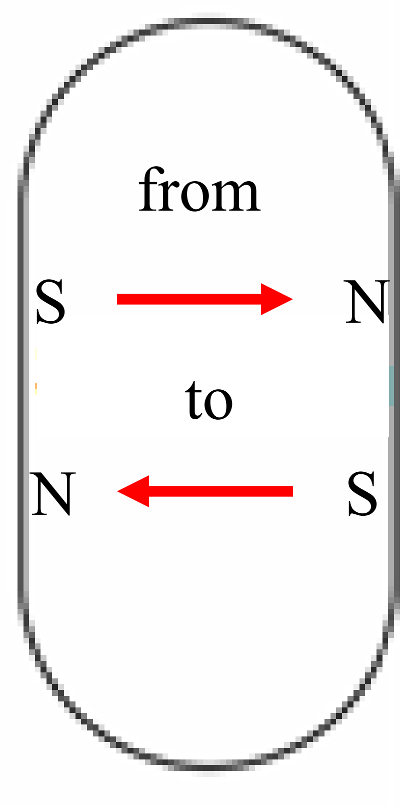
Magnetic Reversal at almost the Nanoscale: Conservation of skyrmion number effects

Pete Eames, **Ming Yan, Chuck Campbell and DD**

In dots the magnetic reversal occurs by the nucleation and propagation of a **vortex**. In stadia the spontaneous nucleation of **vortex-antivortex pairs** to aid the reversal.

Conservation of skymion number produces an asymmetry in the reversal process.

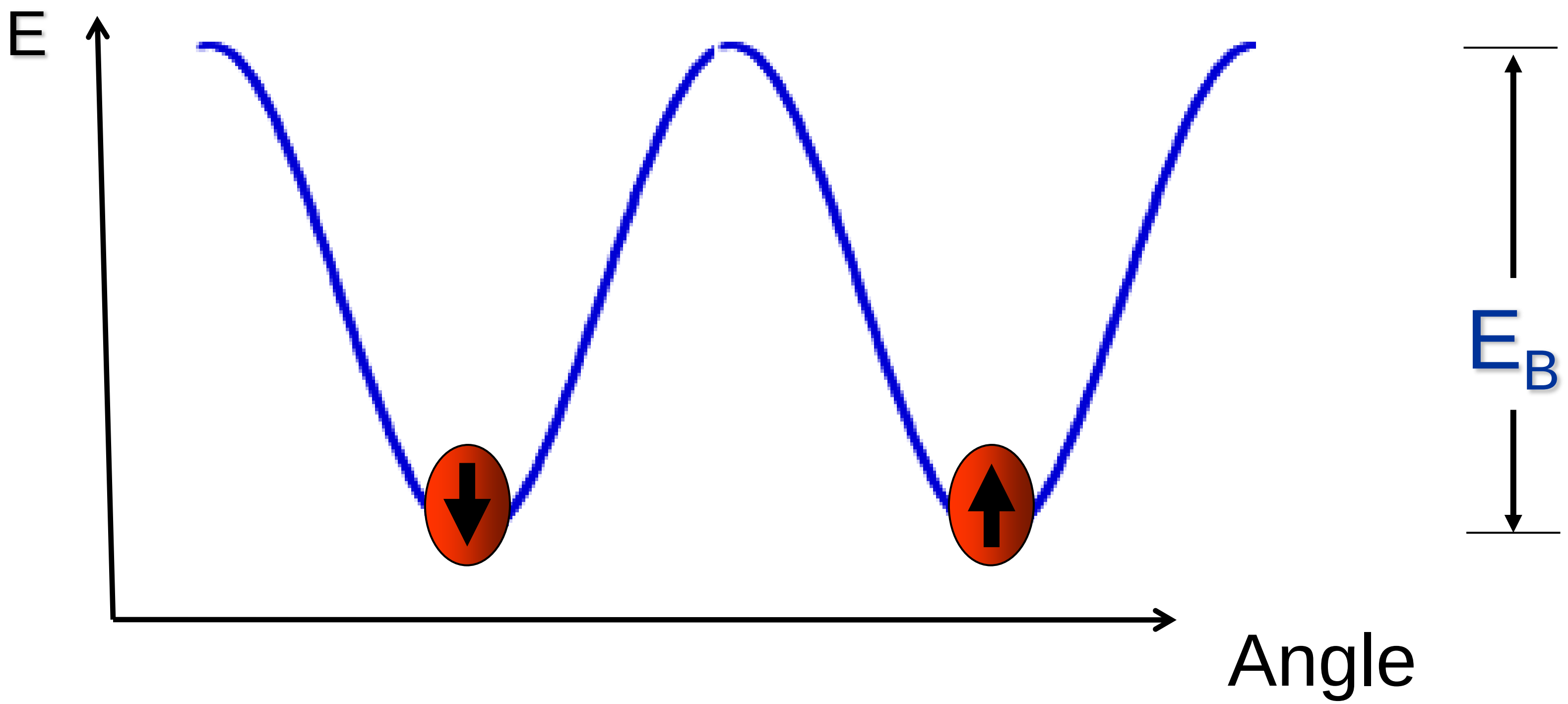


Thanks to NSF and ONR

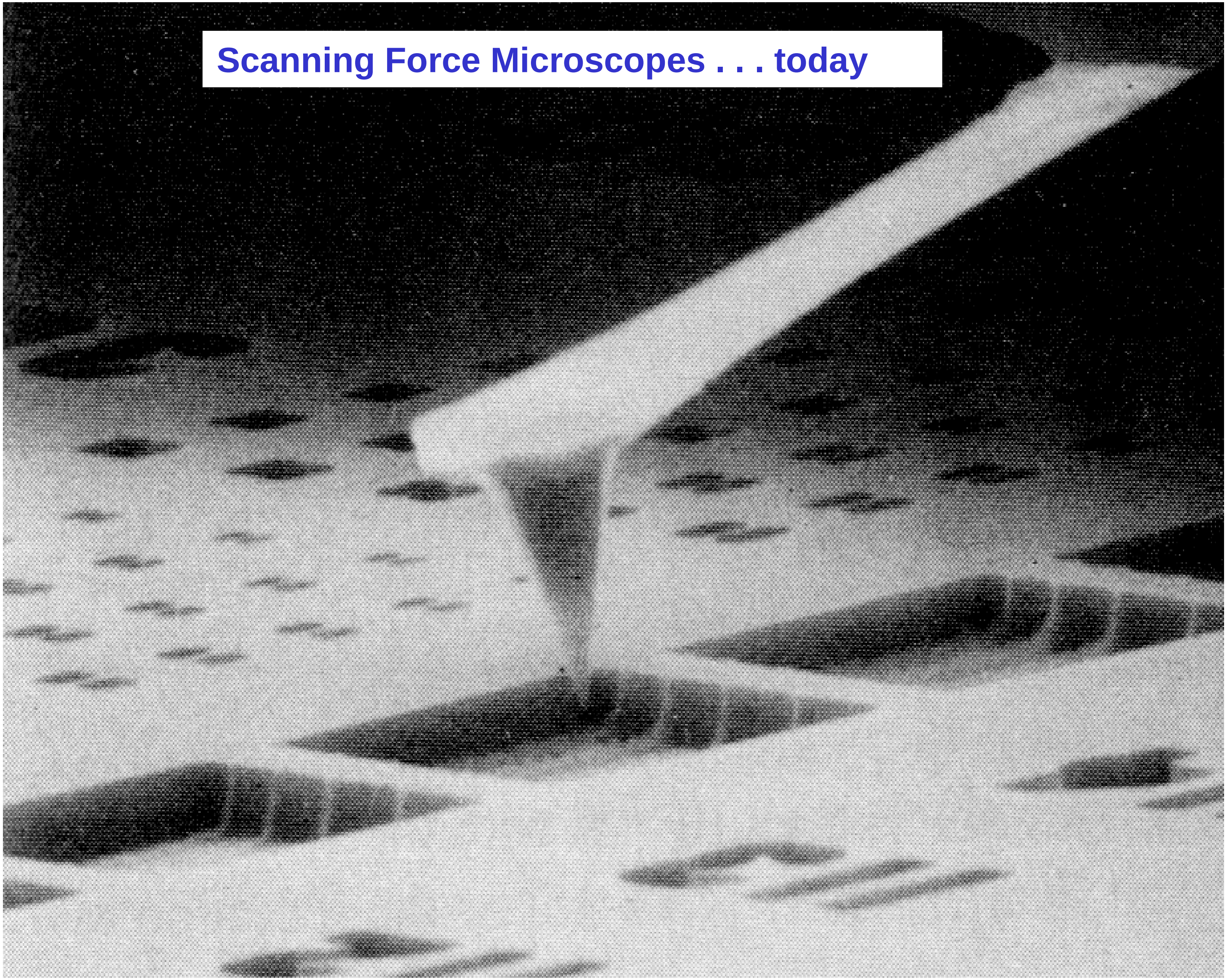
How Does a Magnet Reverse its Magnetization?

Single electron reversals are rather simple, i.e., we understand this process.

Bulk systems are just too complicated for a physicist. A wall nucleates somehow in “some” region and then “propagates” past energy barriers,etc.- UGH!

