Whither Superconductivity?

Superconductivity
The Day Before Yesterday - Yesterday - Today - Tomorrow

Vitaly Lazarevich Ginzburg

Karl Alexander Mueller

"Best wishes, and hang in there, Guys !"

Theory & Modeling

Bob Laughlin's "Theory of Everything" (that matters)

Theory of Everything

$$\mathcal{H} = -\sum_j \frac{\hbar^2}{2m}\nabla_j^2 - \sum_\alpha \frac{\hbar^2}{2M_\alpha}\nabla_\alpha^2 - \sum_{j,\alpha}\frac{Z_\alpha e^2}{|r_j - R_\alpha|} + \sum_{j<k}\frac{e^2}{|r_j - r_k|} + \sum_{\alpha<\beta}\frac{Z_\alpha Z_\beta e^2}{|R_\alpha - R_\beta|}$$

- Hydrogen atom
- Methane molecule
- water
- Air
- Rocks
- Concrete
- Steel
- Glass
- Plastic
- Buildings
- Cities
- Continents

- Proteins
- DNA
- Viruses
- Bacteria
- Yeast
- Slime mold
- Butterflies
- Sharks
- Rats
- Lawyers
- Ebola virus
- Legislatures
- Civilizations

- Flowers
- Trees
- Cows
- Cheese
- Sauce Bernais
- Computers
- Television
- Cars
- Jets
- Lawnmowers
- Sewage
- Spotted Owls
- ...

Where's spin, Pauli and Darwin? Ya screwed up, Bob…should'a used the many body Dirac equation! Oh yeah, and maybe Maxwell, Boltzman and Gibbs, too…and Newton's Apple.

The crunch comes when Σ_i with i >= 3 -> "thermodynamic limit."

"Size Matters !"

"Naked BCS"

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

$$\lambda k\Theta \square \quad E_F$$

Where

Tc = Critical Temperature

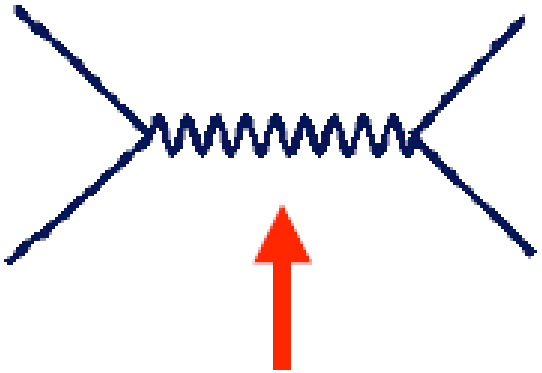
Θ = Boson Characteristic Temperature

λ = Fermion-Boson Coupling Constant

μ^* = Fermion-Fermion Repulsion

a = "Gap Parameter, ~ 1-3"

When “electron-electron” interactions are involved, the phrase “pairing glue” can be a dirty word!



