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Muon-Spin-Relaxation Study of the Cu-Spin Correlation in the Bi-2201 High-T_c Superconductors

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T. Adachi *et al*., Phys. Rev. B 83 (2011) 184522.

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Introduction

- What's unsolved yet in HTSC
- Mysterious Bi-2201 in the viewpoint of the Cu-spin correlation

Results

- μSR in (Bi,Pb)-2201 in a wide doping range
- Comparison with other cuprates

— { Weakness of Cu-spin correlation
  { Novel magnetism ?

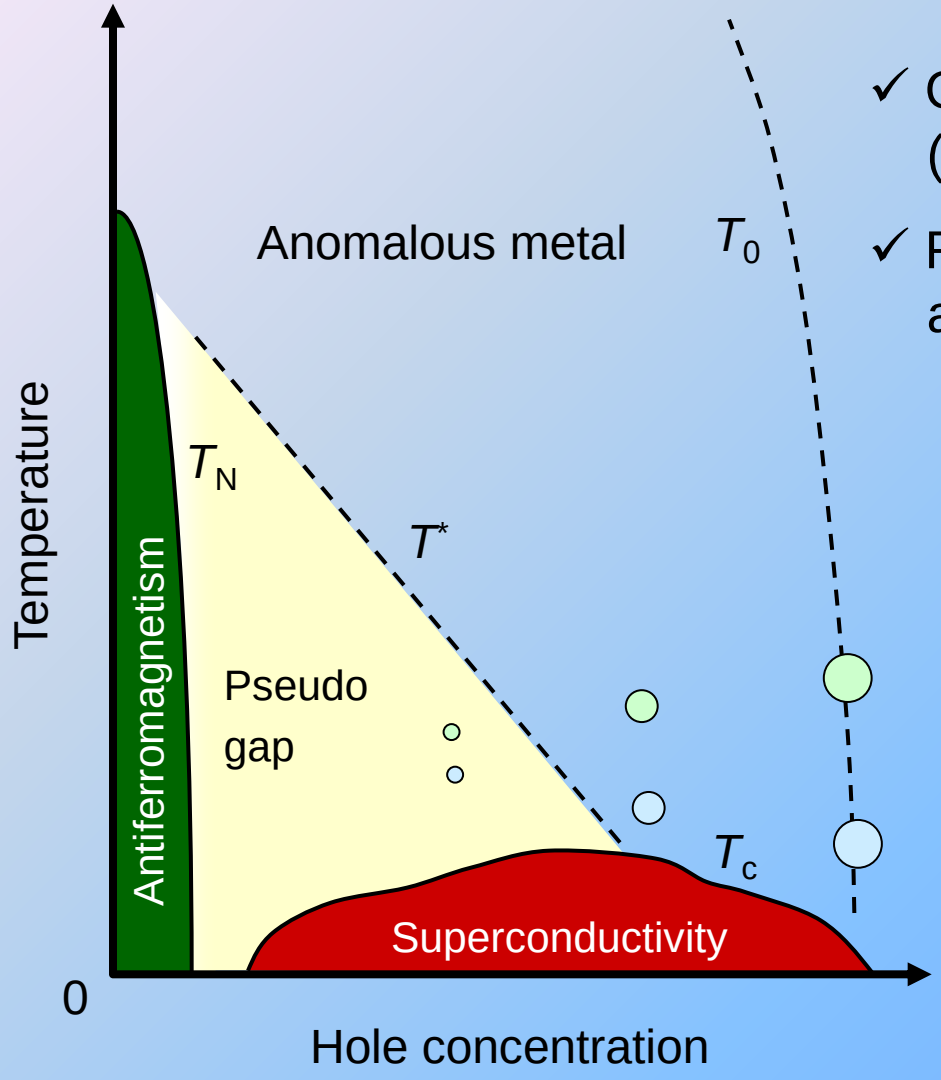
Summary

Phase diagram of high-T_c superconductivity

- What are unsolved yet in high-T_c SC ?

✓ Glue to form an electron pair (Why T_c is high ?)

✓ Relation between the pseudogap and superconductivity



Am I a competitor with superconductivity ?

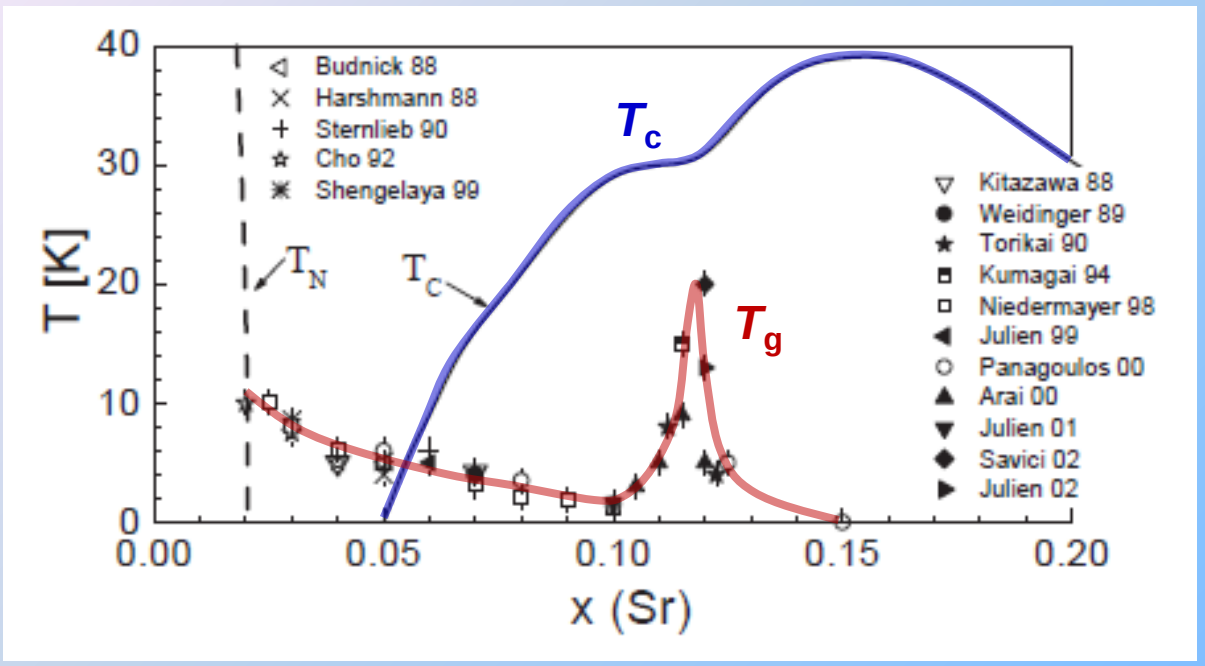
or

Am I a precursor of superconductivity ?

