Room-temperature superconductivity - or not?

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Work in collaboration with Jorge E. Hirsch, University of California, San Diego

Flatclub, 29 April 2022
Is this subject suitable for the flatclub?
Yes!
Why?
It’s all done under pressures of hundreds of GPa.
If you press hard, things tend to get flat
At the center of the earth the pressure is 360 GPa.....
So with all that pressure, the earth is actually flat?
A brief history of high $T_c$ superconductivity in hydrides

1968: **Metallic Hydrogen: A High-Temperature Superconductor?**, N. W. Ashcroft, *PRL* **21**, 1748 (1968). $T_c=0.85T_0e^{-\lambda}$, $\lambda>0.25$, $T_0=3500$ K $\Rightarrow$ $T_c>54$ K.


LOOKS LIKE A DUCK.

QUACKS LIKE A DUCK.

QUACK!

Jared Wood

vikingalligator.deviantart.com
Comments on high $T_c$ superconductivity in hydrides

- Nonstandard superconductivity or no superconductivity in hydrides under high pressure, JE Hirsch & F Marsiglio, PRB 103, 134505 (2021).
- About the pressure-induced superconducting state of europium metal at low temperatures, JE Hirsch, Physica C 583, 1353805 (2021).
- Disconnect between published ac magnetic susceptibility of a room temperature superconductor and measured raw data, JE Hirsch, Preprints 2021120115 (2021).
Timeline of the analysis of Eu and CSH susceptibility data.


12.11.2020: J. E. Hirsch requests raw $\chi'(T)$ data of CSH.


15.02.2022: Editor’s Note: “The editors of Nature have been alerted to concerns regarding the manner in which the data in this paper have been processed and interpreted. Nature is working with the authors to investigate these concerns and establish what (if any) impact they will have on the paper’s results and conclusions. In the meantime, readers are advised to use caution when using results reported therein.”

AC susceptibility

“The background signal, determined from a non-superconducting C–S–H sample at 108 GPa, has been subtracted from the data.”
“...the background can be approximated as linear in the region of the transition, and the susceptibility of the sample extracted after background subtraction. In the raw data a temperature region immediately above and below the transition is selected and a profile subtraction based on the similar temperature range from an additional measurement made at a non-superconducting pressure. The background profile is kept true but scaled to match the same signal strength of the desired measurement. This profile is then subtracted from the raw data, providing a baseline value of zero for the susceptibility above $T_c$ (Figure 6 and 7).”
We selected the background after carefully investigating the temperature dependence of the non-superconducting CSH sample at 108 GPa, the closest pressure prior to the superconducting transition. We note here that we did not use the measured voltage values of 108 GPa as the background. We use the temperature dependence of the measured voltage above and below the $T_c$ of each pressure measurement and scale to determine a user defined background (Fig. 2a). The scaling is such that one achieves an approximately zero signal above the transition temperature; the subtracted background isolates the signal due to the sample. We call this method "user defined background method 1 (UDB_1)" in this report. With UDB_1, one finds a signal as a function of temperature comparable to what one observes on a large sample where the background is insignificant. This procedure is either not understood or intentionally ignored by Hirsch and van der Marel in their recent comments on the arXiv. (3) In other words, the background is not an independently measured signal as Hirsch and van der Marel incorrectly claim. See Fig. 2. We chose the UDB_1 background as opposed to a simple linear function, which we examine later, to make sure we captured the response of the unknown background contributions. Furthermore, the temperature vs time profiles are extremely difficult to accurately replicate between runs and hence why we use the profiles from the same dataset, before and after the superconducting transition to generate a user defined background profile. We will show that the function of the background, although subtly affects the signal to noise, does not detract from the clear presence of the raw, measured susceptibility response of the superconducting transition that clearly matches the independent electrical transport measurements. The user defined background for subtraction is qualitative in nature and does not represent a physical quantity, and we will demonstrate other methods later in this paper.

Fig. 2 AC susceptibility data.

(a) Raw data measured at 160 GPa. The profile of the regions highlighted in blue are used as part of the UDB_1.

(b) Measured voltage from the susceptibility measurement.

