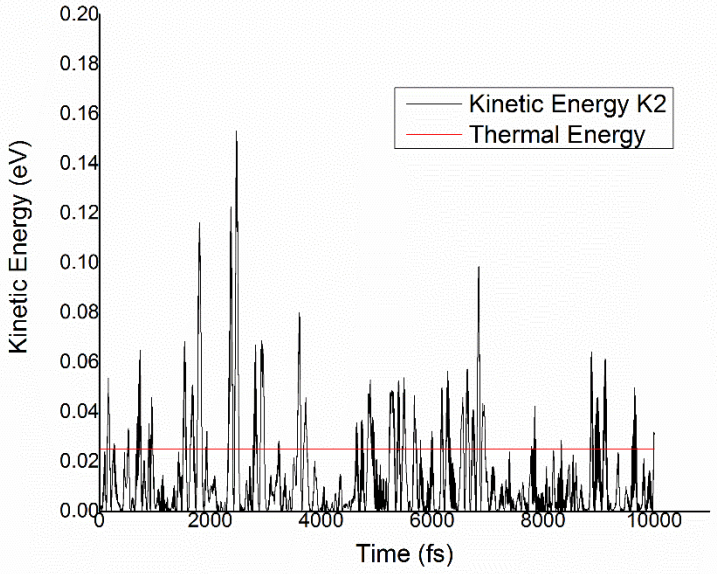
Transmembrane potential= +100 mV



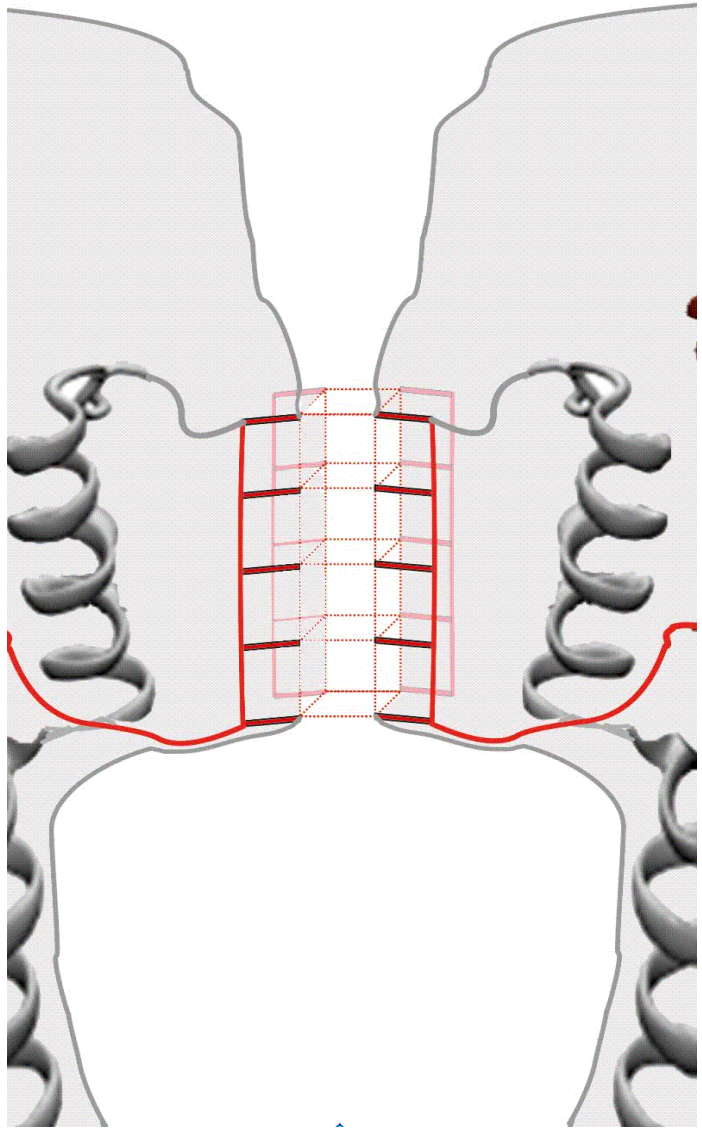
Transmembrane potential= +100 mV



Transmembrane potential= -100 mV

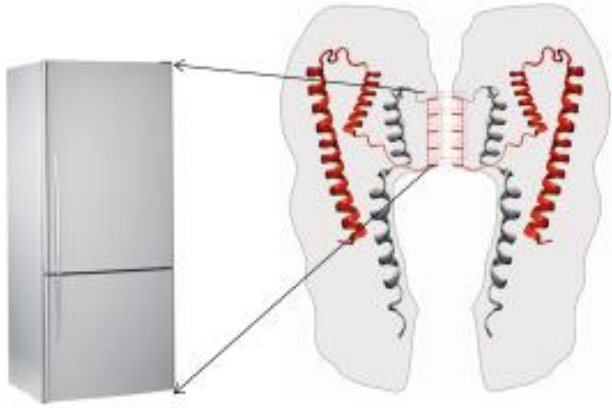


