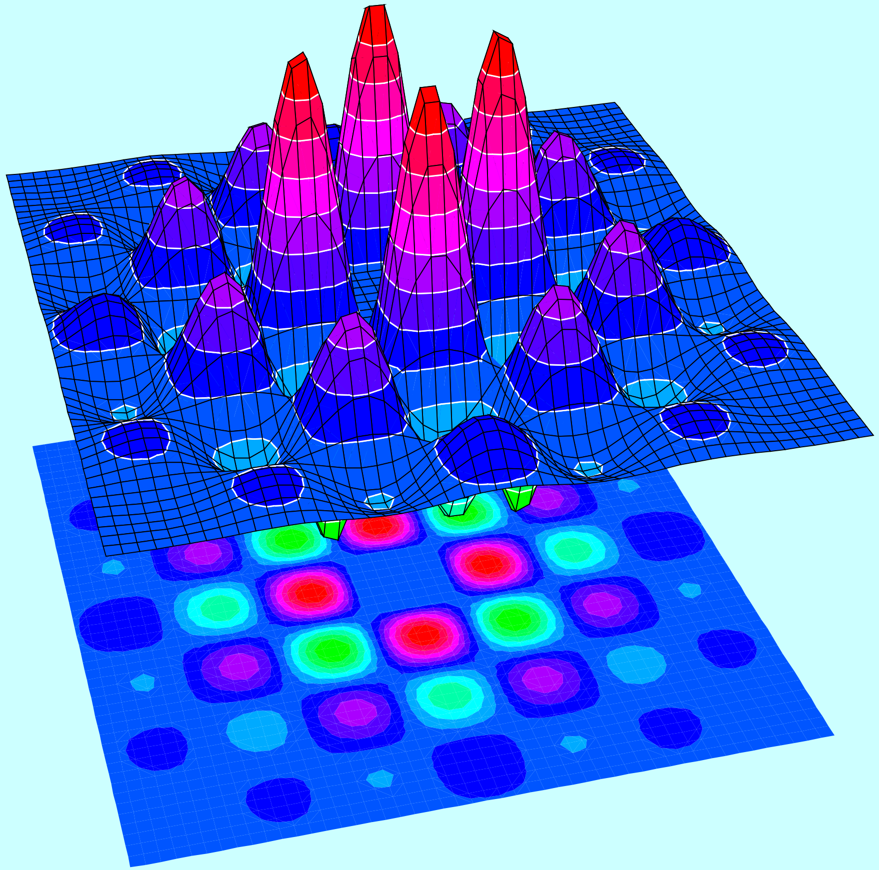

Impurity effects in high T_C superconductors

J. Bobroff, S. Ouazi, H. Alloul, P. Mendels, N. Blanchard

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G. Collin
LLB, CEA-Saclay

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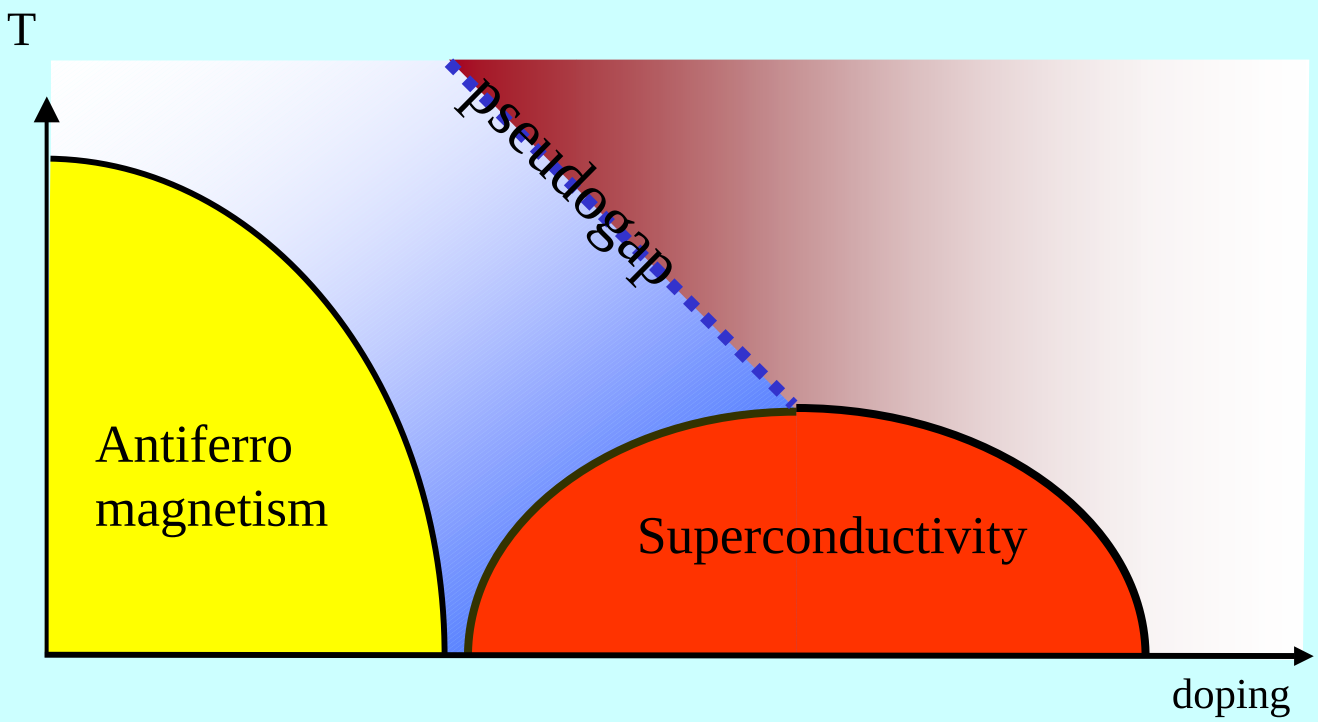
LEMHE, Université Paris XI

D. Colson
SPEC, Saclay

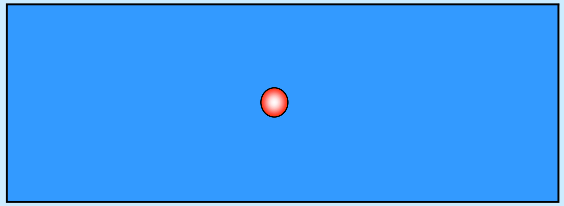
High T_C cuprates



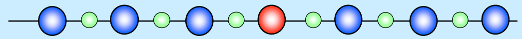
metallicity + correlations + exotic superconductivity

Impurity effects in cuprates

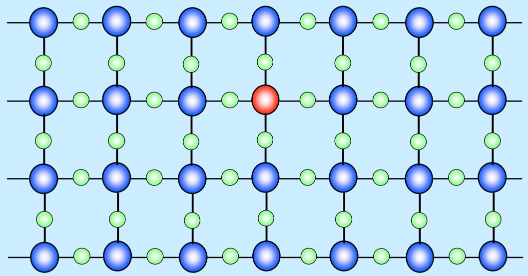
- Impurity in more « simple » systems
  - in a metal
  - in a BCS superconductor



  - in a correlated insulator



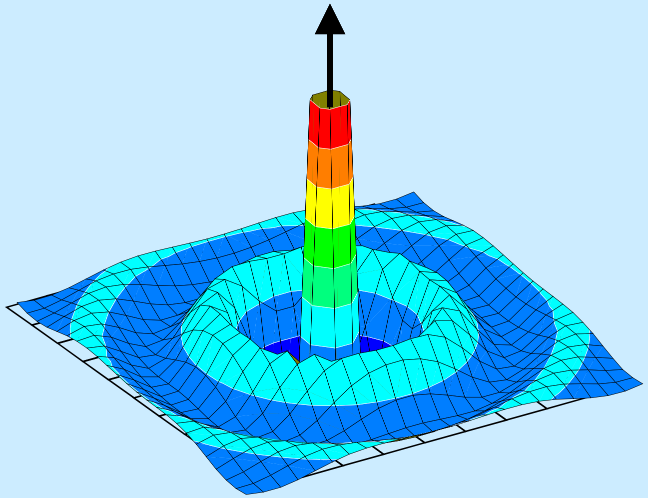
- Impurity in High T_C cuprates
  - in the metallic « normal » state
    - macroscopic properties
    - local magnetism
      in underdoped state
      with increasing doping



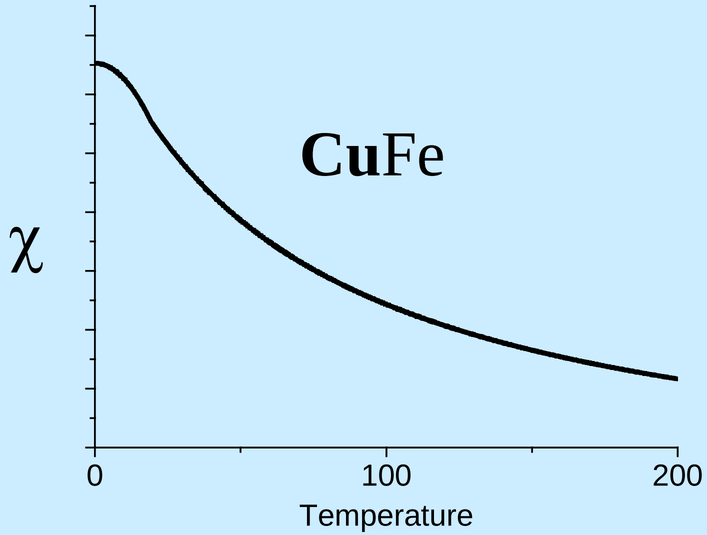
  - in the superconducting state
    - macroscopic properties
    - density of states
    - magnetism

