Room-temperature superconductivity - or not?

Presenter: Dirk van der Marel, Université de Genève

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). $T_c = 0.85 T_D\, e^{-1/\lambda}$, $\lambda > 0.25$, $T_D = 3500$ K => $T_c > 54$ K.

1972: ***Superconductivity at 8-10 K in PdH and 10-12 K in PdD***, T. Skoskiewicz, *Phys. Status Solidi* **A 11**, K123 (1972) ; B. Stritzker and W. Buckel, *Z Physik* **257**, 1 (1972) ; R. Griessen & D. de Groot, *Helvetica Physica Acta* **55**, 699 (1982) ; H. Hemmes, A. Driessen, R. Griessen & M. Gupta, *PRB* **39**, 4110 (1989).

2015: ***Conventional superconductivity at 203 Kelvin at high pressures in the sulfur hydride system***, A. P. Drozdov, M. I. Eremets, I. A. Troyan, V. Ksenofontov & S. I. Shylin, *Nature* **525**, 73 (2015).

2015: ***Superconductivity above 100 K in PH_3 at high pressures,*** A.P. Drozdov, M. I. Eremets, I. A. Troyan, *arXiv*:**1508**.06224.

2016: ***Superconductivity in palladium hydride and deuteride at 52-61 Kelvin***, H. M. Syed, T. J. Gould, C. J. Webb & E. MacA. Gray, *arXiv:***1608**.01774.

2017: ***Potential high-Tc superconducting lanthanum and yttrium hydrides at high pressure***, H. Liu, I. I. Naumov, R. Hoffmann, N. W. Ashcroft & R. J. Hemley, *PNAS* **114**, 6990 (2017).

2019: ***Quantum phase transition in solid hydrogen at high pressure***, R. P. Dias, O. Noked & I. F. Silvera, *PRB* **100**, 184112 (2019).

2019: ***High-temperature superconductivity in sulfur hydride evidenced by alternating-current magnetic susceptibility,*** X. Huang et al, *Nat. Sci. Rev.* **6**, 713 (2019).

2019: ***Evidence for Superconductivity above 260 K in Lanthanum Superhydride at Megabar Pressures***, M.Somayazulu, M. Ahart, A. K. Mishra, Z. M. Geballe, M. Baldini, Y. Meng, V. V. Struzhkin & R. J. Hemley, *PRL* **122**, 027001 (2019).

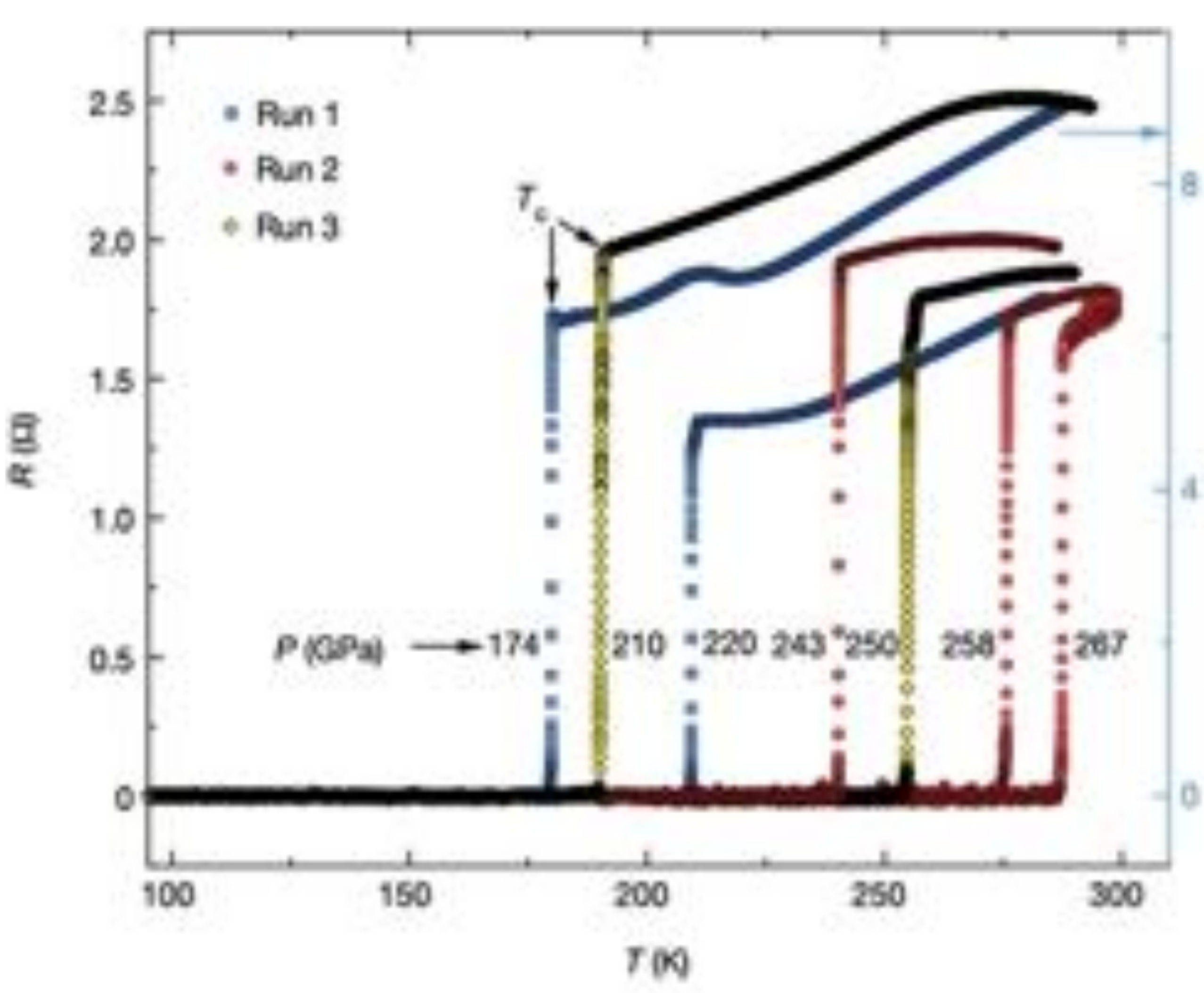
2019: ***Superconductivity at 250 K in lanthanum hydride under high pressures***, A. P. Drozdov, P. P. Kong, V. S. Minkov, S. P. Besedin, M. A. Kuzovnikov, S. Mozaffari, L. Balicas, F. F. Balakirev, D. E. Graf, V. B. Prakapenka, E. Greenberg, D. A. Knyazev, M. Tkacz & M. I. Eremets, *Nature* **569**, 528 (2019).

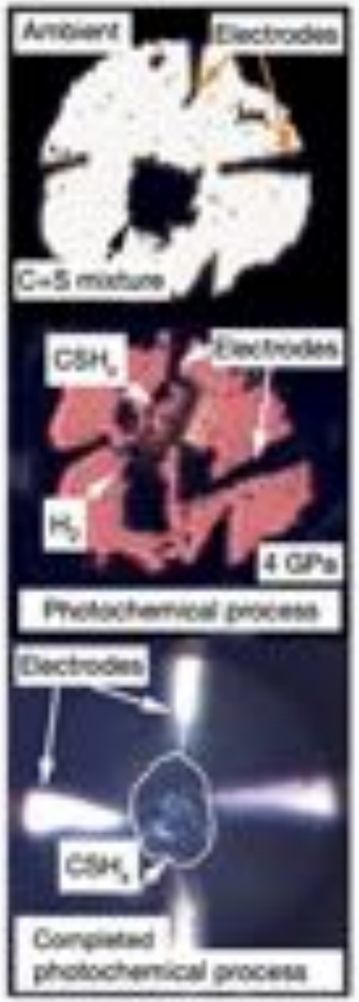
2020: ***Room-temperature superconductivity in a carbonaceous sulfur hydride***, E. Snider, N. Dasenbrock-Gammon, R. McBride, M. Debessai, H. Vindana, K. Vencatasamy, K. V. Lawler, A. Salamat & R. P. Dias, *Nature* **586**, 373 (2020).

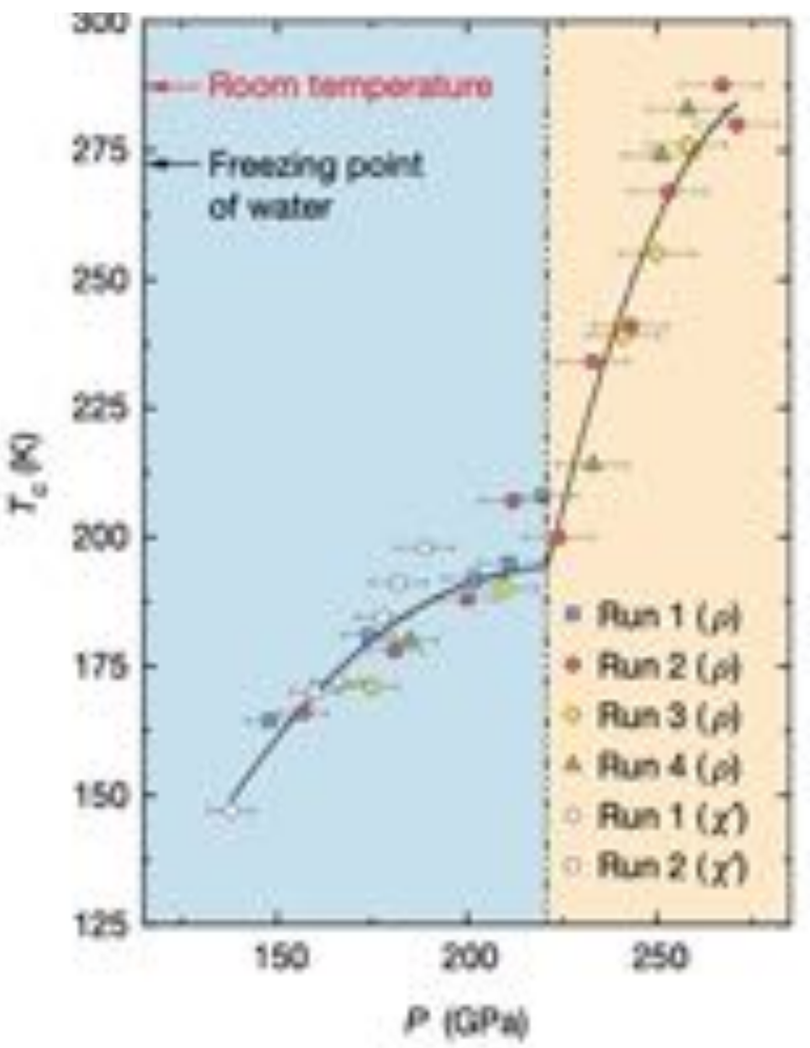
2021: ***Synthesis of Yttrium Superhydride Superconductor with a Transition Temperature up to 262 K by Catalytic Hydrogenation at High Pressures***, E. Snider, N. Dasenbrock-Gammon, R. McBride, X. Wang, N. Meyers, K. V. Lawler, E. Zurek, A. Salamat & R- P. Dias, *PRL* **126**, 117003 (2021).

2022: ***Hot Hydride Superconductivity Above 550 K***, A. D. Grockowiak, M. Ahart, T. Helm, W. A. Coniglio, R. Kumar, K. Glazyrin, G. Garbarino, Y. Meng, M. Oliff, V. Williams, N. W. Ashcroft, R. J. Hemley, M. Somayazulu & S. W. Tozer, *Frontiers in Electronic Materials* **2**, 837651 (2022).

Room-temperature superconductivity in a carbonaceous sulfur hydride, E. Snider, N. Dasenbrock-Gammon, R. McBride, M. Debessai, H. Vindana, K. Vencatasamy, K. V. Lawler, A. Salamat & R. P. Dias, *Nature* **586**, 373 (2020).

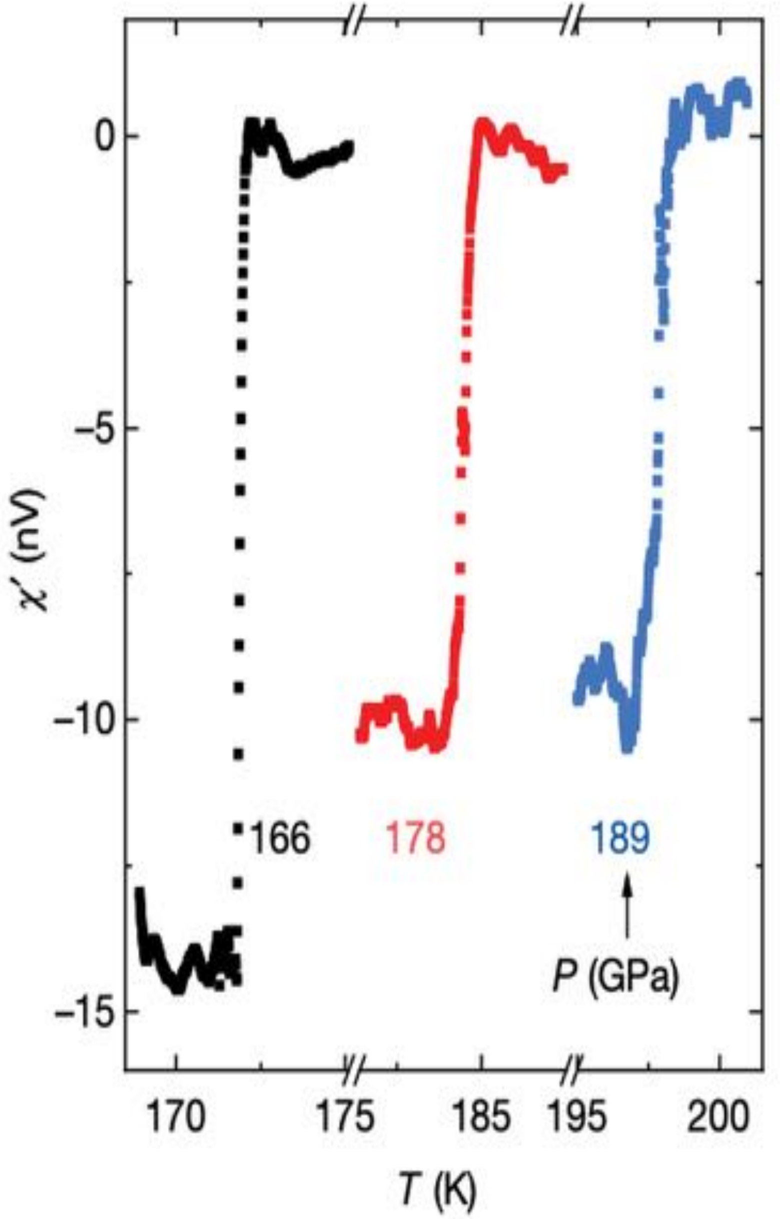


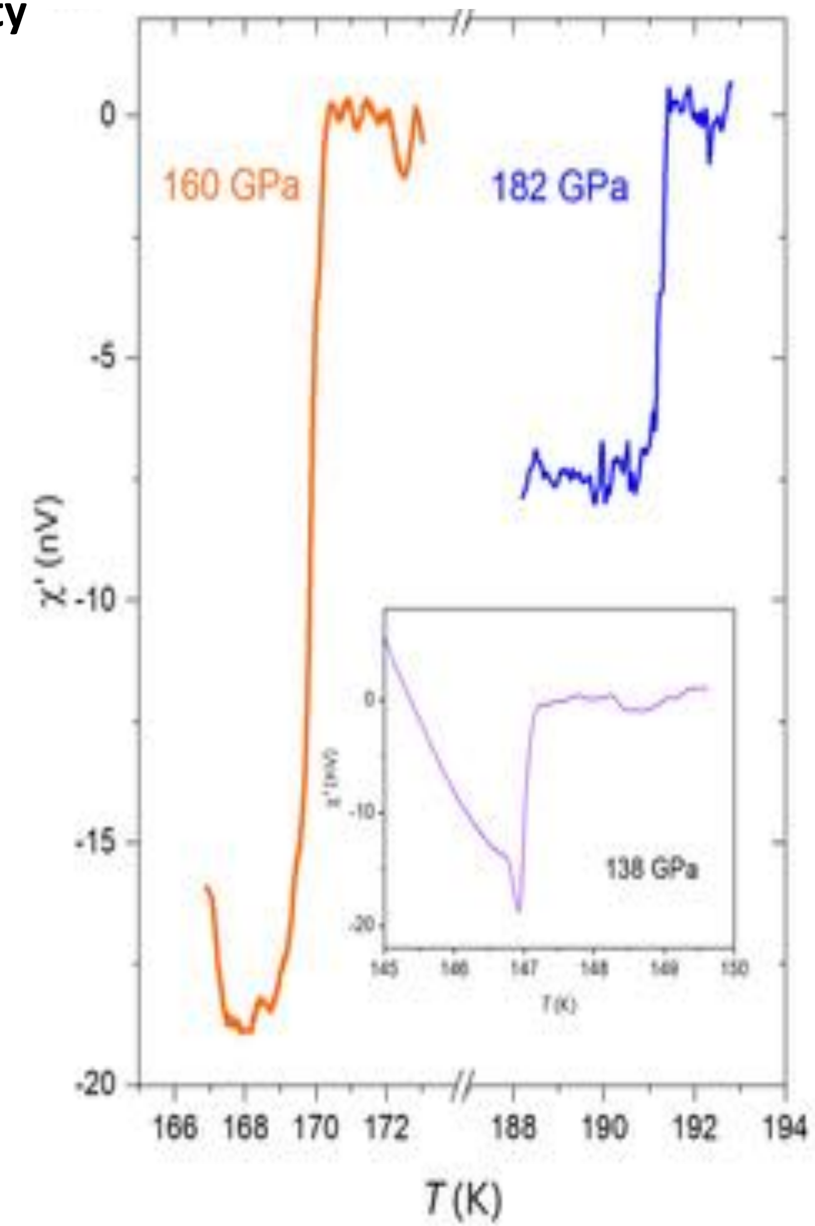




Room-temperature superconductivity in a carbonaceous sulfur hydride, E. Snider et al , *Nature* **586**, 373 (2020).

AC susceptibility





Jared Wood

vikingalligator.deviantart.com

Comments on high T_c superconductivity in hydrides

- *Comment on"Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system" (A. P. Drozdov et al., Nature 525, 73 (2015))*, L.S.Mazov, *arXiv*:**1510**.00123 (2015).
- *Absence of high temperature superconductivity in hydrides under pressure*, JE Hirsch & F Marsiglio, *arXiv*:**2010**.10307 (2020).
- *Comment on "Pressure-Induced Superconducting State of Europium Metal at Low Temperatures"*, JE Hirsch, *arXiv* : **2012**.07537 (2020).
- *Intrinsic hysteresis in the presumed superconducting transition of hydrides under high pressure*, JE Hirsch & F Marsiglio, *arXiv* :**2101**.07208 (2021).
- *Nonstandard superconductivity or no superconductivity in hydrides under high pressure*, JE Hirsch & F Marsiglio, *PRB* **103**, 134505 (2021).
- *Anomalous behavior in high-pressure carbonaceous sulfur hydride*, M Dogan & ML Cohen, *Physica C* **583**,1353851 (2021).
- *About the pressure-induced superconducting state of europium metal at low temperatures,* JE Hirsch, *Physica C* **583**, 1353805 (2021).
- *Absence of magnetic evidence for superconductivity in hydrides under high pressure*, JE Hirsch, F Marsiglio, *Physica C* **584**, 1353866 (2021).
- *Unusual width of the superconducting transition in a hydride*, JE Hirsch & F Marsiglio, *Nature* **596**, E9 (2021).
- *Meissner effect in nonstandard superconductors*, JE Hirsch & F Marsiglio, *Physica C* **587**, 1353896 (2021).
- *Faulty evidence for superconductivity in ac magnetic susceptibility of sulfur hydride under pressure*, JE Hirsch, *arXiv:***2109**.08517 (2021).
- *Absence of evidence of superconductivity in sulfur hydride in optical reflectance experiments*, JE Hirsch & F Marsiglio, *arXiv*:**2109**.10878 (2021).
- *Clear evidence against superconductivity in hydrides under high pressure*, JE Hirsch & F Marsiglio, *arXiv*:**2110**.07568 (2021).
- *On the ac magnetic susceptibility of a room temperature superconductor: anatomy of a probable scientific fraud*, JE Hirsch, *Physica C* 1353964 (2021).
- *Flux trapping in superconducting hydrides under high pressure*, JE Hirsch & F Marsiglio, *Physica C* **589**, 1353916 (2021).
- *Hole superconductivity xOr hot hydride superconductivity*, JE Hirsch, *J. Appl. Phys.* **130**, 181102 (2021).
- *Disconnect between published ac magnetic susceptibility of a room temperature superconductor and measured raw data,* JE Hirsch, *Preprints* 2021120115 (2021) .
- *Superconductivity in Carbonaceous Sulfur Hydride: Further Analysis of Relation between Published AC Magnetic Susceptibility Data and Measured Raw Data,* JE Hirsch, *Europhys. Lett.* **137**, 36001 (2022).
- *Comment on Nature 58, 373 (2020) by E. Snider et al,* D van der Marel & JE Hirsch, *arXiv*:**2201**.07686 (2022).

