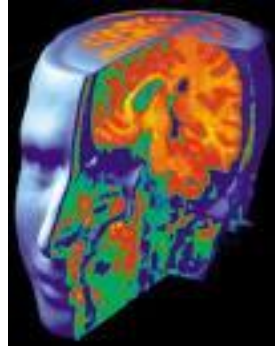


# ***“The Quantum Life”***



***Dimitri V. Nanopoulos***

***Texas A&M University  
Houston Research Advanced Center  
& Academy of Athens***

## ***Motivation***

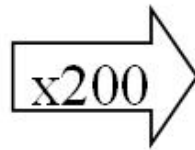
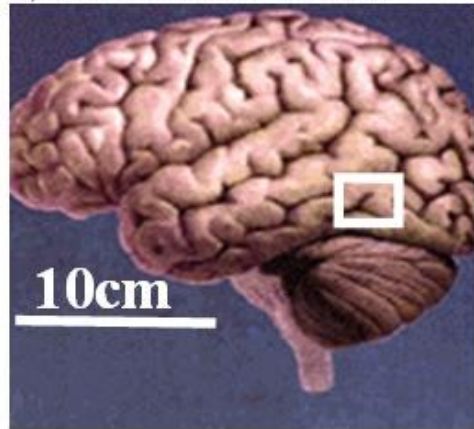
- **Highly controversial claims of quantum effects in neurobiology have been around since the 1970s.**
- **Fascinating predictions of QED-cavity model of MTs. Model highly dependent on value of tubulin dipole moment and other experimentally determinable parameters**
- **Modern bioelectronics and nanotechnology regularly ‘steals’ biomolecules for nanowire, transistor, photodiode and photovoltaic fabrication.**
- **If models for MTs are accurate, perhaps nature has already made BioBits or BioQubits for bio-quantum computation**

# ***Background: How did the Quantum Get Entangled in the Brain?***

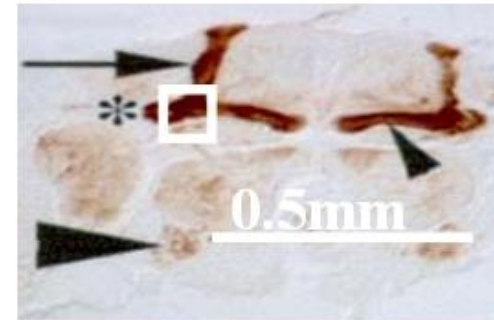
- ***For over 30 years scientists have questioned qualia and the binding problem from fundamental physics standpoint (Frohlich, Penrose et al.). The argument was that classical physics alone cannot explain seeming “Action at a distance”, coherence between neurons, emergence of consciousness etc.***
- ***A lot of pseudoscience ensued “solving one mystery by application of another”. Main argument against quantum in the brain was “wet, warm and noisy” environment –a reasonable objection.***
  - ***PROBLEM: until now no-one had testable hypotheses or controlled experiments. Many things wet hot and noisy yet fundamentally quantum (NMR, black holes, lasers etc.)***
- ***Around 2000, a group of physicists + biologists decided to look into problem doing both theoretical and properly **controlled EXPERIMENTAL research** in biophysics and neurobiology and showed that***
  - A) ***Quantum Brain is experimentally testable at molecular and neurobiological level***
  - B) ***Experimental evidence is consistent with certain aspects of Quantum Brain***

# From the warm, wet and noisy to the single tubulin molecule

(Human) brain tissue ~  $10^{10}$  neurons

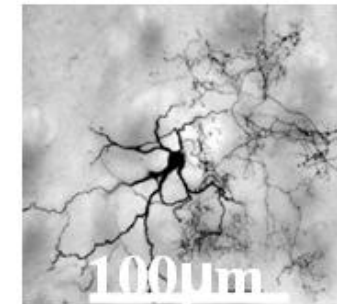
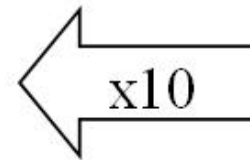


(Drosophila) 2 neural bundles ~  $2 \times 2500$  neurons

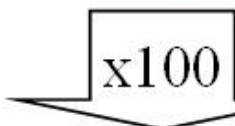


Neural net ~ 10 neurons stained

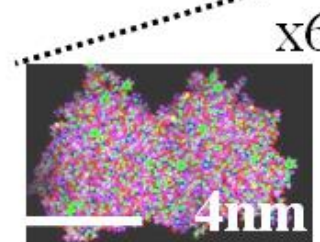
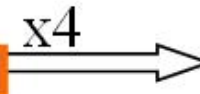
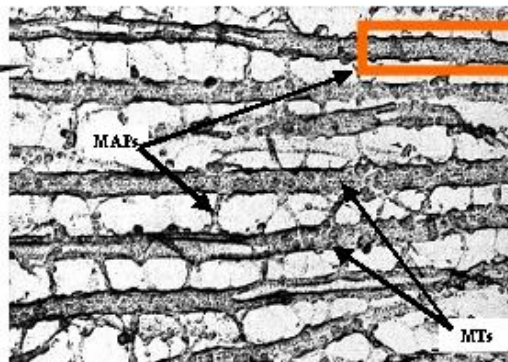
Neural synapse, ~  $10^4$  synapses/cortical neuron



One Microtubule



Axonal cytoskeleton



One tubulin dimer QUANTUM POSSIBLY CONTROLS THIS

# Why Quantum Mind?

## Entanglement possibly explains binding problem

- EPR example: pi-zero decay



$\pi^0$

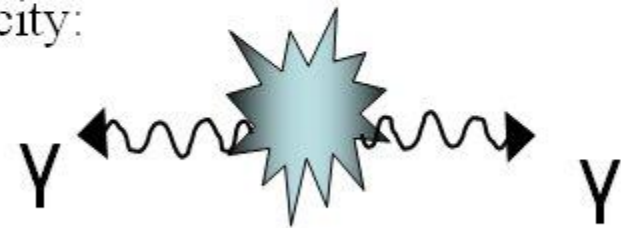


Pi-zero meson with 0 charge and 0 spin

Spontaneously decays into 2 photons of opposite helicity:

Unfactorizable wavefunction

$$|\Psi_{\gamma\gamma}\rangle = \frac{1}{\sqrt{2}} (|1,0\rangle + |0,1\rangle)$$



$$\neq |1,0\rangle + |1,1\rangle = |1\rangle \otimes (|0\rangle + |1\rangle)$$

# ***Quantum computation seems more closely related to brain function than classical***

A “BIT”: “0” or “1”:  $\Psi = |0\rangle$  or  $\Psi = |1\rangle$

A “QU-BIT”: “0” or “1” or anything in between!