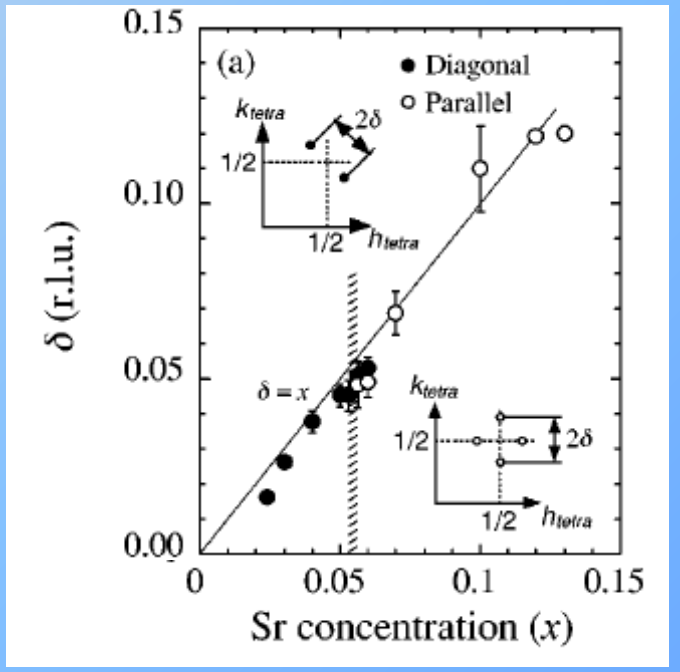
Magnetism (stripes) and superconductivity in underdoped cuprates

μSR, NMR —— $La_{2-x}Sr_xCuO_4$

Neutron scattering in LSCO



M.-H. Julien *et al.*, Physica B **329-333** (2003) 693.



M. Fujita *et al.*, Phys. Rev. B **65** (2002) 064505.

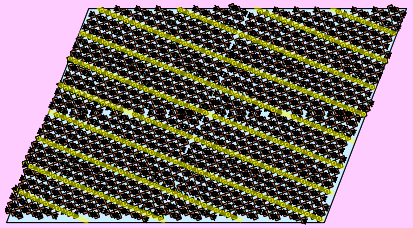
✓ YBCO

C. Niedermayer *et al.*, Phys. Rev. Lett. **80** (1998) 3843.

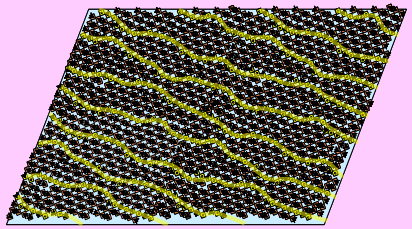
✓ Bi-2212

C. Panagopoulos *et al.*, Phys. Rev. B **66** (2002) 064501.

Stripe-related magnetism



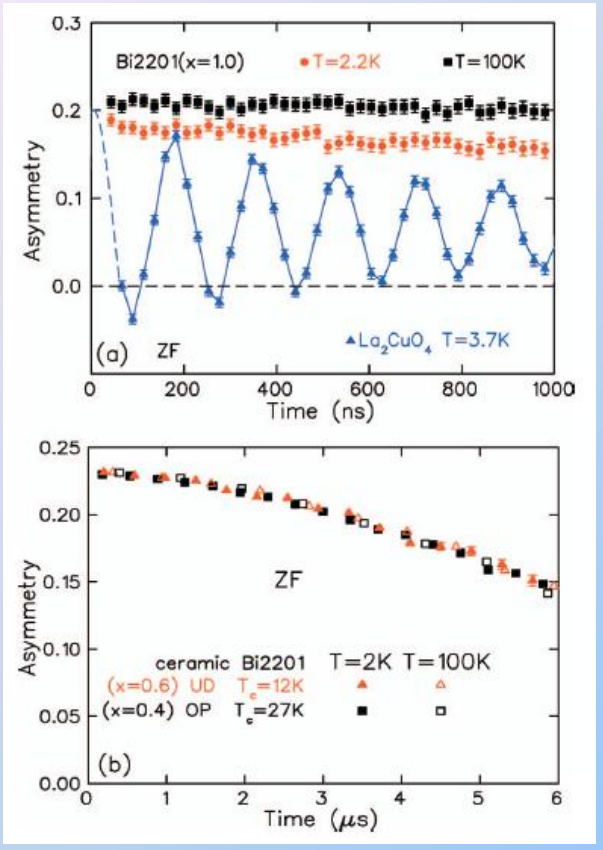
Static stripe (non-SC)



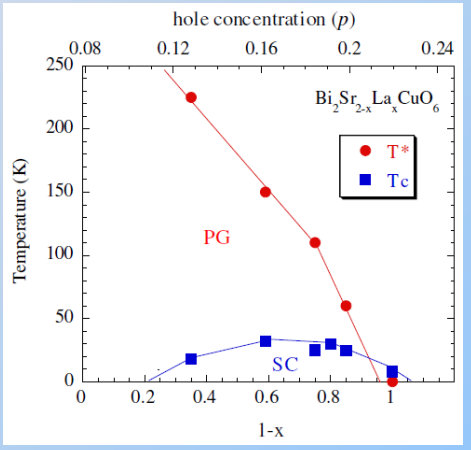
Dynamical stripe (SC)

μSR: Absence of the developed Cu-spin correlation in Bi-2201 ?

$Bi_2Sr_{2-x}La_xCuO_{6+\delta}$



P. L. Russo *et al.*, Phys. Rev. B **75** (2007) 054511.



G.-Q. Zheng *et al.*, Phys. Rev. Lett. **94** (2005) 047006.