Timeline of the analysis of Eu and CSH susceptibiity data.

13.04.2009: ***Pressure-Induced Superconducting State of Europium Metal at Low Temperatures***, M. Debessai, T. Matsuoka, J. J. Hamlin, and J. S. Schilling & K. Shimizu, *PRL* **102**, 197002 (2009).

20.10.2020: ***Room-temperature superconductivity in a carbonaceous sulfur hydride***, E. Snider, N. Dasenbrock-Gammon, R. McBride, M. Debessai, H. Vindana, K. Vencatasamy, K. V. Lawler, A. Salamat & R. P. Dias, *Nature* **586**, 373 (2020).

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

14.11.2020: J. E. Hirsch requests raw $\chi'(T)$ data of Eu.

15.04 2021: ***About the pressure-induced superconducting state of europium metal at low temperatures***, J. E. Hirsch, *Physica C* **583**, 1353805 (2021).

23.09.2021: ***On the ac magnetic susceptibility of a room temperature superconductor: anatomy of a probable scientific fraud***, J. E. Hirsch, *Physica C* 1353964.

29.11.2021: ***Standard Superconductivity in Carbonaceous Sulfur Hydride***, R. P. Dias and A. Salamat, *arXiv*:**2111**.15017v1 (2021). Raw data for 4 pressures.

23.12.2021: Retraction of *PRL* **102**, 197002 (2009): “...the susceptibility data presented in Fig. 2 were not accurately reported. We acknowledge JE Hirsch's contribution to discussions that led us to reexamine our data.”

25.12.2021: ***Standard Superconductivity in Carbonaceous Sulfur Hydride***, R. P. Dias and A. Salamat, *arXiv*:**2111**.15017v2 (2021). Raw and background-corrected data for all 6 pressures.

06.012022: ***Superconductivity in Carbonaceous Sulfur Hydride: Further Analysis of Relation between Published AC Magnetic Susceptibility Data and Measured Raw Data***, J. E. Hirsch, *Preprints* **202201**.0003 (2022).

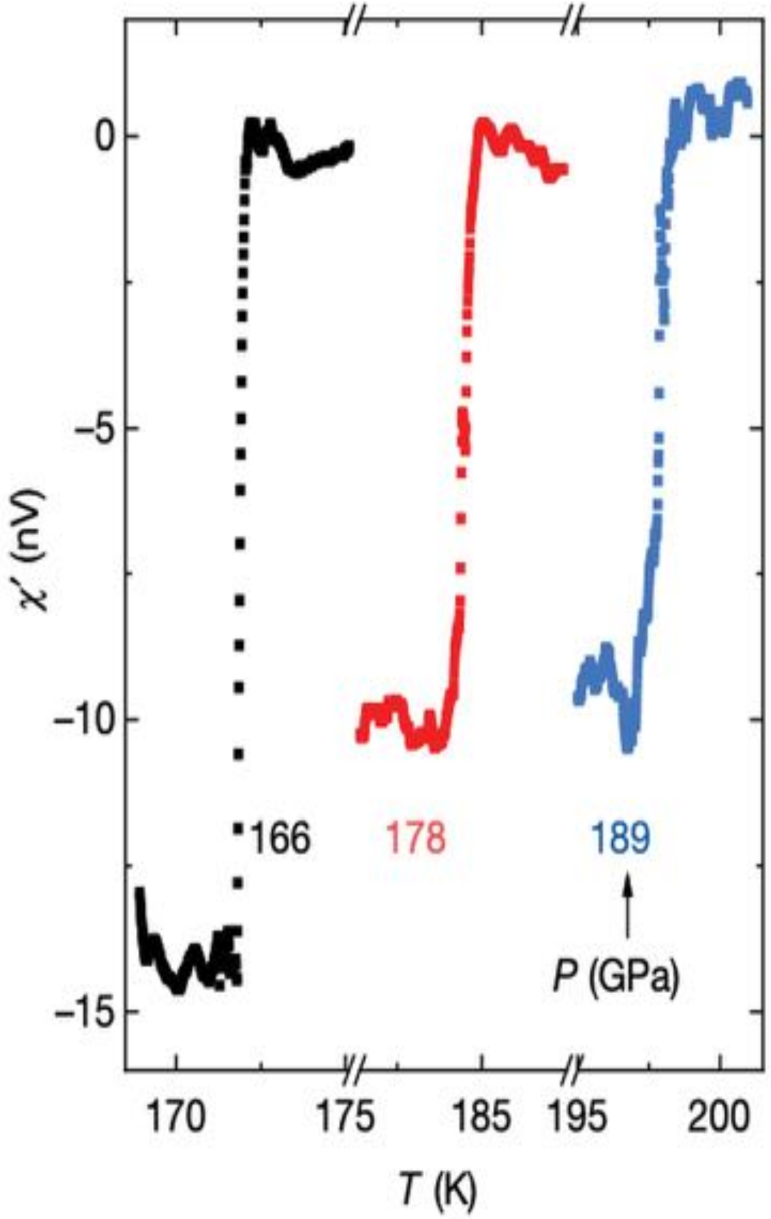
19.012022: ***Comment on Nature 58, 373 (2020) by E. Snider et al***, D. van der Marel & J. E. Hirsch, *arXiv*:**2201**.07686 (2022). Censored on 31.012022 due to “inflammatory content and unprofessional language”. Uncensored on 07.03.2022. **Final update** on 10.04.2022.

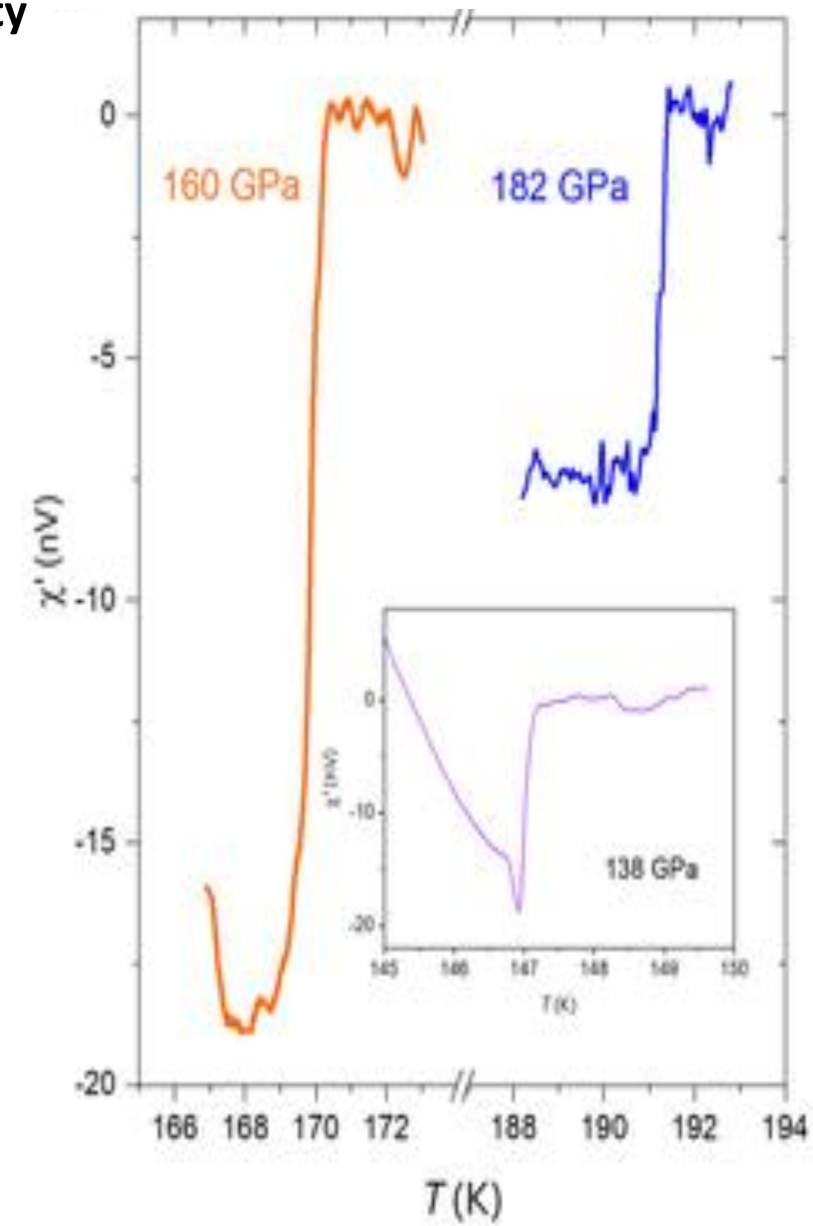
31.01.2022: ***Reply to "Comment on Nature 586, 373 (2020) by E. Snider et al."***, R. P. Dias & A. Salamat, *arXiv*:**2201**.11883 (2022). Censored on 07.03.2022 due to “inflammatory content and unprofessional language”.

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.”

Room-temperature superconductivity in a carbonaceous sulfur hydride, E. Snider et al , *Nature* **586**, 373 (2020).

AC susceptibility





"The background signal, determined from a non-superconducting C–S–H sample at 108 GPa, has been subtracted from the data."

Standard Superconductivity in Carbonaceous Sulfur Hydride, R. P. Dias and A. Salamat, *arXiv*:**2111**.15017 (2021)

"...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)."

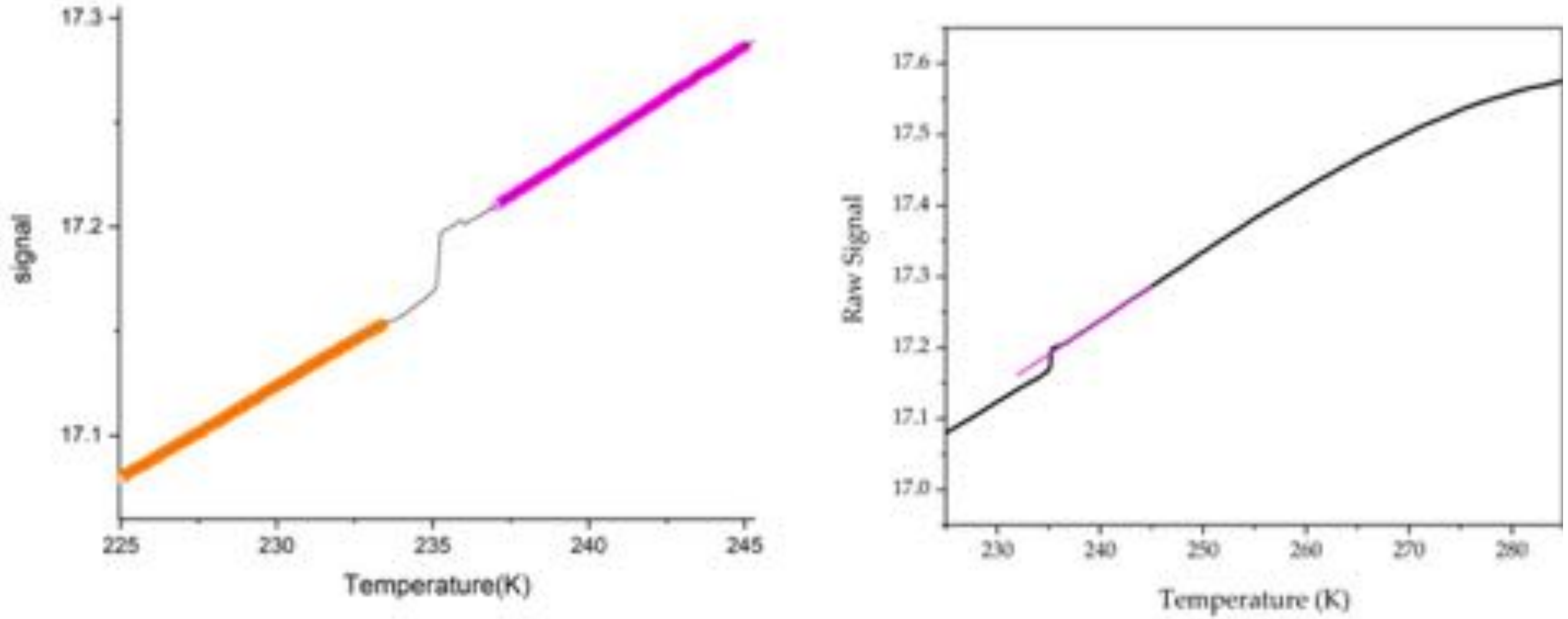


Figure 6. *Demonstration of the raw signal and how a background is subtracted.*
Left: Selected region before the transition temperature from which a line is fit.
Right: Plot showing an expanded range of the raw signal, as well as the line to be subtracted.
Signal is given in nV.

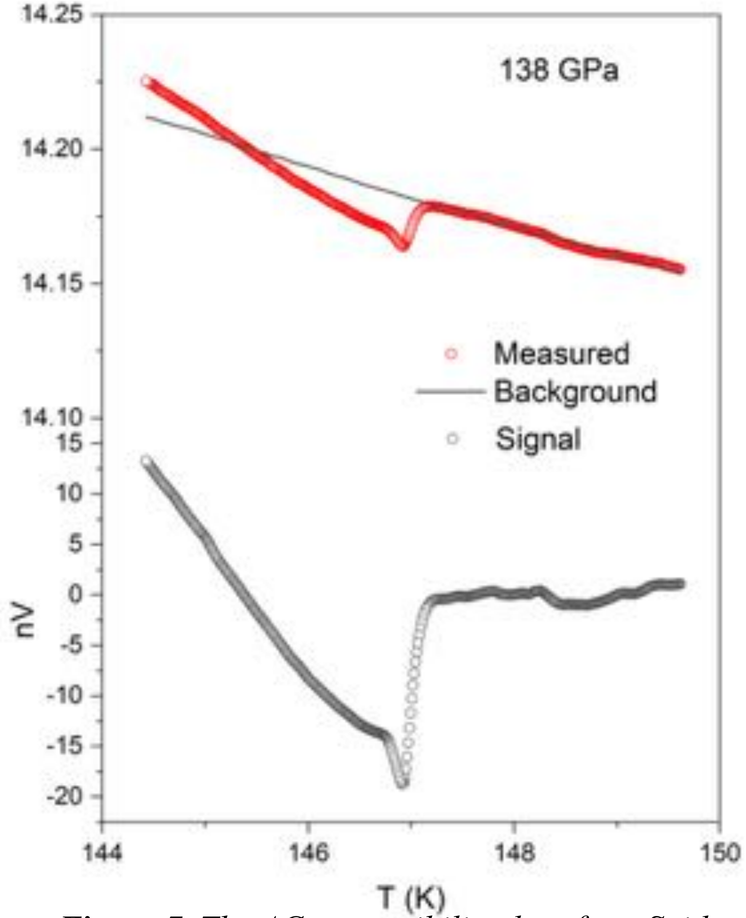


Figure 7. *The AC susceptibility data from Snider et al., showing the raw data, the background used for subtraction and the data shown in the publication.*

Reply to "Comment on Nature 586, 373 (2020) by E. Snider et al.", R. P. Dias & A. Salamat, *arXiv*:**2201**.11883 (2022).

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.

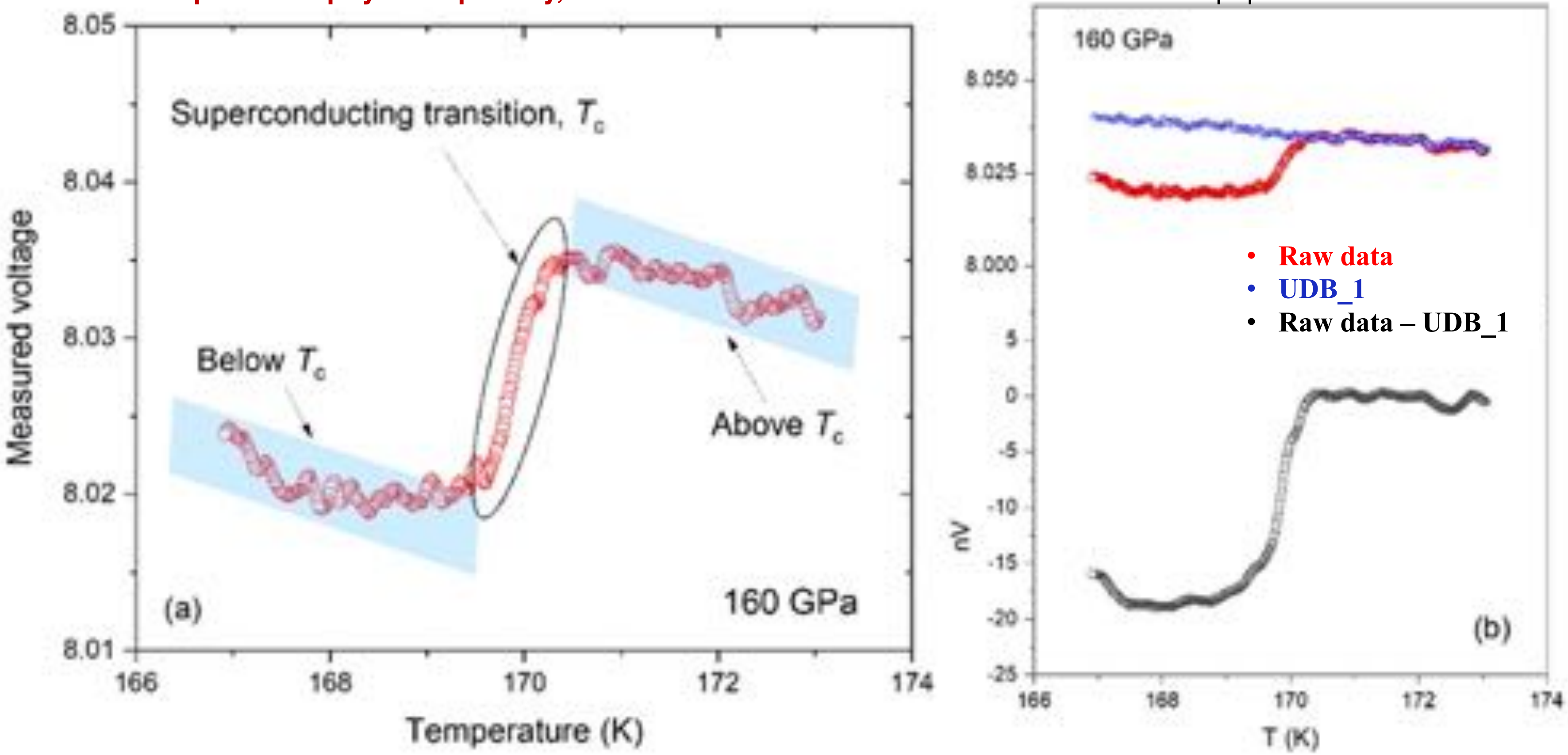


***Fig. 2** AC susceptibility data.*

(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.

