Nonlinearity in Biological Systems: How Can Physics Help?

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Summary

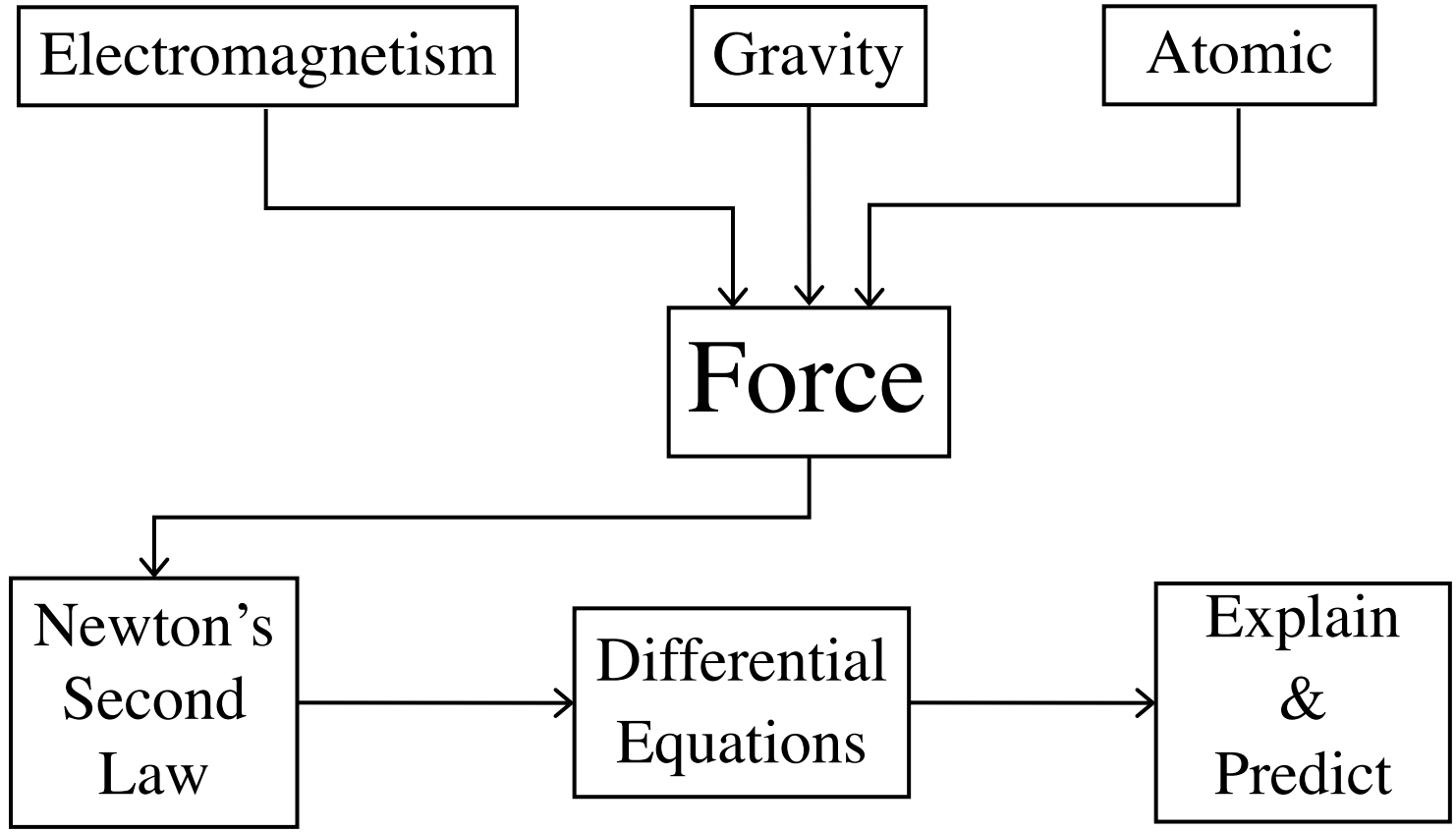
Biological systems → Nonlinear

20th century physics (basic laws that explain and predict) → Not useful in biology

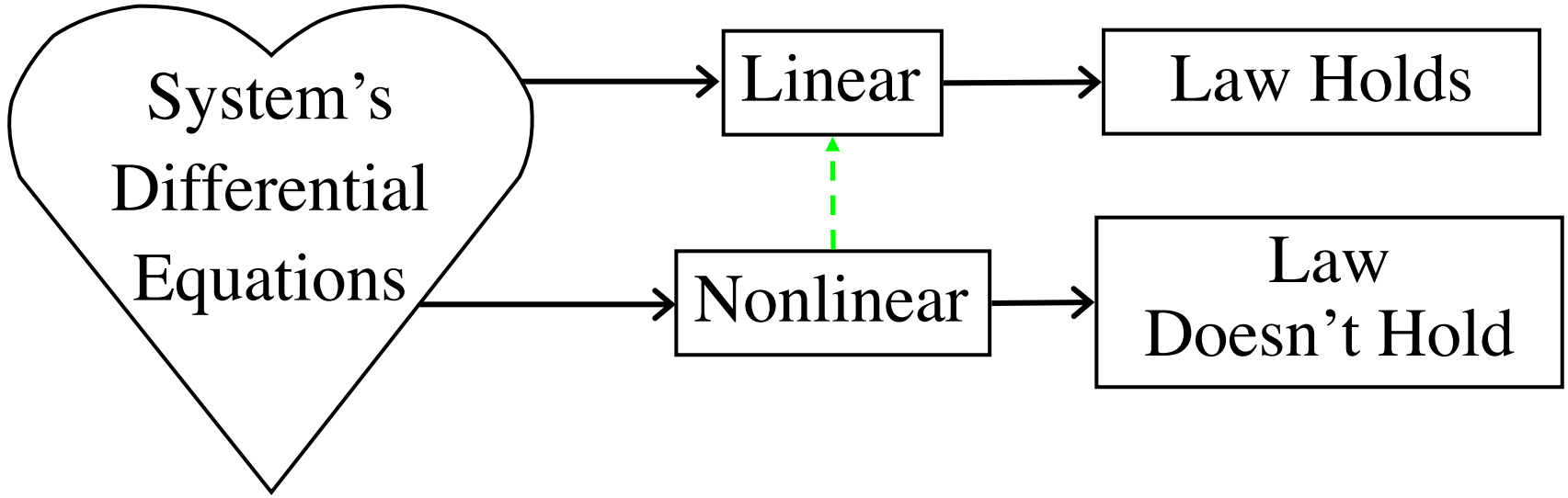
Present-day physics role: →
- Dynamical activity
- Numbers
- Descriptive models
- Probabilistic predictions

