35 YEARS OF METALLIC SUPERLATTICES

IEEE DISTINGUISHED LECTURER

IVAN K. SCHULLER

University of California
San Diego

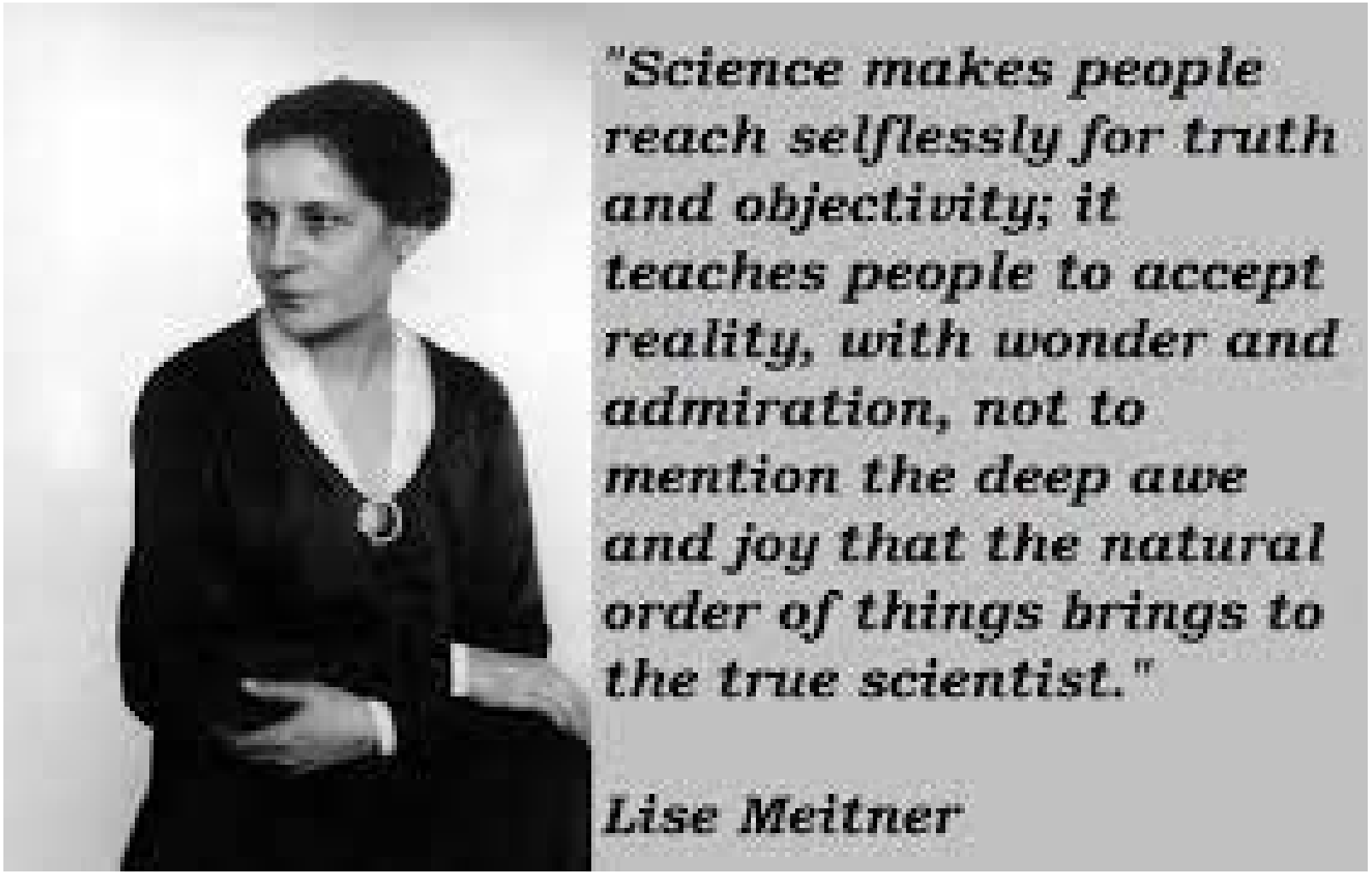
DOE

NSF, AFOSR, ONR

- **IEEE Magnetics Society Home Page:** ***www.ieeemagnetics.org***
  - **3000 full members**
  - **300 student members**
- **The Society**
  - **Conference organization (INTERMAG, MMM, TMRC, etc.)**
  - **Student support for conferences**
  - **Large conference discounts for members**
  - **Graduate Student Summer Schools**
  - **Local chapter activities**
  - **Distinguished lectures**
- ***IEEE Transactions on Magnetics***
  - **~2000 peer reviewed pages each year**
  - **Electronic access to all *IEEE Transactions on Magnetics* papers**
- **Online applications for IEEE membership:** ***www.ieee.org/join***
  - **360,000 members**
  - **IEEE student membership IEEE full membership**

Thank you

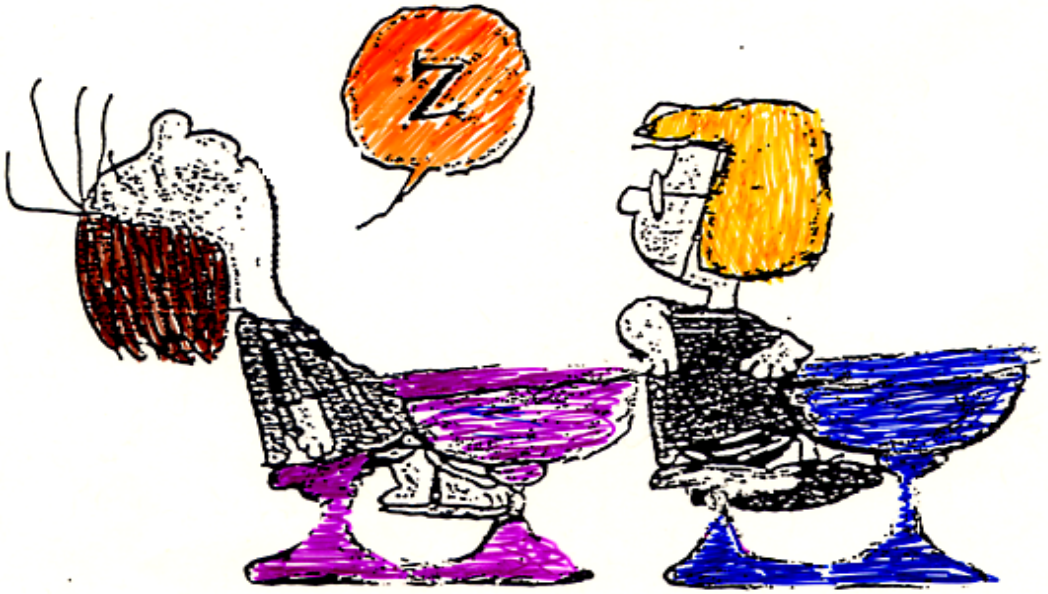
What **WE** think of Science



What the rest of the world thinks

- **Booooooooooring !!!!!!!**
- **That Is The Subject I Never Understood In High School (College)**
- **You Must Be Very Intelligent**

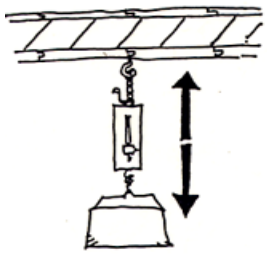
You are very boring

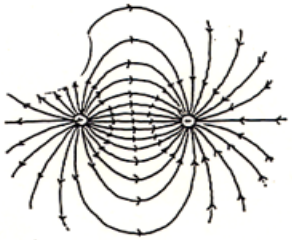


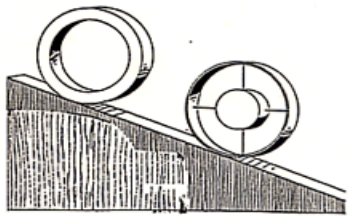
PHYSICS

WHAT IS IT ABOUT ?

Springs
Pulleys
Inclined Planes
Electricity



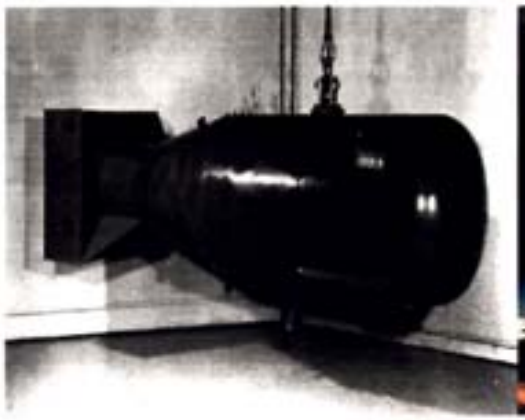




More sophisticated

Bangs

Small Bangs

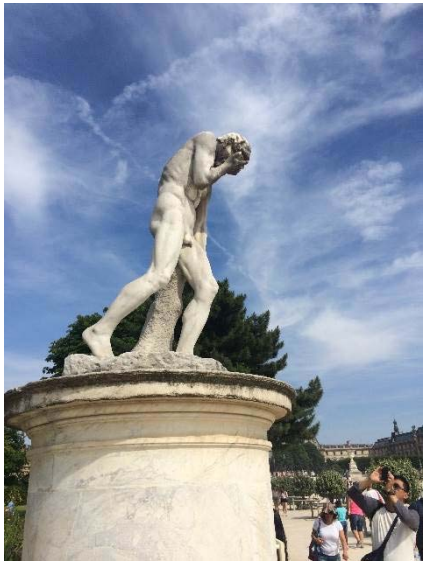


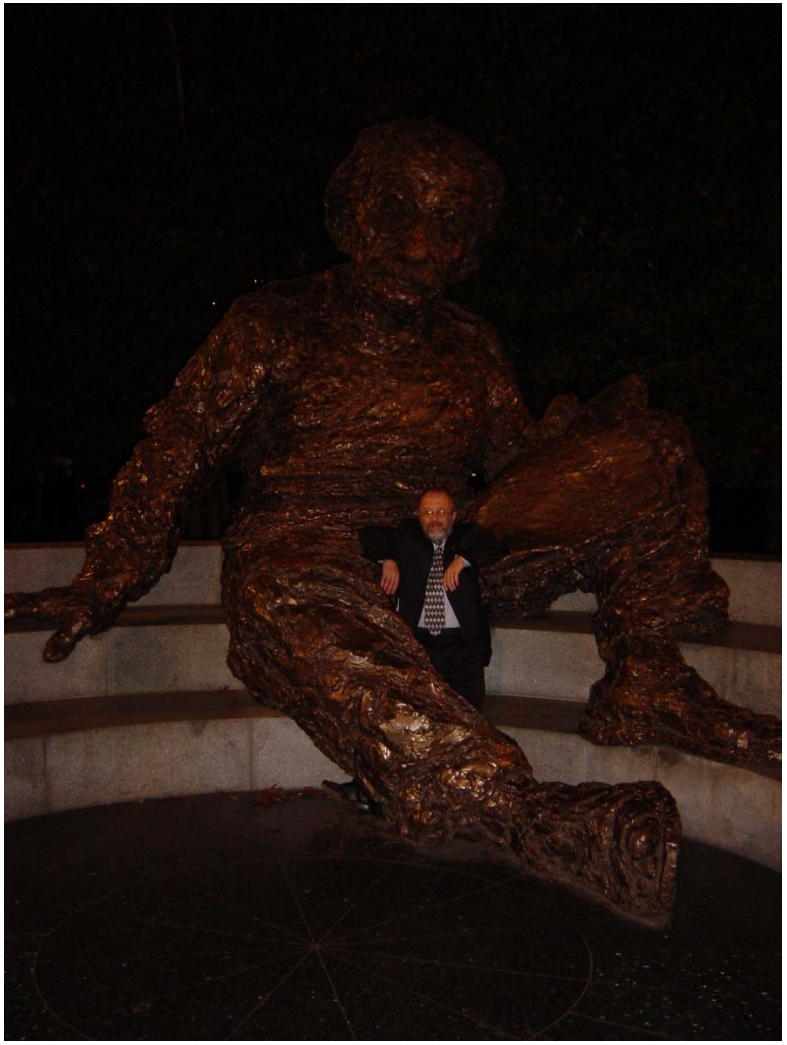
Big Bangs

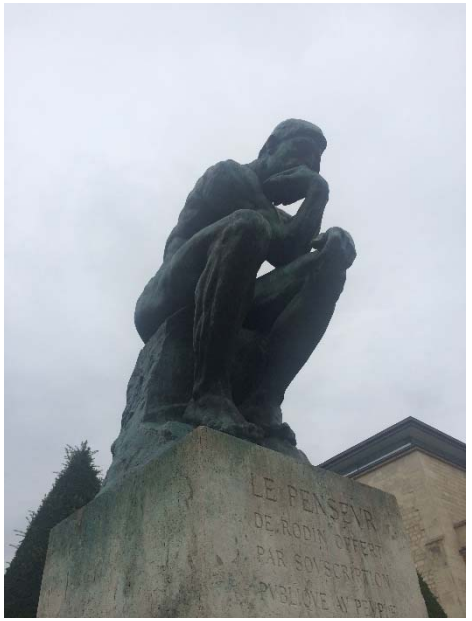
MOST DON'T DO THIS

FASCINATING PHYSICS
USEFUL
YOU USE IT MILLIONS OF TIMES A DAY

WHY PHYSICS







My Start
58 YEARS AGO
1957

Cluj, Kolozsvar, Clausenburg

Lucky to Live in Chile

Danny,
Oceanographer

Jonny,
Physicist

Jackie,
Teacher

"Life need not be easy, provided only that it is not empty."