Open data of pressurized CSH

R. P. Dias and A. Salamat, *arXiv*:**2111**.15017v2 (25.12.2021).

Nomenclature:

- Background corrected data: "Superconducting Signal" = χ_{sc}
- Raw data: "Measured Voltage" = χ_{mv}
- Background data: "User Defined Background" = χ_{UDB}

Provided in tables

- χ_{sc}
- χ_{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

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

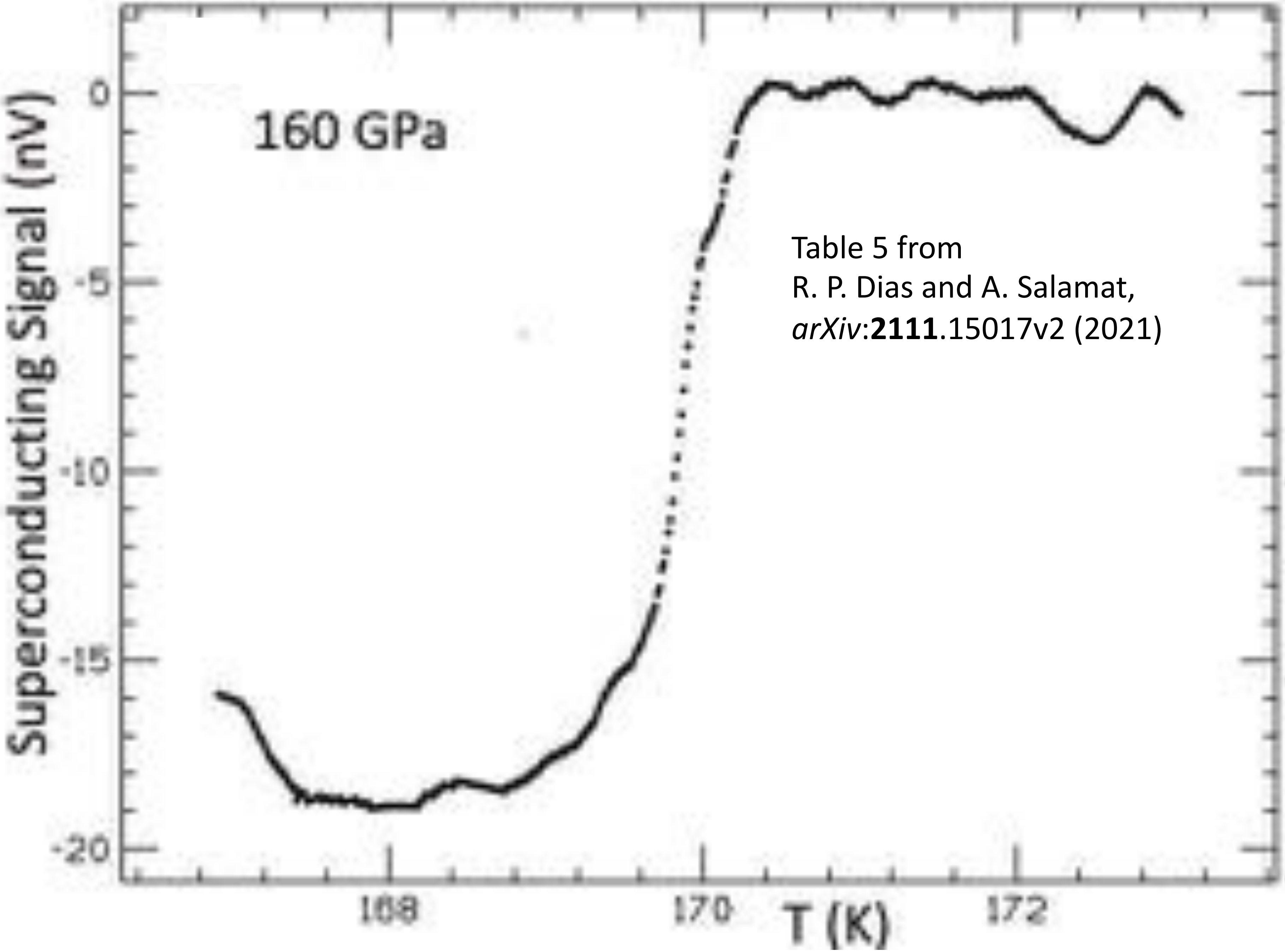
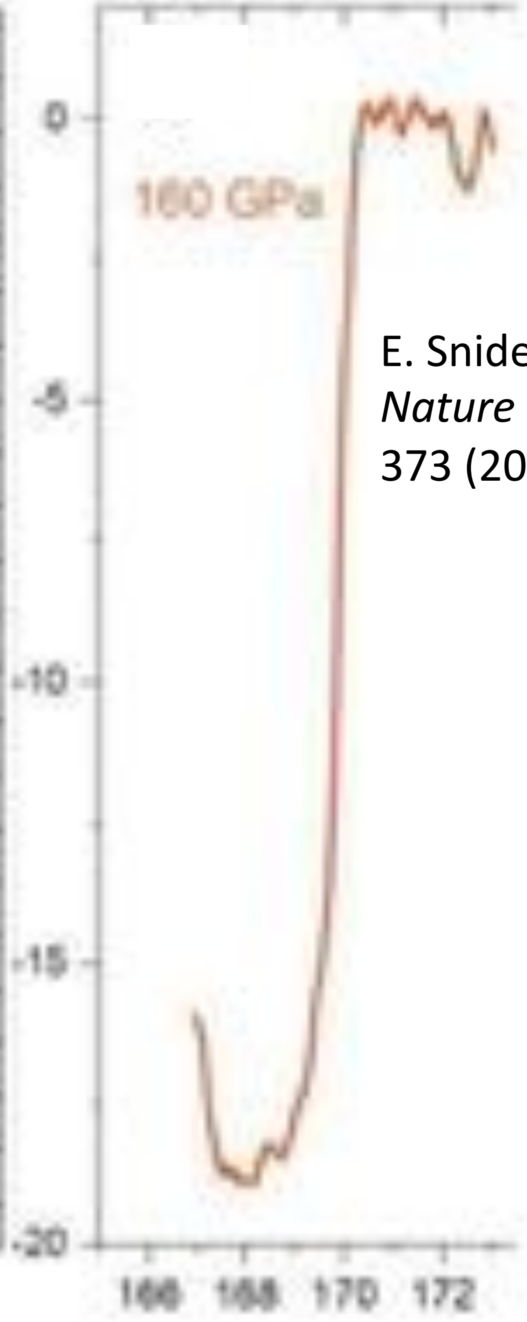


Table 5 from
R. P. Dias and A. Salamat,
arXiv:**2111**.15017v2 (2021)

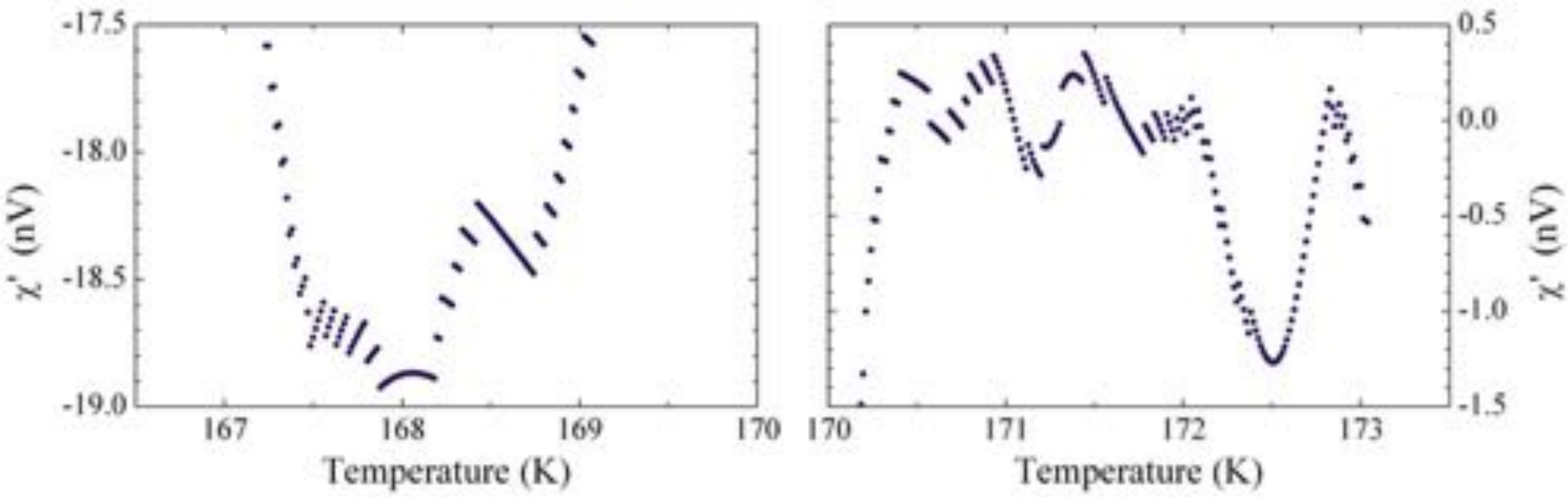


E. Snider et al.
Nature **586**,
373 (2020)

“Superconducting Signal” at 160 GPa

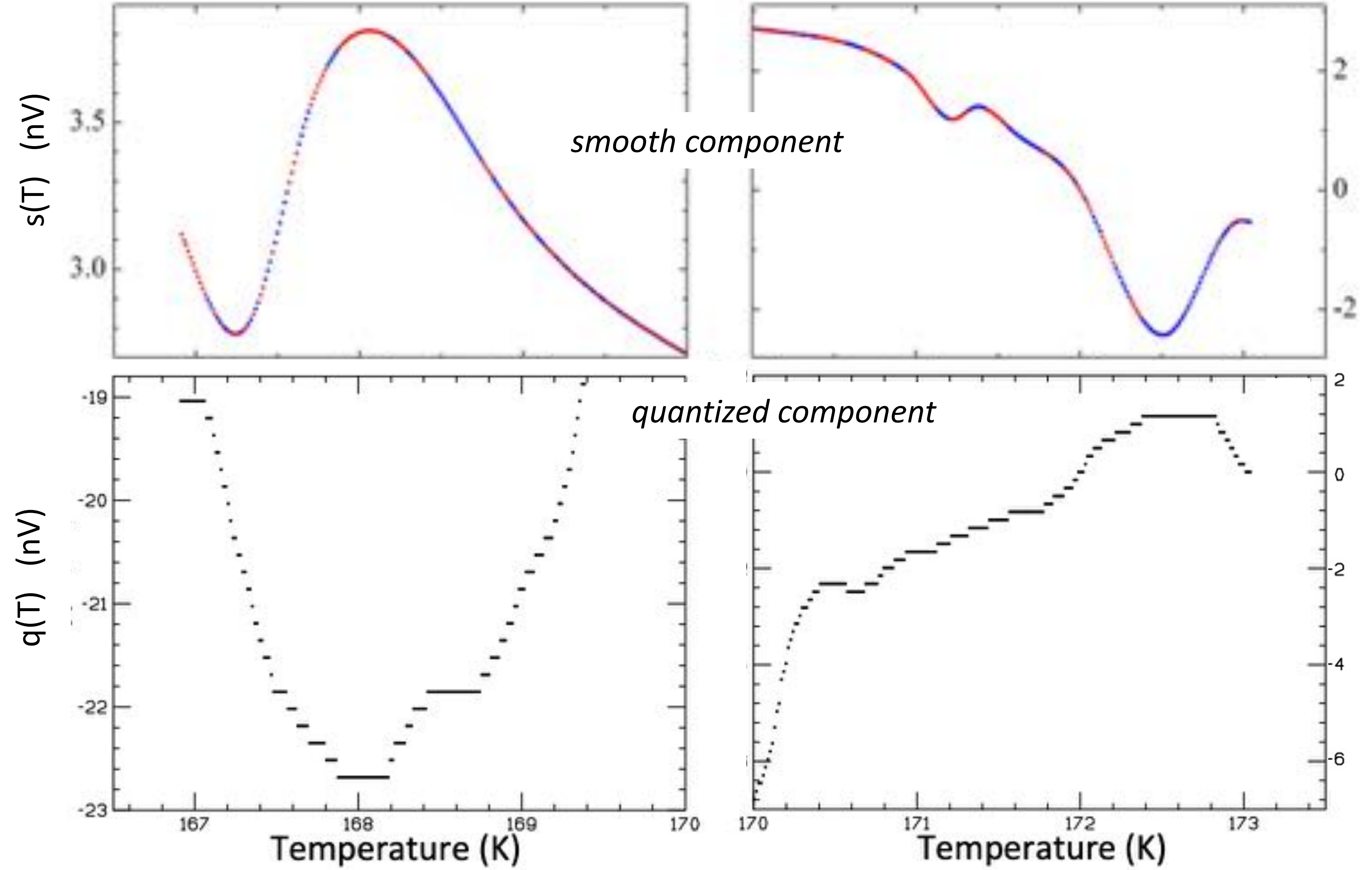
$\chi_{sc} = \chi_{mv} - \chi_{UDB}$

Table 5 from R. P. Dias and A. Salamat, *arXiv*:**2111**.15017v2 (2021)



“Superconducting Signal” at 160 GPa

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

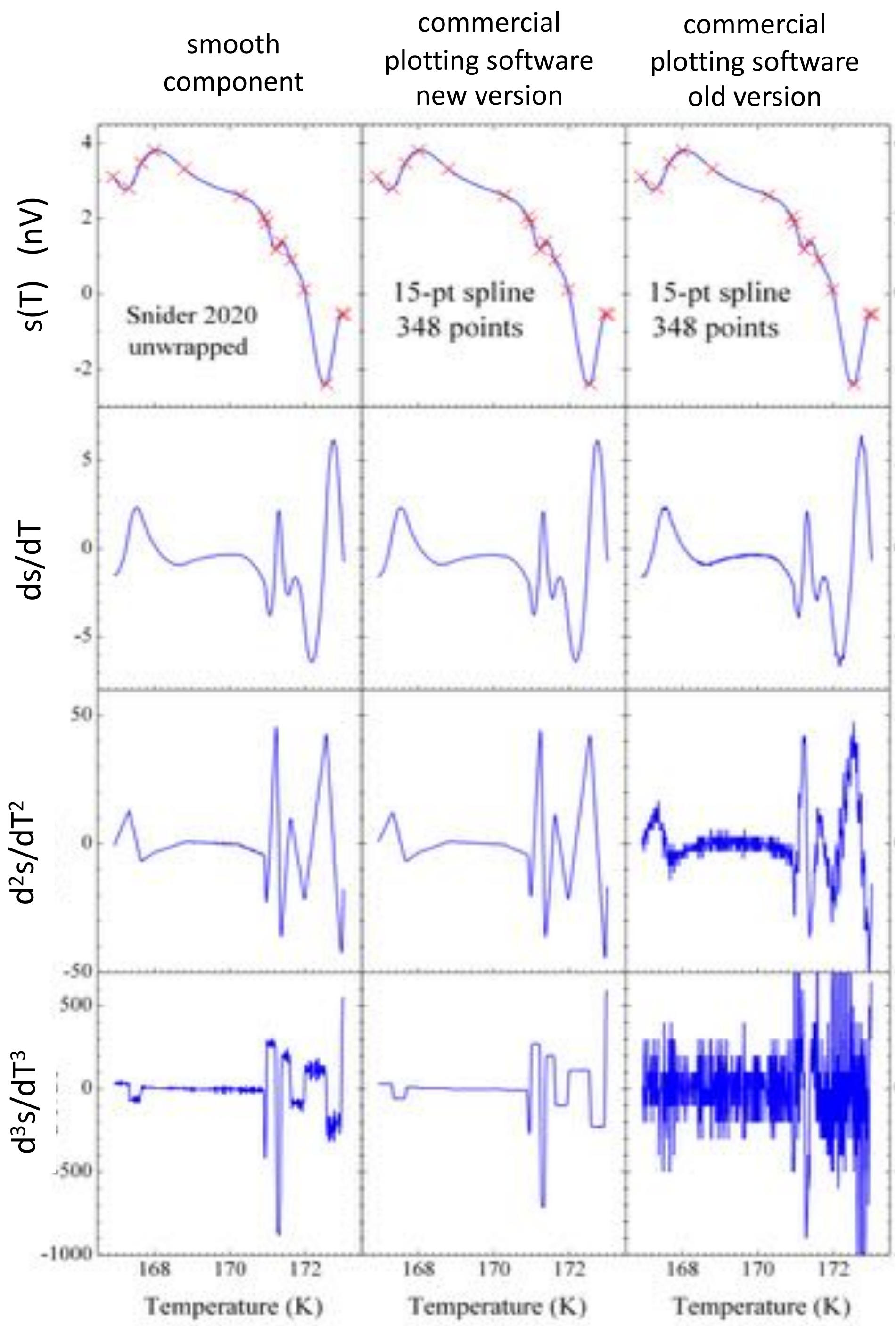


Properties of the quantized component

- *n x 0.1655 (nV)*
- *0 < n < 140*

Properties of the smooth component

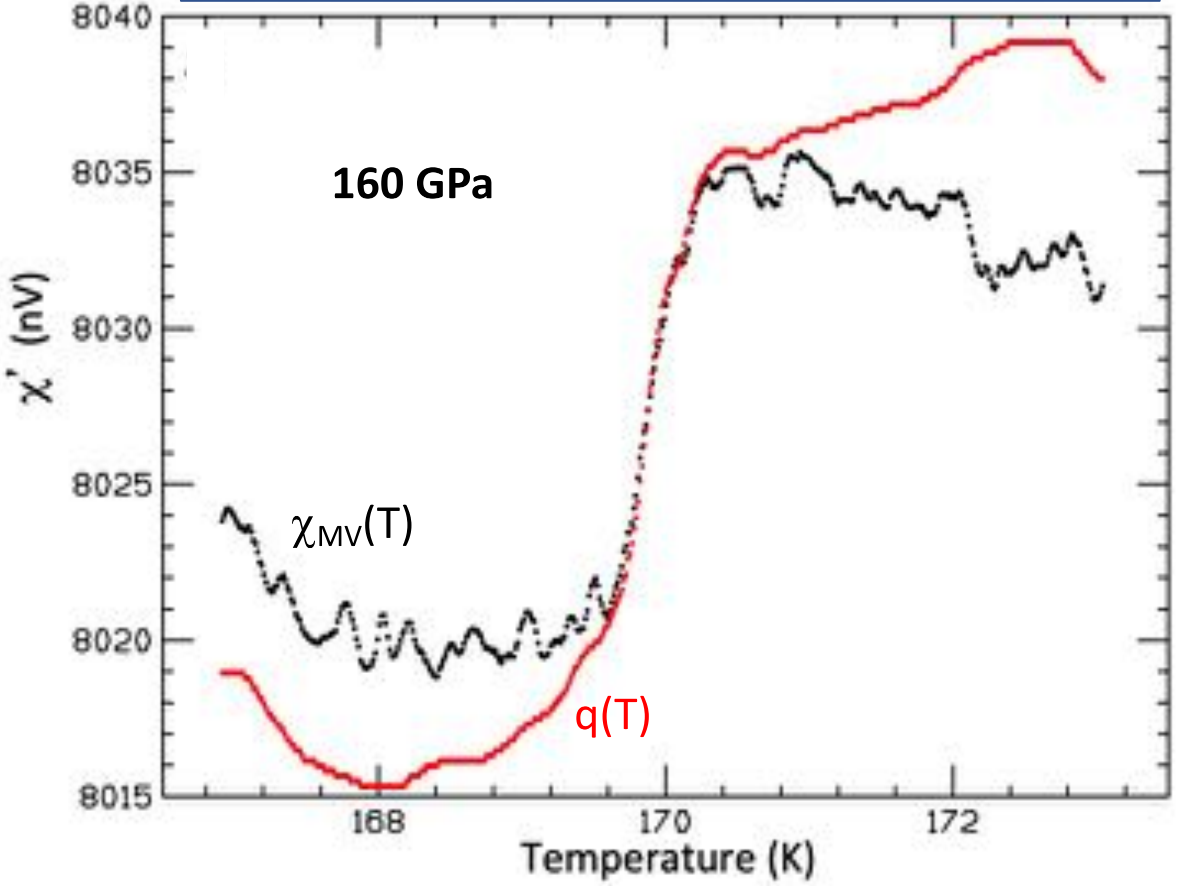
- *spline*
- *number of segments: 14*
- *number of nodes: 15*
- *order: cubic*
- *boundary conditions: natural*



What is the nature of the **"quantized component"** ?
Raw data recorded with 3 digit precision ?