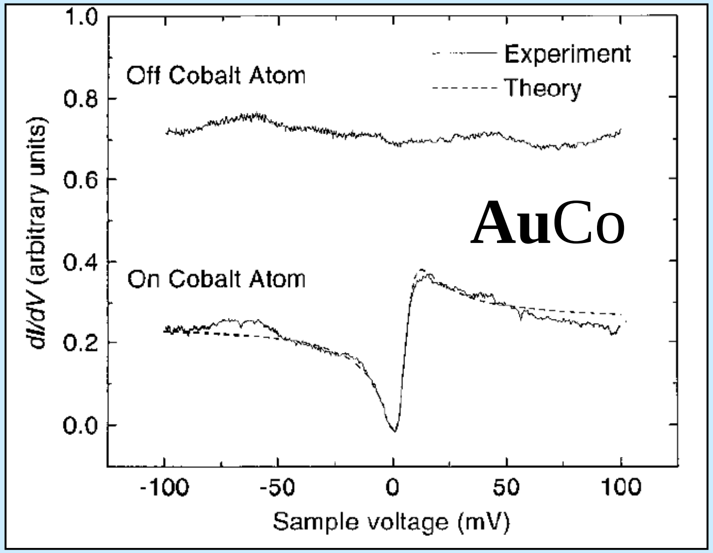
A magnetic impurity in a metal

• RKKY spin polarization of the conduction carriers



• Kondo effect





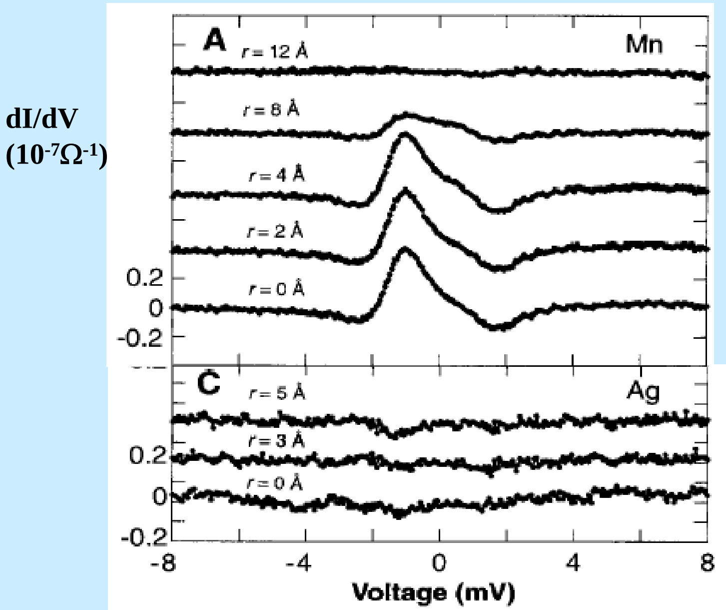
Madhavan *et al.*

A magnetic impurity in an isotropic BCS superconductor

- Decrease of T_C only if it is magnetic (Abrikosov, Gork'ov)

- Possible local bond states

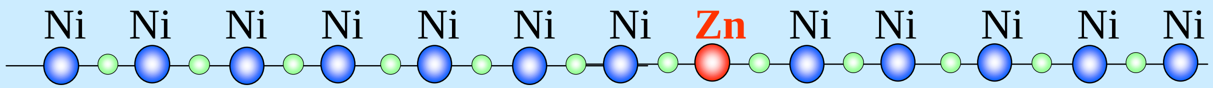
NbMn or **Nb**Ag

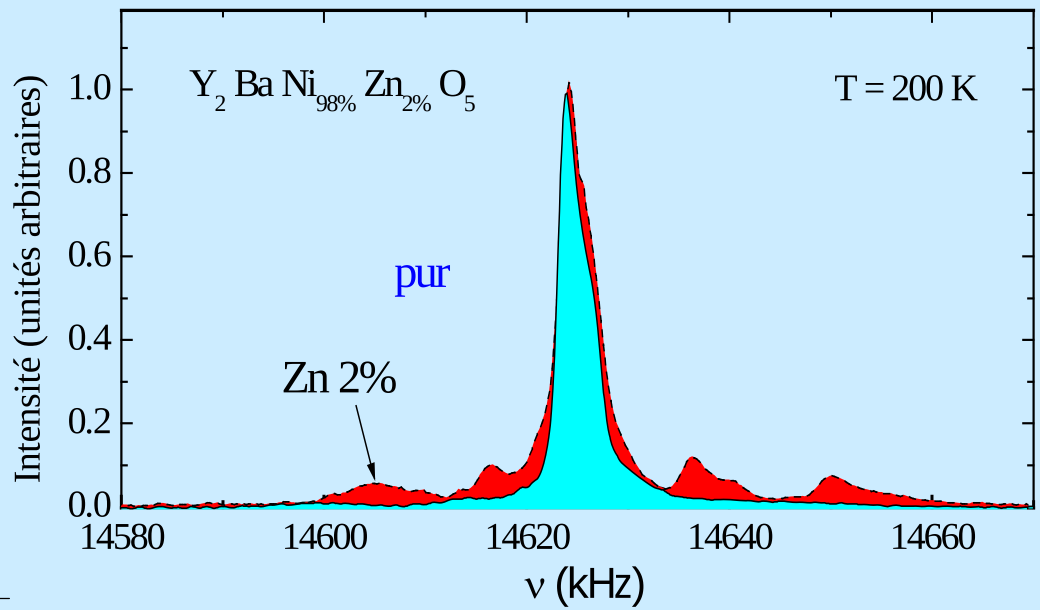


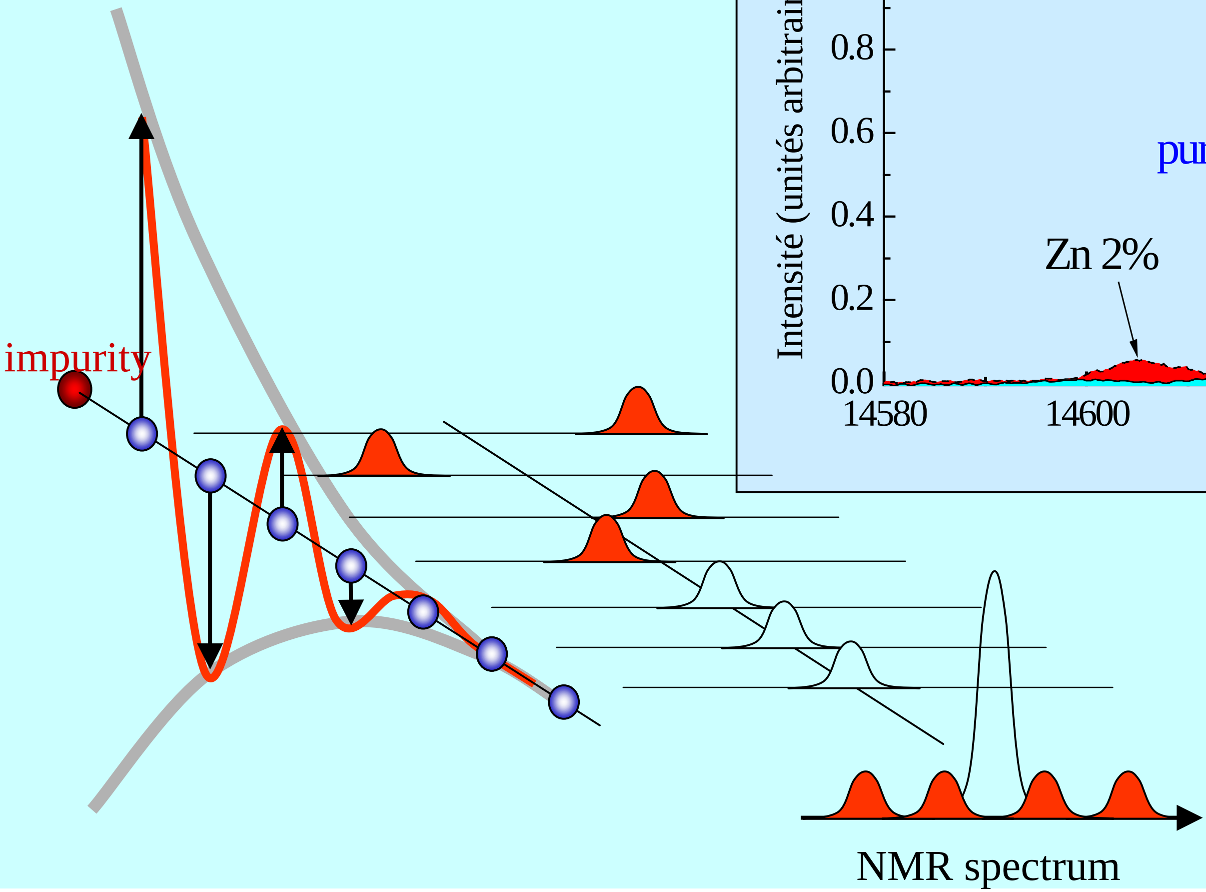
Yazdani *et al.*

An impurity in an insulating correlated system

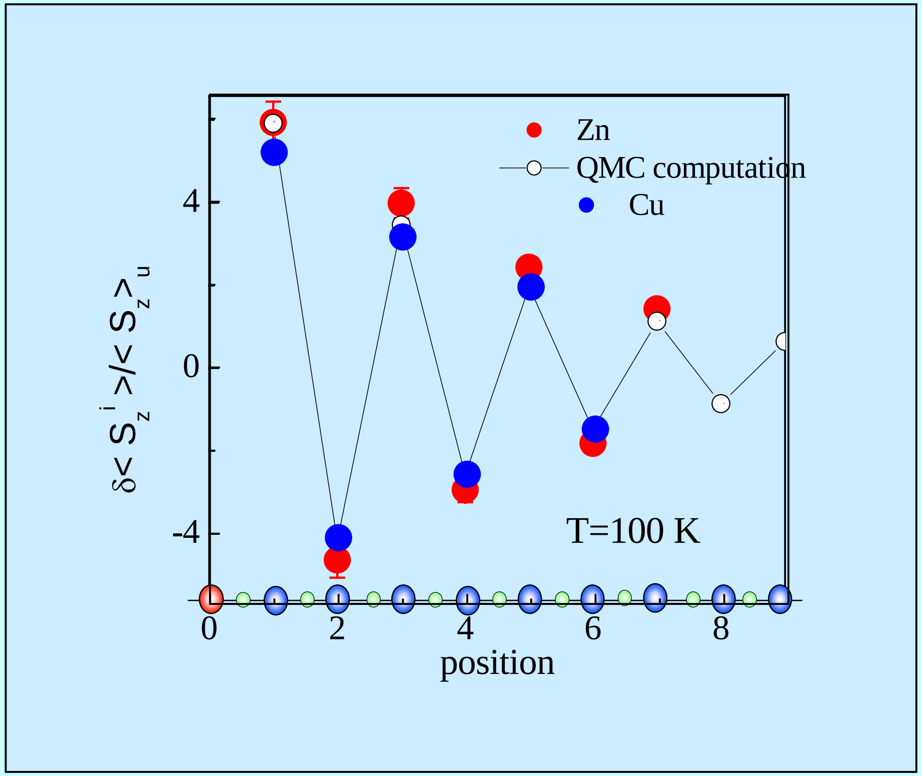
example : Y_2BaNiO_5 as a spin 1 Ni chain with Haldane gap

