Disconnect between published ac magnetic susceptibility of a room temperature superconductor and measured raw data

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In ref. [1], we pointed out that certain anomalies observed in the published data for ac magnetic susceptibility of a room temperature superconductor reported in Nature 586, 373 (2020) [2] would be cleared up once the measured raw data were made available. Part of the measured raw data were recently posted in arXiv:2111.15017 [3]. Here we report the results of our analysis of these raw data and our conclusion that they are incompatible with the published data. Implications of these results to the claim that the material is a room temperature superconductor are discussed.

Keywords: hydride superconductor; room temperature superconductor; pressure; diamond anvil cell; ac magnetic susceptibility; raw data; background signal; random noise

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I. INTRODUCTION

On October 14, 2020, Snider et al reported the discovery of the first room temperature superconductor, carbonaceous sulfur hydride, hereafter called CSH [2]. If this is true, it represents a major scientific breakthrough. "A superior test of superconductivity" [2] demonstrating superconductivity was claimed to be the detection of sharp drops in the ac magnetic susceptibility. Figure 1 shows the results published in ref. [2] in their Figs. 2a and Extended Data Fig. 7d giving susceptibility versus temperature for 5 different pressures.

The curves shown in Fig. 1 were obtained from the subtraction of two independent measurements, namely "raw data" and "background signal", according to the equation

$$data = raw\ data - background\ signal. \qquad (1)$$

According to the caption of Fig. 2a of [2], "*The background signal, determined from a non-superconducting C-S-H sample at 108 GPa, has been subtracted from the data*". Neither of these independent measurements (raw data and background signal) were given in the paper nor in the supplemental material for the 5 pressures shown in Fig. 1. In a subsequent paper posted on arXiv on December 1, 2021 [3], the measured raw data for the three curves shown on the left panel of Fig. 1 were made public by two of the authors of ref. [2]. Neither the background signal data for the 5 curves shown in Fig. 1, nor the raw data for the two curves shown on the right panel of Fig. 1, have been made available.

In addition, the inset of Extended Data Fig. 7d of ref. [2], shown in the inset in the right panel of Fig. 1, presented "raw data" for still another value of the pressure, 138 GPa, according to the caption of the figure [2]. Numerical values measured at this pressure were also reported in ref. [3] and are discussed in Appendix A.

Given the raw data reported in ref. [3] and the data curves from ref. [2] shown in Fig.1, we can extract the
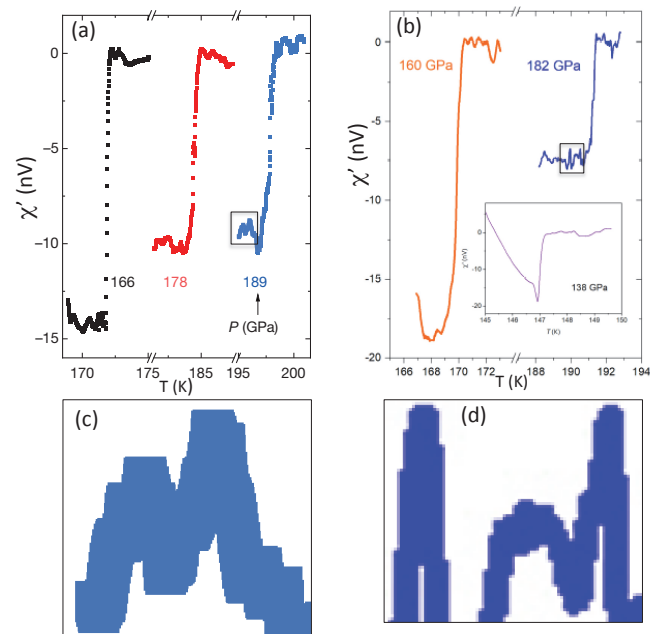

FIG. 1: The top right and left panel show curves for ac magnetic susceptibility of CSH at five different pressure values reported in ref. [2] Figs. 2a and Extended Data Fig. 7d respectively. The inset in the right panel shows raw data reported in ref. [2] for another pressure value. The lower left and right panels show enlarged versions of the upper panels, enclosed by small rectangles in the upper panels. They will be discussed later in the text.

background signal from the relation

$$background\ signal = raw\ data - data. \qquad (2)$$

Figure 2 shows what the raw signal data given in ref. [3] and the background signal resulting from Eq. (2) look like, without high resolution. The qualitative behavior is as expected: there are drops in the raw data superposed to an approximately linear background. By subtracting
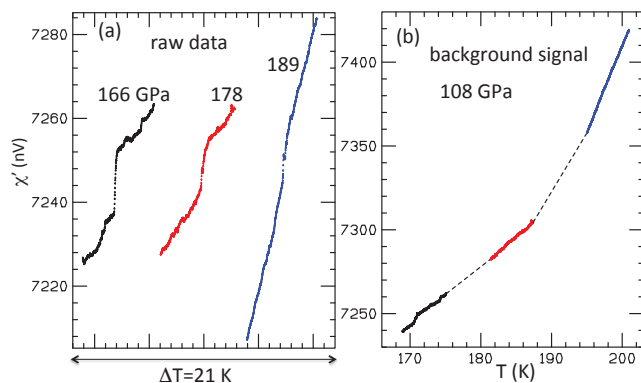
FIG. 2: Raw data from ref. [3] and background signal calculated from Eq. (2) for the data given in the left panel of Fig. 1. On the left panel we have shifted the curves horizontally and vertically so that they all fit in the same graph, without changing the scales. On the right panel we have shifted the background signals obtained from Eq. (1) vertically in order to get a smoothly varying slope. This is justified because the data shown in Fig. 1 have all been shifted vertically by an unknown amount so that they are all close to zero above the jump. The dashed lines on the right panel were inserted to guide the eye.

the background, the data on the left panel of Fig. 1 result, where the drops become much more noticeable.

