Search for conducting stripes in lightly hole doped YBCO

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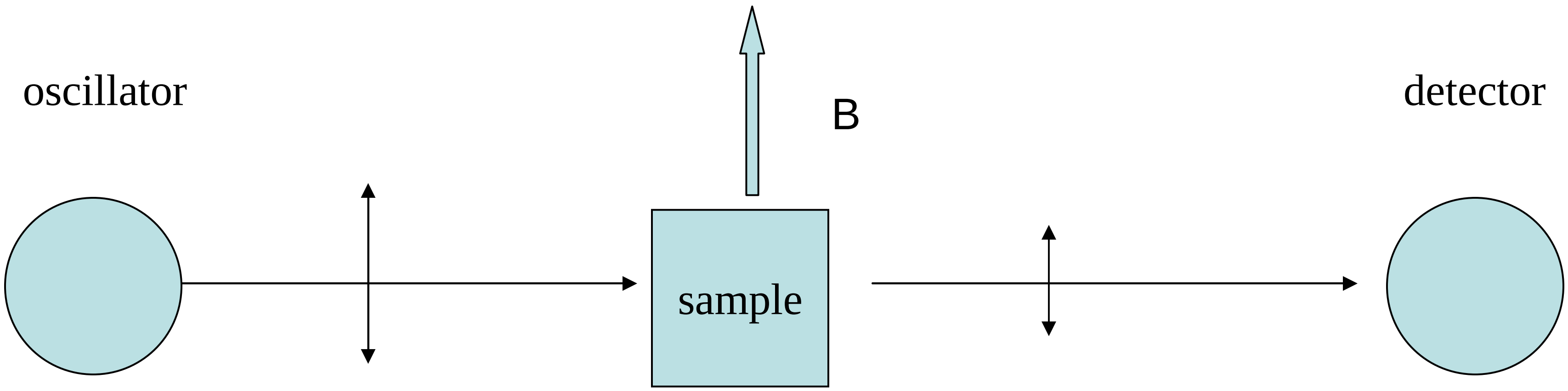
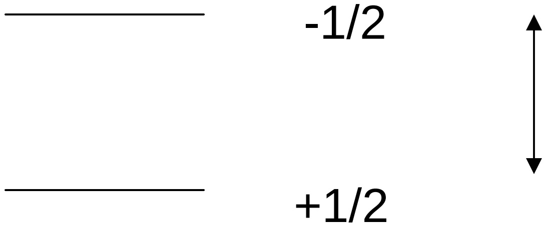
[4]Stony Brook University New York USA

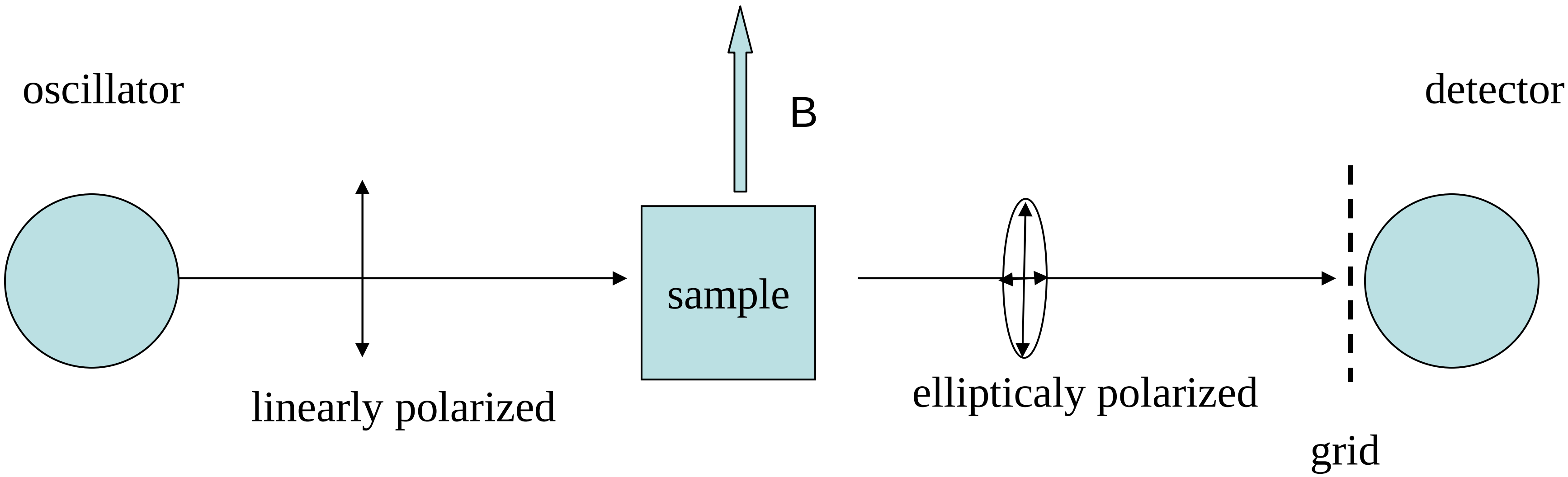
ESR spectrometer

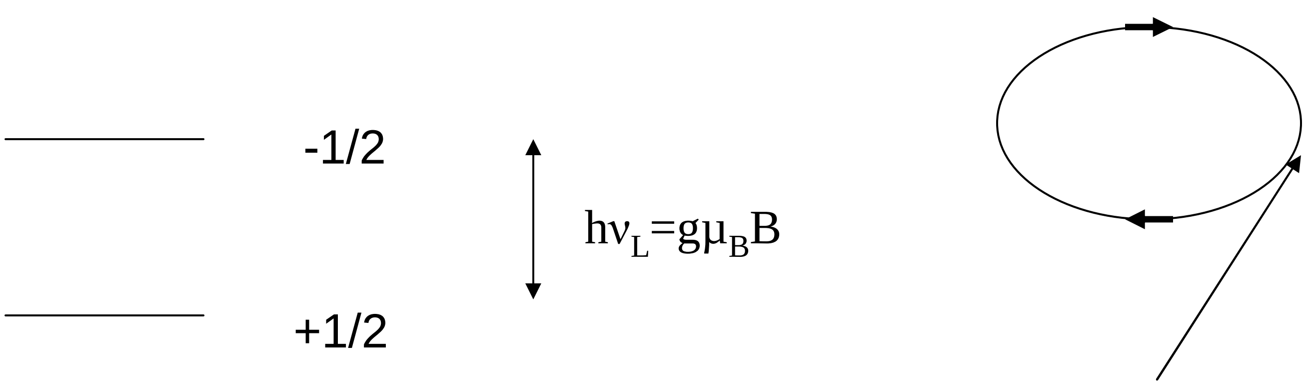




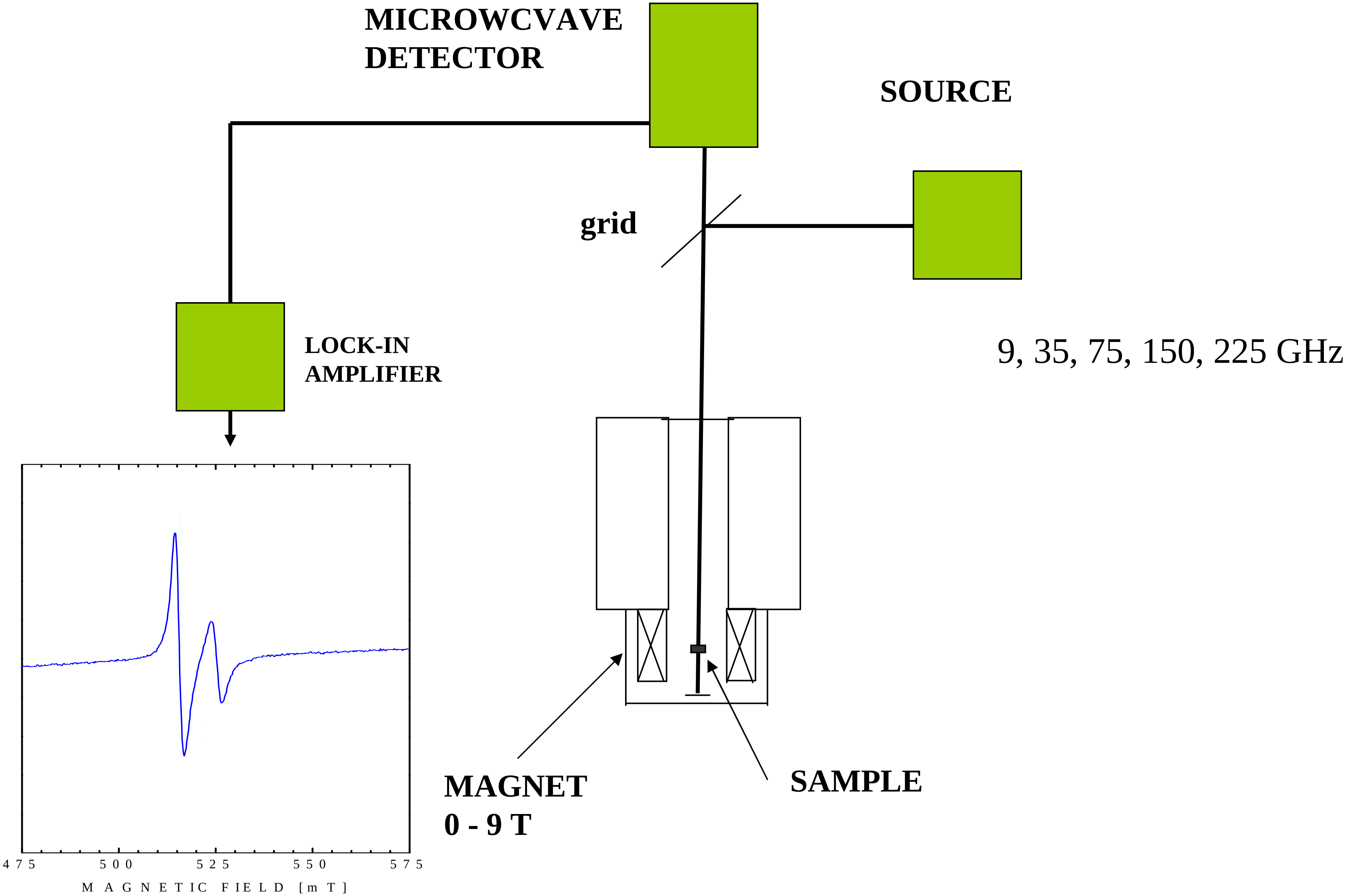
$h\nu_L = g\mu_B B$

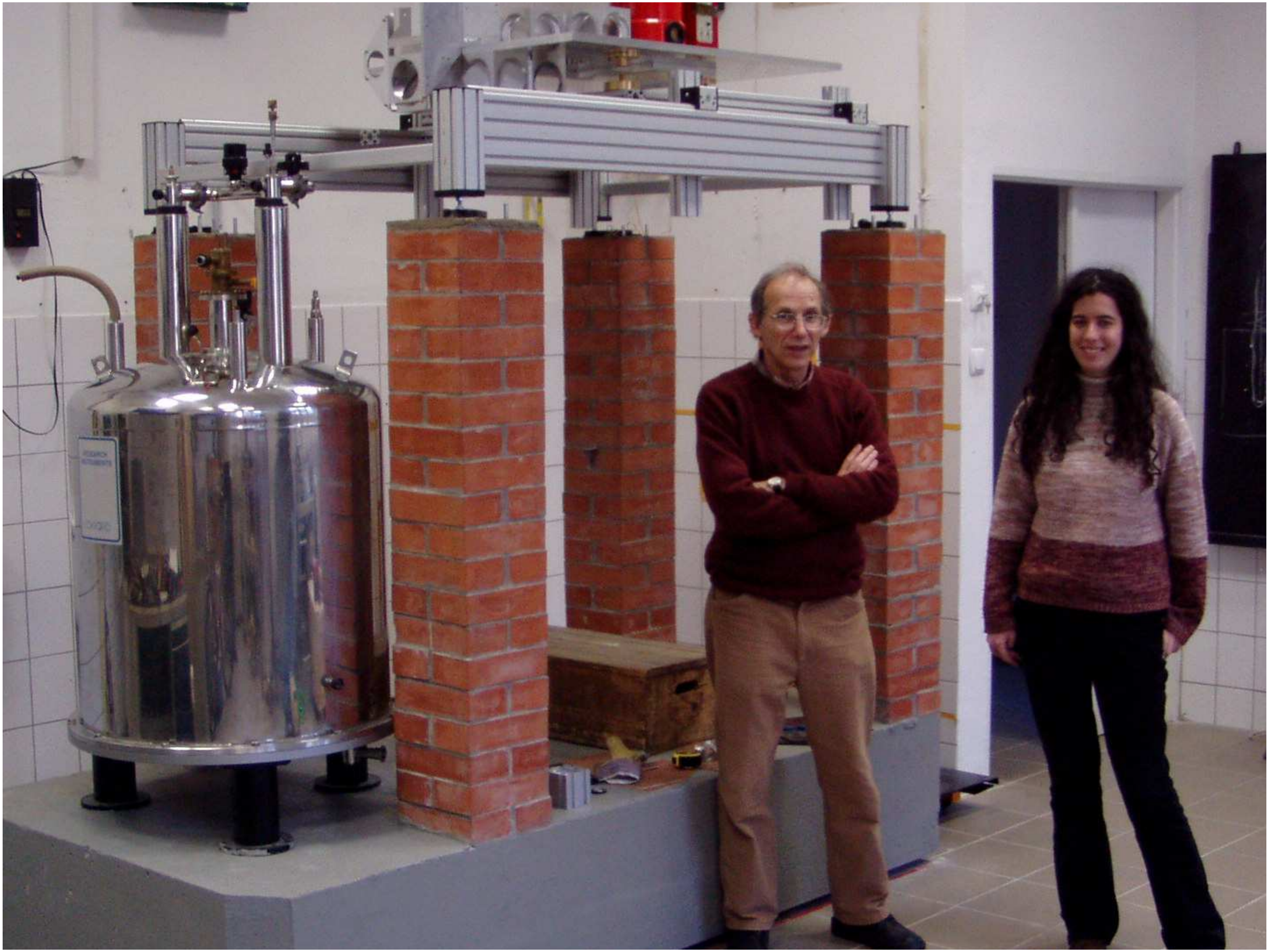
ESR spectrometer





ESR spectrometer





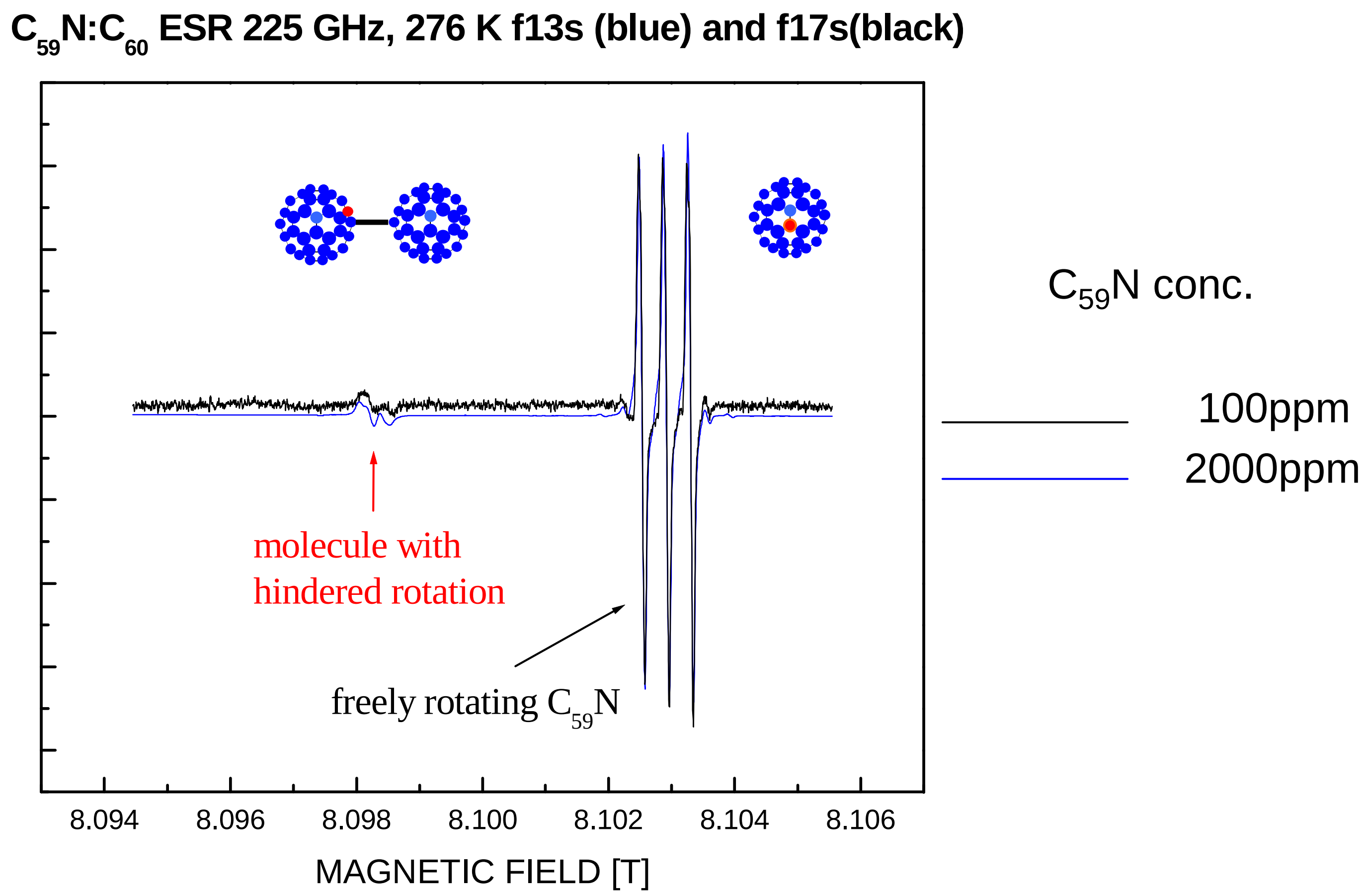
High frequency ESR:

- high resolution

- magnetic field dependence

- high resolution

ESR in
$C_{59}N$ doped solid C_{60}



Outline

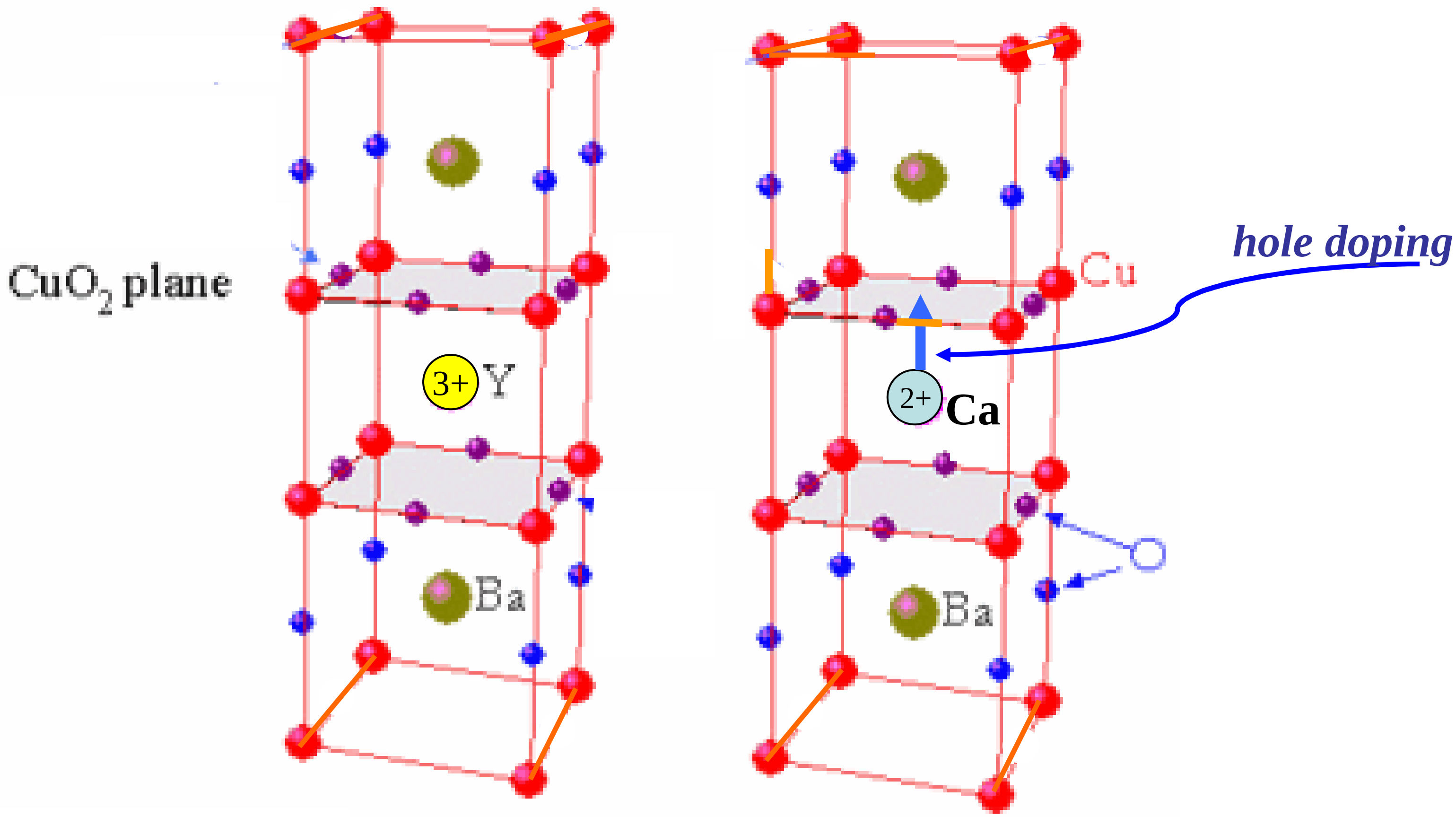
cuprate phase diagram

Gd^{3+} ESR probe

antiferromagnetic domains

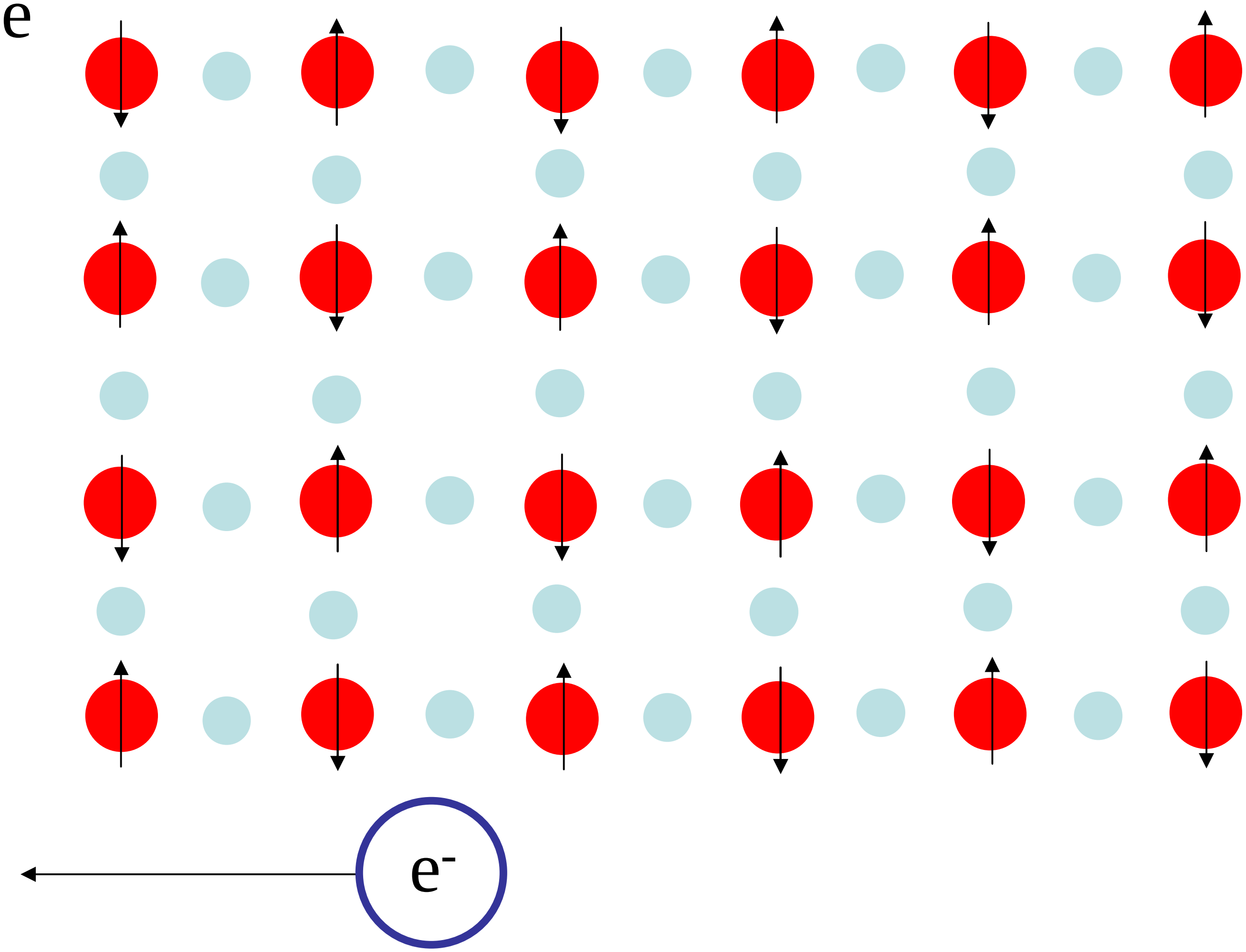
search for conducting stripes

Structure of $Ca_xY_{1-x}\ Ba_2Cu_3O_6$

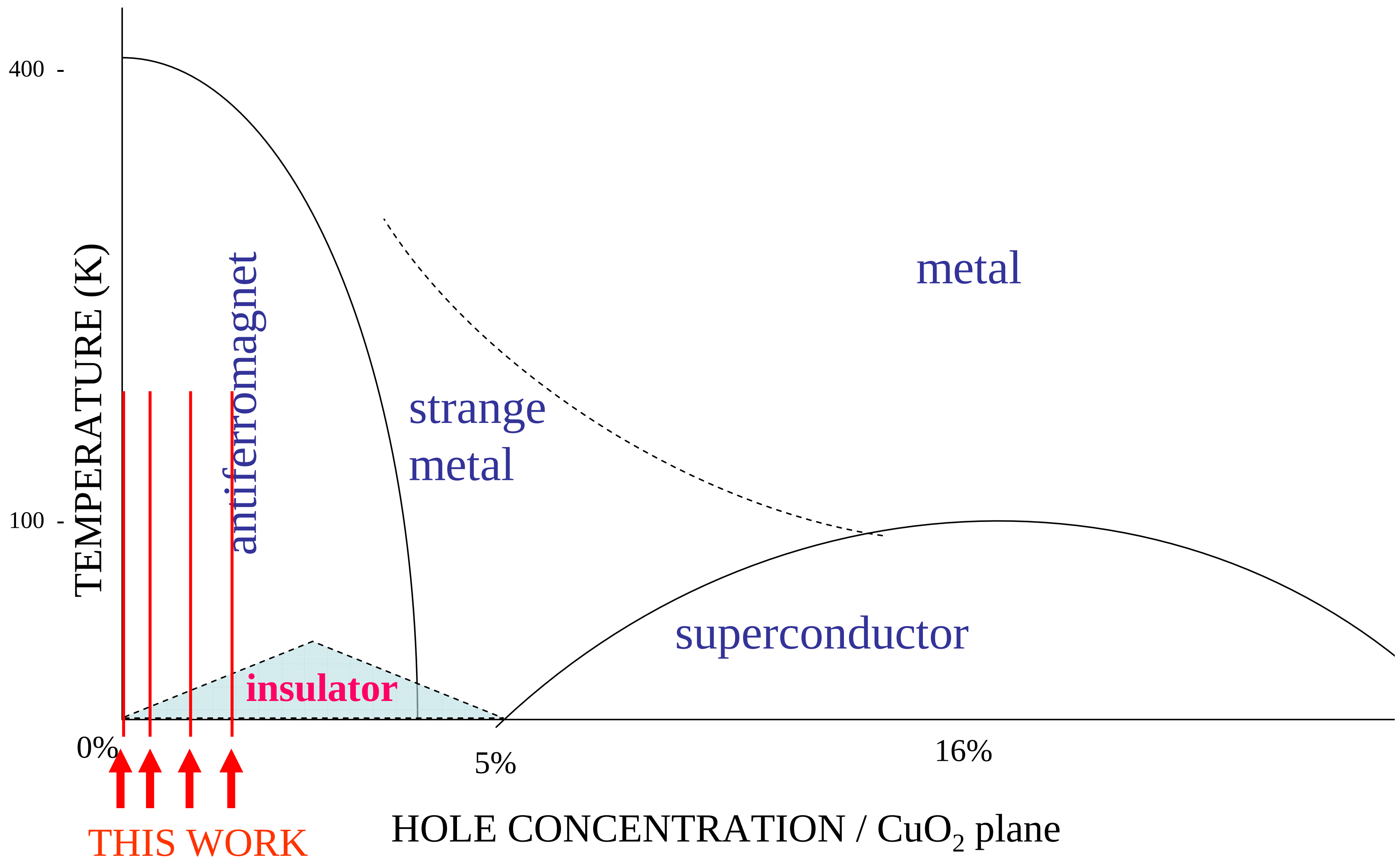


YBCO undoped

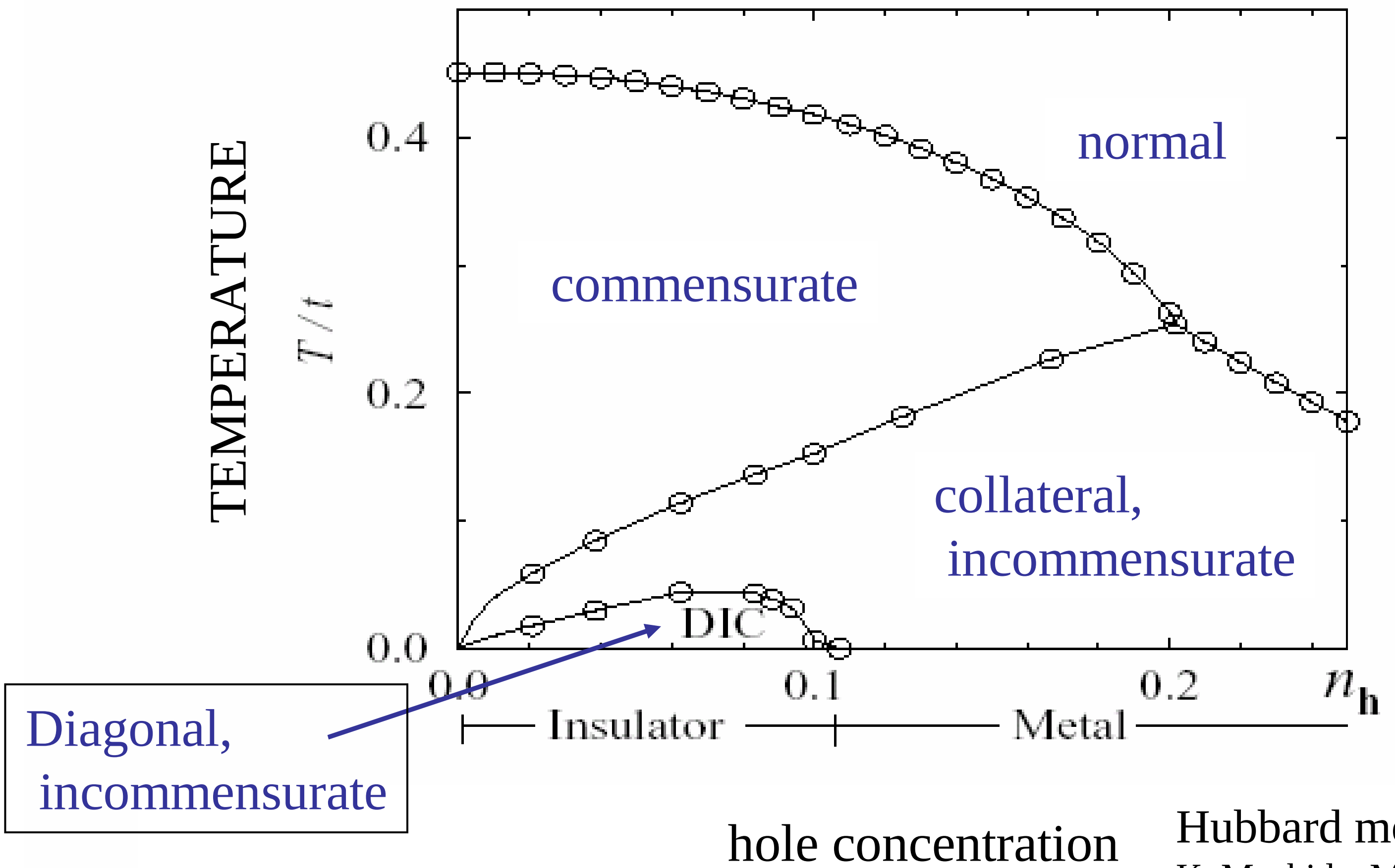
CuO_2 plane



Phase diagram of cuprates



Charge- spin phase separation

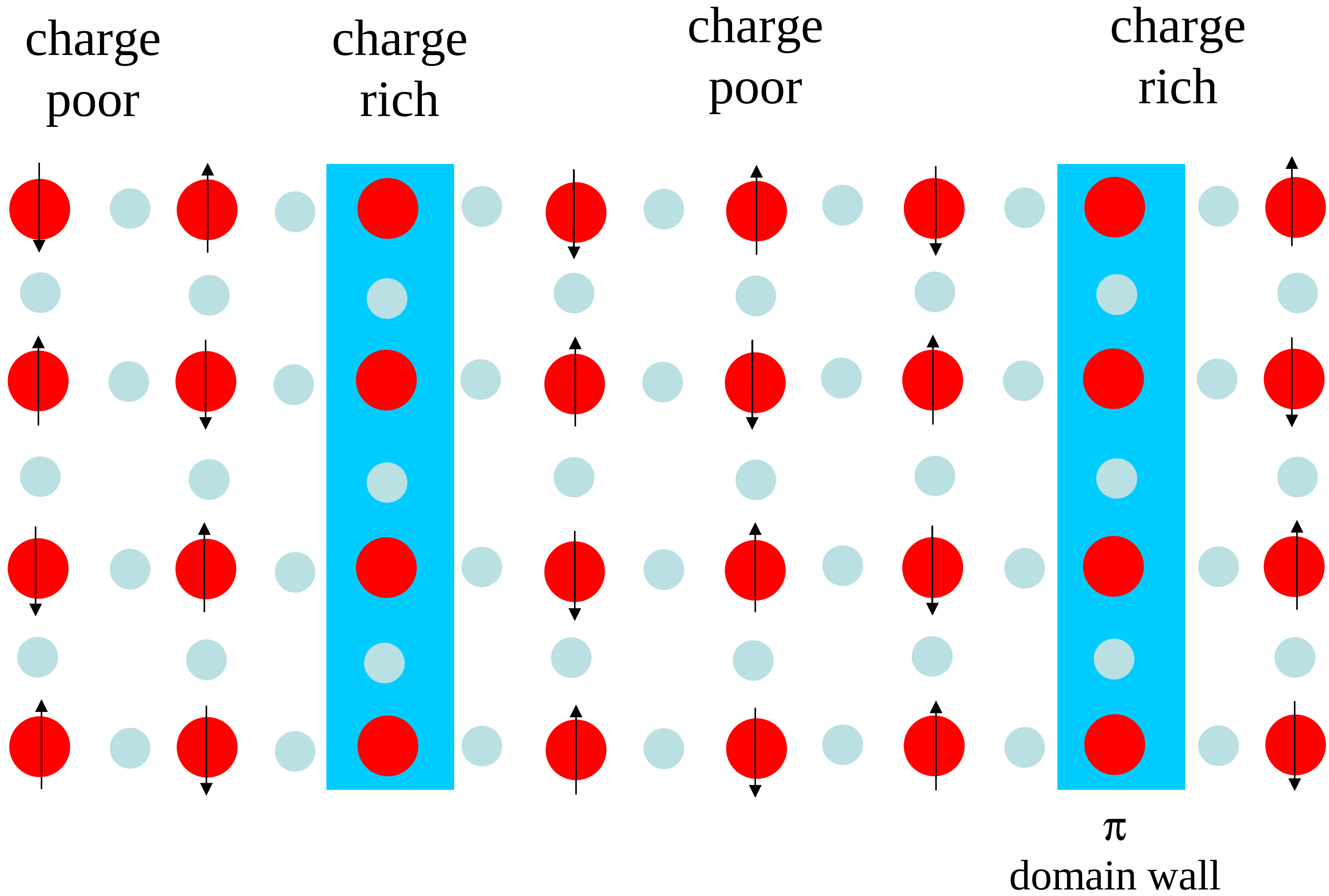


Hubbard model. Mean field.
K. Machida, M. Ichioka J. Phys. Soc. Jpn. 68 2168 1999.

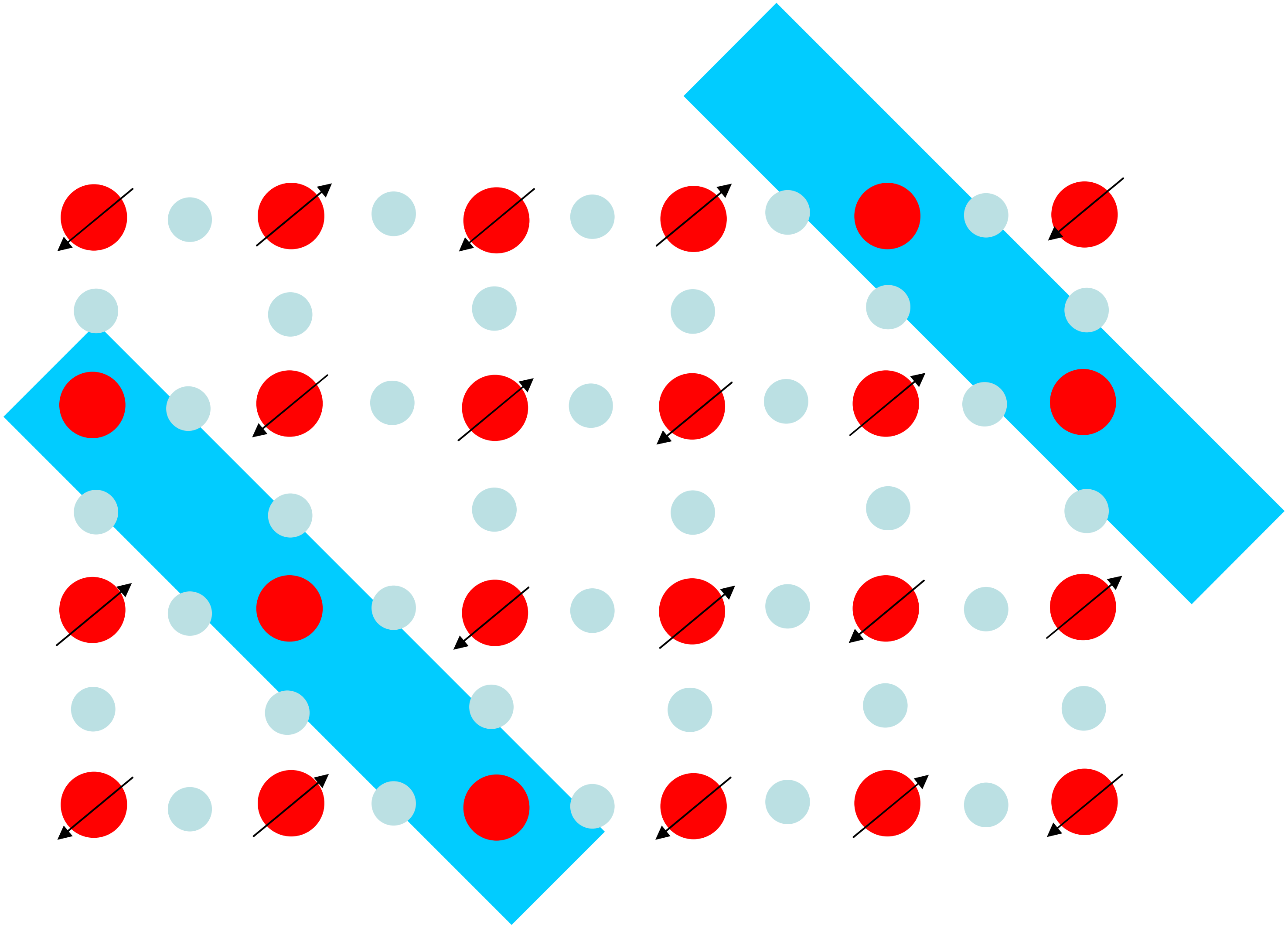
STRIPES

Predictions: J. Zaanen, O. Gunnarsson, 1989
H.J. Schultz 1990
K. Machida 1989

First experiment: J. Tranquada, 1995



collinear incommensurate spin and charge modulation



diagonal incommensurate modulation

Neutron diffraction

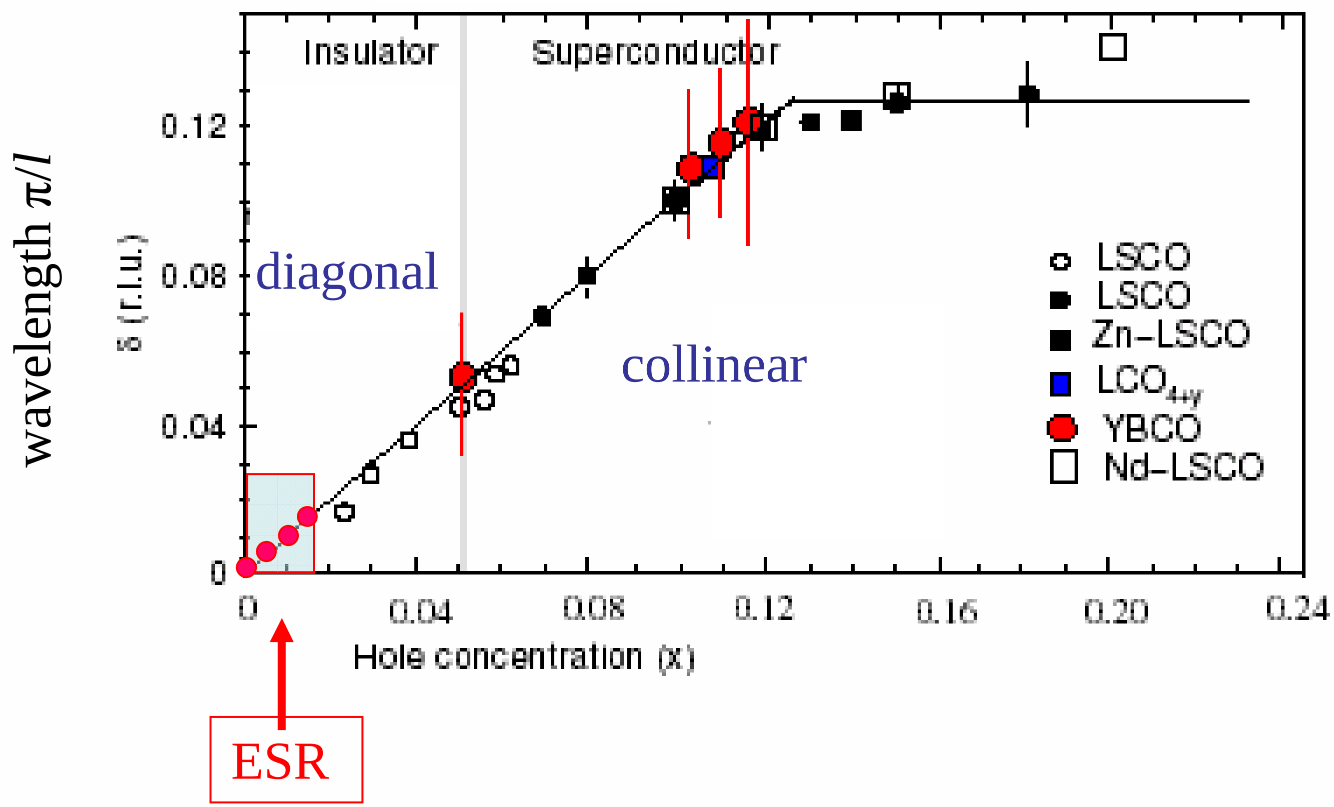
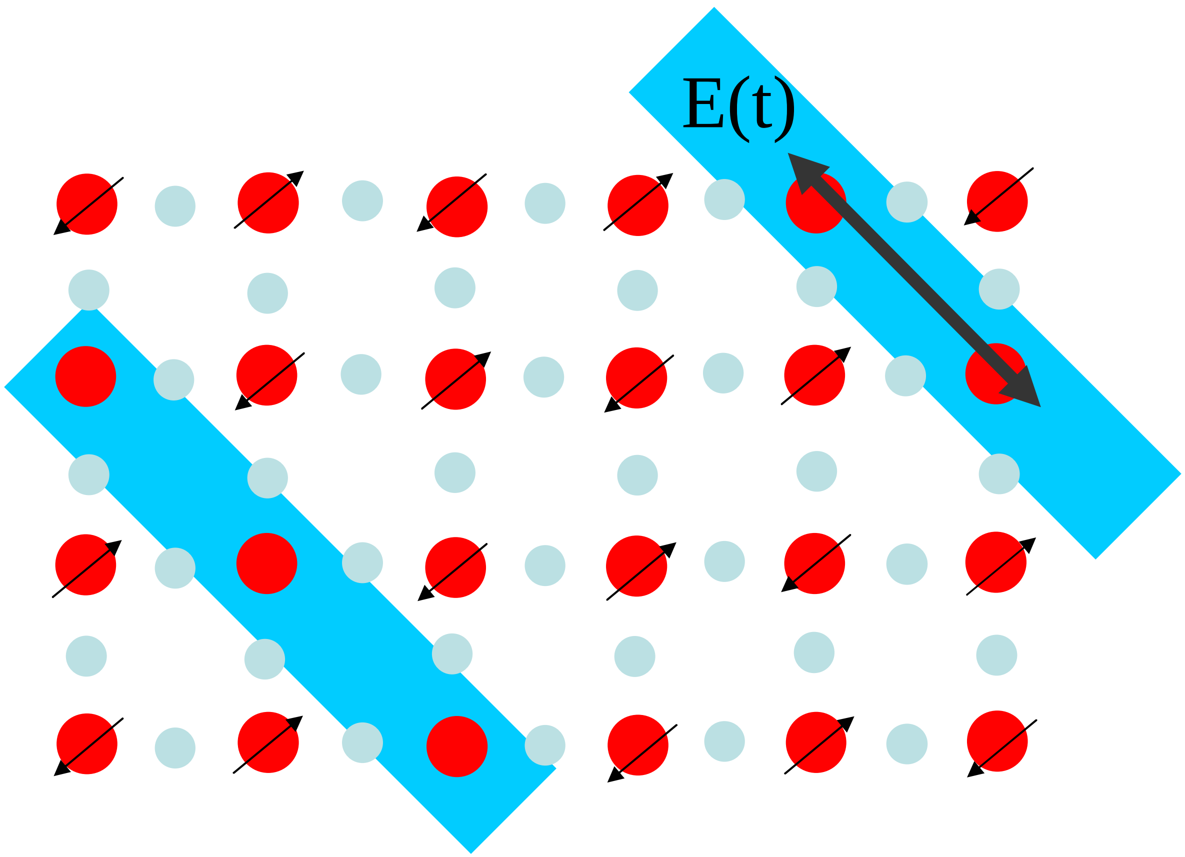


Figure 1.4. Summary of data concerning incommensurability $\delta = \pi/\ell$ as a function of doping concentration x. Data were obtained from neutron-scattering measurements by several groups:

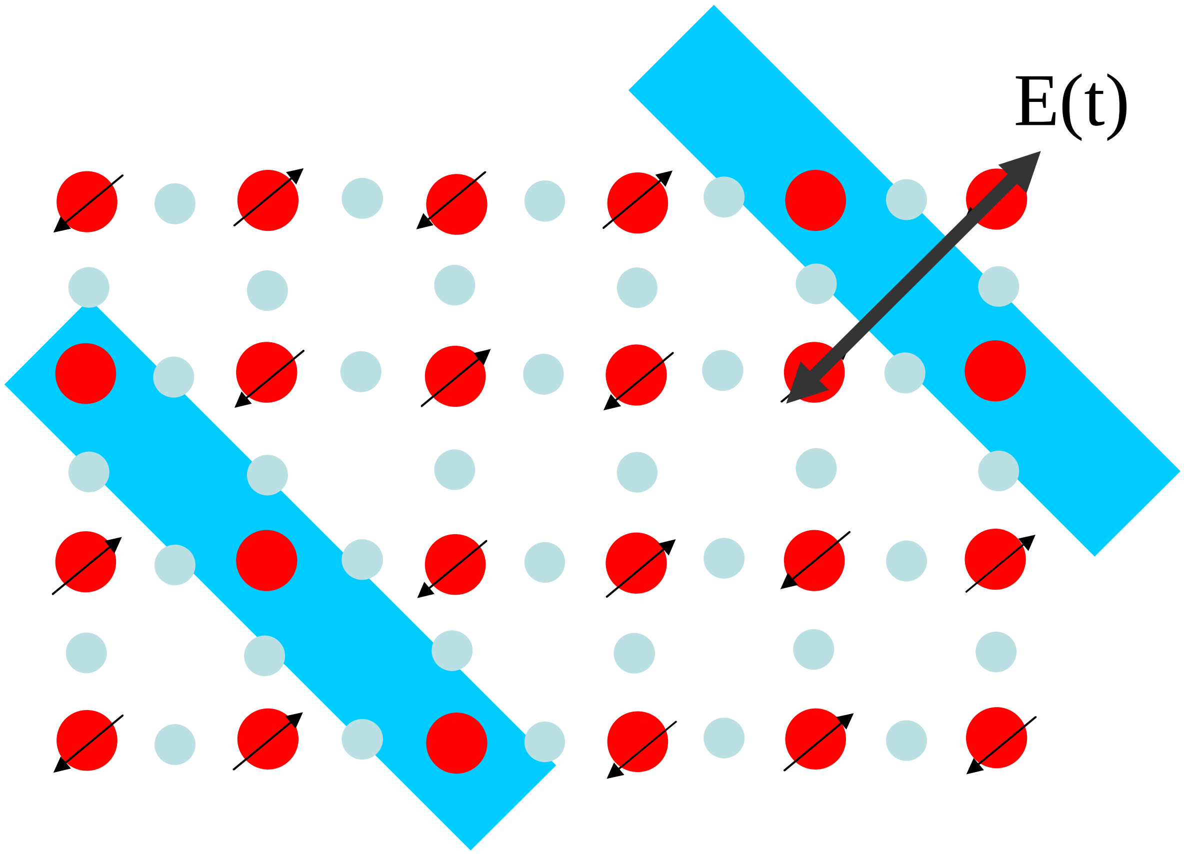
Search for anisotropic conductivity of stripes

