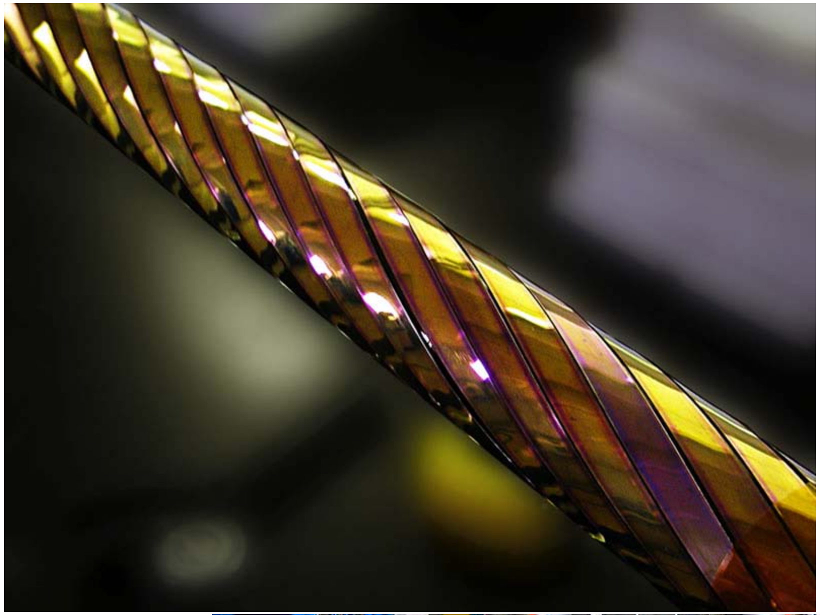
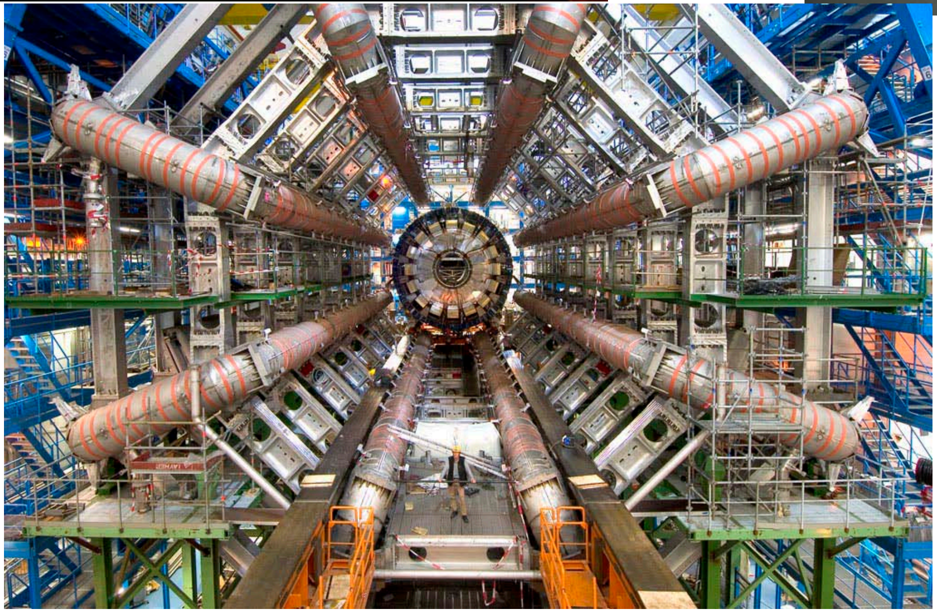
Welcome to the world of Superconductors





Interplay between Magnetism and Superconductivity in High-Temperature Superconductors: Crystal Growth and Neutron Scattering Study

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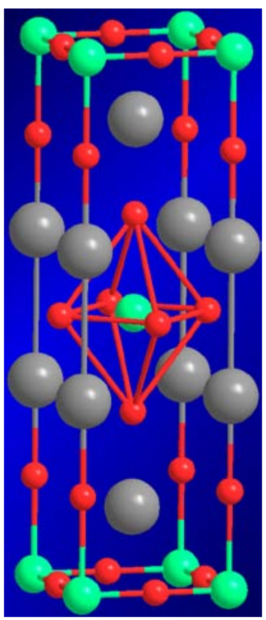
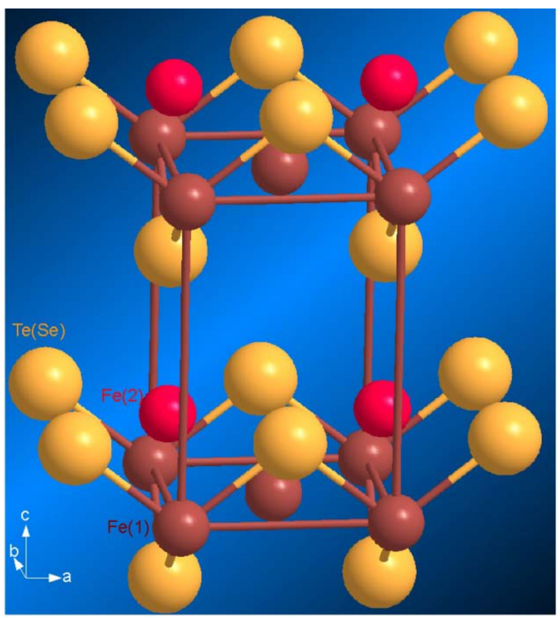
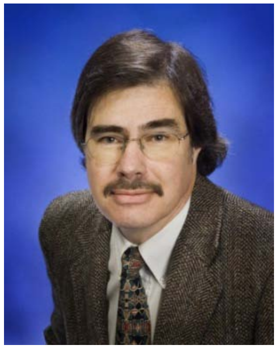




Acknowledgements

- Neutron scattering group @ Brookhaven National Laboratory




John Tranquada | Genda Gu | Guangyong Xu | Zhijun Xu

- Stephen Shapiro
- Igor Zaliznyak
- Markus Hücker

- Qiang Li, Zhi Wei Lin @ Brookhaven National Laboratory

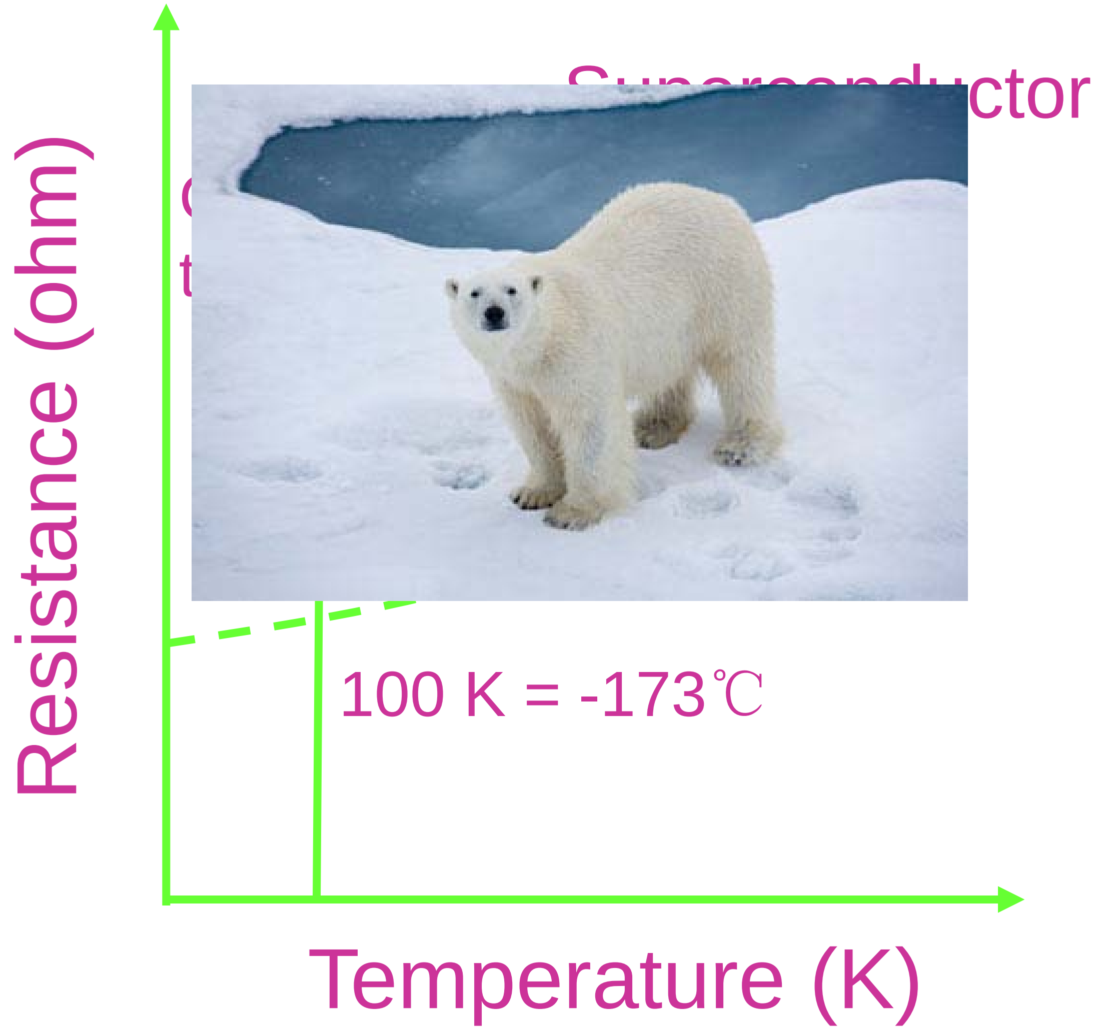
- Hye Jung Kang, Sung Chang, William Ratcliff, Ying Chen, Songxue Chi @ National Institute of Standards and Technology

- Andrey Zheludev, Tao Hong, Wei Tian, Barry Winn, Jerel Zarestky @ Oak Ridge National Laboratory

Outline

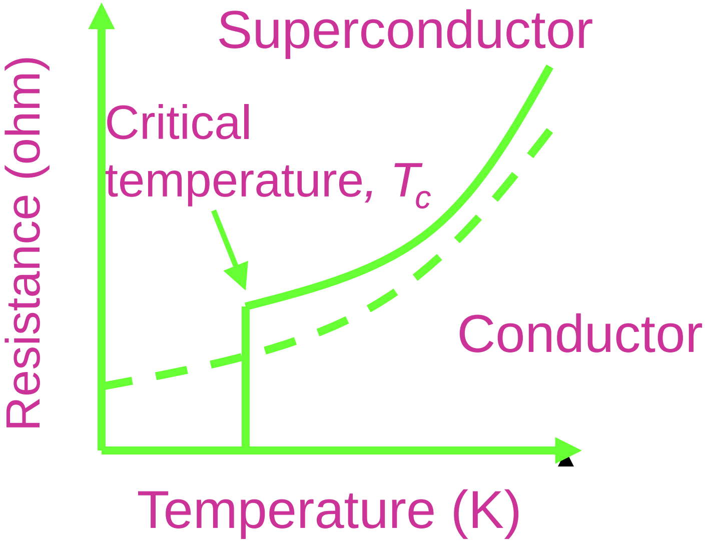
- Introduction
  - High-temperature superconductors
  - Neutron scattering technique
- Results
  - Crystal growth
  - $La_{2-x}BaCuO_4$, static magnetic order
  - $Fe_{1+y}Te_{1-x}Se_x$, magnetic order and fluctuations
- Conclusions