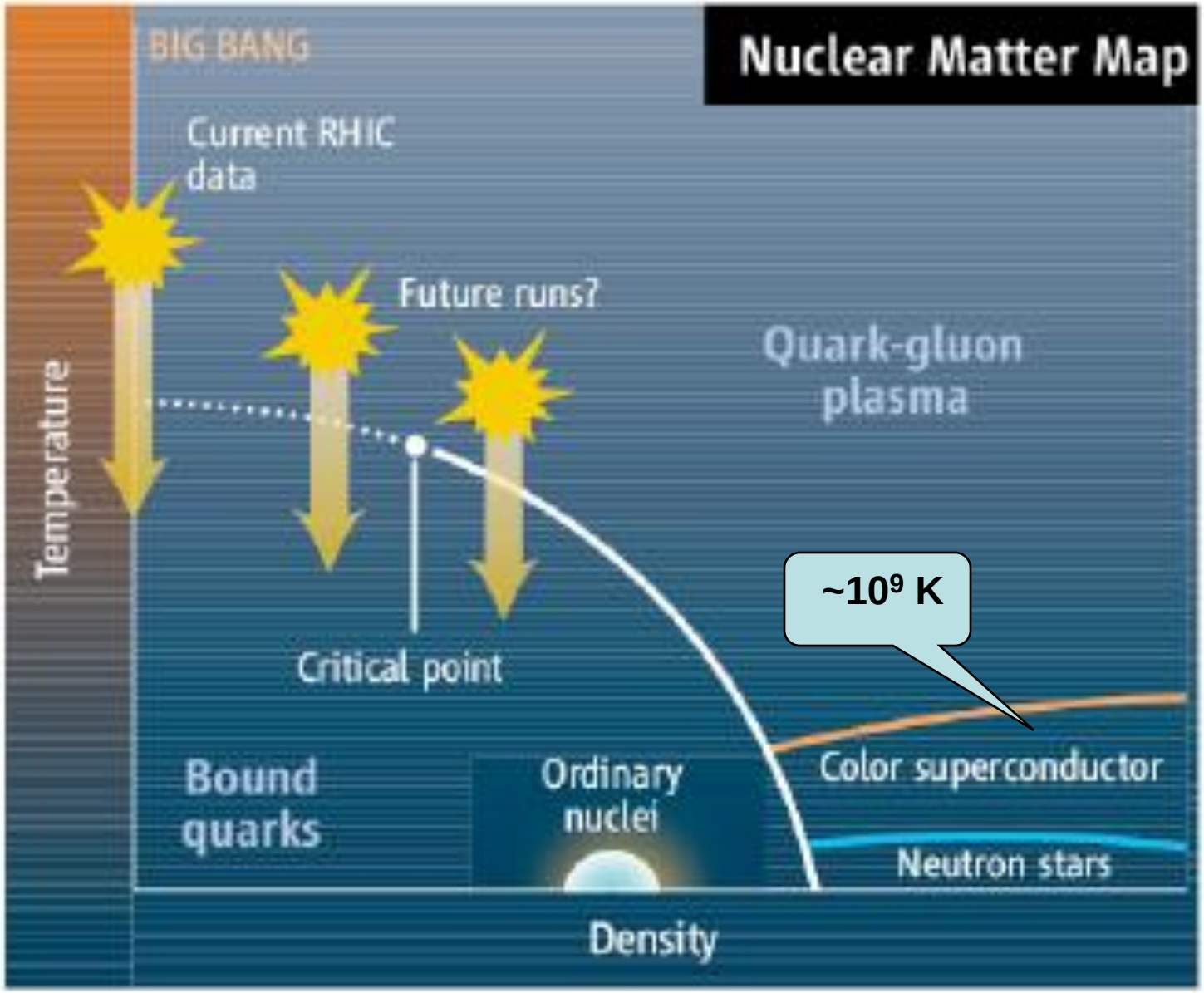
Insert your favorite “on” here

(phonon, magnon, exciton, plasmon, anyon, moron …)

“Put-on !”

Mike Norman, Alexandria, VA 2006

Really High-Tc



Electron-Phonon Coupling a la Migdal-Eliashberg-McMillan

(plus Allen & Dynes)

$$H_{el-ph} = \sum_{\mathbf{k}\mathbf{q}\nu} g^{\mathbf{q}\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}}\, c^{\dagger m}_{\mathbf{k}+\mathbf{q}} c^{n}_{\mathbf{k}}\, (b^{\dagger}_{-\mathbf{q}\nu} + b_{\mathbf{q}\nu}) \qquad (1)$$

First compute this via DFT…

$$\alpha^2 F(\omega) = \frac{1}{N(\varepsilon_F)} \sum_{mn} \sum_{\mathbf{q}\nu} \delta(\omega - \omega_{\mathbf{q}\nu}) \sum_{\mathbf{k}} |g^{\mathbf{q}\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}}|^2 \times \delta(\varepsilon_{\mathbf{k}+\mathbf{q},m} - \varepsilon_F)\delta(\varepsilon_{\mathbf{k},n} - \varepsilon_F), \qquad (2)$$

$$\lambda = 2\int \frac{\alpha^2 F(\omega)}{\omega} d\omega = \sum_{\mathbf{q}\nu} \lambda_{\mathbf{q}\nu}, \qquad (3)$$