- D.C. conductivity (Y. Ando et al)
- IR response (Lucarelli et al, Dumm et al)
- Raman scattering (R. Hackl et al)

anisotropic conductivity

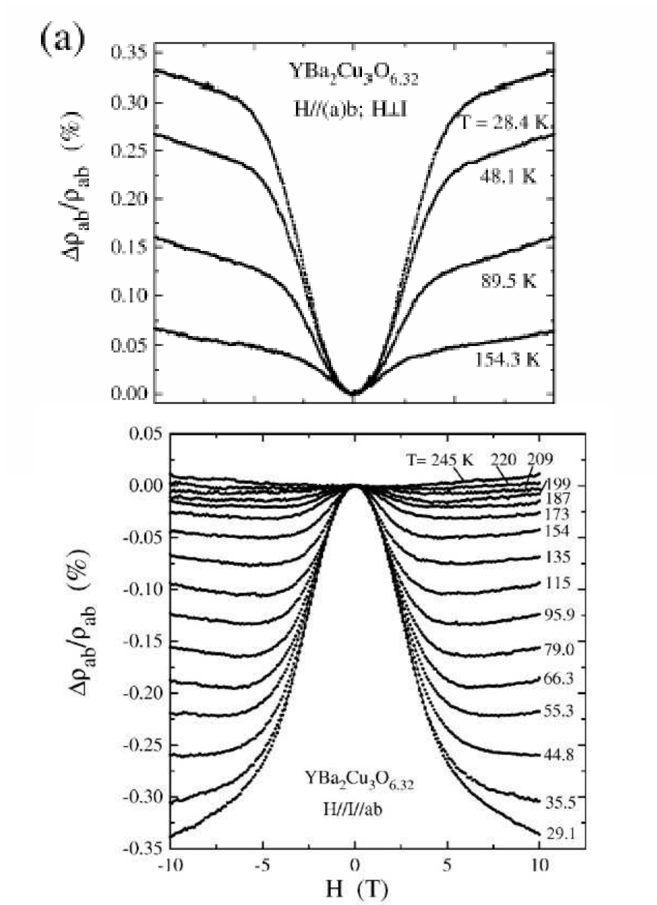


anisotropic conductivity



D.C. resistance in magnetic field

Magneto resistance



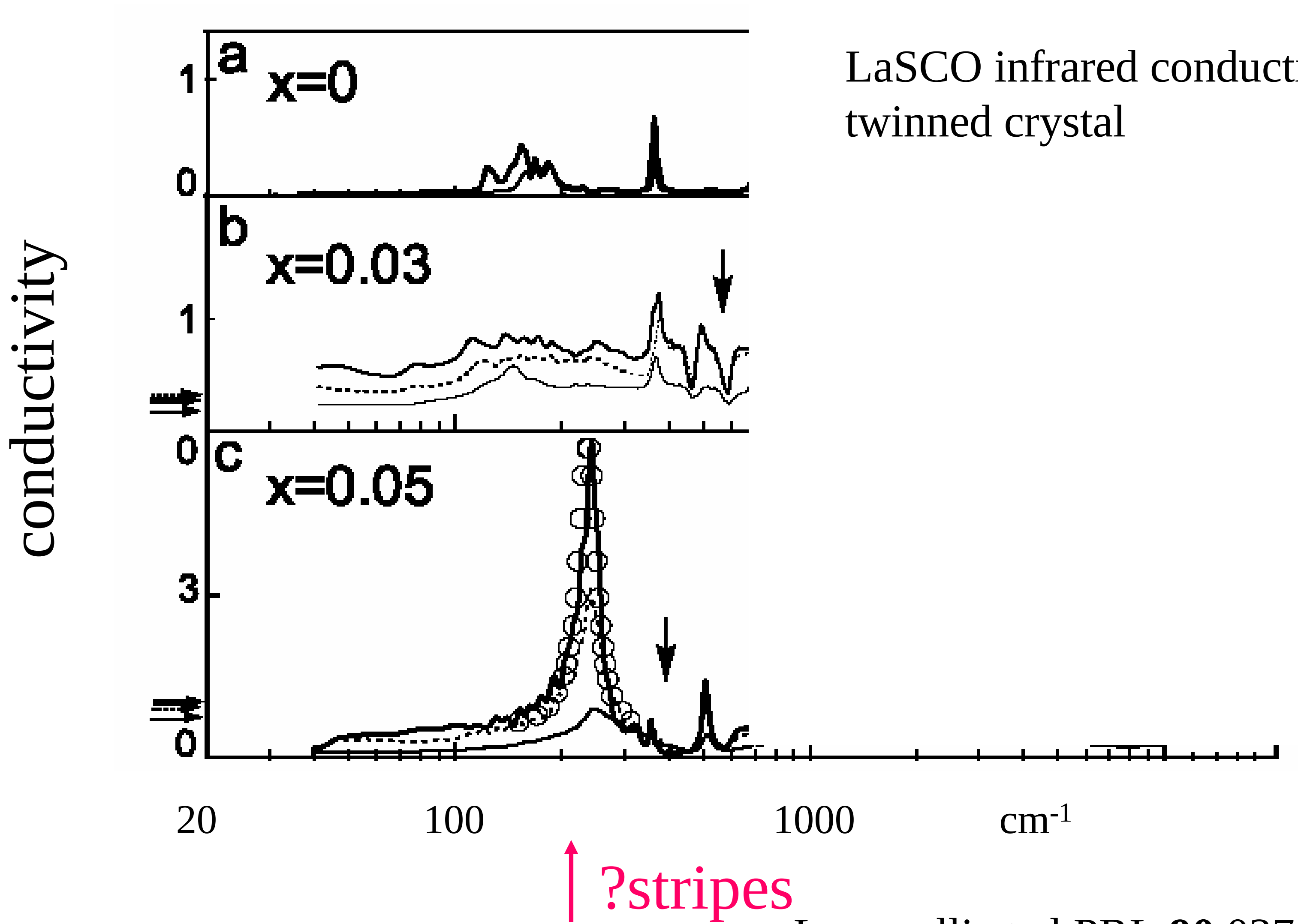
H ⊥ I

H // I

magnetostriction ?

Y. Ando, A. N. Lavrov, and K. Segawa, Phys. Rev. Lett. **83**, 2813 (1999).

Infrared conductivity



LaSCO infrared conductivity
twinned crystal

Lucarrelli et al PRL **90** 037002 (2003)

Raman scattering

X = 0.02 X = 0.10

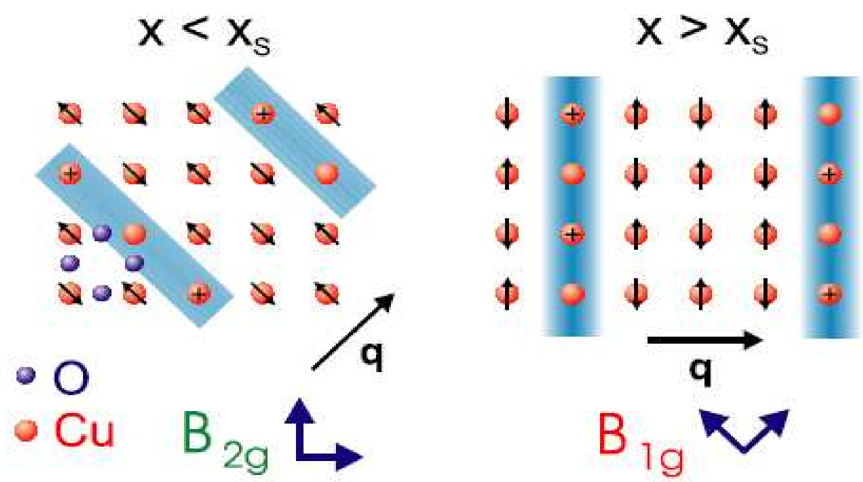
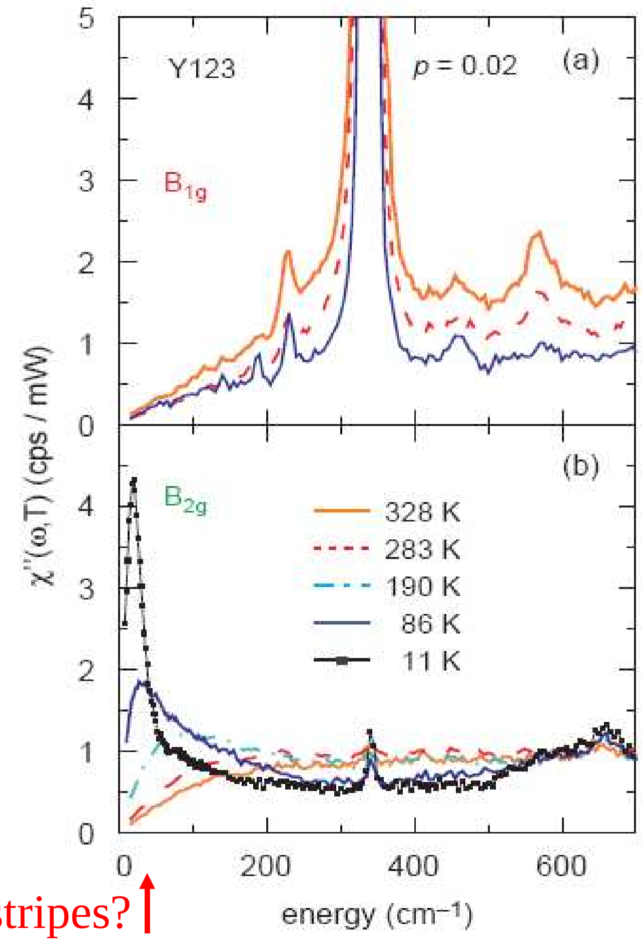


Fig. 1. Sketch of spin-charge-ordered states in the copper–oxygen plane

The response can only be observed if both incoming and outgoing photons have a finite projection on the direction of the stripes or perpendicular to them.

R. Hackl, L. Tassini et al
Journal of Physics and Chemistry of Solids xx (2005) 1–5

Raman scattering, $Ca_xY_{1-x}Ba_2Cu_3O_6$



2 and 3% Ca
Response in B_{2g}:
diagonal

stripes?

Fig. 7. Raman response $X''_{\mu(w,T)}$ of $(Y_{1.97}Ca_{0.03})Ba_2Cu_3O_{6.05}$ in B_{1g} (a) and B_{2g} (b) symmetry. The doping level is close to $p=0.02$.

R. Hackl, L. Tassini et al
Journal of Physics and Chemistry of Solids xx (2005) 1–5

Interactions:
Zeeman + exchange + "crystal field"

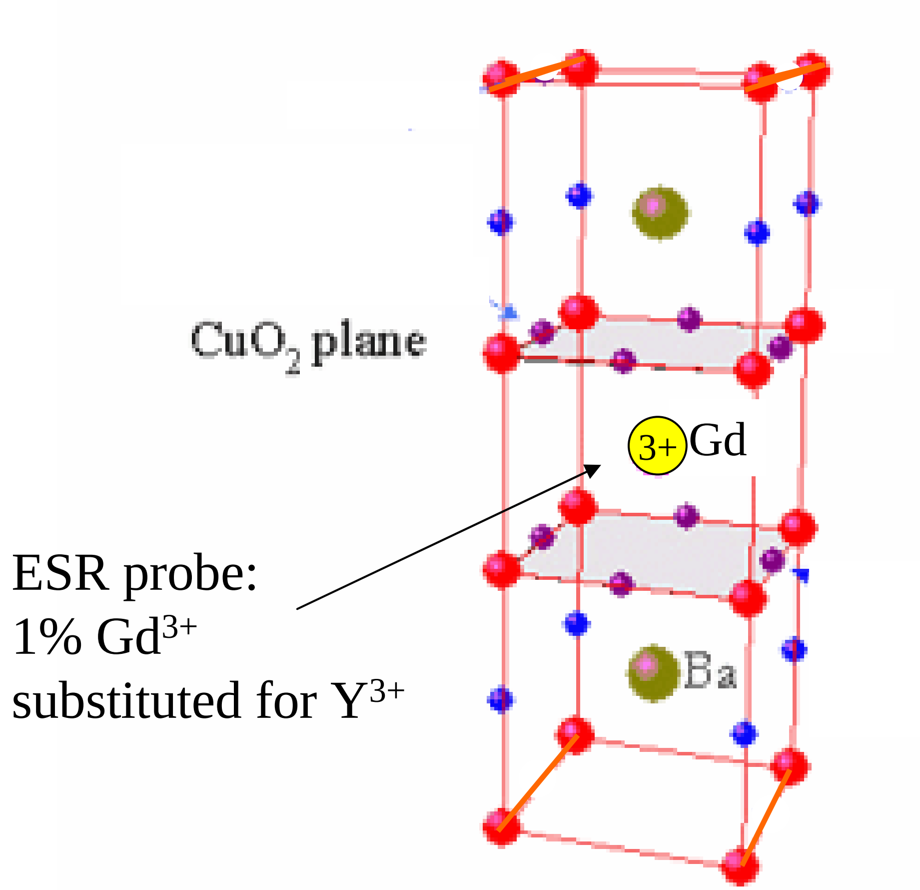
Gd^{3+} ESR measures:

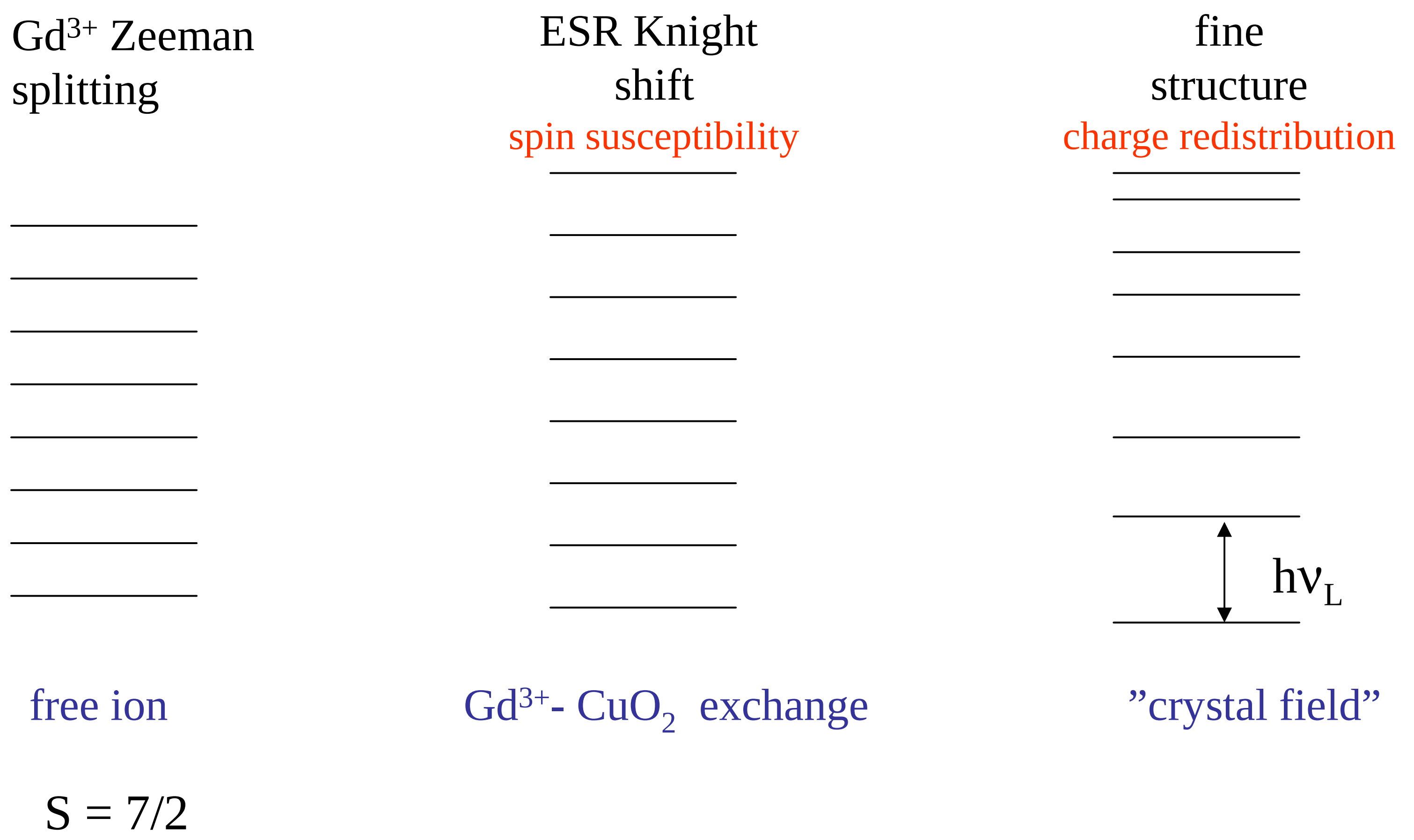
spin susceptibility (ESR Knight shift)

and

lattice distortion or charge redistribution
(J=7/2 fine structure)

