Gli elettroni si respingono e si attraggono: magnetismo e superconduttività nella materia

Pietro Carretta

http://nmrphysics.unipv.it

Incontro del Martedì

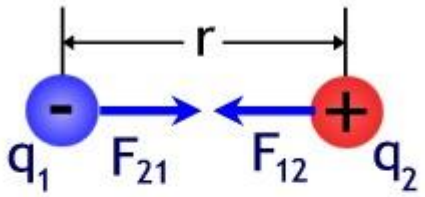
4 Aprile 2017

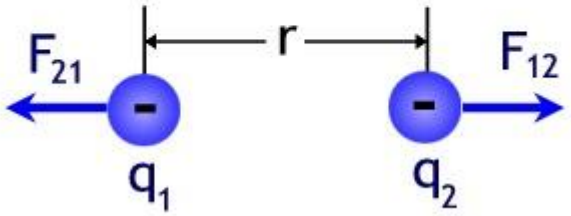
Gli elettroni si respingono e si attraggono: magnetismo e superconduttività nella materia

Forza di Coulomb e momenti magnetici

Charles-Augustin de Coulomb

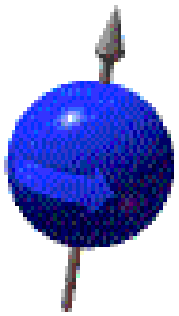
$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}$$



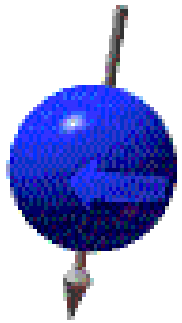


S=1/2

$\overrightarrow{\boldsymbol{\mu}_s} = -2\mu_B \overrightarrow{\mathbf{S}}$



m_s=+1/2

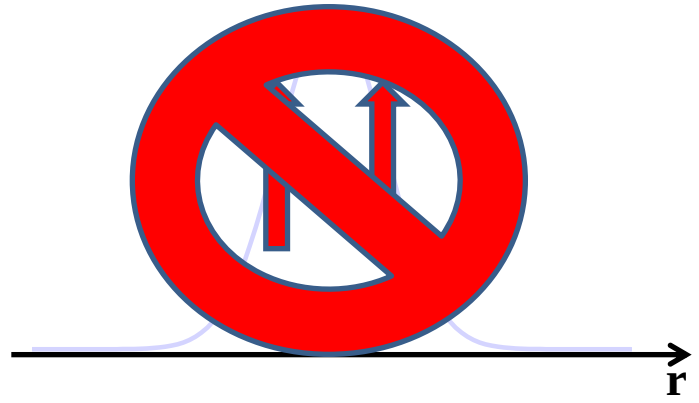


m_s=-1/2

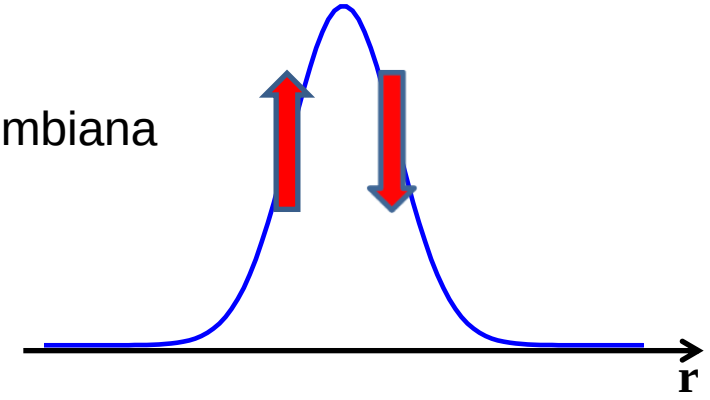
Principio di esclusione di Pauli

”Due elettroni non possono occupare simultaneamente lo stesso stato”

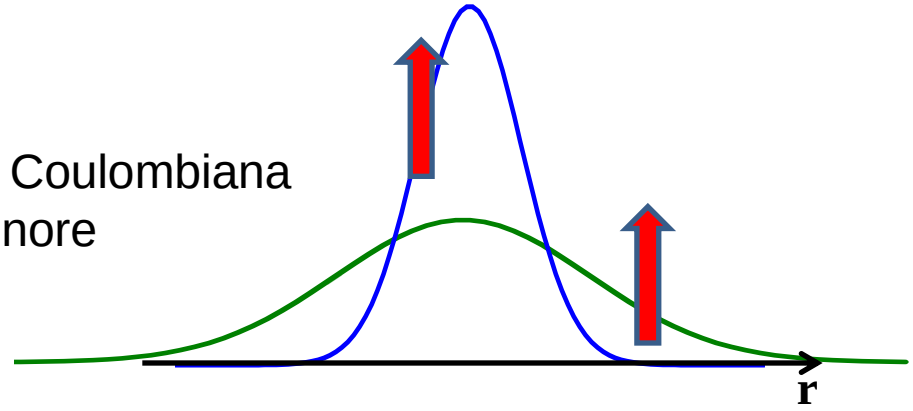
Wolfgang Pauli



Repulsione Coulombiana maggiore



Repulsione Coulombiana minore

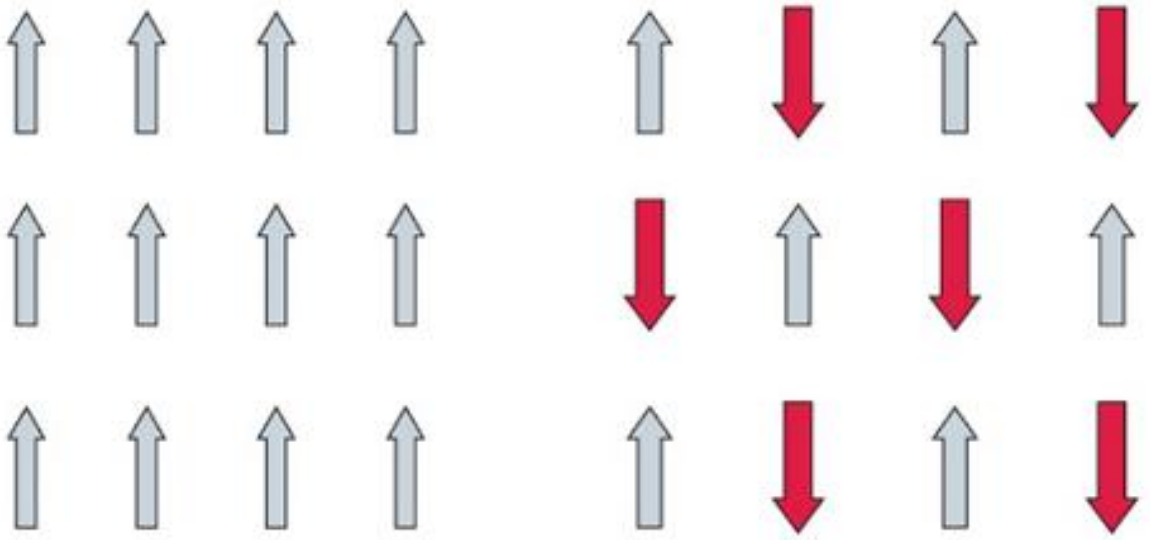


Ferromagnetismo e antiferromagnetismo

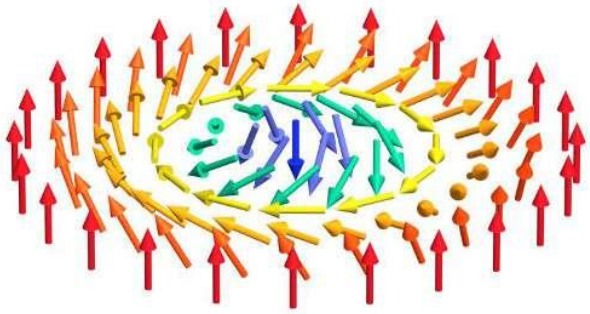
Repulsione Coulombiana + Principio di Pauli

