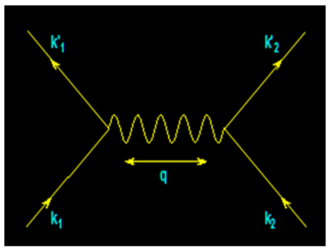
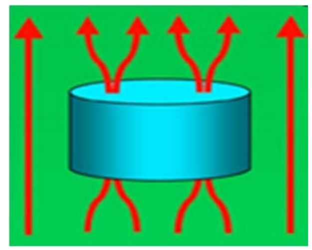
Opening…

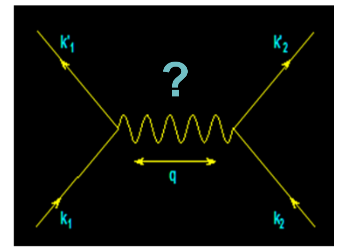
From Electrons Paired



To Electric Power



…And… Back Again



-- A Personal Journey in Superconductivity --
-- IBM, EPRI, and Beyond --

Paul M. Grant
www.w2agz.com

AGING IBM PENSIONER

IBM Almaden Research Center
650 Harry Road
San Jose, CA

ARC Auditorium
10:30AM – 11:30AM
Friday, 6 May 2011

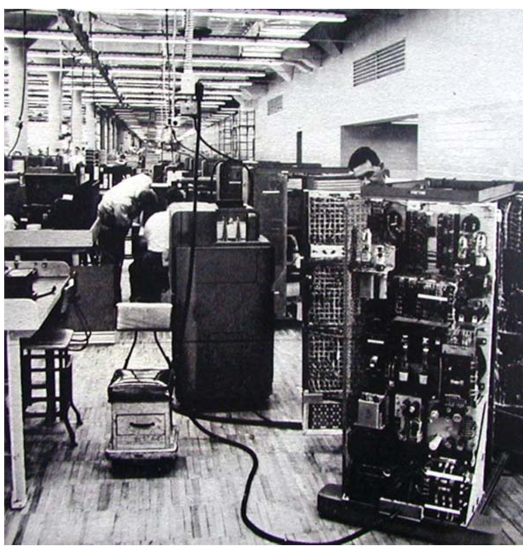
PMG Timeline

- IBM (1953-1993)
  - Project SAGE (IBM, MIT, USAF) (1953-56)
  - IBM Education Plan (1956-65)
  - San Jose/Almaden (1965-90)
  - Sabbatical @ UNAM (1990-93)
- EPRI (1993-2004)
  - Science Fellow (Superconductivity, Power Electronics Devices, Fusion, "Novel Concepts")
- W2AGZ Technologies (2004-?)
  - Visionary Energy Societies (SuperCity, SuperSuburb, SuperGrid)
  - "Due Diligence" Consulting
  - Uncovering the Nature of HTSC !

IBM

IBM – 100 Years

1952



604 (1948)

Grant-Whalen
IBM Family
-Poughkeepsie-

701 (1952)

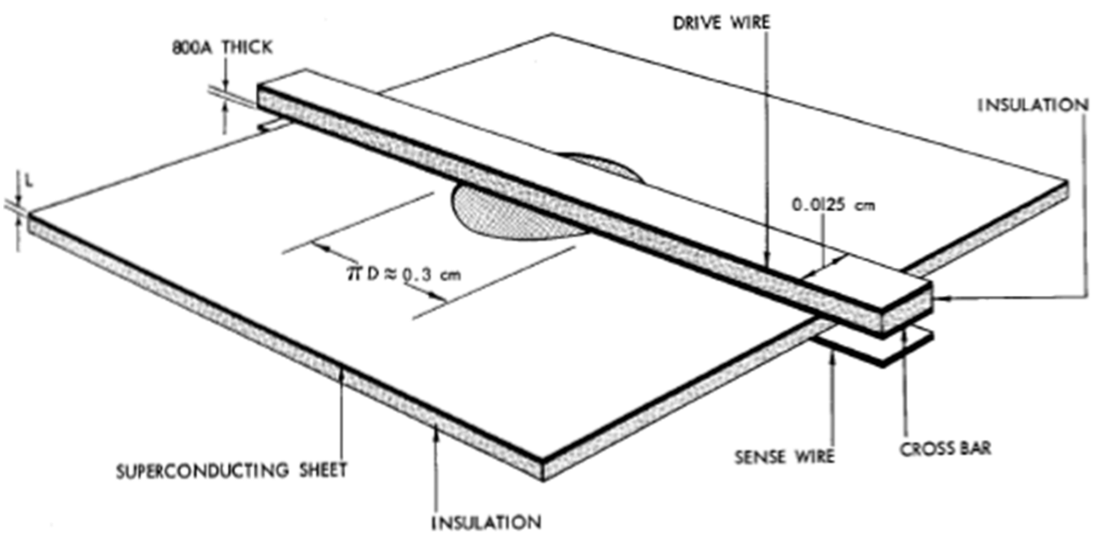
1953

Project Sage – IBM/MIT

J. W. Crowe

Trapped-Flux Superconducting Memory*

Abstract: A memory cell based on trapped flux in superconductors has been built and tested. The cell is constructed entirely by vacuum evaporation of thin films and can be selected by coincident current or by other techniques, with drive-current requirements less than 150 ma. The short transition time of the trapped-flux cell indicates its possible use in high-speed memories. The superconductive film memory does not exhibit the problems of "delta noise" in core memories resulting from the difference in half-select pulse outputs.



Out into the Cold: Early Experiences with Superconductivity

by Dr. Paul Michael Grant, W2AGZ Technologies, w2agz@w2agz.com, www.w2agz.com

The following article is part of a year-long series celebrating the 100th anniversary of the discovery of superconductivity. Contact CSA if you have ideas for submissions: theresa@cryogenicsociety.org.

One of my earliest memories was watching my parents ice skate on frozen Wappingers Pond where they had taken me swimming for my first time only a few months before. The mid-Hudson Valley was, and still is, notorious for its temperature extremes, the river itself usually completely freezing over between its banks. In mid-winter the outside temperature could approach -50°F (-46°C, 228K). I was reminded of the rigors and discomfort of my boyhood cold climate experiences this past July at ICEC-ICMC held in Wroclaw, Poland, as one of a group of attendees who underwent a "cryotherapy" session at a nearby spa, where "room temperature" was approximately -100°C. Thomas Wolfe was wrong…You can go home again!

Ice was the base cryogenics technology of my childhood years throughout the early 1940s, delivered daily, sawdust covered, in carts drawn by horses due to the wartime rationing of gasoline for automobiles and trucks [1]. Household refrigeration didn't really arrive for working class folks until after WWII. However, while I was in grammar school, although we didn't have formal science classes, we had occasional "science demonstrations," usually conducted by engineers from the nearby IBM plant. I remember two in particular, one on something called "dry ice," really cold to the touch, which just sat there and smoked and didn't melt; the other by a gentleman who brought what looked like a large thermos bottle containing "liquid air" into which was dunked a tomato, which was then withdrawn and struck with a hammer, shattering it as if it were glass. Pretty impressive to a seventh grade male (~1948).

My next encounter with cryogenics didn't occur until I was 18. My high school grades were atrocious, to put it mildly, not good enough to get me into college, and I did not want to go anyway—I wanted a job so I could buy a car. So I did what Wappingers Falls boys usually did: I went to work at IBM, first setting pins in the employee bowling alley and then as a mail boy in the mail room of a new IBM lab in downtown Poughkeepsie. I really wanted to be a bench technician, so between delivery runs I hung out with the engineers. One day one of them called to me, "Hey, kid. Come over here and I'll show you something really cool." (He didn't actually say "cool.") His name was Jim Crowe [2].

Jim splattered some solder on his bench top, scraped it off, cut out a small rectangle with his "dikes," wired it in series with a flashlight battery and a resistor of unknown (to me) size, and also hooked up in parallel with leads to a Hewlett-Packard vacuum tube voltmeter. Next to his bench was a huge stainless steel container which Jim told me held liquid helium, saying it was the coldest substance known to man. He dropped the wired up solder chip through a small opening in the top of the "dewar" and we watched the voltage across it slowly drop…and then suddenly disappear! At the time, I knew enough about electricity and Ohm's Law to complain, "The leads must have come off!" Jim said, "No, that's 'superconductivity'. The resistance of the lead-tin in the solder goes away under liquid helium." I thought to myself, "Yeah, sure!"

That evening I had dinner at home with another IBM engineer, my dad. I told him about my experience, and he replied, "Hmm. I've heard some talk about making a superconducting computer. But I don't know…you would have to fill up a whole building with liquid helium." This was 1953.

That was my first and last experience with superconductivity for some time to come. Shortly after turning 21, IBM decided I was worth educating and sent me (as an employee!) to college and graduate school for nine years, and I wound up with a physics doctorate from Harvard (superconductivity was not taught at Harvard in the early 60s!). IBM assigned me to the San Jose, now Almaden, Research Lab, and in 1972, Rick Greene (now at UMD) and I teamed up to start working on organic metals as possible room temperature superconductors, both of us having become disciples of Bill Little's dream that properly prepared polymeric chains might exhibit really high (> 500K) superconductivity, and in 1975 the group indeed discovered the world's first 300 degree superconductor, the inorganic polymer polysulfur nitride…alas, the units were millikelvin! In 1986, 25 years ago, Bednorz and Mueller taught us we should have been spending our time looking at layered copper oxide perovskites instead.

Paul Grant at 17. This photo shows him about six months before he went to work for IBM.

Nevertheless, I remain an ardent fan of the Little/Ginzburg exciton-mediated BCS-pairing proposal to enable superconductivity well above 300K. In 1998, I wrote a "sci-fi" piece for ***Physics Today*** predicting its fulfillment by 2028 [3]. Maybe then I can finally come in from the cold.

References

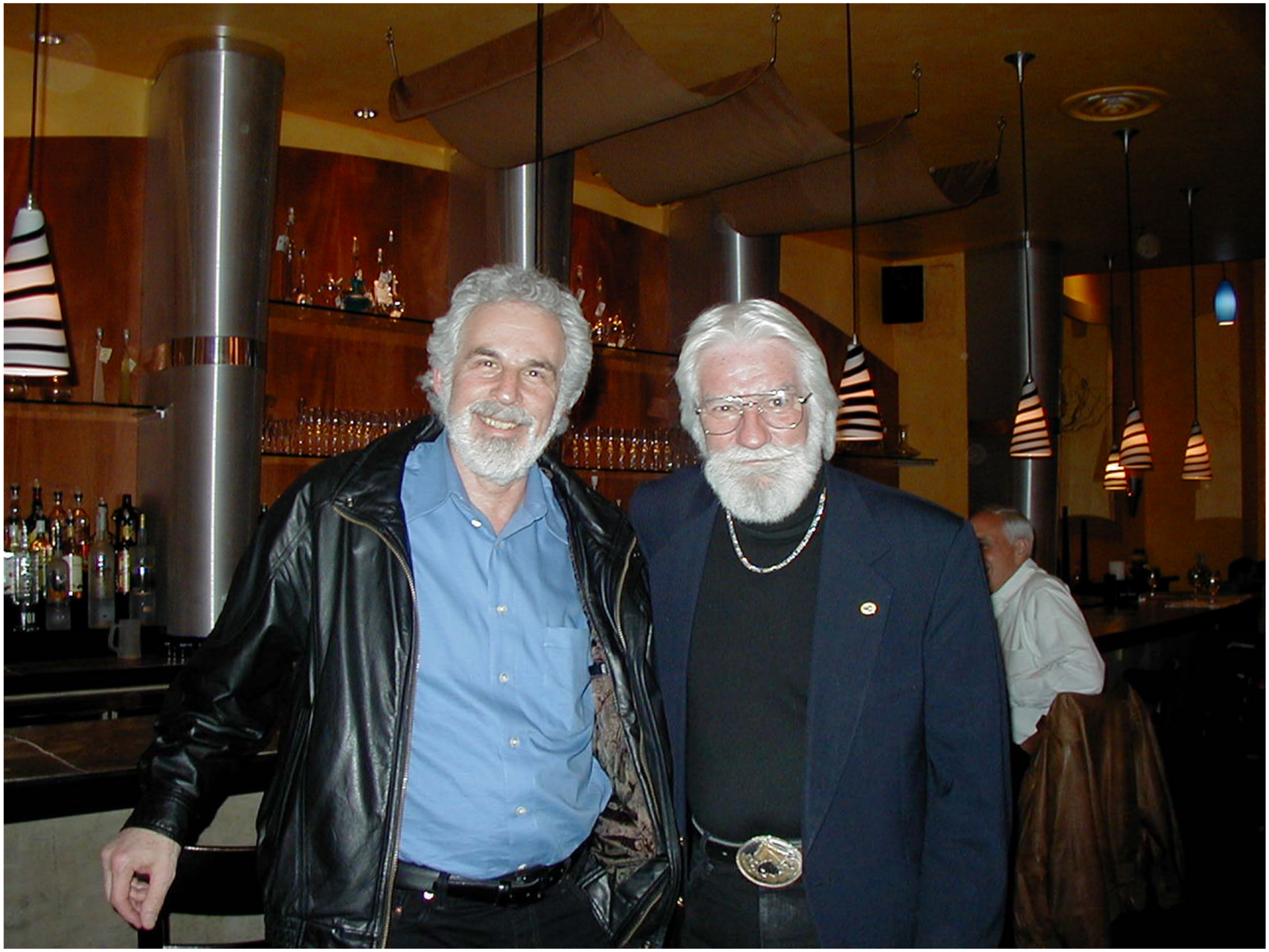
1. A fascinating tale of pre-industrial cryogenics technology can be found in Gavin Weightman's book, "The Frozen Water Trade," (ISBN 0-7868-6740-X), the story of two New England brothers who "farmed" almost every northeastern pond and lake each winter to cool the cocktails of Caribbean resorts in the 19th century.

2. Jim Crowe invented one of the very first superconducting memory elements, and arguably the first to employ trapped flux. See J. W. Crowe, "Trapped-Flux Superconducting Memory," IBM Journal, October 1957, p. 295. Jim Crowe became a good friend, mentor and my manager when I returned to work at IBM summers during my college years.

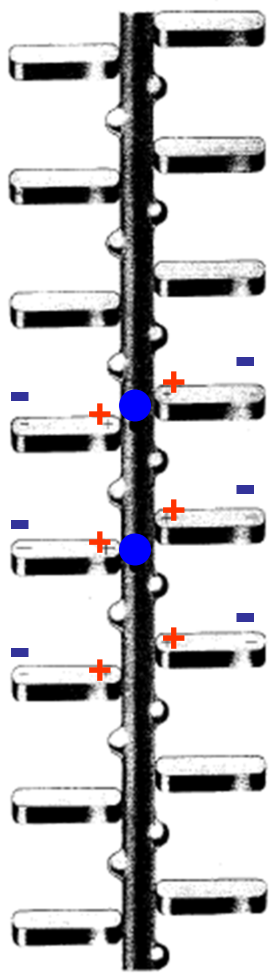
3. P. M. Grant, "Researchers Find Extraordinarily High Temperature Superconductivity in Bio-Inspired Nanopolymer," Physics Today, May 1998. Nineteen more years to go. http://www.w2agz.com/Publications/Popular%20Science/Bio-Inspired%20Superconductivity,%20Physics%20Today%2051,%2017%20(1998)a.pdf

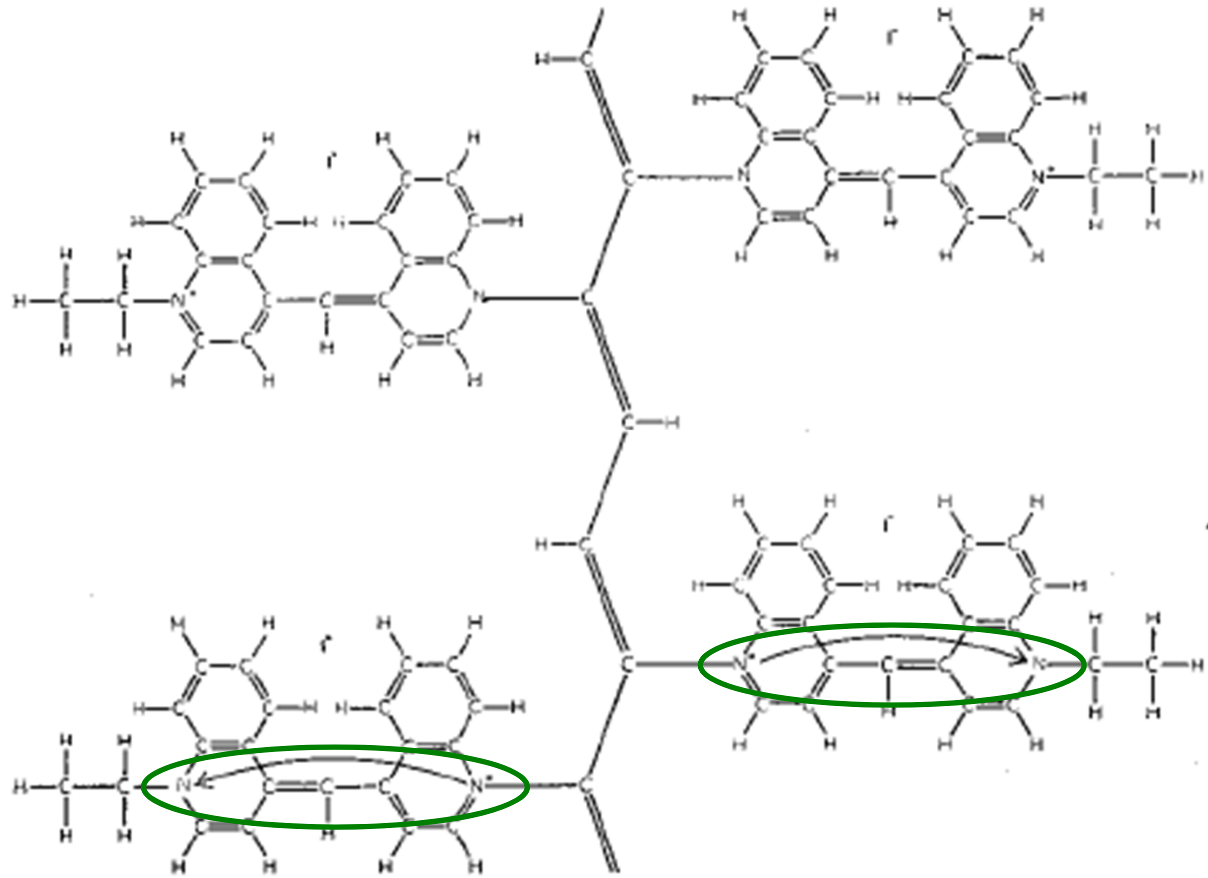
G^2 !

THE BORSCHT BELT BOYS



Little, 1963





Diethyl-cyanine iodide

"Bill Little's BCS"

$$T_C = a\Theta e^{-\frac{1}{\lambda - \mu^*}}$$

Where

Θ = Exciton Characteristic Temperature (~ 22,000 K)

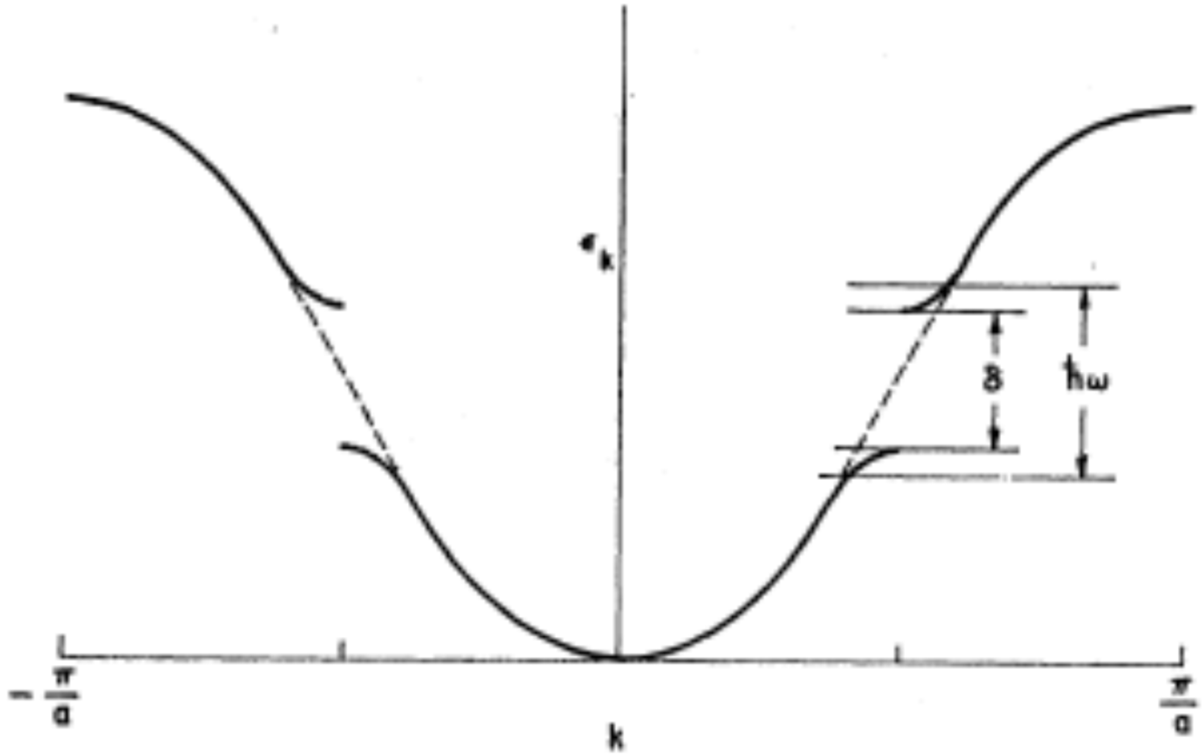
λ = Fermion-Boson Coupling Constant (~ 0.2)

μ^* = Fermion-Fermion Repulsion (?)

a = "Gap Parameter, ~ 1-3"

Tc = Critical Temperature, ~ 300 K

Spine can be a Semiconductor!



False Alarm:

SUPERCONDUCTING FLUCTUATIONS AND THE PEIERLS INSTABILITY IN AN ORGANIC SOLID*

L.B. Coleman, M.J. Cohen, D.J. Sandman, F.G. Yamagishi, A.F. Garito and A.J. Heeger

Department of Physics and Laboratory for Research on the Structure of Matter, University of Pennsylvania, Philadelphia, Pennsylvania 19174, U.S.A.

(*Received* 20 *February* 1973 *by E. Burstein*)

Temperature Dependence of the Near-Infrared Optical Properties of Tetrathiofulvalinium Tetracyanoquinodimethane (TTF-TCNQ)

P. M. Grant, R. L. Greene, G. C. Wrighton,* and G. Castro
IBM Research Laboratory, San Jose, California 95114
(Received 13 August 1973)

We report the near-normal-incidence reflectivity spectrum of single-crystal TTF-TCNQ in the range 0.2–2.0 μm. A Drude-like edge, persisting through the metal-insulator transition at 60°K, is observed near 1.3 μm for light polarized parallel to the conducting axis. The temperature dependence of the optical parameters ϵ_0, τ, and ω_p are discussed in conjunction with Hopfield's relation for the electron-phonon coupling constant.

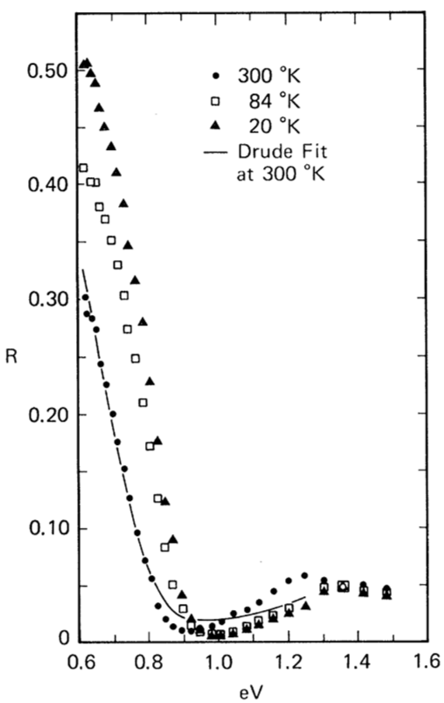


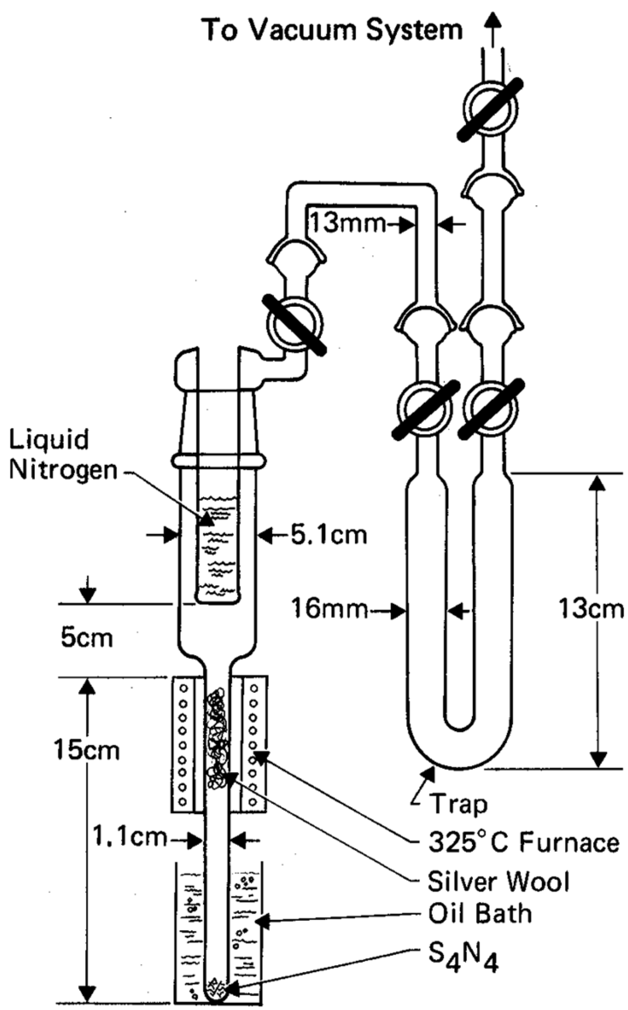
TABLE I. Summary of Drude parameters and the optical conductivity obtained from fitting the data of Fig. 2. At room temperature $\sigma_{dc} \simeq 250\ \Omega^{-1}\ cm^{-1}$.

T (°K)	ϵ_0	ω_p (eV)	τ (10^{-15} sec)	σ_{op} ($\Omega^{-1}\ cm^{-1}$)
300	3.3	1.38	2.3	900
84	2.8	1.41	2.5	1020
67	2.9	1.44	2.7	1170
57	3.0	1.46	3.0	1300
20	3.2	1.52	3.0	1430

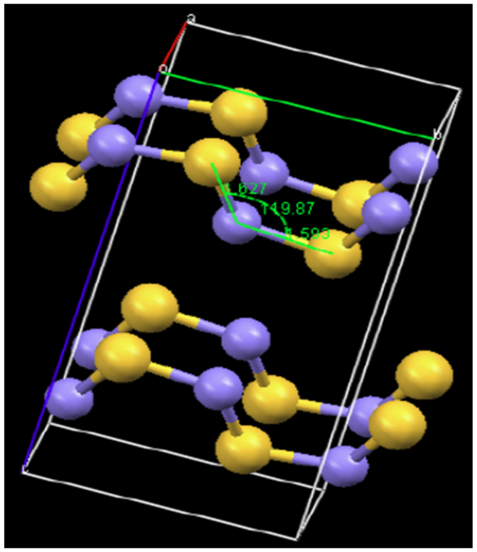
$$\lambda_1 = (\hbar/2\pi kT)\langle \tau_{ep}^{-1}\rangle, \quad \lambda_2 = (\hbar/2\pi k)\omega_p^2\, \partial\rho/\partial T.$$

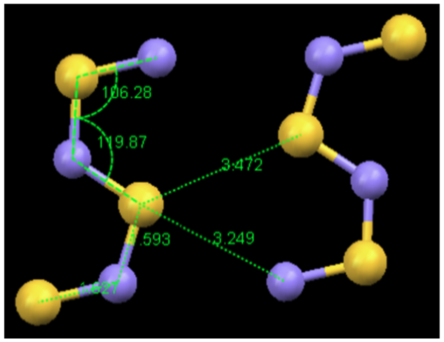
$$\lambda_1 = 1.8, \qquad \lambda_2 = 6.1$$

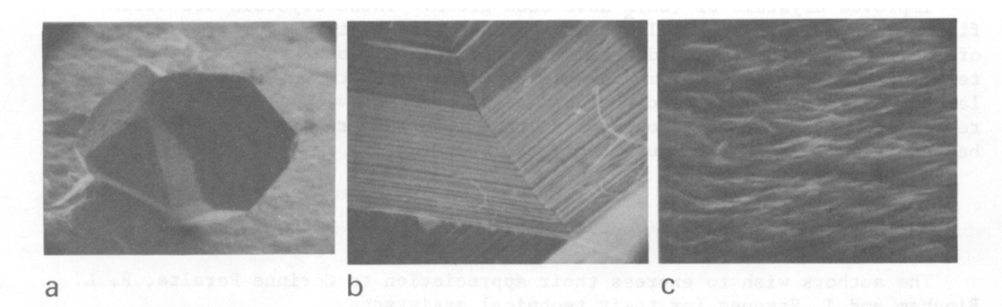
Polysulfur Nitride, (SN_x)



F. B. Burt (1910)
M. Boudeulle (1974)
G. B. Street (1974)







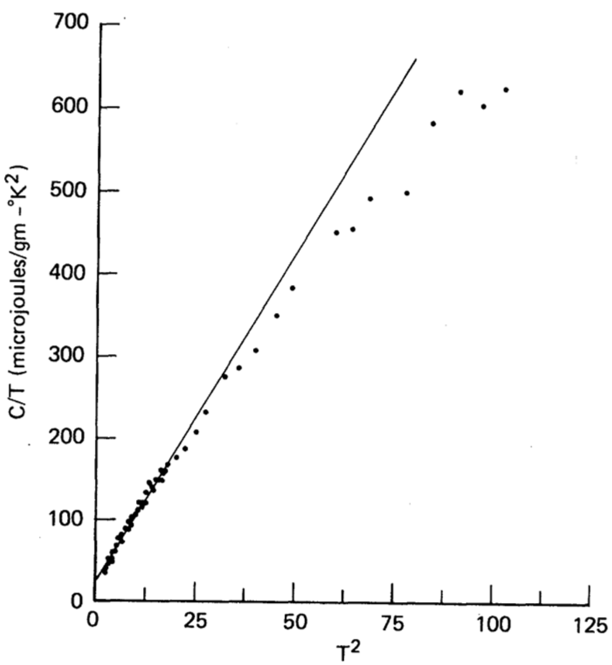
Low-Temperature Specific Heat of Polysulfur Nitride, $(SN)_x$

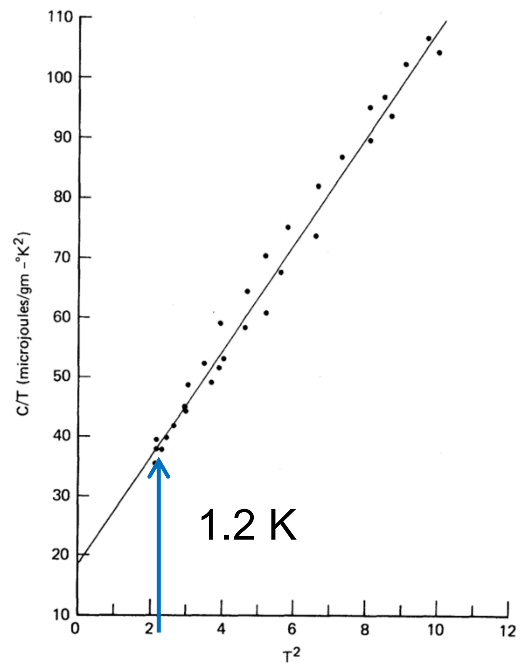
PRL 34, 89 (1975)

R. L. Greene, P. M. Grant, and G. B. Street
IBM Research Laboratory, San Jose, California 95193

(Received 25 September 1974)

Measurements of the specific heat of crystalline $(SN)_x$ in the region 1.5–10°K are reported. A linear temperature contribution to the specific heat is found and interpreted as arising from an electron state density of 0.18 state/(eV spin molecule) and a one-dimensional tight-binding conduction band of width ≥0.9 eV. Analysis of the lattice specific-heat contribution supports existing evidence that $(SN)_x$ is a highly anisotropic crystalline polymer and suggests a possible explanation for the apparent absence of a Peierls transition.