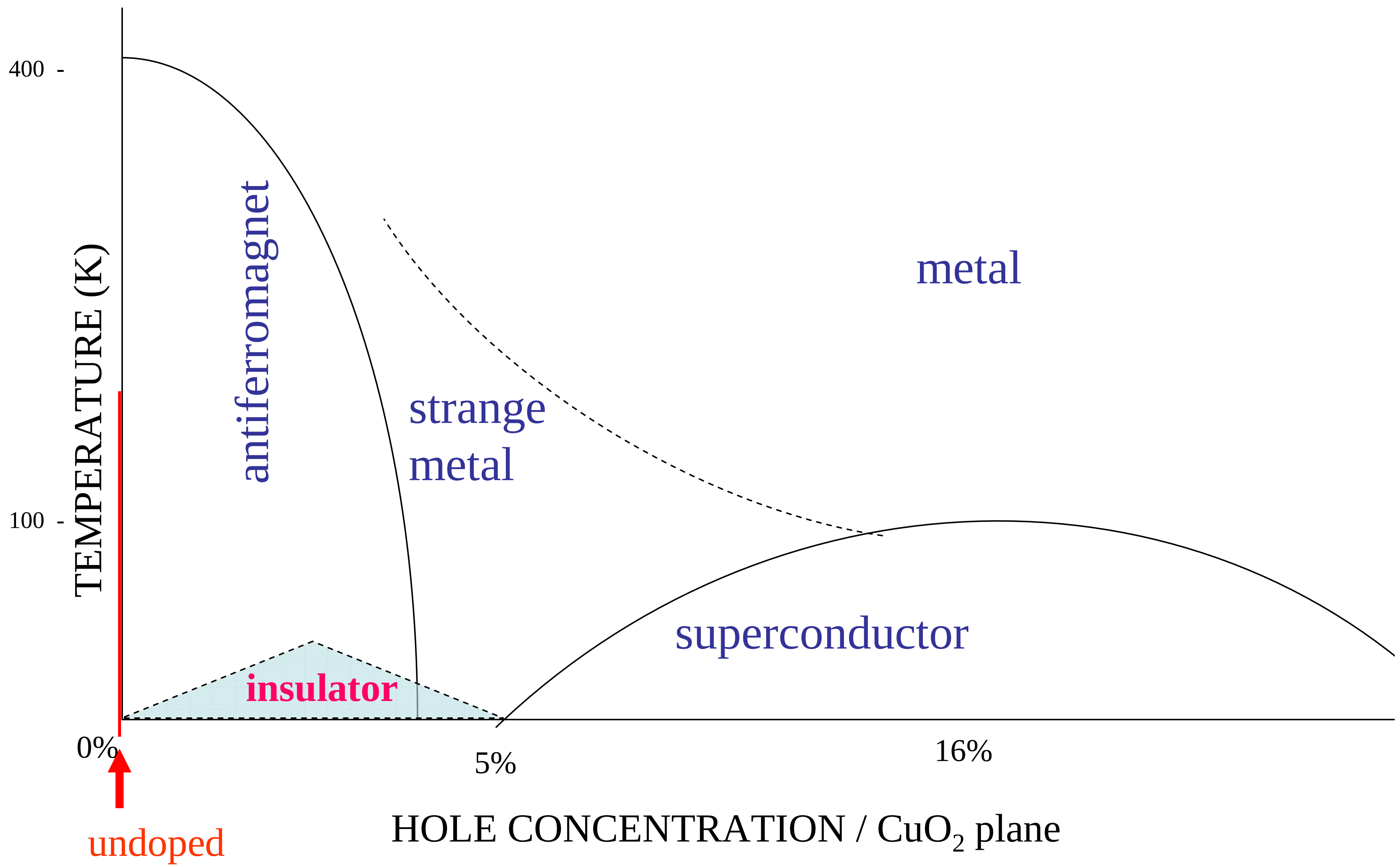
in CuO_2 planes





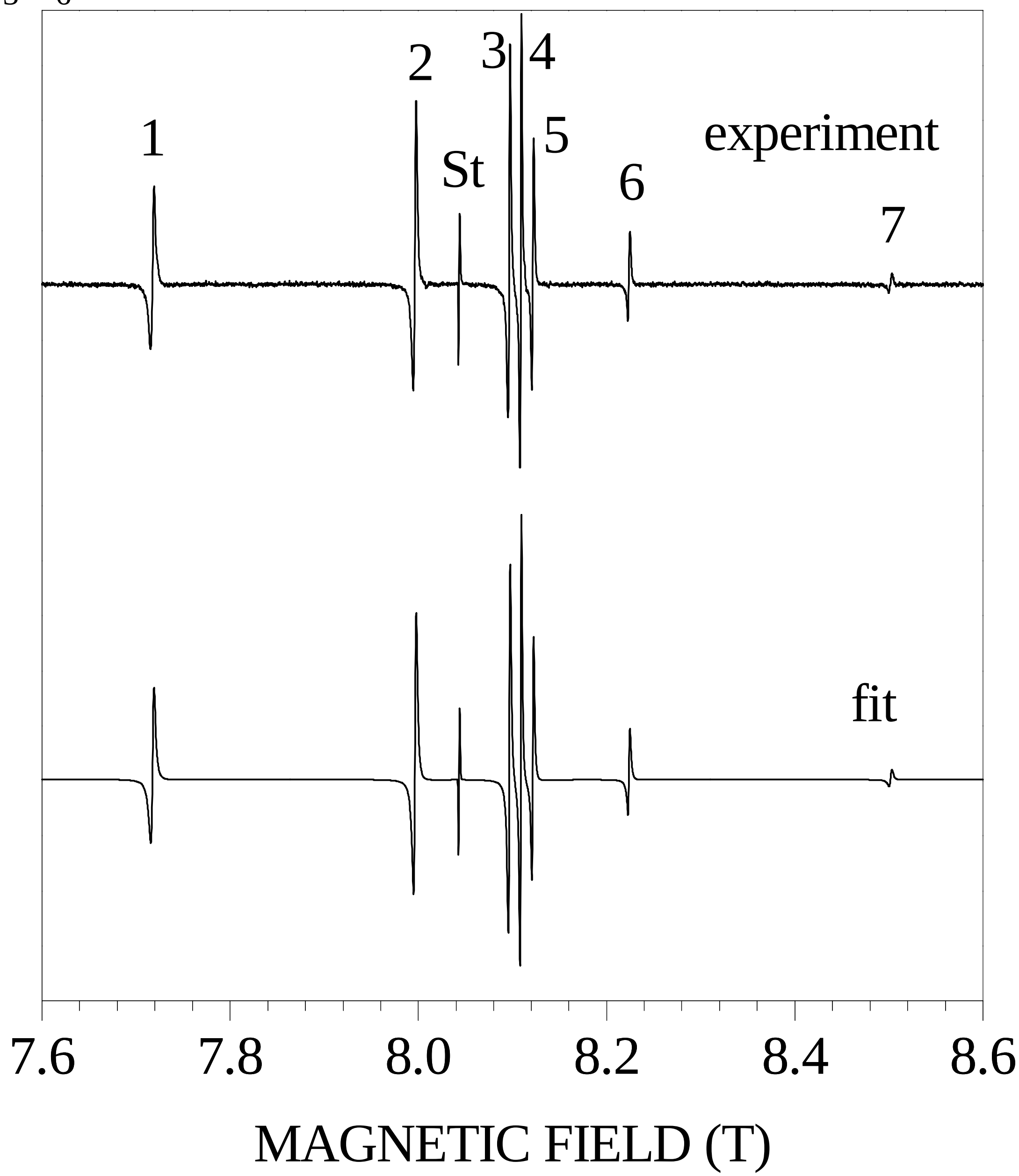
+ second order exchange

Phase diagram of cuprates

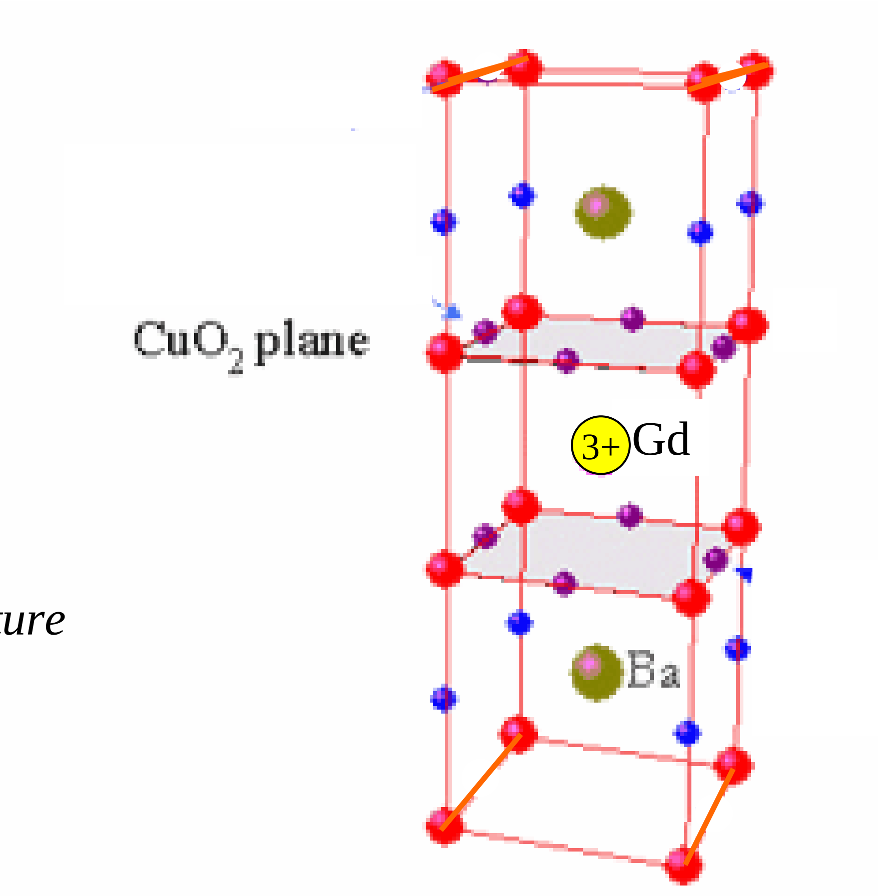


ESR in Gd: $YBa_2Cu_3O_6$

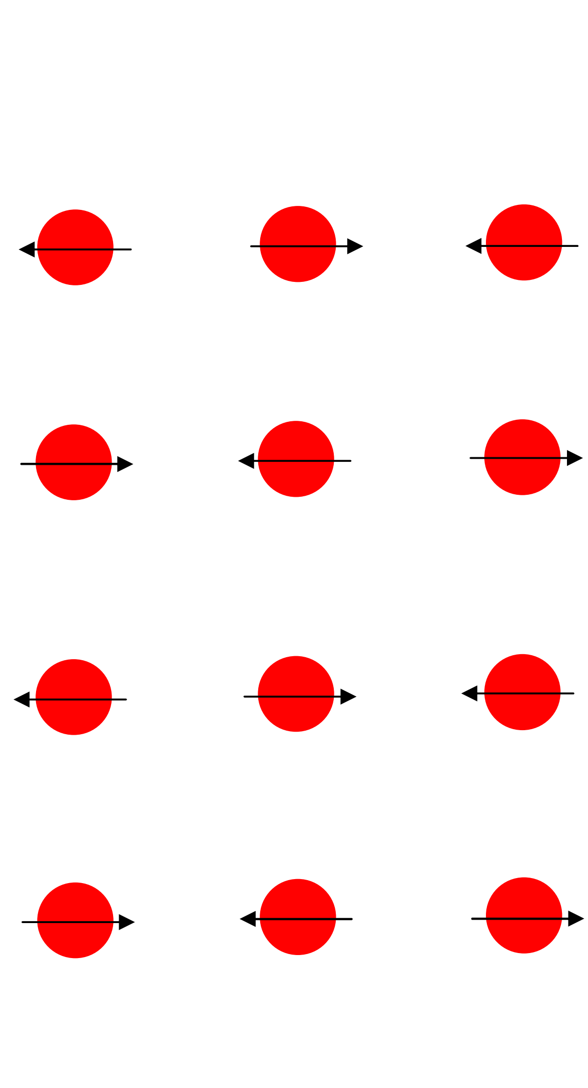
B//c, 225 GHz



- Antiferromagnetic domains
- Orientation of spins



tetragonal structure



90^0 wall

BARUCH HOROVITZ

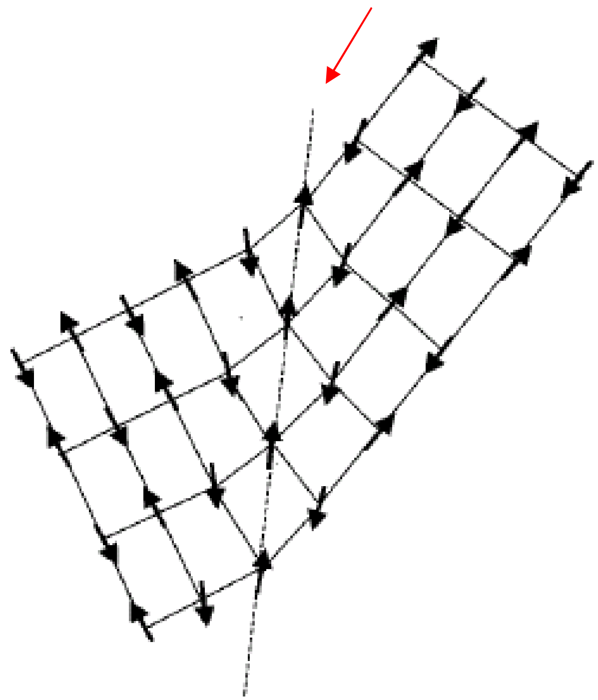
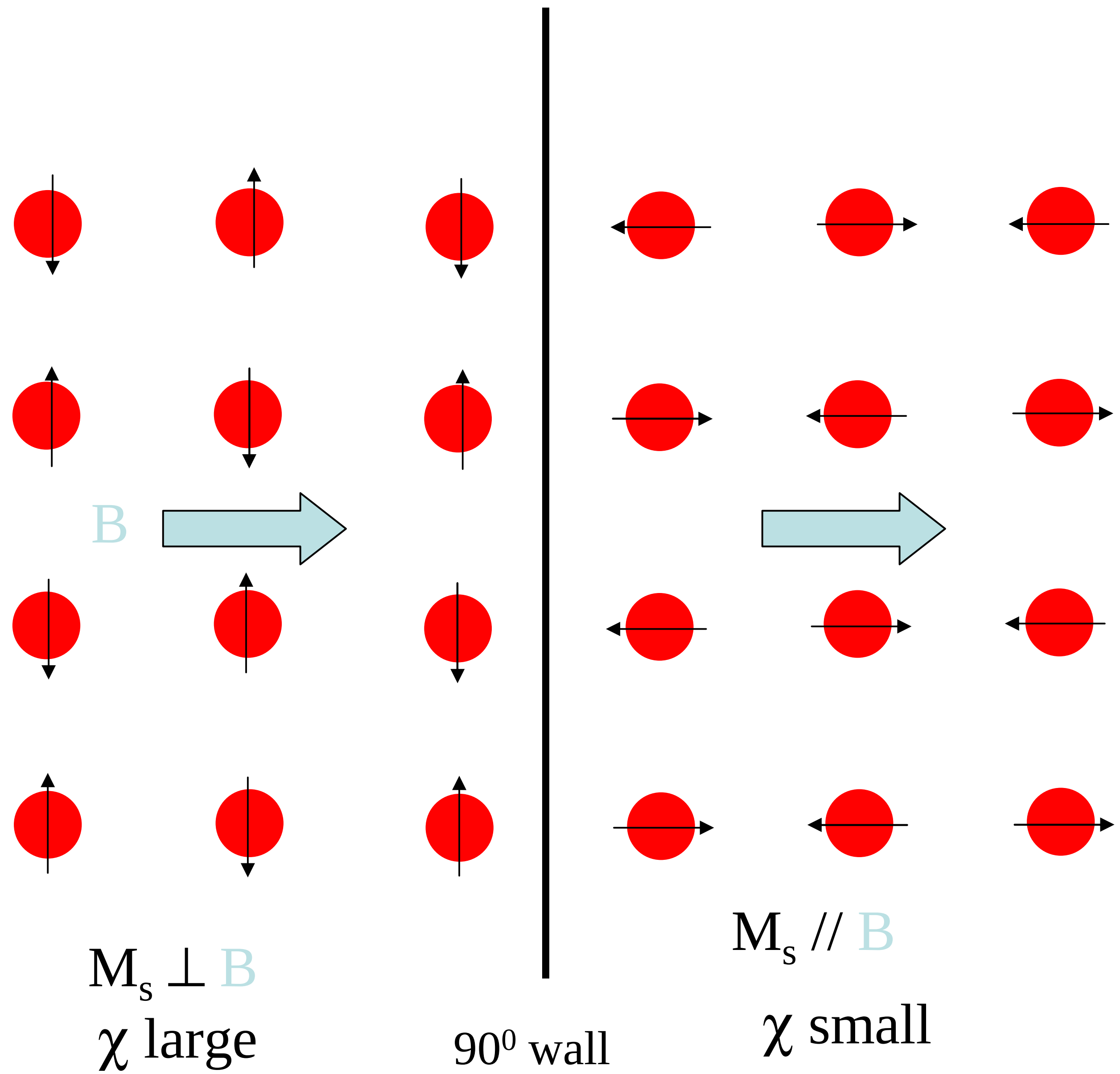


FIG. 1. Twin boundary with spin polarizations (arrows) exhibiting an AF domain wall. The dashed line is in a (110) plane and is

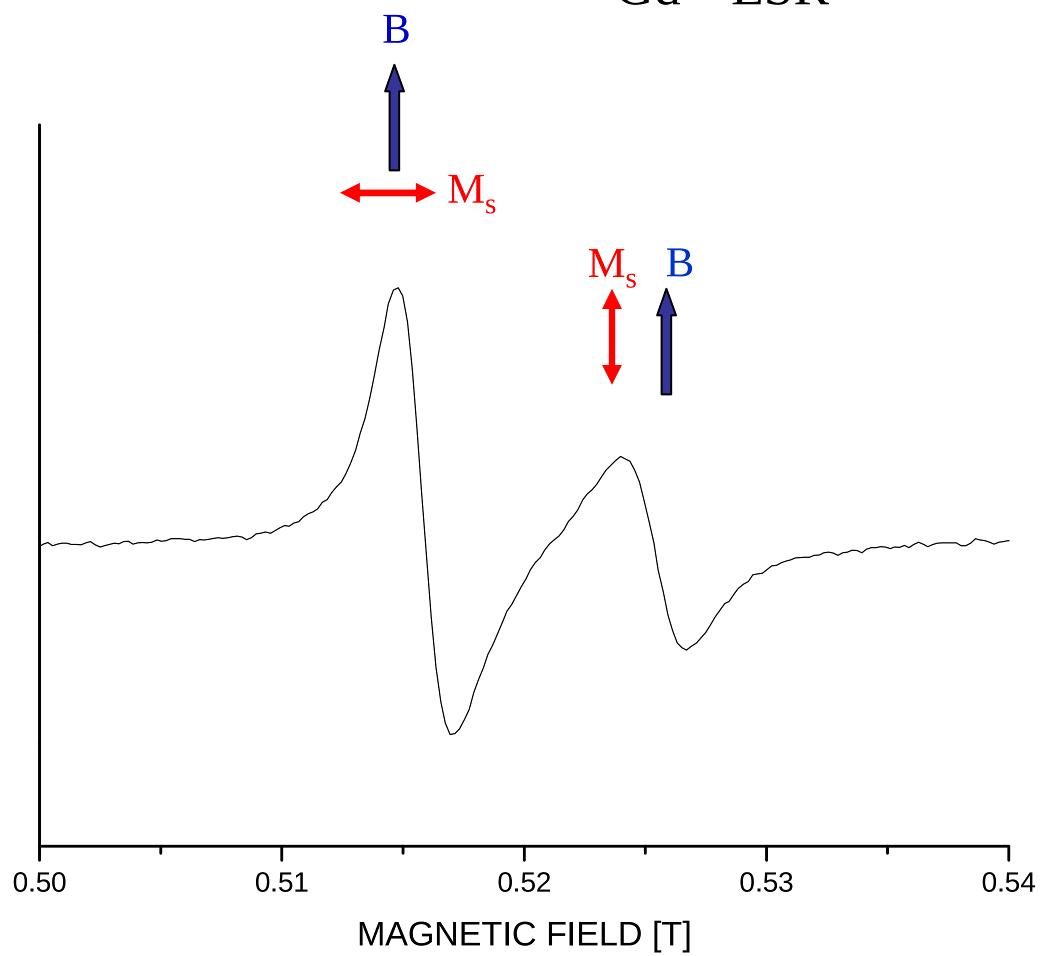
magneto-striction can stabilize collateral spin structure



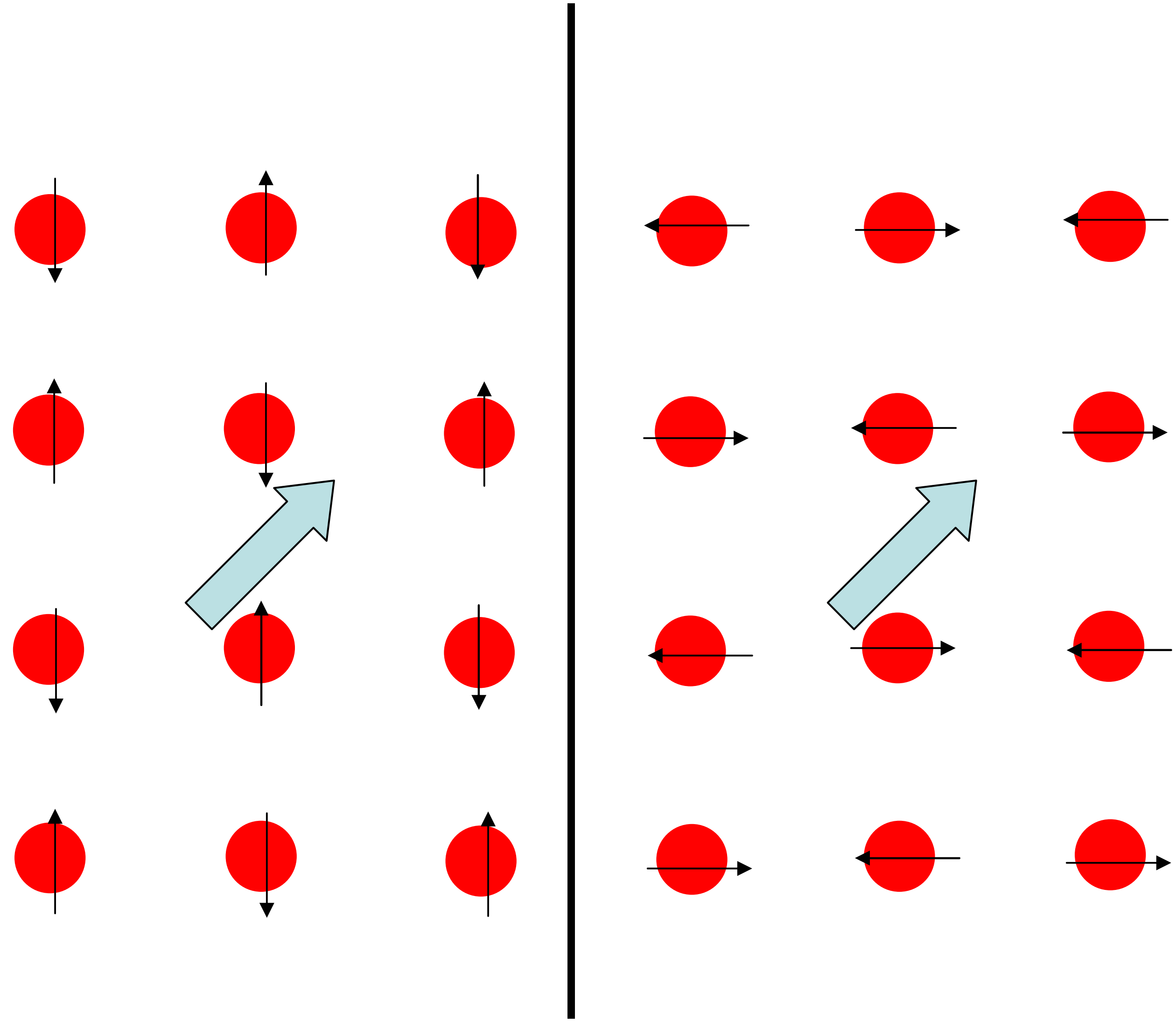
B: magnetic field

undoped

antiferromagnetic domains in $YBaCu_3O_6$
Gd^{3+} ESR

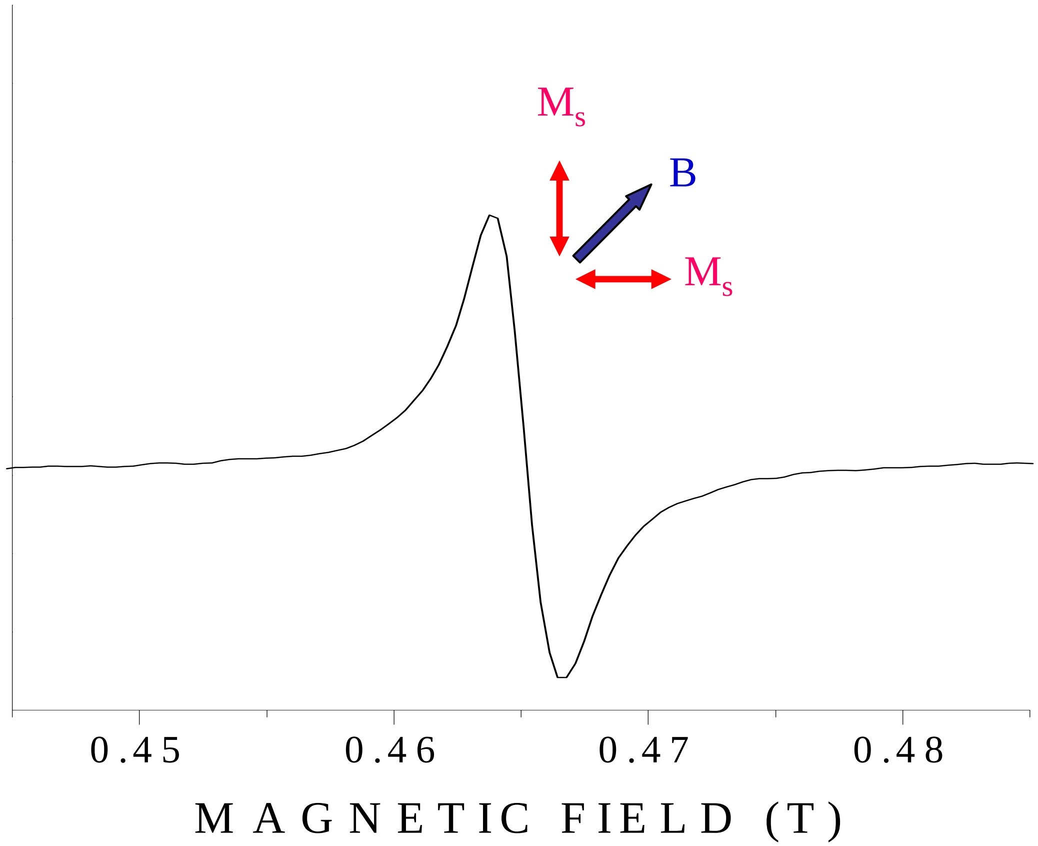


undoped

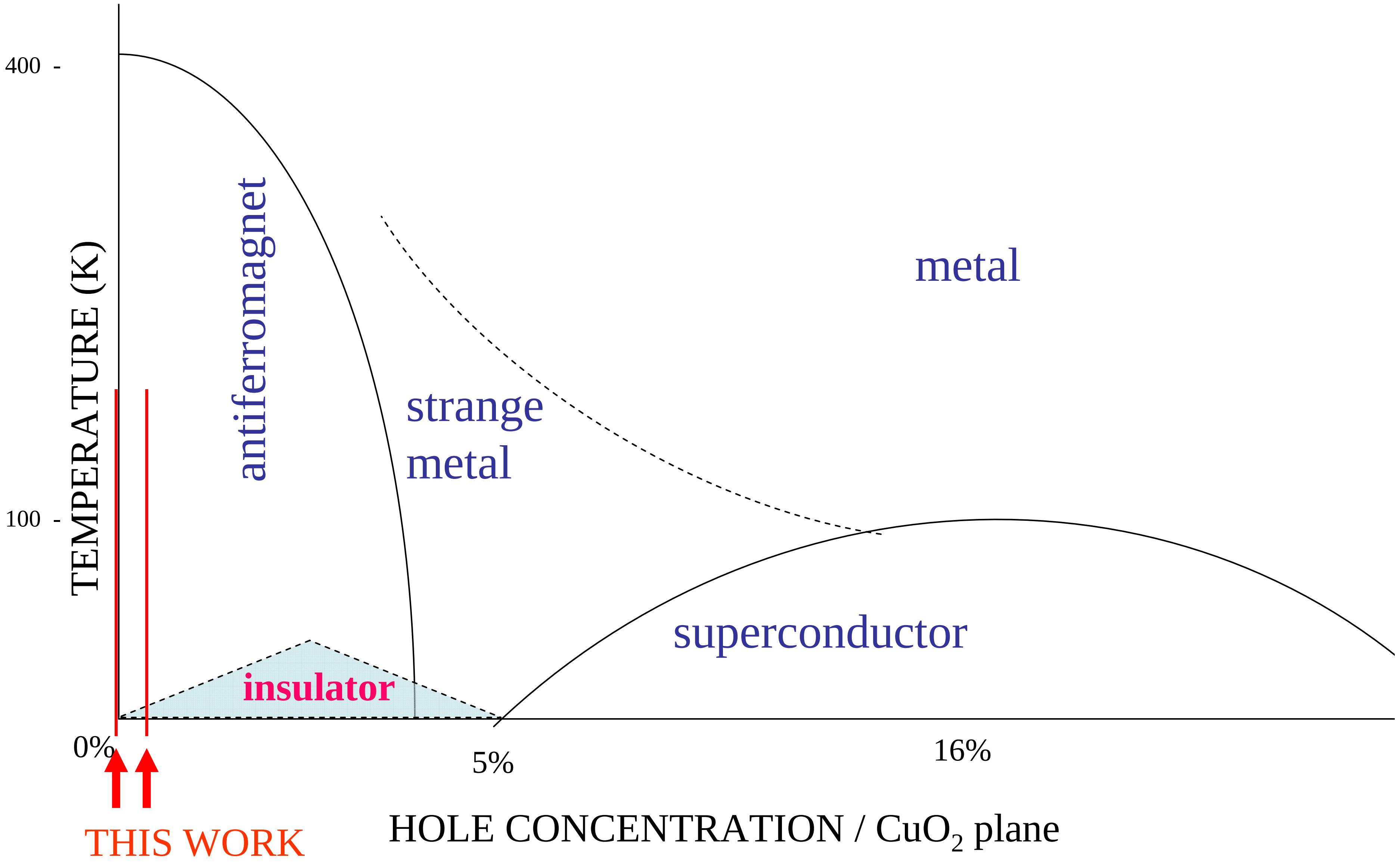


B: magnetic field

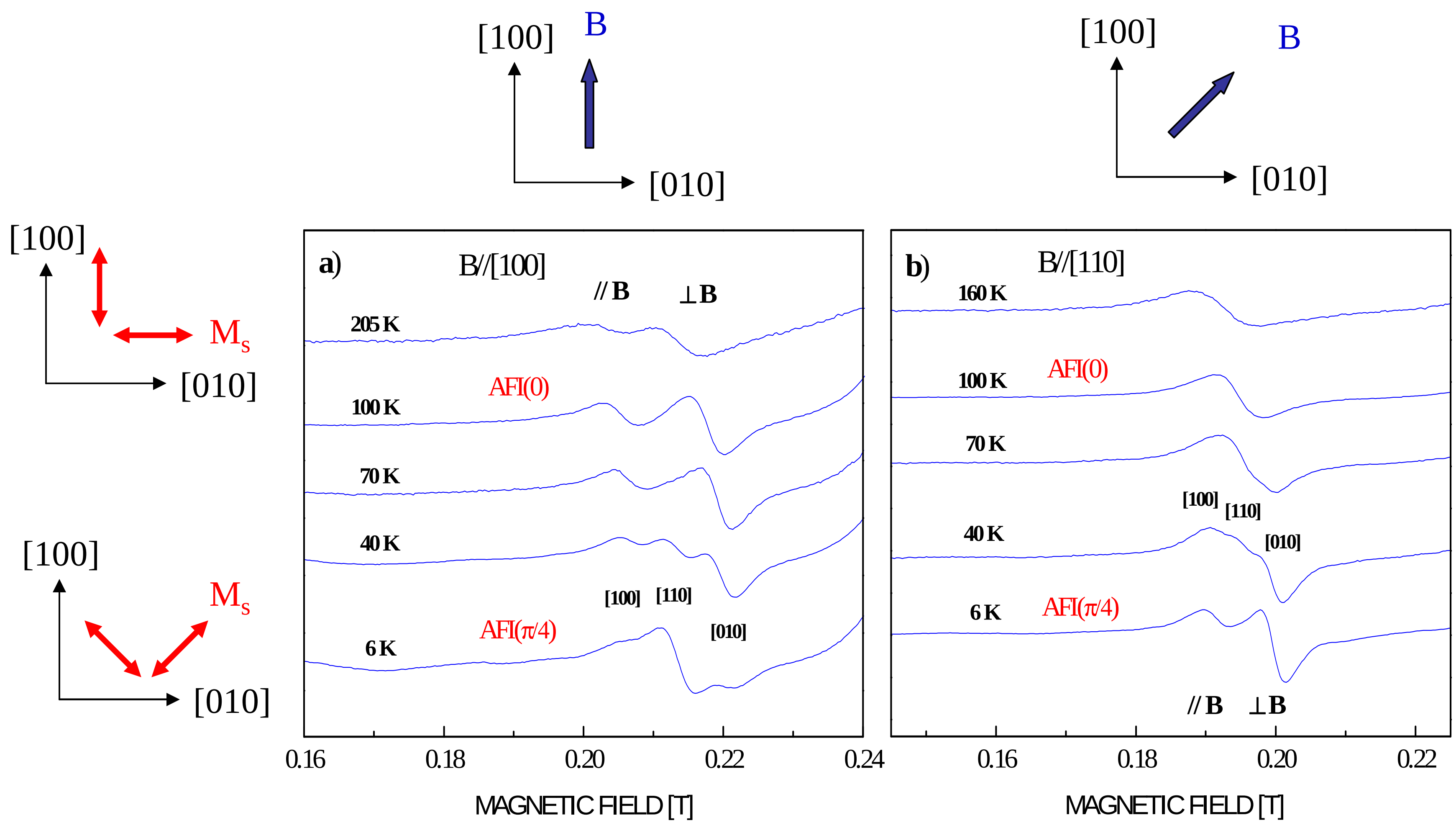
undoped



Phase diagram of cuprates

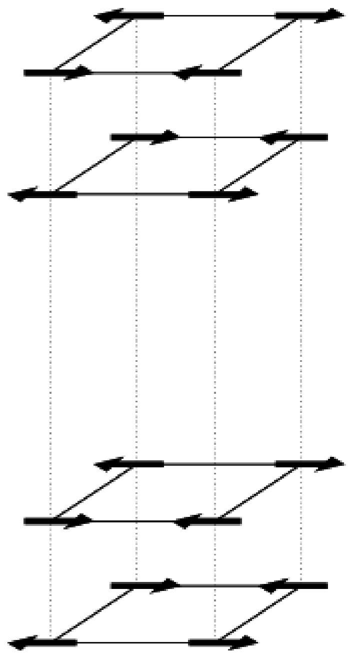


Reorientation of M_s in Ca:YBCO 0.8% Ca



undoped

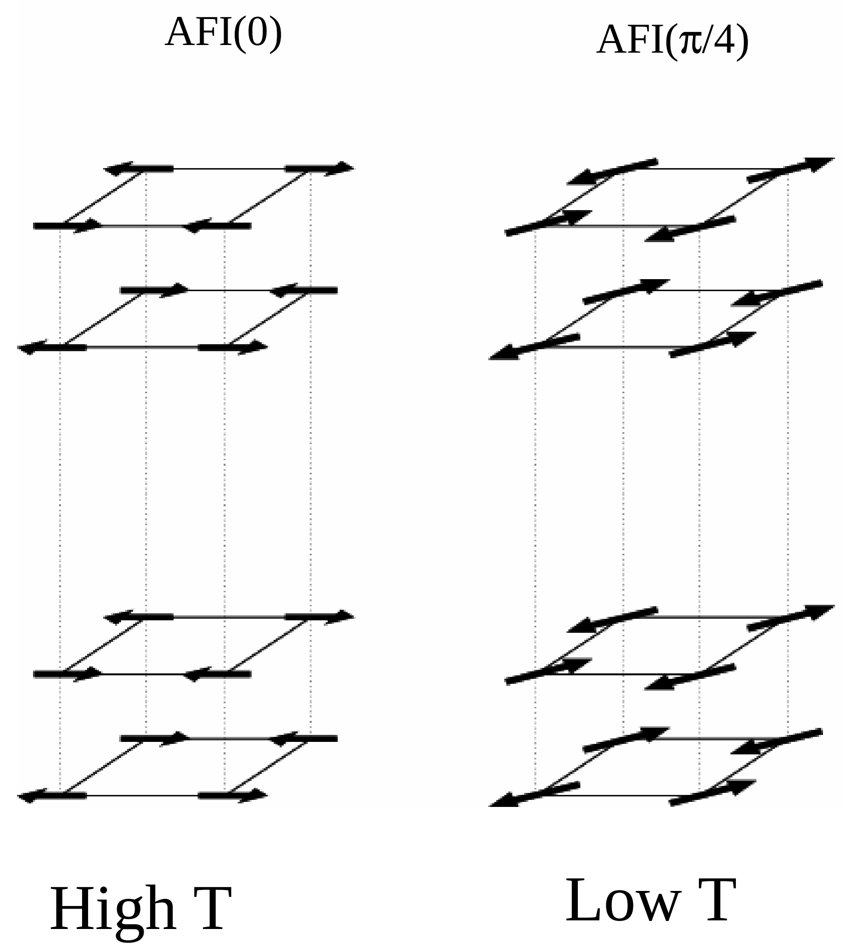
AFI(0)



