Cooperativity and Sensing: from Condensed Matter Physics to High Energy Physics

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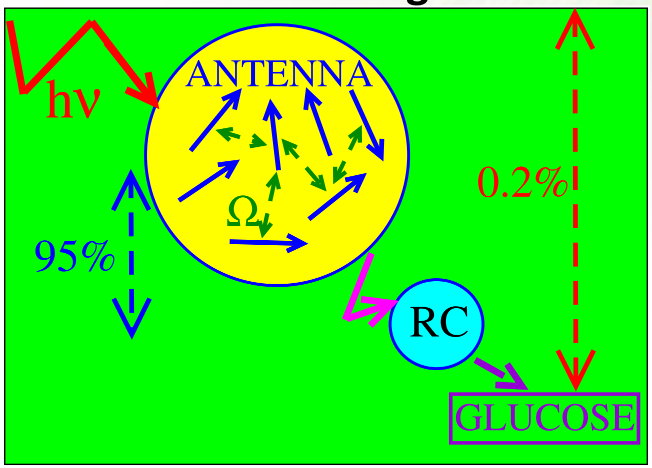
INFN Florence Theory Group Day

Quantum Biology

PHOTOSYNTHESIS / ENERGY PROBLEM

G. Fleming



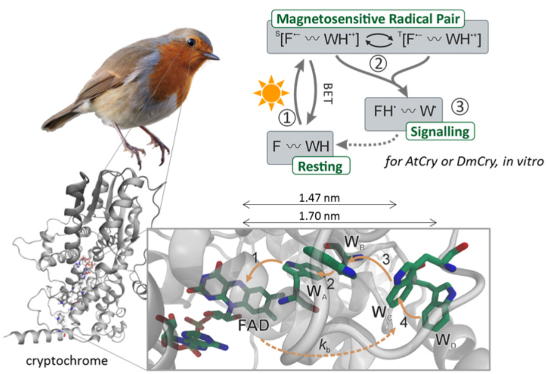
BRAIN FUNCTIONS / CONSCIOUSNESS

J. McFadden, C. Simon, M. Fisher

Li_7 (10 sec) N-spin coherence vs Li_6 (5 min) coherence.

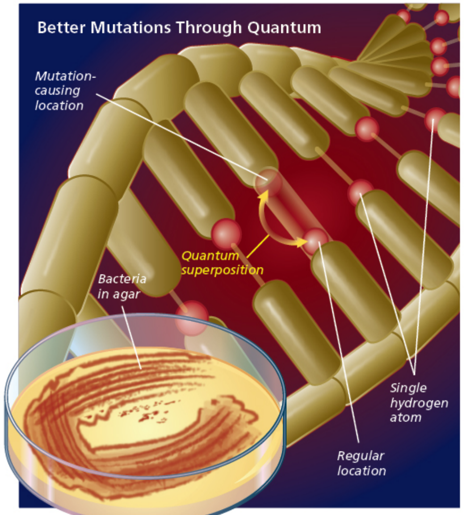
AVIAN COMPASS / SPIN CHEMESTRY

K. Schulten, P. Hore



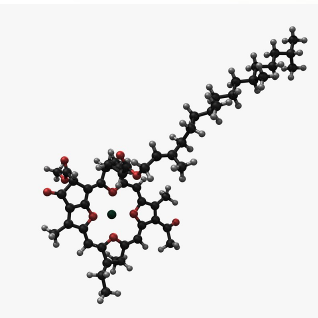
ADAPTATIVE MUTATIONS / GENETIC ENGINEERING

J. McFadden, J. Al-Khalili



Hierarchical complexity in Biology

Biological systems are characterized by an incredible degree of symmetry, order, and organizational complexity.



