APS March Meeting 2011
March 21, 2011; Dallas, Texas

The Arrival of High Temperature Superconductors

- I would like to dedicate this talk to those who have had and will continue to have the privilege to experience many sleepless nights for the health of HTS for the last 25 years and years to come -

Paul C. W. Chu

Texas Center for Superconductivity
University of Houston
&
Lawrence Berkeley National Laboratroy

Ralph Waldo Emerson once said:

“There is properly no history; only biography.”

and

“Whatever course you decide upon, there is always someone to tell you that you are wrong. There are always difficulties arising that tempt you to believe that your critics are right. To map out a course of action and to follow it to the end requires courage.”

100 years of superconductivity study

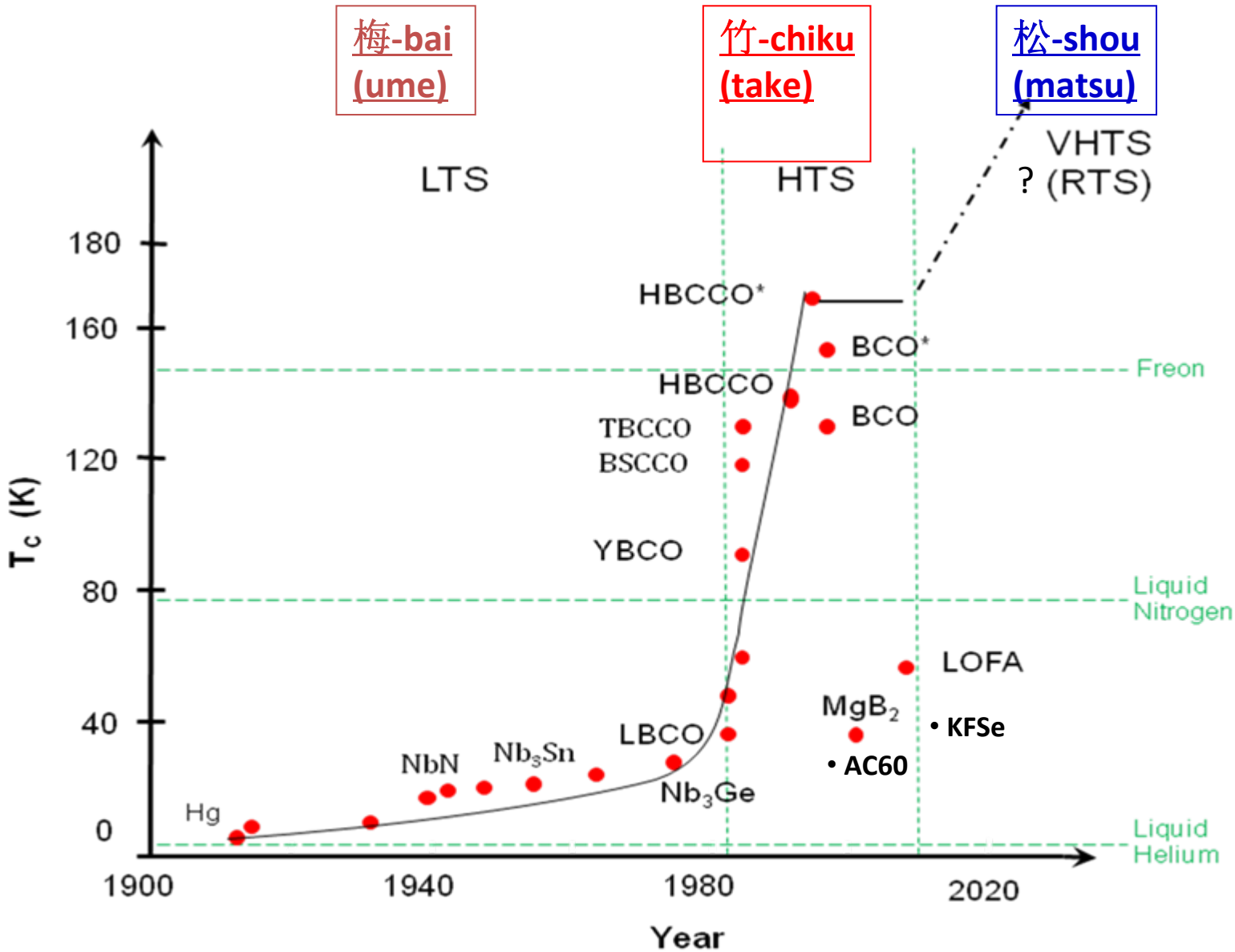
- The lure of superconductivity:
  intellectual challenges and technological promises

- The major driving force:
  the search for superconductors of higher T_c

- The search will go on:
  God is kinder to physicists than to mountaineers to whom the final goal of Mt. Everest is already granted and reached, and the excitement ceases once they get there.

“High Temperature Superconductors (HTS)” or High T_c is a relative term: Superconducting compounds with a T_c comparable to the then existing record, which rises with time.

Three Stages of T_c- Evolution



LTS

$T_c \leq 23.2$ K
Elements &
Intermetallics
A15

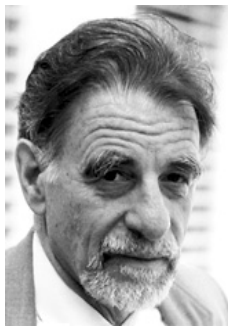

1911


1953


1957

HTS

$T_c \leq 134/164$ K
Cuprates:
m2(n-1)n
Fe-Pnictides:
1111, 111, 11,
122

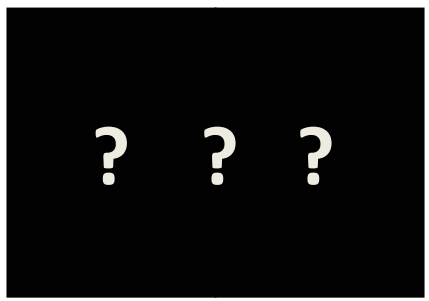

1986


1987


2008

...etc.

VHTS/RTS



?

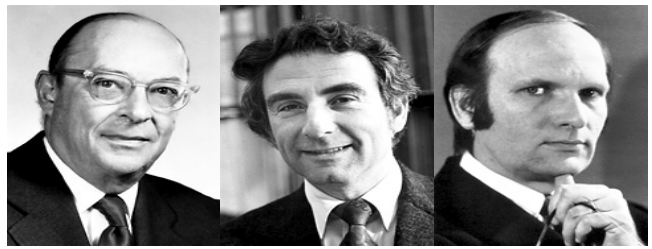
100409CWC

To raise T_c (before 1986)

- **BCS APPROACH:**

  Cooper Pair (1956)

  $T_c = 1.14\theta_D \exp(-1/NV)$ (1957)



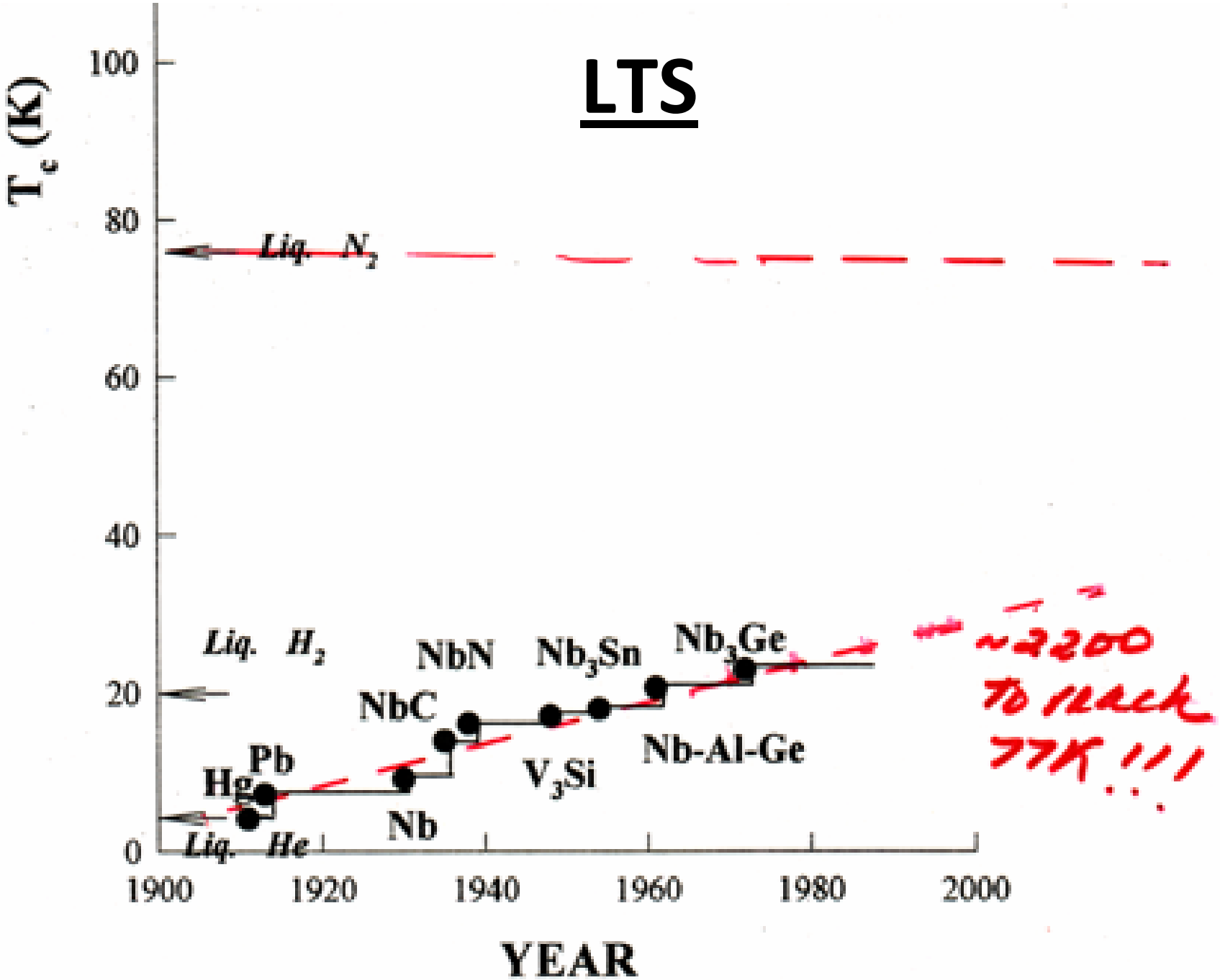
  - To raise the T_c - enhance θ_D, N(0) & V
  - $T_c \leq 23.2$ K (1973-86)
  - Excellent descriptive power but little/no T_c- predictability

- **ENLIGHTENED EMPIRICAL APPROACH:**

  Matthias e/a Rule (1953)

  - Highest T_cs at e/a ~ 4.75 & 6.4
  - Works well for crystalline inter-metallic materials but not for amorphous materials or oxides

LTS

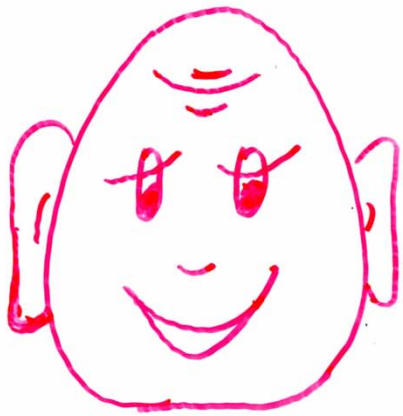

T_c (K)
100
80
60
40
20
0
Liq. N_2
Liq. H_2
Liq. He
Pb
Hg
NbC
NbN
Nb_3Sn
Nb_3Ge
Nb
V_3Si
Nb-Al-Ge
~2200 To reach 77K!!!
1900
1920
1940
1960
1980
2000
YEAR

1950-70's

π ↑

↑

Physics →



1980's

π ←

↑

Physics →

LTS (before 1986)

- Experimentally:

  - $T_c \leq 23.2$ K (1973 - 1986)

- Theoretically:

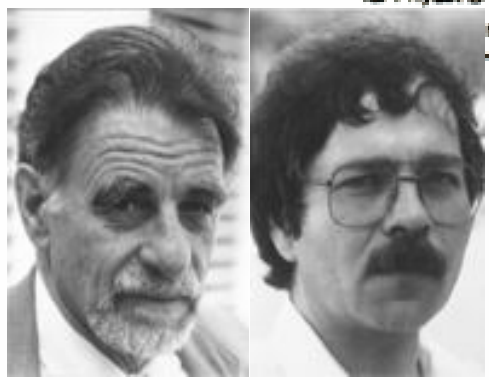
  - $T_c < 30$'s K (instabilities)

Confidence crisis in the search for higher T_c

The New Era of Cuprate-HTS (1986)