In ref. [1] we suggested that various questions that we raised in that paper and in an earlier paper [4] about the validity of the magnetic susceptibility measurements reported in ref. [2] would find answers once the authors released the underlying data. In this paper we report our analysis of the data reported in ref. [3] and the conclusions that this analysis leads to.

II.   COINCIDENCES IN THE PUBLISHED DATA

In ref. [1] we analyzed the vector graphics image embedded in the published figure 2a of ref. [2] to extract the data points used to produce the figure to 6 digits accuracy. Fig. 3 show graphs of the obtained figures, both with the low resolution shown in Fig. 1 above in the left panels and with higher resolution in the right panels. From these data we learned [1] that there were strange coincidences in the data, where numerical values for susceptibility at widely different temperature coincided to 6 digits accuracy. Some of those coincidences are shown as the red lines on the right panels of Fig. 4. The probability that such coincidences would occur due to chance is essentially zero, as can be seen intuitively and is shown quantitatively in Appendix B.

The authors of ref. [3] countered our analysis by claiming that in fact the image in fig. 2a of their paper [2] *"is a raster image and not a vector image. There is not infinite precision and scalability in this form of image, relying on discretization of the image along pixels to assign values, which leads to a limited precision for the values extracted.*
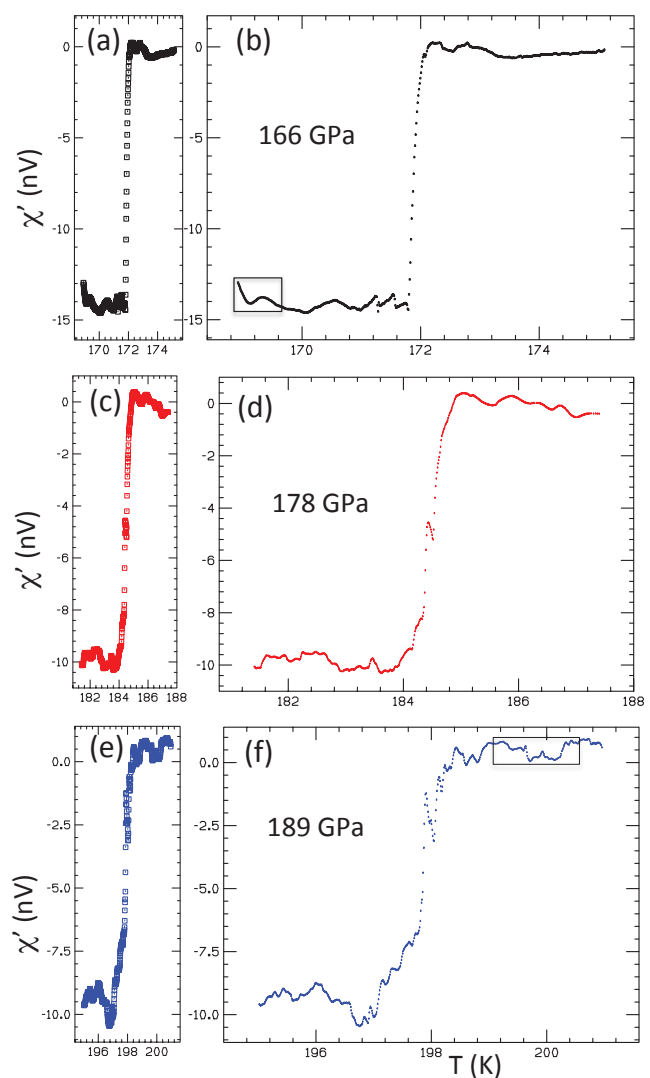

FIG. 3:   Magnetic susceptibility for pressures 166 GPa, 178 GPa and 189 GPa obtained from extraction of the vector image of the published fig. 2a of ref. [2], discussed in ref. [1]. The left panels show the curves with the resolution given in the published fig. 2a of [2], as shown here in Fig. 1 top left panel, the right panels show the same curves with higher resolution. The regions enclosed in the rectangles for 166 GPa and 189 GPa are shown with even higher resolution in Fig. 4.

Analysis of such figures is certainly not accurate to 6 decimal places."

