NAnoMAgnets for quantum Sensing and data SToragE (NAMASSTE)

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(Università degli Studi di Pavia, Pavia INFN Unit)

CSN5

NAMASSTE - Participants

Participants - Pavia, Firenze and Milano Units FTE/year

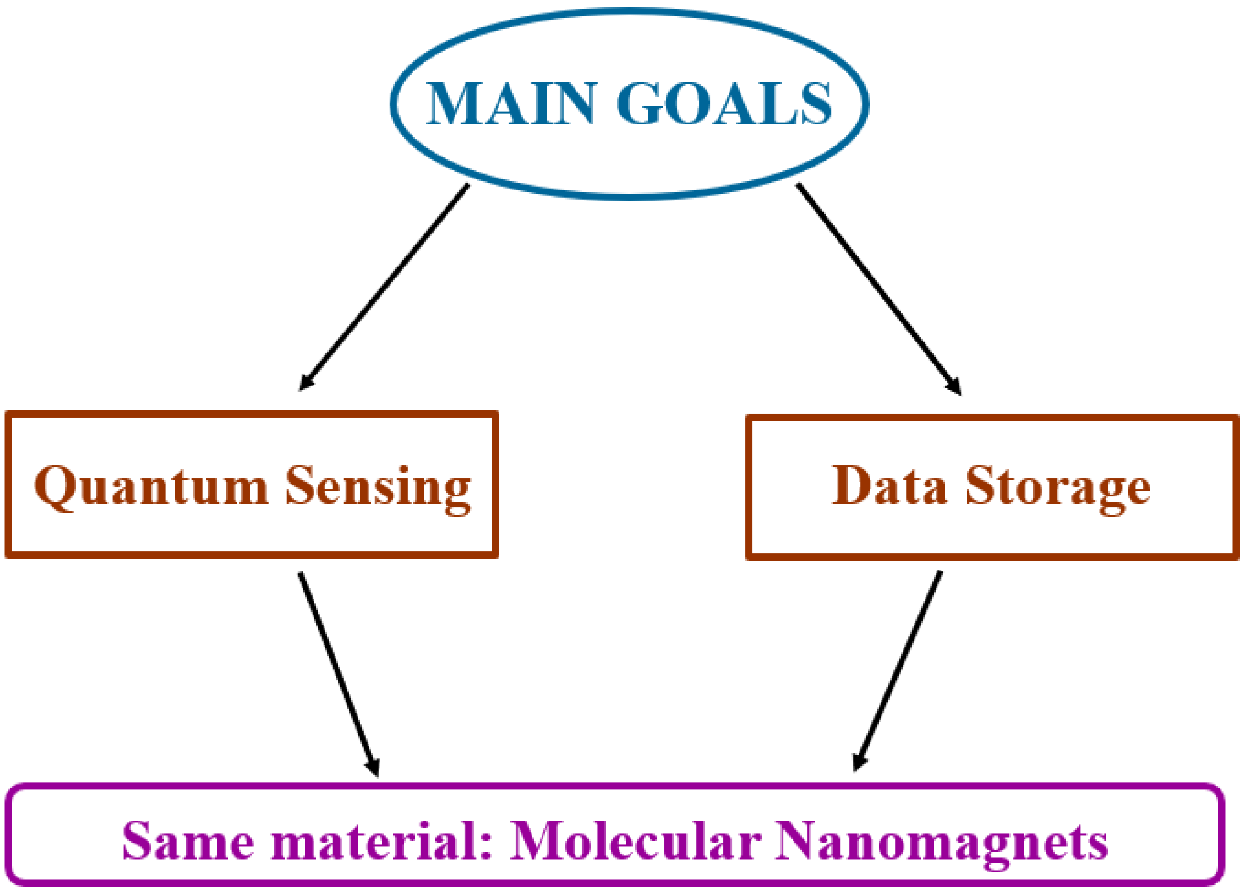
Participant	Unit	FTE/year	Total
Manuel Mariani – RU – UNIPV – PI	**Pavia**	**0.5**	**1.6**
Davide Cicolari – PhD – UNIPV	Pavia	0.3	
Marta Filibian – Technician - UNIPV	Pavia	0.1	
Elio Giroletti – Senior Member – INFN PV	Pavia	0.2	
Alessandro Lascialfari – PO – UNIPV	*Pavia*	*0.2*	
Lisa Rinaldi – PhD – UNIPV	Pavia	0.3	
Fabio Cinti – RTDB – UNIFI	Firenze	0.2	**1.4**
Maria Fittipaldi – RU – UNIFI	*Firenze*	*0.4*	
Giuseppe Latino – PA – UNIFI	Firenze	0.2	
Angelo Rettori – PA – UNIFI	Firenze	0.2	
Lorenzo Sorace – PA – UNIFI	Firenze	0.3	
Diego Redigolo – INFN FI	Firenze	0.1	
Paolo Arosio – RTDB – UNIMI	*Milano*	*0.4*	**0.7**
Francesco Orsini – Technician – UNIMI	Milano	0.3	

