

# The Relevance of Discovery Science for Research on the Health Effects of EMF

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Organization, and other GOs and NGOs

**Opinions are my own and not necessarily those of the US EPA**

# **Opinions Voiced**

**during this talk are my own**

and do not necessarily represent those of the  
US Environmental Protection Agency

# Outline of Talk

- Discovery Science
- Ascendancy of Simple, Linear Science
- Reports Lost in Deliberations
  - Parametric space in EMF & Biology
- Summary & Conclusions

# Discovery Science

Musante 2009 Bioscience 59(1), p 15

- **Scientific investigations are inspired by serendipitous occurrences to practical problems in need of solutions.**
- **The core of science is gathering and interpreting data through testing ideas.**
- **Interact with scientific community - new questions and testing via an iterative, dynamic process involving a community of scientists engaged in many different activities.**

# Discovery Science

Musante 2009 Bioscience 59(1), p 15

- “... Science **cannot** be oversimplified to make a good story.” N. Kuldell, MIT
- That is, data that gets **in the way** of neat conclusions cannot be simply wiped away.

# Regulatory Perspective

Basis for RF exposure limits  
established in 1980s

Work stoppage in rats @ 4 W/kg

Safety margin of 10x -> humans  
0.4 W/kg in occupational  
0.08 W/kg in general population

# Mechanism for Work Stoppage

- Heating as accepted mechanism due to electric field component of EMF
  - Behavioral response ~> CNS
  - Exposures (SAR) established for short-term
- 

Approach identified the nervous system as the most sensitive part of the body

# Discovery Science

data 'in the way' of neat conclusions

Research to explore the EMF & biological parameter spaces under which effects occur, so that:

- experimental results made reproducible
- models developed for
  - testing various biological preparations
  - production of mechanisms of action

# Broadening of Acceptable Information

- Introduction of data from observations without full MOA
- ELF amplitude modulation of RFT
  - > Modification of exposure limits

# Only Exposure Standard Incorporating Discovery Science Results

## National Council of Radiation Protection & Measurements Report 86, 1986

- Incorporated additional exposure safety limit within an RF band if the radiation was amplitude modulated greater than 50%
- Based on reports of calcium ion release, a surrogate measure of neurotransmitter release (GABA), from brain tissue; EEG changes in monkeys and cats; and performance changes in monkeys & humans.

# Risk Assessment

comments by Paul Slovic  
**Risk Analysis 19(4): 689, 1999**

“Risk assessment is inherently subjective and represents a blend of science and judgment with important psychological, social, cultural, and political factors.”

“Whoever controls the definition of risk controls the rational solution to the problem at hand.” ..... “Defining risk is thus an exercise in power.”

“Public views are also influenced by worldviews, ideologies, and values; so are scientists’ views, particularly when they are working at the limits of their expertise.”

# Ascendency of Limited Focus for EMF Exposure Standards

Subsequent standards focused on effects with known mechanisms of action:

- Peripheral nerve stimulation and elevated tissue temperature
- Dramatically reduced or eliminated participation of scientists who studied low intensity, complex EMF signals

# Signal Types

- Radiofrequency (RF)
  - absorption leads to heat
  - some broad frequency specificity
- ELF-modulated RF
  - effects due to “information content” (modulation):  
AM, FM, Pulsed (Broadband)
- ELF signals alone
  - effects due to:
    - 1) electric current, i.e., E field (max 50-60 Hz)
    - 2) magnetic field
    - 3) “information content”

## Low Intensity “Non-Thermal” Effects

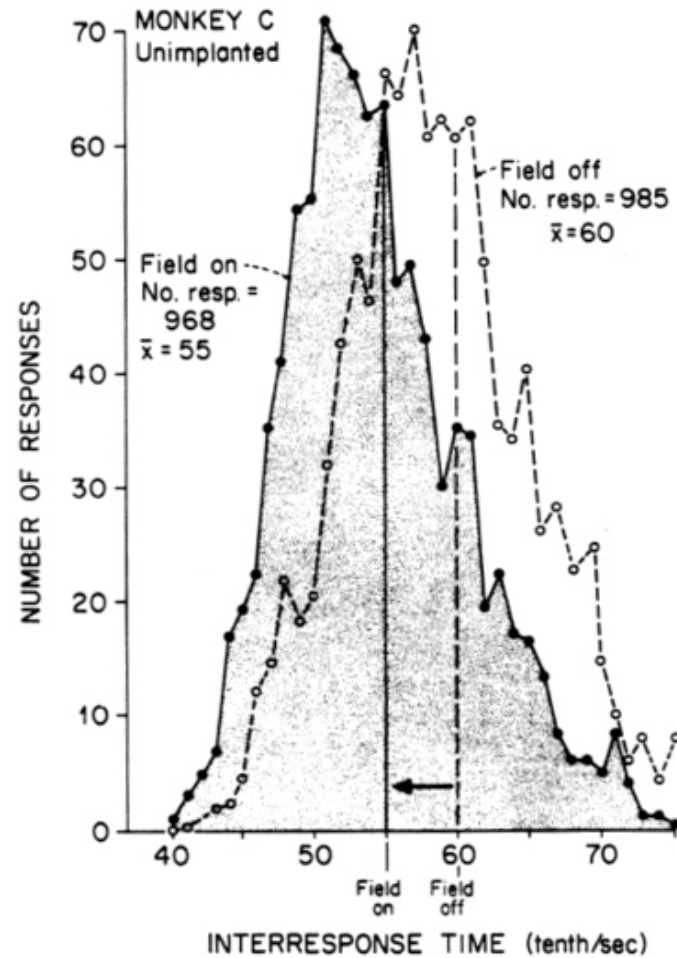
- Effects dismissed because intensities of EMF are often below the assumed thermal “noise level”
- Some physical scientists claim results are impossible, based on “simple” calculations and assumptions, e.g., equilibrium situations
- **But** living biological systems are NOT at “thermodynamic equilibrium”
- Initial reports of sensitivity are doubted unless results are independently replicated - lets us examine some of the reports

