

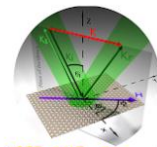
# NANOMAGNETISMO E MATERIALI MAGNETICI NANOSTRUTTURATI

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CNR-IOM, Perugia, Italy



## Group of High-resolution Optical Spectroscopy and related Techniques



1988-2018 30 years!

People

Soft Matter and Glasses

NanoMagnetism and Spin Waves

Elastic properties

Techniques

Publications



The research group at GHOST-laboratory is a mixed Unit that involves personnel from the Department of Physics and Geology, at University of Perugia (Italy) and from the Istituto Officina dei Materiali (IOM) of the National Research Council.



The research activity started in 1988 with the setup of the Brillouin light scattering laboratory, equipped with a tandem-multipass Fabry-Perot interferometer. After a few years entirely devoted to the study of surface phonons in thin films, the research activity has been extended to the study of the dynamics of complex systems (liquids, glasses, polymers) and to the analysis of the magnetic properties of low-dimensional structures and magnonic crystals.



Presently, the main research lines deal with:

- Soft matter, Glasses and Biosamples;
- Nanomagnetism, Spintronics and Spin Waves;
- Elastic properties of Thin Films and Acoustic Resonators

<http://ghost.fisica.unipg.it>

## News

Thematic Workshop "Advances in Brillouin Light Scattering", 12-14 Sept. 2018



12-14 Sept. 2018 – Perugia, Italy

Perugia, 25 Ottobre 2021  
Aula 7, Rettorato, Piazza dell'Università, ore 9:00

### Nanotecnologie in Umbria

Convegno di presentazione di attività in corso nel territorio, in vista della nuova politica regionale nel settore delle nanotecnologie.

Con la partecipazione dell'Assessorato regionale allo Sviluppo Economico e Confindustria Umbria.

NIPS Laboratory  
Noise in Physical Systems

unipg  
Università di Perugia

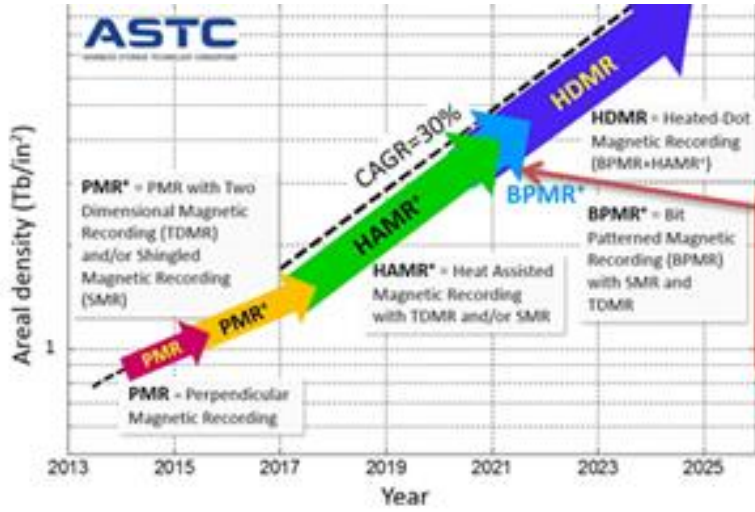
iom  
Istituto Nazionale di Ottica

ISTITUTO OFFICINA DEI MATERIALI

Per la partecipazione è richiesto gree-pass e prenotazione a [info@nipslab.org](mailto:info@nipslab.org)

### (a) Magnetic Recording Roadmap

(From [www.idema.org/](http://www.idema.org/) International Disk Drive Equipment and Material Association, that includes the world leading manufacturers, with an income of \$35 billions. Seagate and Western Digital are the main two companies)

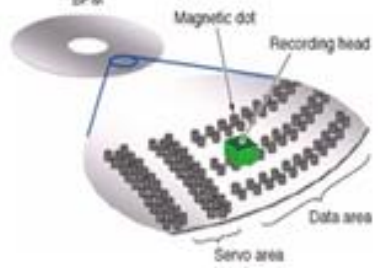


After 2021: Bit-Patterned Magnetic Recording and Heated-Dot Magnetic Recording

### Sistemi Nanomagnetici:

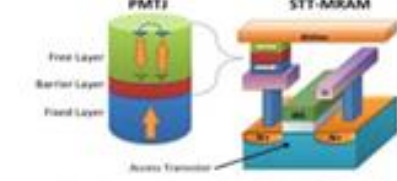
- ✓ Memorie non volatili (Hard Disk, MRAM)
- ✓ Sensori (GMR)
- ✓ Oscillatori nel range dei GHz (telecomunicazioni)
- ✓ Onde di spin con lambda micro- o nano-metrica

### (b) Bit-patterned Hard Disk (BPM)



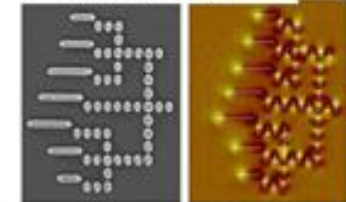
R. Griffiths et al. J. Phys. D Appl. Phys. 46, 503001 (2013)

### (e) STT Magnetic RAM



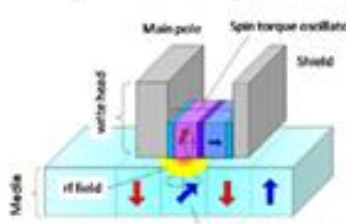
A. Kent, Nat. Nanotech. 10, 187 (2015)

### (g) Nano-Magnetic Logic (NML)



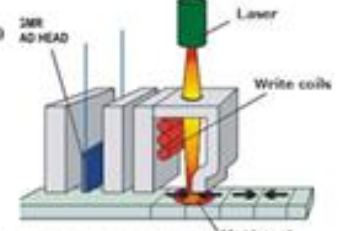
M. T. Niemier et al., J. of Physics: Cond. Mat. 49, 493202 (2011)

### (c) Microwave-assisted magn. recording (MAMR)



S. Okamoto et al. J. Phys. D Appl. Phys. 48, 353001 (2015)

### (d) Heat-assisted magn. recording (HAMR)

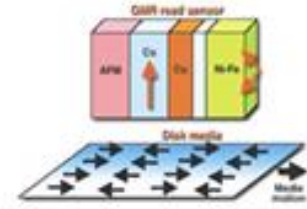


### (f) All-Spin Logic Devices (ASLD)



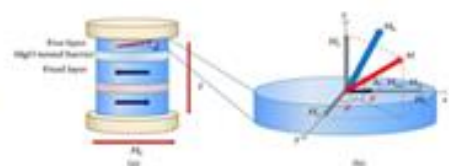
Behin Aein et al., Nat. Nanotech. 5, 266 (2010)

