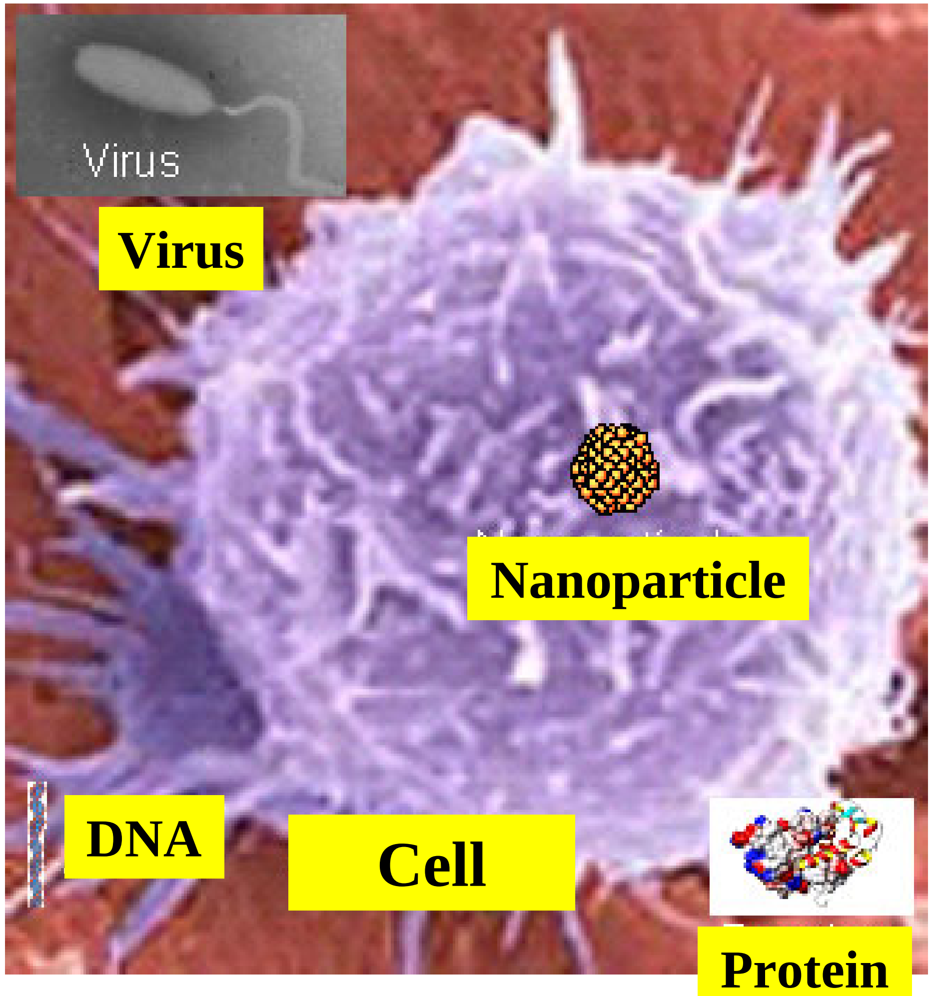
How small is Nano ?



M. A. García, P. Marín, J. M. González, P. Crespo, A. Hernando

QUESTIONS

How small is a nanometer ?

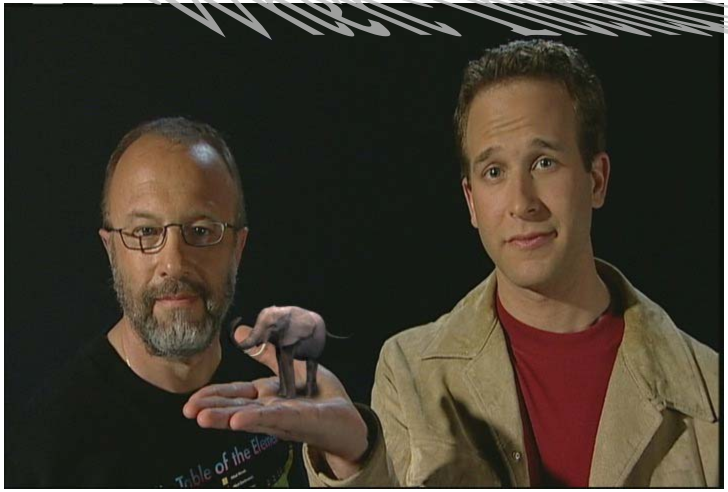
How many atoms in a single hair ?

How many nanostructures could fit in a hair ?

http://ucsd.tv/getsmall

http://ucsd.tv/getsmall

When Things Get Small



AWARDS

- 5 EMMYs

Production, Lighting, Acting, Camera, Special Effects

- 2 TELLYs

- 15 Satellite TV
- Tours

Australia, New Zeeland, India

- Museums

Mexico, Chile, Spain, San Diego

- Public Lectures

NY, San Francisco, Santiago, San Diego, Brusells

HYBRID NANOSTRUCTURES

CONFINEMENT
PROXIMITY
INDUCED PHENOMENA

Ivan K. Schuller

University of California San Diego

DOE, NSF, AFOSR, DARPA

KIMBERLY-CLARK

SURPRISE

THANK YOU KIMBERLY-CLARK

Exciting Times in Solid State Physics

Novel Frontiers

Interesting Developments

Unexpected Applications

Many Jobs

High Salaries

University of California-San Diego

- Top 10 Solid State Groups in the US
- New Institutes-Calit2, MURI, CAN………
- Many Choices

Best Weather

Best Looking Professors

We need a few good men/women

See http://ischuller.ucsd.edu

SCHULLER GROUP

- **Nanoscience:** **Thin Film, Lithography**
- **Magnetism:** **Exchange Bias, Tunneling, Transport**
- **Superconductivity:** **Pinning,Photoinduced,Search**
- **Superlattices:** **Metal, Organic, Oxides, Semicond.**
- **Organics:** **Metallo-Phthalocyanines**
- **Oxides:** **Transition Metals, Perovskites,**
- **Applications:** **Sensors, Storage, Magnetic devices**
- **Movies and Plays**

http://ischuller.ucsd.edu


UCSD
TRITONS

Universidad Complutense Madrid

D. Perez de Lara
E.M. Gonzalez
J. L. Vicent

Magnetic Materials and Devices Group

F. J. Castaño
B. G. Ng
C. A. Ross

AFOSR & DOE

UCSD Schuller Nanoscience Group

Y. ROSEN, M. EREKHINSKI

EX-

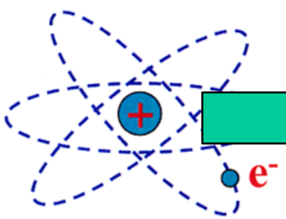
J. MARTIN, J. VILLEGAS,

F. CASANOVA, A. SHARONI

UC DAVIS PHYSICS

R. K. Dumas
Kai Liu

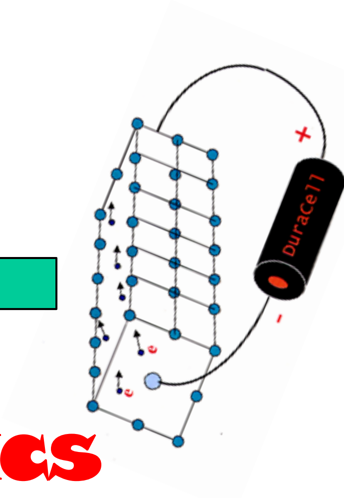
CHARACTERISTIC LENGTH SCALES



NANO SCIENCE

Chemistry

Physics



SURPRISE

Experimental Lab

- BOUNDARY CONDITIONS

VORTICES

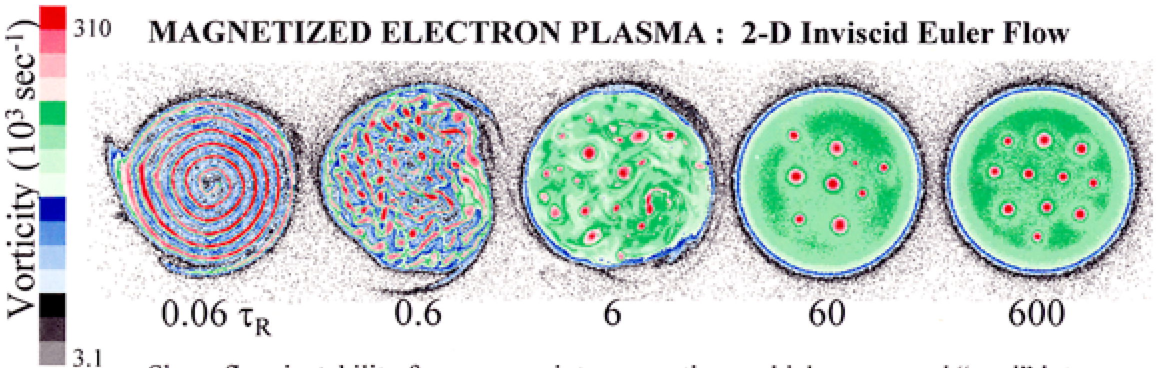
- PROXIMITY

BISTABLITY

- TIME REVERSAL SYMMETRY

RATCHET

VORTICES



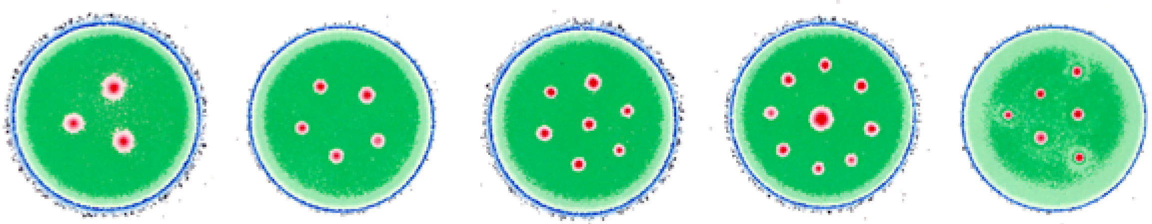
Shear-flow instability forms many intense vortices, which merge and “cool” into a “Vortex Crystal” due to effective “drag” from weak background vorticity.

Conserves : Total Circulation, Angular Momentum, Energy (dissipationless)

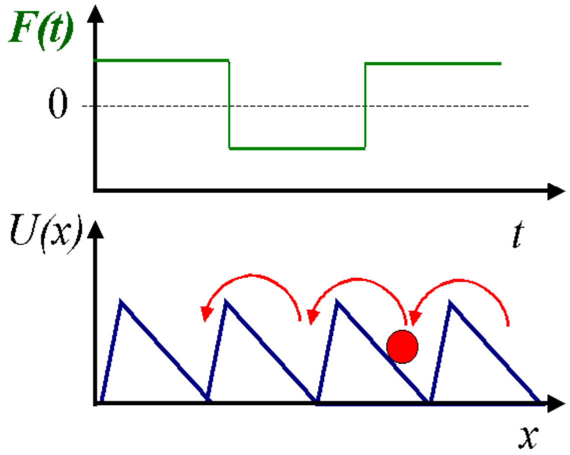
Expt : K.S. Fine … C.F. Driscoll PRL 75, 3277 (1995)

Theory : D.Z. Jin and D.H.E. Dubin PRL 80, 434 (1998)

