室温超导是否可能?

杨义峰

中国科学院物理研究所

http://hf.iphy.ac.cn

多体系统独特的集体行为模式与演化规律

大量机动车导致的交通阻塞，甚至“幽灵堵车”

多体系统独特的集体行为模式与演化规律

大量水分子的集体运动产生的波纹及其干涉现象

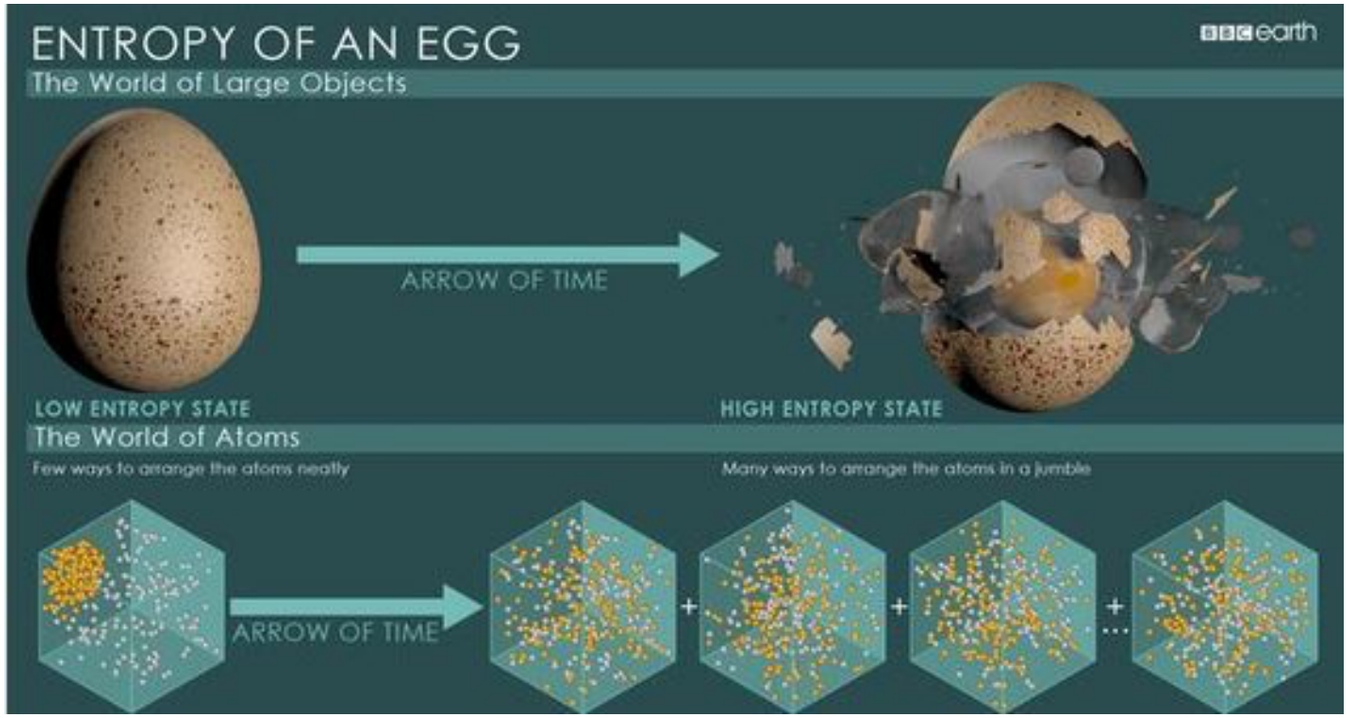
生物群体的集体行为模式

不同层面的行为模式可能是不同的

难以从低层进行简单推演

More is different !

时间箭头



一种最为独特的集体现象：超导的发现

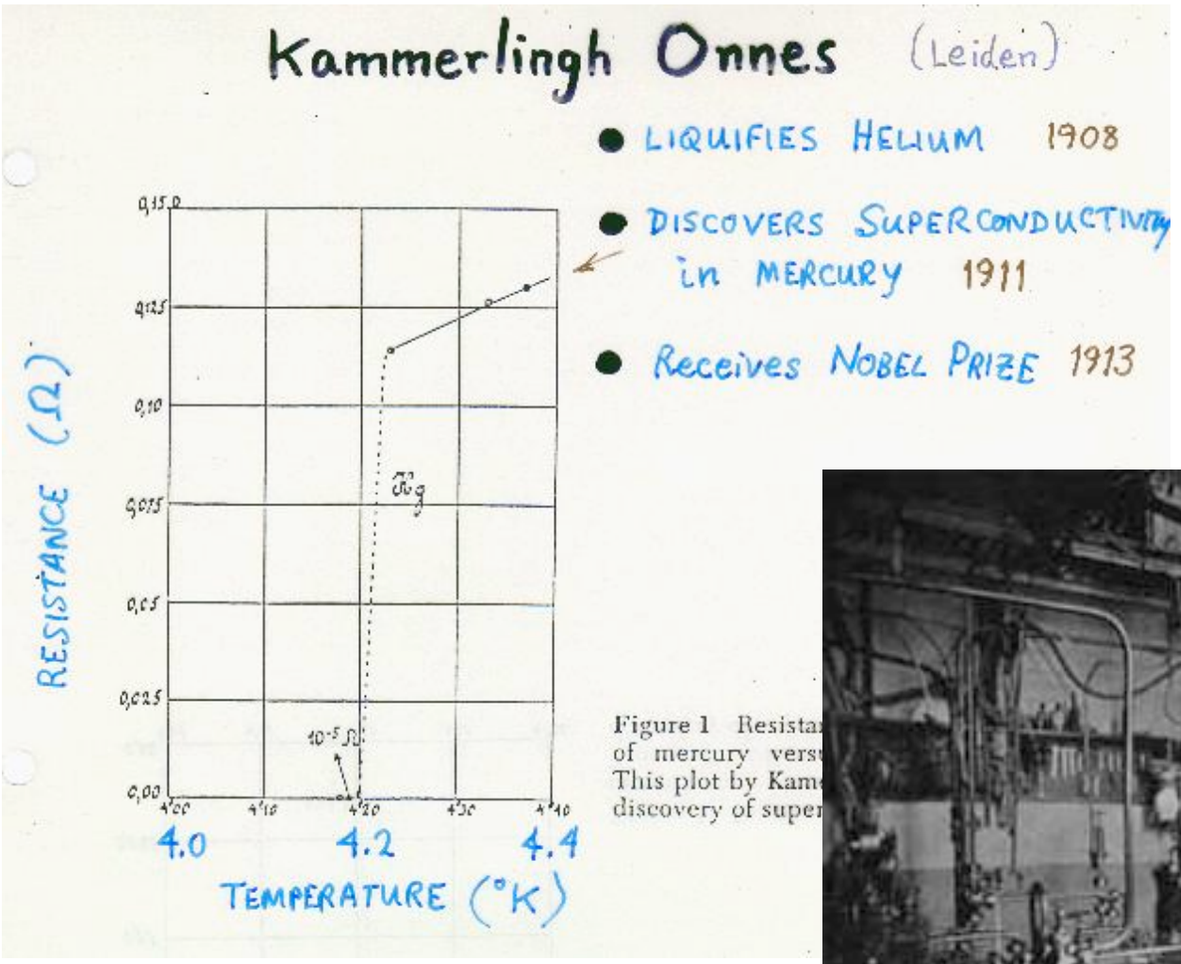
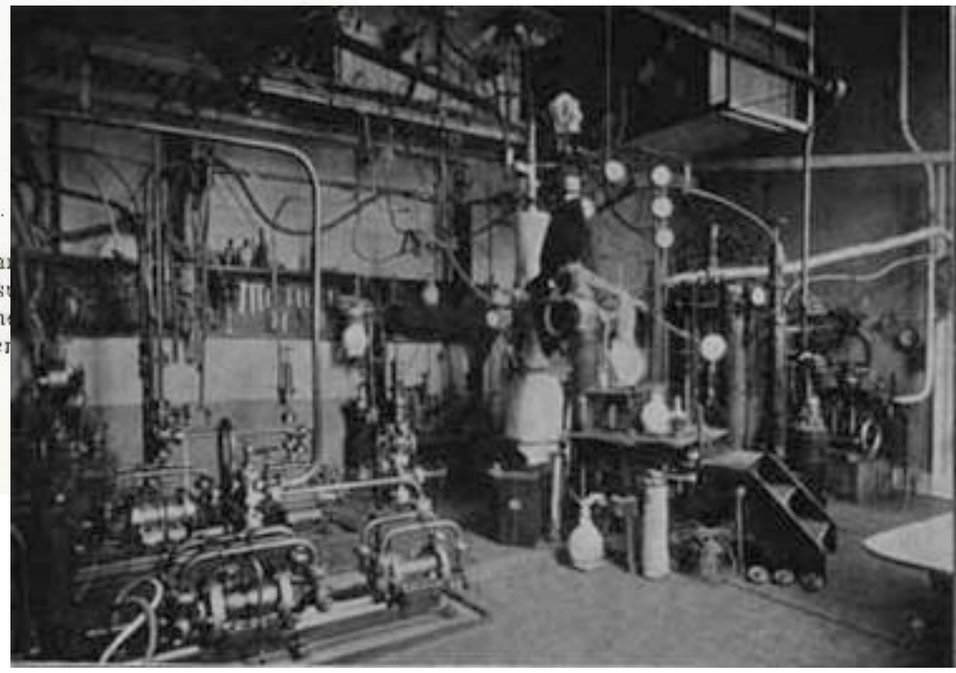
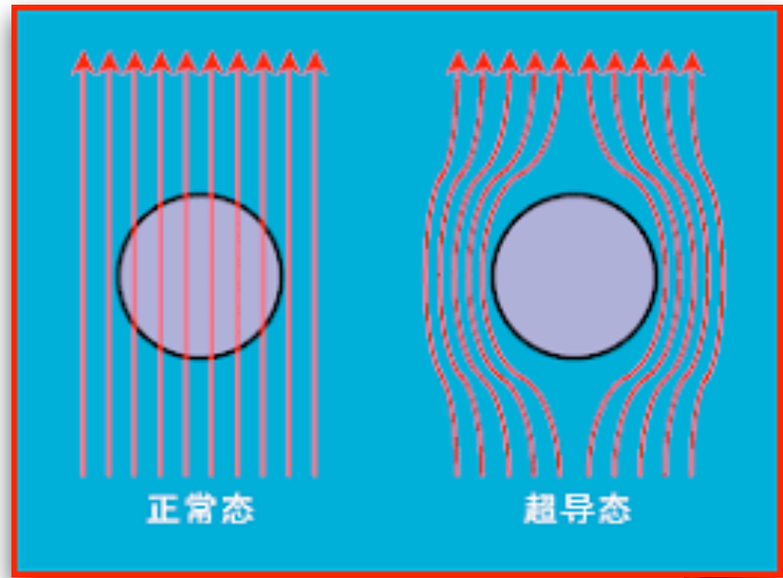
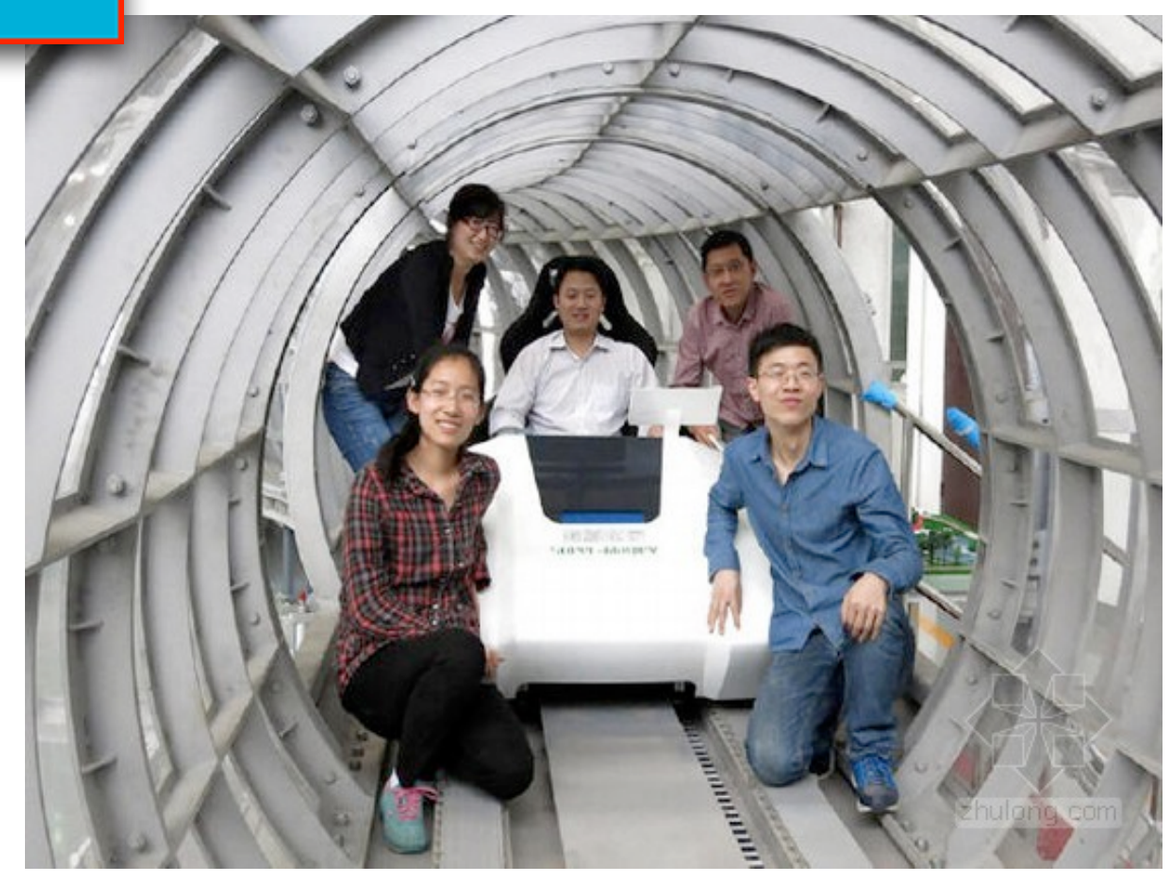