all T

magnetic reorientation in Ca doped $YBa_2Cu_3O_6$

0.8 % Ca

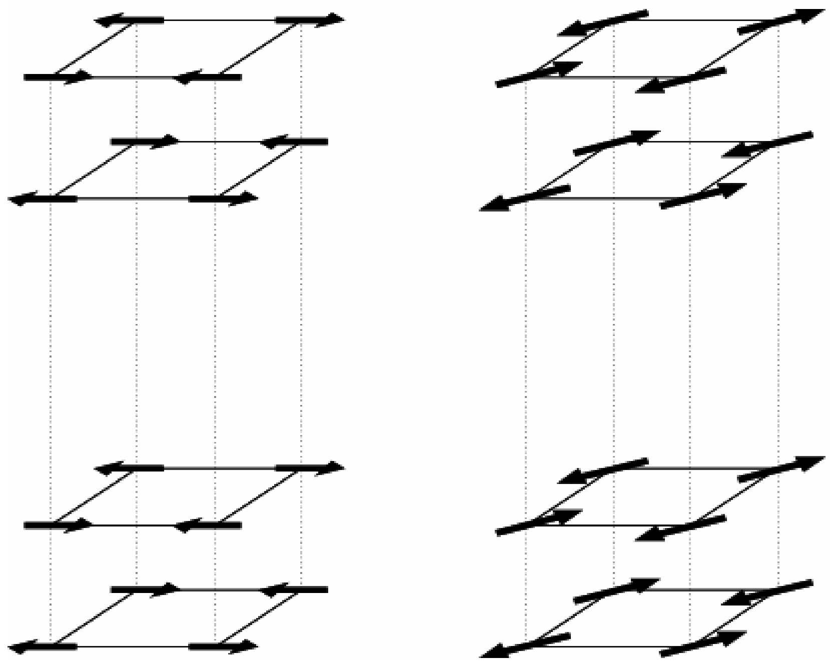


magnetic reorientation in Ca doped $YBa_2Cu_3O_6$

2 % Ca

AFI(0)

AFI(π/4)

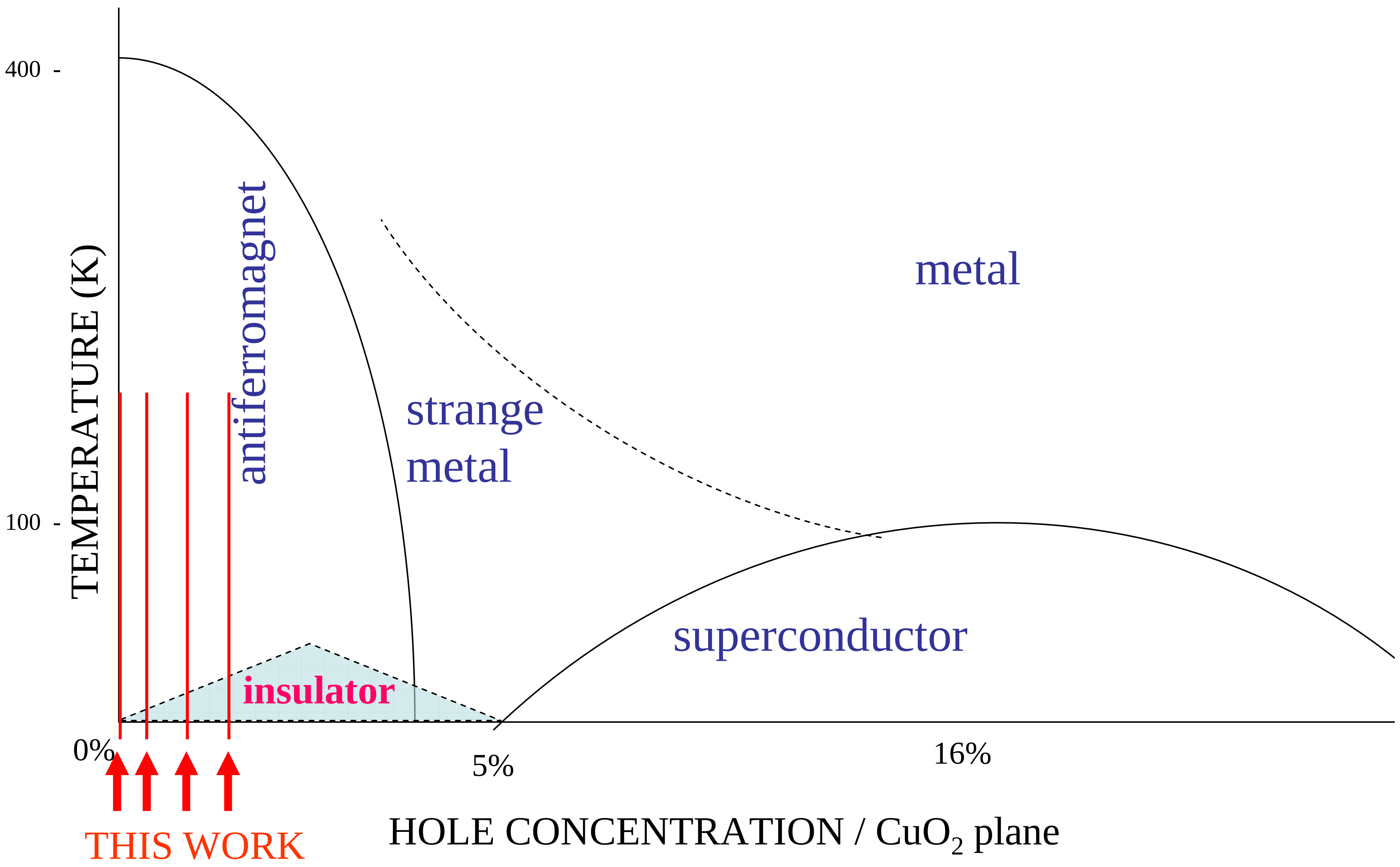


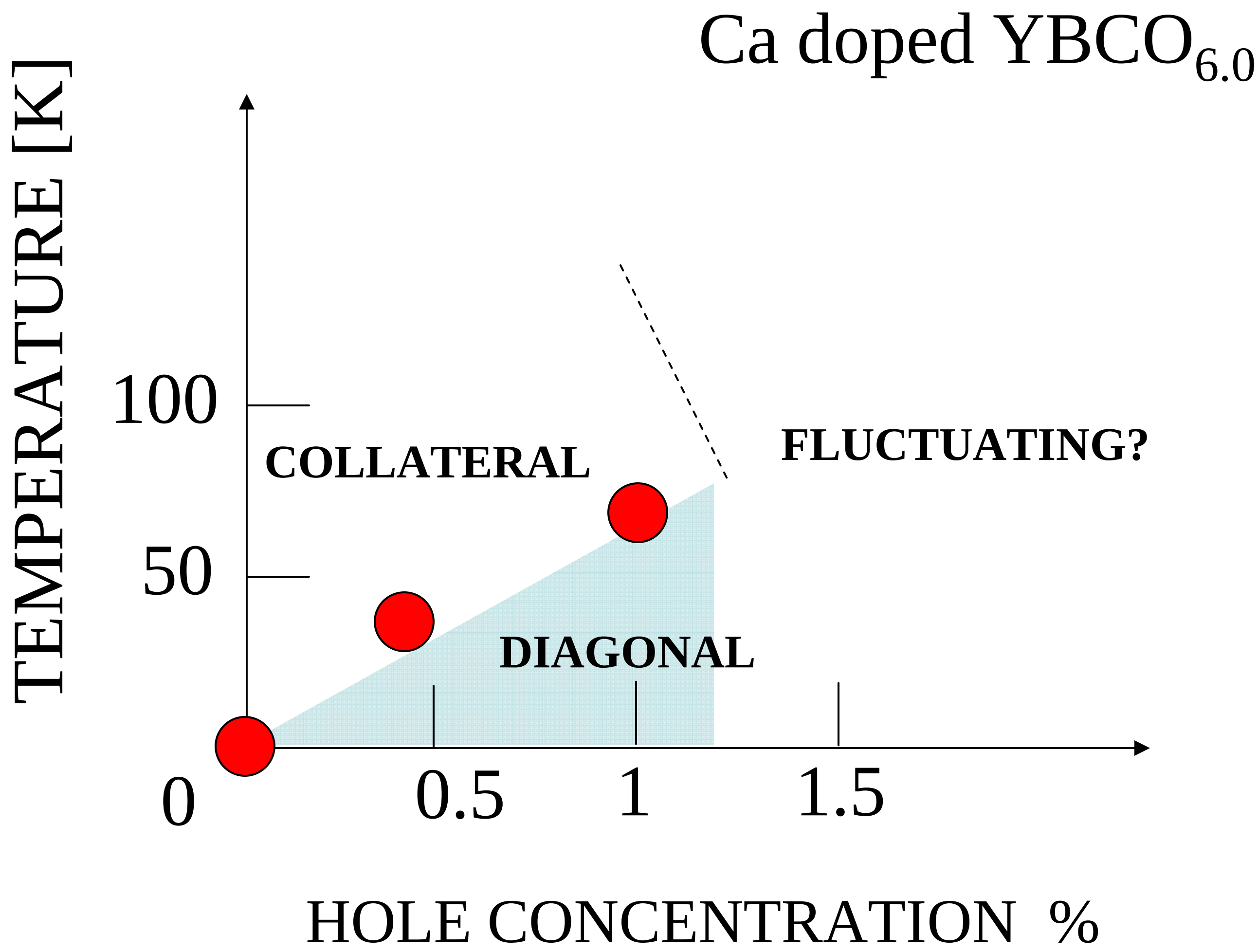
??

High T

Low T

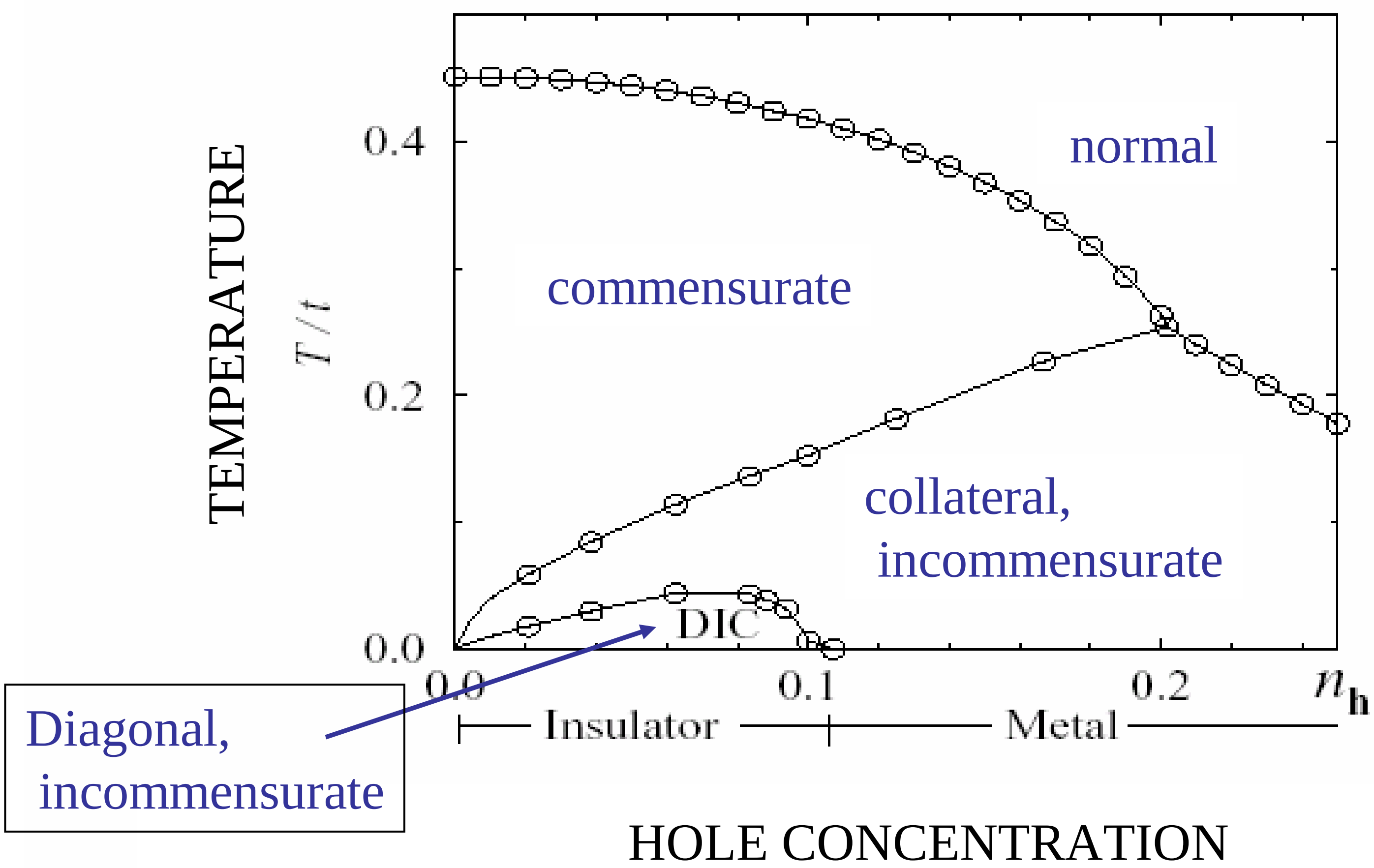
Phase diagram of cuprates





Ca doped YBCO6.0
TEMPERATURE [K]
100
50
0
COLLATERAL
FLUCTUATING?
DIAGONAL
0.5
1
1.5
HOLE CONCENTRATION %

Charge- spin phase separation



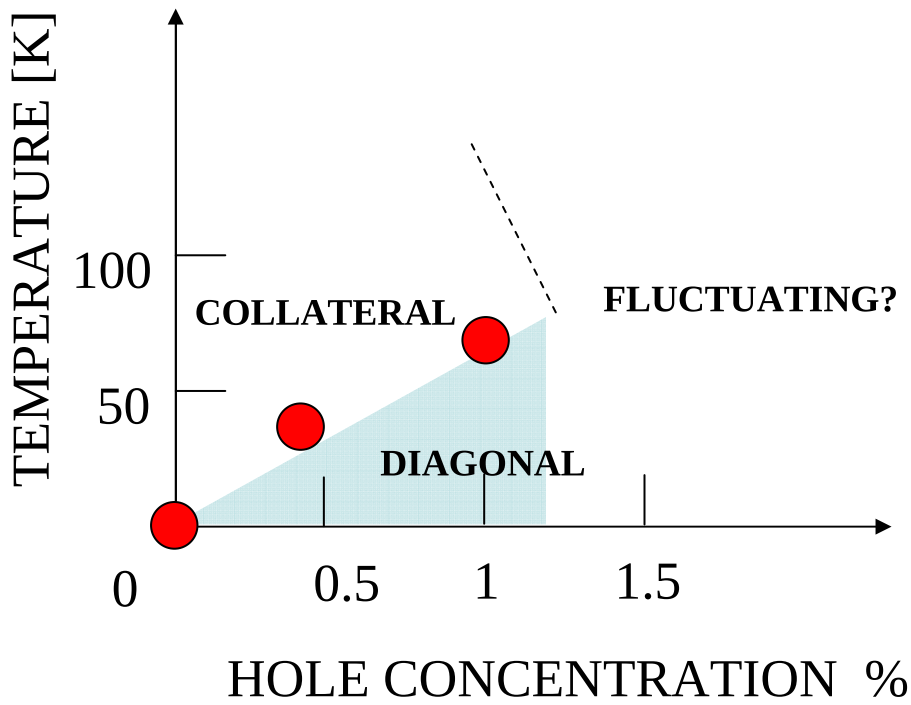
Hubbard model. Mean field.

K. Machida, M. Ichioka J. Phys. Soc. Jpn. 68 2168 1999.

Model:

Low T: charge modulation network
with weakly pinned AF magnetization

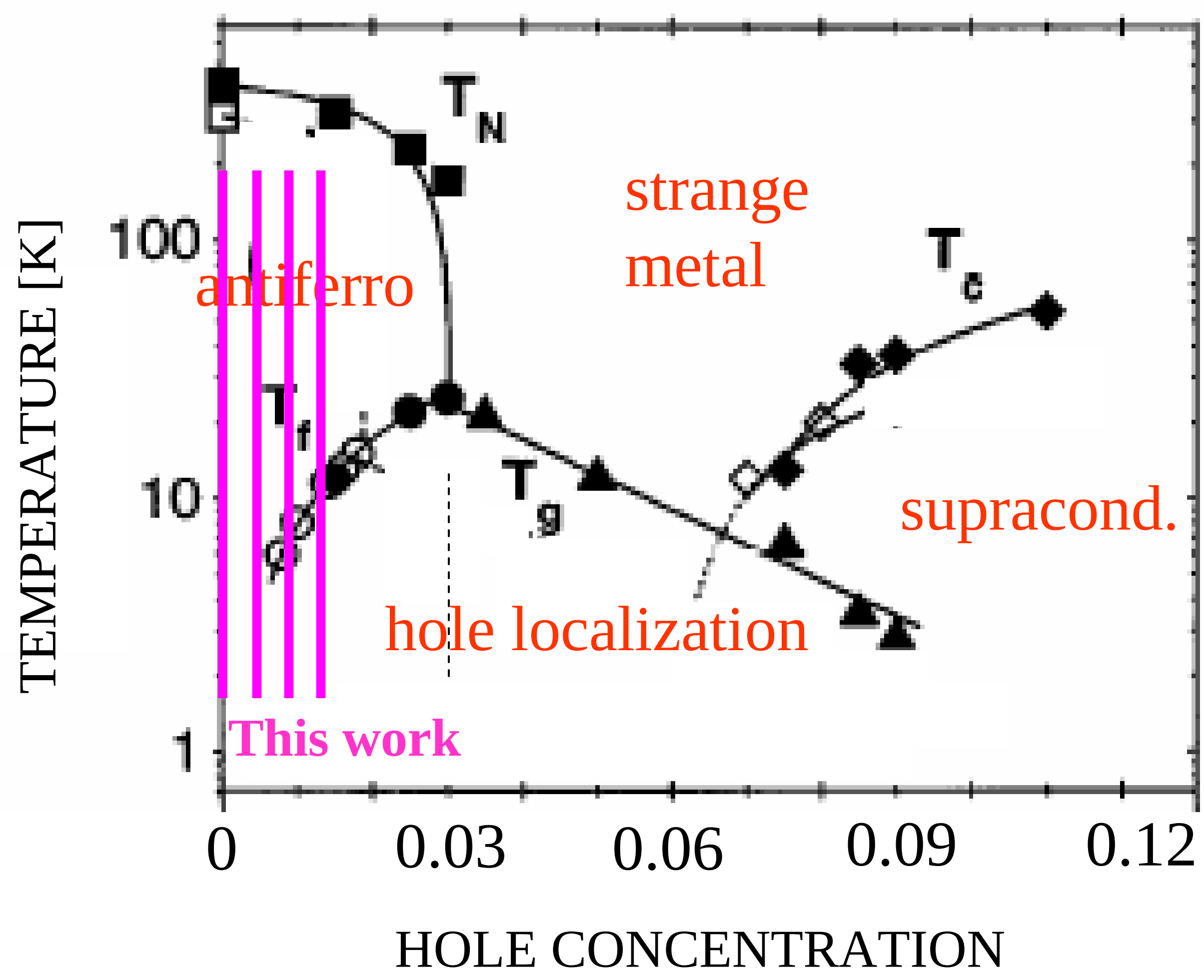
High T: no charge modulation,
spin magnetization fluctuating
or pinned to lattice by
defects or magneto-striction



Localisation of holes

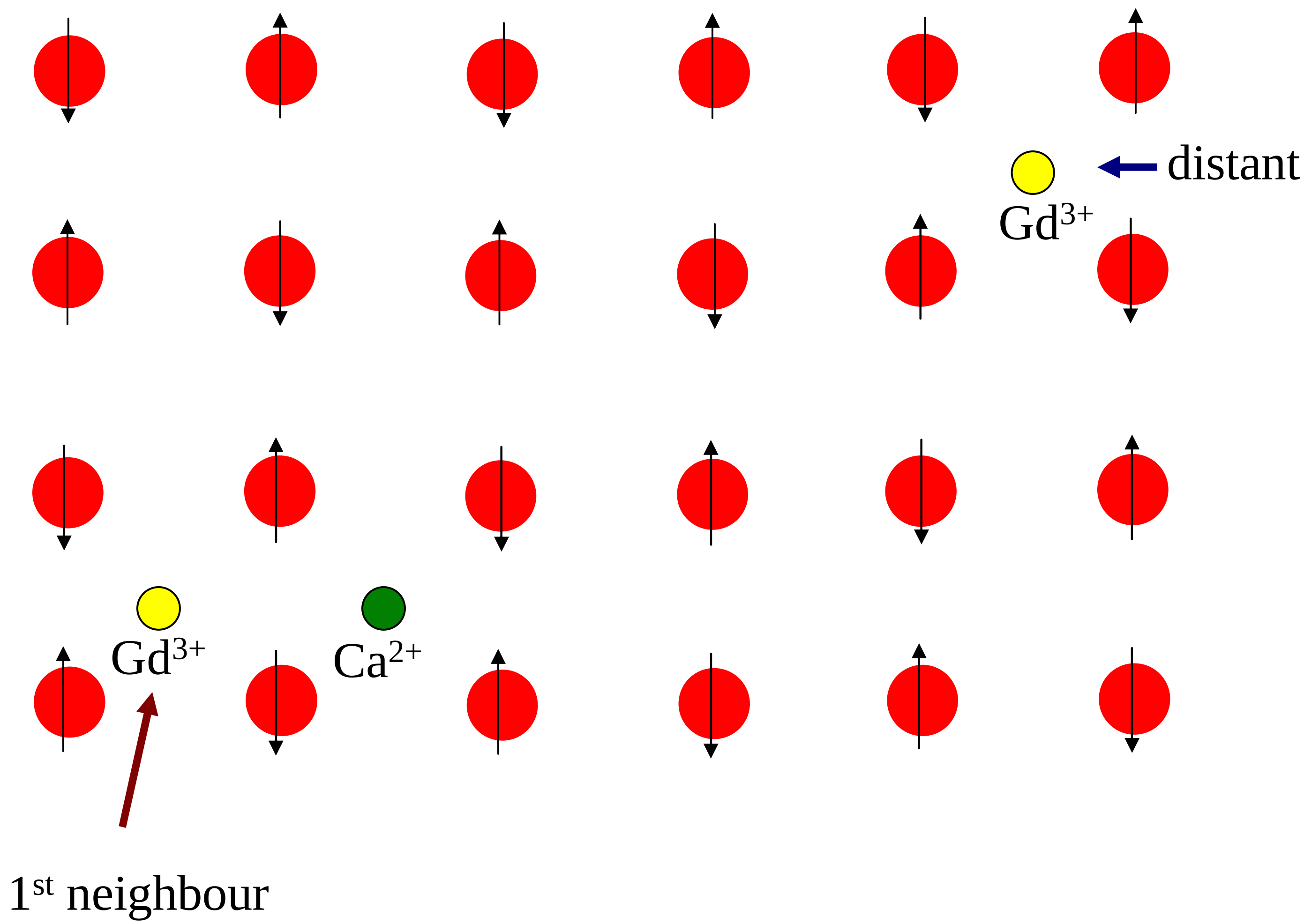
Are holes localised around Ca^{2+} ions at low T ?