http://andrewamarino.com

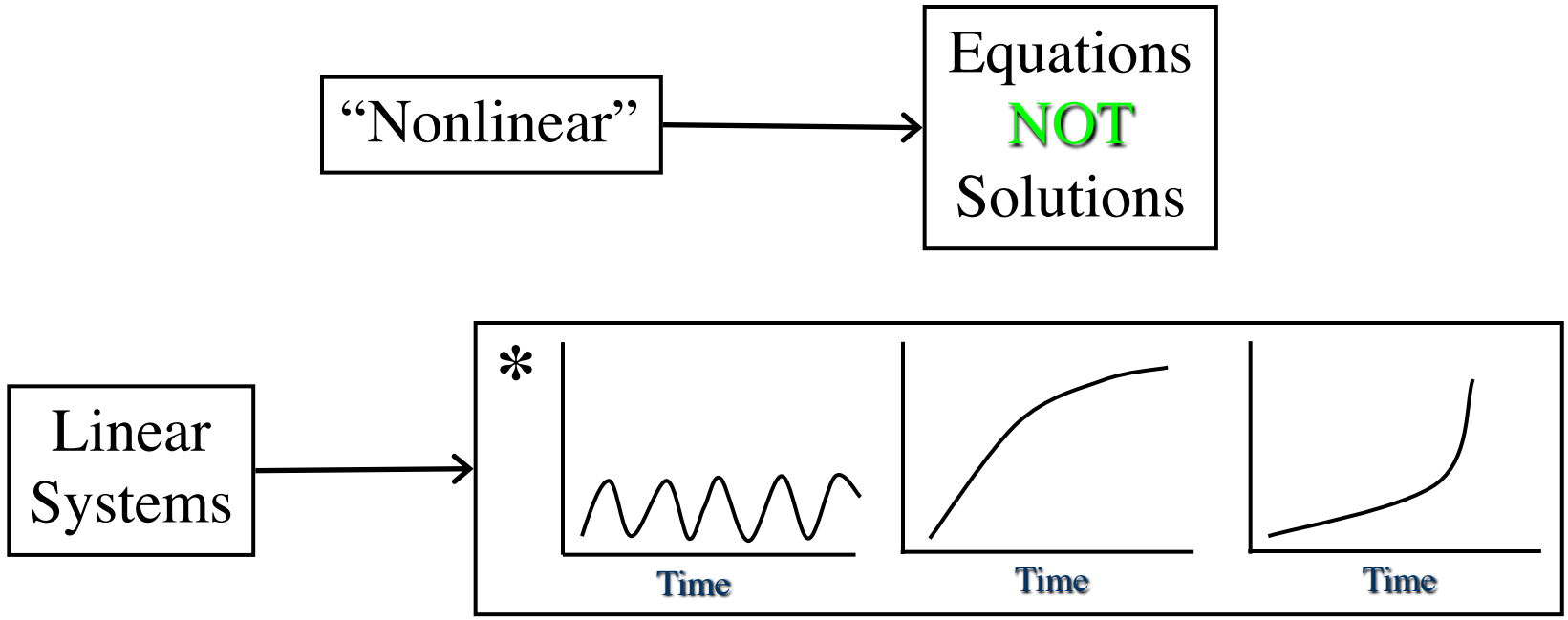
The Physical View of the World



Law of Superposition

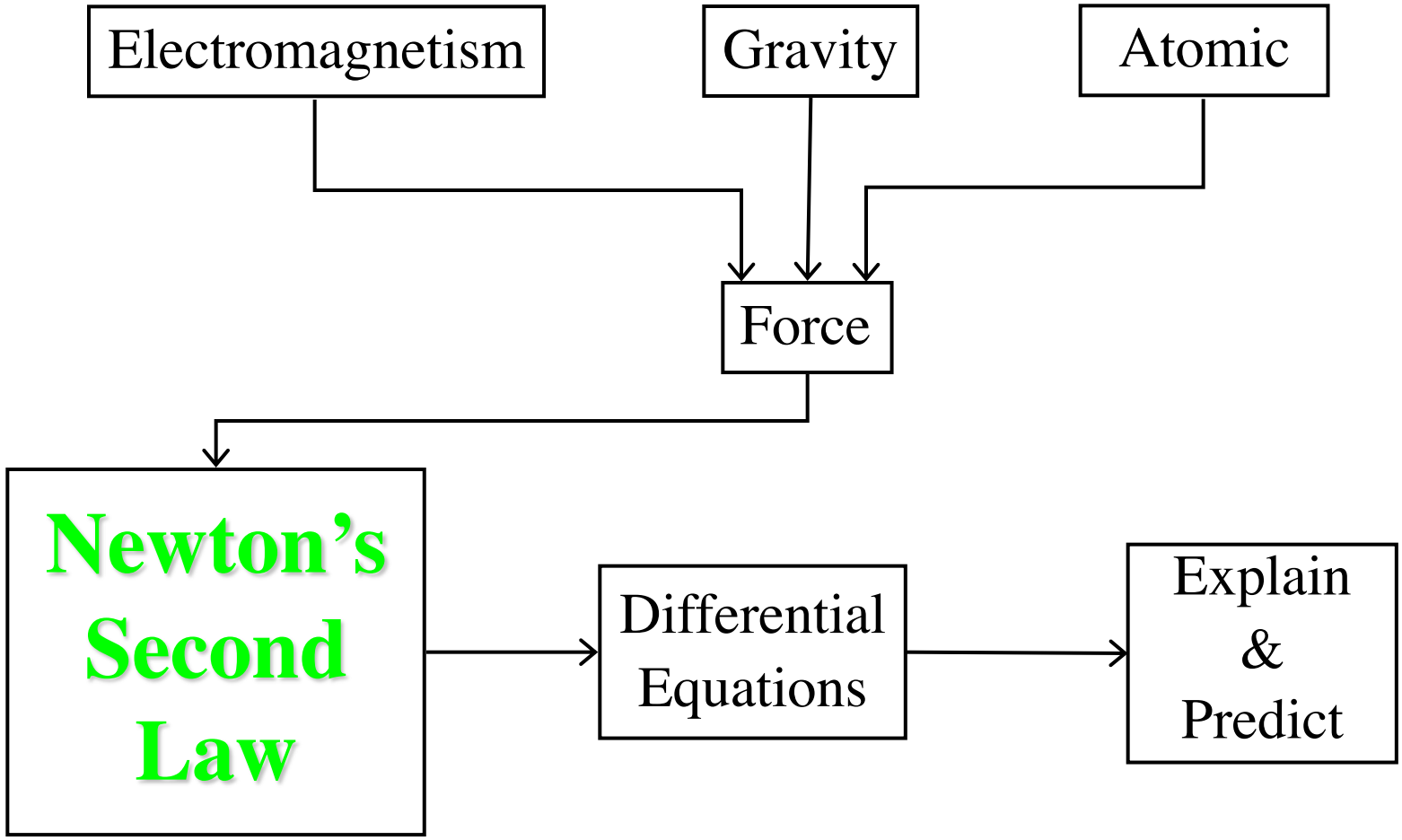


Terminology



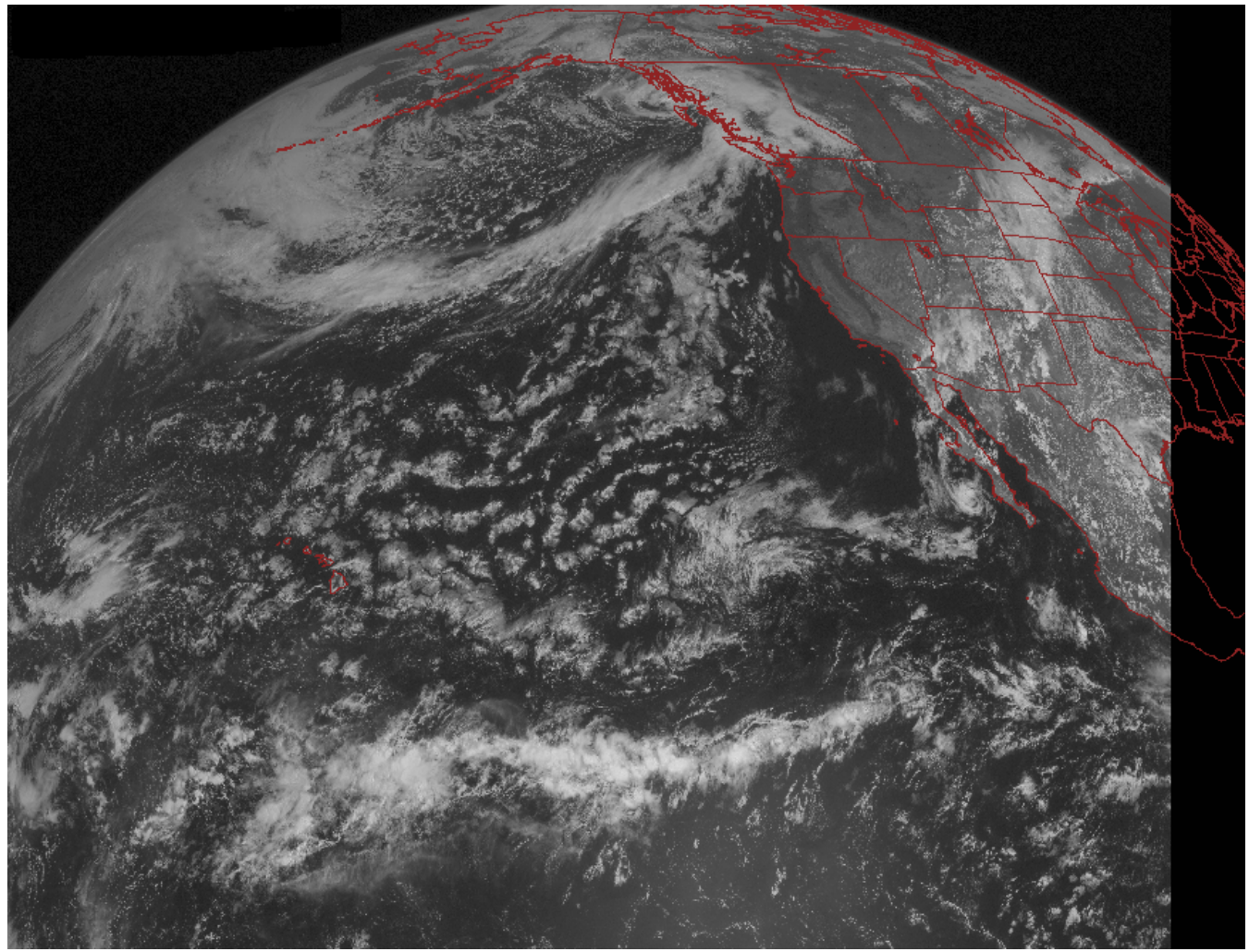
*"Algebraic" Nonlinearity

Where Nonlinearity Comes From



Great Utility of Linear Systems

A Natural Nonlinear System



The Lorenz Equations

Simplified Model of Thermal Convection

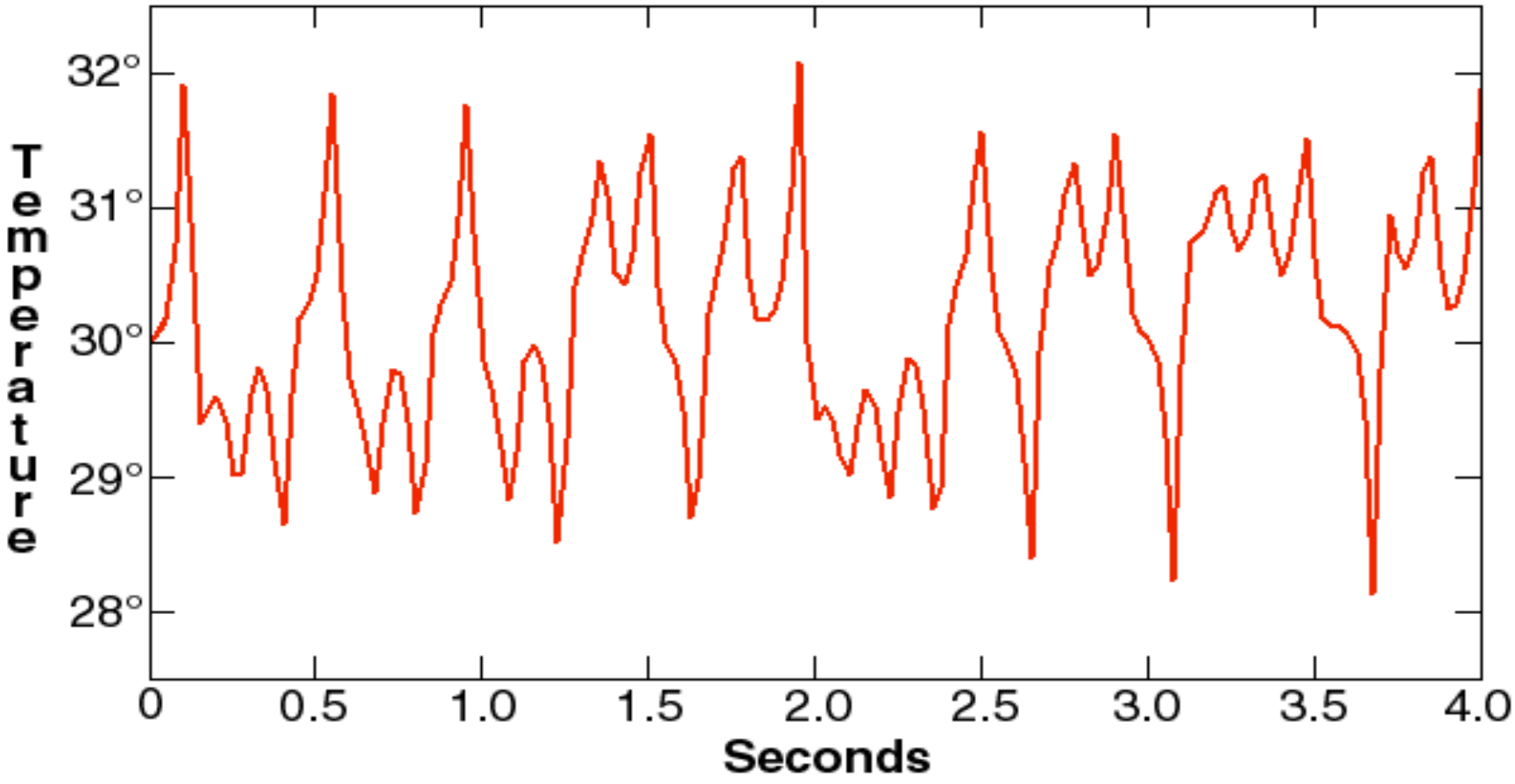