Interazione di scambio

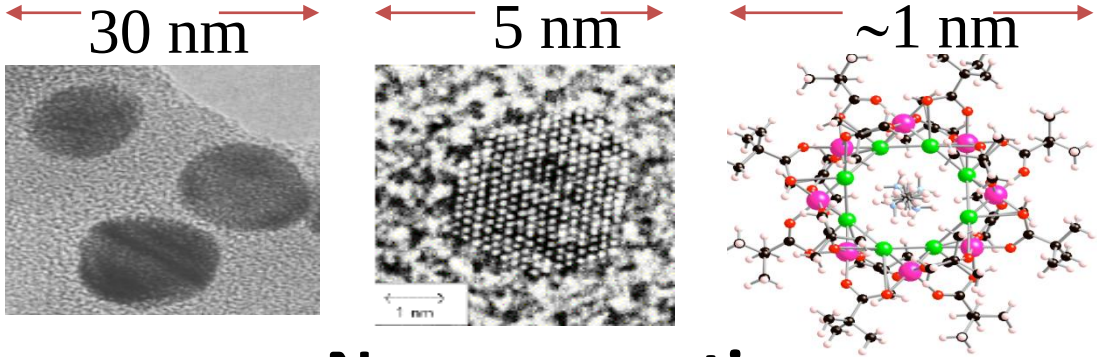
Magnetismo



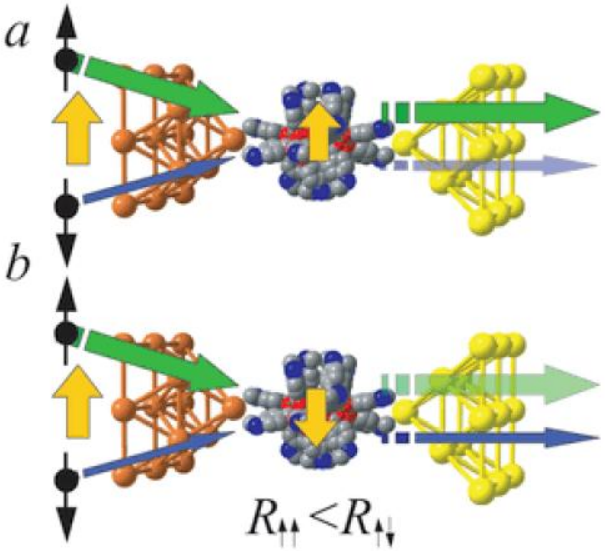
Magnetismo



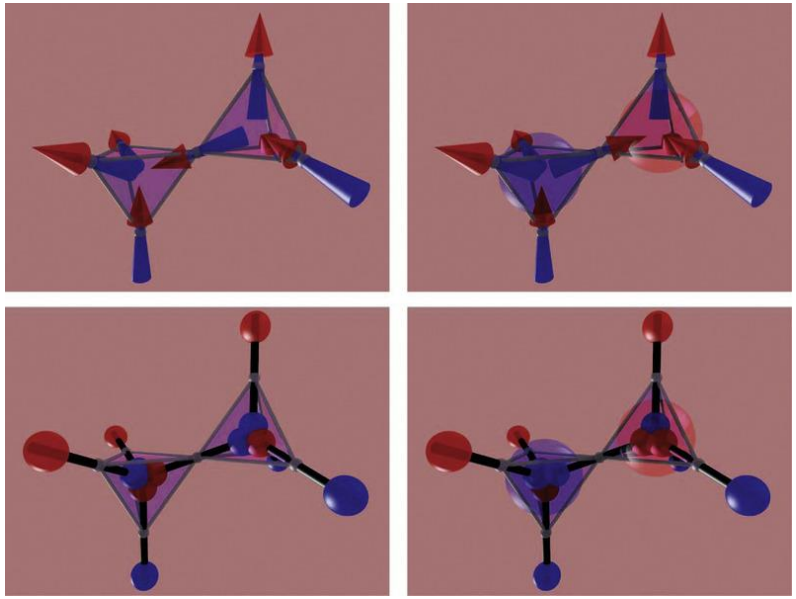
Eccitazioni di spin



Nanomagnetismo



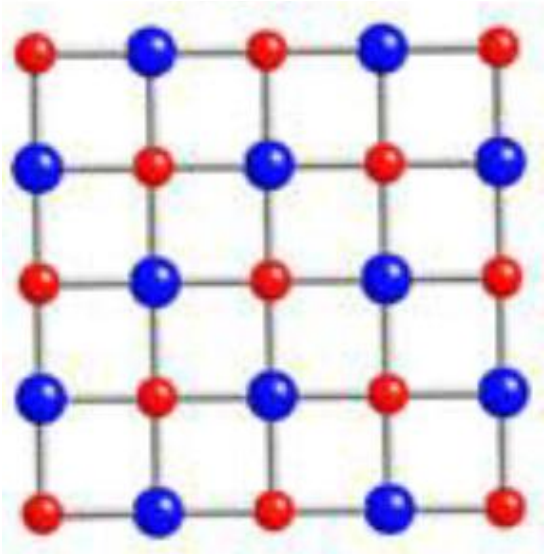
Spintronica



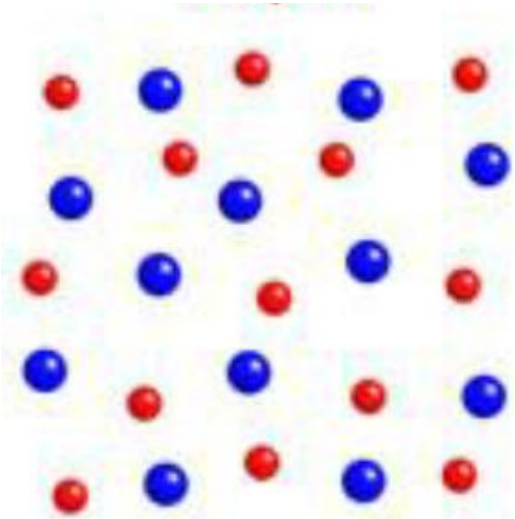
Nuove fasi magnetiche

Fasi di spin: cristalli, liquidi, vetri di spin

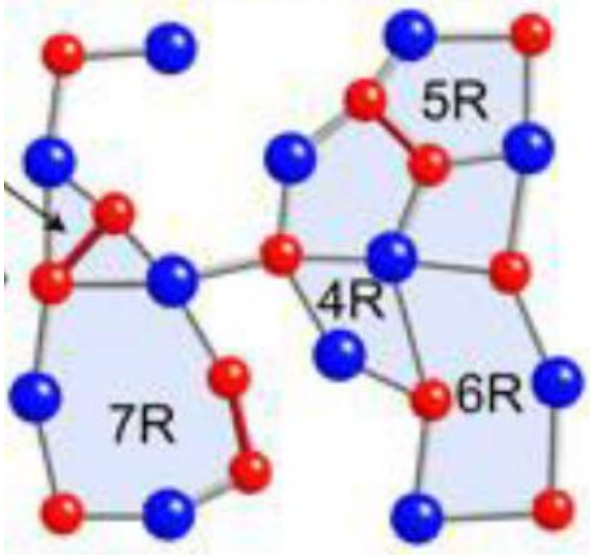
Solidi Cristallini

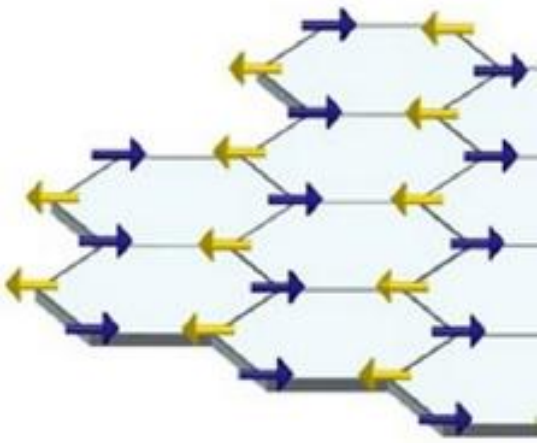


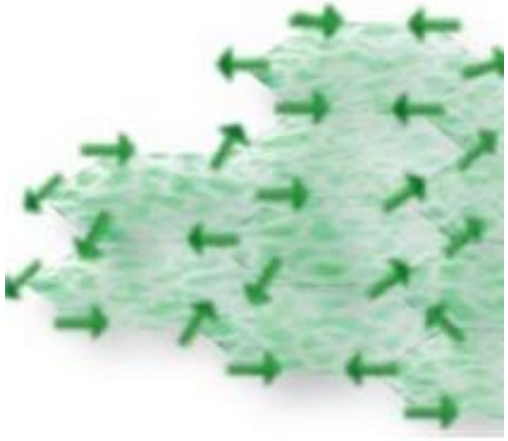
Liquidi

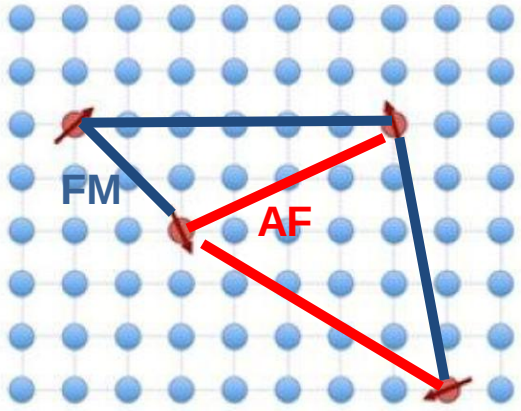


Solidi Amorfi - Vetri

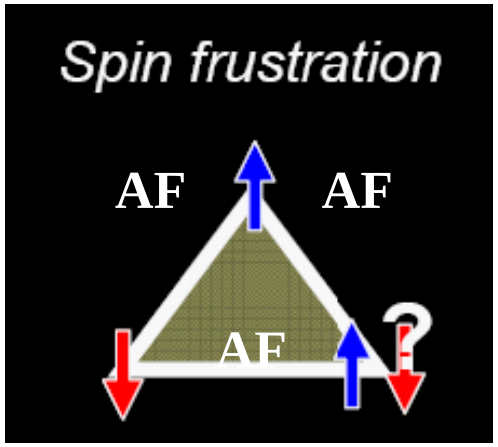


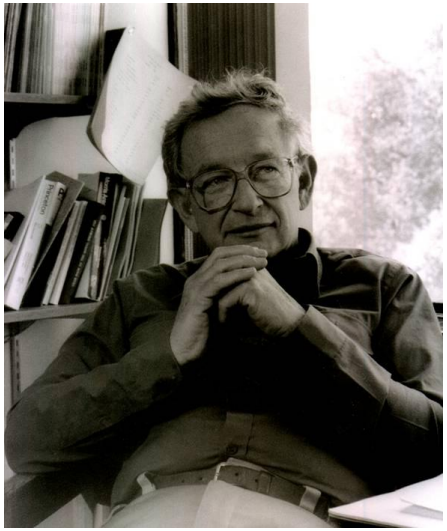






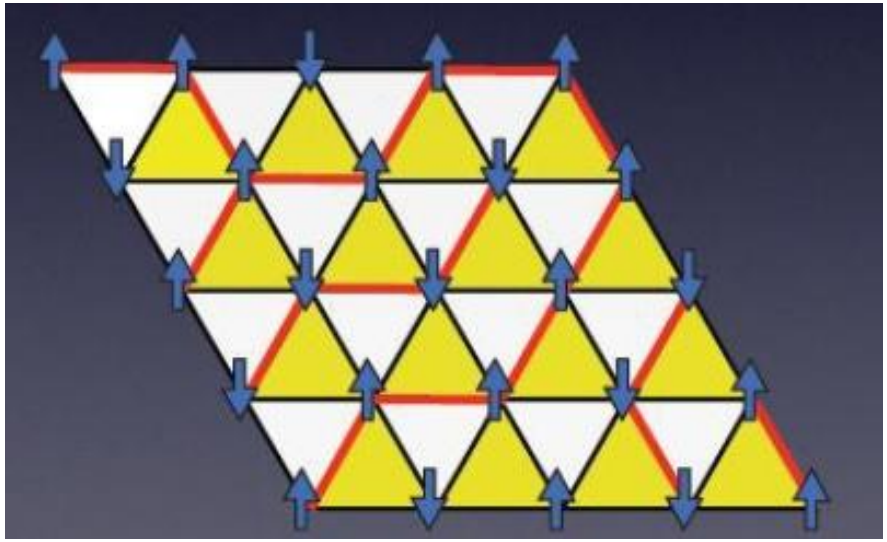
Liquido di spin con interazioni competitive: Magneti Frustrati

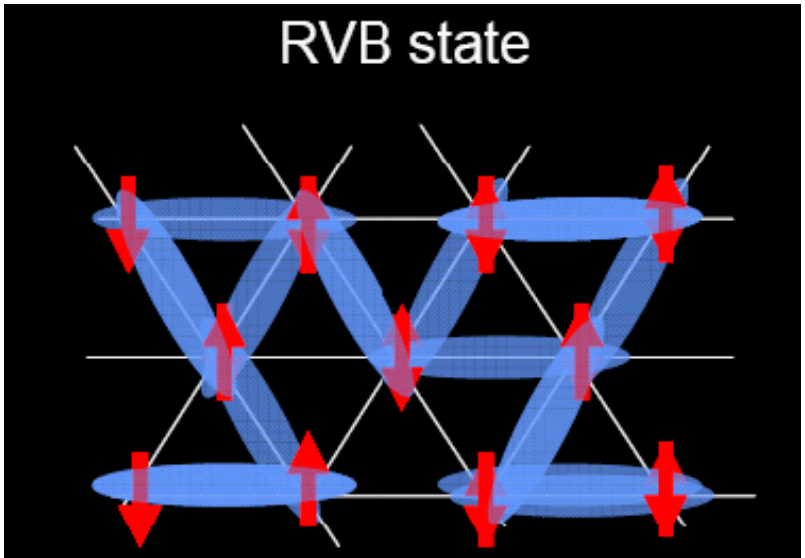




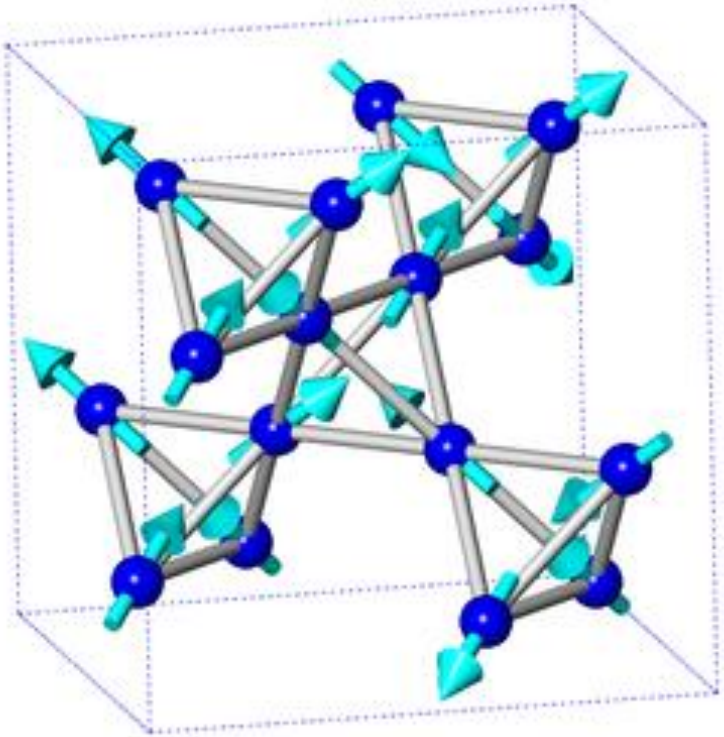
P.W.Anderson Mater.Res.Bull.8, 153 (1973)

$|RVB\rangle = \sum_{\text{all pairs}} |S=0\rangle$

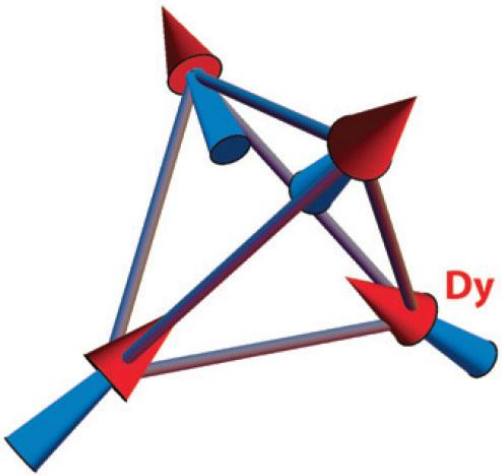


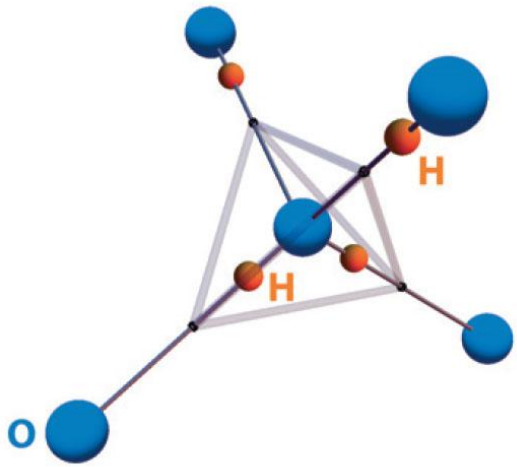


Ghiaccio di Spin



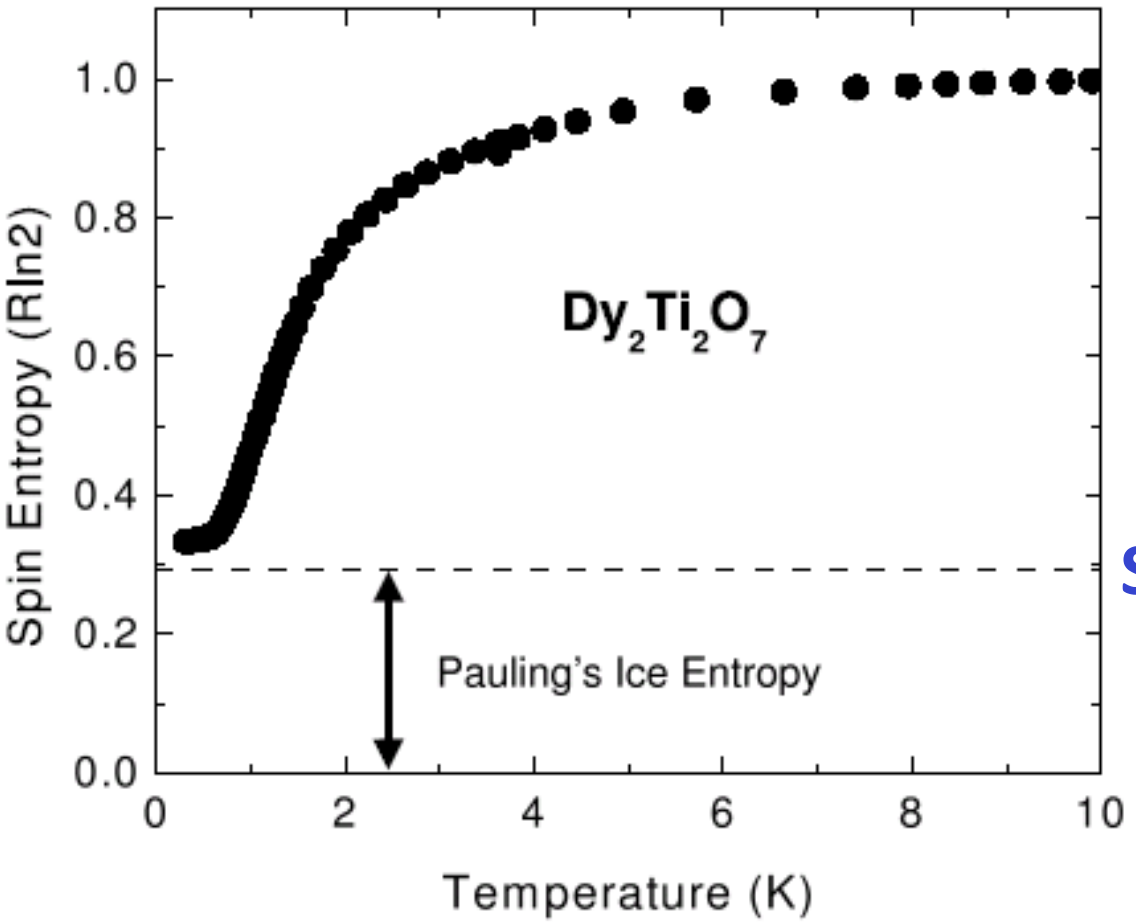
Ice rule:
2 in – 2 out

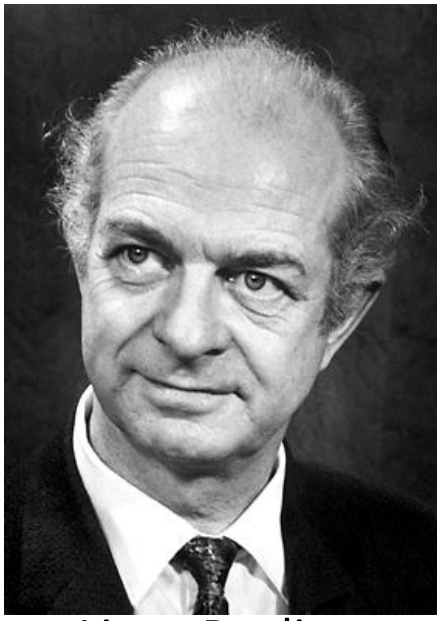




Entropia Residua del Ghiaccio di Spin

$W=(3/2)^{N/2}$ $S=k_B \ln W$





Linus Pauling

$S_0=(Nk_B/2)\ln(3/2)$

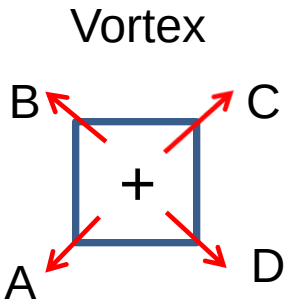
A.P.Ramirez *et al.*, Nature. **399**, 333 (1999)