### (h) GMR Read Head



S. Thompson, J. Phys. D: Appl. Phys. 41, 093001 (2008)

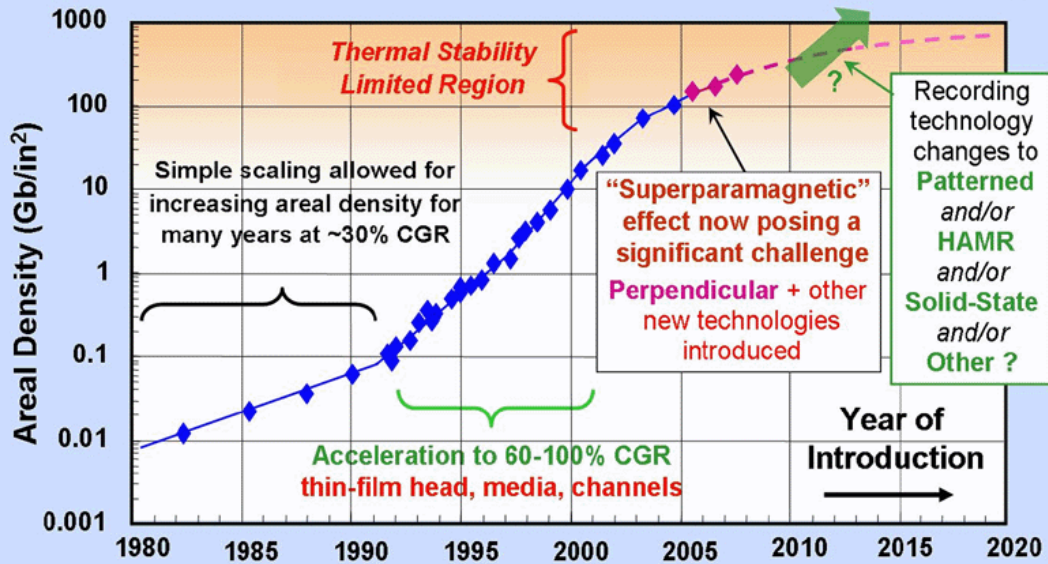
### (i) Spin Torque Oscillator (STO)



J.-V. Kim, Solid State Phys. 63, 217 (2012)



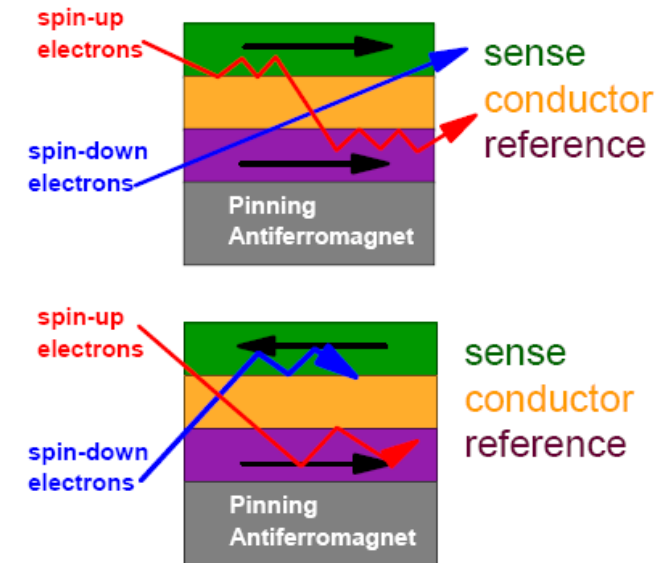
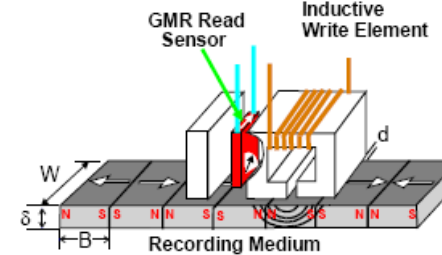
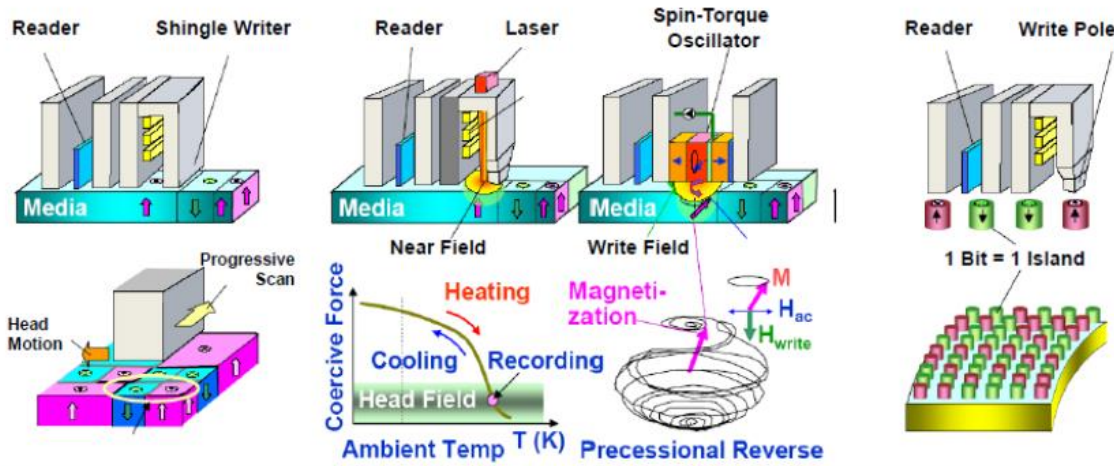
# Growth of Areal Densities for Conventional Recording



Nobel prize 2007!



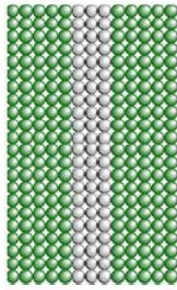
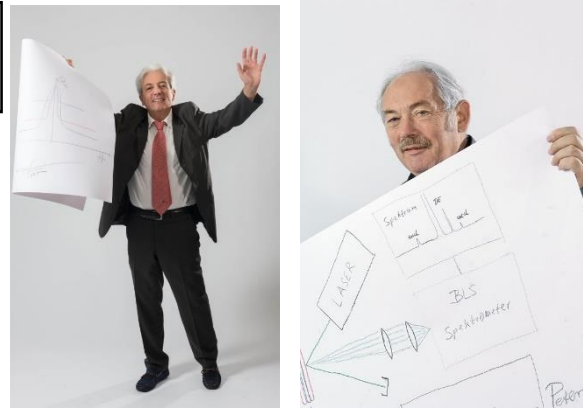
## GMR sensor



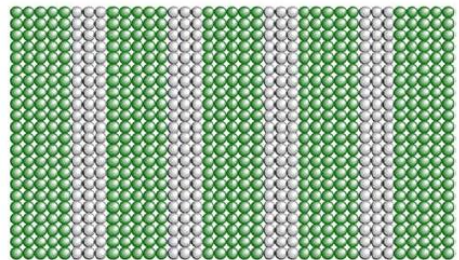
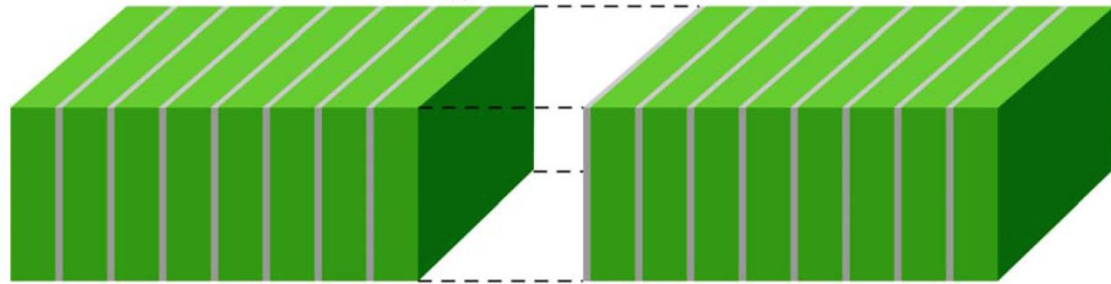
**SMR/TDMR    Energy Assisted Recording    Bit Patterned**

- Continued scaling requires innovations in systems technologies, materials science and process engineering to advance areal density