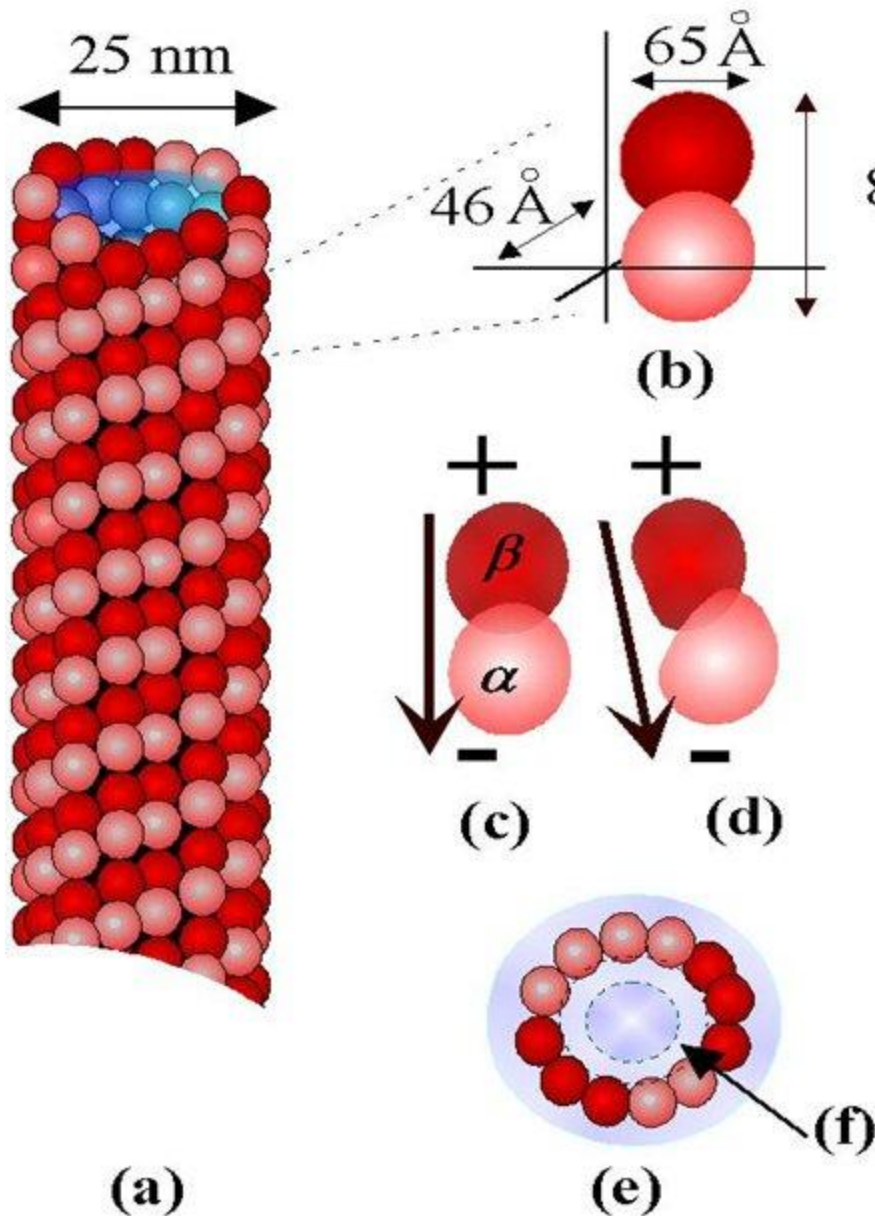
$$\Psi = \alpha |1\rangle + \beta |0\rangle$$

- **A quantum computer accesses all entangled bits in one go**
- **Similar to human brain (or so the logic goes)**

A direct measurement of *Entanglement* among tubulin states would do wonders for the credibility of “Quantum Brain” models.

***Crash Course in Quantum  
Electro Dynamic Cavity  
model of Microtubules and  
its predictions***

# Outline of the QED-Cavity Model of MTs



$$u_n \rightarrow u(x, t)$$

$u_n$  is the displacement field of the  $n$ -th dimer,  $P(u)$  a polynomial in  $u$ , depends on particular potential  $V(u)$  -not shown- describing dipole-dipole interaction depending on parameters  $\rho$  and  $\gamma$  fixed by hand

$$\xi = (x - vt)$$

$$u''(\xi) + \rho u'(\xi) = P(u)$$

$\Rightarrow$

$$u(x, t) \sim c_1 (\tanh[c_2(\xi)]) + c_3$$

For certain forms of the assumed potential we get a solitonic solution which can be responsible for dissipation-free energy transfer along MTs.

Region (f) is modeled as the "QED cavity" based on "ordered water" assumption

$$H_{ow} = \sum_{j=1}^M \left[ \frac{1}{2I} \vec{L}_j^2 + \vec{A} \cdot \vec{d}_j \right]$$

$$\lambda_0 = \frac{d_{twb} \cdot E_{ow}}{\hbar}$$

$H_{ow}$ : ordered water Hamiltonian,  $M$ : number of water molecules,  $\vec{L}_j$ : total angular momentum vector of a single molecule,  $I = av$ . Moment of inertia,  $\lambda$ : Rabi coupling

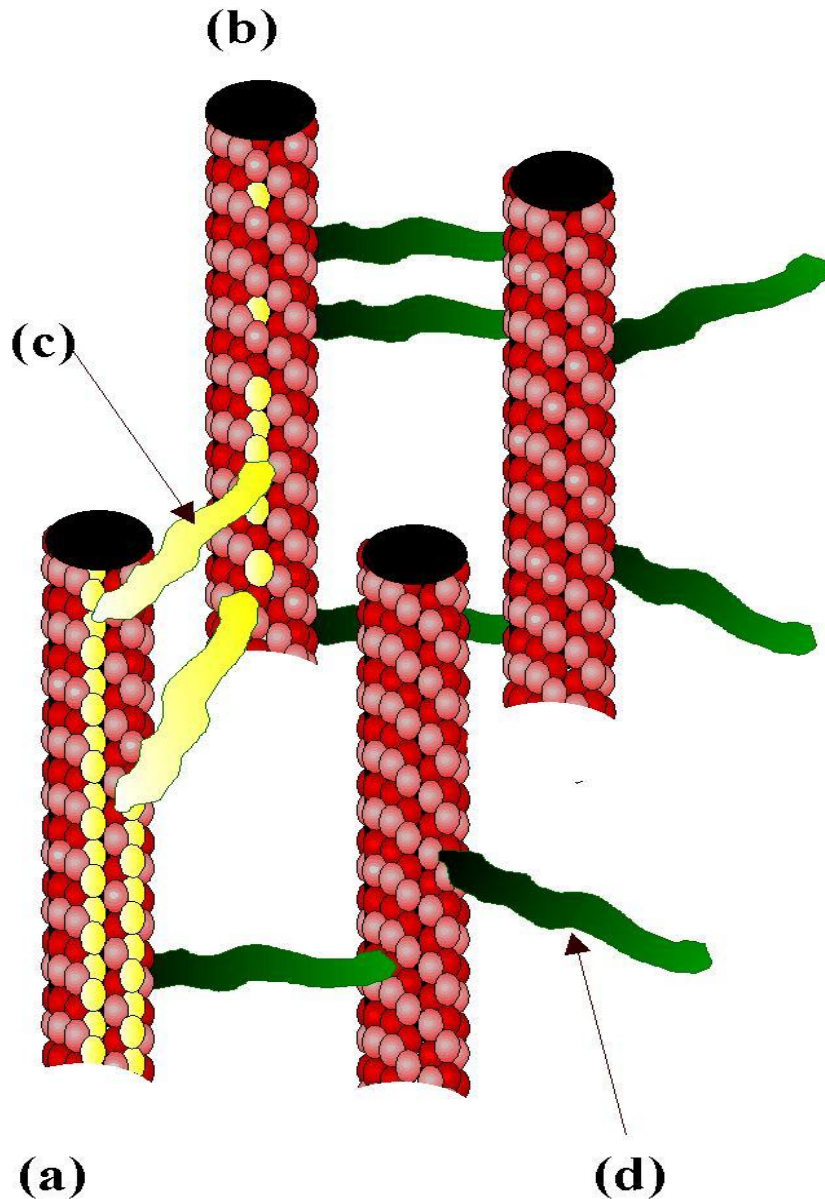
# Consequences of the QED-Cavity Model of MTs