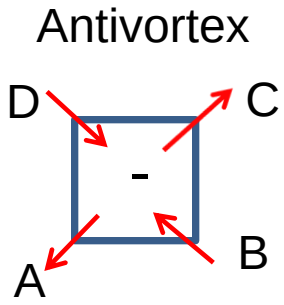
2D→Transizione BKT: KT Nobel 2016

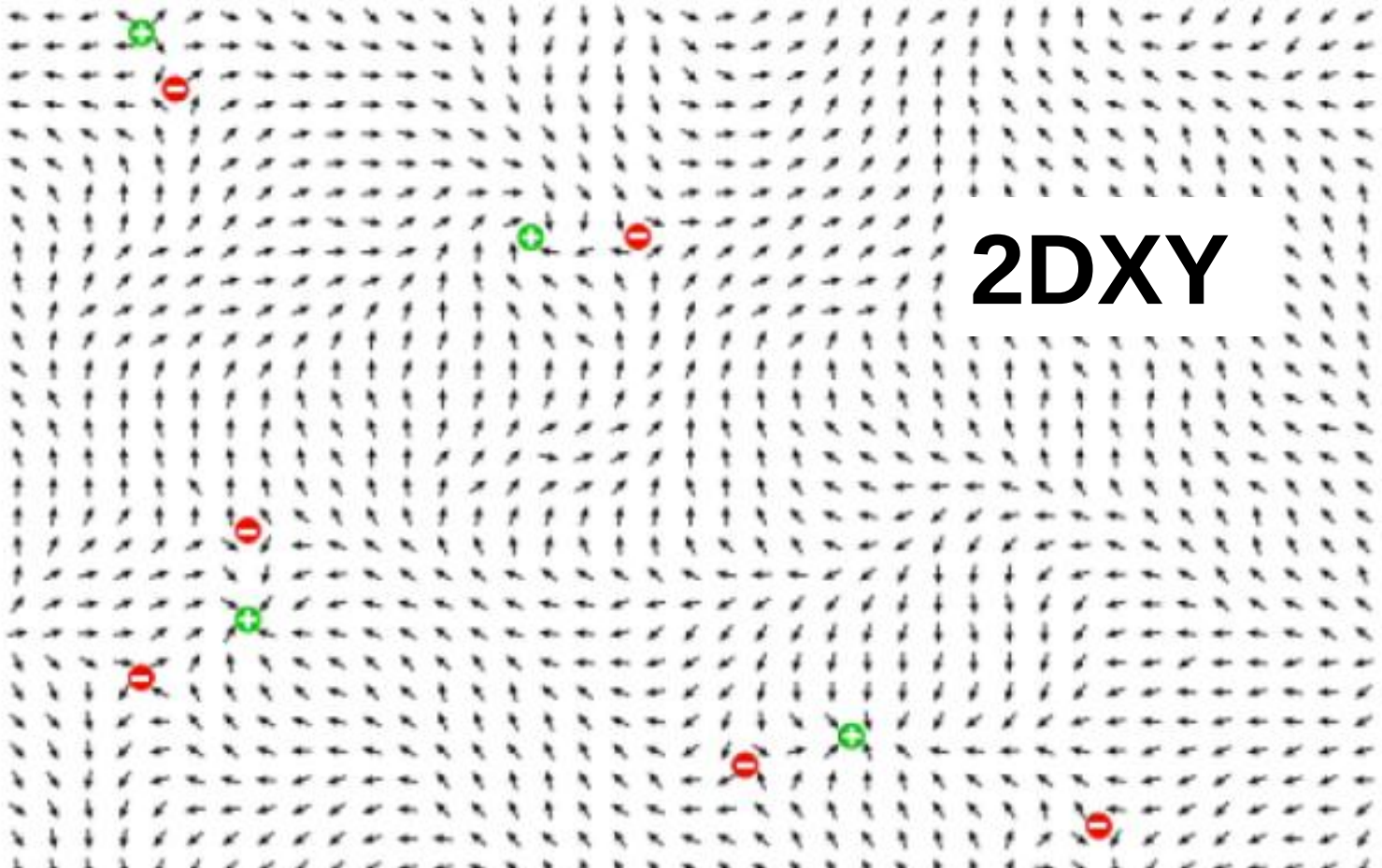
J.M.Kosterlitz

D.J.Thouless

V.L.Berezinskii

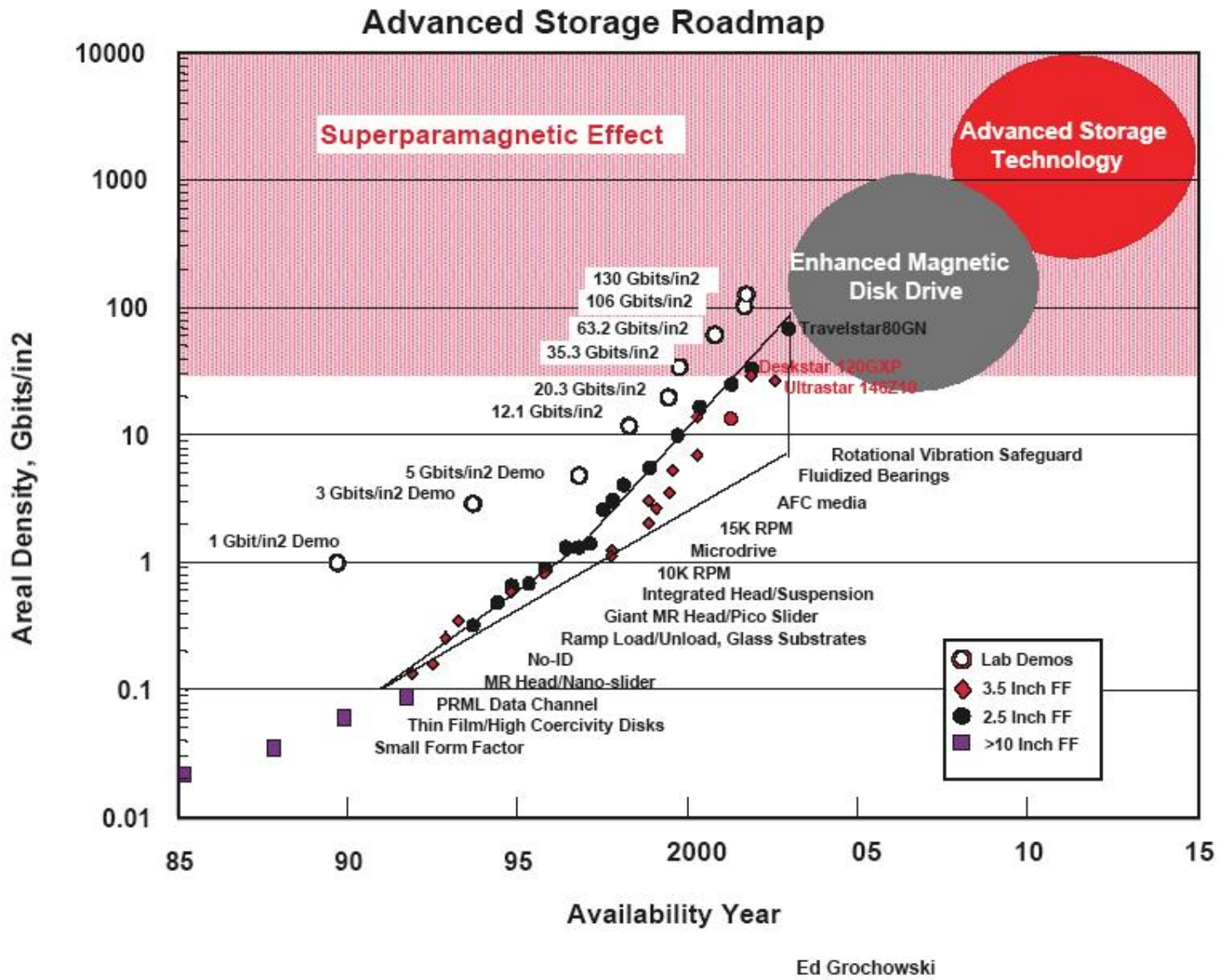






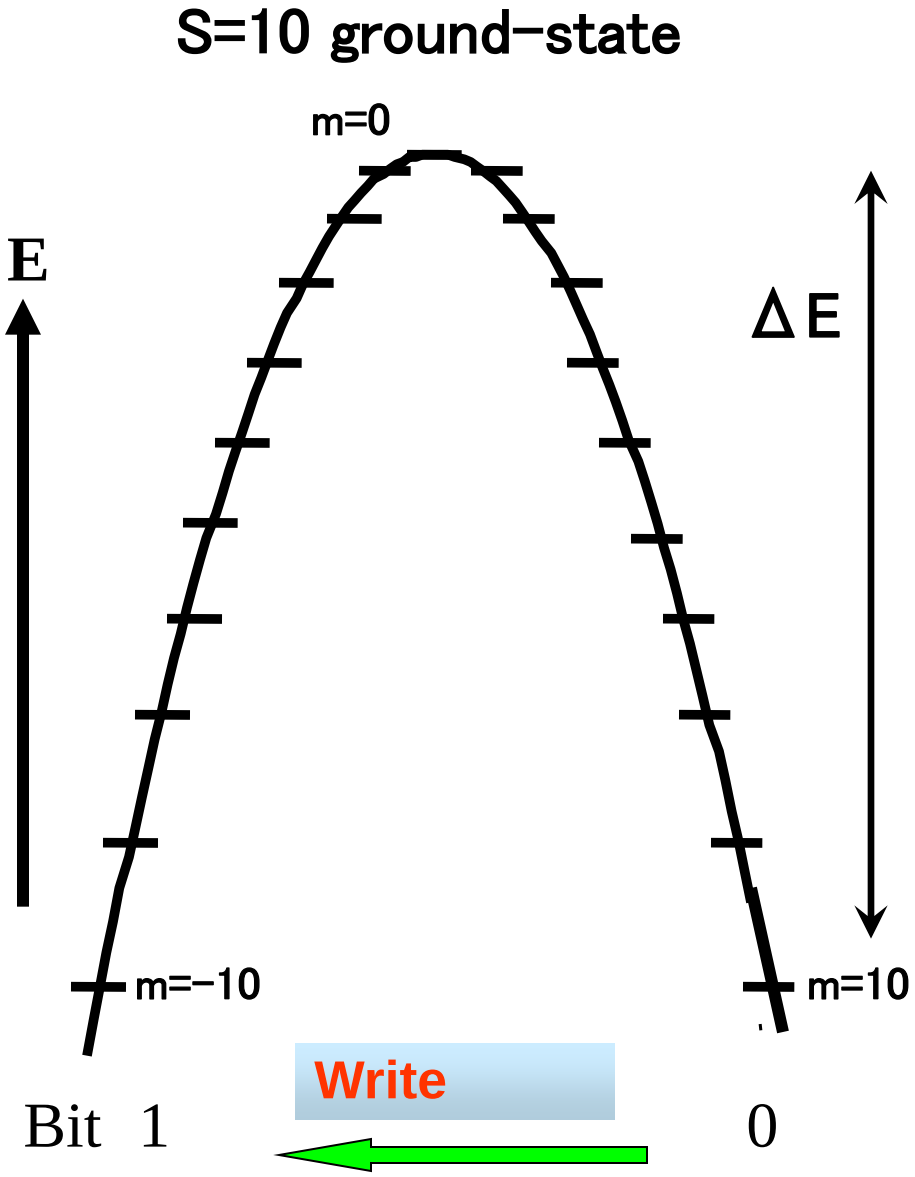
Applicazioni dei magneti 0D

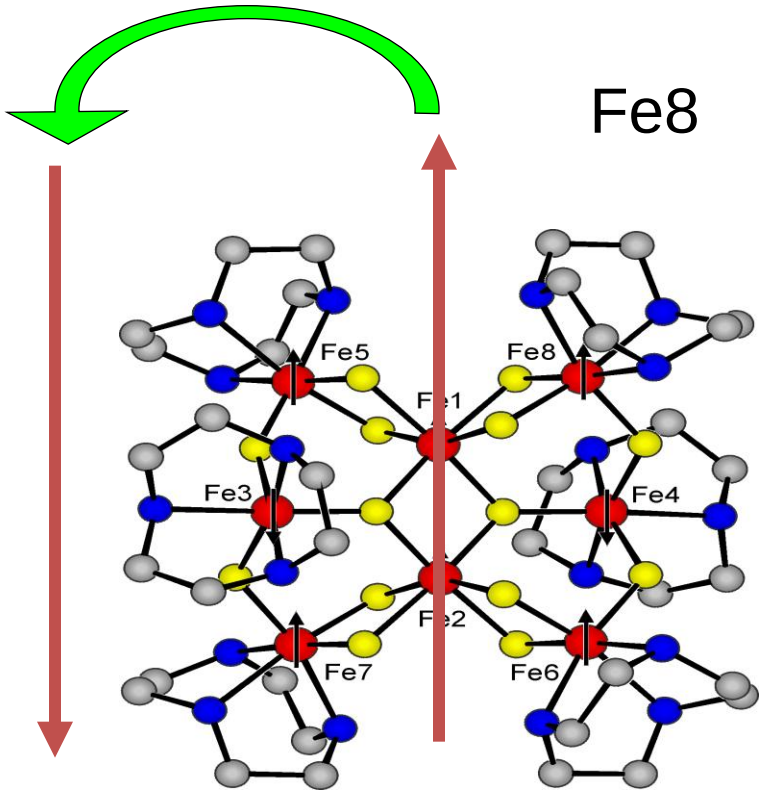
HITACHI
Inspire the Next



Ed Grochowski

Nanomagneti (0D) come bits

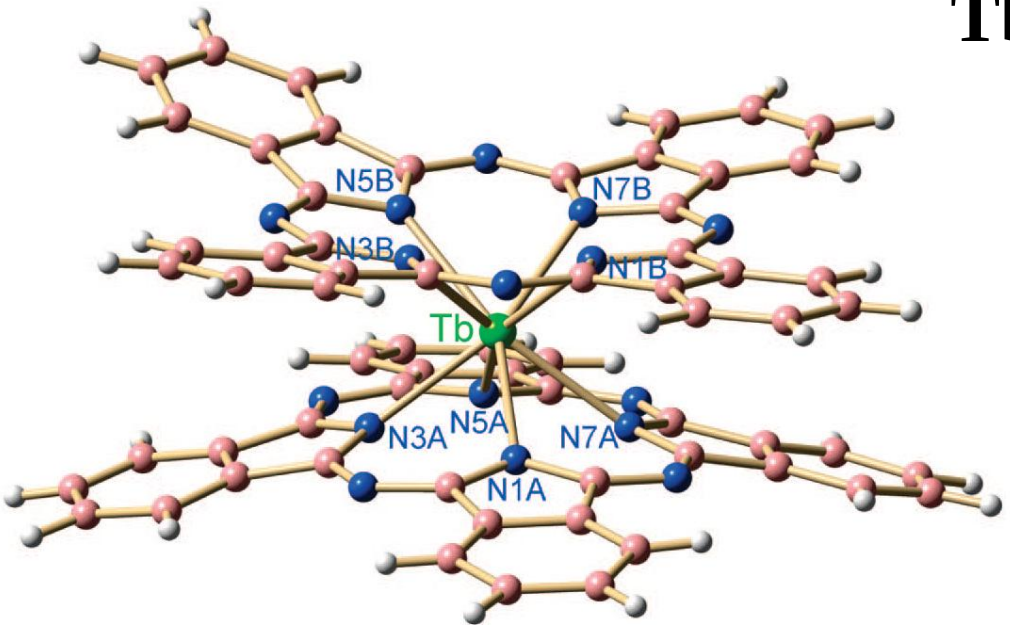




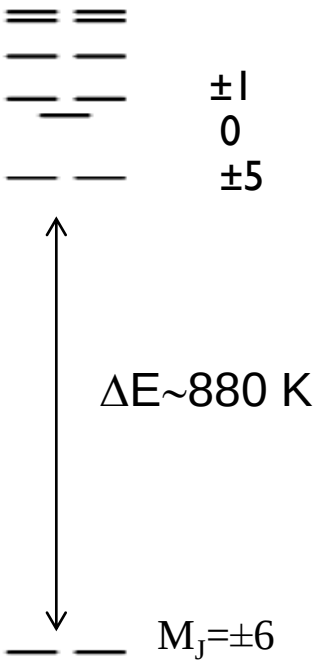
magnetization

$|\psi\rangle = a|m=10\rangle + b|m=-10\rangle$

Nanomagneti di Lantanidi

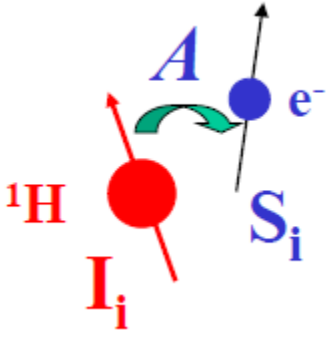


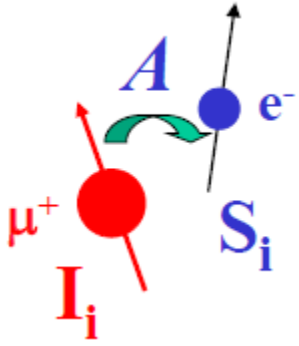
$TbPc_2$



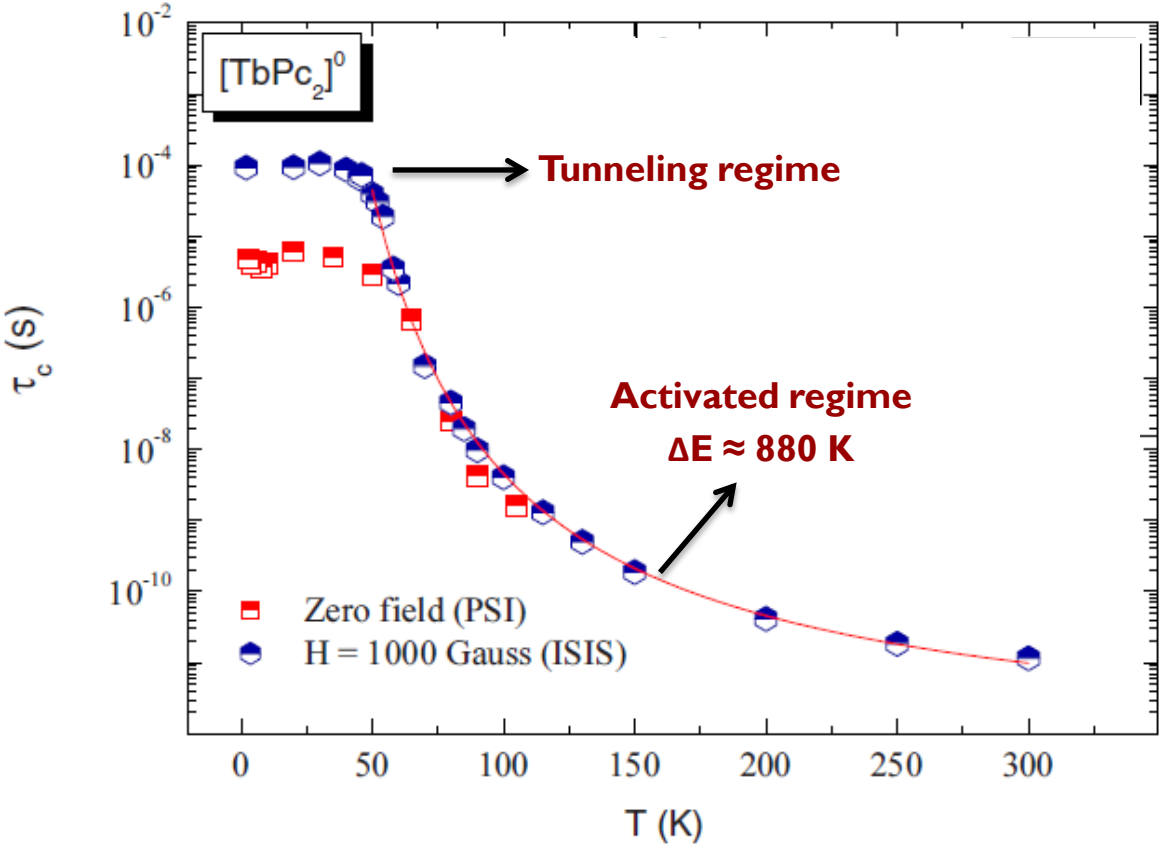
Fluttuazioni di spin sondate con nuclei o muoni