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

Condensed Matter
Zeitschrift für Physik B
...ger-Verlag 1986



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

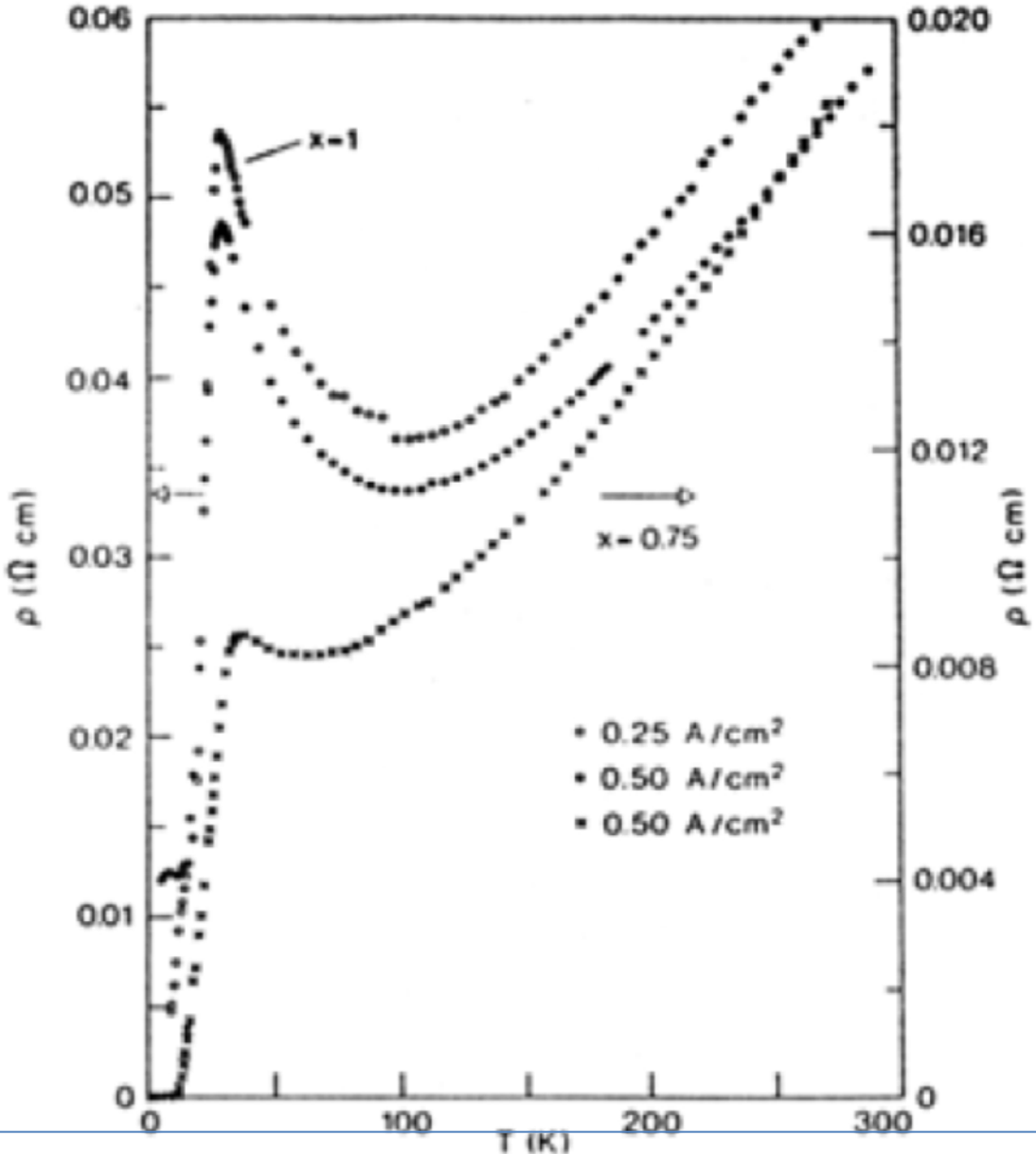
J.G. Bednorz and K.A. Müller
IBM Zürich Research Laboratory, Rüschlikon, Switzerland

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, but possibly also from 2D superconducting fluctuations of double perovskite layers of one of the phases present.

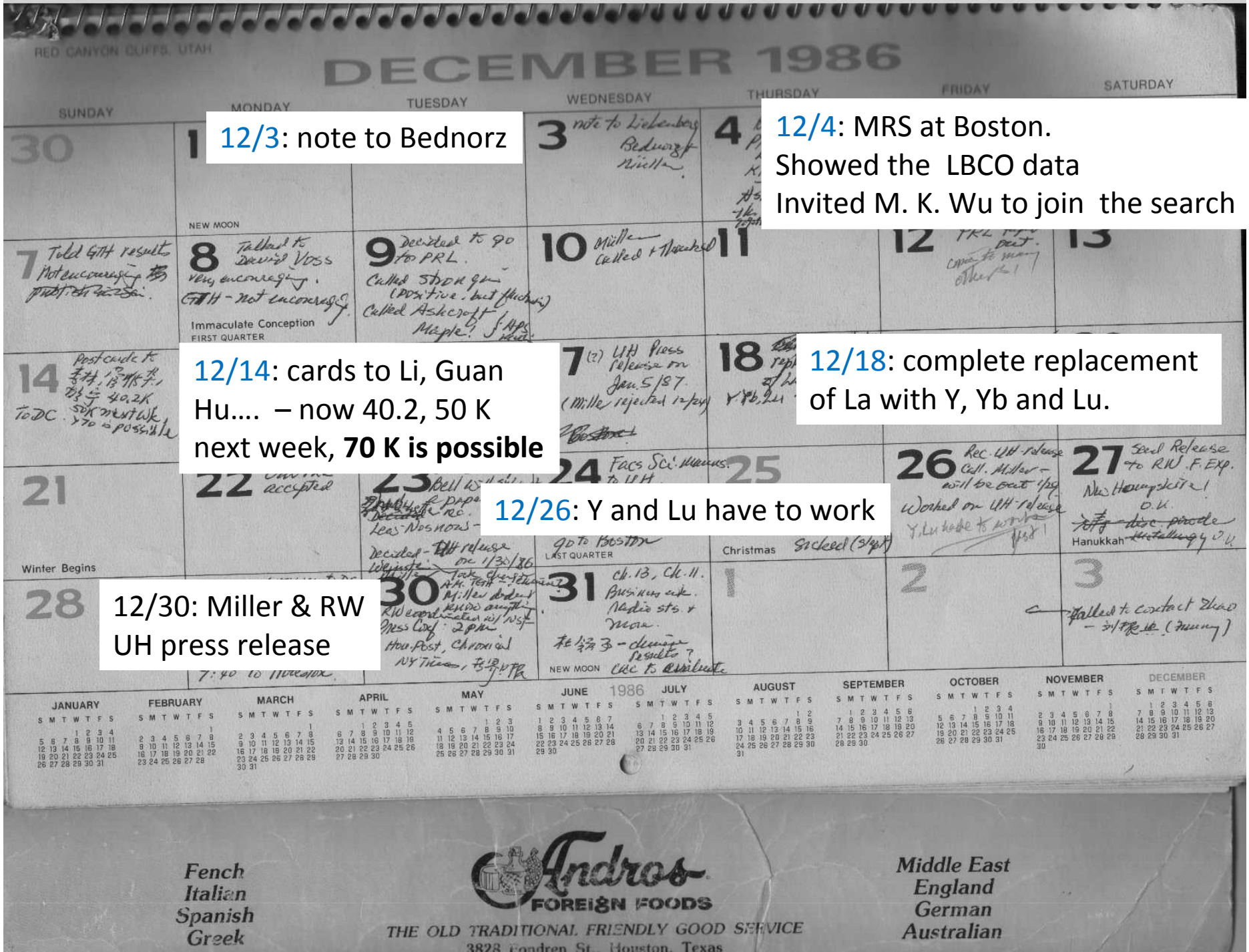
La214: T_c ~ 35 K

100318CWC



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

Faced skepticism before and after the experiment.


RED CANYON CLIFFS, UTAH
DECEMBER 1986
SUNDAY
MONDAY
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
12/3: note to Bednorz
12/4: MRS at Boston.
Showed the LBCO data
Invited M. K. Wu to join the search
12/14: cards to Li, Guan Hu…. – now 40.2, 50 K next week, 70 K is possible
12/18: complete replacement of La with Y, Yb and Lu.
12/26: Y and Lu have to work
12/30: Miller & RW UH press release
NEW MOON
Immaculate Conception
FIRST QUARTER
LAST QUARTER
NEW MOON
Christmas
Hanukkah
Winter Begins
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
1986
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Fench
Italian
Spanish
Greek
Andros
FOREIGN FOODS
THE OLD TRADITIONAL FRIENDLY GOOD SERVICE
3828 Condren St., Houston, Texas
Middle East
England
German
Australian

Reproduced B&M results: note to B&M
later AM called CW Chu thank and comment on CWC's confidence on T_c = 77 K

Submitte
before the
for the A
New Yor

NATIONAL SC
WASHING

Dear Drs. Bednorz + Müller:
This is just to inform
at the U. of Houston ha
results (Z. Phys. B 64, 18
A small ac diamagne
detected. Magnetic fie
the transition. I belie
Now the question is "
phases": Soon, you
Please send me yo

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

P.S. Currently, I am the Dire
at the National Science

Abs
for the Mar
America
Me

Study o
$Ba_xLa_{5-x}Cu_5O_{5(3}$

GAO, P.H. HOR,
ROBERTSON and Z
Recently, possi
~35K was propos
deficient Ba-La
of a large resi
suppressable by
solution and lo
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extremely weak
samples were ex
a 10 fold incre
of the R-drop i
More detailed a
tion and charac

唯幹嫂：
新的一年裡，事事如意！
祝 [illegible]
剛得到最高超導溫度40.2K．下週
很可能到50K．我目前對77K充滿信心！
經武
濮 全上
12/14/86

Christmas
the warmth and joy
of remembering friends

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.

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)

LCO is unusual:
•the high dT_c/dP
•T_c>30s, predicted

The results also suggest that superconductivity at temperature greatly exceeding 40 K is achievable in LBCO and related systems through fine tuning of the sample parameters by physical and chemical means.

Superconductivity at 52.5 K in the Lanthanum-Barium-Copper-Oxide System Science 235, 567 (1987) [Rec. 30 Dec. 1986)]

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

VOLUME 58, NUMBER 4 PHYSICAL REVIEW LETTERS 26 JANUARY 1987

Bulk Superconductivity at 36 K in $La_{1.8}Sr_{0.2}CuO_4$

[redacted]
(Received 29 December 1986)

$(3 \pm 1$ mJ mole^{-1} K$^2)$. Within the framework of this discussion, we therefore conclude that conventional phonon-mediated superconductivity accounts for the high T_c also in this class of materials.

The New York Times

NEW YORK, WEDNESDAY, DECEMBER 31, 1986

Front Page

2 Groups Report a Breakthrough In Field of Electrical Conductivity

By WALTER SULLIVAN

After a dozen years of futile efforts to raise the temperature at which materials become superconducting, researchers at the University of Houston and at A.T.&T. Bell Laboratories in New Jer-

Absolute zero, the total absence of heat, occurs at minus 273 degrees Celsius, or 460 degrees below zero Fahrenheit: 23 Kelvin is equal to minus 250 Celsius, with each degree on the Kelvin scale

....at the University of Houston and at AT&T Bell Laboratories....

per square inch, a compound of lanthanum, barium, copper and oxygen becomes superconducting at 40.2 degrees Kelvin.