## PART I -theory

### Fascinating but not yet detected predicted features:

- Flip waves velocity  $v_{\text{flip}} \sim 2\text{-}20\text{m/s}$  [Tuszynski, Mavromatos-Nanopoulos]
- Flip Waves :  $t_{\text{decoh}} \sim 10^{-6}\text{sec}$
- Time for soliton to travel down one MT  $\sim 10^{-6} - 10^{-7}\text{sec}$
- Electric field amplitude at the center of MT cavity of volume  $V$  and dielectric constant  $\epsilon$ , interacting with photons of frequency  $\omega$  is  $E_c \sim (\hbar\omega/\epsilon V)^{1/2} \sim 10^4 \text{ V/m}$
- QED-cavity model implies **Quantum Optics** e.g. bioinformation  
**TELEPORTATION**

# Theoretical Example: (even classical) solitons, a.k.a. flip-waves can be the basis for Bio Logic Gates



Example of a microtubular logic gate: A XOR logic gate where "0" is represented by absence of flip wave and "1" by presence of flip wave.

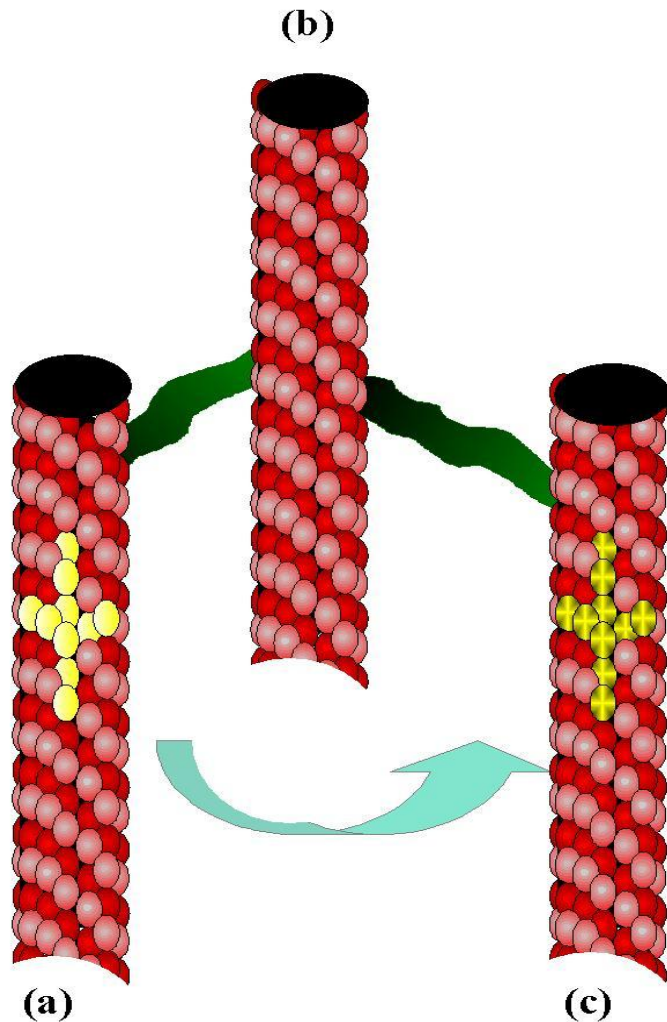
(a) Input MT (b) Output MT (c) A MAP transmitting a flip wave (d) A "quiet" MAP. MT a has two solitons travelling, encountering two MAPs that transmit both solitons to MT b (b). The solitons arrive out of phase at MT b and cancel each other out.

**XOR  
TRUTH  
TABLE**

$0, 0 \rightarrow 0$
$0, 1 \rightarrow 1$
$1, 0 \rightarrow 1$
$1, 1 \rightarrow 0$

What are flip waves for?

# Theoretical Prediction: If MTs are QED Cavities, then teleportation of quantum states possible intra/inter-cellularly



## Schematic of a microtubular quantum teleportation of states.

MT (a) sends its state (represented by a cross) to MT (c) without any transfer of mass or energy.

Both MT a and MT c are entangled with MT b (entanglement represented by presence of connecting MAPs).

# ***Is teleportation and entanglement just crazy theoretical quantum concepts?***

- Photon entanglement is entirely routine (e.g. type II parametric downconversion)
- Teleportation of photon and atom states has been experimentally demonstrated numerous times
- Entanglement of mesoscopic samples of  $10^{12}$  Cs atoms at room T°C for 0.5ms(!) has been experimentally demonstrated.
- To teleport a quantum state one needs a source of entangled particles (routine *in vitro*, who knows *in vivo*?)
- **No-one has seen anything like this in vivo, but there is way to directly test for quantum behavior of biological matter**