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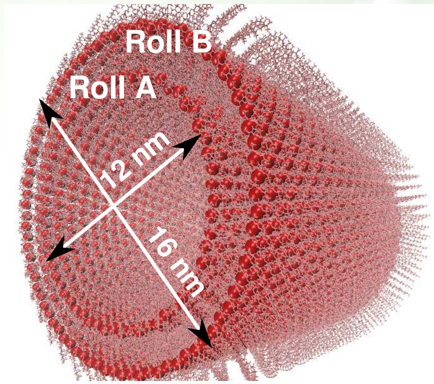

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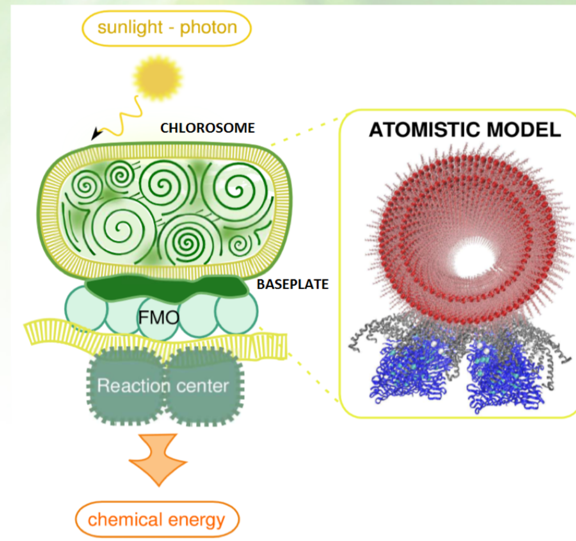
Green Sulfur Bacteria



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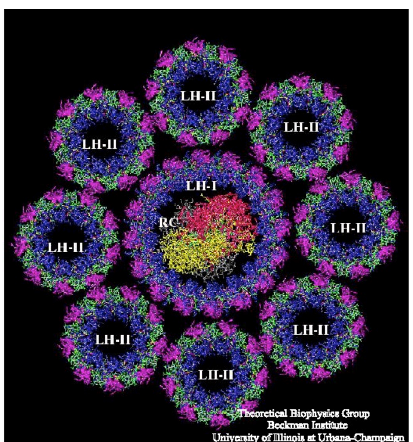

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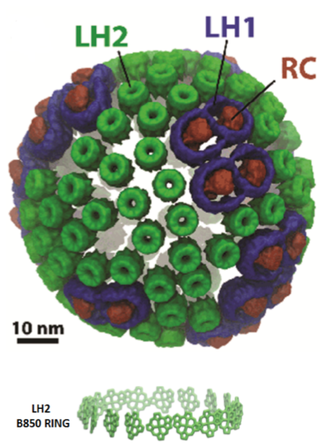
Purple Bacteria

