Cryogenic Engineering Conference &
International Cryogenic Material Conference 2023
Honolulu, July 11, 2023

From High Temperature Superconductivity to Room Temperature Superconductivity*:

from high pressure to ambient; from very high pressure to ambient again!?

L. Z. Deng, T. Bontke, D. Schulze, Z. Wu, M. Gooch, T. Habamohoro, T. W. Kuo and ***C. W. Chu***

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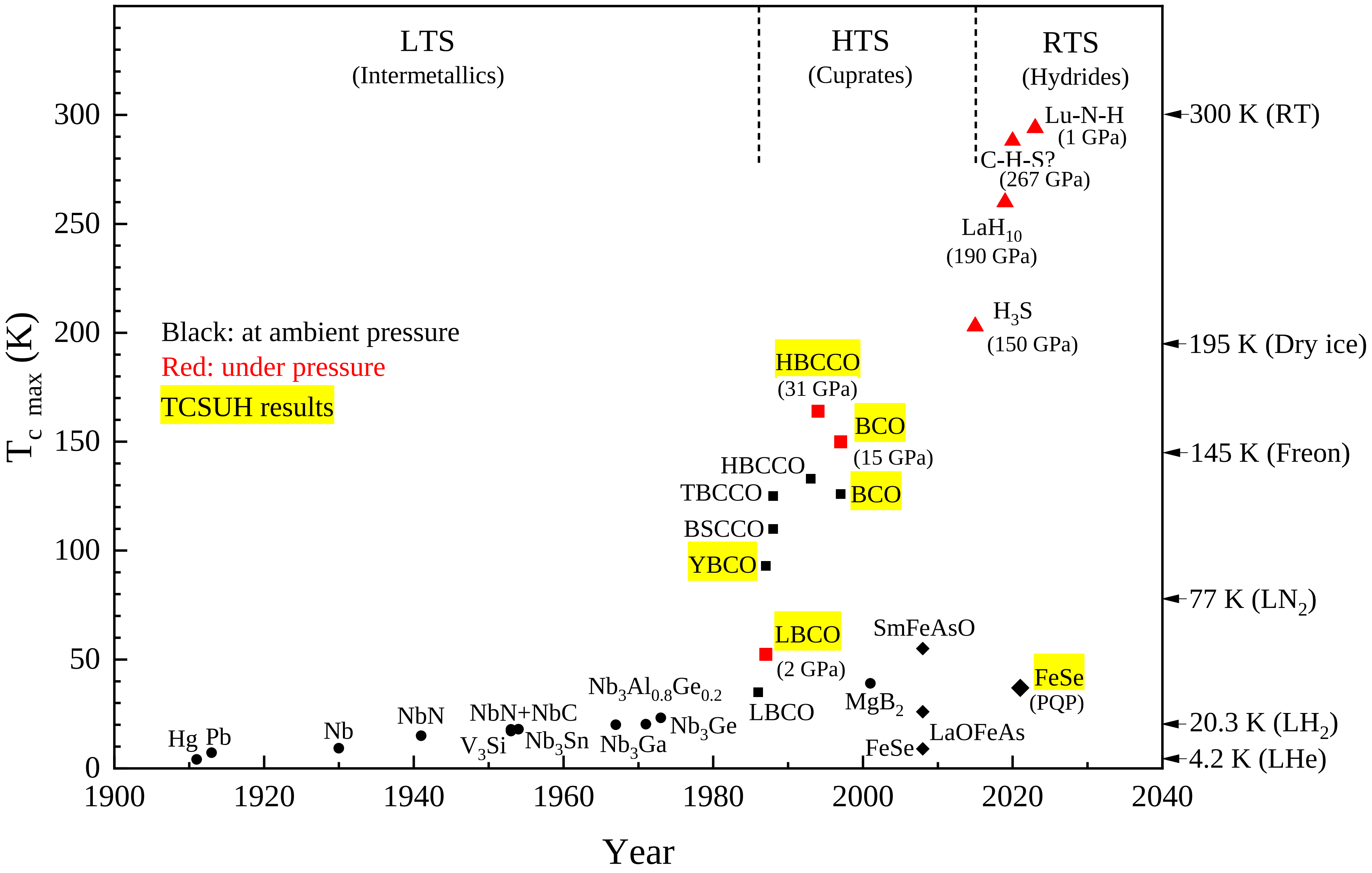
University of Houston, Houston, TX

*Work supported in part by AFOSR, State of Texas, Temple Foundation and Mores Foundation


LTS
(Intermetallics)
HTS
(Cuprates)
RTS
(Hydrides)
300 K (RT)
195 K (Dry ice)
145 K (Freon)
77 K (LN$_2$)
20.3 K (LH$_2$)
4.2 K (LHe)
Lu-N-H
(1 GPa)
C-H-S?
(267 GPa)
LaH$_{10}$
(190 GPa)
H$_3$S
(150 GPa)
Black: at ambient pressure
Red: under pressure
TCSUH results
HBCCO
(31 GPa)
BCO
(15 GPa)
HBCCO
TBCCO
BCO
BSCCO
YBCO
LBCO
(2 GPa)
SmFeAsO
FeSe
(PQP)
Nb$_3$Al$_{0.8}$Ge$_{0.2}$
LBCO
MgB$_2$
NbN+NbC
NbN
Nb
Hg
Pb
V$_3$Si
Nb$_3$Sn
Nb$_3$Ga
Nb$_3$Ge
LaOFeAs
FeSe
$T_{c\ max}$ (K)
Year
0
50
100
150
200
250
300
1900
1920
1940
1960
1980
2000
2020
2040

Milestones in the search for LTS, HTS & RTS

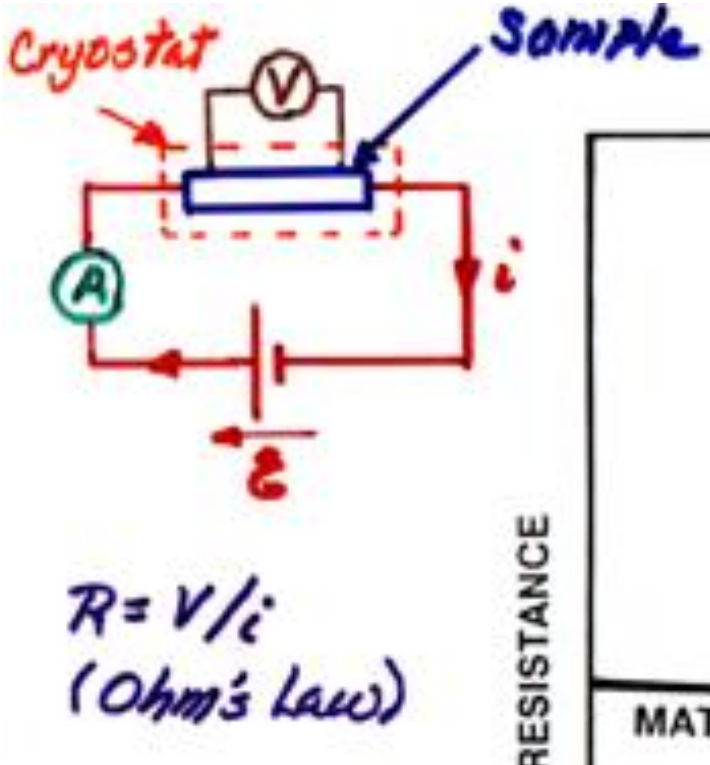
- Liquid H_2 – 20.3 K *[Nb_3(Ge,Al) – 21 K]* (Matthias et al. 1967) **[LTS]**
- Liquid N_2 – 77 K *[RBCO - 90's K]* (Chu et al. 1987) – ***the holy grail then [HTS]***
- Space Shuttle - 100 K *[BSCCO - 110 K]* (Maeda et al. 1988)
- Liquid Natural Gas - 120 K *[TBCCO - 120 K]* (Hermann et al. 1988)
- CF_4 - 148 K *[HBCCO -164 K, 31 GPa]* (Chu et al. 1993) – high pressure required and ozone layer effect
- RTS - ≥ 203 K *[Hydrides under very high pressures]*

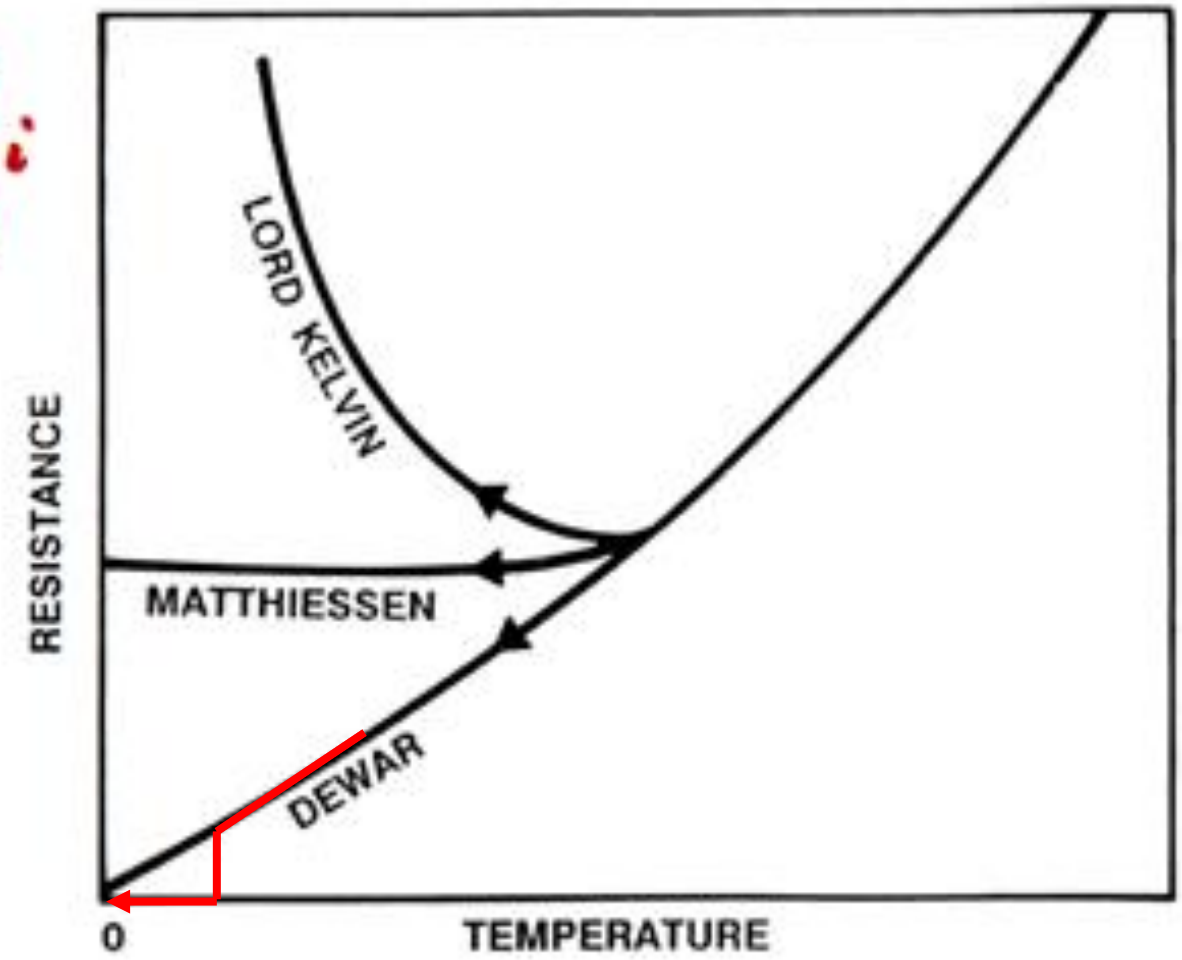
  H_3S – ~ 203 K at ~ 155 GPa (Eremets et al. 2015 **[RTS]**

  LaH_{10} - ~ 260 K at ~ 180-200 GPa (Hemley et al. 2019)

  C-S-H - ~ 287 K at – 267 GPa (Dias et al. 2000)

  Lu-N-H - ~ 294 K at 1GPa (Dias et al. 2023) – ***the holy grail today***

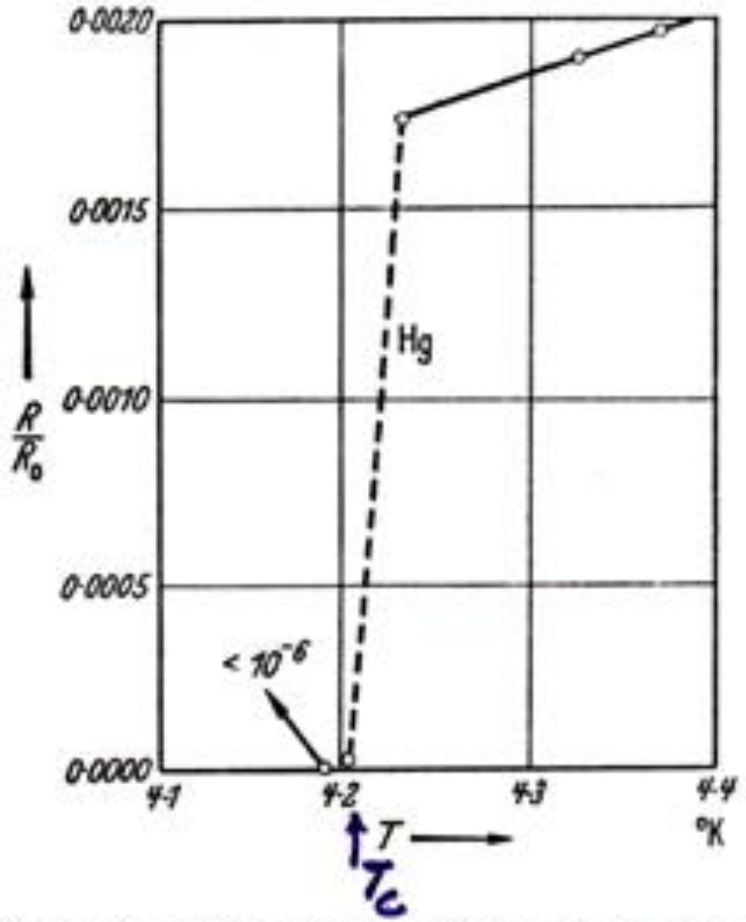




Three predictions of metallic resistance behavior near absolute zero.

Kamerlingh Onnes
(1911)

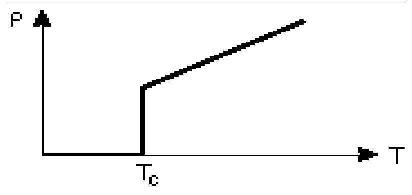
The Discovery (1911)



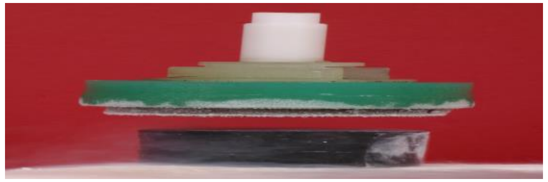
KAMERLINGH ONNES' original observation of superconductivity in mercury (1911). R = resistance of specimen; R_0 = resistance at 0° C. The temperature scale used at the time was incorrect, the transition occurs actually at 4·1° K.

BASIC PROPERTIES OF A SUPERCONDUCTOR

- **COMPLETE DISAPPEARANCE OF ELECTRICAL RESISTANCE (1911)**



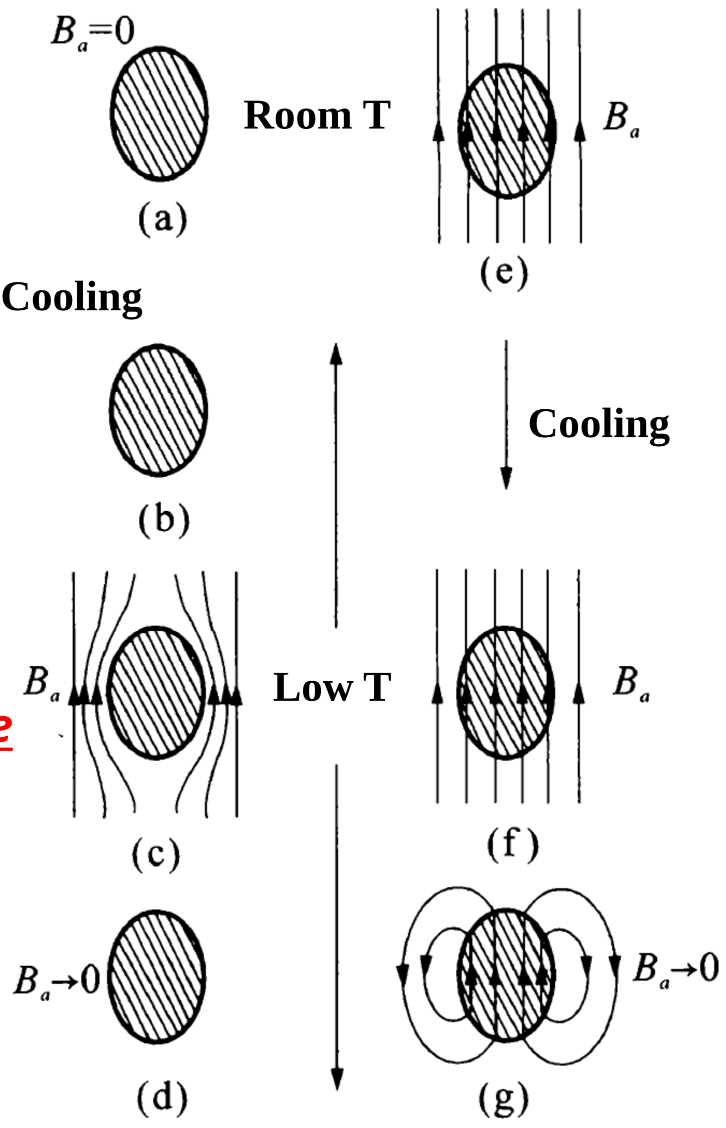
- **COMPLETE EXPULSION OF EXTERNALLY APPLIED MAGNETIC FIELD (1933)**



- **MACROSCOPIC QUANTUM PHENOMENON or A COHERENT QUANTUM STATE (1930's, 1962)**

T_c - SC Transition Temperature
J_c - Critical Current Density
H_c - Critical Magnetic Field

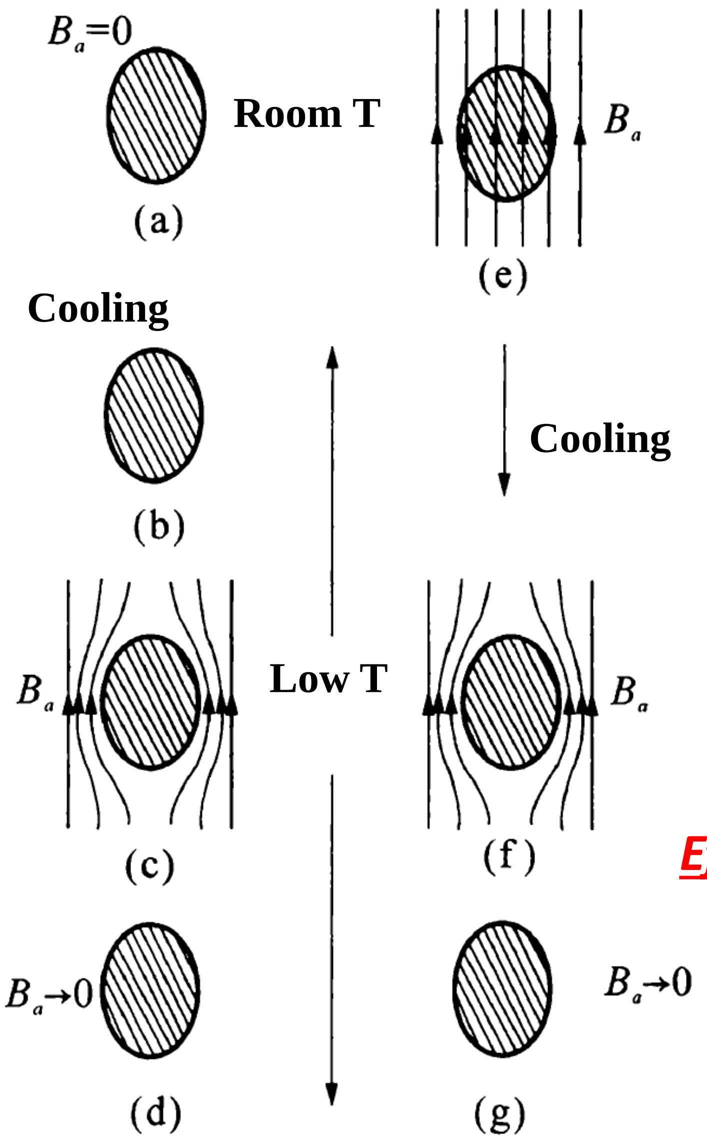
Perfect Conductor



Field Resistance

ZFC ***FC***

Superconductor



Field Expulsion

Meissner-Effect (1933)

ZFC ***ZFC***

- **Superconductivity – Science and Technology**
- **Science – T_c, Mechanism,…. ; Technology…….**
- **Theoretical (Einsteinian) vs, Empirical (Edisonian):**

-BCS: $T_c = 1.14\theta_D \exp(-1/NV)$ – electron pairing, attractive interaction
- McMillan: $T_c = [\theta/1.45]\{-[1.04(1+\lambda)]/[\lambda-\mu^*(1+0.62\lambda)]\}$

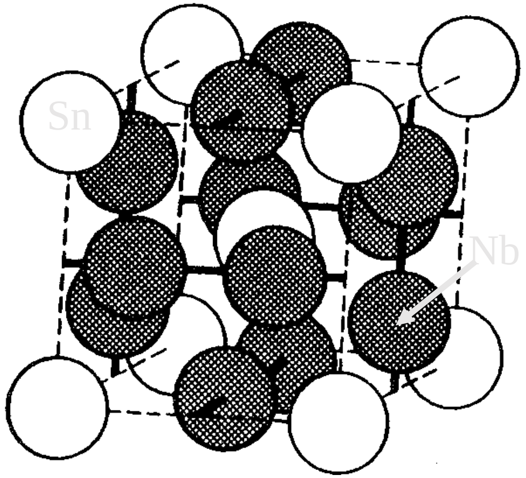
- Matthias: T_c ~ e/a 4.75, 6.4 (LTS);
- Presland: $T_c/T_{c,max+}$ ~ 1~ 82.6 $(n-n_o)^2$ (HTS)

- BCS - characteristic temperature $\Theta \sim 1/M^{-\alpha}$ (Isotope Effect)
- e-ph interaction, mass and instabilities, LTS
- e-e interaction, magnetic fluctuations, e-e correlations, HTS
- e-ph interaction, RTS !?

