EFECTOS DE CONFINAMIENTO Y VISUALIZACIÓN DE CUANTOS DE FLUJO, PLASMONES Y BACTERIAS

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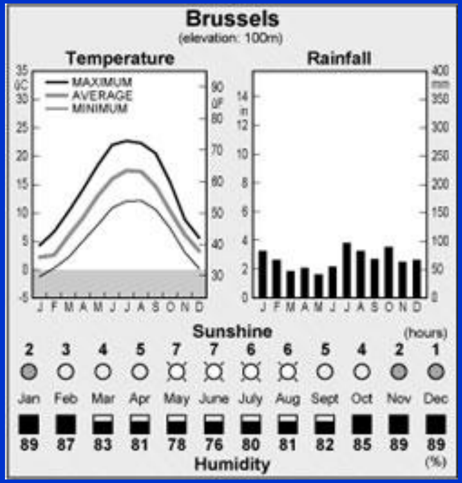
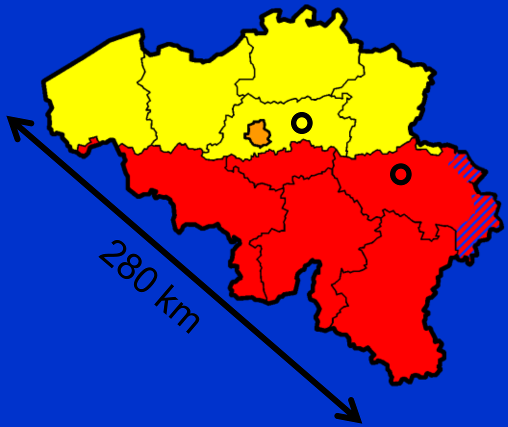
Prof. G. Vandenbosch	Ingenieria, KULeuven





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OUTLINE

EFECTOS DE CONFINAMIENTO: MOTIVACION

VISUALIZACION DE CUANTOS DE FLUJO EN SUPERCONDUCTORES

VISUALIZACION DE OSCILLACIONES DE CARGA EN METALES

CONFINAMIENTO DE MICROORGANISMOS

CONCLUSIÓN

MOTIVACION

• Definición de confinamiento y algunos ejemplos

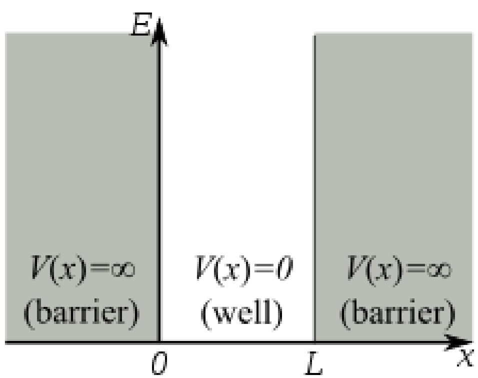
• Qué fenomenos nuevos puden surgir como resultado del confinamiento?

• Porque queremos confinar cosas?

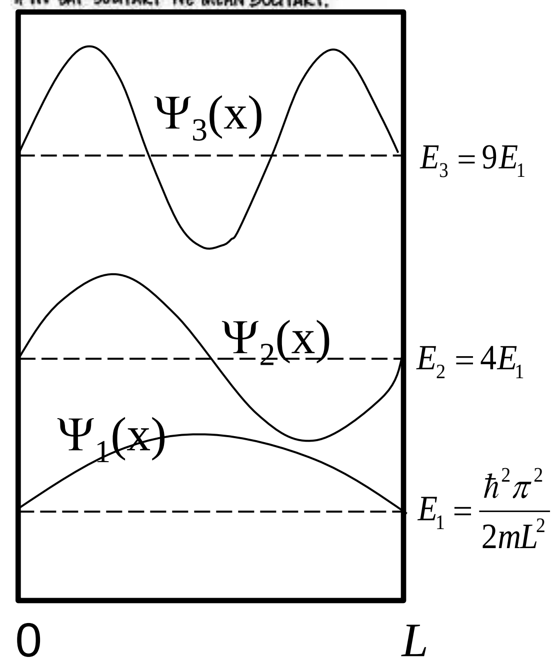
DEFINICION
El acto de estar restringido en movimiento.

IMPACTO DEL CONFINAMIENTO
Aprisionamiento , navegantes solitarios (Cast-away), confinamiento solitario (Papillon), astronautas, etc.

EJEMPLO
Particula en una caja de potencial.



L	E_1	T
1 Å	40 eV	4×10^5 K
1 nm	0.4 eV	4×10^3 K
1 µm	0.4 µeV	4 mK

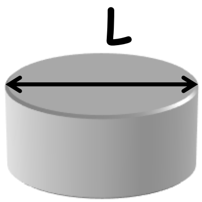


CUANDO LOS EFECTOS DE CONFINAMIENTO SON IMPORTANTES ?

Limite mesoscopico

Condiciones de contorno se vuelven relevantes

cociente volumen/superficie pequeño



$$E_1 = \frac{\hbar^2 \pi^2}{2mL^2}$$

PORQUE ESTUDIAR LOS EFECTOS DE CONFINAMIENTO?

“There is plenty of room at the bottom” (R. Feynman, 1959)

Revolucion de la nanotechnologia y la carrera por la miniaturizacion

Meso, Micro, Nano, Meta

Control y manipulacion de excitationes fundamentales

Superconductivity at the interface between two insulators

Quantum Hall effect

Topological Insulators

Point contacts

Graphene

Quantum dots

Plasmonic excitation

Confinement of phonons

NANOSCIENCE & NANOTECHNOLOGY

CLUSTER SCIENCE
FULLERENES
CARBON NANOMATERIALS

SEMICONDUCTORS
QUANTUM DOTS

NANOELECTRONICS
TRANSISTORS

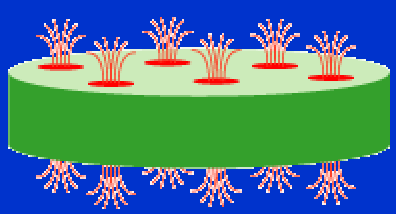
NANOMECHANICS
MEMS

NANOPHOTONICS
PLASMONICS

SUPERCONDUCTIVITY
(ENERGY TRANSPORT)

NANOPLASMONICS
(INFORMATION TECHNOLOGY)

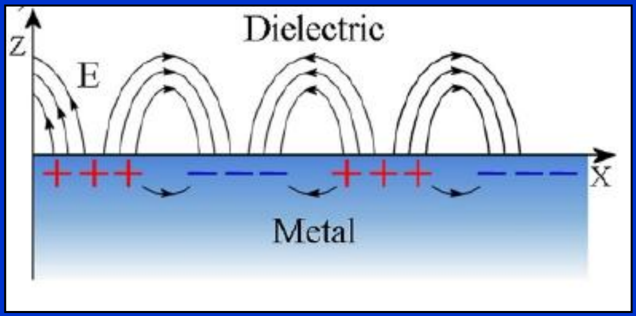
FLUXONS



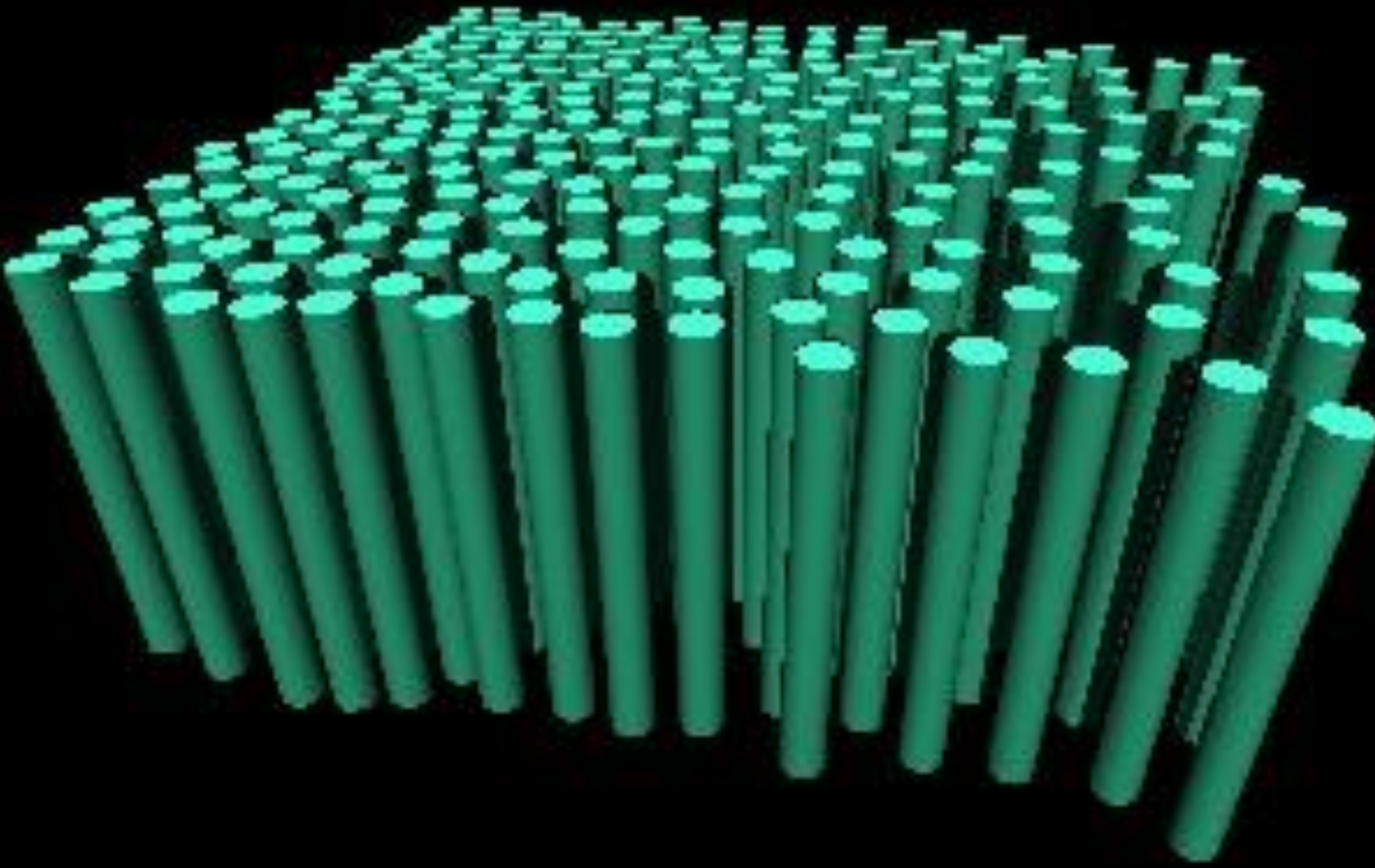
MANIPULATION

ELECTRONS → ELECTRONICS
SPIN → SPINTRONICS
FLUX → FLUXONICS
PLASMONS → PLASMONICS

PLASMONS



CONFINAMIENTO DE CUANTOS DE FLUJO

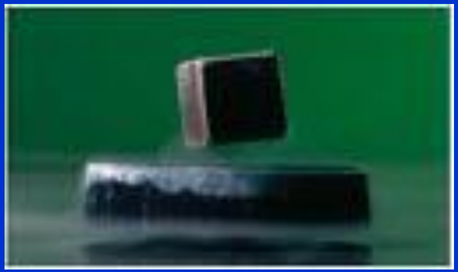


In collaboration with

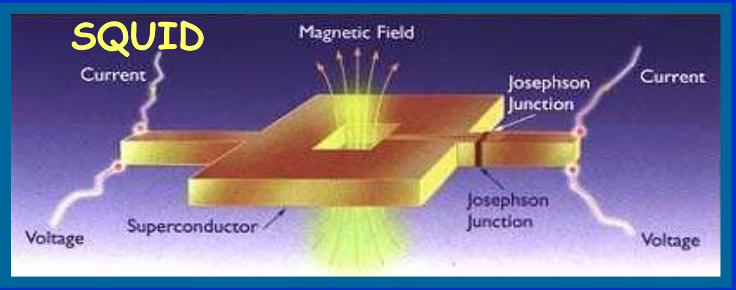
Joffre Gutierrez, Joris Van de Vondel, Bart Raes, Jo Cuppens, Roman Kramer, G.W. Ataklti, Victor Moshchlakov,

SUPERCONDUCTIVIDAD PRESENTE Y FUTURO

R=0

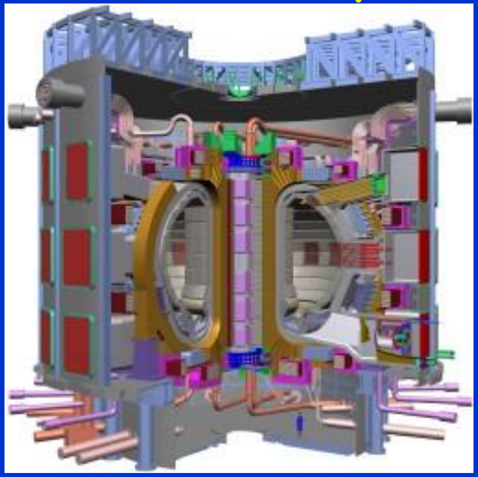


B=0

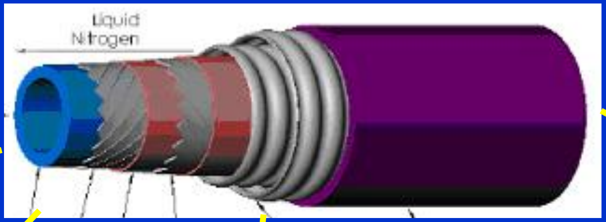


Resonancia Magnética

Confinamiento de plasma



Thermonuclear Reactor and LHC



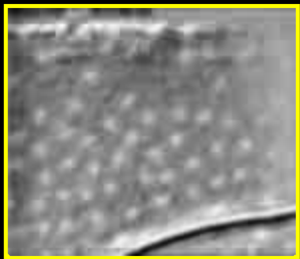
- Cables -
Transmiten de 3 a 5 veces mas energia que cables de cobre

Ingenieria de dispositivos en el espacio exterior

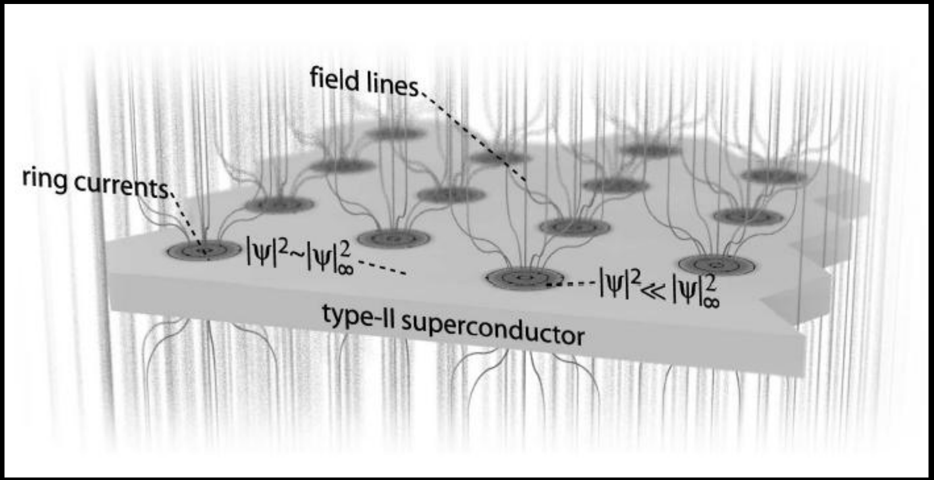
- Transformadores -
Menos contaminantes ya que no se necesitan aceites