Ca doped $YBa_2Cu_3O_6$ phase diagram

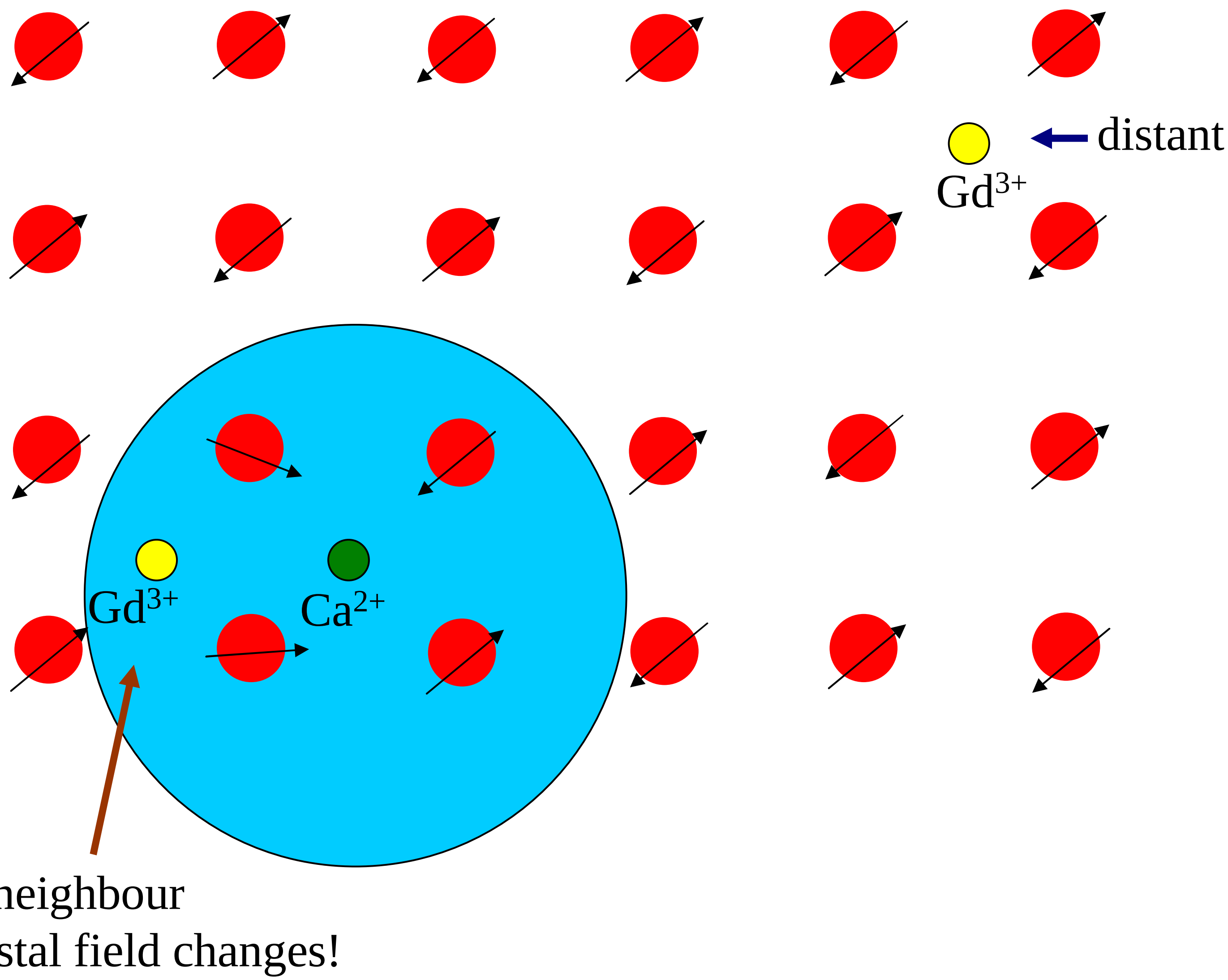


Ch. Niedermayer, C. Bernhard, T. Blasius, A. Golnik, A. Moodenbaugh, and J. I. Budnick
Phys. Rev. Lett.80 (1998) 3843

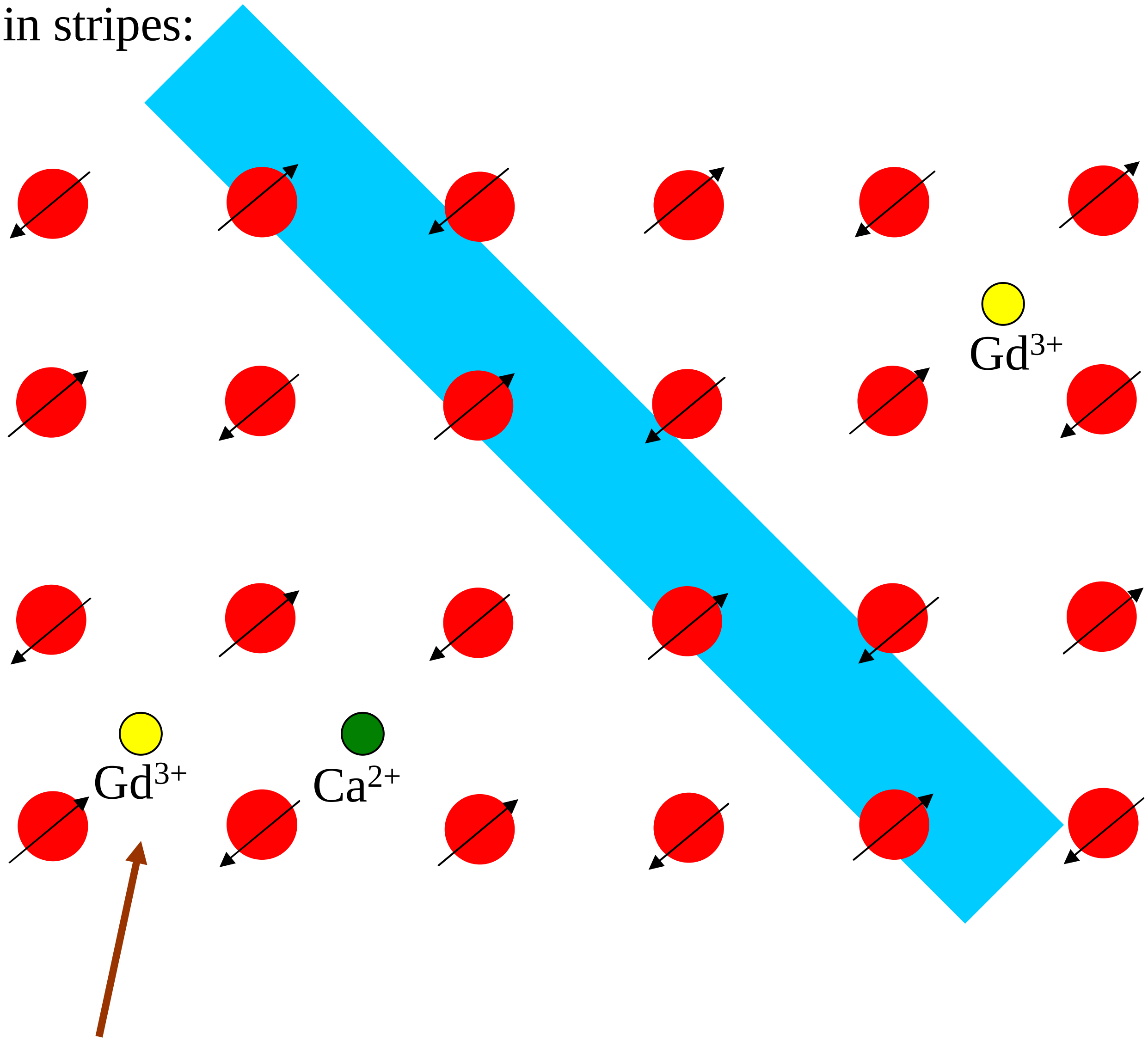
High T:
delocalized holes



low T
if holes were localized near Ca:

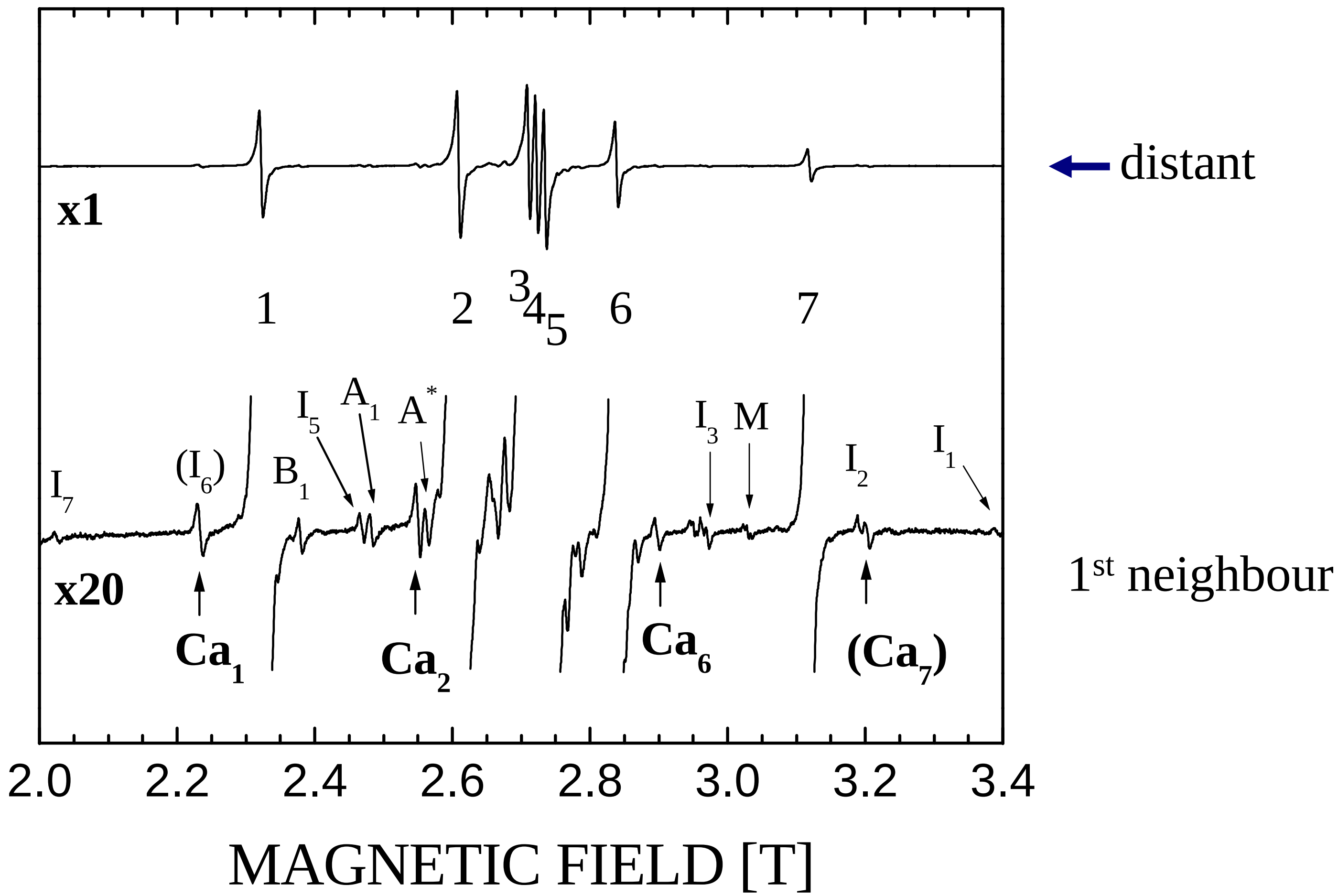


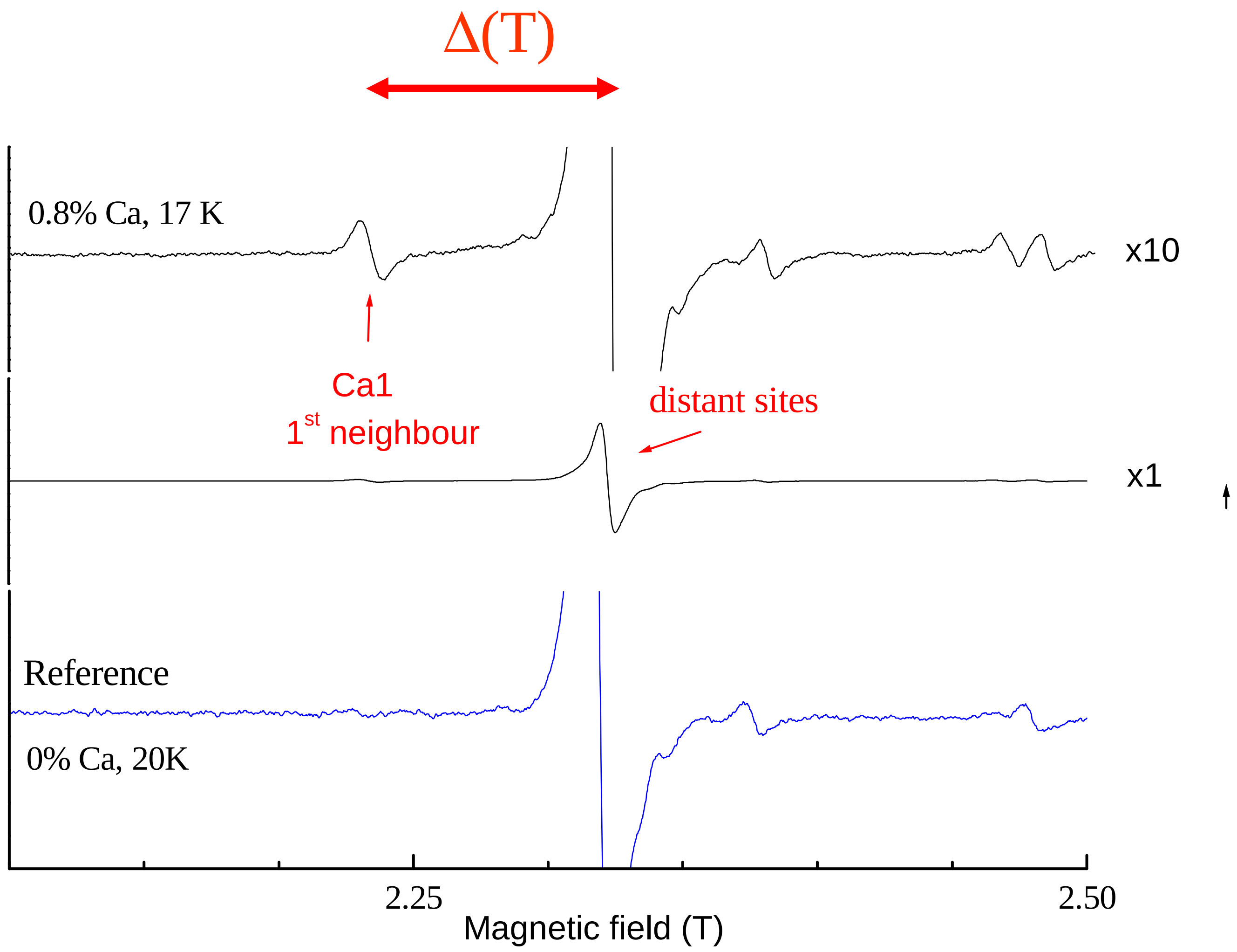
low T
holes ordered in stripes:



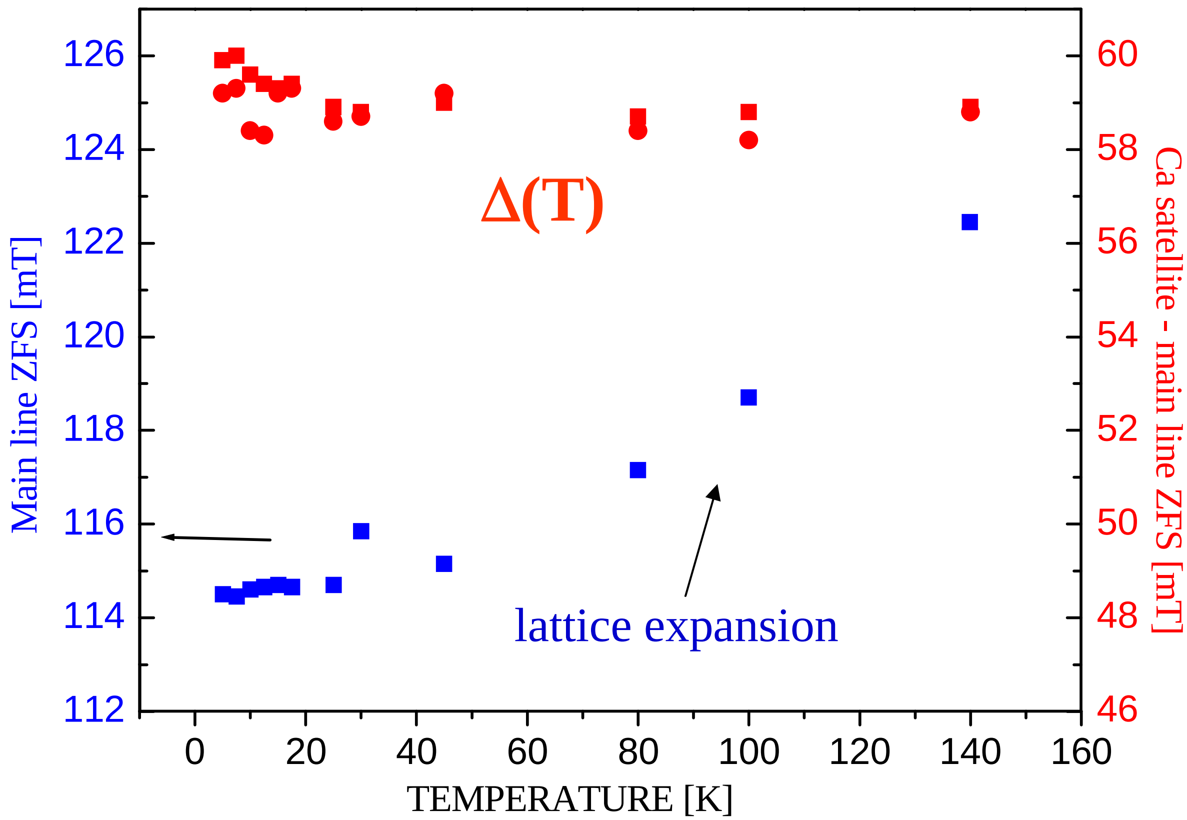
1^{st} neighbour
no crystal field change!

ESR spectrum of Ca first neighbors and distant sites




Δ(T)
0.8% Ca, 17 K
x10
Ca1
1st neighbour
distant sites
x1
Reference
0% Ca, 20K
2.25
2.50
Magnetic field (T)

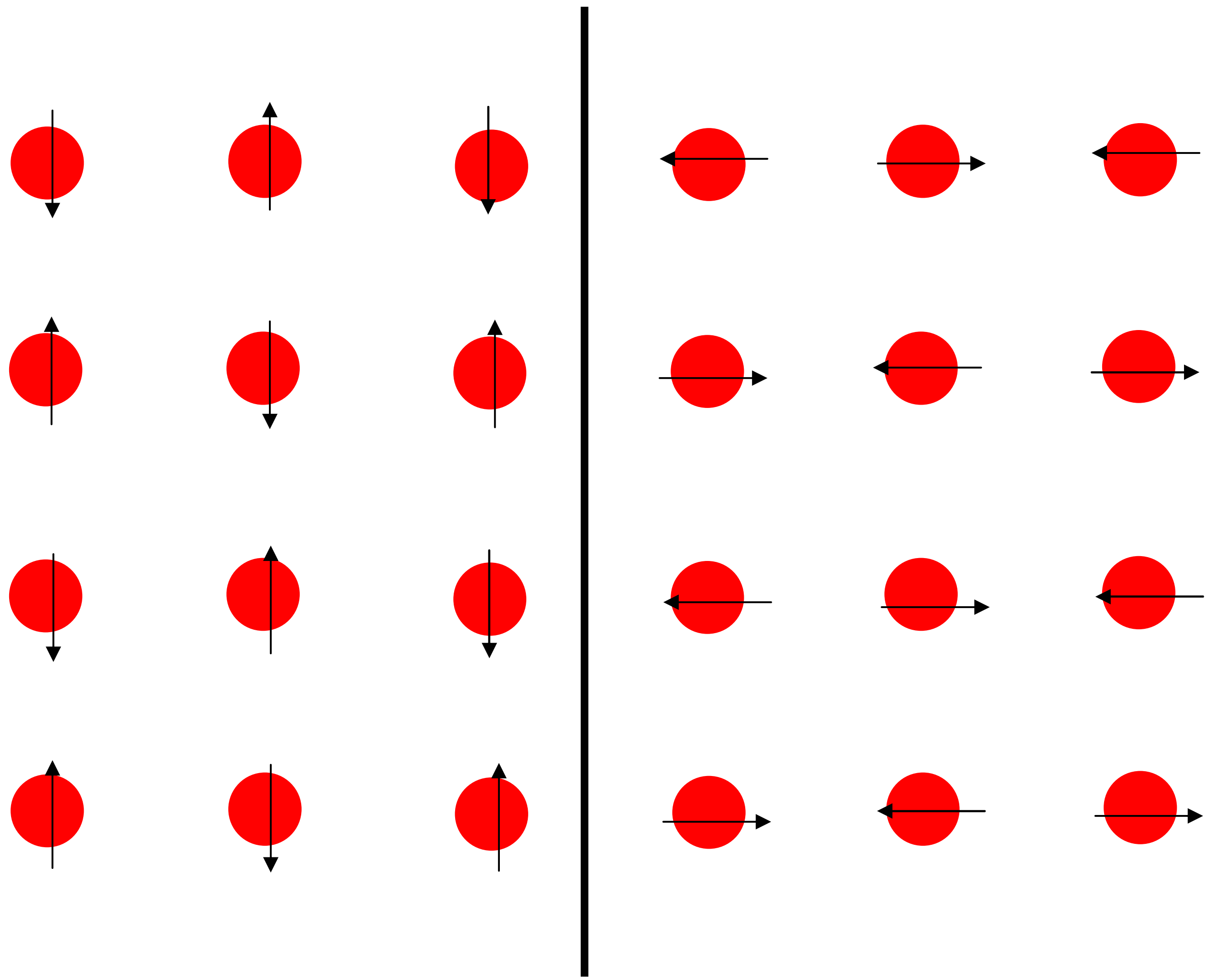
Holes do not localize at the Ca^{2+} sites



$-5/2> \Leftrightarrow |-3/2>$ and $|3/2> \Leftrightarrow |5/2>$ 75 GHz, B//c

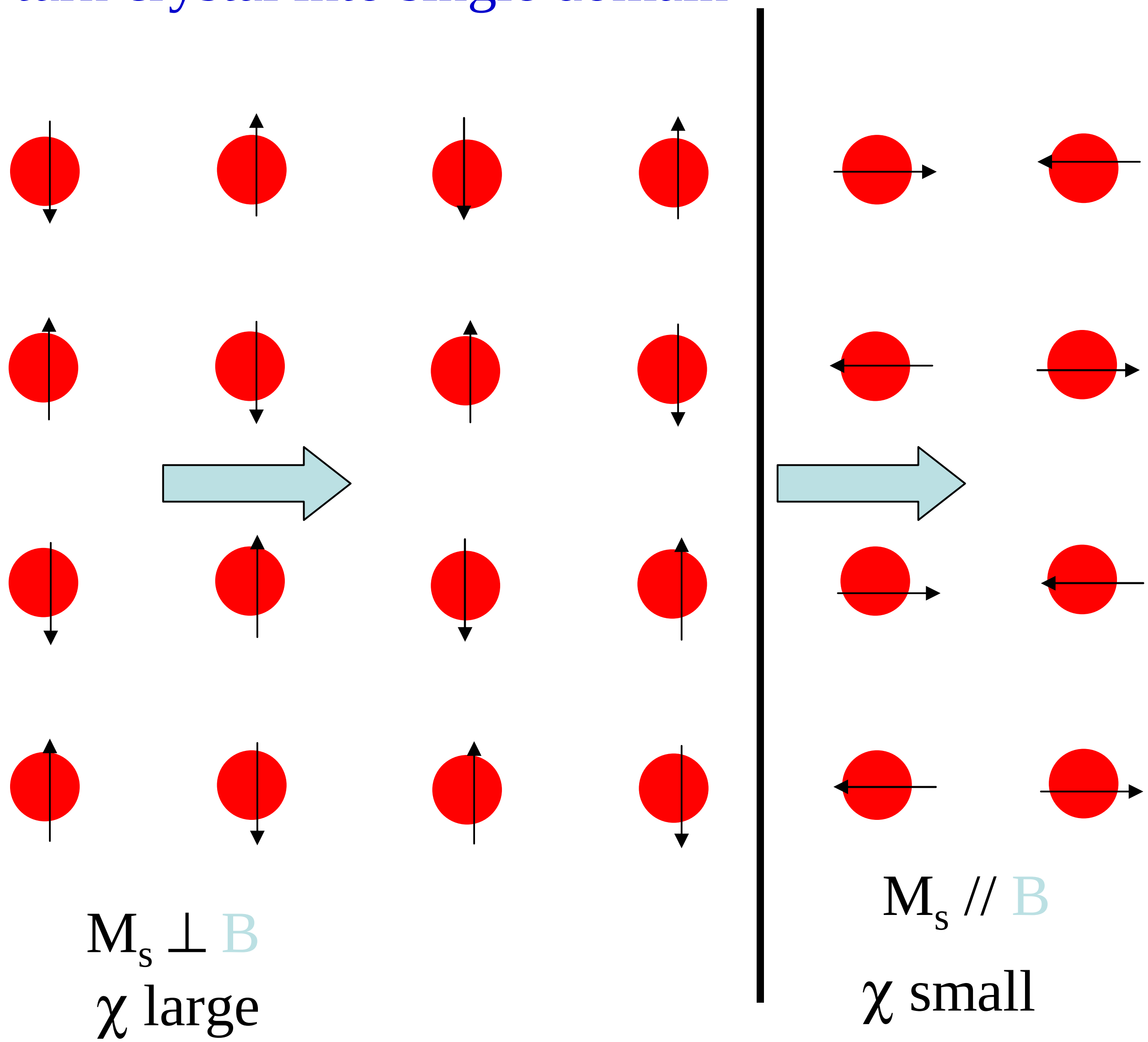
Change of domain structure with magnetic field