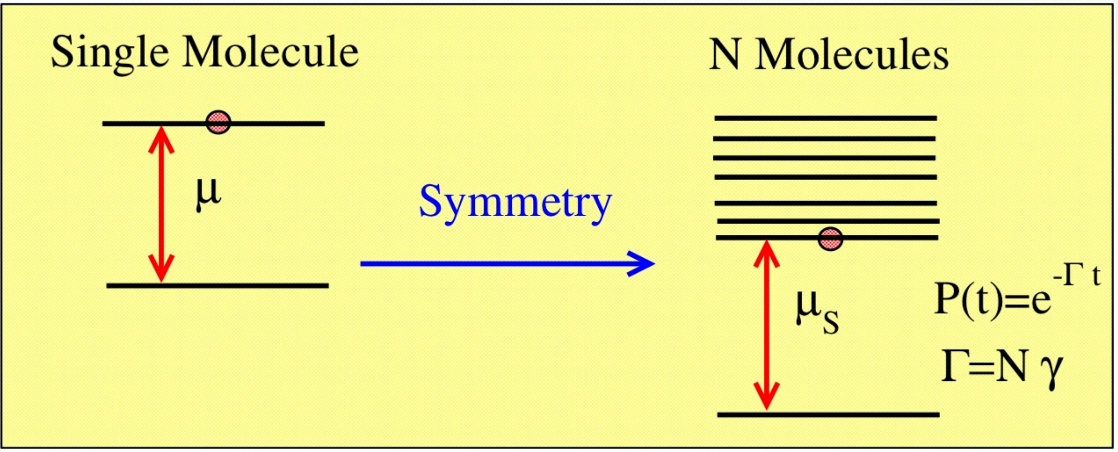


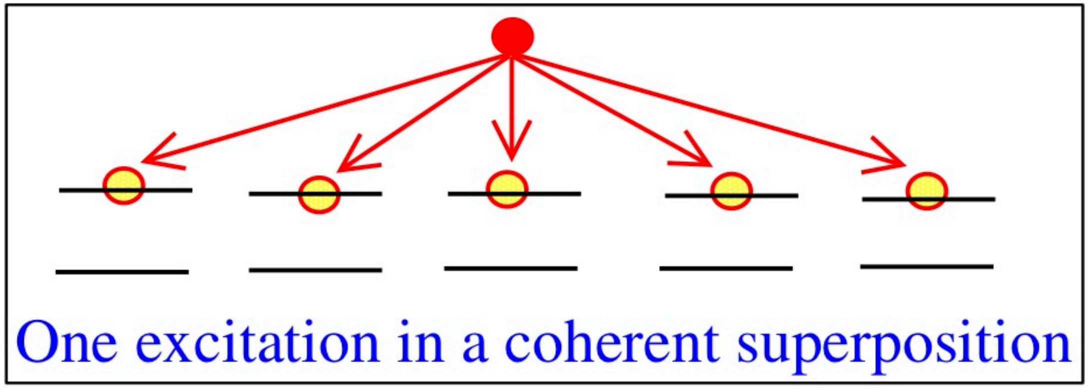
What is the relation between structure and functionality?

Can QM have a functional role in such large aggregates?

Symmetry and Cooperativity

Symmetry favors the emergence of quantum cooperative properties robust to noise.



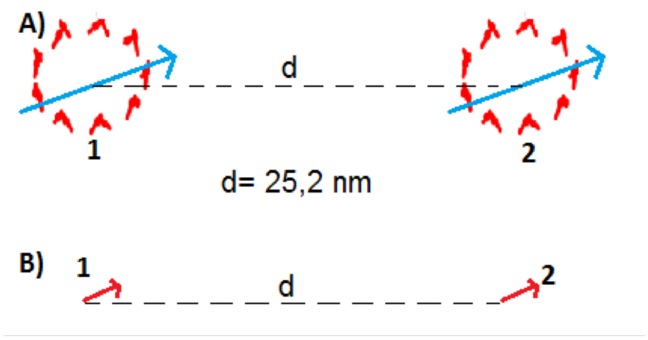


How Cooperativity donate robustness?