- Motores -
Requieren la mitad de espacio que los motores de cobre

VÓRTICES Y FLUXONES



BORDE

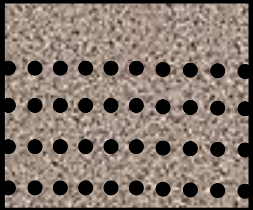


VÓRTICES EN MOVIMIENTO

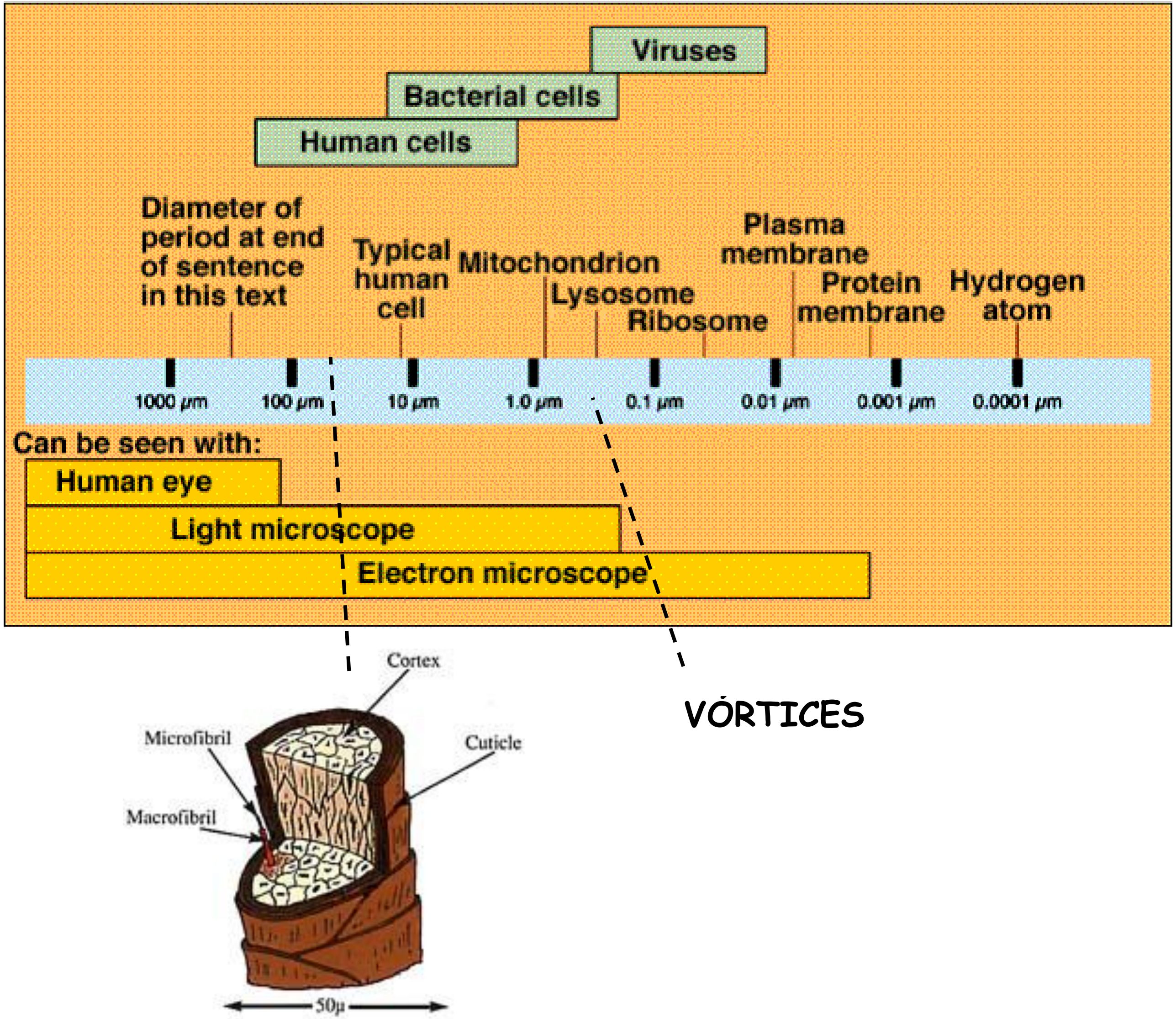
DISIPACIÓN DE ENERGÍA

SOLUCIÓN

ANCLAJE DE VÓRTICES



ES POSIBLE “VER” VORTICES ?



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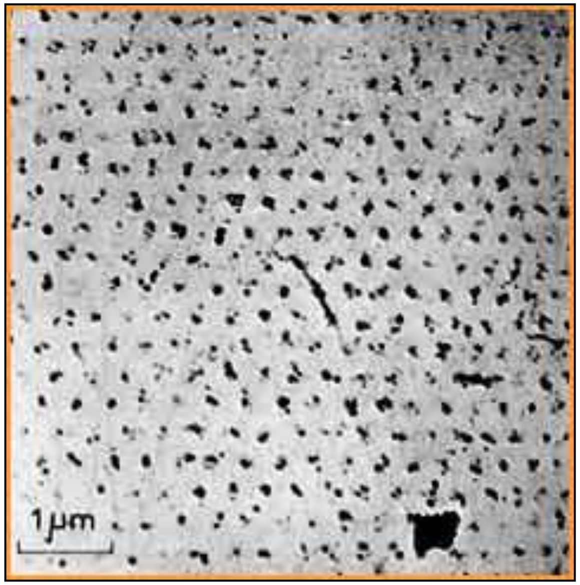
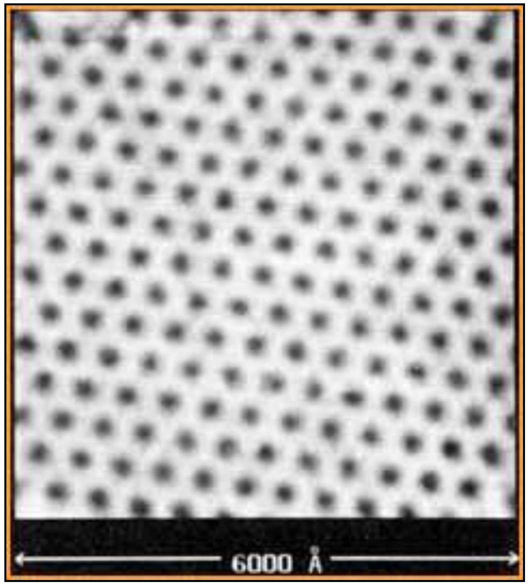
VISUALIZACIÓN INDIRECTA

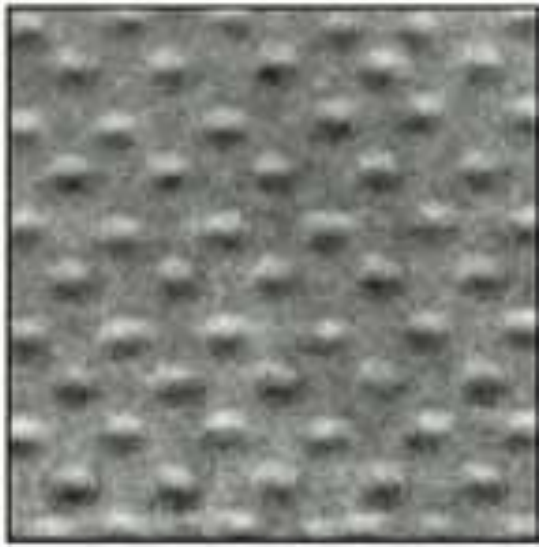
BITTER DECORATION



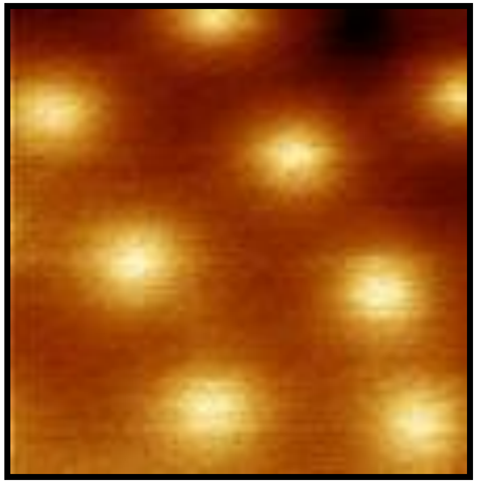
STM



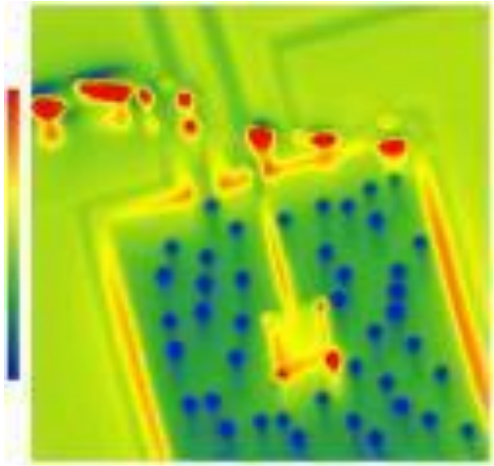
LORENTZ MICROSCOPY



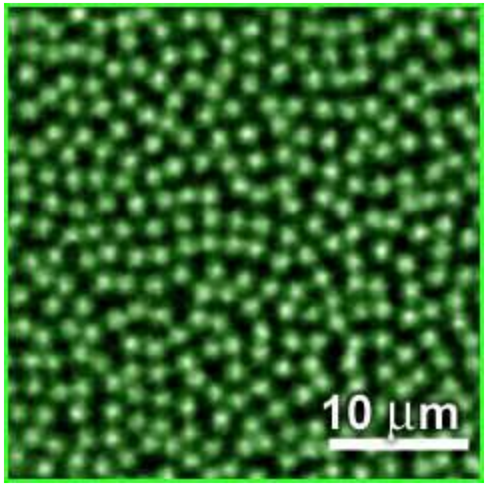
SHPM



SSM



MO



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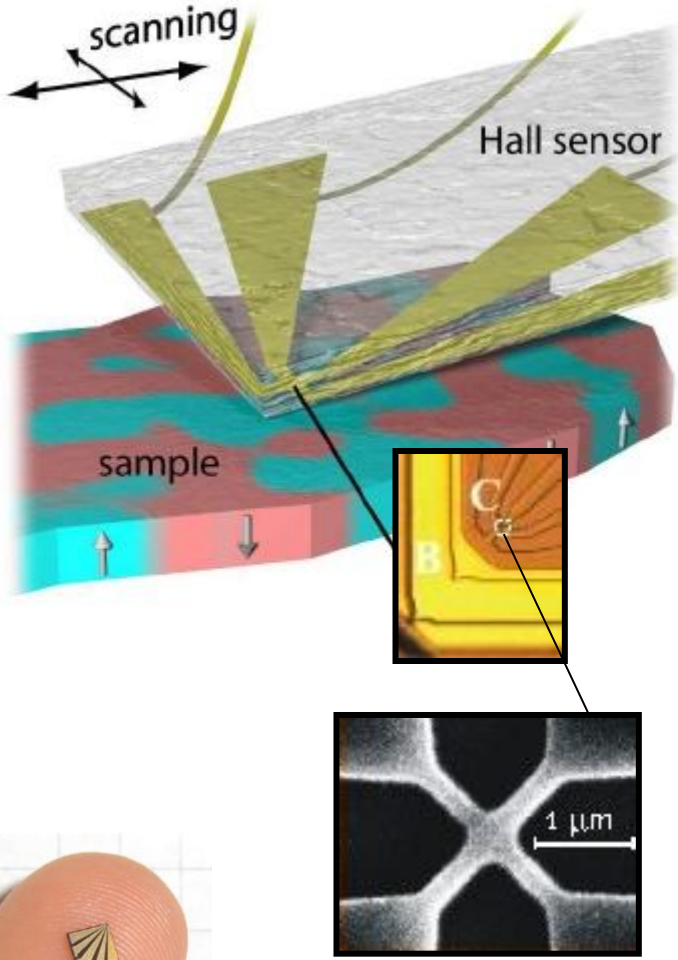
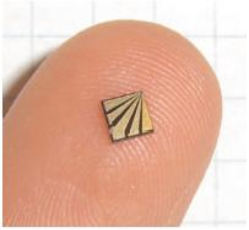
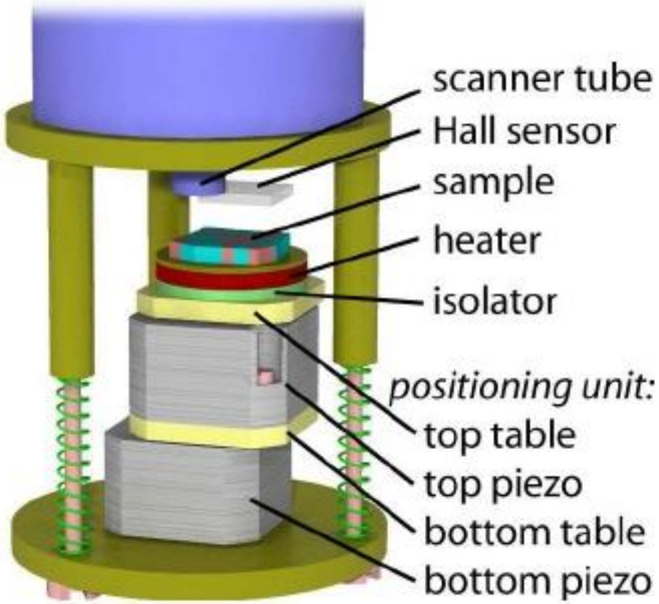
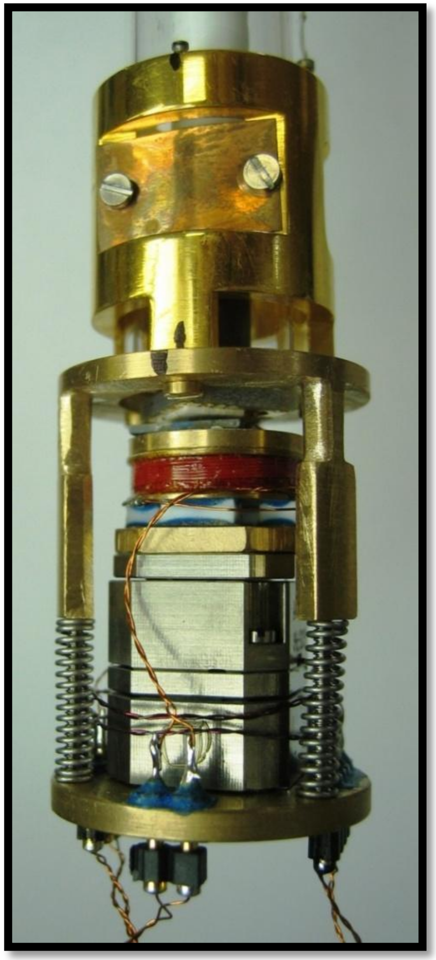
MICROSCOPIA HALL (SHPM)