Superconductor

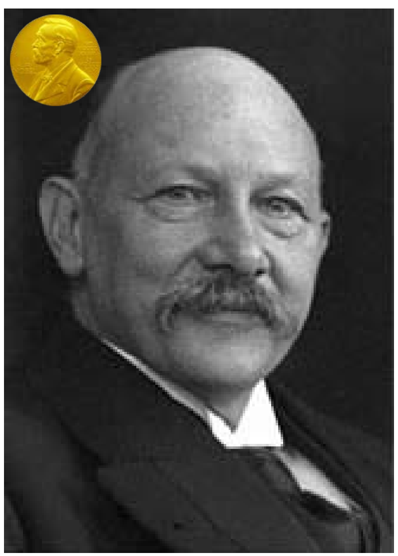


Kevin (K) - 273.15 = Celsius (℃)

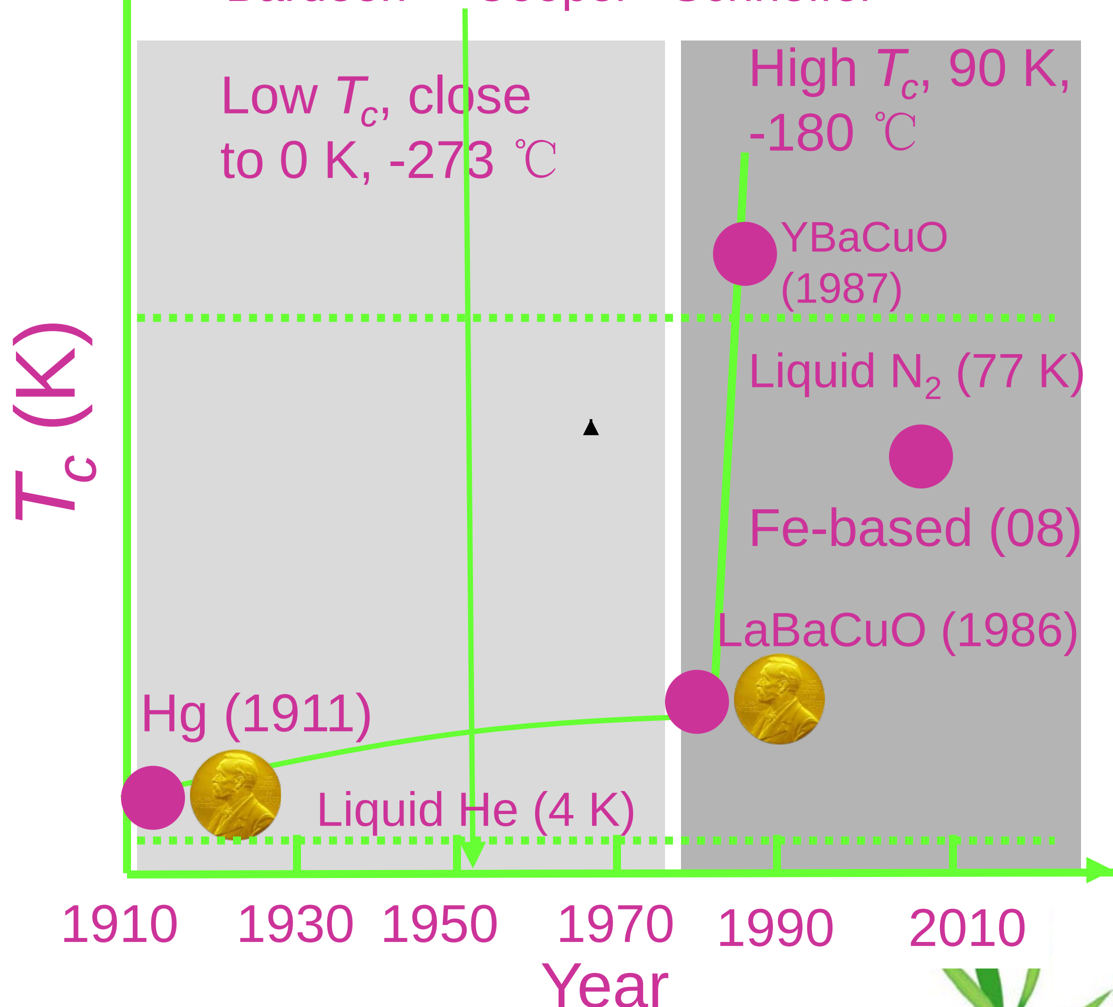
Superconductors



Bardeen Cooper Schrieffer

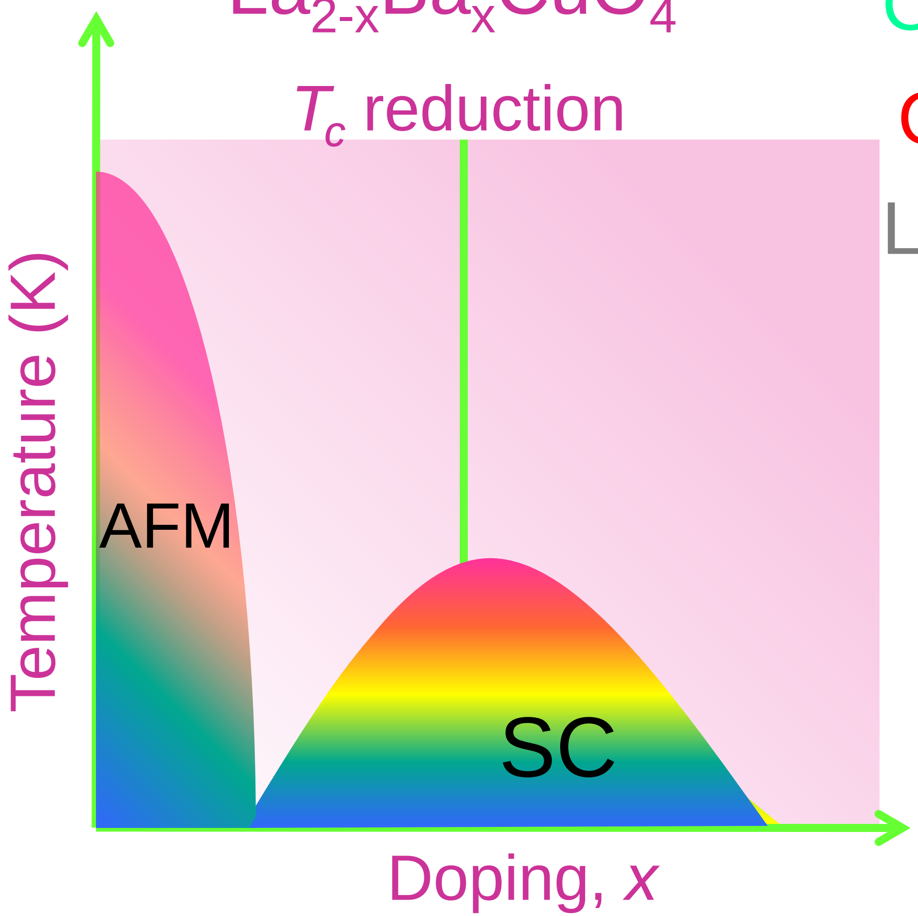


Heike Kamerlingh Onnes



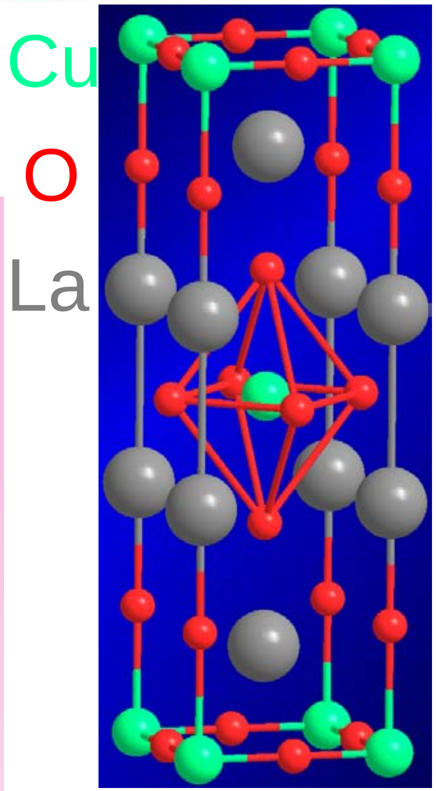
High-Temperature Superconductors

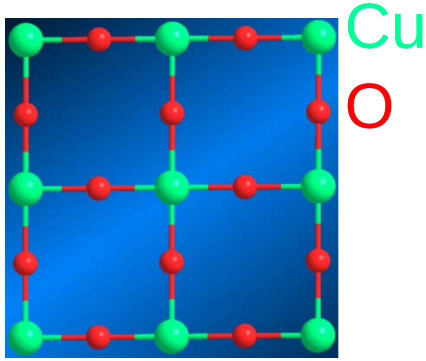
$La_{2-x}Ba_xCuO_4$



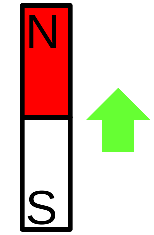
Doping : Replace La by Ba, Sr

La_2CuO_4 : Parent compound
Antiferromagnetic

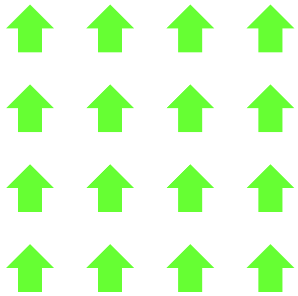




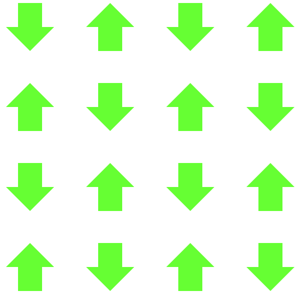
La_2CuO_4



Iron (Fe)-Ferromagnet

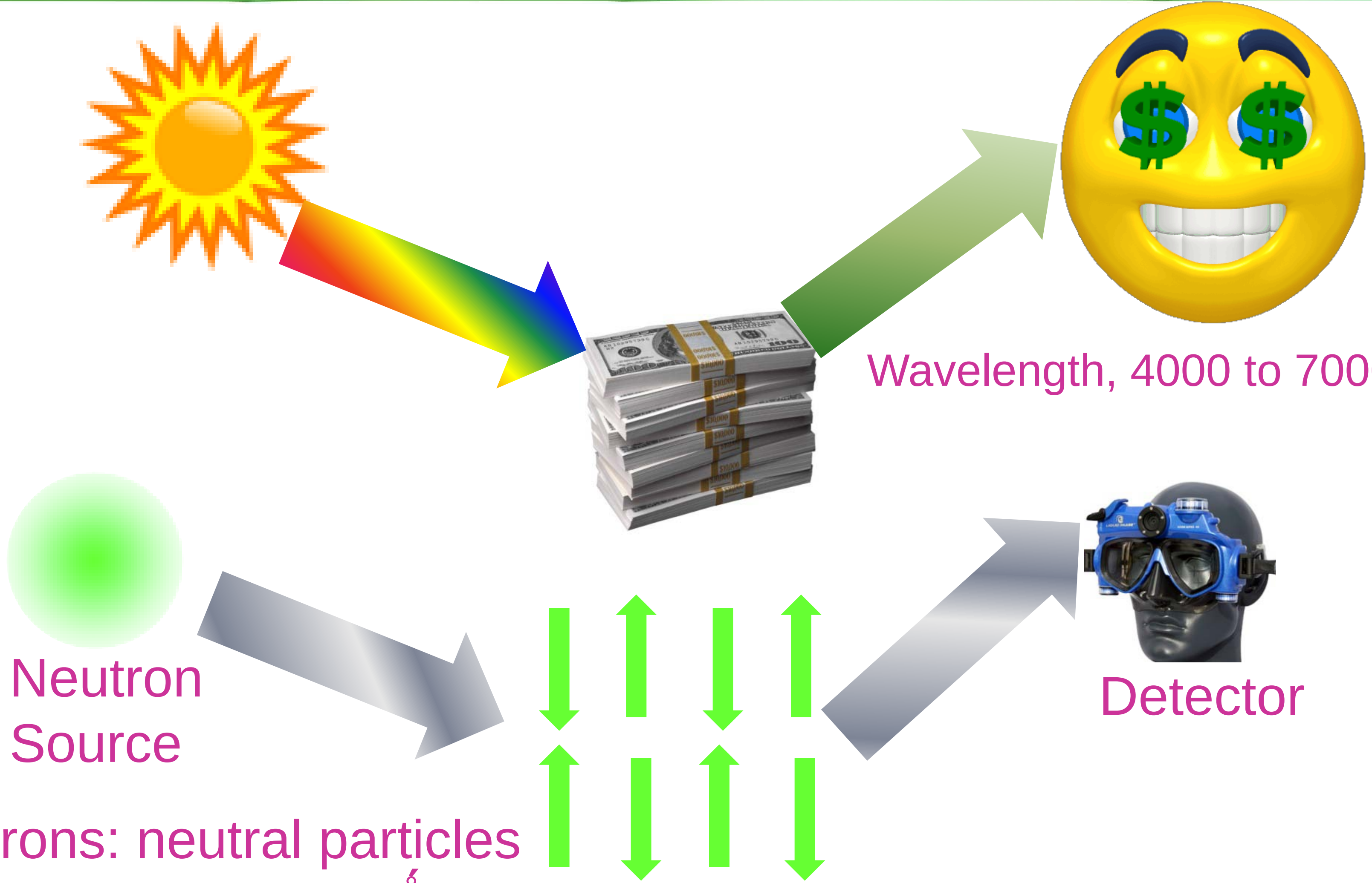


Ferromagnetism



Antiferromagnetism

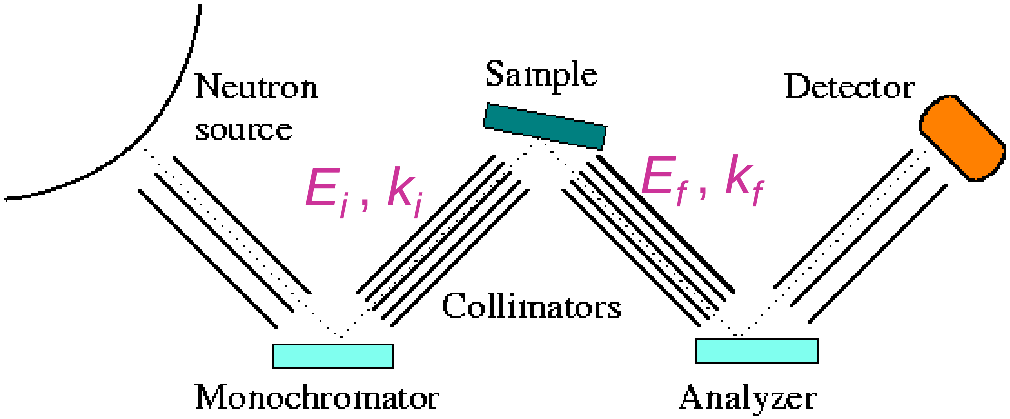
Neutron Scattering



Neutrons: neutral particles
Right wave length, 1 Å
Sensitive to magnetism
Penetrate deeply

Travel!

Neutron Scattering with a Triple-axis Spectrometer



$$\hbar\omega = E_f - E_i$$