Their statement is incorrect. The on-line version of their paper [2] has a vector image for Fig. 2a, and a raster image for Extended Fig. 7d. This can be clearly seen in the lower two panels of Fig. 1 (c) and (d), where we expanded portions of the upper panels (enclosed in small rectangles) by 6400%. The reader can clearly see that Fig. 1 (c) remains sharp and Fig. 1 (d) becomes blurred. That is a hallmark of vector versus raster images. We have verified that fig. 2a in their paper [2] (left panel of fig. 1 above) is a vector image by analyz-
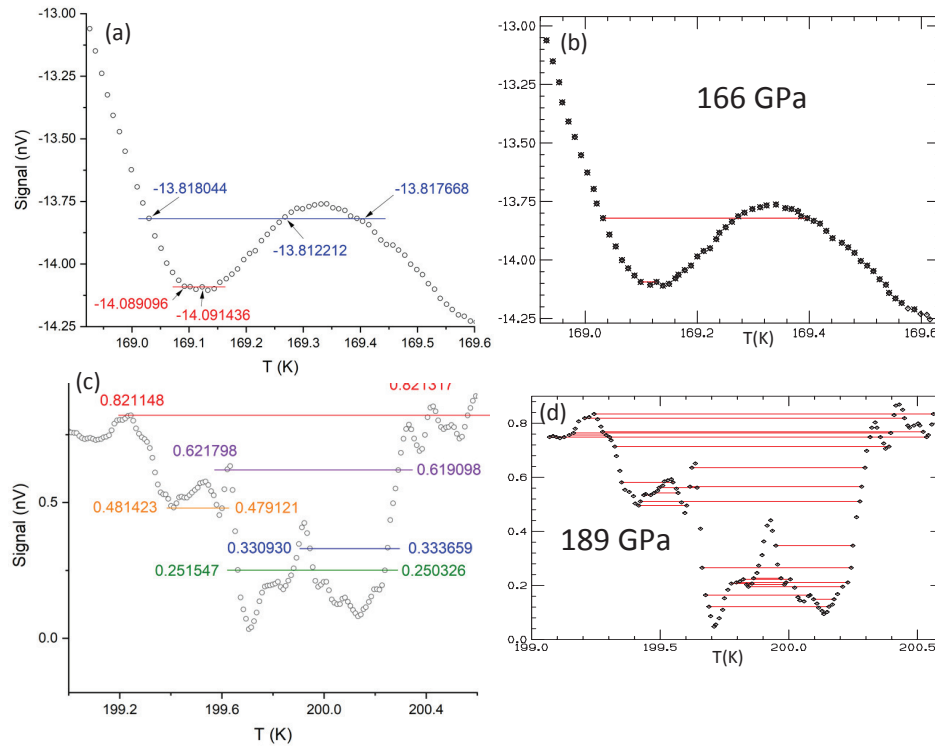
FIG. 4: Right panels ((b) and (d)): the portions of the curves of Fig. 3 (b) and (f) within the rectangles, to higher resolution. The red lines show anomalous coincidences discussed in ref. [1]. The left panels (a) and (c) show the corresponding portions of the curves claimed to be true by the authors in ref. [3]. Note that the shapes of the curves on the left and right panels are identical, the claimed disagreement is in the third significant figure.

ing it with two different software packages, inkscape and adobe illustrator, and getting identical answers to 6 digit accuracy.

On the left panels of Fig. 4 we show what the authors claim are the real numerical values [3] for some of the points where we claimed in ref. [1] that there are 6 digits coincidences: they claim [3] that the coincidences are only two digits, with the numbers given on the left panels of Fig. 4. We don't understand the reason for this disagreement.

Be that as it may however, it is not important for the purposes of this paper. What is important is that by publishing the left panels of Fig. 4 in ref. [3] the authors confirm that our results [1] for the fine structure of their curves published in Fig. 2a of [2] are indeed correct to at least two digits accuracy. That is sufficient to establish the points made in this paper discussed in the following sections.

III.   THE RAW DATA AND THE BACKGROUND SIGNAL

The authors of ref. [2] have not released the background signal used to obtain the data shown in their Fig. 2a of ref. [2] according to Eq. (1), but they have released the numerical values for the measured raw data to at

least 6 digits accuracy in ref. [3]. Using those raw data, and the numerical values for the published data of Fig. 2a of ref. [2] obtained from the vector graphics image, we can infer the background signal from Eq. (2) and expect the background signal thus obtained to be accurate to 6 digits. Figs. 5, 6 and 7 show the raw data from ref. [3], the data published in fig. 2a of ref. [2], and the background signal from Eq. (2), for the three values of the pressure 166, 178 and 189 GPa. The scale on the vertical axis gives the susceptibility in nV as given by the raw data of [3]. The insets show portions of the raw data and background signal amplified, for the regions enclosed by rectangles in the main panels.

What should be apparent to the reader from just looking at the main panels, and becomes even more apparent when looking also at the amplified insets, is that the fine structure in the raw data and the background signal is nearly identical for all cases shown.

Finally, we show in Fig. 8 comparison of the fine structures for the regions that we focused on in our Physica C paper [1], that the authors of ref. [3] also discussed in their figures 8 and 9 of [3], reproduced in the right and left panels of Fig. 4 respectively. For these regions, similarly to the other cases, a high degree of coincidence exists in the fine structures of raw data and background signal, as seen in Fig. 8. Given that the authors have confirmed in their paper [3] that our curves on the left
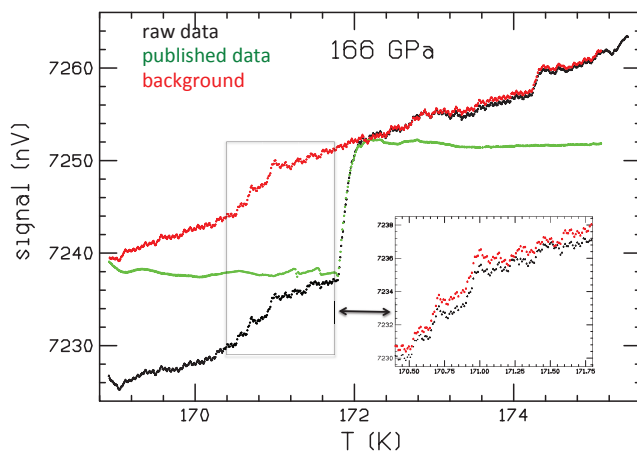
FIG. 5: Pressure 166 GPa. The black dots show the raw data from ref. [3], the green curves show the susceptibility data from the vector image of the published fig. 2a in ref. [2], and the red points are the background signal inferred from the raw data and published data according to Eq. (2). The insets show the regions of the curves enclosed in rectangles in the main panel, with the red points shifted uniformy down to be close to the black points so as to allow comparison of the fine structure.
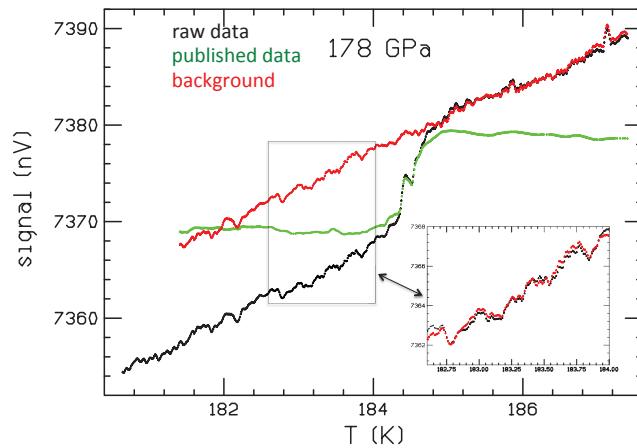