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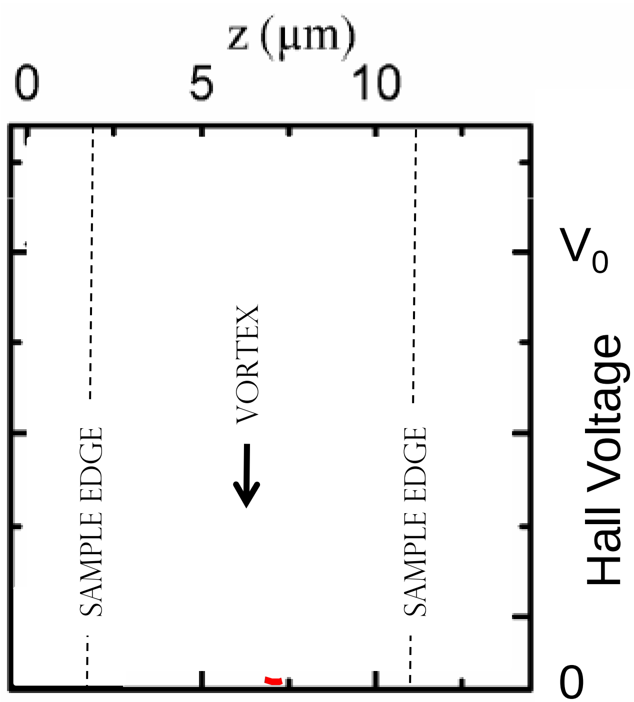
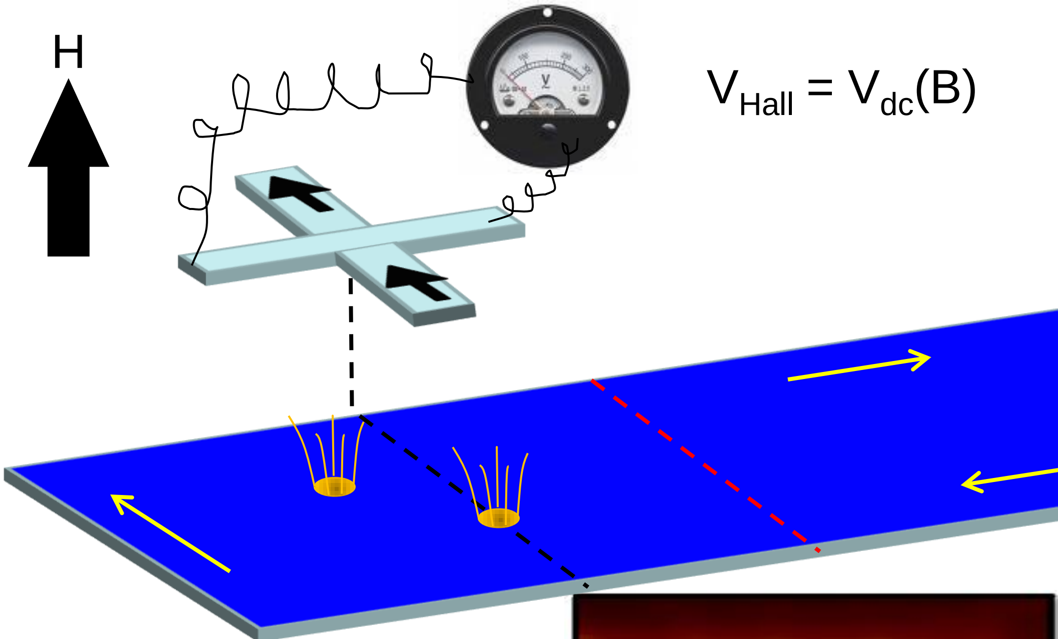
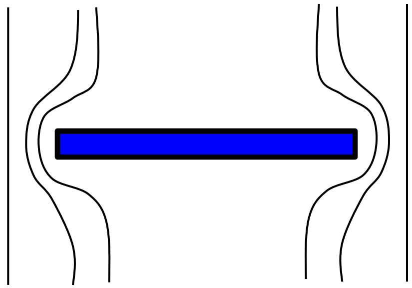
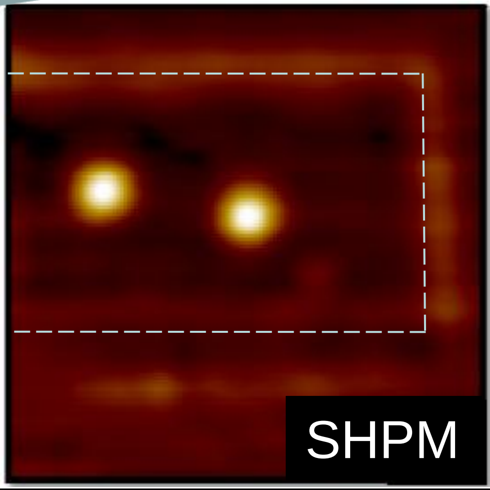
Scanning Hall Probe Microscopy





Scan range→14 x 14 μm² @ 4.2 K
Field resolution → 0.1 G
Typical vortex signal → 2.5 G
Scanning time → ~3'
Scanning height → ~ 0.5 μm



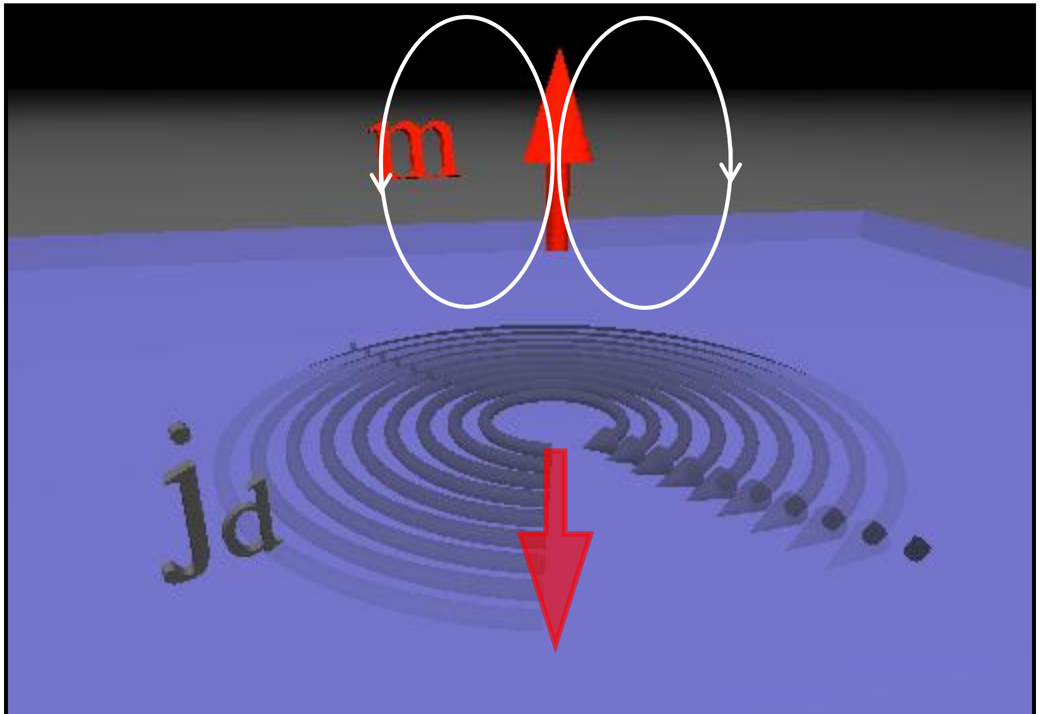


VENTAJAS Y DESVENTAJAS

VENTAJAS
- Resolución de un vórtice
- Técnica no invasiva
- Buena sensibilidad

DESVENTAJAS
- Area de barrido pequeña
- Técnica lenta
- Lejos de contacto
- Máximo campo ~ 7 G

SUPERCONDUCTOR / FERROMAGNET INTERACTION

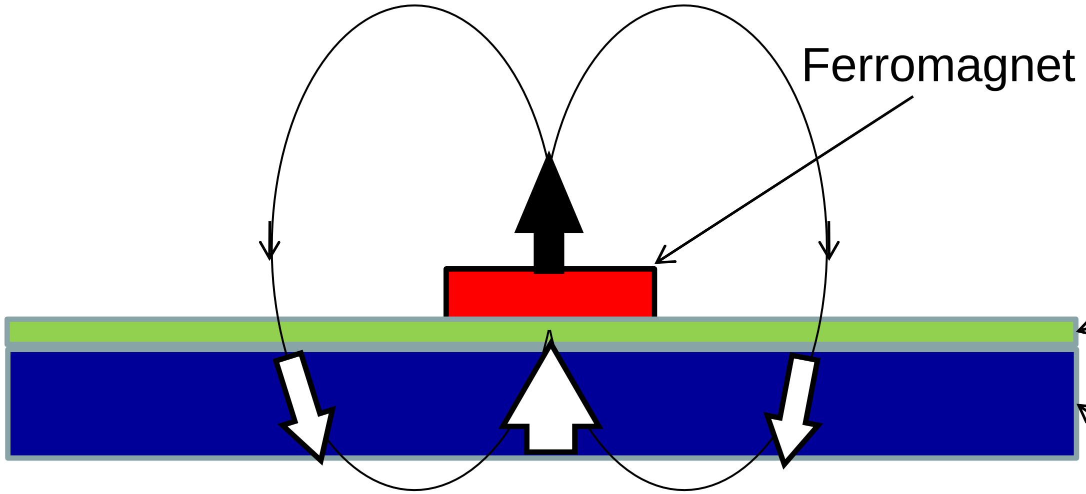


Haley and Fink, *Phys. Rev. B* **53**, 3506 (1996)

What is the origin of the restoring force ?
Suspension cannot be beaten by other forms of levitations !

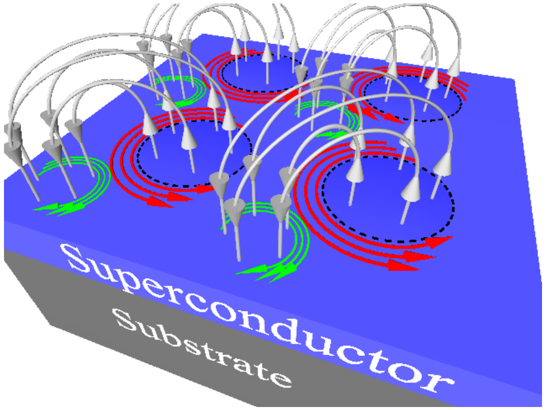
Not only ferromagnet/superconductors produce levitation → Ignoble Prize 2000 to Andre Geim
Diamagnetic levitation, repulsive Casimir forces, acoustic levitation, optical levitation,…

Levitation of a Magnetic dipole

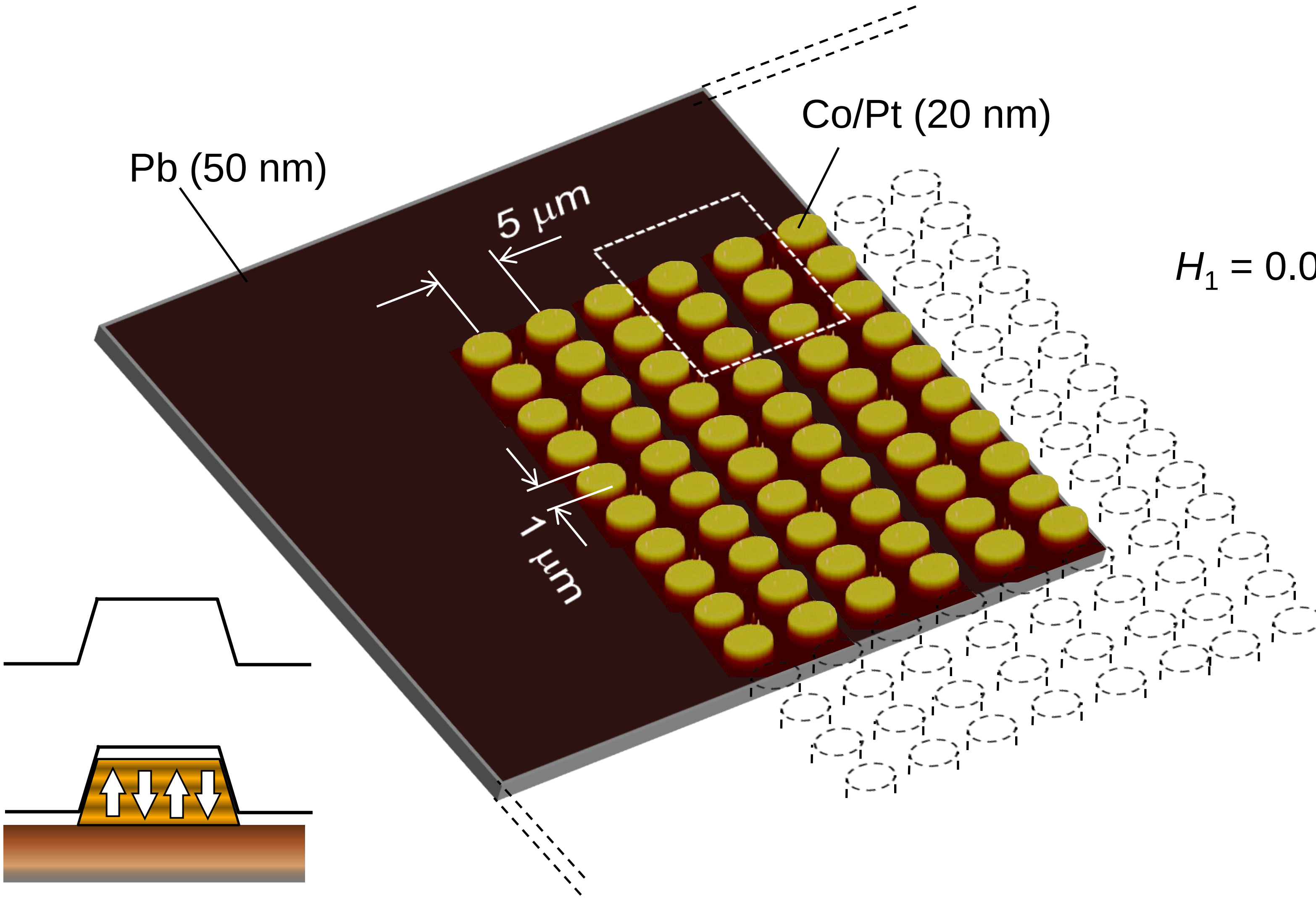


The Levitation height can be quantized !

S.B. Haley, *Phys. Rev. Lett.* **74**, 3261 (2005)