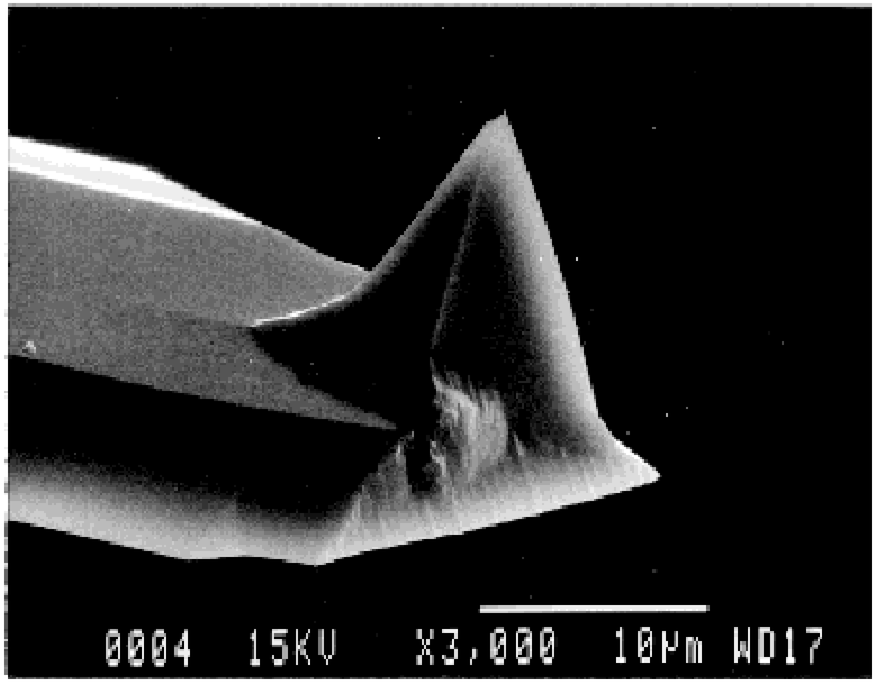


Scanning Force Microscopes . . . today

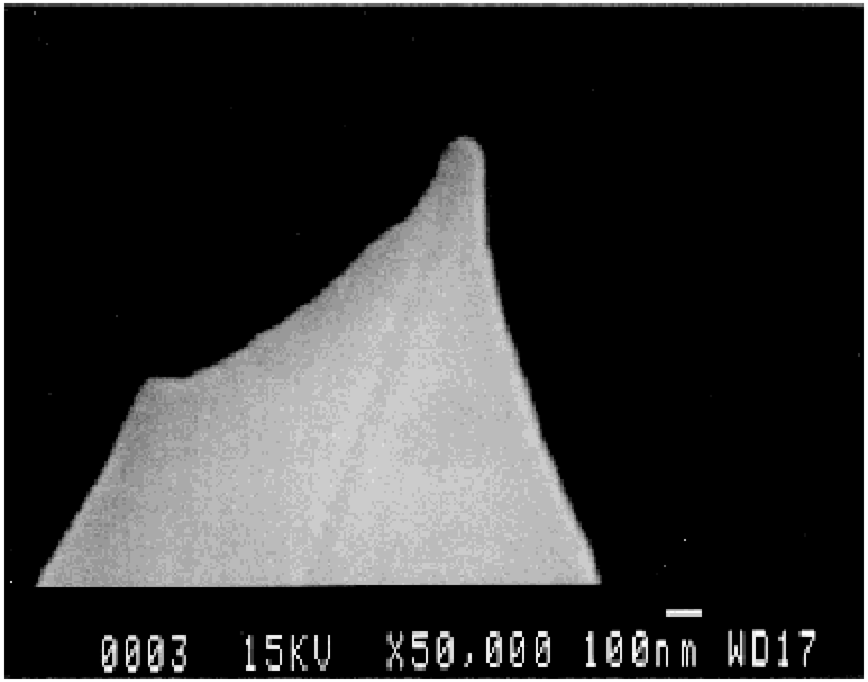


Vertical resolution 0.01 nm

Use magnetic force microscopy to image magnetic state of small particles



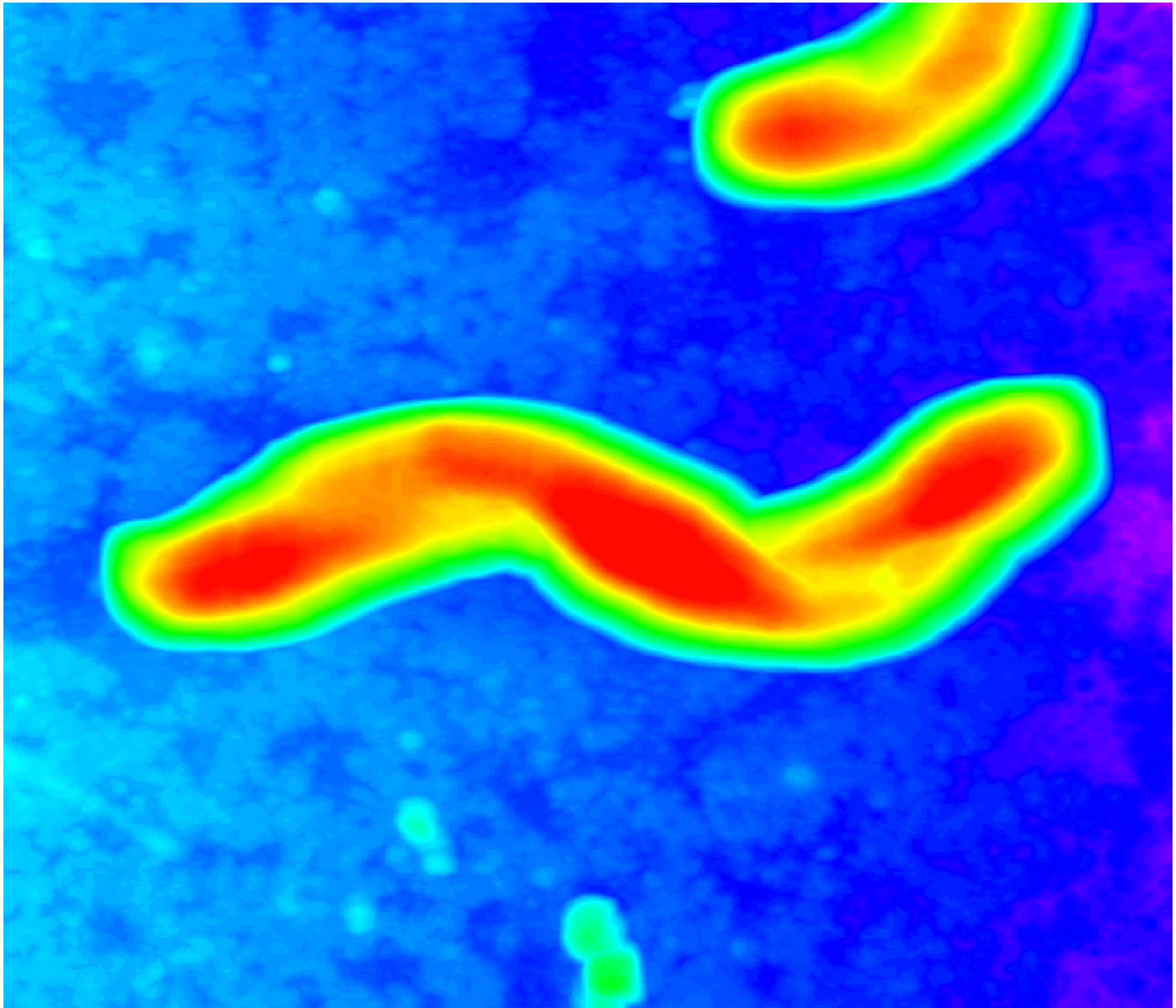
Tip coated with a thin film of CoCr alloy



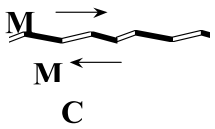
Now to THE BUGS

R. P. Blakemore *Science* 190, 377 (1975).

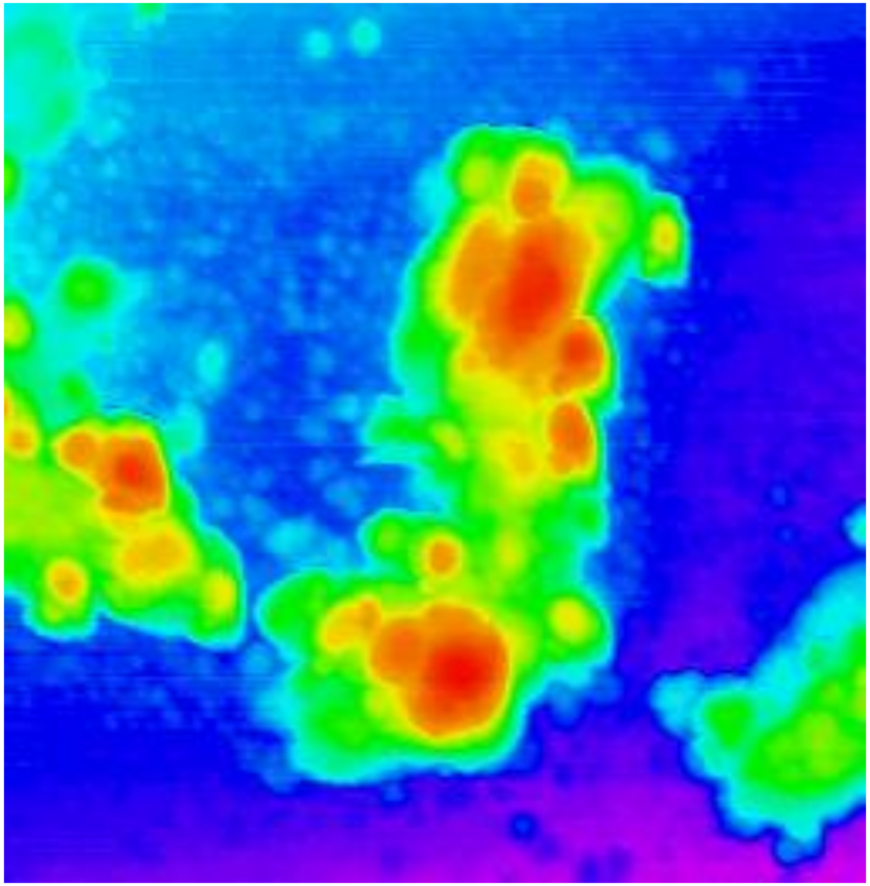
Atomic Force Microscope (AFM) image of MV-1 magnetotactic bacteria

