Elettra Sincrotrone Trieste

# OPENING REMARKS

**Fulvio Parmigiani**

novel SuperConductors and Synchrotron Radiation:
state of the art and perspectives
SCSR2014
Adriatico Guesthouse, Trieste, Italy / 10-11 December 2014

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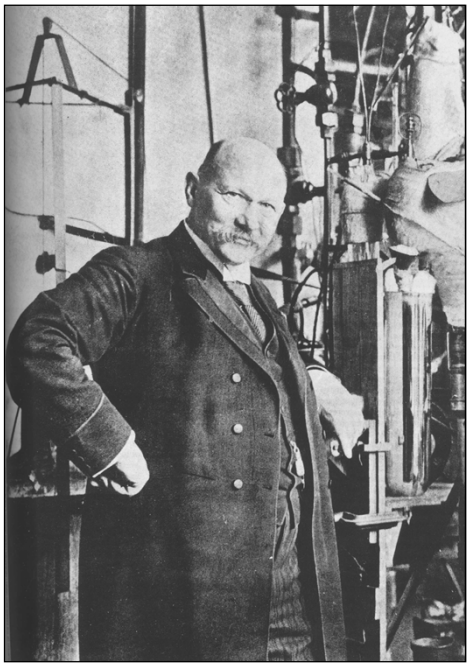
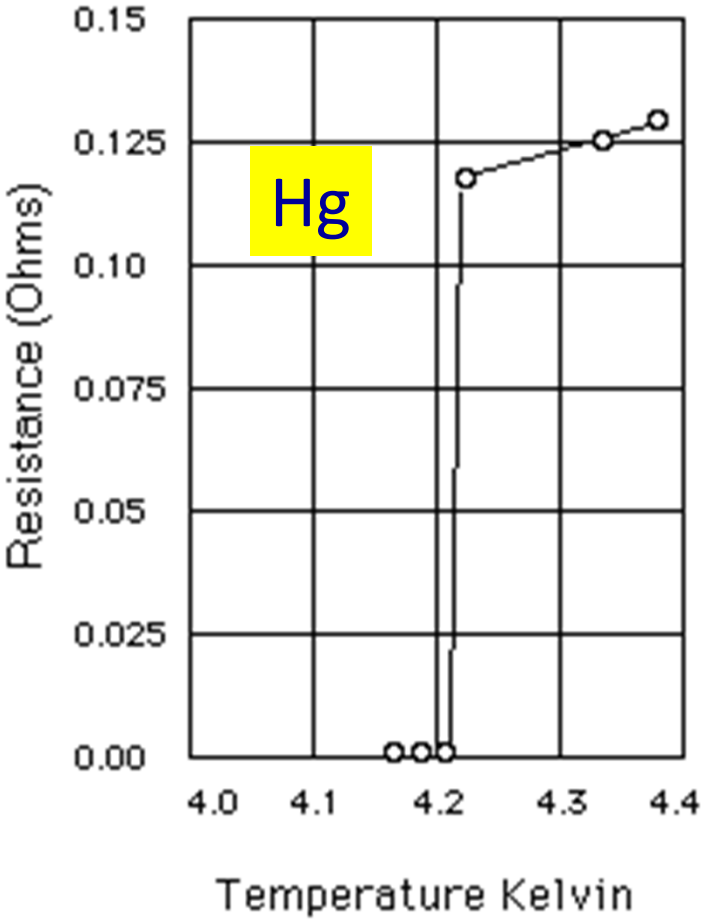
# THE DISCOVERY

## Discovery of superconductivity (1911)



H. Kamerling Onnes

Fig. 1

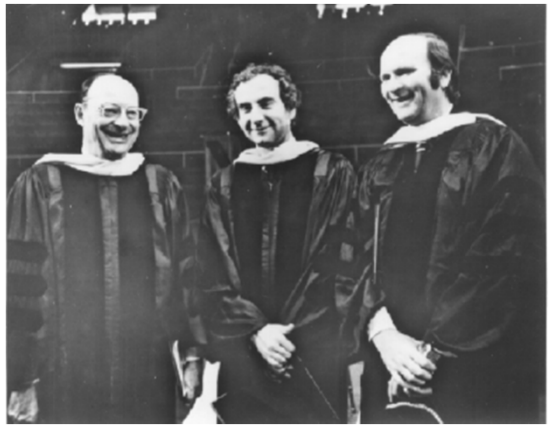


# THE UNDERSTANDING

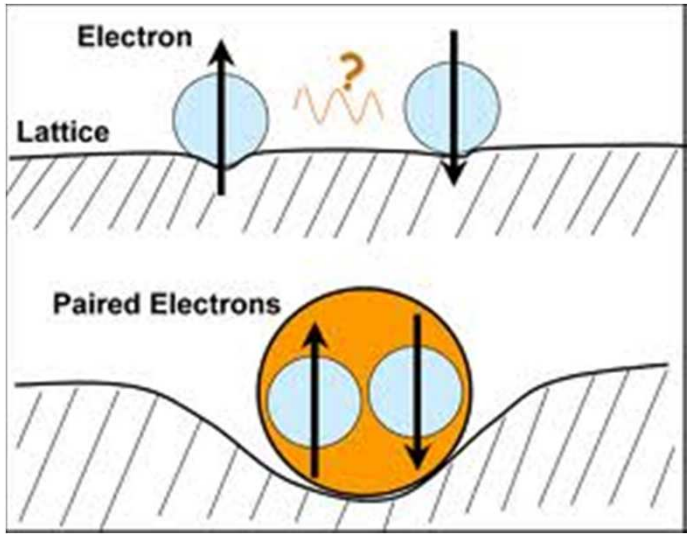
PHYSICAL REVIEW VOLUME 99, NUMBER 4 AUGUST 15, 1955

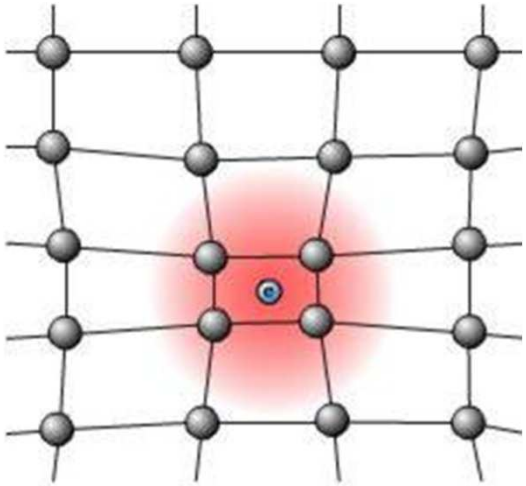
## Electron-Phonon Interaction in Metals*

JOHN BARDEEN AND DAVID PINES†
*Physics Department, University of Illinois, Urbana, Illinois*
(Received April 4, 1955)



**Bardeen, Cooper, Schrieffer (1957)**



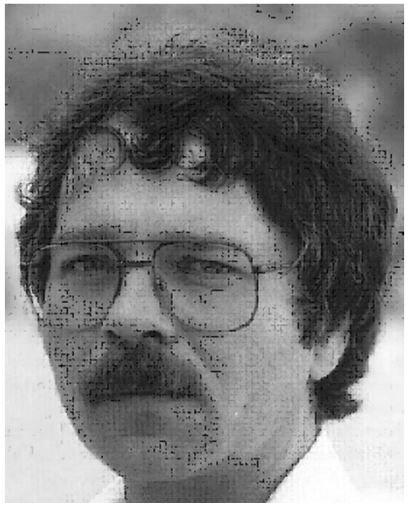
In the BCS model as the Cooper-pairs form they give rise to a Bose-Einstein condensate