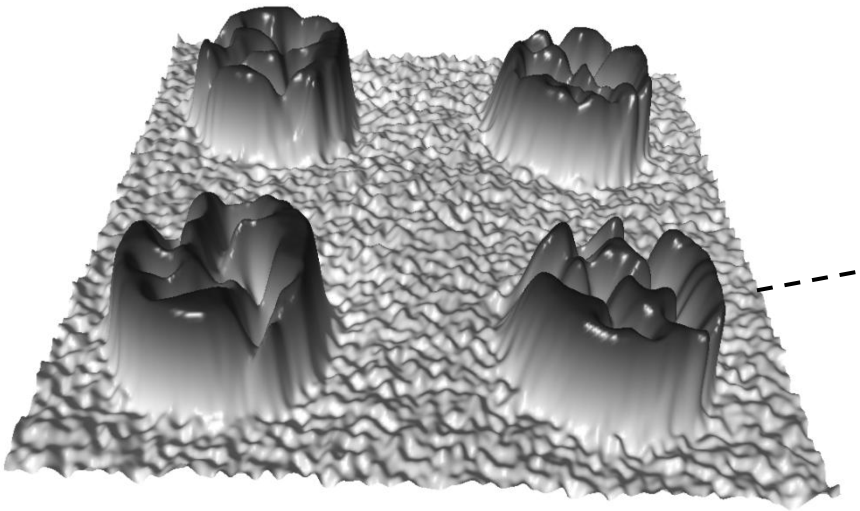
SAMPLE'S DETAILS



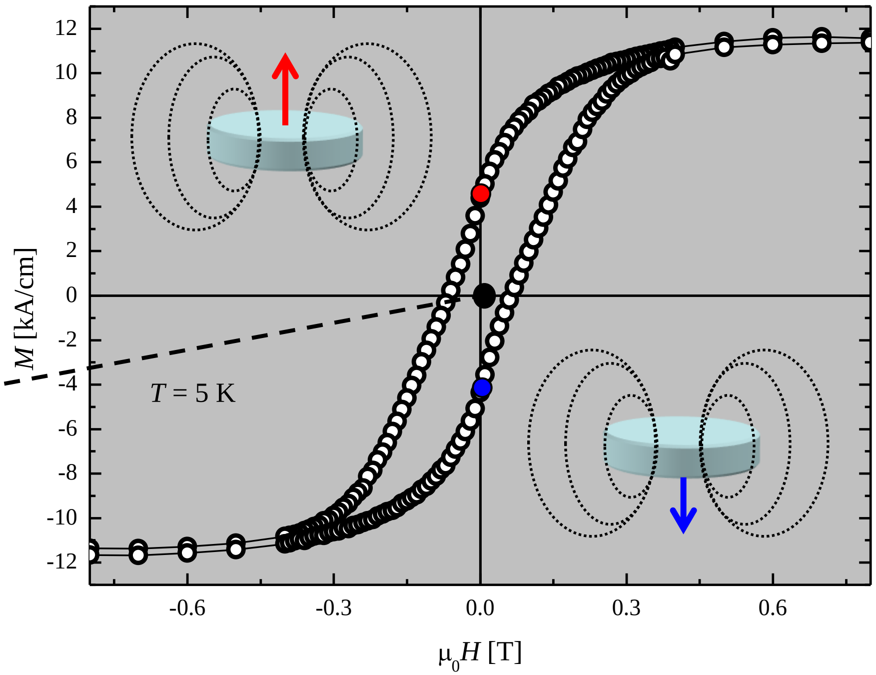
H_1 = 0.0828 mT

CONTROL DEL MOMENTO MAGNETICO NETO

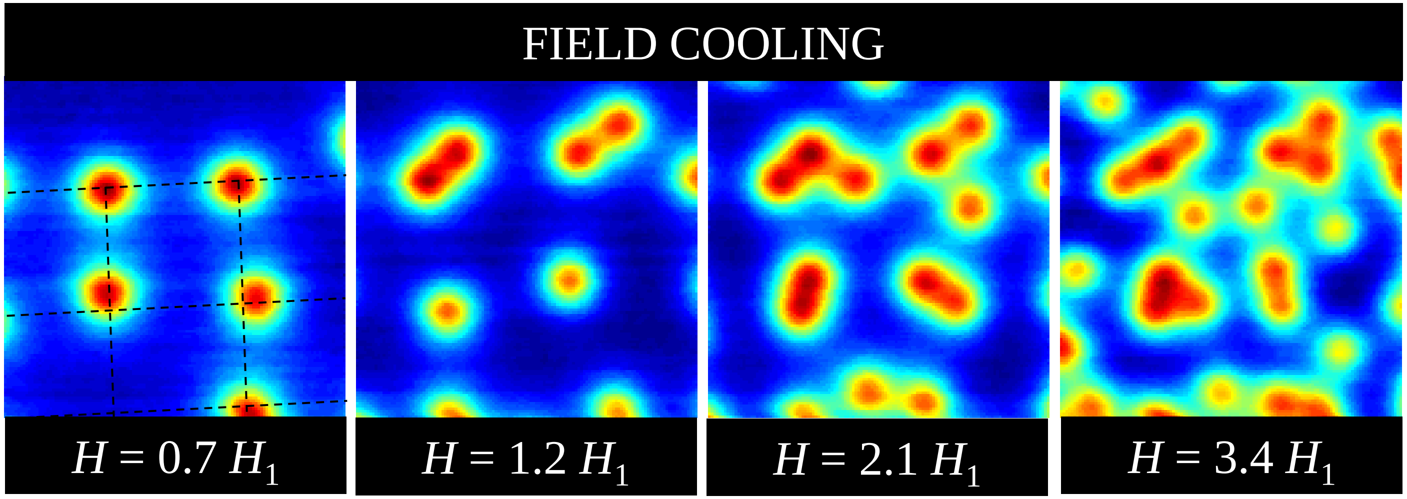
Microscopia de fuerza magnetica



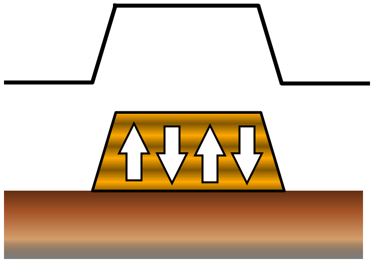
M=0



DEMAGNETIZED DOTS: M=0

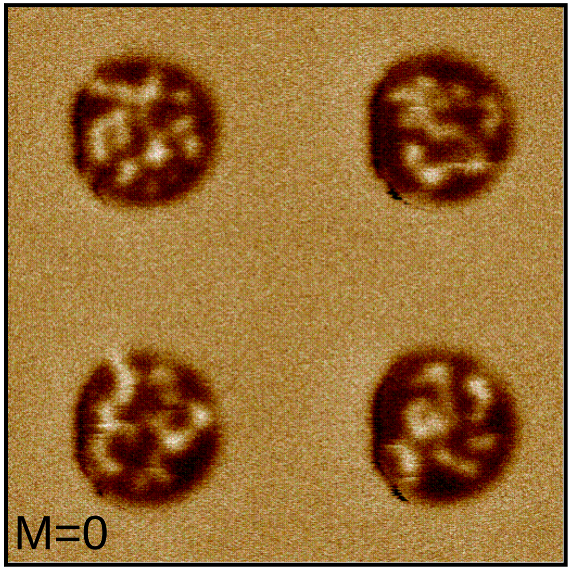


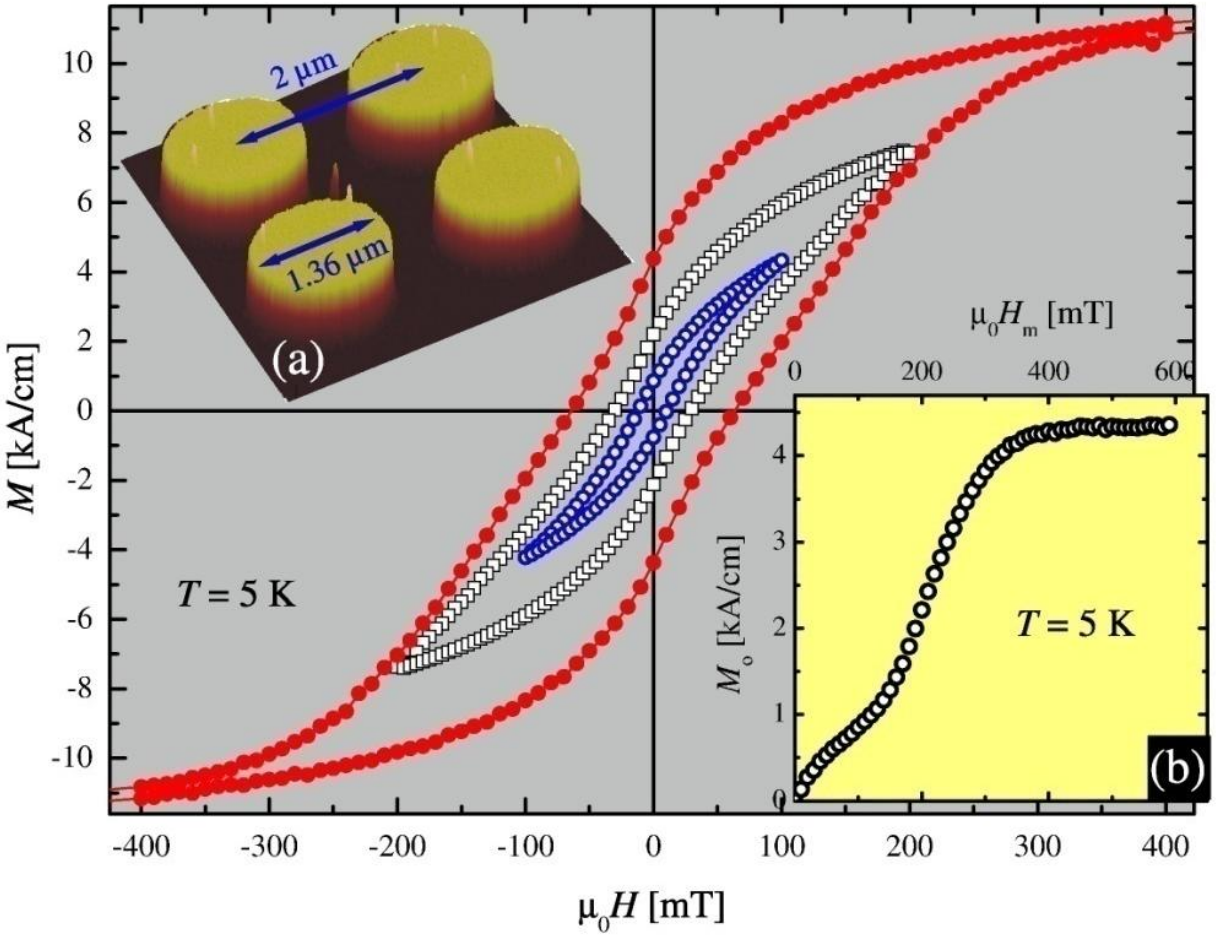
Each dot can trap at least 3 vortices !



Kramer, Silhanek, et al. PRX (2011)

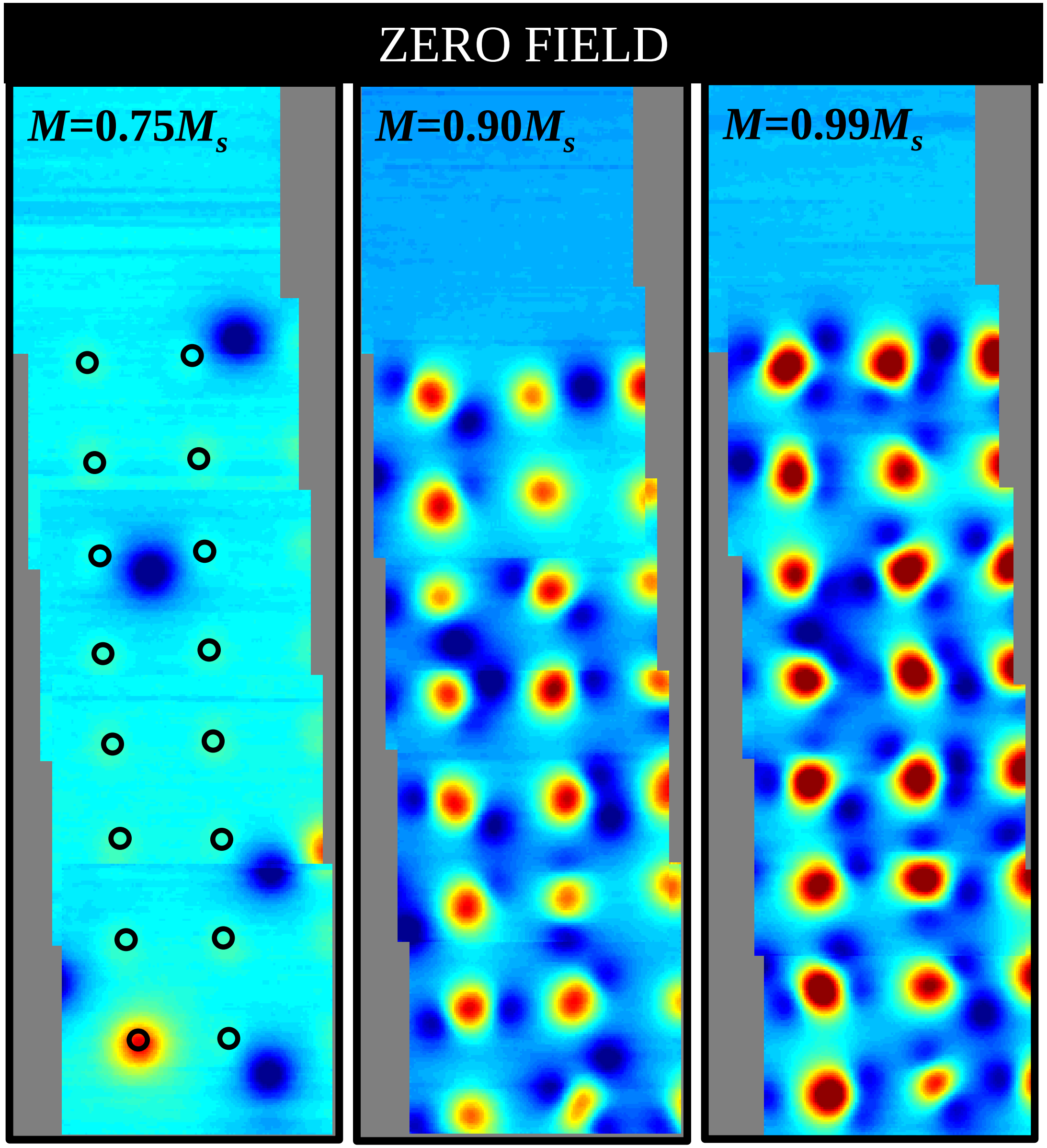
TUNING THE MAGNETIC MOMENT





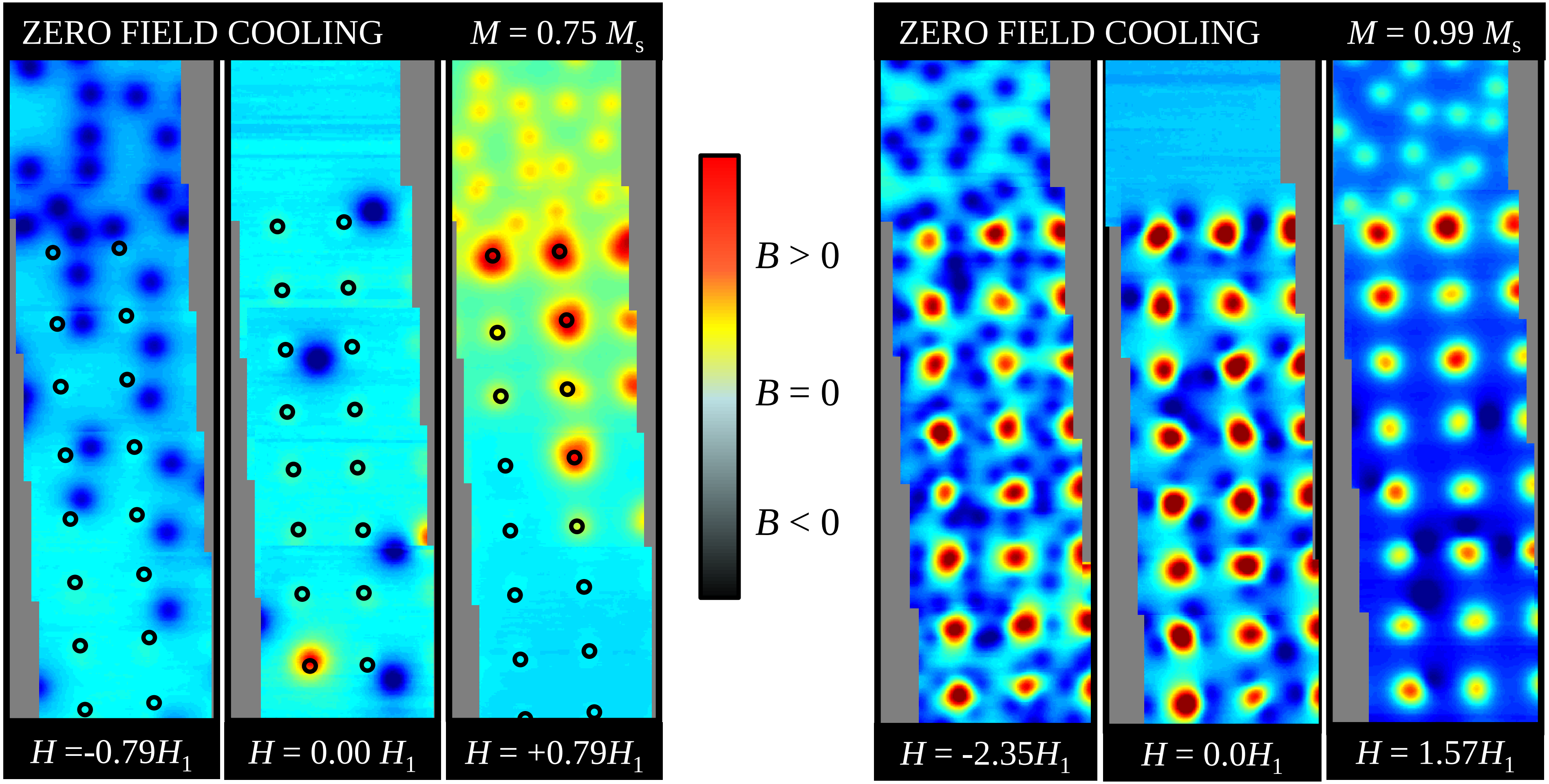
W. Gillijns, A. V. Silhanek, and V. V. Moshchalkov
PHYSICAL REVIEW B **74**, 220509(R) (2006)