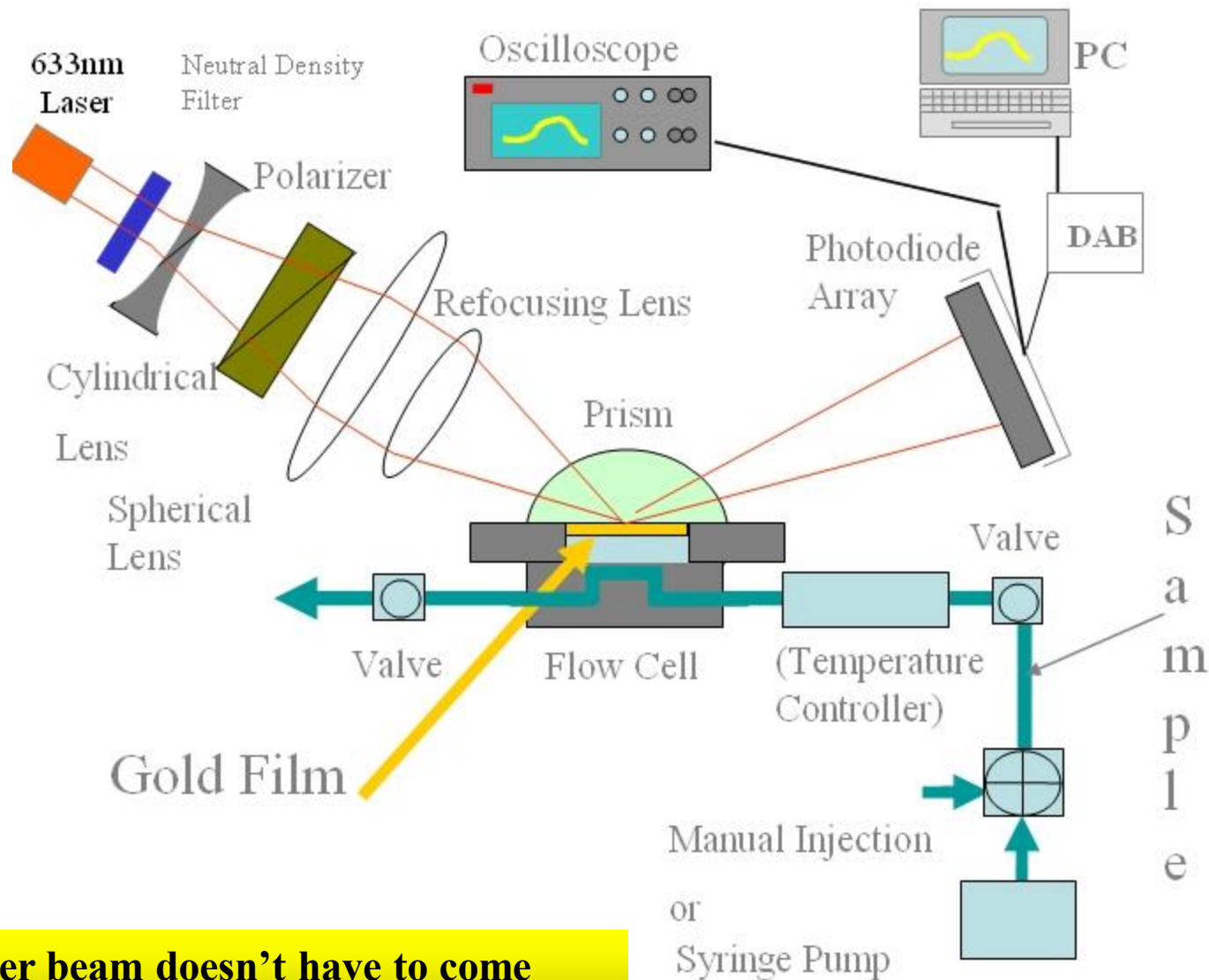
# Consequences of the QED-Cavity Model of MTs

## PART II -experiment

### Immediately testable predictions:

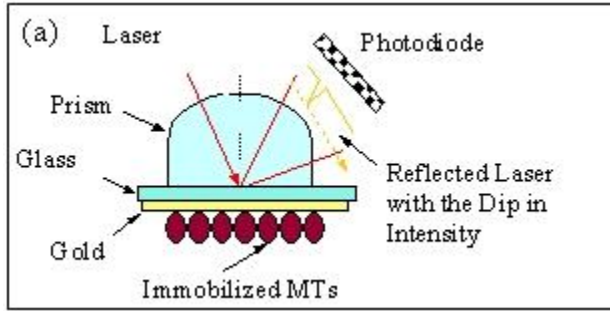
- Tubulin should have a high electric dipole moment – SPR & dielectric spectroscopy **CHECK**
- Very sensitive dependence of memory on MT-MAP stoichiometry – Drosophila neurobiology **CHECK**

# ***Our home-built state-of-the-art SPR biosensor array to determine refractive index, dielectric constant and dynamics***

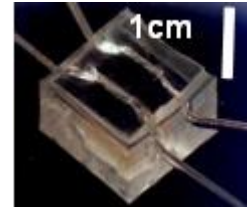
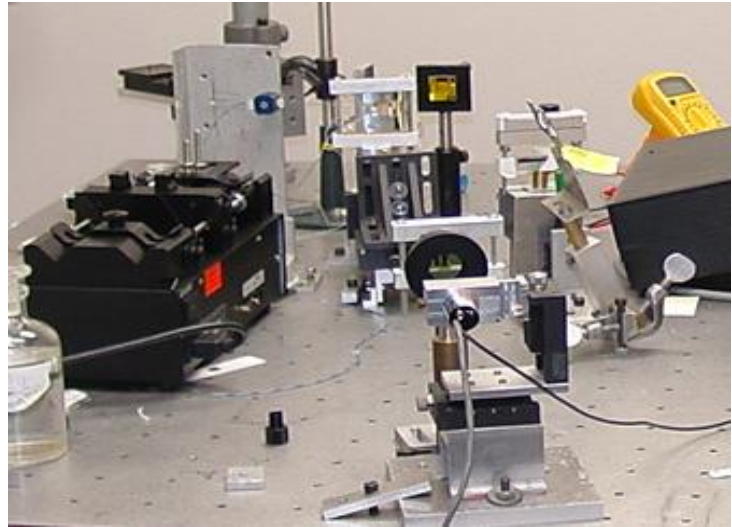


**Note: laser beam doesn't have to come into direct contact with the sample.**

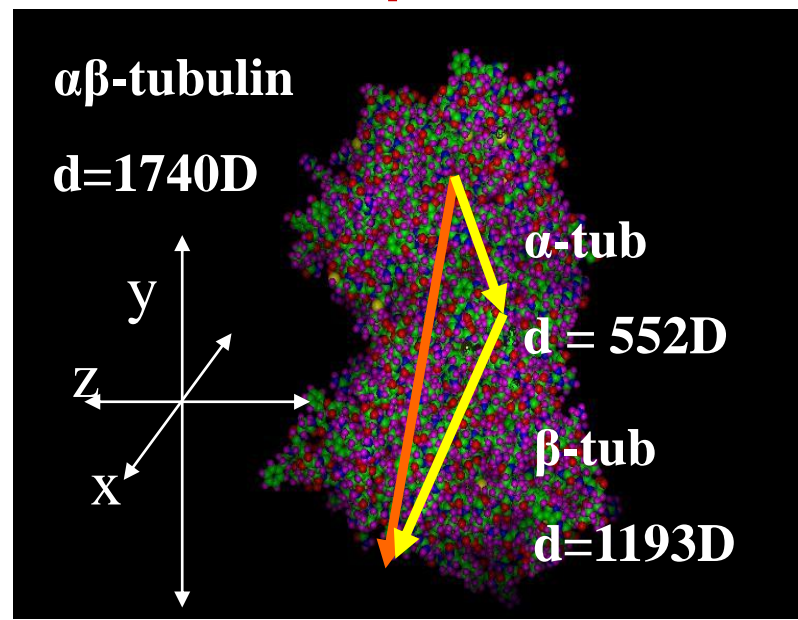
# SPR + Dielectric experiments = give Tub Dipole moment in agreement with QED-MT model and Mol-Dyn simulations