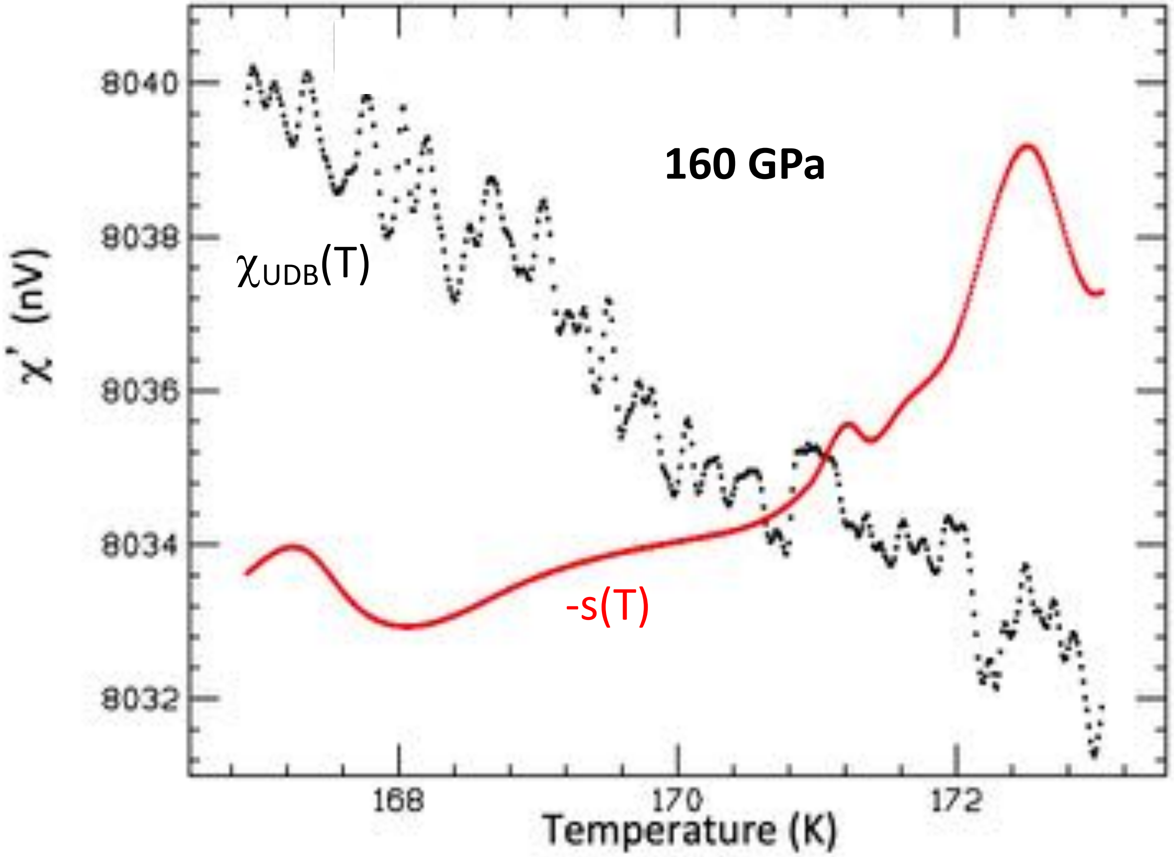
What is the nature of the **"smooth component"** ?
-1 x fitted (or otherwise smooth) "User Defined Background"?

Comparison of **"quantized component"**
and **"Measured Voltage"**



The **"quantized component"** is ***not*** the raw data

Comparison of **"smooth component"**
and **"User Defined Background"**



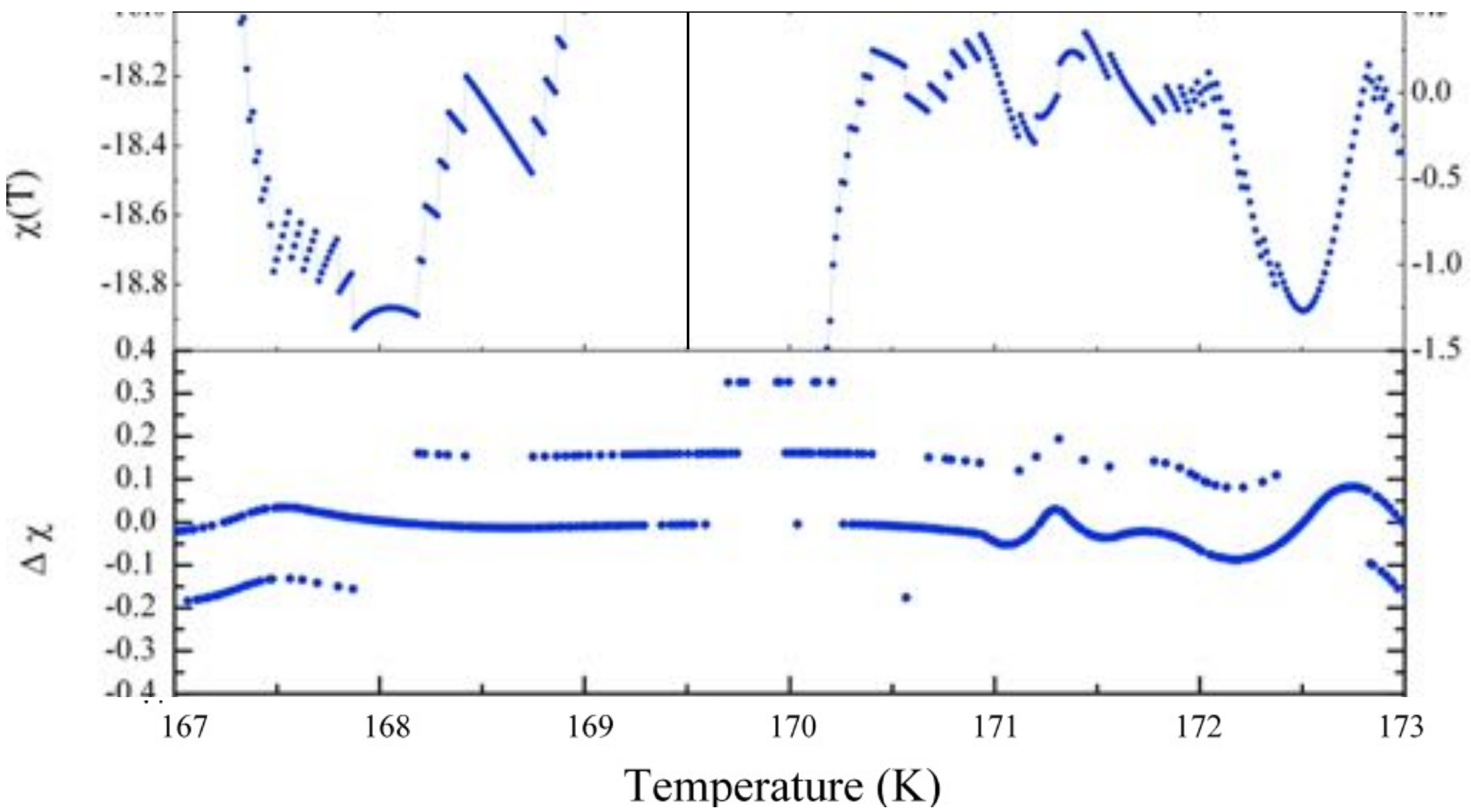
The **"smooth component"** is ***not*** the background

The “Superconducting Signal”

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

JE Hirsch, *Europhys. Lett.* **137**, 36001 (2022)

160 GPa

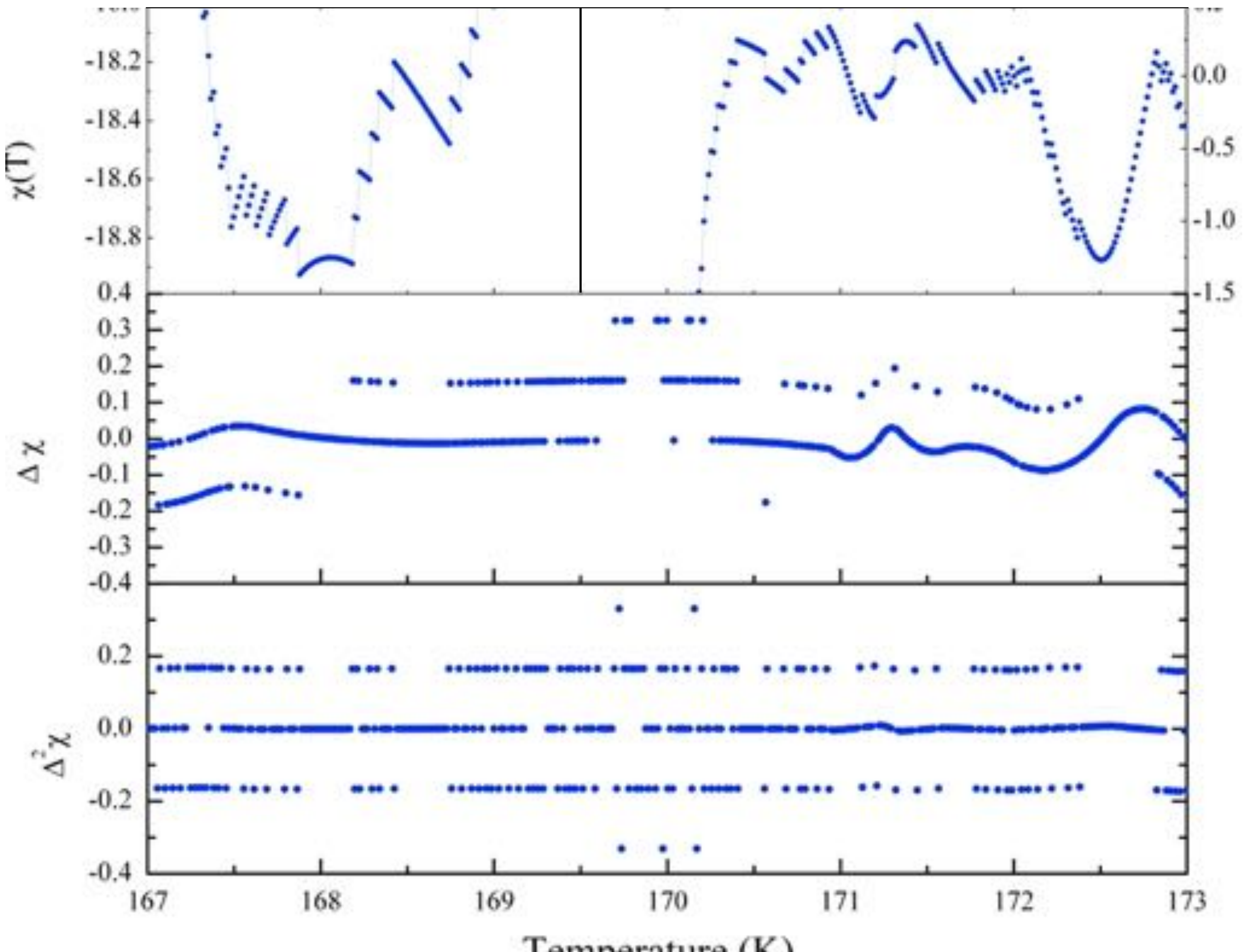


The "Superconducting Signal"

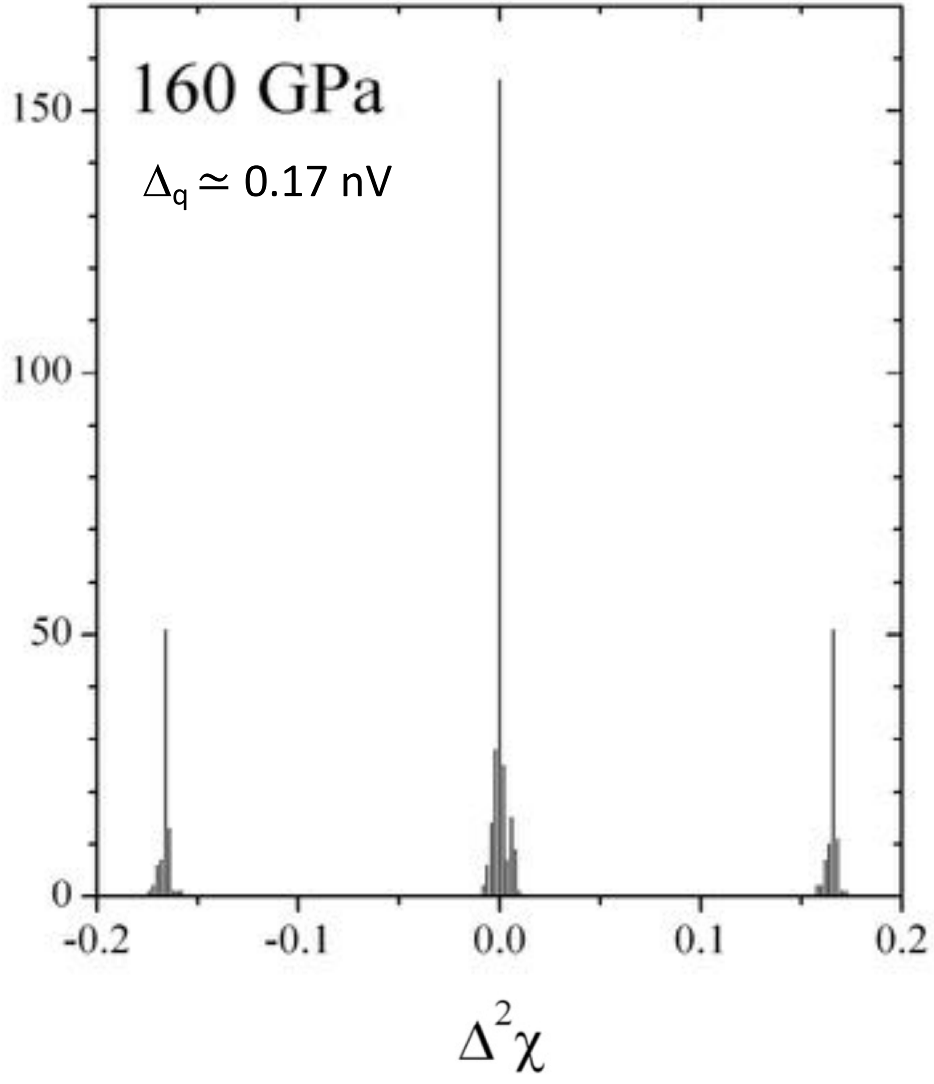
160 GPa

$$\Delta\chi(j) = \chi(j) - \chi(j-1)$$
$$\Delta^2\chi(j) = \Delta\chi(j) - \Delta\chi(j-1)$$

JE Hirsch, *Europhys. Lett.* **137**, 36001 (2022)



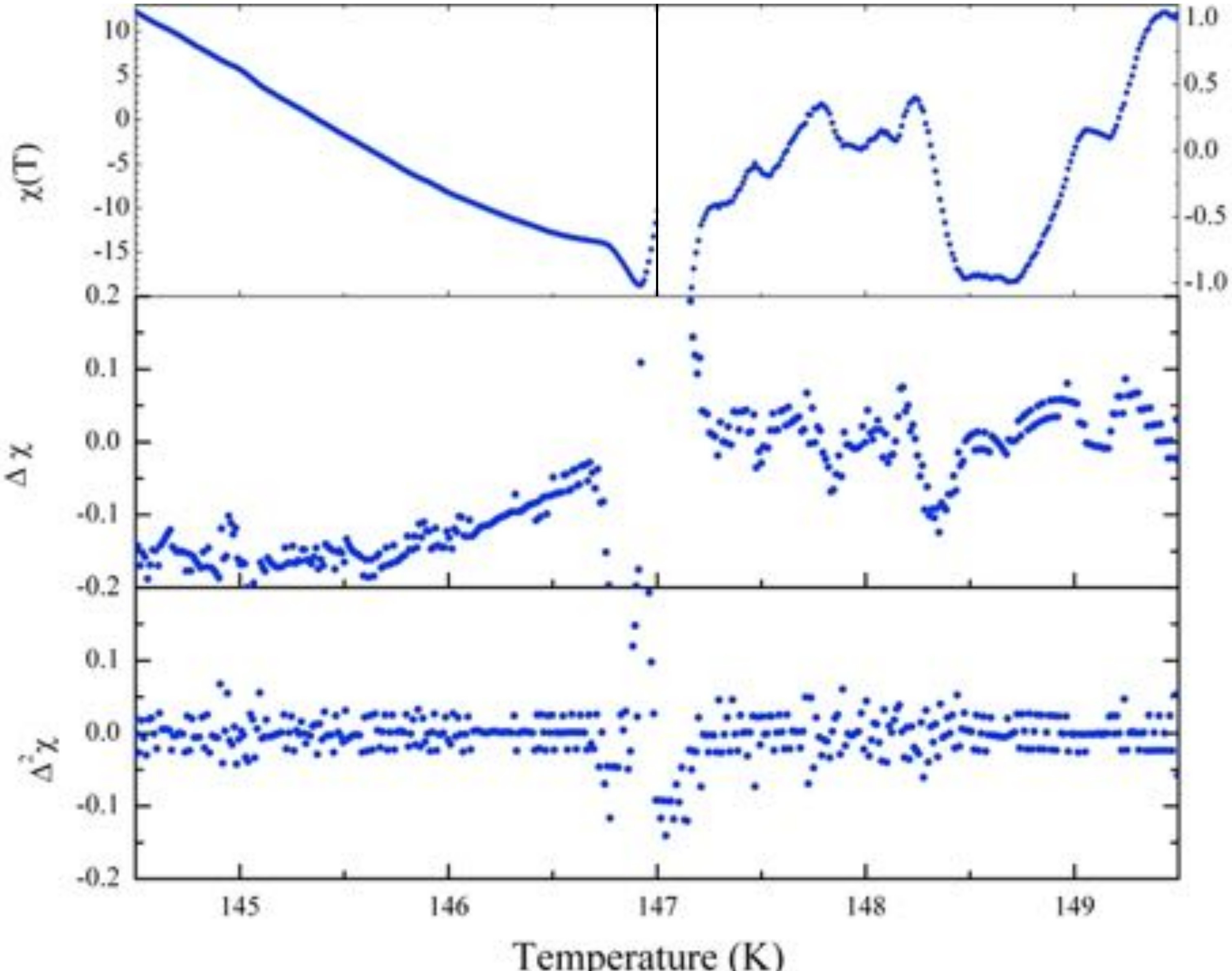
Dukwon, https://imgur.com (2022)