External Participant:

P. Santini – PO, Department of Mathematical, Physical and Computer Sciences, University of Parma

Pavia → Unit 1 **Firenze → Unit 2** **Milano → Unit 3**

Goals of NAMASSTE



A novel combination of experimental techniques:

NMR + ESR + MuSR + SQUID + Magnetometry

Goals of NAMASSTE

A. Synergical collaboration among Chemists and Experimental and Theoretical Physicists (Solid State Physics, Particle Physics)

B. Goals for the project:

1) **experimental and theoretical investigation**, of the spin dynamics and the **magnetic relaxation mechanisms** **of metal ions-based Molecular Nanomagnets (MNMs)**

2) **conceiving of new** design principles for **breaking record** performances of **MNMs** to be used **as magnetic memories for data storage**

3) selection of the **best MNM** to be used as **highly-sensitive quantum sensor** for the **detection of small interactions**, related to tiny perturbations due to external particles (e.g. α, β, neutrinos, Dark Matter, etc)

NAMASSTE - Samples

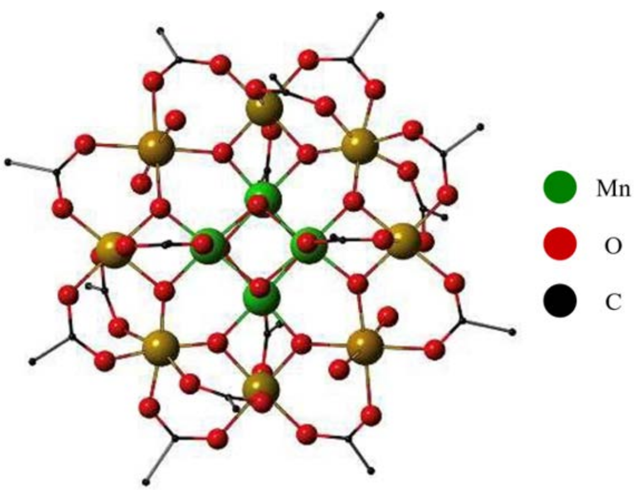
<u>Molecular Nanomagnets (MNMs)</u> (systems size of the order of nanometers):

a) *3d Single - Molecule Magnets (SMMs)* (Mn_{12}, Fe_4)

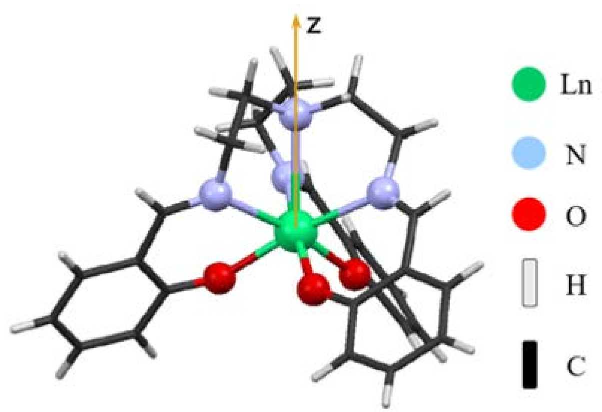
b) *4f Single - Ion Magnets (SIMs*) (Ln – Zn and Ln – tropolonato systems)

Characterized by:

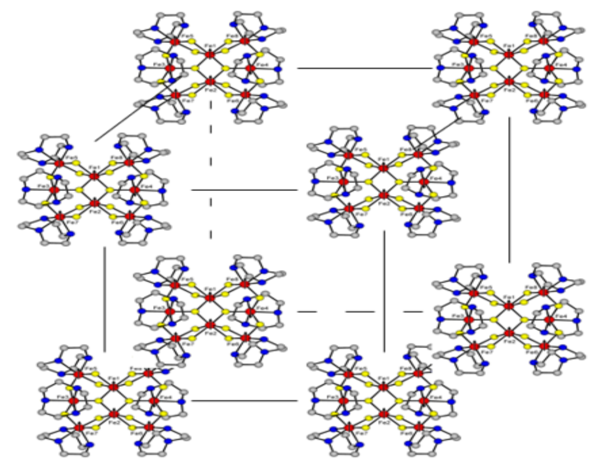
1. regular crystalline structure with a magnetic core of a finite number ($n \geq 1$) paramagnetic centers (strong intramolecular exchange interactions)
2. molecules shielded by organic ligands → weak intermolecular interactions
3. strong uniaxial anisotropy → magnetic bistability (double-well energy levels)