Magnetic fields turn crystal into single domain



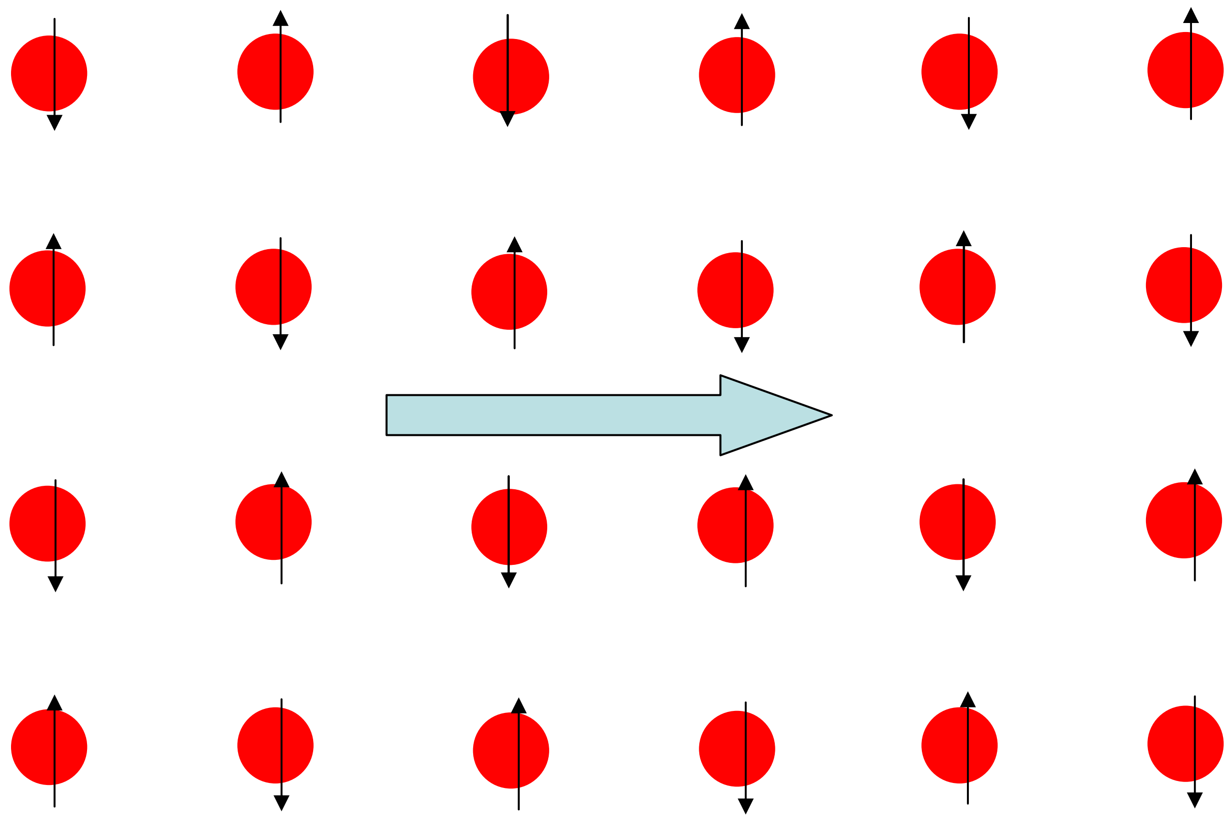
zero magnetic field

Magnetic fields turn crystal into single domain



intermediate magnetic field

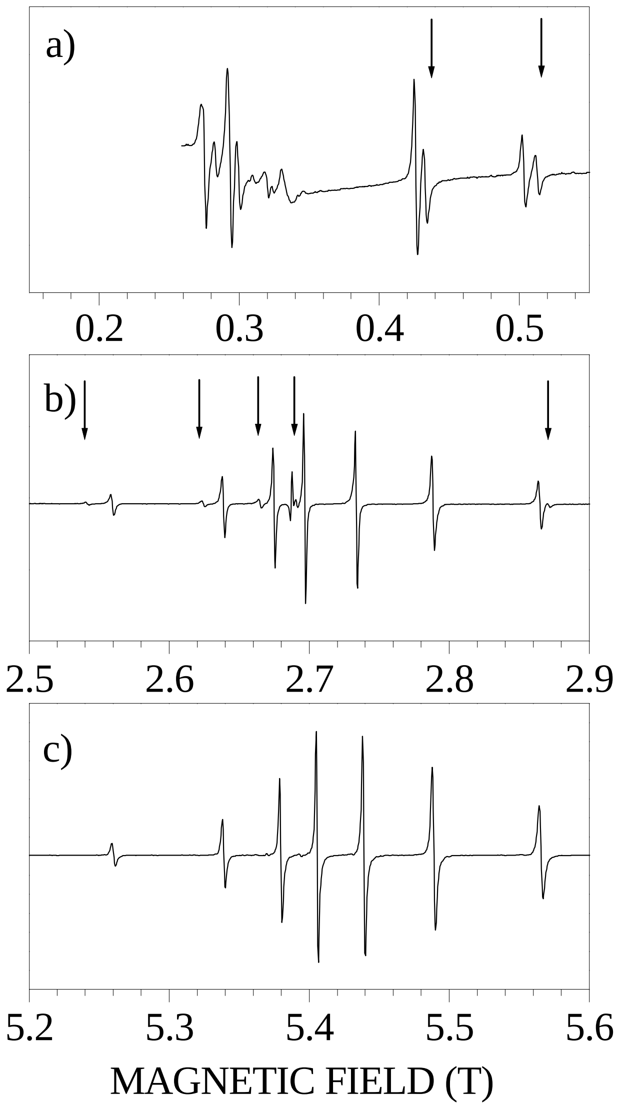
Magnetic fields turn crystal into single domain



$M_s \perp B$

χ large

large magnetic field: magnetically single domain

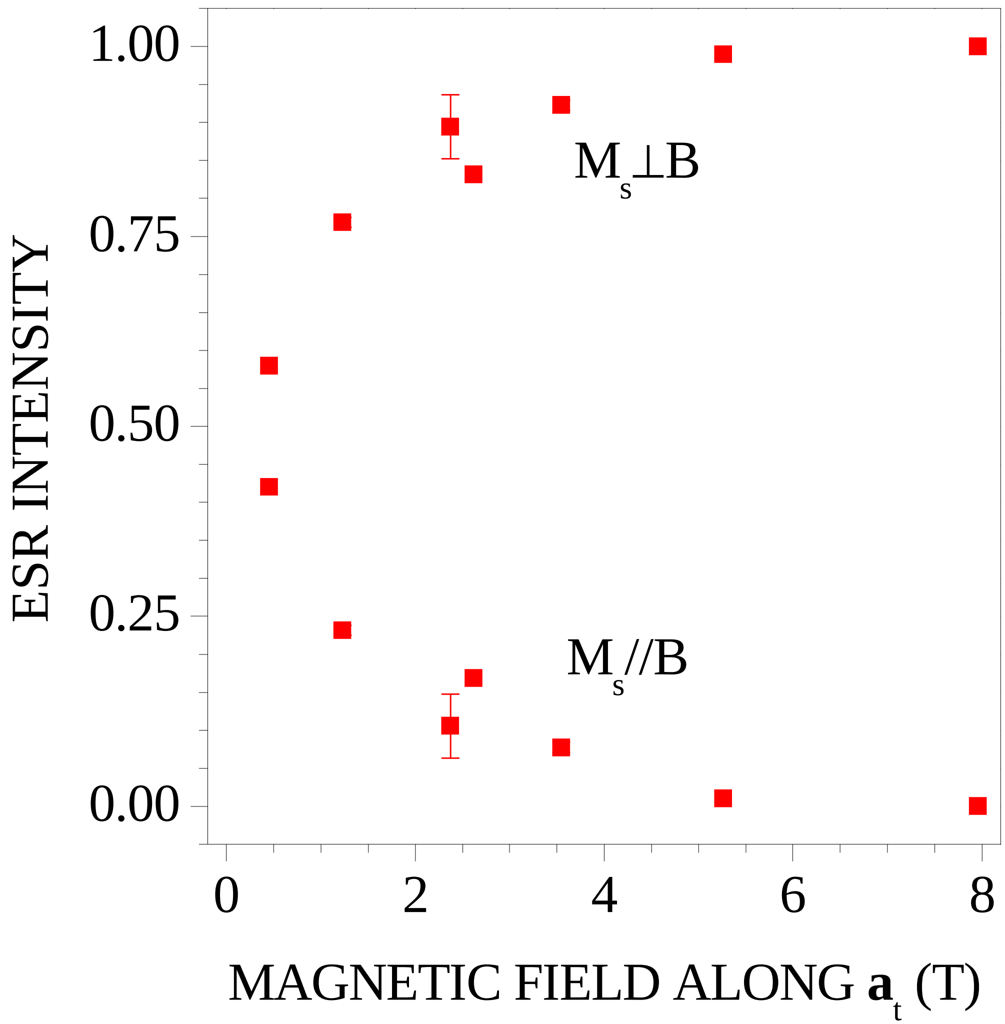


0.2 – 0.5 T (9 GHz)

2.7 T (75 GHz)

5.4 T (150 GHz)

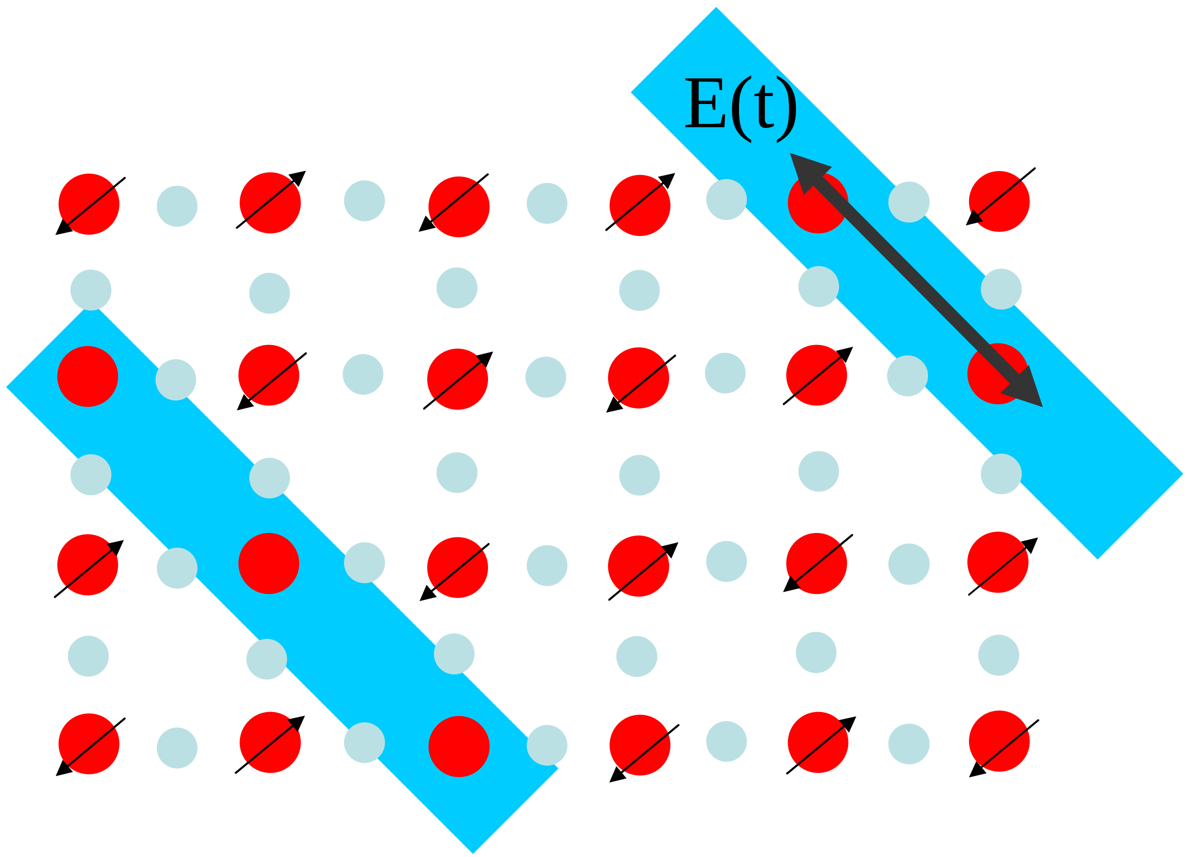
Magnetic fields turn crystal into single domain
Experiment: undoped



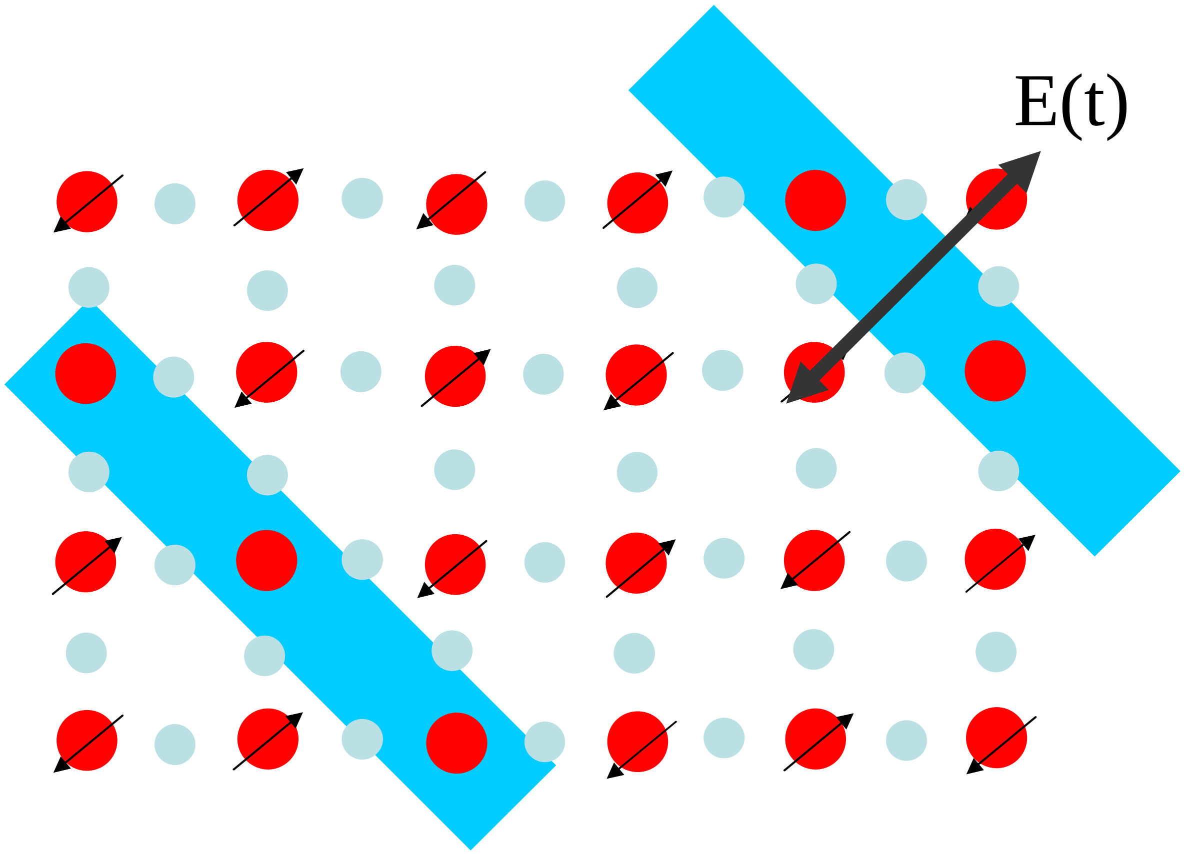
2% Ca YBCO in 8 T field:

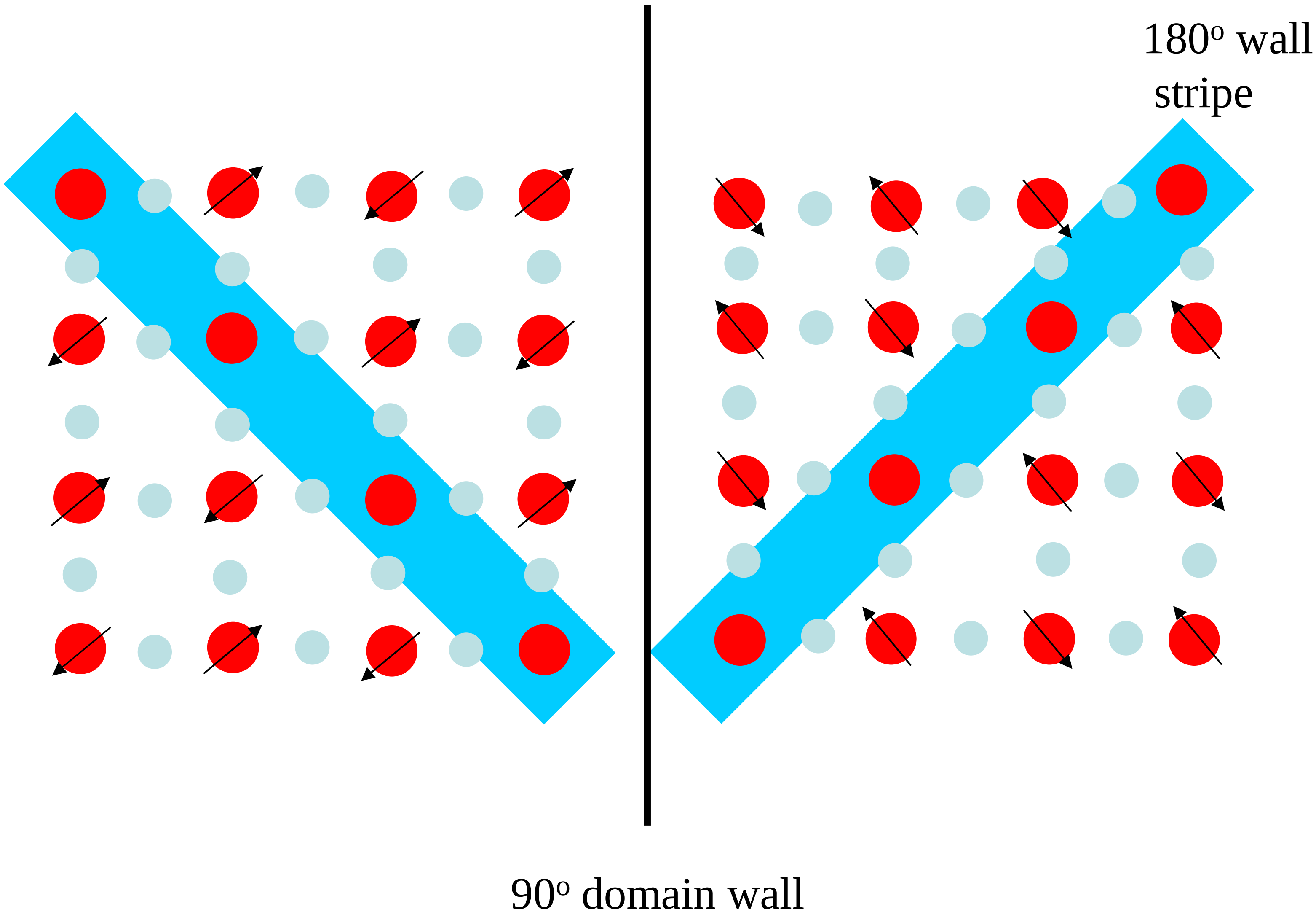
magnetically single domain
for all orientations