CHANGING MAGNETIC MOMENT

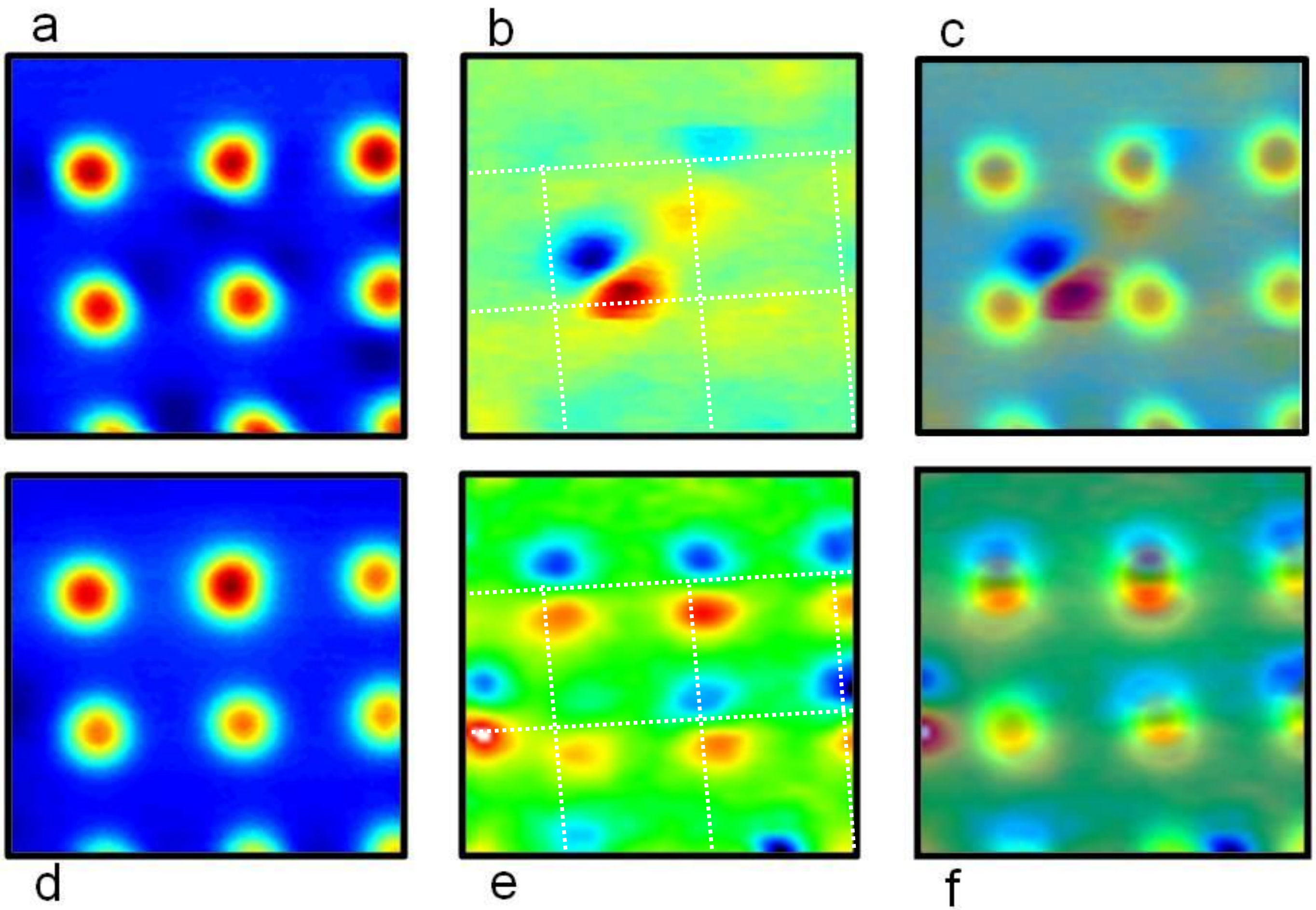


THE NUMBER OF V-AV PAIRS INCREASES WITH *M*

NON-EQUILIBRIUM: FIELD PENETRATION

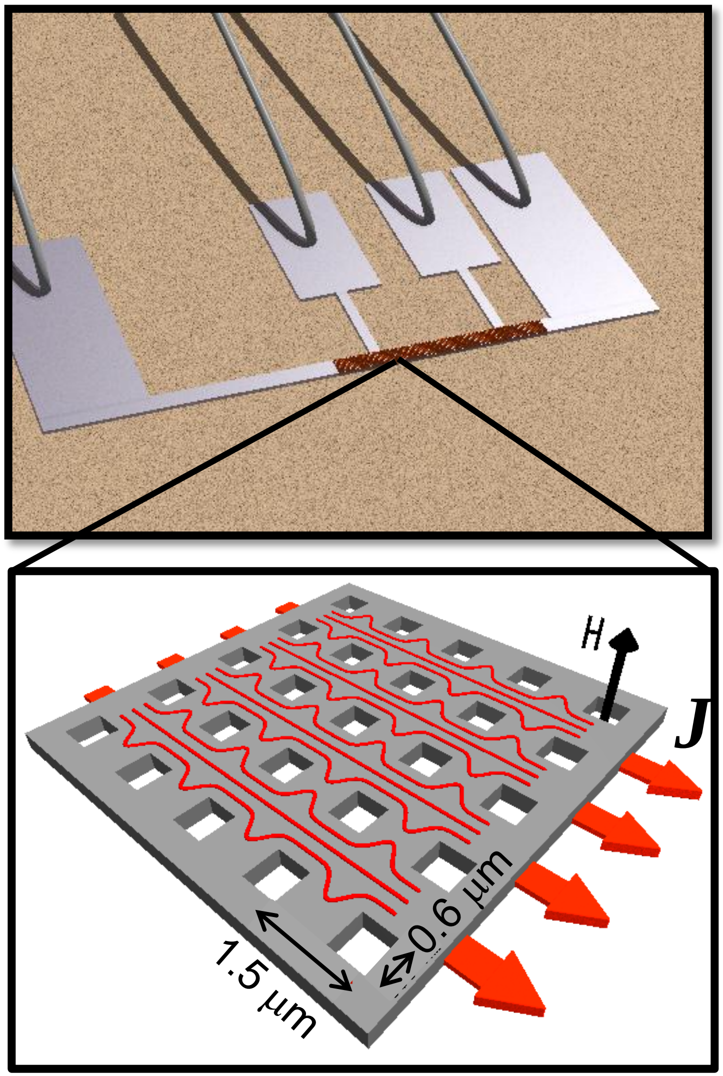


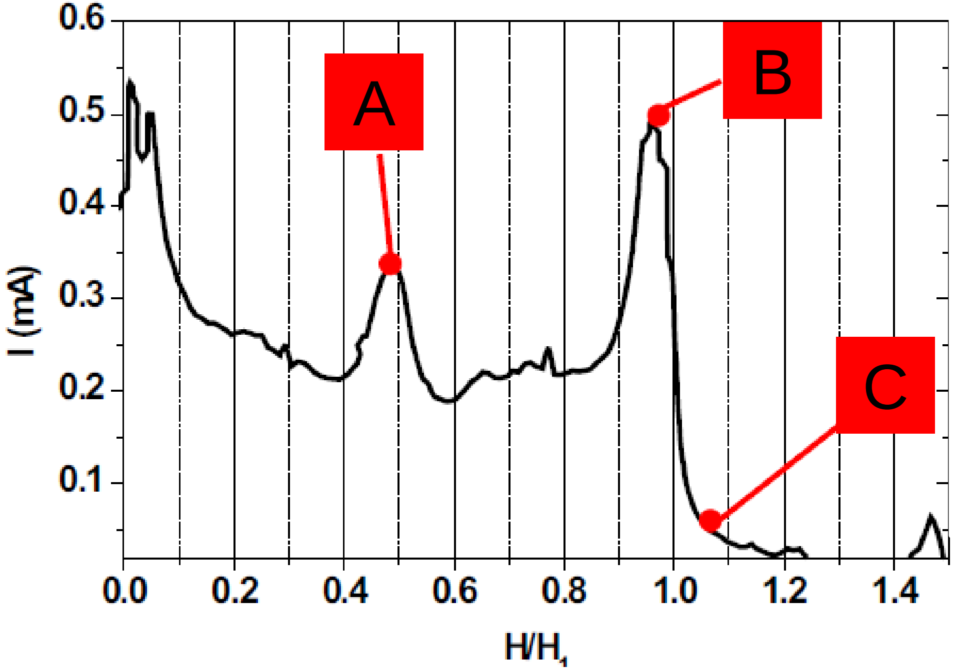
SHAKING THE VORTICES

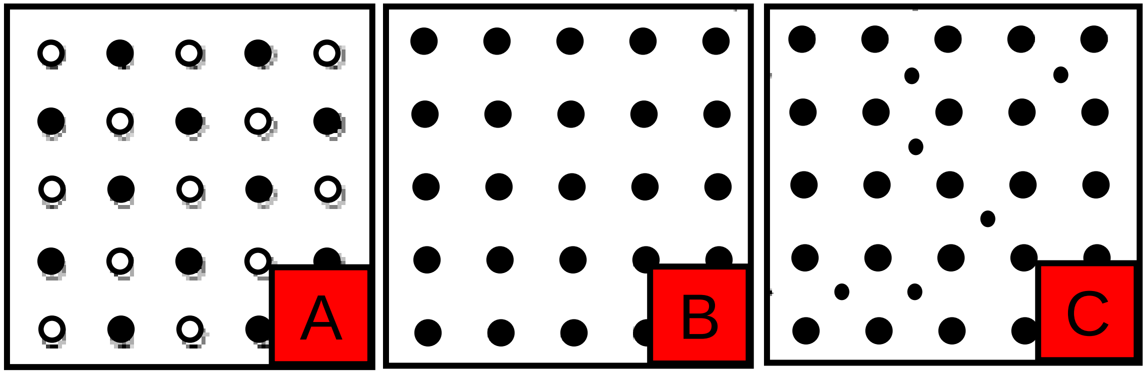


Kramer, Silhanek, Ataklti, Moshchalkov, *PRB* **81**, 144508 (2010)