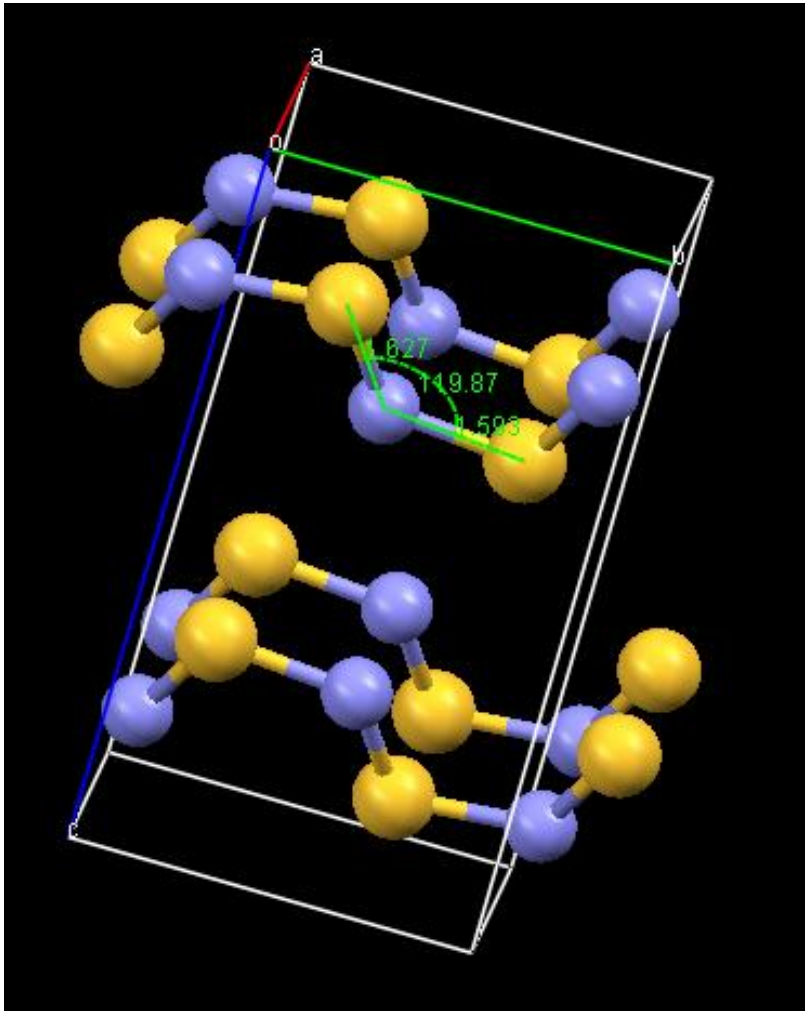
$$\lambda_{\mathbf{q}\nu} = \frac{2}{N(\varepsilon_F)\omega_{\mathbf{q}\nu}} \sum_{mn} \sum_{\mathbf{k}} |g^{\mathbf{q}\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}}|^2 \times \delta(\varepsilon_{\mathbf{k}+\mathbf{q},m} - \varepsilon_F)\delta(\varepsilon_{\mathbf{k},n} - \varepsilon_F). \qquad (4)$$

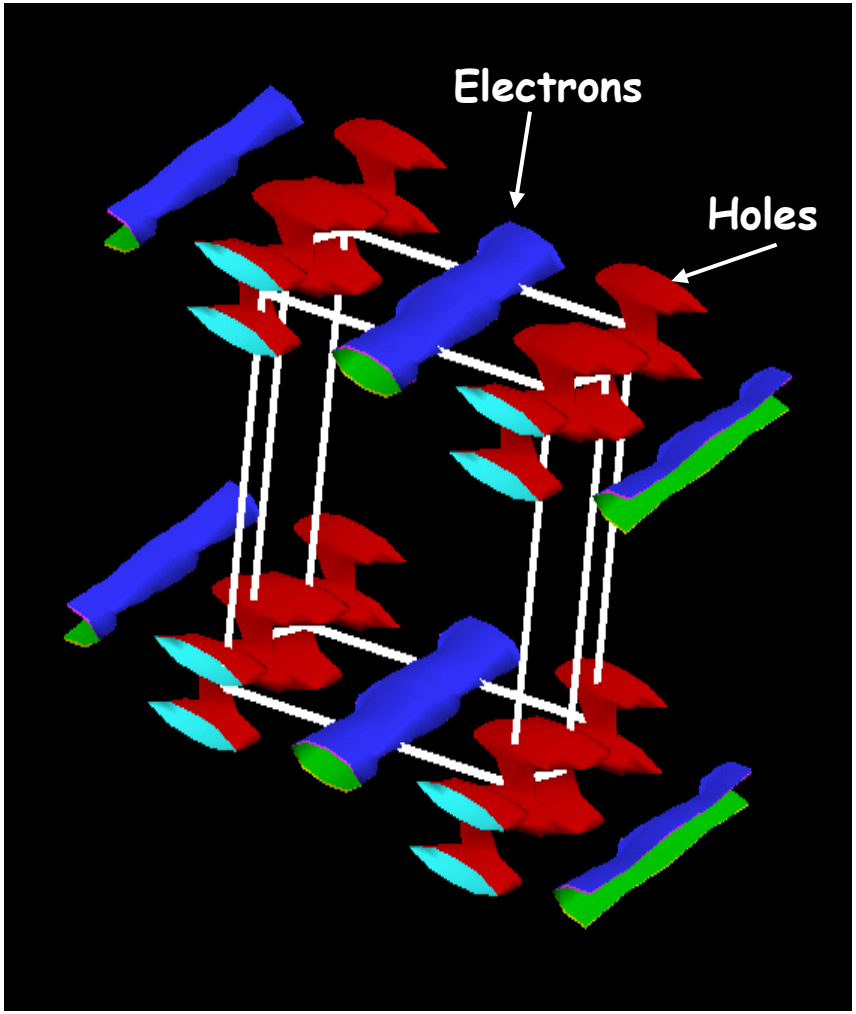
Then this…

Quantum-Espresso (Democritos-ISSA-CNR)

http://www.pwscf.org Grazie!