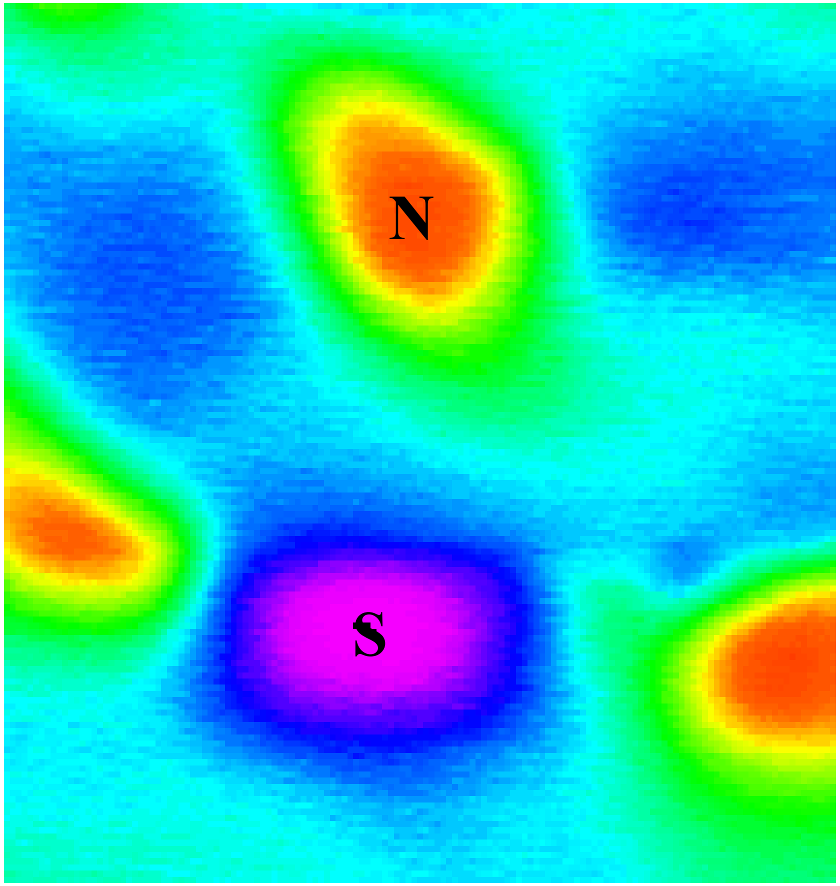


Now to the physics



AFM of freeze dried MV-1



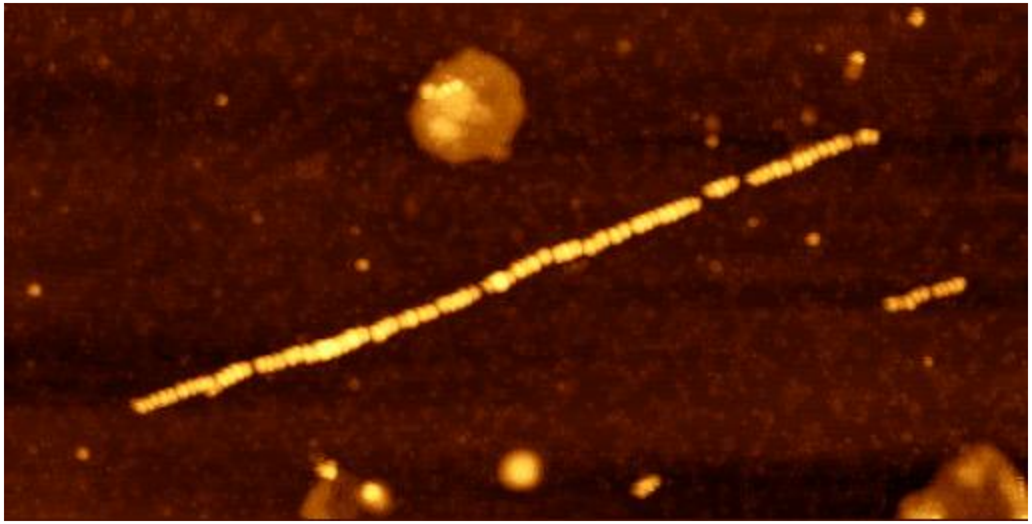


R. B. Proksch et al.

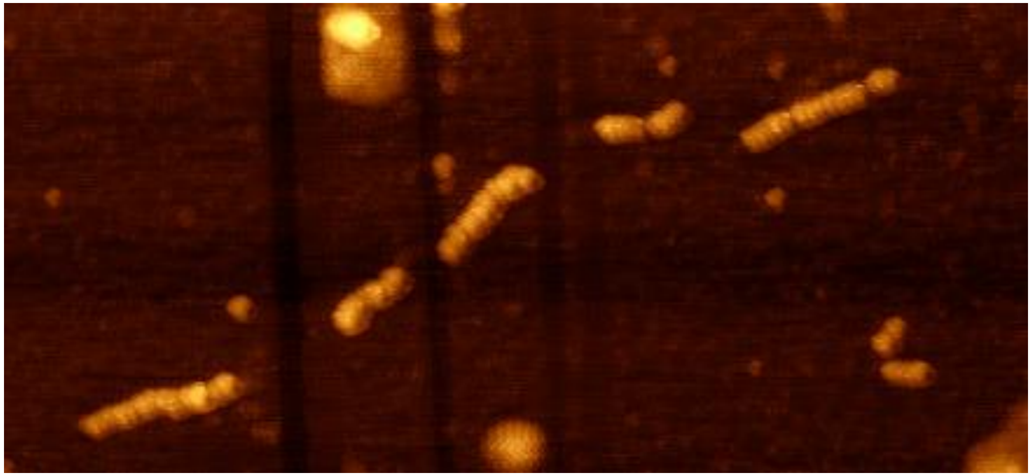
Appl. Phys. Lett. 66, 2582-84 (1995).