Superconductivity in Polysulfur Nitride $(SN)_X$

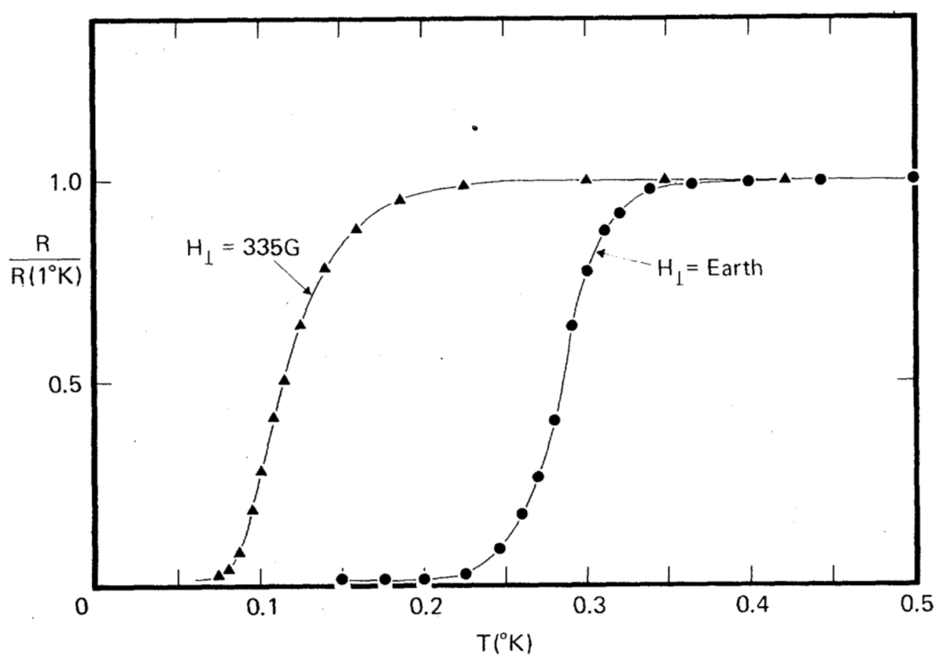
PRL 34, 577 (1975)

R. L. Greene and G. B. Street
IBM Research Laboratory, San Jose, California 95193

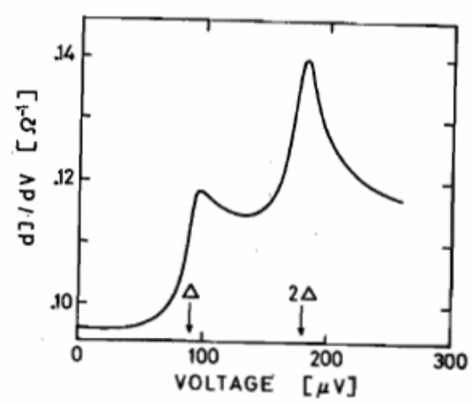
and

L. J. Suter*†
Department of Physics, Stanford University, Stanford, California 94305
(Received 27 January 1975)

The inorganic crystalline polymer polysulfur nitride has been found to become superconducting with a transition temperature of (0.26 ± 0.03)°K.



Precursor to a Nobel Prize



Tunneling Investigation of Superconducting $(SN)_x$

G. Binnig and H.E. Hoenig
Physikalisches Institut der Universität Frankfurt, Germany

Z. Physik B 32, 23 – 26 (1978)

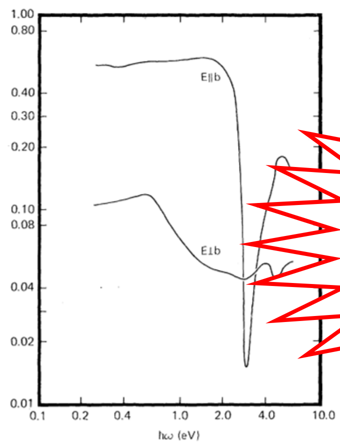
Optical Properties of Polymeric Sulfur Nitride, $(SN)_x$ †

PRL 35, 1743 (1975)

P. M. Grant, R. L. Greene, and G. B. Street
IBM Research Laboratory, San Jose, California 95193

(Received 30 June 1975)

We report polarized reflectivity measurements on crystalline $(SN)_x$ in the range of 0.25–6.0 eV. Our analysis of the data gives $\hbar\omega_p = 4.6$ eV and $m^* = 2m_e$, values considerably different from those previously reported by other workers. The data also suggest that $(SN)_x$ has sufficient electronic dimensionality to suppress a Peierls distortion.



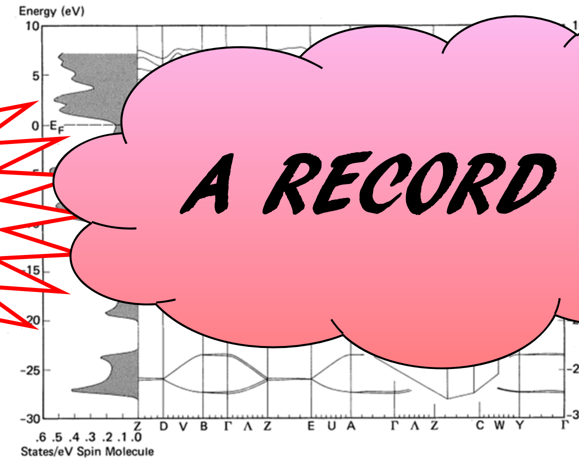
Orthogonalized-Plane-Wave Band Structure of Polymeric Sulfur Nitride, $(SN)_x$

PRL 35, 1799 (1975)

W. E. Rudge and P. M. Grant
IBM Research Laboratory, San Jose, California 95193

(Received 22 September 1975)

We present the first orthogonalized-plane-wave band structures and corresponding densities of states for two reported crystal structures of polymeric surfur nitride, $(SN)_x$, and compare our results with experiment. We examine the band structures in light of the low-temperature stability of the metallic and superconducting states in $(SN)_x$ and conclude that this stability derives from closed Fermi surfaces introduced by electronic interchain coupling.



Three PRLs In One Month!

A RECORD ?

X-Ray-Photoelectron-Spectroscopy Determination of the Valence Band Structure of Polymeric Sulfur Nitride, $(SN)_x$

PRL 35, 1803 (1975)

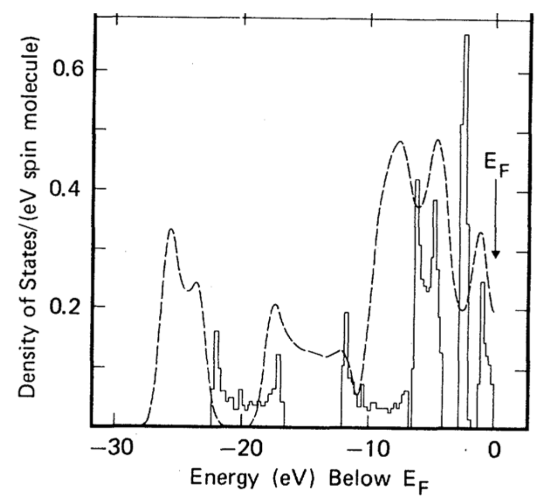
P. Mengel,* P. M. Grant, W. E. Rudge, and B. H. Schechtman
IBM Research Laboratory, San Jose, California 95193

and

D. W. Rice
IBM General Products Division, San Jose, California 95193

(Received 22 September 1975)

We report x-ray photoemission (XPS) measurements on polymeric sulfur nitride, $(SN)_x$. Both valence-band states and core-level binding energies have been studied. The charge transfer δ in the $S^{+\delta}N^{-\delta}$ bond is estimated to be 0.30–0.42 electrons. The XPS spectra are compared with densities of states derived from a single-chain tight-binding calculation and also with three-dimensional orthogonal-plane-wave (OPW) calculations based on the two reported $(SN)_x$ crystal structures. Good quantitative agreement is found with the OPW density of states.



Conference on Organic Conductors and Semiconductors, Siófok, Hungary 1976

ELECTRONIC STRUCTURE AND OPTICAL PROPERTIES OF POLYSULFUR NITRIDE, $(SN)_x$

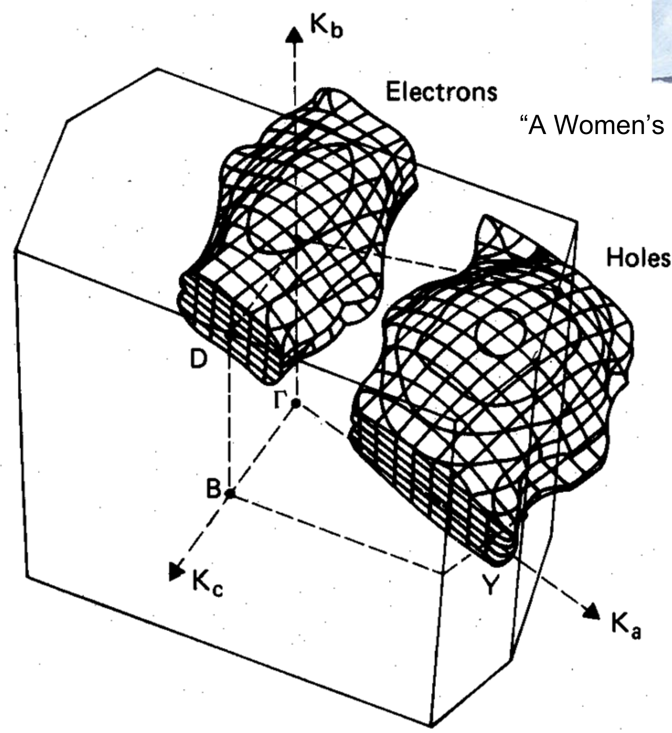
P.M. GRANT, W.E. RUDGE and I.B. ORTENBURGER

IBM Research Laboratory San Jose, California 95193, USA

Two-Band Semimetal

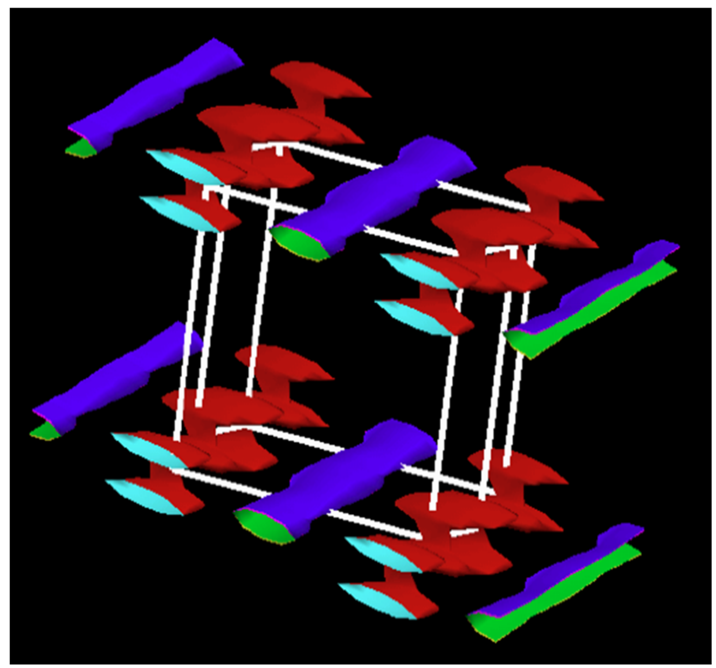
MgB_2 ?
Fe-Pnictides ?

OPW, 1975-6



"A Women's Place is on Top"

Quantum-Espresso, 2009




D10
D12
Delta

Solid State Communications, Vol. 29, pp. 225–229.
Pergamon Press Ltd. 1979. Printed in Great Britain.

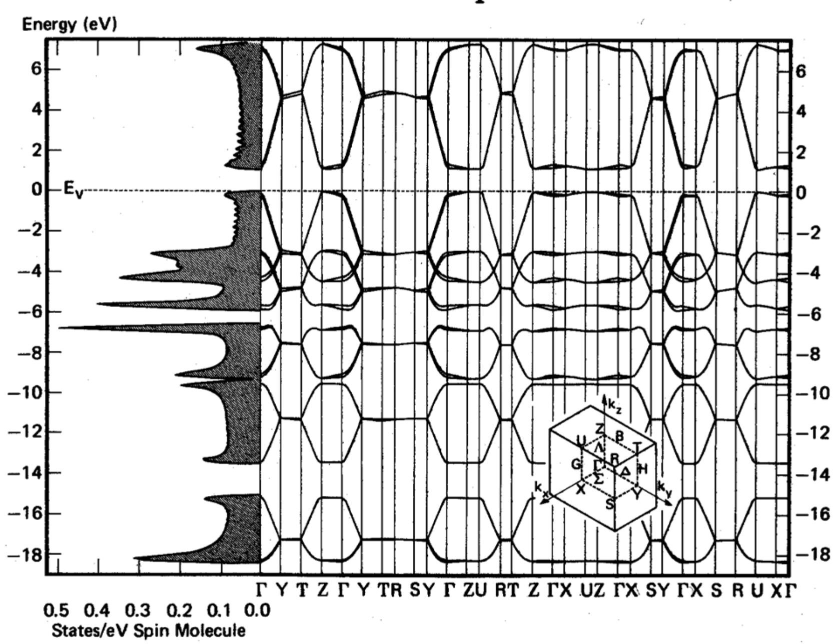
BAND STRUCTURE OF POLYACETYLENE, $(CH)_x$

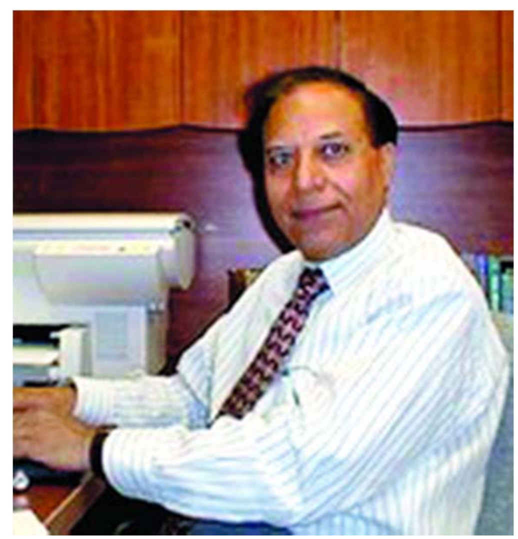
P.M. Grant and I.P. Batra

IBM Research Laboratory, San Jose, CA 95193, U.S.A.

(*Received* 17 *August* 1978 *by A.A. Maradudin*)

The one-electron energy bands and densities of states of polyacetylene in both *cis*- and *trans*-conformations have been investigated. The principal issue addressed is whether the itinerant picture alone is sufficient to explain the experimental properties of this material. We conclude that the one-electron model provides an excellent zeroth-order explanation of current observations of optical and transport effects in both pure and doped forms of this unusual polymer.





JOURNAL DE PHYSIQUE

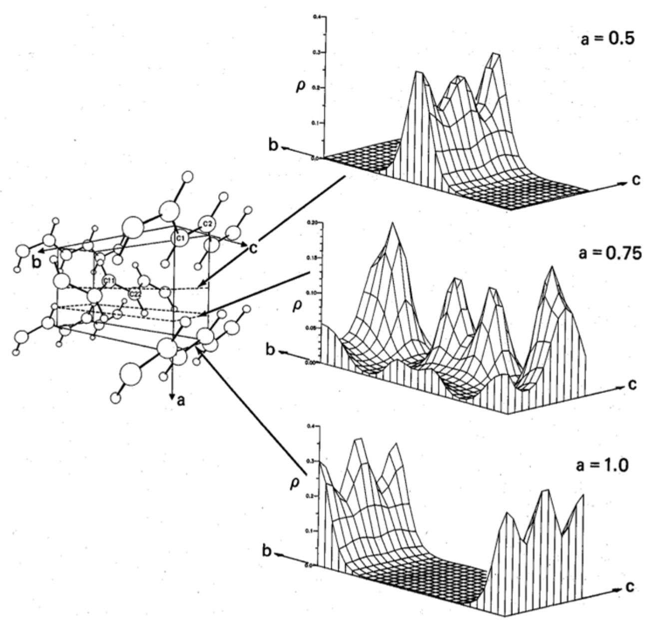
Colloque C3, supplément au n°6, Tome 44, juin 1983

SELF-CONSISTENT CRYSTAL POTENTIAL AND BAND STRUCTURE OF THREE-DIMENSIONAL TRANS-POLYACETYLENE

P.M. Grant and Inder P. Batra

IBM Research Laboratory, 5600 Cottle Road, San Jose, California 95193, U.S.A.

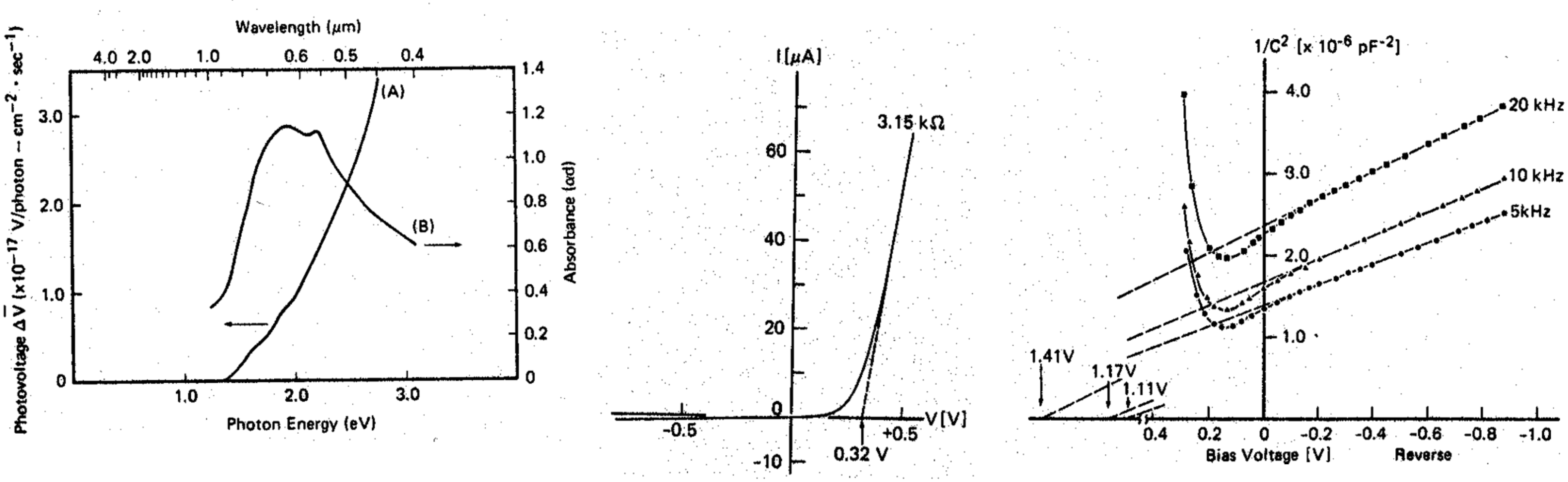
Résumé — Nous avons calculé la structure des bandes à trois dimensions d'un cristal parfait de *trans*-polyacétylène en utilisant une technique self-consistante de pseudopotentiel. Nous avons obtenu la distribution de la densité de charge dans la cellule élémentaire. Nous trouvons que les propriétés à un électron sont extrèmement anisotropes dans le *trans*-polyacétylène. Nous suggèrons que les interactions des solitons (ou <<kink>>) entre chaînes pourraient être assez faibles.



Synthetic Metals, 1 (1979/80) 301 - 306

PHOTOCONDUCTIVITY AND JUNCTION PROPERTIES OF POLY-ACETYLENE FILMS*,**

T. TANI,† W. D. GILL, P. M. GRANT, T. C. CLARKE and G. B. STREET
IBM Research Laboratory, San Jose, Cal. 95193 (U.S.A.)



First paper on polymer electronic and solar devices

VOLUME 50, NUMBER 13 PHYSICAL REVIEW LETTERS 28 MARCH 1983

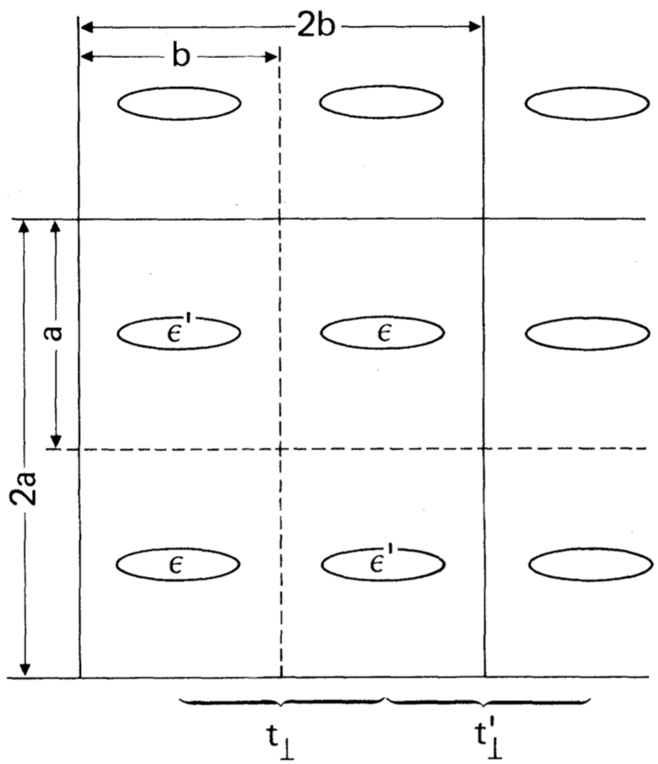
Broken-Symmetry Band Structure of Ditetramethyltetraselenafulvalene-X [$(TMTSF)_2X$]

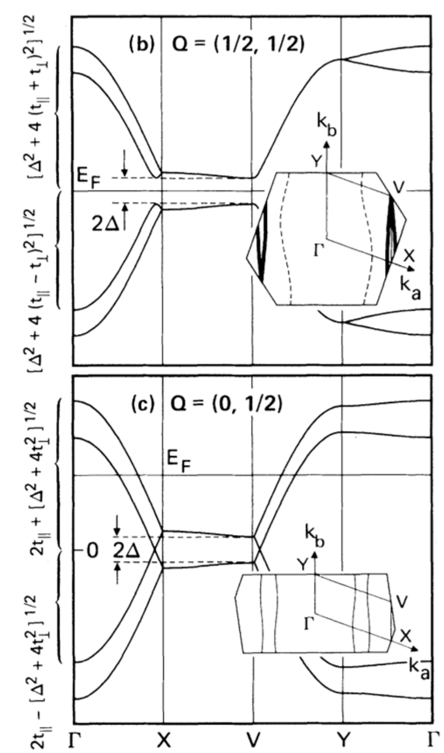
P. M. Grant
IBM Research Laboratory, San Jose, California 95193
(Received 19 November 1982)

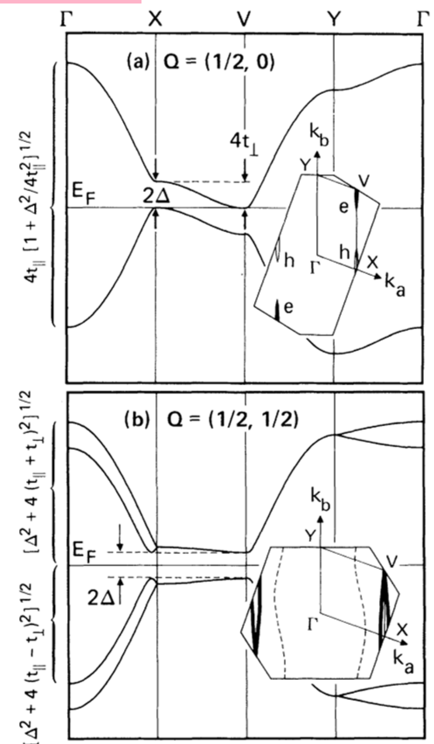
The author derives a set of two-dimensional band structures arising from spin- and/or lattice-induced commensurate symmetry breaking of the high-temperature, ambient-pressure phase of ditetramethyltetraselenafulvalene-X. These band structures are proposed as the framework for many of the low-temperature transport properties of these compounds and are shown to be consistent with experiment in those cases where the broken symme-
try conditic

Relevant to today's T^* - T_C conundrum?