(i) Pairmomentum=0

(ii) Paircondensate = a *macroscopic* quantum state

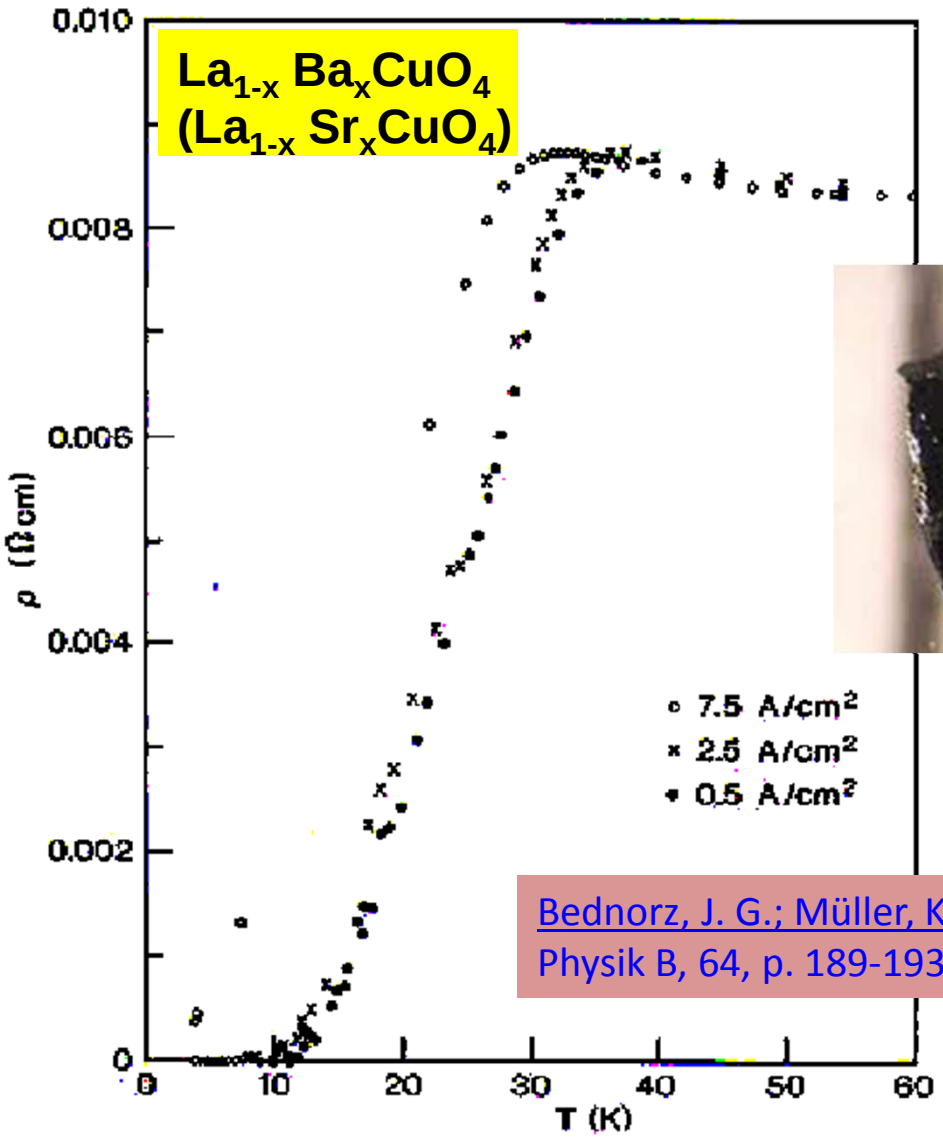
# THE NEW DISCOVERY

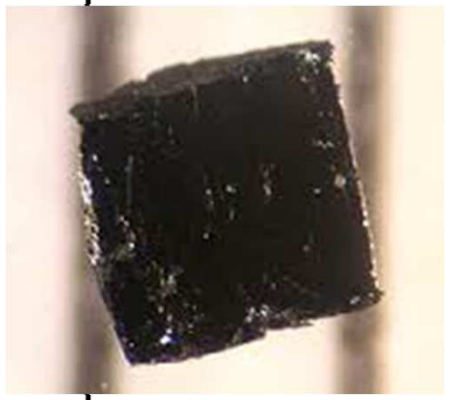
Karl Alex Mueller



Georg Bednorz

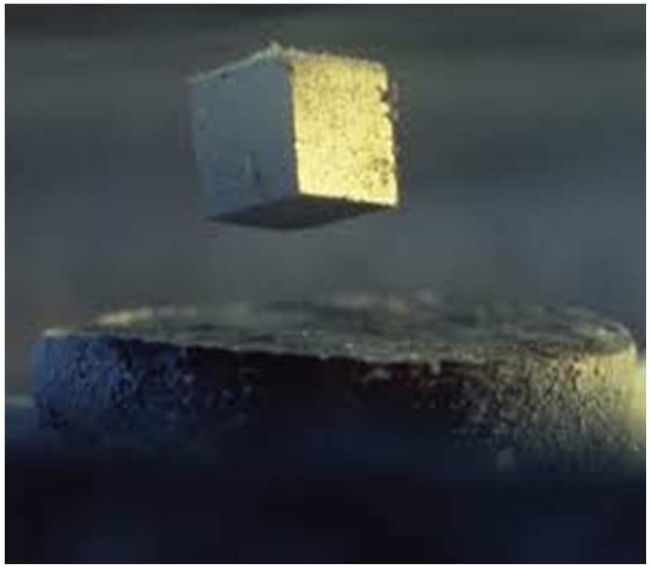
## 1986: THE HIGH TEMPERATURE SUPERCONDUCTORS

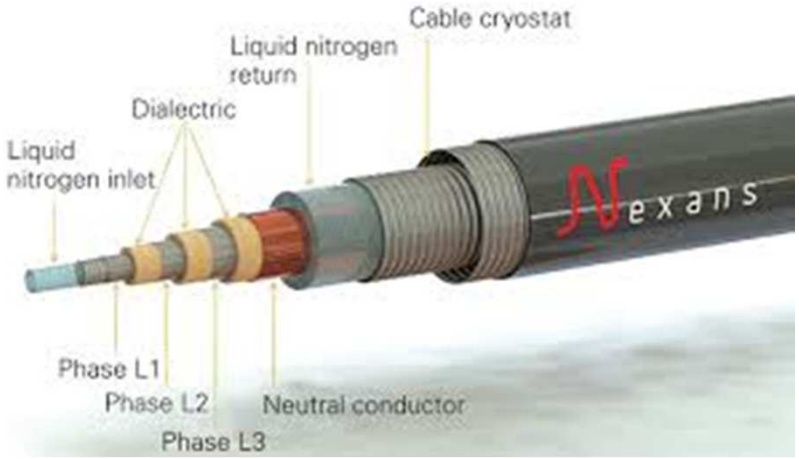


Bednorz, J. G.; Müller, K. A, Zeitschrift für Physik B, 64, p. 189-193 (1986)