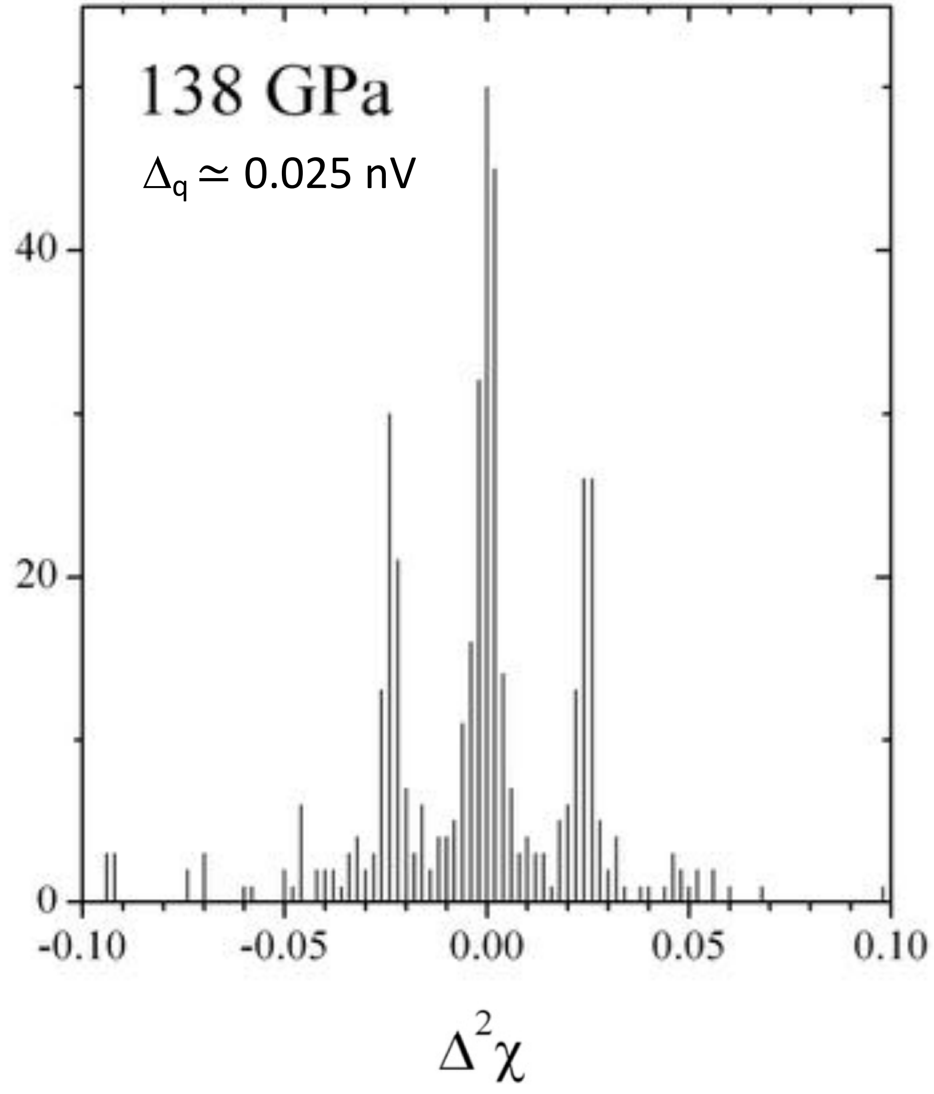


The "Superconducting Signal"

$$\Delta\chi(j) = \chi(j) - \chi(j-1)$$
$$\Delta^2\chi(j) = \Delta\chi(j) - \Delta\chi(j-1)$$

138 GPa

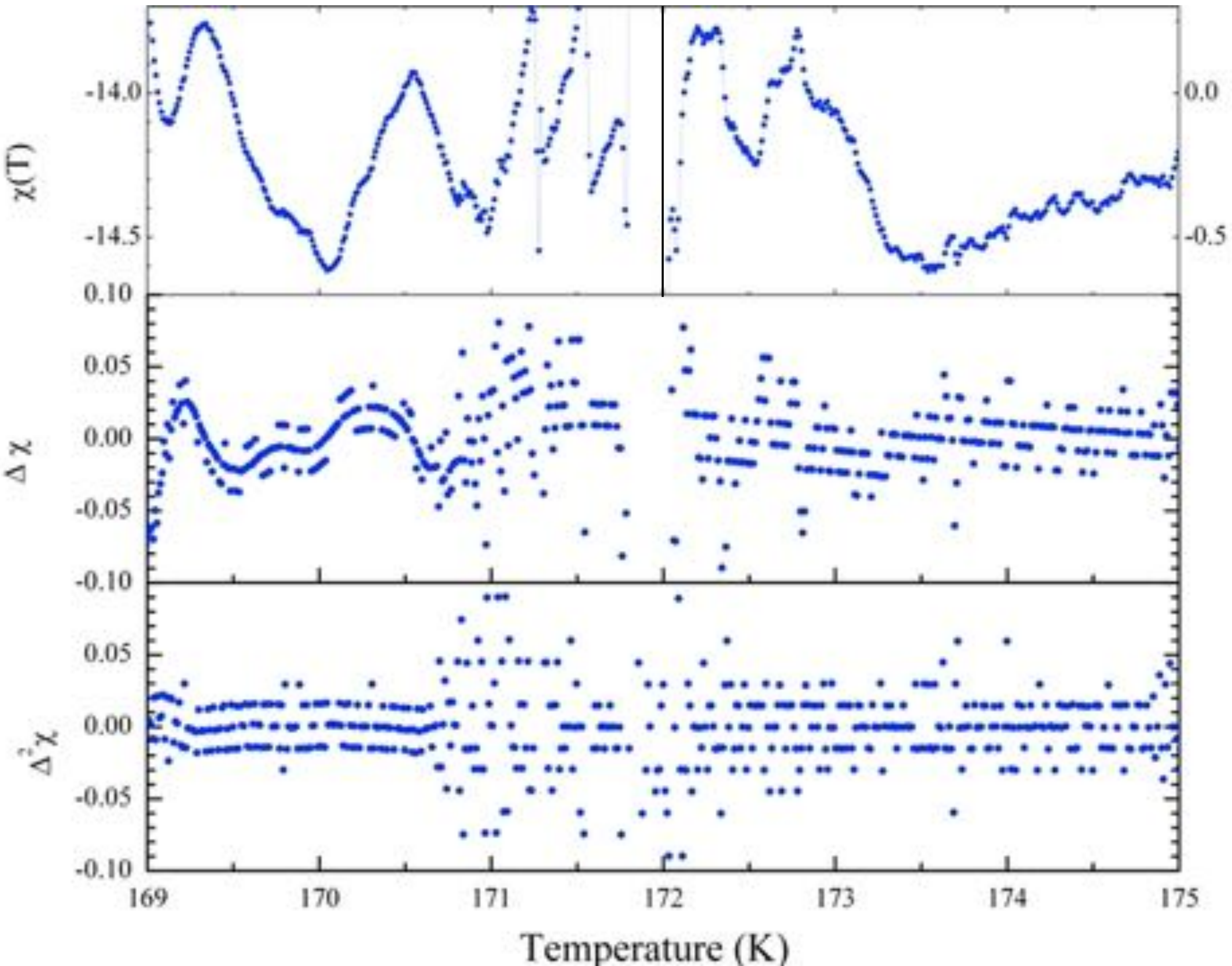


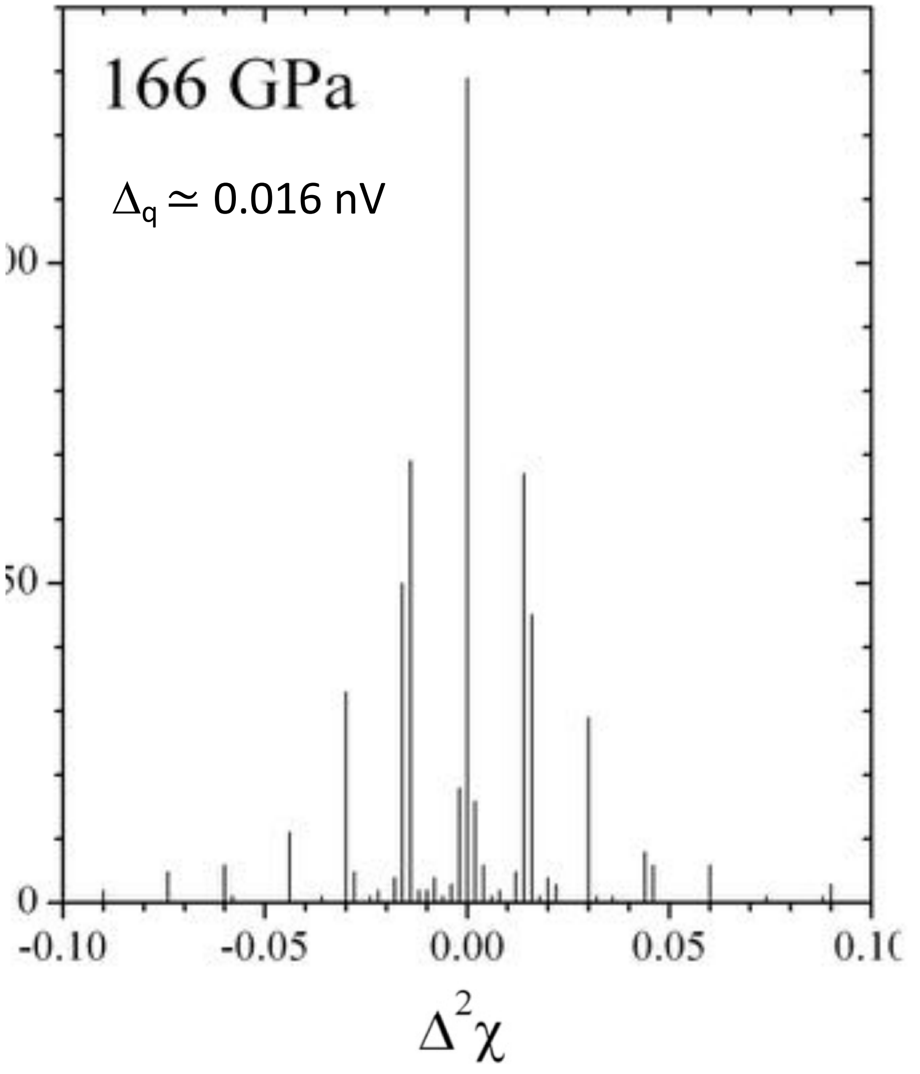


The "Superconducting Signal"

$$\Delta\chi(j) = \chi(j) - \chi(j-1)$$
$$\Delta^2\chi(j) = \Delta\chi(j) - \Delta\chi(j-1)$$

166 GPa

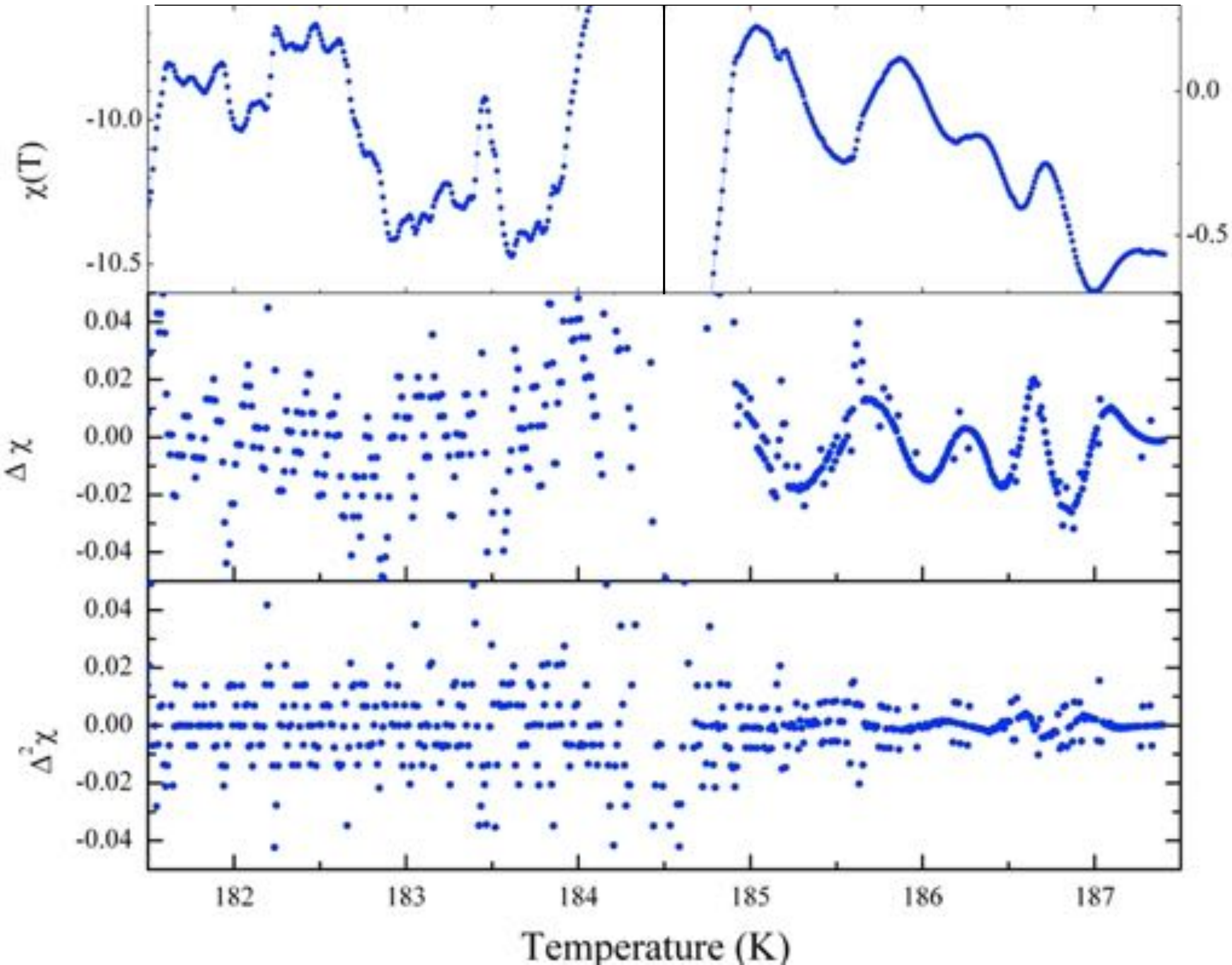


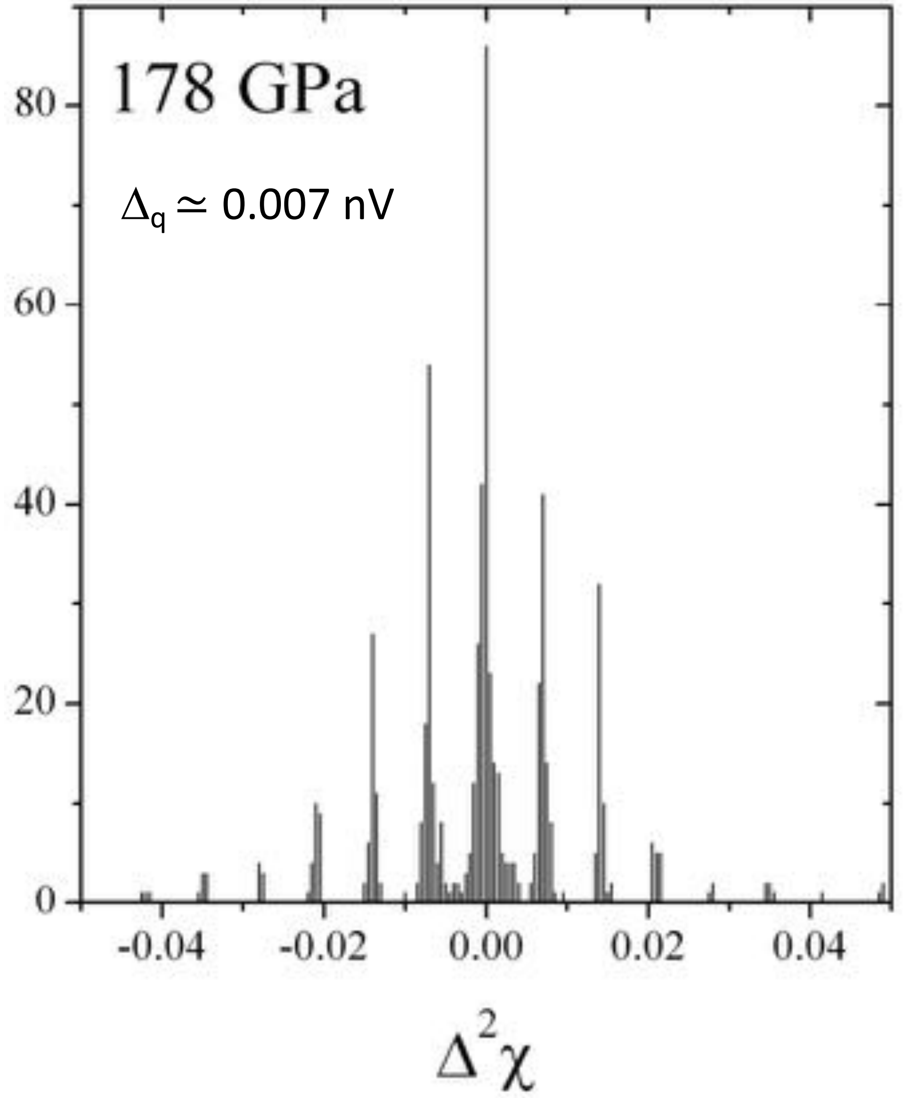


The “Superconducting Signal”

$$\Delta\chi(j) = \chi(j) - \chi(j-1)$$
$$\Delta^2\chi(j) = \Delta\chi(j) - \Delta\chi(j-1)$$