Transmembrane potential= -100 mV

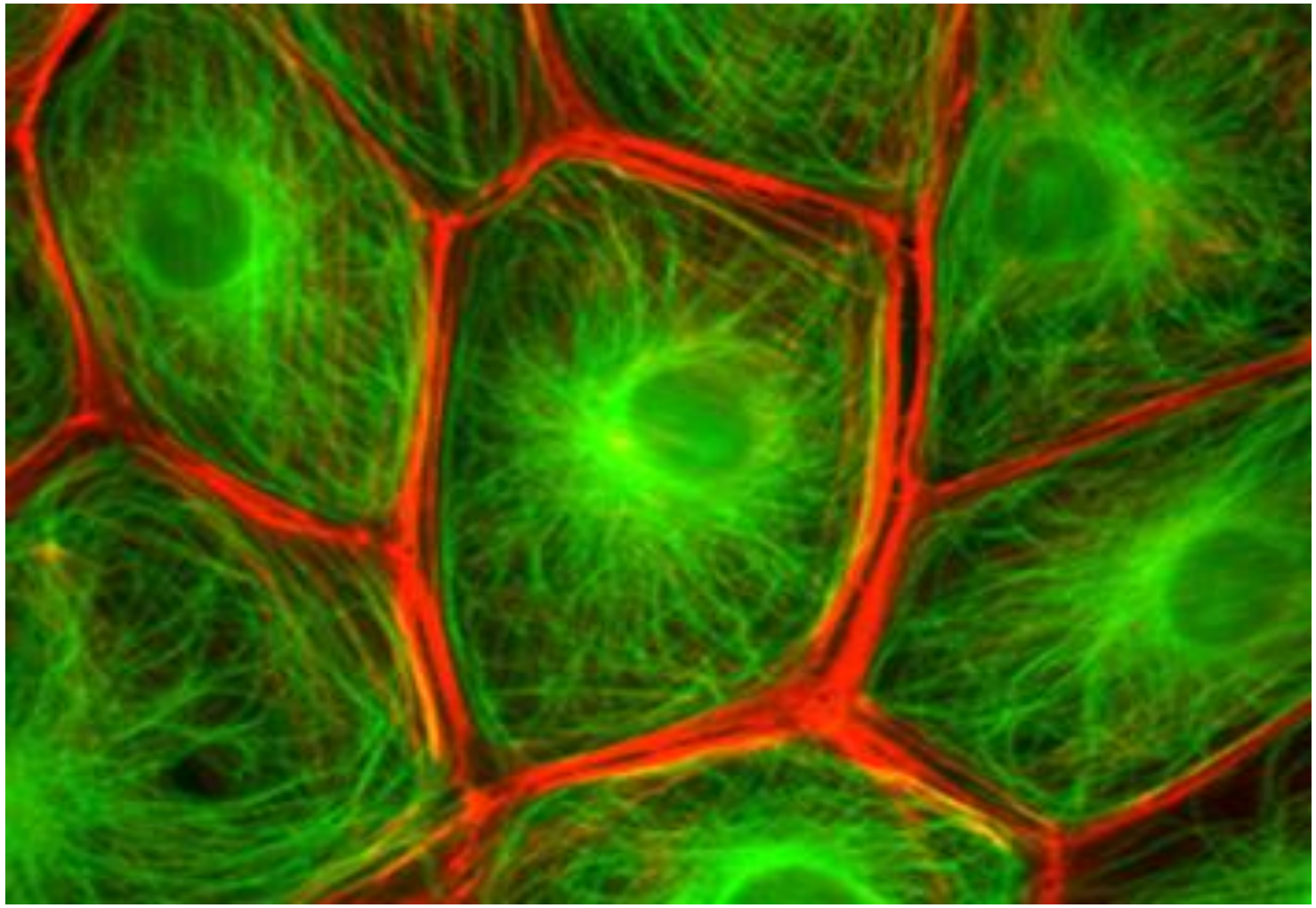


Bio-Nano-Super-Refrigerator

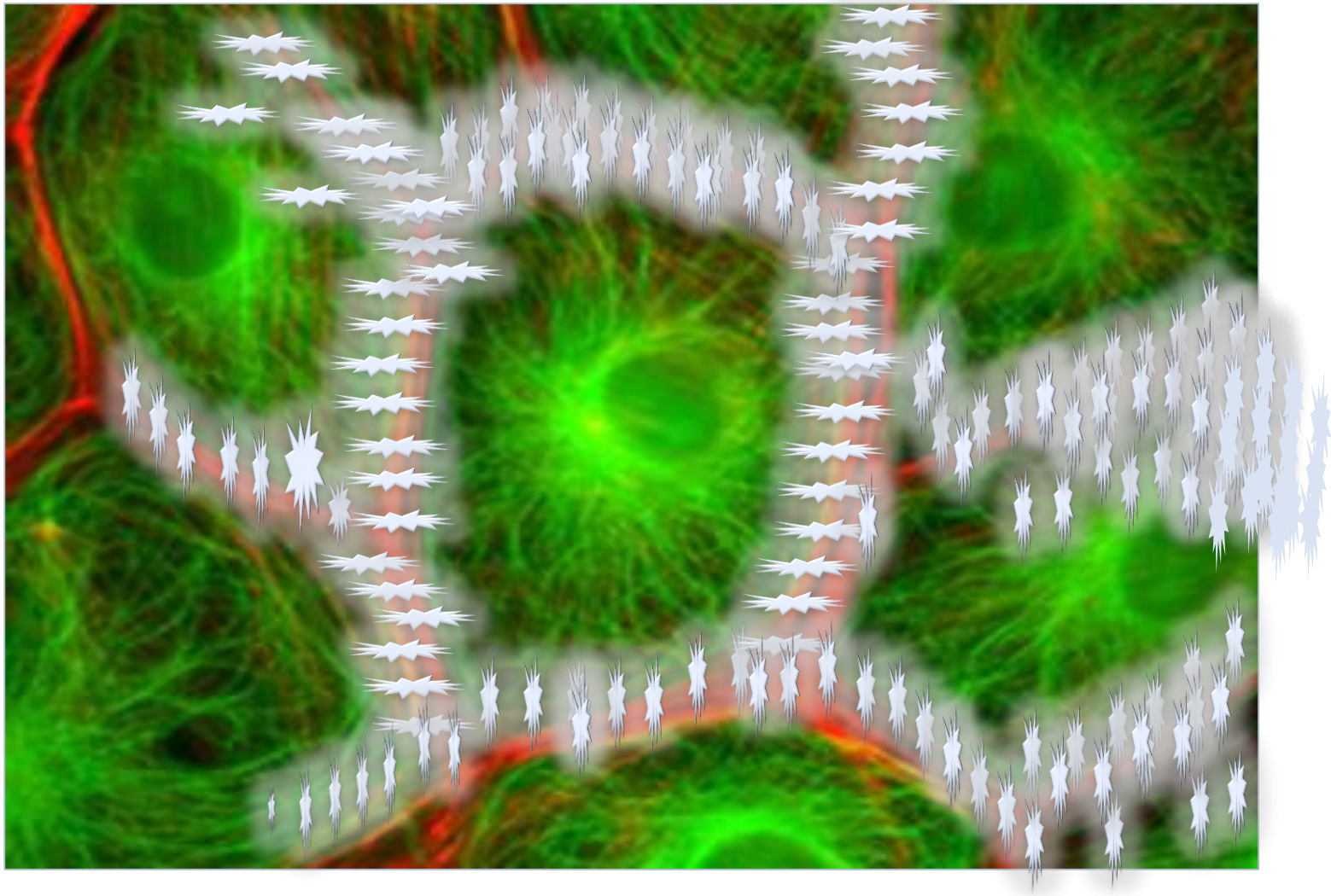
Salari, QuEBS 2012, UC Berkeley, CA
Salari, QuEBS 2010, Harvard U, MA



Matter Wave around a Cell



Matter Wave Interference in a Tissue



Alipasha Vaziri

Experimental Group in Vienna, Austria

Quantum Effects in Ion Channels

Martin Plenio

Theoretical Group in Ulm, Germany

Quantum Effects in Ion Channels

ІМФ

Thank you

for your attention !