Lise Meitner

Lucky to Study in Chile

SOMETHING FROM NOTHING

- Noether's theorem
  - ❖Conservation laws from philosophy

- Ginzburg-Landau 2nd order phase transition
  - ❖Superconductivity, magnetism …….
    from series expansion

ASK FUNDAMENTAL QUESTIONS

Emmy Noether

SYMMETRY AND CONSERVATION LAWS

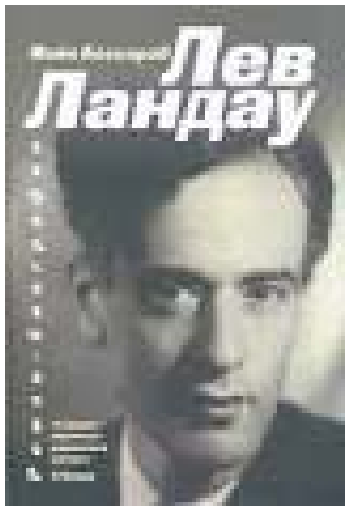
Landau-Ginzburg

Order Parameter: ψ

Superconducting Gap, Magnetization, Distorsion,

TAYLOR EXPANSION

$$F = F_n + \alpha|\psi|^2 + \frac{\beta}{2}|\psi|^4 + \frac{1}{2m}\left|(-i\hbar\nabla - 2e\mathbf{A})\,\psi\right|^2 + \frac{|\mathbf{B}|^2}{2\mu_0}$$



NORTHWESTERN UNIVERSITY

PHOTOEXCITATION IN SUPERCONDUCTORS

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

DOCTOR OF PHILOSOPHY

Field of Physics

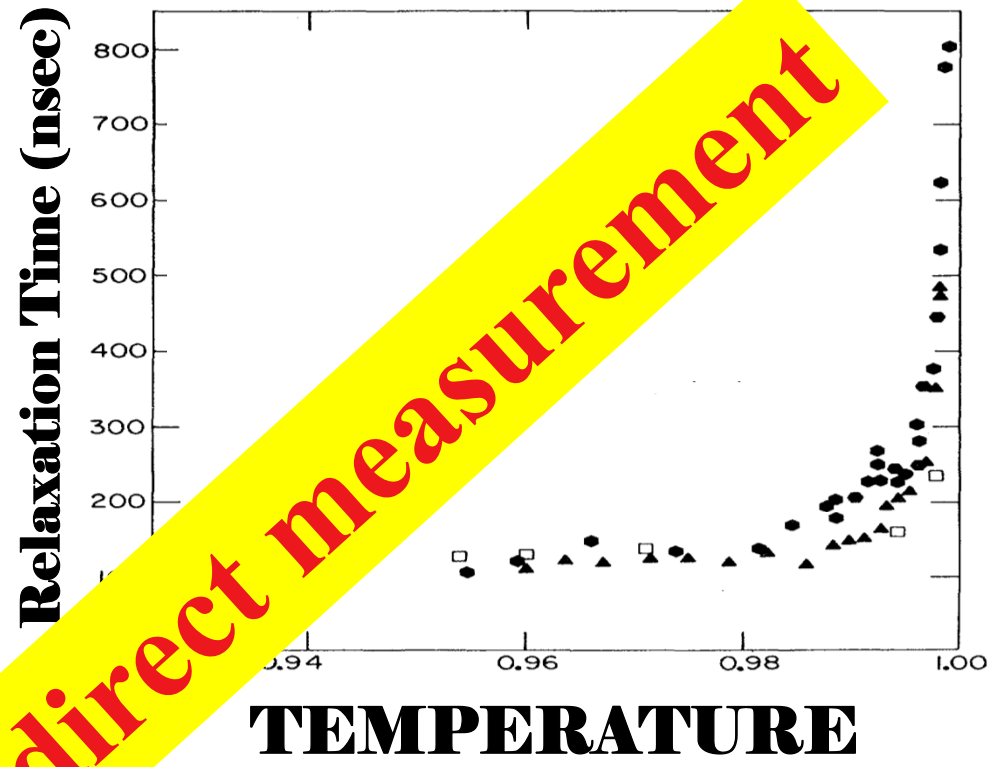
By

IVAN SCHULLER

Evanston, Illinois

June 1976

CRITICAL SLOWING DOWN



First direct measurement

I. K. Schuller and K. E. Gray, PRL36, 429(1976)

MANY YOUNG FRIENDS

HAGAR THE HORRIBLE *by DIK BROWNE*

Why do Physics

- **Universal behavior**
  - ❖Power Laws
- **New Parameters Range**
  - ❖Smaller
- **Weird Behavior**
  - ❖Separate Charge and Spin
- **Big Questions**
  - ❖What is intelligence

Why do Physics

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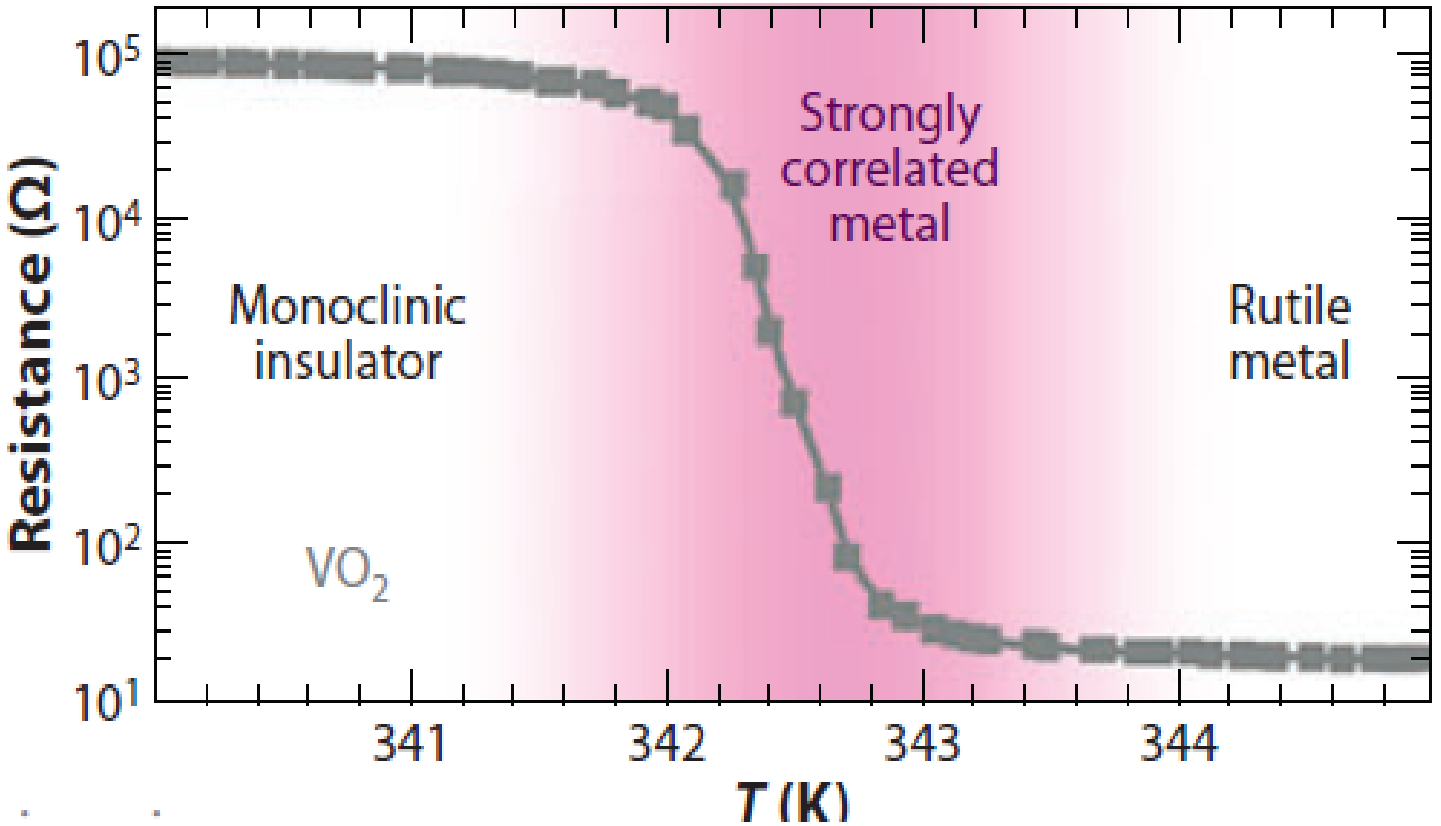
- Big Questions
  - What is intelligence