However, A.T.&T. Bell Laboratories, following a similar line of research, yesterday reported production of an alloy that at normal pressure begins its transition to superconductivity at 40 degrees Kelvin and becomes fully superconducting when cooled to 36 degrees. Participants in that project, while reluctant to provide details until

Possible Applications

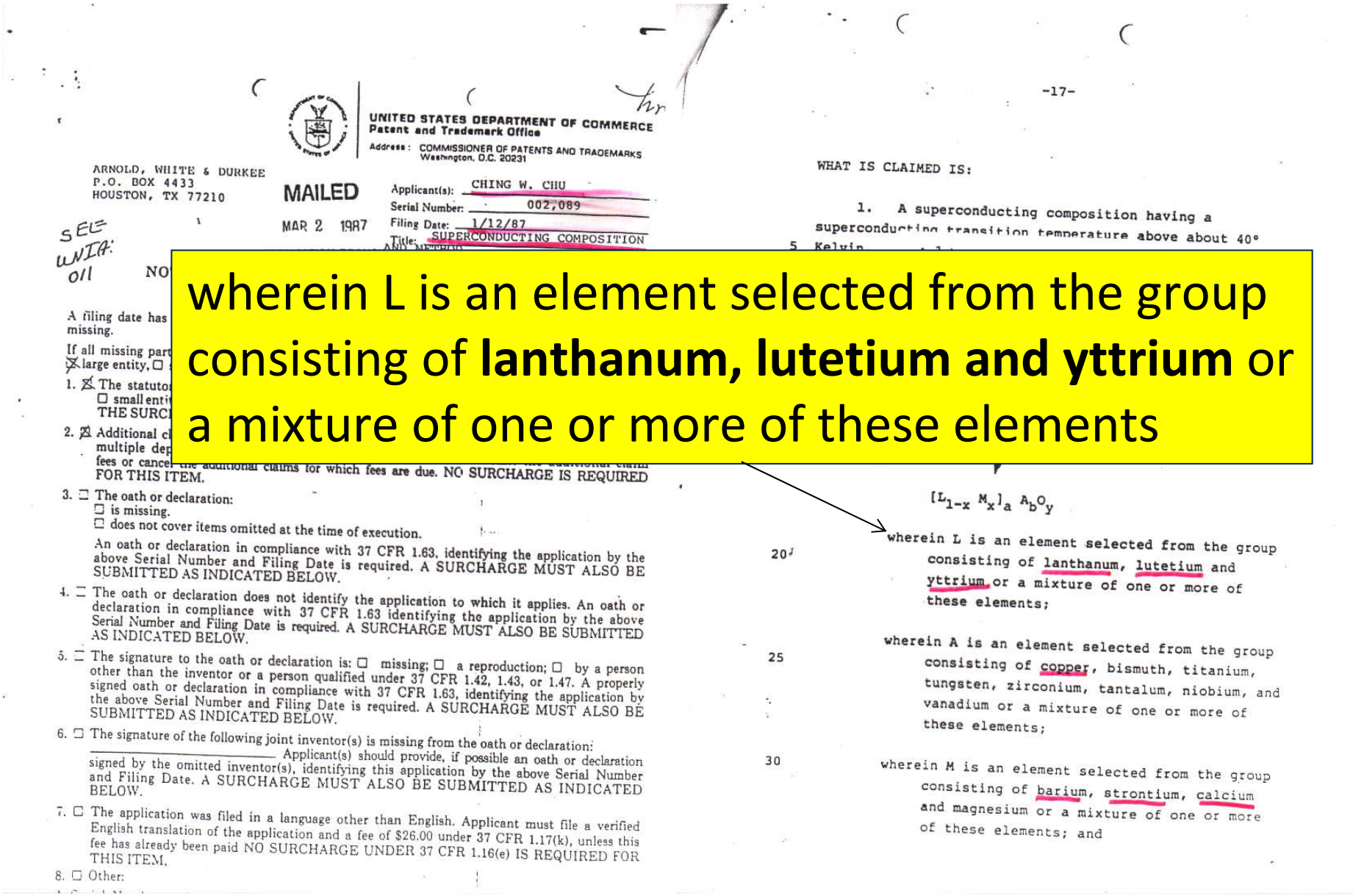
The achievements also mean that superconductivity, in which materials lose all resistance to electricity, can be more widely applied for scientific research and could substantially reduce the cost of the proposed superconducting atom smasher with a 60-mile acceleration ring.

In the early 1970's researchers at Bell Laboratories and Westinghouse found substances that became superconducting when cooled to 23 degrees Kelvin, 23 degrees above absolute zero.

Continued on Page A13, Column 1

060731CWC

1987: The Exciting Year



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

ARNOLD, WHITE & DURKEE
P.O. BOX 4433
HOUSTON, TX 77210

MAILED
MAR 2 1987

Applicant(s): CHING W. CHU
Serial Number: 002,089
Filing Date: 1/12/87
Title: SUPERCONDUCTING COMPOSITION

A filing date has
missing.

If all missing part
☒ large entity, ☐

1. ☒ The statuto
☐ small enti
THE SURC

2. ☒ Additional c
multiple dep
fees or cancel the additional claims for which fees are due. NO SURCHARGE IS REQUIRED FOR THIS ITEM.

3. ☐ The oath or declaration:
☐ is missing.
☐ does not cover items omitted at the time of execution.
An oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Serial Number and Filing Date is required. A SURCHARGE MUST ALSO BE SUBMITTED AS INDICATED BELOW.

4. ☐ The oath or declaration does not identify the application to which it applies. An oath or declaration in compliance with 37 CFR 1.63 identifying the application by the above Serial Number and Filing Date is required. A SURCHARGE MUST ALSO BE SUBMITTED AS INDICATED BELOW.

5. ☐ The signature to the oath or declaration is: ☐ missing; ☐ a reproduction; ☐ by a person other than the inventor or a person qualified under 37 CFR 1.42, 1.43, or 1.47. A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Serial Number and Filing Date is required. A SURCHARGE MUST ALSO BE SUBMITTED AS INDICATED BELOW.

6. ☐ The signature of the following joint inventor(s) is missing from the oath or declaration:
_____. Applicant(s) should provide, if possible an oath or declaration signed by the omitted inventor(s), identifying this application by the above Serial Number and Filing Date. A SURCHARGE MUST ALSO BE SUBMITTED AS INDICATED BELOW.

7. ☐ The application was filed in a language other than English. Applicant must file a verified English translation of the application and a fee of $26.00 under 37 CFR 1.17(k), unless this fee has already been paid NO SURCHARGE UNDER 37 CFR 1.16(e) IS REQUIRED FOR THIS ITEM.

8. ☐ Other:

-17-

WHAT IS CLAIMED IS:

1. A superconducting composition having a superconducting transition temperature above about 40° Kelvin

$$[L_{1-x} M_x]_a A_b O_y$$

wherein L is an element selected from the group consisting of lanthanum, lutetium and yttrium or a mixture of one or more of these elements;

wherein A is an element selected from the group consisting of copper, bismuth, titanium, tungsten, zirconium, tantalum, niobium, and vanadium or a mixture of one or more of these elements;

wherein M is an element selected from the group consisting of barium, strontium, calcium and magnesium or a mixture of one or more of these elements; and

wherein L is an element selected from the group consisting of **lanthanum, lutetium and yttrium** or a mixture of one or more of these elements

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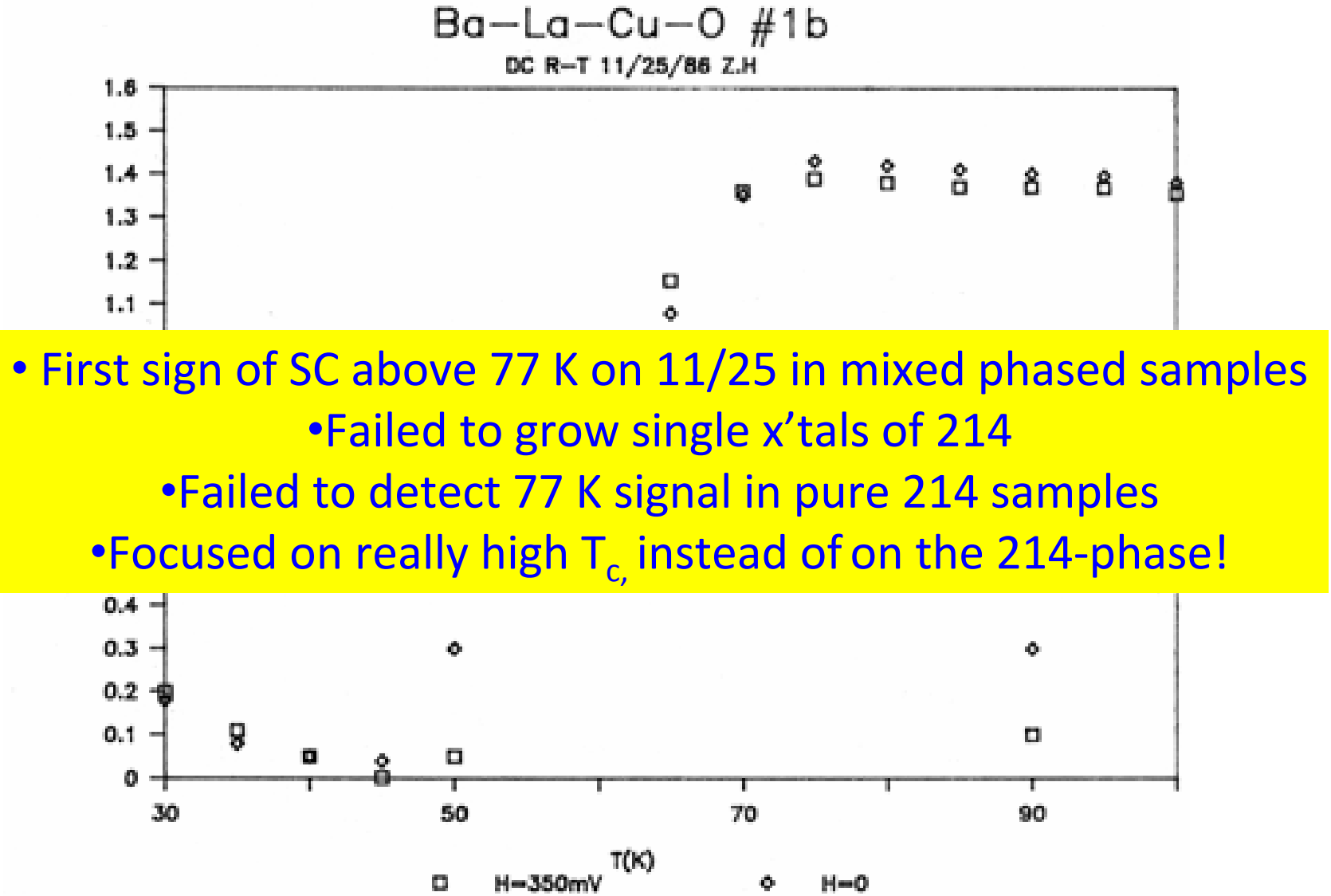
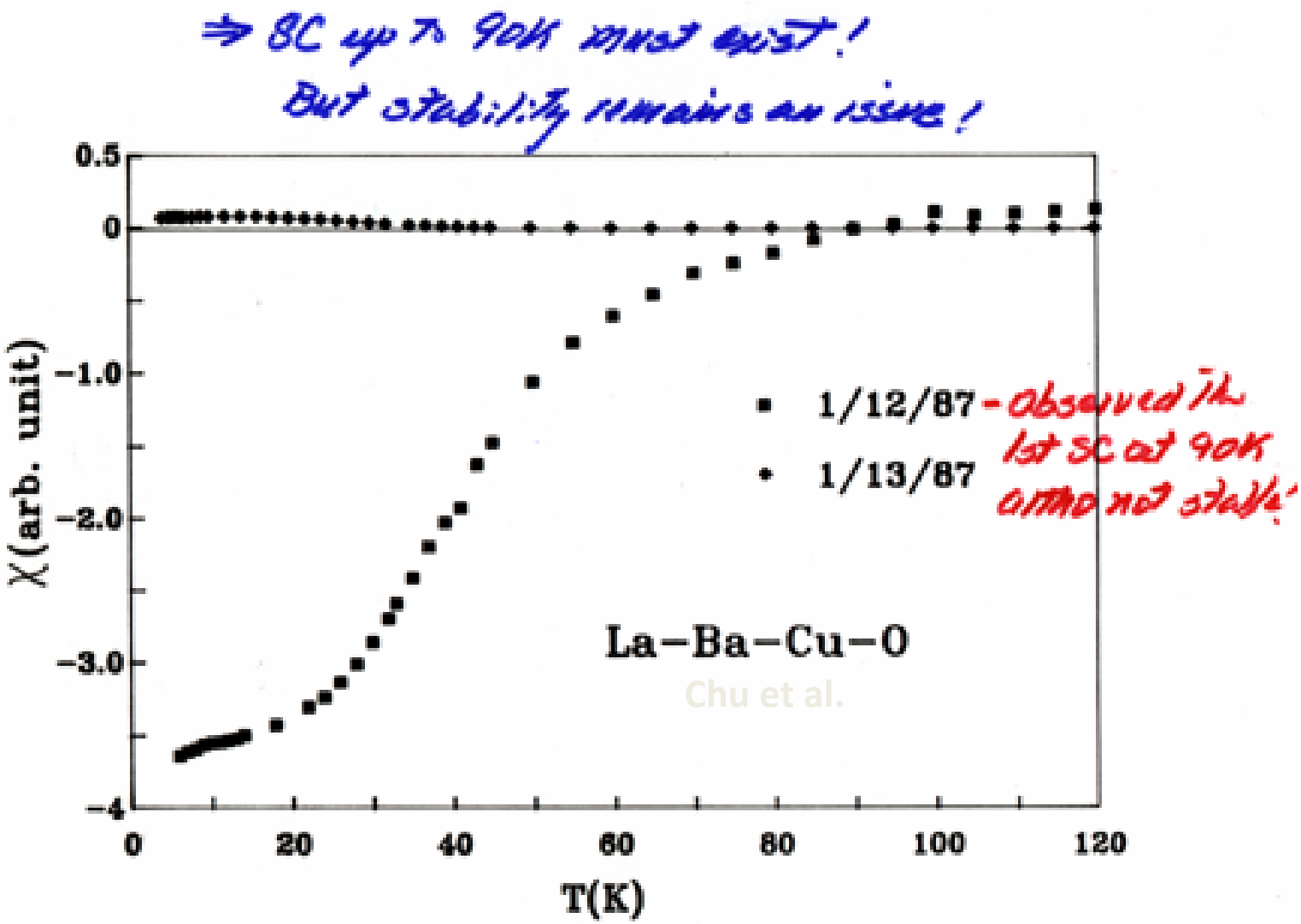


- First sign of SC above 77 K on 11/25 in mixed phased samples
- Failed to grow single x'tals of 214
- Failed to detect 77 K signal in pure 214 samples
- Focused on really high T_c, instead of on the 214-phase!