# ELF & RFR signals

## behavioral and physiological changes

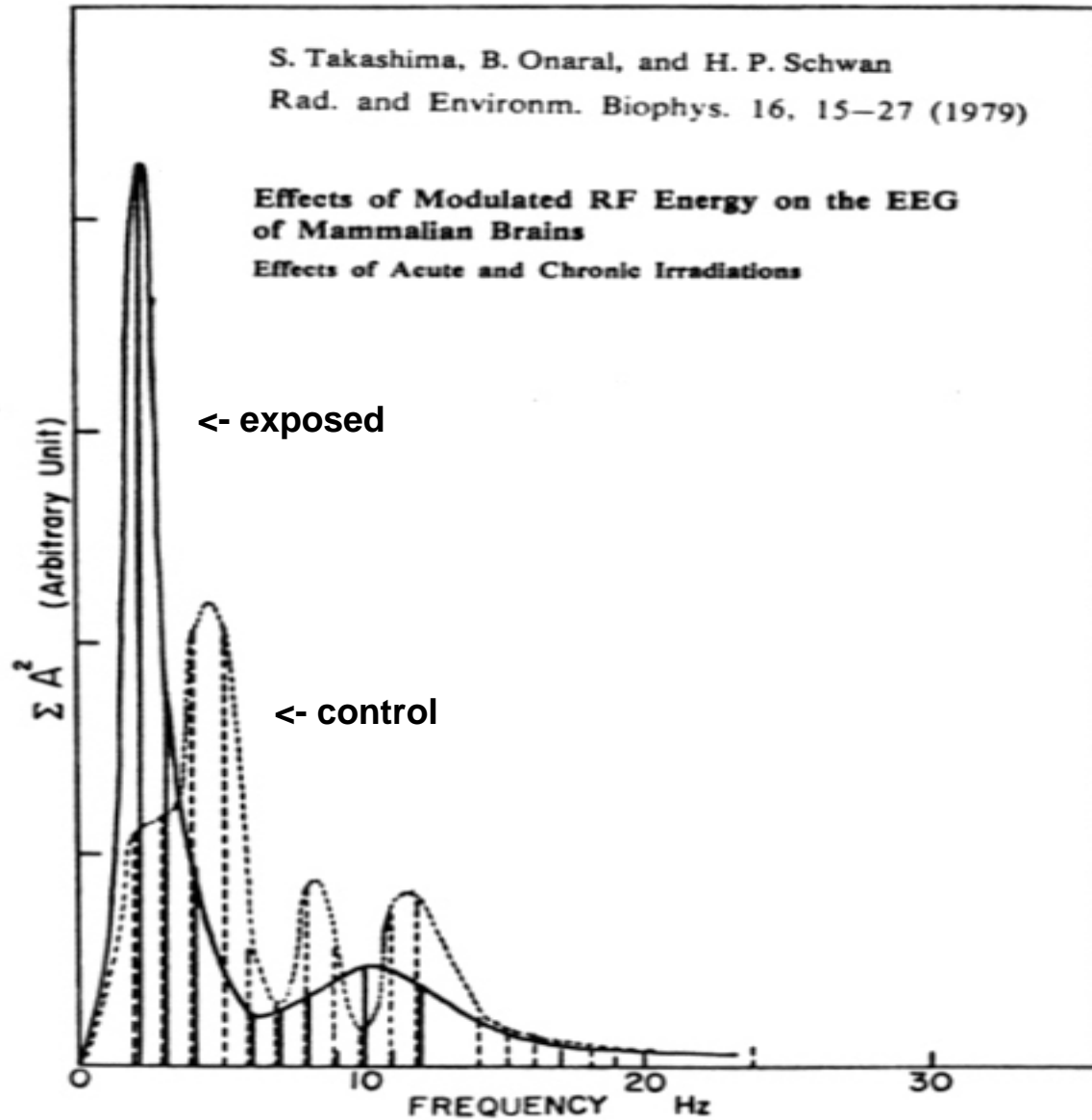
- Human response time changes [ELF]
  - Konig & Ankermuller, Naturwissenschaften 21:486, 1960
  - Friedman et al., Nature 213:949, 1967
  - Hamer, Commun. Behav. Biol 2(5) part A:217, 1968
  - Wever, Int. J. Biometerol. 17:227, 1973
- Monkey response time & EEG changes [ELF]
  - Gavalas et al., Brain Res. 18:491, 1970
  - Gavalas-Medici & Day-Magdaleno, Nature 261:256, 1976
- Rabbit EEG changes [RFR]
  - Takashima et al., Radiat Environ Biophys 16:15, 1979

# Change in Response of Monkeys Exposed to Fields



Gavalas-Medici,  
Day-Magdaleno  
Nature  
261:256-259,  
1976

# EEG Pattern Changes

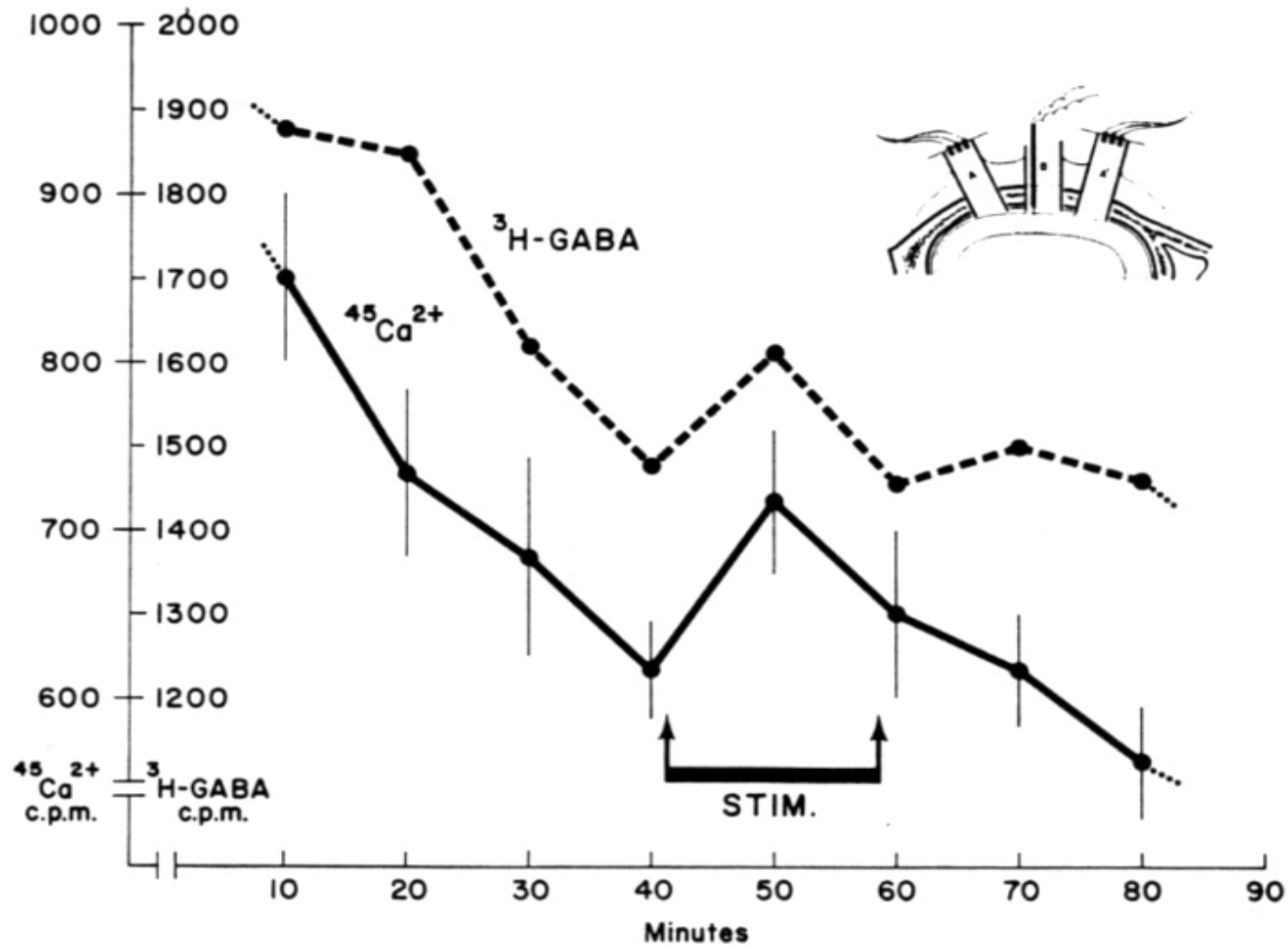


# ELF & RFR Ca<sup>2+</sup> Results (20)

- Cat EEG, GABA & Ca<sup>2+</sup> releases [ELF & RFR] (3)
  - Kaczmarek & Adey, Brain Res. 63:331, 1973; 66:537, 1974
  - Bawin et al., Brain Res. 58:365, 1973
- Chicken Brain Ca<sup>2+</sup> releases [ELF & RFR] (15)
  - Bawin et al., NY Acad of Sci 247:74, 1975; PNAS 73:1999, 1976; PNAS 75:6314, 1978
  - Sheppard et al., Radio Sci. 14(6S):141, 1979
  - Blackman et al., Radio Sci. 14(6S): 93, 1979; Bioelectromagnetics 1:35 & 277, 1980; 6:1 & 327, 1985; 9:127 & 215, 1988; 10:197, 1989; 11:159, 1990; 12:173, 1991; Rad. Res. 92:510, 1982
- Rat Pancreatic Tissue Ca<sup>2+</sup> release [RFR] (1)
  - Albert et al., URSI Ondes Electromagnetique et Biologie, p325, 1980
- Frog Heart, beating, Ca<sup>2+</sup> release [RFR] (1)
  - Schwartz et al., Bioelectromagnetics 11:349