$$\frac{dx}{dt} = sy - sx$$

$$\frac{dy}{dt} = -xz + rx - y$$

$$\frac{dz}{dt} = xy - bz$$

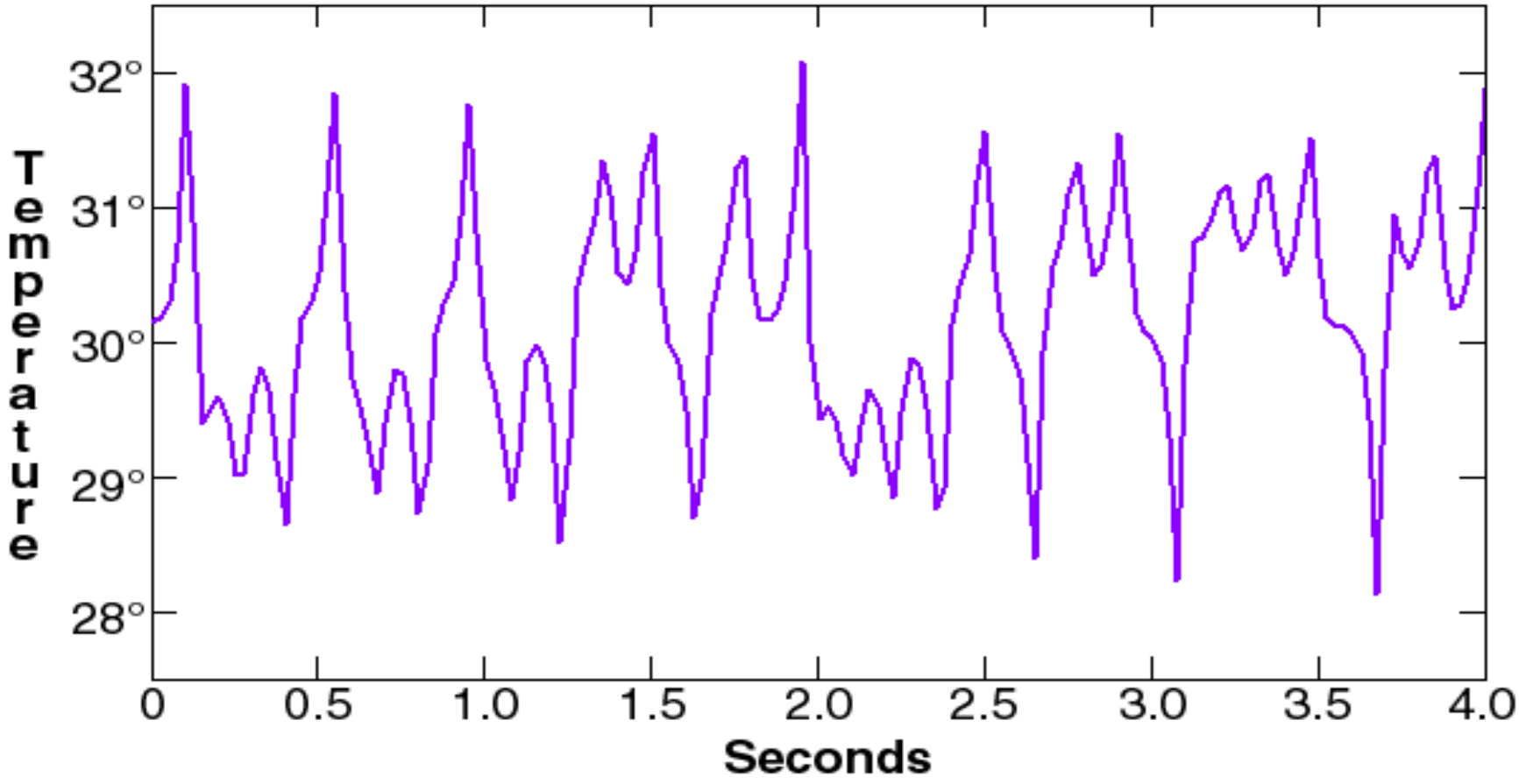
Sensitivity to Initial Conditions

Initial Temperature =



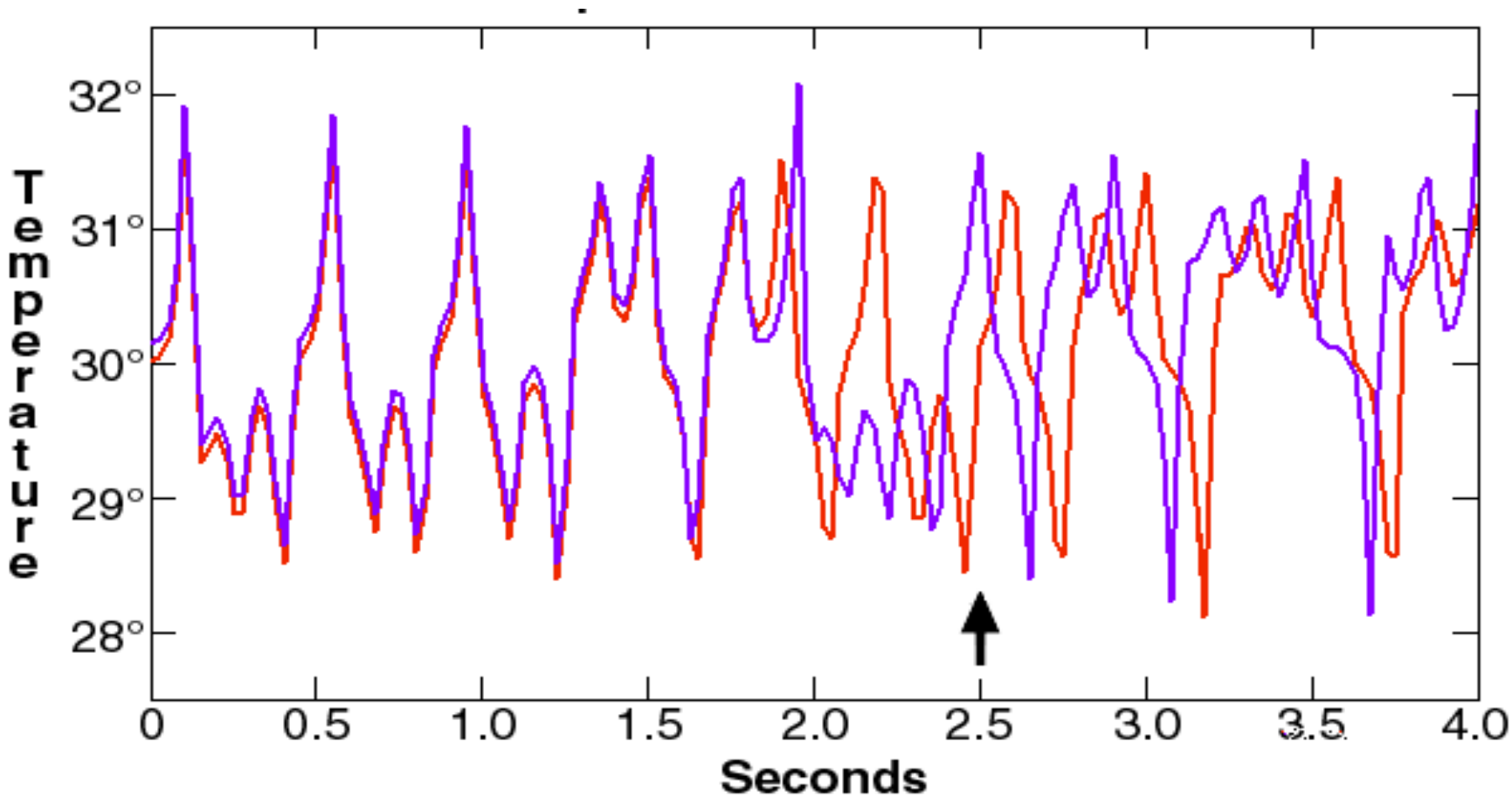
Sensitivity to Initial Conditions

Initial Temperature = 30.000001° C

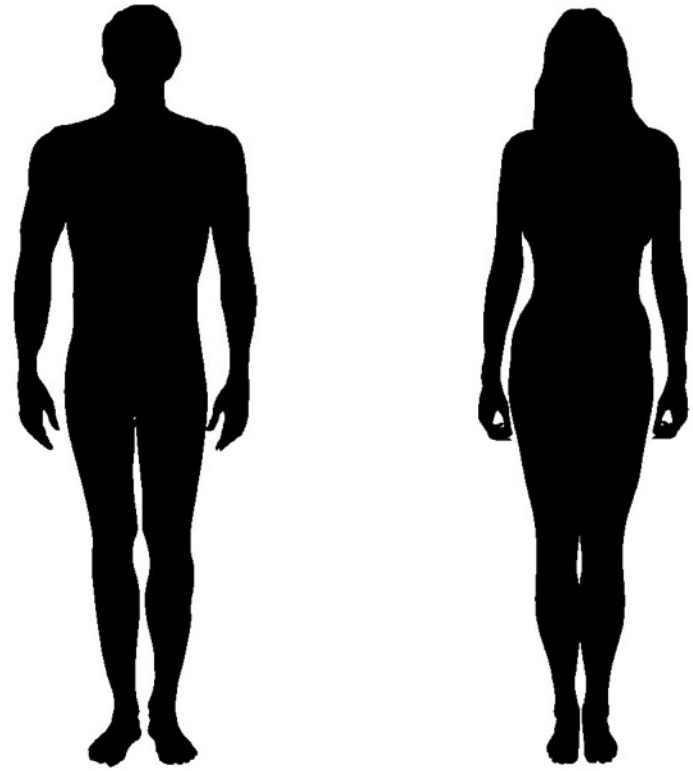


Sensitivity to Initial Conditions

At 2.5 seconds: 28.5° C 31.5° C

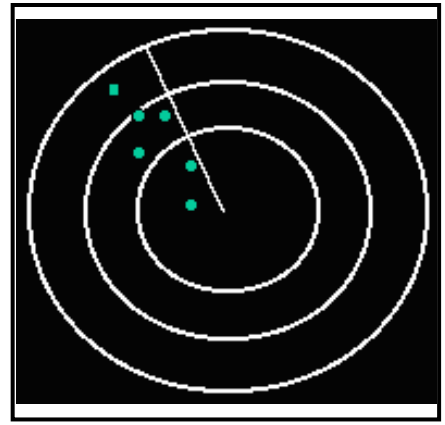


What Hypothesis?