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

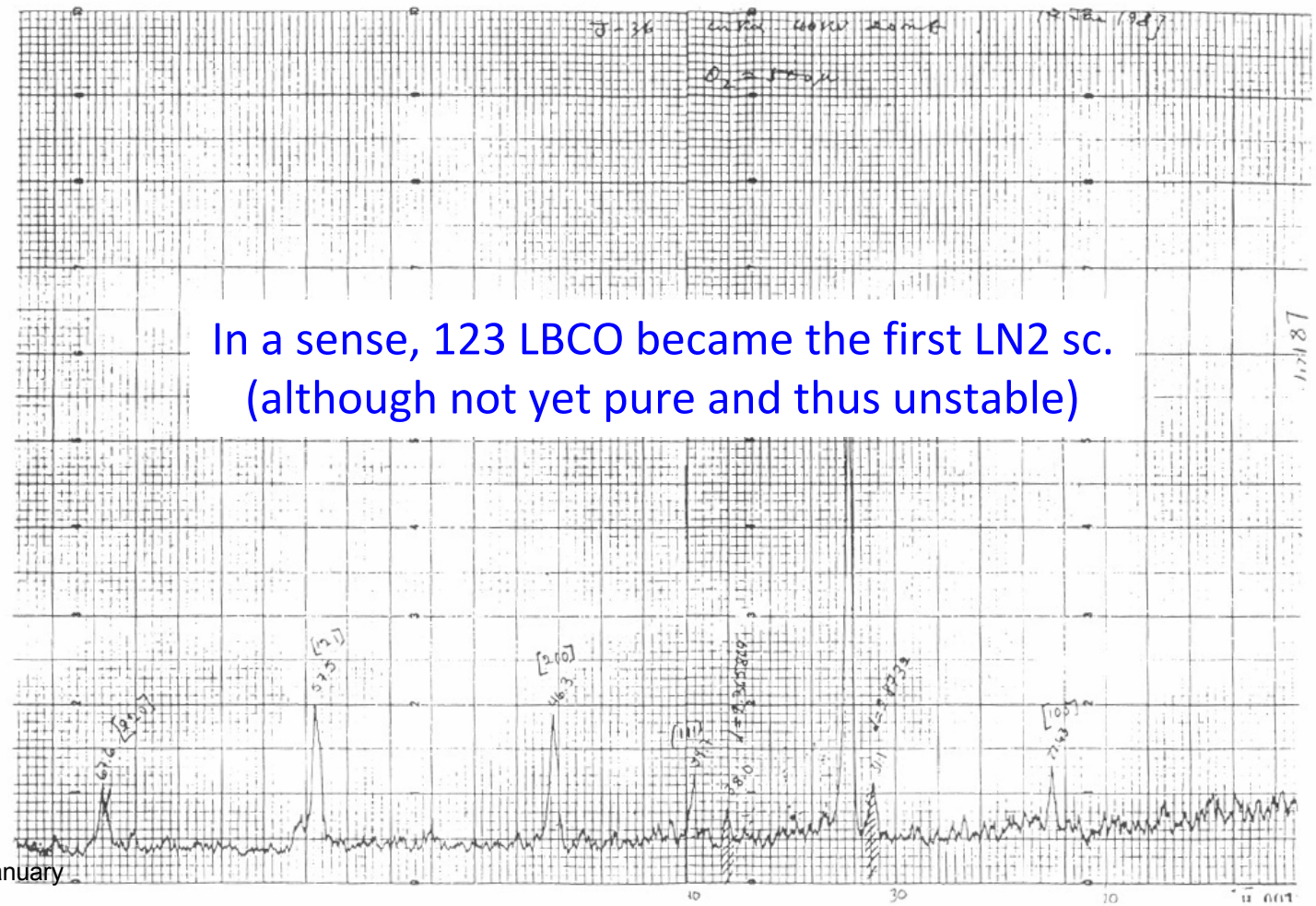
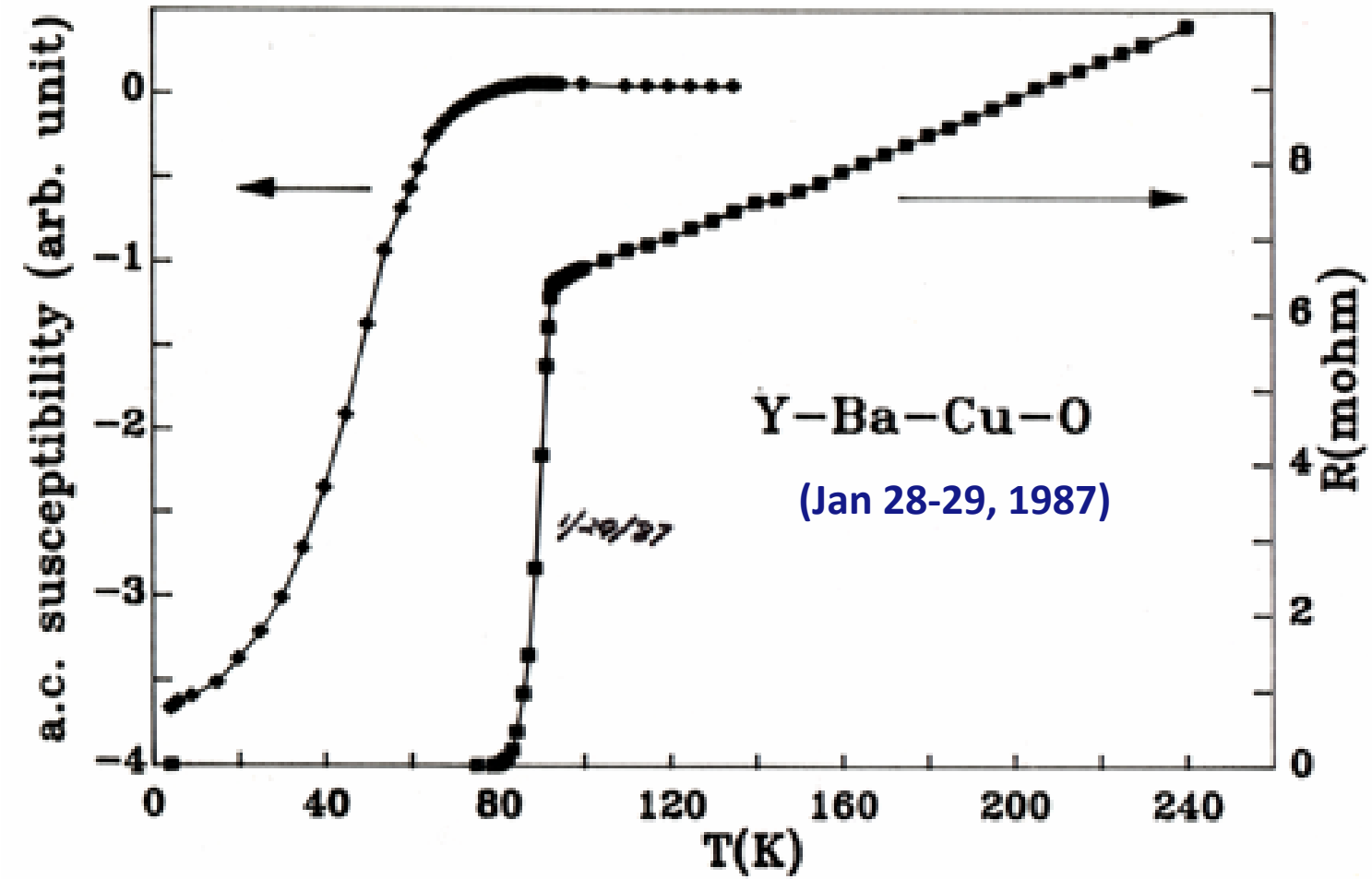


Figure 7. The November 12, 1987 X-ray powder diffraction of the LBCO sample which displayed the large diamagnetic χ_{ac}-shift indicative of a superconducting transition (Fig. 6), showed the R-123 structure but was only recognized later in March when the R-123 structure was solved [C. W. Chu, Proc. Nat. Acad. Sci. USA 84, 4681 (1887)].

1987: The Most Exciting Event - the Call from M.K. Wu

(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.

100409CWC

The Modern Era of HTS 1987

VOLUME 58, NUMBER 9 PHYSICAL REVIEW LETTERS 2 MARCH 1987

Superconductivity at 93 K in a New Mixed-Phase Y-Ba-Cu-O Compo 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.

March 2, 1987 – the Super Day of Physics:
Superconductor above 77 K, Supernova, SSC

100318CWC

Can we find other SCs with $T_c \geq 93$ K?

- The role of Y by partial magnetic substitution (Gd)
  - *no T_c-suppression ==> Y is electronically isolated, other rare earths of similar atomic radii are possible*
  - *$T_c \geq 77$ K sc in mixed phase samples of RBCO with R = Lu, Eu, Gd, Sm very quickly*

- The superconducting phase
  - *the black phase [with Bob Hazen and Dave Mao et al.]*

- The compositions and crystal structure of the black phase
  - *$YBa_2Cu_3O_7$ [with Bob Hazen and Dave Mao et al.]*

- Yes: *the $RBa_2Cu_3O_7$– series, R = all rare earths except Ce, Pr*

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 particular, the high T_c of $ABa_2Cu_3O_{6+x}$ is attributed mainly to the quasi two-dimensional assembly of the CuO_2-Ba-CuO_{2+x}-Ba-CuO_2 layers sandwiched between two A layers, with particular emphasis in the CuO_{2+x} layers. Higher-T_c oxides are predicted for compounds with bigger assemblies of CuO_2 layers coupled by Ba layers.

PACS numbers: 74.10.+v, 74.70.Ya

Superconductivity above 30 K was first reported[1] in 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 are different from those with the K_2NiF_4 structure. Recently, the two phases in the Y-Ba-Cu-O compound system were separated and identified[10]: tetragonal $YBa_2Cu_3O_{6+x}$ (black) and orthorhombic Y_2BaCuO_5 (green). Magnetic measurements on the Y-Ba-Cu-O compounds showed[11] that the black phase is responsible for the high-temperature superconductivity detected. Indeed, single-phase $YBa_2Cu_3O_{6+x}$ samples exhibiting 100% ac diamagnetic shift $\Delta\chi$ were obtained.[11] This is consistent with the most recent reports from other laboratories.[12]

To determine the role of Y and of different structures, e.g., K_2NiF_4 and $YBa_2Cu_3O_{6+x}$ planes, in high-temperature superconductivity, we have synthesized and examined the $ABa_2Cu_3O_{6+x}$ compound systems with A = La, Nd, Sm, Eu, Gd, Ho, Er, and Lu, in addition to Y. They all were found to be superconducting with an onset temperature between 90 and 98 K and a zero-resistance state between 70 and 94 K. This shows that the trivalent A atoms, even if they are magnetic, do not

CuO_2-Ba-CuO_{2+x}-Ba-CuO_2 plane assembly sandwiched 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 technique was employed for the resistance (R) measurements, and a Linear Research ac inductance bridge was used for the magnetic susceptibility (χ) determinations. The temperature was measured by use of an Au ±0.07% Fe–Chromel or Chromel-Alumel thermocouple above 30 K and a Ge thermometer below.

The powder x-ray diffraction patterns showed that all samples except A = Lu possess the single tetragonal $YBa_2Cu_3O_{6+x}$ structure, although for a couple of cases orthorhombic symmetry[12] was also detected. The results show that the difference in the structural symmetries reported[10,12] for the Y-Ba-Cu-O system may be caused by the oxygen content and the slight difference in composition. As will be evident later, the structural symmetry in this class of oxides apparently does not have a large effect on the superconductivity. The lattice parameters are given in Table I. In addition to the orthorhombic $YBa_2Cu_3O_6$ structure, the A = Lu compound exhibits other phases, which we believe can be eliminated by

(reduced atmosphere; 3/16 Harvard colloquium)

Woodstock of Physics, NYC, March 18, 1987

Figure 1.1 The Woodstock of physics: the special session on superconductivity held during the 1987 March Meeting of the American Physical Society (Hilton Hotel, New York City). (Courtesy of the American Institute of Physics Niels Bohr Library.)