SELECTED CRYSTAL STATES

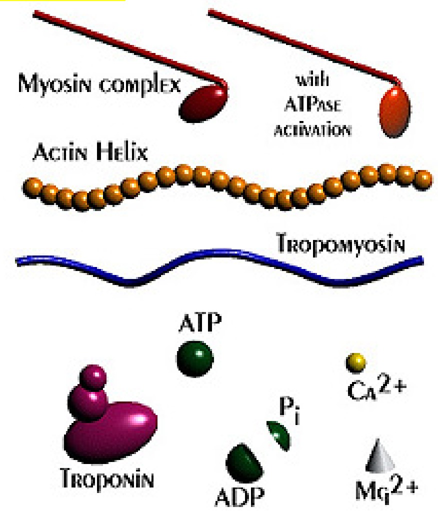


RATCHET



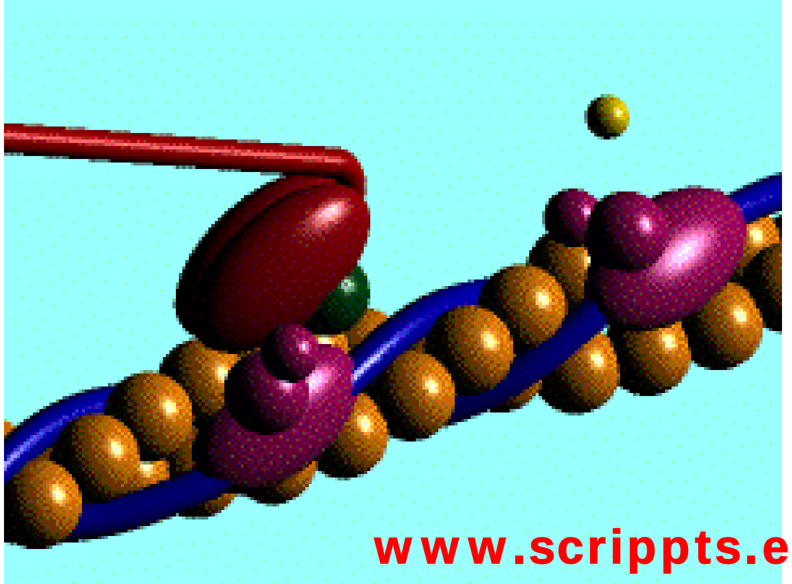
$\langle F \rangle_t = 0$

$\langle v \rangle_t \neq 0$



BIOLOGICAL MOTORS

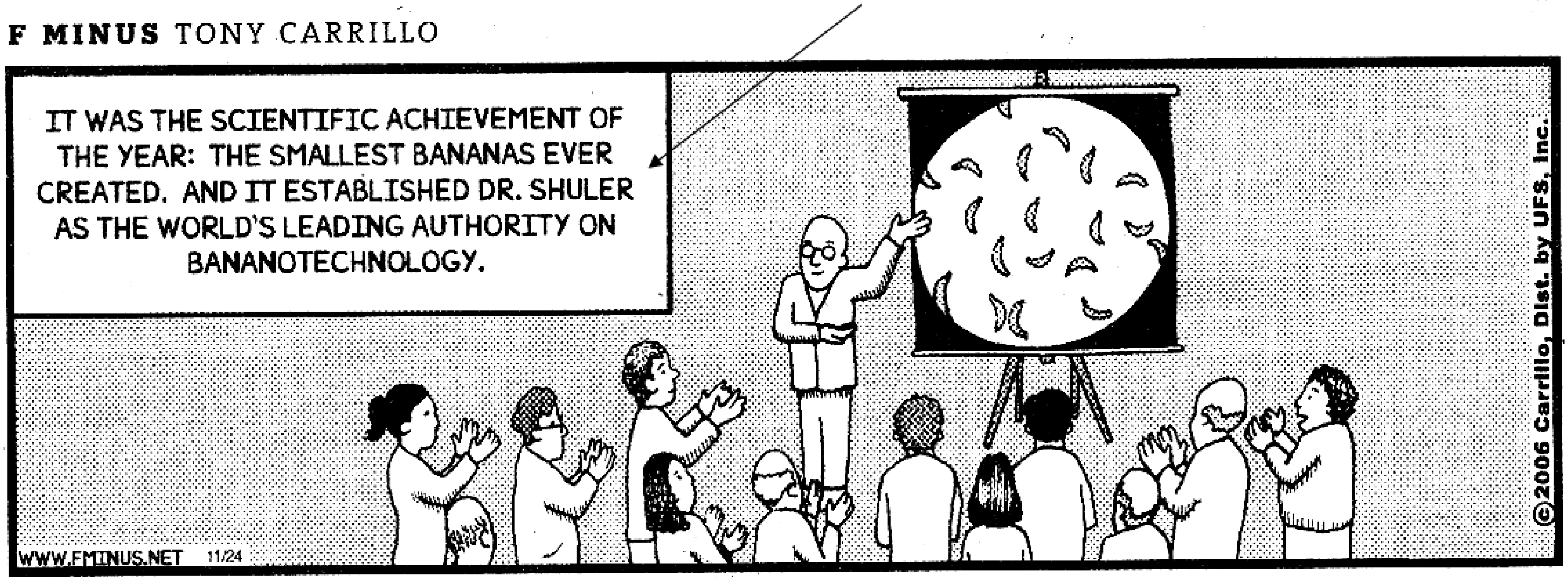
MYOSIN



www.scrippts.edu

SURPRISE

World Expert in BaNano-technology

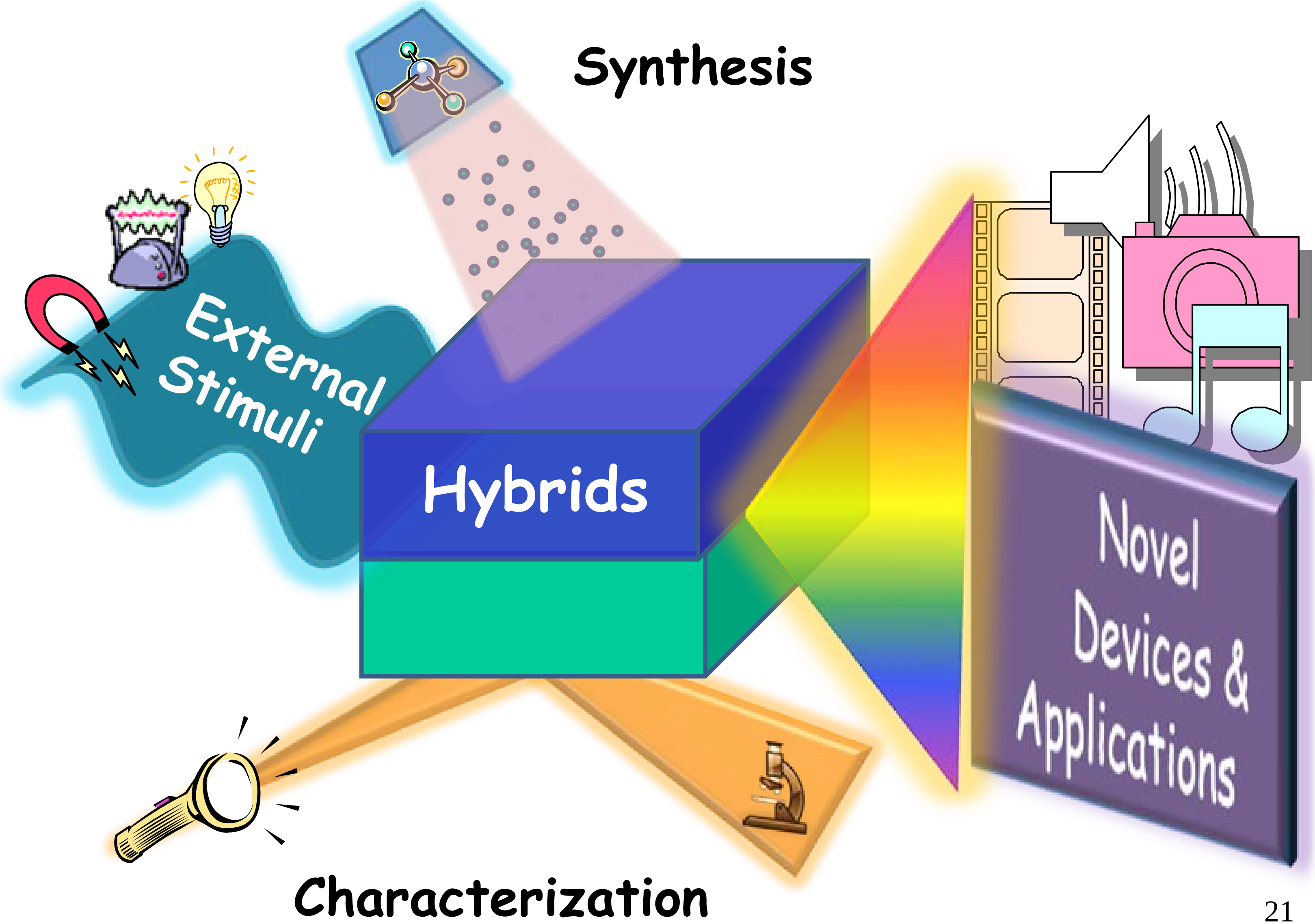


INTRODUCTION

J. Am. Chem. Soc.-Nano

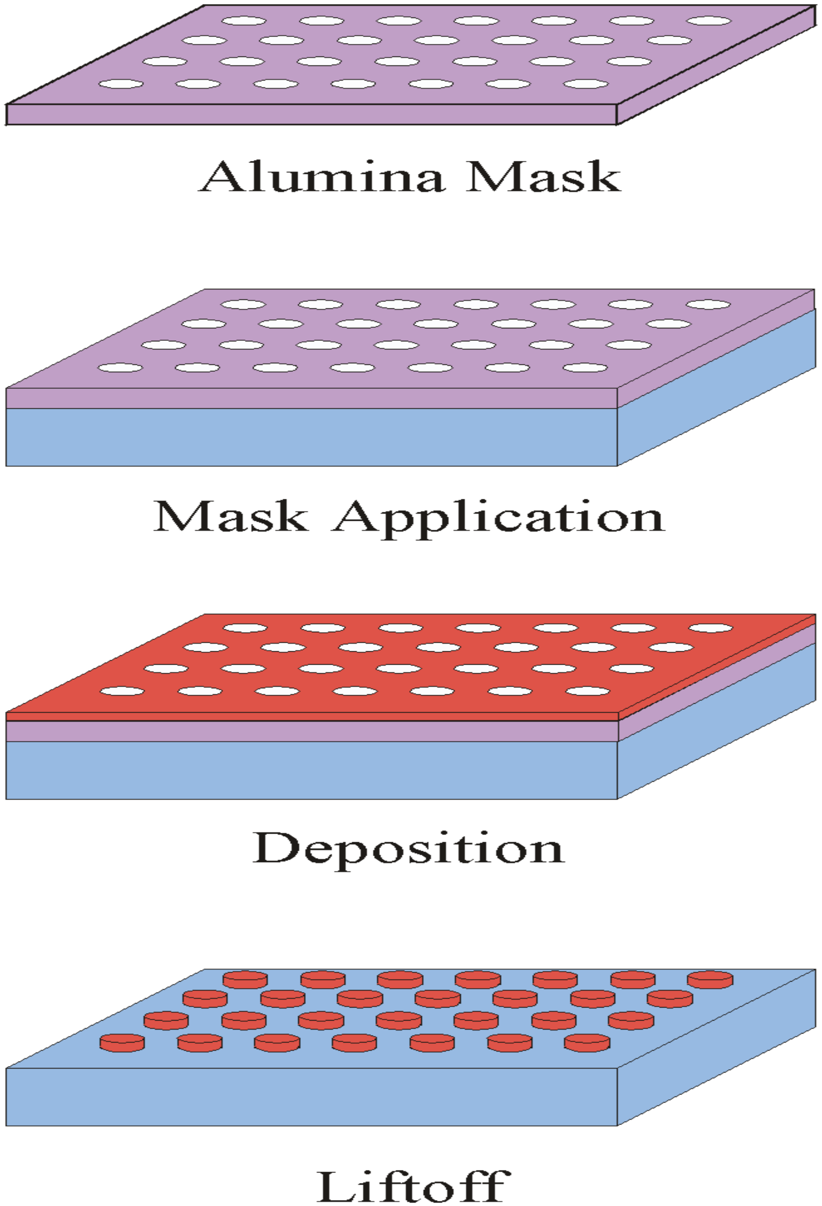
January 2008

E. E. Fullerton and IKS


Synthesis
External Stimuli
Hybrids
Novel Devices & Applications
Characterization

FABRICATION

Shadow Mask



ChangPeng Li
Igor Roshchin
Xavier Batlle

NAN0-FABRICATION

- **Lithography, high technology:**

  electron and ion beams,

  X-ray,

  Scanning Tunneling Microscope

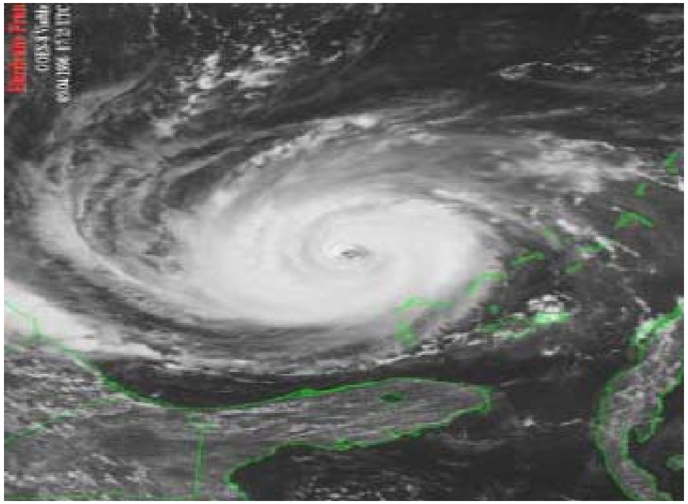
- **Self Assembly :**

  chemical

  biological

NEW FUNCTIONALITIES

- **Confinement**
- **Proximity Effect**
- **External Stimulii**



DESPINA E DON ALFONSO

In poch'ore, lo vedrete,

Per virtù del magnetismo,

Finirà quel parossismo

DESPINA AND DON ALFONSO

In a few hours, you will see

The power of magnetism

Will end this…

(Passion, Excitement, Tumult, Orgasm,…)

Cosi fan tutte

W. A. Mozart-1790

CONFINEMENT

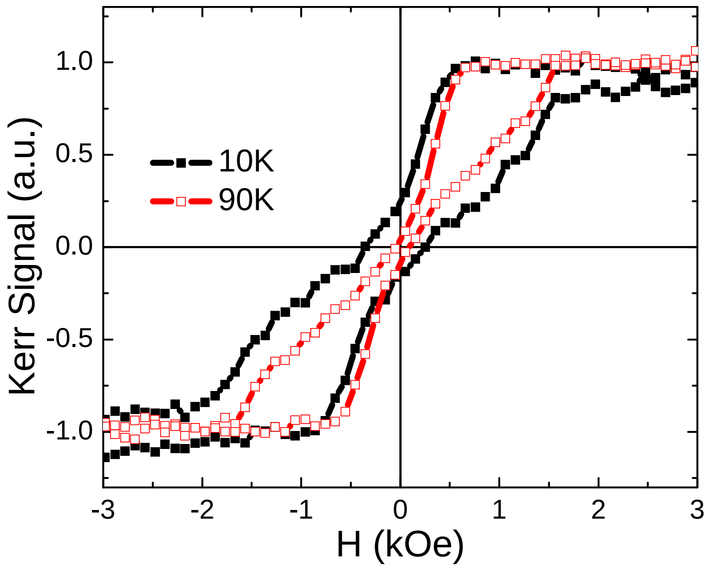
Domain Structure ???

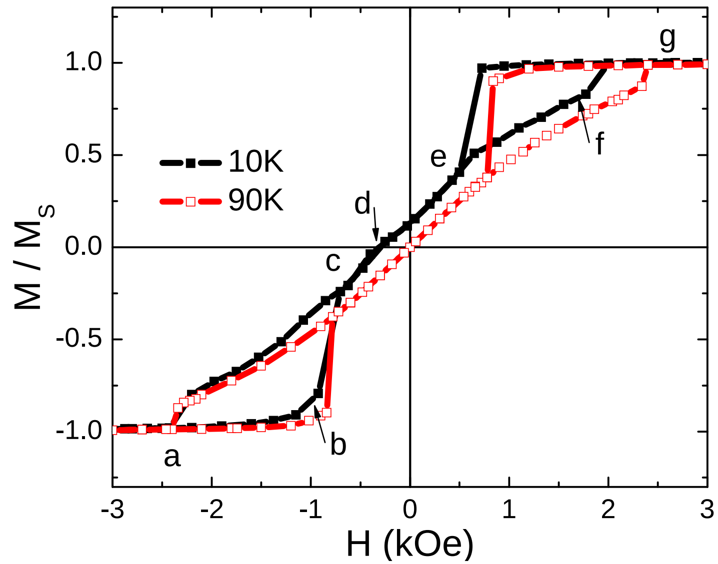
- Flat dot-Coin ???
- Indirect measurements
- Simulations
- Neutron Scattering **(Fitzsimmons-LANL Pynn-Indiana U)**
- Lorentz Microscopy **(Yimei Zhu-BNL)**

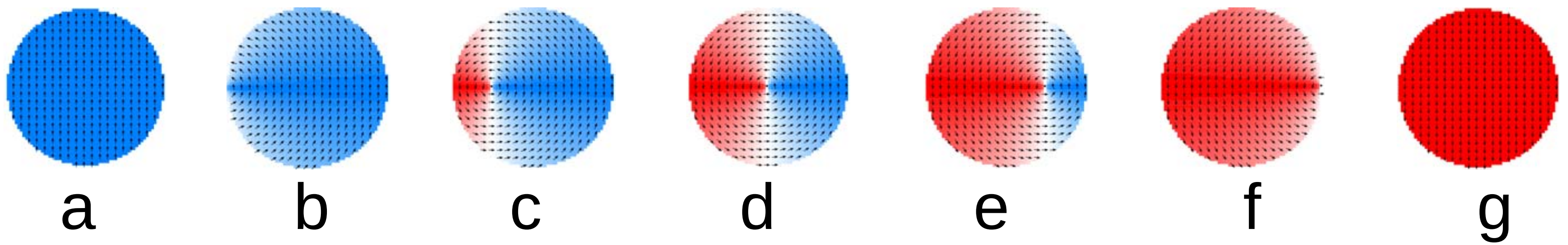
SURPRISE

Magnetization of a Coin

Vortex state- e-beam litho



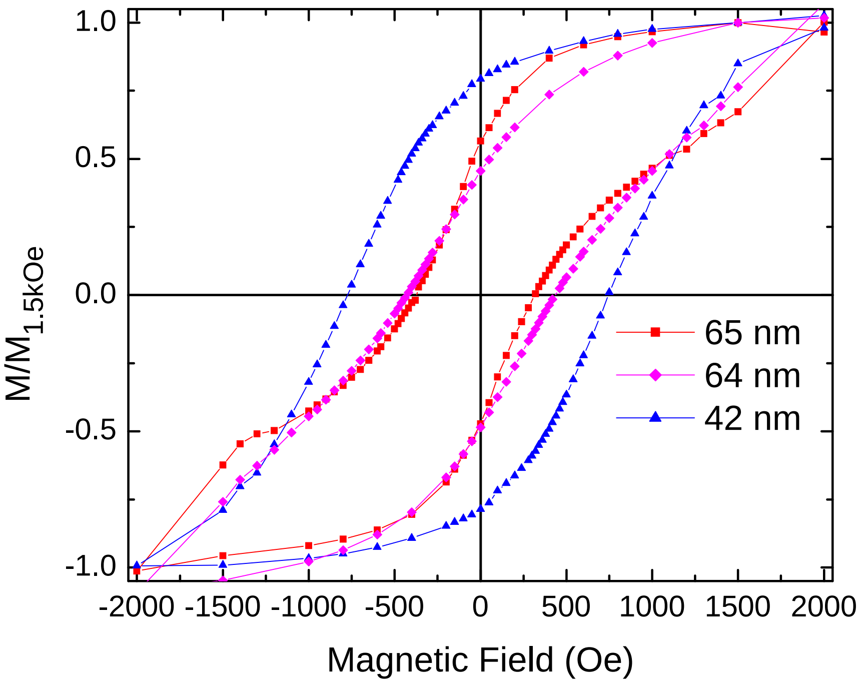


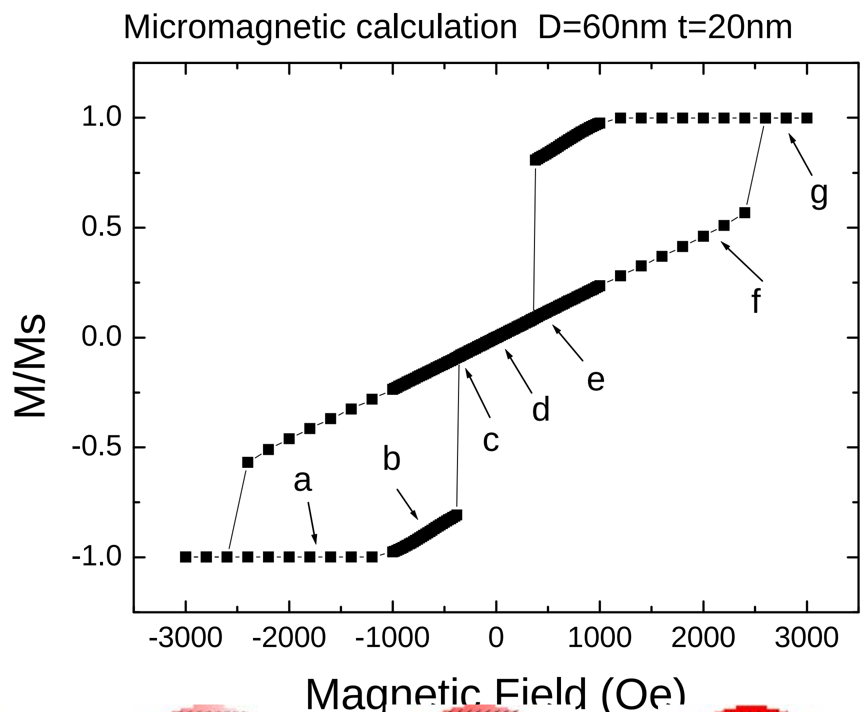


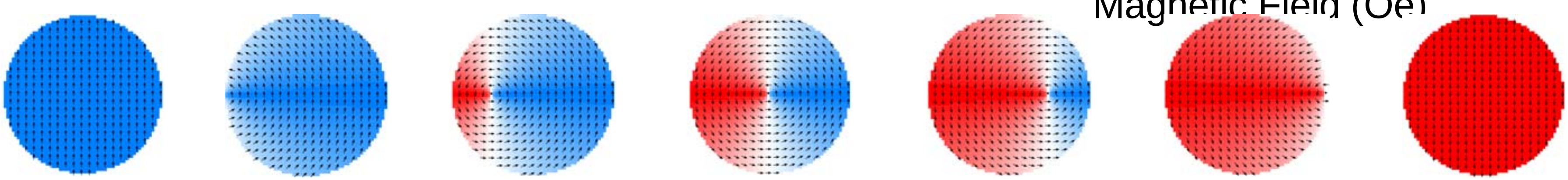
Magnetic Vortex State

Experiment

Micromagnetism





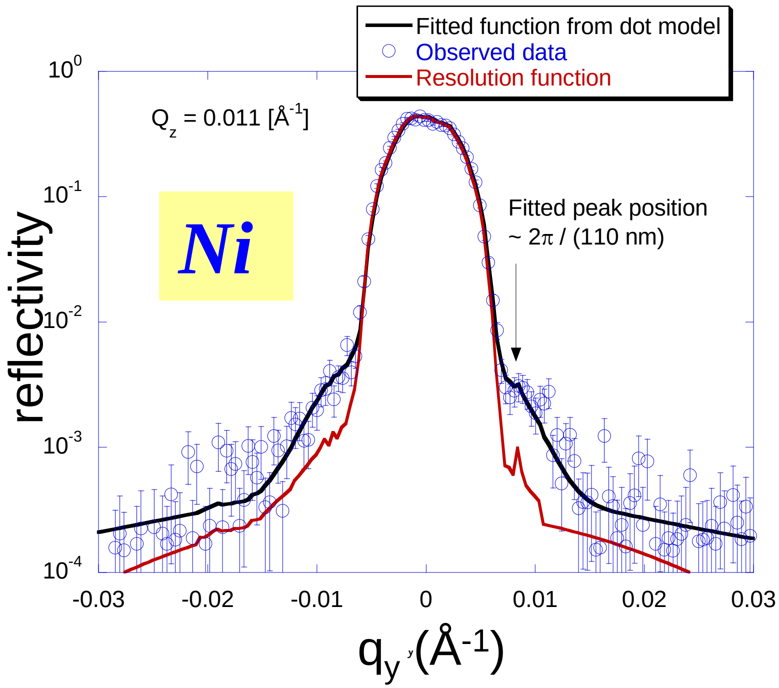


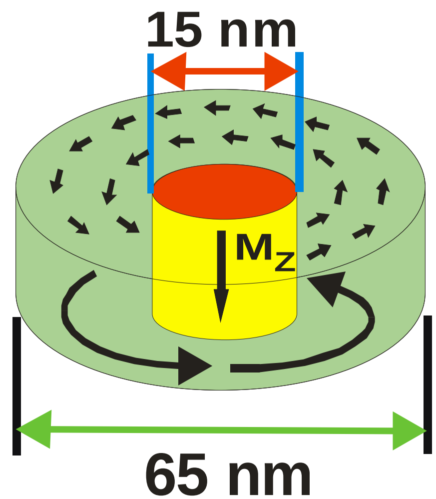
a b c d e f g

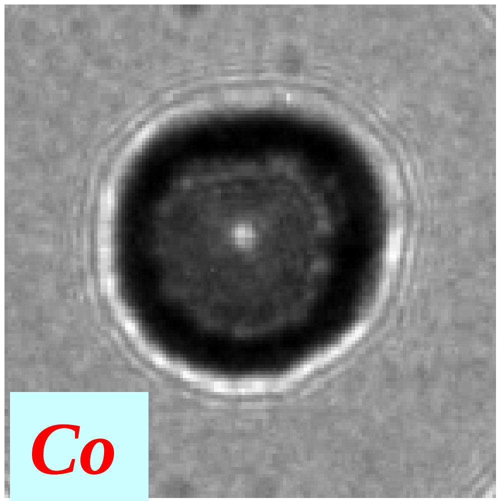
I. Roshchin, X. Batlle, M. Fitzsimmons, D. Altbir, J. Mejia-EPL86, 7008(2009)

Neutron Scattering

Lorentz Microscopy

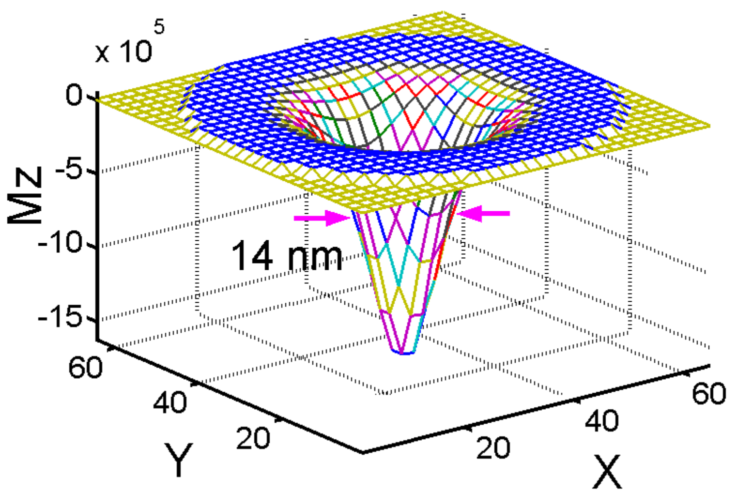






Neutron scattering:

m_z=103 emu/cm^3
Core size 15 nm



Micromagnetic simulation:

m_z=78 emu/cm^3
Core size 14 nm

I. Roshchin, X. Batlle, M. Fitzsimmons, D. Altbir, J. Mejia-EPL86, 7008(2009)

PROXIMITY

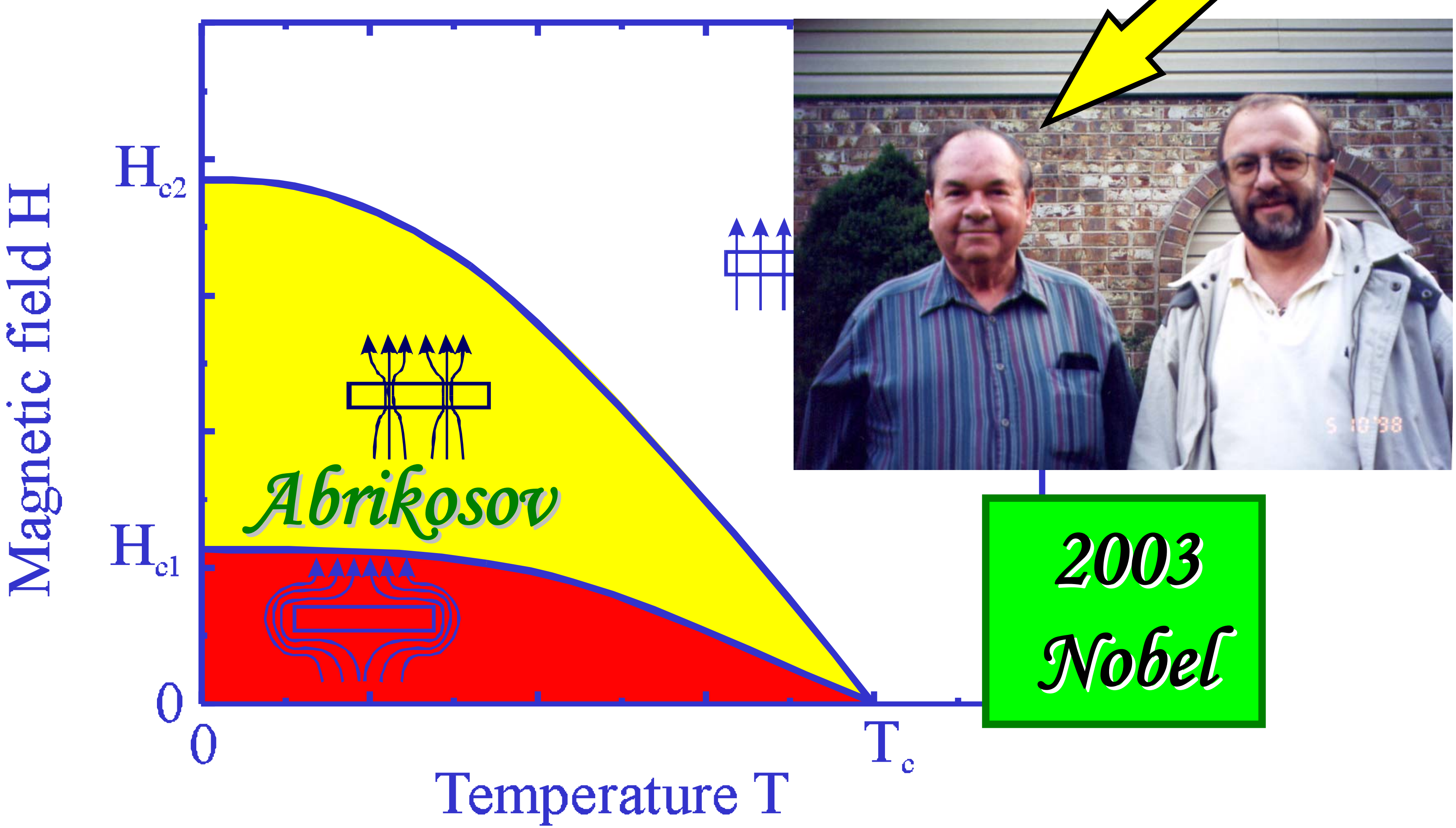
HYBRIDS

Metales como los hombres
cuando llegan a temperatura critica
pierden toda resistencia