# Control of atomic layers...

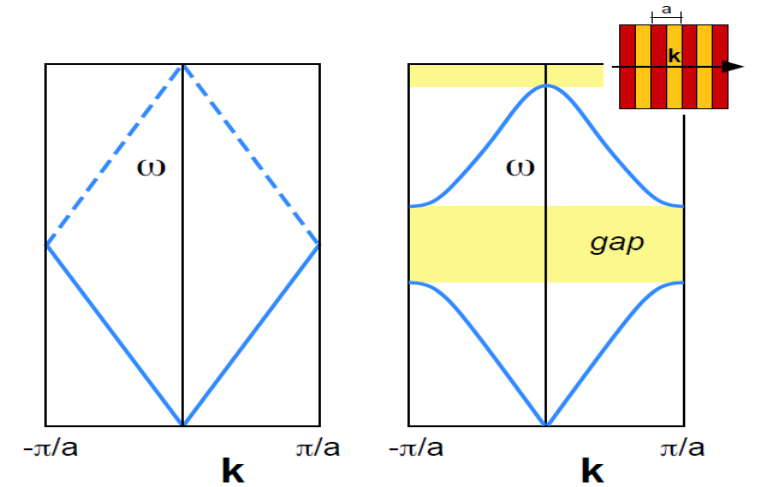
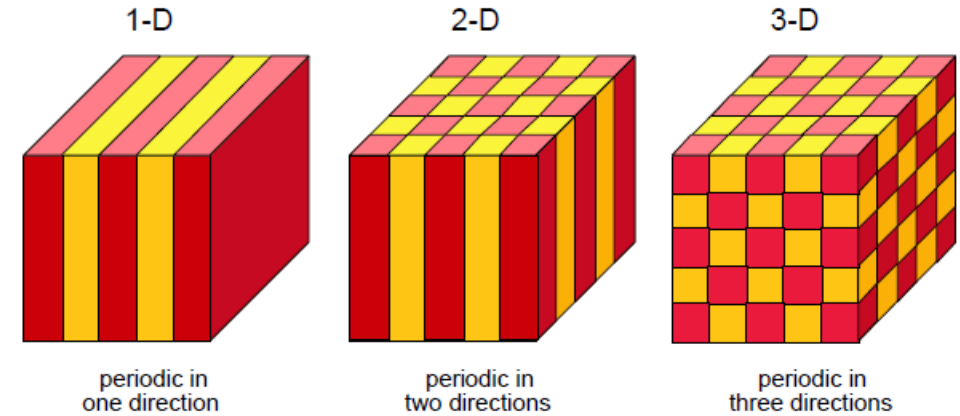


Nanometre



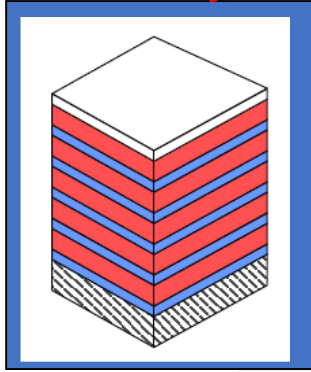
Science or/and Technology?

## Artificial photonic or magnonic Crystal (PC)

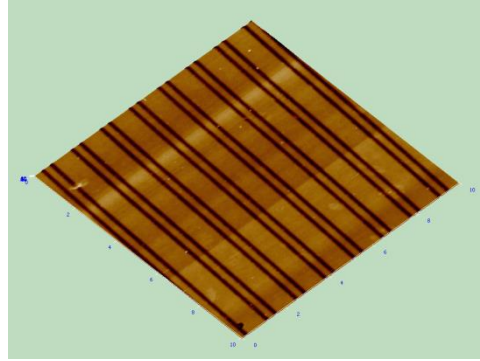


# Magnonic Crystal (MC)

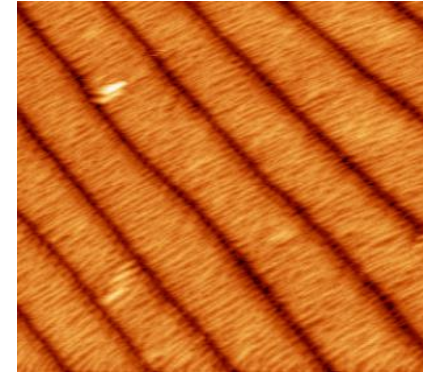
## 1D. Multilayer



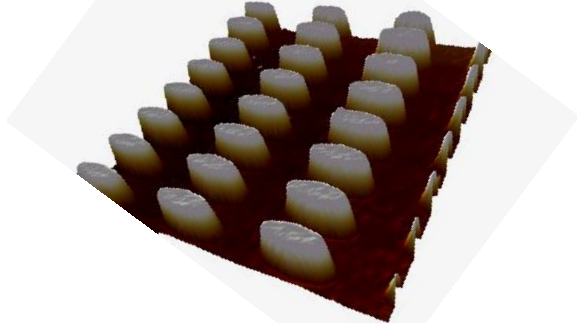
## Array of interacting stripes



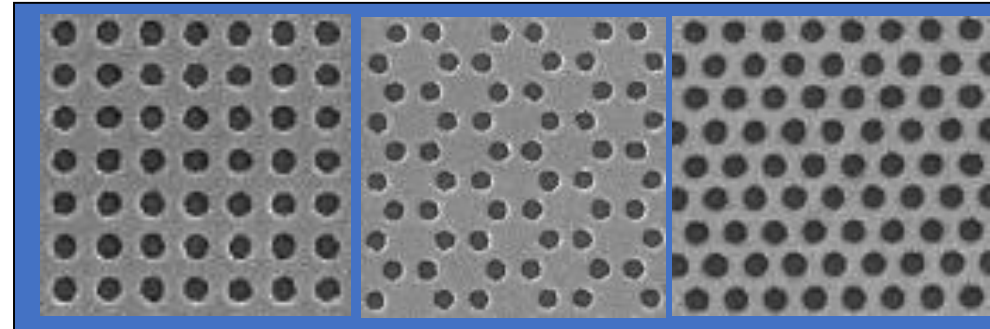
## Periodic profile of magnetic properties