100409CWC

The Origin of the Woodstock of Physics in 1987

Abstract Submitted
for the March 1987 Meeting of the
American Physical Society
March 16-20, 1987 Sort

Study of Oxygen-Deficient Perovskite
$Ba_xLa_{5-x}Cu_5O_{5(3-y)}$ Compounds*. C.W. CHU, K.

GAO, P.H. HOR, Z.J. HUANG, R.L. MENG, S.C. M
ROBERTSON and Z.X. Zhao, U. of HOUSTON -
Recently, possible percolative superconducti
~35K was proposed by Bednorg and MÜller in c
deficient Ba-La-Cu-O compounds following the
of a large resistance R-drop on cooling with
suppressable by current. Coprecipitation fr
solution and low temperature treatments were
to be crucial for the observation of the R-d
However, by employing a non-coprecipitation
we have obtained $Ba_xLa_{5-x}Cu_5O_{5(3-y)}$ compound
nantly with a tetragonal perovskite structur
samples with x=1 exhibit a R behavior simila
previously reported with a ~36 fold R-drop b
An ac diamagnetic signal of <1% occurs at 4K
temperature powder x-ray data for samples wi
without the R-drop are very similar except f
extremely weak lines. The R-drop disappears
samples were exposed to air for six days, re
a 10 fold increase in R. At present, the ex
of the R-drop in $Ba_xLa_{5-x}Cu_5O_{5(3-y)}$ remains
More detailed and systematic studies in samp
tion and characterization are in progress.

Submitted on Nov. 22,1986
The deadline was Dec. 5, 1986

The American Physical Society

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8 December 1986

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Your abstract has been rejected for the meeting of the American Physical Society for which you submitted it because it did not conform to the rules and regulations for submission of abstracts specified by the Executive Secretary and approved by the Council.

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Your abstract was longer than the 4 1/8" allowed
(by 1/2 a line)

The Panel Discussion, March 18, 1987

070221CWC

SUPERCONDUCTIVITY ABOVE 100K

Introduction

30K - Superconductors

$(La\text{-}M)_2 Cu O_{4-\delta}$ - K_2NiF_4 str.

M = Ba, Sr, Ca

90K - Superconductors

$A Ba_2 Cu_3 O_{6+\epsilon}$

A = Y, La, Lu, Eu .....

Discussion

Concluding Remarks

Higher T_c ? - Yes!

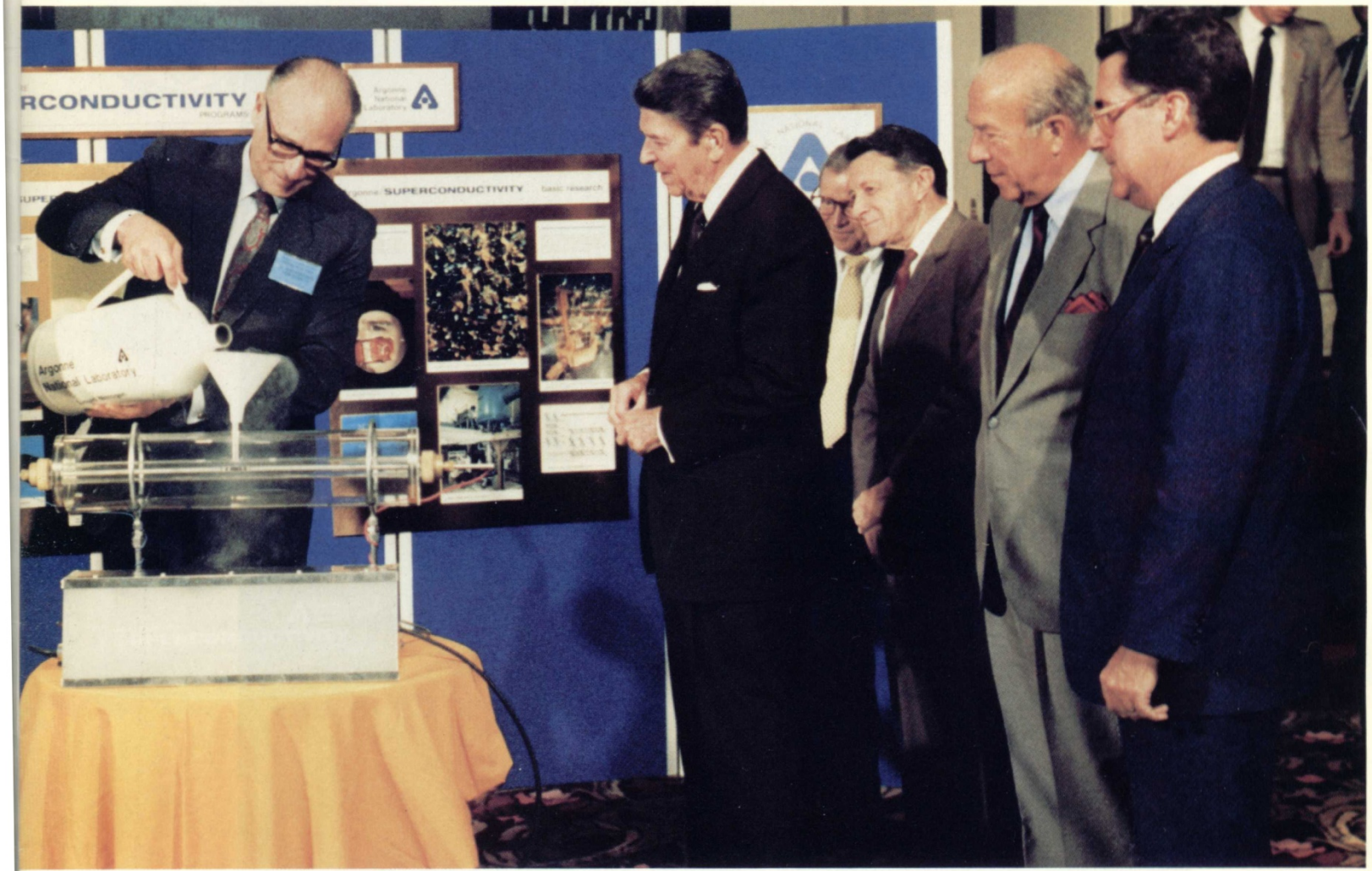
Future - Bright!

7:30 PM

3/18/87

Woodstock of Physics

Figure 1.3 Some of the protagonists of the special session on superconductivity (March 1987, APS Meeting, Hilton Hotel, New York City). From left to right: Alex Müller, Paul Chu, and Shoji Tanaka. (Courtesy of the American Institute of Physics Niels Bohr Library.)

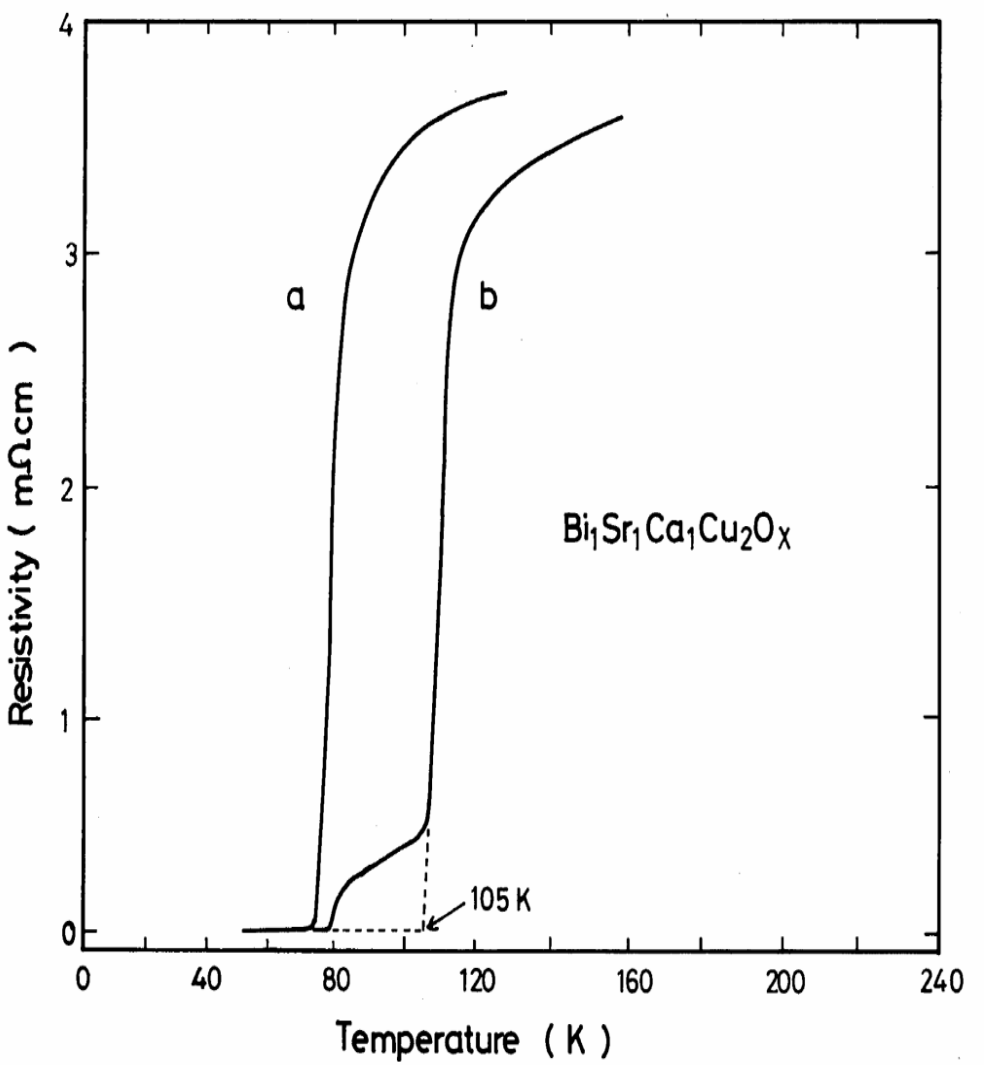


Alan Schriesheim, Director of Argonne National Laboratory, demonstrates superconductivity to the President, Chief of Staff Howard Baker, Secretary of Defense Caspar Weinberger, Secretary of State George Shultz and Secretary Herrington.

The federal conference at DC - July 1987

A New High-T_c Oxide Superconductor without a Rare Earth Element

Hiroshi MAEDA, Yoshiaki TANAKA, Masao FUKUTOMI and Toshihisa ASANO



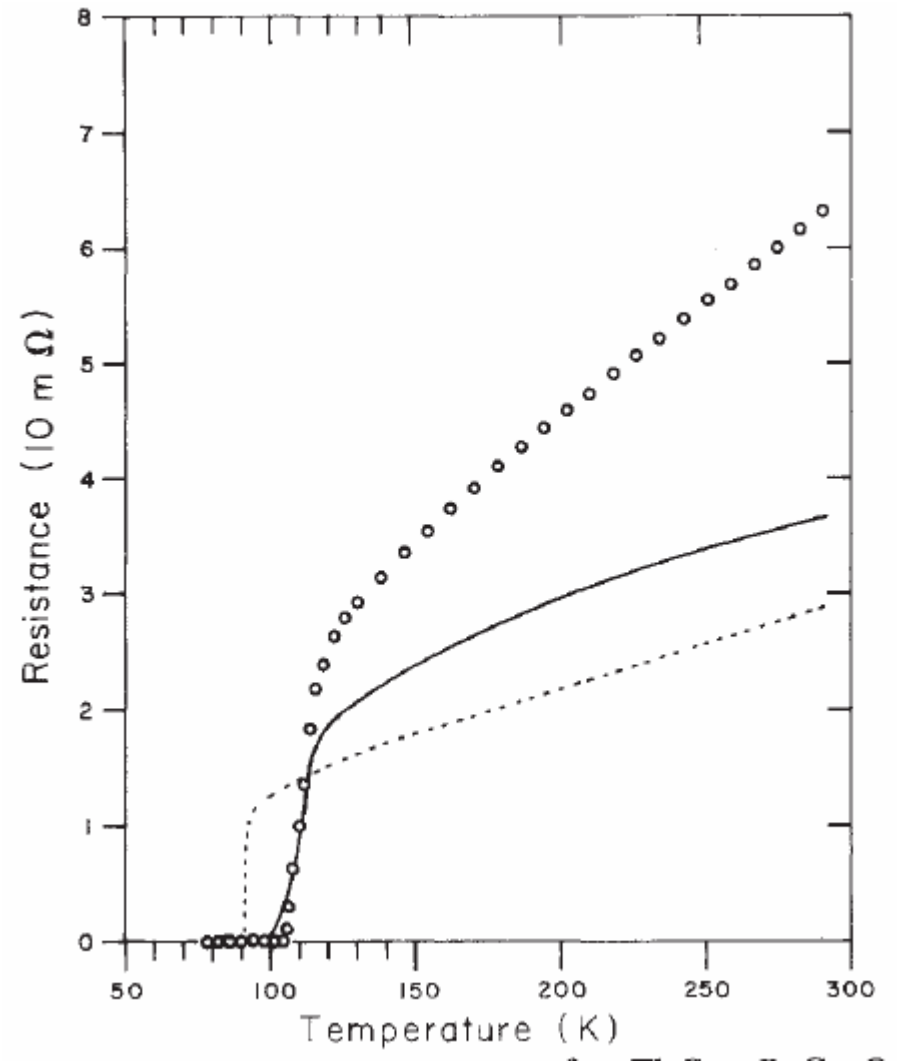
$T_c \leq 110$ K

$Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4}$

Jpn.J.Appl. Phys. 27, L209 (1988)