# GABA & Ca Release

Kaczmarek & Adey, Brain Res. 66:537, 1973



# Reference Frame Chemical Comparisons

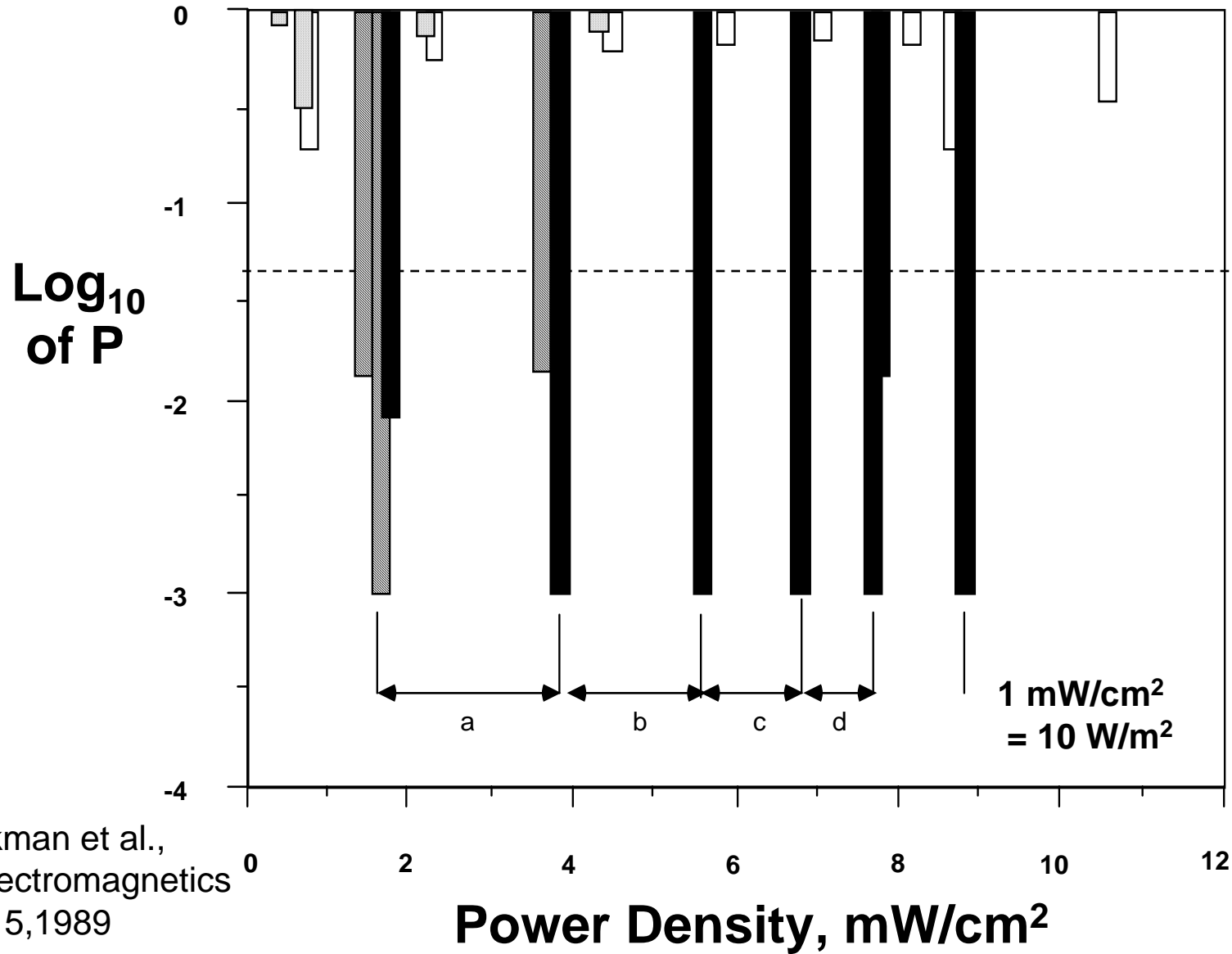
## EMF

- **intensity**
- **frequency**
- **DC magnetic field**
- **electric / magnetic**
- **sine / pulsed**

## Chemical

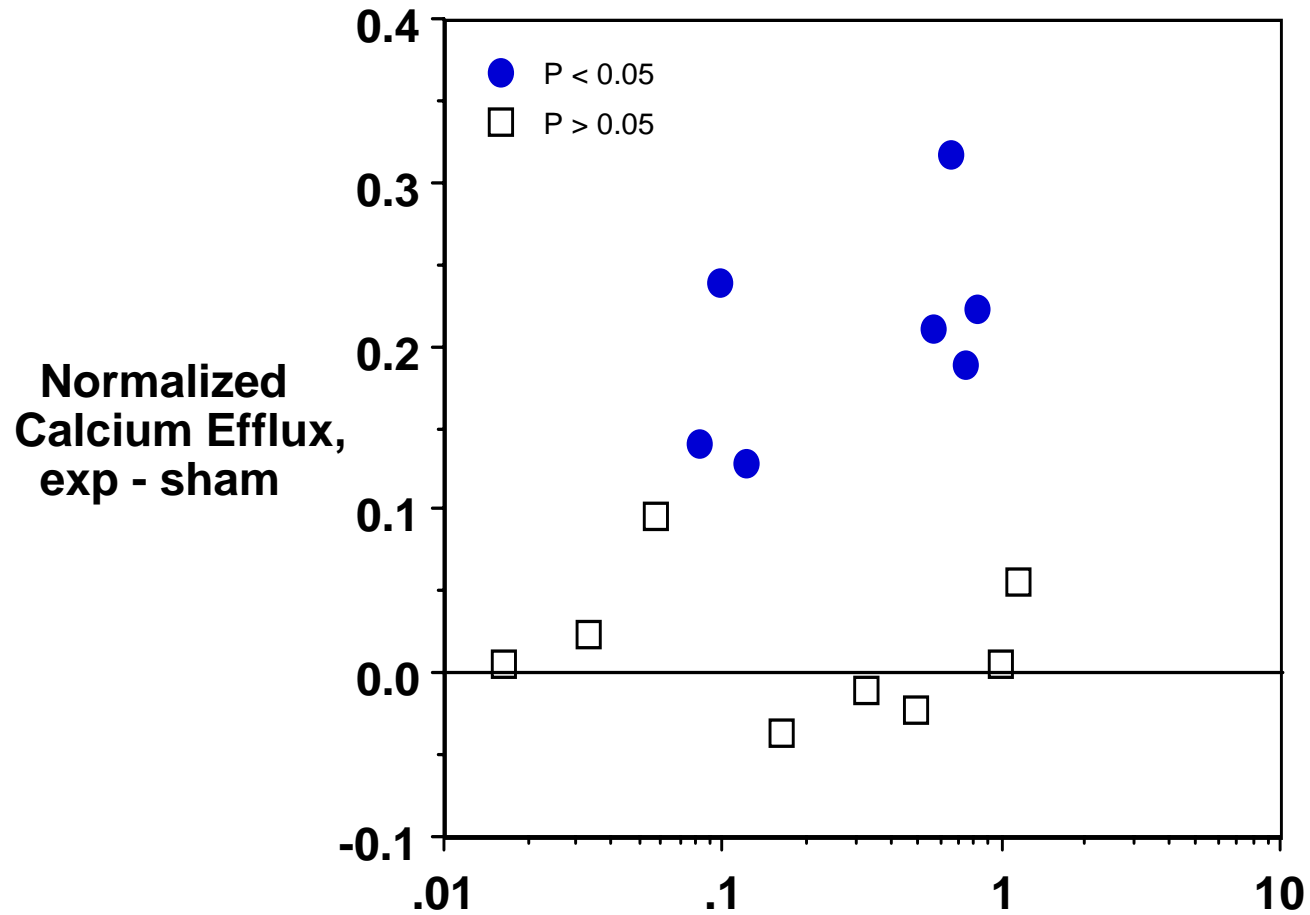
**concentration**  
**analogues**  
**co-factor**  
**optical isomer**  
**individual vs mixture**

# Ca Efflux - RFR (50 MHz, AM 16 Hz)



Blackman et al.,  
Bioelectromagnetics  
10:115,1989

## Intensity - Calcium efflux; 16 Hz



from Blackman et al.  
Rad Res. 92: 510-520, 1982.