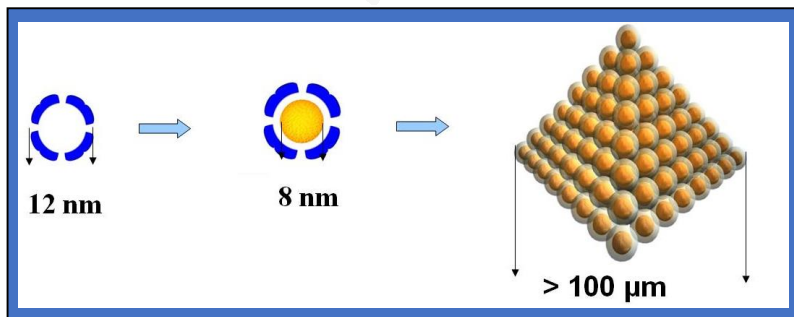
## 2D. Array of interacting elements



## Array of holes embedded into a ferromagnetic film



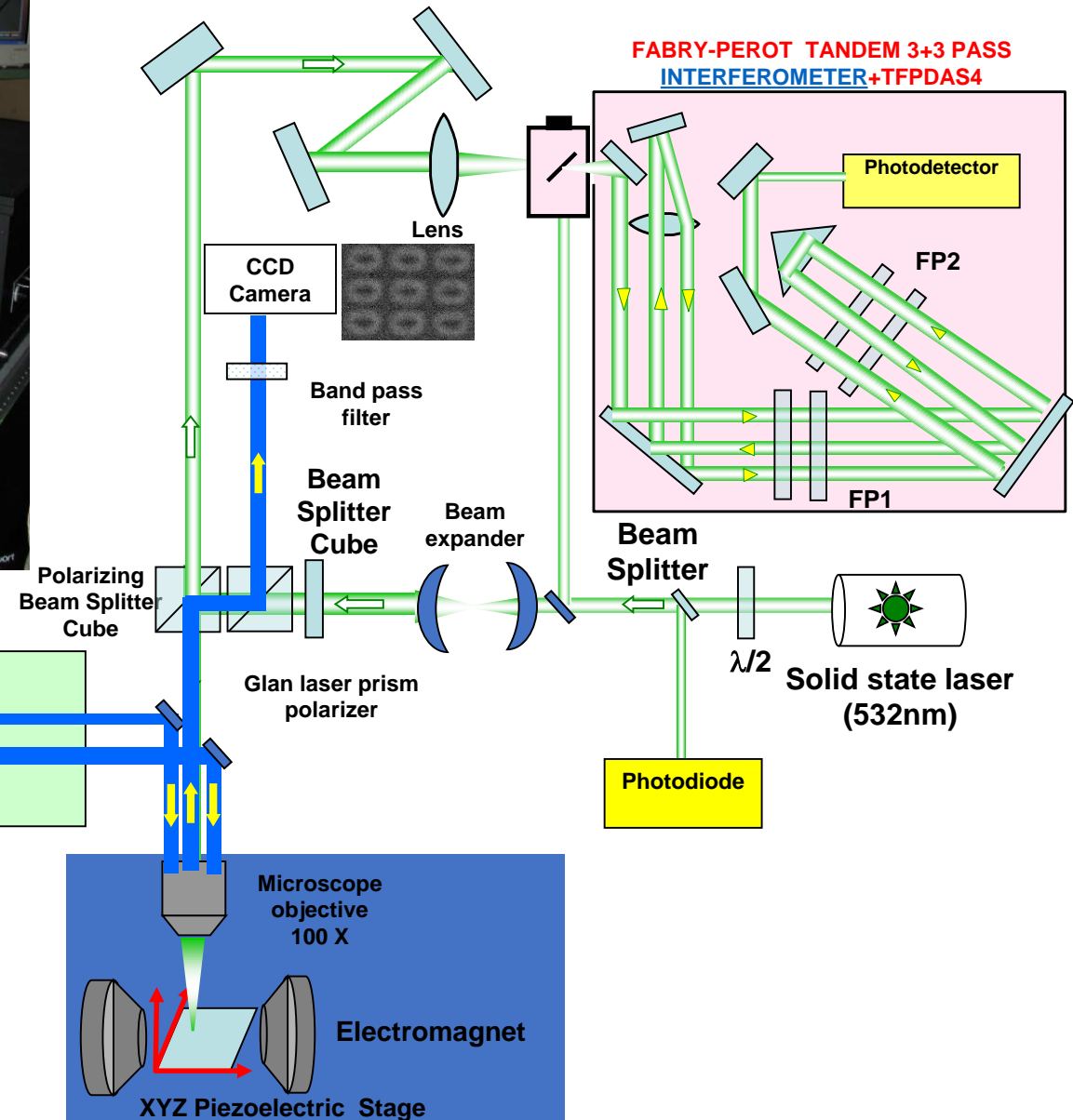
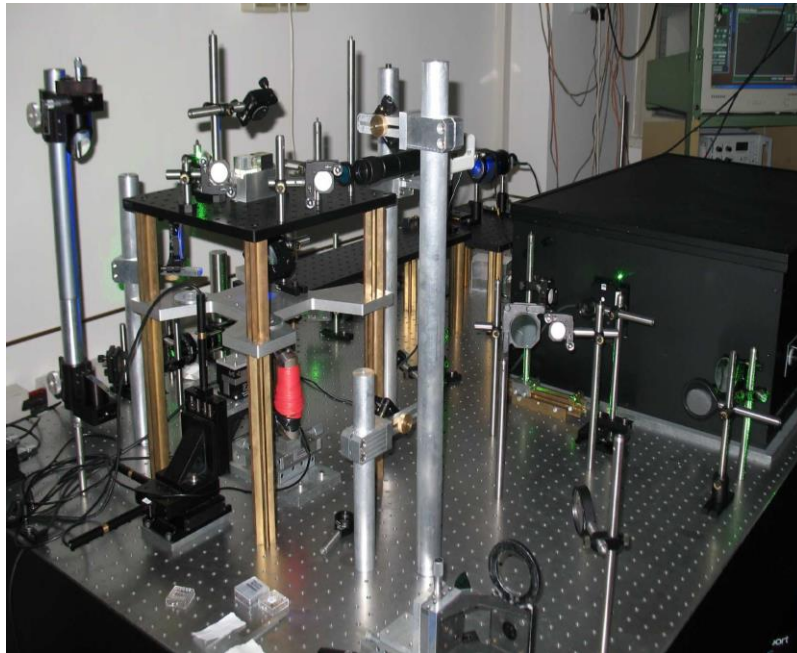
## 3D. Macroscopic ordered magnetic arrays



(Protein based colloidal crystallization technique)



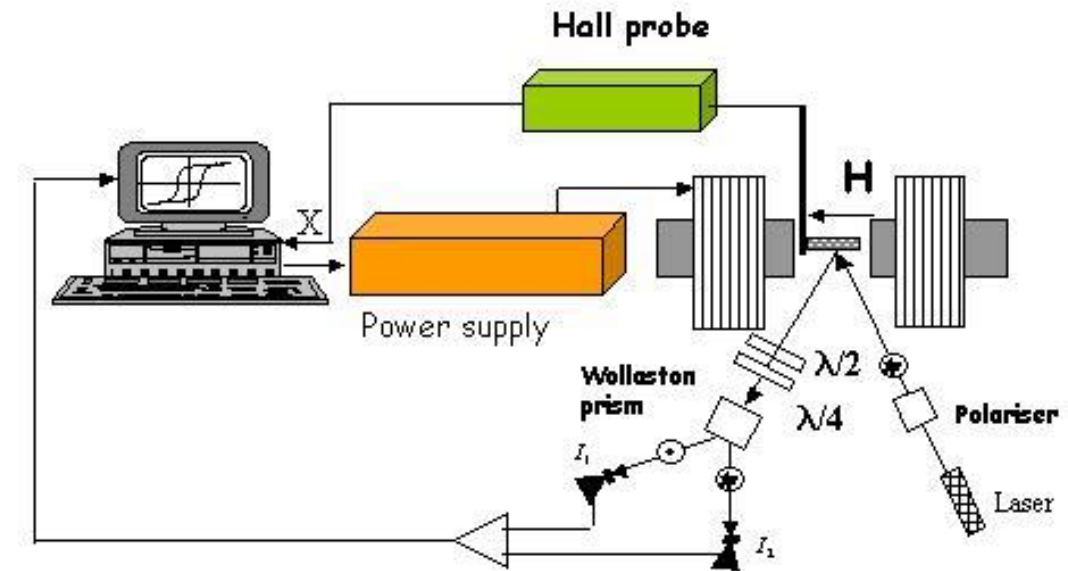
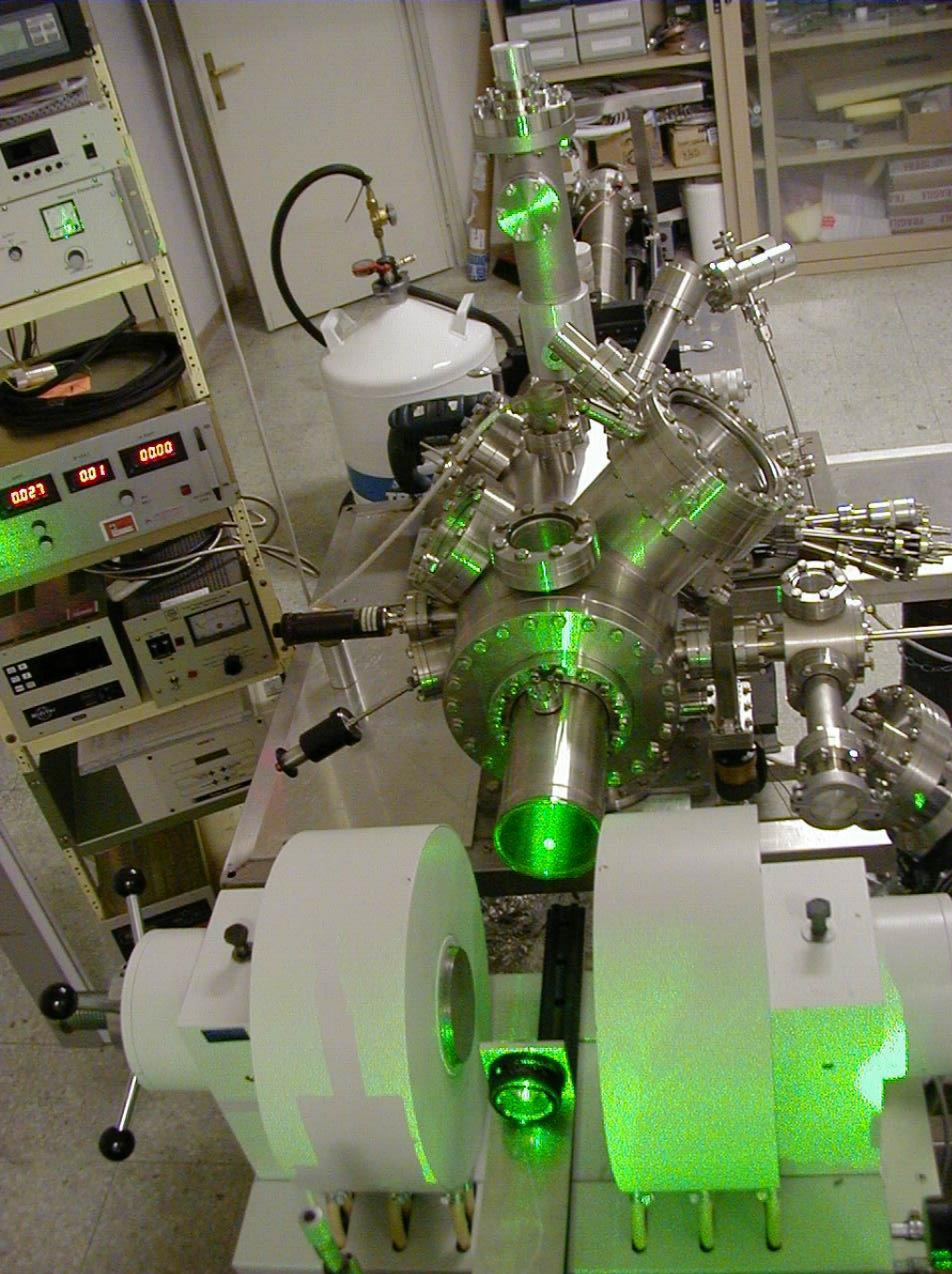
# Scanning micro-focused BLS