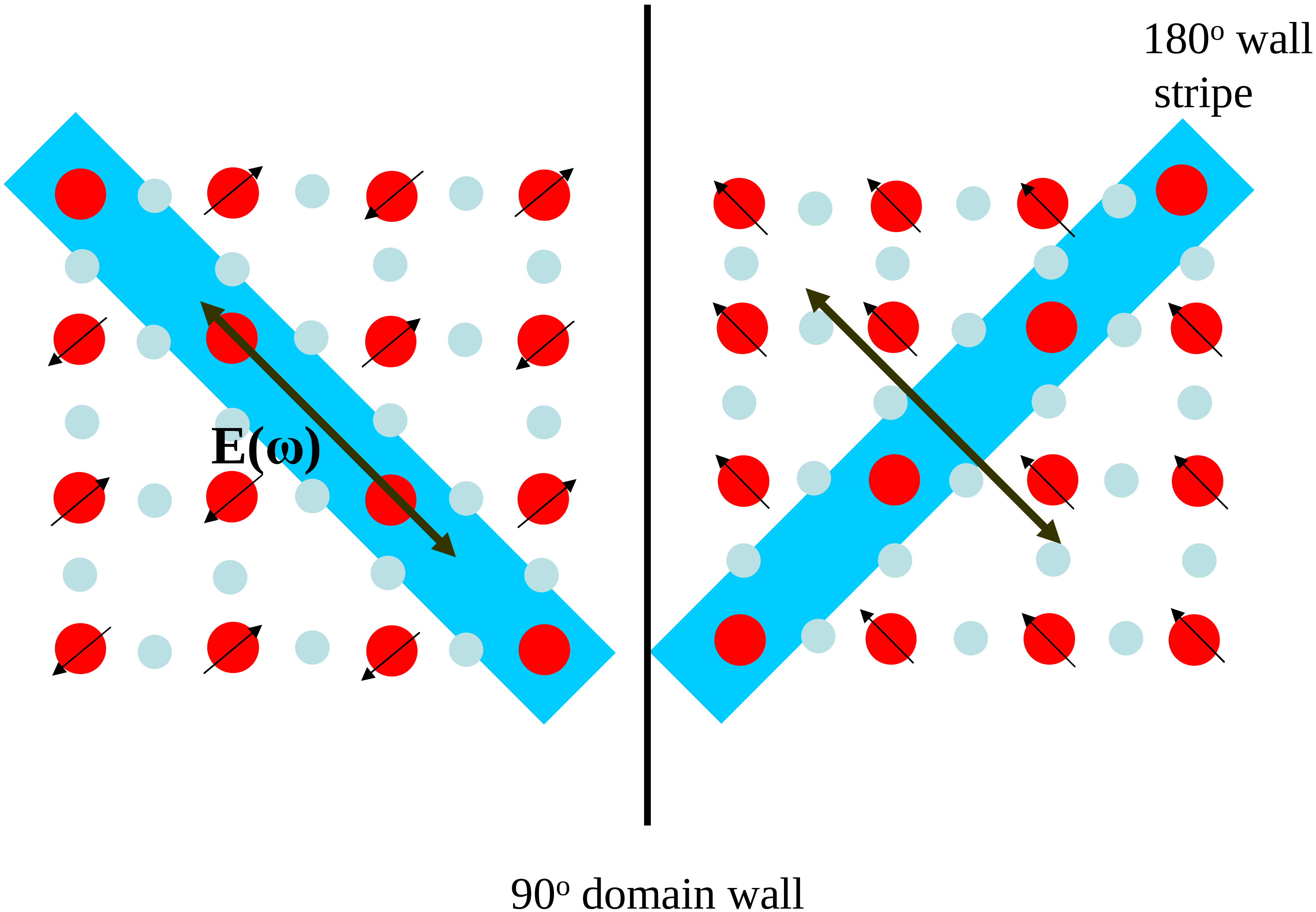
anisotropic conductivity

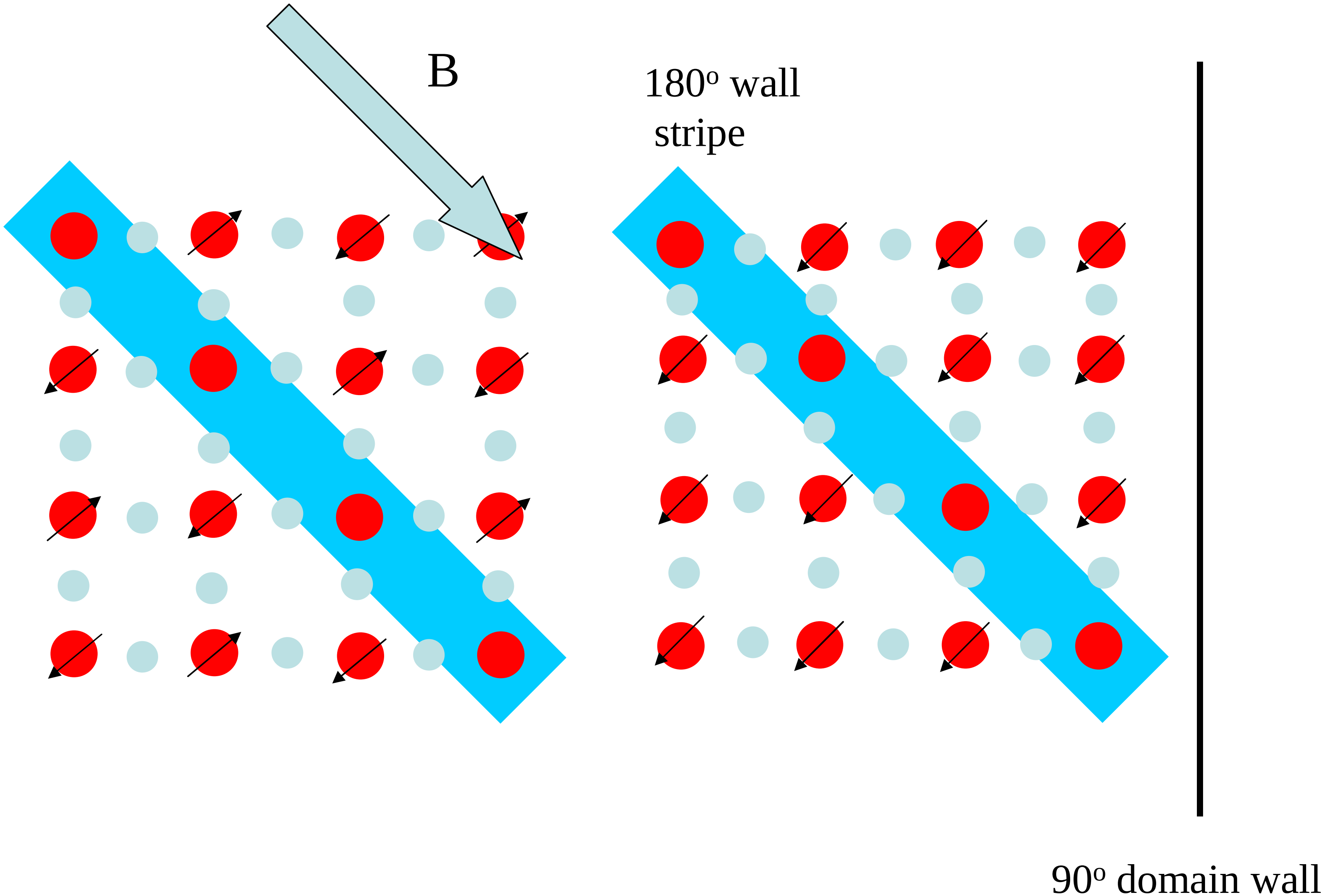


anisotropic conductivity

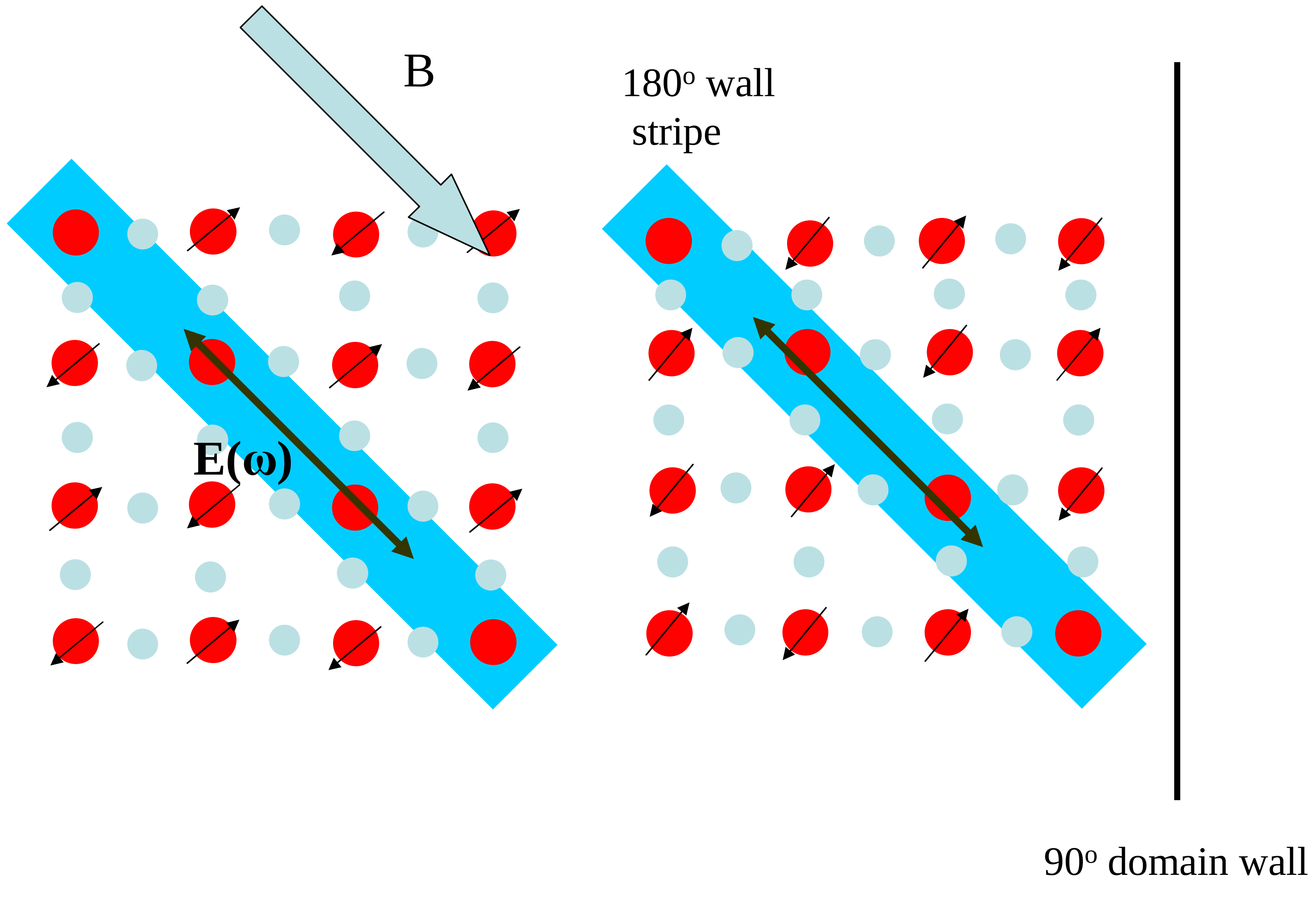



180º wall
stripe
90º domain wall

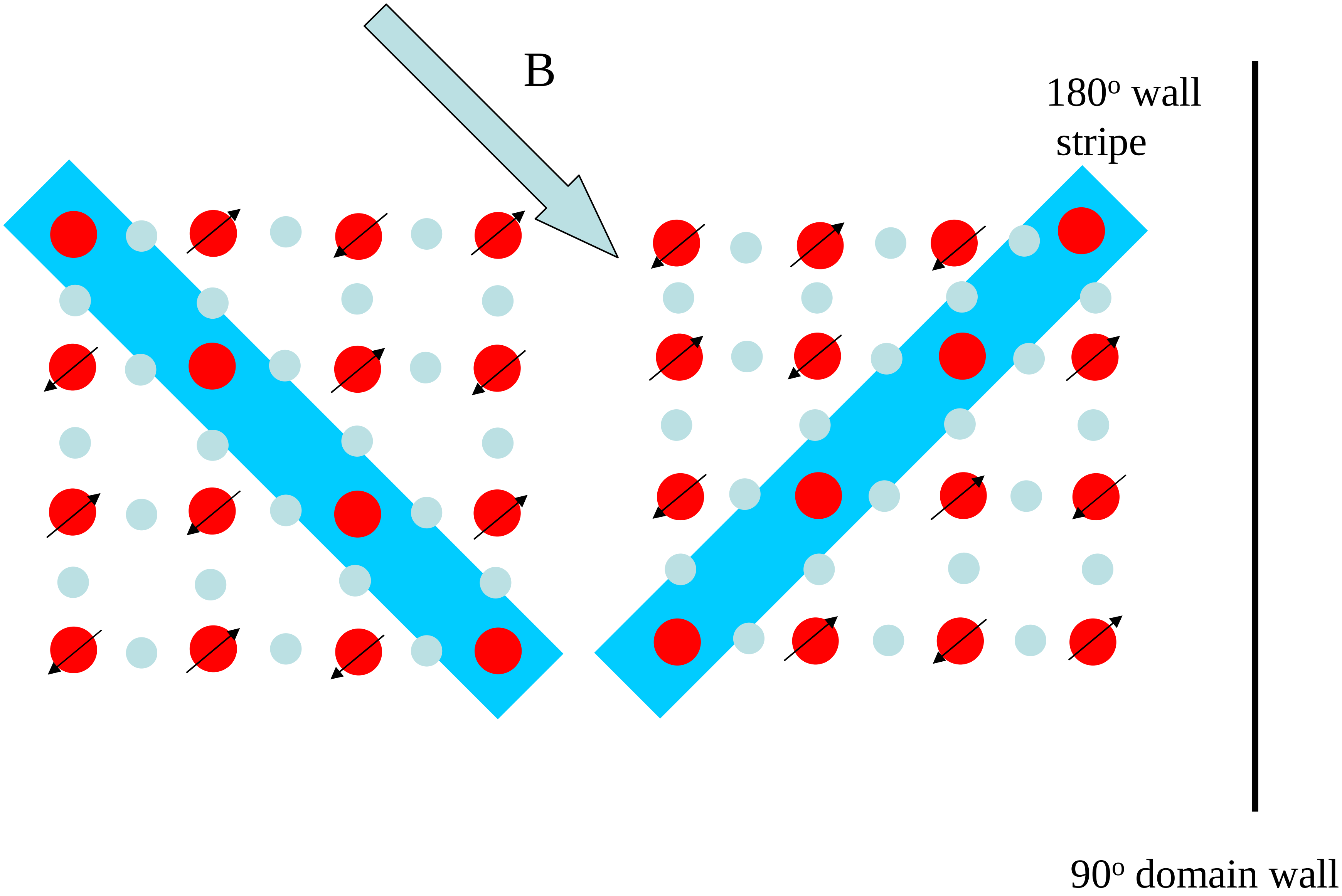

180o wall
stripe
E(ω)
90o domain wall



B
180o wall
stripe
90o domain wall



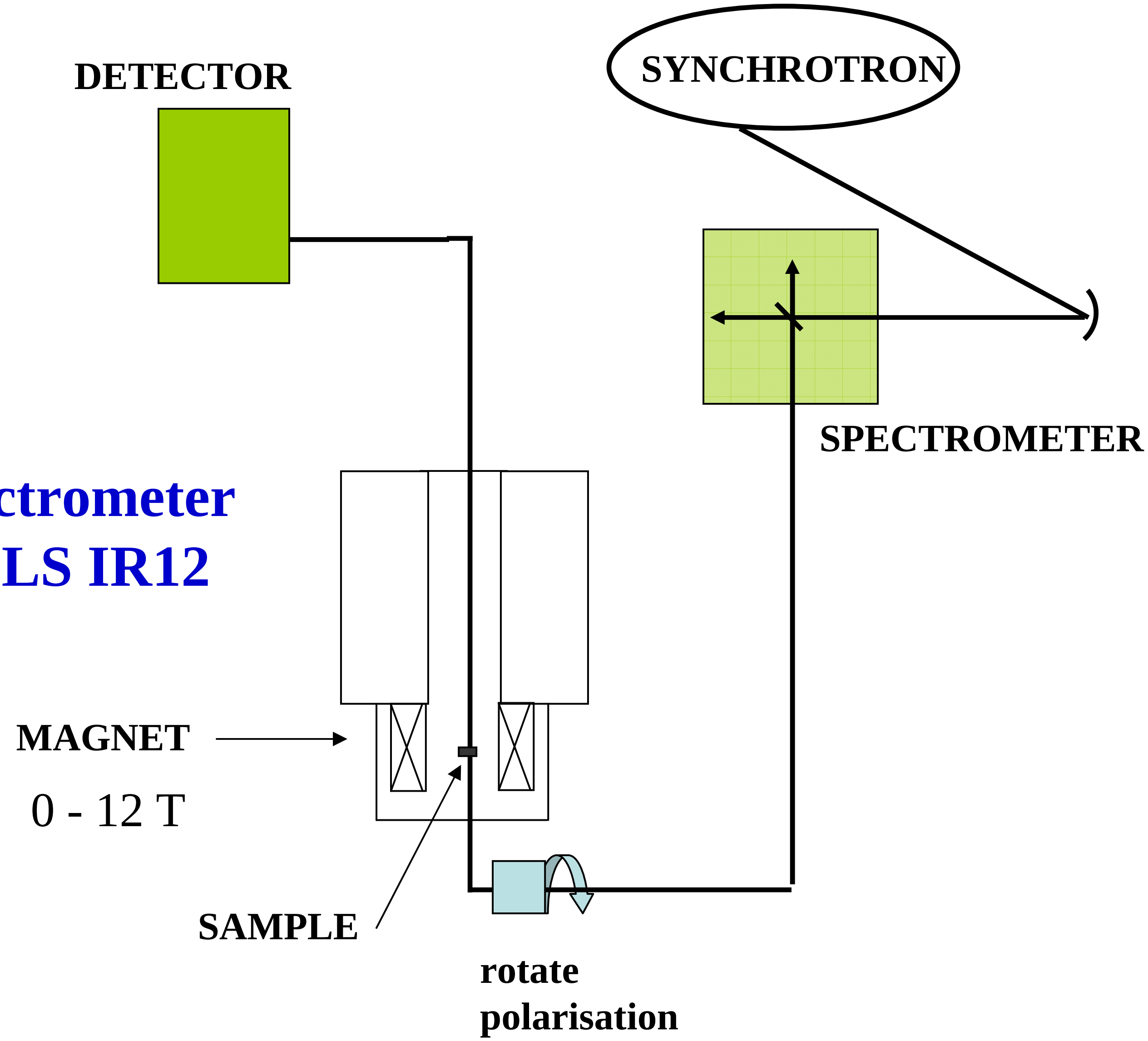
B
180° wall
stripe
E(ω)
90° domain wall



B
180º wall
stripe
90º domain wall

IR transmission in magnetic field

FT-IR ESR spectrometer
Brookhaven NSLS IR12



A. Janossy et al Phys.Rev.B 2007

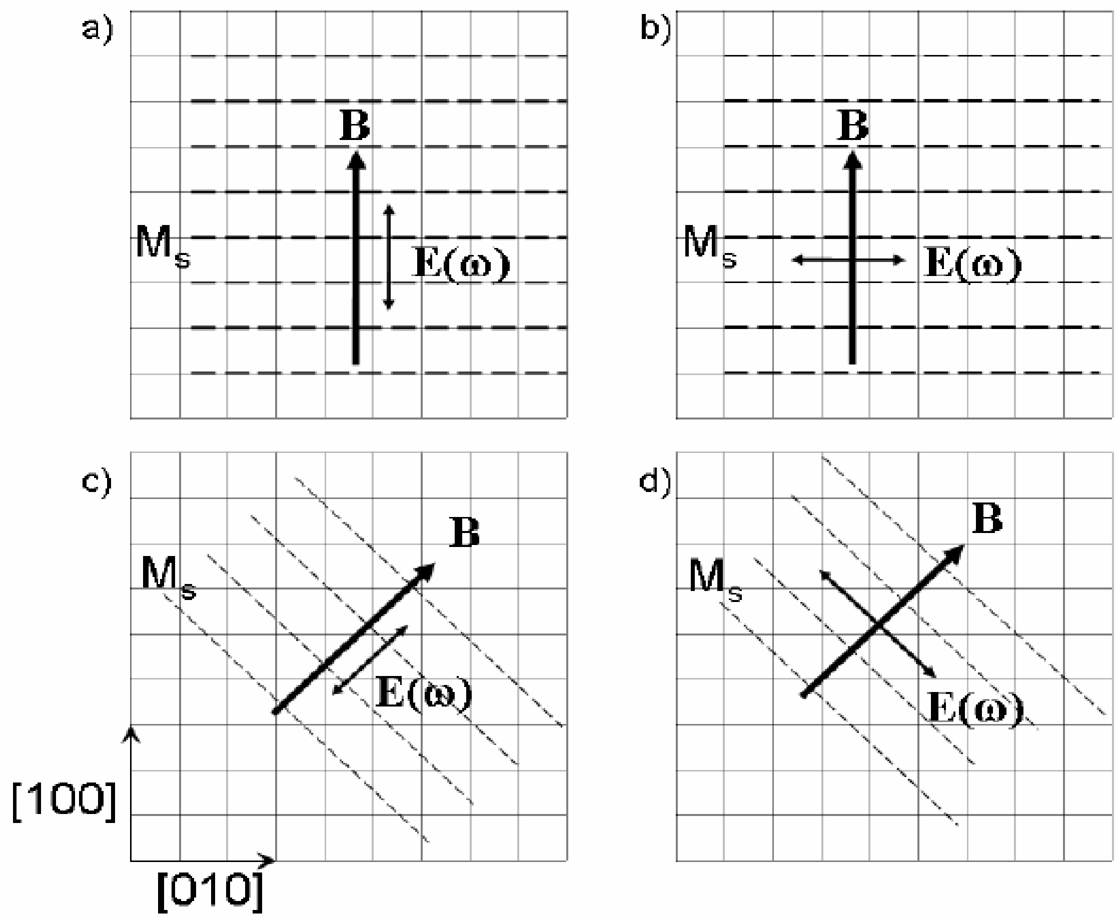


Figure 9. Geometrical arrangements of the infrared (IR) transmission experiments.

IR transmission in magnetic field

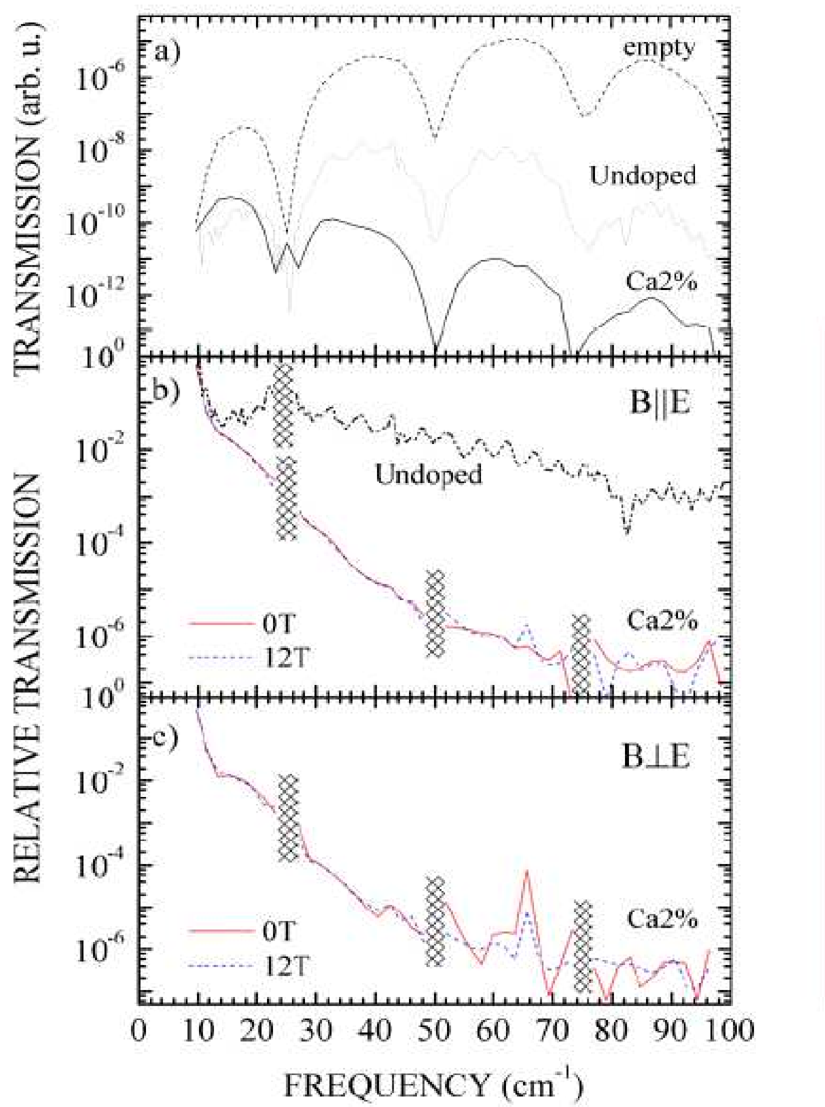
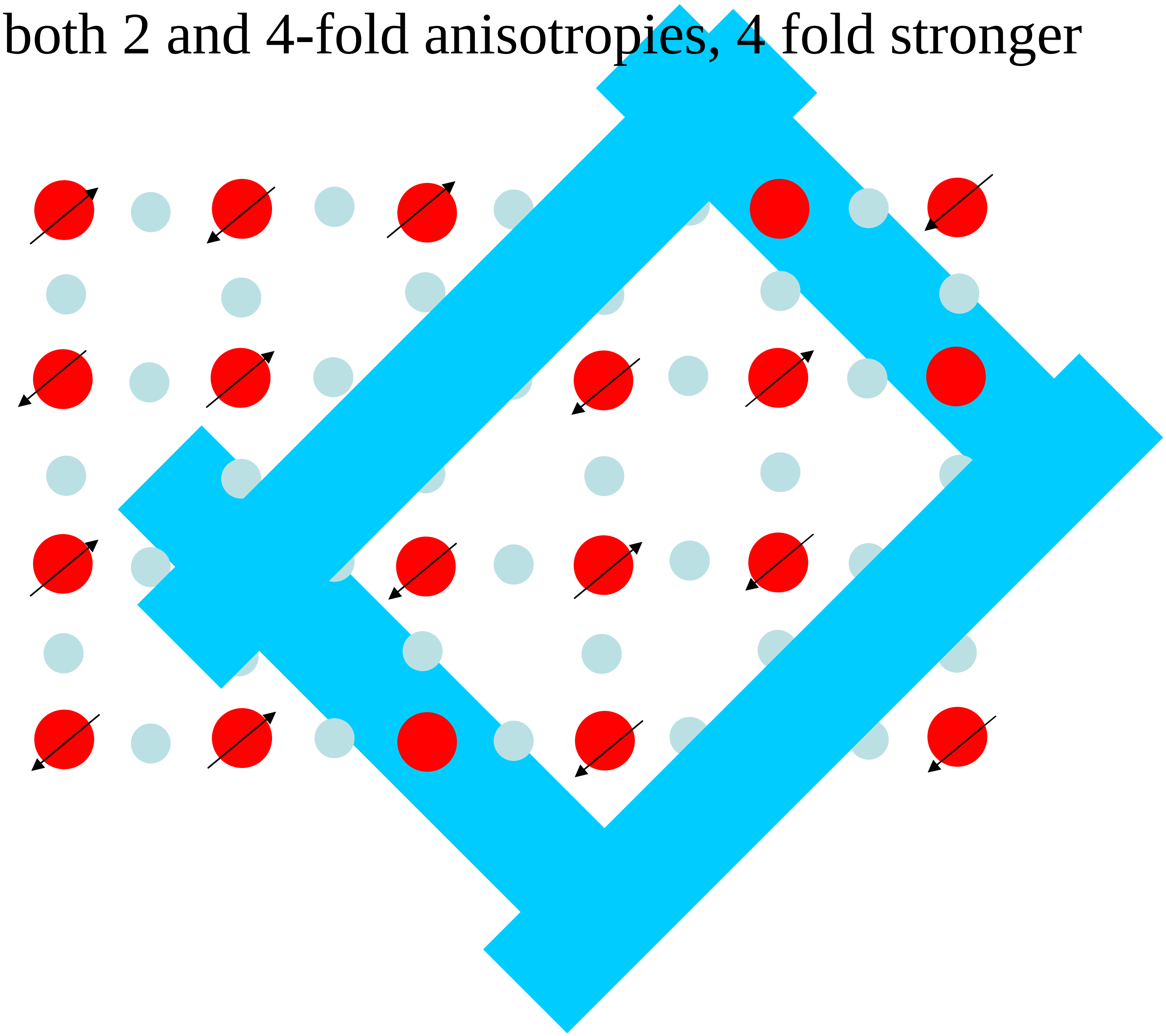
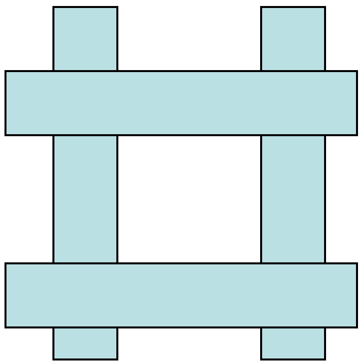
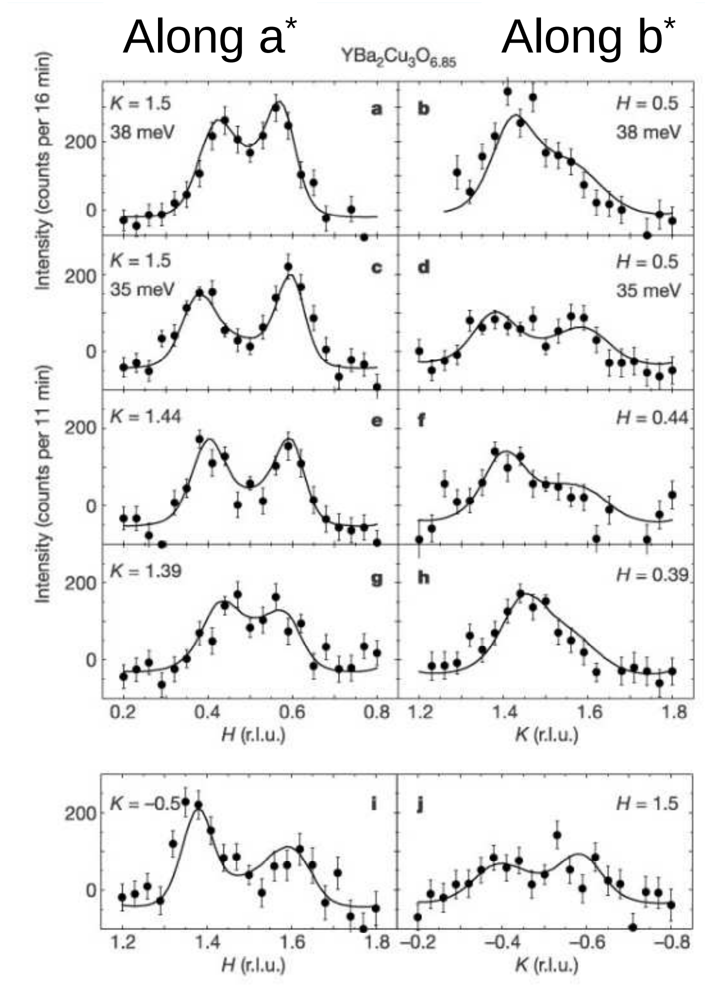


Figure 10. IR transmission through the Ca2% single crystal.

experiment: both 2 and 4-fold anisotropies, 4 fold stronger







$YBa_2Cu_3O_{6.85}$

$YBa_2Cu_3O_{6.6}$

untwinned
T=10K

Two-dimensional geometry of spin excitations in the high-transition-temperature superconductor YBa2Cu3O6+*x*
V. Hinkov, S. Pailhès, P. Bourges, Y. Sidis, A. Ivanov, A. Kulakov, C. T. Lin, D. P. Chen, C. Bernhard and B. Keimer
Nature 430, 650-654 (5 August 2004)

Conclusions:

In lightly hole doped Ca:YBCO
at low temperatures:

-Holes are not localized around Ca
-AF magnetization is diagonal => stripes diagonal
-AF domain structure is static

AF magnetization is weakly pinned to stripes

No anisotropy in $\sigma(\omega)$ below ~70 cm^{-1}
=> No sign of conducting stripes

Charged "stripes" are strongly pinned to lattice