P. Zimmerman, chilean poet

Metals like men
when they reach critical temperature
loose all resistance

Magnetic Phase Diagram
Type II Superconductor

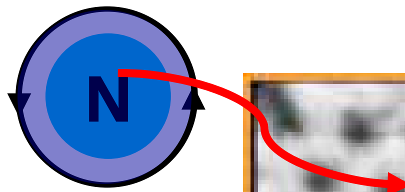


The Colbert Report

Vortex Density

$$\frac{1}{a_0^{\,2}} \approx \frac{B}{\phi_0}$$

Vortex-vortex Interaction → **Abrikosov Lattice**

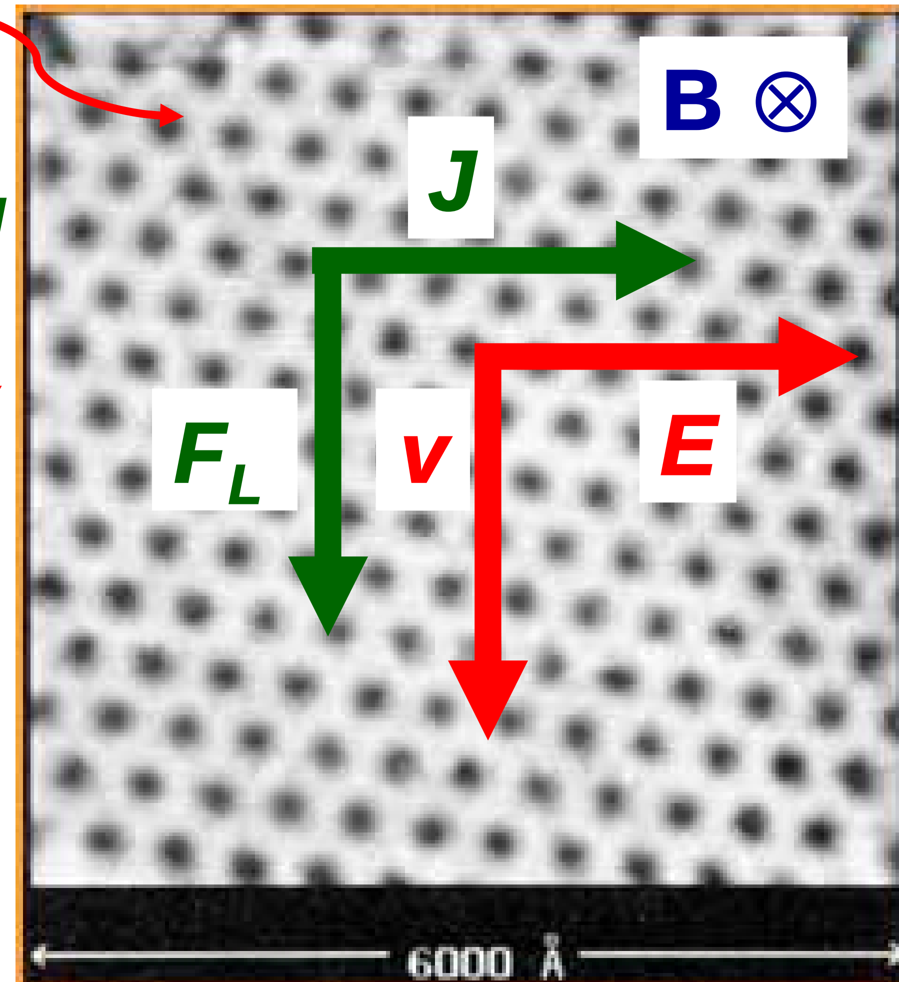


$$\vec{F}_L = \vec{J} \times \vec{B}$$ **$F_L \propto J$**

$$\vec{E} = \vec{B} \times \vec{v}$$ **$E \propto B, v$**

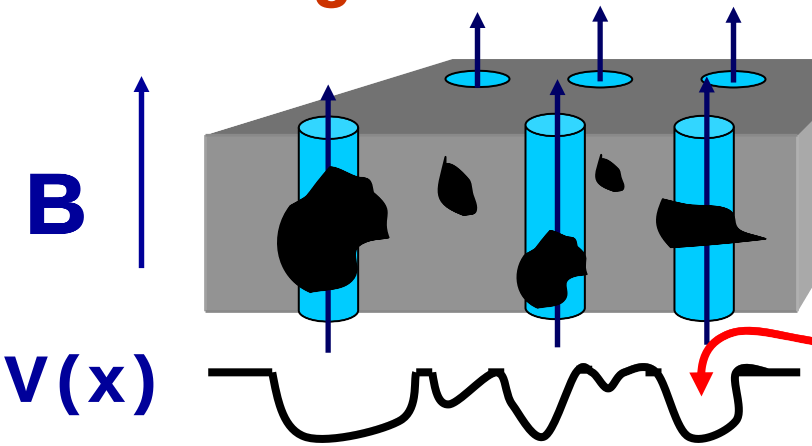
$$\vec{E} = \rho \vec{J}$$

Dissipative transport



H.F. Hess *et al. PRL (1989)*

Pinning

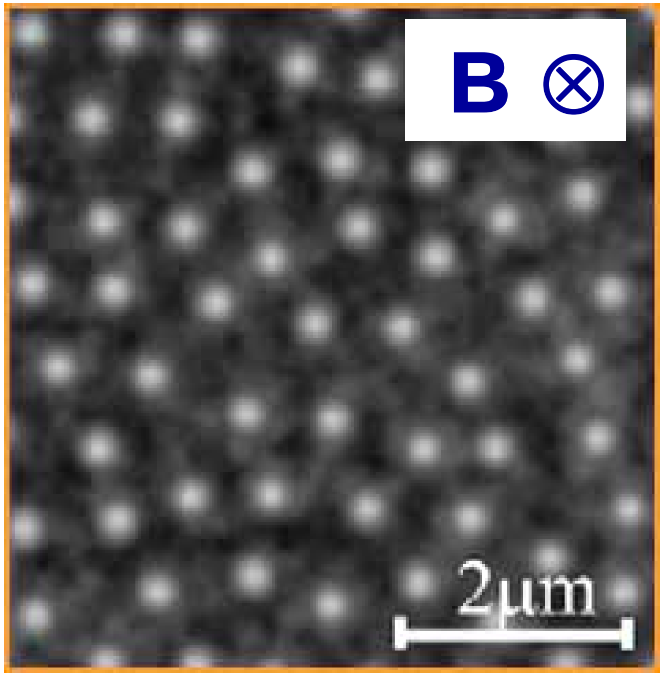


$-dV/dx = F_p$

$F_L < F_P$ ($J < J_c$)

$\rho = 0$

Intrinsic



Artificial
Size?

ξ, λ

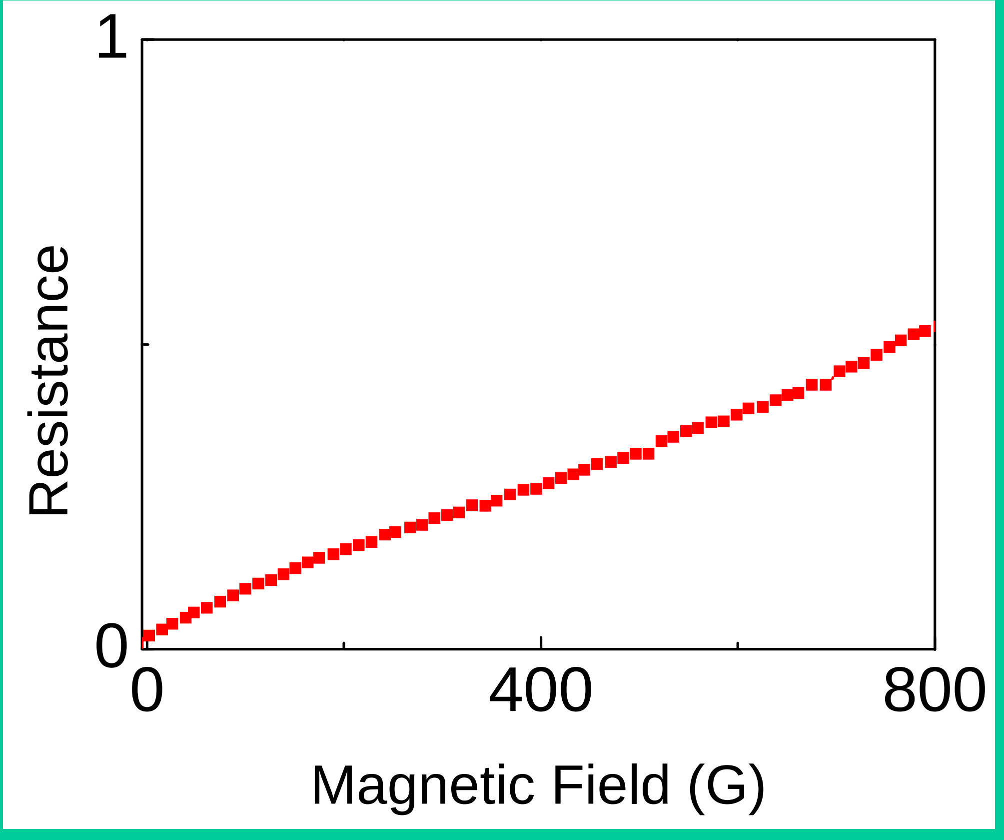
10-100 nm

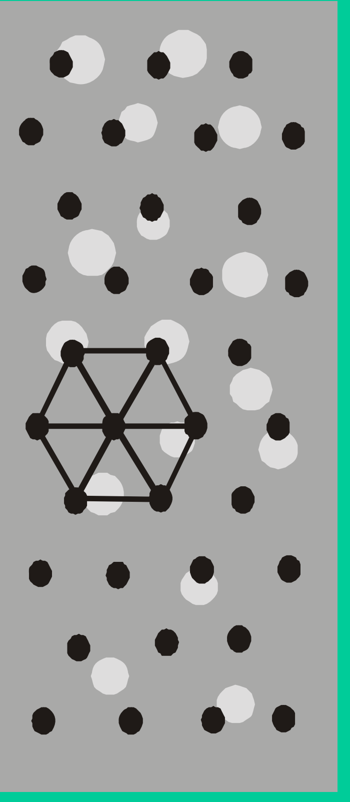
A. Volodin *et al.*, EPL 2002

What to Expect ???

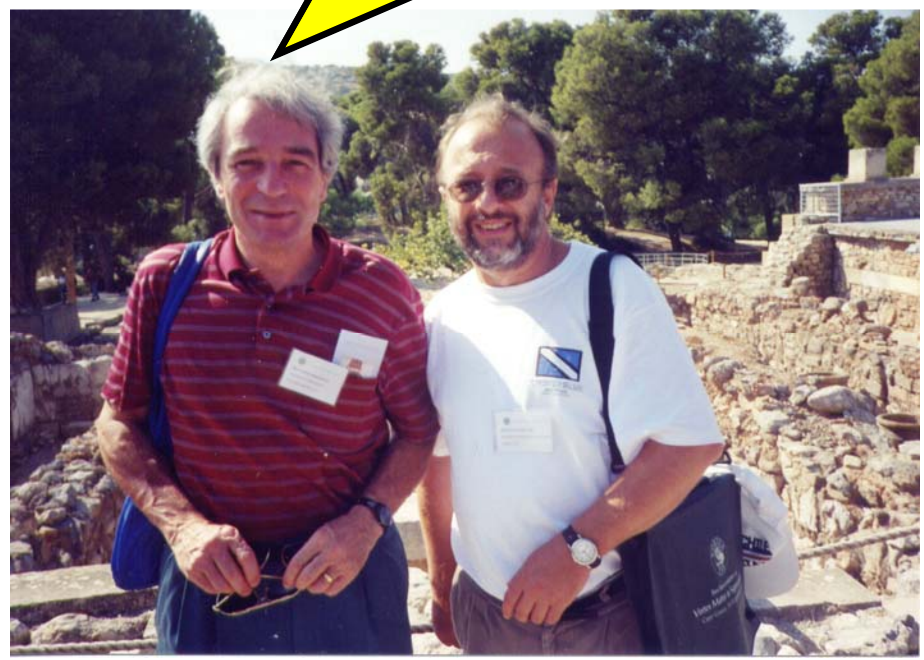
Natural Impurities:
Random Pinning

Nb Film





I wonder what happens if the pinning sites are periodic??????



Piero Martinoli

THE NEW YORK TIMES, TUESDAY, APRIL 27, 2004

The Biggest Jolt to Power Since Franklin Flew His Kite

By BARNABY J. FEDER

SCHENECTADY, N.Y. — In a one-time printing plant on the edge of this tattered manufacturing city, a small company named Superpower churns out sample after sample of what looks like shiny metal tape.

The tape has five layers. The middle one, a ceramic film one-tenth as thick as a human hair, exhibits one of nature's most tantalizing tricks. At very low temperatures, the ceramic abruptly loses all resistance to electrical current.

That free-flowing current generates a strong magnetic field, a feature that Superpower technicians demonstrate by showing visitors how a thumbnail-size magnet floats half an inch or so above a ribbon of chilled tape.

Superconductivity, as the phenomenon is known, has fascinated and baffled scientists since its discovery in 1911. Even now, they have yet to develop a comprehensive theory to explain its appearance in materials as diverse as metal and ceramics.

Such scientific conundrums are of only passing interest at Superpower, a four-year-old subsidiary of Intermagnetics General, and at other companies like it. After years of false starts and setbacks, these companies say they are closing in on the goal of producing relatively inexpensive superconducting wire for power generators, transformers and transmission lines.

Success requires making yard after yard of wire, and eventually mile after mile. The focus at the companies, at national laboratories and at many universities is on questions that call for a genius more like Edison than Einstein.

"We are finding out what works and going with that," said Dr. Jodi L. Reeves, a senior materials scientist at Superpower.

Success could spring superconduc- [illegible]

High-Speed Tape? Try This

Several companies are trying to cut the costs of making superconducting tape-like wire (right), which is wound into cable. Here is one approach.

PRESENT VERSION Now used in commercial products and prototype electrical applications.

NEWER WIRE Cheaper, with potential for higher performance using nanodots.

SILVER ALLOY FRAME

SUPERCONDUCTOR FILAMENTS

SILVER ALLOWS BENDING, PREVENTS OVERHEATING

SUPERCONDUCTOR

THREE LAYERS PREVENT CHEMICAL CONTAMINATION

BASE LAYER PRECISE TEMPLATE ORIENTS SUPERCONDUCTOR ATOMS

SMALL SECTION OF SUPERCONDUCTOR

DESIGNED TO INCREASE FLOW Magnetic fields surround all electric current. As current increases, these "flux lines" impede the path of electricity.

FLUX LINES

"Nanodots," each about 100 atoms [illegible] non-superconducting particles tha[illegible] flux lines and hold them in place. [illegible] lines pinned, current can flow unrestricted.

NANODOTS

Source: American Superconductor Corp.

Bill Marsh/The New York Time[s]

low zero Fahrenheit. To reach that point, they have to be cooled by liquid helium, which is expensive to make and manage.

By contrast, ceramic superconductors work at temperatures above minus 321 Fahrenheit, allowing them to be cooled by liquid nitrogen, an inexpensive industrial refrigerant. For that reason, they are called high-temperature superconductors, though they are still far from the dream of a room-temperature superconductor.

The first reports of ceramic superconductors, in 1986, touched off a global research race to understand them and find others. The excitement peaked at the annual meeting of the American Physical Society in March 1987, when thousands of researchers crowded into a hastily organized midnight presentation.

ness. Experts from Intermagnetics General, a manufacturer of superconducting metals that was spun out of General Electric in 1971, immediately began work on the materials.

"Superconductivity was guaranteed to be a field where everything you did would be new," said Dr. Venkat Selvamanickam, who joined the first wave of research as a graduate student at the University of Houston, home to one of the leading

On the verge of making electricity leaner and meaner

the magnetic field drift through the superconducting layers of the tape like swirling weather systems through the atmosphere. Figuring how to immobilize th[illegible]agnetic vortices, an atomic-sc[illegible] process called pinning, has em[illegible]ed as a crucial area for resear[illegible]

Early cera[illegible] compounds were based on bis[illegible]th. The complexity of manufactu[illegible]g and the need to rely on silve[illegible]ubstrates to provide a workab[illegible]mix of strength and stability to [illegible] bismuth compounds kept cost[illegible] much higher than standard co[illegible]r wires that companies lost [illegible]idence that they could compete [illegible] mass markets.

Although bismuth-based wires have been useful for research and in a few products that help stabilize power grids, the spotlight has shifted to another compound, a mixture of

The last steps will not be easy While the semiconductor industr[y] works on improving technology t[o] produce ever thinner films, super conductivity companies chase th[e] opposite goal, making thicker film[s] to carry more current.

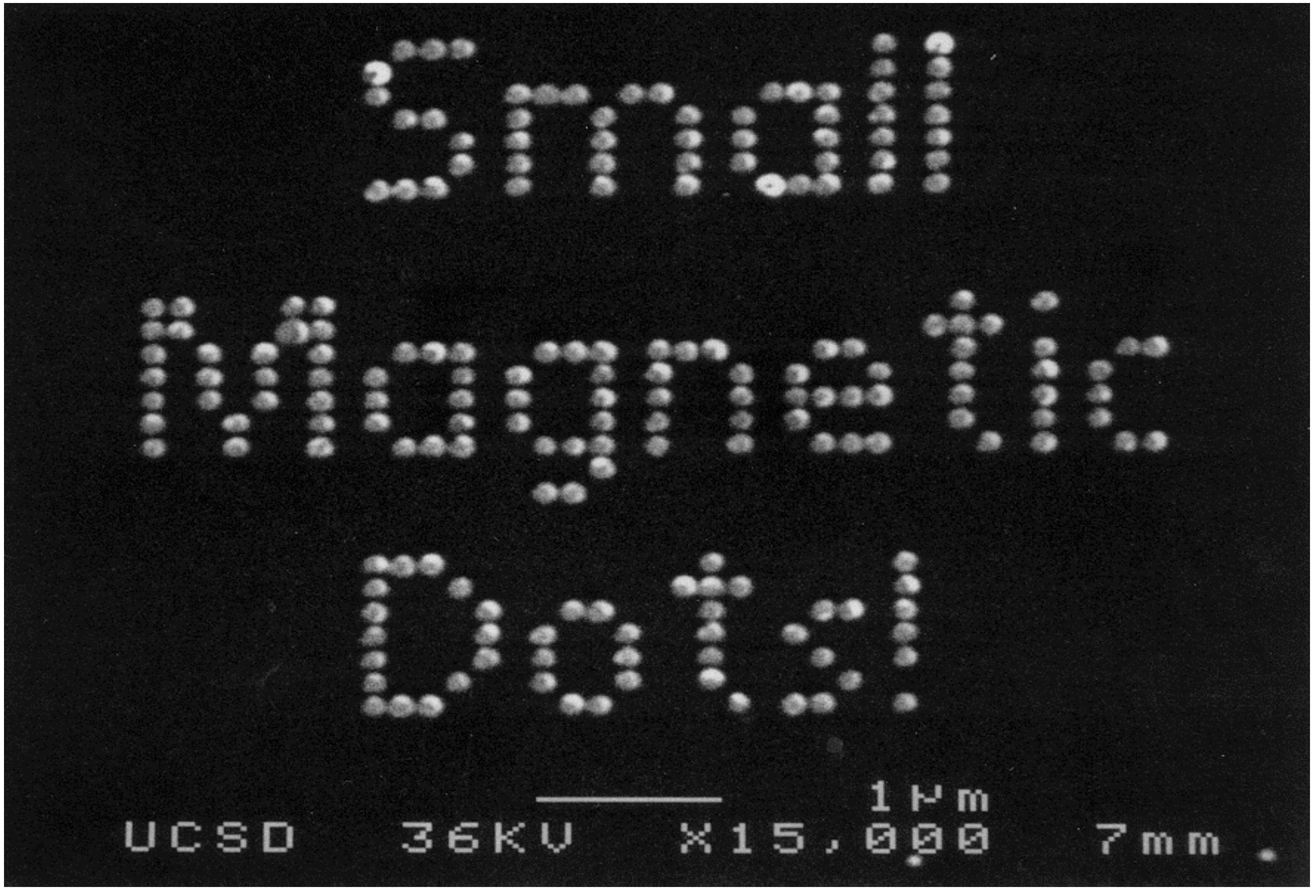
The best available process for de positing YBCO involves blasting [illegible] chunk of it in a vacuum chambe[r] with high-energy laser pulses an[d] running the tape through the result ing plume. But pulsed lasers use to[o] much time and money to produc[e] large quantities of wire. So compa nies are looking for other methods.