MFM image of freeze dried MV-1

Organic matter dissolved away from bacteria

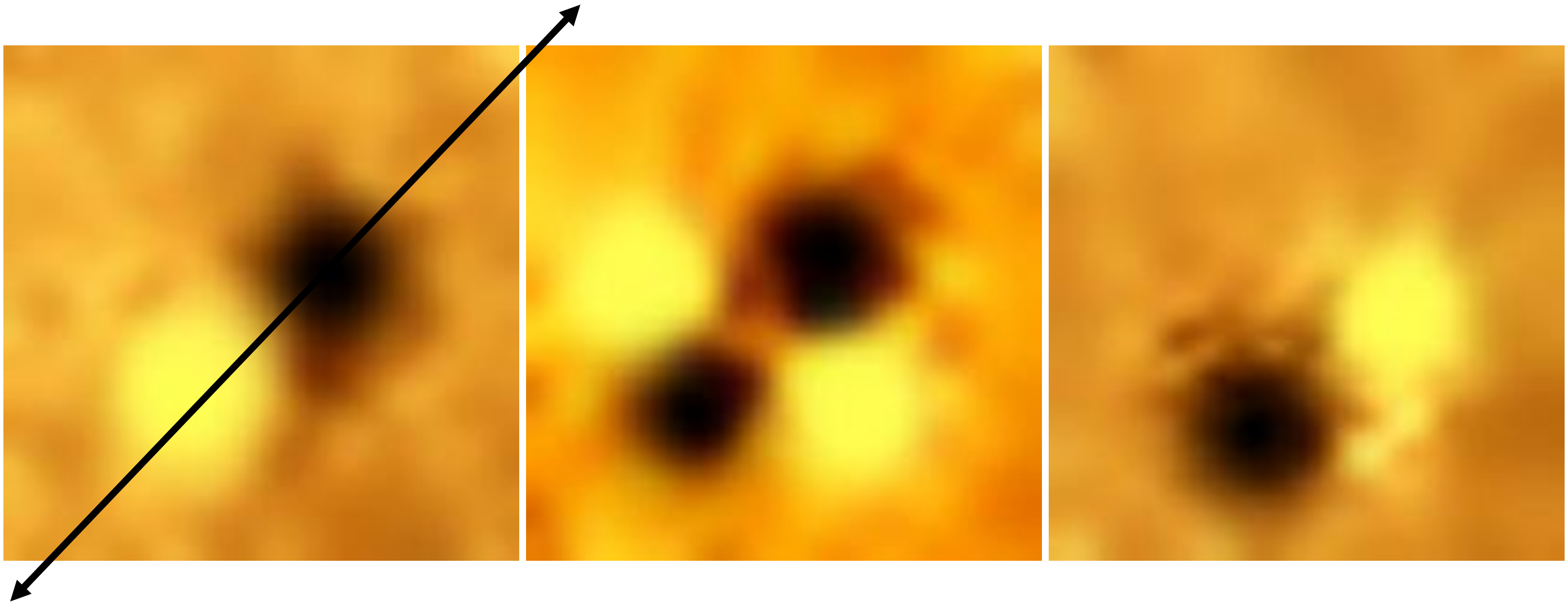


Isolated Magnetosome chain



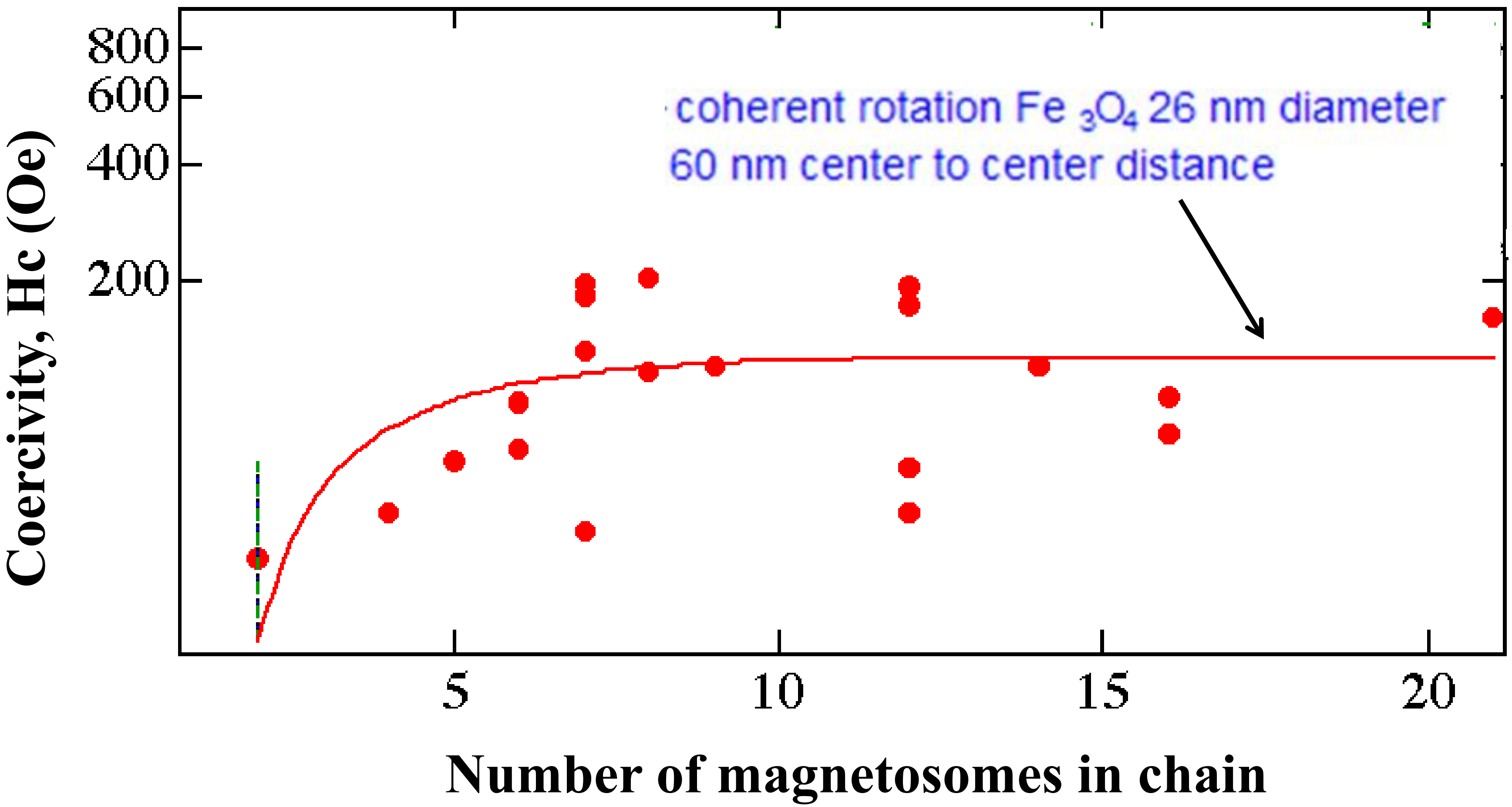
Chain segmented with MFM tip

Magnetic reversal of two magnetosome chain



Apply H along direction shown and change magnitude.

100 nm



Wittborn et al., Nanostructured Materials, 12, 1149-52 (1999).

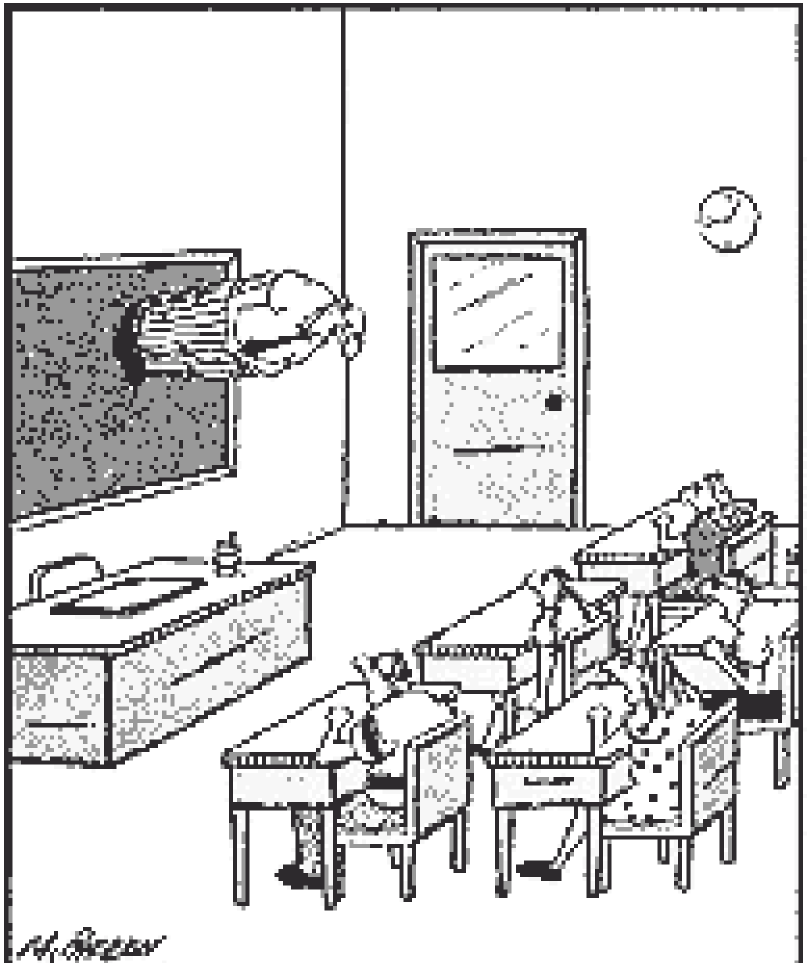
Summary: Magnetic reversal in Fe_3O_4 nanoscale particles

Magnetotactic bacteria are both fun and provide excellent materials for the study of complex reversal in nanoscale magnetic systems.

We see the interactions play a role but there are no surprises in the reversal process.

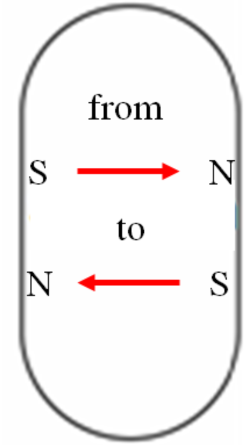
One could try different geometries more favorable to more exotic collective reversal schemes!

Now to the stadia



Welcome to the wonders of physics.

Look at the magnetization processes with the application of external magnetic fields.



Soft magnetic particles with small in-plane or no anisotropy in a circular geometry.

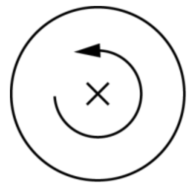
$$E = E_{zeeman} + E_{exchange} + E_{dipole}$$

$$(no\ E_{anisotropy})$$

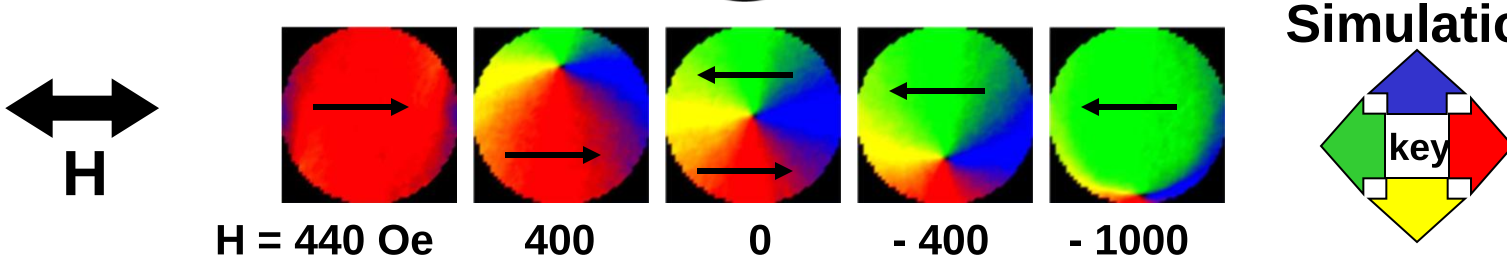
Submicron Permalloy Stadia

Pete Eames

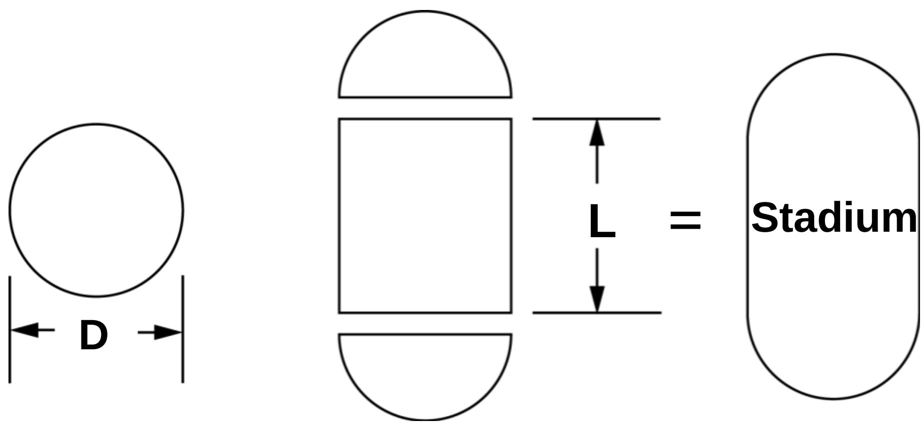
Single vortex in a dot- T. Shigeto et al., APL **80**, 4190 (2002).