Polysulfur Nitride: The World's First 330 Degree Superconductor !





Legal Disclaimer: The Temperature Units are Millikelvin.

So…

- Now we can compute the sc phase diagram of Al, Nb, MgB_2, etc., as accurately as can be measured.
- Then has phonon-mediated superconductivity in s-p (light elements…some not so light) systems become "solved science?"
- Maybe…ask Warren Pickett.
- Unresolved: ultra-strong λ and flux dynamics.

What to do next?

- Develop DFT algorithms to compute "exotic" pairing mechanisms, analogous to e-p.
- Especially polarization ("exciton") and magnetic ("all flavors," particularly "negative-U").
- Marvin ?

Materials & Methods

Guidance from Our Elders

- *"Don't listen to theoreticians"* (B. Matthias, ca. 1970s).
- *"To make a long story short, searches for high-temperature superconductors, especially with the existing obscurities in the area of theory, may lead to unexpected results and discoveries"* (V. L. Ginzburg, 1984).
- *"At the extreme forefront of research in superconductivity is the empirical search for new materials"* (M. R. Beasley (1983), as communicated by K. A. Mueller and J. G. Bednorz, (1986)).
- "*If you find an old metal laying around in the literature, try cooling it down,"* (P. M. Grant, 1976).

Exactly What is a "Superconductor?"

- Does it have to be a "perfect conductor?"
  - i.e., zero TAFF
- Does it have to exclude flux (Meissner)?
- Or does it only need to be a "real good conductor ("ultraconductor")?"
  - 200x σ Cu @ 300 K @ 1000 Hz
    - Ballistic CNTs
    - Sliding P-F CDWs
    - Charged Solitons
    - ???