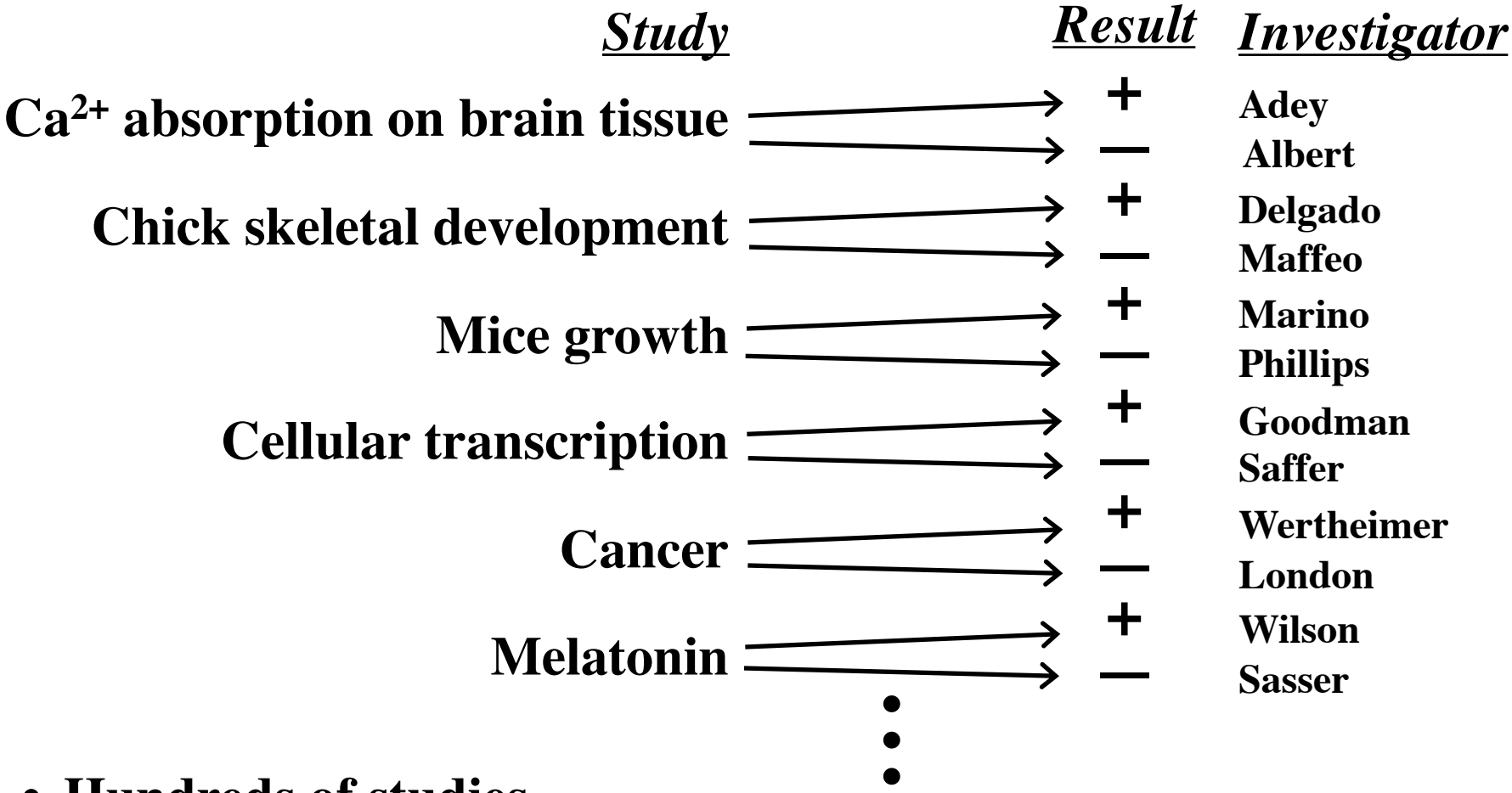


A Particular Case

Health Hazards from Electromagnetic Fields in the Environment

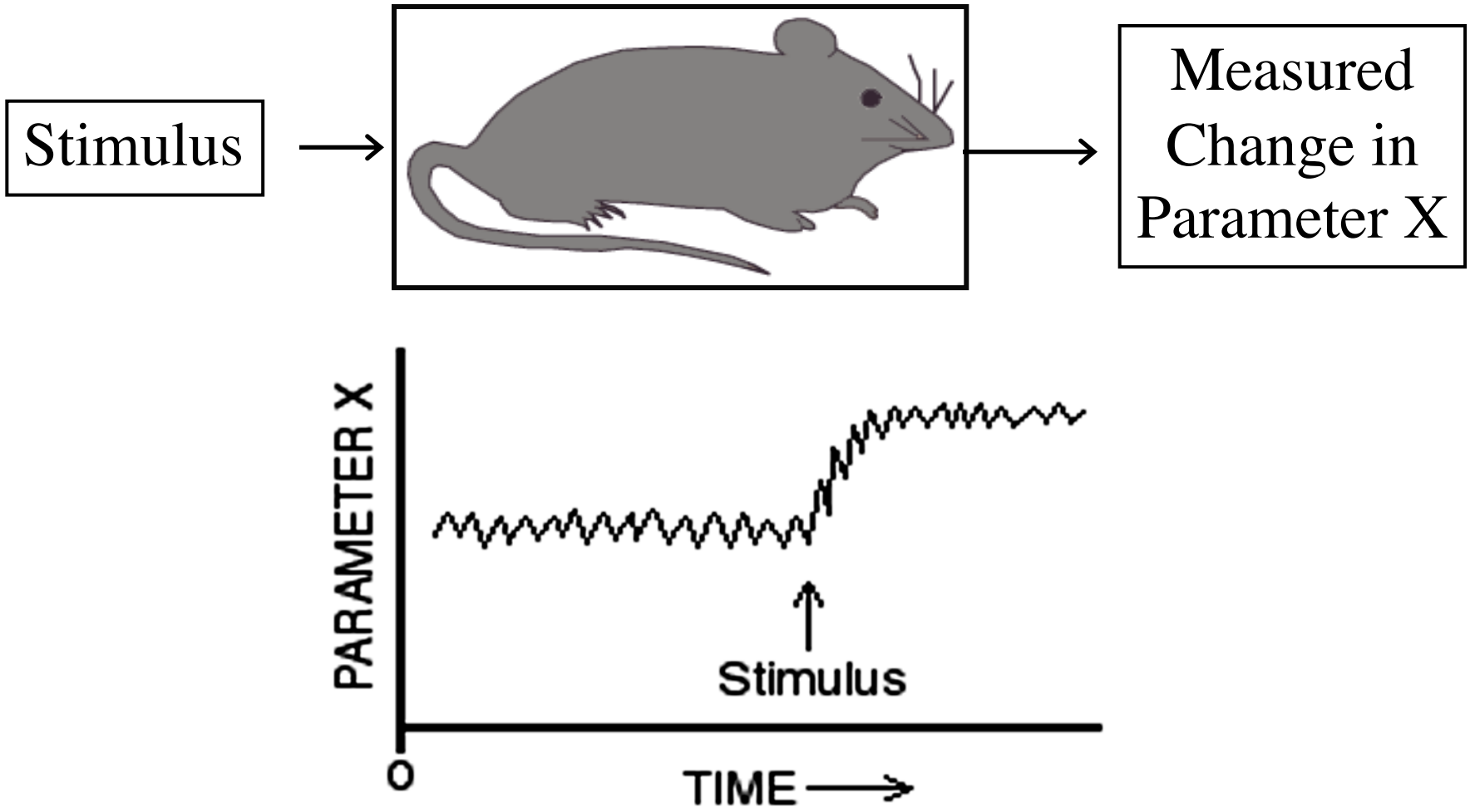


Laboratory Studies of the Biological Effects of EMFs

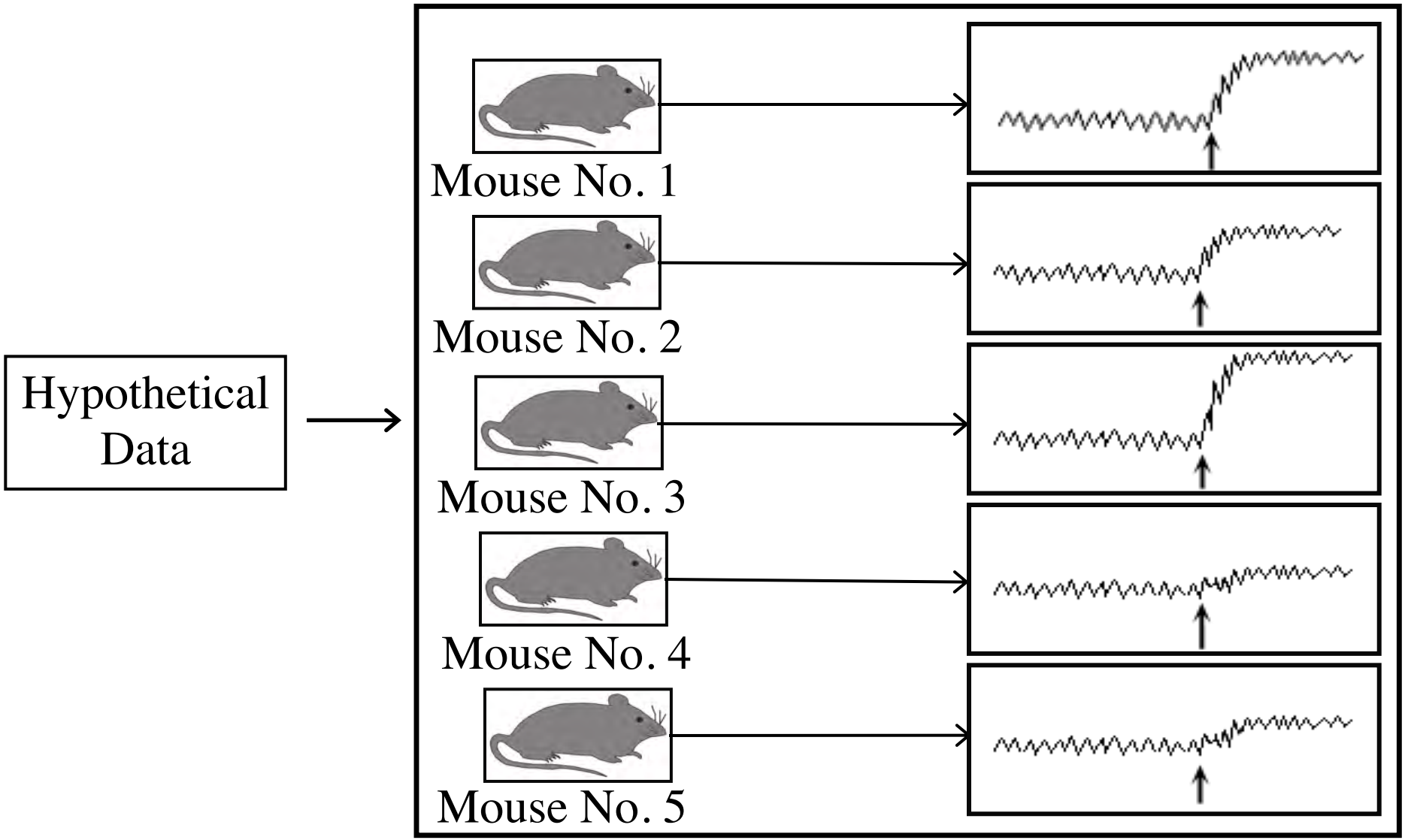


- **Hundreds of studies**
- **No exceptions to this pattern**

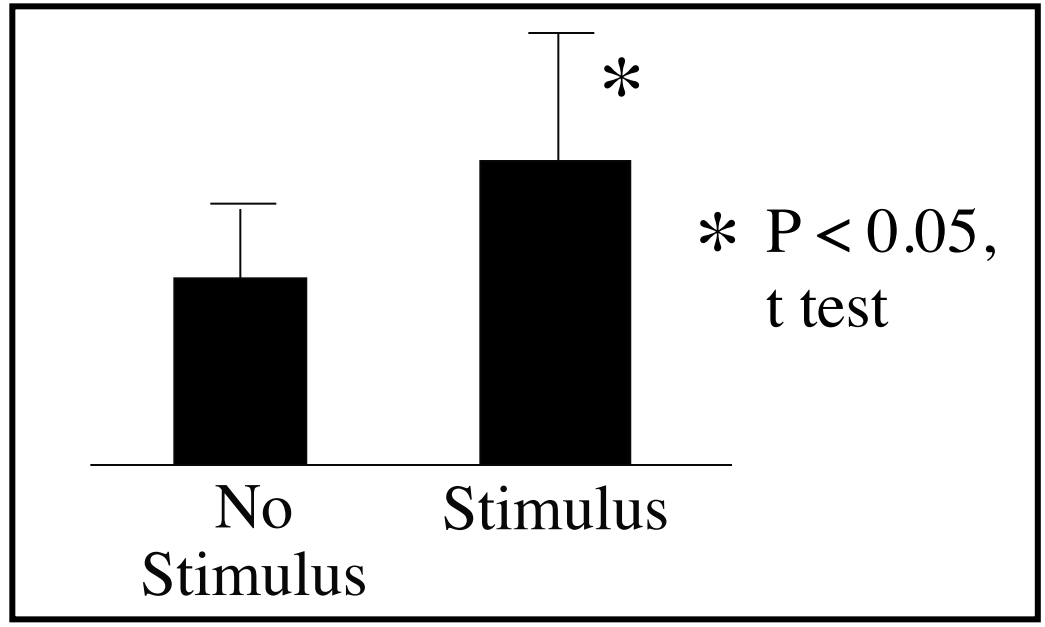
Models and Measurements



Linear Model

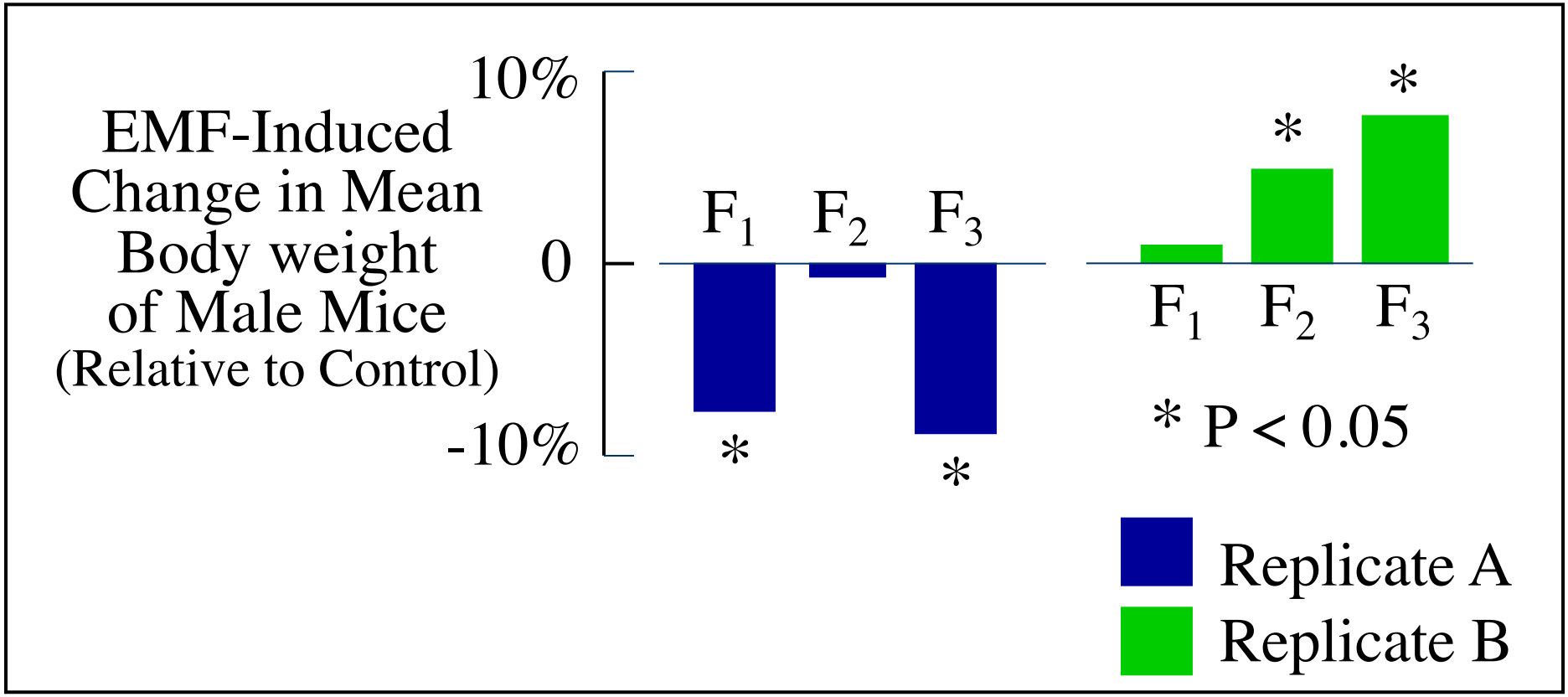


Linear Model



A Representative Case

The Effect of Power-Frequency EMFs on the Growth of Mice



Data from Pacific Northwest Laboratories

Thermal Noise Argument*

Thermal noise in cell membranes $\rightarrow \Delta V_m \approx 30\ \mu V$ (at 37° C)