μSR
($T \geqq 2$ K)

$Bi_{1.76}Pb_{0.35}Sr_{1.89}CuO_{6+\delta}$

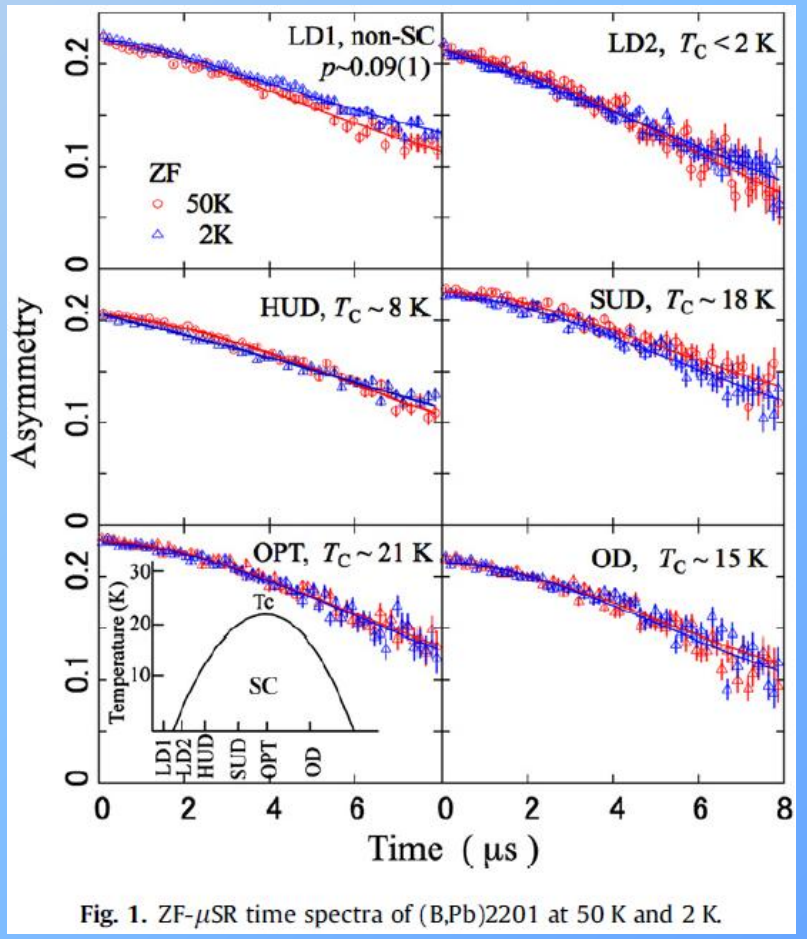


Fig. 1. ZF-μSR time spectra of (B,Pb)2201 at 50 K and 2 K.

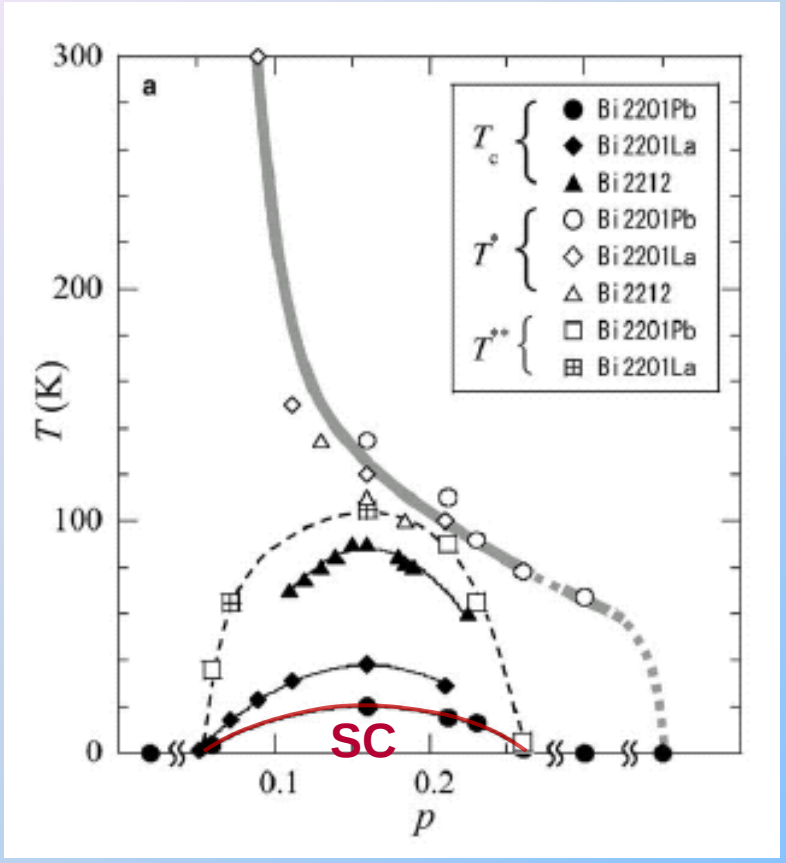
M. Miyazaki *et al.*, Physica C **470** (2010) S55.

⟺ NMR: Magnetic order in the insulating regime

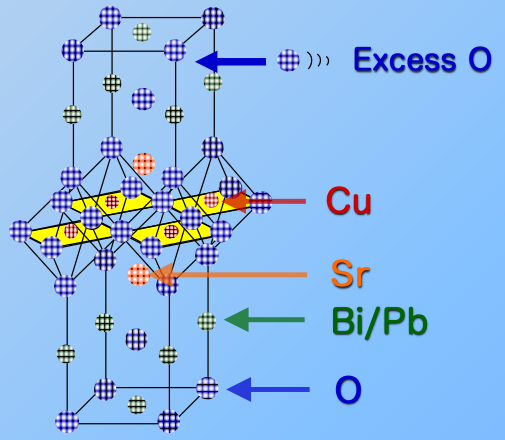
M. Kato *et al.*, J. Solid State Chem. **133** (1997) 372.
S. Kawasaki *et al.*, Phys. Rev. Lett. **105** (2010) 137002.

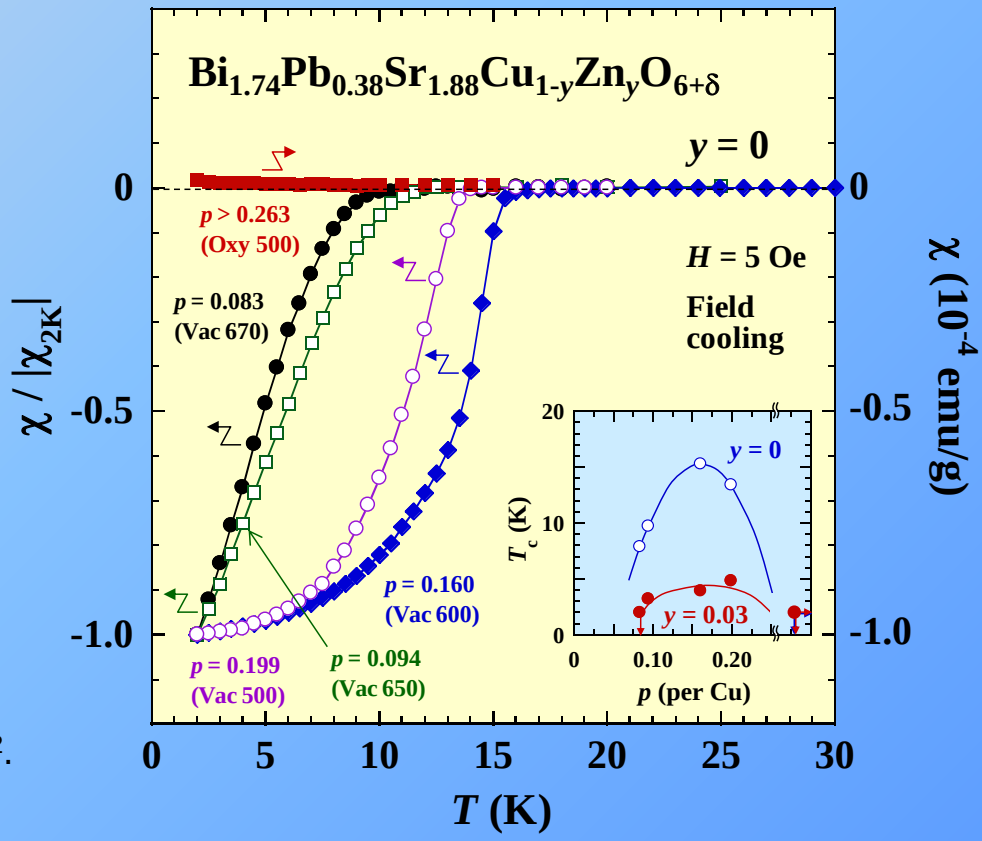
Bi-2201: Clean high-T_c cuprate covering a wide doping range