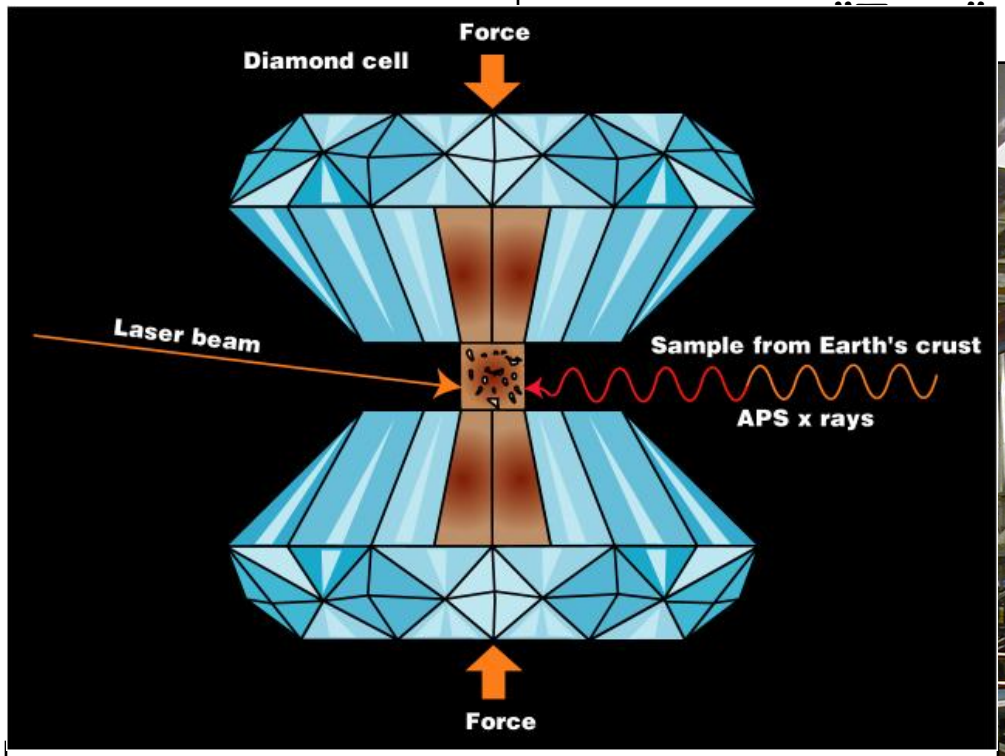
Materials Pathways

- Light Elements
- Heavy Elements
- Many Elements
- All Elements

- *COMBINATORIAL !*

Fabrication

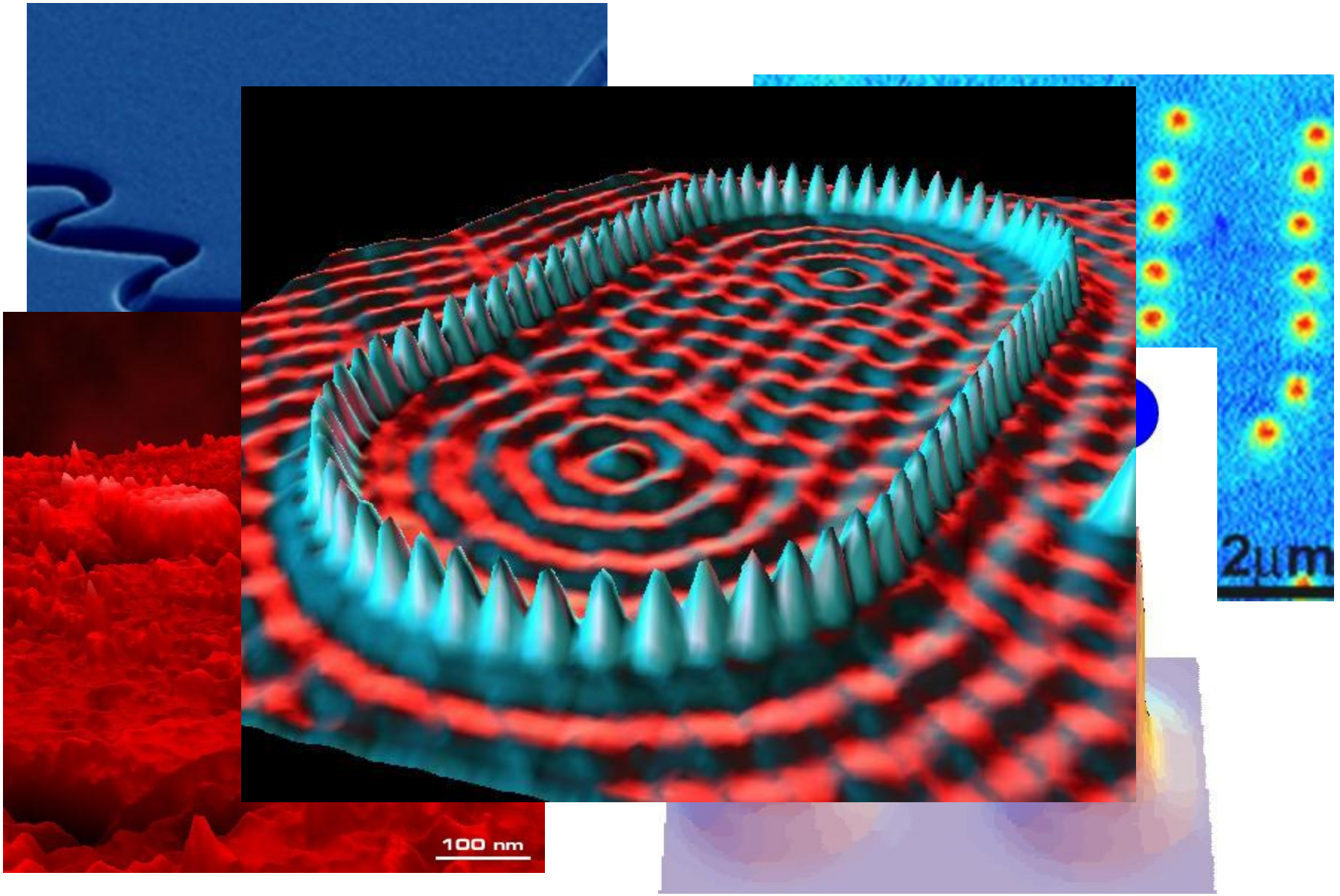