Environmental EMFs $\rightarrow \Delta V_m << 30\ \mu V$

$\Downarrow$

Cells can't detect EMFs

* Science 247:459, 1990.

Press Release

The American Physical Society

WASHINGTON OFFICE

April 1995

… research … failed to substantiate those studies which have reported specific adverse health effects.

… No plausible biophysical mechanisms.

…(no) consistent, significant, and causal relationship.

…conjectures … not scientifically substantiated.

Physicist Nobel Laureates

Nicolaas Bloembergen
Allan Cormack
Walter Gilbert
Sheldon Lee Glashow
Glenn T. Seaborg
Rosalyin Yalow

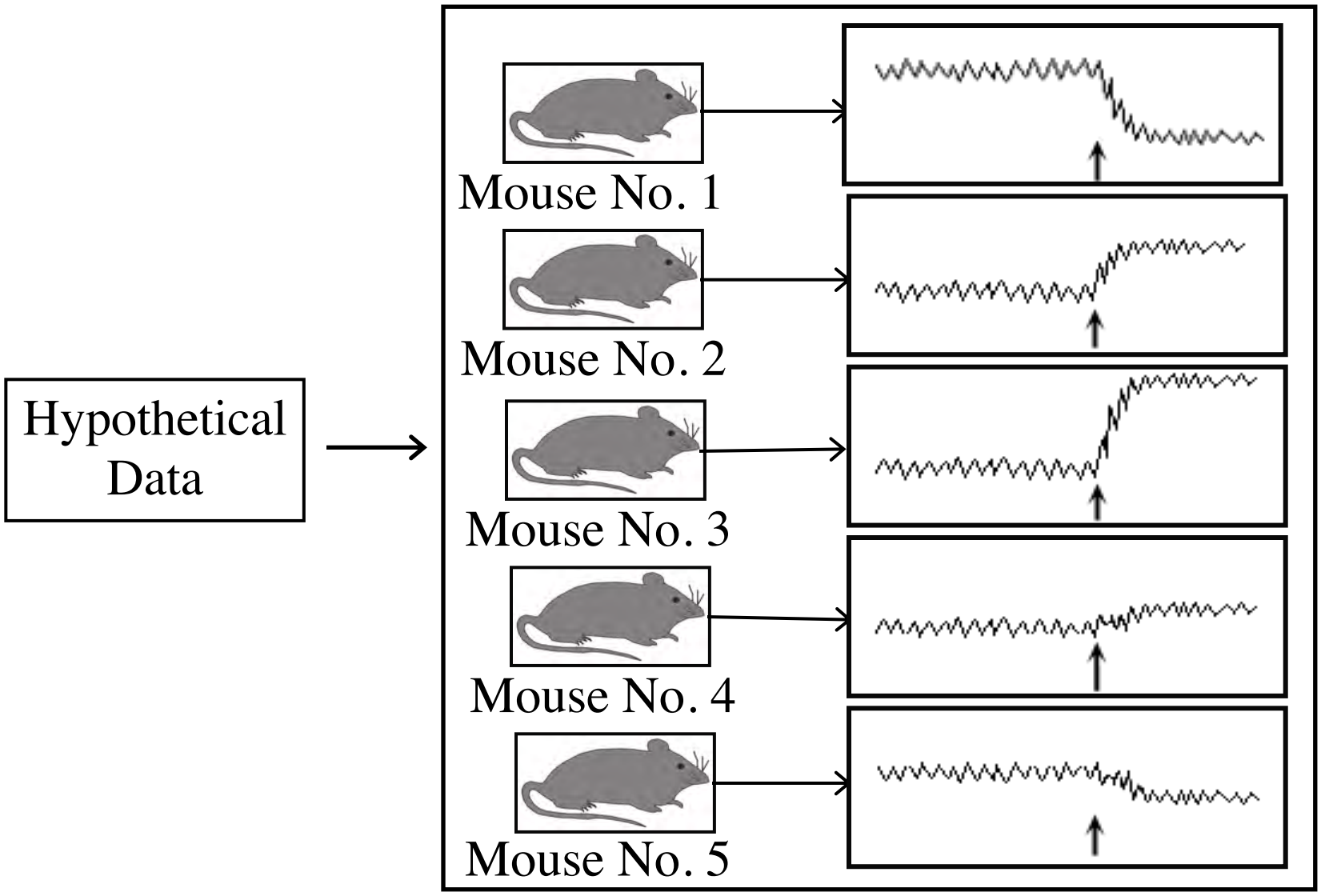
… “(no) mechanisms (for) EMFs to interact with tissue which do not violate the laws of electromagnetism and thermodynamics”