$$Q = k_f - k_i$$

Elastic: $E_f = E_i$

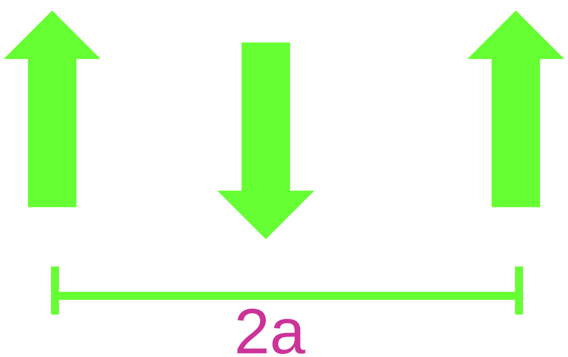
Inelastic: $E_f \neq E_i$

BT7, National Institute of Standards and Technology

What can we learn from neutron scattering?

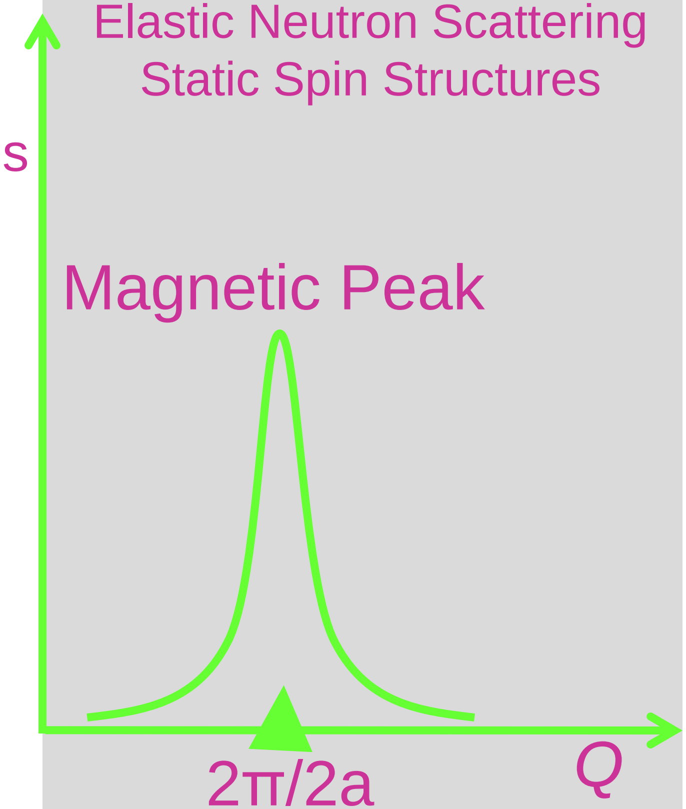
Real Space

Momentum-Energy (Q-E) Space



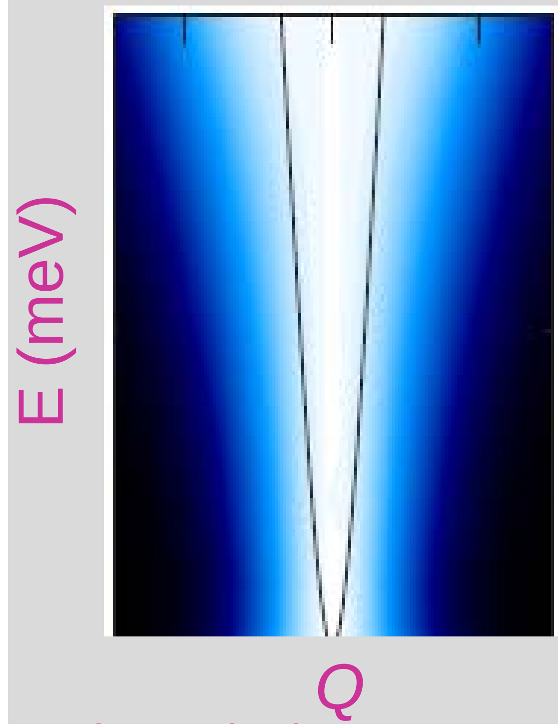
Elastic Neutron Scattering
Static Spin Structures

Intensity
# of Neutrons



Peak position
in *Q*-Space

Inelastic Neutron Scattering
Spin Dynamics



Spin-Excitation Spectrum
Relationship between
fluctuation E and *Q*

What do we know so far?

- What are superconductors and why are they interesting?
  Conductor+Super; Huge application potentials.

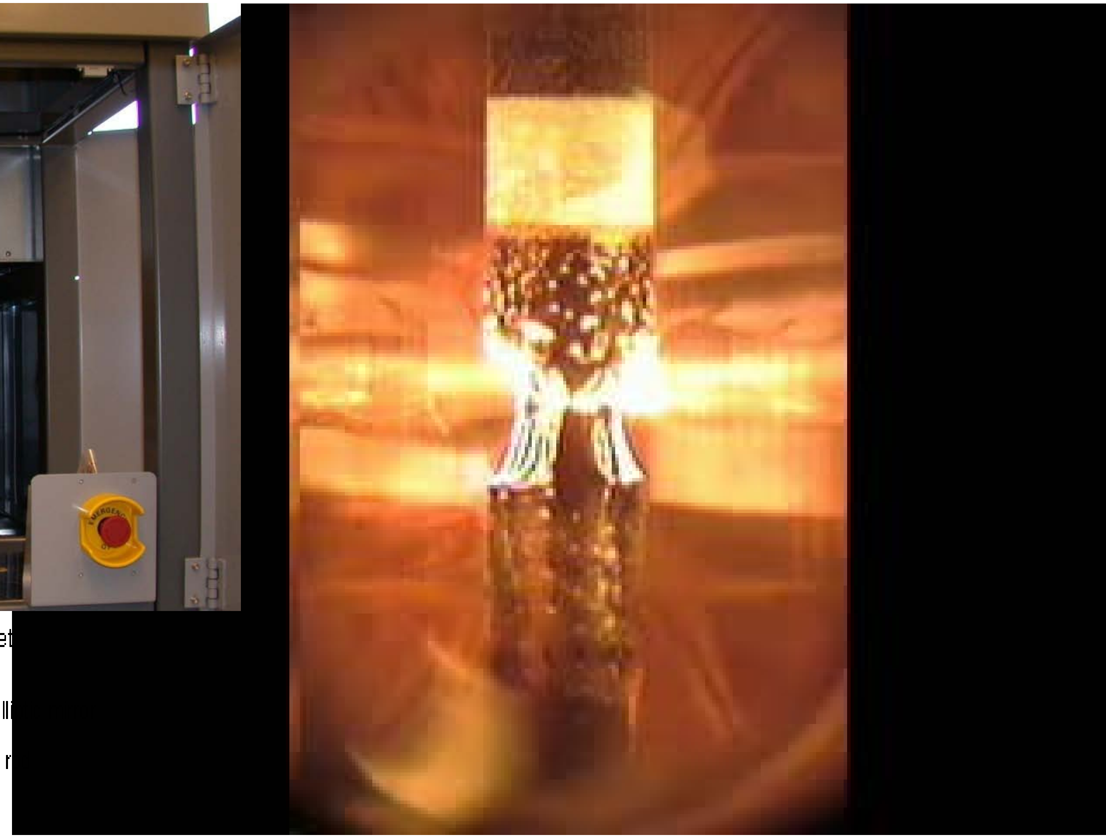
- What to study on high-T_c superconductors?
  Interplay between magnetism and superconductivity.

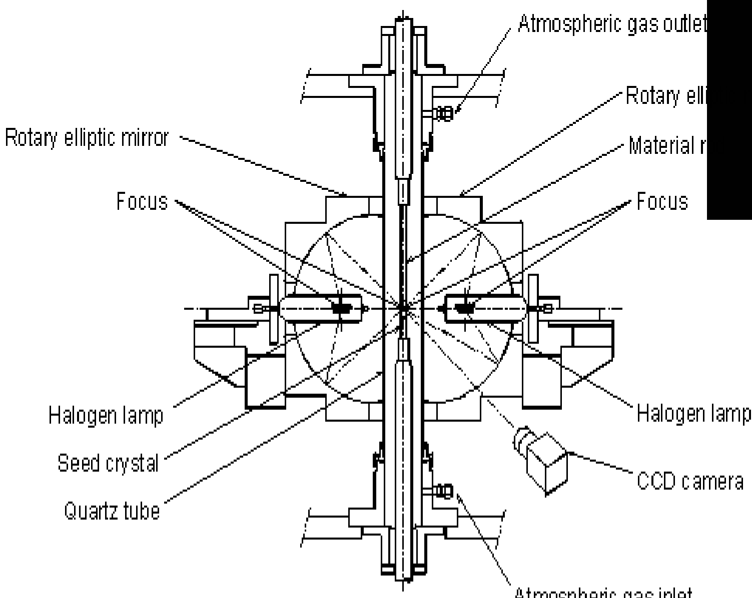
- How to study the magnetism?
  Use neutron scattering techniques.