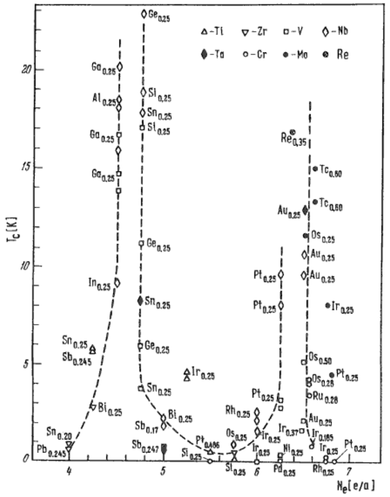
LTS (before 1986)

• The Enlightened Empirical Approach

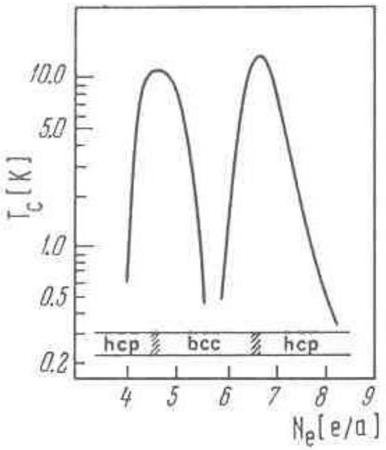
- Matthias empirical rule (1953): T_c peaks at e/a ~ 4.75 and 6.4
- Most effective approach even after 1986



Nb_3Sn



A_3B or A15



Alloys

•Works well for crystalline inter-metallic materials only

• Recognizes the importance of instabilities

LTS (up to 1986)

• The BCS Approach:

$$T_c = 1.14\Theta_D \exp[-1/N(0)V] \quad \text{or} \quad \theta_{CH} \exp[-1/g]$$

- To raise the T_c - enhance θ_D, N(0) & V; or θ_{CH} & g
- Excellent descriptive power but no or poor predictive ability
  - Almost all parameters are closely coupled – instabilities (structural, CDW, SDW, magnetic, Peierls, I-M...)
  - The small energy scale of superconductivity
- New mechanisms: phonon, electron, magnetic, charge…
  - *1D - Little (64): organic materials
  - *2D – Ginzburg (64): TaS_2 (71), Al/organic……
  - *oxides – Matthias (64): A_xWO_3, $LiTi_2O_4$ (73), $BaPbBiO_3$ (75)
  - *interfacial – ABB (73): Pb/Te, Au/Ge,…

1986: the critical year

Z. Phys. B – Condensed Matter 64, 189-193 (1986)

Condensed Matter
Zeitschrift für Physik B
© Springer-Verlag 1986

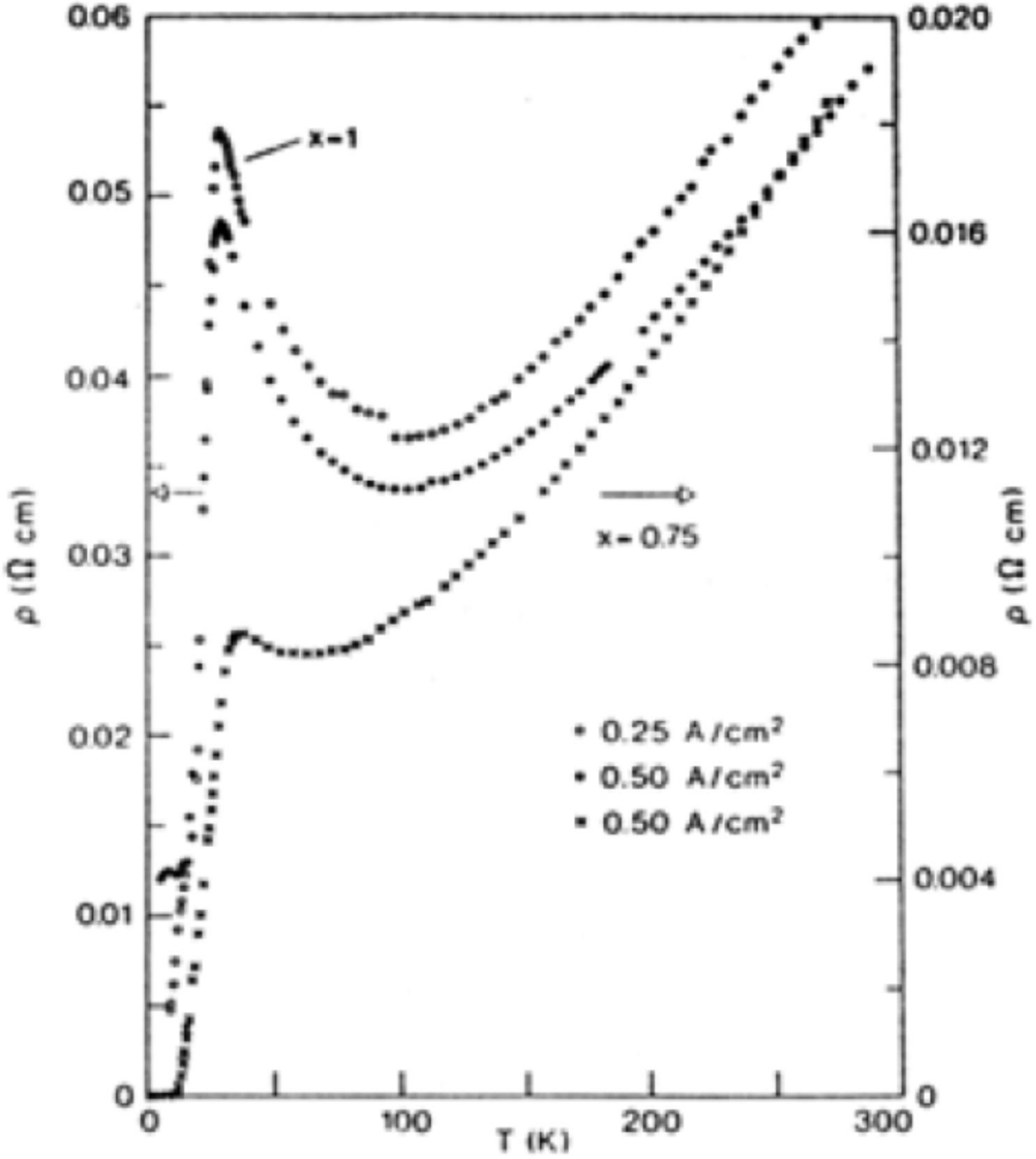
Possible High T_c Superconductivity in the Ba – La – Cu – O System

J.G. Bednorz and K.A. Müller
IBM Zürich Research Laboratory, Rüschlikon, Switzerland

Received April 17, 1986

Metallic, oxygen-deficient compounds in the Ba – La – Cu – O system, with the composition $Ba_xLa_{5-x}Cu_5O_{5(3-y)}$ have been prepared in polycrystalline form. Samples with $x=1$ and 0.75, $y>0$, annealed below 900 °C under reducing conditions, consist of three phases, one of them a perovskite-like mixed-valent copper compound. Upon cooling, the samples show a linear decrease in resistivity, then an approximately logarithmic increase, interpreted as a beginning of localization. Finally an abrupt decrease by up to three orders of magnitude occurs, reminiscent of the onset of percolative superconductivity. The highest onset temperature is observed in the 30 K range. It is markedly reduced by high current densities. Thus, it results partially from the percolative nature, bute possibly also from 2D superconducting fluctuations of double perovskite layers of one of the phases present.

$La_{2-x}Ba_xCuO_4$ (214) – new T_c record to 35 K in a new oxide



G. Bednorz and A. Mueller *Z. Phys. B* **64**, 189 (1986).

- The paper was initially greeted with skepticism by most except a few groups (Tokyo, Houston, Beijing, IBM-Yorktown)

- The Houston group and the Tokyo group confirmed their results and

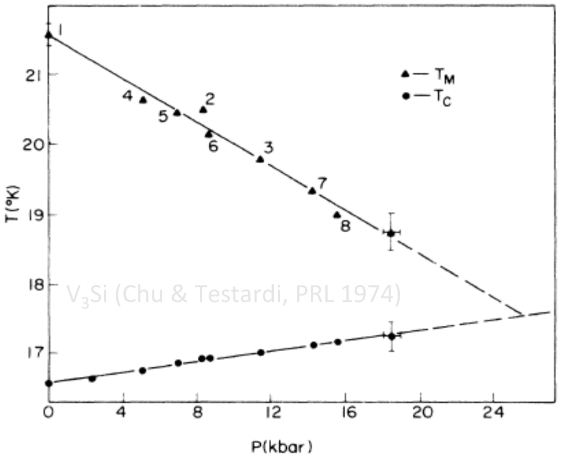
- The Tokyo group further identified the 214 superconducting phase

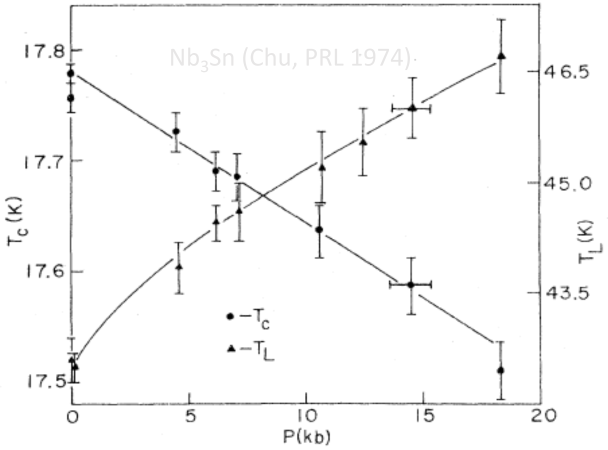
- The MRS Meeting, December 4, 1986

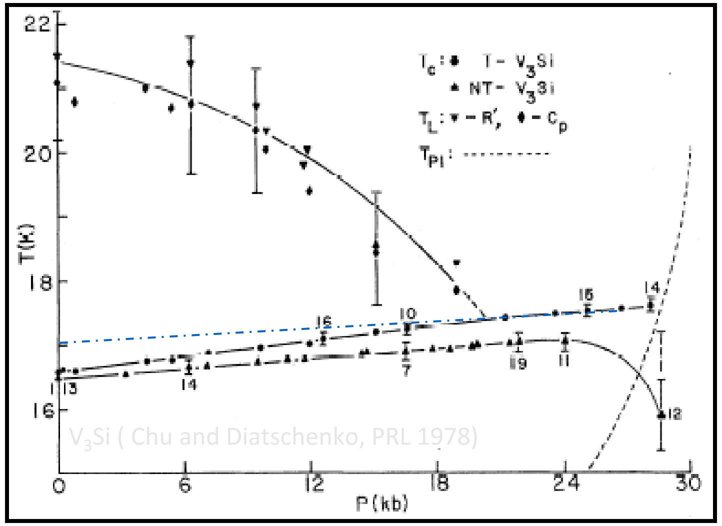
Before 1986 we were doing:

- **The BCS Approach:** $T_c = 1.14\Theta_D \exp[-1/N(E_F)V]$

- instabilities: (structural, CDW, SDW, magnetic, Peierls, I-M......)







- Soft modes help T_c, but structural transformation affects T_c only slightly.
- Higher T_c is possible and high pressure may help make it happen

⬇

- To use HP for the study of cuprates is not accidental.

VOLUME 58, NUMBER 4 PHYSICAL REVIEW LETTERS 26 JANUARY 1987

Evidence for Superconductivity above 40 K in the La-Ba-Cu-O Compound System

C. W. Chu,[a] P. H. Hor, R. L. Meng, L. Gao, Z. J. Huang, and Y. Q. Wang
Department of Physics and Magnetic Information Research Laboratory
University of Houston, Houston, Texas 77004
(Received 15 December 1986)

An apparent superconducting transition with an onset temperature above 40 K has been detected under pressure in the La-Ba-Cu-O compound system synthesized directly from a solid-state reaction of La_2O_3, CuO, and $BaCO_3$ followed by a decomposition of the mixture in a reduced atmosphere. The experiment is described and the results of effects of magnetic field and pressure are discussed.

PACS numbers: 74.70.Ya

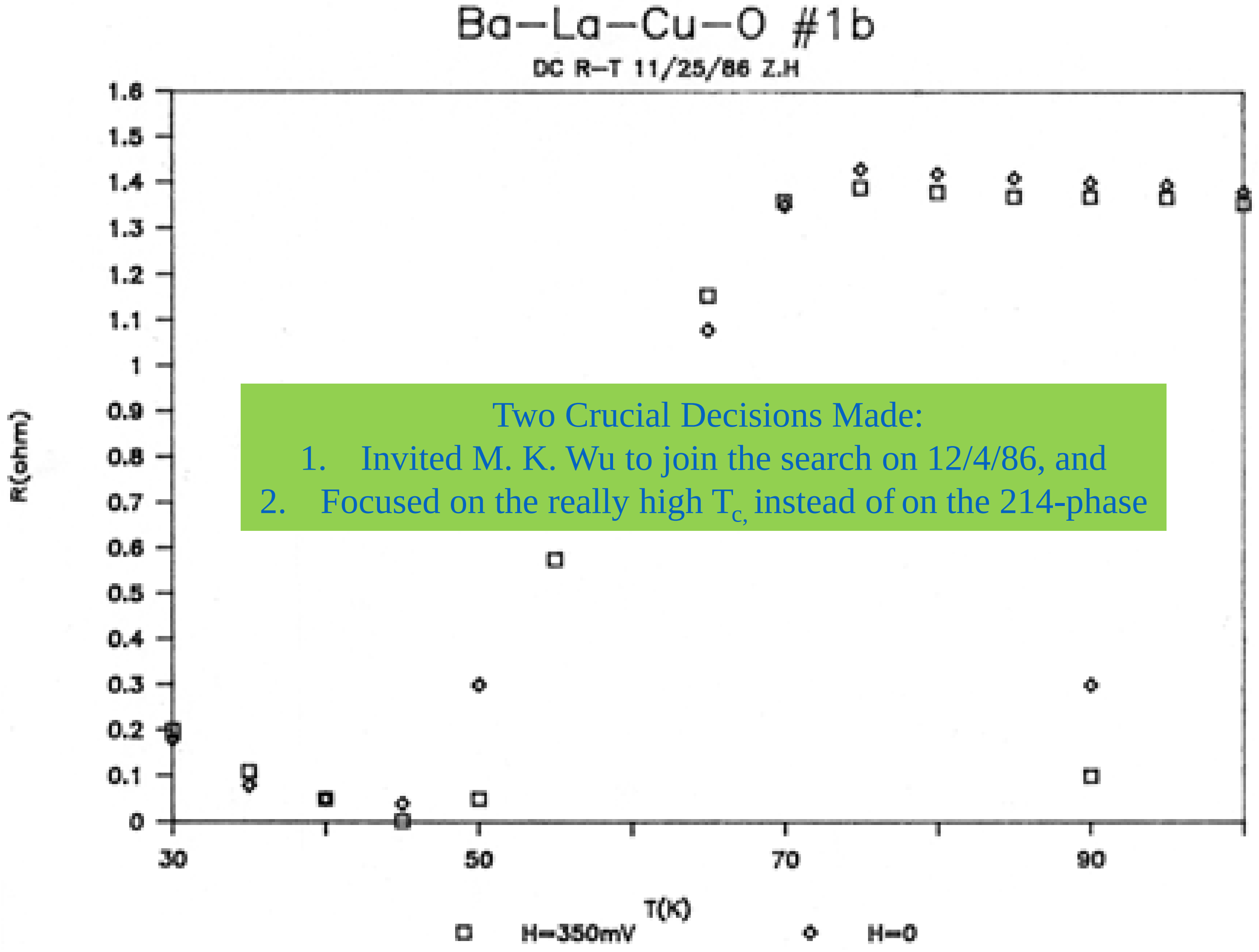
Superconductivity at 52.5 K in the Lanthanum-Barium-Copper-Oxide System

Science235,567(1987)

C. W. CHU,* P. H. HOR, R. L. MENG, L. GAO, Z. J. HUANG

A superconducting transition with an onset temperature of 52.5 K has been observed under hydrostatic pressure in compounds with nominal compositions given by $(La_{0.9}Ba_{0.1})_2 CuO_{4-y}$. Possible causes for the high-temperature superconductivity are discussed.

The unusually large pressure effect on T_c
Enhanced T_c to 40.2 and then to 52.4 K
=> The compound is unusual!!!
A T_c> 40 K defies the then theoretical prediction!!!



Two Crucial Decisions Made:

1. Invited M. K. Wu to join the search on 12/4/86, and
2. Focused on the really high $T_{c,}$ instead of on the 214-phase

First sign of SC slightly < 77 K was detected on November 25, 1986
in multi-phased but not pure 214 samples!
Decided the real high T_c phase cannot be 214 &
to stabilize the phase by replacing La with Y & Lu !

070503CWC

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

Dear Drs. Bednorz + Müller, 12/3/86

This is just to inform you that my group at the U. of Houston has reproduced your results (Z. Phys. B 64, 189 (86)) three weeks ago. A small ac diamagnetic signal was also detected. Magnetic field was found to suppress the transition. I believe that it is superconductivity. Now the question is "what phase" or "mixed phases". Soon, you will here from me more. Please send me more information!