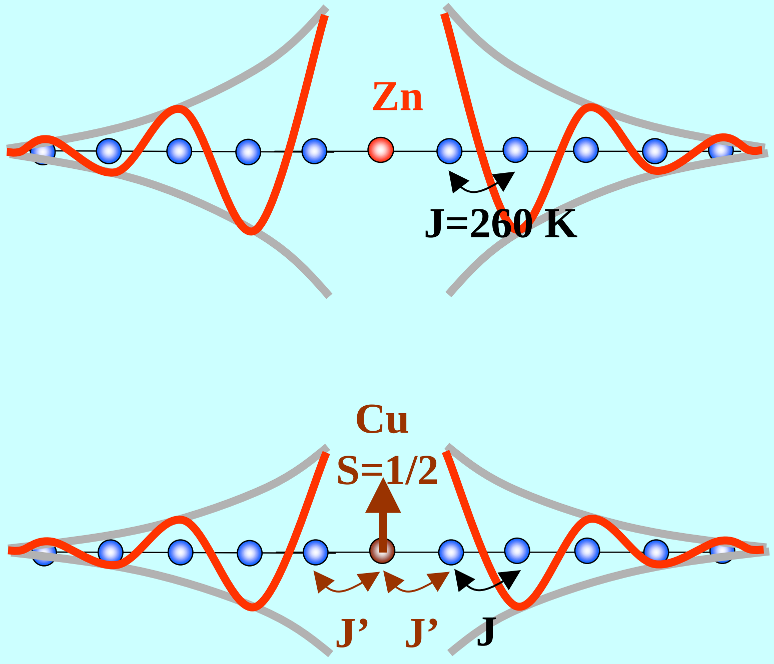






An impurity in an insulating correlated system



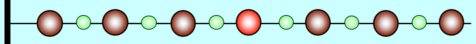
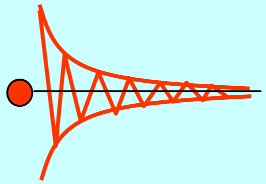
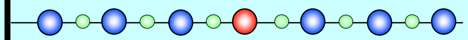
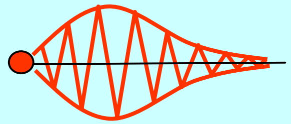
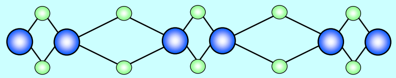
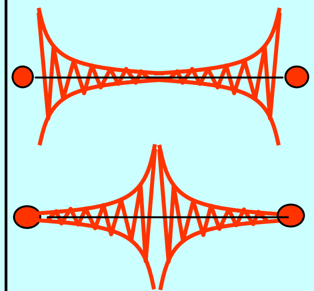
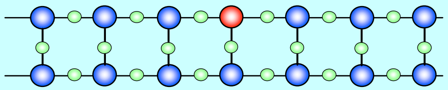
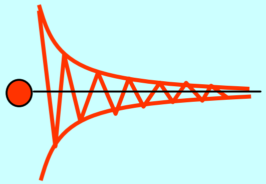


$<S_Z(i)> \sim e^{-r/\xi(T)} / T$ $\quad\quad$ $< S_i.S_j > \sim e^{-r/\xi}$

Das et al., 2004

Tedoldi et al., 2000

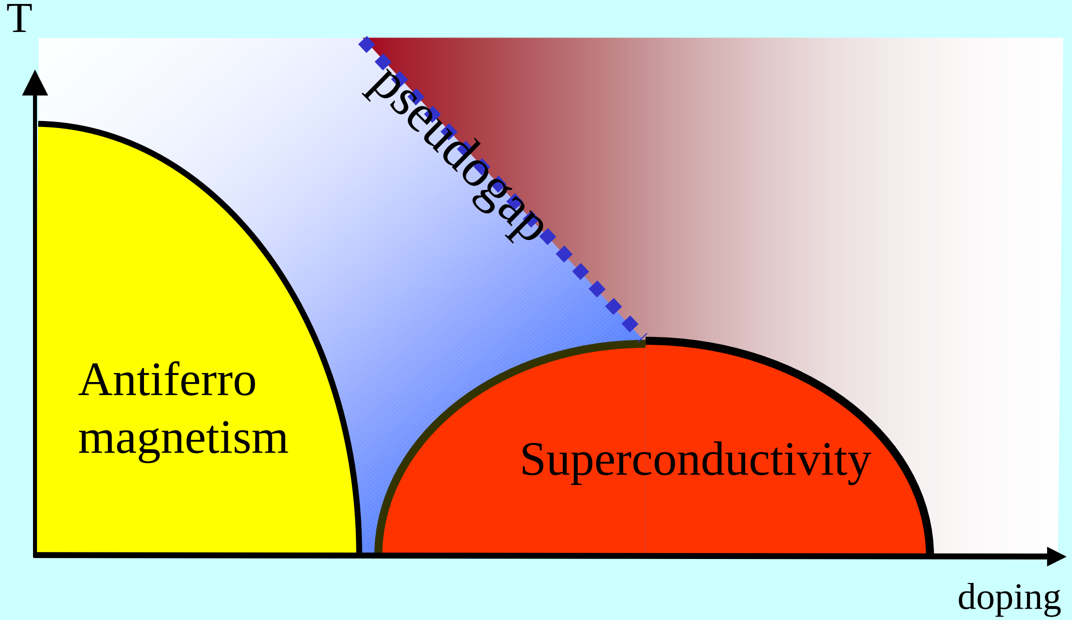
Some other low dimension spin systems

Spin 1 Chain 	Gap $\xi < 6$		AF ?
Spin ½ Chain 	$\xi \sim 1/T$		No order
Spin-Peierls Chain 	Gap Dimer isation		AF order
2-leg ladder 	Gap $\xi < 3$		AF order

Common mechanism : breaking of a singlet

Non magnetic impurity effects in cuprates

The normal state



Why choosing YBaCuO ?

VOLUME 78, NUMBER 19 PHYSICAL REVIEW LETTERS 12 MAY 1997

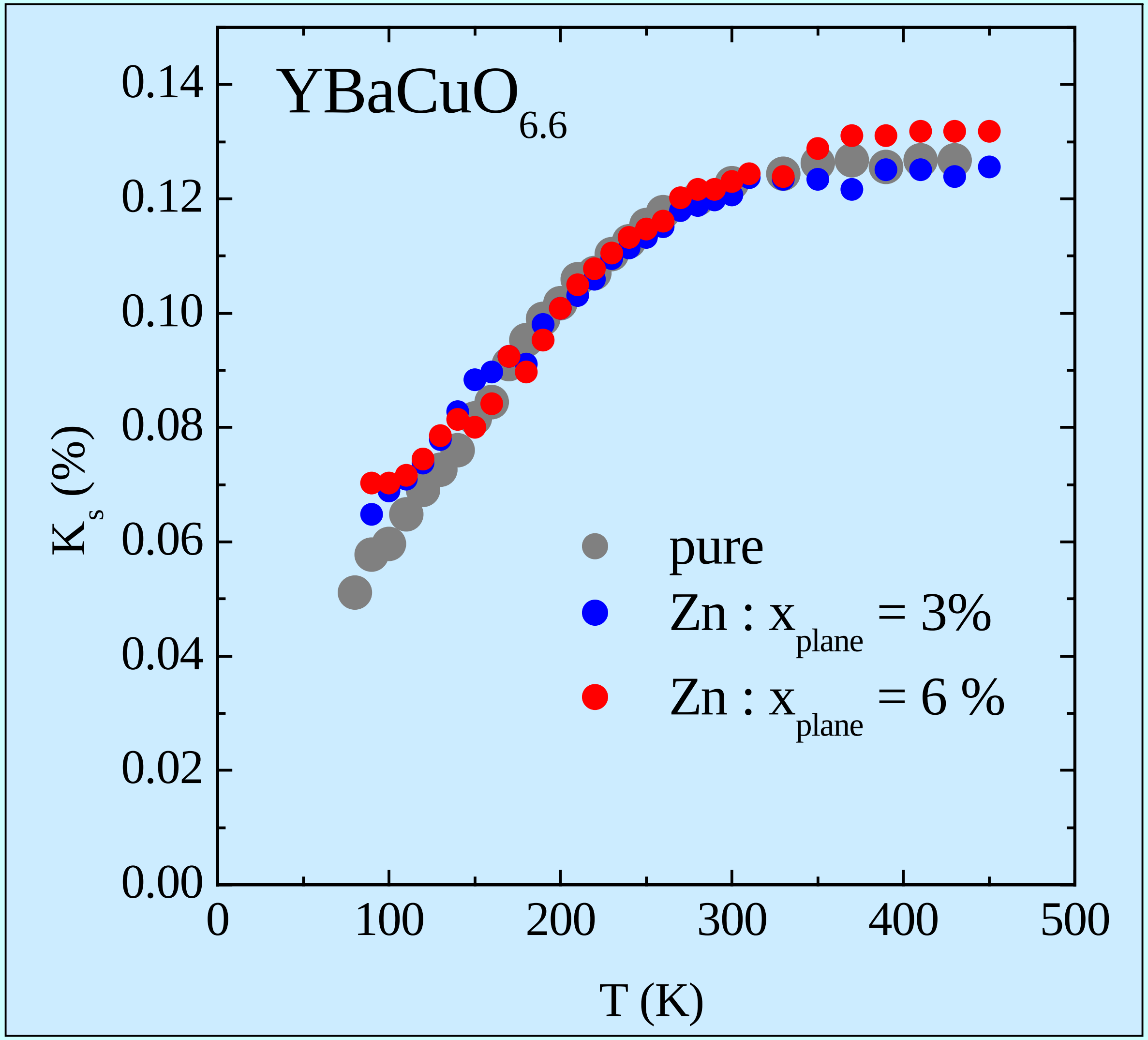
^{17}O NMR Evidence for a Pseudogap in the Monolayer $HgBa_2CuO_{4+\delta}$

J. Bobroff,[1] H. Alloul,[1] P. Mendels,[1] V. Viallet,[2] J.-F. Marucco,[2] and D. Colson[2]

TABLE I. The different monolayer compounds with the associated T_c and NMR oxygen width.

	T_c^{max}(K)	^{17}O full width kHz/% of K_s
$HgBa_2CuO_{4+\delta}$	95	30 kHz/50%
$Tl_2Ba_2CuO_{6+\delta}$	85	15 kHz/20% [11]
$La_{2-x}Sr_xCuO_4$	38	90 kHz/120% [12]
$Bi_2Sr_2CuO_6$	10	70 kHz/110% [10]
$YBaCuO_7$	92	12 kHz

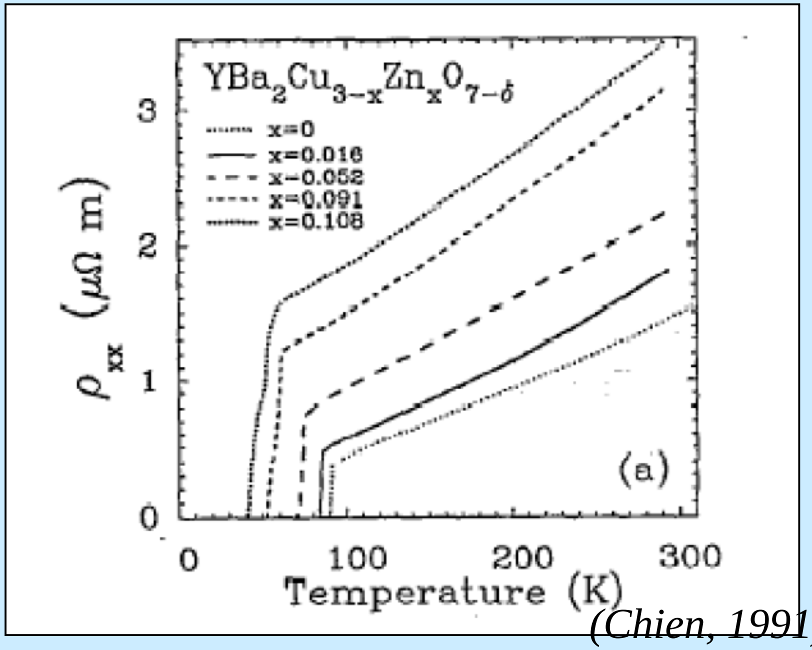
Impurity effects on doping and pseudogap