# Summary of Intensity Results

- Intensity “windows” exist -> not due to heating
- Unusual and not traditional results
- “Non-linear” phenomenon mostly IGNORED in standard setting situations

# Laboratory Studies

[not obviously due to induced currents or heating]

- A. Gene Induction - Goodman/Henderson; Phillips/Haggren;  
Blank/Goodman
- B. Transmembrane Signaling Cascades -  
Byus; Luben; Blackman
- C. Metabolic Cooperation (GJC) - Cain; Ubeda
- D. Immune System Deficit [NKC Activity] - Lyle
- E. Enhanced Rate of Transformation - Phillips
- F. Breast cancer cell growth - Liburdy; Blackman; Girgert
- G. Melatonin "role" in carcinogenesis - Stevens; Reiter
- H. Enhanced DNA strand breakage – Lai/Singh, & others

# Reference Frame Chemical Comparisons

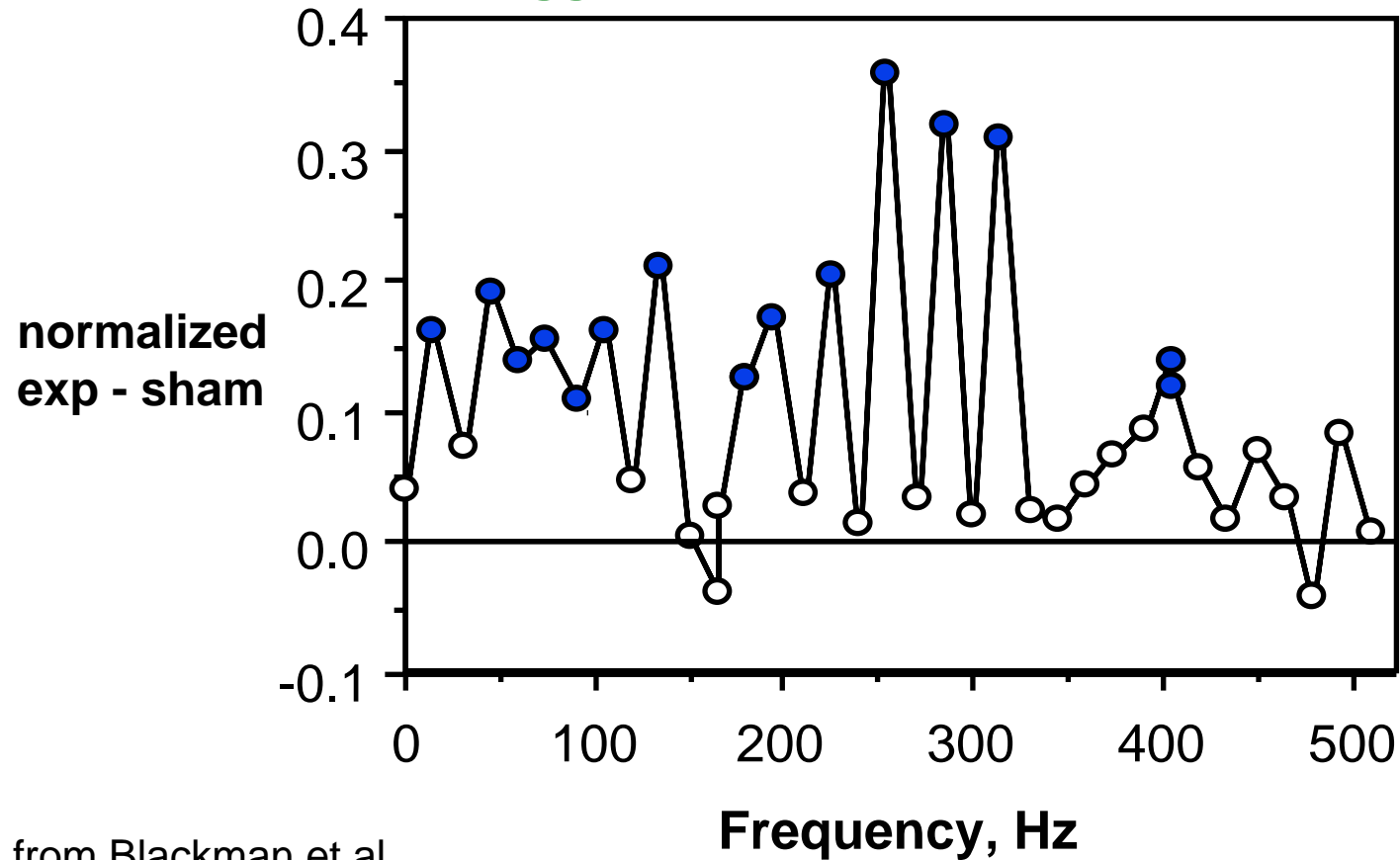
## EMF

- intensity
- frequency
- DC magnetic field
- electric / magnetic
- sine / pulsed