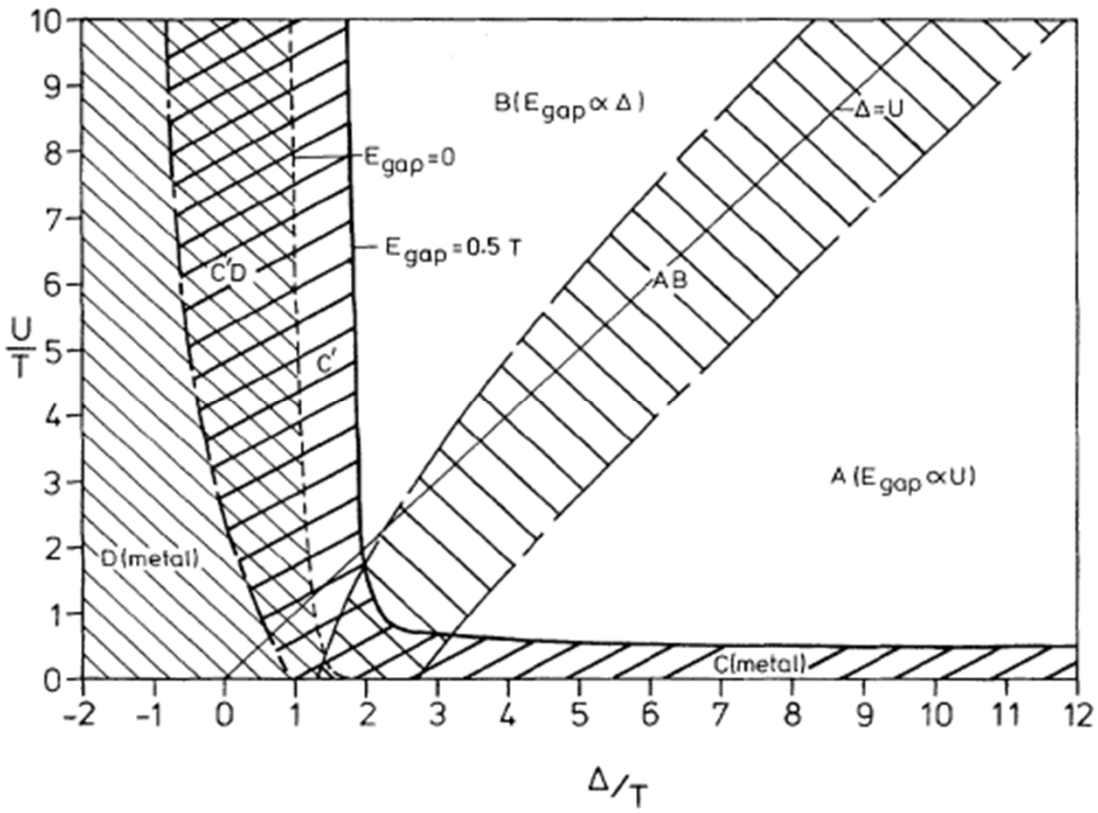
# HTSCs TECHNOLOGY




# THE ZSA PHASE DIAGRAM

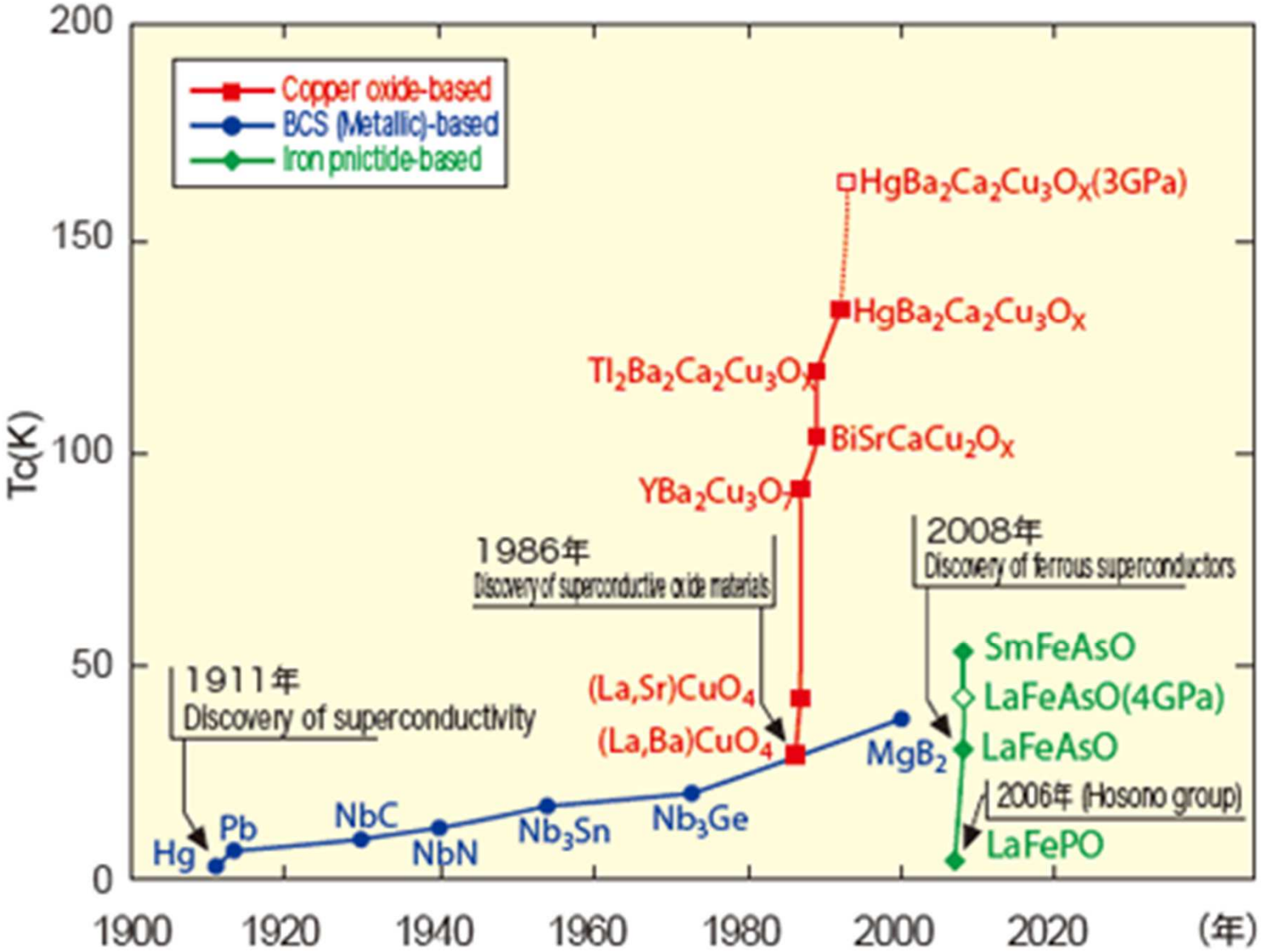
## The Zaanen-Sawatzky-Allen phase diagram




Varma poited out that on the ZSA model LaCuO4 belongs to the charge transfer class.

**Zaanen, Sawatzky, Allen, *Phys. Rev. Lett.* 55 (1985) 418–421.**

# SUPERCONDUCTORS: A COMPLEX WORD



# SOME MILESTONES

- ✓ The doping dependence of the **O 1s XAS in LSCO** by CT Chen with Hao Tjeng at Bell Labs was a very important measurements demonstrating the spectral weight transfer theoretically predicted for a Hubbard model by Eskes Sawatzky and Meinders. This result has more recently led to the terminology of Mottness.

- ✓ **ARPES development** to high resolution demonstrating the **pseudo-gap and the d-wave like superconducting gap as well as the "kink"** which is reminiscent of the effects of an electron Boson interaction be it phonons or magnons. However, the study of kinks by different groups has generated many controversies. No agreement has been reached on its origin and on its significance. Similarly**, the pseudo-gap is still a complete mystery**, and probably for this issue NMR had a more important role. (A. Damascelli)

- ✓ **Measurement of the Fermi surface** of over-doped Tl2201 by ARPES in agreement with bulk (dHvA, a couple of years later). M[ Plate et al, Phys. Rev. Lett. 95, 077001 (2005)]

- ✓ The development of **resonant elastic and more recently inelastic X-ray scattering** was of great importance.

- ✓ Abbamonte demonstrated the stripy nature via a superstructure seen in resonant **X-ray scattering at the Cu and O edges**. The first dedicated resonant elastic soft x ray scattering facility was designed and build by the Sawatzky team (Abbamonte).