X =
PF_6
AsF_6
SbF_6
TaF_6
ClO_4
ReO_4
NO_3

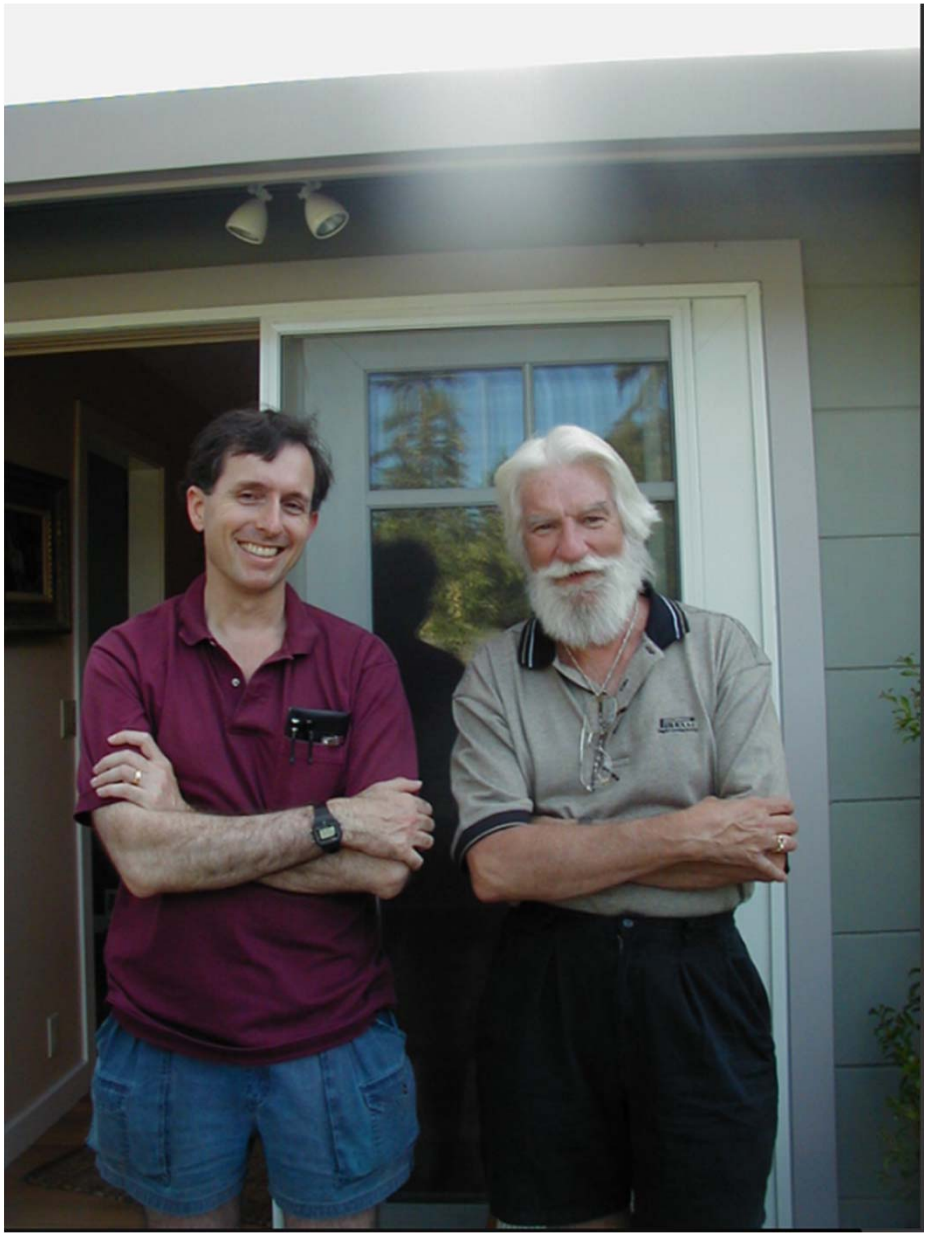




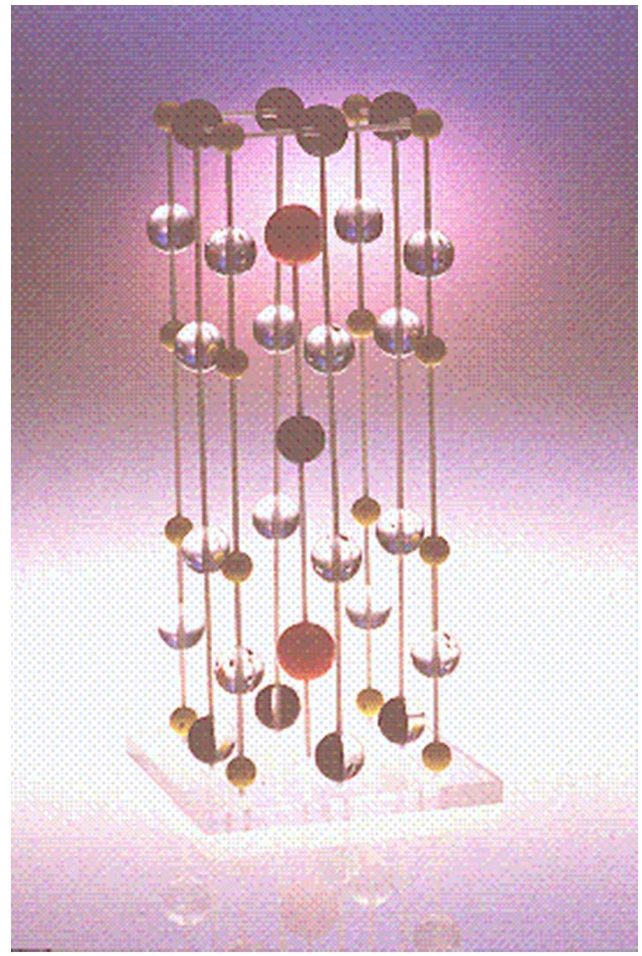


26 February 1987
Back from UCSB

The Almaden 1-2-3 Story: 1986-89



2 March 1987
"1-2-3"



2 March 1987
"1-2-3"

Superconductivity above Liquid Nitrogen Temperature: Preparation and Properties of a Family of Perovskite-Based Superconductors

JACS 109, 2848 (1987)

E. M. Engler,* V. Y. Lee, A. I. Nazzal, R. B. Beyers, G. Lim, P. M. Grant, S. S. P. Parkin, M. L. Ramirez, J. E. Vazquez, and R. J. Savoy

IBM Almaden Research Center
San Jose, California 95120

Received March 25, 1987

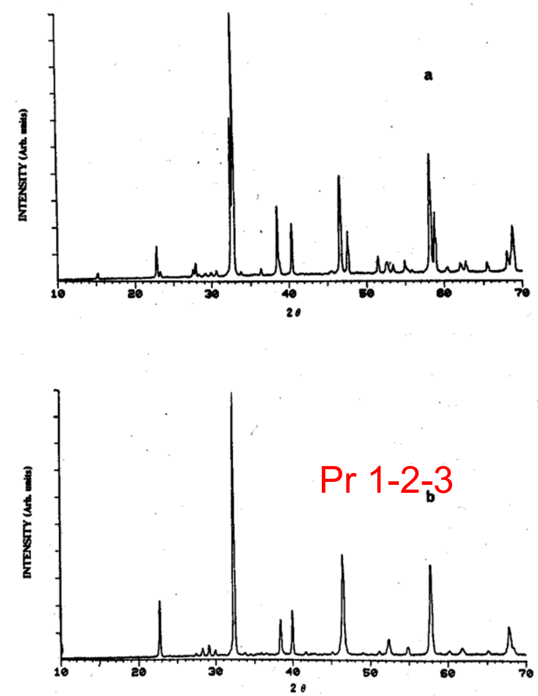


Figure 1. X-ray powder diffraction patterns for (a) $Y_1Ba_2Cu_3O_y$ and (b) $Pr_1Ba_2Cu_3O_y$.

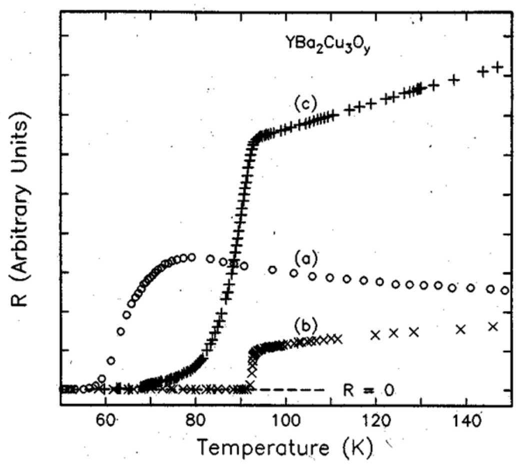


Figure 2. Plot of four-probe electrical resistivity vs. temperature for $Y_1Ba_2Cu_3O_y$ under various preparative conditions: (a) fast removal of pellets from oxygen anneal at 900 °C; (b) slow cooling of oxygen annealed sample from 900 to 200 °C over 5 h; (c) same as (b) except air anneal.

Table I. Superconducting Properties of $Y_1Ba_2Cu_3O_y$ Derivatives

compd	*T* onset	T_c(midpoint), K	ΔT_c(90–10% value), K
$YBa_2Cu_3O_y$	98	94	2
$NdBa_2Cu_3O_y$	80	~45	~50
$SmBa_2Cu_3O_y$	90	85	8
$EuBa_2Cu_3O_y$	98	92	1
$GdBa_2Cu_3O_y$	92	86	8
$DyBa_2Cu_3O_y$	95	91	2
$HoBa_2Cu_3O_y$	96	92	1
$YbBa_2Cu_3O_y$	93	90	2
$LuBa_2Cu_3O_y$	45	32	~20
$Y_{0.5}Sc_{0.5}Ba_2Cu_3O_y$	94	90	4
$Y_{0.5}La_{0.5}Ba_2Cu_3O_y$	90	80	10
$Y_{0.5}Lu_{0.5}Ba_2Cu_3O_y$	96	92	1
$YSrCaCu_3O_y$	85	82	3
$YBaSrCu_3O_y$	89	85	1
$YBaCaCu_3O_y$	87	82	1
$YbBaSrCu_3O_y$	85	81	2
$YbBaCaCu_3O_y$	85	81	2

17 – 19 March 1987
The Woodstock of Physics

VOLUME 58, NUMBER 23 PHYSICAL REVIEW LETTERS 8 JUNE 1987

Evidence for Superconductivity in La_2CuO_4

P. M. Grant, S. S. P. Parkin, V. Y. Lee, E. M. Engler, M. L. Ramirez, J. E. Vazquez, G. Lim, and R. D. Jacowitz
IBM Almaden Research Center, San Jose, California 95120

and

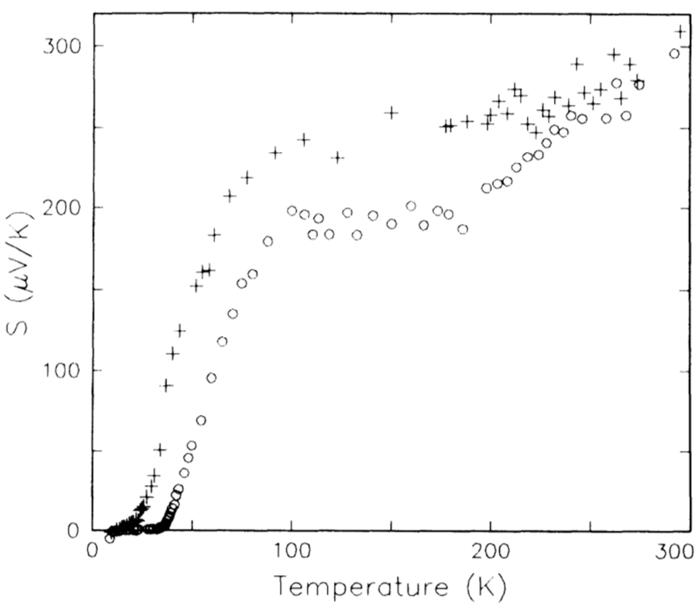
R. L. Greene
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598

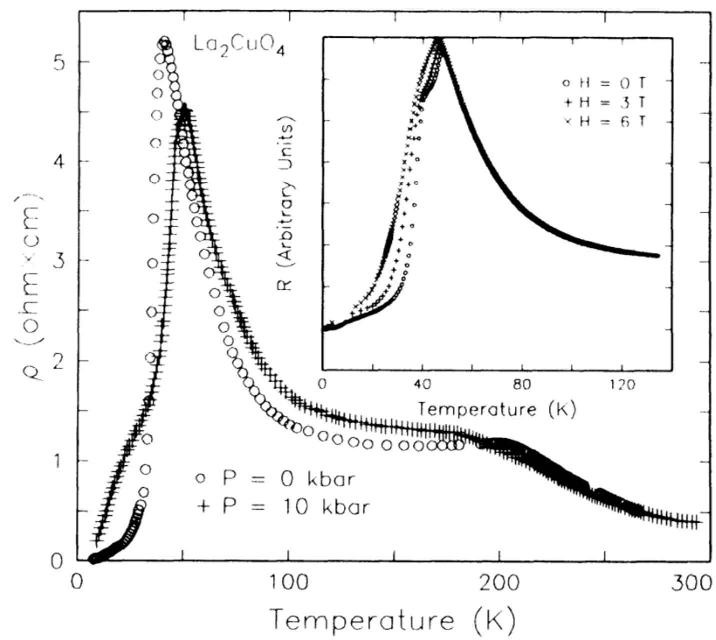
(Received 28 April 1987; revised manuscript received 15 May 1987)

We report evidence for superconductivity in undoped La_2CuO_4 obtained from resistivity, thermoelectric power, and susceptibility measurements. The onset temperature is near 40 K and we have deter-

and can be controlled by oxygen pressure. We discuss several likely sources for the superconducting activity.

High-Tc could have been discovered in the 1960s !



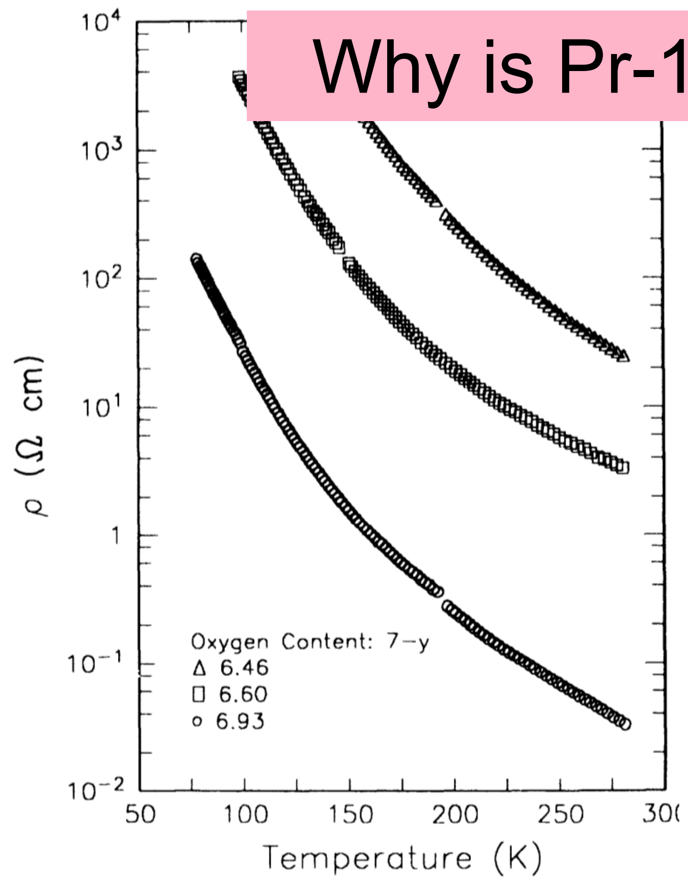


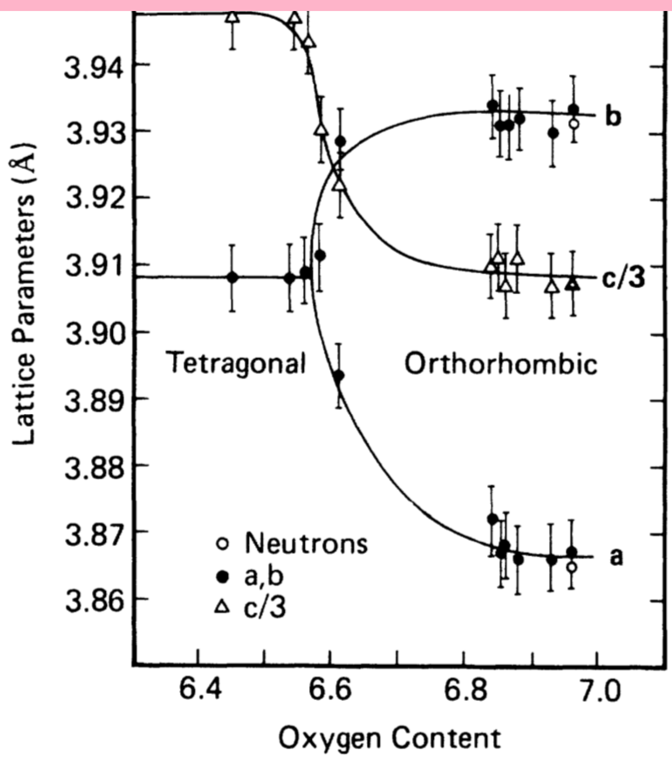
The Praseodymium Paradox

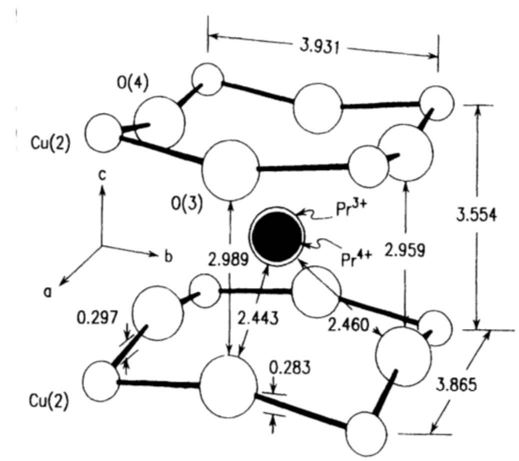
Role of oxygen in $PrBa_2Cu_3O_{7-y}$: Effect on structural and physical properties

M. E. López-Morales,* D. Ríos-Jara, J. Tagüeña, and R. Escudero
Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México,

Why is Pr-123 not even a conductor?







A Clue to the mystery of HTSC?

1989: World Record T_C in n-Type T' Copper Oxide Perovskites

THE EFFECTS OF SYNTHESIS AND REDUCTION PROCESSING ON THE PHYSICAL PROPERTIES OF CERAMIC

$Nd_{1.85}Ce_{0.15}CuO_{4-y}$

M. E. López-Morales*, B. T. Ahn,
R. B. Beyers,
and P. M. Grant

IBM Research Division
Almaden Research Center
650 Harry Road
San Jose, California 95120-6099

"Effects of Synthetic Conditions and Reduction Processing on the Physical Properties of Ceramic $Nd_{2-x}Ce_xCuO_{4-y}$." M. E. López-Morales, B. T. Ahn, R. B. Beyers and P. M. Grant, *Proceedings of the XI Winter Meeting on Low Temperature Physics (14-17 January 1990, Cocoyoc, Morelos, México): Progress in High Temperature Superconductivity, Vol. 26,* ed. by J. A. Cogordan, E. Sansores, T. Akachi and A. A. Valladares (World Scientific, Singapore, 1991), p. 93.

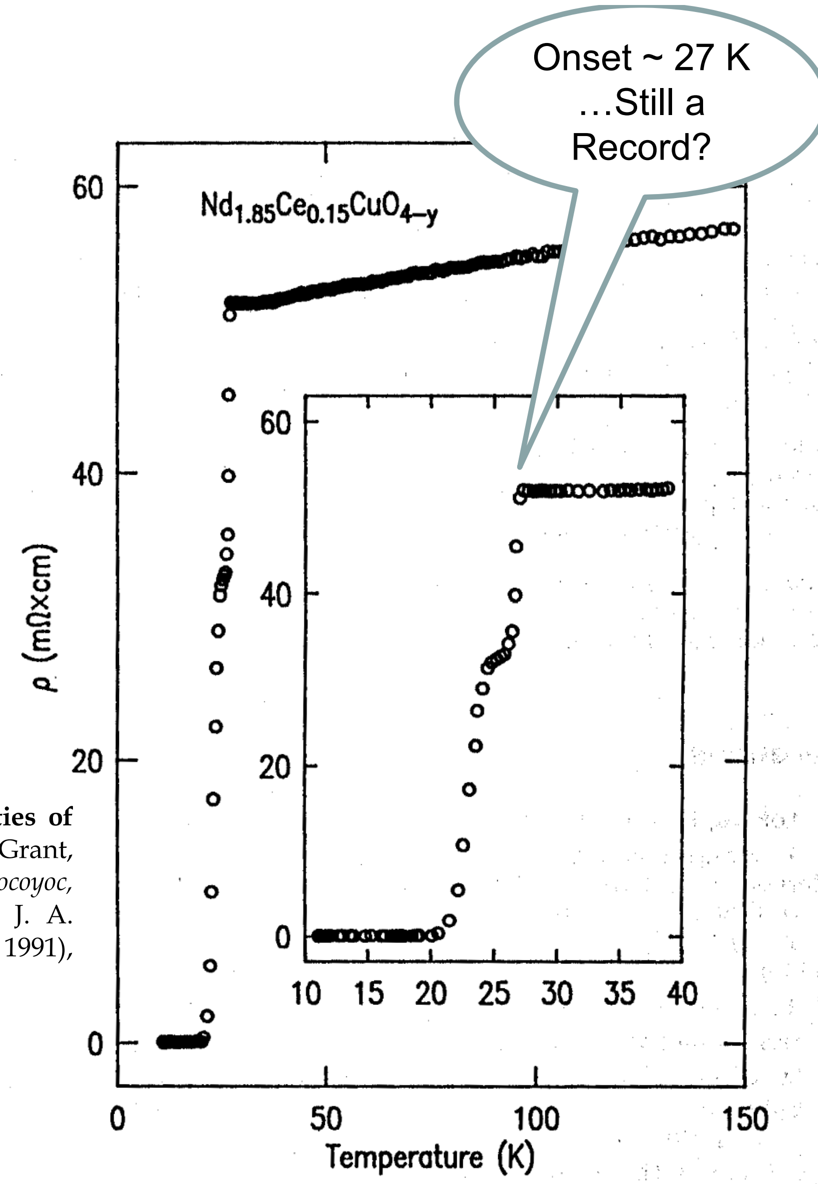


Fig. 2. Temperature dependence of the resistivity of $Nd_{1.85}Ce_{0.15}CuO_{4-y}$

- Why is T_C so low in the n-types?
- Well?
- Maybe that's another clue to the mystery of High-T_C

Field Dependence of Diamagnetic Shielding Fraction with Carrier Concentration in HTSCs

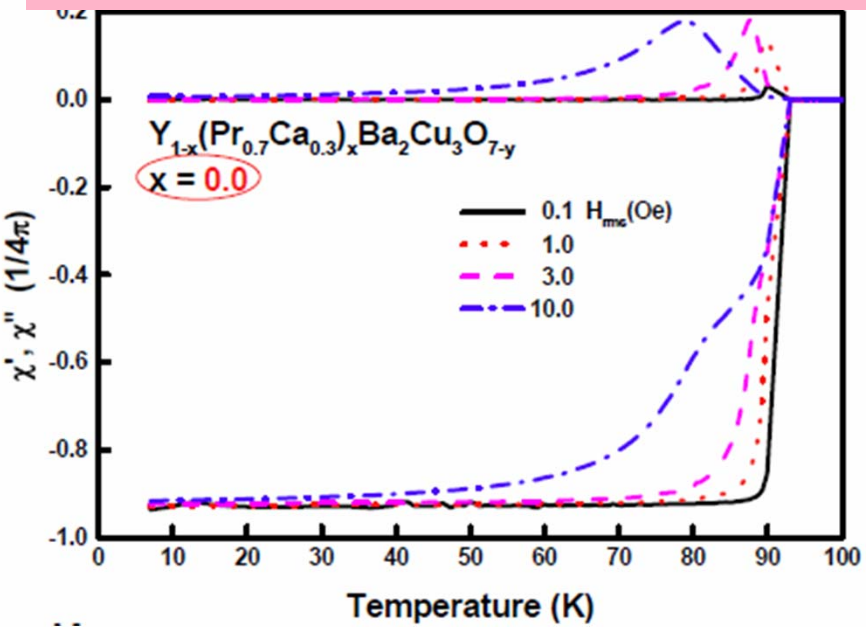
100th Anniversary of APS, Atlanta, GA

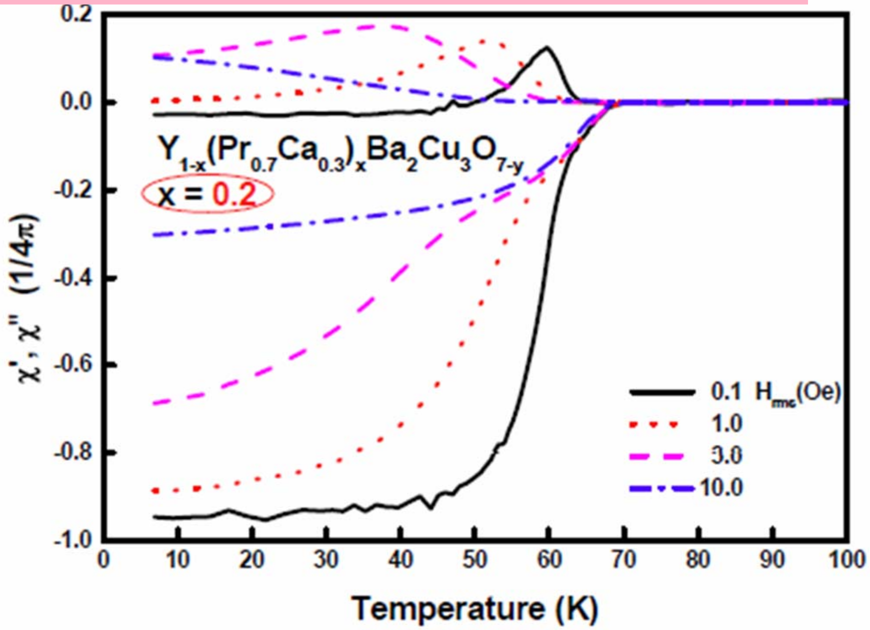
P.M. Grant, W.Y. Lee, A. Nazzal (IBM Almaden Research Center),
M.E. López-Morales (IIM-UNAM)

Work performed at IBM ARC and IIM-UNAM, May 1992-January 1993

WC25.03: 14:24 24 March 1999

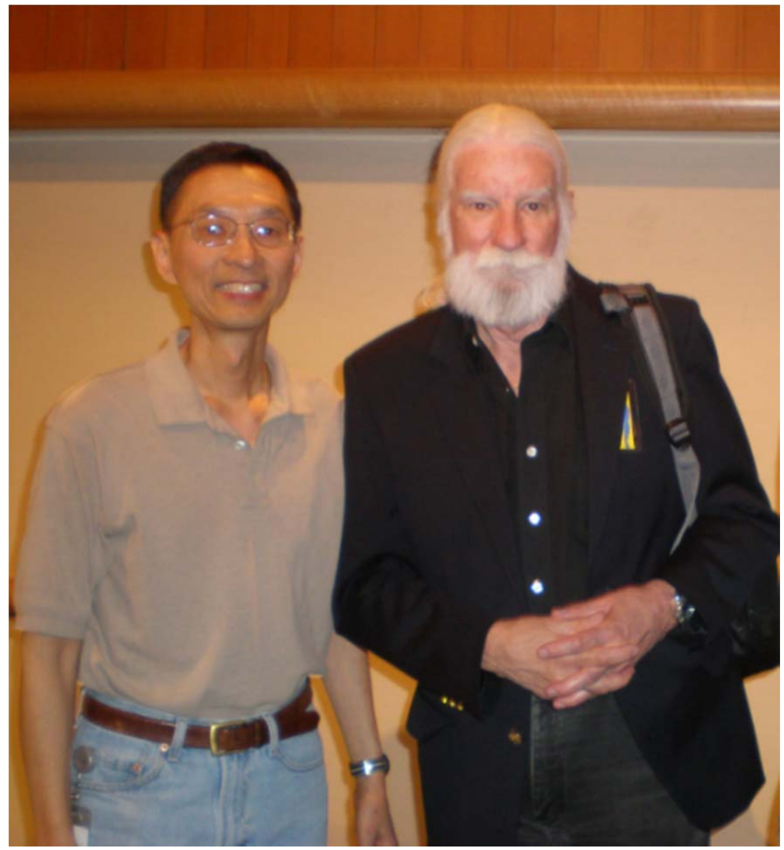
Is this evidence of "electronically granular" superconductivity?
Stripes, perhaps?





Band of Brothers (and a Sister!)

http://www.w2agz.com/The%20Picture%20Story.htm



Almaden Superconductivity Scoreboard

- Polysulfur Nitride
  - January, 1976
  - $T_C = 0.3$ K
- "ET" $(BEDT\text{-}TTF)_4(ReO_4)_2$
  - 1982
  - $T_C \sim 2$ K
- Undoped La_2CuO_{4+x}
  - January, 1987
  - $T_C = 40$ K
- Tl-2223 ($Tl_2Ba_2Ca_2Cu_3O_z$)
  - February, 1988
  - $T_C = 125$ K
- Tl-1223 ($TlBa_2Ca_2Cu_3O_z$)
  - March, 1988
  - $T_C = 110$ K

IBM RD Scoreboard

Almaden	5
Zurich	2
Yorktown	0

New Scientist 30 July 1987

Do-it-yourself superconductors

It is extremely easy to make high-temperature superconductors. Schools in the United States and Britain have already produced their own samples. Here is the recipe

Paul Grant

"Shake 'n' bake" recipe for 1-2-3 ($YBa_2Cu_3O_{7-x}$)

Mix 1·13 grams yttrium oxide, 3·95 grams barium carbonate, 2·39 grams copper oxide
Compact
Grind in mortar and pestle
Bake in air at 950 °C (1650 °F)
Regrind in mortar and pestle
Press into pellets
Rebake pellets in flowing oxygen at 950 °C (1650 °F)
Allow to cool very slowly

Recipe by Heidi Grant

Left: Heidi Grant demonstrates superconductivity at the US National Science Foundation

- Distributed to members of US Congress (at their request)
- 35,000 copies distributed to high schools worldwide by ICTP-Trieste

Rio de Janeiro
4-6 May 1988

Nova 1988

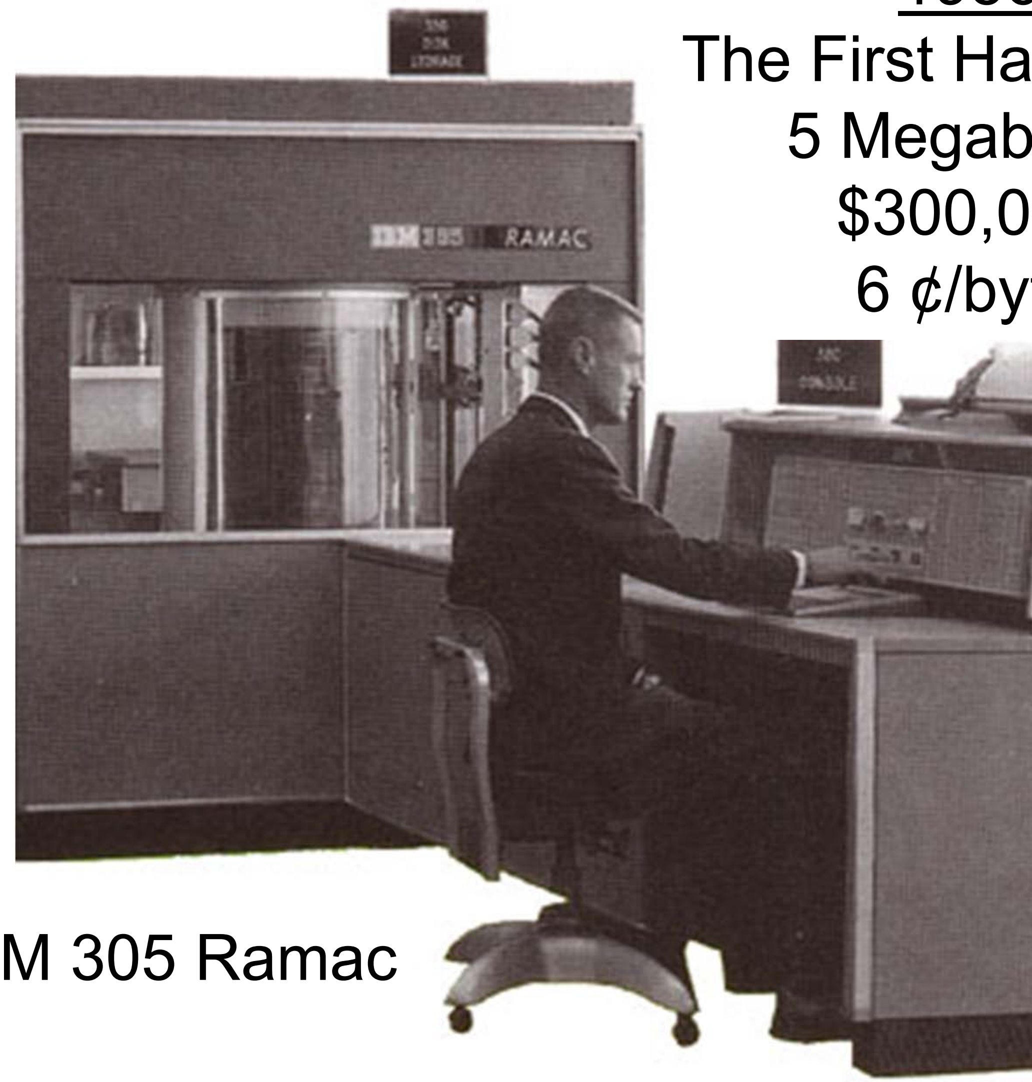
PMG Questioned on Demise of IBM's Josephson Computer Effort

EPRI

…in their shoes…

- Paul Archibald Grant
  - W2AGZ
  - US Navy, WWII
  - IBM, 1948-1974
  - Ski Patrol, 1948-1970
- Mary Ann Whalen Grant
  - CYO BB Champ, 1921
  - NYS Bowling Champ, 1939
  - Women’s Baseball, ‘33-’47
  - CHG&E, 1927-1965

From this:..faster, smaller, cooler…and cheaper!