## Chemical

- concentration
- analogues
- co-factor
- optical isomer
- individual vs mixture

## Frequency @ 0.69 mGrms (69 nT) - calcium efflux Eggs incubated in 60-Hz fields

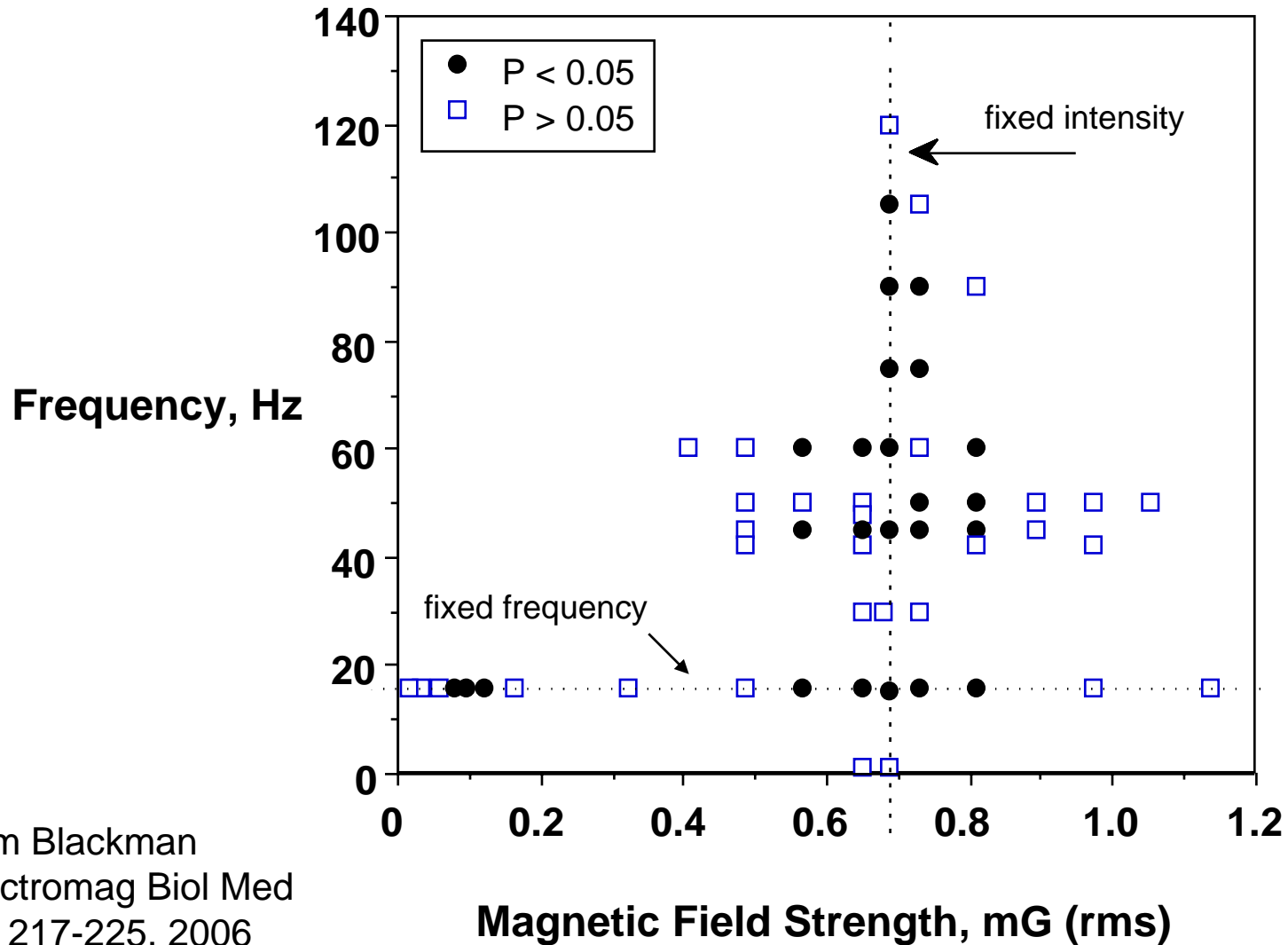


from Blackman et al.  
Bioelectromagnetics 9:215, 1988

# Combined Effects intensity and frequency

Identifies “islands” of effects,  
in a “sea” of null effects

## Frequency and magnetic-field strength combinations that influence calcium ion efflux from brain tissue in vitro



from Blackman  
Electromag Biol Med  
25: 217-225, 2006

# Review of Information

- **Two major features of EMF exposure**  
**Intensity**  
**Frequency**
- **“Non-linear” responses**
- **Responsible mechanism - unknown**
- **Present Standards IGNORE these responses**

# Reference Frame Chemical Comparisons

## EMF

- intensity
- frequency
- **DC magnetic field**
- electric / magnetic
- sine / pulsed

## Chemical / response

/ “windows”

/ “windows”

**co-factor**

**optical isomer**

**individual vs mixture**

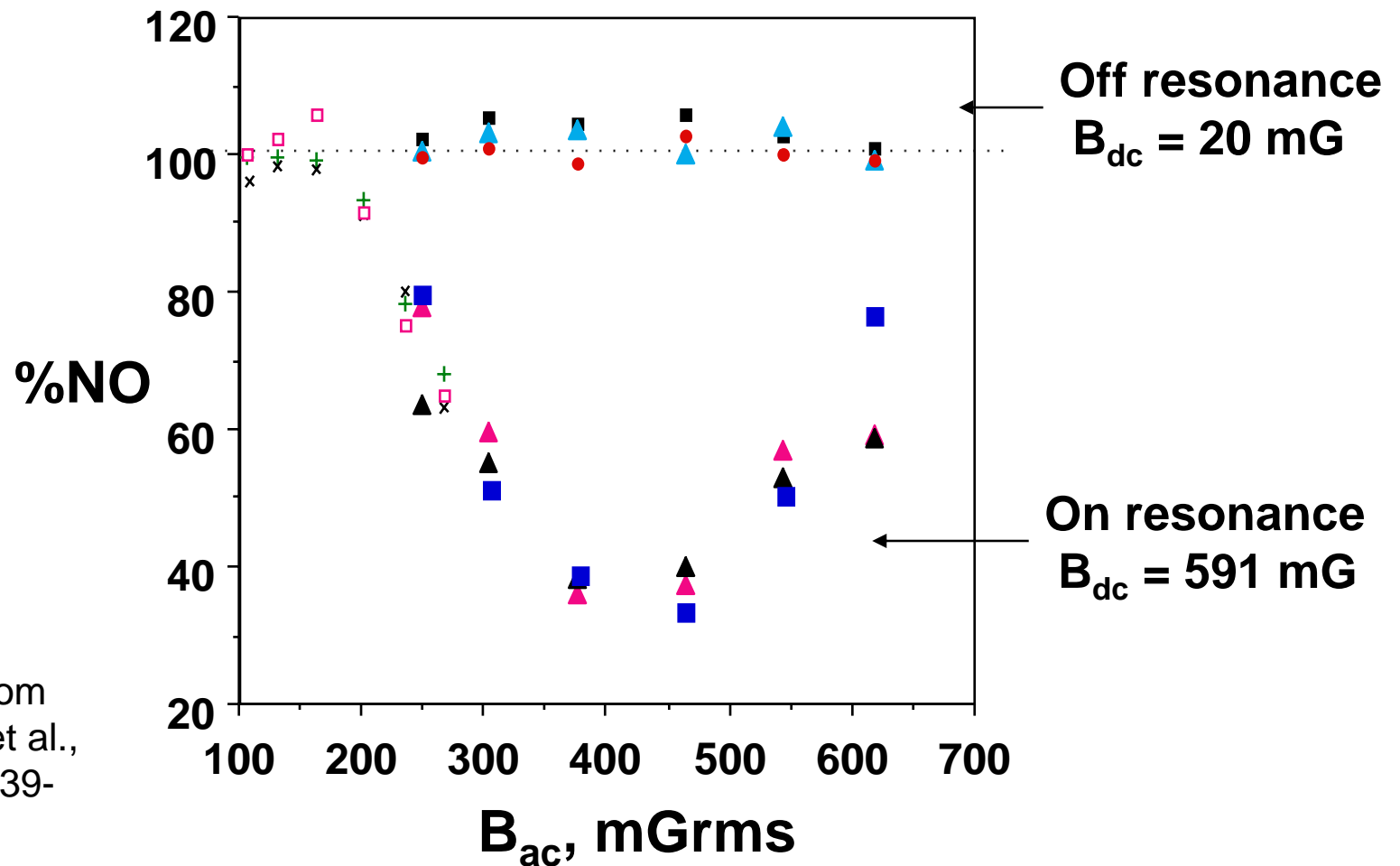
# EMF Parameter

## Static (DC) magnetic field

- Generated by the earth
- Analogous to a second chemical acting as a reaction co-factor
- Experimental results
  - static field intensity
  - orientation of static & AC magnetic fields