Metal-Insulator Transition

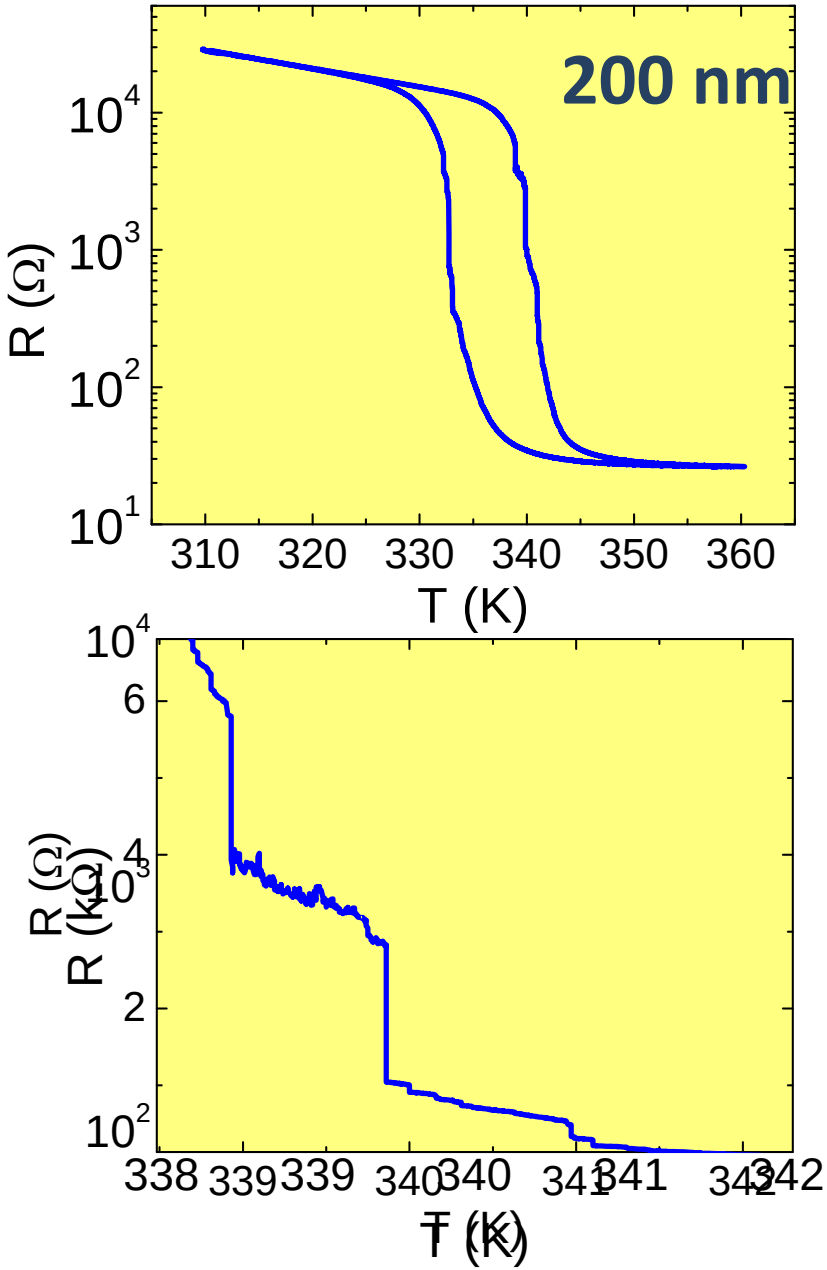
VO_2

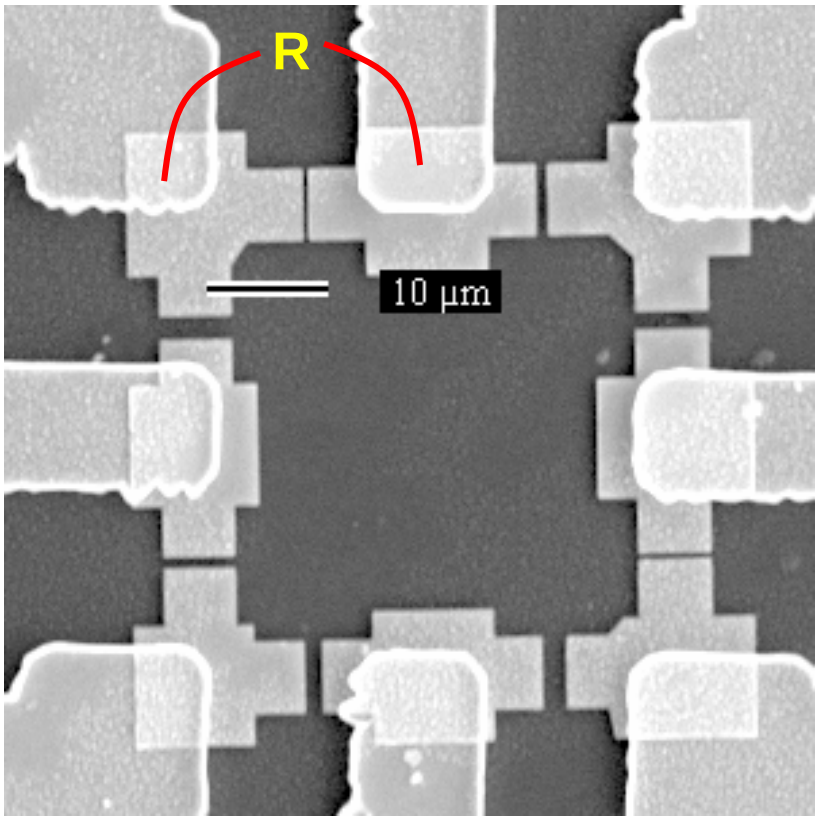


Z. Yang, C. Ko, and S. Ramanathan, Annu. Rev. Mater. Res. 41 (2011)

24

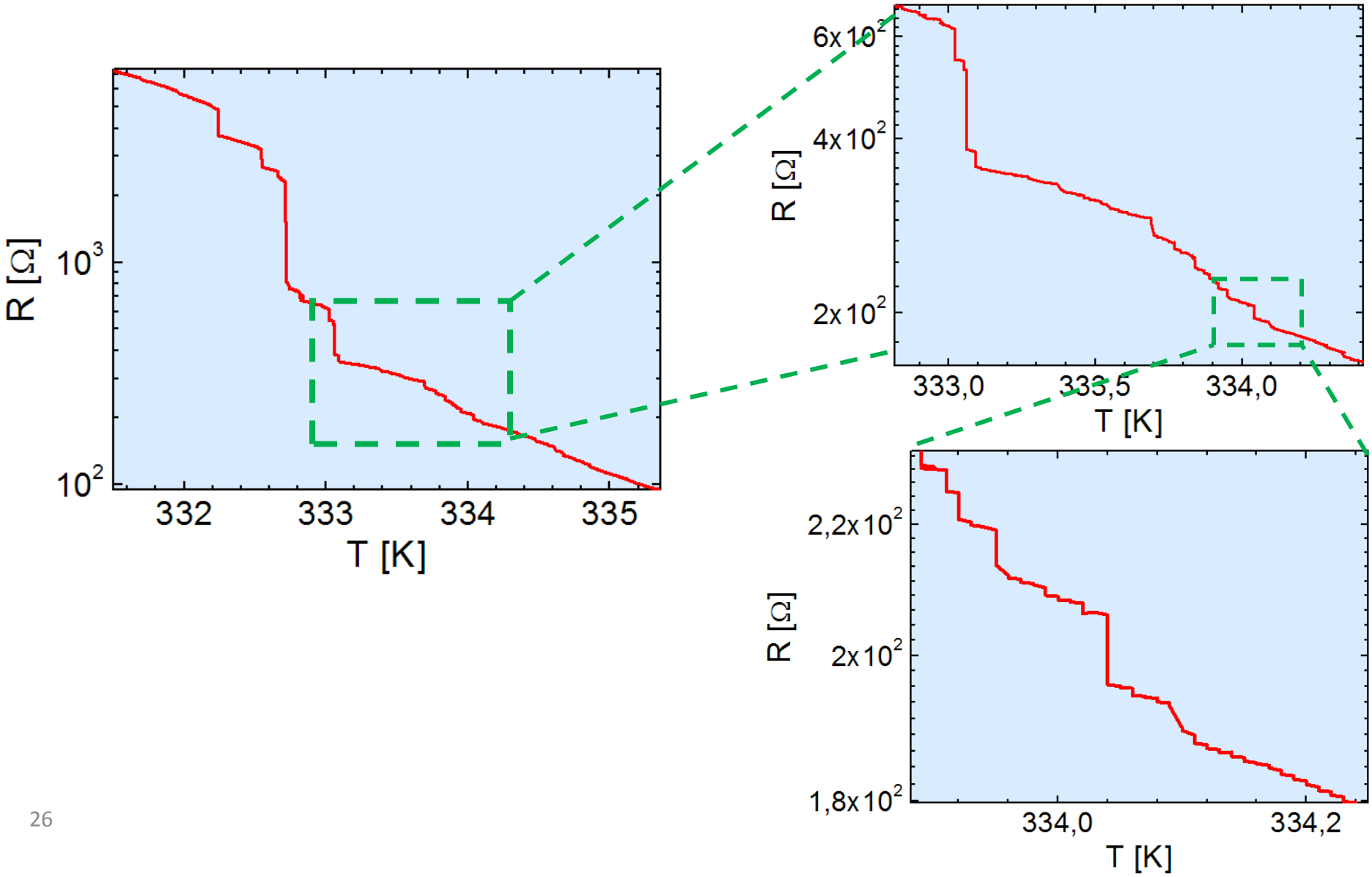
Nano-scale VO_2



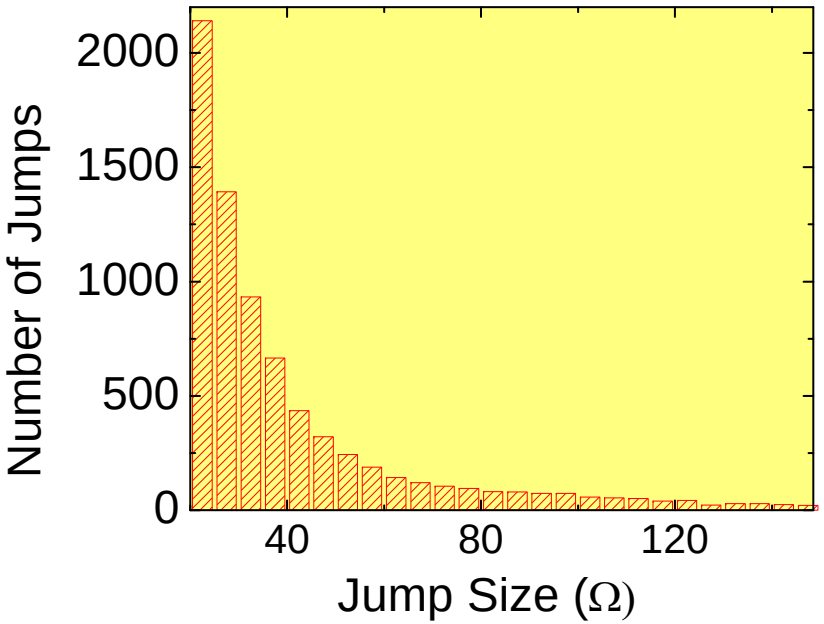


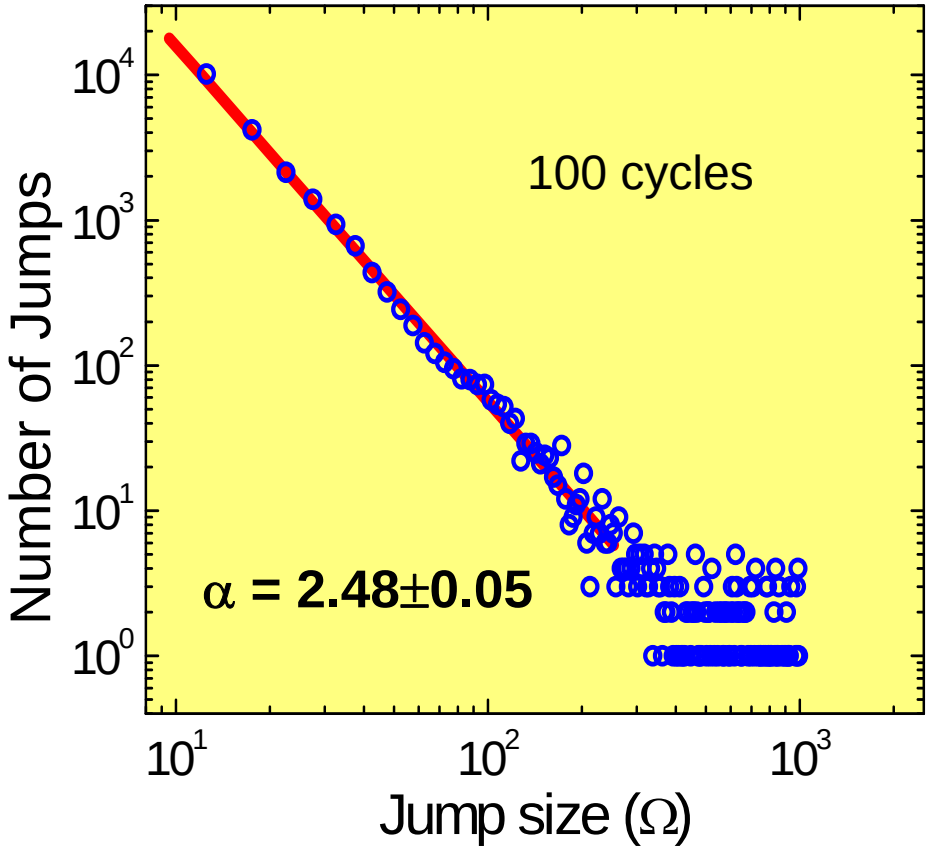
Multiple jumps across the metal-insulator transition

Scale Invariance



Statistics of Jumps





Power law: $p(A) \propto A^{-\alpha}$

p-probability **A**- jump size

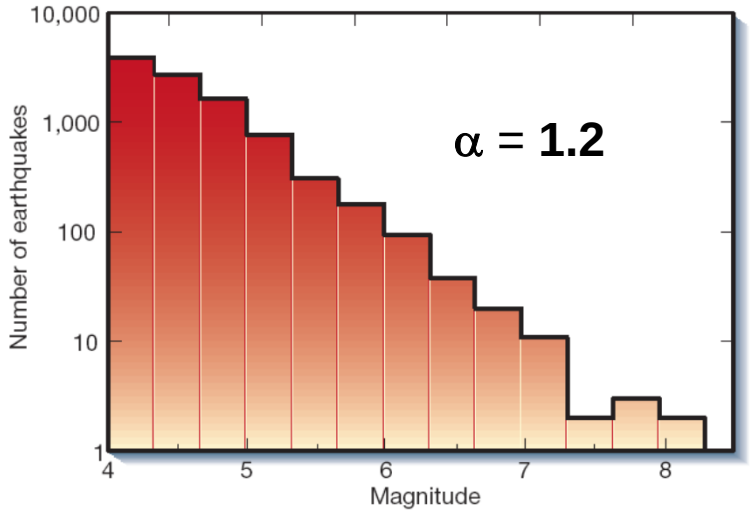
Avalanches

- Triggered and develops
- Many Small avalanches
- A few big ones

UNIVERSALITY OF PHYSICS

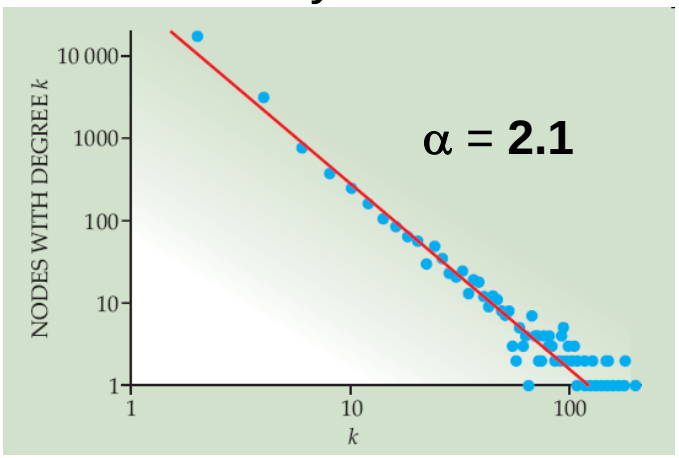
Power Laws

Earthquake Magnitude



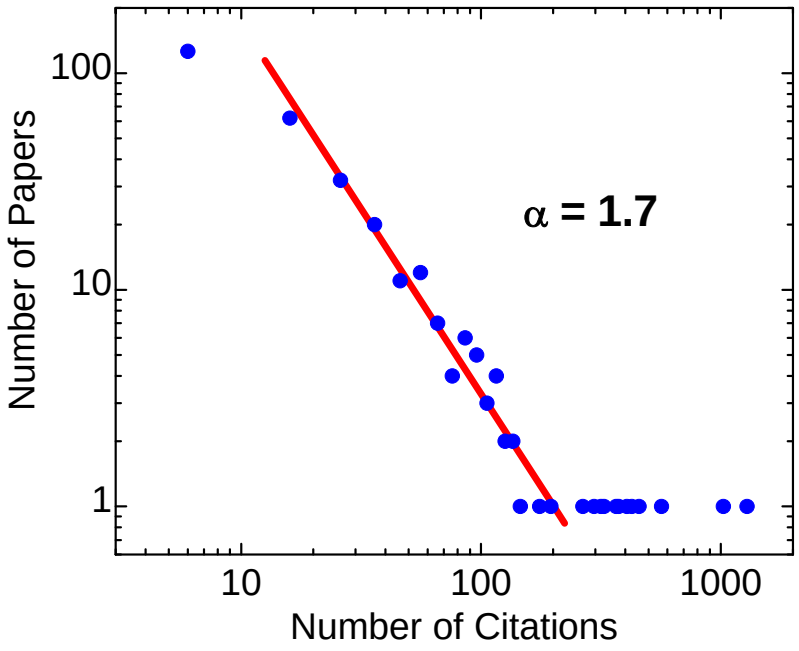
JP. Sethna *et al.*, Nature **410,** 242 (2001)

Connectivity of Internet



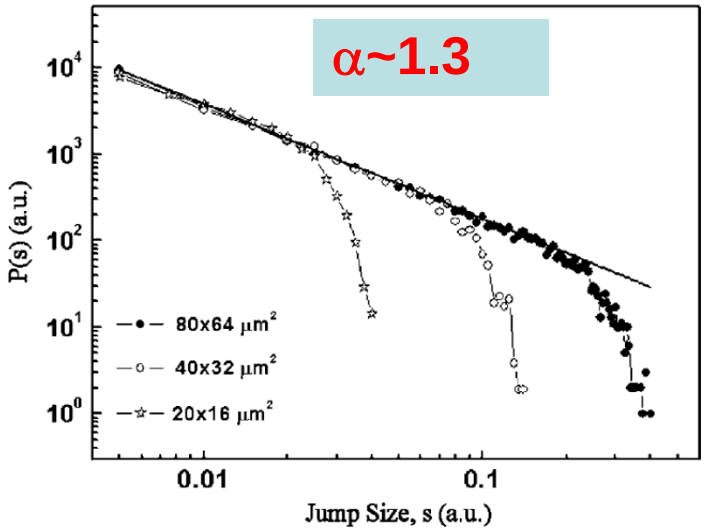
M. Newman Phys. Today, P. 33 Nov. 2008

Citations (I.K. Schuller)

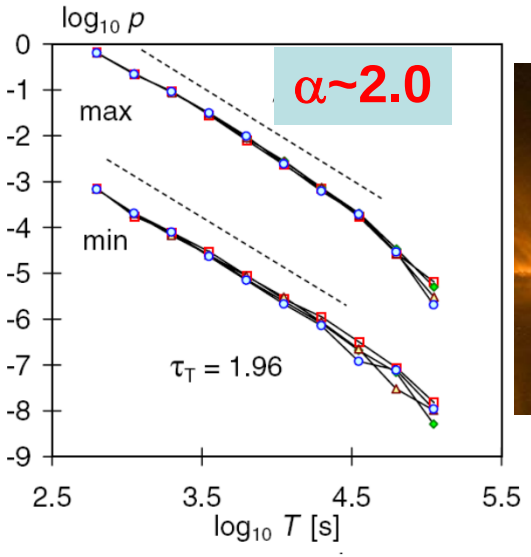


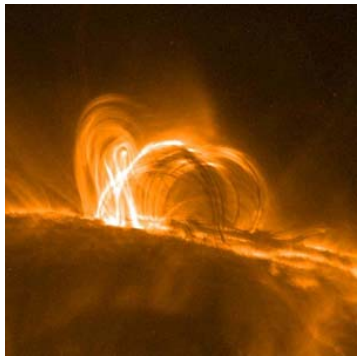
Avalanches with Power Laws

Barkhausen Noise

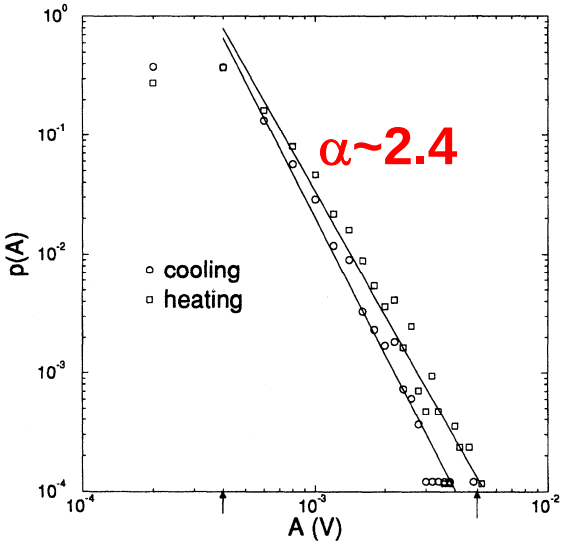


Plasma Burst (sun)

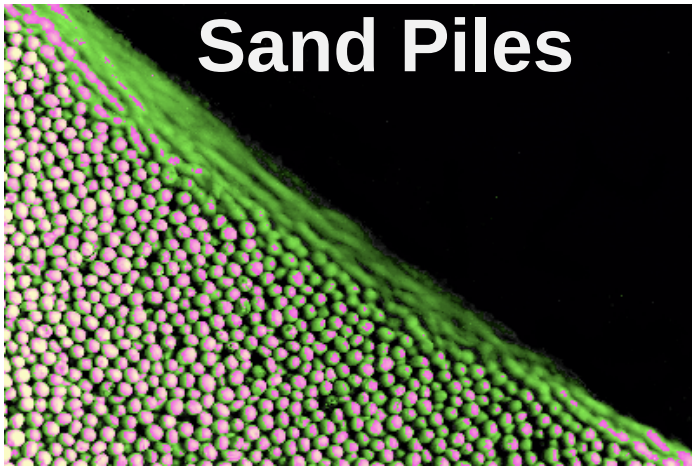




Martensites



Sand Piles



α~1 - 3, depends on sand

Why do Physics

- **Universal behavior**
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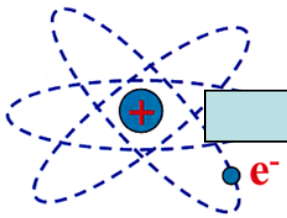
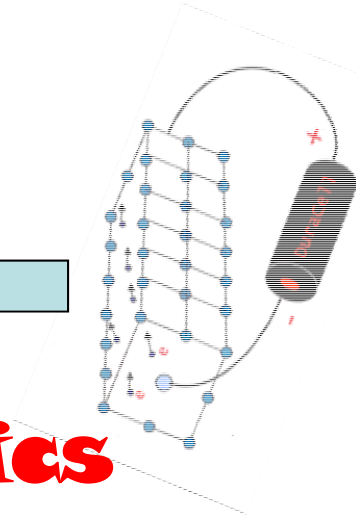
  - Smaller
- **Weird Behavior**
  - Separate Charge and Spin
- **Big Questions**
  - What is intelligence