… “no serious danger”

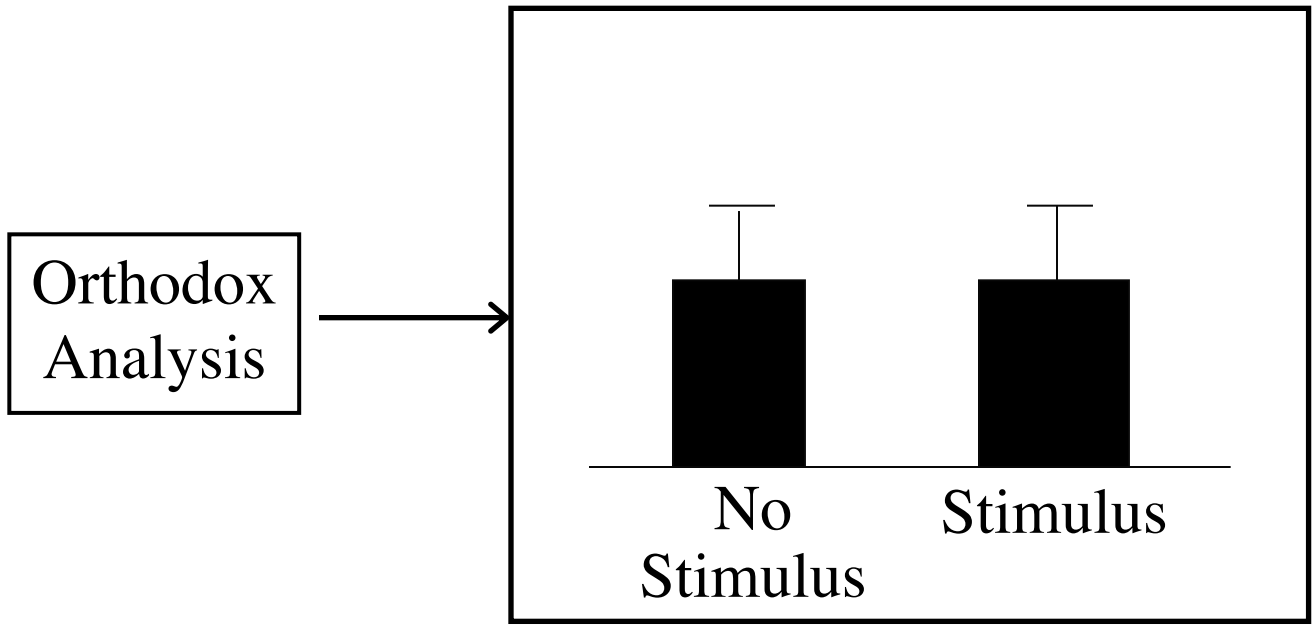
… “no convincing evidence”

… “not scientifically reasonable to believe that EMFs (cause) cancer”

Nonlinear Model



Nonlinear Model



Study of Nonlinearity in the Immune System

Nonlinear Response of the Immune System

*Summary of Four Experiments

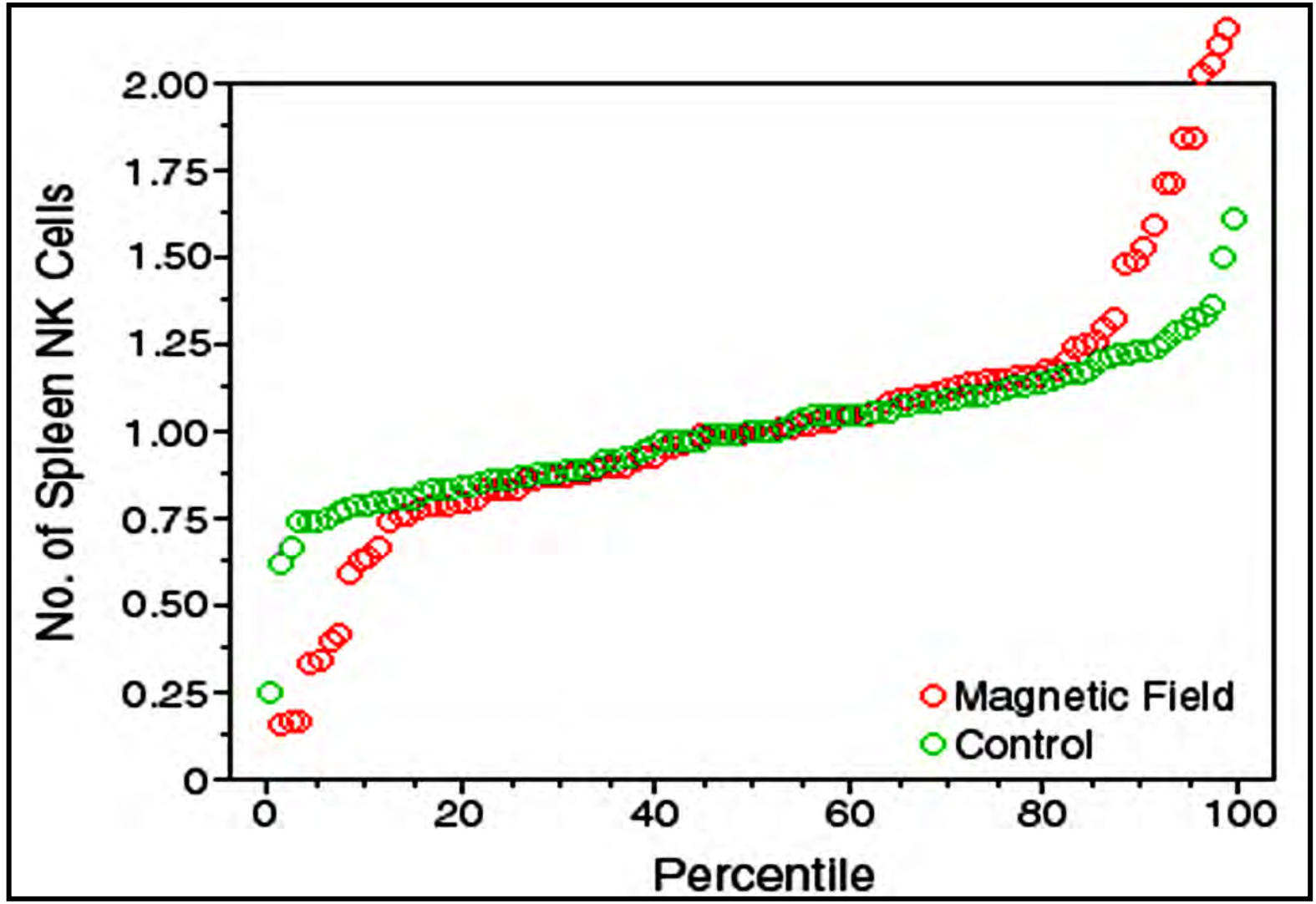
EMFs → 1 and 5 G, 60 Hz
Exposure duration: 1→175 days
Immune parameters: 20, measured in each mouse

Assumed Model	Statistical Test	Result
Nonlinear	"L test"	**+, +, +, +**
Linear	t-test	**−, −, −, −**