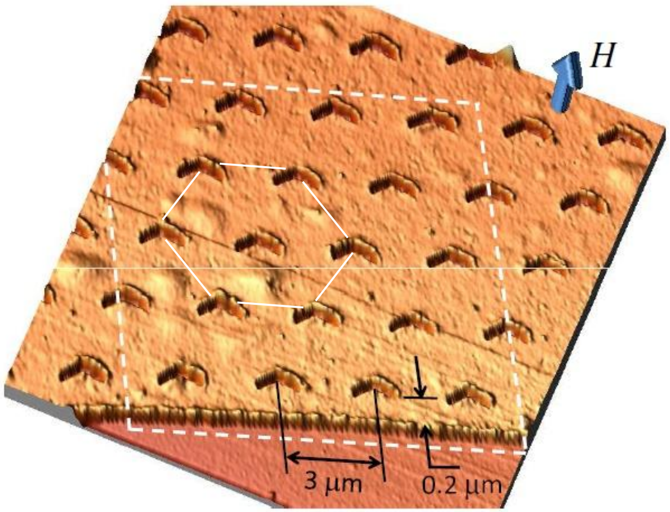
ARREGLO PERIODICO DE AGUJEROS

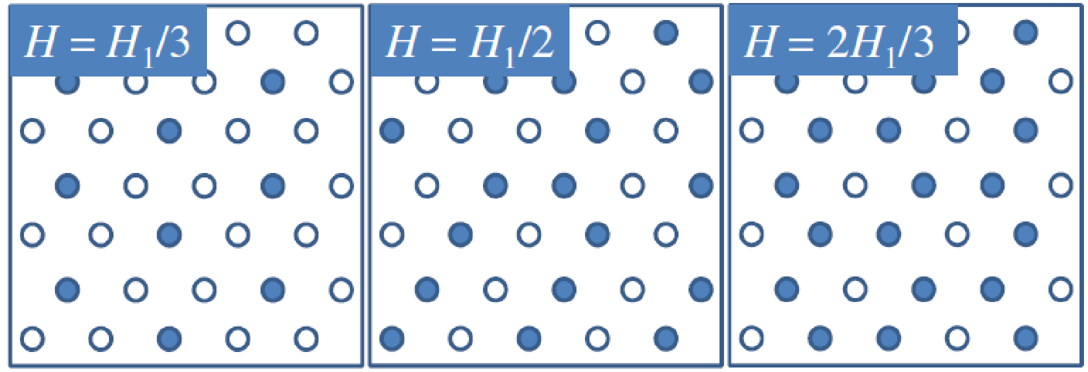




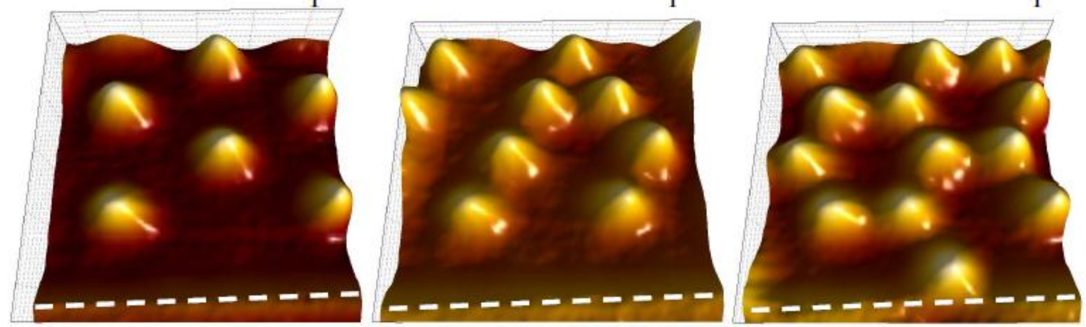


ARREGLO TRIANGULAR DE AGUJEROS

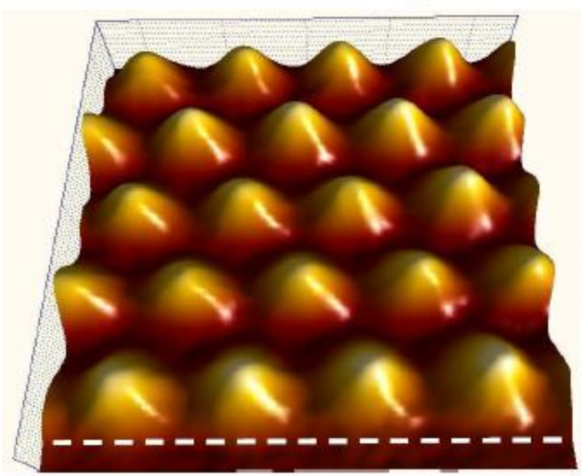


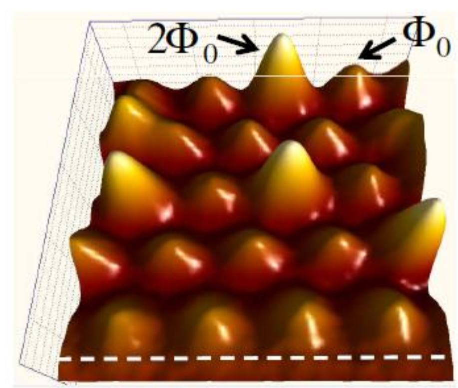


$H = 0.33\, H_1$ $H = 0.52\, H_1$ $H = 0.63\, H_1$

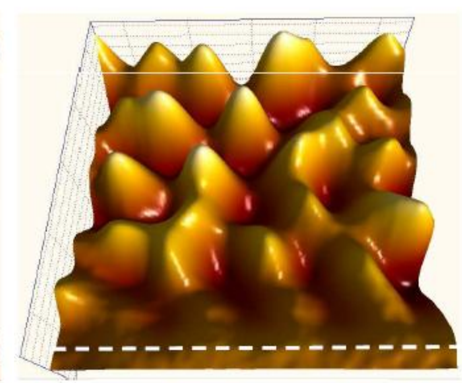


$H = H_1$



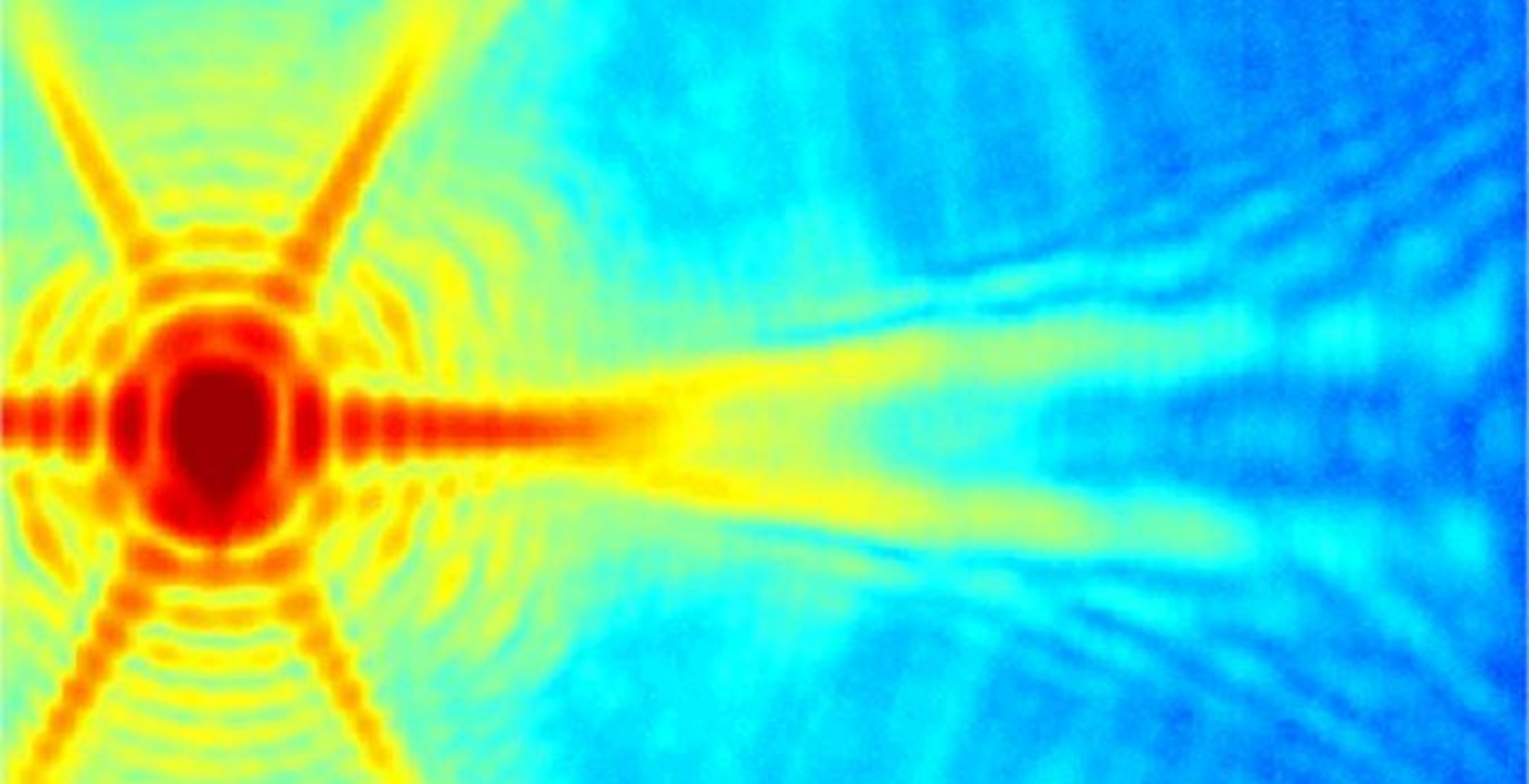


$H = 1.3H_1$



$H = 2H_1$

CONFINAMIENTO DE PLASMA Y ONDAS ELECTROMAGNETICAS



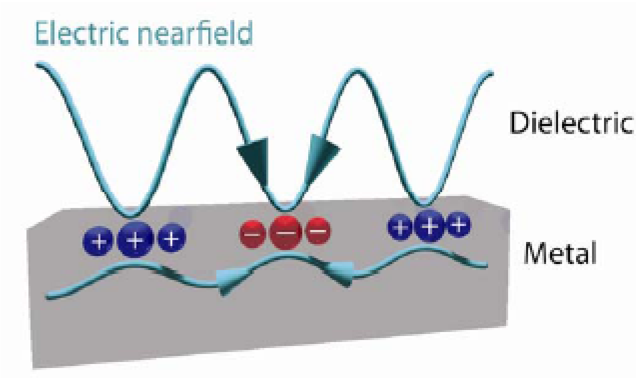
In collaboration with

Ventsi Valev, Yogesh Jeyaram, Denitza Denkova, Thierry Verbiest, Victor Moshchlakov, Guy Vandenbosch, Niels Verellen, Marcel Ameloot, Ben de Clerq, Oleg Atksipetrov

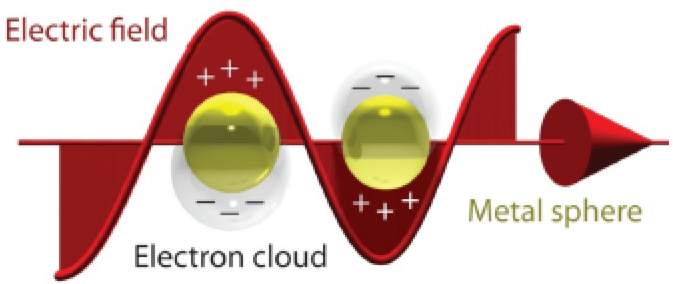
Plasmons for beauty, enlightenment and… wealth

The colorful images on the windows of cathedrals were created by making use of plasmonic particles. Even though, at the time, people did not understand the processes at work. What are plasmons?

What are surface plasmon resonances?



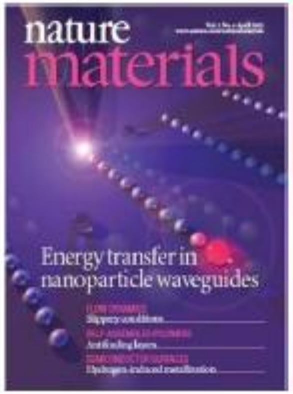
Surface plasmons are coherent electron oscillations that exist at the interface between any two materials where the real part of the dielectric function changes sign across the interface (e.g. a metal-dielectric interface, such as a metal sheet in air).

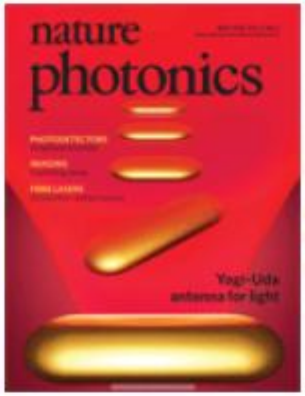


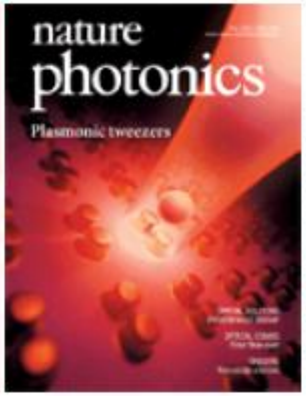
These waves can be excited very efficiently with light in the visible range of the electromagnetic spectrum, especially in nanoparticles.

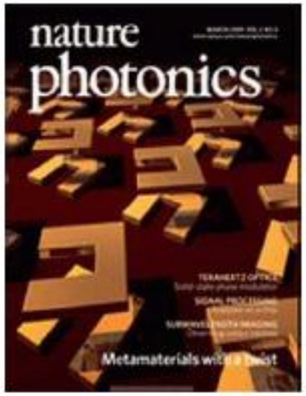
Nowadays, new revolutionary phenomena and applications are due to plasmonics.

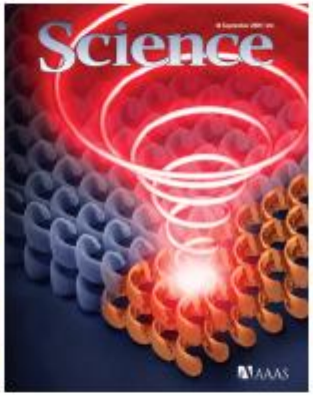
Highlights in the field of plasmonics



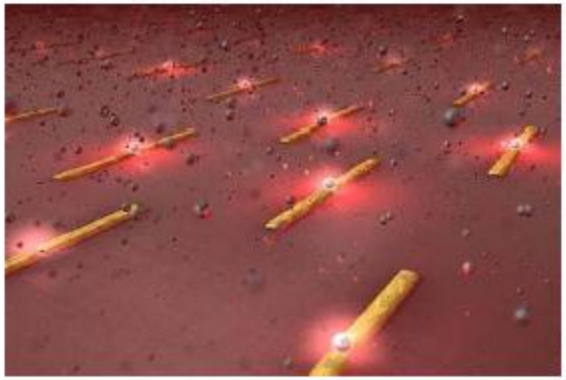








Light-based computing



Cancer treatment

Cloaking

What is the current state of the field?

Experimental mapping of plasmons

•Cathodoluminescence

E. J. R. Vesseur, R. de Waele, M. Kuttge, and A. Polman, Nano Lett. 7, 2843 (2007).

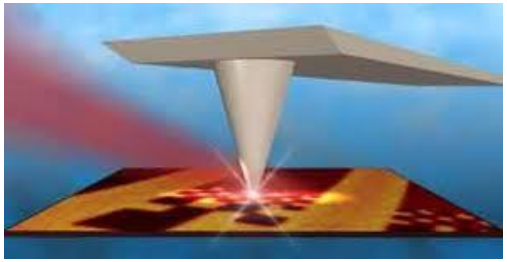
•Electron energy loss spectroscopy

J. Nelayah, M. Kociak, O. Stephan, F. J. G. de Abajo, M. Tence, L. Henrard, D. Taverna, I. Pastoriza-Santos, L. M. Liz-Marzan, and C. Colliex, Nature Phys. 3, 348 (2007).

+ offer the resolution of SEM

- requires vacuum

•Apertureless Scanning Nearfield Optical Microscope

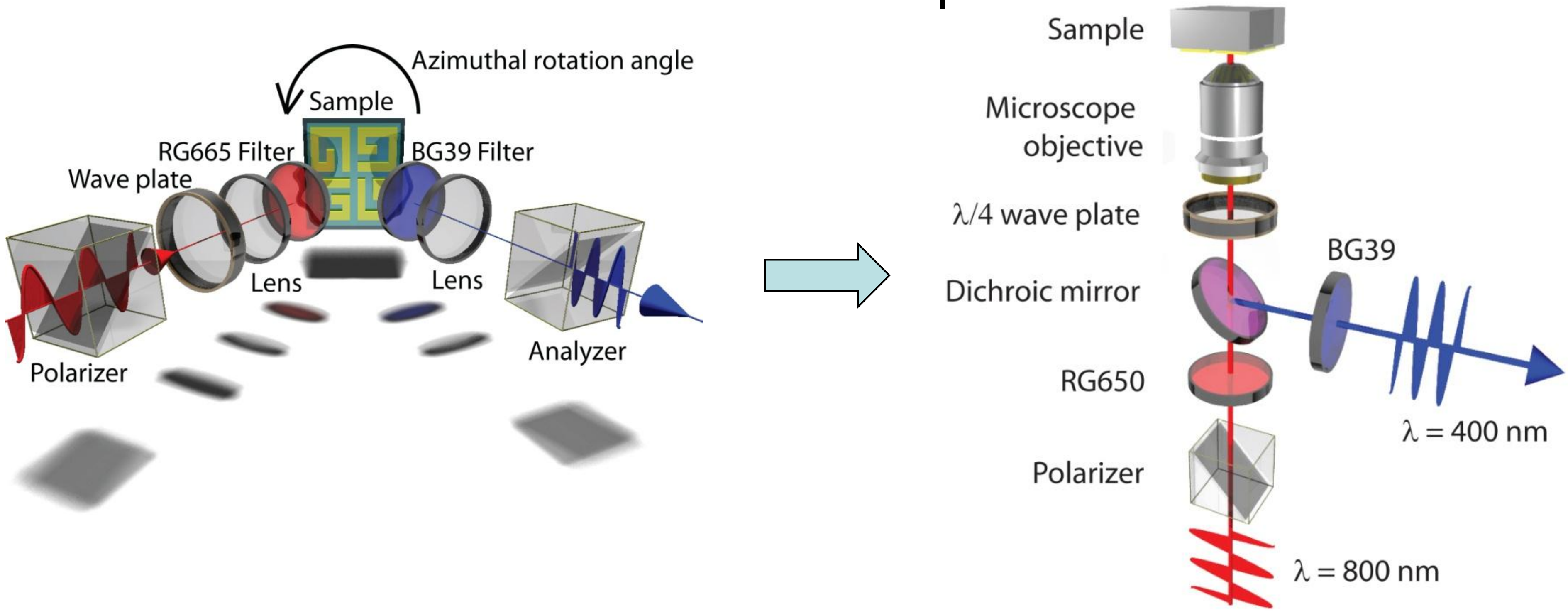


+ aSNOM can measure amplitude, direction and phase

- influence of the tip, complexity, very slow

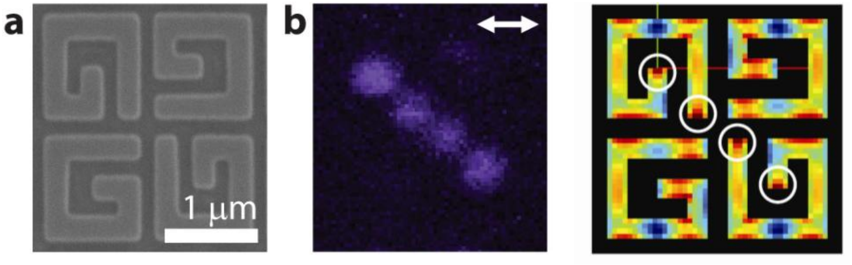
Although there are experimental techniques for mapping plasmons, their increase in resolution comes at a corresponding increase in cost and complexity.

Second Harmonic Imaging Microscopy



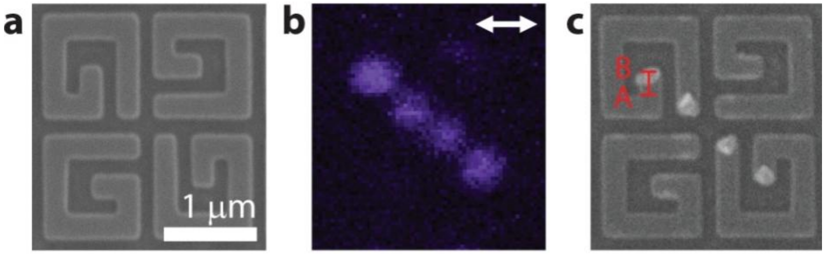
$$P = \varepsilon\,(\chi_1 E + \chi_2 E^2 + \chi_3 E^3 + \ldots)$$

Mapping plasmonic patterns with the resolution of an AFM



SHG microscopy shows hotspots.