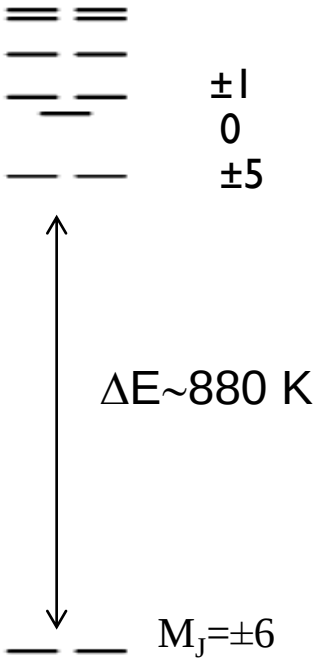
NMR





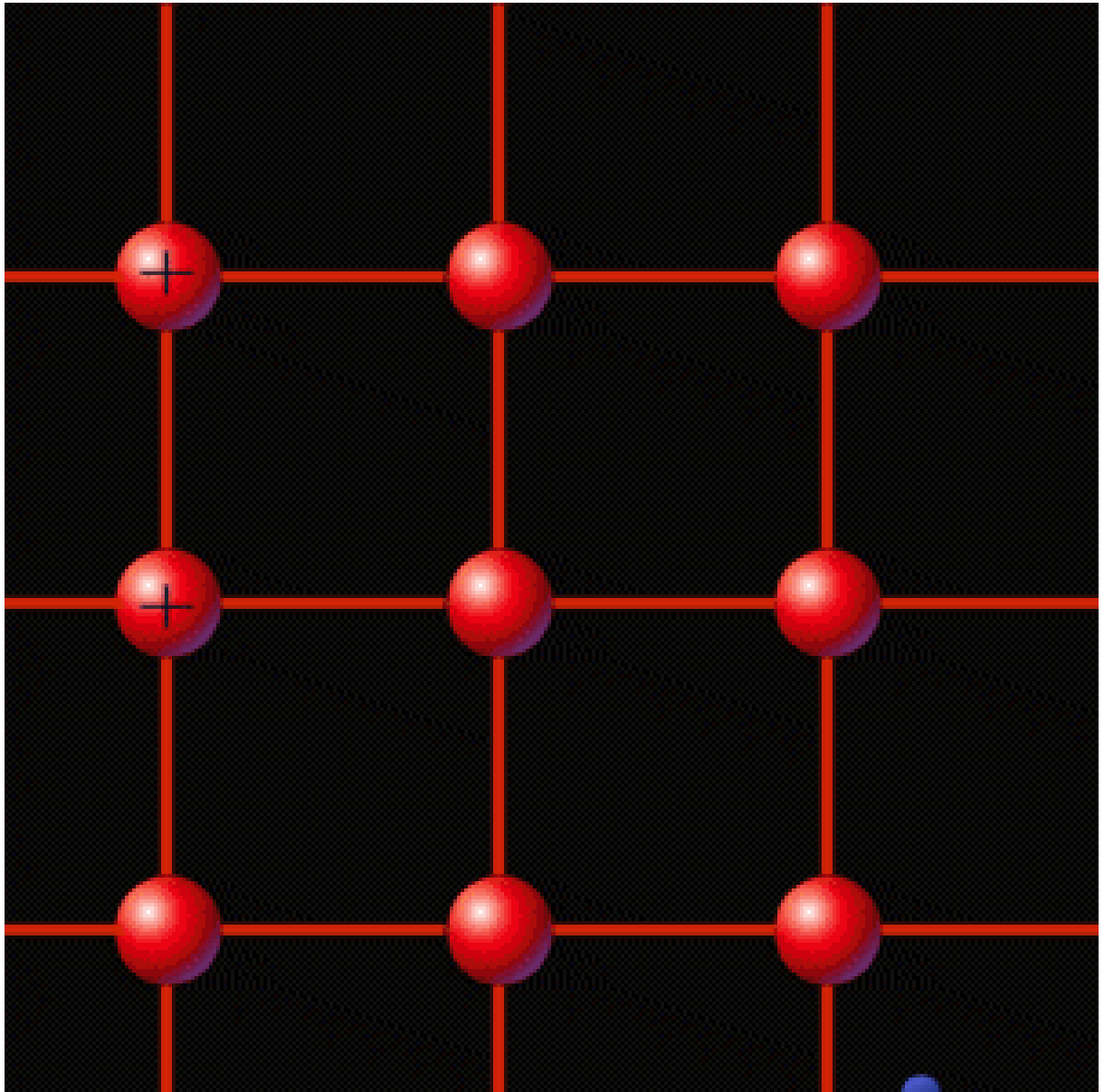
μSR



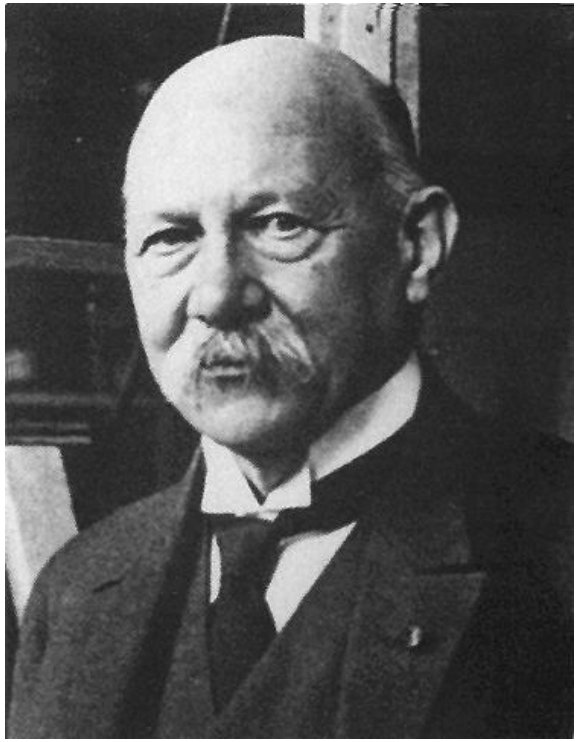


Gli elettroni si attraggono

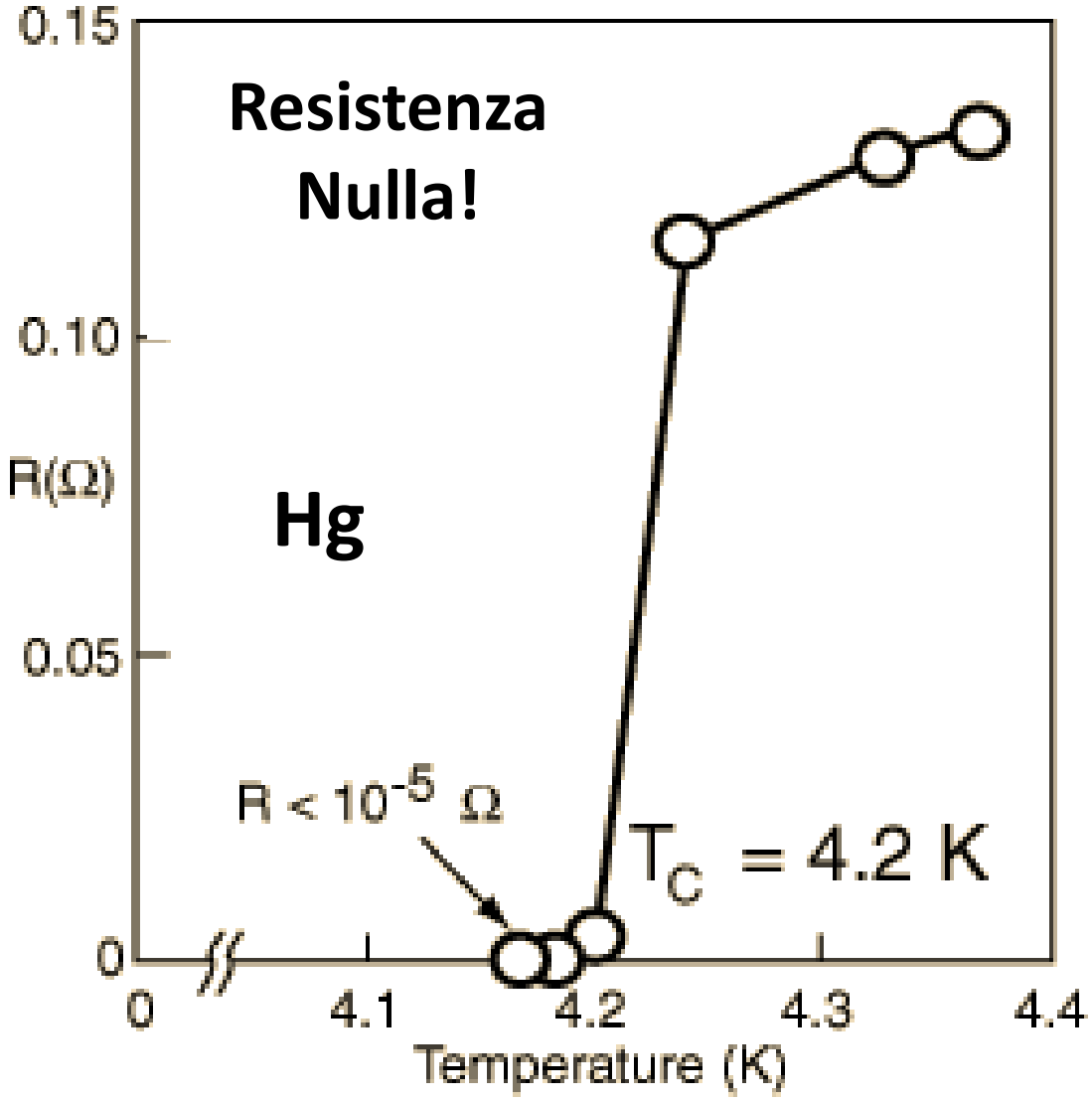
Formazione dinamica di coppie di elettroni (Coppie di Cooper)



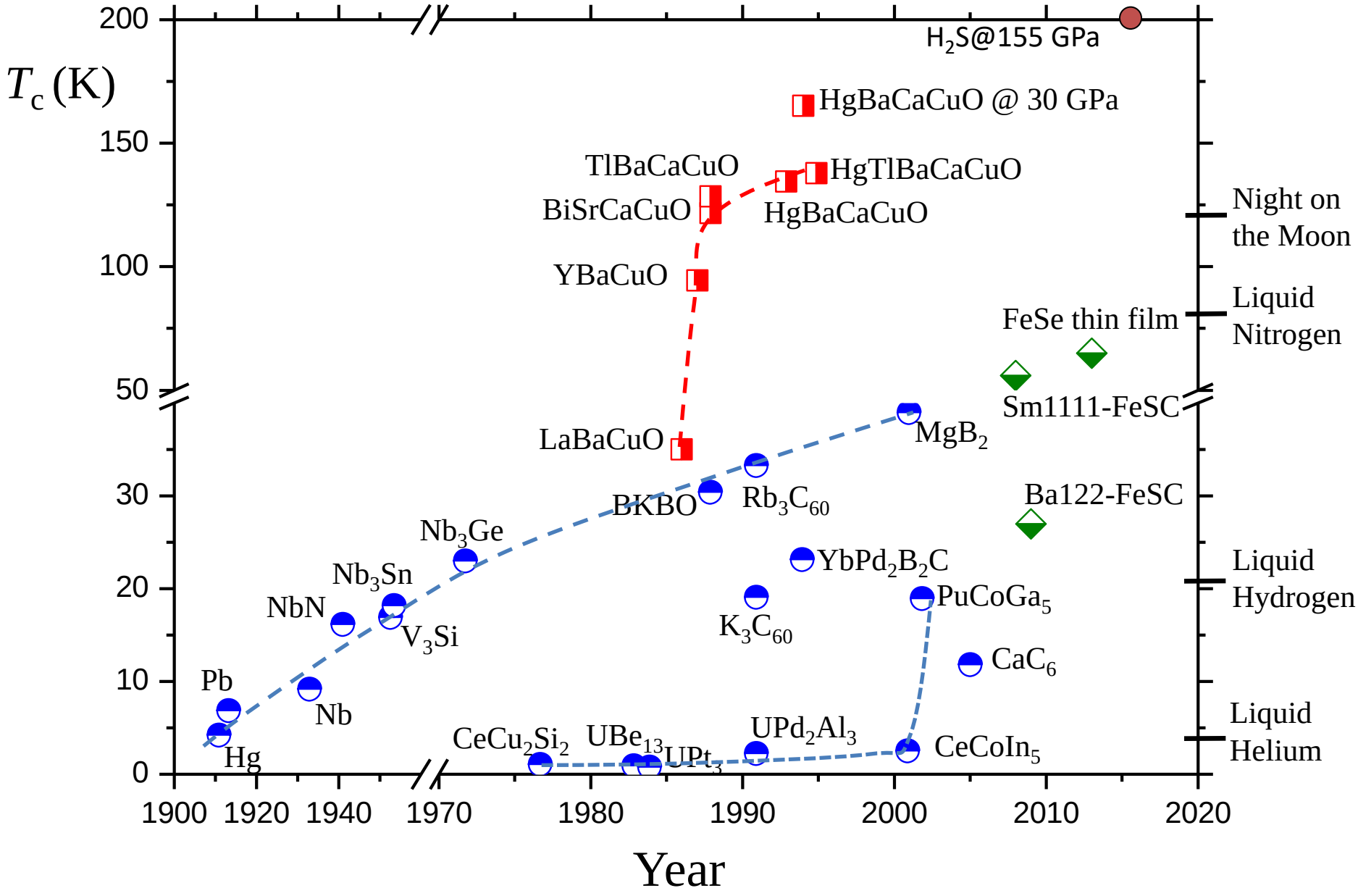
Superconduttività



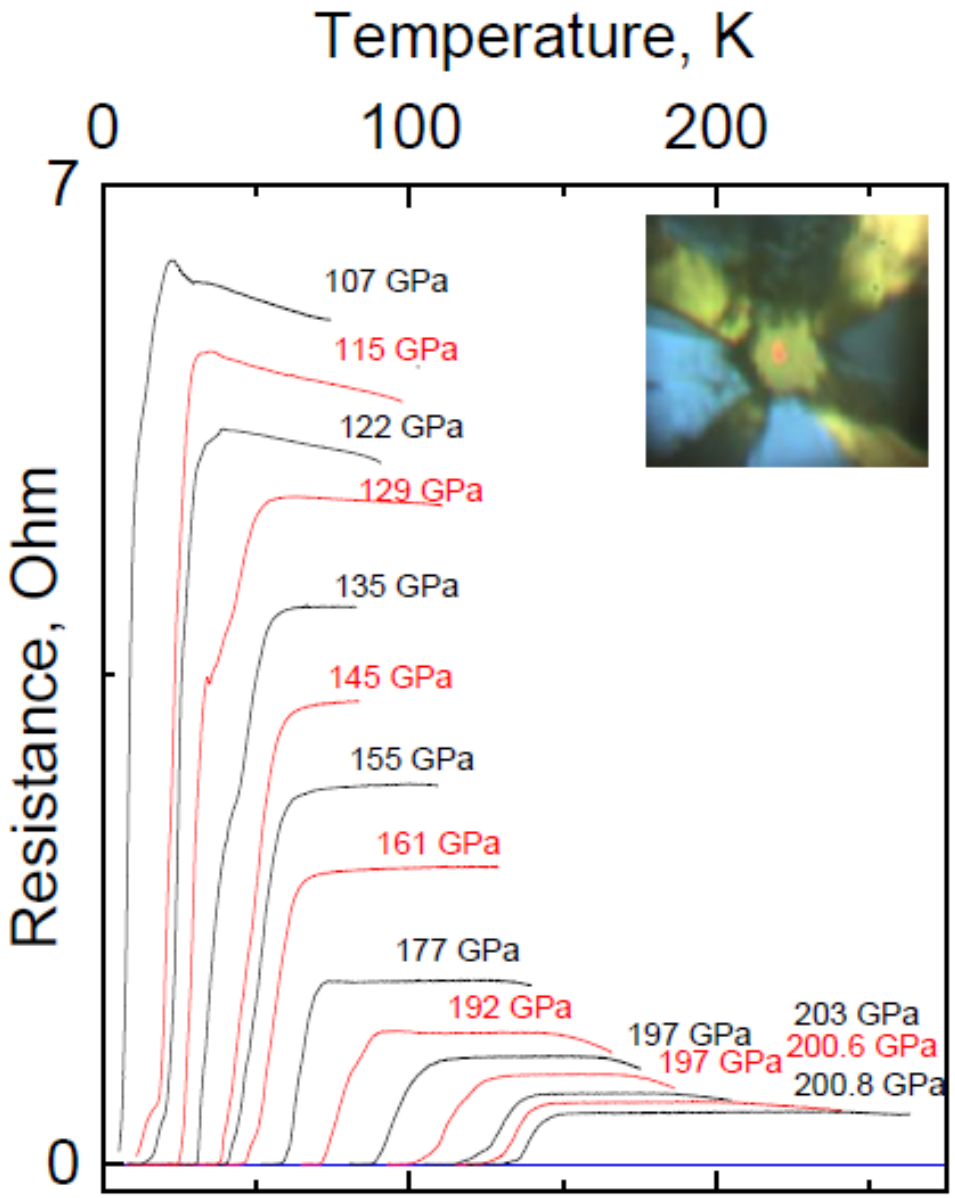
H.Kamerlingh Onnes

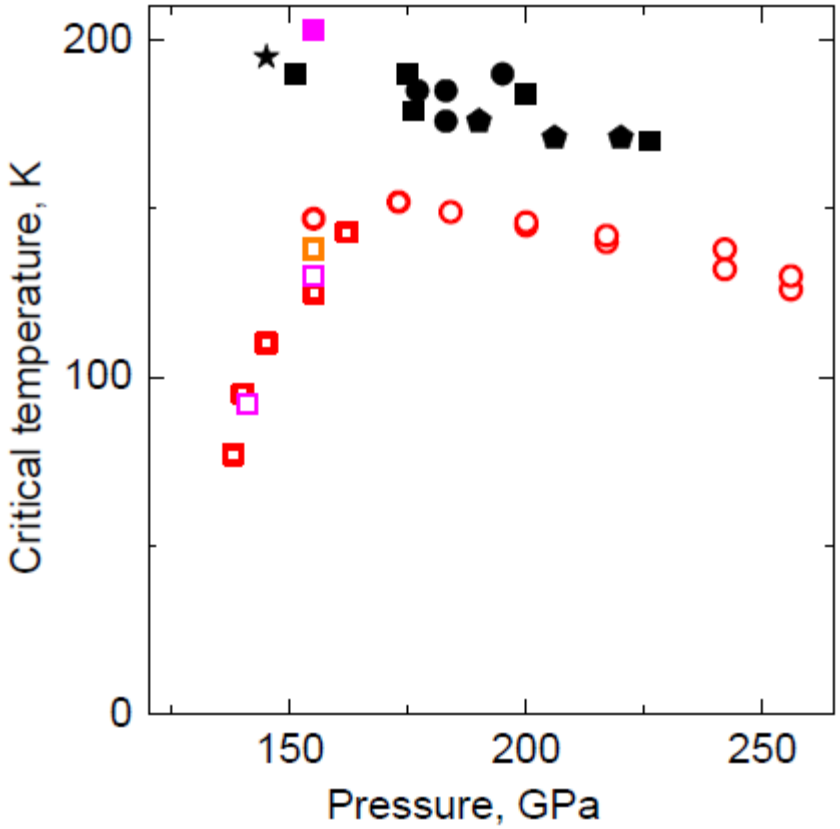


Superconduttività dal 1911 ad oggi



H_2S superconductivity





A.P.Drozdov et al.,Nature 525, 73 (2015)