CHARACTERISTIC LENGTH SCALES



NANO SCIENCE



Chemistry

Physics

SURPRISE

French Theorist

Francois-Marie Arouet

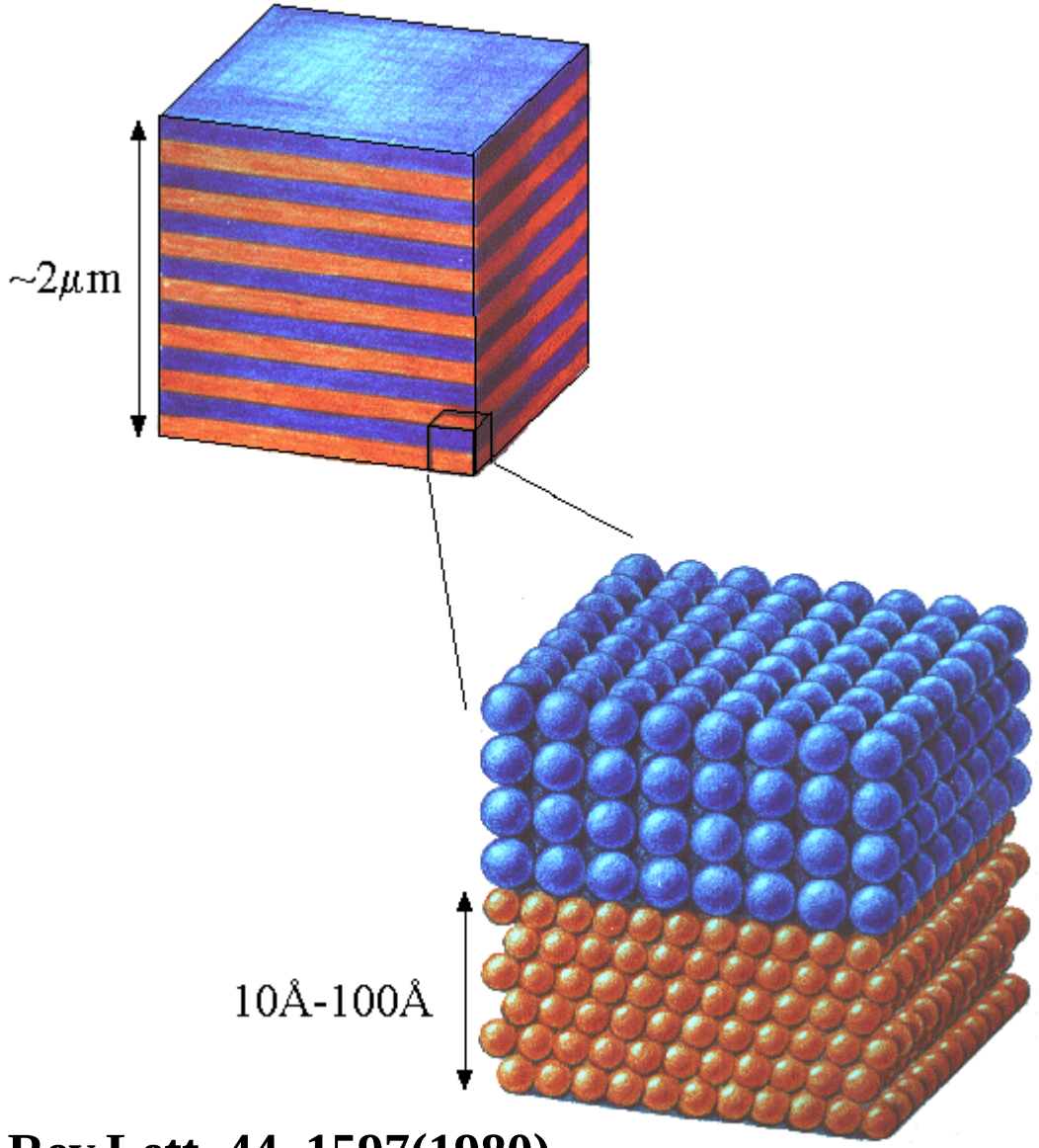
NANO VOLTAIRE

NanoBio

Un homme de six pieds fait sur la terre la meme figure precisement que fait sur une boule de quatre pieds de circonference un animal qui serait a cette circonference de roue comme 1 est a 91 500 000 **~10nm**

Merci Andre Magnan
President Soc. Voltaire
KVAB, U. de Nanterre

SCIENCE DRIVEN RESEARCH



I.K.Schuller, Phys.Rev.Lett. 44, 1597(1980)

AIP Conference Proceedings
Series Editor: Hugh C. Wolfe
Number 53

MAGNETO-TRANSPORT

Modulated Structures–1979

(Kailua Kona, Hawaii)

Editors
J.M. Cowley, Arizona State University
J.B. Cohen, Northwestern University
M.B. Salamon, University of Illinois
B.J. Wuensch, Massachussetts Institute of Technology

American Institute of Physics
New York 1979

resistance is quadratic at low fields and then linear up to 70 kG. On the other hand the Hall coefficient (Figure 5) of all three samples is typical of that observed in pure nickel.[3,5,6,7]

In summary, we have measured the electric transport properties of Cu/Ni compositionally modulated alloys. The electrical resistivity and the magnetoresistance show anomalous behavior as a function of modulation amplitude. On the other hand, the thermopower and Hall coefficient show typical behavior of a ferromagnet. More detailed measurements are presently underway in order to clarify these points and their relationship to the anomalous elastic and magnetic properties.

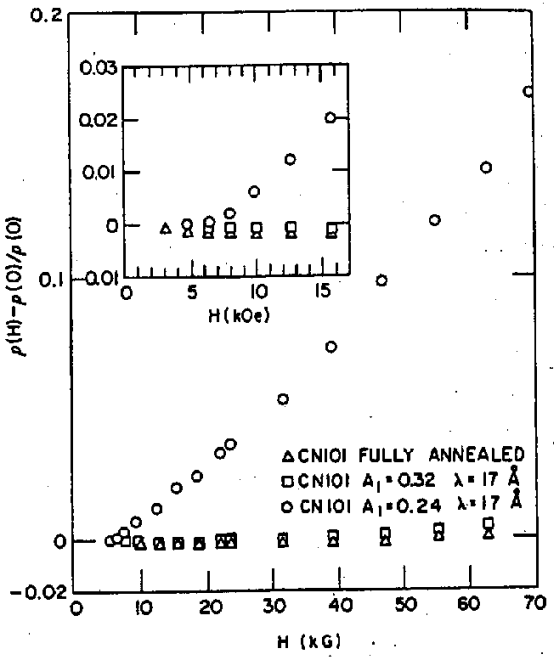
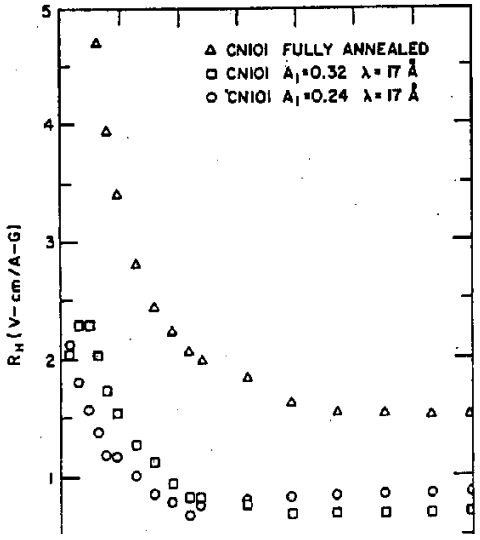


Fig. 4. Transverse magnetoresistance versus magnetic field. The inset shows in detail the low field behavior.

magnetoresistance shows anomalous behavior....

~ 20 % MR



Giant MagnetoResistance- **GMR**

April, 1981

. . . superlattices may lead to a new breed of electronic devices.

. . . metal superlattices. . . for use in computer memories

In 4 or 5 years, this will be THE field in materials science.

2007 PHYSICS NOBEL

Grunberg  *Fert*

GIANT MAGNETORESISTANCE

GMR

KUNGL. VETENSKAPSAKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Scientific Background on the Nobel Prize in Physics 2007

The Discovery of Giant Magnetoresistance

compiled by the Class for Physics of the Royal Swedish Academy of Sciences

has to greatly exceed the interlayer separations so that the electrons can travel through magnetic layers and pick up the GMR effect. Without the ... perimental growth techniques this requirement could not have been fulfilled and the GMR effect would ... ave remained unknown. In this connection it should be mentioned that, in several publicat... ns prior to t... e work of Fert and Grünberg, there were reports of observations of substantial (of the ord... of a few p... cent) magnetoresistance effects (9,10,11,12). In none of them were the observations rec... ized ... a new effect.

9. I. Schul..., C.M. Falco, J. Williard, J. Ketterson, B. Thaler, R. Lacos, and R. Dee, "Transport Properties of the Compositionally Modulated Alloy Cu/Ni," AIP Conference Proceedings **53**, 417 (1979).

10. J.P. Renard and ... Beauvillain, "Interface Effects in Ultrathin Ferromagnetic Films", Physica Scripta T**19** B, 4... 5 (1987).

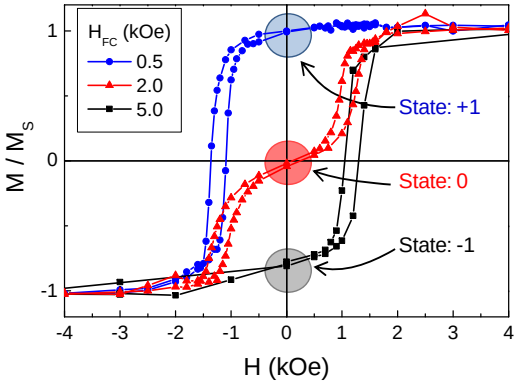
11. E. Vélu, C. Dupas, ... d, J.P. Renard, and J. Seiden, "Enhanced Magnetoresis...nce of Ultrathin $(Au/Co)_n$ Multilayers with Perpendicular Anisotropy", Phys. Rev. B**37**, 6... 8 (1988).

Phone: +46 8 673 95 00, Fax: +46 8 15 56 70, E-mail: info@kva.se, Website: www.kva.se