Principle of Surface Plasmon Resonance (SPR) to measure dipole moment, detect flip-waves, test entanglement



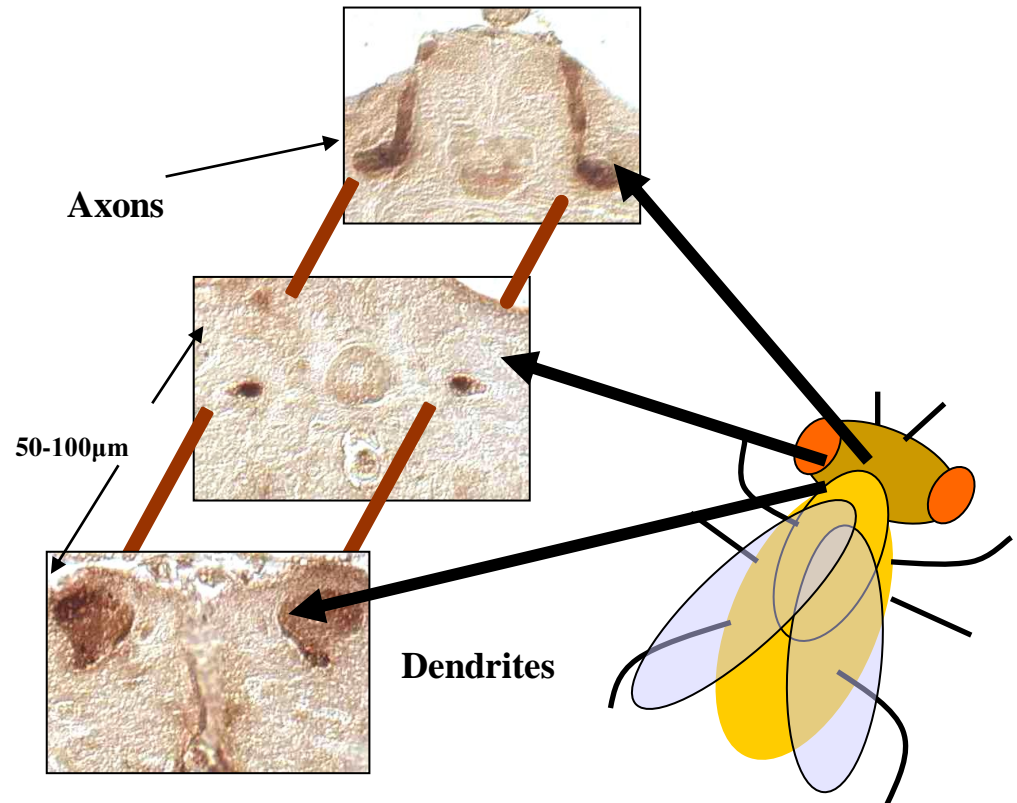
## RESULT as predicted:



# Why use *Drosophila* to check for quantum effects ?

- Powerful genetics
- Simple brain wiring
- Neurons, tubulin-MTs adequately similar to vertebrates