Figure 1 Resistan
of mercury versu
This plot by Kam
discovery of super



超导体的完全抗磁性





超导的两个基本性质：

1、零电阻

2、完全抗磁性

超导现象的物理起源的早期探索

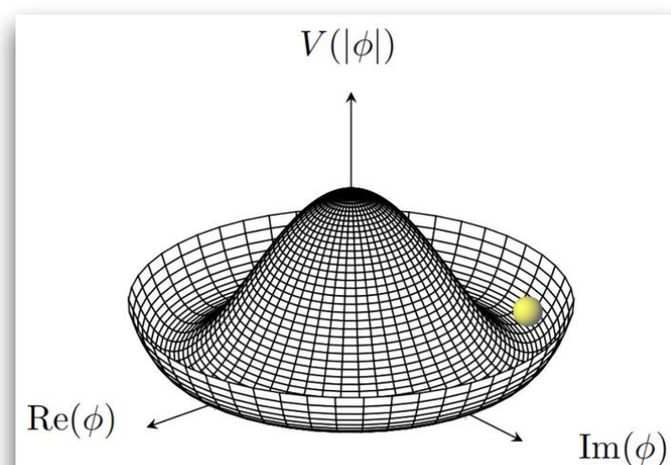
Fig. 1. Albert Einstein, Paul Ehrenfest, Paul Langevin, Heike Kamerlingh Onnes, and Pierre Weiss discussing superconductivity during the "Magnet-Woche" in Leiden in November 1920 (Photo: AIP)

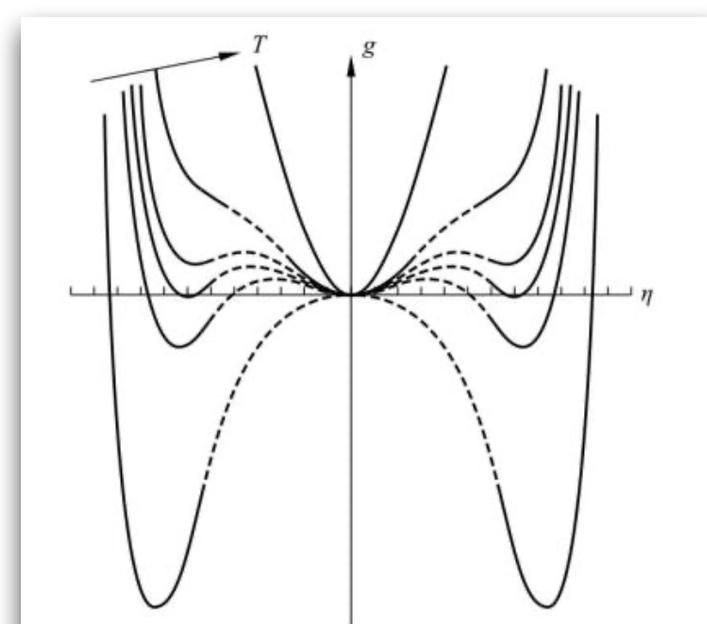
朗道的对称性破缺思想

$$f = f_{n0} + \alpha|\psi|^2 + \frac{\beta}{2}|\psi|^4 + \frac{1}{2m^*}\left|\left(\frac{\hbar}{i}\nabla - \frac{e^*}{c}\mathbf{A}\right)\psi\right|^2 + \frac{H^2}{8\pi}$$