- ✓ The important development of relatively **high resolution inelastic x ray scattering** by G. Ghiringelli and collaborators demonstrating the magnon dispersion in YBCO. [Ghiringhelli et al., Science 337, 821 (2012)]

*Credit to G. Sawatzky*

# THE SUPERCONDUCTING GAP

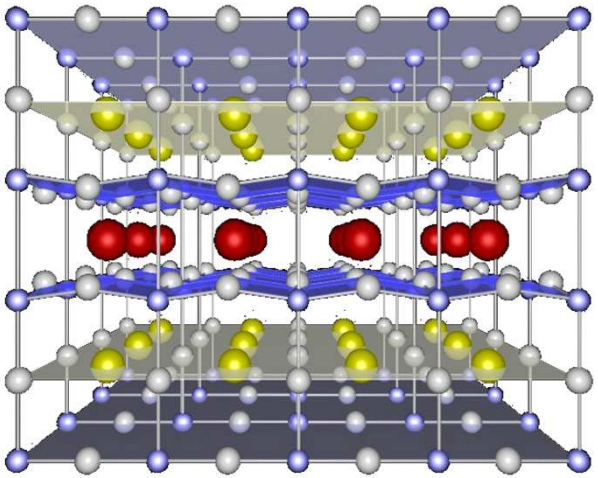
The of course the importance of **spin fluctuations** as in P.W. Andersons papers and the very important result by Patrick Lee who demonstrated that spin fluctuations would yield a **d-wave superconductor.**

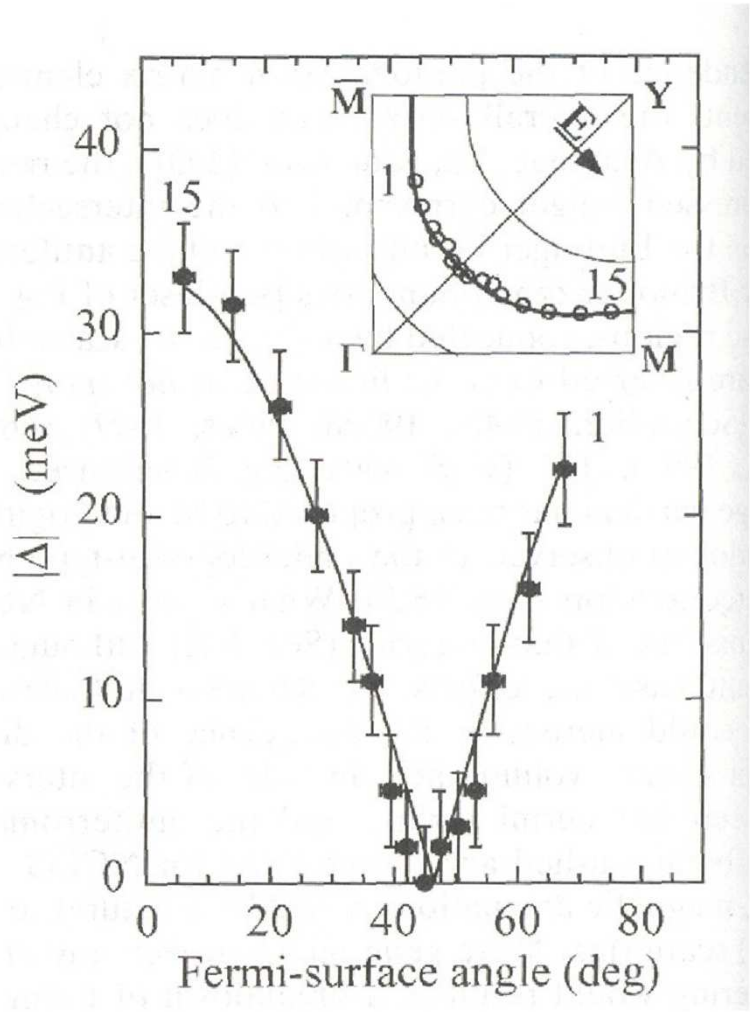
Bonn and Hardy from **microwave** transport properties on the very pure and rather defect free YBCO.