Superconduttività

Superconduttori Convenzionali

$E_F >> \hbar\omega_D$

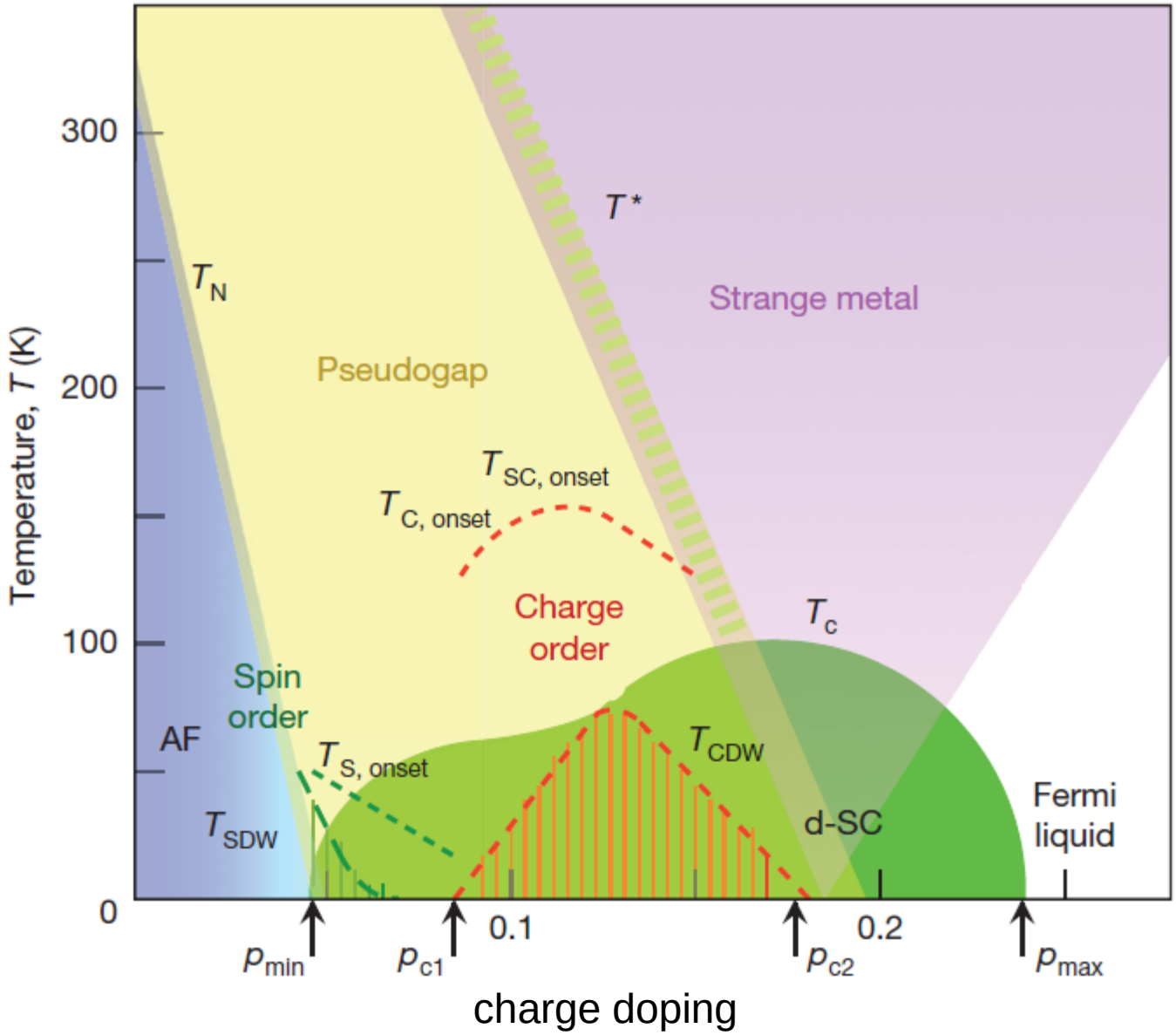
$$T_c = \frac{1.14\hbar\omega_D}{k_B} exp[-1/D(E_F)V]$$

Superconduttori a base di Cu e Fe

$U_C \sim E_F \gtrsim J \gtrsim \hbar\omega_D$

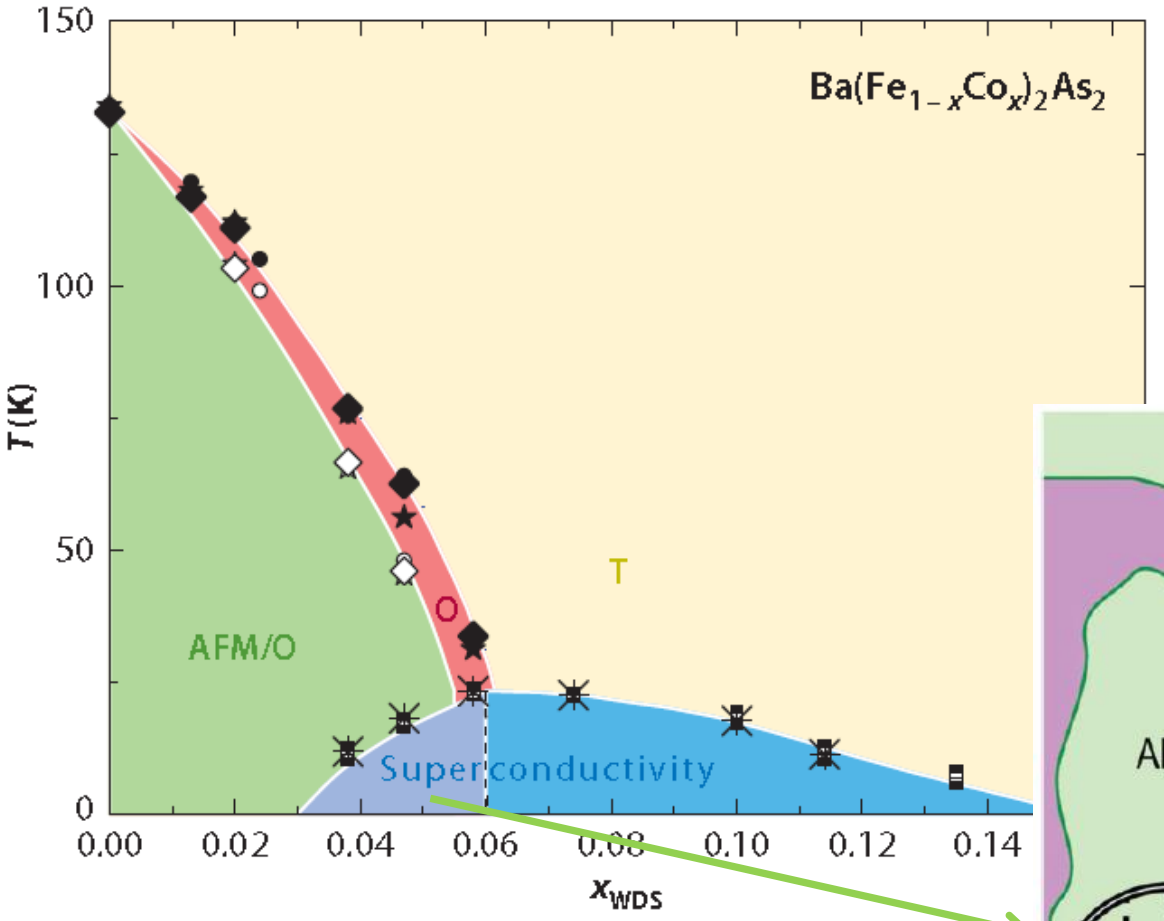
Superconduttori ad alta Tc a base di Cu

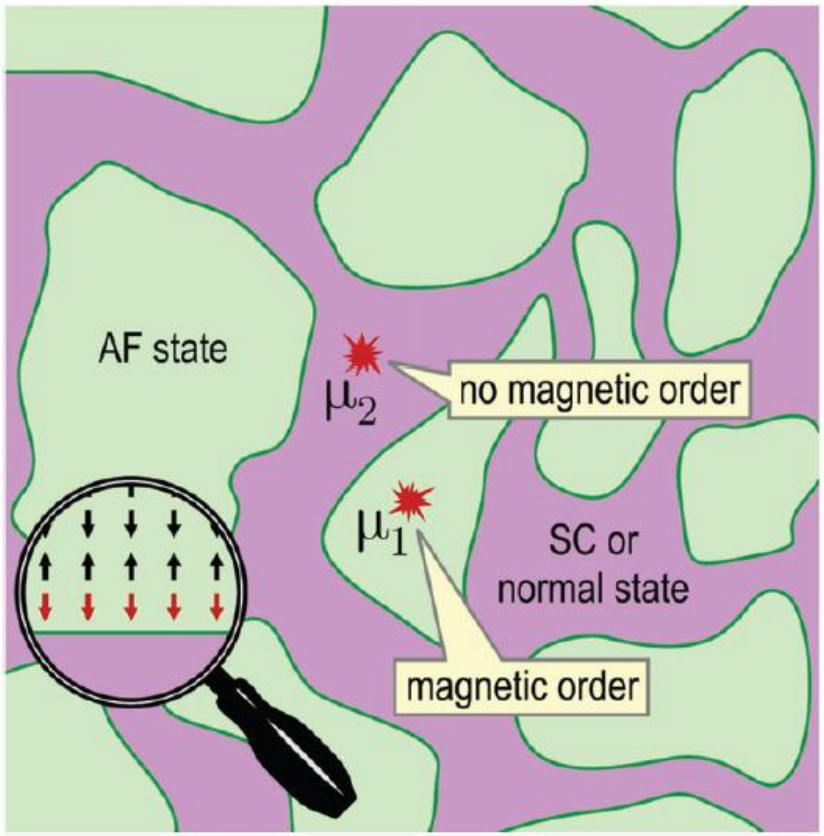
B.Keimer et al., Nature. **518**, 179 (2015)



Magnetismo e Superconduttività competono

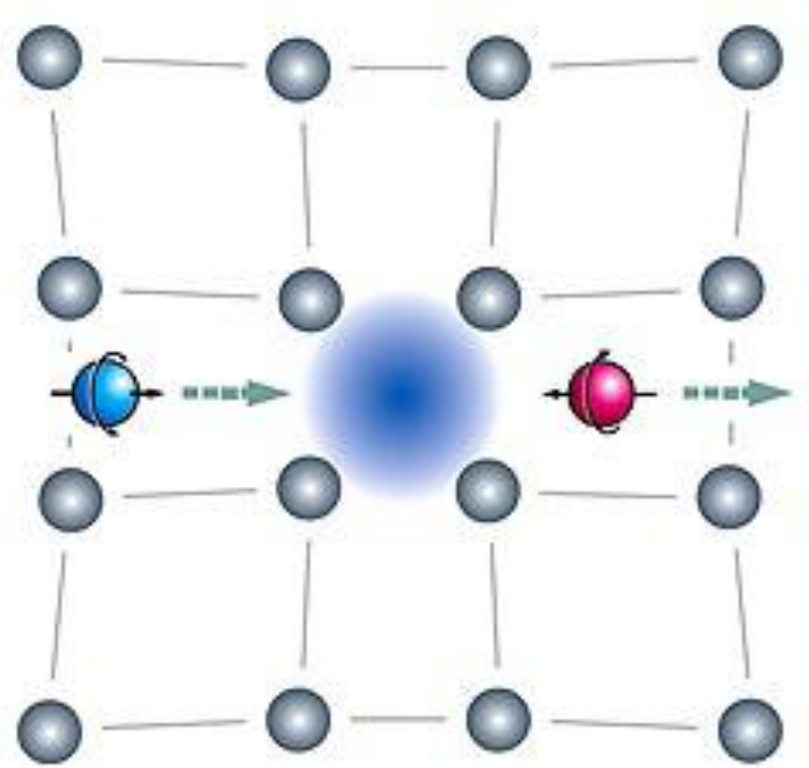
Magnetismo e Superconduttività Coesistono





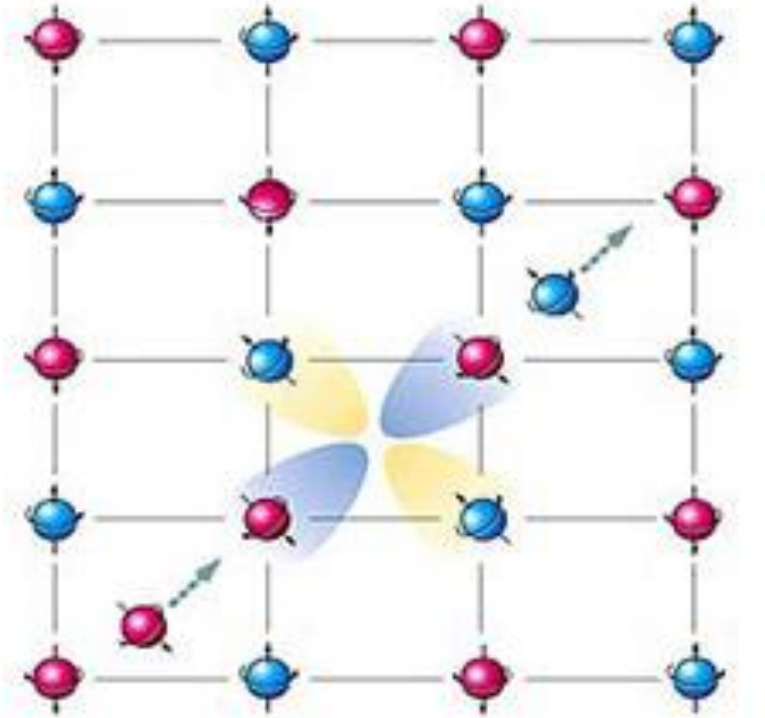
Superconduttività indotta dal magnetismo…

Accoppiamento
fononico
(vibrazioni reticolari)



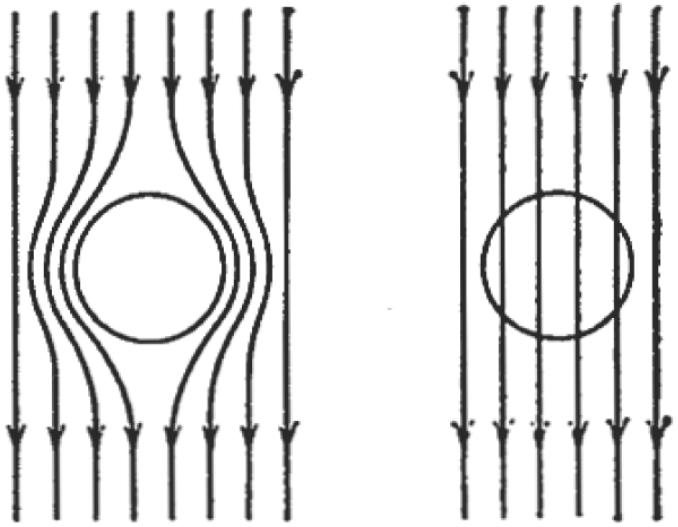
Superconduttori
convenzionali

Accoppiamento
magnetico
(eccitazioni di spin)