Mushroom bodies stained

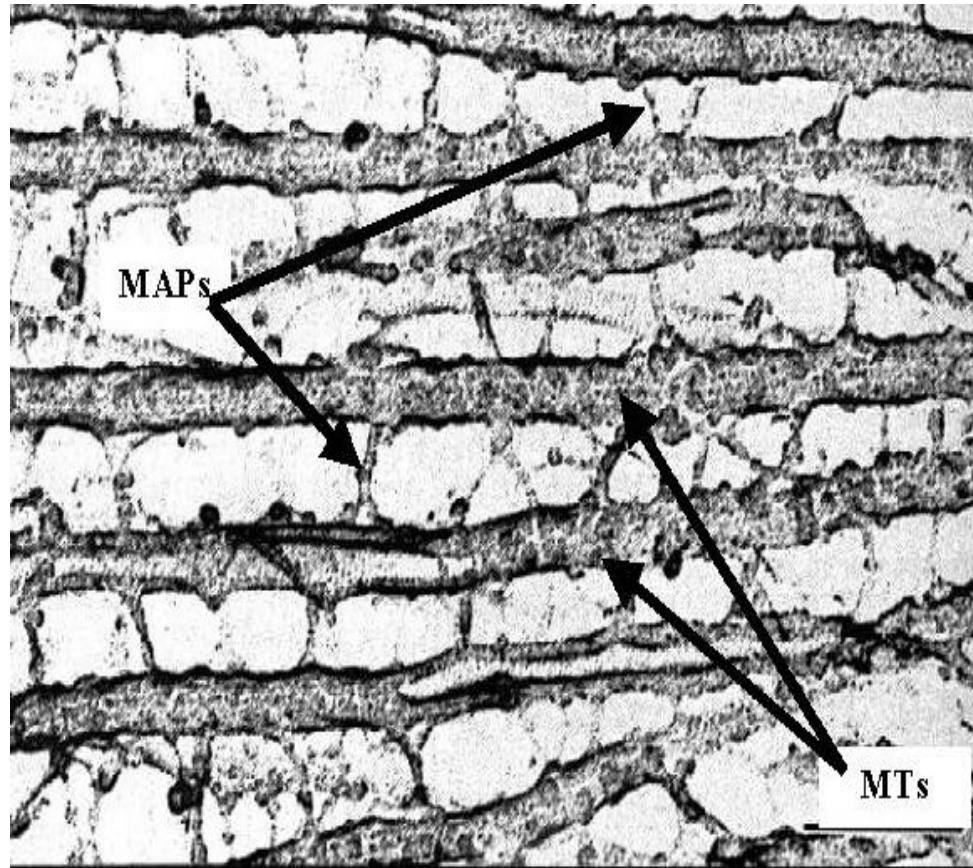


“mushroom bodies” in fly ~ Hippocampus in human

Responsible for associative memory

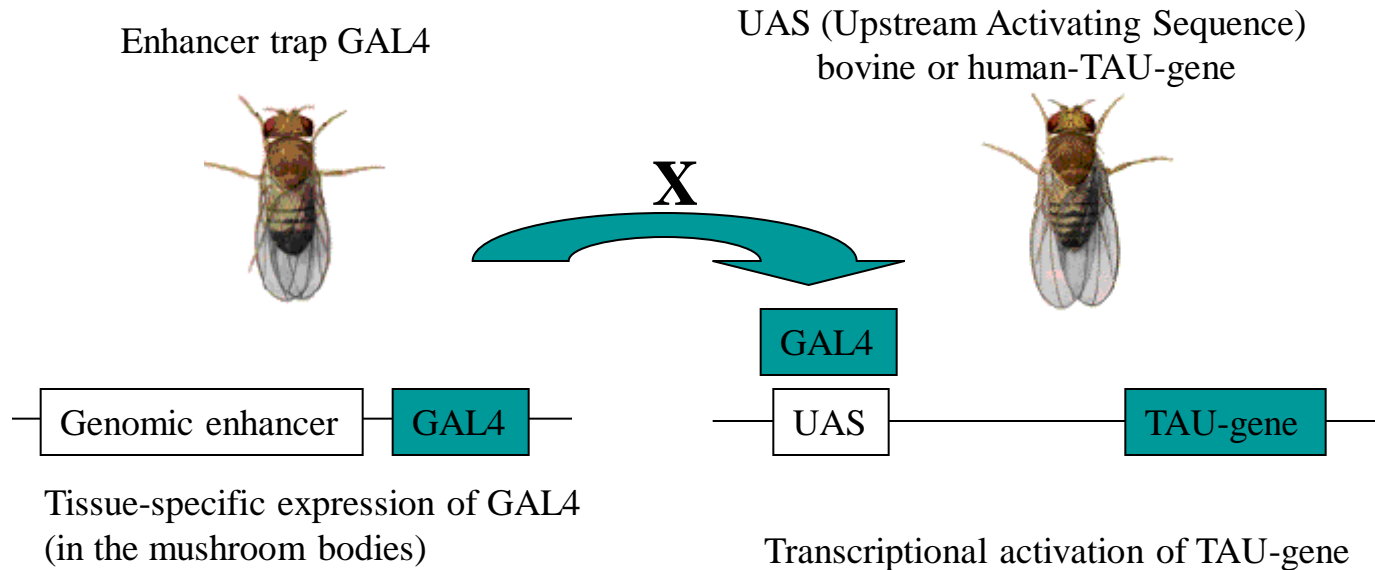
# ***Is the cytoskeleton and MTs directly involved in memory formation as the QED-MT model would imply ?***

- Disturb MTs by binding EXTRA MAP-*tau* creating more nodes in cytoskeleton.
- Ties in with possible Logic Gate function



To mean anything must make sure neural cells and whole animal OK otherwise!

# Transgenic *Drosophila Melanogaster* fruitflies



- Directed overexpression of MAP-*tau* (bovine, human or native).
- Spatial and temporal control possible
- Expect MTs to be disturbed, resembling early AD

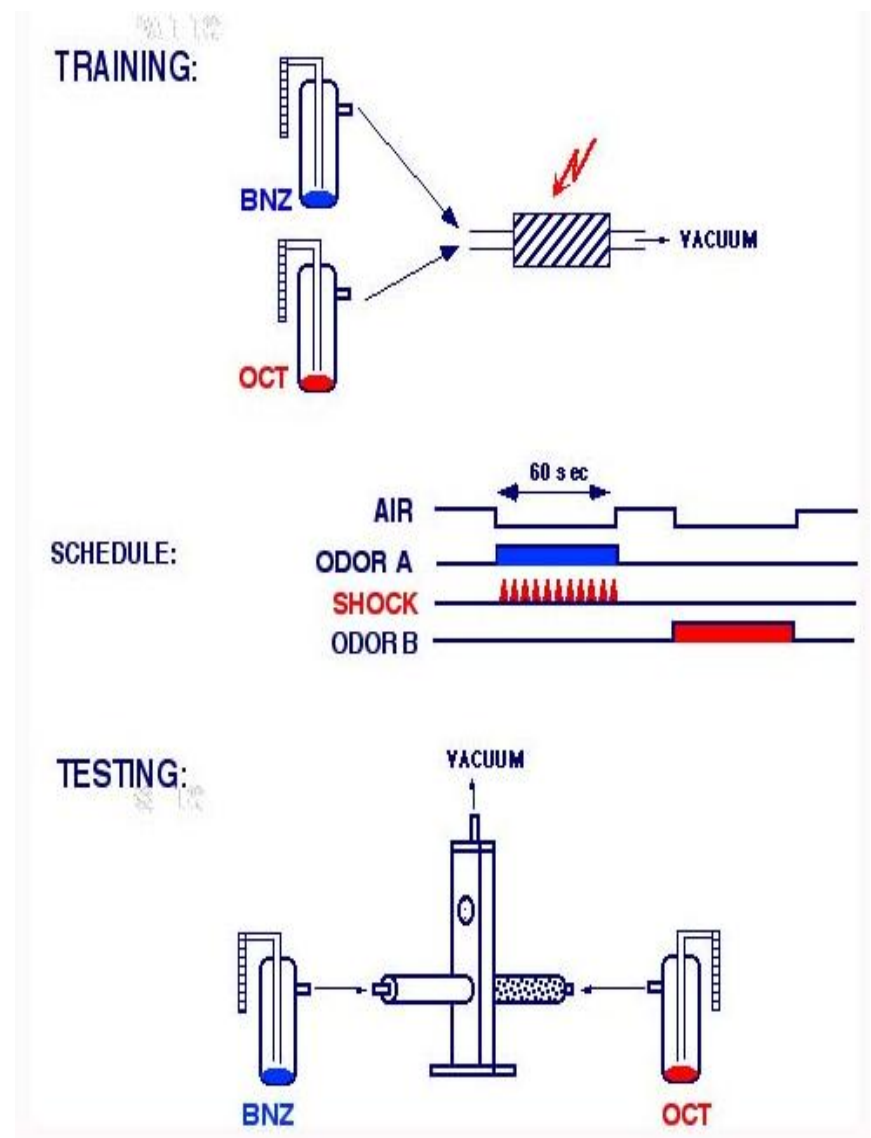
•Does the extra tau bind to MTs? Yes!

# Training *Drosophila Melanogaster* fruitflies

- Negatively reinforced olfactory assay
- Equally aversive odors (conditioned stimuli) coupled to electric shock (unconditioned stimulus)
- Performance index *P.I.* quantifies ‘memory’

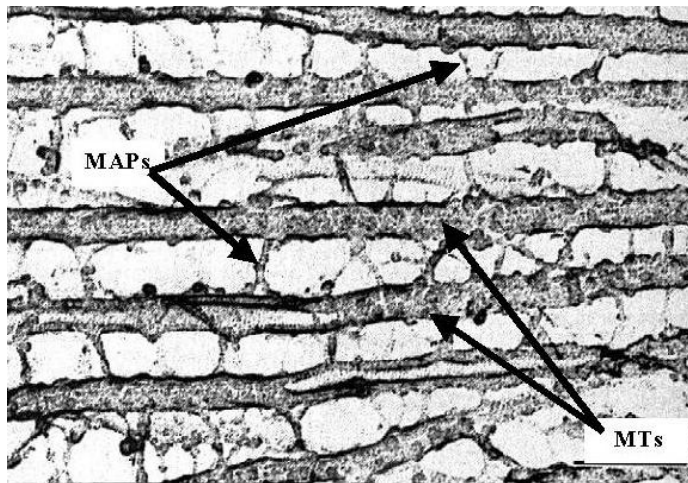
$$P.I. = \frac{C - W}{total} \times 100\%$$