$(Bi,Pb)_2Sr_2CuO_{6+\delta}$



K. Kudo *et al.*, Physica C **426** (2005) 251.

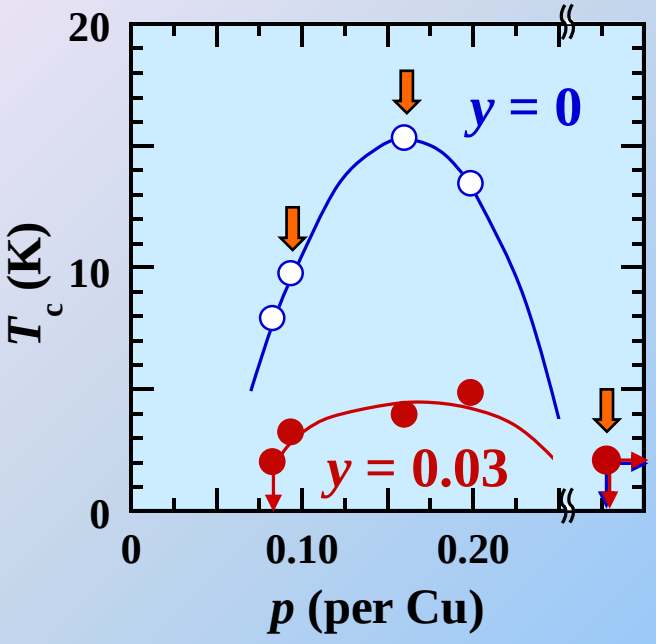


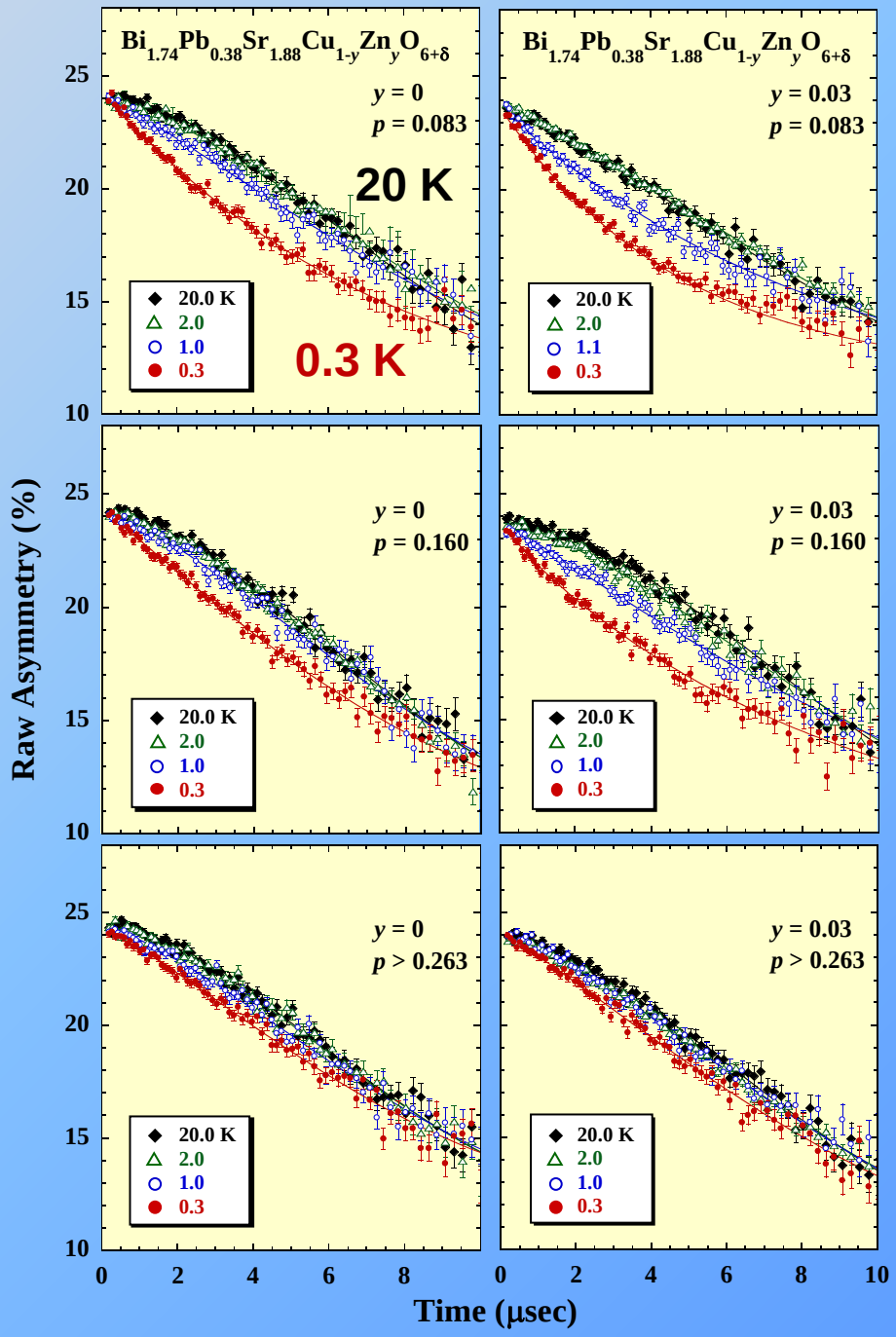


The p is estimated from $T_c / T_c^{max} = 1 - 82.6(p - 0.16)^2$.