Superconduttori
a base di Cu e Fe

Effetto Meissner

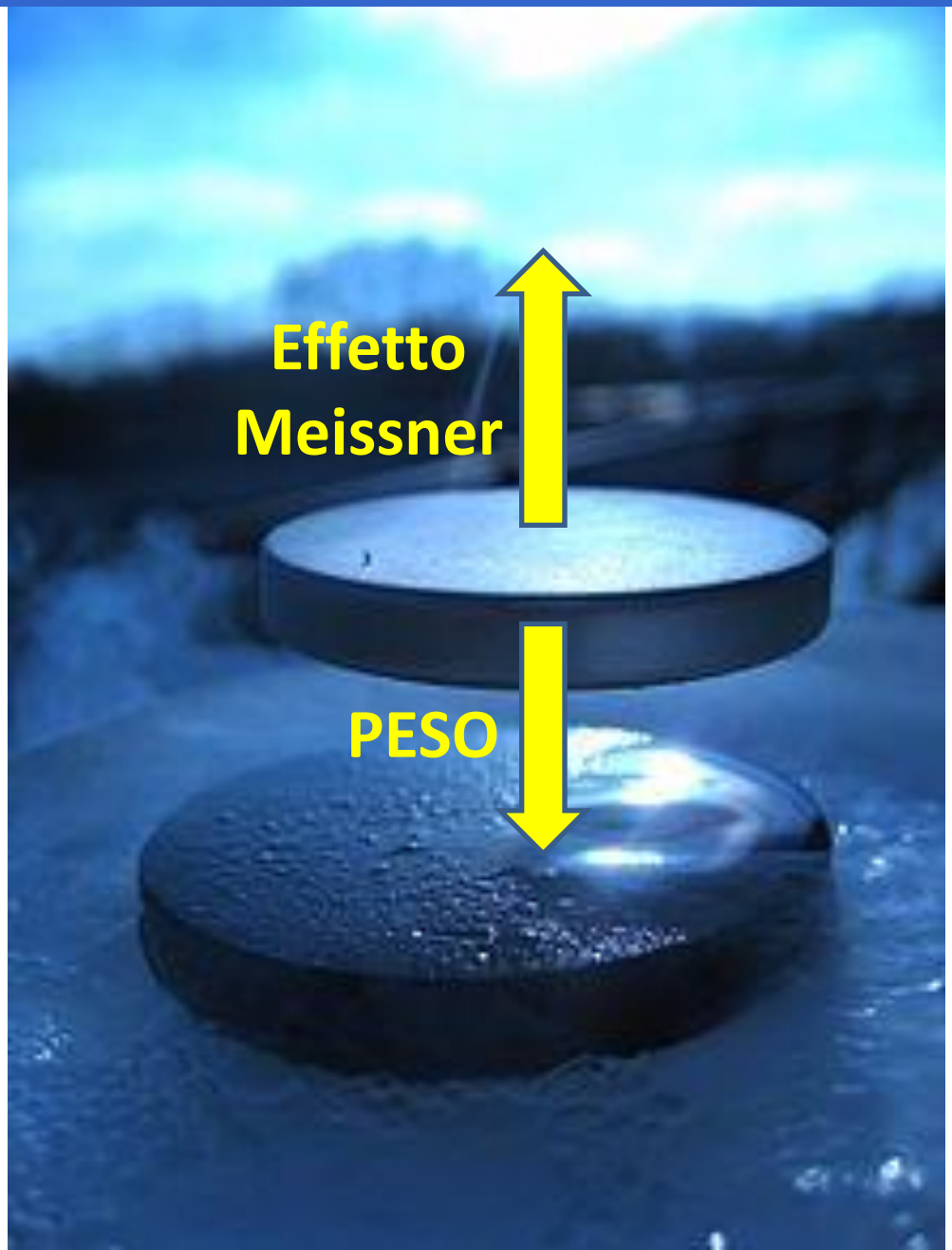


Campo Magnetico Espulso dal Superconduttore

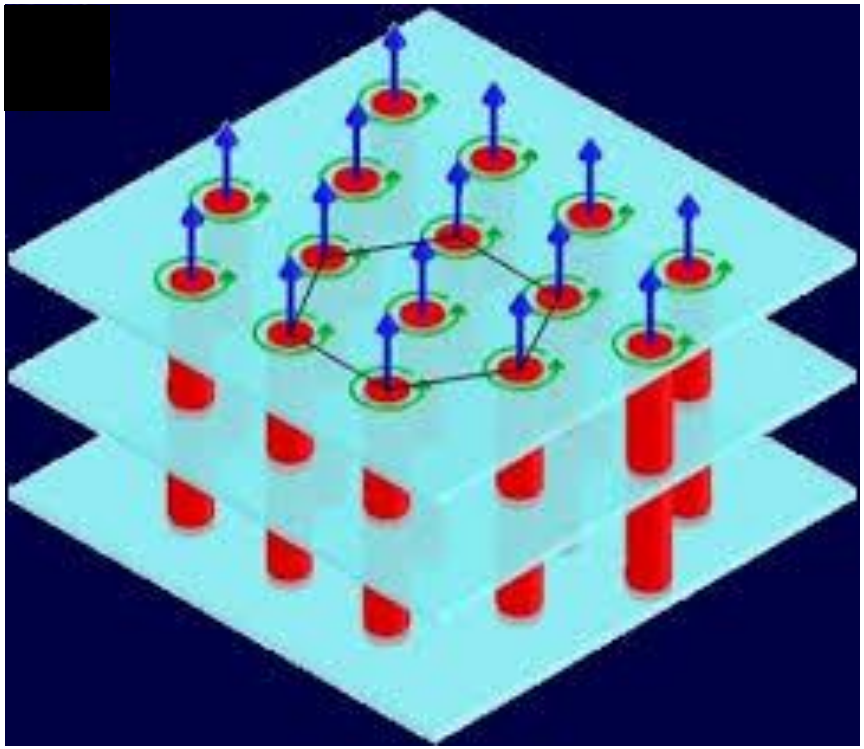
Superconduttore "espulso dal campo magnetico"

Walther Meissner

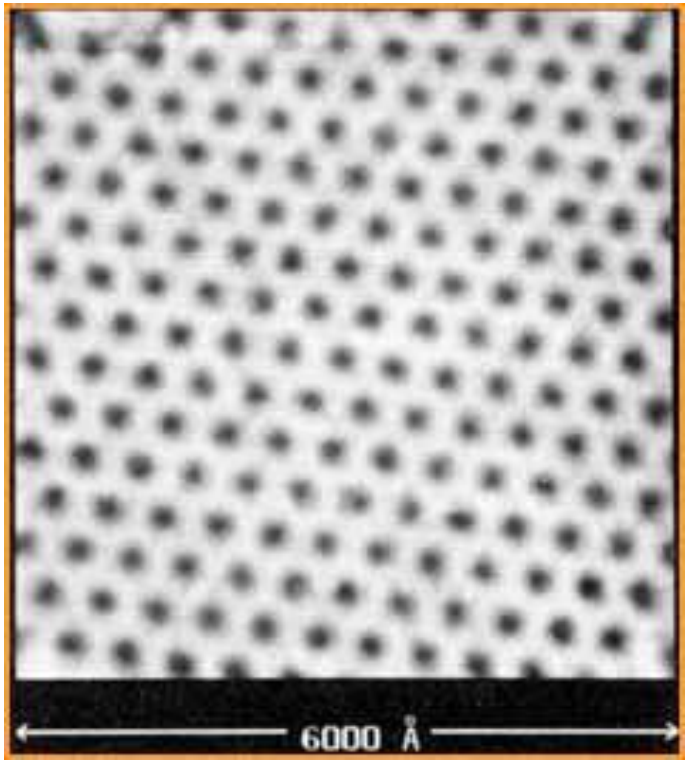
Levitazione Magnetica



Reticolo di linee di flusso: $H > H_{c1}$

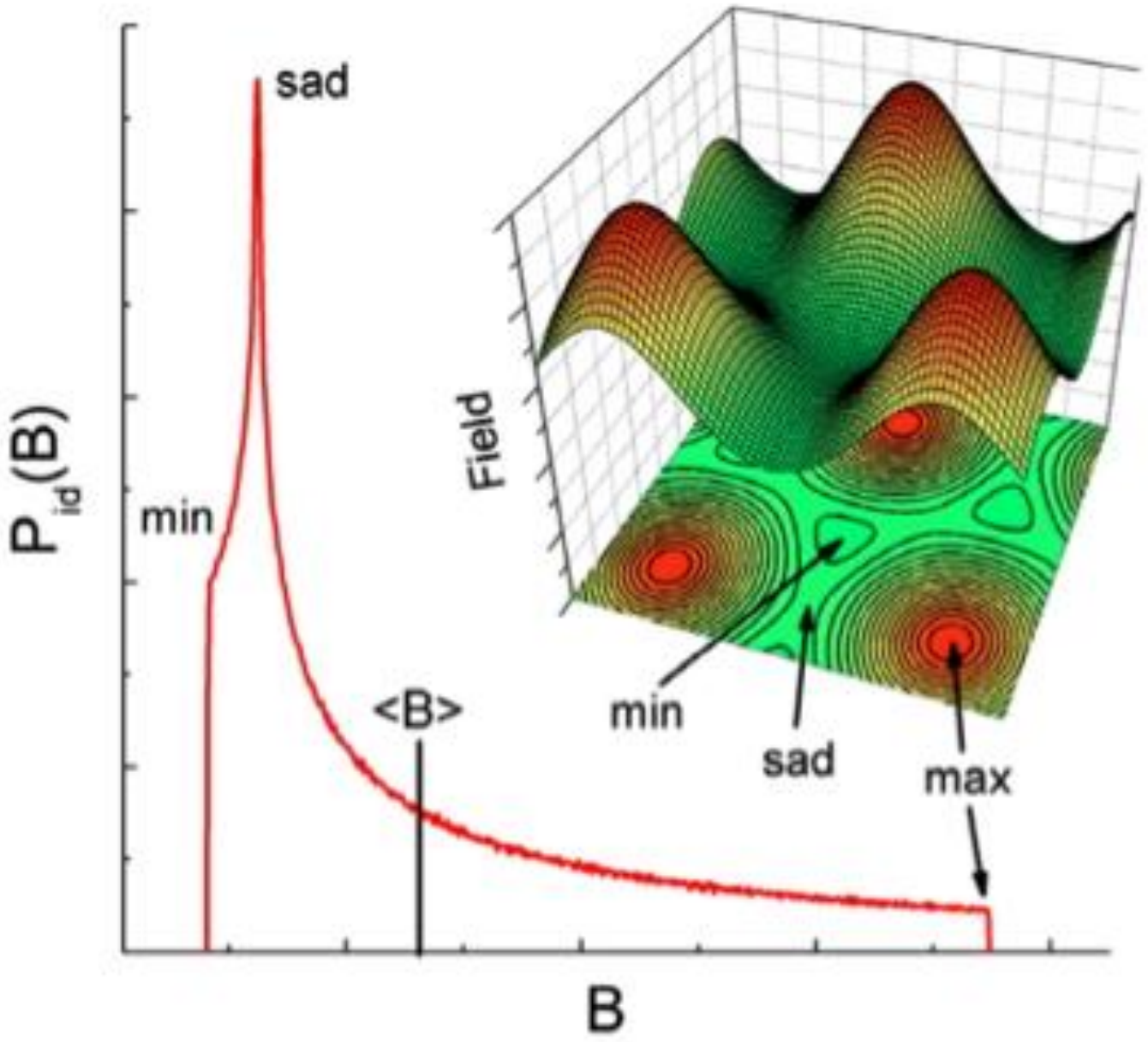


$NbSe_2$ (STM)

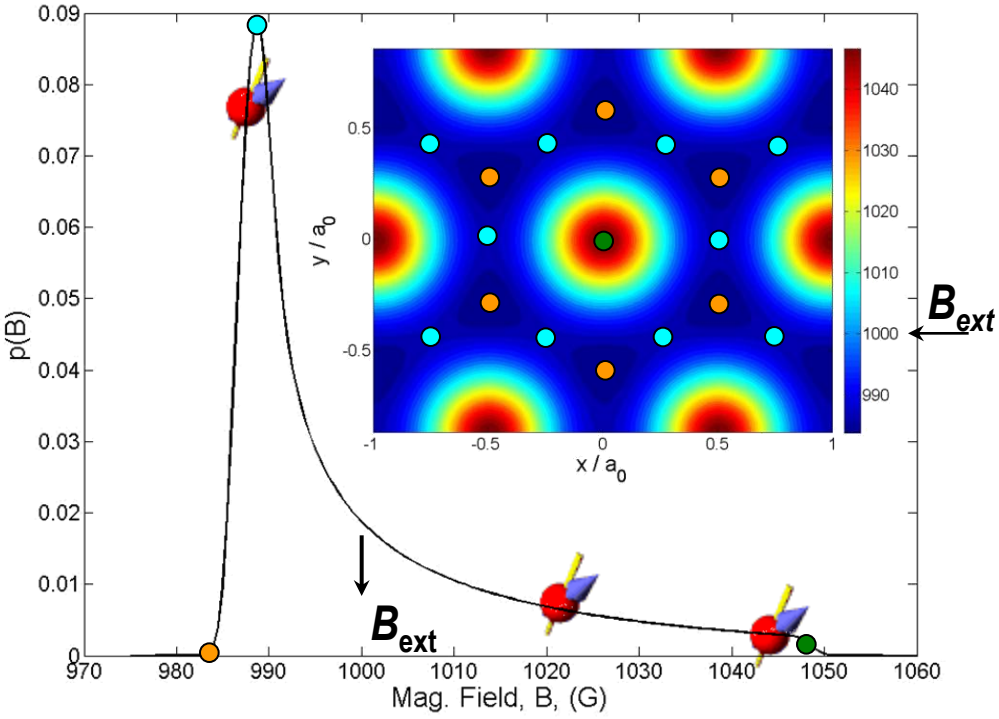


H.F.Hess *et al.*, Phys. Rev. Lett. **62**, 214 (1989)