Then, can we start?

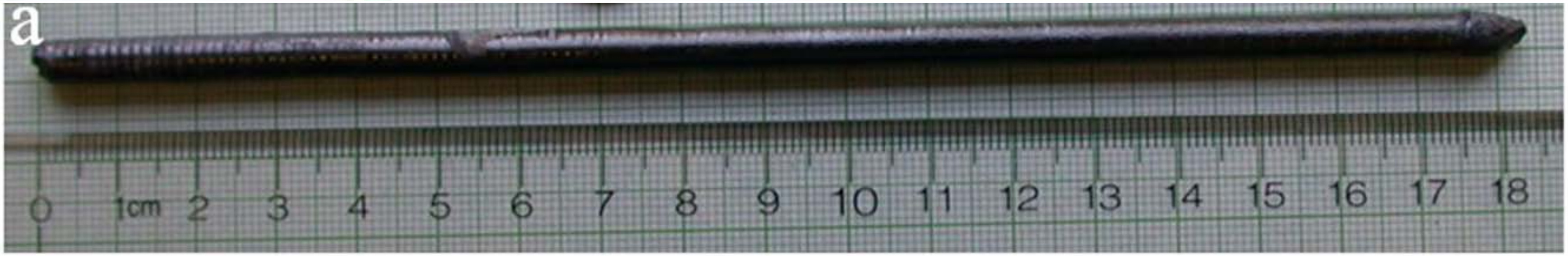
Where is the crystal?

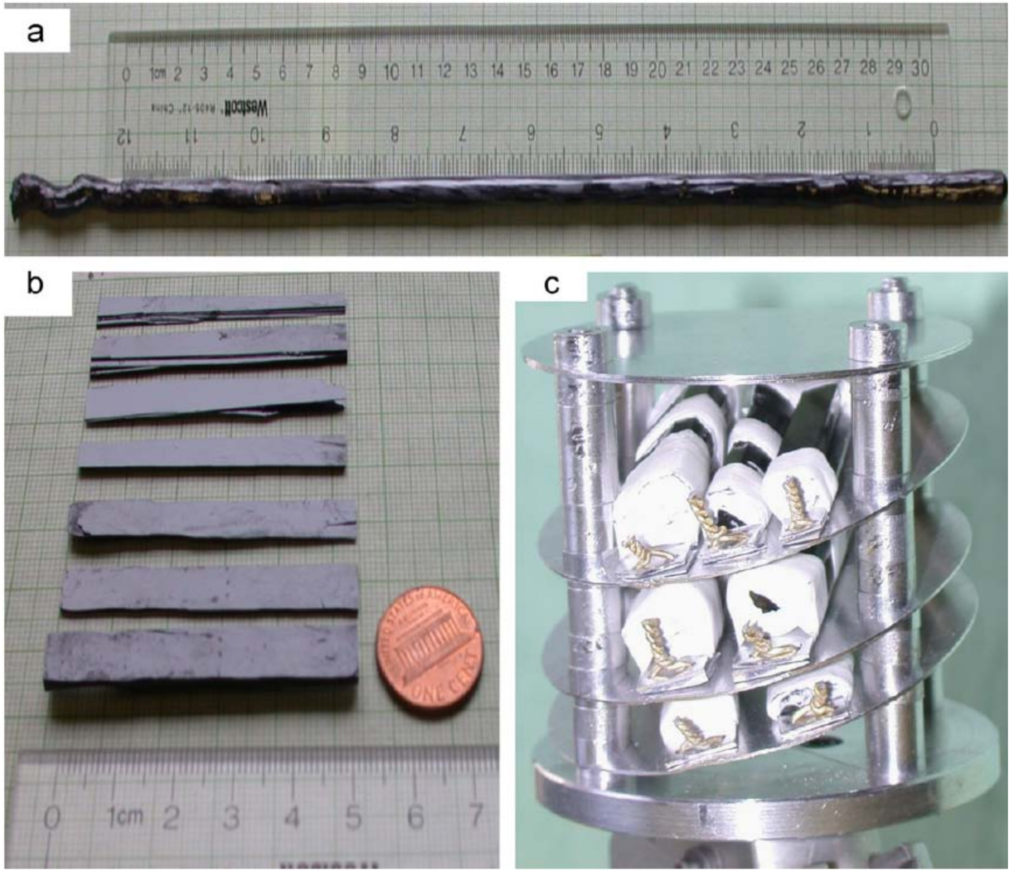
Crystal Growth---Floating-zone Technique

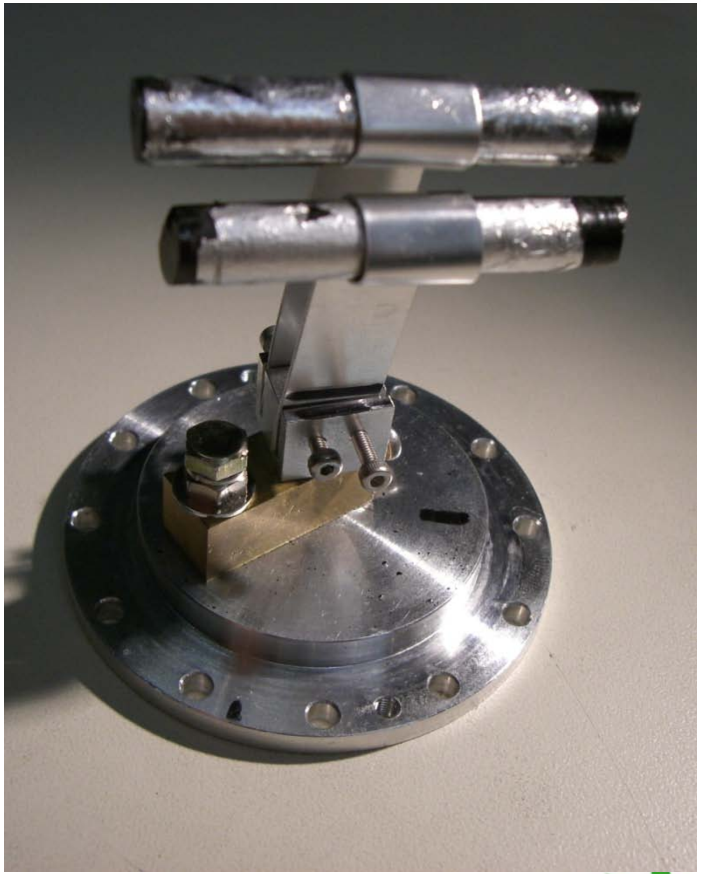




Crystal Growth---Floating-zone Technique

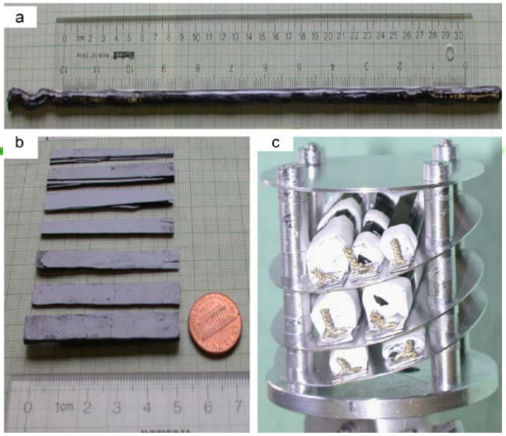


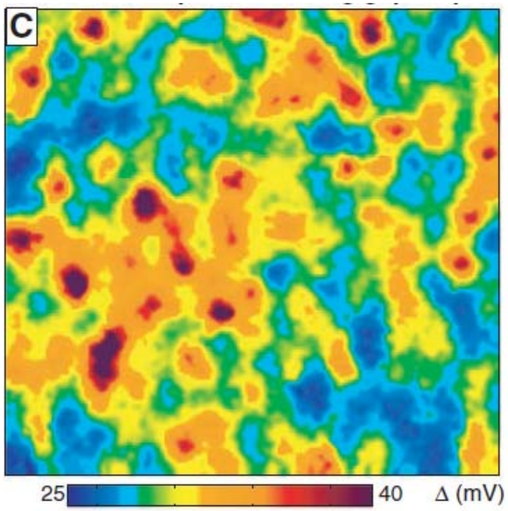




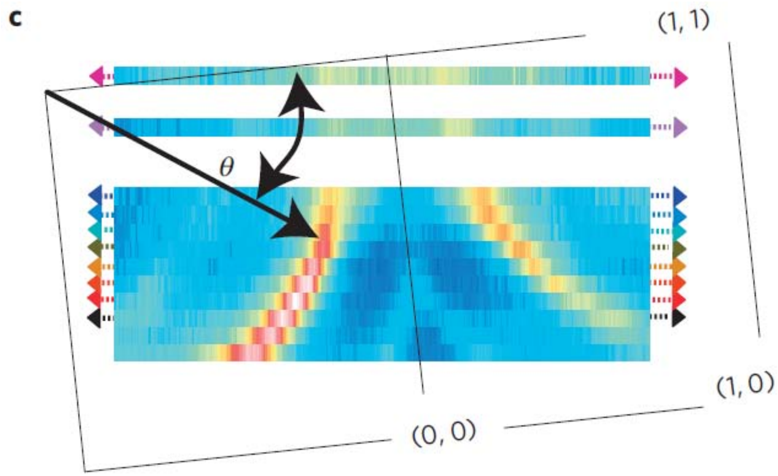
Wen et al., J. Crystal Growth (2008).

Other Measurements on the Crystals

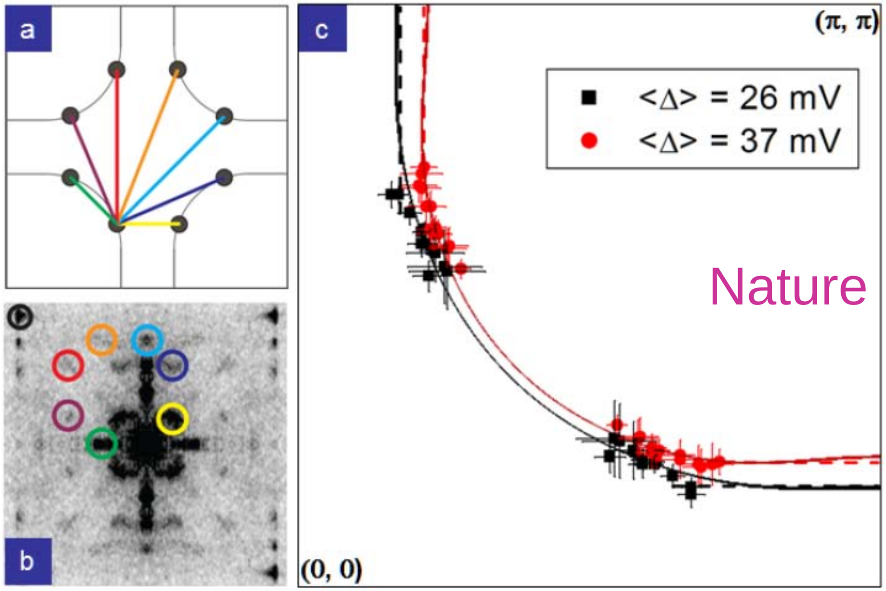




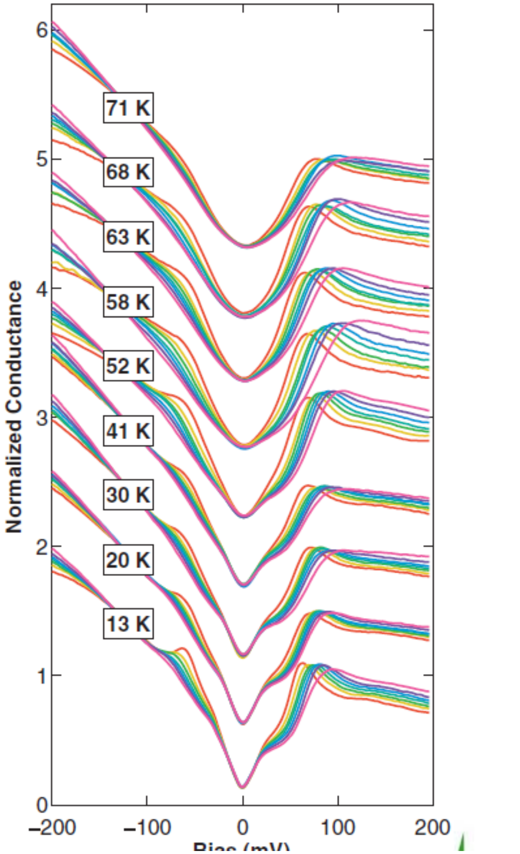
Science (2008).