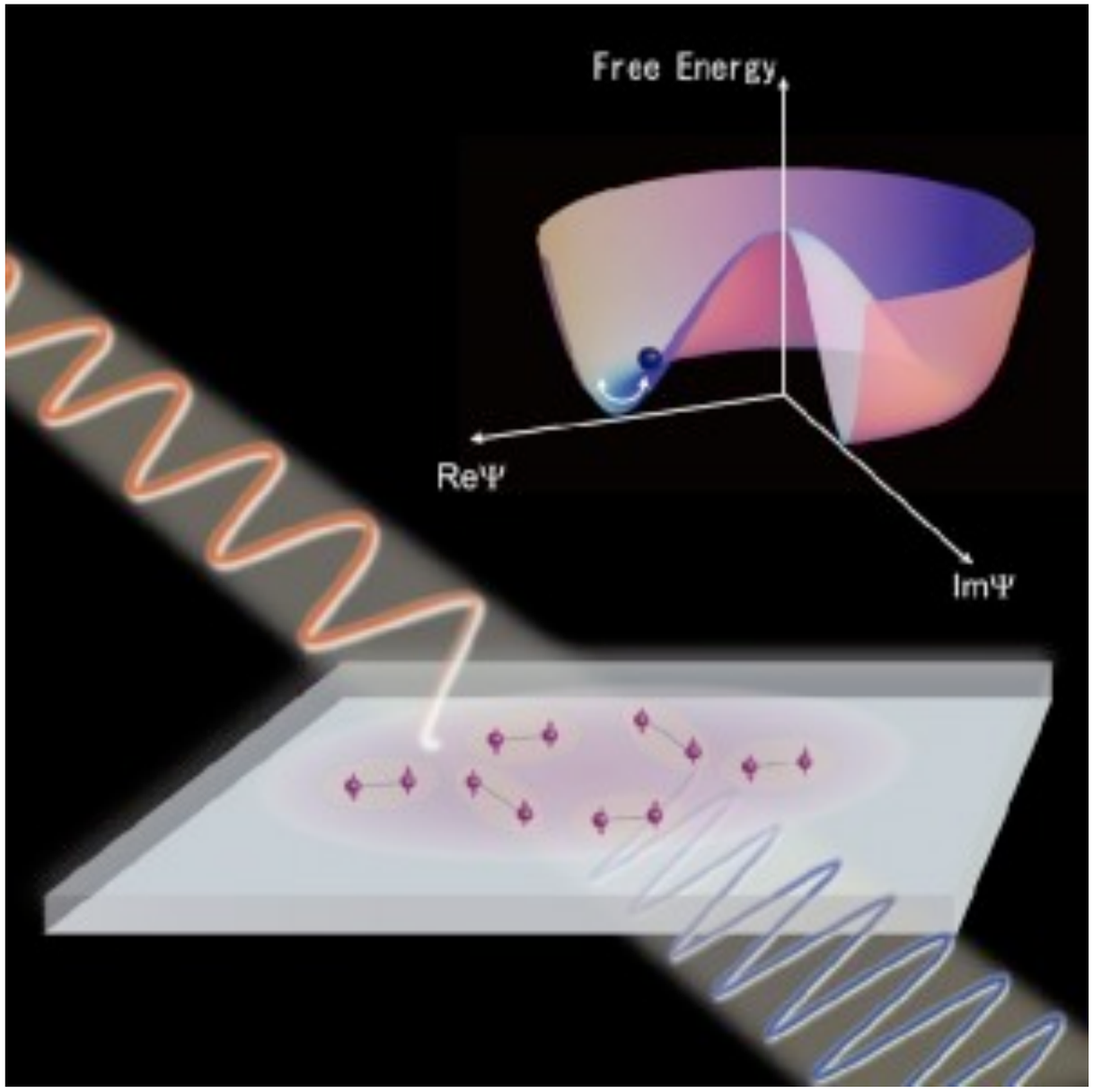
朗道

小心，他很凶！

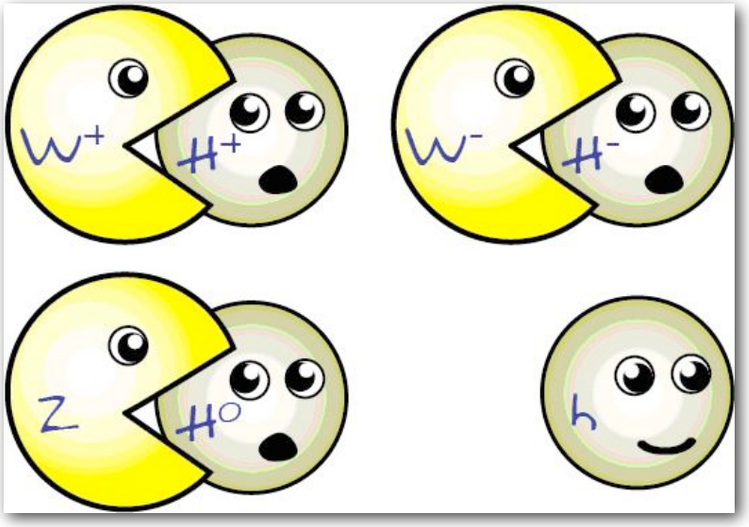




质量的起源



Anderson-Higgs机制



光子获得质量

“常规”超导的BCS理论

PHYSICAL REVIEW VOLUME 108, NUMBER 5 DECEMBER 1, 1957

Theory of Superconductivity*

J. Bardeen, L. N. Cooper,† and J. R. Schrieffer‡
Department of Physics, University of Illinois, Urbana, Illinois

(Received July 8, 1957)

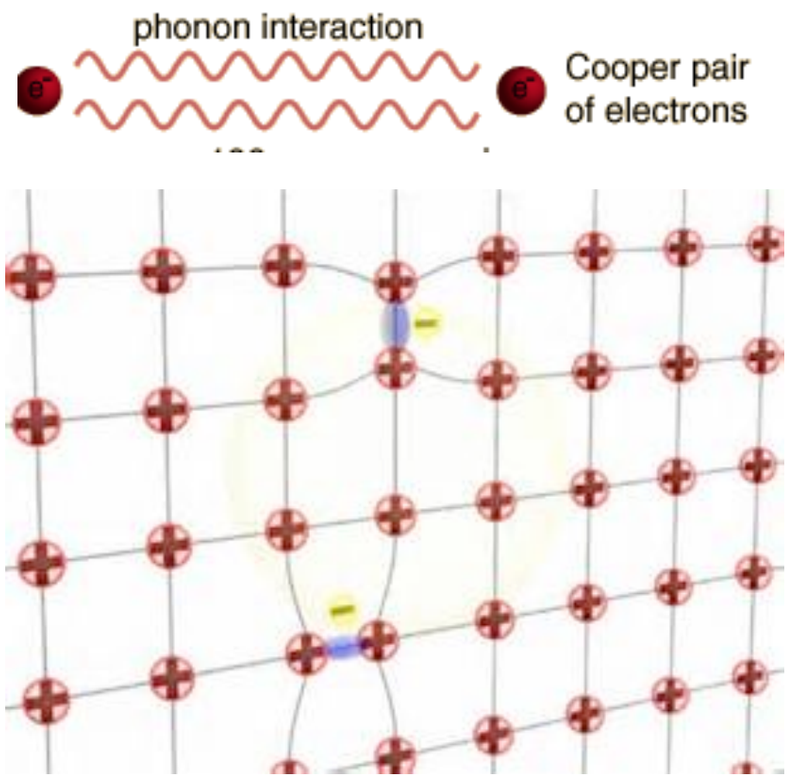
A theory of superconductivity is presented, based on the fact that the interaction between electrons resulting from virtual exchange of phonons is attractive when the energy difference

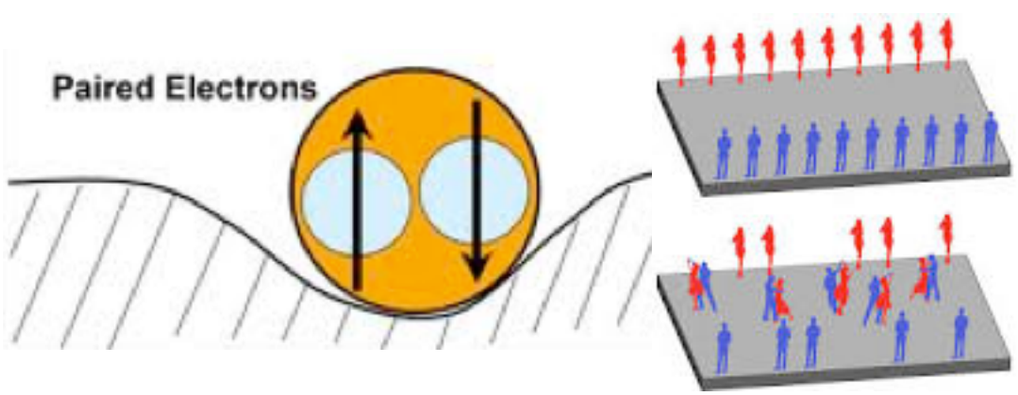
one-to-one correspondence with those of the normal phase is obtained by specifying occupation of certain Bloch states and by using the rest to form a linear combination of virtual pair con-