**ARPES DATA**

**|Δ| depends strongly on the direction of the electron-momentum**

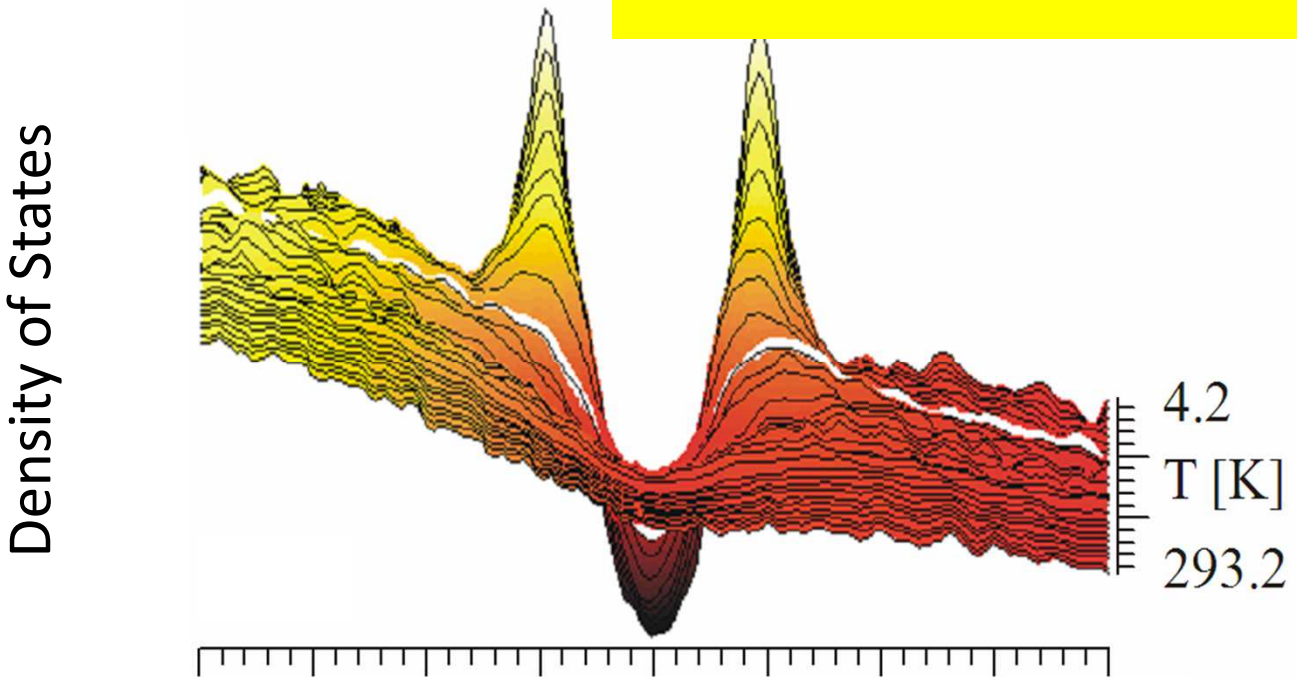
ZX Shen





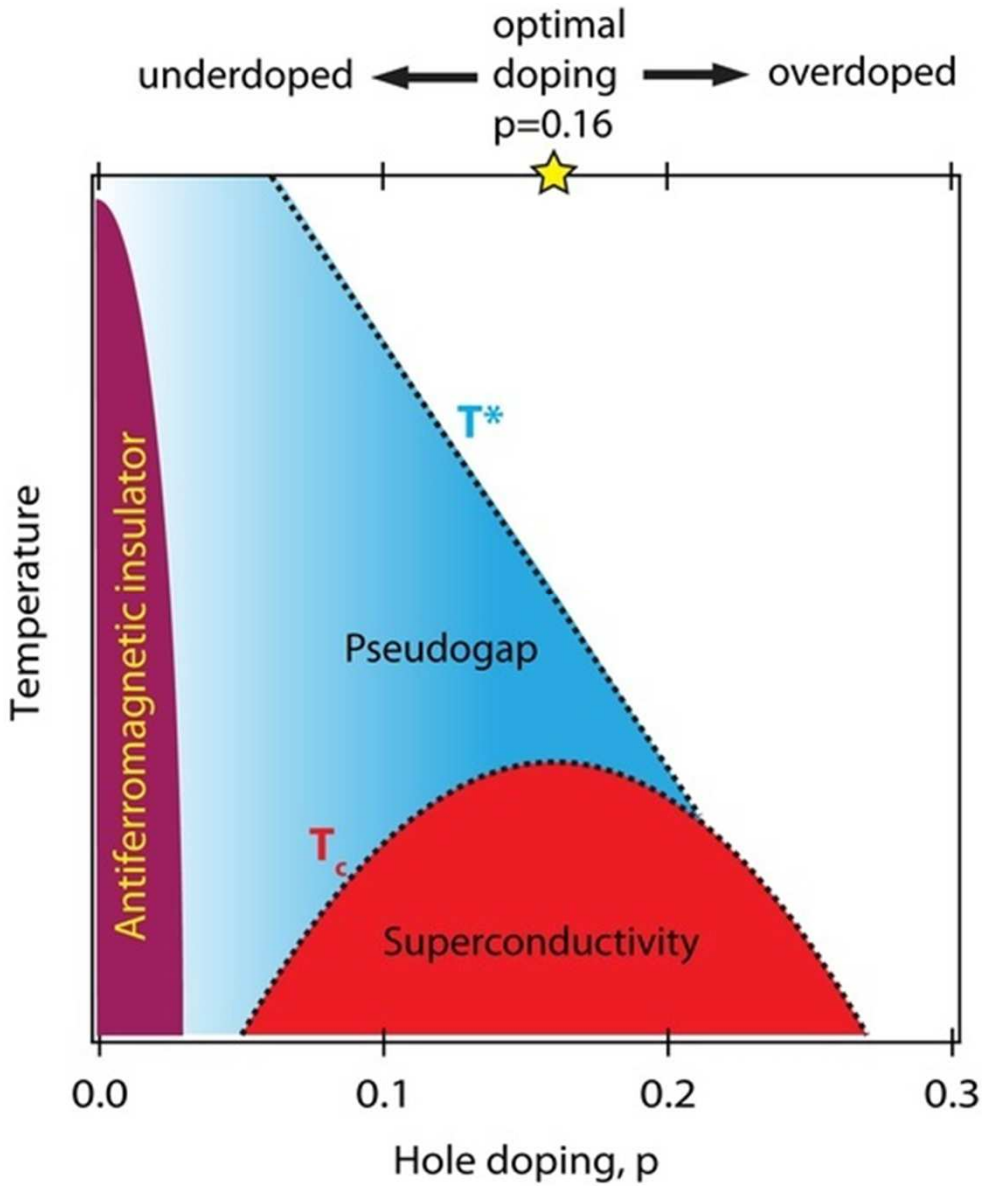
# THE PSEUDO-GAP GAP

**STM:**
**Evidence for a pseudo-gap far above Tc**

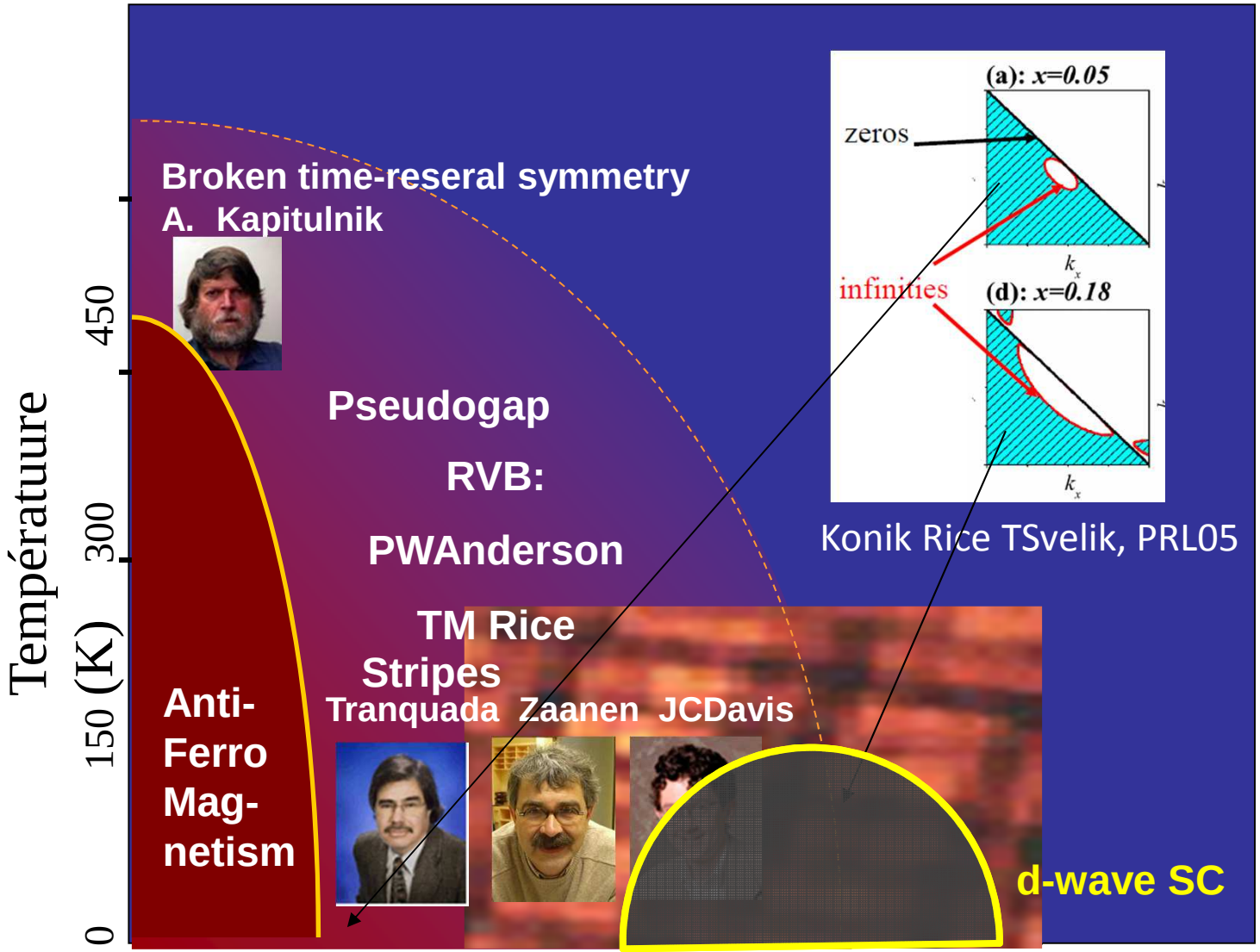



Renner, Fischer, et al.,
PRL **80**,149 (1998)