"There's probably a dozen ways t[o] deposit the superconductor," sai[d] Dr. Dean Peterson, head of the re search program at the Los Alam[os] National Laboratory, which has bee[n] researching the alternatives an[d] how to improve them.

NANODOTS

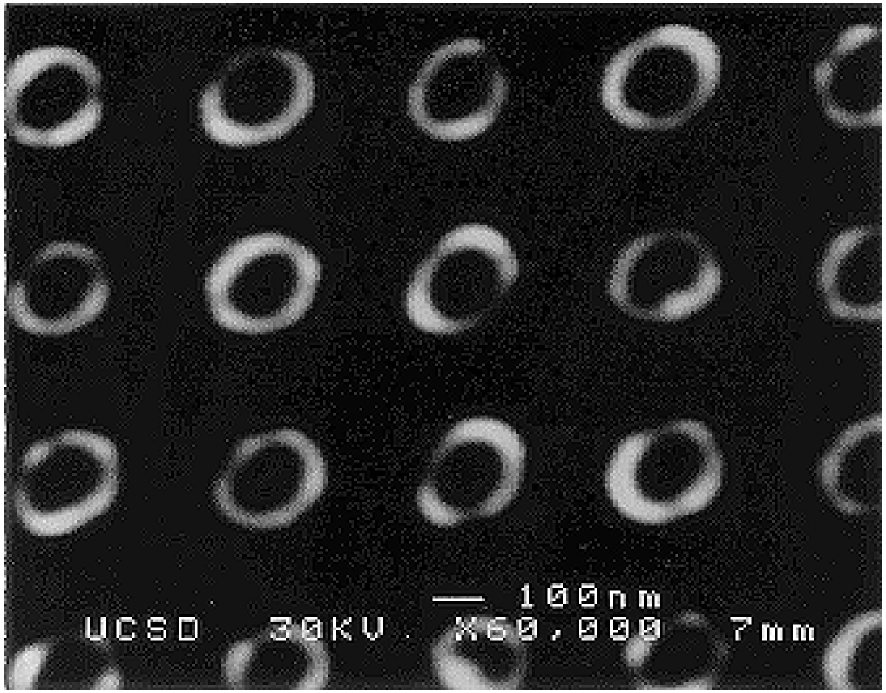
Figuring how to immobilize the magnetic vortices,
an atomic scale process called pinning,
has emerged as a crucial area of research

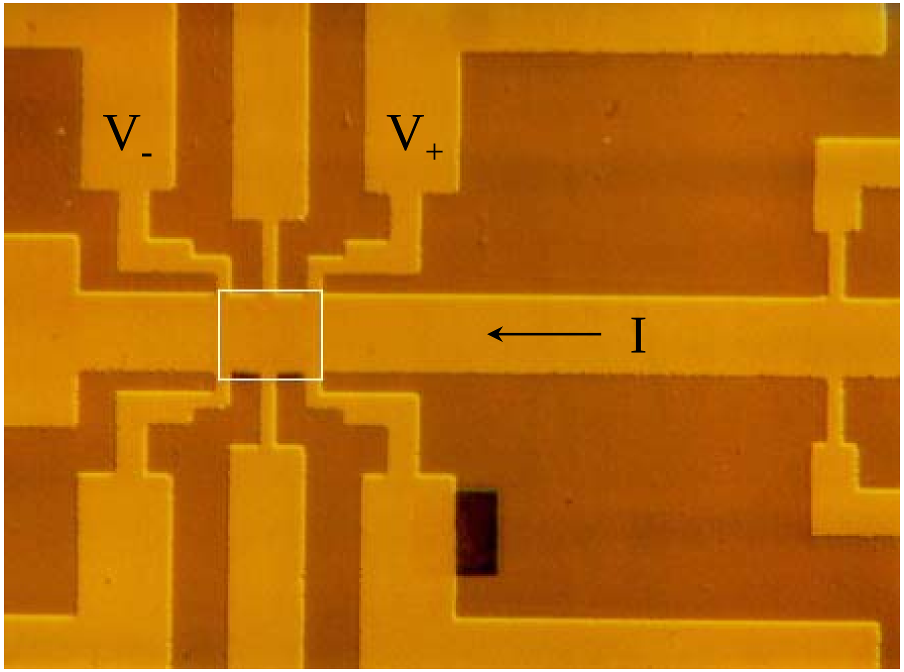
Periodic Vortex Pinning with



**Javier Villegas, Maribel Montero, Jose Martin,
Pilar Gonzalez, Elvira Gonzalez, Axel Hoffmann
Jose L. Vicent, Ivan K. Schuller**

Nanostructures Microstructures

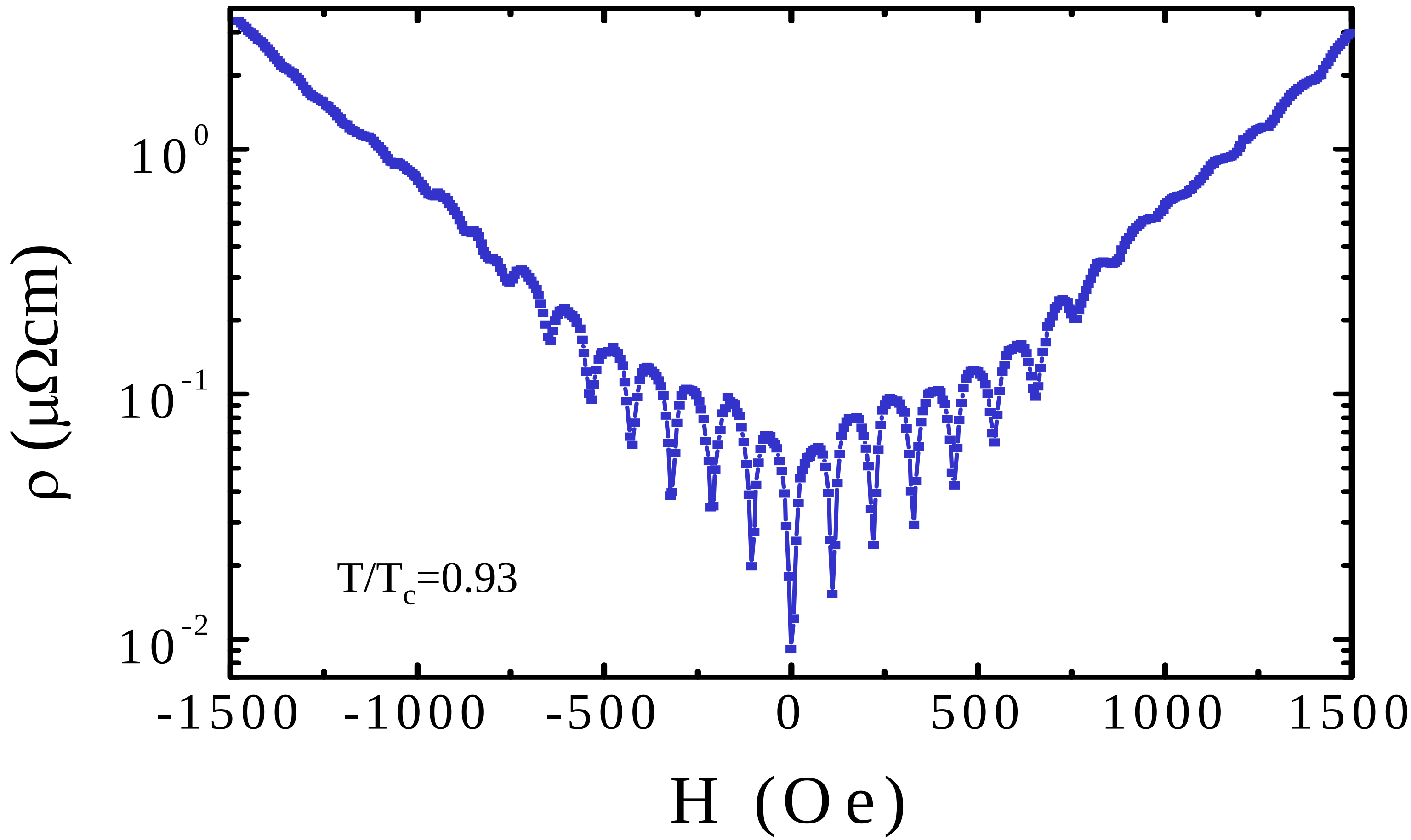




Magnetic Dots Nb Film

SURPRISE

Magnetoresistance
Collective Pinning



- up to 8th order peaks!
- square lattice of Ni dots (∅ 340 nm)

REMEMBER

H proportional

to

number of vortices

n=1 implies 1 vortex/plaquette

n=2 implies 2 vortices/plaquette

……………………

NEW PHENOMENA

- **Distortion of the vortex lattice**

(J. Martin, PRL 1999)

- **Vortex channeling**

(J. Villegas, PRB 2005)

- **Fractal lattices**

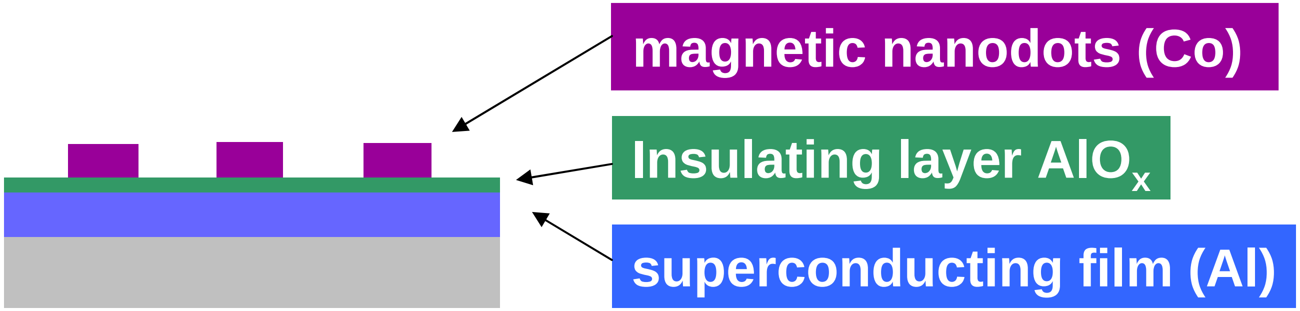
(J. Villegas, PRL 2006)

- **BISTABLE SUPERCONDUCTIVITY**

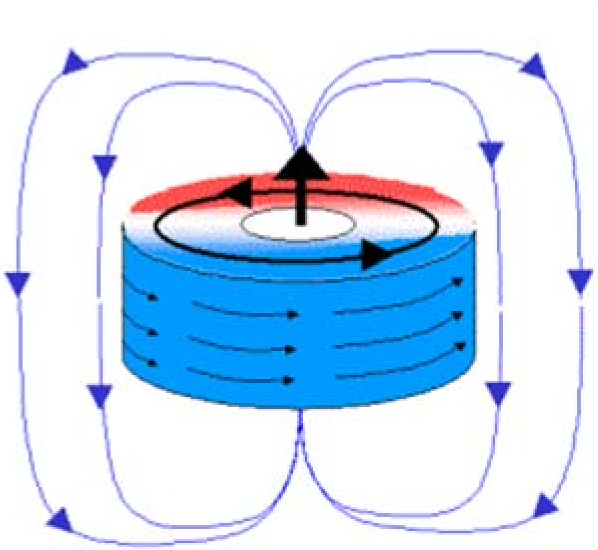
(J. Villegas, PRL 2007)

- **RATCHETS**

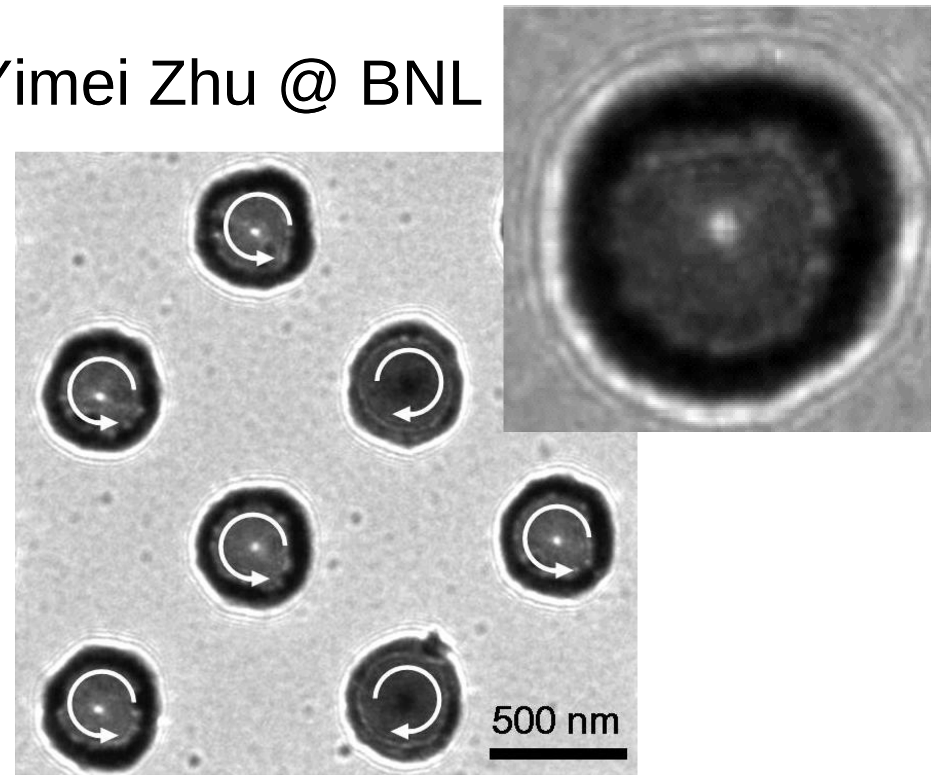
(D. Perez, PRB 2009, 2010)



"magnetic vortex"



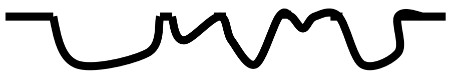
Yimei Zhu @ BNL



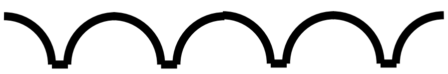
Lorentz microscopy images

48

Switchable pinning landscapes



MAGNETIC
HISTORY



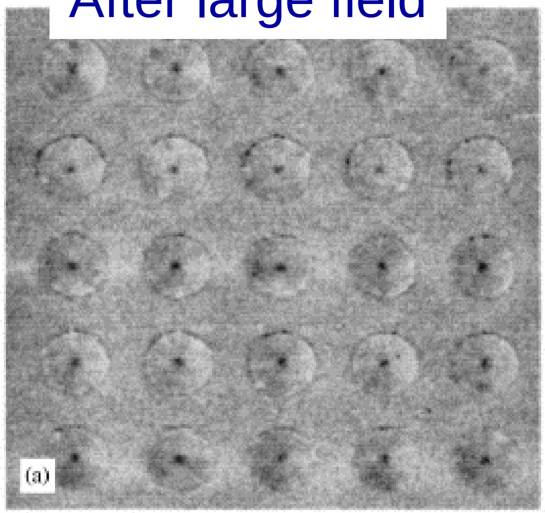
disordered
pinning landscape

ordered
pinning landscape

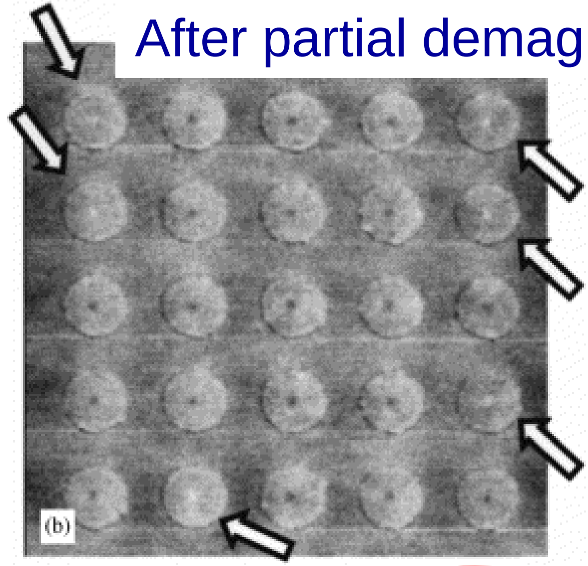
J.E. Villegas *et al.* PRB **77**, 134510 (2008)

Remanent states

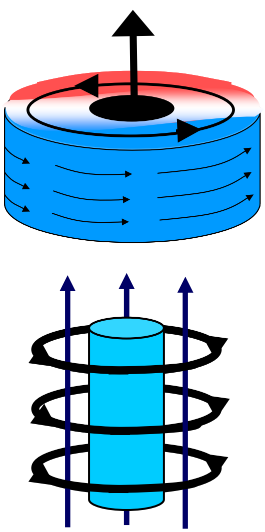
After large field

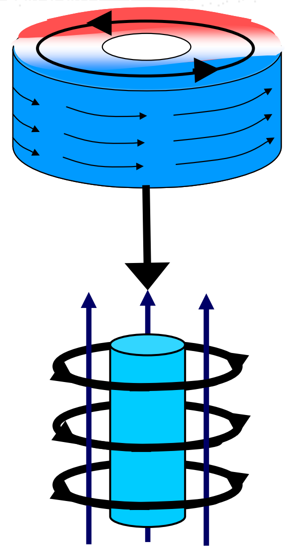


After partial demagnetization



MFM images
T. Okuno *et al.*
JMMM (2001)





50

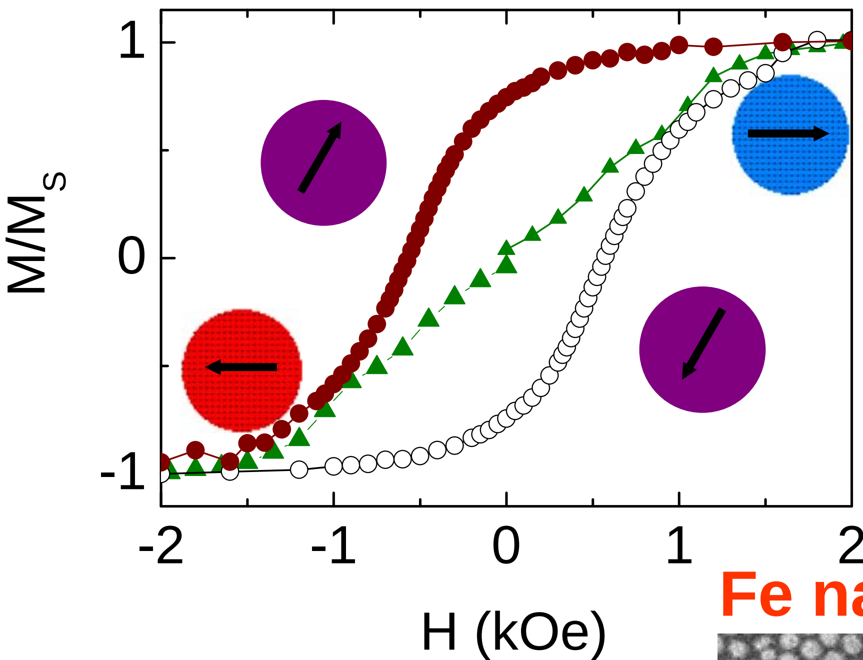
Bistable superconductivity

A REAL HYBRID BEHAVIOR

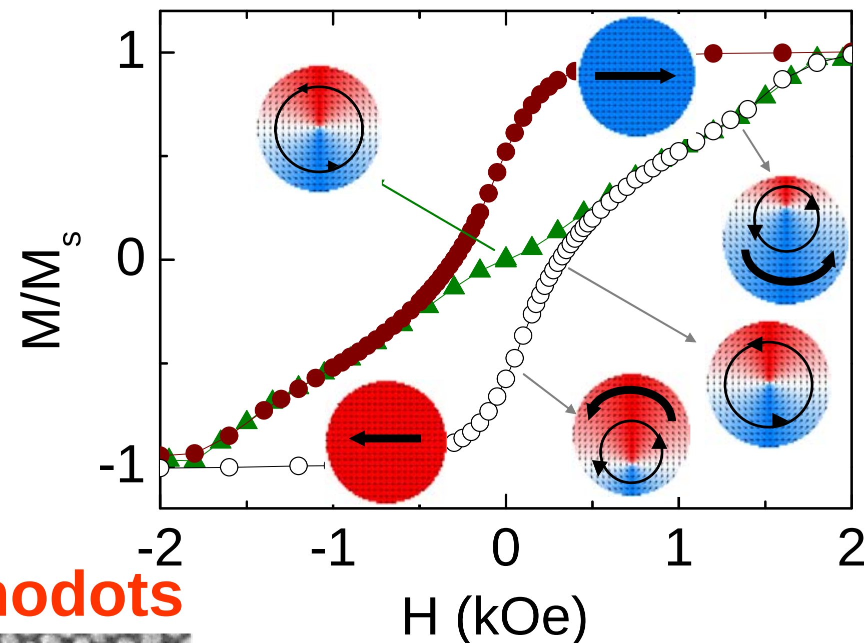
J.E. Villegas, C.-P. Li and I.K. Schuller
Physical Review Letters 99, 227001 (2007)
Appied Physics Letters, (2009)