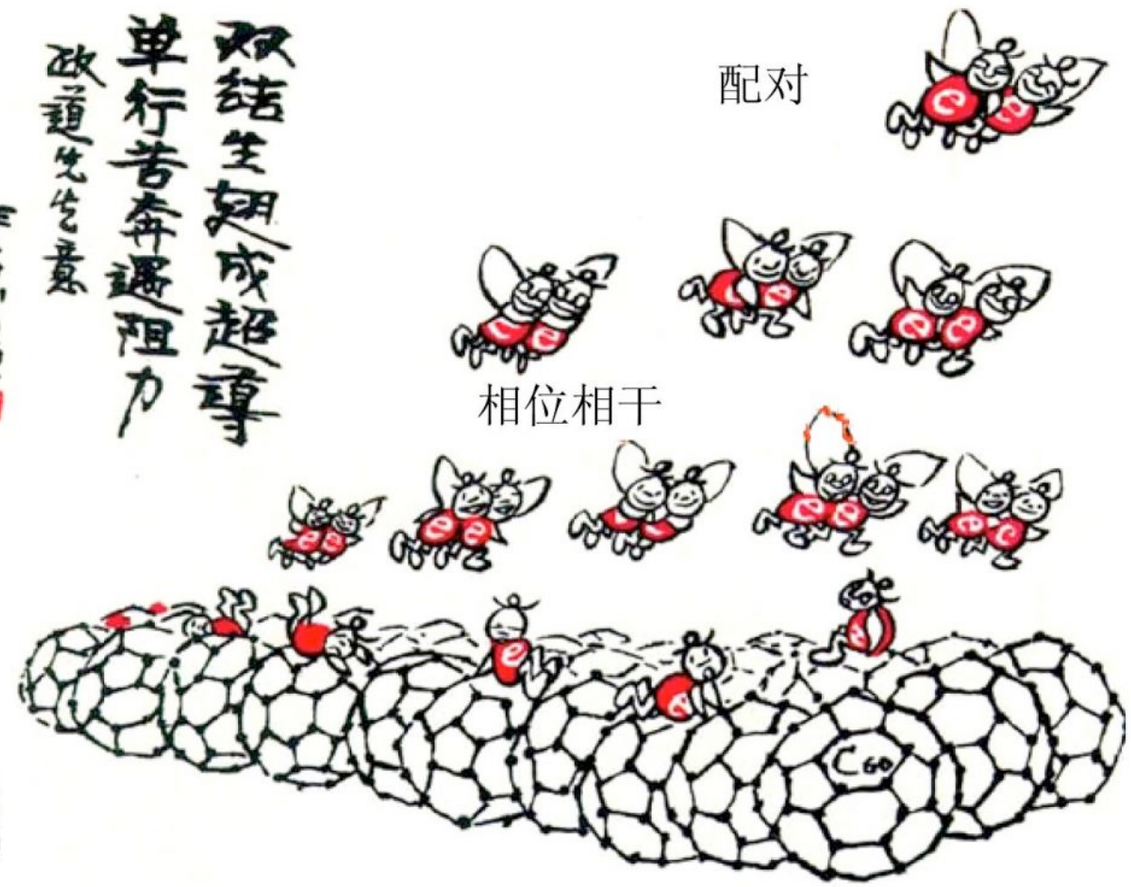
David Pines

Nobel Prize 1972

常规超导中由电子-声子耦合导致的电子配对机制



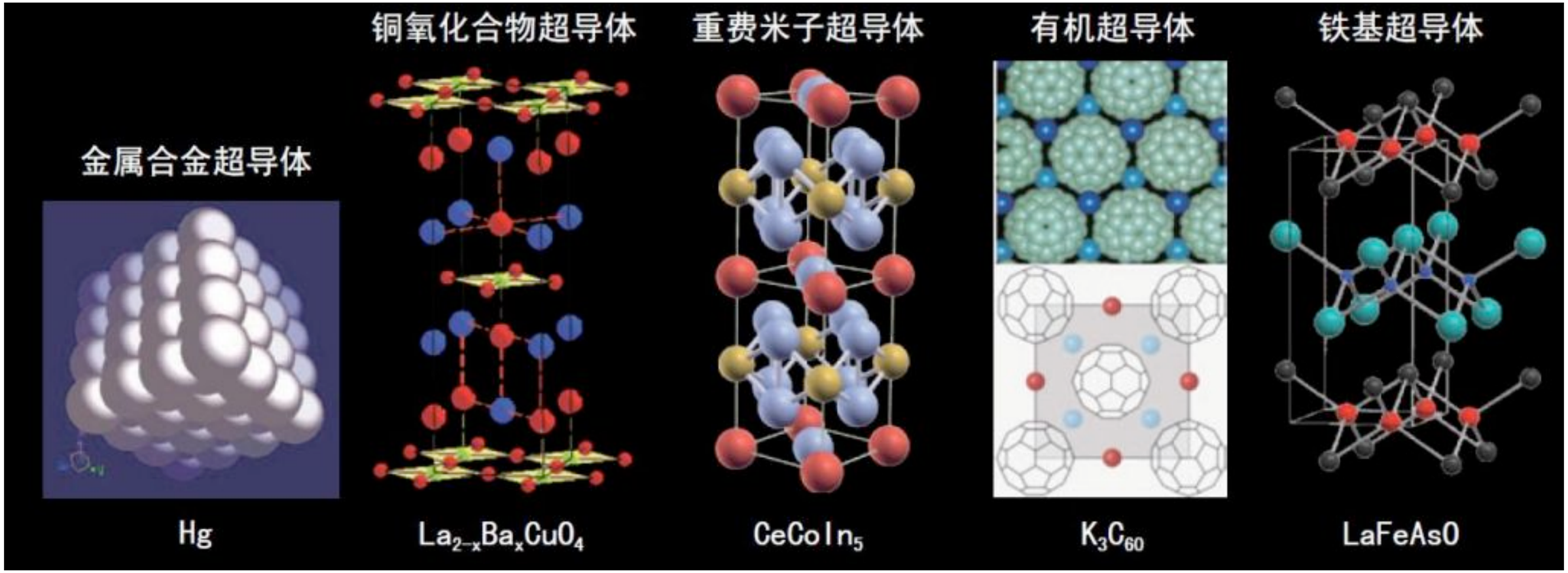




单行苦奔遇阻力，双结生翅成超导
（李政道 创意）

超导的两个基本要素：1、可配对的电子；2、“配对胶水”

超导家族的扩大：非常规超导



NATURE | NEWS

Superconductivity record breaks under pressure

Everyday compound reported to conduct electricity without resistance at a record-high temperature, outstripping more exotic materials.

Conventional superconductivity at 190 K at high pressures

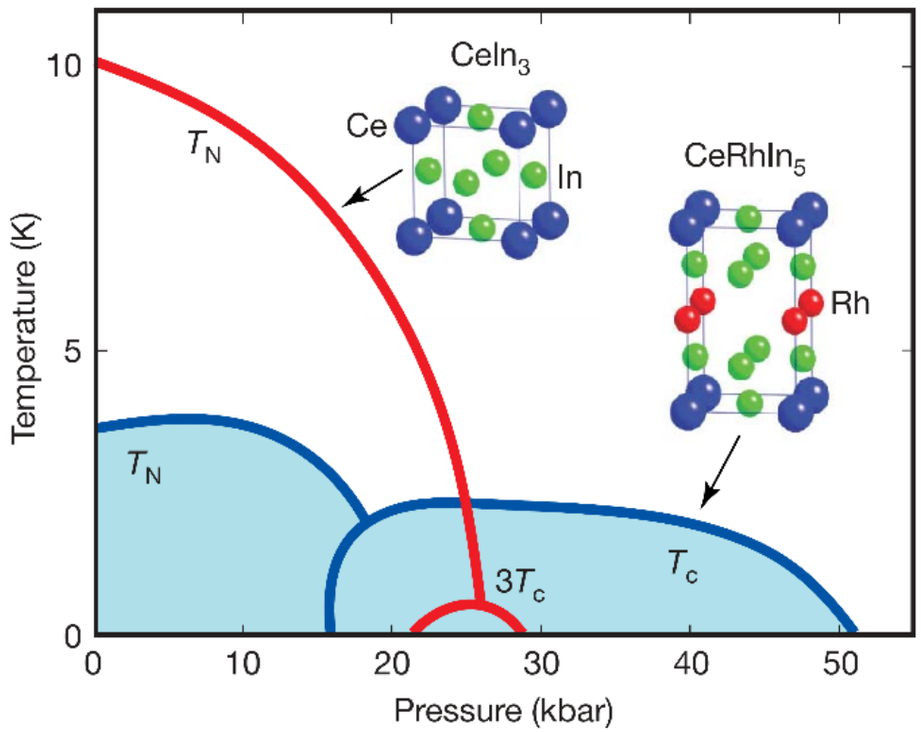
A.P. Drozdov, M. I. Eremets*, I. A. Troyan

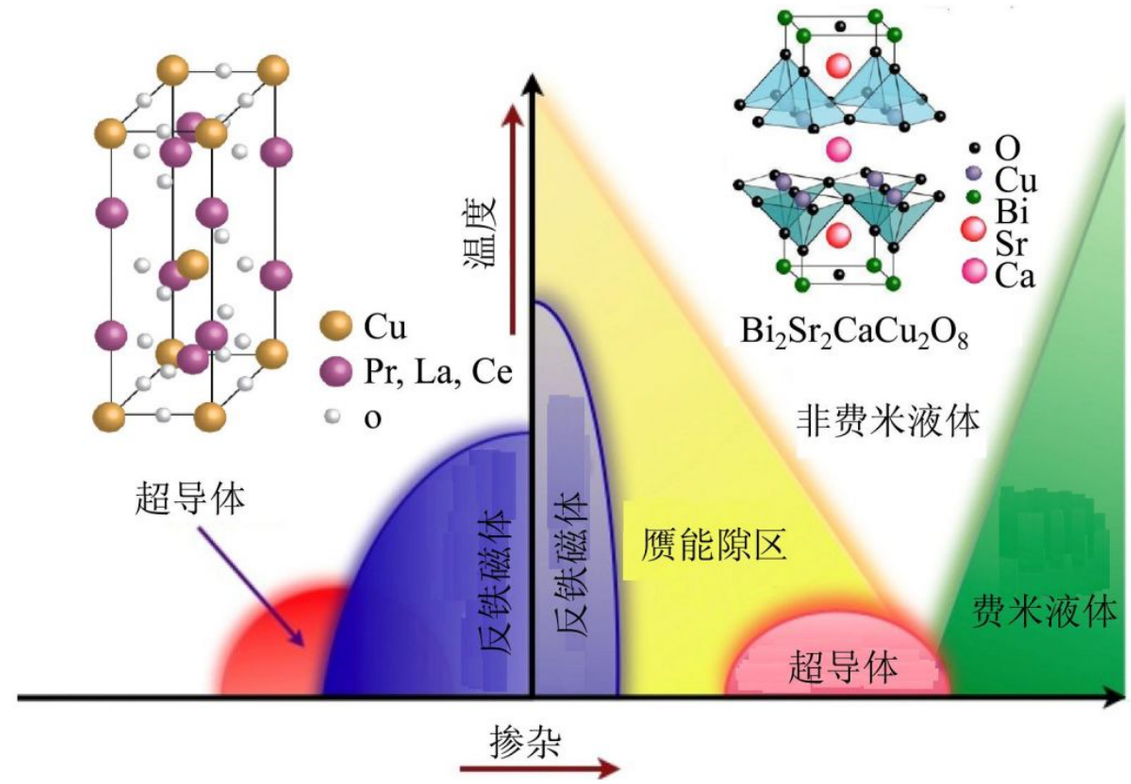
Max-Planck Institut fur Chemie, Chemistry and Physics at High Pressures Group