FIG. 6: Pressure 178 GPa. Black dots: raw data from ref. [3]. Green curves: susceptibility data from the vector image of the published fig. 2a in ref. [2]. Red points: background signal inferred from the raw data and published data according to Eq. (2).

panels of Fig. 8 are accurate to at least 2 significant digits (see Fig. 4 in this paper), it is significant that the fine structure is very similar on a much larger scale on the right panels of Fig. 8.

To assess the significance of these results, it should be remembered that the background signal, that has not been released by the authors of [2], was reportedly obtained from independent measurements at a much lower pressure, 108 GPa. What is the probability that the fine structure obtained in those independent measurements is identical to the fine structure found in the measurements
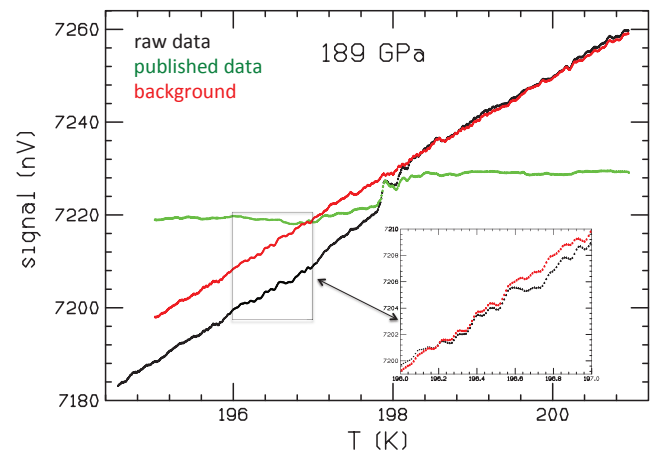

FIG. 7: Pressure 189 GPa. Black dots: raw data from ref. [3]. Green curves: susceptibility data from the vector image of the published fig. 2a in ref. [2]. Red points: background signal inferred from the raw data and published data according to Eq. (2).

of the raw data at pressures 166 GPa, 178 GPa, and 189 GPa, as shown in figs. 5-8? The reader can make his/her own best estimate.

In our view, it is *impossible* that the raw data and background signal have the similar fine structure shown in Figs. 5-8 resulting from independent measurements. This then leads us to consider the following possible explanations for this conundrum:

(1) The raw data reported in [3] are not the raw data corresponding to the published data in ref. [2]. If that was the case, our procedure for obtaining the background signal Eq. (2) would be invalidated. However, the authors of ref. [3] claim they are. In addition, it can be seen in Figs. 5, 6 and 7 that in the regions of the transitions there is a good coincidence between the published data (green curves) and raw data (black curves). Therefore, we have to discard this explanation.

(2) The published data in ref. [2] resulted from a smoothing procedure performed on the difference between measured raw data and measured background signal that were independently noisy, that eliminated the fine structure. If so, in obtaining the background signal from the subtraction in Eq. (2), we would artificially introduce the raw data fine structure into the extracted background signal. However it would not make sense to smoothen the data to eliminate fine structure in the raw data of the magnitude shown in the figures and at the same time retain the fine structure in the data displayed in fig. 4, that the authors themselves acknowledge [3] exists in the published data [2]. Therefore, we have to discard this explanation.

(3) Either the raw data given in ref. [3], or the published data in fig. 2a of ref. [2], or both, do not display the reality of what the papers claim they display.
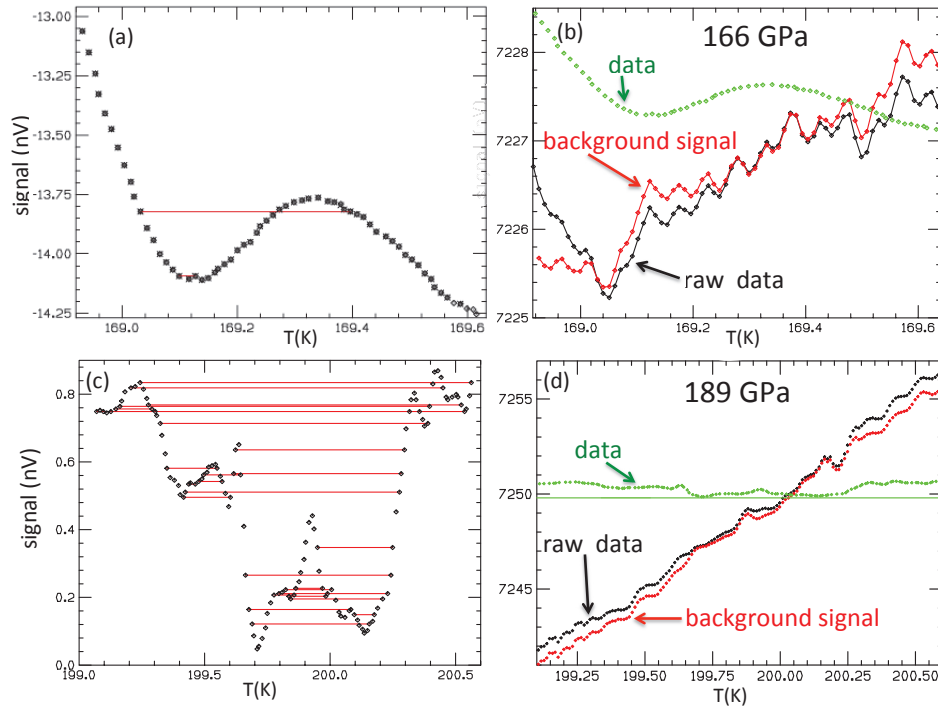
FIG. 8: For the temperature intervals shown in Fig. 4 for pressures 166 GPa and 189 GPa, the right panels show comparison of the fine structure for raw data (black dots) and background signal (red dots). The left panels show the data in that region, from our Physica C paper [1].