Dozens of controls must be performed

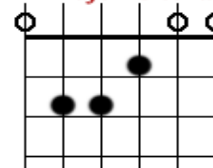


# (Super/Bio) Strings

**The QED-MT model predicts MAP binding essential to memory formation prior to synaptic Long Term Potentiation**



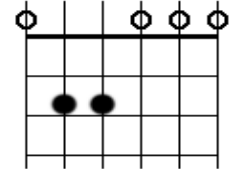
*E Major Chord*



Initial



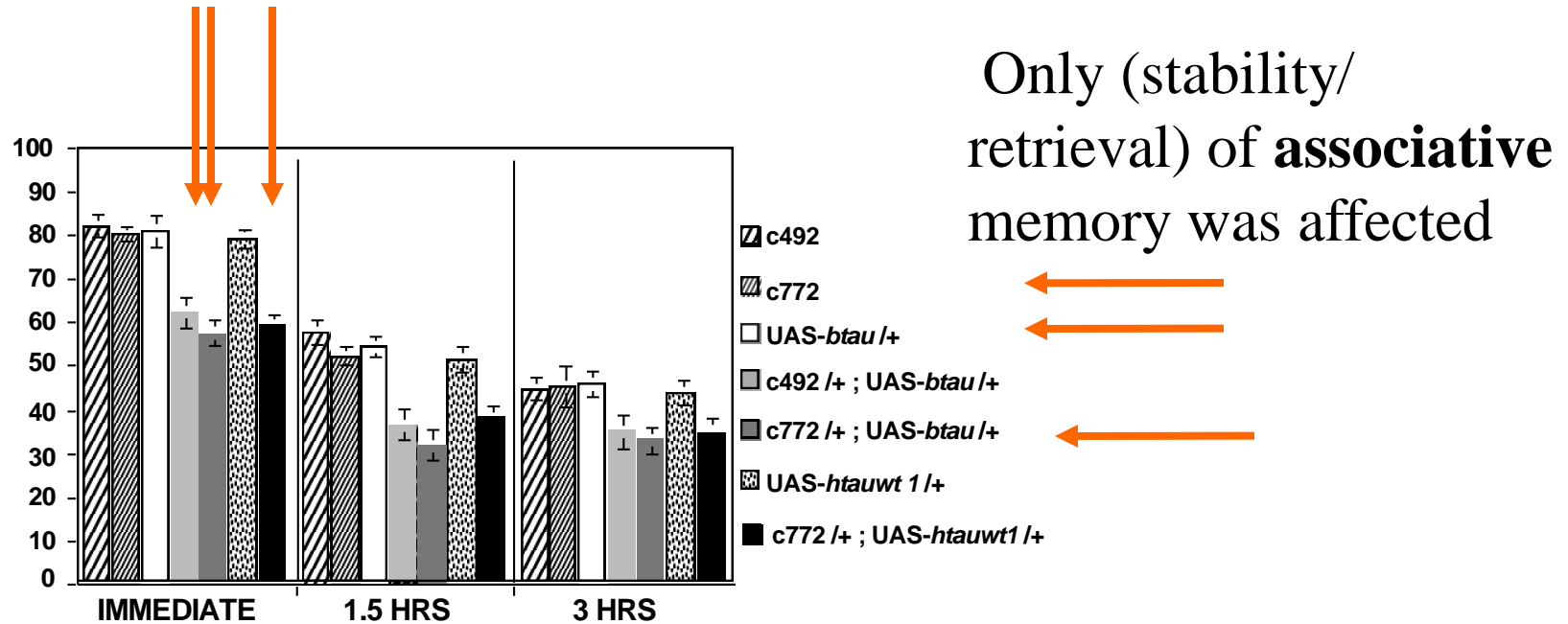
*E Minor Chord*



Final

- Microtubular Cytoskeleton QM “Guitar String Model” predicts stoichiometry of MAPs (TAU) to TUB is important in memory encoding. **Vibrations!** But how to test ?

# **Result as predicted: Transgenic flies are memory deficient, due to slight perturbation in cytoskeleton**



Results suggest behavioral neuroplasticity decrement may be earliest detectable symptoms of tauopathies such as AD (non-invasive diagnosis?)

No neurodegeneration! (strongly suggesting effects directly due to cytoskeletal perturbation)

# ***Will "Quantum Biophysics", "Biobit", "Bioqubit" make the dictionary like "G.U.T.", "slepton" etc?***

## ***Where do we stand? Is the Brain fundamentally Quantum ?***

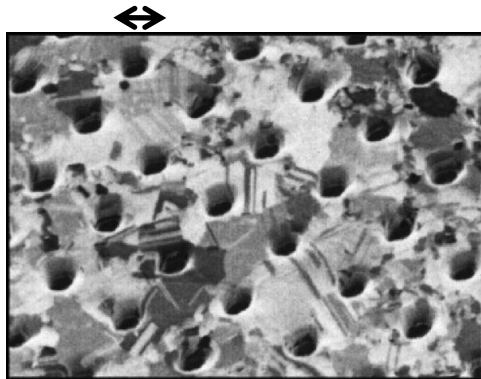
- We have moved from pure speculation to experimentally testable and tested hypotheses
  - 1) SPR and Diel. Spec. have shown uncharacteristically high electric dipole moment of tubulin dimer as predicted by QED-MT
  - 2) Behavioral neurobiology has shown conclusively and unexpectedly that precise cytoskeletal stoichiometry is crucial to associative olfactory memory in *Drosophila*
- All experimental evidence so far consistent with predictions of QED-MT and suggestive of intimate involvement of MTs and their quantum properties in brain function
- No claims of grand unified theory of brain function yet !
- More work has to be done, we have ideas for directly testing quantum entanglement in tubulin molecules

# FUTURE:

**Can we check *DIRECTLY* for quantum effects in biological matter?**

**Yes: Surface Plasmons are true quantum beasts**

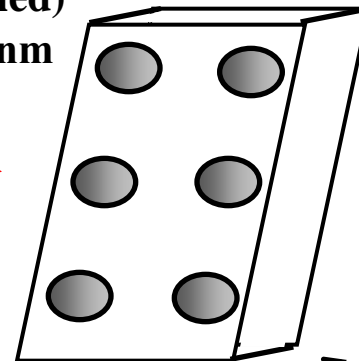
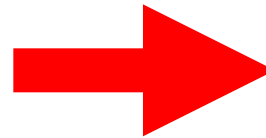
Hole DIA = 200nm



## Surface Plasmon Assisted Entangled Photon Transmission

•Altewischer et.al.NATURE 418, 304-306 (2002)