Nature Physics (2010).



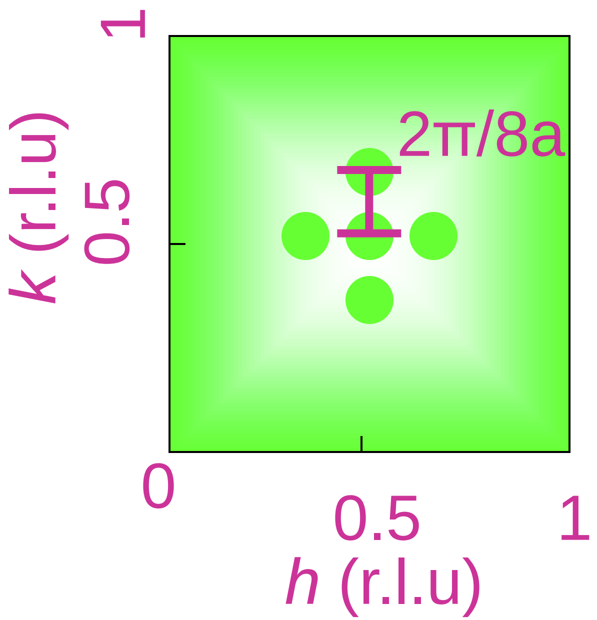
Nature Physics (2009).



Science (2009).

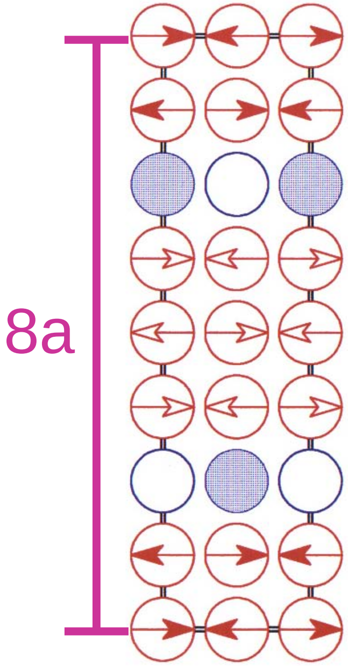
Static Magnetic Order in $La_{2-x}Ba_xCuO_4$

Momentum Space



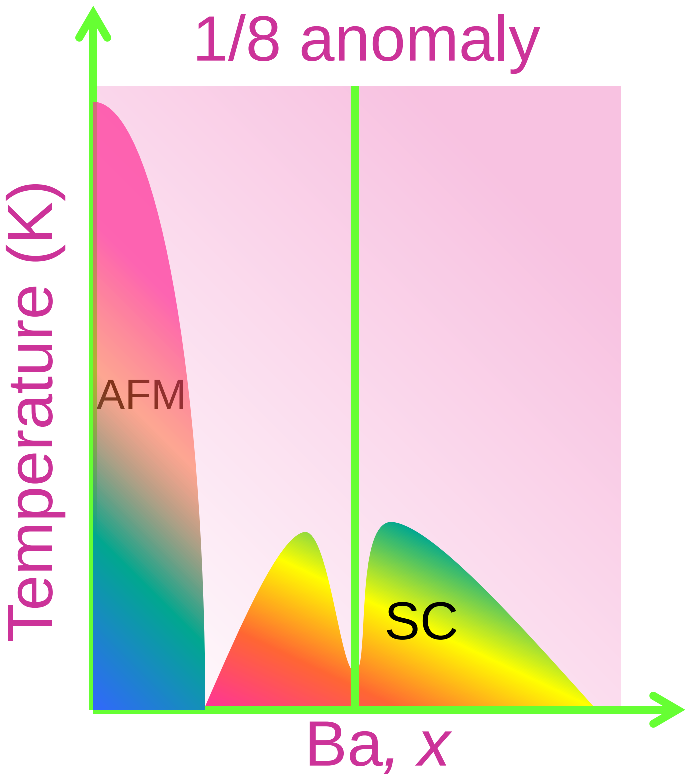
Magnetic peaks

Real space



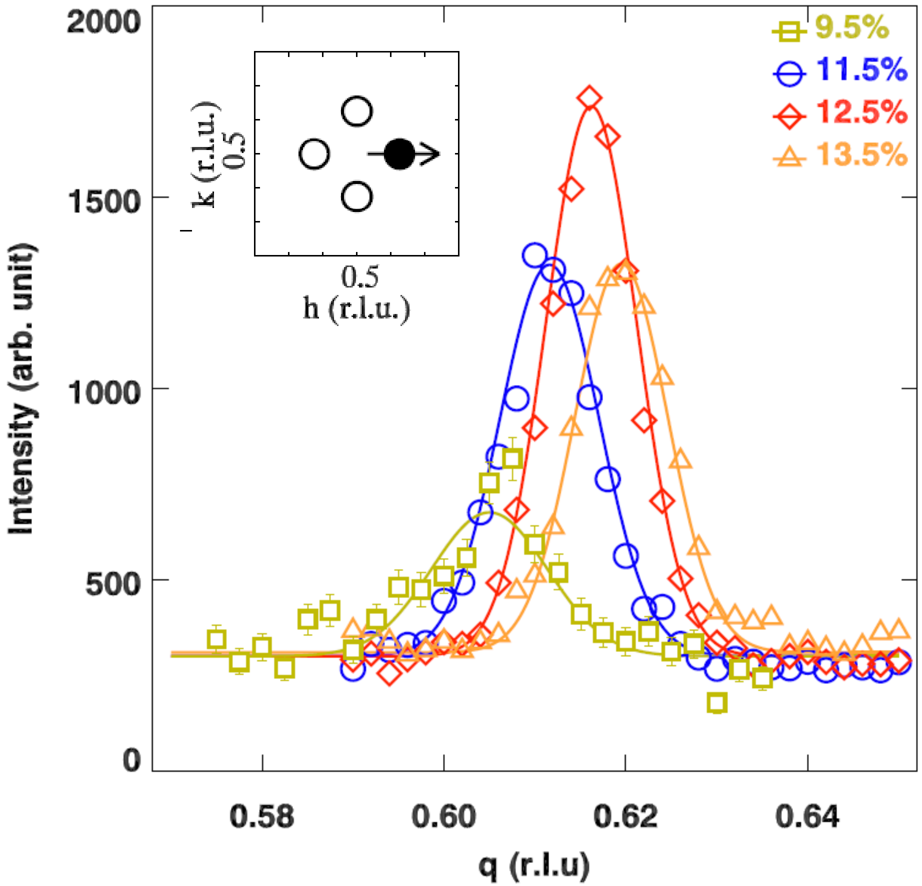
Stripe

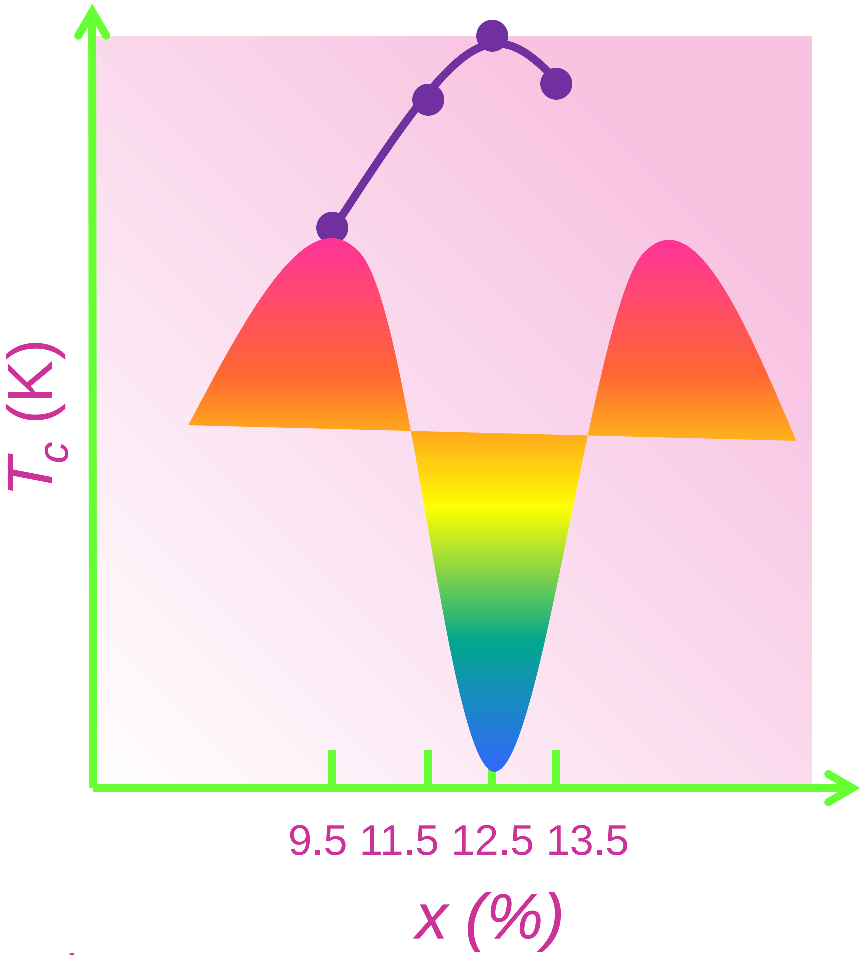
T_c reduction: bad superconductivity



Moodenbaugh et al., PRB (1988).
Tranquada et al., Nature (1995).