Nature of the Effect

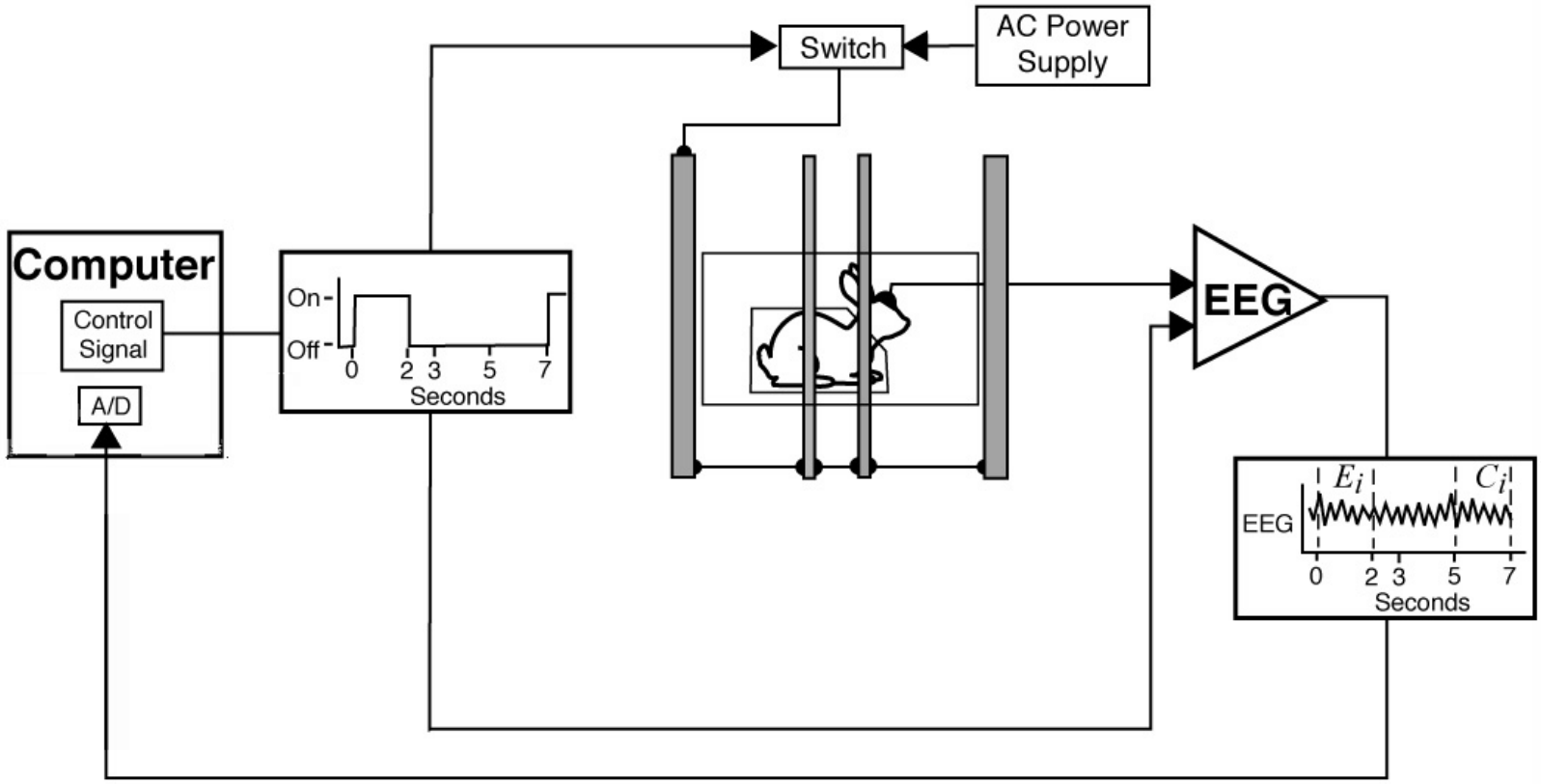
*Am. J. Physiol. R761, 2000; BEMS 529, 2001; Neuroimmunomodulation 65, 2001; Immunol. Invest. 313, 2001.

Natural Killer Cells in Mice

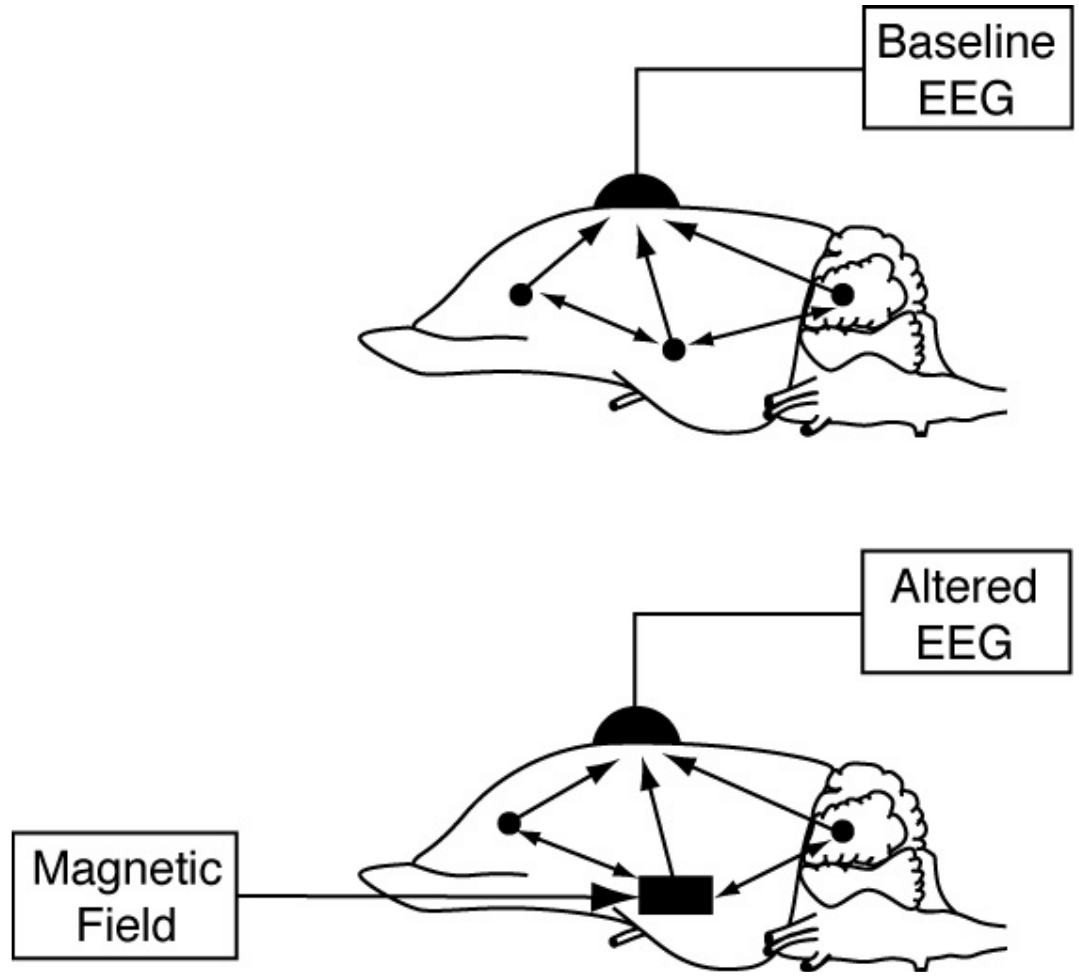


Analysis of Time-Series Data

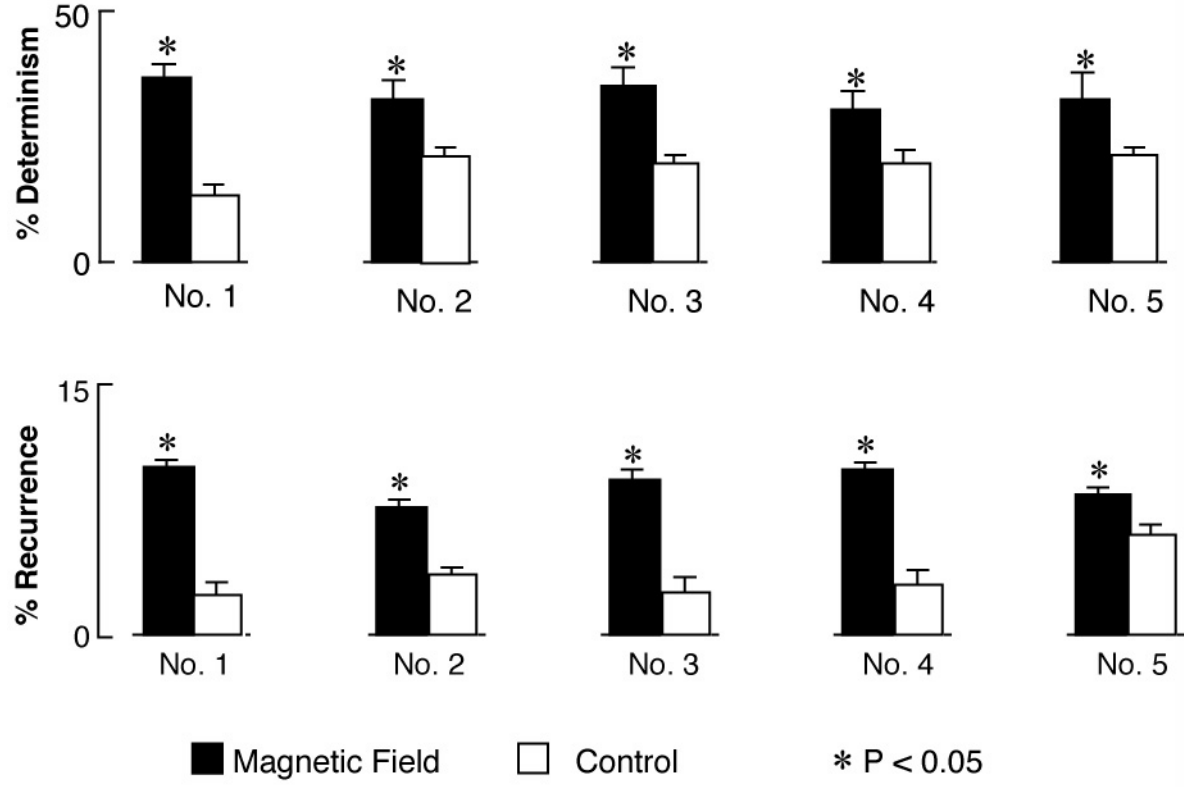
System for Studying Nonlinearity in Brain Electrical Activity



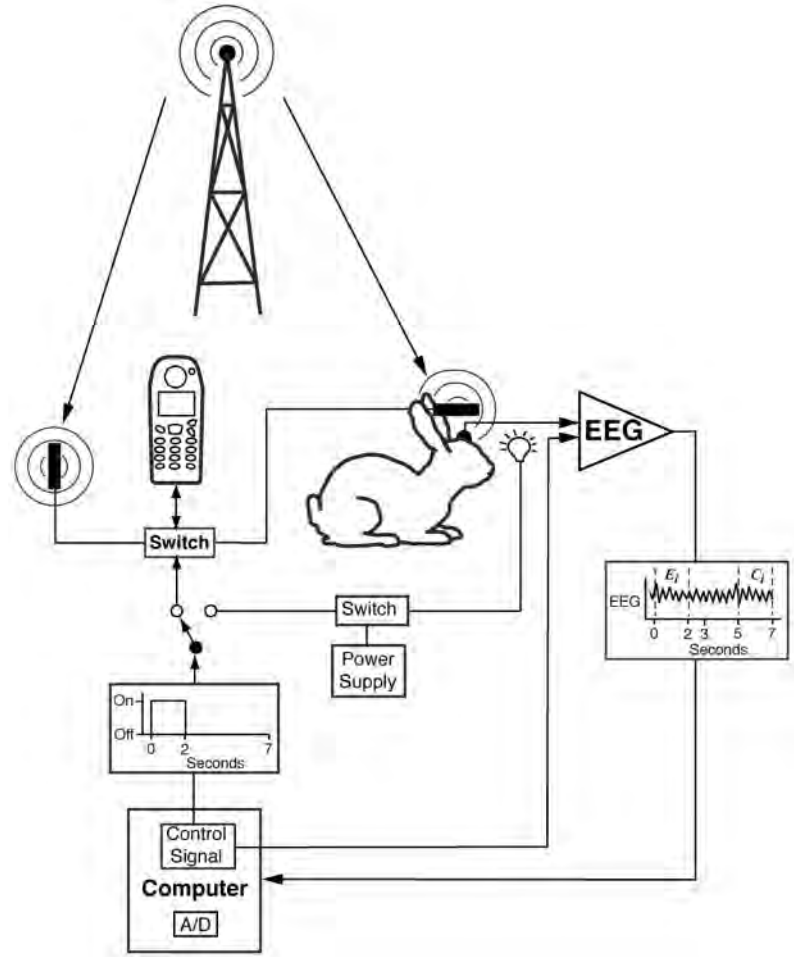
Study Hypothesis: The Complexity Conjecture