1956
The First Hard Drive
5 Megabytes
$300,00
6 ¢/byt

IBM 305 Ramac

2011 (+55)
HP Personal Media
2 Terabytes
$100
5 nano-¢/byte

I got two of ‘em!

To this…

…and this…


Texas ‘03
New York ‘99
Chicago ‘99
Detroit ‘00
Northern California ‘01
West Coast ’96
San Francisco ‘00
Atlanta ‘99
Delaware ‘99
New Orleans ‘99

…and this!

PUC orders PG&E to let customers opt out of SmartMeter program

The PUC order is a stunning turnabout on a technology that many consider a key to managing energy use in the future. Utilities around the country have installed the electronic meters -- which can be monitored and adjusted wirelessly -- with little incident. But in Northern California, angry residents have expressed concerns that the meters can lead to overbilling and cause health problems, and PG&E has struggled to counter the bad publicity.

Bob Park!
Where are you when we need you!

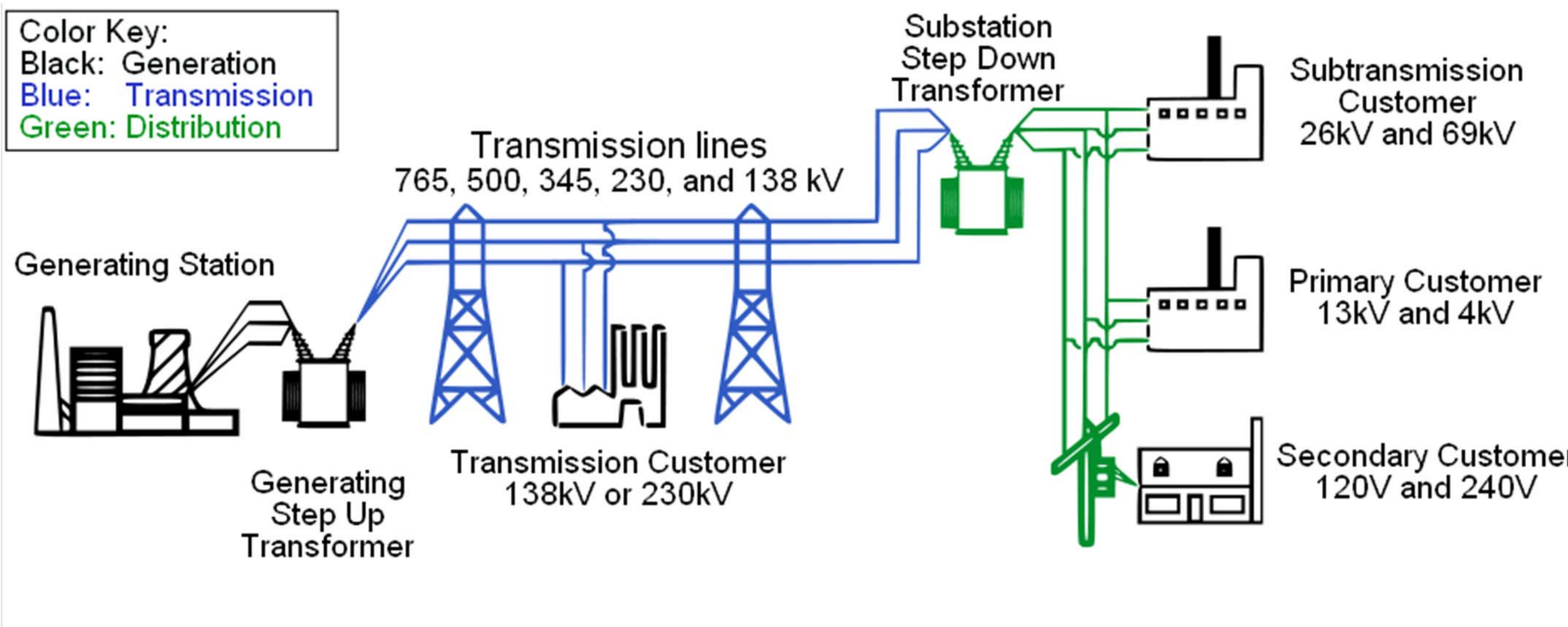
…and…Finally This!

AP/Kyodo News

Blast at Japan nuke plant; thousands missing

Spraying water to cool stressed reactor…Sure. Duh! It's a gas/petrol storage port!

Where Can We Apply Superconductivity to Electric Power?



Potentially Everywhere

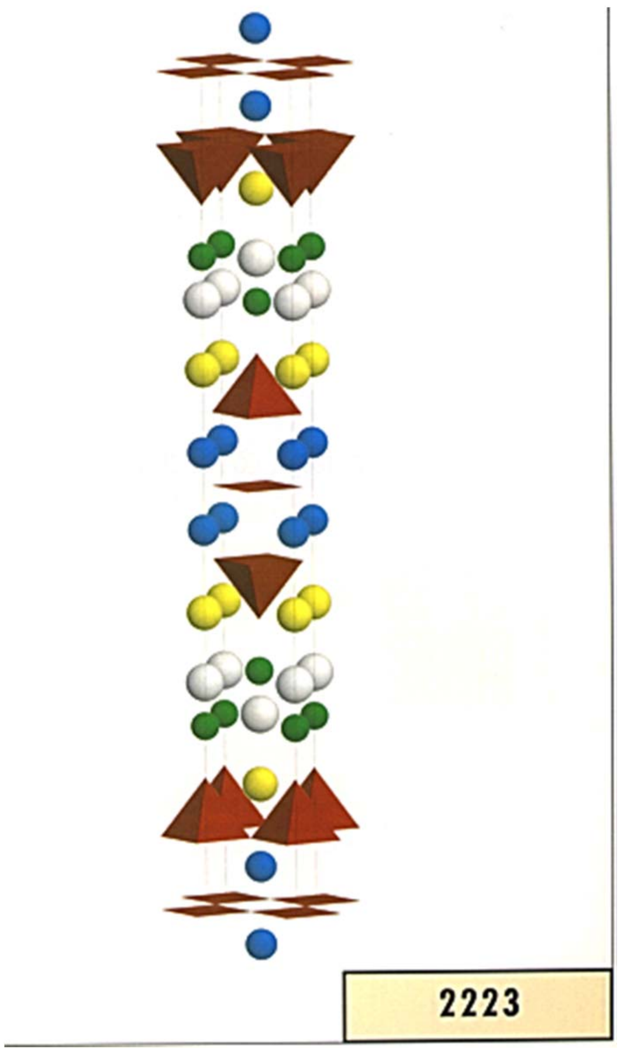
EPRI & Superconductivity

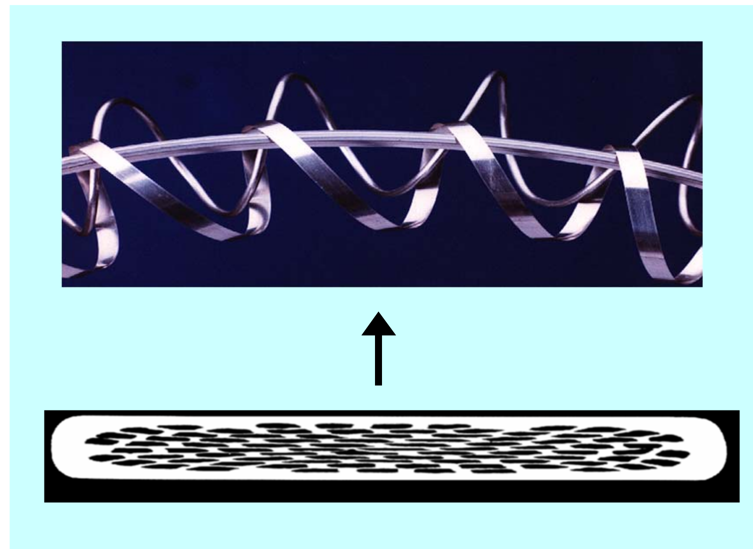
1993-2003 ($18M)

Universities	Industry	Institutions
Wisconsin	AMSC*	LANL
Stanford	Superpower	LBNL
MIT	IBM	ORNL
Houston	Pirelli	DOE (Partner)
Maryland	Westinghouse	CCAS
	Detroit Edison	

*Coated Conductor Alliance ($4M(EPRI)+$6M(AMSC))

First HTSC "Wire"

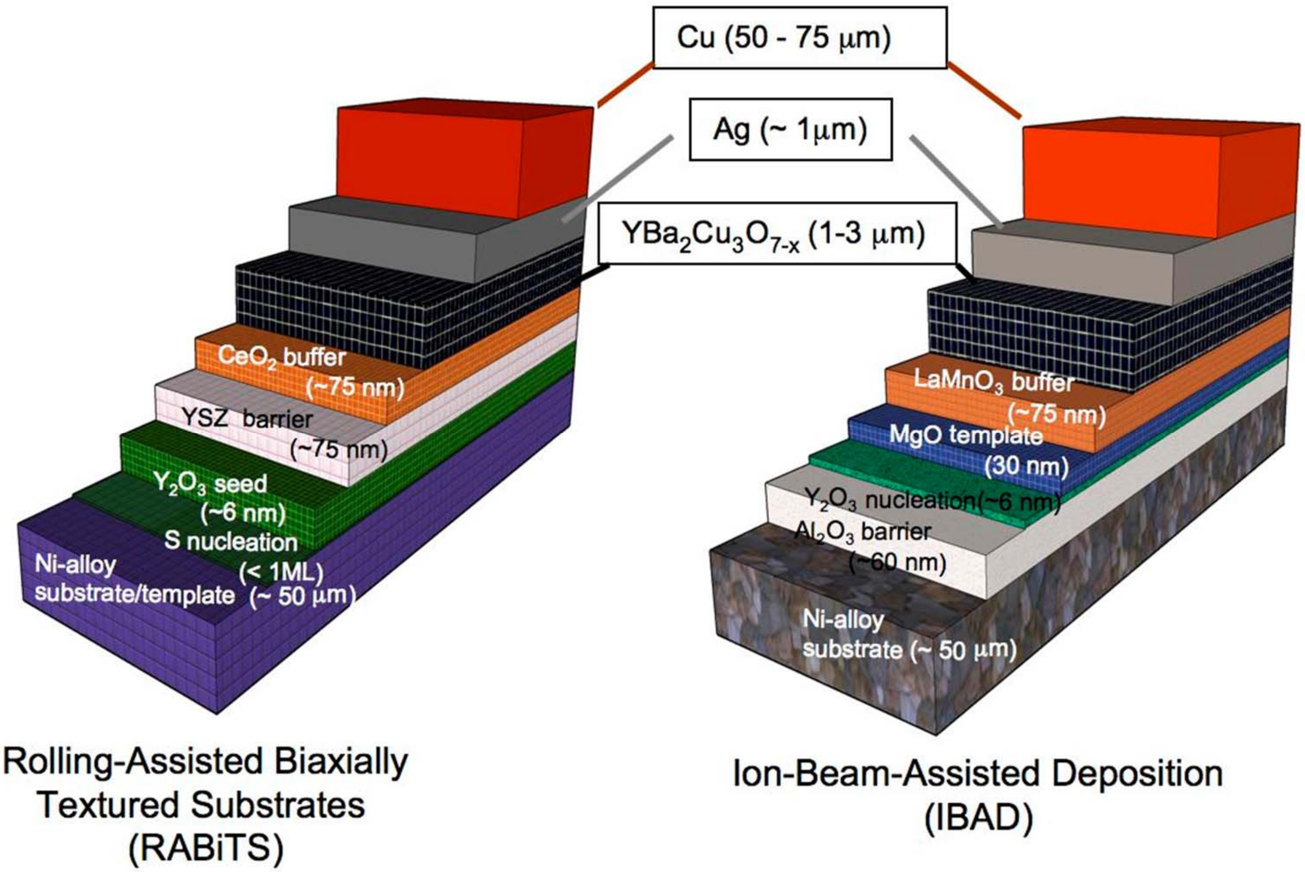




Gen 1

Pirell

Gen II Coated Conductor

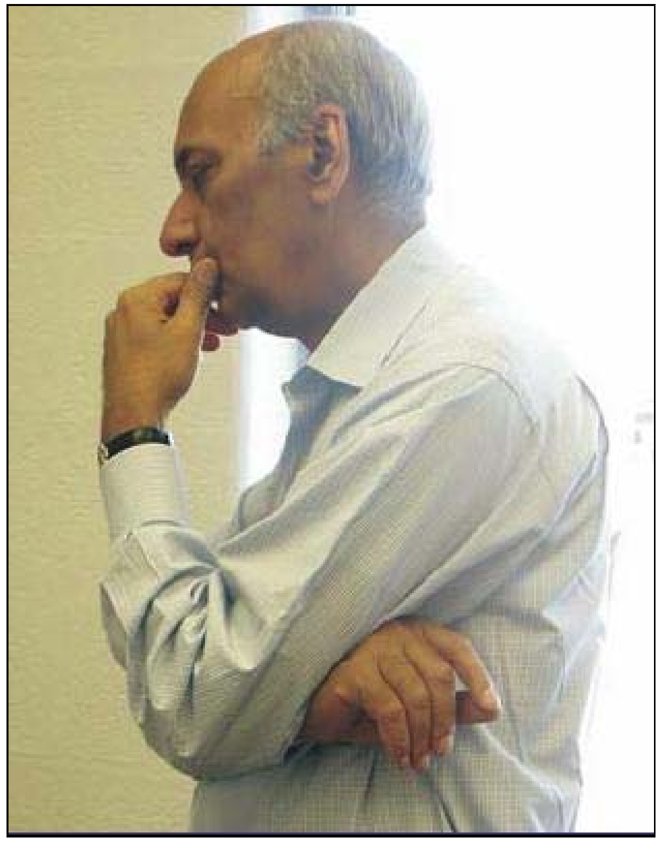


American Superconductor

SuperPower

Orientation Dependence of Grain-Boundary Critical Currents in $YBa_2Cu_3O_{7-\delta}$ Bicrystals

D. Dimos, P. Chaudhari, J. Mannhart, and F. K. LeGoues
Thomas J. Watson Research Center, IBM Research Division,
Yorktown Heights, New York, 10598
(Received 4 May 1988)



Praveen Chaudhari, 1937 - 2010

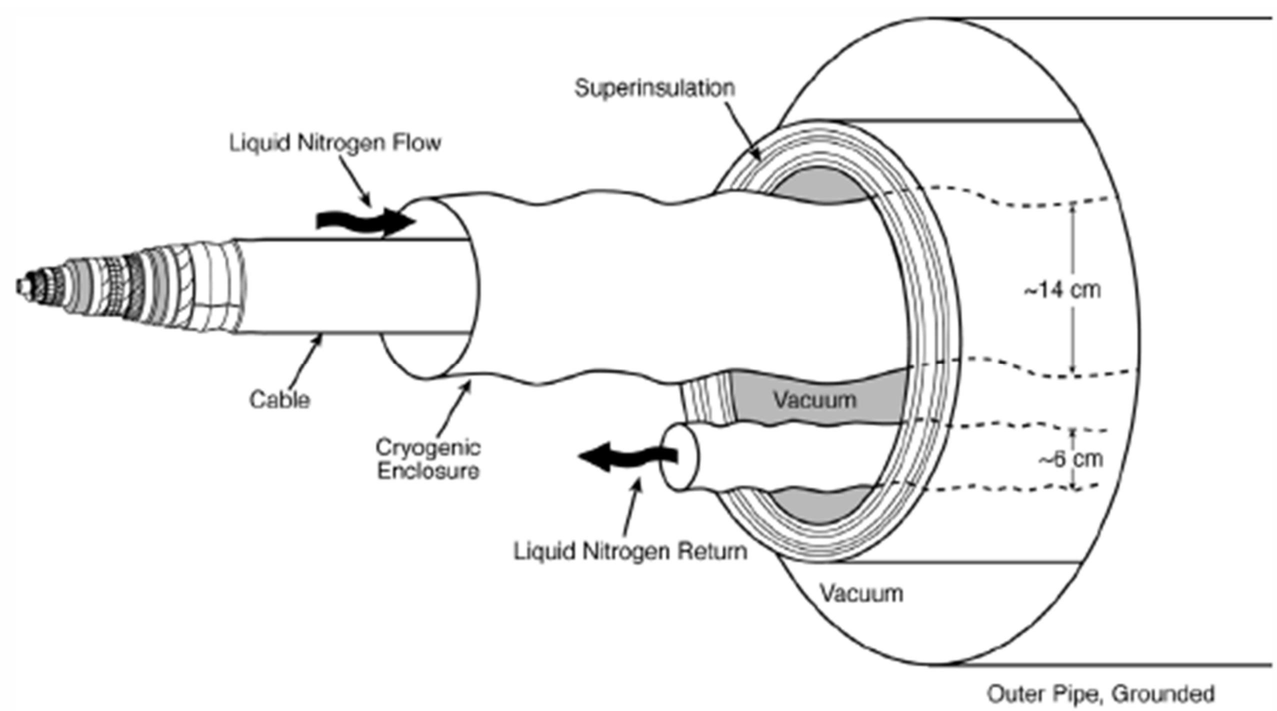
Physics Today, p.64, April 2010

AMSC/Nexans
Long Island Power Authority

A Superconducting dc Cable

EPRI Report 1020458 (2009)

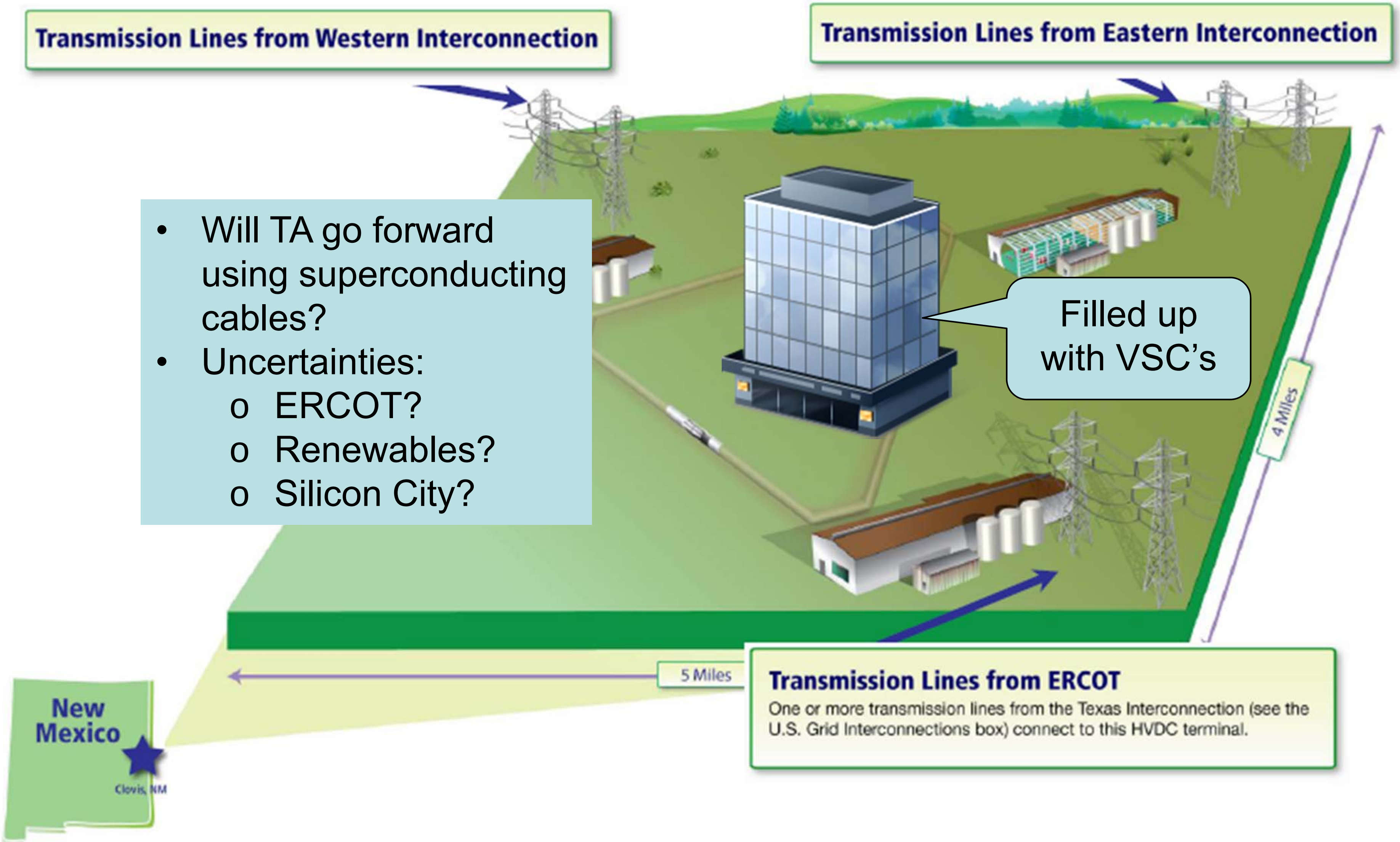
Hassenzahl, Gregory, Eckroad, Nilsson, Daneshpooy, Grant



<u>Monopole Specs</u>

100-kV, 100-kA, 10-GW
66 K < T< 69 K

The Tres Amigas SuperStation



- Will TA go forward using superconducting cables?
- Uncertainties:
  - ERCOT?
  - Renewables?
  - Silicon City?

Filled up with VSC's

US Department of Energy

Budget of the Office of Electricity Delivery and Energy Reliability: FY 2010-11 (10^3 USD)

	FY 2009		FY 2010	FY 2011
	Current Appropriation	ARRA Appropriation	Current Appropriation	Congressional Request
Research and Development				
High Temperature Superconductivity	23,130		?	?
Visualization and Controls	24,461			
Energy Storage and Power Electronics	6,368			
Renewable and Distributed Systems Integration	29,160			
Clean Energy Transmission and Reliability			38,450	35,000
Smart Grid Research and Development			32,450	39,293
Energy Storage			14,000	40,000
Cyber Security for Energy Delivery Systems			40,000	30,000
SUBTOTAL Research and Development	**83,119**		**124,900**	**144,293**
Permitting, Siting, and Analysis	5,271		6,400	6,400
Infrastructure Security and Energy Restoration	6,180		6,187	6,188
Program Direction	21,180		21,420	29,049
Congressionally Directed Activities	19,648		13,075	
American Recovery and Reinvestment Act, 2009		4,495,712		
Use of prior year balances	-769			
TOTAL	**134,629**	**4,495,712**	**171,982**	**185,930**

WOW ! “Obama Cash”

A Modest Proposal
-Upbraiding the Utilities-

- More than a half-century of successful demonstrations/prototyping power applications of superconductivity (1950s - >2000, in Japan and US)…low- and high-Tc…now sitting “on the shelf.”
- Why aren’t they “in the field” today?
- Is their absence due to…
  - Cost?
  - Hassle?
  - or “lack of compelling” need?
  - or “all of the above?”

- US utilities have long claimed to “want”…
  - Efficient long-length cables
  - Oil-free transformers
  - Energy Storage
  - Fast fault current limiters at high voltage (FCLs)
  - Efficient rotating machinery (aka, motors and generators)
- Well, we got ‘em. Utilities claim:
  - They’re too high-cost, because,
    - The wire is too expensive.
    - They have to be kept too cold.
    - Electricity is cheap, and “in field” energy efficiency is not a “compelling” driver
  - Anyway, we can solve our needs by incrementally improving the “old” ways (<u>don’t ever underestimate the ingenuity of a utility engineer to improvise, adopt and adapt</u>)

“Then…a modest proposal…”

- If the “cost” of the wire in any given application were to be “zero,”…
- Would the utilities then “buy them?” And sign a “letter of intent” to purchase “x” number?
  - e.g., Fault Current Limiters, for which US utilities have long claimed a need
- “Zero cost” would be obtained as a Federal or State “tax credit” for the wire cost of the quantity purchased by the utility equipment vendor or the utility itself…
- Well?

Questions for US HTSC Wire Manufacturers

- AMSC
  - Estimated gross revenue from wire sales (and actual delivery) for FY2011?
  - Note: 3Q10 gross revenue from wire sales was 1.8% of total quarter
- SuperPower
  - Same as AMSC #1 above
  - Estimated employee/manpower growth in CY2011
- Ultera/Southwire
  - Is Carrolton plant cable (Gen 1) still in operation?
  - Plans to replace/extend?
- Nexans/AMSC/LIPA
  - Status of Gen II wire/cable upgrade
- AMSC/ConEd/DHS
  - Status/funding of Project Hydra

My Virtual Grandfather (@ 94)

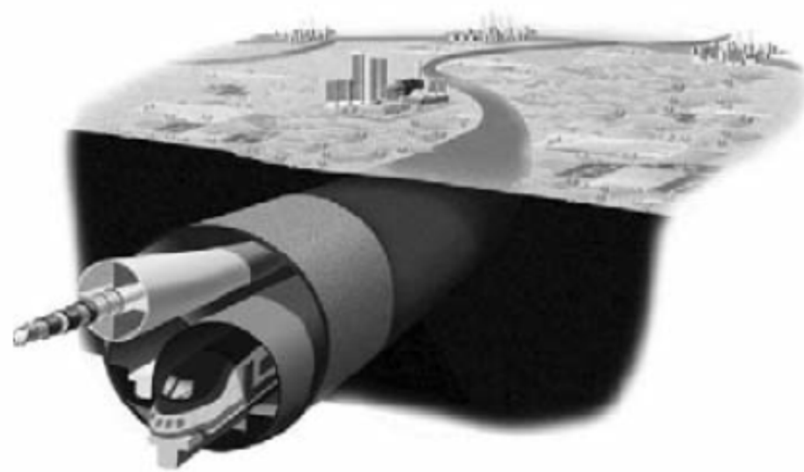
W2AGZ & Beyond

Superconductivity: 100 Years and Counting

First in a year-long series of editorial pieces celebrating the history and progress of superconductivity

by Dr. Paul Michael Grant, W2AGZ Technologies, w2agz@w2agz.com, www.w2agz.com

The following invited article is based on a presentation by Dr. Paul Grant at the July 2010 ICEC/ICMC in Wroclaw, Poland. It is the first in a year-long series of articles in which Cold Facts will be celebrating the 100th anniversary of the discovery of superconductivity.