Static Magnetic Order in $La_{2-x}Ba_xCuO_4$

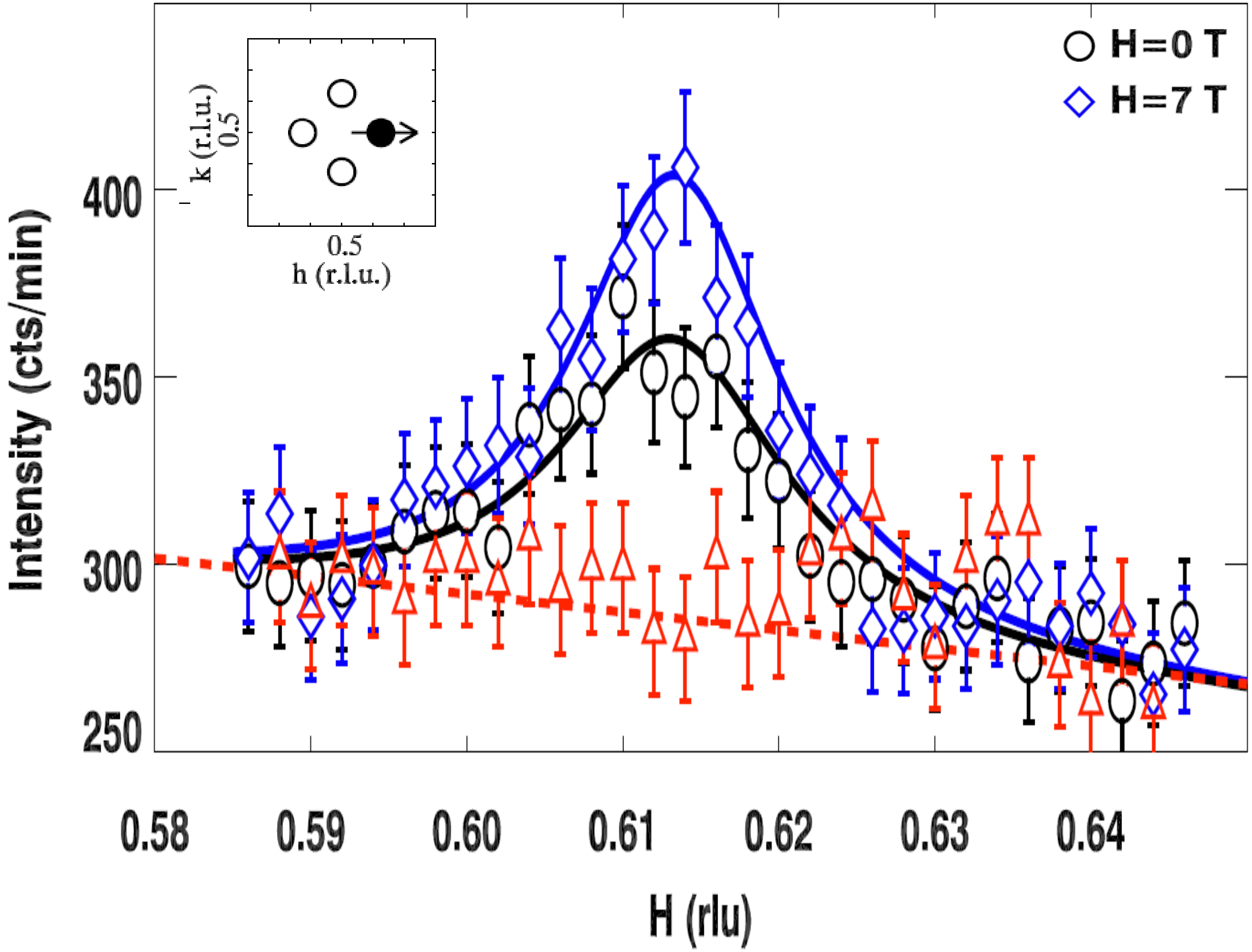




Peak intensity: measure of the order strength

Magnetic-field Effect

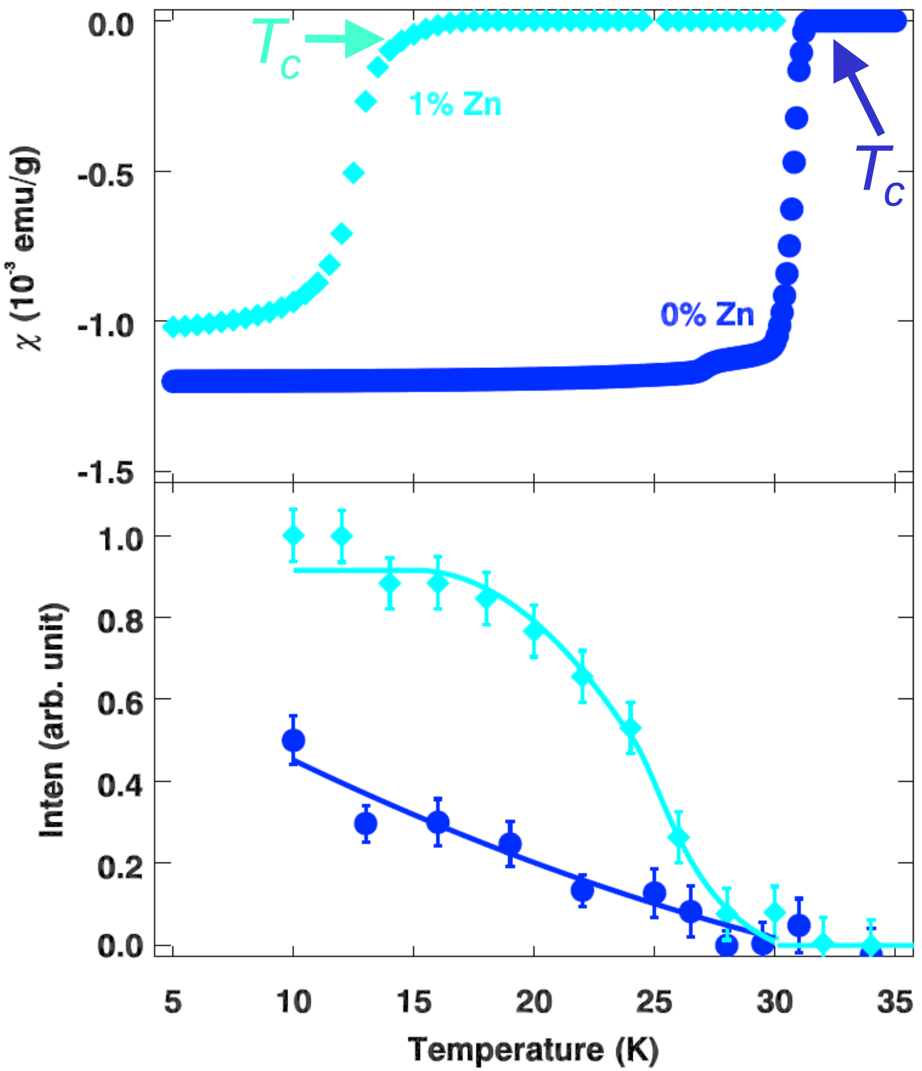
$La_{2-x}Ba_xCuO_4$, x = 0.125



Wen et al., PRB (2008).

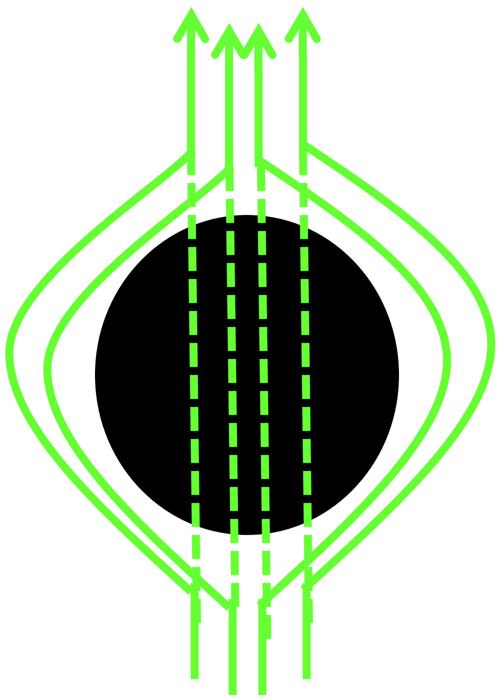
Zn-doping Effect

$La_{2-x}Ba_xCu_{1-y}Zn_yO_4$, $x = 0.095$



Meissner Effect

Expel internal magnetic field



Iron-based Superconductors

2006

Iron-Based Layered Superconductor: LaOFeP

2008

Iron-Based Layered Superconductor $La[O_{1-x}F_x]FeAs$ ($x = 0.05-0.12$) with $T_c = 26$ K

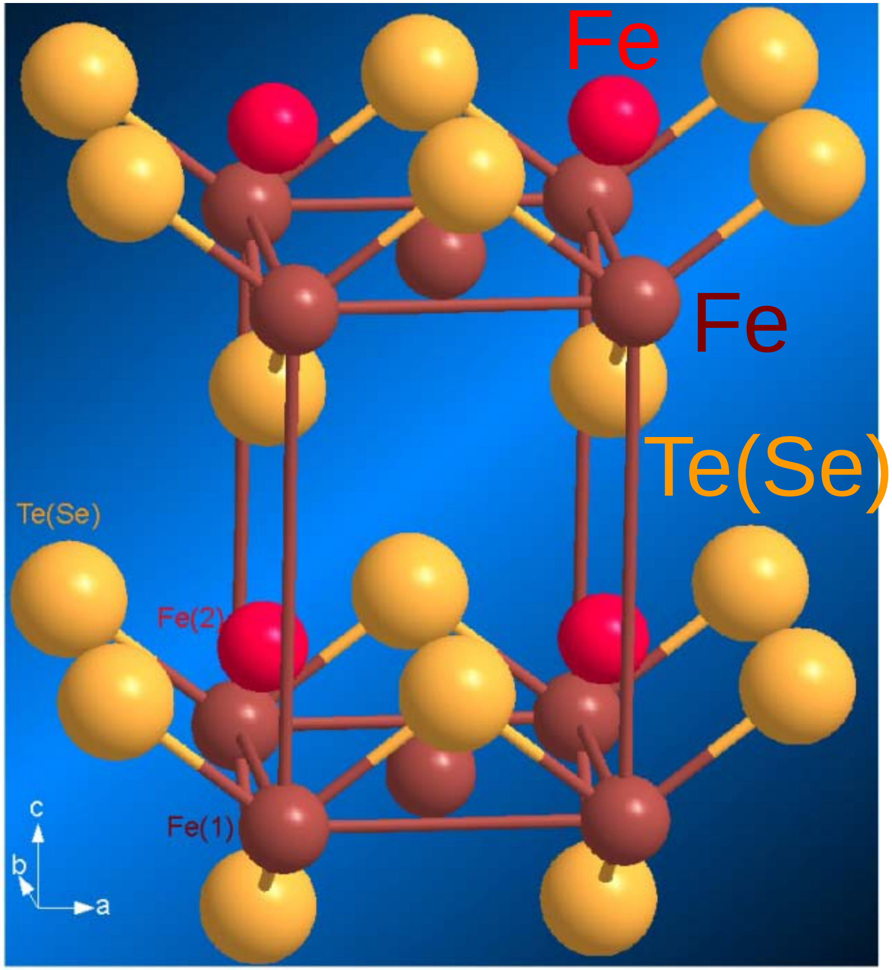
Superconductivity at 55 K in Iron-Based F-Doped Layered Quaternary Compound $Sm[O_{1-x}F_x]FeAs$ *