Effect of 2.5 G, 60 Hz on the EEG from Five Rabbits, Assessed using Nonlinear Quantifiers

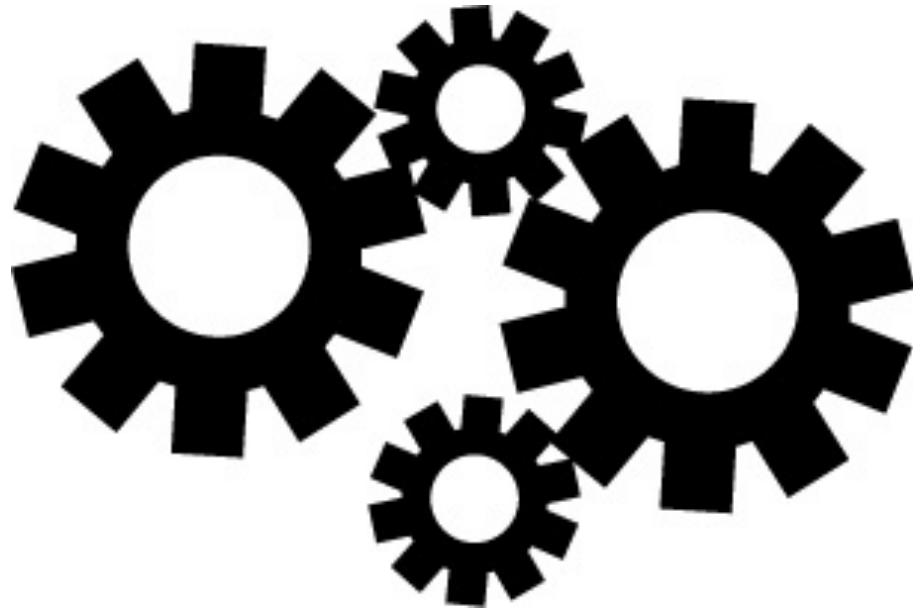


Apparatus for Studying the Effect of Cell Phone Fields on the Rabbit EEG



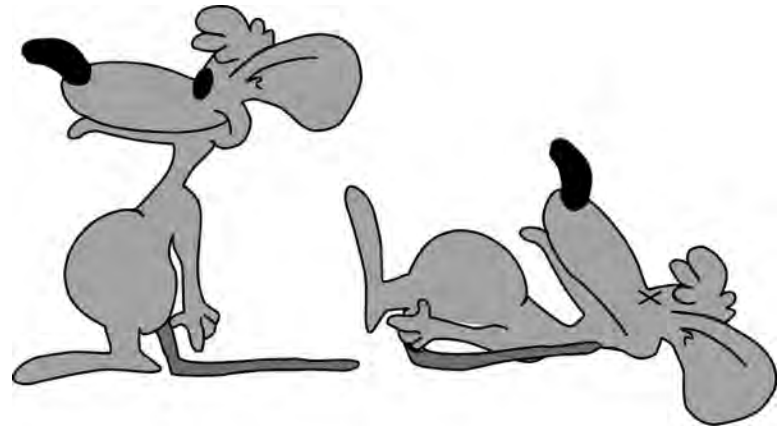
Summary of Physical Systems

- **Fundamental laws linear**
- **Linear mechanical models**
- **Reductionism**
- **Certainty**



Summary of Biological Systems

- **Empirical dynamical laws**
- **Nonlinear models**
- **Emergent properties**
- **“Probability”**



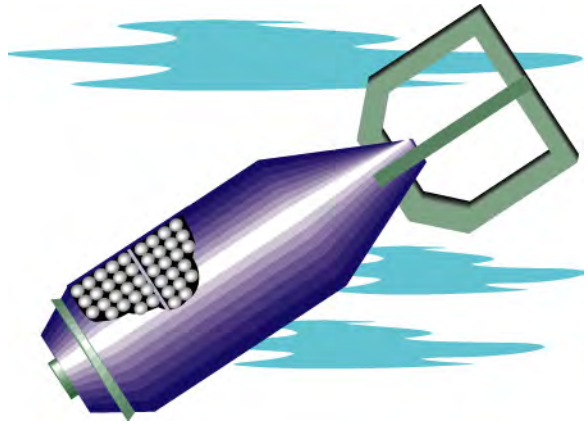
Alive Dead

Biological "Probability"

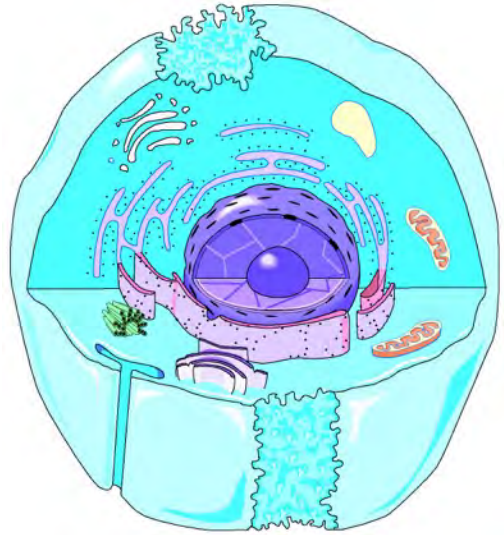
- Not like statistical laws (pressure, temperature)
- Not like Schrodinger's equation (which is linear)
- Fundamental ungoverned uncertainty (predict better than a guess)

Alice falling down
the rabbit hole

Living and Nonliving Objects Differ Fundamentally

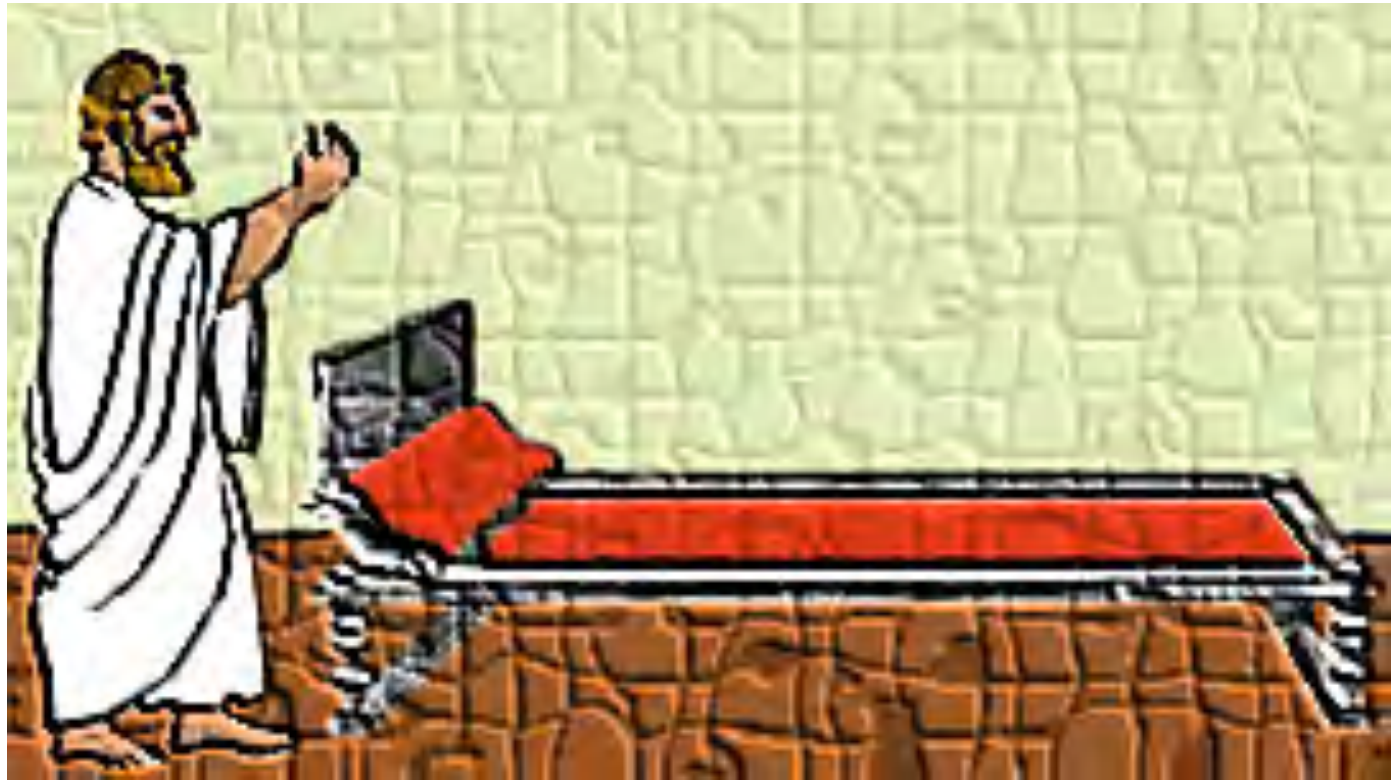


⇐ IS an equation



⇐ Never will be an equation

How Can Physics Help?
1. Do no harm



Procrustes and His Bed

How Can Physics Help?

2. Numbers and Nature

Pythagoras at Crotone

DUKE UNIVERSITY MEDICAL CENTER

DEPARTMENT OF MOLECULAR GENETICS AND MICROBIOLOGY

Ph.D. Program

All students entering the program take a set of required courses. Required courses include:

- Gene Regulation
- Virology and Viral Oncology
- Microbial Pathogenesis
- Genetic Analysis

Commonly chosen electives:

- Genome Technologies
- Genetic Analysis of Cellular Function
- Human Genetics
- Modern Techniques in Molecular Biology
- Molecular Cell Biology
- Mechanisms of Development
- Principles of Immunology

Note: No physics; No mathematics; No experimental design; No time-series analysis

Conclusion