Sincerely yours

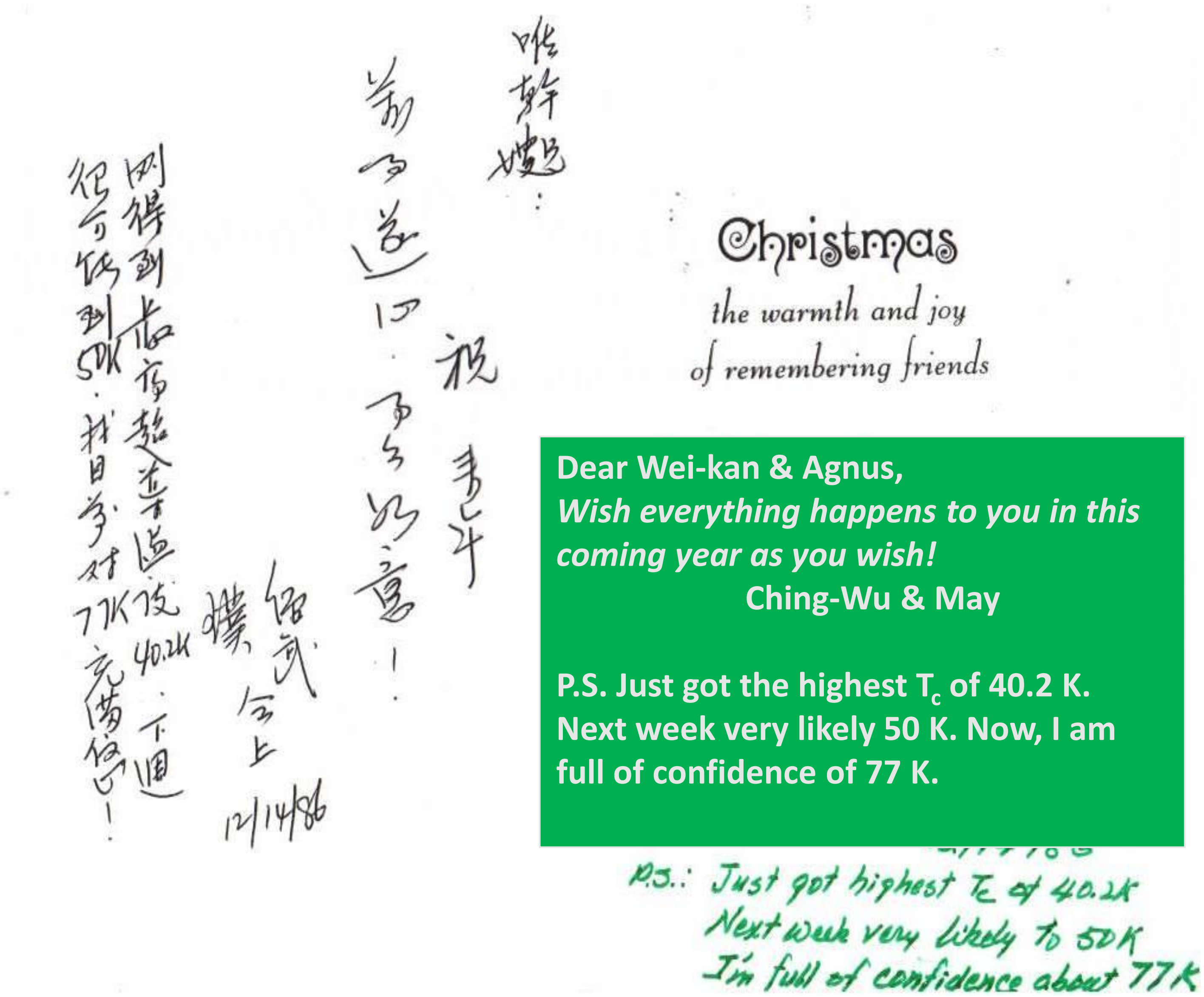
C. W. Chu

(also Physics. Univ. of Houston
Houston, TX 77004)

my phone:
(202) 357-9737
or
(713) 749-2842
Your phone No.?

P.S. Currently, I am the Director of Solid Physics Program at the National Science Foundation.

(From G. Bednorz) & a phone call from Mueller



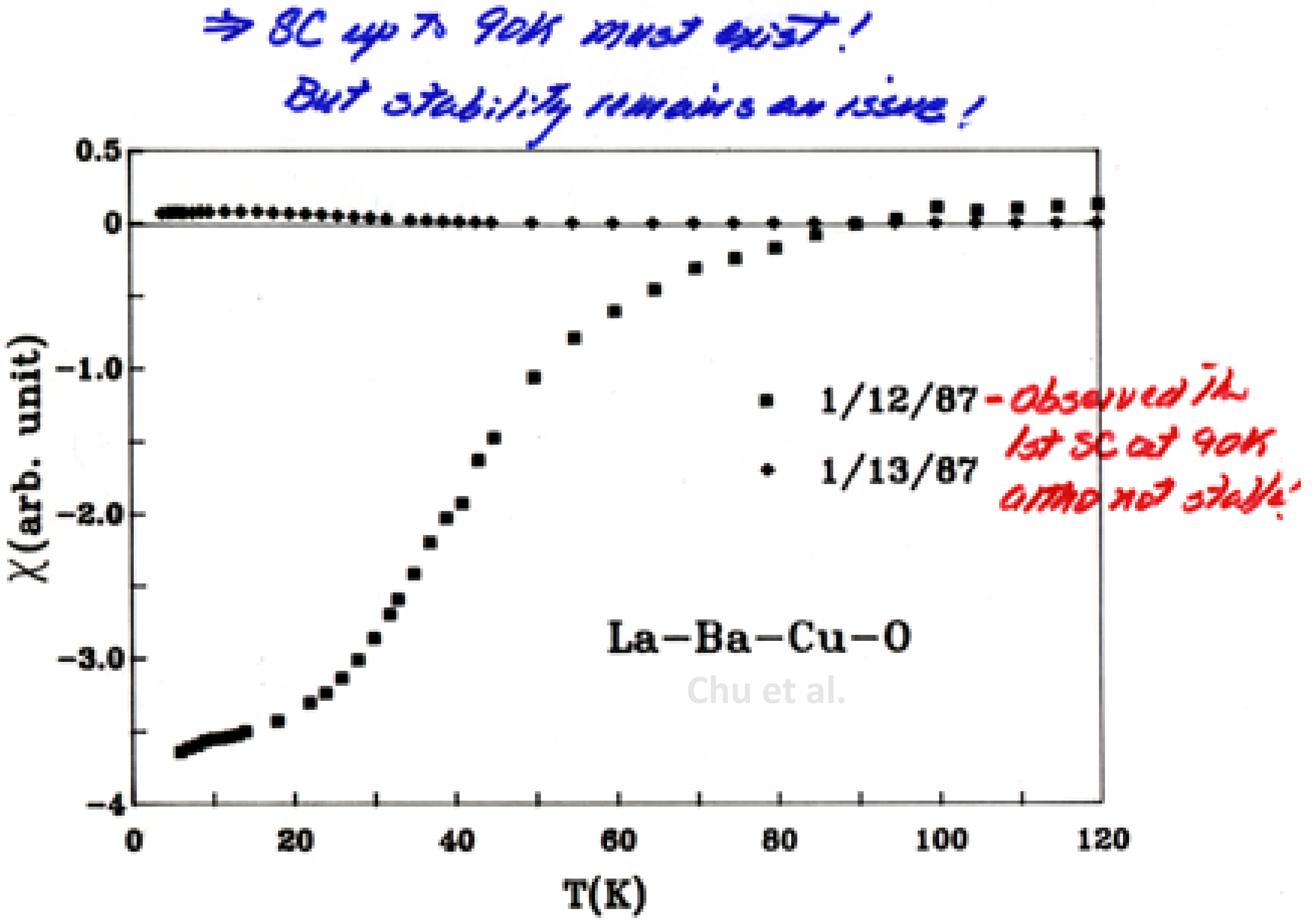
Dear Wei-kan & Agnus,
Wish everything happens to you in this coming year as you wish!
Ching-Wu & May

P.S. Just got the highest T_c of 40.2 K. Next week very likely 50 K. Now, I am full of confidence of 77 K.

(From W. K. CHU)

070503CWC

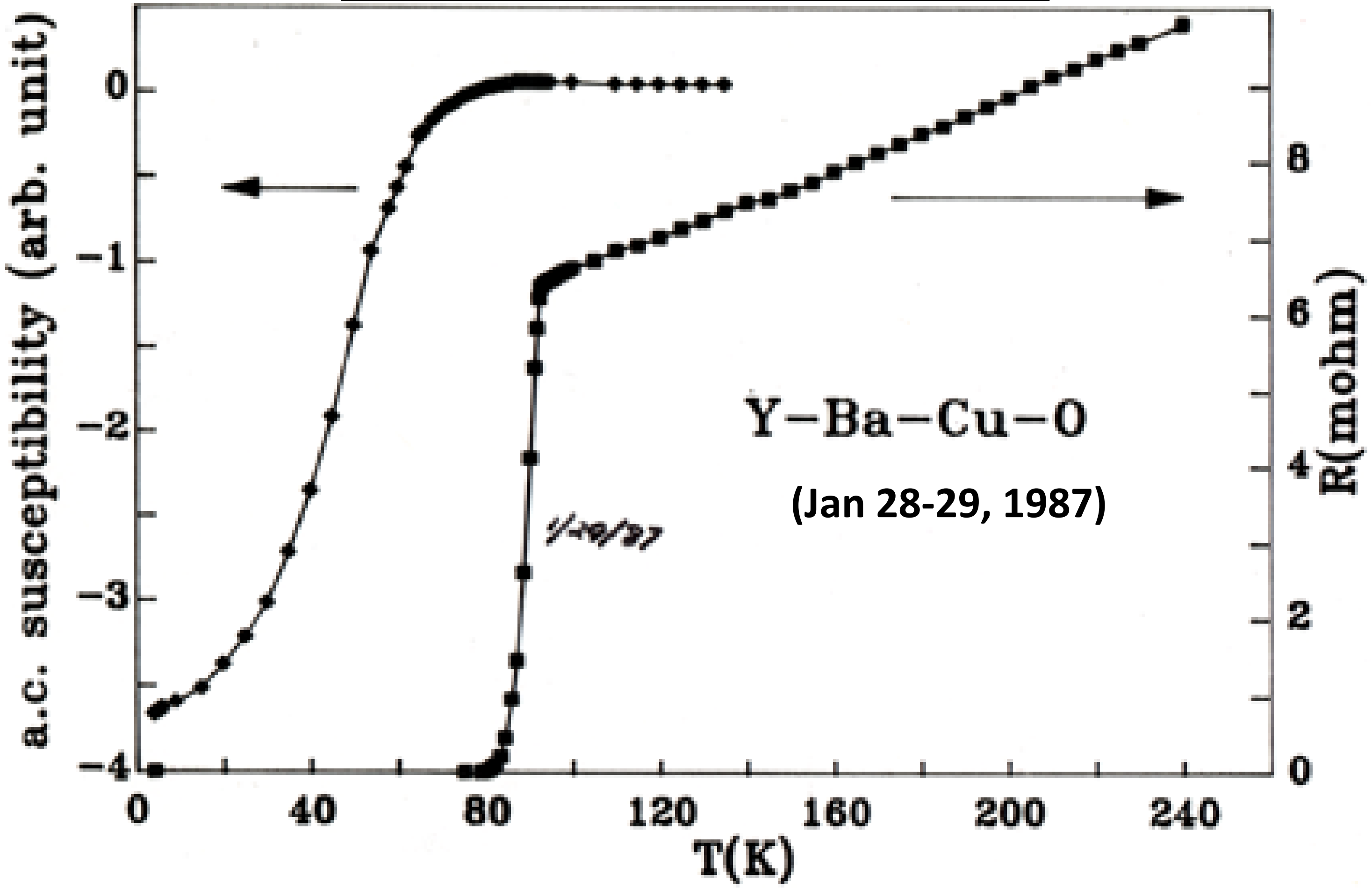
1987: the exciting year



First 90 K - SC was unambiguously observed, although not yet stable.
Later analysis of the X-ray data showed it was
$LaBa_2Cu_3O_7$(123 or LBCO)

1987: The Exciting Year

M. K. Wu et al./C. W. Chu et al.



SC above 77 K was finally stabilized.

$YBa_2Cu_3O_7$ (123 or YBCO)

the first stable liquid-nitrogen-temperature superconductor.

1987: The Exciting Year

VOLUME 58, NUMBER 9 PHYSICAL REVIEW LETTERS 2 MARCH 1987

1979

Superconductivity at 93 K in a New Mixed-Phase Y-Ba-Cu-O Compound System at Ambient Pressure

M. K. Wu, J. R. Ashburn, and C. J. Torng
Department of Physics, University of Alabama, Huntsville, Alabama 35899

and

P. H. Hor, R. L. Meng, L. Gao, Z. J. Huang, Y. Q. Wang, and C. W. Chu[a]
Department of Physics and Space Vacuum Epitaxy Center, University of Houston, Houston, Texas 77004

(Received 6 February 1987; Revised manuscript received 18 February 1987)

A stable and reproducible superconductivity transition between 80 and 93 K has been unambiguously observed both resistively and magnetically in a new Y-Ba-Cu-O compound system at ambient pressure. An estimated upper critical field $H_{c2}(0)$ between 80 and 180 T was obtained.

$YBa_2Cu_3O_7$ (YBCO or 123)
[was intended to be a one sentence paper]

March 2, 1987 was a super-day for physics – >90K SC, supernova, SSC!!!

1987: The Exciting Year

VOLUME 58, NUMBER 18 PHYSICAL REVIEW LETTERS 4 MAY 1987

Superconductivity above 90 K in the Square-Planar Compound System $ABa_2Cu_3O_{6+x}$ with A = Y, La, Nd, Sm, Eu, Gd, Ho, Er, and Lu

P. H. Hor, R. L. Meng, Y. Q. Wang, L. Gao, Z. J. Huang, J. Bechtold, K. Forster, and C. W. Chu[(a)]
Department of Physics and Space Vacuum Epitaxy Center, University of Houston, Houston, Texas 77004
(Received 16 March 1987; revised manuscript received 13 April 1987)

We have found superconductivity in the 90-K range in $ABa_2Cu_3O_{6+x}$ with A = La, Nd, Sm, Eu, Gd, Ho, Er, and Lu in addition to Y. The results suggest that the unique square-planar Cu atoms, each surrounded by four or six oxygen atoms, are crucial to the superconductivity of oxides in general. In partic-

- Found R electronically decoupled from the sc system
- Synthesized and discovered all RBCOs in about 48 hours in a reduced atmosphere

the mixed-phase La-Ba-Cu-O compound system. Subsequent studies attributed[1,2] the superconductivity observed in this and other related compounds to the single layeredlike K_2NiF_4 structural phase. With the steady improvements in sample conditions and the application of pressure, the superconducting transition temperature has been raised to above 40 K at ambient pressure[3,4] and 57 K under pressure,[5] and the transition width has been reduced[3] to 1.4 K. Recently, superconductivity starting at 98 K with a zero-resistance state at 94 K was discovered[6,7] in the mixed-phase Y-Ba-Cu-O system with nominal compositions represented by $Y_{1.2}Ba_{0.8}CuO_{4-\delta}$. Later, superconductivity near 90 K with a zero-resistance state at ~70 K was also reported[8] in the mixed-phase $Lu_{1.8}Ba_{0.2}CuO_4$ compounds. Preliminary examinations showed[9] that the Y-Ba-Cu-O compounds

between the A layers. The significance of the interplane coupling or screening within the layer assembly is especially evident from the enhancement of the superconducting transition from ~30 K in the K_2NiF_4 structure[1,2] to ~90 K in the $ABa_2Cu_3O_{6+x}$ structure in the La-Ba-Cu-O system observed in this study. Bigger layer assembly is predicted for higher-T_c superconducting oxides.

All samples with the $ABa_2Cu_3O_{6+x}$ structure and A = Y, La, Nd, Sm, Eu, Gd, Ho, Er, and Lu were synthesized by the solid-state reaction of appropriate amounts of sesqui-oxides of La, Nd, Sm, Eu, Gd, Ho, Er, and Lu, $BaCO_3$, and CuO in a fashion similar to that previously described.[5] Structural analyses were carried out with a Rigaku D-MAX x-ray powder diffractometer. Samples of dimensions ~1 mm×0.5 mm×4 mm were cut from the sintered cylinders. A standard four-lead

HTS Cuprates

- All Cuprate HTSrs – Represented by a Generic Formula & a Perovskite-Like

Layered Structure $A_mE_2R_{n-1}Cu_nO_{2n+m+2}$

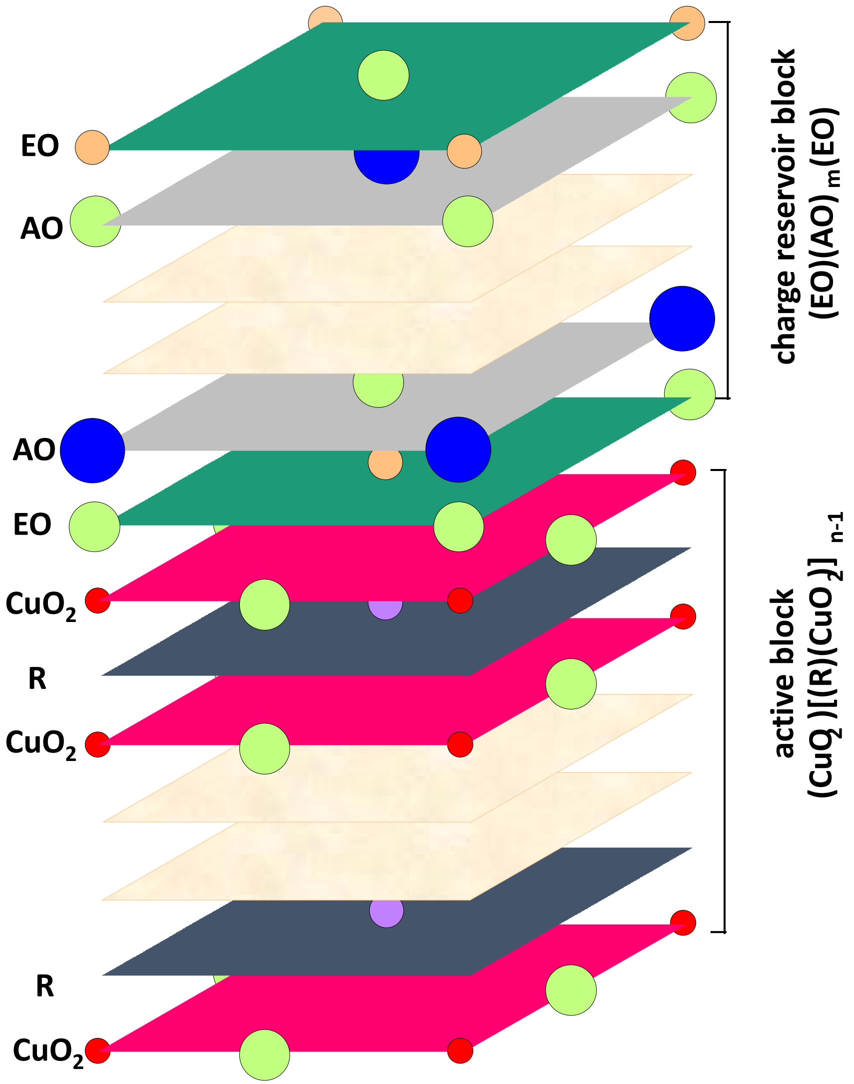
||

$[(EO)(AO)_m(EO)]$ + $\{(CuO_2)[R(CuO_2)]_{n-1}\}$

Charge Reservoir Block *Active Block*

[A-m2(n-1)n or 02(n-1)n when A is absent][A, E, R – cations, often with E = Ba or Sr and R = Ca or a rare-earth element; (AO) may be replaced by more complex slabs; R may be replaced by (RO)-slab]

Current Status - *Known*



A – Bi, Tl, Pb, Cu…(AO)
E – Ca, Sr, Ba
R – Ca, RE, (REO)