Superconductivity: 100 years of history physicsworld.com

Down the path of least resistance

Since its discovery 100 years ago, our understanding of superconductivity has developed in a far from smooth fashion. Paul Michael Grant explains exactly why this beautiful, elegant and profound phenomenon continues to confound and baffle condensed-matter physicists today

physicsworld.com Superconductivity: Top five applications

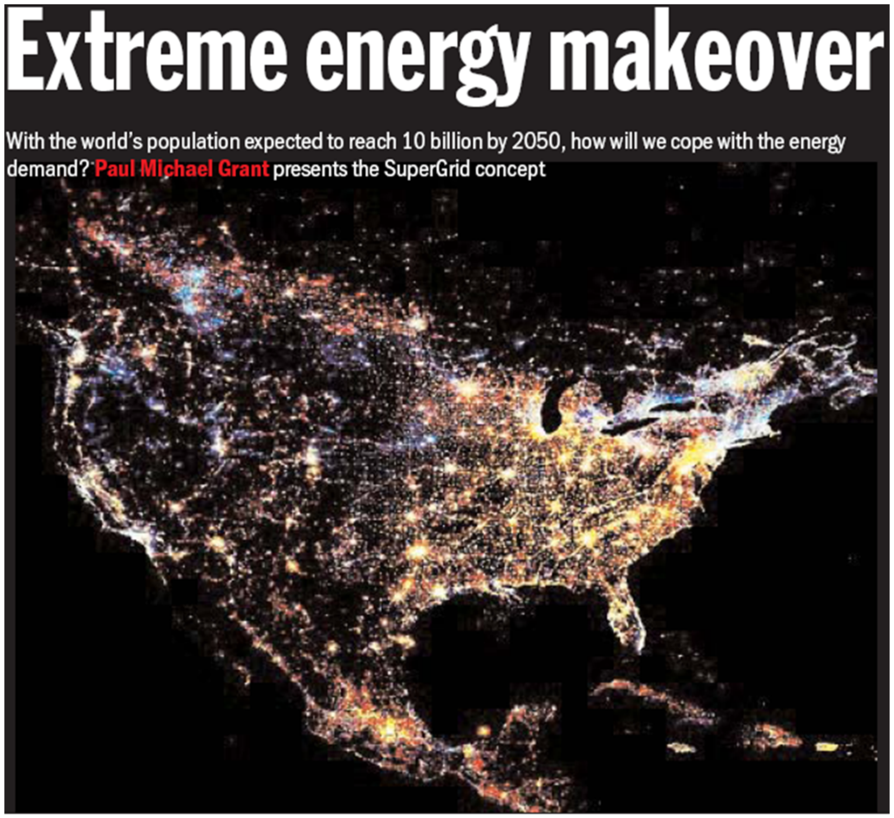
Five of the best

Superconductivity may be a beautiful phenomenon, but materials that can conduct with zero resistance have not quite transformed the world in the way that many might have imagined. Presented here are the top five applications, ranked in terms of their impact on society today

1. Wires & Films **2. Medical Imaging** **3. High Energy Physics**

4. Rotating Machinery **5. Dark Matter**

Physics World, October 2009



From The Times
October 3, 2009
Science: Stand by for the Supergrid
Why the world needs an 'extreme energy makeover'
Anjana Ahuja

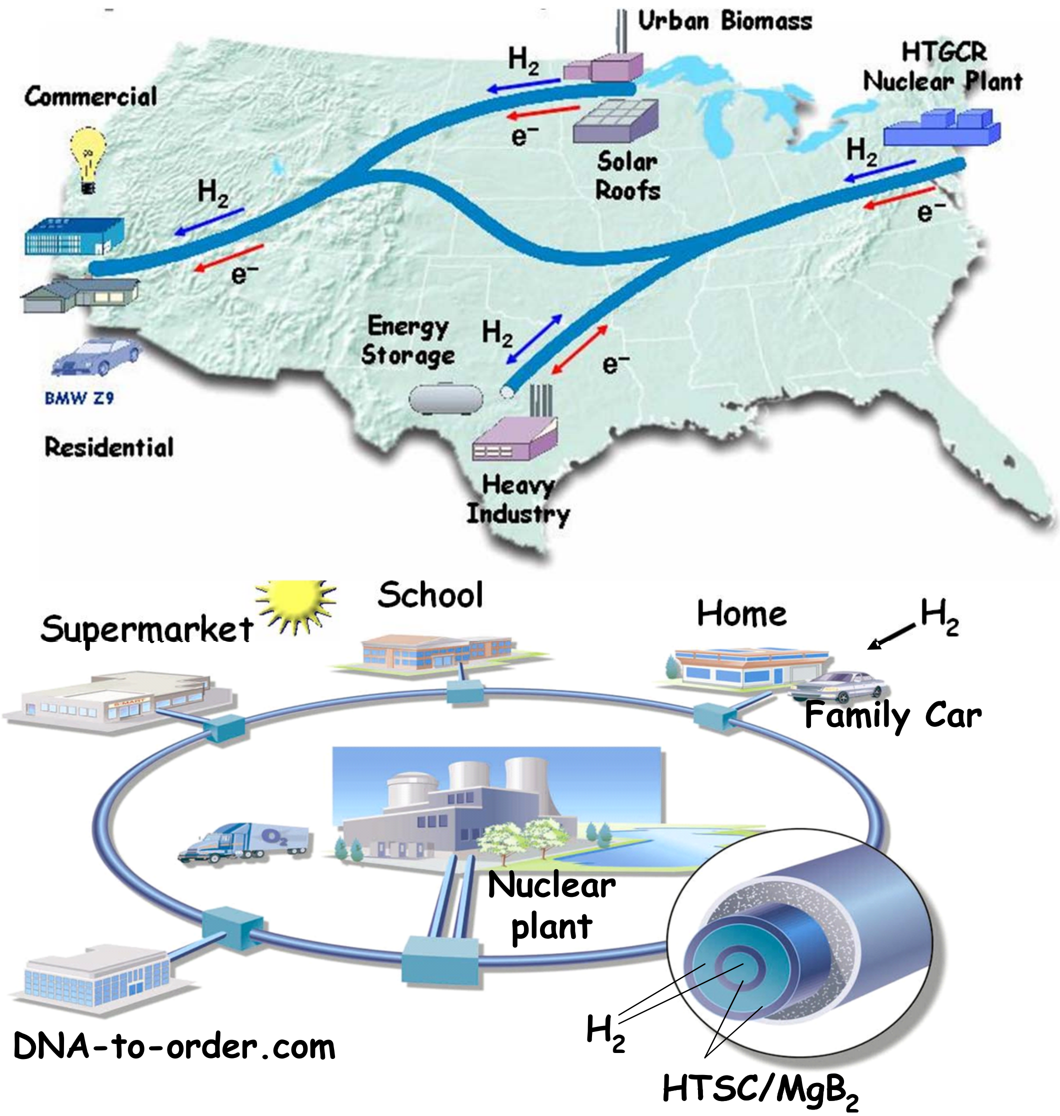
…a future editor of Nature…?

The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

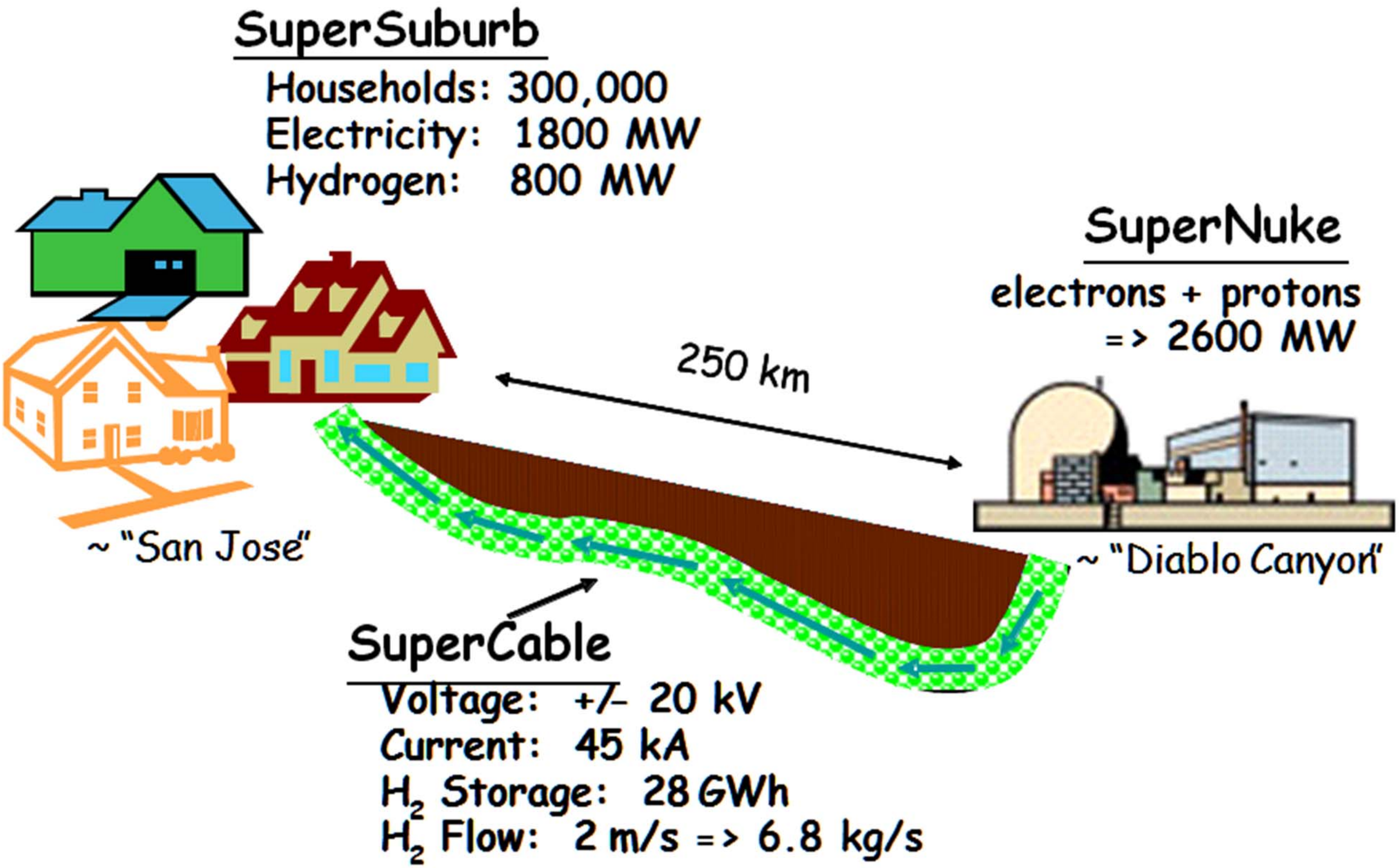
1220 km
18 GW-thermal
2006 - 2010

SuperCities & SuperGrids



- Nuclear Power can generate both electricity and hydrogen – “Hydricity”
- Hydricity can be distributed in underground pipelines like natural gas
- The infrastructure can take the form of a **SuperGrid**
- …or a **SuperCity**

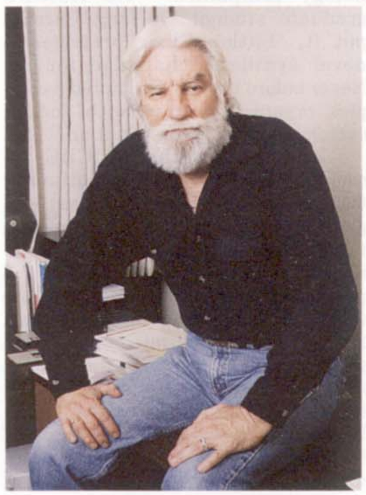
SuperSuburb



The Future?

Physics Today, November 1998

PHYSICS TOMORROW: ESSAY CONTEST WINNER



RESEARCHERS FIND EXTRAORDINARILY HIGH TEMPERATURE SUPERCONDUCTIVITY IN BIO-INSPIRED NANOPOLYMER

Paul M. Grant

May 2028

700 K !

May, **2028**

So Now We Have a Room Temperature Superconductor… So What?

(Will We Be Able to Use It?)

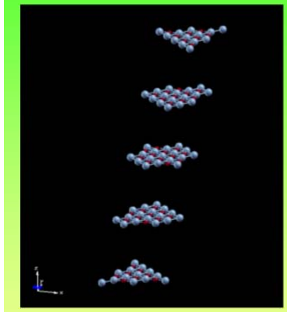
Finally Enable the Hydrogen Economy ?

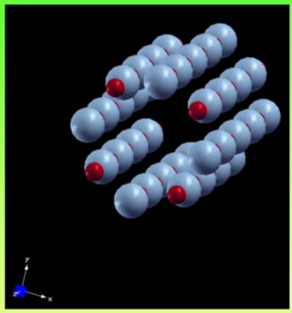
Paul M. Grant
Visiting Scholar, Stanford
IBM Research Staff Member Emeritus
EPRI Science Fellow (Retired)
Principal, W2AGZ Technologies

The Road to Room Temperature Superconductivity
Loen, Norway
17-22 June 2007
http://www.w2agz.com/rtsc06.htm

Road2RTS

A DFT (LDA+U) Study of the Electronic Properties of Square-Planar Coordinated Copper Monoxide Structures



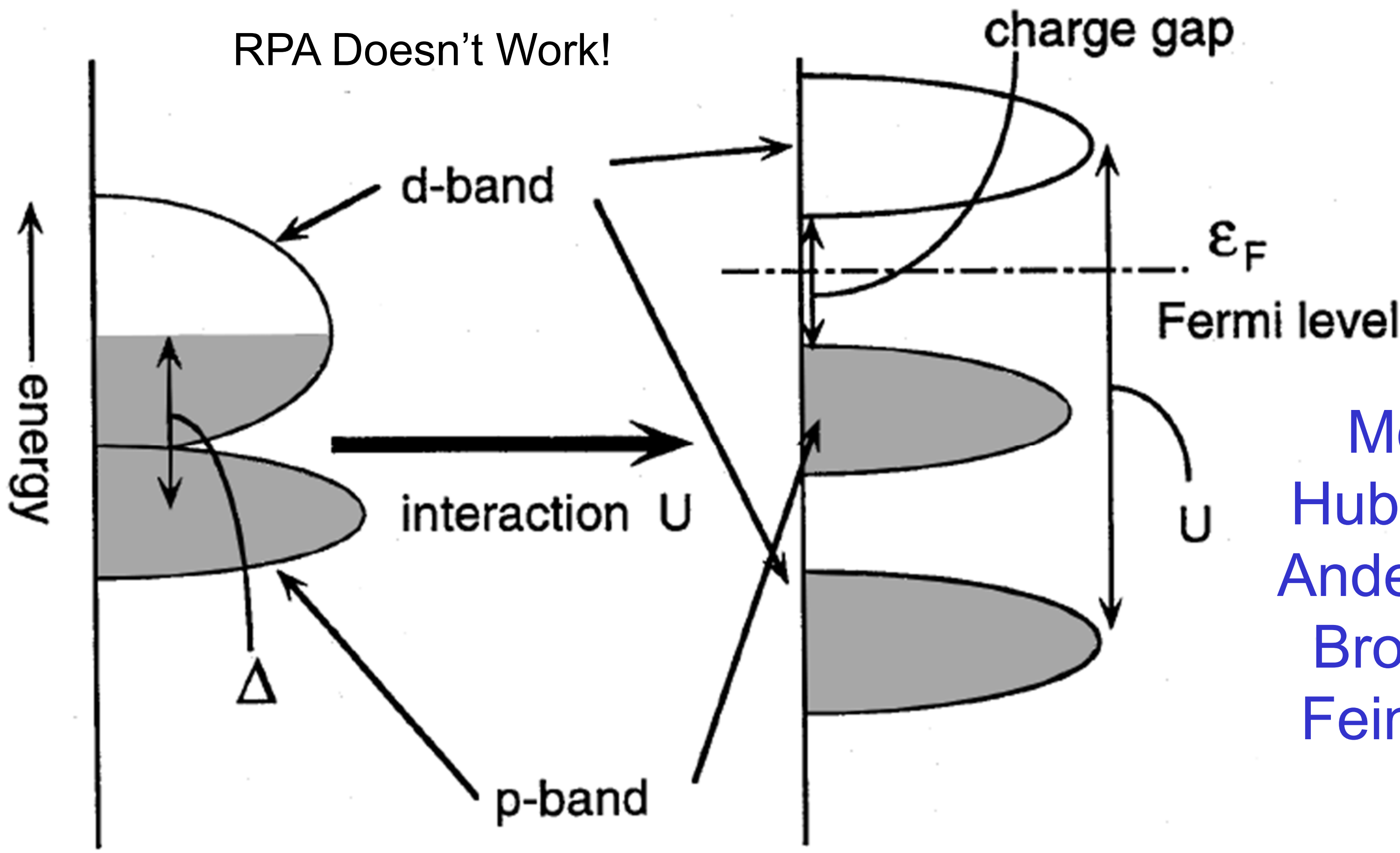


… And Now for Something Completely Different …

Back to the Future…
My SJRL Day Job of the 60s and 70s…
Electronic Structure Calculations

Transition Metal Oxides
"Should be Metals, But Aren't"
(Charge Transfer Insulators, Instead)

RPA Doesn't Work!

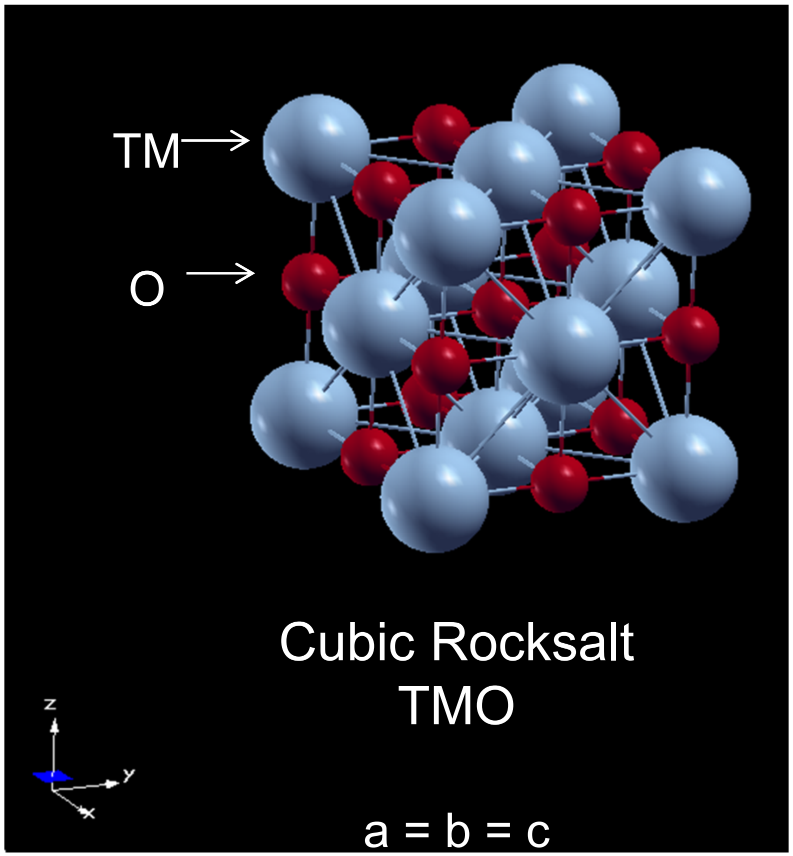


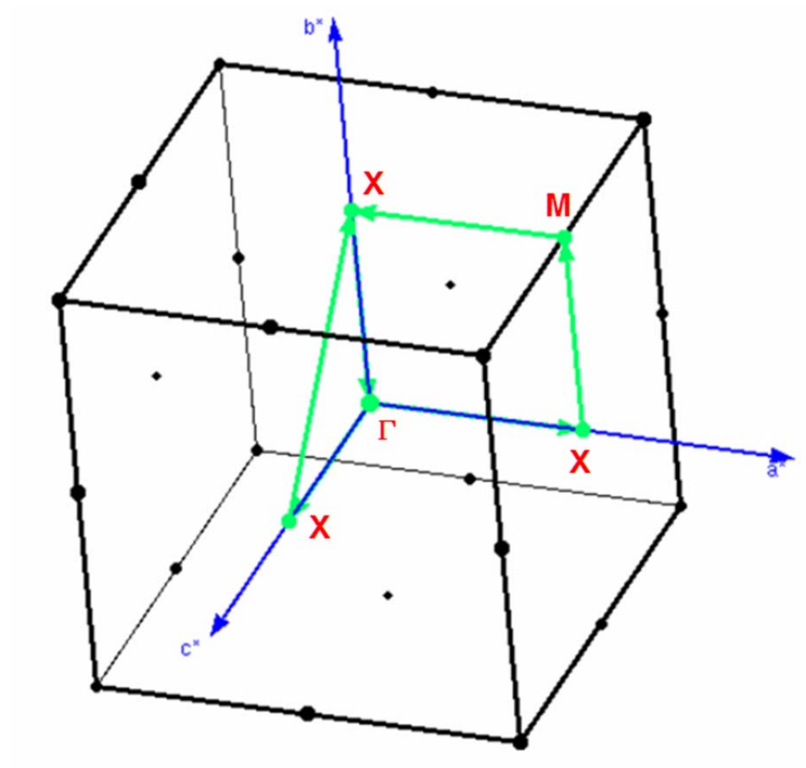
Mott
Hubbard
Anderson
Brooks
Feinlieb

After Imada, et al, RMP 70, 1039 (1998)

Cubic Rocksalt TMOs

Direct and Reciprocal Lattices





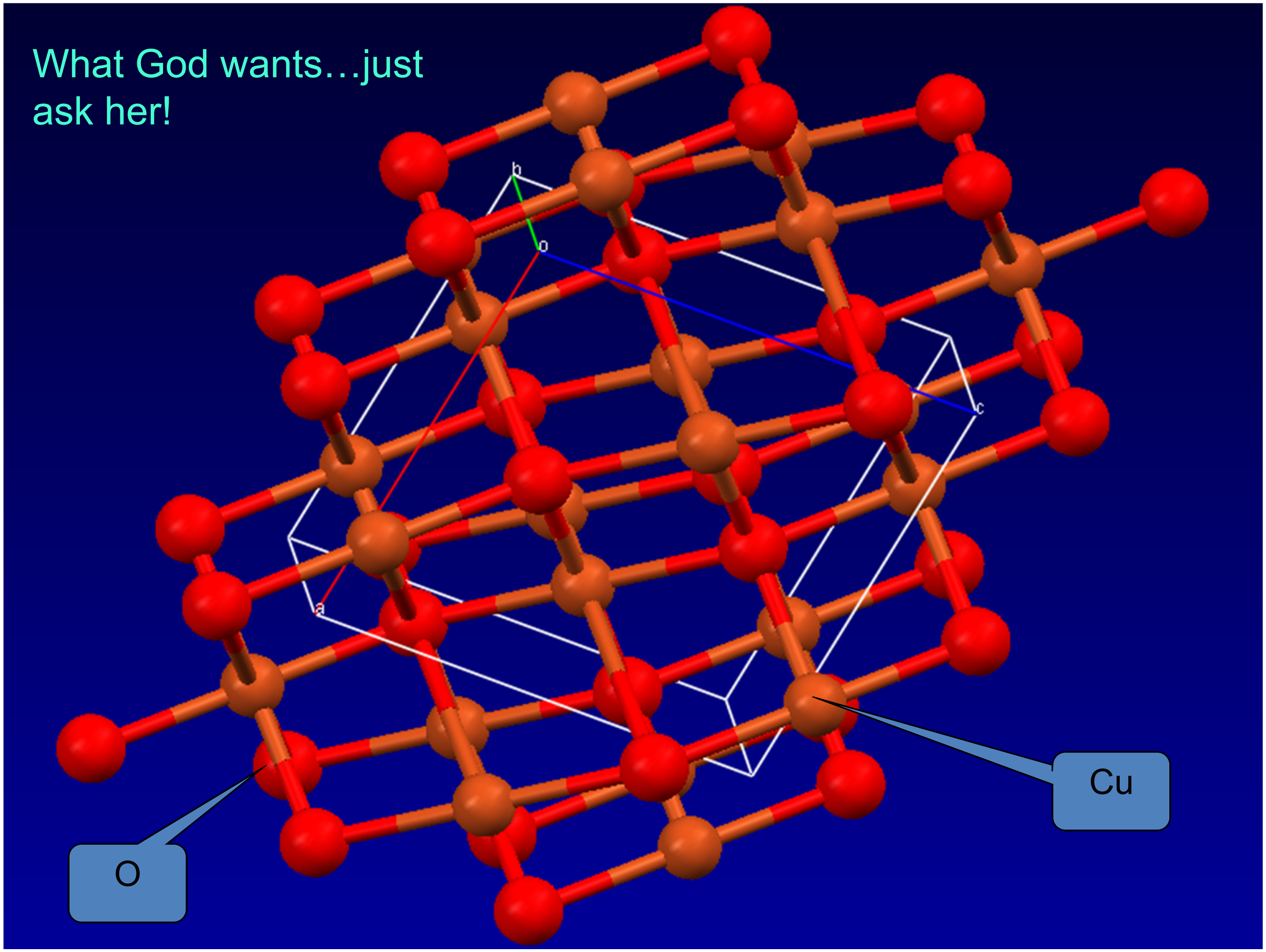
Cubic Rocksalt Divalent TMOs

TMO	3d Config	Properties
MnO	5	MH-CTI (5.6)
FeO	6	MH-CTI (5.9)
CoO	7	MH-CTI (6.3)
NiO	8	MH-CTI (6.5)
CuO	9	**XX *Doesn't Exist!***

See Imada, Fujimore, Tokura, RPM 70 (1988)

Why Not?

Tenorite (Monoclinic CuO)



Can Application of DFT (LDA+U) Help Unravel the Cubic Rocksalt CuO Enigma?

…Let’s see…

DFT & (LDA + U)

$$E_{\mathrm{LDA+U}}\left[n(\mathbf{r})\right] = E_{\mathrm{LDA}}\left[n(\mathbf{r})\right] + E_{\mathrm{HUB}}\left[\left\{n_m^{l\sigma}\right\}\right] - E_{\mathrm{DC}}\left[\left\{n^{l\sigma}\right\}\right]$$

- Implemented in LMTO by Anisimov, et al, JPCM 2, 3973 (1990)
  - Applied to NiO, MnO, FeO, CoO and La_2CuO_4
- Plane-Wave Pseudopotential Implementation by Cococcioni and de Gironcoli, PRB 71, 035105 (2005)
  - Applied to FeO and NiO
  - Download open-source package from http://www.pwscf.org

Proxy Structures
A New Materials Science Discipline

- You want to understand the basic physics of some given system…(e.g., HTSCs)
- So try to synthesize a simple proxy…(e.g., rocksalt CuO)
- But “Mother Nature” won’t “agree.” (She’s a woman!)
- However, you can build it in a computer and perform various “ab initio” experiments.
- And from such, numerically calculate “observables,” e.g., “response functions.”
- Try it out…it’s lots of fun! And perhaps you’ll discover something as well!

Tools

QUANTUM-ESPRESSO Suite of Codes

DFT (LDA+U) plus electron-phonon

Graphics by Tone Kolalj (XCrysDen)

www.quantum-espresso.org

"Dial-in" Parameters

G^2 = 40 Ry   ρ = 320 Ry

Convergence ≤ 10^{-6} Ry

"Smearing" = Methfessel-Paxton

Psuedopotentials: Ultrasoft, XC = Perdew-Zunger

Cu: $3d^94s^2$ O: $2s^22p^4$

Viva Italia!