**Lateral resolution of ~250 nm**

**Power on the sample ~ 3mW**

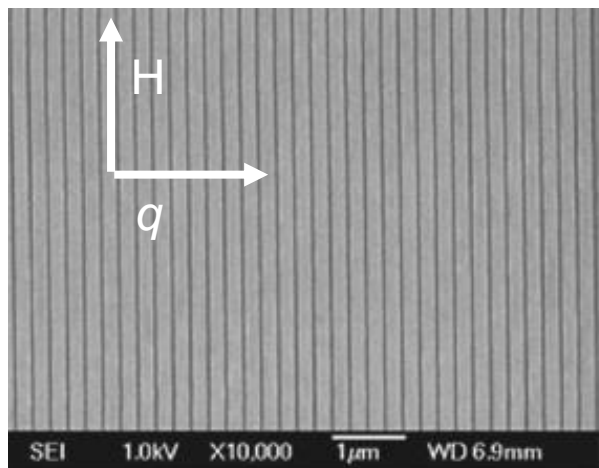
# In-situ optical measurement (UHV chamber)



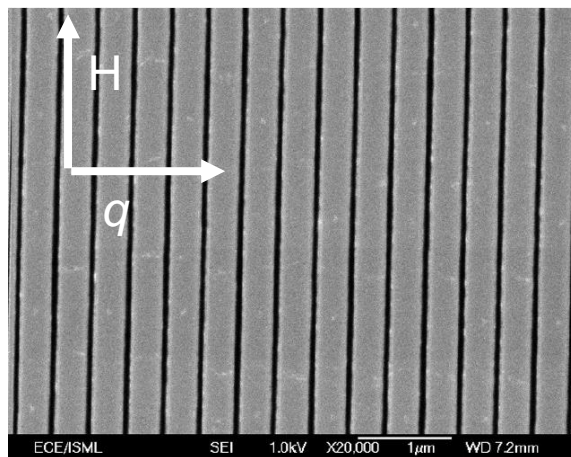
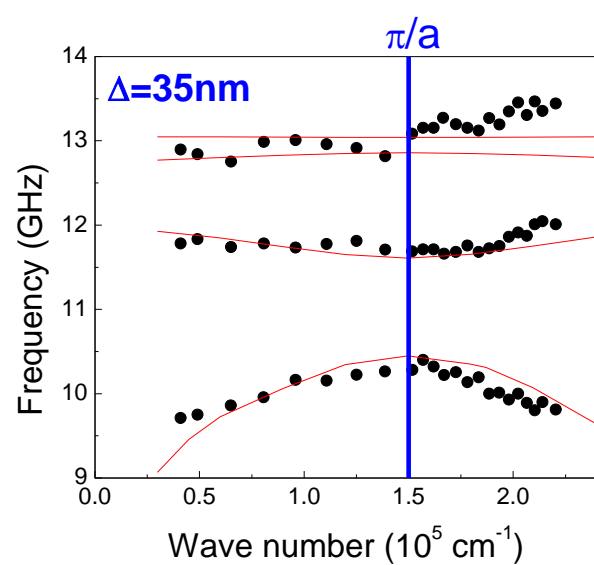