M.R. Presland *et al.*, Physica C **176** (1991) 95.

Observation of the developed Cu-spin correlation below 2 K in the SC regime

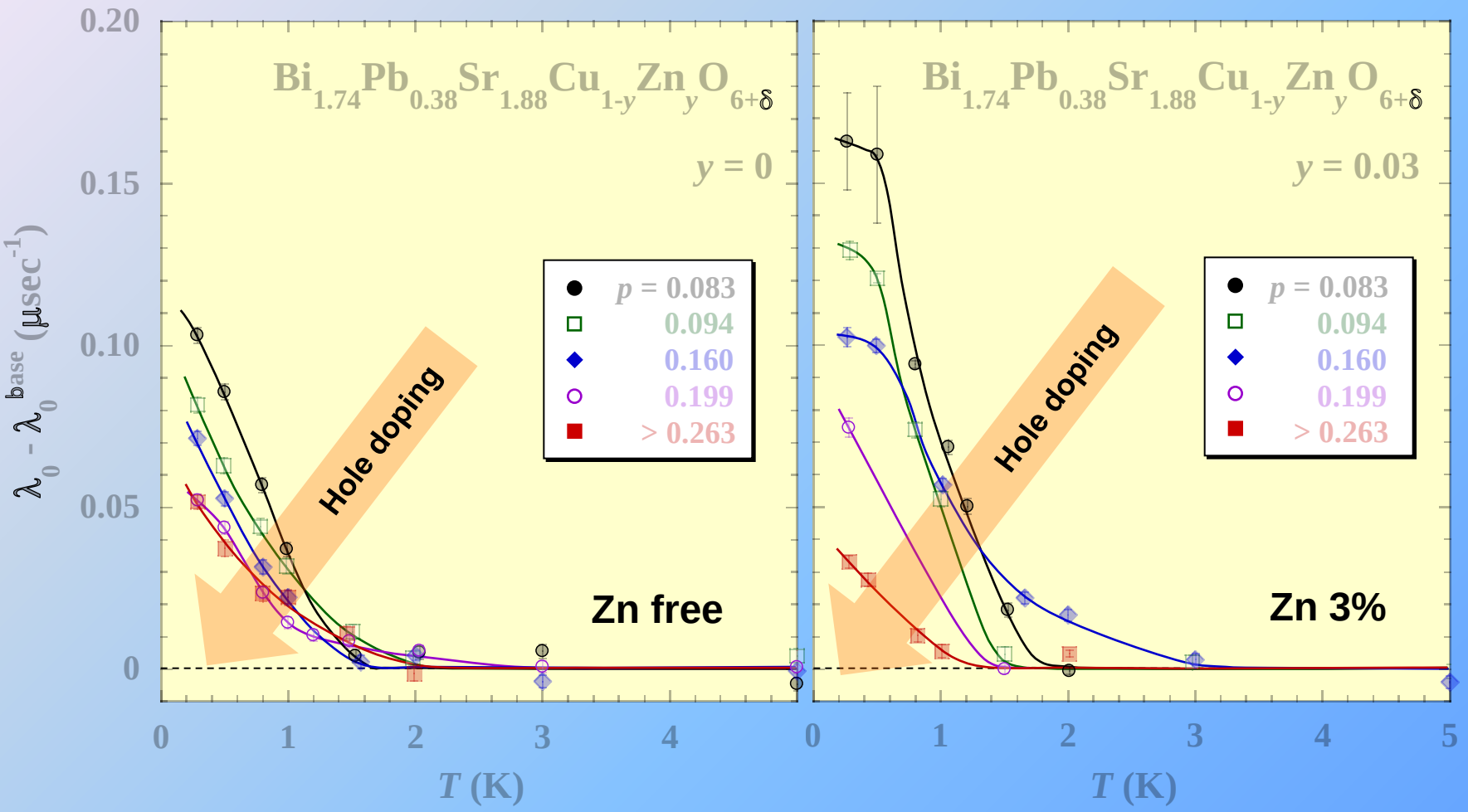




- ✓ Fast depolarization of muon spins below 2 K
- ✓ At 2 K, weakening of the depolarization with increasing hole concentration
- ✓ Apparent change of the spectra in the non-SC heavily overdoped regime

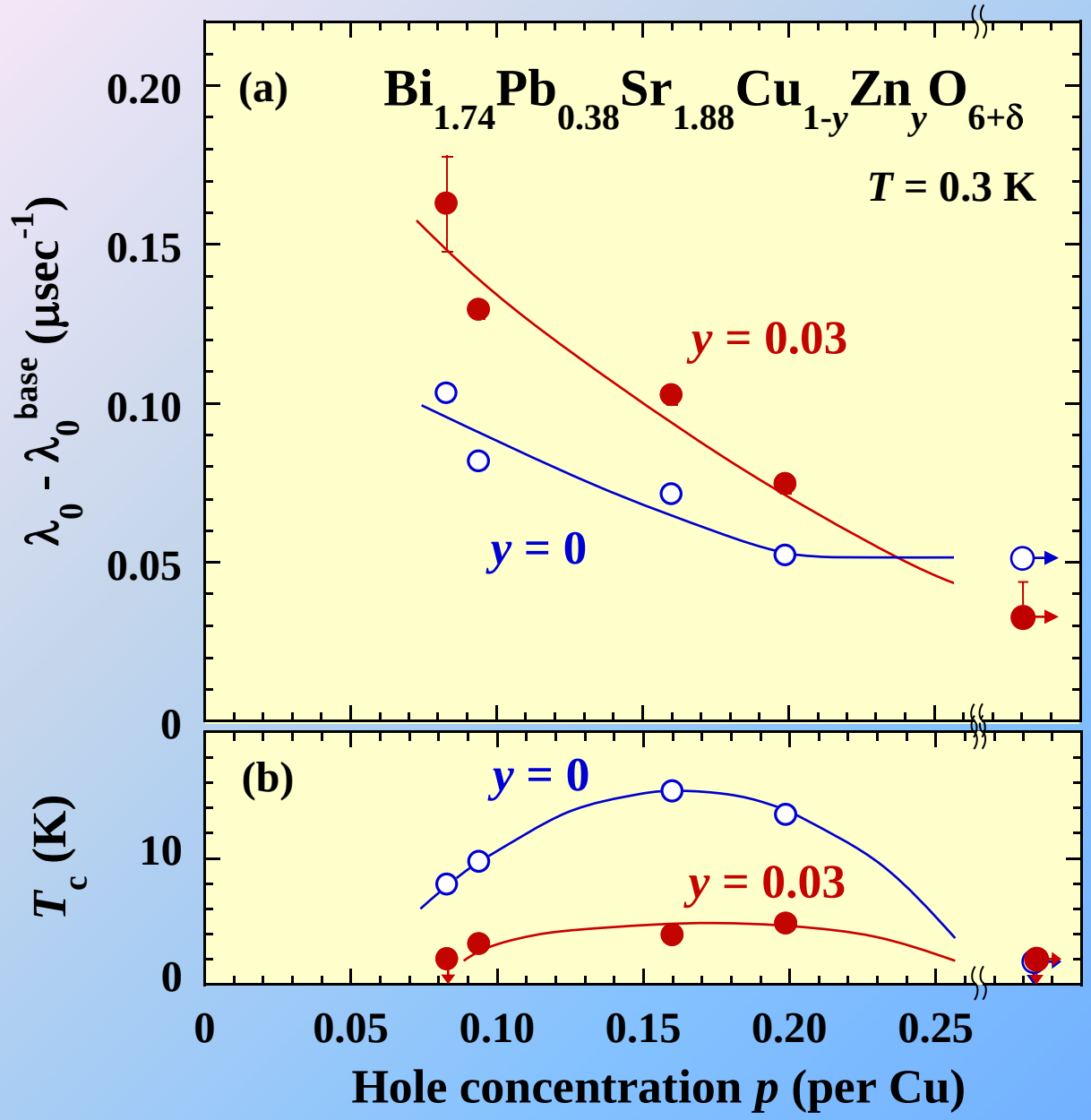
Development of the Cu-spin correlation depending on the hole and Zn concentrations