- No effect on doping
- No effect on pseudogap

Impurity effects on macroscopic properties

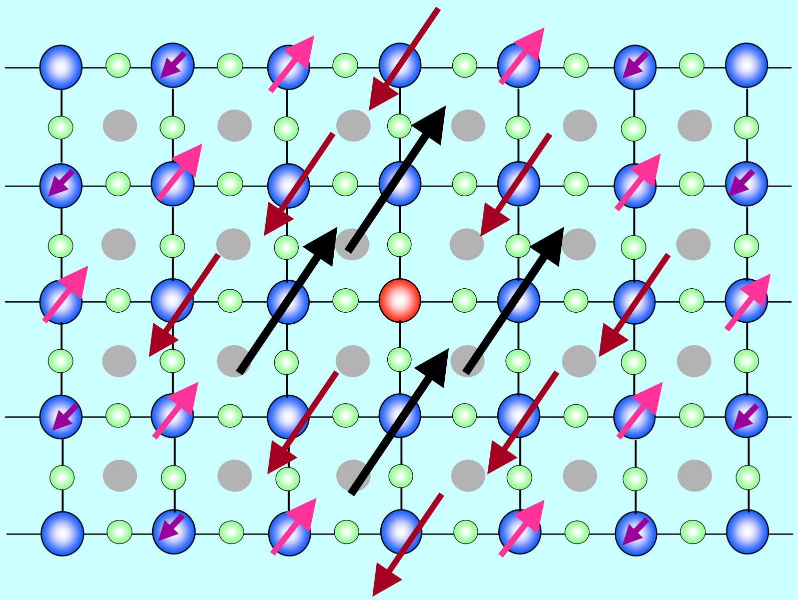
- Effect on resistivity :
  - Zn : strong scattering center
  - Ni : weaker

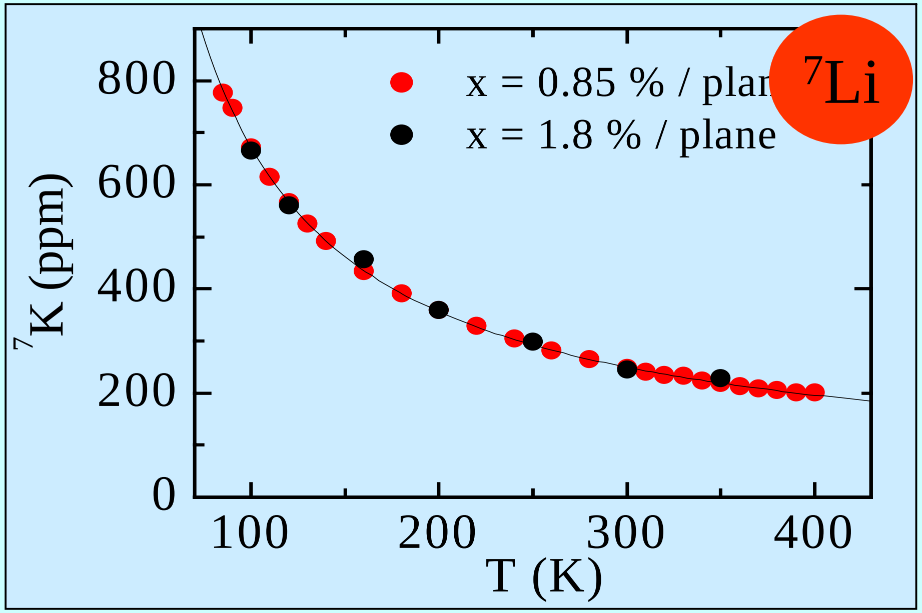


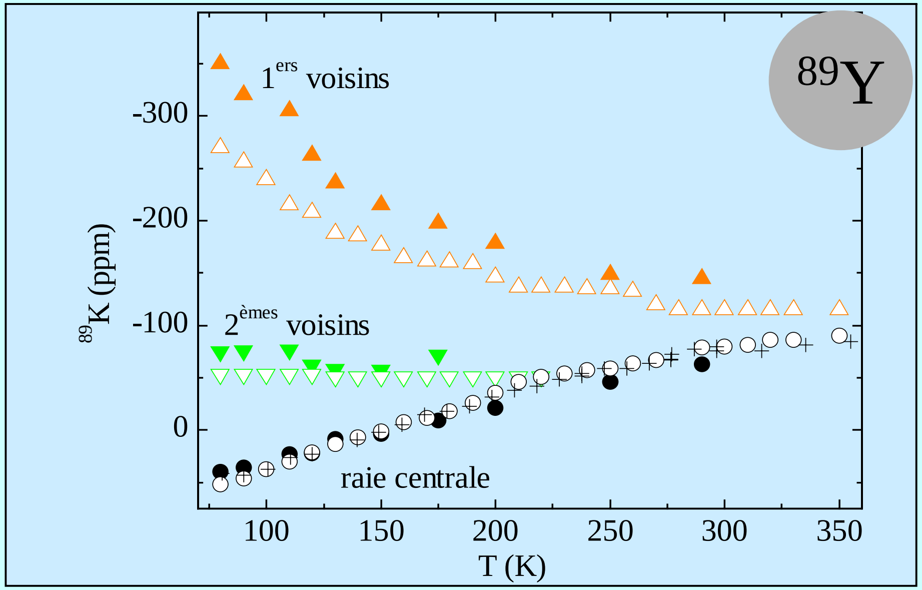
(Chien, 1991)

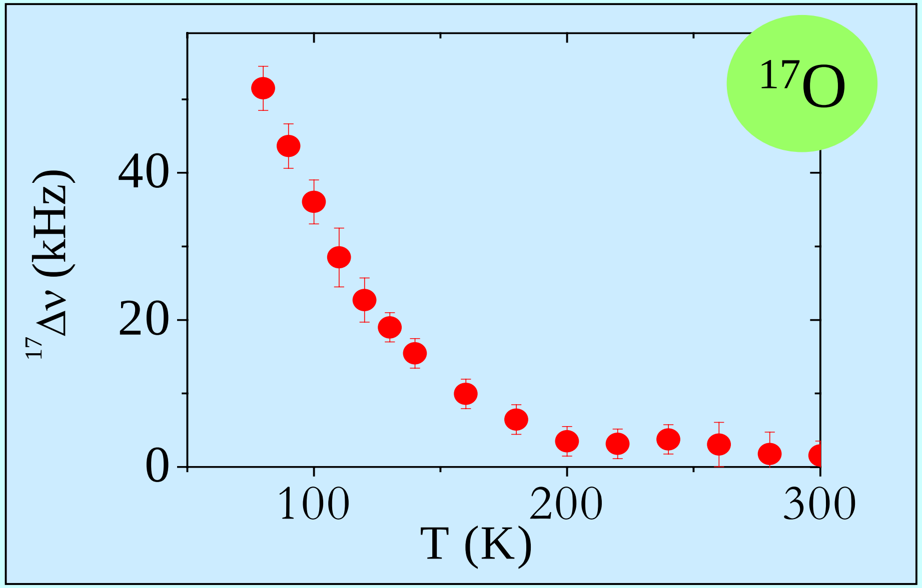
- Effect on macroscopic susceptibility :
  - Zn induces an effective paramagnetic moment S<1/2 which decreases with increasing doping
  - Ni induces a moment ≠ S=1 *(Mendels, 1994,1999; Zagoulaiev, 1995)*

Nonmagnetic Impurity in Pseudogap regime







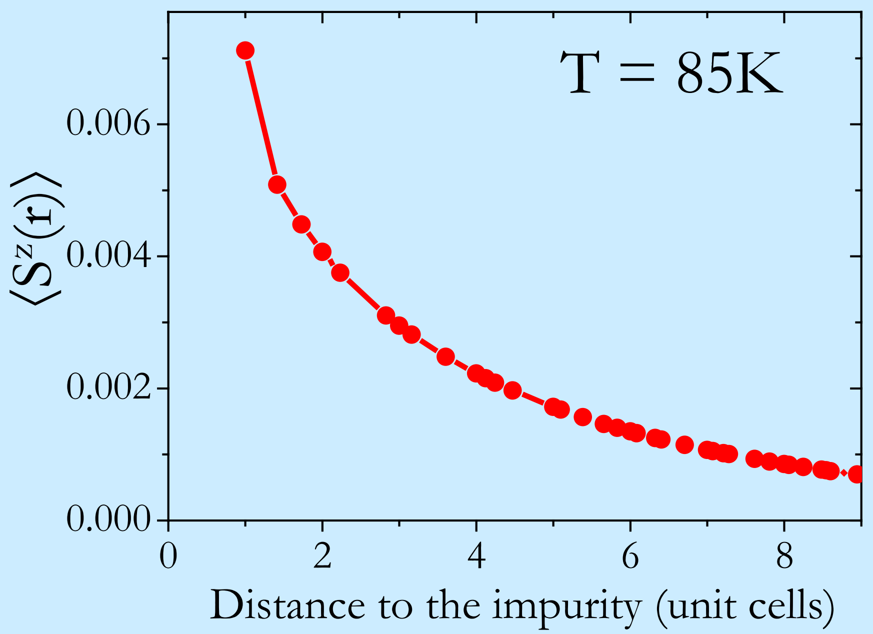


Alloul,91;Walstedt,93;Mahajan,94; Williams,95; Ishida,97; JB,97,99; Julien,2000; Itoh,2003; ***Ouazi, 2004***

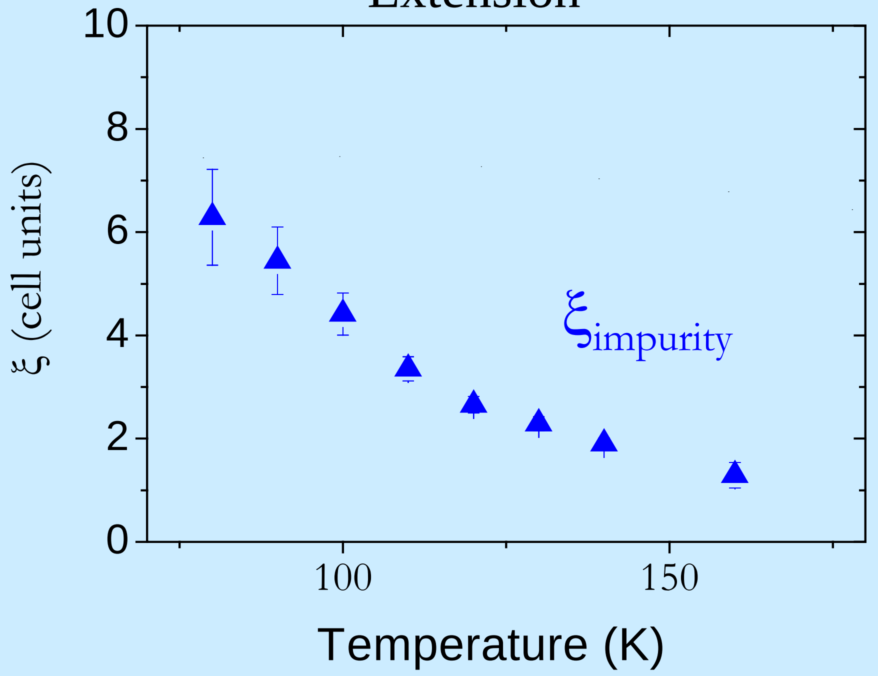
Nonmagnetic Impurity in Pseudogap regime