Critical magnetic sizes

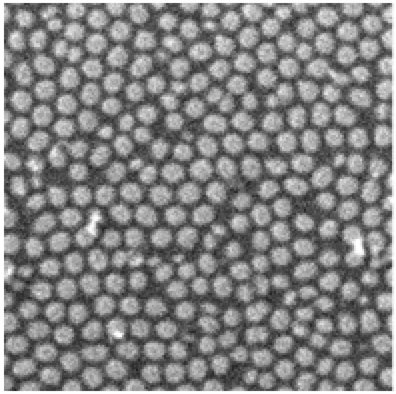
single-domain state



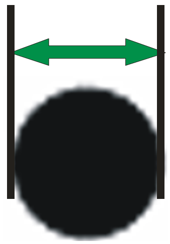
vortex-state



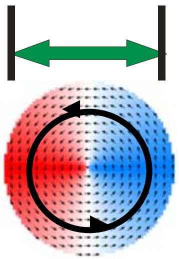
Fe nanodots



55 nm



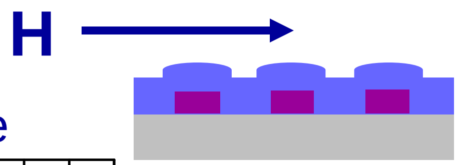
75 nm

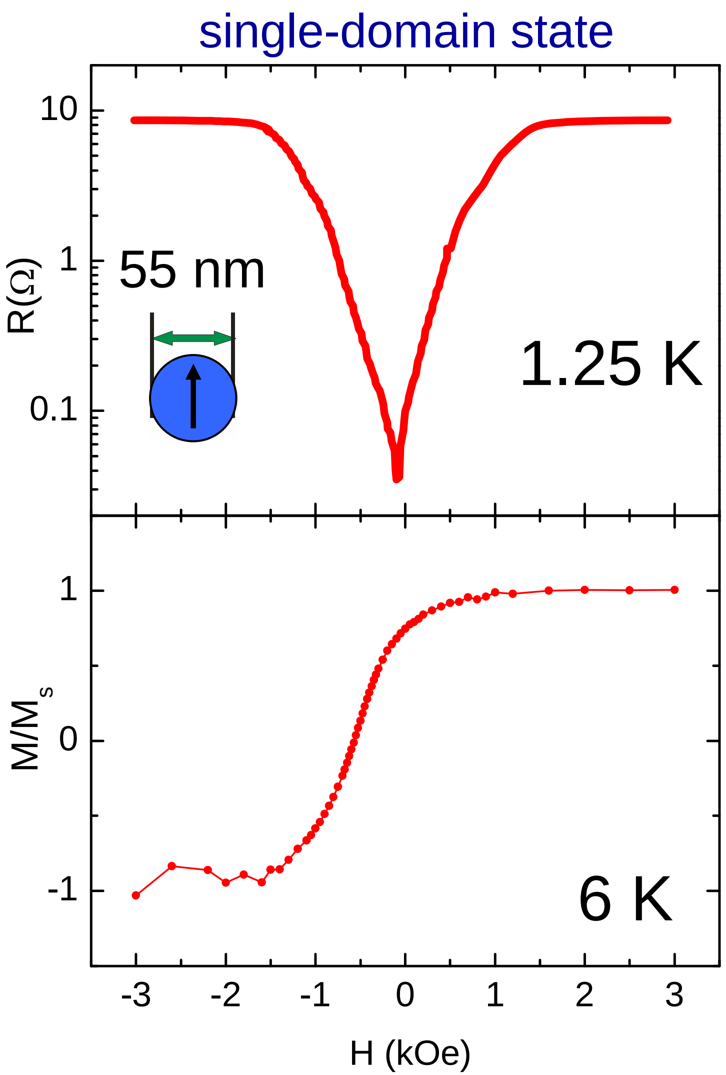


52

Al film on a nanodot array

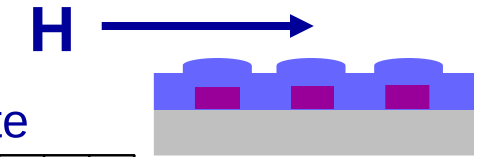
T_c=1.4 K

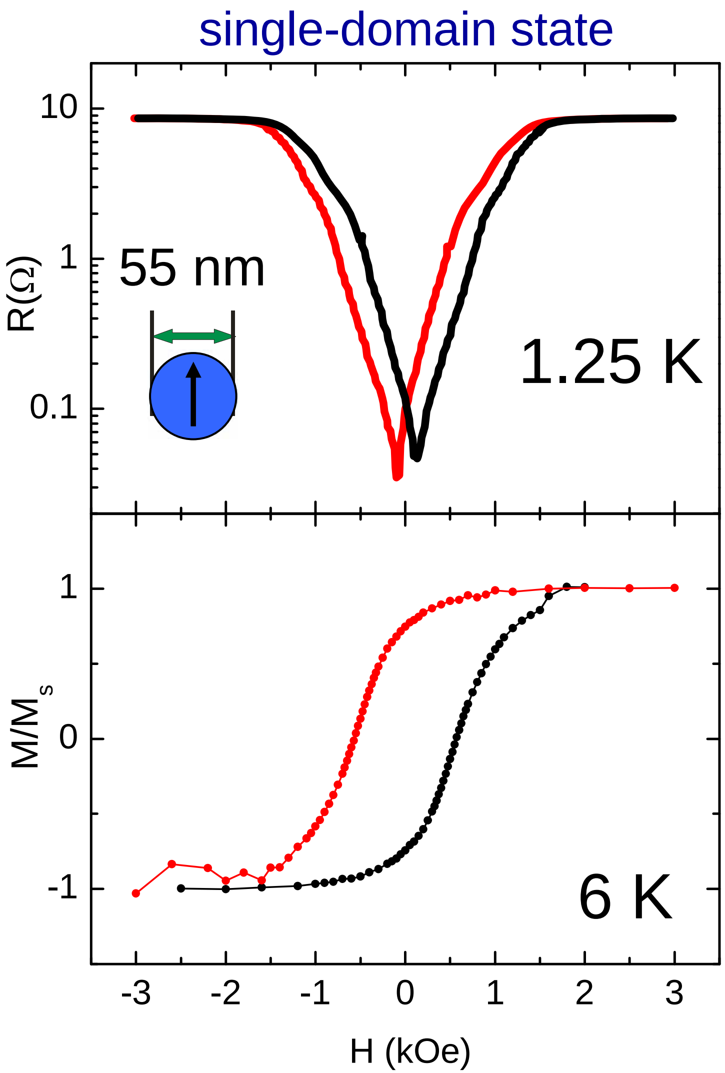




Al film on a nanodot array

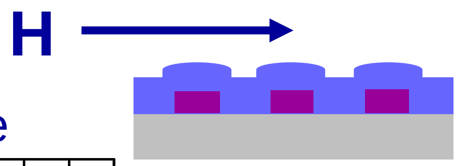
T_c=1.4 K

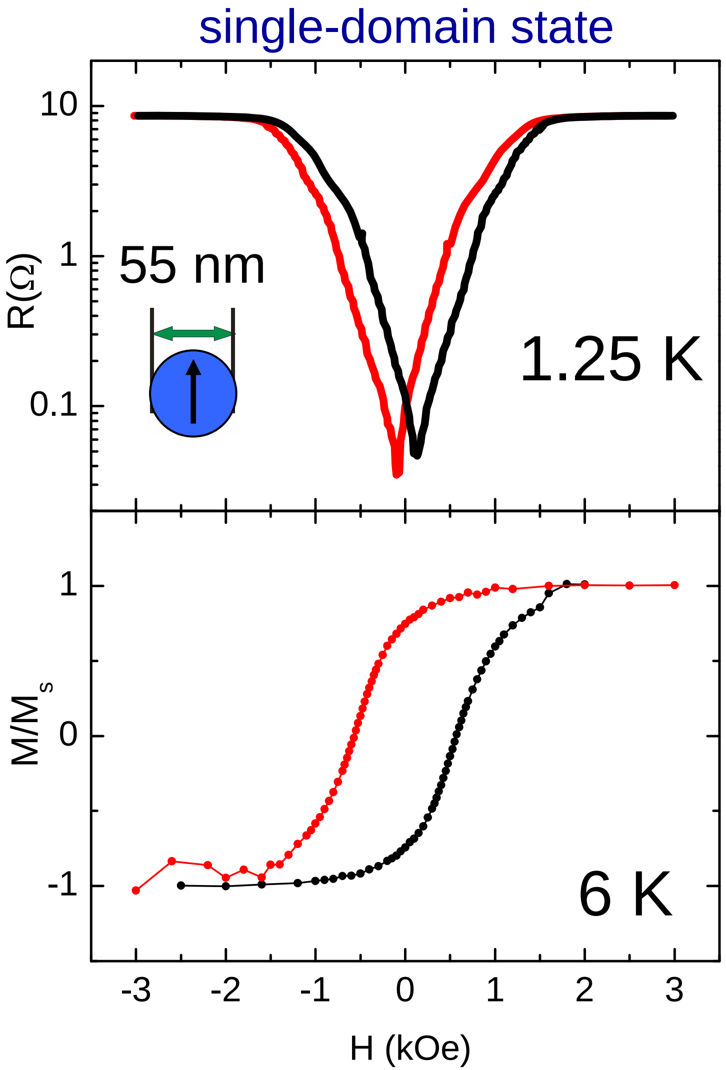


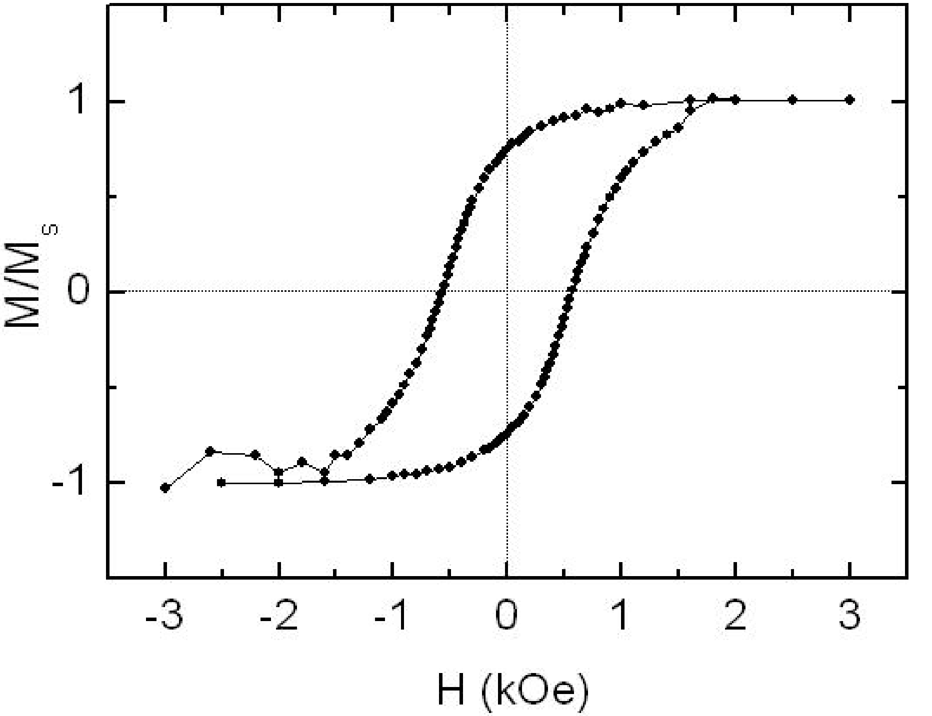


Al film on a nanodot array

T_c=1.4 K

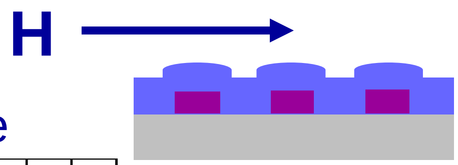


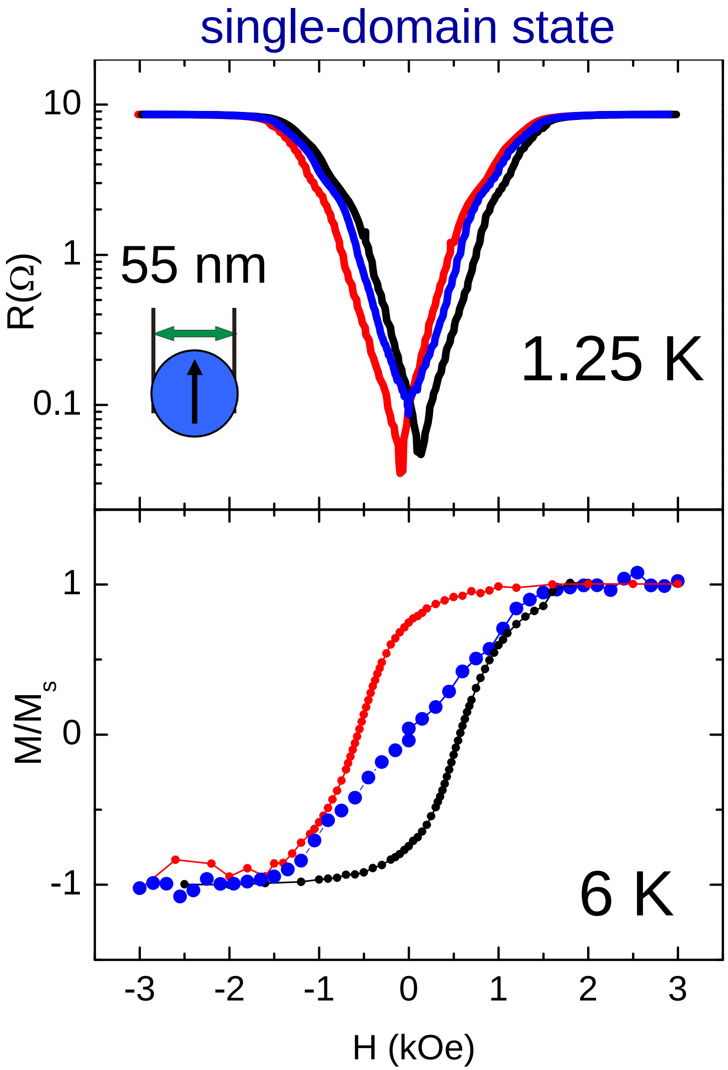




Al film on a nanodot array

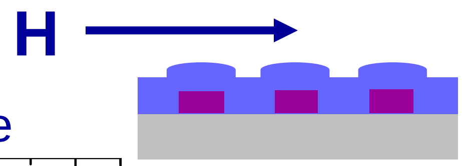
T_c=1.4 K

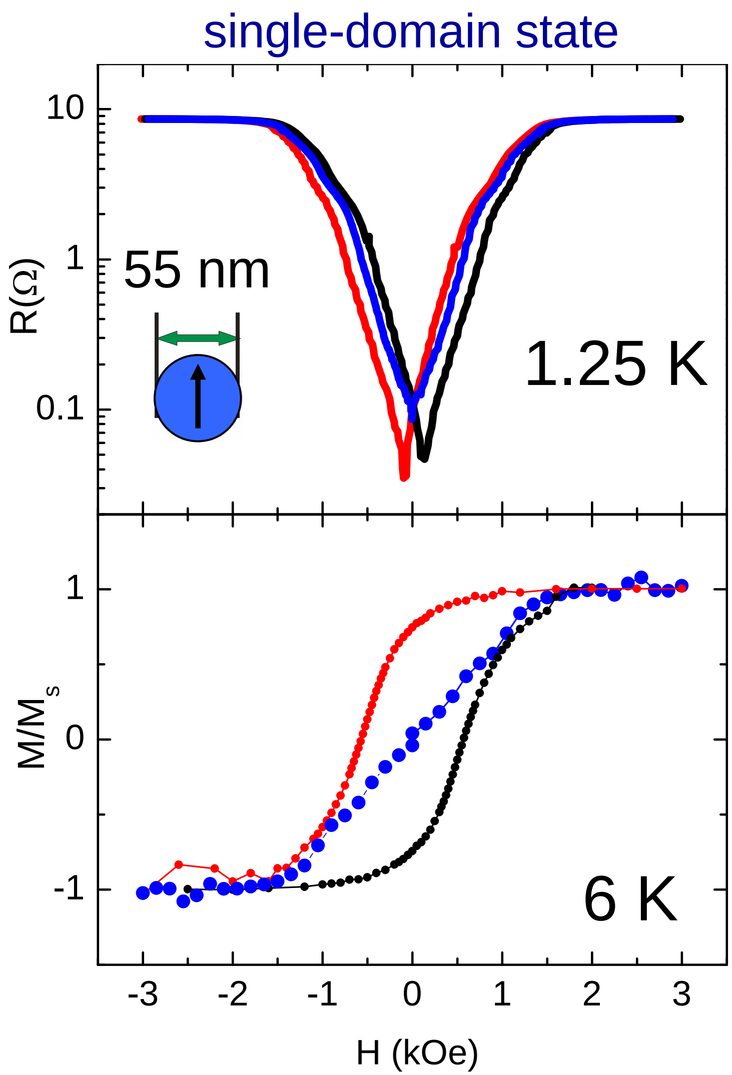




Al film on a nanodot array

T_c=1.4 K

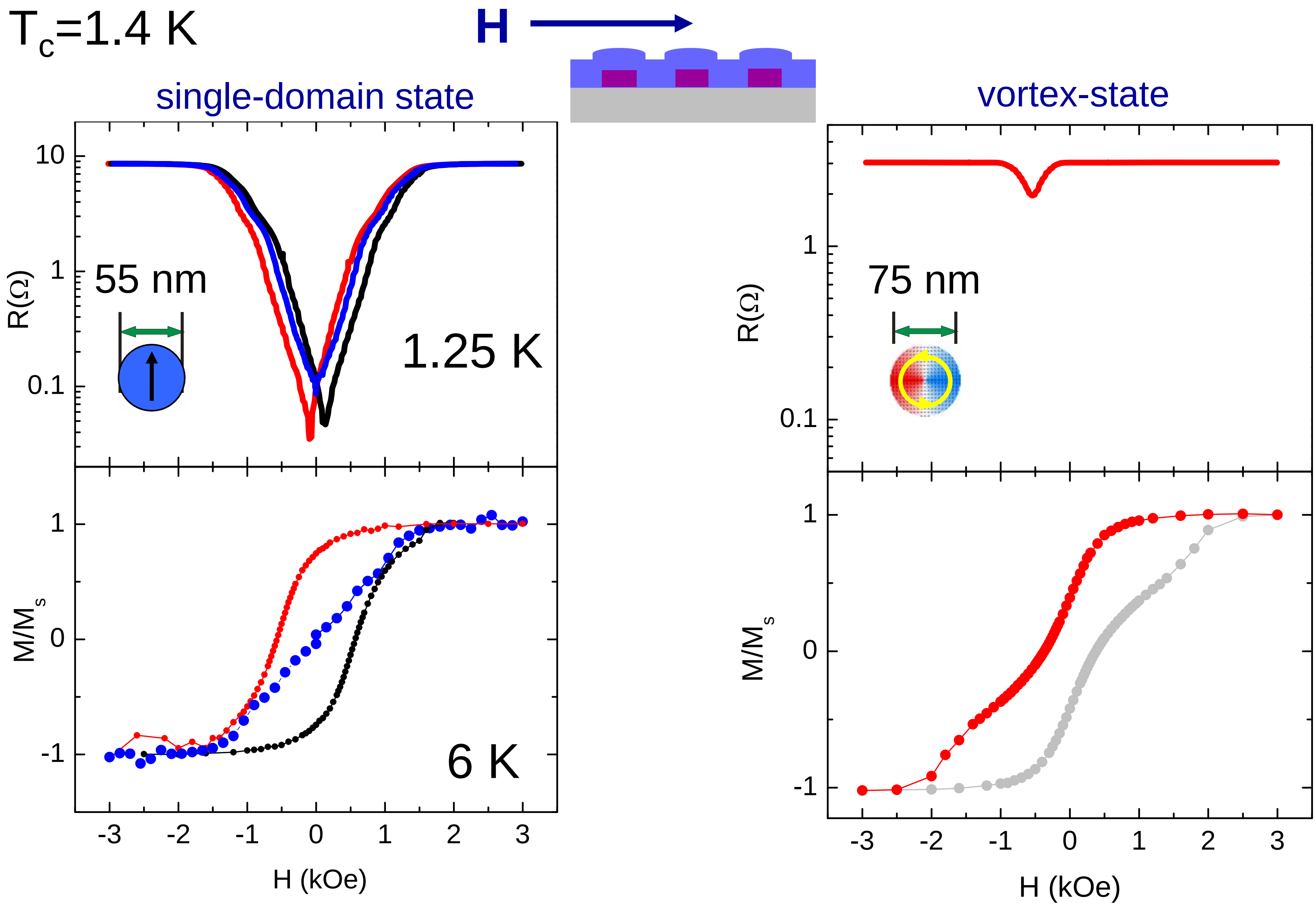




NOT VERY INTERESTING!