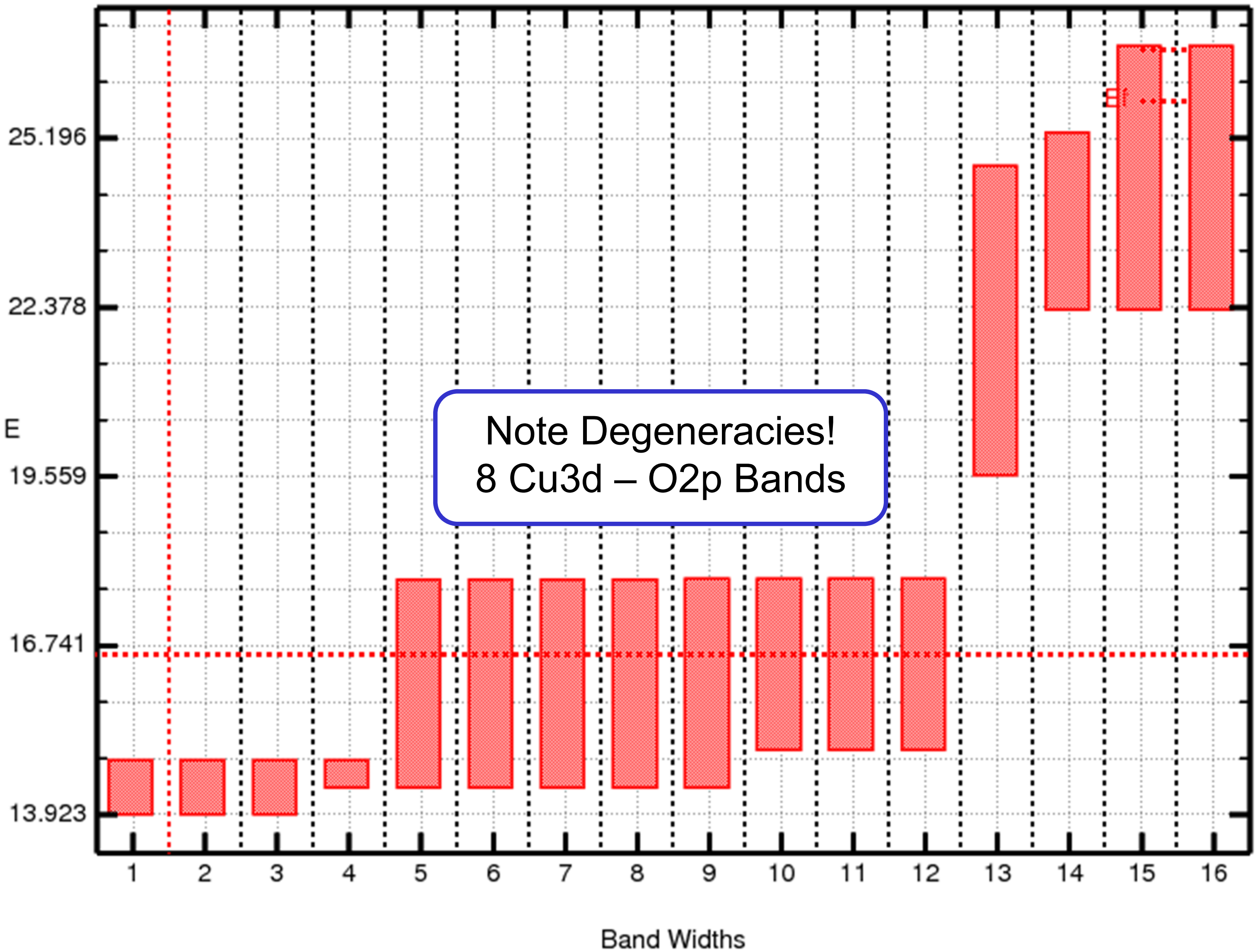
Hardware

3.33 GHz Intel Core i7 – 12 GB+ (Gaming Box – Home Built)

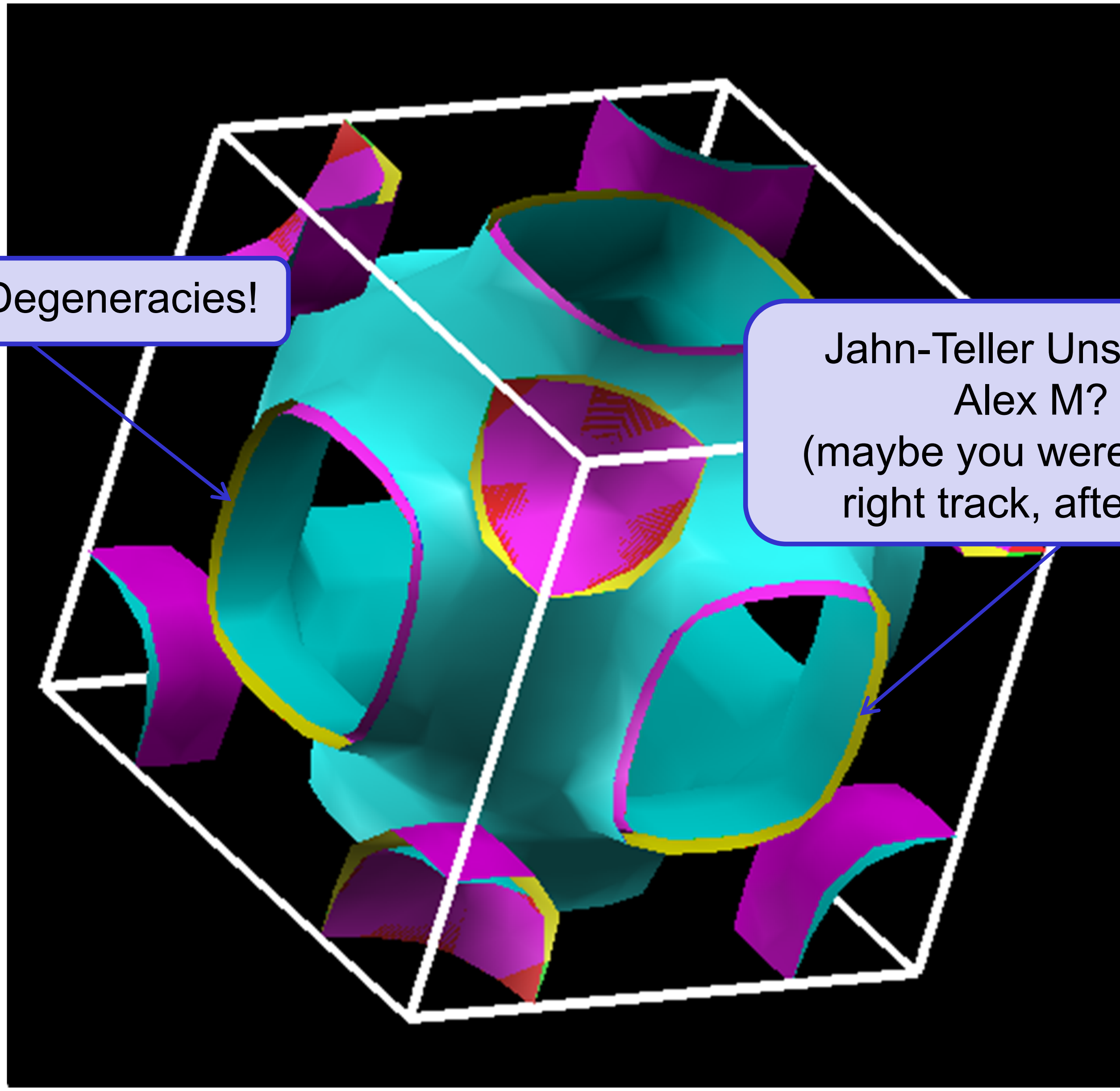
Software

Linux Kubuntu

Rocksalt CuO Band Widths
U = 0 eV



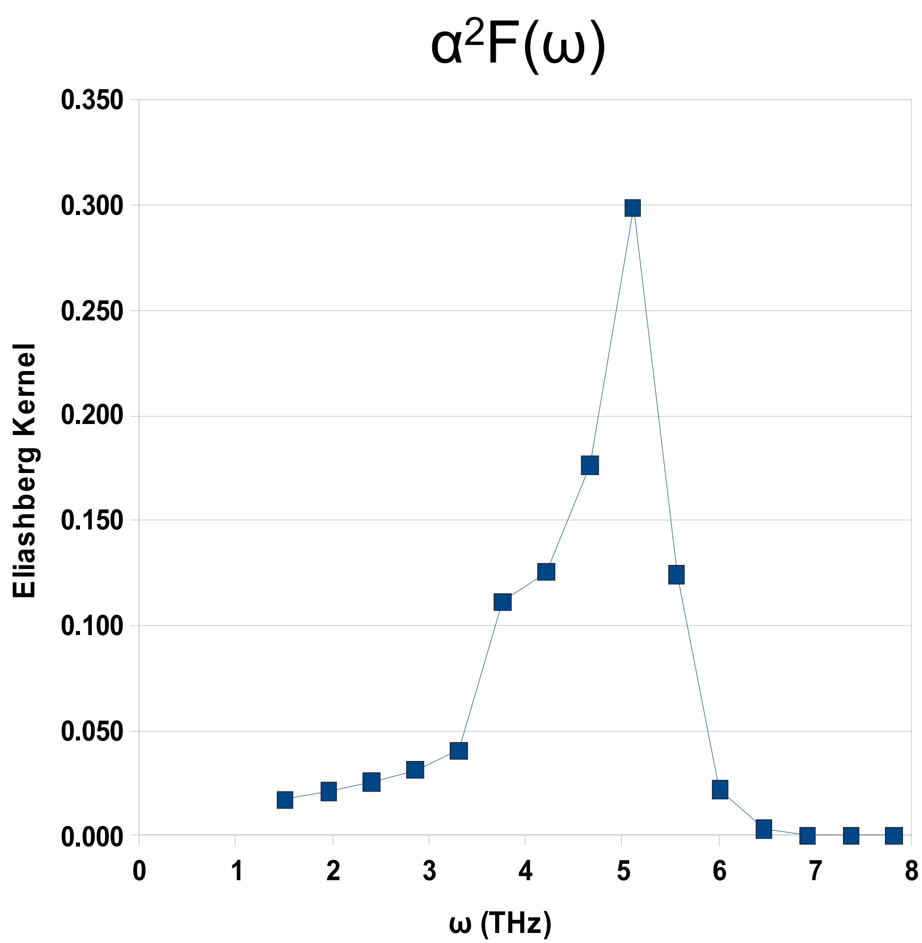
Rocksalt CuO Fermiology (U = 0 eV)
(8 Bands Combined)



Note (Near) Degeneracies!

Jahn-Teller Unstable?
Alex M?
(maybe you were on the right track, after all!)

Non-Magnetic (U = 0) Cubic Rocksalt CuO
-- Electron-Phonon Properties --



σ = 0.04

- λ ~ 0.6 – 0.7
- Consistent with other non-magnetic "HTSCs"

$$T_C = a\Theta e^{-\frac{1}{\lambda-\mu^*}} \qquad \lambda k\Theta \ll E_F$$

	T_C (K)	λ	μ*
K_3C_{60}	16.3	0.51	-
Rb_3C_{60}	30.5	0.61	-
Cs_3C_{60}	47.4	0.72	-

Are There Phonons w/ High-Tc in YBCO?

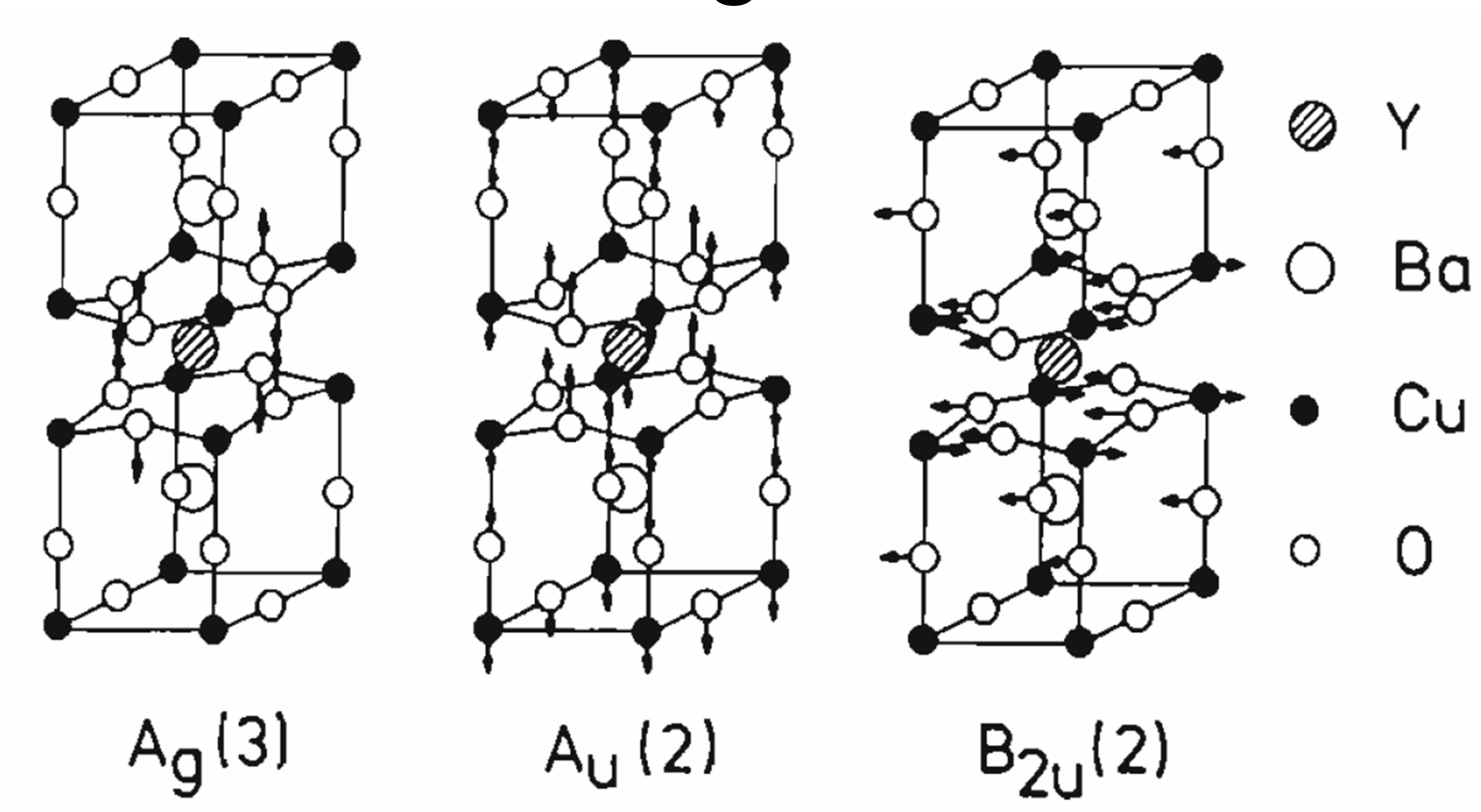
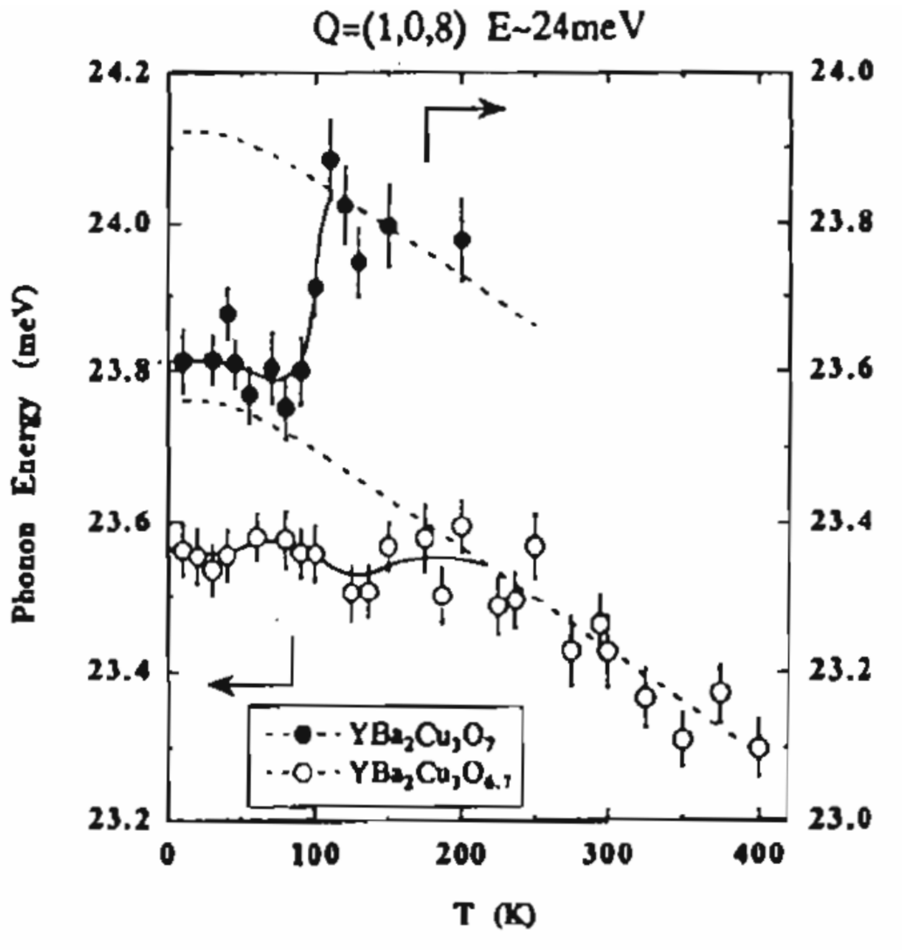
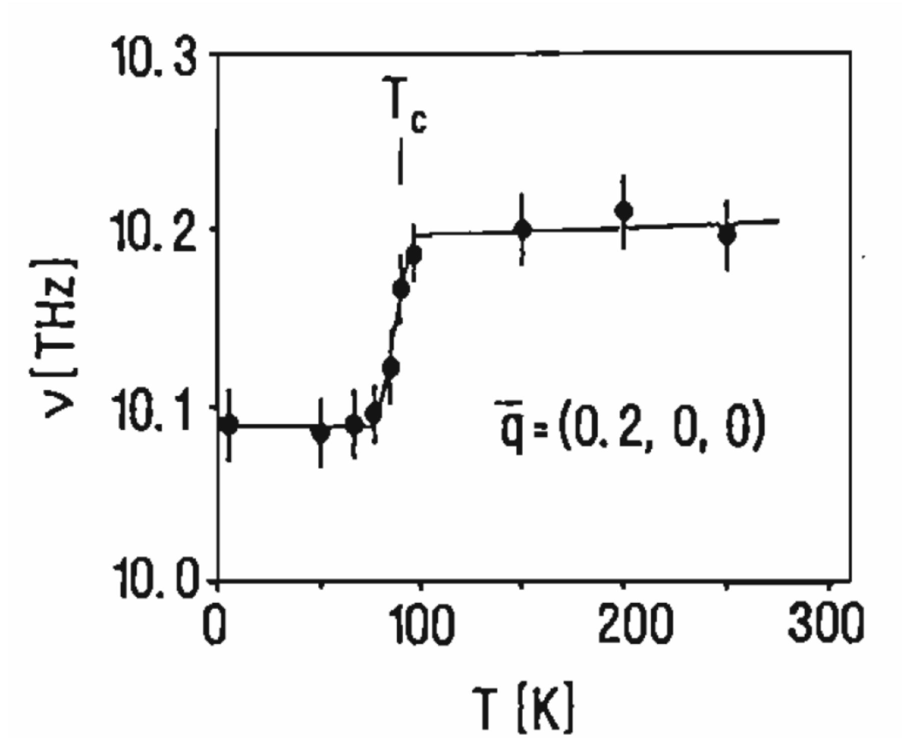


Fig. 38: Pintschovius and Reichardt, in Furrer, ISBN 0-7923-5226-2

Yes -- They're There!



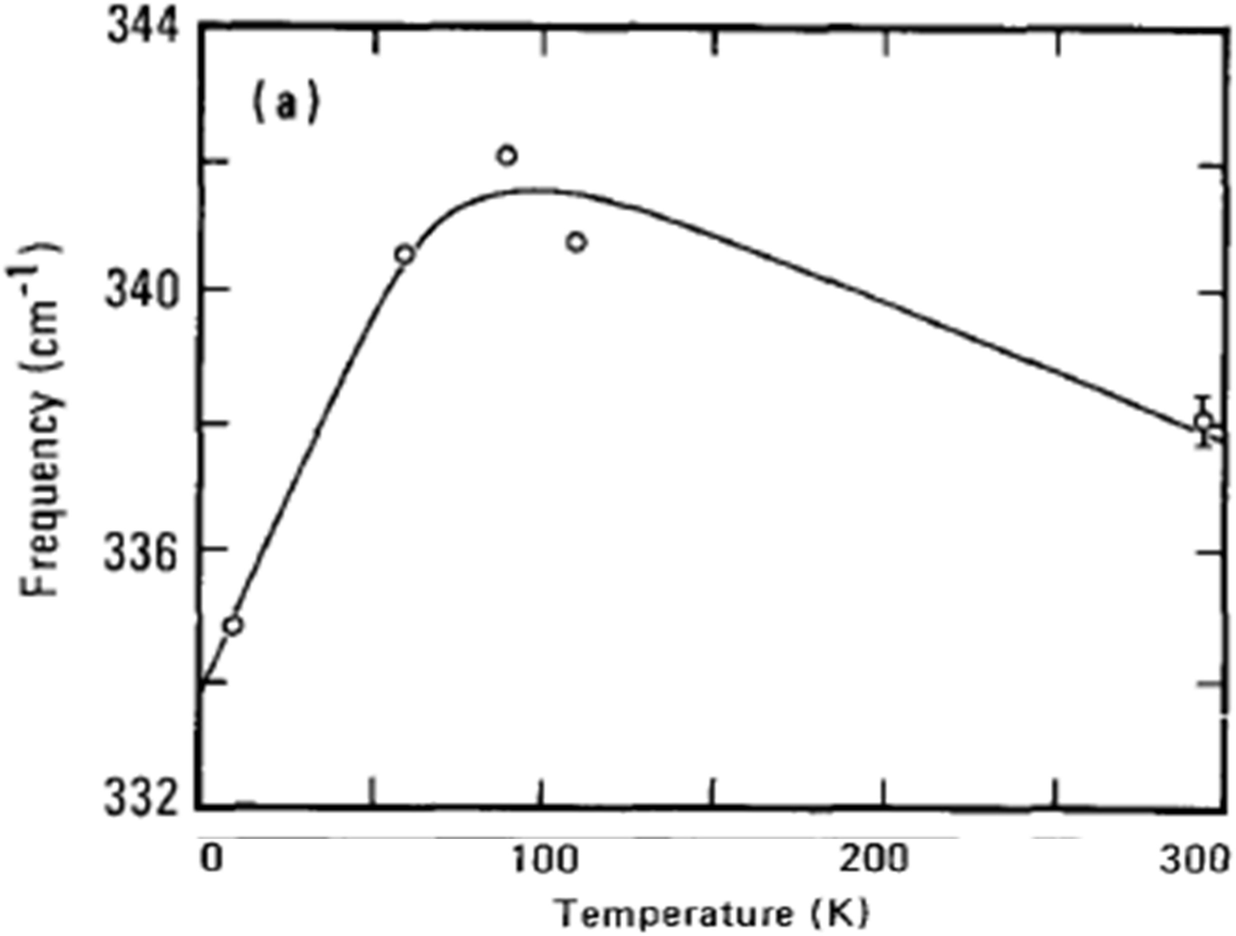


Pyka, et al., PRL 70, 1457, (1993)

Harashima, et al., Physica C263, 257 (1996)

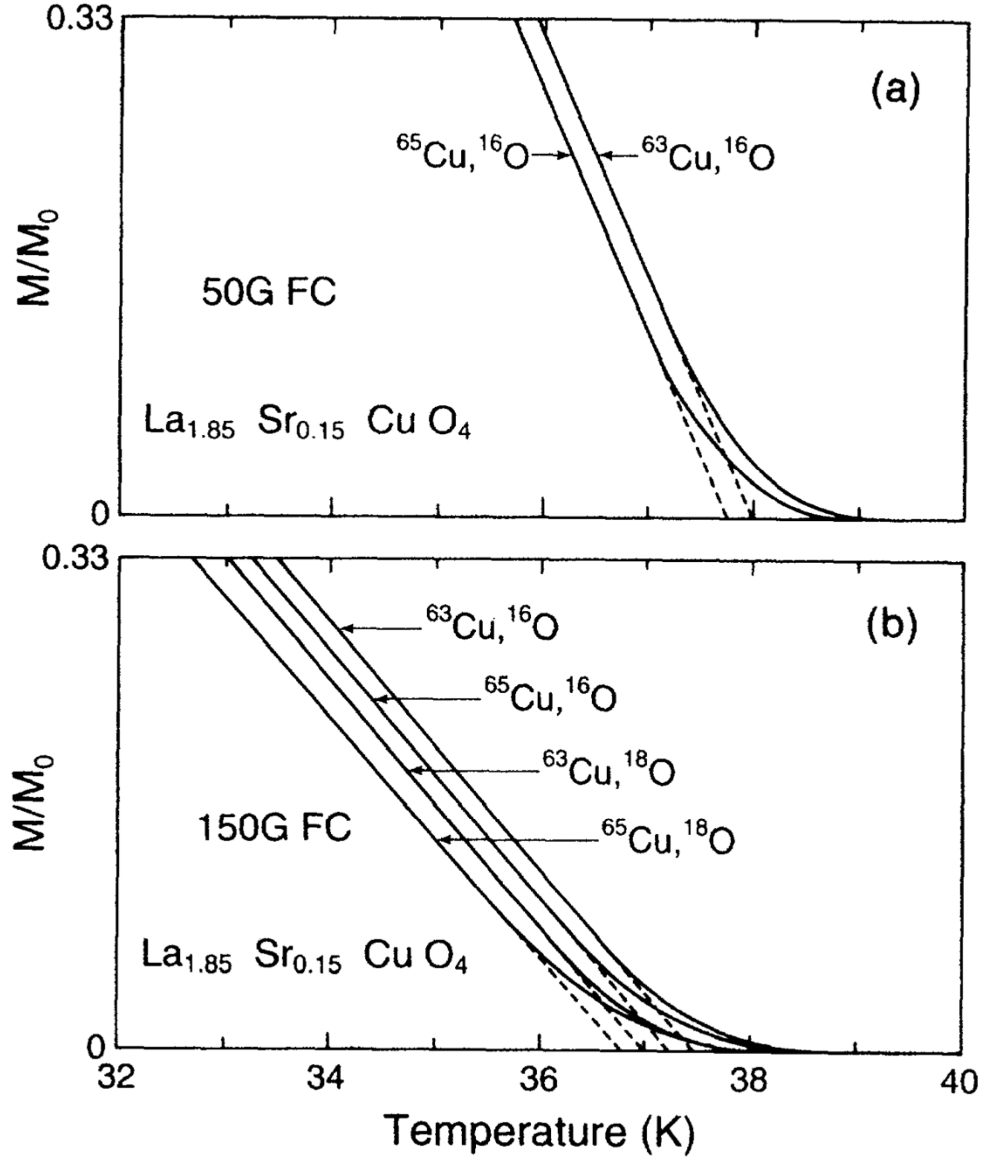
Macfarlane, Rosen, Seki, SSC 63, 831 (1987)

Raman Spectroscopy of YBCO

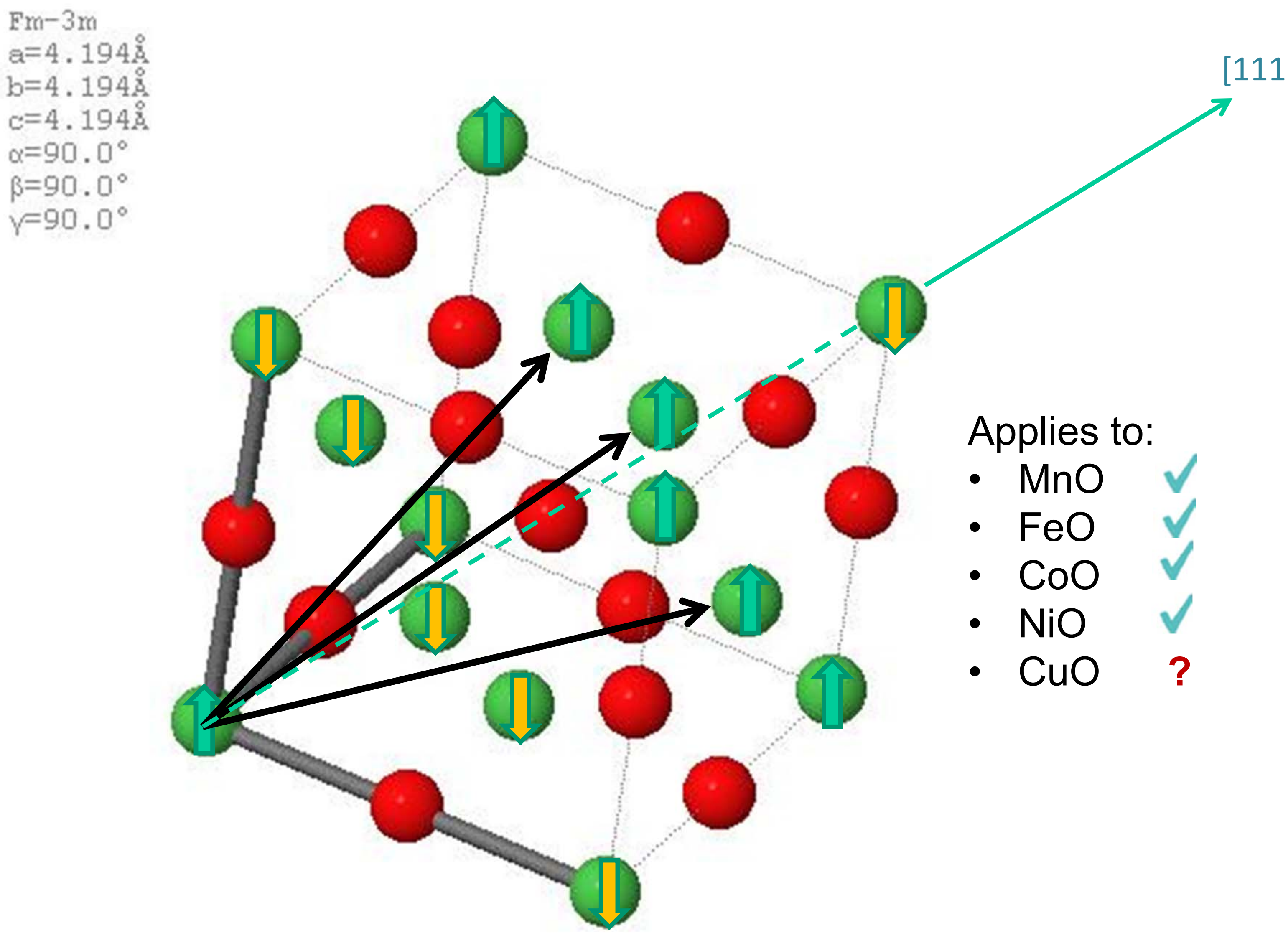


Copper and Oxygen Isotope Effects in $La_{2-x}Sr_xCuO_4$

J. P. Franck,[1] S. Harker,[1] and J. H. Brewer[2]



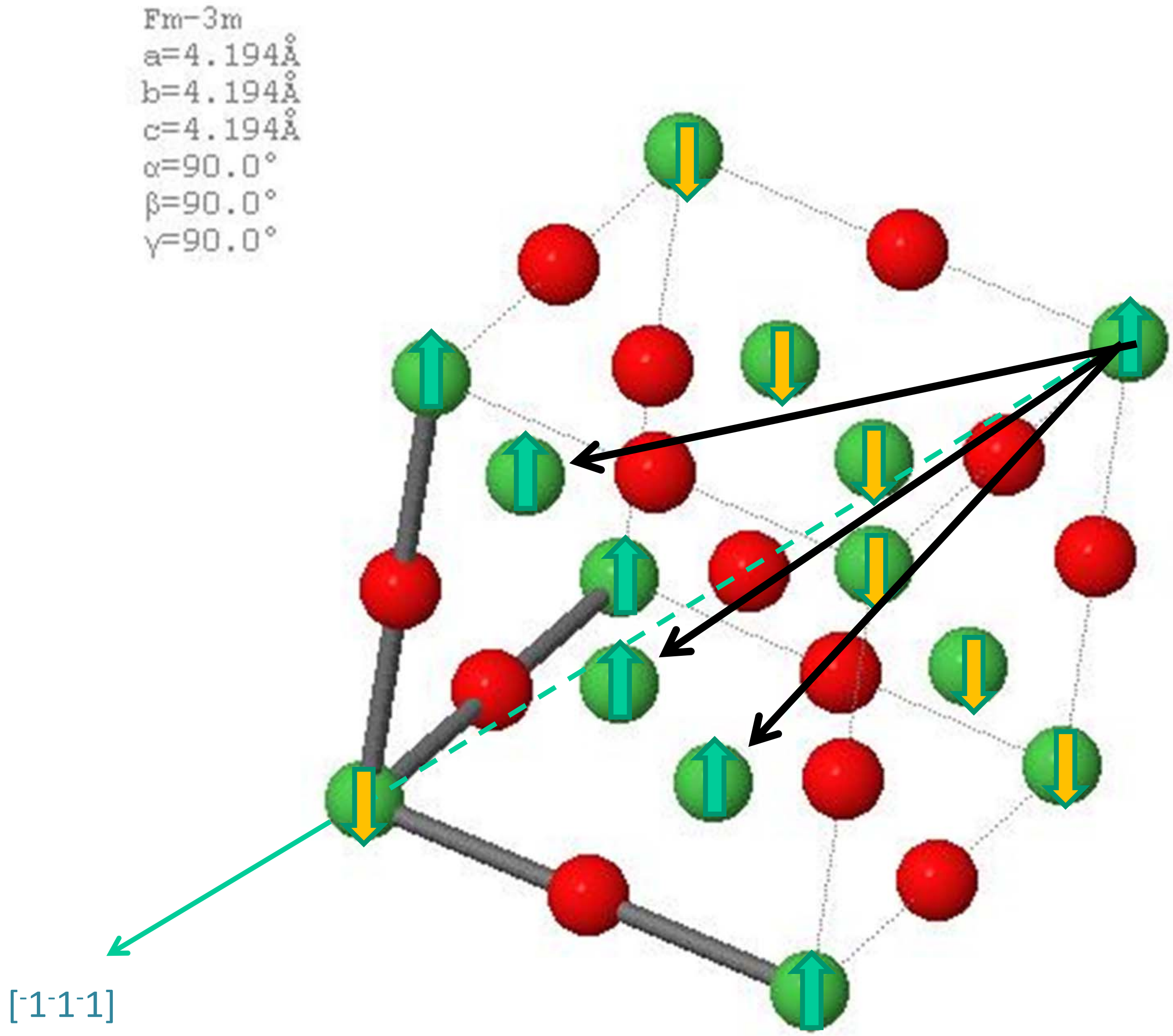
Proto-TMO AF-II Rocksalt Unit Cell



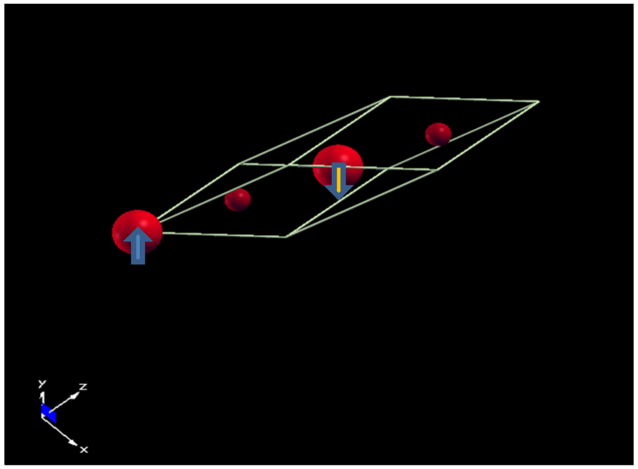
Applies to:

- MnO ✓
- FeO ✓
- CoO ✓
- NiO ✓
- CuO ?