Bulk superconductivity at 120 K in the Tl–Ca/Ba–Cu–O system

Z. Z. Sheng & A. M. Hermann



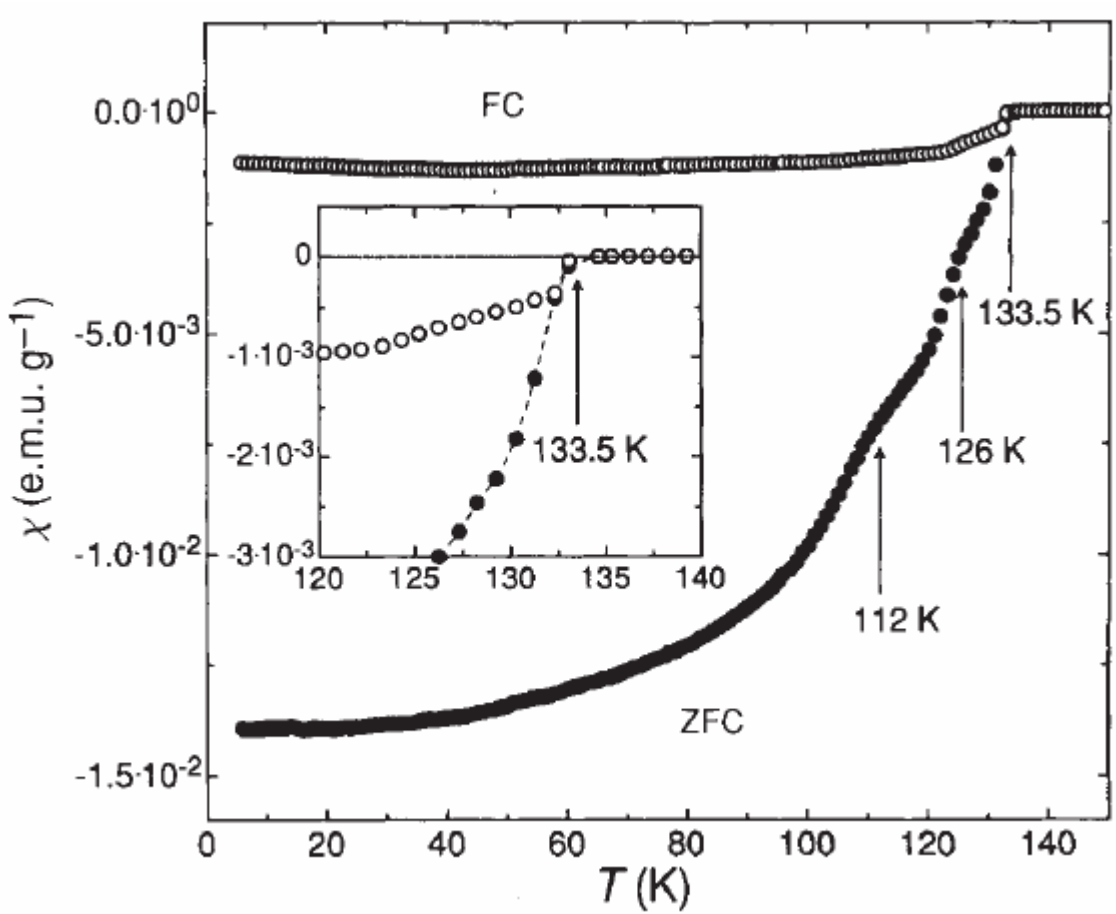
$T_c \leq 125$ K

$Tl_2Ba_2Ca_{n1}Cu_2O_{2n+4}$

Nature 332, 138 (1988)

Superconductivity above 130 K in the Hg–Ba–Ca–Cu–O system

A. Schilling, M. Cantoni, J. D. Guo & H. R. Ott



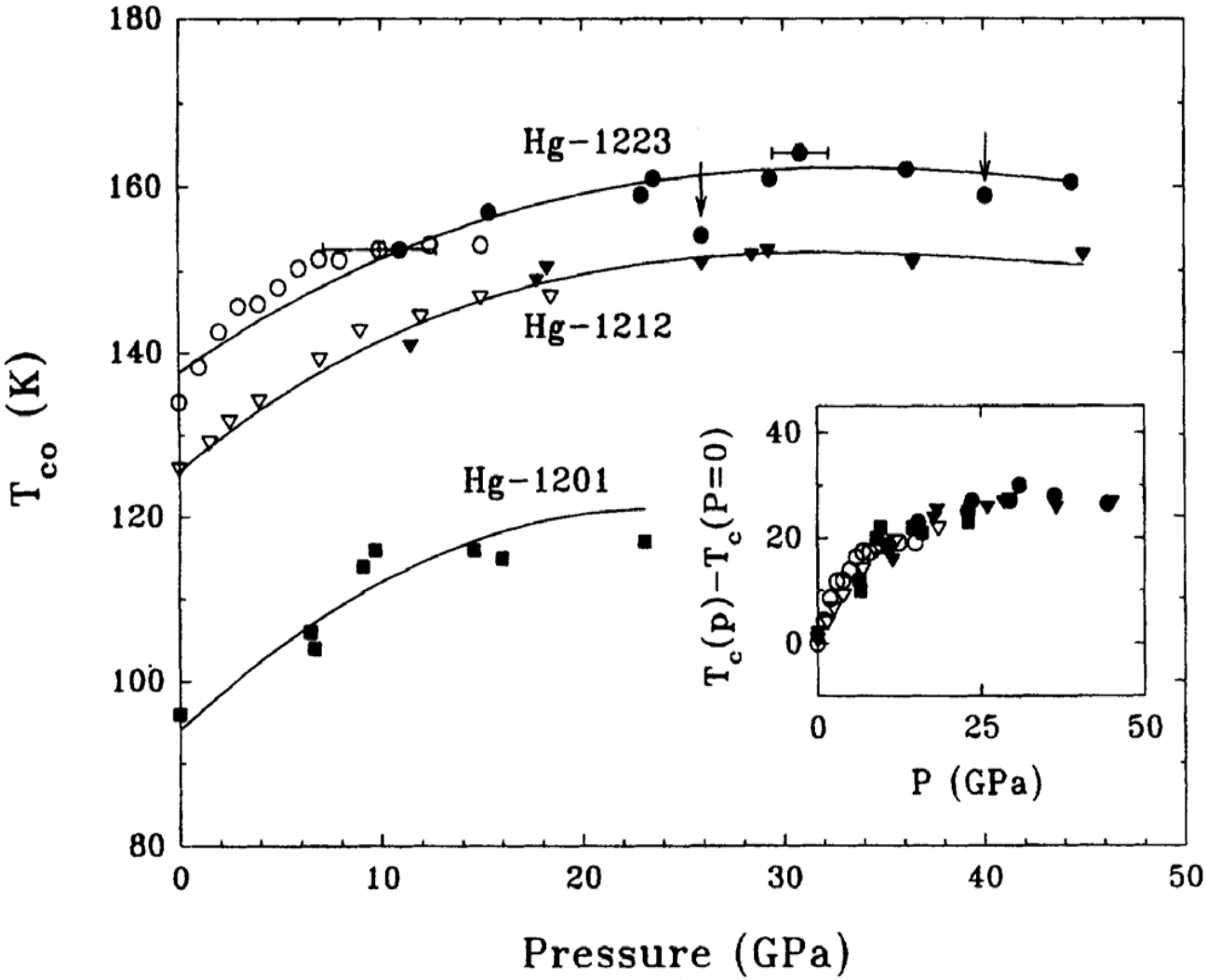
$T_c \leq 134$ K

$HgBa_2Ca_{2n-1}Cu_nO_{3+2n-\delta}$

Nature 363, 56 (1993)

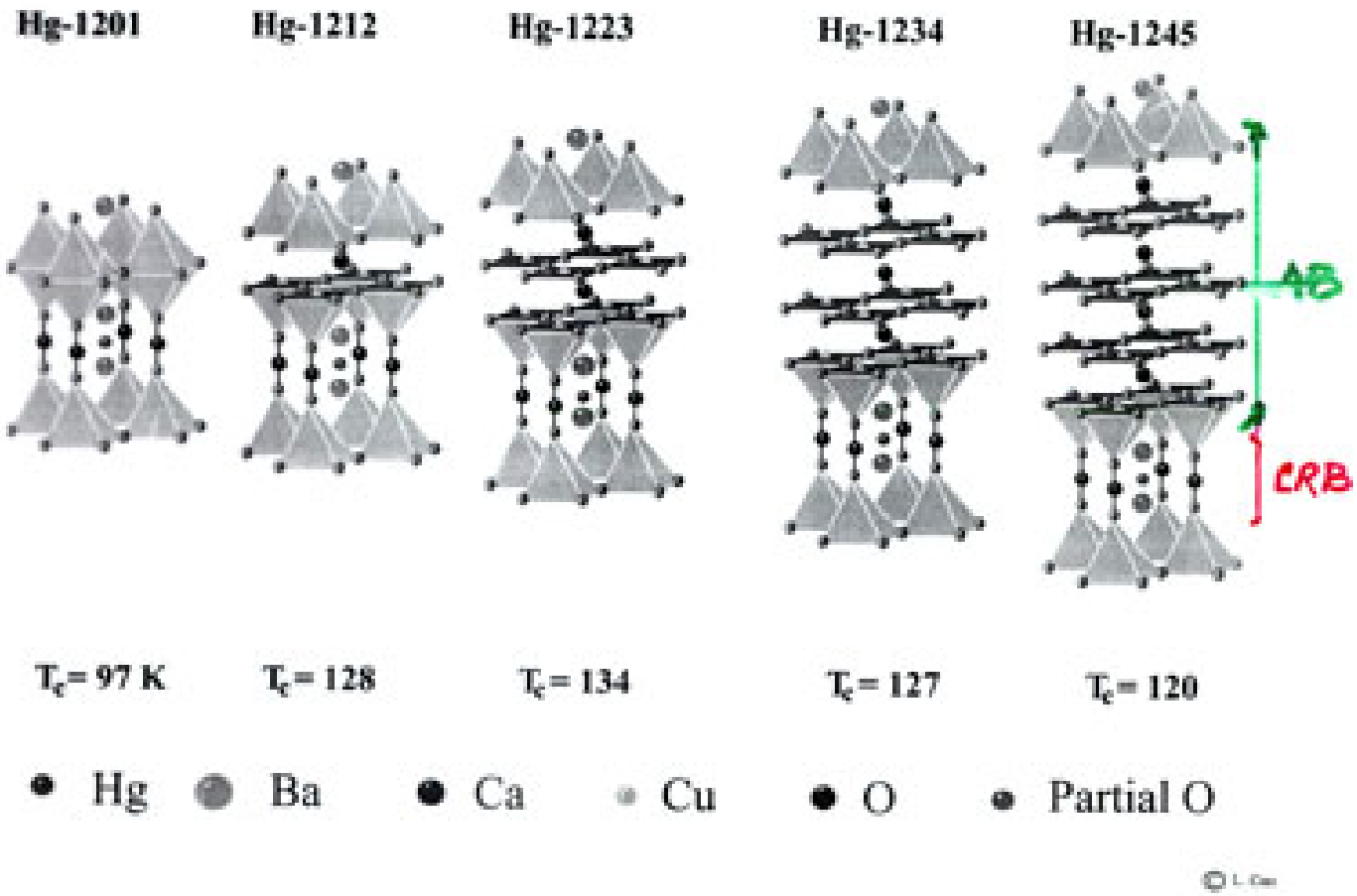
Superconductivity up to 164 K in $HgBa_2Ca_{m-1}Cu_mO_{2m+2+\delta}$ ($m=1$, 2, and 3) under quasihydrostatic pressures

L. Gao, Y. Y. Xue, F. Chen, Q. Xiong, R. L. Meng, D. Ramirez, and C. W. Chu
J. H. Eggert and H. K. Mao



$T_c \leq 164$ K
$HgBa_2Ca_{2n-1}Cu_nO_{3+2n-\delta}$
Phys. Rev. B (R) 50, 4260(1994)

Schematic Structures of the Hg-Compounds



Highly Anisotropic

YBCO remains to be the compound of choice for HTS science and technology:

easier for doping, easier for single crystal, large grain and epi-film growths, high J_c & high H_i above 77 K, robust, less costly