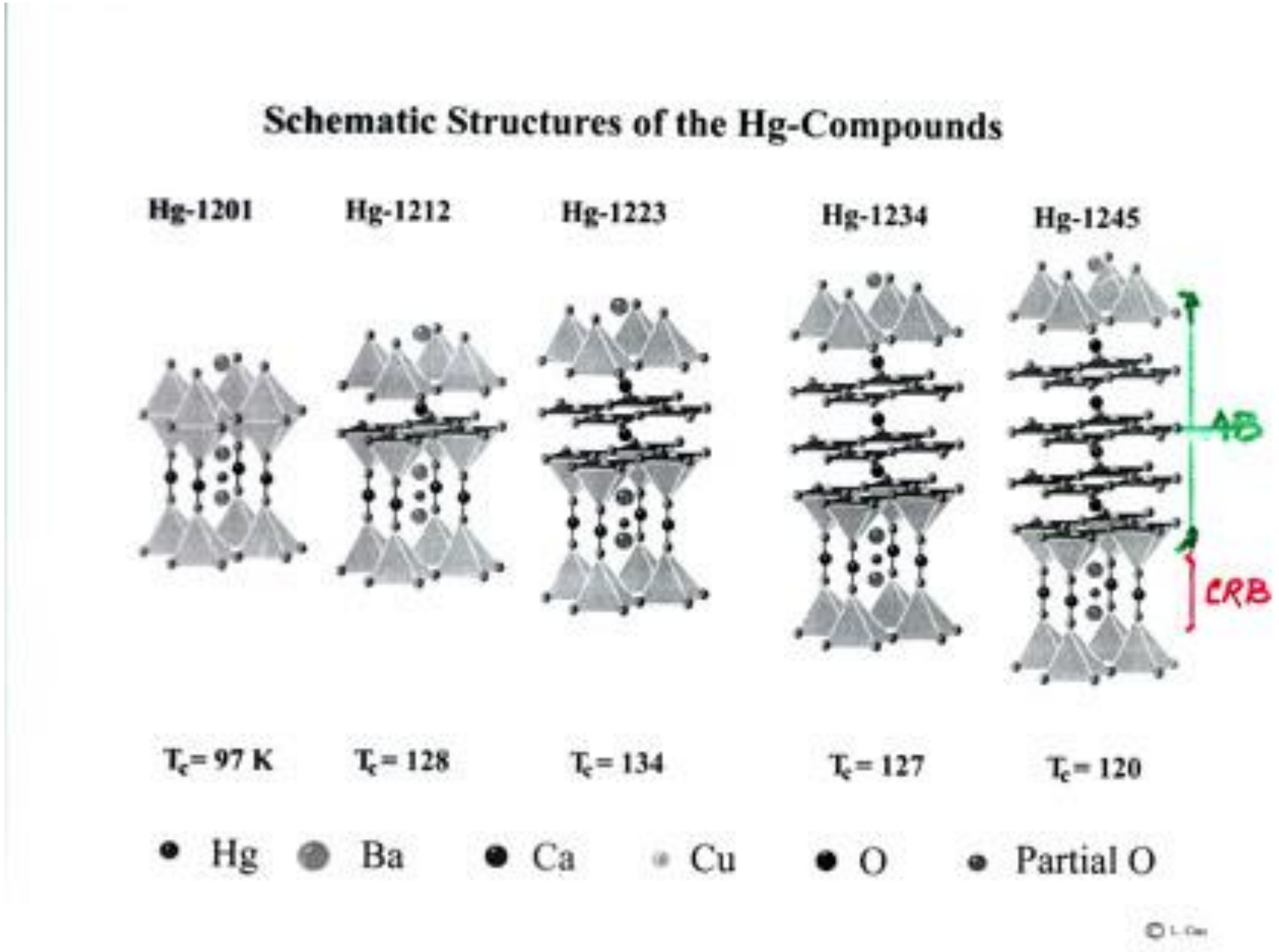
e.g. $YBa_2Cu_3O_7$
$= CuBa_2YCu_2O_7$
= Cu1212

Layered Structure $A_mE_2R_{n-1}Cu_nO_{2n+m+2}$

$\Rightarrow$ $[(EO)(AO)_m(EO)]$ + $(CuO_2)[R(CuO_2)]_{n-1}$

Am(n-1)n
0m(n-1)n

061027CWC


Schematic Structures of the Hg-Compounds
Hg-1201
Hg-1212
Hg-1223
Hg-1234
Hg-1245
AB
CRB
Tc= 97 K
Tc= 128
Tc= 134
Tc= 127
Tc= 120
Hg
Ba
Ca
Cu
O
Partial O

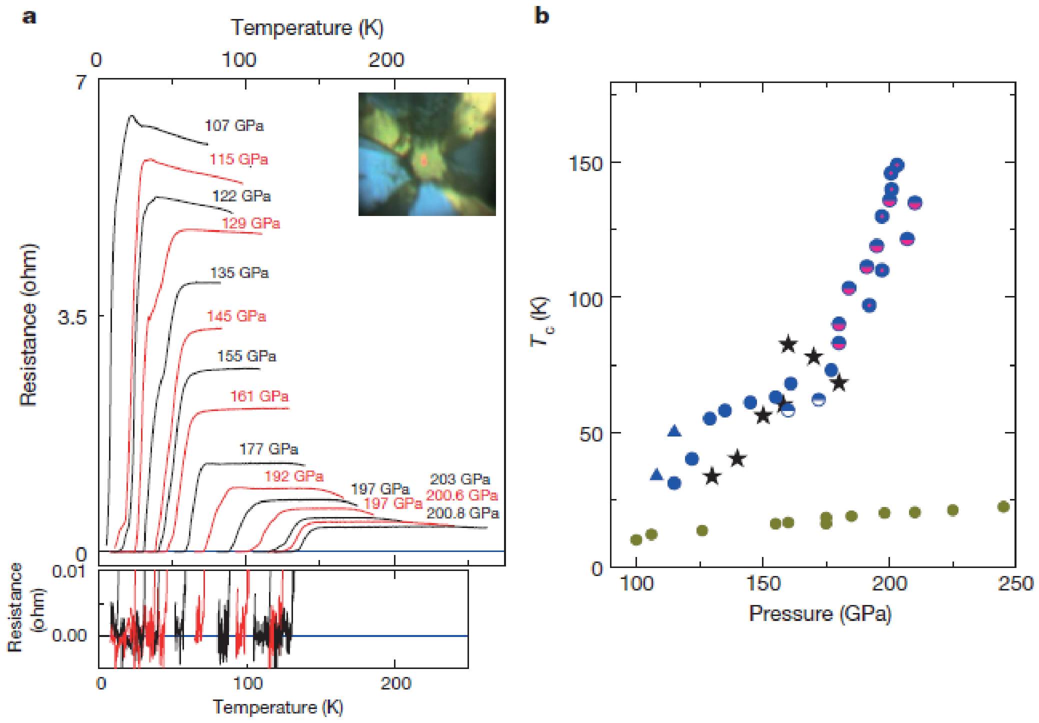
Room Temperature Superconductors?

A Room Temperature Superconductor was found in 2009 by James Cameron

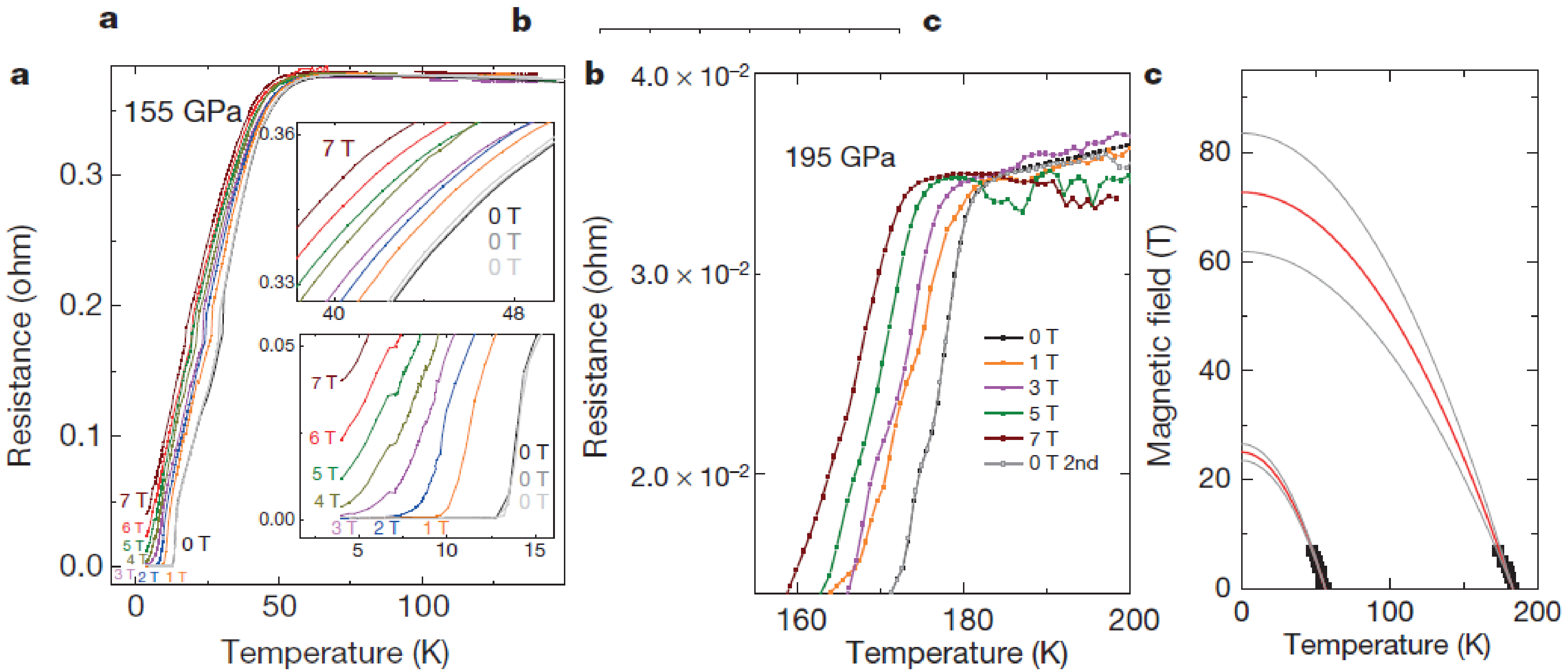
RTS (2005- the dawn of RTS, VHP)

Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system *Nature 525, 73-76 (2015).*

A. P. Drozdov[1]*, M. I. Eremets[1]*, I. A. Troyan[1], V. Ksenofontov[2] & S. I. Shylin[2]



Parallel Down-shift by field?



RESEARCH ARTICLE
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Magnetic Penetration Depth and Coherence Length in a Single-Crystal $YBa_2Cu_3O_{7-\delta}$

Ahmed Abou El Hassan, Abdelaziz Labrag, Ahmed Taoufik, Mustapha Bghour, Hassan El Ouaddi, Ahmed Tirbiyine, Brahim Lmouden, Abdelhalim Hafid, and Habiba El Hamidi*

Phys. Status Solidi B **2021**, *258*, 2100292

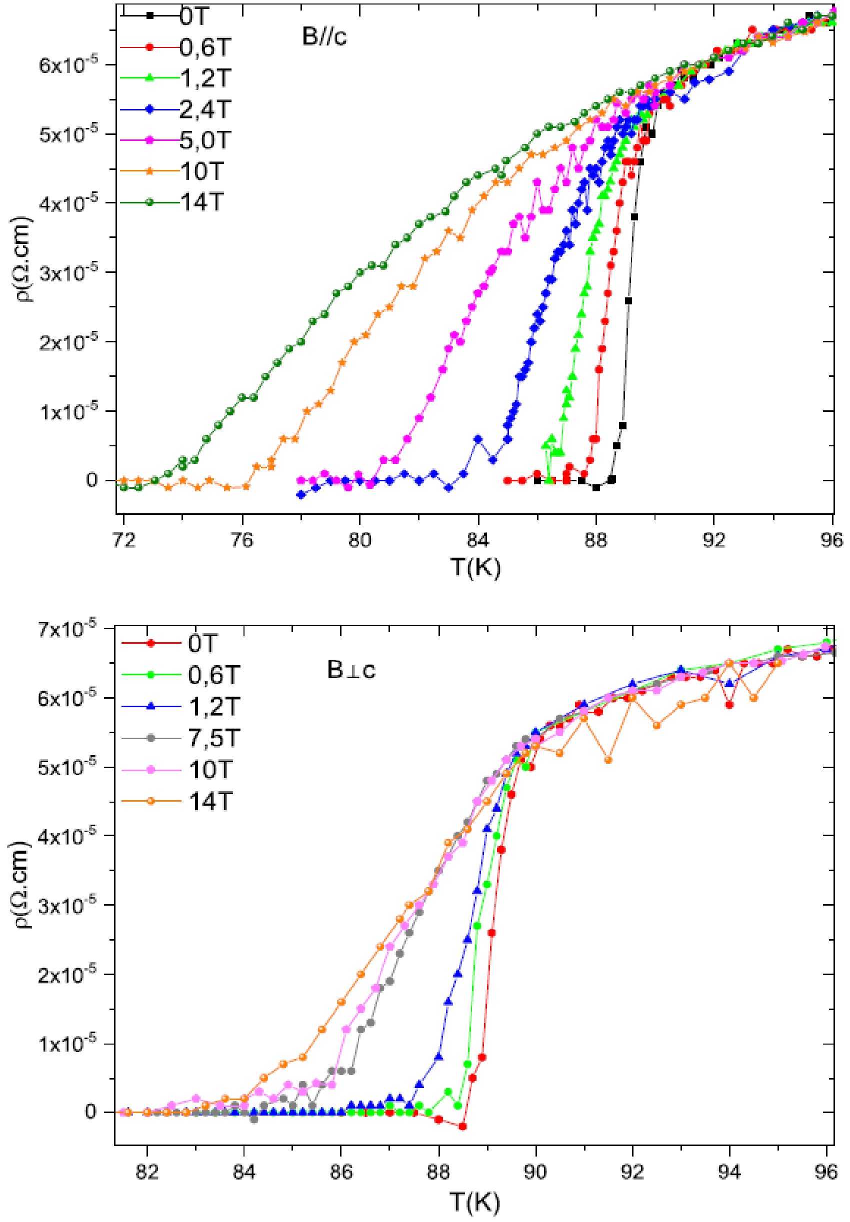
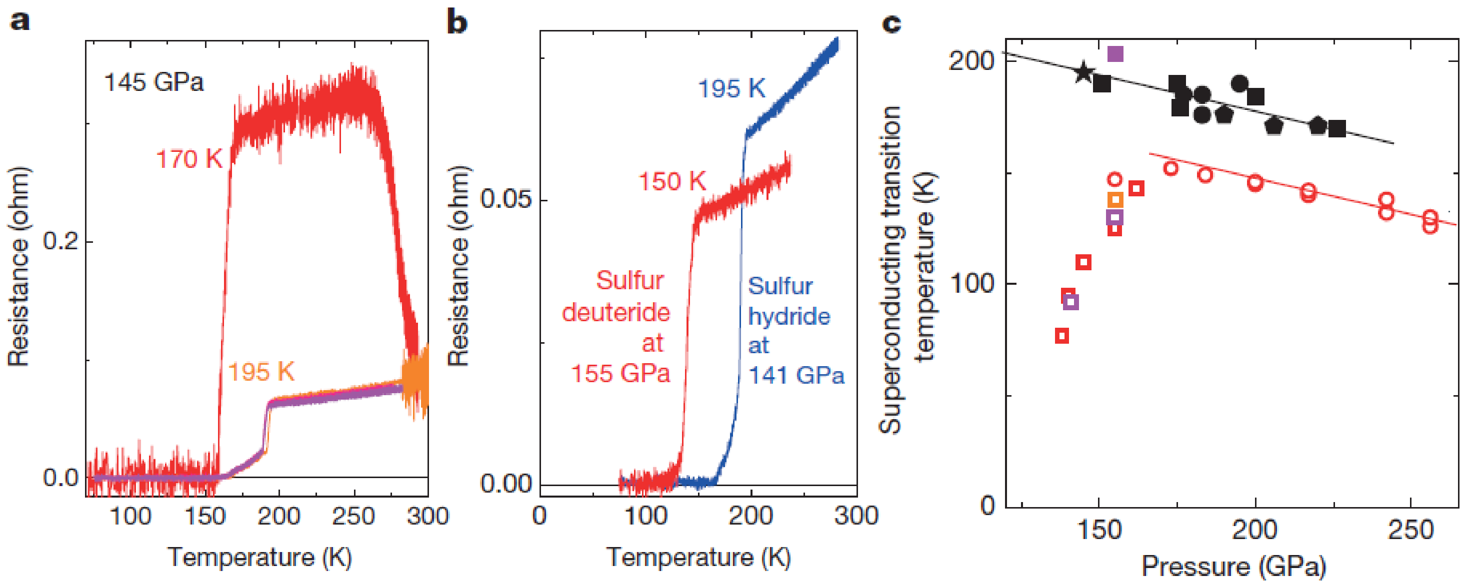


Figure 4. Resistivity plots of $YBa_2Cu_3O_{7-\delta}$ for several magnetic fields i the *c*-axis direction and the *ab*-plane direction with a DC transport curre of 100 nA.

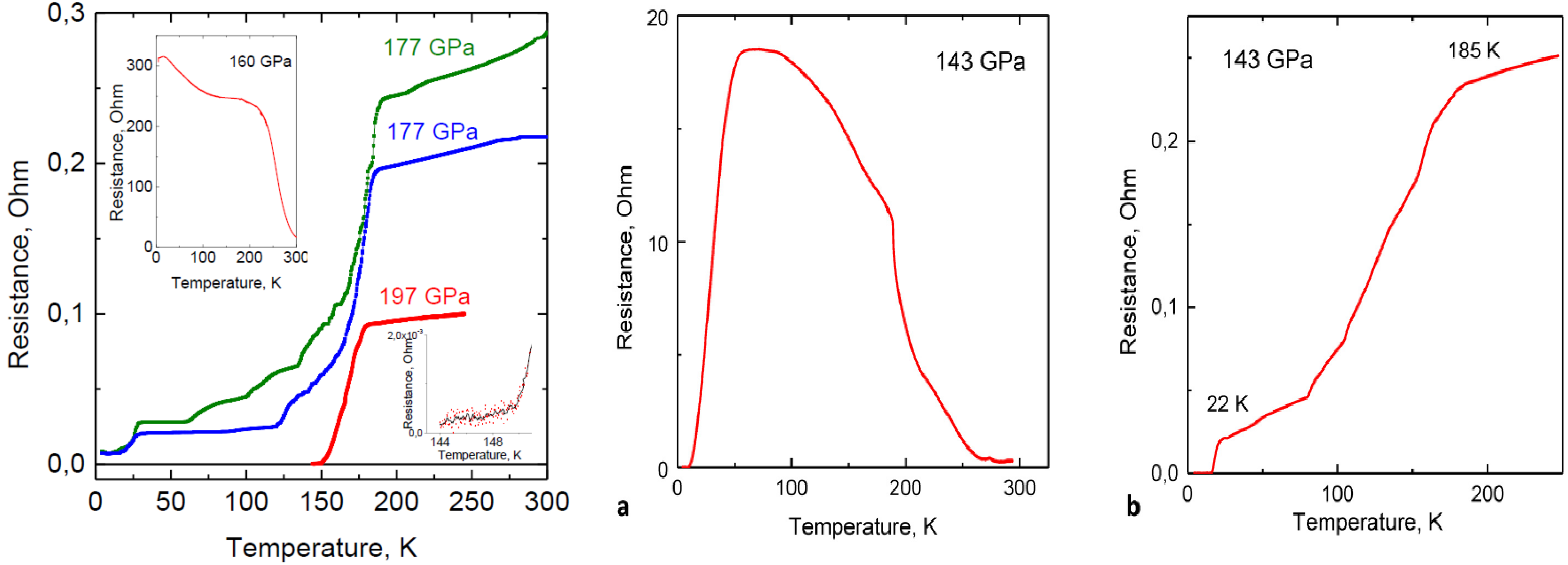
Isotope Effect



R vs T of H_nS to show the transition is P-T path dependent

From Ref.11, fig.3

From Ref 3, extended data fig 2



(i)