- Raw data
- UDB_1
- Raw data – UDB_1
Open data of pressurized CSH


Nomenclature:
• Background corrected data: “Superconducting Signal” = $\chi_{sc}$
• Raw data: “Measured Voltage” = $\chi_{mv}$
• Background data: “User Defined Background” = $\chi_{UDB}$

Provided in tables
• $\chi_{sc}$
• $\chi_{mv}$

Implicit
• $\chi_{UDB} = \chi_{mv} - \chi_{sc}$

Pages 12-139
138 GPa. Temperature (low to high), Measured Voltage. Format: text
166 GPa. Temperature (low to high), Measured Voltage. Format: text
178 GPa. Temperature (low to high), Measured Voltage. Format: text
189 GPa. Temperature (low to high), Measured Voltage. Format: text
160 GPa. Temperature (high to low), Measured Voltage, Superconducting Signal. Format: image
182 GPa. Temperature (low to high), Measured Voltage, Superconducting Signal. Format: image
138 GPa. Temperature (low to high), Superconducting Signal. Format: image
166 GPa. Temperature (low to high), Superconducting Signal. Format: image
178 GPa. Temperature (low to high), Superconducting Signal. Format: image
189 GPa. Temperature (low to high), Superconducting Signal. Format: image
\[ \chi_{sc} = \chi_{mv} - \chi_{UDB} \]

Table 5 from
R. P. Dias and A. Salamat,

E. Snider et al.
“Superconducting Signal” at 160 GPa

\[ \chi_{sc} = \chi_{mv} - \chi_{UDB} \]

Table 5 from R. P. Dias and A. Salamat, arXiv:2111.15017v2 (2021)
"Superconducting Signal" at 160 GPa

Superconducting Signal = quantized component + smooth component: \( \chi_{sc}(T) = q(T) + s(T) \)
Properties of the quantized component

- $n \times 0.1655 \ (nV)$
- $0 < n < 140$

Properties of the smooth component

- spline
- number of segments: 14
- number of nodes: 15
- order: cubic
- boundary conditions: natural
What is the nature of the “quantized component”? Raw data recorded with 3 digit precision?

What is the nature of the “smooth component”? -1 x fitted (or otherwise smooth) “User Defined Background”?

Comparison of “quantized component” and “Measured Voltage”

Comparison of “smooth component” and “User Defined Background”

The “quantized component” is not the raw data.

The “smooth component” is not the background.

\[ \chi'_M(T) \]

\[ \chi'(T) \]

\[ q(T) \]

\[ -s(T) \]

\[ \chi_{UDB}(T) \]

160 GPa

160 GPa
The “Superconducting Signal”

\[ \Delta \chi(j) = \chi(j) - \chi(j - 1) \]

160 GPa

JE Hirsch, Europhys. Lett. 137, 36001 (2022)
The “Superconducting Signal”

160 GPa

\[ \Delta \chi(j) = \chi(j) - \chi(j-1) \]
\[ \Delta^2 \chi(j) = \Delta \chi(j) - \Delta \chi(j-1) \]


Dukwon, https://imgur.com (2022)

\[ \Delta_q \approx 0.17 \text{ nV} \]
The “Superconducting Signal”

\[
\Delta \chi(j) = \chi(j) - \chi(j-1) \\
\Delta^2 \chi(j) = \Delta \chi(j) - \Delta \chi(j-1)
\]

138 GPa

\[\Delta_q \approx 0.025 \text{ nV}\]
The “Superconducting Signal”

\[ \Delta \chi(j) = \chi(j) - \chi(j-1) \]
\[ \Delta^2 \chi(j) = \Delta \chi(j) - \Delta \chi(j-1) \]

166 GPa

\[ \Delta_q \approx 0.016 \text{ nV} \]
The “Superconducting Signal”

\[ \Delta \chi(j) = \chi(j) - \chi(j - 1) \]

\[ \Delta^2 \chi(j) = \Delta \chi(j) - \Delta \chi(j - 1) \]

\[ \Delta_q \approx 0.007 \text{ nV} \]
The “Superconducting Signal”

\[ \Delta \chi(j) = \chi(j) - \chi(j-1) \]
\[ \Delta^2 \chi(j) = \Delta \chi(j) - \Delta \chi(j-1) \]

182 GPa

\[ \Delta_a \approx 0.006 \text{ nV} \]
The “Superconducting Signal”