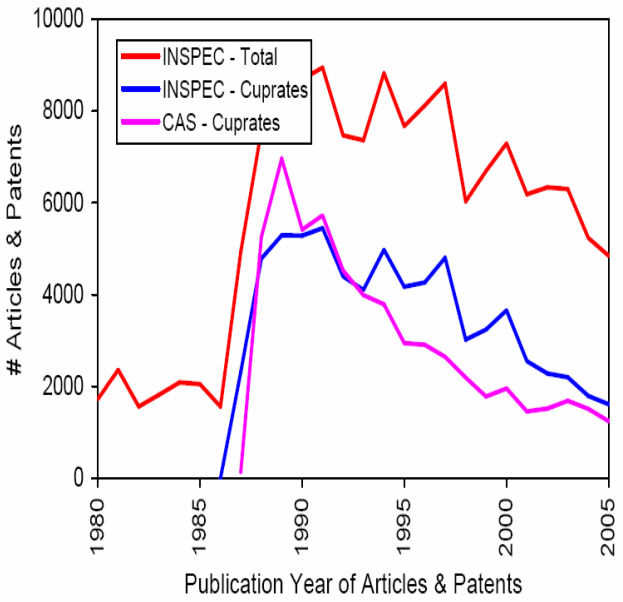
YBCO was included in the White House Millennium Time Capsule

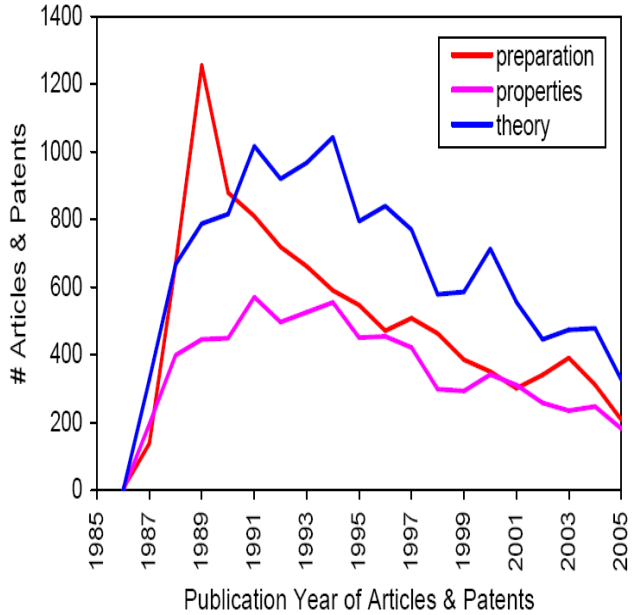
Closing Ceremony - December 6, 2000 in the National Archives, Washington DC

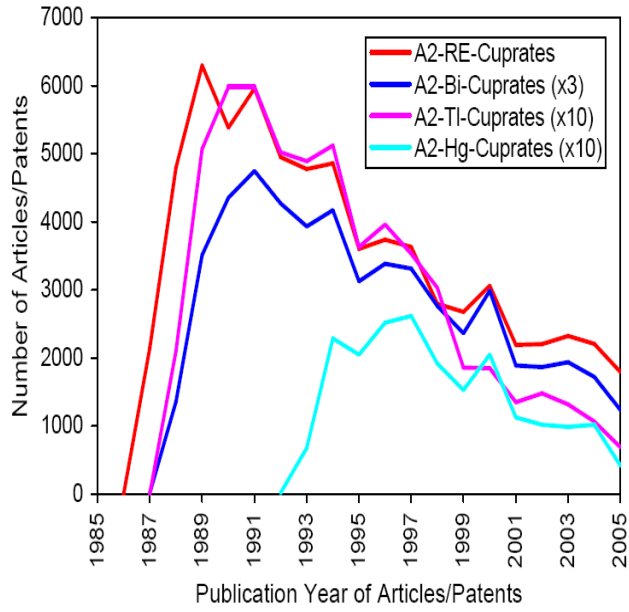
050204CWC

The winter of HTS S&T in 2006

A.Barth and W. Marx analyzed the HTS science publication statistics scientometrically in 2006, and sentenced it to die in 2010-2015 by extrapolation.







However, new discoveries cannot be predicted from past statistics

Mark Twain (Benjamin Disraeli):

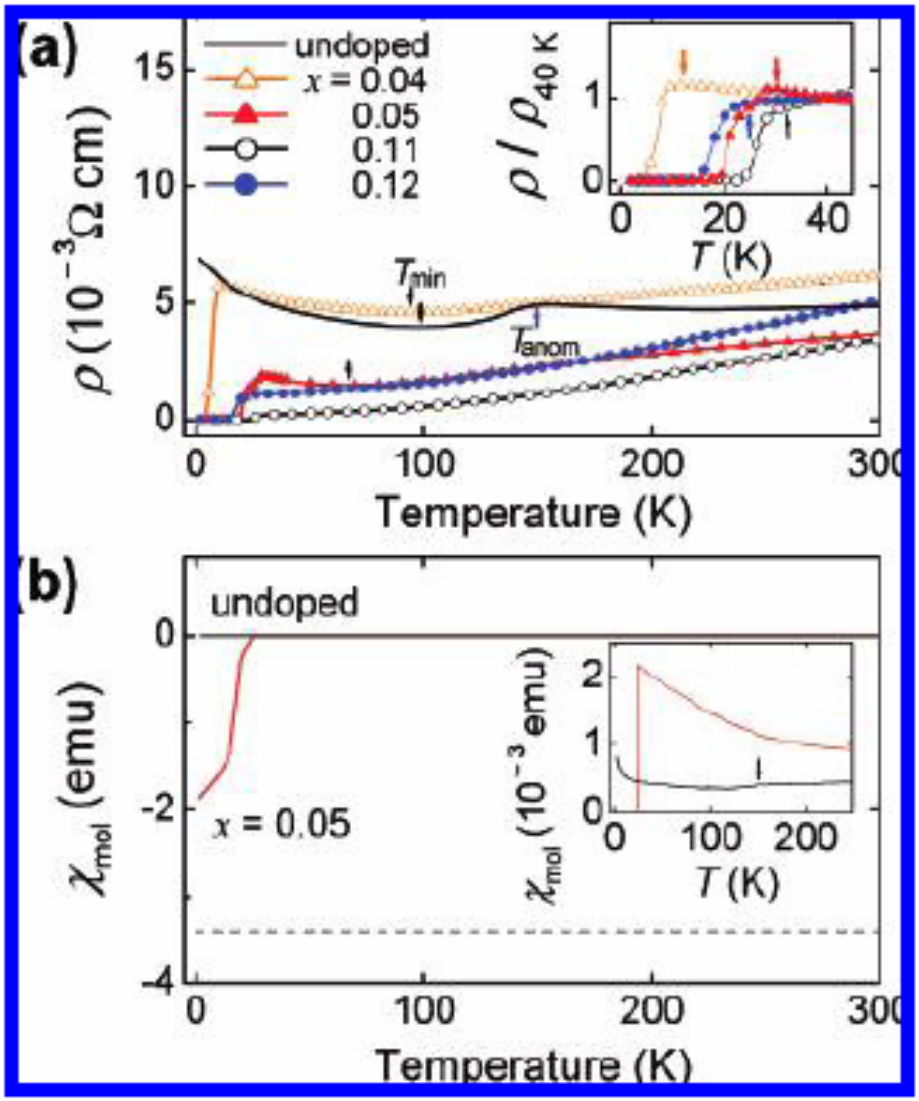
There are lies,
there are damned lies and
there are statistics.

SC was once sentenced to die before in 1986-87.

Fe-pnictides superconductors were discovered in 2008

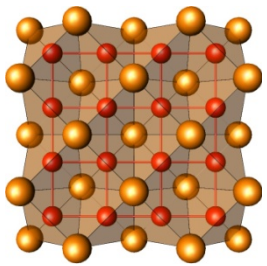
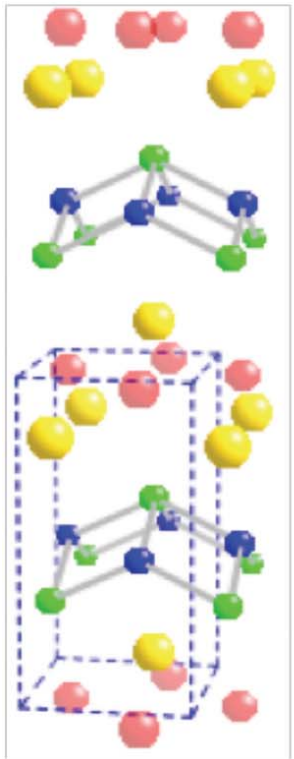
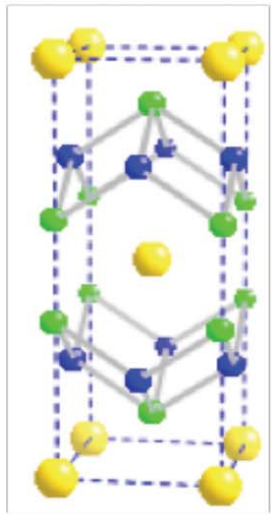
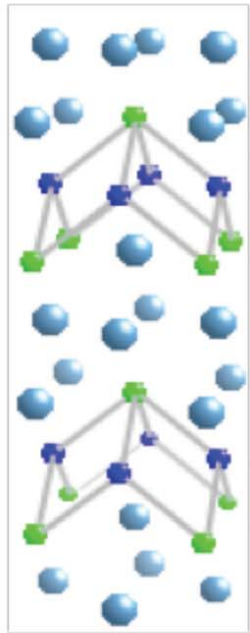
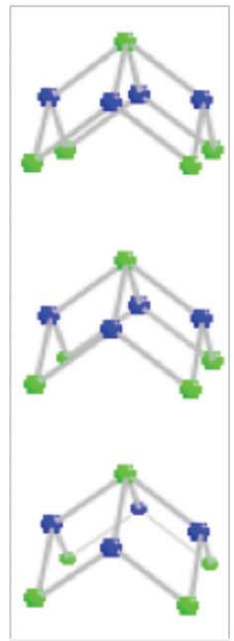
Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs ($x = 0.05-0.12$) with $T_c = 26$ K

Yoichi Kamihara,*,† Takumi Watanabe,‡ Masahiro Hirano,†,§ and Hideo Hosono†,‡,§



Tc ≤ 57 K
R(O,F)FeAs
JACS 130, 3296 (2008)
1111, 11, 122, 111

Fe- Pnictides & Fe-Chalcogenides

	"1111"	"122"	"111"	"11"
Perovskite-like Fe-As layers or Fe-Se layers 				
	≤ 57 K	≤ 38 K	≤ 20 K	
	H. Hosono et al.	M. Rotter et al. X. L Chen et al.	C. W. Chu et al. C. Q. Jin et al.	M. K. Wu et al.
		≤ 33 K		≤ 10 K

Some Questions on HTS Science

- *What is the mechanism responsible for HTS?*
- *Is there a comprehensive microscopic theory?*
- *Do HTSs form a class of materials of their own?*
- *Can there be a room temperature superconductor?*

100 years after the discovery of superconductivity,
54 years after the development of BCS &
24 years after the discovery of YBCO,
we have learned:

- *There is no evidence, experimental or theoretical, that prevents room temperature superconductivity from happening.*

- *Whatever physics law doesn't say won't happen will happen.*

- *RTS will be the next grand challenge in SC research – DoE, AFOSR*

One Possible Approach

["A possible path to RTS" - C. W. Chu, AAPPS 18, 9-21 (2008)]