Analysis function: $A(t) = A_0\exp(-\lambda_0 t)G_Z(\Delta,t) + A_1\exp(-\lambda_1 t)$



✓ The depolarization rate is enhanced by Zn substitution in the SC regime.

Development of the Cu-spin correlation depending on the hole and Zn concentrations



- ✓ Weakening of the developed Cu-spin correlation with hole doping
- ✓ Enhancement of the developed Cu-spin correlation with Zn
- ✓ Development of the Cu-spin correlation even in the non-SC heavily overdoped samples

Development of the stripe correlations in Bi-2201

In Bi-2201 cuprates,

- ✓ Development of the Cu-spin correlation in the SC regime
- ✓ Weakening of the Cu-spin correlation with hole doping
- ✓ Enhancement of the Cu-spin correlation through Zn substitution in the SC regime

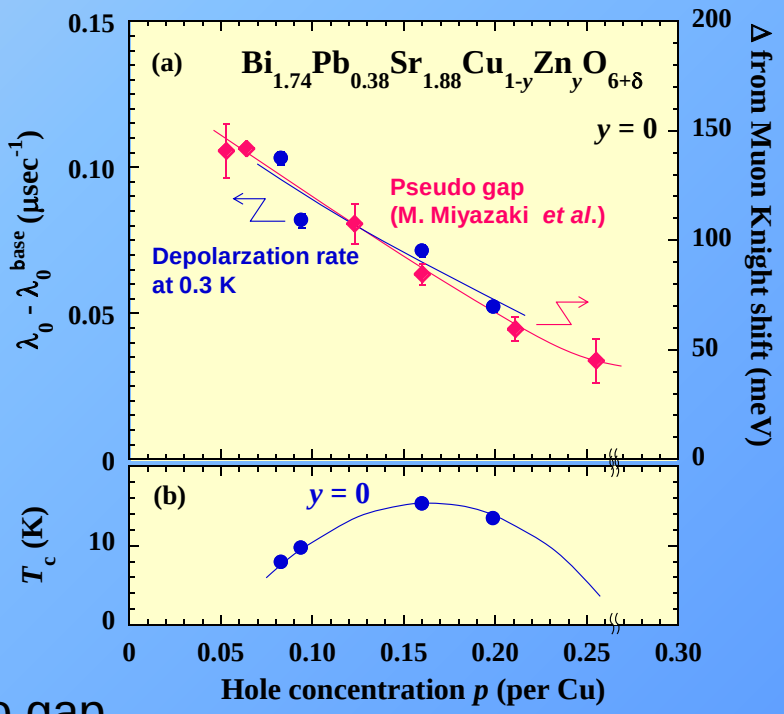
Similar to the La-214 cuprates

I. Watanabe *et al*., PRB (2002)
T. Adachi *et al*., PRB (2004, 2008).
Risdiana *et al*., PRB (2008).

Incommensurate Cu-spin correlation from inelastic neutron scattering

M. Enoki *et al*., unpublished.

Dynamical stripe correlations exist in the whole SC regime and are pinned and stabilized through Zn substitution in the Bi-2201 cuprate.