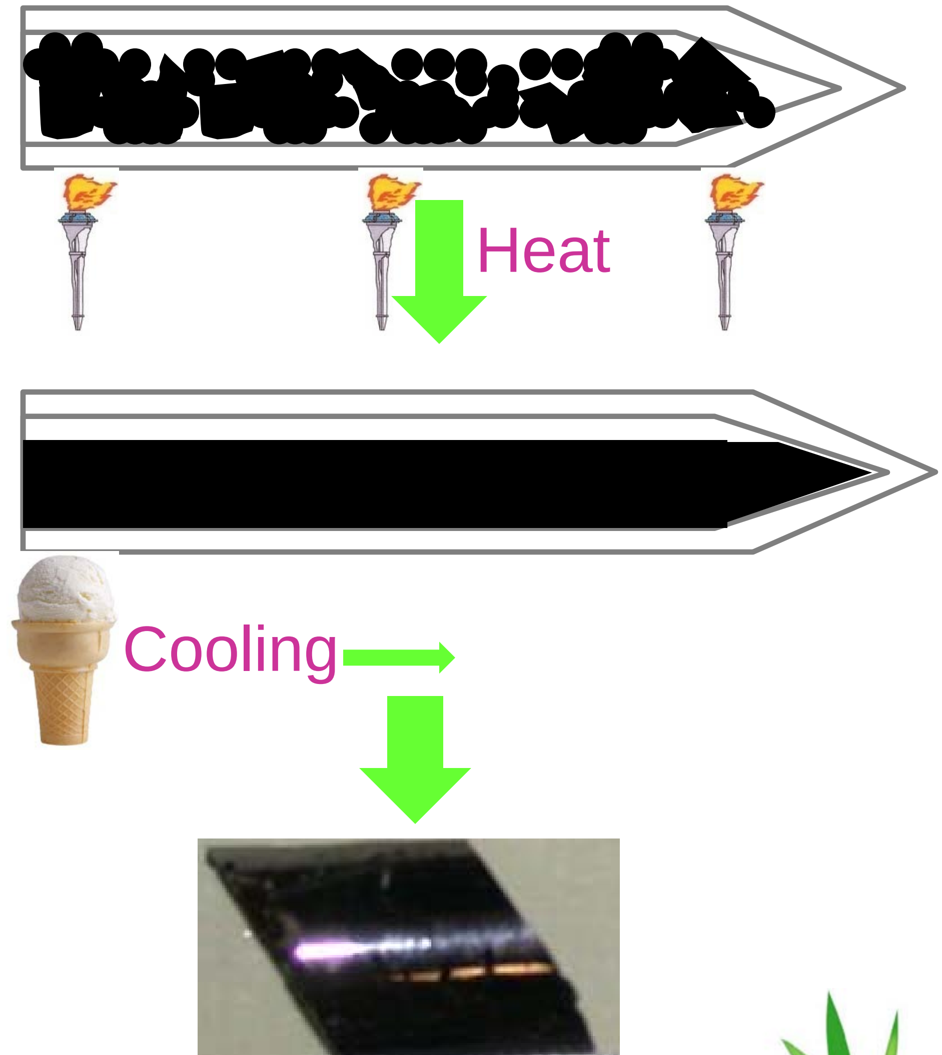
Magnetic order close to superconductivity in the iron-based layered $LaO_{1-x}F_xFeAs$ systems

Superconductivity in the PbO-type structure α-FeSe

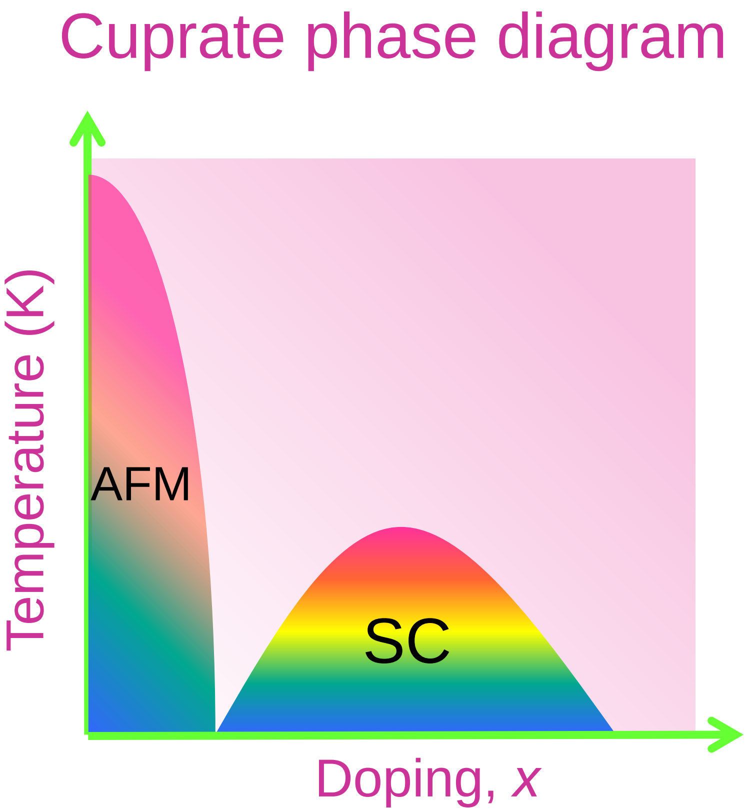
Electronic properties of single-crystalline $Fe_{1.05}Te$ and $Fe_{1.03}Se_{0.30}Te_{0.70}$