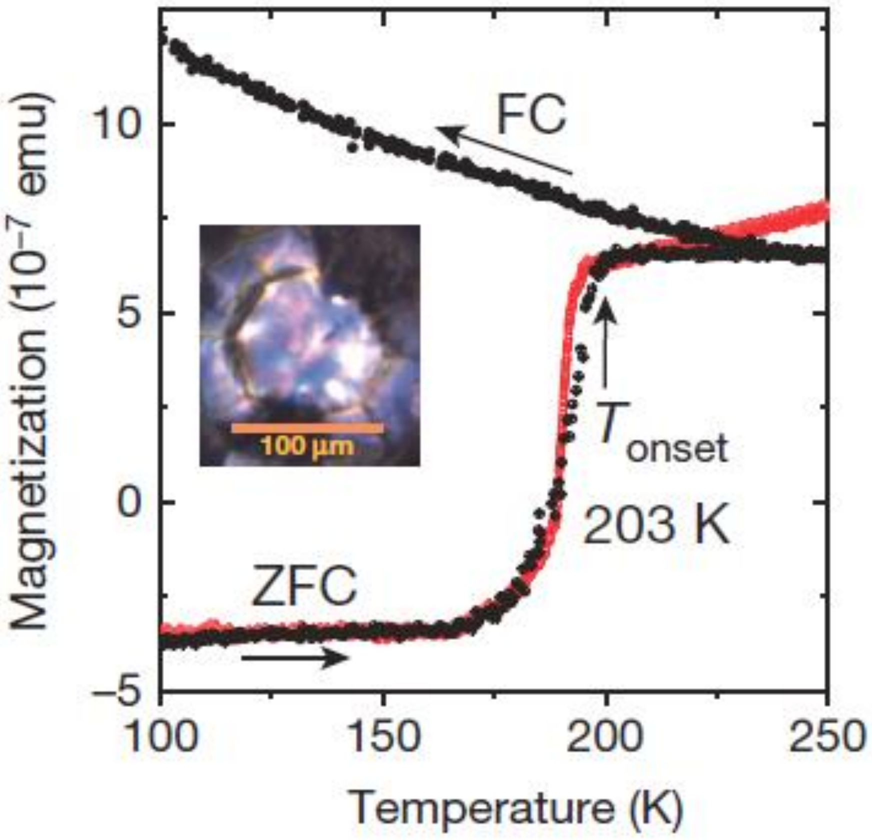
(ii)

(iii)

Fig. 2

M vs T of H_3S under 155 GPa

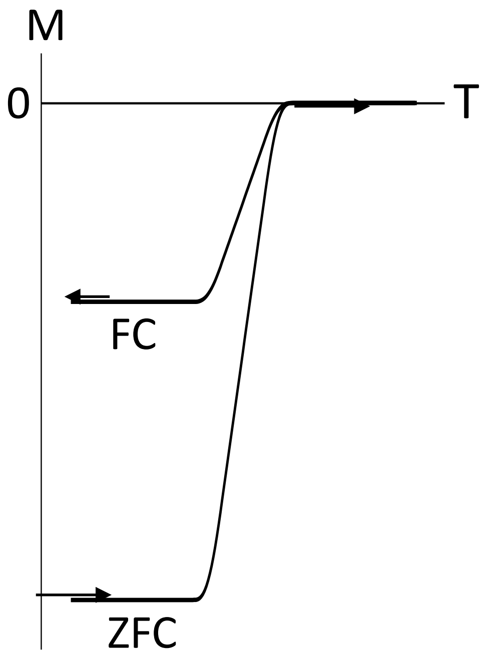
(from Ref.3 - fig. 4a)



(i)

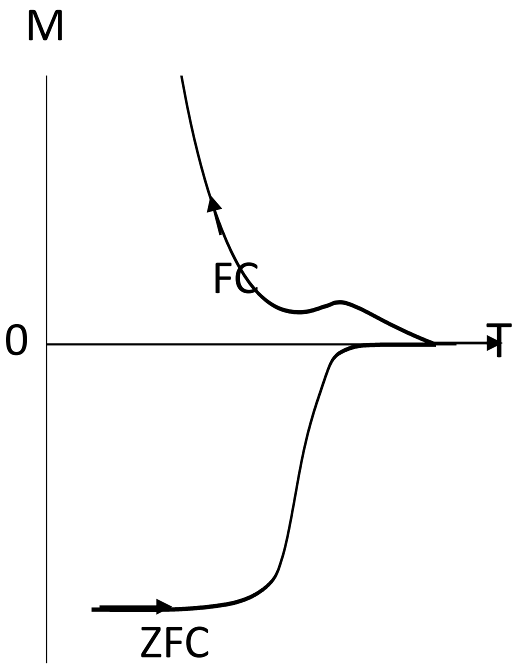
Schematic M vs T of a typical superconductor for comparison

that has no magnetic component



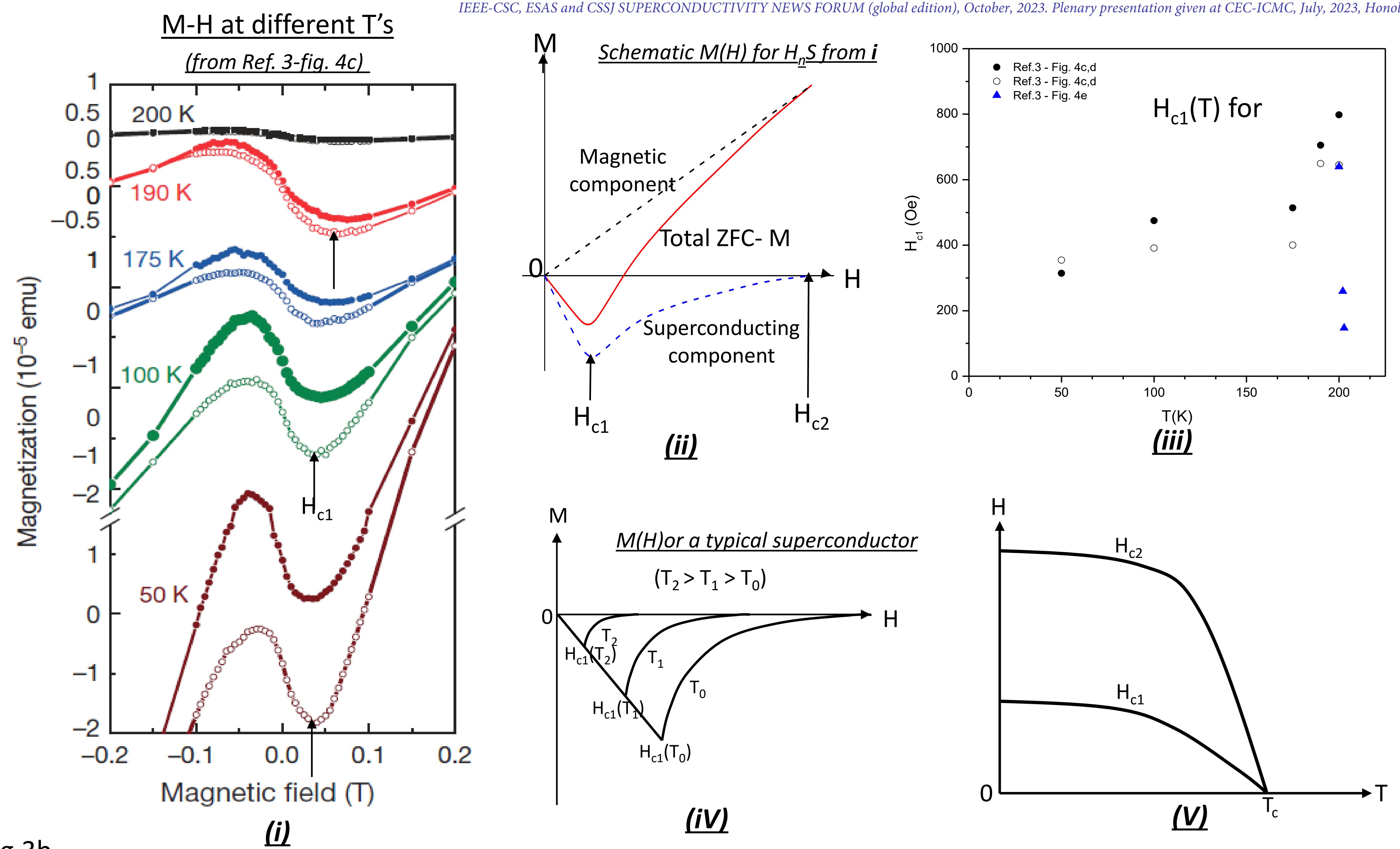
(ii)

that has a magnetic component



(iii)

Fig. 3a



M-H at different T's
(from Ref. 3-fig. 4c)
200 K
190 K
175 K
100 K
50 K
H_{c1}
Magnetization (10^{-5} emu)
Magnetic field (T)
(i)
M
Schematic M(H) for H_nS from i
Magnetic component
Total ZFC- M
Superconducting component
0
H
H_{c1}
H_{c2}
(ii)
Ref.3 - Fig. 4c,d
Ref.3 - Fig. 4c,d
Ref.3 - Fig. 4e
H_{c1}(T) for
H_{c1} (Oe)
T(K)
(iii)
M
M(H)or a typical superconductor
($T_2 > T_1 > T_0$)
H
T_2
T_1
T_0
$H_{c1}(T_2)$
$H_{c1}(T_1)$
$H_{c1}(T_0)$
(iV)
H
H_{c2}
H_{c1}
0
T
T_c
(V)

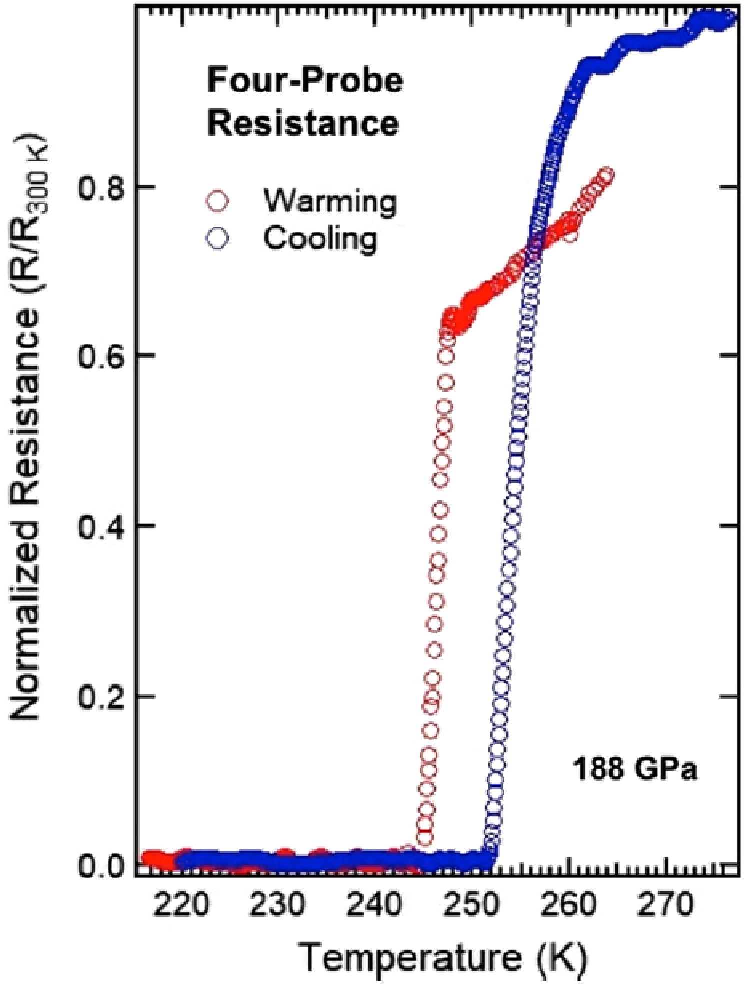
Fig.3b

PHYSICAL REVIEW LETTERS **122,** 027001 (2019)

Suggestion | Featured in Physics

Hemley et al. - 269 K at189-100 GPA

Evidence for Superconductivity above 260 K in Lanthanum Superhydride



Reverse thermal hysteresis

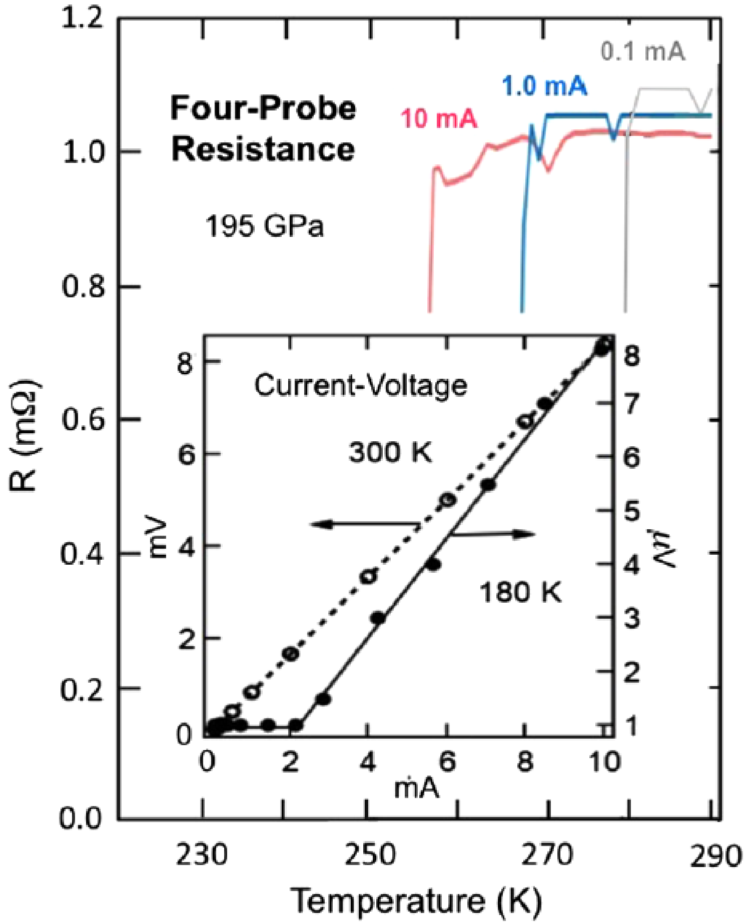


FIG. 4. Electrical resistance measurements using the four-prob

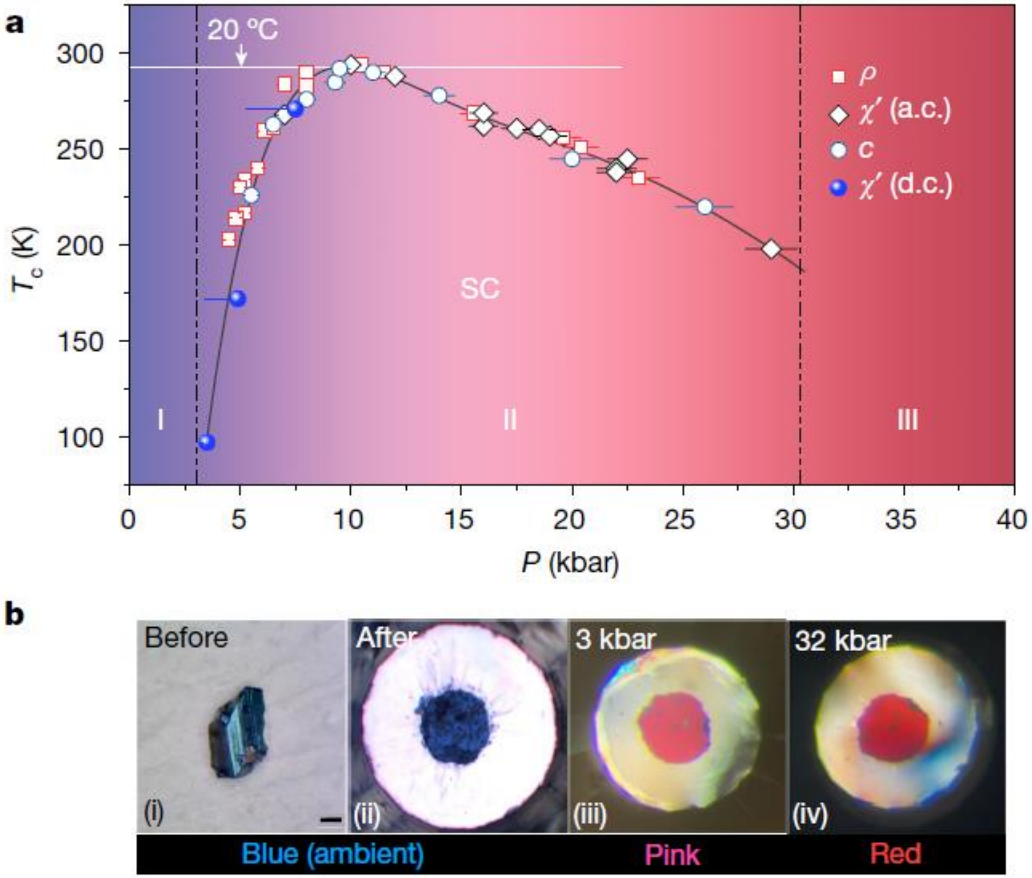
Evidence of near-ambient superconductivity in a N-doped lutetium hydride