Superconductor Sandwiches



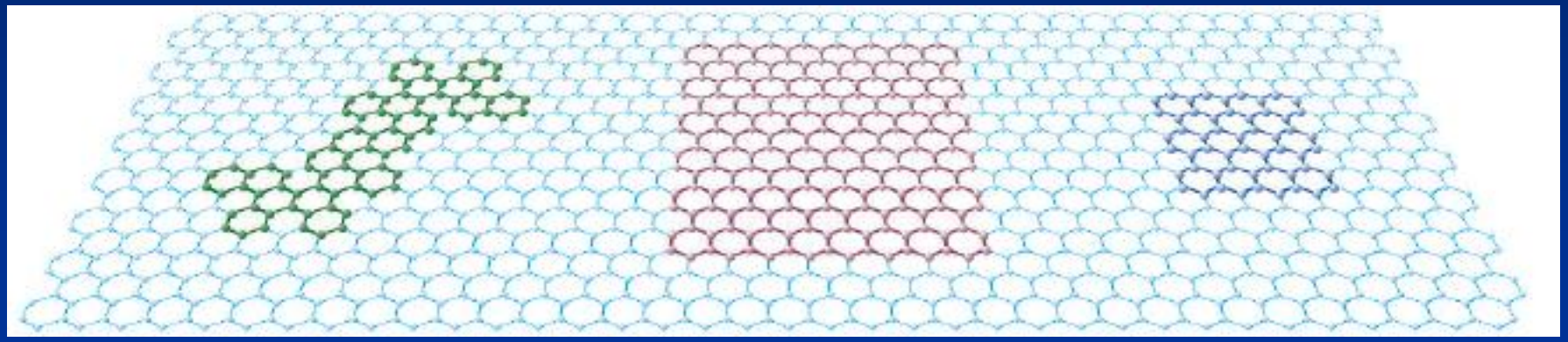
Squeeze Play

'em 'n' Beat 'em

NanoMachining

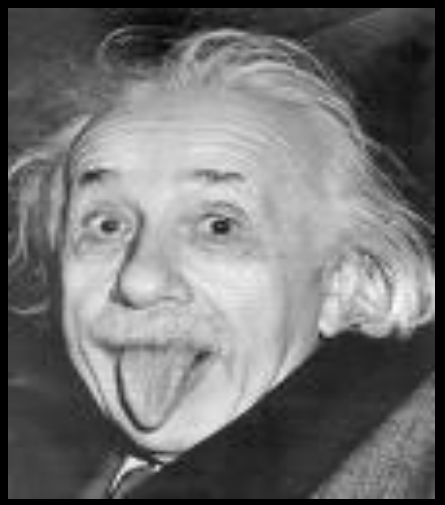


“Magic Carpet”