1. Fast time scales (faster than thermal relaxation).

Super-Absorption $\propto N$

Super-Transfer: NV

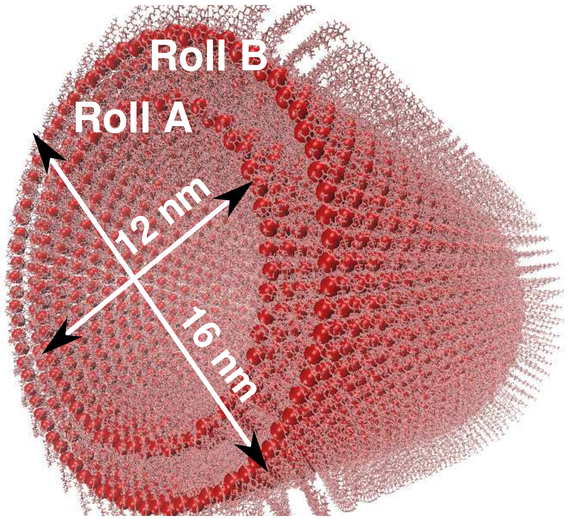


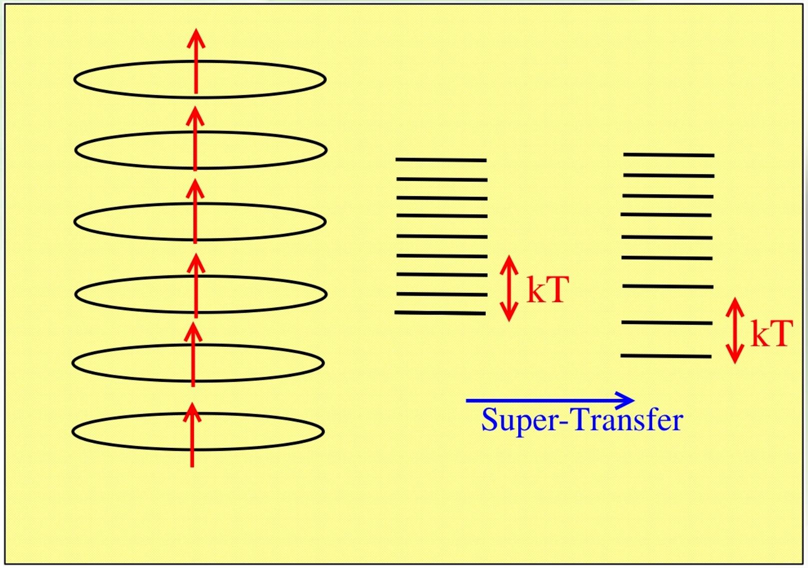
Emergent Macroscopic Coherence

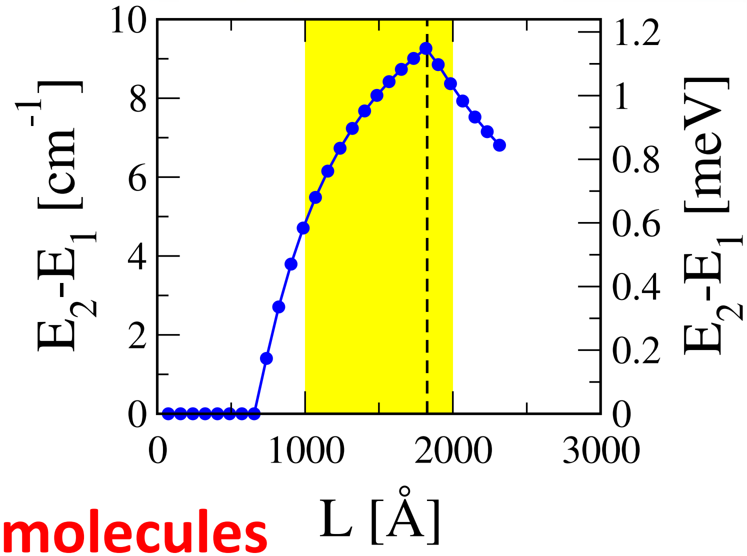
2. Suppression of density of states, energy gaps.

On the existence of superradiant excitonic states in microtubules G. L. C. et al. New J. Phys. 21 023005 (2019). Macroscopic coherence as an emergent property in molecular nanotubes M. Gull et al. ; New J. Phys. 21 013019 (2019).

Green Sulfur Bacteria



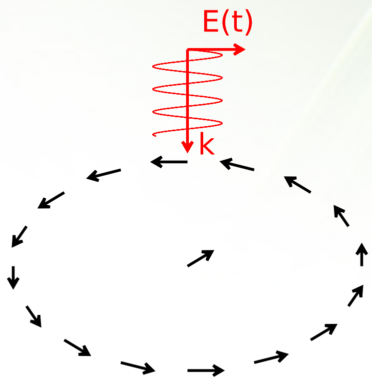




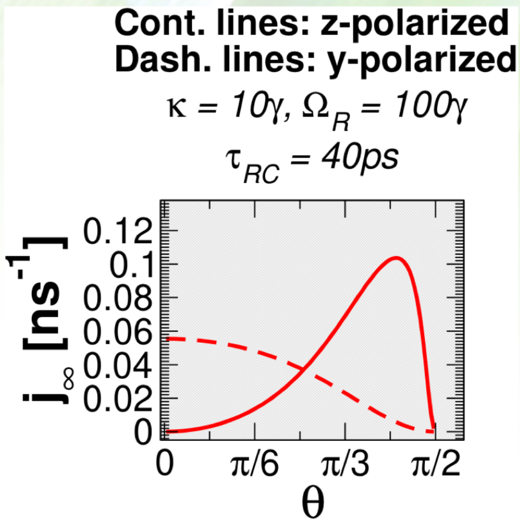
At T=300K excitation coherent over 10^3 molecules