Mn_{12} SMM



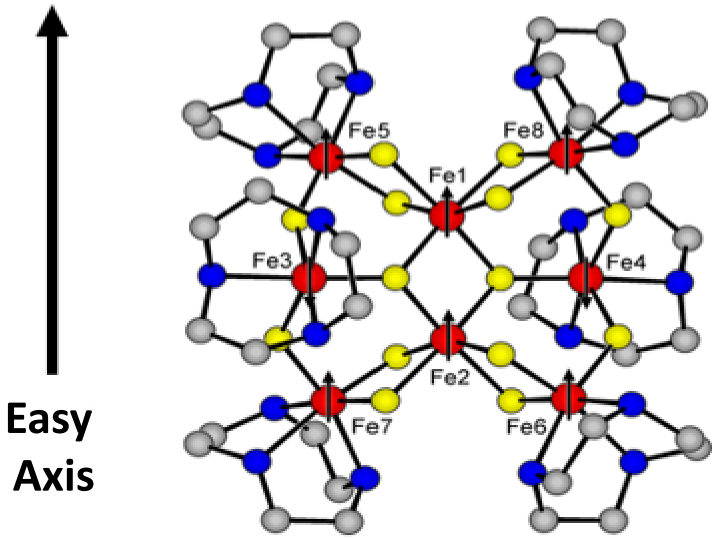
Ln-based SIM



Crystal of Fe_8

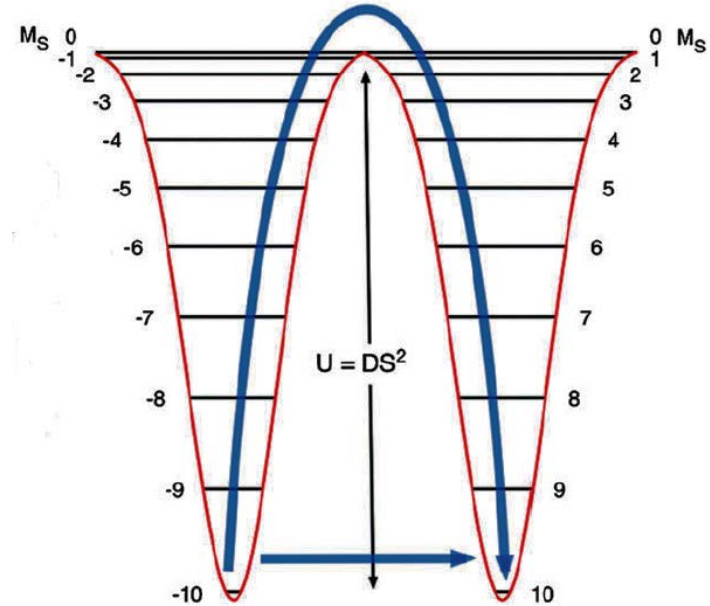
NAMASSTE - Samples

Ground State Spin Configuration



Fe$_8$ - S_T = 10 (giant spin)

Fe^{3+} s = 5/2



***Magnetic Bistability in MNMs**

a. Progressive severe slowing down of **Magnetization** at intermediate temperature: $\tau = \tau_0 e^{\frac{\Delta E}{k_B T}}$ (10^{-8}s < τ_0 < 10^{-10}s)

b. Quantum Tunneling of **Magnetization** at very low temperature: the energy of these transitions is lower than ΔE.

*Juan M. Clemente-Juan et al., *Chem. Soc. Rev.,* 2012, **41**, 7464–7478

NAMASSTE – Techniques

- ac and dc magnetometry measurements versus temperature and magnetic field (2K < T < 300K, 0 < $\mu_0 H$ < 5T) - **Unit 1** and **Unit 2**
- Zero and high magnetic field wide-band NQR/NMR on ^{1}H and transition-metal nuclei as a function of temperature and magnetic field applied in the ranges 1.5K < T < 300K and 0.1T < $\mu_0 H$ < 9T respectively - **Unit 1**
- Low-field and FFC wide-band ^{1}H NMR as a function of temperature and magnetic field applied (temperature range: 100K < T < 300K, field range: 0.0025T < $\mu_0 H$ < 0.25T) - **Unit 3**
- ESR measurements at variable frequency, as a function of temperature and magnetic field (range: 4.2K - 300K and 0.1T - 4T) - **Unit 2**
- MuSR measurements in longitudinal and transverse configurations vs temperature and magnetic field applied (1.8K - 300K, 0 – 0.6T) **at PSI facility** - **Unit 1** and **Unit 3**