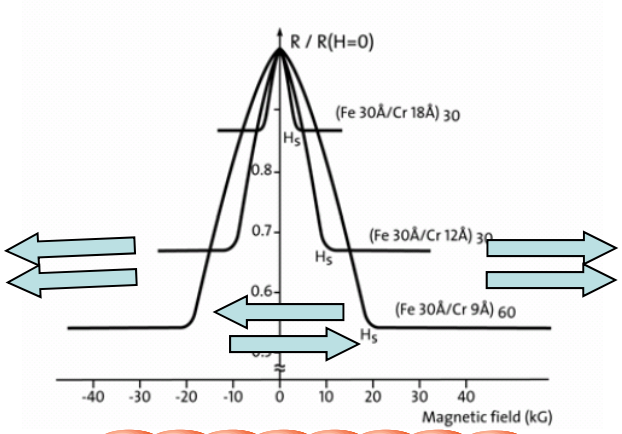
SCIENCE

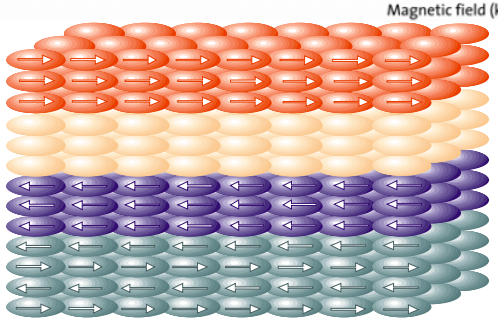
APPLICATIONS

EXCHANGE BIAS

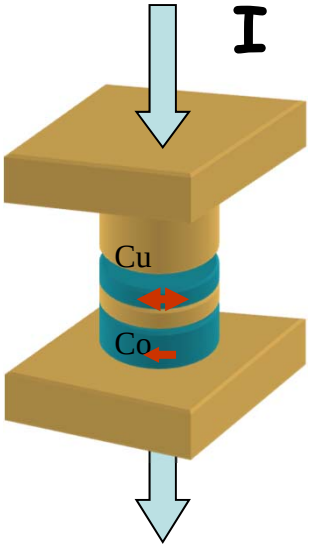


GMR

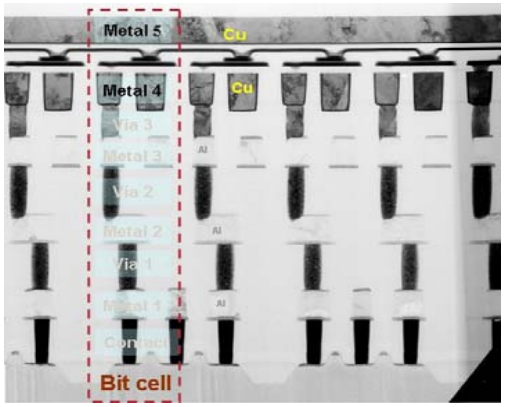




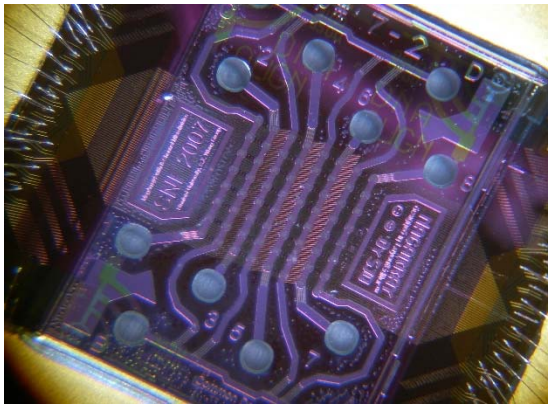
SPIN TORQUE



Hard disk drives



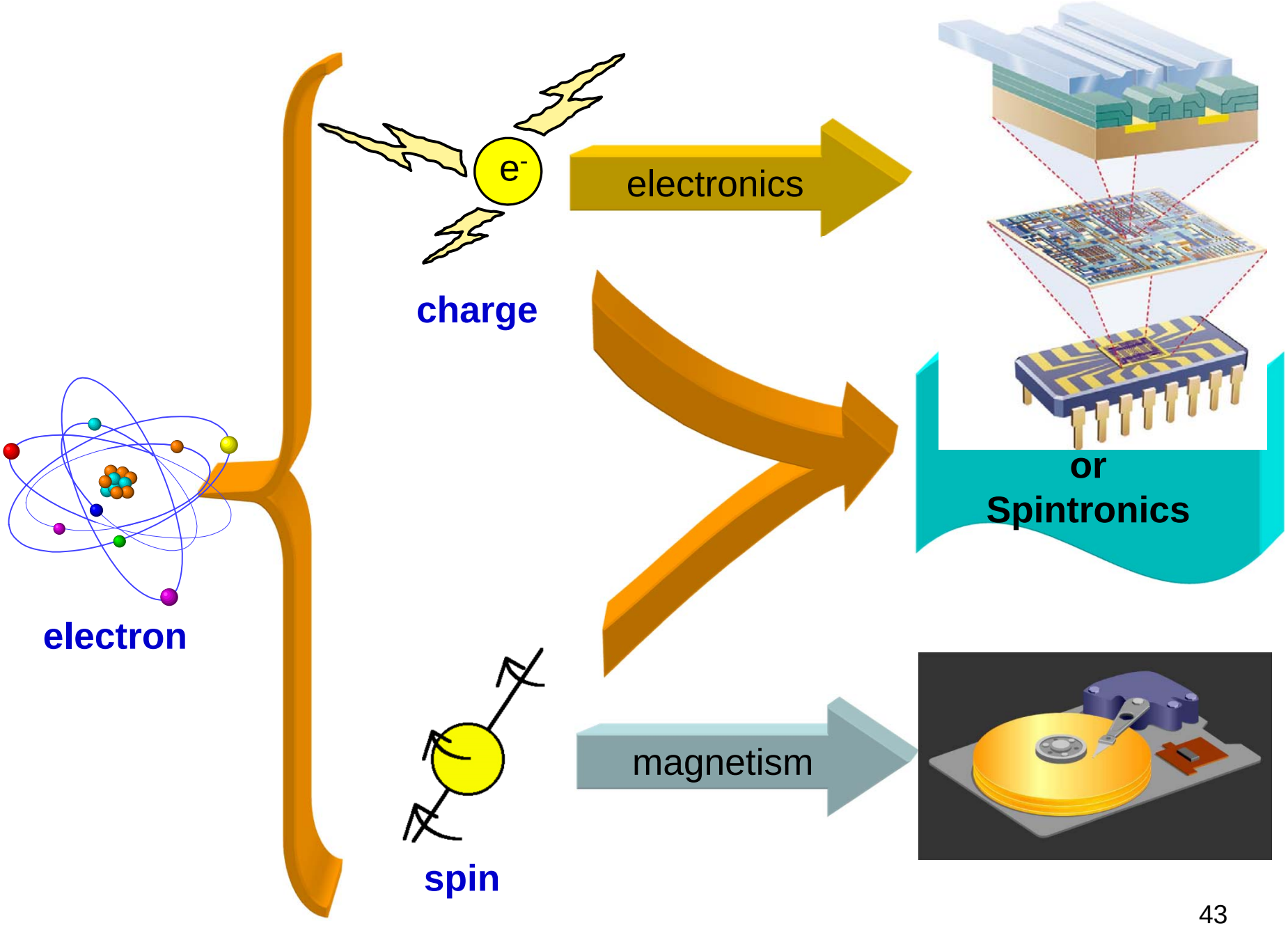
MRAM

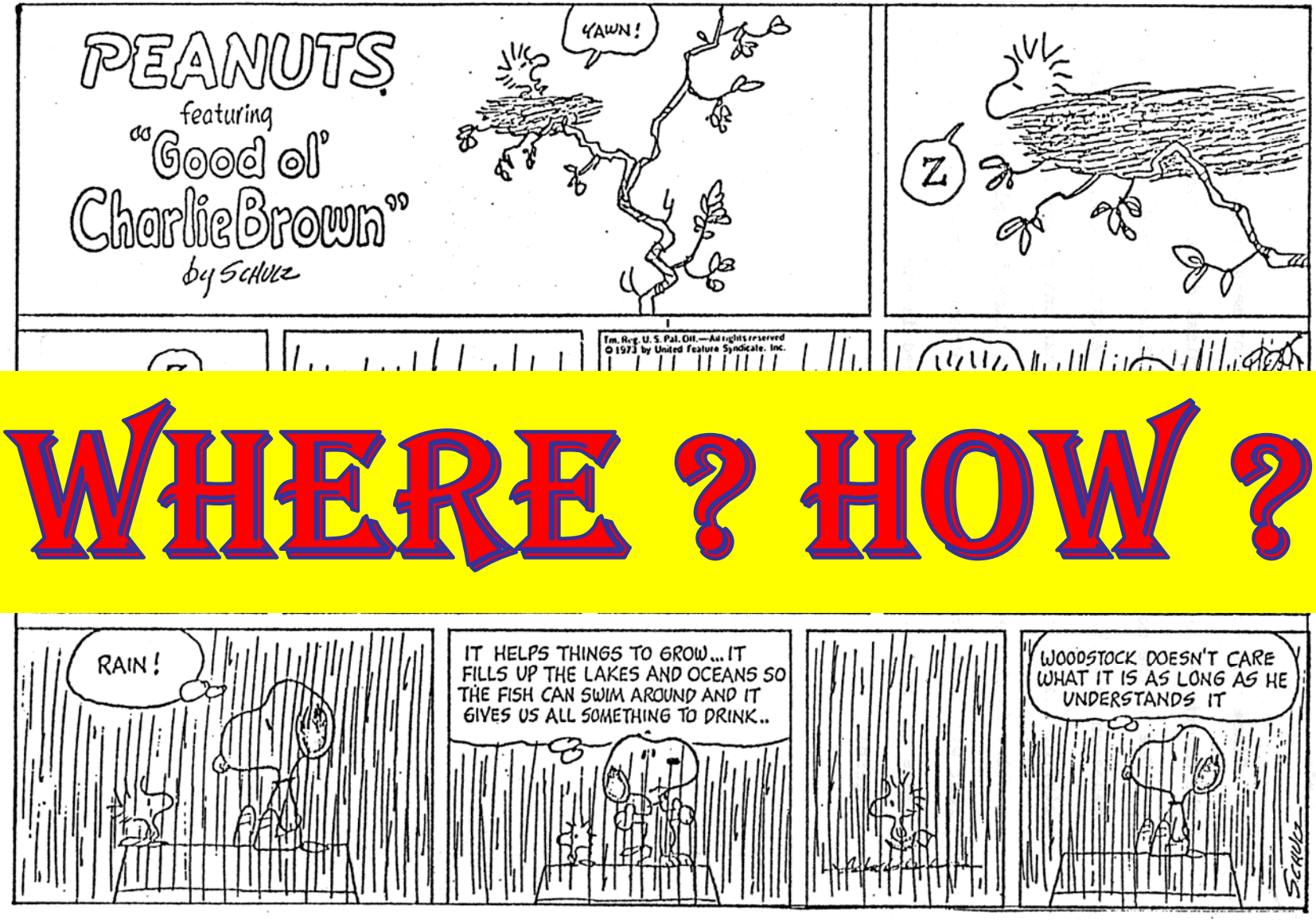


Sensors

Nanoscience
(when things get small)

TunnelSchroedv8_1-desktop.m4v


e-
electronics
charge
electron
or
Spintronics
spin
magnetism



WHERE ? HOW ?

Basic Research=Transformative Technology

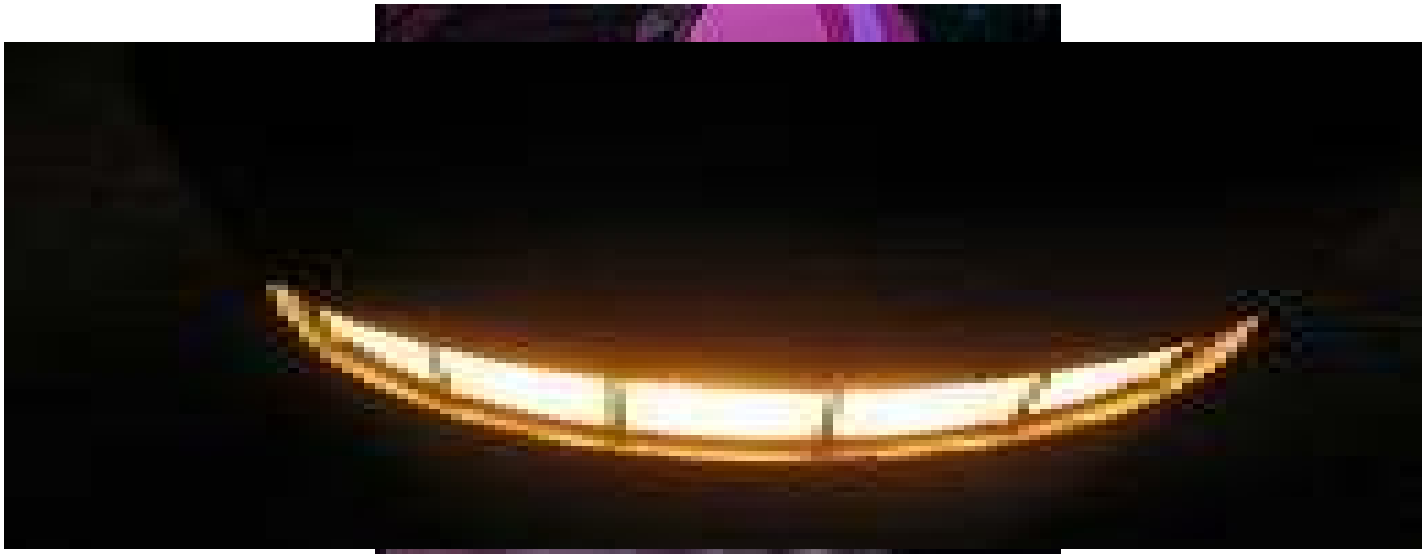
Why do Physics

- **Universal behavior**
  - ❖Power Laws
- **New Parameters Range**
  - ❖Smaller
- **Weird Behavior**
  - ❖Separate Charge and Spin
- **Big Questions**
  - ❖What is intelligence

THE REAL CHESHIRE CAT

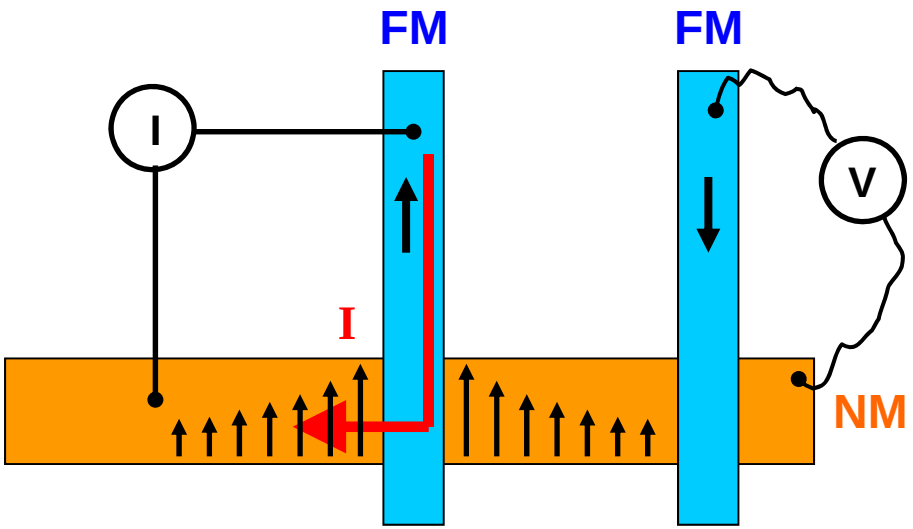
Went away and

left behind his smile



A CRAZY EXPERIMENT

NON-LOCAL SPIN VALVE



FM: ferromagnetic

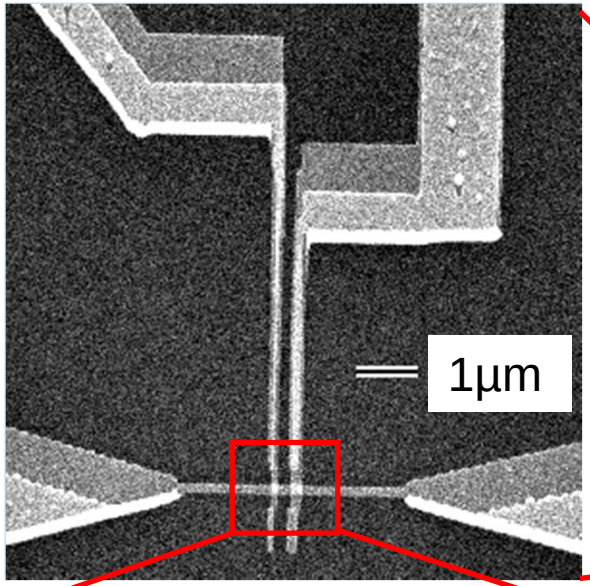
NM: non-magnetic

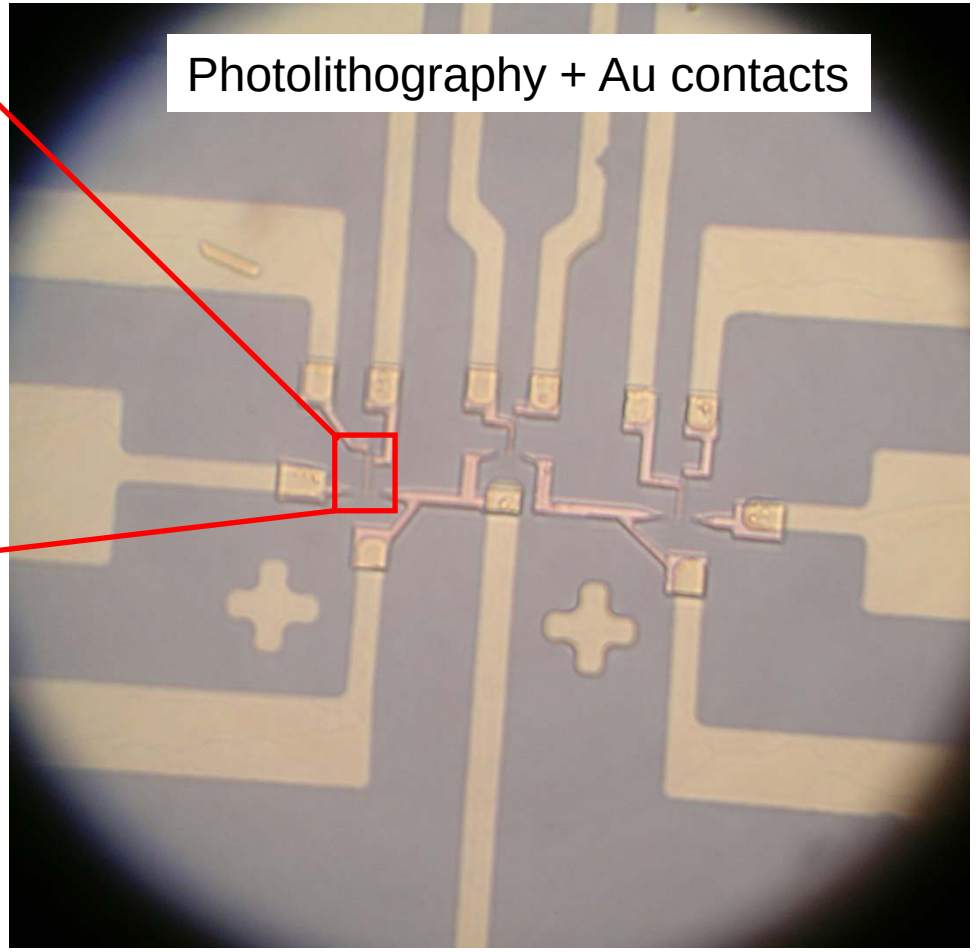
Decouple

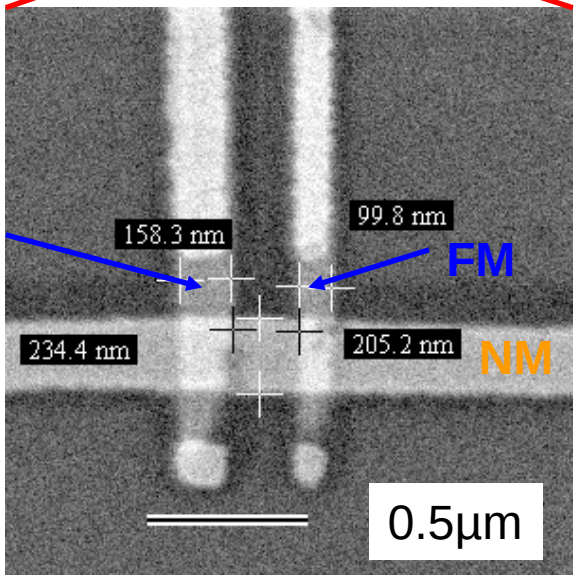
SPIN current from CHARGE current

Valenzuela et al.,PRL **94**, 196601 (2005)

