



# DSO

DEFENSE SCIENCES OFFICE



# Quantum Effects in Biological Environments (QuBE)

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*June 17, 2010*

*Quantum Effects in Biological Systems 2010*



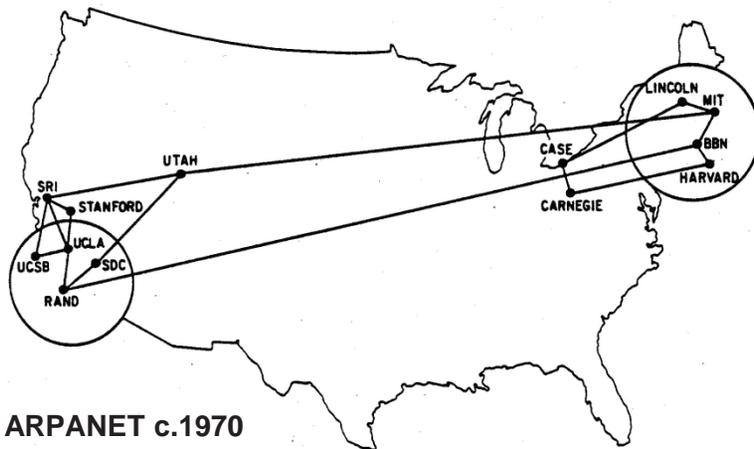
# DARPA



The Soviet Union's launch of Sputnik showed that a fundamental change was needed in America's defense science and technology programs. DARPA was formed to meet this need and rejuvenated our defense technological capabilities.

## Some of DARPA's best (and least known) accomplishments:

### 1. The internet



### 2. The computer mouse



### 3. GPS technology





It cannot be done...



The New York Times

“The flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanics in from one million to ten million years”

October 9, 1903

“We started assembly today”

Orville Wright's Diary  
October 9, 1903





# Quantum Effects in a Biological Environment (QuBE)



- **Biological sensors have long been the envy of device fabricators**
  - Incredible selectivity and sensitivity, robust to noisy environments
  - Room temperature fabrication from readily available materials, compact
- **Unfortunately, attempts to emulate these sensors through reproducing the structure and chemistry have not met expectations**

## **Current world view:**

- Biological sensors operate using “classical” physics

## **New world view:**

- Mimicking biological sensors requires exploiting quantum effects

## **Goal: Change the paradigm of biomimetic sensor development**

1. Develop a comprehensive quantum mechanical model biological quantum effects.
2. Establish beyond any doubt that manifestly quantum effects occur in biology
3. Design and fabricate biomimetic sensors that exploit these quantum effects

## Example Effect

### Magnetic navigation:

Quantum Zeno effect controls the singlet/triplet reaction in a magnetic field

### Olfactory sensors:

Phonon assisted tunneling augments the physical response to odorants

### Photosynthetic apparatus:

Coherent quantum transport increases the rate and efficiency of exciton transport

## DoD application

- Magnetic field navigation
- Magnetic field sensor

- Chemical detection and identification

- Single photon detectors
- Quantum information transport

## Current Examples



Navy fluxgate magnetometer

Fido® detector  
ICx Technologies



Stryker infantry soldier with Night Vision Goggle

**Other biological systems may also utilize quantum effects**

**Nature repeats itself – Specific effects are usually pervasive**

**Specific biological systems use specific quantum effects**



# QuBE Workshop



## Statistics:

1. Held Oct 14-15, 2008
2. 39 attendees
3. Majority in physics but also biologists and chemists
4. Some skeptics of the use of quantum effects by biology invited

## Consensus Needs:

1. Develop better simulation tools beyond ad hoc Hamiltonians
2. Understand how proteins “isolate” the quantum system from the environmental bath
3. Develop open system quantum models
4. Learn how to couple biological quantum systems to a controllable quantum system
5. Develop synthetic implementations of the biological quantum system



**Great excitement in the community for these effects**



# Program Status



- **BAA announced** **March 9, 2010**
- **Proposal abstracts due** **April 8, 2010**
- **Proposal abstracts feedback** **~April 13, 2010**
- **Full proposals due** **May 3, 2010**

DARPA is always looking for exceptional ideas

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BAA 10-55 Defense Sciences Research & Technology  
<http://www.darpa.mil/dso/solicitations/baa10-55.htm>