Applications

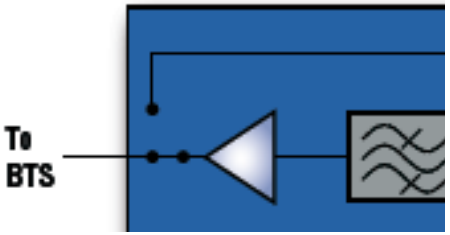
Low-Tc Today

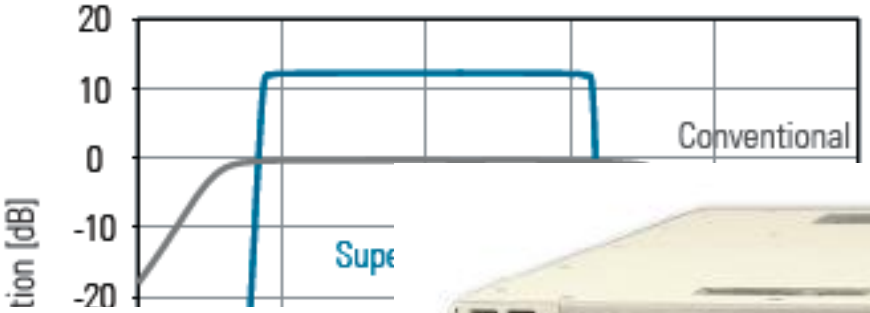


Quantum

Computing

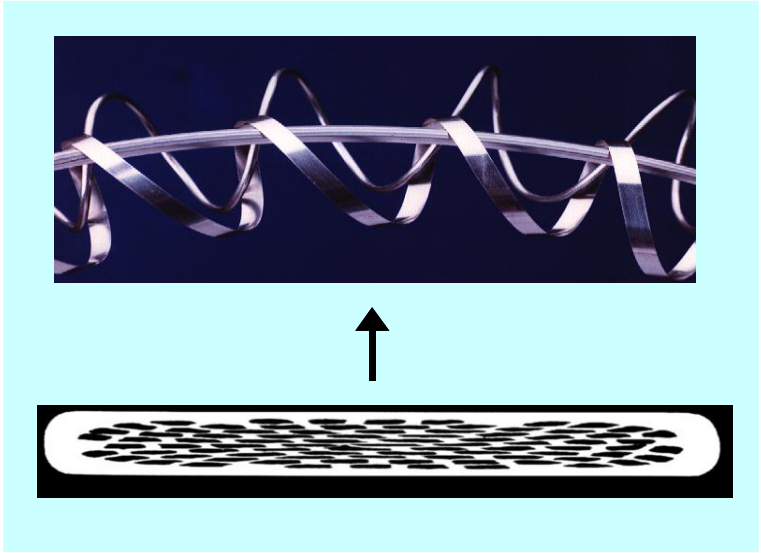
Electronics



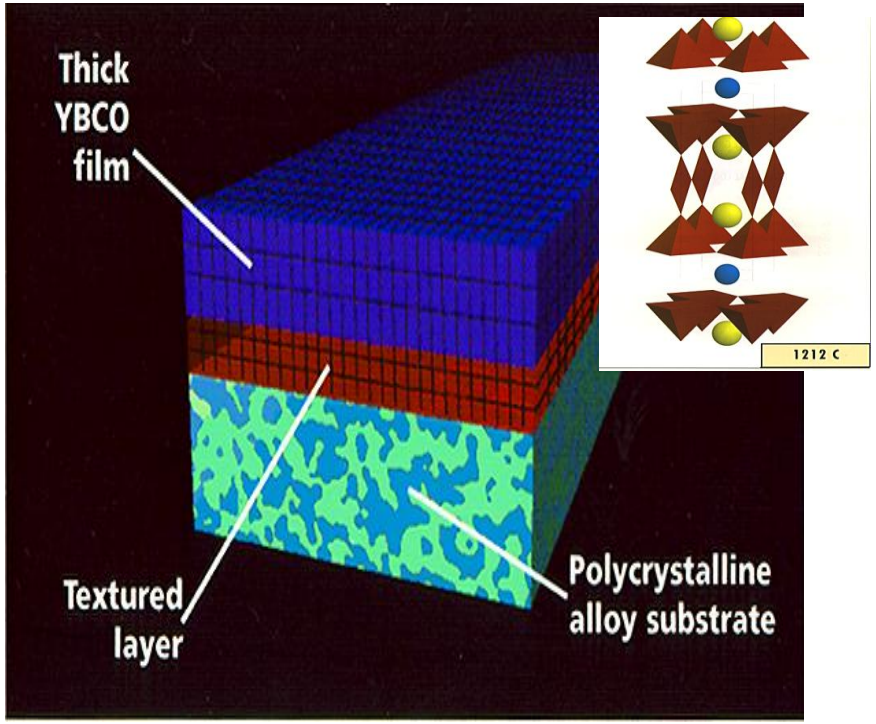


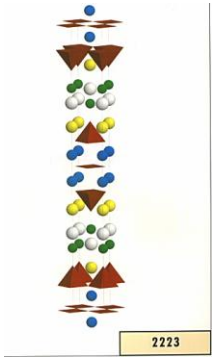
“A room temperature device !”