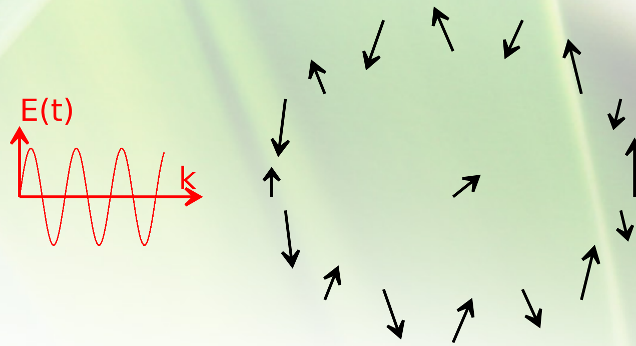
From Photosynthesis to Photon Sensors

Collaborations: M. Sarovar, Sandia Natl. Labs. USA

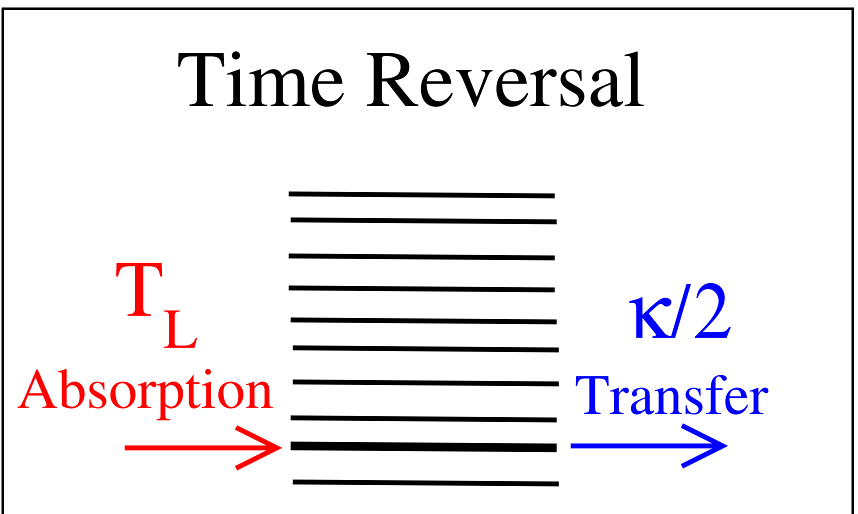


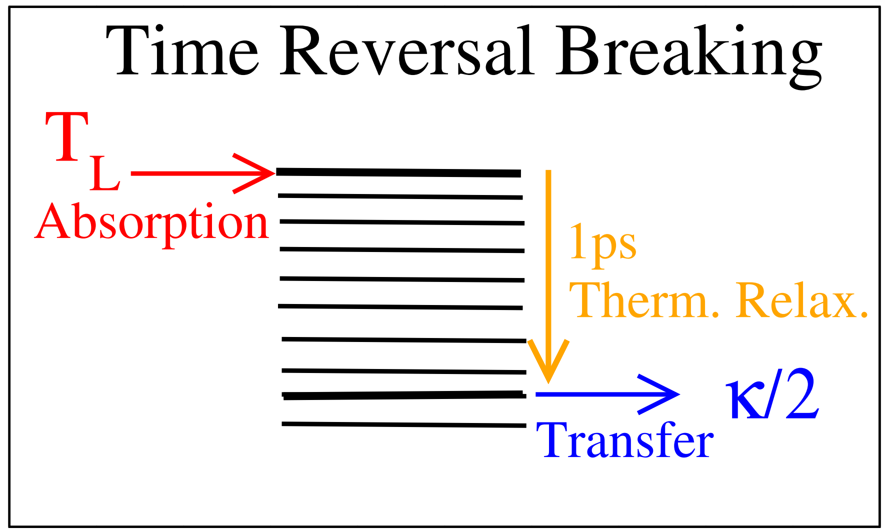
$\theta=0$





$\theta=\pi/3$

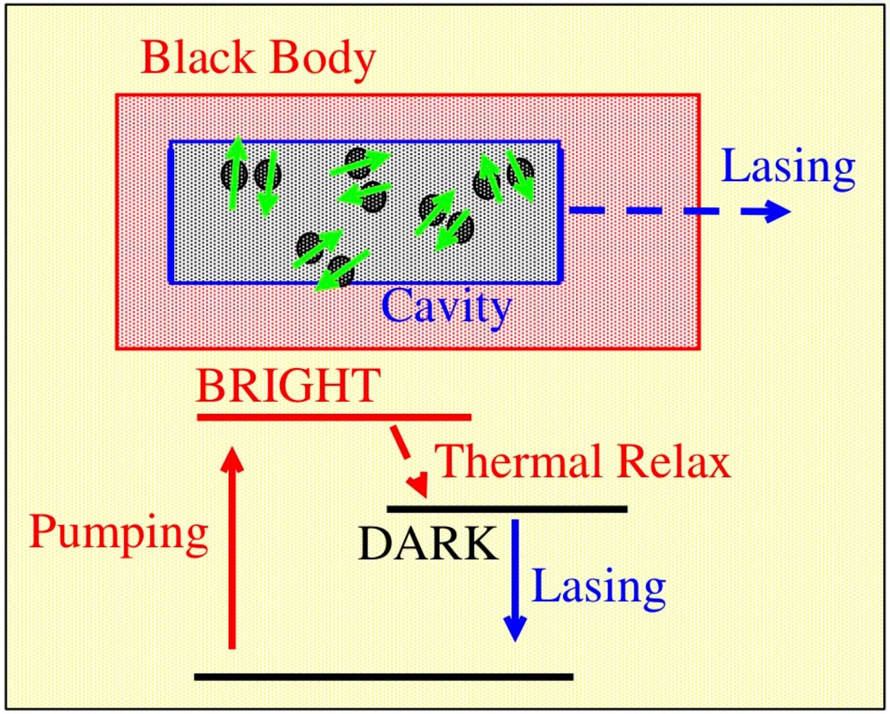


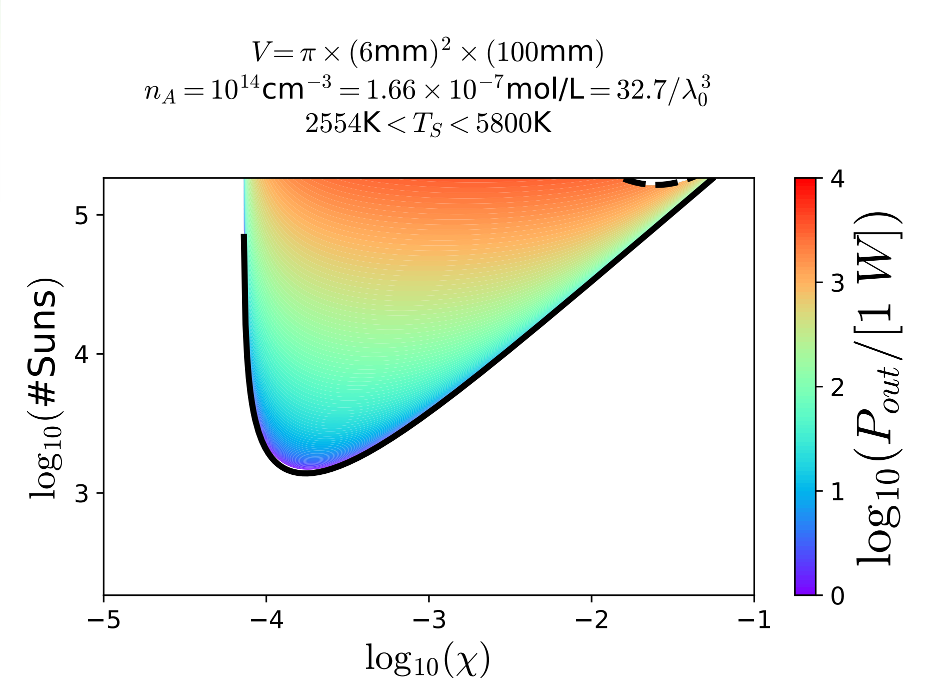


Sun-Light pumped bio-inspired Lasing

Collaborations: E. Gauger, Heriot-Watt, U.K., N. Piovella, Univ. Milan, Italy

Sun-light pumped lasing is an extremely promising technology for renewable energy source (magnesium cycle), distribution and storing of sun-light energy and space technology.