# Collective spin modes in dipolarly coupled stripes 1D-magnonic crystal

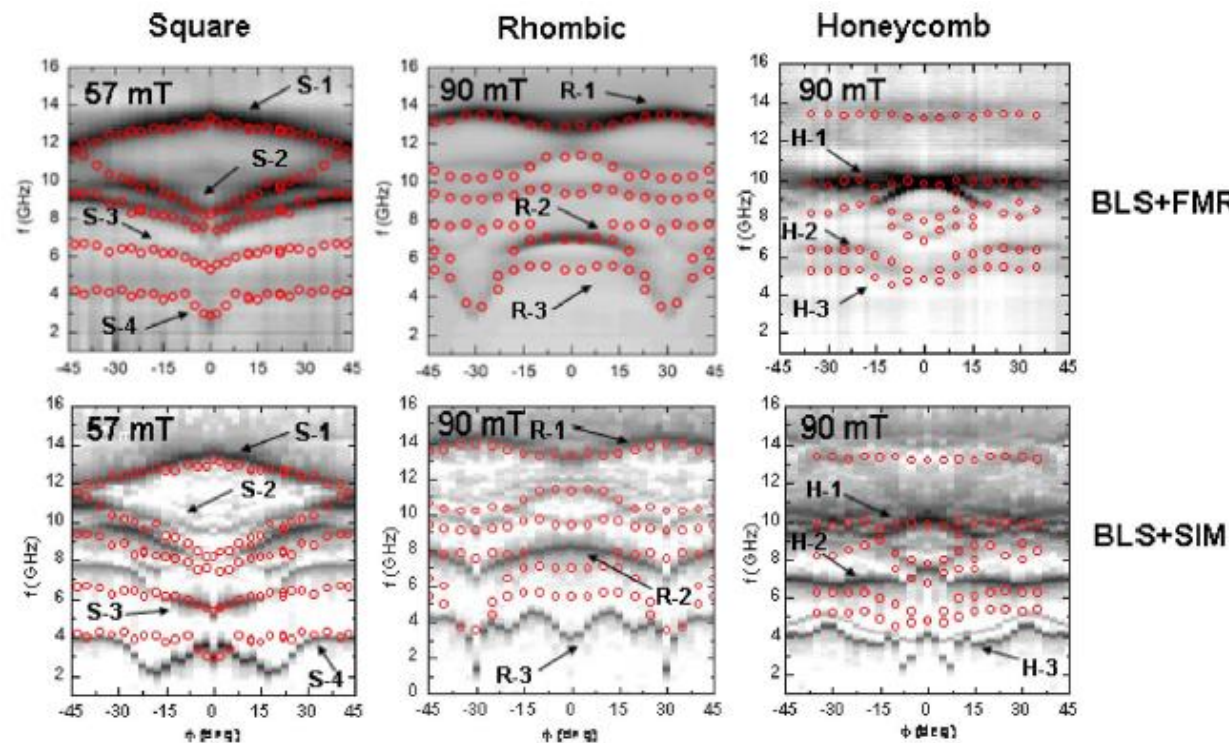
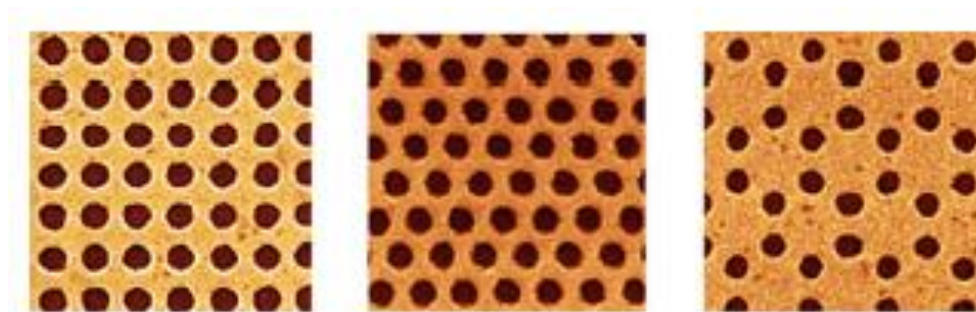
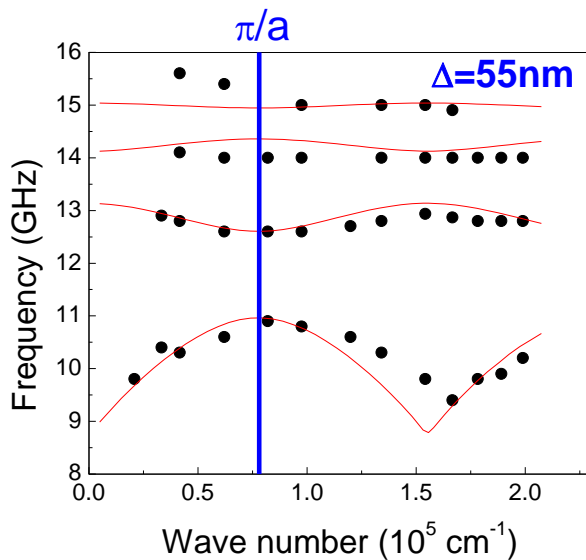
# NiFe Antidot arrays with different mesh 2D-magnonic crystal



$w_1 = w_2 = 175 \text{ nm}$ ;  $L = 20 \text{ nm}$   
 $a = 210 \text{ nm}$ ;  $B_z = 1.5 \times 10^5 \text{ cm}^{-1}$



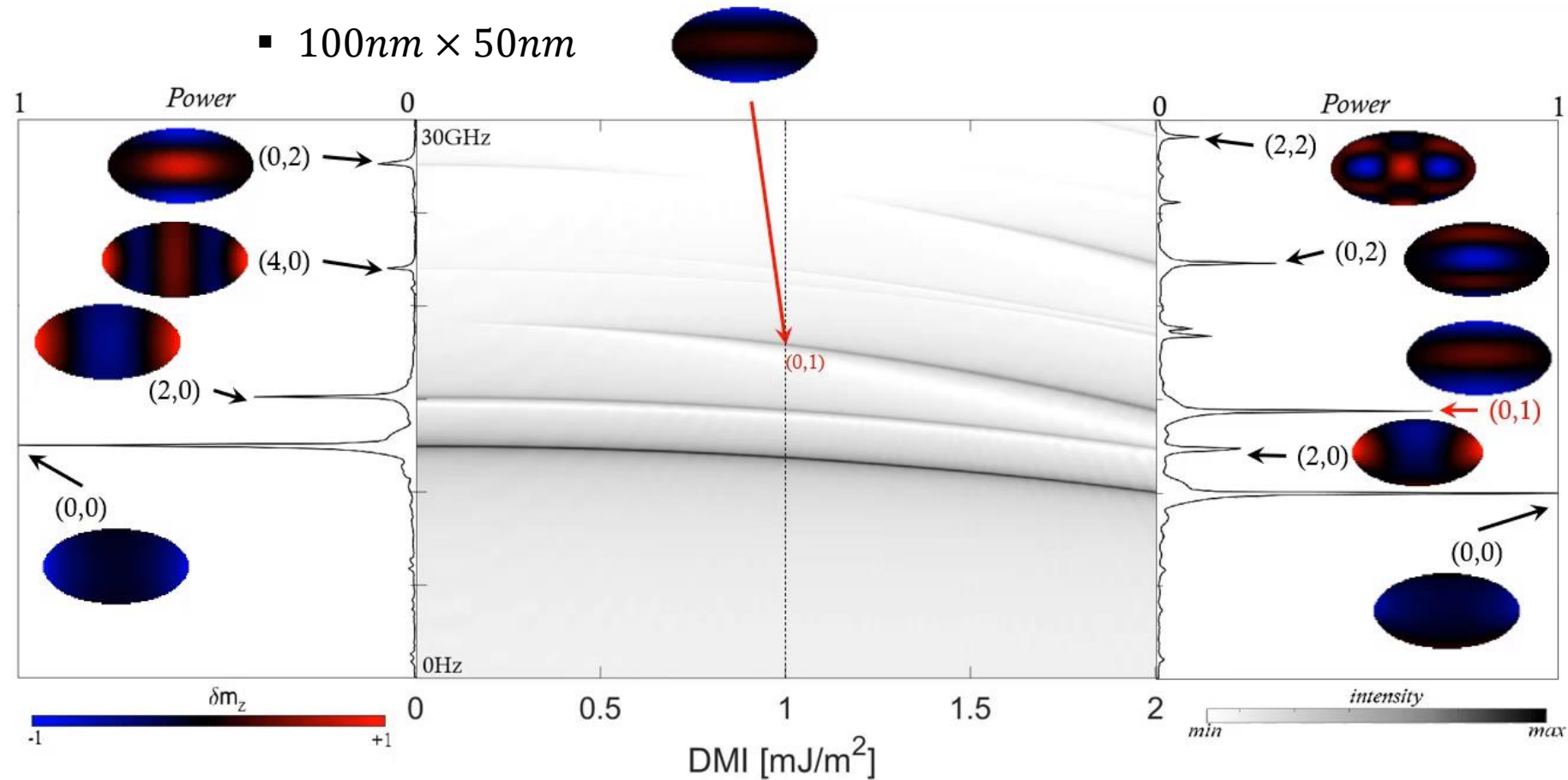
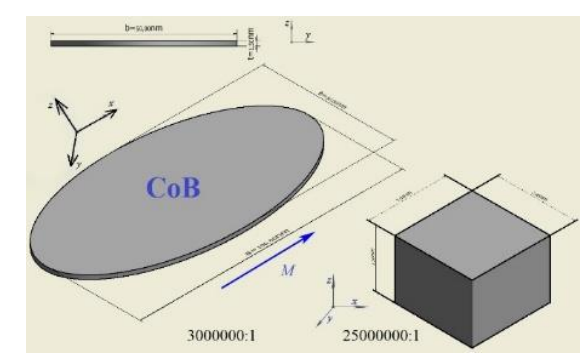
$w_1 = w_2 = 350 \text{ nm}$ ;  $L = 30 \text{ nm}$   
 $a = 405 \text{ nm}$ ;  $B_z = 0.78 \times 10^5 \text{ cm}^{-1}$