Multi-nuclei quantitative analysis of the induced staggered polarization

Spatial dependence



Extension



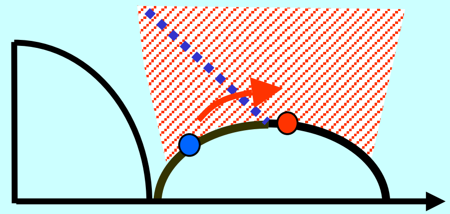
Ouazi, 2004

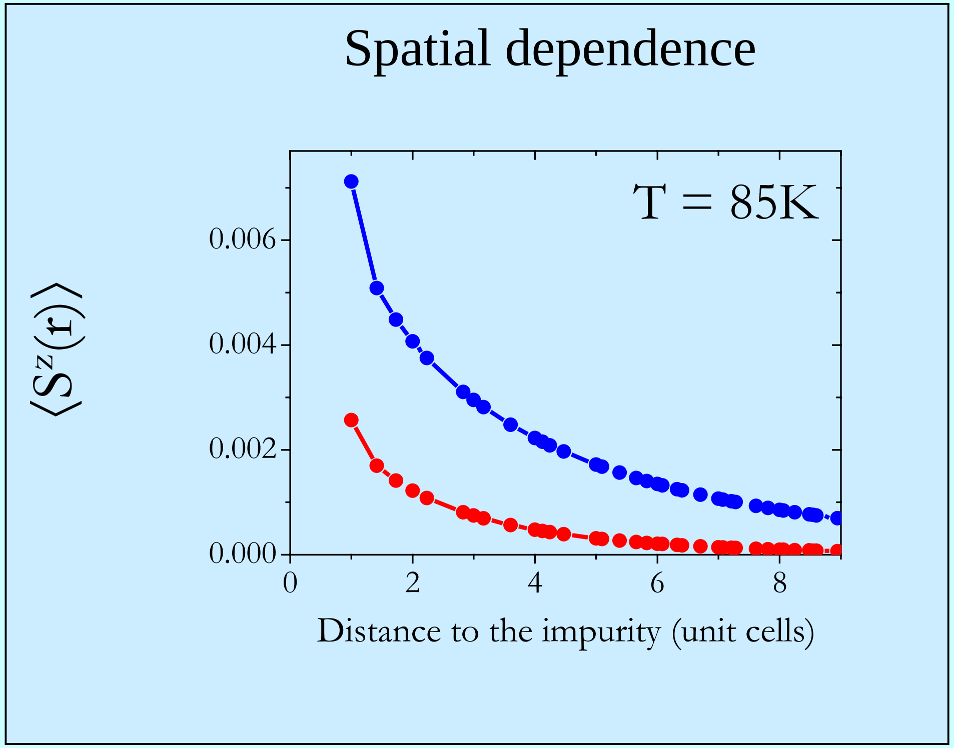
- Analogy with spin chains
- Theoreticall justifications :

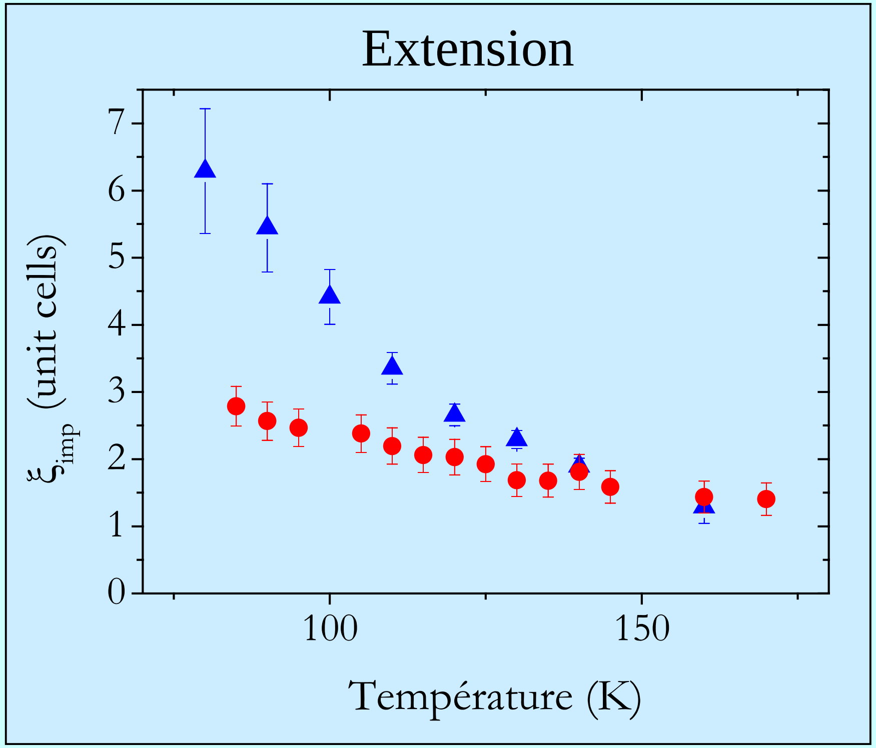
  t-J (Poilblanc)

  RVB (Khaliullin, Gabay, Nagaosa & Lee)

Effect of hole doping on the induced polarization



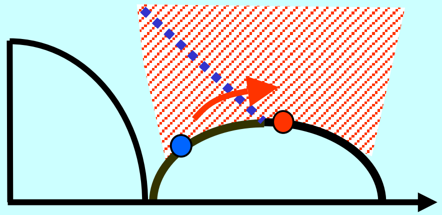


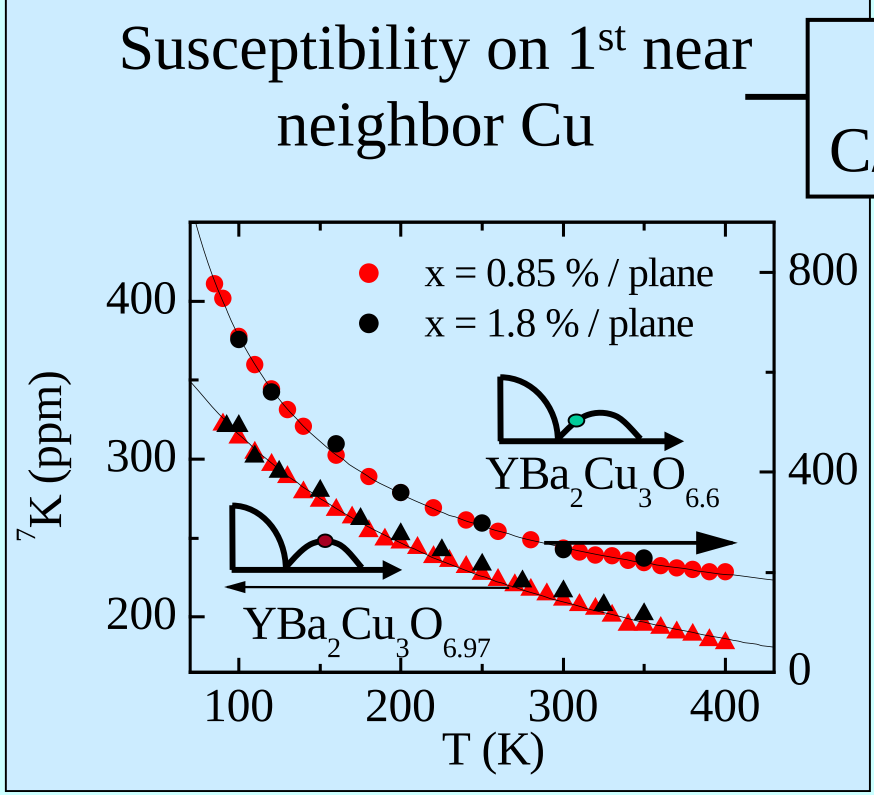


• persistence of corrélations at optimal doping

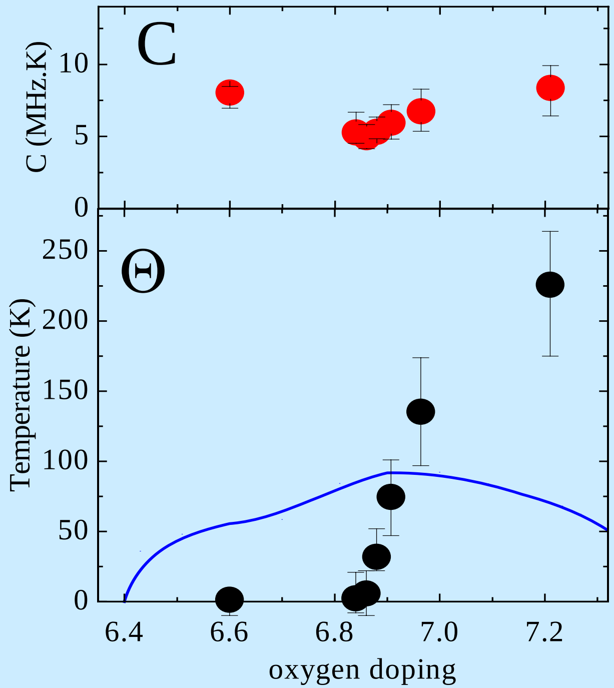
NAFL, SCR (Bulut, Ohashi)

Effect of hole doping on the induced polarization





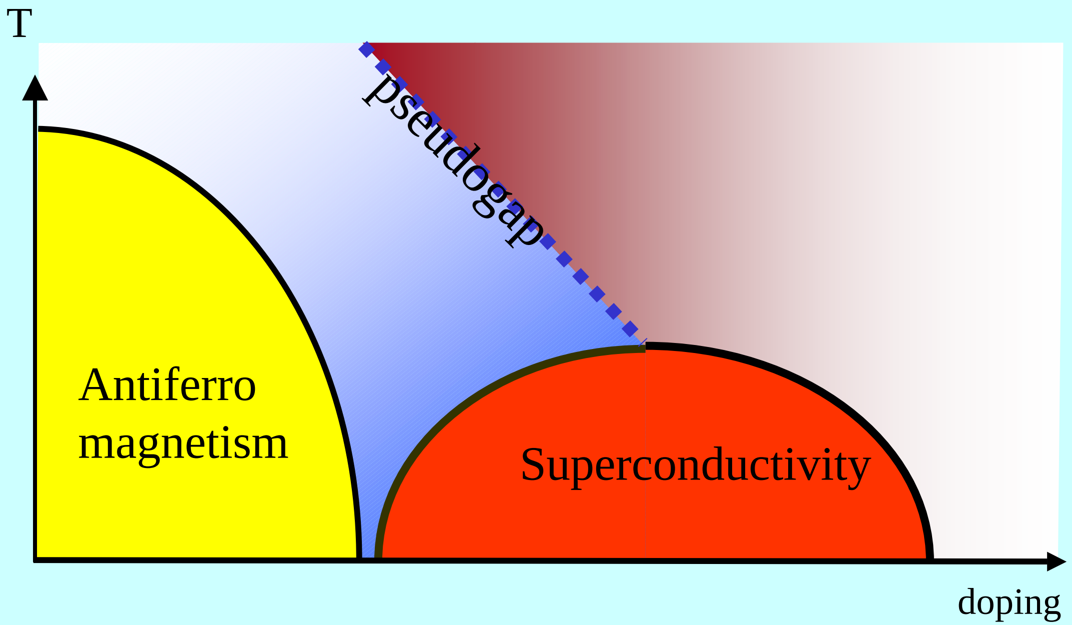
Fit in C/(T+Θ)