# Only Change DC Field

## Response of NGF-stimulated PC-12 cells On & Off Ca Resonance Conditions



compiled from  
Blackman et al.,  
BEMS 15:239-  
260, 1994

# Reference Frame Chemical Comparisons

## EMF

## Chemical / response

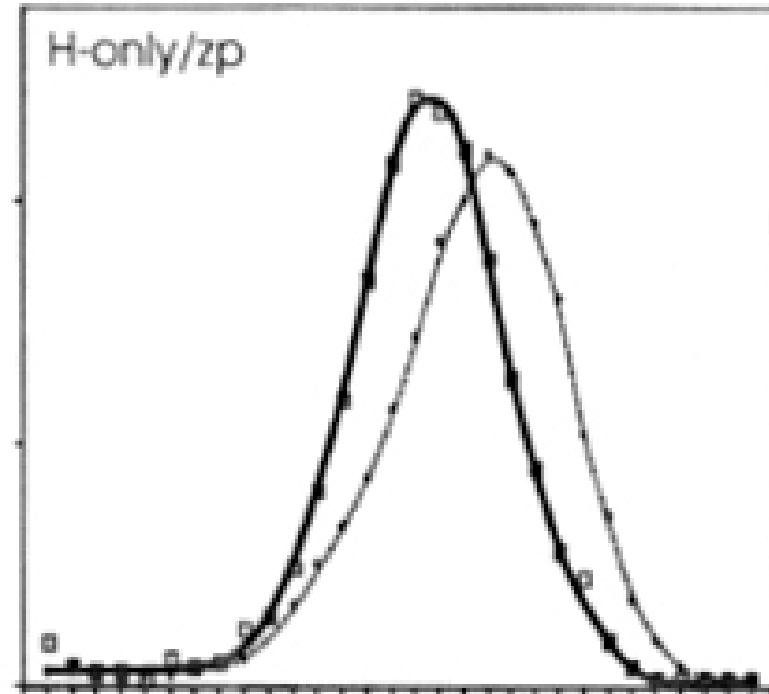
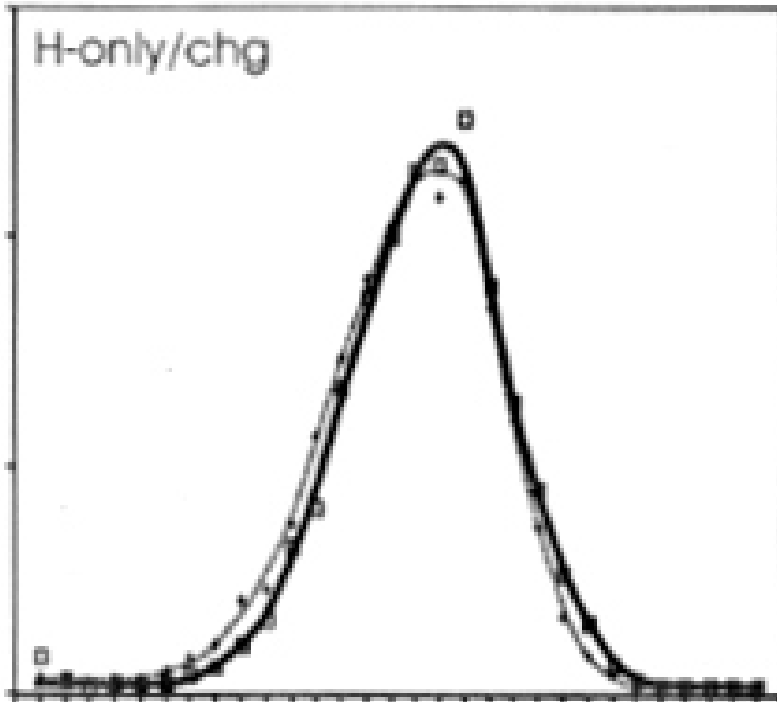
- **intensity** / “windows”
- **frequency** / “windows”
- **DC magnetic field** / selects frequency &
- **electric / magnetic** **optical isomer**
- **sine / pulsed** **individual vs mixture**

# Magnetic Field

0.1 mT<sub>rms</sub> (= 1 G), 60 Hz, 24 hr

Marron et al., FEBS Ltrs 230:13, 1988

Decrease in hydrophobicity



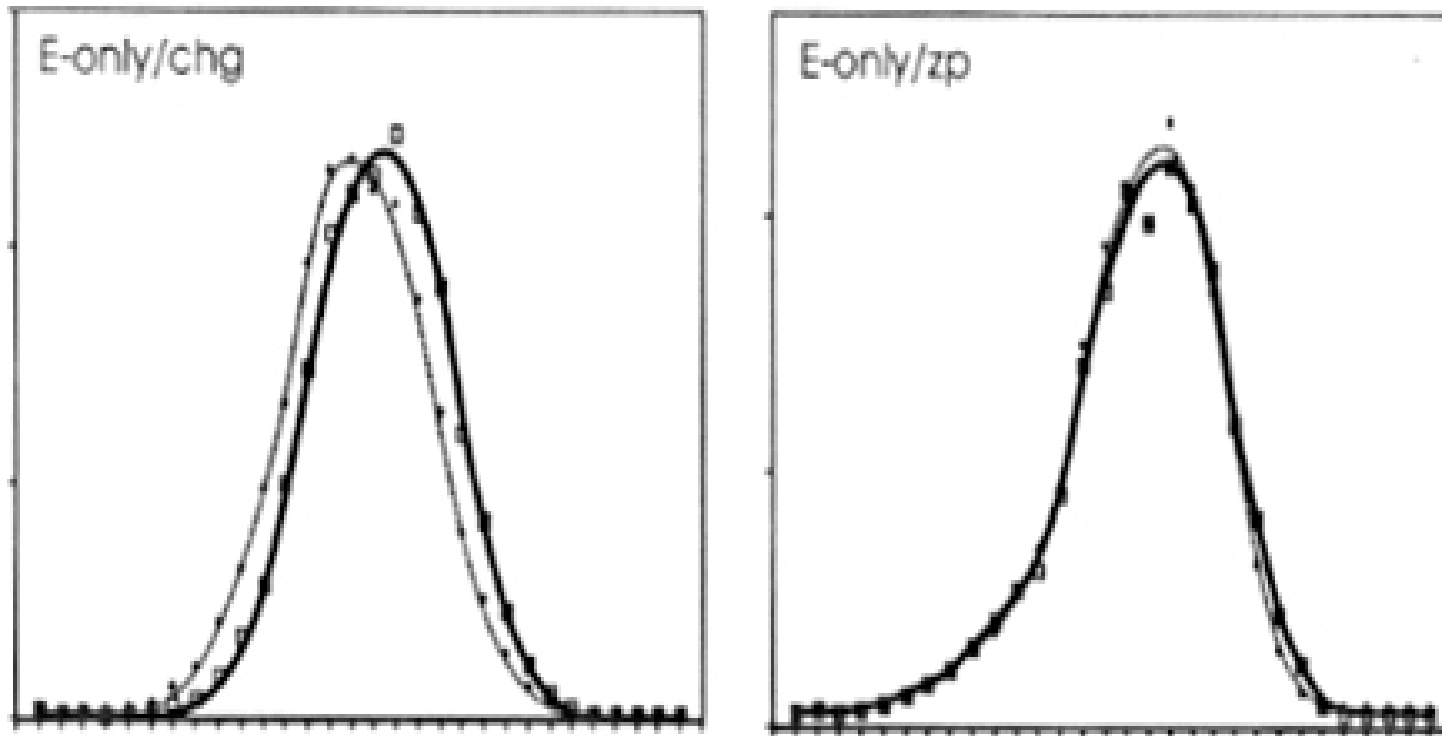
Ameobae, *Physarum polycephalum*

## Electric Field

1 V/m<sub>rms</sub> in solution, 60 Hz, 24 hr

Marron et al., FEBS Ltrs 230:13-16, 1988

Increase negative surface charge



Ameobae, *Physarum polycephalum*

# Electric versus Magnetic Fields effects on cells in culture

Electric fields

increase in negative charge density

Magnetic fields

reduce hydrophobic character

# Reference Frame

## Chemical Comparisons

### EMF

- **intensity**
- **frequency**
- **DC magnetic field**
- **electric / magnetic**
- **sine / pulsed**

### Chemical / response

- / **“windows”**
- / **“windows”**
- / **selects frequency &**
- / **charge vs hydrophobic**
- individual vs mixture**

# Factors for Pulsed Fields

- Frequency of pulses
  - Width of pulse
  - Intensity (height) of pulse
  - Rise and fall rates of pulse
- > Frequency within pulse