Sample

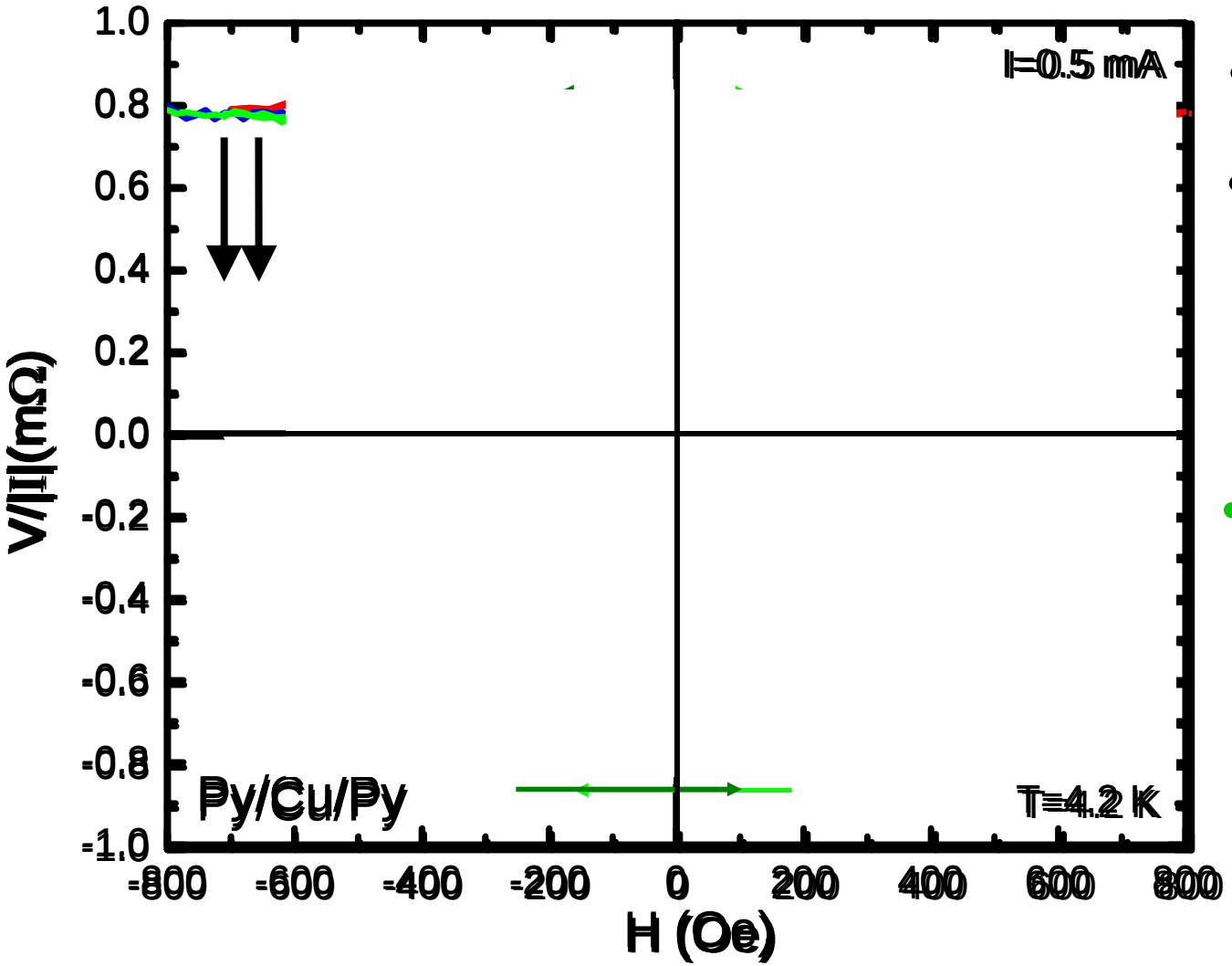






Py/Cu/Py **Co/Al/Co**

Non-local spin valve effect



- Bipolar switching
- Spin signal:

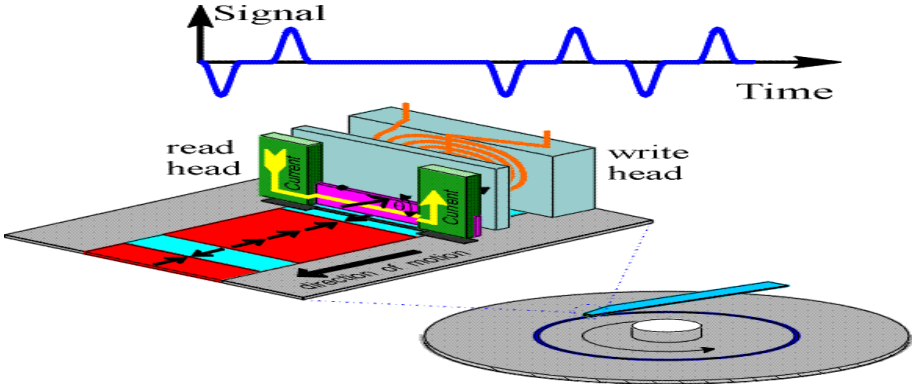
$$\frac{\Delta V}{|I|} = \frac{V_P - V_{AP}}{|I|}$$

- Memory effect

Spintronics: applications

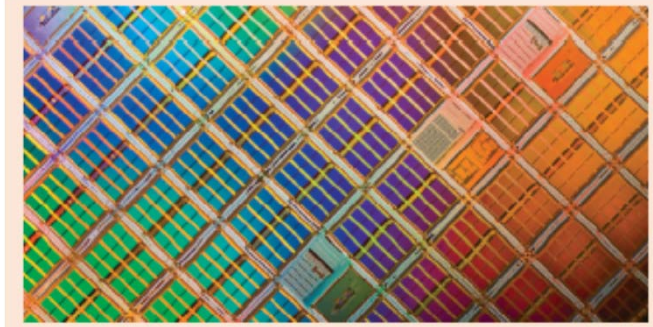
Giant magnetoresistance (GMR)

Magnetoresistive read head
Discovery: 1988
Market: IBM 1997



Tunnel magnetoresistance (TMR)

Magnetic RAM
4 Mbit chip
Revisited: 1995
Demo: Motorola 2003
Market: Freescale 2006



Micrograph of multiple 4 Mbit die on a Si wafer. (Courtesy of Freescale, Inc.)

Why do Physics

- **Universal behavior**
  - ❖Power Laws
- **New Parameters Range**
  - ❖Smaller
- **Weird Behavior**
  - ❖Separate Charge and Spin
- **Big Questions**
  - ❖What is intelligence

ASCI Q
LANL
LOS ALAMOS
HP ALPHASERVER SC
Rmax: 7.7 TFlops

Jonathan Schuller
6 months old

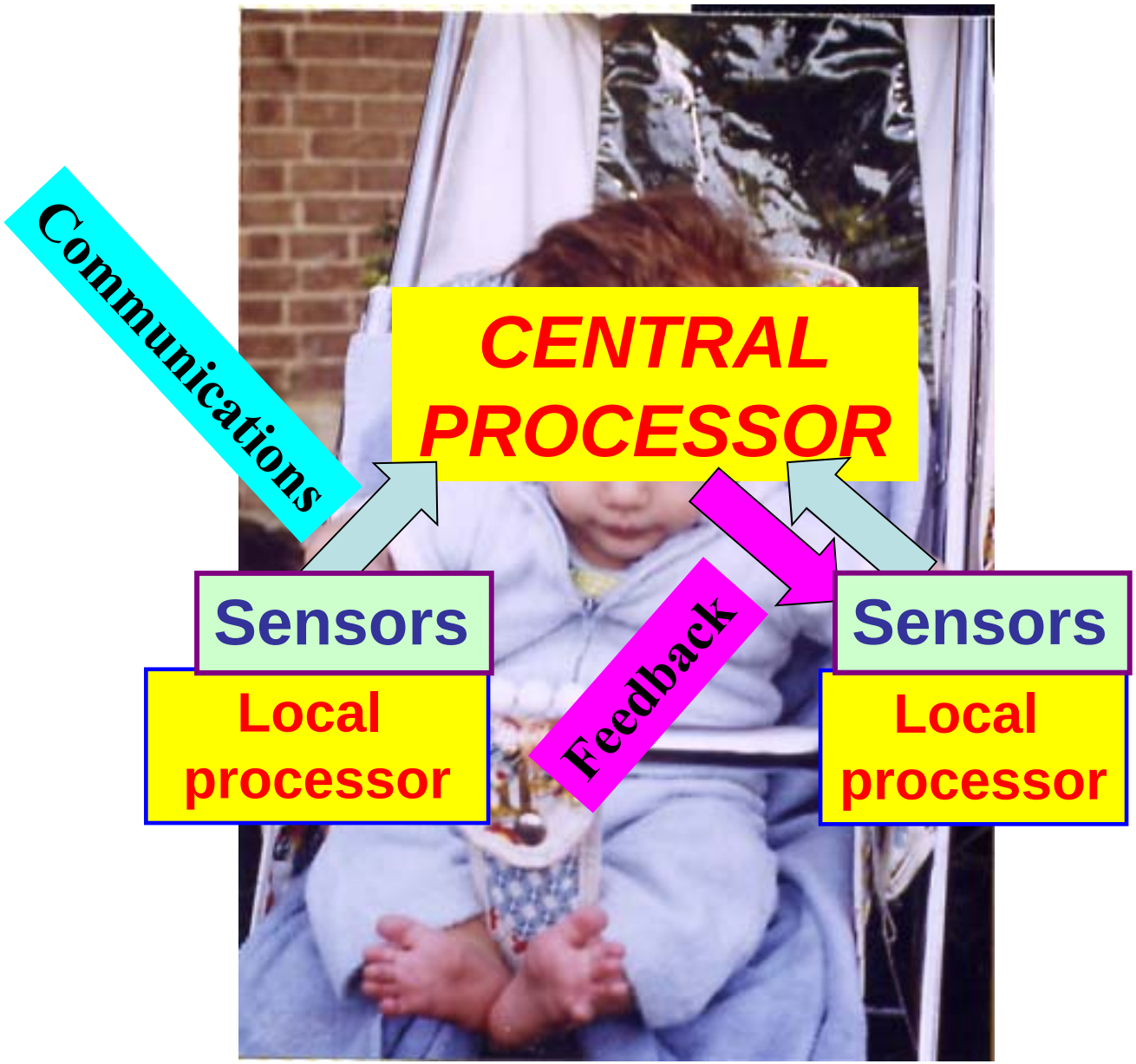
WHAT CAN HE TEACH US ???

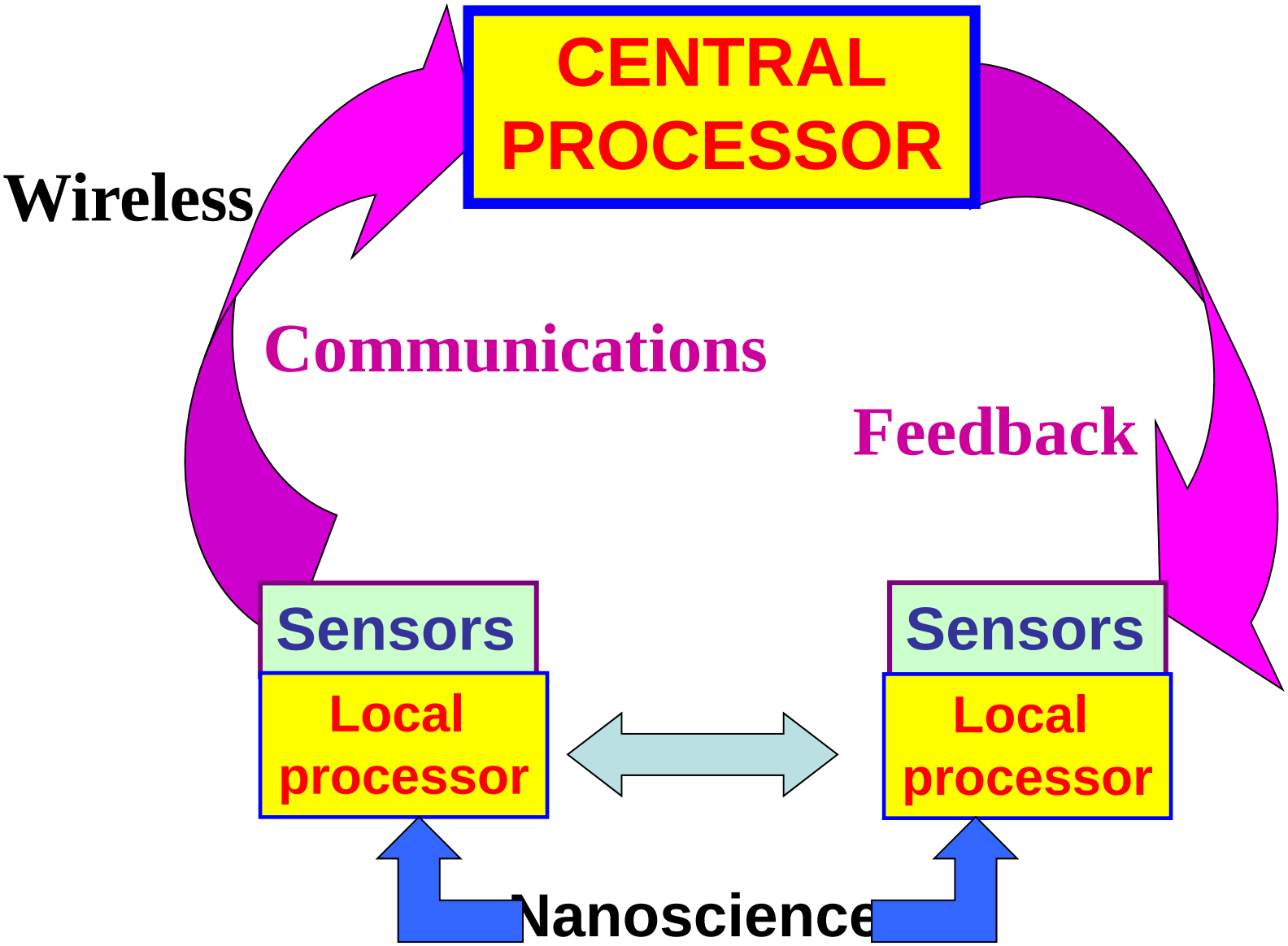
11,968 processors,
12 Terabytes memory,
600 Terabytes disk storage

Unifying Principles for Intelligence ?