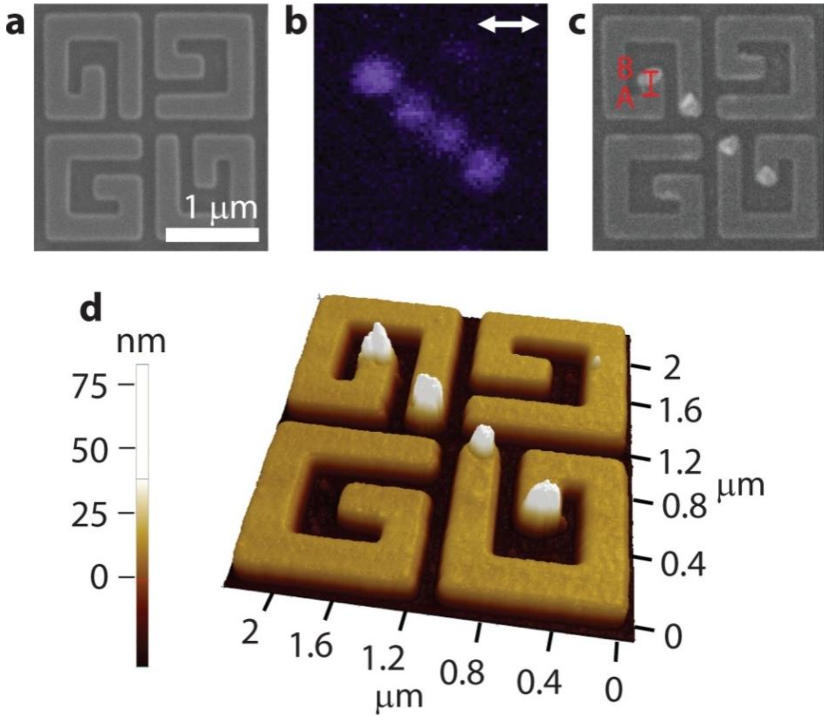
Mapping plasmonic patterns with the resolution of an AFM



SHG microscopy shows hotspots.

After illumination, SEM shows that the plasmonic pattern has been imprinted on the sample.

Mapping plasmonic patterns with the resolution of an AFM

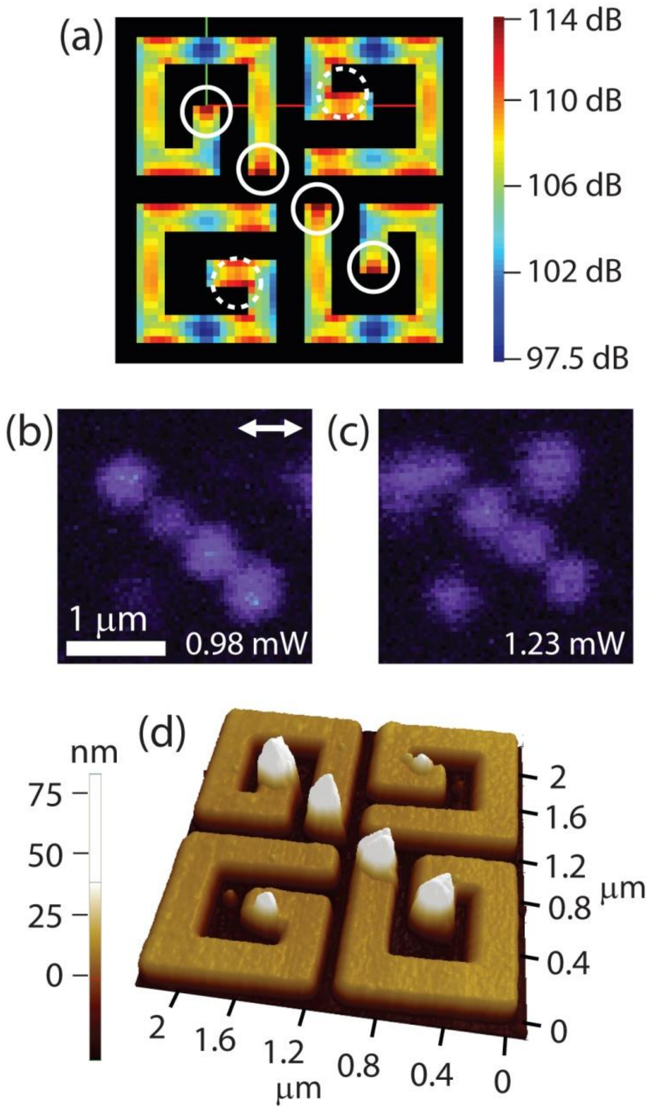


SHG microscopy shows hotspots.

After illumination, SEM shows that the plasmonic pattern has been imprinted on the sample.

AFM reveals that the hotspots have been decorated with peaks of extra material.

Hotspot Decoration: HD Mapping

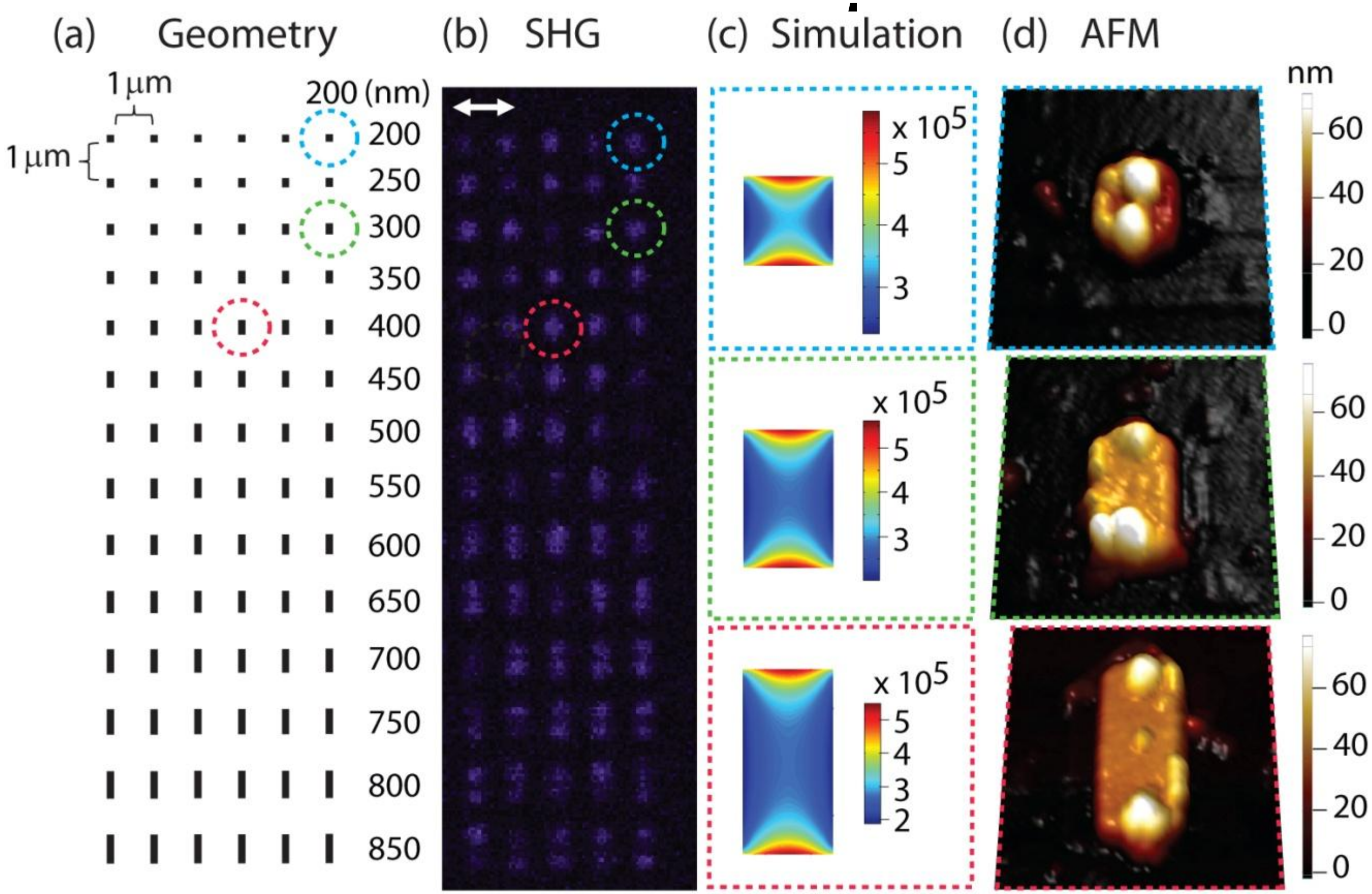


The advantages of HD Mapping are:

- High resolution
  - we use an AFM to obtain micrographs
- User friendliness
  - training with optical microscope is sufficient
- Speed
  - it takes under 10 min to imprint samples
- Robustness
  - the plasmon patterns are “written in stone”

But could HD Mapping be applied to other geometries?

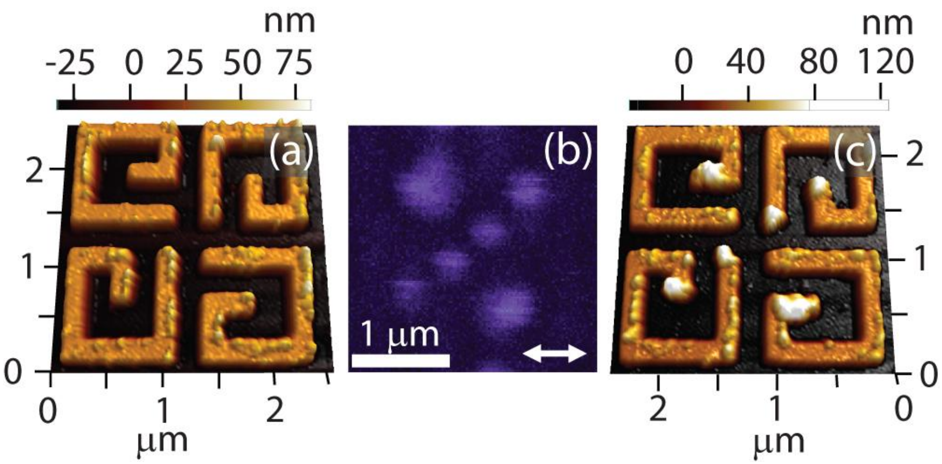
Mapping beyond the G-shaped



Is HD Mapping restricted to nickel?

V. K. Valev, *et al.*, "*Hotspot Decorations map plasmonic patterns with the resolution of scanning probe techniques*", Phys. Rev. Lett. 106, 226803 (2011).

Mapping beyond nickel



Palladium can also be imprinted.

But we have seen no imprints in gold.

What is the mechanism for growing these “decorations”?

Is there a way to apply this technique to mapping plasmons in gold?

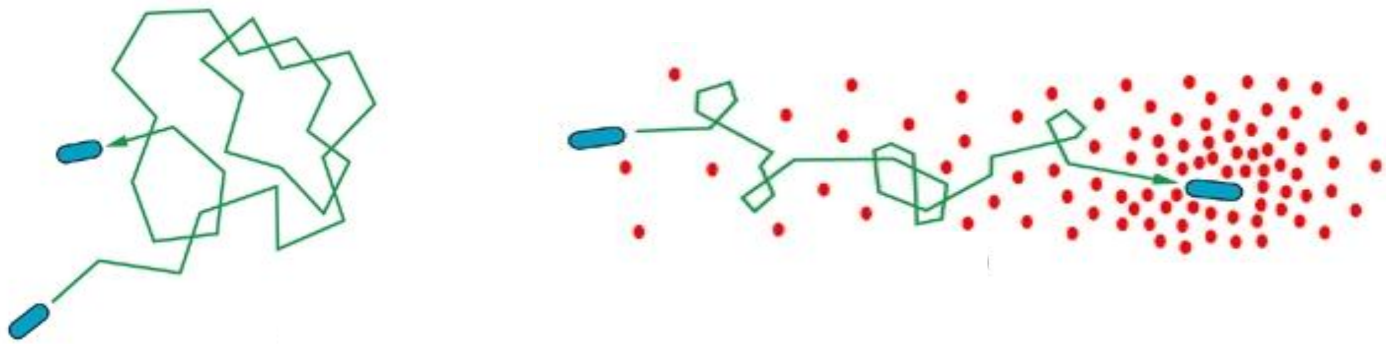
V. K. Valev, *et al*., “*Hotspot Decorations map plasmonic patterns with the resolution of scanning probe techniques*”, Phys. Rev. Lett. 106, 226803 (2011).

Taming bacteria by micro-patterned substrates

In collaboration with
Yogesh Jeyaram, Victor Moshchlakov,
Lyn Venken, Seppe Dierckx, Jos Vanderleyden,
Ivan Berdakin, Veronica Marconi, Carlos Condat, Francisco Tamarit

BACKGROUND

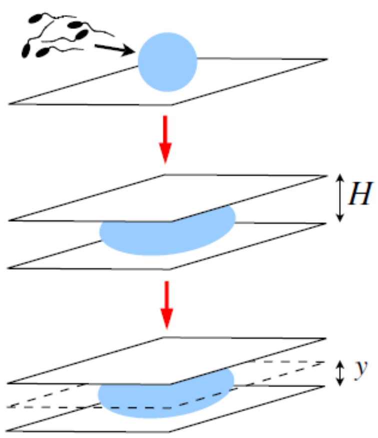
A LOT IS KNOWN ABOUT EVOLUTION, MOTILITY, REPRODUCTION, ETC. OF MICROORGANISMS IN AQUEOUS LIQUID CULTURES.

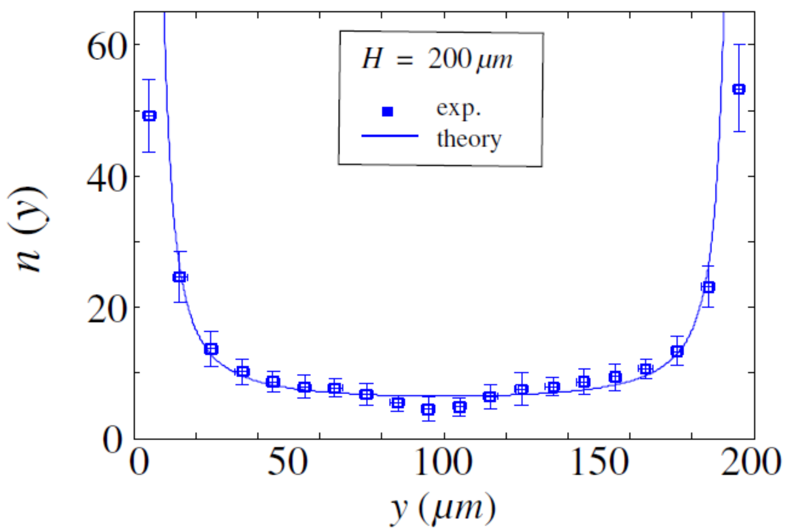


HOW DO THESE PARAMETERS CHANGE IN CONFINED HABITATS ?