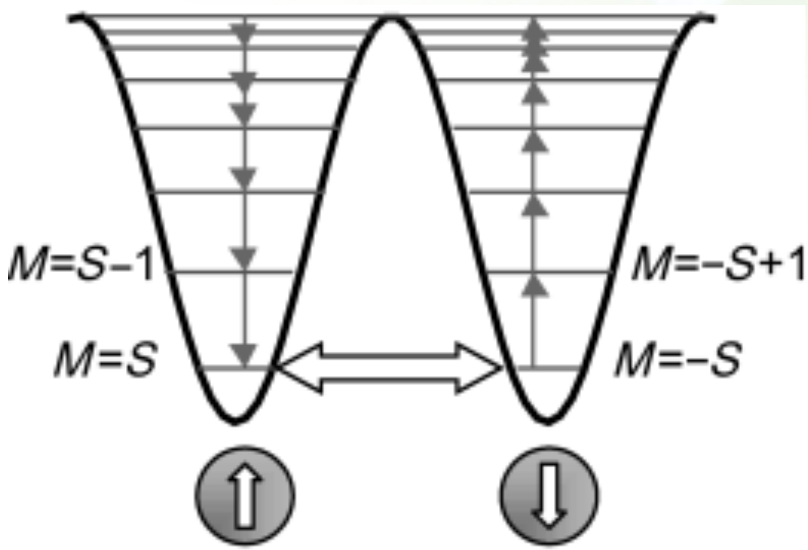




1 Sun = 0.1 W/cm^2

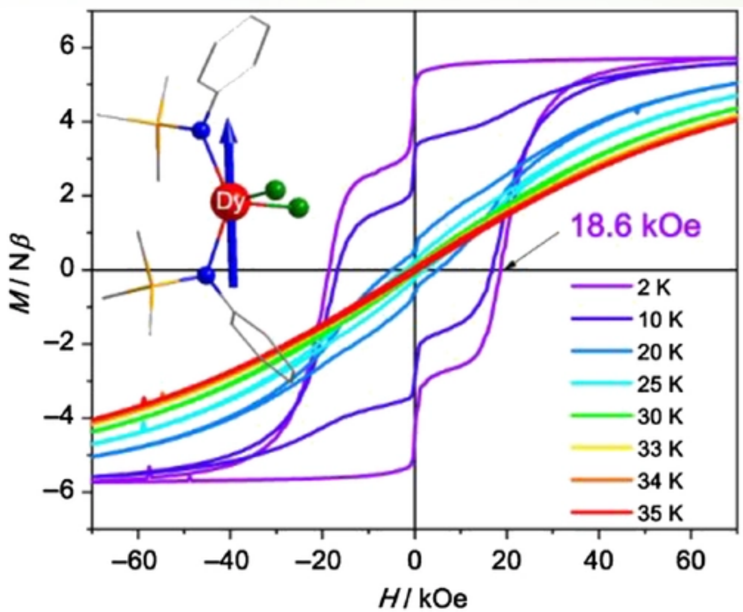
MACROSCOPIC QUANTUM TUNNELING

Single Molecule energy levels: Mn12



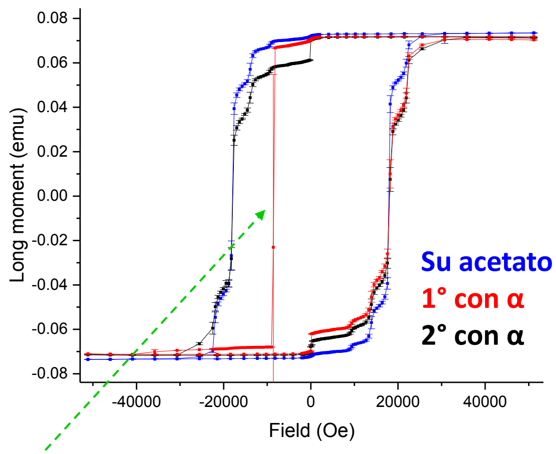
Hysteresis jumps

Magnetization shows hysteresis with steps occurring at values of the applied field where the energies of different collective spin states of the manganese clusters coincide. At these special values of the field, relaxation from one spin state to another is enhanced above the thermally activated rate by the action of resonant quantum-mechanical tunnelling.