Al film on a nanodot array

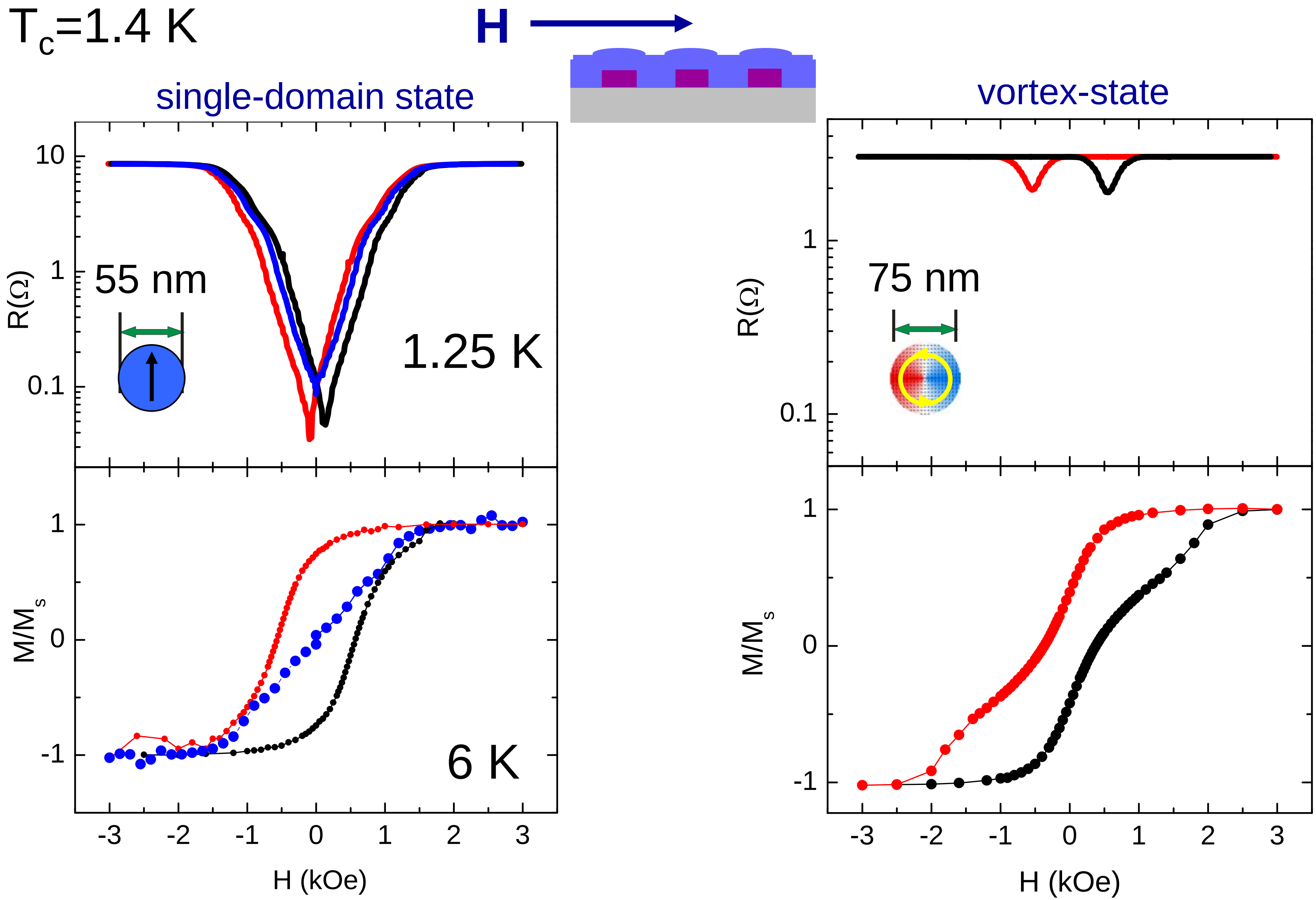
T_c=1.4 K



58

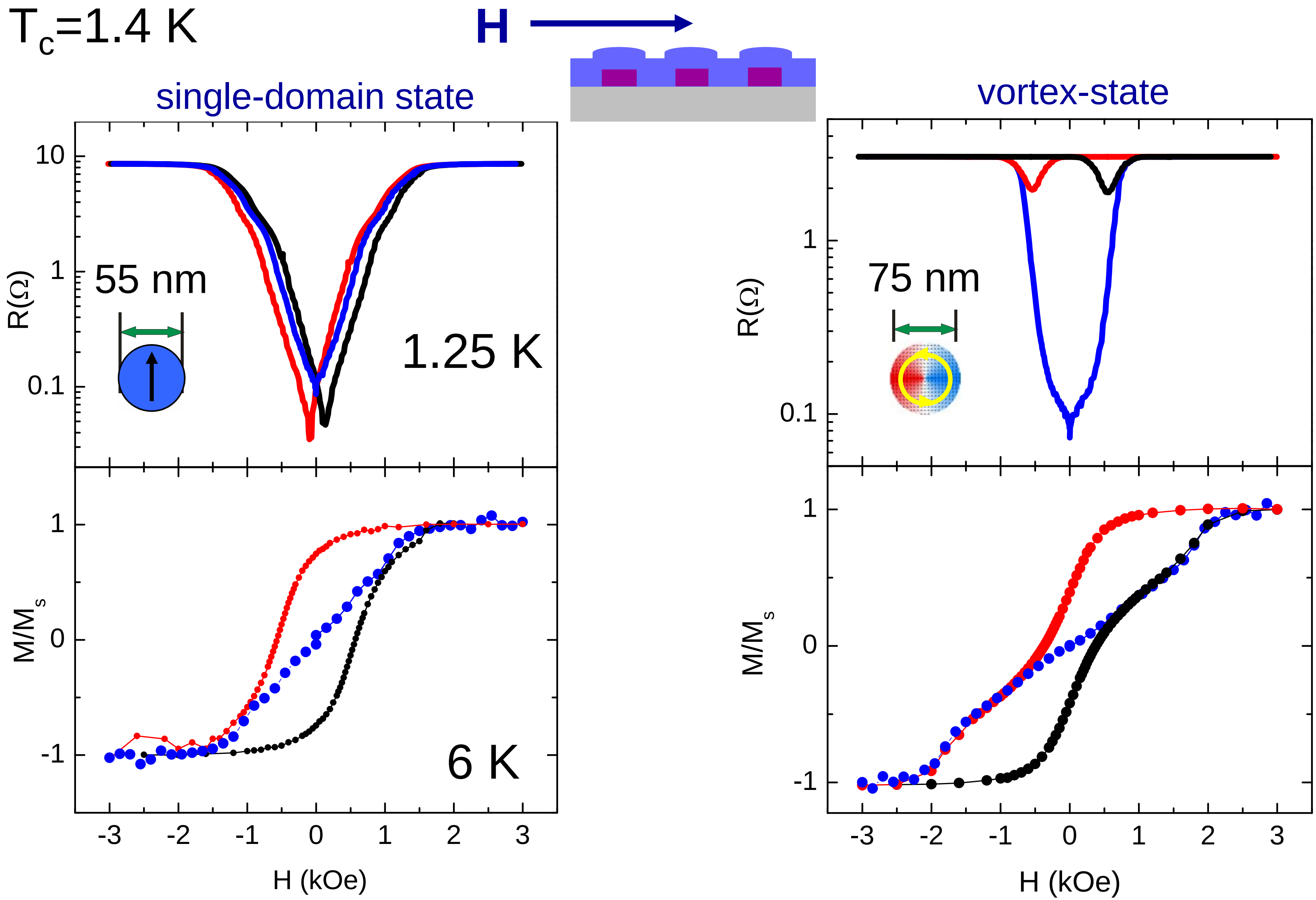
Al film on a nanodot array

T_c=1.4 K



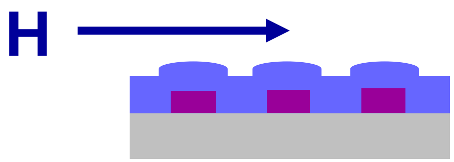
BISTABILITY

T_c=1.4 K

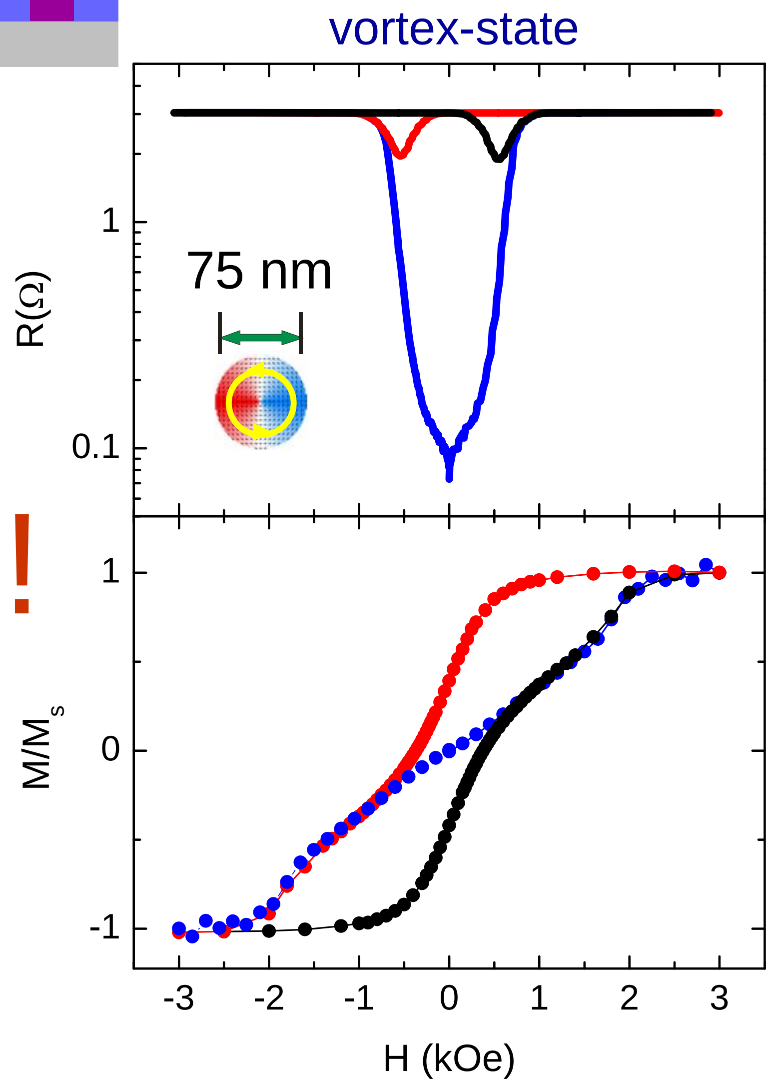


BISTABILITY

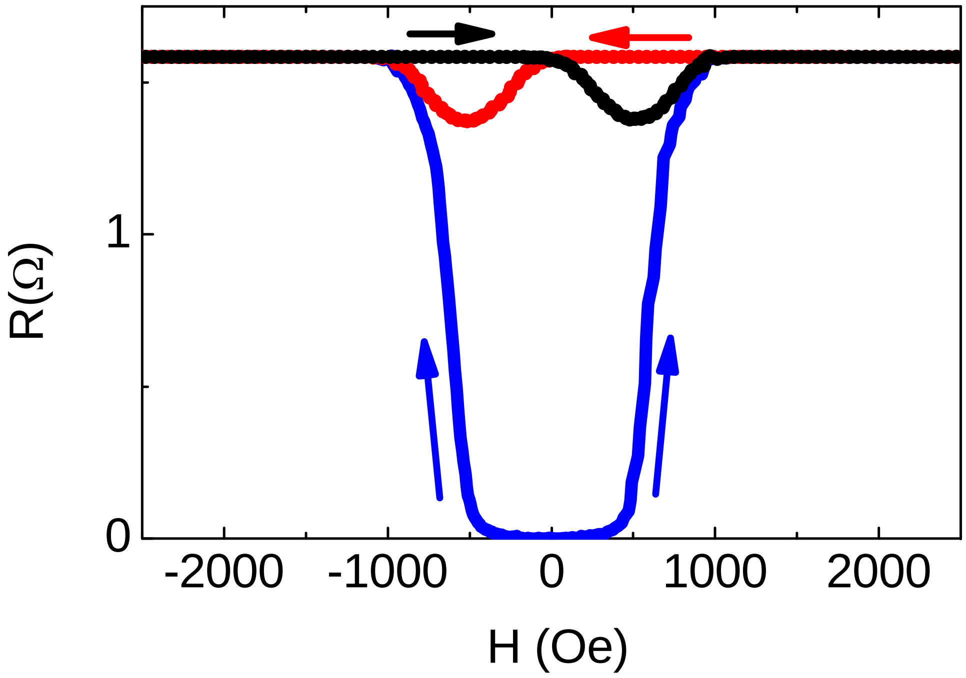
T_c=1.4 K

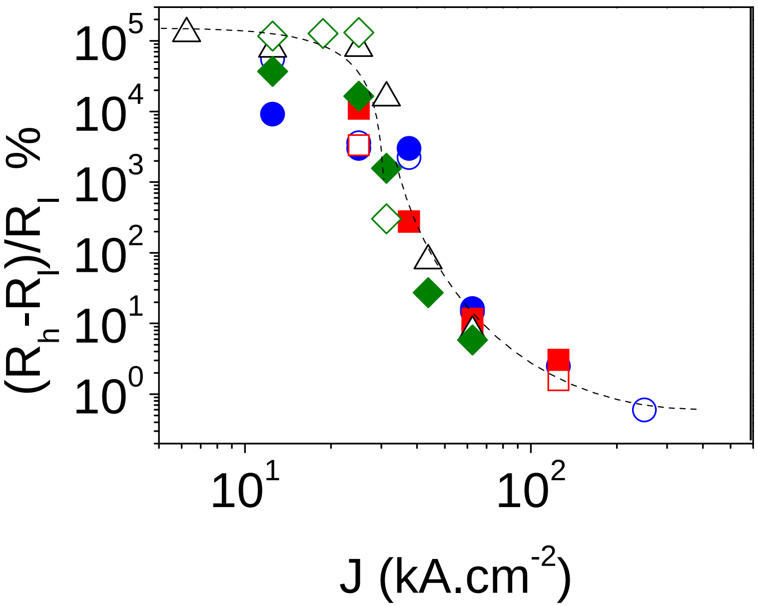


VERY INTERESTING!



BISTABILITY
GIANT, REMANENT, HYSTERETIC MAGNETORESISTANCE



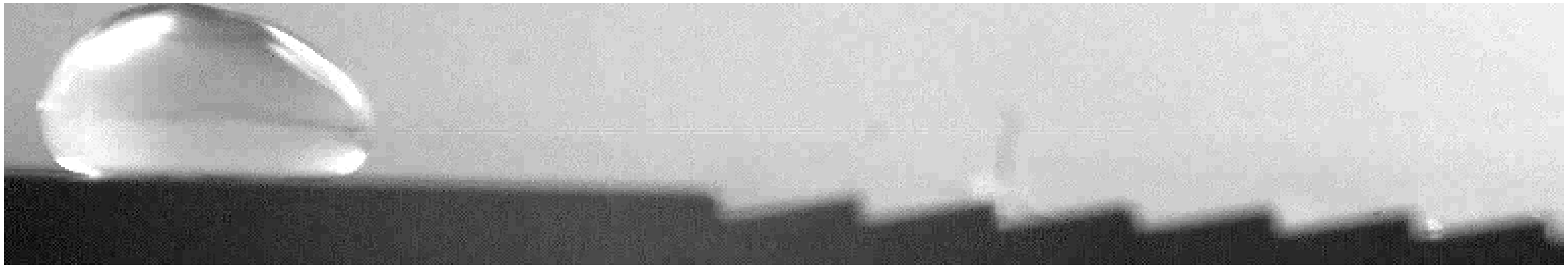


NEW PHENOMENA

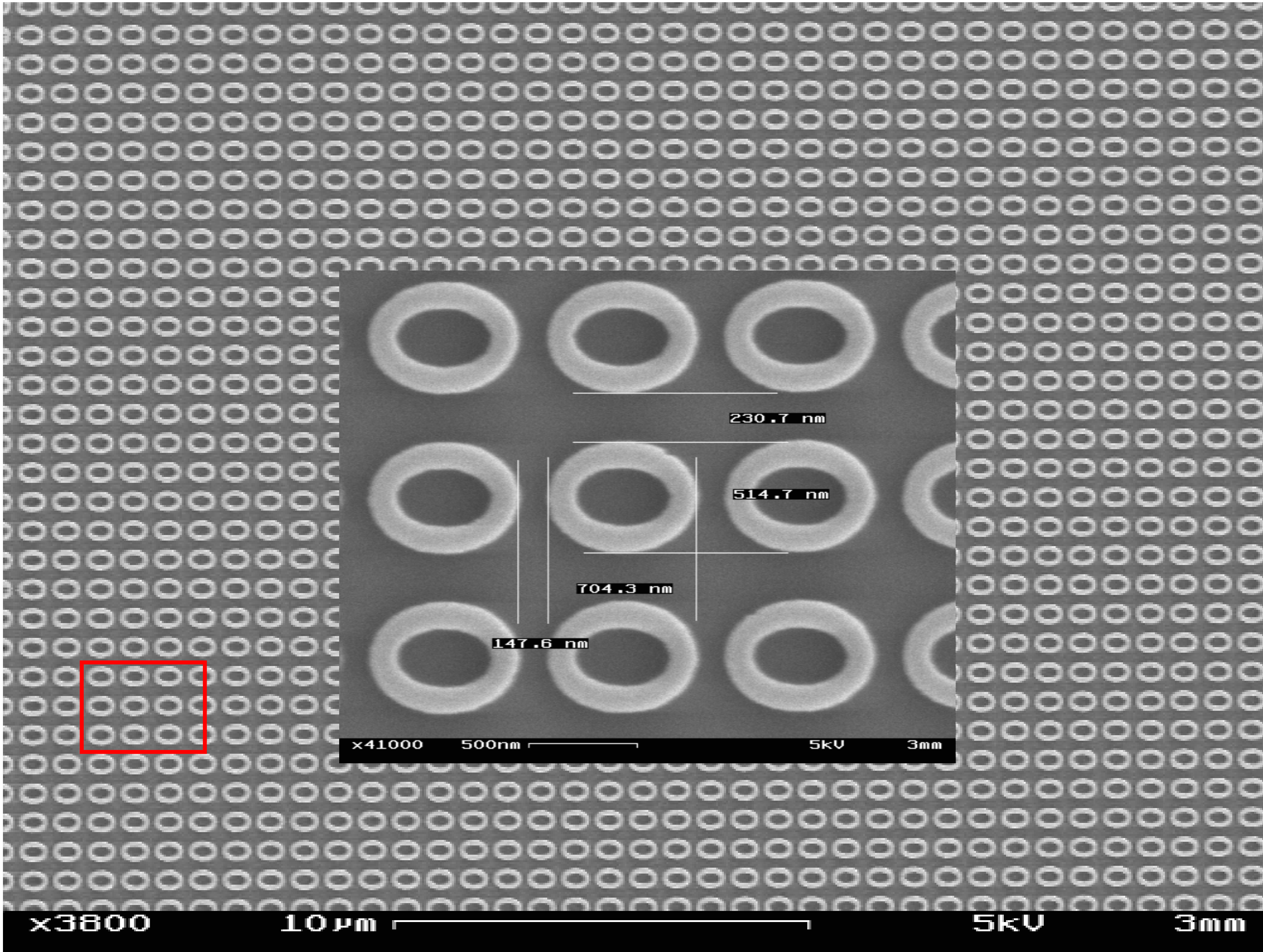
- **New “Josephson Like Effect**
- **Distortion of the vortex lattice**
- **Vortex channeling**
- **Fractal lattices**
- **Bistable superconductivity**