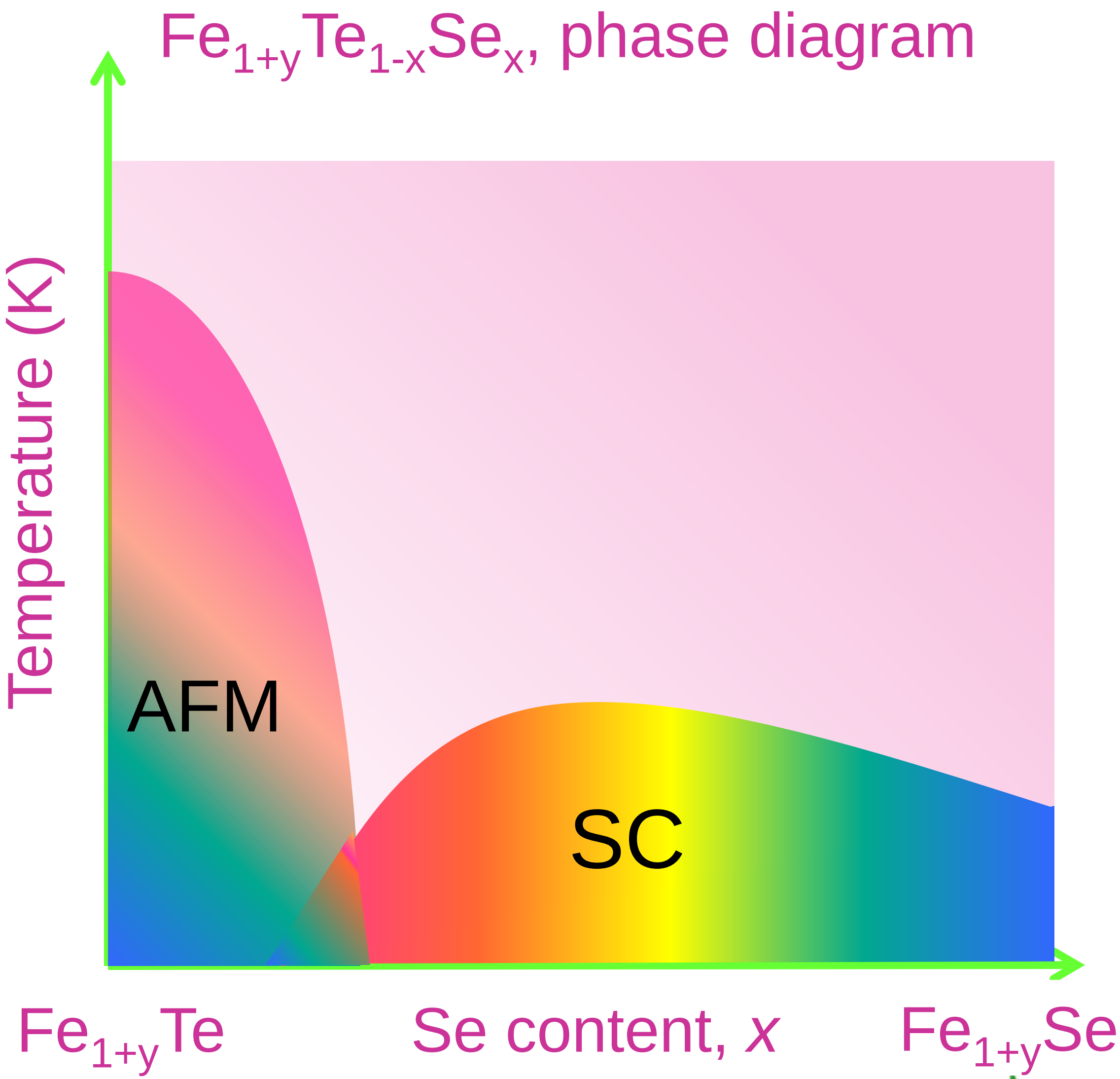
$Fe_{1+y}Te_{1-x}Se_x$



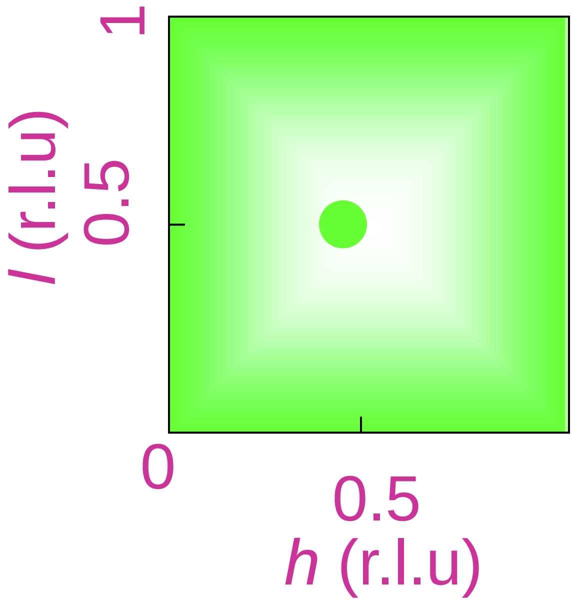


$Fe_{1+y}Te_{1-x}Se_x$



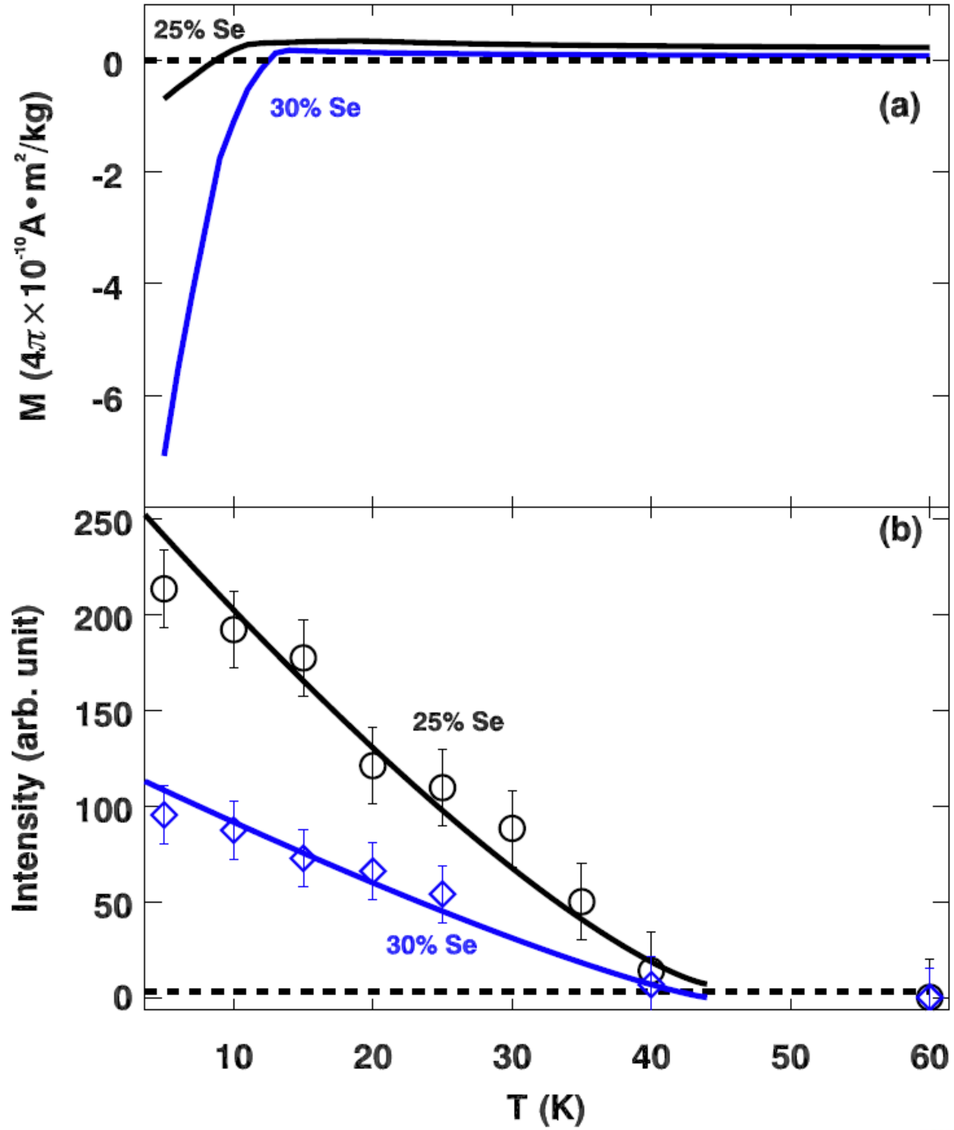


$Fe_{1+y}Te_{1-x}Se_x$, Static Magnetic Order



Magnetic peak

$Fe_{1+y}Te_{1-x}Se_x$
$x = 0.25, 0.30$



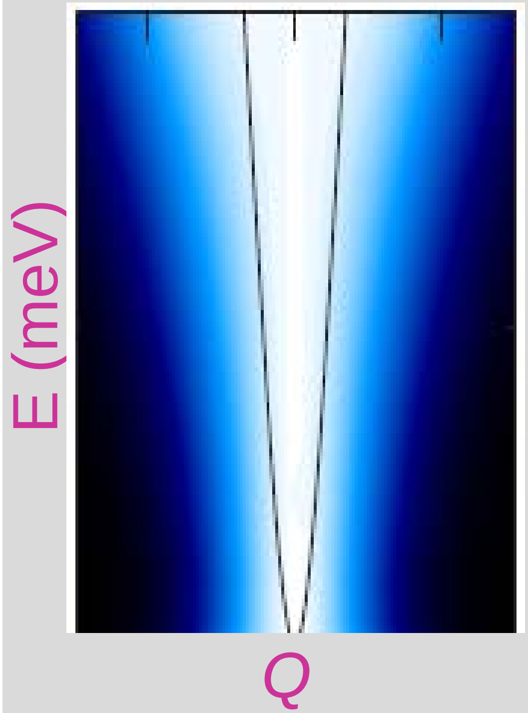
Wen at al., PRB (2009).

Elastic and Inelastic Neutron Scattering

Elastic Neutron Scattering:
Static magnetic order is competing with superconductivity

Inelastic Neutron Scattering

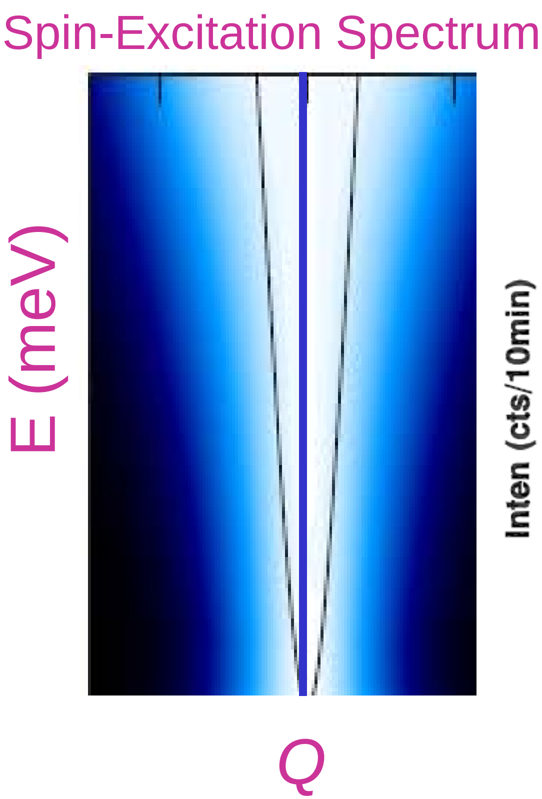
Spin-Excitation Spectrum
Relationship between fluctuation E and *Q*

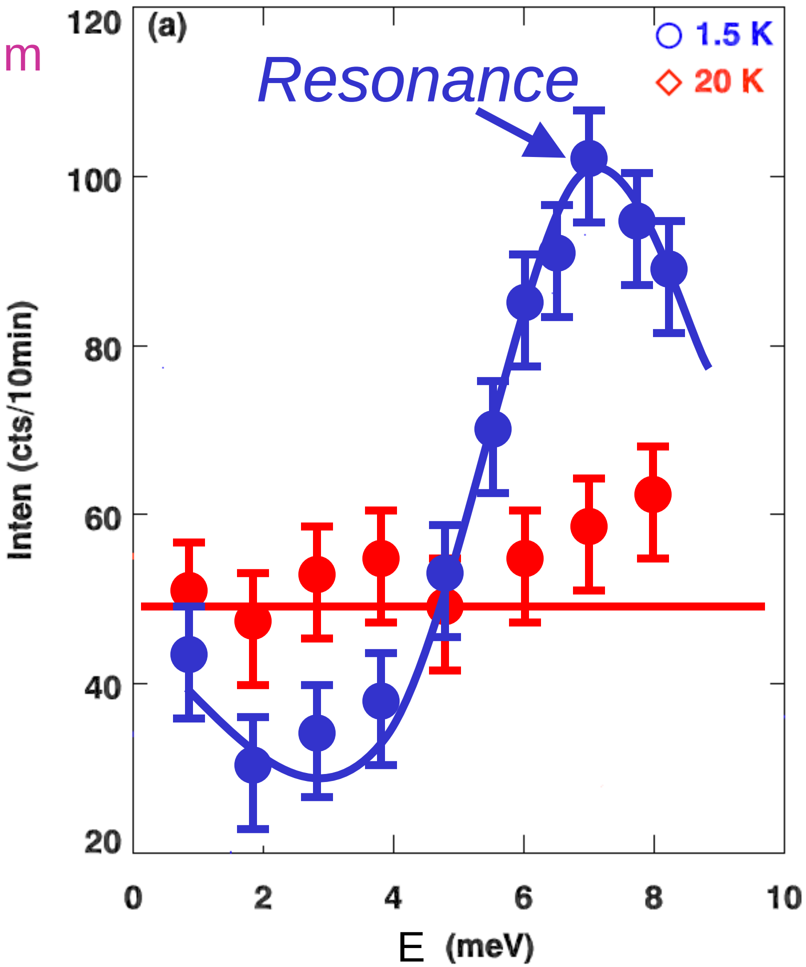


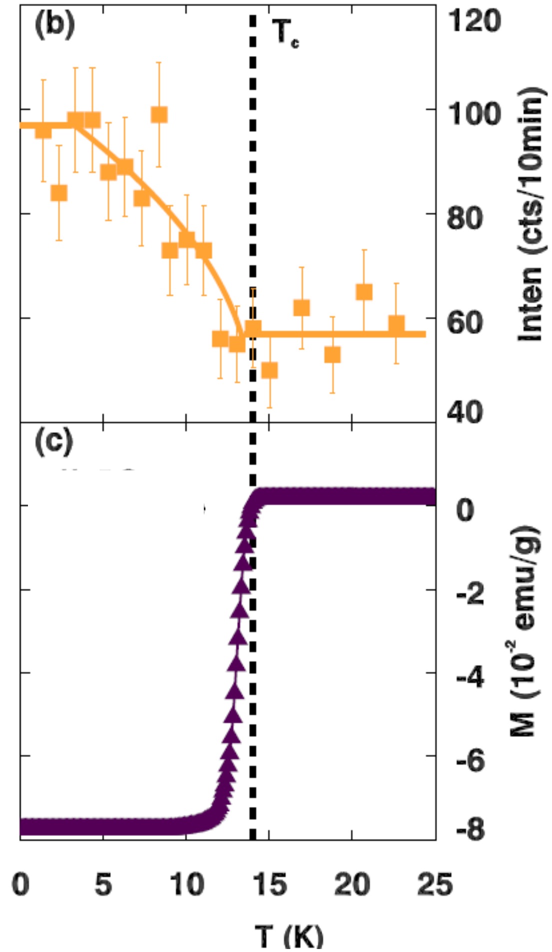
Spin Dynamics

$FeTe_{0.5}Se_{0.5}$, Resonance

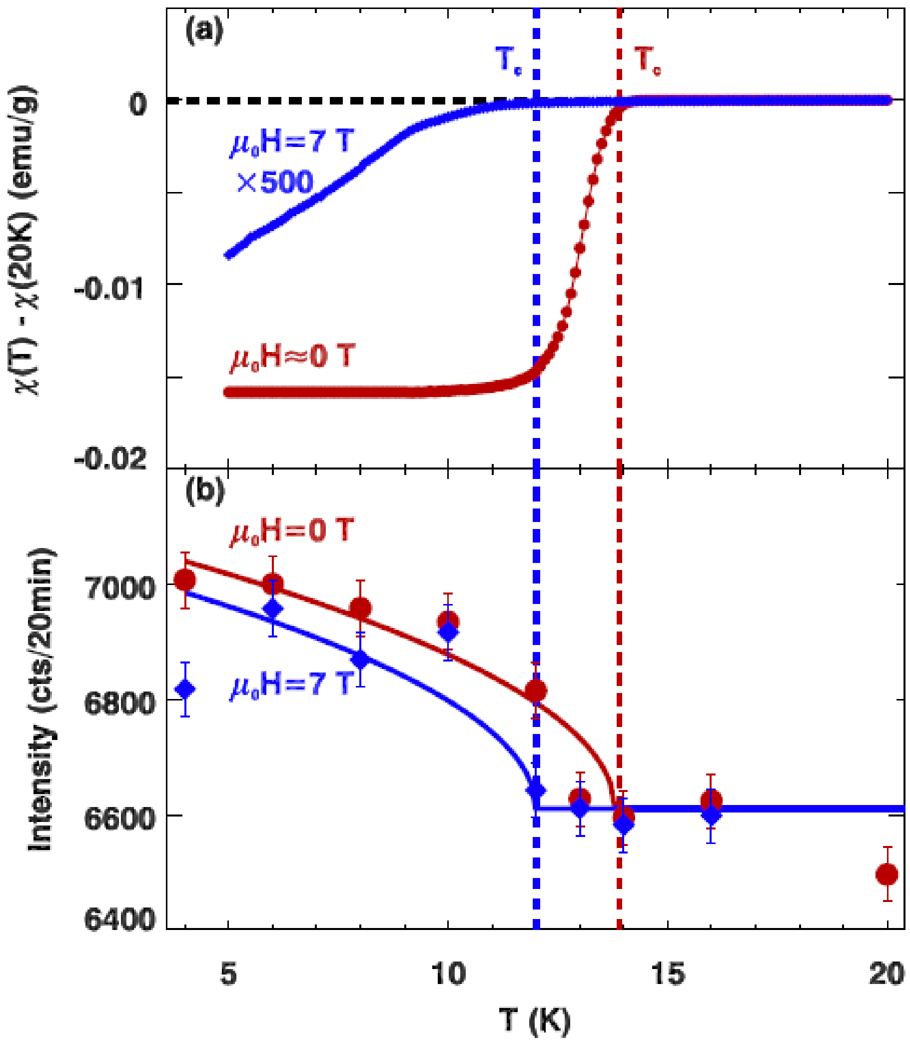
T_c = 14 K







$FeTe_{0.5}Se_{0.5}$, Resonance



Wen at al., PRB Rapid Comm. (2010).

Dynamic spins promote superconductivity

Static spins destroy superconductivity

More Static Spins → Less Dynamic spins

Conclusions

Magnetic fluctuation appears to be an important ingredient for the high-T_c superconductivity.

Lots of things remain to be done...