IV.   FURTHER COMPARISON OF RAW DATA AND PUBLISHED DATA

From the analysis of the previous section we concluded that there is an unexpected *disconnect* between the published data for magnetic susceptibility in ref. [2] and the raw data for the same measurements posted in ref. [3]. Our analysis in the previous section relied on extracting the background signal. Here we do further comparison between raw data and published data without relying on an inferred background signal.

In fig. 9 we plot the temperature *increments* between subsequent points, ΔT, for the raw data given in [3] and the corresponding published data from [2], versus temperature. It is apparent that they are substantially different for all cases, with the published data showing significantly more values of ΔT than the raw data, and values that don't coincide with any of the values seen for the raw data. This of course also implies that the temperature values given in the raw data and in the published data don't coincide. It is difficult to understand why the published data would show measurements at different temperatures than the measured raw data.

In fig. 10 we plot susceptibility increments $\Delta\chi$ between subsequent temperature points for the raw data given in [3] and the corresponding published data from [2], versus temperature. It is apparent that they are substantially different. Namely, away from the transition region the published data show significantly smaller $\Delta\chi$ increments

than the raw data. It is impossible to understand why the published data would show increments in susceptibility measurements for neighboring temperature values so substantially smaller than seen in the raw data.

In fig. 11 we show the data of fig. 10 for a small range of susceptibility increments around zero. The qualitatively different nature of the published and raw data is apparent. The published data show a *quantification* of the susceptibility increments in discrete steps. A closer look shows that in fact there are steps and much smaller substeps on the right panels of fig. 11. Instead, for the left panels of fig. 11, i.e. the raw data, no quantification whatsoever is apparent.

We have recently learned [5] that the quantification of measured voltages shown on the right panel of fig. 11 is in fact expected when measurements are obtained using a digital lock-in amplifier, according to information given to us by S. Weir. However the most common situation is to have a single step and a single substep [5], while an analysis of the published data shows a more complicated step structure.

Be that as it may, the important point for the purposes of this paper is that the increments in temperature and susceptibility shown in figs. 9-11 exhibit a complete disconnect between what is published in ref. [2] and the raw data reported in ref. [3]. In particular, assuming the steps in $\Delta\chi$ shown on the right panels of Fig. 11 originated in the measurement apparatus (lock-in amplifier) rather that somehow being artificially introduced in the
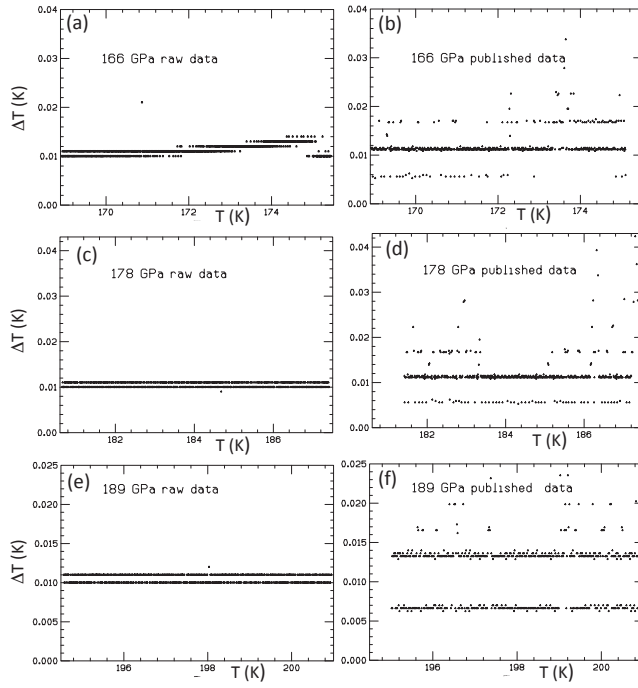
FIG. 9: Temperature increments ΔT between subsequent points versus temperature for the raw data of ref. [3] (left panels) and the published data of ref. [2] (right panels).