JB, 1999

Impurity effects in cuprates

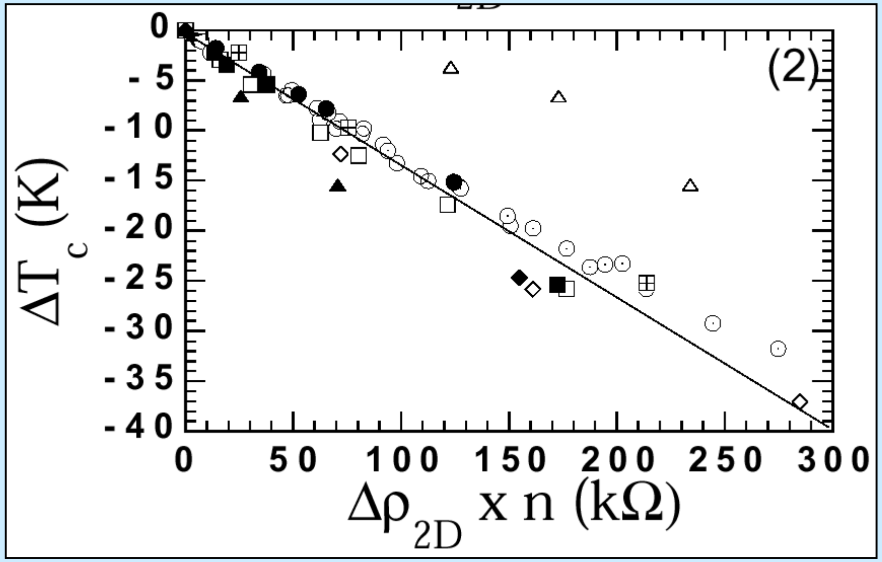
The superconducting state



Impurity effects in the superconducting state

- Effect on T_C :

  only dependent on
  scattering potential (d-wave)



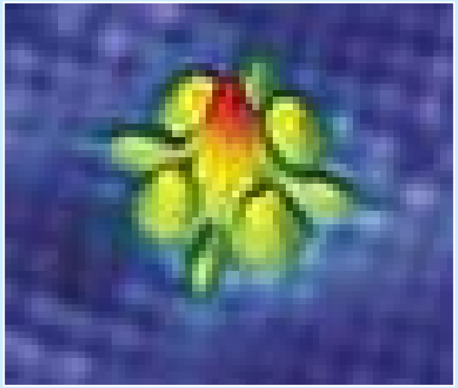
(Rullier-Albenque, 2000)

- Effect on penetration depth :

  λ increases with impurity content,
  n_s decreases with impurity content *(Bonn, 1993;Bernhard, 1996)*

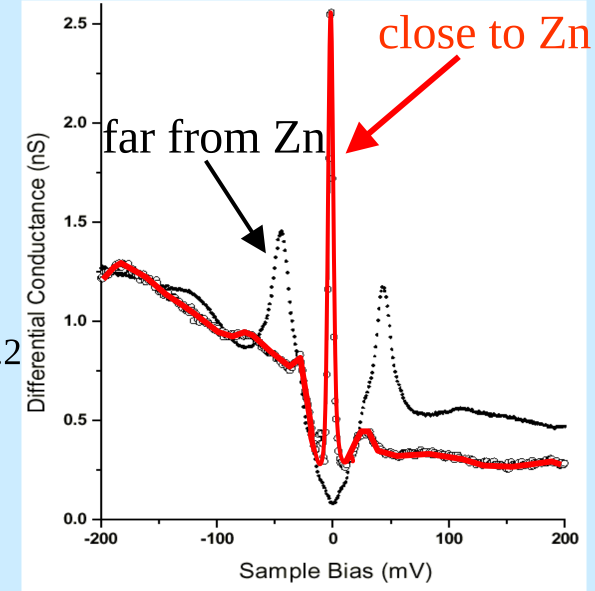
Impurity effects in the superconducting state

Effect on local Density Of States

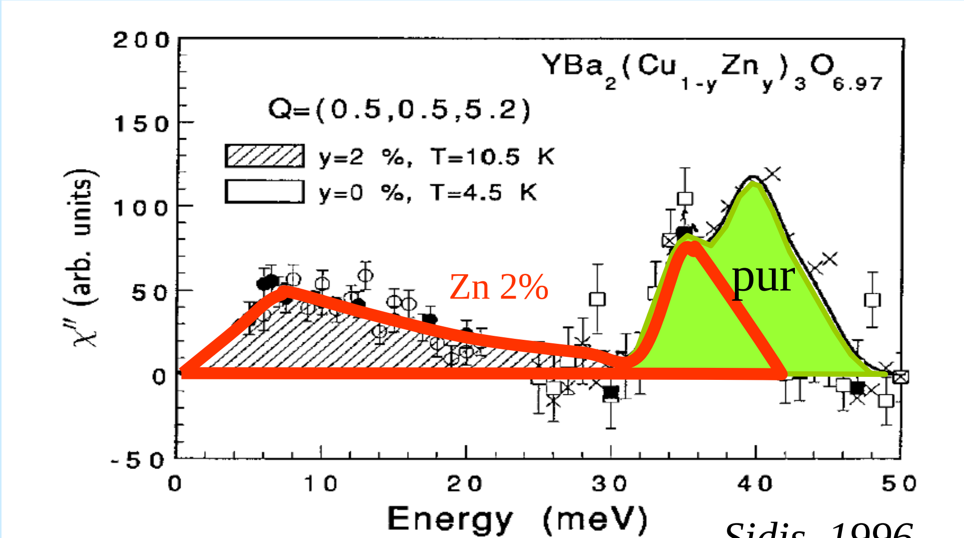


Pan, Nature 2000
Hudson, Nature 2001

Bi2212 + Zn T = 4.2



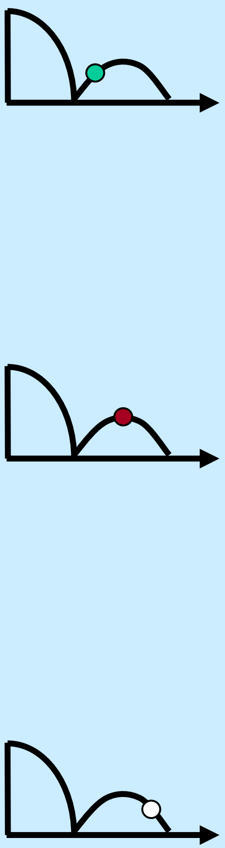
Effect on magnetic response $\chi''(Q_{AF},\omega)$