Simulation



D = 400 nm

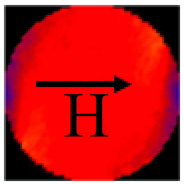


D = 400 nm
L = 300 nm

- Structures
- Nucleation
- Interactions

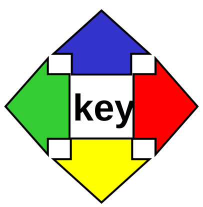
Micromagnetics- Again

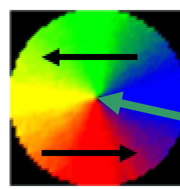
$$E = E_{zeeman} + E_{exchange} + E_{magnetostatic} + \cancel{E_{anisotropy}}$$



H = 440 Oe

$$\mathbf{E}_{\text{magnetostatic}} \approx \frac{\mathbf{m}_1 \cdot \mathbf{m}_2}{r_{12}^3}$$





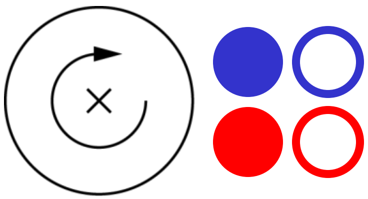
H = 0 Oe

$$\mathbf{E}_{\text{exchange}} \approx \mathbf{m}_1 \cdot \mathbf{m}_2$$

In very center exchange wins, M out ● or into ○ plane

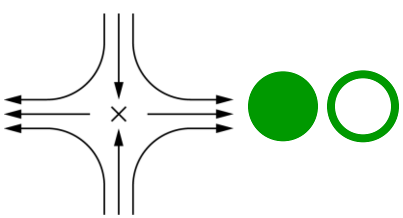
Domain Structures- Small & Large Stadia

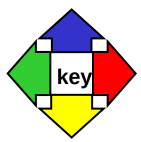
Vortex



H=0

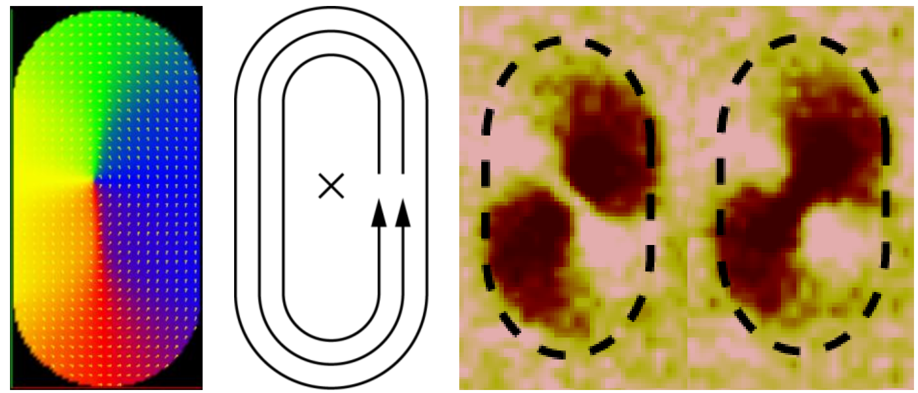
Antivortex





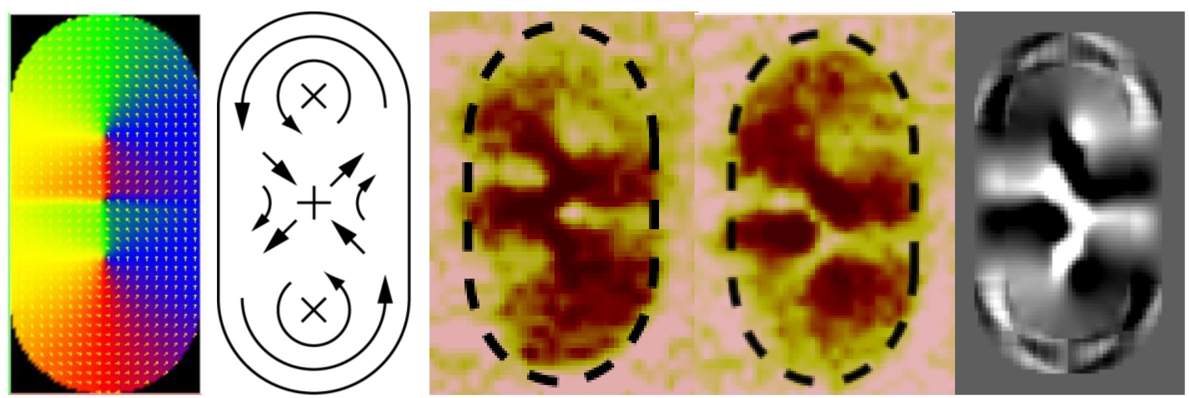
Single Vortex

Simulation **MFM**

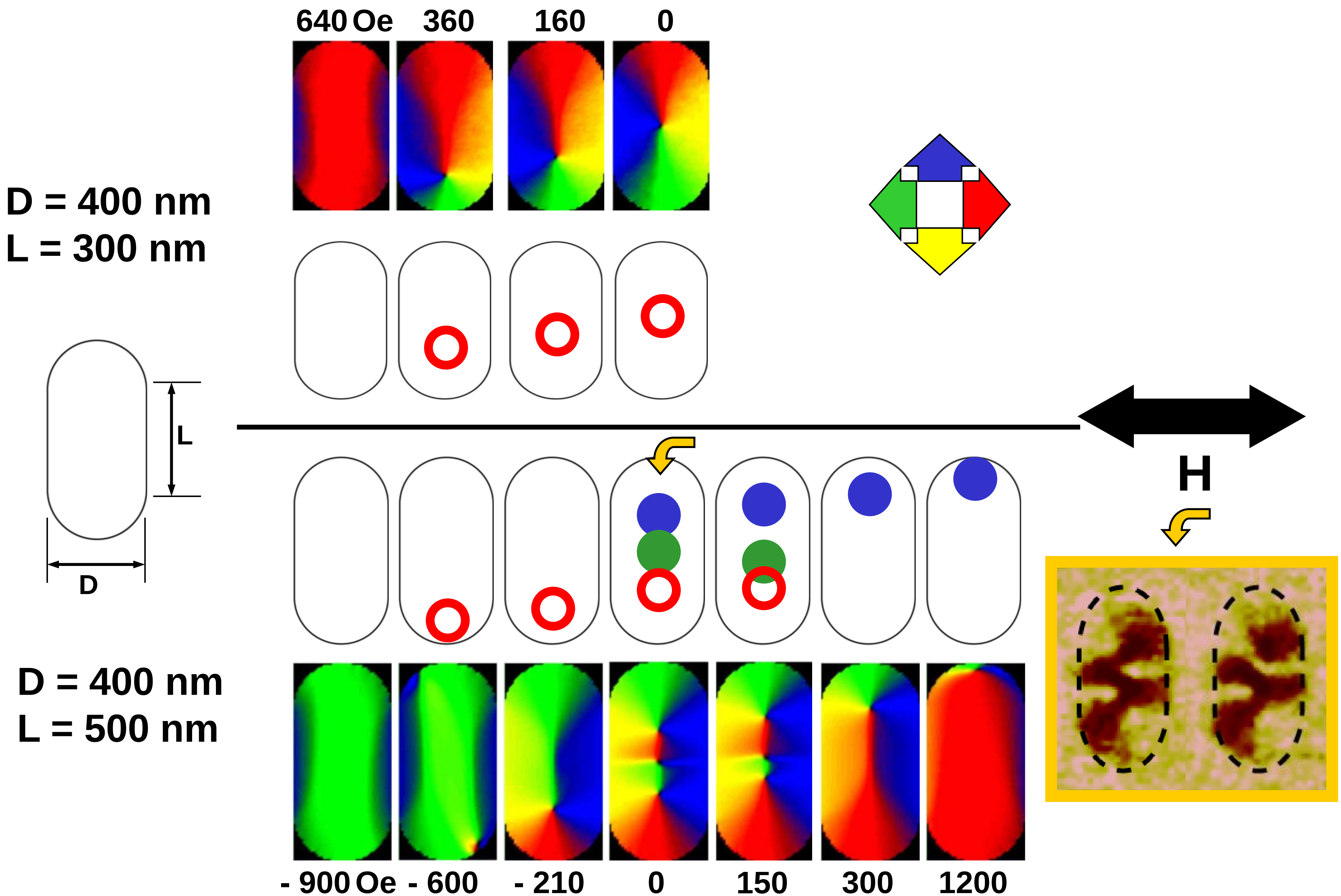


Vortex / Antivortex / Vortex