FIG. 10: Susceptibility increments $\Delta\chi$ between subsequent points versus temperature for the raw data of ref. [3] (left panels) and the published data of ref. [2] (right panels).
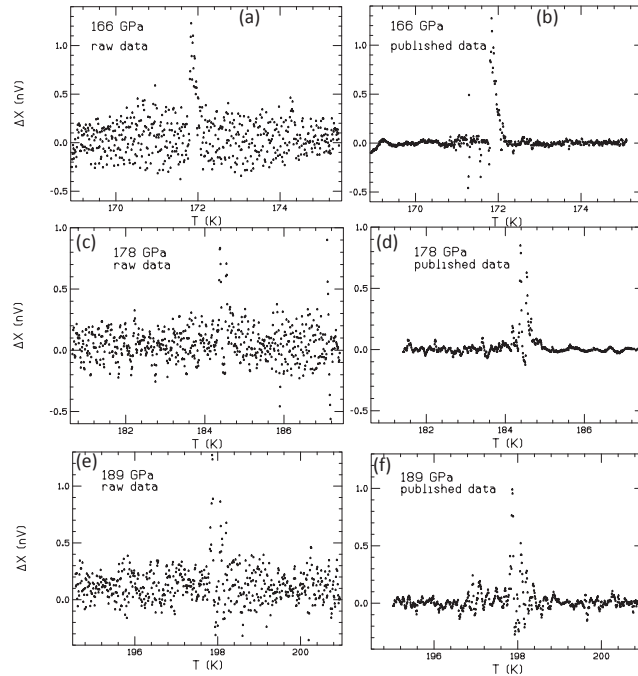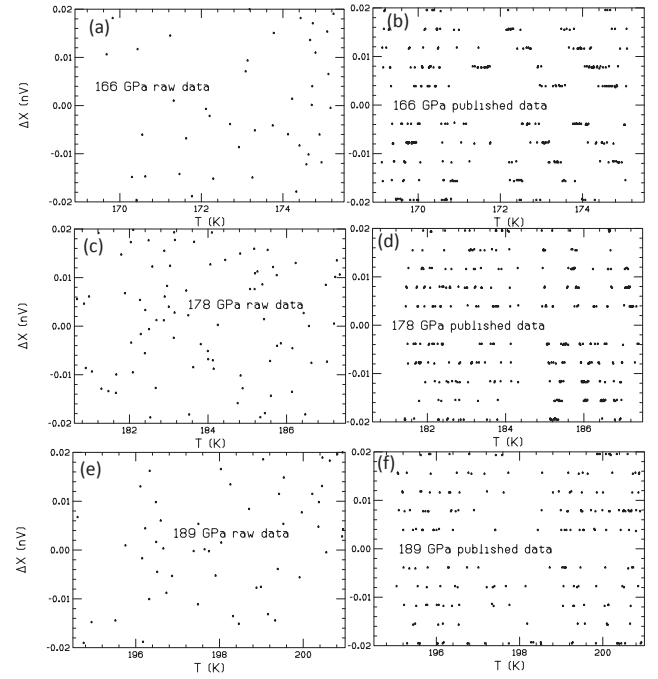

FIG. 11: Susceptibility increments $\Delta\chi$ between subsequent points versus temperature for the raw data of ref. [3] (left panels) and the published data of ref. [2] on a finer scale, showing the quantification of steps in the published data.

process of creating Fig. 2a of ref. [2], it would be *impossible* that measured raw data (left panels of Fig. 11) don't show such steps and yet the data obtained from them and an independently measured background signal using Eq. (1) would show the steps.

In Appendix A, we discussed other points addressed in the recently posted paper ref. [3].

V.   DISCUSSION

For over one year we have been waiting [1] to receive the underlying data associated with the published susceptibility curves in ref. [2], and for an explanation of the anomalous change in slope in the raw data susceptibility curve shown in the inset of Fig. 1 [4]. Now we have finally been provided with some answers to these questions in the paper [3] recently posted in arxiv. Unfortunately, the answers provided do not answer the questions and instead raise additional troubling questions.

As discussed in Appendix A, no physical explanation was provided in [3] for the anomalous rise of χ below the jump in the raw data shown in the inset of Fig. 1 noted in refs. [1, 4]. None of the references cited in [3] (refs. 20, 21 and 22 in [3]), claimed in [3] to show such anomalous rise, do in fact show such behavior within a range of less than 2% of the presumed critical temperature as the inset of Fig. 1 shows, as readers can easily verify by reading those references. Nor has it been explained why the anomalous
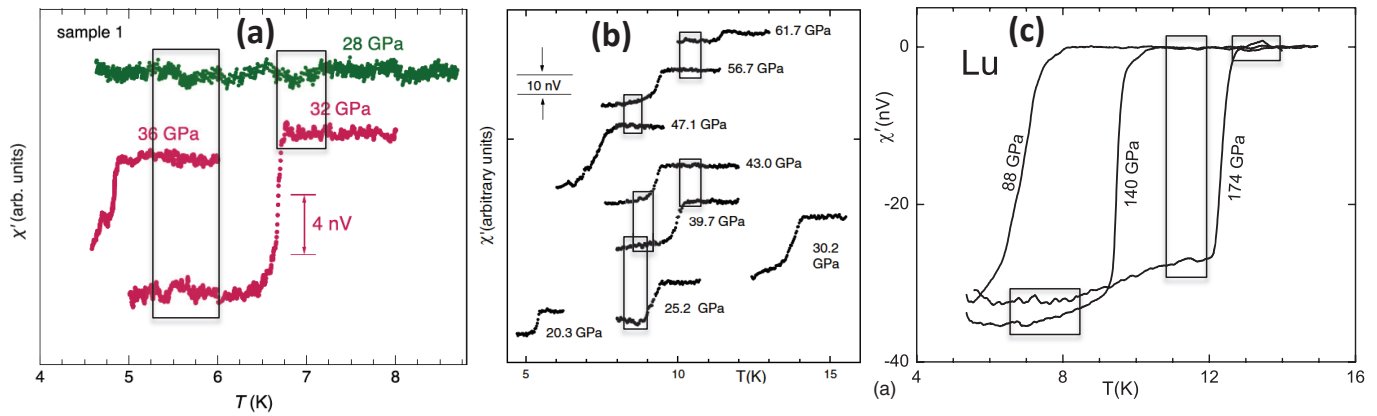
FIG. 12: (a) Susceptibility measurements for: (a) platinum hydride under pressure, from Fig. 2 of ref. [8]; (b) Li metal under pressure, from Fig. 2 of ref. [9]; Lu metal under pressure, from fig. 4a of ref. [7]. The rectangles were inserted to facilitate comparison of the fine structure of different curves in the same temperature range.

raw data of the inset of Fig. 1 were chosen to be shown in ref. [2] instead of any of the typical raw data shown in Fig. 2 that *don't* show such an anomalous rise.