# A PUZZLING PHASE DIAGRAM



# A PUZZLING AND COMPLEX PHASE DIAGRAM



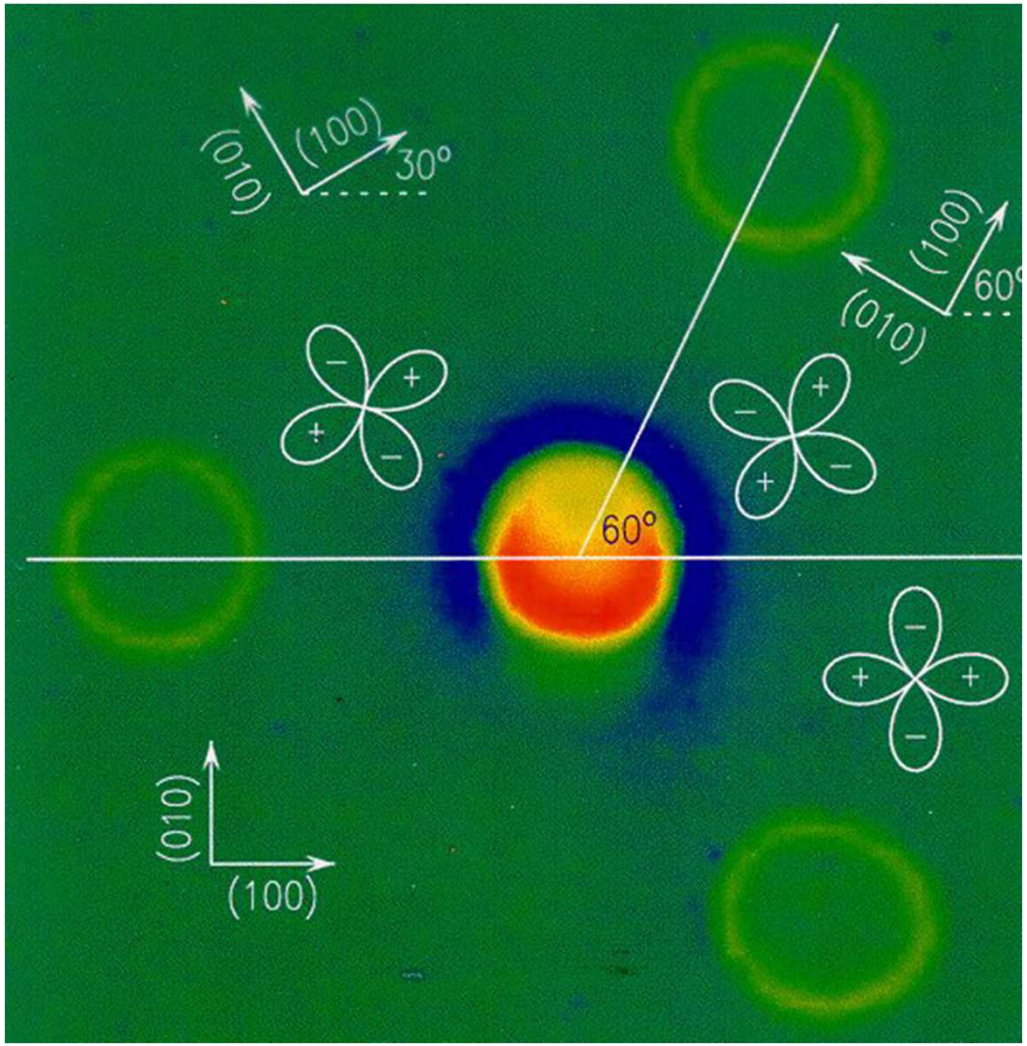

Credit D. van der Marel

# NATURE OF THE VORTEX IN HTSCs

Magnetic imaging demonstrated ***half-integer* vortex** at tri-crystal junction: Δ changes sign as a function of direction of the electron-momentum

**J.R. Kirtley, C. Tsuei,**
**Nature 373, 225 (1995).**

**d-wave**
**L=2**
**S=0**



# QUANTUM CRITICAL BEHAVIOUR

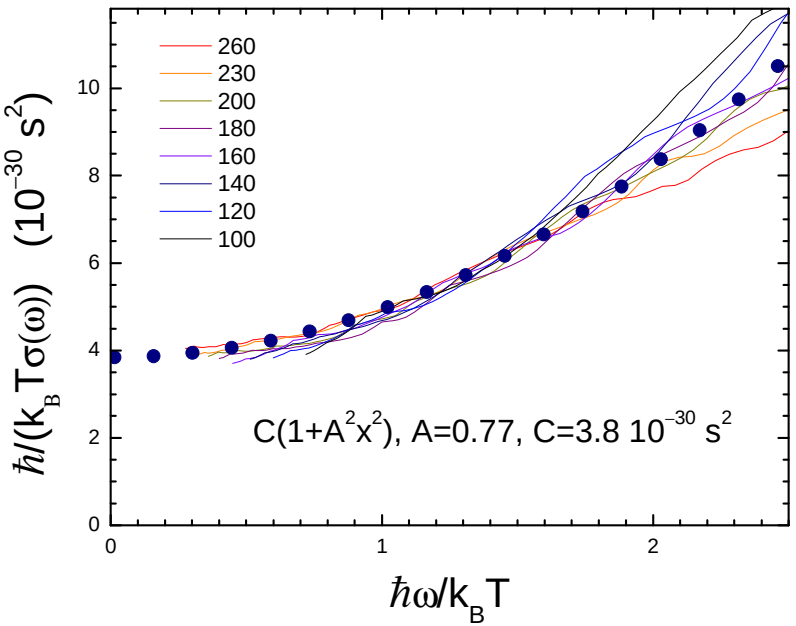
Optical conductivity:
universal scaling
Planckian dissipation

$$\frac{1}{\tau} = A\frac{k_B T}{\hbar}$$

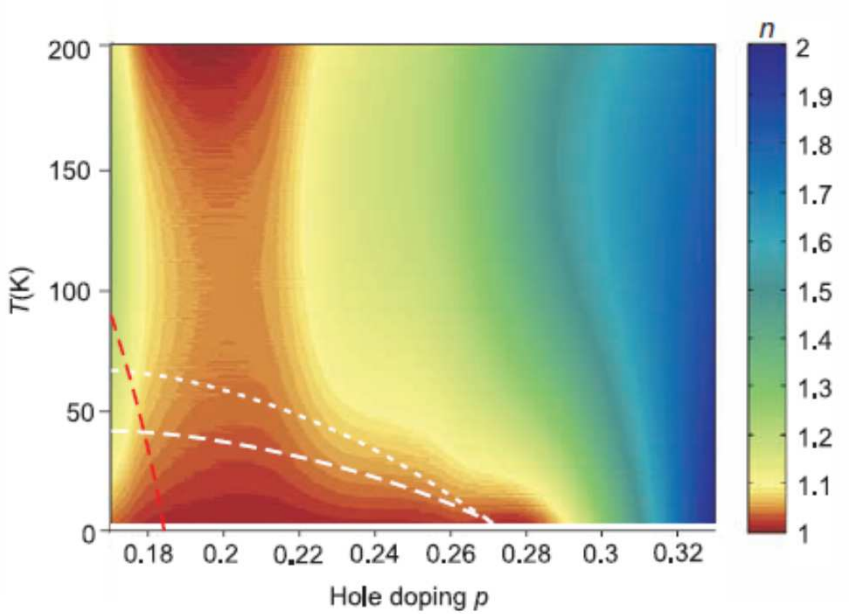
Resistivity:

$1/\tau = T_0 + A\,T$

A correlates with SC dome

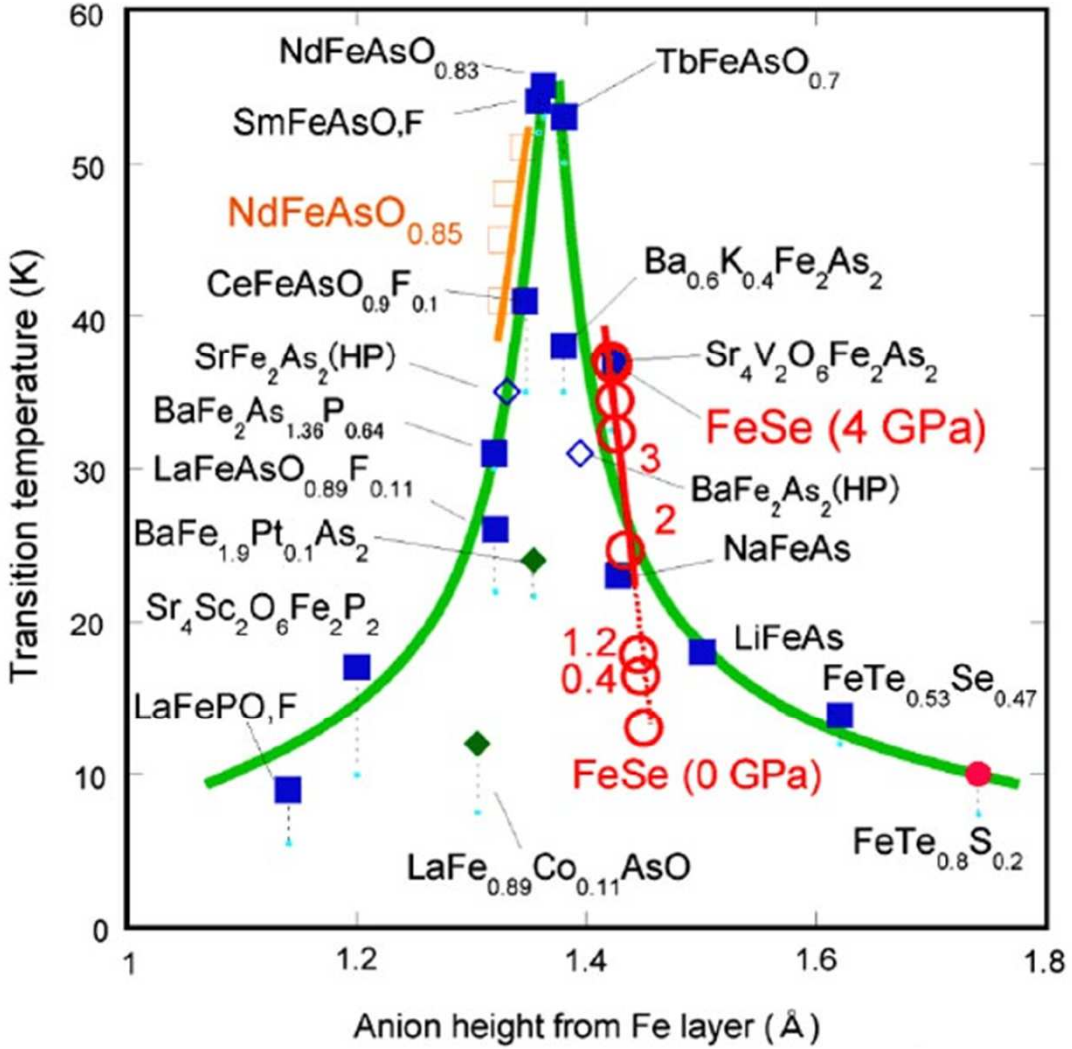


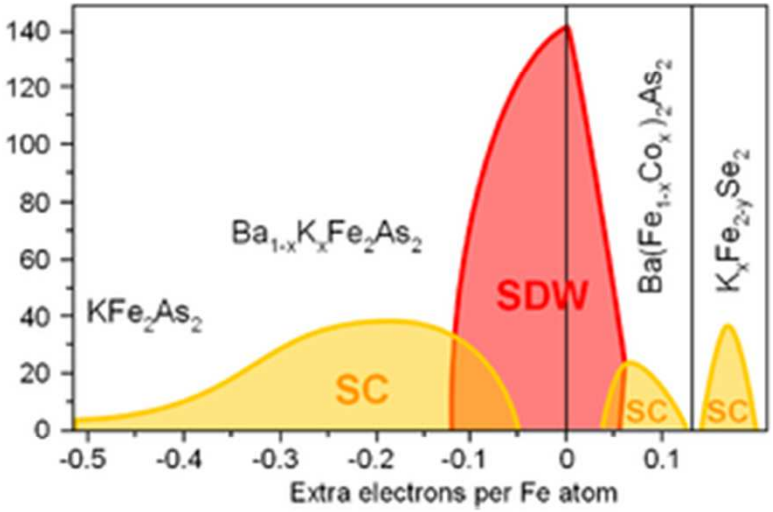

D. van der Marel, H. J. A. Molegraaf, J. Zaanen, et al., Nature 425, 271-274 (2003)




Science 323, 603 (2009);
R. A. Cooper, N. Hussey, et al.