Reticolo di linee di flusso



Distribuzione di campi sondata con la μSR



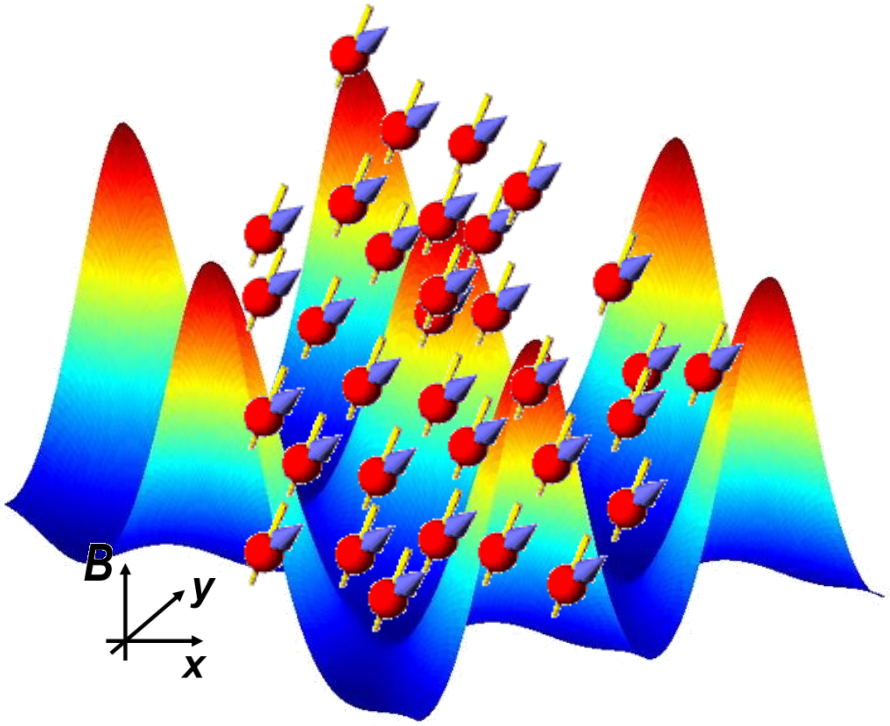


Diagramma di fase dell'Acqua

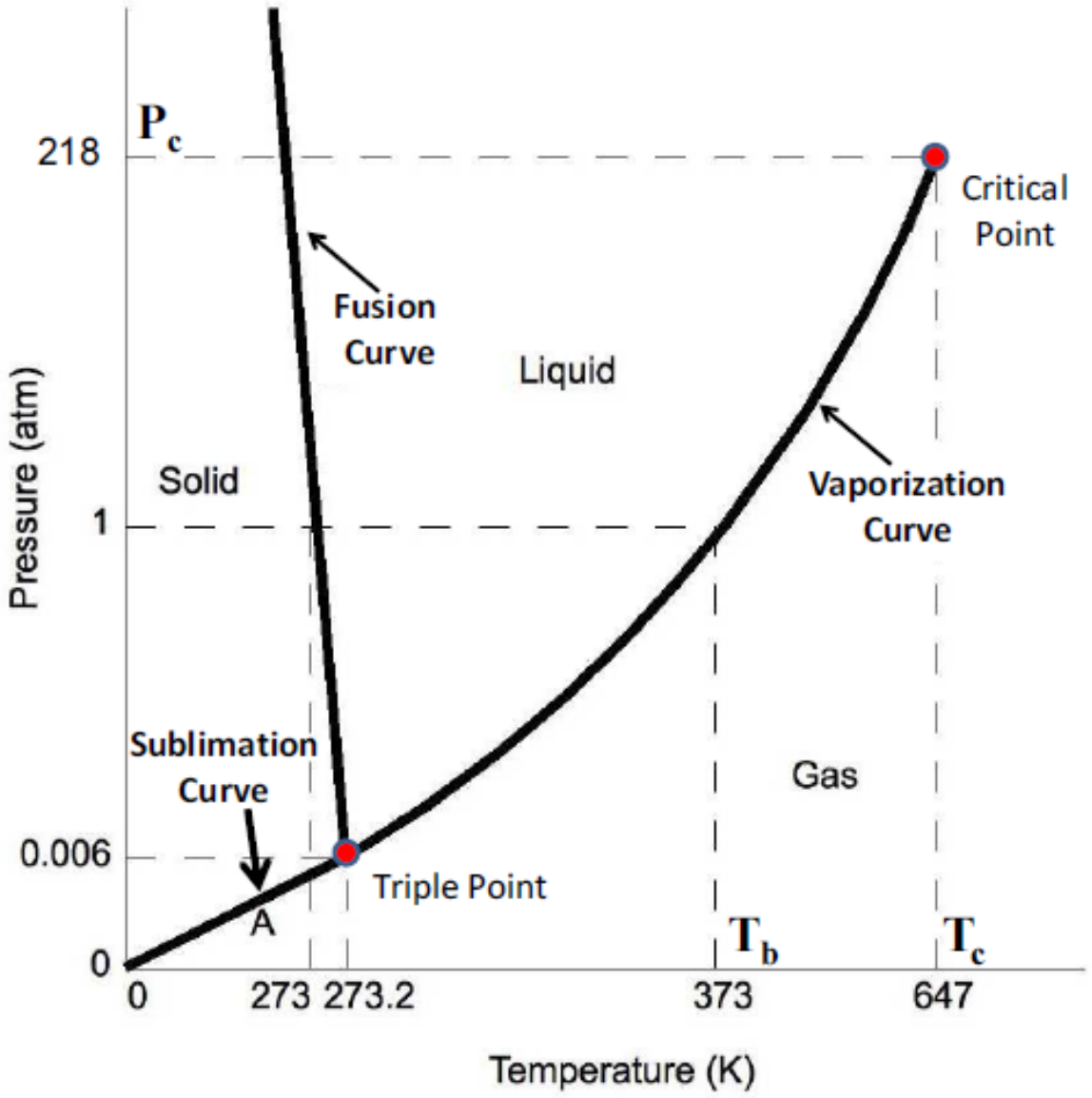
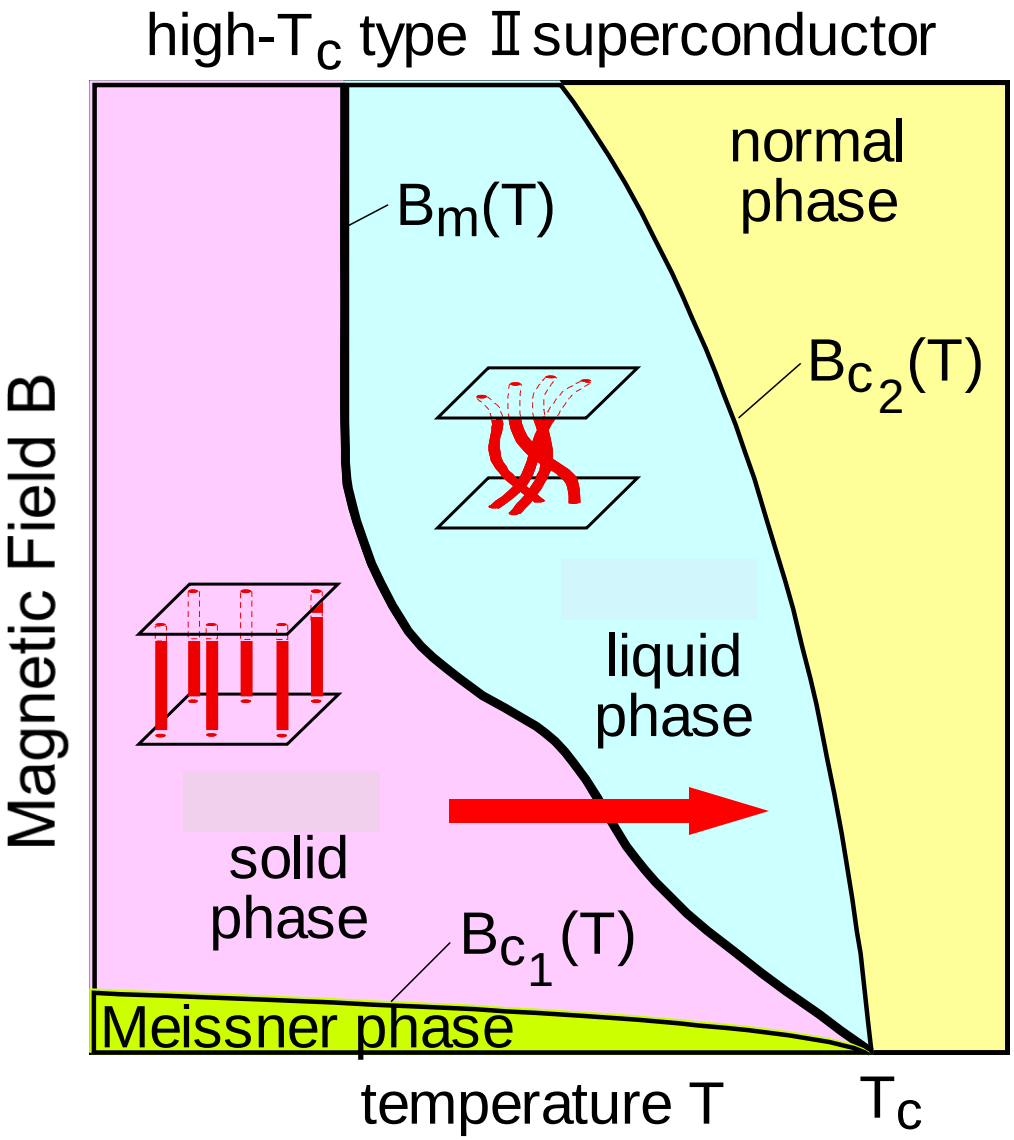
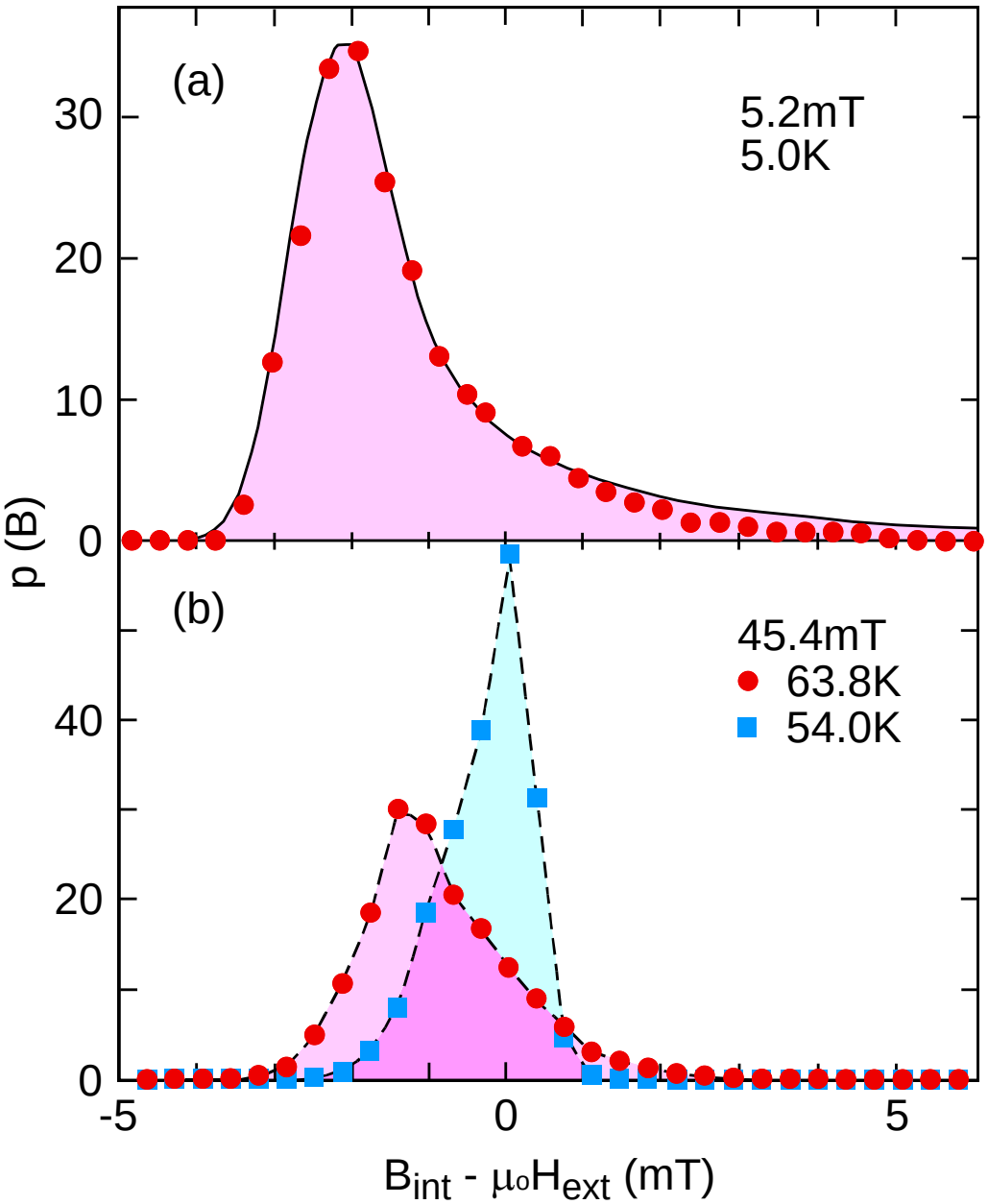


Diagramma di fase di un Superconduttore



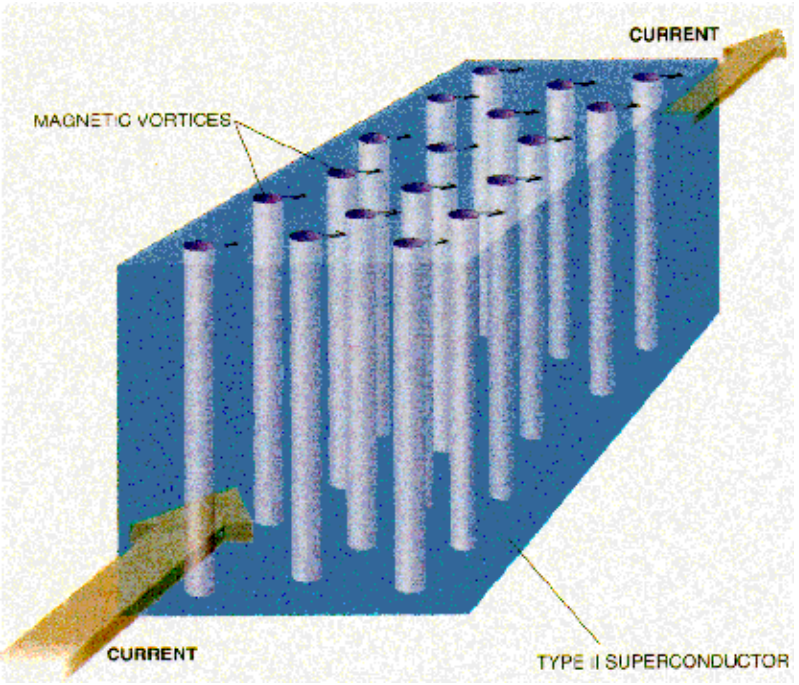
Fusione del reticolo di linee di flusso

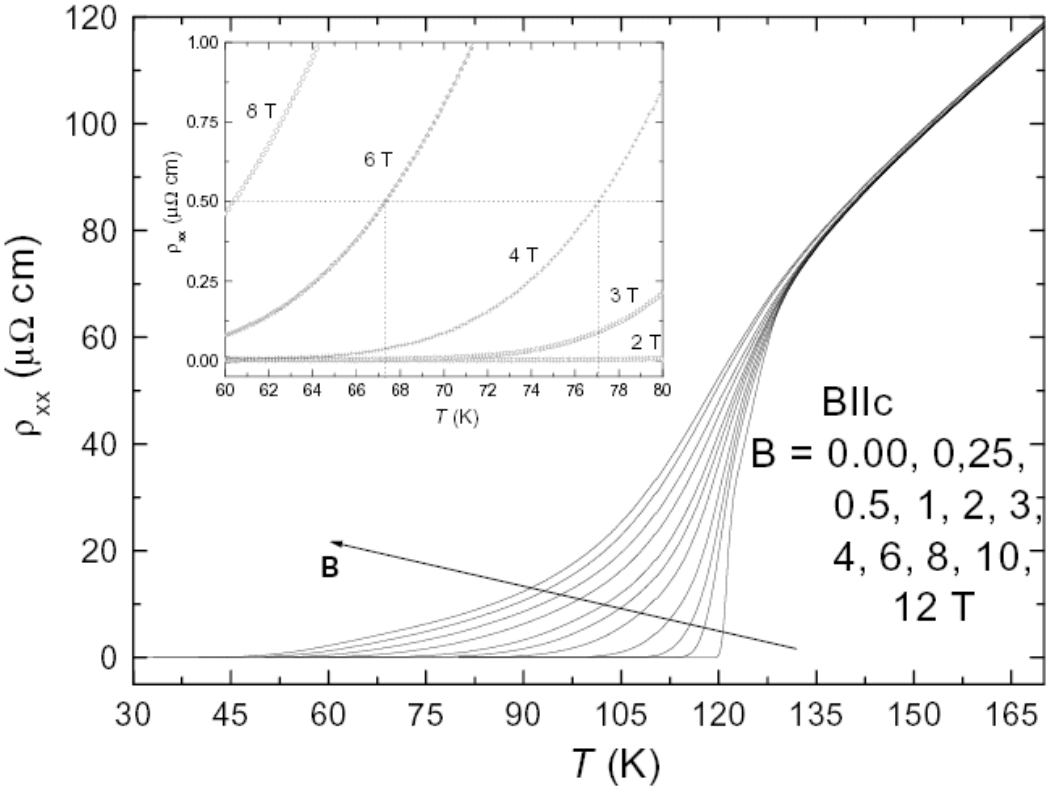


Lee *et al.*, Phys. Rev. Lett. **71**, 3862 (1993)

$Bi_{2.15}Sr_{1.85}CaCu_2O_{8+\delta}$

Moto dei flussoni: resistività non nulla

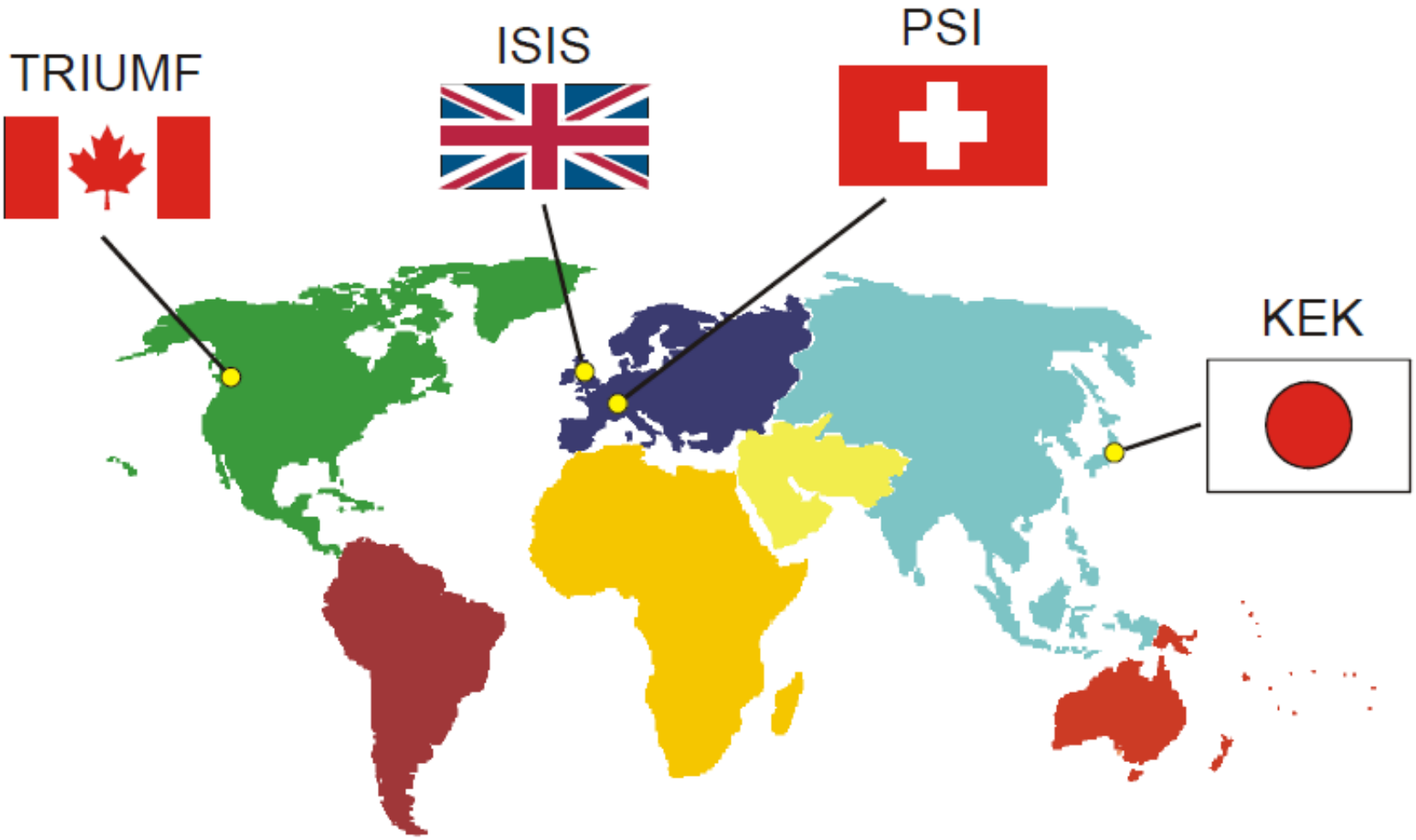




Dove studiare Magnetismo e Superconduttività ?