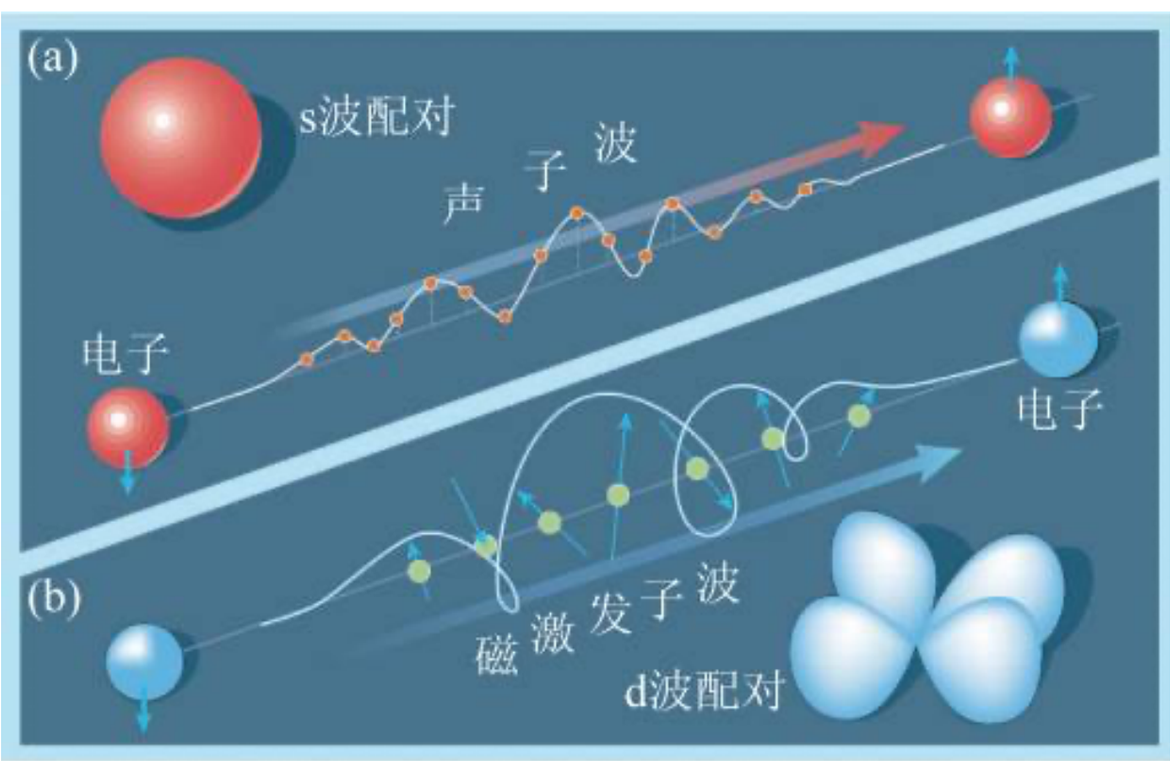
Postfach 3060, 55020 Mainz, Germany

“臭鸡蛋味”的超导?