178 GPa

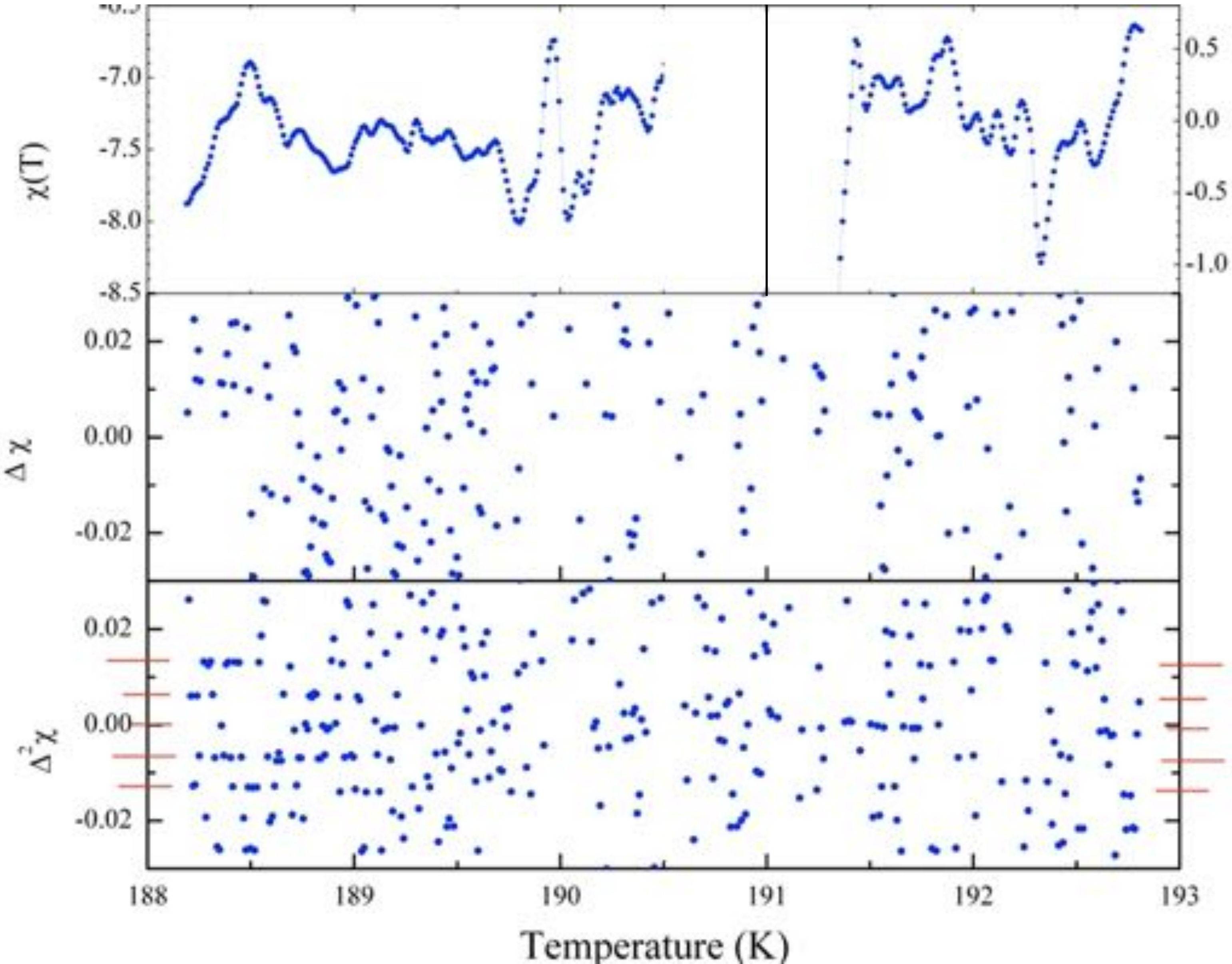


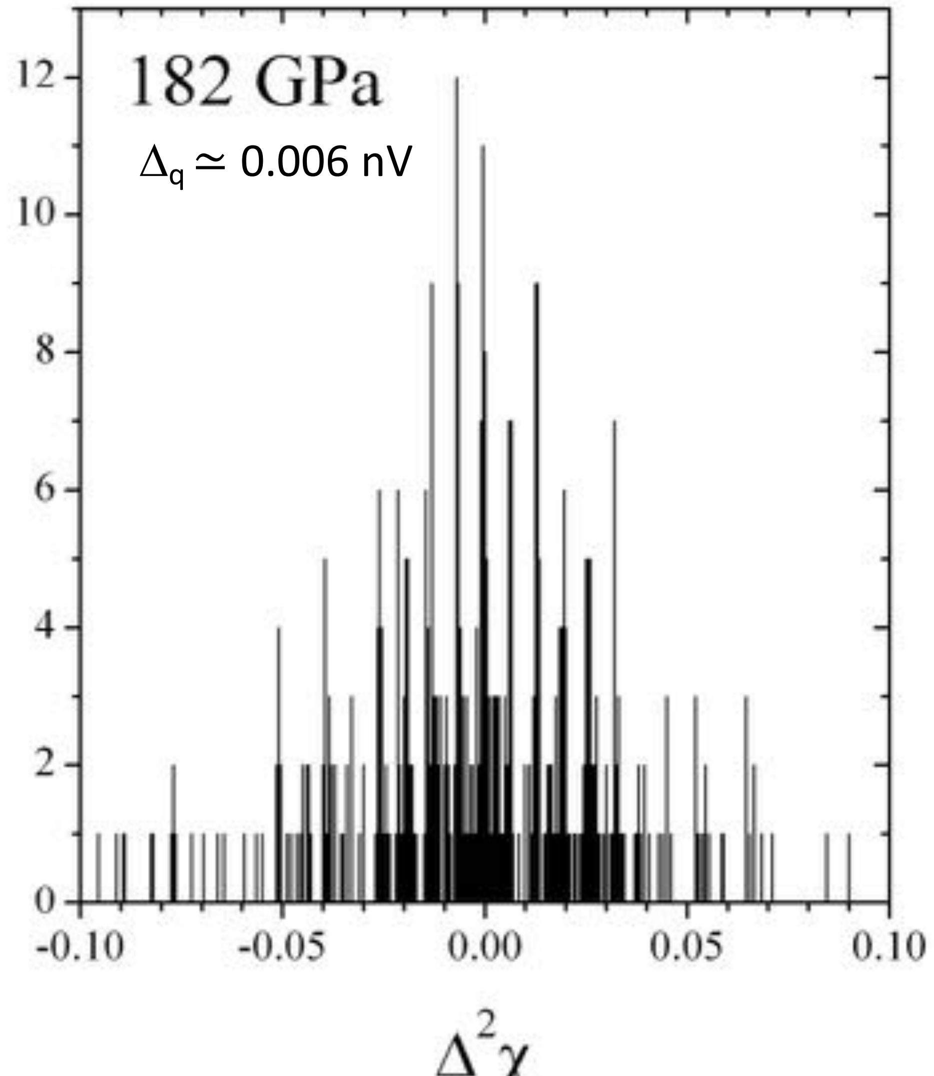


The "Superconducting Signal"

$$\Delta\chi(j) = \chi(j) - \chi(j-1)$$
$$\Delta^2\chi(j) = \Delta\chi(j) - \Delta\chi(j-1)$$

182 GPa

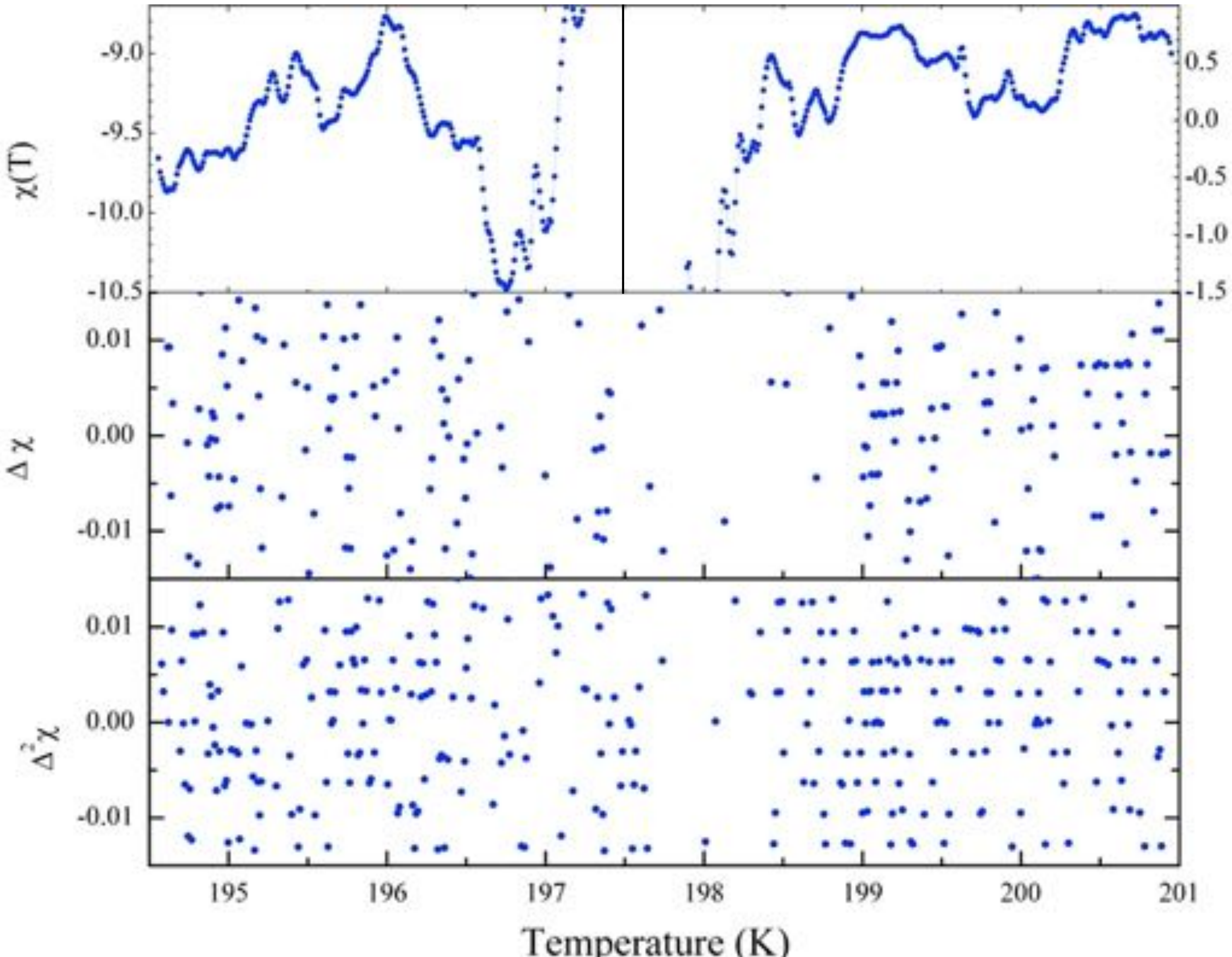


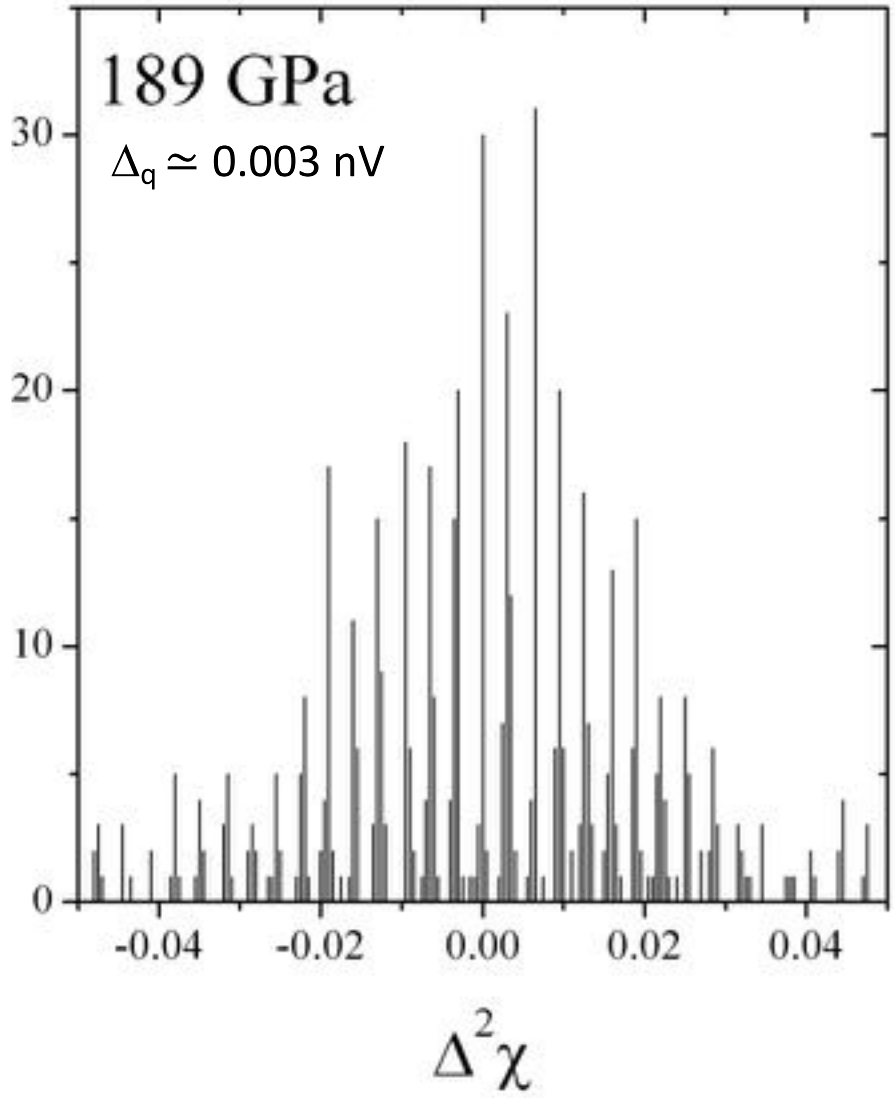


The "Superconducting Signal"

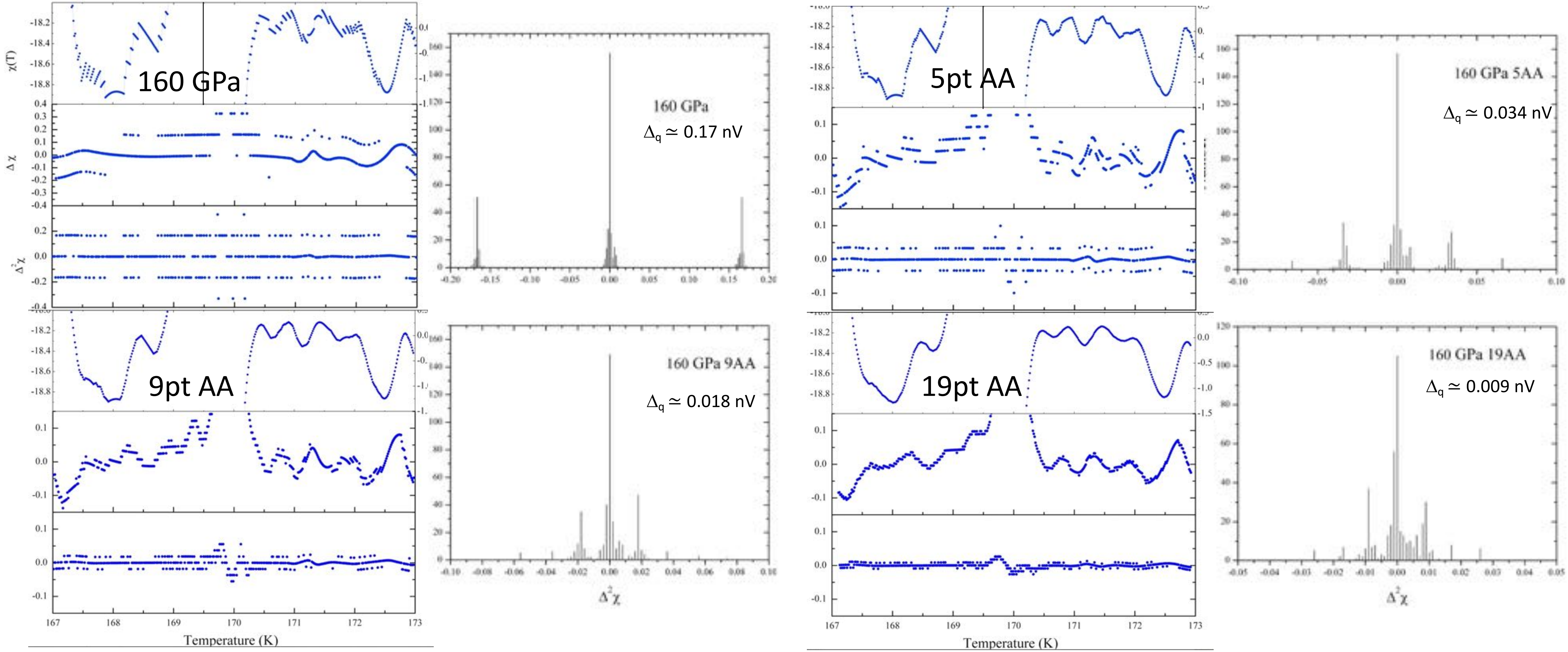
$$\Delta\chi(j) = \chi(j) - \chi(j-1)$$
$$\Delta^2\chi(j) = \Delta\chi(j) - \Delta\chi(j-1)$$

189 GPa



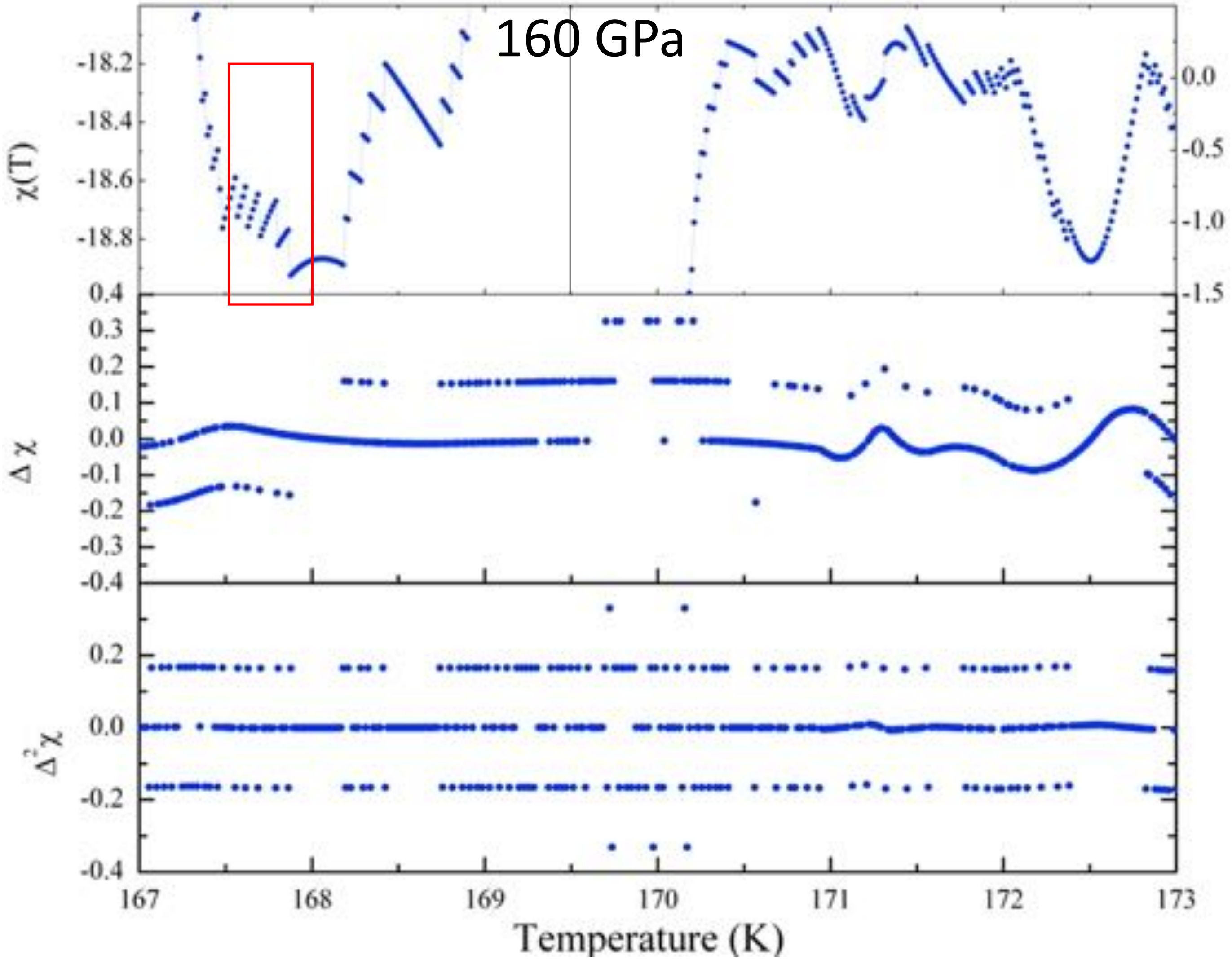


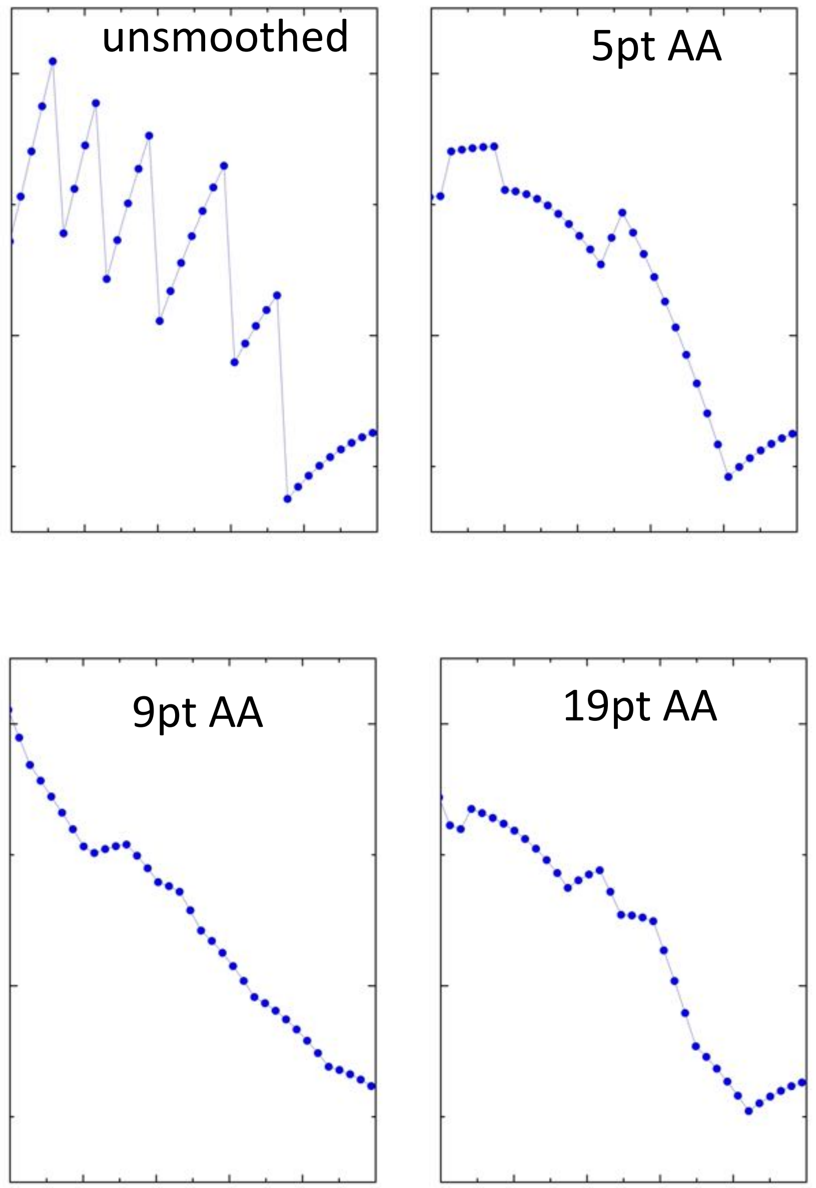
The “Superconducting Signal” and Adjacent Average smoothing