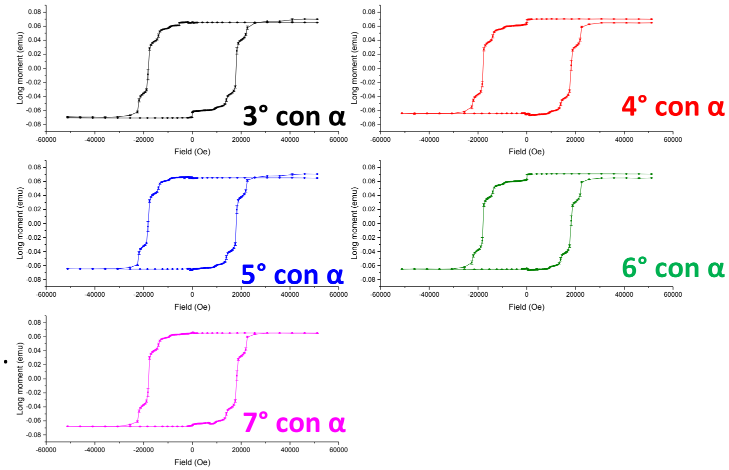


NAMASTE: QUANTUM DETECTORS FOR PARTICLES

SUMMARY FEBBRAIO 2022: Misure di ISTERESI a 1.9 K



(~ 1 α al min. sull'area del campione)



- **Valanga a -8500 Oe nel primo ciclo di isteresi fatto con sorgente α**
- **Presenza di altri salti nella magnetizzazione (non visti in assenza di sorgente)**
- **Salti (principalmente attorno a campo 0) presenti anche nei cicli successivi**
- **Cicli di isteresi trovati nuovamente "regolari" rimuovendo la sorgente α**

- **Necessità di misurare isteresi su el. no alpha**

PHYSICAL REVIEW D 95, 095001 (2017)

Magnetic bubble chambers and sub-GeV dark matter direct detection

NUMERICAL SIMULATIONS

NAMASSTE

nicedirac

July 2022

1 Electric and Magnetic Field of a point charge moving at constant velocity

SI (mks) units

$$E = \gamma mc^2, \quad \text{with} \quad \gamma = \frac{1}{\sqrt{1-(\frac{v}{c})^2}}$$

Kinetic Energy: $T = mc^2(\gamma - 1)$.
Fields produced in $\vec{r}$ by a particle moving at constant velocity:

$$\vec{E}(\vec{r},t) = \frac{q}{4\pi\epsilon_0}\frac{1-(v/c)^2}{\left(1-\frac{v^2 sin^2\theta}{c^2}\right)^{3/2}}\frac{\hat{R}}{R^2} \qquad \text{and} \quad \vec{B} = \frac{\vec{v}\times\vec{E}}{c^2}$$

where $\vec{R} = \vec{r} - \vec{v}t$ and θ is the angle between $\vec{R}$ and $\vec{v}$.
Note that the magnetic field is directed according to the right handed rule w.r.t. the particle velocity, and so it is perpendicular to its trajectory.
The maximal magnetic field as a function of the distance can be written as:

$$B_{max} = \frac{q\mu_0}{4\pi}\gamma\frac{v}{R^2}$$

where $\mu_0 = 4\pi \cdot 10^{-7} N/A^2$, $c = 3 \cdot 10^8 m/s$, $e = 1.6 \cdot 10^{-19} C$. Note $1T = 10^4 Oe$.
Thus for α and β particles, measuring R in nm, I get:

$$B_{\alpha}^{max} = \frac{4012.4}{R^2}Oe \qquad \text{and} \quad B_{\beta}^{max} = \frac{31497.8}{R^2}Oe$$

α particle	β particle
$M_\alpha = 3,727\ \frac{\text{GeV}}{c^2}$	$M_\beta = 0,51\ \frac{\text{MeV}}{c^2}$
$T_\alpha = 5$ MeV	$T_\beta = 100$ keV
$v_\alpha = 0,042$ c	$v_\beta = 0,55$ c

Table 1: Mass, kinetic energy and velocity for α and β particles.

CONCLUSIONS

- **EXPLOITINIG COOPERATIVITY TO BUILD SCALABLE QUANTUM DEVICES ABLE TO OPERATE AT ROOM TEMPERATURE.**
- **APPLICATIONS IN CONDENSED MATTER AND HIGH ENERGY PHYSICS**

THANK YOU!