More troubling is the fact that the raw data provided in ref. [3] that purportedly underly the published susceptibility data in ref. [2] exhibit a complete disconnect with the published curves they are supposed to represent. In sections III and IV of this paper we have provided evidence that we regard as conclusive that the raw data presented in [3] cannot possibly give rise to the numerical values for susceptibility that we extracted from the vector graphics figure 2a published in ref. [2].

The authors of [3] have disputed our claim [1] that the published Fig. 2a of their paper [2] is a vector image that allows for extraction of the numerical values used to create the figure to 6 digits accuracy. Knowledgeable readers will know to check this out for themselves and understand who is right and who is wrong in this respect. But even if one were to accept the authors' claim that our numerical values are not accurate to 6 digits accuracy, the authors themselves have accepted that they are correct to at least 2 digit accuracy, as comparison of the left and right panels of fig. 4 shows, at the very least for the temperature ranges shown in fig. 4. Given that fact, the fact that in the right panels of fig. 8 the fine structure of the background and the signal closely track each other in the same temperature range indicates that *the background signal and raw data cannot have originated in independent physical measurements of susceptibility at pressure values 166GPa/189 GPa and 108 GPa*, as references [2] and [3] claim.

For readers that may think it is possible that the coincidences that we found in the fine structure of the raw data and inferred background signals in Figs. 5-8 may be real reproducible features associated with the measuring apparatus that do not change as a function of pressure, we show in Fig. 12 examples of susceptibility measurements of the same type for other materials, where the authors show measurement results for overlapping ranges of temperature, unlike what was done in ref. [2]. By comparing the regions highlighted by the rectangles for curves at different pressures, it is apparent in Fig. 12 that the fine structure does change substantially with pressure in these type of measurements in diamond anvil cells.

Furthermore, independently of the background we showed in Figs. 9-11 that there is a complete disconnect between the *increments* in temperature and susceptibility between neighboring points for raw data and published data. For example, according to Figs. 10 (a) and (b), the increments in susceptibility for the raw data ((a)) are approximately an order of magnitude larger than for the data ((b)). We cannot imagine a plausible explanation for this. This suggests consideration of the following equation that follows from Eq. (1) or Eq. (2):

$$raw\ data = data + background\ signal. \qquad (3)$$

In words, that a physically reasonable approximately linear background signal with fine structure, as given by the red curves in Figs. 5 to 7, added to the data published in Fig. 2a of ref. [2], would give rise to 'raw data' identical to the black curves shown in Figs. 5 to 7, obtained from ref. [3]. It would of course be a misnomer to call such numbers obtained through Eq. (3) 'raw data'.

In conclusion, we argue that we have shown in this paper that the ac magnetic susceptibility curves reported in Fig. 2a of ref. [2] claimed to provide a "superior test of superconductivity" of CSH cannot have been obtained from Eq. (1) with the raw data published by two authors of ref. [2] in ref. [3]. Consequently, those susceptibility curves provide no evidence for the claimed room temperature superconductivity of CSH [2], since they are unsupported by valid raw data. Why the authors of ref. [3] chose to present as raw data underlying Fig. 2a of ref. [2] numbers [3] that are not consistent with the published data in Fig. 2a is a question for each reader to answer for themselves.

Appendix A: History and remarks on other points made in ref. [3]

Starting on November 12, 2020, we had attempted to obtain the raw data and background signal that were used to obtain the measurements shown in Fig. 1 from the corresponding author and coauthors of ref. [2]. Details of this saga are described in ref. [1]. Finally, on December 1, 2021, part of those data, namely the measured raw data for the three curves shown on the left panel of Fig. 1, as well as for the inset on the right panel of Fig. 1, were made public in ref. [3] by two of the authors of ref. [2]. Neither the background signal data for the 5 curves shown in Fig. 1, nor the raw data for the two curves shown on the right panel of Fig. 1, that we also requested more than a year ago, have been made available so far.

Figure 4 of [3] compares the raw data for CSH shown in the inset of fig. 1 top right panel of this paper with similar-looking data for susceptibility of europium metal reported in ref. [6]. Such a comparison was made by us in refs. [4] and [1]. Ref. [3] states *"Remarkably, the measured signal strength is different in two samples, indicating different sample sizes."* Indeed, fig. 4 of [3] shows a susceptibility jump of approximately -20nV for CSH and -40nV for Eu. It should be pointed out however that the susceptibility jump published in ref. [6] for exactly the same case showed a jump of -20nV and not -40nV. Ref. [3] makes the cryptic statement in the caption of fig. 4 *"Note that drop in signal in Eu is $\sim$ -40nV as observed before scaling due to different warming rates."* There is however no statement in ref. [6] indicating that the warming rate would require scaling of the signal, quite the contrary, ref. [6] only stated that *"the observed $\Delta\chi' \sim 20nV$ jump at T_c is consistent with perfect diamagnetism, the hallmark of a superconductor."* There is also to our knowledge no physical reason for why the warming rate would cause a susceptibility drop due to onset of superconductivity to change by a factor of 2. Regarding ref. [6], it should be noted that on Nov. 19, 2021, a retraction was accepted by the journal [10].