Imitate Nature

"Biologically Inspired"


Communications
CENTRAL PROCESSOR
Sensors
Local processor
Feedback
Sensors
Local processor


CENTRAL PROCESSOR
Wireless
Communications
Feedback
Sensors
Local processor
Sensors
Local processor
Nanoscience

The New York Times

Education Life

Section 4A/April 13, 2003

How Learning Goes Wrong

A learning disability interferes with a child's ability to interpret what is seen and heard, or to link information from different parts of the brain.

IN LEARNING, INFORMATION ENTERS THE BRAIN VIA THE SENSES . . .

Visual perception

SEES LETTERS REVERSED OR ROTATED
An e might look like a 9. The letters d, b, p, g and q may be confused.

"FIGURE-GROUND" PROBLEMS
In normal visual perception, a figure stands out against an undifferentiated background. With this disability, a child has difficulty locating one thing among many, like a pencil on a crowded desk. Words or lines may be skipped while reading.

TROUBLE GAUGING DISTANCE AND DEPTH
May lead to problems with activities like catching a ball.

Auditory perception

CAN'T DISTINGUISH SUBTLE DIFFERENCES
Similar sounds in words like "ball" and "bell" may be confused.

"AUDITORY FIGURE-GROUND" PROBLEMS
Has trouble picking up a single sound amid background noise, like a teacher's voice while music plays.

Sources: "The Misunderstood Child," by Dr. Larry B. Silver; Dr. Marie T. Banich, University of Colorado at Boulder

IS PROCESSED . . .

Sequencing

TROUBLE PUTTING THINGS IN ORDER
May read d-o-g as g-o-d or have trouble relating events in the proper sequence.

TROUBLE EXTRACTING INFORMATION
Can memorize a list, but has trouble isolating single elements — for example, answering "What comes after Tuesday?"

Abstract thinking

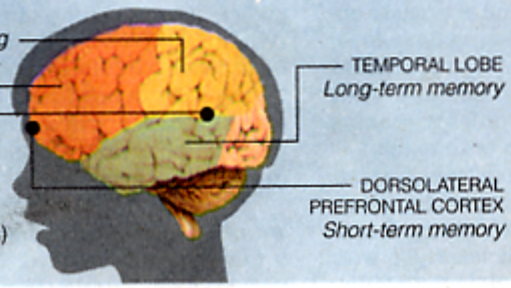
CONCEPTUAL PROBLEMS May have trouble with abstract concepts like figures of speech and reading for content.

STORED . . .

Memory

SHORT-TERM MEMORY LOSS
Frequently forgets new information, like how to spell a word, unless concentrating.

LONG-TERM MEMORY LOSS
Troubles here would severely impair normal learning.



AND THEN USED IN MOVEMENT OR LANGUAGE.

Movement

FINE MUSCLES DON'T WORK WELL TOGETHER
Problems may show up when a child begins to write, with poor and slow handwriting.

TROUBLE USING LARGE MUSCLE GROUPS
A child may seem clumsy and fall or stumble often.

Language

ANSWERS QUESTIONS POORLY
While not struggling with spontaneous language, a child with a "demand language" problem needs more time to organize thoughts and find the right word.

COMMON CONDITIONS *(A child may have a combination of these.)*

Dyslexia
Trouble reading and understanding words and sentences.

Dyscalculia
Trouble with math problems and concepts.

Dysgraphia
Trouble forming letters or writing in a defined space.

Attention Deficit/Hyperactivity Disorder
Characterized by inattention, hyperactivity and impulsive behavior. While not a learning disability, it afflicts about a third of children who have one.

Kathleen O'Brien/The New York Times

IMPLEMENTATION

Reduce to practice
Imitate nature

FUNDING

What is needed

- **Expertise- physicists, chemists, biologists, engineers**
- **Techniques-Nanoscience, Materials, Wireless,Engineering**
- **High Tech Facilities**
- **Various implementations**
- **Interactions**
- **Steady Support**

An experiment on its own

Is this pie in the sky ???

Organic Thin Films

Structure, Transport, SELECTIVE Sensing

Physics

Corneliu N. Colesniuc, Amos Sharoni, Casey W. Miller, Ge Liu,

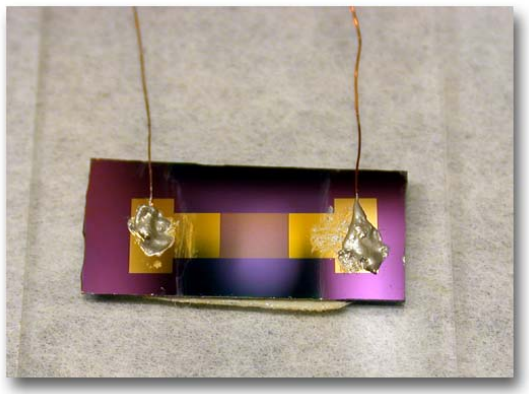
Chemistry,

Richard D. Yang, Forest Bohrer ,Andy C. Kummel, William Trogler,

Engineering

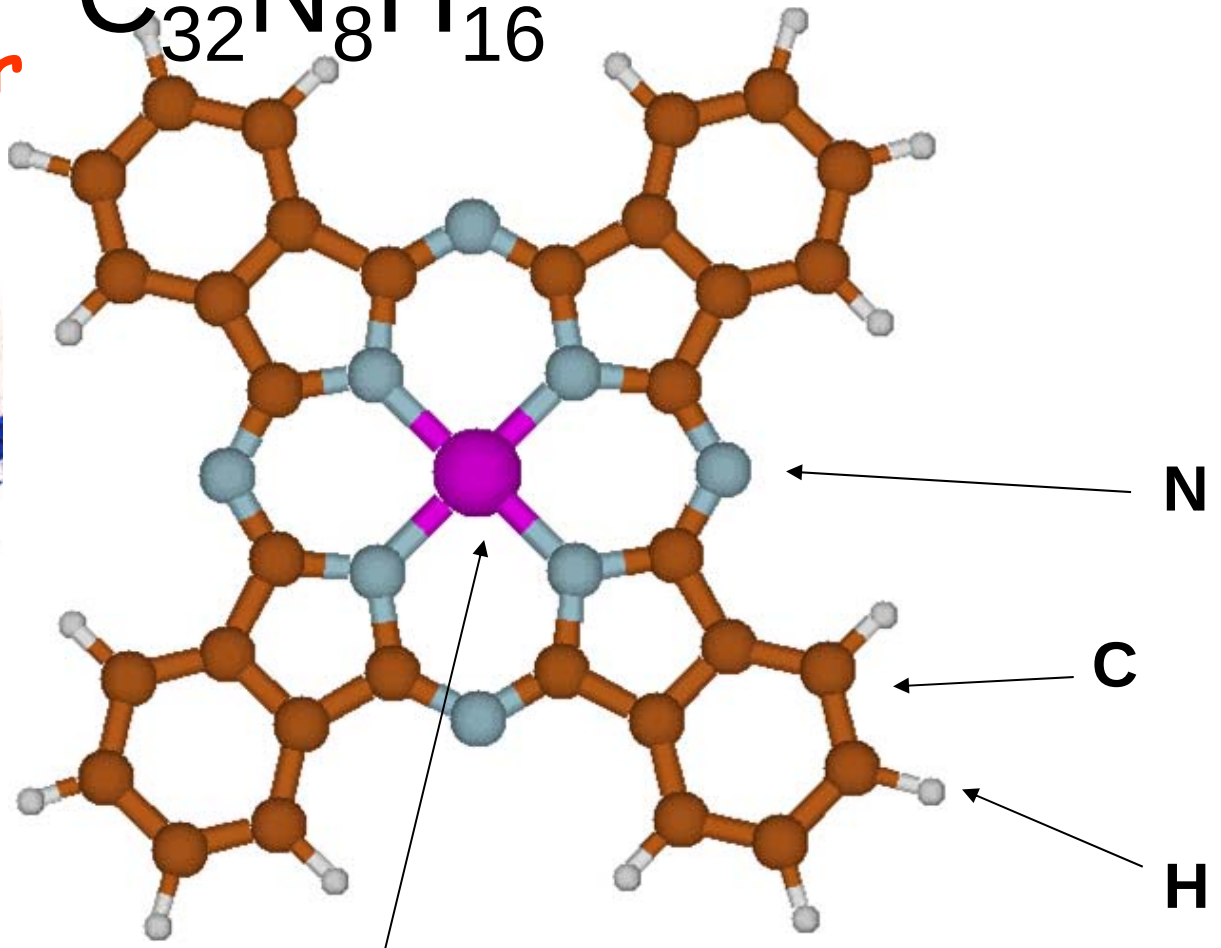
Jeongwon Park

Work supported by AFOSR-MURI



Metallo Phthalocyanine – M $C_{32}N_8H_{16}$

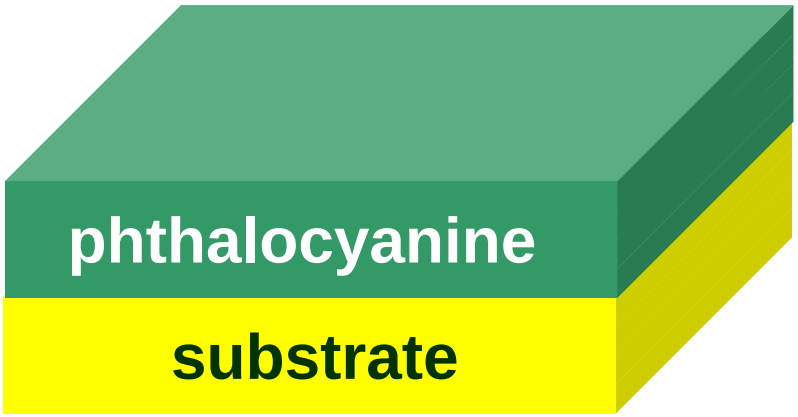
Model System for Planar Organics



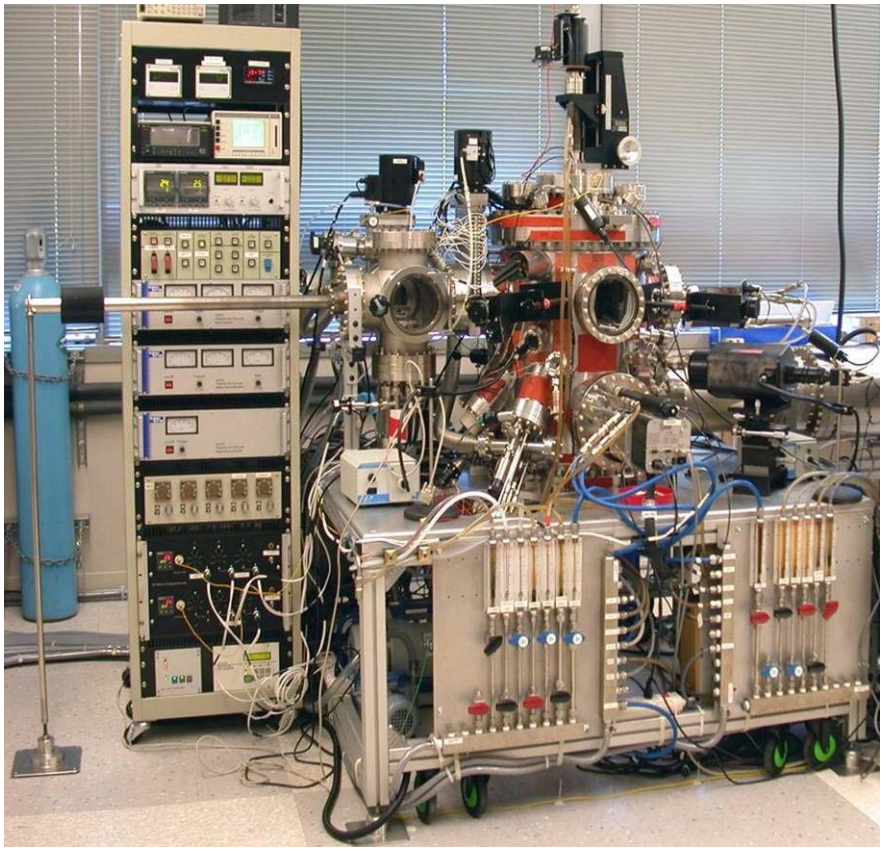
M = Cu, Fe, Ni, Co, ...or 2H

Organic Molecular Beam Epitaxy (OMBE)