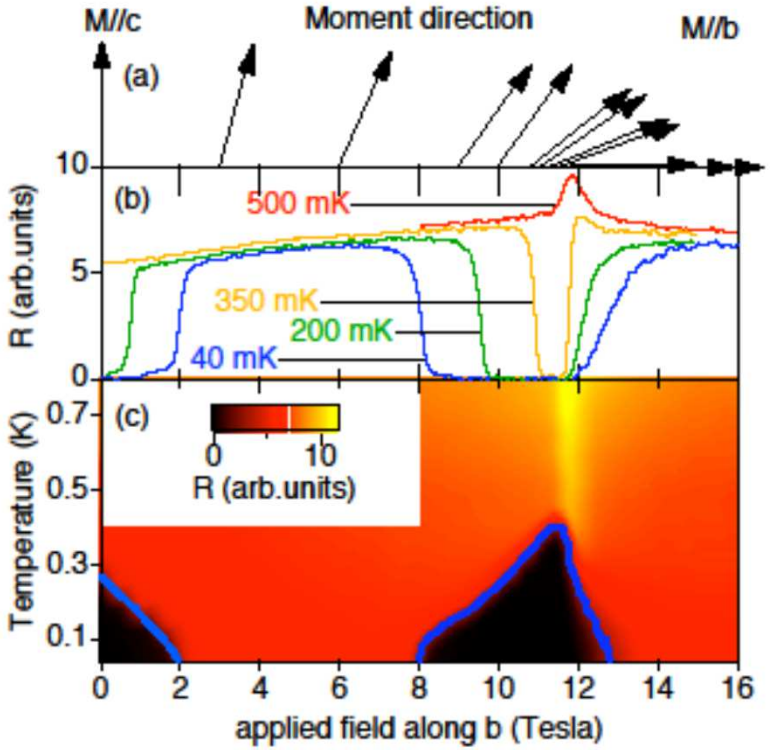
# NON CU-O BASED S.C

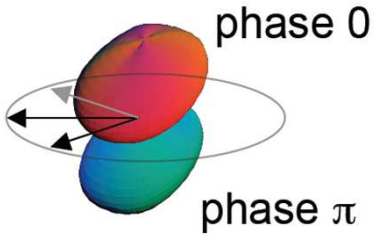


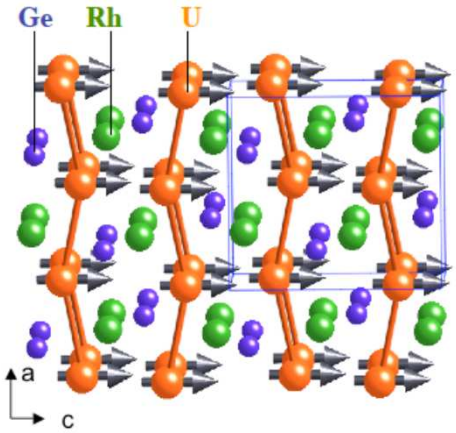



# NON CU-O BASED S.C

**$URh_2Ge_2$**




Credit D. van der Marel

F. Lévy, I. Sheikin and A. Huxley
Nature Physics (2007)

**p-wave**

**L=1**

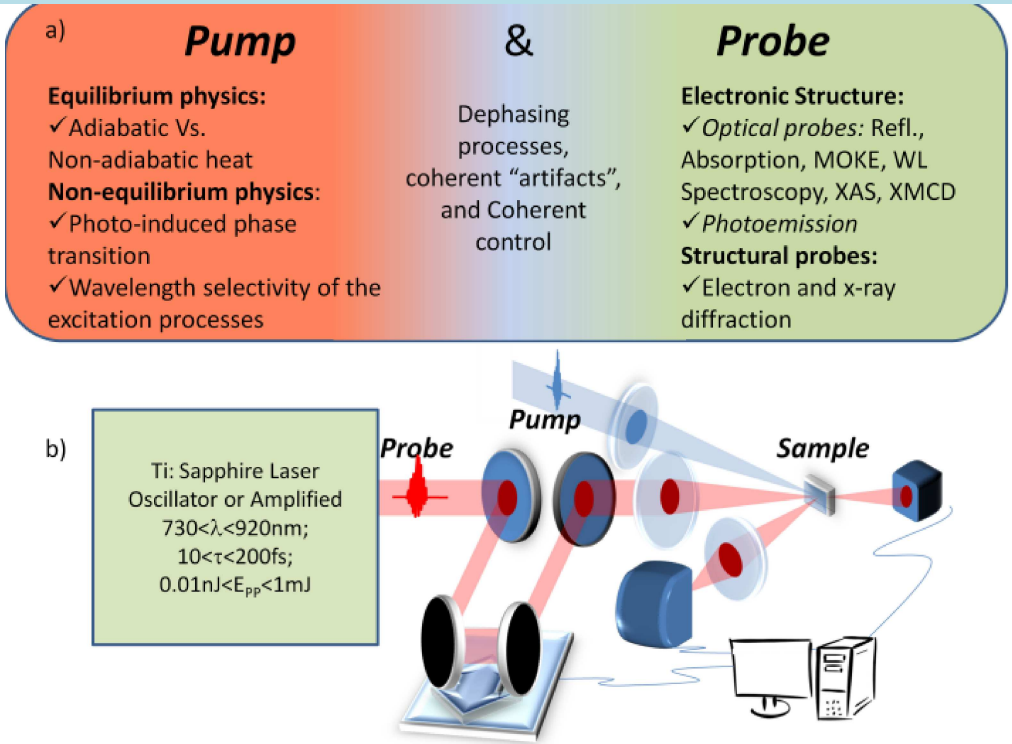
**S=1**

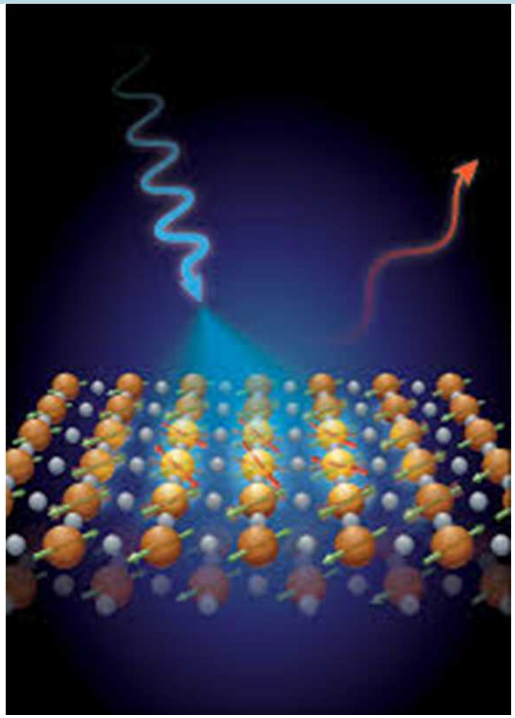
# NON-EQUILIBRIUM SUPERCONDUCTIVITY

- ✓ The effective lattice, Coulomb and magnetic interactions in cuprates, pnictides and other related materials conspire to give high temperature superconductivity as an emergent phenomenon. How exactly that happens is still an open question, which is also primarily experimental.

- ✓ New methods developed in the last two decades have given us a much deeper understanding on the electron dynamics, symmetry and electronic structure in different phases of these materials. Time-domain spectroscopies have elucidated the inhomogeneous nature of the superconducting state, with localised and itinerant excitations of a composite nature coexisting over the majority of the phase diagram. Further understanding into their dynamics in reciprocal space has been obtained from new time-resolved angle-resolved photoemission techniques, and resonant elastic or inelastic X-ray scattering techniques.

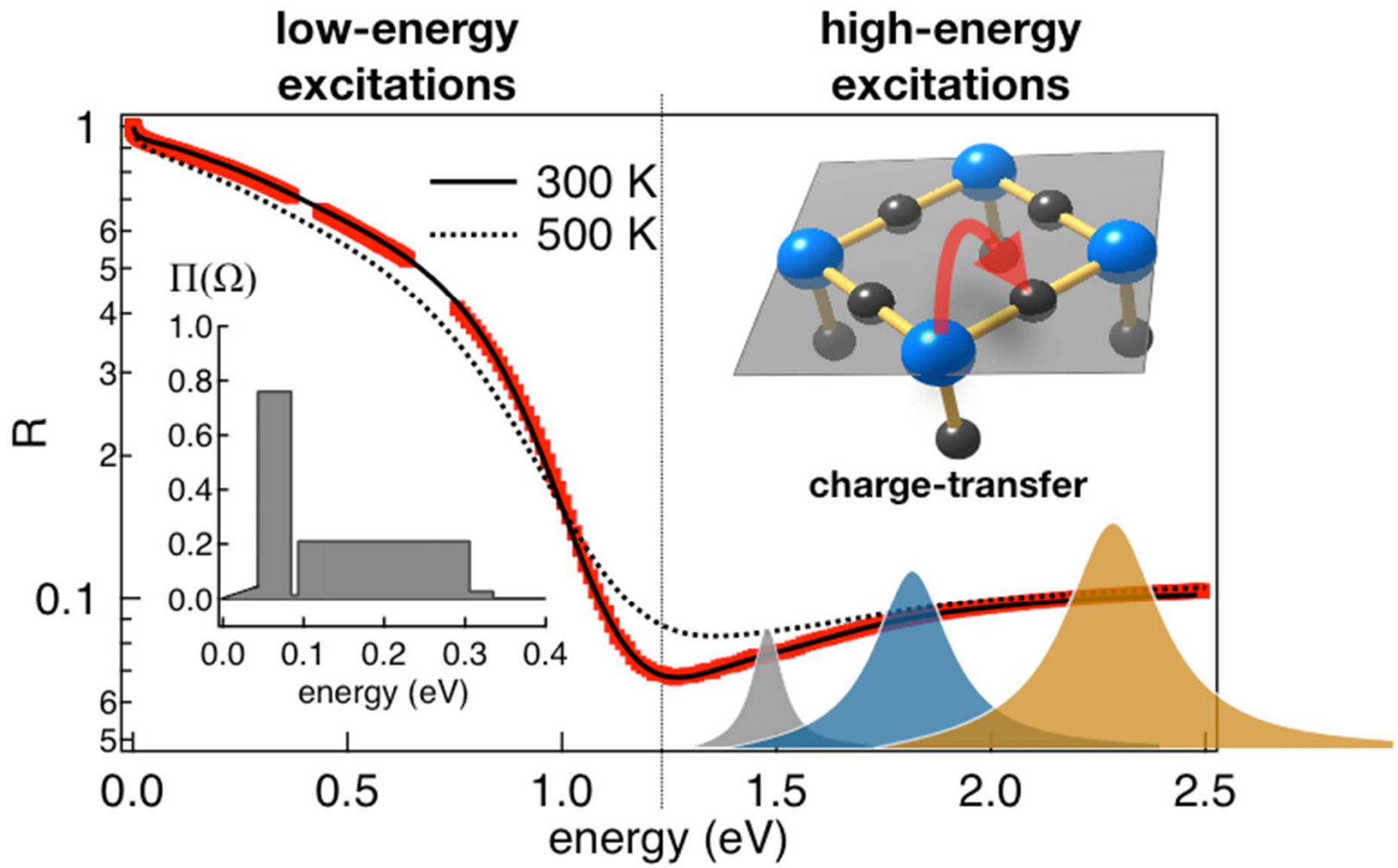
*Credit D. Mihailovic*



# NON-EQUILIBRIUM SUPERCONDUCTIVITY

**A step toward understanding the nature of the bosonic-glue**




C. Giannetti et al., Science 2012

- What is our understanding of the physics of HTSC and exotic s.c. 28 year after the Bednorz and Müller discovery?

- What are the 5 most important questions to address today on the nature of the HTSCs?

- What is the role of the optical based experiments in the time domain?