After adjacent averaging a quantized component still shows up in $\Delta\chi$ and $\Delta^2\chi$.
The steps are reduced to $\Delta_q = \Delta_0 / n_{AA}$.

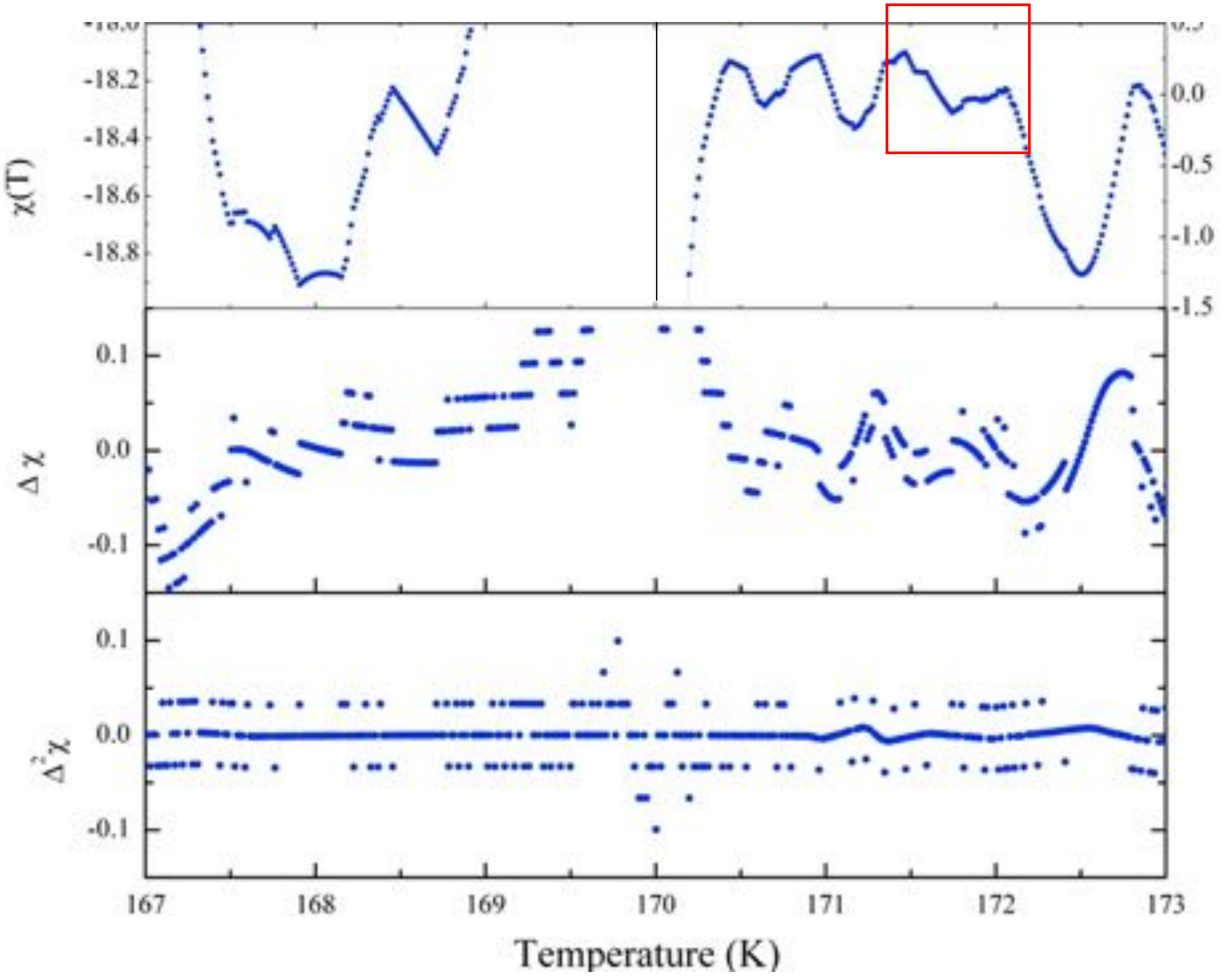
The “Superconducting Signal” and Adjacent Average smoothing



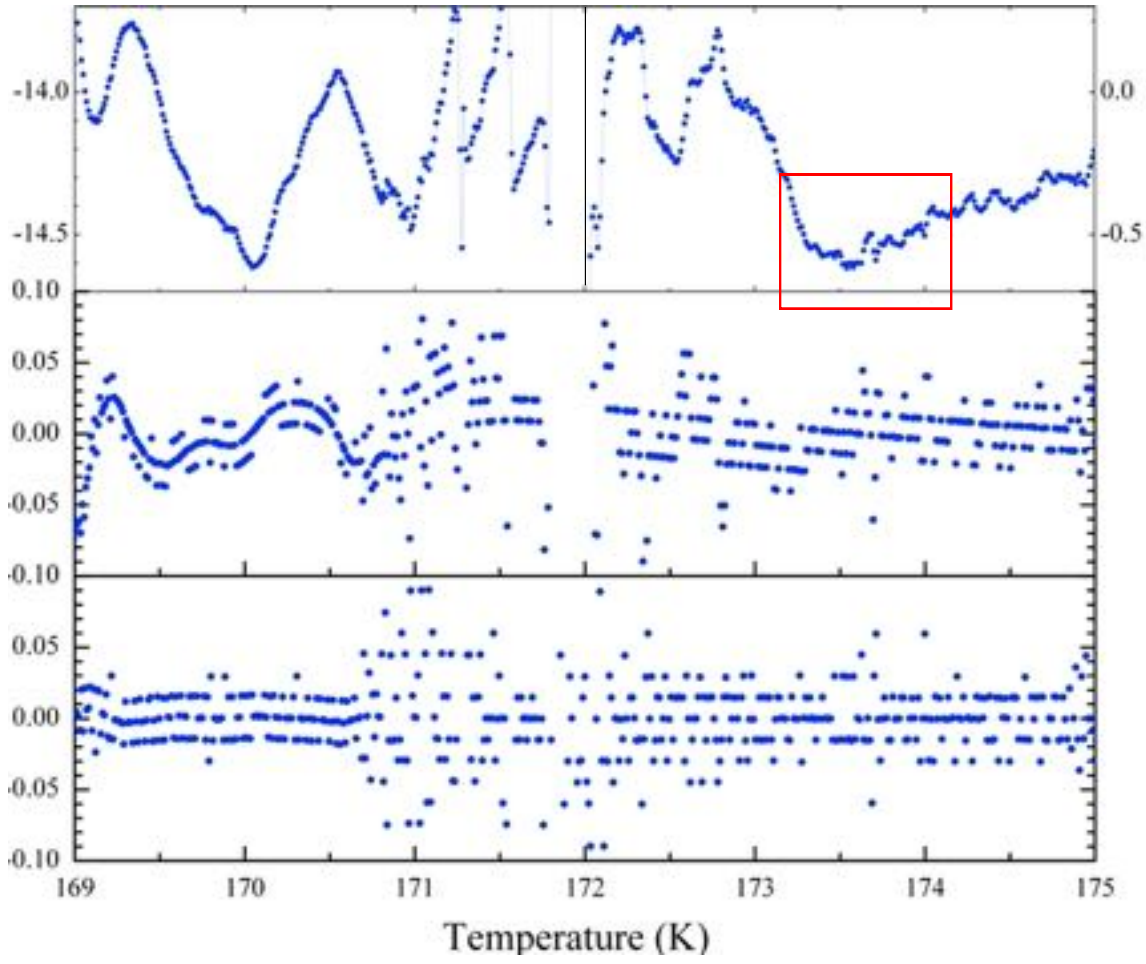


The “Superconducting Signal” and Adjacent Average smoothing

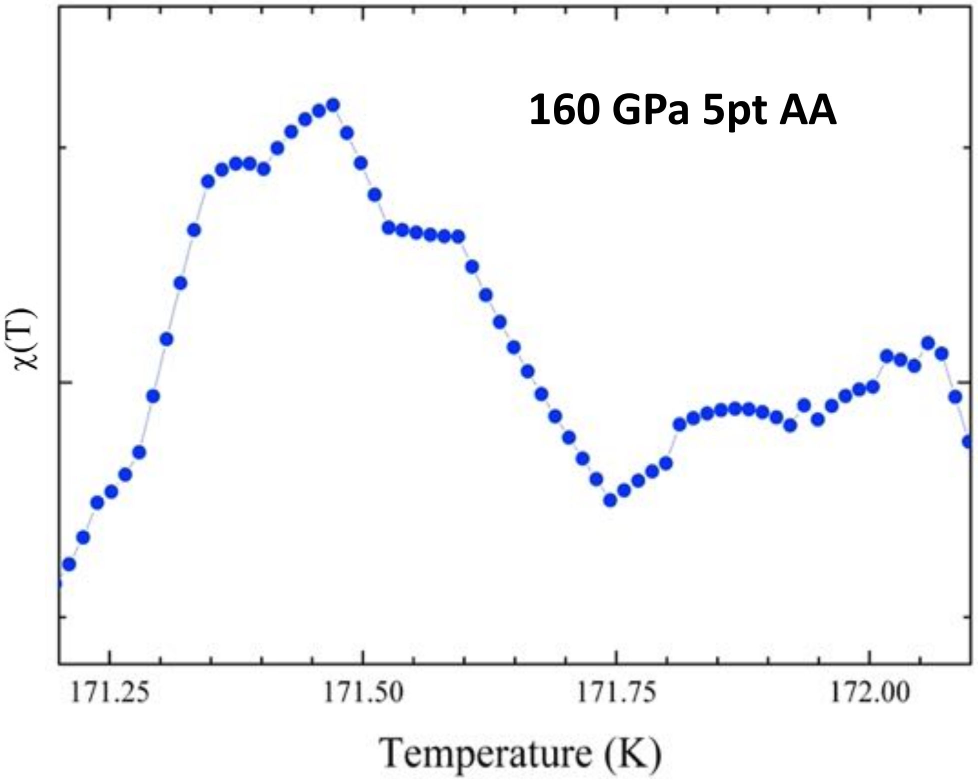
160 GPa 5pt AA

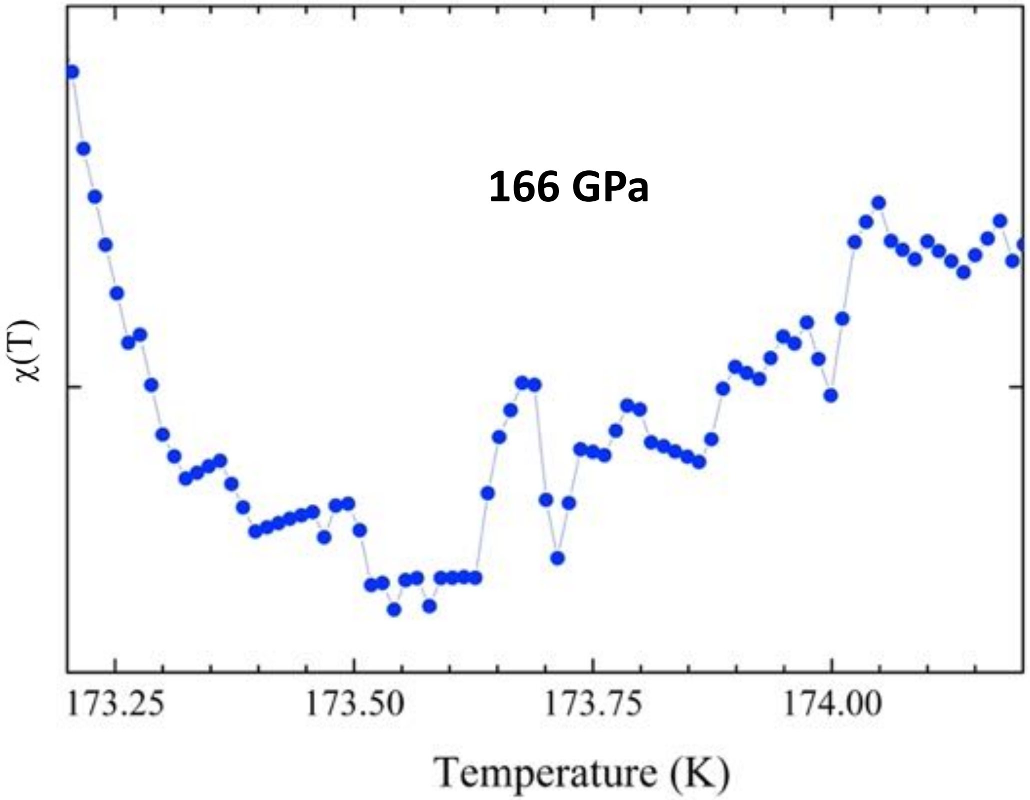


166 GPa



The “Superconducting Signal” and Adjacent Average smoothing





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 $\chi_{sc}(T) = a(T)$.

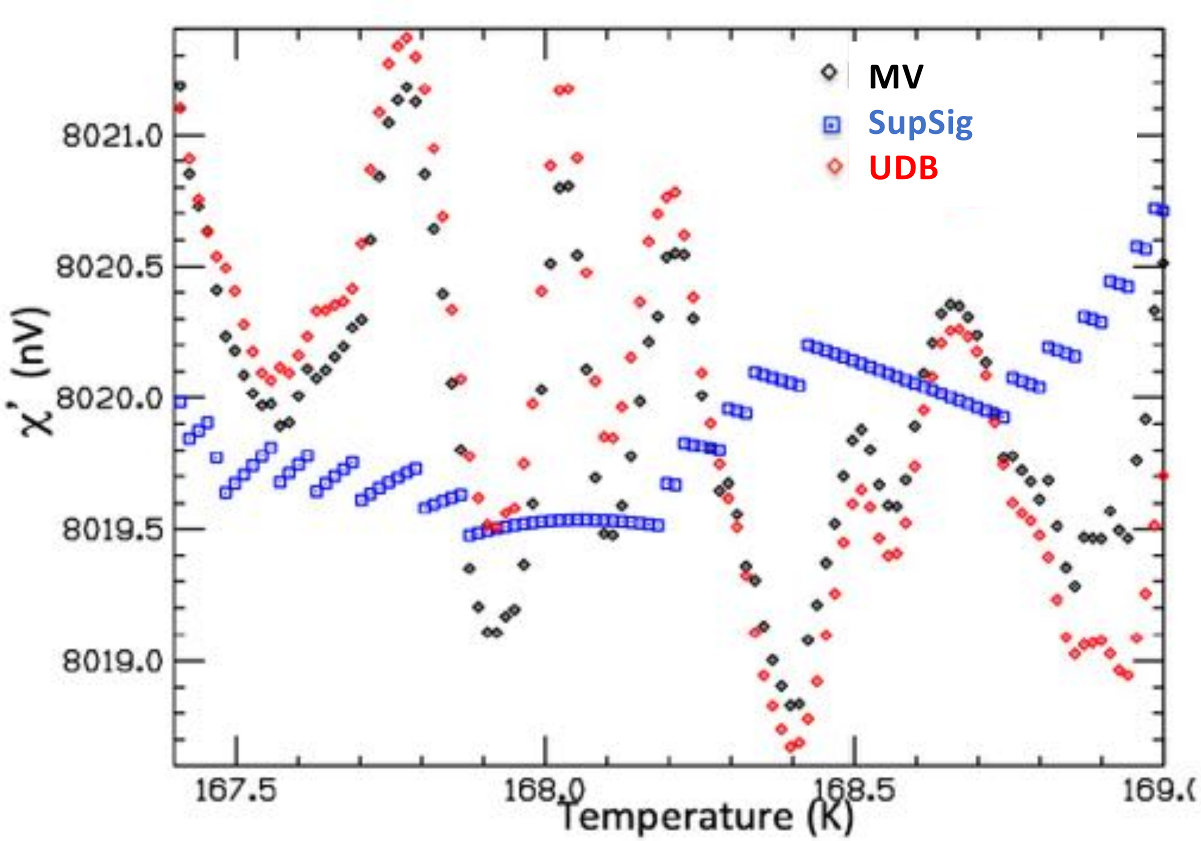
The noise conundrum

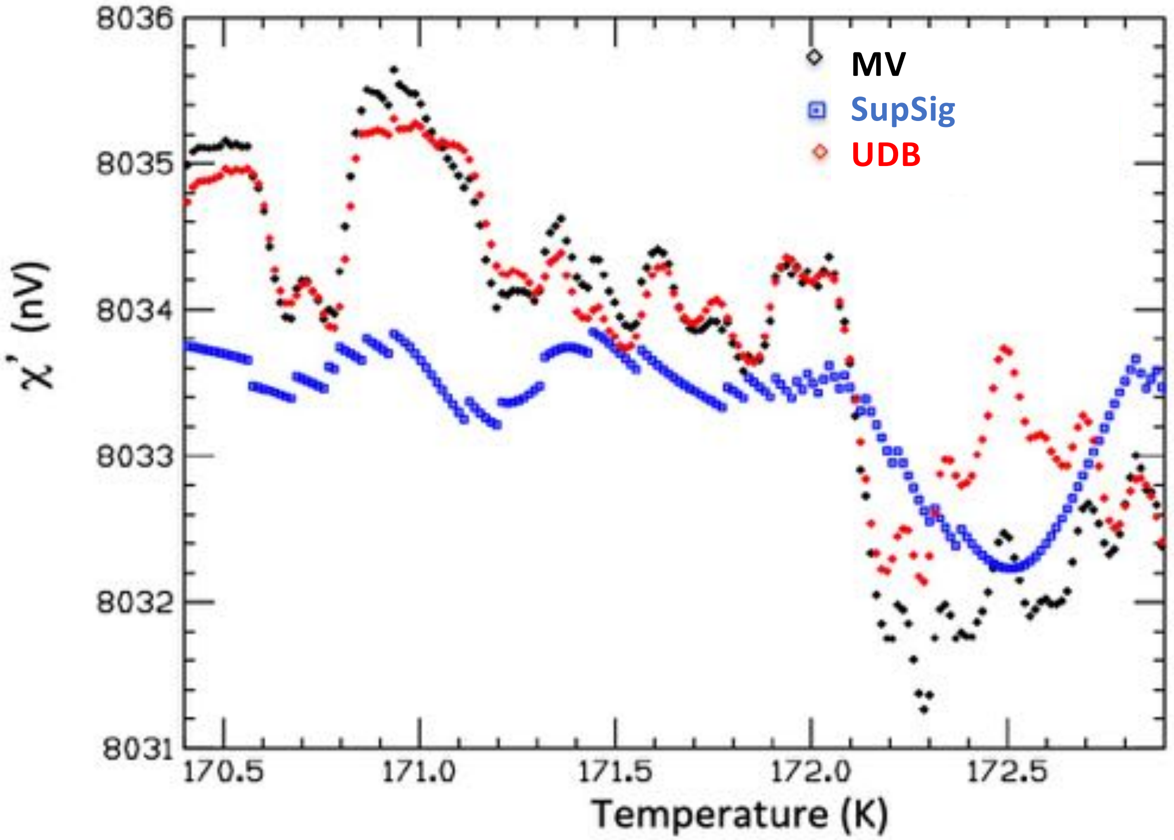
JE Hirsch, *Preprints* , 202112.0115 (2021)