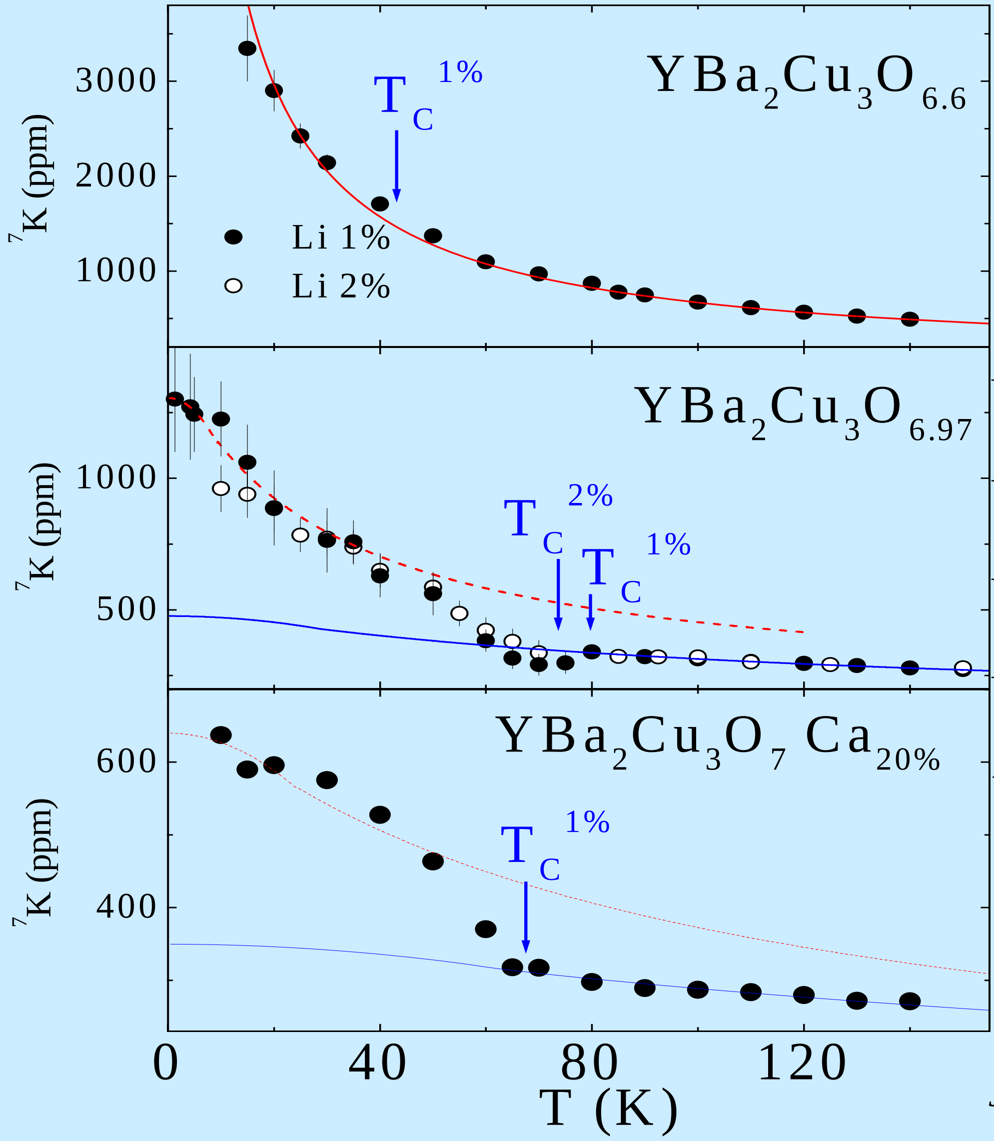


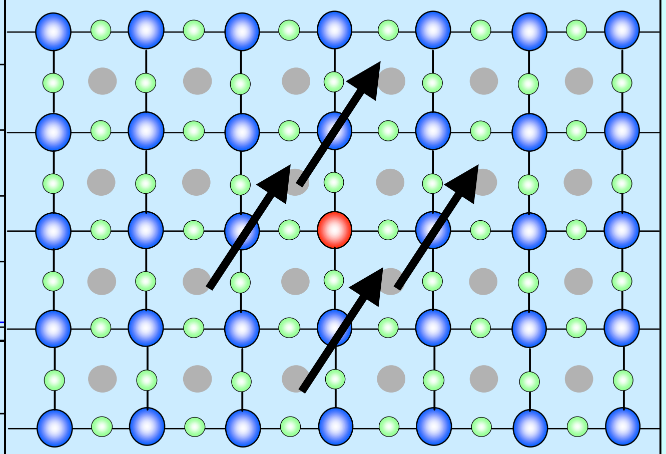
Sidis, 1996

Impurity effects in the superconducting state

Magnetic effect on 1st near neighbor Cu of non magnetic Li



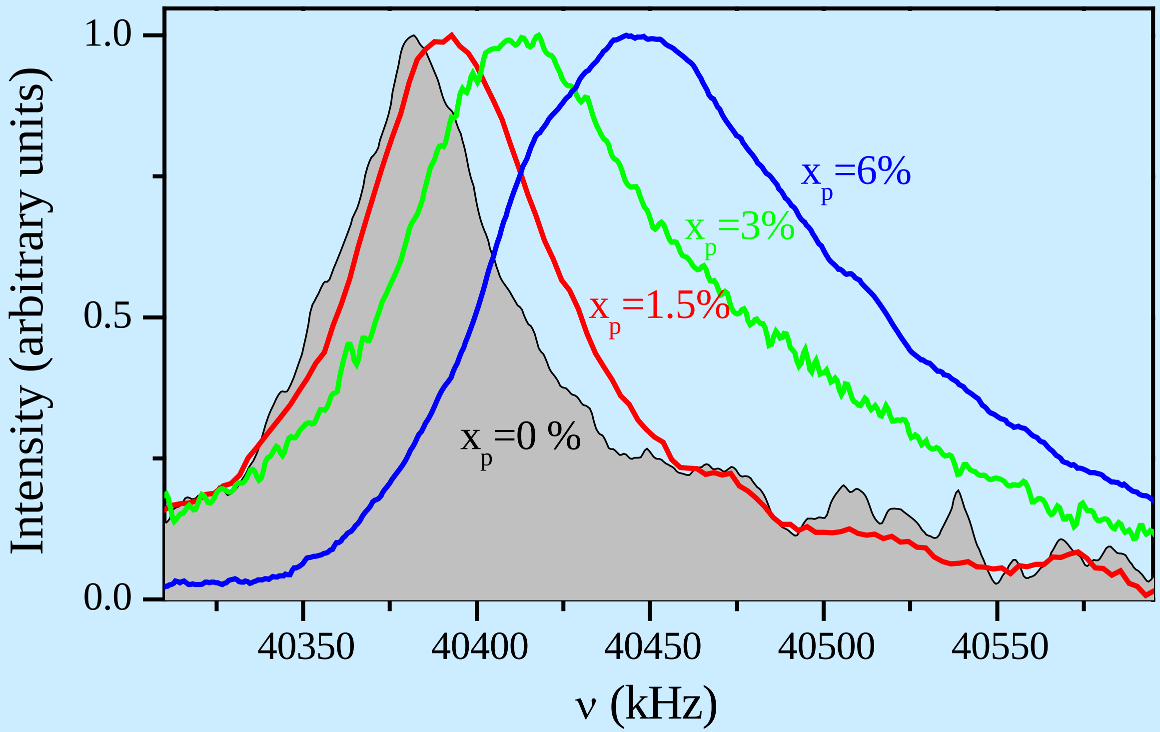




JB, 2001

Impurity effects in the superconducting state

Induced polarization by non Magnetic Zn or magnetic Ni

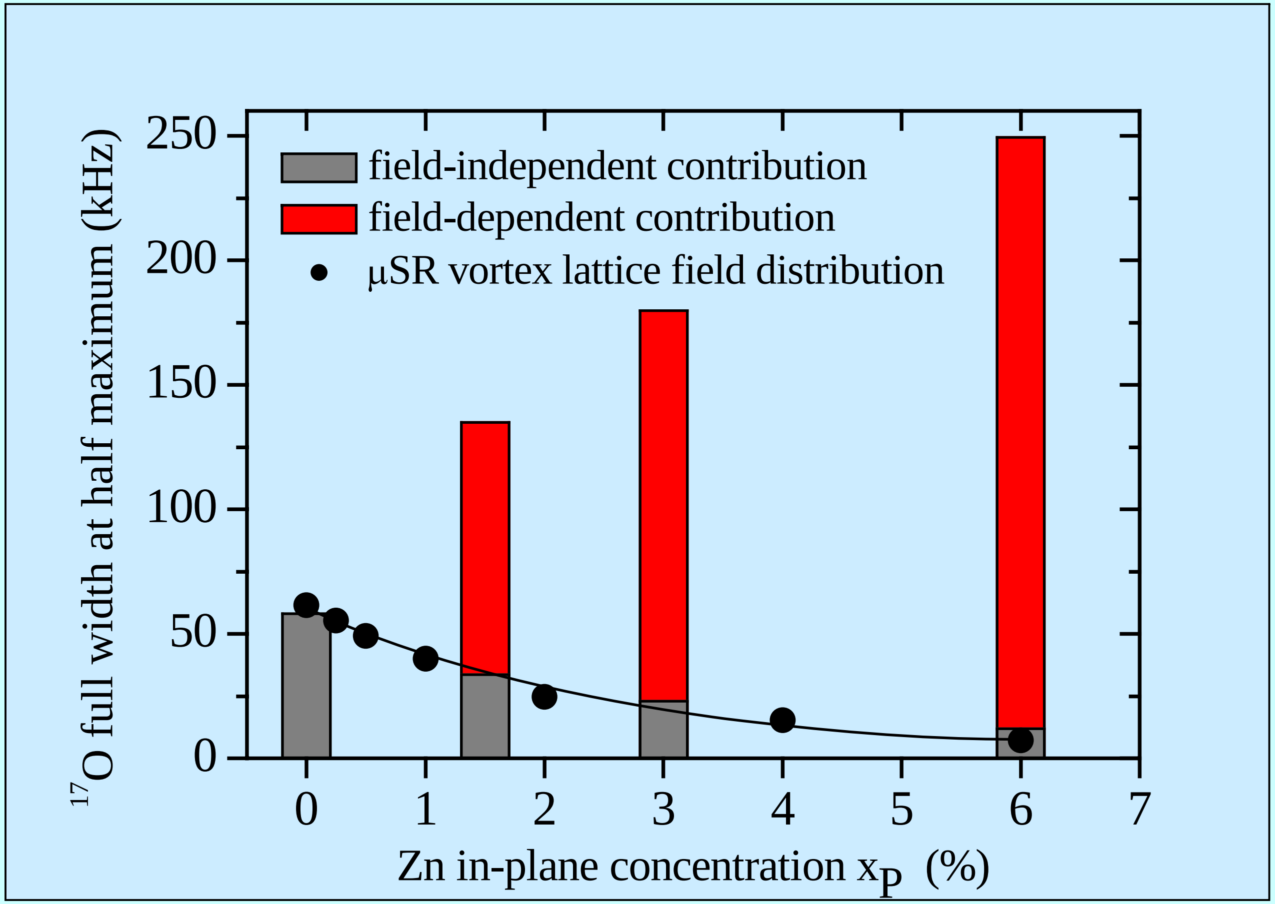


In-plane ^{17}O NMR in $YBaCuO_7$ (optimal doping) with Zn at T=10K

Ouazi et al., 2005

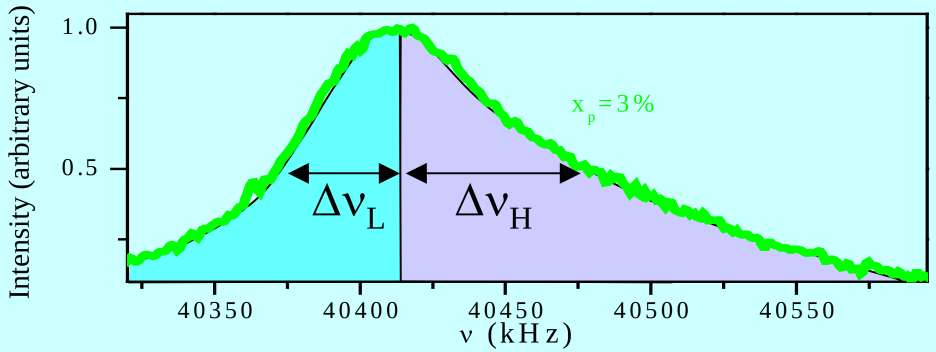
Impurity effects in the superconducting state

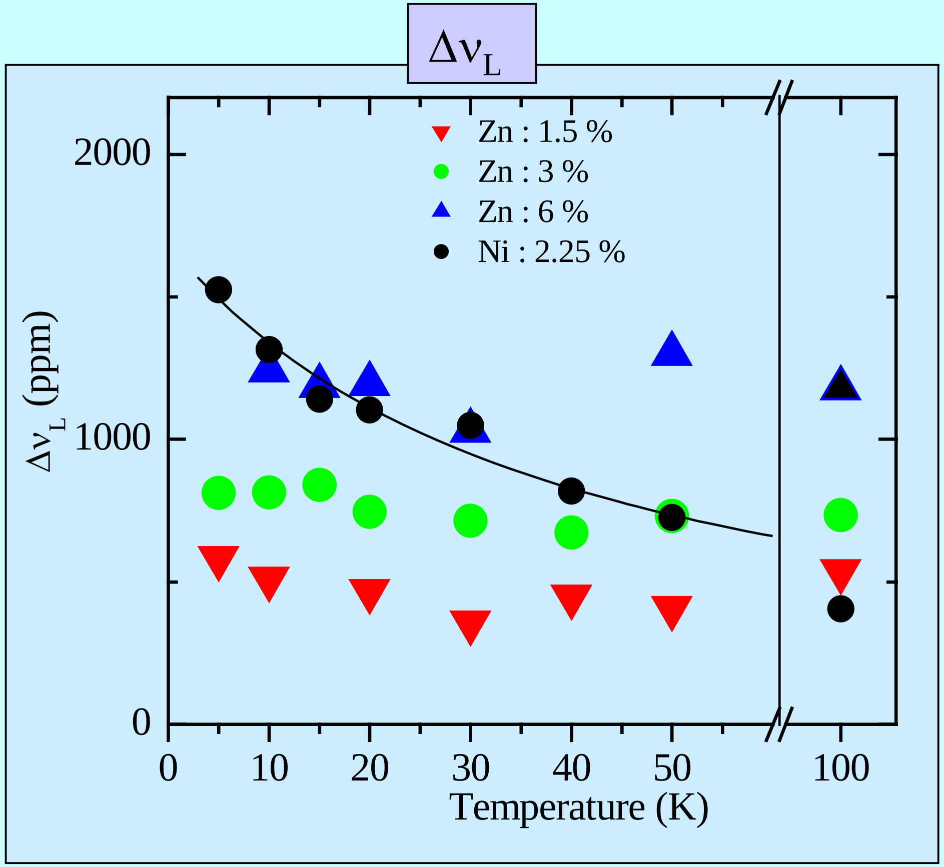
Induced polarization by non Magnetic Zn or magnetic Ni