NEW PHENOMENA

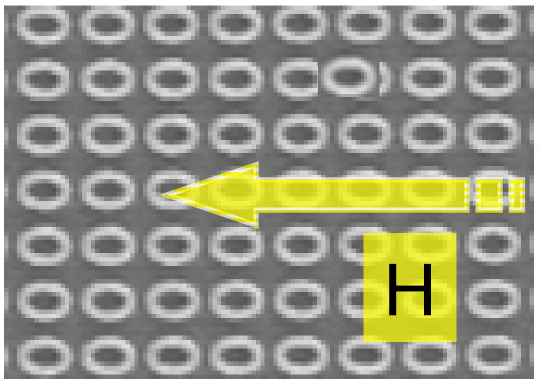
- **New “Josephson Like Effect**
- **Distortion of the vortex lattice**
- **Vortex channeling**
- **Fractal lattices**
- **Bistable superconductivity**
- **Ratchets (Vicent, Villegas, Perez……**

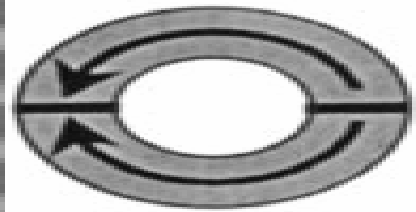


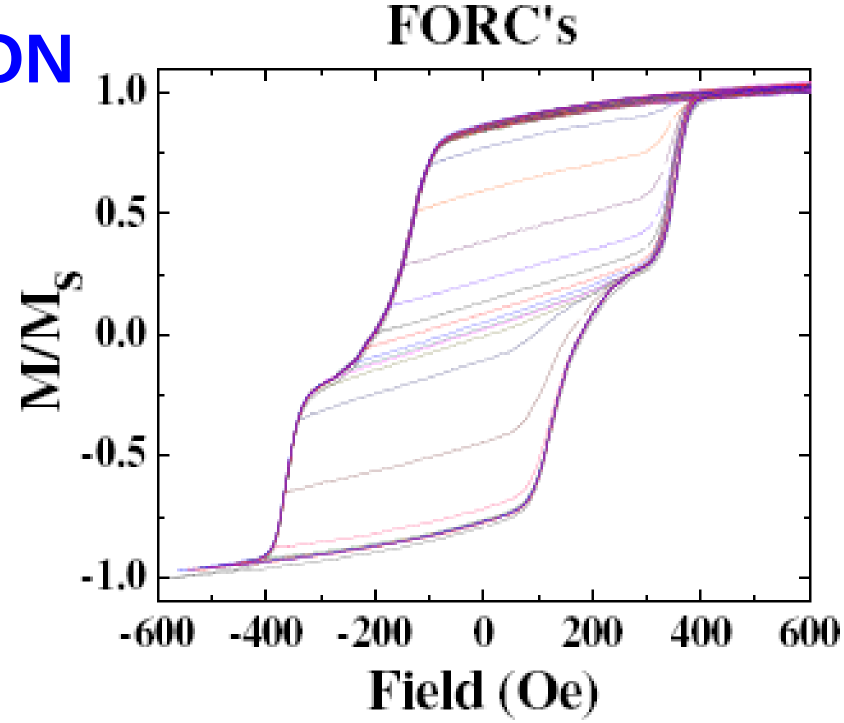
http://www.uoregon.edu/~linke/dropletmovies/

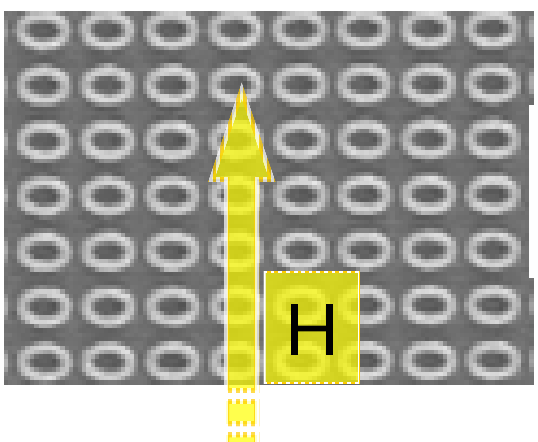

230.7 nm
514.7 nm
704.3 nm
147.6 nm
x41000 500nm 5kV 3mm
x3800 10μm 5kV 3mm

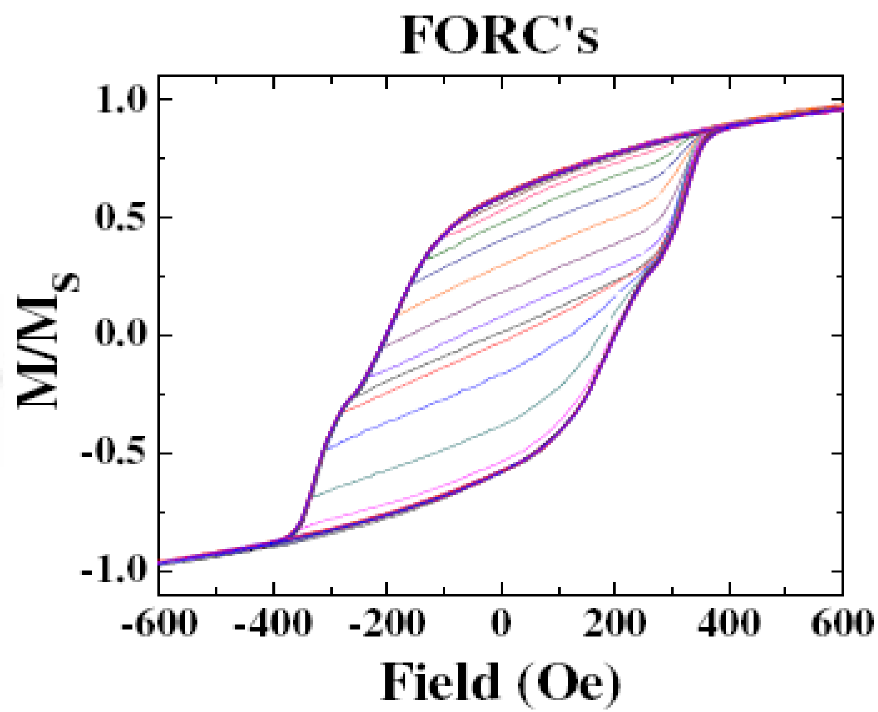
MAGNETIC CHARACTERIZATION



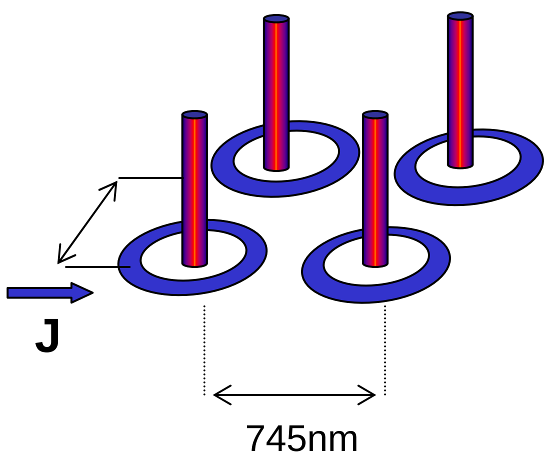


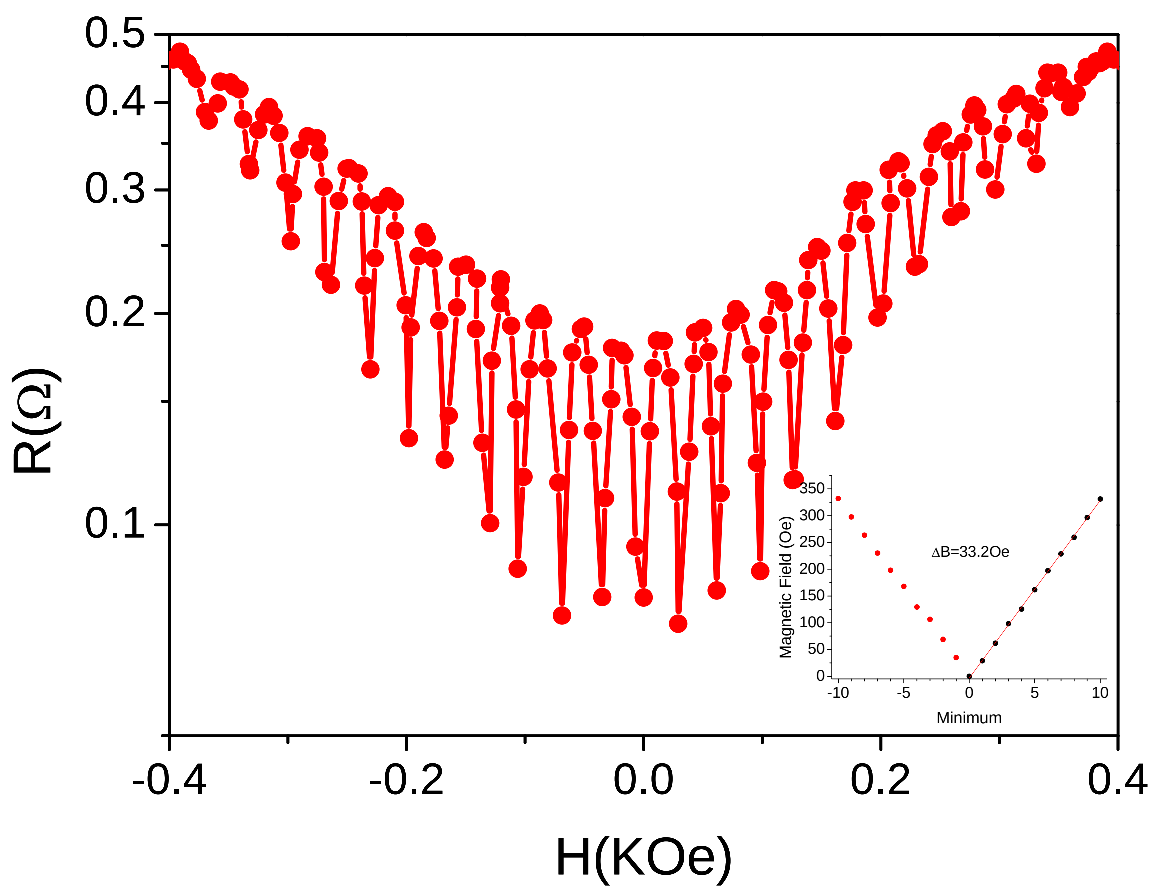


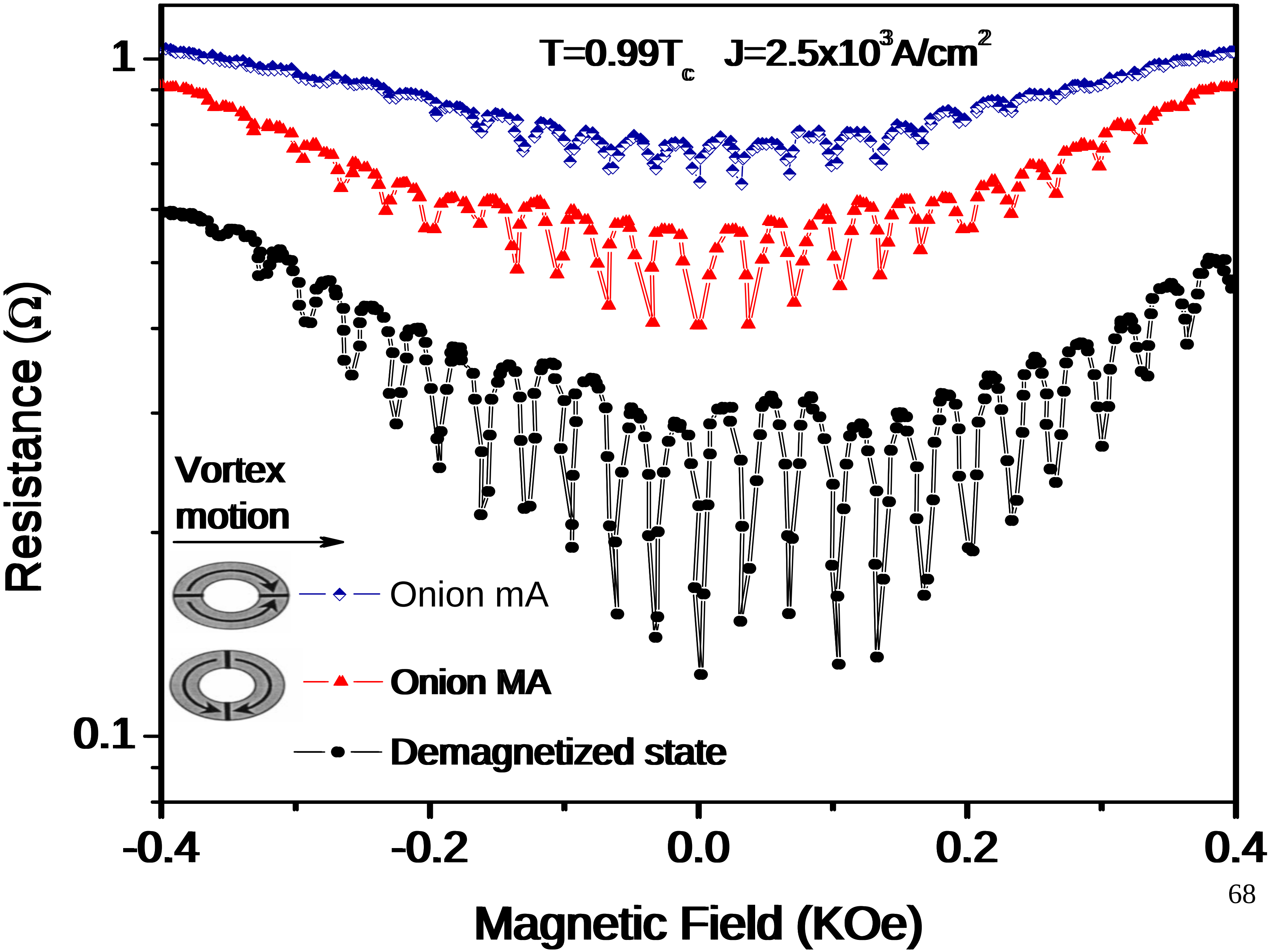




MATCHING
COLLECTIVE PINNING

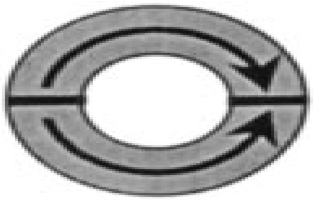


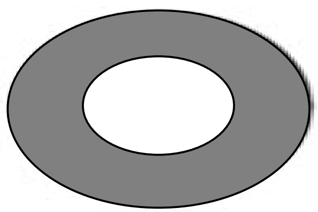




T=0.99T$_c$ J=2.5x10^{3}A/cm^2
Resistance (Ω)
1
0.1
Magnetic Field (KOe)
-0.4
-0.2
0.0
0.2
0.4
Vortex motion
Onion mA
Onion MA
Demagnetized state

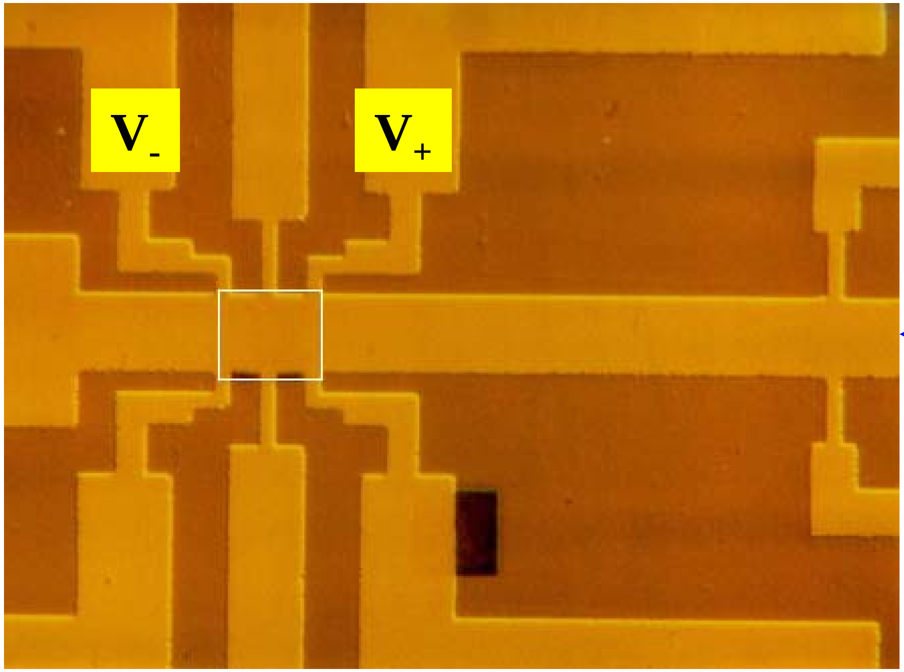
MAGNETIC STATE





AC drive

Measure DC



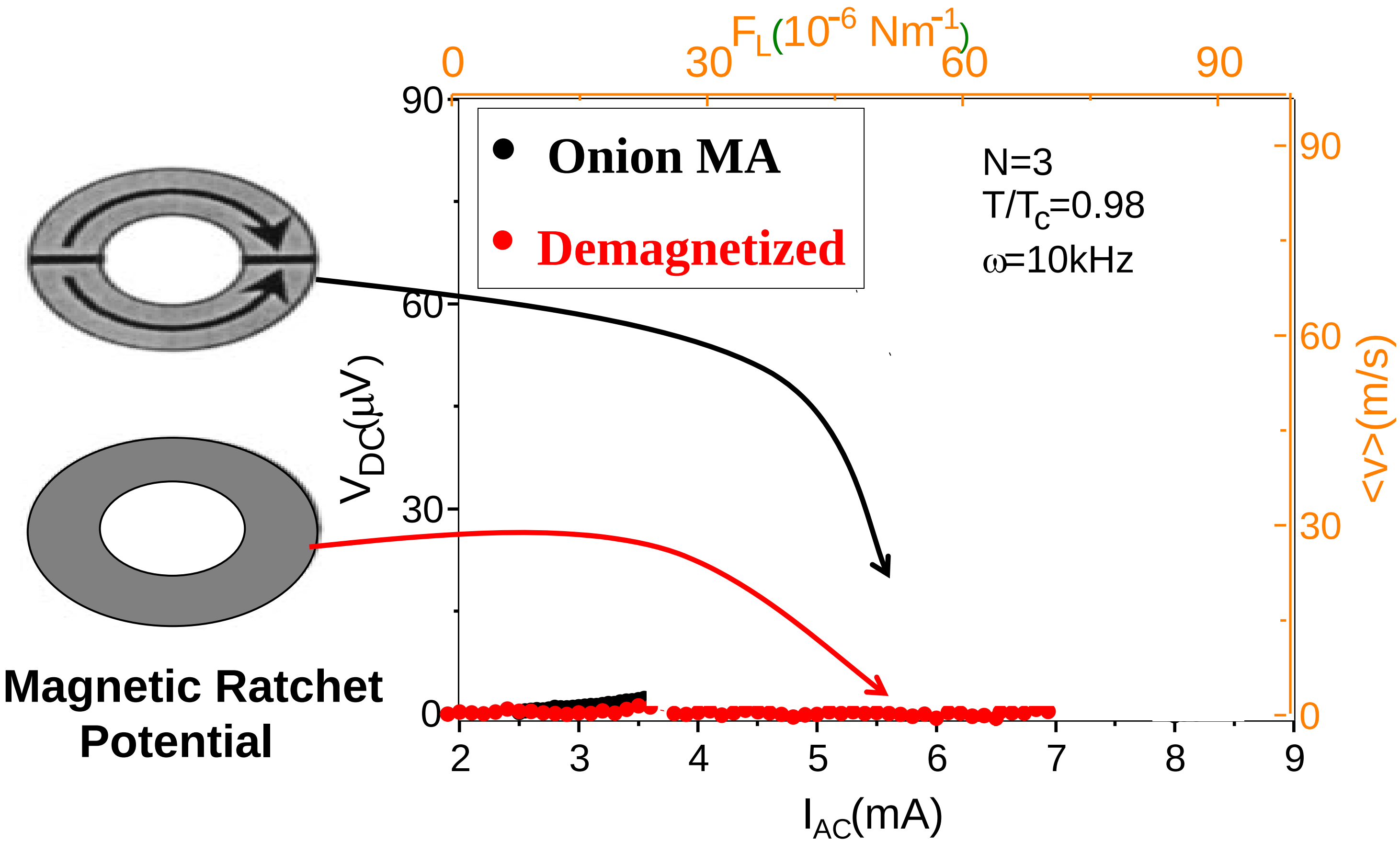
I_{AC}

What to Expect ?