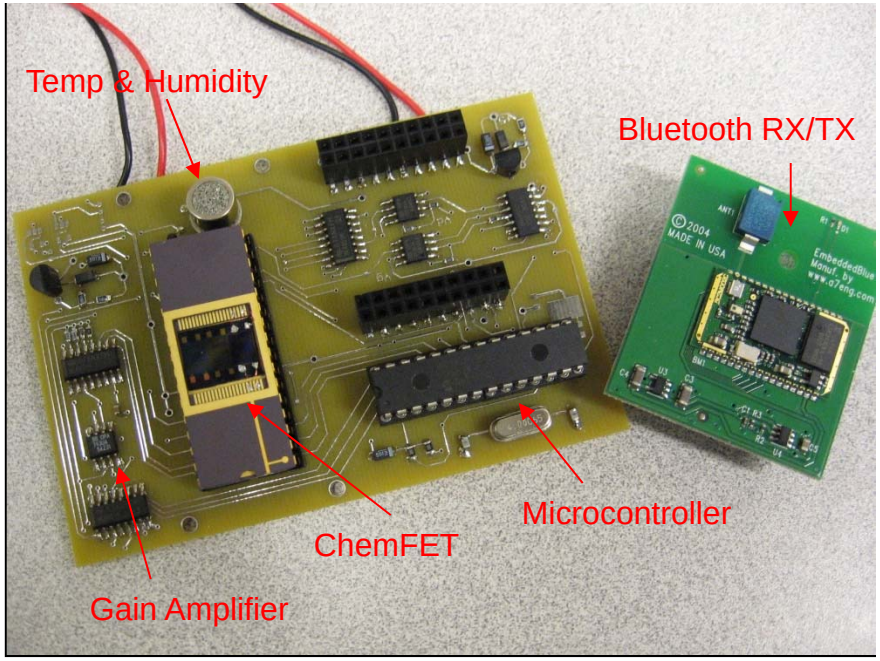
Phthalocyanine
sublimes near 400^{o}C

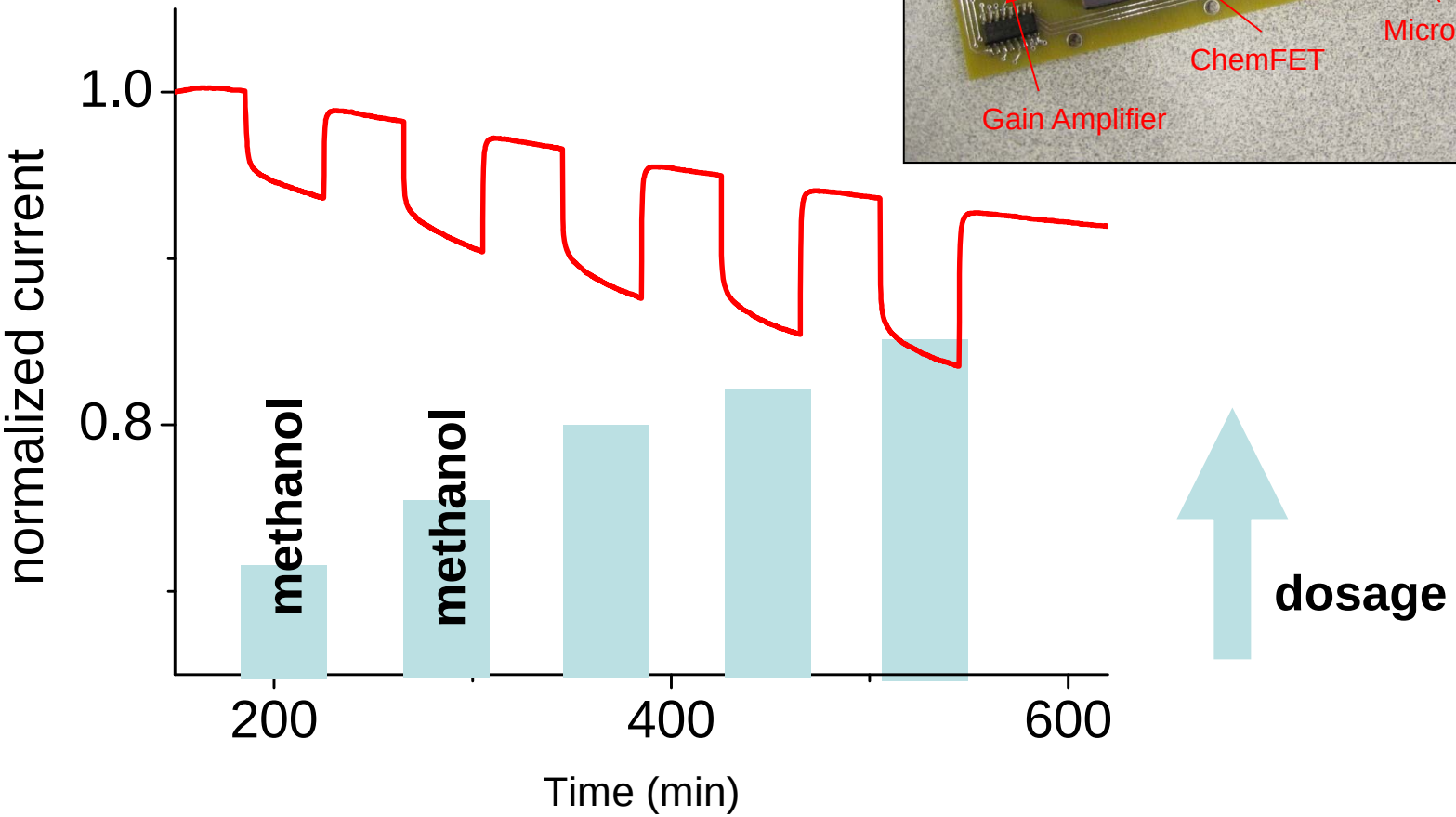


Substrate Temperature
T=30^{o}C – 250^{o}C



Chemical Sensors Change Resistance






30th ANNIVERSARY
Discoveries & Breakthroughs
DBIS #453
Sniffing Out Bombs
3
PKG 1:37
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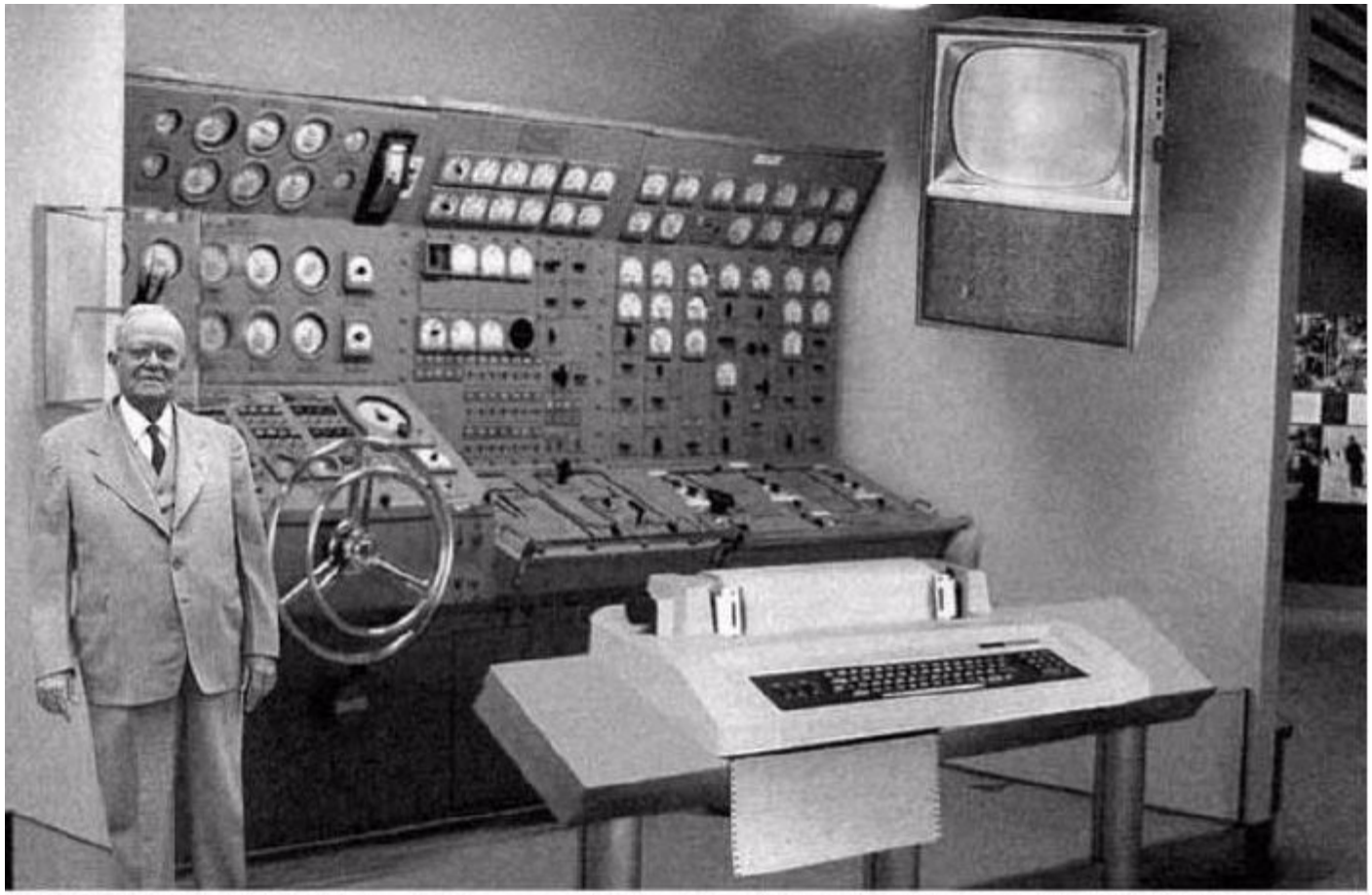
Targeted Research



Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems. With teletype interface and the Fortran language, the computer will be easy to use.

DISRUPTIVE TECHNOLOGY

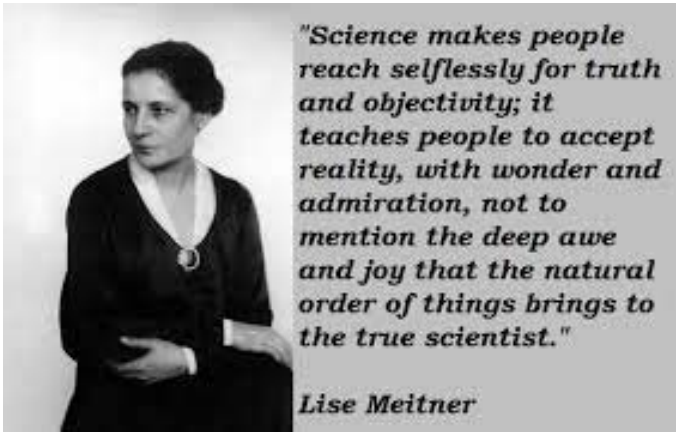
ARISES **UNEXPECTEDLY** FROM

REVOLUTIONARY BASIC SCIENCE

SUMMARY

Do what you like,
but above all
like what you do

Francisco Schuller
Paraphrasing
Lise Meitner



Enjoy the Process

- **Caminante no hay camino,**
  se hace el camino al andar.

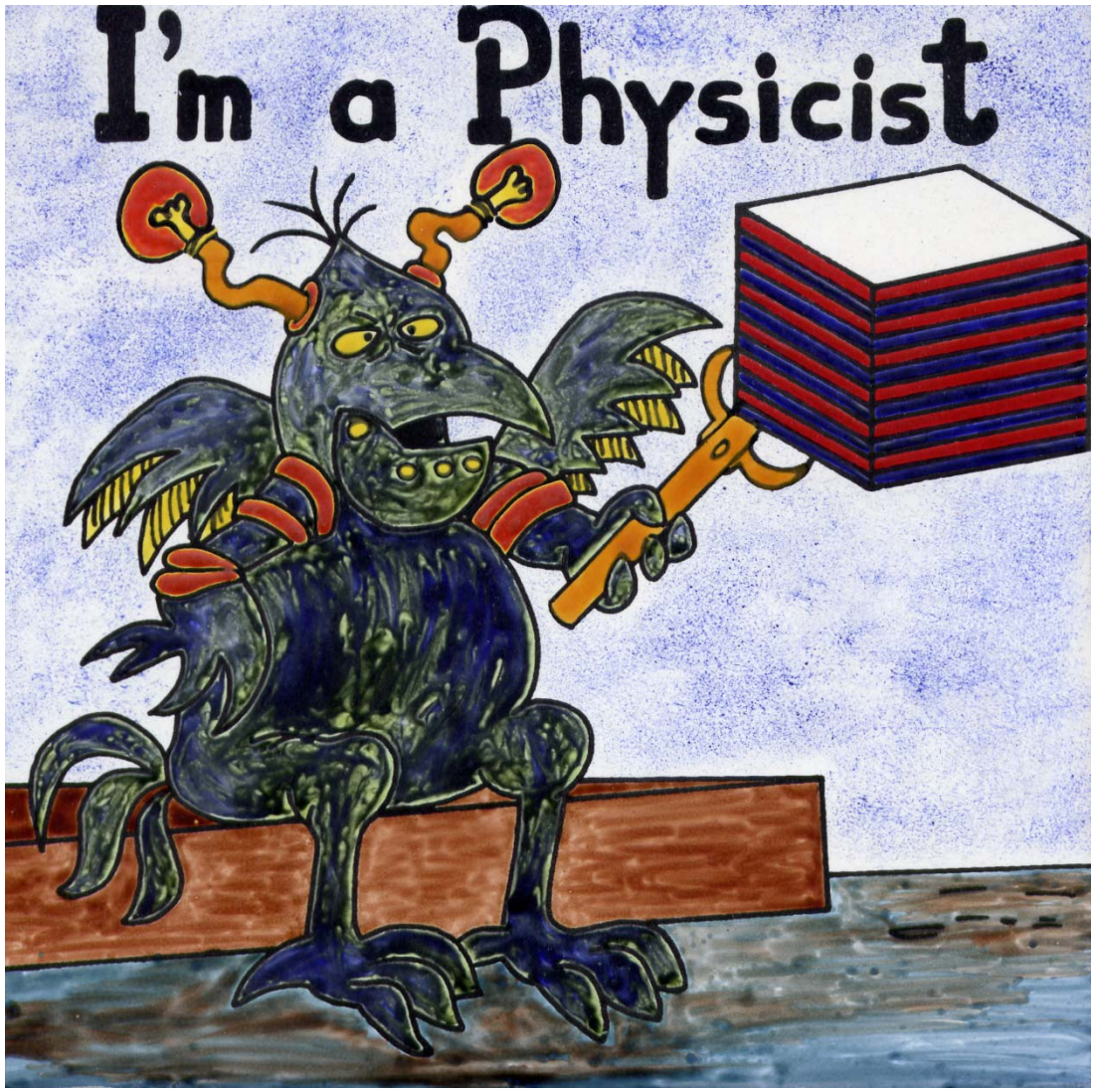
Antonio Cipriano José María y Francisco de Santa Ana Machado y Ruiz

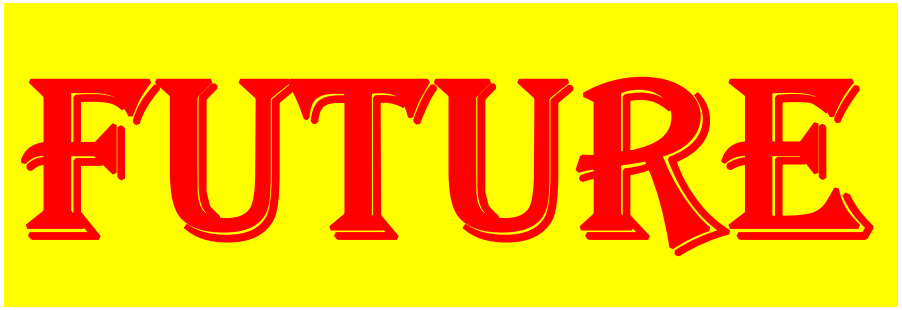
(26 July 1875 – 22 February 1939)

- **Wanderer, there is no road,**
  the road is made by walking.

Why Do Physics ?

This is Why




FUTURE