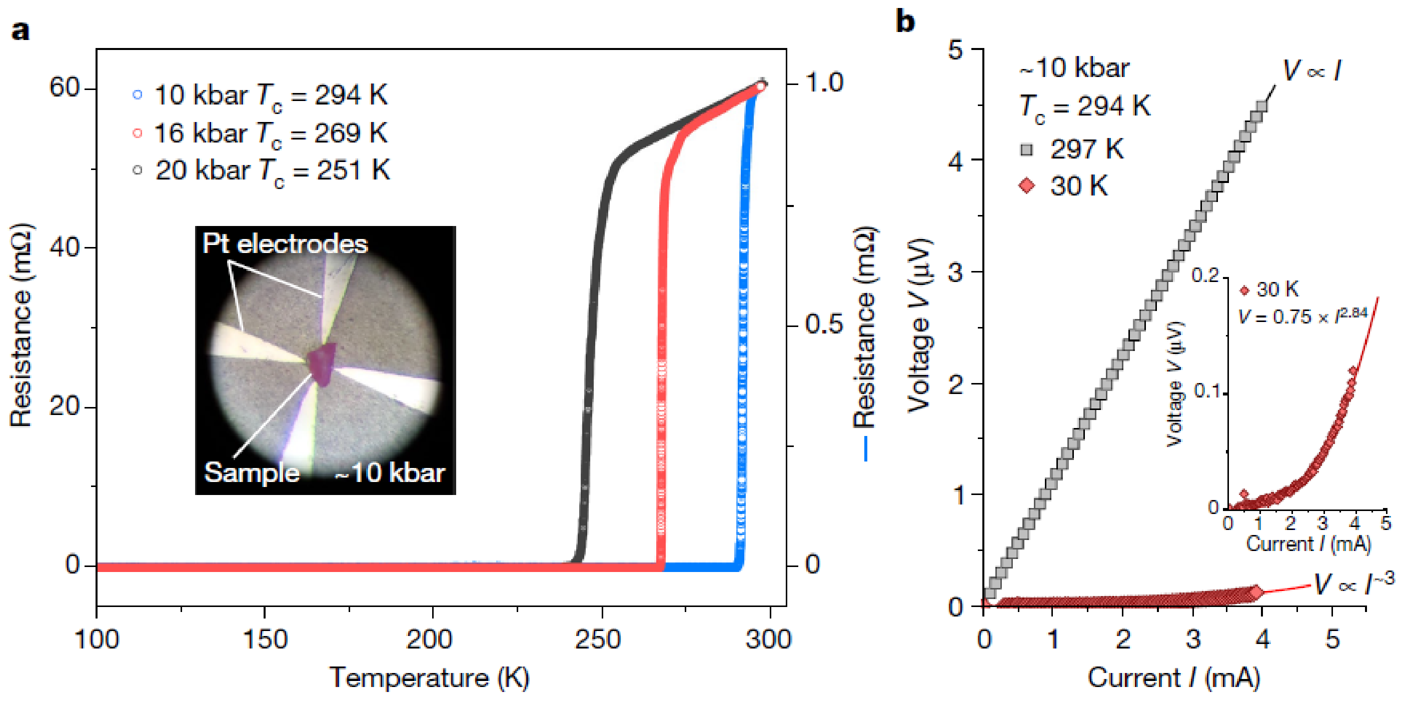
Dias et al, - Lu-NH - 294 K at 1GPa

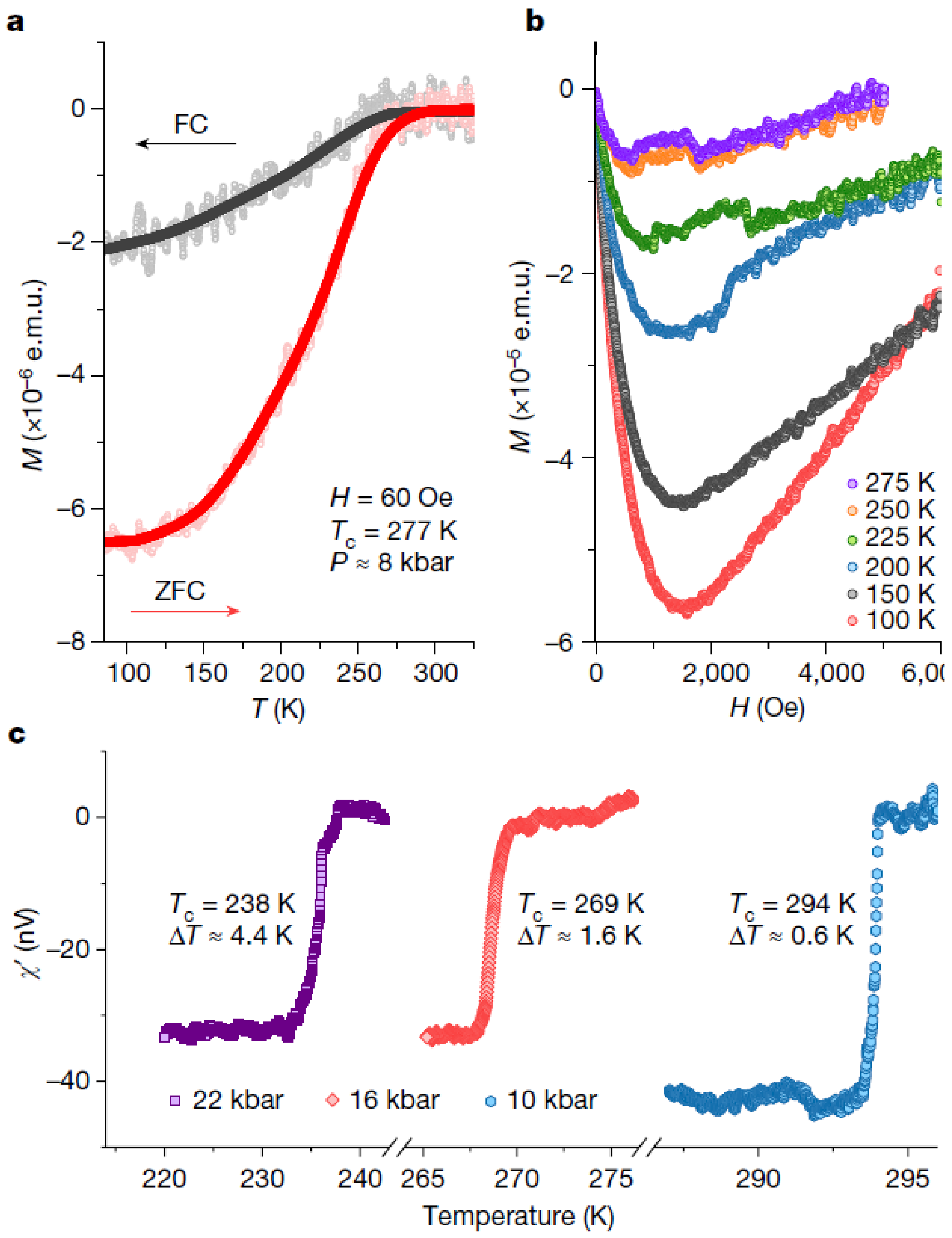
https://doi.org/10.1038/s41586-023-05742-0

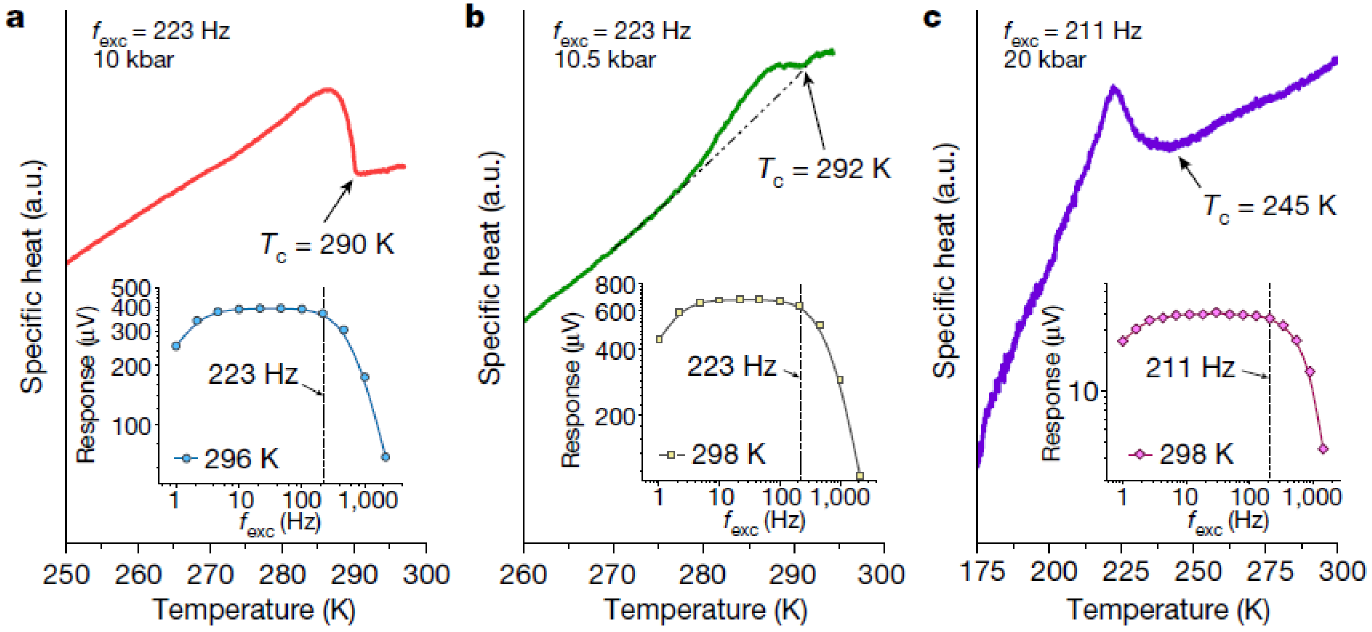
Received: 26 April 2022

Nathan Dasenbrock-Gammon[1,4], Elliot Snider[2,4], Raymond McBride[2,4], Hiranya Pasan[1,4], Dylan Durkee[1,4], Nugzari Khalvashi-Sutter[2], Sasanka Munasinghe[2], Sachith E. Dissanayake[2], Keith V. Lawler[3], Ashkan Salamat[3] & Ranga P. Dias[1,2]✉




a
10 kbar T_c = 294 K
16 kbar T_c = 269 K
20 kbar T_c = 251 K
Pt electrodes
Sample
~10 kbar
Resistance (mΩ)
Temperature (K)
b
~10 kbar
T_c = 294 K
297 K
30 K
$V \propto I$
$V \propto I^{\sim 3}$
30 K
$V = 0.75 \times I^{2.84}$
Voltage V (μV)
Current I (mA)

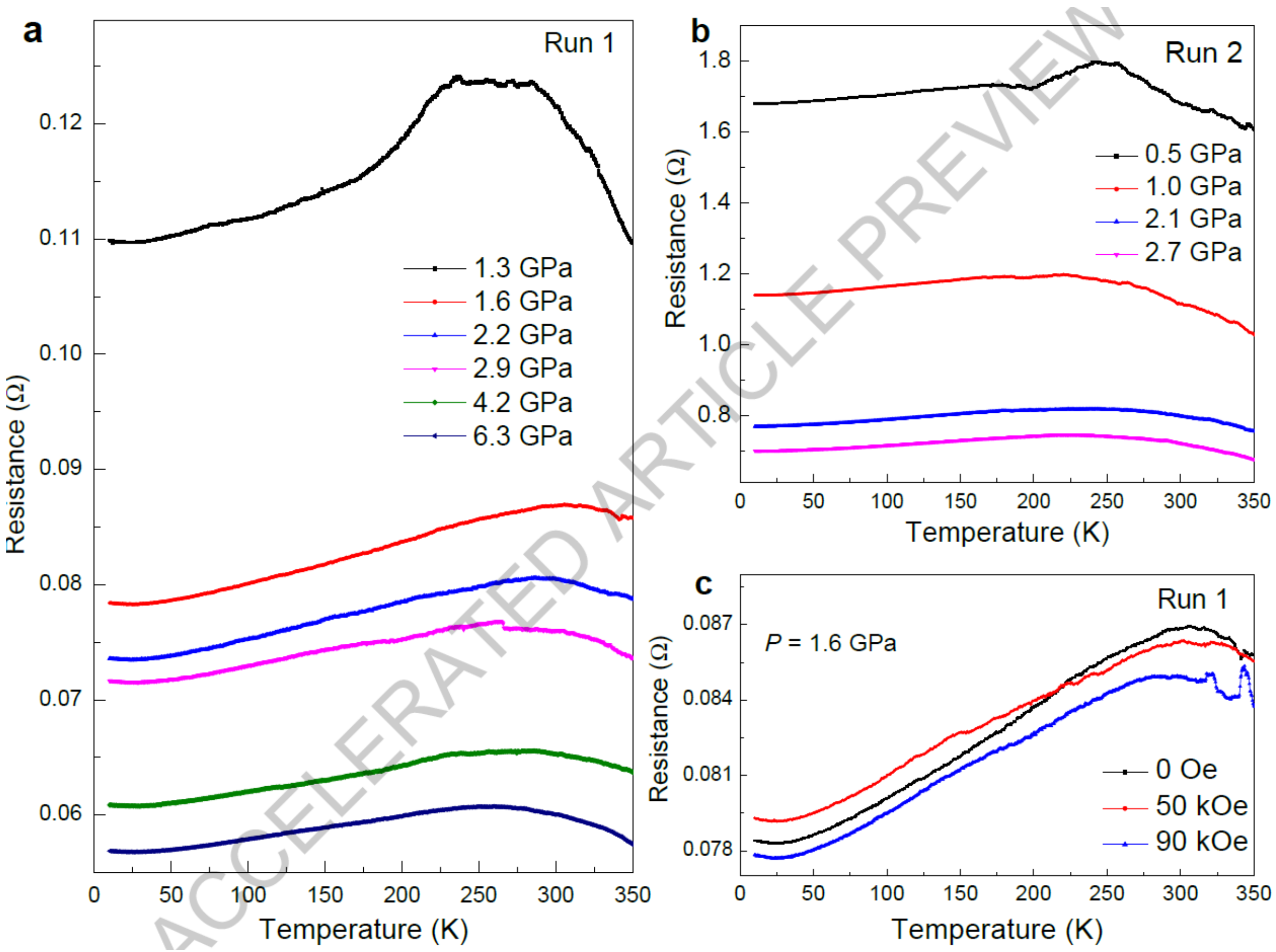

a
FC
ZFC
H = 60 Oe
Tc = 277 K
P ≈ 8 kbar
M (×10−6 e.m.u.)
T (K)
b
275 K
250 K
225 K
200 K
150 K
100 K
M (×10−5 e.m.u.)
H (Oe)
c
Tc = 238 K
ΔT ≈ 4.4 K
Tc = 269 K
ΔT ≈ 1.6 K
Tc = 294 K
ΔT ≈ 0.6 K
22 kbar
16 kbar
10 kbar
χ′ (nV)
Temperature (K)


a
f_exc = 223 Hz
10 kbar
T_c = 290 K
Specific heat (a.u.)
Response (μV)
223 Hz
296 K
f_exc (Hz)
Temperature (K)
b
f_exc = 223 Hz
10.5 kbar
T_c = 292 K
223 Hz
298 K
c
f_exc = 211 Hz
20 kbar
T_c = 245 K
211 Hz
298 K

nature
https://doi.org/10.1038/s41586-023-06162-w
Accelerated Article Preview

Absence of near-ambient superconductivity in $LuH_{2\pm x}N_y$

<u>*Wen et al. Nature 2023*</u>

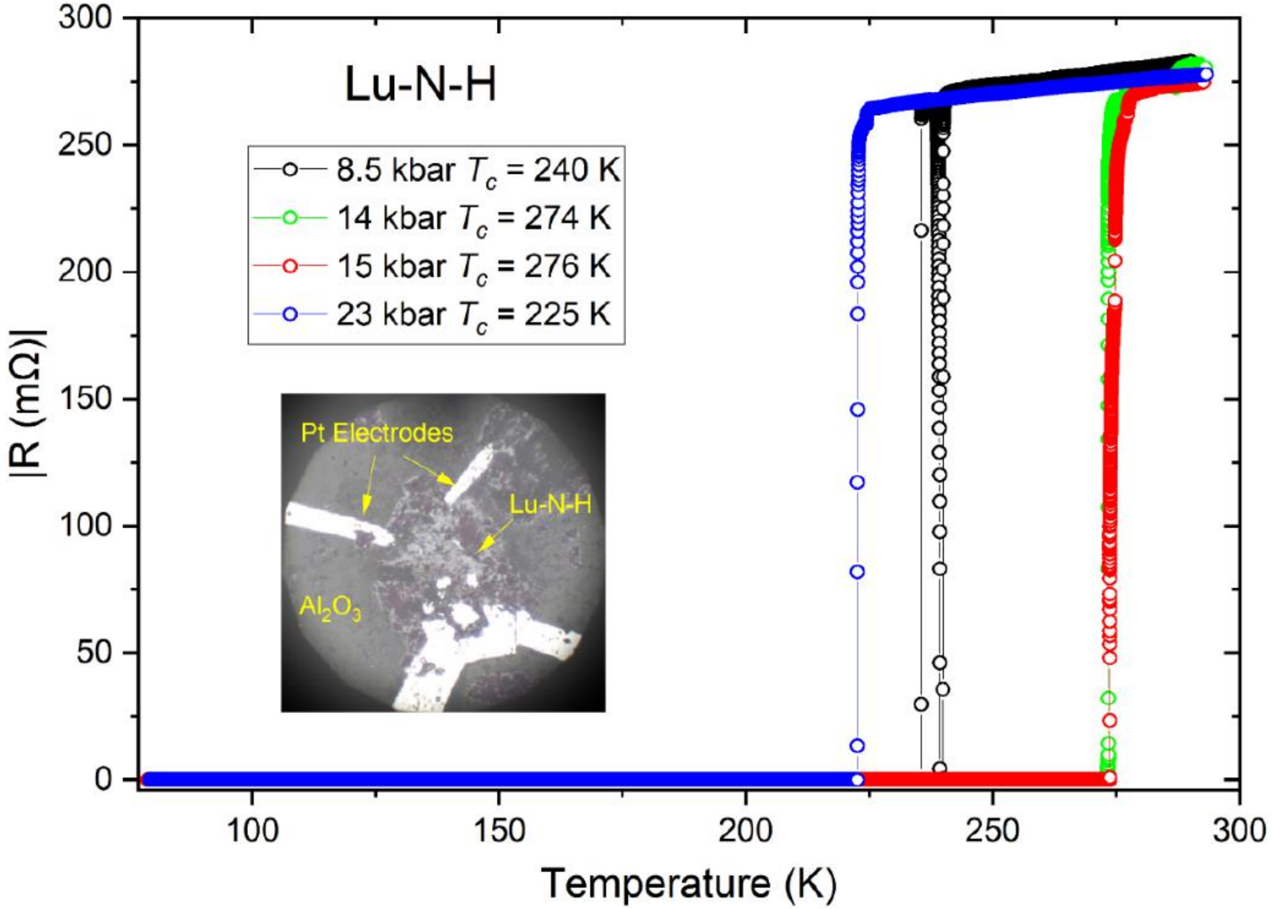


Evidence for Near Ambient Superconductivity in the Lu-N-H System

arXiv. 6/9/23

Nilesh P. Salke[1], Alexander C. Mark[1], Muhtar Ahart[1], Russell J. Hemley[1, 2, 3]

[1]*Department of Physics*, [2]*Department of Chemistry*, [3]*Department of Earth and Environmental Sciences, University of Illinois Chicago, Chicago, IL 60607 USA*



The near room-temperature upsurge of electrical resistivity in Lu-H-N is not superconductivity, but a metal-to-poor-conductor transition

arXiv. 7/1/23

Di Peng[1,2,3], Qiaoshi Zeng[1,4,*], Fujun Lan[1], Zhenfang Xing[1,5], Yang Ding[1], Ho-kwang Mao[1,4,*]

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2. *Key Laboratory of Materials Physics, Institute of Solid State Physics, HFIPS, Chinese Academy of Sciences, Hefei 230031, China*
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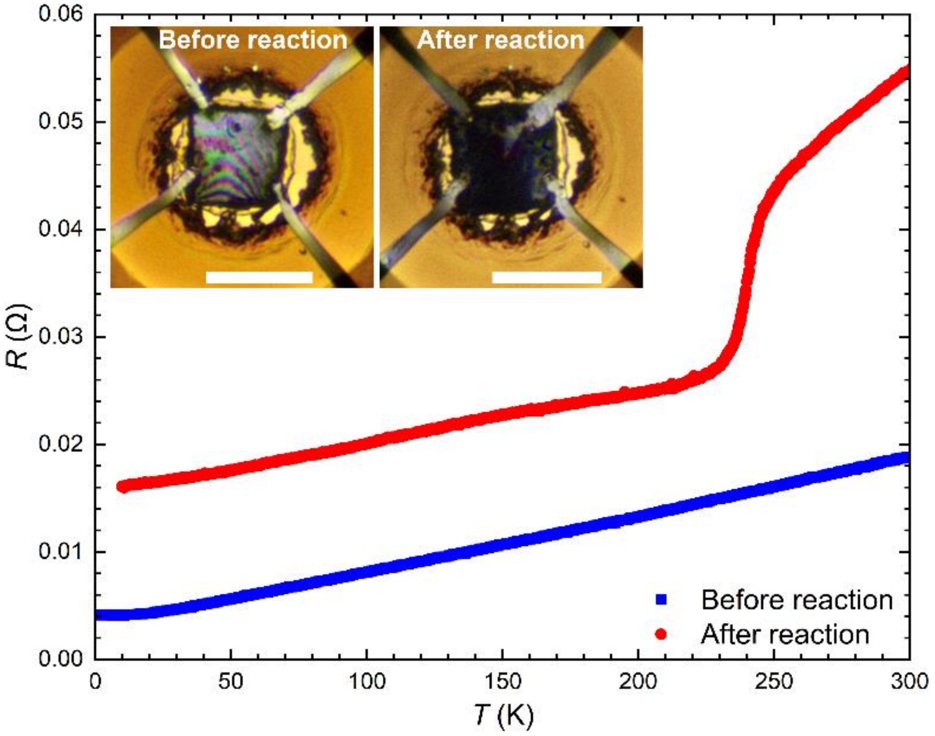
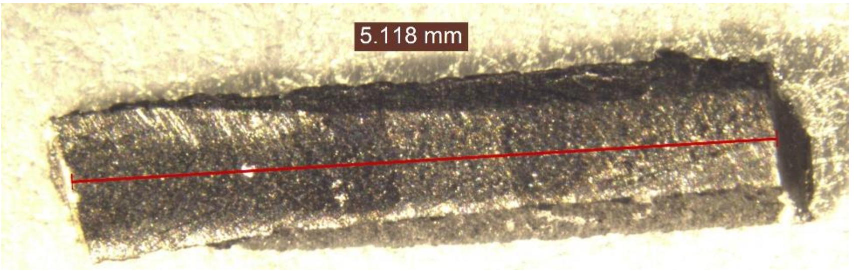
4. *Shanghai Key Laboratory of Material Frontiers Research in Extreme Environments (MFree), Shanghai Advanced Research in Physical Sciences (SHARPS), Shanghai 201203, China*
5. *State Key Laboratory of Superhard Materials, Institute of Physics, Jilin University, Changchun 130012, China*