Wire



Gen 2

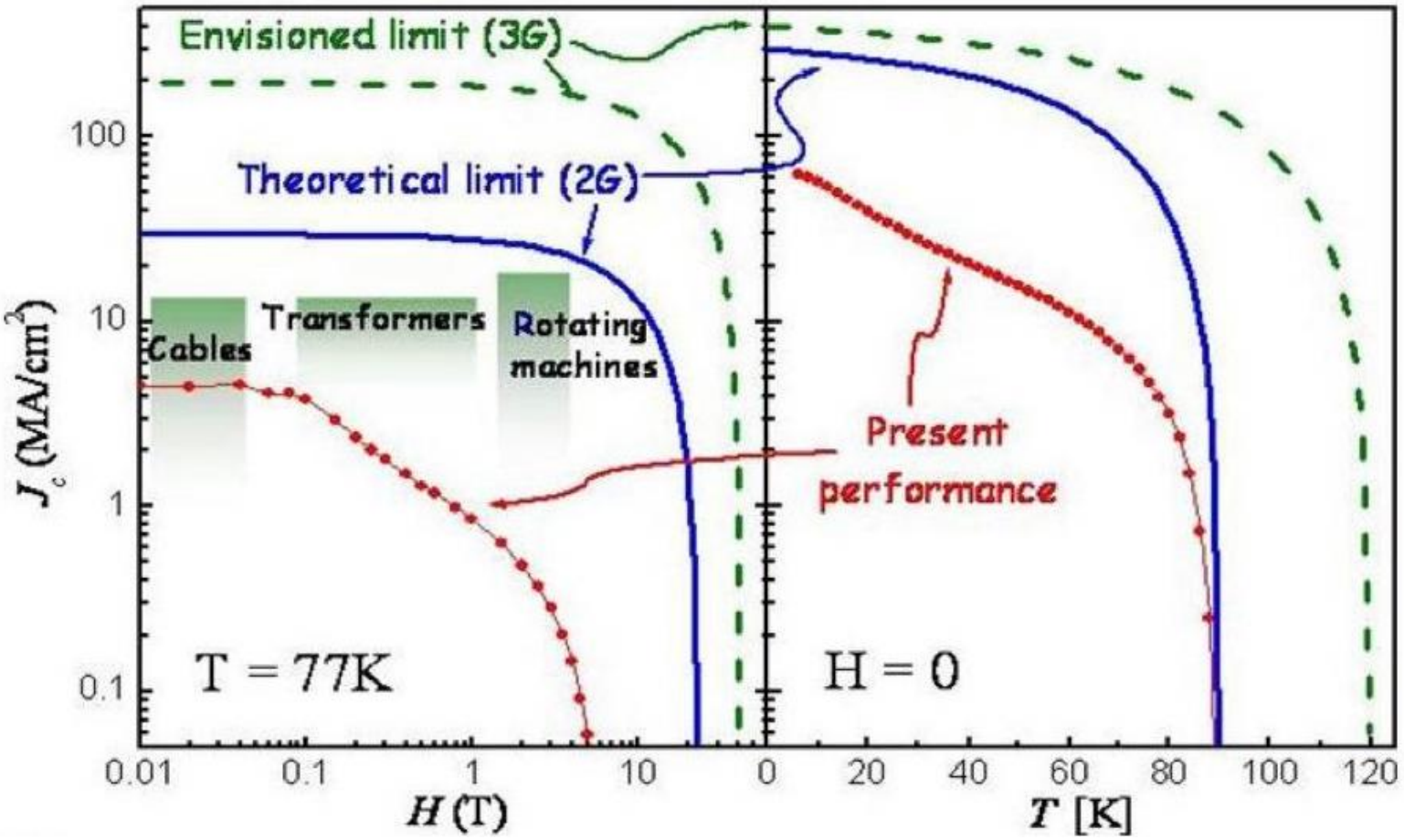




Gen 1

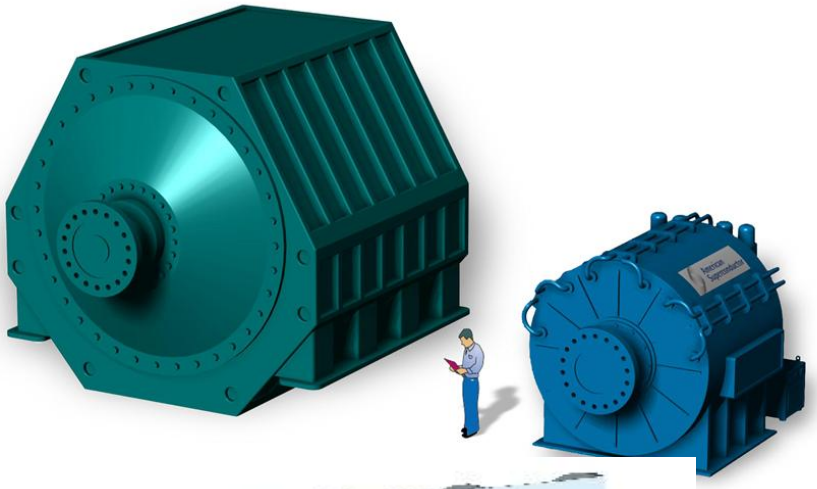
Major Players: US, Japan, China

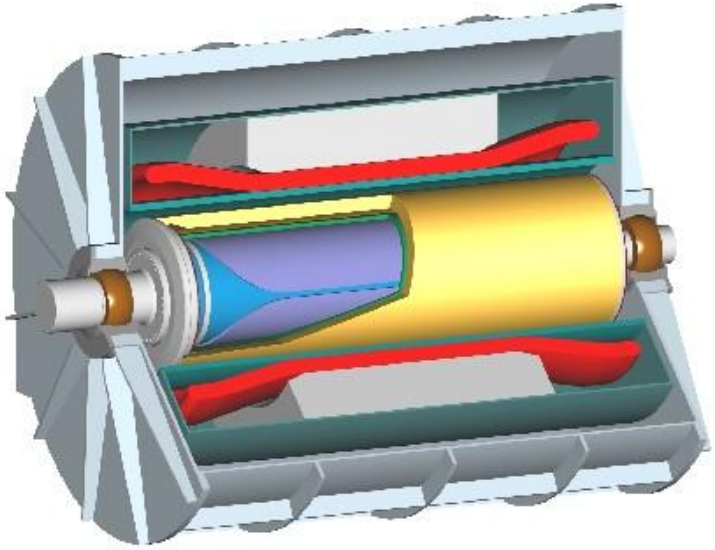
Wire Performance

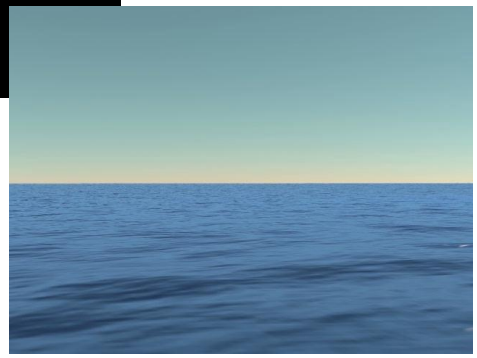


Rotating Machinery

Courtesy AMSC



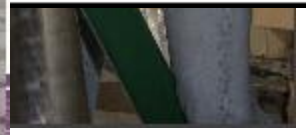




Major Players:

- AMSC
- SEI

Cables



Secure Super Grids

“You can’t always get what you want…”

"...you get what you need!"

Where there is no vision,
the people perish…

Proverbs 29:18