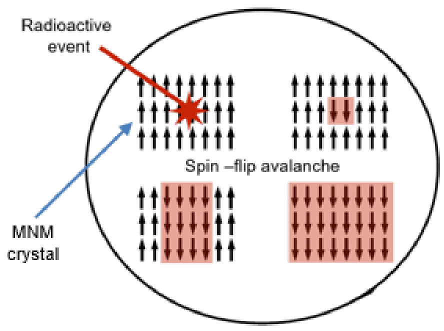
Experiments of MNMs as Sensors

- Starting from:
  a) the detection of a **spin - flip avalanche** in a crystal of MNMs after energy deposition due to radioactive event#
  b) recent experiments* validating **MNMs as sensors**.

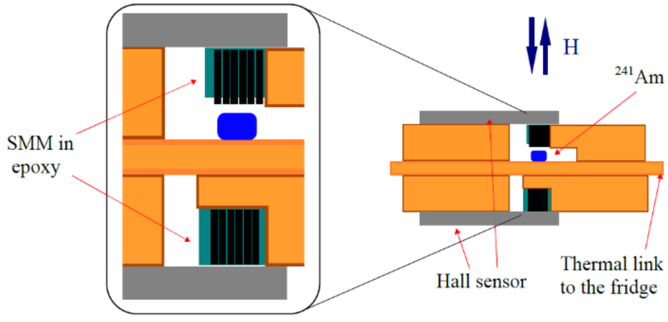
- Comparison of NMR, ESR and SQUID Magnetometry, results on MNMs in normal conditions and in presence of a radioactive source respectively, to:

  a) increase overall the **detection sensitivity** (more sensitive techniques)

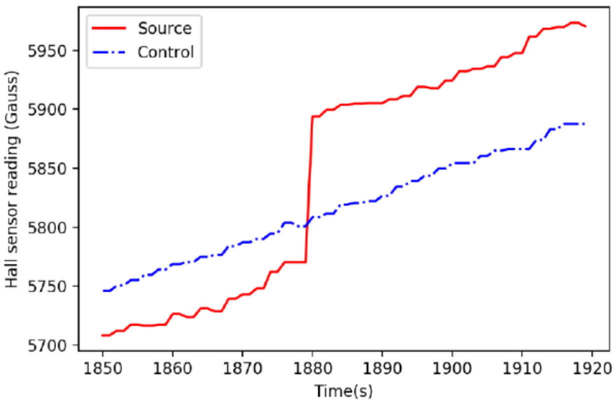
  b) increase the temperature of use of MNMs as sensors (higher energy barriers and T_B)