Proto-TMO AF-II Rocksalt



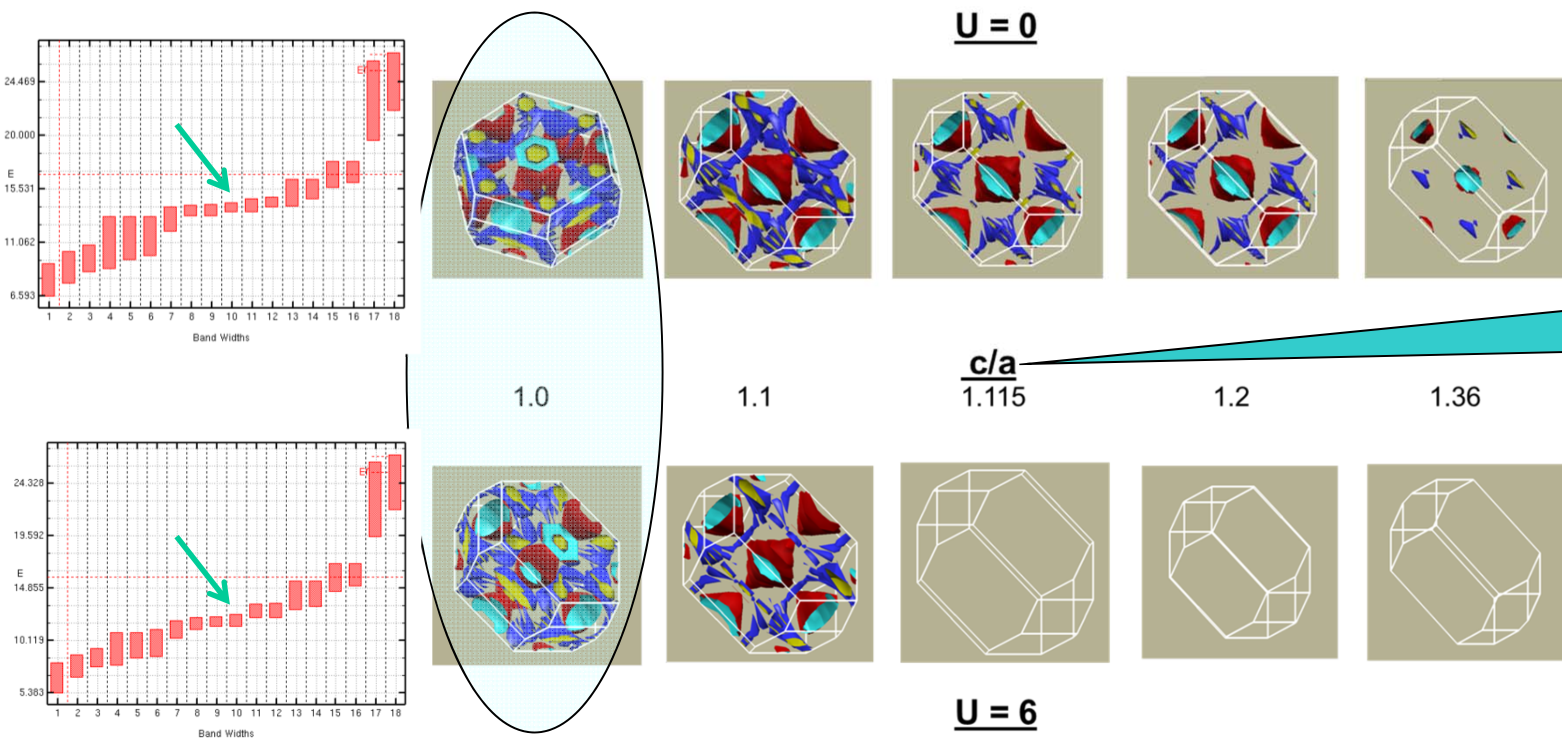
The Answer(s) !



TMO Asymmetric Type II
af-CuO Cell

LDA+U Calcs

Grant, IOP-CS 129 (2008) 102042
(Click Here)



Tetragonal Distortion

Siemons, et al, PRB 79 (2009) 195122
(Click Here)

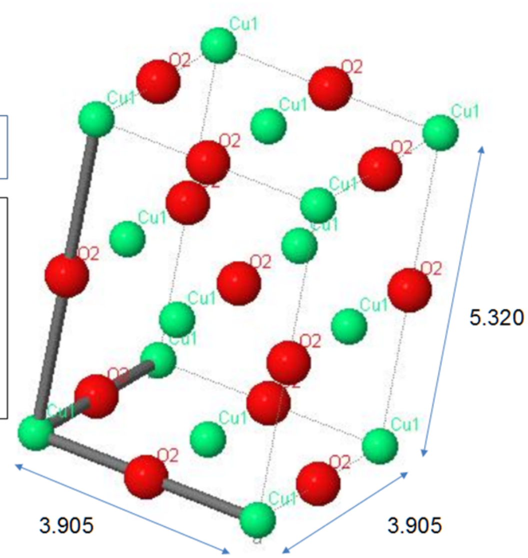
Tetragonal Rocksalt CuO

Fm-3m
a=3.905Å
b=3.905Å
c=5.320Å
α=90.0°
β=90.0°
γ=90.0°

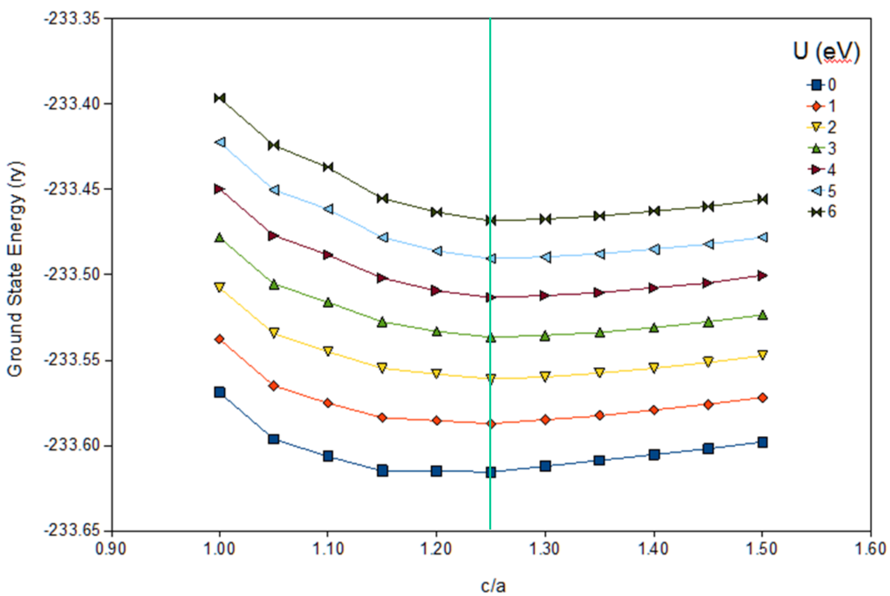
c/a = 1.36

Measurements
(Wolter Siemons)

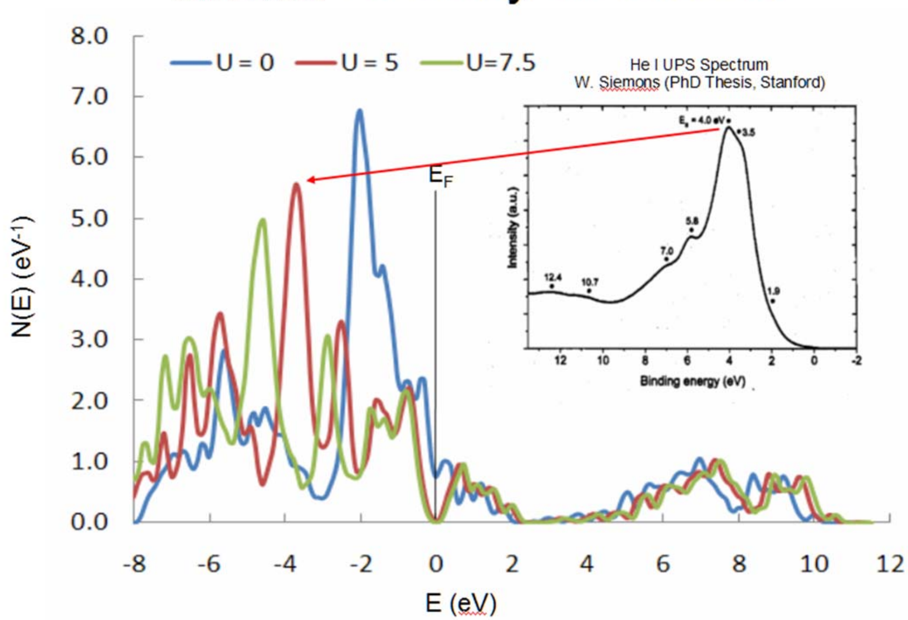
- 2-4 ML epi on STO
- No Fermi Edge
- No Exchange Bias on ferro-SRO (Tc ~ 100-150 K)



Ground State Energy vs c/a & U(ev)



t-CuO Density-of-States



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Journal of Physics: Conference Series **129** (2008) 012042 doi:10.1088/1742-6596/129/1/012042

Electronic properties of rocksalt copper monoxide: A proxy structure for high temperature superconductivity

Paul M. Grant[*]

W2AGZ Technologies

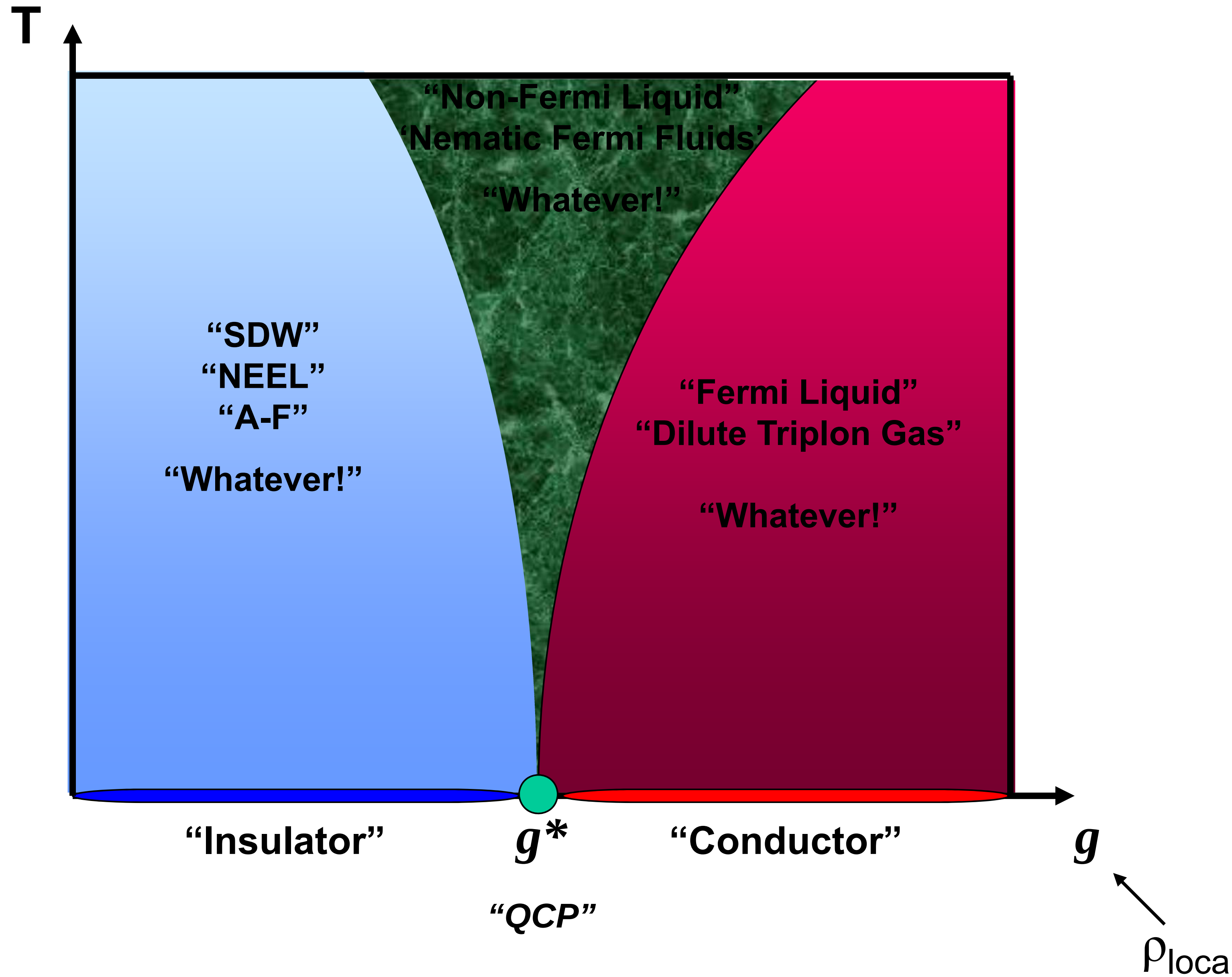
"**Electronic Properties of Rocksalt Copper Monoxide**,"
APS MAR09-2008-006217, P. M. Grant, Pittsburgh (2009)

PHYSICAL REVIEW B **79**, 195122 (2009)

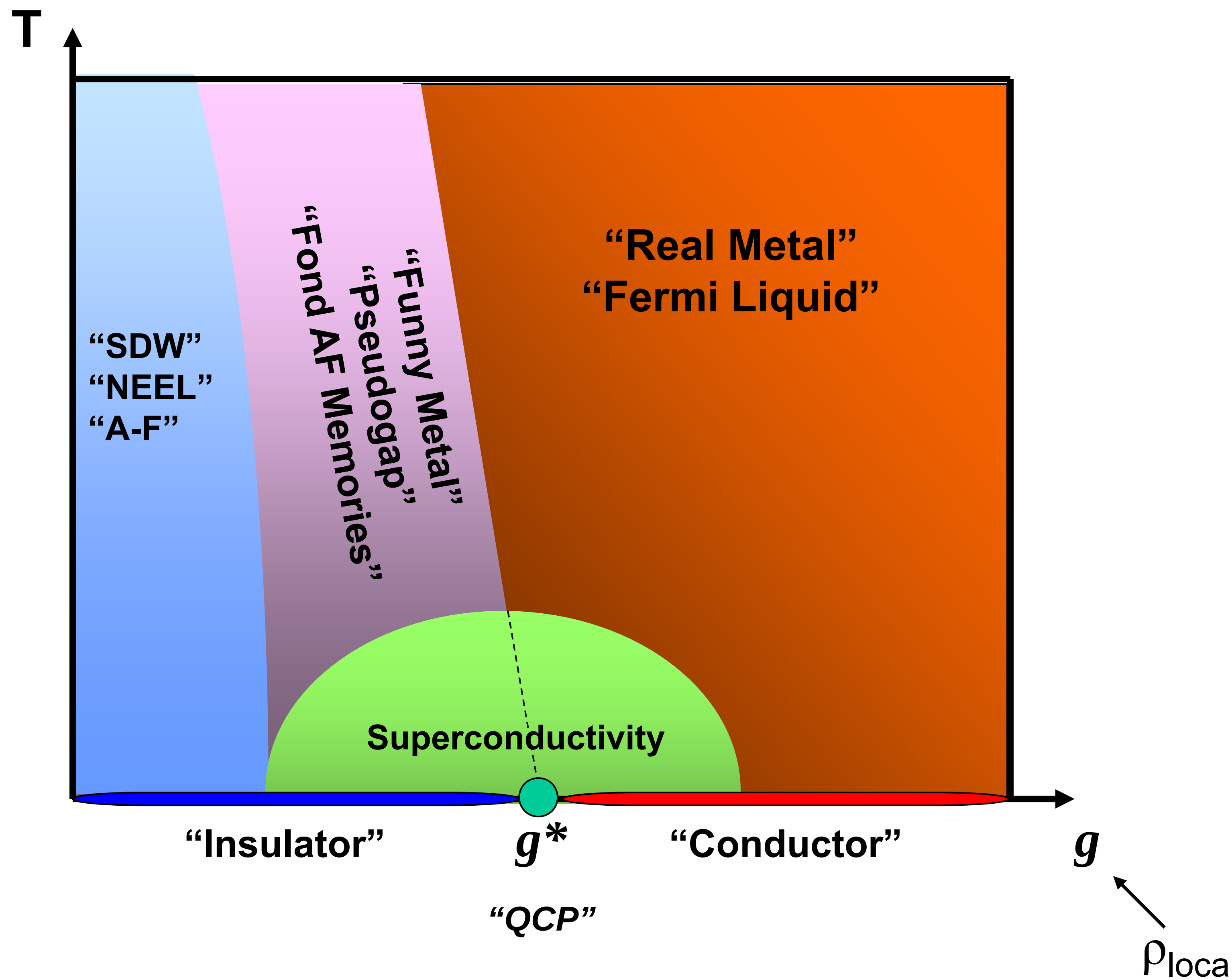
Tetragonal CuO: End member of the 3*d* transition metal monoxides

Wolter Siemons,[1,2] Gertjan Koster,[1,2,*] Dave H. A. Blank,[1] Robert H. Hammond,[2] Theodore H. Geballe,[2] and Malcolm R. Beasley[2]

The Great Quantum Conundrum



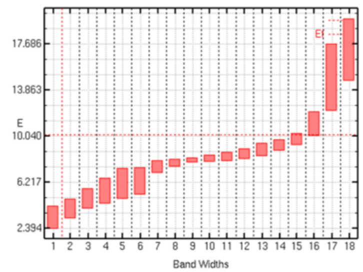
The Colossal Quantum Conundrum

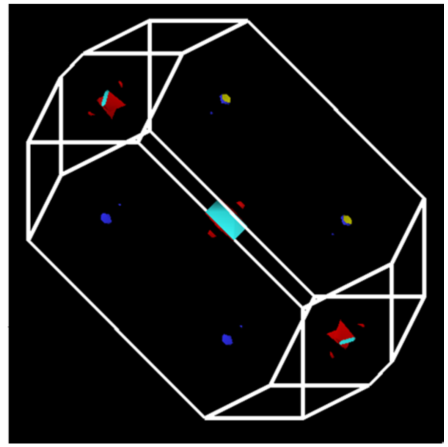


Hubbard (eV)

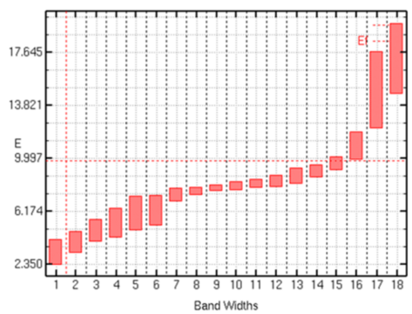
"Doping" (-e/CuO)

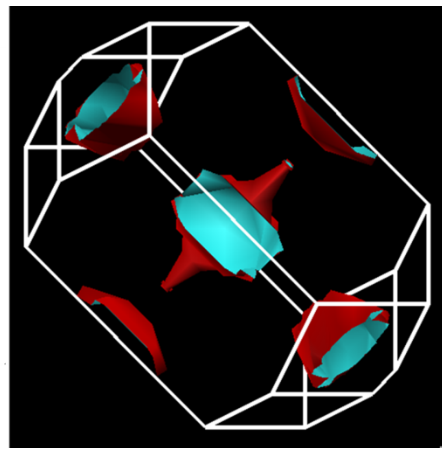
U = 0



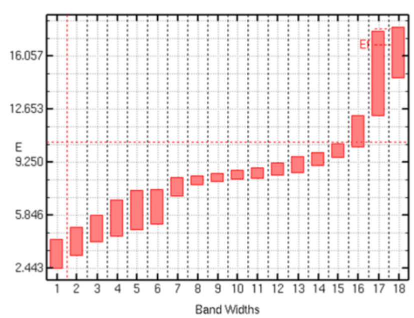


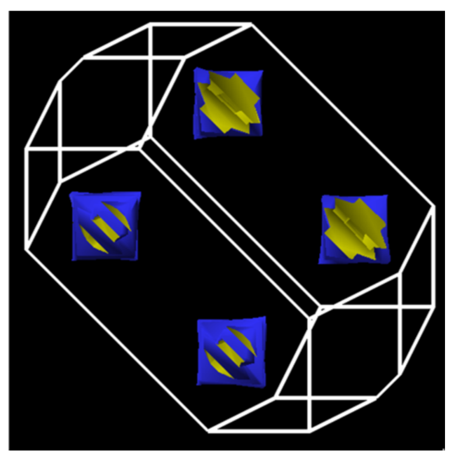
n = 0.00





n = +0.15



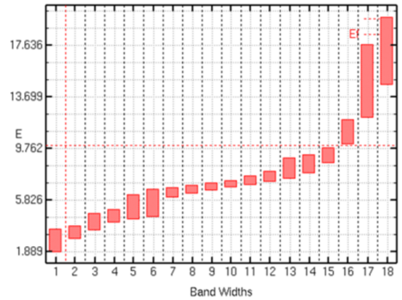


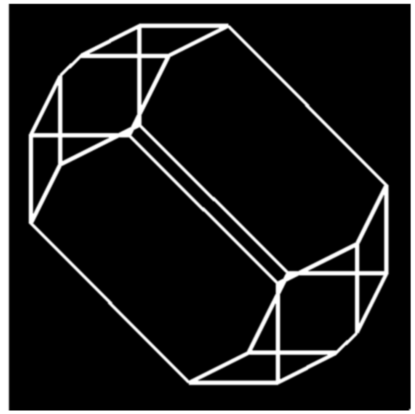
n = -0.15

Hubbard (eV)

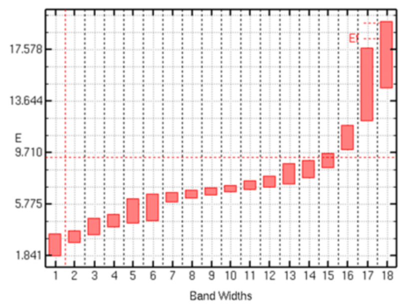
“Doping” (-e/CuO)

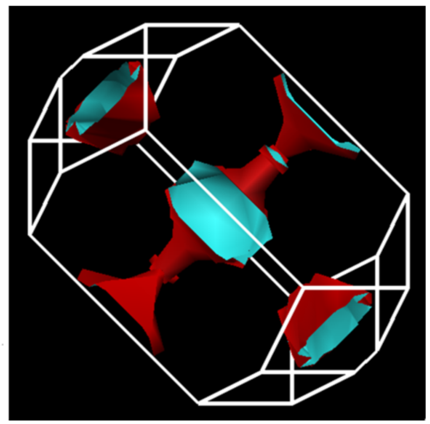
U = 3



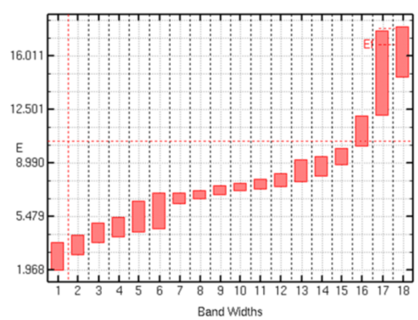


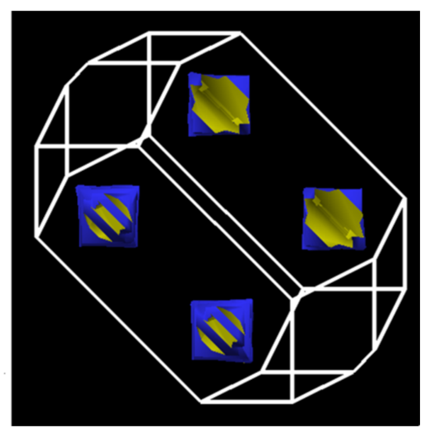
n = 0.00





n = +0.15



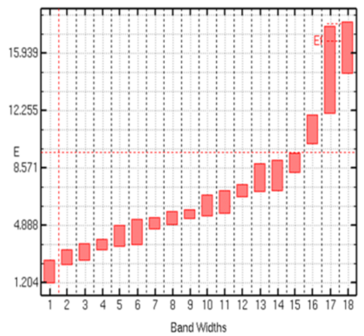


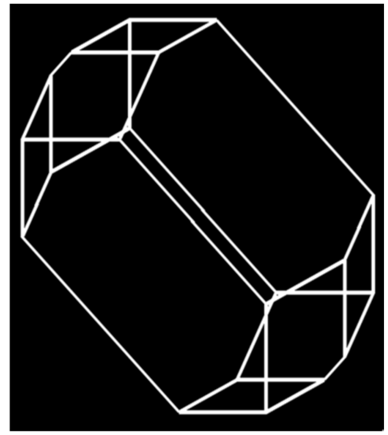
n = -0.15

Hubbard (eV)

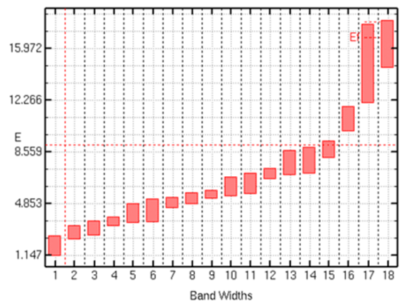
“Doping” (-e/CuO)