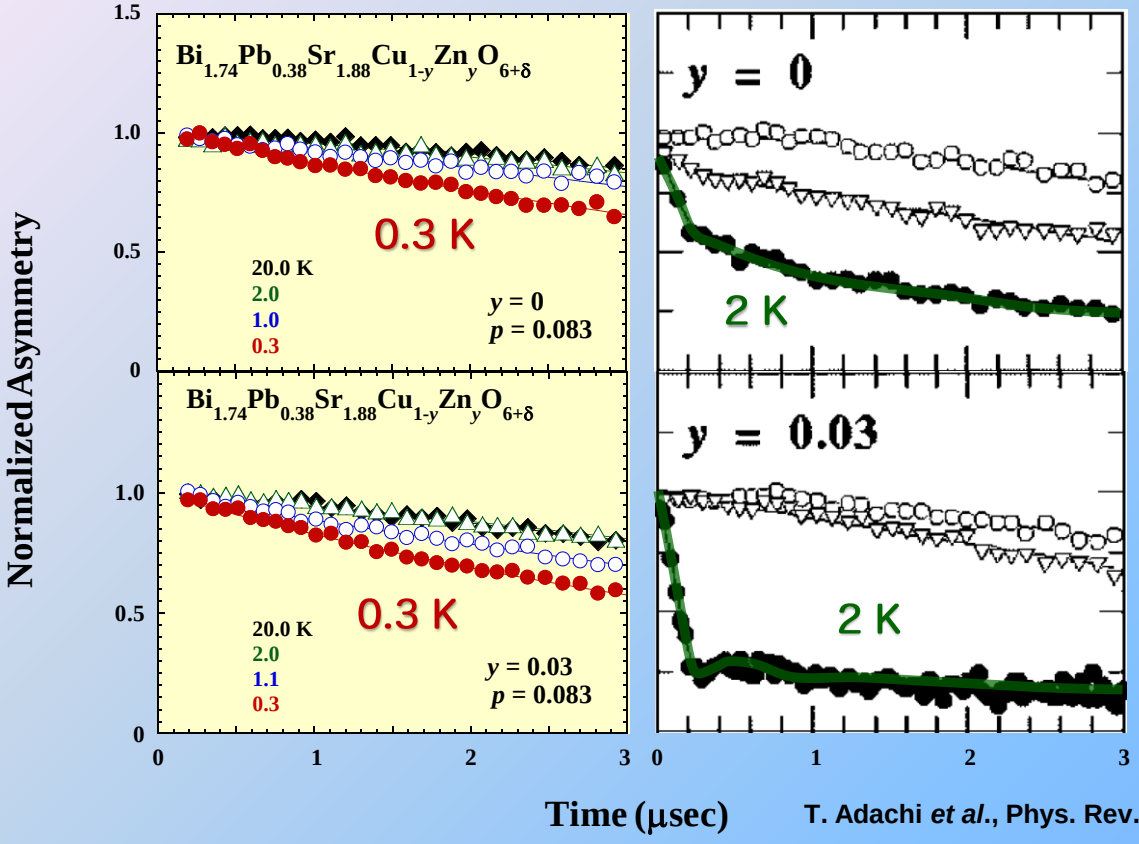


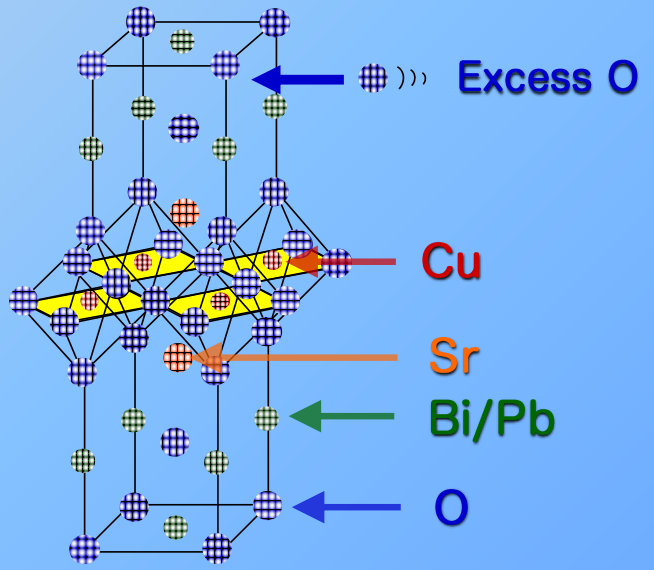
M. Miyazaki *et al*., in this session.

● Developed Cu-spin correlation ⟺ ? Pseudo gap

Weakness of the developed Cu-spin correlation in Bi-2201

Bi-2201 (p = 0.083) LSCO (x = 0.10)



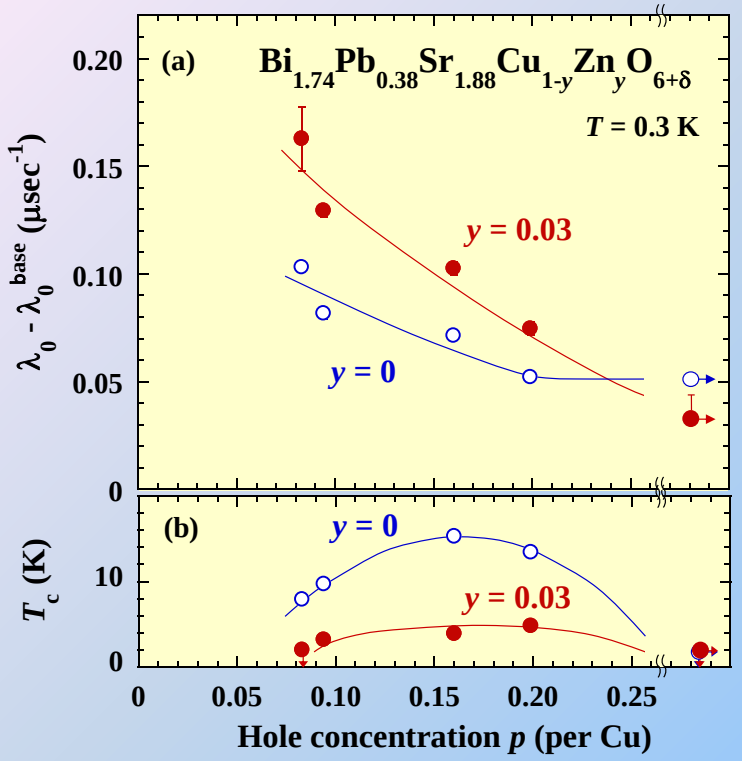


T. Adachi *et al.*, Phys. Rev. B 69 (2004) 184507.

Possible reasons

- ✓ Weakness of the stripe correlations only in Bi-2201 ?
- ✓ Strong two-dimensionality of the crystal structure ?

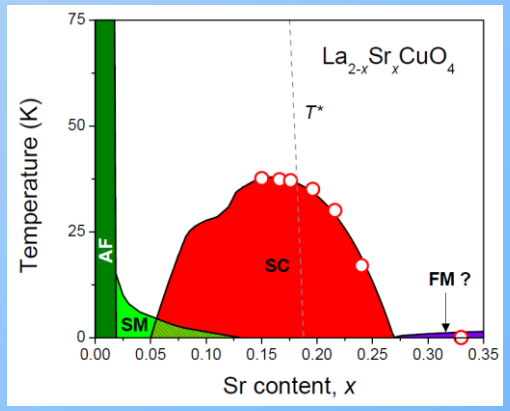
Novel magnetic state in the heavily overdoped regime ?