非常规超导的配对机理

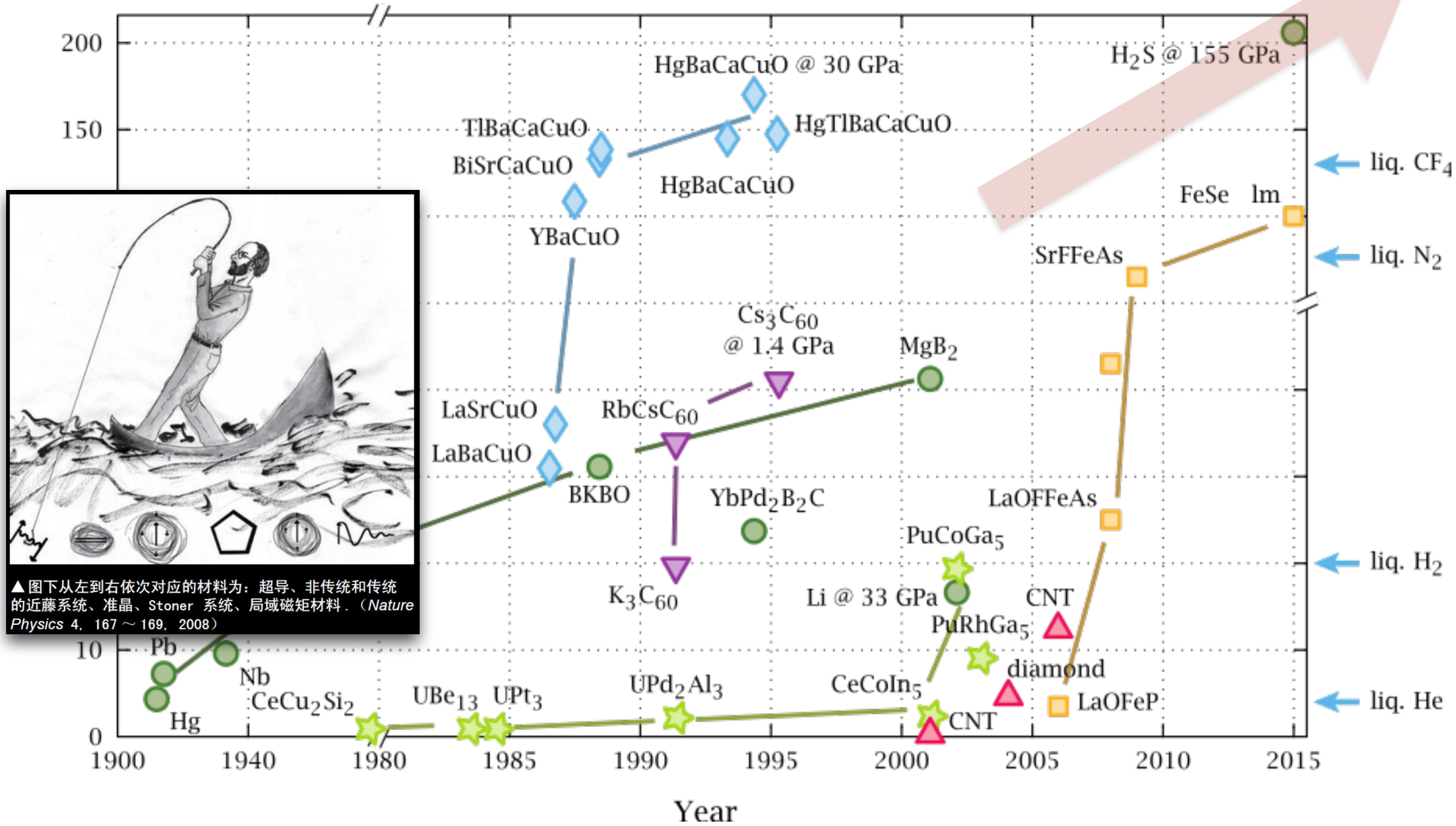






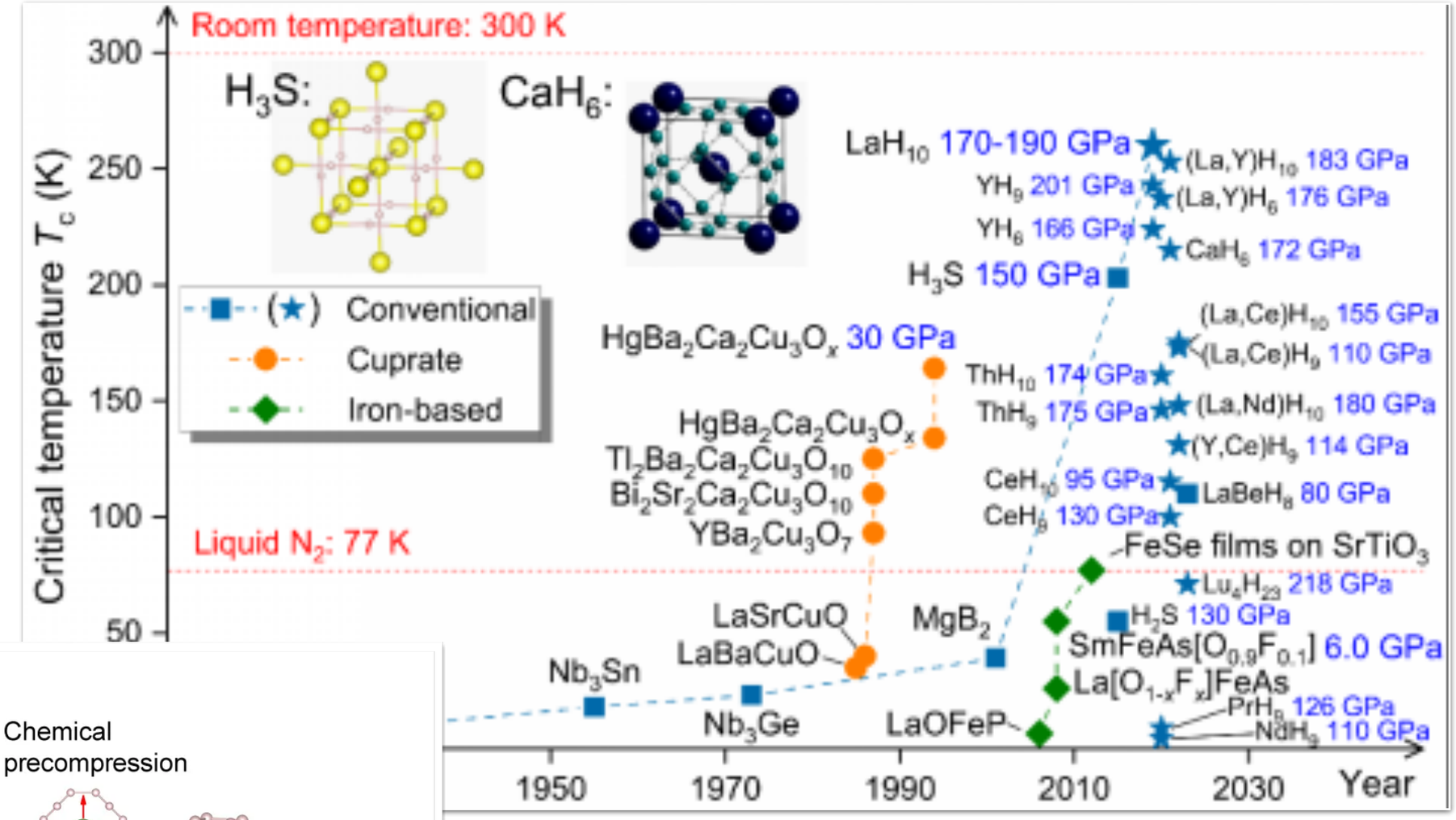
用电子的集体激发，
如自旋涨落、磁激子等，
替代声子作为配对胶水

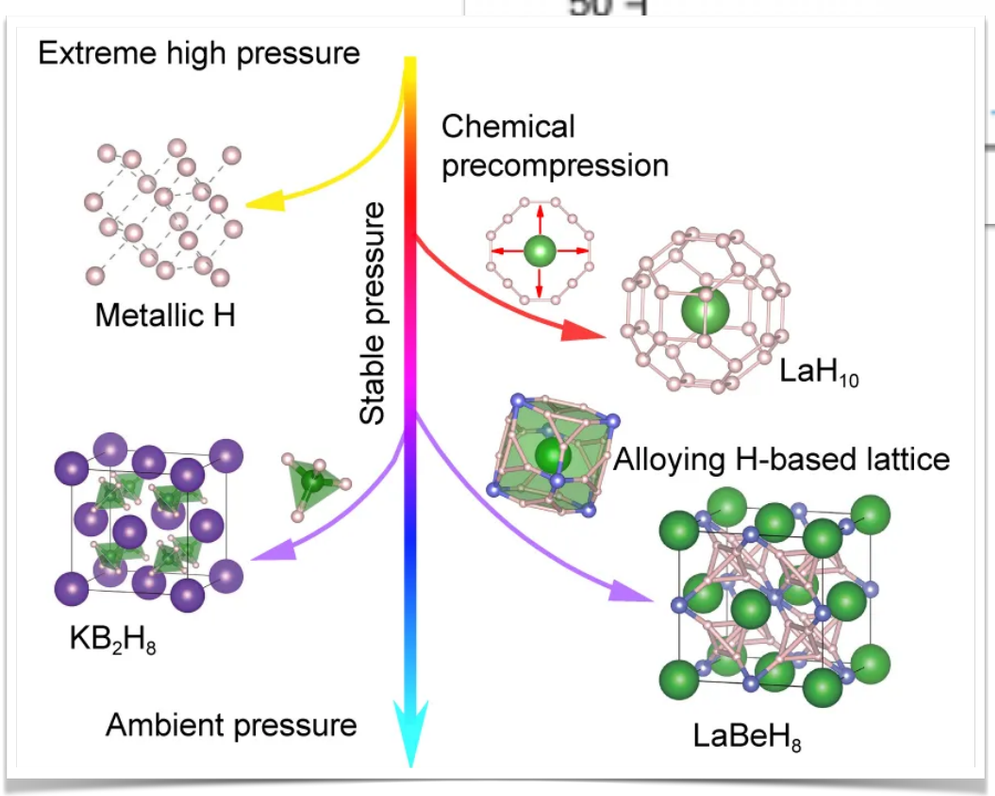
皇冠上的明珠：常压室温超导



▲图下从左到右依次对应的材料为：超导、非传统和传统的近藤系统、准晶、Stoner 系统、局域磁矩材料．（*Nature Physics* 4，167～169，2008）

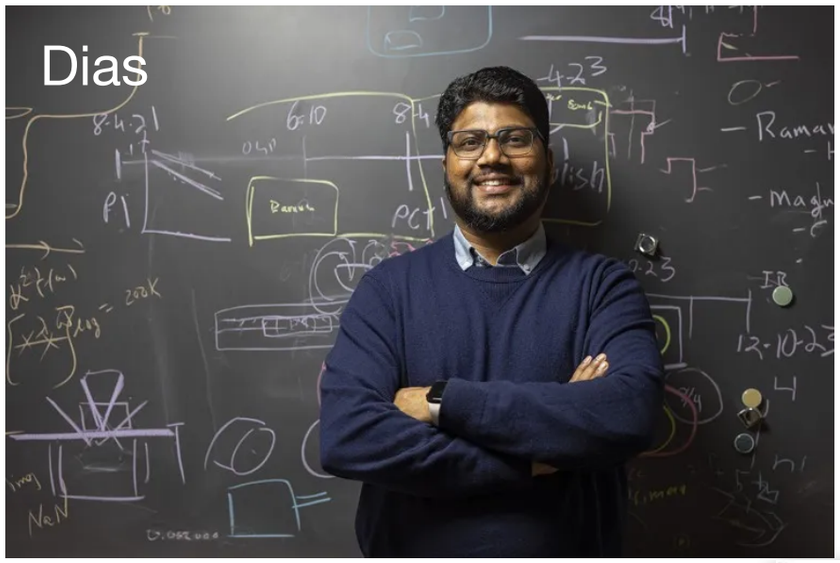
高压富氢超导



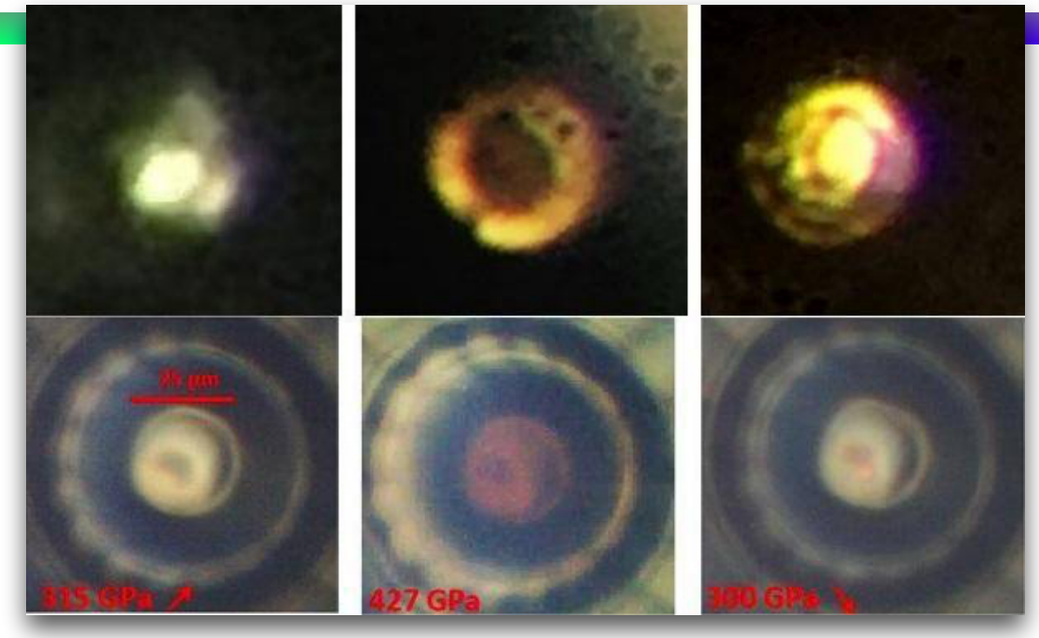


目前认为，仍然是常规的电-声耦合配对机制；常规超导体常压最大T_c目前不超过40 K

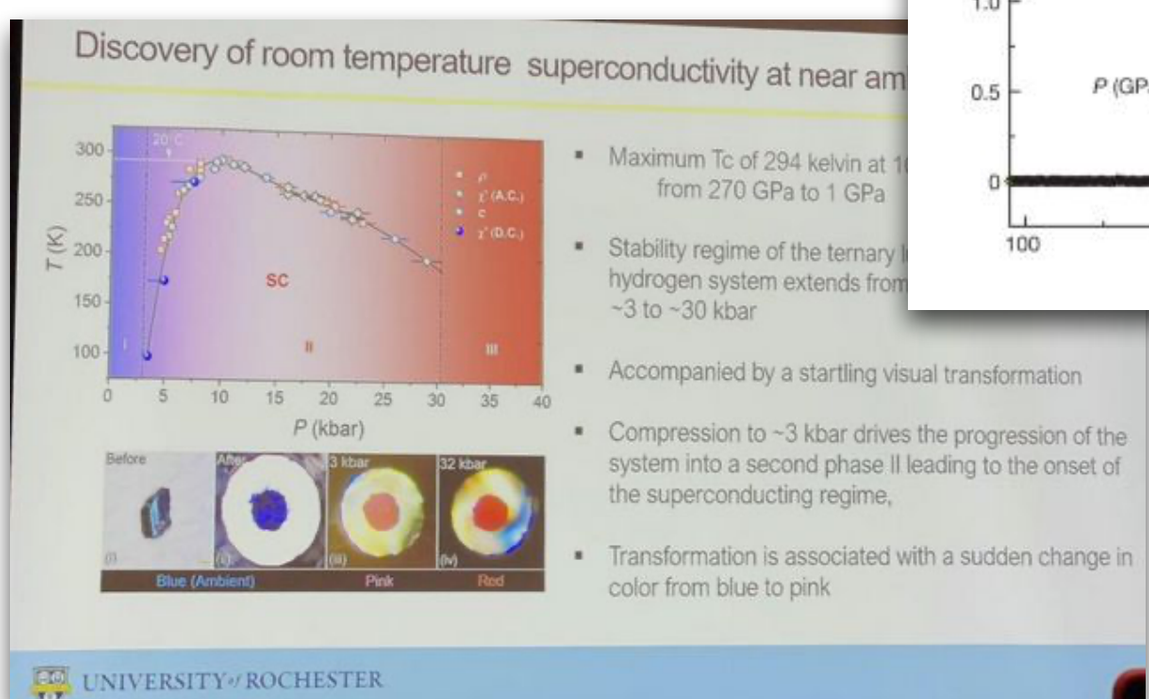
室温超导骗局和噱头?