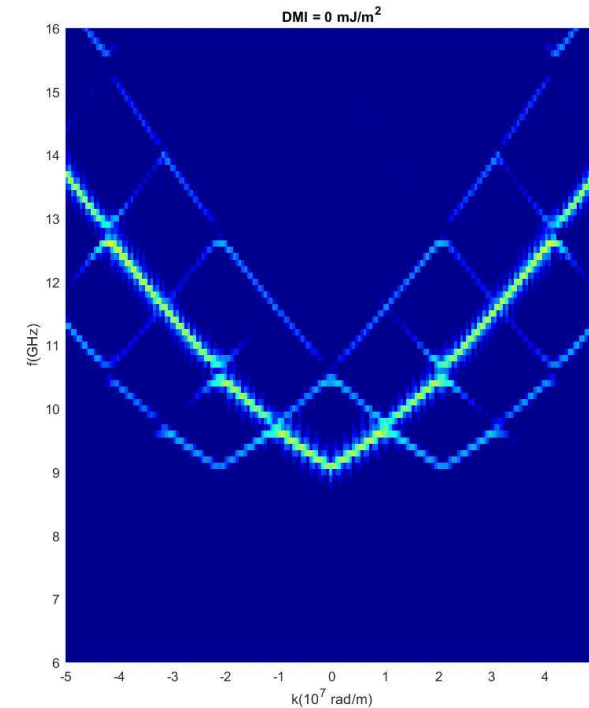
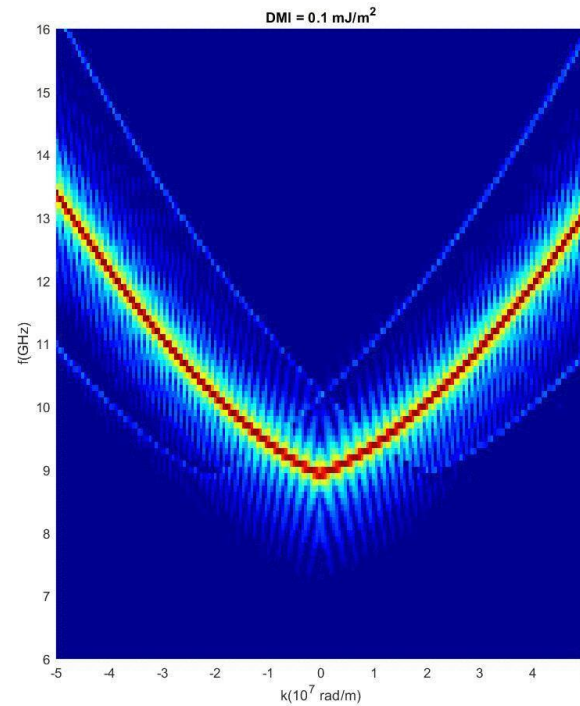
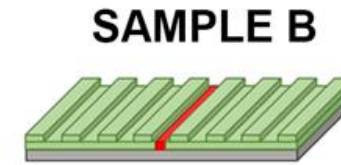
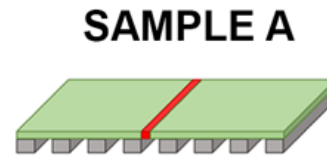
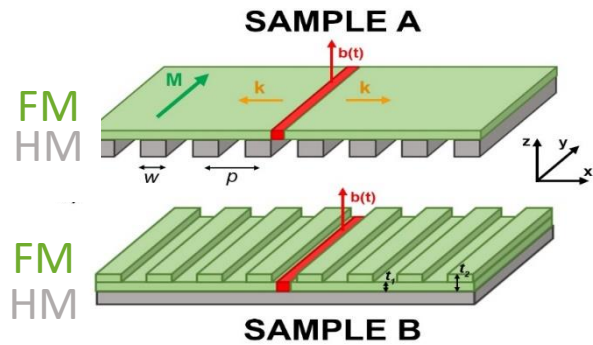


# Eigenmodes of elliptical nanodots: a computational study

MuMax 3 micromagnetic simulations  
Dots saturated along the long-axis  
by an external field  $H = 1$  kOe  
Thickness  $d = 1.5$  nm



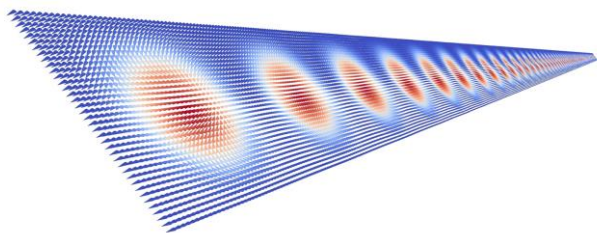
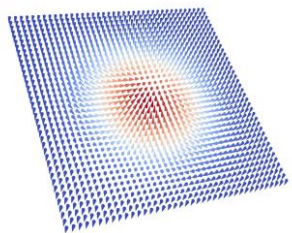
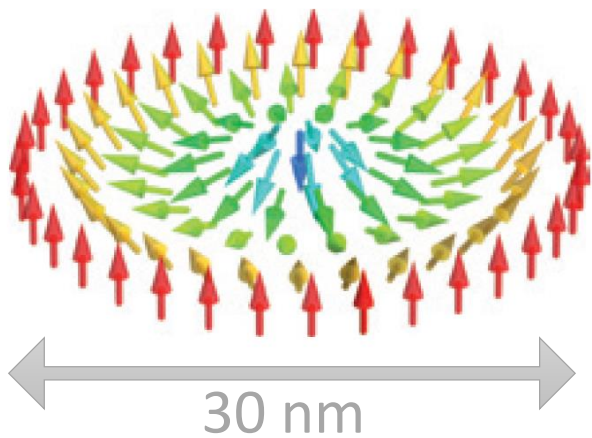
# Band structure of 1D-MC consisting of alternated stripes



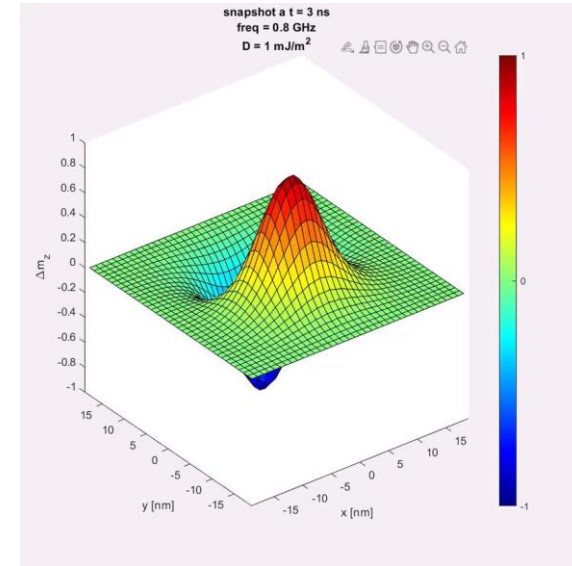
	Ms	730 kA/m
	A	10 pJ/m
	p	300 nm
	w	150 nm
SAMPLE A	t	2 nm
SAMPLE B	t <sub>1</sub>	2 nm
SAMPLE B	t <sub>2</sub>	4 nm