**Proposals currently under review**



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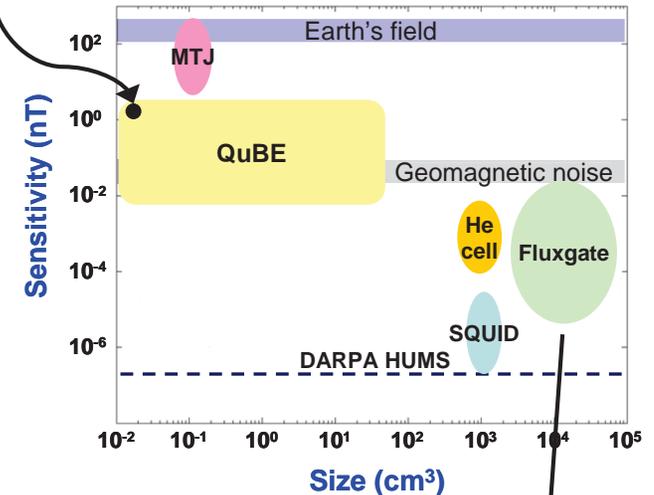
## Magnetic field sensors:

1. High sensitivity magnetic field sensors are large which limits their deployability
2. Small sensors have  $>10^5$  lower sensitivity which limits their usefulness

## Magnetic sensing:

- Passive, covert
- Magnetic fields penetrate:
  - walls
  - metal
  - smoke
  - fog
  - night
- Can gauge brain functional state (MEG)

limit to behavioral effects in birds ( $10^0$  nT)

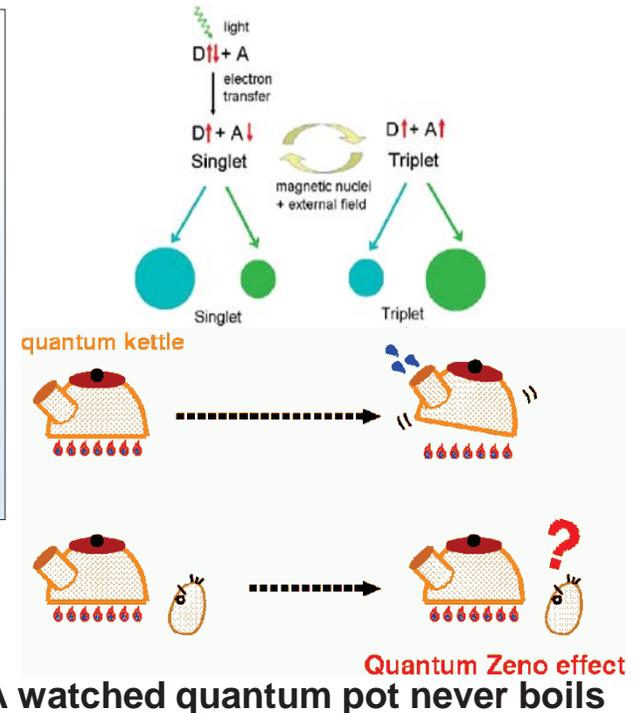


Navy fluxgate magnetometer

**Detection through obstacles**

## Two theories:

1. Biogenic magnetite particles whose orientation is sensed
  - compass needle model proven in bacteria
  - magnetite needles found in bird beaks
2. Cryptochrome protein forms photoinduced singlet and triplet states
  - cryptochrome found in bird eyes
  - each state has different reactivity
  - lifetime of singlet depends on quantum Zeno effect

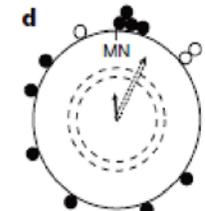
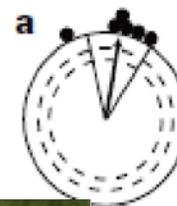


## Evidence for singlet/triplet mechanism:

- Severing nerves that senses magnetite needles does not disrupt orientation in birds but disrupting nerve to cryptochrome does
- Magnetic orientation is disrupted by RF signal scrambles the putative singlet and triplet states
- Deleting protein in *Drosophila* eliminates effect



Control      Magnetite nerve severed      Cryptochrome nerve severed



European Robin

Nature 461, 2009, 1274

Quantum effects appear to be important in biological magnetic field sensing





# Why now? (Why isn't the New World View Crazy?)



## **Biological systems that potentially display quantum effects have been identified:**

1. Exciton migration in photosynthesis complexes display quantum correlation at low temperature and probably at room temperature
  - exciton finds minimum energy location faster than possible through random walk
2. Magnetic field navigation by birds involves a light sensing protein that performs magnetic field dependant chemistry through the Quantum Zeno effect
  - disconnecting magnetic particles doesn't affect magnetic field sense
3. Odor recognition is postulated to utilize phonon assisted tunneling in the receptor protein binding site
  - molecules with the same shape but different vibrations have different odors
  - differently shaped molecules have same odor
4. Other systems have been proposed

## **Necessary tools to link quantum mechanics to biology have been developed:**

- Theoretical techniques to handle large quantum systems have been demonstrated
- Advanced spectroscopic techniques such as 2-D IR make possible the probing of the dynamics of protein quantum states
- Genetic techniques amenable to large protein structures permit the controlled modification of the biological sensor

**Both promising sensors and techniques available**