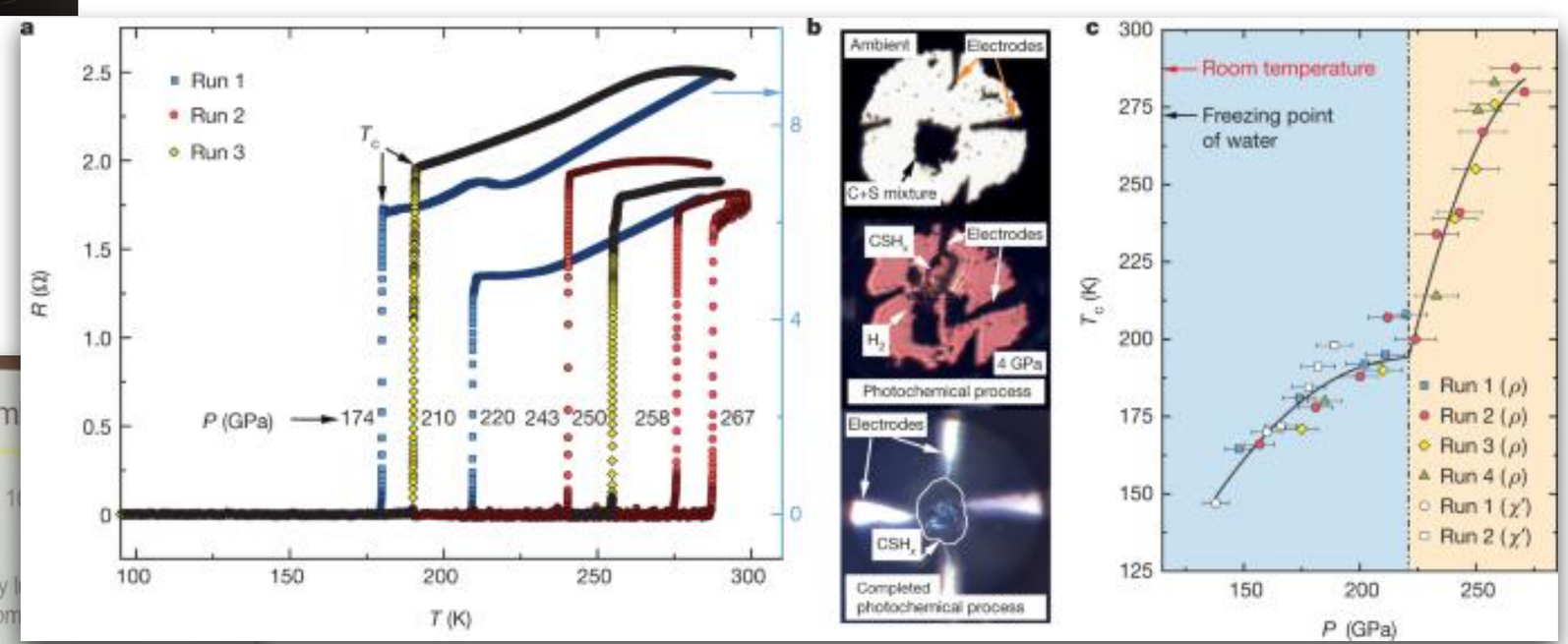


金属氢
(2017)



Lu-N-H (2023)



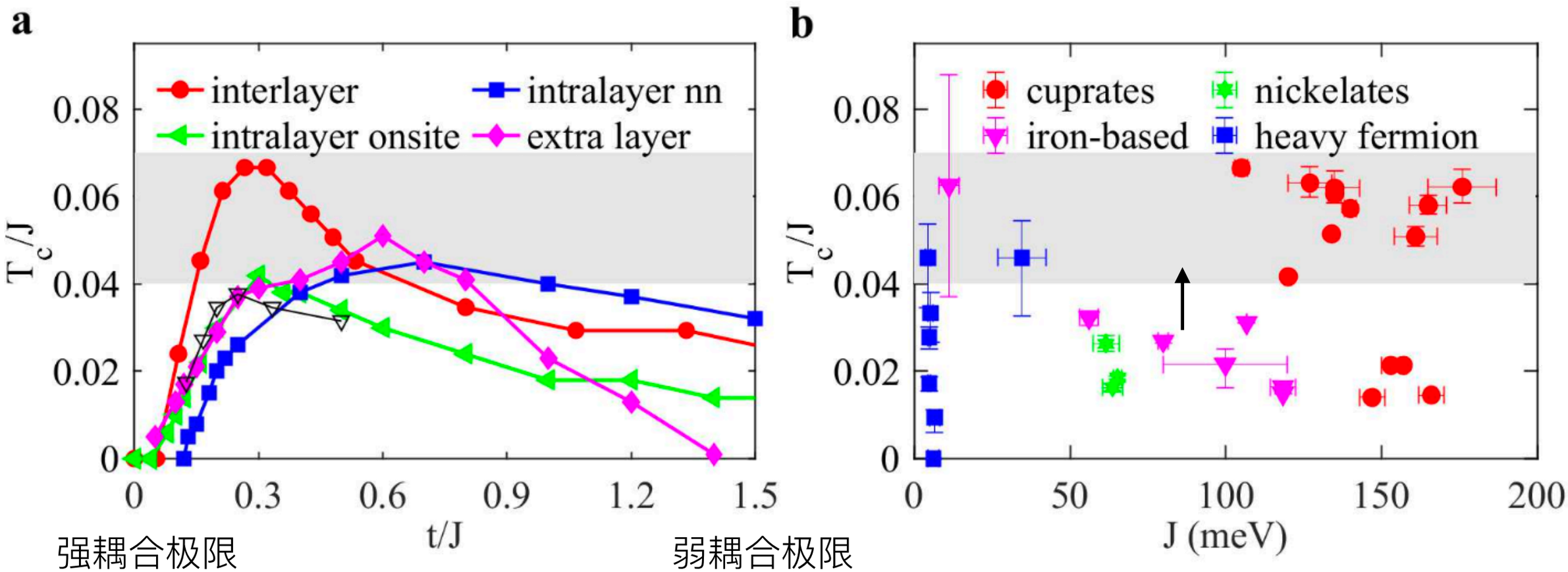


C-S-H (2020)

韩国LK99……

非常规超导的T_c上限?