BACTERIUM-WALL INTERACTION

HYDRODYNAMIC ATTRACTION



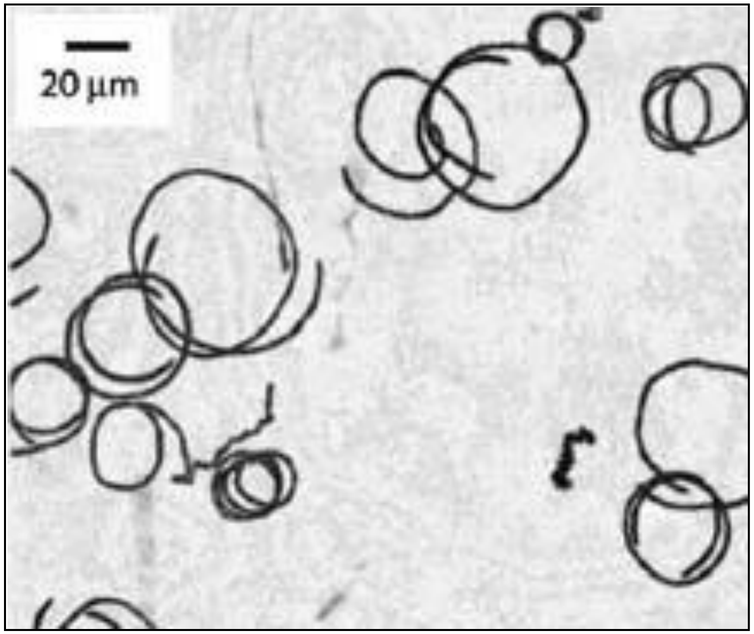


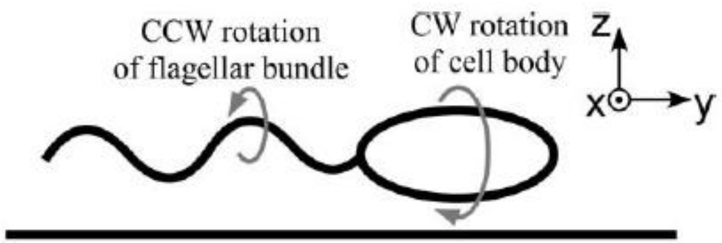
Berke *et al., Phys.Rev.Lett.* **101**, 038102 (2008)

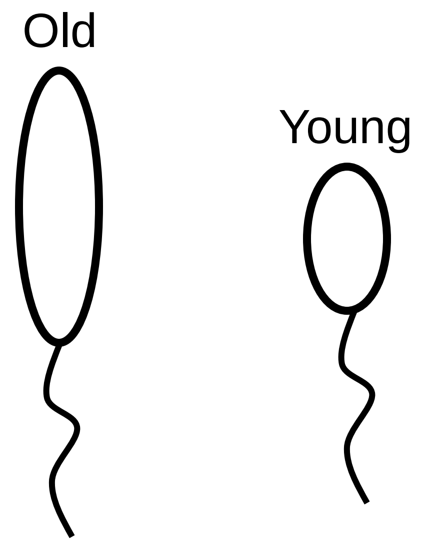
PHYSICS COMES INTO PLAY

Bacterium-wall interaction

HYDRODYNAMIC ROTATION



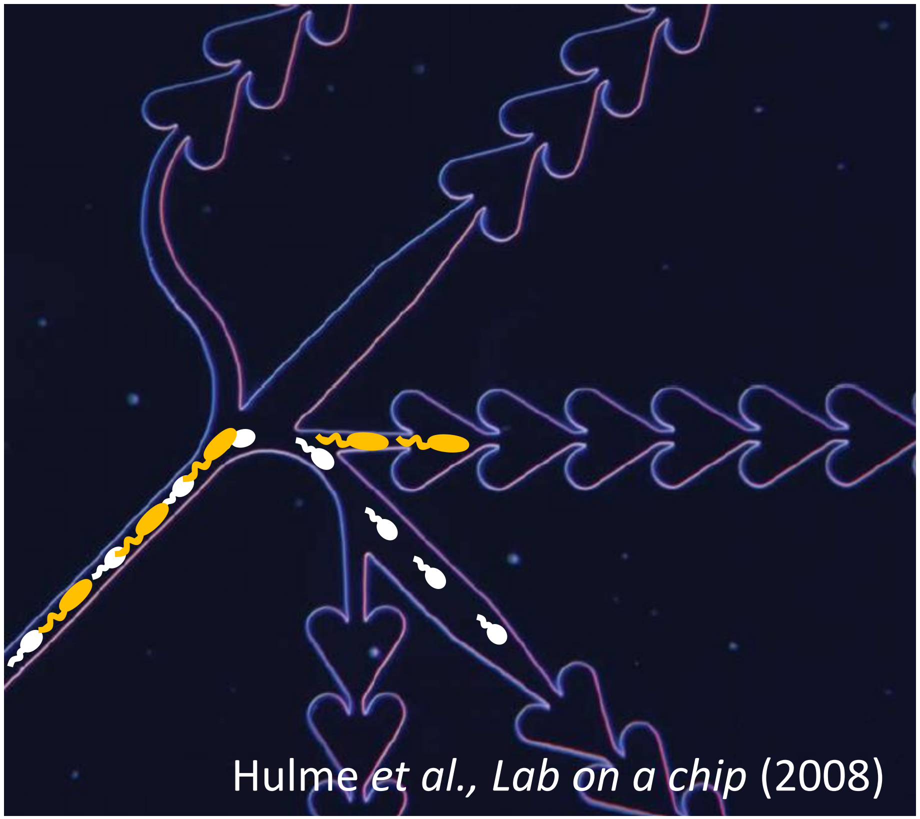


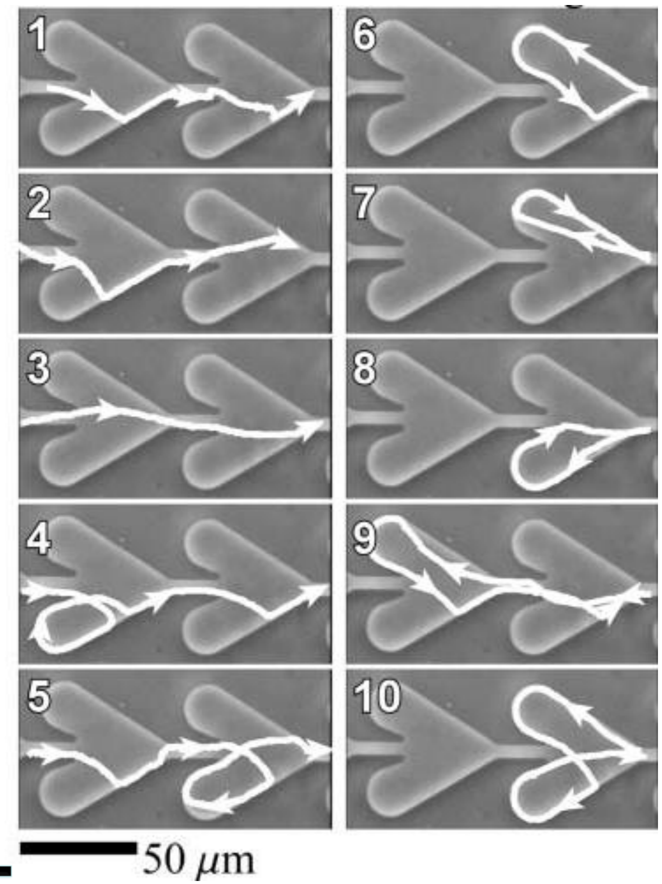


DiLuzio *et al.*, *Nature* **435**, 1271 (2005)
Lauga *et al.*, *Biophys. J.* **90**, 400 (2006)

KEY QUESTION

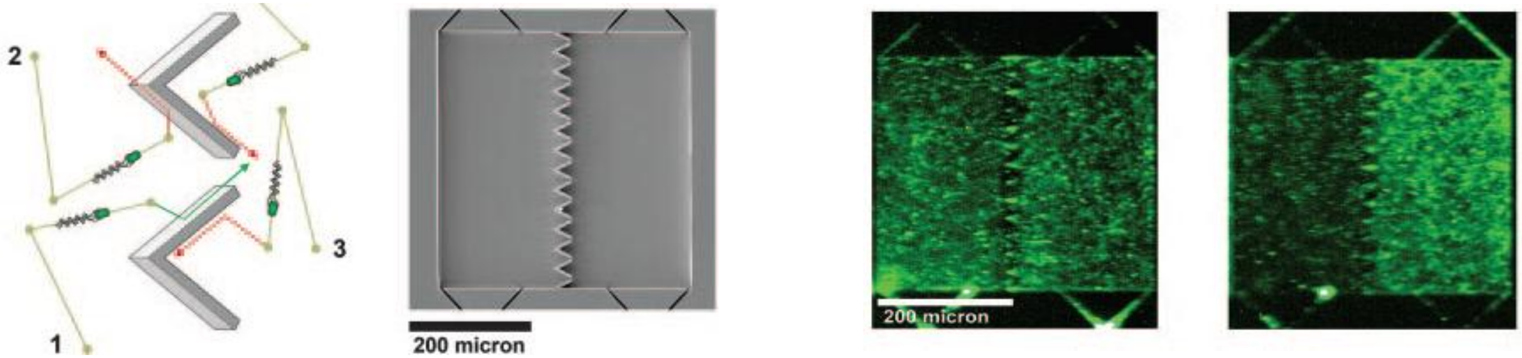
CAN WE USE THE CONFINEMENT EFFECTS TO CONTROL THE MOTION OF BACTERIA?





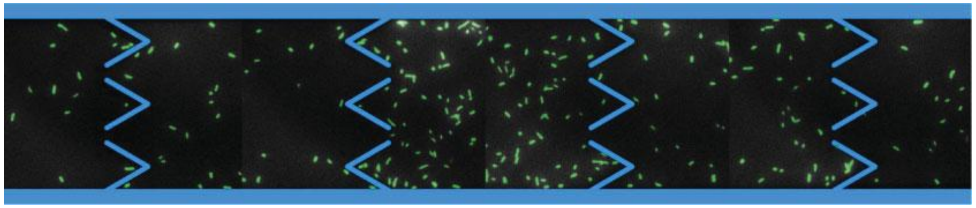
SEPARATION BY AGE

FUNNEL SHAPED MEMBRANES



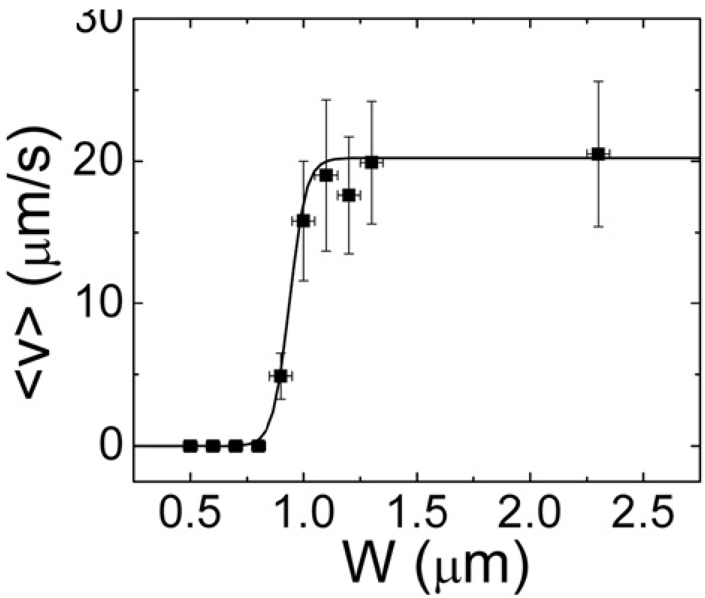
Galajda *et al., J. Bacteriol.* **189**, 8704 (2007)

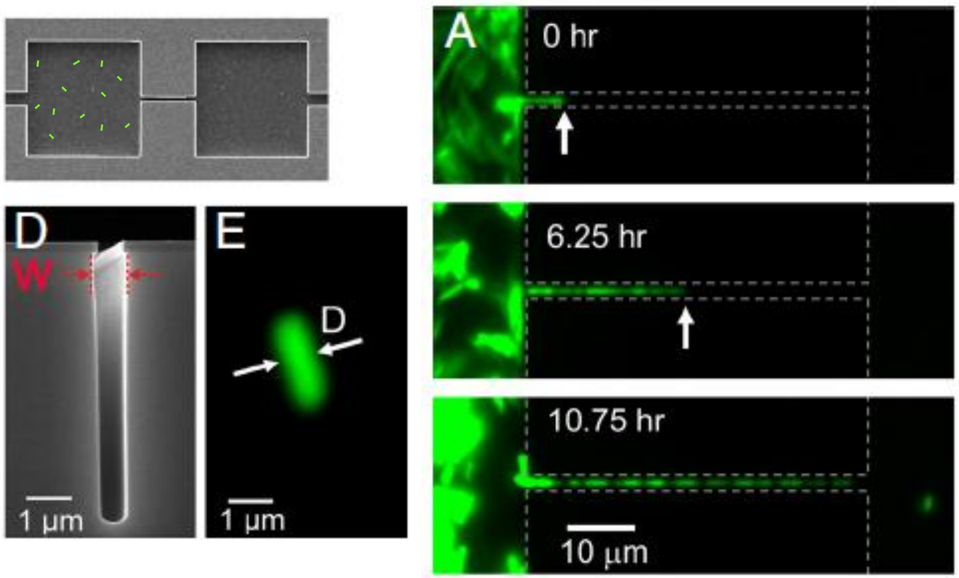
SEPARATION BY MOTILITY



Mahmud *et al., Nature Physics* **5**, 606 (2009)
Lambert *et al., Phys. Rev. Lett.* **104**, 168102 (2010)

MOTILITY IN SUBMICRON CONSTRICTIONS





Mannik *et al., PNAS* **106**, 14861 (2009)

SEPARATION BY CELL WALL'S THICKNESS

INNOVATIVE ASPECTS OF THE KUL-UNC PROJECT

OBJECTIVE

TO CONTROL THE ADAPTATION, MUTATION RATE, AND SEPARATION OF MIXED SYSTEMS OF MICROSWIMMERS BY MASTERING BOUNDARY EFFECTS

- Assuming heterogeneity in a bacteria population, say different “smartness”, for instance a bimodal distribution in the run lenght or velocity, can we separate them?

- Is it possible to observe genetic adaptation to small habitats ?

Consequences and Impact

TECHNOLOGICAL IMPACT

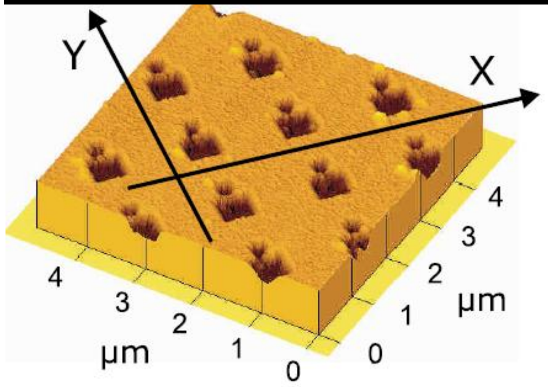
- Water purification
- Medical implants
- Lab-on-a-chip and biosensors
- Applicable not only to bacteria but to any kind of cells

ACADEMIC IMPACT

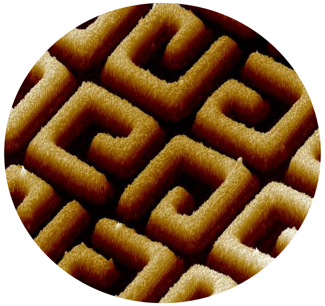
- To understand the hydrodynamic interactions between self-propelled objects
- System optimum to investigate dynamics of elastic media through an array of obstacles
- Adaptation and mutation of cells in microhabitats

CONCLUSION: A COHERENT RESEARCH STRATEGY

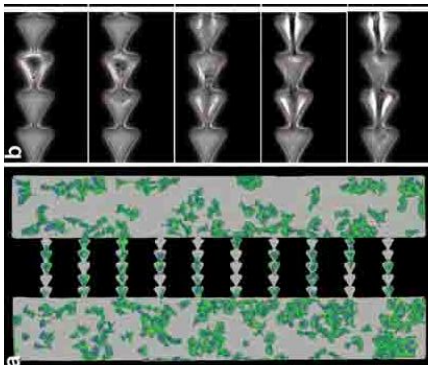
SUPERCONDUCTORS



PLASMA RESONANCES



BIOSYSTEMS



- ✓ CONFINEMENT EFFECTS LEAD TO NEW PHENOMENA
- ✓ MANIPULATION VIA BOUNDARY EFFECTS
- ✓ PATTERNING INVOLVES SIMILAR DESIGNS AND DIMENSIONS
- ✓ INTERDISCIPLINARY
- ✓ IMMEDIATE IMPACT DUE TO MAPPING WITH APARENTLY DISSIMILAR TOPICS

THE END