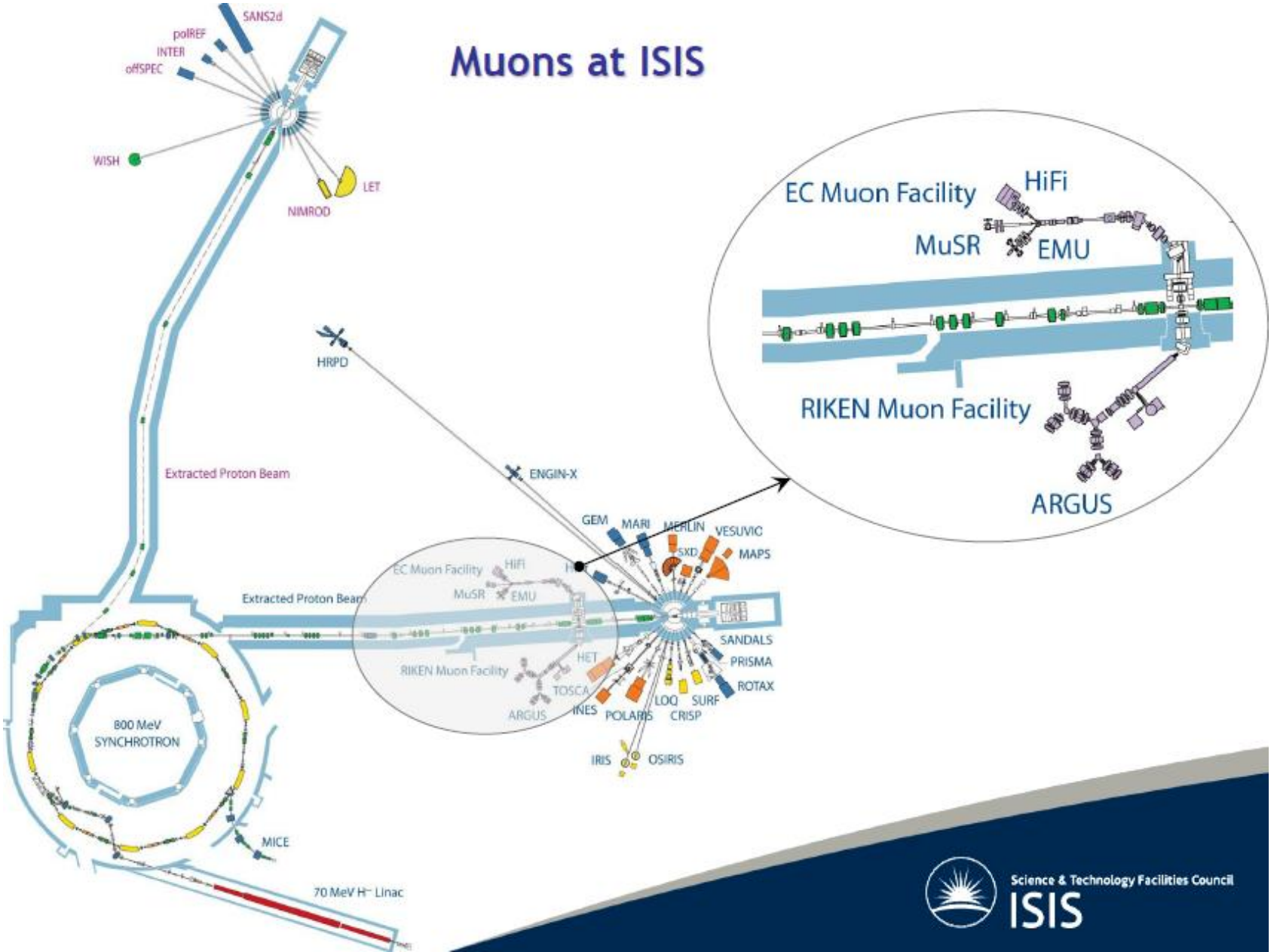
Dipartimento di Fisica:
NMR, NQR, Magnetometria SQUID

μSR: in giro per il mondo

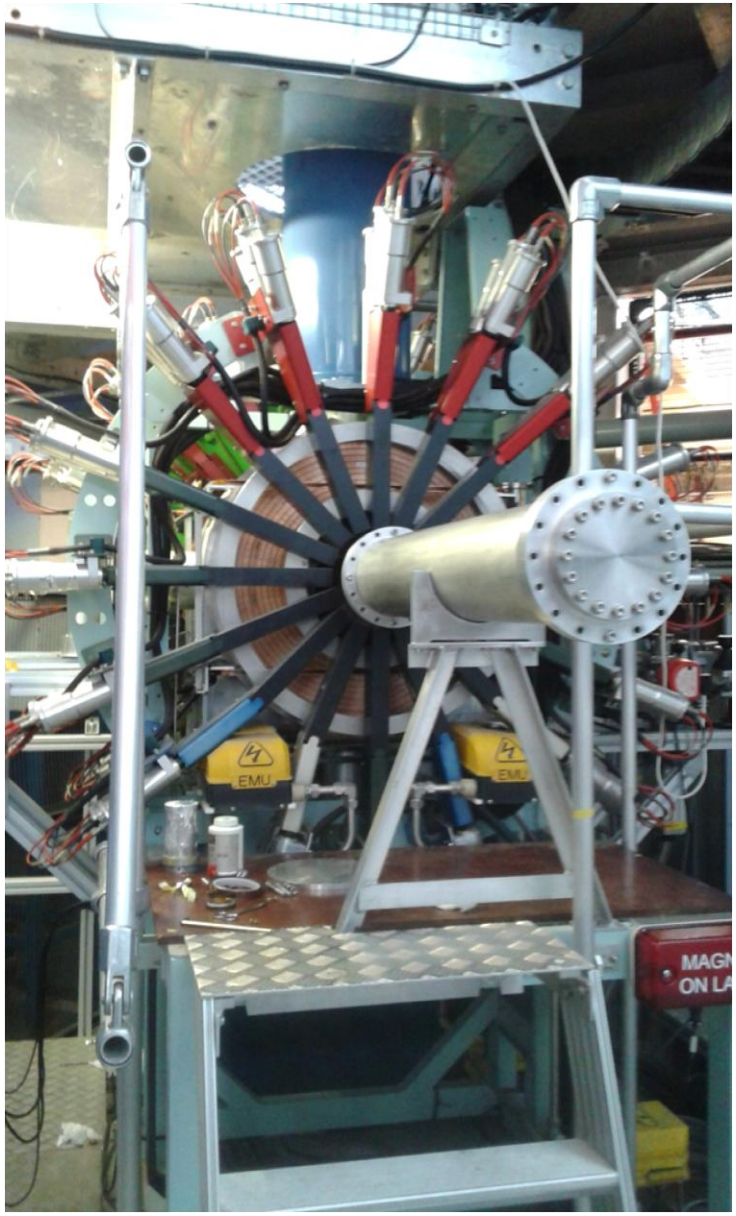


μSR facilities of the world.

μSR LSF di ISIS at RAL

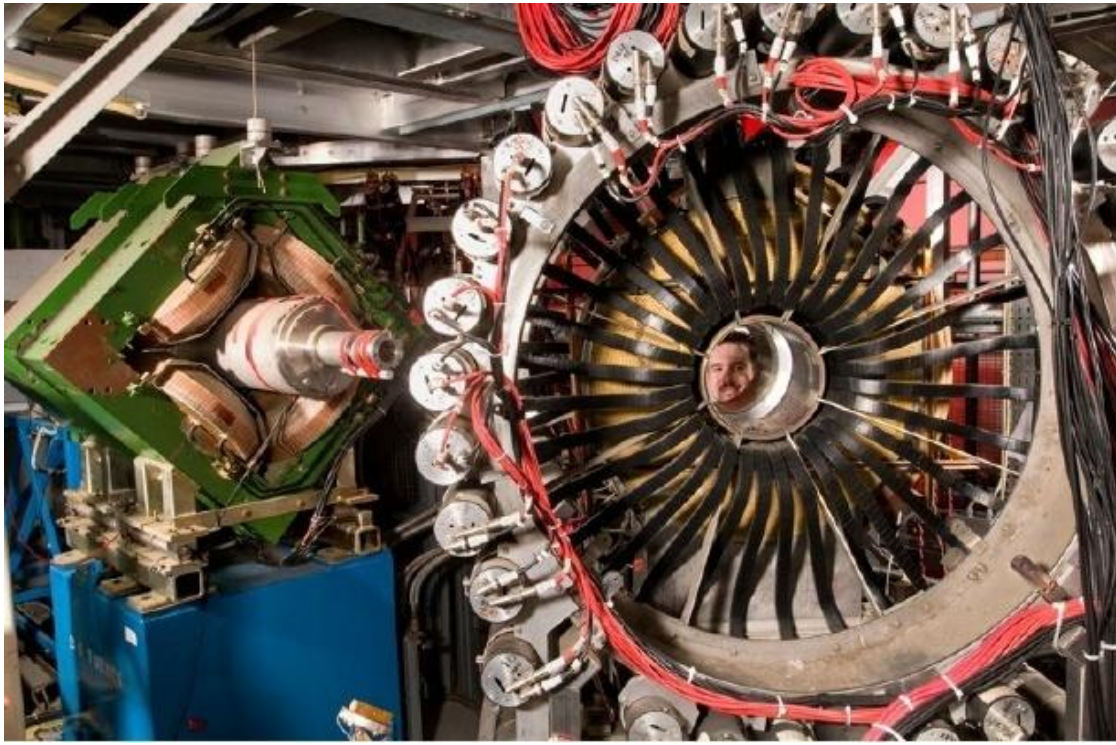


μSR LSF di ISIS at RAL

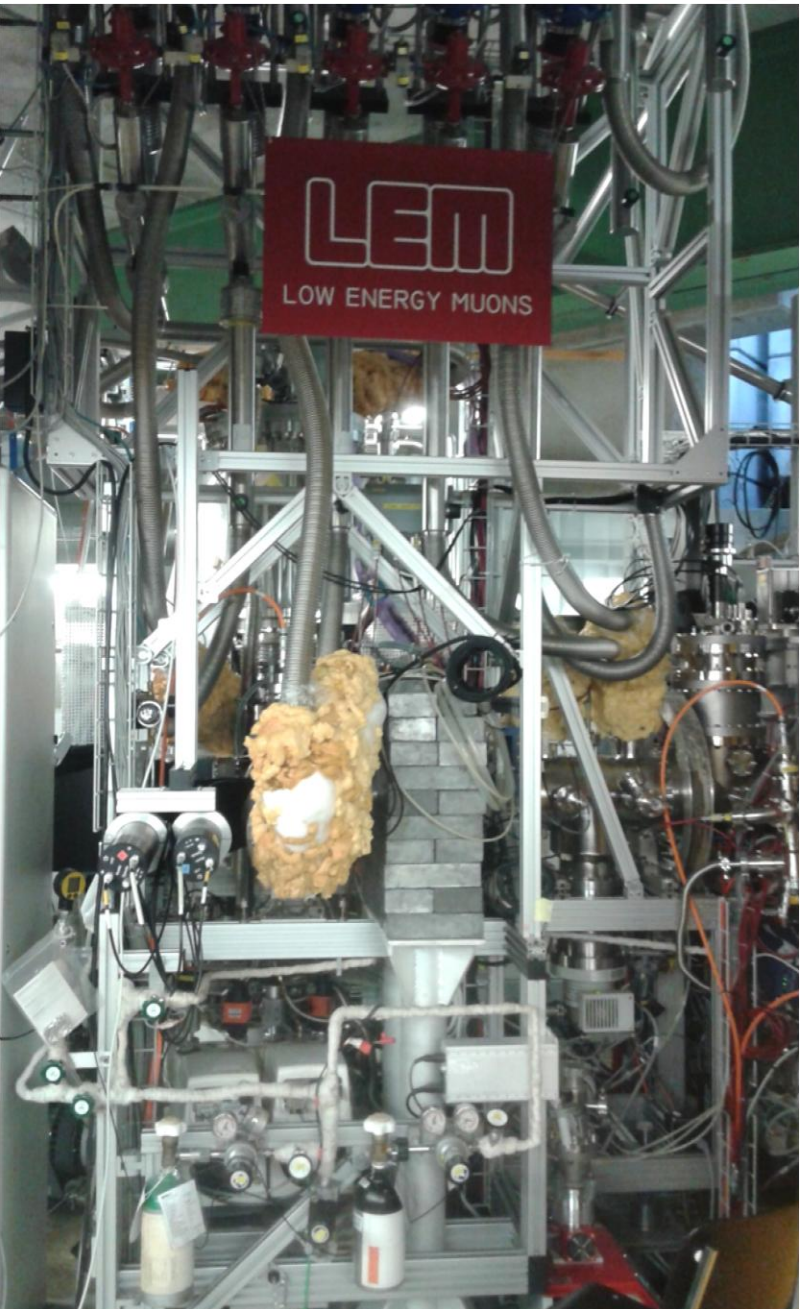


EMU

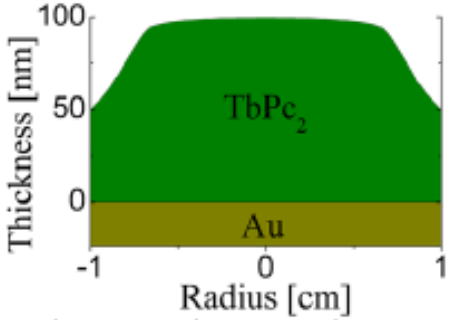
MUSR

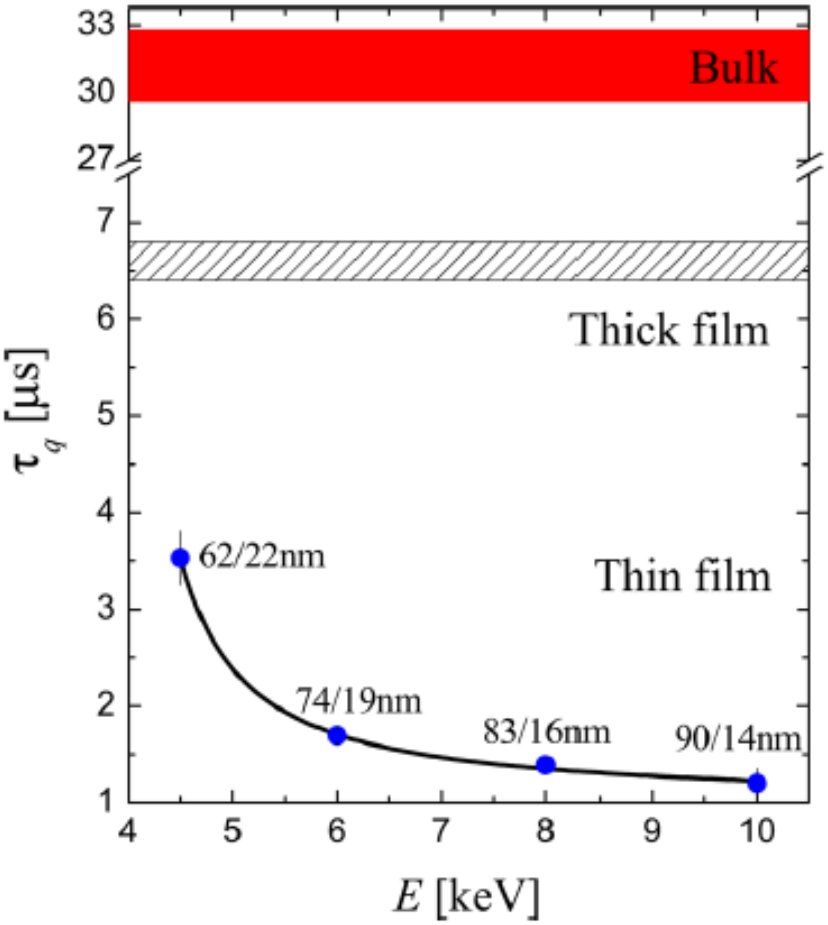


Low-energy (keV) muons at PSI



A.Hofmann et al., ACS Nano. **6**, 8390 (2012)





Really low-energy muons !!!