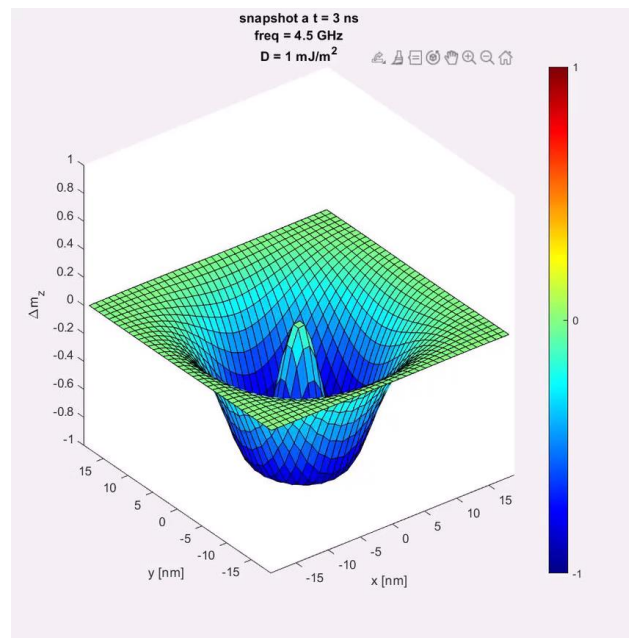
# Eigenmodes of Néel Skyrmions



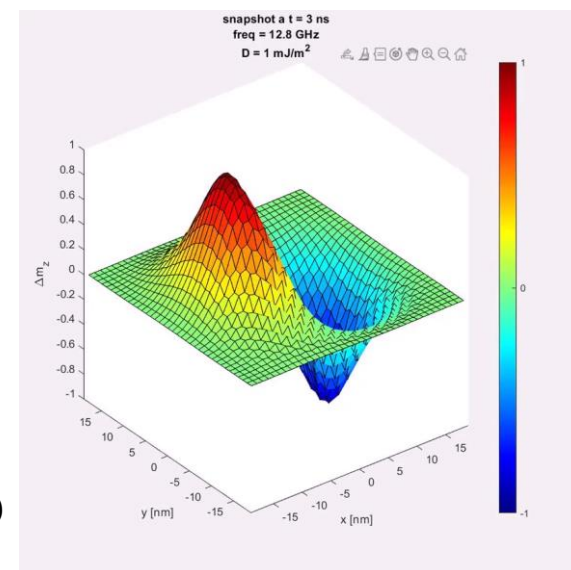
CCW  
(0.8 GHz)



BR  
(4.5 GHz)



CW  
(12.8 GHz)

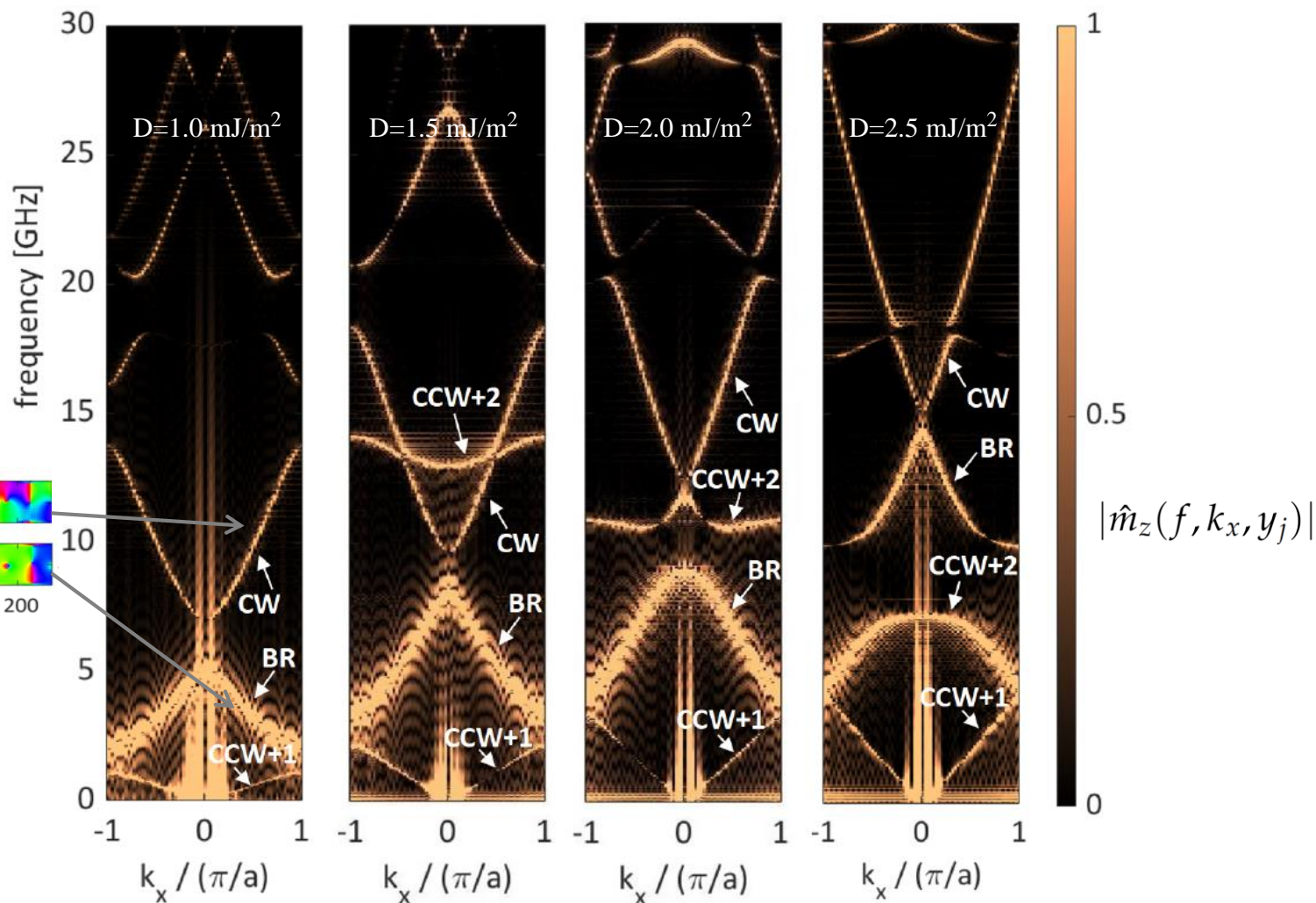
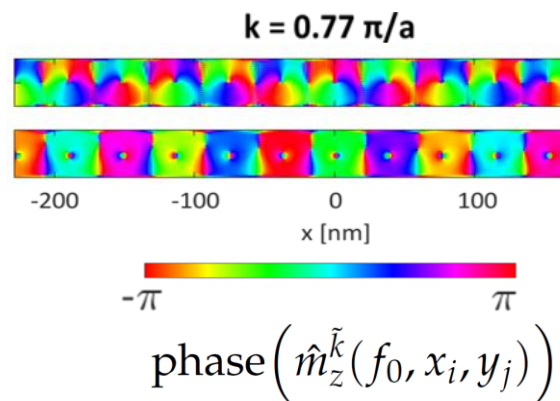


# Chain of skyrmions: 1D magnonic

$$\vec{B} = (0, 0, B_{\text{ext}}(t))$$



Magnonic bands, with either positive or negative dispersion, are formed starting from the eigenmodes of the isolated skyrmions (low-DMI)





# Nanomagnetismo@UniPG

- ✓ Sistemi nanoscopici con proprietà che emergono quando la dimensionalità viene ridotta alla scala nanometrica.
- ✓ Possibilità di formazione e training sia teorico che sperimentale.  
Simulazioni numeriche agli elementi finiti
- ✓ Stretta connessione con AiMagn (Italia) e Spintronic Factory (EU)