Q. Qin & YF, arXiv:2402.07128



强耦合极限
实空间预配对

弱耦合极限
动量空间配对

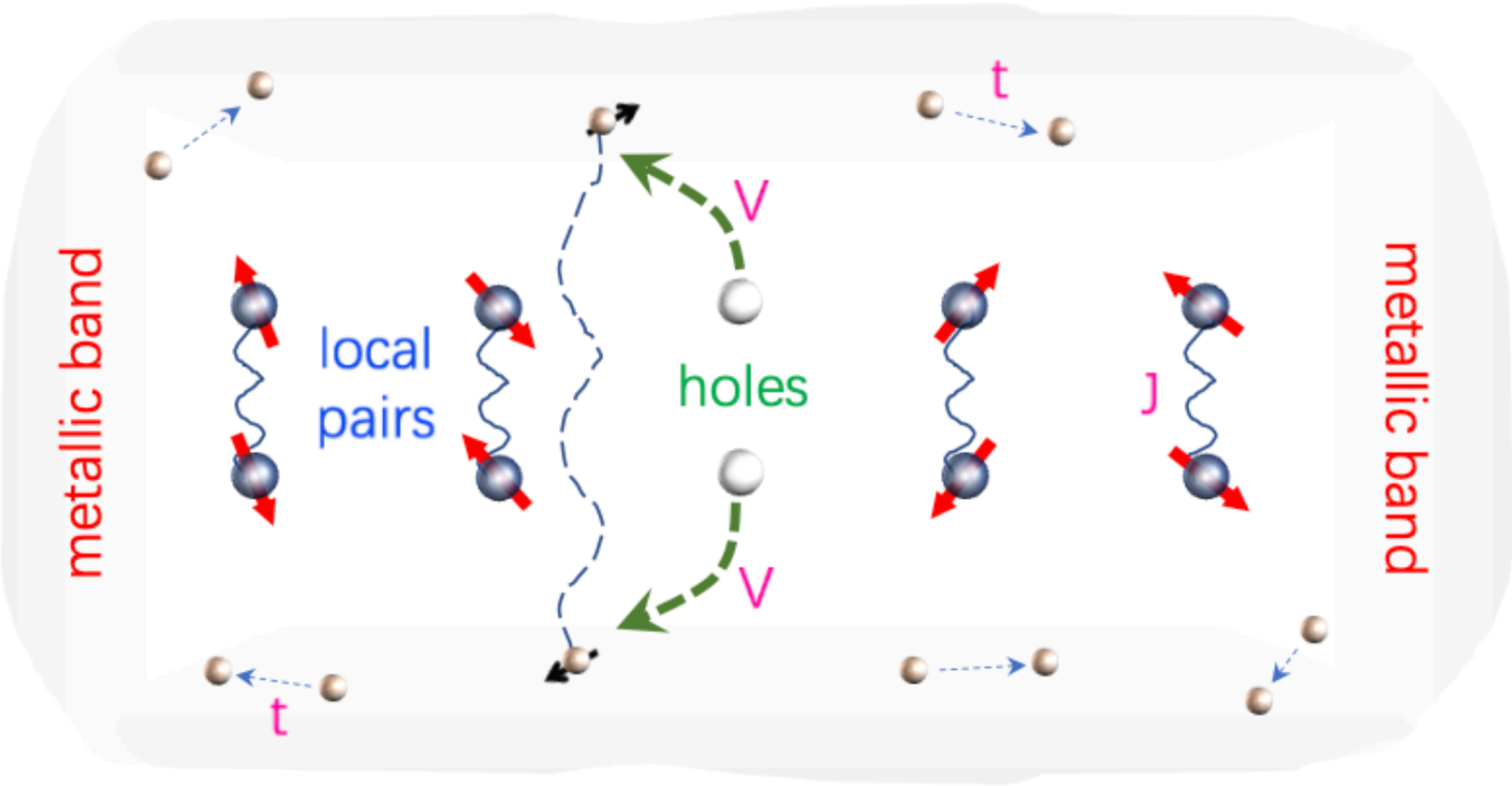
$T_c^{max} \sim 0.04\text{–}0.07\ J$

已知超导体系已达到或接近自身磁作用允许的最大T_c！！！

实现常压室温超导 需要至少 400-700 meV的配对相互作用！！！

实空间配对 和 两分量机制

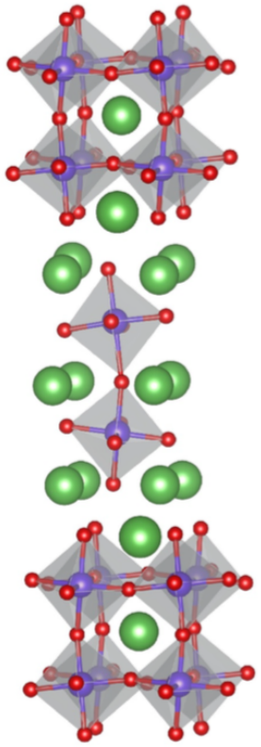
单一轨道很难同时具有很强的配对作用（局域性）和比较大的动能（巡游性）！

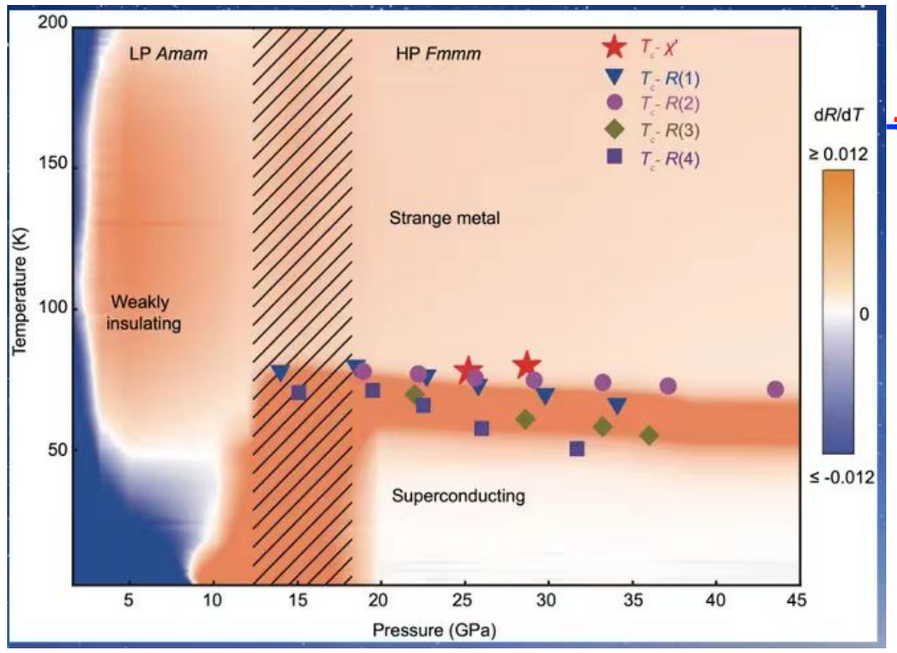


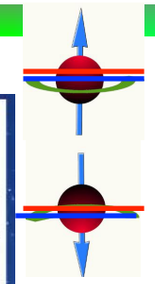
先形成足够强（大J）的局域配对，再通过其他能带跑起来，相干产生超导

材料上怎么实现，欢迎大家一起研究

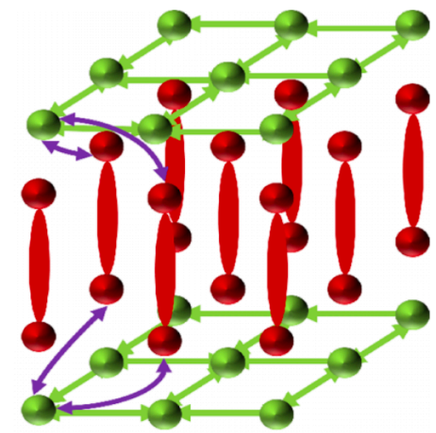
镍基高温超导：一个可能的例子?



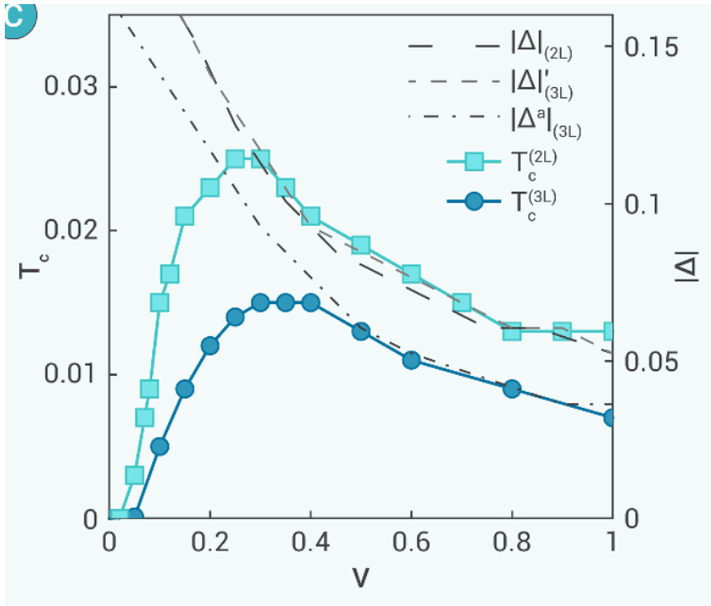


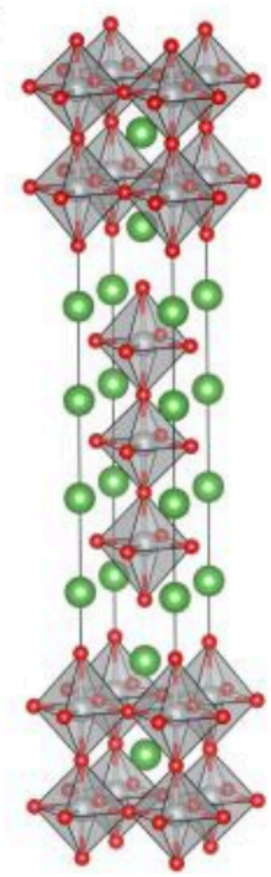


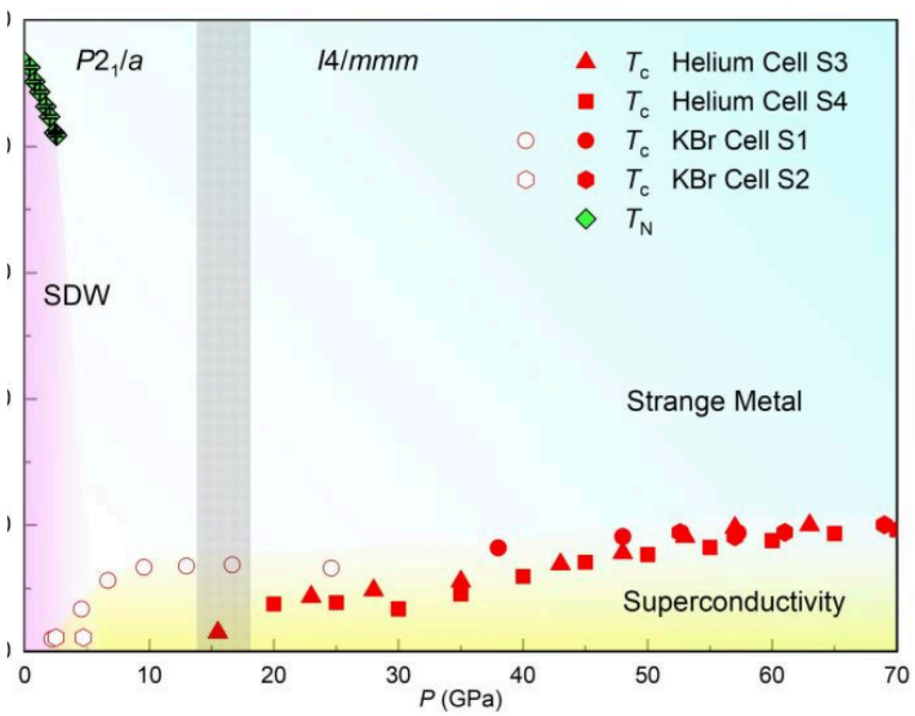
Maximum $T_c/J \sim 0.04$-0.05

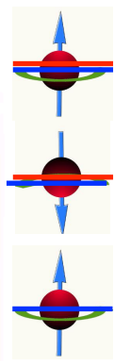


Maximum $T_c/J \sim 0.02$-0.03







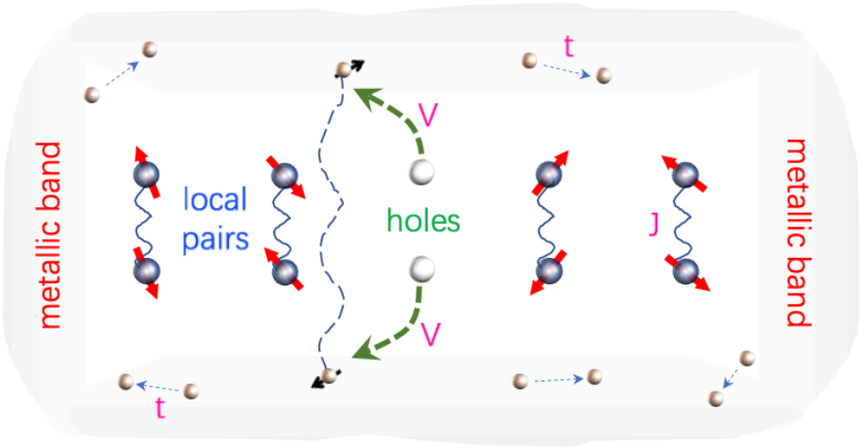


J=150 meV ?

bilayer: T_c=70-90 K vs 80 K
trilayer: T_c=30-50 K vs 30 K

Q. Qin, J. Wang, & YF, The Innovation Materials 2, 100102 (2024)

新型高温超导设计?



先形成足够强（大J）的局域配对，

再通过其他能带跑起来，相干产生超导

1、怎么设计合适的材料结构?

2、怎么提高配对相互作用J?

新机制? 理论认识上的突破?

超导相关

Nobel奖

获得者

有更多的

强关联相关

Nobel奖

获得者