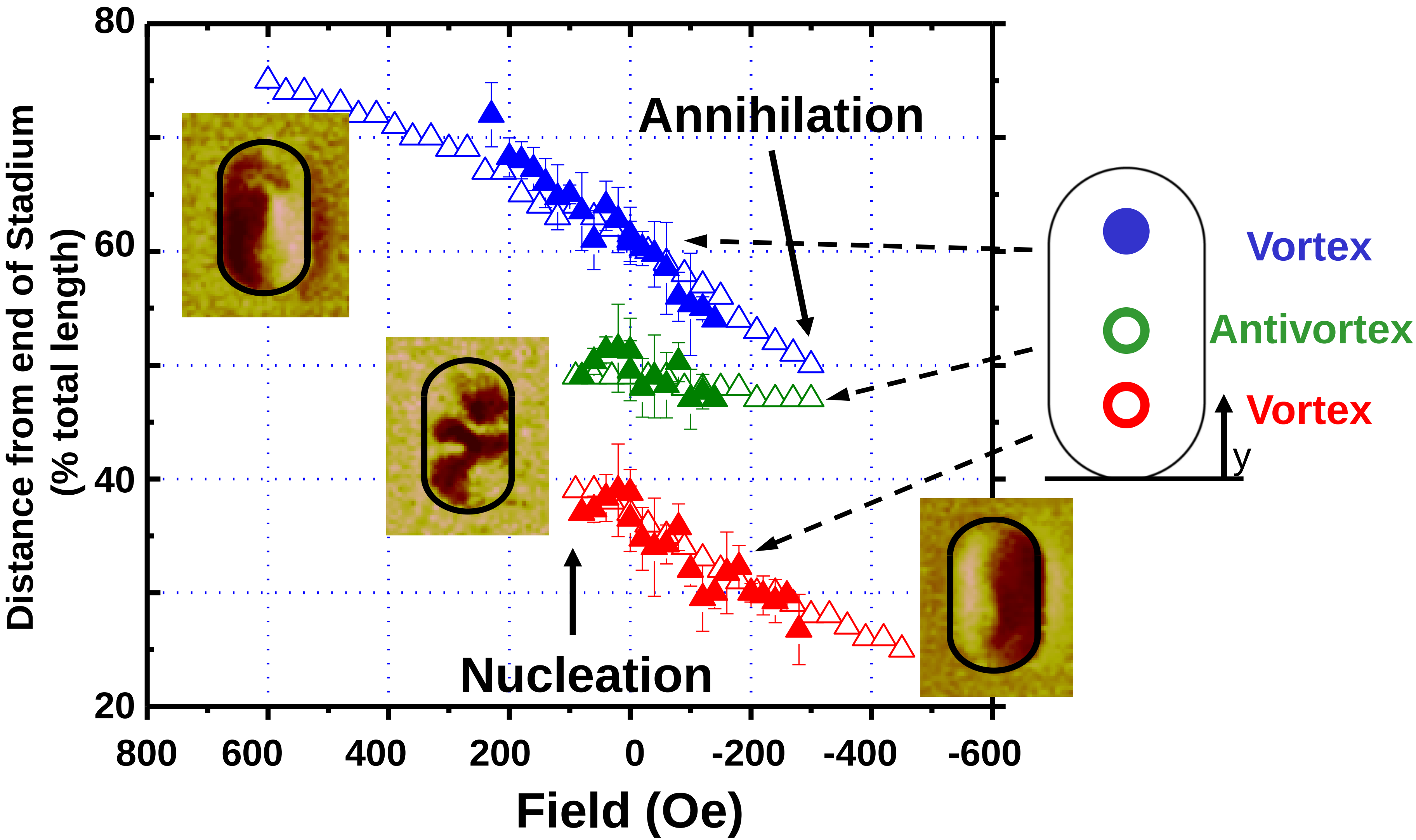
Simulation **MFM** **Simulated MFM**



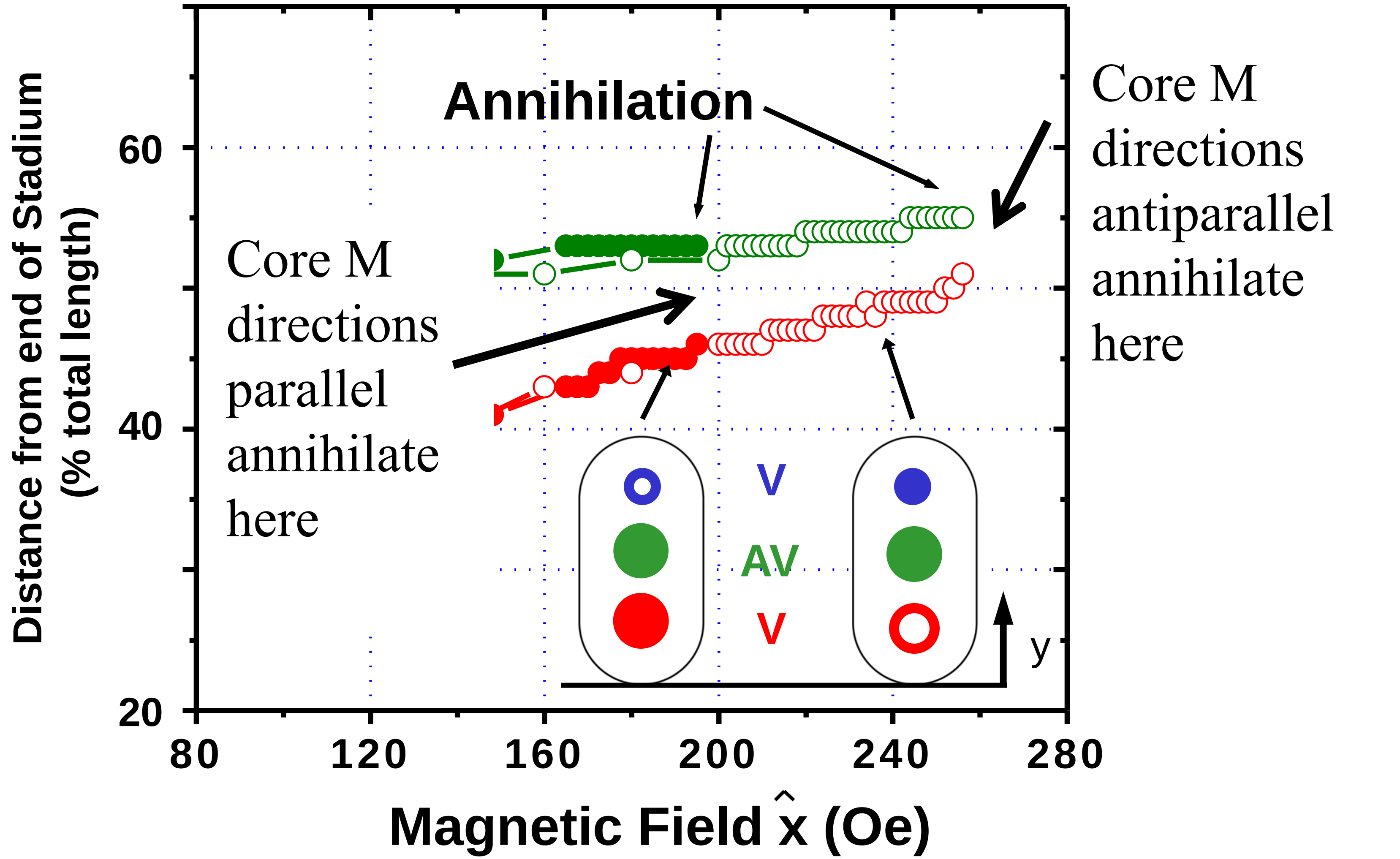
Virtual Particles



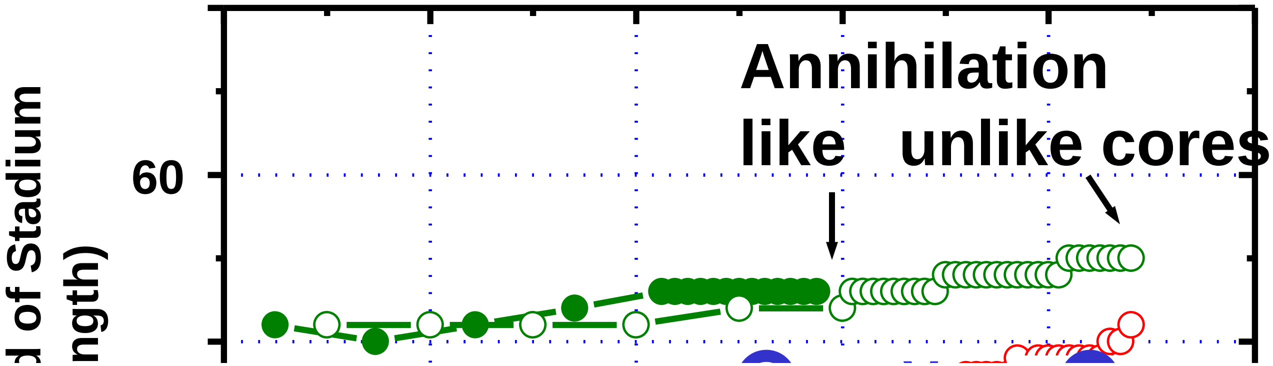
Nucleation / Annihilation



Core Interactions



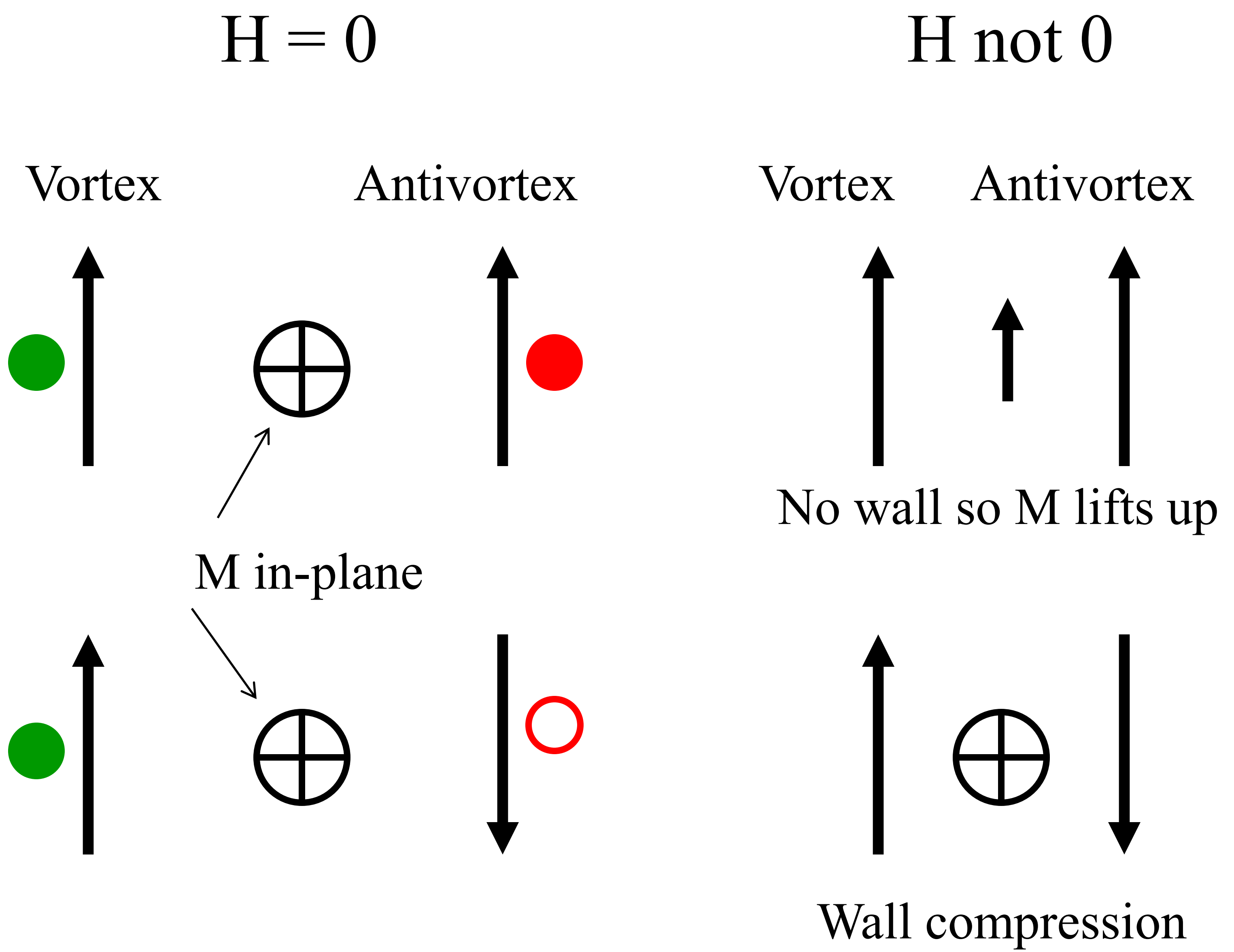
Core Interactions

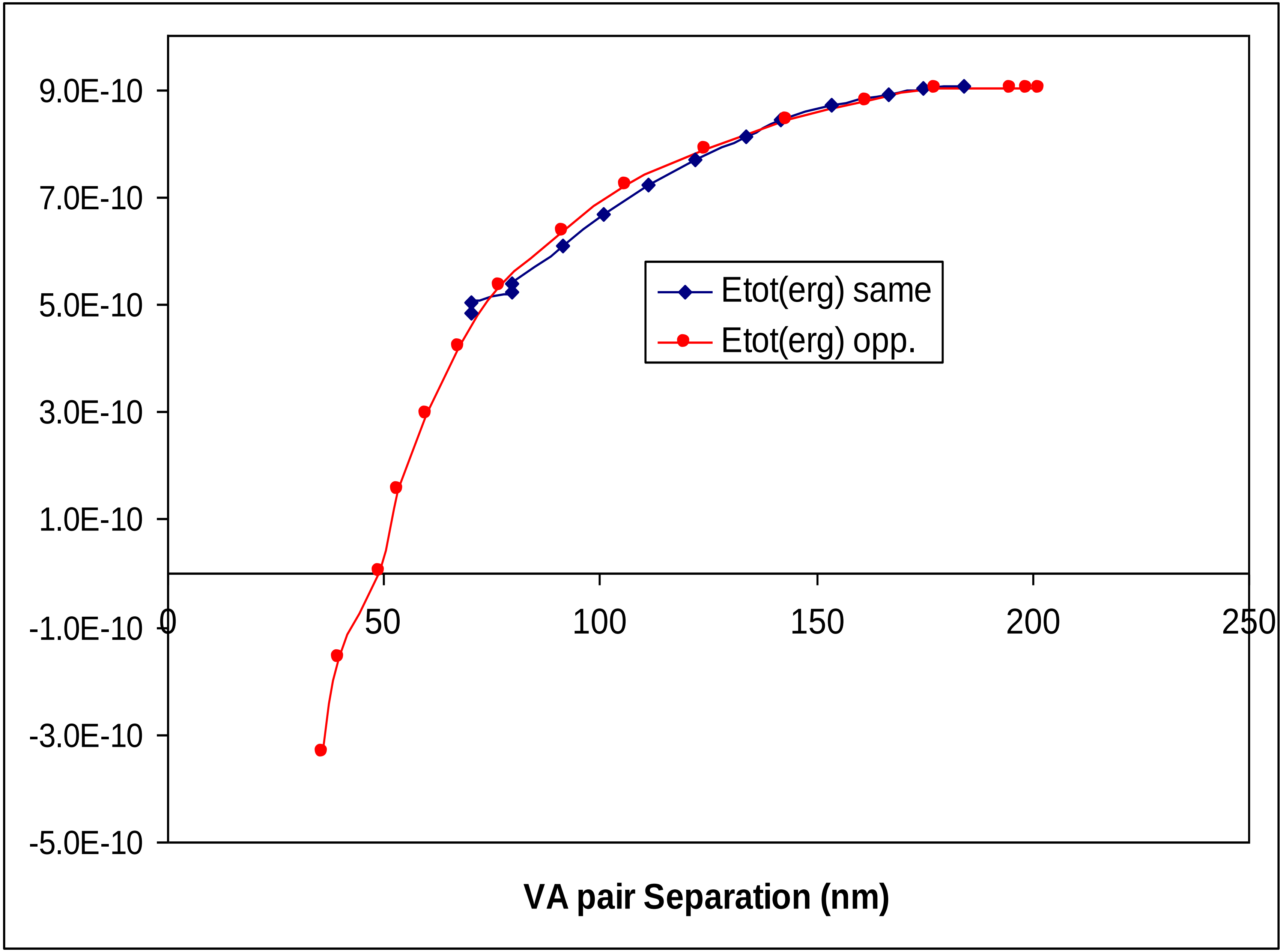


Vortex	Antivortex	Annihilation Field
		260 Oe
		180 Oe

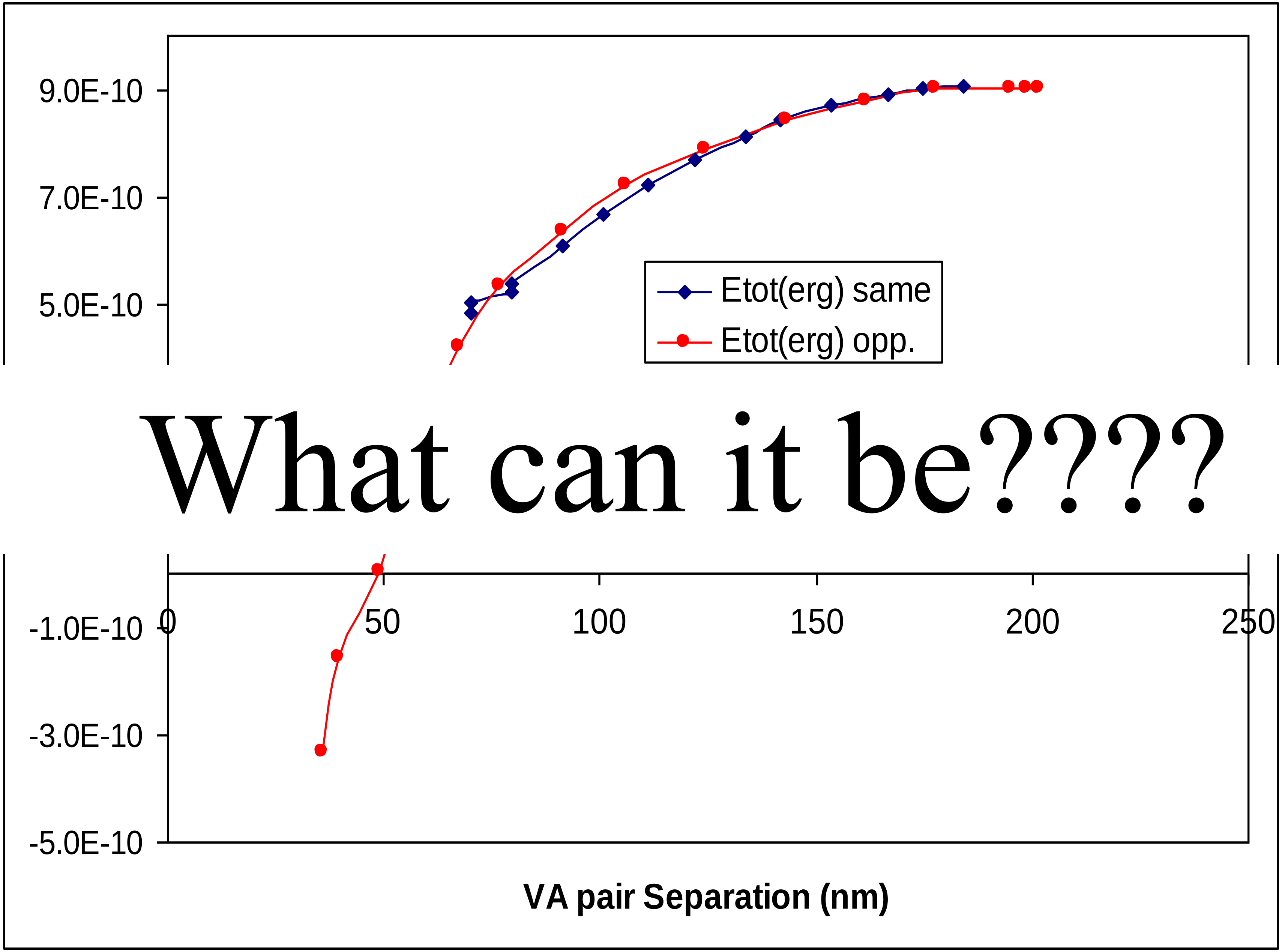
WHY THE ASYMMETRY????

Why the difference?