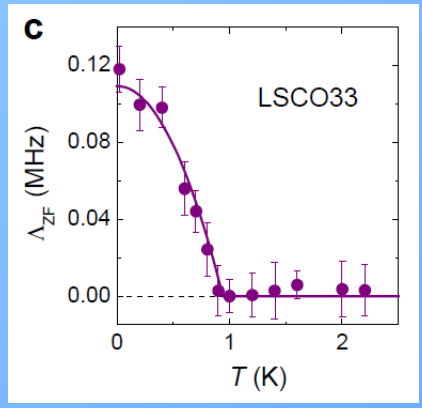


Development of the Cu-spin correlation even in the non-SC heavily overdoped samples

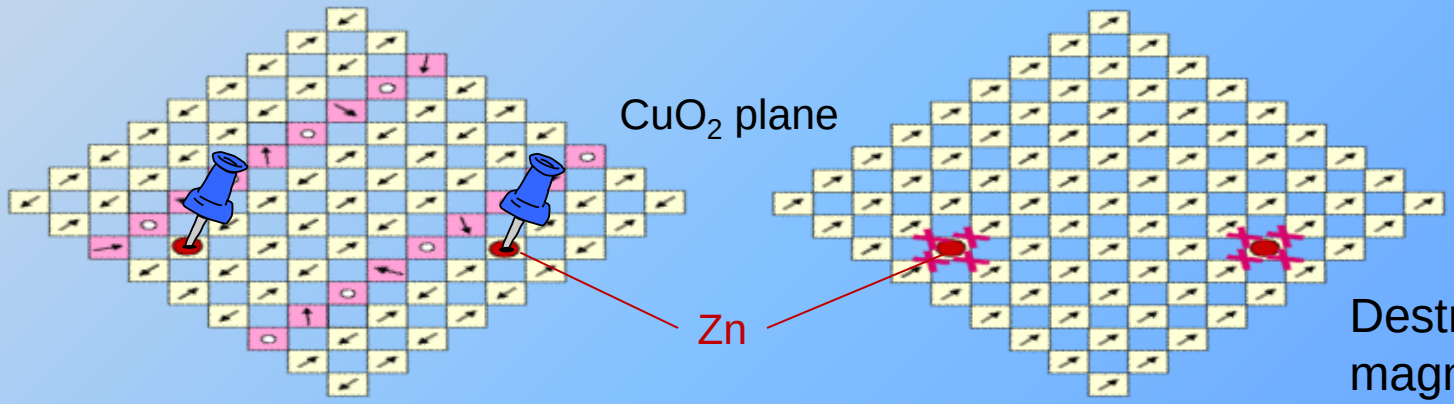
Observation of the developed Cu-spin correlation in LSCO (x = 0.33)
(Ferromagnetism ?)

J. E. Sonier *et al.*, PNAS **107** (2010) 17131.





Pinning of stripe



Destruction of ferro-magnetic network

Summary

- **Zn-induced development of the Cu-spin correlation in the whole SC regime of both Bi-2201 and LSCO**

  Dynamical stripe correlations exist in the whole SC regime and are pinned and stabilized through Zn substitution.

Intimate relation between the stripe correlations and high-T_c superconductivity is much convinced.

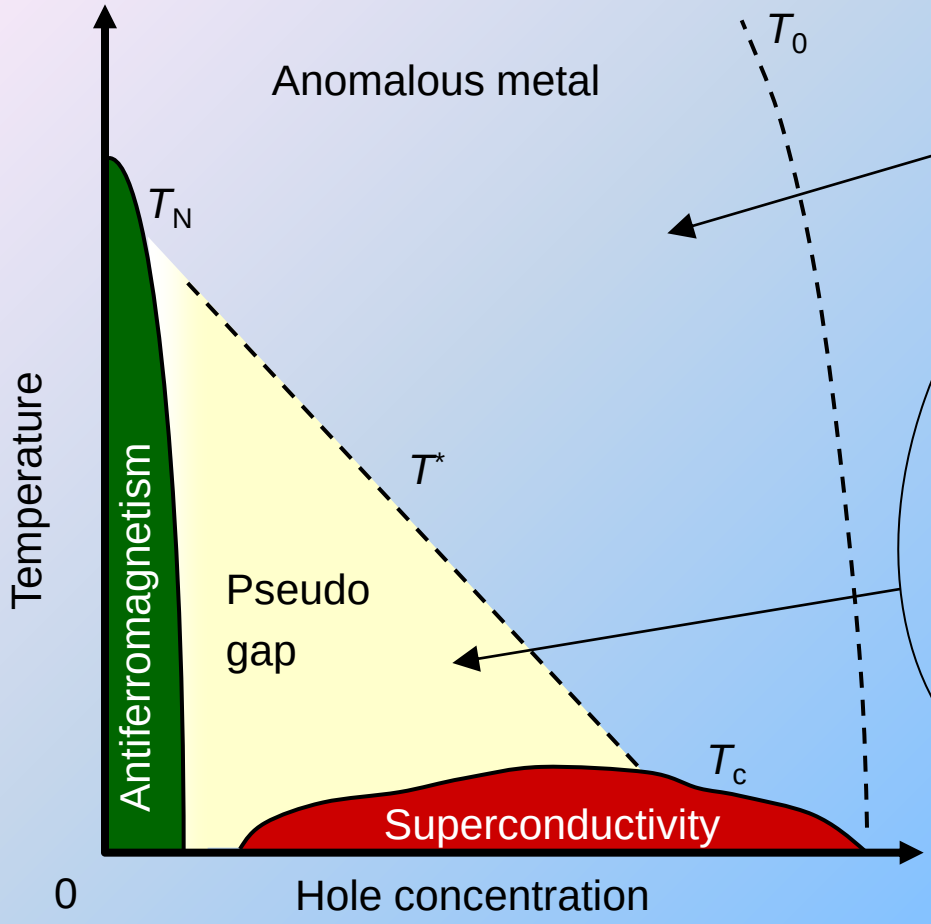
- **Development of the Cu-spin correlation even in the non-SC heavily overdoped sample in Bi-2201**

  Due to recently suggested ferromagnetism in non-SC LSCO with x = 0.33 ?

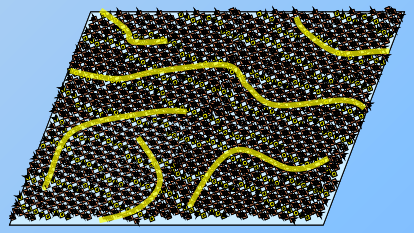
J. E. Sonier *et al*., PNAS **107** (2010) 17131.

Whole view of high-T_c superconductivity relating to the stripes

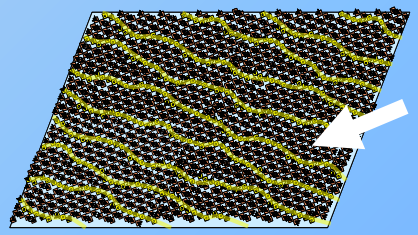
S. A. Kivelson *et al.*



Fluctuating stripe



Formation of electron pairs by stripe correlation



Spin gap in spin domain

⇨ Electron pairs in hole domain

- ✓ Glue to form an electron pair ⇨ Antiferromagnetic (stripe) correlation
- ✓ Relation between the pseudogap and superconductivity ⇨ Pseudogap as a precursor of superconductivity