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

$\text{noise}_{MV} \neq \text{noise}_{UDB}$

Consequently $\text{noise}_{Supsig} \geq \max\{\text{noise}_{MV}, \text{noise}_{UDB}\}$

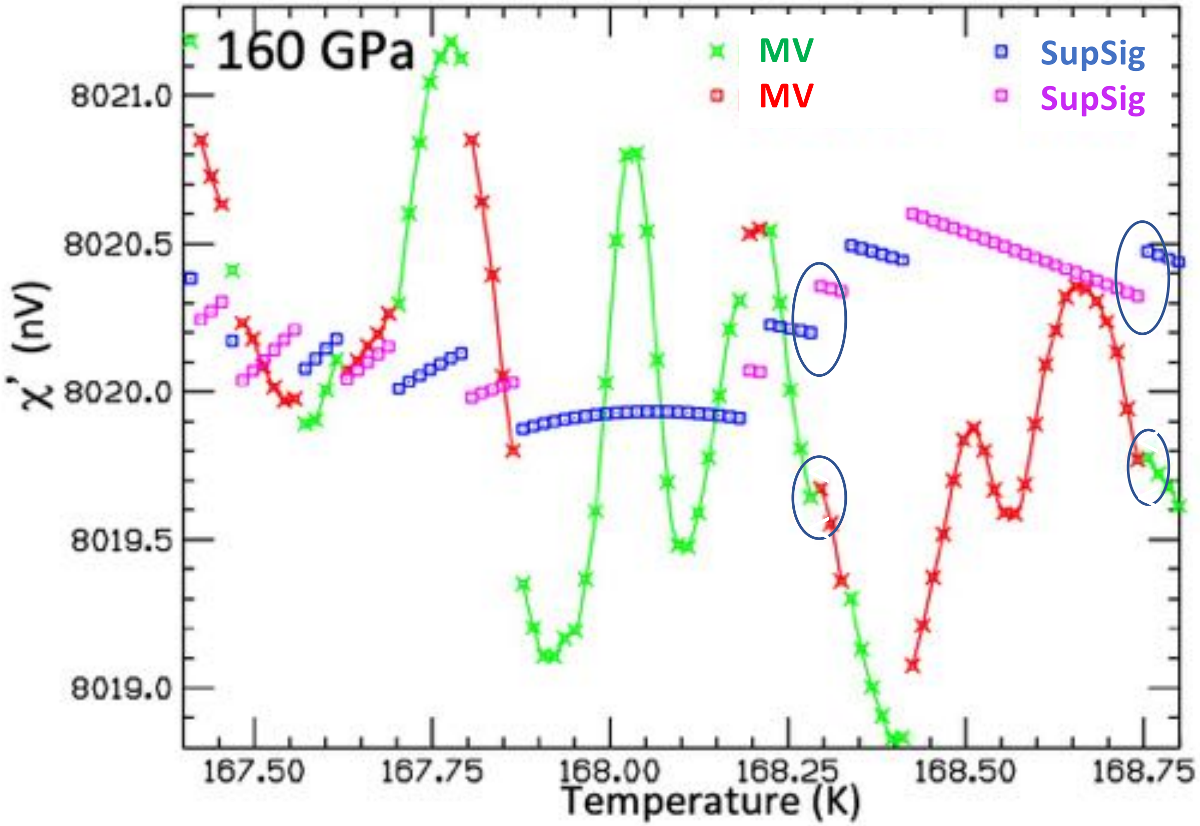


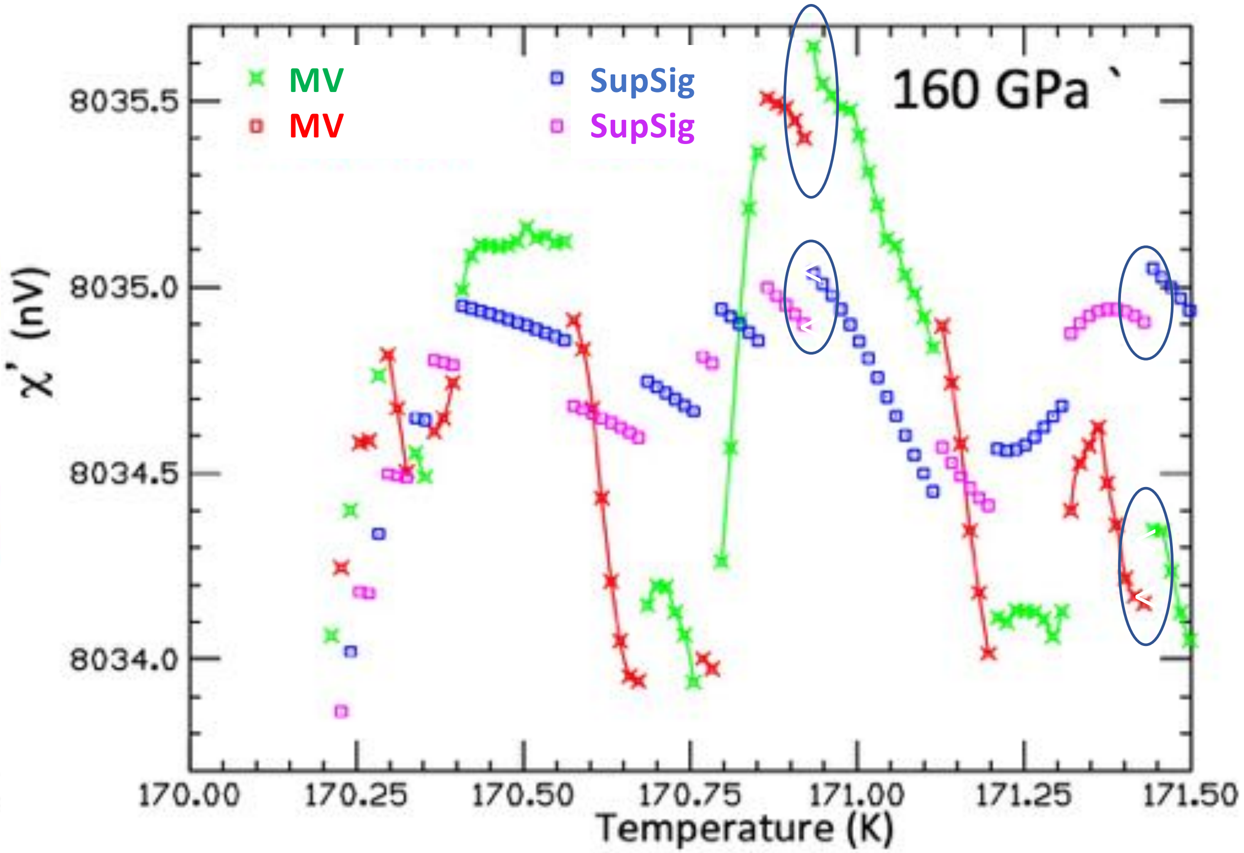


The data suggest:

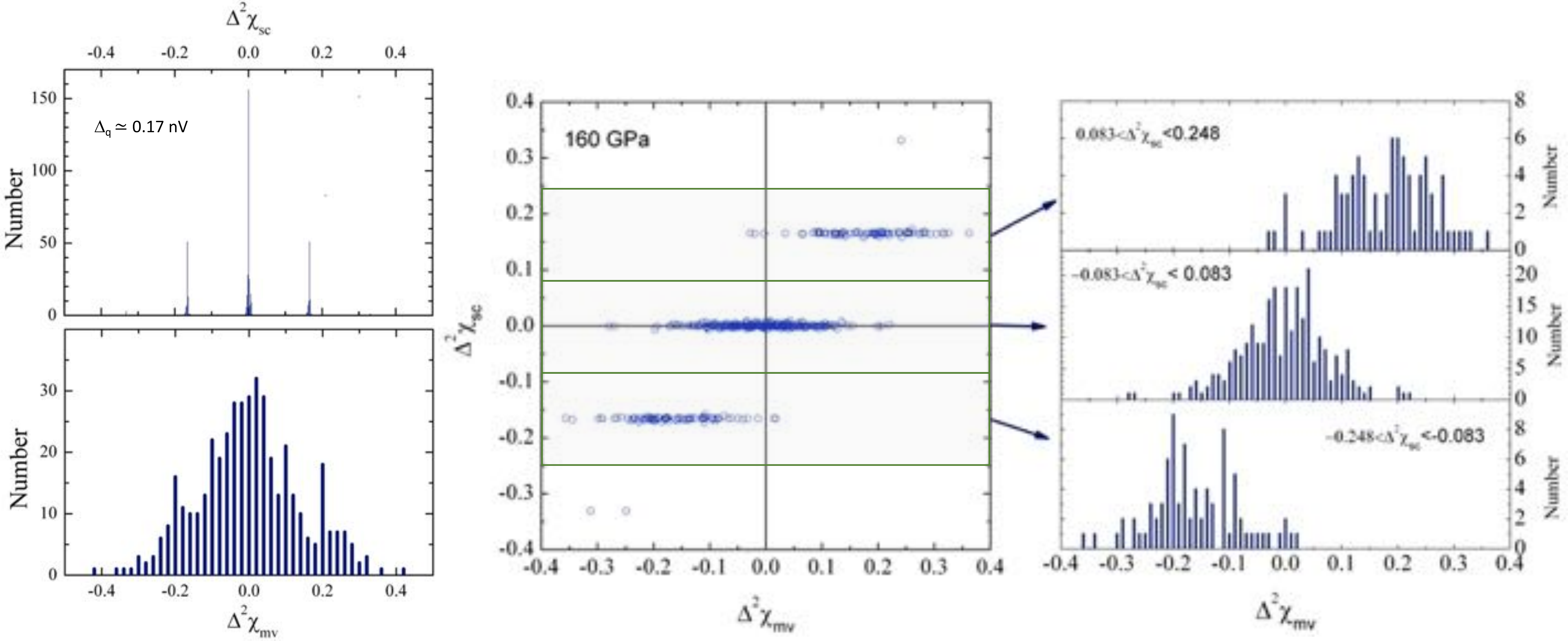
$\chi_{mv} = \chi_{sc} + \chi_{UDB}$ Consequently $\text{noise}_{MV} \geq \max\{\text{noise}_{sc}, \text{noise}_{UDB}\}$

Quantized component in the “Measured Voltage” ?

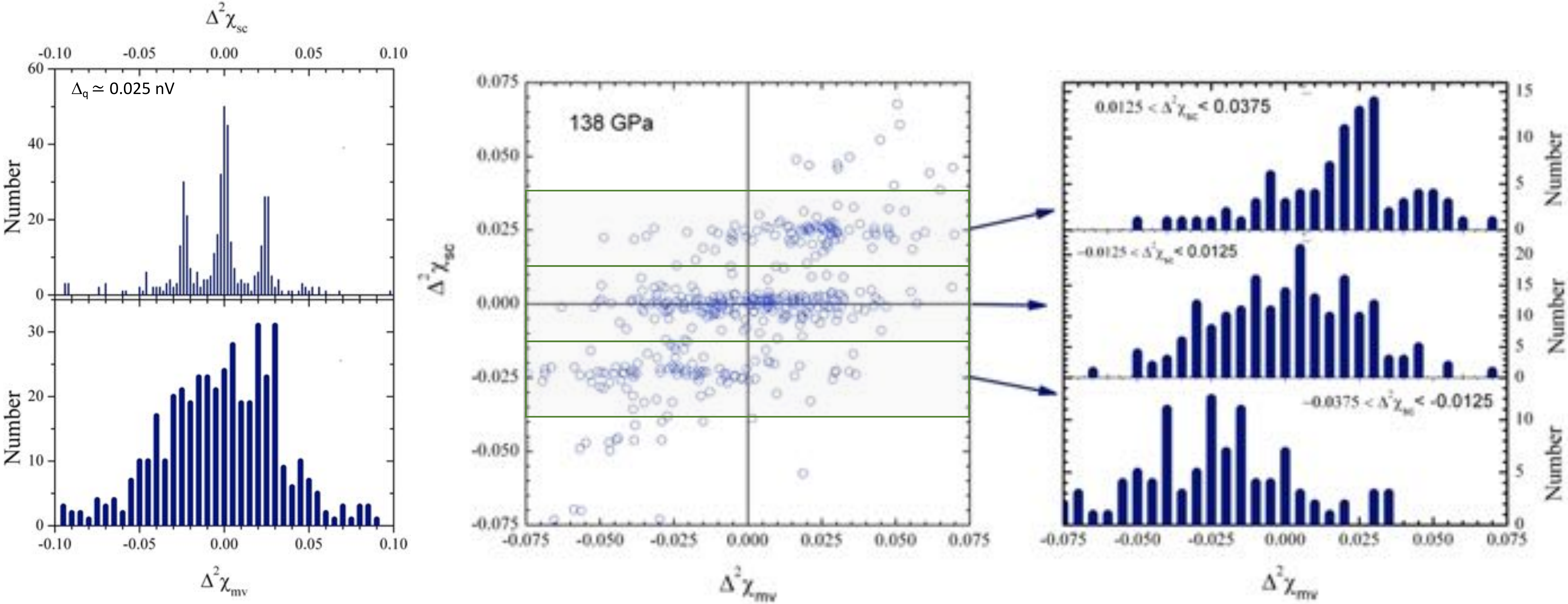




Correlation between quantized steps in χ_{mv} and quantized steps in χ_{sc}



Correlation between quantized steps in χ_{mv} and quantized steps in χ_{sc}



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.

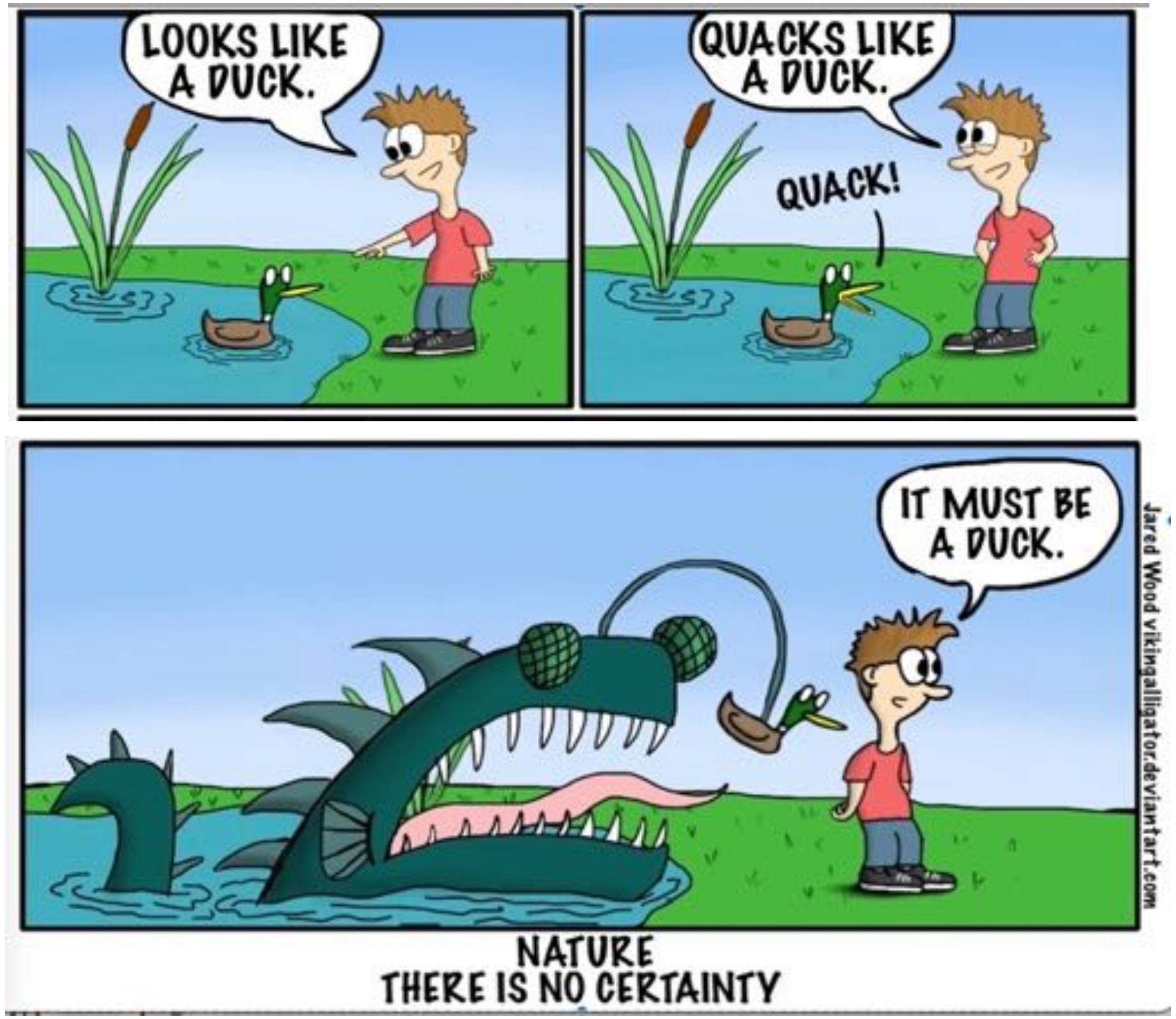
The single case without adjacent averaging is a 15-node cubic spline with natural boundary conditions. Other than that the origins of smooth component and quantized component are unknown.

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



Jared Wood

vikingalligator.deviantart.com

Further reading: D van der Marel & JE Hirsch, *arXiv*:**2201**.07686 (2022).

Why a duck ?

T*he Cocoanuts*
Marx Brothers, 1929