Ref. [3] then shows in their fig. 7 two plots of susceptibility of CSH at 138 GPa, reproduced here in Fig. 13. The bottom curve is the same as the inset of our Fig. 1 (b), which the caption of Extended Data fig. 7d of ref. [2] said are "raw data". Yet Fig. 13 (Fig. 7 of [3]) shows a red curve at the top of the figure which it
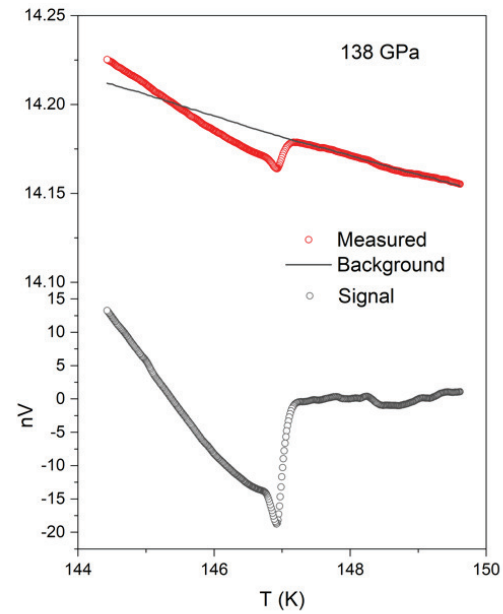

FIG. 13: Figure 7 of ref. [3]. The figure caption reads: *"The AC susceptibility data from Snider et al., showing the raw data, the background used for subtraction and the data shown in the publication."*

calls "raw data" in the caption, and explains that the bottom curve is obtained after subtraction of a linear background. This is in contradiction with the figure caption of Extended Data fig. 7d of ref. [2]. According to ref. [3], the raw data are given by the red curve at the top in our Fig. 13 (their Fig. 7), and the numerical values are given in Table 1 of ref. [3]. It should also be pointed out that, as ref. [6] explains in connection with the Eu curve shown in fig. 4 of [3] that looks similar to the bottom curve of their Fig. 7, *"The inset shows the raw data at 118 GPa before this background subtraction."* Quite generally, "raw data" are understood to mean data measured *before* background subtraction. This implies that the statement in ref. [2] that the inset of their Extended data fig. 7d was "raw data" was incorrect.

So according to ref. [3], the top red curve of Fig. 13 is "raw data", the straight line is "background", and the bottom curve is "data" as given by Eq. (1). It remains a puzzle why both curves show a large change in slope between above and below T_c, an anomaly first noted in refs. [4] and [1]. It is also perplexing that the lower "data" curve in Fig. 13 looks qualitatively different from the other 5 "data" curves for susceptibility shown in fig. 1 that reportedly also had background subtracted.

Note also that the raw data for pressures 166 GPa, 178 GPa and 189 GPa shown on the left panel of Fig. 2 (graphed from the data tables provided in ref. [3]) look typical and *qualitatively* different from the so-called raw data for pressure 138 GPa shown in Fig. 13. The slopes on the left panel of Fig. 2 are approximately the same before and after the drop interpreted as onset of

superconductivity, and their sign is opposite to that of the raw data in Fig. 13. Given those typical raw data of Fig. 2 it is incomprehensible that the authors would have chosen to show in ref. [2] the highly atypical "raw data" or "data" for 138 GPa shown in the inset of Fig. 1.

Continuing with ref. [3], it shows in figure 5 a curve for "*AC susceptibility of a sample which superconducts at 235K*", that shows a drop in susceptibility of approximately 60nV, which is four to eight times larger than the drops shown in fig. 1. Since the magnitude of the jump attributed to superconductivity is supposed to be proportional to the volume of the sample [7], it is perplexing that the same sample would show jumps that differ by factors of up to eight as these results would indicate.

Finally, the explanation given in ref. [3] for the process of background subtraction associated with figs. 6 and 7 of ref. [3] is puzzling. It states "*The background profile is kept true but scaled to match the same signal strength of the desired measurement.*" However, the amplitude of signal changes in susceptibility measurements in diamond anvil cells reflects the physics of what is being measured [7], so it is unclear what is meant by this "scaling". It certainly does not provide a physical explanation for the large change in slope from above to below the jump in susceptibility shown in the inset of fig. 1, the anomalous behavior that raised our concern with these measurements originally [4].

Appendix B: Quantitative estimate of probability of coincidences in Fig. 4.

As discussed in Sect. II, the red lines in Figs. 4 (b) and (d) connect points that are the same within 6 digits.

Here we show that this cannot be due to random chance.

Consider Fig. 4 (d). The range of values of the points is approximately L=1nV, and there are n=136 points in the figure. The probability that two points are within a range $w = 10^{-5}nV$ of each other is $w/L = 10^{-5}$. The expected number of pairs that would show such coincidence is certainly not larger than

$$n_c = \frac{n!}{2!(n-2)!}\frac{w}{L} \sim 0.1 \qquad \text{(B1)}$$

i.e. much less than one. Eq. (B1) is an overestimate since it assumes that any two points have the possibility of showing such coincidences, which is clearly not so since the curve is not flat, but is sufficient for our purposes. Now there are 22 pairwise coincidences in Fig. 4(d), as well as some where even more points coincide. Taking n_c to be the probability that two points chosen at random from the set of n points would coincide within range w, the probability that this would happen for 22 pairs of points can be estimated to be

$$p \sim (0.1)^{22} = 10^{-22}. \qquad \text{(B2)}$$

Therefore, the possibility that the coincidences shown in Fig. 4 (d) are due to chance can be ruled out.

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