Incident (entangled) photons  $\lambda=406.7\text{nm}$



Holes 700nm apart

Insulator T = 0.55%

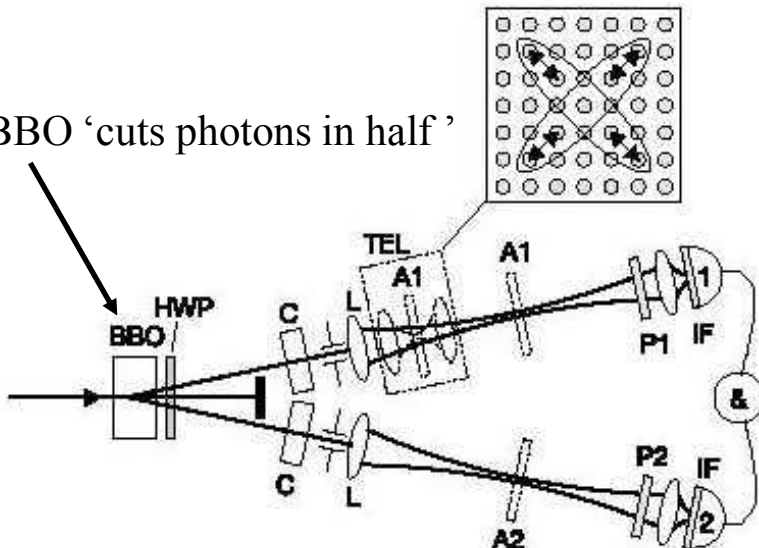


Metal T = 5.00%



Au thickness = 200nm

BBO 'cuts photons in half'

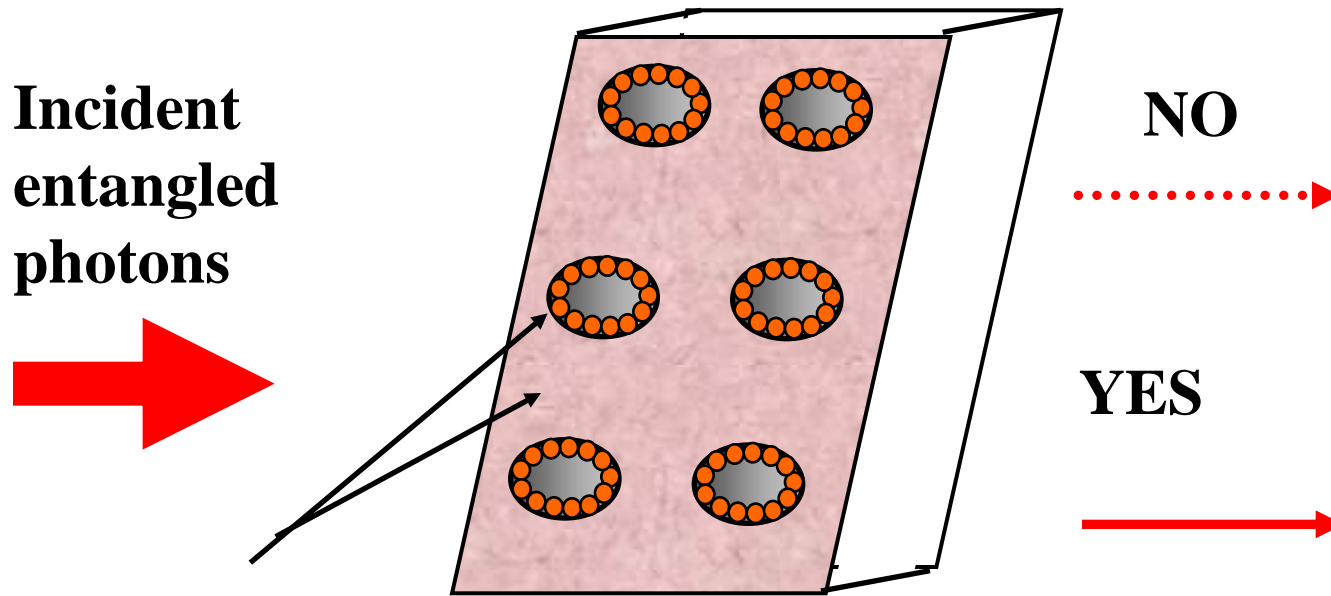


Quantum entangled state, survives

**TRANSDUCTION**

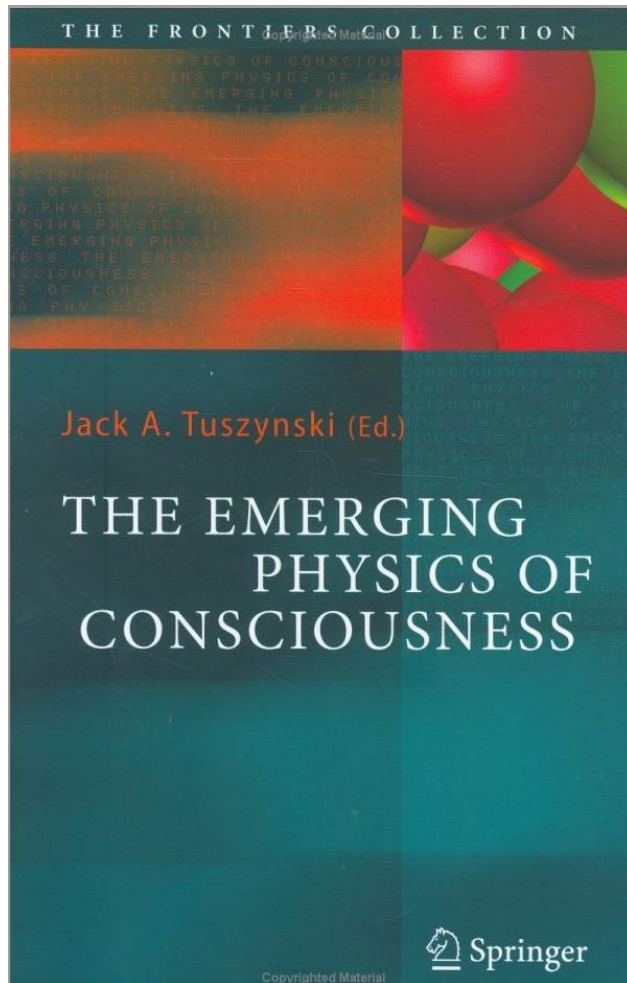
photon  $\longrightarrow$  plasmon  $\longrightarrow$  photon  
(at room Temp)

***It is possible to directly determine ability of MTs to sustain quantum entangled states.***



Amine coupled MTs to gold surface. Photons see MTs, have to tunnel "ON THEM" by coupling to dipole quanta

# In Summary: "Emerging" is right: this is only the beginning



<b>4 Towards Experimental Tests of Quantum Effects in Cytoskeletal Proteins</b>	
<i>Andreas Mershin, Hugo Sanabria, John H. Miller, Dharmakeerthna Nawarathna, Efthimios M.C. Skoulakis, Nikolaos E. Mavromatos, Alexandre A. Kolomenskii, Hans A. Schuessler, Richard F. Luduena, Dimitri V. Nanopoulos</i>	95
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## Thank You !

# Acknowledgements

- Massachusetts Institute of Technology

*Dr. Andreas Mershin*



Massachusetts  
Institute of  
Technology

- Alexander Fleming Biomedical Science Research Center

*Prof. Makis Skoulakis*

**ALEXANDER FLEMING**  
Biomedical Sciences Research Center

- Texas A&M University



- Academy of Athens

ΑΚΑΔΗΜΙΑ



ΑΘΗΝΑΝ

- Ms Vicky Gerontopoulou