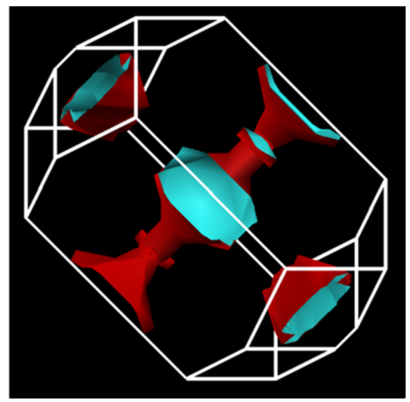
U = 6



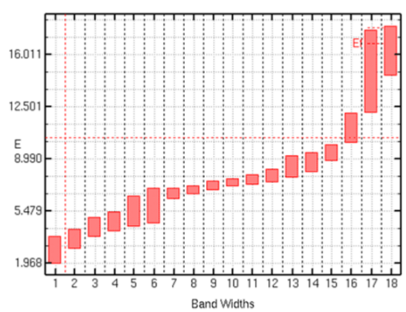


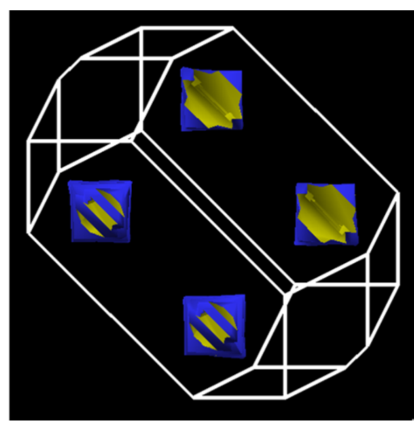
n = 0.00



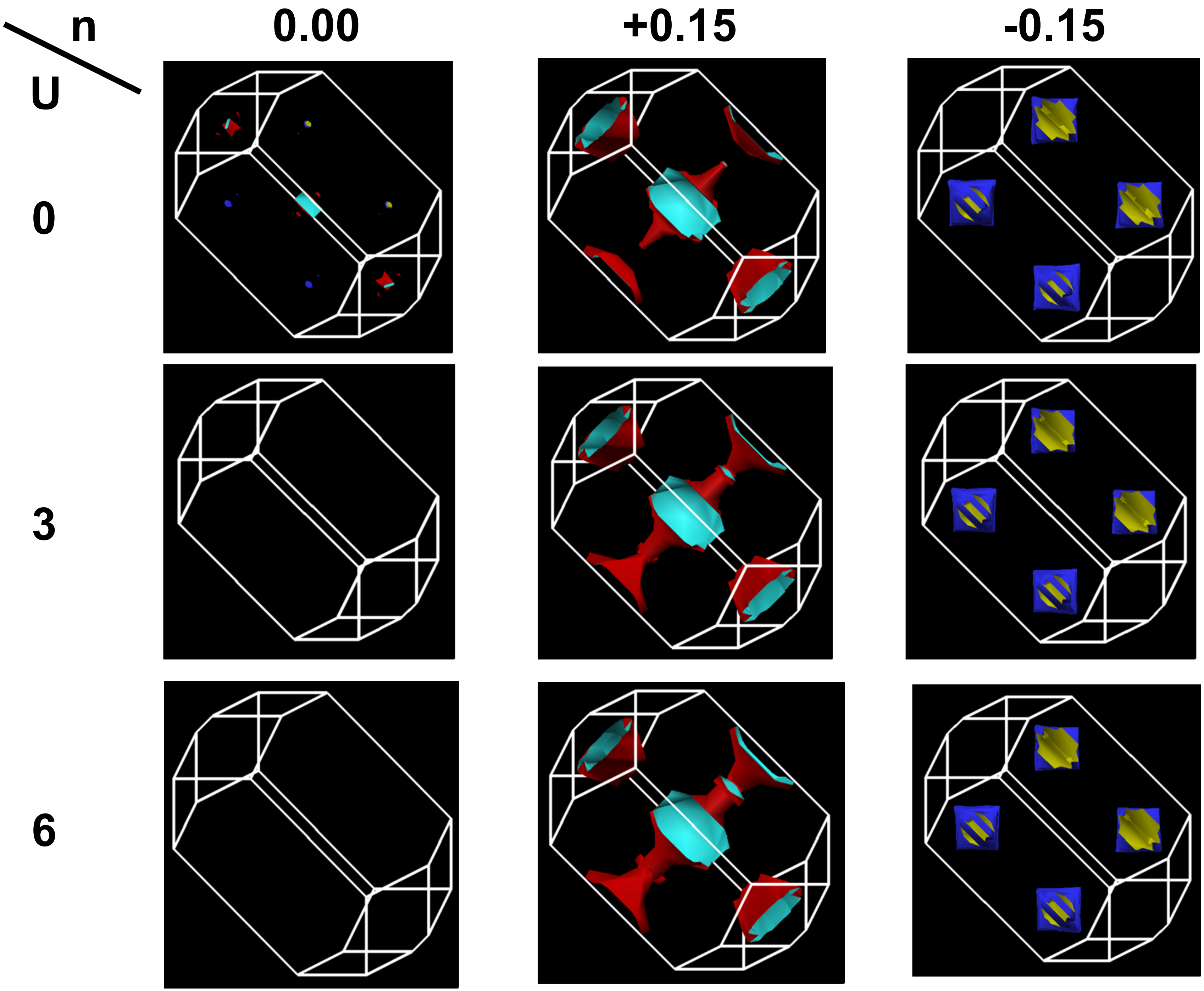


n = +0.15





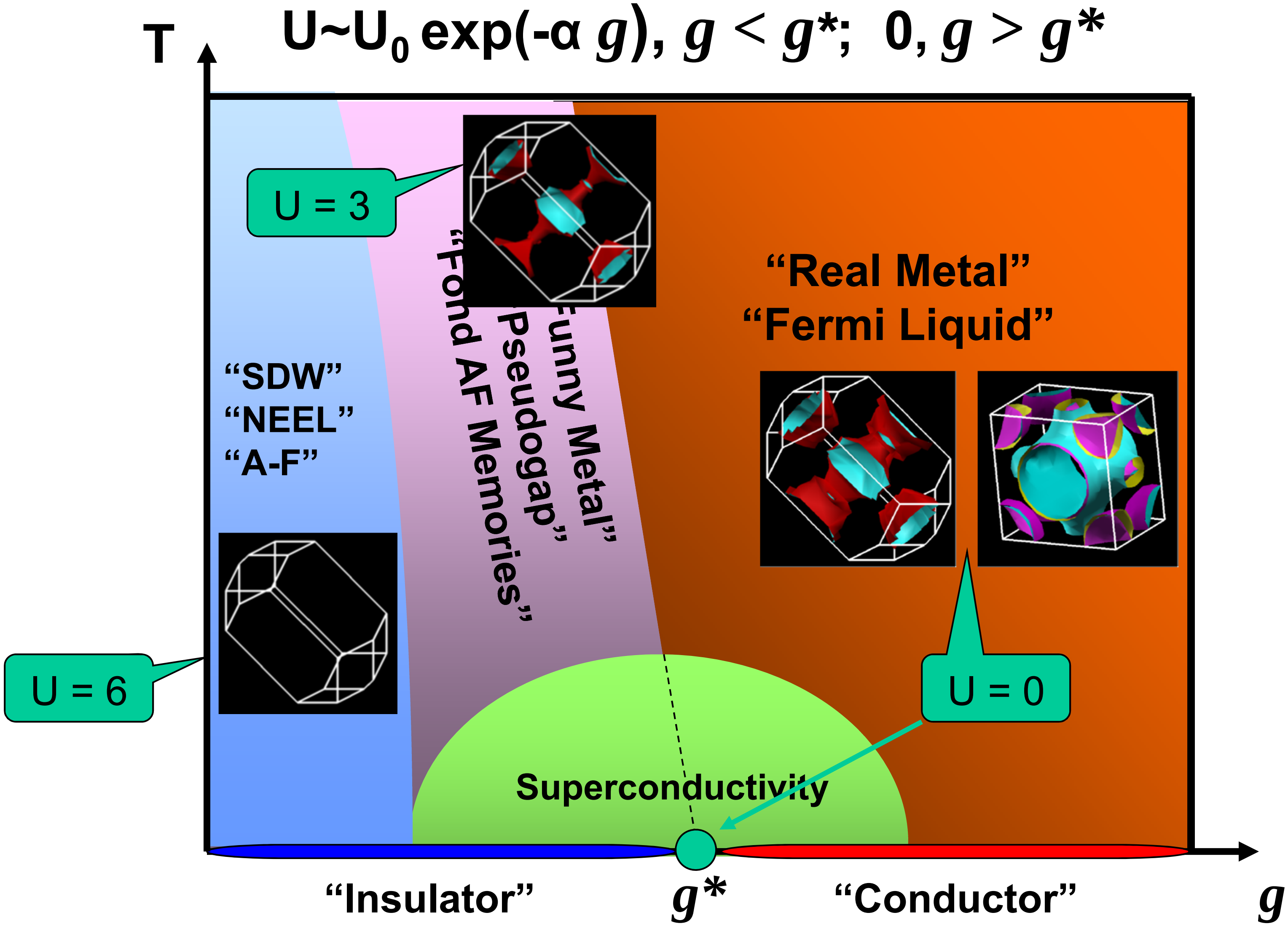
n = -0.15



n
U
0.00
+0.15
-0.15
0
3
6

The Colossal Quantum Conundrum

$U \sim U_0 \exp(-\alpha\, g),\ g < g^*;\ \ 0,\ g > g^*$



Somewhere in here there has to be “BCS-like” pairing!

Shakes or Spins or Both?

Are They Copacetic, Competitive…or…

…just another Conundrum?

What formalism is the HTSC analogy to Migdal-Eliashberg-McMillan?

(In other words, how do I calculate the value of the BCS gap?)

- Original Strong Coupling, Eliashberg *(JETP, 1960), McMillan (PR, 1968)*
- Generalized Linhard Response Function (RPA + fluctuations) *Hu and O'Connell (PRB 1989)*
- Dielectric Response Function *Kirznits, Maximov, Khomskii (JLTP 1972)*

McMillan Strong Coupling

(Computationally implemented by Wierzbowska, et al., cond-mat/0504077, 2006)

$$T_c = \frac{\Theta}{1.45} \exp\left[-\frac{1.04(1+\lambda)}{\lambda - \mu^*(1+0.62\lambda)} \right]. \qquad (18)$$

$$\lambda = 2 \int \frac{d\omega\, \alpha^2(\omega) F(\omega)}{\omega} = \frac{N(0) \langle \mathcal{J}^2 \rangle}{M \langle \omega^2 \rangle}, \qquad (23)$$

What's the HTSC equivalent?

$$\alpha^2(\omega) F(\omega) = \int_S \frac{d^2p}{v_F} \int_{S'} \frac{d^2p'}{(2\pi\hbar)^3 v_F'} \sum_\nu g_{pp'\nu}{}^2 \delta(\omega - \omega_{p-p'\nu}) \Big/ \int_S \frac{d^2p}{v_F}, \qquad (19)$$

where the integral $\int d^2p$ is taken over the Fermi surface and the electron-phonon matrix elements are given by[14]

$$g_{pp'\nu} = (\hbar/2MNV\omega_{p-p'\nu})^{1/2} \mathcal{J}_\nu(p, p'), \qquad (20)$$

where $\mathcal{J}_\nu(pp')$ is the electronic matrix element of the change in the crystal potential $\mathcal{U}$ as one atom is moved:

$$\mathcal{J}_\nu(pp') = \int \psi_p^* (\boldsymbol{\varepsilon}_{p-p'\nu} \cdot \nabla \mathcal{U}) \psi_{p'} d\mathbf{r}. \qquad (21)$$

Generalized Linhard Function

$$\chi^0(\mathbf{q},\omega)=\sum_{\mathbf{k},\sigma}\frac{f(\mathbf{k})-f(\mathbf{k}+\mathbf{q})}{\hbar\omega-(\varepsilon_{\mathbf{k}+\mathbf{q}}-\varepsilon_{\mathbf{k}})+iDq^2}$$

$$D=\lim_{t\to\infty}\frac{1}{2t}\overline{\delta\mathbf{R}^2(t)}$$

$$V(\mathbf{q})=4\pi e^2/q^2$$

$$\epsilon(\mathbf{q},\omega)=1-V(\mathbf{q})\chi^0(\mathbf{q},\omega)$$

$$\epsilon_1(x,y)=1+\frac{q_{\mathrm{TF}}^2}{8k_F^2x^2}\left[1+\frac{1}{8x}\left[(1+b^2x^2-\nu_+^2)\ln\left[\frac{(1+\nu_+)^2+b^2x^2}{(1-\nu_+)^2+b^2x^2}\right]+(1+b^2x^2-\nu_-^2)\ln\left[\frac{(1+\nu_-)^2+b^2x^2}{(1-\nu_-)^2+b^2x^2}\right]\right]\right.$$
$$\left.-\frac{b}{2}\left\{\nu_+\left[\arctan\left[\frac{1-\nu_+}{bx}\right]+\arctan\left[\frac{1+\nu_+}{bx}\right]\right]+\nu_-\left[\arctan\left[\frac{1-\nu_-}{bx}\right]+\arctan\left[\frac{1+\nu_-}{bx}\right]\right]\right\}\right]$$

where

$$x=\frac{q}{2k_F},\quad y=\frac{\hbar\omega}{4\varepsilon_F},\quad q_{\mathrm{TF}}^2=\frac{4me^2k_F}{\pi\hbar^2},\quad b=\frac{2mD}{\hbar},\quad \nu_\pm=x\pm y/x\ ,$$

“Fluctuations?”
“Empirical?”

HO (1989)

Dielectric Response Function

$$G(\mathbf{k}, i\omega_n) = 1/(i\omega_n - \xi_k)$$

$$F(\mathbf{p}, i\omega_n) = -G(\mathbf{p}, i\omega_n)G(-\mathbf{p}, -i\omega_n)T_c \sum_{\mathrm{m}} \int [d^3k/(2\pi)^3] \times V(\mathbf{p}-\mathbf{k}, i\omega_n - i\omega_{\mathrm{m}})F(\mathbf{k}, i\omega_{\mathrm{m}})$$

$$V(\mathbf{q}, i\omega_n) = \frac{4\pi e^2}{q^2}\left[1 - \int_0^\infty \frac{dE^2 \rho(\mathbf{q}, E)}{\omega_n^2 + E^2}\right]$$

In principle, KMK can calculate the BCS gap for general “bosonic” fields, be they phonons, magnons, spin-ons, excitons, plasmons…or morons!

KMK (1972)

Bottom Line

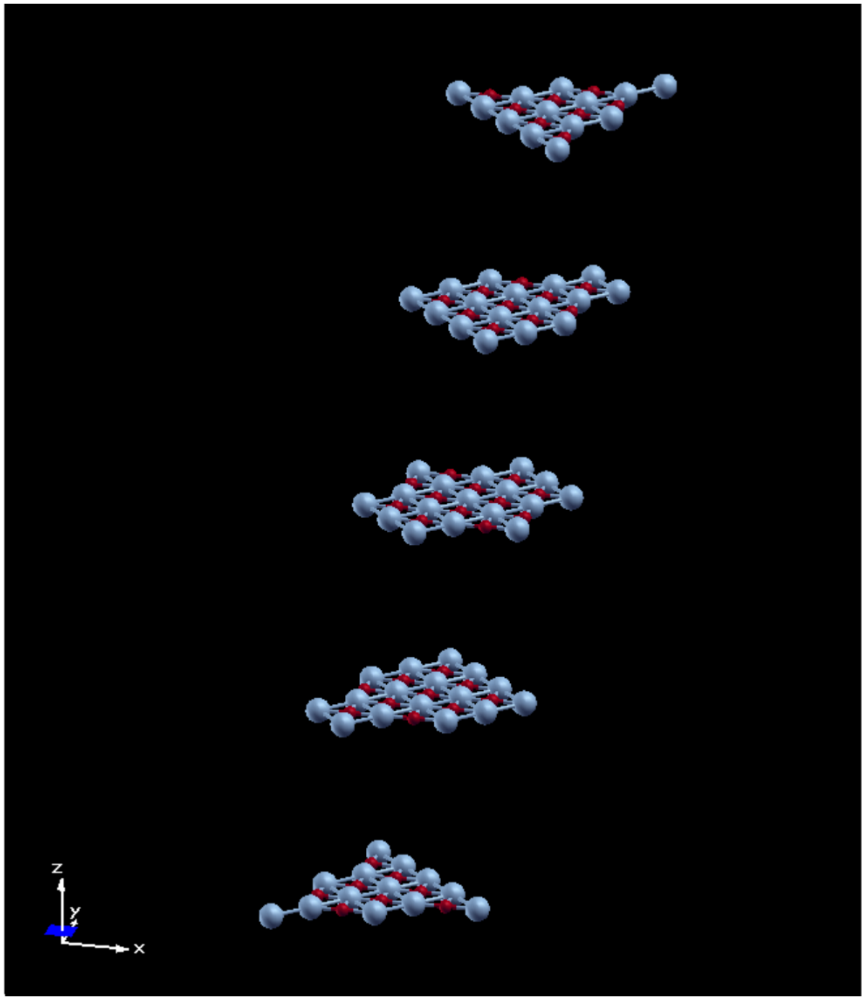
Can studying CuO proxies with DFT
+ LDA+U
+ phonons
+ spins
provide insight into the origins of High-T_C?

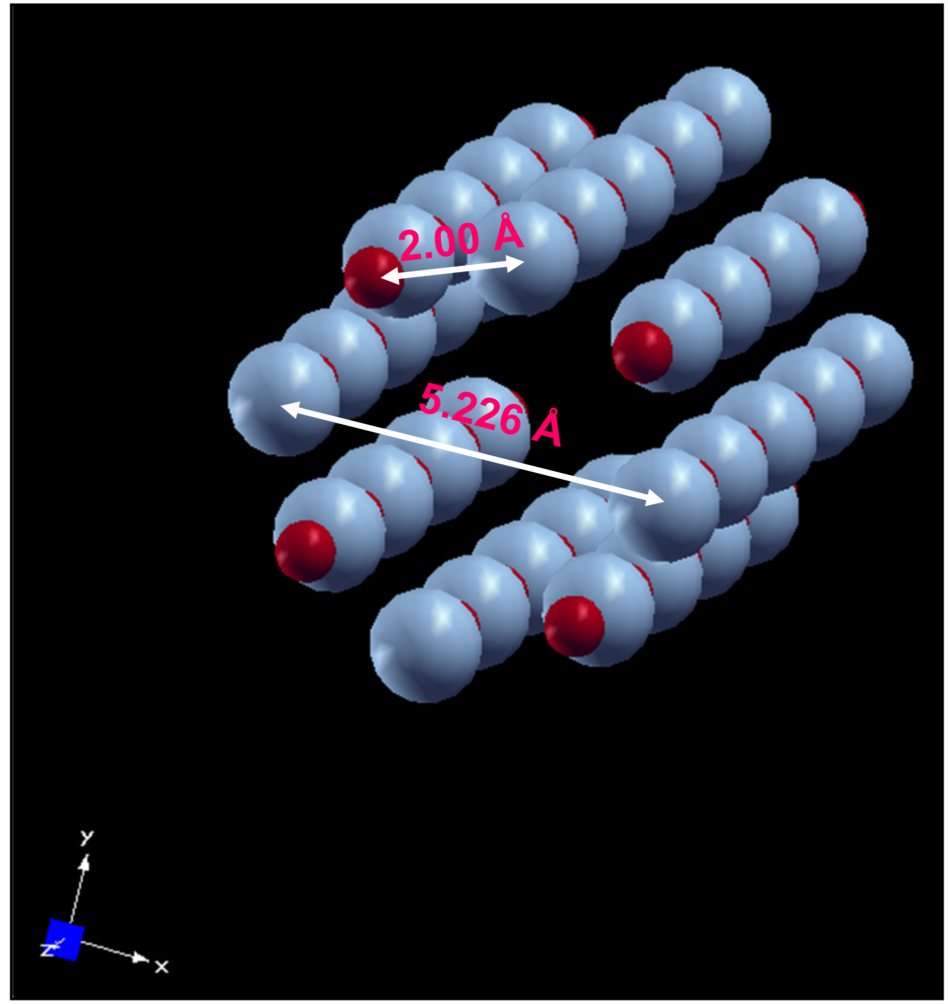
I say “Yes,” but…
Size Matters…
…and I need a…
BIGGER COMPUTER!

Other CuO Proxy Structures

- Studies in Progress -

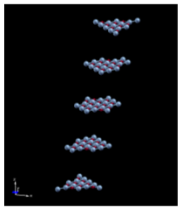
Films & Tubes



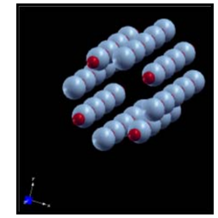


a = b = 3.905 Å
c = 6 x 3.905 = 23.43 Å

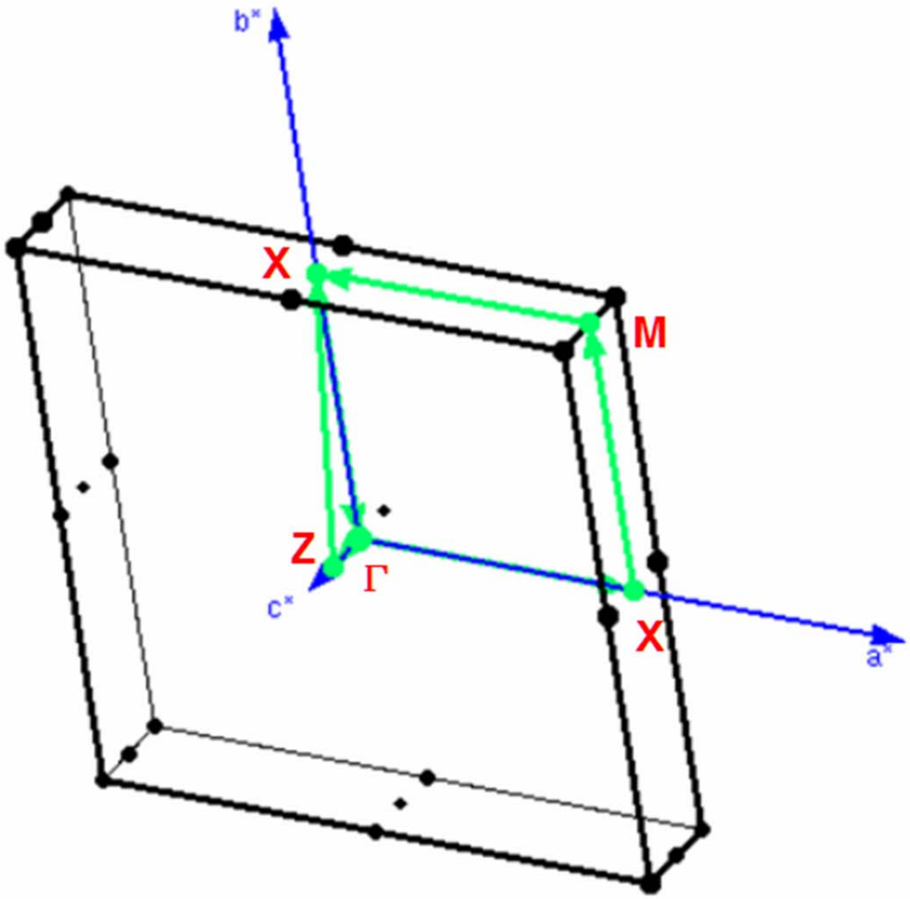
2 CuO segments per quadrant
16 Å between tubes

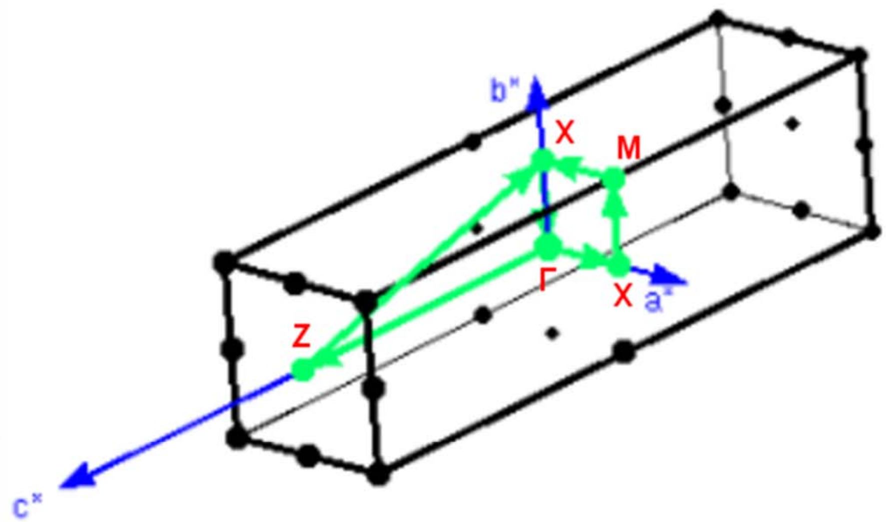


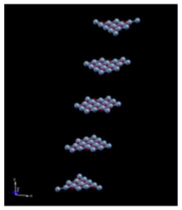
Films & Tubes



Zones

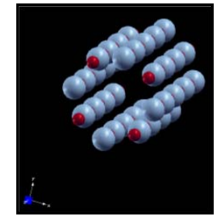


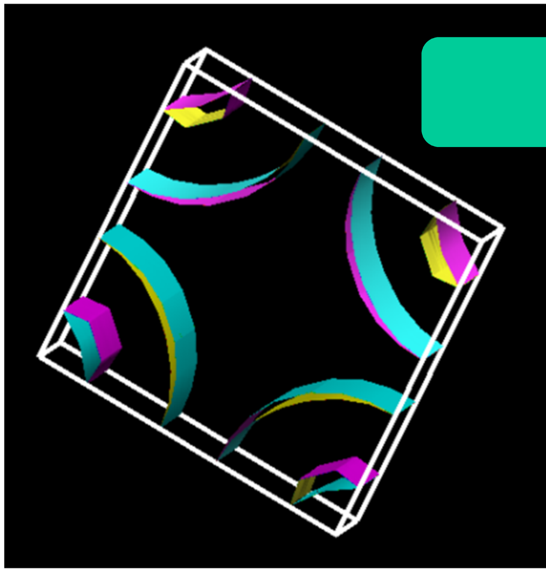


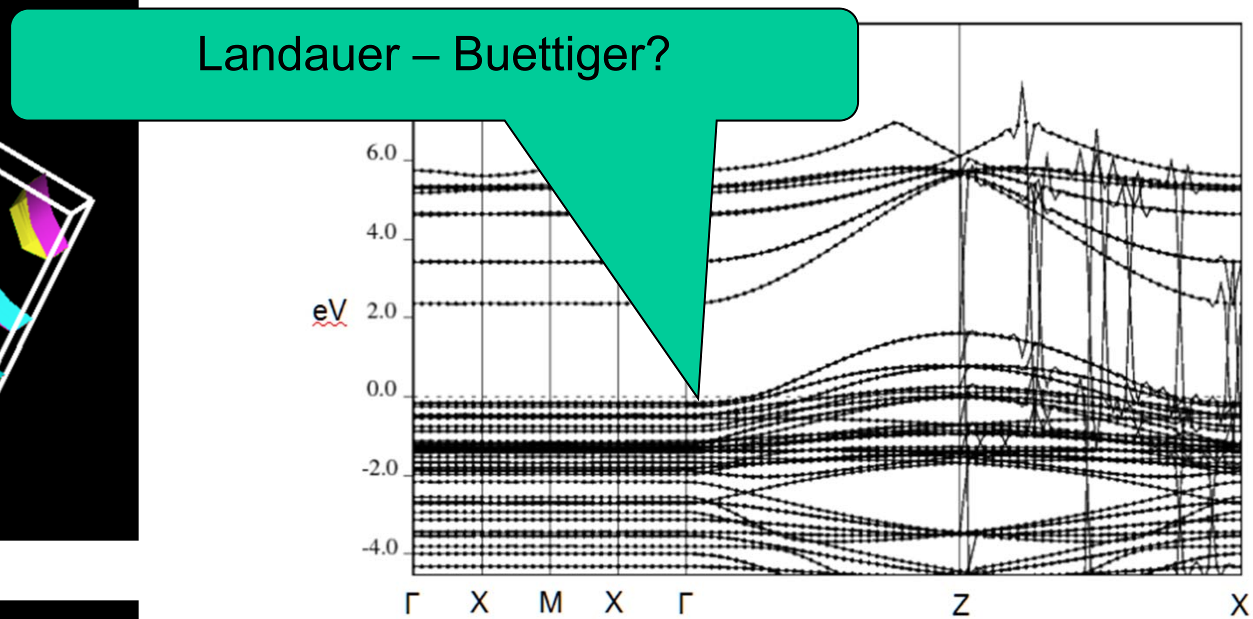


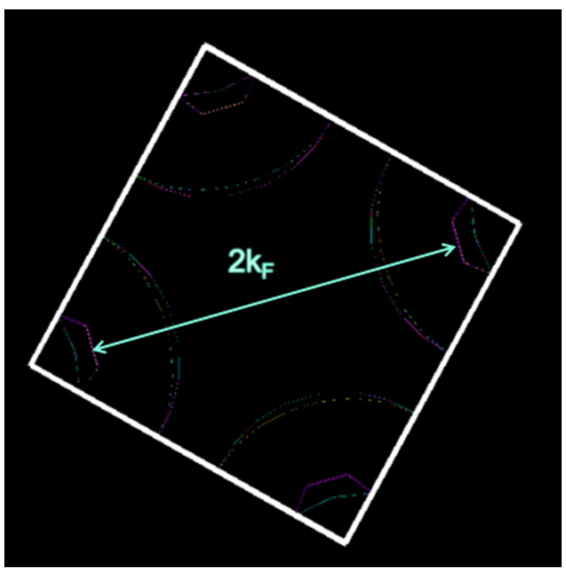
Films & Tubes

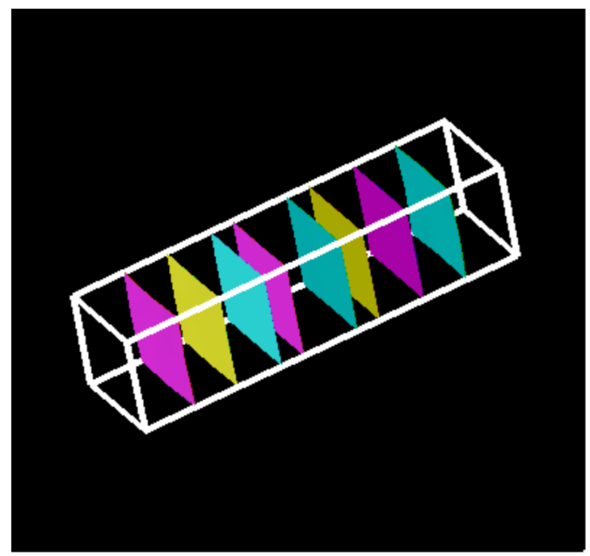
States











-- OK…Enough Already !

-- That’s all for now !

-- But Stayed Tuned…