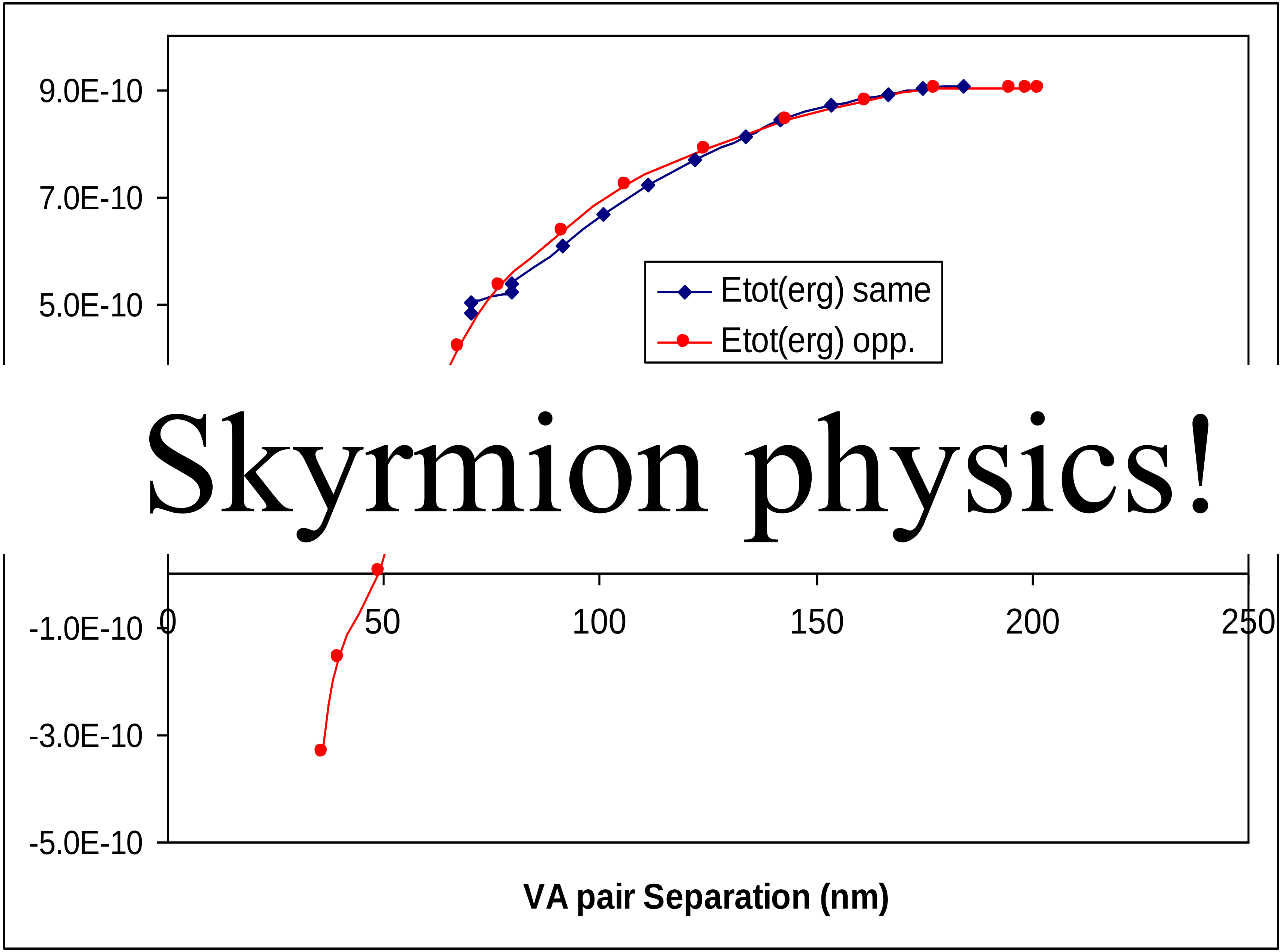


9.0E-10
7.0E-10
5.0E-10
3.0E-10
1.0E-10
-1.0E-10
-3.0E-10
-5.0E-10
0
50
100
150
200
250
Etot(erg) same
Etot(erg) opp.
VA pair Separation (nm)



What can it be????

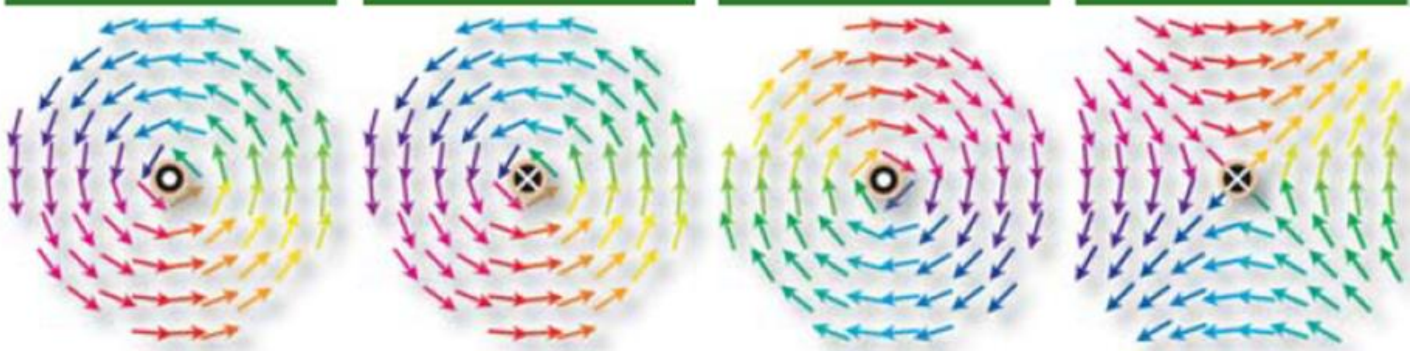
Skyrmion physics!



What is a skyrmion?

Well, wikipedia says it is:

A skyrmion is a homotopicallly non-trivial classical solution of a nonlinear sigma model with a non-trivial target manifold topology —a particular case of a topological soliton.

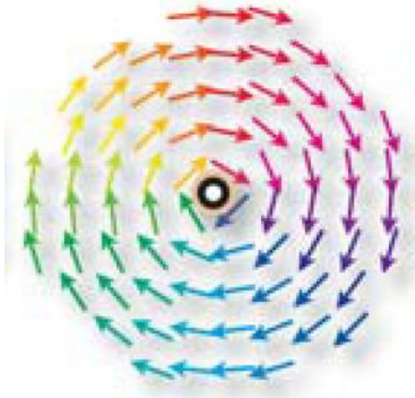


	Vortex	Vortex	Vortex	Antivortex
Chirality	CCW	CCW	CW	
p	1	–1	1	–1
n	1	1	1	–1
q	$^1/_2$	$-^1/_2$	$^1/_2$	$^1/_2$

$q = np/2$

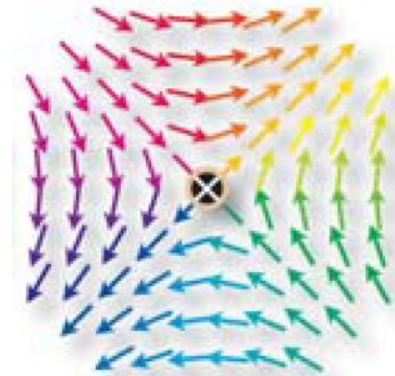
Chien, Zhu and Zhu- Physics Today p.40 June 2007

"The winding number AND skyrmion number are conserved during a continuous deformation of the magnetic configuration."



n = 1
q = 1/2

+

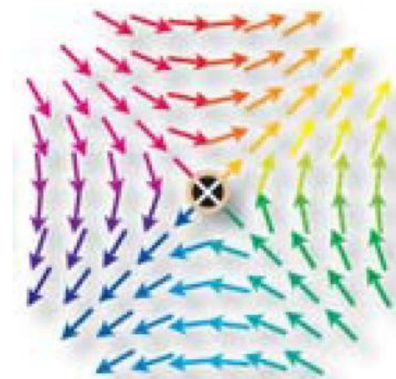


n = -1
q = 1/2

Annihilation does not conserve q.

n = 1
q = -1/2

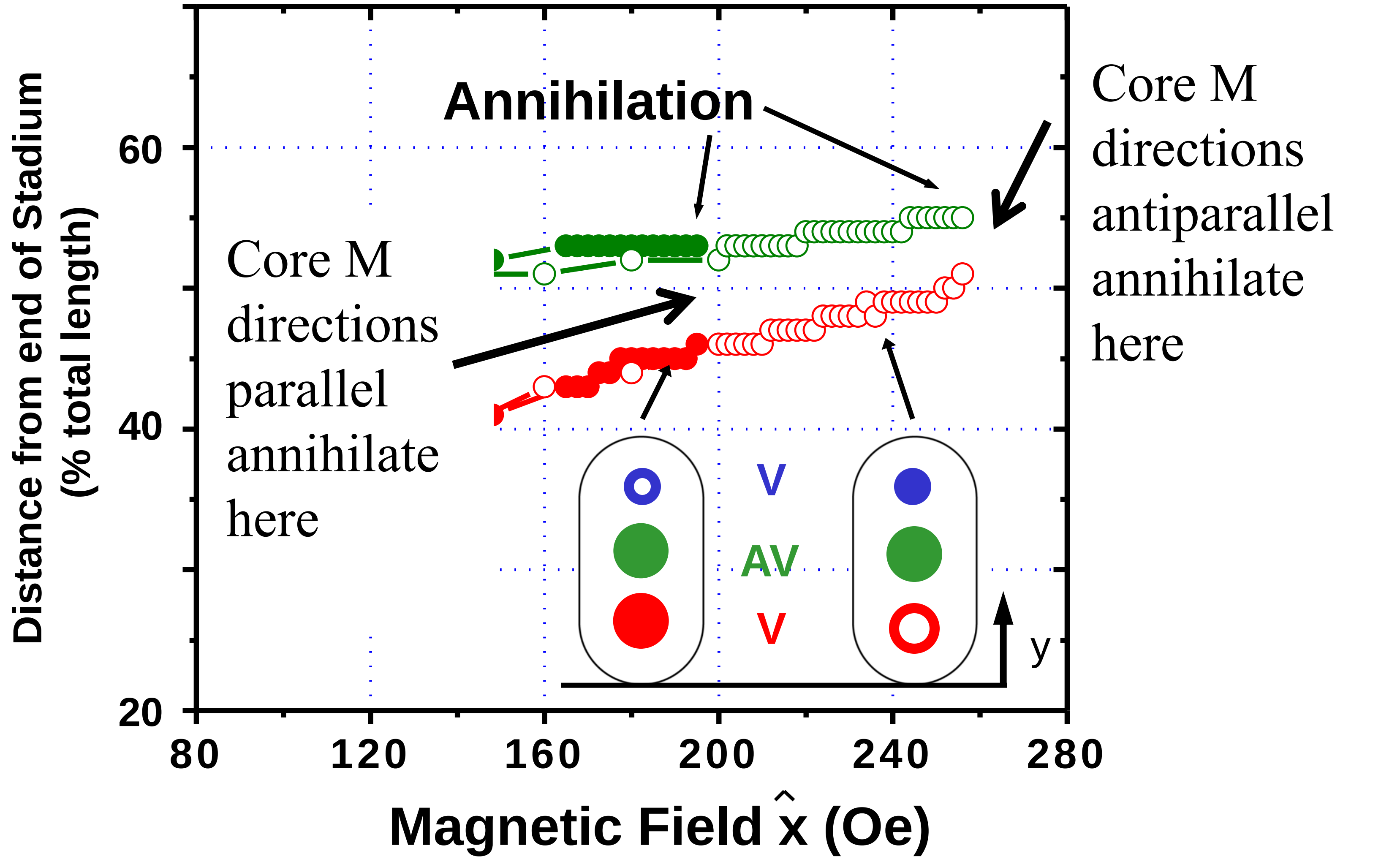
+



n = -1
q = 1/2

Annihilation conserves BOTH n and q.

Core Interactions



Summary: Magnetic reversal in NiFe stadia

Using geometry and applied magnetic fields we can create and study model systems for magnetic reversal.

In the reversal process, past a critical aspect ratio, vortex-antivortex pair creation facilitates the reversal.

Understanding the vortex-antivortex nucleation and annihilation is not as simple as we thought as the associated energies do not vary much so it is all hidden in the dynamics. But maybe skymion physics is the answer!

Important for K-T transition, cross-tie walls, …

Cuteness factor- pair creation where anti-partner in pair annihilates with original particle like vacuum state processes AND not unlike the Casimir effect with vacuum fluctuations where geometry determines excitations.