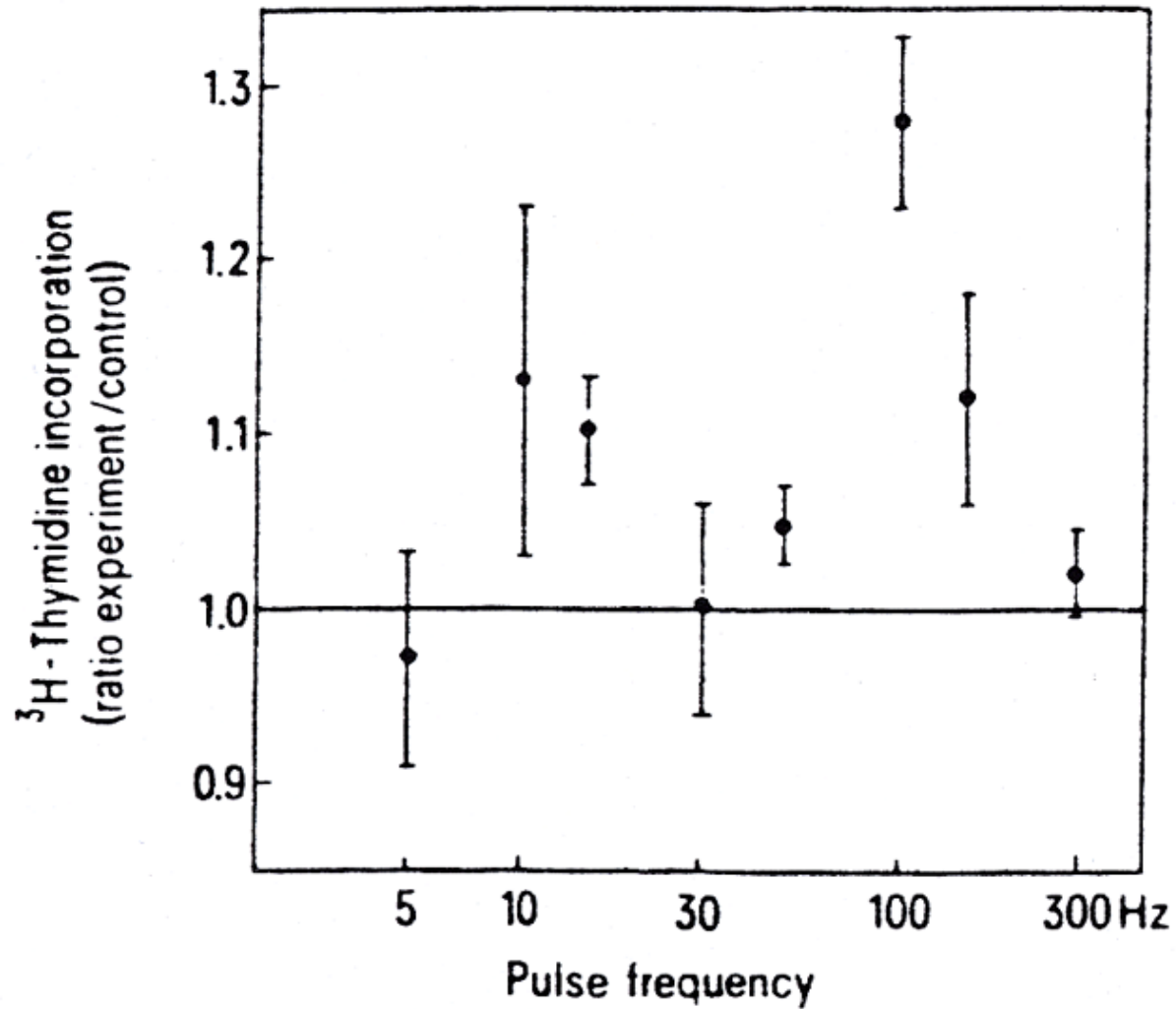
**ELF - pulsed signals**  
**(sum of sine waves)**

**Dedifferentiation - Chiabrera et al.**  
**amphibian RBC**

**Micro-nuclei - Scarfi et al.**  
**WBC from Turner's Syndrome patients**

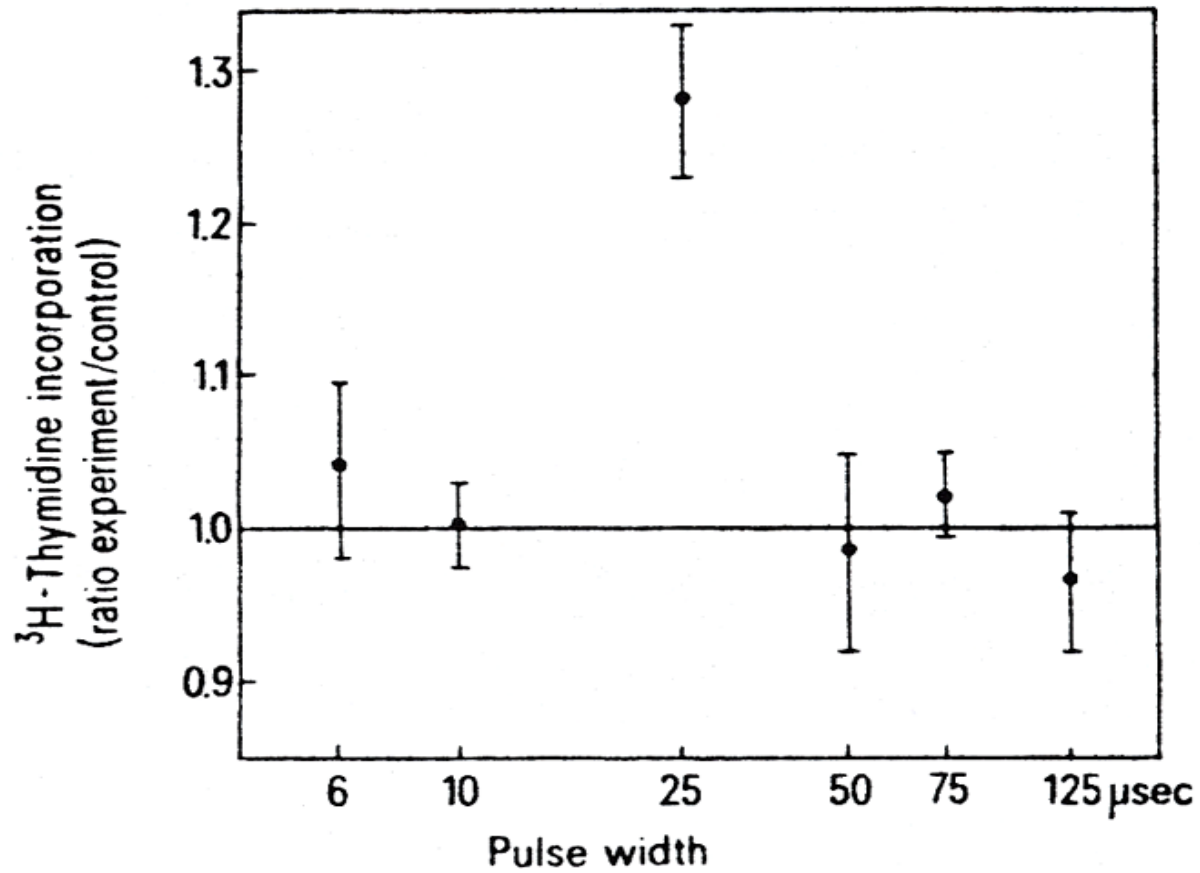
**DNA synthesis - Takahashi et al.**  
**Chinese hamster V-79 cells**