Rational – reason is the source of knowledge

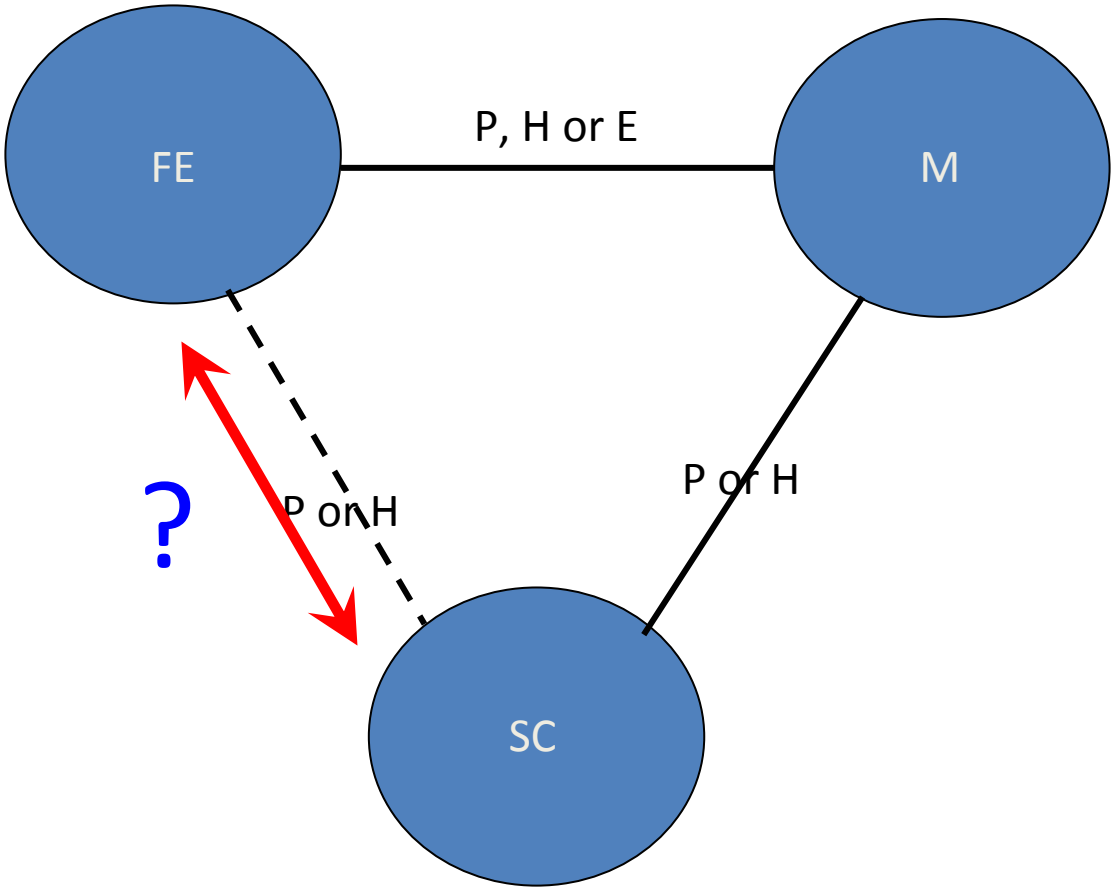
Empirical – experience is the source of knowledge

Enlightened Empirical – experience, intuition and reason are the sources of knowledge

Holistic Multidisciplinary Enlightened Empirical – holistic experience, intuition and reason from different fields are the sources of knowledge of VHTS and RTS

ONE EXAMPLE

Optimizing Multiple interactions in highly correlated electron systems with high ordering temperatures

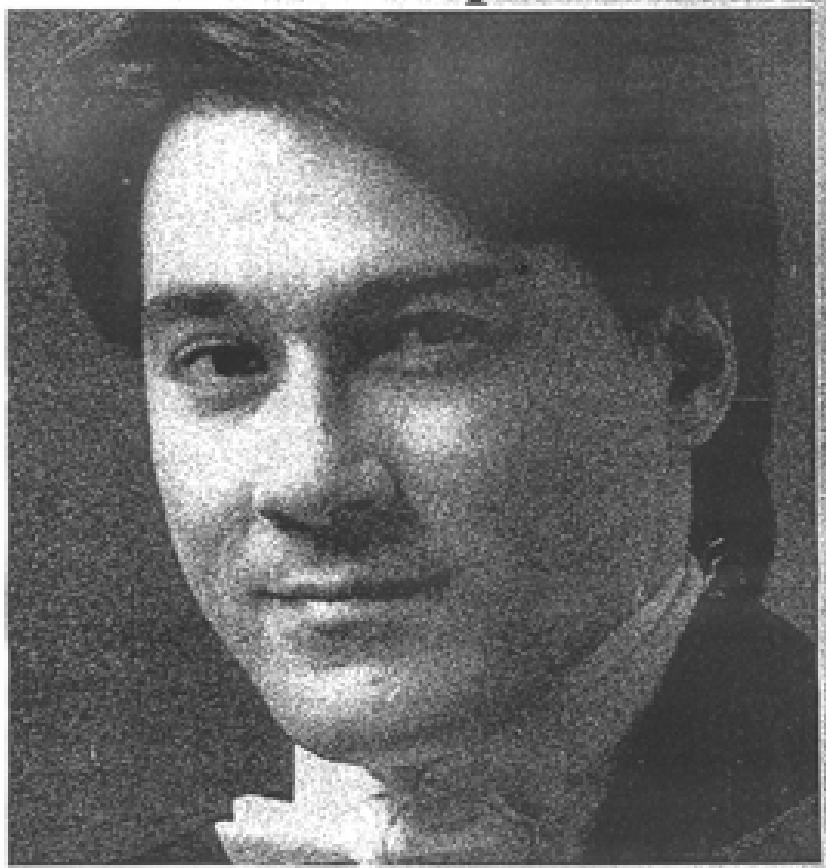


Superconductivity close to a ferroelectric instability ?

In October 1989

Announcing The First Superconductor That Works At Room Temperature.

Oct. 1989



KIM ALLEN KLUGE

ALEXANDRIA SYMPHONY

FOR MORE INFORMATION, CONTACT THE ALEXANDRIA SYMPHONY AT 548-0045

1989.

20 years later, James Cameron announced in Avatar the discovery of a Room Temperature Superconductor in 2009

The arrival of HTS has profoundly impacted science and technology.

- Gave new hope to superconductivity at higher temperatures
- posed more challenges to physicists, material scientists and chemists
- Created a new subfield in physics
- Accelerated the development of material science
- Brought superconductivity technology a giant step closer to reality – for a sustainable global economic development in the future

The future of HTS science and technology research and development will continue to be exciting!

THANKS TO

Alex Müller + George Bednorz -

Bernd Matthias + Art Sleight -

John Bardeen . Marvin Cohen . Ted Geballe +

C. Y. Huang -

Art Freeman -

NSF . NASA + UH -

My Colleagues + Students -

Students & Visiting Scientists (UH): L. Gao, P.H. Hor, P. Huang, R. L. Meng, K. Foster, Y. Q. Wang, Y. Y. Xue, A. Testa, D. Campbel,

Colleagues: B. Hazen, D. Mao (Geophysical Lab), S. Moss (UH)

The unusual arrangement [Joe Trivosono, L. Nasnow (NSF), R Weinstein (UH) : personal supervision of lab work

- daily phone calls
- ½ my time in Houston while a program director in NSF, especially, mid-February and mid-March, 1987)

Thank you
and

all "comrades", young and old,
Inside and outside the trenches
of HTS, who will never die, only
fade away.

The usefulness of high RTS?!

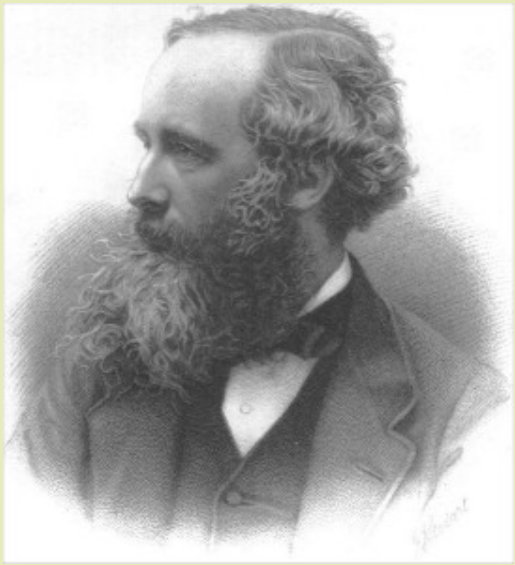
Small coherent length
Large anisotropy
Small J_c

Early 1930's

THE USEFULNESS OF USELESS KNOWLEDGE

BY ABRAHAM FLEXNER

Is it not a curious fact that in a world steeped in irrational hatreds which threaten civilization itself, men and women—old and young—detach themselves wholly or partly from the angry current of daily life to devote themselves to the cultivation of beauty, to the extension of knowledge, to the cure of disease, to the amelioration of suffering, just as though fanatics were not simultaneously engaged in spreading pain, ugliness, and suffering? The world has always been a sorry and confused sort of place—yet poets and artists and scientists have ignored the factors that would, if attended to, paralyze them. From a practical point of view, intellectual and spiritual mental problems. I have no quarrel with this tendency. The world in which we live is the only world about which our senses can testify. Unless it is made a better world, a fairer world, millions will continue to go to their graves silent, saddened, and embittered. I have myself spent many years pleading that our schools should become more acutely aware of the world in which their pupils and students are destined to pass their lives. Now I sometimes wonder whether that current has not become too strong and whether there would be sufficient opportunity for a full life if the world were emptied of some of the useless things that give it spiritual sig-



James Clerk Maxwell
1831 - 1879

Heinrich Hertz
1857 - 1894

Guglielmo Marconi
1874 - 1937

$$\nabla \cdot \boldsymbol{E} = \rho \qquad \nabla \times \boldsymbol{B} = \boldsymbol{j} + \frac{\partial}{\partial t}\boldsymbol{E}$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial}{\partial t}\boldsymbol{B} \qquad \nabla \cdot \boldsymbol{B} = 0$$

Maxwell's Equations 1861

observed radio waves in his laboratory 1887

sends radio signal across Atlantic 1901

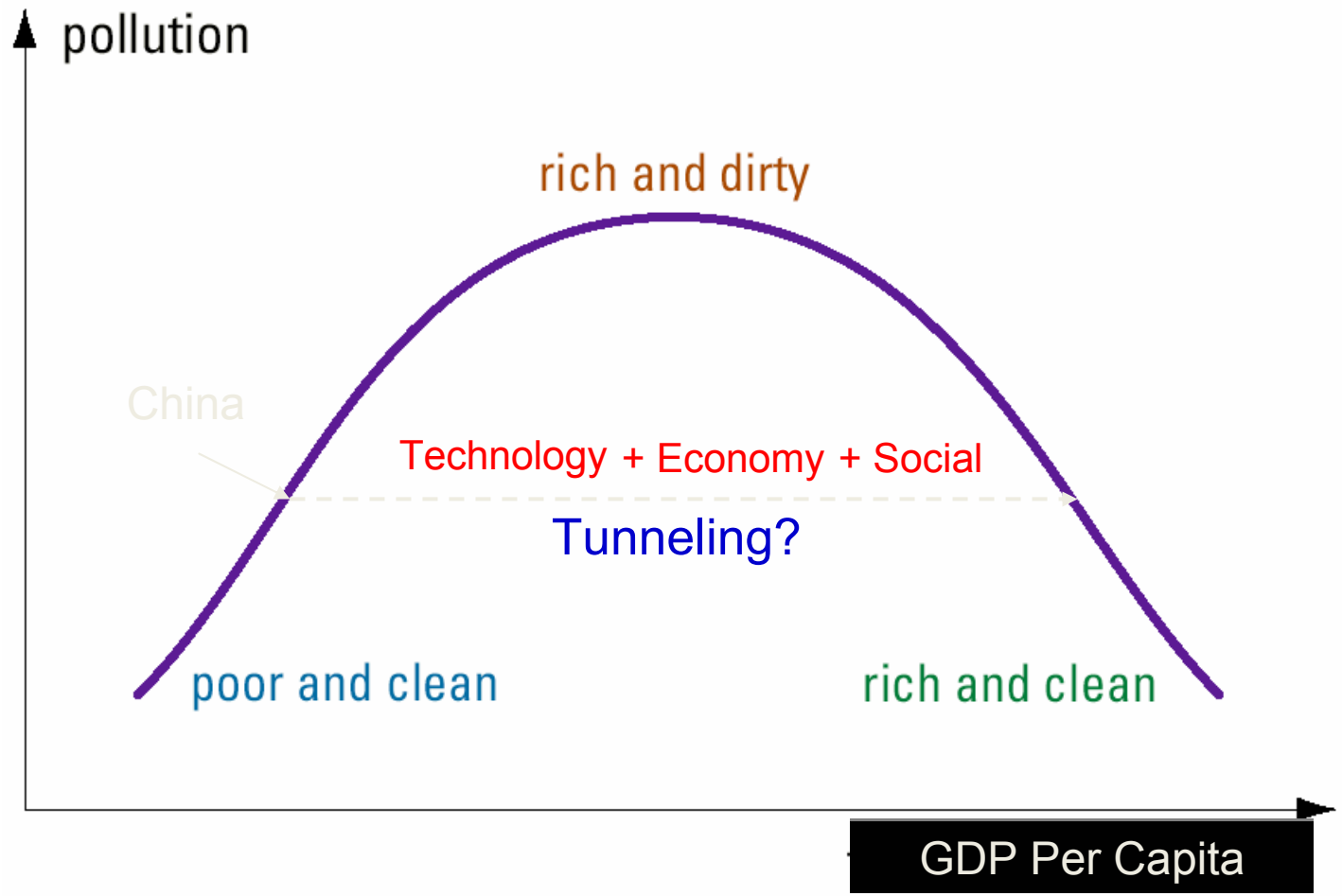
Usefulness often originates from basic and useless knowledge.

Constraints for Future global economic growth:

Energy, Environment and Resources

Energy is the key
and HTS can play a crucial role in electricity use, and electric power quantity delivery and quality control.

Traditional Path for Industrialization



(Xu K. D., President, CAE)