$\Delta \chi(j) = \chi(j) - \chi(j-1)$

$\Delta^2 \chi(j) = \Delta \chi(j) - \Delta \chi(j-1)$
After adjacent averaging a quantized component still shows up in $\Delta \chi$ and $\Delta^2 \chi$. The steps are reduced to $\Delta_q = \Delta_0 / n_{AA}$. 
The “Superconducting Signal” and Adjacent Average smoothing

160 GPa

unsmoothed

5pt AA

9pt AA

19pt AA
The “Superconducting Signal” and Adjacent Average smoothing

160 GPa 5pt AA

166 GPa
The "Superconducting Signal" and Adjacent Average smoothing

![Graph 1: 160 GPa 5pt AA](image)

![Graph 2: 166 GPa](image)
A word about superpositions

“Superposition of feathers and the main ingredient of a famous pekingese dish”
Protocol consistent with all data of $\chi_{sc}(T)$

- A curve $a(T)$ is generated as the superposition of a quantized component $q(T)$ and a smooth function $s(T)$: $a(T) = q(T) + s(T)$.

- The “superconducting signal" $\chi_{sc}(T)$ is generated by smoothing $a(T)$ using the adjacent averaging method.

- The 160 GPa data are not smoothed, so that in this case $\chi_{sc}(T) = a(T)$. 
The noise conundrum

\[ \chi_{sc} = \chi_{mv} - \chi_{UDB} \]

Consequently, \( \text{noise}_{MV} \neq \text{noise}_{UDB} \)

The data suggest:

\[ \chi_{mv} = \chi_{sc} + \chi_{UDB} \]

Consequently, \( \text{noise}_{MV} \geq \max\{\text{noise}_{sc}, \text{noise}_{UDB}\} \)
Quantized component in the “Measured Voltage”?

![Graphs showing temperature vs. voltage at 160 GPa]
Correlation between quantized steps in $\chi_{mv}$ and quantized steps in $\chi_{sc}$

$\Delta^2 \chi_{sc} \approx 0.17 \text{nV}$

$\Delta^2 \chi_{mv}$

$\Delta^2 \chi_{sc}$

160 GPa
Correlation between quantized steps in $\chi_{mv}$ and quantized steps in $\chi_{sc}$

$D_q \approx 0.025 \text{ nV}$
L’aile ou la cuisse
Réalisation: Claude Zidi - Scénario: Claude Zidi, Michel Fabre - Musique: Vladimir Cosma
Acteurs principaux: Louis de Funès, Coluche, Julien Guiomar
Sociétés de production: Christian Fechner - Sortie: 1976
Protocol consistent with all data of $\chi_{sc}(T)$ and $\chi_{mv}(T)$

- A curve $a(T)$ is generated as the superposition of a quantized component $q(T)$ and a smooth function $s(T)$: $a(T) = q(T) + s(T)$.

- The “superconducting signal" $\chi_{sc}(T)$ is generated by smoothing $a(T)$ using the adjacent averaging method (exception: 160 GPa).

- A “user defined background" $\chi_{UDB}(T)$ is determined.

- The “measured voltage" $\chi_{mv}(T)$ is generated as the superposition of the “user defined background" and the “superconducting signal": $\chi_{mv}(T) = \chi_{sc}(T) + \chi_{UDB}(T)$. 
Summary

For the 6 reported pressures the “superconducting signal” was not obtained using one of the 3 different descriptions provided in *Nature* **586**, 373 (2020), *arXiv*:2111.15017 and *arXiv*:2201.11883.

Instead, the “superconducting signal” for all 6 pressures is the superposition of a quantized component and a smooth component, adjacent averaged for 5 pressures.

The single case without adjacent averaging is a 15-node cubic spline with natural boundary conditions. Other than that the origins of smooth component and quantized component are unknown.

Correlation diagnostics indicates that for 2 pressures the “measured voltage” is not obtained by recording the voltage of the pickup coil of a susceptibility rig.

Instead, the “measured voltage” is the superposition of a “user defined background” and the “superconducting signal”. For the remaining 4 pressures the signal-to-noise ratio does not allow to decide one way or another.

The origin of the “user defined background” for the different pressures is unknown.
Conclusion

Why a duck?

*The Cocoanuts*
Marx Brothers, 1929