Sketch of the spin-flip avalanche mechanism#



*Experimental Set-up as conceived by Chen et al.**



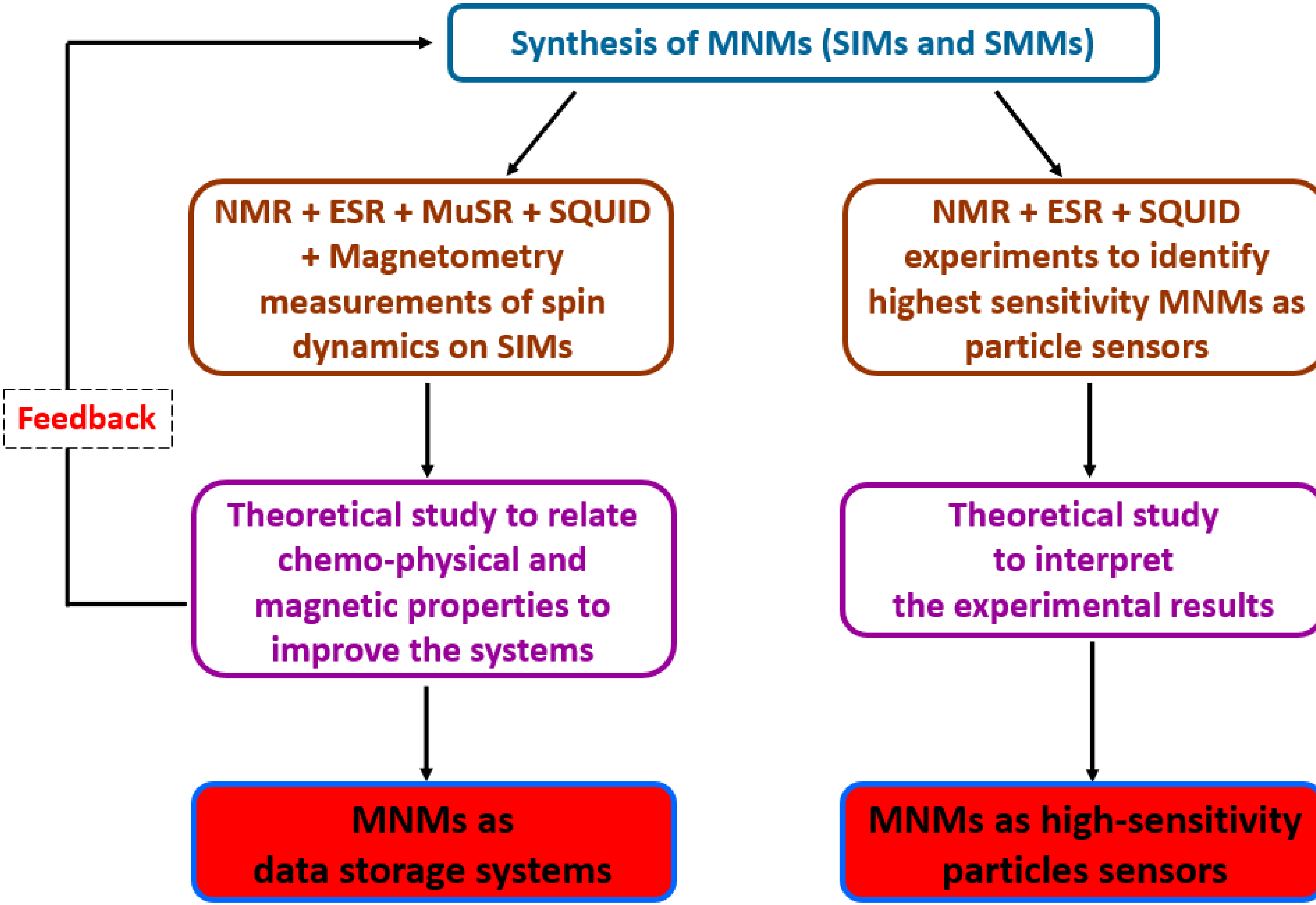
*Detection of spin-flip avalanche**

P. C. Bunting, G. Gratta, T. Melia, S. Rajendran, *Phys. Rev. D* 95, 095001 (2017)
* H. Chen, R. Mahapatra, G. Agnolet, M. Nippe, M. Lu, P. C. Bunting, T. Melia, S. Rajendran, G. Gratta and J. R. Long, arXiv:2002.09409v2

NAMASSTE - WorkPackages

- **WP1 – *Synthesis and first characterization of 3d SMM and 4f SIMs* (participants: Unit 2 with feedbacks from Unit 1, Unit 3 and Paolo Santini) – Responsible: Unit 2**
- **WP2 – *Quantum memories: experimental study of spin dynamics and relaxation of SMM and 4f SIMs* (Participants: Units 1, 2, 3) – Responsibles Unit 1 and Unit 2**
- **WP3 – *Theory of the 3d SMMs and 4f SIMs relaxation* (participant: Unit 2 and Paolo Santini) – Responsible Unit 2**
- **WP4 – *Experimental study for the characterization of MNMs as particle quantum detectors* (participants: Unit1 and Unit 2) – Responsible Unit 1**

NAMASSTE – Methodology



NAMASSTE – Expenses 2021

Pavia Unit (Unit 1)	
Expense	Amount (keuro)
Liquid Helium for NMR and SQUID Measurements	16
Low-Activity Radioactive Sources for Quantum Sensors Experiments	7.5
Missions for project meetings and MuSR/Joint Experiments	6
	29.5
Firenze Unit (Unit 2)	
Liquid Helium for ESR and SQUID Measurements	8
Liquid Nitrogen and Exchange Gas for ESR Measurements	1
Low-Activity Radioactive Sources for Quantum Sensors Experiments	7.5
Materials for Samples Synthesis	1.5
Instrumentation Maintenance	0.5
Other Consumables for Instrumentation	0.5
Purchase of PC for ESR Instrument	8.5
Missions for project meetings and Joint Experiments	3
	30.5
Milano Unit (Unit 3)	
Cooling Liquid Galden sv 110 for FFC NMR Instrument	1.5
NMR Sample Holders for NMR Measurements	0.5
Other Consumables	1
NMR Electronic Board for NMR Instrument	1.5
Variable Capacitors for NMR Instrument	1
Missions for project meetings and MuSR experiments	2.5
	8
	TOTAL
	68