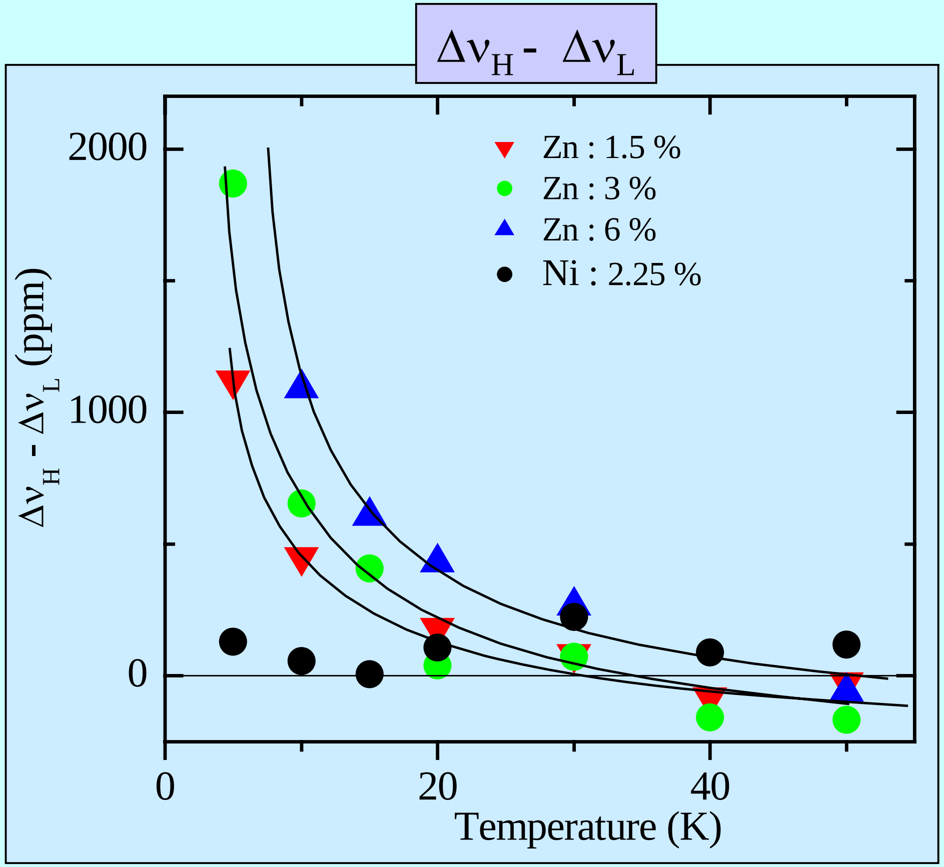


In-plane ^{17}O NMR in $YBaCuO_7$ (optimal doping) with Zn at H = 7 Tesla

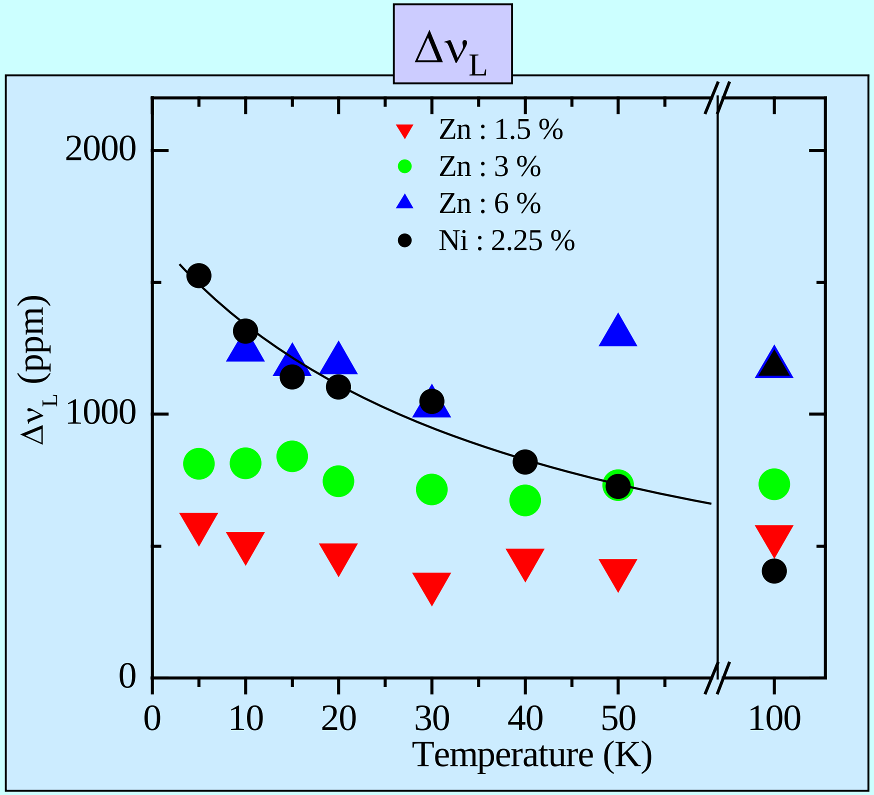
Induced polarization by non Magnetic Zn or magnetic Ni below T_C

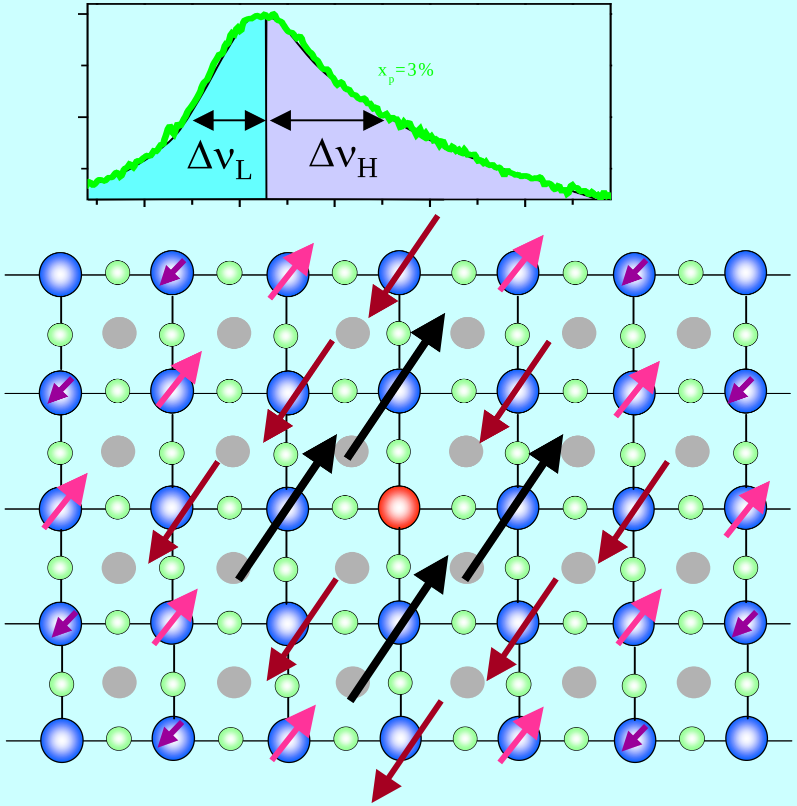






Induced polarization by non Magnetic Zn or magnetic Ni below T_C



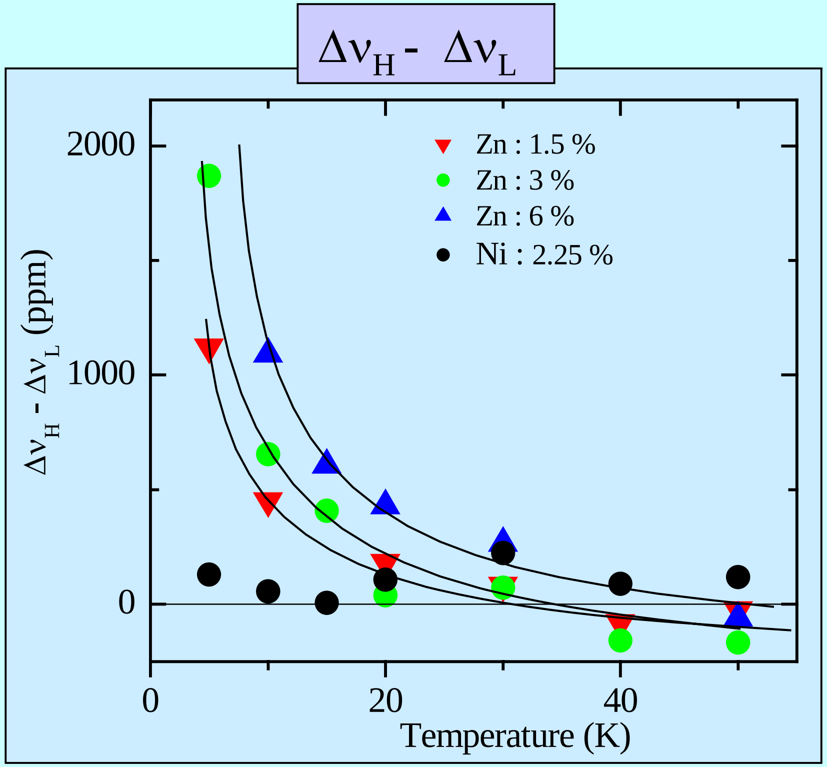


Staggered magnetization survives below T_C for Zn and Ni

- Zn : no T-dependence – saturation of $\xi \sim 3$ cells
- Ni : Curie-Weiss T-dependence – local moment on Ni

in the Ni case at least, coexistence between superconductivity and staggered magnetism

Induced polarization by non Magnetic Zn or magnetic Ni below T_C



Ouazi et al., 2005

New low temperature asymetry for Zn, not for Ni

- Local Space-Varying Density of States effect <u>near E_F</u>
- Confirmation of STM measurements, in YBaCuO bulk
- T-dependence : sharp decrease when increasing T

Some models for an impurity in the superconducting state

- BCS + unitary scattering
  (Hirschfeld, Balatsky, Salkola, Flatté ...)
- RPA (Ohashi)
- t-J + d-wave superconductivity (Wang & Lee)
- Kondo (Povkolnikov, Vojta, Sachdev)

Conclusions

Normal state of cuprates :

- Pseudogap analogous to low dimension insulating spin systems : strong correlations
- Optimal doping : still some correlations
- Quantitative estimate of the polarization : strong constraint for any microscopic model

Superconducting state :

- Many features typical of an anisotropic BCS superconductivity, especially DOS effects
- Zn and Ni Induced moments very similar to normal state
- Coexistence of staggered moments and superconductivity (Ni case)