## Influence of frequency on DNA synthesis



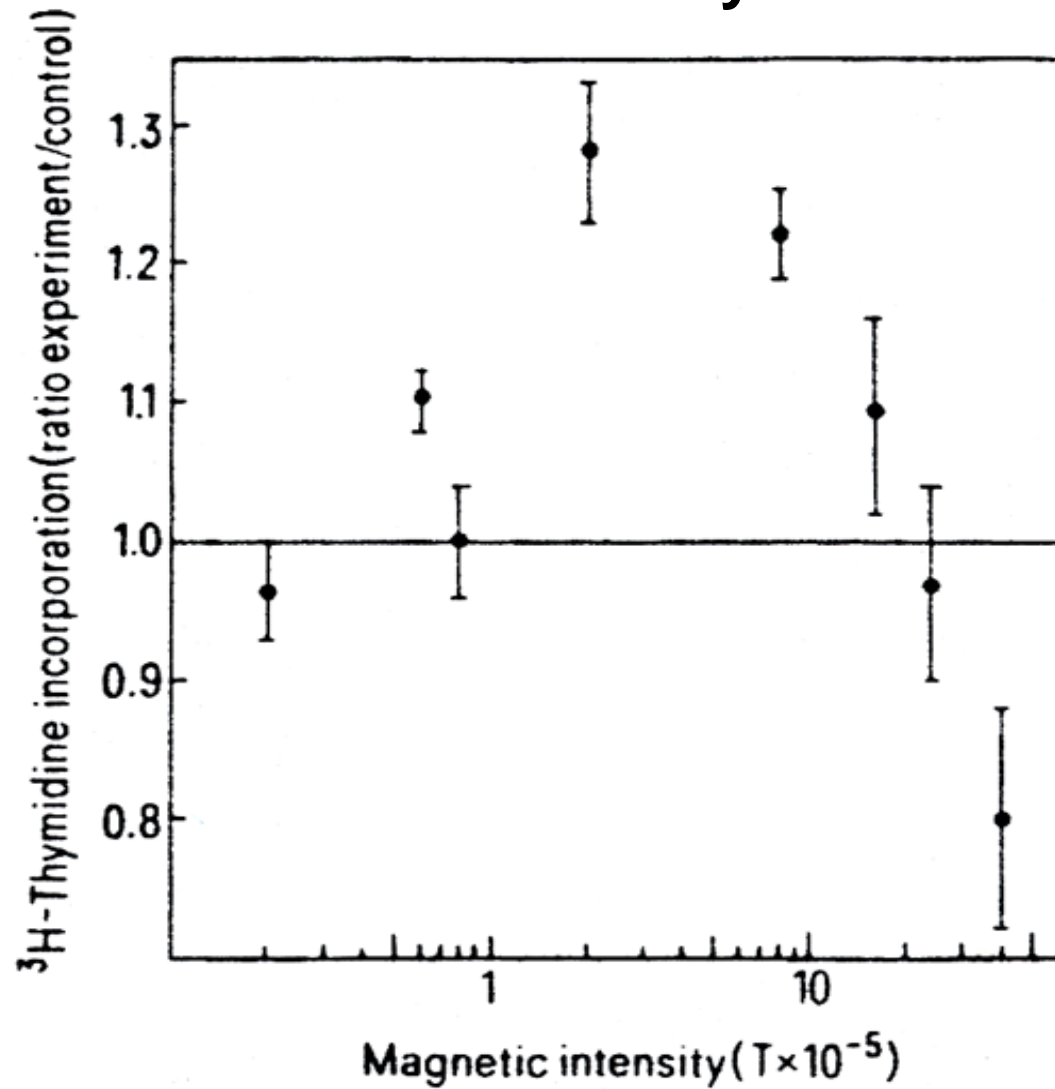
Takahashi et al., *Experientia* 42: 185-6, 1986

## Influence of pulse width on DNA synthesis



Takahashi et al., *Experientia* 42: 185-6, 1986

## Influence of intensity on DNA synthesis



Takahashi et al., *Experientia* 42: 185-6, 1986

# Reference Frame Chemical Comparisons

## EMF

- **intensity**
- **frequency**
- **DC magnetic field**
- **electric / magnetic**
- **sine / pulsed**
- **Physiology**

## Chemical / response

**/ “windows”**  
**/ “windows”**  
**/ selects frequency &**  
**/ charge / hydrophobic**  
**/ multiple “windows”**  
**metabolism & inherent**  
**instability**

# Contributions from Biology

## two examples

- **Metabolism**
- **Endpoint measurements**

# Fundamental Model

Chiabrera et al., *Bioelectromagnetics* 21:312, 2000

- Examines interaction between ion and protein
- Applicable from DC to microwave frequencies
- Includes influence of thermal energy
- Demonstrates critical role for metabolism
- Implications
  - Possibility of low intensity effects

# Involvement of Biological Factors

## an example

- **Physiological State**
  - metabolism rate
  - age - young, old, pregnant
  - susceptibility - polymorphisms**
  - chemical or disease co-insult
- **Measurement of biological response**
  - including nonlinear determinism

# New Approach to Analysis

- **Standard analyses -**
  - **Uses averages of exposed & control groups**
- **Marino demonstrated a new analysis**
  - **Few reports noted changes in nonlinear determinism**
  - **Has potential to alter analytical approaches**

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**Conclusion -> there is much that remains to be explained in EMF biological effects research**

# Measure of EMF Effect in Dynamical Systems - Nonlinear Determinism

## Publications - Marino & colleagues

Marino et al., Am J Physiol Regul Integ Comp Physiol 279:R761, 2000; Immun Invest 30:313, 2001; BEMS 22:529, 2001 & 24:339, 2003; Neuroimmunomod 9:65, 2001; Clin Neurophys 115:1195, 2004; Physiol & Behav 79:803, 2003; Brain Res 964:317, 2003

Carrubba et al., J Neurosci Methods 157:39, 2006 & 173:356, 2007 & 173:41, 2008; Neurosci Ltrs 417:212, 2007; Neurosci 144:356, 2007; Neurosci Res 60:95, 2008

# Human Responses to Cell Phone Frequencies (1998-2000)

- Preece et al.
  - 915 MHz (IJRB 75:447, 1999)
  - Reduced reaction time during exposure
  - 50 Hz (IJRB 74:463, 1998)
  - Temporary deterioration in attention
- Koivisto et al.
  - 902 MHz (Neuroreport 11:414 & 761, 2000)
  - Reduced response time to simple tasks
  - Altered EEG during a memory task
- Freude et al.
  - Cell phone frequency (Eur J Appl Physiol 81:18, 2000)
  - Decrease in slow brain potential during a visual monitoring task

# Conclusions from Lab Results

In Vitro results do **NOT** demonstrate health risks  
however, results do demonstrate:

Cautious when evaluate exposure scenarios  
-> exact EMF exposure conditions are critical

Physiological state of cells is very important  
-> location in cycle (seconds to days)

Can use in vitro findings to identify exposure  
parameters to examine in vivo

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Do **NOT** treat EMF as a single chemical

# Bioinitiative Report

[www.BioInitiative.org](http://www.BioInitiative.org) Aug 2007

Pathophysiology 2009 Mar 3 epub

# Conclusions/Recommendations

- Reduce the funding for epidemiological studies
  - Epi studies can't address the complexity of exposure parameters
  - Fund laboratory studies: in vitro, in vivo, human, mechanistic models
- Support research through unbiased awarding of grants
  - Firewalls between funding sources and decision makers
  - Situate funding sources to compete to fund the 'best' research
- Research should use
  - EMF signals with information-content (modulation)
  - Biological assays that are known to respond to such signals
- Educate the public and regulatory communities about complexities in exposure conditions
- Help industry design safer EMF-emitting products
  - Analogy: the auto is hazardous, but it & its use has been made safer

**The End**