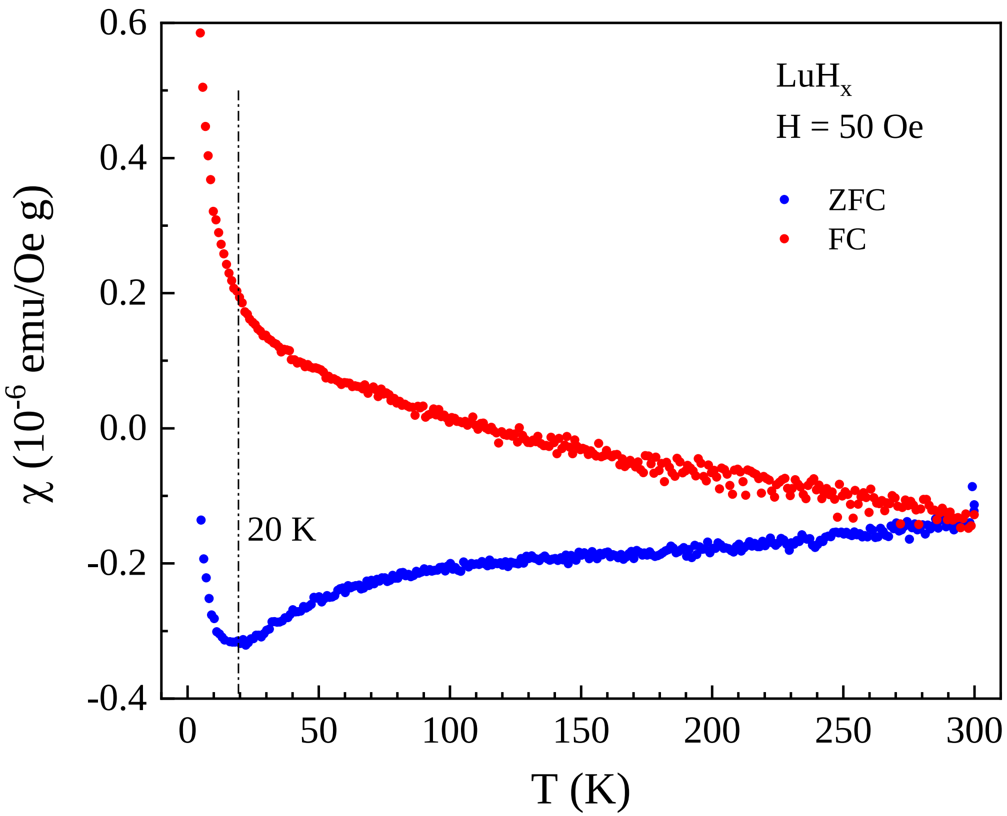
* *E-mail: zengqs@hpstar.ac.cn, or maohk@hpstar.ac.cn*

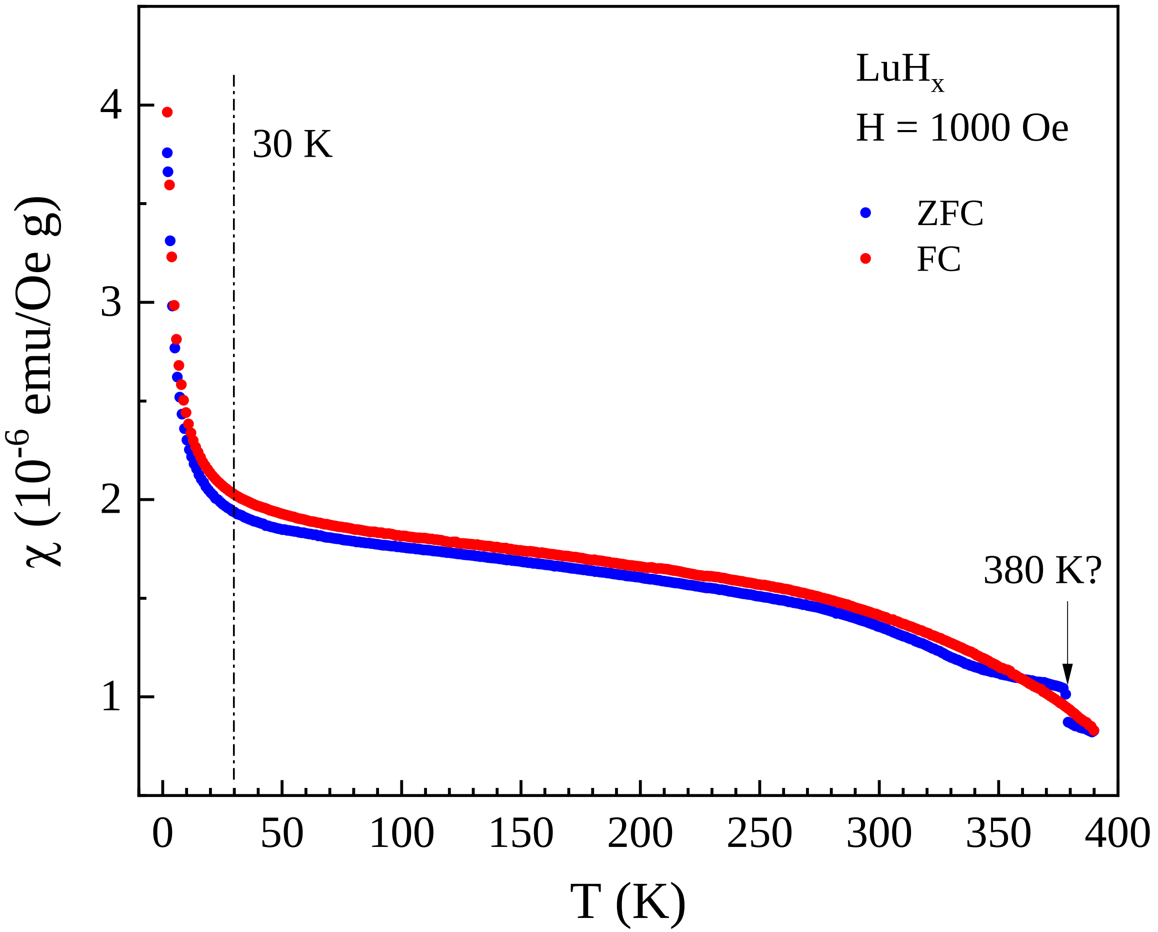


Some Lu-H work at Houston

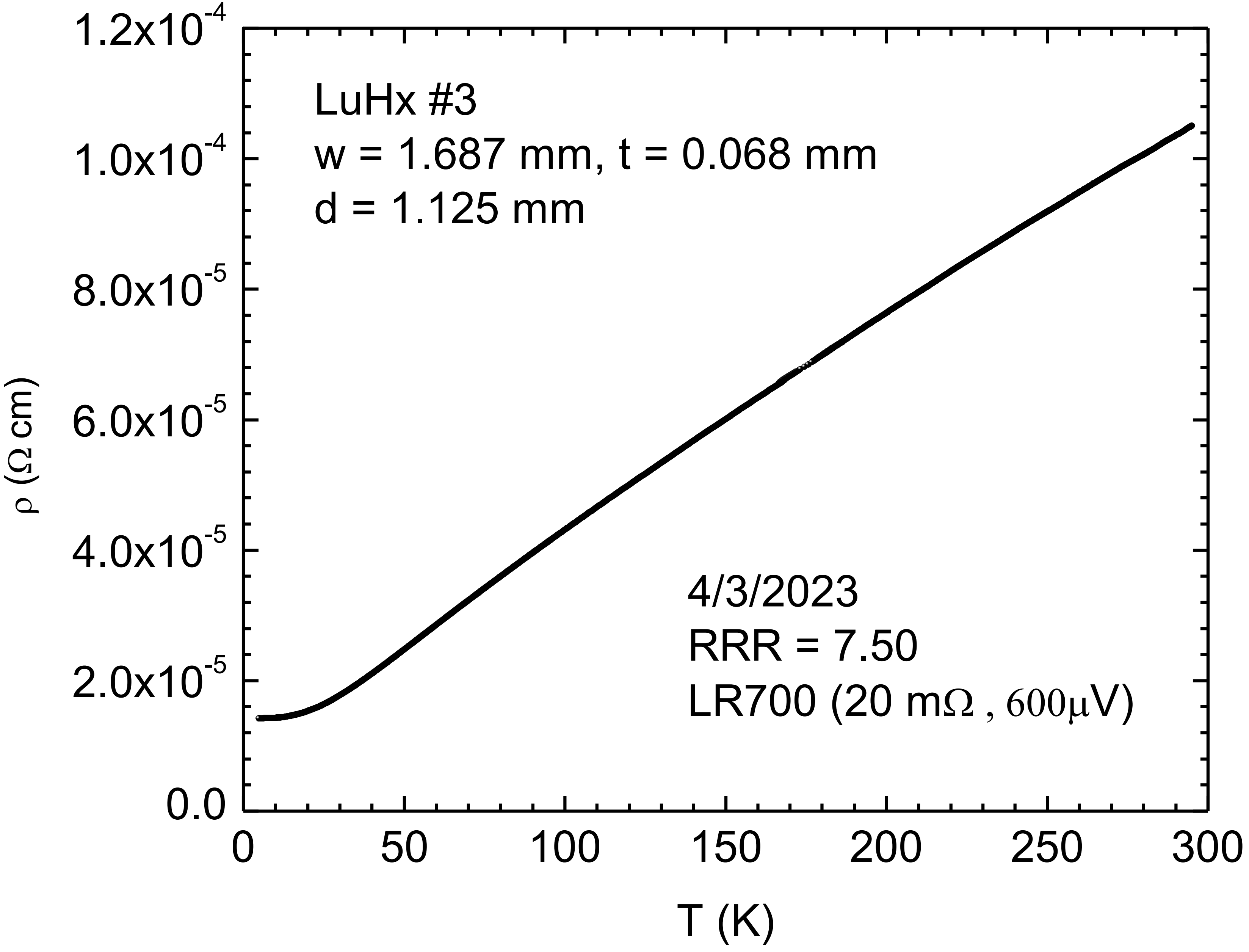


- #1 LuH_x: 5.118 mm × 1.152 mm × 0.495 mm
- mass: 23 mg
- Under continuous H_2, 65 C, for 28.5 hours





03/26-27/23

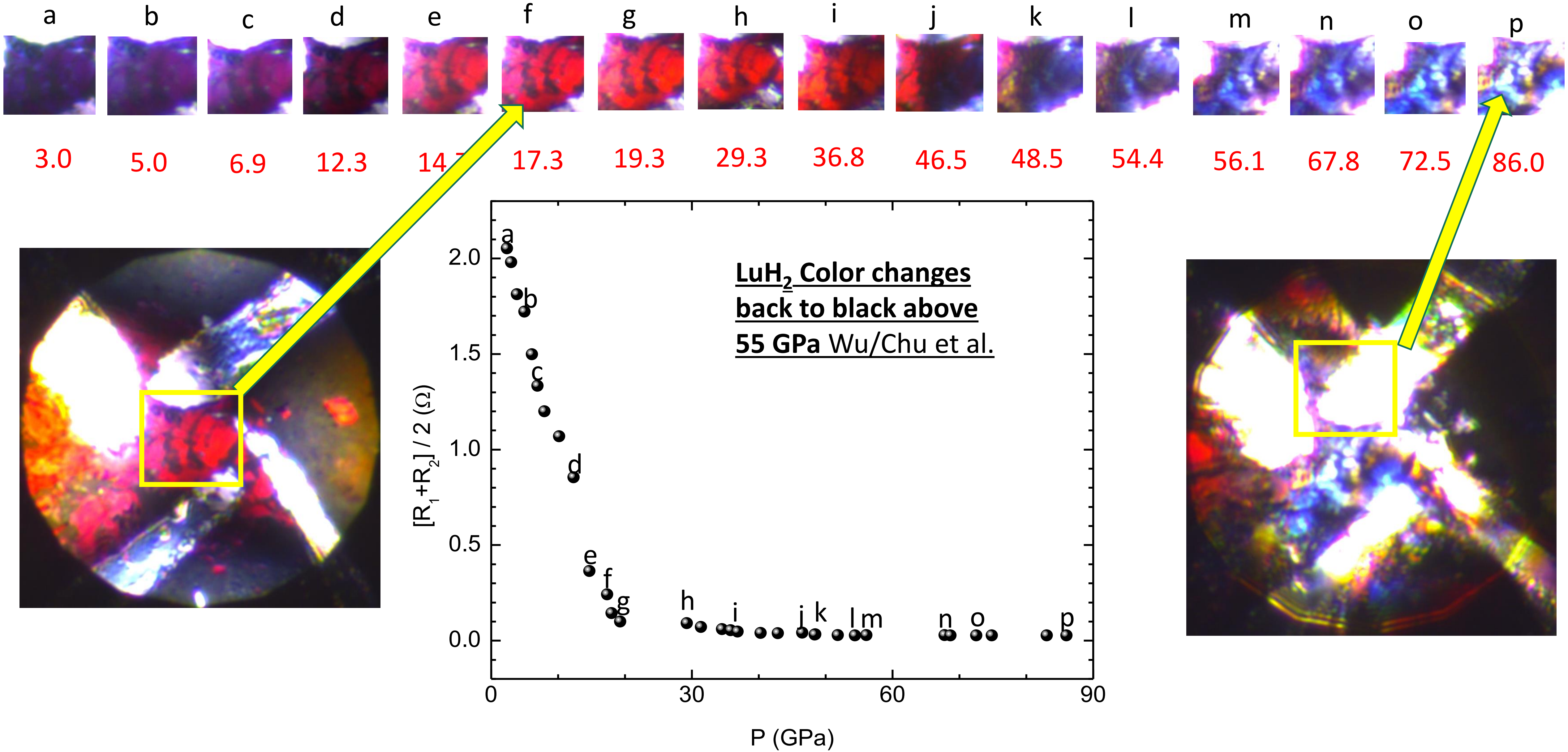

LuHx #3
w = 1.687 mm, t = 0.068 mm
d = 1.125 mm
4/3/2023
RRR = 7.50
LR700 (20 mΩ , 600μV)
ρ (Ω cm)
T (K)
1.2x10-4
1.0x10-4
8.0x10-5
6.0x10-5
4.0x10-5
2.0x10-5
0.0
0
50
100
150
200
250
300

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), October, 2023. Plenary presentation given at CEC-ICMC, July, 2023, Honolulu, Hawaii, USA

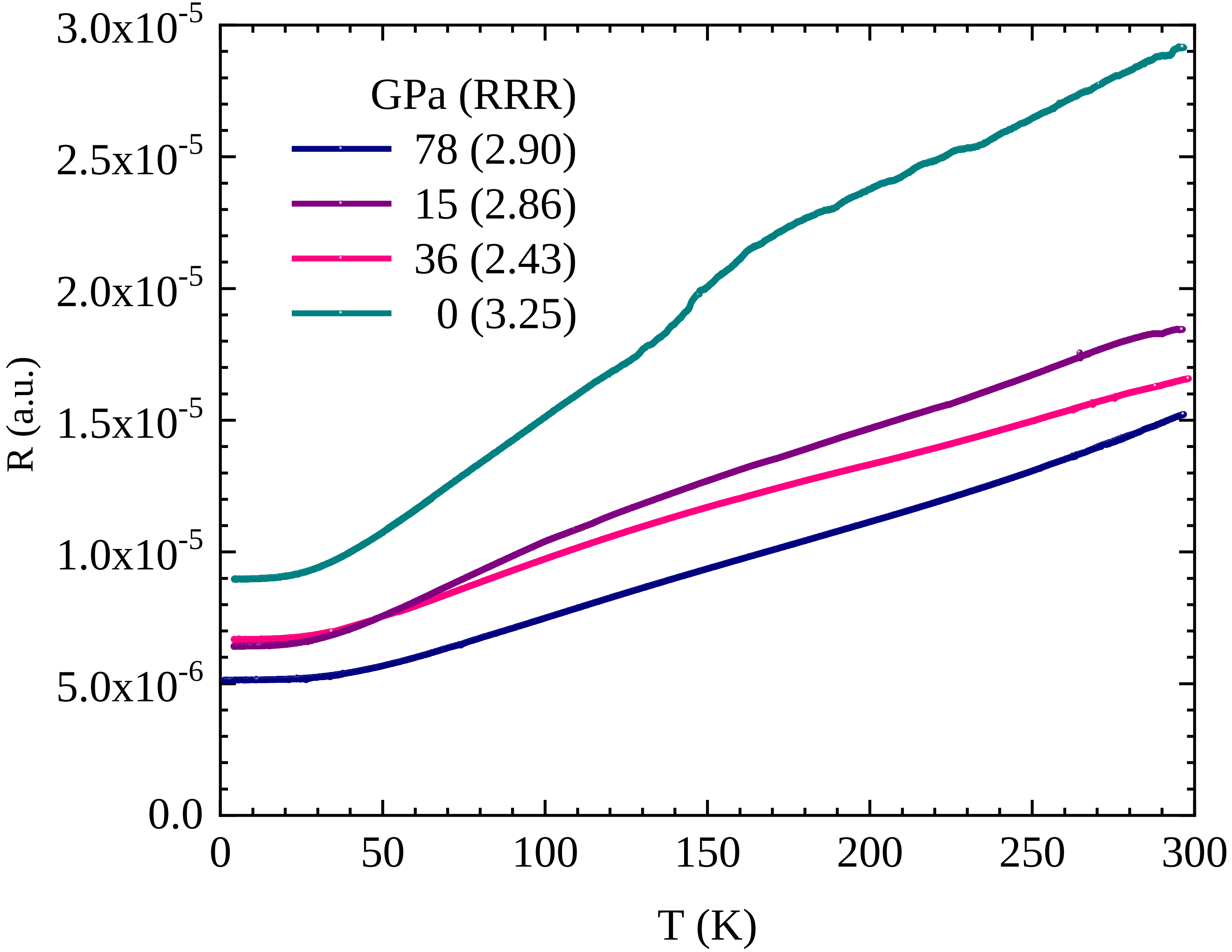
LuH2 – from China

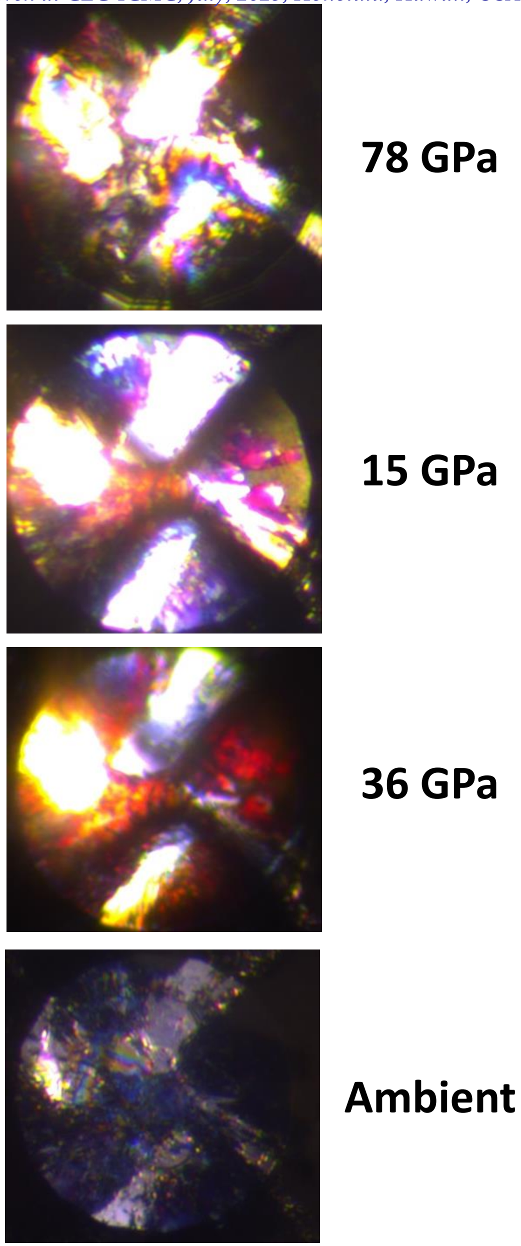
Detected the color change with P

Shultz, dlz/cwc et al. at TCSUH.



IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), October, 2023. Plenary presentation given at CEC-ICMC, July, 2023, Honolulu, Hawaii, USA





D. Schulze, Z. Wu

#5

- If all proven to be true, we now enter the RTS era of hydrides/HTS by replacing the formidable temperature barrier unfortunately by an even more challenging pressure barrier

- A possible solution- controlled PQP

Pressure-Quench-Process (PQP) the concept is not new but it is first time used for superconductivity

- "Most of the alloys used in industrial applications are actually metastable at atmospheric pressure and room temperature, and these metastable phases possess desired and/or enhanced properties that their stable counterpart lack."

- Pol Duwez- metastable, supercooled, splat-cooling, Nb_3Ge thin film, diamond

- The high-pressure-induced phases in HTS and RTS may be considered metastable, i.e. kinetically stable but thermodynamically not, protected only by energy barriers. We have taken advantage of these energy barriers to stabilize the metastable or "supercooled" states via pressure-quench at a specific quench-pressure (P_Q) and a chosen quench-temperature (T_Q)

- Simple element -> binary FeSe -> HBCCO -> hydrides

The PQP for HTS and RTS

#9

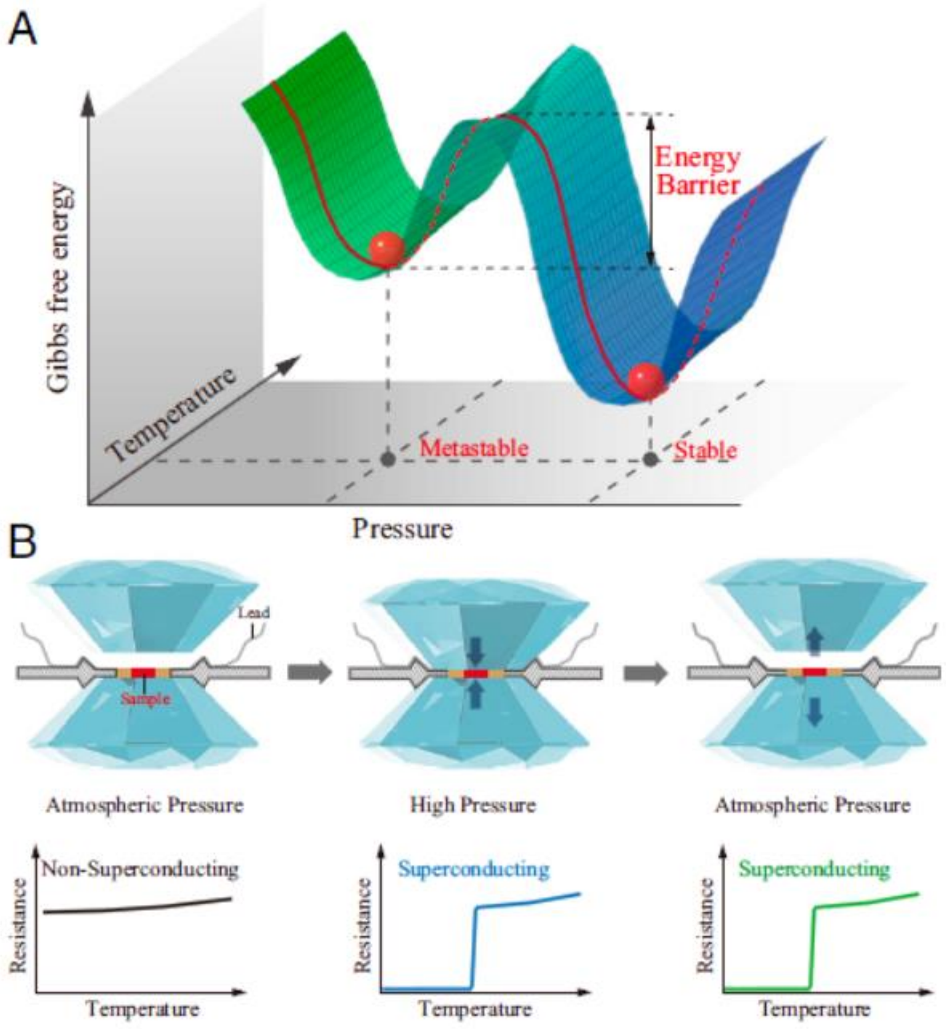
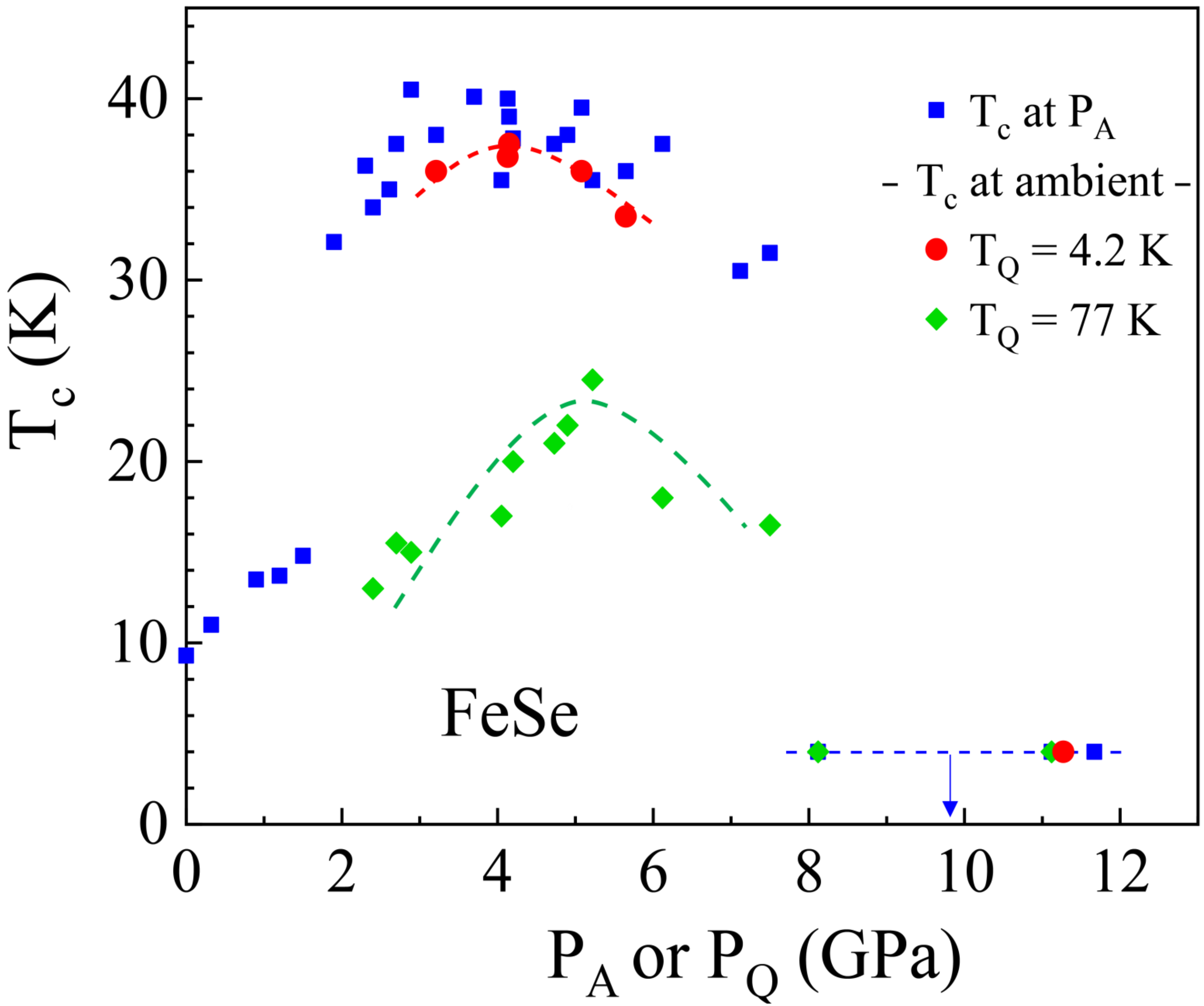
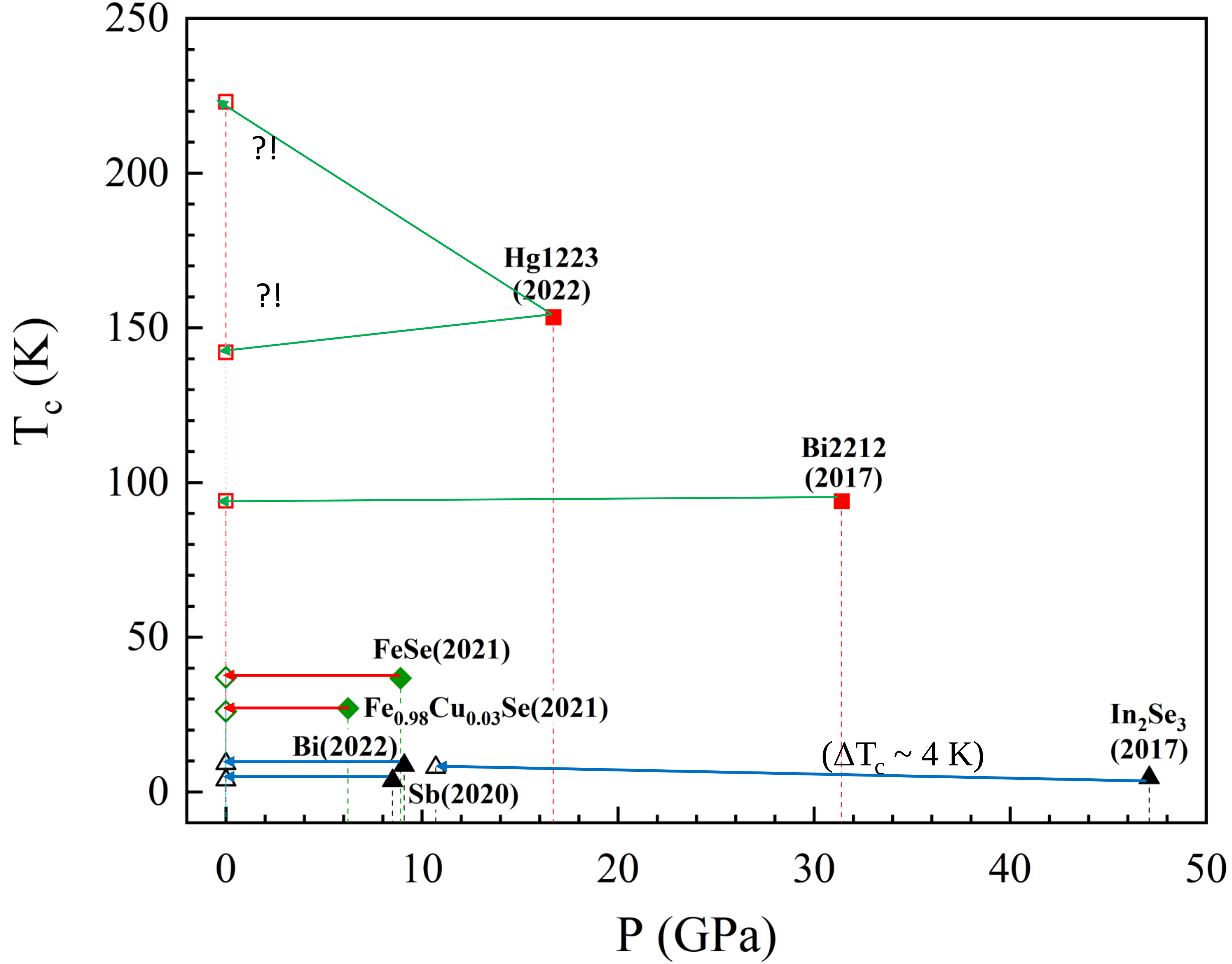


Fig. 1. Schematic diagrams of (*A*) Gibbs free energy and the energy barrier between the metastable and stable states and (*B*) the sequence of main experimental steps.

Deng et al. PNAS (2021)



The PQed Superconducting phases achieved



IEEE CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), January 2021.

Room-temperature Superconductivity – What More Needs to be Further Studied!

C. W. Chu

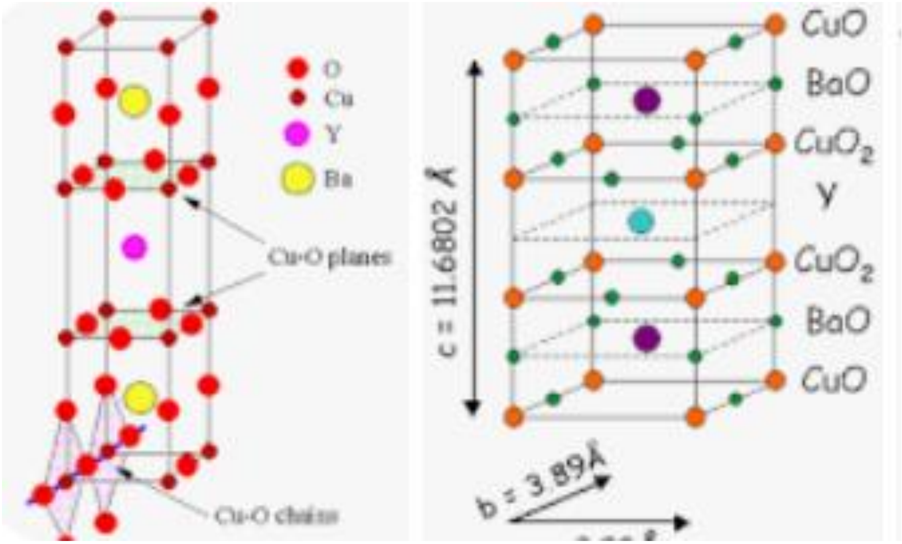
TCSUH, University of Houston, Texas

1. The existence of a pressure-induced insulator-metal (I-M) transition at a temperature T_m above T_c – this is important for exacting information about the normal-state behavior of the superconductor [21].
2. The achievement of a real “zero-resistance” state – it is extremely challenging to determine the “zero-resistance” or more so the “zero-resistivity” state due to the small size of the sample and the large change of resistance at the transition.
3. The field effect on the transition – a similar effect has been observed for the not-superconducting I-M transition [22].
4. The isotope effect on the transition – a similar effect has been observed for the not- superconducting I-M transition [23].
5. The diamagnetic shift in ac magnetic susceptibility – a similar effect has been detected in a temperature region where resistance changes greatly due to the eddy current.
6. Only the detection of the true Meissner effect (in the field-cooled mode) can clarify the above confusion, although the possible inherent defects in the sample under pressure may make such a test difficult. However, the sharpness of the transition may imply that the defects in the sample are small.
7. The very sharp transition and the almost downward shift of the transition in the presence of field suggest that the absence of flux flow is very puzzling for a type-II superconductor with such high a T_c [24].
8. The absence of a systematic experiment on the same individual sample for different types of measurements makes difficult the judgement of the reproducibility of the experiment – this is especially critical in determining the isotope effect [25].
9. The exact role of hydrogen in the samples investigated appears not to be clear – for instance, the role of B in the B-rich superconducting ZrB_{12} is rather limited [26].
10. The retention at ambient without pressure of the ultrahigh-pressure-induced room-temperature superconducting phase in these hydrogen-rich molecular solids should be the most exciting and rewarding endeavor in superconductivity science and technology research and development. Recent preliminary work on several superconducting elements and compounds has demonstrated such a possibility [2].

A Complex Superconductor needs a Skeleton to host substructures
Active Component + Charge Reservoir

1. Laves Phase $RERu_2$
2. A15 $NbSn_3$
3. Chevrel Phase $REMo_6S_8$
4. Rhodium Borides $RERh_4B_4$
5. Cuprates 123 $REBa_2Cu_3O_7$
6. Rare-Earth Hydrides REH_X

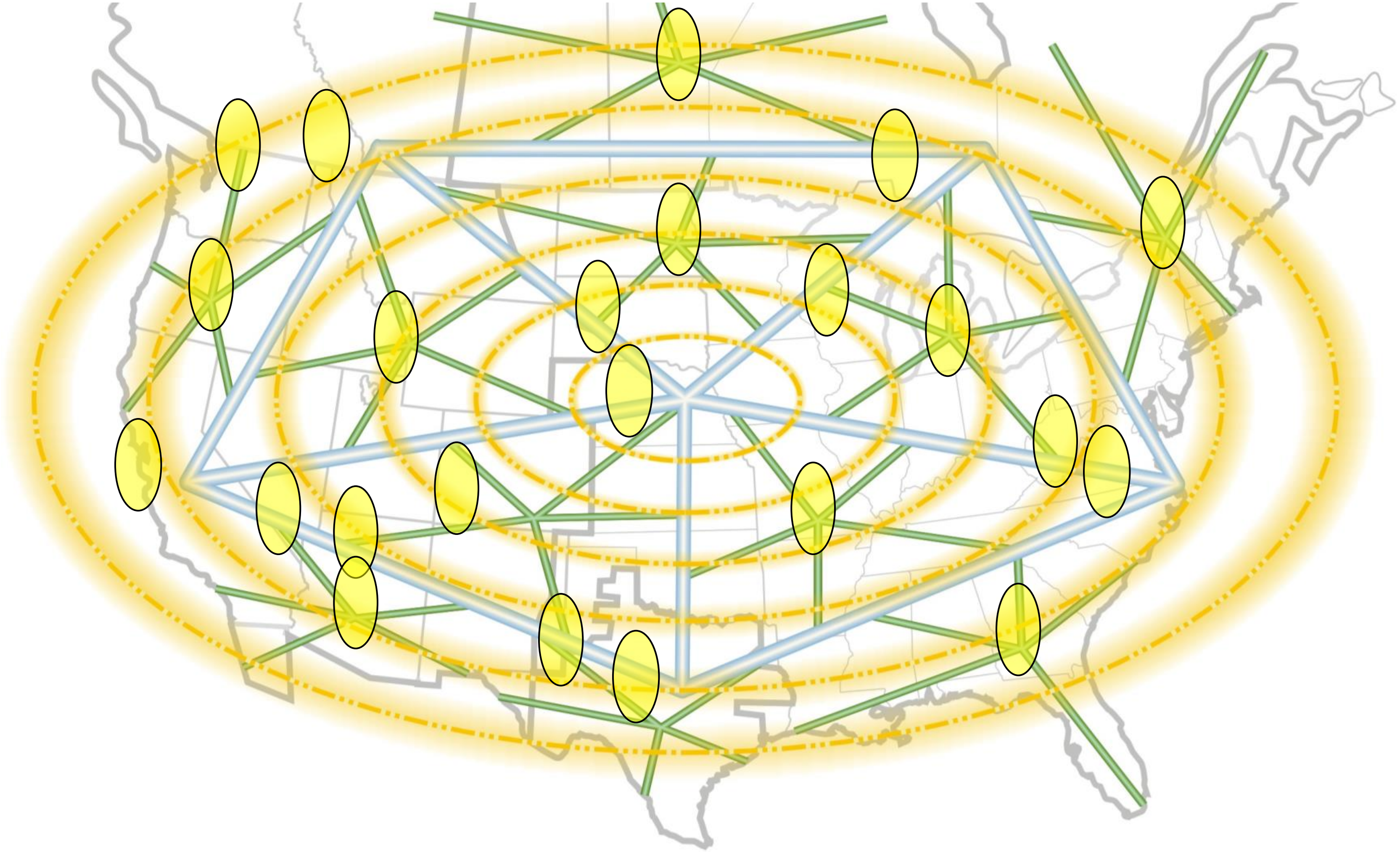
<u>RE – skeleton, H – active part & charge reservoir? – need more data!</u>



<u>RE affects (1-4) or does not (5, 6?) affect SC. [cwc]</u>

NationalGrid (Jimmy Glotfelty)

Plus Integrated Communications and Controls Architecture



Thank You!