Nichts, Nada, Niente, Rien

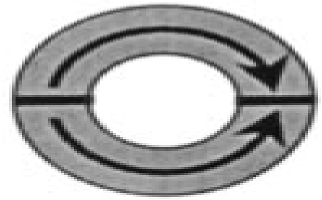
MAGNETIC RATCHET

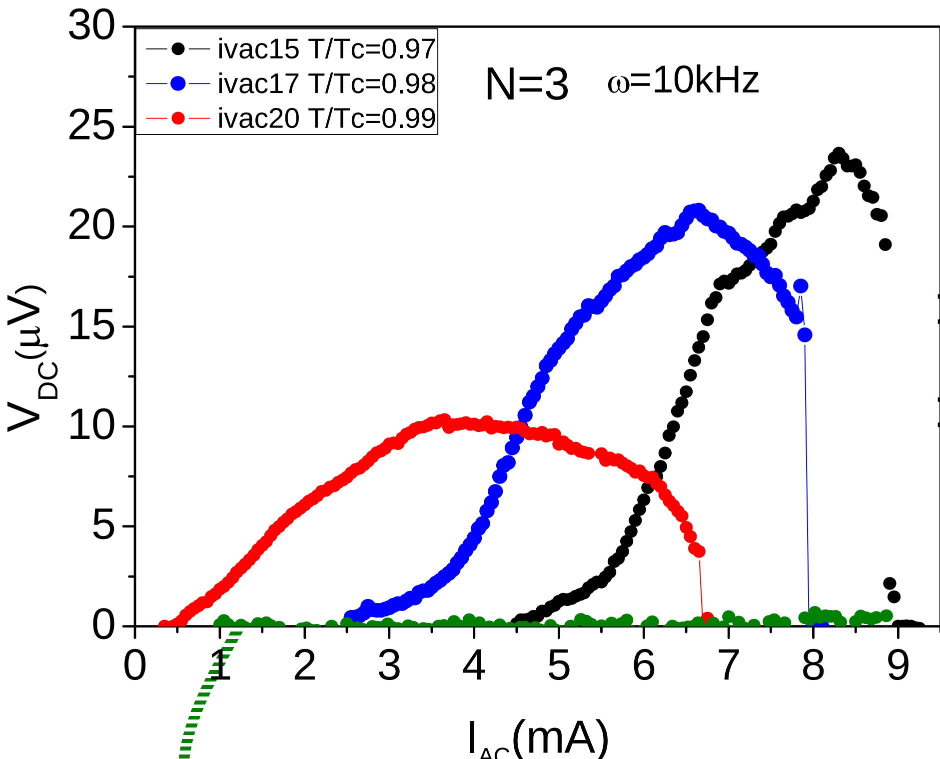
AC DRIVE → DC RESPONSE

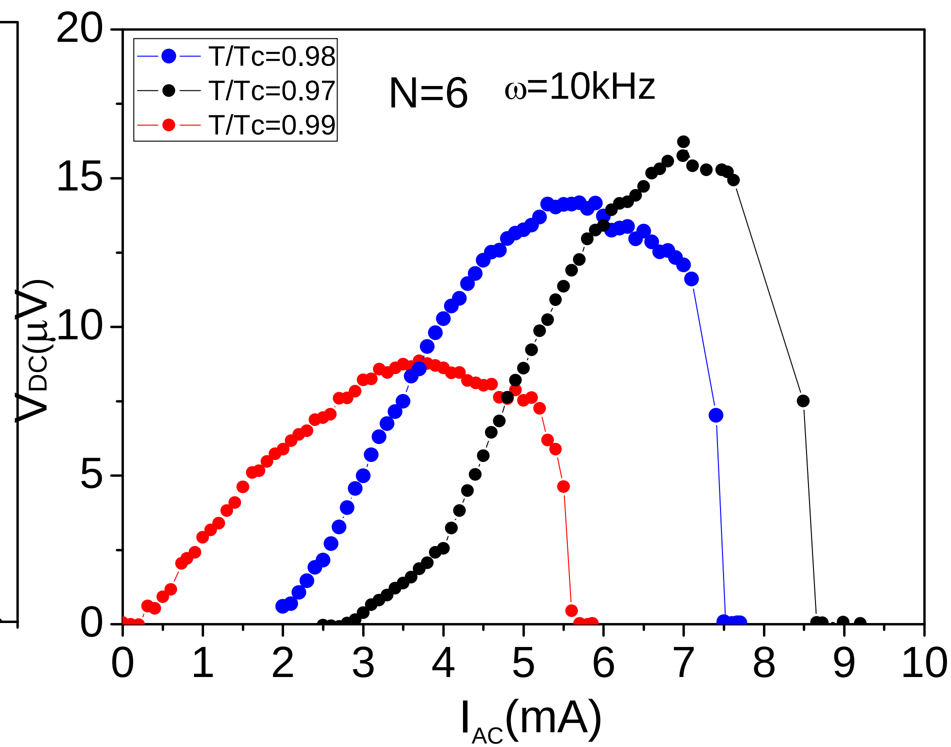


D. Perez de Lara *et al.* **Phys. Rev. B,** 224510(2009)

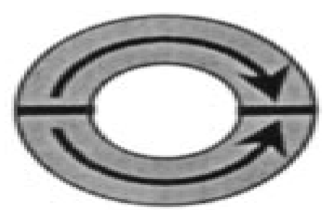
Vortex motion







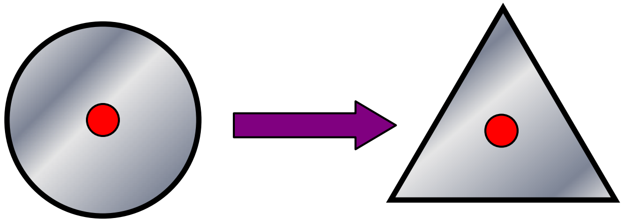
Vortex motion

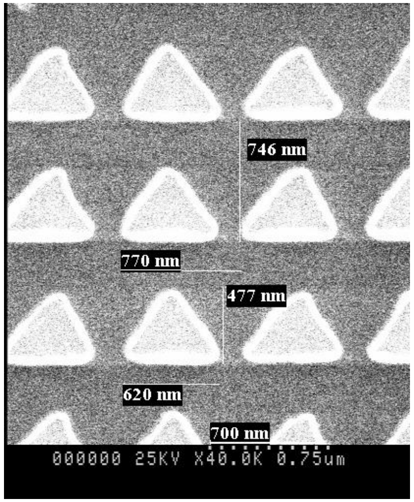


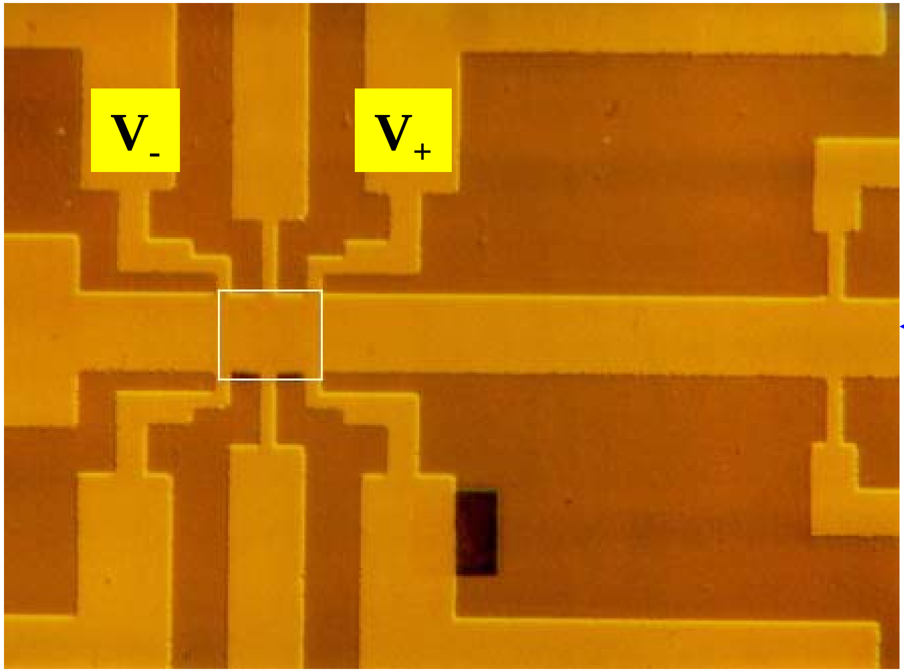
Asymmetric

AC drive

Measure DC





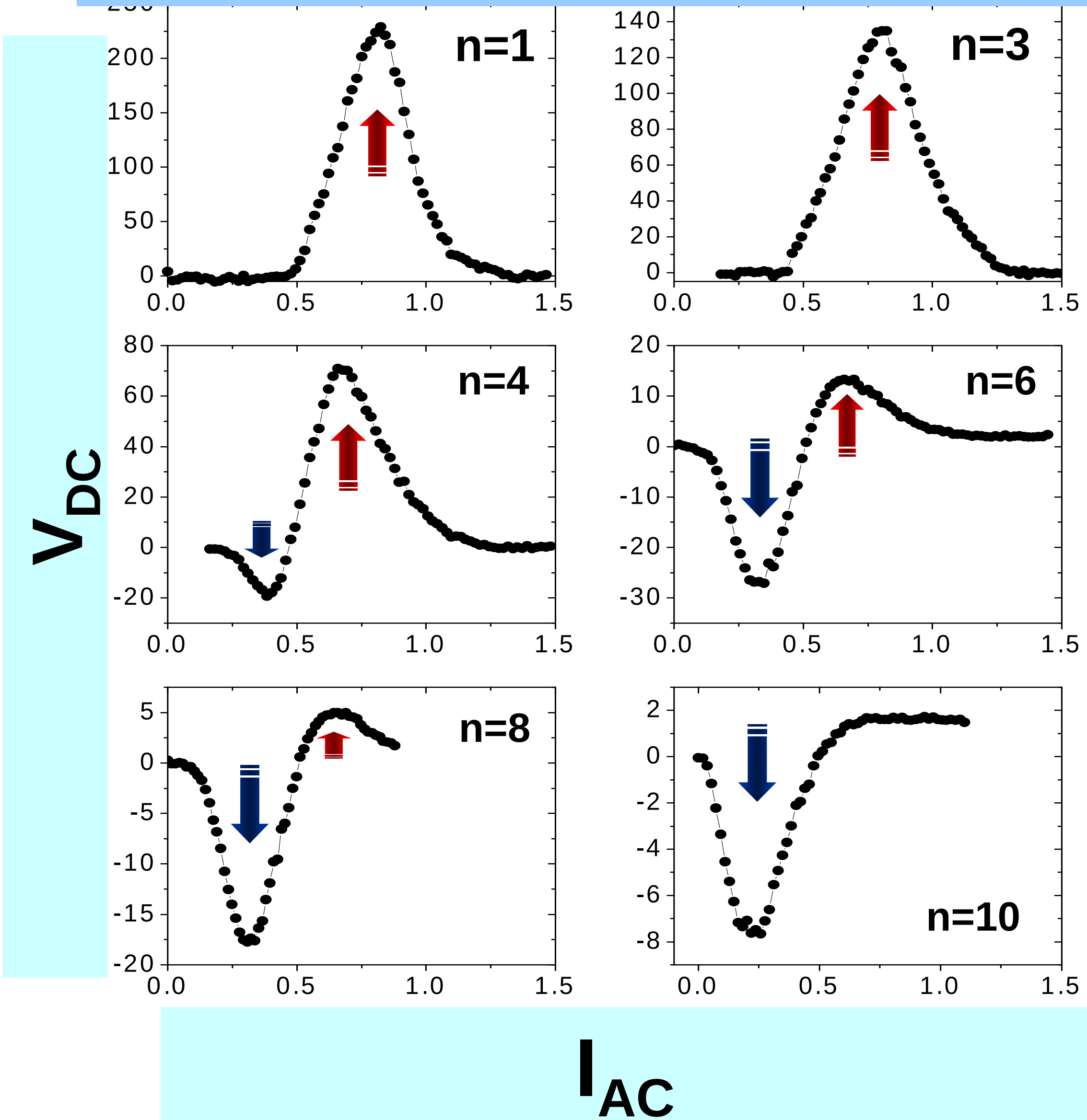


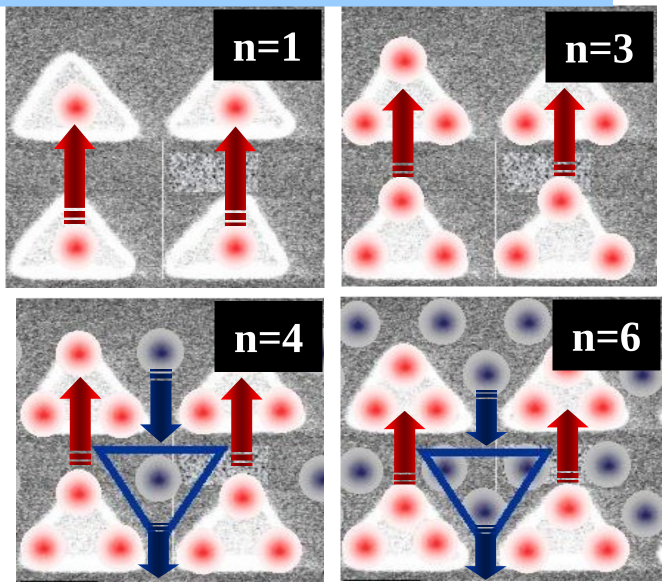
Expect Anything New ?

NICHTS, NADA, NIENTE,RIEN

SURPRISE

TOPOLOGICAL RATCHET





n number of vortices per unit cell
$T = 0.98T_c$
F = 10 kHz

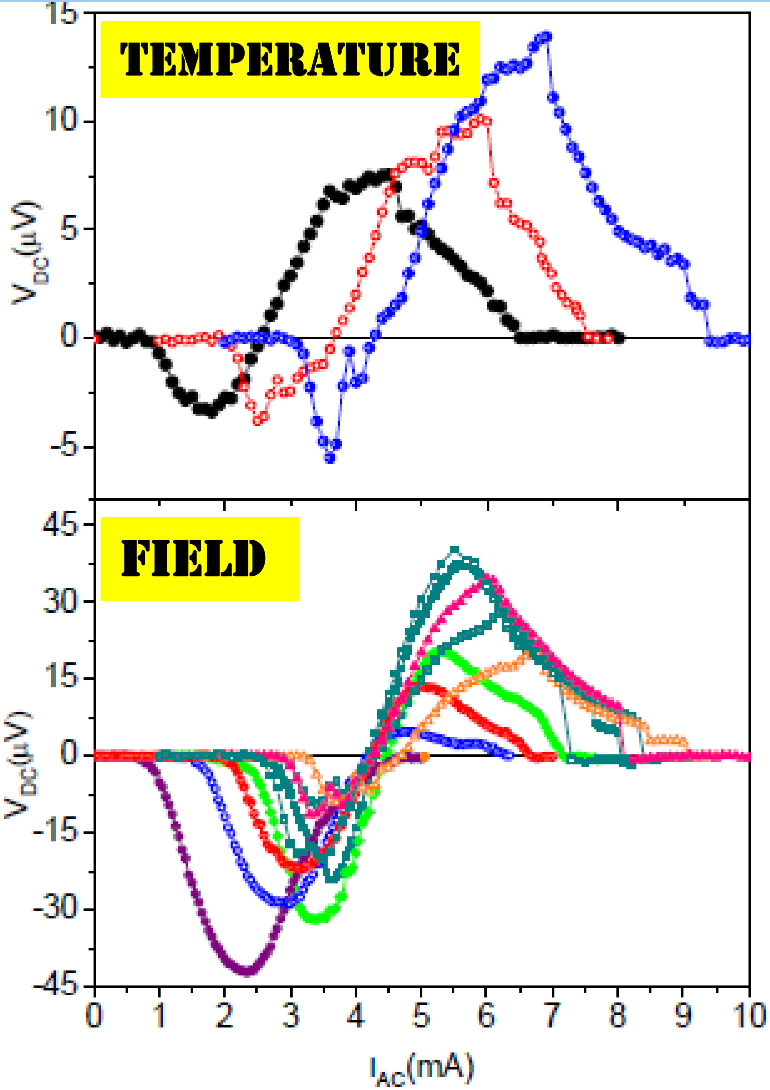
Amplitude Controlled Rectification

J. E. Villegas, J. Vicent *et al.* **Science 302,** 1189 (2003)

Thank you
American Airlines

Expect no ratchet reversal

TOPOLOGICAL RATCHET



D. Perez, et al- to be published

NanoMagnetic-Superconducting Hybrids

- BOUNDARY CONDITIONS

VORTICES

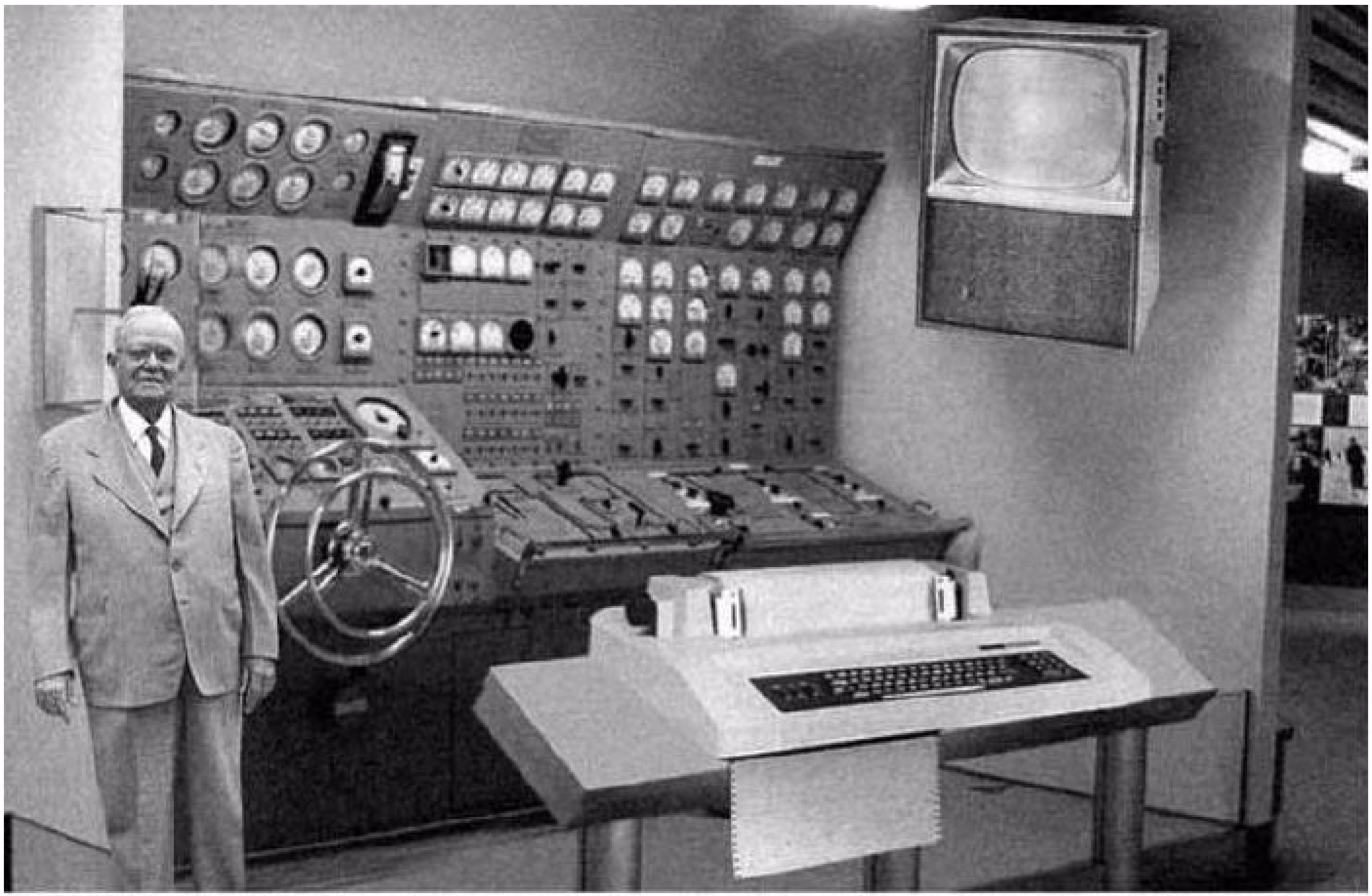
- PROXIMITY

BISTABLITY

- TIME REVERSAL SYMMETRY

RATCHET

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.

Fini-End-Fin-Ende